1998 → 2022

LSST@Illinois

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Argonne National Laboratory, May 30, 2013

SDSS, First Light, 1998

Deep Lens Survey/LSST

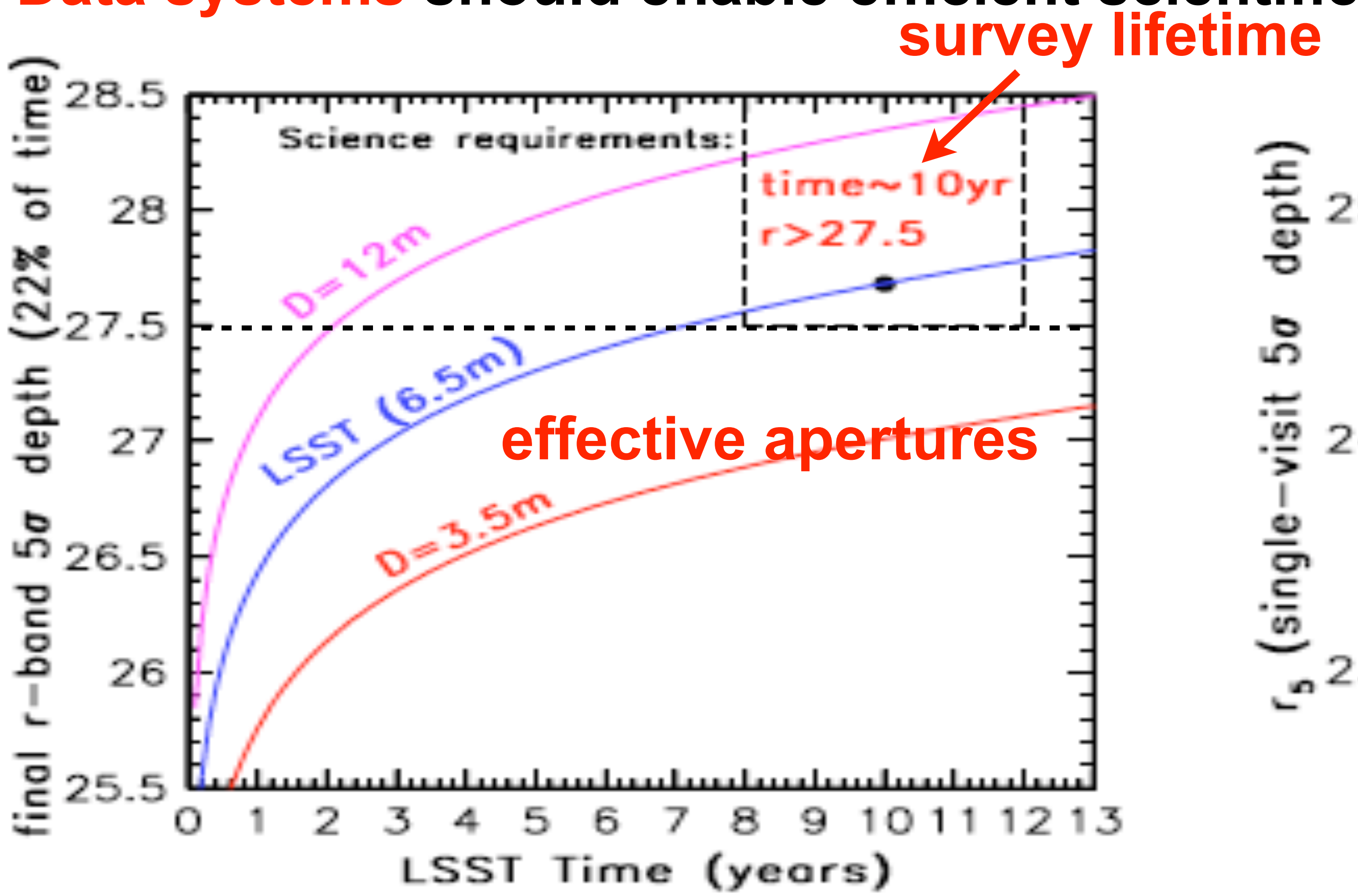
LSST

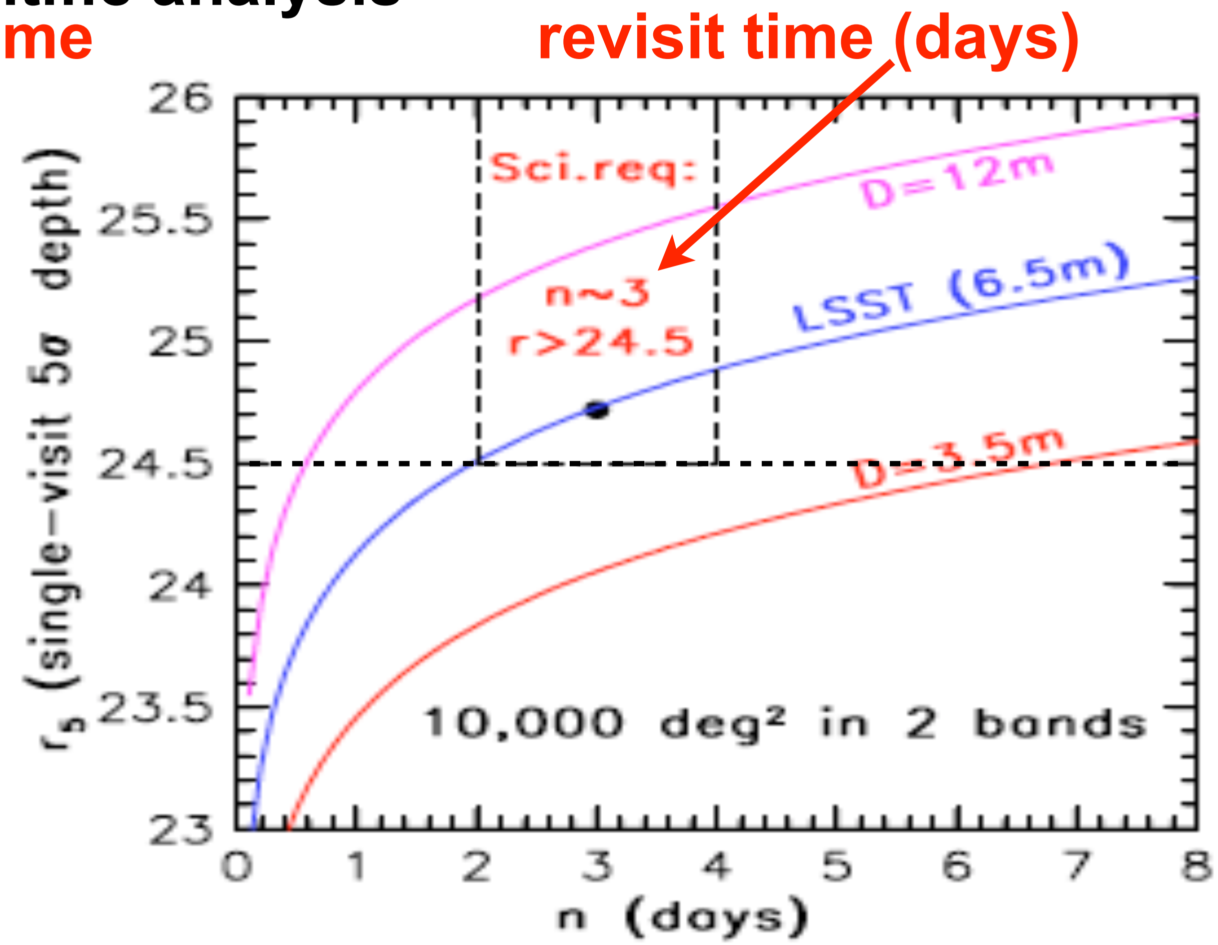
LSST Survey Requirements: ‘One Size Fits All’

- LSST is part of a new direction in ‘Big Science’ as astro/physics communities come together (example: cosmology as a probe of fundamental physics)
- Community-led development of main LSST themes:
  [1] Inventory of the Solar System (Science Book (SB) Ch. V)
  [2] Mapping the Milky Way (SB Chs. VI & VII)
  [3] The Transient/Variable Optical Sky (SB Ch. VIII)
  [4] Galaxy Evolution (SB Chs. IX & X)
  [5] Cosmology, Dark Energy and Dark Matter (Chs. XI - XV)
- Key role of statistical precision, billions of objects, will lead to world’s largest non-proprietary database (~300 PB)
- Many exposures in multiple bands to control systematics
- History: mid-late 90’s various preliminary ideas and new CCD cameras pioneered by Tony Tyson (e.g., BTC) leading to Roger Angel’s 3-mirror design (DMT for solar system plus weak lensing), 2000 Decadal Review names LSST, 2002 LSST Corporation founded, 2008 mirrors cast, 2010 Decadal Review ranks LSST #1, in FY14 President’s budget, --
- Single telescope enables wide, fast, deep survey

LSST Science Requirements

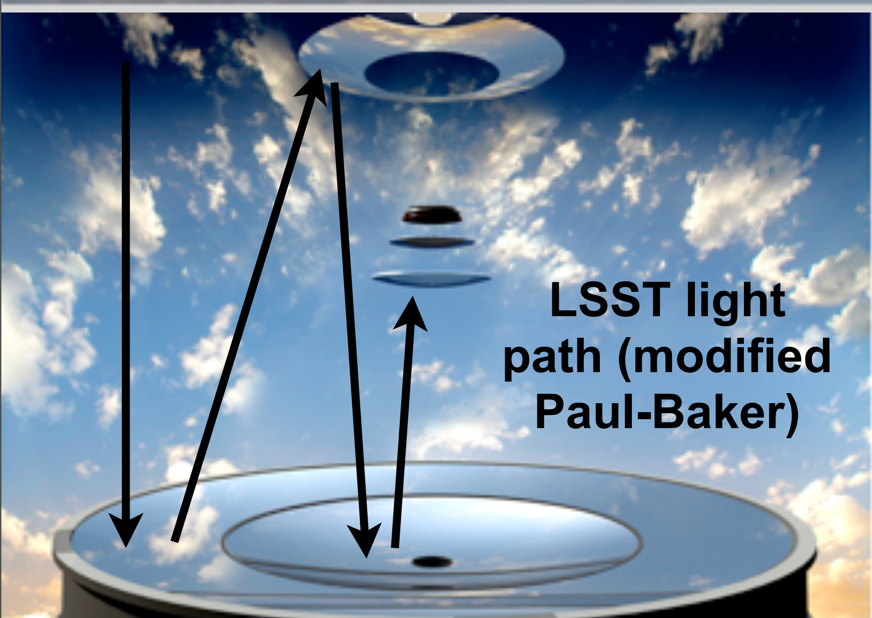
- **Single visit depth** r~24.5 (fast asteroids, transients, stars, weak lensing, --)
- **Photometric repeatability** ~0.005 mag (photo-z, stellar population separation, --)
- **Single visit exposure time** <1min (prevent trailing, control atmosphere, --)
- **Filters**, six from 320-1050 nm (photo-z, stellar typing, obscuration, --)
- **Revisit time distribution** (solar system orbits, SN light curves, --)
- **Total number of visits to one area** ~1000 (weak lensing, asteroids, stars, --)
- **Coadded survey depth** r~27.5 (weak lensing, --)
- **Visit distribution per filter**, r/i preferred (photo-z, stellar populations, --)
- **Distribution of visits on the sky** ~20,000 sq. degs. (weak lensing, LSS, --)
- **Data systems** should enable efficient scientific analysis



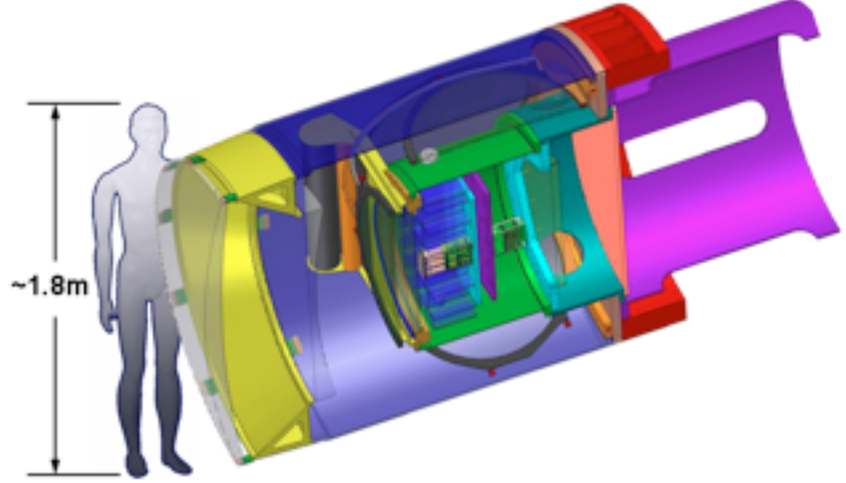


An Informal View of LSST

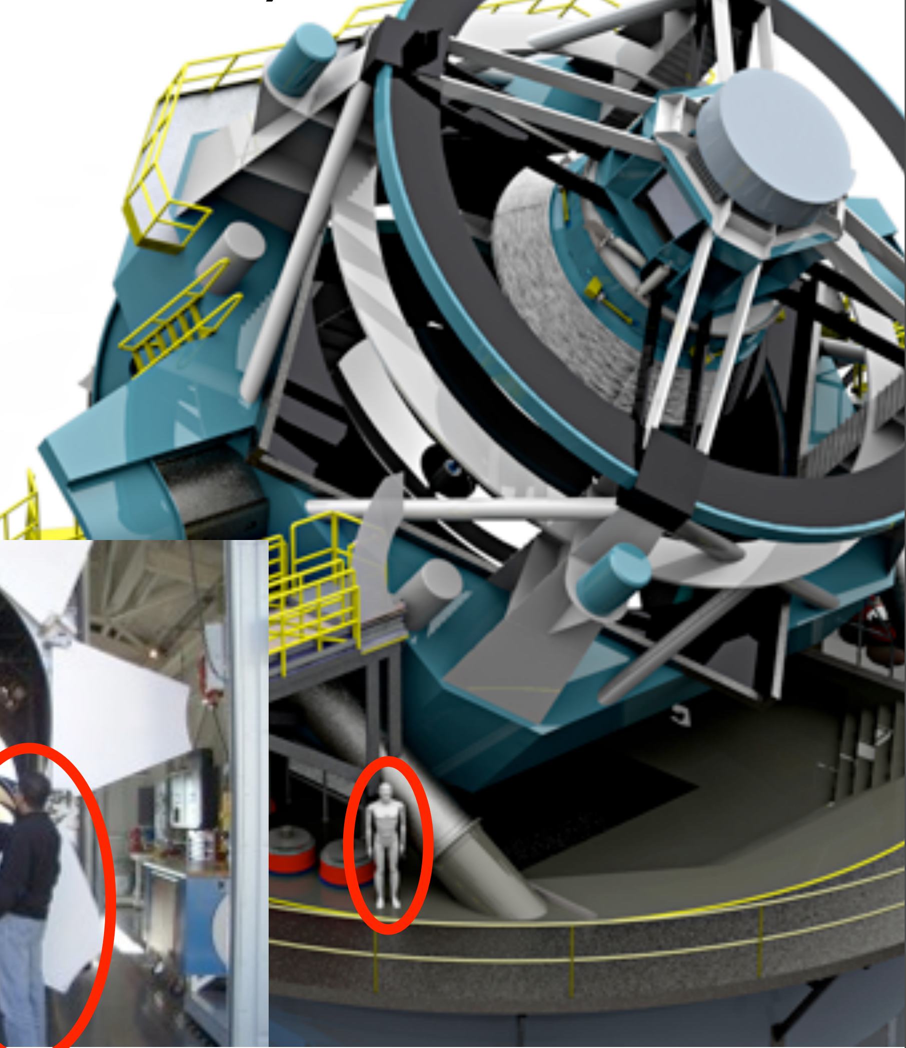
LSST on Cerro Pachon (~9000 feet)



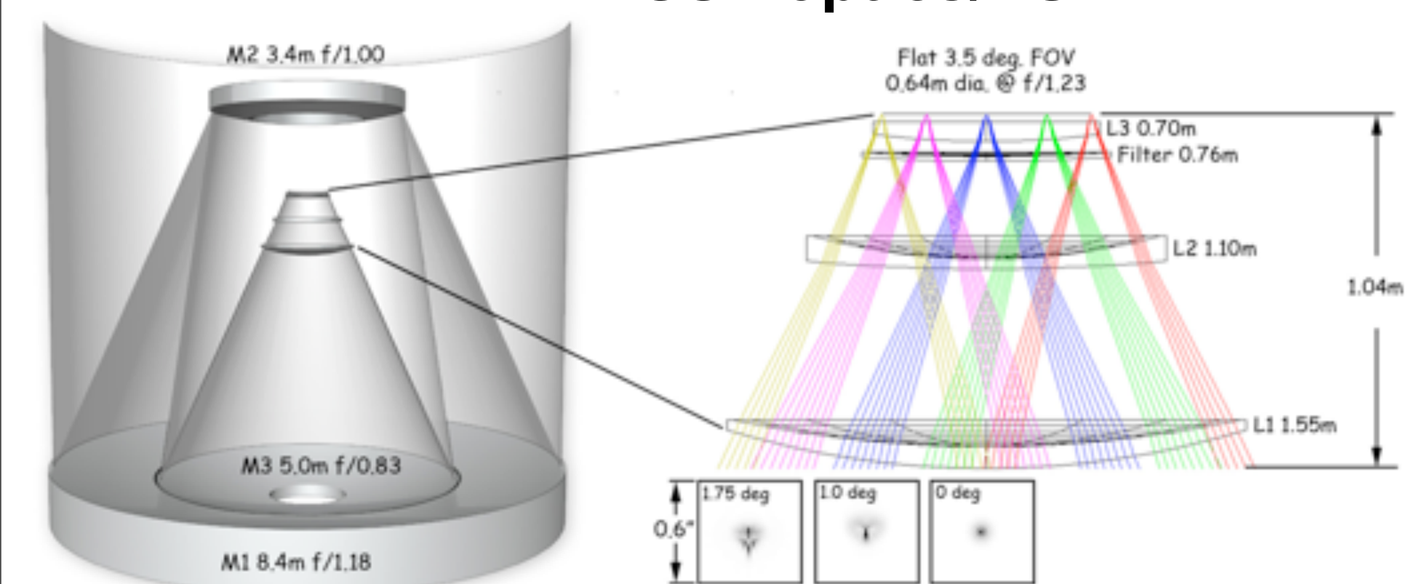
LSST camera



LSST telescope (vs. SDSS)

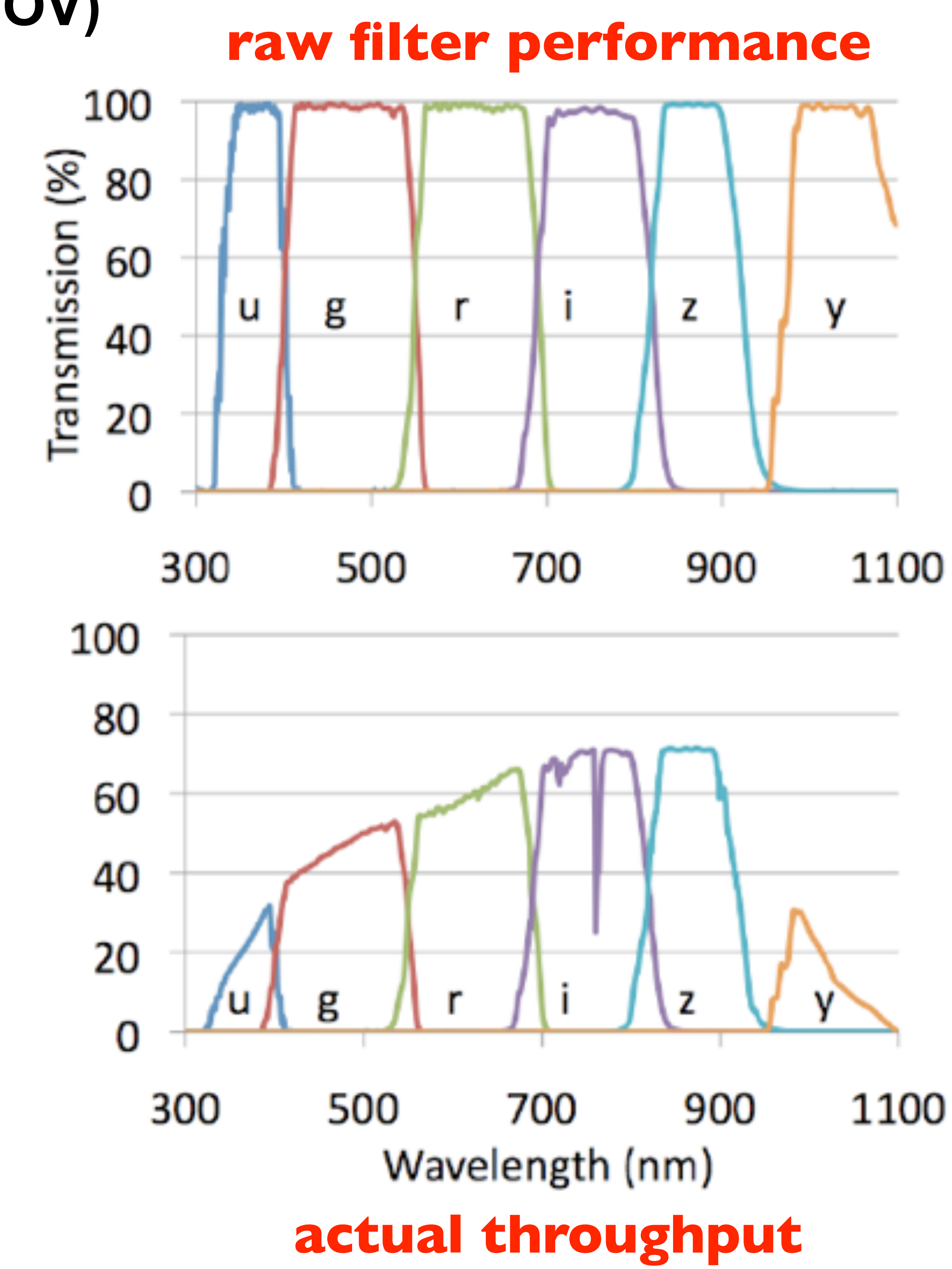


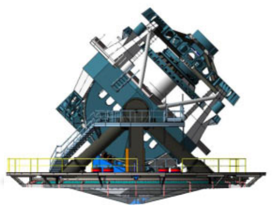
LSST optics/PSF



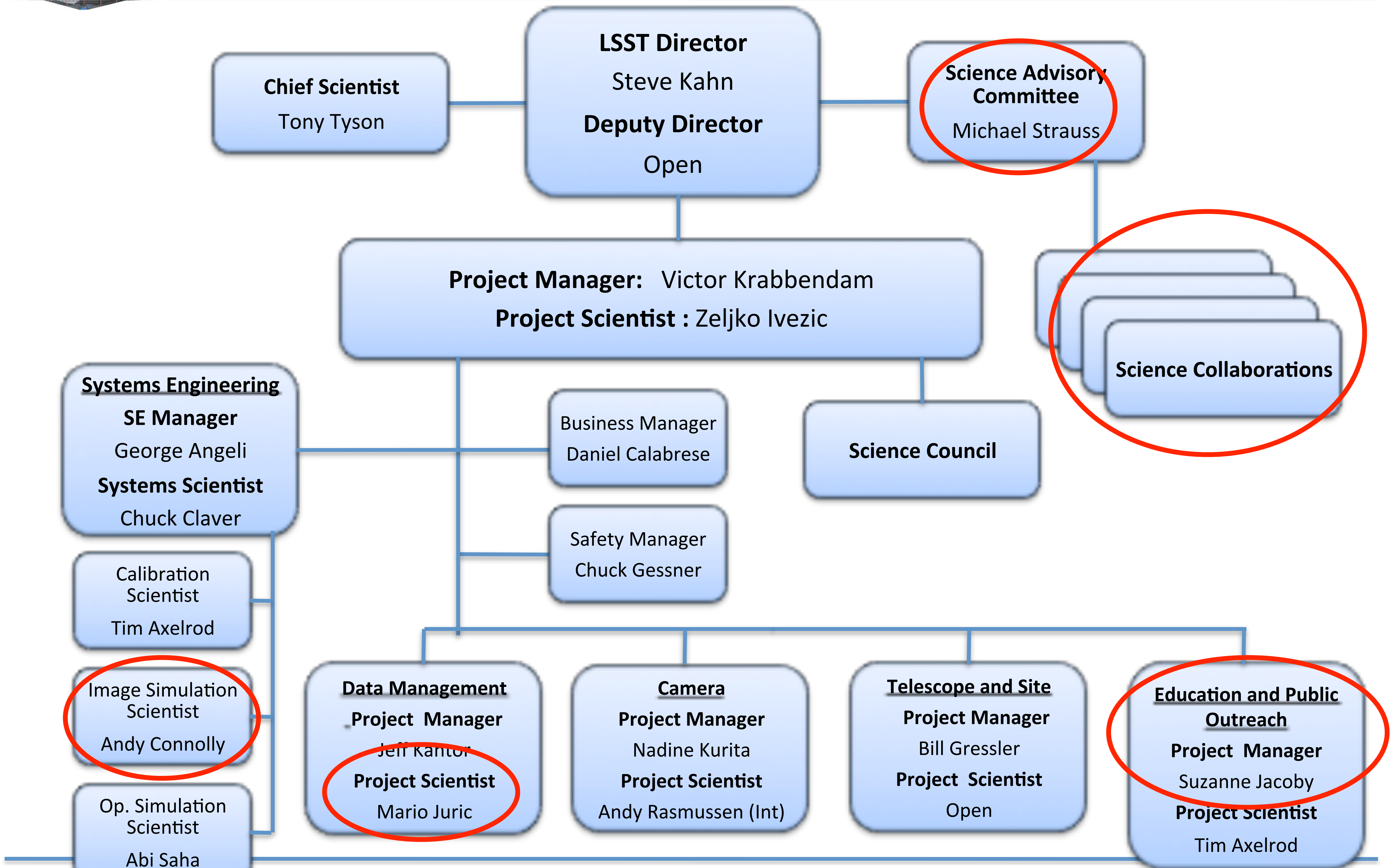
LSST by the Numbers

- Effective aperture, on-axis, 6.7 m (physical diameter, 8.4 m), area, 35 sq. m
- Field of View, 9.6 sq. deg. (3.5 deg diameter)
- Entendue, 319 sq. m sq. deg. (prim. area X FOV)
- wavelength coverage, 320-1080 nm
- Filters, u,g,r,i,z,y, 5 at a time
- Visits, u:70, g:100, r:230, i:230, z:200,y:200
- Sky coverage, 20000 sq. deg.
- Focal length, 10.3 m
- f/ratio, f/1.23 (needed for good FOV)
- Geometric scale distortion, <0.1% over FOV
- Pixel size, 10 micron (0.2 arcsec)
- Camera pixel count, 3.2 Gpixels
- Focal plane flatness, <10 micron
- Photometric calibration goal, 1%
- Readout time, 2 sec
- Raw pixel data/night, 15 TB
- Final dataset, 200 PB
- Construction cost, $600M
- Operations, $40M/yr





LSST Project Organization Structure



LSST Timeline Info

- NSF FDR review in Fall 2013
- DOE CD-2 in Spring 2014
- Grinding of M1/M3 completed
- Fully representative sensor prototypes, meeting all requirements, procured and tested
- Prototype sensor read out with prototype electronics and DAQ system
- Filter auto-changer and carousel prototypes constructed
- 21-day continuous run of novel refrigeration system completed
- Easily installable DM software stack
- Education/PO moving forward
- Now that construction is about to start, role of LSSTC ("3rd funding agency?") needs redefinition -- dues generate $850K/ year, what for?

LSST Science Engagement

- Supposed to happen via Science Working Groups: Supernovae, Weak Lensing, AGN, Solar System, Galaxies, Transients/Variable stars, LSS, Stars/Milky Way, Strong Lensing, Informatics, DESC
- Engagement is spotty for a variety of reasons: (i) still time to go, (ii) people busy with real data, (iii) no funding, (iv) issues re career prospects, (v) wait till data appears
- Maybe ok for some things, but not for all --
- DOE and NSF have very different views of LSST; DOE sees LSST as a ‘DE experiment’, NSF as a ‘facility’
- LSST Dark Energy Science Collaboration (DESC) started as a way to get more of the DOE viewpoint expressed to the community
- Despite the logo, LSST DESC is NOT a HEP experiment! Need to find one’s niche -- not always obvious how

LSST DESC
Dark Energy Science Collaboration

LSST@Illinois I

- LSST as system -- Hardware, Software, Science
- Key hardware roles pretty much established (in absence of a crisis)
- Software -- DM software written by LSSTC/Princeton/SLAC/etc., Data Access Center will be at NCSA; **other data centers are possible for specialized tasks (with associated computing resources for Level III analysis)**
- Level 1 = camera datastream/alerts; Level 2 = yearly data release (image catalog, etc.); Level 3 = **Science level, left to community, will require a serious amount of work**
- **Science Collaborations (includes outreach) -- how to develop a local community?**
- Example -- Argonne has a strong theory/computing presence, but lacks observers and experience with astro software (Sn is an exception), partnerships highly welcome!

LSST@Illinois II

- This is just a start -- but we have 60 people signed up already! (Did not expect so many)
- Judging from current responses, have a wide spectrum of interests, covering **ALL** LSST WGs, and including data management
- Objective today is to get a big picture view of what is happening at the different institutions (“plenary” discussion session), get people with common interests to meet/discuss (“breakout” sessions), plan future activities --
- Aim to end with concrete **Next Steps**

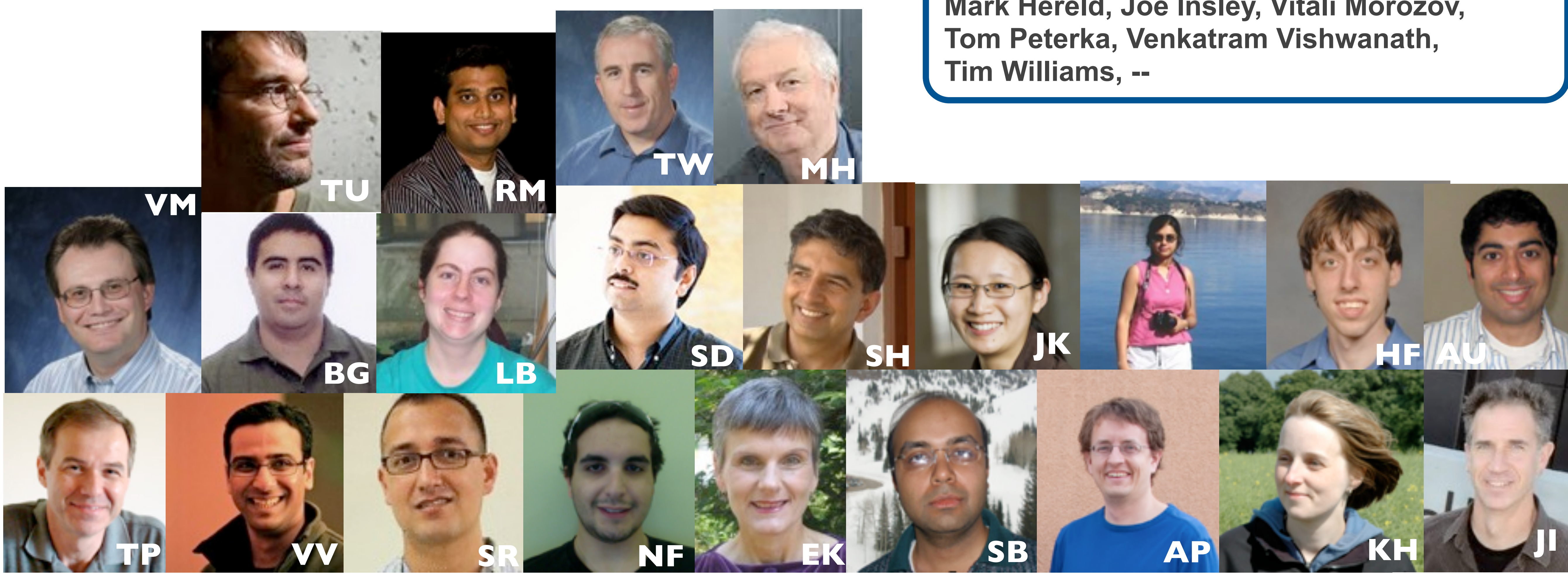
Agenda

- 9.00am-9.30am Welcome/Intro
- 9.30am-10.00am LSST and Adler
- 10.00am-10.30am LSST and Argonne
- 10.30am-10.45am **BREAK**
- 10.45am-11.15am LSST and Fermilab
- 11.15am-11.45am LSST and UIUC/NCSA
- 11.45am-12.15pm LSST and Northwestern
- 12.15pm-1.00pm LSST Discussion **LUNCH**
- 1.00pm-1.30pm Plan Breakouts
- 1.30pm-2.30pm Breakouts
- 2.30pm-3.15pm Breakout reports/discussion
- 3.15pm-3.45pm **BREAK**
- 3.45pm-4.45pm Next Steps

Argonne Group: Cosmic Computing and Big Data

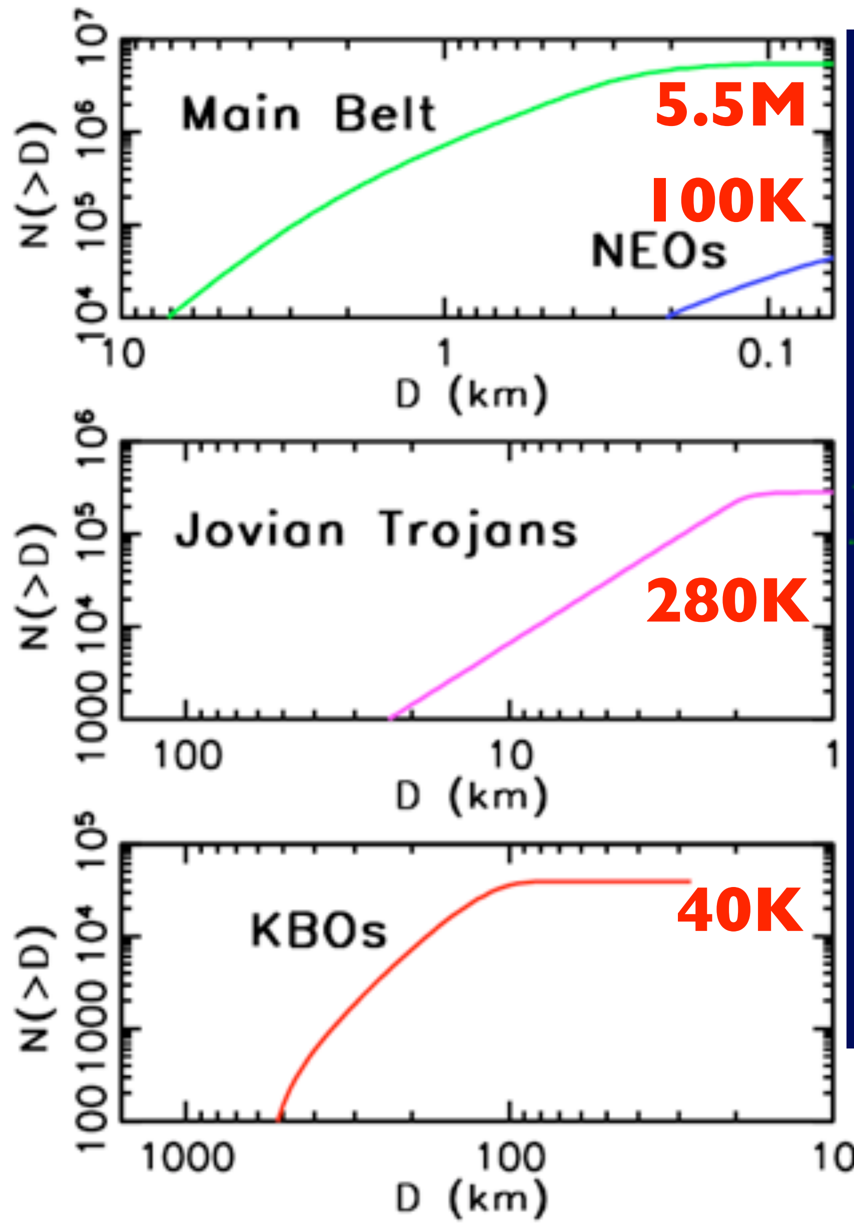
HEP staff:
Salman Habib, Katrin Heitmann, Eve Kovacs, Peter van Gemmeren, Qizhi Zhang
Post-docs:
Suman Bhattacharya, Rahul Biswas, Lindsey Bleem, Sanghamitra Deb, Sudeep Das, Ben Gutierrez (w/ ALCF), Hal Finkel (w/ ALCF), Juliana Kwan, Adrian Pope, Amol Upadhye
Students:
Nick Frontiere (Chicago), Steve Rangel (Northwestern)

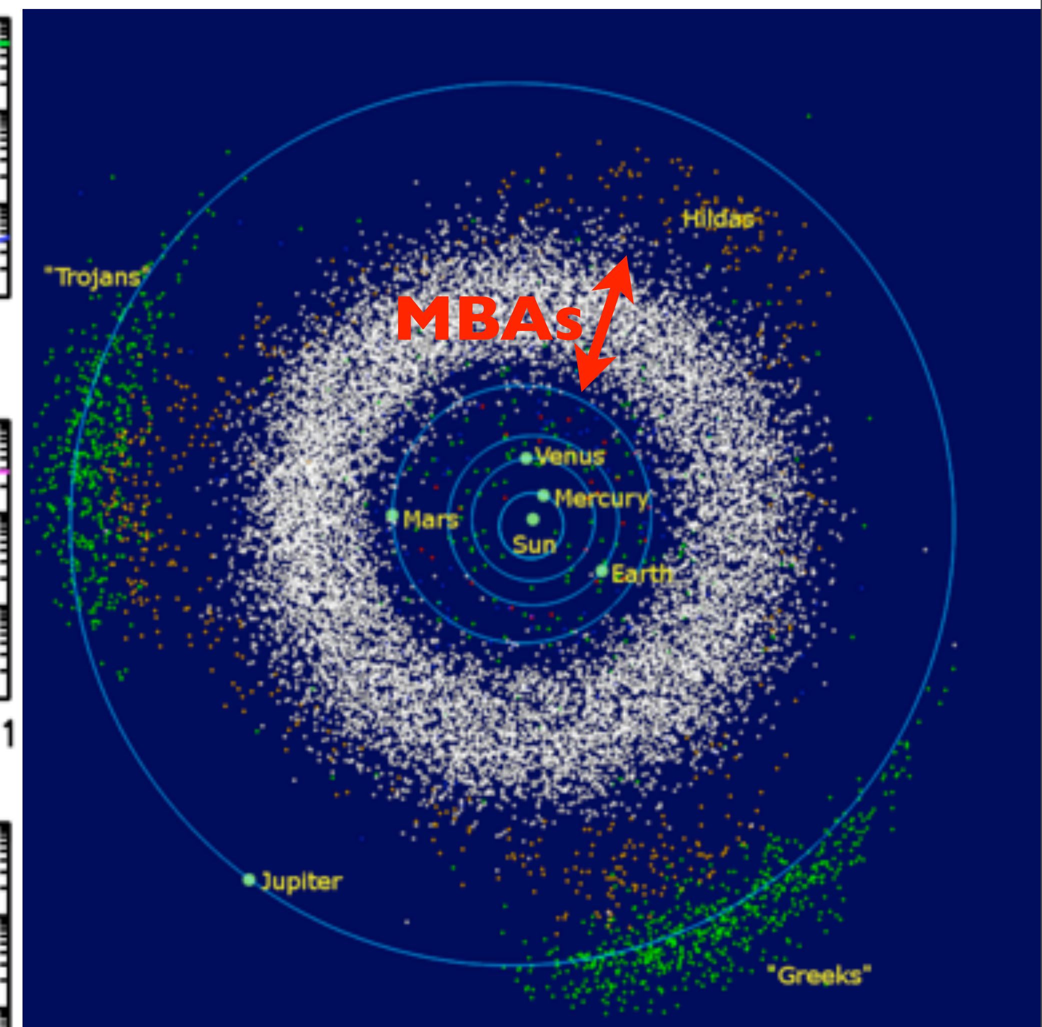
ALCF/MCS staff:
Mark Hereld, Joe Insley, Vitali Morozov, Tom Peterka, Venkatram Vishwanath, Tim Williams, --



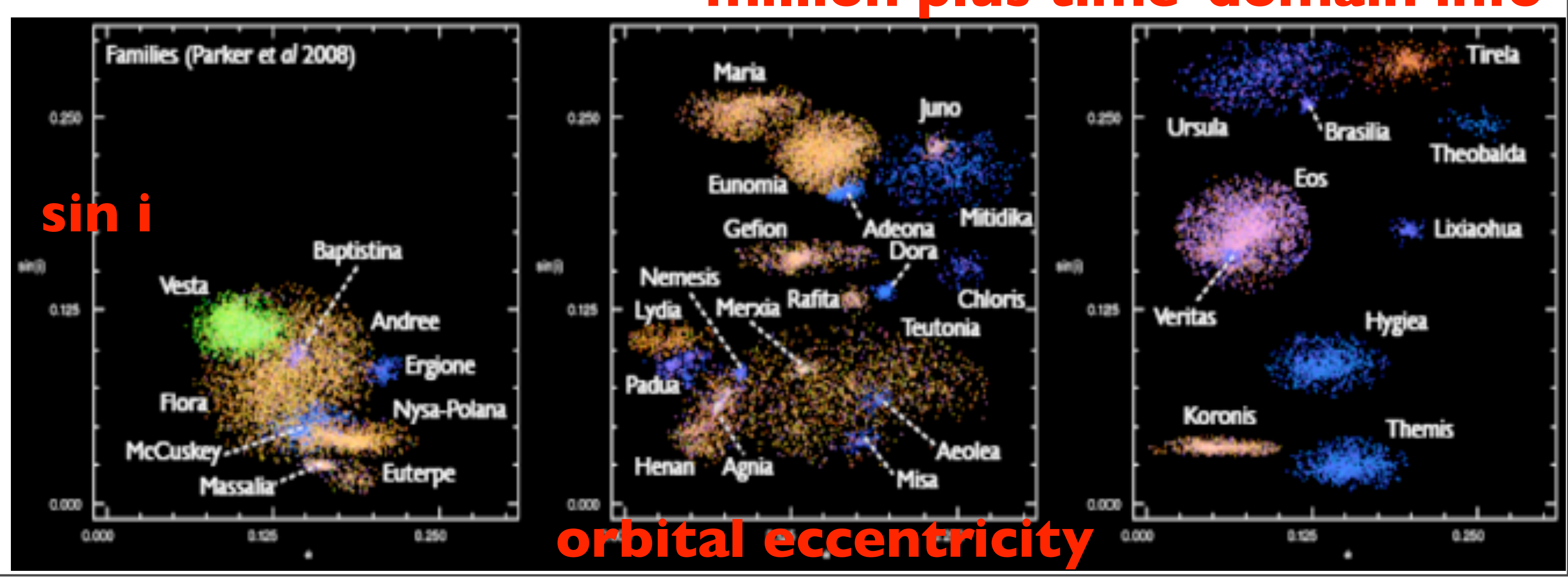
The Solar System: "Small Bodies"

- 90% of Near Earth Asteroids (NEAs) down to sizes of ~150 m
- Census of Main Belt Asteroids (MBAs) along with size distribution (will find 5.5 million)
- Orbital distribution of small bodies probes dynamical history of giant planets (migration), LSST's Trans-Neptunian Objects (TNOs, ~40K) particularly suited for this (since only <2000 known currently)
- Color (not simultaneous) information helps to tag asteroid families
- Time variability information from LSST photometry useful as probe of rotation, shape, composition, --



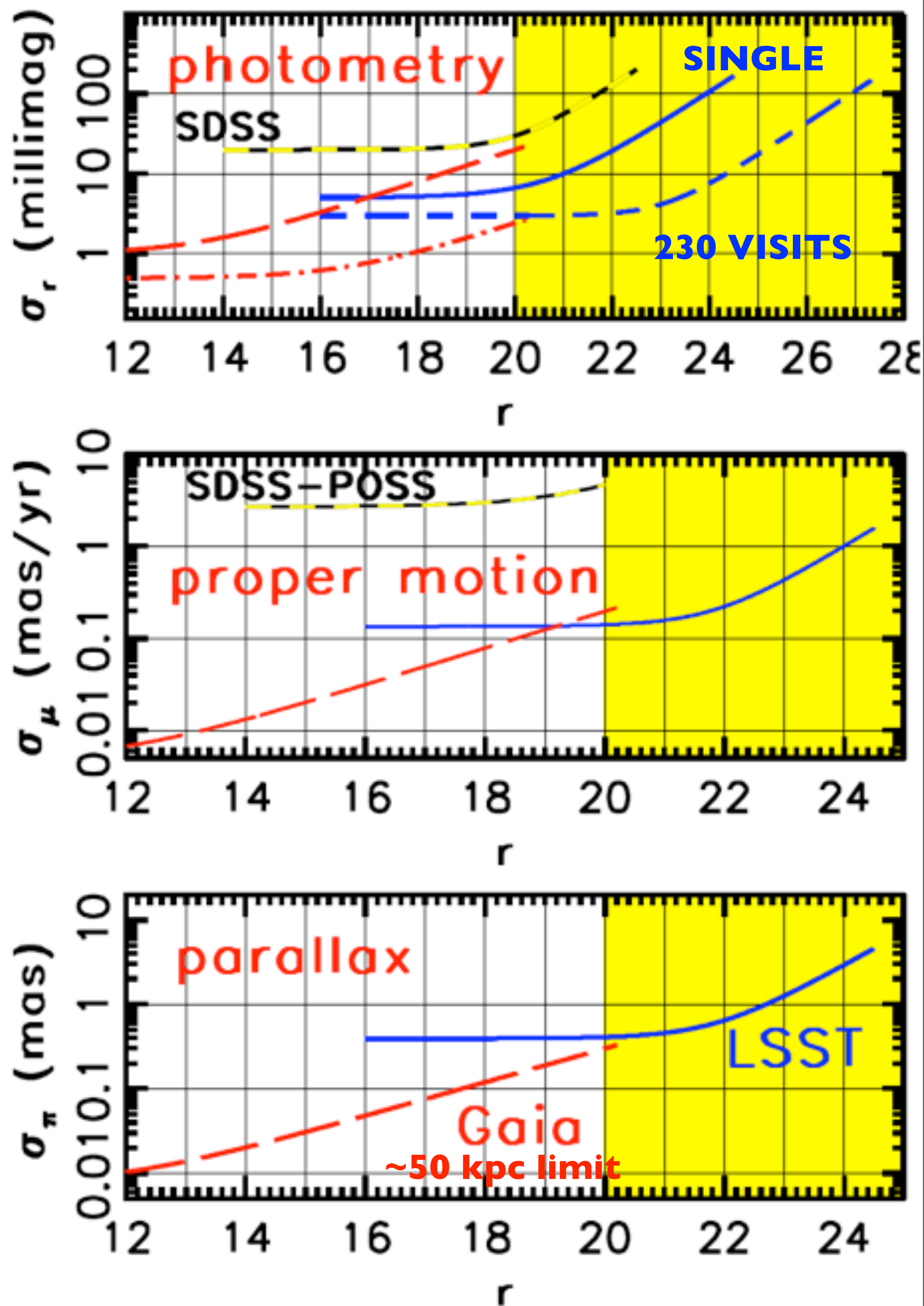


SDSS: 88000 objects; several million plus time-domain info



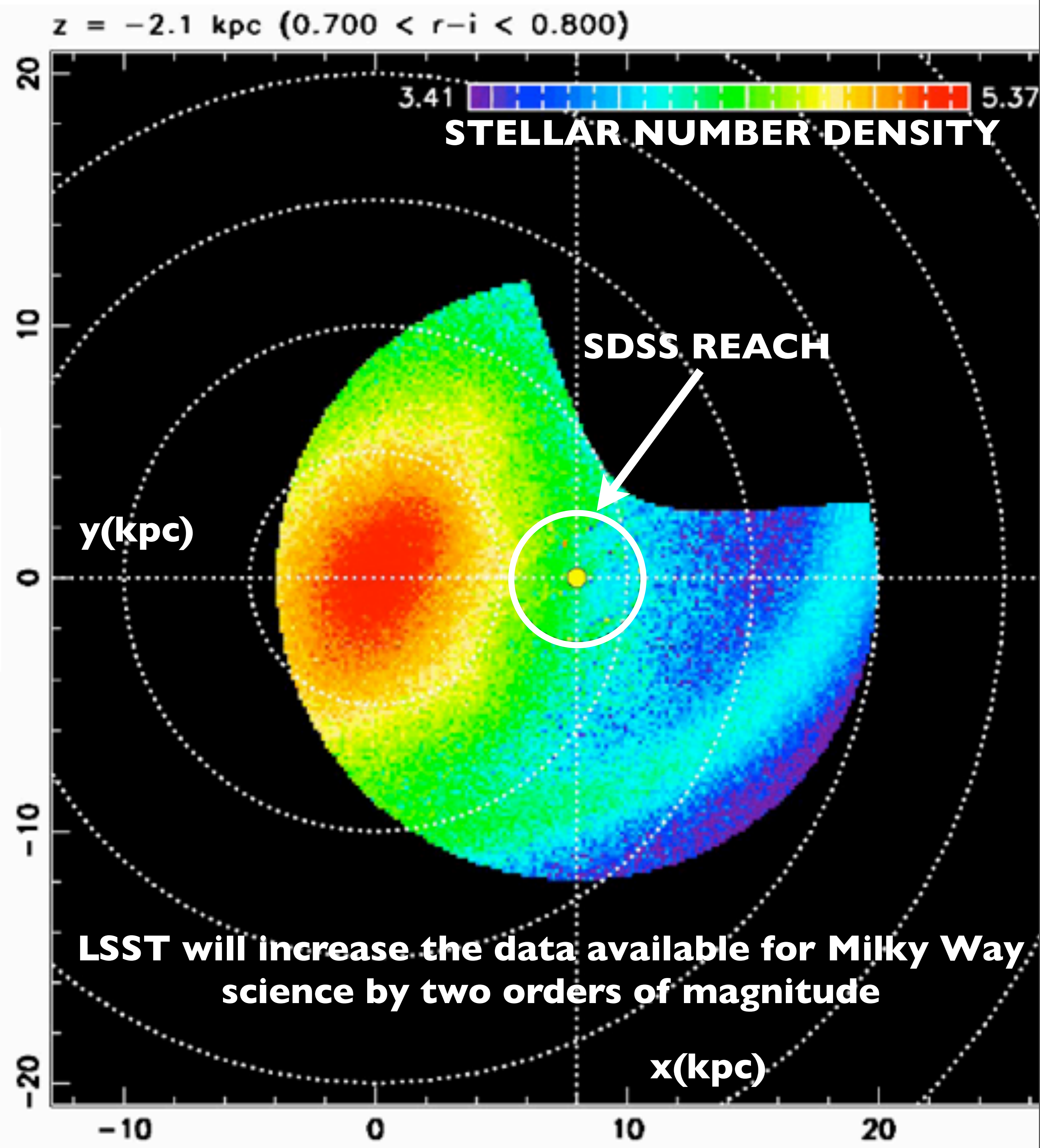
Stellar Populations: Milky Way and Nearby Galaxies

- Smooth extension of Gaia capability (Gaia launch in 2012/13), get billions of stars
- ~6M Eclipsing Binaries (EBs) with ~1.6M at S/N>10, short-period EBs complete to r~22, 80K EBs in LMC/SMC
- SDSS improved White Dwarf sample by a factor of 10, to >10000 (disk only), LSST will get ~400K halo WDs to r<24.5
- VLM Stars and Brown Dwarfs, will get ~40K BDs out to 200 pc (vs. 750 known), >350K M dwarfs
- Photometric search for metal-poor stars will reach ~100 kpc (via SDSS approach)
- Stellar astrophysics in the LMC & SMC, 100K new RR Lyraes, search for stars in the Magellanic Stream
- In nearby galaxies, brightest RGB stars visible to LSST out to ~10 Mpc, crowding limits this to ~4 Mpc
- Distance ladder improvements via study of Cepheid systematics, investigate LPVs as robust distance indicators (since HST search for Cepheids limited to ~40 Mpc), aim to improve H_0 to better than 3%



Milky Way and Local Volume Structure

- **Mapping ~10 billion main sequence stars to 100 kpc over 20000 sq. degs.**
- **Metallicity indicators for ~200 M stars**
- **More luminous tracers (e.g., RR Lyrae) to 400 kpc, the virial radius, 3-D velocities enable new mass measurements of the dark halo**
- **Complexity of Milky Way disk as a test of theories of galaxy formation**
- **M dwarfs to ~30 kpc, with parallaxes to ~300 pc (vs. Gaia ~10 pc), ~7 billion stars**
- **3-D dust map of the Milky Way using M dwarf photometry (to ~15 kpc)**
- **Debris streams, ~100 out to 50 kpc, and ~100 beyond (vs. 11 known)**
- **Correlate Local Group dwarf galaxy orbits with star formation history**
- **Search for UFDs, LSST can find ~500 out to the Milky Way virial radius**
- **Photometric characterization of the globular clusters of every accessible galaxy within ~30 Mpc**



Transients and Variable Stars I

- **Transients in the Local Universe (d<200 Mpc), novae/SN gap, correlation with new observational windows (cosmic rays, GWs, neutrino detectors, --)**
- **Local Universe, a-LIGO follow-ups with negligible false positives, assumed 12 sq. deg. localization and follow-up depth of r<24**
- **Need to eliminate foreground and background events (asteroids, M dwarf flares, --)**

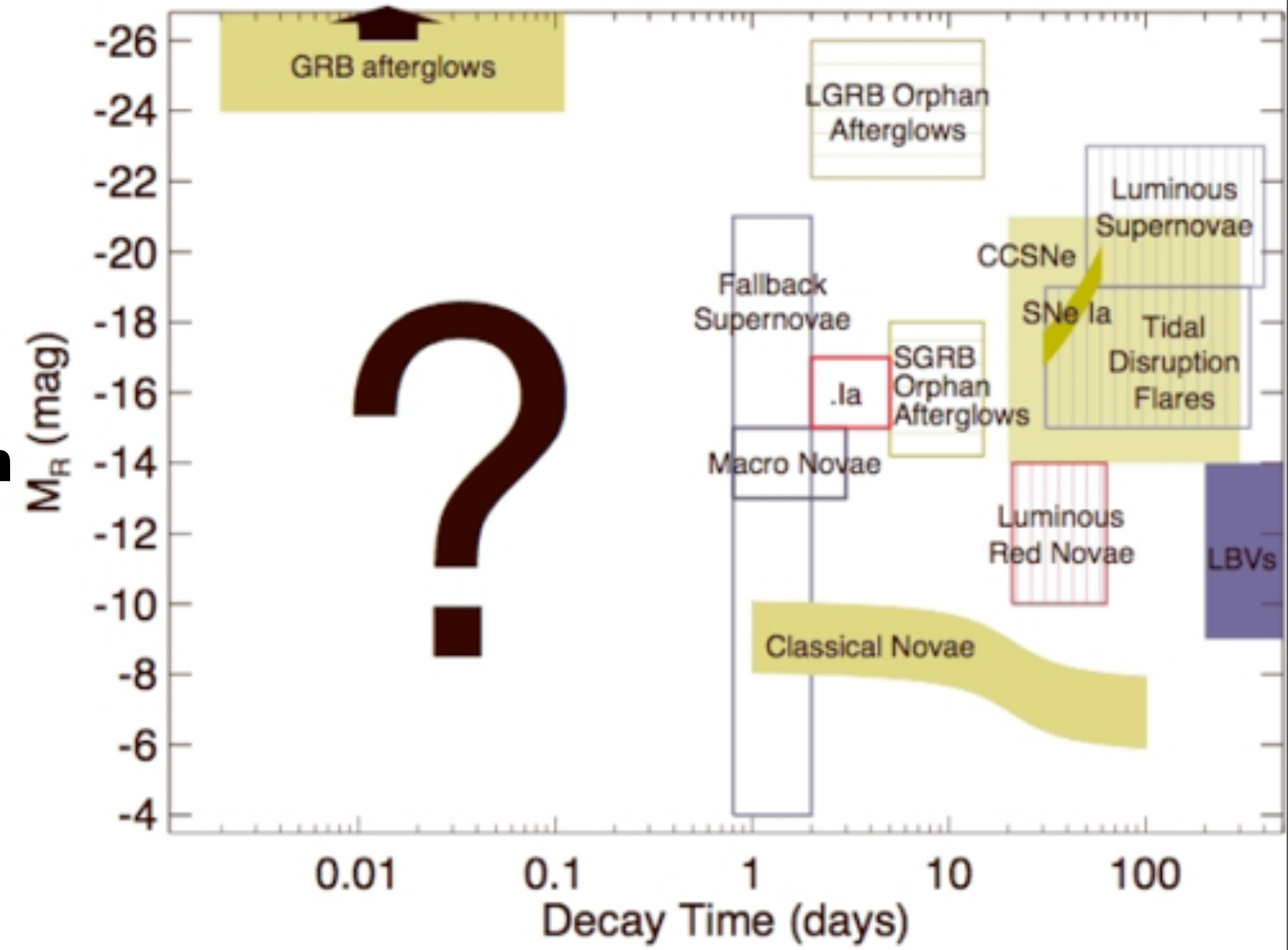


Table 8.2: Properties and Rates for Optical Transients[a]

Class	M_v [mag]	τ^b [days]	Universal Rate (UR)	PTF Rate [yr^{-1}]	LSST Rate [yr^{-1}]
Luminous red novae	$-9..-13$	20..60	$(1..10)\times10^{-13}\,yr^{-1}\,L_{\odot,K}^{-1}$	0.5..8	80..3400
Fallback SNe	$-4..-21$	0.5..2	$<5\times10^{-6}\,Mpc^{-3}\,yr^{-1}$	<3	<800
Macronovae	$-13..-15$	0.3..3	$10^{-4..-8}\,Mpc^{-3}\,yr^{-1}$	0.3..3	120..1200
SNe .Ia	$-15..-17$	2..5	$(0.6..2)\times10^{-6}\,Mpc^{-3}\,yr^{-1}$	4..25	1400..8000
SNe Ia	$-17..-19.5$	30..70	[c] $3\times10^{-5}\,Mpc^{-3}\,yr^{-1}$	700	200000[d]
SNe II	$-15..-20$	20..300	$(3..8)\times10^{-5}\,Mpc^{-3}\,yr^{-1}$	300	100000[d]

Transients and Variable Stars II

- **Transients in the Distant Universe, ‘long’ orphan GRB afterglows can be used to determine beaming fraction and universal associated rate**
- **Hybrid GRBs, anomalous supernovae, tidal disruption flares --**
- **LSST micro/mesolensing (MACHO census, planets, solar neighborhood, --)**
- **LSST will discover ~135 million variable stars (~60M pulsating, ~60M eclipsing/ ellipsoidal, ~2M flaring, ~1M planetary transits)**

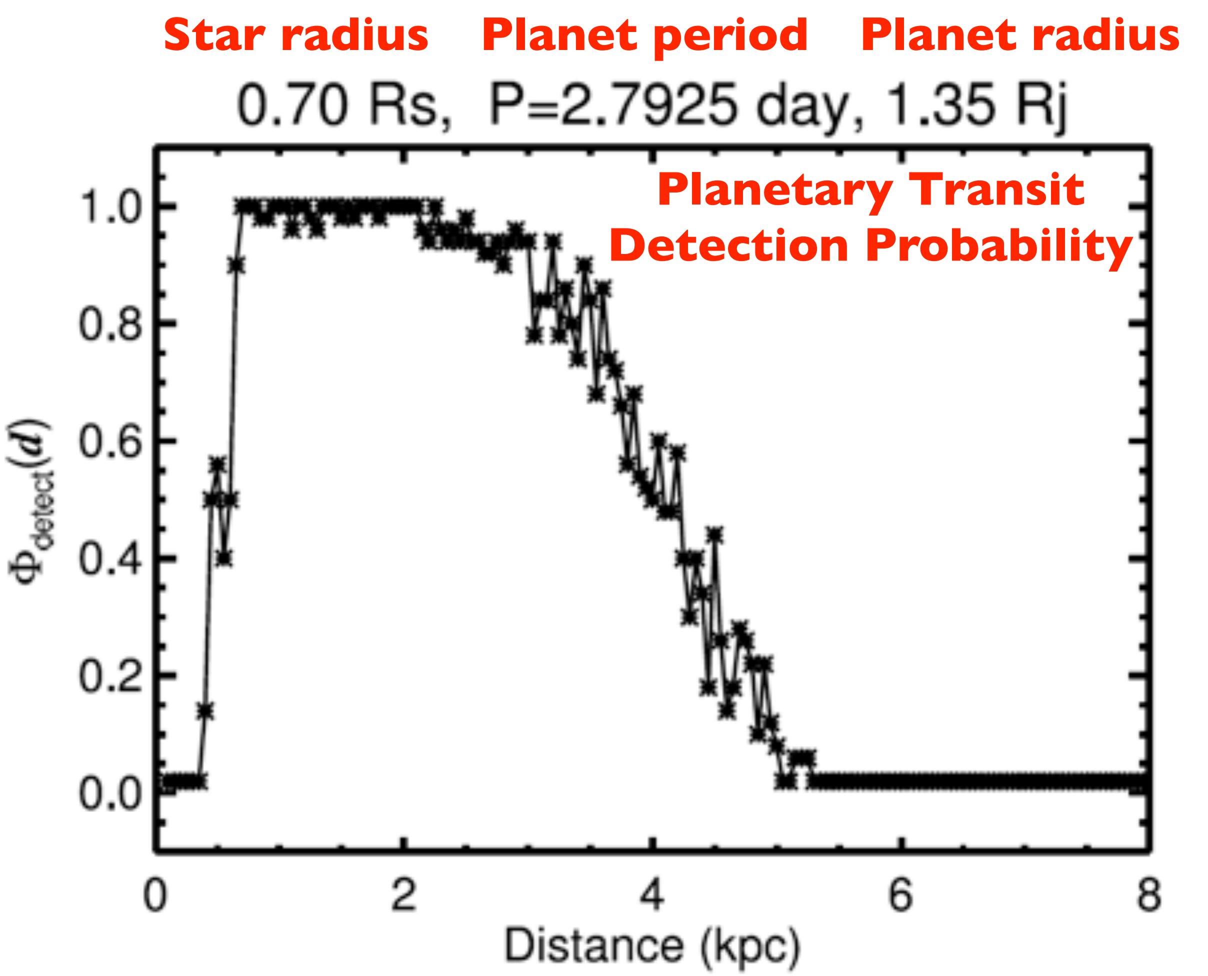
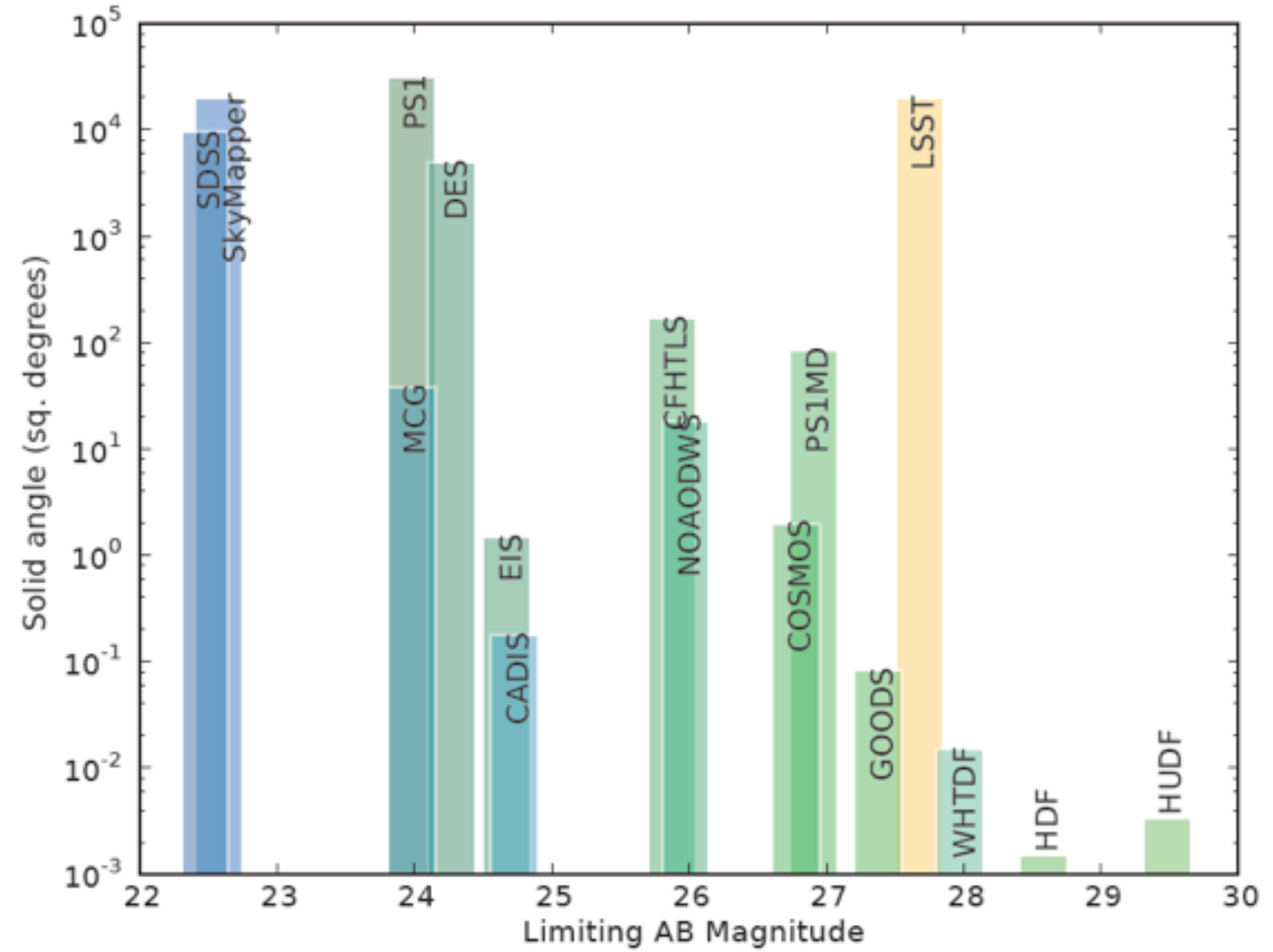


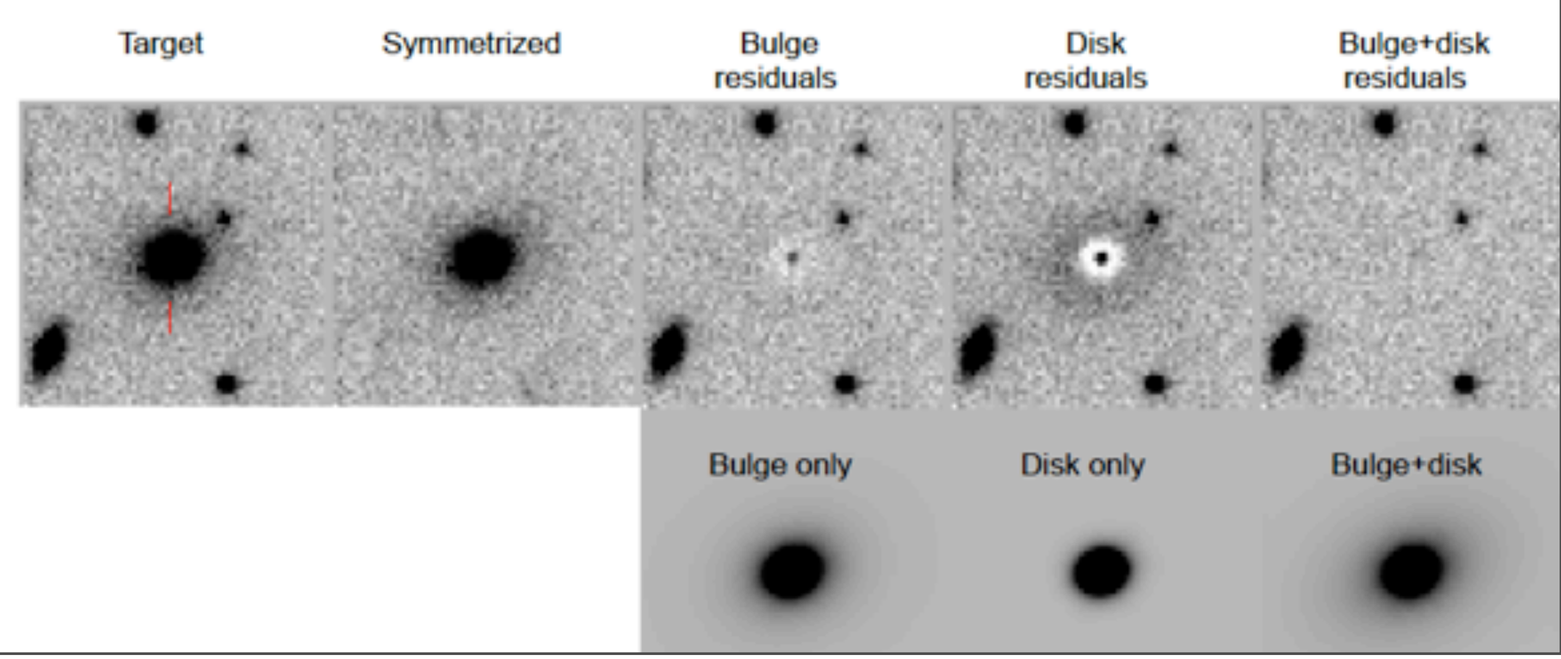
Table 8.3: Properties and Rates for Optical Cosmological Transients[a]

Class	M_v [mag]	τ^b [days]	Universal Rate (UR)	LSST Rate [yr^{-1}]
Tidal disruption flares (TDF)	$-15..-19$	30..350	$10^{-6}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}$	6,000
Luminous SNe	$-19..-23$	50..400	$10^{-7}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}$	20,000
Orphan afterglows (SHB)	$-14..-18$	5..15	$3\times10^{-7..-9}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}$	~10–100
Orphan afterglows (LSB)	$-22..-26$	2..15	$3\times10^{-10..-11}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}$	1,000
On-axis GRB afterglows	$..-37$	1..15	$10^{-11}\,\mathrm{Mpc}^{-3}\,\mathrm{yr}^{-1}$	~50

Galaxies

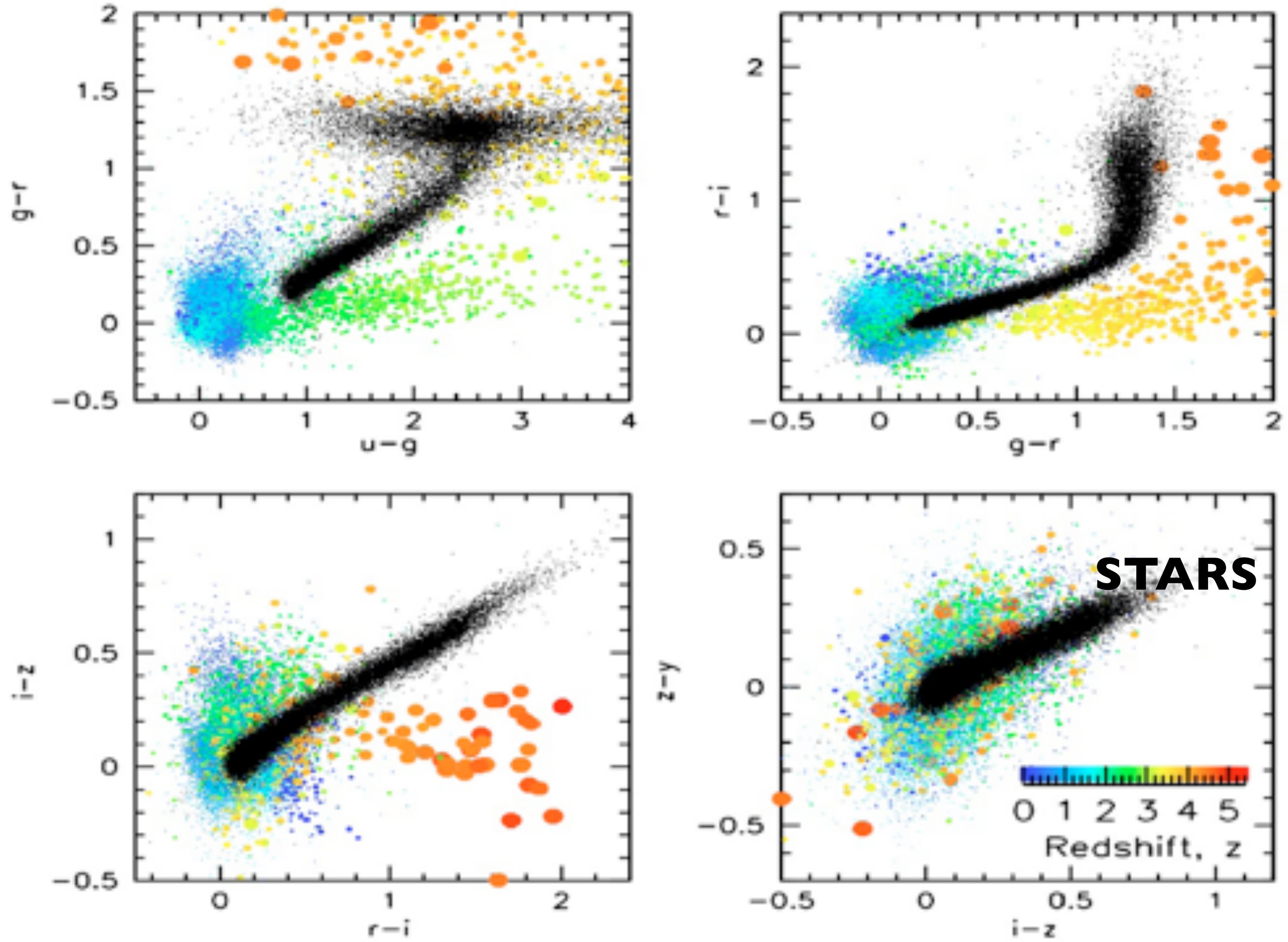
- Measurements for billions of galaxies
- Morphology for L* galaxies out to z~0.5 (res~4 kpc)
- Passively evolving L* galaxies captured to z~2 (and z~3 in deep-drilling fields)
- High-z star-forming galaxies, ~1 billion (z>2), 10 million (z>4.5)
- LSST should be good for LSB dwarfs, but more work needed
- Galaxy color-magnitude diagram
- Galaxy and host DM halo properties, not clear?
- Optical clusters, ~100K at z>1 (since red sequence in place by z~1.5)
- Evolution of galaxy properties using angular correlations in photo-z bins
- Merger rates from morphological disturbances



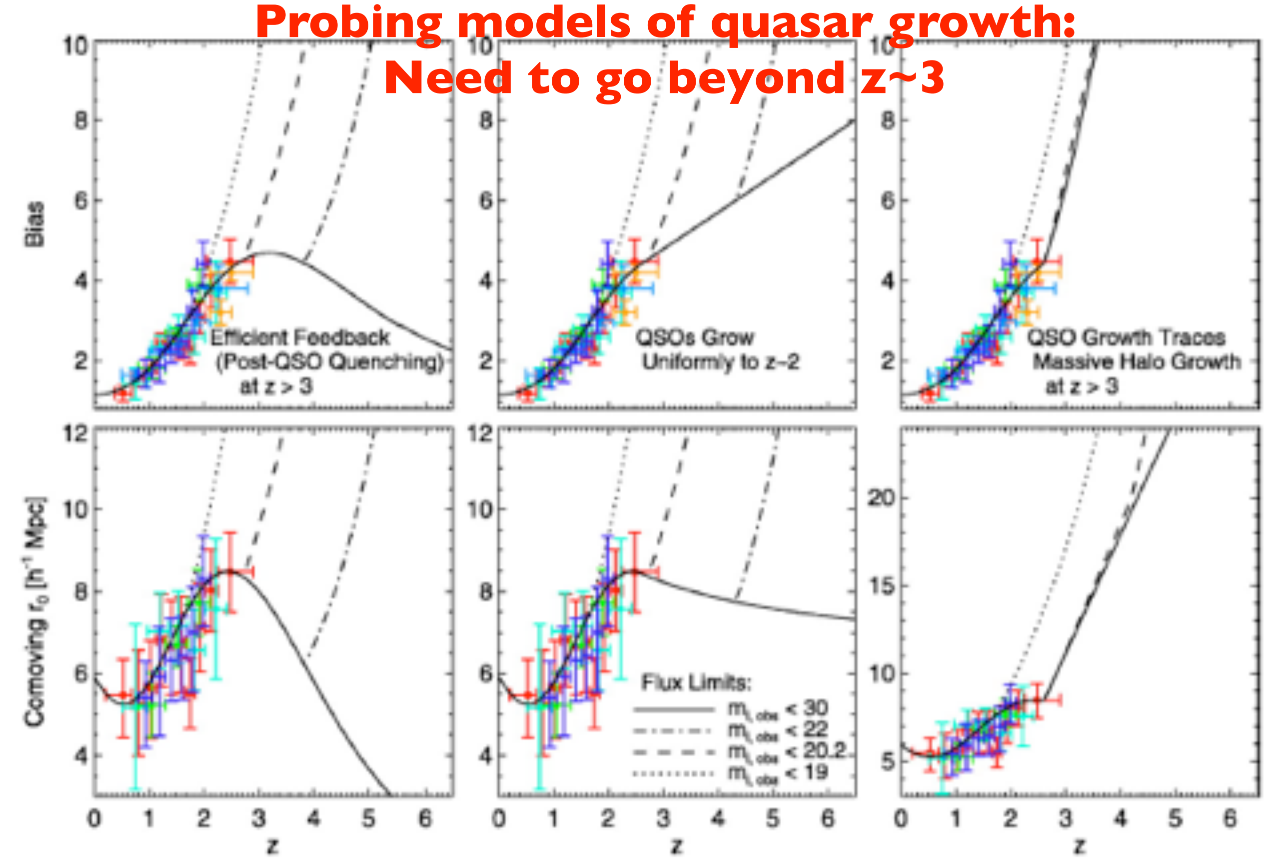


Active Galactic Nuclei

- Find quasars using color selection, lack of proper motion, and variability (LSST's cadence will provide 200 epochs for each candidate)
- photo-z's to dz=+/-0.3 at least (following SDSS)
- ~10 million photometric quasars (SDSSX10)
- LSST census of quasars at z~7 important to understand the end of the reionization epoch and on SMBH accretion history
- Trace SMBH evolution through AGN luminosity function (systematics limited)
- Use AGN clustering to understand SMBH and host halo relationships
- Observations at other wavelengths needed
- LSST will enable variability studies to constrain models for origins of AGN emission (instabilities, jet evolution, --)
- Tidal disruption events, ~130/year



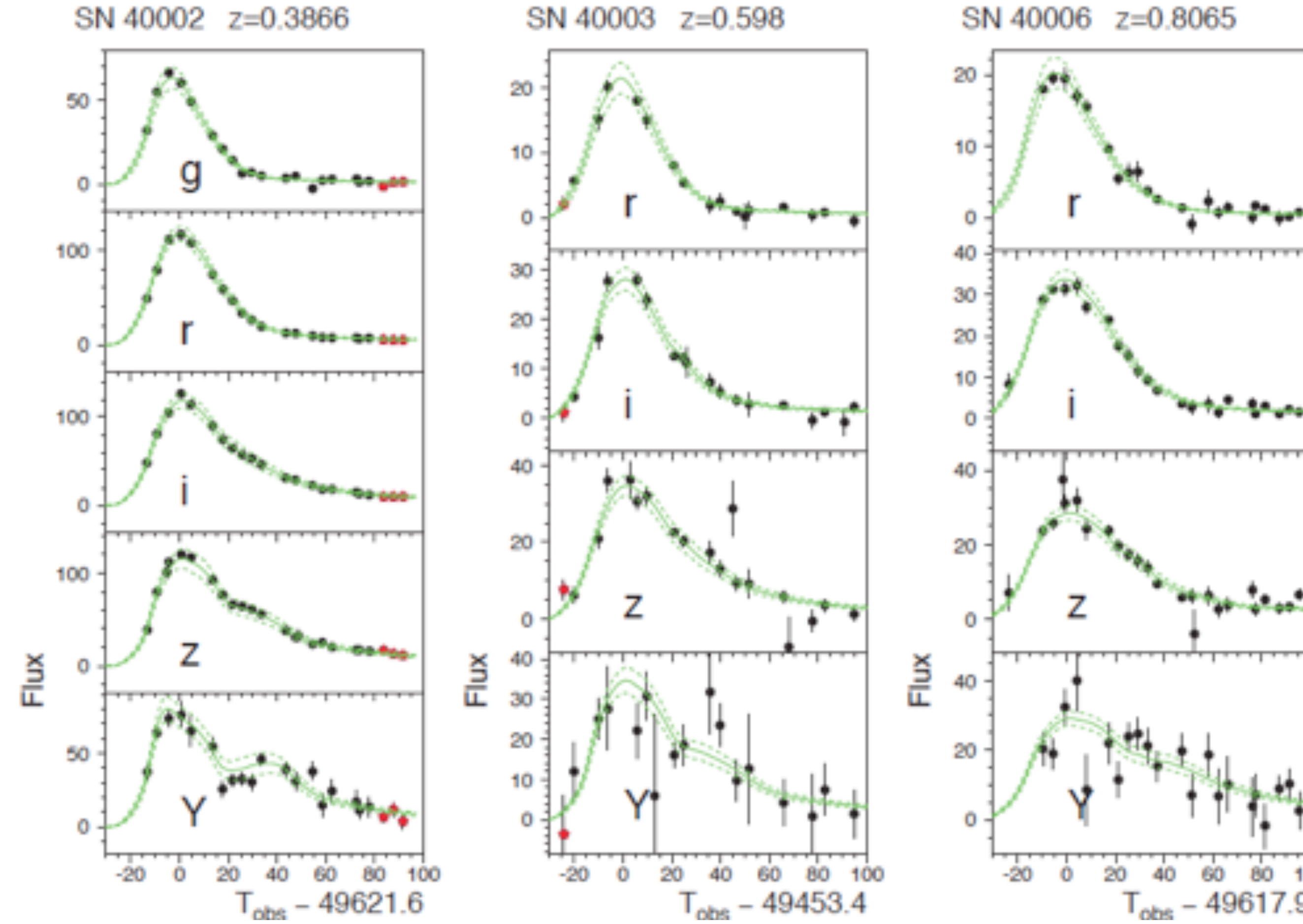
Probing models of quasar growth: Need to go beyond z~3

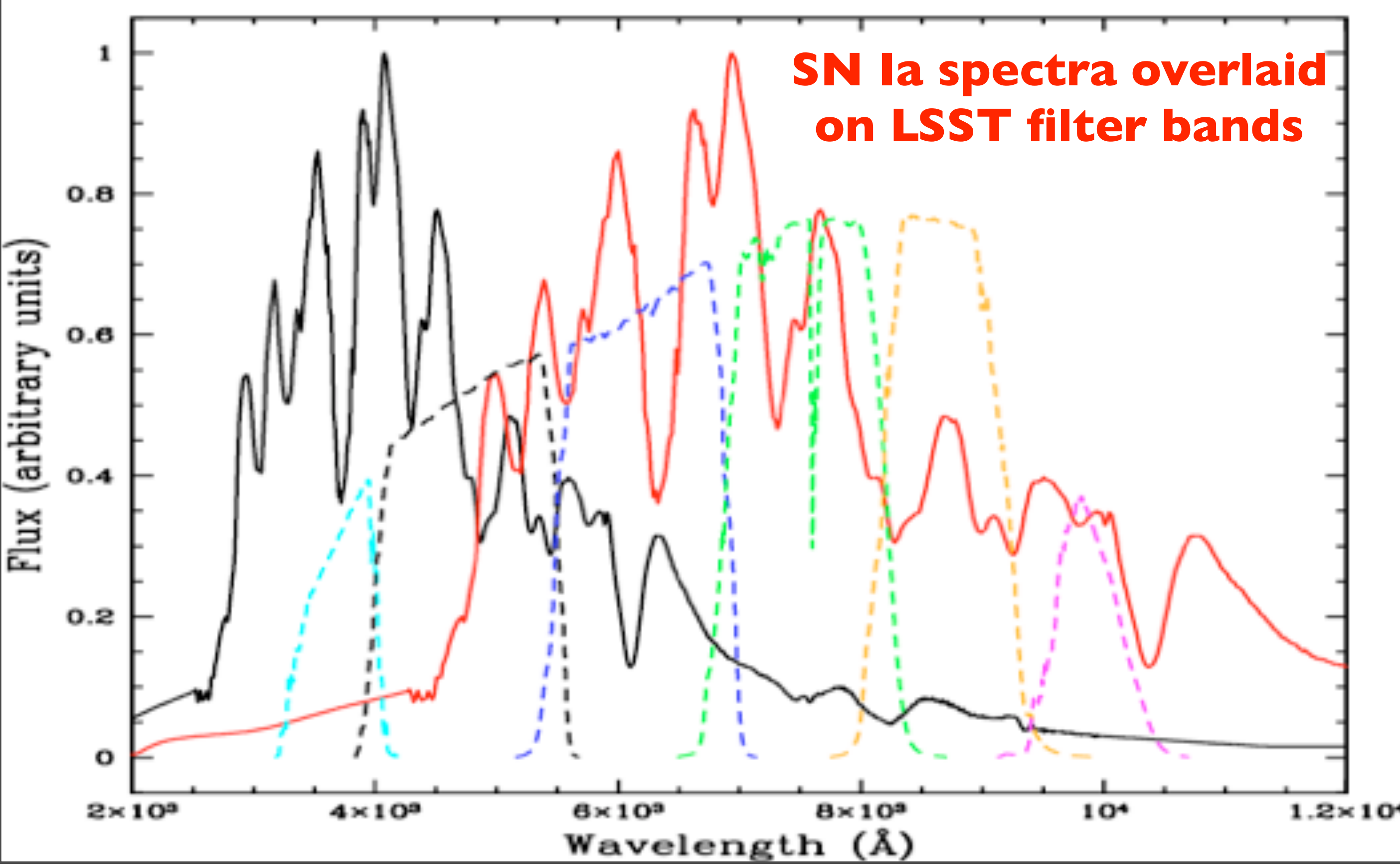


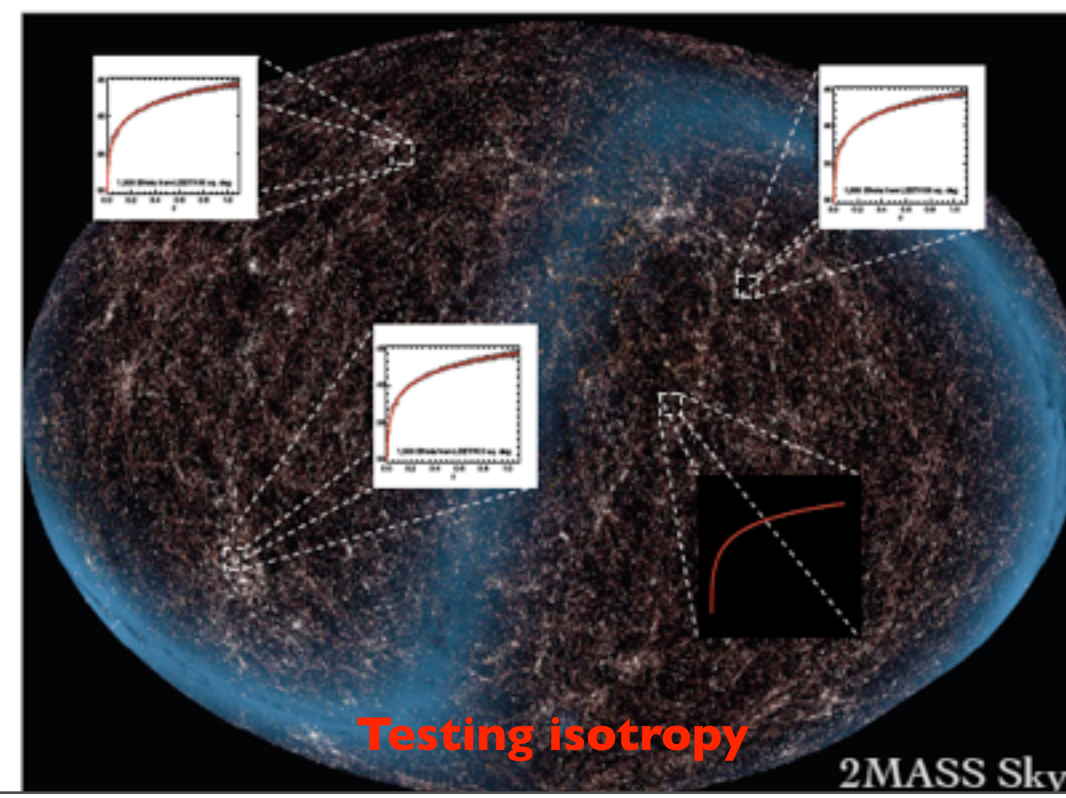
Supernovae

- Compared to ~1000 SN found so far, LSST will deliver 10 million
- ~100K SN Ia (use this to test homogeneity/isotropy), ~10K (deep survey)
- Need to see how well SN photo-z will work
- SN Ia properties as function of host galaxy type
- SN Ia baryon acoustic oscillations
- Many Type II --

Simulated SN Ia light curves for LSST deep drilling survey

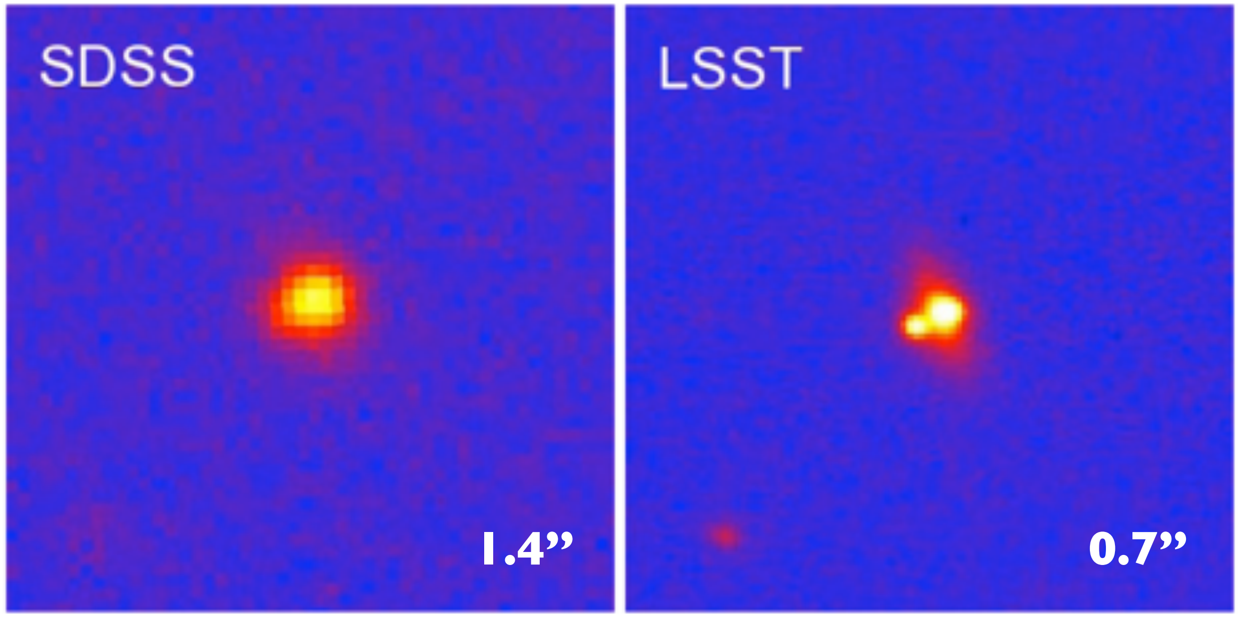


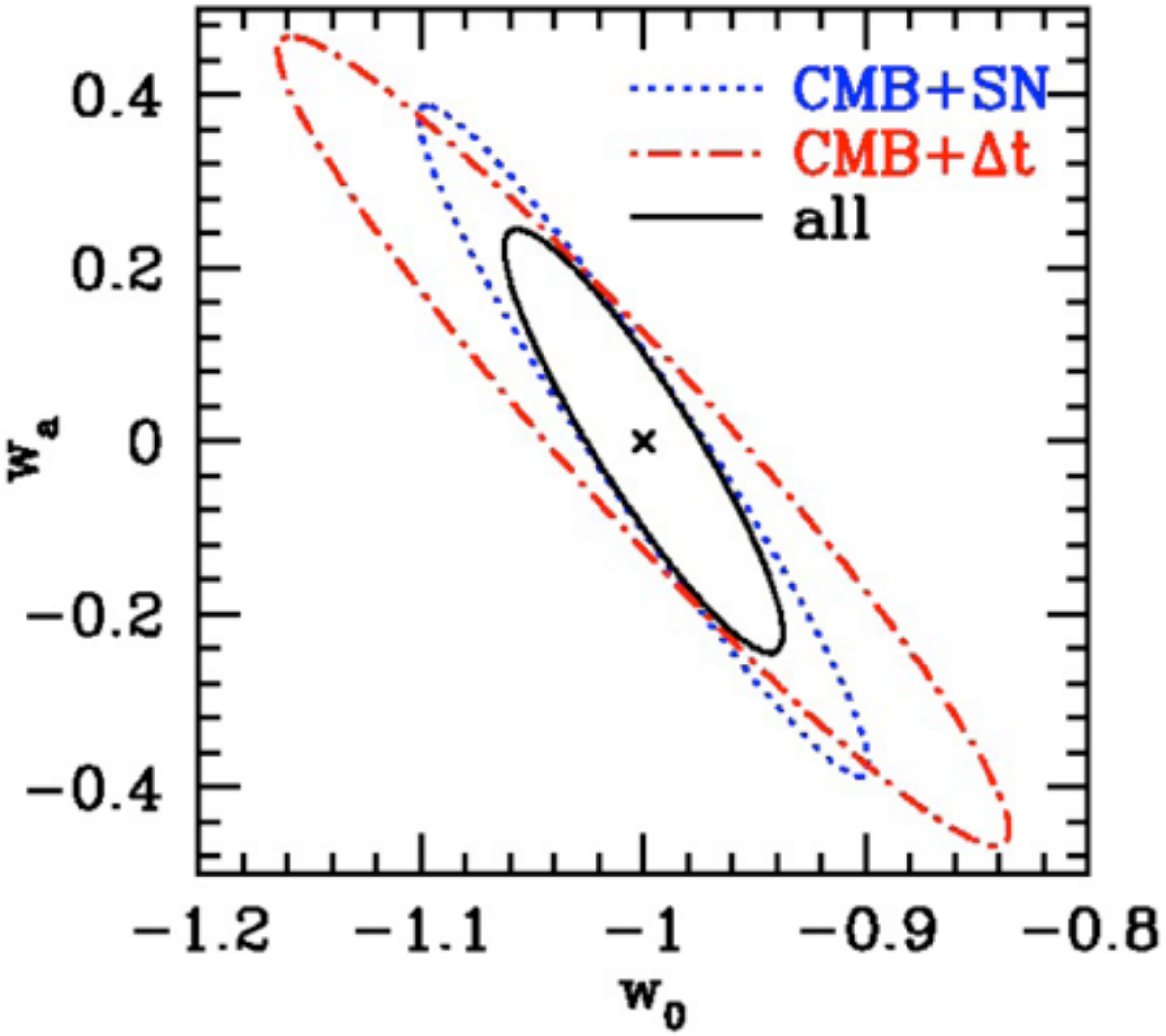




Strong Lensing

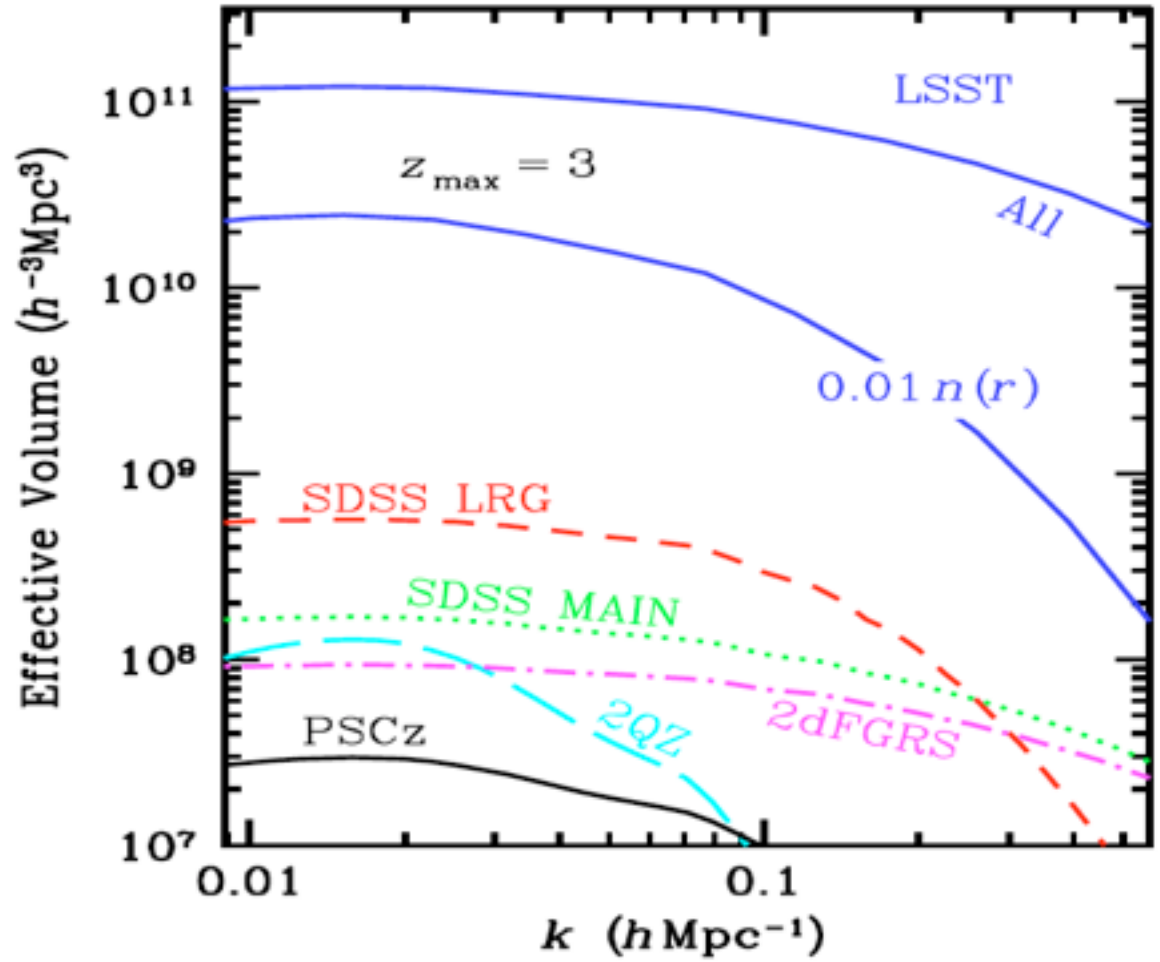
- Most strong lensing events due to massive ellipticals
- ~10000 galaxy-galaxy strong lenses over LSST lifetime (~300 for DES)
- ~2600 lensed quasars (temporal information useful here)
- ~330 lensed supernovae at typical z~0.8 (90 Ia)
- Cluster strong lenses ~1000
- Study mass function of lens galaxies
- Measurements of galaxy mass density profiles to z~1
- Usefulness of time delay measurements for cosmography not fully clear
- Increase of strong lensing dataset for substructure studies (X100)
- Lensing studies of LSST masive cluster sample (~1000 clusters)

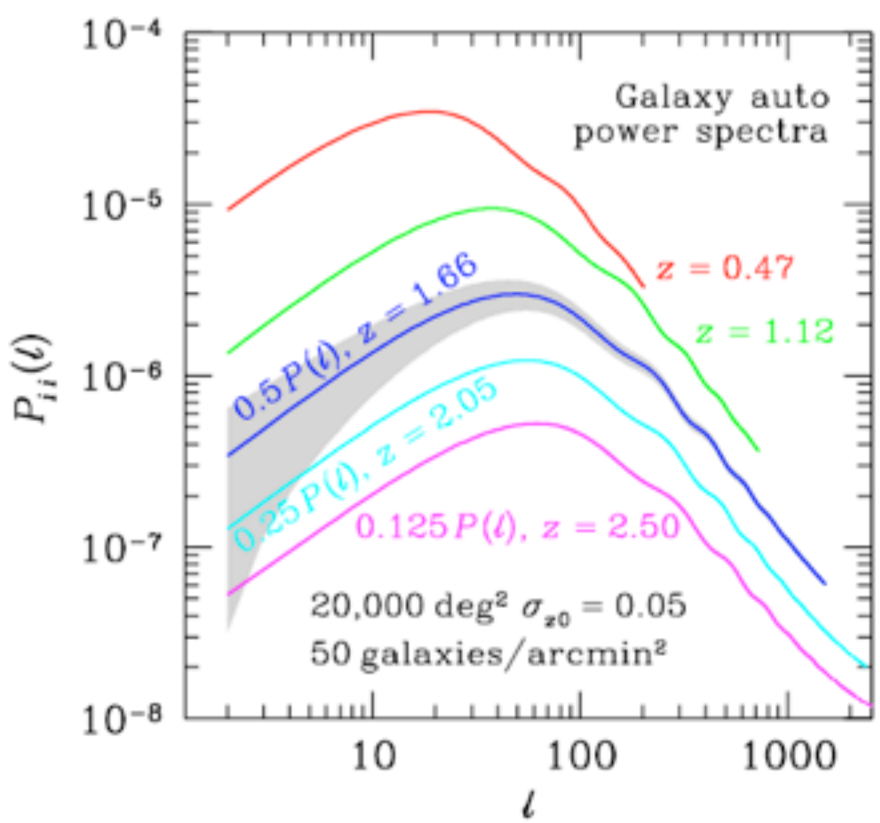


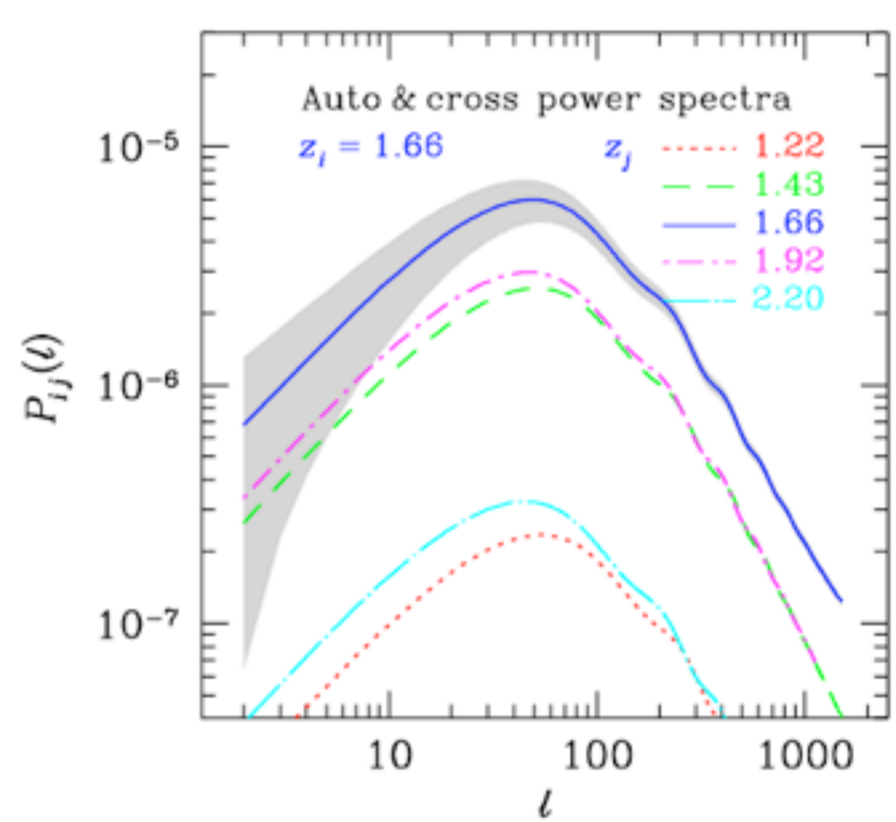


Large-Scale Structure

- **Very large effective survey volume although statistical power reduced due to use of photo-z's (factor of ~20)**
- **Can measure P(k) turn-over at k~0.02 h/Mpc**
- **BAO via angular power spectra (linear scales here) in 30 redshift bins, improves over current situation by order of magnitude but not competitive alone with a large redshift survey (e.g., BigBOSS)**

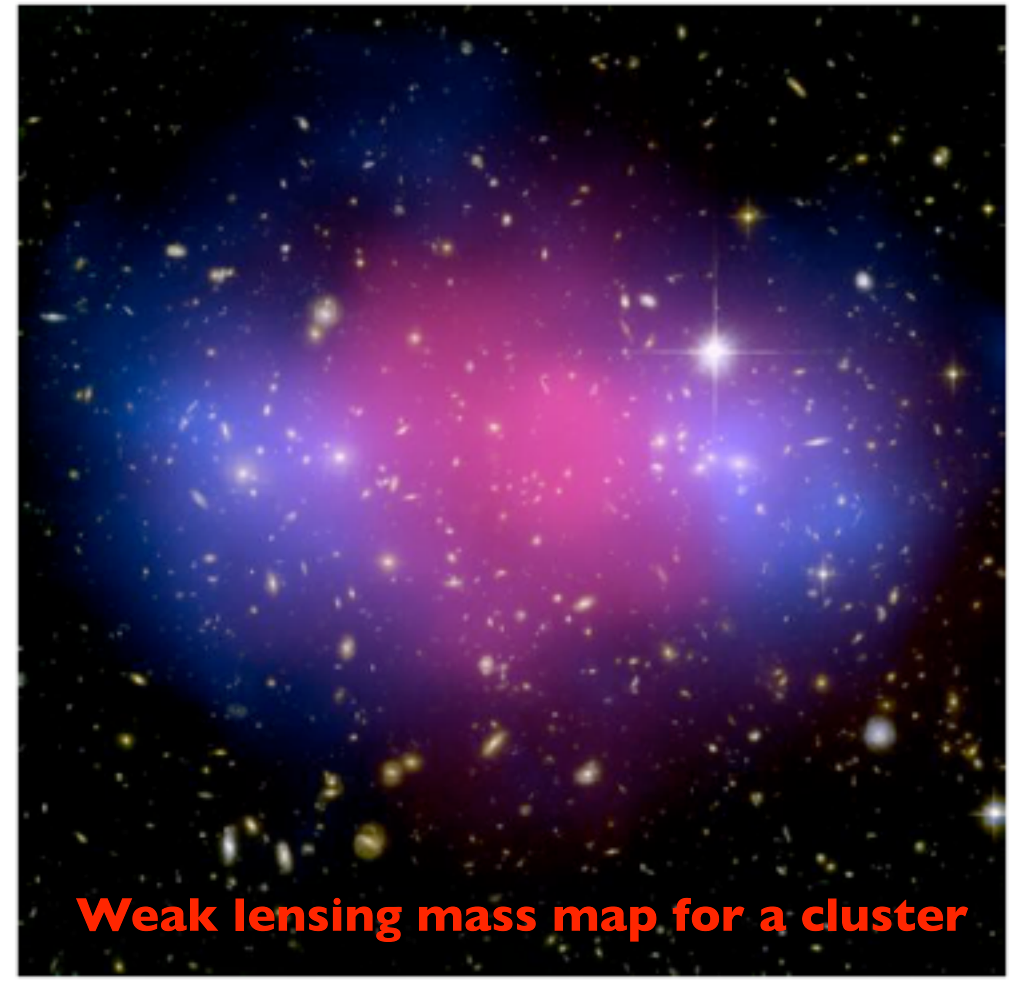


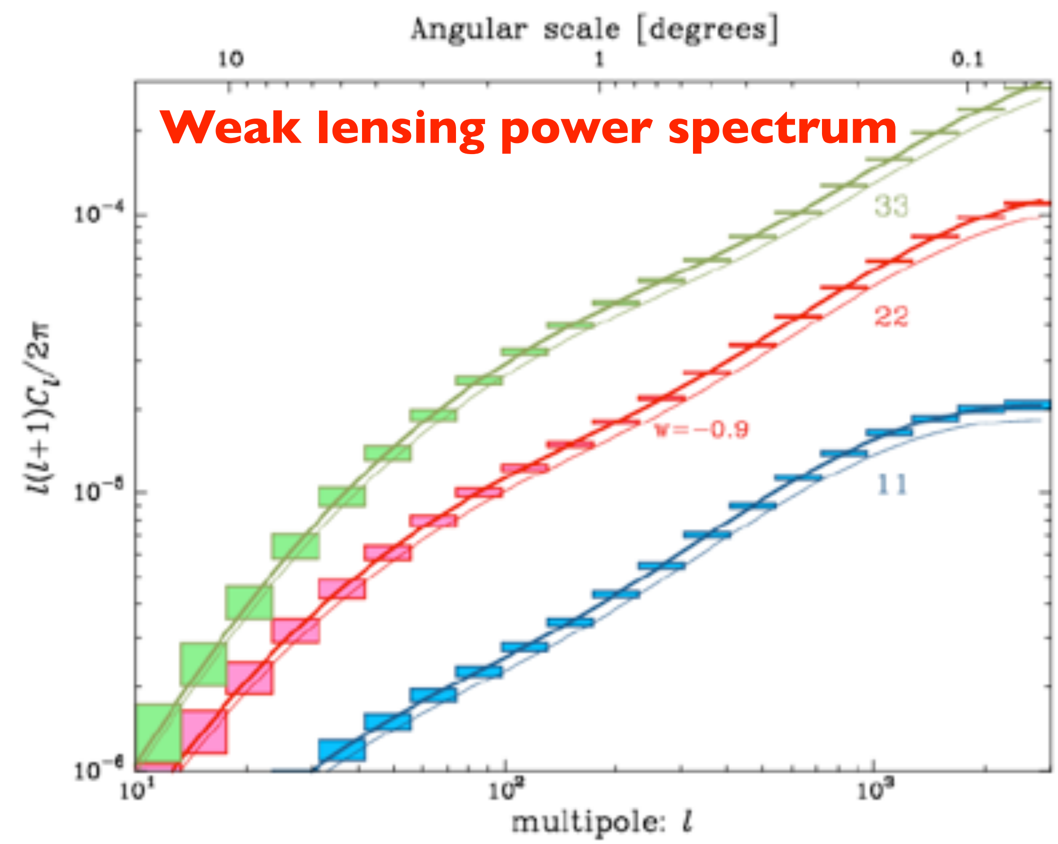




Weak Lensing

- Most direct method for mass mapping
- Key variables are (i) shear from galaxy shapes, and (ii) source redshifts from photo-z observations
- Galaxy-galaxy lensing with stacked sample of lenses (halo mass as function of stellar mass, halo ellipticity, combine with galaxy clustering to get matter correlation function)
- Measure 10% accurate masses for 20000 clusters with mass >1.510^14 M_sun (~40 background galaxies/(am)^2)
- Constrain cosmology from shear peaks, needs more work
- Weak lensing shear is a very powerful probe of cosmology, but systematics will have to be controlled (e.g., intrinsic alignments, PSF, baryonic effects, --)
- Measure mean magnification by (stacked) clusters to calibrate masses -- must have good measurements of galaxy density (e.g., from deep drilling fields)





Interlude: What is Modern Cosmology?

Cosmology: The study of the Universe as a **dynamical** system

LSST as a driver for this --

- **Propose and test laws governing the dynamics of the large-scale Universe (matter and geometry)**
- **Propose and test theories of initial conditions**
- **Develop rigorous methodology for ‘cosmological experiments’**
- **Sharpen cosmology as a tool for fundamental discoveries**

Lev Landau ....

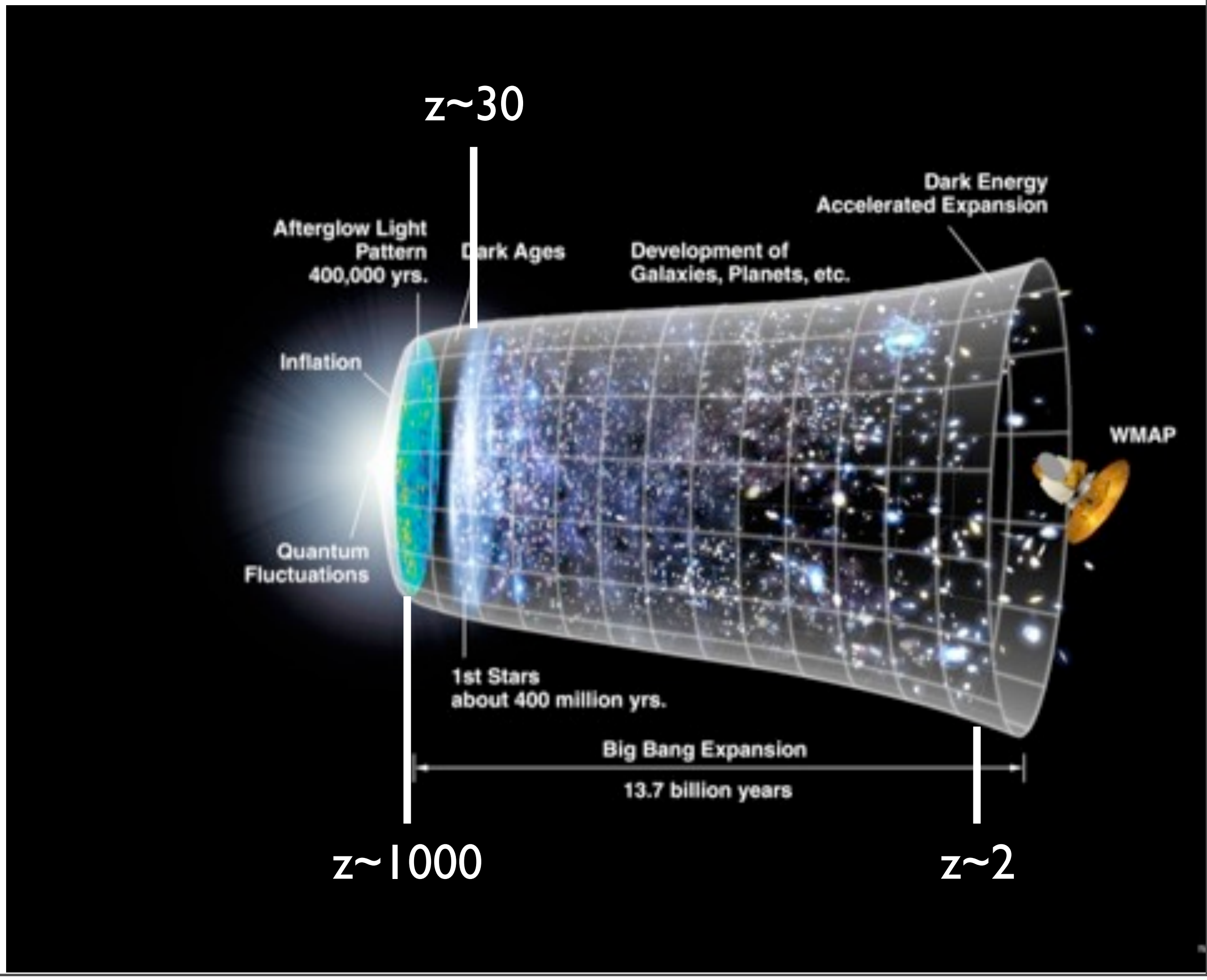
The Cosmological 'Standard Model'

Nuts and Bolts

- Expansion history of the Universe known reasonably well (but still spotty)
- Initial conditions -- Gaussian random field with power-law primordial spectrum
- Cross-validated constraints on ~10 cosmological parameters, including primordial fluctuation amplitude and spectral index, optical depth, Hubble constant, spatial flatness, --
- Accuracy of parameter determination ~10% (some better, some worse)
- For comparison, the particle physics Standard Model has parameters measured to the 0.1% level

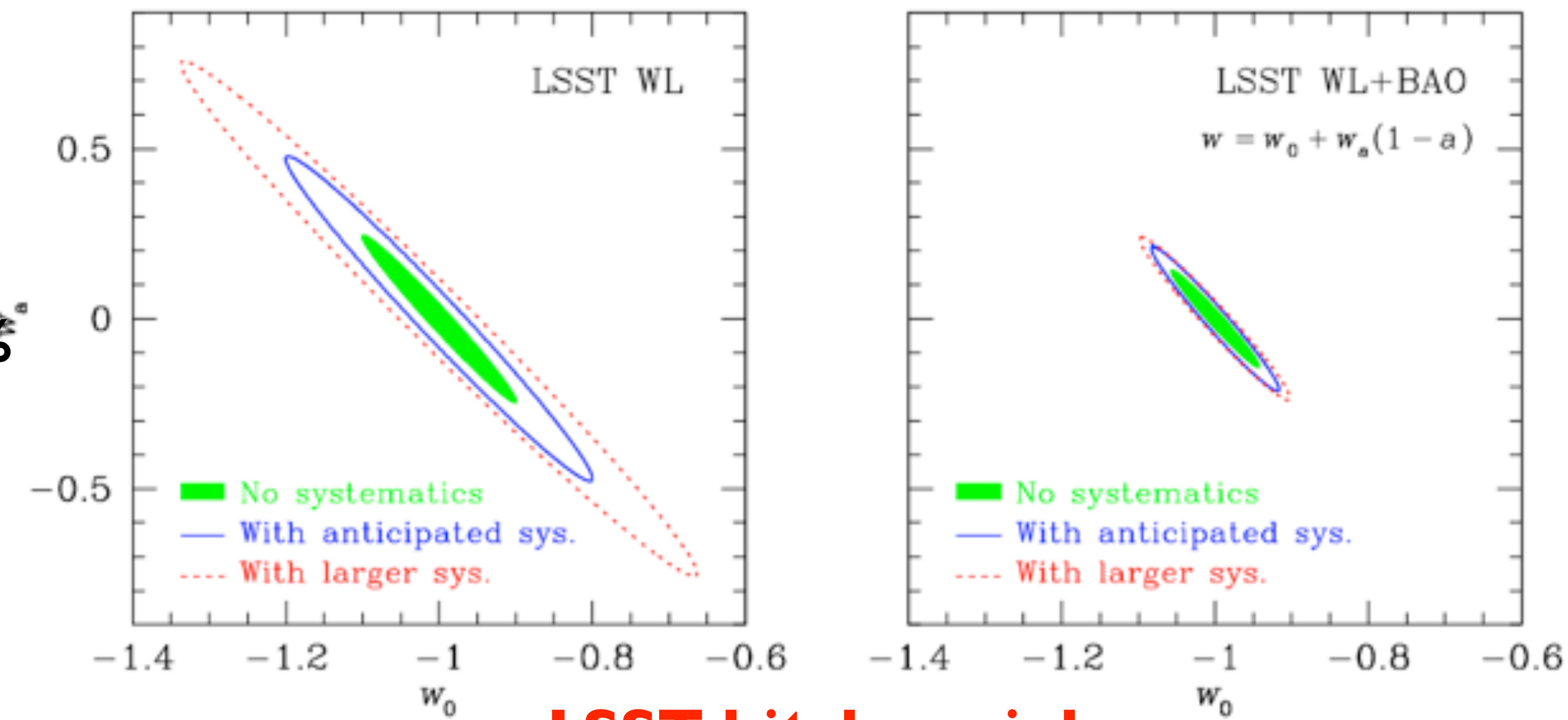
However,

- Late-time acceleration ('Dark Energy') not understood, dark matter also mysterious
- Theory of initial conditions not very satisfactory (inflation or something else?)
- Is GR valid on large length scales?
- Theory and observations must work together to understand the unknowns of the Standard Model

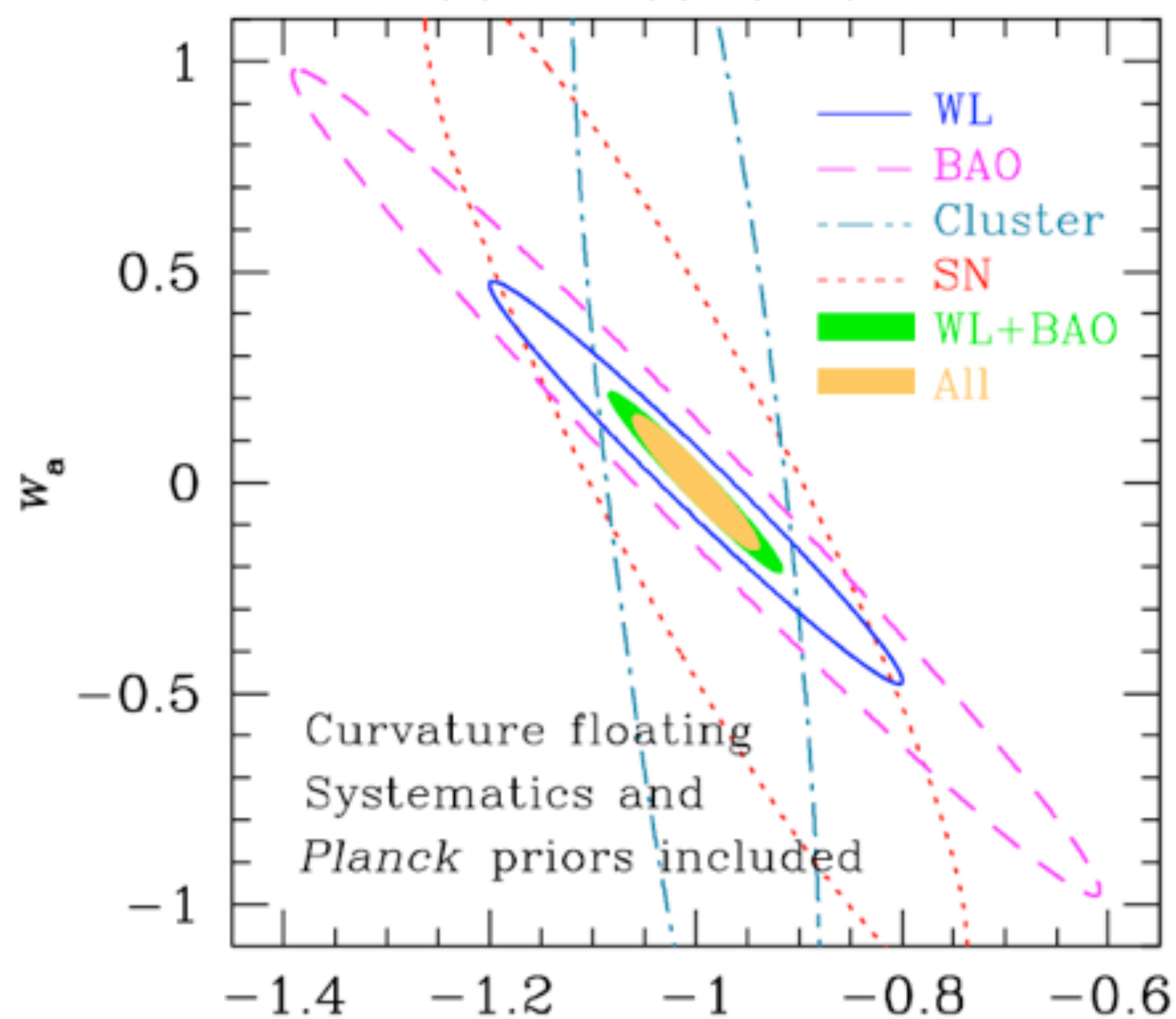


Cosmological Physics

- **Power of joint analyses, e.g., weak lensing + BAO, adds immunity to photo-z errors**
- **WL + BAO can achieve ~0.5% precision on distance and ~2% on the growth factor from z=0.5-3 in bins of dz~0.3 -- can use this to distinguish between dark energy and modified gravity**
- **WL + BAO can measure the spatial curvature to <.001**
- **WL + Planck gives strong constraints on sum of neutrino masses, dm~0.03 eV, and on N_v, dN_v~0.08**
- **Clustering on the largest scales, dark energy anisotropy?**
- **Next-generation simulations needed to work the theory out --**



LSST kitchen sink



Coming (Relatively) Soon --