Science data management for the E-ELT: usecase MICADO

Gijs Verdoes Kleijn, MICADO dataflow lead
NOVA/ OmegaCEN / Kapteyn Astronomical Institute / Target
University of Groningen

MICADO DFS team: Werner Zeilinger, Joao Alves, Oliver Czoske, Helmut Dannerbauer, Robert Greimel, Wolfgang Kausch, Rainer Köhler, Martin Leitzinger, Kieran Leschinski, Michael Mach, John McFarland, Stefan Meingast, Norbert Przybilla, Ronny Ramlau, Thorsten Ratzka, Veronika Schaffenroth, Gijs Verdoes Kleijn, Willem-Jan Vriend, Roland Wagner

Vienna
Innsbruck
Linz
Graz

Groningen

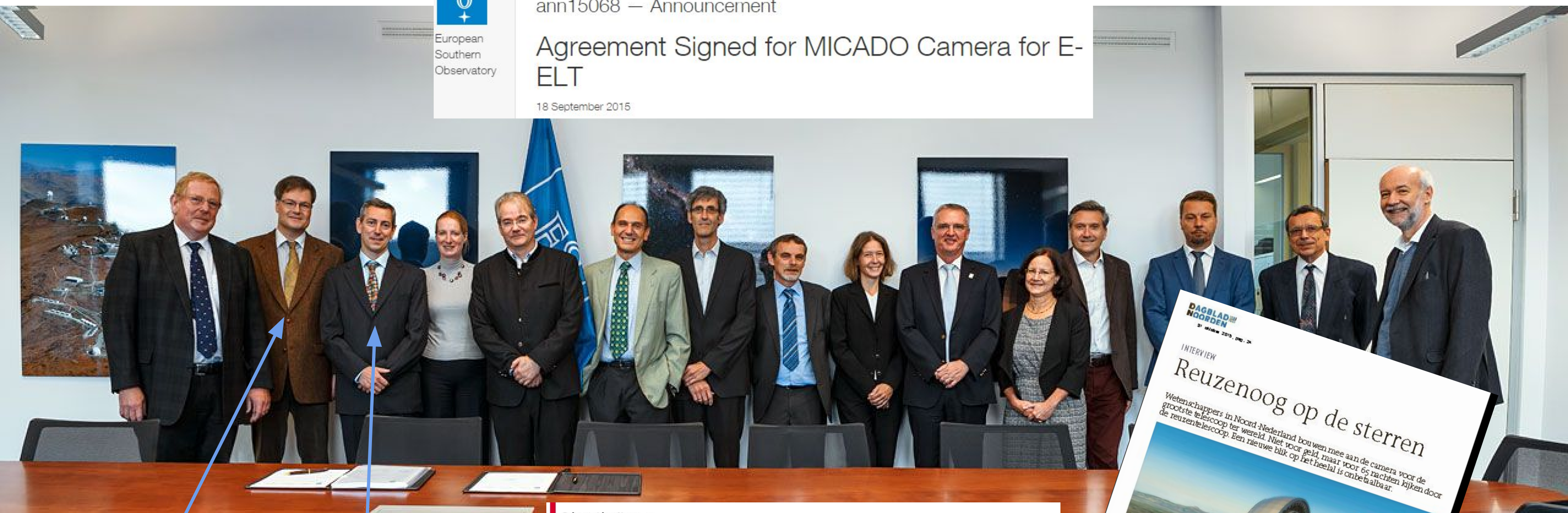
Gathering all information
in a single system
maximizes chance
of extracting knowledge

ann15068 — Announcement

Agreement Signed for MICADO Camera for E-ELT

18 September 2015

European Southern Observatory



Ric Davies
MICADO PI

Florian Kerber
ESO PM

Science Linx News

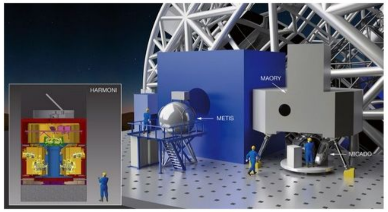
Astronomers from Groningen to set the universe in motion

October 28, 2015

Astronomers from Groningen and engineers from Drenthe are collaborating to make the eyes of the new European Extremely Large Telescope (E-ELT) sharp enough to observe the motion of stars in the universe. Eline Tolstoy, Gijs Verdoes Kleijn and Ramon Navarro say they are going to set the previously motionless sky in motion.

Go back to
• Science

A mirror with a diameter of 39.3 metres in a dome 80 metres in height and 100 metres in diameter. The E-ELT, which will stand in Chile, will be the largest telescope in the world when it starts operating in 2024. In recent months the contracts have been signed for the delivery of the first three instruments that will process the light from the enormous mirror. MICADO (Multi-AO Imaging Camera for Deep Observations) is one of these, and Groningen and Drenthe will play an important role in its



e-ELT and its instruments | Illustration ESO

Key Capabilities

- Imaging
  - 0.8-2.4μm with >30 broad/narrow filters
  - 1.5 & 4mas pixels for 19” & 51” FoV at 6-12mas
  - Similar sensitivity to JWST, and 6× better resolution
- Astrometric imaging
  - 50μas precision across full field
  - 10μas/yr = 5km/s at 100kpc after 3-4 years
  - bring precision astrometry into mainstream
- Spectroscopy
  - ideal for compact sources
  - fixed configuration for 0.8-1.45μm & 1.45-2.4μm
  - R ~ 8000 across slit, higher for point sources
- High Contrast imaging
  - focal plane coronagraph & lyot stop
  - angular differential imaging
  - small inner working angle
- Time Resolved Astronomy
  - windowing for frame rates up to ~100Hz

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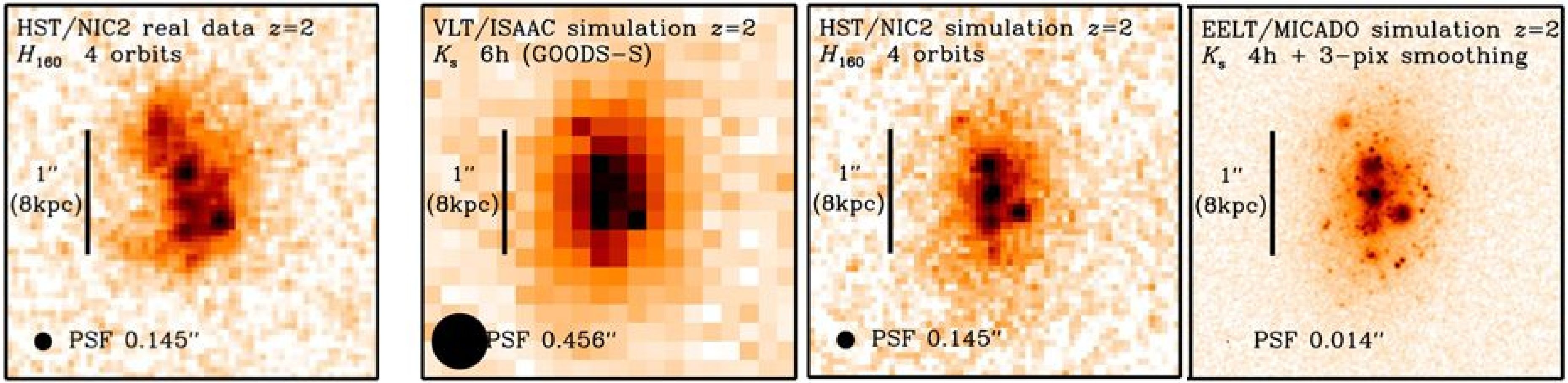
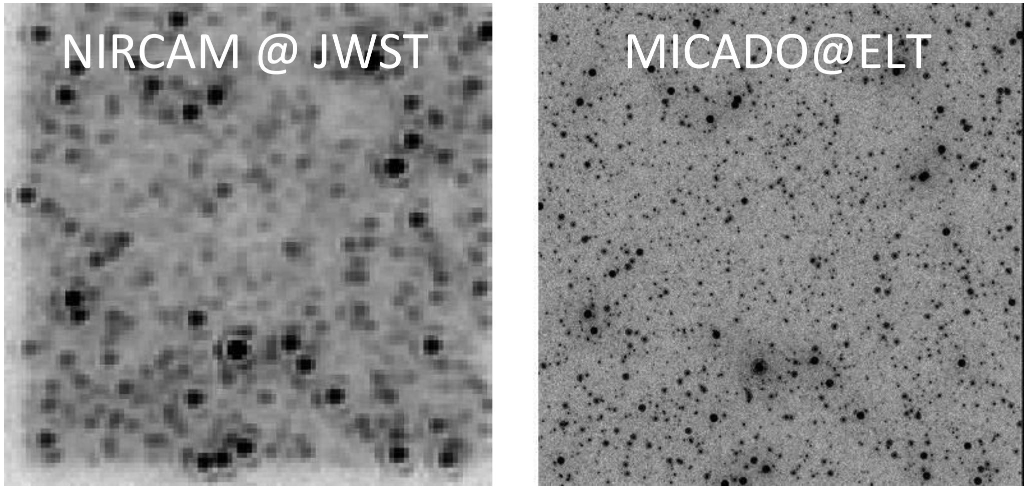
Many science cases

- **Imaging**
  - cosmic star formation history: resolved stellar populations
  - structure of high-z galaxies on 100pc scales
  - nuclei of nearby galaxies (stellar cusps, star formation, BHs)
- **Astrometric imaging**
  - stellar motions within light hours of Sgr A*
  - IMBHs in stellar clusters & dwarf galaxies
  - MW formation: proper motion of clusters & dwarf galaxies
- **Spectroscopy**
  - ages, metallicities, masses of first elliptical galaxies at z=2-3
  - spectra of first supernovae at z=1-6
  - redshifts, velocities, metallicities of SFGs at z=4-6
- **High Contrast imaging**
  - Giant/massive planets at a few AU around nearby stars
  - Direct detection of planets discovered via RV measurements
- **Time Resolved Astronomy**
  - Pulsars & magnetars
  - Accreting white dwarfs
  - Compact binary systems
  - Transits & occultations

Anticipated MICADO data



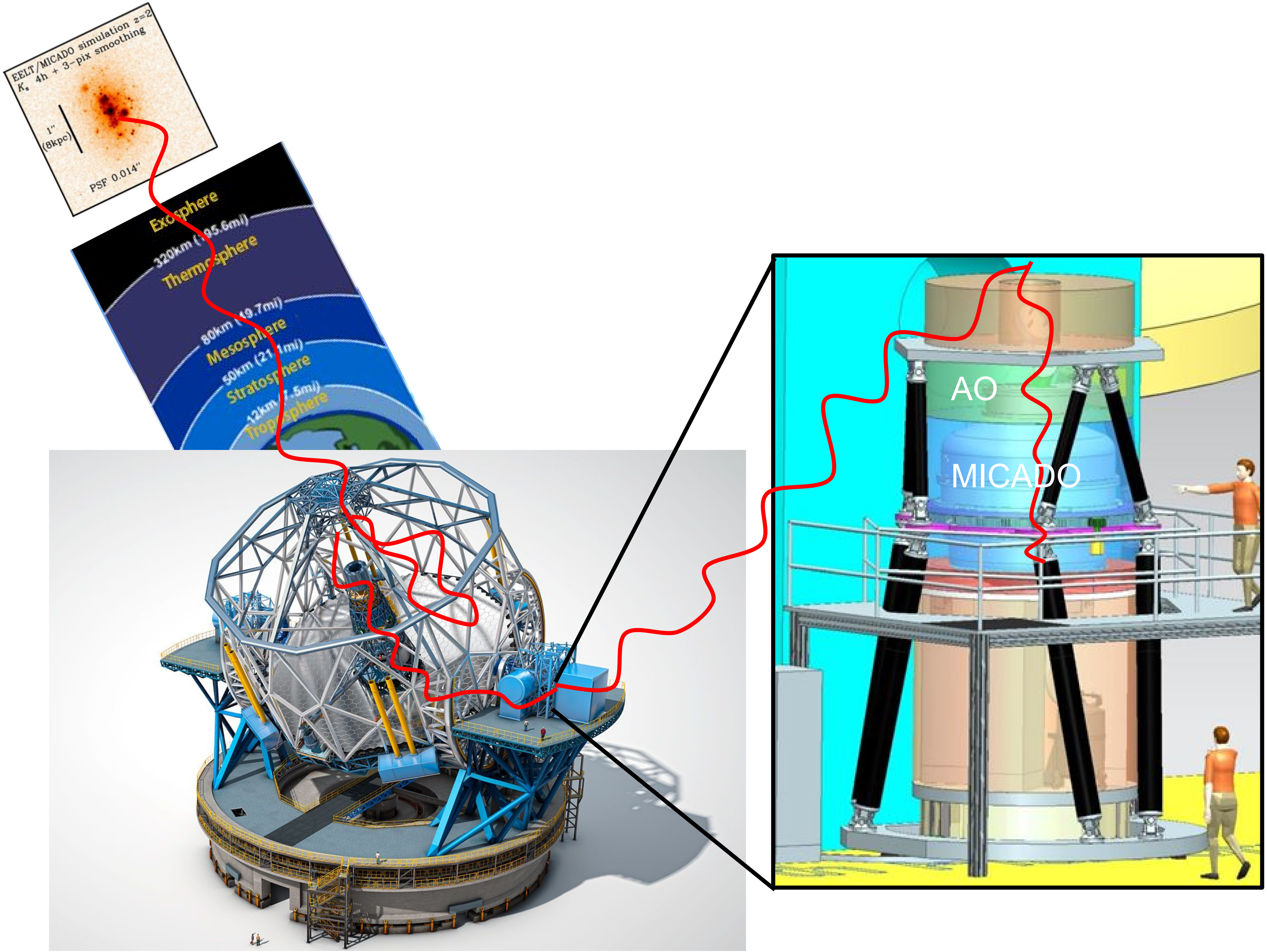


5-hr K-band simulated exposures on stellar field

Courtesy Falomo, Deep, MICADO consortium

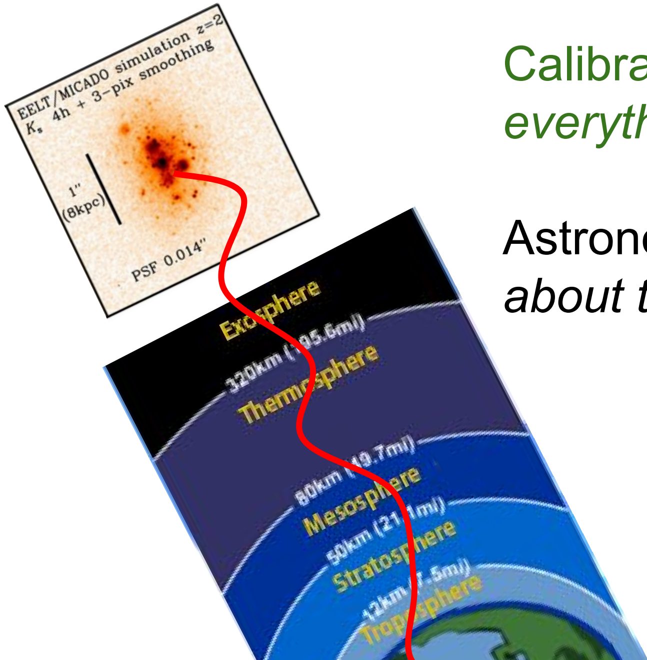
MICADO Dataflow team

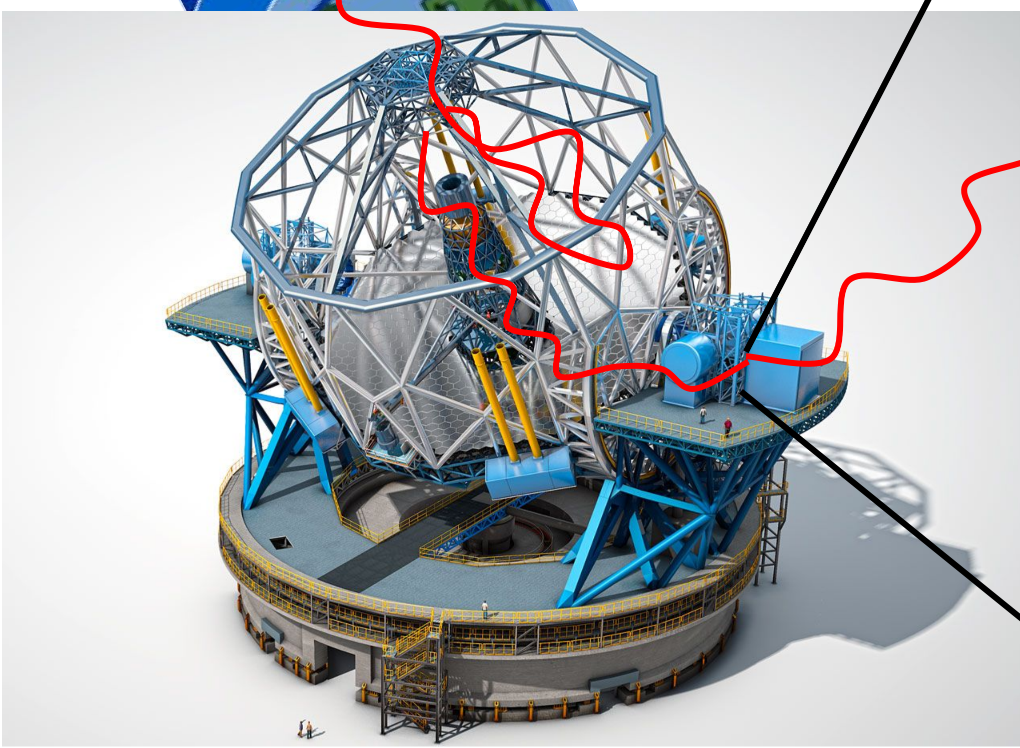
Lead: Gijs Verdoes Kleijn, A*-lead: Werner Zeilinger		
Area	**Partner**	**Expertise**
Imaging	NL-NOVA	Surveys, ESO DFS
Precision Astrometry	NL-NOVA	NL science team
Spectroscopy	A-Ibk/Graz	Atmosmodels, ESO pipelines
MICADO monitoring and calibration	NL-NOVA	ESO OmegaCAM long-term monitoring
Data handling	NL-NOVA	National datacenter, ESO
Simulator	A-Vienna	Science cases
PSF reconstruction	A-Linz	AO, ESO deliveries

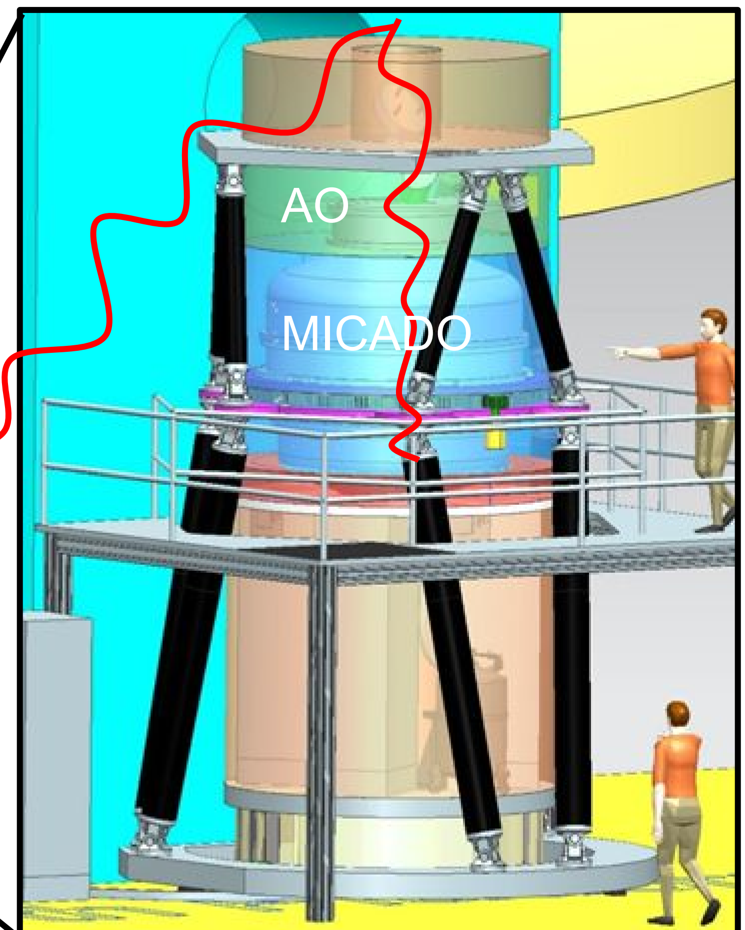

EELT/MICADO simulation z=2
K_s 4h + 3-pix smoothing
1"
(8kpc)
PSF 0.014"
Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
AO
MICADO

Calibration scientist: *"Great observations! They will tell me everything about the state of my Observatory"*

Astronomer:*"Great observations! They will tell me everything about the state of my Universe."*







Pipeline design phase: question 1

	Outerspace	Atmosphere	Telescope	AO	MICADO
Physical components	Science object	Composition model (thermal / non-thermal)	M1	SCAO	Entrance window
	Galactic extinction	Kinematical model for ~32 layers (AO)	M2	MCAO	Derotator
	Cosmic rays		M3		Collimator
	Moon, planets, bright stars		M4		Filter
	Zodiacal light		M5		ADC
			M7		Imager optics, reimager
					Pedestal, pixelsensitivity, persistence, crosstalk, dark current, read-outl

Observables	**Astrophysical laws**	**On-site measurements (T, r, H, P, v..)**	**DM telemetry**	**WFS telemetry**	**Detector exposures**

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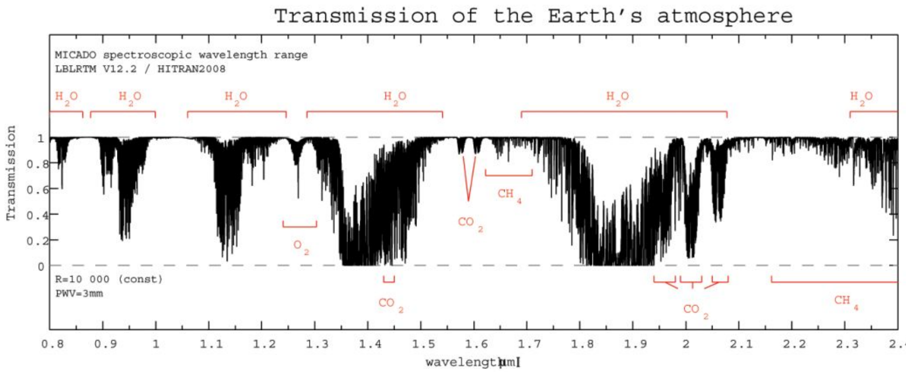
Atmospheric composition model

Transmission



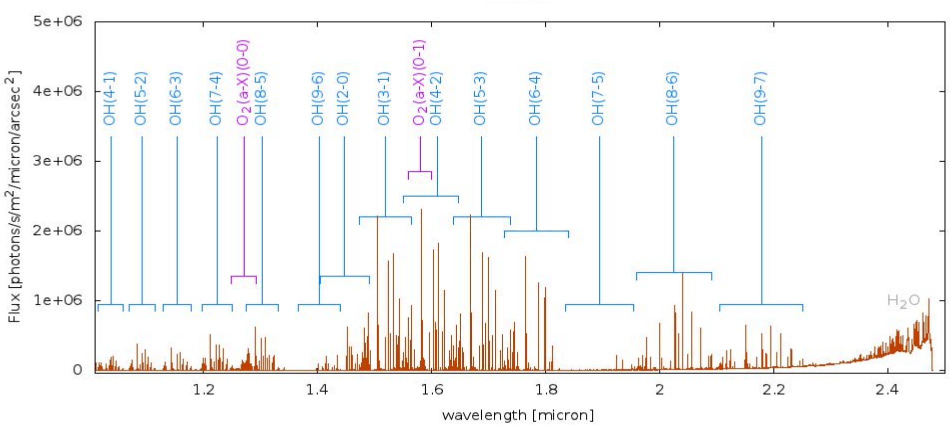
Thermal components:

- Transmission (absorption)
- Thermal radiation

taken into account by ([1], [2], [3]):

- Atmospheric composition height profiles
- Radiative transfer code
- Line database

Emission (airglow)



Non-thermal components

- Chemiluminescence by OH, OI, NaD,…..

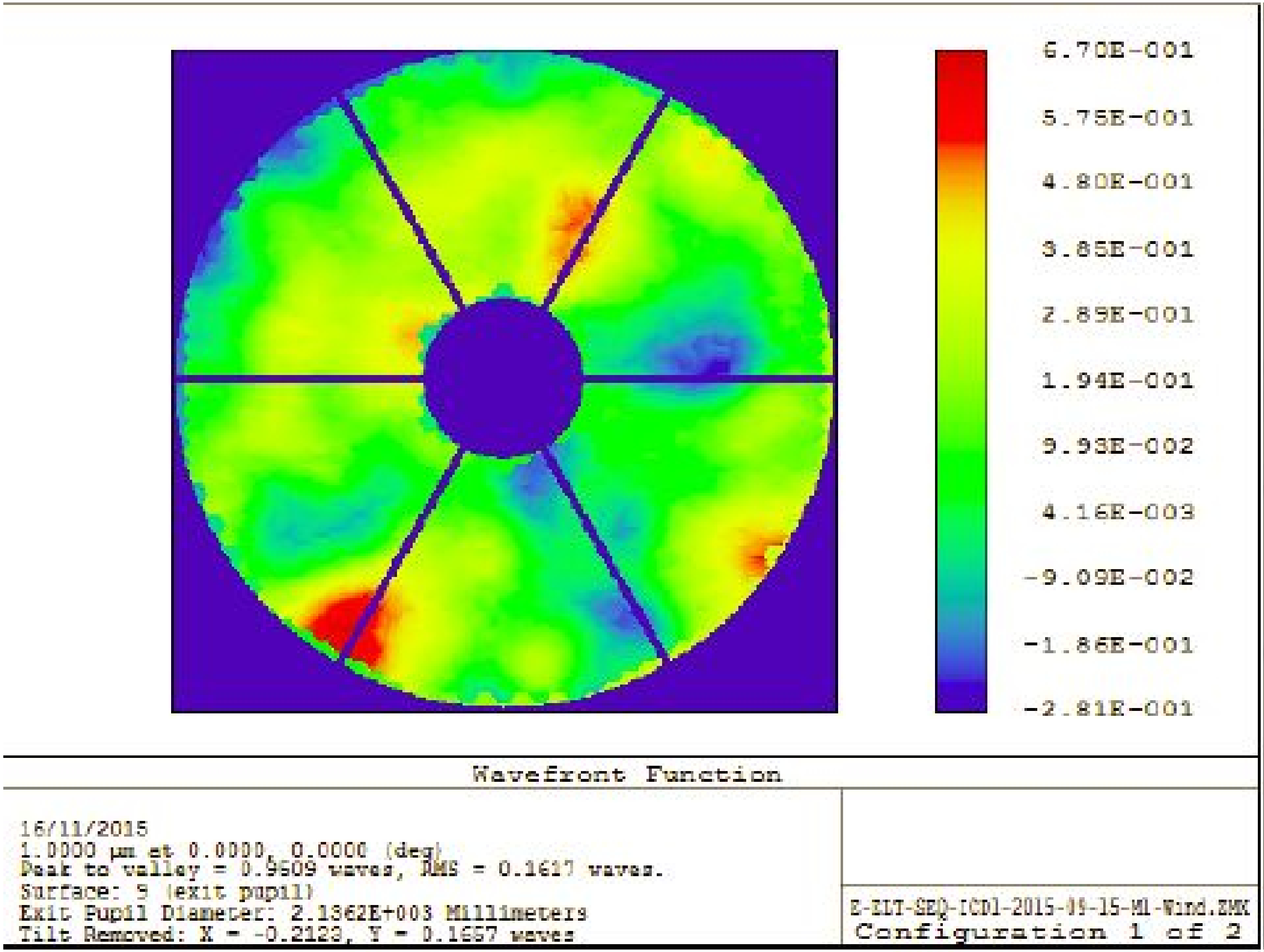
taken into account by ([4], [5]):

- advanced airglow model

[1] Noll et al., 2012, A&A, 543, 92
[2] Smette et al., 2015, A&A, 576, A77
[3] Kausch et al., 2015, A&A, 576,A78
[4] Noll et al, 2014, A&A, 568, 9
[5] Noll et al., 2015, ACP, 15, 3647

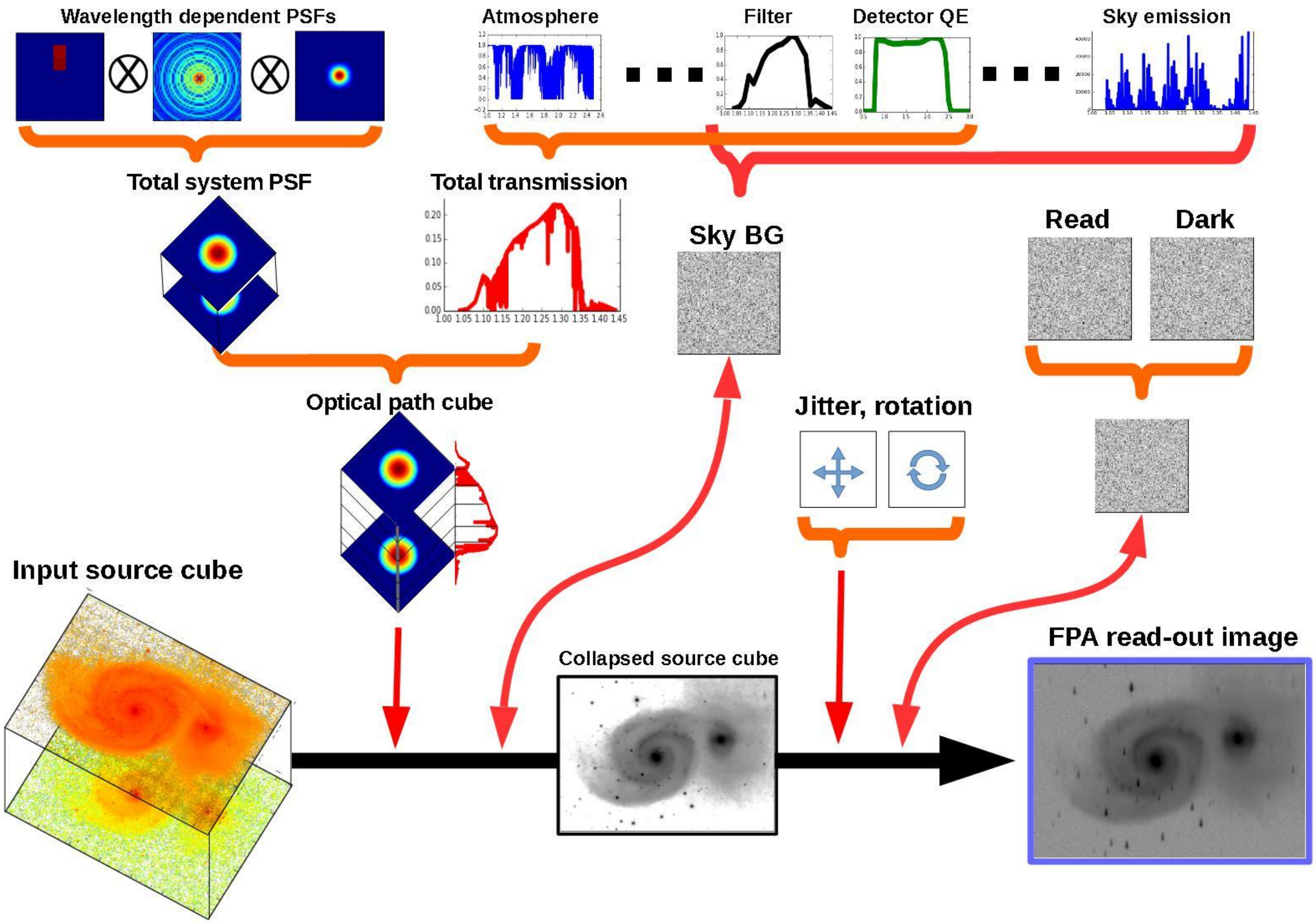
Telescope model

Pistion, tip, tilt of each segment, Exit pupil wind on M1, RMS = 162nm



Pott, Rodeghiero (MPIA)

SimCADO



Leschinski, Czoske, et al. ADASS 2015, in press

observing an Observatory
AND
observing a Universe

Pipeline design phase question 2:

([science-pixdata],[observatory-pixdata] | Observables)

observing an Observatory
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Pipeline design phase question 2:

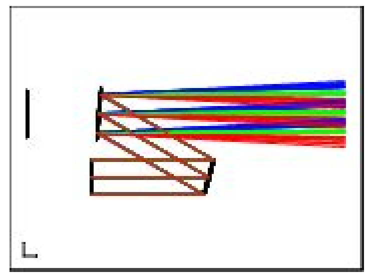
P([science-pixdata],[observatory-pixdata] | Observables)

Spectroscopic calibration

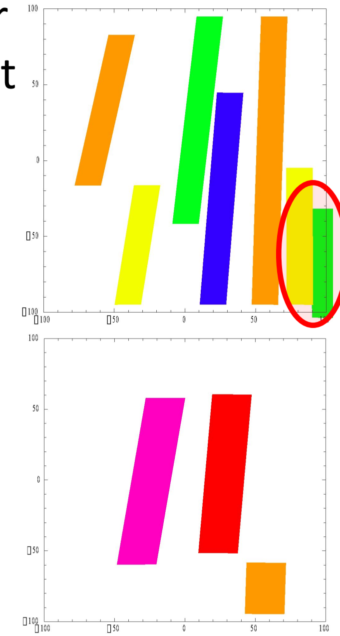
Basic workflow known, but some major challenges / unknowns:

- Adaptive optics influence on flux calibration
- Rectification / merging of the Echelle orders
- No Flux/Telluric/RV Standards available yet

Cross disperser



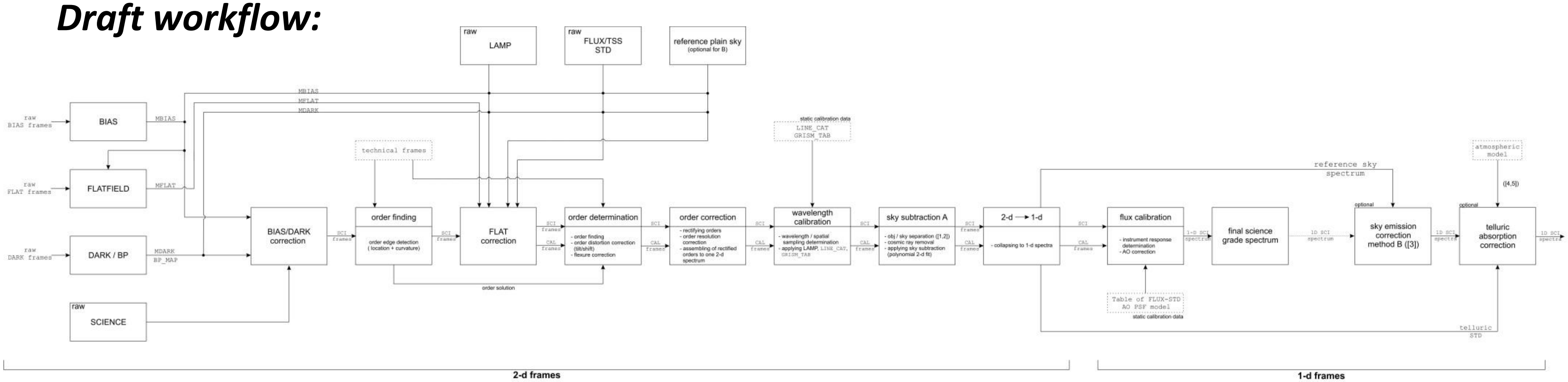
Order layout



order X-talk!!

(R. Davies)

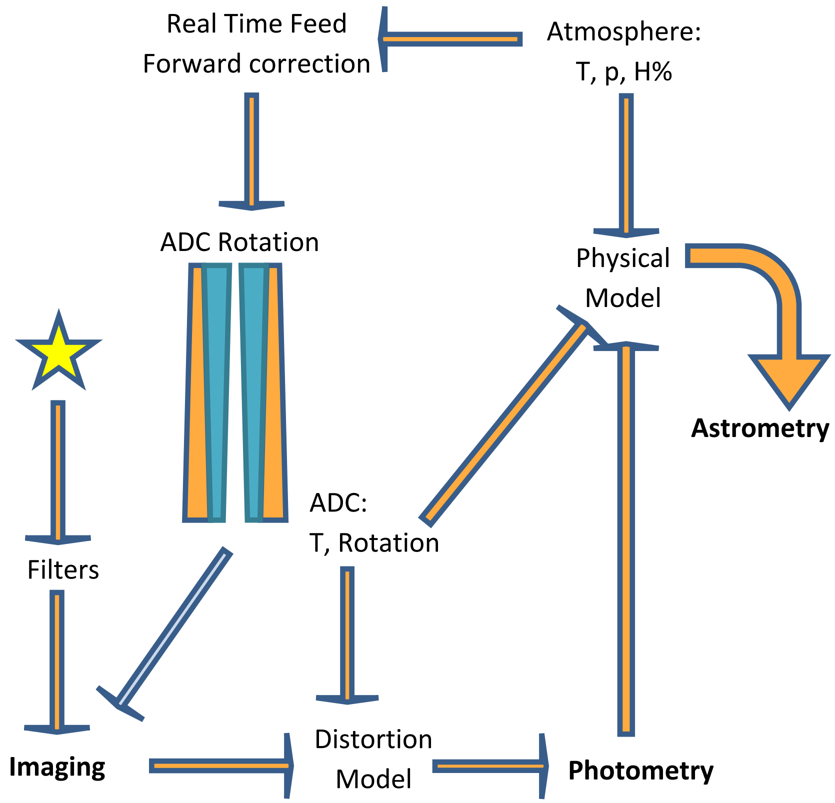
Draft workflow:



preparation calibration / rectification / correction post processing

Photometric / astrometric calibration

.



Calibration scientist's view:

	Outerspace	Atmosphere	Telescope	AO	MICADO
Pixel data = observatory ⊛ science	Science object	Composition model (thermal / non-thermal)	M1	SCAO	Entrance window
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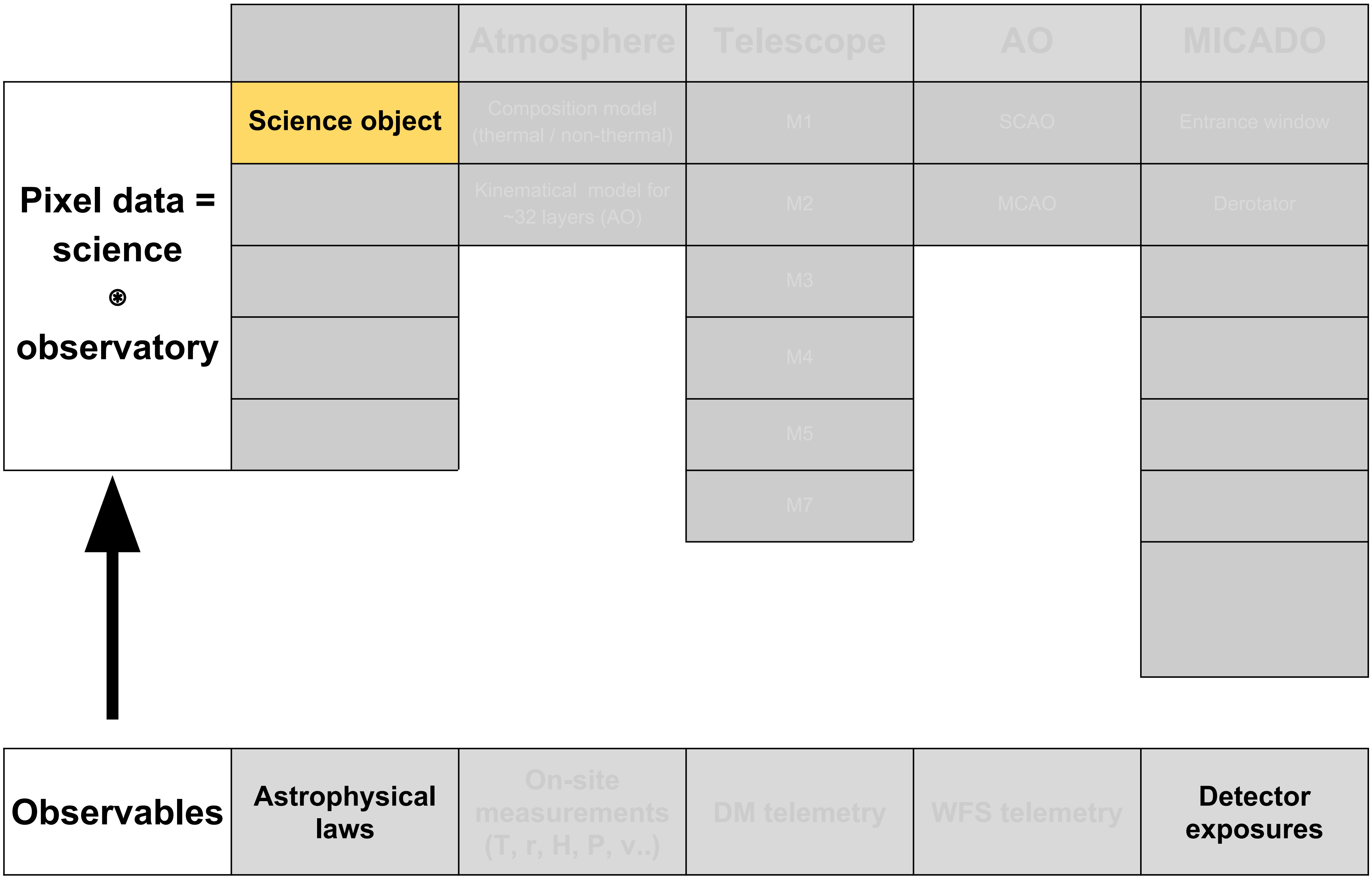
Observables	**Astrophysical laws**	**On-site measurements (T, r, H, P, v..)**	**DM telemetry**	**WFS telemetry**	**Detector exposures**

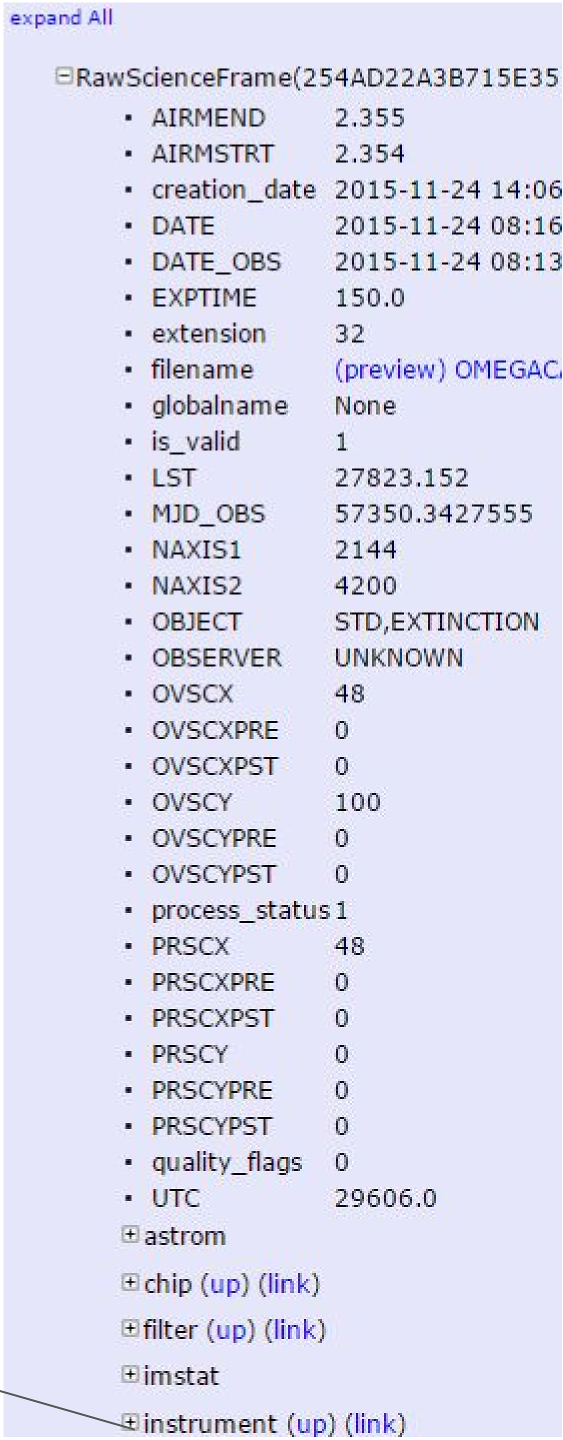
Astronomer's view



Model of the data

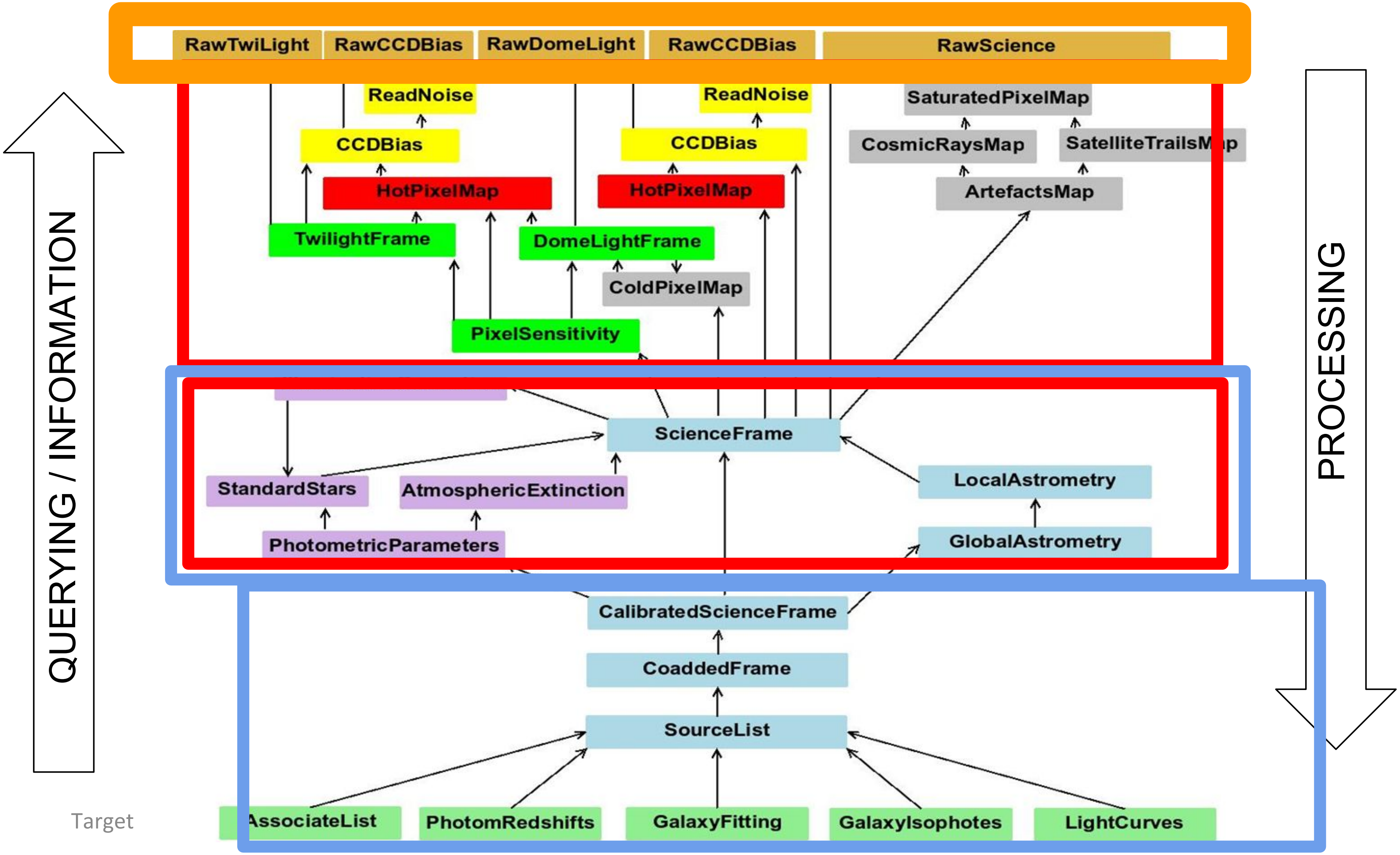
Identical observables (incl. “raw data”)
Different metadata

Derotator angle, temperature, ADC-status,...,...

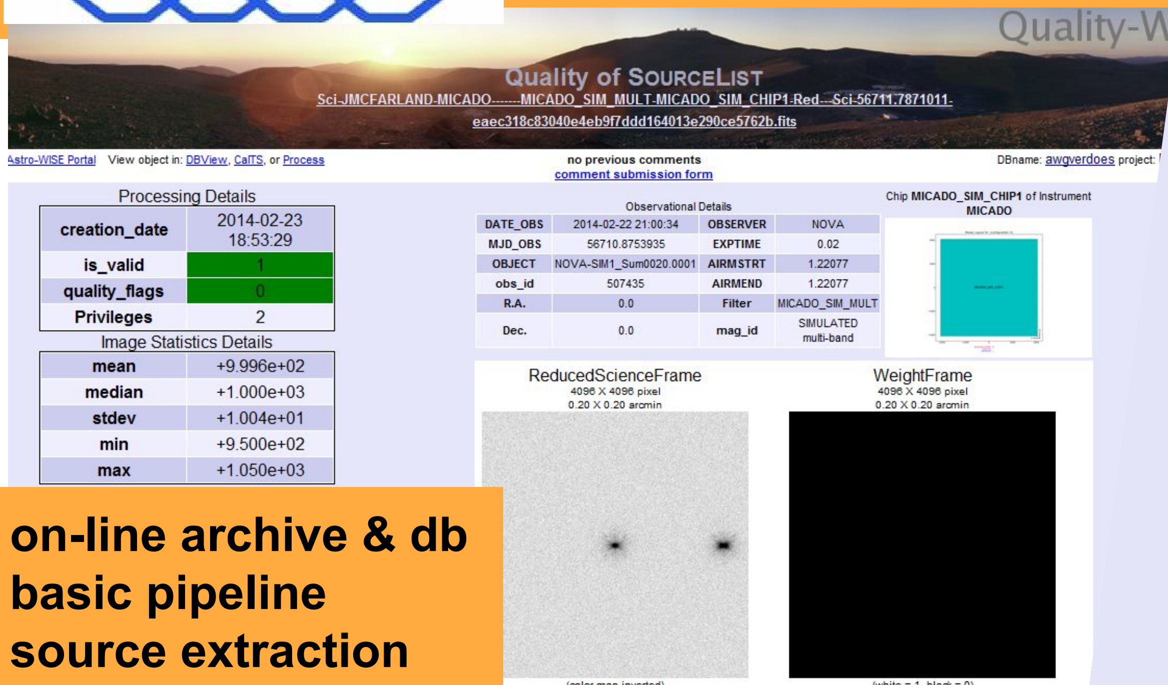


Data model

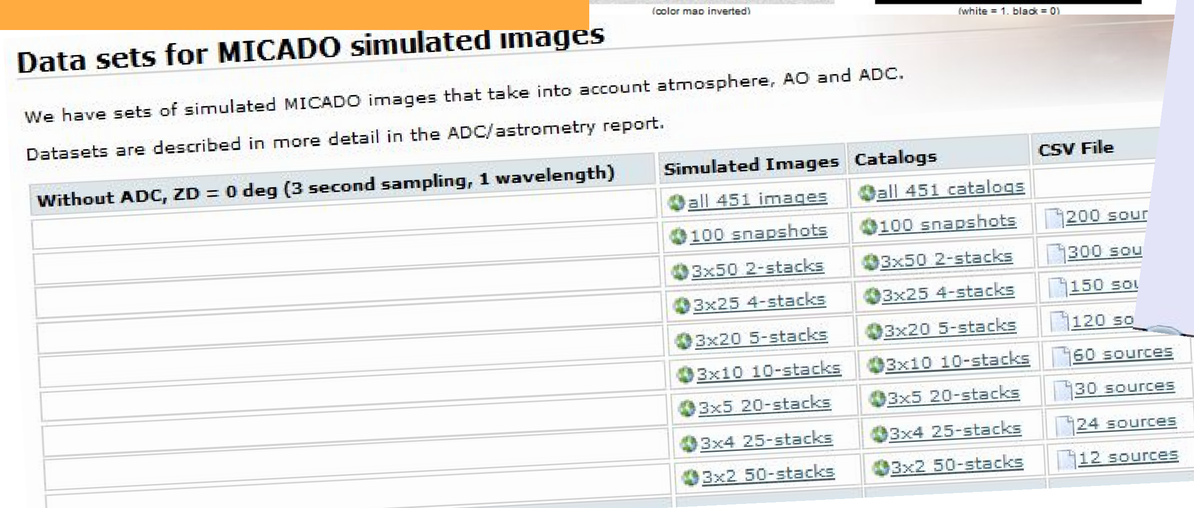
(Example from the optical imaging domain with CCDs)



ASTRO WISE : MICADO dataflow play-ground



- on-line archive & db
- basic pipeline
- source extraction



time

Everything changes in time

- Physical changes
- Our insight in modeling
- Methods, code, bugs

- > time tagging all objects in your system

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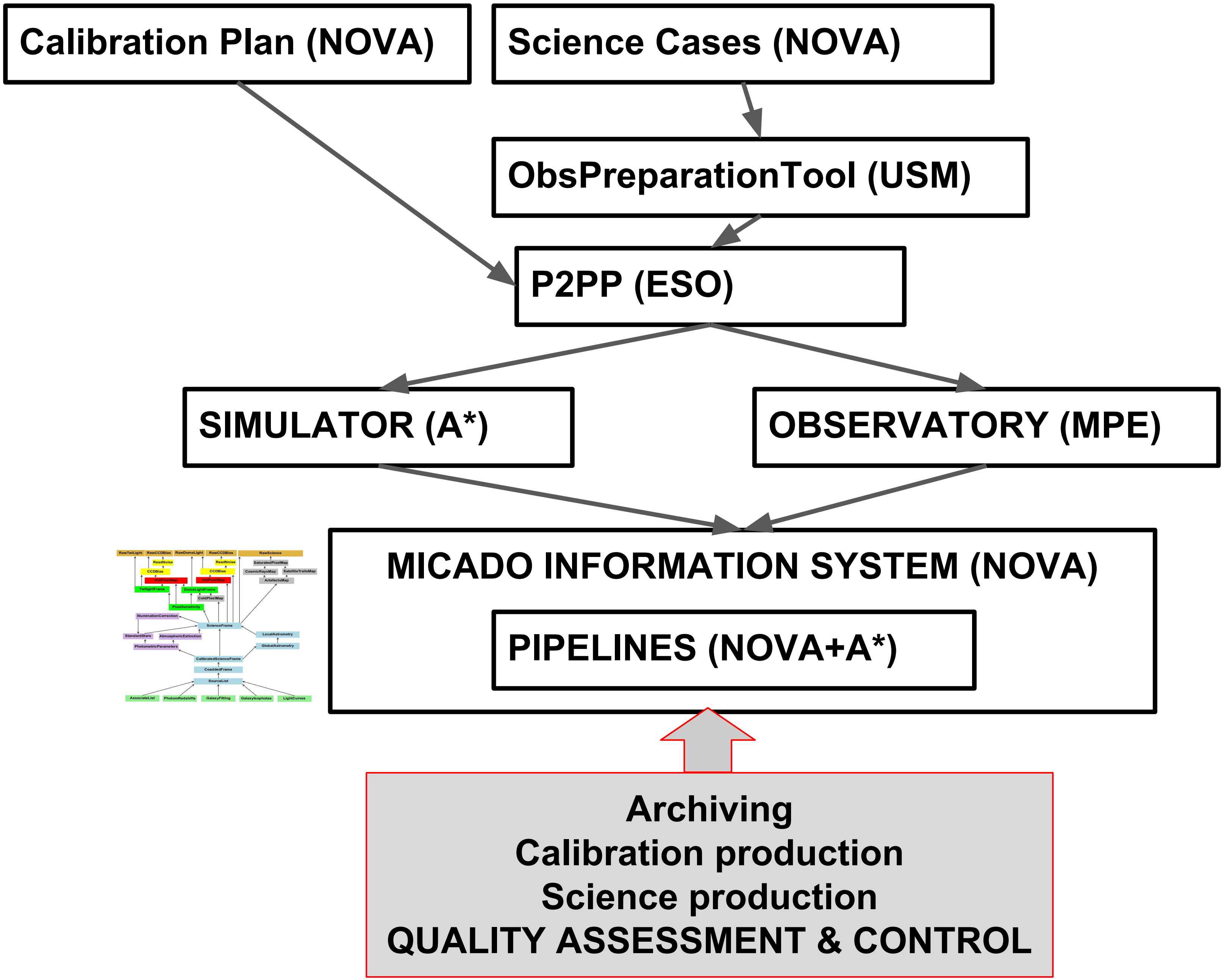
See talk by Edwin Valentijn tomorrow

See MuseWise poster by Willem-Jan Vriend before lunch

MICADO Data Flow



Approach to pipeline and information system development

1. Translate physical model into observables model
2. Use simulated observables for
   a. science case feasibility
   b. trade-off study of calibration via hardware vs via software
   c. capture “observing an observatory” AND “observing a universe” in a SINGLE data model
3. Iterate on 1-2 cycle:
   a. toy simulations -> detailed sims
   b. toy data model -> detailed data model
4. Implement a single information system for calibration scientist and astronomer

Integrate two information systems* :

- the calibration scientist
- the astronomer

*An information system integrates archiving & processing: it is a “living” archive

Integrate two information systems* :

- the calibration scientist
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Explore relations with talks by Steffen Mieske/ Burkard Wolff, Roland Walter, Ivan Zolotukhin, Pascal Ballester, Reinhard Hanuschik,...among others

*An information system integrates archiving & processing: it is a “living” archive

Find out more about MICADO here:

- Leschinski, Czoske et al., 2015, ADASS, in press
- Kausch et al., 2015, A&A, 576,A78

#	Bibcode Authors	Score Title	Date	List of Links Access Control Help
1	2014SPIE.9148E..6IV Vidal, F.; Gendron, E.; Clenet, Y.; Gratadour, D.; Rousset, G.; Davies, R.	1.000 Adaptive optics simulations for the MICADO SCAO system	08/2014	A E L T R U
2	2014SPIE.9148E..33C Cohen, Mathieu; Chemla, Fanny; Busy, Tristan; Gendron, Eric; Hubert, Zoltan; Hartl, Michael; Clenet, Yann; Davies, Richard	1.000 Optical design of the relay optics for the MICADO SCAO system	08/2014	A E L T R
3	2014SPIE.9147E..9EB Baudoz, Pierre; Boccaletti, Anthony; Lacour, Sylvestre; Galicher, Raphaël; Clenet, Yann; Gratadour, Damien; Gendron, Eric; Busy, Tristan; Rousset, Gerard; Hartl, Michael; Davies, Richard	1.000 The high contrast imaging modes of MICADO	08/2014	A E L T R U
4	2014SPIE.9148E..0ZC Clenet, Yann; Buey, Tristan M.; Rousset, Gerard; Cohen, Mathieu; Feautrier, Philippe; Gendron, Eric; Hubert, Zoltan; Chemla, Fanny; Gratadour, Damien; Baudoz, Pierre; and 14 coauthors	1.000 Overview of the MICADO SCAO system	07/2014	A E L T R C U
5	2014SPIE.9147E..9FL Lacour, S.; Baudoz, P.; Gendron, E.; Boccaletti, A.; Galicher, R.; Clenet, Y.; Gratadour, D.; Buey, T.; Rousset, G.; Hartl, M.; Davies, R.	1.000 An aperture masking mode for the MICADO instrument	07/2014	A E L X T R
6	2014SPIE.9145E..4HK Keck, Alexander; Pott, Jörg-Uwe; Sawodny, Oliver	1.000 Accelerometer-based position reconstruction for the feedforward compensation of fast telescope vibrations in the E-ELT/MICADO	07/2014	A E L T R
7	2013aoel.confE..29C Clenet, Yann; Gratadour, Damien; Gendron, Eric; Rousset, Gerard; Sevin, Arnaud	1.000 First GPU-based end-to-end AO simulations to dimension the E-ELT MICADO SCAO mode	12/2013	A E F L T U
8	2012SPIE.8447E..4WK Keck, Alexander; Pott, Jörg-Uwe; Ruppel, Thomas; Sawodny, Oliver	1.000 Development of new concepts to minimize the impact of fast telescope vibrations seen by the E-ELT/MICADO wavefront sensors	07/2012	A E L T R
9	2011aoel.confP..23C Clenet, Y.; Bernardi, P.; Chapron, F.; Gendron, E.; Rousset, G.; Hubert, Z.; Davies, R.; Thiel, M.; Tromp, N.	1.000 The SCAO module of the E-ELT adaptive optics imaging camera MICADO	09/2011	A E
10	2010SPIE.7736E..3QC Clenet, Y.; Bernardi, P.; Chapron, F.; Gendron, E.; Rousset, G.; Hubert, Z.; Davies, R.; Thiel, M.; Tromp, N.; Genzel, R.	1.000 SAMI: the SCAO module for the E-ELT adaptive optics imaging camera MICADO	07/2010	A E L T C
11	2010SPIE.7735E..5GM Magrin, Demetrio; Ragazzoni, Roberto; Freeman, David E.; Eisenhauer, Frank; Tromp, Niels; Drost, Marco; Navarro, Ramon; Davies, Richard; Genzel, Reinhard	1.000 MICADO: optical configuration, performance, and folding	07/2010	A E L T
12	2010SPIE.7735E..2AD Davies, Richard; Ageorges, N.; Barl, L.; Bedin, L. R.; Bender, R.; Bernardi, P.; Chapron, F.; Clenet, Y.; Deep, A.; Deul, E.; and 36 coauthors	1.000 MICADO: the E-ELT adaptive optics imaging camera	07/2010	A E L X T R C
13	2010Msngr.140...32D Davies, R.; Genzel, R.	1.000 MICADO: The Multi-adaptive Optics Imaging Camera for Deep Observations	06/2010	A F L R C S U
14	2010MNRAS.402.1126T Trippe, S.; Davies, R.; Eisenhauer, F.; Schreiber, N. M. Förster; Fritz, T. K.; Genzel, R.	1.000 High-precision astrometry with MICADO at the European Extremely Large Telescope	02/2010	A E F L X D R C S
15	2010aoel.confE1002D Davies, Richard; Ageorges, N.; Barl, L.; Bedin, L.; Bender, R.; Bernardi, P.; Chapron, F.; Clenet, Y.; Deep, A.; Deul, E.; and 36 coauthors	1.000 Science and Adaptive Optics Requirements of MICADO, the E-ELT adaptive optics imaging camera	00/2010	A E L X T R

Atmospheric / Sky Background papers

Refereed:

Lakicevic et al, 2015, in prep
Jones et al. 2015, A&A, subm
Noll et al., 2015, acpd-15-30793-2015
Noll et al., 2015, ACP, 15, 3647
Smette et al., 2015, A&A, 576, A77
Kausch et al., 2015, A&A, 576,A78
Moehler et al, 2014, SPIE, Volume 9149, id. 91490L
Moehler et al, 2014, A&A, 568, 9
Noll et al, 2014, A&A, 568, 9
Jones et al., 2013, A&A, 560, 91
Noll et al., 2012, A&A, 543, 92

Non-Refereed:

Kimeswenger et al., 2015, AtmoHEAD 2014, EPJ Web of Conferences, Vol. 89, id.01001
Unterguggenberger et al., 2015, EGU2015-8662
Noll et al, 2015, EGU2015-2554
Kausch et al., 2015, EGU2015-3807
Moehler et al., 2014, The Messenger, vol. 158, p. 16-20
Jones et al., 2014, The Messenger, vol. 156, p. 31-34
Jones et al., 2014, AAS Meeting #224, #405.03
Noll et al., 2014, ASPC, 485, 99
Kausch et al, 2014, EGU2014-13979
Noll et al., 2014, EGU2014-12008
Unterguggenberger et al., 2014, EGU2014-11548
Jones et al., 2014, EGU2014-11013
Noll et al., 2014, ASPC, vol. 485, 99
Kausch et al., 2014, ASPC, vol. 485, 403
Jones et al., 2014, ASPC, vol. 485, 91
Noll et al., 2013, EGU2013-7980
Jones et al., 2013, EGU2013-8478
Kausch et al, 2013, EGU2013-7425
Noll et al., 2012, EGU2012-9813
Kausch et al, 2012, EGU2012-9239

END
(auxiliary slides after this)

Timeline

Date	Milestone	Comments
2015, Oct	Kick-Off	Preliminary Design Phase (B) begins with a 1.5-year baseline & interface consolidation phase.
2017, Apr	System Requirements Internal Review	Once the system baseline is defined, the design will be developed more fully over the following 1.5 years
2018, Oct	**Preliminary Design Review**	Following this review, the project can begin the Final Design Phase (C).
2020, Oct	**Final Design Review**	Following this review, project will enter Manufacturing, Assembly, Test, and Integration Phase (D).
2022, May	MAIT Mid-term Meeting	Progress will be formally assessed half-way through the MAIT Phase.
2023, Oct	PAE Document Review (= Test Readiness Review, start of PAE process)	This will take place 6 months before the scheduled date for the European Acceptance Review, to confirm the instrument is ready to begin formal testing during that period
2024, Jun	**Preliminary Acceptance Europe**	This will take place once testing is completed and the reports are written. The instrument will be shipped to the observatory once this review is passed.
From 2025	**Provisional Acceptance in Chile**	Telescope technical first light with ~480 segments early 2024; Telescope commissioning with all segments from Dec 2024; MICADO commissioning 1 with SCAO module; MICADO commissioning 2 with MAORY.

06 Oct 2015 Kick-Off Design Phase → Dec 2024 MICADO First Light

Florian Kerber
ESO PM

Ric Davies
MICADO PI

Eckhardt Sturm
MICADO PM

Joseph Schubert
MICADO SE

Eline Tolstoy
MICADO Project Scientist

Joerg-Uwe Pott
MICADO Calibration Scientist

Ramon Navarro
NOVA PM / hardware