


The LSST Data Management Systems: Infrastructures for Enabling Multi-Messenger Astrophysics

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LSST
Large Synoptic Survey Telescope

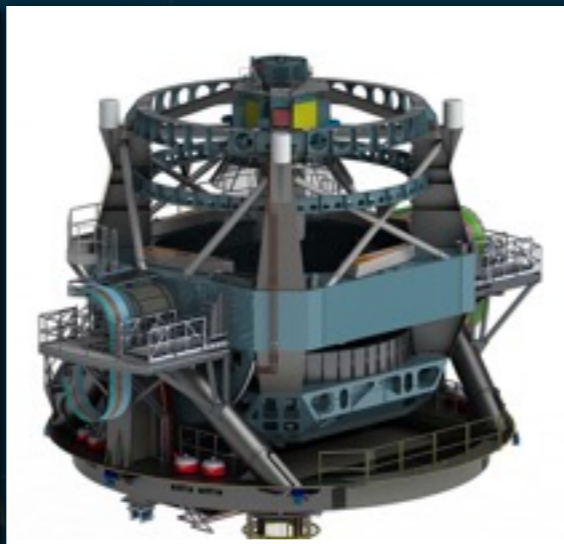
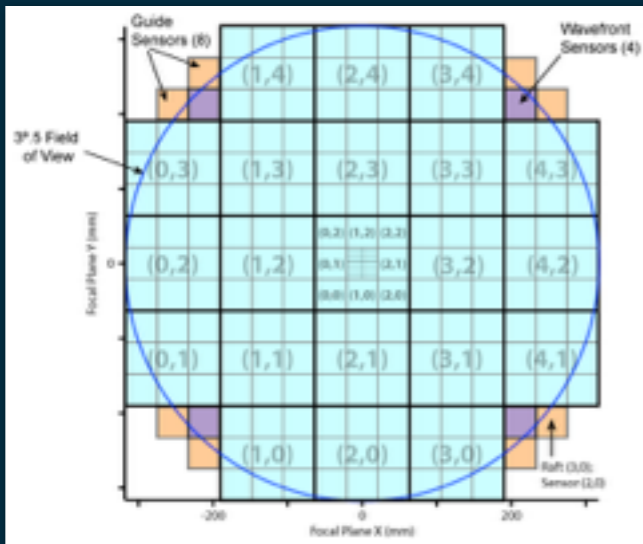
The LSST logo features the letters 'LSST' in a bold, black, sans-serif font. The letter 'S' is filled with a blue-to-white gradient, representing a galaxy or nebula. Below the logo, the full name 'Large Synoptic Survey Telescope' is written in a smaller, italicized, white font.

Talk Outline



- (1) How might an LSST ToO for an GW-triggered imaging survey work?**
- (2) What are the relevant LSST Prompt Data products for MMA?**
- (3) When will the LSST data products be available?**
- (4) How will users access the LSST data products?**
- (5) MMA & LSST ToO: An Infrastructure Timeline**

Proposed GW ToO Imaging Surveys with LSST



Relevant for LIGO Optical Searches

field of view	9.6 deg ²
camera fill factor	>90 %
max slew (180° az)	<120 sec
filters	<i>u g r i z y</i>
max filter change	90 sec
standard visit exposure	30s (2x15s)
standard visit depth	~ 24, 25, 24.7, 24, 23, 22
standard visit processing time	60 sec



LSST's fast response, large aperture, wide field of view, optical filter set, and prompt processing (difference imaging) make it an ideal facility for ToO surveys for GW optical counterparts.

Proposed GW ToO Imaging Surveys with LSST



LSST Observing Strategy White Paper
“ToO Observations of GW Events with LSST”
(Margutti+18, arXiv:1812.04051)

proposes **how** LSST could best survey for optical counterparts (OC).

For example, the minimal strategy proposed for NSNS:

$\Omega < 20 \text{ deg}^2$

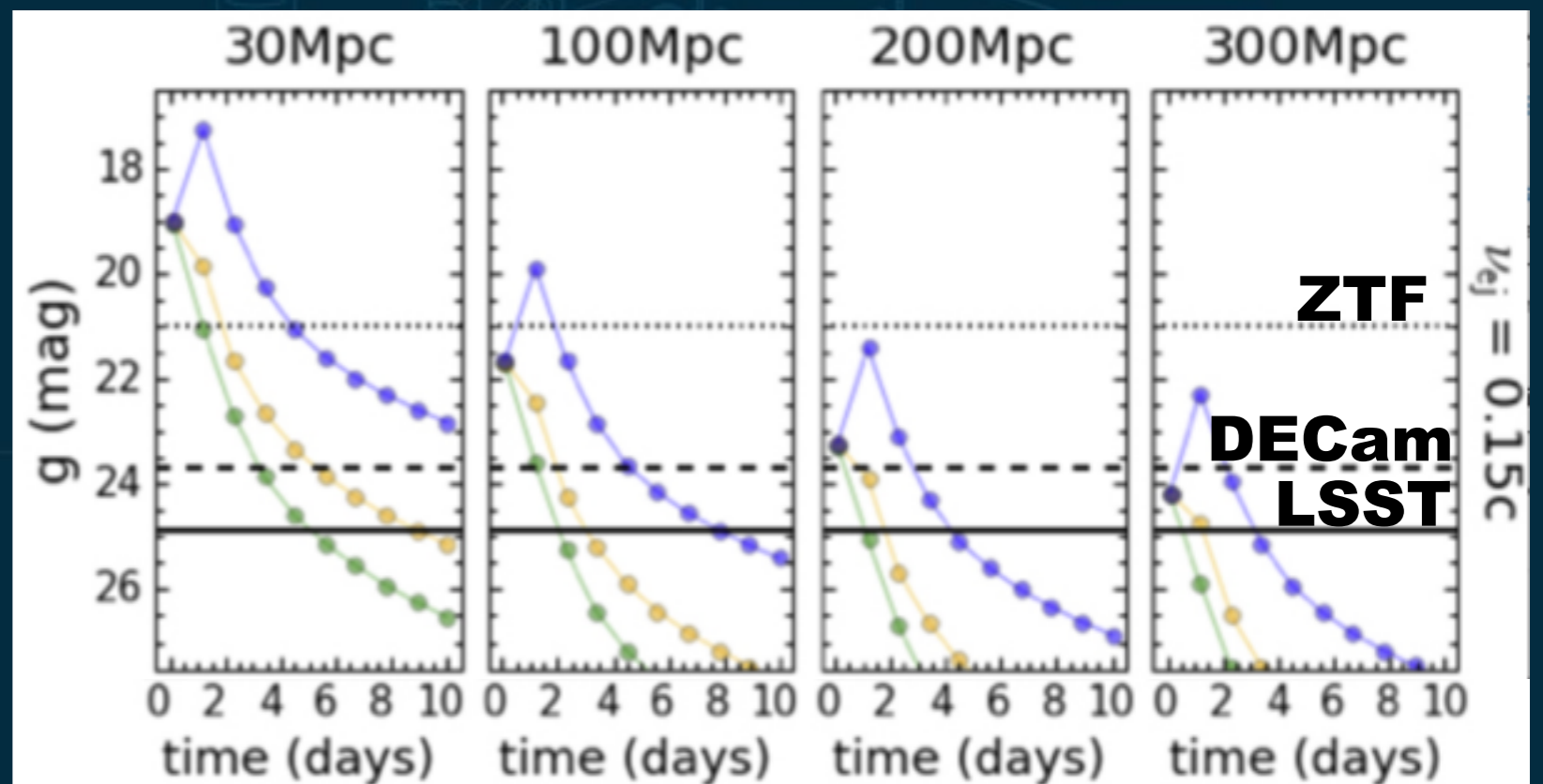
- 4 pointings
- *griz* (+*u* or *y*)

$20 \text{ deg}^2 < \Omega < 100 \text{ deg}^2$

- 6 to 20 pointings
- *g+z* (for max sensitivity)

Both Localization Regimes

- 30 sec integrations
- at 1, 2, 4, 8 hours; 1, 2 days
- stop when OC detected and released to community



Simulated light-curves of two-component KNe in the LSST g-band filter with ejecta masses **0.005**, **0.01**, **0.05** M_{\odot} at 30, 100, 200, and 300 Mpc (left-to-right panels). Horizontal lines are the 5σ detection thresholds for 30 sec exposure times.

Mortensen et al. 2019, RNAAS, 3, 1

Additional LSST Observing Strategy White Papers of interest:

“A strategy for LSST to unveil a population of kilonovae without gravitational-wave triggers”, Andreoni+18, arXiv:1812.03161

“Discovery of Strongly-lensed Gravitational Waves – Implications for the LSST Observing Strategy”, Smith+18 (ls.st/Document-30578)

(1) Can LSST handle targets of opportunity?

*Yes. The LSST scheduler shall be capable of accepting ToO, and they may specify their scientific priority and time urgency. (OSS-REQ-0381)
The process for ToO proposals remains To Be Determined.*

(2) Will the LSST schedule be available in advance?

Yes. Scheduled observations shall be published 2 hours in advance. (OSS-REQ-0378)

(3) Will the schedule for *rapid* (<2 h) ToO be available?

*Yes. This is an expected functionality.
The implementation and distribution method for the LSST schedule (e.g., posted on a website) is To Be Determined.*

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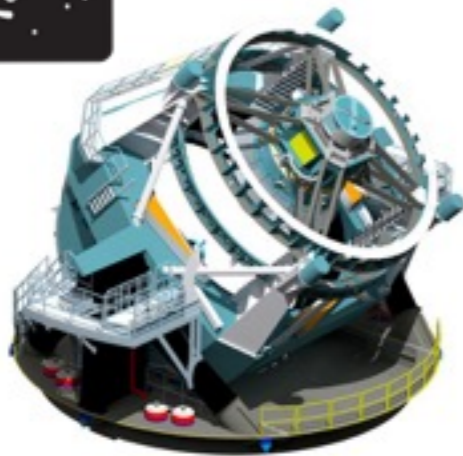
(5) MMA & LSST ToO: An Infrastructure Timeline

Data Management System Overview



Raw Data: 20TB/night

Sequential 30s images that cover the entire visible sky every few days.



Prompt Data Products

Alerts: up to 10 million per night

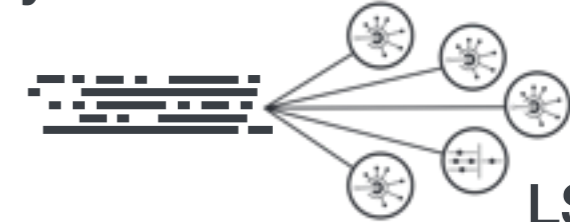
Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~6 million by year 10

Data Release Data Products

Final 10 year Data Release images: 5.5 million x 3.2 Gpx catalogs: 37 billion objects, 15PB

via nightly alert streams



Community Brokers

LSST Alert Filtering Service

via Prompt Products Database



LSST DACs (Chile & NCSA)

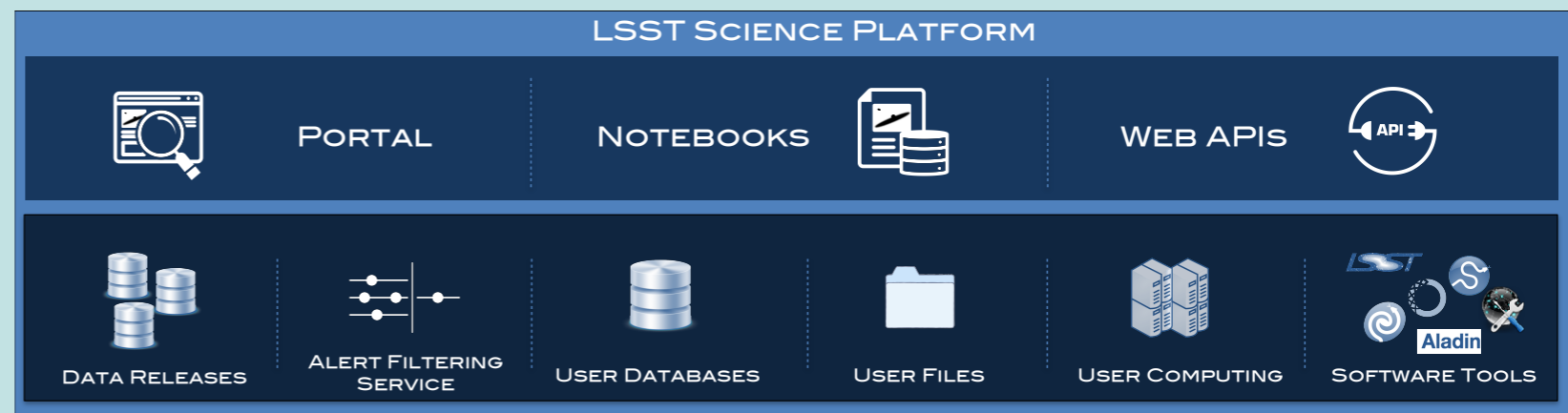
Independent DACs (iDACs)

via Data Releases



LSST Science Platform

Provides access to LSST Data Products and services for all science users and project staff.

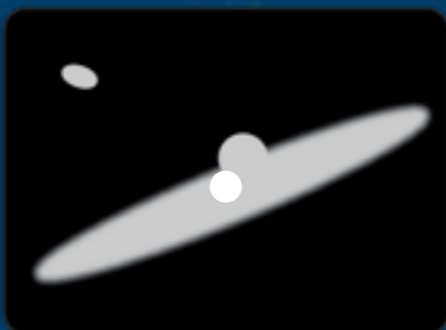


Processing Pipeline for Prompt Products

Difference Image Analysis (DIA) begins immediately after image acquisition.



template image



new image



difference image

← (1) Source detection is run on the **difference image**.

- (2) **DIA**Sources with signal-to-noise ratio > 5 are “detected”.
- (3) **DIA**Sources are associated by location into **DIA**Objects.
- (4) Measurement and characterization for **DIA**Sources and **DIA**Objects.

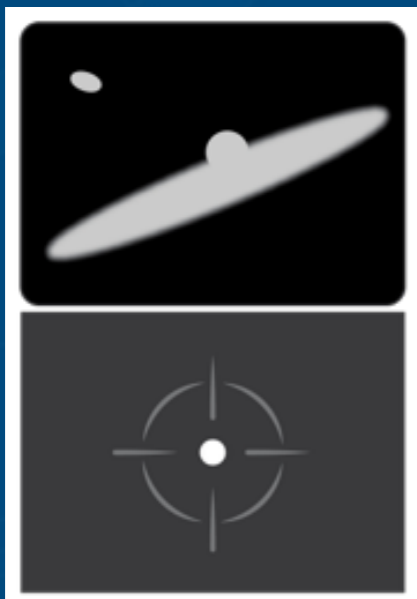
Product:
Stream of Alert Packets
one per **DIA**Source
60_s

Products:
DIA Source & Object Catalogs
Difference and Direct Images
24_h

Contents of an Alert Packet



60s



DIA Source Parameters

- astrometry, photometry, shape (FWHM, trail, dipole, etc.)
- signal-to-noise ratio, **spuriousness*** (real/bogus)
- association with static and moving **DIA** object catalogs

DIA Object Parameters (~12 month history)

- proper motion, parallax, mean flux, orbital elements
- variability parameters, e.g., (non)periodic features
- association with latest static-sky Data Release catalogs

Image Stamps (e.g., FITS)

- at least 6"x6" for both **difference** and template
- flux, variance, and mask frames
- includes metadata (WCS, zero-point, PSF)

*Thresholds in spuriousness will be provided to filter stream to desired completeness & purity.

Prompt Data Products



DIA Source and Object Catalogs with:

- all the same information as in the Alert Packet
- **forced photometry** in **difference** images at the locations of **DIA**Objects with detections in the past ~12 months
- precovery **forced photometry** for new unassociated **DIA**Sources at their location in the last ~30 days of **difference** images

Processed single-visit direct and **difference** images.





Reprocessed DIA Source and Object Catalogs:

- full-survey characterization parameters (e.g., variability)
- full-survey forced photometry in all difference images

Processed Images and Deep Stacks:

- source and object catalogs built from direct images
- full-survey forced photometry in all images and stacks
- data for the host galaxy or variable star

Reprocessed images:

- single-visit, template, and difference
- deep stacks





Does your science require data products that are not produced by the Prompt or Data Release Pipelines? (E.g., image coadds with nightly/weekly timescales.)

User-Generated Data Products can be created by scripting processing routines from the existing code base (the LSST Stack) in the LSST Science Platform.



UGDP formats consistent with Prompt/DR products.

UGDPs can be kept private to groups/individuals.

More info about the LSST Science Platform in later slides.

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- (5) MMA & LSST ToO: An Infrastructure Timeline**

LSST Alert Filtering Service*

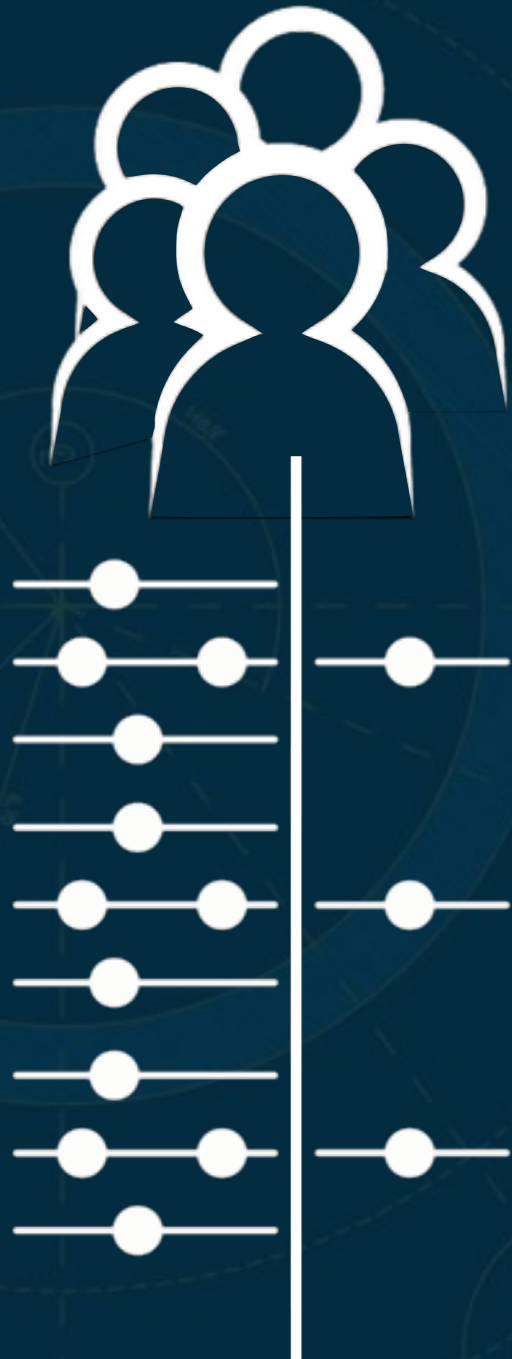


A basic, limited capacity, alert filtering service, the details of which are **an ongoing development**.

- filters may be composed with a simple query language
 - e.g., an SQL- or python-like language
- alerts forwarded using VOEvent Transport Protocol
- limited types of pre-defined filters to be available
 - e.g., “is the light curve consistent with an RR Lyrae?”
- filters may use alert packet contents only
 - no cross-matching to other catalogs
 - no access to other LSST data products

Required Minimum Capabilities

- the equivalent of 20 full-size alerts per visit
- 100 simultaneous users filtering the stream



Community Alert Brokers



Software developed independently of LSST to receive, characterize, prioritize, and/or redistribute Alerts.

Modular components for, e.g., photometric classification.

GUI components for humans: defining filters, making queries.

Several brokers will be selected by LSST via a proposal process, for which Letters of Intent are due May 15.

ls.st/LDM-682

Examples of Community Alert Brokers Currently Processing ZTF Alerts



<https://antares.noao.edu/>



<https://lasair.roe.ac.uk/>



<http://alerce.science/>

Target Observation Managers (TOMs)



Software developed to conduct follow-up observations, be they triggered automatically or by humans.

Built on mixed-format databases (e.g., images/spectra).

GUI components for analysis: model fitting, ToO preparation.

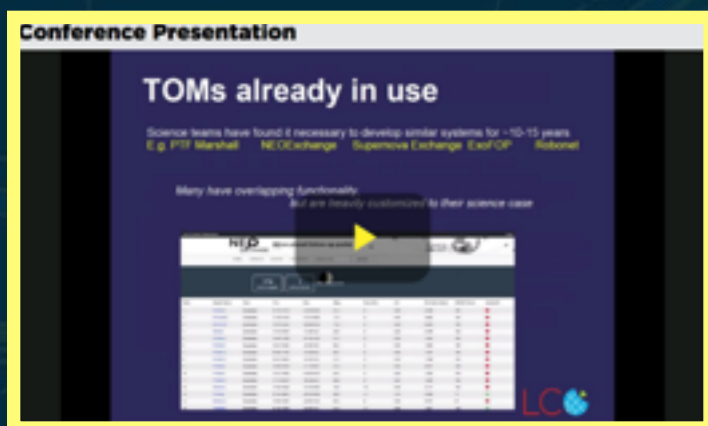
Functionality for collaboration (e.g., comments, tags).

Portal for queue submissions for networked telescopes.



Examples:

- the Las Cumbres Observatory “Supernova Exchange (SNEEx)”
- open source “TOM Toolkit” <https://lco.global/tomtoolkit/>
- the Palomar/Zwicky Transient Facility “Marshal”
Kasliwal et al. 2019, arXiv:1902.01934



General-purpose software for managing astronomical observing programs in the LSST era.

Street, Bowman, Saunders, & Boroson. 2018SPIE10707E..11S

The LSST Science Platform: A Collaborative Research Environment



A set of integrated web applications & services deployed at LSST Data Access Centers (DACs) through which the scientific community will access, visualize, subset and perform next-to-the-data analysis of LSST Data products.

Portal To Discovery



exploratory analysis and visualization of the LSST archive



JupyterLab Notebooks



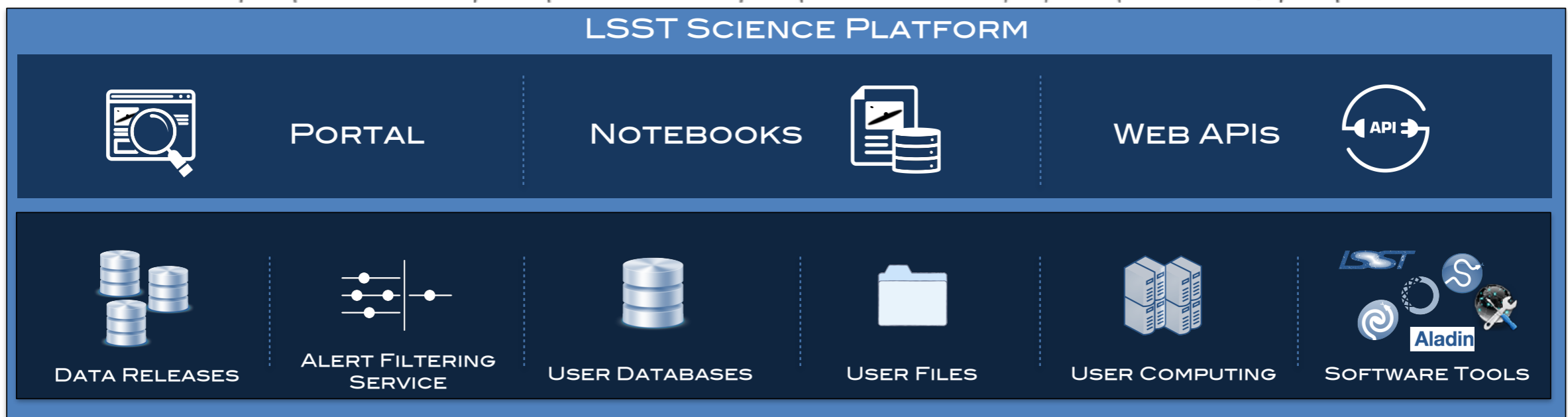
in-depth 'next-to-data' analysis and creation of added-value data products



Web APIs



remote access to the LSST archive via industry-standard APIs



The LSST Science Platform: A Collaborative Research Environment



Portal To Discovery



exploratory analysis and visualization of the LSST archive

JupyterLab Notebooks



in-depth 'next-to-data' analysis and creation of added-value data products

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remote access to the LSST archive via industry-standard APIs

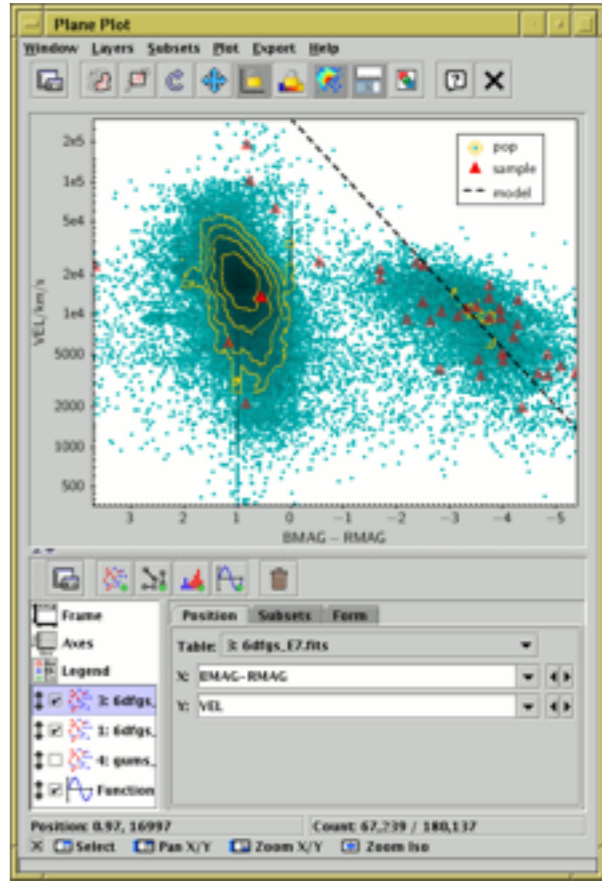
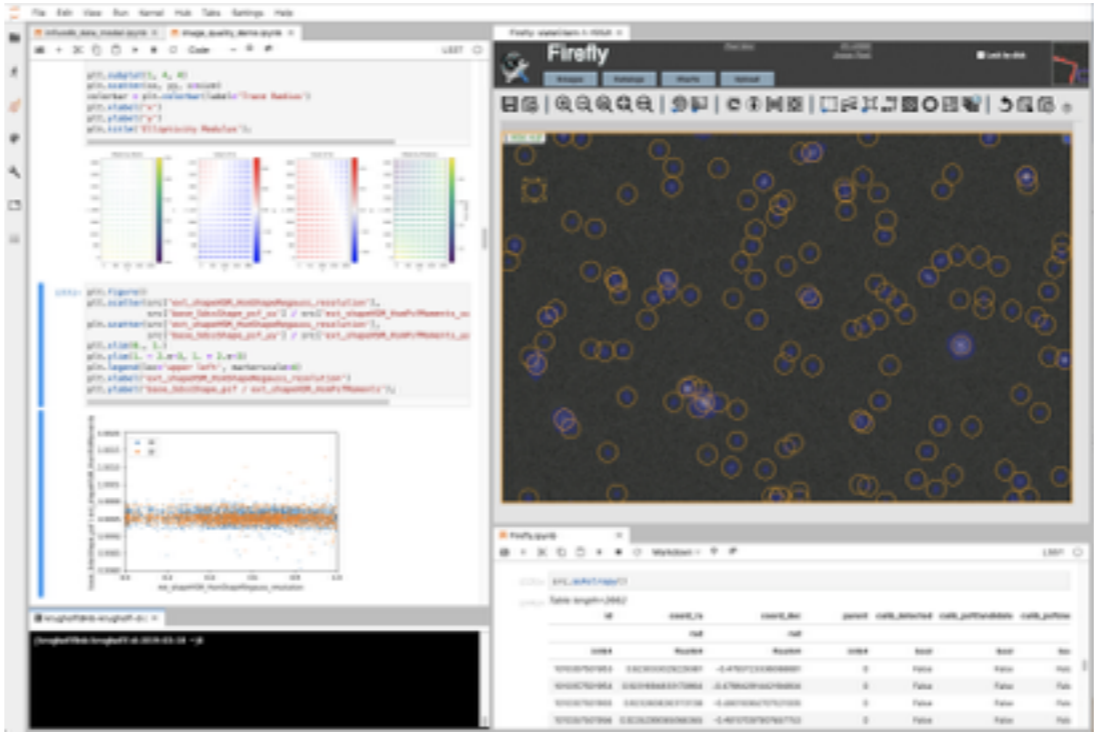
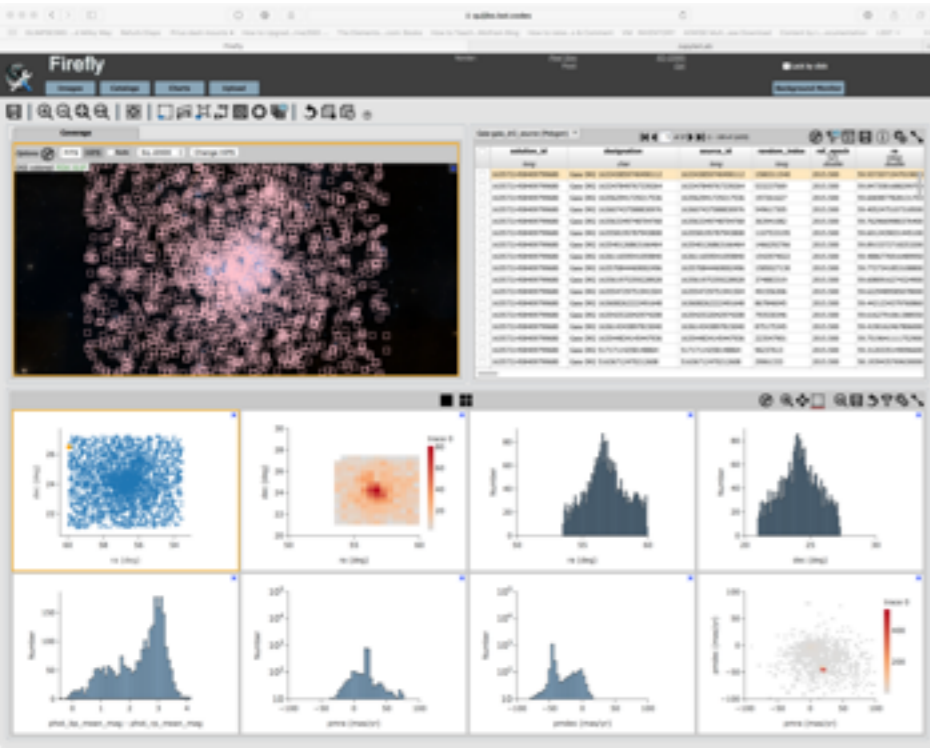


Figure credit: Mark Taylor, <http://www.star.bris.ac.uk/~mbt/topcat/sun253/sun253.html>.

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MMA ToO with LSST: An Infrastructure Timeline



The following example of how various infrastructures **might** play a role in GW optical counterpart searches assumes that a proposal for an LSST ToO survey has been accepted.

The number of such proposals, and the process by which they would be accepted and implemented, remains To Be Determined.

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓

LIGO

Comm.
Brokers

TOMs

LSST
AFS

LSST
Sci.Plat.

Human
Review

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						

MMA ToO with LSST: An Infrastructure Timeline



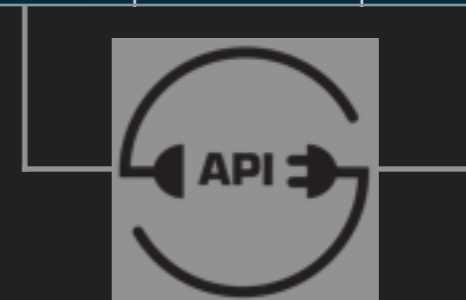
Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						

The details of this step remain To Be Determined.



Role of LSST Science Platform

E.g., human runs a script in LSP on latest DR catalogs to identify likely hosts (or a TOM runs this script via an API) and generates an observing pattern (for any facility, including LSST).

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						

Standard visits (i.e., 30 second integration) are processed by the LSST Prompt Pipeline. Alerts are released on all detections with $SNR > 5$ within 60 sec of readout.

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						

Standard visits (i.e., 30 second integration) are processed by the LSST Prompt Pipeline. Alerts are released on all detections with $SNR > 5$ within 60 sec of readout.

Three cases where ToO imaging might require humans involved:

- (1) Non-standard visits (e.g., longer or shorter exposure times) might require a user-generated processing pipeline to run on the raw data.
- (2) Obtaining DIA detections with $SNR < 5$ might require a user-generated pipeline to run on processed images.
- (3) Stacking (non)standard visits might also require a user-generated processing pipeline to run on processed (or raw) images.

Raw/processed images would be accessible to user-generated pipelines within:
















MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						
LSST Alerts Filtered for Counterpart						

















MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						
LSST Alerts Filtered for Counterpart						
Counterpart Prioritized for Follow-Up						















MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						
LSST Alerts Filtered for Counterpart						
Counterpart Prioritized for Follow-Up						
Follow-Up Data Analysis						

MMA ToO with LSST: An Infrastructure Timeline



Progression of Events ↓	LIGO	Comm. Brokers	TOMs	LSST AFS	LSST Sci.Plat.	Human Review
GW Detected and Alert Released						
GW Alerts Filtered and Prioritized						
LSST ToO Designed and Scheduled						
Prompt Processing and Alerts Released						
LSST Alerts Filtered for Counterpart						
Counterpart Prioritized for Follow-Up						
Follow-Up Data Analysis						

Continued iteration becomes monitoring of the most likely (or confirmed) optical counterpart.

- (1) An LSST ToO imaging survey for GW optical counterparts described in Margutti+18 could use the LSST Prompt Data Products, Community Brokers, TOMs, and human review and analysis.
- (2) The LSST Prompt Data Products are the alerts packets, source catalogs, and images that result from **Difference Image Analysis**.
- (3) The LSST Prompt Data Products are available within 60 seconds of image readout (alerts) or within 24 hours (everything else).
- (4) Users will access the LSST Data Products via the LSST Alert Filtering Service, Community Brokers, TOMs, and/or the LSST Science Platform.

Thank you very much.

Questions Welcome

You're also welcome to contact me at mlg3k@uw.edu