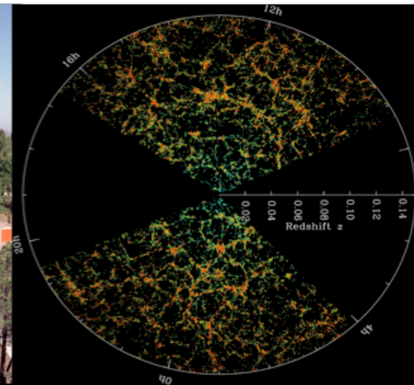
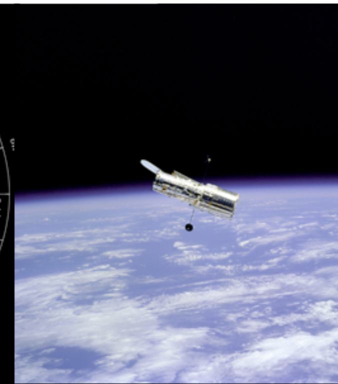
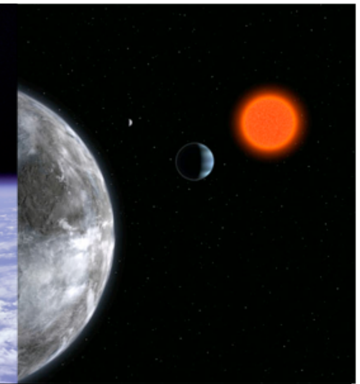
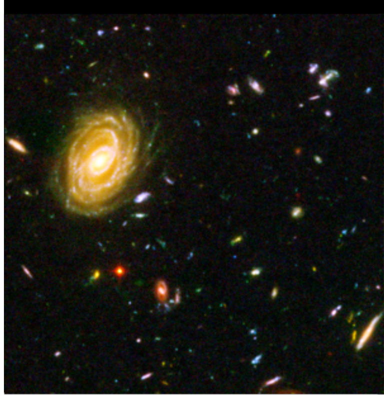
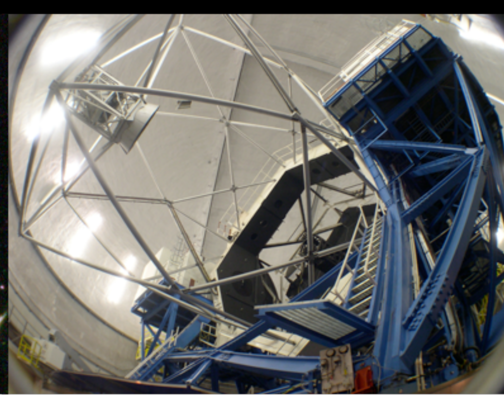


Simulating the Large Synoptic Survey Telescope

Andrew Connolly
University of Washington

What are the science questions of the next decade?

Finding the unusual

- Billion sources a night
- Nova, supernova, GRBs
- Instantaneous discovery

Finding moving sources

- Asteroids and comets
- Proper motions of stars

Mapping the Milky Way

- Tidal streams
- Galactic structure

Dark energy and dark matter

- Gravitational lensing
- Slight distortion in shape
- Trace the nature of dark energy

How do they map to computational challenges?

Finding the unusual

- Anomaly detection
- Dimensionality reduction
- Cross-matching data

Finding moving sources

- Tracking algorithms
- Kalman filters

Mapping the Milky Way

- Density estimation
- Clustering (n-tuples)

Dark energy and dark matter

- Computer vision
- Weak Classifiers
- High-D Model fitting

Science is driven by precision and issues of complexity:

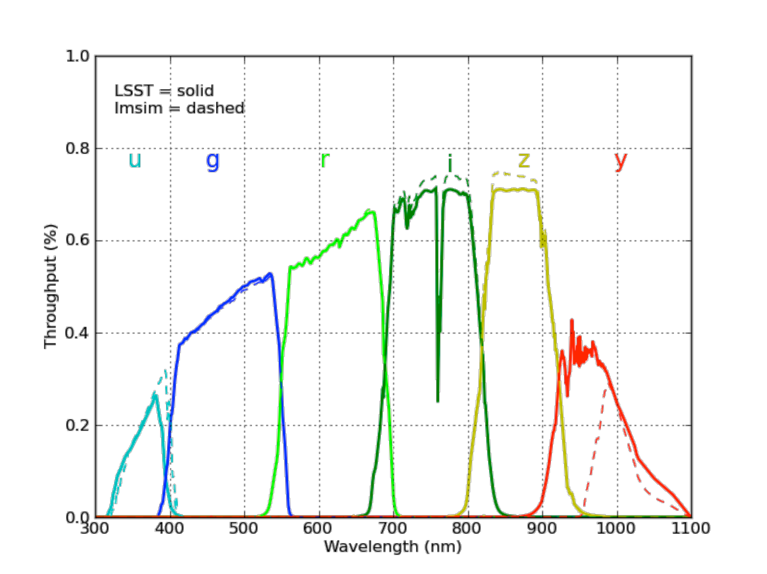
1. **Complex models of the universe**
   What is the density distribution and how does it evolve
   What processes describe star formation and evolution

2. **Complex data streams**
   Observations provide a noisy representation of the sky

3. **Complex scaling of the science**
   Scaling science to the petabyte era
   Learning how to do science without needing a CS degree

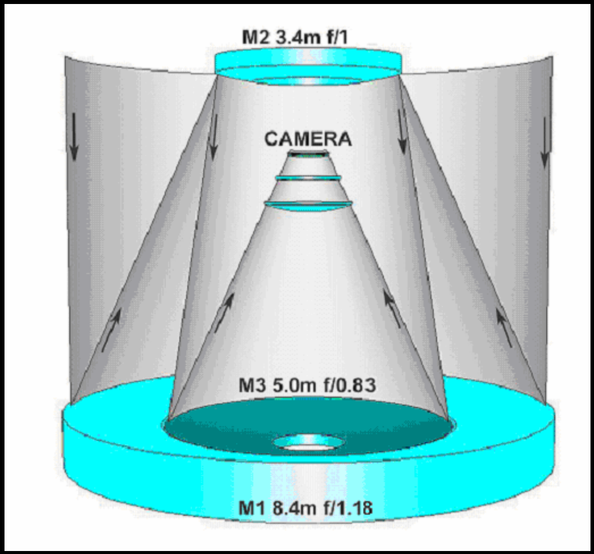
The LSST drives this complexity

- 6-band Survey: *ugrizy*
  - 320–1080 nm
- Frequent revisits
  - 2x15s, 25 AB mag/visit
- Sky area covered
  - >20,000 deg^2, 0.2 arcsec/pixel
- Each 9.6 sq.deg FOV revisited
  - ~1000 times
- 10-Year Duration
  - Yields 27.7 AB magnitude @5σ
- Photometric precision
  - 0.01 mag absolute; 0.005 mag repeatability

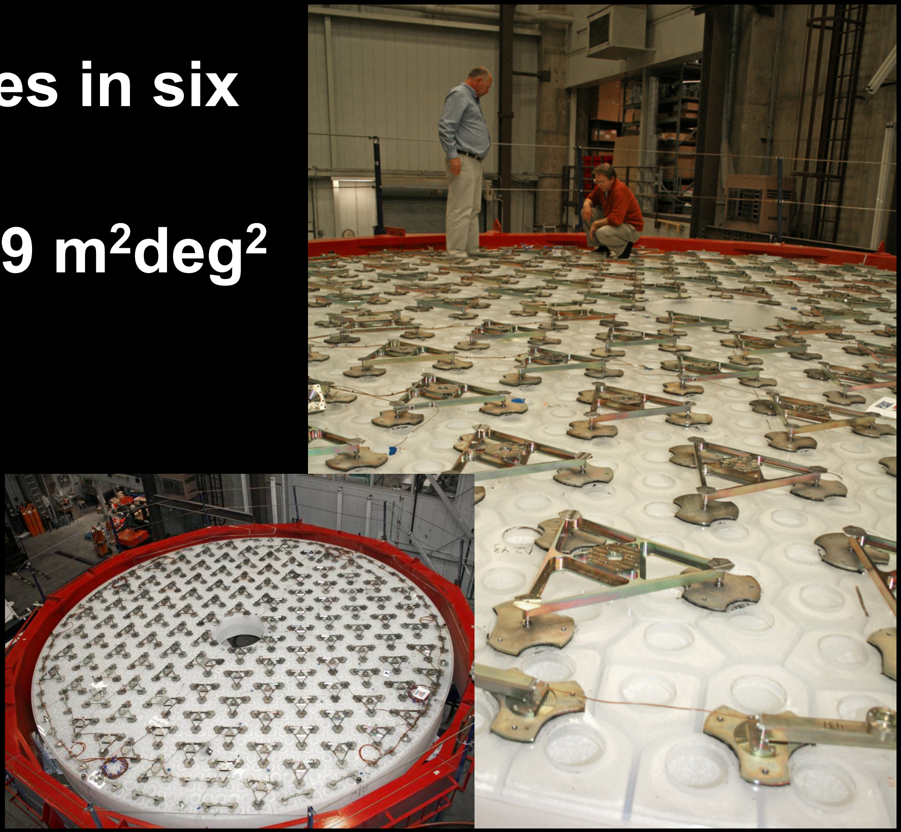


LSST Optical Design

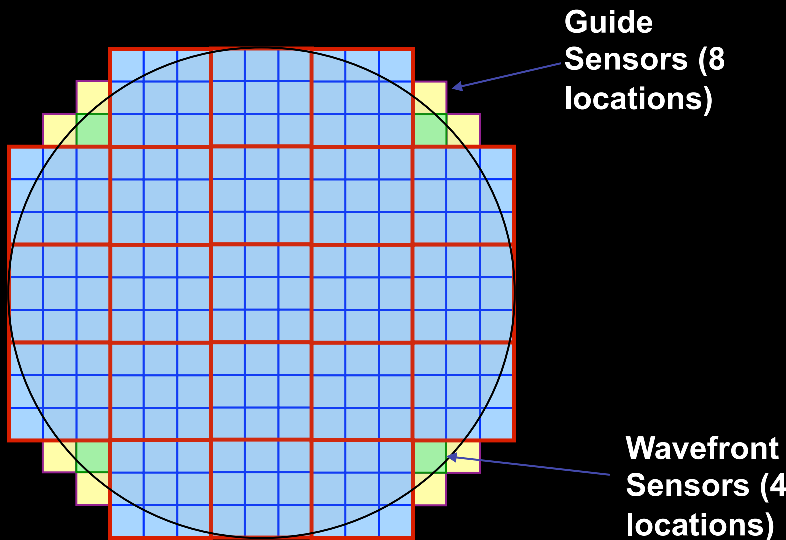
- *f/1.23*
- < 0.20 arcsec FWHM images in six bands: 0.3 - 1 μm
- 3.5 ° FOV → Etendue = 319 m^2deg^2

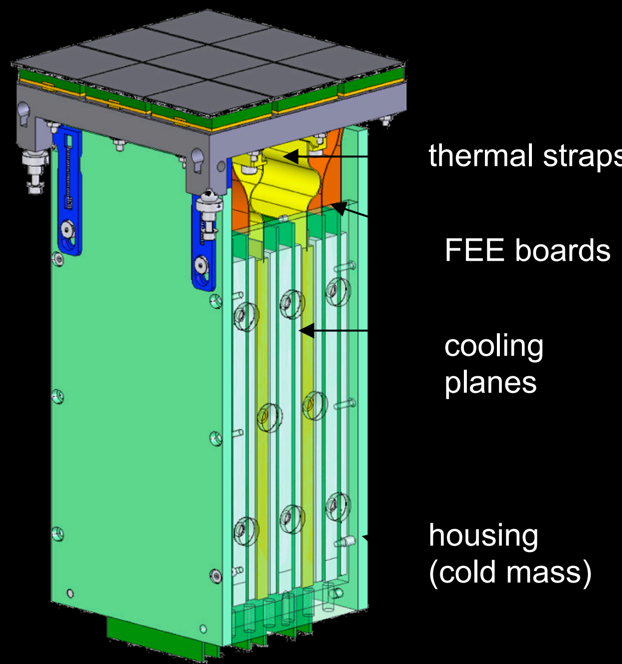


LSST optical layout



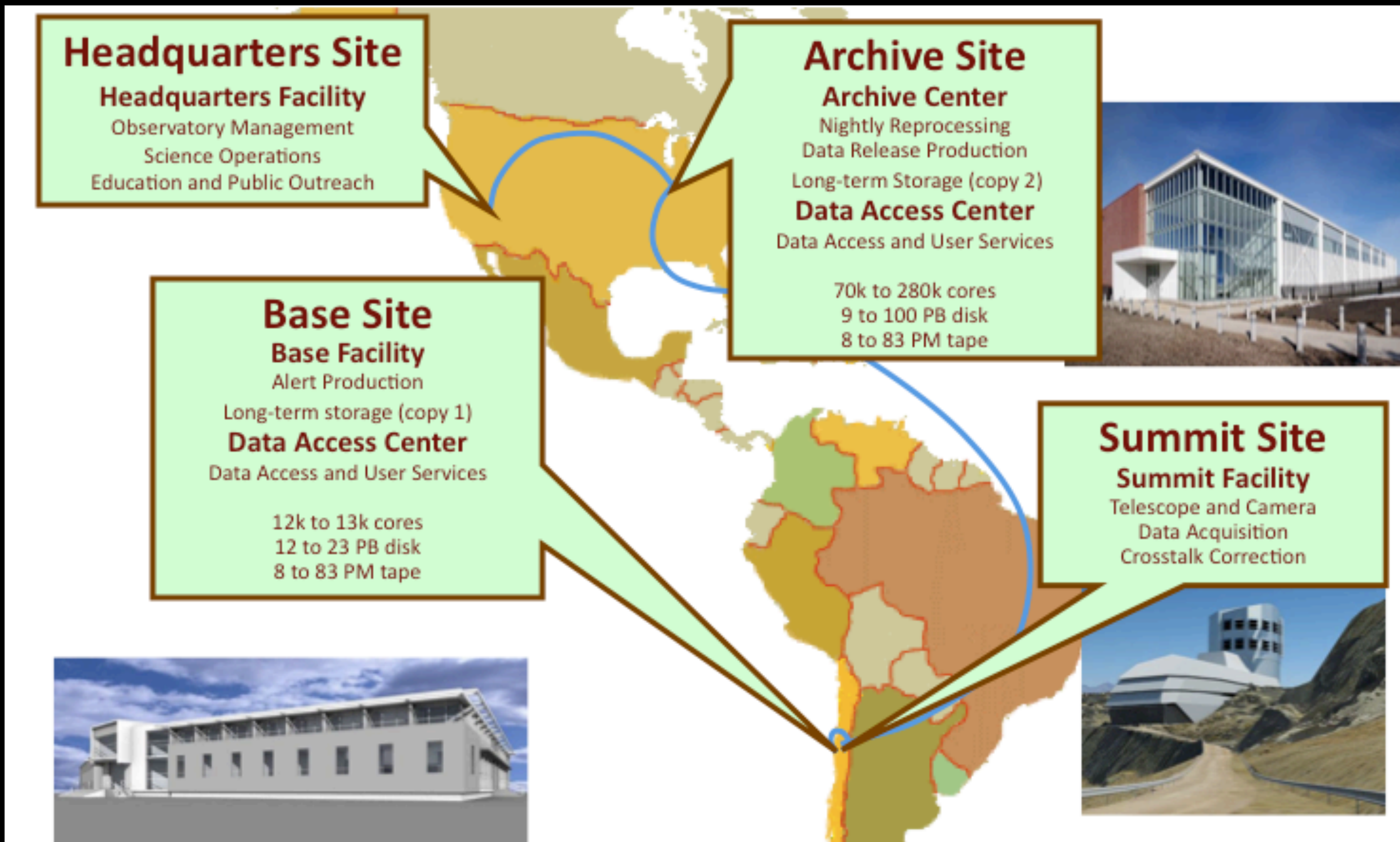
The LSST Focal Plane - 64 cm in Diameter



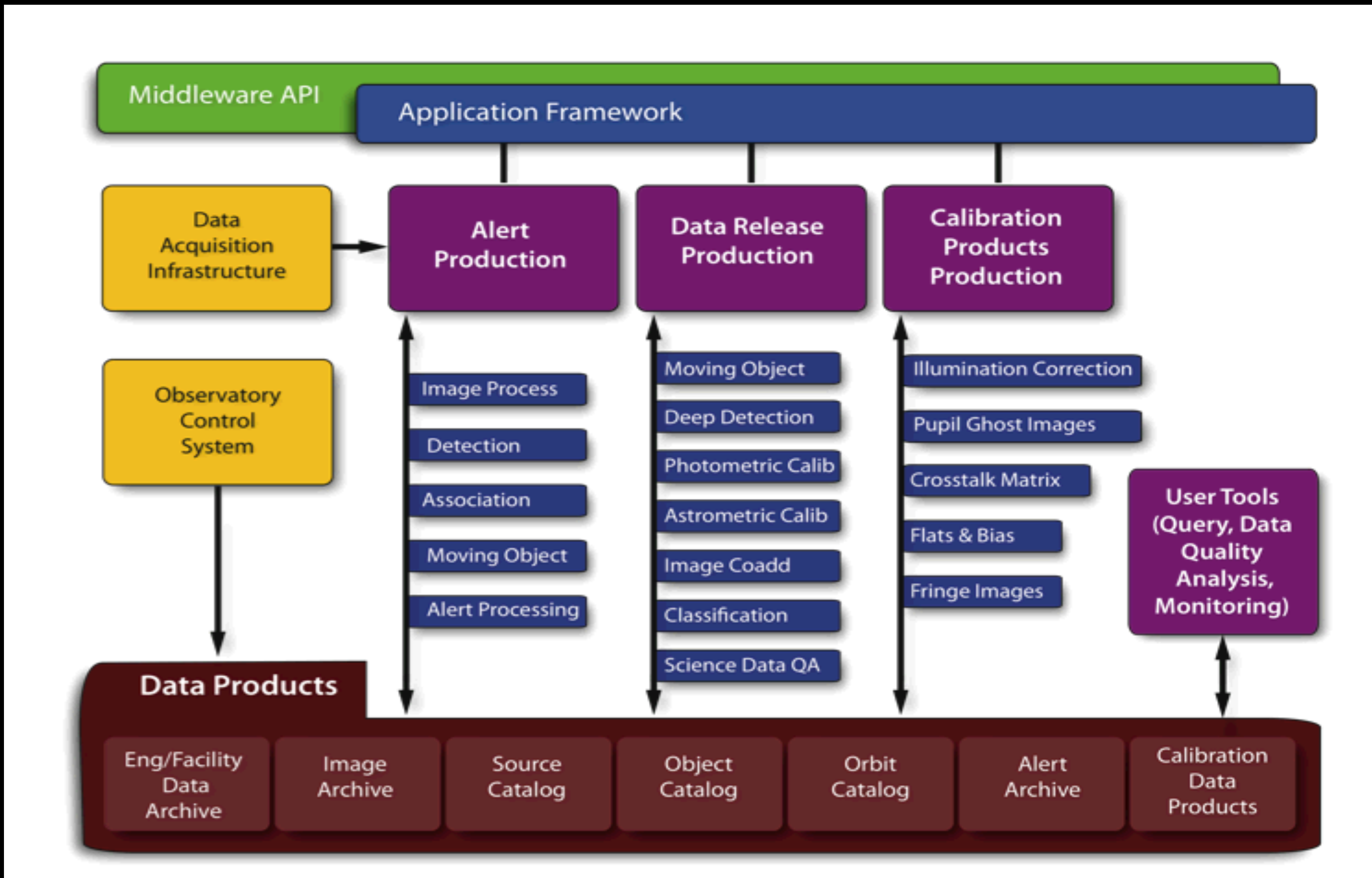


TOWER
- CCDs + front end electronics
- 180K operation
- An autonomous, fully-testable
144 Mpixel camera

One System, Two Continents, Four Sites



Overall Data Management Pipeline Organization



How do we prepare for and optimize a survey?

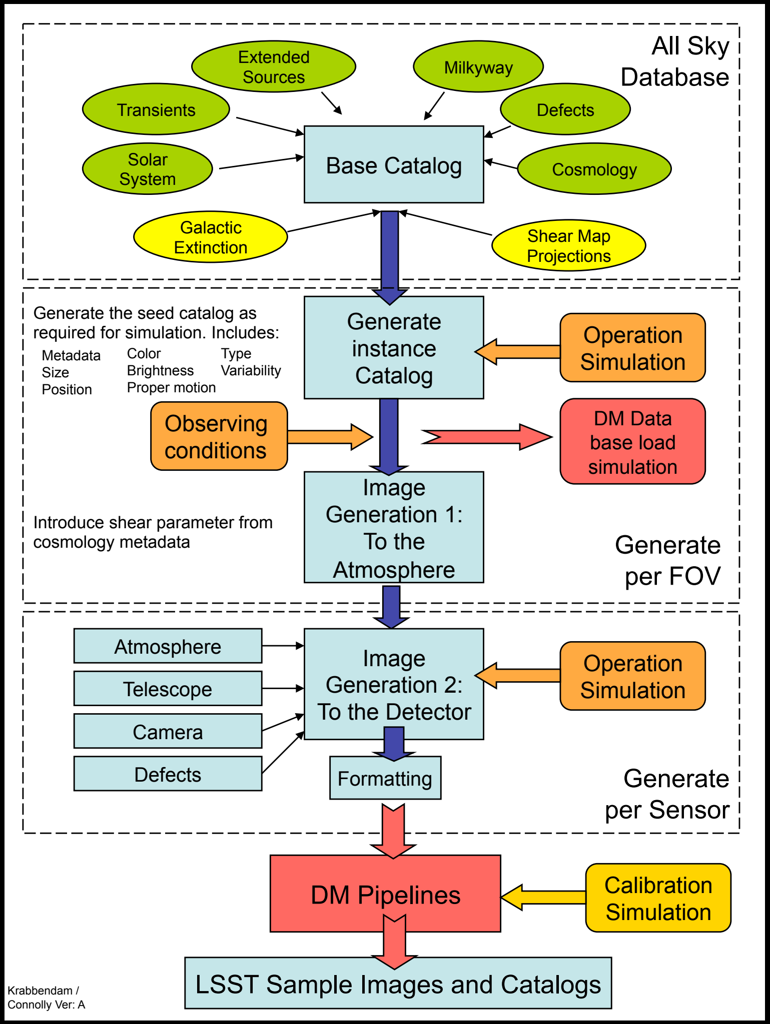
New philosophy of development through high fidelity simulations

Components:

- Survey strategy
- Source catalogs
- Images
- Processing
- End-to-end processing

Algorithms:

- Source detection and image subtraction
- Classification
- Linkage of moving sources
- Scalability



Broad range of sources

Galaxies (de Lucia et al)

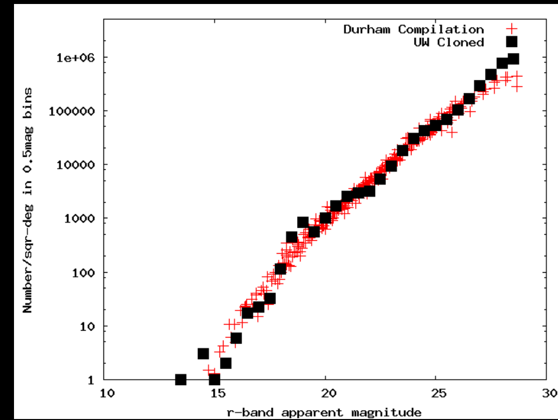
Cosmology from n-body simulations
10^6 sources/ sq deg (r<28)
Morphology, AGN, lenses, variability

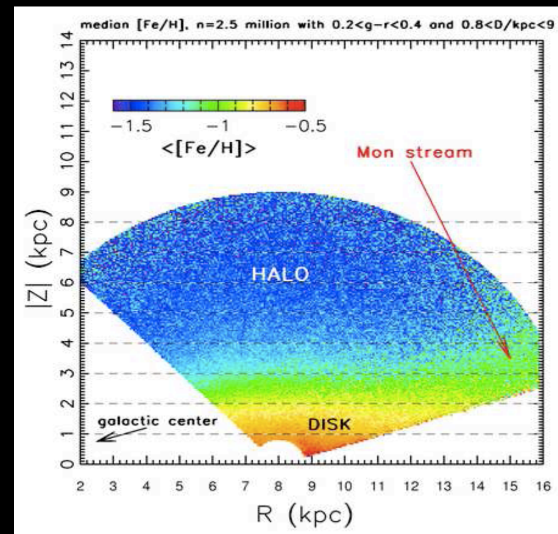
Stars (Juric et al)

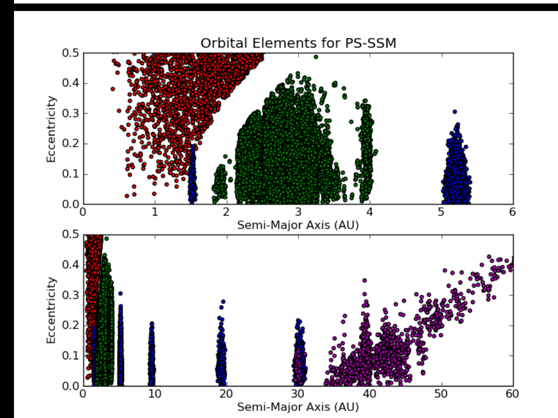
Galactic structure model
Main sequence, giants, dwarfs
Cepheids, flare stars, micro-lensing
Proper motion, parallax

Asteroids (Grav et al)

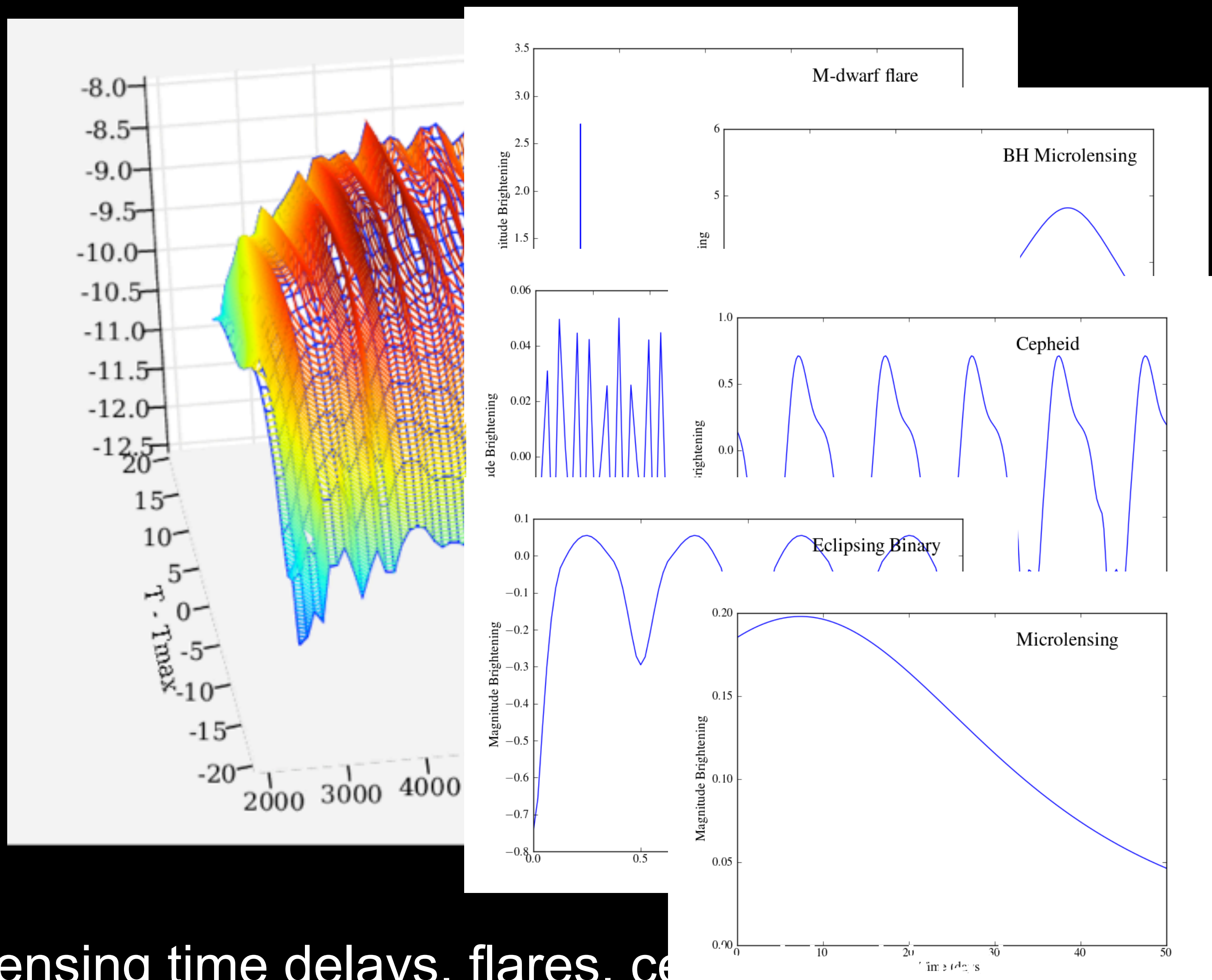
Solar system model
10 million main belt
KBO, TNO, Trojans….





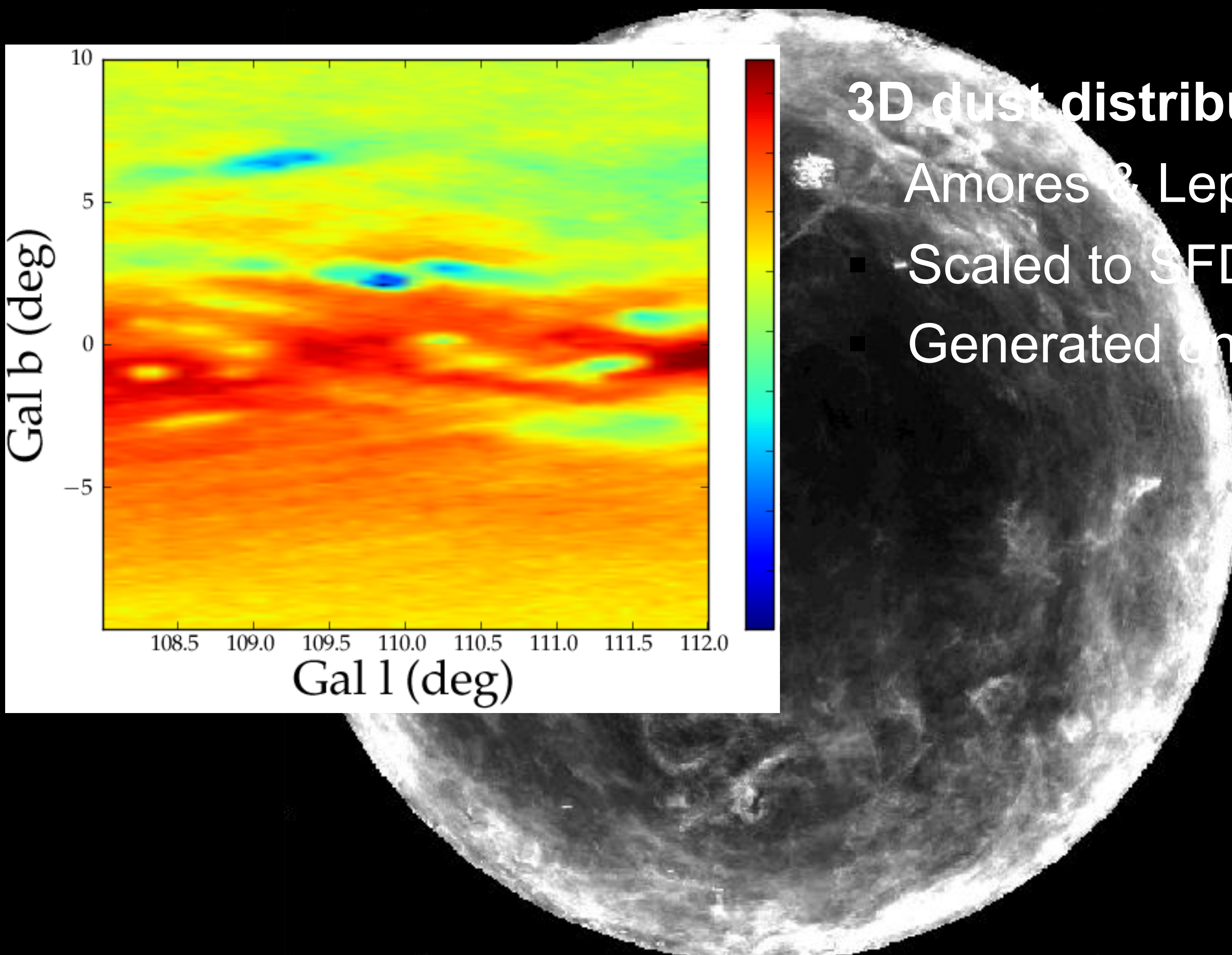


Variability in the universe



AGN, lensing time delays, flares, ce

Modeling the distribution of dust



3D dust distributions

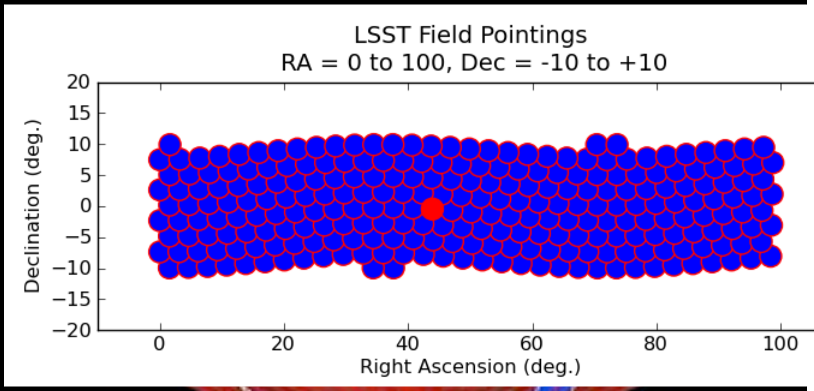
- Amores & Lepine (2005)
- Scaled to SFD at 100 kpc
- Generated on the fly

Distance is 1 kpc, compare to SFD98 maps

"Observing" the LSST simulation

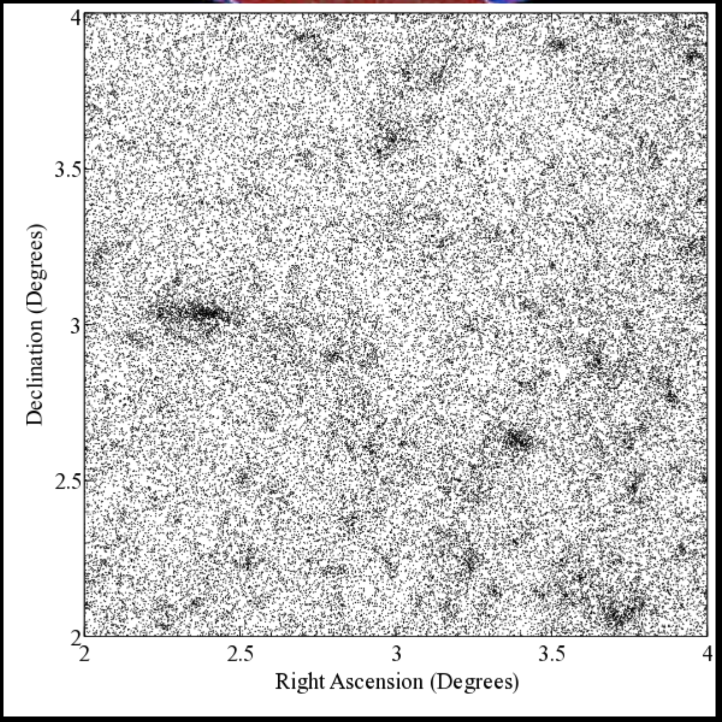
Reference catalogs

SQL queries return the properties of stars, galaxies (at a common time and airmass)



Observing sequences

Operations simulator provides lists of pointings with positions, filter, time, airmass, atmosphere…



Customized views

Different physics and populations can be selected (Solar System sources or the effect of aberration) and for large areas and volumes

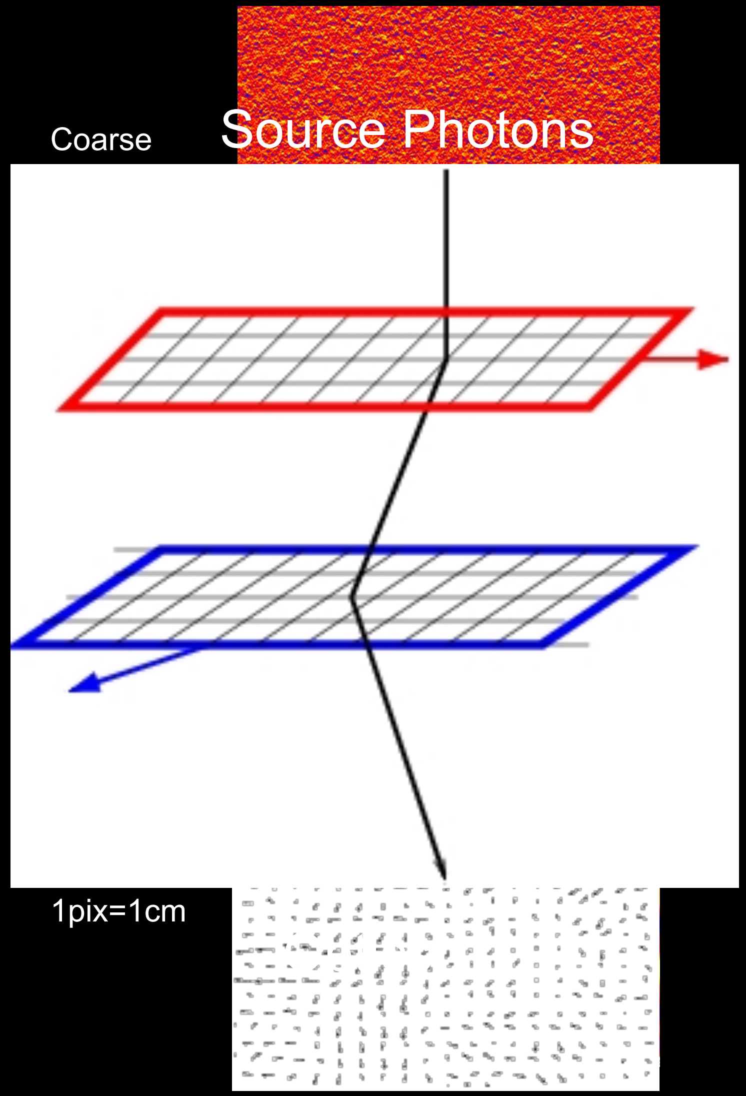
From points to pixels (and back)

Generating images

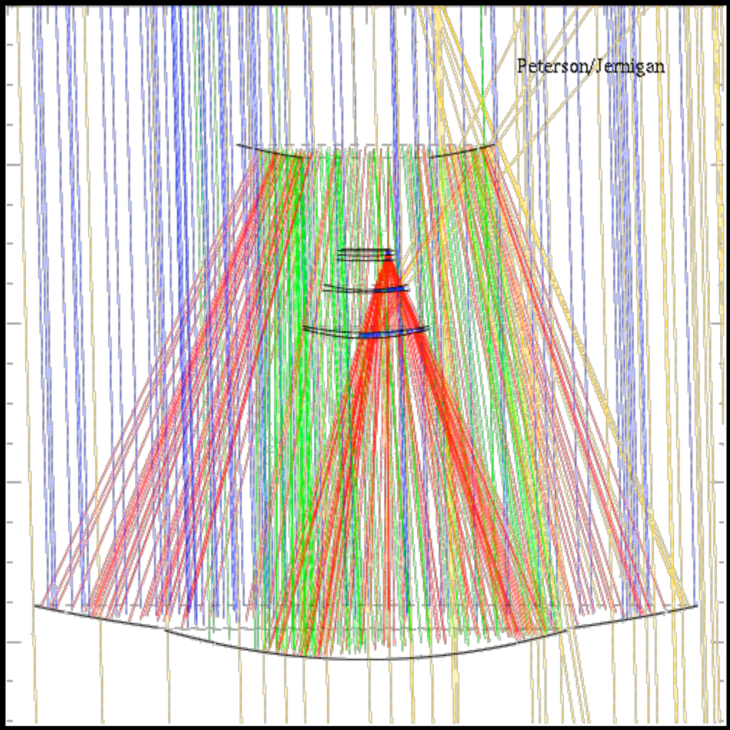
From a parameterized view above the atmosphere to the distortions from the atmosphere, telescope and camera

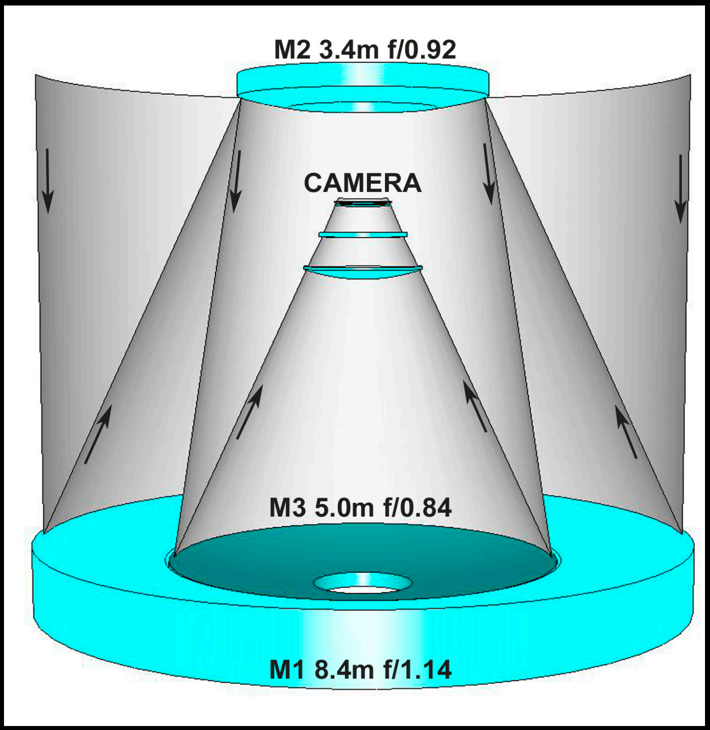
Turbulent atmosphere

Modeled as a series of frozen screens moving at 20m/s, refracting light based on the wavelength, cloud scattering and atmosphere.



The impact of optics

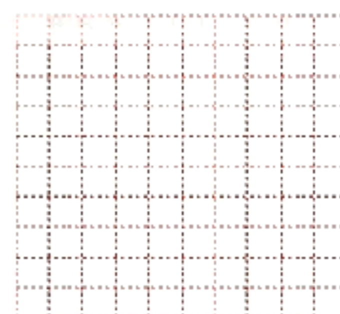




Telescope model

Three mirror modified Paul-Baker design
Fast ray-trace algorithm
Perturb the surfaces (1300) to determine the impact of control system
Conversion of photons to electrons

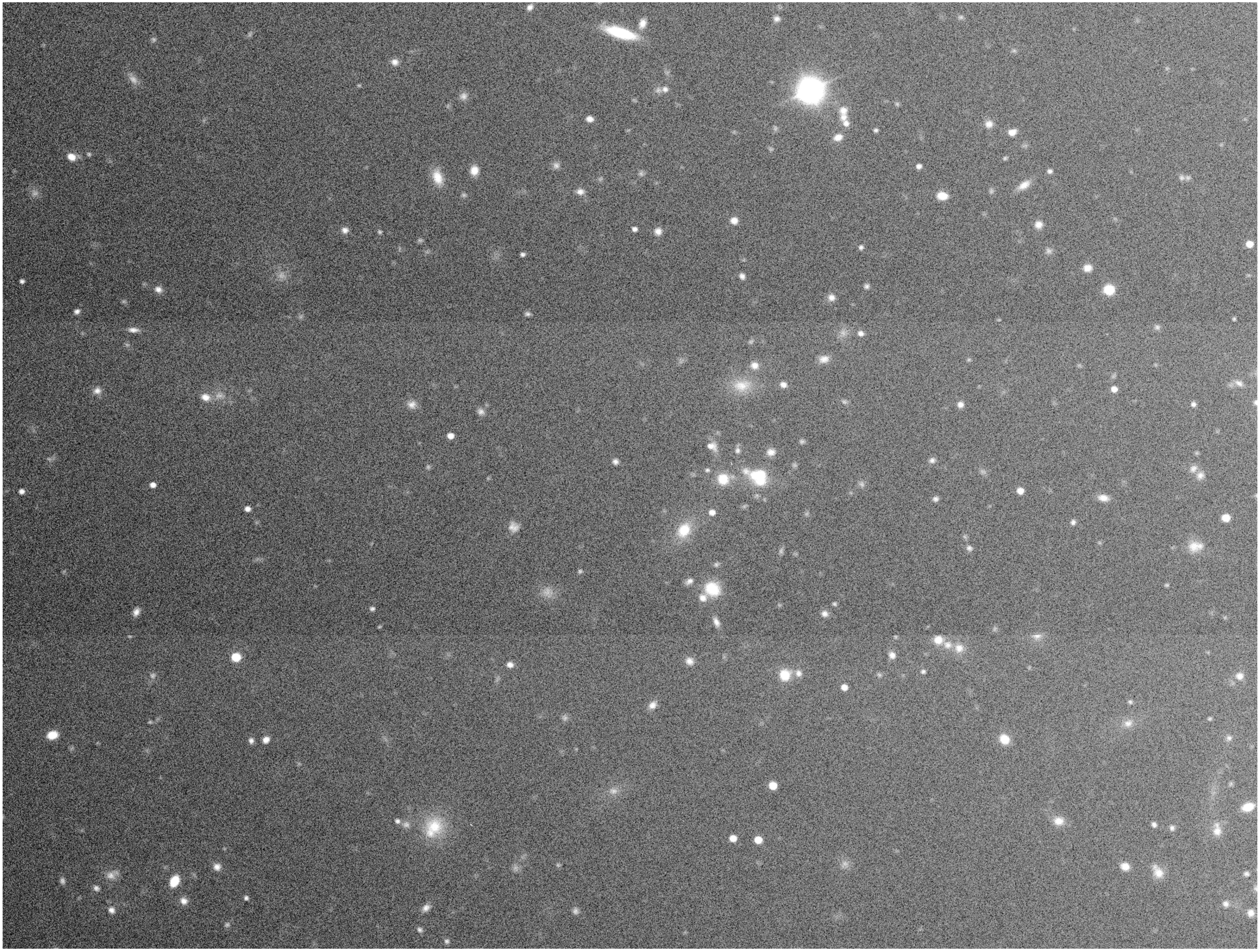
Following the photon flow…

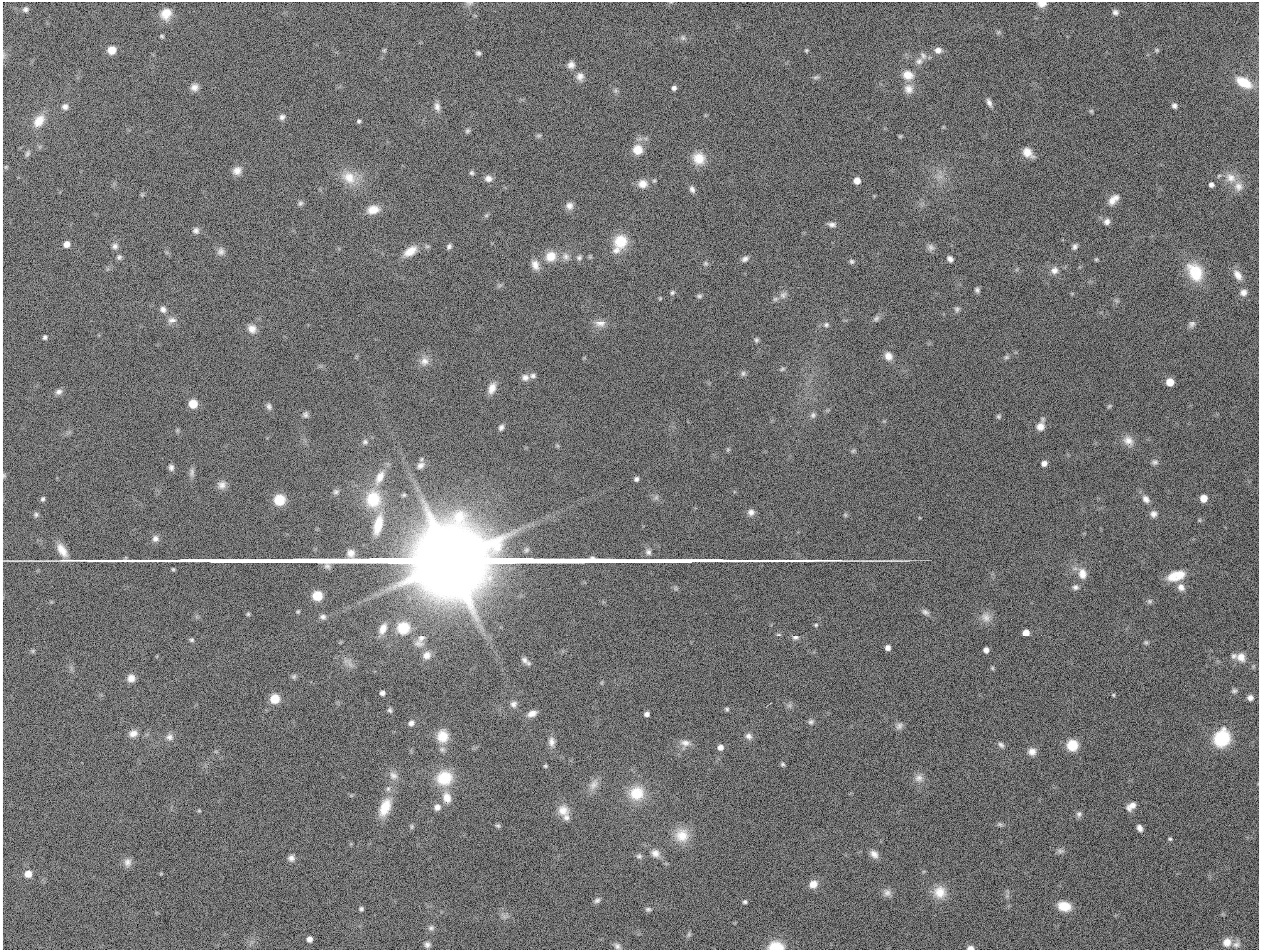


John Peterson 2010

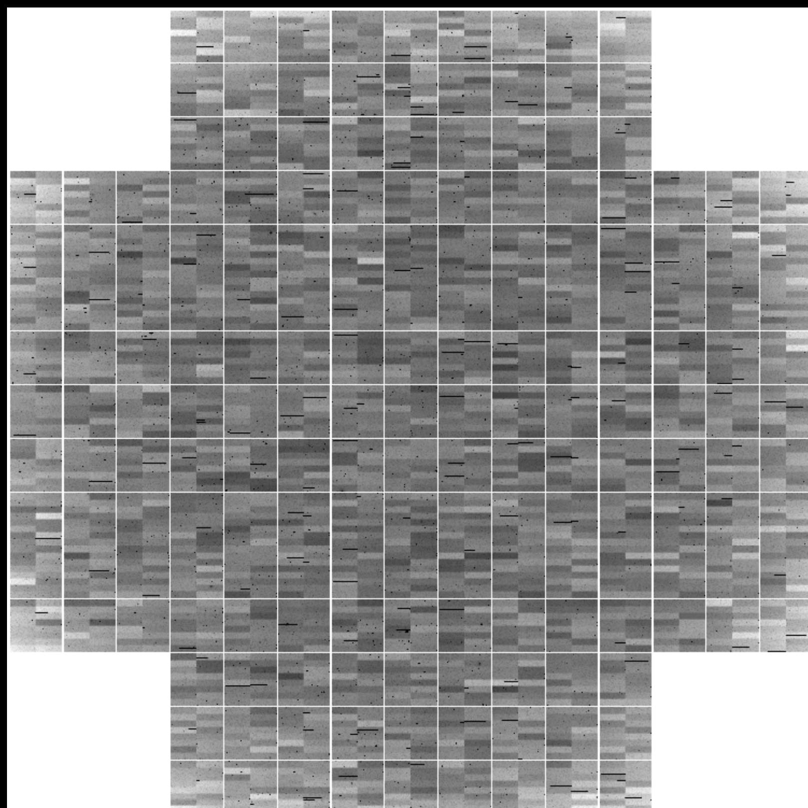

Optics
+Tracking
+Diffraction
+Detector
Misalignments &
Perturbations
+Lens Misalignments
+Mirror Misalignments
Perturbations,
& Micro-roughness
+Detector
+High Altitude
Atmosphere
+Mid Altitude
Atmosphere
+Low Altitude
Atmosphere
+Pixelization
+Saturation &
Blooming


−4°54′48.0″
55′00.0″
12.0″
24.0″
36.0″
Dec (J2000)
49.00^s
48.00^s
47.00^s
0^{h}05^{m}46.00^s
RA (J2000)





A full end-to-end system



189 CCDs
16 amplifiers per CCD
10^{10} photons

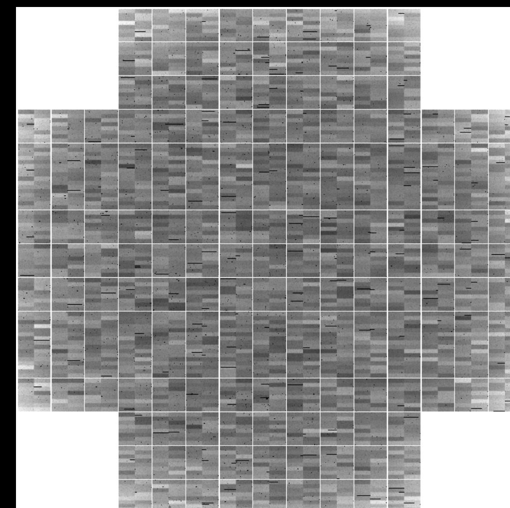
2.5 hrs per CCD

Science at the scale of the LSST
With the same cadence and similar systematics
Catalogs, images and scalable science

Producing a Simulator Run

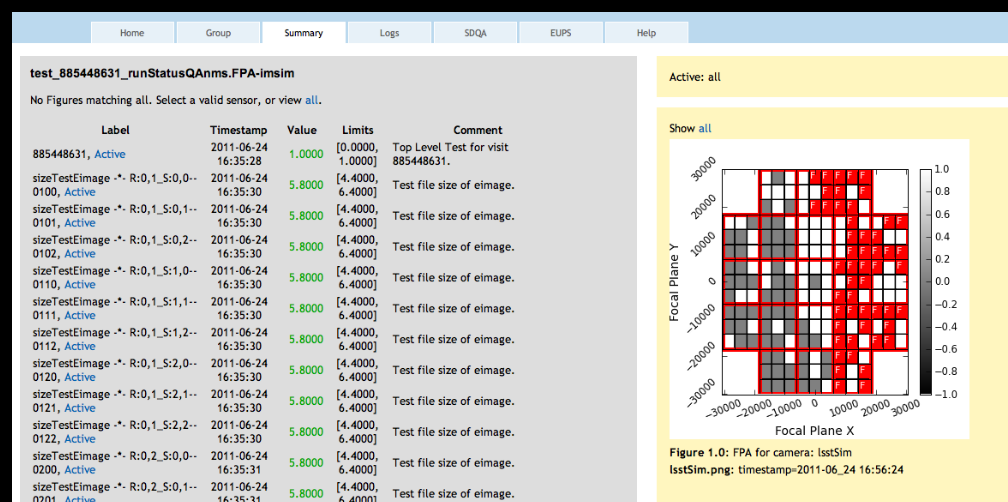
Generating runs

- 600,000 CPU hrs (DC3b), 2.5 millions hours for next data challenge
- Google Exacycle program



Optimizing production

- Utilize grids (OSG, Teragrid), clusters, Condor (Purdue)
- CPU and GPU
- Runs tracked with pipeQA interface



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sizeTestEimage -*- R:0,1_S:0,1--0101, Active	2011-06-24 16:35:30	5.8000	[4.4000, 6.4000]	Test file size of eimage.
sizeTestEimage -*- R:0,1_S:0,2--0102, Active	2011-06-24 16:35:30	5.8000	[4.4000, 6.4000]	Test file size of eimage.
sizeTestEimage -*- R:0,1_S:1,0--0110, Active	2011-06-24 16:35:30	5.8000	[4.4000, 6.4000]	Test file size of eimage.
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Users and Contributors

Contributions of Physics

- Science Collaborations (variability, solar system model, astrometry test cases, AGN, lensing, SNe, LSB galaxies)

Requests for Simulations

- MOPS, Stellar Pops SC, Weak Lensing SC, Strong Lensing SC, Transients and SNe SC, Astrometry
- Requests from outside of LSST (New Horizons missions)

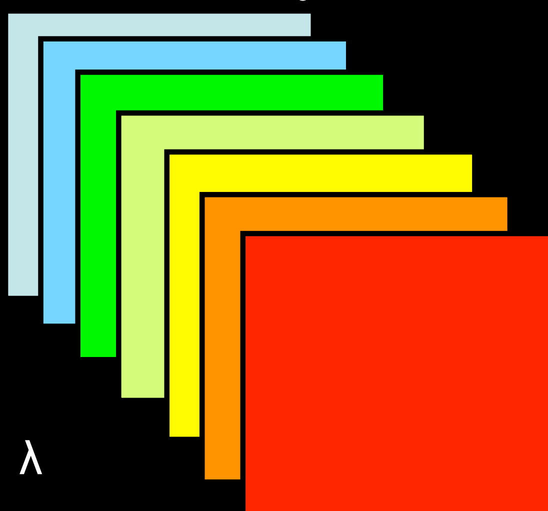
Data Management and end-to-end testing

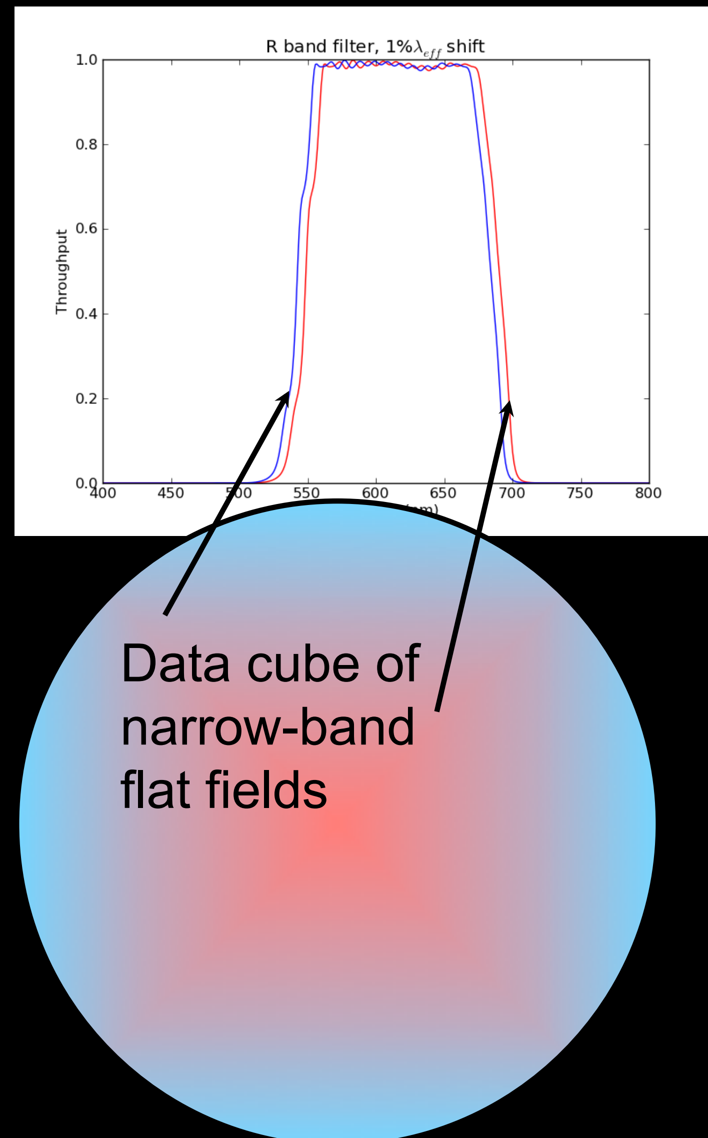
- 449 visits, ~60 sq degrees, 142 day time span
- g(59 visits), r(134), i(160), z(70), y(26) filters

Measuring the shape of hardware response

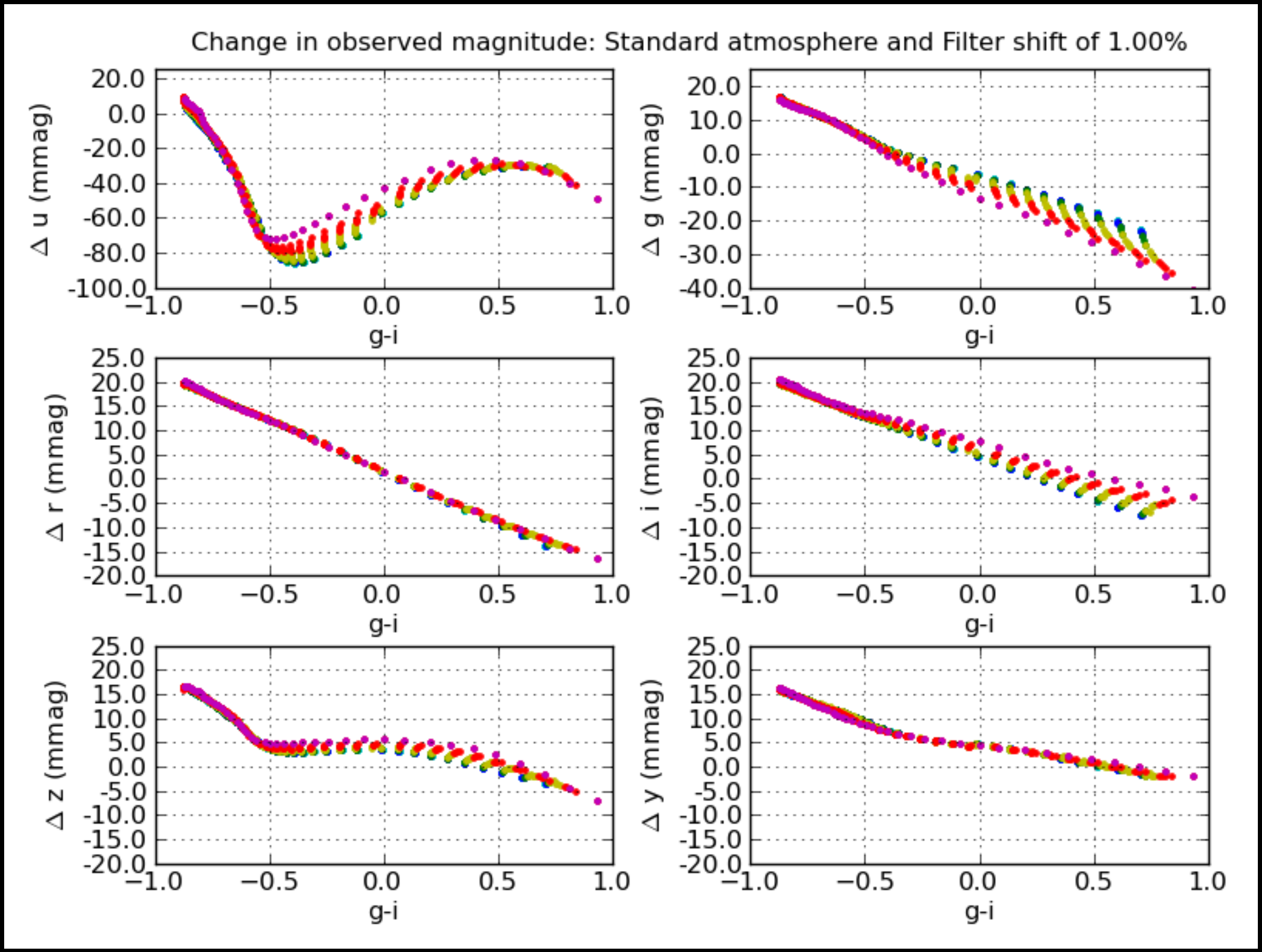
Narrow-band flat fields

- Correct for wavelength-dependent effects (shape of hardware throughput)
- Filter non-uniformity, coating changes with age ..
- Larger spatial scales
- Monthly time scales





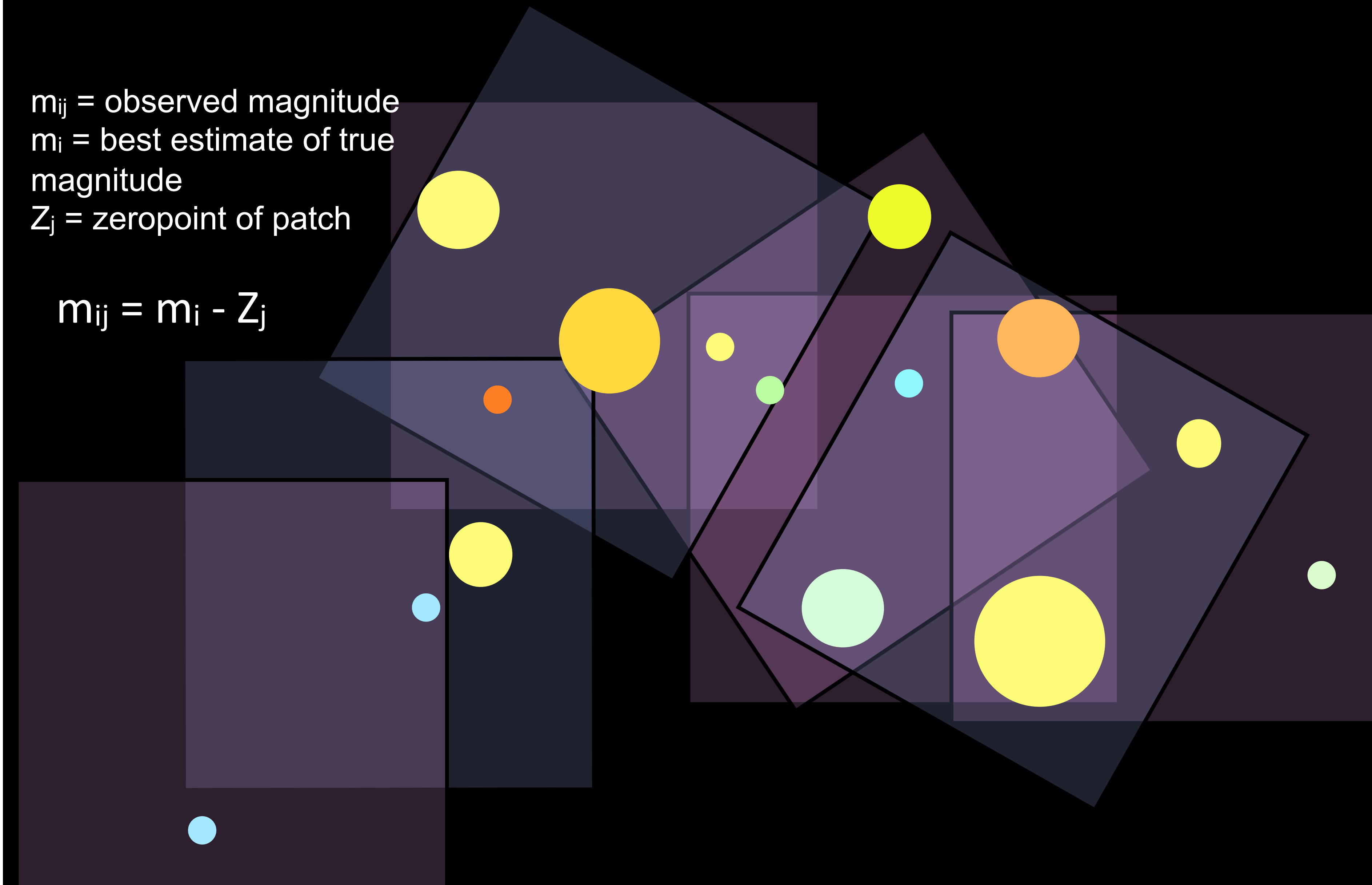
Photometric effect of a shift in filter wavelength



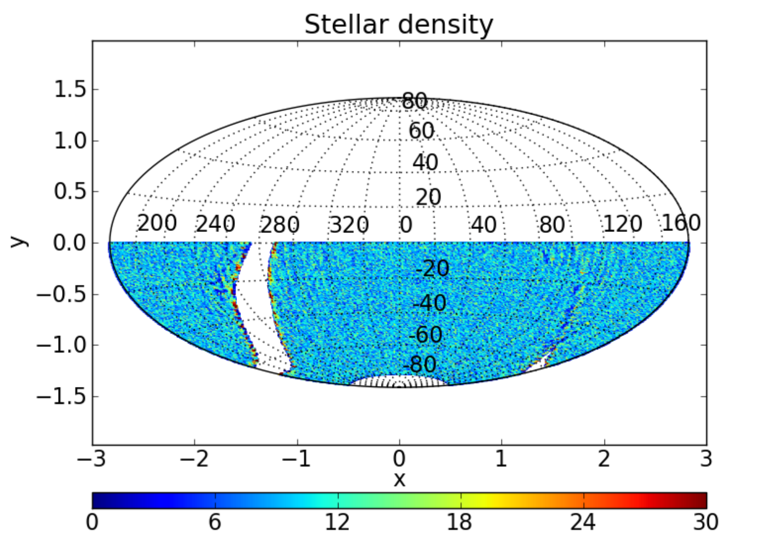
Self-calibration procedure

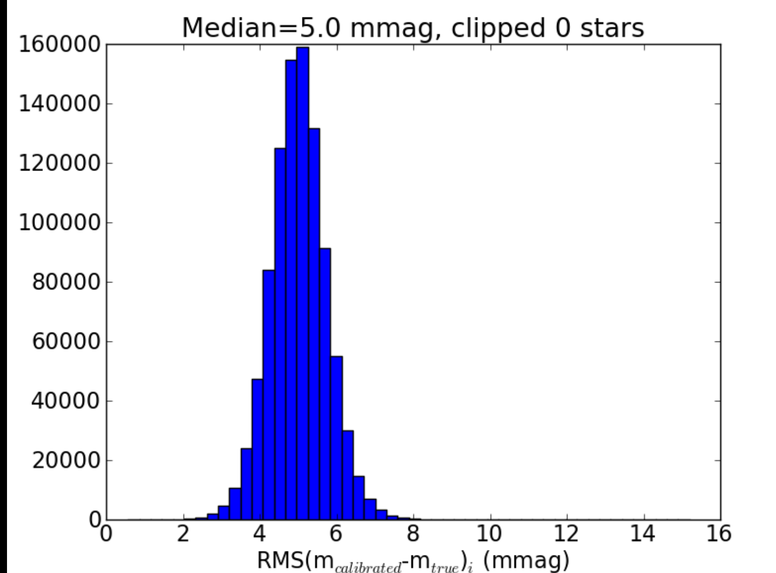
m_{ij} = observed magnitude
m_i = best estimate of true magnitude
Z_j = zeropoint of patch

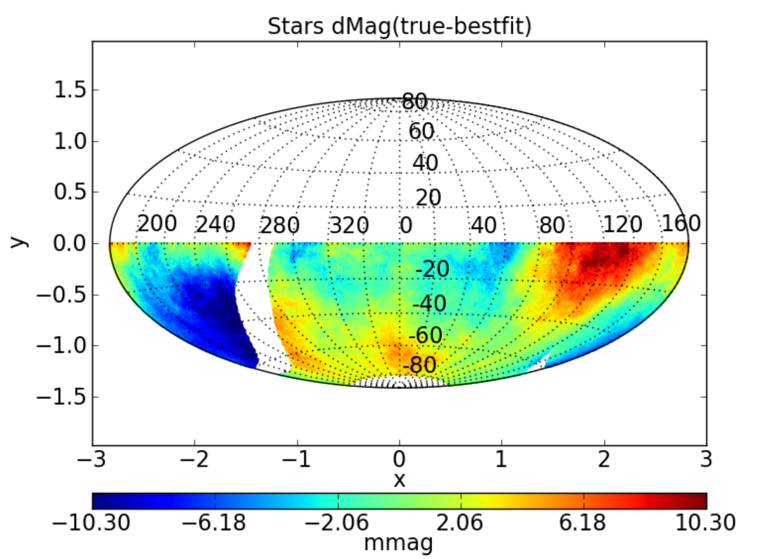
$$m_{ij} = m_i - Z_j$$

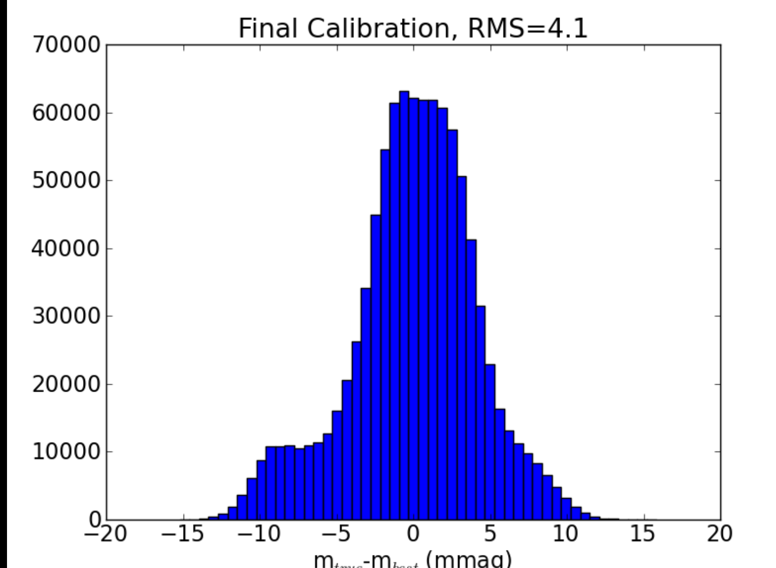


Self-calibration test results









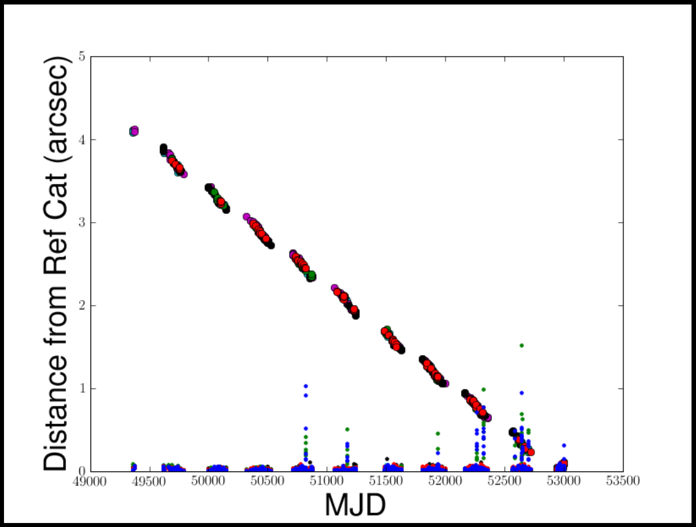
Validation Process (review Nov 2011)

Data flow and consistency

- Unit tests and pipeQA
- Validation of photometry

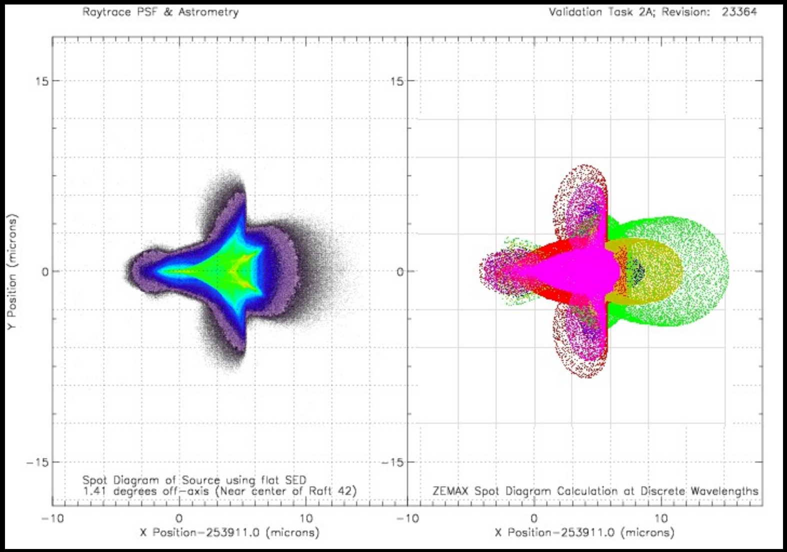
Source Physics

- Comparison to observations
- Light curves from science collaborations



Optics and Camera

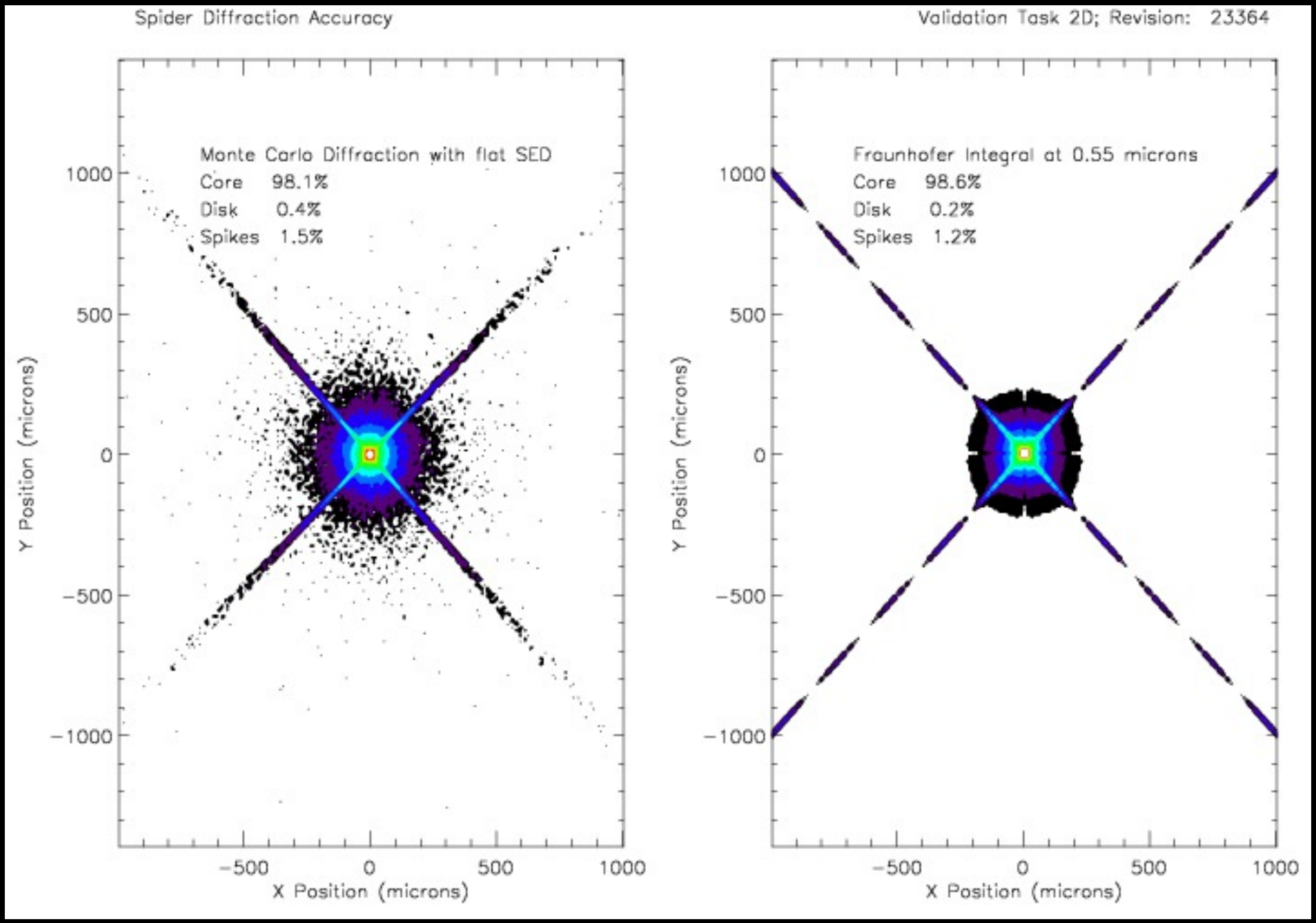
- Comparison with Zemax
- Fast diffraction approximation



Atmosphere

- Comparisons of PSF and image motion with PS and Subaru

Modeling diffractive effects with photons



Likeness 1977, Freniere 1993

What lessons can we learn?

Develop in concert with the analysis framework (build the complexity to match the analysis)

Science requirements are complex, relying on multidimensional distributions that are not easy to model as a “mean and variance”. Simulations can provide the flow down from the requirements.

Validate, validate, validate…

Why a Simulated View?

Simulations enable the evaluation of the performance of complex systems in a manner astrophysics has not previously embraced

Combined with observational data sets simulations should be able to reduce the commissioning time for the next generation of telescopes

End-to-end simulations, tied to science requirements, will enable better (and quicker) science from the LSST

With thanks to:

Garret Jernigan
John Peterson
Simon Krughoff
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Phil Marshall
Mario Juric
Lynne Jones
Dave Monet
Steve Kahn
the LSST Collaboration