
Science from the LSST
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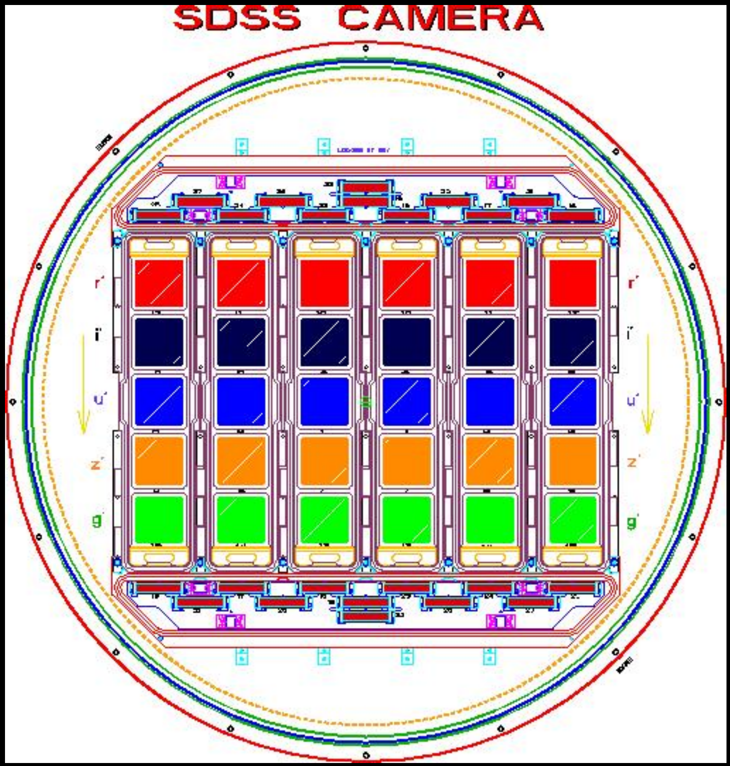
Era of surveys: the Sloan Digital Sky Survey



- Digital sky survey with a 120 Megapix CCD camera
- Precise measurements for 470,000,000 objects (DR8)
- Revolution in astronomy: public databases

The Decadal Survey (2010)

Top rank accorded to LSST is a result of:

(1) "its **compelling science case** and capacity to address so many of the science goals of this survey",

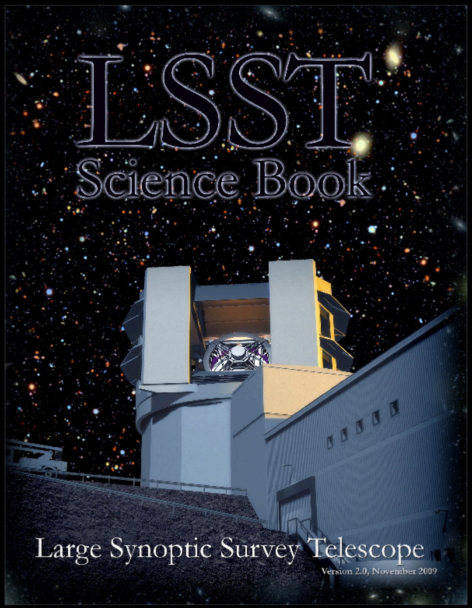
[and]

(2) "**its readiness** for submission to the MREFC process as informed by its technical maturity, the survey's assessment of risk, and appraised construction and operations costs."

LSST Science Book

Summarizes the basic parameters of the LSST hardware, software, and observing plans, discusses educational and outreach opportunities, and describes a broad range of science that LSST will revolutionize

245 authors, 15 chapters, 600 pages



Outline

1. LSST system summary

Science Themes
System Characteristics

2. LSST science examples

Extragalactic astronomy and cosmology
The Milky Way and the Local Group
Time Domain

3. Science in the era of big data

Scaling the analysis and tools

LSST science themes

1. Dark matter, dark energy, cosmology

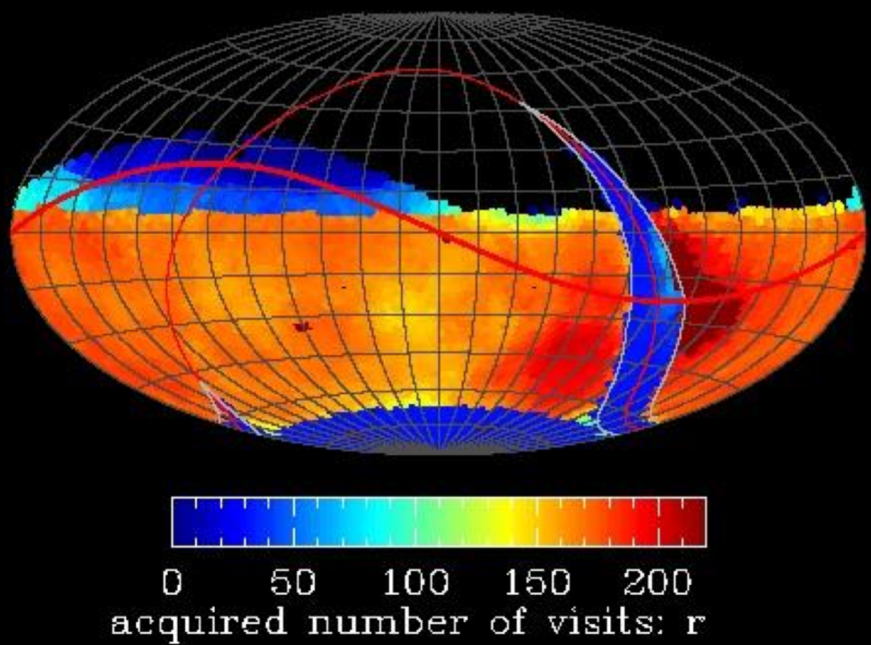
2. Time domain

3. The Solar System structure

4. The Milky Way structure

These drivers not only require similar hardware and software systems, but also motivate a uniform cadence

Basic idea behind LSST: a uniform survey



LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 1000 visits over 10-year period: deep wide fast.

- **90% of time will be spent on a uniform survey:** every 3-4 nights, observable sky is scanned twice per night
- **after 10 years, half of the sky 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 20 billion objects

Required system characteristics

Large primary mirror (at least 6m) to go faint and to enable short exposures (30 s)

Agile telescope (5 sec for slew and settle)

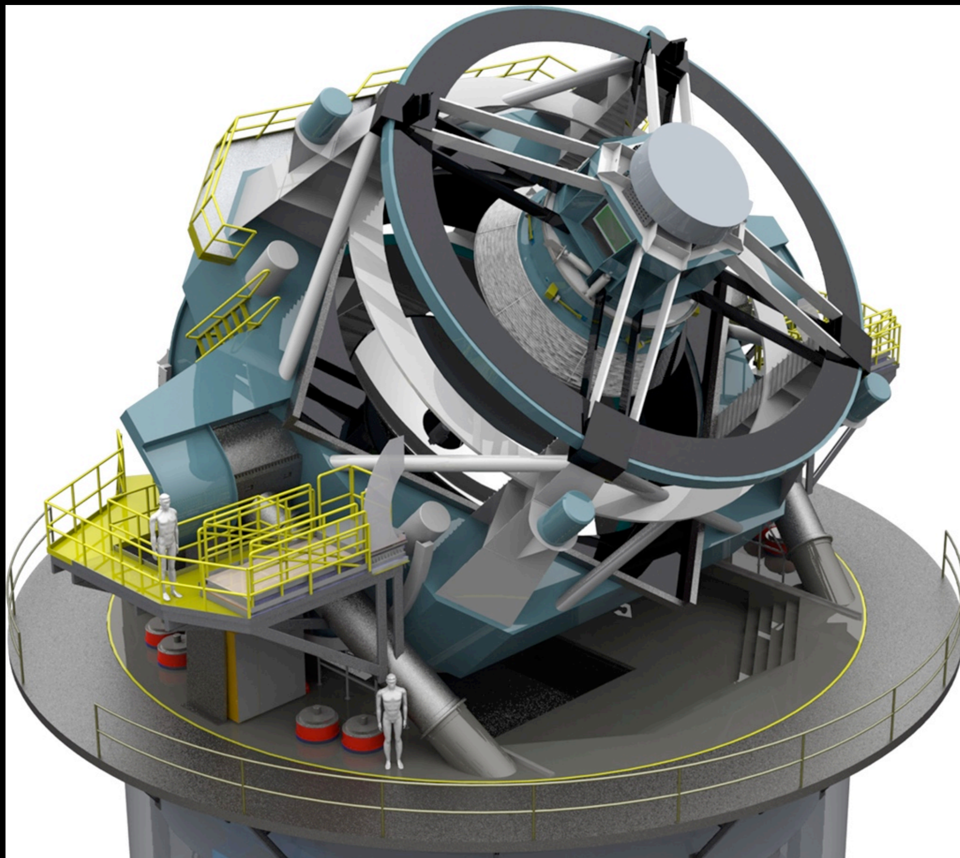
Large field of view to enable fast surveying

Impeccable image quality (weak lensing)

Camera with 3200 Mpix

Sophisticated software (20,000 GB/night, 20 billion objects, 20 trillion measurements)

LSST telescope



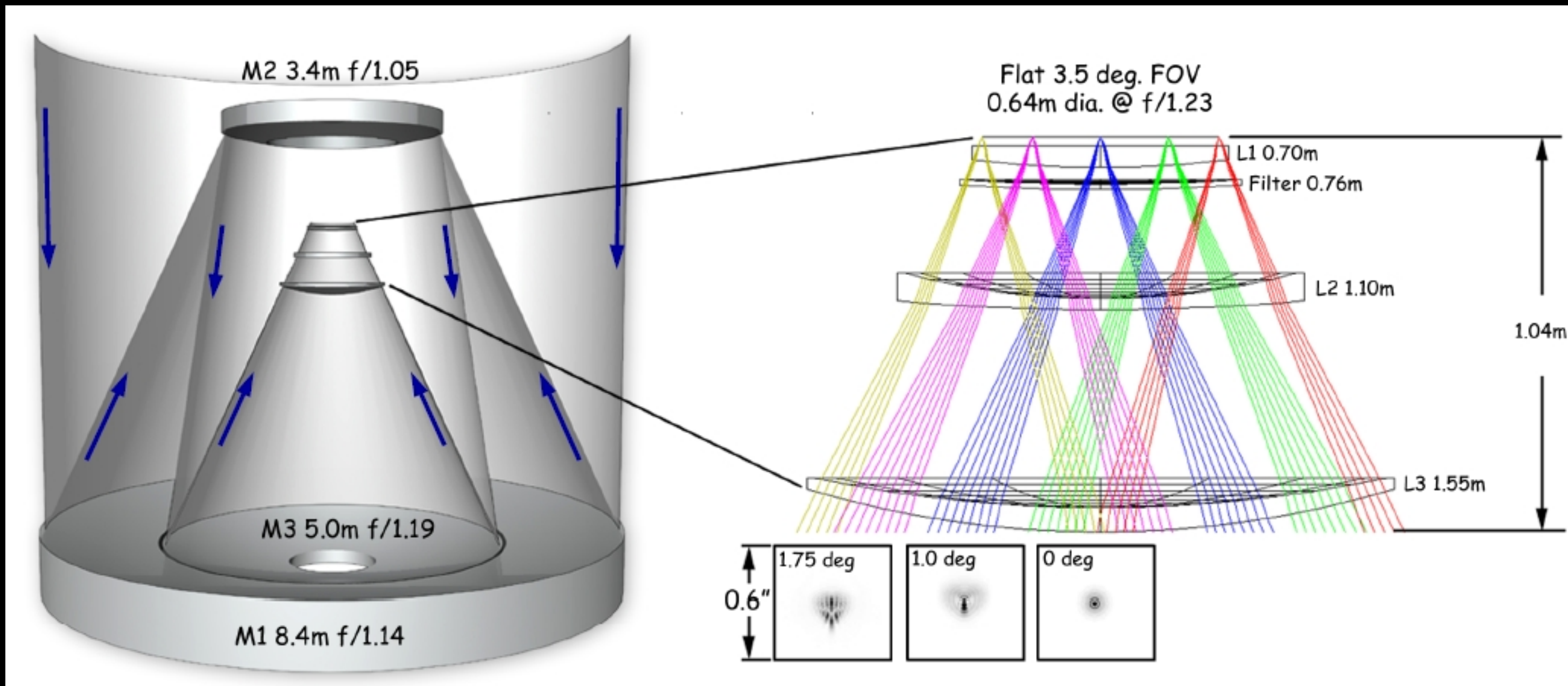
8.4m, 6.7m effective

3.5° field-of-view

5 sec slew & settle


April 12,
2011
Approximate location
of telescope and pier
Approximate leveling for telescope
enclosure

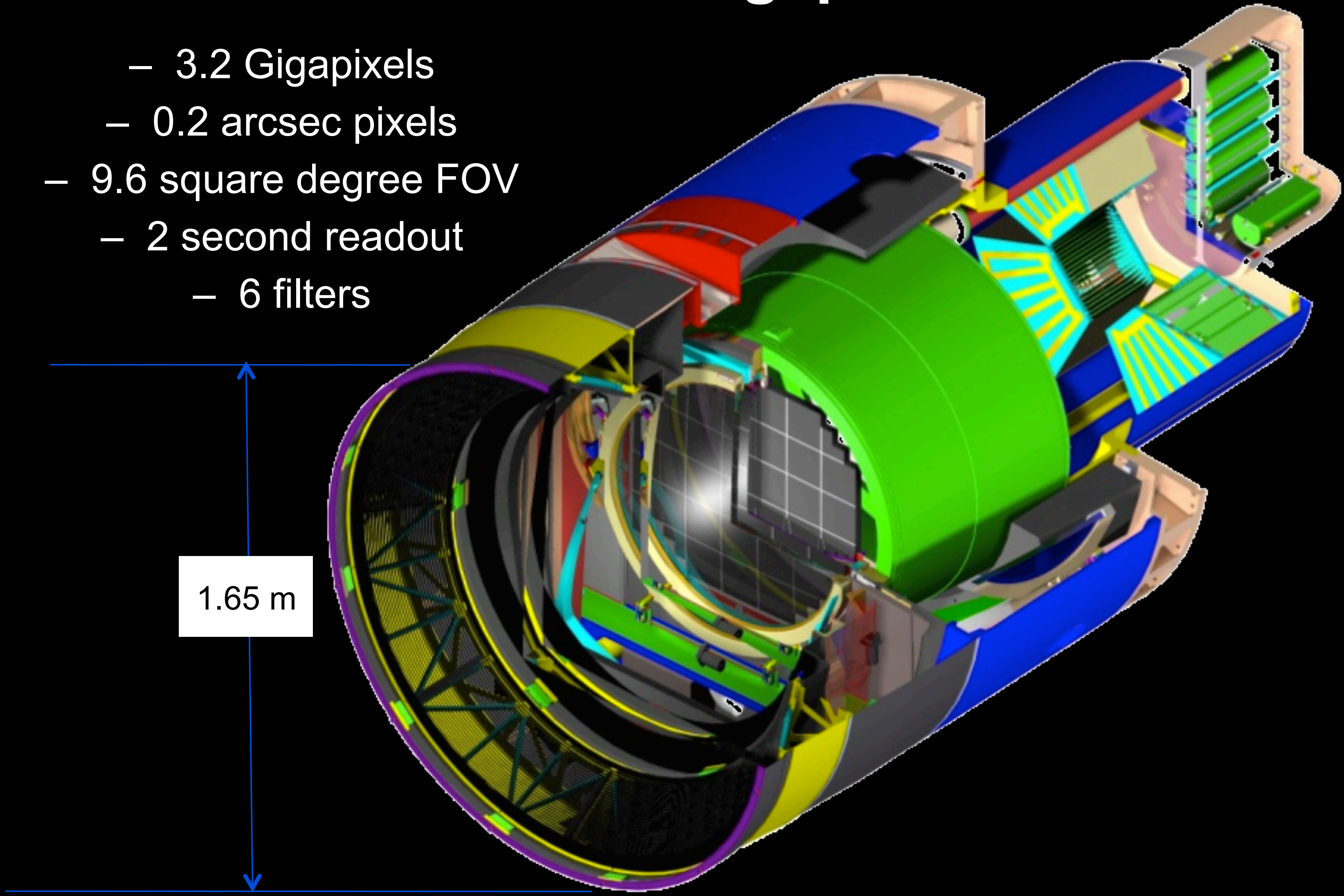
Optical design for LSST



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

LSST camera: A 3.2 Gigapixel camera

- 3.2 Gigapixels
- 0.2 arcsec pixels
- 9.6 square degree FOV
- 2 second readout
- 6 filters



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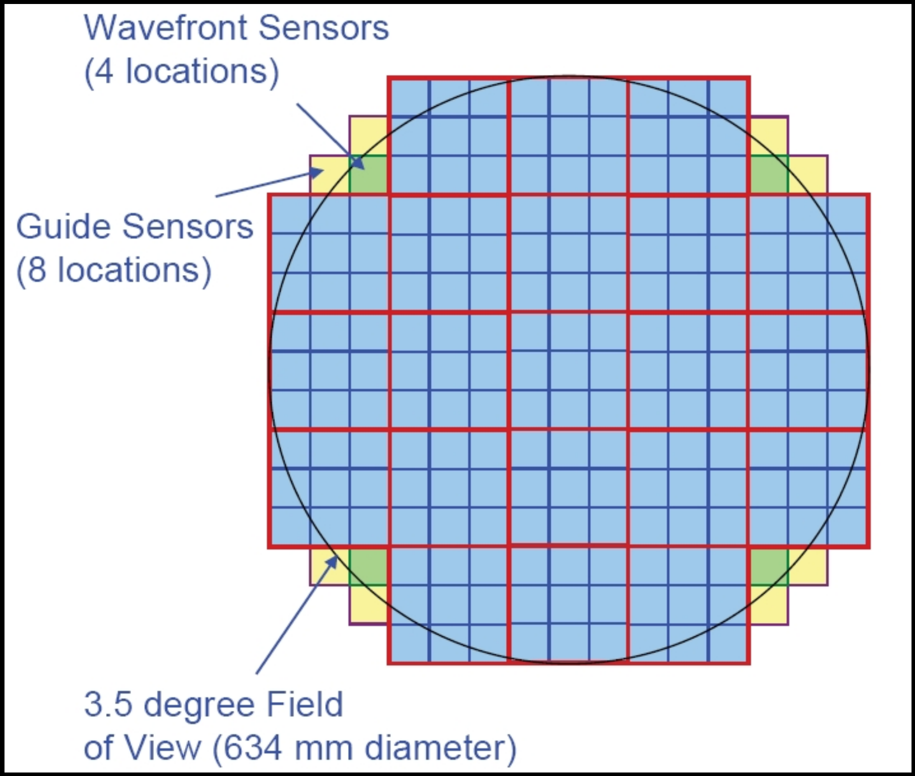
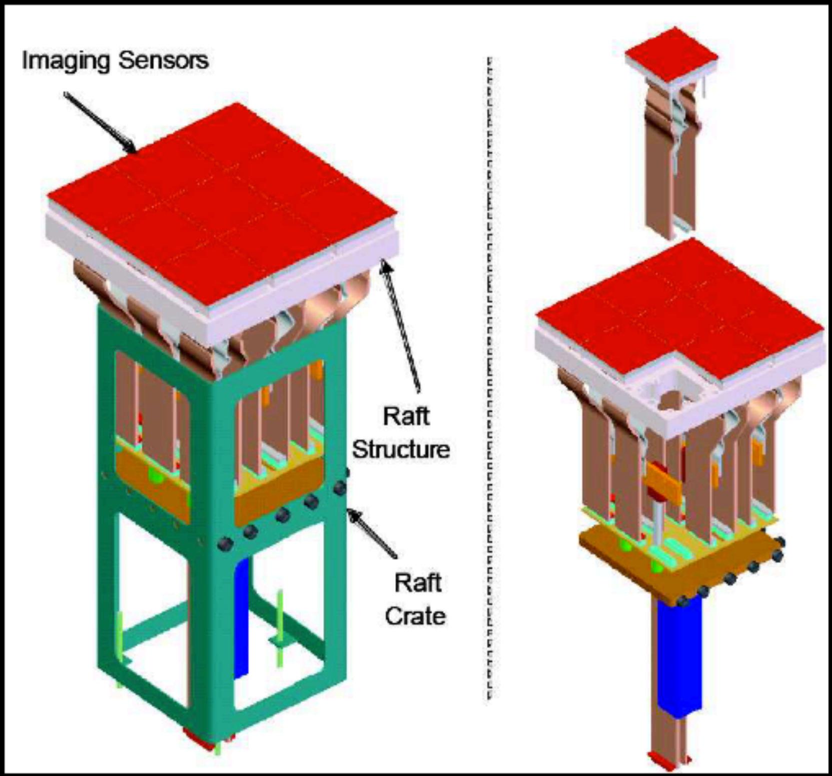




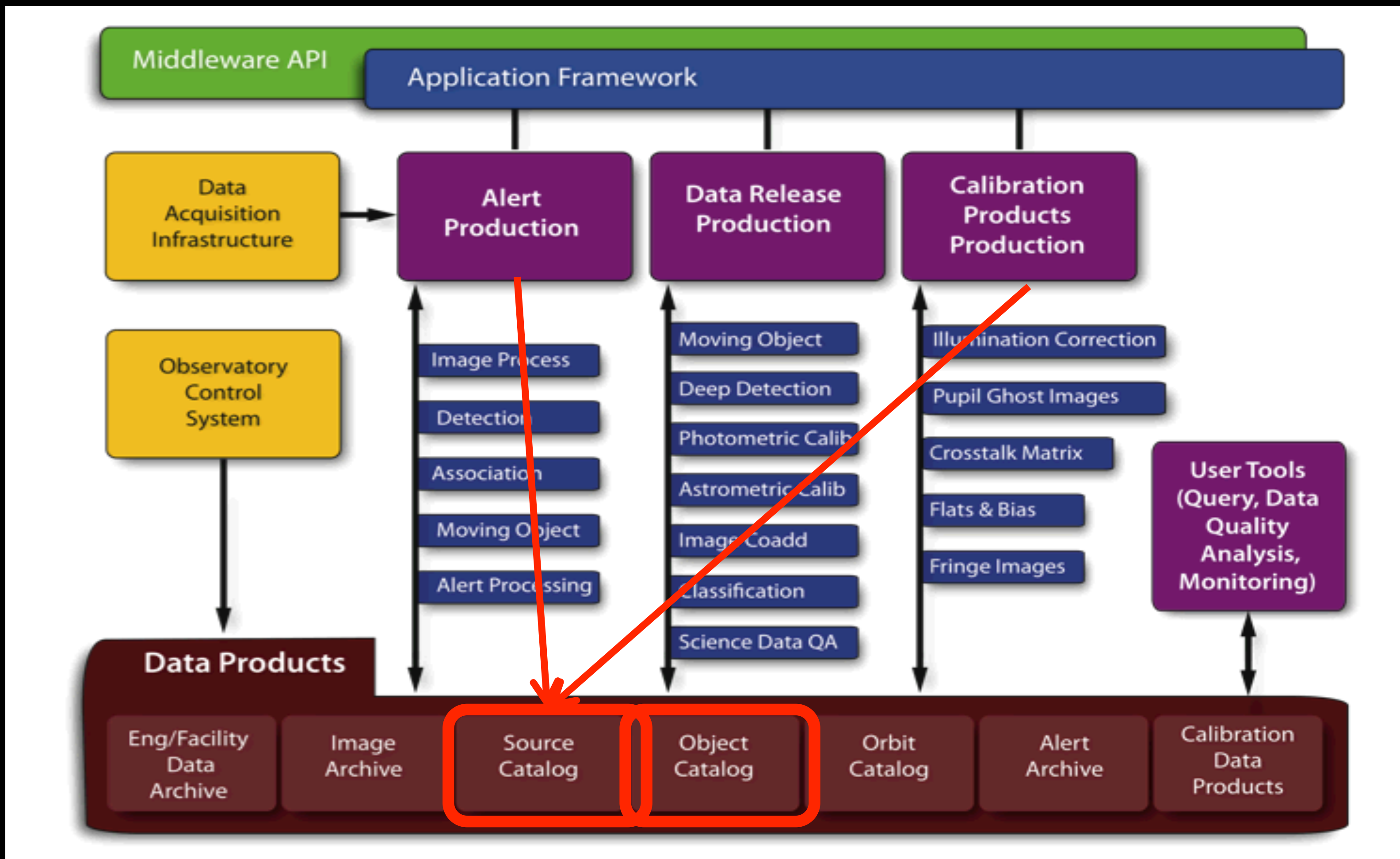
Modular design: 3200 Megapix = 189 x16 Megapix CCD
9 CCDs share electronics: raft (=camera)
Problematic rafts can be replaced relatively easily

Processing the data flow from the LSST

- Each "Visit" comprises a pair of back-to-back exposures
  - 2x15 sec exposure; duration = 34 seconds with readout
- The data volume associated with this cadence is unprecedented
  - one 6.4-gigabyte image every 17 seconds
  - 15 terabytes of raw scientific image data / night
  - 100-petabyte final image data archive
  - 20-petabyte final database catalog
  - 2 million real time events per night every night for 10 years

Processing the data flow from the LSST

LSST data processing pipelines are being designed prototyped and tested

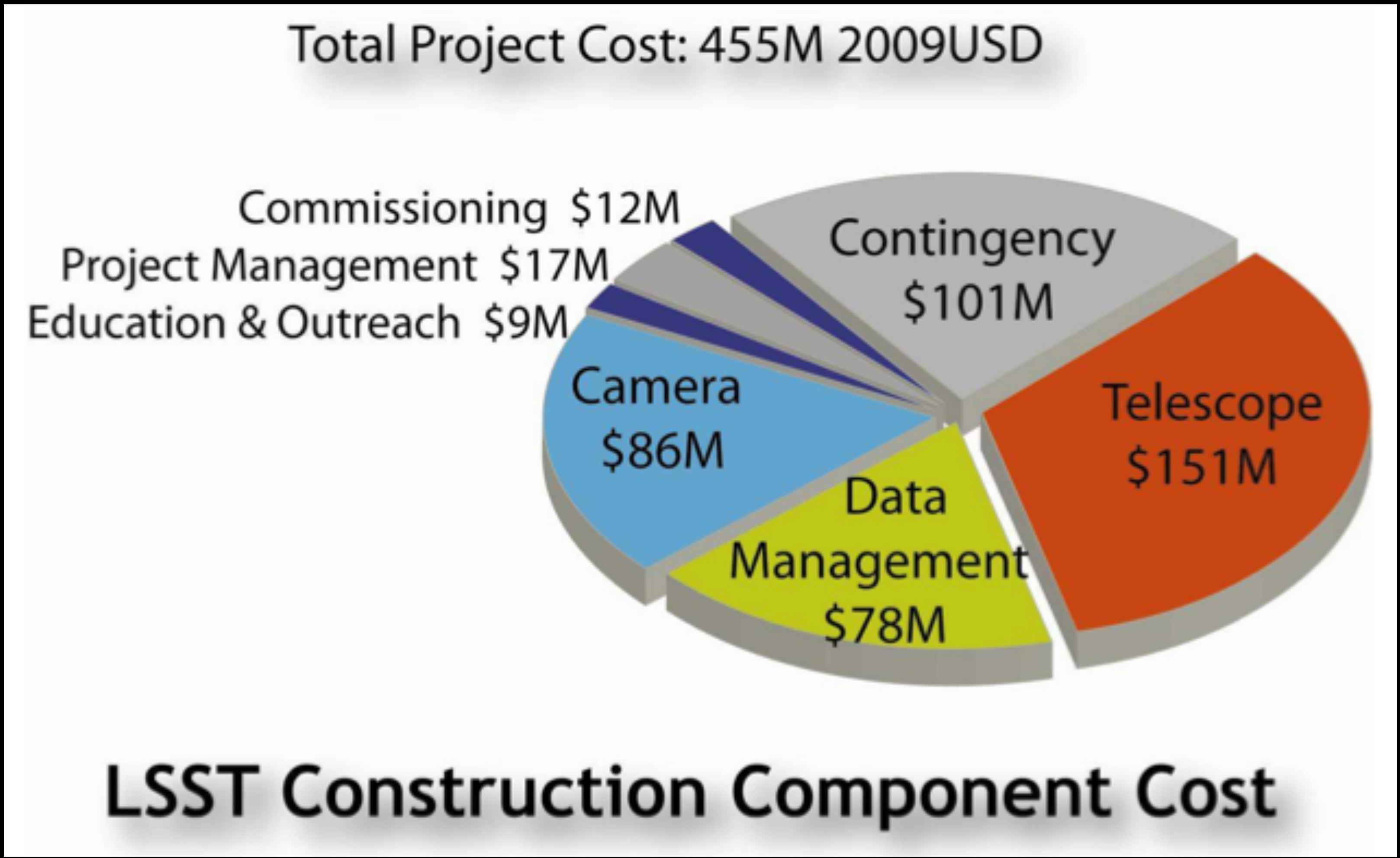


LSST timeline

- **Estimate: commissioning in late 2020 (if MREFC in FY2014)**
  - Primary/Tertiary Mirror being polished, have secondary mirror blank
  - Sensor development program delivered first prototype sensors
  - Processing pipelines under construction, hand-in-hand with simulations of Operations, Images, Catalogs
- **Cost: about the same as CATE estimate**
  (~$850M in $2011, contributions from NSF, DOE and private gifts)

Budgeting of the LSST

Half for construction, half for 10 years of operations



First light: around 2020 (if federal constr. in FY2014)

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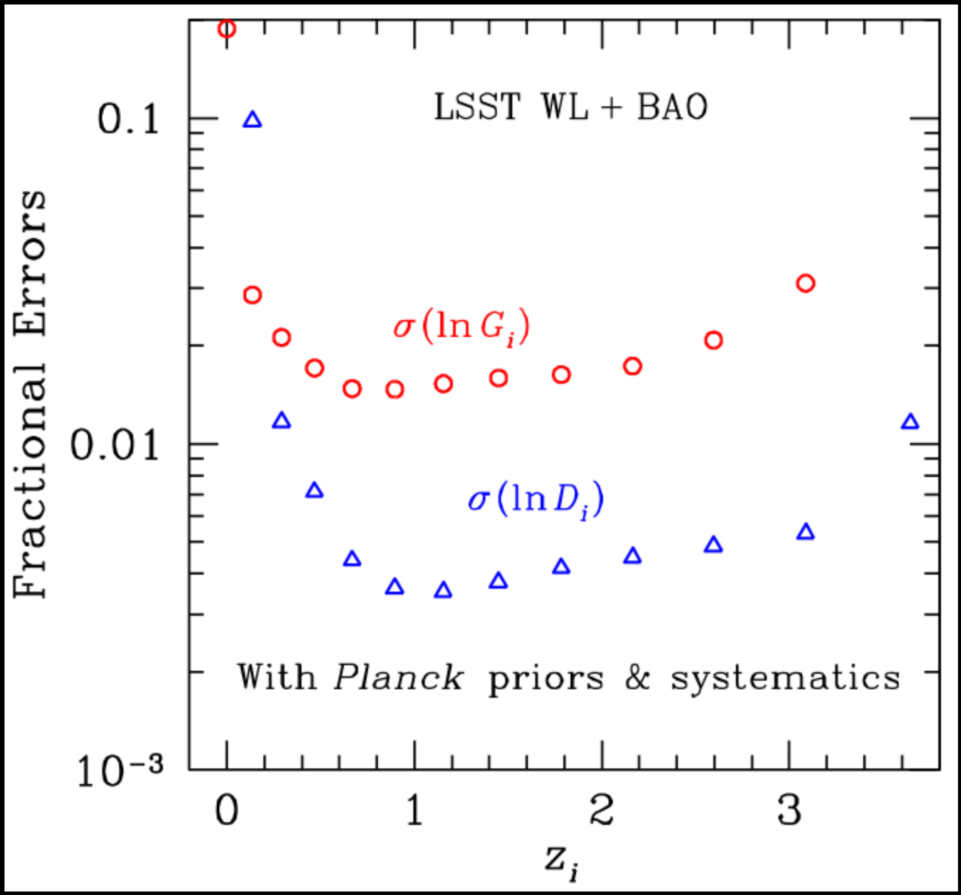
Modern cosmological probes

- Cosmic Microwave Background
  - the state of the Universe at the recombination epoch, at redshift ~1100)
- 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)

Cosmology with LSST

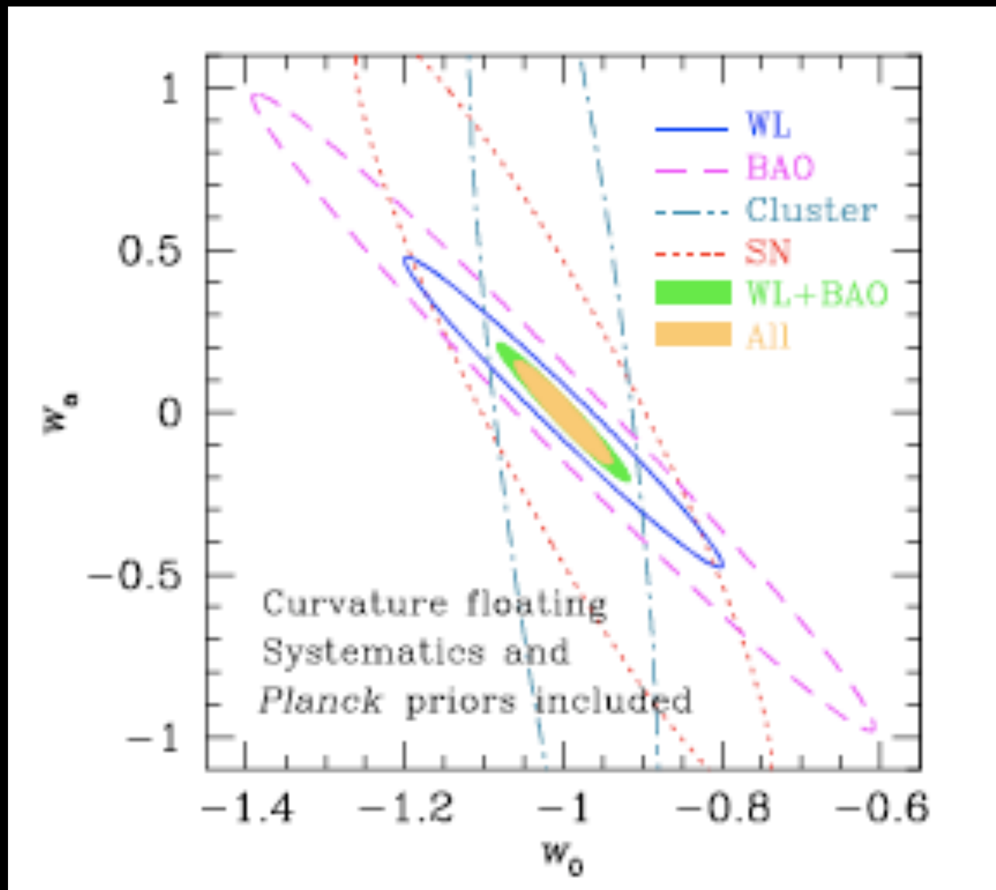


Derived from 4 billion galaxies (i<25.3, SNR>20) with accurate photo-z and shape measurements

Measuring distances and growth of structure with 1% accuracy for 0.5 < z < 3

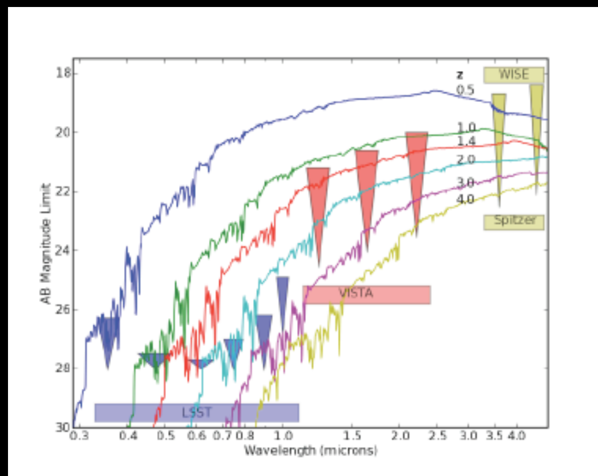
SNe will provide a high angular resolution probe of homogeneity and isotropy of the Universe

Separate and joint constraints on the dark energy equation of state

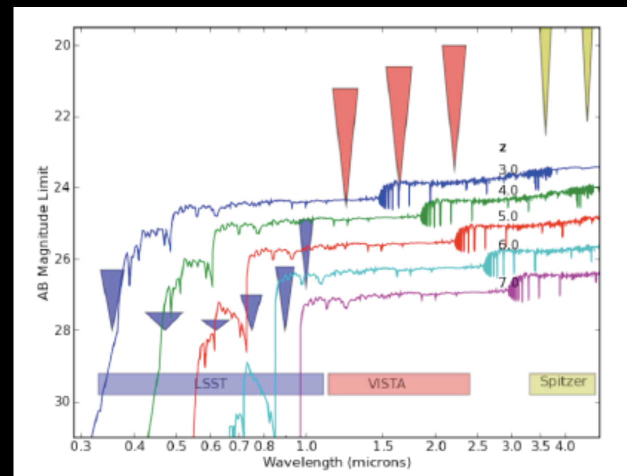


$$w(a) = w_0 + w_a(1+a)$$

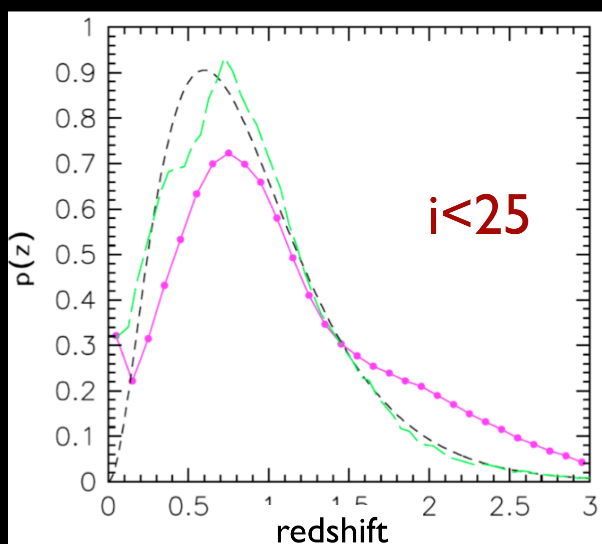
Extragalactic astronomy: galaxies



Fiducial Red Sequence Galaxy

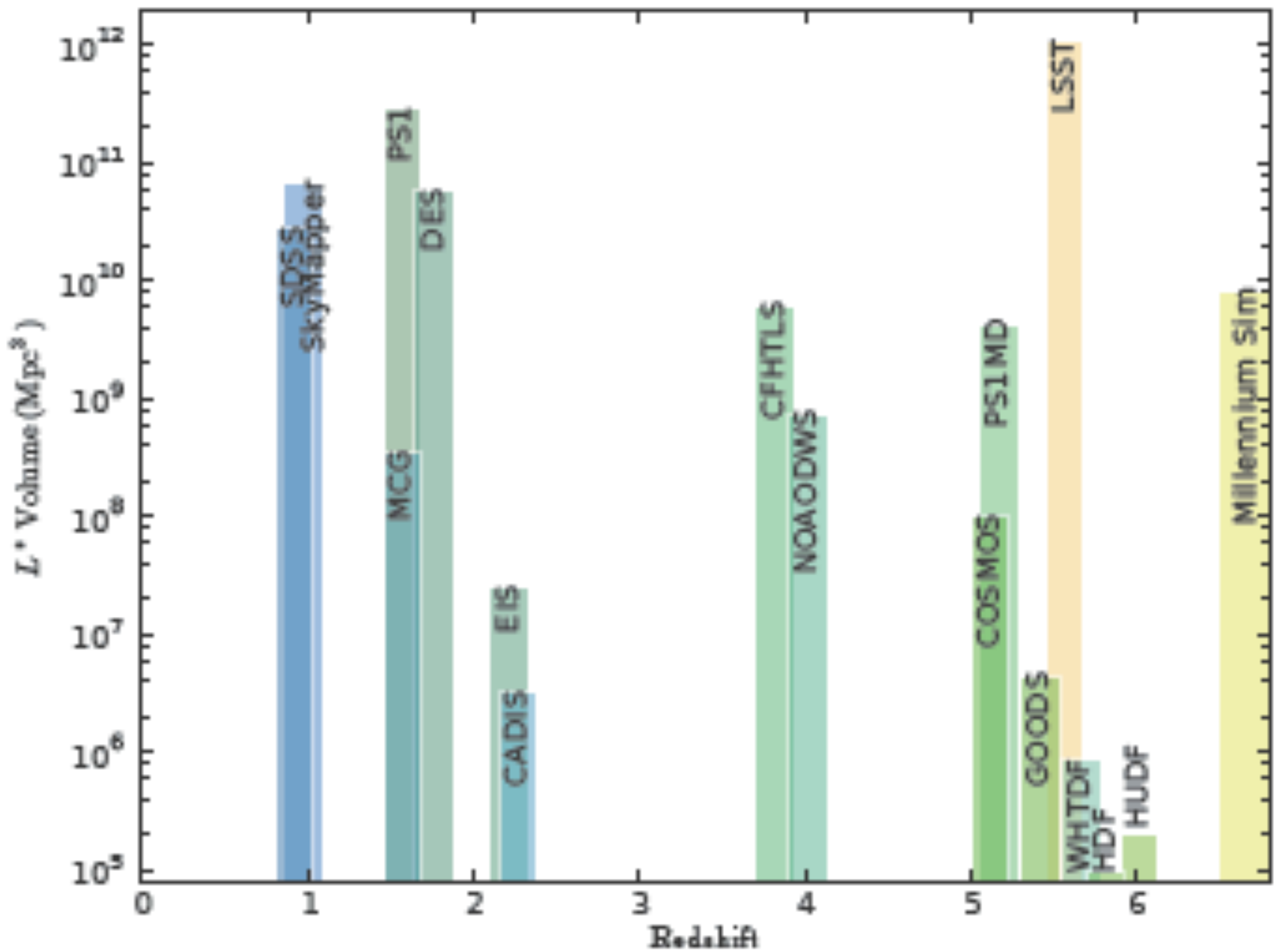


Fiducial Lyman-Break Galaxy



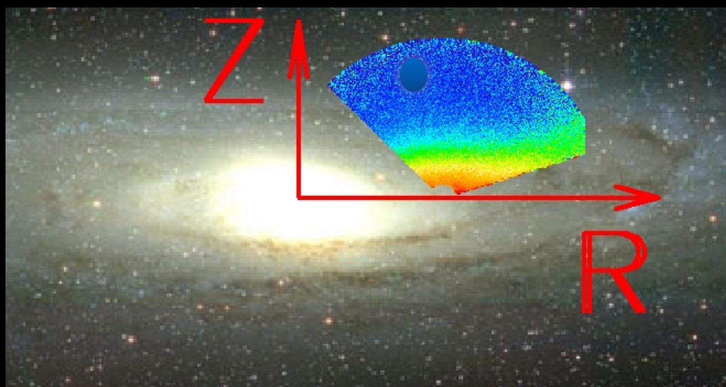
- **About 10 billion galaxies, with 4 billion in a "gold" sample defined by i<25.3**
- **The "gold" sample extends to redshifts of >2.5: evolution**

LSST's effective volume

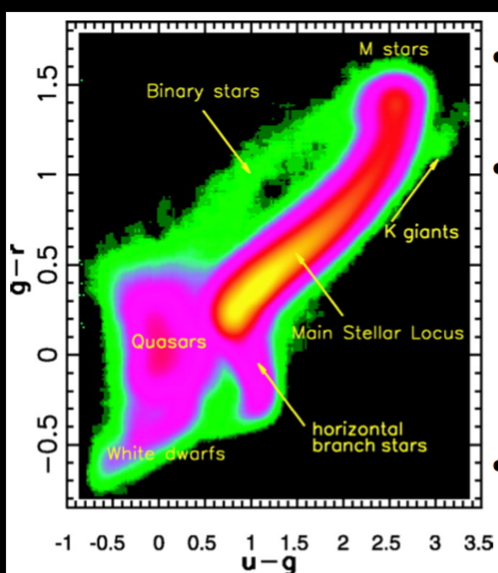


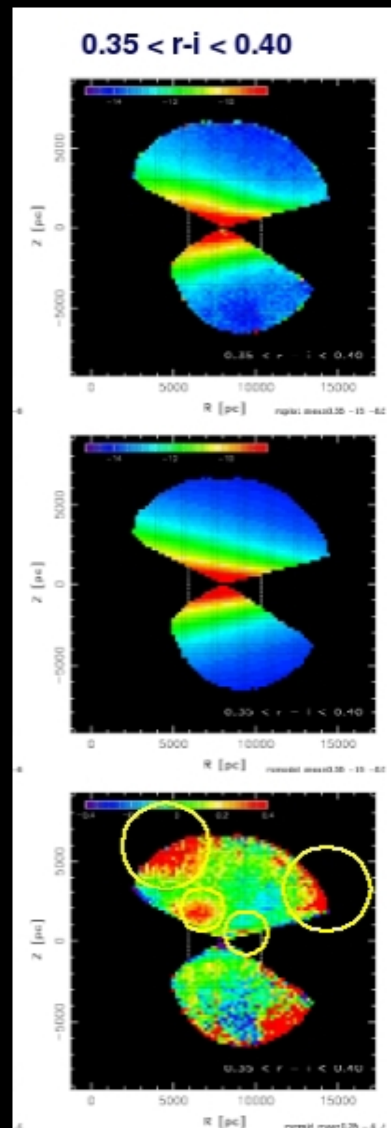
The Milky Way structure: 10 billion stars

Main sequence stars

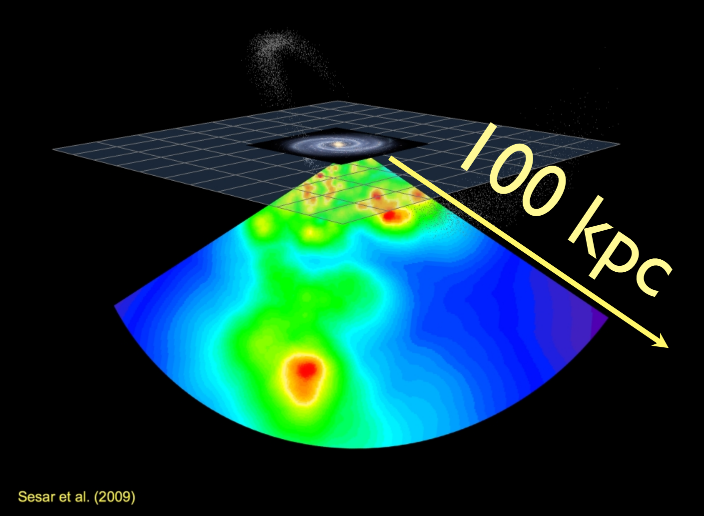


Distance and [Fe/H]:





Compared to SDSS: LSST can "see" 10 times further away and over twice as large an area

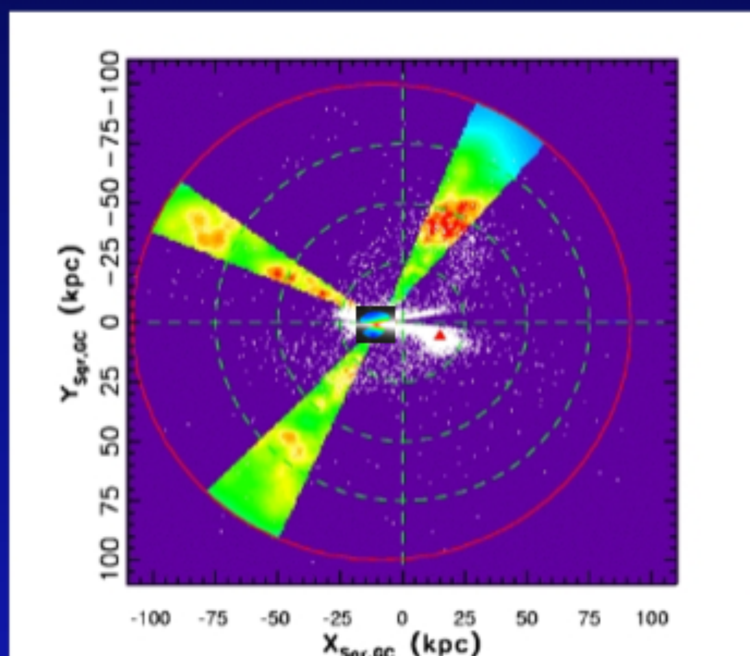


SDSS RR Lyrae

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

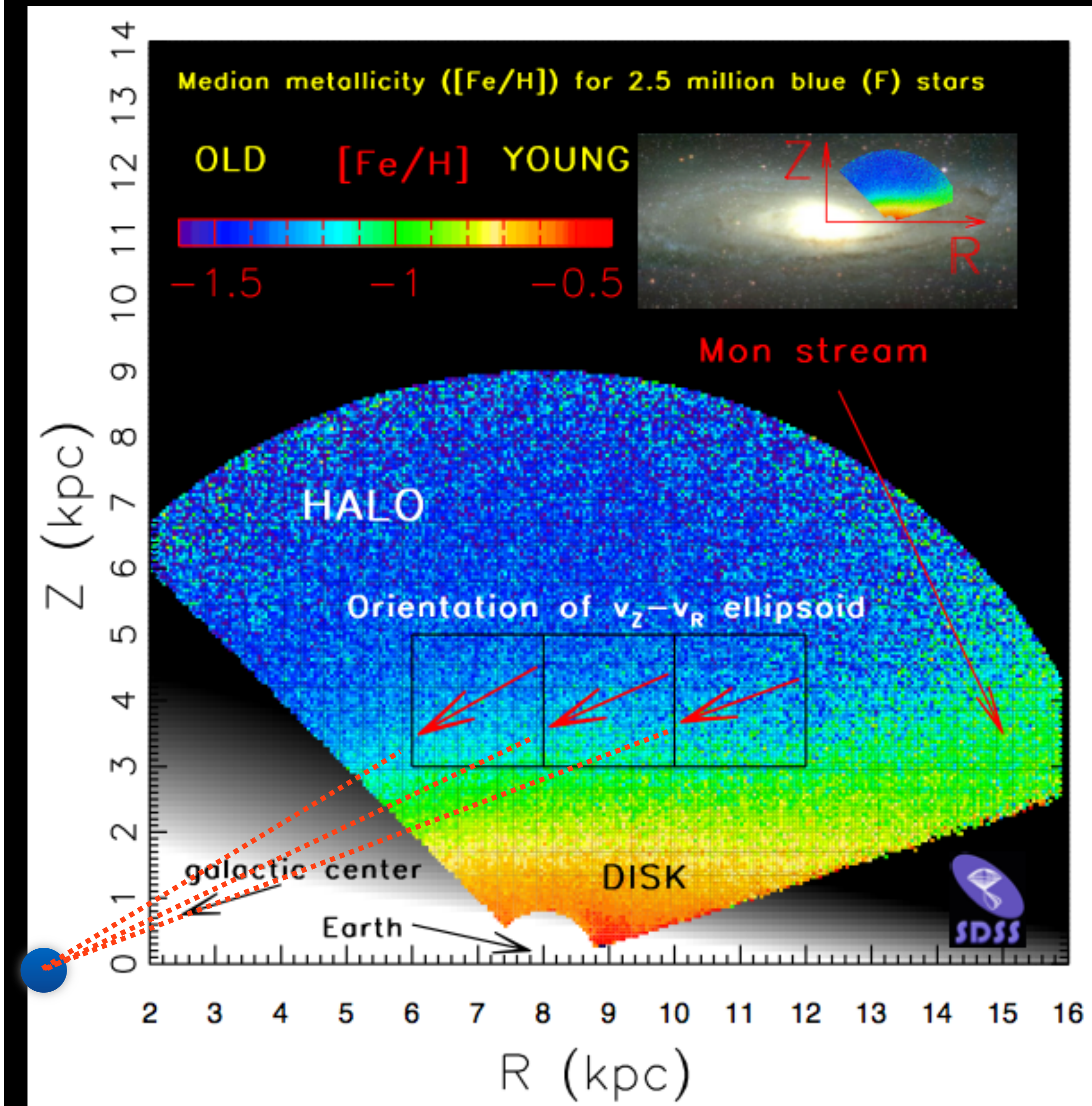
LSST limit for RR Lyrae: 400 kpc

The large red circle: the ~100 kpc limit of future LSST studies based on main-sequence stars (and the current limit for RR Lyrae studies)



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

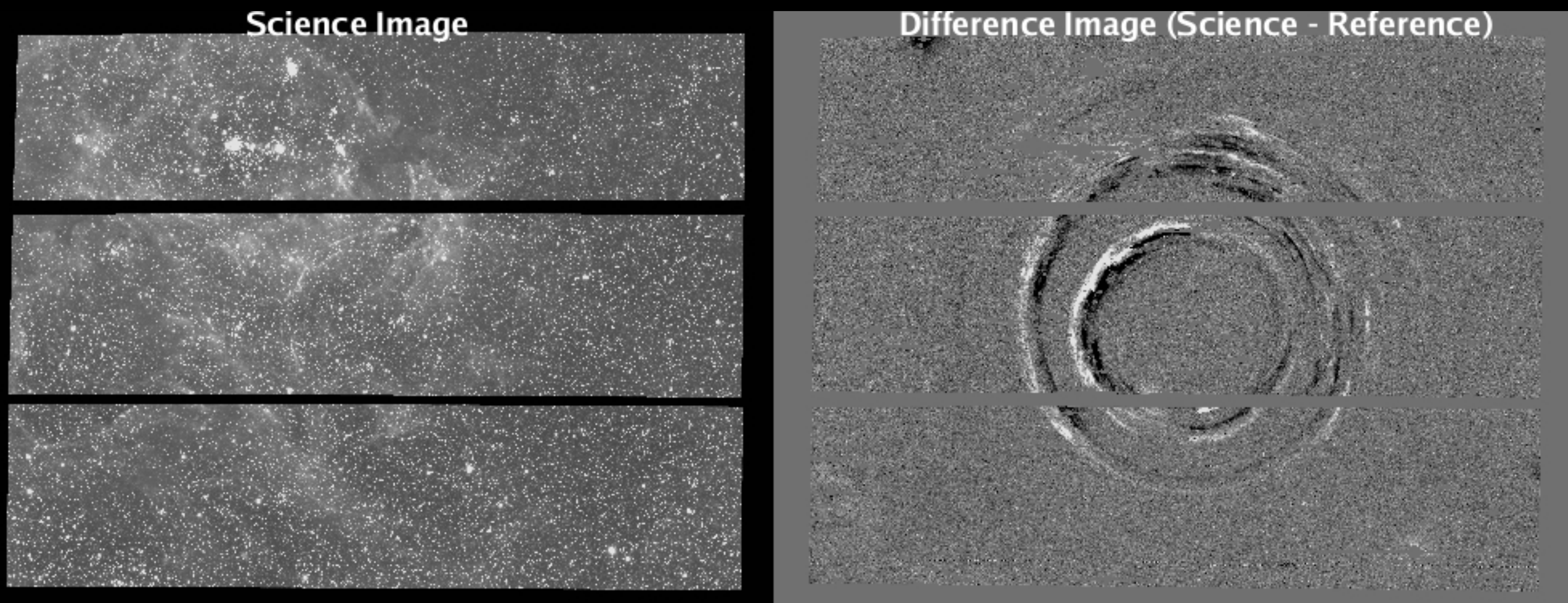
Extending the time domain: proper motions



Kinematics of halo stars based on SDSS-POSS proper motions: velocity ellipsoid is nearly invariant in spherical coordinate system, which implies that the gravitational potential must be nearly spherical!

Extending the time domain: variability

Not only point sources - echo of a supernova explosion:



Becker et al.

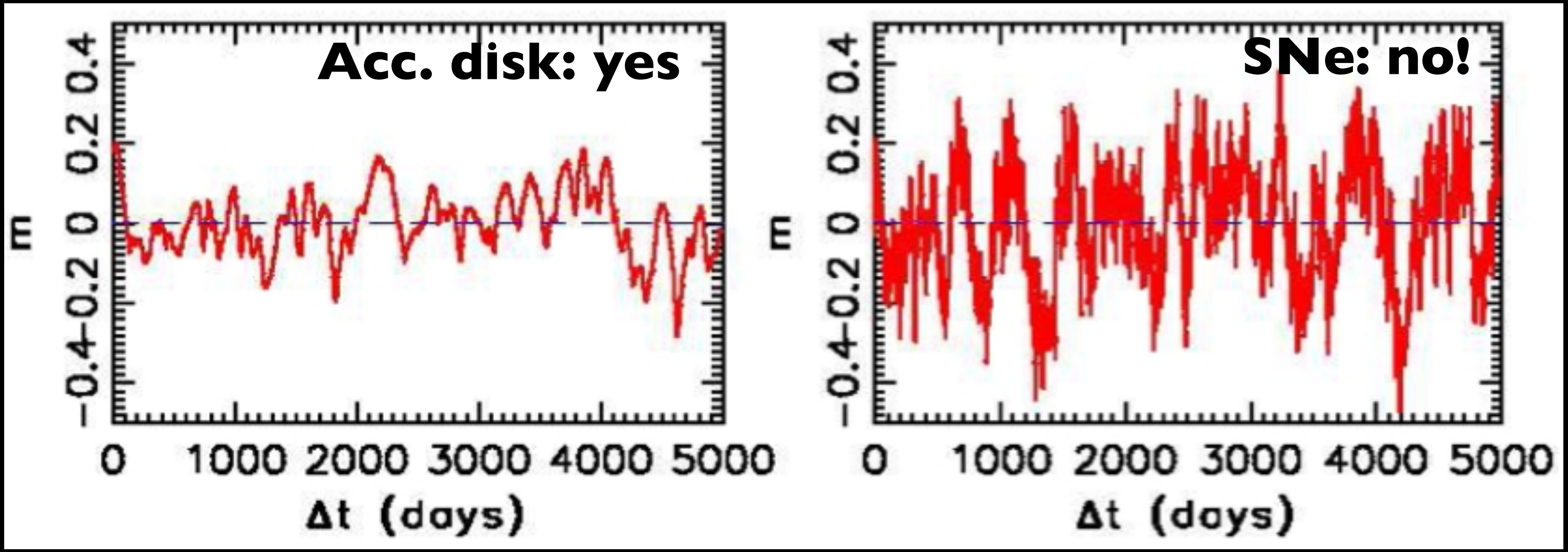
As many variable stars from LSST, as all stars from SDSS

stream with data for transients within 60 seconds

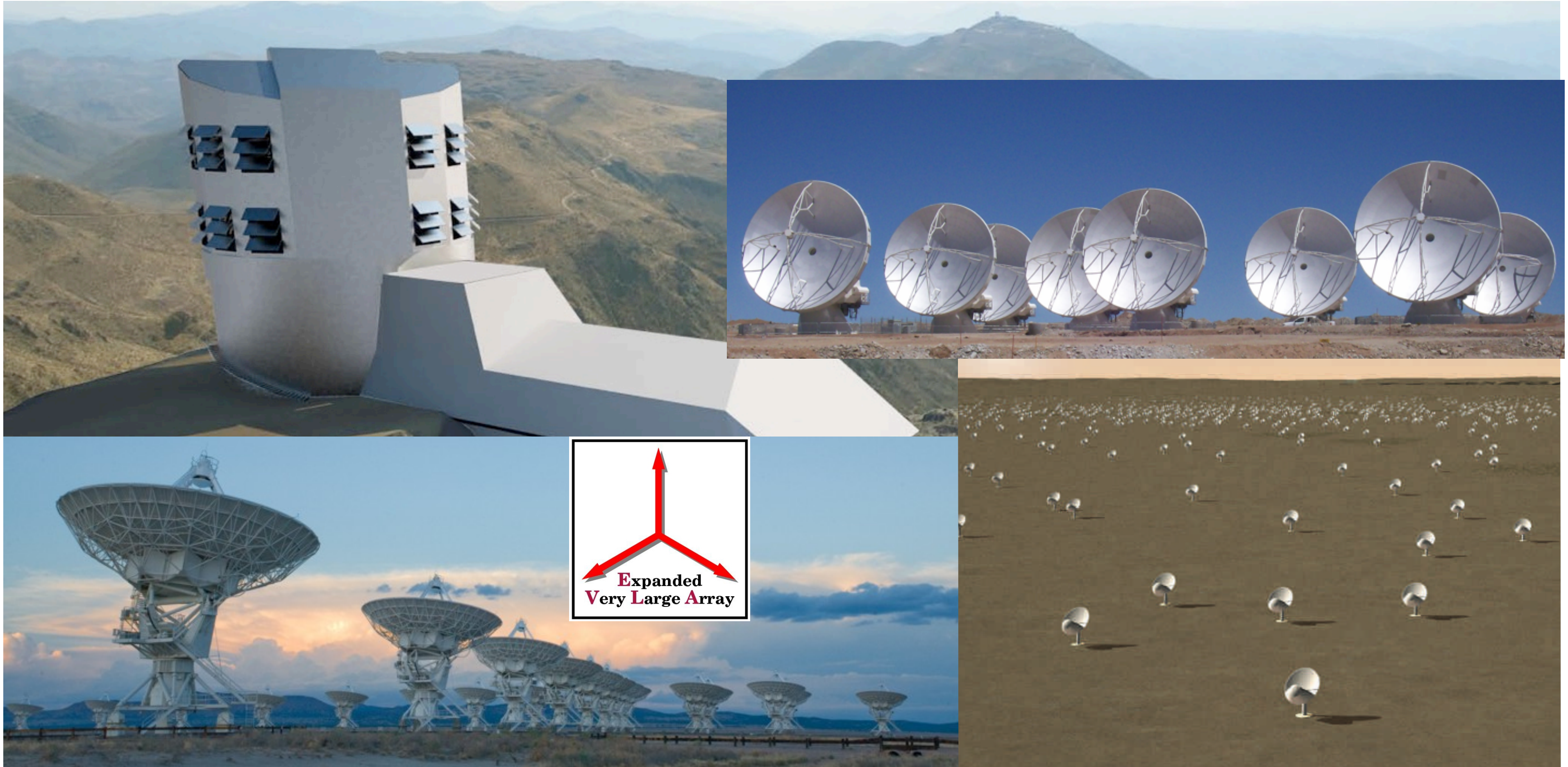
Extending the time domain: quasar variability

Competing theories for the origin of variability:
Microlensing - Bursts of Supernovae - Accretion disk instabilities

SDSS Stripe 82 observations indicate rich information content and can already reject some models (MacLeod et al. 2010):



Variability is a tool, just like imaging, spectroscopy and multi-wavelength X-ray to radio observations, for studying quasars



The impact of LSST on other wavelengths, and vice versa:

1) Science Results (e.g. galaxy/AGN evolution)
2) Tools and Methods (e.g. massive databases [radio])
3) Supplemental data (coeval, identification, physical processes)
   Also non-EM: e.g. Advanced LIGO

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Statistics, Data Mining and Machine Learning in Astronomy

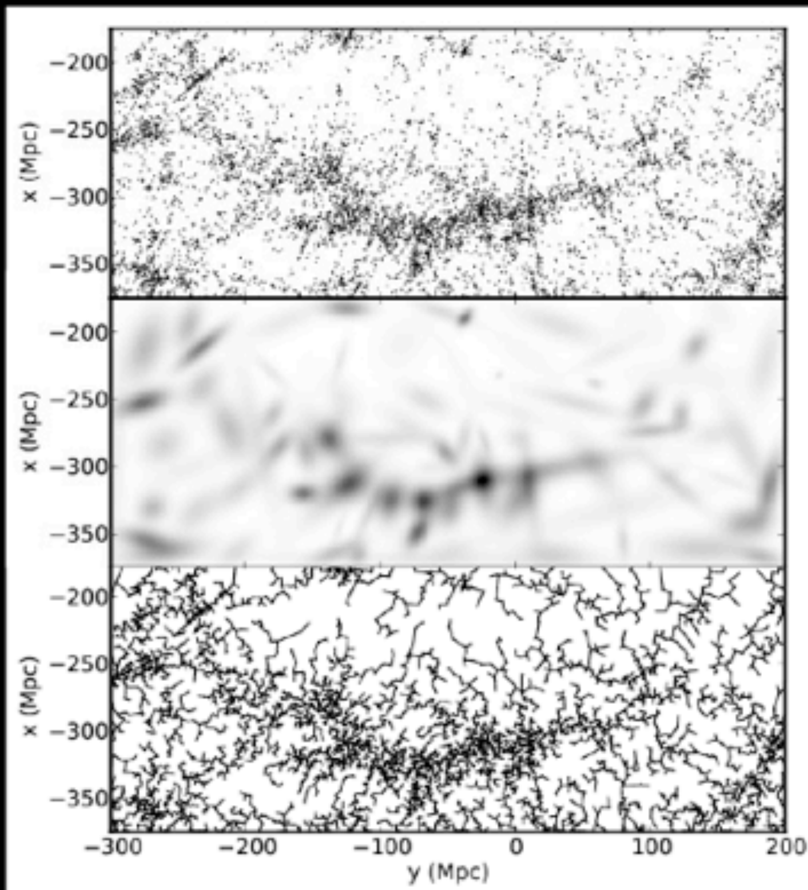
Zeljko Ivezic, Andrew Connolly,
Jacob Vanderplas, Alex Gray

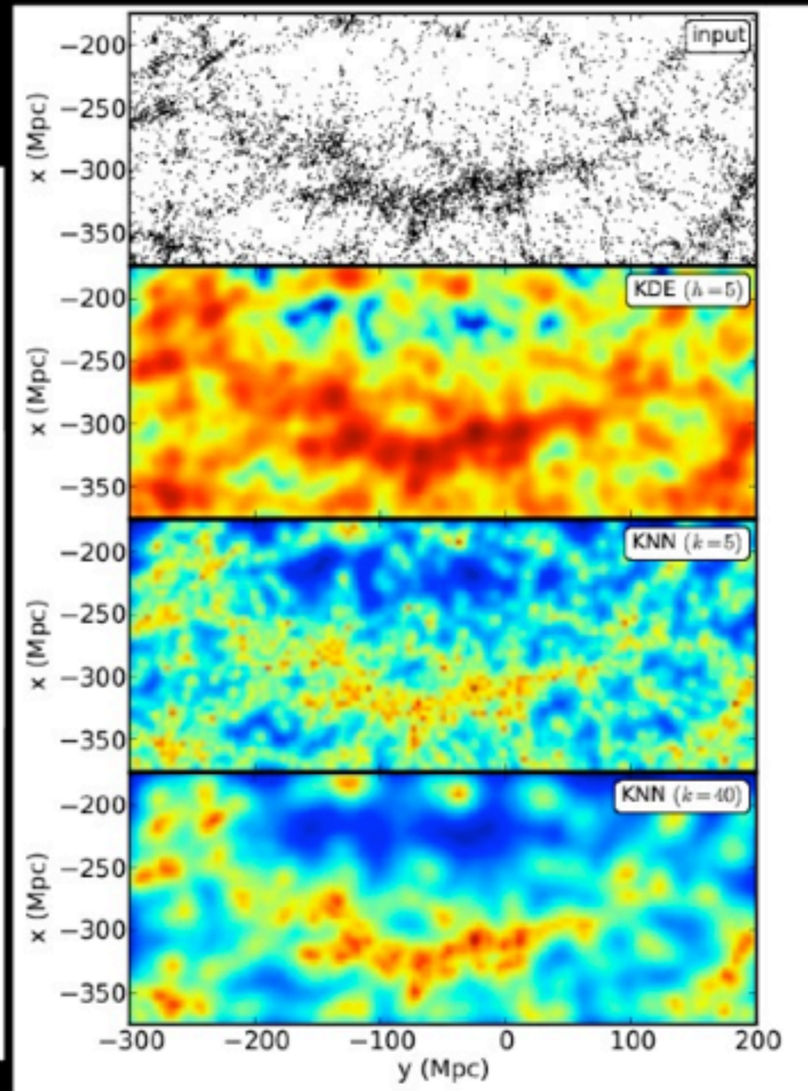
Princeton University Press, 2013

- Complete *Practical* guide to statistical analysis, data exploration, and machine learning
- Example-driven approach, using real data (SDSS, LIGO, LINEAR, WMAP, and others)
- All book figures and examples generated in python (matplotlib), with code available online – for free!
- Makes use of *numpy, scipy, matplotlib, scikit-learn, pymc, healpy,* and others
- Supporting python package: *astroML*

New book!

Clustering and Density Estimation: SDSS Great Wall





One of >100 examples

LSST in one sentence:

An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 based on 1000 visits over a 10-year period:

More information at www.lsst.org
arXiv:0805.2366

a catalog of 10 billion stars and 10 billion galaxies with exquisite photometry, astrometry and image quality.