The Large Synoptic Survey Telescope: Overview for 4MOST

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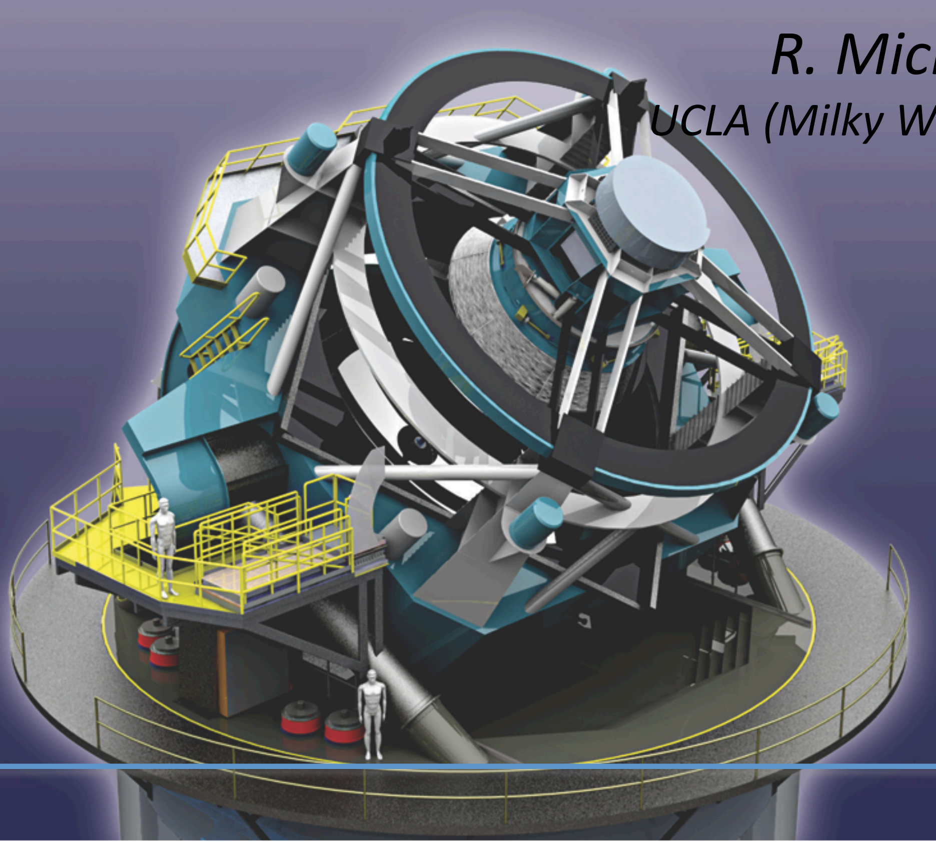
With thanks to
Michael Strauss
Beth Willman



The next generation of imaging survey

Large Synoptic Survey Telescope

Many of the most important science questions for the next decade require a wide-field, deep multi-band optical imaging survey:

- Cosmological studies using supernovae, large-scale structure, weak lensing
- Mapping the distribution of stars in the Milky Way
- Studying variable and transient objects of all sorts
- Studying the evolution of galaxies and quasars with cosmic time
- Mapping the distribution of asteroids in the Solar System, including those that might hit the Earth.

The LSST has been designed to address all these science areas (and more!) with a single coherent dataset. See the LSST Science Book

LSST science requirements driven by four science themes:

- *Constraining Dark Energy and Dark Matter:* Lensing, supernovae, large-scale structure
- *Taking an Inventory of the Solar System:* Near-Earth Asteroids to the Kuiper Belt
- *Exploring the Transient Optical Sky:* Opening new regions of discovery space
- *Mapping the Milky Way:* Structure of the disk, halo, and substructure; companion galaxies

These together exercise all relevant aspects of the survey design.

LSST Science Requirements

Satisfy science requirements in 10 yr requires a survey that covers a large survey area (**WIDE**), has many repeated short exposures (**FAST**), and probes the faint universe (**DEEP**).

- 6.7m (equivalent) aperture allows us to go to r=24.7 in 30 seconds. (Actual mirror is 8.4 m annulus)
- System must deliver the best psf possible
- 9.6 deg^2 field of view allows us to cover the visible sky in a single band in three nights.
- Six filters for photo-zs, spectral energy distributions.
- In ten years, we can go about 3 magnitudes deeper in six bands over 20,000 deg^2.
- Exposure time is short enough that asteroids are not streaked, and appear as point sources.
- 2000 exposures for each area of sky give extensive probe of variability, proper motion, and asteroid orbits, and allow quantification of weak lensing systematics.

Uniform Sky Survey:

90% of time spent on uniform survey:
Every 3-4 nights whole observed sky scanned 2x/night

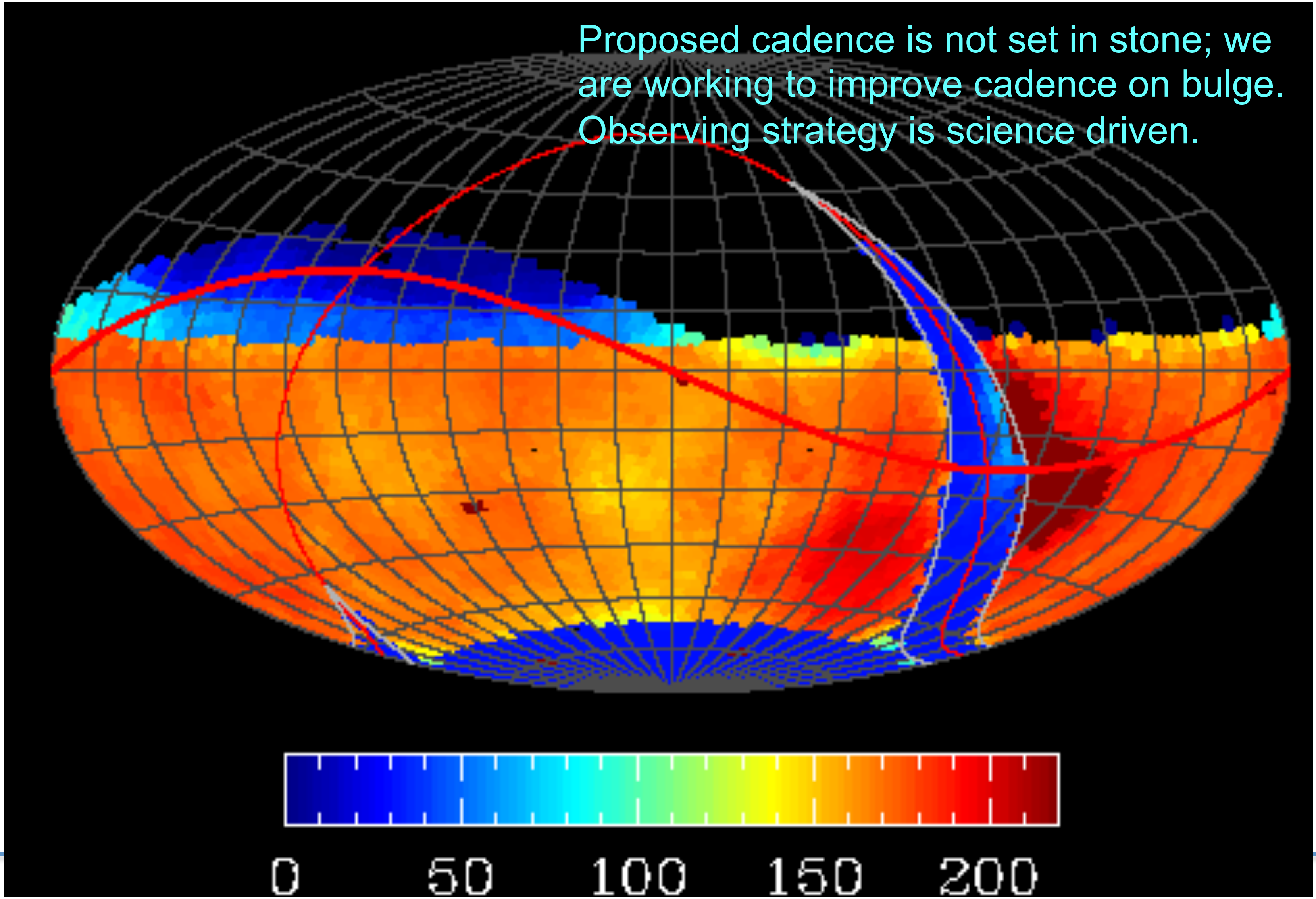
After 10 yrs, half sky imaged 1000 times in 6 bandpasses

~100PB of data, one billion 16 Mpix image> measures for 20 billion objects

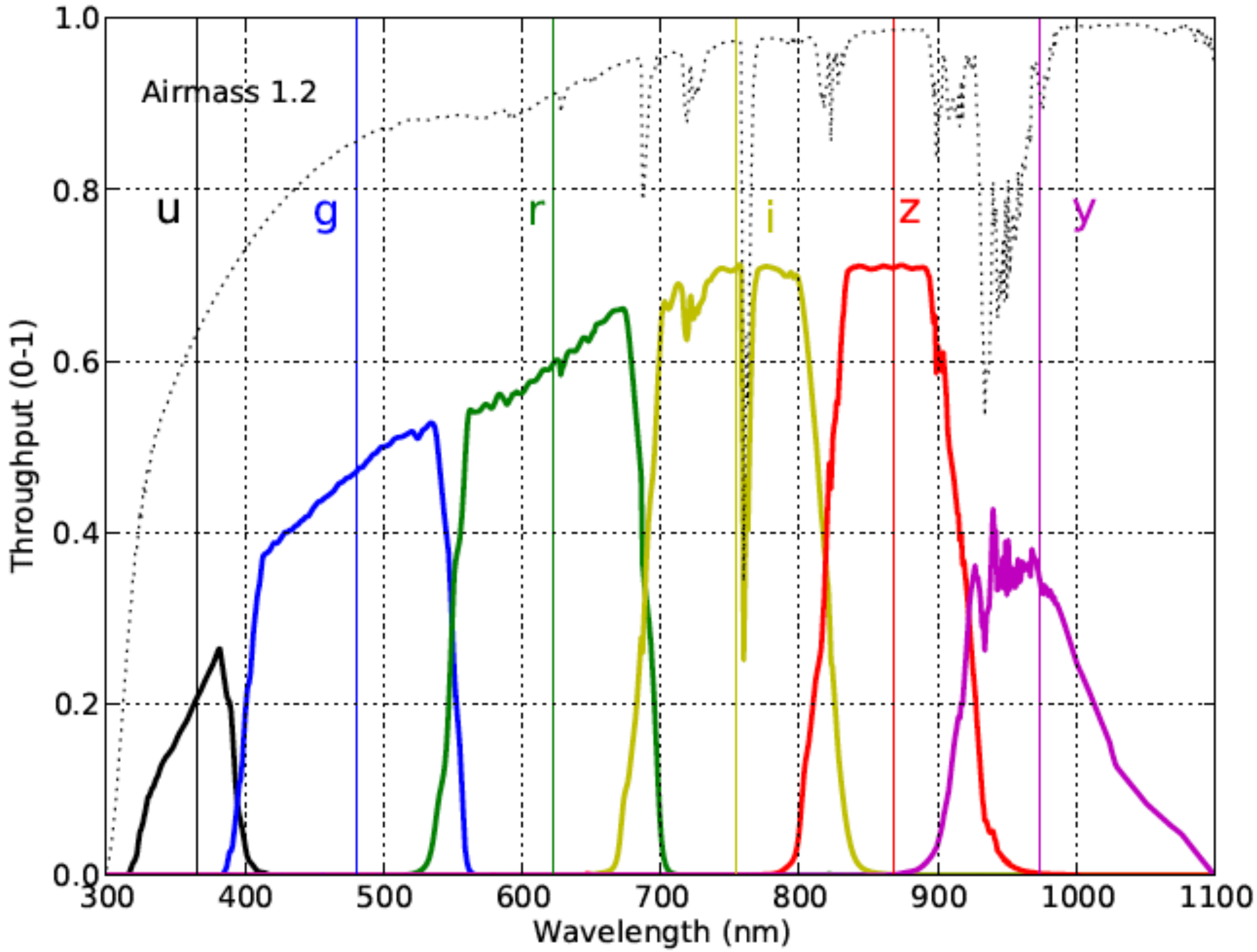
An optical/near-IR survey of half the sky in *SDSS ugrizy*
Bands to r~27.5 = 36 nJy, based on 1000 visits
over 10 yr period: deep, wide, fast, cadenced

Number of 30-sec visits in *r* across the sky in ten years.

Large Synoptic Survey Telescope



Photometric system similar to SDSS (with addition of y filter)



Extremely high-quality data

- Median delivered image quality of 0.67".
- Can cover all the available sky in a given filter in roughly 3 nights.
- Probes of variability on timescales from 15 seconds to 10 years.
- Stellar photometric calibration to 1% or better; stellar repeatability to 0.5%.
- Astrometry to 10 milli-arcsec per visit, allowing proper motion uncertainty of 0.2 mas/year, and parallax uncertainty of 1 mas over the course of the survey. LSST matches Gaia's astrometric precision at r~20, and extends it 4 magnitudes fainter.

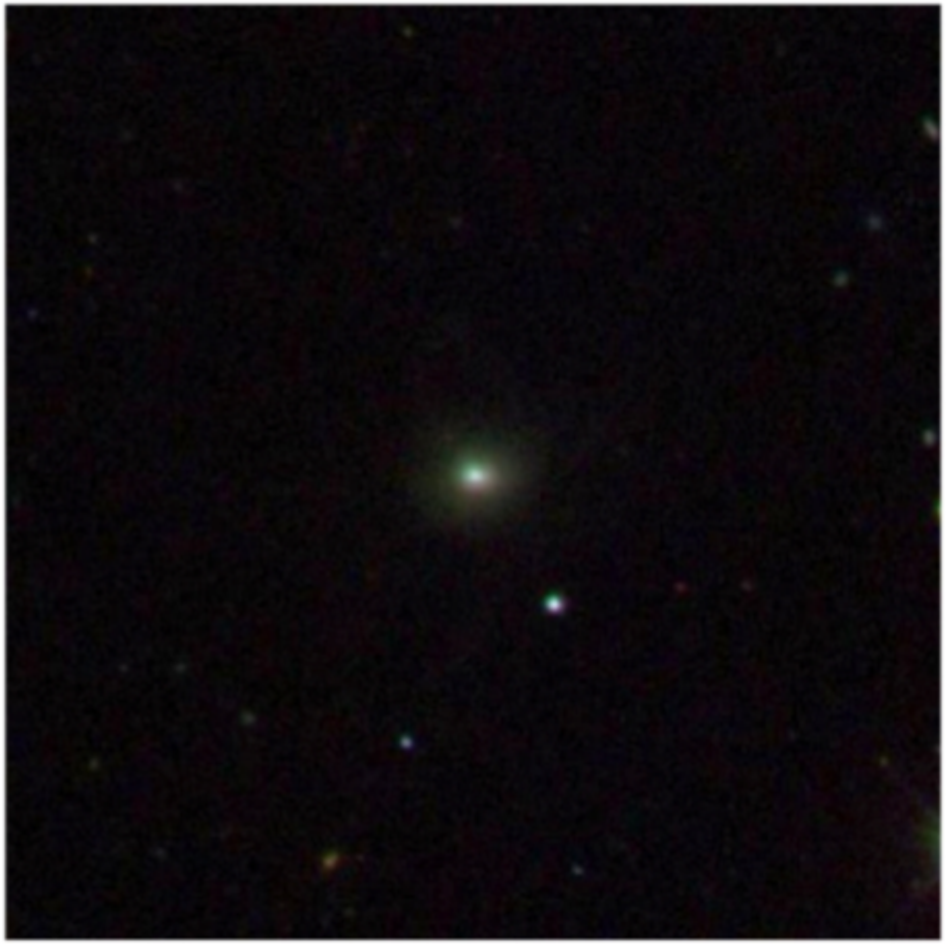
Simulated LSST image (one exposure, 3 bands)

gri composite image of about 6' on a side, representing 10^{-9} of the LSST data.
A single 15-sec exposure.

Courtesy Andy Connolly

LSST will go 5 mag fainter than SDSS

SDSS



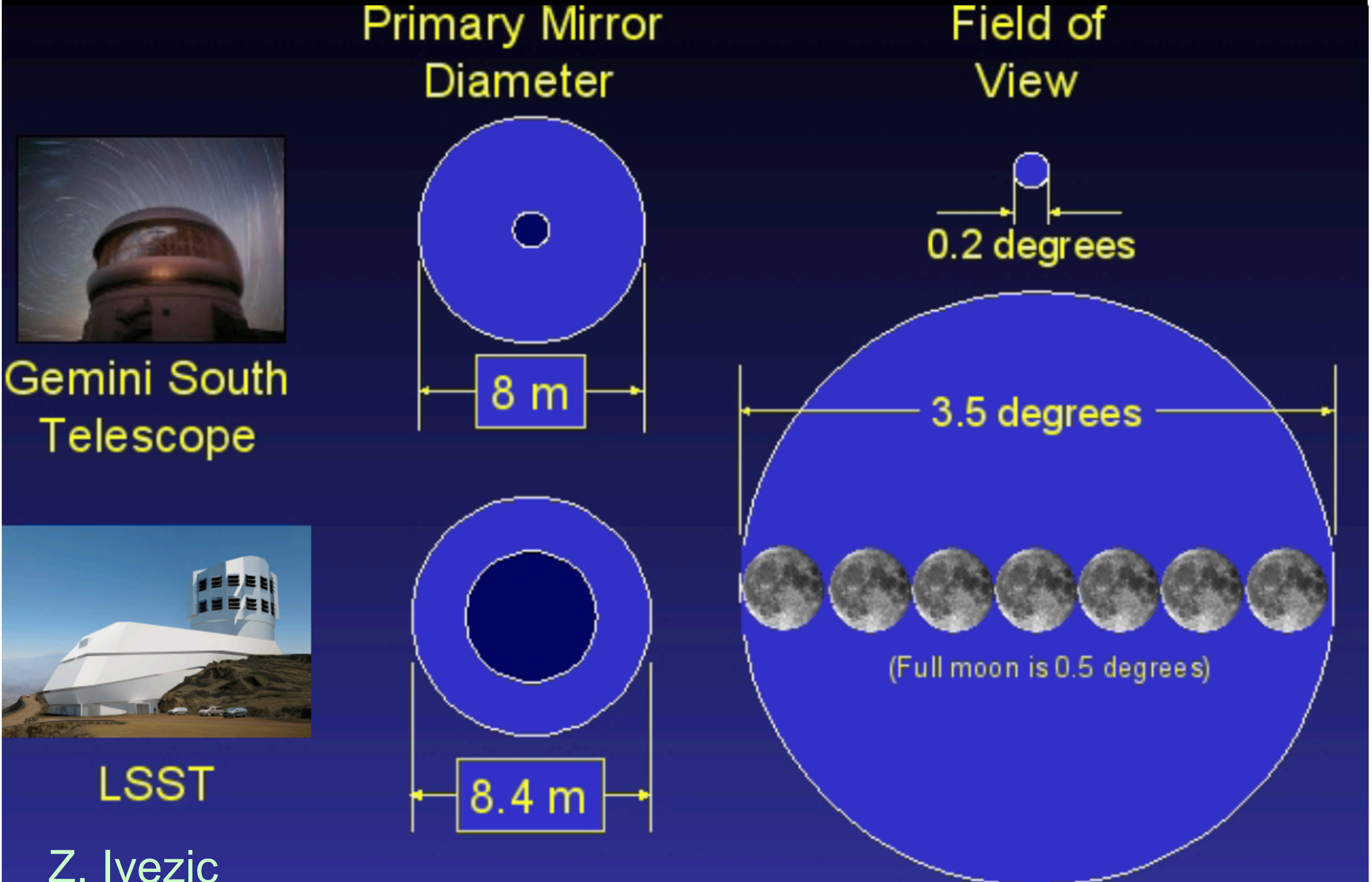
MUSYC

MUSYC is 1.5 mag shallower than LSST

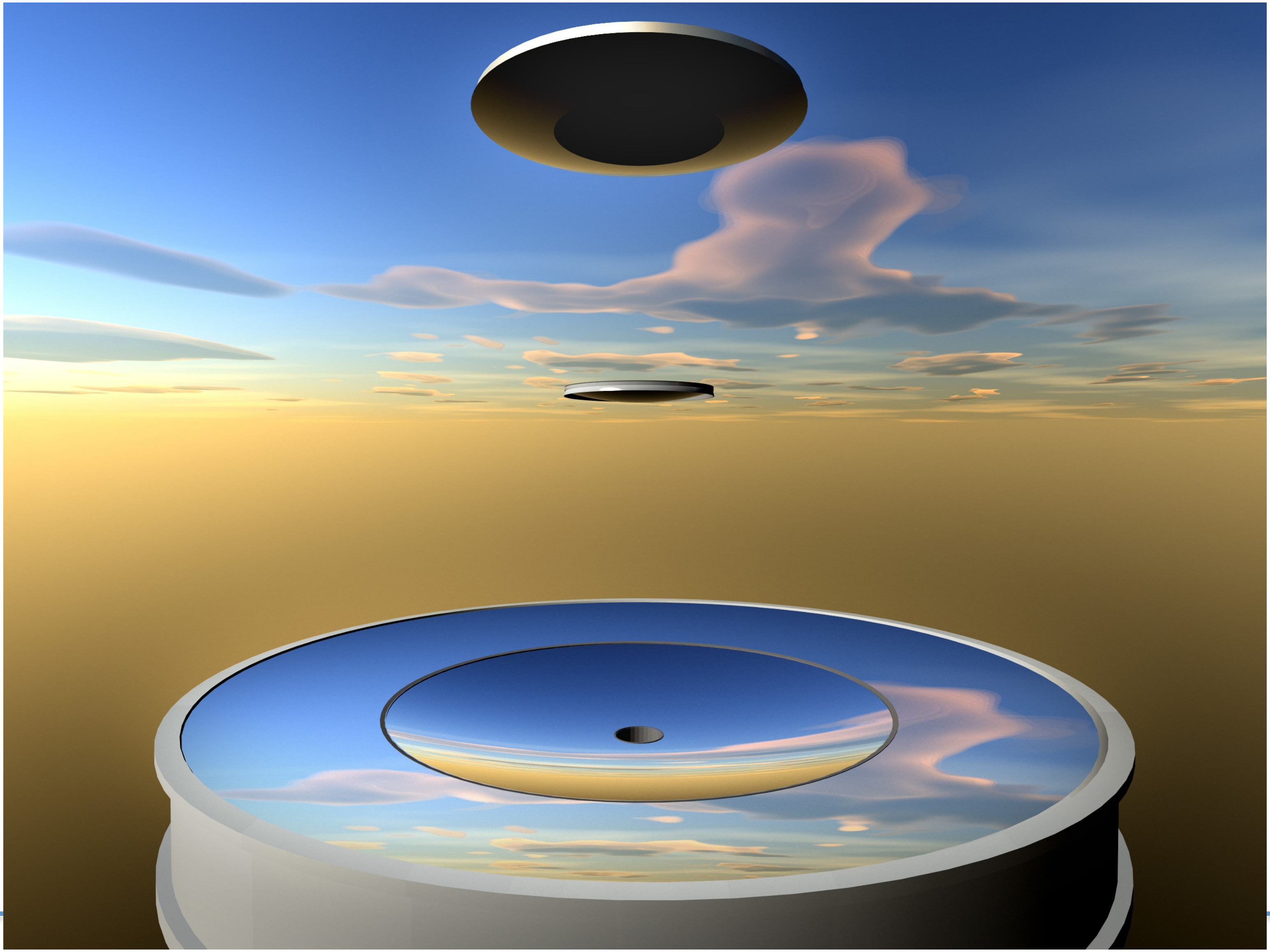
Lessons from Sloan Digital Sky Survey

- SDSS was designed with goal of mapping the large-scale distribution of galaxies. But the data gathered for this purpose is useful for a ***huge*** range of other scientific projects, including many not anticipated at the start of the survey.
- Strong emphasis on data quality; we want to be limited by photons, not systematics. The better the data (calibration, uniformity, quality assurance, etc), the better the science that comes out of it!

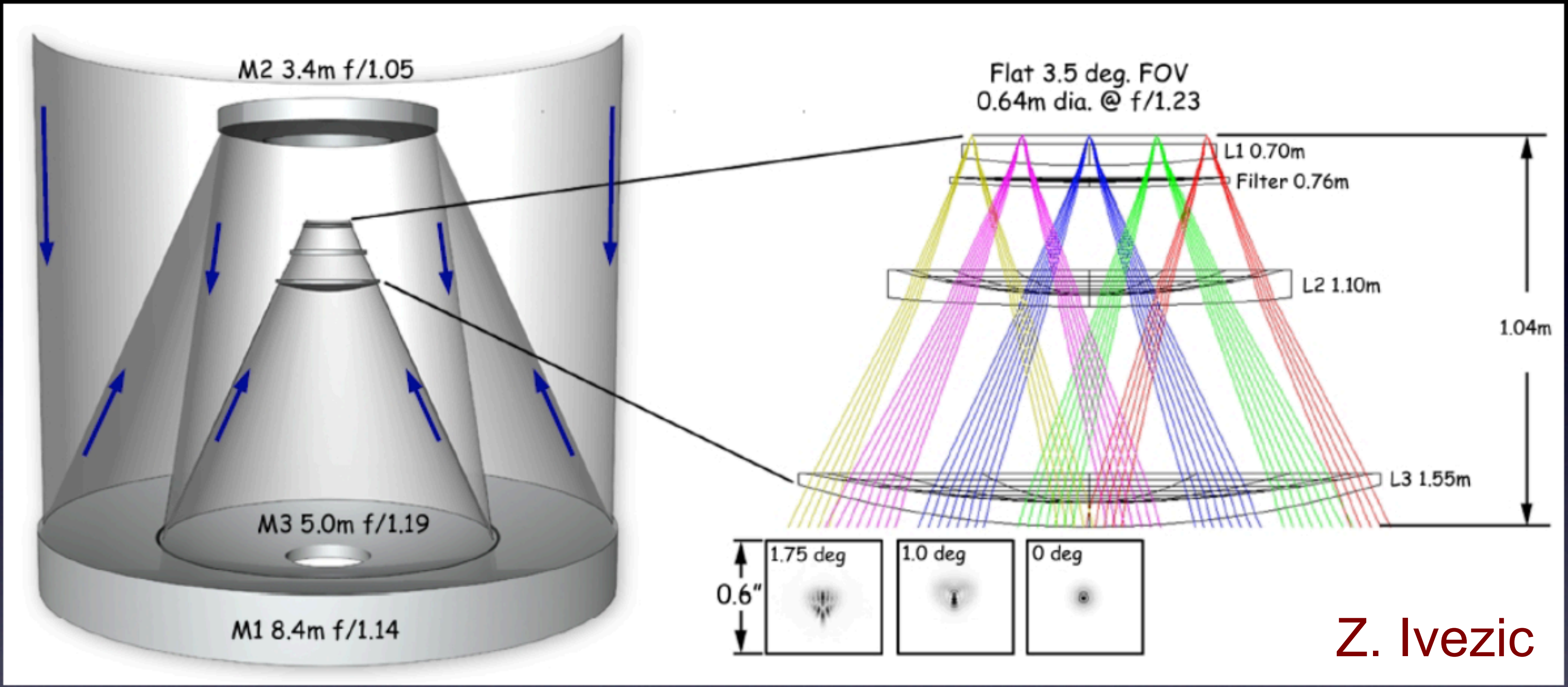
The field-of-view comparison: Gemini vs. LSST



The LSST optics

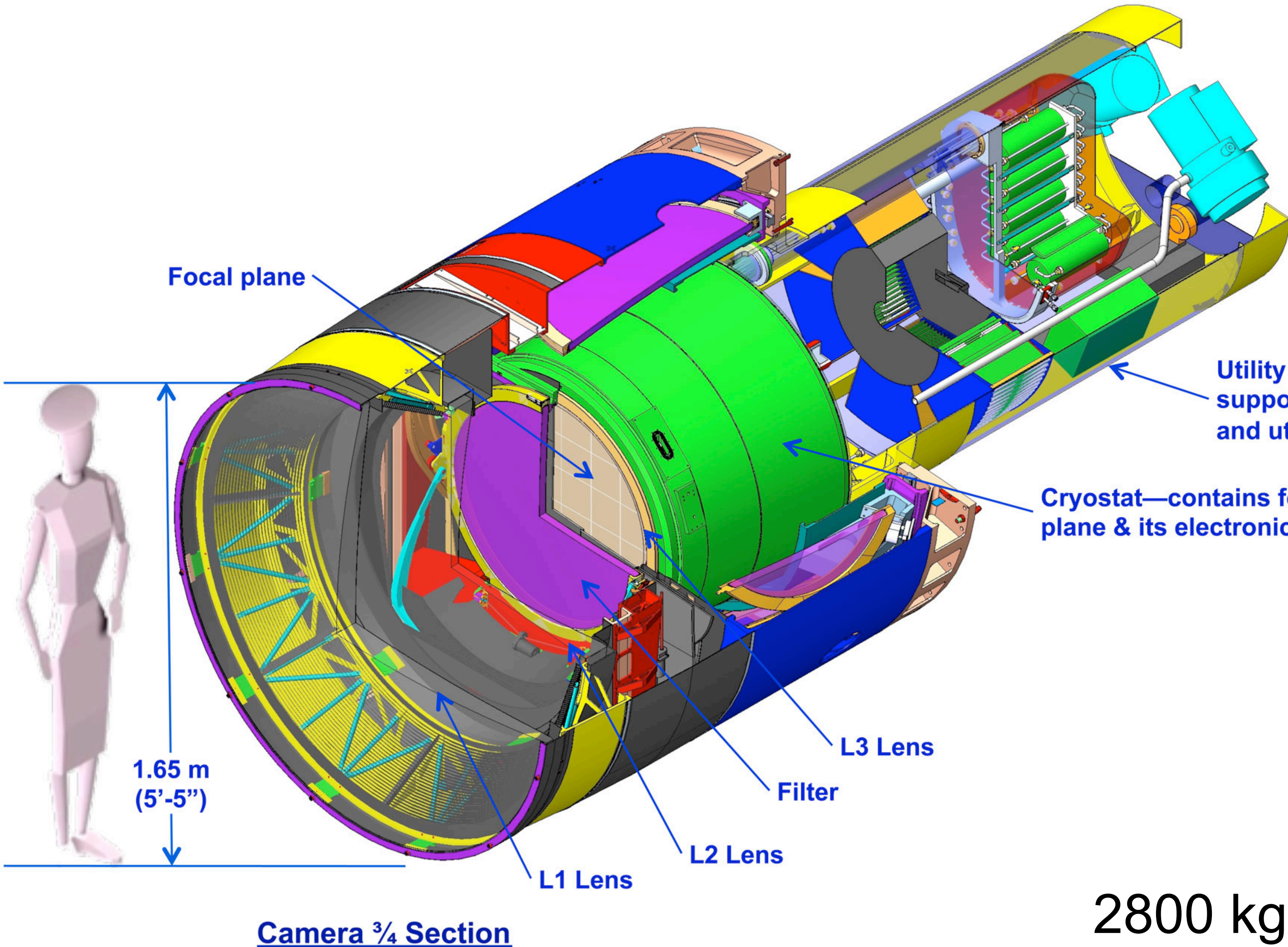


Optical Design for LSST



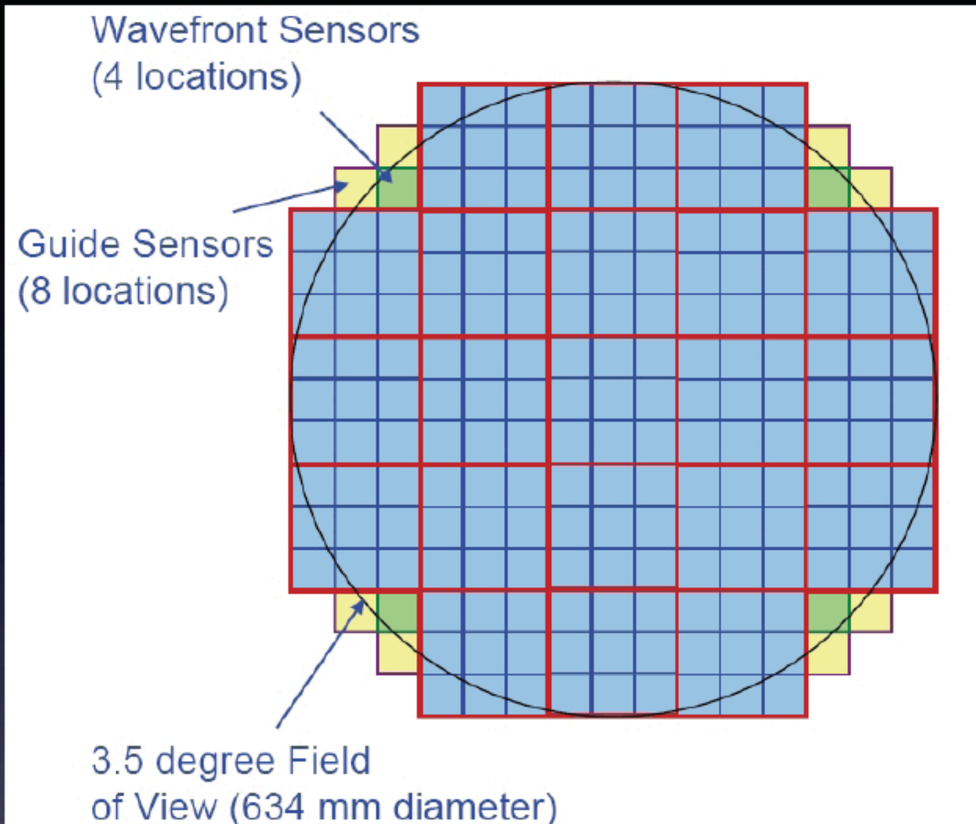
Three-mirror design (Paul-Baker system) enables large field of view with excellent image quality: delivered image quality is dominated by atmospheric seeing

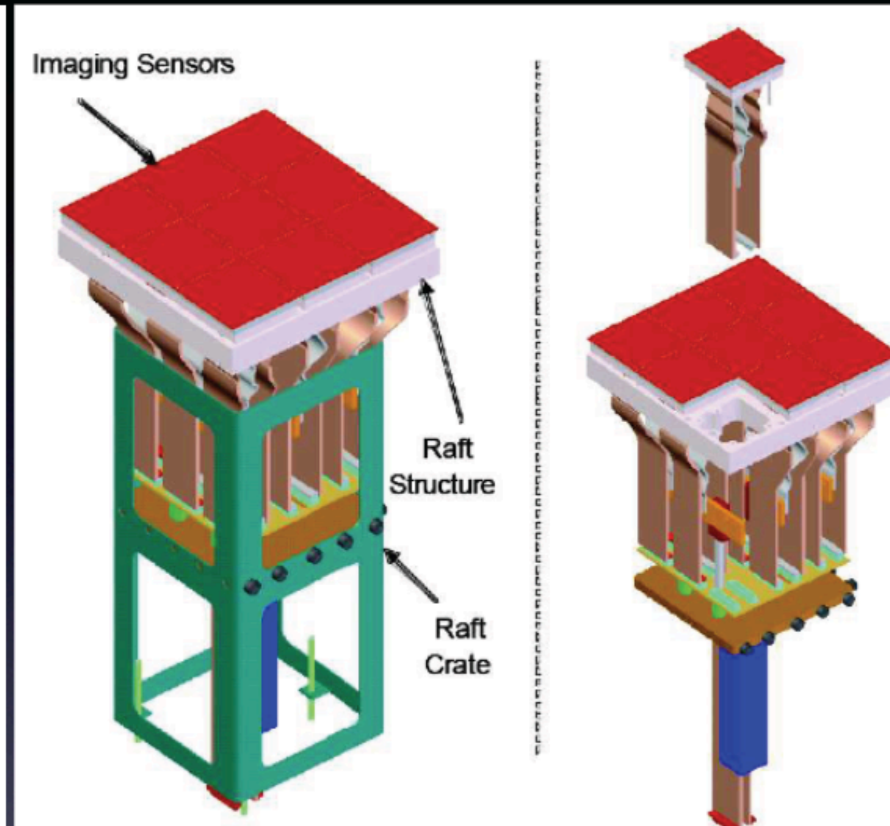
Camera



2800 kg, 3.2 Gpix

LSST camera





Modular design: 3200 Megapix = 189 x16 Megapix CCD

9 CCDs share electronics: raft (=camera)

Problematic rafts can be replaced relatively easily

LSST: A dedicated 10-year survey

Large Synoptic Survey Telescope

- Main survey will cover 20,000 deg^2, 2000 exposures across 6 filters.
- 5σ point-source depth after two exposures: 23.9 (*u*), 25.0 (*g*), 24.7 (*r*), **24.0** (*i*), 23.3 (*z*), 22.1 (*y*)
- Depth at end of the survey: 26.3 (*u*), 27.5 (*g*), 27.7 (*r*), **27.0** (*i*), 26.2 (*z*), 24.9 (*y*)
- Perhaps 10% of the time will be devoted to 'deep fields' ~1 mag deeper; cadence good for faint Kuiper Belt Objects, good light curves for supernovae, and short-timescale transients.
- ***20 trillion observations of 20 billion objects***

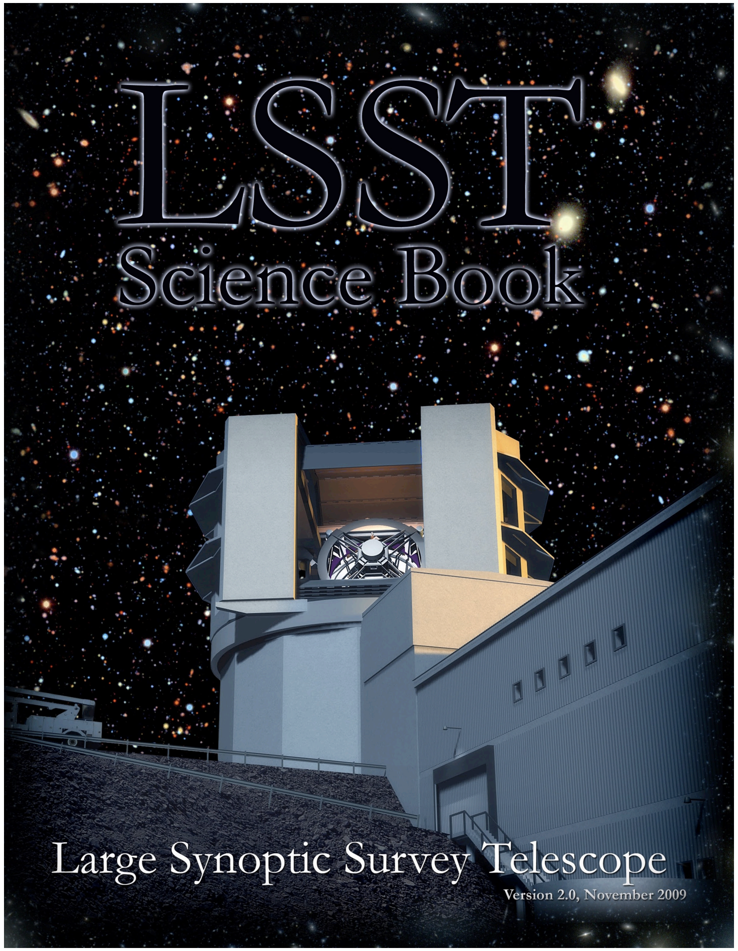
A Series of Science Collaborations

(*and their chairs*)

- Weak lensing (*Bhuvnesh Jain and Dave Wittman*)
- Strong lensing (*Phil Marshall*)
- Supernovae (*Michael Wood-Vasey and Richard Kessler*)
- Large-scale structure/BAO (*Hu Zhan and Eric Gawiser*)
- AGN (*Niel Brandt*)
- Galaxies (*Harry Ferguson*)
- Galactic structure (*Beth Willman and Marla Geha*)
- Stellar populations (*Abi Saha and Kevin Covey*)
- Variability and transients (*Lucianne Walkowicz and Josh Bloom*)
- Solar system (*Lynne Jones and Michael Brown)*
- Informatics and Statistics *(Kirk Borne)*

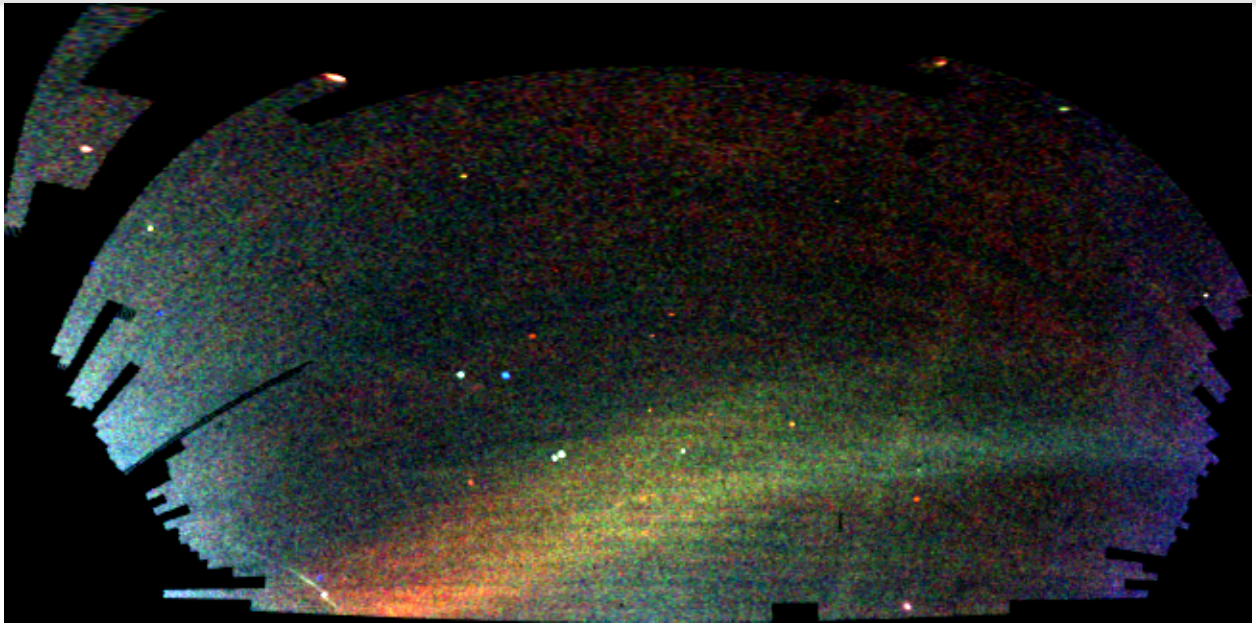
Science Collaborations led the writing of the LSST Science Book

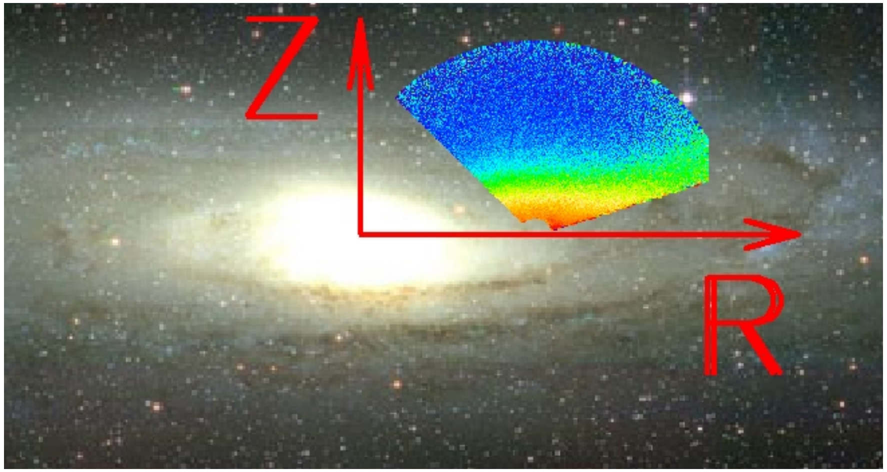
Completed two years ago.
596 pages, 245 authors,
15 chapters and 4 appendices.
Available at:
http://www.lsst.org/lsst/scibook



All science areas not covered in this talk (e.g. lensing, Sne, etc)

Milky Way structure

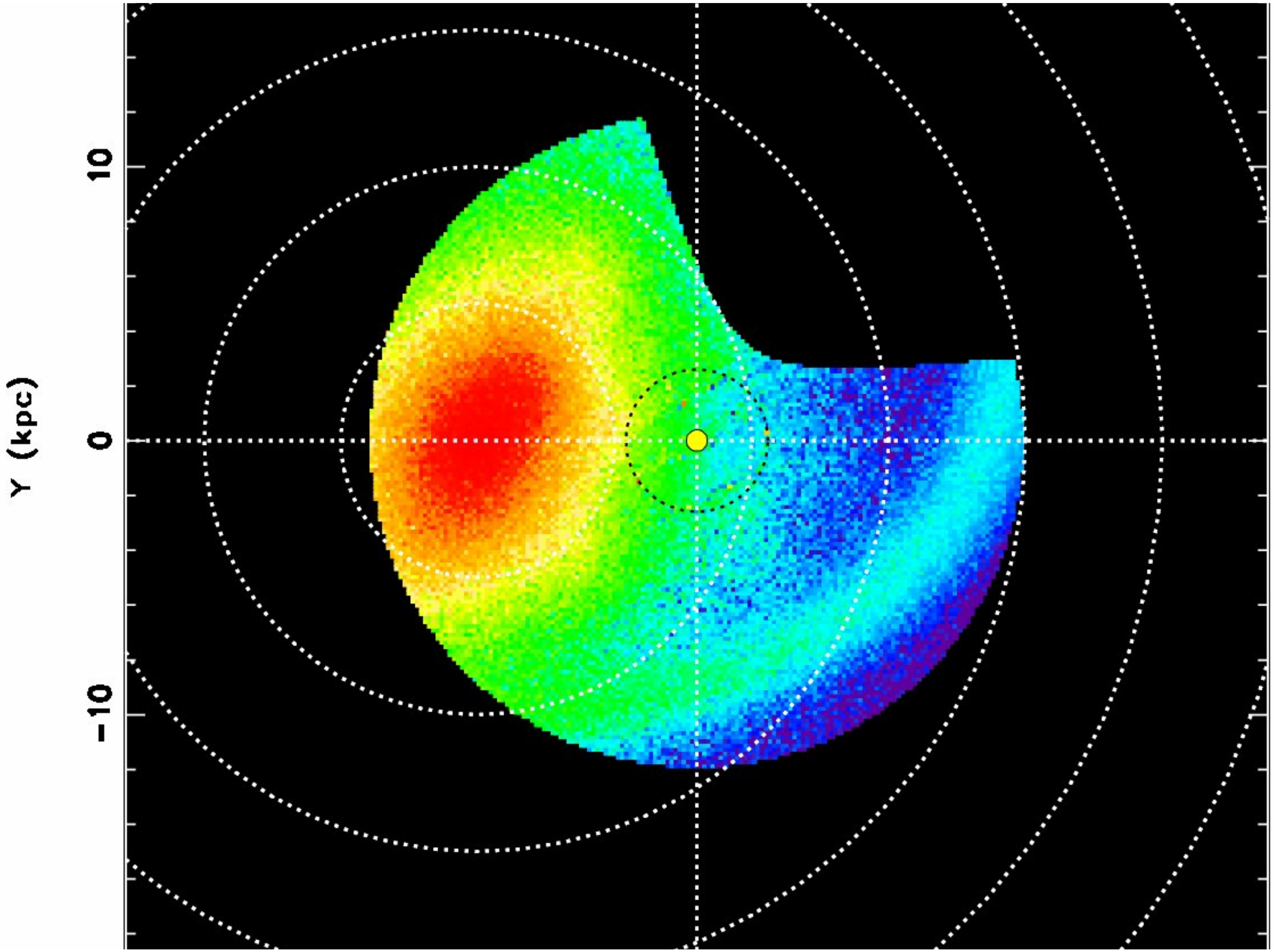




SDSS has shown that the halo of the Milky Way is greatly structured, reflecting its interactions with neighboring galaxies.

But SDSS goes to only 8 kpc for F stars.

What LSST will be able to do



Model of a slice parallel to the Galactic Plane. Dotted line is reach of SDSS (Juric et al. 2008).

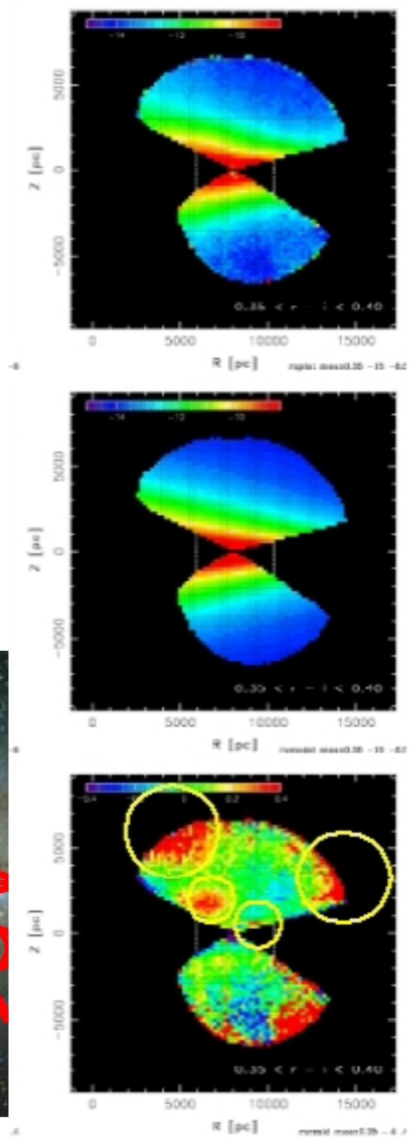
Milky Way structure: 10 billion stars, time domain

Large Synoptic Survey Telescope

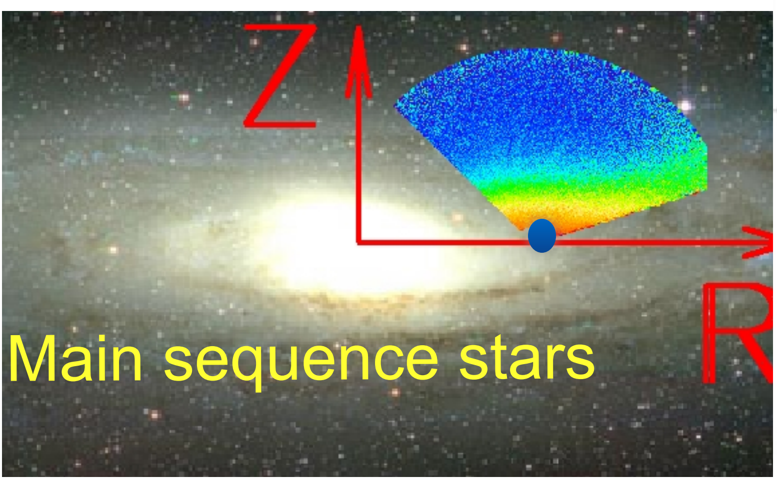
5-sigma limits

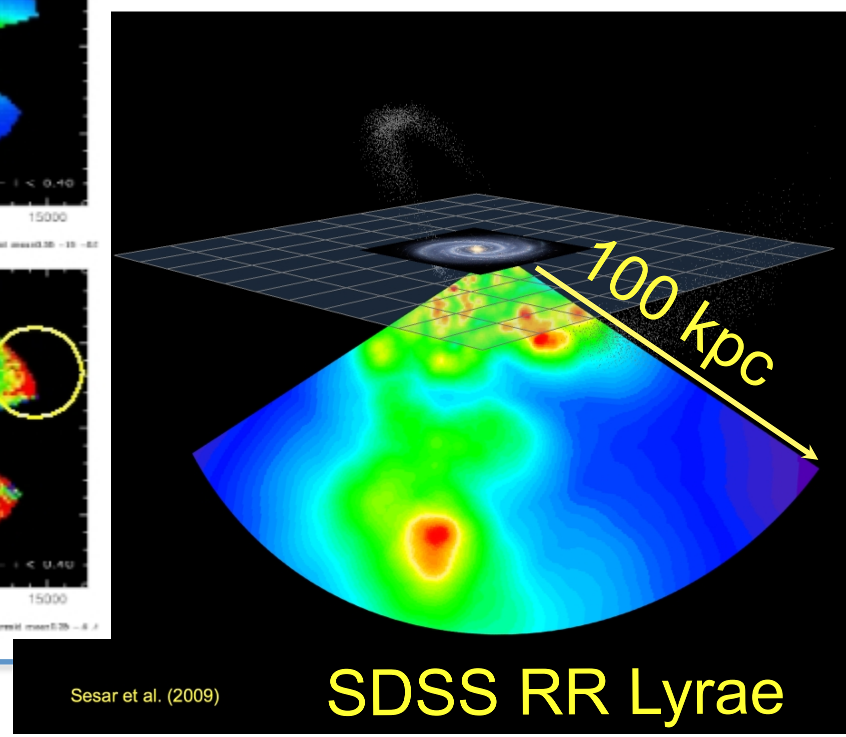
	u	*g*	*r*	*i*	*z*	*y*
single	23.9	25.0	24.7	24.0	23.3	22.1
co-add	26.3	27.5	27.7	27.0	26.2	24.9

0.35 < r-i < 0.40



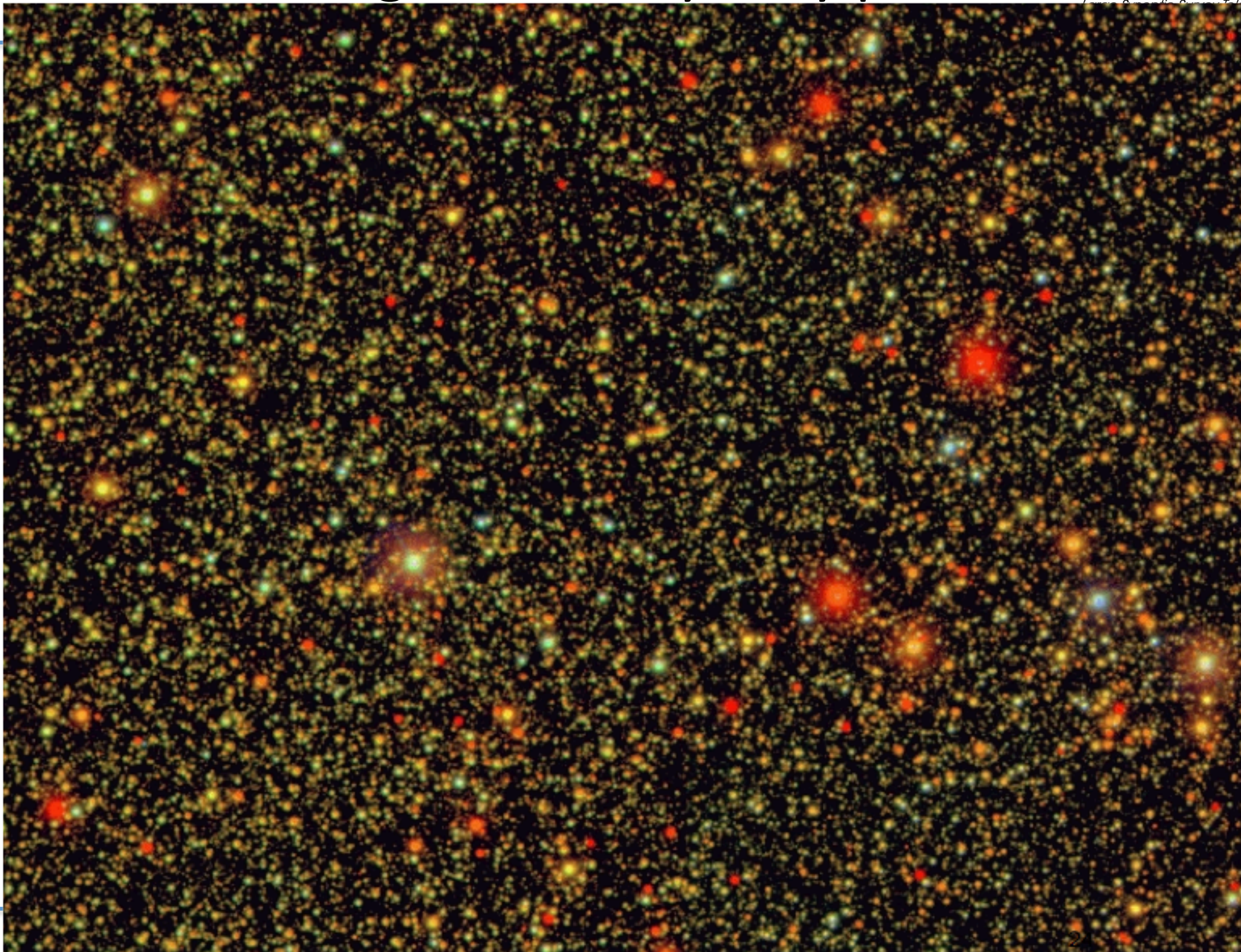
Compared to SDSS: LSST can “see” 10 times further away and over twice as large an area





Distance and [Fe/H]:

SDSS view through the Milky Way plane



3D Spatial-[Fe/H]-v_{tan} Maps with LSST

Half of sky and six filters (ugrizy)

time domain: entire visible sky every 3 nights for 10 years

precision astrometry:

0.2 mas/yr at r = 21

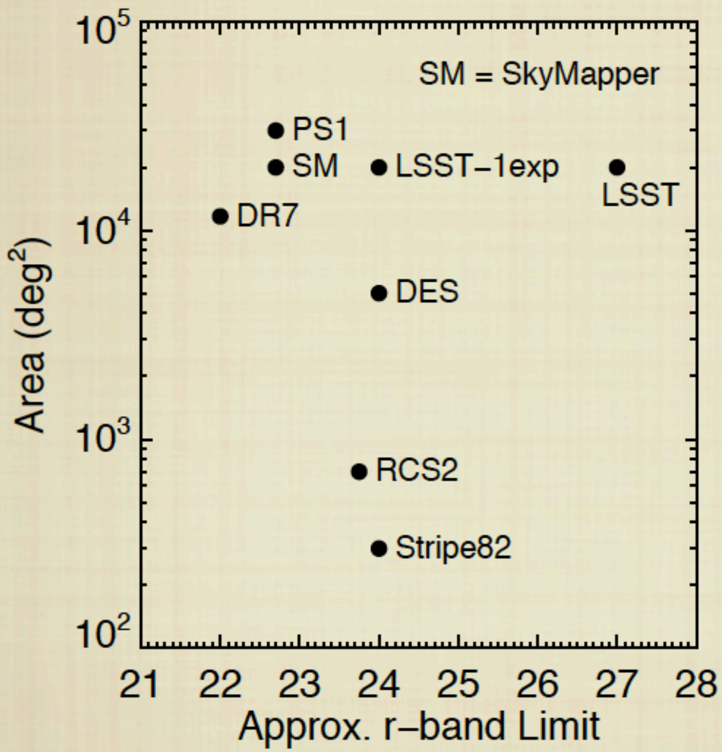
1.0 mas/yr at r = 24

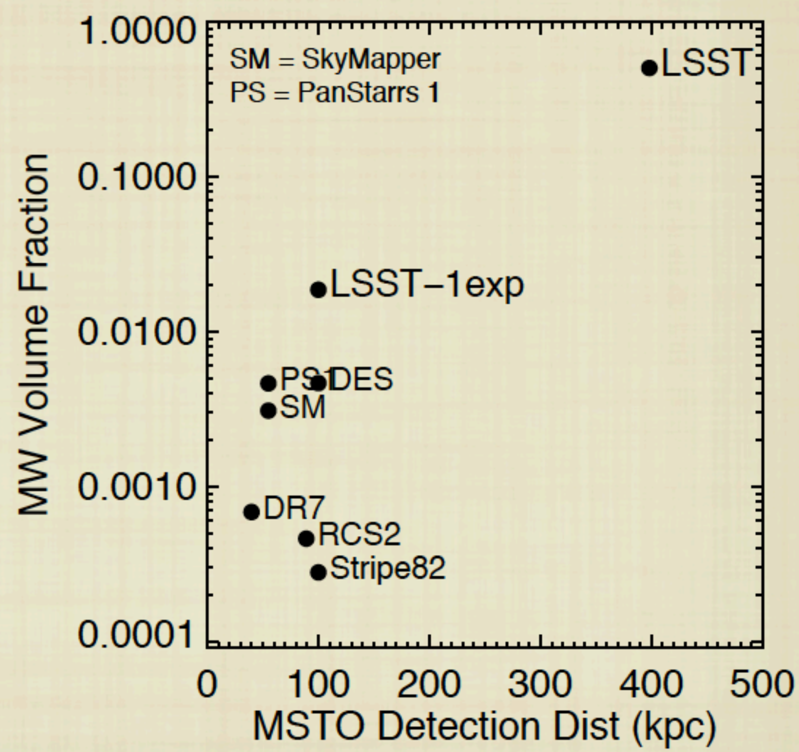
Tangential velocity field to
at least 10 kpc (at 10 km s^{-1} precision)
as far as 25 kpc (at 60 km s^{-1} precision)

B. Willman

Current, imminent, future optical surveys

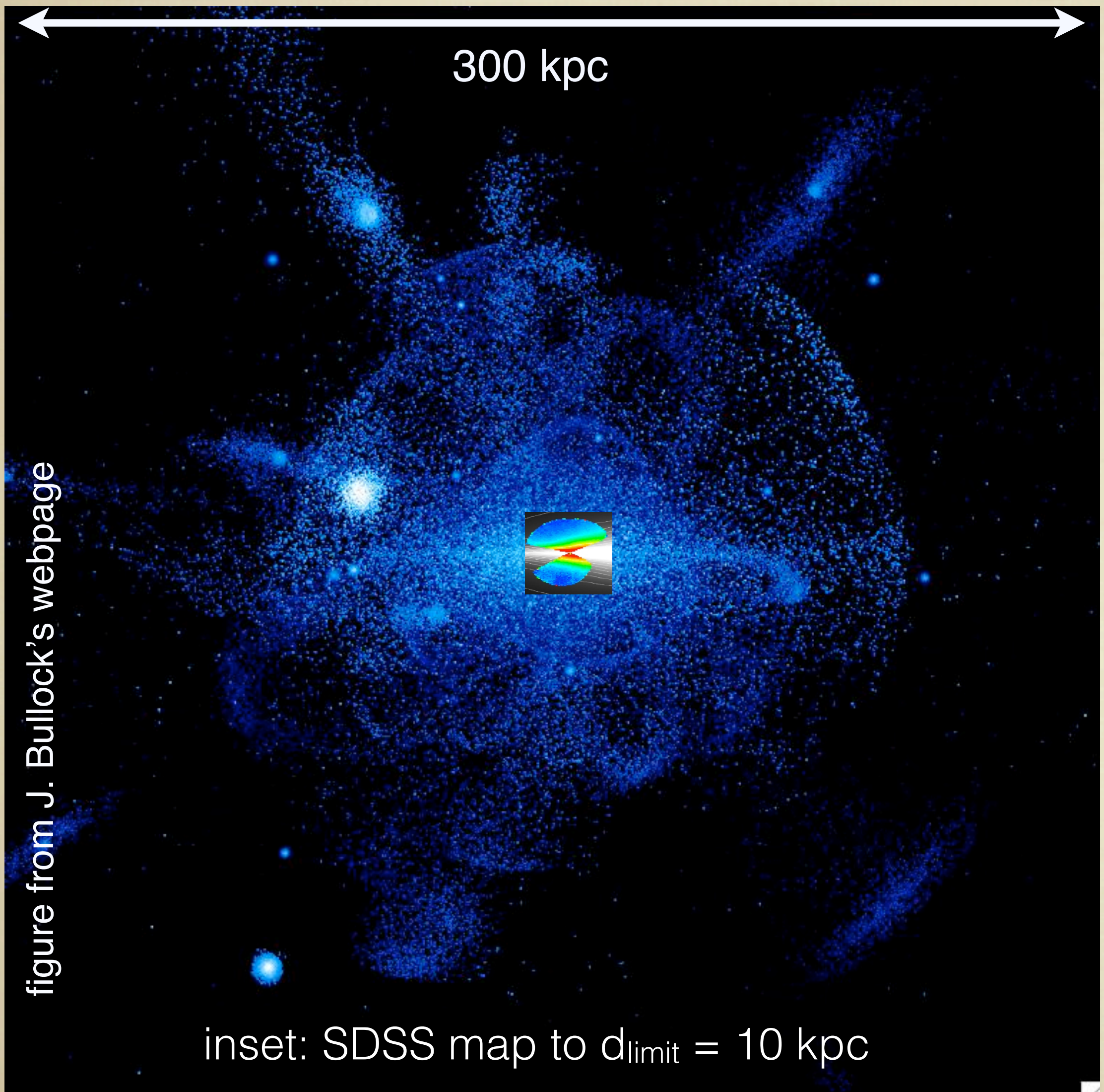
Detecting old, metal-poor MSTO stars





B. Willman

3D Spatial-[Fe/H]-v_{tan} Maps with LSST

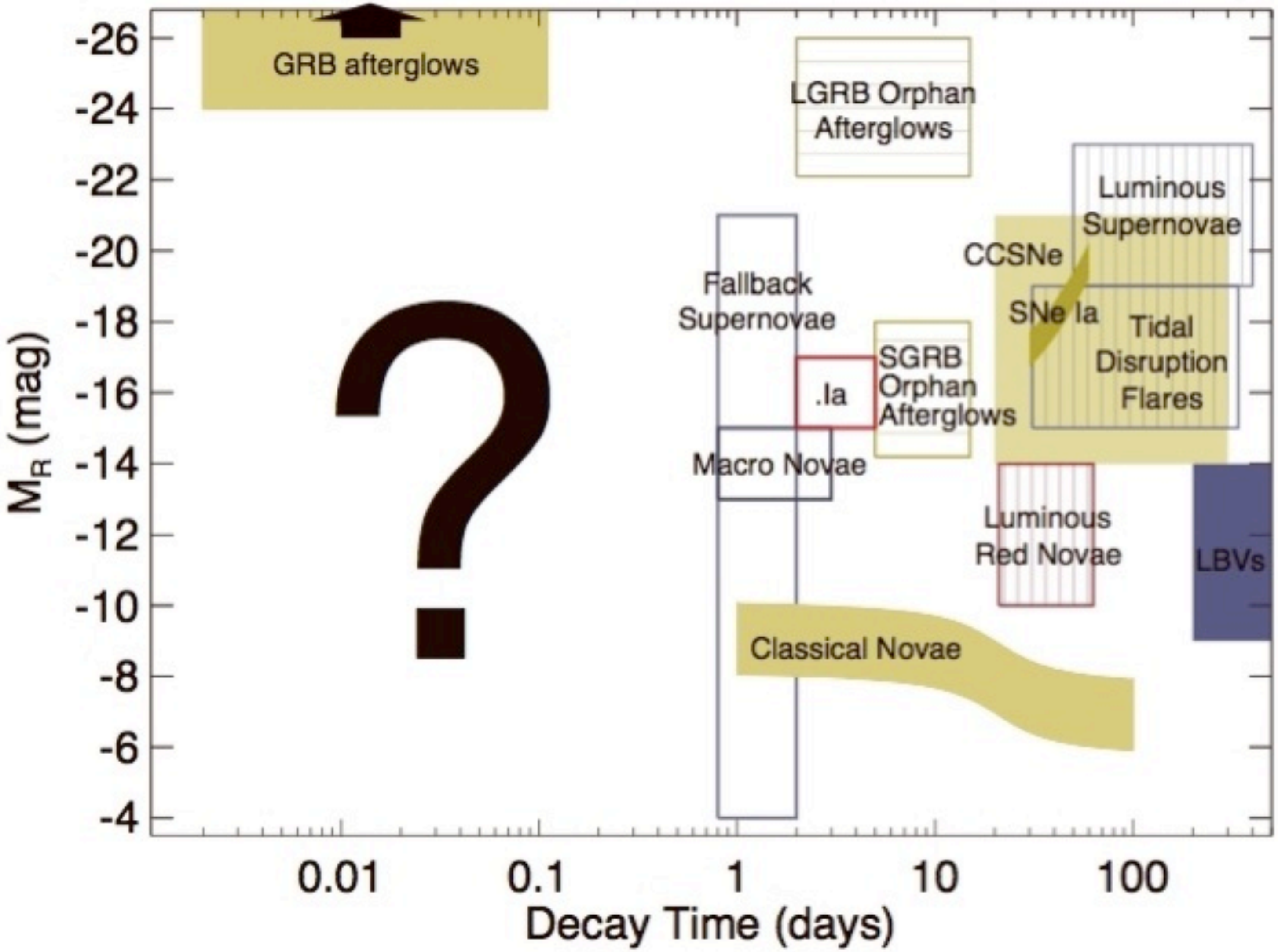


Photometric [Fe/H] as precise as 0.1 - 0.2 dex for 200 million stars to 100 kpc.

Old, metal-poor MSTO stars detected to 300 kpc.

Courtesy B. Willman

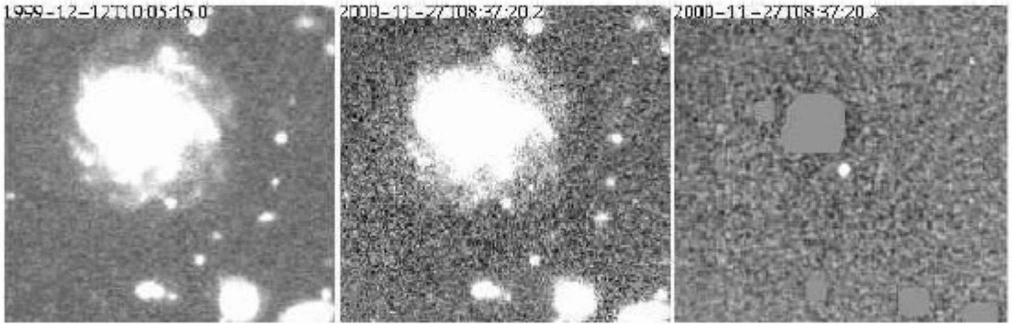
The Variable Universe



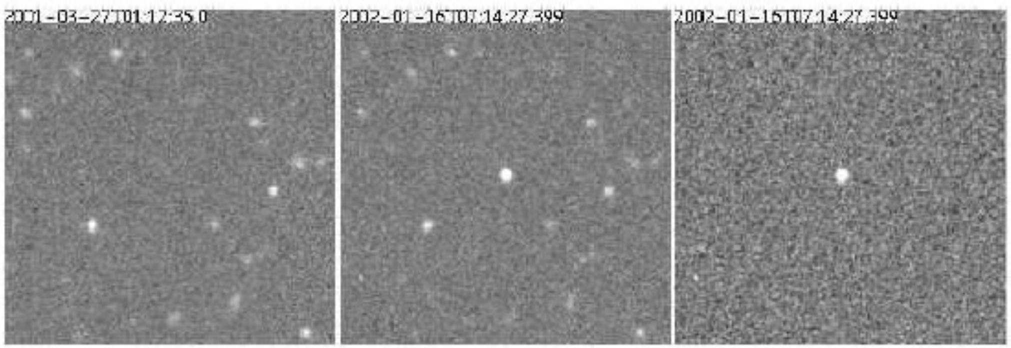
Are there new populations of transients at faint magnitudes? In the distant Universe?

Courtesy Mansi Kasliwal

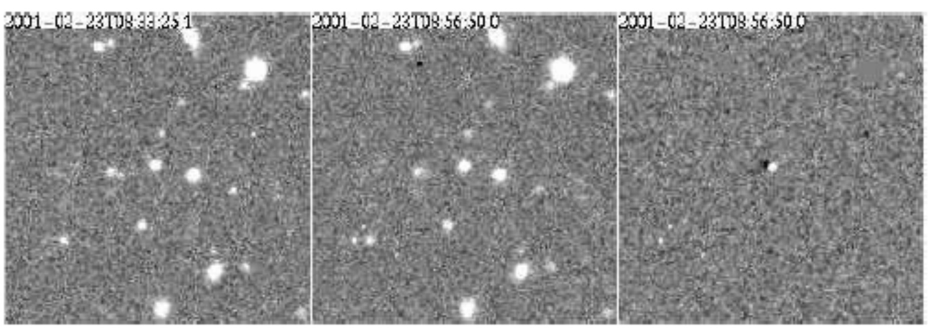
Transients from the Deep Lens Survey



Supernova



Unknown
R = 23.1

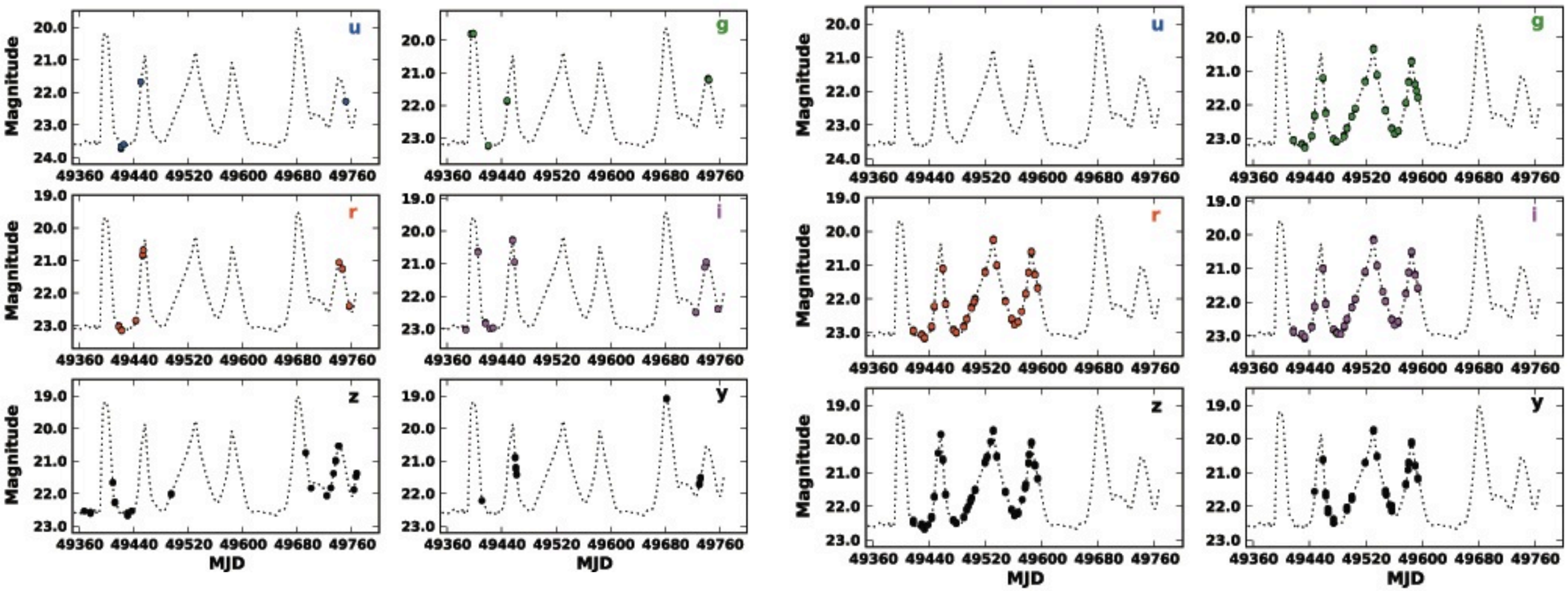


Asteroid (slow-moving)

Courtesy Dave Wittman

Characterizing transients and variables

LSST
Large Synoptic Survey Telescope



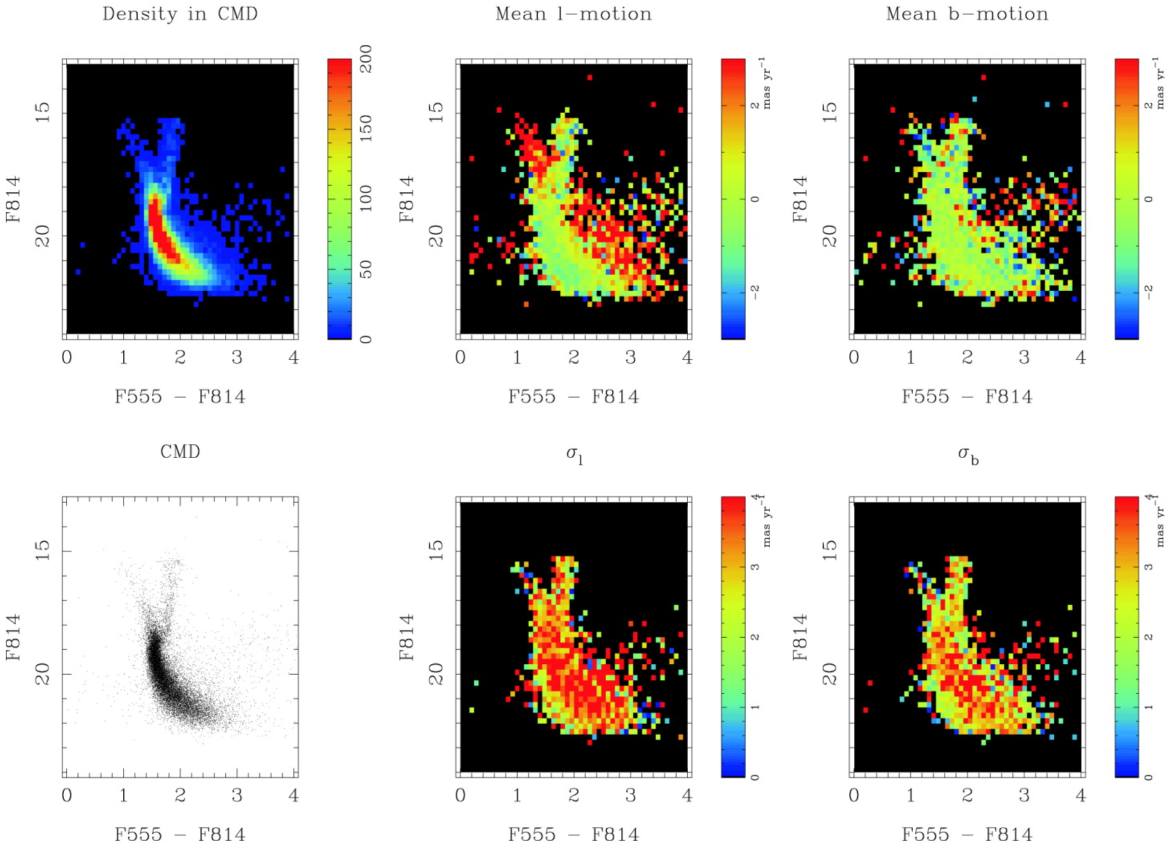
Cataclysmic variable star “observed” with normal and deep-drilling cadence (two years observations). Will we be able to classify these? Will we recognize particularly interesting classes of variables and transients for follow-up?

Follow-up

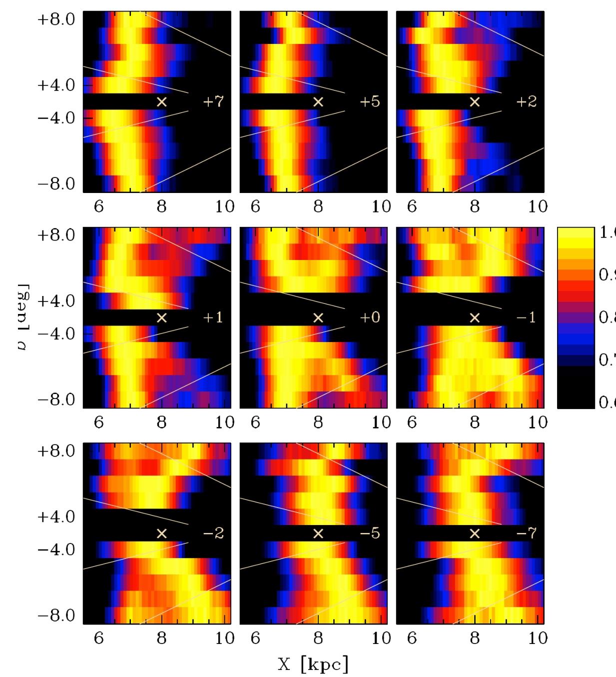
- We will want to follow up unusual variables and transients (GRB afterglows, new types of stellar explosions, extreme AGN variables, etc) photometrically and spectroscopically in many wavebands. Do we have the resources to do so?
- Large-scale spectroscopic surveys, of stars, galaxies will be desirable for all sorts of science investigations. We could keep all the large telescopes in the world busy. 4MOST

Bulge Science

PM Separation



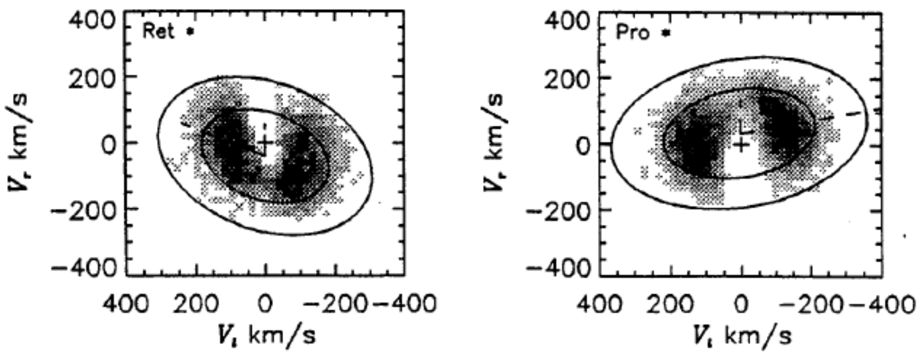
Kuijken & Rich 2002



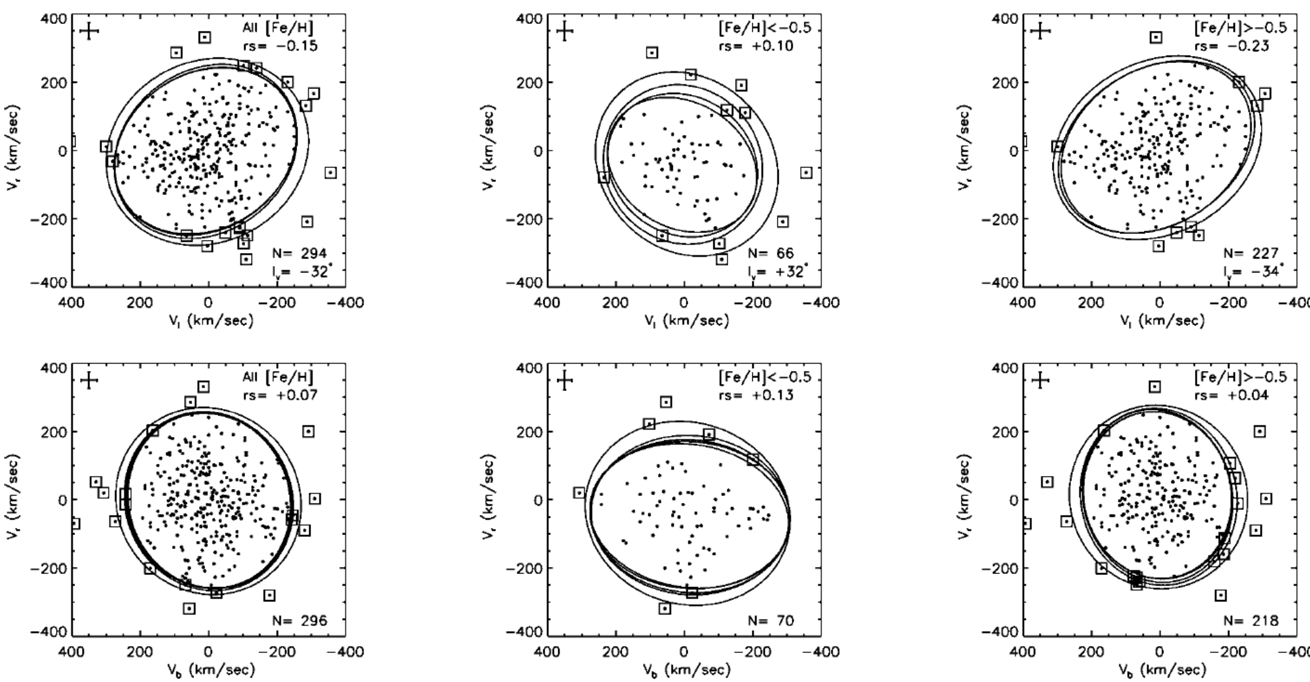
Saito et al. 2011

LSST PM + 4MOST spectra = Huge sample

Vertex Deviation

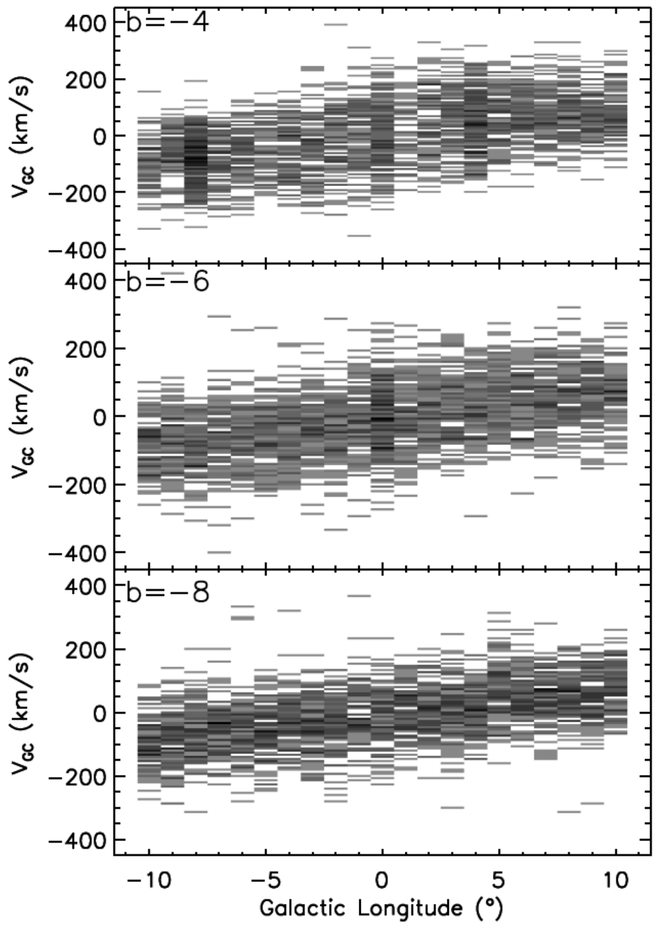


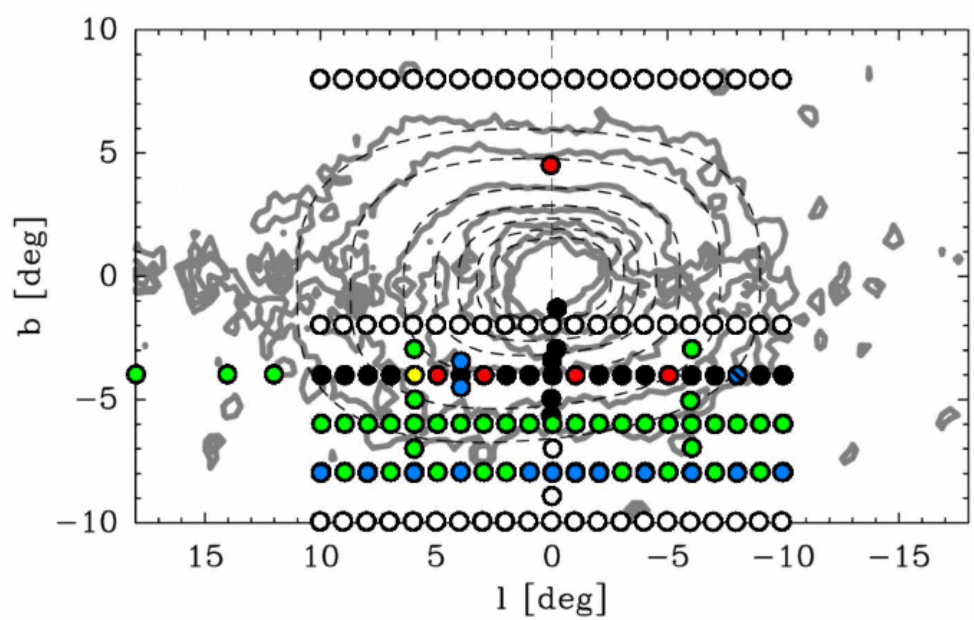
Zhao, Rich, Spergel 1994



Observed: Soto, Rich, & Kuijken 2007

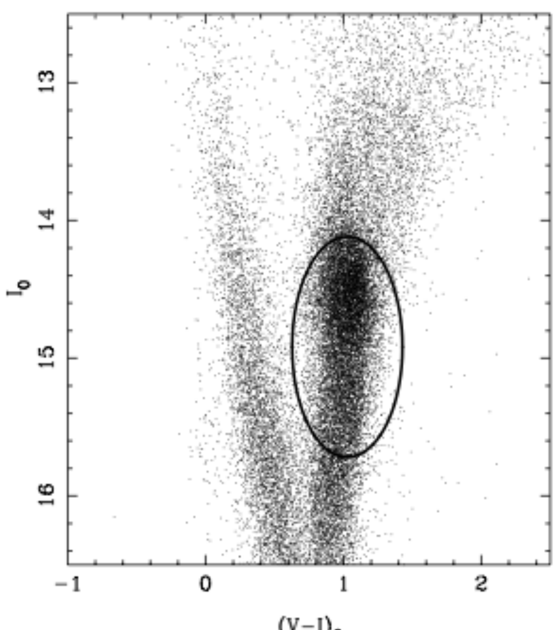
BRAVA survey (Rich et al. 2007; Kunder et al. 2011; public on IRSA 9,500 KM giants

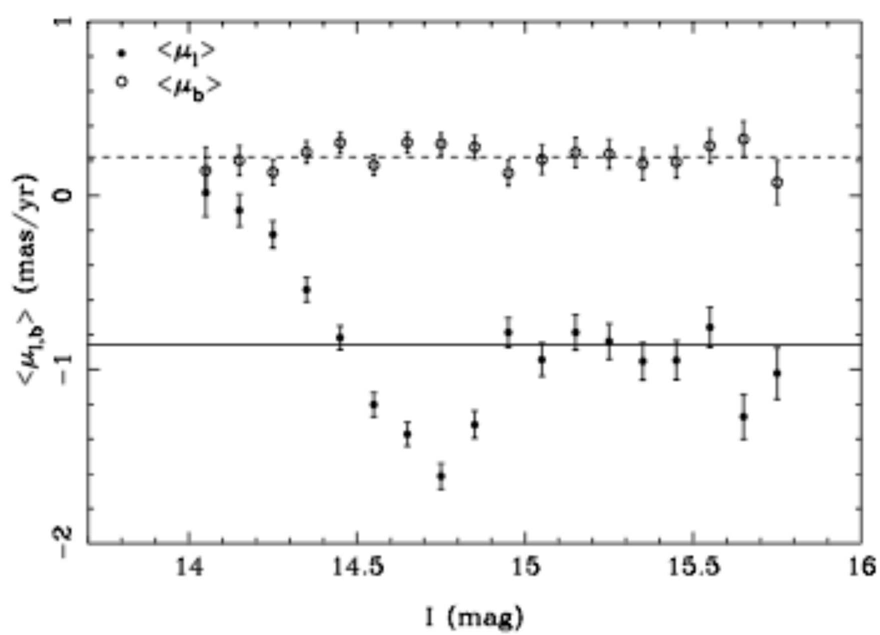




What PM precision is useful? W. Clarkson

- Disk/Bulge separation & kinematic investigation
  - Relative proper motions ***sufficient*** for most science.
  - PM precision < 1.5 mas/yr per star **(kinematics)**
  - < 0.5 mas/yr per star preferred. **(population sepn)**
- Example: OGLE-II (Sumi et al. 2004)





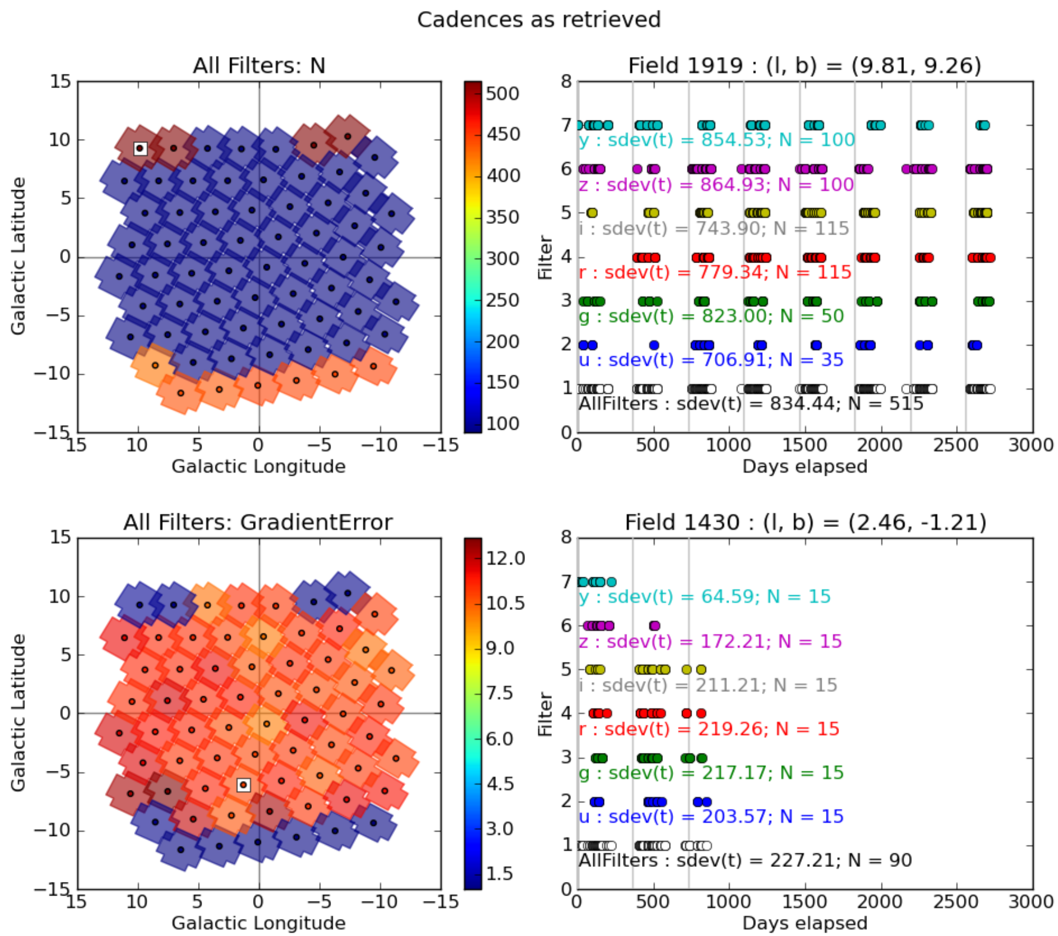
Cadence as-retrieved from OpSim

PM error **~10x** worse than baseline

1-2 mas/yr

$$\sigma_X = \left(\sum_{i}^{N} \frac{(t_i - \bar{t})^2}{\sigma_{iX}^2} \right)^{-1/2}$$

W. Clarkson



Baseline

Bulge region

* I assume observations at each filter contribute to PM precision equally

** σ_i^2 = (FWHM/SNR $)^2$+ (10mas$)^2$ --- LSST Science Book v2

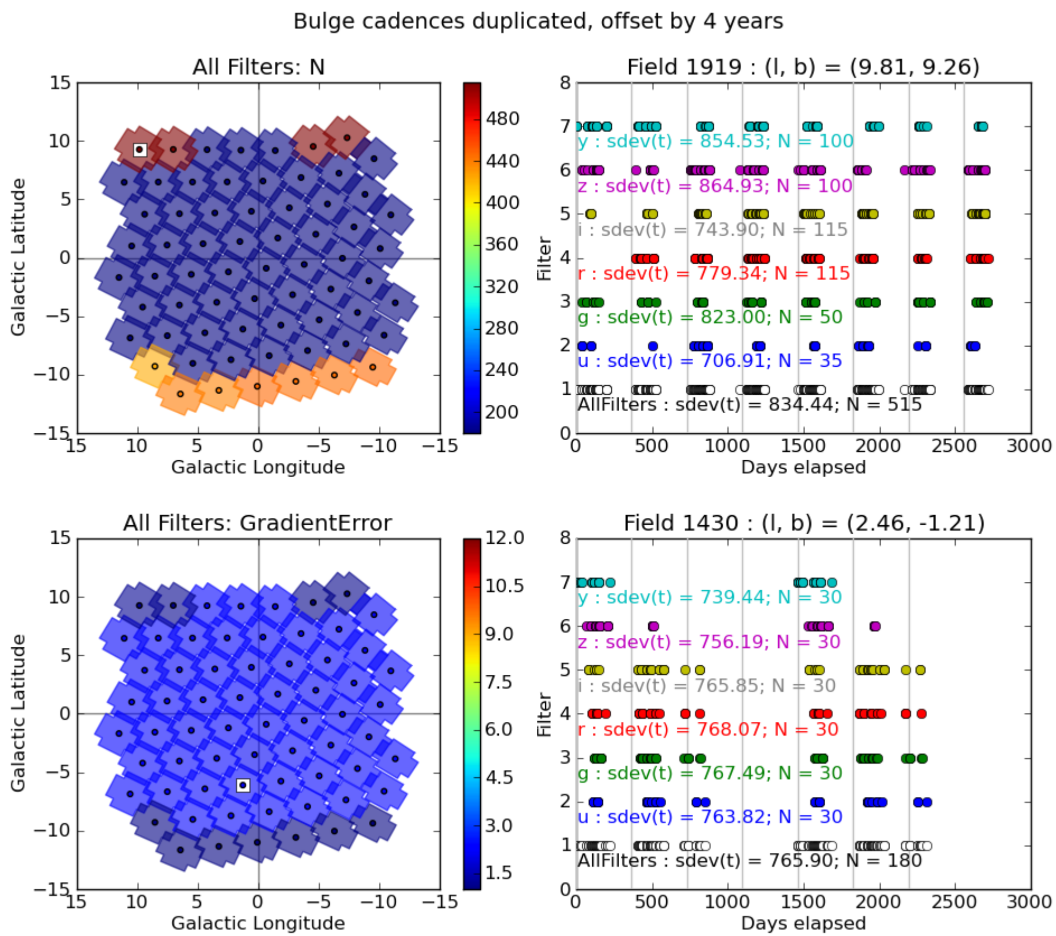
180 observations spread over 7 years

$$\sigma_X = \left(\sum_i^N \frac{(t_i-\bar{t})^2}{\sigma_{iX}^2}\right)^{-1/2}$$

PM error **~2.2x** worse than baseline

0.25-0.45 mas/yr

W. Clarkson



Baseline

Bulge region

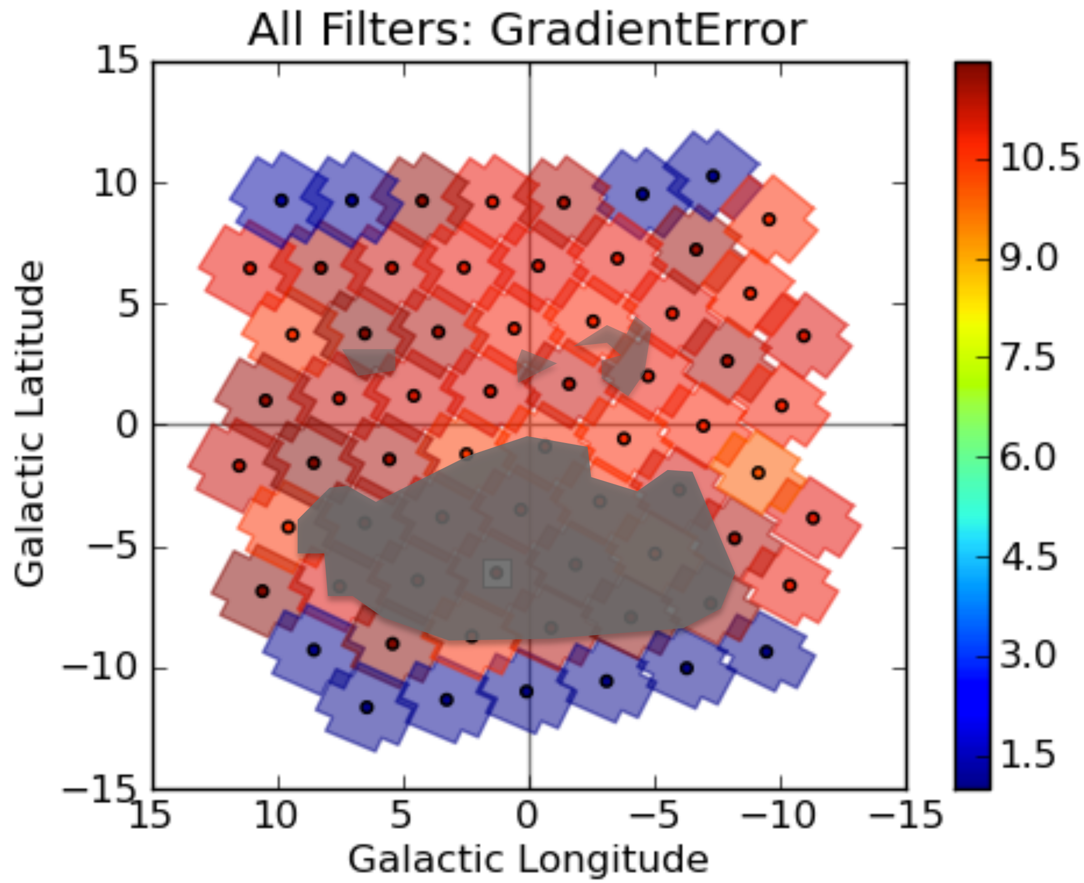
* I assume observations at each filter contribute to PM precision equally

** $\sigma_i^2 = (FWHM/SNR)^2 + (10mas)^2$ --- LSST Science Book v2

GAIA crowding limit ~167 stars / sq.arcmin at G~20. ***If LSST is similar, this still leaves significant regions of the Bulge available.***

$$\sigma_X = \left(\sum_i^N \frac{(t_i - \bar{t})^2}{\sigma_{iX}^2}\right)^{-1/2}$$

W. Clarkson



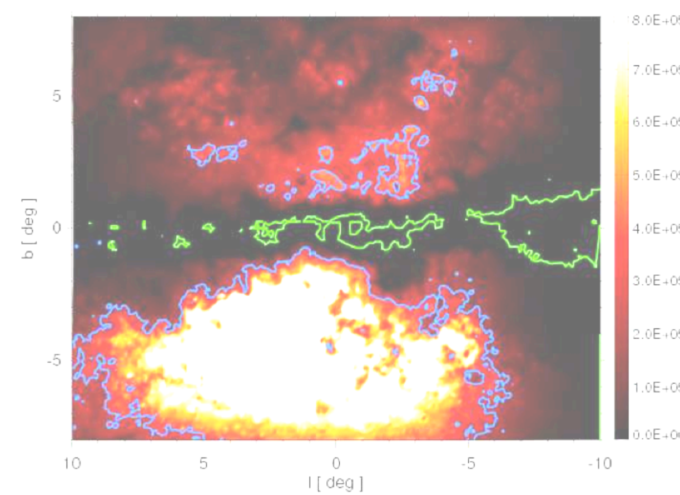


Figure from Reyle et al. 2008 is on approximately the same scale as the pointing-map.

LSST data will not be proprietary: so why join a science collaboration?

Large Synoptic Survey Telescope

- Be in a position to actively influence and contribute to LSST design, including cadence and software. Science Collaborations are advocates for their science needs within the LSST.
- Interact with those developing LSST infrastructure.
- Get a running start on planning to do science once LSST data begin to flow.
- Become fully cognizant of LSST data strengths and quirks, and become familiar with LSST software.
- The survey needs you!

4MOST and LSST

Large Synoptic Survey Telescope

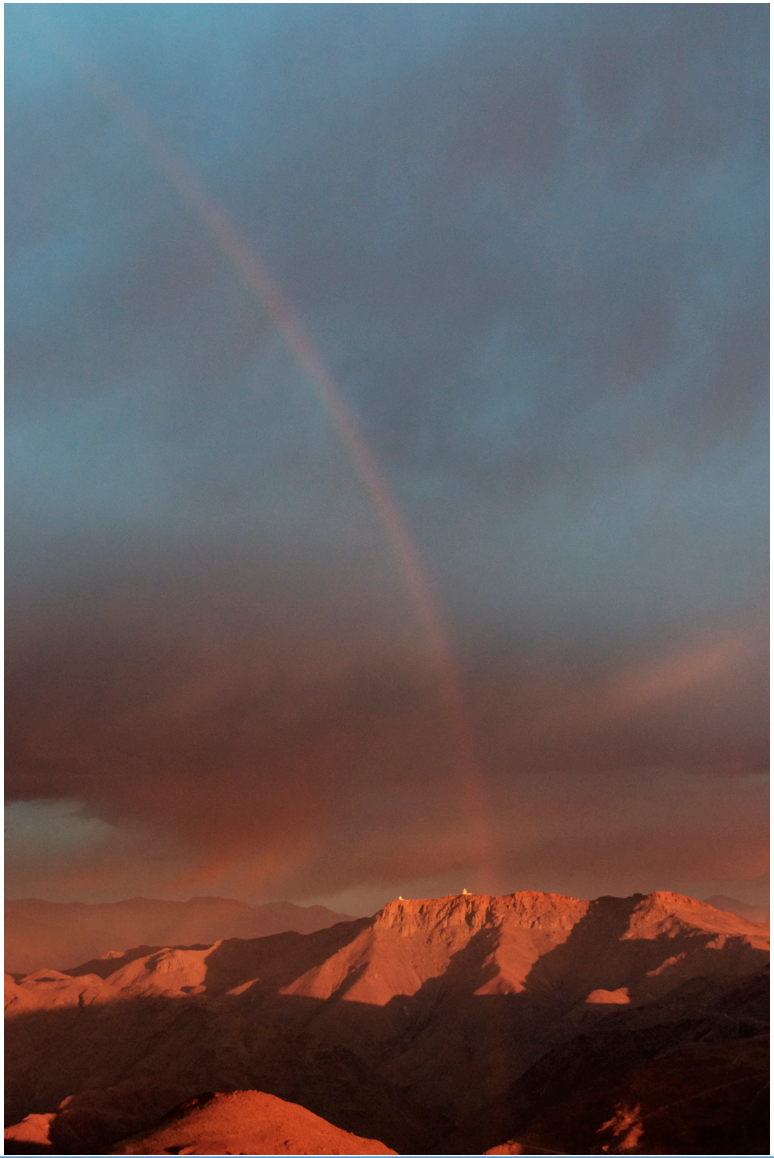
- LSST has greatest impact in areal coverage, time domain, photometric accuracy, and depth
- 4MOST limited to relatively bright 16-20 mag targets (brighter for High res mode).
- Other surveys, like Dark Energy Survey (DECam), Pan STARRS, SkyMapper may be concluded sooner than LSST. GAIA?
- LSST will remain unique in some aspects (photometric quality, time domain, image quality, astrometry)

Substructure: 4MOST spectra of giants, LSST detects system photometrically

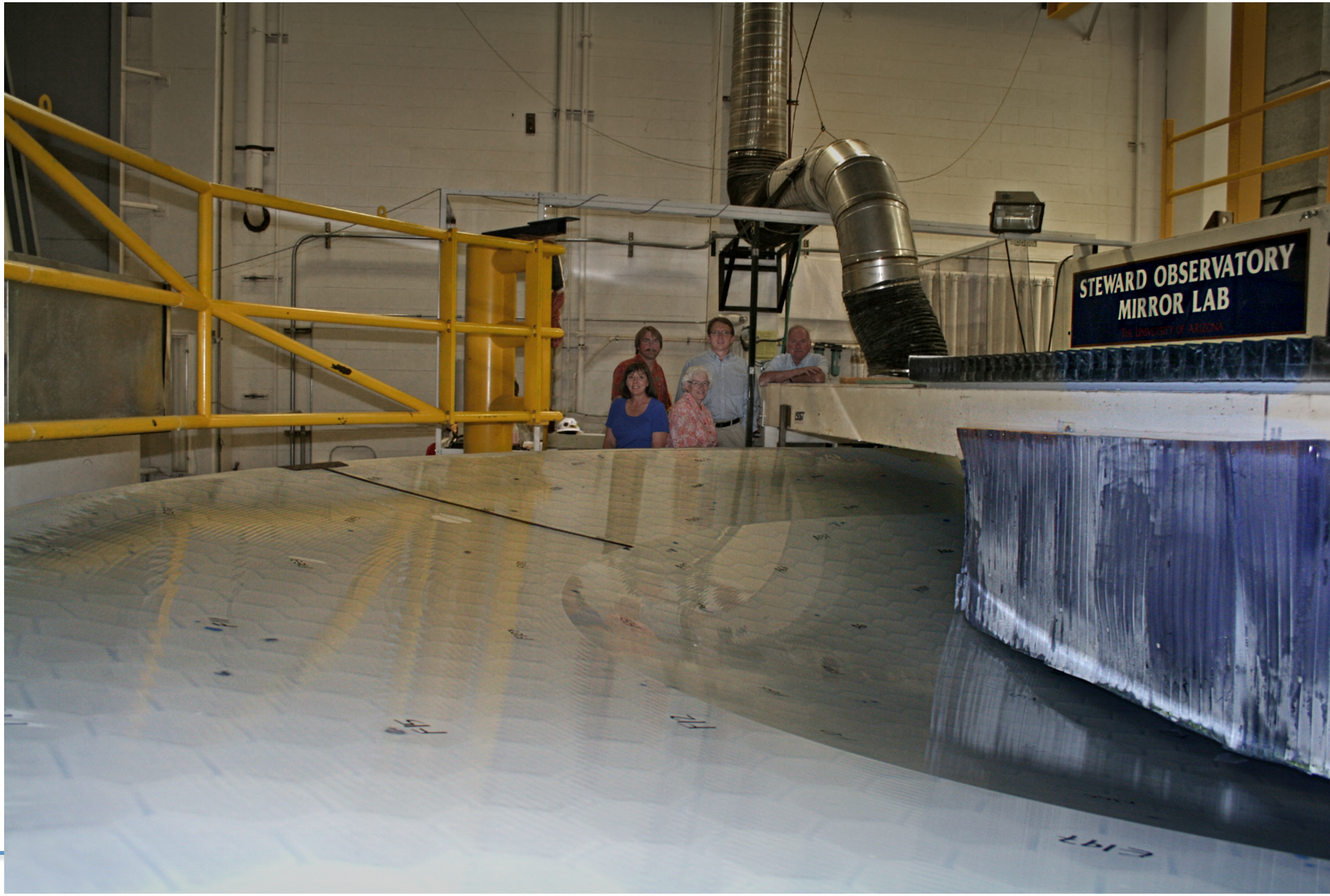
Photometric Metallicities; Populations

- Photometric metallicities, parallaxes for dwarfs, a great potential for LSST (Ivezic et al. 2008). 4MOST spectra to improve calibration
- Reduced proper motion can create "virtual" HR diagrams from transverse velocity measures "Parallax" for stars < 10 kpc
- LSST gives proper motions for bulge, inner halo stars; combined with 4MOST velocities, metallacities. Bar orbit families, streams in bulge

Cerro Pachón, as seen from Tololo, April 9, 2011, Photo by Chuck Claver



Grinding/polishing is well advanced



Large Synoptic Survey Telescope

Site leveling is underway!

Photo by Chuck Claver, April 2011