Big Data Sets in Astronomy

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LSST

SDSS

Sao Paulo School of Advanced Science on Learning from Data, July 31 - Aug 2, 2019

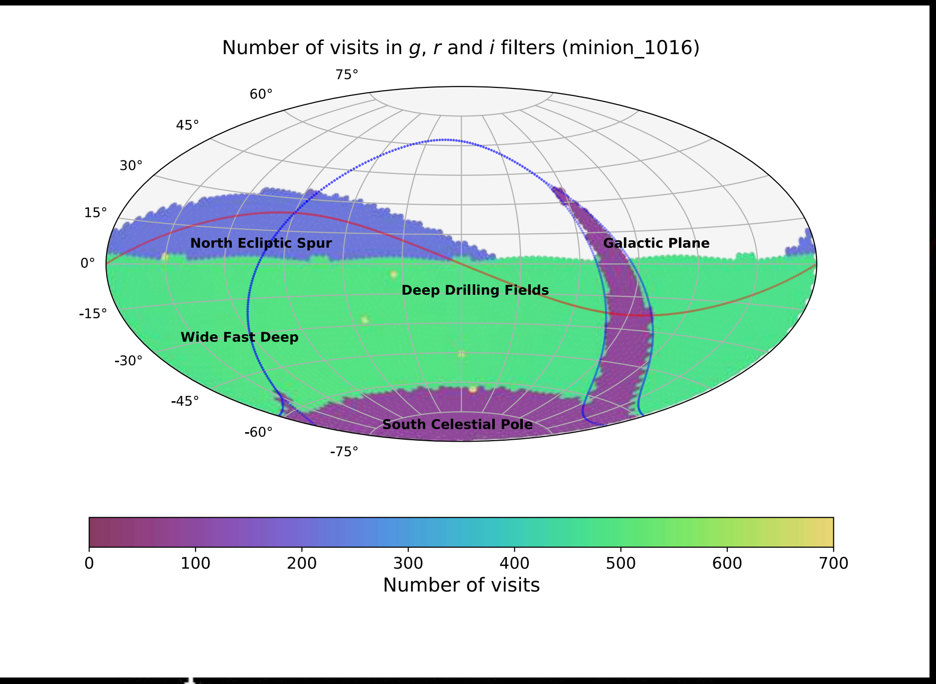
Large Synoptic Survey Telescope (LSST)

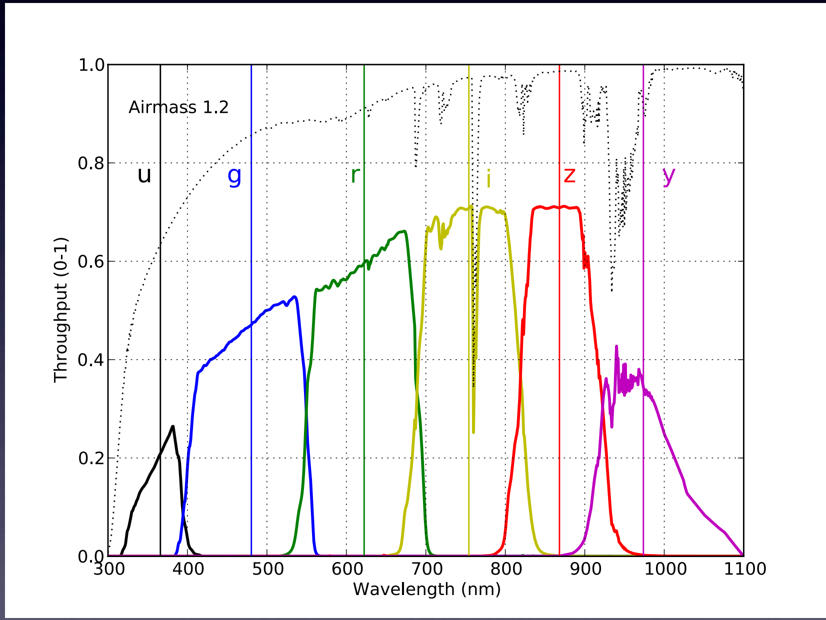
SDSS:
a digital color map
of the night sky

LSST:
a digital color
movie of the sky

Basic idea behind LSST: **a uniform sky survey**

- 90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky

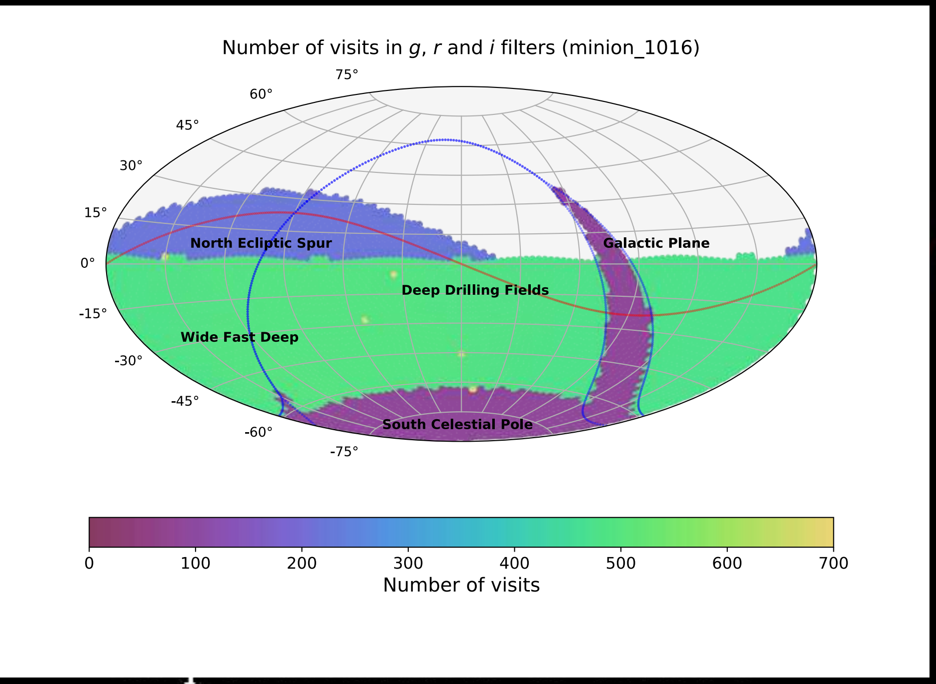




Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

Basic idea behind LSST: **a uniform sky survey**

- 90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about a billion 16 Mpix images, enabling **measurements for 40 billion objects**



LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 825 visits over a 10-year period: deep wide fast.

Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

Outline

- LSST science drivers
  - cosmology (dark matter and dark energy)
  - time domain
  - the Milky Way structure
  - the Solar System structure
- Rapid tour of LSST and status report
  - multi-color time-resolved faint sky map
  - 20 billion stars and 20 billion galaxies
- Data analysis challenges ahead of us
  - large data sets
  - complex analysis
  - aiming for small systematics

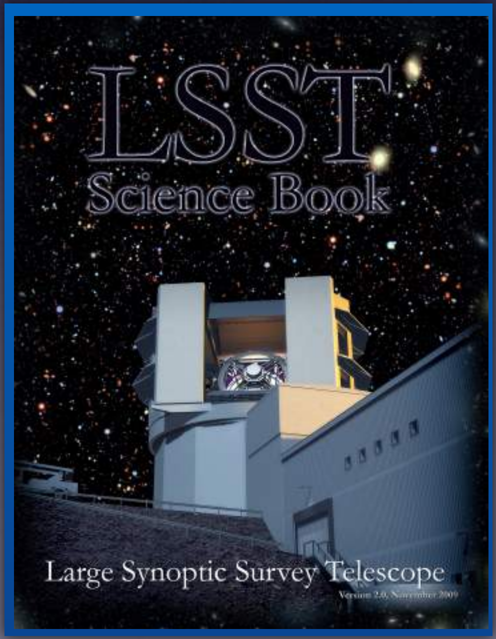
LSST Science Themes

- Dark matter, dark energy, cosmology (spatial distribution of galaxies, gravitational lensing, supernovae, quasars)
- Time domain (cosmic explosions, variable stars)
- The Solar System structure (asteroids)
- The Milky Way structure (stars)

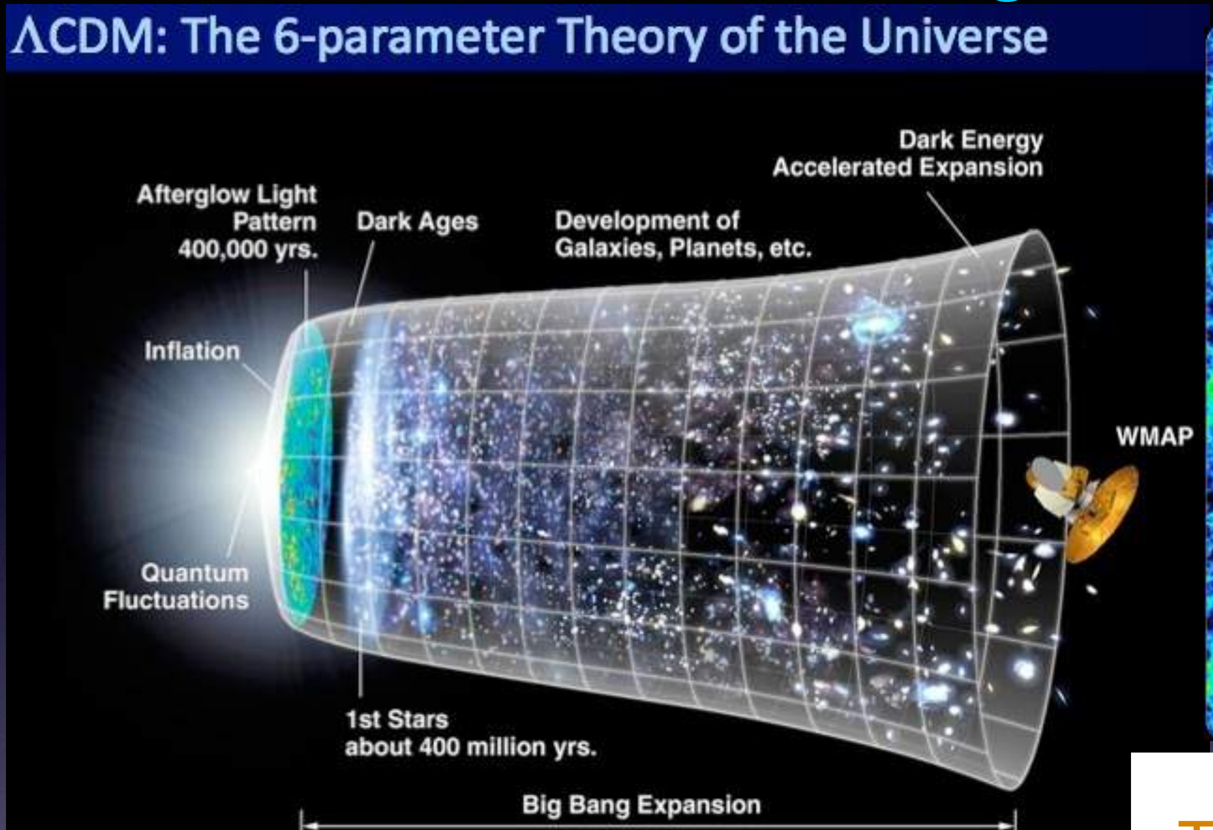
LSST Science Book: arXiv:0912.0201

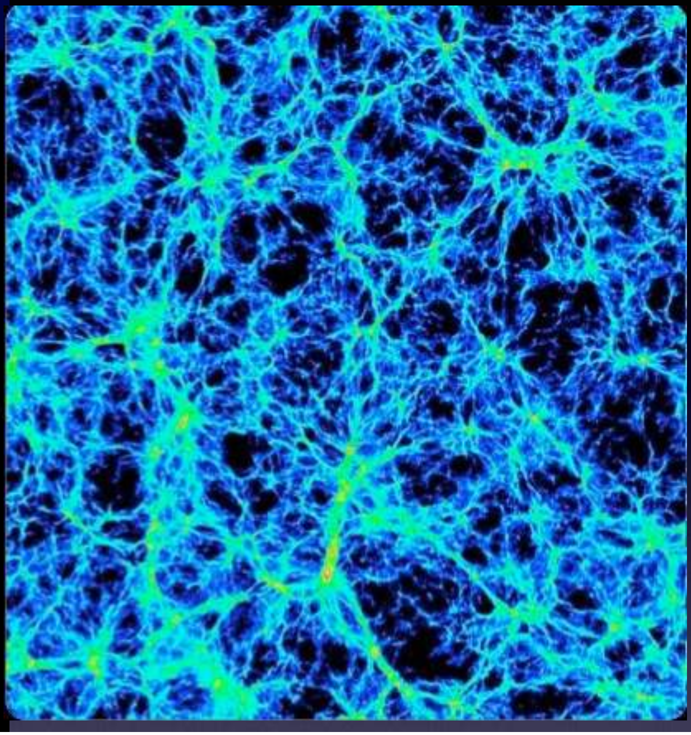
Summarizes LSST hardware, software, and observing plans, science enabled by LSST, and educational and outreach opportunities

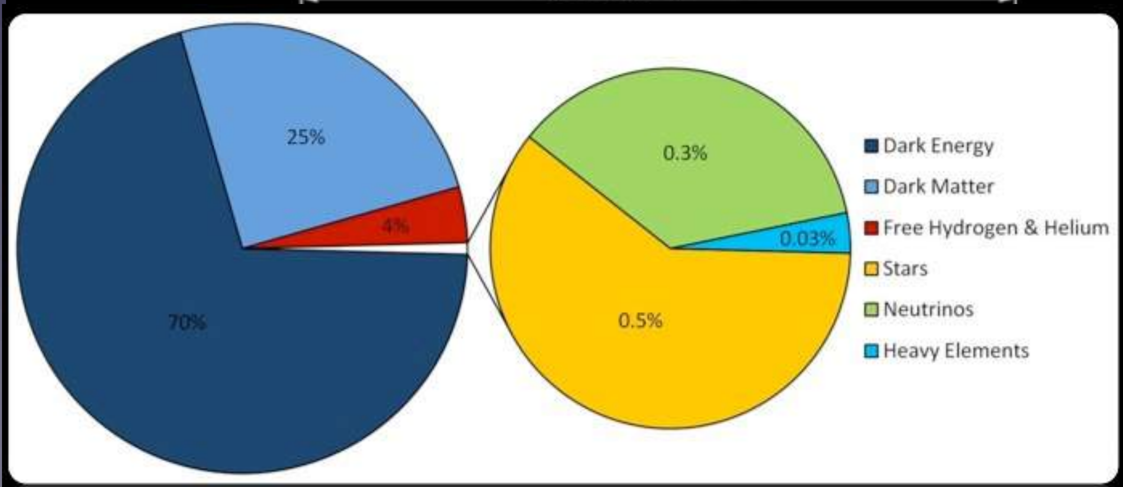
245 authors, 15 chapters, 600 pages



New Cosmological Puzzles







The modern cosmological models can explain all observations, but need to **postulate** dark matter and dark energy (though gravity model could be wrong, too)

Modern Cosmological Probes

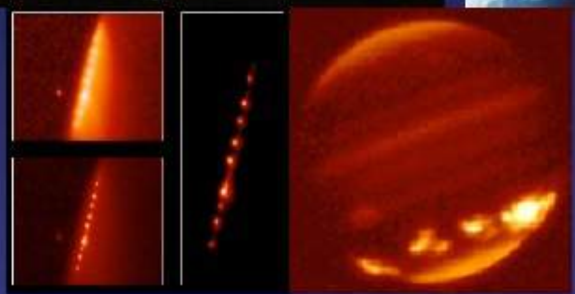
- Cosmic Microwave Background (the state of the Universe at the recombination epoch, at redshift ~1000)
- Weak Lensing: growth of structure
- Galaxy Clustering: growth of structure
- Baryon Acoustic Oscillations: standard ruler
- Supernovae: standard candle

Except for CMB, measuring H(z) and growth of structure G(z)
$H(z) \sim d[\ln(a)]/dt$, $G(z) = a^{-1}\delta\rho_m/\rho_m$, with $a(z) = (1+z)^{-1}$

Killer asteroids: the impact probability is not 0!

photomontage!

LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)

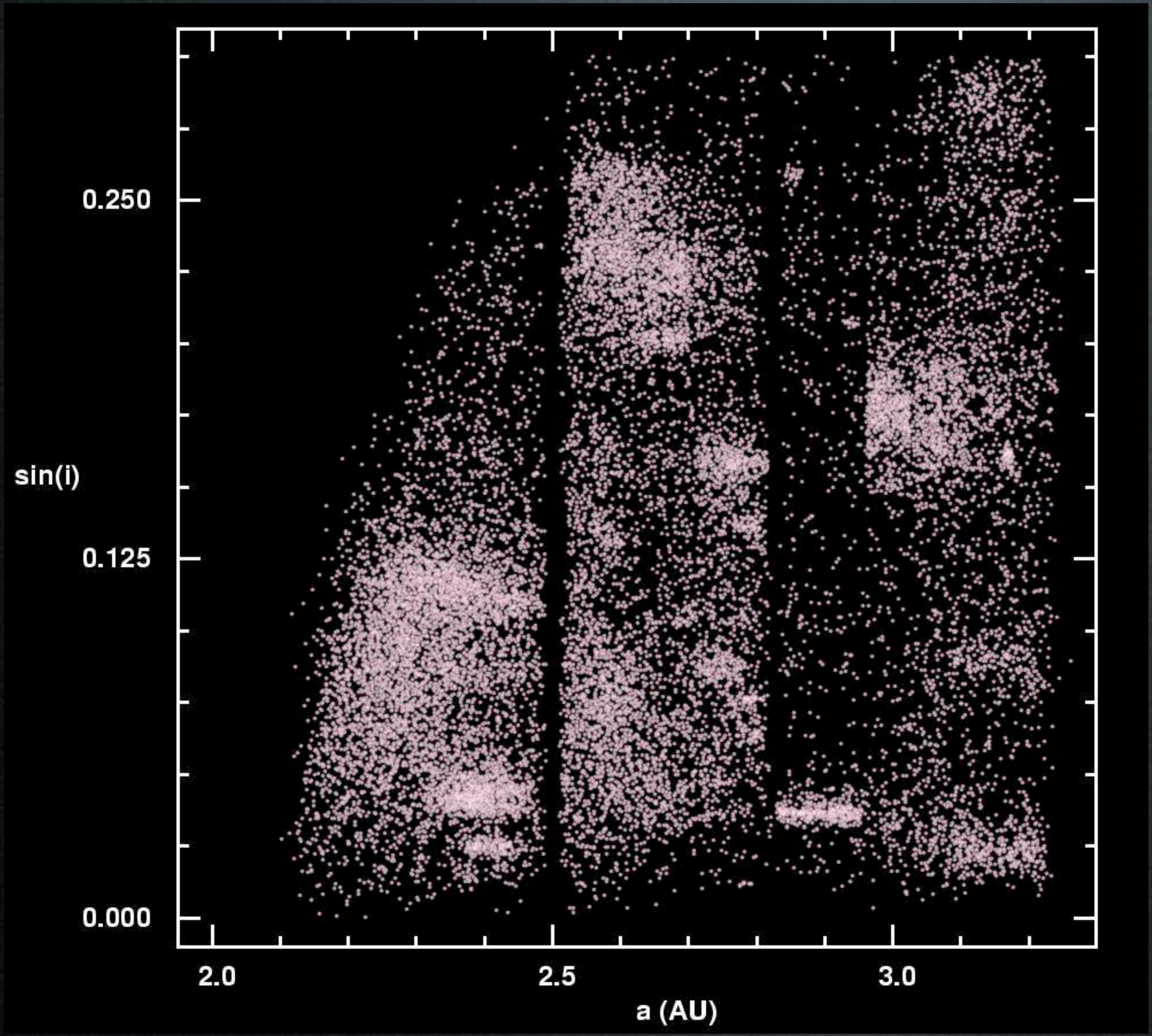


Shoemaker-Levy 9 (1994)

Tunguska (1908)

The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

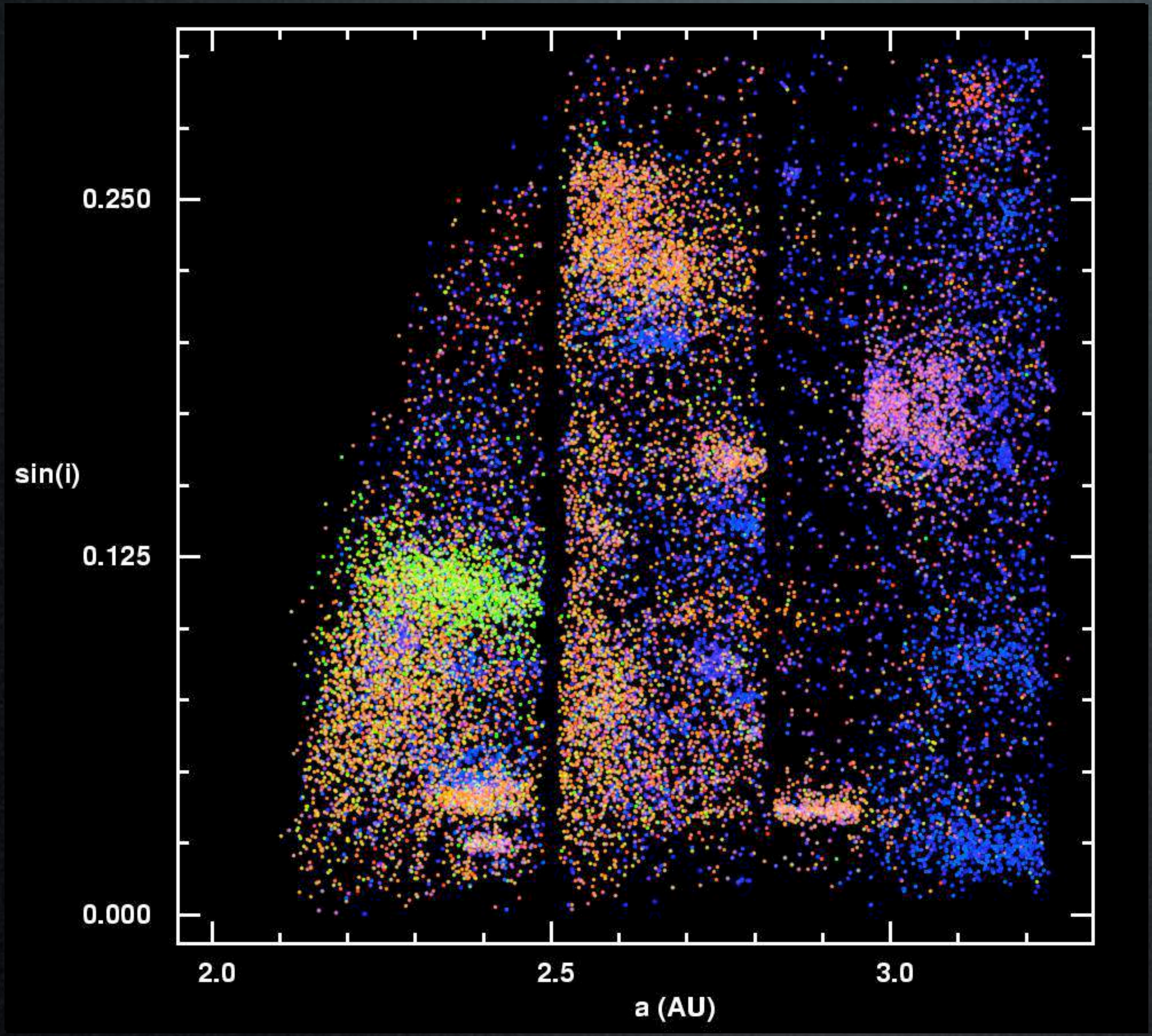
Main-belt Inventory



30,000
Asteroids with
SDSS colors and
proper
orbital elements

(Ivezic, Juric, Lupton 2002)

Main-belt Inventory



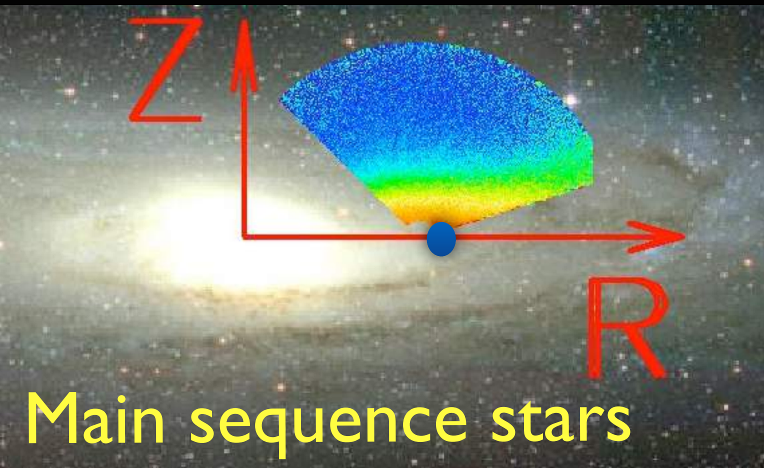
30,000
Asteroids with
SDSS colors and
proper
orbital elements

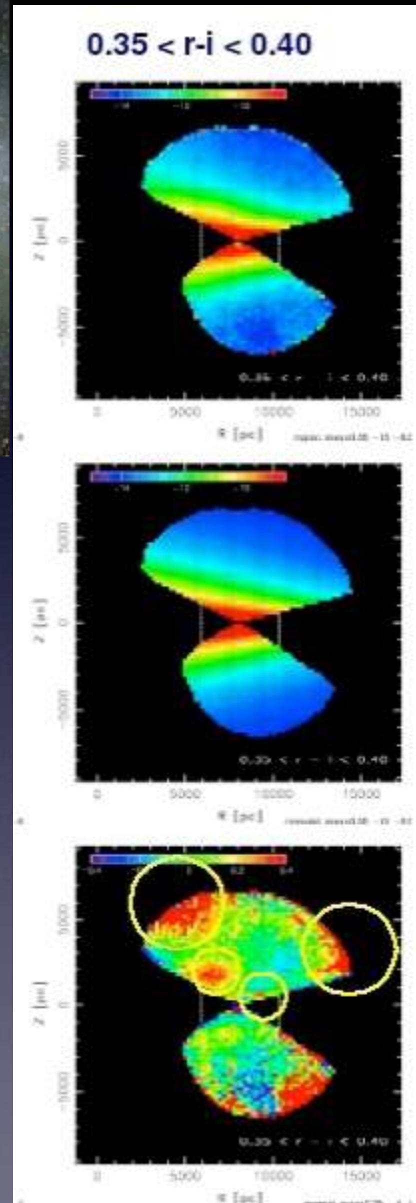
(Ivezic, Juric, Lupton 2002)

Color-coded with
SDSS colors

Colors help with the definition of asteroid families.
LSST will also provide color light curves!

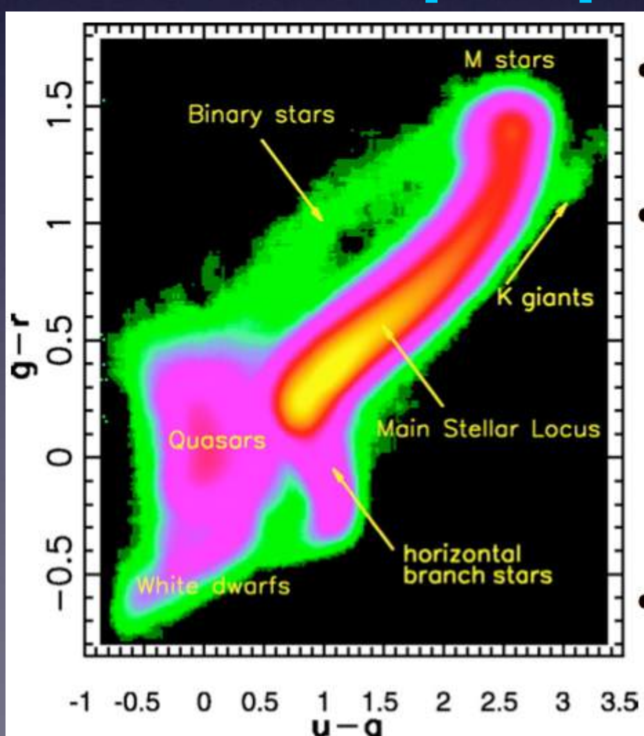
The Milky Way structure: 20 billion stars, time domain massive statistical studies!

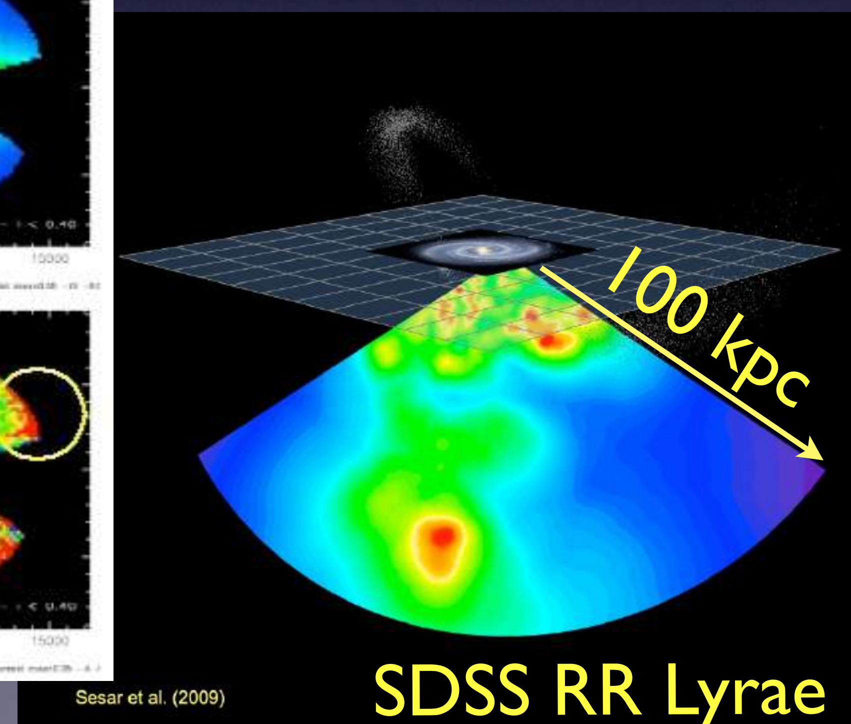




Compared to SDSS: LSST can "see" about 40 times more stars, 10 times further away and over twice as large sky area

Distance and [Fe/H]:





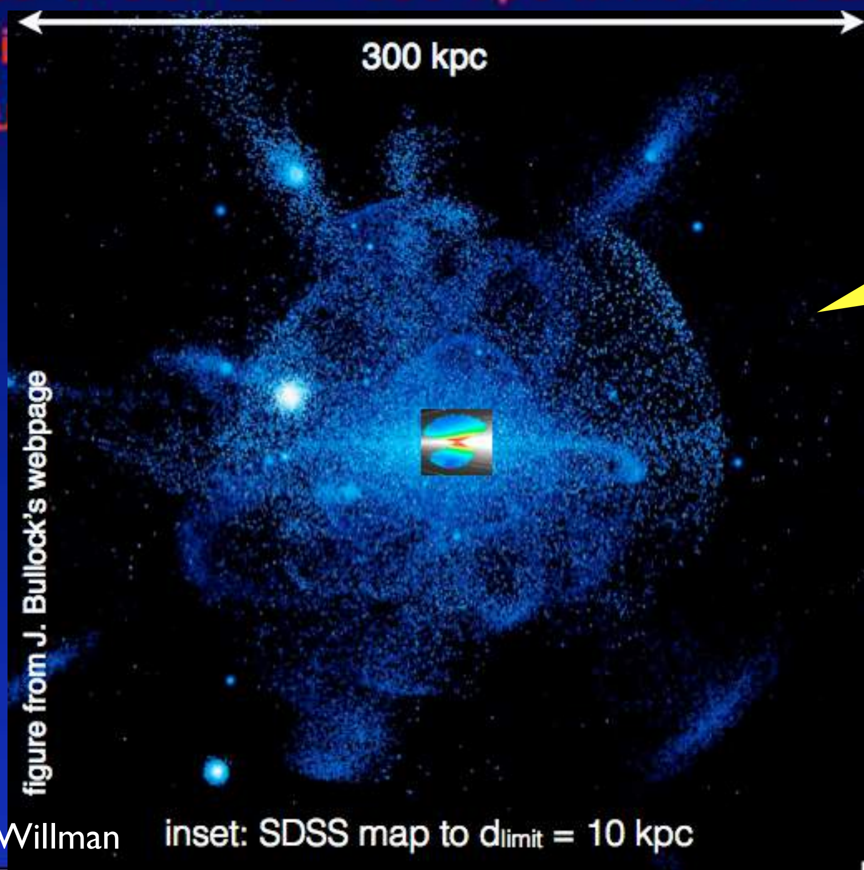
The large blue circle: the ~400 kpc limit of future LSST studies based on RR Lyrae

LSST limit for RR Lyrae: 400 kpc

The large red circle: the ~100 kpc limit of future

LSST studi

(and the cu



200 million stars from LSST!

The small insert:
~10 kpc limit of SDSS and future Gaia studies for kinematic & $[Fe/H]$ mapping with MS stars

montage from B. Willman

SDSS
gri
3.5’x3.5’
r~22.5

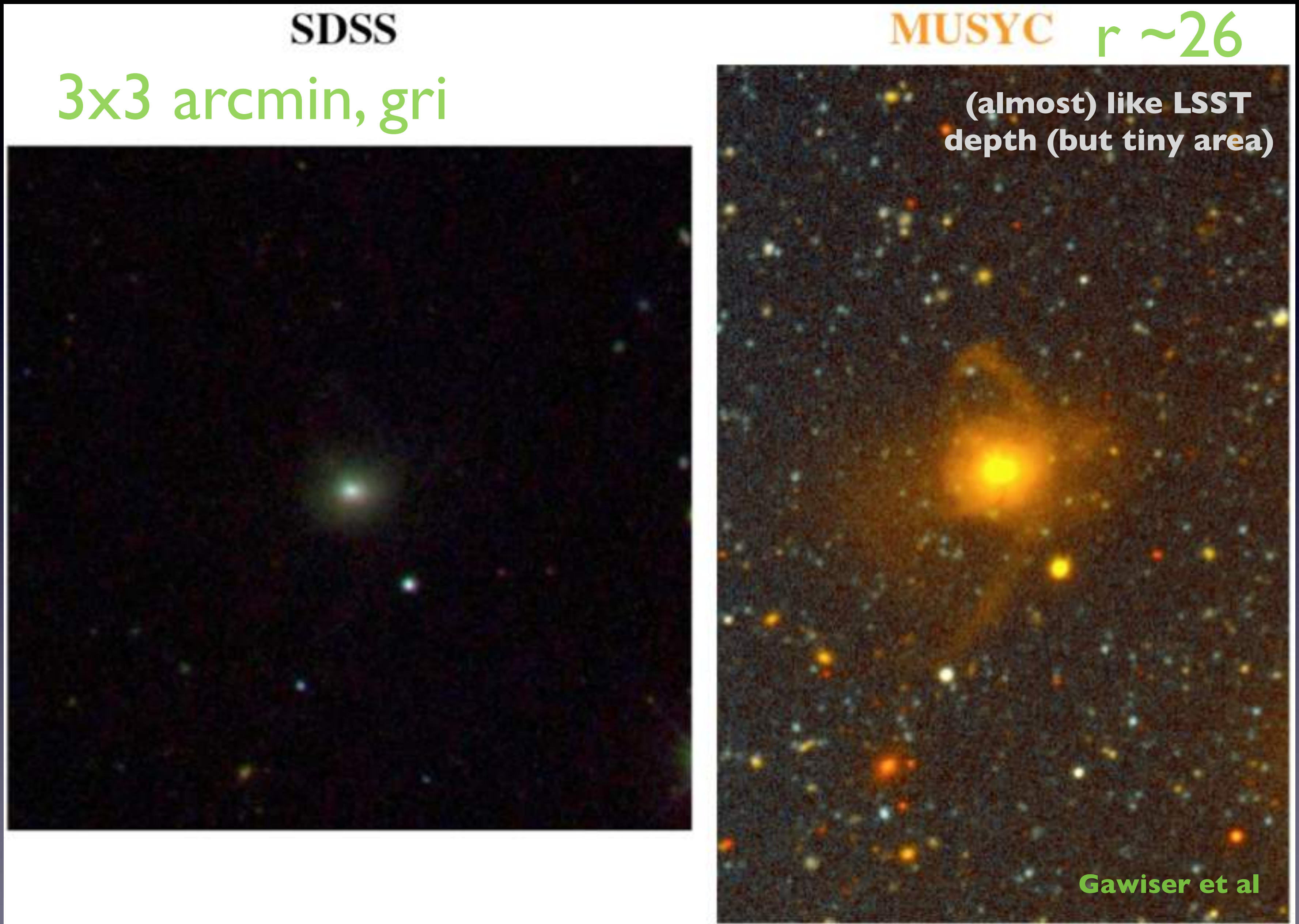
HSC
gri
3.5’x3.5’
r~27

3 arcmin is 1/10 of the full Moon’s diameter

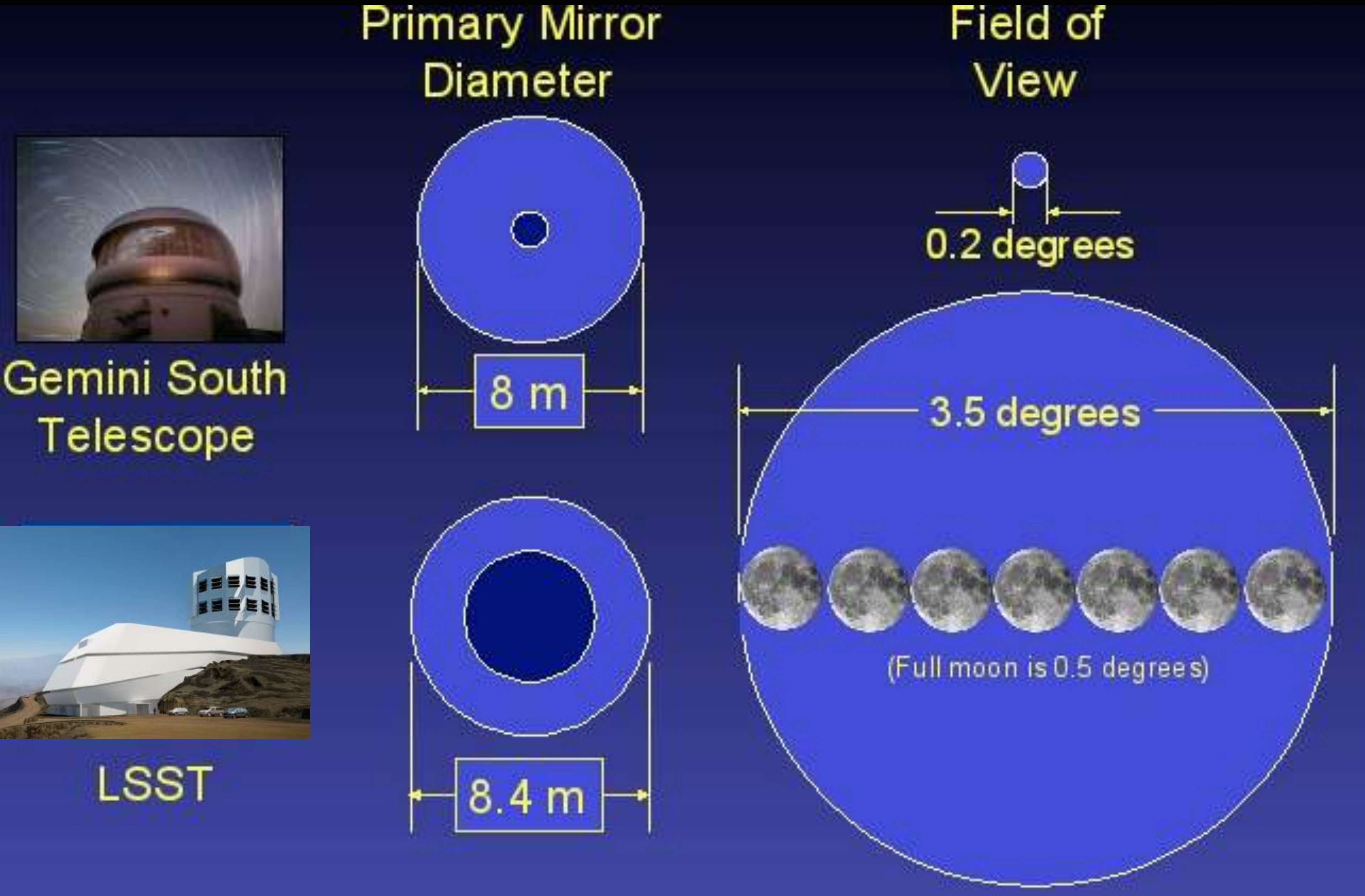
like LSST depth (but tiny area)

LSST will deliver 5 million such images

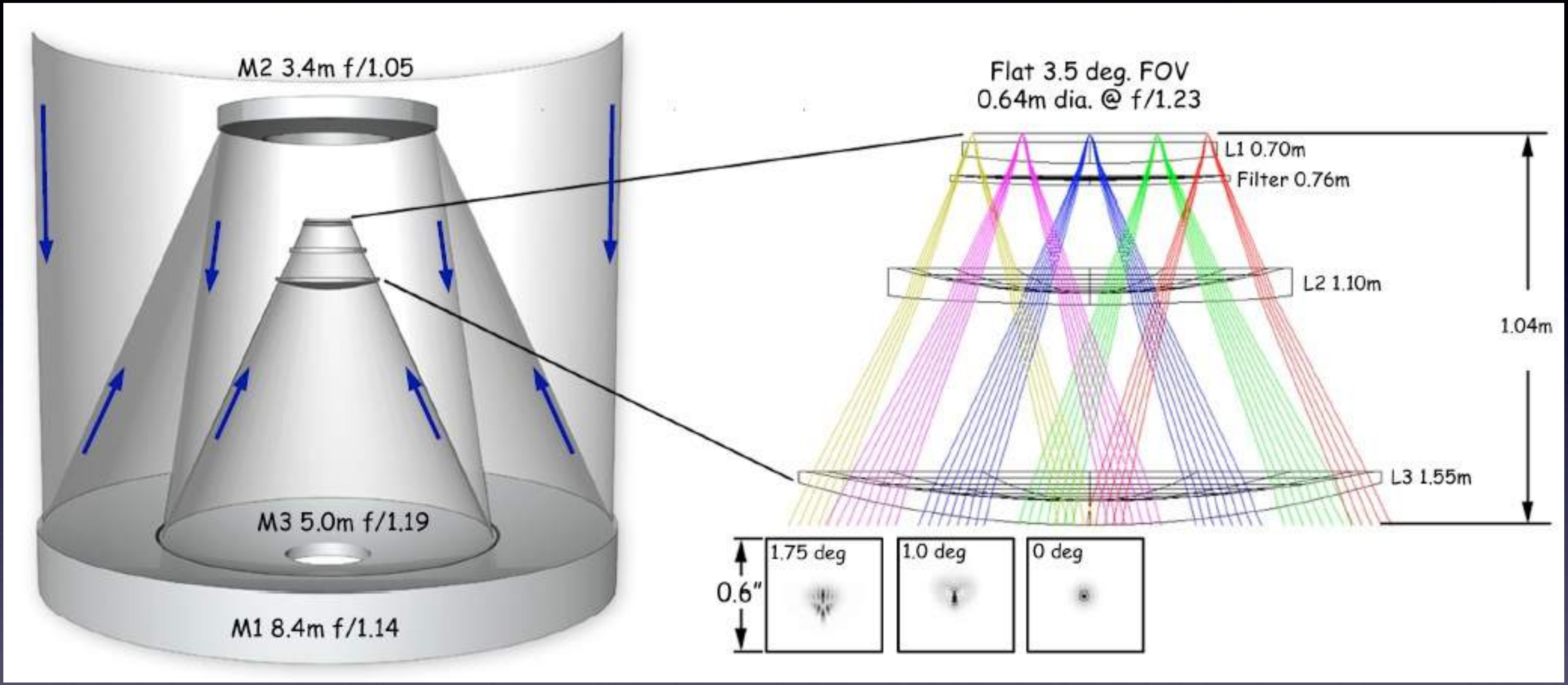
Extragalactic astronomy: faint surface brightness limit



The field-of-view comparison: Gemini vs. LSST

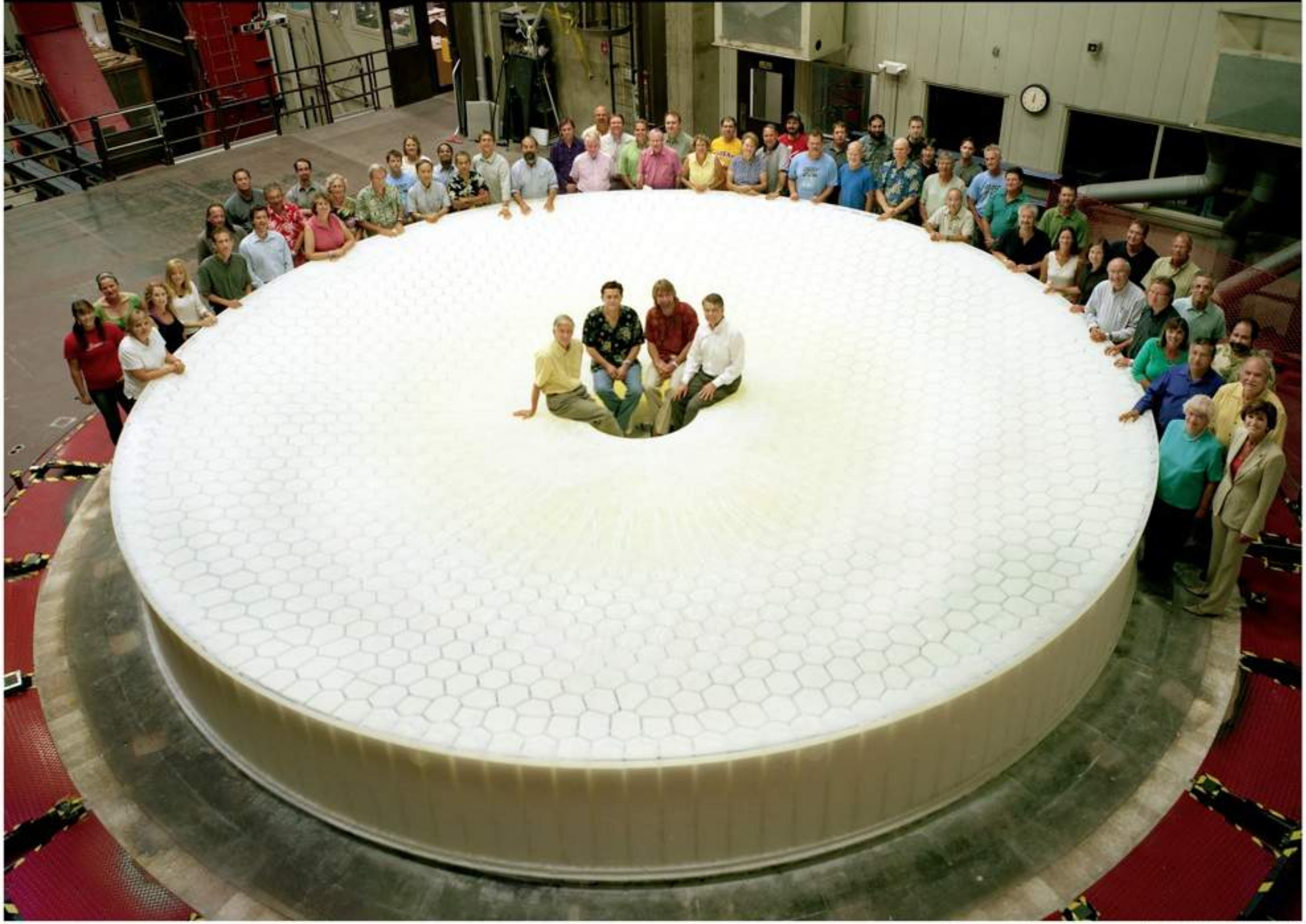


Optical Design for LSST



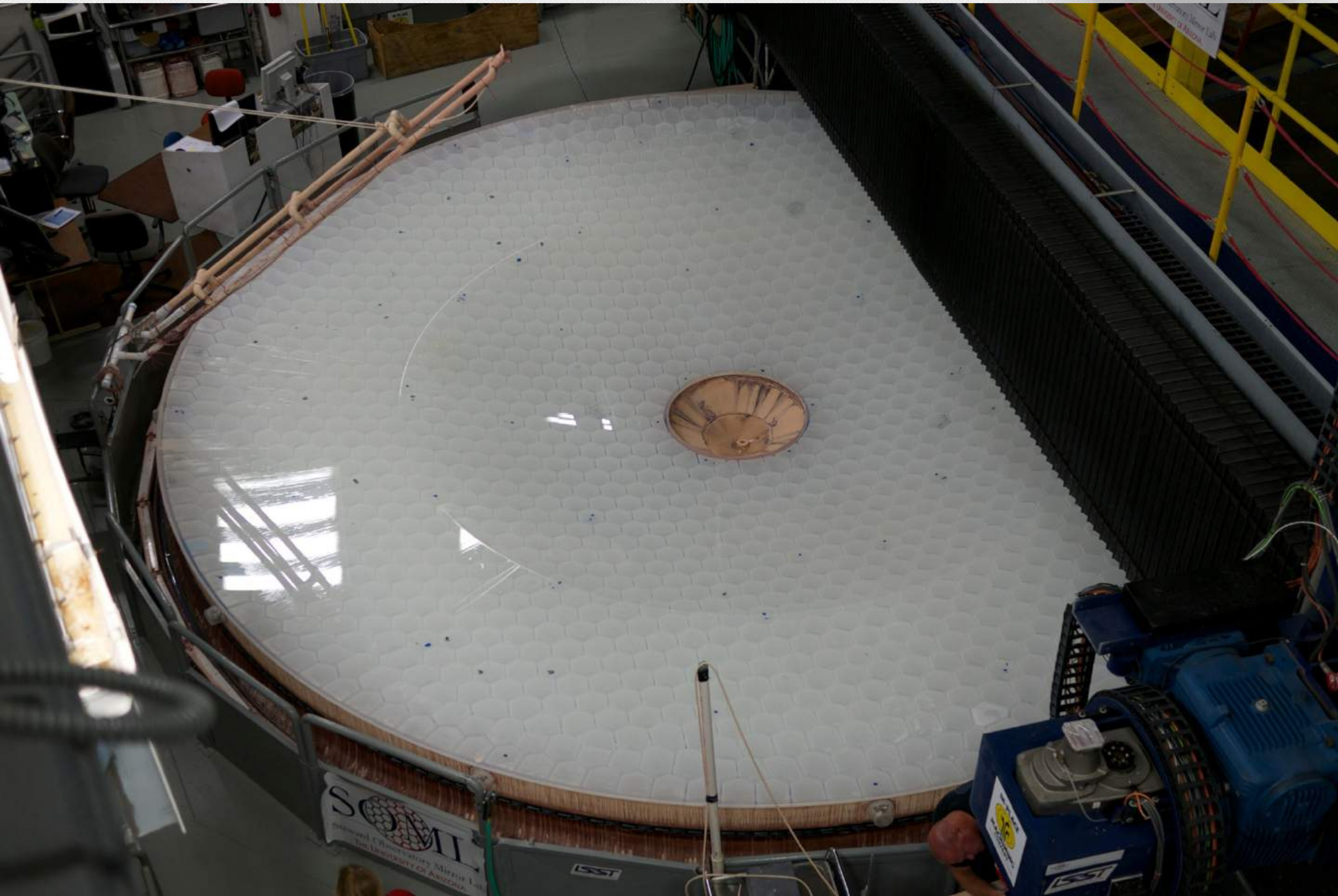
Three-mirror design (Paul-Baker system)
enables large field of view with excellent image quality:
delivered image quality is dominated by atmospheric seeing

Large Synoptic Survey Telescope



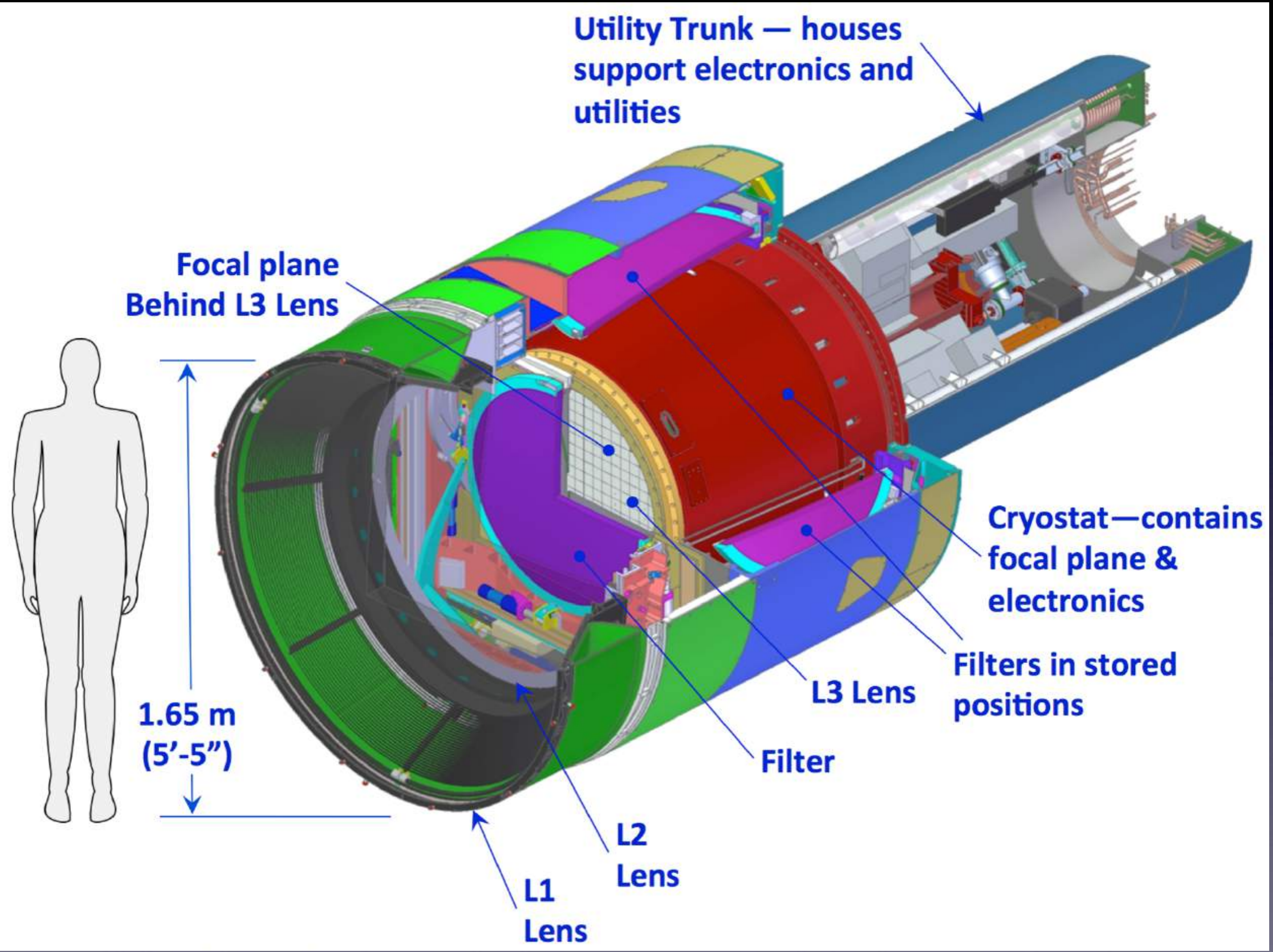
LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

The University of Arizona, Tucson Arizona · SOML · LSST Large Synoptic Survey Telescope



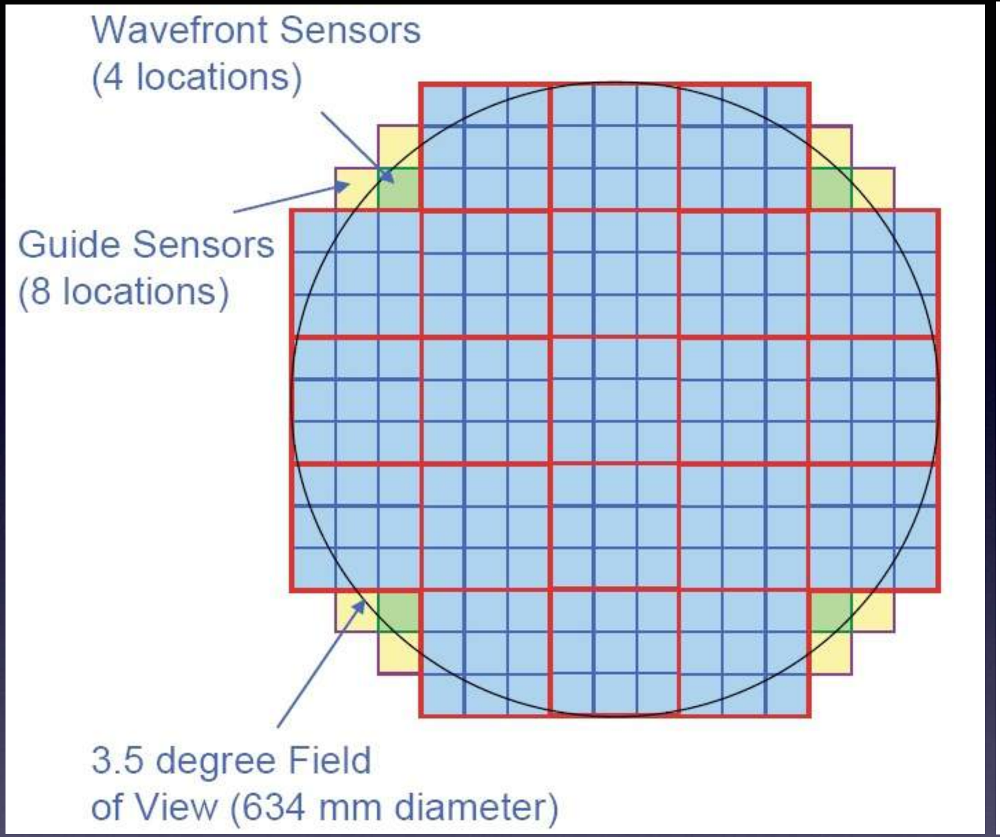
Telescope Mount Assembly before going from Spain to Chile

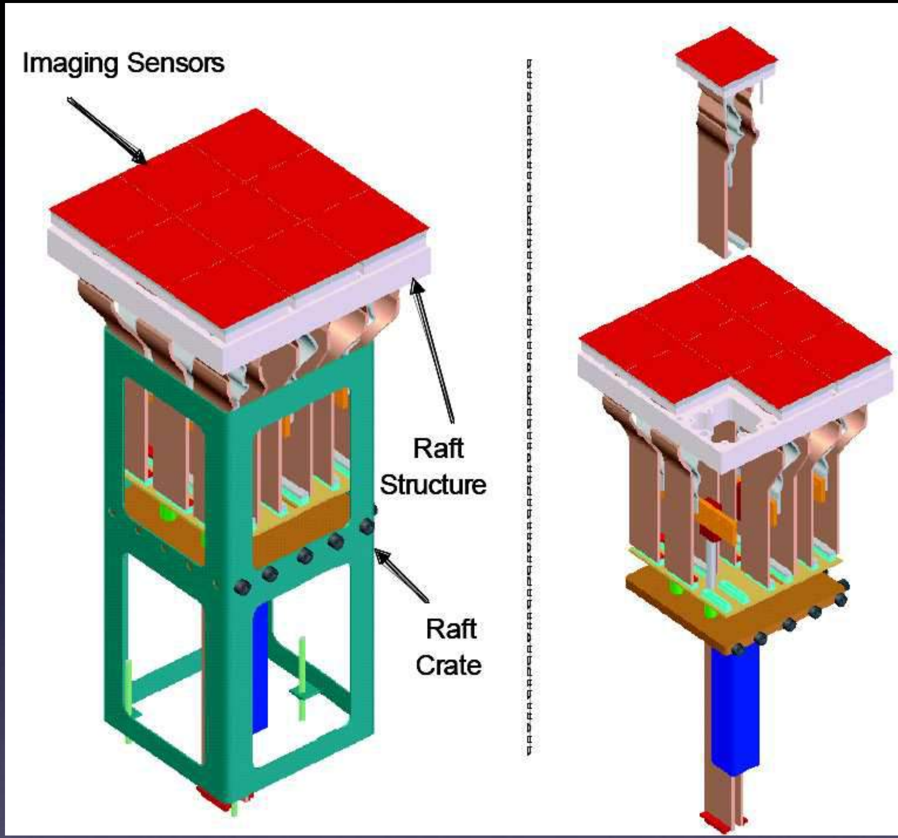
LSST camera



The largest astronomical camera: 2800 kg, 3200 Megapix

LSST camera





Modular design: 3200 Megapix = 189 x16 Megapix CCD

9 CCDs share electronics: raft (=camera)

Problematic rafts can be replaced relatively easily

First light: 2021


Large Synoptic Survey Telescope
LSST Operations:
Sites & Data Flows
French Site
Satellite Processing Center
Data Release Production
Long-term Storage (copy 3)
Archive Site
Archive Center
Alert Production
Data Release Production
Calibration Products Production
EPO Infrastructure
Long-term Storage (copy 2)
Data Access Center
Data Access and User Services
HQ Site
Science Operations
Observatory Management
Education & Public Outreach
Base Site
Base Center
Long-term storage (copy 1)
Data Access Center
Data Access & User Services
Summit Site
Telescope & Camera
Data Acquisition
Crosstalk Correction
United States
Mexico
Cuba
Guatemala
Honduras
Nicaragua
Costa Rica
Panama
Venezuela
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Chile
Uruguay
Argentina
La Serena
Cerro Pachón
Google

At the highest level, LSST objectives are:

1) Obtain about 5.5 million images, with 189 CCDs (4k x 4k) in the focal plane; this is about **a billion 16 Megapixel images of the sky**

2) Calibrate these images (and provide other metadata)

3) Produce catalogs ("model parameters") of detected objects (37 billion)

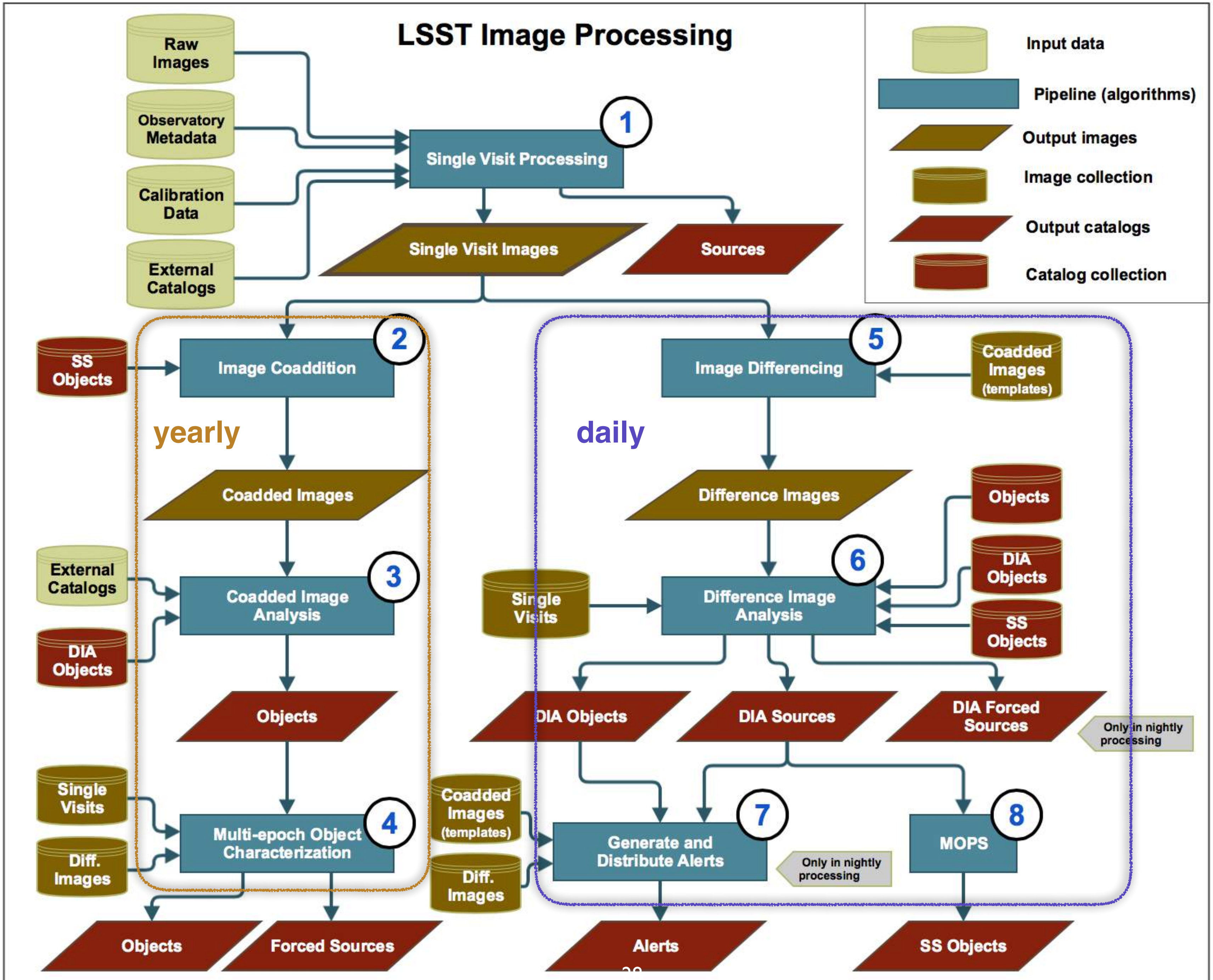
4) Serve images, catalogs and all other metadata, that is,
serve LSST data products to LSST users

The ultimate deliverable of LSST is not just the telescope, nor the camera, but **the fully reduced science-ready data** as well.
Software!

LSST Data Management System ("software")

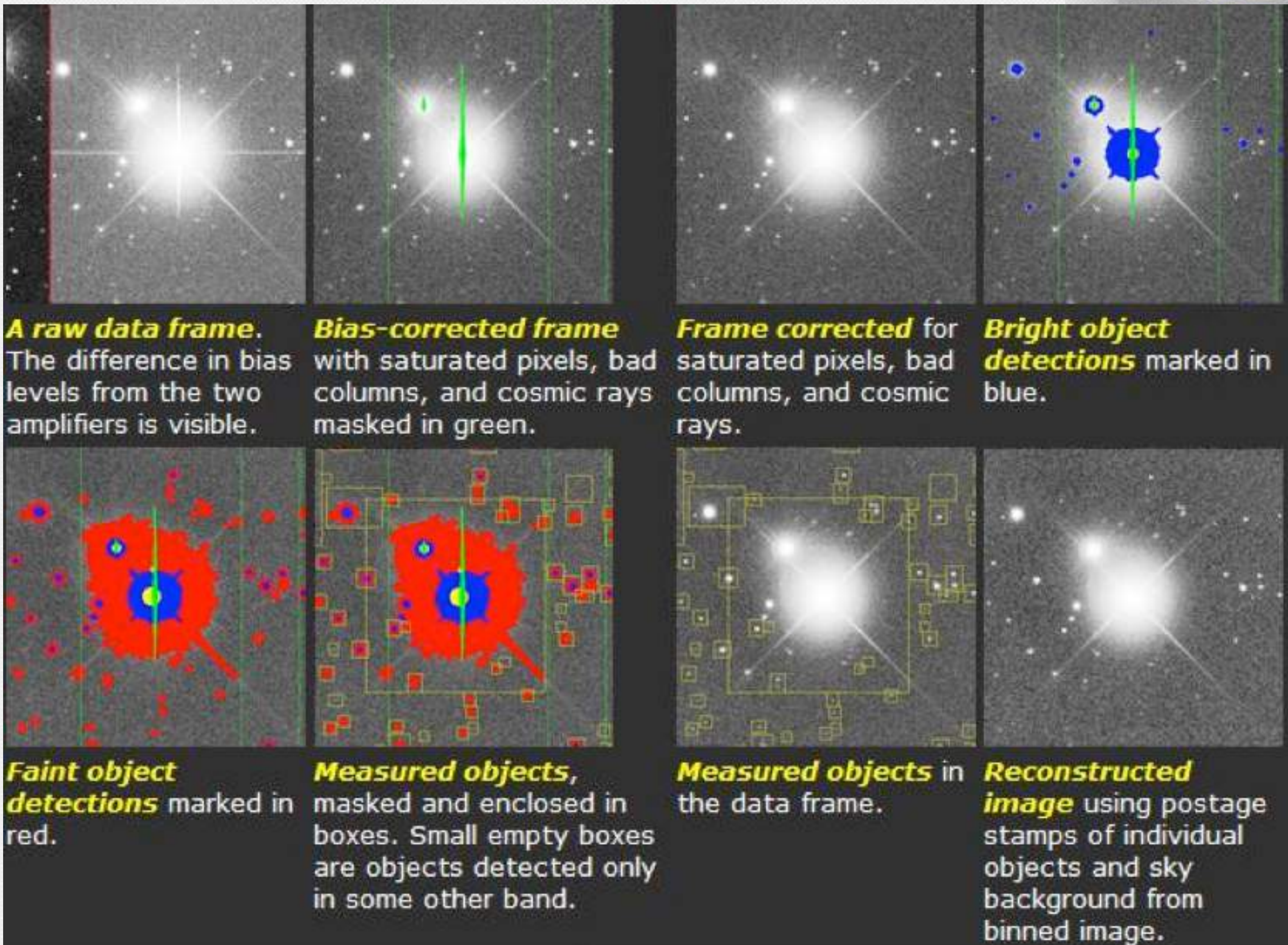
- 20 TB of data to process every day (~one SDSS/day)
- 1000 measurements for 40 billion objects during 10 years
- Existing tools and methods (e.g. SDSS) do not scale up to LSST data volume and rate (100 PB!)

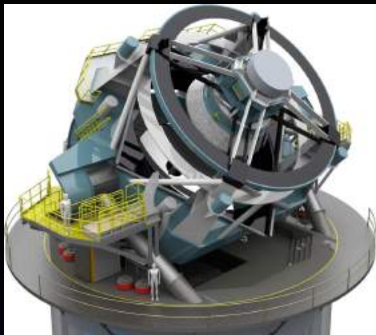
- About 5-10 million lines of code (C++/python)

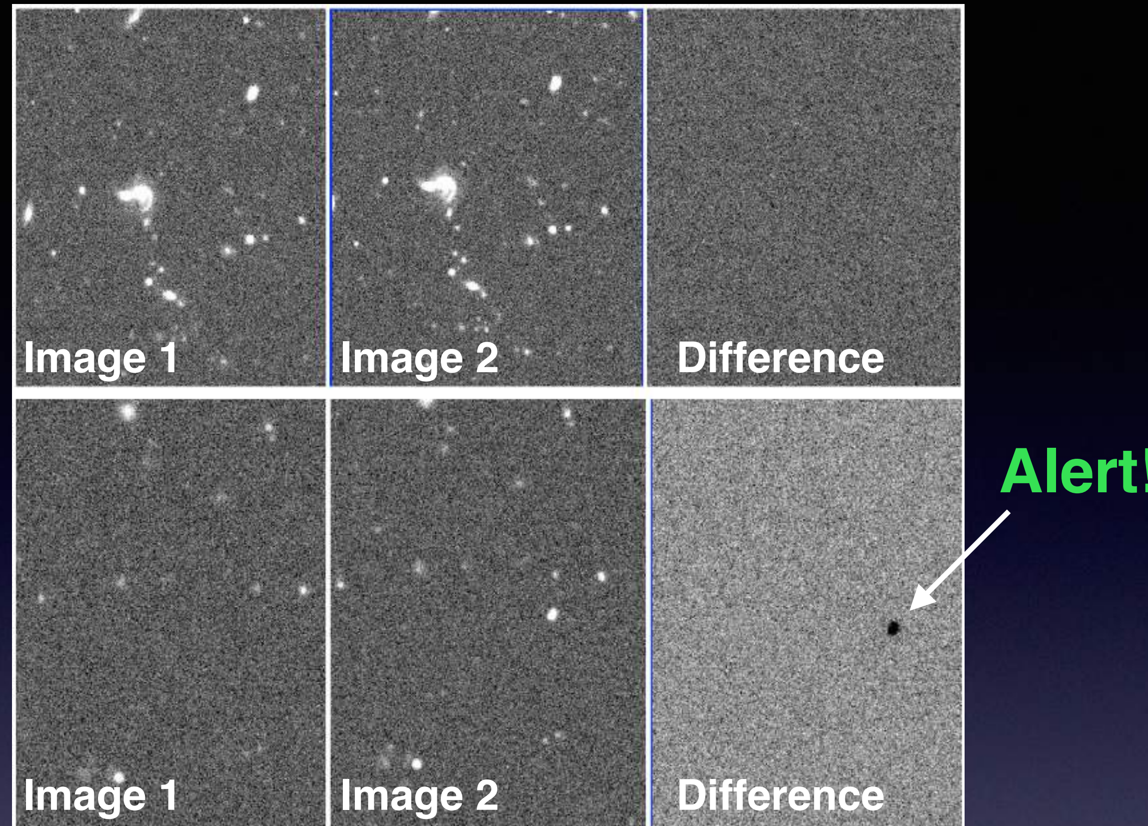

LSST Image Processing
Input data
Pipeline (algorithms)
Output images
Image collection
Output catalogs
Catalog collection
Raw Images
Observatory Metadata
Calibration Data
External Catalogs
Single Visit Processing
1
Single Visit Images
Sources
yearly
daily
SS Objects
Image Coaddition
2
Coadded Images
External Catalogs
DIA Objects
Coadded Image Analysis
3
Objects
Single Visits
Diff. Images
Multi-epoch Object Characterization
4
Objects
Forced Sources
Image Differencing
5
Coadded Images (templates)
Difference Images
Objects
DIA Objects
SS Objects
Single Visits
Difference Image Analysis
6
DIA Objects
DIA Sources
DIA Forced Sources
Only in nightly processing
Coadded Images (templates)
Diff. Images
Generate and Distribute Alerts
7
Only in nightly processing
MOPS
8
Alerts
SS Objects

Astronomical Image Formation (ground based optical telescopes)

Basic steps in astronomical image processing







Additional "followup" data obtained to:
- confirmation and classification
- provide better temporal resolution
- use different filters/wavelengths
- obtain spectra (distance!)
- other measurements (e.g. polarimetry)

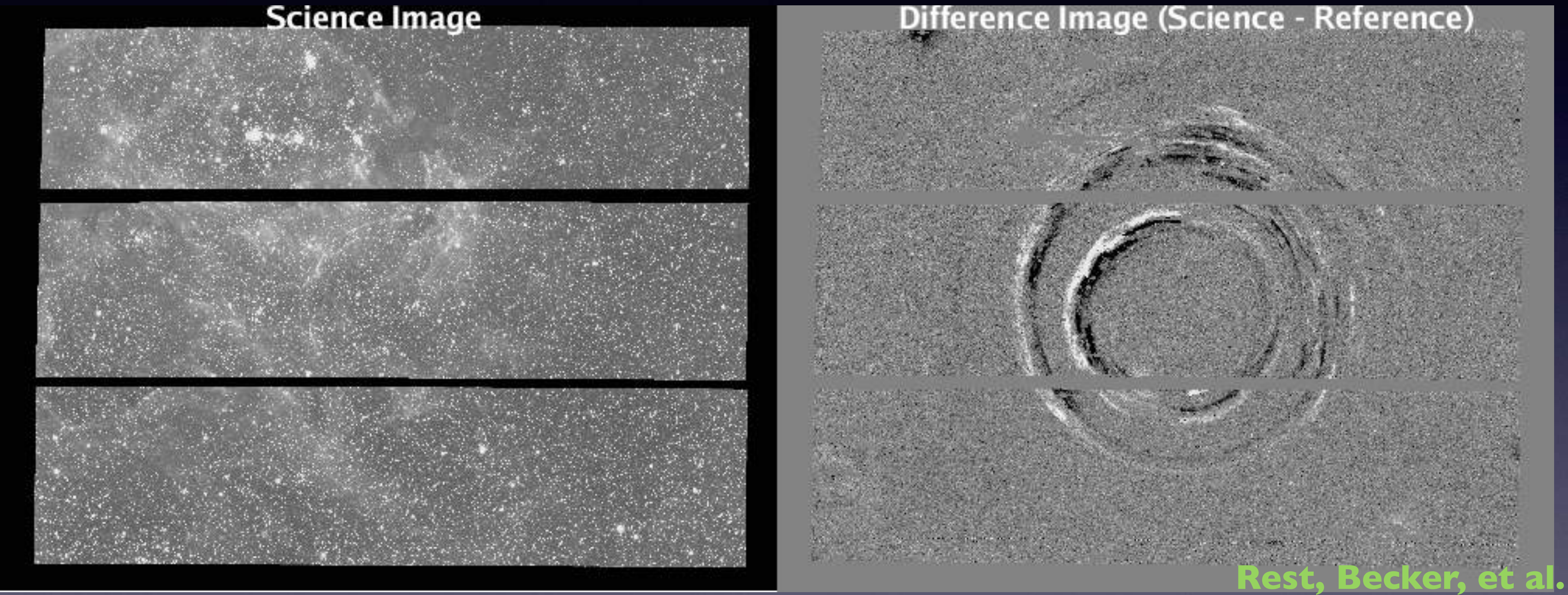
Alerts can trigger "Followup" observations:

Time Domain: objects changing in time

positions: asteroids and stellar proper motions

brightness: cosmic explosions and variable stars

Not only point sources - echo of a supernova explosion:



As many variable stars from LSST, as all stars from SDSS

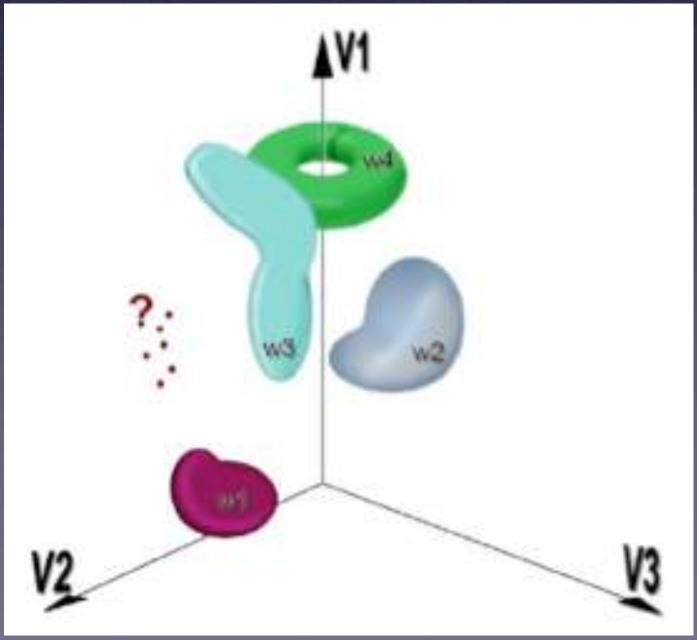
Web stream with data for transients within 60 seconds.

Real time alerts!

Statistical analysis of a massive LSST dataset

- A large (100 PB) database and sophisticated analysis tools: for each of 40 billion objects there will be about 1000 measurements (each with a few dozen measured parameters)

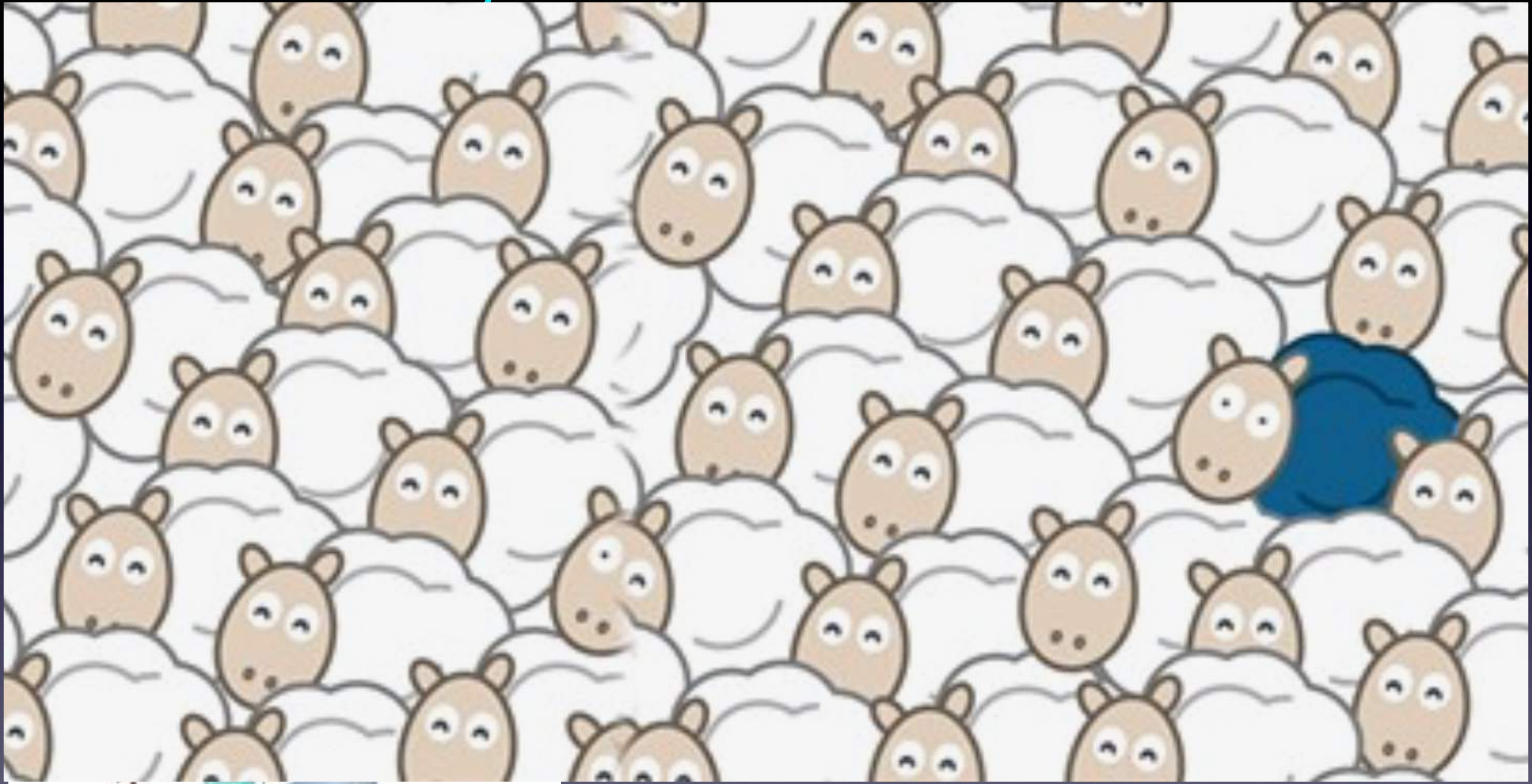
Data mining and knowledge discovery

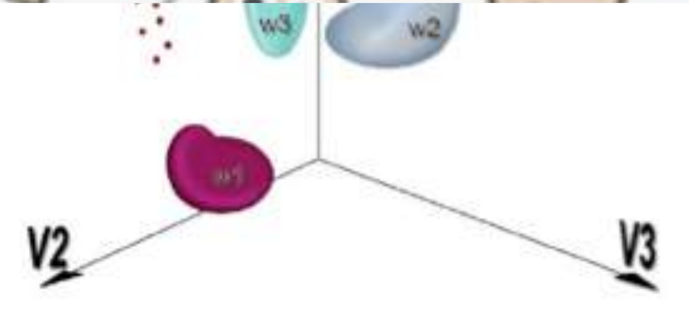


- 10,000-D space with 40 billion points
- Characterization of known objects
- Classification of new populations
- Discoveries of unusual objects

Clustering, classification, outliers

Statistical analysis of a massive LSST dataset





- Classification of new populations
- Discoveries of unusual objects

Clustering, classification, outliers

1) Introduction

- astroML

astroML

Home | User Guide | Book Figures | Examples Plots

Google™ Custom Search

News

October 2012: astroML 0.1 has been released! Get the source on Github

Our Introduction to astroML paper received the CIDU 2012 best paper award.

Links

astroML Mailing List

GitHub Issue Tracker

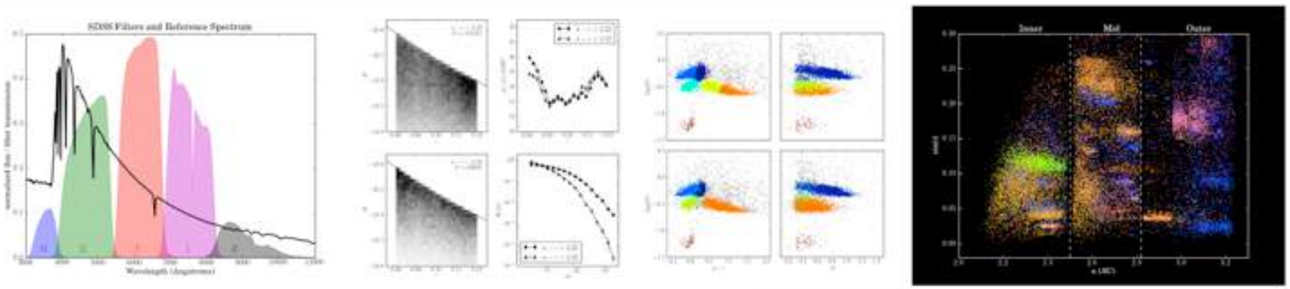
Videos

Scipy 2012 (15 minute talk)

Citing

If you use the software, please consider citing astroML.

AstroML: Machine Learning and Data Mining for Astronomy

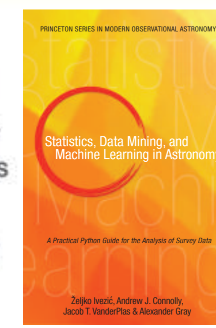


AstroML is a Python module for machine learning and data mining built on numpy, scipy, scikit-learn, and matplotlib, and distributed under the 3-clause BSD license. It contains a growing library of statistical and machine learning routines for analyzing astronomical data in python, loaders for several open astronomical datasets, and a large suite of examples of analyzing and visualizing astronomical datasets.

Downloads

- Released Versions: Python Package Index
- Bleeding-edge Source: github

The goal of astroML is to provide a community repository for fast Python implementations of common tools and routines used for statistical data analysis in astronomy and astrophysics, to provide a uniform and easy-to-use interface to freely available astronomical datasets. We hope this package will be useful to researchers and students of astronomy. The astroML project was started in 2012 to accompany the book **Statistics, Data Mining, and Machine Learning in Astronomy** by Zeljko Ivezic, Andrew Connolly, Jacob VanderPlas, and Alex Gray, to be published in late 2013. The table of contents is available here: `here(pdf)`.



User Guide

1. Introduction

- 1.1. Philosophy

Open source!

www.astroML.org

Textbook Figures

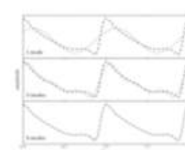
This section makes available the source code used to generate every figure in the book *Statistics, Data Mining, and Machine Learning in Astronomy*. Many of the figures are fairly self-explanatory, though some will be less so without the book as a reference. The table of contents of the book can be seen **here(pdf)**.

Figure Contents

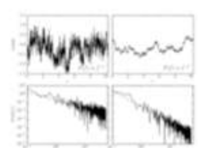
Each chapter links to a page with thumbnails of the figures from the chapter.

Chapter 10: Time Series Analysis

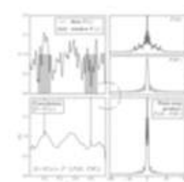
This chapter covers the analysis of both periodic and non-periodic time series, for both regularly and irregularly spaced data.



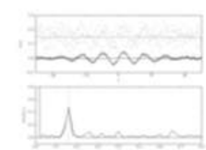
Fourier Reconstruction of RR-Lyrae Templates



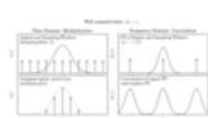
Generating Power-law Light Curves



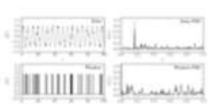
Plot a Diagram explaining a Convolution



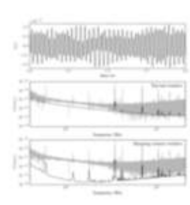
Fast Fourier Transform Example



The effect of Sampling



The effect of Sampling



Plot the power spectrum of the LIGO big dog event

Examples of Wavelets

1) Introduction
- astroML

If you haven’t already, please install astroML by following instructions at:
https://www.astroml.org/user_guide/installation.html

or google for “astroML”, go to
https://www.astroml.org
and scroll down to the table of contents.

Disclaimer: you may need to run python 2.7 (that is, not python 3.x) as I noticed some errors I didn’t understand when testing this morning! Sorry!

1) Introduction
- astroML

To test, start ipython shell and do:

```
Macintosh-3:~ ivezic$ ipython
[TerminalIPythonApp] WARNING | Config option `ignore_old_config` not recognized
by `TerminalIPythonApp`.
Python 2.7.13 |Anaconda custom (x86_64)| (default, Dec 20 2016, 23:05:08)
Type "copyright", "credits" or "license" for more information.

IPython 5.3.0 -- An enhanced Interactive Python.
?         -> Introduction and overview of IPython's features.
%quickref -> Quick reference.
help      -> Python's own help system.
object?   -> Details about 'object', use 'object??' for extra details.

In [1]: from astroML.datasets import fetch_sdss_spectrum

In [2]: spec = fetch_sdss_spectrum(1615, 53166, 513)

In [3]:
```

If there are no error messages, you are good to go!
If there are problems (e.g. with “GMM”) go to py2.7

We need more downloads, which you can do by tomorrow:

Download dataAll.tar.gz (245 MB) as https://ls.st/e3k **SLOW!**

Make a directory astroML_data in your home directory and download dataAll.tar.gz to that directory.

Then unpack it:

```
> cd ~/astroML_data
> gunzip dataAll.tar.gz  (possible done by your machine)
> tar -xvf dataAll.tar
```

and you should see 4 *.fit files, 2 *.npy files and one *.npz file.

In addition, clone my directory with lectures (wherever):

```
> git clone git@github.com:dirac-institute/SPSAS2019.git
```

ALSO SLOW!

Test astroML and git repository installation

by starting jupyter notebook with file

…/SPSAS2019/lectures/test.ipynb and executing the code there:

> jupyter notebook …/SPSAS2019/lectures/test.ipynb &

It should produce this figure: