LSST DESC Dark Energy Science Collaboration

LSST DESC Science Roadmap

Version v2.2

Change Record

Version	Date	Description	Owner name
v1.0	11/13/2015	Initial Release	Rachel Bean
v1.1	09/04/2017	Summer 2017 Update	Phil Marshall
v1.2	11/14/2017	Fall 2017 Refactor	Phil Marshall
v1.3	04/29/2018	May 2018 Operations Review	Phil Marshall
v1.4	01/12/2019	Fall 2018 Update	Phil Marshall
v2.0	11/05/2019	Restructuring and Fall 2019 Update	Rachel Mandelbaum
v2.1	12/20/2019	Additional minor updates not captured in v2	Rachel Mandelbaum
v2.2	08/27/2020	Maintenance of v2.1 and significant PZ updates	Rachel Mandelbaum

LSST DESC Science Roadmap

Contents

1 Executive Summary and User Guide

The Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) Dark Energy Science Collaboration (DESC) was established in June 2012 with the goal of developing and executing a high-level plan for the study of dark energy and associated fundamental physics of the Universe with LSST data. The Rubin Observatory Project will create "prompt" (nightly alerts) and "data release" (annual catalog) data products that meet Project requirements, but will not perform science analyses with those datasets. The DESC is focused on undertaking a precise and timely analysis of the Rubin Observatory data release products LSST to optimally extract the dark sector science and create "user-generated" catalogs and analysis products for public release.

This document, the *Science Roadmap (SRM)*, outlines the research needed to fully understand sources of systematic uncertainties in dark energy probes due to instrumental, physical and astrophysical effects, and to develop algorithms for use in the collaboration's data analysis. It then lays out the mission-critical "operations" deliverables that must be completed in order for the collaboration to have its simulation, processing and analysis pipelines and infrastructure, and its team coordination, in place so as to successfully analyze the first year of LSST data for dark energy science. This includes work to build and validate a suite of collaboration-wide software to perform integrated cosmological analyses using LSST's key cosmological probes.

The SRM is structured around the working groups in the Collaboration: those focused on primary cosmological probes (weak and strong gravitational lensing, large scale structure [galaxy clustering and baryonic acoustic oscillations], galaxy clusters, and Type Ia supernovae) and those cross-cutting groups that provide essential inputs to enable the primary probe analyses. For each, the SRM lays out a set of key research priorities. The deliverables that make up the simulation, processing and analysis pipelines and related software infrastructure are organized into key products for each working group.

The SRM focuses on the period prior to the start of the LSST, 2016–2022. An incremental, data challenge-driven approach is used to build the necessary analysis infrastructure and team coordination. Two Data Challenges (DCs) of increasing scope and complexity, referred to as DC1 and DC2, are being used to test and validate the tools and software infrastructure that will be used to analyze the LSST data. DC2 involves a collaboration-wide, fully coordinated analysis of a dataset of substantial scale and complexity. After DC2, during the preparations for Science Readiness, the collaboration will engage in a variety of activities with real and simulated data to go beyond what was learned from DC2 and to ensure readiness for the first year of LSST data. Simulated datasets provide a controlled environment for testing systematic effects and for code validation. External precursor datasets, including Rubin Observatory-selected verification datasets, and later Rubin Observatory LSST commissioning and science verification data will also be used to test DESC software on real data.

The initial version (v1.0) of this SRM was developed from June through November 2015 through a collaboration-wide process based upon working group discussions and collective authorship of the sections. Since then, the SRM has been updated regularly and re-versioned approximately annually, as the working groups' plans have evolved under a "rolling wave" development model. Points of contact – individuals who played major roles in coordinating and authoring each section in the latest SRM version and can provide further details if needed – are listed in Section 2.2.

1.1 How to use this document

Readers who are new to the SRM and/or to DESC may wish to begin with Section 2, which describes the structure of the document and the overall approach DESC has taken to preparing for constraining fundamental cosmological physics with LSST. For those interested in particular working groups, Section 3 and Section 4 contain subsections that each provide an overview of the overarching goals of each DESC working group, including their research priorities and auto-generated lists of ongoing DESC Projects and of infrastructure (software pipelines and/or datasets) being developed before the first LSST data release. Section 5 and Section 6 focus on mission-critical "operations" deliverables that must be completed in order for the collaboration to have its simulation, processing and analysis pipelines and infrastructure in place so as to successfully analyze the first year of LSST data for dark energy science.

The remainder of the content consists of automatically generated lists that serve as quick references without explanatory descriptions:

- Section 7 contains the list of infrastructure deliverables from Section 5 and Section 6.
- Section 8.2 contains a list of *completed* DESC Publications resulting from work on either research or infrastructure deliverables within DESC Projects in accordance with our Publication Policy.
- Section 8.3 contains a list of *all approved* DESC Projects (ongoing or completed).

Finally, other useful references that provide context and/or definitions of terminology include the acronym list (Section 1.2); list of individuals to contact with questions (Section 2.2); and definitions of simulation-related terminology (Section 8.1).

1.2 Acronym Definitions

API	Application Programming Interface
BAO	Baryon Acoustic Oscillations
BL	Blending, a DESC technical working group
CI	Computing Infrastructure (one of the DESC Operations teams)
CO	Computing, a DESC computing working group
COM	Commissioning, the DESC data & validation working group
CL	Galaxy Clusters, a DESC analysis working group
CMB	Cosmic Microwave Background
ComCam	LSST Commissioning Camera
CPU	Central Processing Unit
CS	Cosmological Simulations, a DESC computing working group
DC	Data Challenge (see Section 2 for details)
DDF	Deep-Drilling Field (deeper regions of observation within the LSST survey footprint)
DES	Dark Energy Survey
DESC	Dark Energy Science Collaboration
DESI	Dark Energy Spectroscopic Instrument
DKM	Dark Matter, a DESC analysis working group
DM	LSST Project Data Management
DM Stack	The suite of LSST Project data processing software
DOE	U.S. Department of Energy
DP	Data Product
DR	Data Release (typically referring to LSST's data releases once the survey starts)
ES	External Synergies, a DESC analysis working group
FY	U.S. federal financial year (e.g., FY20 started in October 2019)
HPC	High Performance Computing
HST	Hubble Space Telescope
IFU	Integral Field Unit
ISW	Integrated Sachs-Wolfe
JWST	James Webb Space Telescope
KP	Key Project (one of the main areas of infrastructure work within a DESC working group)
LSS	Large Scale Structure, a DESC analysis working group
LSST	Large Synoptic Survey Telescope

MAF	Metrics Analysis Framework (containing tools to characterize the LSST survey and its scientific performance for various observational strategies)
NERSC	National Energy Research Scientific Computing Center
OS	Observing Strategy, a DESC technical working group
PB	PetaByte
PC	Photometric Corrections, a DESC technical working group
PFS	Prime-Focus Spectrograph
PSF	Point-Spread Function, also one of the DESC technical working groups
PZ	Photometric Redshifts, a DESC analysis working group
R&D	Research & Development, or basic research activities (as opposed to work on building infrastructure)
RQ	Requirements
SA or SAWG	Sensor Anomalies, a DESC technical working group
SED	Spectral Energy Distribution
SFH	Star-Formation History
SFR	Star-Formation Rate
SL	Strong Lensing, a DESC analysis working group
SN	Supernovae, a DESC analysis working group
SR	Science Readiness
SRD	Science Requirements Document (either for the LSST project or the DESC, depending on context)
SSim	Survey Simulations, a DESC computing working group
SV	Science Verification
SW	Software
SZ	Sunyaev-Zeldovich
TJP	Theory and Joint Probes, a DESC analysis working group
VA	Validation
WFD	Wide-Fast-Deep (a term used to describe the basic observational strategy of the main LSST survey)
WFIRST	Wide-Field Infrared Survey Telescope
WG	Working Group
WL	Weak Gravitational Lensing, a DESC analysis working group

2 Introduction

2.1 Overview of the Science Roadmap

The Dark Energy Science Collaboration: The Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST) Dark Energy Science Collaboration (DESC) was established in June 2012 with the goal of preparing for the study of dark energy and associated fundamental physics of the Universe with LSST data. The DESC is separate from, but works closely with, the Rubin Observatory Project. While Rubin Observatory is responsible for generating and processing the petabyte-scale imaging data to create science-ready catalogs (not to mention constructing LSST itself), the science analysis of these catalogs falls to the community. The DESC is one aspect of this community effort, focused principally on the use of LSST to study observable signatures of "dark sector" physics, including dark energy, dark matter, neutrinos, and signatures of inflation.

The Collaboration has grown steadily, with over 950 members from 15 countries (including 222 voting Full Members and 24 Builders) as of August 2020. The DESC's science activities are structured and overseen through its Governance Plan. Work is distributed across eighteen working groups organized under Analysis, Computing & Simulation, Data, and Technical Coordinators, who in turn report to the Spokesperson.

Five working groups each focus on a single cosmological probe: weak gravitational lensing (WL), large-scale structure (LSS), galaxy clusters (CL), strong lensing (SL), and Type Ia supernovae (SN). The remaining working groups are 'cross-cutting' in the sense that they are centers of activity for key enabling activities that cut across multiple probes. They provide critical interfaces to the Rubin Observatory Project hardware and Data Management (DM) development efforts, to other external resources, are responsible for the computing model and hardware infrastructure, and characterize important sources of systematic contamination.

The role of the Science Roadmap: The DESC produced a White Paper at its inception that articulated the need for the collaboration within the cosmological community and identified high priority tasks it would tackle in its first three years. This document, the *Science Roadmap (SRM)*, presents the next step in the DESC's planning. The SRM outlines the critical research and development activities needed to fully understand the various sources of systematic uncertainty in dark energy probes (due to both observational and astrophysical effects), incorporate these effects with the required fidelity in simulations[1] at all levels, and build and validate (with simulations and real precursor data) the software pipelines and infrastructure for the key cosmological analyses using the first year of LSST data.

[1]A summary of simulation-related nomenclature used throughout this document can be found in Section 8.1.

The primary audience for this document is the Collaboration members themselves: the SRM presents the Collaboration's science priorities and planned activities. It provides details of high-priority operations deliverables and research activities which members (existing or new) can sign up to contribute to, and presents the broader context for those priorities. All of the DESC working groups have identified the high-priority activities for their group to achieve SRM goals.

The SRM is intended to be an evolving text. Versioned, publicly available releases of the Science Roadmap will be produced approximately twice per year, following periodic review by the DESC Management team and working group conveners, with non-leadership review requests as needed. The SRM GitHub repository will allow dynamic SRM updates, on an ongoing basis, between formal versioned releases.

The SRM in the context of DESC Operations: In April 2017 the LSST DESC's operations plan was reviewed by the U.S. Department of Energy Office of High Energy Physics (OHEP), after which OHEP recognized DESC as an operating experiment. The planned operations tasks include the development of mission-critical software and datasets; these key products are defined in Section 5 and Section 6 of this document, with a summary in Section 7. This deliverable list provides the majority of a quasi-work breakdown structure (WBS) for DESC operations, along with activities relating to the logistical support of the collaboration's interactions and its dataset production. This quasi-WBS allows us to assess the work needed to be done by specialist operations staff, alongside the contributions needed from the wider collaboration. The organization of these operations specialists is described in the LSST DESC Operations Management Plan (OMP), while their various role descriptions and staffing levels (both actual and planned) are given in the LSST DESC Operations Prioritization Plan. This detailed operations plan was reviewed by OHEP in May 2018. Updates to Section 5 and Section 6 are factored directly into DESC operations planning and deployment of operations personnel. Other relevant documents for DESC Operations include the Science Requirements Document (The LSST Dark Energy Science Collaboration et al. 2018), a risk registry summarizing key risks for the collaboration's operations, and the DESC's computing plan (summarizing needed computing resources, and those that were secured at various facilities).

The Collaboration goals driving the SRM: The scale and complexity of the preparations ahead are substantial and will require:

- continued construction and validation of the collaboration simulation, (re-)processing, and analysis pipelines that will perform world-class cosmological analyses with the LSST data using the five main probes;
- characterization of instrumental, atmospheric, Galactic and extragalactic systematic contaminants to the level necessary to achieve the collaboration's dark sector science goals,

as encapsulated in the DESC Science Requirements Document (SRD; The LSST Dark Energy Science Collaboration et al. 2018);

- implementation and utilization of a computing infrastructure that meets the DESC data re-processing requirements and efficiently interfaces with the prompt and data release products[2] from the Project;
- effective utilization of external datasets and incorporation of lessons learned from precursor surveys;
- determination of quantitative requirements on, and use of corollary data from, other facilities (e.g., spectroscopy, multi-wavelength data and complementary, concurrent photometric survey data), as highlighted in a recent NRC report (Elmegreen 2015); and
- the development of the capabilities and coordination of the DESC team, including the training of the next generation of DESC researchers and leaders.

Prioritization of these activities will be driven by our understanding of the key limiting systematic uncertainties that must be reduced/mitigated in order to achieve our scientific goals. The DESC SRD (The LSST Dark Energy Science Collaboration et al. 2018) places requirements on our level of systematics control for elements of the analysis that are under our influence (beyond those that are already described by the Rubin Observatory Project's SRD). How close we are to meeting those requirements will determine some elements of how the DESC's work is prioritized, and/or how it is carried out: are we close enough that we can expect incremental improvements of existing algorithms to be sufficient, or might totally new approaches be needed? The initial DESC SRD version includes requirements on several pipelines: SHEARMEASUREMENTPIPE (control of redshift-dependent weak lensing shear calibration), PZSUMMARIZE (understanding of photometric redshift error distributions), WLNULLTEST (control of systematic biases in PSF models and understanding of stellar contamination), and several of the Photometric Corrections working group R&D plans and pipelines (control of several different issues that affect photometric calibration and its impact on supernova cosmology). Future versions of the SRM will include text highlighting key issues from the DESC SRD and commenting on how they affect the prioritization of work and on evaluation of the relevant pipelines in more detail.

[2]Throughout the SRM, we refer to the standard categorization of LSST data products. The Rubin Observatory LSST alert production (AP) pipeline will perform "prompt" data processing, generating products continuously every observing night, including alerts to objects with changes in brightness or position. The LSST data release production (DRP) data products are made available by Rubin Observatory annually, including images and measurements of positions, fluxes, shapes and variability information. "User-generated" products are created by the community to achieve their LSST science goals. See Ivezić et al. (2019) and Rubin Observatory document LSE-163 for details.

An incremental approach: To prepare for the first year of LSST data, we will incrementally build the necessary analysis infrastructure and team coordination. To this end, a central component of the SRM is a pair of Data Challenges of increasing scope and complexity (referred to as DC1 and DC2) followed by a period in which a variety of tools (both real and simulated data) will be used in the next steps toward science readiness. The DCs are collaboration-centered activities that use tailored simulated and real datasets to test and validate the tools and software infrastructure that will be used to analyze the LSST data. Activities in DC1 were largely tailored to two individual working groups' needs. DC2 features increased sophistication and more cross-working group analyses, with a coordinated collaboration-wide approach to simulation design, production, and validation, followed by analysis within working groups.

During the era of science readiness (referred to as SR: between DC2 and Science Validation), we will prepare for our re-processing and analysis of the LSST data, first during commissioning and then during the survey. DESC is providing inputs into the design of commissioning surveys in response to solicitations from the Project, and will eventually make use of data from the Rubin Observatory LSST Commissioning Camera (ComCam) instrument and the LSST Science Validation (SV[3]) data (from the full LSST Camera), to test DESC analysis pipelines and their interfaces to Rubin Observatory LSST DM products. We aim to get our pipelines set up and working at the appropriate scale to enable us to learn as much as possible from the SV commissioning data. More information on the Data Challenges and on Project Datasets is given in Section 6.1 and Section 6.2, respectively.

Each Data Challenge involves assessing and validating the required fidelity of survey simulation tools, producing the simulated data sets, and utilizing the datasets to validate analysis codes and isolate specific systematic effects in a controlled environment. The goal of the increasing complexity of the data challenges is to test our ability to mitigate increasingly subtle systematics together as well as in isolation[4]. The goal of the increasing scope is two-fold: first, to check that our systematics floor is lowering appropriately towards where it needs to be in order to handle the LSST data, which typically requires a substantial data volume; and second, to develop a workflow that involves running our pipelines (nearly) at LSST scale, as will be needed when there is real LSST data (FY23).

At that time, we anticipate that building systematic error budgets will require some repro-

[3]Within the Rubin Observatory Project, early engineering observations with both ComCam and LSSTCam are part of Science Verification, while sustained LSSTCam observing is part of Science Validation. DESC will most likely benefit from data from both the verification and the validation phases, but for simplicity we will refer to the overall body of work carried out by DESC using that data as "SV". The more detailed DESC Commissioning plan that outlines the details of tests to be performed will, of course, have to identify the exact datasets to be used for specific tests.

[4]While the simulated datasets contain many effects together, it is often possible to isolate individual ones by using the truth tables and/or by carrying out systematic tests that are particularly sensitive to just a single effect.

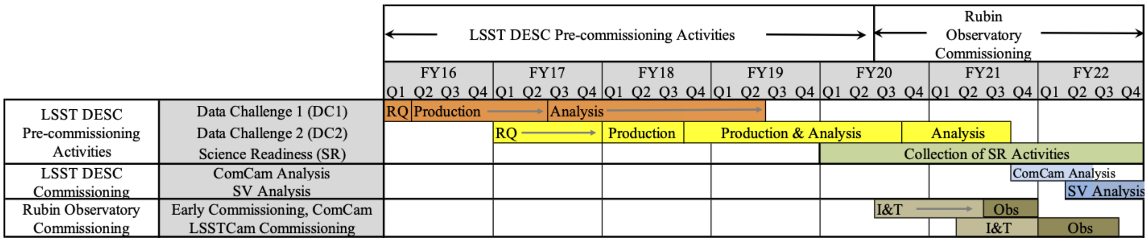

Figure 2.1.1: The DESC schedule through U.S. Fiscal Year 2022: Filled in sections represent work being completed by the end of that fiscal year quarter (e.g. work in Q3 would be completed by end of June). We are holding two simulated Data Challenges (DC1 and DC2) to support the incremental creation and validation of the data analysis and simulation pipelines. The timeline shows timeframes for setting the simulation requirements, data production and analysis in each challenge. The time period following DC2 includes the next steps to achieving science readiness, including work on simulated datasets, precursor data, and ComCam data through to the LSSTCam Science Validation (SV) survey data. *This timeline does not yet reflect the to-be-determined impacts of the pandemic on the schedule of either Rubin Observatory or DESC.*

cessing of the LSST images, at the level of $\sim$ 10 runs through $\sim 10\%$ of the dataset, even when running our analysis pipelines on the Rubin Observatory release data for the main scientific results. Hence, in order to be prepared for LSST data in terms of both data volume and systematics control, the increase in scope and complexity of our reprocessing of real or simulated data to something on the order of 10% of the first year LSST dataset is essential. Taking the multiple re-processings into account, we expect to need to be able to work with 300,000 visit images by the start of the survey in early FY2023. We aim to re-process and analyze the SV data in the same way as we will the Year 1 survey data: the goal of the data challenges is to realize a fully functional re-processing and analysis system by the time of the SV data release, that can demonstrate performance at the appropriate scale such that we are ready for the Year 1 data.

While the DCs will be a driver of the collaboration work through mid-2020, they do not represent the full scope of work during the pre-commissioning period. DESC activities also involve software development and theoretical research that does not wholly fall into the DC framework. They also utilize the availability of precursor datasets as testbeds to develop, refine and validate the software and tools. We expect to fully leverage any Rubin Observatory Project-processed external precursor datasets that Rubin Observatory makes available during the data challenge era. DESC re-processing of precursor datasets selected by the Project will help us make further early connections with the Project DM processing pipelines.

Figure 2.1.1 gives the DESC schedule from the start of DC1 in FY16 to the end of SV analysis in FY22. Based on the experience gained in DC1, the DC2 schedule was defined to allow extra time to learn from the results, with a longer analysis phase than in DC1. However, schedule delays during DC2 led to further updates to the schedule shown in Figure 2.1.1; the Rubin Observatory Project timelines also shifted somewhat later during this time period. The challenge datasets drive development of the analysis pipelines, providing validation datasets against which the code can be continuously tested. During the time period marked "science readiness", the focus will be on the final stages of preparing our simulation, processing, and analysis pipelines for LSST SV. In practice, the amount of ComCam analysis that can be undertaken by DESC may be limited due to recent reductions in the time period of ComCam observing (already reflected in Figure 2.1.1). Moreover, the time frame shown for ComCam and LSSTCam SV analysis presumes early access to images that DESC can download and process, the mechanism for which is still under discussion. The Rubin Observatory pre-operations team will release images and catalogs 6 and 9 months (respectively) after these datasets are taken. The SV dataset will lead to a well-tested suite of survey-ready simulation, processing and analysis tools.

The scope of the SRM: We emphasize that the activities and deliverables described in the SRM are not meant to be an exhaustive list of all work to be carried out within DESC. Rather, the SRM is focused on those mission-critical activities *essential to develop, build and validate the pipelines and infrastructure to undertake the core DESC cosmological analyses*. We make a distinction between the research and development needed to design the DESC algorithms (some of which is speculative or aspirational by nature), and the development work needed to implement them as production pipelines, execute them at appropriate scale with the necessary software infrastructure, and test them using challenge datasets. This construction work makes up the majority of the collaboration's operations activity in the period FY16–FY22. Note that since the SRM is focused on articulating the infrastructure that must be produced, activities such as ongoing software maintenance may not be well-captured by it.

The level of detail provided is intended to be sufficient to: **1)** coordinate and provide an integrated timeline for activities across the working groups and **2)** determine the scope of operations support (for both computing resources and personnel) needed to enable the DESC's science activities. A complete breakdown of activities to the task level is left to a more dynamic progress tracking system, based on the repositories used by the working groups for developing the tools and analyses, and the collaboration-wide "confluence" wiki.

The SRM process: The first version of the SRM was developed from June through October 2015 through a collaboration-wide process based upon working group discussions and collective authorship of the science probe and enabling sections. Since then, the SRM has evolved in several ways beyond basic updates in plans: work on operations deliverables was more cleanly distinguished from basic R&D, and once DESC had fully adopted the collaborative project-based model for its work as in the Publication Policy, the SRM was restructured to refer to projects defined within that system. A list of individuals who played major roles in coordinating and authoring the current version of each section and can provide further details on SRM plans is provided in Section 2.2.

DESC's collaborative model: Although the activities of different working groups are generally presented in separate sections of the SRM, we remain a single collaboration working together to achieve common goals, with many projects and other collaborative activities crossing multiple working groups. In addition to working together across working group lines within DESC, leveraging the knowledge and expertise of individuals associated with the Rubin Observatory Project is essential to our success. To this end, a set of individuals with key leadership roles within the Project serve as liaisons and work within DESC, facilitating information transfer and identifying opportunities for coordination of efforts.

DESC's collaborative, inclusive, project-driven approach to our common goals is described in the Publication Policy. A collaborative approach also enables the development and comparison of multiple, alternative algorithms and solutions to technical problems and their inclusion in the analysis pipeline. It is essential to have appropriate structures in place to facilitate and motivate collaborative coordination of DESC activities, and give appropriate recognition for sustained and critical efforts in preparing for the LSST data analysis. Career development opportunities for junior members are essential as they transition through graduate, postdoc and junior faculty positions, to be the future leaders of the collaboration. DESC must ensure visibility of junior members through speaking opportunities and recognition of effort reflected in publications, senior member mentoring and support, through letters of reference, and paths to leadership roles in science and governance activities. The DESC Builder Status Policy provides another mechanism for recognizing those who have carried out extensive efforts towards DESC's success. Finally, DESC has developed and adopted a Code of Conduct and a set of related practices that emphasize the Collaboration's commitment to collegial and respectful behavior between members in every aspect of collaboration life. This is essential to make certain that all members, from junior to senior, from all nations and backgrounds, feel able and encouraged to fully contribute to the Collaboration without fear of harassment, marginalization or exclusion.

2.2 Points of Contact

For questions about this version of the SRM, please contact the following people (the relevant working group conveners or coordinators). The current list of people serving in these convener and coordinator roles can be found on DESC internal and external contact pages.

Section	**Primary points of contact**
1 **Executive Summary and User Guide**, 2 **Introduction**, 8 **Appendices**	Spokesperson, Deputy Spokesperson
3 Primary Probe Working Groups	Analysis Coordinator and conveners of primary probe working groups for the subsection of interest
4 Cross-cutting Working Groups, 5 Pipelines and Computing Infrastructure, 6 Datasets	Technical, Computing & Simulations, Data, or Analysis Coordinators and working groups conveners for the subsection of interest

3 Primary Probe Working Groups

The DESC is organized around five main probes of dark energy enabled by the LSST data:

1. Weak gravitational lensing (WL) – the deflection of light from distant sources due to the bending of space-time by baryonic and dark matter along the line of sight, which allows a measurement of the growth rate of cosmic structure (and therefore is also sensitive to dark energy).

2. Large-scale structure (LSS) – the large-scale power spectrum for the spatial distribution of matter as a function of redshift. This includes the Baryonic Acoustic Oscillations (BAO) measurement of the distance-redshift relation.

3. Type Ia Supernovae (SN) – luminosity distance as a function of redshift measured with Type Ia SN as standardizable candles.

4. Galaxy clusters (CL) – the spatial density, distribution, and masses of galaxy clusters as a function of redshift.

5. Strong gravitational lensing (SL) – the angular displacement, morphological distortion, and time delay for the multiple images of a source object due to a massive foreground object.

Both weak and strong lensing can also probe the evolution of cosmic geometry. This list includes the four techniques (WL, LSS, SN, CL) described in the 2006 Report of the Dark Energy Task Force (DETF). The goal of the DESC is not just to carry out these analyses in isolation, but also to combine them; joint analysis is one goal of the Theory & Combined Probes working group (TJP), which also has the goal of addressing theoretical and statistical issues underlying the main probe analysis and cosmological constraints.

In this section we describe and lay out the key research priorities for each of these 5 individual probe analyses to prepare for dark energy science with LSST. These descriptions motivate the design of the analysis pipelines defined in Section 5.

3.1 Weak Lensing

Summary: Weak lensing (WL) as a cosmological probe is based on the fact that light emitted from background galaxies is continuously deflected as it travels through the gravitational potential of the matter density field. The statistical properties of the distorted galaxy images,

quantified by the shear field, reflect the statistical properties of the matter density field, which constrain the growth of structure and the geometry of the universe.

The primary observables that DESC-WL extract from the LSST data set are the shapes of galaxies, from which we infer the shear signal. A second necessary component is the redshift distribution of the galaxies inferred from multi-band photometry. Measuring and validating shear measurements, and validating sample photometric redshift distributions in collaboration with the PZ WG are essential tasks of DESC-WL.

In addition to acquiring the basic observables, DESC-WL has active R&D projects on techniques to constrain cosmological parameters via a number of summary statistics of the shear field. In a likelihood analysis these summary statistics are forward modeled as a function of cosmological and systematics parameters and compared to the observations, taking into account the correlation and statistical uncertainties of the data (quantified by the covariance matrix).

The most commonly used summary statistics in WL include cosmic shear (correlating galaxy shapes with galaxy shapes) and galaxy-galaxy lensing (correlating galaxy positions and galaxy shapes). Combining these two summary statistics with galaxy clustering (correlating galaxy positions with galaxy positions) forms a set of three two-point functions that is often referred to as the "3×2pt analysis". These 3×2pt analyses combines the power of WL and the large-scale structure (LSS), which increases not only the cosmological constraining power, but also the robustness to systematics. Beyond two-point statistics, there is also a large range of higher-order statistics that capture the non-Gaussian information in the matter field.

Systematics control and mitigation is at the heart of DESC-WL and the level to which WL from LSST data can constrain cosmology will be determined by our ability to 1) control uncertainties in measuring the shear and redshifts from our galaxies and 2) model astrophysical systematics, such as baryonic feedback processes, the intrinsic alignment of galaxies (which can masquerade as shear correlations), the non-linear evolution of the matter density field, and the galaxy-halo connection. Simulations, analytical calculations, and improved statistical methods play a critical role in this endeavor.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Images to shear catalog
   (a) Generate and test shear catalog on Data Challenge 2 (DC2): We are developing several WL shear estimation pipelines (e.g. Metacalibration, Bayesian Fourier Domain) to generate shear catalogs from DC2 images.
   (b) Develop a testing suite for shear catalog (combined with photo-z): A testing suite

for shear catalogs requires image simulations, but also a dedicated software framework that encodes all relevant tests ranging from catalog level to summary statistics.

(c) Quantify residual uncertainties in shear calibration due to instrumental and observing systematics (in close collaboration with BL, PSF and SAWG)

2. Shear, photo-z, LSS catalog to summary statistics (in close collaboration with PZ and LSS)
   (a) Extract reliable second-order summary statistics such as the 3×2pt analysis
   (b) Working with PZ and LSS to quantify, at the summary statistics level, residual uncertainties in shear calibration and photo-z for relevant galaxy samples
   (c) Develop blinding strategy (catalog level and downstream)
3. Summary statistics to cosmology
   (a) Develop WL-only and 3×2pt covariance matrices (in close collaboration with TJP)
   (b) Develop WL-only and 3×2pt forward modeling machinery (in close collaboration with TJP)
   (c) Quantify residual modeling uncertainties for astrophysics systematics (e.g. baryons, IA) and for theory approximations (in close collaboration with TJP)
   (d) Reliable sampling and inference method, as well as metrics to quantify internal consistency and external consistency (non-LSST data sets)
   (e) Optimize observing strategy for cosmology from WL and 3×2pt analyses (in close collaboration with OS)

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for this working group are as follows.

1. Develop pipeline for non-Gaussian statistics: Higher-order statistics (bi-spectra, tri-spectra, log-transformations of the shear field, etc) or direct map-reconstruction based inference contain valuable cosmological information, that will add to the standard two-point function analysis.
2. Joint analyses with synergistic data sets that specifically target WL systematics: Joint analysis of WL+X, or 3×2pt+X will increase cosmological information, but the cost-benefit calculation varies strongly as a function of X. Identifying the most important synergistic data sets to offset WL systematics (Baryons, IA, shear+photo-z calibration) is critical to efficiently allocate DESC's limited resources for building corresponding analysis pipelines.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 2: Analyzing the Impact of Brighter-Fatter on WL Observables. Other WG: SA.

→ Project 5: Atmospheric PSF interpolation with Gaussian Processes. Other WG: PSF.

→ Project 11: DC2 Project: 3x2pt analysis with DC2 catalogs. Other WGs: LSS, PZ, TJP.

→ Project 18: DC2 Project: Mass-mapping from DC2 catalogs.

→ Project 20: DC2 Project: Probabilistic shear maps from BFD.

→ Project 21: DC2 Project: Producing BFD catalogs.

→ Project 23: DC2 Project: Production of metacalibration shape catalog for DC2.

→ Project 36: Forecasting the Potential of Weak Lensing Magnification at LSST. Other WGs: LSS, TJP.

→ Project 37: Galaxy blending effects in deep imaging probes of cosmology. Other WG: BL.

→ Project 39: Impact of Higher Order Moments Error of PSF Model on WL. Other WG: PSF.

→ Project 43: Implementation of Metadetection and Validation with Simulations.

→ Project 44: Intrinsic alignment self-calibration. Other WGs: CS, TJP.

→ Project 45: Joint DC2 LSST-WFIRST pixel-level simulations and analysisDC2/DC3 image simulation. Other WG: PZ.

→ Project 48: LSST Observing Strategy 3x2pt FoM Emulator.

→ Project 50: n(z) shape + galaxy bias degeneracies in 3x2 point. Other WGs: PZ, TJP.

→ Project 53: Optimal weak lensing non-Gaussian statistics.

→ Project 67: Requirements on PZ errors for 3x2pt. Other WGs: PZ, TJP.

→ Project 71: Test Piff PSF Models on DC2 Images.

→ Project 75: Using TXPipe to re-analyze precursor surveys. Other WG: LSS.

→ Project 76: Using TXPipe to re-analyze precursor surveys. Other WGs: LSS, PZ.

- Project 79: Deblending galaxies with variational autoencoders. Other WG: BL.

- Project 80: Effects of Overlapping Sources on Cosmic Shear Estimation: Statistical Sensitivity and Pixel-Noise Bias. Other WG: BL.

- Project 82: Observing strategy studies for weak lensing. Other WG: OS.

✓ Project 84: Shear measurement bias due to spatially varying spectral energy distributions in galaxies.

✓ Project 92: Re-analysis of Precursor Cosmic Shear Surveys.

✓ Project 93: Sparse Bayesian mass-mapping with uncertainties.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

3.2 Large-scale Structure

Summary: The Large-scale Structure (LSS) working group is in charge of delivering cosmological constraints from the statistics of galaxy positions (for this reason, this probe is also commonly called *galaxy clustering*). In the standard description, the distribution of galaxies acts as a proxy of the underlying matter fluctuations, and therefore it can be used to reconstruct some of the features left by the cosmic evolution in the distribution of structures through gravitational collapse. The main source of uncertainty in galaxy clustering measurements therefore lies in the details of the relation between the matter density fluctuations and the inhomogeneities in the number density of galaxies. Although on sufficiently large scales there are good reasons to expect that this relation should be sufficiently well described by a linear bias factor connecting both overdensities, a non-linear, stochastic and possibly non-local relation is needed on smaller scales. This relation may also depend on local environmental properties, or on the merging history of the dark matter halos hosting these galaxies. This group is therefore responsible for making sure that we are able to reliably account for these astrophysical uncertainties in the final cosmological constraints.

Galaxy clustering measurements are particularly sensitive to any observational systematic that could induce artificial variations in the number density of observed sources. The LSS group is therefore invested in quantifying the key systematics that could cause these variations (e.g. variations in observing conditions, dust, stars etc.), accurately mapping them on the sky, and developing robust methods to minimize their impact on the key summary statistics used to extract cosmological information (e.g. two-point functions and power spectra).

Because the overdensity of galaxies traces the local matter fluctuations (as opposed to e.g. the projected ones in the case of weak lensing), LSS is also sensitive to the quality of photometric redshifts, since they limit our ability to recover information from small radial scales. Together with the higher signal-to-noise ratio of the galaxy clustering observables (again compared to e.g. weak lensing), this has two consequences: on the one hand, cosmological constraints can benefit significantly from using a small sample of galaxies with high-quality photo-zs, and therefore optimal sample selection is a key concern for this group. On the other hand, galaxy clustering constraints are more sensitive to uncertainties in the redshift distribution, and these must therefore be carefully quantified.

Research priorities: Historically, accurate measurements of the power spectrum and its uncertainties has been a major research topic of the LSS working group. However, the recent power spectrum estimation packages `NaMaster` is sufficiently optimal and validated that it will serve the need of this group for the foreseable future. It also calculates the disconnected part of the covariance matrix and other subdominant contributions of measurement uncertainty will be handled as part of Theory & Joint Probes research priorities. Instead, the research priorities of the LSS group can be articulated around the main sources of astrophysical and observational systematics described in the previous section:

1. Modeling the galaxy-matter relation.
   (a) Ensuring that a sufficiently broad range of bias models (e.g. perturbation theory and effective field theory approaches, halo models) are implemented in the DESC theory pipelines.
   (b) Quantifying the scales on which existing galaxy bias models can be used reliably without biasing the final cosmological constraints.
2. Survey geometry, systematics mapping and 2-point functions.
   (a) Software infrastructure for survey geometry representation.
   (b) Accurate methods to map observing conditions, depth variations and other possible sky systematics. Develop requirements on the precision of these maps.
   (c) Robust estimate of two-point statistics (and their uncertainties) in the presence of these systematics.
3. Sample selection.
   (a) Develop science-driven methods to identify the optimal sub-sample of galaxies for large-scale structure analyses.
   (b) Place requirements on the properties of the clustering sample needed to meet the DESC science objectives.

   (c) Investigate the performance of different approaches (e.g. target specific populations, blind color-based sampling, photo-z-based sampling) and their sensitivity to observational and photo-z systematics.

4. Photo-z uncertainties.

   (a) Develop methods to marginalize over the relevant uncertainties related to the redshift distribution of the clustering samples. Compare different approaches (e.g. shifts and widths, full marginalization over $N(z)$ amplitudes, simultaneous likelihood-level $N(z)$ sampling, auto-calibration). The method's requirements will probably be distinct from those of other WGs (e.g. weak lensing).

   (b) Place requirements on the accuracy with which the redshift distributions and their uncertainties must be known to avoid biasing the final cosmological constraints (or degrading them below the DESC science goals). These will map onto requirements on spectroscopic coverage or redshift overlap (in the case of clustering redshifts).

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for LSS are as follows.

1. Develop software to estimate higher-order statistics (bispectra, Minkowski functionals etc.) and to use them for cosmological constraints.

2. Investigate the potential of LSS data from LSST to constrain the level of primordial non-Gaussianity, including through multi-tracer techniques and lensing cross-correlations. Quantify the requirements on the level of systematics contamination needed to make a competitive measurement.

3. Develop infrastructure for likelihood-free inference methods and for Bayesian large-scale structure reconstruction techniques.

4. Develop data compression methods that would enable a robust 3D analysis of large-scale structure with photometric redshifts. Explore the potential of this method to reduce the dimensionality of the LSST data vector.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 11: DC2 Project: 3x2pt analysis with DC2 catalogs. Other WGs: PZ, WL, TJP.

→ Project 14: DC2 Project: Galaxy Clustering Analysis.

→ Project 19: DC2 Project: Non-linear bias and assembly bias modelling. Other WG: TJP.

→ Project 35: Extreme Emission Line Galaxies as an LSS Platinum Sample.

→ Project 36: Forecasting the Potential of Weak Lensing Magnification at LSST. Other WGs: WL, TJP.

→ Project 40: Impact of LSS systematics.

→ Project 75: Using TXPipe to re-analyze precursor surveys. Other WG: WL.

→ Project 76: Using TXPipe to re-analyze precursor surveys. Other WGs: PZ, WL.

- Project 81: Galaxy Clustering in the Public HSC DR1 data.

- Project 83: Simultaneous Estimation of LSS and Milky Way Dust.

✓ Project 85: DC1 Analysis. Other WGs: CO, SSIM.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

3.3 Supernovae

Summary: Type Ia supernovae (SNIa) are standardizable candles first used to the discover the accelerating expansion of the Universe. It is an incisive cosmological probe that is sensitive probe of the expansion history, and therefore can strongly constrain the difference between the amount of dark energy, $\Omega_{\rm DE}$ and the amount of dark matter, $\Omega_{\rm M}$. The calibrated apparent magnitude of each SNIa is used to derive a luminosity distance $d_{\rm L}(z)$, while the redshift, z, of each source (either spectroscopic or photometric) can be directly converted into a recession velocity. The combination of the two quantities traces the expansion history of the Universe. LSST will produce hundreds of thousands of supernovae over an extremely large redshift range; two orders of magnitude more objects than all extant supernova surveys combined. This large homogenous sample of objects will provide strong constraints on the equation of state of dark energy, w, any potential evolution over cosmic time, w_a, as well as a high-precision test of the homogeneity and isotropy of the dark energy.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Optimizing measurement of the SNIa flux
   (a) Validating LSST difference image analysis with simulated images and external datasets
   (b) Testing alternate methods of subtracting background e.g. scene modeling
   (c) Measuring biases in photometry as a function of host-brightness, S/N, galactocentric distance
   (d) Optimizing LSST cadence to improve SNIa distances and ensure best leverage in cosmological parameter space
2. Identifying SNIa within the LSST alert stream
   (a) Testing different methods to identify SNIa in the realtime LSST alert stream
   (b) Working with broker teams to incorporate a DESC SNIa classifier
   (c) Ensuring we can measure the selection function imposed by the full measurement chain, even if brokers are independent of DESC
   (d) Ensure that the selection function imposed by classifiers/brokers does not introduce any cosmological bias
   (e) Determine the impact of contamination from other classes of SNe on cosmology
3. Spectroscopic followup of a subset of SNIa
   (a) Devising and testing a recommendation system that determines what SN candidates identified in the alert stream merit spectroscopy
   (b) Identifying and applying to use community resources for spectroscopic followup, coordinating with the External Synergies Working Group wherever possible
   (c) Examining the utility of an active learning system that improves classifier performance with every spectrum obtained
   (d) Constructing and validating a full pipeline for a spectroscopic sample analysis based on DDFs after year 1
4. Extracting calibrated SNIa light curves, together with necessary metadata from LSST images
   (a) Identifying what features of the SN host-environment we should extract from the images for downstream analysis
   (b) Work alongside Point Spread Function Working Group (PSFWG) to estimate the impact of PSF errors on SN analysis and improve PSF modeling

(c) Work alongside Photometric Calibration Working Group (PCWG) to ensure that the time-dependent flux calibration and model of throughput system is monitored for SN analysis

(d) Work alongside Photo-z working group (PZWG) to ensure that photometric redshifts for SN hosts are available

(e) Work alongside LSST Galaxies Science Collaboration to collect metadata from each host such as stellar mass or star-formation rate

5. Understanding the correlations between SNe and their host environment

   (a) Determining how host-galaxy information can be used to improve classification
   (b) Determining how to plausibly embed SNe in host-galaxies in a manner that preserves correlations
   (c) Identifying the underlying physics of the SN-host mass correlation and determine how best to model the effect for our cosmological analysis

6. Developing improved models to standardize SNIa and measure distances

   (a) Improving light curve fitting methods to better model the diversity of SNIa
   (b) Extending light curve fitters into the rest-frame ultraviolet and infrared, for use at higher redshift
   (c) Extending light curve fitters to accept photometric redshift distributions, and produce confidence that object in a SNIa for use with photometric cosmology methods (e.g. SCIPPR)
   (d) Extending light curve fitters to incorporate host-galaxy information to better model distances
   (e) Determining how many SNIa need infrared observations for tighter cosmological constraints from a combined optical + NIR sample

7. Forward modeling the entire measurement chain to understand the biases introduced in cosmological inference

   (a) Propagating knowledge of time-dependent calibrations into simulations of SN
   (b) Refining SN rate models, and incorporate realistic photometric contamination
   (c) Incorporating SN-host galaxy correlations into simulations at the pixel level
   (d) Generalizing bias model to account for more complex effects
   (e) Determining what subsample reduces/eliminates bias corrections

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for this working group are as follows.

1. Detection of SNIa within dwarf galaxies, to define a subset that may lead to lower biases on cosmological inference
2. Using SNe to test assumptions of isotropy and homogeneity
3. Using Hubble diagram residuals to measure peculiar velocities to infer cosmological growth rate.
4. Understanding the impact of WL on distance determination for SNIa
5. Using strongly lensed supernovae for cosmological inference
6. Investigating the cosmological utility of gravitational wave sources as standard sirens, or other explosive transients as standard candles

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 1: A New Deep Learning Model for Photometric Redshift Estimation with DC2. Other WG: PZ.

→ Project 3: Application of snmachine to PLAsTiCC data.

→ Project 8: Cosmology bias from photometric SNe Ia redshift systematics.

→ Project 27: DESC Broker services.

→ Project 30: Developing improved image subtraction methods on DC2 dataset.. Other WG: SL.

→ Project 32: Efficiency of detection of variable sources in DC2.

→ Project 33: Evaluating the impact of the observing strategy on supernova Ia classification for cosmology. Other WG: OS.

→ Project 41: Impact of Saturation on LSST SN cosmology.

→ Project 42: Impact of Weak Lensing Magnification on SN Cosmology. Other WG: CS.

→ Project 47: Leveraging Host Galaxy Correlations for Supernova Classification. Other WG: PZ.

→ Project 52: Obtaining Peculiar Velocities From SN.

→ Project 54: Optimising a spectroscopic training sample for photometric classification of transients. Other WG: OS.

→ Project 55: Optimizing multi-class spectroscopic follow-up in PLAsTiCC using active learning.

→ Project 56: Placing Supernovae Realistically in Galaxies in the LSST Simulated Sky.

→ Project 57: PLAsTiCC Papers.

→ Project 58: PLAsTiCC Papers I.

→ Project 59: PLAsTiCC Papers II.

→ Project 60: PLAsTiCC Papers III.

→ Project 61: PLAsTiCC Papers IV.

→ Project 62: PLAsTiCC Papers V.

→ Project 65: Recovering Sub-threshold Gravitational Wave Signals with LSST Data.

→ Project 68: RESSPECT: REcommendation System for SPECTroscopic follow-up.

→ Project 70: Supernova SRD studies.

→ Project 72: The Electromagnetic and Gravitational-Wave Selection Functions for Detections of Binary Neutron Star Mergers.

✓ Project 89: Detectability of Kilonovae.

✓ Project 90: Enabling LSST simulations Of transients.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

3.4 Clusters of Galaxies

Summary: Measurements of the mass function of galaxy clusters (the number density as a function of mass and redshift) are sensitive to both the expansion history and growth of structure in the Universe. These measurements can provide powerful constraints on dark energy and fundamental physics, and are critical in distinguishing between dark energy and modified gravity models of cosmic acceleration. Measurements of the clustering of clusters, the baryonic

mass fraction in clusters, and of the tomographic lensing signatures through clusters, provide additional ways to constrain cosmology. As with all cosmological probes, the key to extracting robust cosmological constraints from clusters is the control of systematic uncertainties, particularly those associated with relating the observed properties of clusters to the underlying matter distribution. This requires a coordinated, multi-wavelength approach and the application of rigorous statistical methods, informed by simulations.

The four main steps in extracting robust cosmological constraints from the observed number density of galaxy clusters are: 1) predicting the mass function as a function of cosmological parameters; 2) constructing the observed catalogs of clusters; 3) determining the statistical relationships between observed cluster properties and halo mass; and 4) extracting the cosmological information of interest using a self-consistent likelihood analysis. LSST data will be critical for steps 2 and 3, while DESC analyses will define the state-of-the-art for steps 1–4.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Accurate cosmological predictions
   (a) Develop accurate emulators of the halo mass function, and the halo–mass and halo–halo correlation functions.
   (b) Characterize robustness of these predictions to baryonic feedback.
2. Cluster Detection
   (a) Develop and characterize one or more high-quality photometric cluster finders.
3. Characterization of the Survey Observable–Mass Relation
   (a) Develop parametric models that adequately describe the relation between the survey mass proxy (e.g. cluster richness) and cluster mass, including the impact of cluster miscentering, halo triaxiality and projection effects. Parameterize how these effects impact the recovered weak lensing profiles of galaxy clusters.
   (b) Develop tools for analyzing the weak lensing profile of galaxy clusters for the purposes of determining the mean relation between cluster observable and cluster mass.
   (c) Utilize simulated and multi-wavelength cluster data sets to provide critical priors on the shape of the paramatric model, and the scatter in cluster observable at fixed mass.
4. Likelihood Framework

(a) Combine the above components into a single cosmological-inference pipeline, and stress-test the pipeline by applying to simulated and existing cluster data sets, as well as early commissioning data.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 12: DC2 Project: Cluster Mass Calibration.

→ Project 25: DC2 Project: Running redMaPPer on DC2 Cosmo and Sim Catalogs. Other WG: PZ.

→ Project 28: DESC+DES: Quantifying the effects of cluster triaxiality on cosmology with simulations. Other WG: CS.

→ Project 31: Effects of blending on galaxy cluster shear measurements. Other WG: BL.

→ Project 77: Validation and characterization of redMaPPer cluster catalogs on DESC simulations.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

3.5 Strong Lensing

Summary: The Strong Lensing (SL) working group is responsible for finding, characterizing and monitoring strong lens systems from LSST, and performing the cosmological analysis of the lenses. These lens systems include lensed quasar and supernova systems that result in time delays and require multi-year light curves, and multiple source plane lenses (or "compound lenses"). Cosmographic inference from these systems requires detailed mass modelling and spectroscopic follow up.

Strong lensing is unique among LSST cosmological probes in two respects. First it relies on a smaller number of carefully selected and very well characterised systems, rather than on inference based on extracting statistical properties hidden in correlations between millions of objects. Second, it is the only technique that uses a dimensional quantity (time delays are measured in units of time, as opposed to example angles and redshifts), which gives us a much more direct and less theoretically dependent measurement of the expansion rate. As such it offers important cross check and complementary information to other LSST probes.

The three main tasks of the SL working group therefore are lens detection, time delay measurement and environment characterization. The SL working group will find new lens systems using an LSST strong lens finder code/pipeline. The working group will monitor the time-variable lenses using a complementary monitoring pipeline, including external data, which are needed for modelling of both lensed quasars and SNe systems. The time delays of the variable systems will be inferred using the strong lens timing pipeline. The lens environments and properties of the lens systems will be modeled with the SL environment counter and SL mass mapper pipelines.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Develop and test a pipeline to find, monitor and characterize time-delay strong lens systems from LSST difference images.
   - (a) Develop and test SL monitoring pipeline on simulations and precursor data.
   - (b) Develop code for time delay inference and test on simulations and precursor data.
   - (c) Develop a strategy for ground-based follow up of strong lensing systems, including lensed SNe systems and lensed quasar systems
2. Develop and test a pipeline to find and model compound lens sources from LSST static images.
   - (a) Develop lens candidate extraction algorithm, and test on simulations and precursor data.
   - (b) Develop code to estimate the weak lensing effects from weighted galaxy number density.
   - (c) Build code to compute the line-of-sight mass reconstruction of compound lens sources, test on simulations.
   - (d) Build a pipeline for coadding LSST images to discover fainter compound systems.
3. Build and test pipeline to infer cosmological parameters from the modeled compound and time-delay systems, test on simulations and precursor data.
   - (a) Develop and test the modelling of self calibrated lensing systematics including lens model assumptions (lens galaxy mass distribution), environment effects (including

halo vs. stellar mass relation), line-of-sight structure, compound lensing in double source plane

(b) Build and test the pipeline for including calibrated lensing systematics including time delay measurement systematics, selection bias, photometry issues including blending, photo-z and $\mathcal{M}$ errors in environment analysis

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for this working group are as follows.

1. Enabling community-driven model of inferring time delays, to compute more accurate diagnostics and strong lensing Figures-or-Merit.

2. Enabling community-mass modeling of compound lenses.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 4: Apply Deep Learning to Identify and Deblend Strong Lenses for LSST. Other WG: CS.

→ Project 17: DC2 Project: Machine Learning Catalog-level Emulation and Detection of Lensed AGN Systems in DC2.

→ Project 30: Developing improved image subtraction methods on DC2 dataset.. Other WG: SN.

→ Project 38: Hierarchical Inference of Cosmological Parameters from Deep-Learned LSST Time Delay Lens Models.

→ Project 73: The Lensing Sprinkler: Software for Strong Lensing Simulations.

→ Project 74: Time-delay measurements of SL SNe Ia. Other WG: OS.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4 Cross-cutting Working Groups

Many DESC working groups encapsulate high-priority activities that enable, relate to, or combine results from the dark energy probes from Section 3. We call these "cross-cutting" WGs; they are each described, and research priorities highlighted, below.

4.1 Blending

Summary: Two or more objects are described as "blended" if their images overlap enough that each object's properties cannot be accurately measured independently. The current LSST DM science pipeline addresses the challenges presented by blended objects in three steps: (i) object *detection,* which includes identification of above-threshold regions and approximate positions of objects within them; (ii) construction of individual object images or models in which a portion of the flux in each pixel is assigned to each blended object (*deblender*); and (iii) measurement of position, shape, flux, etc., for the deblended object. Detection, deblending and measurement can be an iterative process, and pairs of these operations, such as deblending and measurement, could be done simultaneously.

The current LSST DM deblender is derived from the single-band SDSS deblender and has been used in all Hyper Suprime-Cam releases to date, but is known to be inadequate for LSST depths. A new multi-band deblender, called Scarlet[5], is being integrated in DM and evaluated. The Multi-object Fitting deblender[6] (MOF), first developed within the DES, is also being used for comparisons. Given the challenges in dealing with blended objects, LSST DM has said that it welcomes research, development, and testing of new and existing algorithms.

Early goals of the BL WG include establishing quantitative metrics for the impacts of blending and measuring the baseline performance of existing algorithms to compare to established requirements (e.g., on shear biases). In addition, missing requirements will be established (e.g., impacts of blending on photometric redshifts). An additional goal of the WG is to explore and test new algorithms for detection, deblending, and/or measurement of blended objects, including machine-learning approaches that leverage recent advances in "deep learning".

Some studies of performance metrics will involve working with pixel-level simulations or data. For detection algorithms, performance metrics could describe whether blended objects are accurately recognized as blends, unrecognized as blends, iteratively recognized as blends, shredded into multiple objects, etc. The metrics for deblending and measurement algorithms will include the accuracy of shape measurements and photometry for blended objects. Impacts

[5]https://github.com/pmelchior/scarlet
[6]https://github.com/esheldon/mof

of detection failures on higher level quantities, such as photo-z estimates or 2-point correlation functions, could be studied with pixel-level datasets, or with catalog-level simulations (with no pixel simulation) if accurate surrogates for detection and deblending performance can be identified based on only catalog-level quantities.

In support of these goals, BL WG activities include design and implementation of tools for training and testing algorithms, and the coordination and curation of real data sets (ground and space) and simulations, including injection of simulated objects into real data. These are described later in the software and dataset sections of the SRM.

As a cross-cutting WG, BL provides a communication channel and the sharing of relevant expertise across the many WGs touched by blending challenges, and between the DESC and LSST DM. Many of the research priorities and DESC Projects described below involve more than one DESC WG and are coordinated within the BL WG. A few activities are focused within a particular WG (e.g., CL) but benefit from feedback from the broader community engaged in the BL WG. In addition to regular BL WG meetings, the BL WG engages in organizing workshops that involve experts in LSST DM and members of other LSST science collaborations who have relevant expertise in areas impacted by blending.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Develop blending requirements for dark energy science. Connect shear calibration requirements and photometric redshift requirements to requirements on residual blending effects, to feed into the DESC Science Requirements Document.

2. Evaluate techniques being developed to calibrate the impacts of blending on shear estimation and photometric redshift measurements, including Metacalibration and Metadetection algorithms, and simulation-based forward modeling.

3. Explore new algorithms for detection, deblending, and/or measurement of blended objects, including machine-learning (ML) approaches that leverage recent advances in "deep learning". Deep morphology priors are being incorporated in the Scarlet framework. While ML approaches to deblending may not be mature enough to be included in DM pipelines for initial processing, these approaches may have a significant role to play in deblending later in LSST operations.

4. Study the impacts of blending on galaxy cluster shear measurements. Investigate the impact of multi-band deblending and whether color information can be used to identify blends and correct the measured shear and photometric redshift in cluster analyses.

5. Explore the effectiveness of joint pixel-level processing of deep LSST images and high spatial resolution space-based images for mitigating blending-related systematic effects on shear estimation and redshift measurements — for example, using deep LSST coadds with forced deblending based on a catalog derived from space data, or joint pixel processing of LSST and Euclid / WFIRST data. Note that DESC does not have the resources to carry out a full joint pixel processing; however, smaller scale proccessing to inform a full processing with additional resources, and studies to understand the benefits of forced deblending versus joint pixel-level processing, would be valuable and in scope here.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 6: BlendingToolKit: A framework to generate images of blended objects and evaluate performance metrics for different algorithms..

→ Project 29: Detecting unrecognized blends from residual images.

→ Project 31: Effects of blending on galaxy cluster shear measurements. Other WG: CL.

→ Project 37: Galaxy blending effects in deep imaging probes of cosmology. Other WG: WL.

→ Project 63: PZ blending. Other WG: PZ.

- Project 79: Deblending galaxies with variational autoencoders. Other WG: WL.

- Project 80: Effects of Overlapping Sources on Cosmic Shear Estimation: Statistical Sensitivity and Pixel-Noise Bias. Other WG: WL.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.2 Observing Strategy

Summary: The observing strategy of LSST (including footprint, choice of filter changes, cadence, choice of deep drilling fields etc.) has critical impact on almost every science case done with LSST. The goal of the Observing Strategy Working Group is to study the impact of observing strategy on DESC science and to work with the LSST Project to develop an observing strategy that will maximise the cosmological constraining power of LSST, without detrimentally impacting the other major science themes. We work with the Operations Simulator[7] (OpSim) team to produce realistic observing strategy simulations, develop metrics (coded in the Metric Analysis Framework[8]) to evaluate these simulations and feed back our conclusions to the Project.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Develop metrics to evaluate observing strategy simulations. These metrics are critical to determine the effectiveness of various strategies for cosmological constraints and consist of two different types of metrics:
   (a) Heuristic metrics such as sky area and number of visits per field that are expected to correlate with improved cosmological constraints.
   (b) Emulated cosmological constraints in the form of the DETF Figure of Merit, both for static science probes and supernovae.
2. Perform studies of residual systematics due to observing strategy, to feed back into the DESC working groups and inform their analysis pipeline development.
3. Propose changes to observing strategies, evaluate existing simulations and feed back conclusions to the Project team and eventually, to the Survey Strategy Committee, to make a final recommendation of the LSST observing strategy.
4. Continue to evaluate and suggest changes to the observing strategy while the LSST survey is underway.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 33: Evaluating the impact of the observing strategy on supernova Ia classification for cosmology. Other WG: SN.

→ Project 34: Exploring time-dependence of atmospheric PSF parameters. Other WG: PSF.

→ Project 54: Optimising a spectroscopic training sample for photometric classification of transients. Other WG: SN.

→ Project 74: Time-delay measurements of SL SNe Ia. Other WG: SL.

- Project 82: Observing strategy studies for weak lensing. Other WG: WL.

[7] https://www.lsst.org/scientists/simulations/opsim
[8] https://www.lsst.org/scientists/simulations/maf

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.3 Photometric Corrections

Summary: Photometric calibration uncertainties have a major impact on the measurement of the Dark Energy equation of state with SNe Ia – as well as other dark energy probes, via their impact on photometric redshifts. DESC-specific calibration requirements, essentially driven by SN Ia cosmology, are especially stringent and may be summarized with two key quantities: the *relative* (band-to-band) flux calibration needs to be controlled at the 0.1% level, and the mean wavelength of the survey passbands should be known with an accuracy of 0.1-nm according to the LSST DESC Science Requirements Document v1 (The LSST Dark Energy Science Collaboration et al. 2018) and to the study performed by Hazenberg et al. (2018).

The Photometric Corrections Working Group (PCWG) works alongside LSST Project to ensure that these requirements will be met shortly after first light. The production of calibrated magnitudes involves algorithms and procedures implemented in Level 1 and Level 2 pipelines and is ultimately under the responsibility of LSST DM. PCWG work focuses on (1) the characterization of the Primary flux standards used to set the survey flux scale (2) the validation of DM algorithms, notably point source photometry and survey uniformity (3) in-situ filter metrology using the Collimated Beam Projector (4) the measurement of the atmospheric transmission from the Auxiliary telescope. All these aspects require a close connection with LSST Project. Other aspects of photometric calibration are more specific to DESC, e.g. the mitigation of the effects of Galactic extinction on calibrated magnitudes. Within DESC, PCWG works with the Science Working Groups to evaluate how the expected photometric calibration uncertainties impact dark energy probes.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. *Primary flux scale:* as of today, the primary flux references are defined using models of white dwarf atmospheres. While there are hints that this is probably accurate at the

1% level, this needs to be checked to reach an accuracy of 0.1%. Several projects aim at a direct comparison of the white dwarf flux scale (above) and the detector-based flux scale maintained at NIST. Two of these projects are being carried out by members of PCWG. starDICE re-observes primary flux standards with a dedicated photometric telescope whose calibration is monitored in real time with a stable, NIST-calibrated light source, made of 24-narrow-spectrum LEDs. SCALA carries out a similar program, with the SNIFS instrument, mounted on the UH-2.2-m. Both projects have reached a precision of ∼1% (SCALA) and ∼2-3% (starDICE) and are being upgraded to reach sub-percent accuracy. starDICE is also used as a test bench for filter metrology.

2. *Validate DM point source photometry:* point source photometry algorithms are the main link in the flux calibration chain. It is therefore essential to check that DM flux measurements are not sensitive to observing conditions (seeing, background level) and are not affected by known biases (linearity, PSF chromaticity) at the per-mil level. This validation work may be carried out on precursor datasets, such as SNLS, DES, or HSC, or on simulated data.

3. *Survey uniformity:* As with the validation of the point source photometry, quantifying and improving survey uniformity will require a combination of internal data checks and comparison to external datasets such as Gaia.

4. *Filter metrology:* to compare supernova or galaxy fluxes to model predictions (e.g. to deliver SN distances or galaxy photometric redshifts), one needs models of the survey passbands. Such models are assembled from testbench measurements of the optical components (mirrors, lenses and filters). To monitor the evolution of survey passbands as a function of time, LSST base plan is to use a Collimated Beam Projector (CoBP), a monochromatic pencil beam to perform in situ measurements of the survey passbands. The accuracy of this method is being investigated. PCWG members are currently experimenting with a "precursor CBP" to measure and then to monitor in situ the passbands of the starDICE telescopes – with plans to use this precursor CBP on larger survey telescopes (Blanco, ZTF, Subaru).

5. *Atmospheric transmission monitoring & participation to the commissioning and operations of the Auxiliary telescope (AuxTel)*: The transmission of the atmosphere at the time of observation is part of the effective passband determination. The 1.2-m LSST Auxiliary telescope is equipped with an instrument that can deliver either images or low-resolution slitless spectroscopy. Monitoring spectra of stars using AuxTel allows constraints on the (wavelength-dependent component) of the variations of the atmospheric transmission along the line of sight. PCWG is involved in the preparation of the AuxTel

observing plan, and also in the development and validation of the AuxTel photometric and spectroscopic pipeline.

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for this working group are as follows.

1. Obtaining a flux calibration and survey passband determination more accurate than the survey base plans is obviously an enhancement of the survey baseline.

2. SN cosmology will greatly benefit from a survey calibrated at the per-mil level, as the constraints on a varying dark energy equation of state will go from "marginal" to "stringent".

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.4 Point-Spread Function

Summary: The LSST point spread function (PSF) is a required element of most measurement algorithms, including those for astrometry, photometry, and morphology. As such, systematic errors in the PSF can potentially impact all DESC probes. The goals of this working group are to characterize and mitigate the impact of LSST PSF errors on LSST dark energy constraints.

Research priorities: The research priorities of the PSF working group can be broadly characterized as follows.

1. Analysis of PSF systematic errors:

   (a) Estimate the impact of specific PSF errors – for example, low-order PSF moment residuals, chromatic effects, and correlations thereof, on DESC dark energy constraints.

   (b) Develop requirements on PSF residuals and correlation functions, that will limit the impact of PSF systematics.

(c) Develop mitigation strategies, such as techniques that can accurately marginalize PSF systematic errors, or mitigations originating in survey strategy.

(d) Study how residual CCD systematics that are not strictly a convolution, but that can contaminate PSF models through their impact on the images of stars used for PSF estimation, impact dark energy constraints.

2. PSF modeling improvements:

   (a) In concert with Data Management's plans for level-2 PSF estimation (see section 6.11.3, Full Visit PSF Estimation, of LDM-151), analyze new PSF modeling approaches – for example, a consistent physics-based model across the entire LSST focal plane – in the context of dark energy science.

   (b) Investigate use of LSST wavefront sensor information to constrain the optical contribution to the PSF.

   (c) Explore methodology for modeling PSF chromaticity and including it in object measurement.

3. Increased understanding of PSF physics:

   (a) Review existing data, including specialized observations or laboratory measurements, that can enhance our PSF modeling accuracy and/or help create better PSF simulations.

Research projects: Below is a list of approved PSF WG research projects with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 5: Atmospheric PSF interpolation with Gaussian Processes. Other WG: WL.

→ Project 34: Exploring time-dependence of atmospheric PSF parameters. Other WG: OS.

→ Project 39: Impact of Higher Order Moments Error of PSF Model on WL. Other WG: WL.

4.5 Sensor Anomalies

Summary: In the context of LSST, sensor anomalies refer to the departure of CCDs' response from a perfectly cartesian sampling of the image, with a linear response. These departures from perfection impact core measurements such as positions, fluxes and shapes. The Sensor

Anomalies Working Group works in close connection to the LSST Project and aims at characterizing the LSST CCDs and developing the methods to handle these anomalies, with a goal of minimizing their impact on dark energy measurements to within tolerances.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Dynamic distortions: these are the image geometrical distortions which are sourced by the charges accumulating during the image exposure, due to electrostatic forces. The most striking manifestation of these distortions is the so-called “brighter-fatter effect”
    (a) Refine the relation between flat-field statistics and electrostatic quantities. Characterize how the covariance of flat-fields evolves with the signal level.
    (b) Develop a detailed Poisson solver for deep-depleted CCDs that allows one to simulate drift trajectories, and study their alterations as charge accumulates.
    (c) Acquire CCD data on test benches in order to improve the use of flat-fields in the definition of the correction.
    (d) Characterize the demography of LSST science chips regarding the brighter-fatter related quantites.
    (e) Study whether real science images can provide direct input to a correction method, in particular because they contain strong charge gradients which are absent from flat-fields.
    (f) Provide improvements to the DM stack algorithms as knowledge improves.
2. Static distortions: these are image distortions which are independent of the observed image, typically due to drift field in-homogeneity. Two main sources are well known: poor field on the sensor edges, and spatial variations of the impurity density. Other sensor anomalies not involving electrostatics should also be studied.
    (a) The variations of impurity density are mostly visible as “tree rings”, which slowly modulate the effective size (and position) of pixels. A correction scheme has to finely measure those tree rings on flat-fields.
    (b) The distortion at the sensor edges can be partially corrected for, using some effective drift field distortion model. Refining and testing these models will eventually extend the usable sensor area.
    (c) The electronic chains are affected by some non-linearity, which should be corrected. Developing the non-linearity measurement and analysis methodology for the LSST $\sim$3000 channels is mandatory.

(d) The sensors are affected by charge transfer inefficiencies, and the DESC accuracy requirements suggest to revisit the impact of these on position, shapes and fluxes measurements.

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for this working group are as follows.

1. Once we have real image data with LSST sensors, expected in 2020 from the Auxiliary Telescope, we can characterize the quality of our corrections, and possibly carry out specific engineering sky observations, ideally in coordination with the PSF working group.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 2: Analyzing the Impact of Brighter-Fatter on WL Observables. Other WG: WL.

✓ Project 91: Exact form of the Photon Transfer Curveof CCDs.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.6 Computing

Summary: The Computing (CO) group must provide several capabilities to the DESC: effective usage of the available computing resources, tools to run and manage large productions, a software environment for collaboration and external code to function in, and common tools needed by the various WGs. DESC must also have a distributed code development environment to allow the geographically dispersed DESC membership to work together on a common DESC code base. The overarching vision for the DESC computing environment is that scientists should find it easy to access the project tools, develop their own code, generate pipelines with modules written by others within the collaboration, incorporate external code (such as the HEALPix library and camb), and track results. This will enable the collaboration to identify the optimal algorithms, modules, and pipelines for different problems.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Exploration of new computing architectures for DESC codes

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 24: DC2 Project: Run 1 and 2. Other WG: SSIM.

✓ Project 85: DC1 Analysis. Other WGs: LSS, SSIM.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.7 Cosmological Simulations

Summary: Cosmological simulations and mock catalogs derived from these simulations enable the data challenges as well as a broad range of activities such as the testing and development of analysis pipelines as described in this document. The required simulated datasets come in a number of forms, including halo catalogs from gravity-only simulations, simulated observational catalogs, and inputs from which to simulate images. For each of these datasets there are a variety of levels of required fidelity in order to meet the intended scientific goals for their use. Thus, the validation of the simlated datasets against both observational data and

theoretical predictions is an important and integral component of the effort. The improvement in fidelity, which, in general, involves optimizing a complex set of requirements can only be achieved in close coordination with other working groups and a detailed understanding of the interfaces, requirements and available resources. Another key component of the effort is the generation of fast prediction tools to enable the development of inference pipelines for cosmological analyses.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Galaxy-Halo Connection

   At present, the only feasible method for constructing large-scale galaxy catalogs involves modeling the galaxy-halo connection to populate dark-matter halos with galaxies. These models necessarily contain a variety of approximations. The level of detail and the demands on the fidelity of the models will increase commensurately with the sophistication of the cosmological analyses that are being pursued. The CS group, in collaboration with the analysis working groups, must develop a series of staged improvements to the existing galaxy-halo connection models.

2. Validation

   The level of fidelity of simulated catalogs to the real Universe is assessed by validation testing. The translation of the evolving science goals of the analysis working groups into tests that can be applied to simulated catalogs is ongoing collaborative work with the cosmological simulations group. An understanding of the tests that can be applied, the data that is available and relevant for the tests and the interpretation of the test results are all critical for determining the limitations of the catalogs. The test results also serve as a guide for prioritizing the improvements for the simulations.

3. Hydrodynamical simulations and characterization of baryon effects

   High-fidelity simulations including gas physics and sub-grid models pose a tremendous challenge for the cosmological simulations group. Nevertheless, they will play a very important role for understanding systematic effects, partcularly for cluster and weak lensing studies. Over the next few years, both the scale and fidelity of these simulations needs to be improved. In parallel with this work, complementary efforts to develop alternative methods for including baryons effects and to develop strategies for mitigating baryonic effects must also be continued.

4. Development of prediction tools

The development of fast and accurate prediction tools for quantities of cosmological interest such as mass functions, power spectra, concentration-mass relations etc. for many different cosmologies will be a critical capability for upcoming analyses. These will be used in inference pipelines for extracting cosmological information from the simulated data sets and later from observational data.

5. Covariance estimation

   The accurate estimation of covariances, which will be crucial for future cosmological analyses, is an outstanding problem that needs to be solved. Brute-force methods are not currently feasible, but will become more viable in the future. In the meantime, it is important to continue to develop approximate methods and to understand better the number and scale of the simulations required to obtain sufficiently accurate estimated for cosmological inference.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 4: Apply Deep Learning to Identify and Deblend Strong Lenses for LSST. Other WG: SL.

→ Project 13: DC2 Project: Extragalactic Catalog Validation.

→ Project 15: DC2 Project: GCR Catalogs. Other WG: CO.

→ Project 16: DC2 Project: High Dimensional DESC Metrics.

→ Project 22: DC2 Project: Production and validation of IA mock catalogs for DC2. Other WG: TJP.

→ Project 28: DESC+DES: Quantifying the effects of cluster triaxiality on cosmology with simulations. Other WG: CL.

→ Project 42: Impact of Weak Lensing Magnification on SN Cosmology. Other WG: SN.

→ Project 44: Intrinsic alignment self-calibration. Other WGs: WL, TJP.

→ Project 49: Matter Power Spectrum Emulator for f(R) Modified Gravity Cosmologies. Other WG: TJP.

→ Project 69: SkySim5000.

✓ Project 86: DC2 Project: CosmoDC2 Production.

✓ Project 87: DC2 Project: Generating synthetic cosmological data with GalSampler.

✓ Project 88: DC2 Project: ProtoDC2 Catalog Production.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.8 Survey Simulations

Summary: The main goal of the Survey Simulation group (SSim) is to work with the analysis, computing and technical working groups to produce and validate the simulated images and catalogs needed for the various data challenges (DC) of the SRM. The construction, validation, and usage of the DC datasets will involve multiple groups. SSim will help coordinate the development and application of DESC software for simulating LSST-like images (imSim). As LSST nears operations, the SSim group will support applications of image simulation for validating survey performance during commissioning, science verification, and operations.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Tools for image simulations.
   (a) Development of image simulation tools: for example imSim, batoid, etc.
   (b) Improvement of image simulation fidelity.
      i. Improve LSST system modeling – for example atmospheric modeling, sensor effects, optical path, observational cadence, etc.

ii. Improve source modeling: more realistic galaxy profiles, diverse source populations, etc.

(c) Support usage of image simulation tools: e.g., support usage of the simulation tools for data challenges and specialized image simulation campaigns proposed by the Science Working Groups.

2. Validate products of image simulations.

   (a) Perform validation in conjunction with the relevant Science Working Groups.

   (b) Establish validation framework – for example use DESCQA, tools developed by or in collaboration with the LSST Project, and tools provided by the Science Working Groups.

3. Investigate object injection frameworks (in coordination with the Project): this would include injecting simulated sources into real data as well as other possible combinations of real and simulated data.

4. Study feasibility of catalog emulation framework.

5. Establish object injection framework.

6. Establish emulation framework

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 24: DC2 Project: Run 1 and 2. Other WG: CO.

→ Project 26: DC2 Project: Validation of DC2 images and DM products.

✓ Project 85: DC1 Analysis. Other WGs: CO, LSS.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.9 Commissioning

Summary: As LSST operations approaches, the LSST project commissioning team will commission both the telescope and the associated software systems. The LSST commissioning team will verify that the system is built to specifications and can achieve a set of defined performance goals. A set of tests will be performed that, if passed, will demonstrate that each specification has indeed been met.

The DESC collaboration has its own set of requirements on the performance of the LSST system which are necessary to achieve the DESC science goals. In some cases, these requirements are more stringent than those specified in the LSST construction plans, in other cases the DESC requirements are in fact unique to the DESC. These unique requirements are not currently envisioned to be undertaken by the LSST commissioning team.

The DESC Commissioning Working Group (CWG) acts as an interface between the needs of the DESC science and cross-cutting working groups and the LSST project commissioning team. The CWG acts both to support the LSST project commissioning team, and to design and carry out its own tests on the LSST commissioning data which will ensure the DESC can carry out precise fundamental physics measurements. The CWG has a broad membership from across the DESC, which represents all of the working groups.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. The production of lists of targets and fields which could be observed during commissioning. Fields from pre-cursor surveys which contain well measured targets are useful to the entire LSST effort, and a range of targets visible over the year will give the commissioning team both information and flexibility to match observing needs with targets on the sky.

2. Highlighting and prioritizing particular fields to the commissioning team which will allow the DESC working groups to test their pipelines and analysis tools.

3. Designing new tests for the commissioning team to undertake while utilizing DESC expertise to help design and improve tests which are already envisioned.

4. Creating a comprehensive DESC commissioning plan.

5. Developing validation tests for assessing the quality and survey readiness of commissioning and early operations data.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.10 Dark Matter

Summary: The Dark Matter (DKM) Working Group aims to utilize LSST data to study the fundamental nature of dark matter, including its particle mass, self-interaction strength, non-gravitational couplings to the Standard Model, and compact object abundances. Studies of the fundamental nature of dark matter with LSST are highly synergistic, both scientifically and technically, with studies of dark energy. The DKM WG serves as a central location for coordinating analyses of dark matter physics within LSST DESC. This working group helps initiate cross-working group analyses, hosts discussions of dark matter probes with LSST, and helps coordinate the theoretical interpretation of multiple dark matter probes. The DKM WG also helps coordinate dark-matter-related interactions between DESC and the larger LSST science community.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Measuring the minimum halo mass to test light thermal relics and other dark matter models that suppress halo formation.

    (a) Developing methods to enhance the identification and characterization of ultra-faint galaxies and stellar streams around the Milky Way, such as improved methods of star-galaxy separation, using multi-band stellar photometry and proper motions to identify candidate member stars, and removing imaging artifacts.

    (b) Collaborating in the search for strong lens systems and developing methods to characterize dark matter substructures and line-of-sight halos using, for example, gravitational imaging, flux ratio anomalies, and time-delay anomalies (with SL working group).

   (c) Promoting theory efforts to advance predictions of the abundance of low mass dark matter halos and to model the galaxy-halo connection for various dark matter models (with TJP working group).

2. Measuring halo profiles and shapes to test if they have been altered by dark matter microphysics.

   (a) Mitigating systematics affecting measurements of the halo profile for a stacked sample of dwarf galaxy lenses, including photometric redshift estimation for the lens sample, contamination by more distant and higher mass galaxies in the lens sample, and characterizing our ability to accurately measure shear at very small angular scales where PSF modeling and deblending may pose a greater challenge.

   (b) Developing analysis methodology for interpreting cluster weak lensing profiles and locations of member galaxies to characterize features such as the halo radial profile and shape, splashback radius, substructures, and spatial offsets between baryonic and dark matter in merging clusters.

   (c) Promoting theory efforts to predict halo radial profiles and shapes for various dark matter models (with TJP working group)

3. Identifying compact objects (e.g., primordial black holes) which may make up some fraction of the dark matter.

   (a) Developing methods to enhance searches for microlensing by primordial black holes, for example by improving crowded field photometry, deblending, and light curve analysis.

   (b) Advancing theory efforts to model the abundance of compact objects due to conventional astrophysical processes and primordial black holes (with TJP working group).

4. Using large-scale structure to explore dark matter and dark sector physics.

   (a) Studying light relics and other new physics in the dark sector (e.g., potential solutions to the H_0 tension, correlations between dark matter and dark energy). This may involve work to control and measure survey systematics at large scales and baryonic systematics at small scales.

   (b) Studying from theory perspective the impact of dark matter microphysics on the relationship between tracers and structure (with TJP working group).

5. Probing anomalous energy losses in stars: dark matter that couples to the standard model may change the thermodynamics of stars, altering their internal structure, evolution, and lifetime.
    (a) Enhancing stellar population studies, such as measurements of the white dwarf luminosity function, as well as characterization of globular clusters. This may entail developing improved methods of star-galaxy separation, detailed estimates of the survey response function, and developing improved proper motion measurements and photometric calibration.
    (b) Developing techniques to identify and study core-collapse supernovae (with SN working group).

4.11 External Synergies

Summary: To make maximal use of LSST, we will require additional follow-up data from other observational resources. Additionally, there will be a variety of projects that would benefit from joint analyses that combine data from LSST and other cosmology experiments. The External Synergies Working Group will serve as a clearing-house and forum to help develop how we can work together across working groups and across collaborations to gain access to the data we need, and ultimately to shepherd cross-working group observing proposals to achieve this.

Research priorities: The research priorities of this working group can be broadly characterized as follows.

1. Making and maintaining an inventory of DESC needs for external data (e.g., follow-up) or datasets.
    (a) Where possible, quantifying the gains from such data as a function of sample size / depth / time invested
2. Making and maintaining an inventory of potential telescope/instrument resources that may be used to meet these needs.
3. Based on these inventories, identifying synergies between different DESC science cases for additional data.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.12 Photometric Redshifts

Summary: Almost all of LSST's dark energy probes rely on knowledge of the redshifts of extragalactic objects (LSST Science Collaboration et al. 2009). Because it will be infeasible to measure spectroscopic redshifts for the large samples of targets observed by LSST, redshifts will be estimated from imaging, primarily the observed photometric fluxes in the 6 bands, though ancillary information, including the shapes, sizes, and relative positions of galaxies may also be used.

The PZ WG is tasked primarily with gleaning individual galaxy redshift information from LSST's data but also works closely with the PWGs to improve the estimation of science-specific summary statistics that propagate ensemble redshift information to constraints on the cosmological parameters. LSST-DESC will use photo-z s in many ways, so the estimates thereof must be sufficiently accurate and precise, and, more importantly, must correctly convey the uncertainty landscape of such estimates.

The systematic uncertainty on inference of the dark energy equation of state w from weak lensing measurements is roughly five times the uncertainty in the actual mean redshift of photo-z-selected samples; calibration must reach an accuracy of $\sim 0.002(1+z)$ to enable DESC to reach its science goals with the first year of LSST data (The LSST Dark Energy Science Collaboration et al. 2018). For many static probes of dark energy, we must also determine the overall redshift distributions of galaxy samples with photometric redshift estimates. The requirements on photo-z training and calibration necessary to achieve the necessary certainty are presented in Newman et al. (2015).

The PZ WG thus aims to address three challenges in parallel: developing and understanding algorithms for *constraining* photo-z s, optimally *informing* our photo-z estimation procedures, and using other redshift proxies for *calibrating* photo-z estimates and summary statistics thereof.

In order to *constrain* photo-z s for LSST samples accurately, a number of technical challenges must be addressed. Any source of observational error that can cause differences between measured galaxy colors and their true colors will degrade photo-z estimates. Typical examples of effects that will require further study include variations in photometric zero-points, mis-corrected reddening by intervening dust, or unaccounted-for variations in filter throughputs or atmospheric absorption.

Additionally, photo-z s are subject to unavoidable physical limitations — two galaxies with different SEDs at different redshifts can have indistiguishable fluxes, even under perfect observing conditions. Some sources of systematic error may be a combination of observational and physical, such as imperfect deblending of galaxies coincidental in the line of sight. The uncertainties associated with photo-z estimates must be well-characterized and provided to the probe working groups in accessible formats.

While many algorithms exist for constraining photo-z s, they all share a need for prior information, be it in the form of an SED template library, a spectroscopic training sample, or an empirical combination thereof. To effectively *inform* photo-z algorithms, we must mitigate systematic non-representativity in both spectroscopic redshift samples used by data-driven photo-z estimation routines and SED template libraries used by model-based photo-z approaches. That is to say, photo-z prior information must be complete, with mutual coverage, or completeness, between the data and the training or template sets. The PZ WG will develop a framework to characterize the constraining power of photo-z estimators in the presence of such incompleteness, rather than relying on the assumption of complete coverage of the underlying galaxy distribution.

Given the high incompleteness of deep spectroscopic surveys, it is unlikely that our training sets of redshifts will be sufficient to achieve an accurate calibration of actual photo-z biases and uncertainties (or aggregate redshift distributions of LSST samples). Traditional assessment by comparing with spectroscopic samples can give a false measure of photo-z performance due to systematic biases in the populations that fail to yield secure redshifts. Instead, we expect to rely on cross-correlation methods for calibration (Newman et al. 2015; The LSST Dark Energy Science Collaboration et al. 2018). Key challenges for *calibration* are optimizing these methods in the presence of confounding effects such as dust extinction, lensing magnification and bias evolution and demonstrating that they will achieve the high accuracy needed for LSST.

In addition to developing methods of dealing with these challenges, the Photometric Redshift working group must develop the infrastructure needed for generating redshift estimates required by LSST DESC (whether point estimates, probability distribution functions, or samples from a PDF), optimizing those algorithms, and calibrating the results.

Research priorities:

1. Characterization of redshifts of individual objects:

   (a) Enabling characterization of individual object redshift from incomplete training data.
   (b) Unbiased and optimal (or nearly optimal) compression of the redshift likelihood function.

2. Calibration of the redshift distribution ($N(z)$) for a set of objects:
   (a) Calibration of $N(z)$ by cross-correlation with spectroscopic samples.
   (b) Calibration of $N(z)$ using other external or internal data such as CMB lensing or internal shear cross-correlation.
   (c) Statistically robust marginalization over residual uncertainty.

3. Guidance to the definition of tomographic clustering or weak lensing samples from primary observables that are optimal for individual analysis, in collaboration with the LSS and WL working groups.

Enhancements:

1. Joint 2D probability distributions of redshift and other quantities, the so-called 2D photometric PDF $p(z, \alpha)$, where α is some ancillary property such as stellar mass or star formation rate.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 1: A New Deep Learning Model for Photometric Redshift Estimation with DC2. Other WG: SN.

→ Project 10: DC2 project [PZ]: Testing cross-correlation redshift calibration.

→ Project 11: DC2 Project: 3x2pt analysis with DC2 catalogs. Other WGs: LSS, WL, TJP.

→ Project 25: DC2 Project: Running redMaPPer on DC2 Cosmo and Sim Catalogs. Other WG: CL.

→ Project 45: Joint DC2 LSST-WFIRST pixel-level simulations and analysisDC2/DC3 image simulation. Other WG: WL.

→ Project 46: Joint redshift inference with clustering and SED fitting.

→ Project 47: Leveraging Host Galaxy Correlations for Supernova Classification. Other WG: SN.

→ Project 50: n(z) shape + galaxy bias degeneracies in 3x2 point. Other WGs: WL, TJP.

→ Project 63: PZ blending. Other WG: BL.

→ Project 64: PZ DC2: How do photo-z PDF methods respond to imperfect priors?.

→ Project 66: Redshift inference using a hierarchical Bayesian model.

→ Project 67: Requirements on PZ errors for 3x2pt. Other WGs: WL, TJP.

→ Project 76: Using TXPipe to re-analyze precursor surveys. Other WGs: LSS, WL.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

4.13 Theory and Joint Probes

Summary: The Theory and Joint Probes (TJP) working group is responsible for delivering constraints on cosmological parameters from the combination of all probes and handling the theoretical interpretation of those results. Combining multiple probes allows us to make more precise measurements of cosmological parameters, break degeneracies between them and with systematic uncertainties, and examine internal inconsistencies that could point towards new physics (or unidentified systematic effects). In general, it is the responsibility of TJP to combine all of the work done by the single-probe working groups to produce the ‘headline’ cosmological constraints from LSST.

To achieve this, we need a consistent way of computing theoretical predictions for cosmological models, including astrophysical effects, across all probes; a way of comparing models with the summary statistics provided by the individual probe working groups (i.e. by computing the likelihood); and a way of modelling the noise and signal covariance between the individual probes to properly take into account the correlations between them. The main software infrastructure provided by TJP is a self-consistent suite of codes that manage each of these steps.

Another responsibility of TJP is to work with other working groups to ensure that non-standard cosmological models can be tested. While most work is carried out under the assumption of a wCDM cosmological model, some assumptions need to be relaxed in order to test alternative models in a consistent manner. TJP is responsible for collecting information about such models, and helping to identify areas where additional infrastructure is needed (e.g.

simulations of alternative models), and analysis steps where wCDM-based assumptions have been made and need to be relaxed.

Finally, TJP is the host working group for the DESC analysis blinding effort. In order to avoid cognitive biases in how we solve complex systematic errors and interpret our results, it is becoming common practice to obfuscate the results of the analysis until such time that the collaboration is confident that the results can be trusted. Once final versions of the data, pipeline, and analysis choices have been locked in, the obfuscation is removed, leaving us with a final measurement that should not be susceptible to issues like confirmation bias. The machinery and planning required to carry out a blinded analysis are coordinated from within TJP.

Research priorities: The research priorities of the TJP working group center around finding accurate, rigorous, and computationally efficient ways to combine information from multiple probes. In the first instance, this involves improving existing methods to handle the increased volume and precision of LSST data, but we are also interested in finding fundamentally new approaches that can overcome some of the limitations of standard methods such as likelihood-based inference. As part of our role in ensuring that alternative cosmological models can be tested with LSST, we are also interested in finding ways to make observable predictions for such models, and finding new combinations of observables that can test them more stringently.

An itemized list of our main research priorities is as follows:

1. Fast and accurate predictions for cosmological observables
   (a) Research into predicting cosmological observables, consistent across all probes, with validated precision and accuracy.
   (b) Fast methods for nonlinear modeling.
   (c) Fast methods of calculating real-space correlation functions.
   (d) Modeling of systematic effects, especially astrophysics, and consistent inclusion in observable predictions.
2. Multi-probe likelihoods and parameter estimation
   (a) Research into how to best combine data, theoretical predictions, and covariances into a likelihood-based inference framework.
3. Modeling multi-probe covariance matrices
   (a) Analytic models of multi-probe covariance matrices in real and Fourier space.
   (b) Simulation-based and hybrid estimators of covariance matrices.

   (c) Absolute targets for covariance matrix accuracy, and effects of uncertainty in covariances.
   (d) Relative accuracy of different ways of estimating covariance matrices.
   (e) Effective lower-dimensional parameterizations of covariance matrices.

4. Effective blinding strategies
   (a) Determining effective blinding strategies for single- and joint-probe analyses.
   (b) Defining criteria for when the data can be unblinded.

Enhancements: Some research topics that could lead to enhancements to the baseline LSST analysis for the TJP working group are as follows:

1. Combining data from external probes
   (a) Theoretical predictions for external probes (such as CMB).
   (b) Requirements for modeling covariances between DESC probes and external probes.
   (c) Ways of integrating external information into DESC cosmological parameter constraints.
   (d) Measures of consistency between data sets and criteria for combination.
2. Beyond-wCDM cosmological models
   (a) Identification and prioritization of alternative cosmological models to test with DESC observations.
   (b) Infrastructure to model and simulate observables in alternative cosmologies.
   (c) Identification and implementation of new observables or combinations of observables that can test alternative theories.
3. Improved statistical inference techniques
   (a) Improved Monte Carlo sampling methods, especially for high-dimensional parameter spaces.
   (b) More accurate modeling of the likelihood function when data residuals are not Gaussian.
   (c) Likelihood-free inference techniques.

DESC Projects: Below is a list of approved DESC Projects associated with this WG with a status of active (→), review (-), or complete (✓) from the DESC publication system. These are auto-generated from the publication system.

→ Project 7: Comparison of E_G vs a multiprobe analysis for testing gravity with LSST.

→ Project 9: DC2 CMBxLSST analysis.

→ Project 11: DC2 Project: 3x2pt analysis with DC2 catalogs. Other WGs: LSS, PZ, WL.

→ Project 19: DC2 Project: Non-linear bias and assembly bias modelling. Other WG: LSS.

→ Project 22: DC2 Project: Production and validation of IA mock catalogs for DC2. Other WG: CS.

→ Project 36: Forecasting the Potential of Weak Lensing Magnification at LSST. Other WGs: LSS, WL.

→ Project 44: Intrinsic alignment self-calibration. Other WGs: CS, WL.

→ Project 49: Matter Power Spectrum Emulator for f(R) Modified Gravity Cosmologies. Other WG: CS.

→ Project 50: n(z) shape + galaxy bias degeneracies in 3x2 point. Other WGs: PZ, WL.

→ Project 51: Non-local No-Nonsense Non-Limber Numerical Knockout.

→ Project 67: Requirements on PZ errors for 3x2pt. Other WGs: PZ, WL.

- Project 78: Testing Covariance Matrices.

Key project table: Below is an autogenerated list of infrastructure (software and datasets) for which work is led by this WG, with links to the sections where these are described. This WG is also involved with efforts led by other groups.

5 Pipelines and Computing Infrastructure

In this section we describe the mission critical software that we will need to build in order to carry out our planned cosmological analysis of the LSST survey data. The pipelines described here should enable us to carry out the key analysis steps defined in Section 3, while the datasets in Section 6 should be sufficient to support the development, validation and system testing of the pipelines. We note that some pipeline components – the analysis tools – already exist as external code, leaving just the "plumbing" to be done by the DESC as deliverables in this section. The pipeline stages that need to be built are laid out in a series of "pipeline diagrams." Each pipeline constitutes a Key Product, while each stage to be built is a Deliverable.

Each major pipeline Deliverable should include a verification analysis that answers the question, "did we build what we said we would build?" presented as a research Note or journal paper (or part of one). Each Key Product should include a validation analysis describing a system test that answers the question, "is what we built fit for purpose?" also presented as a research Note or journal paper. The collaboration needs to understand its own tools, and pipeline builders need to be recognized for their efforts. These Notes and papers are therefore extremely important.

The software Key Products are (currently) largely organized by working group. This organization may be revisited as construction proceeds and the design of the pipelines evolves, and so we employ a numbering-free system for labeling (and referring to) the Deliverables and products below. (We therefore anticipate the titles of these items evolving to become more like names over time.) For a summary table of all software Key Product and Deliverables, see Section 7.

NB: in the text below, deliverables are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

5.1 Blending Software Infrastructure

BL Key Product (SR): Blending Tool Kit (BlendingToolKit)
Objective: The goal of this Key Project is to develop a software tool kit for evaluating performance metrics for detection, deblending and measurement algorithms, applied to images of

blended objects. This toolkit can then be used to measure and compare the performance of the current DM science pipelines and detection, deblending and measurement algorithms under development – including the existing multiband Scarlet deblender and future machine learning algorithms.

The intent of the toolkit development is to allow users to ingest images or efficiently generate images of blended objects for testing algorithms and for training machine learning algorithms. Computation of performance metrics on identical datasets will enable both optimization of algorithms and comparison between different algorithms. The deliverables described below are in support of this key project.

This Key Project builds on an existing DESC Project, the Blending Tool Kit, which is being developed on GitHub with documentation here.

Active deliverable: *Production of Training and Testing Images (DC2 SW)*

Host: BL *Started, originally due:* 10/01/19, 12/31/22 *Expected:* 12/31/22
Objective: Implement options for ingesting or producing images of blended objects to be used in training or testing algorithms:

1. Ingest already-simulated images and the catalog from which they were generated. These datasets include deliverables described in Section 6.

2. Ingest a catalog of (groups of) objects, or generate catalog information drawn randomly from defined distributions, and generate images on the fly (using the GalSim package). Include an option for producing independent (but reproducible) noise realizations of the same image.

3. For both ingested and generated images, include an option for data augmentation.

Active deliverable: *Processing of Training and Testing Images (DC2 SW)*

Host: BL *Started, originally due:* 10/01/19, 12/31/22 *Expected:* 12/31/22
Objective: Provide infrastructure for processing images with different detection, deblending and/or measurement algorithms, including the relevant parts of the DM science pipeline, the Scarlet deblender, and other algorithms under development.

Active deliverable: *Evaluation of Blending Metrics (DC2 SW)*

Host: BL *Started, originally due:* 10/01/19, 12/31/22 *Expected:* 12/31/22
Objective: Evaluate performance metrics for detection, deblending and measurement algo-

rithms. The performance metrics are an outcome of a BL WG research priority described in Section 4.1.

Anticipated deliverable: *SV-era blending software infrastructure (SR SW)*

Host: BL *Started, originally due:* 12/31/22, 10/01/23 *Anticipated:* 10/01/23
Objective: Carry out necessary upgrades to blending-related software infrastructure as revealed by tests during SV.

BL Key Product (SR): Fake Source Injection (BL-FSI)
Objective: The goal of this Key Project is to develop expertise in the DESC in running and developing the fake source injection pipeline being built by DM. Fake source injection will be used for testing and measuring the impact of detection, deblending, and measurement on realistic images. While initial tests might happen with simulated images or data from precursor surveys, the eventual goal is to be able to run this pipeline with LSST survey data. We expect that this pipeline will be essential to calibrating the observational transfer function of the survey and relating LSST survey data products to those from other surveys.

Active deliverable: *Interface for generation and access to fake injected images (SR SW)*

Host: BL *Started, originally due:* 08/04/20, 12/31/22 *Expected:* 12/31/22
Objective: Provide an interface to generate and access real images with fake injected sources. The goal of this interface is to facilitate following studies of the impact of blending/deblending. This deliverable should enable access to:

1. Original real images and detection catalogs,

2. Fake injected images that contain the real images with the fakes,

3. Catalog of the properties of the fakes.

Active deliverable: *Diagnostic tools for evaluating the performance of fake source injection (SR SW)*

Host: BL *Started, originally due:* 08/04/20, 12/31/22 *Expected:* 12/31/22
Objective: Develop, implement and evaluate performance metrics for fake source injection itself. As opposed to developing new base images for fake source injection, we will instead use DC2 images. Thus we will be injecting fakes onto fakes, giving us the ability to both evaluate

the fake injection source pipeline itself.

Active deliverable: *Diagnostic tools using fake source injection for measurement algorithms (SR SW)*

Host: BL *Started, originally due:* 08/04/20, 12/31/22 *Expected:* 12/31/22
Objective: Develop, implement and evaluate performance metrics (which require fake source injection) for measurement algorithms. Again this deliverable will use DC2 images as the base image set upon which to inject fakes. The performance metrics for measurement algorithms will in part be an outcome of a BL WG research priority described in Section 4.1.

5.2 Observing Strategy Software Infrastructure

The focus of this subsection is the creation of metrics to assess various observing strategies, and finding a consensus of optimized observing strategy and effectively communicating this consensus to the greater LSST community. The observing strategy working group collaborates with the SN, WL, LSS, and SL observing groups to create metrics to evaluate observing strategies. Many of the projects discussed below are co-hosted by these groups.

The high-level work flow is as follows:

- **DC1 era**: Focus on a response to the LSST Call for Observing Strategy Recommendations Era: initial development of metrics by WL, LSS, SN, SL working groups. General observing strategies recommended. Done January 2019.
- **DC2 era**: Focus on evaluating new observing strategy simulations delivered by the Project and on refining new metrics. This work culminates in the writing and submission of a journal article that assesses all new simulations, and reaches convergence of final recommendations, aimed for completion in January 2021.
- **SR era**: Respond to future inquires and/or new simulations to motivate DESC-approved observing strategy. Interact with the Survey Cadence Optimization Committee as required. Done October 2023.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in DESC Notes and GitHub issues.

OS Key Product (DC2): Observing Strategy Pipeline Components (OSMetrics)
Objective: Build the OS-specific pipeline pieces. The overall goal of the OSWG is to gather

metrics and recommendations from each working group on both WFD and DDF strategies, combine/understand the results, and present final recommendations.

Active deliverable: *Observing strategy recommendations for supernova cosmology (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable supernova cosmology, including metrics and high-level conclusions.

Active deliverable: *Observing strategy recommendations for strong lensing cosmology (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable strong lensing cosmology, including metrics and high-level conclusions.

Active deliverable: *Observing strategy recommendations for weak lensing systematics (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy for weak lensing systematics, including metrics and high-level conclusions.

Active deliverable: *Observing strategy recommendations for large-scale structure (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable large-scale structure systematics and cosmology, including metrics and high-level conclusions.

Active deliverable: *Observing strategy recommendations for photometric redshifts to enable dark energy probes*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable robust photometric redshifts

for dark energy probes, including metrics and high-level conclusions.

OS Key Product (DC2): Response to the LSST Call for White Papers on Observing Strategy (OS) done

Objective: The DESC had an opportunity to provide input on the LSST Observing Strategy through White Papers due November 30, 2018. This has resulted in two white papers: Lochner et al. (2018) and Scolnic et al. (2018).

OS Key Product (DC2): Observing Strategy Recommendations (OS12)

Objective: Synthesize results from all the metrics from each working group. First form general recommendations from the static and transient science cases, then synthesize these further into general WFD and DDF recommendations.

Active deliverable: *Observing strategy recommendations for all static science cases (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable the static science cases collectively (WL, LSS, and CL), including metrics and high-level conclusions.
Prerequisites: Deliverable *"Observing strategy recommendations for weak lensing systematics"*, Deliverable *"Observing strategy recommendations for large-scale structure"*, Deliverable *"Observing strategy recommendations for photometric redshifts to enable dark energy probes"*

Active deliverable: *Synthesized strategy recommendations for all transient science cases (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: The goal of this activity is to provide input to the Observing Strategy Working Group on the important factors for observing strategy to enable the transient science cases collectively (SN, SL), including metrics and high-level conclusions.
Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*,

Deliverable *"Observing strategy recommendations for strong lensing cosmology"*

Active deliverable: *Synthesized WFD observing strategy recommendations across all probes (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: This activity will result in a synthesized set of observing strategy recommendations for the WFD survey, to feed back to the Project team.
Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*, Deliverable *"Observing strategy recommendations for strong lensing cosmology"*, Deliverable *"Observing strategy recommendations for weak lensing systematics"*, Deliverable *"Observing strategy recommendations for large-scale structure"*, Deliverable *"Observing strategy recommendations for photometric redshifts to enable dark energy probes"*, Deliverable *"Observing strategy recommendations for all static science cases"*

Active deliverable: *Synthesized DDF observing strategy recommendations across all probes (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 11/01/18 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: This deliverable is for a synthesized set of observing strategy recommendations for the Deep Drilling Fields, to feed back to the Project team.
Prerequisites: Deliverable *"Observing strategy recommendations for supernova cosmology"*, Deliverable *"Observing strategy recommendations for weak lensing systematics"*

Active deliverable: *Metrics summary for observing strategy across all probes (DC2 DP)*

Host: OS *Started, originally due:* 09/30/17, 01/01/20 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/ObsStrat
Objective: This deliverable is to provide a clear summary of all metrics that contributed the synthesized observing strategy from DESC, so that the LSST Project and broader scientific community can understand the origin of our observing strategy recommendations. All metrics will be integrated into MAF concurrently with the production of this metrics summary. This will result in a journal article.
Prerequisites: All previous Deliverables in this Key Project.

OS Key Product (SR): Observing Strategy Recommendations after SCOC Communication (OS-SCOC)

Objective: Provide a recommended observing strategy for WFD and DDF that is optimal for cosmology with LSST and to continue to liaise with the Survey Cadence Optimization Committee about observing strategy.

Active deliverable: *Recommendations for Observing Strategy (SR DP)*

Host: OS *Started, originally due:* 09/30/17, 01/01/21 *Expected:* 03/01/21
URL : https://github.com/LSSTDESC/ObsStrat
Objective: White paper in response to call from SCOC providing summary of metric analysis on observing strategy simulations.
Prerequisites: "Observing Strategy Recommendations" (OS12)

Anticipated deliverable: *Observing strategy tests with LSST SV (SV SW)*

Host: OS *Started, originally due:* 01/01/21, 10/01/23 *Anticipated:* 10/01/23
Objective: This deliverable is for software for observing strategy tests with LSST SV, to provide further feedback using real LSST data.

5.3 Photometric Corrections Pipeline

PC Key Product (DC1 & DC2 & SR): Photometric Correction Pipeline Components (PC7)
Objective: Fully integrated photometric corrections pipeline for application to the SV data. Note that, ideally, a significant fraction of these components will be part of the DM level 2 pipeline. PC works alongside project to validate the DM algorithms on precursor data and/or simulated SR data. PC also proposes and develops new strategies to reach the DESC-specific calibration accuracy goals (e.g. recalibration of the primary flux standards, filter metrology).

Defunct deliverable: *Analytical Models for PC Biases (DC1 SW)*

Host: PC *Started, originally due:* 10/01/15, 12/31/17
Objective: This software Deliverable describes the development of analytical models to describe the scale and magnitude of various biases. This includes, but is not limited to, typical seeing variations and atmospheric transmission variations with time (and space, depending on observing strategy); extinction mis-corrections; raft-to-raft photometric residuals on degree

scales; varying response variations as determined from SA WG.

Active deliverable: *PC Bias on Individual Probes (DC2 SW)*

Host: PC *Started, originally due:* 10/01/16, 12/31/17 *Expected:* 03/31/20
Objective: A software module that is used to determine the impact on parameters measured by individual cosmological probes (e.g., SN Ia distance moduli; cluster redshifts; BAO scale). While the analysis has been carried out for the SN Hubble diagram, i.e. the probe that is the most sensitive to photometric calibration, similar analysis is needed for photo-zs and perhaps other WGs.

Active deliverable: *PC Observing Strategy Metrics (DC2 SW)*

Host: PC *Started, originally due:* 10/01/16, 12/31/17 *Expected:* 03/31/20
Objective: This Deliverable is a set of software tools that will analyze the performance of a given observing strategy which holds promise to detect, mask, and reduce systematics. At the same time, recommendations to the observing strategy will be made based on these results.

Active deliverable: *Validation of DM point source photometry (SR SW)*

Host: PC *Started, originally due:* 07/01/19, 12/31/20 *Expected:* 12/31/20
Objective: This deliverable consists in a thorough study of DM photometry of point sources, on a precursor dataset. Work has started on the HSC Ultra-Deep and Deep components. Other precursor datasets are possible, notably the DES SN fields as well as the SNLS exposures. To help with this analysis, we will also carry out direct comparison of DM photometry with photometry delivered by previous generation pipelines (e.g. SNLS).

PC Key Product (SV): Closing the photometric calibration loop with AuxTel (PC-AUXTEL)

Objective: The Auxiliary telescope will deliver one of the fundamental ingredient of the calibration chain: the determination of the mean atmospheric transmission on the LSST site, along with its variations with time. Although all the gray variations of the telescope throughput can be captured with field star photometry on the main LSST imager, we need spectroscopy to model the sub-percent chromatic variations of the survey passbandes. Also, as the first LSST-like sensor on the sky, AuxTel will allow early characterization of DM photometry. PCWG will participate on AuxTel commissioning, and use this dataset to first close the photometric calibration loop, i.e. demonstrate that we are able to deliver calibrated natural magnitudes (from

AuxTel imaging), along with a measurement *model* that allows to interpret them at the per-mil level.

Anticipated deliverable: *Integrated AuxTel pipeline (SV SW)*

Host: PC *Started, originally due:* 06/01/20, 09/30/22 *Anticipated:* 09/30/22
Objective: The AuxTel instrument delivers slitless spectra of monitoring stars, from which we can assess the instantaneous transmission of the atmosphere around the LSST line of sight. Forward modeling has been show (on a AuxTel precursor dataset) to be promising approach to extract simultaneously the spectrum and the atmospheric transmission. PCWG members develop a pipeline based on this approach, that will eventually be ported into the AuxTel analysis pipeline.

Anticipated deliverable: *AuxTel observation strategy (SV SW)*

Host: PC *Started, originally due:* 06/01/20, 09/30/22 *Anticipated:* 09/30/22
Objective: The survey baseline strategy consists in tying AuxTel and LSST observations, and ensure that AuxTel is always observing a (mag<10) star in the current LSST pointing. Alternate strategies have been proposed. This deliverable consists in a study, based on simulation and early AuxTel data, to determine the optimal AuxTel observing strategy.

PC Key Product (SV): Integrated PC Pipeline, Adapted to SV Data (PC-SV)
Objective: Fully integrated photometric corrections pipeline for application to the SV data.

Anticipated deliverable: *Integrated PC Pipeline (SV SW)*

Host: PC *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23
Objective: Fully integrated end-to-end pipeline for carrying out photometric corrections and quantifying their impact and uncertainty.

Anticipated deliverable: *Recalibration of CALSPEC Primary standards (SV SW)*

Host: PC *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23
Objective: This deliverable consists essentially in a smooth recalibration function, along with an uncertainty covariance matrix, to apply to the CALSPEC Spectral Energy Distributions. This function will be the output of a joint comparison of the SCALA and starDICE results. If internal tensions within CALSPEC are found, the deliverable may consist instead in a recalibration of a subset of the CALSPEC stars, especially those located in the southern hemisphere.

Anticipated deliverable: *CBP characterization of stage-3 survey telescopes (SV SW)*

Host: PC *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23
Objective: This deliverable consists in a series of re-measurements of the throughput of stage-3 survey telescopes with a precursor version of the Collimated Beam Projector (CoBP). These determination are important ingredient of a combined LSST+stage-3 SN Ia sample. Also, carrying out these measurements will allow to develop experience on analyzing CoBP data, and validate the CoBP data analysis software.

5.4 Point-Spread Function Software Infrastructure

Simulating, modeling, and analyzing the delivered LSST point spread function - and the impact of PSF modeling errors on dark energy observables - are significant components of LSST DM and DESC pipelines. While we currently do not define any specific PSF software infrastructure, PSF expertise will contribute to a number of deliverables associated with other working groups. These deliverables include: *"Add major features to IMSIM"*, *"Increase the realism of IMSIM"*, *"Null test pipeline (WLNULLTEST)"*, *"Identify and characterize PSF systematic uncertainties"*, and *"Proper handling of chromatic effects"*.

5.5 Sensor Anomalies Pipeline

SA Key Product (DC1 & DC2 & SR): Sensor Anomalies Pipeline Components (SA5)

Objective: Build the SA-specific pipeline pieces.

Active deliverable: *Implemented and Validated Correction Algorithm for the BF Effect (DC2 SW)*

Host: SA *Started, originally due:* 10/01/16, 06/30/18 *Expected:* 12/31/21
Objective: The final step on the BF effect is to develop and validate BF signature removal algorithm(s).The optimal BF signature removal that will be implemented in DM will be validated by SAWG.

Active deliverable: *Validation of correction algorithms for static effects (DC2 VA)*

Host: SA *Started, originally due:* 10/01/16, 06/30/18 *Expected:* 12/31/21
Objective: The signature removal of the static sensor effects will be implemented in DM. The implementation will need to be validated.

Active deliverable: *Studies of sensor systematics with Auxiliary Telescope and ComCam (SR VA)*

Host: SA *Started, originally due:* 10/01/18, 12/31/20 *Expected:* 12/31/21
Objective: This work includes the sensor studies, validation of the signature removal algorithms and propagation of the residual systematics in to the science observables in the Auxiliary Telescope imaging data and in ComCam data. The Auxiliary Telescope offers an opportunity to study sensor effects on real scientific data on an ITL sensor, before ComCam sees the sky.

SA Key Product (SV): Integrated SA Pipeline, adapted to SV Data (SA-SV)
Objective: Fully integrated sensor anomaly correction and testing and pipeline, for application to SV data.

Anticipated deliverable: *Integrated SA Pipeline (SV SW)*

Host: SA *Started, originally due:* 12/31/20, 10/01/23 *Anticipated:* 10/01/23
Objective: Fully integrated end-to-end pipeline for testing for sensor anomalies, enabling custom corrections, and quantifying their impact and uncertainty.

5.6 Computing

The DESC simulation, processing and analysis pipelines have some needs in common, to enable them to be run efficiently at the required scale on the computing resources we have access to. In this Section we collect the common pieces to build the mission-critical computing infrastructure hosted by the Computing Working Group (CO; formerly referred to as Computing Infrastructure, or CI).

SSim Key Product (operations): Well-integrated End-to-End Simulation Capability (CO4)

Objective: Image simulations play an important role within DESC. In order to test the different components of the image simulation pipeline the development of an automated end-to-end pipeline is crucial. For example, improvements of imSim or newly developed interfaces between the different steps in the end-to-end pipeline need to be easily and quickly testable.

Completed deliverable: *Efficient end-to-end small scale image pipeline (DC2 SW)*

Host: SSim *Started, originally due:* 02/18/19, 12/31/21 *Completed:* 12/12/19
URL : https://github.com/LSSTDESC/sims_ci_pipe
Objective: We need to develop an automated end-to-end pipeline that enables easy testing of new developments in our image simulation work.

Planned deliverable: *Interface designs and improvement between workflow components (DC2 SW)*

Host: SSim *Started, originally due:* 01/01/20, 12/31/21 *Expected:* 12/31/21
Objective: Some interfaces will change between workflow components, and we should try to update all interfaces to eliminate manual intervention. The aim is to eliminate the need for instance catalogs that are currently used as input to the image simulation tool and replace them with a new set of catalogs (currently called "sky catalogs") that simplify the end-to-end image simulation workflow.

CO Key Product (DC2): The Initial Elements of a Software Framework (CO2)
Objective: Large collaborations need a standard environment for their code to be developed and operated in and workflow tools to facilitate running their software at a variety of scales. DESC will exploit the broad expertise within the collaboration to reduce the tendency to reinvent the wheel so that the WGs can concentrate on the content of their code rather than on the infrastructure surrounding it. Standard interfaces will define how code modules interact with each other and with the data, and will thus dictate how the DESC code is structured and how external packages will be configured and executed to be used by the DESC code. Powerful workflow tools will facilitate the submission of large jobs and will enable groups to track results.

Given the constraints of DESC member efforts, deviations from Project/DM standards should be considered carefully; we should concentrate on those elements unique to our needs and reuse what we can.

Completed deliverable: *Software Framework Implementation (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://confluence.slac.stanford.edu/x/fJesCw

Objective: The framework will include definitions of software interfaces (APIs) as well as interfaces to data services. External tools like OpSim, CatSim, PhoSim, and the Data Management pipeline will be considered in an integrated fashion with the DESC code.

Completed deliverable: *Distributed Code Development Environment (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 02/28/18 *Completed:* 02/28/18 *URL :* https://confluence.slac.stanford.edu/display/LSSTDESC/NERSC+Software+Installations;https://github.com/LSSTDESC

Objective: The DESC software development environment should have tools and policies in place to facilitate efficient distributed development. Recommendations for a distributed code repository (such as GitHub), C++/python build tools, policies for code package management, and continuous integration tools will be made, with consideration of the applicability of existing or planned LSST DM development tools.

Completed deliverable: *Workflow & Data Management Tools (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 02/28/18 *Completed:* 02/28/18
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DESC+Workflow+Management+System+Evaluation

Objective: DESC simulations and data processing will require tools to manage and track large numbers of batch jobs and data files. Existing workflow management systems – such as Pegasus, Parsl, or Airflow – should be evaluated, and a recommendation for a final candidate made, keeping in mind the need to be able to operate with the LSST DM Project tools.

CO Key Product (DC1 & DC2): Targeted Frameworks for Use by the Analysis Working Groups (CO3)

Objective: For DC1, we found that the best path forward to attain the ultimate objective of a framework used by all members of DESC was to *work with analysis teams on several Key Projects, enabling them to work together*. CI and the relevant analysis group produced mini-frameworks for each of these smaller projects. Although these smaller interactions did not produce all of the elements that will eventually be required, they gave important feedback as to which ideas work and which do not. They will therefore feed into the Key Projects in DC2.

Completed deliverable: *A framework for Twinkles light curve generation (DC1 SW)*

Host: CO *Started, originally due:* 10/01/15, 06/30/16 *Completed:* 06/30/16

URL : https://github.com/LSSTDESC/Monitor/tree/master/python/desc/monitor
Objective: SNIa and time delay lenses need to be detected in catalog space (using the outputs of the DM stack deblender, object aggregator, and MULTIFIT) and classified in pixel space (either in a "SuperFit", or some other user-generated tool). Light curves must be extracted for both, so that time domain model parameters (stretch, time delay) can be inferred. These commonalities suggest that the development of the software instrumentation needed to detect and measure both types of system can be carried out using the same test dataset, the `Twinkles` survey.

The production of the `Twinkles` images, and their "standard" pipeline processing using the LSST DM stack, can be used to drive the development of several aspects of DESC computing infrastructure at DC1. The design should be able to scale to DC2 requirements. The construction of a Twinkles image and catalog mock dataset (see "`Twinkles`" (SL7)) will involve building DESC CO group expertise in operating CATSIM, PHOSIM, and the DM stack at scale, and will provide a valuable testing ground for (at least) the deblender, image differencing and forced photometry DM DRP algorithms.

Defunct deliverable: *A Framework for TJP (DC1 RQ)*

Host: CO *Started, originally due:* 10/01/15, 06/30/16
Objective: CO and TJP will produce guidelines for the development of TJPCOSMO, which will provide a key set of metrics for systematics. This will be an excellent test case for the larger software framework. The framework will define standard APIs so that different members of the collaboration can work on different aspects of the same problems, will include an environment where code can be checked in, and will provide access to relevant (pseudo-) data sets.

CO Key Product (DC1 & DC2): Distributed Code Development Environment (CI4)

Objective: Implement policies describing best practices in code development and management in order to maximize the productivity of the geographically dispersed team. These policies should cover code repository and organization, issue tracking tools, software standards and code review processes, and testing policies and usage of continuous integration services.

Completed deliverable: *An initial development environment (DC1 SW)*

Host: CO *Started, originally due:* 10/01/15, 01/31/16 *Completed:* 01/31/16
URL : https://github.com/LSSTDESC/pipeline-package-template

Objective: The development environment will start with a distributed repository. Standards will be developed for organization of code and packages in the repository, so that each WG will use a similar directory structure when developing their software.

Completed deliverable: *Software coding standards and code review policies (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 02/28/18 *Completed:* 02/28/18
URL : https://docs.google.com/document/d/1v54bVQI2NejK2UqACDnGXj1t6IGFgY3Uc1R7iV2uLpY/edit
Objective: Software coding standards and code review policies will be developed.

CO Key Product (SR): NERSC Support (CI-NERSC)
Objective: With NERSC as DESC's primary computing host, effort is required to maintain a working environment there.

Active deliverable: *Maintain Software Environment at NERSC (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 10/01/23 *Expected:* 10/01/23
Objective: This deliverable is for setting up and maintaining a computing environment at NERSC that enables the DESC community to use LSST and DESC packages in a unified way and to access DESC data products.

Active deliverable: *Manage storage at NERSC (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 10/01/23 *Expected:* 10/01/23
Objective: The DESC computing environment at NERSC also needs constant attention with regard to file placement, storage management, etc.

CO Key Product (DC2): Common Pipeline Infrastructure (CO12)
Objective: For DC2, the collaboration is writing a number of pipelines for generating simulated images, for image processing, and for science analyses. Since these tasks will entail a variety of software packages, some of which have interfaces and usage patterns inherited from other contexts, it will be essential to define a common set of software abstractions to define the interfaces between the pipeline components for both the software and data product elements. Having standard interfaces will enable the use of existing workflow and data management

tools that have been used by other large projects for running their analysis and data processing pipelines. Such abstraction layers will also help decouple the particular choice of workflow and data management system from the DESC software, so that alternative technologies can be more easily used in the future.

Completed deliverable: *Pipeline Software Interfaces and Abstractions (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/ceci https://github.com/LSSTDESC/Pipelines
Objective: This will include a set of tools to help the WGs design their pipelines (e.g., DAG drawing tools and utilities to help convert the design-level descriptions to actual code). It will also comprise a set of base classes that define the interfaces between the underlying simulation and analysis software and the workflow and data management systems, as well as data format specifications so that information such as metadata can be easily associated with the main data content. These latter software abstractions will provide a context in which the inputs and outputs to any processing software will be well-defined so that standard workflow software can manage the execution of the DESC pipelines in a correct and consistent manner.

CO Key Product (SR): Common Pipeline Infrastructure for SR and SV (SV-CPI)

Anticipated deliverable: *SV-Ready Pipeline Software Interfaces and Abstractions (SR SW)*

Host: CO *Started, originally due:* 10/01/20, 03/01/22 *Anticipated:* 10/01/21
Objective: Upgraded pipeline interfaces to support SR, ComCam and SV simulation, processing and analysis.

CO Key Product (DC1): `DC1 Phosim Deep` Workflow and Data Management Configuration (CO8)

Objective: Simulations will involve large amounts of computing time, on the scale of hundreds of thousands of jobs and the resulting datasets will need to be tracked. Workflow and dataset tracking/provenance tools are needed to provide full visibility into the resulting dataset and to minimize the FTE effort needed to produce it. Workflow tools with capable web UIs have proven essential to allow easy access to job logs, etc., rollback of failed jobs and monitoring of progress. Logical file catalogs provide virtual filesystems with the added benefit of metadata to permit identifying which files in datasets are needed for different analyses. The largest DC1 datasets identified are for the PhoSim Deep dataset. Note that projected datasets for DC2 are not significantly larger than for DC1 and so should be able to be accommodated by a similar system.

Completed deliverable: *Tracking Tools for DC1* PhoSim *Datasets (DC1 SW)*

Host: CO *Started, originally due:* 10/01/15, 01/31/16 *Completed:* 01/31/16 *URL :* https://confluence.slac.stanford.edu/display/~dragon/DC1+PhoSim+28and+dmtcp29+Task

Objective: The `DC1 Phosim Deep` dataset is estimated to require some 4M CPU-hrs to execute. The workflow tools must make this as efficient a process as possible, while tracking the outputs of the simulations, running on computing resources available to the collaboration.

Approach: Work with the Survey Simulations WG to configure the early workflow and dataset management tools to run the simulation.

CO Key Product (DC2): DC2 Workflow and Data Management Configuration (CO10)

Objective: DC2 is expected to be a moderately large simulation and could tax the sites where the code will be run. Careful optimization will be needed to reduce failure rates to low levels. Additionally, the workflow and catalog tools must scale to handle the dataset volume and not suffer in performance. Data access tools will need to provide for efficient transfer from the host sites to collaborators' institutes.

Defunct deliverable: *Workflow and Dataset Tracking Tools for DC2 (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 06/30/18

Objective: The `DC2` dataset is estimated to be some 30x larger than for DC1. The workflow tools must scale effectively to minimize the FTE effort needed to run the processing and maximize use of the computing resources.

CO Key Product (SR): SR Workflow and Data Management Configuration (CO14)

Objective: The simulated datasets generated by DESC have the potential to be very large, and could significantly tax the sites where the simulation and processing pipelines will be run. Careful optimization will be needed to reduce failure rates to low levels. Additionally, the workflow and catalog tools must scale to handle potentially millions of datasets and not suffer in performance. Data access tools will need to provide for efficient transfer from the host sites to collaborators' institutes.

Current estimates indicate challenging dataset sizes, and will have to be studied for feasibility. This project will need to respond as best as possible to that determination.

Planned deliverable: *Workflow and Dataset Tracking Tools (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 06/30/20 *Expected:* 06/30/20
Objective: The simulated and emulated datasets generated during the science readiness period could be very large. The workflow tools must scale effectively to minimize the FTE effort needed to run the processing and maximize use of the computing resources.

CO Key Product (SV): SV-Era Workflow and Data Management Configuration (CO17)

Objective: Based on the DC2 experience, we will upgrade the DRP workflow and configuration for the SV data.

Anticipated deliverable: *Workflow and Dataset Tracking Tools for SV (SR SW)*

Host: CO *Started, originally due:* 07/01/20, 10/01/21 *Anticipated:* 10/01/23
Objective: The workflow tools must be able to cope with the variety of reprocessings that we want to do on the SV data, and also the idiosyncracies of real data at high throughput.

CO Key Product (SR): Upgraded DM DRP Processing Pipeline and Data Service (CO15)

Objective: The Science Readiness datasets should provide a 30%-scale test of survey conditions (Section 6.3): we must demonstrate that we can reprocess significant amounts of survey data and execute DESC analysis pipelines on that data. Ideally the use case is development of DESC algorithms that would be fed back to the Project for inclusion in their subsequent reprocessings. This software addresses reprocessing at scale, using candidate DESC-modified DRP algorithms, running DESC analysis algorithms on the reprocessed data and enabling final analysis of the resulting data. The processed data and analysis pipeline output would need to be in standard catalog form, and by the current DM plan, accessed via a Qserv database server.

Active deliverable: *Development of Gen-3 Butler based DM Processing Pipeline (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 06/30/20 *Expected:* 06/30/21
Objective: During the DC2 era, we developed a DM processing pipeline based on the SLAC SRS workflow and used it at CC-IN2P3 in production mode. In the future, we will need to develop a new pipeline that is based on the Gen-3 Butler and an easy to use and extended workflow system. The overall aim is to build a well functioning pipeline that works at scale at least at CC-IN2P3 and NERSC, and possibly at other computing centers.

Active deliverable: *Upgraded Replica of the DM Catalog Technology (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 06/30/20 *Expected:* 06/30/21
Objective: DESC must upgrade its replica of the Project/DM catalog technology to continue capturing its reprocessings of survey data.

Active deliverable: *Demonstrate capability to process a subset of LSST data at NERSC (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 06/30/20 *Expected:* 06/30/21
Objective: Define a test dataset, e.g., a 10-year-deep tract from DC2, which would be appropriate for doing pipeline development and for scaling in order to assess this capability

Active deliverable: *Collect resource requirements for Y1 data access and analysis (SR SW)*

Host: CO *Started, originally due:* 10/01/18, 06/30/20 *Expected:* 06/30/21
Objective: Identify interactive data exploration needs; Identify programmatic data processing needs; Identify high-performance large-value processing needs; Map identified needs to LSST Science Platform (LSP); Identify missing mappings, identify mappings to incomplete LSP elements;Plan DESC activities to develop new needed functionality and shim incomplete elements.

5.7 Cosmological Simulation Infrastructure

CS Key Product (DC2): DESCQA2 Validation Framework (CS10)
Objective: This project follows on from the DC1 project DESCQA, which developed a framework suitable for testing and validating a wide variety of synthetic sky catalogs against ob-

servational or other validation data. DESCQA2 expands this framework to include light-cone catalogs and to incorporate additional tests that will be developed in collaboration with the analysis working groups.

Completed deliverable: *DESCQA validation framework with full functionality (DC2 SW)*

Host: CS *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/descqa
Objective: The DESCQA2 framework will operate on any available catalog and automatically run a suite of tests to check the properties of each catalog against observational or other data as deemed appropriate by the analysis working groups.

CS Key Product (DC2): Generic Catalog Reader (GCR) (CS11)
Objective: The Generic Catalog Reader (GCR) is a tool to facilitate the comparison of different sky catalogs by providing the interface to convert an arbitrary input catalog to a uniform output schema with known units. The GCR was developed as part of the DESCQA framework and the DC1 R&D project, CS3, but it now also exists as a stand-alone product that can be used by any aanalysis WG wishing to compare a number of different catalogs within the same analysis module.

Completed deliverable: *GCR interface available for all Sky Catalogs (DC2 SW)*

Host: CS *Started, originally due:* 10/01/16, 01/31/18 *Completed:* 01/31/18
URL : https://github.com/LSSTDESC/gcr-catalogs
Objective: The GCR will be available for use with any sky catalog, including DC2 extragalactic catalogs and special-purpose catalogs.

CS Key Product (DC2): Generic Catalog Reader (GCR) for Data-Release-Product (DRP) Catalogs (CS14)
Objective: The Generic Catalog Reader (GCR) provides an interface to convert arbitrary input catalogs to a uniform output schema and underlies the DESCQA validation framework. Validation of the inputs and outputs from the image simulations is enabled by the development of new readers for DRP catalogs that have been cross-matched with the truth information for

objects found in the simulated images.

Completed deliverable: *GCR interface available for cross-matched DRP catalogs (DC2 SW)*

Host: CS *Started, originally due:* 9/01/19, 06/30/20 *Completed:* 06/30/20
URL : https://github.com/LSSTDESC/gcr-catalogs
Objective: The GCR will be available for use with DRP catalogs that have been cross-matched with truth information for each object.

CS Key Product (DC2): DESCQA for DC2 Validation (CS16)
Objective: This project follows on from the DESCQA2 project CS10, which is a framework developed for testing and validating synthetic extragalactic catalogs against observational or other validation data. DESCQA-DC2 expands this framework to include DRP catalogs, which are the outputs of the image simulations. This project will enable the use of previously developed tests to validate the results of the image simulations.

Completed deliverable: *DESCQA validation with ability to run on DRP catalogs (DC2 SW)*

Host: CS *Started, originally due:* 9/01/19, 06/30/20 *Completed:* 06/30/20
URL : https://github.com/LSSTDESC/descqa
Objective: The DESCQA2 framework will operate on available DRP catalogs to check the properties of the objects against truth information and provide validation testing for the end-to-end image simulation pipeline.

CS Key Product (SR): Interface for Image Simulations (CS17)
Objective: This project is aimed at improving the interface between the extragalactic catalogs and the inputs to the image simulations, which currrently suffers from several inefficiencies. The storage footprint and the incoporation of time-domain objects need to be improved. Unit testing and validation testing need to be incorporated into the pipeline.

Active deliverable: *Interface for Image Simulations (SR SW)*

Host: CS *Started, originally due:* 11/01/19, 06/30/20 *Expected:* 06/30/21
Objective: The interface between the extragalactic catalogs, time domain catalogs and truth

catalogs will be improved and streamlined.

CS Key Product (SR): Production of the 5000 sq. deg. Catalog (CS18)
Objective: An extragalactic catalog covering a large area (5000 sq. deg.) of the sky to projected LSST depths is essential for analyses needing high statistics for rare objects. This project will develop infrastructure required for the production of such a catalog.

Active deliverable: *Large-Area Catalog Production (SR SW)*
Host: CS *Started, originally due:* 11/01/19, 06/30/20 *Expected:* 09/30/20
Objective: We will produce a large-area (5000 sq. deg.) extragalactic catalog using the infrastructure developed as part of this project.

CS Key Product (SR): Production of Snapshot Catalogs (CS19)
Objective: Catalogs produced from simulation snapshots are essential for a number of analyses and are used for the study of several systematic effects. This project will develop a pipeline for producing snapshot catalogs from N-body simulation snapshots.

Completed deliverable: *Snapshot Catalog Production (SR SW)*
Host: CS *Started, originally due:* 11/01/19, 06/30/20 *Completed:* 06/30/20 *URL :* https://confluence.slac.stanford.edu/display/LSSTDESC/ProtoDC2+and+CosmoDC2+Information
Objective: We will develop a pipeline to produce snapshot catalogs from N-body simulation snapshots.

CS Key Product (SR): Advanced Tooling for Working with Cosmological Simulation Outputs (CS15)
Objective: In the Science Readiness era, we expect to need to upgrade the various tools we have for manipulating and transforming cosmological simulation outputs: this Key Product defines that suite of tools.

Anticipated deliverable: *Advanced Tooling (SR SW)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host: CS *Started, originally due:* 01/01/21, 10/01/23 *Anticipated:* 10/01/23
Objective: We will develop and upgrade a set of tools for manipulating and transforming cosmological simulation outputs.

5.8 Survey Simulation and Image Processing Pipelines

A realistic simulated LSST dataset requires an extragalactic catalog (Section 5.7), a catalog of Milky Way stars, and a visit list (e.g. from an OPSIM cadence simulation). Using these inputs, we can follow one of two paths: (a) we can simulate the LSST survey and produce mock LSST images, and then process them using the LSST DM stack software to make a mock LSST catalog, or (b) we can emulate a mock LSST catalog directly. We refer to "simulation" and "processing" as the separate, sequential steps in the first path, because the processing pipeline is the same code we would run on real LSST images. This path allows us to probe systematics in the processing pipeline. The second path,"emulation", is currently an R&D activity (Section 4.8). In this section we describe the components of the image simulation and processing pipelines, starting with the tools needed for image simulation.

SSim Key Product (SR): IMSIM Development (imSim1)
Objective: We describe current development efforts on IMSIM, a GalSim based Large Synoptic Survey Telescope (LSST) image simulation package used in the DESC. IMSIM development work is a wide ranging effort across the DESC and LSST project focused on improvements to fidelity, realism and performance. IMSIM development is focused both on creating simulated data to be used both for large (such as the data challenges) and small scale studies, and also for use in analysis during our data taking period. IMSIM development is managed by the IMSIM development team.

Active deliverable: *Improve IMSIM performance (DC2 SW & SR SW & ComCam SW)*

Host: SSim *Started, originally due:* 01/01/18, 01/01/21 *Expected:* 09/30/22
URL : https://github.com/LSSTDESC/imSim
Objective: Increasing run speeds and decreasing memory usage of IMSIM and underlying tools will allow us to scale up the area and depth of our large data challenges. Coupled with new features, these changes could also allow us to build detailed IMSIM simulations which include the control systems of the telescope. The goal would be to quickly simulate extended observing periods with time correlations. This work focuses on file formats, code restructuring,

leveraging advanced computer architecture features etc.

Active deliverable: *Add major features to* IMSIM *(DC2 SW & SR SW & ComCam SW)*

Host: SSim *Started, originally due:* 01/01/18, 01/01/21 *Expected:* 09/30/22
URL : https://github.com/LSSTDESC/imSim
Objective: A major strength of IMSIM is the flexibility of having multiple algorithms and approaches for most important features. The user can easily select a full physics model for calculations such as the atmospheric PSF, or if not needed for a particular run, can choose parameterized models for increased speed instead. Crucially, the parameterized models can be tuned with the full models. Some pieces of the simulation, most notably the treatment of the telescope optics, are missing a full detailed simulation. This task will deliver new major functionality such as a full optical ray-tracer in IMSIM and the interfaces to the software packages it relies on.

Active deliverable: *Increase the realism of* IMSIM *(SR SW & ComCam SW)*

Host: SSim *Started, originally due:* 01/01/18, 01/01/21 *Expected:* 09/30/22
URL : https://github.com/LSSTDESC/imSim
Objective: This task encompasses work which make the IMSIM output more realistic. Increased realism will result both in a better test of the DESC and LSST pipelines and also eventually make the output more useful for analysis during the period of data taking. Work on this deliverable includes increases in fidelity to the sky model including variability, realistic morphology of astronomical sources, other galactic sources of light, important optical effects in the telescope including diffraction and ghosting, more realistic CCD sensor response etc. Some of this work is dependent on the addition of major features as outlined above.

SSim Key Product (SR): Development of DM Catalog Validation Tools (SSimValid1)

Objective: Develop tools to validate catalog data products. Apply validation to simulated data sets. Close coordination with the DM Project is essential to avoid duplication of effort.

Active deliverable: *Development of Validation Tools (DC2 SW & SR SW)*

Host: SSim *Started, originally due:* 01/01/18, 09/30/19 *Expected:* 10/01/23
URL : https://github.com/LSSTDESC/DC2-Production
Objective: Develop tools to validate catalog data products. Apply validation to simulated data

sets. Close coordination with the DM Project is essential to avoid duplication of effort.

SSim Key Product (DC1): DC1 Survey Simulation Tools (SSim1)

Objective: Design the necessary software tools for production of the DC1 datasets and validate the fidelity of the output. This work will be done in collaboration with the analysis working groups and the computing infrastructure groups. Specifically, enable the production of the `Twinkles` and `DC1 Phosim Deep` DC1 datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the LSST images using millions of galaxy postage stamps produced by GALSIM.

The DC1 data challenges will predominantly rely on existing tools. `Twinkles` will use PHOSIM. However, the SL and SN groups also require oversampled and time dependent SN and lenses in the produced images for `Twinkles` which is currently not possible. The SSim group will work with the Twinkles team and the LSST Project simulation team to implement the needed features in the production of the PHOSIM instance catalogs.

Completed deliverable: *Survey Simulation Tools for DC1 (DC1 SW)*

Host: SSim *Started, originally due:* 10/01/15, 01/01/16 *Completed:* 01/01/16
URL : https://github.com/LSSTDESC/SSim_DC1

Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements for the DC1 datasets `Twinkles` and `DC1 Phosim Deep`. The emphasis is studying the capabilities of the tools, their interfaces, and the necessary infrastructure.

Prerequisites: All analysis working group DC1 requirements (DC1 RQ)

Approach: First, collate requirements from the analysis working groups into a single, integrated image requirements document for each of the `Twinkles` and `DC1 Phosim Deep` datasets. Next, study the user and deveoper interfaces to check whether the implemented capabilities are sufficient to meet the analysis requirements of the working groups for DC1. Then extend the CATSIM framework to return multiple strongly lensed galaxies. In the `Twinkles` dataset the SL group requires multiple sources to be returned for each lensed object. Finally, validate the simulation tool fidelity. The goal will be to demonstrate sufficiency according to the requirements of DC1 set by the analysis working groups. Methods of validation should be specified.

Defunct deliverable: *An LSST module in* GALSIM *(DC1 SW)*

5: Pipelines and Computing Infrastructure - Survey Simulation and Image Processing Pipelines

Host: WL *Started, originally due:* 10/01/15, 06/30/16

Objective: As the first step in building WLImSim, construct an LSST-specific GalSim module, including optics and (short-exposure) atmosphere PSFs, sensor response models adapted from SAWG models, key features of the sensor focal plane array layout, and image contributions from the 'spider' and vignetting. The LSST-specific features should be as simple as possible to yield useful forecasts and calibration of galaxy shear systematic errors.

Prerequisites: Deliverables *"Validation of the BF effect in simulations"*, *"Validation of static effects in PhoSim"*

SSim Key Product (DC2): DC2 Survey Simulation Tools (SSim3)

Objective: Design the necessary tools and validate the tools for the DC2 datasets, in collaboration with the analysis working groups and the Computing Infrastructure group. Enable the production of the DC2 datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the WL PSF modeling software *"Identify and characterize PSF systematic uncertainties"*. The DC2 data challenges will emphasize increased fidelity and sophistication along with an increase in simulated volume. DC2 will for the first time emphasize unification of data challenges across working groups. Time dependent sources, which in the past were included in the Twinkles framework, will now also be included in the DC2 dataset. Additionally, a field oversampled in time dependent sources will be embedded in the main data set. In coordination with the Project, the simulation framework will also be updated to allow more realistic time-dependent SEDs for SN and lensed sources, and lensed SN will for the first time be considered.

Active deliverable: *Survey Simulation Tools for DC2 (DC2 SW)*

Host: SSim *Started, originally due:* 10/01/16, 06/30/18 *Expected:* 03/31/21

URL : https://github.com/LSSTDESC/DC2-analysis/tree/master/validation

Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements of the DC2 dataset. The analysis working groups will be requested to finalize a list of DC2 requirements for proposed analysis and validation projects and finally agree upon needed improvements and extensions to be implemented in our simulation tools. After the resulting code is initially validated, a limited test run will be produced and the analysis working groups will then use this data to validate that all effects were properly included.

Prerequisites: All analysis working group DC2 requirements (DC2 RQ), such as *"DC2 Specifications"*, *"DC2 Time Domain Requirements"*

Approach: The approach here is similar to DC1, starting with collecting requirements and studying user and developer interfaces. The validation work is more elaborate than in DC1 and will use 1) real data (laboratory or from other telescopes), 2) other test codes, 3) simplified analytic calculations, or 4) basic sanity check-type simulations. The goal will be to demonstrate sufficiency according to the DC2 requirements set by the analysis groups. Methods of validation should be specified.

Defunct deliverable: *Validation of static effects in* PHOSIM *(DC2 VA)*

Host: SA *Started, originally due:* 10/01/16, 12/31/19
Objective: Perform necessary studies to validate the static effects in PHOSIM code.

Defunct deliverable: *Validation of the BF effect in simulations (DC2 VA)*

Host: SA *Started, originally due:* 10/01/16, 12/31/19
Objective: The BF effect implementation in PHOSIM is based on an electrostatic model where the electric field is dependent on the charge stored in CCD wells. The implementation details need to be validated with respect to the data and adjusted if needed. This may require iterations with the PHOSIM team, and should result in validated BF simulation software.

CO Key Product (DC2): DC2 DM DRP Processing Pipeline and Data Service (CO11)

Objective: The DC2 dataset should provide an intermediate scale test of survey conditions: we must demonstrate that we can reprocess significant amounts of survey data and execute DESC analysis pipelines on that data. This Key Product is the DESC's replica of the LSST DM data release production (DRP) pipeline, and a system for storing and serving the catalog data to the collaboration. This software addresses image processing at scale, and enabling final analysis of the resulting data. The processed data would need to be in standard catalog form, and by the current DM plan, accessed via a Qserv database server.

Completed deliverable: *A DESC-modified DM DRP Reprocessing Pipeline (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/ImageProcessingPipelines
Objective: DESC must replicate the LSST Project DM data release production (DRP) pipeline

technology, such that the algorithms can be investigated and potentially replaced.

Completed deliverable: *Replica of the DM Catalog Technology (DC2 SW)*

Host: CO *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/gcr-catalogs
Objective: DESC must replicate the Project/DM catalog technology to capture and serve its reprocessings of survey data.

SSim Key Product (SR): SR Era Survey Simulation Tools (SSim5)
Objective: Design and validate the necessary tools for the SR-era datasets, in collaboration with the analysis working groups and the CO group. Enable the production of simulated datasets used by multiple working groups, and coordinate with teams developing simulation tools within individual working groups, such as the WL shear calibration simulation effort. These datasets will be an order of magnitude larger than the previous DC simulations and will need to be run on large scale dedicated resources. The output will be processed by the LSST image pipeline which will require deblending, multi-epoch photometry, multi-epoch fitting, and PSF estimation algorithms.

The Science Readiness era will involve work on a variety of data sets that will be defined by the science working groups.

The SSim group will work with CO to ensure the necessary infrastructure is in place for the simulation pipelines to run efficiently in the chosen computer data center environment as specified in the Key Product "SR Workflow and Data Management Configuration" (CO14).

Active deliverable: *Survey Simulation Tools for the Science Readiness Era (SR SW)*

Host: SSim *Started, originally due:* 10/01/18, 09/30/19 *Expected:* 01/01/22
Objective: To create a complete set of validation tests and a suite of survey simulation tools that meet the requirements for the simulated SR datasets.

Prerequisites: All analysis working group SR requirements (SR RQ)

Approach: The approach for simulations in the Science Readiness era is similar to those of the DC1 and DC2 eras, starting with listing requirements, studying user and developer interfaces, and carrying out a comprehensive validation study.

CO Key Product (ComCam): SV-Ready DRP Processing Pipeline and Data Service (SV-DRP)
Objective: We will use the ComCam dataset to prepare a data release production pipeline and hosting service that is ready to go on the SV data.

Anticipated deliverable: *SV-Ready DESC DRP Pipeline (ComCam SW)*
Host: CO *Started, originally due:* 10/01/20, 09/30/22 *Anticipated:* 09/30/22
Objective: For SV the DESC's DRP pipeline will need to be upgraded to keep pace with the DM team's development, and be able to reproduce exactly the ComCam and SV catalogs released by the Project.

Anticipated deliverable: *SV-Ready Replica of LSST Science Platform (ComCam SW)*
Host: CO *Started, originally due:* 10/01/20, 09/30/22 *Anticipated:* 09/30/22
Objective: DESC must implement a replica of the Project's Science Platform to host its re-processings of the SV data, including the infrastructure needed in the replication, eg a qserv instance.

5.9 Commissioning Software Infrastructure

COM Key Product (ComCam): SV-Ready Commissioning Software (COM-SV)
Objective: The commissioning working group will produce software (ideally based on LSST Project tools to the extent possible) for DESC-specific tests during LSST SV.

Anticipated deliverable: *SV-Ready Commissioning Software integrated within LSST Project tools (ComCam SW)*
Host: COM *Started, originally due:* 10/01/20, 10/01/22 *Anticipated:* 10/01/22
Objective: This deliverable captures effort on DESC-specific software for tests during LSST SV.

5.10 Dark Matter Software Infrastructure

The dark matter (DKM) working group shares pipeline infrastructure with many other working groups (i.e. , SL, WL, CL). The DKM group expects to contribute to the development, testing, and application of those pipelines; however, we leave those discussions to the other working groups. Here, we focus on pipeline infrastructure that is unique to DKM and will not be provided elsewhere. Specific pipeline infrastructure products and deliverables will be added in this section as the DKM group develops its plans.

5.11 External Synergies Software Infrastructure

The ES working group does not yet have a plan for software infrastructure development; this may change as the group develops its plans.

5.12 Weak Lensing Pipeline

In this section, we focus on the development of pipelines to go from input images to accurate two-point statistics and cosmology derived from them. The WL and LSS working groups are collaboratively building a pipeline for joint analysis of these probes to the point of summary statistics. A schematic of that pipeline, TXPIPE, is shown in Figure 5.12.1. The rest of the analysis, in particular the likelihood analysis that goes from summary statistics to cosmological parameters, will take place within TJPCOSMO. In practice, the "images to catalogs" and "catalogs to cosmology" parts of the pipeline are developed in separate stages. The high-level development path is as follows:

- **DC1 era**: development of "catalogs to cosmology" pipeline for shear-shear correlations within WL group (and parallel LSS clustering development within LSS group).
- **DC2 era**: development of "images to catalogs" shear pipeline and extension of "catalogs to cosmology" pipeline to include additional two-point correlations (galaxy-shear and galaxy-galaxy), so as to have a complete TXPIPE implementation that covers the WL and LSS analyses; development of systematics models for modeling and marginalization purposes.
- **SR era**: further development of systematics models and algorithms in TXPIPE to ensure it meets DESC requirements for systematics control. The deliverables for this era are most uncertain, since the DC2 pipeline development and validation will inform our priorities for SR.
- **SV era**: application of TXPIPE to the SV data, including adaptation of the code to real data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

WL Key Product (DC1): Weak Lensing Pipeline (WLPIPE)
Objective: Build the prototype weak lensing pipeline WLPIPE WL pipeline analysis stages. WLPIPE constitutes a well-defined subset of the analysis process that will eventually be carried out by DC2-era software TXPIPE (Figure 5.12.1), in two respects: it does not include the "images to catalogs" part of the process, and it only covers shear-shear correlations, not the full 3×2-point analysis (with galaxy-shear and galaxy-galaxy correlations included).

Completed deliverable: *Pipeline for WL Cosmology Constraints from a Shear Catalog (DC1 SW)*

Host: WL *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe
Objective: The goal of this deliverable is to produce a prototype of the "catalogs to cosmology" pipeline, which should be able to take catalogs with shear estimates that have already been calibrated, and photometric redshift estimates, and produce cosmological parameter constraints from shear-shear correlations.

Completed deliverable: WLPIPE *Validation (DC1 VA)*

Host: WL *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe
Objective: WLPIPE validation is carried out through analysis of catalogs from precursor survey, in addition to internal cross-checks. A cross-survey cosmic shear comparison paper should result from this process.
Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Completed deliverable: *Workflow management system applied to DC1 WL workflow* WLPIPE *(DC2 SW)*

Host: WL *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/WLPipe/tree/master/parsl_wlpipe
Objective: In collaboration with the CI working group, evaluate and use a workflow management system to coordinate the flow of data within WLPIPE, impose the dependencies of each step on previous steps, and provide a coherent structure for the overall pipelines. This should include the ability to submit jobs on HPC facilities.

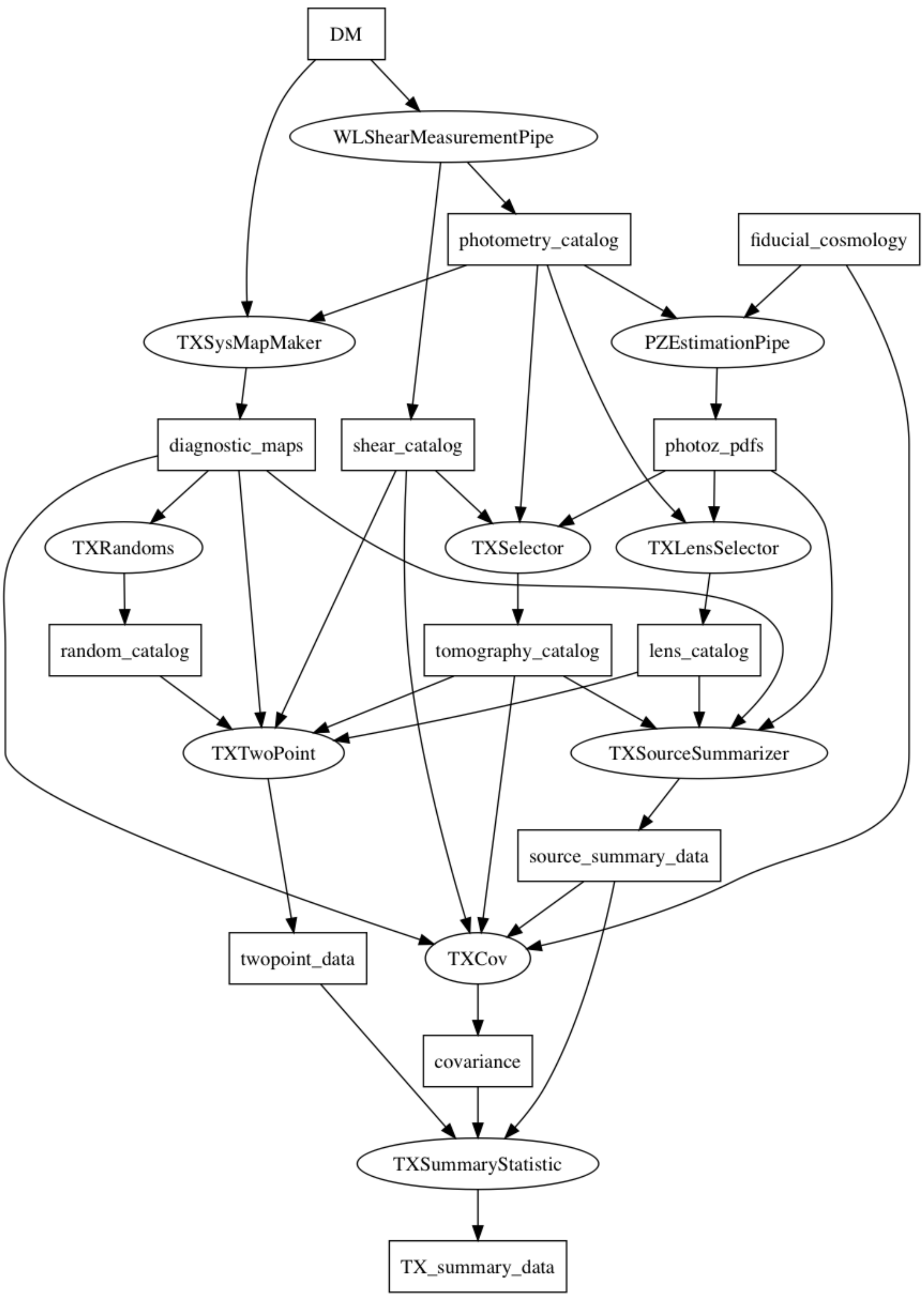

Figure 5.12.1: A schematic of the joint WL + LSS pipeline (TXPIPE), where ovals indicate analysis stages and rectangles indicate data that gets passed around.

Prerequisites: Deliverable *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*

Completed deliverable: *Extension of* WLPIPE *to 3x2-point analysis (DC2 SW)*

Host: WL *Started, originally due:* 10/01/17, 07/01/18 *Completed:* 07/01/18
URL : https://github.com/LSSTDESC/WLPipe
Objective: Extend the WLPIPE framework to include the full 3x2-point analysis, i.e., shear-shear, shear-galaxy, galaxy-galaxy correlations.
Prerequisites: Deliverables *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*, *"Workflow management system applied to DC1 WL workflow* WLPIPE*"*

WL Key Product (DC2): Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC2)
Objective: Build the more complete WL pipeline illustrated in Figure 5.12.1. Note that the analysis stage called "PZEstimationPipe" is provided by PZ, while "TXSysMapMaker" and "TXRandoms" are provided by LSS. These stages are not listed below, since this subsection is specifically for WL infrastructure activities. For the analysis stages listed below, some will have contributions from multiple groups, but WL is leading or coordinating the effort.

Completed deliverable: *Pipeline tools that connect to workflow management system (*CECI*) (DC2 SW)*

Host: WL *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 05/21/20
URL : https://github.com/LSSTDESC/ceci
Objective: After exploration of workflow management tools in general, develop a lightweight framework (CECI) for using our adopted DC2-era WMS (Parsl) to easily run DESC pipelines.
Prerequisites: Deliverables *"Pipeline for WL Cosmology Constraints from a Shear Catalog"*, *"Workflow management system applied to DC1 WL workflow* WLPIPE*"*

Active deliverable: *Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*) (DC2 SW)*

Host: WL *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 03/01/21 *URL :* https://github.com/lsst-dm/meas_extensions_ngmix,https://github.com/esheldon/metadetect,https://github.com/LSSTDESC/descwl-shear-sims
Objective: Using as many DM tools as possible, put together an end-to-end pipeline (the analysis stage in Figure 5.12.1 called SHEARMEASUREMENTPIPE) to process a set of images and produce a shear catalog. The catalog should include estimators of the shear, size, S/N, and a covariance matrix of these quantities, along with ancillary information such as the mean PSF

size and shape used for the analysis, the list of positions on the focal plane that were used, etc.. Note that not all methods produce a useful shape estimate on each object – certain hierarchical methods, for example, generate the ensemble shear estimation from a set of quantities of the galaxy sample. A first implementation of SHEARMEASUREMENTPIPE based on MetaCalibration (Metacal, Sheldon 2014) is currently available and directly integrated as a DM task. Refinements of this approach, a.k.a. MetaDetection (Metadetect, Sheldon et al. 2019) are under investigation, along with the Bayesian Fourier domain (BFD, Bernstein and Armstrong 2014) method as a second proposed algorithm. In addition, some thought will be required to see how hierarchical methods that do not even do this can fit into this framework. To facilitate the development of these shear measurement methods, a set of flexible, small-scale image simulations are developed with instrumental effects such as bleed trails and bad pixels/columns.
Prerequisites: Deliverables *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of correction algorithms for static effects"*

Active deliverable: *Source selector and tomographic binning definition software (TXSOURCESELECTOR) (DC2*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 03/01/21
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/selector.py
Objective: Develop the TXSOURCESELECTOR analysis stage (see Figure 5.12.1), which selects sources to use and divides them into tomographic bins for WL and LSS analysis.
Prerequisites: Deliverable *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"*, *"Pipeline tools that connect to workflow management system (CECI)"*

Completed deliverable: *Source summarizer analysis stage (SOURCESUMMARIZER) (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Completed:* 08/01/20
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/metadata.py
Objective: Develop the SOURCESUMMARIZER analysis stage (see Figure 5.12.1), which computes ensemble summary statistics for the tomographic bins (e.g., number densities, shape noise). These values will be input to the covariance calculation in *"Covariances for the joint WL+LSS analysis (TXCOV)"*.
Prerequisites: Deliverable *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"*, *"Pipeline tools that connect to workflow management system (CECI)"*

Active deliverable: *Software for two-point statistics (TXTWOPOINT) (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 03/01/21
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/twopoint.py
Objective: Develop the TXTWOPOINT analysis stage (see Figure 5.12.1) that can efficiently

calculate the relevant two-point statistics given a catalog, building on relevant pre-existing software. Note that unlike the two-point correlation analysis stage in DC1 software WLPIPE, TXTWOPOINT should generalize beyond shear-shear correlations to other relevant two-point correlations, such as shear-galaxy and galaxy-galaxy correlations. The null tests of the Deliverable *"Null test pipeline (WLNULLTEST)"* should be applied to these statistics. In practice, there will be a configuration- and Fourier-space version of this analysis stage.
Prerequisites: Deliverable *"Software for characterizing mask as a function of pixelization"*; overlap with Deliverable *"Power-spectrum estimation code (TXTWOPOINT)"*

Active deliverable: *Covariances for the joint WL+LSS analysis (TXCOV) (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 03/01/21
Objective: Develop the TXCOV analysis stage (see Figure 5.12.1), which estimates quick covariances for the pipeline using simple methods or serves as an interface to the TJPCOV framework. The likelihood analysis will use TJPCOV, but for some purposes (like null tests and sanity checks) having a simple covariance estimator in the pipeline at an earlier stage is necessary.
Prerequisites: Deliverable *"Pipeline tools that connect to workflow management system (CECI)"*

Completed deliverable: *Summary statistic collector (TXSUMMARYSTATISTIC) (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Completed:* 08/01/20
URL : https://github.com/LSSTDESC/sacc
Objective: Develop the TXSUMMARYSTATISTIC analysis stage (see Figure 5.12.1), which aggregates information in a form to be ingested by TJPCOSMO. This is effectively the stage that puts the data vector, covariance matrix, and other metadata into a SACC file.
Prerequisites: Deliverable *"Pipeline tools that connect to workflow management system (CECI)"*, *"Software for two-point statistics (TXTWOPOINT)"*

Active deliverable: *Validation of TXPIPE (DC2 VA)*

Host: WL *Started, originally due:* 03/31/19, 12/31/19 *Expected:* 03/01/21
Objective: Once the DC2 prototype of TXPIPE is put together, it should be validated using precursor survey datasets and DC2 simulations.
Prerequisites: All previous deliverables in this KP.

WL Key Product (DC2): Weak Lensing Mass Maps and Map-Based Statistics (WLMASSMAP-

DC2)

Objective: Build a pipeline that generates weak lensing mass maps and evaluates certain map-based statistics. This pipeline will reuse components of TXPIPE (e.g. CECI, TXSOURCESELECTOR, SOURCESUMMARIZER) whenever possible.

Active deliverable: *Pipeline to generate weak lensing mass maps (DC2 SW)*

Host: WL *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 03/01/21
URL : https://github.com/LSSTDESC/WLMassMap
Objective: A Pipeline that takes in a shear catalog and generates weak lensing convergence maps as well as a number of map-based statistics.
Prerequisites: Most deliverables in "Weak Lensing and Large-Scale Structure Pipeline" (TXPIPE-DC2).

WL Key Product (DC2): WL Systematic Uncertainty Characterization Framework (WL2)

Objective: Develop a framework for handling systematic errors, including both errors in the shear catalog, and theoretical systematics (e.g., intrinsic alignments, baryonic mass), including (where appropriate) developing models of the systematics to be used within this framework and a process for marginalizing over them. The software developed here will be used as a separate stage to validate outputs of the shear measurement pipeline from TXPIPE, and/or as inputs to the TJPCOSMO likelihood modeling framework.

Active deliverable: *Null test pipeline (WLNULLTEST) (DC2 SW)*

Host: WL *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 03/01/21
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/diagnostics.py
Objective: Set up a pipeline, WLNULLTEST, that can run a set of lensing-related null tests on catalog-level data, including one a variety of one-point and two-point statistics. Examples of one-point statistics include shear vs PSF shape, star-galaxy correlations, mean shear vs. galaxy properties, B-mode, consistency of shear correlation functions and systematics when dividing by observational conditions and galaxy properties, etc.. Examples of two-point statistics include tests that $\xi_{\pm}$ are not different when splitting on airmass, PSF size, PSF shape, etc.. See e.g., Jarvis et al. 2015 and Becker et al. 2015; Zuntz et al. 2018 for a list of these null tests. *Note: At least for DC2, this Deliverable is distinct from the two-point estimators* LSSTWOPOINT *(Deliverable "Power-spectrum estimation code (*TXTWOPOINT*)") because of the need to develop shear E/B mode correlation estimators on a short timescale.* This pipeline will be

extended in SR to include null tests for higher-order statistics.
Prerequisites: Deliverable *"Software for two-point statistics (TXTWOPOINT)"*, *"Pipeline to generate weak lensing mass maps"*, *"Software for characterizing mask as a function of pixelization"*

Active deliverable: *Identify and characterize PSF systematic uncertainties (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 03/01/21
Objective: Here we separate PSF-related systematic uncertainties from other sources of systematics for its unique role in shear estimation. PSF systematics here is categorized to include atmosphere, optics, and sensor image transfer functions, including chromatic effects at each stage. This deliverable provide models of their impact in shear correlation measurements. This is connected to the PSF modeling and interpolation framework to be used by the shear estimation analysis stage (c.f. Deliverable *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"*). Work is needed within the DESC on evaluation of the new algorithm in comparison with other state-of-the-art methods such as PIFF, in comparison with our requirements for WL science. The development and testing of models for PSF systematics will use DC2 simulations and simulation codes for sensor systematics including POISSON_CCD[9]. Validate the systematics model effectiveness with the null test pipeline from the Deliverable *"Null test pipeline (WLNULLTEST)"*.
Prerequisites: Deliverables *"Validation of the BF effect in simulations"*, *"Validation of static effects in PHOSIM"*, *"Null test pipeline (WLNULLTEST)"*

Active deliverable: *Identify and characterize non-PSF systematic uncertainties (DC2 SW)*

Host: WL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 03/01/21
Objective: Provide computational implementations of models for how observational systematics that we want to marginalize over impact the WL observables (shear-shear and galaxy-shear correlations), plus priors on the parameters of those models in the TJPCOSMO pipeline (we do not expect all WL-specific systematics to be available in TJPCOSMO without this Deliverable). Validate the systematics model effectiveness with the null test pipeline from the Deliverable *"Null test pipeline (WLNULLTEST)"*. The systematics to be considered here include star/galaxy separation, blending, impact of unresolved sources, shear calibration errors, photo-z errors, and depth variation across the survey area.
Prerequisites: Deliverables and Activities *"Null test pipeline (WLNULLTEST)"*, *"$p(z)$ for*

[9] https://github.com/craiglagegit/Poisson_CCD

DC1 Galaxies"

WL Key Product (SR): Updated Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-SR)

Objective: Further upgrade the combined WL+LSS pipeline illustrated in Figure 5.12.1 as needed for future analyses, aimed at reaching the level of systematics control needed for LSST. This key project includes some work that was deliberately deferred to a later stage in pipeline development, and will be updated later based on lessons learned during DC2 about additional functionality that is needed to meet the DESC science requirements.

Planned deliverable: *Improved shear pipeline (SR SW)*

Host: WL *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 07/01/21

Objective: Make necessary improvements to the shear measurement pipeline to handle the larger data volume and additional realism of the SR simulated data and any data from precursor datasets that is used to test the pipeline. In addition to the shear estimates, the pipeline should also be producing accurate size estimates of the galaxies for use in magnification measurements (along with corresponding null tests).

Prerequisites: Deliverables *"Pipeline for Producing a Shear Catalog (SHEARMEASUREMENTPIPE)"*, *"Identify and characterize PSF systematic uncertainties"*

Planned deliverable: *Proper handling of chromatic effects (SR SW)*

Host: WL *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 07/01/21

Objective: Include in the shear estimation pipeline proper handling and testing of chromatic effects in the data. This involves estimating the appropriate PSF to use for each galaxy based on its SED and the wavelength dependence of the PSF. There should also be a number of new null tests being run to test for systematics related to chromaticity.

Prerequisites: Deliverables *"Null test pipeline (WLNULLTEST)"*, *"Identify and characterize PSF systematic uncertainties"*, *"Validation of the BF effect in simulations"*, *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of static effects in PHOSIM"*, *"Validation of correction algorithms for static effects"*

Planned deliverable: *Proper handling of neighbors (SR SW)*

Host: WL *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 07/01/21

Objective: Make sure the shear measurement pipeline is properly handling blended objects and neighbors. The code for doing this should have been developed through analysis of DC2.

The WL-specific task within this Key Project is to develop null tests to confirm that there are not significant artifacts in the shear catalog due to blending or close neighbors. In particular, this includes two regimes: bright nearby objects that affect the local background level (both amplitude and slope) and fainter objects that are very close to the object being measured for which deblending techniques are required for accurate shear measurements.
Prerequisites: Deliverables *"Null test pipeline (WLNullTest)"*, *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*

Planned deliverable: *Pipeline for magnification (WLMagPipe) (SR SW)*

Host: WL *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/22
Objective: Develop a pipeline, WLMagPipe, that can produce accurate lensing magnification estimates as an additional WL probe.
Prerequisites: Deliverables *"Improved shear pipeline"*

Planned deliverable: *Pipeline for validating shear calibration (SR SW)*

Host: WL *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 07/01/21
Objective: Work with LSST DM and the computing working groups to set up a software pipeline that can automatically test the shear catalogs. This will likely tie closely to the pipeline produced by Key Project "Weak Lensing and Large-Scale Structure Pipeline" (TXPipe-DC2).

Prerequisites: *"Improved shear pipeline"*.

WL Key Product (SV): Applied Weak Lensing and Large-Scale Structure Pipeline (TXPipe-SV)
Objective: Adapt the combined WL+LSS pipeline to SV data, incorporating lessons learned during the SR era (including ComCam testing). Extend the pipeline to support alternative advanced algorithms.

Anticipated deliverable: *At-scale TXPipe Application (SV SW)*

Host: WL *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23
Objective: Adapt the TXPipe code to the real SV data, to run at scale and without error.

Anticipated deliverable: TXPipe *SV Extensions (SV SW)*

Host: WL *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23

Objective: Extend the TXPIPE pipeline to support additional advanced algorithms.

5.13 Large Scale Structure Pipeline

The focus of this subsection is development of a pipeline for large-scale structure analysis. The WL and LSS working groups are collaboratively building a pipeline for joint analysis of these probes to the point of summary statistics. A schematic of that pipeline, TXPIPE, is shown in Figure 5.12.1. The rest of the analysis, in particular the likelihood analysis that goes from summary statistics to cosmological parameters, will take place within TJPCOSMO. The high-level development path is as follows:

- **DC1 era**: development of LSS-only pipeline within the LSS working group, largely independent of other working groups.
- **DC2 era**: development of TXPIPE jointly with the WL working group and other relevant groups such as PZ, so as to have a complete TXPIPE implementation that covers the WL and LSS analyses; development of systematics models for modeling and marginalization purposes.
- **SR era**: further development of systematics models and algorithms in TXPIPE to ensure it meets DESC requirements for systematics control. The deliverables for this era are most uncertain, since the DC2 pipeline development and validation will inform our priorities for SR.
- **SV era**: application of TXPIPE to the SV data, including adaptation of the code to real data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

LSS Key Product (DC1): DC1 LSS Pipeline (LSS-DC1)
Objective: Build the LSS pipeline for DC1 analysis.

Completed deliverable: *Software for storing correlation function and covariance information (SACC) (DC1 SW)*

Host: LSS *Started, originally due:* 10/01/15, 04/01/17 *Completed:* 04/01/17

URL : https://github.com/LSSTDESC/sacc
Objective: Build software for storing and transferring information about two-point correlations and their covariances.

Completed deliverable: *Two-point preliminary studies (DC1 SW)*

Host: LSS *Started, originally due:* 04/01/17, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/2pt_validation
Objective: Explore optimal techniques to estimate reliable two-point functions: Exploratory study of existing (and non-existing) methods for two-point estimation for large-area datasets in the presence of systematic uncertainties. Optimality should be evaluated in terms of computational speed, robustness against systematics, simplicity and error bar size.
Prerequisites: Deliverable *"Temporary survey coverage tools"*

Completed deliverable: *Validation tests of DC1-era LSS pipeline on simulations (DC1 VA)*

Host: LSS *Started, originally due:* 04/01/17, 06/30/18 *Completed:* 09/25/19
URL : https://github.com/LSSTDESC/LSS_DC1_paper
Objective: Apply DC1-era LSS tools to DC1 simulations to validate them and develop understanding of future needs.
Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*, Deliverable *"Temporary survey coverage tools"*, Deliverable *"Two-point preliminary studies"*

Completed deliverable: *Validation tests of DC1-era LSS pipeline on precursor datasets (DC1 VA)*

Host: LSS *Started, originally due:* 04/01/17, 06/30/18 *Completed:* 10/23/19
URL : https://github.com/LSSTDESC/DEHSC_LSS
Objective: Apply DC1-era LSS tools to the HSC survey dataset to validate them and develop understanding of future needs.
Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*, Deliverable *"Temporary survey coverage tools"*, Deliverable *"Two-point preliminary studies"*

LSS Key Product (DC2): LSS Pipeline Components of TXPIPE (LSS4/TXPIPE)
Objective: Build the LSS-specific pipeline pieces of the Key Project "Weak Lensing and Large-Scale Structure Pipeline" (TXPIPE-DC2) and illustrated in Figure 5.12.1. In some cases, this

involves building a Fourier-space version of analysis stages for which the WL group is building configuration-space versions, hence the analysis stage appears in multiple sections.

Completed deliverable: *Power-spectrum estimation code (TXTWOPOINT) (DC2 SW)*

Host: LSS *Started, originally due:* 10/01/17, 06/30/18 *Completed:* 01/16/19
URL : https://github.com/DESC/NaMaster
Objective: Measure power spectra for any number of spin-0 and spin-2 projected quantities.

The main Deliverable of this effort is a well-written and documented code (a Fourier-space version of TXTWOPOINT, a module in TXPIPE) that can compress positions of billions of objects, their shear estimates, their photo-z estimates and their window function into a 2-point function measurement in either Fourier or configuration space, using the information gathered in the Deliverable *"Two-point preliminary studies"*. This code can marginalize over systematic templates and provides uncertainty estimates based on several different methods. It should also be possible to use this code for null tests (e.g. correlation with known systematics), which will be necessary at any validation stage.
Prerequisites: Deliverable *"Two-point preliminary studies" "Software for characterizing mask as a function of pixelization"*

Completed deliverable: *Two-point storage framework (DC2 SW)*

Host: LSS *Started, originally due:* 10/01/17, 07/01/18 *Completed:* 06/27/19
URL : https://github.com/LSSTDESC/sacc
Objective: Optimized file format for two-point statistics and covariances

Development of self-contained and well documented file format able to store a large number of generic two-point statistics between pairs of tracers, as well as all of the information needed to perform a science analysis of them, including spins, tracer types, binning schemes, units, window functions, and covariance matrices.

Ideally, the format should be extended to also accommodate 1-point measurements (e.g. cluster number counts), possibly linked to the two-point functions of the same samples.
Prerequisites: Deliverable *"Software for storing correlation function and covariance information (SACC)"*

Active deliverable: *Optimal catalog splits into samples (TXLENSSELECTOR) (DC2 SW)*

Host: LSS *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 01/01/21
URL : https://github.com/LSSTDESC/tomo_challenge
Objective: Study optimal methods for sample separation

It is not a priori clear what the optimal way of dividing a given photometric sample into subsamples is, in order to preserve the maximum amount of cosmological information. Optimality here can be defined in different terms, e.g. signal-to-noise maximization, robustness against known systematics or minimum variance of final parameters. This Deliverable will explore different possibilities based on true observables (fluxes), derived quantities (photo-z properties) or physical properties of the galaxy population. It will be addressed in collaboration with the PZ and WL WGs if needed, and will result in the creation of a version of the TXLENSSELECTOR analysis stage in TXPIPE.

Completed deliverable: *Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO *(DC2 SW)*

Host: LSS *Started, originally due:* 10/01/17, 12/31/19 *Completed:* 11/13/18
URL : https://github.com/LSSTDESC/LSSLike
Objective: Develop likelihood code with realistic nuisance parameters

Develop a likelihood code able to transform a set of measured two-point statistics (stored in the format of the Deliverable *"Two-point storage framework"*) into constraints on cosmological and basic nuisance parameters (e.g. bias parameters, photo-z systematics), making use of CCL. This will involve interfacing with TJP to make sure the LSS theory needs are met (e.g. in terms of bias parametrizations or clustering models) and potentially also with WL and PZ.

Active deliverable: *Validation tests of DC2-era LSS pipeline on simulations (DC2 VA)*

Host: LSS *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 01/01/21
URL : https://github.com/LSSTDESC/DC2-LSS
Objective: Apply DC2-era LSS tools, as implemented in TXPIPE and TJPCOSMO, to DC2 simulations to validate them.
Prerequisites: Deliverable *"Two-point storage framework"*, Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, Deliverable *"Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO*"*

Active deliverable: *Validation tests of DC2-era LSS pipeline on precursor datasets (DC2 VA)*

Host: LSS *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 01/01/21
URL : https://github.com/LSSTDESC/txpipe-reanalysis
Objective: Apply DC2-era 3×2-point tools, as implemented in TXPIPE and TJPCOSMO, to existing precursor datasets. This is a continuation of the analysis of the HSC DR1 data *"Validation tests of DC1-era LSS pipeline on precursor datasets"* as well as other precursor data (DES and KiDS) to probe different ranges of data volume and scales.
Prerequisites: Deliverable *"Two-point storage framework"*, Deliverable *"Power-spectrum estimation code (*TXTWOPOINT*)"*, Deliverable *"Basic LSS likelihood module (*LSSCOSMO*)*

contribution to TJPCosmo*"*

LSS Key Product (DC1 & DC2): Survey geometry (CX3)
Objective: Several of the analysis Working Groups will need a *mask* in order to extract cosmological results from catalogs. While different groups have different needs, the following type of functionality should generically be supported: identifying regions in which galaxies could not be observed even if present, such as those near bright stars; quantifying position-dependent information about survey depth and number density (which goes beyond a binary yes/no and requires floating point numbers such as limiting magnitudes in various bands to be tracked). The dependence of the mask on depth and SED may also not be trivial, since dust extinction may differentially obscure galaxies with different SEDs. Since there will be multiple definitions of magnitude and each of these applies in different bands, there will be a large variety of masks produced and used by the analysis WGs.

The Large Scale Structure WG will produce accurate clustering statistics of galaxies only if the expected number of galaxies in the absence of clustering in every pixel is known. The covariance matrix on estimates of shear statistics that will be produced and used by the WL WG will be informed by the number density of galaxies as a function of redshift used in each pixel, a number that relies on the mask. The richness of galaxy clusters will require a mask that uses multiple bands and has particular angular requirements. Photometric redshifts cut across many of the WG's, and these too will require a wide variety of masks. Even photometric redshift algorithms based solely on colors require depth masks in different bands to ensure completeness; those that use clustering information are even more heavily dependent on accurate masks.

Beyond these masks aimed at the *signal*, the collaboration will produce maps of systematics, and these too rely on having a robust framework to map survey geometry. Various observational quantities that might be relevant for masking and more generally for null tests, such as the mean and median seeing, sky noise, and airmass, should be stored in a pixelized format similar to that used for the mask.

LSST DM plans to produce tools for some of the above; among the first part of this task is to more fully investigate what they will produce and when, to enable the DESC to use as much of their infrastructure as possible. This key project is hosted by LSS but requires input from other working groups.

Defunct deliverable: *Temporary survey coverage tools (DC1 SW)*

Host: LSS *Started, originally due:* 10/01/15, 06/30/18
URL : https://github.com/LSSTDESC/LSS_utils

Objective: Since DM tools for quantifying survey geometry are not available during DC1, the LSS group must port over pre-existing tools for use during DC1 and the start of DC2. A variety of tools are under consideration for this purpose.
Prerequisites: None

Completed deliverable: *Survey mask use cases (DC2 RQ)*

Host: LSS *Started, originally due:* 07/01/18, 04/30/19 *Completed:* 05/15/19
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/LSS+related+documents+and+talks?preview=/125469885/267386951/survey_report.pdf
Objective: In order to further understand our needs and to properly convey them to LSST DM, it will be helpful to collect a set of use cases for survey geometry tools, including their requirements with respect to flexibility in the range of scales represented, speed, etc. The results of this survey should be discussed within the collaboration and with DM.
Prerequisites: None

Completed deliverable: *Software for characterizing mask as a function of pixelization (DC2 SW)*

Host: CI *Started, originally due:* 03/31/19, 12/31/19 *Completed:* 06/19/19
URL : https://github.com/lsstdesc/healsparse
Objective: Develop code to define survey geometry with sufficiently fine angular resolution and scalable storage functionality. Liaise with DM to make this useful for the collaboration.
Prerequisites: Deliverable *"Survey mask use cases"*

Active deliverable: *Random points software (*TXRandoms*) for* TXPipe *(DC2 DP)*

Host: LSS *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 01/01/21
URL : https://github.com/LSSTDESC/TXPipe/blob/master/txpipe/random_cats.py
Objective: The combined WL+LSS pipeline TXPipe needs a module to generate random points using the tools developed as part of *"Software for characterizing mask as a function of pixelization"*. Since these tools may take some time to develop, preliminary work will take place using in-house software based on the LSS work carried out as part of *"Validation tests of DC2-era LSS pipeline on precursor datasets"*.
Prerequisites: Deliverable *"Software for characterizing mask as a function of pixelization"*

Completed deliverable: *Maps of systematics:* TXSysMapMaker *for* TXPipe *(DC2 DP)*

Host: LSS *Started, originally due:* 07/01/18, 12/31/19 *Completed:* 04/08/20
URL : https://github.com/LSSTDESC/supreme
Objective: Apply the mask framework from the Deliverable *"Software for characterizing mask*

as a function of pixelization" to make maps of systematics (seeing, PSF asymmetry, airmass, sky noise, dust extinction, stellar density, survey depth) for the DC2 dataset. The resulting software will serve as the TXSysMapMaker analysis stage in TXPipe. Since the mask framework may take some time to develop, preliminary work will take place using in-house software based on the LSS work carried out as part of *"Validation tests of DC2-era LSS pipeline on precursor datasets"*. These maps will be shared with all working groups and used as templates for systematics searches including null tests.
Prerequisites: Deliverables *"Software for characterizing mask as a function of pixelization"*, *"DC2 Simulated Images"*

LSS Key Product (SR): Improved LSS Pipeline Components (TXPipe-LSS)
Objective: Further upgrade the LSS-specific pipeline components illustrated in Figure 5.12.1 as needed for future analyses, aimed at reaching systematics control and improved statistical precision. This key project includes some work that was deliberately deferred to a later stage in pipeline development, and will be updated later based on lessons learned during DC2 about additional functionality that is needed to meet the DESC science requirements.

Planned deliverable: *Joint pipeline with CMB data (SR SW)*

Host: LSS *Started, originally due:* 03/31/19, 06/30/20 *Expected:* 06/30/21
Objective: Extend DC2-era LSS analysis pipeline (e.g. *"Power-spectrum estimation code (TXTwoPoint)"* and *"Two-point storage framework"*) to include the joint analysis of LSS data with external CMB data, with a particular emphasis on secondary anisotropies (lensing, SZ and ISW). Validate the new tools making use of simulations and precursor LSS and CMB data.
Prerequisites: Deliverables *"Power-spectrum estimation code (TXTwoPoint)"*, *"Two-point storage framework"*, *"Final LSS likelihood module (LSSCosmo) contribution to TJPCosmo"*

Planned deliverable: *Optimal deblending for LSS (SR SW)*

Host: LSS *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: Study optimal methods for deblending of sources at weaker SNR Blending of sources will be a major issue for LSST LSS analysis. It is clear that deblending of sources for use in WL will have more stringent requirements than for sources than only need to separate fluxes to be used as point tracers. We will study if sources that are rejected for use for shear can be salvaged for use as point tracers and if probabilistic catalog can be used for better

systematic control and smaller statistical errors. These will eventually become part of TXPIPE.

Active deliverable: *Final LSS likelihood module (LSSCOSMO) contribution to TJPCOSMO (SR SW)*

Host: LSS *Started, originally due:* 10/01/19, 06/01/20 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/firecrown
Objective: Develop likelihood code with realistic nuisance parameters and sophisticated non-linear models

Implement a range of non-linear galaxy bias models in the LSS component of TJPCOSMO using CCL, and robustly propagate redshift distribution uncertainties.
Prerequisites: Deliverables *"Basic LSS likelihood module (LSSCOSMO) contribution to TJPCOSMO"*

Anticipated deliverable: *Improved LSS pipeline based on application to LSST SV (SV SW)*

Host: LSS *Started, originally due:* 06/01/20, 10/01/23 *Anticipated:* 10/01/23
Objective: Further develop LSS pipeline components through application to LSST SV data.

5.14 Clusters Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with galaxy clusters. The galaxy clusters (CL) working group has two parallel analysis pathways: a fully stacked analysis pathway that includes cluster 1- and 2-point statistics, and a pathway that involves individual cluster shear profiles. While both can rely on similar inputs to the data analysis and similar analysis stages, the likelihood analysis for the two approaches is rather different. The high-level development path is as follows:

- **DC1 era**: pre-DC2 work has focused on development of CLMASSMOD, a package for fitting weak lensing profiles.

- **DC2 era**: development of the cluster-specific parts of the stacked analysis pipeline, which will rely on TXPIPE and the WL shear calibration pipeline; and development of the likelihood analysis for that analysis pathway within TJPCOSMO. Continued development of tools to validate WL mass estimates on simulations with CLMASSMOD.

- **SR era**: further development of the stacked analysis pipeline; integration of algorithms for the individual cluster analysis pathway (based on work in precursor surveys) into TJPCOSMO.

- **SV era**: integration of the CL pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

A diagram exemplifying the required information flow is given in Figure 5.14.1. Deliverables will include the development of codes that enable a complete and general modeling of multi-wavelength cluster scaling relations, and the extension of the code to handle very large data sets without loss of efficiency or information. As opportunities arise, the code will be applied to real data to determine state-of-the-art cosmological constraints (see Key Product "CL Cosmology Likelihood Module CLCosmo" (CL5)). We expect this pipeline design to evolve as the collaboration iterates towards an efficient multi-probe analysis design.

CL Key Product (DC2 & SR): CL Pipeline Components for use with TXPipe (CL7)

Objective: Build the CL-specific pipeline pieces in Figure 5.14.1.

Completed deliverable: *Cluster Finder (CLFinder) (DC2 SW)*

Host: CL *Started, originally due:* 10/01/16, 12/31/19 *Completed:* 12/31/19

URL : https://github.com/erykoff/redmapper

Objective: RedMaPPer is currently the most robust, well-tested optical cluster finder, and will be (at least one of) the primary algorithm(s) to identify clusters from LSST data. While much of its further development is currently being performed outside the DESC (as part of the Dark Energy Survey), the findings of this Key Project will be used to further refine the algorithm. The goal of this deliverable is to produce a version of RedMaPPer that has been ported to python for use within DESC.

Prerequisites: Deliverables *"$p(z)$ for DC1 Galaxies"*,`HaloCat`

Active deliverable: *Cluster Finder (CLFinder) Validation (DC2 VA)*

Host: CL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 07/01/21

Objective: To validate cluster finders for DESC, we require simulated galaxy catalogs including accurate galaxy colors/clustering in all LSST bands (DC2 extragalactic and image simulations). Where deemed useful to compare the impact of different assumptions made in cluster finding, validation will include a systematic comparison across cluster finders using a range of

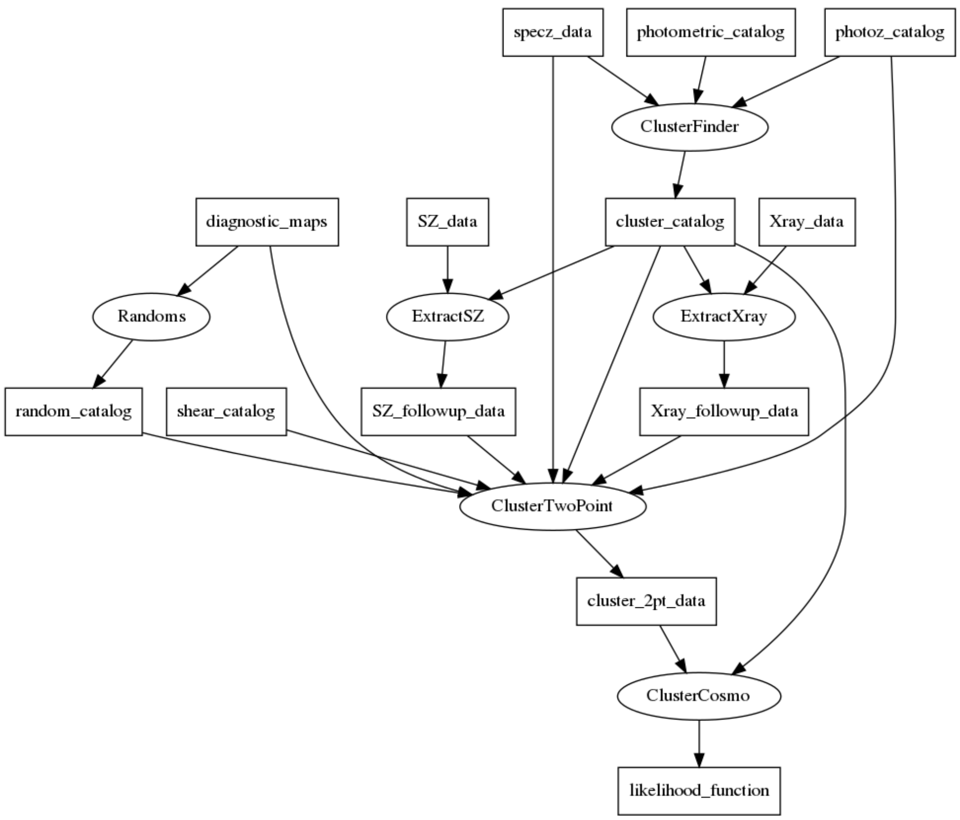

Figure 5.14.1: Pipeline diagram illustrating the components of cluster count cosmology inference. In practice, the analysis will use TXPIPE (Figure 5.12.1) with the addition of some cluster-specific components.

metrics including completeness and purity.
Prerequisites: Deliverables *"$p(z)$ for DC1 Galaxies"*,`HaloCat`, *"Cluster Finder (CLFINDER)"*

Active deliverable: *Cluster Finder Updates (CLFINDER) (SR SW)*

Host: CL *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: The goal of this deliverable is to produce a version of the cluster finding algorithm that is updated to address issues identified during DC2 analysis and/or as a result of work in precursor surveys, to ensure the cluster finding algorithm meets our needs for LSST.
Prerequisites: Deliverables *"Cluster Finder (CLFINDER)"*, *"Cluster Finder (CLFINDER) Validation"*

Planned deliverable: *Validation of Cluster Finder Updates (CLFINDER) (SR SW)*

Host: CL *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 09/30/21
Objective: SR-era updates of CLFINDER should be validated with SR-era simulations and/or precursor datasets.
Prerequisites: Deliverables *"Cluster Finder (CLFINDER)"*, *"Cluster Finder (CLFINDER) Validation"*, *"Cluster Finder Updates (CLFINDER)"*

Planned deliverable: *Shear calibration in the cluster regime (SR SW)*

Host: CL *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 09/30/21
Objective: The goal of this deliverable is to update the shear calibration routines in TXPIPE to include shear calibration in the cluster lensing regime.

Planned deliverable: *Photo-z estimates in cluster fields (SR SW)*

Host: CL *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 09/30/21
Objective: The goal of this deliverable is to update the photo-$z$photo-z routines in TXPIPE, PZESTIMATE, and PZSUMMARIZE to include training data specific to cluster fields.

CL Key Product (DC1 & DC2): CL Cosmology Likelihood Module CLCOSMO (CL5)

Objective: Build an efficient and self-consistent likelihood calculator for cluster data. This will ultimately be used within the multi-probe cosmology analysis code being developed by the TJP group, and we will work closely with TJP on this project. An initial likelihood code already exists, but it will need to be refined and expanded continuously over the course of the data challenge period. We plan in parallel (again in collaboration with TJP) to provide a faster Fisher matrix calculator suitable for cluster data, for use in forecasting applications; however, the Fisher matrix code is not part of this Key Project.

Defunct deliverable: *DC1-era CL Likelihood Code (DC1 SW)*

Host: CL *Started, originally due:* 10/01/15, 06/30/18
Objective: Preparation for the final LSST likelihood code will require work all the way up to the beginning of the LSST survey. This Deliverable covers development needed on the DC1 timescale. Halo mass function emulator was developed externally to DESC, while CLMASSMOD is in active development within DESC.

Active deliverable: *DC2-era CL Likelihood Code (DC2 SW)*

Host: CL *Started, originally due:* 10/01/16, 12/31/19 *Expected:* 12/31/21
Objective: This Deliverable covers continuing development of the code on the DC2 timescale. Existing code will be extended to incorporate a fully general cluster scaling relation model, which will be necessary to optimally extract information from clusters with data at multiple wavelengths. To keep the calculations tractable, this will likely require the use of different algorithms than the current codes use, and we will work closely with the computing group at this stage to maximize the efficiency of the resulting code. As part of this process, additional cluster probes (such as clustering) which the forecasting projects indicate are worthwhile will be implemented. Apply the code to contemporaneous data, including masses and mass proxies and implementing blinding strategies.
Prerequisites: Mass and bias functions for cosmologies of interest, plus self-consistent estimates of systematic uncertainties spanning halo finding algorithms, mass profile model, cluster miscentering, projection effects, and baryonic physics prescription. (Deliverable *"Cosmological Emulator Integration"*); data models and the associated uncertainties for cluster observables).

Active deliverable: *Validation of DC2-era CL Likelihood Code (DC2 VA)*

Host: CL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 12/31/21
Objective: This deliverable covers work to validate the DC2-era clusters likelihood code using DC2 simulations.
Prerequisites: Deliverable *"DC2-era CL Likelihood Code"*

Planned deliverable: *SR-era CL Likelihood code (SR SW)*

Host: CL *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 12/31/22

Objective: This Deliverable covers continuing development of the code on the SR timescale. Final development of the likelihood code will focus on extending it to handle stage 4 (i.e. very large) cluster catalogs without loss of efficiency or information. This includes investigating the effects of binning for surveys where a only small fraction of clusters have information beyond the basic survey observables. The final step will be to apply the software to contemporaneous data, including carrying out a comprehensive lensing mass analysis with low-scatter mass proxies, and implementing blinding strategies.
Prerequisites: Mass and bias functions for cosmologies of interest, plus self-consistent estimates of systematic uncertainties spanning halo finding, cluster centering and baryonic physics prescription (Deliverable *"Cosmological Emulator Integration"*); data models and the associated uncertainties for cluster observables).

CL Key Product (SV): CL Pipeline Integration and Adaptation to the SV Data (CLIA)

Objective: Integrate the CL-specific pipeline in Figure 5.14.1 with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Anticipated deliverable: *Integrated CL Pipeline (SV SW)*

Host: CL *Started, originally due:* 09/30/21, 10/01/23 *Anticipated:* 10/01/23
Objective: Fully integrated CL pipeline, for application to SV data and further development based on that application.

5.15 Strong Lensing Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with strong lenses. Figure 5.15.1 shows the SL workflow diagram.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

SL Key Product (DC1 & DC2 & SR): SL Pipeline Components (SL6)

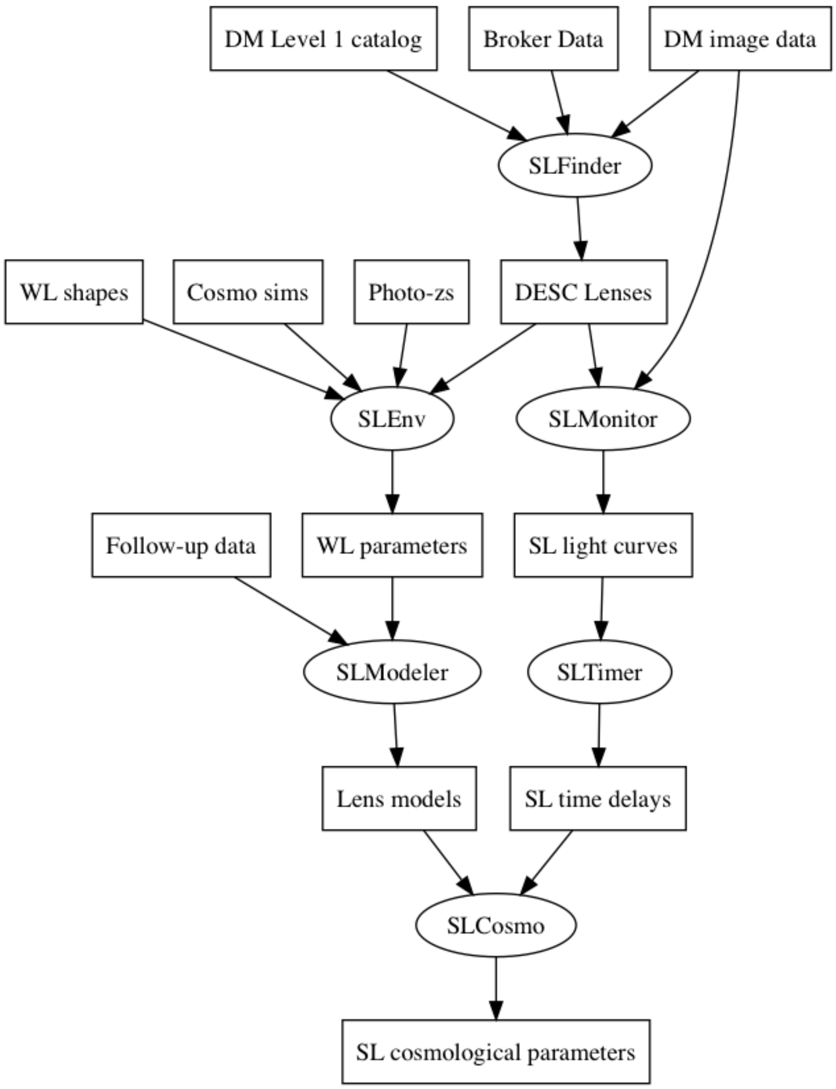

Figure 5.15.1: Graphical representation of the SL workflow.

Objective: Build the SL-specific pipeline pieces illustrated in Figure 5.15.1.

Completed deliverable: SLMONITOR *(DC1 SW)*

Host: SL *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/Monitor/tree/master/python/desc/monitor
Objective: Extract light curves for all time-variable lens candidates. Completed by Deliverable *"A framework for Twinkles light curve generation"*.
Prerequisites: Deliverable *"A framework for Twinkles light curve generation"*

Defunct deliverable: SLMODELER *(DC1 SW)*

Host: SL *Started, originally due:* 10/01/15, 06/30/18
Objective: Construct models of lenses from high resolution imaging. Has been implemented in surveys prior to DESC.
Prerequisites: None

Active deliverable: SLFINDER *Lens Candidate Extractor (DC2 SW)*

Host: SL *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 6/30/20
Objective: Develop lens candidate extraction algorithms and build prototype code, based on community pixel-leveling modeling experience to date, that can operate on the DC2 cutout images. The Einstein Ring extraction code should be able to work on sets of postage stamps centered on either lensed supernova or compound lens targets; the variable lens extractor should be able to work on sets of postage stamps centered on either lensed quasar or lensed supernova targets.
Prerequisites: None

Active deliverable: SLENVCOUNTER *(DC2 SW)*

Host: SL *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 12/31/20
Objective: Build prototype code, based on community experience of estimating weak lensing effects from weighted galaxy number density to date, that can operate on the DC2.
Prerequisites: Deliverable *"DC2 Time Domain Requirements"*

Active deliverable: SLTIMER *(DC2) (DC2 SW)*

Host: SL *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 12/1/20
Objective: Develop lensed transient detection algorithm through difference imaging and the DIA pipeline. Build tools to test the output of the difference imaging pipeline, and estimate the efficiency of lensed source recovery.

Prerequisites: Deliverable *"DC2 Time Domain Requirements"*

Active deliverable: SLMASSMAPPER *(DC2 SW)*

Host: SL *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 12/31/20
Objective: Build prototype code, based on community line of sight mass reconstruction experience to date, that can operate on the DC2.
Prerequisites: Deliverable *"DC2 Time Domain Requirements"*

Active deliverable: *Validation of DC2-era pipeline components (DC2 VA)*

Host: SL *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 12/31/20
Objective: Validate DC2-era pipeline components using DC2 simulations.
Prerequisites: Deliverables "SLFINDER *Target Selection Code*", "SLFINDER *Lens Candidate Extractor*", "SLENVCOUNTER", "SLMASSMAPPER"

Planned deliverable: SLTIMER *(Science Readiness) (SR SW)*

Host: SL *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: Develop algorithms for time delay inference and build prototype code, based on community time delay estimation experience to date. This code will be able to operate on the TDC3 light curves, and enter the third Time Delay Challenge. Test on the TDC2 light curves.

Planned deliverable: SLCOSMO *(SR SW)*

Host: SL *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: Implement cosmological parameter inference code for SL, including realistic lens samples, time delay measurements, and environment characterisation, and a hierarchical model for the lens population. This will make use of the TJP cosmological likelihood library developed in the Deliverable *"Single-probe likelihood for Strong Lensing"*, and also depend on R&D on lens environments.
Prerequisites: Deliverable *"Single-probe likelihood for Strong Lensing"*.

Planned deliverable: *Validation of SR-era pipeline components (SR VA)*

Host: SL *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 09/30/21
Objective: Validate SR-era pipeline components using SR simulations.
Prerequisites: Deliverables "SLTIMER *(Science Readiness)*", "SLCOSMO"

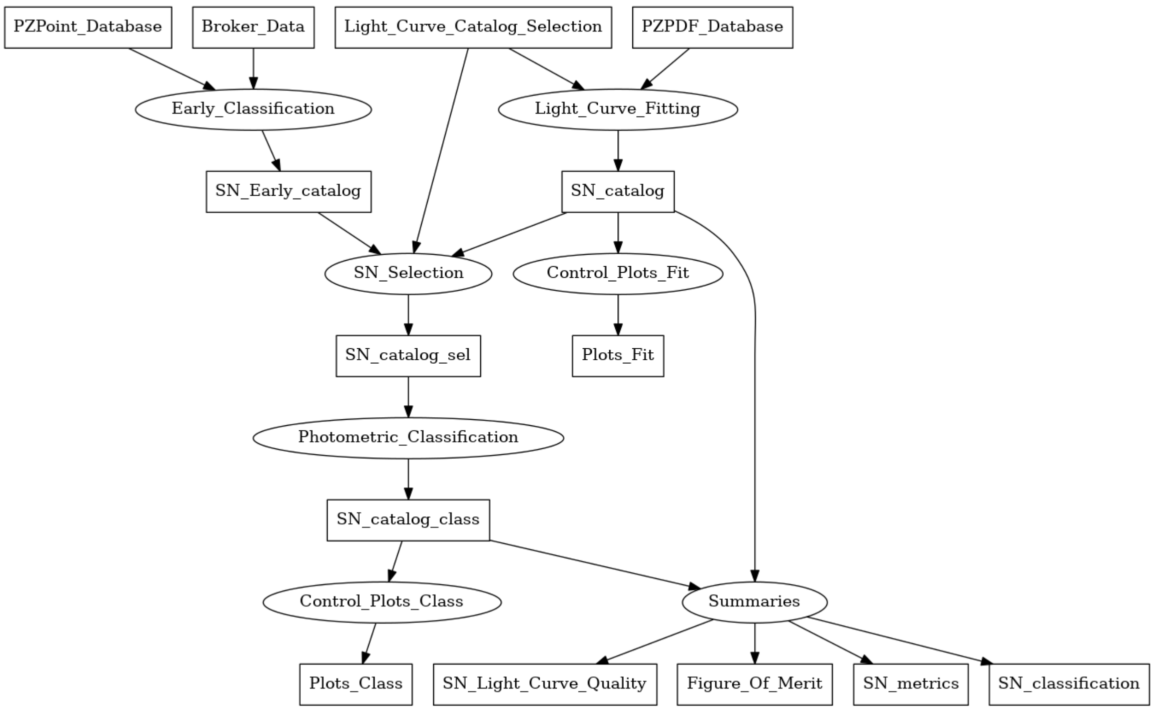

Figure 5.16.1: Pipeline diagram illustrating the components of the SN analysis pipeline at the catalog level.

SL Key Product (SV): SL Pipeline Integration and Adaptation to the SV Data (SLIA)

Objective: Integrate the SL-specific pipeline with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Anticipated deliverable: *Integrated SL Pipeline (SV SW)*

Host: SL *Started, originally due:* 09/30/21, 10/01/23 *Anticipated:* 10/01/23

Objective: Fully integrated SL pipeline, including improvements from application to SV data.

5.16 Supernova Pipeline

The focus of this subsection is development of a pipeline for cosmological analysis with supernovae. The high-level development path is as follows:

- **DC1 era**: The DC1 era focused on building up template libraries for different populations of supernovae and transients, developing classification algorithms and frameworks, developing catalog and image simulation software and initiating image-level pipeline analyses through efforts like the `Twinkles` challenge.

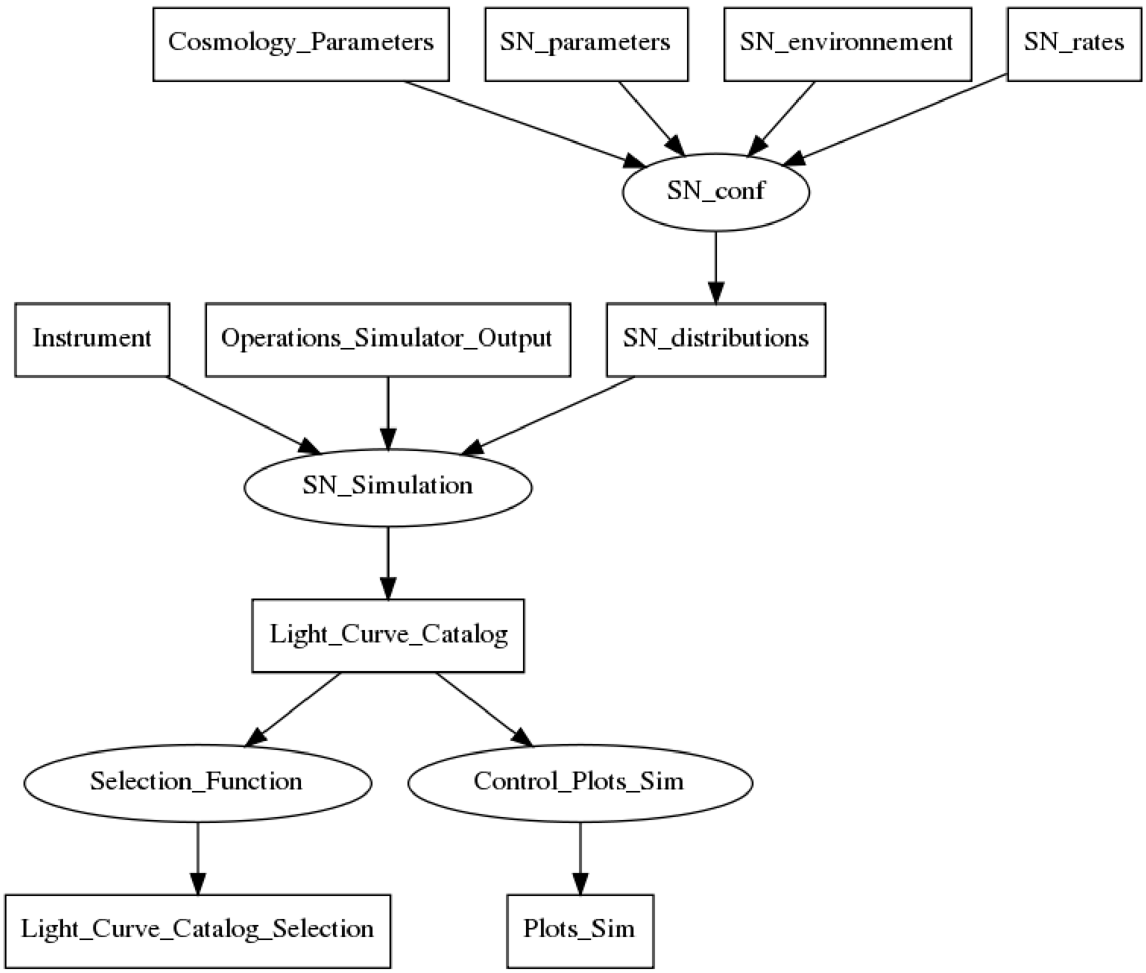

Figure 5.16.2: Pipeline diagram illustrating the components of the SN simulation pipeline at the catalog level.

- **DC2 era**: There are four parallel DC2 activities: work on the image-level characterization (classification etc.) pipeline, developments of the SN simulation and analysis pipelines, and development of likelihood analysis routines within TJPCosmo.
- **SR era**: This will focus on expanding the SN likelihood frameworks to take account of classification probabilities, redshift uncertainty and light-curve parameters, and integrating these more complicated frameworks into TJPCosmo, following the prescriptions developed in DC2. It will include comprehensive follow-up procedure planning for both transient and host redshift follow-up.
- **SV era**: integration of the SN pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms.

The software that needs to be built is summarized in Figure 5.16.1 and Figure 5.16.2.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways.

SN Key Product (DC1): DC1-era codes for simulating SN at Cadences from OpSim (SN-OpSim)

Completed deliverable: *SN simulation software integrated with OpSim (DC1 SW)*

Host: SN *Started, originally due:* 10/01/15, 07/01/18 *Completed:* 07/01/18

URL : https://github.com/rbiswas4/OpSimSummary

Objective: Code up components to enable integrating with LSST Project-supplied data products like OpSim outputs, and produce catalog and image simulations of supernovae.

SN Key Product (DC1): DC1-era SN Pipeline Components (SupernovaType)

Objective: Build the DC1-era pipeline components from Figure 5.16.1 and Figure 5.16.2.

Completed deliverable: *Classification Code: SupernovaType (DC1 SW)*

Host: SN *Started, originally due:* 10/01/15, 07/01/18 *Completed:* 07/01/18

URL : https://github.com/LSSTDESC/snmachine

Objective: The main Deliverable is SupernovaType code to run a variety of classification algorithms. Development of SUPERNOVAREALIZER will involve development and testing of competing algorithms and approaches to photometric classification in SUPERNOVATYPE.

Prerequisites: Catalog of simulated SN from difference images from SUPERNOVAREALIZER. In addition, an estimate of the selection function of the survey.

SN Key Product (DC2): DC2-era SN Pipeline Components (SNPipe)
Objective: Build the DC2-era pipeline components from Figure 5.16.1 and Figure 5.16.2.

Active deliverable: *SN Simulation Pipeline (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 11/01/20
URL : https://github.com/lsstdesc/sn_simulation
Objective: A simulation pipeline to generate supernovae (of all types) light curves (see Figure 5.16.2). Input to this code would be a set of parameters related to the supernovae (SN parameters, environnement, rate, cosmology), an instrument model and observing strategy. The output would be made of catalogs of light curves that may be selected according to criteria defined by the user.
Prerequisites: Observing strategy simulations.

Active deliverable: *SN Light fitting code (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 11/01/20
URL : https://github.com/lsstdesc/sn_fit_lc
Objective: The light curve fitting formalism specified here will produce posterior distributions (or summaries thereof) of SN light curve model parameters from the light curves and the photo-z pdf database. As shown in Figure Figure 5.16.1, this fitter differs from the light curve fitting codes developed in DC1 in that they will include information on the photo-z of the host. Preliminary R&D work in exploring such a light curve fitting code has started in the working group.
Prerequisites: Photo-z database, and the light curve catalog from deliverable “SN Simulation Pipeline”.

Active deliverable: *SN selection function to produce a SN catalog for classification (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 01/01/21
Objective: The SN selection function/code will take as input the catalog of early sources and the catalog of general SN sources and build a final catalog of sources for classification, based

on defined data quality cuts.
Prerequisites: Early SN catalog, full SN catalog from the above deliverables.

Defunct deliverable: *SN summaries code (DC2 SW)*

Host: SN *Started, originally due:* 12/01/17, 03/31/19
Objective: The SN Summaries part will be composed by a set of python scripts devoted to a list of deliverables. Inputs and outputs will depend on the type of deliverable.code will take as input the SN catalog, and classification output and compute various figures of merit in the classification, discovery, LC quality and cosmological uncertainty space. These metrics will be used to constrain different cadence scenarios.

Completed deliverable: *SN metrics code (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 07/01/20
URL : https://github.com/lsstdesc/sn_metrics
Objective: The SN metrics code will estimate a set of metrics to assess observing strategy wrt SN science. Input to this code is a simulation database (either in the LSST scheduler format (sqllite) or a numpy file (dumped from the scheduler database). Output will depend on the metric considered. These metrics should be fast to process. Proxies may be used to improve time processing, but the precision level of the results should be quoted and easy to reproduce.
Prerequisites: Simulated observations

Active deliverable: *SN classification summary code (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 04/01/21
Objective: The SN classification summary code will perform SN classication of a set of supernovae. It will use the results from the photometric classification algorithms. Input will be composed of a catalog of supernovae and of the results of the photometric classification. The output catalog will be a copy of the input catalog with additional information (related to the classification) for each supernova.
Prerequisites: photometric classification results, SN catalog

Active deliverable: *SN Light Curve Quality code (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 07/01/21
Objective: The SN Light Curve Quality code will monitor the quality of the light curves and select SN (depending on quality cuts chosen by the user) that will be used for cosmological measurements. Input to the script would be a SN catalog (ideally produced at the stage *"SN classification summary code"*) and the output will be made of a catalog of selected supernovae.

Prerequisites: SN catalog after photometric classification.

Active deliverable: *SN FoM code (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 07/01/21
URL : https://github.com/lsstdesc
Objective: The SN FoM code will produce a figure of merit (for example in the (w0,wa) plane) taking statistical and systematic uncertainties into account. Input to the script would be a SN catalog (ideally produced at the stage *"SN Light Curve Quality code"*) and the output the figure of merit.
Prerequisites: SN catalog after quality selections.

Completed deliverable: *Multi-type transient simulations (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 01/21/19
URL : https://plasticcblog.wordpress.com
Objective: In order to test classification algorithms, simulations of LSST-type surveys containing multiple types of transients will be produced, to test classification algorithms. These simulations have been achived within the successuful Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC), a community-wide challenge to spur development of algorithms to classify astronomical transients.
Prerequisites: The "DC1-era codes for simulating SN at Cadences from OpSim" (SN-OpSim) code, updated to contain more models and updated LSST-like cadence.

Active deliverable: *Photometric classification (DC2 SW)*

Host: SN *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 01/01/21
Objective: Using the updated simulations mentioned above, multiple classification schemas will be tested based on DC2-era simulations with multiple transients and updated cadence and simulation volume.
Prerequisites: The *"Multi-type transient simulations"* suite of simulations.

Active deliverable: *SN Light curves from processed DM difference images (DC2 RQ)*

Host: SN *Started, originally due:* 07/01/18, 03/31/19 *Expected:* 01/01/21
Objective: Building on work done as part of `Twinkles`, and to ensure a reliable catalog of light curves can be produced for analysis, work at the image level DC2 will focus on building a difference image pipeline, SNPIPEvi, from the DM image data base. Source detection on difference images that result from the DM pipeline. These are defined through the subtraction of a science image from a single visit and templates (which may be compiled from several visits).

It will be easier to detect dimmer SN from multiple science images: the simplest strategy could be co-adding/stacking science images in the same band within short time periods, that are less than the time scale of a SN light curve change, and then performing the difference image with the template.

The work to determine how these calculations will be performed is both an essential pipeline requirement for the SNWG, and also an active area of R&D. In particular, the detection of objects from multiple visits is not included in the current DM pipeline, so this will be developed within the SNWG. Tests will need to be run on the pipeline to test for precision and accuracy of photometry on difference images and forced photometry light curves.

Prerequisites: DC2 simulations

Active deliverable: *SN Analysis Pipeline Validation (DC2 VA)*

Host: SN *Started, originally due:* 07/01/18, 03/31/19 *Expected:* 01/01/21
Objective: Validate the catalog pipeline through tests based on the Summary codes

Planned deliverable: *Detection Efficiency of SN (DC2 VA)*

Host: SN *Started, originally due:* 07/01/18, 03/31/19 *Expected:* 01/01/21
Objective: Using the *"SN Light curves from processed DM difference images"*, calculate the efficiency of detection of SN from single epochs under different observing conditions and astrophysical backgrounds. This will also be part of the validation of *"SN Light curves from processed DM difference images"*.
Prerequisites: The DC2 image simulations, DIA processing of the DC2 simulations using *"SN Light curves from processed DM difference images"* in the uDDF region.

Active deliverable: *Discrepancy Modelling for SN light Curves (DC2 VA)*

Host: SN *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 01/01/21
Objective: Study the performance of the image processing pipeline in terms of comparing catalog expectations with the forced photometry applied on difference images as part of the DIA processing pipeline *"SN Light curves from processed DM difference images"*.

Active deliverable: *Validating Surface Brightness of Host Galaxy (DC2 VA)*

Host: SN *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 07/01/21
Objective: Validate the values of local surface brightness of host galaxies as determined from the parameters measured in the emulated DRP catalogs obtained from DC2 processing against the truth values from the DC2 cosmo simulations.
Prerequisites: The DC2 image simulations and DRP processing of them in the main survey

region.

SN Key Product (DC2): Enhanced Twinkles Framework to Handle DC2-level Requirements (CI7)

Objective: At DC2, the Twinkles program will also support the development of user-generated "SuperFit" algorithms, built against the MultiFit API to handle time-variable point sources and mixed point source / extended source models for optimal light curve extraction. The host is changing from the CO WG to the SN WG, given the interaction of the SN and SL WGs with the difference image pipeline through the DIA Topical Team. Twinkles will provide an end-to-end testbed to prototype the software framework and develop the infrastructure to support distributed code development. The Twinkles images will be absorbed into `DC2`, and will extend `Twinkles` with additional DM algorithms, like deblending, photometry and multi-fit algorithms.

We will develop the framework for running the monitoring pipelines in parallel with the development of that code, and then use the framework to carry out the calculations in a scaleable way.

Active deliverable: *Pipeline for Extracting DC2 Light Curves (DC2 SW)*

Host: SN *Started, originally due:* 10/01/16, 06/30/18 *Expected:* 01/01/21

Objective: The Deliverable *"A framework for Twinkles light curve generation"* will be extended to include the additional pipeline elements needed for `DC2`.

Active deliverable: *Workflow to execute the Light Curve Extraction pipeline. (DC2 SW)*

Host: SN *Started, originally due:* 10/01/16, 06/30/18 *Expected:* 01/01/21

Objective: The Deliverable *"A framework for Twinkles light curve generation"* will be extended to include the additional pipeline elements needed for `DC2` and must extend the workflow definitions to allow running the full pipeline.

SN Key Product (SR): SR-era SN Pipeline Components (SNType)

Objective: Build the SR-era pipeline components from Figure 5.16.1 and Figure 5.16.2.

Planned deliverable: *SR-era SN Analysis Pipeline updates (SR VA)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21
Objective: The deliverable will be the components of the difference imaging pipeline, including providing catalog of supernovae based on difference images and modelling.
Prerequisites: SR image simulations, *"SN Light curves from processed DM difference images"*, *"SN Light curves from processed DM difference images"*

Planned deliverable: *Verification of the difference imaging pipeline on SR data (SR VA)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21
Objective: The deliverable will validate the difference imaging pipeline based on SR simulations and precursor datasets
Prerequisites: SR image simulations, *"SR-era SN Analysis Pipeline updates"*

Planned deliverable: *Code for photometric supernova cosmology (SR SW)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21
Objective: Software tools for photometric sample, including SUPERNOVATYPE and SUPERNOVADISTANCE, ready to be applied to LSST data, using blinded analysis strategy, if feasible.

Planned deliverable: *Verification of photometric supernova code in different scenarios (SR VA)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21
Objective: Validate codes on precursor datasets and SR era simulations

Active deliverable: *SR-era SN summaries code (SR SW)*

Host: SN *Started, originally due:* 10/01/18, 09/30/21 *Expected:* 10/01/21
Objective: The SN Summaries code be updated from the DC2 implementation, but will include additional ancillary information such as information on nearest neighbours and host properties. The code will take as input the SN catalog, and classification output and compute various figures of merit in the classification, discovery, LC quality and cosmological uncertainty space. These metrics will be used to constrain different cadence scenarios
Prerequisites: Early SN catalog, full SN catalog from the above deliverables, classification output, ancillary products from DC2 simulations.

Planned deliverable: *SN summaries code validation on SR simulations (SR SW)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21
Objective: The full SN summary pipeline will be tested on simulations.

SN Key Product (SV): SN Pipeline Integration and Adaptation to the SV Data (SNIA)

Objective: Integrate the SN-specific pipeline in Figure 5.14.1 with the other DESC pipelines, and adapt it to run at scale on the real SV data.

Anticipated deliverable: *Integrated SV-era SN Pipeline (SV SW)*

Host: SN *Started, originally due:* 09/20/21, 10/01/23 *Anticipated:* 10/01/23

Objective: Fully integrated SN pipeline, for application to SV data and with improvements based on that application.

SN Key Product (SR): DESC Broker (SN)

Objective: Develop a broker for DESC by providing components additional to with the SN and SL working groups. This cross working group project is hosted by the SNWG.

Completed deliverable: *SLWG Broker Requirements (DC2 RQ)*

Host: SL *Started, originally due:* 10/01/17, 07/01/18 *Completed:* 07/01/19

URL : https://github.com/LSSTDESC/DESCNote_TransientBroker

Objective: Determine SLWG requirements for an LSST broker, provided that research efforts suggest a DESC-specific one is needed. The WG will use the broker to identify strongly lensed supernovae.

Prerequisites: None

Planned deliverable: *Broker Sandbox (SR SW)*

Host: SN *Started, originally due:* 03/31/19, 06/30/20 *Expected:* 06/30/20

Objective: This work will proceed with the research and development cross working group project Key Project "DESC Broker" (SN). This broker would be to interface Community Brokers with DESC studies, to understand the pros and cons of each broker environment.

Active deliverable: *Early SN classification system (SR SW)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21

URL : https://github.com/LSSTDESC/DESCNote_TransientBroker

Objective: The early classification code specified in Figure 5.16.1, will provide classification of sources using a few points in the light curve. Developing this classification system will depend on the output of the LSST broker.

Active deliverable: SLFINDER *Target Selection Code (SR SW)*

Host: SL *Started, originally due:* 10/01/17, 09/30/21 *Expected:* 10/01/21

Objective: Develop target selection algorithms and build prototype code,based on community catalog querying and machine learning experience to date, that can operate on the DC2 object catalogs (and possibly alerts), and return lists of lens targets. Part of this Deliverable will involve arc and ring target selection, as the first step in compound lens target selection. For lensed supernova detection the Deliverable will need to include the ability to interact with LSST agents to rapidly identify possible lensed transients as a trigger for followup.

Prerequisites: *"SLWG Broker Requirements"*

Planned deliverable: *Verification of the DESC SN broker infrastructure on SR simulations (SR VA)*

Host: SN *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 10/01/21

Objective: Validate *"Early SN classification system"* with SR simulations and precursor datasets

Prerequisites: *"Early SN classification system"*, precursor data, Classification Algorithms, interfaced community brokers.

5.17 Theory & Joint Probes Pipeline

The focus of this subsection is development of pipelines for the TJP working group. There are three such pipelines: the Core Cosmology Library (CCL), TJPCOV (for covariance matrix estimation), and TJPCOSMO (for individual and joint probe likelihood analysis). TJPCOSMO will integrate theoretical predictions from CCL, the covariances generated by TJPCOV, and a consistent set of models for systematics effects. The high-level development path is as follows:

- **DC1 era**: Focus on CCL development.
- **DC2 era**: Continued CCL development; initial construction of the TJPCOSMO framework with basic functionality; beginning of TJPCOV and joint systematics modules.
- **SR era**: Maturation of TJPCOSMO and full integration of TJPCOV and joint systematics modules. Integration of TJPCOSMO into the CI infrastructure.
- **SV era**: Adaptation of the TJP code to the real SV data. Possible extension of the framework to support additional advanced algorithms.
- **Survey era**: Continued development of extensions and advanced algorithsm for new models, statistical methods, and performance improvements.

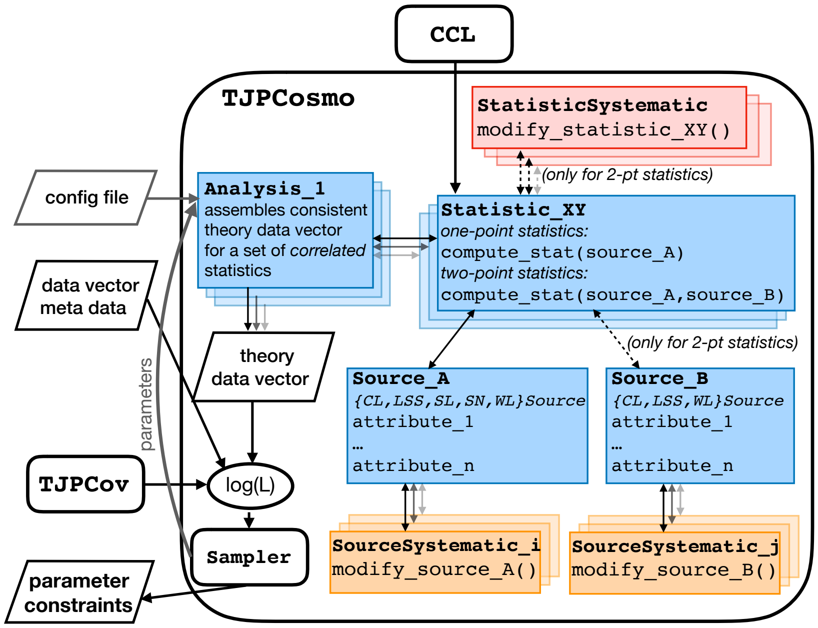

Figure 5.17.1: Pipeline diagram illustrating the components of TJPCosmo pipeline.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents (DESC Notes and GitHub issues). All major pipeline activities will be documented in one of the above ways. Note that many pipeline deliverables depend on R&D work.

The TJP analysis pipeline TJPCosmo is summarized in Figure 5.17.1, with CCL illustrated in more detail in Figure 5.17.2.

TJP Key Product (DC1 & DC2): Core Cosmology Library (TJP5A)

Objective: The Core Cosmology Library (CCL) is a general-purpose, accuracy-validated library to make standardized predictions for cosmological observables. It is one of the core components of the TJPCosmo likelihood pipeline, and a required dependency for systematics modules. The main purpose of this key product is to provide a standardized method of computing cosmological quantities and observables that can be used by all pipeline software, with the aim of guaranteeing consistency and accuracy of predictions. As such, CCL will be held to a particularly high standard of code validation, and will be capable of calculating all cosmological quantities needed by other analysis working groups (to the greatest extent possible).

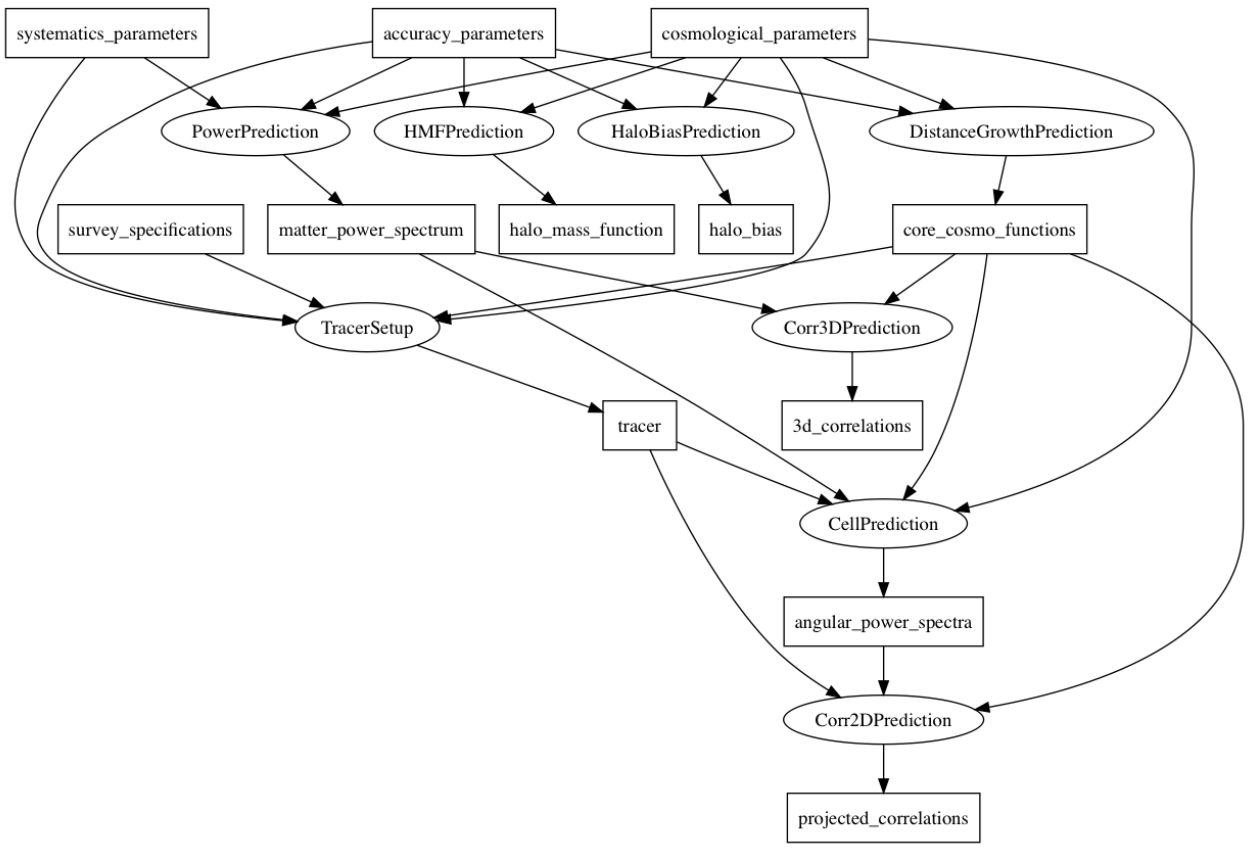

Figure 5.17.2: Structure and capabilities of CCL.

Beyond its role in TJPCosmo, CCL is intended to be a broadly applicable tool both within DESC and for the broader community.

Defunct deliverable: *Cosmology library prototypes (DC1 SW)*

Host: TJP *Started, originally due:* 10/01/15, 03/31/16
Objective: Draft preliminary computing environment for cosmology analyses. Provide function prototypes for core cosmology library to inform early pipeline development efforts.
Prerequisites: "The Initial Elements of a Software Framework" (CO2)

Defunct deliverable: *Cosmological Emulator Integration (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/16, 02/28/18
Objective: Integrate state-of-the-art emulators for non linear power spectrum, halo mass function, bias modeling in CCL, which will be incorporated into TJPCosmo. This deliverable is superseded by *"Enhanced cosmological observable predictions"*.

Completed deliverable: *Basic cosmological observable predictions (DC1 SW)*

Host: TJP *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/CCL/releases/tag/0.2
Objective: Develop and validate a core cosmology library to compute basic observables for cosmological models with dark energy parameterized by w0 and wa ($w_0 w_a$CDM models). The library will include the basic building blocks that are needed for single-probe predictions. Modules in this version of the library will include, but not be limited to: redshift distributions, cosmological distance measures, the growth rate and growth factor, linear as well as non-linear power spectra, and lensing weight functions.
Prerequisites: Deliverable *"Cosmology library prototypes"*

Completed deliverable: *Enhanced cosmological observable predictions (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 07/01/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/CCL/releases/tag/v0.9
Objective: Extend the core cosmology library to make more realistic predictions for the quantities needed by single-probe likelihoods. This includes adding the ability to calculate angular correlation functions and the halo mass function and halo bias; integrating available emulators for the non-linear matter power spectrum; and implementing baryonic effects and massive neutrino models. This version of the library should be accompanied by extensive documentation and validation tests, and a publication describing it. (This deliverable is considered complete with the availability of the CCL paper.)

Prerequisites: Deliverable *"Basic cosmological observable predictions"*

Completed deliverable: *Fast and accurate correlation function predictions (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 04/03/20
URL : https://github.com/LSSTDESC/CCL
Objective: Extend the core cosmology library to include accurate correlation function predictions, using state-of-the-art tools such as fast perturbation theory approaches (e.g. `FAST-PT`) for galaxy clustering and intrinsic alignments, and new power spectrum emulators. A more complete implementation of all relevant cross-correlations between large-scale structure observables and other cosmological probes should also be included, to prepare for joint probes analyses. *Intermediate deliverable* (10/31/19): Complete implementation of "generalized tracers" framework for flexible model inputs.
Prerequisites: *"Enhanced cosmological observable predictions"*

Active deliverable: *Cosmological model extensions beyond wCDM (SR SW)*

Host: TJP *Started, originally due:* 10/01/18, 09/30/21 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/CCL
Objective: Extend the range of cosmological models supported by CCL to include beyond-wCDM models. This will mostly be focused on providing linear theory predictions for beyond-wCDM models, but may also include basic quasi-linear/non-linear predictions using emulators.
Prerequisites: *"Enhanced cosmological observable predictions"*

TJP Key Product (DC2 & SR): Systematics Models for Joint Analyses (CX5)
Objective: While the importance of astrophysical and instrumental systematic effects has long been recognized for individual probes, their impact on joint analyses is less well understood. The TJPCosmo joint probes analysis will produce significantly tighter cosmological constraints than any individual tracer, and so it seems likely that the relative importance of systematic effects will be correspondingly greater. Systematic effects may be probe-specific however, potentially making it easier to separate them out in a joint probe analysis. In response to these considerations, this Key Product will deliver a consistent, integrated package of multi-probe systematics models, implemented as modules within the TJPCosmo or CCL libraries. In some cases, these modules can be existing external software that is validated and linked to the relevant library. These will be used for exploratory work during the DC2 era, and then developed into a mature systematics package within TJPCosmo ready for analyses with LSST precursor datasets following SR. While individual probe working groups are expected to pro-

vide the base systematics models and code to feed into this work, it will be the responsibility of TJP to ensure consistency between the models, and to curate them in the event that multiple competing models are available.

Active deliverable: *Software module for astrophysical systematics (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 9/30/21
Objective: To produce software modules for astrophysical systematics and incorporate them into existing software infrastructure, particularly TJPCOSMO. Develop software modules, or identify and validate existing modules, that implement mitigation schemes for intrinsic alignments, galaxy bias (including assembly bias), and baryonic effects. These modules should interface with TJPCOSMO and CCL. Note that the (assembly) bias mitigation modules should include cluster cosmology capabilities.

As part of this deliverable, the interactions of photometric redshifts and photometric redshift uncertainties with the systematics for each of the primary LSST cosmology probes should also be quantified. Validation of these modules in the context of cosmological analyses is essential.

Active deliverable: *Workflow for testing accuracy of systematics mitigation (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
Objective: Set up an easy-to-use software pipeline to analyze input data vectors containing sophisticated systematics models (or simulation results) with the TJPCOSMO baseline model. This software will enable everyone to quantify the impact of different systematic effects on cosmological parameters for well-defined LSST-like single/joint probe analyses.

Due to the timeline, this workflow will be developed simultaneously with the individual probe systematics modules in Deliverable *"Software module for astrophysical systematics"*. Initial development may therefore happen outside of the TJPCOSMO framework that will ultimately host the systematics modules (e.g. from the point that Deliverable *"Preliminary joint probes likelihood pipeline"* becomes available). Where possible, new code will be written to allow integration of the systematics modules into CCL or TJPCOSMO.
Prerequisites: *"Software module for astrophysical systematics"*

Planned deliverable: *Consistency of systematics modeling across all probes (SR SW)*

Host: TJP *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 09/30/21
Objective: TJPCOSMO requires systematics classes developed by a single probe WG to include methods that can also calculate the impact of the systematic on all cross-correlations included in the joint likelihood analysis. This Deliverable will implement a factory method

in TJPCosmo that checks consistency of the systematics model choices across all probes included in a joint analysis, and provide guidelines for the integration of new systematics classes into TJPCosmo.
Prerequisites: *"Software module for astrophysical systematics"*

Planned deliverable: *Incorporate spatial variations into joint systematics models (SR SW)*

Host: TJP *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: Update and expand the joint systematics model employed in Deliverable *"Preliminary joint probes likelihood pipeline"* to incorporate systematics models with spatial variations.
Prerequisites: *"Preliminary joint probes likelihood pipeline"*

TJP Key Product (DC2 & SR): TJPCov: Covariance Matrices for Joint Analyses (CX7)

At the core of the likelihood pipeline developed in TJPCosmo is a set of appropriate multi-probe covariance matrices that can accurately account for correlations in the cosmological signals measured by the individual probes. The covariance matrices required are unprecedented in size and complexity, and it is likely that new methods will need to be developed to keep the computational cost of generating them in check, whilst also meeting accuracy requirements (to avoid biasing cosmological parameter estimates). TJPCov will provide a covariance framewrk that provides different methods to produce covariances for single and combined probes. For all implemented methods, the framework will connect with other TJP and DESC pipelines, especially TJPCosmo, CCL, and TXPipe. At the start of development, simple placeholder covariances (e.g. analytic Gaussian) can be delivered to allow TJPCosmo developments and initial proof-of-concept joint-probe analyses. By the time of SR, more sophisticated covariance estimation solutions will need to be in place, along with an understanding of the computational complexity of covariance estimation for the DESC Y1 analysis. Since this Key Product is likely to have the largest computational burden of any component of the analysis pipeline, it should be considered a high priority for cross-working-group development. Where possible, TJPCov will utilize CCL for internal calculations.

Active deliverable: *Gaussian and other available covariances for* TJPCosmo *(DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
Objective: Develop basic covariance estimators for the single-probe LSS and WL likelihoods, using Gaussian assumptions or other available methods. These may be implemented using

analytic methods (e.g. CosmoLike), fast N-body simulations, or existing collections of mock catalogs. These covariances will be used as placeholders to develop covariance-related infrastructure in TJPCosmo, and for initial testing and validation of the TJPCosmo likelihood pipeline during DC2.

Active deliverable: *Improved covariance estimators for single- and joint-probe analyses (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
Objective: Develop and implement novel covariance estimators which combine mock survey realizations and theory templates (e.g. using shrinkage techniques). Test and refine the estimators for single-probe, 2-point statistic covariances before proceeding to joint covariance estimation.

Large-scale structure and weak lensing 2-point statistics will serve as pilot projects for more comprehensive joint covariance estimation that takes advantage of the availability of suitable number of mock catalogs on the timescale of DC2 and yields useful scientific results that may be exploited by the LSS and WL working groups as well as other science collaborations.
Prerequisites: *"Workflow for testing accuracy of systematics mitigation"*, *"Parameterization of the Extragalactic Catalogs for DC2 and SR"*, *"Gaussian and other available covariances for TJPCosmo"*
Approach: Implement and test shrinkage estimator on LSS mock catalogs. Extend shrinkage covariance estimator to WL, and test performance on WL mock catalogs available within the collaboration.

Active deliverable: *Numerical routines for fast covariance estimation (SR SW)*

Host: TJP *Started, originally due:* 07/01/18, 09/30/21 *Expected:* 03/31/21
Objective: Implement optimized numerical routines to enable fast covariance estimation. The most useful covariance estimation methods studied in Deliverable *"Improved covariance estimators for single- and joint-probe analyses"* need to be optimized to reduce their computational cost before they are integrated into the TJPCosmo pipeline. The target performance of these methods should be defined with respect to Deliverable *"Framework Requirements for Joint Analysis Pipelines"*.
Prerequisites: *"Framework Requirements for Joint Analysis Pipelines"*, *"Improved covariance estimators for single- and joint-probe analyses"*.

Active deliverable: *Consistent joint probe covariances (SR SW)*

Host: TJP *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 12/31/21
Objective: Build a joint covariance matrix suitable for a WL + LSS + GC joint probe analysis

that satisfies pre-determined accuracy requirements. This will extend the covariance estimation methods developed in *"Improved covariance estimators for single- and joint-probe analyses"* as appropriate, and may build off sets of simulations developed as part of DC2. The emphasis will be placed on building a covariance matrix that is sufficiently accurate (in terms of minimizing bias on recovered cosmological parameters) while maintaining a high level of theoretical consistency between probes. The impact of systematic effects on the covariance must be consistently included.
Prerequisites: *"Improved covariance estimators for single- and joint-probe analyses"*

TJP Key Product (DC2 & SR): TJPCOSMO: Likelihood Pipeline for Joint Analyses (TJP5B)

Objective: The joint analysis of correlated cosmological probes as planned by DESC is an emerging line of research, and there exist only limited previous results to inform the joint probes analysis software pipeline development. In this Key Project, TJP will lead the development of a preliminary pipeline for the joint cosmological analysis of the primary cosmological probes.

The study will identify modeling complexities due to, for example, unprecedented demand on precision and systematic uncertainties that are correlated across probes, and will determine requirements on computing frameworks for such analyses. In close collaboration with CI, TJP will provide a library of core cosmology routines, which individual probe working groups will use to develop preliminary single-probe likelihood modules. These single-probe likelihood modules should incorporate the key systematic uncertainties, using placeholder routines if models/parameterizations will be determined at later times, so that TJP can identify cross-correlations and work with the individual working groups to develop consistent parameterizations. TJP will then curate and package a consistent combination of single-probe likelihoods and systematic models as joint probes analysis pipeline.

Individual probe working groups are encouraged to develop more detailed modeling for their probe-specific cosmology analysis pipeline within TJPCOSMO, but TJP cannot guarantee that all such modifications will be consistent with, or supported by the Joint Probes pipeline.

Completed deliverable: *Single-probe likelihood for Weak Lensing (DC2 SW)*
Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 03/31/19
Objective: Develop and document (preliminary) single-probe likelihood for weak lensing, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later

times. This has a higher priority than other single-probe likelihoods, as it is needed for preliminary work on 3x2pt statistics in TJPCosmo.
Prerequisites: .

Completed deliverable: *Single-probe likelihood for Large-Scale Structure (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 03/31/19 *Completed:* 03/31/19
Objective: Develop and document (preliminary) single-probe likelihood for large-scale structure/galaxy clustering, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a higher priority than other single-probe likelihoods, as it is needed for preliminary work on 3x2pt statistics in TJPCosmo.

Active deliverable: *Single-probe likelihood for Galaxy Clusters (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 12/31/20
Objective: Develop and document (preliminary) single-probe likelihood for galaxy clusters, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods but will now include work on 3x2pt statistics for clusters in TJPCosmo.
Prerequisites: *"DC2-era CL Likelihood Code"*

Planned deliverable: *Single-probe likelihood for Supernovae (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 12/31/19 *Expected:* 03/31/21
Objective: Single-probe likelihood for SN. Develop and document (preliminary) single-probe likelihood for supernovae, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods, as it is not needed for preliminary work on 3x2pt statistics in TJPCosmo.

Planned deliverable: *Single-probe likelihood for Strong Lensing (DC2 SW)*

Host: TJP *Started, originally due:* 10/01/17, 06/30/20 *Expected:* 03/31/21
Objective: Develop and document (preliminary) single-probe likelihood for strong lensing, built on CCL routines. This can initially be a 'straw-man' likelihood, making liberal use of placeholder routines for systematic effects if models/parameterizations are to be determined at later times. This has a lower priority than the WL and LSS likelihoods, as it is not needed for preliminary work on 3x2pt statistics in TJPCosmo.

Prerequisites: *"SLCosmo"*

Planned deliverable: *Validation of single-probe likelihoods on DC2 (DC2 VA)*

Host: TJP *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 12/30/20
Objective: Validate all available single-probe likelihoods by applying them to DC2 mock light-cone data and checking for biases and other issues. This phase of testing will most likely use the Gaussian covariances from Deliverable *"Gaussian and other available covariances for TJPCosmo"*, and should incorporate any systematic effect modules that are already available as a result of Deliverable *"Software module for astrophysical systematics"*. If the single probe likelihoods are already sufficiently well-integrated into TJPCosmo this will be used to run the validation tests; otherwise, the systematics testing workflow from Deliverable *"Workflow for testing accuracy of systematics mitigation"* may be used instead. The expectation is that, at minimum, the WL and LSS likelihoods will be ready for validation testing; the GC and SN likelihoods should be ready; and the SL likelihood is unlikely to be ready.
Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Single-probe likelihood for Galaxy Clusters"*, *"Single-probe likelihood for Supernovae"*, *"Single-probe likelihood for Supernovae"*, *"Gaussian and other available covariances for TJPCosmo"*, *"Workflow for testing accuracy of systematics mitigation"*

Completed deliverable: *Preliminary joint probes likelihood pipeline (DC2 SW)*

Host: TJP *Started, originally due:* 07/01/18, 12/31/19 *Completed:* 03/31/19
Objective: Develop preliminary likelihood module for joint probes data vectors, including placeholder modules for forthcoming development. Integrate joint likelihood modules from individual probe likelihoods and identify cross-correlations of systematic effects, starting from the single-probe systematics models from Deliverable *"Software module for astrophysical systematics"*. The main focus of this deliverable is to get preliminary 3x2pt (WL and LSS) joint analysis capabilities up and running.
Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Gaussian and other available covariances for TJPCosmo"*, *"Software module for astrophysical systematics"*

Active deliverable: *Forecasting module in likelihood pipeline (DC2 SW)*

Host: TJP *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 12/31/20
Objective: Develop forecasting capabilities, including Fisher matrix and MCMC methods, built within the TJPCosmo framework. Perform single- and joint-probe forecasts consistent with the state-of-the-art analysis pipeline, update requirements in the SRD, and forecast the perfor-

mance of cosmological analyses, systematics mitigation, and constraints on novel physics.
Prerequisites: *"Single-probe likelihood for Weak Lensing"*, *"Single-probe likelihood for Large-Scale Structure"*, *"Gaussian and other available covariances for* TJPCosmo*"*, *"Software module for astrophysical systematics"*

Completed deliverable: CosmoParams*: Common exchange format for cosmological parameter sets (DC2 SW)*

Host: TJP *Started, originally due:* 07/01/18, 12/31/19 *Completed:* 03/31/19
Objective: Develop a common data format for exchanging sets of cosmological parameters between different codes. This should include a standard interchange file format that can be used to pass around sets of parameters, as well as in-memory data formats that can be shared between codes. Methods should be provided for validating and comparing sets of parameters to ensure consistency with the standard format. The primary goal of this deliverable is to ensure that sets of cosmological (and nuisance) parameters can be passed between various DESC codes in a robust and unambiguous way, and that default values for parameters etc. are consistent between codes. In the first instance, the CosmoParams standard will be implemented by CCL, TJPCosmo, and TJPCov, and should ultimately be supported by any DESC code that needs to interact with any of these codes. Note: this deliverable has been absorbed into CCL, which sets the cosmology parameters and definitions to be used by DESC pipelines - `pyccl` can be used to pass these parameters between codes.

Planned deliverable: *Modules for data compression and alternative inference methods (SR SW)*

Host: TJP *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: This deliverable is for improved data compression and alternative inference methods that will ease the process of inferring cosmological parameters from high-dimensional data vectors while marginalizing over many nuisance parameters.

Planned deliverable: *Modules for implementing parameter level blinding (SR SW)*

Host: TJP *Started, originally due:* 03/31/20, 09/30/21 *Expected:* 09/30/21
Objective: This deliverable is for implementing part of the blinding strategy to do be determined as part of R&D activities. It will supplement catalog-level blinding and data-vector level blinding (e.g. implemented in TXPipe).

Planned deliverable: *Cosmological analysis pipeline for LSST precursor data (SR SW)*

Host: TJP *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 09/30/21
Objective: Produce and disseminate a complete software pipeline that can be used to perform cosmological analyses using core cosmology probes operating at the precision of LSST

precursor data sets. This pipeline will include software to predict core observables, mitigation of systematic errors (developed in the Deliverable *"Preliminary joint probes likelihood pipeline"*), and infer cosmological parameters, all sufficiently well developed and integrated to address forthcoming large data sets. This effort is a refinement and further development of Deliverable *"Preliminary joint probes likelihood pipeline"*, and is intended to provide a focus for the integration and finalization of TJPCosmo components required to enable an end-to-end joint probes analysis with real data. No systematic effect or covariance placeholders should remain in the 'standard' run-mode of TJPCosmo pipeline at this point.
Prerequisites: Deliverables *"Preliminary joint probes likelihood pipeline"*, *"Consistency of systematics modeling across all probes"*, *"Consistent joint probe covariances"*

TJP Key Product (SR): Integration of TJPCosmo into the CI Framework (TJP5C)

Objective: Implement detailed cosmological likelihood analysis pipeline for joint probes analyses. This project upgrades Key Product "TJPCosmo: Likelihood Pipeline for Joint Analyses" (TJP5B) to the requirements of SR analyses, by incorporating refined systematics modeling and mitigation techniques developed by individual working groups during DC2 and integrating the likelihood pipeline into the overall framework. The application of the final pipeline produced in this Key Project to SR mock catalogs and precursor data sets will likely be postponed to the ComCam analysis phase.
Prerequisites: "TJPCosmo: Likelihood Pipeline for Joint Analyses" (TJP5B),"WL Systematic Uncertainty Characterization Framework" (WL2)

Active deliverable: *Framework Requirements for Joint Analysis Pipelines (DC2 RQ)*
Host: TJP *Started, originally due:* 10/01/17, 07/01/18 *Expected:* 12/31/20
Objective: Identify conceptual and computational bottle necks in the individual and joint probes likelihoods developed in the Deliverable *"Preliminary joint probes likelihood pipeline"*. Present these findings to the CO group to solicit advice on potential updates to remove/minimize those bottle necks.
Prerequisites: *"Preliminary joint probes likelihood pipeline"*

Planned deliverable: TJPCosmo *pipeline integration and validation (SR VA)*
Host: TJP *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 09/01/21
Objective: Integrate the TJPCosmo joint probe likelihood pipeline into the CI framework. This will take the essentially complete TJPCosmo library from *"Modules for implementing*

parameter level blinding", finalize the integration of any remaining systematics models or covariance modules, and begin integration testing and basic validation tests, including simple test runs of single- and joint-probes likelihoods.
Prerequisites: *"Modules for implementing parameter level blinding"*

Planned deliverable: *Apply* TJPCOSMO *joint likelihood pipeline to SR-era simulations (SR DP)*

Host: TJP *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 12/31/21

Objective: Perform end-to-end validation tests of the complete TJPCOSMO joint likelihood pipeline on Science Readiness-era simulations.
Prerequisites: *"*TJPCOSMO *pipeline integration and validation"*

TJP Key Product (SV): TJP Pipeline Adaptation to the SV Data (TJP-SV)
Objective: Adapt the TJP pipeline on the real SV data, extending it to include more advanced algorithms as needed.

Anticipated deliverable: *Extended TJP Pipeline (SV SW)*

Host: TJP *Started, originally due:* 09/30/21, 10/01/23 *Anticipated:* 07/31/23
Objective: Adapted and extended TJP pipeline, for application to SV data.

5.18 Photometric Redshifts Pipeline

The focus of this subsection is development of pipelines for the PZ working group. There are three such pipelines: PZESTIMATE (left panel Figure 5.18.1), for eventual production of photo-z posterior probability density functions (PDFs); PZSUMMARIZE (right panel Figure 5.18.1), for assisting the PWGs with the calibration of ensemble $N(z)$ for tomographic redshift samples used in e.g. TXPIPE; and PZVALIDATE (Figure 5.18.2), for quantification and mitigation of the impact of imperfect prior knowledge (in spectroscopic training samples, SED template libraries, and other model parameters) on photo-z posterior PDFs and tomographic redshift samples. The high-level development path is as follows:

- **DC1 era**: Initiation of PZESTIMATE, focusing just on univariate posterior PDFs.
- **DC2 era**: Initiation of PZVALIDATE and PZSUMMARIZE, solidification/refinement of PZESTIMATE and integration thereof with PZVALIDATE and PZSUMMARIZE.

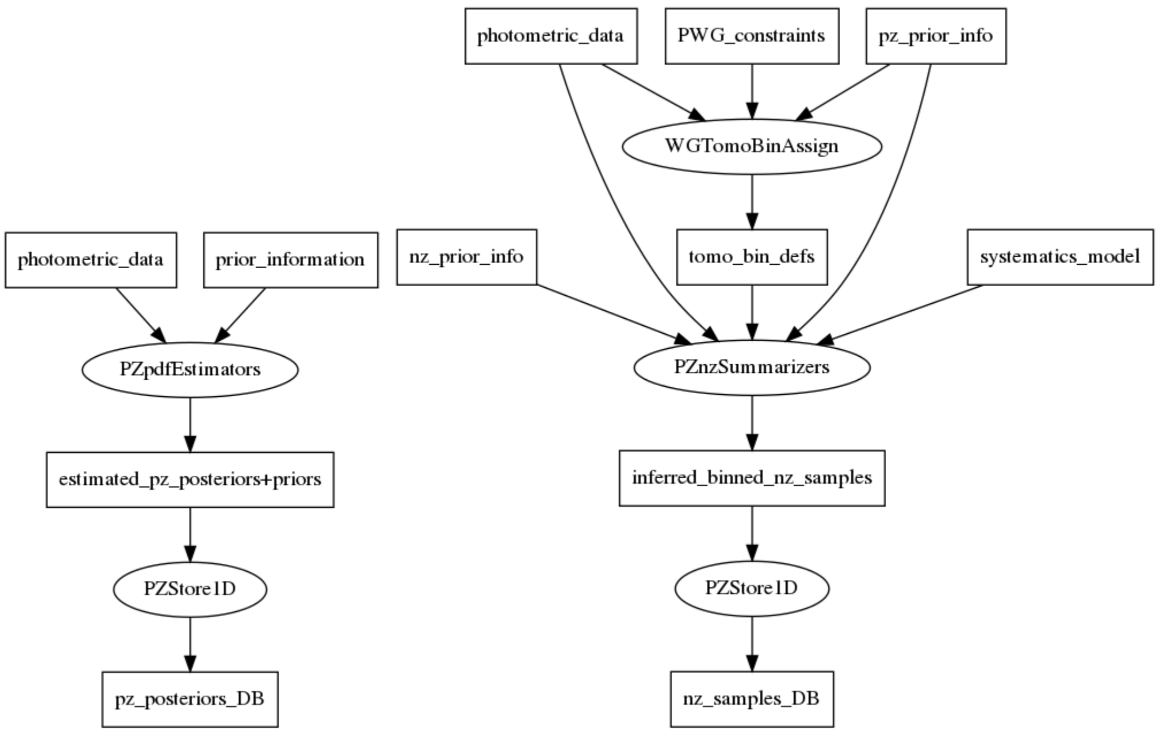

Figure 5.18.1: Left: Pipeline diagram illustrating the components of the PZESTIMATE workflow. Right: Pipeline diagram illustrating the components of the PZSUMMARIZE workflow.

- **SR era**: Further development and validation of software to meet science goals of LSST Y1 data.
- **SV era**: Integration of the PZ pipeline and adaptation to the real SV data. Possible extension of the framework to support additional advanced algorithms and external data.

Documentation of the plans at a higher level of detail, and more finely grained timelines, will be included in more transient documents, specifically DESC Notes and GitHub issues. All major pipeline activities will be documented in one of the above ways.

PZ Key Product (DC1 & DC2 & SR): Photometric Redshifts Pipeline PZESTIMATE (PZ5)

Objective: The PZESTIMATE key product is a pipeline that accepts a catalog of photometric data (fluxes and observational errors) and some prior information (such as a template library or spectroscopically confirmed training set) and outputs a catalog of photo-z posterior probability

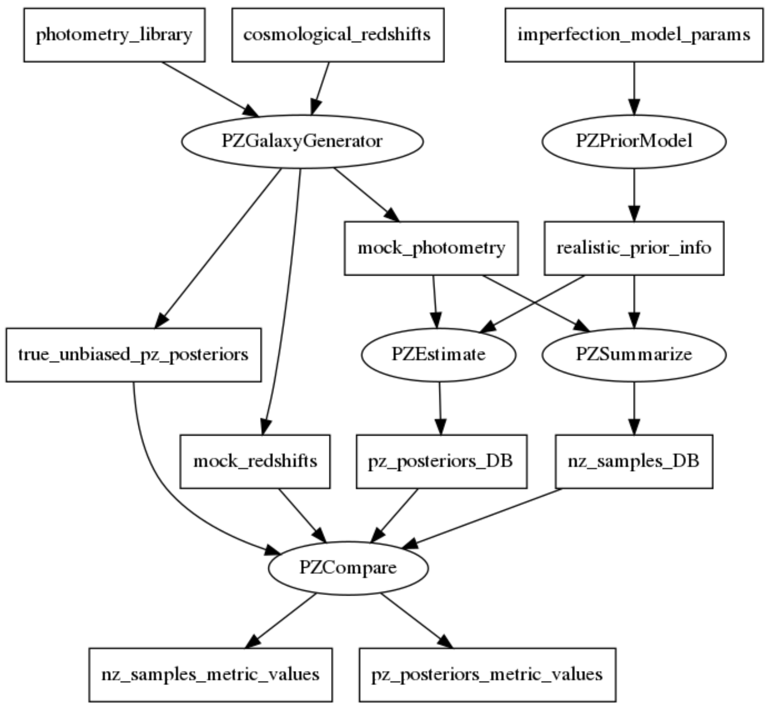

Figure 5.18.2: Pipeline diagram illustrating the components of the PZVALIDATE workflow, which stress-tests and constrains the errors of the PZESTIMATE and PZSUMMARIZE pipelines.

density functions (PDFs) (left panel Figure 5.18.1). The associated deliverables are projects that build the PZESTIMATE infrastructure and validate it.

Completed deliverable: *Baseline* PZPDFESTIMATORS *for photo-z posterior PDFs (DC1 SW)*

Host: PZ *Started, originally due:* 01/01/16, 01/01/18 *Completed:* 01/01/18
URL : https://github.com/LSSTDESC/pz_pdf
Objective: This deliverable consists of scripts that call external codes to compute photo-z posterior PDFs.

Completed deliverable: *Baseline* PZCOMPARE *metrics for photo-z posterior PDFs (DC1 SW)*

Host: PZ *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/PZDC1paper/tree/master
Objective: The deliverable is a precursor version of PZCOMPARE and constitutes a code base to calculate standard metrics of photo-z point estimates (bias, scatter, outlier rates) as well as metrics of estimated photo-z posteriors.

Completed deliverable: *Validation of baseline* PZCOMPARE *(DC1 VA)*

Host: PZ *Started, originally due:* 10/01/15, 06/30/18 *Completed:* 06/30/18
URL : https://confluence.slac.stanford.edu/pages/viewpage.action?pageId=238561496
Objective: The deliverable is a demonstration of the preliminary version of PZCOMPARE applied to photo-z PDF estimates of the DC1 extragalactic simulations from a set of external photo-z PDF codes, a first version of PZPDFESTIMATORS. These serve both to validate the metric scripts of PZCOMPARE, assess the appropriateness of the various PZCOMPARE metrics, and establish a baseline for the performance of the PZPDFESTIMATORS estimators in the absence of realistic imperfections in prior information.
Prerequisites: Deliverables *"Baseline* PZCOMPARE *metrics for photo-z posterior PDFs"*, *"Baseline* PZPDFESTIMATORS *for photo-z posterior PDFs"*, and *"*PZSTORE1D *at scale"*

Completed deliverable: *Baseline* PZSTORE1D *for one-dimensional photo-z posteriors (DC1 SW)*

Host: PZ *Started, originally due:* 01/01/17, 07/01/18 *Completed:* 07/01/18
URL : https://github.com/aimalz/qp
Objective: This deliverable consists of the prototype code that compresses, stores, and extracts the photo-z PDFs yielded by PZPDFESTIMATORS.

Completed deliverable: *Validation of baseline* PZSTORE1D *(DC1 VA)*

Host: PZ *Started, originally due:* 01/01/17, 07/01/18 *Completed:* 07/01/18
URL : https://github.com/aimalz/qp
Objective: This deliverable consists of the validation of the prototype code that compresses, stores, and extracts the photo-z PDFs yielded by PZPDFESTIMATORS and the investigation necessary to determine an optimal storage format.
Prerequisites: Deliverable *"Baseline* PZSTORE1D *for one-dimensional photo-z posteriors"*, *"Baseline* PZCOMPARE *metrics for photo-z posterior PDFs"*

Completed deliverable: *Validation of* PZPDFESTIMATORS *(DC1 VA)*

Host: PZ *Started, originally due:* 01/01/17, 01/01/19 *Completed:* 01/01/19
URL : https://github.com/LSSTDESC/PZDC1Paper
Objective: This deliverable consists of the comparison between the baseline PZPDFESTIMATORS outputs under conditions of optimistic prior information to assess performance.
Prerequisites: Deliverable *"Baseline* PZSTORE1D *for one-dimensional photo-z posteriors"*, *"Baseline* PZCOMPARE *metrics for photo-z posterior PDFs"*

Active deliverable: *Photo-z posterior PDFs for DC2 data using* PZESTIMATE *(DC2 DP)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20

Objective: This deliverable is simply the photo-z PDF catalog output by PZpdfEstimators using the DC2 data set as inputs, compressed using PZStore1D. This deliverable is provided to the analysis WGs for their DC2 studies and infrastructure development.
Prerequisites: Deliverables *"Baseline* PZpdfEstimators *for photo-z posterior PDFs"*, *"Baseline* PZStore1D *for one-dimensional photo-z posteriors"*

Active deliverable: *Validation of photo-z posterior PDFs for DC2 using* PZEstimate *(DC2 VA)*

Host: PZ *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 12/31/20
Objective: This deliverable is for the validation of the DC2 photo-z posterior PDFs, an ongoing process concurrent with *"Photo-z posterior PDFs for DC2 data using* PZEstimate*"*.
Prerequisites: Deliverables *"Photo-z posterior PDFs for DC2 data using* PZEstimate*"*, *"Baseline* PZCompare *metrics for photo-z posterior PDFs"*, "PZStore1D *at scale"*

Defunct deliverable: *PZCombineResults for one-dimensional photo-z posteriors (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19
URL : https://github.com/LSSTDESC/pz_pdf
Objective: This deliverable aimed to combine photo-z posterior PDF results derived by different algorithms. This deliverable is now considered defunct because DC1-era experimentation revealed a methodological problem with this approach.
Prerequisites: Deliverable *"Baseline* PZpdfEstimators *for photo-z posterior PDFs"*

Planned deliverable: PZpdfEstimators *at scale (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 06/30/21
URL : https://github.com/LSSTDESC/pz_pdf
Objective: This deliverable develops PZpdfEstimators into a series of autonomous modules compatible with probe WG analysis pipelines, including TXPipe.
Prerequisites: Deliverable *"Baseline* PZpdfEstimators *for photo-z posterior PDFs"*

Planned deliverable: PZStore1D *at scale (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 06/30/21
URL : https://github.com/LSSTDESC/qp
Objective: This deliverable consists of the at-scale code that compresses, stores, and extracts the photo-z PDFs yielded by PZpdfEstimators.
Prerequisites: Deliverable "PZpdfEstimators *at scale"*, *"Baseline* PZStore1D *for one-*

dimensional photo-z posteriors"

Planned deliverable: PZCompare *at scale (DC2 SW)*

Host: PZ *Started, originally due:* 03/01/20, 09/01/20 *Expected:* 06/30/21
URL : https://github.com/LSSTDESC/qp
Objective: The deliverable is a more advanced version of PZCompare and constitutes a code base to calculate standard metrics of photo-z point estimates (bias, scatter, outlier rates) as well as metrics of estimated photo-z posteriors in the context of evaluating estimated photo-z posteriors. This version is expected to run at scale for on-the-fly evaluation with PZValidate.
Prerequisites: Deliverables *"Baseline* PZCompare *metrics for photo-z posterior PDFs"*

Planned deliverable: PZPriorModel *for* PZEstimate *(SR DP)*

Host: PZ *Started, originally due:* 12/01/19, 12/31/21 *Expected:* 12/31/21
Objective: The final PZPriorModel deliverable represents the best prior information PZEstimate will have for running on real data. This data product will be constructed using the PZValidate framework and input from the ES WG regarding available data sets.
Prerequisites: Deliverables "PZPriorModel *with PZMakePhot"*, "PZPriorModel *with MakeSpec"*, "PZpdfEstimators *at scale"*

Planned deliverable: *Needs assessment for two-dimensional* $p(z, \alpha)$ *for* PZEstimate *(SR RQ)*

Host: PZ *Started, originally due:* 07/01/18, 10/01/20 *Expected:* 12/31/20
Objective: Assess working group needs for multidimensional $p(z, \alpha)$, including a set of concrete use cases, to motivate development of robust algorithms for estimating such posterior PDFs.

Planned deliverable: *Two-dimensional* $p(z, \alpha)$ *implementation for* PZEstimate *(SR SW)*

Host: PZ *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 06/30/22
Objective: Incorporate robust algorithms for obtaining multidimensional $p(z, \alpha)$ into the PZEstimate pipeline according to the needs from Deliverable *"Needs assessment for two-dimensional* $p(z, \alpha)$ *for* PZEstimate*"*.
Prerequisites: Deliverable *"Needs assessment for two-dimensional* $p(z, \alpha)$ *for* PZEstimate*"*

Planned deliverable: *Validation of* $p(z, \alpha)$ *for* PZEstimate *on SR (SR VA)*

Host: PZ *Started, originally due:* 07/01/20, 09/30/21 *Expected:* 12/31/22
Objective: Validate the $p(z, \alpha)$ of SR-era mock data.
Prerequisites: Deliverables *"Needs assessment for two-dimensional* $p(z, \alpha)$ *for* PZEstimate*"*,

"Two-dimensional $p(z, \alpha)$ implementation for PZESTIMATE*"*

PZ Key Product (DC2 & SR): Photometric Redshifts Pipeline PZSUMMARIZE (PZSUMMARIZE)

Objective: The PZSUMMARIZE (right panel Figure 5.18.1) pipeline constitutes the infrastructure necessary to assist the probe WGs in deriving the tomographic redshift distributions ($N(z)$) derived from photo-z posterior PDFs using information beyond the LSST sample photometry alone, including but not limited to the data from a reference sample, galaxy position information, selection functions, and models of physical systematics.

Active deliverable: *WGTomoBinOptimize for* PZSUMMARIZE *(DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/TXSelector%3A+optimizing+the+tomographic+binning+strategy
Objective: This deliverable is a series of WL- and/or LSS-hosted projects aiming to develop an approach to optimally define tomographic bin assignments in consultation with the PZ WG. By defining appropriate metrics for WL and LSS goals, this deliverable will also enhance the PZCOMPARE software for application to PZSUMMARIZE.
Prerequisites: Deliverables *"Source selector and tomographic binning definition software (*TXSOURCESELECTOR*)"* and *"Optimal catalog splits into samples (*TXLENSSELECTOR*)"*.

Active deliverable: *Metrics pipeline for evaluation of* PZSUMMARIZE *methods (DC2 SW)*

Host: PZ *Started, originally due:* 12/01/19, 06/30/21 *Expected:* 06/30/21
Objective: The deliverable includes scripts to calculate standard metrics of clustering redshift point estimates (bias, scatter, outlier rates) as well as metrics of clustering redshift posteriors and estimated redshift distributions for the benchmarking of potential PZSUMMARIZE back-end algorithms (PZNZSUMMARIZERS).
Prerequisites: Deliverable *"*PZCOMPARE *at scale"*

Active deliverable: PZNZSUMMARIZERS *for* PZSUMMARIZE *(DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 06/30/21
URL : https://github.com/LSSTDESC/pz_calibrate
Objective: This deliverable constitutes software modules to estimate the redshift distribution in tomographic bins, using any subset of traditional clustering-based redshift PDFs and red-

shift distributions, calibration against a reference data set (such as weighted direct calibration and SOM calibration), hierarchical inference based on photo-z posteriors (such as CHIPPR or Delight), and any other combination of their positions and their photometry.

Planned deliverable: *DC2-era* PZSUMMARIZE *validation (DC2 VA)*

Host: PZ *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 06/30/21
Objective: This deliverable consists of the validation of PZSUMMARIZE on the DC2 simulations and precursor data sets. This will enable a comparison of the different approaches to estimating $N(z)$ in their ability to recover the true redshift distributions from mock catalogues.
Prerequisites: Deliverables *"SR-era* PZSUMMARIZE *updates"*, "PZCOMPARE *at scale"*, *"WG-TomoBinOptimize for* PZSUMMARIZE*"*, "PZNZSUMMARIZERS *for* PZSUMMARIZE*"*.

Defunct deliverable: *PZBiasEvolutionEstimator for* PZSUMMARIZE *(DC2 VA)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19
Objective: This deliverable entails the study of mitigation strategies for redshift-dependent galaxy bias in the clustering redshift analysis of PZSUMMARIZE, including code implementing at least one performance evaluation metric, code implementing at least one mitigation strategy, the validation of the mitigation strategy code on DC2 data, and a publication reporting the effectiveness of all such strategies considered. This deliverable is now a component of Deliverable D:pzincomplete-physics.
Prerequisites: Deliverable "PZNZSUMMARIZERS *for* PZSUMMARIZE"

Defunct deliverable: *MagnificationCorrection for* PZSUMMARIZE *(DC2 VA)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19
URL : https://github.com/LSSTDESC/pz_calibrate
Objective: This deliverable entails the study of mitigation strategies for lensing magnification bias in the clustering redshift analysis of PZSUMMARIZE, including code implementing at least one performance evaluation metric, code implementing at least one mitigation strategy, the validation of the mitigation strategy code on DC2 data, and a publication reporting the effectiveness of all such strategies considered. This deliverable is now a component of Deliverable D:pzincomplete-physics.
Prerequisites: Deliverable "PZNZSUMMARIZERS *for* PZSUMMARIZE"

Active deliverable: *Interface with WL and LSS for* PZSUMMARIZE *(DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/TXSelector%3A+optimizing+

the+tomographic+binning+strategy

Objective: The deliverable entails the development of infrastructure connecting PZSUMMARIZE to WL and LSS pipelines, including TXPIPE. It will be developed in consultation with the PZ WG as part of a series of WL- and/or LSS-hosted projects aimed at propagating estimated tomographic redshift distributions to cosmology constraints.
Prerequisites: Deliverables *"WGTomoBinOptimize for* PZSUMMARIZE*"*, *"*PZNZSUMMARIZERS *for* PZSUMMARIZE*"*

Planned deliverable: *SR-era* PZSUMMARIZE *updates (SR SW)*

Host: PZ *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 06/30/22
URL : https://github.com/LSSTDESC/pz_calibrate
Objective: This deliverable will update PZSUMMARIZE in accordance with the findings of *"*PZVALIDATE *under physical systematics"*.
Prerequisites: Deliverables *"WGTomoBinOptimize for* PZSUMMARIZE*"*, *"DC2-era* PZSUMMARIZE *validation"*, *"*PZVALIDATE *under physical systematics"*

Planned deliverable: *SR-era* PZSUMMARIZE *validation (SR VA)*

Host: PZ *Started, originally due:* 03/31/19, 09/30/21 *Expected:* 06/30/22
Objective: This deliverable consists of the validation of PZSUMMARIZE on the SR simulations and precursor data sets after the completion of Deliverable *"SR-era* PZSUMMARIZE *updates"*.
Prerequisites: Deliverable *"SR-era* PZSUMMARIZE *updates"*

PZ Key Product (DC2): Photometric Redshifts Pipeline PZVALIDATE (PZVALIDATE)

Objective: The PZVALIDATE (Figure 5.18.2) pipeline constitutes the infrastructure for testing the impact of imperfect prior information and physical systematics on the estimation of photo-z posterior PDFs and the redshift distribution in tomographic bins, necessary steps in the identification of robust back-end algorithms to PZPDFESTIMATORS for PZESTIMATE and PZNZSUMMARIZERS for PZSUMMARIZE. Since the most interpretable PZCOMPARE metrics require a fully self-consistent forward model of photometry, much of PZVALIDATE pertains to the production of appropriate mock data for such tests.

Active deliverable: PZGALAXYGENERATOR *PZMakePhot (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20

URL : https://github.com/LSSTDESC/RAIL
Objective: This deliverable is the first-order infrastructure for forward-modeling mock photometry with corresponding true photo-z posteriors, using the DC2 extragalactic catalog as a starting point. PZMAKEPHOT will then be used to implement simple empirical models for systematics between spectroscopic training sets and photometric test sets and assess the influence thereof on the data-driven codes of PZPDFESTIMATORS using the criteria of PZCOMPARE.

Active deliverable: PZPRIORMODEL *with PZMakePhot (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 12/31/20
URL : https://github.com/LSSTDESC/RAIL
Objective: The PZPRIORMODEL deliverable is software to model realistically imperfect prior information that feeds into PZPDFESTIMATORS, i.e. the unavoidable imperfection of spectroscopic training sets and SED template libraries. PZPRIORMODEL will be used to determine how sensitive PZPDFESTIMATORS is to realistically imperfect prior information, thereby contributing to the decision of which photo-z posterior estimation codes will be included in PZPDFESTIMATORS. This deliverable is a precursor version that models realistically complex prior imperfections at the level of photometry.
Prerequisites: Deliverable "PZGALAXYGENERATOR *PZMakePhot*"

Planned deliverable: *Validation and testing of* PZVALIDATE *using DC2 simulations (DC2 VA)*

Host: PZ *Started, originally due:* 07/01/18, 12/31/19 *Expected:* 06/30/21
Objective: Validate PZVALIDATE using the DC2 simulations, resulting in lessons that can feed into further PZESTIMATE development.
Prerequisites: DC2 simulations and deliverables "PZGALAXYGENERATOR *PZMakePhot*", "PZPRIORMODEL *with PZMakePhot*", "PZPDFESTIMATORS *at scale*", "PZCOMPARE *at scale*", "PZSTORE1D *at scale*"

Planned deliverable: PZGALAXYGENERATOR*: PZMakeSpec (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/pz_incomplete
Objective: This deliverable extends the PZMAKEPHOT infrastructure to a forward model of spectra with corresponding true photo-z posteriors using a basis of SR-era simulated catalogs. As an end-to-end forward model, PZMAKESPEC will be used to model realistically complex prior information in both training sets and template libraries, including the addition of emission lines. Its validation will entail an assessment of the impact thereof on the photo-z PDF codes of PZPDFESTIMATORS using the criteria of PZCOMPARE.

Prerequisites: SR simulations and Deliverables *"PZGalaxyGenerator PZMakePhot"*

Defunct deliverable: PZGalaxyGenerator*: PZAddEmissionLines (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19
URL : https://github.com/LSSTDESC/pz_incomplete
Objective: Software to add emission lines based on continuum spectra. This deliverable has been subsumed into Deliverable *"PZGalaxyGenerator: PZMakeSpec"*, as the steps are not separable under a forward model.
Prerequisites: Deliverable *"PZGalaxyGenerator: PZMakeSpec"*

Planned deliverable: PZPriorModel *with MakeSpec (DC2 SW)*

Host: PZ *Started, originally due:* 10/01/17, 03/31/19 *Expected:* 09/30/21
URL : https://github.com/LSSTDESC/RAIL
Objective: The PZPriorModel deliverable is software to model realistically imperfect prior information that feeds into PZpdfEstimators, i.e. the unavoidable imperfection of spectroscopic training sets and SED template libraries. PZPriorModel will be used to determine how sensitive PZpdfEstimators is to realistically imperfect prior information, thereby contributing to the decision of which photo-z posterior estimation codes will be included in PZpdfEstimators. This deliverable extends Deliverable *"PZPriorModel with PZMakePhot"* to a physically realistic model of prior imperfections informed by spectroscopic systematics.
Prerequisites: Deliverables *"PZGalaxyGenerator: PZMakeSpec"* and *"PZPriorModel with PZMakePhot"*

Planned deliverable: PZValidate *under image systematics (DC2 VA)*

Host: PZ *Started, originally due:* 03/01/21, 09/30/21 *Expected:* 09/30/21
Objective: This deliverable aims to quantify the impact of imperfect deblending, suboptimal observational conditions, mischaracterized sensor anomalies, undercorrected photometry, and PSF systematics on PZEstimate and PZSummarize by connecting the unified CO simulation infrastructure (associated with the BL, SSim, SA, PC, PSF working groups) to PZGalaxyGenerator and PZPriorModel in a cross-working group project.
Prerequisites: DC2 simulations and fake object injection pipeline and deliverables *"Evaluation of Blending Metrics"*, *"Processing of Training and Testing Images"*, *"Survey Simulation Tools for DC2"*, *"Add major features to imSim"*, *"Implemented and Validated Correction Algorithm for the BF Effect"*, *"Validation of correction algorithms for static effects"*, *"PC Bias on Individual Probes"*, *"PC Observing Strategy Metrics"*, *"Identify and characterize PSF sys-*

tematic uncertainties", and *"Null test pipeline (*WLNULLTEST*)"*, *"*PZPDFESTIMATORS *at scale"*, *"DC2-era* PZSUMMARIZE *validation"*, *"*PZGALAXYGENERATOR *PZMakePhot"*.

Planned deliverable: PZVALIDATE *under physical systematics (SR VA)*

Host: PZ *Started, originally due:* 06/30/21, 06/30/22 *Expected:* 06/30/22

Objective: This deliverable aims to quantify the effect of physical model choices, such as magnification and galaxy bias evolution, on the PZSUMMARIZE back-ends that require such assumptions as prior information. This deliverable will guide the choice of how to correct for these effects in PZNZSUMMARIZERS.

Prerequisites: Deliverable *"*PZNZSUMMARIZERS *for* PZSUMMARIZE*"*

Planned deliverable: *Quantifying spectroscopic imperfection (SR SW)*

Host: PZ *Started, originally due:* 03/31/19, 07/01/20 *Expected:* 12/31/21

Objective: This deliverable consists of a series of papers that use PZCOMPARE to evaluate the performance of PZESTIMATE and PZSUMMARIZE run on realistically imperfect prior information modeled in stages by PZVALIDATE. These investigations constitute a sensitivity analysis of PZPDFESTIMATORS and PZNZSUMMARIZERS that quantifies the impact of realistic imperfect prior information, both in training sets for machine learning codes and in template libraries for model-based codes.

Prerequisites: PZVALIDATE and Deliverables *"*PZPDFESTIMATORS *at scale"*, *"*PZCOMPARE *at scale"*, *"*PZPRIORMODEL *for* PZESTIMATE*"*

PZ Key Product (SV): Integrated PZ Pipeline, Adapted to SV Data (PZ-SV)

Objective: Fully integrated PZ pipeline for application of PZESTIMATE and PZSUMMARIZE to the SV data.

Anticipated deliverable: *Integrated PZ Pipeline (SV SW)*

Host: PZ *Started, originally due:* 07/01/20, 10/01/23 *Anticipated:* 10/01/23

Objective: Fully integrated end-to-end pipeline for producing DESC photo-z posterior PDFs and redshift distributions os galaxy samples, including lessons from application to SV data.

6 Datasets

In this section we explain in more detail the different precursor datasets (simulated and real data) we use to test and develop our pipelines. We define two data challenges and a Science Readiness phase. We then provide a set of Key Products and Deliverables to be built as part of the collaboration's operations activity to generate and/or process the precusor datasets.

6.1 DESC Data Challenges

In this Roadmap (and in the collaboration more generally) we use the term "data challenge" to refer to the use of simulated or real data (at either image or catalog level) to develope and validate one or more components of the DESC software pipelines or associated infrastructure. Examples of data challenges include: quantifying the effects of systematics and the ability of pipeline tools to remove them; testing the performance of an algorithm when scaling up to data of increased size and/or complexity; determining the ability of the pipeline to recover an input cosmology; and demonstrating the successful operation of a pipeline at the required scale. The key common feature of all of these data challenges is that they involve the use of large, LSST-like datasets to address one or more well-defined and critical questions for LSST DESC in a controlled environment. A crucial requirement for the success of the data challenge activities that use simulations is the validation of the fidelity of the simulated data, to ensure that they meet the requirements for each of the activities that depend on them.

Economy of scale leads us to define a small number of "challenge datasets," and organize their assembly and analysis into discrete timeframes, leading to the concept of there being, in DESC, two discrete data challenge "eras" followed by one Science Readiness era. These can be seen in the schedule shown in Figure 2.1.1.

We summarize the expectations for each era as follows:

- DC1: The first data challenge, DC1, was defined in such a way that the necessary simulation and analysis infrastructure was essentially already in place in 2016. A full end-to-end simulation pipeline to generate LSST-like data products was implemented. DC1 covers ten years of data taking in an area of $\approx$40 deg^2 and the simulations were carried out in r-band only. The input catalog for DC1 was based on the Millennium simulation semi-analytic galaxy catalog, which is embedded in the LSST catalog simulation framework, CatSim. Image simulations were carried out with imSim, and the resulting dataset was then processed with the LSST science pipeline. The main focus in DC1 was the investigation of systematic effects relevant for large-scale structure measurements (the galaxy catalog within CatSim does not provide shear measurements), as well as the validation and verification of its end-to-end workflow.

- DC2: The second data challenge, DC2, has several enhancements compared to DC1 to enable tests across a broad range of science cases. DC2 covers all six optical bands $ugrizy$ that will be observed by LSST and the area is increased by a factor of 7.5 to $\approx$300 deg^2 for the WFD area. DC2 also contains a DDF area of $\approx$1 deg^2. Working groups within DESC plan to use DC2 for tests of prototype analysis pipelines that are being developed, including pipelines for measuring weak gravitational lensing correlations, large-scale structure statistics, galaxy cluster abundance and masses based on weak lensing, supernova light curve recovery, and inference of ensemble redshift distributions for samples based on photometric redshifts. A major development compared to DC1 is the integration of a new extragalactic catalog, called cosmoDC2. Based on the Outer Rim simulation, cosmoDC2 not only covers a large area (440 deg^2) but also includes shear measurements and employs an enhanced galaxy modeling approach. A new interface to CatSim was developed followed by a workflow for the image simulation generation analogous to DC1 (the technical implementation of the workflow itself was completely redone to enable scaling to thousands of nodes). The image simulation tool, imSim, has been improved to enhance performance on different architectures. DC2 is being carried out across several computing sides, including NERSC, the Grid in the UK/Europe, the ALCF, and CC-IN2P3. The simulated DC2 images are being processed with the LSST science pipeline to generate data products for the collaboration closely matching what will be delivered by the telescope. DC2 has been essential for starting to develop data access methods for DESC as well.

- Science Readiness: This is the final era to prepare DESC for the arrival of first year LSST data. The DC2 data set will still play a very important role for testing and validation activities as well as data processing at scale. In addition, new data sets will be generated, targeted at specific science goals that cannot be satisfied by either DC2 or other precursor data. Time and resources permitted, DESC is planning to generate a large-area emulated data set as well. The aim during the Science Readiness era is to use LSST data release pipeline-reduced data products from simulations and/or precursor datasets to test analysis methods at the scale of that anticipated for the LSST commissioning Science Validation (SV) data, develop the infrastructure to be ready for the first year of LSST data. The main aim is to finalize and validate the data analysis pipeline for the primary cosmological probes (including photo-z determination, etc.), in order to demonstrate that we can produce data-limited analyses of the ComCam and SV data.

Details of the simulations for each era are provided in Section 6.3.

6.2 Rubin Observatory Project Datasets

DESC also intends to make full use of opportunities to analyze real datasets produced by the Rubin Observatory Project to complement the analysis of simulated data challenge datasets:

- *Project-reprocessed external precursor data:* The Project is anticipating processing a number of precursor datasets, having characteristics ranging from a few square degrees at LSST depth to shallower but wide surveys, as "verification datasets."

  The timelines for and expected products from these datasets are still being finalized. The SRM will be updated to incorporate their use, to build and validate interfaces with Rubin Observatory Project DM software and to perform tests of the DESC analysis pipeline that are complementary to those done via simulated data. One important use of these precursor image sets will be in exercising the DESC's replica of the DM data release production pipeline: we need to be able to reproduce the Rubin Observatory LSST catalogs in order to then probe the systematic errors in them.

- *The Commissioning Camera (ComCam):* ComCam is a single-raft camera that will be installed on the Simonyi Survey Telescope in advance of the full science instrument. It is planned to have 6 filters ($ugrizy$), 9 CCDs, and cover $0.7 \times 0.7 \sim 0.5$ deg^2 per image. The primary objectives of ComCam are early system integration and testing. More details may be found in the LSST Commissioning Plan.

  It is very likely that early commissioning will produce data that DESC could profitably analyze and learn from. While details depend on the amount of time ComCam is on-sky (see schedule forecast as of summer 2019 in Figure 2.1.1), the LSST Commissioning Plan includes three short (~ 4 night) observing campaigns surveys taken with the ComCam to test the DM pipeline. To test the system's Key Performance Metrics, we expect a non-contiguous area of some 10 square degrees to be imaged 25 times in each of 6 filters, reaching a depth of about 26 magnitudes in r, plus a second set that goes to 10-year depth in ri only, to test the full-depth Key Performance Metrics (e.g., ellipticity residuals). For the system's 20-year depth test, we expect an area of 5 square degrees to be imaged in all filters to a depth of about $r \approx 28$.

  Imaging and catalog data are expected to be made available to the science collaborations within a 6 and 9 months (respectively) of data taking, albeit with a lower level of support than is expected for survey operations. The DESC will coordinate with the Project on this, and on the potential for unsupported earlier access via bulk download.

- *Science Validation:* The timeline for Science Validation observations with the full LSSTCam/telescope/DM system (according to the summer 2019 forecasts) is shown in Figure 2.1.1. SV is slated to include short observing campaigns (totalling 3 months on the sky) to characterize performance relative to LSST System Requirements and to test operations readiness using the initial survey cadence.

The LSST Commissioning Plan includes a "Wide Area" survey, imaging 1600 square degrees at 15 epochs in each of 6 filters over about 40 nights. It also includes a 10-year depth survey, covering 300 square degrees with 825 visits per field over the full filter set, also over about 40 nights. Together, these data will comprise some 40,000 visit images.

It is anticipated that the Project will seek external input on this Science Validation survey design. The DESC will actively seek opportunities to engage with the Project on this as early as possible. Again, the SV data is expected to be released for science collaboration use within 6 (images) and 9 (catalogs) months of the data being taken.

By design, the analysis of precursor datasets and targeted simulations during the Science Readiness era will conclude at the time when Science Validation data will become available. We will then use the DESC processing and analysis pipelines developed through the DCs to analyze the SV data, and in doing so scale them up to be able to operate on the initial LSST data.

COM Key Product (SR): DESC Commissioning Efforts (COM1)
Objective: We describe a set of activities undertaken by DESC members to support the LSST commissioning effort.

Completed deliverable: *DESC technical note with suggested observing fields (SR RQ)*

Host: COM *Started, originally due:* 07/01/18, 7/1/19 *Completed:* 08/1/20
URL : https://github.com/LSSTDESC/LSST-Commissioning
Objective: The DESC collaboration will suggest a set of survey fields which can be used by the commissioning team during both the ComCam and LSST Camera commissioning periods. These fields and tests will cover a range of times of year and will supply important test data to evaluate LSST performance metrics beyond those specified in the Rubin Observatory Project documents. The DESC can use this data to evaluate the system performance for metrics which are relevant to dark energy science.

This work will be undertaking by a large cross-section of the analysis and technical groups in the DESC including the Weak Lensing, Large Scale Structure, Galaxy Cluster, Supernovae, and Strong Lensing groups. The outcome of the work will be a DESC technical note to be delivered to the Rubin Observatory Project.

Planned deliverable: *DESC Commissioning Plan Document (SR RQ)*

Host: COM *Started, originally due:* 01/01/20, 06/01/20 *Expected:* 01/01/22
URL : https://github.com/LSSTDESC/LSST-Commissioning
Objective: The DESC collaboration will create a DESC commissioning plan document including suggested science validation tests associated with the DESC commissioning fields note. These tests will including both existing tests used by the project during commissioning, and tests specific to the DESC which can be used with collected or simulated data to test the DESC pipelines and tools.

This work will be undertaken by a large cross-section of the analysis and technical groups in the DESC including the Weak Lensing, Large Scale Structure, Galaxy Cluster, Supernovae, and Strong Lensing groups. The note will encompass a comprehensive plan of all DESC commissioning related activities.

6.3 DESC Dataset Properties

In this section we focus on simulated datasets. The data requirements defined by the Working Groups can be addressed by a small number of common datasets. The generation of these common datasets requires substantial computational resources together with the development of an end-to-end framework that can both generate and process simulated data. In this section we describe the common datasets.

There are four cross-working group datasets that comprise cosmology simulations, simulated "extragalactic" catalogs, simulated images, and catalogs derived from the processing of the simulated images through the DM pipelines. These simulated datasets address the needs and requirements of the working groups as detailed in the following section. We anticipate that different working groups will use subsets of the data (e.g. the cosmology simulations, the extragalactic catalogs, the simulated images and so on), depending on their objectives.

For DC1, a small image simulation dataset spanning 40 deg^2 in r-band was generated based on the Millenium extragalactic catalog that is embedded in CatSim. The images were then processed with the LSST science pipeline. DC1 projects were focused on the resulting catalogs. A few cosmological simulations and extragalactic catalogs that were readily provided by DESC members, such as the Buzzard catalogs, formed the foundation of several simulation-based projects in this era as well.

For DC2, the main cosmological simulation used is the Outer Rim simulation, a gravity-only simulation spanning a volume of $(4.225\text{Gpc})^3$ and a mass resolution of roughly $2.6{\cdot}10^9\text{M}_\odot$.

Snapshots and light-cone data (particles and halos) are available for a diverse set of DC2 projects. Shear measurements are provided as well. The extragalactic catalog, generated for DC2, is called cosmoDC2 and covers an area of 440 deg^2. The catalog has been created using a combination of semi-analytical and empirical modeling. The simulated images for DC2 are generated with imSim. The DC2 survey includes a wide-fast-deep (WFD) area of $\sim$300 deg^2 as well as a deep drilling field (DDF) of $\sim$1 deg^2. All six optical LSST bands are covered and the current aim is to simulated 5 years of observations. The simulated images are then processed to generate DPDD(-like) object catalogs that are merged static-sky coadd catalogs with forced-position photometry at fixed RA, Dec across the bands. In addition to these four main products, auxilliary data is provided as well, such as truth catalogs and catalogs at different stages of the processing.

For the Science Readiness era, we are planning to augment the DC2 dataset with a range of smaller, targeted simulated datasets and possibly emulated catalogs over a larger area. Readiness for SV places an upper limit on the required scale of the simulated image set. Reprocessing 10% of the LSST Year 1 dataset 10 times (in 2023) corresponds to a scale of 300,000 processed visit images. Re-processing the LSST Science Validation data once (in 2022) would involve about 40,000 visit images, so doing 7 re-processings would get us up to Year 1 scale. Following this logic, a sensible upper limit for the scale of the final test dataset is 100,000 visit images, the geometric mean of the scale of DC2 (30,000) and LSST Year 1.

The CPU time cost of the simulation scales (roughly) with the area of sky simulated, while the storage cost scales (roughly) with the number of visit images processed. We have a few avenues for meeting our science goals within a fixed amount of computing time without having to generate a full end-to-end simulated dataset. First, depending on further algorithm development, we may be able to emulate at least some catalog-level data products at a fidelity that enables tests of our pipelines without image simulations. Second, we could consider remaining at DC2 scale in terms of mock sky area covered (300 deg^2 for 10 years, or 3000 deg^2 for 1 year), and re-processing these images 3-4 times with different settings in DM designed to enable tests of our sensitivity to algorithmic choices. Alternative options with varying levels of computational expense and complexity, meeting different scientific needs, could include reprocessing of precursor datasets on their own or with synthetic galaxies injected (Balrog or SynPipe methodology). It is likely that the Science Readiness dataset that jointly meets the needs of different working groups is actually a combination of several of the above options.

6.4 DESC Dataset Requirements

The detailed design of each challenge dataset must be primarily determined by the analysis groups who will be using it. To this end, we collect the requirements of all the groups in the following deliverables.

NB: in the text below, deliverables are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

CS Key Product (DC1): DC1 Requirements (CS12)
Objective: We describe the DC1 requirements from a range of working groups. Since DC1 is a collection of smaller simulation projects, these requirements have to be fullfilled by a range of different simulations.

Defunct deliverable: *`HaloCat` Requirements (DC1 RQ)*

Host: CS *Started, originally due:* 10/01/15, 12/31/15
Objective: The delivery of a document listing the DC1 tasks that can be accomplished from large, gravity-only simulations and describing the requirements from the analysis WGs for the `HaloCat` dataset

Defunct deliverable: *CL Requirements for `HaloCat` (DC1 RQ)*

Host: CL *Started, originally due:* 10/01/15, 12/31/15
Objective: To provide the Cosmological Simulations group with requirements for `HaloCat`, including considerations relating to halo definitions and centering methods that should enable the best match to observational data possible. We note that the cluster work requires `HaloCat` to provide self-consistent determinations of halo masses, halo centers and shear maps.

Completed deliverable: *PZ Requirements for and development of DC1 simulations (DC1 RQ)*

Host: PZ *Started, originally due:* 10/01/15, 06/30/16 *Completed:* 06/30/16
URL : https://github.com/LSSTDESC/PZDC1paper/tree/pz_metrics
Objective: For DC1, we will need to generate (with PZGalaxyGenerator) a catalog of simulated galaxy colors based on a extragalactic catalog with realistic galaxy SEDs; photo-z algorithms can then be run on this catalog. Work on PZGalaxyGenerator will continue into DC2.

Completed deliverable: *`Twinkles` CS, SS and DM Stack Requirements (DC1 RQ)*

Host: SL *Started, originally due:* 10/01/15, 03/31/17 *Completed:* 03/31/17

Objective: Provide minimum and/or desired science requirements for the simulated or precursor data to be used in DC1 to develop and test the initial SN and SL monitoring codes. Key tasks will involve setting the cosmological simulations (CS) and survey simulations (SS) requirements, as well as our requirements for the DM stack software (i.e. the deblender, image differencer and forced photometer) and DESC computing infrastructure, based on the tests that we need to do. These tests must first be specified, in terms of a set of quantitative performance metrics. Due to the pilot nature of the `Twinkles` project, many of these requirements will emerge as R&D proceeds.
Prerequisites: None

CS Key Product (DC2): DC2 Requirements (CS5)
Objective: Here we list the DC2 requirements, from the simulation as well as analysis point of view. While, for DC1 these are relatively straightforward, requirements on the DC2 and SR simulations will be more challenging. This Key Product will define the DC2 requirements, and inform the process for collecting the SR requirements. The requirements should be collected in a DESC Note that describes the DC2 plan, and which later becomes part of the the planned DC2 survey and catalog papers.

Completed deliverable: *CS Requirements for DC2 (DC2 RQ)*
Host: CS *Started, originally due:* 10/01/16, 09/30/17 *Completed:* 9/30/17
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md
Objective: The different data challenges have a range of requirements for the extragalactic catalogs. For example the depth of, the area covered by, and magnitude of the galaxies in the catalog dictates the simulation volume as well as force and mass resolution required. In addition, different methods for generating mock galaxy catalogs have different requirements on resolution. In all cases, the process will certainly be iterative. A document that maps the second data challenge into detailed simulation requirements with regard to simulation methodology, cosmological physics, fidelity, volume, mass resolution, and properties of the mock catalogs.
Prerequisites: Deliverables *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"$p(z)$ for DC1 Galaxies"*, *"DC2 Specifications"*,

Defunct deliverable: *Methods beyond brute-force cosmological simulations (DC2 RQ)*
Host: CS *Started, originally due:* 10/01/16, 12/31/17
Objective: For different DCs, different methods of enhancing resolution in the simulations can

be employed, e.g. for clusters it could be re-simulation techniques, or merger trees that serve as input for semi-analytic models could be enhanced in resolution by approximate methods.
Prerequisites: Already available simulations at different resolutions.

Completed deliverable: *DC2 Time Domain Requirements (DC2 RQ)*

Host: SL *Started, originally due:* 10/01/16, 09/30/17 *Completed:* 09/30/17
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md
Objective: Provide minimum and/or desired requirements for the time domain part of the DC2 survey, in order to drive development of SLFinder target selection, SupernovaMonitor and SLMonitor light curve extraction, and catalog level SL and SN emulation. In the process, best-estimate lens-finding requirements for the LSST DRP data and LSST DM software, could be made, for completeness. We will have a good idea of what the time domain parts of DC2 will need to look like based on the Twinkles experience.
Prerequisites: None

Completed deliverable: *PZ Requirements for Incompleteness (DC2 RQ)*

Host: PZ *Started, originally due:* 10/01/16, 12/31/17 *Completed:* 12/31/17
URL : https://github.com/LSSTDESC/DC2-production/pull/152
Objective: Using results of PZ2, determine what further ingredients are needed in DC2 photo-z-specific simulations for realistic tests of the impact of SED bias and incompleteness on photo-z analyses. We need Stellar Mass, SFR, SFH, and metallicity in order to construct incompleteness models, we will examine what level of detail is needed for DC2 incompleteness models.
Prerequisites: Deliverable *"$p(z)$ for DC1 Galaxies"*

Completed deliverable: *PZ Requirements for Cross-correlation Method (DC2 RQ)*

Host: PZ *Started, originally due:* 10/01/16, 12/31/17 *Completed:* 12/31/17
URL : https://github.com/LSSTDESC/DC2-production/pull/152
Objective: Set requirements for simulations of cross-correlation method and assess whether they may be included in the standard DC2 simulation.

Completed deliverable: *DC2 Specifications (DC2 RQ)*

Host: SSim *Started, originally due:* 10/01/16, 04/30/18 *Completed:* 4/30/18
URL : https://github.com/LSSTDESC/DC2_Repo/blob/master/Documents/README.md
Objective: Refine the area, depth, input catalog, selection of systematic effects, and properties of simulated systematics for the DC2 data set for the Key Product "DC2 Production" (SSim4). Refinements should be made based on the results of DC1 Deliverables in TJPForecast, im-

SIM, and WLNULLTEST.
Prerequisites: Deliverables *"Null test pipeline (WLNULLTEST)"*, *"Validation of the BF effect in simulations"*, *"Validation of static effects in PHOSIM"*; overlap with Deliverables *"Identify and characterize PSF systematic uncertainties"*, *"Identify and characterize non-PSF systematic uncertainties"*, *"Survey Simulation Tools for DC2"*

Completed deliverable: *WL Requirements on the depth of the DC2 and SR extragalactic catalogs (DC2 RQ)*

Host: WL *Started, originally due:* 10/01/16, 12/31/16 *Completed:* 12/31/16
URL : https://github.com/LSSTDESC/DC2-production/issues/336
Objective: Hoekstra et al. (2015) found that they needed to include galaxies down to 1.5 magnitudes fainter than their detection limit in order not to bias their shear calibration. This result may be dependent on the shear algorithm used. They used a moments-based method, and it is unclear how this translates to other shear estimation algorithms. We need to know how faint the input catalogs need to go for DC2 and SR simulations.

CS Key Product (SR): SR Requirements (CS13)
Objective: As for DC2, we list the SR requirements from the simulation as well as analysis point of view. The requirements should be addressed in the DESC Note that describes the SR plan and can later become part of the the planned DC2 survey and catalog papers.

Completed deliverable: *Requirements on SR simulated datasets (SR RQ)*

Host: SSim *Started, originally due:* 10/01/18, 09/30/19 *Completed:* 09/30/19
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DC3+Specification+Note
Objective: Set the SR requirements on the input galaxy catalog (correlated morphologies, sizes, colors, limiting magnitudes), PSF contributions from the atmosphere, optics, and sensor effects (including chromaticity), clustering of input sources, and cosmological models to enable SR Deliverable targets.

Completed deliverable: *CL Requirements for Science Readiness Simulations (SR RQ)*

Host: CL *Started, originally due:* 10/01/18, 09/30/19 *Completed:* 09/30/19
URL : https://confluence.slac.stanford.edu/display/LSSTDESC/DC3+Specification+Note
Objective: On the basis of the results from the DC1 and DC2 Key Projects, determine the optimum cosmological simulation strategy for SR. Utilize CLFORECAST to assess whether more precise mass functions are required in order to exploit LSST commissioning/SV data. If

so, request as a SR Deliverable from CS.

Defunct deliverable: *SL Requirements for SR (SR RQ)*

Host: SL *Started, originally due:* 10/01/18, 09/30/19
Objective: Provide minimum and/or desired requirements for simulated datasets during the Science Readiness era such that all the SL analysis codes can be tested for science readiness. The most important one here will probably be the high density of lenses (and lens-like non-lenses) required.
Prerequisites: None

Defunct deliverable: *WL Observing strategy for SR image simulations (SR RQ)*

Host: WL *Started, originally due:* 10/01/18, 09/30/19
Objective: We will develop an observing strategy that can be used on ComCam to validate our findings for optimal survey strategies. Here it will be tested on the Science Readiness image simulations.

6.5 DESC Dataset Production

Dataset production can be usefully seen as a three-step process:

1. **Extragalactic catalog production**, in which a noise-free mock galaxy catalog is produced from an N-body cosmological simulation halo catalog "painted" with observable galaxies via some prescription.

2. **Image simulation**, in which simulated LSST images are produced from "instance catalogs" derived from the extragalactic catalog combined with a visit list, typically provided from an LSST schedule simulation tool such as OpSim.

3. **Image processing**, in which the simulated LSST images are passed through the Rubin Observatory LSST DM pipelines, resulting in tables of Object, Source, DIASource etc. measurements.

Steps 2 and 3 can be circumvented by *emulating* the LSST DM catalogs from an extragalactic catalog and a visit list, directly.

In this Section we outline the Key Products in each data challenge era that will result from each of these dataset production steps. We organize these products chronologically, first by challenge era, and then within each era.

NB: in the text below, deliverables are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

CS Key Product (DC1): `HaloCat` Dataset Production (CS14)
Objective: The `HaloCat` dataset will be based on dark-matter-only simulations. According to current requirements from CL and LSS, ~2-4 Gpc cube volumes should be sufficient. For the CL working group, we will use cluster catalogs from the Outer Rim simulation, a $(4.225\mathrm{Gpc})^3$ volume, to deliver cluster shear maps. For LSS we will continue using one of the Mira-Titan Universe simulations ($2.1\mathrm{Gpc}^3$ volume, described in Heitmann et al. 2015). This simulation has been populated with galaxies using an HOD. We will additionally use the Buzzard galaxy catalog based on a lightcone derived from 1–4 Gpc^3 simulations, populated with a different galaxy prescription including LSST colors. This data set can be used for CL and LSS DC1 tasks. Galaxy and halo catalogs for both simulations are available to the collaboration at NERSC.

Defunct deliverable: `HaloCat` *Test catalogs for LSS measurement codes (DC1 DP)*
Host: CS *Started, originally due:* 01/01/16, 03/31/17
Objective: Deliver large volume test catalogs based on, e.g. Halo Occupancy Distribution (HOD) modeling, that can be used by the LSS working group to test out algorithms and code for power spectrum and cross-power spectrum measurements. This will enable work described in the Deliverable *"Two-point preliminary studies"*.

SL Key Product (DC1): `Twinkles` (SL7)
Objective: The `Twinkles` simulation is a small (on the scale of a single CCD) image simulation of strong lenses and supernovae. The functionality to generate the simulated catalogs and images is already in place using the CatSim and PhoSim simulation tools. The depth of the input catalog need only be such that the visit images yield the expected detected Sources; no analysis is planned on the faintest Objects found in the coadds. The images will be processed by the LSST DM pipelines, requiring the existence of deblending and single epoch photometry algorithms. The volume and computational resources required are minimal ($<$1 TB of data and 1000 CPU hrs) but the production of these data will require the development of a prototype end-to-end simulation and image processing framework. The development of this framework

is addressed in the Deliverable *"A framework for Twinkles light curve generation"* and the validation of the input data in the Key Product "DC1 Survey Simulation Tools" (SSim1).

Completed deliverable: `Twinkles` *Images and DM Catalogs (DC1 DP)*

Host: SSim *Started, originally due:* 01/01/16, 04/01/17 *Completed:* 04/01/17

URL : https://github.com/LSSTDESC/Twinkles/tree/Run3-phoSim-v2

Prerequisites: None

Objective: A 100 arcmin^2 dataset composed of 10 years of simulated catalogs, the resulting $ugrizy$ PHOSIM images (simulated using a Deep Drilling Field cadence) and the catalogs of emulated DM DRP object measurements. The dataset will be generated via a prototype end-to-end framework for the simulation and processing of LSST-like images, the Deliverable *"A framework for Twinkles light curve generation"*.

SSim Key Product (DC1): `DC1 Phosim Deep` (SSim2)

Objective: The `DC1 Phosim Deep` simulation is a general imaging dataset defined to address image processing and analysis of temporal or coadded data. Functionality to generate the simulated catalogs and images is in place and the catalogs used as input to the images will be those derived from the current CATSIM datasets. The volume of data and computational resources required to generate this dataset is $<$50 TB of data and 4M CPU hrs.

Completed deliverable: `DC1 Phosim Deep` *Images (DC1 DP)*

Host: SSim *Started, originally due:* 01/01/16, 03/31/17 *Completed:* 03/31/17

URL : https://github.com/LSSTDESC/SSim_DC1

Objective: Several 80 deg^2 datasets composed of 10 years of observations in the r passband (simulated using a main survey (WFD) cadence).

Prerequisites: Deliverable *"Survey Simulation Tools for DC1"*

Approach: Design DC1 simulations cover hundreds of visits in a single filter (r) over multiple overlapping LSST fields-of-view (FOVs). At least 4 FOVs are needed in order to trace the angular separations of "triple points" at the intersections of the hexagonal lattice used to tile the sky. Several versions of this simulation will be run with (and without) translational and rotational dithers performed at each visit. Simulation inputs must include realistic, coupled LSS and weak lensing shear. It is understood that DM will not yet correct for BFF and static sensor effects, so most of our simulations will not include these effects. We will however run undithered and fully dithered versions that include these effects. The production run to generate `DC1 Phosim Deep` input catalogs and simulated images will be carried out at NERSC and the resulting data will be hosted at NERSC.

Completed deliverable: *$p(z)$ for DC1 Galaxies (DC1 DP)*

Host: PZ *Started, originally due:* 01/01/16, 10/31/17 *Completed:* 10/31/17
URL : https://github.com/aimalz/qp/tree/issue/54/paper/docs/desc-0000-qp-photo-z_approximation

Objective: We will generate a catalog of redshift probability distributions based on the DC1 extragalactic catalog for working groups to use as input for cosmological error propagation. An important component of this work will be determining the storage format for the redshift estimates, and assuring that the format is compatible with the needs of other working groups. As a comparative review of probability distribution accuracy for current production codes is valuable to the community this will be written up as a journal article.
Prerequisites: Deliverable *"PZ Requirements for and development of DC1 simulations"*

CS Key Product (DC2): Extragalactic Catalogs for DC2 (CS7)
Objective: The DC2 and SR data sets will require the development of new extragalactic catalogs that express the shear, color-morphology correlations, morphology-density correlations, and complex morphologies. Part of this process will be deciding on the most appropriate prescription for predicting the galaxy properties for the various mock catalogs.

Completed deliverable: *Parameterization of the Extragalactic Catalogs for DC2 and SR (DC2 SW)*

Host: CS *Started, originally due:* 10/01/16, 04/30/18 *Completed:* 04/30/18
URL : https://github.com/LSSTDESC/cosmodc2
Objective: Develop the tools and the validation of the various prescriptions for generating extragalactic catalogs including appropriate colors, sizes, morphologies and correlations with density (based on the requirements defined in DC1).
Prerequisites: Deliverable *"DC2 Specifications"*

Completed deliverable: *Validation of the DC2 Extragalactic Catalogs (DC2 VA)*

Host: CS *Started, originally due:* 10/01/16, 06/30/18 *Completed:* 06/30/18
URL : https://github.com/LSSTDESC/descqa
Objective: Extragalactic catalog generation is accompanied by ongoing validation testing that uses the DESCQA validation framework to compare observational and simulated data. Additional tests, developed in collaboration with the analysis working groups are incorporated as

the catalog needs become better understood.

Active deliverable: *`HaloCat` Cluster shear maps (DC2 DP)*

Host: CS *Started, originally due:* 10/01/17, 06/30/18 *Expected:* 12/31/20
Objective: A set of cluster shear maps extracted from a large N-body simulation that also serves for predictions of the halo mass function.

Completed deliverable: *Extragalactic Catalogs for the `DC2` Simulation (DC2 DP)*

Host: CS *Started, originally due:* 10/01/17, 06/30/18 *Completed:* 06/30/19
URL : https://arxiv.org/abs/1907.06530
Objective: Based on the requirements for `DC2` and the most effective prescription for generating extragalactic catalogs, generate the cosmological simulations and mock catalogs required for `DC2`. Shears will be derived by ray-tracing through the dark matter halo distribution.
Prerequisites: Deliverable *"Compilation of precursor survey data to test the shear pipeline"*

CS Key Product (SR): Extragalactic Catalogs beyond DC2 (CS7)
Objective: Several projects will require the availability of large-area (5000 sq. deg.) extragalactic catalogs containing all of the complexity of the smaller DC2 extragalactic catalog, cosmoDC2, as well as improvements to the galaxy-halo model. A limited set of snapshot catalogs will also be generated.

Active deliverable: *Generation of the Extragalactic Catalogs (SR SW)*

Host: CS *Started, originally due:* 10/01/19, 03/31/20 *Expected:* 09/30/20
URL : https://github.com/LSSTDESC/cosmodc2
Objective: Develop the tools and the validation tests for generating a 5000 sq. deg. extragalactic catalog and snapshot catalogs based on the work for DC2.

Planned deliverable: *Generation of the Special Purpose Extragalactic Catalogs (SR SW)*

Host: CS *Started, originally due:* 01/01/21, 06/30/22 *Expected:* 06/30/22
URL : https://github.com/LSSTDESC/cosmodc2
Objective: Develop the tools and the validation tests for generating special-purpose extragalactic catalog and snapshot catalogs based on the work for DC2.

Anticipated deliverable: *Generation of the Next-Generation Extragalactic Catalogs (SR SW)*

Host: CS *Started, originally due:* 10/01/20, 03/31/23 *Anticipated:* 03/31/23
Objective: Develop tools and validation tests for generating extragalactic catalogs and snapshot catalogs based on new, very high-resolution simulations.

Anticipated deliverable: *Generation of the Extragalactic Catalogs based on Hydrodynamic Simulations (SR SW)*

Host: CS *Started, originally due:* 10/01/22, 03/31/24 *Anticipated:* 03/31/24
Objective: Develop tools and validation tests for generating extragalactic catalogs and snapshot catalogs based on new hydrodynamics simulations.

SSim Key Product (DC2): `DC2` Production (SSim4)
Objective: The `DC2` dataset is the first cross-working group simulated dataset that includes several working groups in the input data and simulated images. The `DC2` images will be processed by the LSST DM pipelines, requiring the existence of deblending, multi-epoch photometry, and PSF estimation algorithms. Production of these data will use the DESC developed end-to-end simulation and image processing framework.

For time domain cosmography, a fraction of the `DC2` survey area will contain supernovae and strong lens systems: the `DC2` dataset will extend `Twinkles` to greater levels of realism, both in the physics inputs but also the image processing and object detection and measurement. The astrophysical inputs will utilize temporally evolving supernova spectral energy distributions (see the Deliverable *"Survey Simulation Tools for DC2"*), and also a wider range of time-variable "backgrounds" (to enable experiments in transient and variable classification). Lensed supernovae will also be included, as will microlensing effects in all lenses. The DM MULTIFIT algorithm may become available during the DC2 era; the `DC2` images should enable user-generated "scene modeling" to be investigated.

This image dataset supports several static sky DC2 projects. It also supports the following time domain Deliverables: "SLFINDER *Target Selection Code*", "SLFINDER *Lens Candidate Extractor*".

Completed deliverable: *`DC2` Simulated Images (DC2 DP)*

Host: SSim *Started, originally due:* 10/01/17, 06/30/18 *Completed:* 07/01/20
URL : https://github.com/LSSTDESC/DC2-production
Objective: Define the detailed specifications for a 300 deg^2 simulated imaging survey in the $ugrizy$ passbands. Cadence will be WFD with possible extensions, plus a small "deep drilling field" region designed to support time domain studies.

Approach: We will generate instance catalogs based on the extragalactic catalog produced in Deliverable *"Extragalactic Catalogs for the DC2 Simulation"*. We will then produce and serve simulated images.
Prerequisites: Deliverables *"Survey Simulation Tools for DC2"* and *"Extragalactic Catalogs for the DC2 Simulation"*, and all the analysis working group DC2 requirements (DC2 RQ) Deliverables: *"DC2 Specifications"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*, *"DC2 Time Domain Requirements"*

Active deliverable: *DC2 DM DRP Catalogs (DC2 DP)*
Host: CO *Started, originally due:* 10/01/17, 06/30/18 *Expected:* 01/01/21
Objective: Run the DESC's DM data release production (DRP) pipeline on the DC2 simulated images to make DM DRP catalogs (including Object, Source, DIASource etc. tables), and serve them to the collaboration.
Approach: We will run the pipeline built as Deliverable *"A DESC-modified DM DRP Reprocessing Pipeline"*, first at CC-IN2P3 and then later at NERSC.
Prerequisites: Deliverables *"DC2 Simulated Images"*, *"A DESC-modified DM DRP Reprocessing Pipeline"*, *"Workflow and Dataset Tracking Tools for DC2"*, and *"Replica of the DM Catalog Technology"*.

SSim Key Product (SR): Science Readiness Era Data Set Production (SSim7)
Objective: During the Science Readiness Era we will generate a range of datasets that will enable targeted science projects for which the DC2 dataset or other precursor datasets are not sufficient. These datasets might be more detailed, small-area simulations, or they might cover a larger area than the DC2 dataset. Some of the data will be produced by the end-to-end simulation and image processing framework and some will be possibly emulated catalog data (provided that ongoing research can deliver algorithms that perform as needed for emulated catalogs for various DESC science cases). Simulated image data will be processed by the LSST DM pipelines, requiring the existence of deblending, photometry, shear, and PSF estimation algorithms.

Planned deliverable: *Simulated Images (SR DP)*
Host: SSim *Started, originally due:* 01/01/22, 12/30/20 *Expected:* 10/01/23
Objective: Generate simulated images as needed by the working groups.

Planned deliverable: *DM DRP Catalogs (SR DP)*

Host: CO *Started, originally due:* 10/01/19, 06/30/20 *Expected:* 12/30/20
Objective: Run the DESC's DM data release production (DRP) pipeline on the simulated images to make DM DRP catalogs (including Object, Source, DIASource etc. tables), and serve them to the collaboration.
Approach: We will run the upgraded SR-era DM DRP pipeline.

WL Key Product (DC2): WL Precursor Dataset Production (WL10)
Objective: Obtain or re-process precursor data for use by various Working Groups.

Active deliverable: *Compilation of precursor survey data to test the shear pipeline (DC2 DP)*

Host: WL *Started, originally due:* 10/01/16, 06/30/17 *Expected:* 02/28/21
Objective: The simulated data to be produced for DC2 has the advantage that the true shear field can be known. However, real data is useful in that it includes all the actual systematic effects from the telescope, sensors, atmosphere, etc. In particular, while the true signal is not known, shear estimates from the real data should pass all relevant null tests. We will need to determine which real data sets are appropriate to use as test beds for our code, and possibly repackage the data into the format needed. Where possible, we will take advantage of processing done by DM as part of their own validation exercises, rather than re-processing within the DESC. For example, we expect to run the DM and DESC shear measurement code on images from the Subaru Hyper-SuprimeCam (*HSC*) survey public release 1.
Prerequisites: Deliverable *"Null test pipeline (WLNullTest)"*,*"Pipeline for Producing a Shear Catalog (shearMeasurementPipe)"*.

CO Key Product (SV): The DESC-reprocessed ComCam Dataset (DESC-ComCam)

Objective: We anticipate re-processing the ComCam dataset several times, to test our ability to cope with real images, and reproduce the Rubin Observatory release data.

Anticipated deliverable: *DESC-Reprocessed ComCam DRP Catalogs (ComCam DP)*

Host: CO *Started, originally due:* 10/01/21, 09/30/22 *Anticipated:* 09/30/22
Objective: Re-process the ComCam images using the DESC DRP pipeline, and verify that it reproduces the key cosmological summary statistics derived from the Rubin Observatory data

release.

Anticipated deliverable: *DESC-Processed Alternative ComCam DRP Catalogs (ComCam DP)*

Host: CO *Started, originally due:* 10/01/21, 09/30/22 *Anticipated:* 09/30/22
Objective: We will produce alternative DRP catalogs for the ComCam dataset, probing the systematic effects due to various configurations and algorithm choices.

CO Key Product (SV): The DESC-reprocessed SV Dataset (DESC-SV)
Objective: The DESC's MO in survey operations is to re-process $\sim 10\%$ of the available LSST imaging ~ 10 times. As described in Section 6.3 above, we anticipate re-processing the SV dataset several times, as part of a scaling up process to reach readiness for the Year 1 survey dataset.

Anticipated deliverable: *DESC-Reprocessed SV DRP Catalogs (SV DP)*

Host: CO *Started, originally due:* 04/01/22, 12/30/22 *Anticipated:* 09/30/22
Objective: Re-process the SV images using the DESC DRP pipeline, and verify that it reproduces the key cosmological summary statistics derived from the Rubin Observatory data release.

Anticipated deliverable: *DESC-Processed Alternative SV DRP Catalogs (SV DP)*

Host: CO *Started, originally due:* 04/01/22, 09/30/22 *Anticipated:* 09/30/22
Objective: We will produce alternative DRP catalogs for subsets of the SV dataset, probing the systematic effects due to various configurations and algorithm choices.

6.6 DESC Follow-up Datasets

In many cases DESC analyses will incorporate data from telescopes other than LSST. In this subsection we describe activities needed to ensure that collaboration members have access to the data products needed to pursue their work. The work defined in this subsection is primarily coordinated by the External Synergies Working Group (ES).

ES Key Product (DC2): Coordinate production of white papers and proposals for non-

LSST datasets (ES1)

Active deliverable: *Response to Calls for White Papers (DC2/SR/ComCam/SV DP)*

Host: ES *Started, originally due:* 10/1/18, 02/22/19 *Expected:* 1/1/23
Objective: Datasets needed to make optimal use of LSST data may not be feasible to obtain without new capabilities being implemented or new observational programs being carried out. The External Synergies Working Group will help to coordinate cross-collaboration white papers and proposals as necessary to help ensure these data may be obtained. As an example the DESC provided input to the Astro2020 Decadal Survey through the call for science white papers due in January 2019. It would be valuable to submit white papers which lay out the science case for any large-scale datasets we are likely to need that would not be feasible with currently available resources. Cross-working-group white papers would fall under the umbrella of ES. In many cases this may require quantification of the science gains from additional data, which may lead to separate publications. This activity (led by the ES) covers all primary probe working groups, as well as the photometric redshifts group.

ES Key Product (DC2): Develop and maintain inventories of external data set needs (ES2)

Objective: For DESC to understand its met and unmet needs for external data to complement LSST, it is necessary to assess those needs across the collaboration as well as the potential telescope resources and datasets that could be used to fulfill them. This effort will also assist collaboration management in assessing the utility for DESC science of potential in-kind contributions of telescope time. These should be living documents which may be continually updated.

Active deliverable: *First Inventories of Data Needs and Resources (DC2 DP)*

Host: ES *Started, originally due:* 8/1/19, 1/1/20 *Expected:* 1/1/20
Objective: The first inventories of external data needs, telescope resources, and external datasets have begun being collected in anticipation of the need for LSST international partners to provide proposals for in-kind contributions, which should be due in spring of 2020.

ES Key Product (SR): Develop Inter-Collaboration Agreements (ICAs) with External

Projects (ES3)

Active deliverable: *Facilitate Inter-Collaboration Agreements (SR DP)*

Host: ES *Started, originally due:* 1/1/19, 01/1/23 *Expected:* 01/1/23
Objective: In many cases, data which will be vital for pursuing DESC science will be proprietary to other collaborations. In such situations, it will be necessary to negotiate mutually beneficial arrangements that allow the best science to be pursued. The External Synergies Working Group will act as a clearinghouse which helps to connect the DESC working groups with external collaborations and, by putting into place concrete examples, will assist in developing the format and requirements for inter-collaboration agreements between DESC and other collaborations that ensure necessary data access, and facilitate the development of at least one signed ICA. The 4MOST/TiDES project is one example of a possible partner in such an ICA. This activity involves all primary probe working groups, as well as the photometric redshifts group.

ES Key Product (SR): Help Develop Policies for Internal Data-Sharing (ES4)
Objective: There will be many cases in which subsets of a DESC working group have proprietary access to data which may not be broadly shared. In such cases, we will need to have policies and procedures in place which allow the working groups to pursue cosmological measurements efficiently without breaking the restrictions placed upon non-LSST datasets. The External Synergies Working Group will work with working group leadership and DESC management to develop broadly applicable policies that serve this need. Such policies will be central to the inter-collaboration agreements (ICAs) that the DESC will enter into with external collaborations. As per the DESC External Collaborator Policy, such agreements should be negotiated by the Spokesperson, and ratified by the Collaboration Council. The role of the ES WG will be to facilitate the collaboration's discussion of relevant data-sharing needs, and synthesize those discussions for inclusion in an ICA. This activity involves all primary probe working groups, as well as the photometric redshifts group.

Active deliverable: *Draft data-sharing policy (SR DP)*

Host: ES *Started, originally due:* 1/1/19, 09/01/20 *Expected:* 09/01/20
Objective: The ES WG will help to develop a draft data-sharing policy for an initial example

case, to be included as a key part of an inter-collaboration agreement with an external group.

ES Key Product (SV): Help Develop Cross-Working Group Observing Proposals (ES5)

Objective: For many of DESC's data needs, submitting large-scale, long-term proposals for telescope time will be desirable to make sure the collaboration accomplishes its goals. The External Synergies Working Group can help to serve as a clearinghouse for the development of those proposals which span more than one working group.

Anticipated deliverable: *Large and Long-Term Proposals (SV DP)*

Host: ES *Started, originally due:* 1/1/22, 1/1/23 *Anticipated:* 1/1/23

Objective: Large/long-term proposals for data complementary to LSST Year 1 observations will generally need to be submitted before survey operations begin. Work may be necessary beforehand to develop the detailed science cases for these proposals.

7 Pipeline, Infrastructure and Dataset Deliverables

The deliverables of the previous two sections constitute all the mission-critical pipeline and infrastructure software, and accompanying test data, that we need to develop, operate and maintain in order to be ready to analyze commissioning data. This short section simply lists all of these Key Products, and their Deliverables, so as to provide an overview of these operations tasks. NB: in the text below, deliverables are presented with color coding determined by their status, as follows: "done" deliverables have hyperlinks like this, "defunct" deliverables have hyperlinks like this, "active" deliverables have hyperlinks like this, "planned" deliverables have hyperlinks like this, and "anticipated" deliverables have hyperlinks like this.

Pipelines and Computing Infrastructure

BL Key Product (SR): Blending Tool Kit (BlendingToolKit)

Active deliverable: *Production of Training and Testing Images* 12/31/22

Active deliverable: *Processing of Training and Testing Images* 12/31/22

Active deliverable: *Evaluation of Blending Metrics* 12/31/22

Anticipated deliverable: *SV-era blending software infrastructure* 10/01/23

BL Key Product (SR): Fake Source Injection (BL-FSI)

Active deliverable: *Interface for generation and access to fake injected images* 12/31/22

Active deliverable: *Diagnostic tools for evaluating the performance of fake source injection* 12/31/22

Active deliverable: *Diagnostic tools using fake source injection for measurement algorithms* 12/31/22

OS Key Product (DC2): Observing Strategy Pipeline Components (OSMetrics)

Active deliverable: *Observing strategy recommendations for supernova cosmology* 11/01/18

Active deliverable: *Observing strategy recommendations for strong lensing cosmology* 11/01/18

Active deliverable: *Observing strategy recommendations for weak lensing systematics* 11/01/18

Active deliverable: *Observing strategy recommendations for large-scale structure* 11/01/18

Active deliverable: *Observing strategy recommendations for photometric redshifts to enable dark energy probes* 11/01/18

OS Key Product (DC2): Response to the LSST Call for White Papers on Observing Strategy (OS)

OS Key Product (DC2): Observing Strategy Recommendations (OS12)

Active deliverable: *Observing strategy recommendations for all static science cases* 11/01/18

Active deliverable: *Synthesized strategy recommendations for all transient science cases* 11/01/18

Active deliverable: *Synthesized WFD observing strategy recommendations across all probes* 11/01/18

Active deliverable: *Synthesized DDF observing strategy recommendations across all probes* 11/01/18

Active deliverable: *Metrics summary for observing strategy across all probes* 01/01/20

OS Key Product (SR): Observing Strategy Recommendations after SCOC Communication (OS-SCOC)

Active deliverable: *Recommendations for Observing Strategy* 01/01/21

Anticipated deliverable: *Observing strategy tests with LSST SV* 10/01/23

PC Key Product (DC1 & DC2 & SR): Photometric Correction Pipeline Components (PC7)

Defunct deliverable: *Analytical Models for PC Biases* 12/31/17

Active deliverable: *PC Bias on Individual Probes* 12/31/17

Active deliverable: *PC Observing Strategy Metrics* 12/31/17

Active deliverable: *Validation of DM point source photometry* 12/31/20

PC Key Product (SV): Closing the photometric calibration loop with AuxTel (PC-AUXTEL)

Anticipated deliverable: *Integrated AuxTel pipeline* 09/30/22

Anticipated deliverable: *AuxTel observation strategy* 09/30/22

PC Key Product (SV): Integrated PC Pipeline, Adapted to SV Data (PC-SV)

Anticipated deliverable: *Integrated PC Pipeline* 10/01/23

Anticipated deliverable: *Recalibration of CALSPEC Primary standards* 10/01/23

Anticipated deliverable: *CBP characterization of stage-3 survey telescopes* 10/01/23

SA Key Product (DC1 & DC2 & SR): Sensor Anomalies Pipeline Components (SA5)

Active deliverable: *Implemented and Validated Correction Algorithm for the BF Effect* 06/30/18

Active deliverable: *Validation of correction algorithms for static effects* 06/30/18

Active deliverable: *Studies of sensor systematics with Auxiliary Telescope and ComCam* 12/31/20

SA Key Product (SV): Integrated SA Pipeline, adapted to SV Data (SA-SV)

Anticipated deliverable: *Integrated SA Pipeline* 10/01/23

SSim Key Product (operations): Well-integrated End-to-End Simulation Capability (CO4)

Completed deliverable: *Efficient end-to-end small scale image pipeline* 12/31/21

Planned deliverable: *Interface designs and improvement between workflow components* 12/31/21

CO Key Product (DC2): The Initial Elements of a Software Framework (CO2)

Completed deliverable: *Software Framework Implementation* 06/30/18

Completed deliverable: *Distributed Code Development Environment* 02/28/18

Completed deliverable: *Workflow & Data Management Tools* 02/28/18

CO Key Product (DC1 & DC2): Targeted Frameworks for Use by the Analysis Working Groups (CO3)

Completed deliverable: *A framework for Twinkles light curve generation* 06/30/16

Defunct deliverable: *A Framework for TJP* 06/30/16

CO Key Product (DC1 & DC2): Distributed Code Development Environment (CI4)

Completed deliverable: *An initial development environment* 01/31/16

Completed deliverable: *Software coding standards and code review policies* 02/28/18

CO Key Product (SR): NERSC Support (CI-NERSC)

Active deliverable: *Maintain Software Environment at NERSC* 10/01/23

Active deliverable: *Manage storage at NERSC* 10/01/23

CO Key Product (DC2): Common Pipeline Infrastructure (CO12)

Completed deliverable: *Pipeline Software Interfaces and Abstractions* 06/30/18

CO Key Product (SR): Common Pipeline Infrastructure for SR and SV (SV-CPI)

Anticipated deliverable: *SV-Ready Pipeline Software Interfaces and Abstractions* 03/01/22

CO Key Product (DC1): `DC1 Phosim Deep` Workflow and Data Management Configuration (CO8)

Completed deliverable: *Tracking Tools for DC1* PhoSim *Datasets* 01/31/16

CO Key Product (DC2): DC2 Workflow and Data Management Configuration (CO10)

Defunct deliverable: *Workflow and Dataset Tracking Tools for DC2* 06/30/18

CO Key Product (SR): SR Workflow and Data Management Configuration (CO14)

Planned deliverable: *Workflow and Dataset Tracking Tools* 06/30/20

CO Key Product (SV): SV-Era Workflow and Data Management Configuration (CO17)

Anticipated deliverable: *Workflow and Dataset Tracking Tools for SV* 10/01/21

CO Key Product (SR): Upgraded DM DRP Processing Pipeline and Data Service (CO15)

Active deliverable: *Development of Gen-3 Butler based DM Processing Pipeline* 06/30/20

Active deliverable: *Upgraded Replica of the DM Catalog Technology* 06/30/20

Active deliverable: *Demonstrate capability to process a subset of LSST data at NERSC* 06/30/20

Active deliverable: *Collect resource requirements for Y1 data access and analysis* 06/30/20

CS Key Product (DC2): DESCQA2 Validation Framework (CS10)

Completed deliverable: *DESCQA validation framework with full functionality* 06/30/18

CS Key Product (DC2): Generic Catalog Reader (GCR) (CS11)

Completed deliverable: *GCR interface available for all Sky Catalogs* 01/31/18

CS Key Product (DC2): Generic Catalog Reader (GCR) for Data-Release-Product (DRP) Catalogs (CS14)

Completed deliverable: *GCR interface available for cross-matched DRP catalogs* 06/30/20

CS Key Product (DC2): DESCQA for DC2 Validation (CS16)

Completed deliverable: *DESCQA validation with ability to run on DRP catalogs* 06/30/20

CS Key Product (SR): Interface for Image Simulations (CS17)

Active deliverable: *Interface for Image Simulations* 06/30/20

CS Key Product (SR): Production of the 5000 sq. deg. Catalog (CS18)

Active deliverable: *Large-Area Catalog Production* 06/30/20

CS Key Product (SR): Production of Snapshot Catalogs (CS19)

Completed deliverable: *Snapshot Catalog Production* 06/30/20

CS Key Product (SR): Advanced Tooling for Working with Cosmological Simulation Outputs (CS15)

Anticipated deliverable: *Advanced Tooling* 10/01/23

SSim Key Product (SR): IMSIM Development (imSim1)

Active deliverable: *Improve* IMSIM *performance* 01/01/21

Active deliverable: *Add major features to* IMSIM 01/01/21

Active deliverable: *Increase the realism of* IMSIM 01/01/21

SSim Key Product (SR): Development of DM Catalog Validation Tools (SSimValid1)

Active deliverable: *Development of Validation Tools* 09/30/19

SSim Key Product (DC1): DC1 Survey Simulation Tools (SSim1)

Completed deliverable: *Survey Simulation Tools for DC1* 01/01/16

Defunct deliverable: *An LSST module in* GALSIM 06/30/16

SSim Key Product (DC2): DC2 Survey Simulation Tools (SSim3)

Active deliverable: *Survey Simulation Tools for DC2* 06/30/18

Defunct deliverable: *Validation of static effects in* PHOSIM 12/31/19

Defunct deliverable: *Validation of the BF effect in simulations* 12/31/19

CO Key Product (DC2): DC2 DM DRP Processing Pipeline and Data Service (CO11)

Completed deliverable: *A DESC-modified DM DRP Reprocessing Pipeline* 06/30/18

Completed deliverable: *Replica of the DM Catalog Technology* 06/30/18

SSim Key Product (SR): SR Era Survey Simulation Tools (SSim5)

Active deliverable: *Survey Simulation Tools for the Science Readiness Era* 09/30/19

CO Key Product (ComCam): SV-Ready DRP Processing Pipeline and Data Service (SV-DRP)

Anticipated deliverable: *SV-Ready DESC DRP Pipeline* 09/30/22

Anticipated deliverable: *SV-Ready Replica of LSST Science Platform* 09/30/22

COM Key Product (ComCam): SV-Ready Commissioning Software (COM-SV)

Anticipated deliverable: *SV-Ready Commissioning Software integrated within LSST Project tools* 10/01/22

WL Key Product (DC1): Weak Lensing Pipeline (WLPIPE)

Completed deliverable: *Pipeline for WL Cosmology Constraints from a Shear Catalog* 06/30/18

Completed deliverable: WLPIPE *Validation* 06/30/18

Completed deliverable: *Workflow management system applied to DC1 WL workflow* WLPIPE 06/30/18

Completed deliverable: *Extension of* WLPIPE *to 3x2-point analysis* 07/01/18

WL Key Product (DC2): Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-DC2)

Completed deliverable: *Pipeline tools that connect to workflow management system (*CECI*)* 03/31/19

Active deliverable: *Pipeline for Producing a Shear Catalog (*SHEARMEASUREMENTPIPE*)* 12/31/19

Active deliverable: *Source selector and tomographic binning definition software (*TXSOURCESELECTOR*)* 12/31/19

Completed deliverable: *Source summarizer analysis stage (*SOURCESUMMARIZER*)* 12/31/19

Active deliverable: *Software for two-point statistics (*TXTWOPOINT*)* 12/31/19

Active deliverable: *Covariances for the joint WL+LSS analysis (*TXCOV*)* 12/31/19

Completed deliverable: *Summary statistic collector (*TXSUMMARYSTATISTIC*)* 12/31/19

Active deliverable: *Validation of* TXPIPE 12/31/19

WL Key Product (DC2): Weak Lensing Mass Maps and Map-Based Statistics (WLMASSMAP-DC2)

Active deliverable: *Pipeline to generate weak lensing mass maps* 03/31/19

WL Key Product (DC2): WL Systematic Uncertainty Characterization Framework (WL2)

Active deliverable: *Null test pipeline (*WLNULLTEST*)* 03/31/19

Active deliverable: *Identify and characterize PSF systematic uncertainties* 12/31/19

Active deliverable: *Identify and characterize non-PSF systematic uncertainties* 12/31/19

WL Key Product (SR): Updated Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-SR)

Planned deliverable: *Improved shear pipeline* 07/01/20

Planned deliverable: *Proper handling of chromatic effects* 07/01/20

Planned deliverable: *Proper handling of neighbors* 07/01/20

Planned deliverable: *Pipeline for magnification (*WLMAGPIPE*)* 09/30/21

Planned deliverable: *Pipeline for validating shear calibration* 07/01/20

WL Key Product (SV): Applied Weak Lensing and Large-Scale Structure Pipeline (TXPIPE-SV)

Anticipated deliverable: *At-scale* TXPIPE *Application* 10/01/23

Anticipated deliverable: TXPIPE *SV Extensions* 10/01/23

LSS Key Product (DC1): DC1 LSS Pipeline (LSS-DC1)

Completed deliverable: *Software for storing correlation function and covariance information (SACC)* 04/01/17

Completed deliverable: *Two-point preliminary studies* 06/30/18

Completed deliverable: *Validation tests of DC1-era LSS pipeline on simulations* 06/30/18

Completed deliverable: *Validation tests of DC1-era LSS pipeline on precursor datasets* 06/30/18

LSS Key Product (DC2): LSS Pipeline Components of TXPIPE (LSS4/TXPIPE)

Completed deliverable: *Power-spectrum estimation code (*TXTWOPOINT*)* 06/30/18

Completed deliverable: *Two-point storage framework* 07/01/18

Active deliverable: *Optimal catalog splits into samples (*TXLENSSELECTOR*)* 12/31/19

Completed deliverable: *Basic LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO 12/31/19

Active deliverable: *Validation tests of DC2-era LSS pipeline on simulations* 12/31/19

Active deliverable: *Validation tests of DC2-era LSS pipeline on precursor datasets* 12/31/19

LSS Key Product (DC1 & DC2): Survey geometry (CX3)

Defunct deliverable: *Temporary survey coverage tools* 06/30/18

Completed deliverable: *Survey mask use cases* 04/30/19

Completed deliverable: *Software for characterizing mask as a function of pixelization* 12/31/19

Active deliverable: *Random points software (*TXRANDOMS*) for* TXPIPE 03/31/19

Completed deliverable: *Maps of systematics:* TXSYSMAPMAKER *for* TXPIPE 12/31/19

LSS Key Product (SR): Improved LSS Pipeline Components (TXPIPE-LSS)

Planned deliverable: *Joint pipeline with CMB data* 06/30/20

Planned deliverable: *Optimal deblending for LSS* 09/30/21

Active deliverable: *Final LSS likelihood module (*LSSCOSMO*) contribution to* TJPCOSMO 06/01/20

Anticipated deliverable: *Improved LSS pipeline based on application to LSST SV* 10/01/23

CL Key Product (DC2 & SR): CL Pipeline Components for use with TXPIPE (CL7)

Completed deliverable: *Cluster Finder (*CLFINDER*)* 12/31/19

Active deliverable: *Cluster Finder (*CLFINDER*) Validation* 12/31/19

Active deliverable: *Cluster Finder Updates (*CLFINDER*)* 09/30/21

Planned deliverable: *Validation of Cluster Finder Updates (*CLFINDER*)* 09/30/21

Planned deliverable: *Shear calibration in the cluster regime* 09/30/21

Planned deliverable: *Photo-z estimates in cluster fields* 09/30/21

CL Key Product (DC1 & DC2): CL Cosmology Likelihood Module CLCOSMO (CL5)

Defunct deliverable: *DC1-era CL Likelihood Code* 06/30/18

Active deliverable: *DC2-era CL Likelihood Code* 12/31/19

Active deliverable: *Validation of DC2-era CL Likelihood Code* 12/31/19

Planned deliverable: *SR-era CL Likelihood code* 09/30/21

CL Key Product (SV): CL Pipeline Integration and Adaptation to the SV Data (CLIA)

Anticipated deliverable: *Integrated CL Pipeline* 10/01/23

SL Key Product (DC1 & DC2 & SR): SL Pipeline Components (SL6)

Completed deliverable: SLMONITOR 06/30/18

Defunct deliverable: SLMODELER 06/30/18

Active deliverable: SLFINDER *Lens Candidate Extractor* 12/31/19

Active deliverable: SLENVCOUNTER 12/31/19

Active deliverable: SLTIMER *(DC2)* 12/31/19

Active deliverable: SLMASSMAPPER 12/31/19

Active deliverable: *Validation of DC2-era pipeline components* 12/31/19

Planned deliverable: SLTimer *(Science Readiness)* 09/30/21

Planned deliverable: SLCosmo 09/30/21

Planned deliverable: *Validation of SR-era pipeline components* 09/30/21

SL Key Product (SV): SL Pipeline Integration and Adaptation to the SV Data (SLIA)

Anticipated deliverable: *Integrated SL Pipeline* 10/01/23

SN Key Product (DC1): DC1-era codes for simulating SN at Cadences from OpSim (SN-OpSim)

Completed deliverable: *SN simulation software integrated with OpSim* 07/01/18

SN Key Product (DC1): DC1-era SN Pipeline Components (SupernovaType)

Completed deliverable: *Classification Code:* SupernovaType 07/01/18

SN Key Product (DC2): DC2-era SN Pipeline Components (SNPipe)

Active deliverable: *SN Simulation Pipeline* 03/31/19

Active deliverable: *SN Light fitting code* 12/31/19

Active deliverable: *SN selection function to produce a SN catalog for classification* 12/31/19

Defunct deliverable: *SN summaries code* 03/31/19

Completed deliverable: *SN metrics code* 03/31/19

Active deliverable: *SN classification summary code* 03/31/19

Active deliverable: *SN Light Curve Quality code* 03/31/19

Active deliverable: *SN FoM code* 03/31/19

Completed deliverable: *Multi-type transient simulations* 03/31/19

Active deliverable: *Photometric classification* 12/31/19

Active deliverable: *SN Light curves from processed DM difference images* 03/31/19

Active deliverable: *SN Analysis Pipeline Validation* 03/31/19

Planned deliverable: *Detection Efficiency of SN* 03/31/19

Active deliverable: *Discrepancy Modelling for SN light Curves* 12/31/19

Active deliverable: *Validating Surface Brightness of Host Galaxy* 12/31/19

SN Key Product (DC2): Enhanced Twinkles Framework to Handle DC2-level Requirements (CI7)

Active deliverable: *Pipeline for Extracting DC2 Light Curves* 06/30/18

Active deliverable: *Workflow to execute the Light Curve Extraction pipeline.* 06/30/18

SN Key Product (SR): SR-era SN Pipeline Components (SNType)

Planned deliverable: *SR-era SN Analysis Pipeline updates* 09/30/21

Planned deliverable: *Verification of the difference imaging pipeline on SR data* 09/30/21

Planned deliverable: *Code for photometric supernova cosmology* 09/30/21

Planned deliverable: *Verification of photometric supernova code in different scenarios* 09/30/21

Active deliverable: *SR-era SN summaries code* 09/30/21

Planned deliverable: *SN summaries code validation on SR simulations* 09/30/21

SN Key Product (SV): SN Pipeline Integration and Adaptation to the SV Data (SNIA)

Anticipated deliverable: *Integrated SV-era SN Pipeline* 10/01/23

SN Key Product (SR): DESC Broker (SN)

Completed deliverable: *SLWG Broker Requirements* 07/01/18

Planned deliverable: *Broker Sandbox* 06/30/20

Active deliverable: *Early SN classification system* 09/30/21

Active deliverable: SLFinder *Target Selection Code* 09/30/21

Planned deliverable: *Verification of the DESC SN broker infrastructure on SR simulations* 09/30/21

TJP Key Product (DC1 & DC2): Core Cosmology Library (TJP5A)

Defunct deliverable: *Cosmology library prototypes* 03/31/16

Defunct deliverable: *Cosmological Emulator Integration* 02/28/18

Completed deliverable: *Basic cosmological observable predictions* 06/30/18

Completed deliverable: *Enhanced cosmological observable predictions* 07/01/18

Completed deliverable: *Fast and accurate correlation function predictions* 03/31/19

Active deliverable: *Cosmological model extensions beyond wCDM* 09/30/21

TJP Key Product (DC2 & SR): Systematics Models for Joint Analyses (CX5)

Active deliverable: *Software module for astrophysical systematics* 03/31/19

Active deliverable: *Workflow for testing accuracy of systematics mitigation* 03/31/19

Planned deliverable: *Consistency of systematics modeling across all probes* 07/01/20

Planned deliverable: *Incorporate spatial variations into joint systematics models* 09/30/21

TJP Key Product (DC2 & SR): TJPCov: Covariance Matrices for Joint Analyses (CX7)

Active deliverable: *Gaussian and other available covariances for* TJPCosmo 03/31/19

Active deliverable: *Improved covariance estimators for single- and joint-probe analyses* 03/31/19

Active deliverable: *Numerical routines for fast covariance estimation* 09/30/21

Active deliverable: *Consistent joint probe covariances* 09/30/21

TJP Key Product (DC2 & SR): TJPCosmo: Likelihood Pipeline for Joint Analyses (TJP5B)

Completed deliverable: *Single-probe likelihood for Weak Lensing* 03/31/19

Completed deliverable: *Single-probe likelihood for Large-Scale Structure* 03/31/19

Active deliverable: *Single-probe likelihood for Galaxy Clusters* 12/31/19

Planned deliverable: *Single-probe likelihood for Supernovae* 12/31/19

Planned deliverable: *Single-probe likelihood for Strong Lensing* 06/30/20

Planned deliverable: *Validation of single-probe likelihoods on* DC2 12/31/19

Completed deliverable: *Preliminary joint probes likelihood pipeline* 12/31/19

Active deliverable: *Forecasting module in likelihood pipeline* 12/31/19

Completed deliverable: CosmoParams*: Common exchange format for cosmological parameter sets* 12/31/19

Planned deliverable: *Modules for data compression and alternative inference methods* 09/30/21

Planned deliverable: *Modules for implementing parameter level blinding* 09/30/21

Planned deliverable: *Cosmological analysis pipeline for LSST precursor data* 09/30/21

TJP Key Product (SR): Integration of TJPCosmo into the CI Framework (TJP5C)

Active deliverable: *Framework Requirements for Joint Analysis Pipelines* 07/01/18

Planned deliverable: TJPCosmo *pipeline integration and validation* 07/01/20

Planned deliverable: *Apply* TJPCosmo *joint likelihood pipeline to SR-era simulations* 09/30/21

TJP Key Product (SV): TJP Pipeline Adaptation to the SV Data (TJP-SV)

Anticipated deliverable: *Extended TJP Pipeline* 10/01/23

PZ Key Product (DC1 & DC2 & SR): Photometric Redshifts Pipeline PZEstimate (PZ5)

Completed deliverable: *Baseline* PZpdfEstimators *for photo-z posterior PDFs* 01/01/18

Completed deliverable: *Baseline* PZCompare *metrics for photo-z posterior PDFs* 06/30/18

Completed deliverable: *Validation of baseline* PZCOMPARE 06/30/18

Completed deliverable: *Baseline* PZSTORE1D *for one-dimensional photo-z posteriors* 07/01/18

Completed deliverable: *Validation of baseline* PZSTORE1D 07/01/18

Completed deliverable: *Validation of* PZPDFESTIMATORS 01/01/19

Active deliverable: *Photo-z posterior PDFs for DC2 data using* PZESTIMATE 03/31/19

Active deliverable: *Validation of photo-z posterior PDFs for DC2 using* PZESTIMATE 12/31/19

Defunct deliverable: *PZCombineResults for one-dimensional photo-z posteriors* 03/31/19

Planned deliverable: PZPDFESTIMATORS *at scale* 03/31/19

Planned deliverable: PZSTORE1D *at scale* 03/31/19

Planned deliverable: PZCOMPARE *at scale* 09/01/20

Planned deliverable: PZPRIORMODEL *for* PZESTIMATE 12/31/21

Planned deliverable: *Needs assessment for two-dimensional* $p(z, \alpha)$ *for* PZESTIMATE 10/01/20

Planned deliverable: *Two-dimensional* $p(z, \alpha)$ *implementation for* PZESTIMATE 09/30/21

Planned deliverable: *Validation of* $p(z, \alpha)$ *for* PZESTIMATE *on SR* 09/30/21

PZ Key Product (DC2 & SR): Photometric Redshifts Pipeline PZSUMMARIZE (PZSUMMARIZE)

Active deliverable: *WGTomoBinOptimize for* PZSUMMARIZE 03/31/19

Active deliverable: *Metrics pipeline for evaluation of* PZSUMMARIZE *methods* 06/30/21

Active deliverable: PZNZSUMMARIZERS *for* PZSUMMARIZE 03/31/19

Planned deliverable: *DC2-era* PZSUMMARIZE *validation* 12/31/19

Defunct deliverable: *PZBiasEvolutionEstimator for* PZSUMMARIZE 03/31/19

Defunct deliverable: *MagnificationCorrection for* PZSUMMARIZE 03/31/19

Active deliverable: *Interface with WL and LSS for* PZSUMMARIZE 03/31/19

Planned deliverable: *SR-era* PZSUMMARIZE *updates* 07/01/20

Planned deliverable: *SR-era* PZSUMMARIZE *validation* 09/30/21

PZ Key Product (DC2): Photometric Redshifts Pipeline PZVALIDATE (PZVALIDATE)

Active deliverable: PZGALAXYGENERATOR *PZMakePhot* 03/31/19

Active deliverable: PZPRIORMODEL *with PZMakePhot* 03/31/19

Planned deliverable: *Validation and testing of* PZVALIDATE *using DC2 simulations* 12/31/19

Planned deliverable: PZGALAXYGENERATOR*: PZMakeSpec* 03/31/19

Defunct deliverable: PZGALAXYGENERATOR*: PZAddEmissionLines* 03/31/19

Planned deliverable: PZPriorModel *with MakeSpec* 03/31/19

Planned deliverable: PZValidate *under image systematics* 09/30/21

Planned deliverable: PZValidate *under physical systematics* 06/30/22

Planned deliverable: *Quantifying spectroscopic imperfection* 07/01/20

PZ Key Product (SV): Integrated PZ Pipeline, Adapted to SV Data (PZ-SV)

Anticipated deliverable: *Integrated PZ Pipeline* 10/01/23

Datasets

COM Key Product (SR): DESC Commissioning Efforts (COM1)

Completed deliverable: *DESC technical note with suggested observing fields* 7/1/19

Planned deliverable: *DESC Commissioning Plan Document* 06/01/20

CS Key Product (DC1): DC1 Requirements (CS12)

Defunct deliverable: `HaloCat` *Requirements* 12/31/15

Defunct deliverable: *CL Requirements for* `HaloCat` 12/31/15

Completed deliverable: *PZ Requirements for and development of DC1 simulations* 06/30/16

Completed deliverable: `Twinkles` *CS, SS and DM Stack Requirements* 03/31/17

CS Key Product (DC2): DC2 Requirements (CS5)

Completed deliverable: *CS Requirements for DC2* 09/30/17

Defunct deliverable: *Methods beyond brute-force cosmological simulations* 12/31/17

Completed deliverable: `DC2` *Time Domain Requirements* 09/30/17

Completed deliverable: *PZ Requirements for Incompleteness* 12/31/17

Completed deliverable: *PZ Requirements for Cross-correlation Method* 12/31/17

Completed deliverable: `DC2` *Specifications* 04/30/18

Completed deliverable: *WL Requirements on the depth of the DC2 and SR extragalactic catalogs* 12/31/16

CS Key Product (SR): SR Requirements (CS13)

Completed deliverable: *Requirements on SR simulated datasets* 09/30/19

Completed deliverable: *CL Requirements for Science Readiness Simulations* 09/30/19

Defunct deliverable: *SL Requirements for SR* 09/30/19

Defunct deliverable: *WL Observing strategy for SR image simulations* 09/30/19

CS Key Product (DC1): `HaloCat` Dataset Production (CS14)

Defunct deliverable: `HaloCat` *Test catalogs for LSS measurement codes* 03/31/17

SL Key Product (DC1): `Twinkles` (SL7)

Completed deliverable: `Twinkles` *Images and DM Catalogs* 04/01/17

SSim Key Product (DC1): `DC1 Phosim Deep` (SSim2)

Completed deliverable: `DC1 Phosim Deep` *Images* 03/31/17

Completed deliverable: $p(z)$ *for DC1 Galaxies* 10/31/17

CS Key Product (DC2): Extragalactic Catalogs for `DC2` (CS7)

Completed deliverable: *Parameterization of the Extragalactic Catalogs for DC2 and SR* 04/30/18

Completed deliverable: *Validation of the* `DC2` *Extragalactic Catalogs* 06/30/18

Active deliverable: `HaloCat` *Cluster shear maps* 06/30/18

Completed deliverable: *Extragalactic Catalogs for the* `DC2` *Simulation* 06/30/18

CS Key Product (SR): Extragalactic Catalogs beyond DC2 (CS7)

Active deliverable: *Generation of the Extragalactic Catalogs* 03/31/20

Planned deliverable: *Generation of the Special Purpose Extragalactic Catalogs* 06/30/22

Anticipated deliverable: *Generation of the Next-Generation Extragalactic Catalogs* 03/31/23

Anticipated deliverable: *Generation of the Extragalactic Catalogs based on Hydrodynamic Simulations* 03/31/24

SSim Key Product (DC2): `DC2` Production (SSim4)

Completed deliverable: `DC2` *Simulated Images* 06/30/18

Active deliverable: `DC2` *DM DRP Catalogs* 06/30/18

SSim Key Product (SR): Science Readiness Era Data Set Production (SSim7)

Planned deliverable: *Simulated Images* 12/30/20

Planned deliverable: *DM DRP Catalogs* 06/30/20

WL Key Product (DC2): WL Precursor Dataset Production (WL10)

Active deliverable: *Compilation of precursor survey data to test the shear pipeline* 06/30/17

CO Key Product (SV): The DESC-reprocessed ComCam Dataset (DESC-ComCam)

Anticipated deliverable: *DESC-Reprocessed ComCam DRP Catalogs* 09/30/22

Anticipated deliverable: *DESC-Processed Alternative ComCam DRP Catalogs* 09/30/22

CO Key Product (SV): The DESC-reprocessed SV Dataset (DESC-SV)

Anticipated deliverable: *DESC-Reprocessed SV DRP Catalogs* 12/30/22

Anticipated deliverable: *DESC-Processed Alternative SV DRP Catalogs* 09/30/22

ES Key Product (DC2): Coordinate production of white papers and proposals for non-LSST datasets (ES1)

Active deliverable: *Response to Calls for White Papers* 02/22/19

ES Key Product (DC2): Develop and maintain inventories of external data set needs (ES2)

Active deliverable: *First Inventories of Data Needs and Resources* 1/1/20

ES Key Product (SR): Develop Inter-Collaboration Agreements (ICAs) with External Projects (ES3)

Active deliverable: *Facilitate Inter-Collaboration Agreements* 01/1/23

ES Key Product (SR): Help Develop Policies for Internal Data-Sharing (ES4)

Active deliverable: *Draft data-sharing policy* 09/01/20

ES Key Product (SV): Help Develop Cross-Working Group Observing Proposals (ES5)

Anticipated deliverable: *Large and Long-Term Proposals* 1/1/23

8 Appendices

This appendix contains:

- A Summary of the Simulations Nomenclature
- List of all DESC Publications
- List of ongoing and completed DESC Projects

8.1 Simulations and Catalogs Nomenclature

Both the word simulation and the word catalog have multiple meanings when used without any context. For example, a simulation can be a simulated image, a simulated catalog, or the output of a cosmological simulation. Similarly a catalog can refer to a database of idealized objects used by CATSIM to realize a simulated image, or a text file containing the results of a simulated observation.

Because of this overloading, it is often confusing when different groups talk about simulations or catalogs. We propose that neither of these words be used alone and always are used with other describing words to give the context. We itemize here some of the more common data products in use by the various working groups and suggest that we consistently use similar phrases when describing the same products elsewhere in documentation.

We list below the different ways the terms "simulation" and "catalog" are used in the DESC.

8.1.1 Simulations

- **Cosmological Simulations:** These are any result of cosmological simulations, including both gravity-only and hydrodynamical simulations. The results of cosmological simulations are rarely used "as is." They are used in various ways, e.g. to build prediction tools for different cosmological statistics, such as mass functions or power spectra, to investigate systematic effects, such as intrinsic alignments or mis-centering, and to provide estimates for covariances.

  Often, they are used as inputs to other systems for validation. In these cases, gravity-only simulations are populated with galaxies using a variety of prescriptions, depending on the resolution of the simulations as well as the targeted galaxy population. The prescriptions used, including semi-analytic models, subhalo abundance matching, halo occupation distribution models and many others, are still being developed and refined and for the purposes of LSST DESC the generation and validation of reliable input simulations is a major research task. For example, the input simulations described next can come from a cosmological simulation with realistic galaxy properties assigned using a standardized prescription.

Sometimes you hear the term **"Input Simulations"**. These are cosmological (or in principle, galactic) simulations that are used as input to CatSim.

- **Image (or "Pixel-level") Simulations:**

  These come in two kinds, as follows:

  - **Simulated calibrated images, or "e-images":** these have none of the low level sensor effects included. This is the same as producing images where instrument signature removal (ISR; flat field, bias, etc.) is done perfectly. These images can be fed to the DM processing pipelines or other pipelines for measurement. With all simulated images, a major concern is choosing the observation parameters correctly.
  - **Simulated raw images.** For studies that probe the contribution of image calibration algorithms to down-stream measurements, it is likely necessary to simulate raw images and the associated calibration frames. Calibration products are very expensive to simulate correctly because of the vast number of photons needed (by far the most photons seen by any telescope are in the process of producing calibrations). Along with the other concerns, it is important to plan production of master calibration frames along with the catalog and reduction/analysis times.

- **Catalog-level Simulation.** This typically refers to the simulation of an LSST catalog dataset directly, without processing an image and automatically detecting and measuring objects on it. In the DESC, this process is also known as *emulation*, because our default method for making mock LSST catalogs is to simulate images and process them.

8.1.2 Catalogs

- **Input All-Sky Source Catalog:** This is a catalog produced using a cosmological simulation, Milky Way simulation, or other model to produce a realistic representation of the sky including realistic spatial distributions and realistic distributions of observables. These will be used by CatSim and so should adhere to a pre-arranged schema for the catalog contents.

- **Idealized Realization Input Catalogs:** Many times, it is beneficial to produce analysis catalogs with non-physical distributions of objects: e.g. grids of stars for PSF analysis, higher density than normal variable objects to test detection and characterization algorithms. These are also input catalogs, but are idealized in some sense over a purely realistic distribution.

- **Halo Catalogs.** These are a processed output of a cosmological simulation, made by running a halo finder on the particle (or density field) data.

- **Milky Way Catalog.** This is an input to CatSim, that contains stars drawn from a model for the Galaxy.

- **Extragalactic Catalogs.** These are catalogs of galaxies painted onto the halos in a halo catalog via some algorithm. It's called an extragalactic catalog because it does not contain stars or solar system objects, and by contrast with the Milky Way catalog used by CatSim.

- **Data Release Catalogs.** The LSST annual data releases will consist of an image archive and an automatically-generated catalog, both produced by the data release production (DRP) pipeline. The data release catalog will be a database including tables of Objects, Sources, DIAObjects and DIASources, as well as many other tables of metadata (such as the CcdVisit table). It may be important to specify that a data release catalog has been made from simulated images by calling it a "simulated data release catalog."

- **Simulated observed, or "mock" catalogs.** Catalogs reflecting known error models at various levels of calibration can be produced. Elsewhere these are sometimes known as "mock catalogs," because they contain "mock data" like noisy apparent magnitudes. Mock catalogs are typically made by applying an observational error model to an extragalactic catalog directly. If the machine that does this transformation has been trained on a simulated data release catalog, then that machine is known in DESC as an "emulator," because it is enabling the user to avoid doing more image simulation and instead "emulate" the process of simulating images and running the DRP pipeline.

8.2 DESC Publications

This subsection includes the complete list of DESC Publications to date.

1. LSST Dark Energy Science Collaboration, 2012, *Large Synoptic Survey Telescope: Dark Energy Science Collaboration*, arXiv e-prints, arXiv:1211.0310

2. Mao, Y.-Y. et al., 2018, *DESCQA: An Automated Validation Framework for Synthetic Sky Catalogs*, ApJS, 234 (2), 36

3. Malz, A. I. et al., 2018, *Approximating Photo-z PDFs for Large Surveys*, AJ, 156 (1), 35

4. Leonard, C. D., Mandelbaum, R., and LSST Dark Energy Science Collaboration, 2018, *Measuring the scale dependence of intrinsic alignments usingmultiple shear estimates*, MNRAS, 479 (1), 1412–1426

5. The LSST Dark Energy Science Collaboration et al., 2018, *The LSST Dark Energy Science Collaboration (DESC) Science Requirements Document*, arXiv e-prints, arXiv:1809.01669

6. The PLAsTiCC team, Allam, Tarek, J., et al., 2018, *The Photometric LSST Astronomical Time-series Classification Challenge (PLAsTiCC): Data set*, arXiv e-prints, arXiv:1810.00001

7. Lochner, M. et al., 2018, *Optimizing the LSST Observing Strategy for Dark Energy Science: DESC Recommendations for the Wide-Fast-Deep Survey*, arXiv e-prints, arXiv:1812.00515

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8.3 DESC Projects

This subsection includes all ongoing and complete DESC Projects, with more complete information than in the WG subsections. The names of the projects are links to internal DESC confluence pages (accessible to DESC members), while the working group acronyms are links to the place where the project is mentioned in the relevant WG overview section within the SRM, i.e., within Section 3 or Section 4. Within each status category, projects are alphabetized by title.

Project status: Active

1. A New Deep Learning Model for Photometric Redshift Estimation with DC2 (Lead: Andrew Engel, Gautham Narayan, Alex Gagliano): We are in development of novel deep learning models for estimation of photometric redshifts– specifically for transient host classification. WG(s): PZ, SN.

2. Analyzing the Impact of Brighter-Fatter on WL Observables (Lead: Emily L Phillips Longley): Analyze the impact of the brighter-fatter effect on shear correlation functions and inferred cosmological parameters. WG(s): WL, SA. DC2, thesis project.

3. Application of snmachine to PLAsTiCC data: Apply the DESC product snmachine (https://github.com/LSSTDESC/snmachine) to data from the Photometric Astronomical Time-Series Classification Challenge (PLAsTiCC). WG(s): SN. Thesis project.

4. Apply Deep Learning to Identify and Deblend Strong Lenses for LSST (Leads: Nan Li, Nesar Ramachandra): Identifying strong lenses with deep learning approaches has been proved successfully, we plan to involve the process of extracting background images from cutouts centered at massive elliptical galaxies with deep learning to improve the performance of lens finding further. WG(s): CS, SL. DC2 project.

5. Atmospheric PSF interpolation with Gaussian Processes (Lead: Pierre-Francois Leget): Development of practical Gaussian process interpolation of the atmospheric part of the PSF across the full field of view of ground-based telescopes. WG(s): WL, PSF.

6. BlendingToolKit: A framework to generate images of blended objects and evaluate performance metrics for different algorithms. (Leads: Sowmya Kamath, Ismael Mendoza): A toolkit for generationofblended-object images "on the fly", along with a uniform framework for evaluating and comparing performance of detection and deblending algorithms. WG(s): BL.

7. Comparison of E_G vs a multiprobe analysis for testing gravity with LSST (Lead: Danielle Leonard): Forecasting project to determine the trade-offs between testing GR with the E_G statistics and with a 3x2pt++ analysis. WG(s): TJP.

8. Cosmology bias from photometric SNe Ia redshift systematics (Lead: Eric Linder): We aim to derive requirements on redshift systematics for a LSST sample of photometric supernovae, in order to avoid cosmology bias. WG(s): SN.

9. DC2 CMBxLSST analysis (Leads: Patricia Larsen, Chihway Chang): Perform a 5x2 CMBxLSST analysis on DC2 simulation data. WG(s): TJP.

10. DC2 project [PZ]: Testing cross-correlation redshift calibration (Lead: Christopher Morrison): Testing methods of calibrating redshift distributions, n(z), by cross-correlation with spectroscopic data sets. WG(s): PZ.

11. DC2 Project: 3x2pt analysis with DC2 catalogs (Lead: Joseph Zuntz): Example weak lensing + galaxy clustering analysis, going from DC2 catalogs, to 3x2pt functions, to cosmological parameters. WG(s): LSS, PZ, WL, TJP.

12. DC2 Project: Cluster Mass Calibration (Leads: Camille Avestruz, Alex Malz): Mass estimate calibration for galaxy clusters. WG(s): CL.

13. DC2 Project: Extragalactic Catalog Validation (Leads: Eve Kovacs, Yao-Yuan Mao): Validation tests and results carried out on the Extragalactic Catalogs for DC2. WG(s): CS.

14. DC2 Project: Galaxy Clustering Analysis (Lead: John Ellison, Zilong Du): Large scale structure clustering angular power spectrum using DC2 catalogs. WG(s): LSS. Thesis project.

15. DC2 Project: GCR Catalogs (Lead: Yao-Yuan Mao): Develop and maintain the GCR-Catalogs Python package to provide a unified access across a wide variety of catalogs and use cases. WG(s): CO, CS.

16. DC2 Project: High Dimensional DESC Metrics (Leads: Jianhua Huang, Eve Kovacs): Explore metrics for the comparison of distributions in high dimensional spaces. WG(s): CS.

17. DC2 Project: Machine Learning Catalog-level Emulation and Detection of Lensed AGN Systems in DC2 (Leads: Ji Won Park, Phil Marshall): Machine learning detection of lensed AGN in the DC2 Object and Source tables, using training sets made via simple mixture modeling emulations of strong lens systems in the DM DRP catalogs. WG(s): SL. Thesis project.

18. DC2 Project: Mass-mapping from DC2 catalogs (Lead: Francois Lanusse): Validate mass-mapping pipeline on DC2 data processed through DM + shape measurement pipeline. WG(s): WL.

19. DC2 Project: Non-linear bias and assembly bias modelling (Lead: Anze Slosar, Jonathan Blazek): Testing non-linear bias models and the effects of assembly bias using clustering information from DC2 catalogs. WG(s): LSS, TJP.

20. DC2 Project: Probabilistic shear maps from BFD (Lead: Bob Armstrong): We will construct probabilistic maps of g1,g2 and kappa from BFD outputs. WG(s): WL.

21. DC2 Project: Producing BFD catalogs (Lead: Bob Armstrong): We will produce BFD catalogs for DC2 to use for weak lensing. WG(s): WL.

22. DC2 Project: Production and validation of IA mock catalogs for DC2 (Lead: Francois Lanusse): Production of DC2 mock galaxy catalogs with intrinsic alignments, populated using different empirical models. WG(s): CS, TJP.

23. DC2 Project: Production of metacalibration shape catalog for DC2 (Lead: Erin Sheldon): Production of a metacalibration shape catalog from DC2 images. WG(s): WL.

24. DC2 Project: Run 1 and 2: Run 1 and Run 2 specifications, production, and testing. WG(s): CO, SSIM.

25. DC2 Project: Running redMaPPer on DC2 Cosmo and Sim Catalogs (Lead: Eli Rykoff): Run redMaPPer cluster finder on DC2 cosmological and image-simulated catalogs, and compare performance and to "truth". WG(s): CL, PZ.

26. DC2 Project: Validation of DC2 images and DM products: This project aims to validate and verify DC2 images and data management products. WG(s): SSIM.

27. DESC Broker services: Discuss broker like infrastructural necessities for DESC. WG(s): SN.

28. DESC+DES: Quantifying the effects of cluster triaxiality on cosmology with simulations (Lead: Yuanyuan Zhang): Determine the impact of halo orientation and shape on cluster richness and weak lensing. WG(s): CL, CS. DC2 project.

29. Detecting unrecognized blends from residual images (Lead: Sowmya Kamath): Improve detection performance by identifying unrecognized blends from their Scarlet-modeled residual images using convolutional neural networks and iterative detection. WG(s): BL. Thesis project.

30. Developing improved image subtraction methods on DC2 dataset. (Lead: Shu liu): Compare the Alard & Lupton algorithm and the ZOGY algorithms for image subtraction on DC2 dataset and investigate improvements for each method. WG(s): SN, SL. Thesis project.

31. Effects of blending on galaxy cluster shear measurements (Lead: Shenming Fu): Measure the impact of blends on cluster shear profiles. WG(s): CL, BL. Thesis project.

32. Efficiency of detection of variable sources in DC2: Understand the ability to detect transients like supernova and classify transients/variables as astrophysical transients rather than artifacts of detection. WG(s): SN.

33. Evaluating the impact of the observing strategy on supernova Ia classification for cosmology: —. WG(s): OS, SN.

34. Exploring time-dependence of atmospheric PSF parameters (Lead: Claire-Alice Hebert): Study the temporal behavior of atmospheric PSF parameters by leveraging datasets of fast speckle images series of 1000 images of stars with 60-ms exposure times, with high spatial resolution taken with Zorro, a speckle camera instrument, at Cerro Pachon. WG(s): OS, PSF. Thesis project.

35. Extreme Emission Line Galaxies as an LSS Platinum Sample (Lead: Adam Broussard, Eric Gawiser): Quantify photo-z improvements and number density for Extreme Emission Line (EEL) galaxies as potentially improved samples for galaxy clustering. WG(s): LSS.

36. Forecasting the Potential of Weak Lensing Magnification at LSST (Lead: Constance Mahony): Forecasting project to determine whether including magnification in a 3x2pt analysis provides additional cosmological constraining power, and whether not including magnification biases cosmological parameter results. WG(s): LSS, WL, TJP. Thesis project.

37. Galaxy blending effects in deep imaging probes of cosmology (Leads: Erfan Nourbakhsh, Tony Tyson): Investigate the sensitivity of the cosmological parameter estimation to galaxy blending via 3x2pt correlations in a mock catalog. WG(s): BL, WL. Thesis project.

38. Hierarchical Inference of Cosmological Parameters from Deep-Learned LSST Time Delay Lens Models (Leads: Ji Won Park, Phil Marshall): Investigation of accurate joint inference of cosmological and other hyper-parameters from samples of thousands of LSST lensed AGN and SNe, by modeling each lens LSST data with a Bayesian Neural Network, characterizing its posterior PDF with sufficient accuracy, and combining all the lenses efficiently. Also known as the "All the Lenses" initiative. WG(s): SL. Thesis project.

39. Impact of Higher Order Moments Error of PSF Model on WL (Lead: Tianqing Zhang, Rachel Mandelbaum): Study the impact of higher order moments error in PSF modeling on weak lensing measurement. WG(s): WL, PSF.

40. Impact of LSS systematics (Lead: Humna Awan): Quantify the impact of different systematics on large-scale structure studies. WG(s): LSS. Thesis project.

41. Impact of Saturation on LSST SN cosmology: The impact of saturated pixels on LSST SNIa cosmology. WG(s): SN.

42. Impact of Weak Lensing Magnification on SN Cosmology: Use Outer-rim simulations underlying CosmoDC2 catalog to calculate the probability distribution of magnification as a function of redshift. WG(s): CS, SN. DC2 project.

43. Implementation of Metadetection and Validation with Simulations (Leads: Erin Sheldon, Matthew R Becker): —. WG(s): WL.

44. Intrinsic alignment self-calibration (Leads: Mustapha Ishak, Eske Pedersen): Implement the intrinsic alignment self-calibration mitigation method in DESC pipeline and apply it to DESC mock catalogs and precursory data such as DES. WG(s): CS, WL, TJP. Thesis project.

45. Joint DC2 LSST-WFIRST pixel-level simulations and analysisDC2/DC3 image simulation (Lead: Michael Troxel): Creating joint pixel-level simulations of LSST and WFIRST observations in DC2 for tests of joint pixel-level analysis. WG(s): PZ, WL.

46. Joint redshift inference with clustering and SED fitting (Lead: Markus Rau): The goal of this project is to develop a Bayesian model to estimate redshift distributions jointly with clustering redshifts and more traditional template fitting. WG(s): PZ. DC2 project.

47. Leveraging Host Galaxy Correlations for Supernova Classification (Leads: Alexander Gagliano, Gautham Narayan, Andrew Engel): We hope to accurately classify transient phenomena from host galaxy information, with low enough latency to allow for rapid follow-up. WG(s): PZ, SN. Thesis project.

48. LSST Observing Strategy 3x2pt FoM Emulator (Leads: Tim Eifler, Humna Awan, Husni Almoubayyed, Xiao Fang, Rachel Mandelbaum, Eric Gawiser): We forecast the dark energy FoM as a function of survey depth, area, redshift and shear calibration uncertainty. We are building a easy to use emulation tool that returns the FoM given the corresponding input parameters. WG(s): WL.

49. Matter Power Spectrum Emulator for f(R) Modified Gravity Cosmologies (Leads: Georgios Valogiannis, Nesar Ramachandra): —. WG(s): CS, TJP.

50. n(z) shape + galaxy bias degeneracies in 3x2 point (Lead: Imran Hasan): Impact of P(z) shape error + galaxy bias degeneracy in 3x2 point. WG(s): PZ, WL, TJP. DC2 project.

51. Non-local No-Nonsense Non-Limber Numerical Knockout (Leads: Danielle Leonard, David Alonso, Elisa Chisari, Anze Slosar): Determine the best algorithm for non-limber integration which suits the speed and accuracy needs of DESC 3x2pt analysis. WG(s): TJP.

52. Obtaining Peculiar Velocities From SN (Lead: Anita Bahmanyar): Study the detection of peculiar velocitiesof SN. WG(s): SN. DC2, thesis project.

53. Optimal weak lensing non-Gaussian statistics (Lead: Francois Lanusse, Jia Liu): Our goal is to investigate the complementarity of several non-Gaussian (higher-order) statistics (bispectrum, PDF, Minkowski functionals, peak counts, higher-order moments, etc.)

and the 2pt statistics, to propose the most promising combination for cosmological analysis. WG(s): WL.

54. Optimising a spectroscopic training sample for photometric classification of transients: This project aims to use simulations to test photometric classification of LSST transients with different spectroscopic training samples. The long-term goal is to inform the design of the 4MOST-TiDES survey to produce an optimal training sample in a fixed amount of observing time. WG(s): OS, SN.
55. Optimizing multi-class spectroscopic follow-up in PLAsTiCC using active learning: —. WG(s): SN. Thesis project.
56. Placing Supernovae Realistically in Galaxies in the LSST Simulated Sky: —. WG(s): SN. DC2 project.
57. PLAsTiCC Papers: Papers related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
58. PLAsTiCC Papers I: First paper related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
59. PLAsTiCC Papers II: Second paper related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
60. PLAsTiCC Papers III: Third paper related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
61. PLAsTiCC Papers IV: Fourth paper related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
62. PLAsTiCC Papers V: Fifth paper related to the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) catalog classification challenge being generated for DC2-era transient catalogues. WG(s): SN.
63. PZ blending (Lead: HyeYun Park): The "PZ-blending" project will study the photo-z estimation from the MLZ and BPZ with FoF(Friends of Friends) DC2 input-output catalog matching to connect photoz with de-blending. WG(s): PZ, BL.

64. PZ DC2: How do photo-z PDF methods respond to imperfect priors? (Lead: Alex Malz): Sensitivity analysis of photo-z PDF methods under realistically complex systematics in prior information. WG(s): PZ.

65. Recovering Sub-threshold Gravitational Wave Signals with LSST Data (Lead: Christian Setzer): We will quantify how LSST detections of kilonovae from binary neutron star mergers, beyond the range of detection by gravitational wave observatories, will improve the priors used for gravitational wave signal detection to identify counterpart signals in noisy data below the standard trigger threshold. WG(s): SN. Thesis project.

66. Redshift inference using a hierarchical Bayesian model (Lead: Bela Abolfathi): This project aims to apply the hierarchical Bayesian framework described in Sanchez & Bernstein 2018 to galaxies in DC2. WG(s): PZ. DC2, thesis project.

67. Requirements on PZ errors for 3x2pt (Lead: Husni Almoubayyed): Place improved requirements on our understanding of photo-z errors for WL (shear-shear and 3x2pt) beyond the DESC SRD v1. WG(s): PZ, WL, TJP.

68. RESSPECT: REcommendation System for SPECTroscopic follow-up: The project aims to explore the potential of active learning (AL) techniques in the construction of a recommendation system for spectroscopic follow-up targeting. WG(s): SN.

69. SkySim5000: Produce the 5000 sq. deg. extragalactic catalog based on the Outer Rim N-body simulation. WG(s): CS.

70. Supernova SRD studies (Leads: Renee Hlozek, Daniel Scolnic): We are pulling the work from the SRD into a paper on supernova simulations for Science Requirements, with discussion on the degeneracy directions between cosmological parameters. WG(s): SN.

71. Test Piff PSF Models on DC2 Images (Lead: Mike Jarvis): Run Piff on the DC2 images and test the quality of the PSF reconstructions. WG(s): WL.

72. The Electromagnetic and Gravitational-Wave Selection Functions for Detections of Binary Neutron Star Mergers: We aim to self-consistently model approximate electromagnetic and gravitational waveform signals from populations of compact binary objects and demonstrate their respective selection functions given LSST and contemporaneous gravitational wave detector networks. WG(s): SN. Thesis project.

73. The Lensing Sprinkler: Software for Strong Lensing Simulations: The Lensing Sprinkler is used to simulate lensed AGN and supernovae as well as their host and lens galaxies. WG(s): SL. DC2 project.

74. Time-delay measurements of SL SNe Ia: Optimizing cadence for time-delay measurement of strongly lensed SNe Ia with LSST data. WG(s): OS, SL. DC2 project.

75. Using TXPipe to re-analyze precursor surveys (Leads: Andrina Nicola, David Alonso, Chihway Chang): —. WG(s): LSS, WL.

76. Using TXPipe to re-analyze precursor surveys (Leads: Chihway Chang, Emily, Phillips Longley, Maria, Elidaiana): Reproduce published cosmic shear measurements/constraints from precursor survey and test the sensitivity to analysis choices. WG(s): LSS, PZ, WL.

77. Validation and characterization of redMaPPer cluster catalogs on DESC simulations (Lead: Marina Ricci): The goal of this project is to develop tools and metrics to validate and characterize the cluster catalogs obtained from the redMaPPer algorithm ran on DESC simulations (see this project). WG(s): CL. DC2 project.

Project status: Review

78. Testing Covariance Matrices (Leads: Scott Dodelson, Sukhdeep Singh): We develop a suite of methods to compare covariance matrices and apply them to matrices analytically generated by different codes. WG(s): TJP. Thesis project.

79. Deblending galaxies with variational autoencoders (Leads: Bastien Arcelin, Cyrille Doux): Investigate a new multi-band/multi-instrument deblending method based on variational autoencoders using GalSim-simulated images for LSST and Euclid. WG(s): BL, WL. Thesis project.

80. Effects of Overlapping Sources on Cosmic Shear Estimation: Statistical Sensitivity and Pixel-Noise Bias (Lead: Javier Sanchez): We assess two impacts of blending on galaxy shape measurement and cosmic shear estimation: loss of statistical sensitivity and increase in pixel-noise bias. WG(s): BL, WL.

81. Galaxy Clustering in the Public HSC DR1 data (Lead: Andrina Nicola, David Alonso, Anze Slosar): Demonstrate DESC-LSS analysis pipeline by measuring angular power spectra of HSC galaxies in photo-z bins. WG(s): LSS.

82. Observing strategy studies for weak lensing (Lead: Husni Almoubayyed): Optimizing the LSST survey strategy for weak lensing science by testing the latest opsim runs. WG(s): OS, WL.

83. Simultaneous Estimation of LSS and Milky Way Dust (Lead: Matias Bravo): New method to produce MW dust extinction maps from LSS, and Bayesian extension to improve existing maps. WG(s): LSS.

Project status: Complete

84. Shear measurement bias due to spatially varying spectral energy distributions in galaxies (Lead: Sowmya Kamath): Studying the impact of galaxy color gradients on weak lensing measurements with the LSST. WG(s): WL. Thesis project.

85. DC1 Analysis: Description of DC1 simulated products and LSS analysis results. WG(s): CO, LSS, SSIM.

86. DC2 Project: CosmoDC2 Production (Leads: Dan Korytov, Andrew Hearin, Eve Kovacs): Production of extra-galactic catalog cosmoDC2 with area of 440 sq. deg. to cover the image-simulation area. WG(s): CS.

87. DC2 Project: Generating synthetic cosmological data with GalSampler (Leads: Andrew Hearin, Eve Kovacs): We present a new hybrid method for adding realistic distributions of galaxies to simulated dark matter halos that blends traditional approaches based on semi-analytic and empirical models. WG(s): CS.

88. DC2 Project: ProtoDC2 Catalog Production (Leads: Andrew Hearin, Eve Kovacs, Dan Korytov): Production steps for protoDC2, a small extra-galactic catalog, to be used for testing pipelines and developing code in advance of the full-sized DC2 catalog. WG(s): CS.

89. Detectability of Kilonovae: This project will study the influence of observing cadence strategies on non-Target-of-Opportunity detection of kilonovae. WG(s): SN.

90. Enabling LSST simulations Of transients: Connecting OpSim outputs to transient/variable simulations. WG(s): SN.

91. Exact form of the Photon Transfer Curveof CCDs: Derive brighter-fatter constraints from the shape of PTC (and covariance curves) of CCDs. WG(s): SA.

92. Re-analysis of Precursor Cosmic Shear Surveys: Re-analyzing published cosmic shear results from DLS, CFHTLenS, DES-SV and KiDS-450 using a common framework. WG(s): WL.

93. Sparse Bayesian mass-mapping with uncertainties (Lead: Matthew Price): Sparse Bayesian mass-mapping with uncertainties. WG(s): WL.

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