LSST

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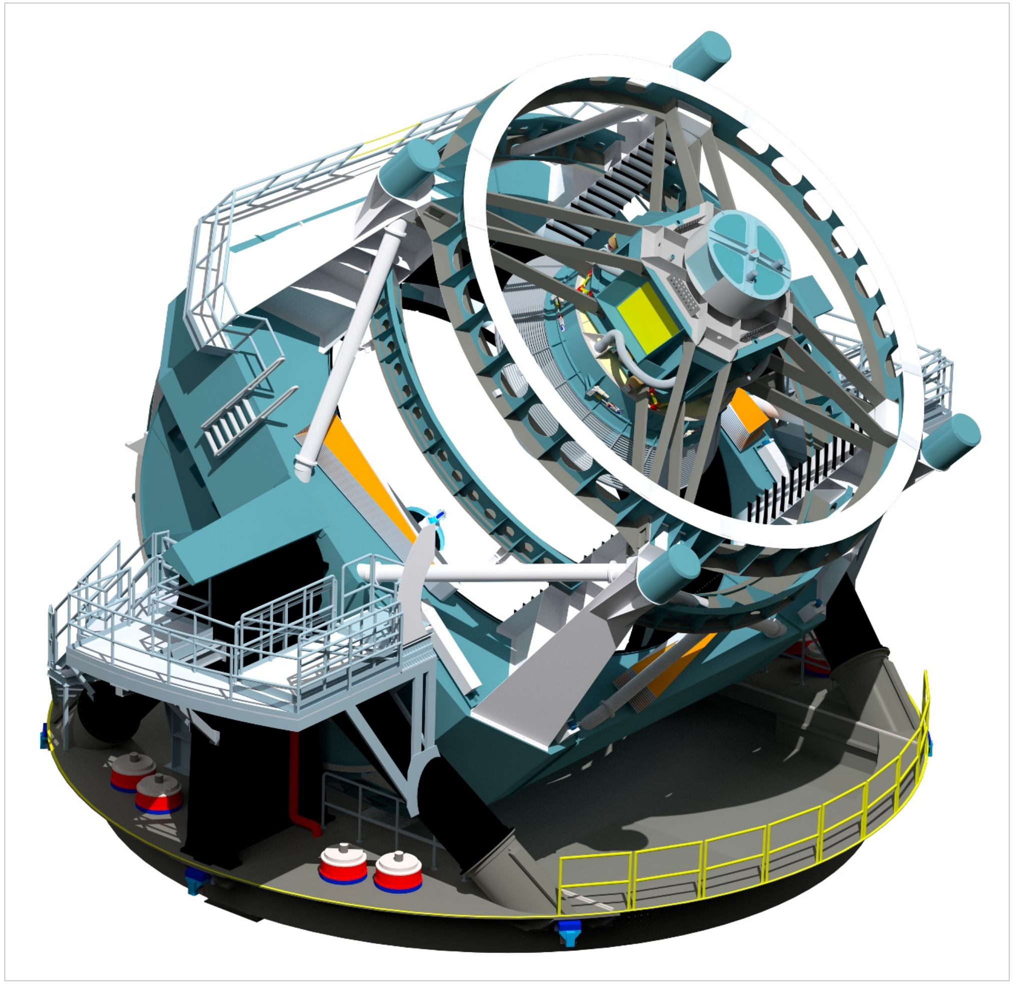
THCA Student Seminar



Opening a Window of Discovery on the Dynamic Universe

OUTLINE

- What is **L**arge **S**ynoptic **S**urvey **T**elescope?
- Scientific motivation and areas
- Telescope design and mission schedule
- Science on solar system bodies
- Science on dark matter and dark energy
- Summary

WHAT IS LSST?

Large

- **8.4-meter** primary mirror
- **largest digital camera(3.2 G-pixel)** in the world
- **large Etendue, enormous survey sky area(20000deg^2)**
- **largest public data set(200 PB)** in the world

Synoptic

- **Billions** of objects imaged in **six colors** in an unprecedented large volume of our universe
- At a frequency that enables images of **every part** of the visible sky to be obtained **every few nights**

Survey

- **Near real time(60s** response time), operating **over a decade** to collect the deepest, widest, image of the Universe

DESIGNATED SCIENCE AREAS

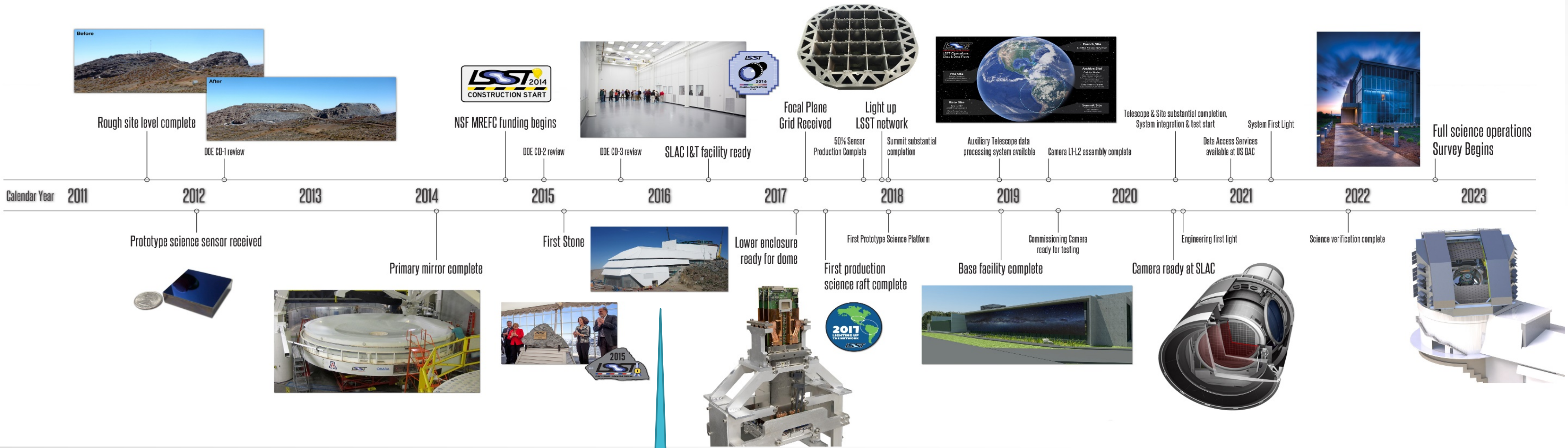
- **Hazardous Asteroids and the Remote Solar System**
- **Understanding the Mysterious Dark Matter and Dark Energy**
- The Transient Optical Sky(Transits, SNe etc.)
- The Formation and Structure of the Milky Way

- *Single data set serves most science programs (instead of science-specific surveys executed in series), massively parallel astrophysics. –" LSST Science Book"*

Telescope design and mission schedule

MISSION SITE AND FACILITIES

MISSION SCHEDULE



LSST Summit Facility
completed March 23, 2018

THE DESIGN

Configuration: 3-mirror
Mount: Alt-azimuth

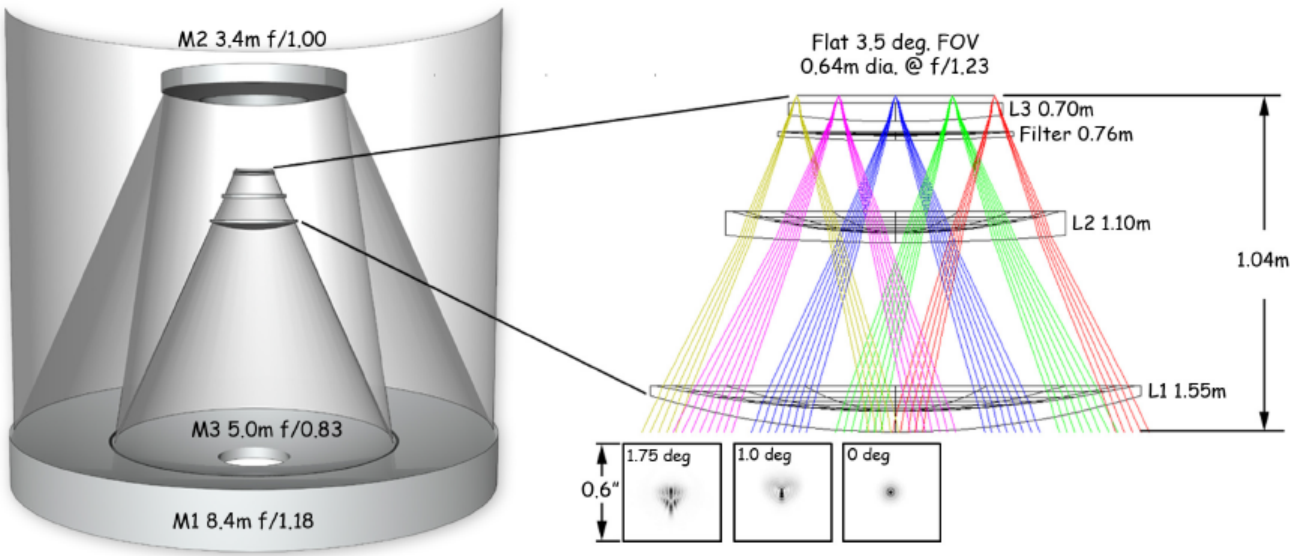
Effective on-axis clear aperture(accounting for obscuration) : 6.7m

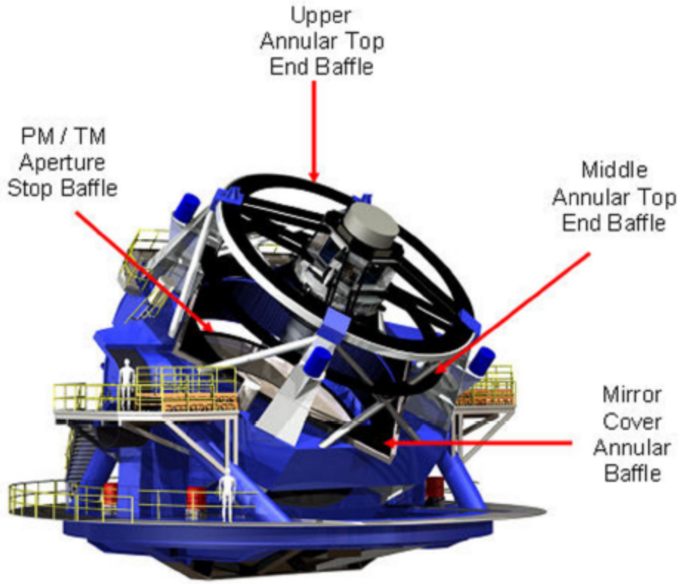
Focal plane diameter: 63cm(FOV)

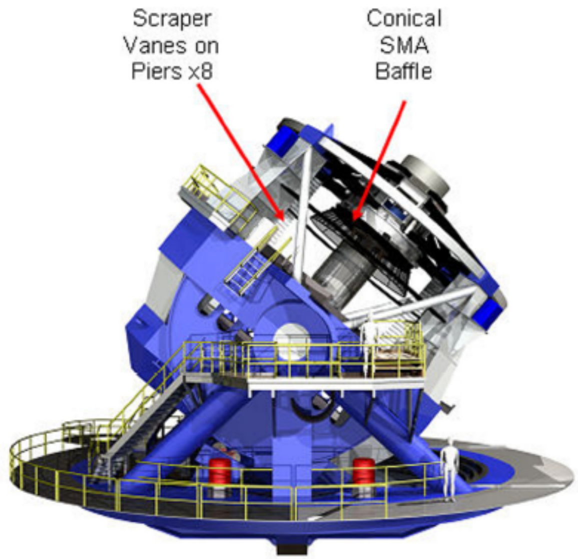
Final f ratio: 1/1.23

Plate scale: 50 microns/arcsec

´Etendue: 319m^2deg^2







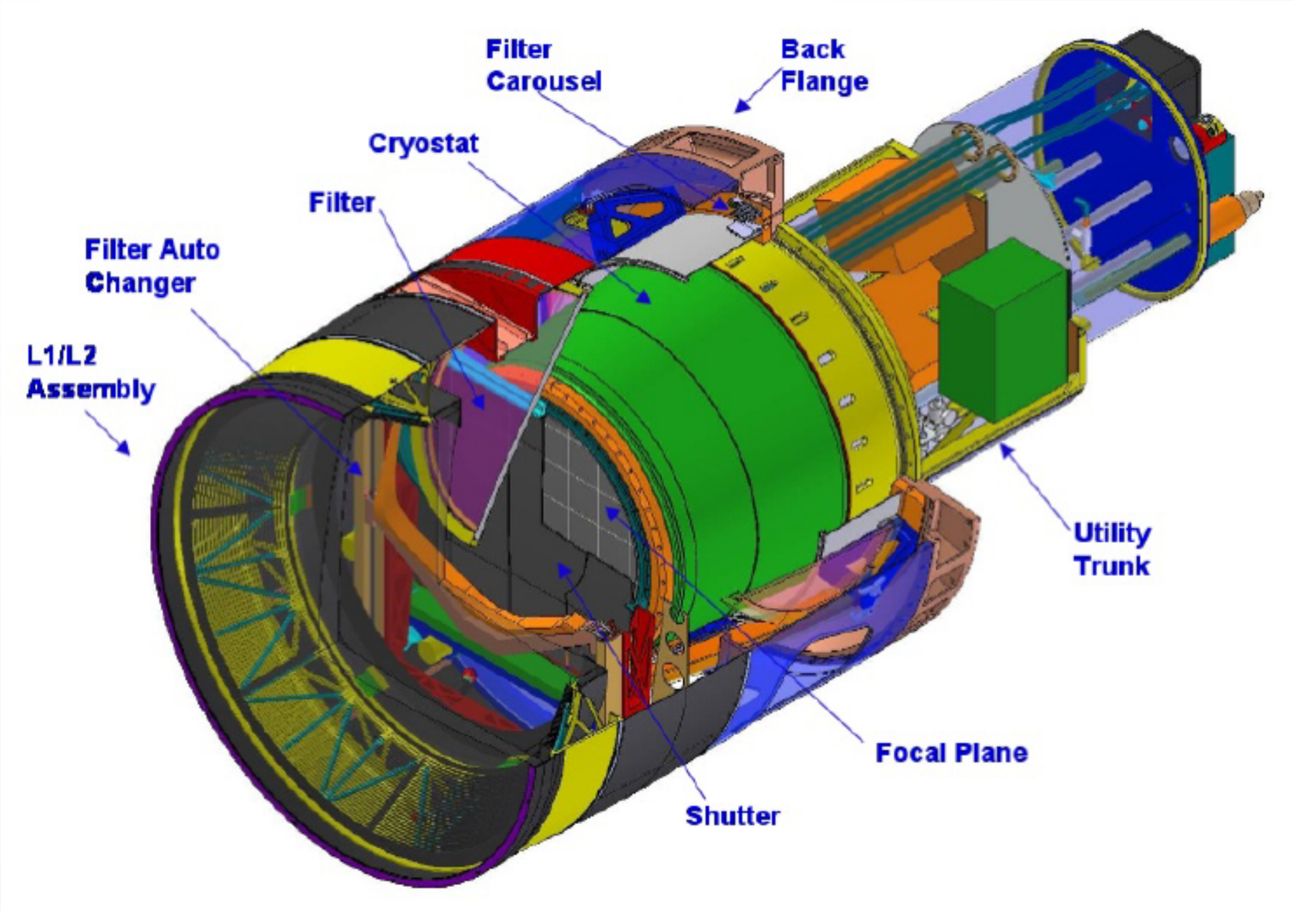
CCD CAMERA

Pixel size: 10microns(0.2 arcsec)

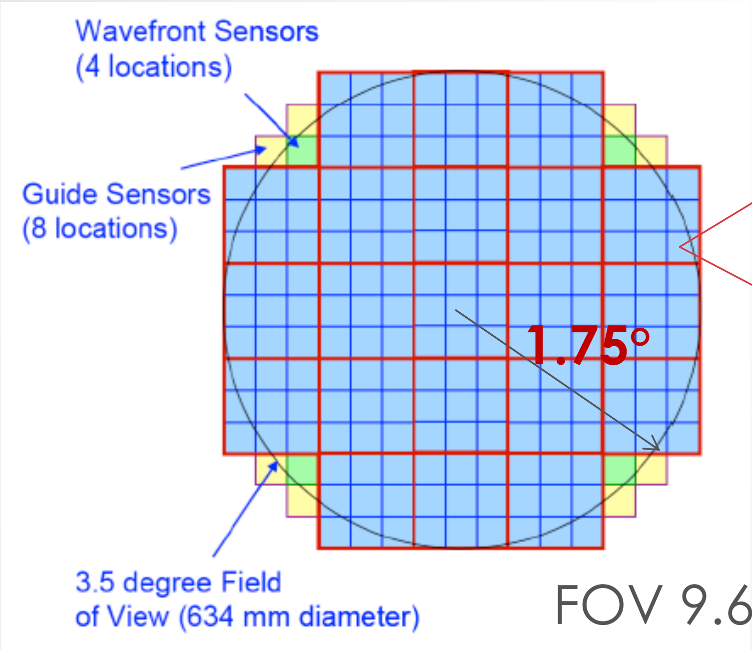
Readout time: 2s

Filter change time: 120s

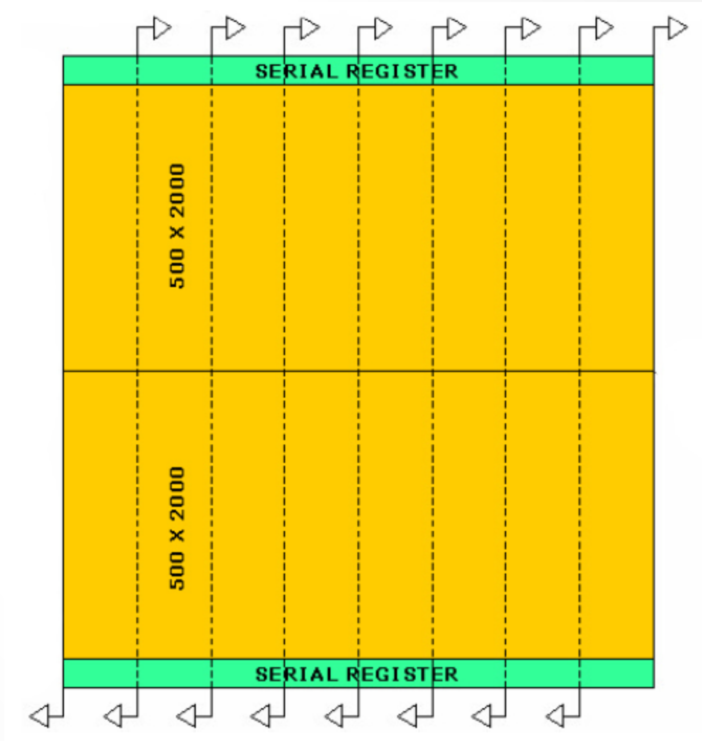
Dynamic range: 16bit



CCD SENSOR



FOV 9.6deg^2



16 Mega-pixel/sensor

21x9 = 189 sensors
4x wavefront sensors(AO)
8x guide sensors(slew & tracking)

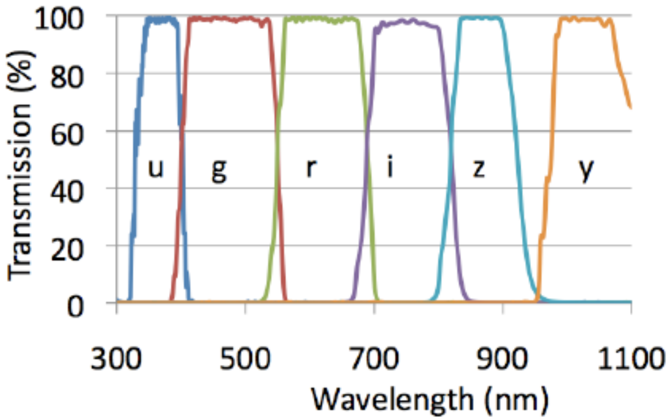
3.2 Giga-pixel in total!

FILTERS

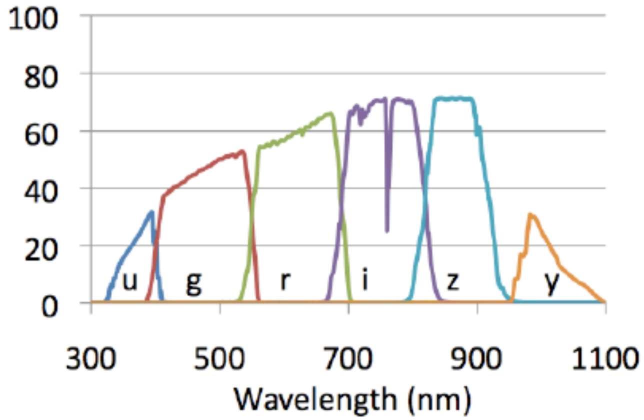
- Wavelength: 320-1080nm
- Single visit depth(point source 5σ): u23.9, g25.0, r24.7, i:24.0, z23.3, y22.1
- Coadded depth(10 yrs): u26.3, g27.5, r27.7, i:27.0, z26.2, y24.9
- # of visits(10 yrs): u70, g100, r230, i:230, z200, y200
- Photometric error(r-22): ~0.02mag(single visit), ~0.005mag(coadded)

Table 2.1: Design of Filters: Transmission Points in nanometers

Filter	Blue Side	Red Side	Comments
u	320	400	Blue side cut-off depends on AR coating
g	400	552	Balmer break at 400 nm
r	552	691	Matches SDSS
i	691	818	Red side short of sky emission at 826 nm
z	818	922	Red side stop before H_2O bands
y	950	1080	Red cut-off before detector cut-off



Filter



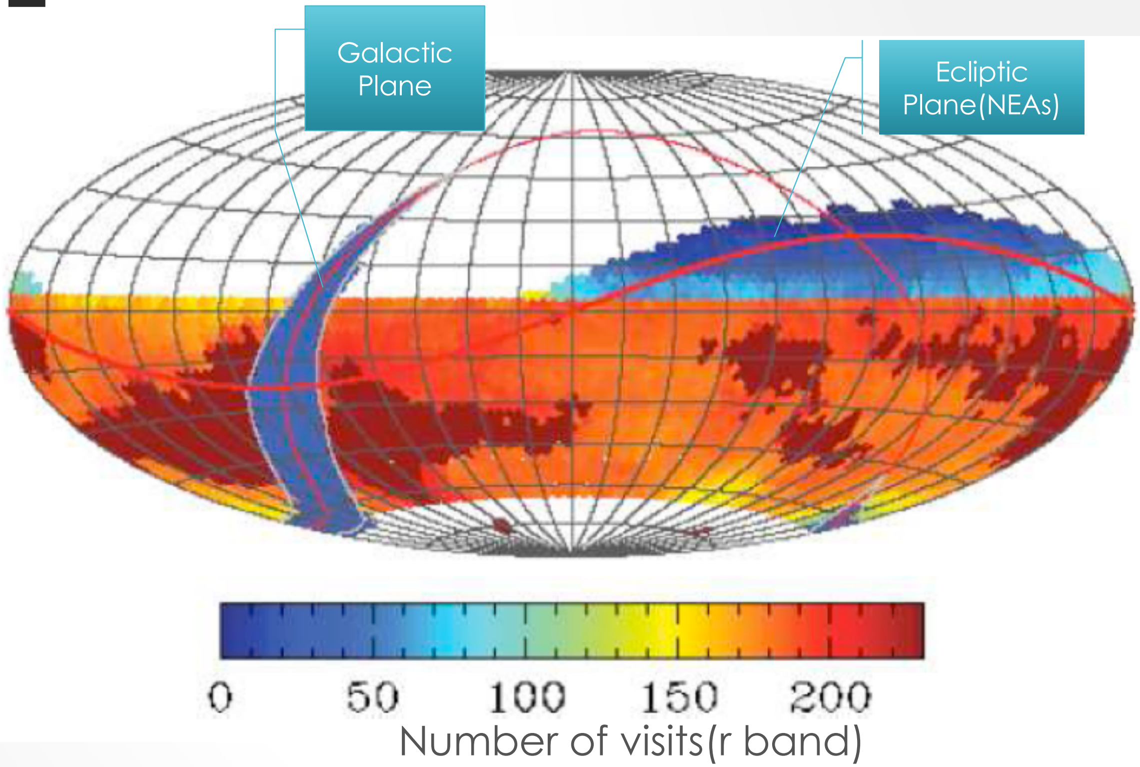
Overall

SURVEY SKY COVERAGE

- 20000deg^2 main survey (90%time), wide-deep-fast mode, r~24.5 depth
- Visit: 2x 15s exposures b2b in a given band, with 4s readout
- Survey efficiency: t_{vis} = 30s, t_{slew}=5s, $t_{readout}$ =4s

$$\epsilon = \frac{t_{\rm vis}}{t_{\rm vis} + 9 \text{ sec}}$$

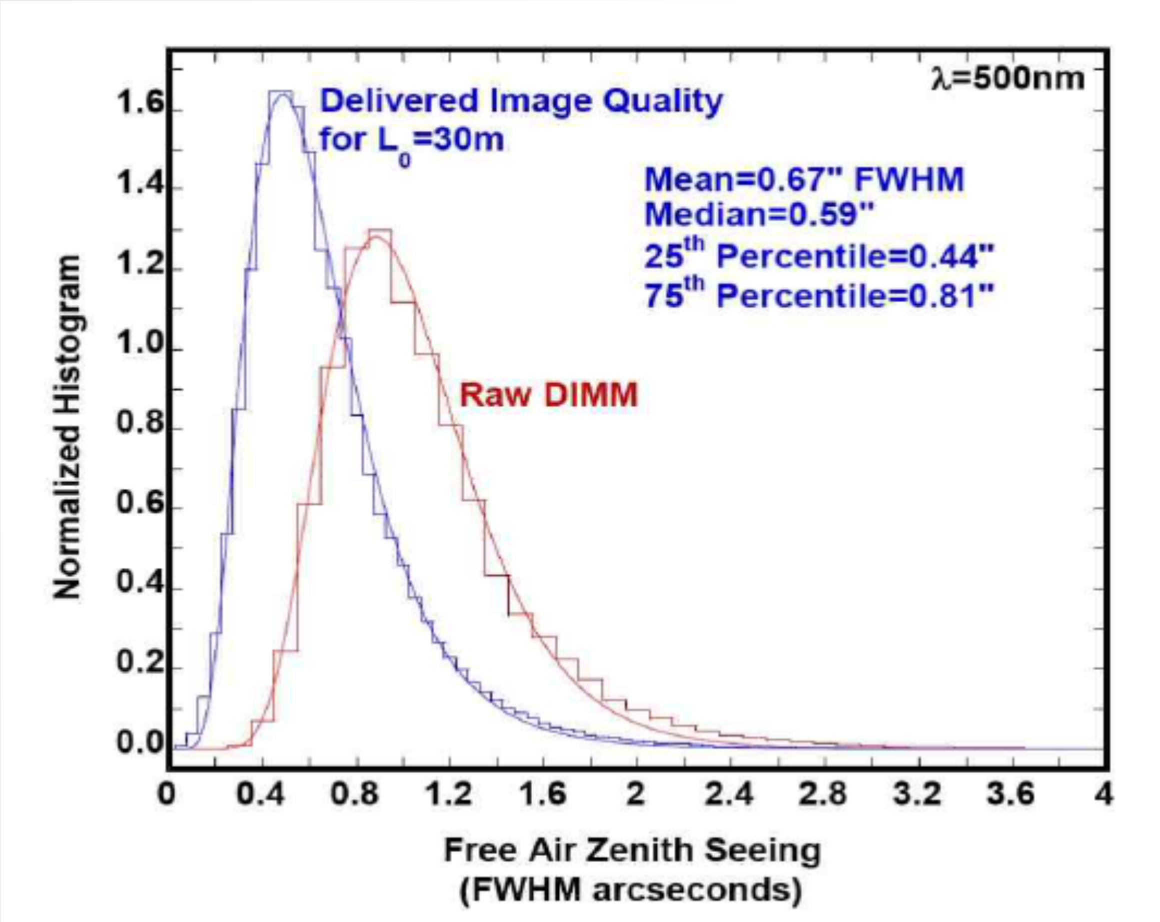
- Period: 15-60mins for each band of the same aperture
- Transient alert: 60s



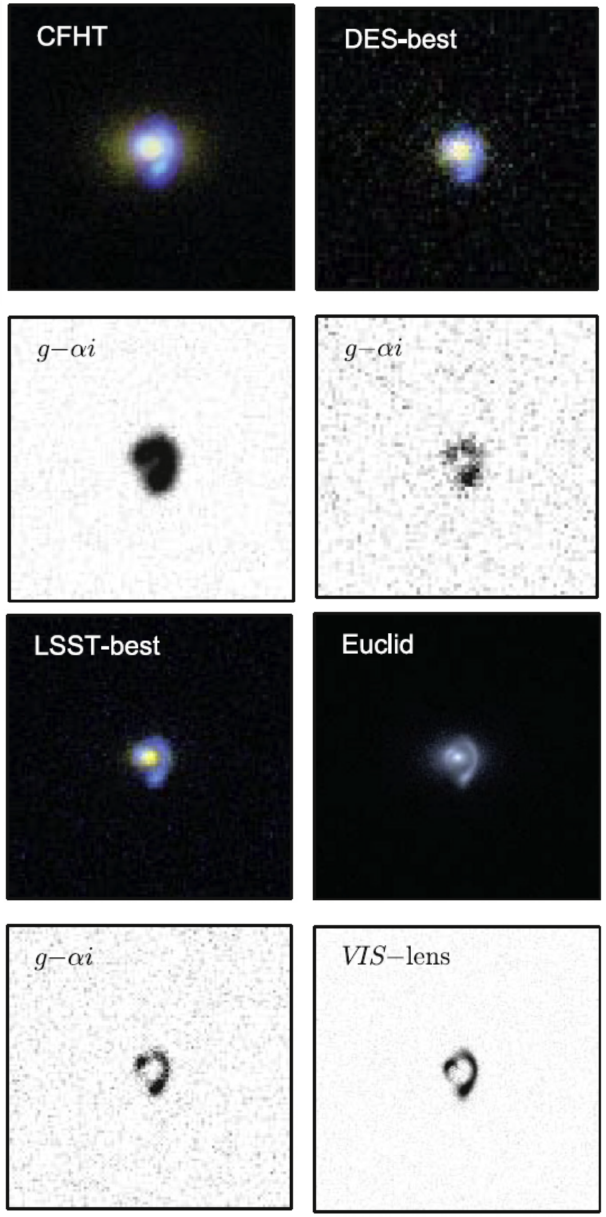
10% time: very deep(r~26) survey; LMC, SMC, Galactic Plane, Ecliptic Plane etc.

1% time: micro surveys, 25 nights in total

SEEING



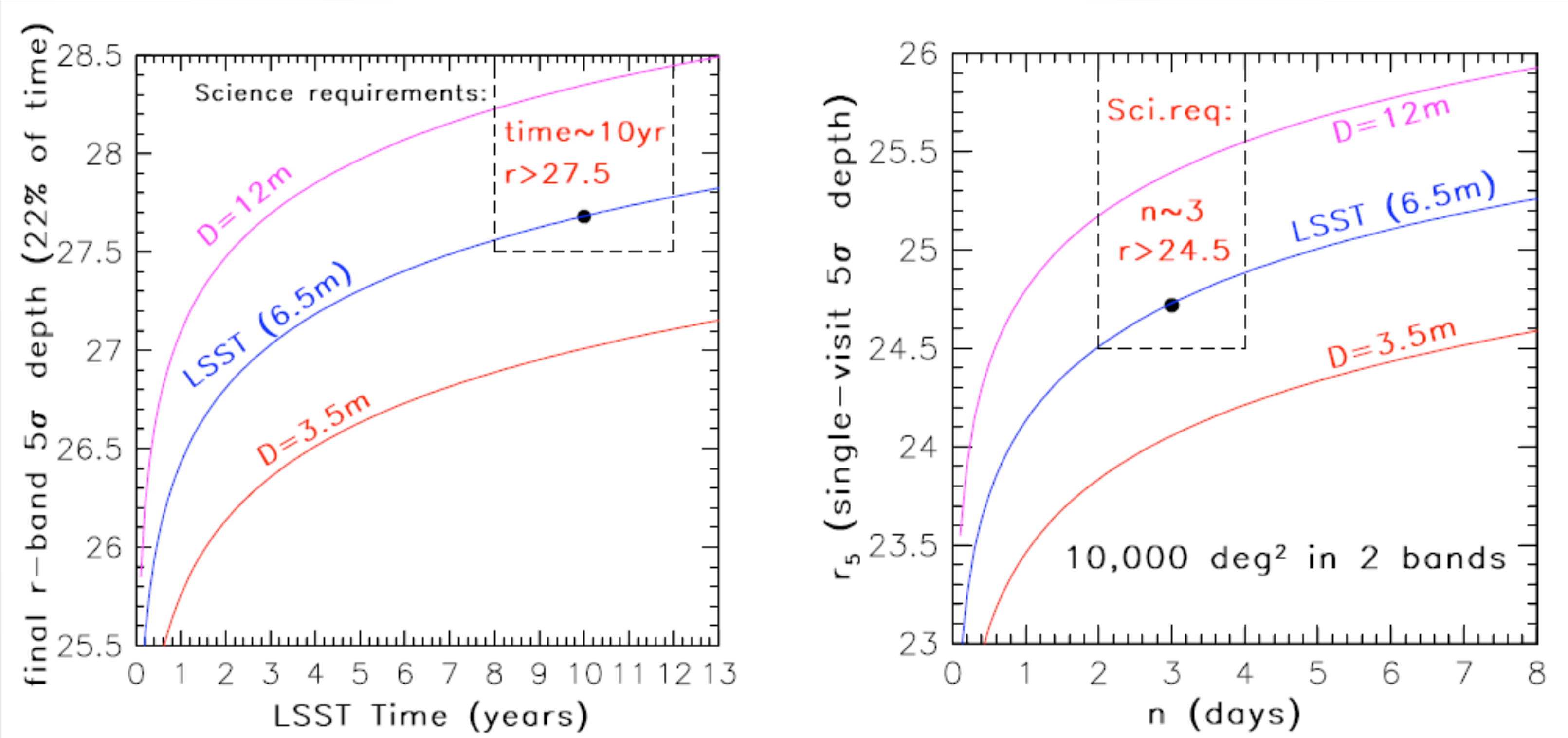
Simulated strong lensing images (Collett. 2015)



THE EFFECTIVE APERTURE

Why these parameters?

A: the most optimal choice to meet the scientific requirements of the mission



Science on solar system bodies

EXPECTED NUMBERS FOR SOLAR SYSTEM SMALL BODIES

Table 1: Summary of small body populations observed with LSST

Population	Currently known[1]	LSST discoveries[2]	Num. of obervations[3]	Arc length (years)[3]
Near Earth Objects (NEOs)	12,832	100,000	($H \leqslant 20$) 90	7.0
Main Belt Asteroids (MBAs)	636,499	5,500,000	($H \leqslant 19$) 200	8.5
Jupiter Trojans	6,387	280,000	($H \leqslant 16$) 300	8.7
TransNeptunian and Scattered Disk Objects (TNOs and SDOs)	1,921	40,000	($H \leqslant 6$) 450	8.5

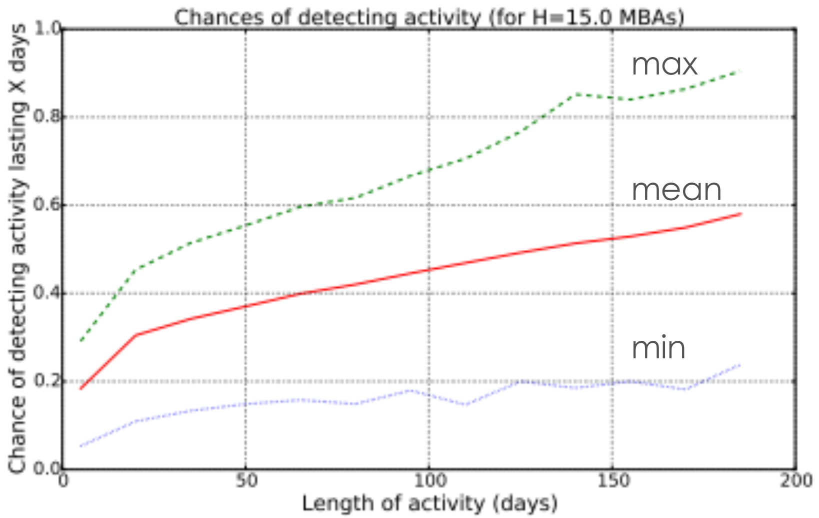
Until: May, 2015

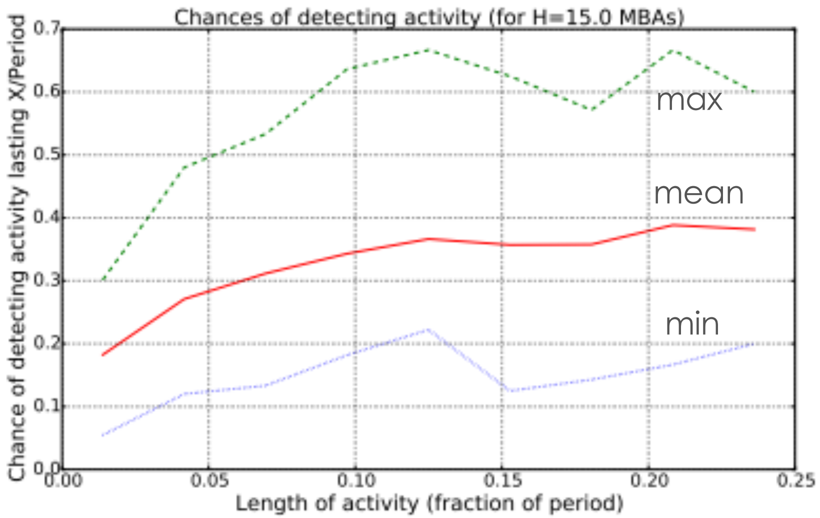
DETECTION WITH MOPS

LSST Moving Object Pipeline System(MOPS)

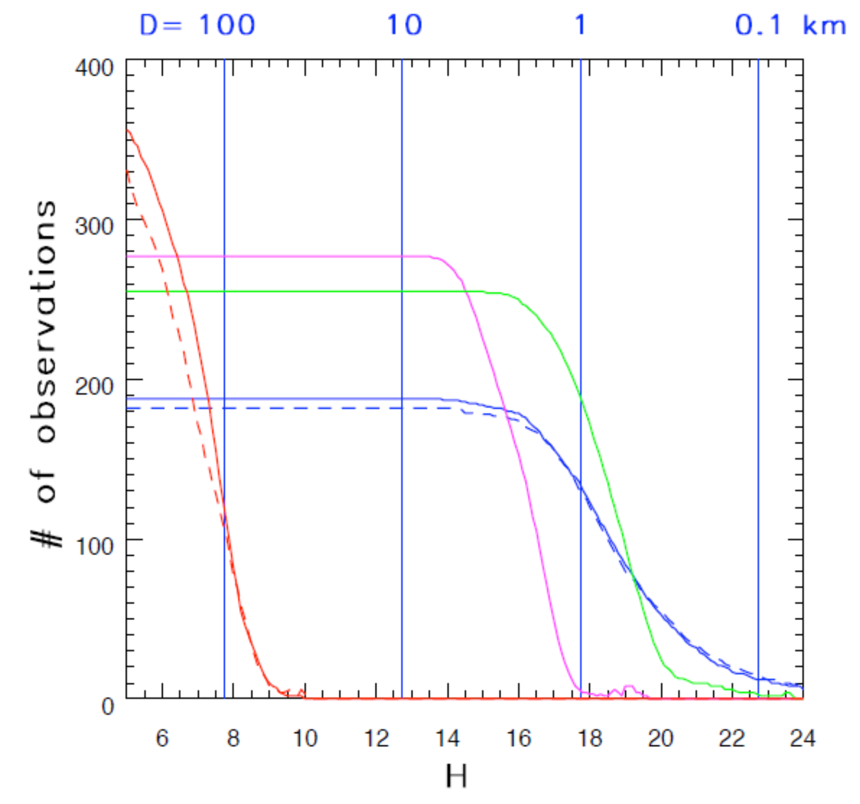
- Detected at 3 separate nights within 15-night window
- 2 visits each night(separated by 15-90 mins)
- Single night image -> tracklet
- Multiple night images -> track
- Orbital determination algorithms to determine √ or ×

False positive rate goal: 13:1(noise:real)



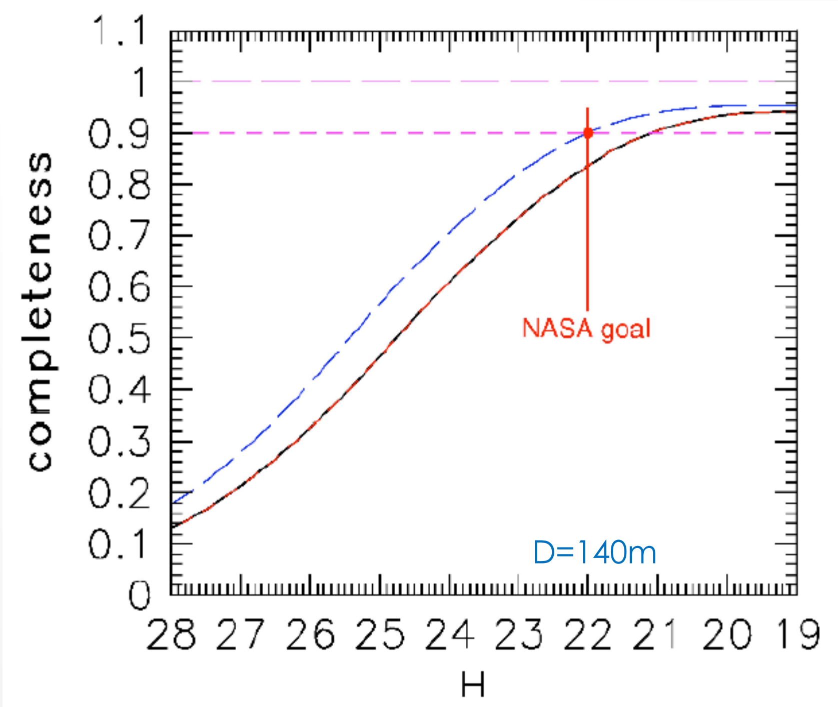


DETECTION EFFICIENCY



Solid lines: classical TNOs (red), Jovian Trojans (magenta), Main Belt Asteroids (green), NEAs (blue)

Dashed lines: scattered disk objects(red), potential hazardous asteroids(blue)

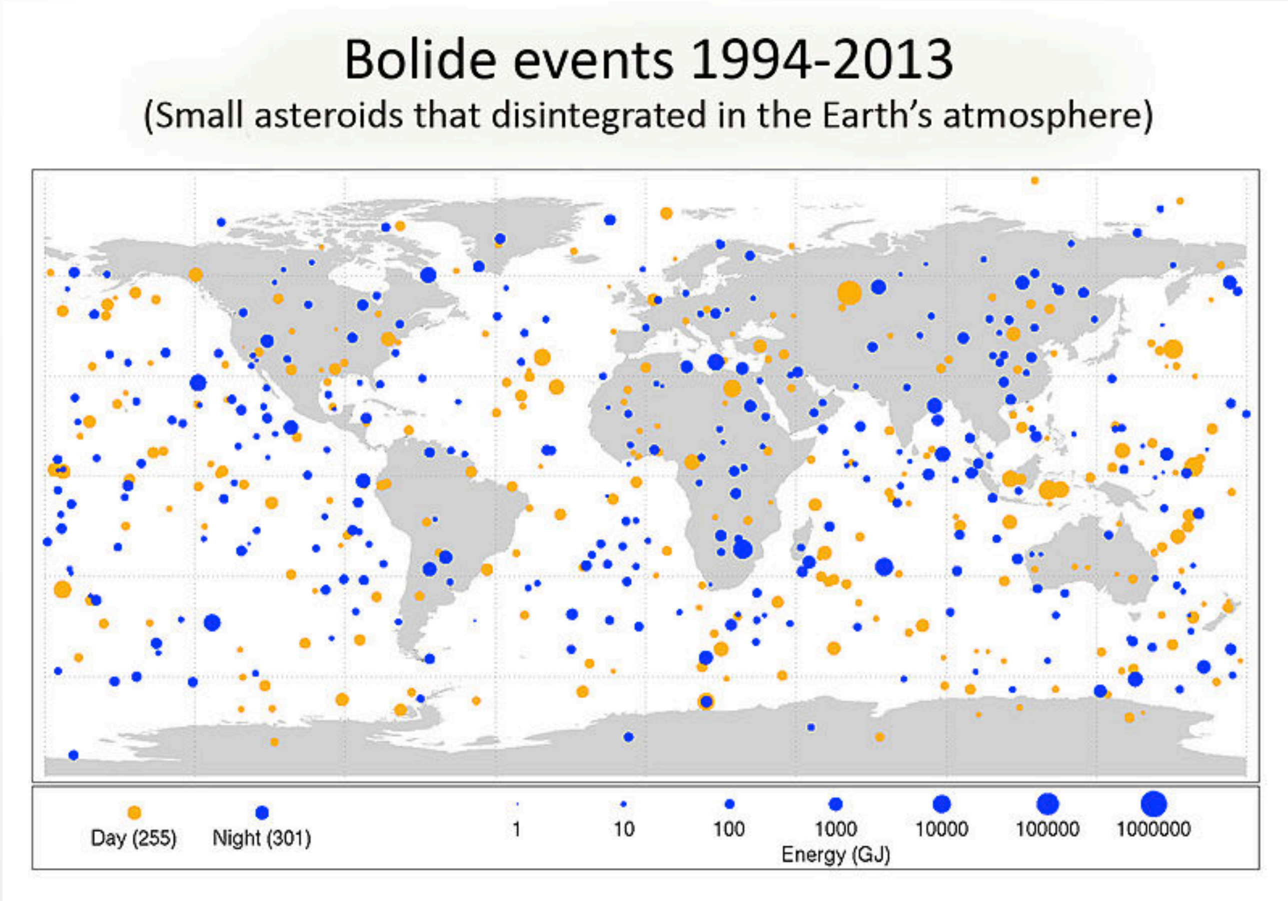


5% time(10yrs) VS 15% time(12yrs)

PHA completeness: 84% VS 90%

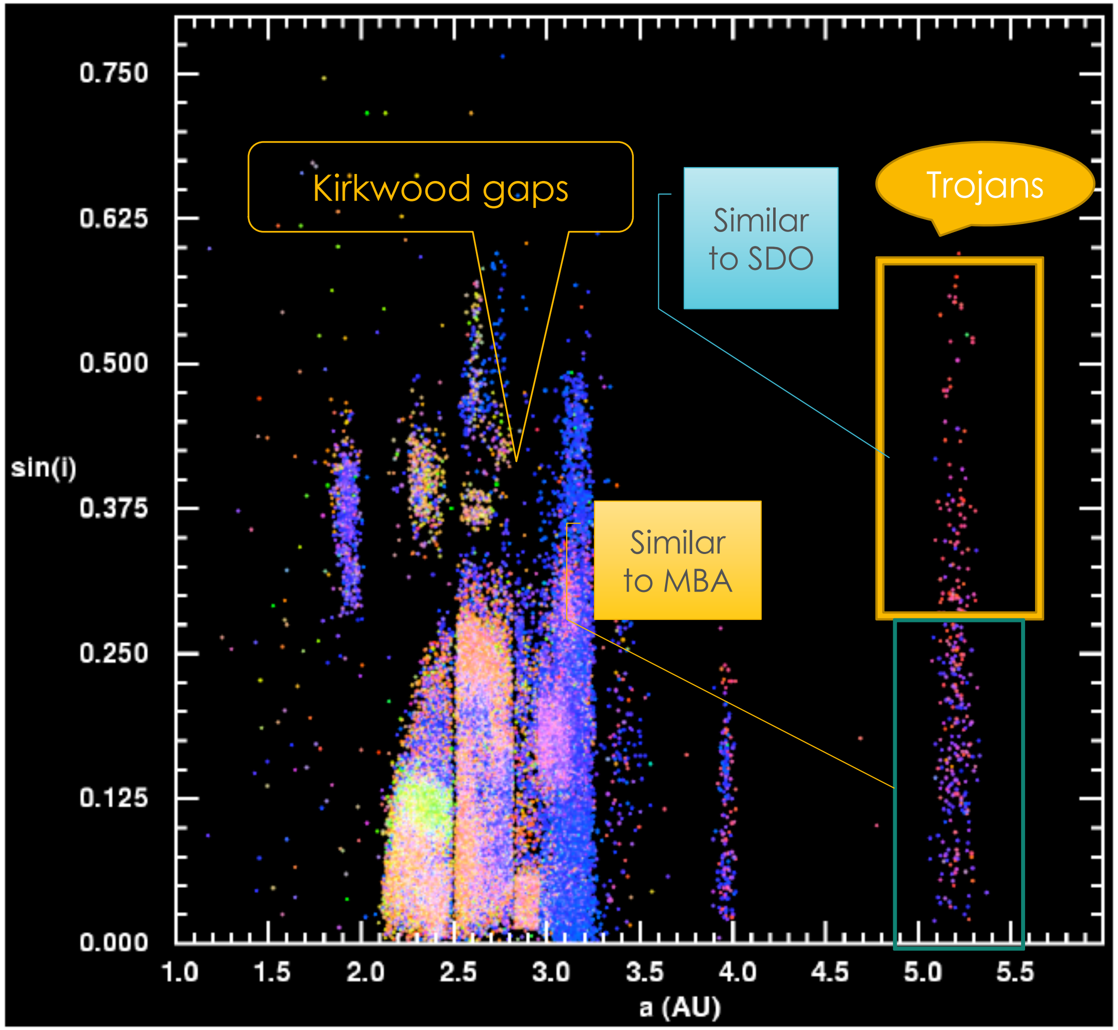
NECESSITY OF SURVEYING PHA

- Potential hazardous asteroids(PHAs) are NEAs that has closest encounter with Earth <0.05AU
- ~100m PHAs can cause catastrophic events to create Tsunami and drastic climate change
- Possible targets for future space missions(resembling Rosetta)



SOLAR SYSTEM AND PLANET FORMATION

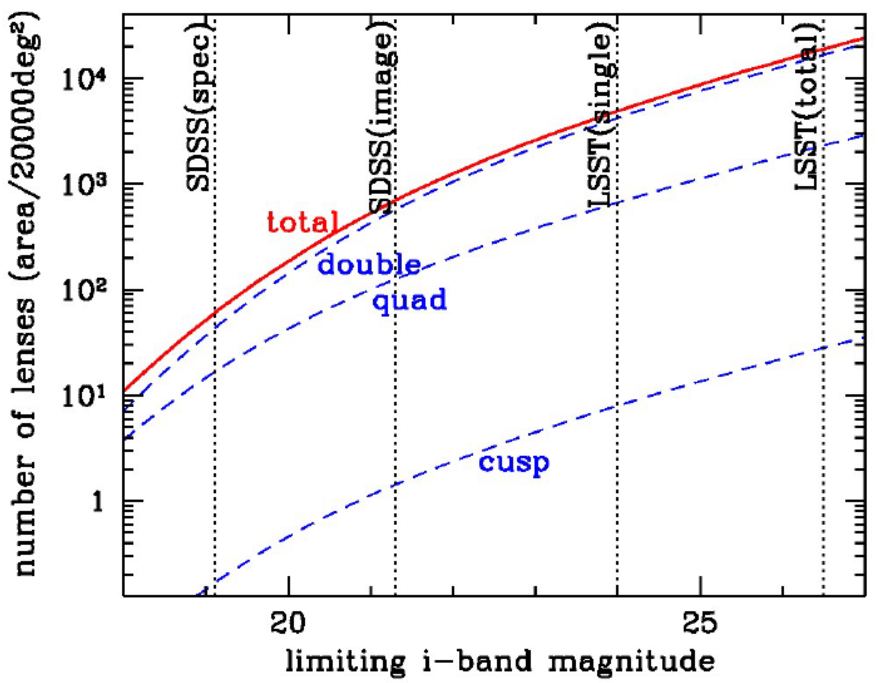
- **Simultaneous formation** of Trojans **with Jupiter**(Peale 1993)
- But Trojans with large orbital inclination are **similar to SDOs** in color
- **Ex situ** formation of Trojans, indicating **gas drag** importance in early solar system
- **Nice model**: Trojans built up by planetesimals *trapped after the 1:2 mean-motion resonance crossing of Saturn and Jupiter*
- ~10^6 small bodies expected by LSST will provide stringent constraint on these competitive theories of planet formation

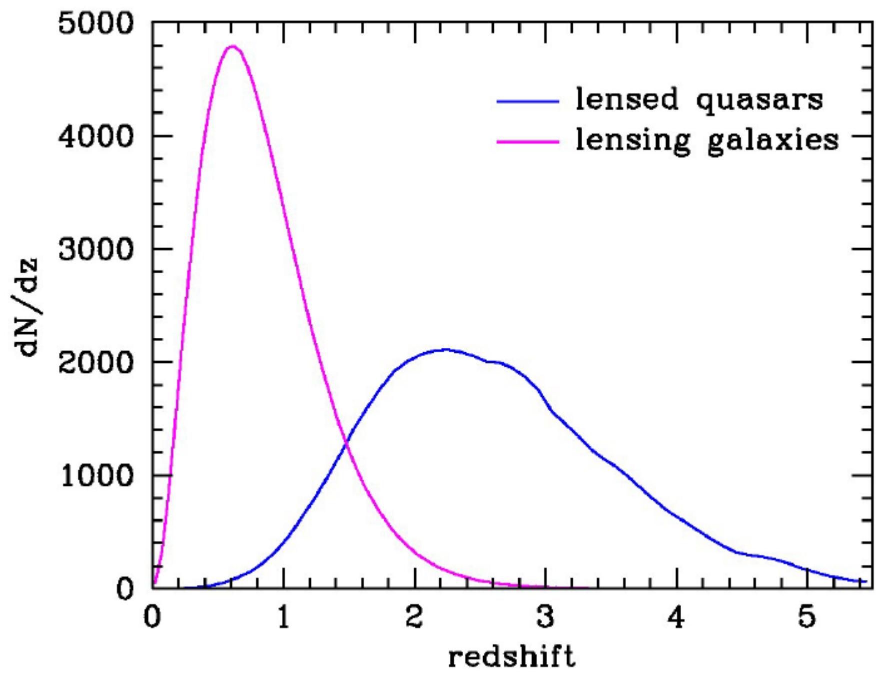


Science on dark matter and dark energy

EXPECTED LENSED QSO DISTRIBUTION

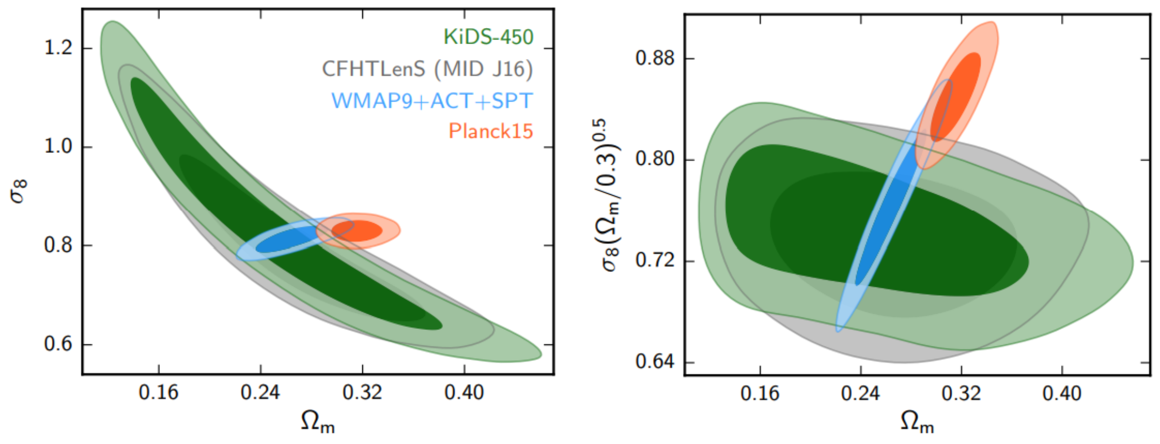
- More robust detection compared to galaxy-galaxy lenses
- Time delay measurements for %-level precision cosmology(H_0)
- Substructure discoveries from QSO flux-ratio anomaly





WEAK LENSING MOTIVATION

- Maps all matter (projected)distribution along line of sight
- Shape measurements only, susceptible to noise
- Systematics: galaxy intrinsic alignments, photometric redshift etc.
- Tension between CMB and WL drives larger statistical sample
- Survey efficiency

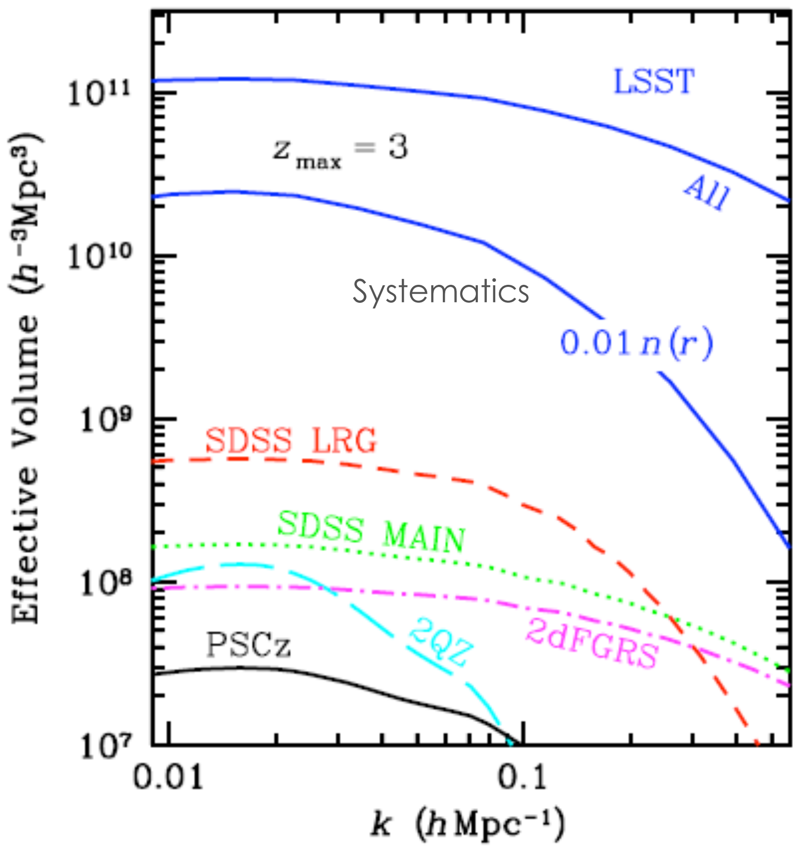


EFFECTIVE SURVEY VOLUME

Effective survey volume:

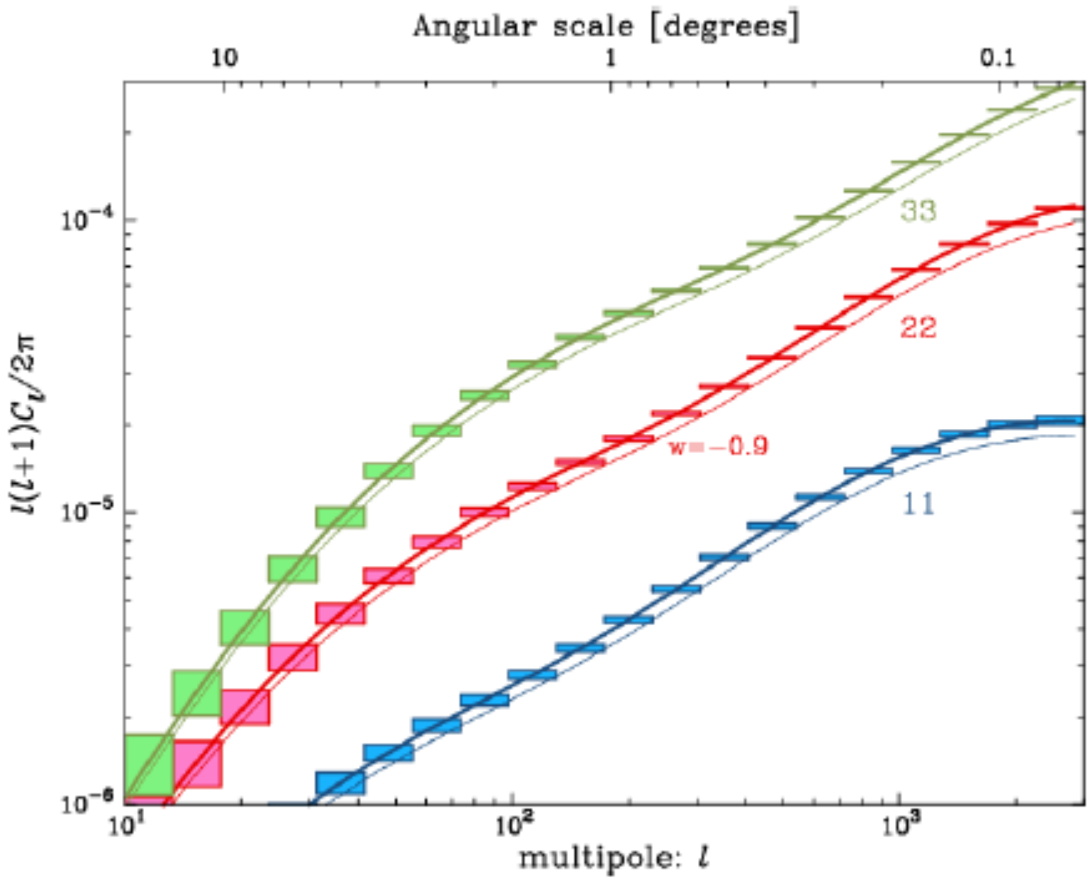
$$V_{\rm eff}(k) = \int \left[\frac{n_g(\boldsymbol{r})P_g'(k)}{n_g(\boldsymbol{r})P_g'(k)+1}\right]^2 d^3r$$

LSST: unprecedented survey volume and depth. Large statistical samples for both strong and weak lensing

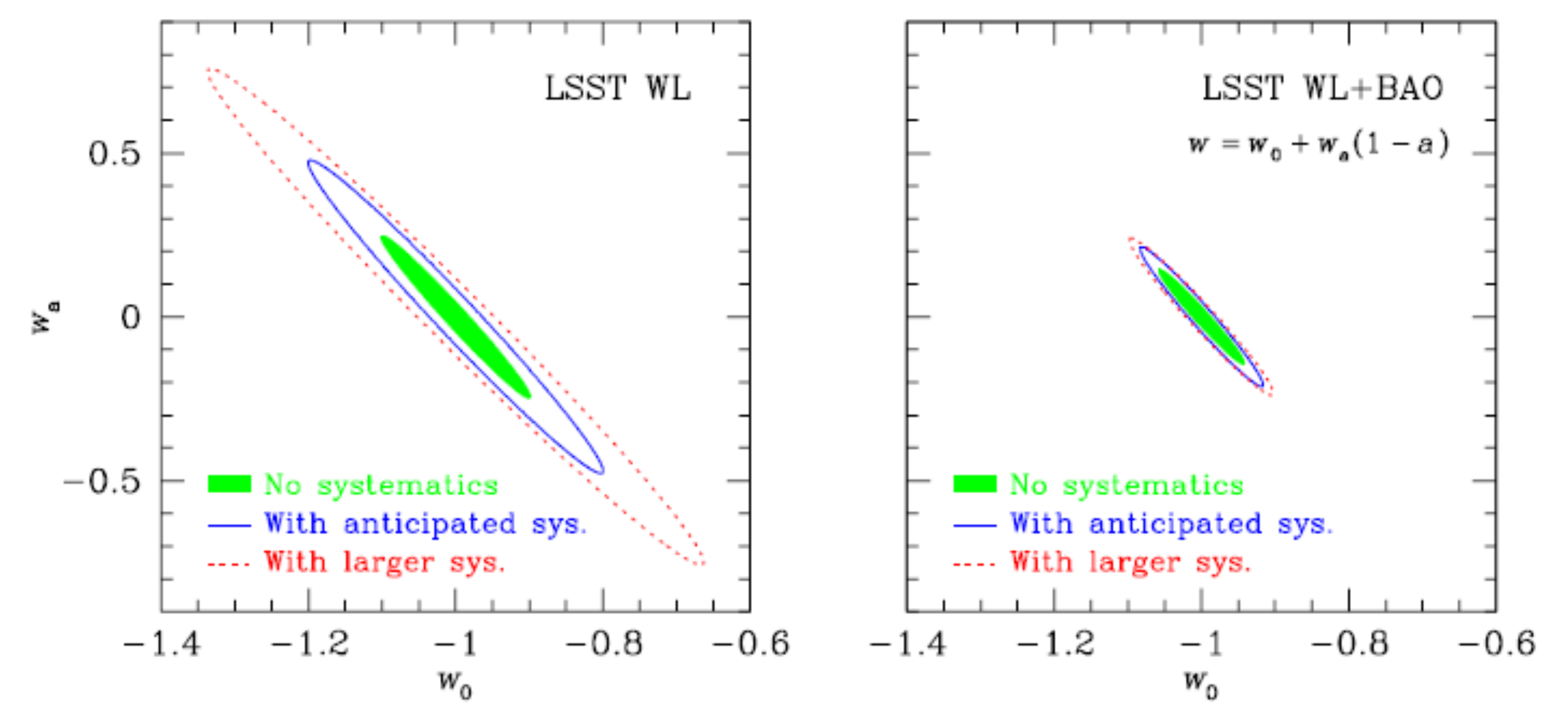


LENSING POWER SPECTRA

- Redshift bins: z<0.7, 0.7<z<1.2, 1.2<z<3
- Solid curves: fiducial ΛCDM model+non-linear evolution
- Dashed curves: dark energy model with w = -0.9
- Power spectra very sensitive to dark energy EOS(w)
- Boxes: error due to sample variance and intrinsic ellipticity
- LSST: ~100 auto- & cross-correlated power spectra



BAO+WL



LSST WL
No systematics
With anticipated sys.
With larger sys.
LSST WL+BAO
$w = w_0 + w_a(1-a)$
No systematics
With anticipated sys.
With larger sys.
0.5
0
−0.5
w_a
−1.4
−1.2
−1
−0.8
−0.6
w_0

SUMMARY

- Wide, deep, fast
- Addressing the key issues of the dynamic universe
- Massively parallel astrophysics
- Public dataset, contribution to the community

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Thanks for listening!