Dark Energy Projects

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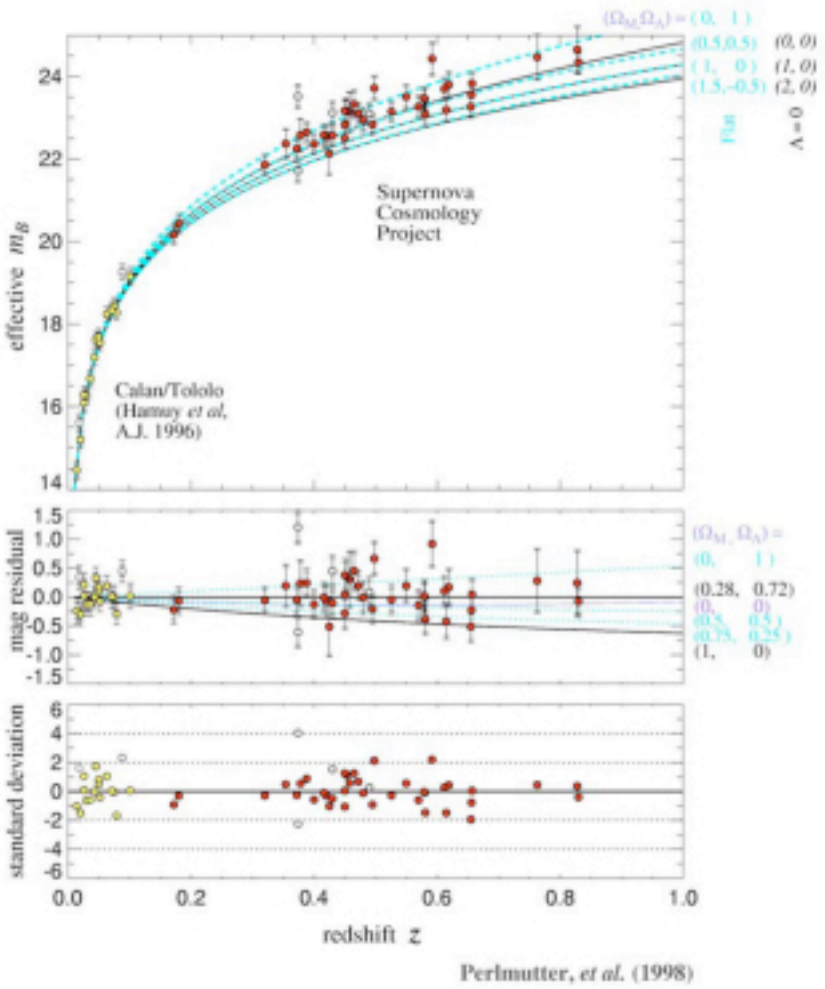
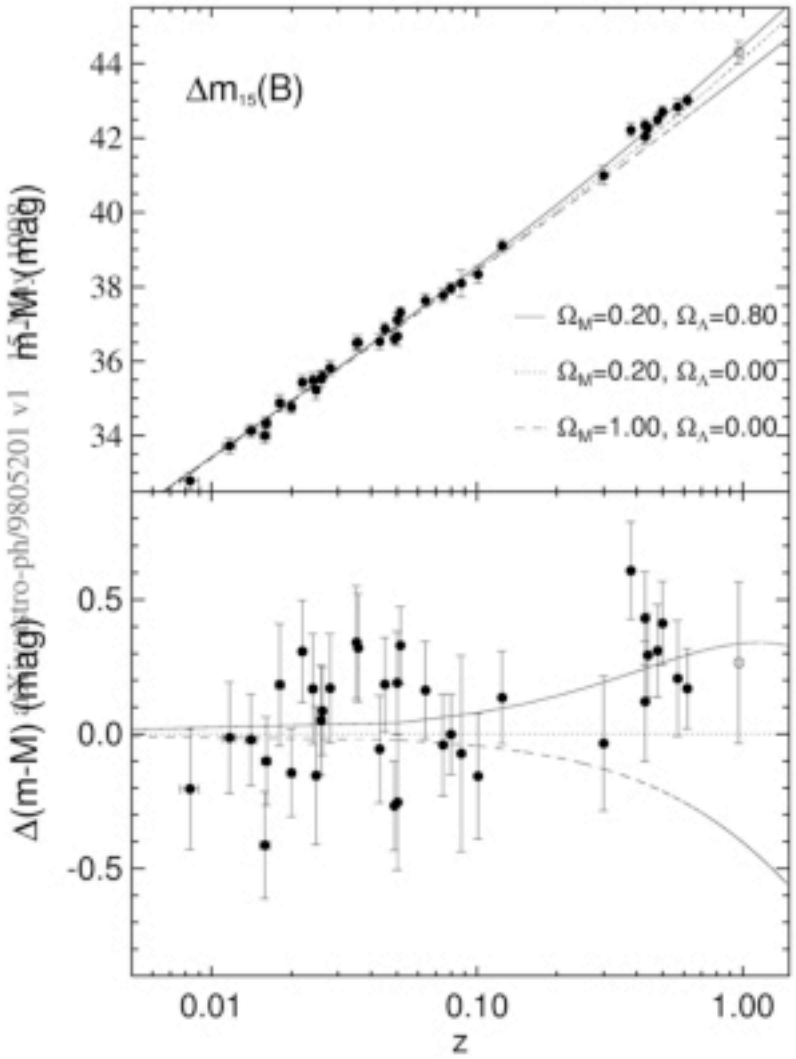
Discovery of

the acceleration of the expansion of the Universe

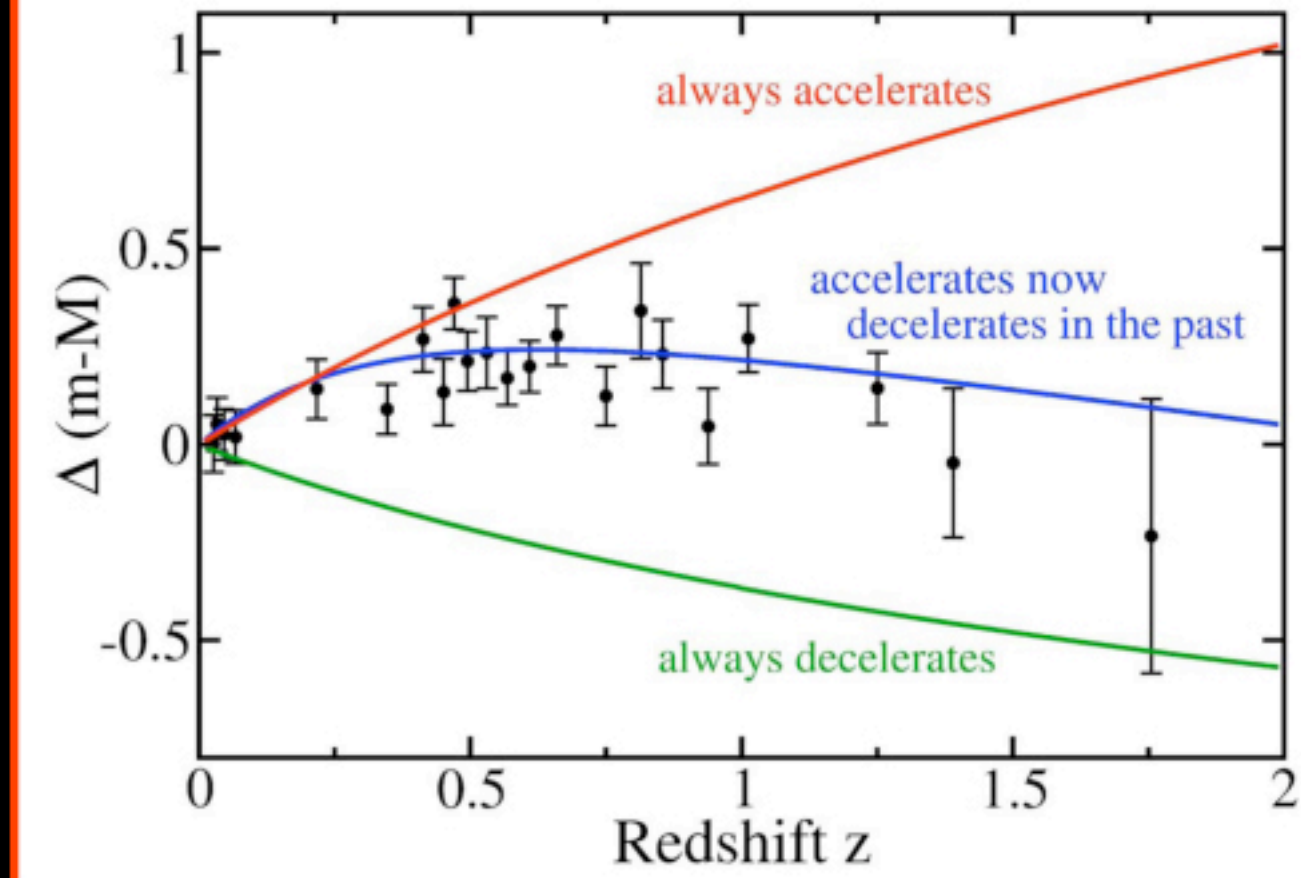
Perlmutter et al, 1998



Riess et al, 1998

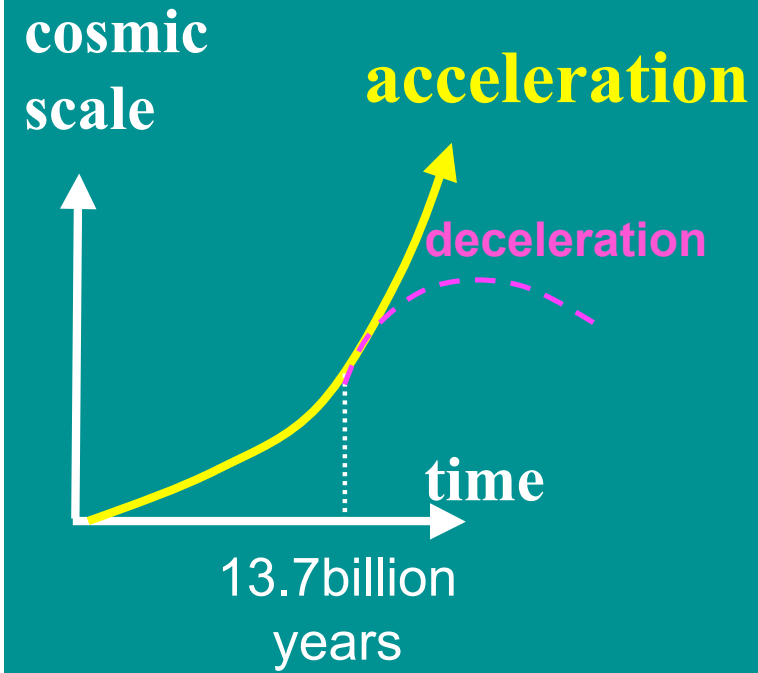


Consistent with past deceleration, and accelerate now



HST ACS Sample of high-z SNe: A. Riess et al, Ap.J **607**, 665 (2004)

Why is the Universe's expansion accelerating ?



$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2} + \frac{\Lambda}{3}$$

$(k = 0$ for flat universe$)$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda}{3}$$

$$p_i = w_i \rho_i \qquad (w_{\text{matter}} = 0, w_{\text{radiation}} = 1/3)$$

$$\rho_i \propto a^{-3(1+w_i)} = (1+z)^{3(1+w_i)}$$

$$\text{deceleration parameter: } q(z) \equiv -\frac{\ddot{a}}{aH^2} = \frac{1}{2}(1+3w)$$

What is Dark Energy ?

- Static i.e. constant in time ?
  - Cosmological constant
  - Vacuum energy
- Dynamic i.e.varies in time ?
  - 5th element (quintessence) with negative pressure
- Failure of general relativity at large scale

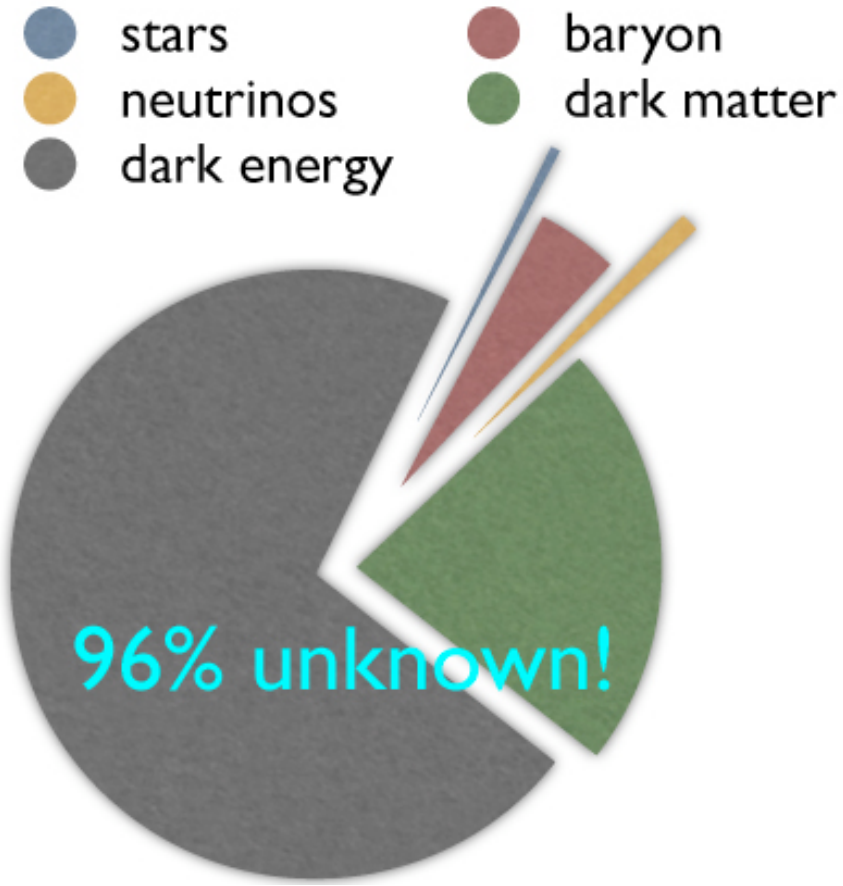
Constituents of the current Universe

Stars and galaxies are only ~0.5%
Neutrinos are ~0.1–1.5%
Atoms (baryons) are only 4.4%
Dark Matter 20%

Dark Energy 76%

$$\rho_{\text{Dark Energy}} \sim 6 \times 10^{-9}\,\text{erg/cm}^3$$

Static or Dynamic ?



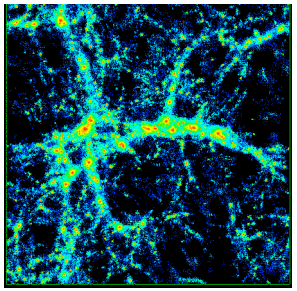
How to probe Dark Energy ?

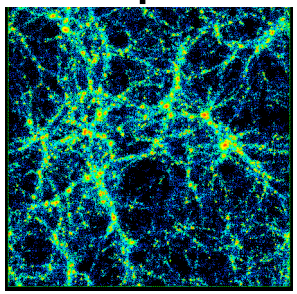
$$p / \rho = w(a) = w_0 + w_a(1-a)$$

- Use the expansion history of the Universe.

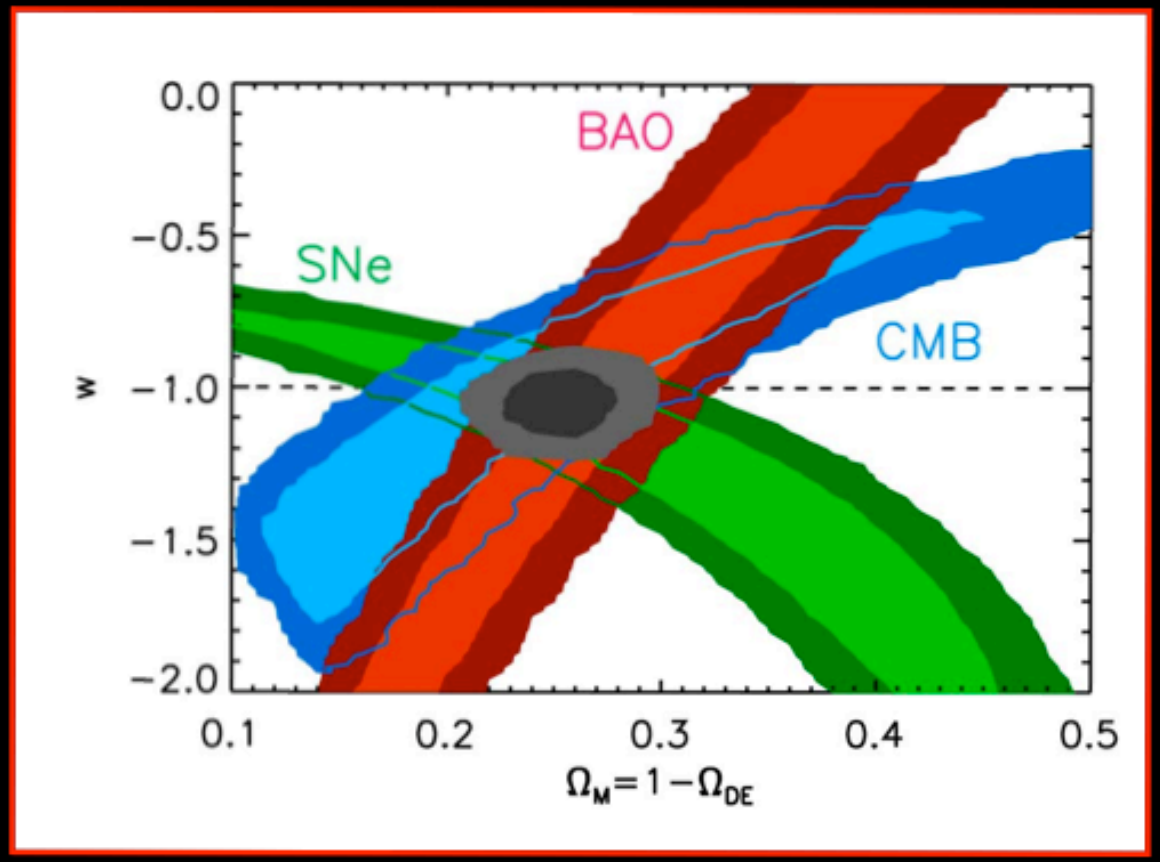
$$H(a)^2 = H_0^2 \left[\Omega_m a^{-3} + (1-\Omega_m) a^{-3(1+w_0+w_a)} e^{3w_a(a-1)} \right]$$

- Geometrical: distances (SN,…)
- Dynamic : Growth of structure
  - The redshift at which structures of a given mass start to form is very sensitive to the expansion history





Present Status

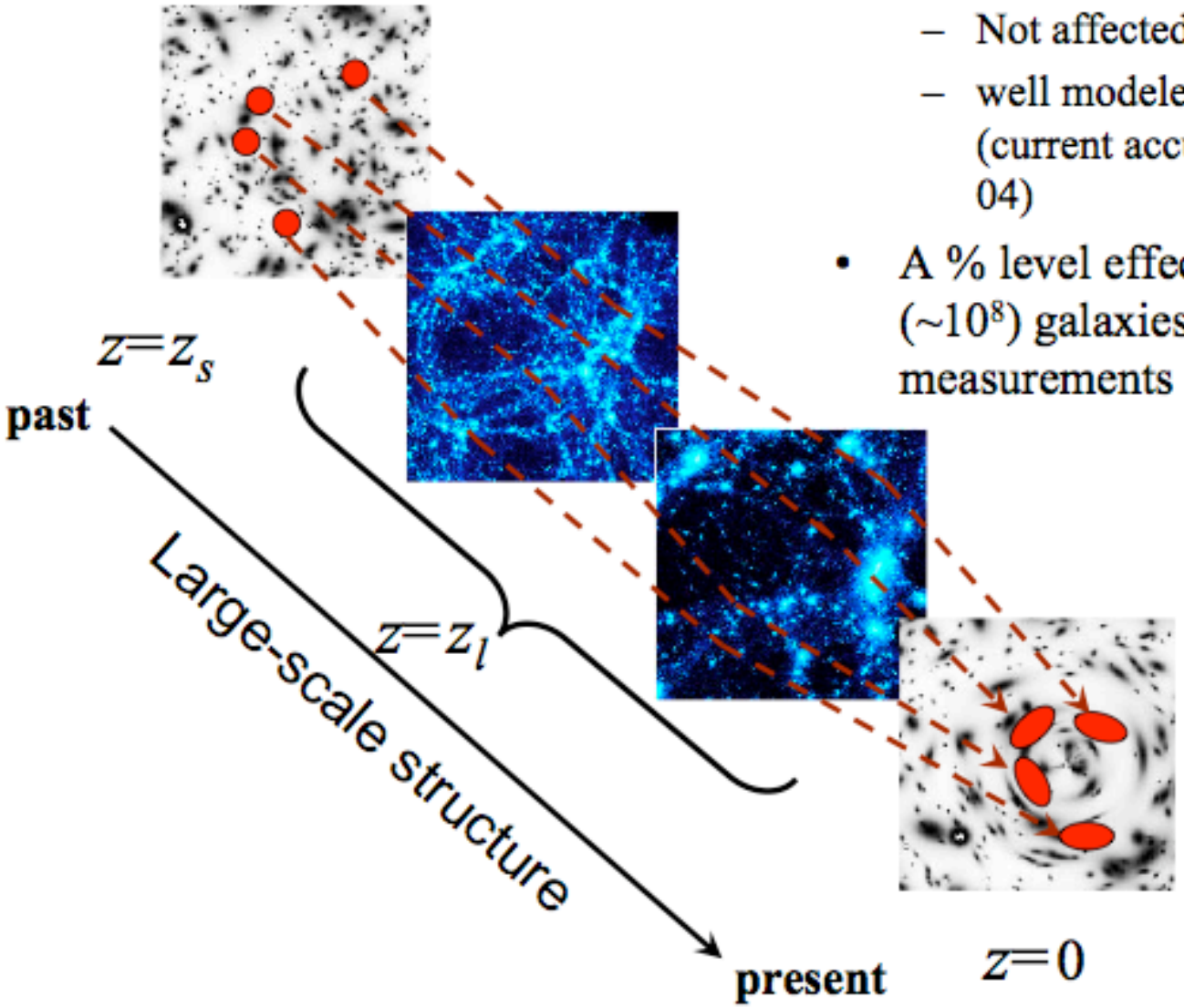


$\Omega_{DE} = 0.71 \pm 0.05$ $w = -1 \pm 0.1 \pm 0.1$ (const)

No constraint on wa

Cosmological weak lensing – cosmic shear

- Arises from total matter clustering
  - Not affected by galaxy bias uncertainty
  - well modeled based on simulations (current accuracy, <10% White & Vale 04)
- A % level effect; needs numerous (~10^8) galaxies for the precise measurements



observables

$$\gamma = \frac{a-b}{a+b}$$

$$\gamma_1 = \gamma \cos 2\varphi$$

$$\gamma_2 = \gamma \sin 2\varphi$$

Signal & noise

Signal:

$$\text{Signal} \propto \text{Mass}^{1/3} f(z_L, \langle z_S \rangle)$$

$$f(z_L, \langle z_S \rangle) = \frac{D_L D_{LS}}{D_S}$$

Noise:

$$e_{\text{obs}} = e_{\text{lensing}} + e_{\text{intrinsic}}$$

$$\langle e_{\text{obs}} \rangle = e_{\text{lensing}} + \sigma_e / \sqrt{n_{\text{gal}}}$$

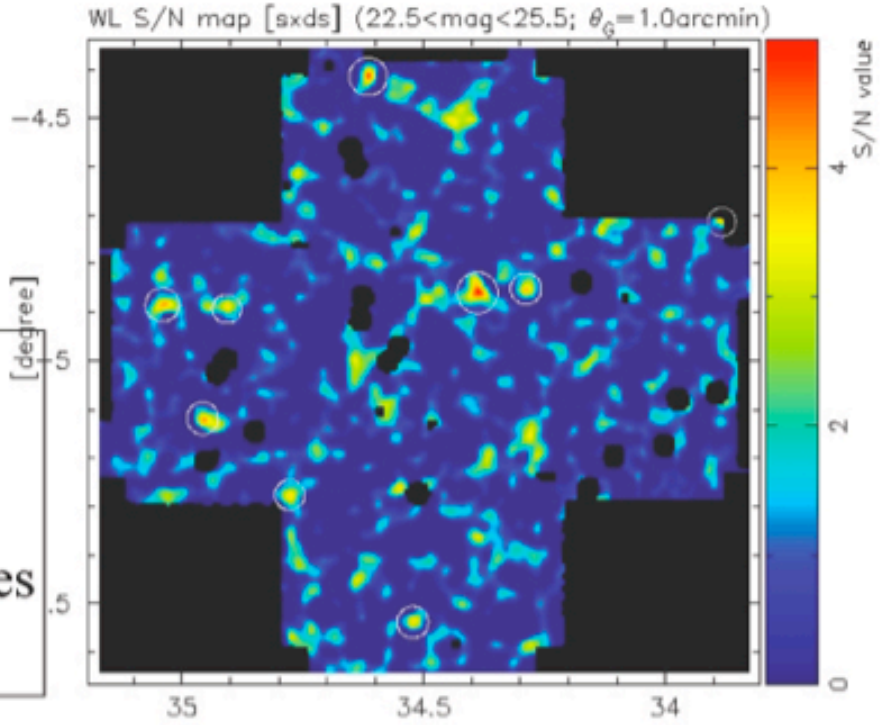
σ_e : RMS of galaxy ellipticities

n_{gal} : galaxy number density

Typical Suprime-Cam obs
(seeing FWHM < 0.7")

$\sigma_e \sim 0.4$

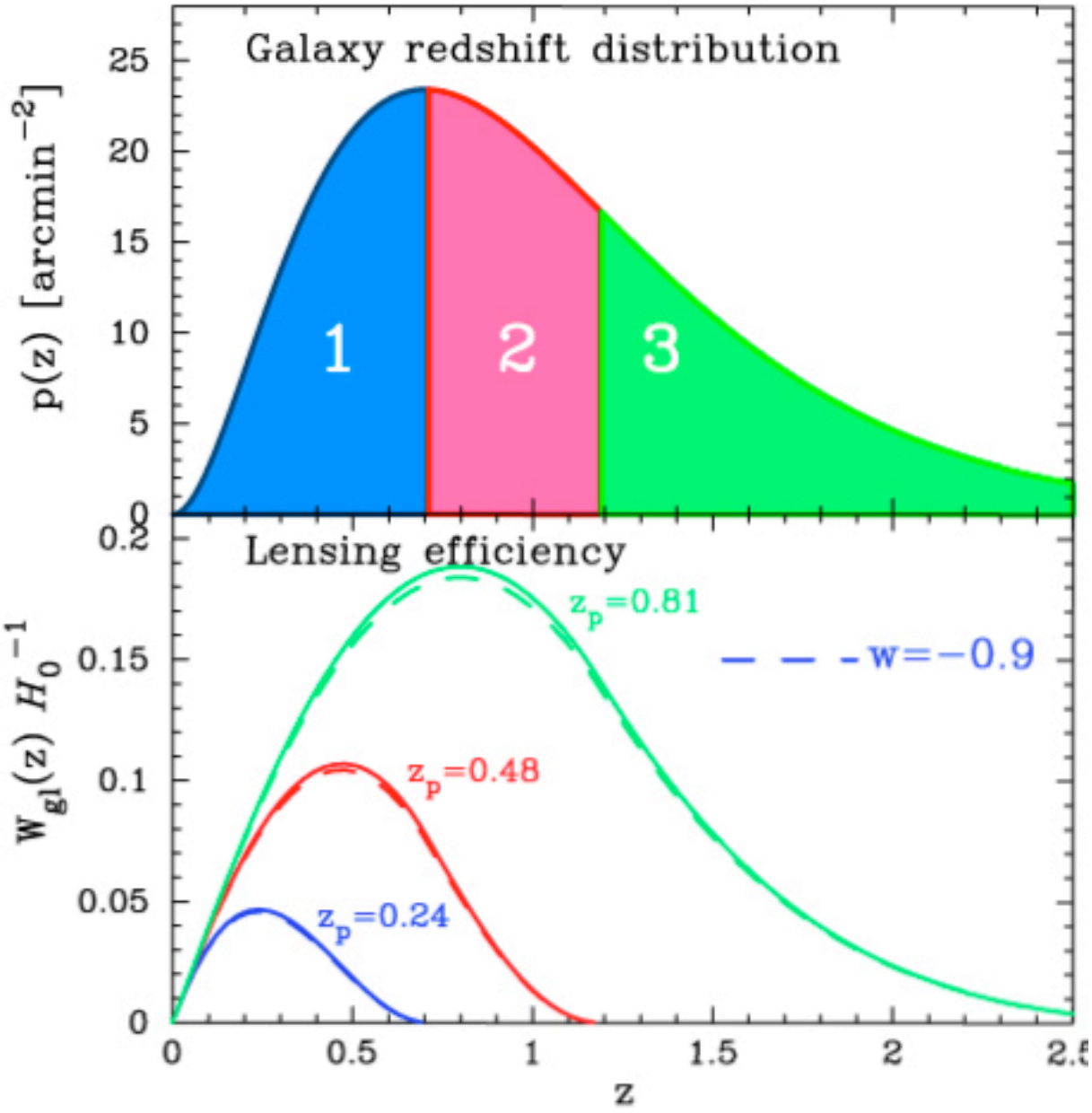
$n_{\text{gal}} \geq 30 / \text{arcmin}^2$



Detection S/N is basically determined by the number density of the "usable galaxies" n_{gal}

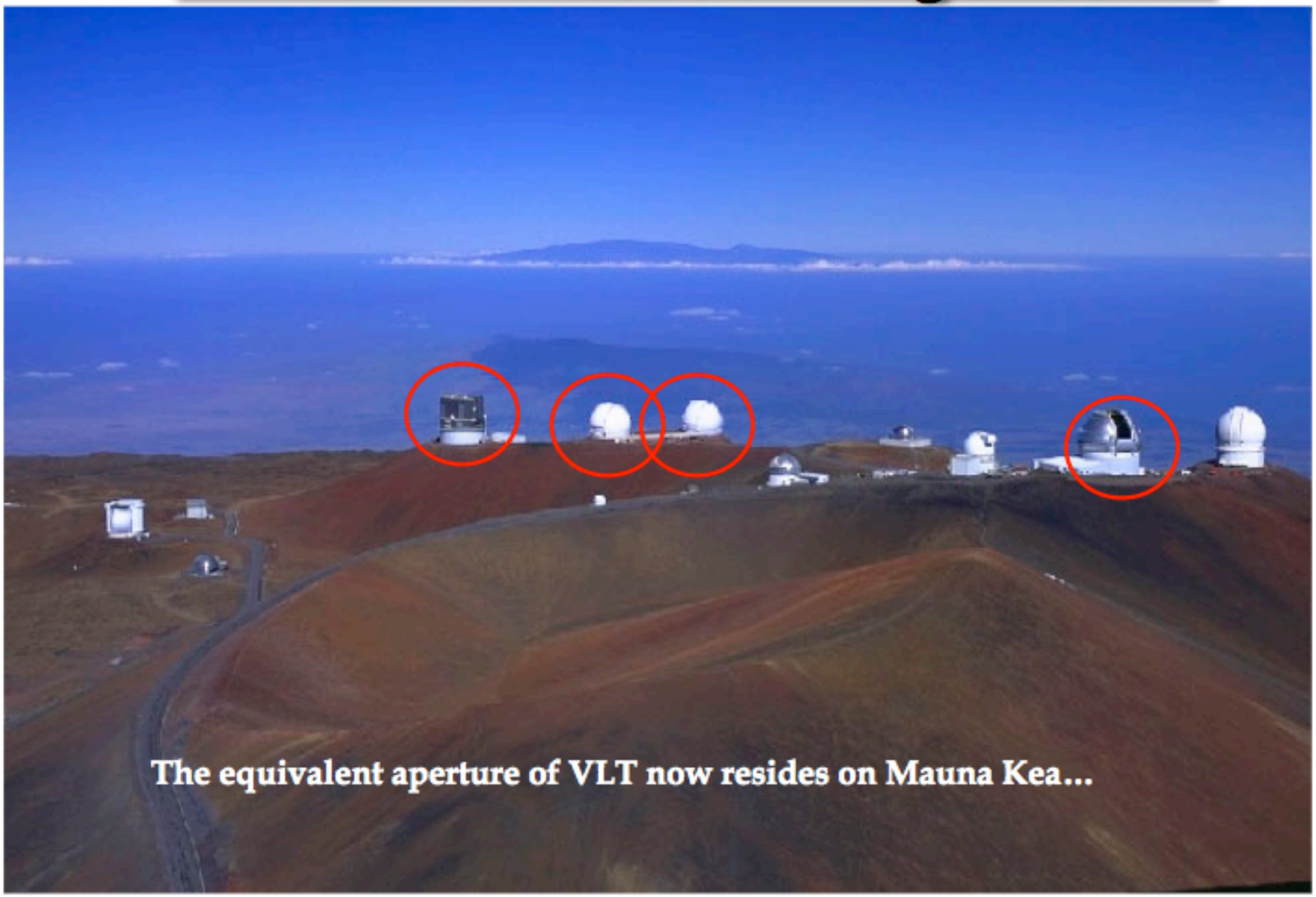
Weak Lensing Tomography (contd.)

- Subdivide source galaxies into several bins based on photo-z derived from multi-colors (4 colors for HSC).
- Adds some ``depth'' information to lensing – improve cosmological paras (including DE).



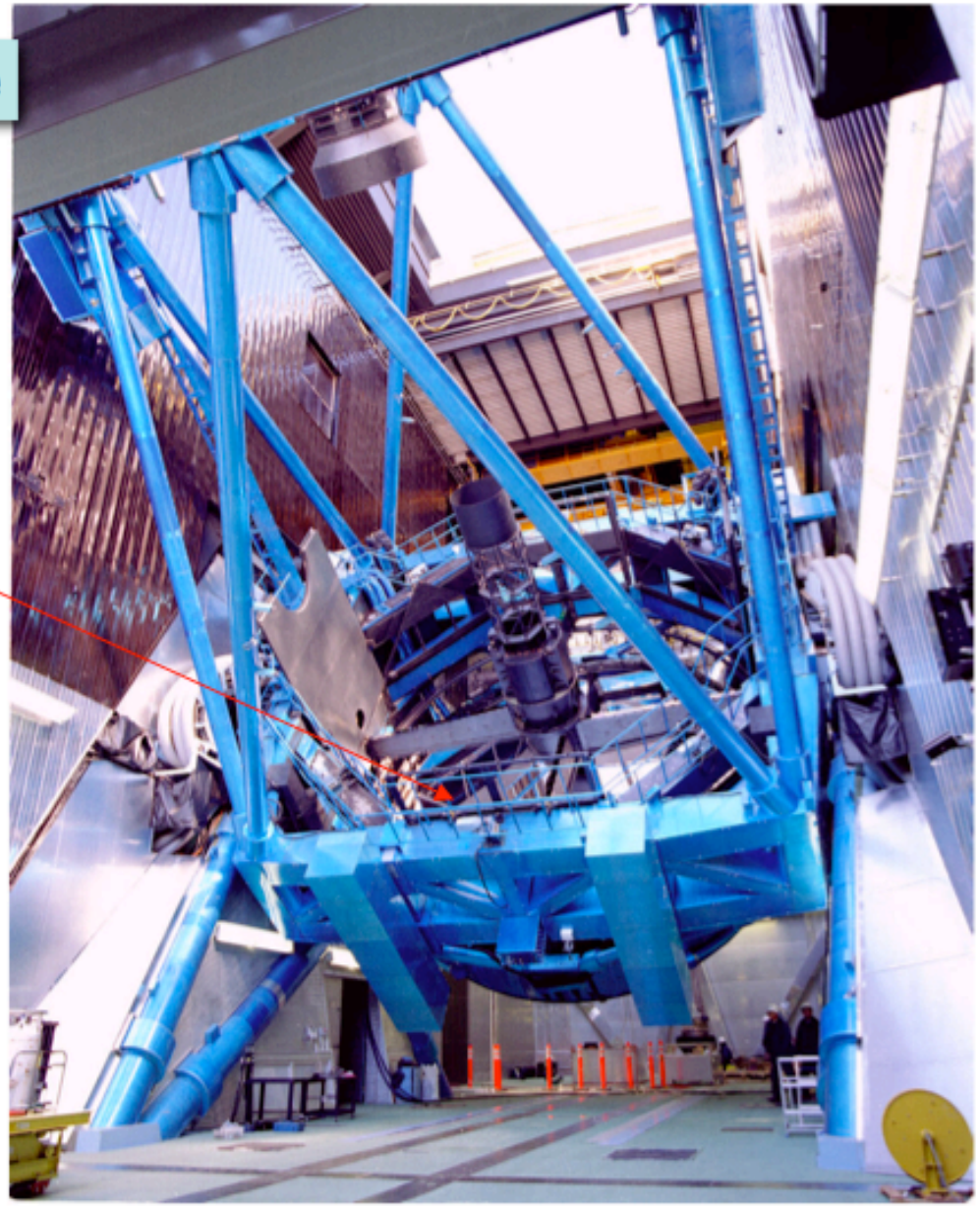
Instrumentation for Imaging survey

“Mauna Kea Convergence”

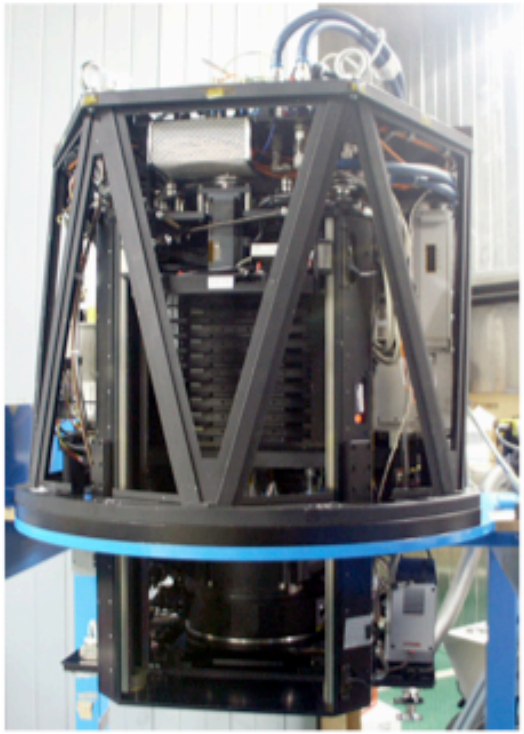


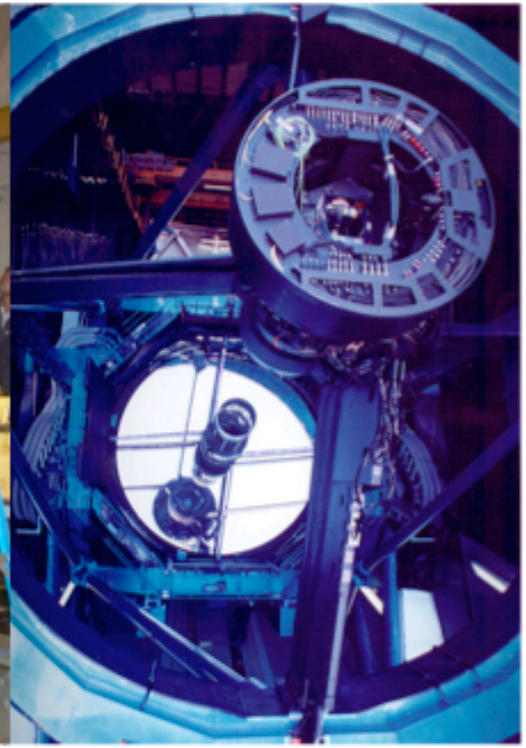
Subaru Telescope

8.2m diameter mirror



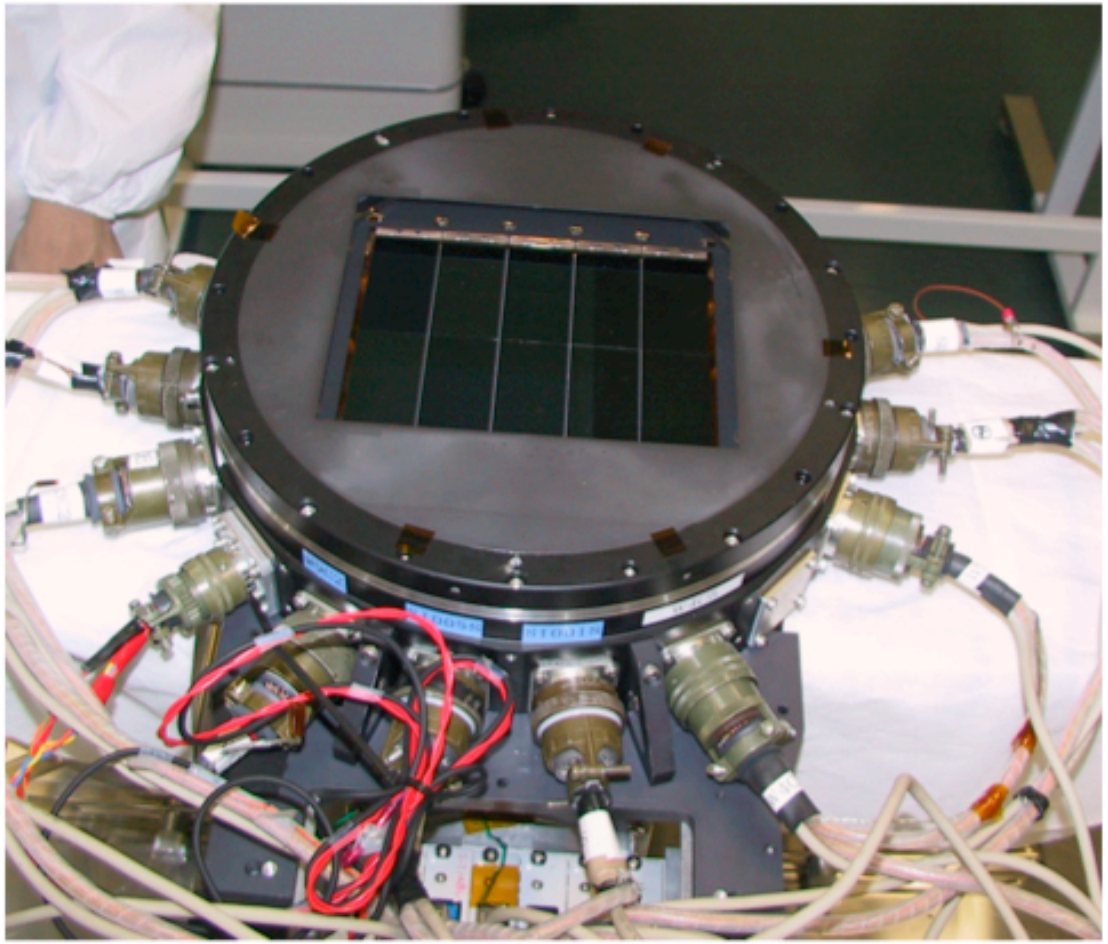
Subaru Prime focus Camera (Suprime-Cam)





- Field of View: 34.1 arcmin x 27.3 arcmin filled with 2k x 4k CCDs
- Pixel scale: 0.2 arcsec/pixel, F ratio: F/2
- Good image quality (median seeing ~0.7arcsec; best seeing 0.35arcsec)

Seeing = Atmospheric turbulence

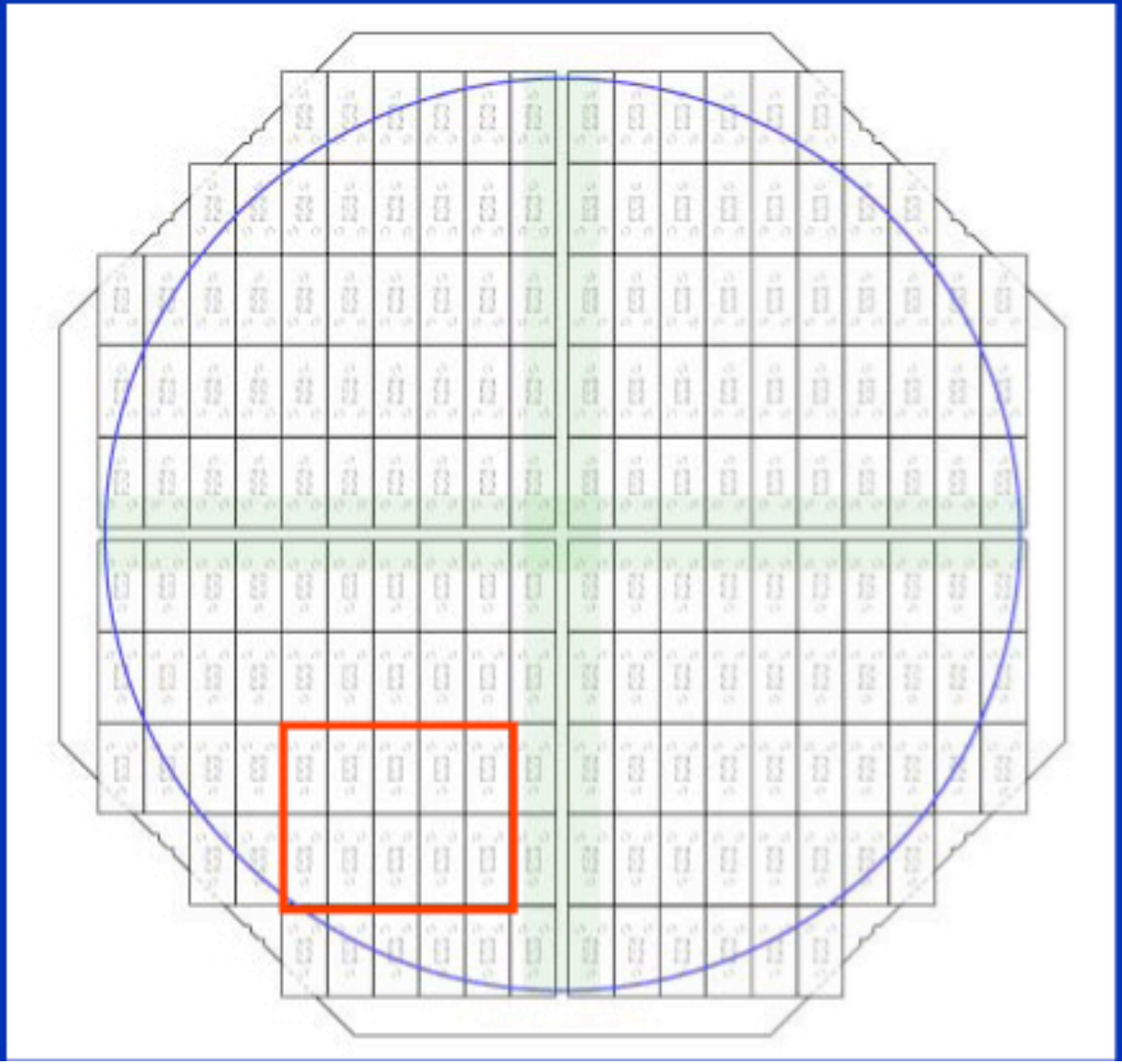


Hyper Suprime Cam (HSC)

- Wide field of view : 1.5 - 2.0 deg ϕ(diameter) (SC: 0.5 deg ϕ)
  (1.77-3.14 deg^2) (SC: 0.2 deg^2)
- 600nm < λ < 1100nm
- Image quality : 0.3 arcsec

- Large focal plane
- Fully depleted CCD
- Large corrector lens system

Focal Plane of HSC

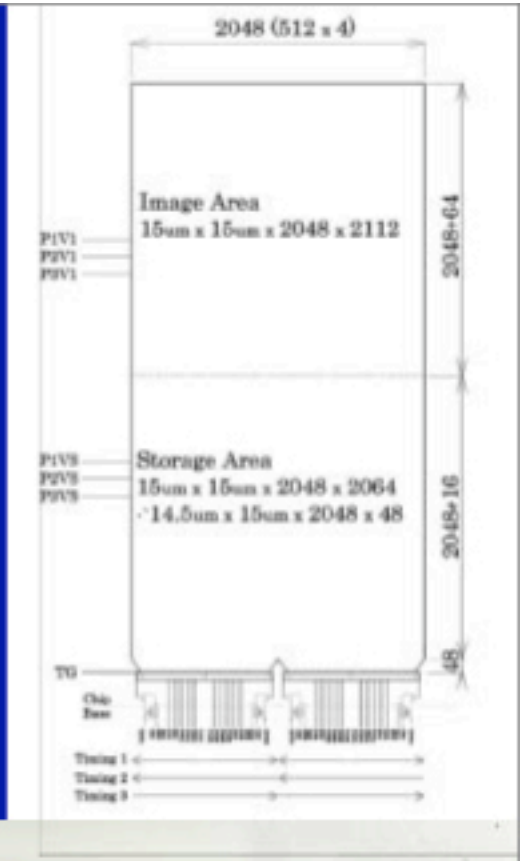


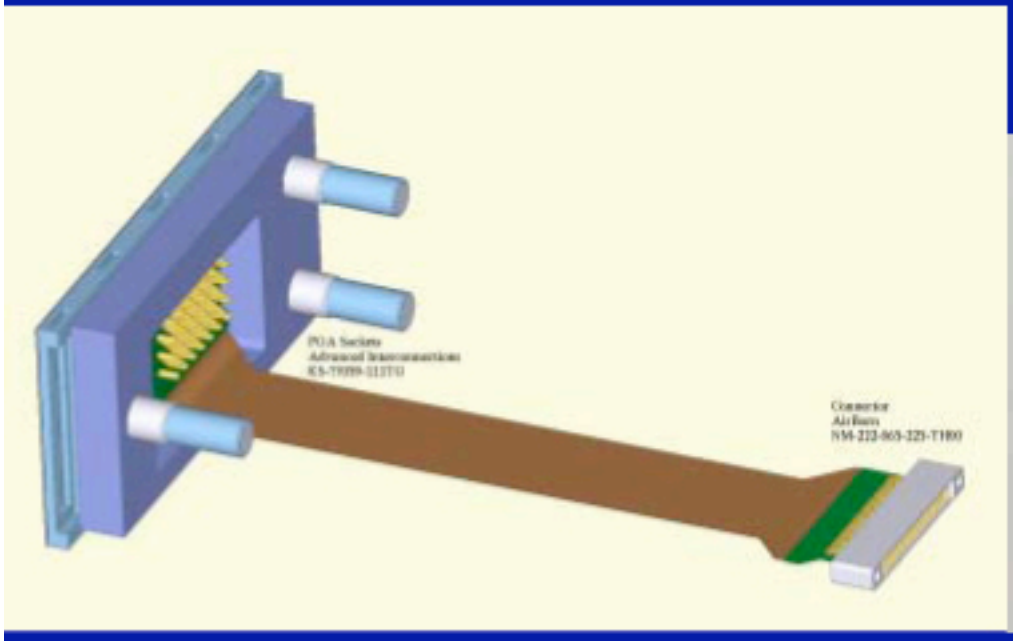
2 degree
60 cm

168 2k4k
CCDs

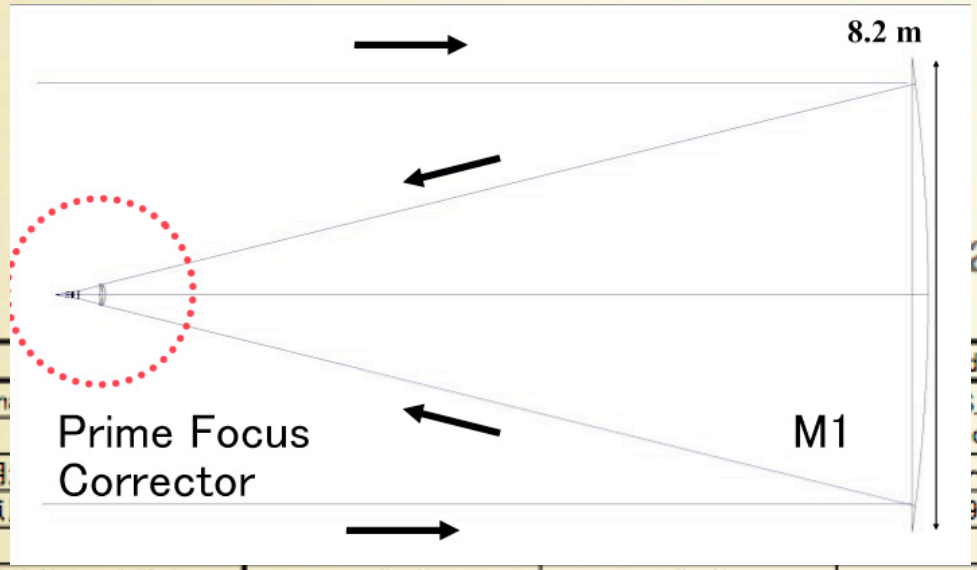
CCD

- Hamamatsu (n-type silicon)
  - 2k4k (15μm) 4 side buttable
  - 4 output amplifier
  - 200μm fully depleted



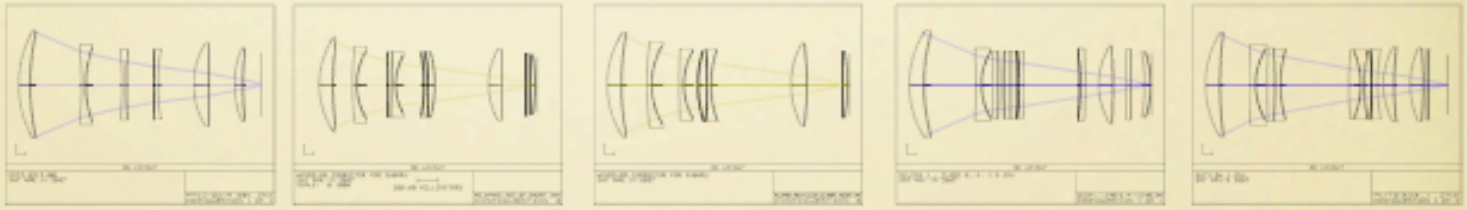


Large Optics



al shift

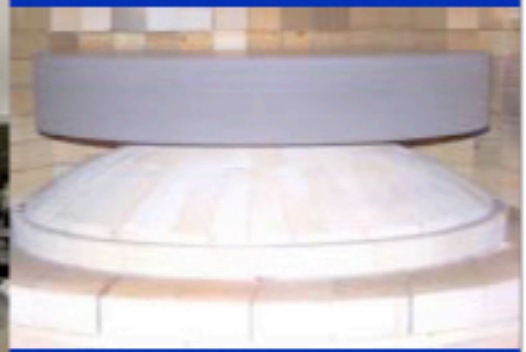
			degシフト式AD	成合氏1.5degPrism式ADC	田中1.5degシフト式ADC
file n			_PBL6Y_slide_ort.ZMX	SILICA 1_-_2-ADC-3_-4-1.5.ZMX	
使用			~1000	500～1100	420～1050
焦点			9916	19147	18441
構成枚数(F.Fを除く)	6群6枚	6群8枚	6群7枚	8群10枚	7群9枚
G1有効径(mm)	1180	880	880	873	880
使用非球面枚数	3面	2面	3面	3面	3面
非球面最大有効径(mm)	1161	662	856	839	626



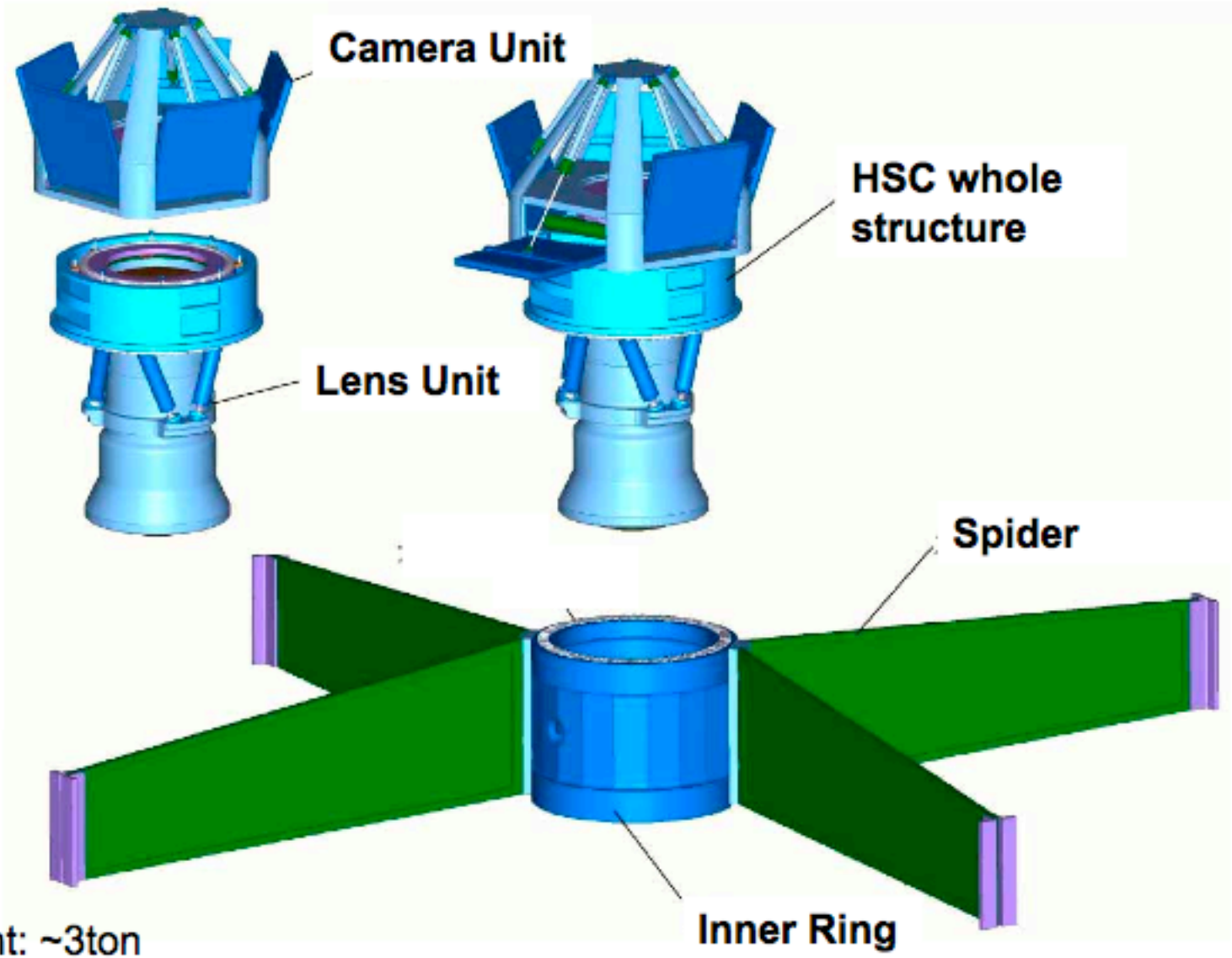
Takeshi Gillingham Gillingham Nariai Tanaka

Large Optics Fabrication

LBT
D=80 cm
Lens



HSC design (1.5 deg)



Weight: ~3ton

HSC survey strategy

- First light Dec. 2010
- 2000 deg^2 in 2 years

  (150million galaxies/1000deg^2)
- Measure w_0 to ±0.09
- Measure w_a to ±0.26 (dynamic origin or not ?)

- Produces ~ 1TB/night of high quality image data

Competition

Stage III & IV facilities

Pan-STARRS

University of Hawaii

`The immediate goal of Pan-STARRS is to discover and characterize Earth-approaching objects, both asteroids & comets, that might pose a danger to our planet....'

Pan-STARRS

Four 1.8-m telescopes (PS1-PS4) at Mauna Kea
(take over UH88....)

Field of view: 7 deg^2

Filter set: 6 (grizyw)

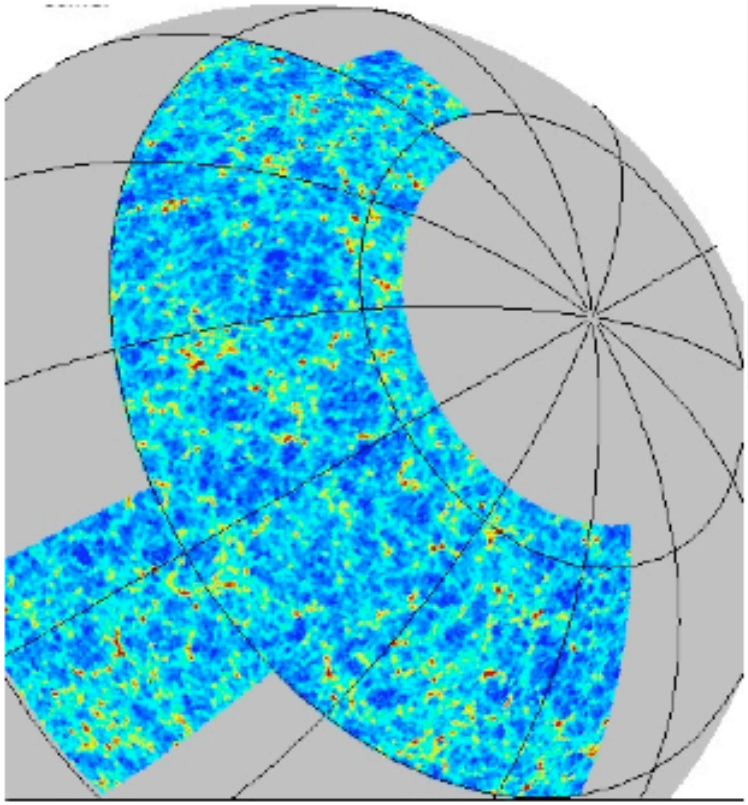
~30 sec exposure, 2 sec readout

~24 mag per visit

Multiple scans (LSST-like) to find transients
(each scan data will not be stored....)

DES Dark Energy Survey (Fermilab)

Blanco 4-m telescope
at CTIO,
survey 5000deg^2



Four probes of dark energy:

1. cluster counts (+SPT)
2. weak lensing
3. BAO
4. supernovae

DES

Large camera on Blanco 4-m at CTIO, Chili
(~0.7" seeing, ~0.9" at focal plane)

Field of view: 3 deg^2

Filter set: 4 (griz)

Survey 5000deg^2 sky (S. Galactic cap) in 525 nights (5yr)
to 24.5 mag

40deg^2 repeat for supernovae

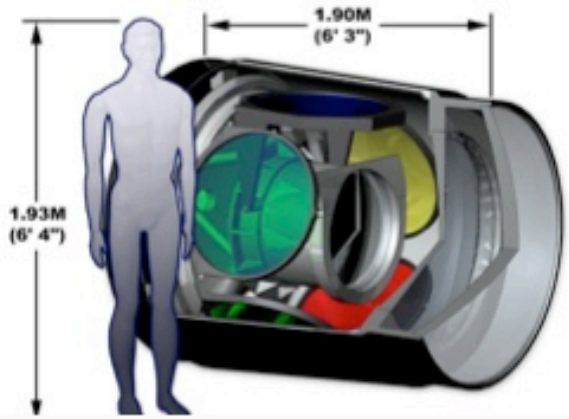
Construction : 2005-2009
Survey start : 2010

Stage-IV

LSST

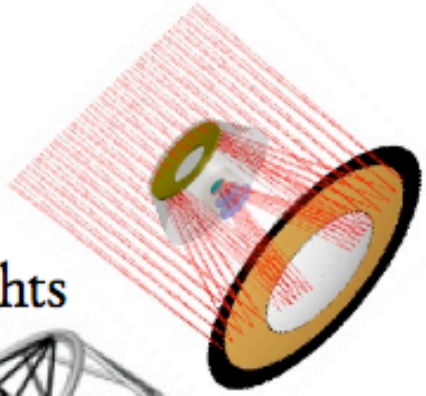
SLAC

Large Synoptic Survey Telescope



High etendue survey telescope

- 6m effective aperture
- 10 sq degree field
- 24.5 mag in 30 seconds
- Visible sky mapped in three nights
- Ten year movie



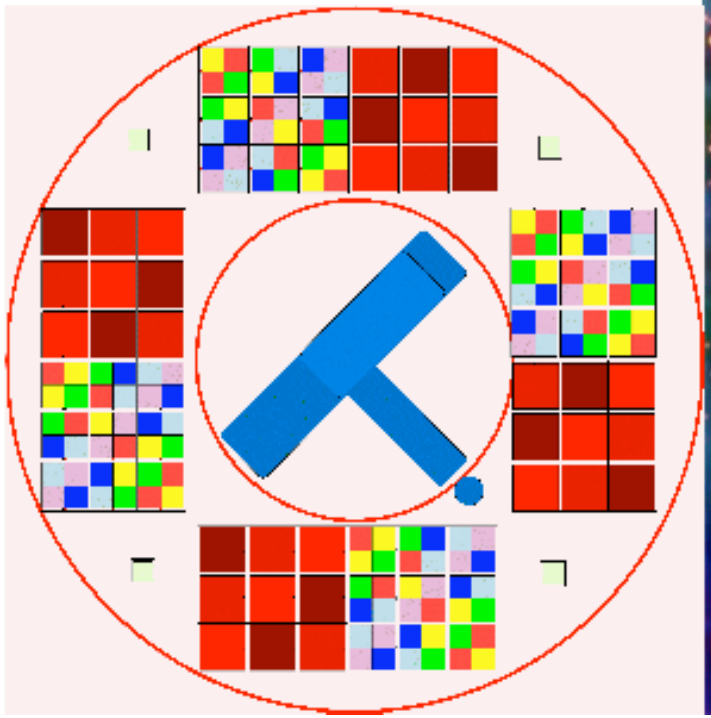
First light ~2015

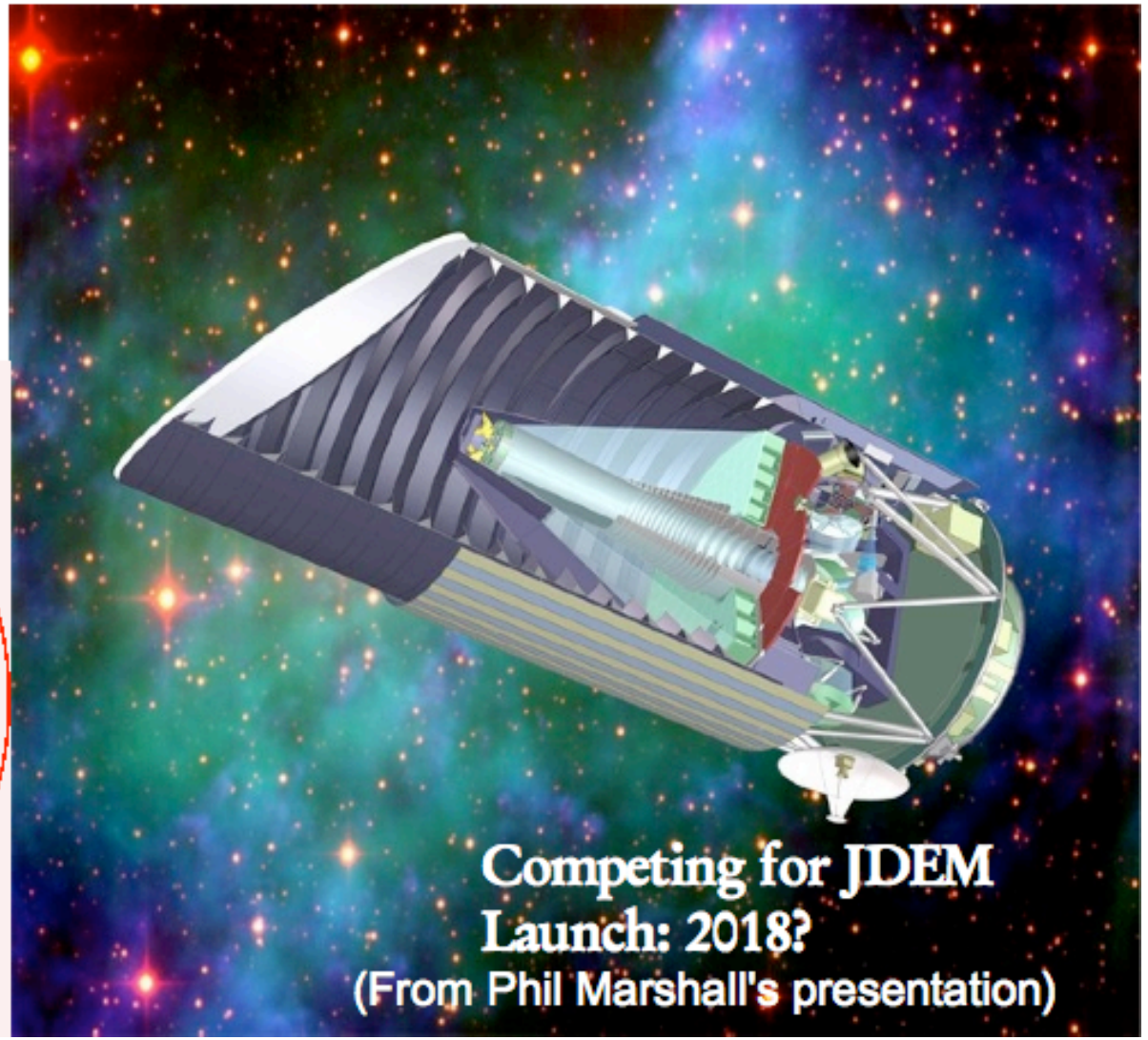
20,000deg^2

A factor 3 improvement over Stage- III facilities

SNAP @LBNL

- 2m class telescope, 0.7 sq degree field of view
- IF Spectrograph for SNe
- 9 filters (350nm–1700nm)
- PSF 0.13 arcsec FWHM
- 0.1 arcsec pixels, HST-quality imaging





Planned SNAP Survey

"Deep" Type Ia SN survey:

- 15 sq deg, I mag limit 30.3 (27.7 per visit), 4 day cadence
- Total observing time 32 months

"Wide" Weak lensing survey

- 1000 sq deg, I mag limit 27.7, single epoch (6-way dither)
- Total observing time 16 months

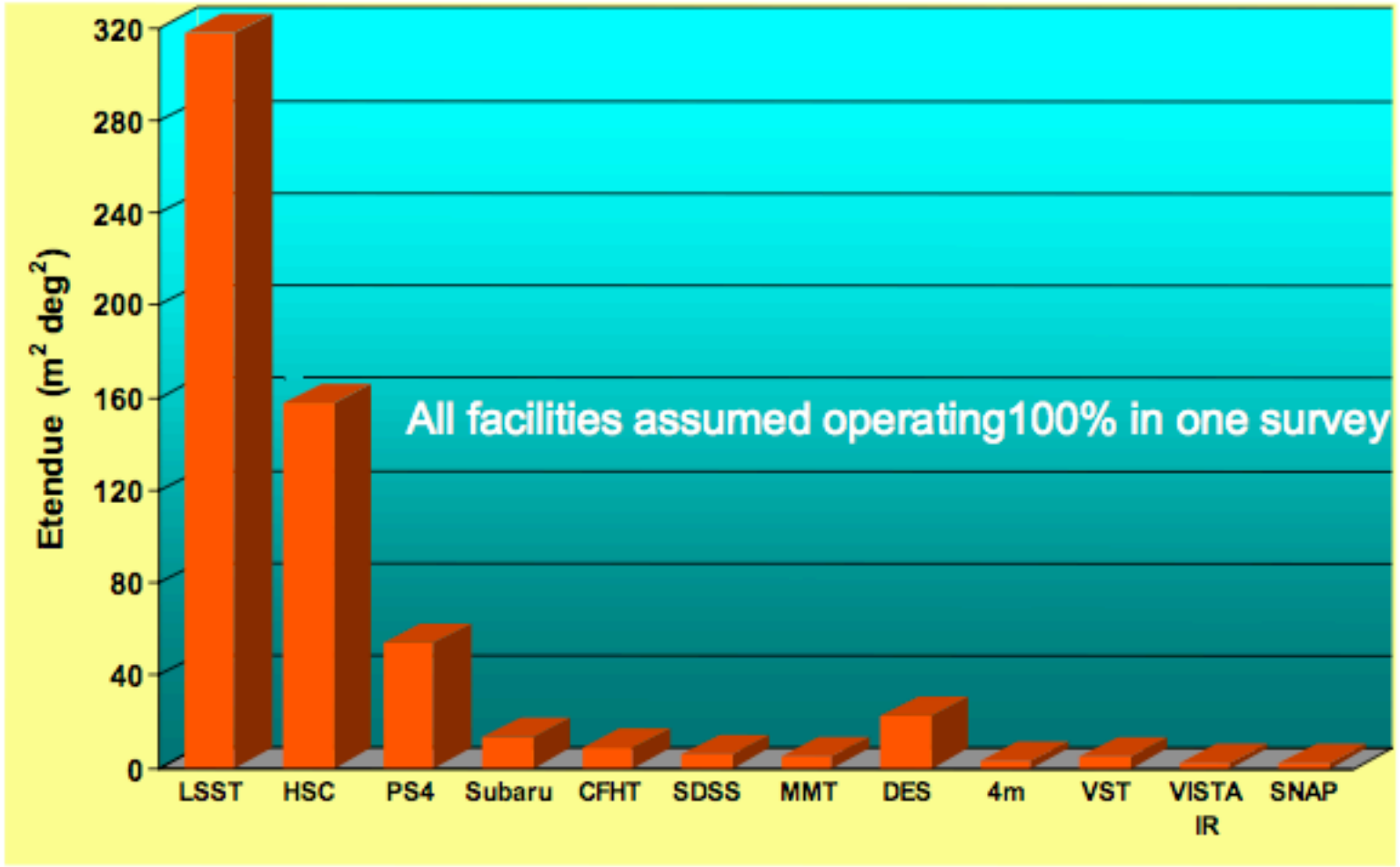
"Panoramic" legacy survey

- 10000 sq deg, I mag limit 26.5
- Observing time 3 years
- Suggested use of community time...

Etendue (~*luminosity*) is a fundamental metric of survey capability

Large Synoptic Survey Telescope

Information/time ~ rate of sky coverage ~ Etendue



Conclusion

- Dark Energy : a big mystery
- Next goal is to probe time dependence.
- Statistical astronomy
- Stage III facilities : HSC, PanStarrs4, DES ~ 2010
- Stage IV facilities : LSST, JDEM ~2015