Probing dark energy with the Large Synoptic Survey Telescope (LSST)

Alexia Gorecki

On behalf of the LSST collaboration

Third year PhD student

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Context:
Accelerated expansion of the Universe

- Observations:

  Type 1a Supernovae don't follow the Hubble law (Riess et al. and Perlmutter et al. 1999)

  The temperature anisotropies of the CMB showed that the Universe is flat ($\Omega_{tot} \approx 1$) (WMAP)

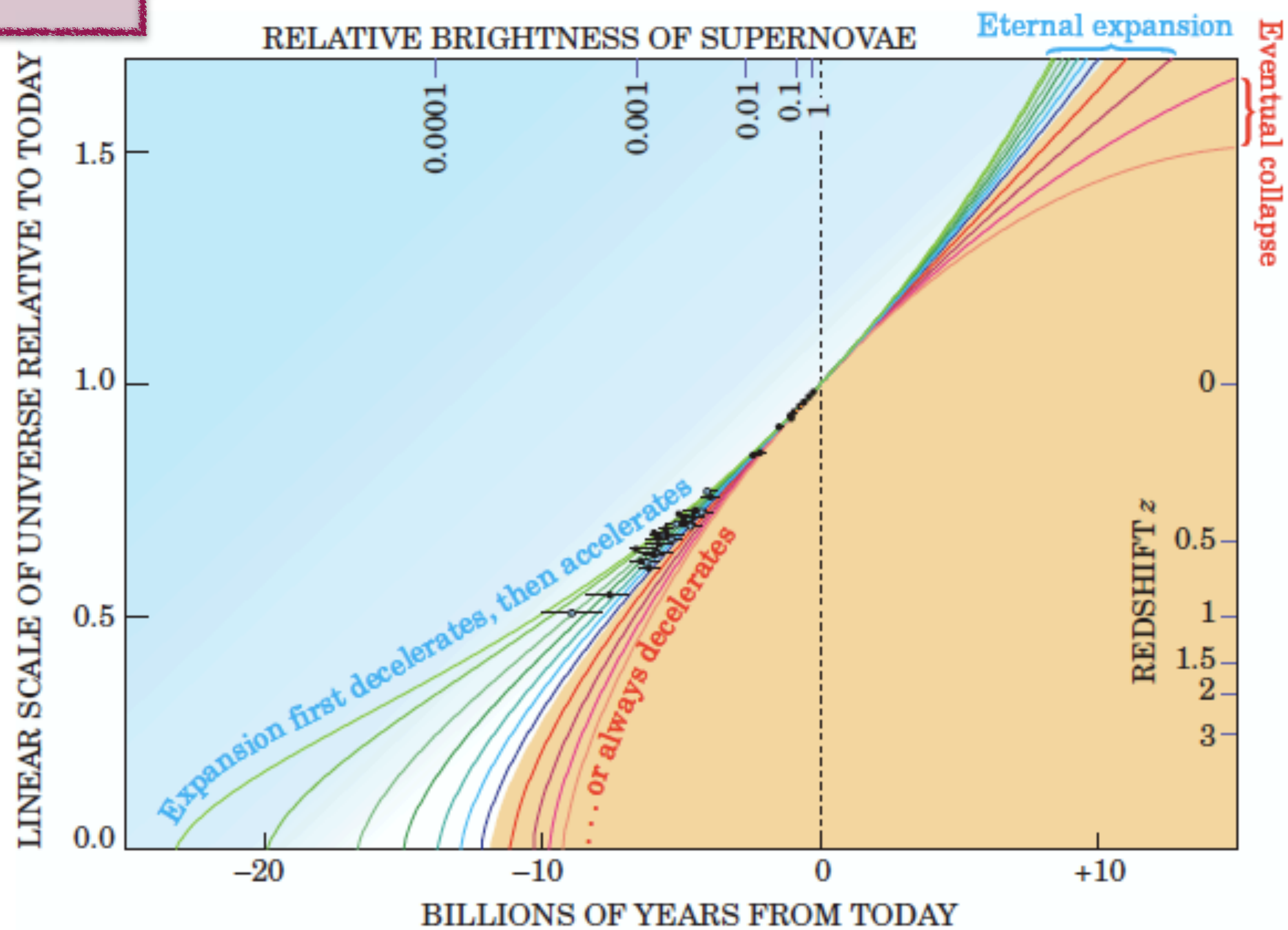
- Theoretical explanations:

  Failure of the GR ⇒ GR modification, New field, Backreactions from inhomogeneities, ..., Cosmological constant.

- Effective dark energy equation of state:

$$P = w_{DE}\,\rho$$

- $w_{DE} = -1.00 \pm 0.15$ from a combined analysis of CMB, SNIa and BAO by Kowalski et al. 2008.



Saul Perlmutter, Physics Today 2003

Measure of **H(z)** which depends on w_{DE}:

Luminosity distance $d_L(z)$ (angular diameter distance d_A)

The growth of structure with mass over-density field $\delta = (\rho - \rho_0)/\rho_0$ (ρ is the density field, ρ_0 mean density)

c f Sahni and Starobinsky 2006

Probes of Dark Energy with LSST

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- ✓**Type Ia Supernovae**
- ✓Thermonuclear explosion of white dwarf
- ✓Standard candles:

  Absolute magnitude vs. time can be calibrated
- ✓Probe: **Distance modulus vs redshift**:

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✓deflection and magnification of light source caused by an foreground massive object

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✓Baryon acoustic oscillations

✓Acoustic wave in the primordial plasma of photons, baryons, electrons, neutrinos and dark matter. Shape of the wave froze at decoupling → Standard ruler

✓Standard ruler evolves with the Universe expansion

✓Probe: Matter power spectra as a function of redshift

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Dark energy science requirements:

- ✓ **Wide:**

  Weak lensing, BAO and galaxies cluster.

- ✓ **Fast:**

  Limit the systematic uncertainties for weak lensing,

  Fast cadence for SNIa.

- ✓ **Deep:**

  Explore high redshift to test the variability of w_{DE} as a function of the scale factor.

- ✓ **Precise calibration:**

  Color zero points must be known for photometric redshift,

  High quality images for SN1a and weak lensing.

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LSST will conduct all the 4 dark energy science programs with the same data sample.

Other science programs with LSST

- **Solar system:**

  Identification of Near Earth Objects with 90% of completeness:

  diameter>140 m,

  distance<0.05 UA.

- **Milky way:**

  Over densities of red stars originated from dwarf galaxy with our galaxy,

  Study of star cinematic to probe the halo structure (inner and outer halo in opposite direction).

- **Transients:**

  Gamma ray burst, AGN structure, black hole or/and neutron star binary systems...

- **Dark matter** will be probed through LSS and strong lenses.

The LSST

www.lsst.org

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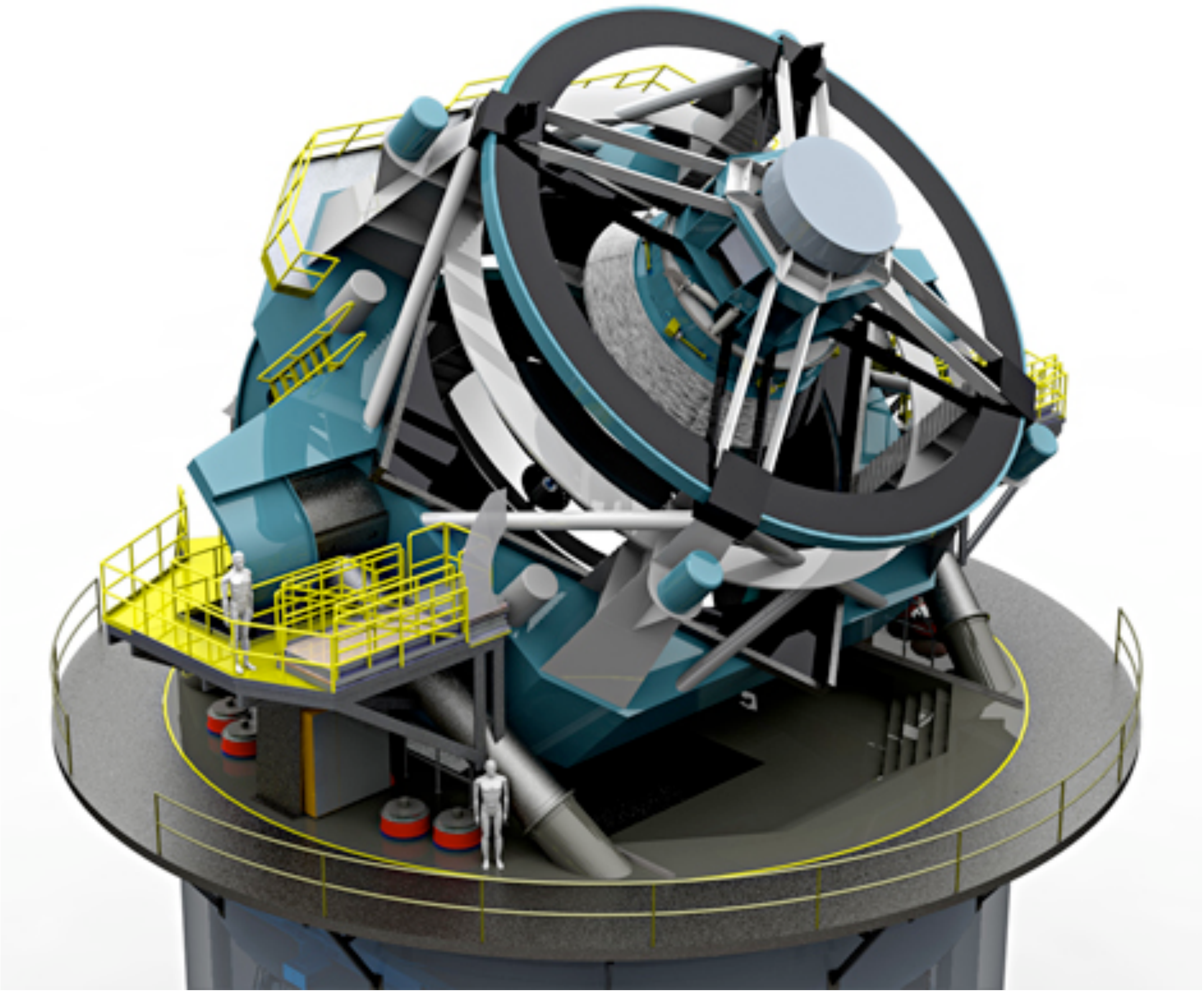

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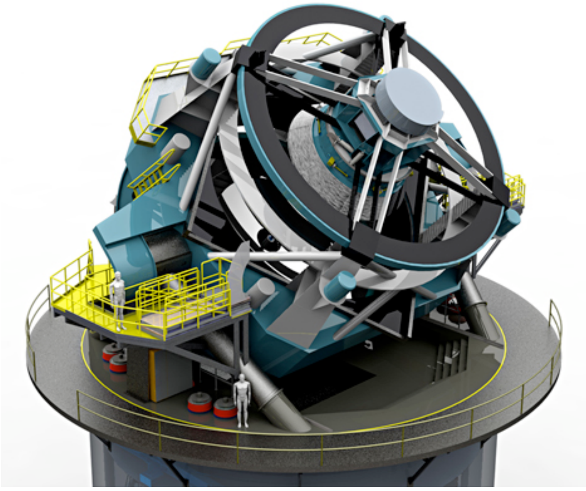

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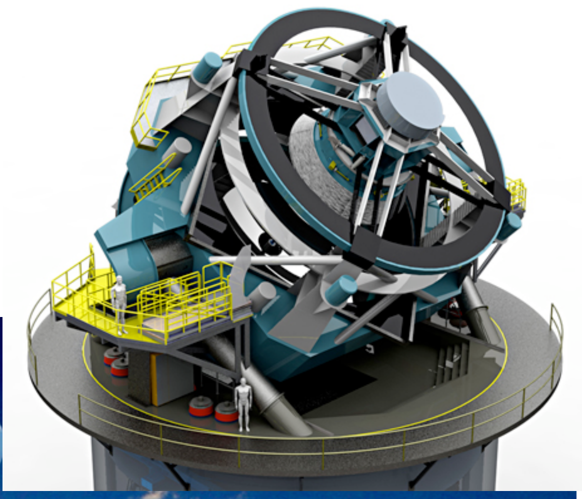

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- ✓ 9.6 deg^2 (3.5 deg) field of view,
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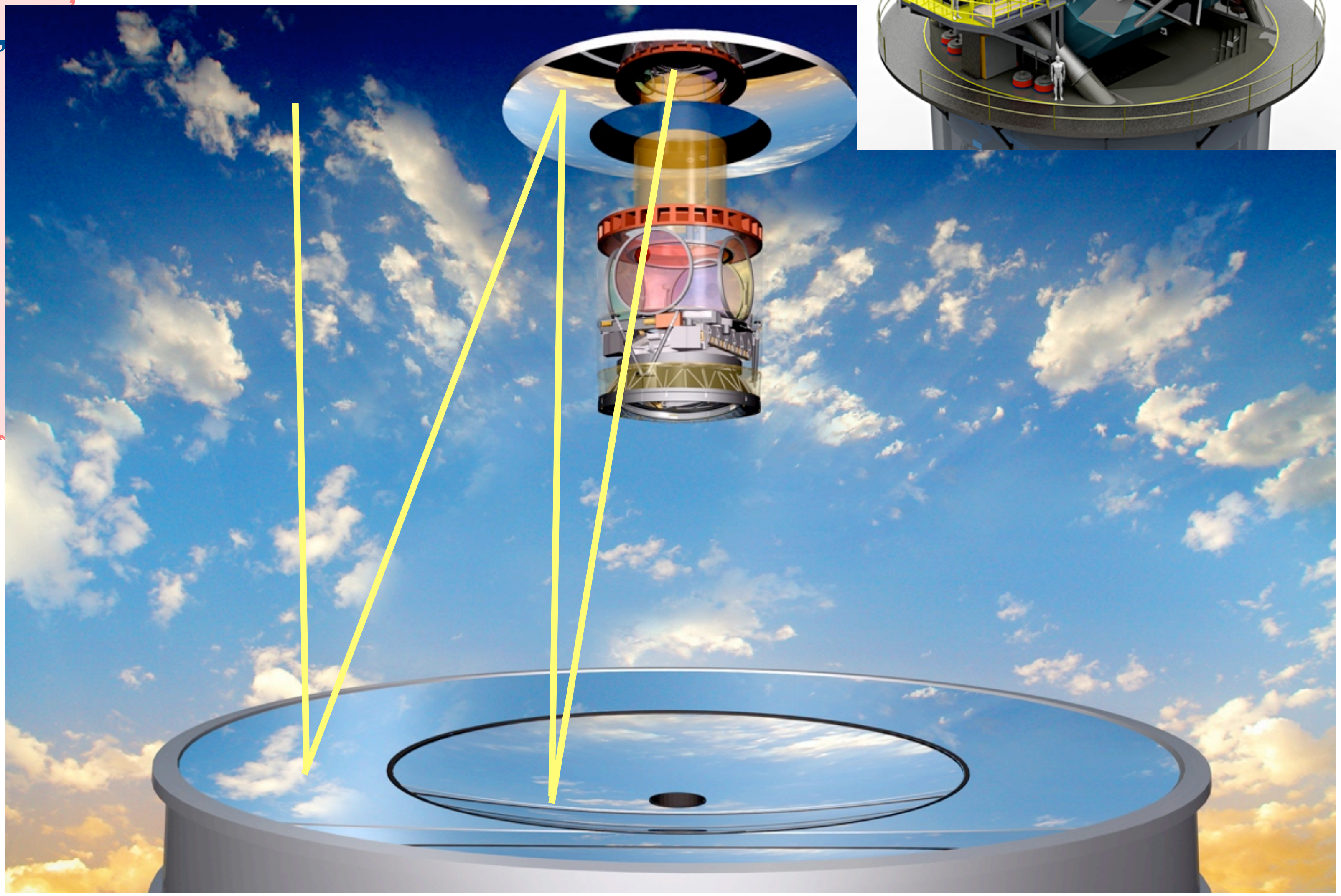

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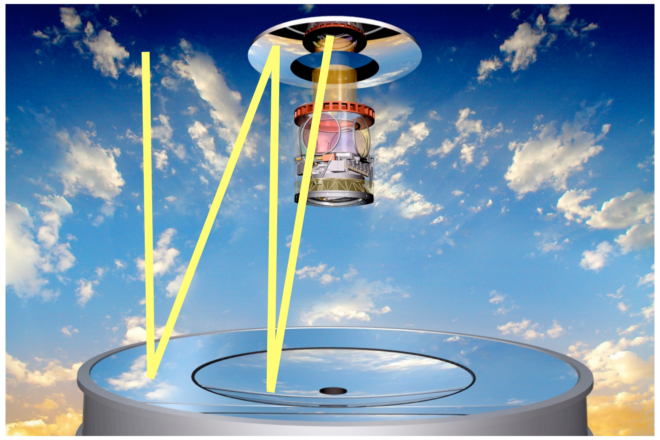

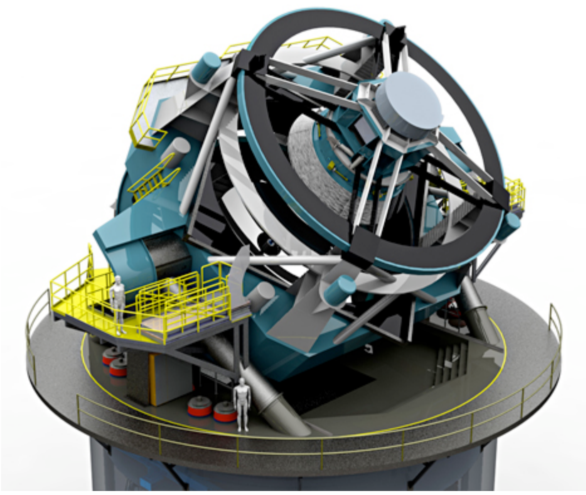

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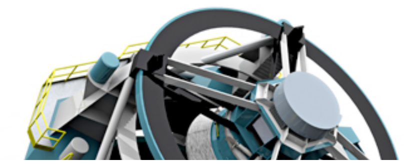

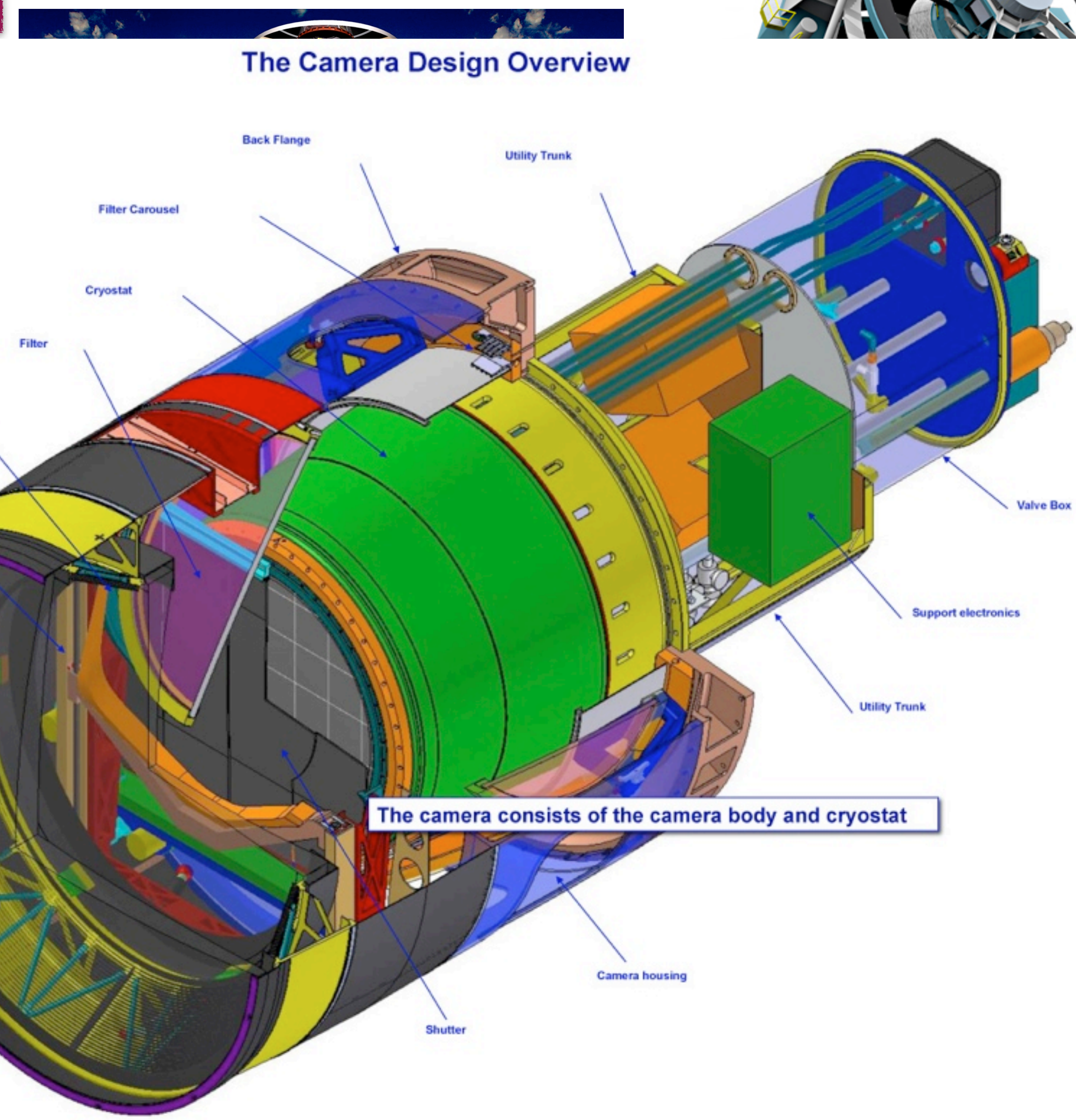

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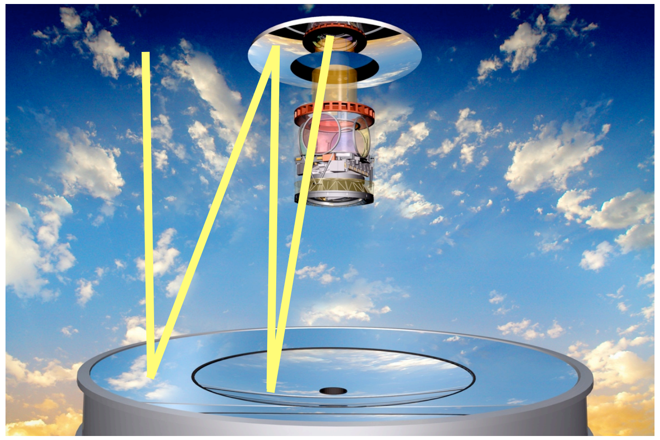

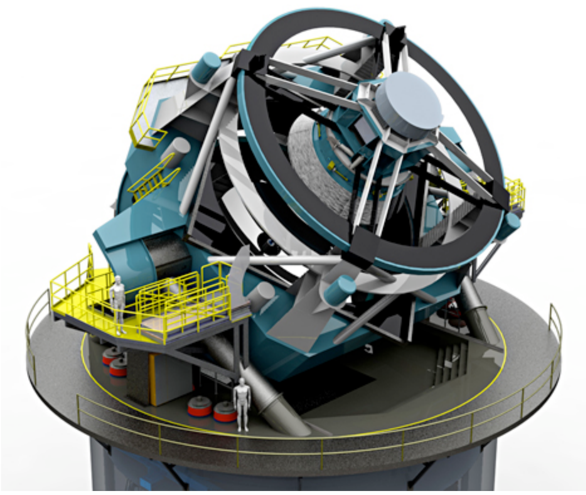

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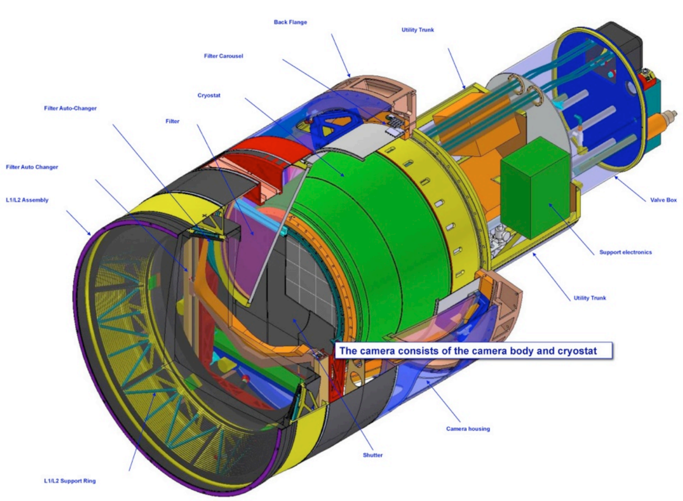

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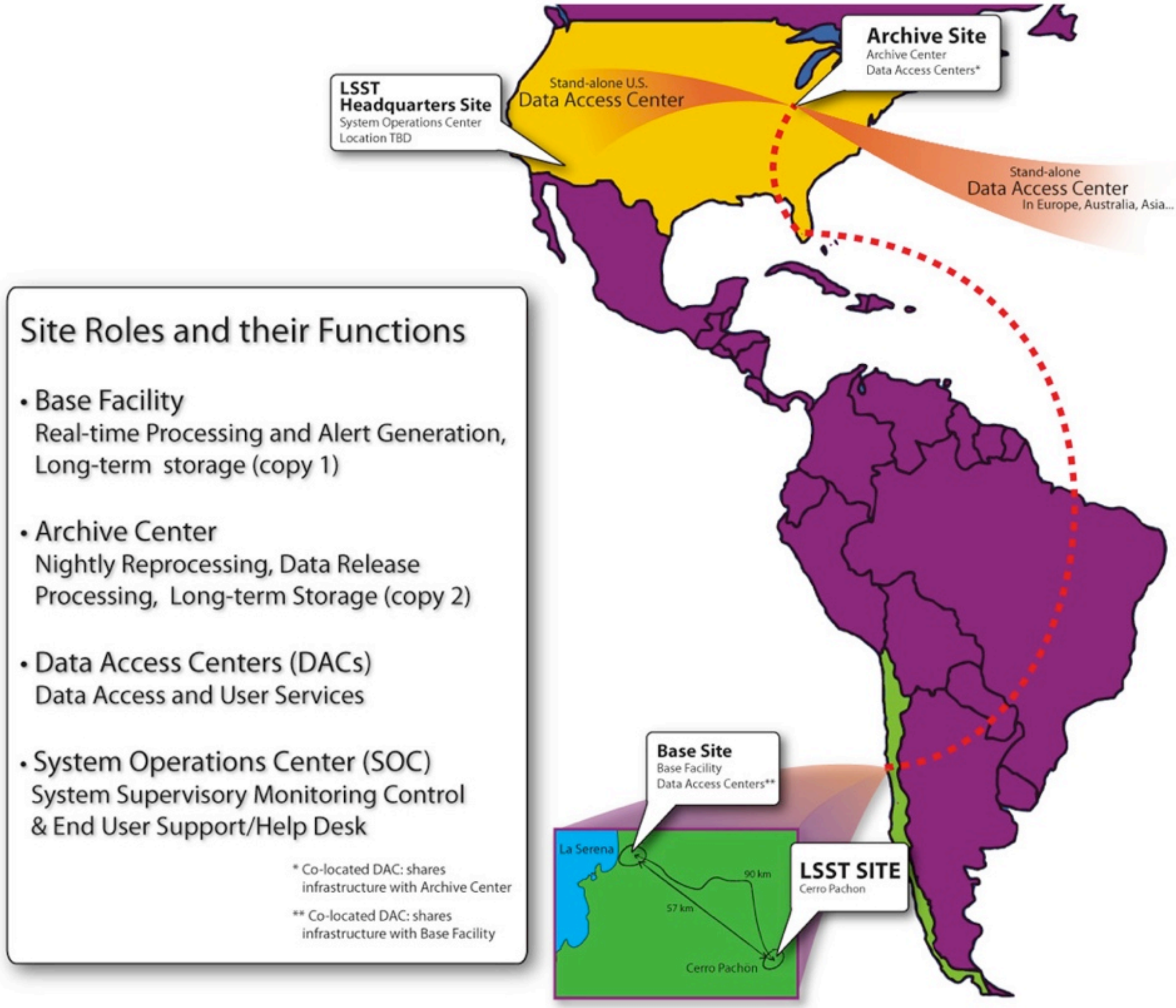

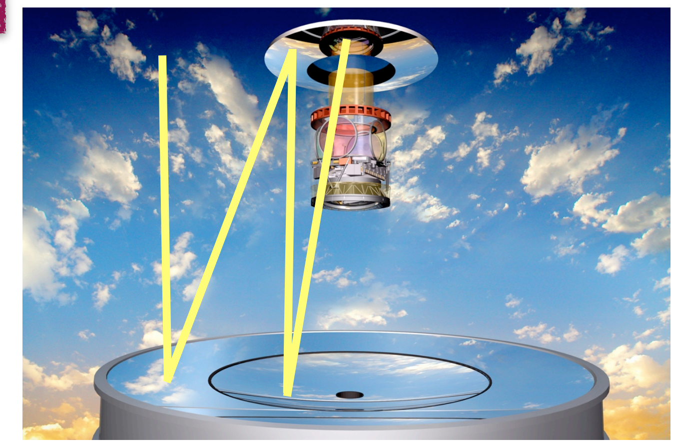

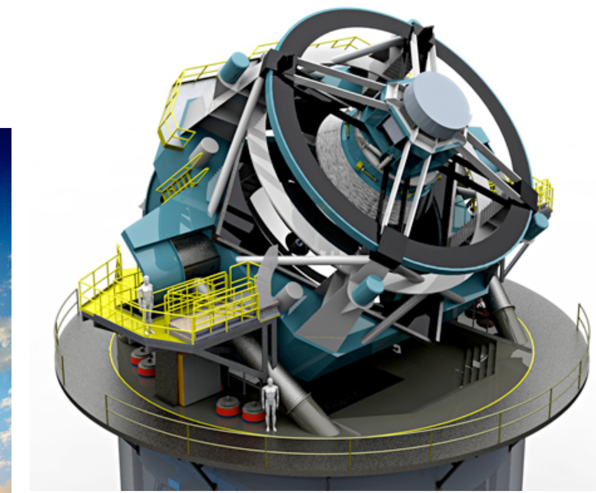

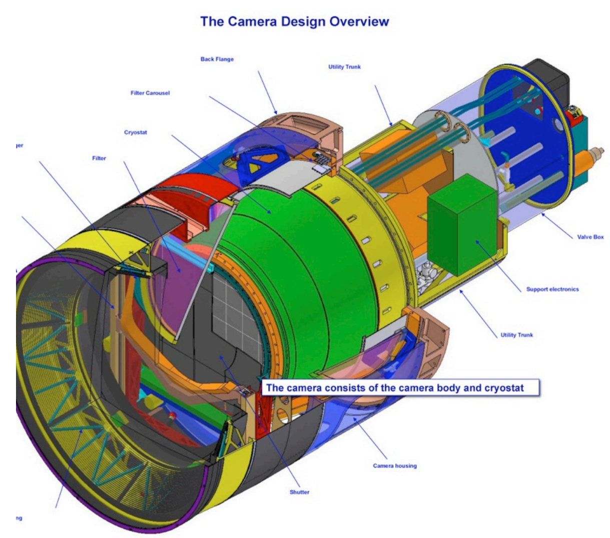

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✓Public data release of stacked catalog each year.

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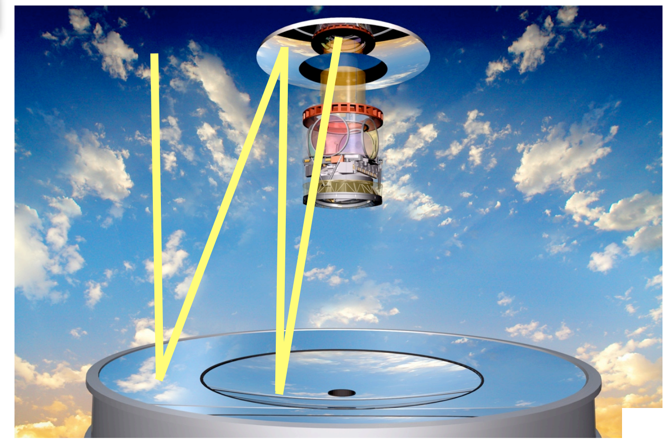

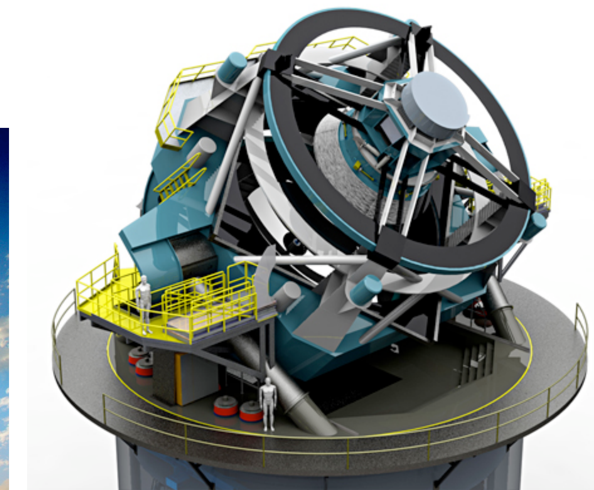

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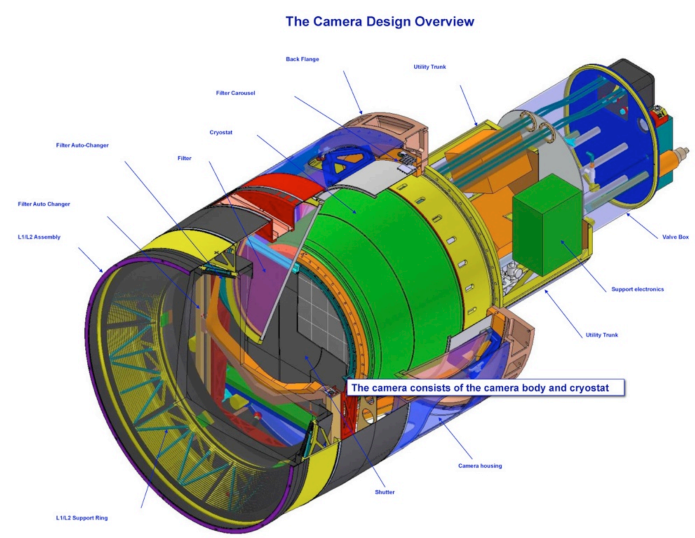

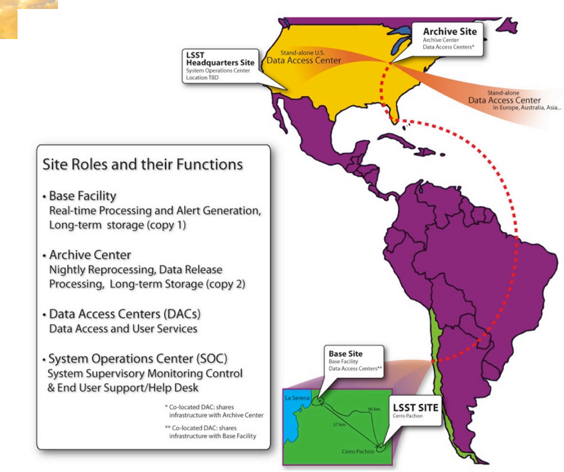

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✓ Mirrors and level site are under construction

✓ 2014 : NSF/DOE fundings,

✓ 3 → 4 years of construction,

✓ 2 years of commissioning/calibration

✓ **Operations begin in 2019-2020.**

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- Limit apparent magnitudes:

Limit Apparent Magnitude	u	g	r	i	z	y
LSST (10 years)	26.1	27.5	27.6	27.0	26.2	25.0
SDSS	22	22.2	22.2	21.3	20.5	

Photometric redshifts

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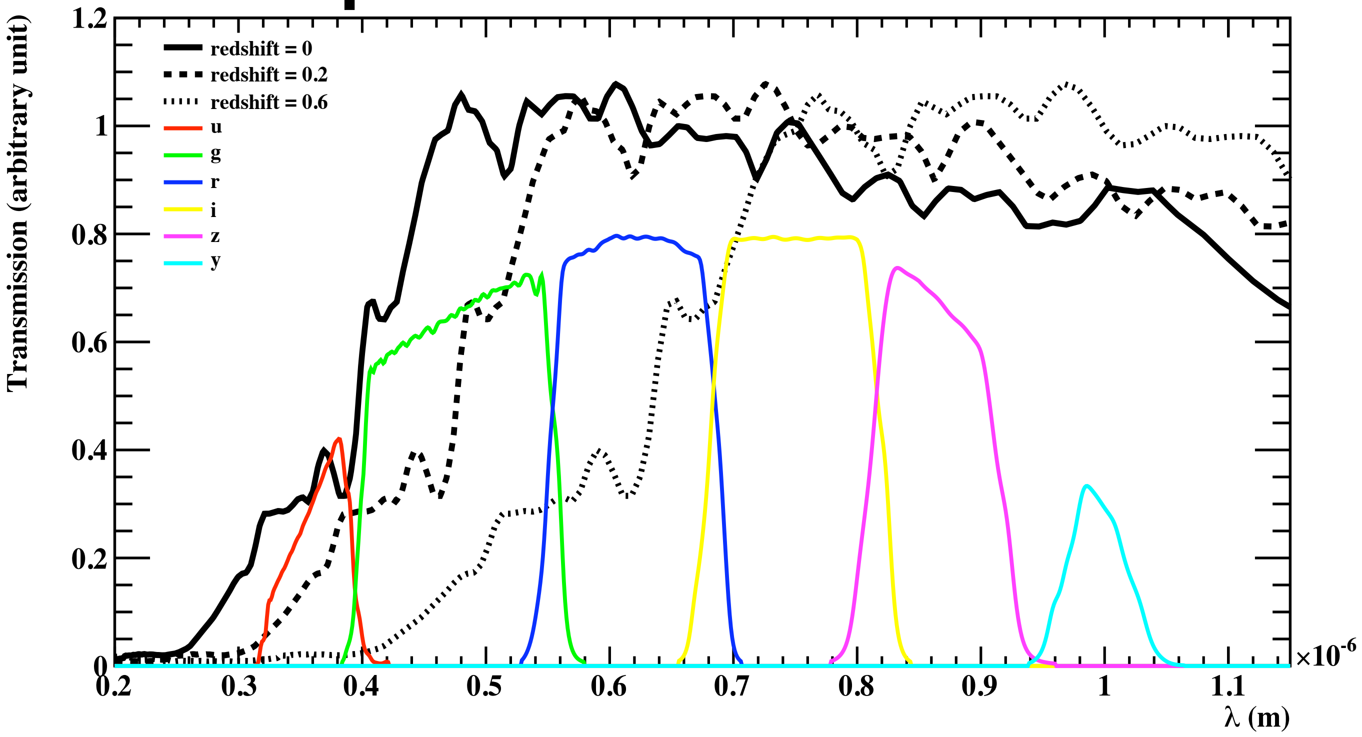
Spectrum redshifted



Photometric redshifts

- Central to any dark energy science program,
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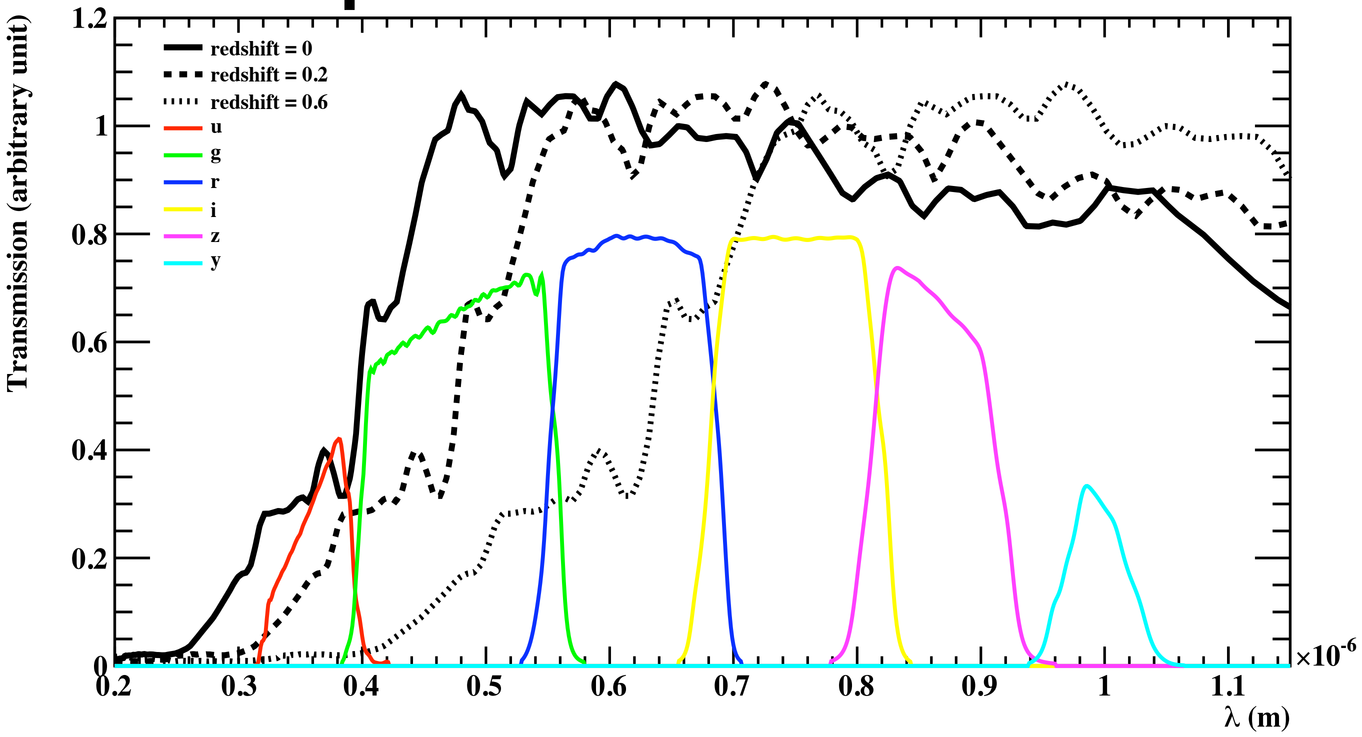

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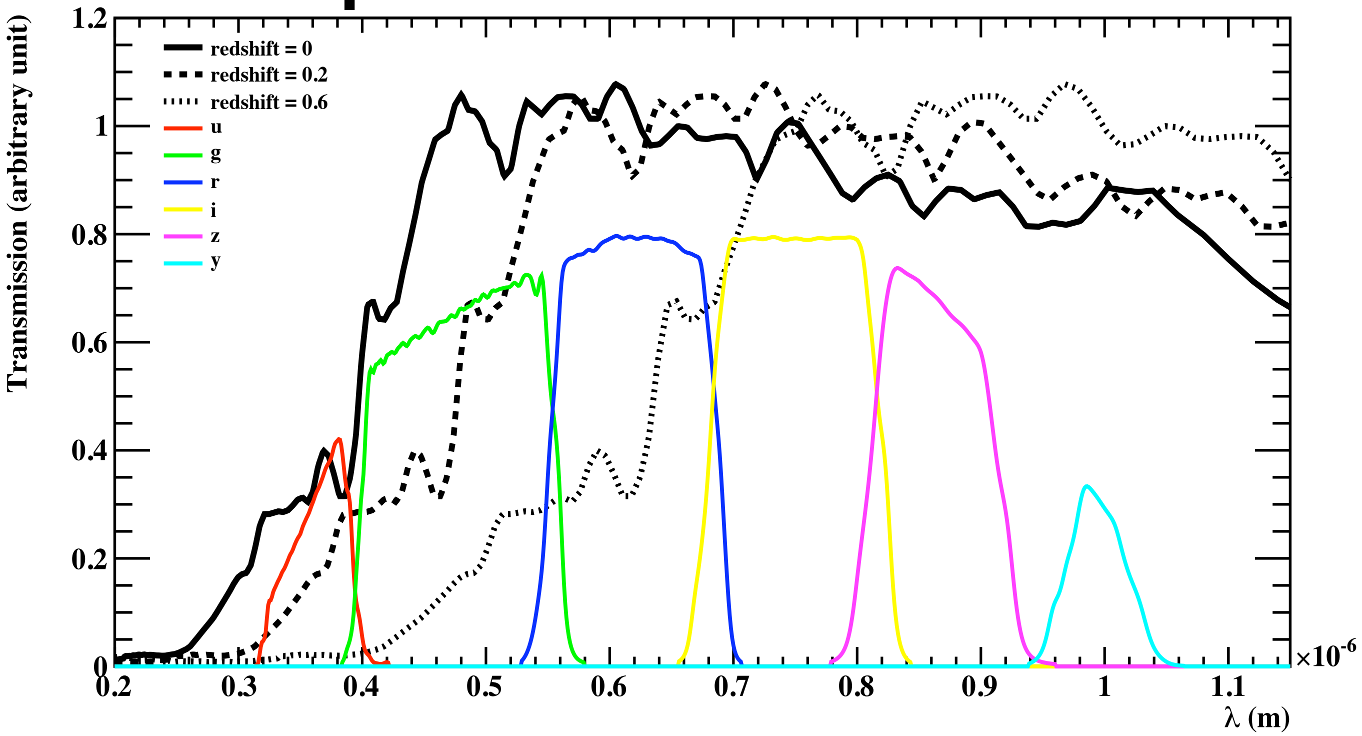

Apparent magnitudes-redshift **empirical relation** from a training sample (like neural network):

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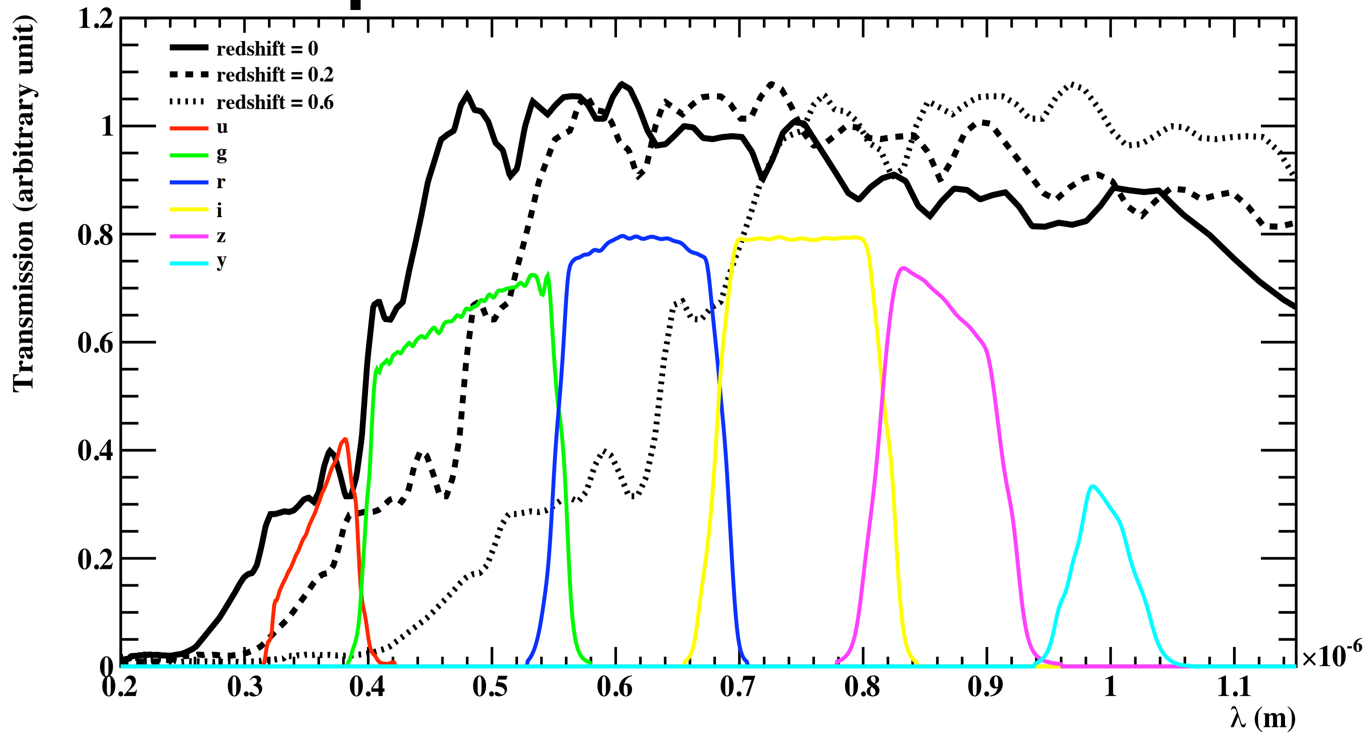

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Spectral energy density (SED) **template fitting**:

T= SED type, E(B-V)= excess color, N= normalization, z= redshift.

Likelihood maximization:

posterior probability density function (pdf) of parameters and parameter estimates.

Template fitting method expected resolution with LSST

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✓Statistical test that allow to remove outliers:

Likelihood ratio based on characteristics of the posterior pdf of T, E(B−V) and z.

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✓ Reach the LSST requirements up to redshift 2.5:

Bias of |zp−zs|/(1+zs)<0.003,

RMS of (zp−zs)/(1+zs)<0.02,

Percentage of outliers such that

|zp−zs|/(1+zs)>0.15 below 10%.

✓ Model:

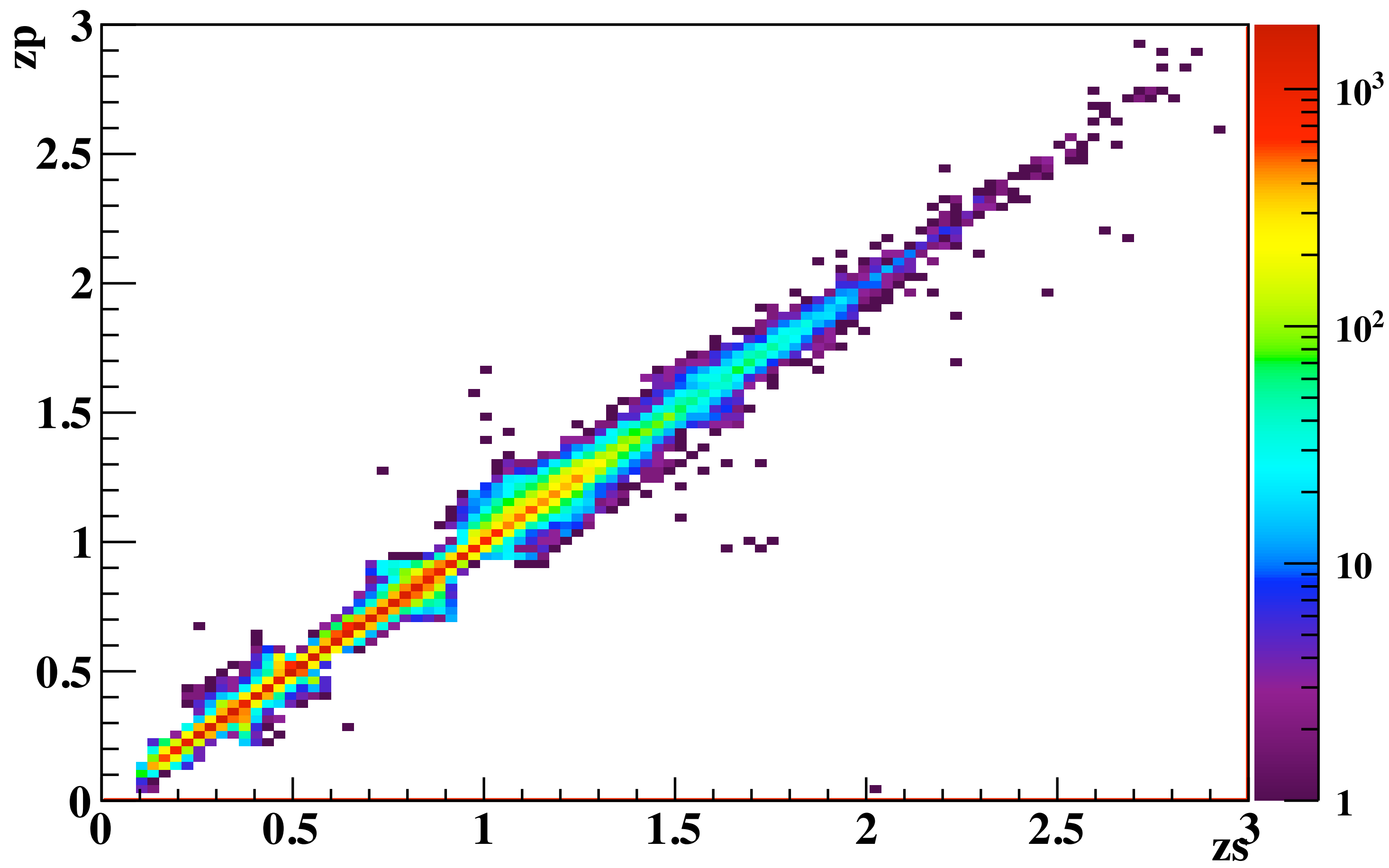
CWW+Kinney templates,

Cardelli and Calzetti dust extinction law,

Madau IGM law.

✓ Prior: Prob(T,z|i) (cf Benitez 2000).

✓ Photometric catalog simulation for 10 years of observations with S/N>5 in all bands.



A.Gorecki et al to be submitted

Prospective performances, some examples

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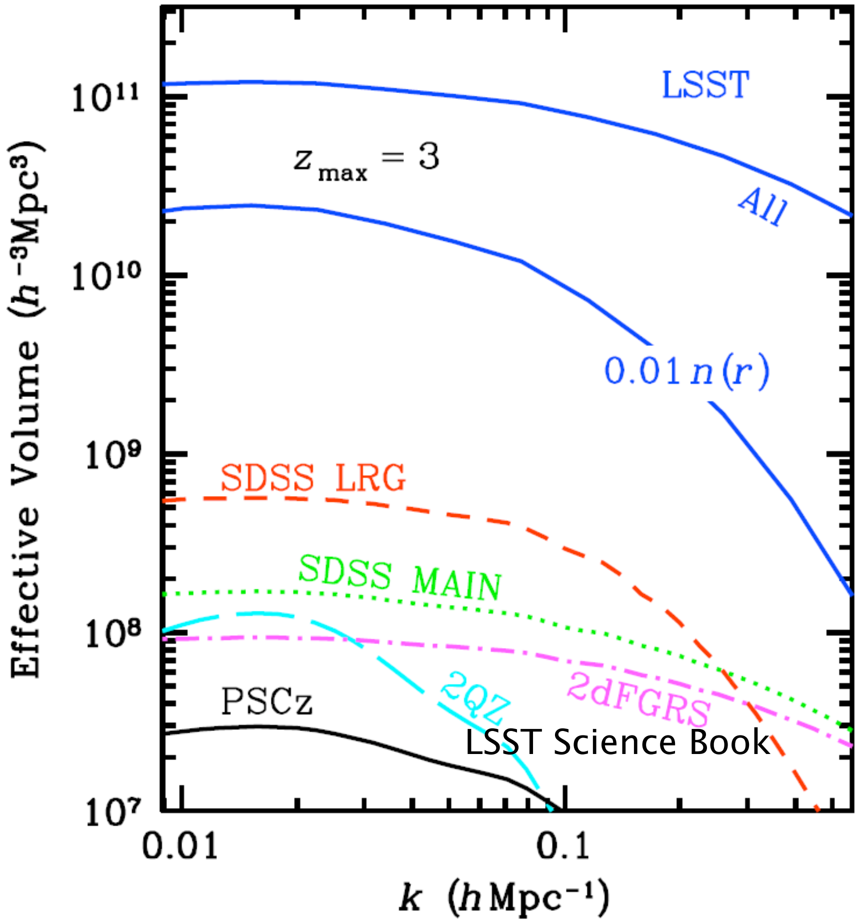
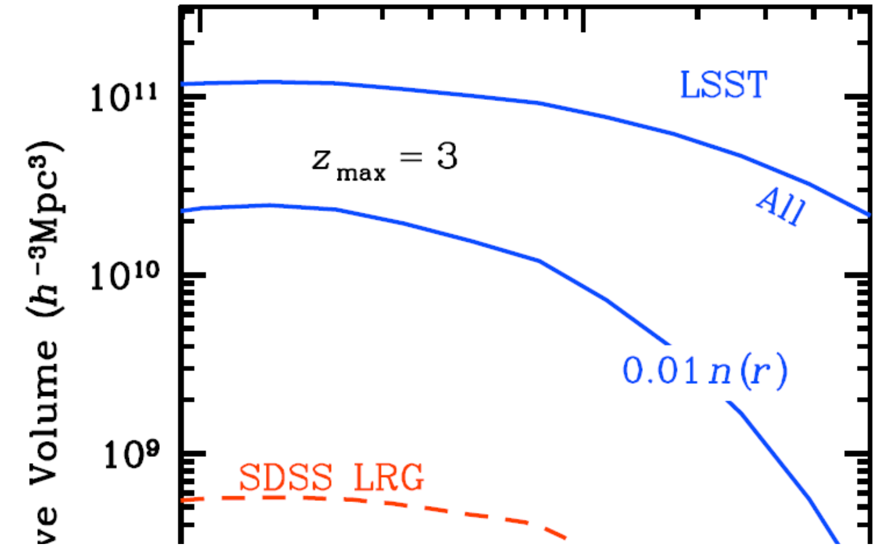


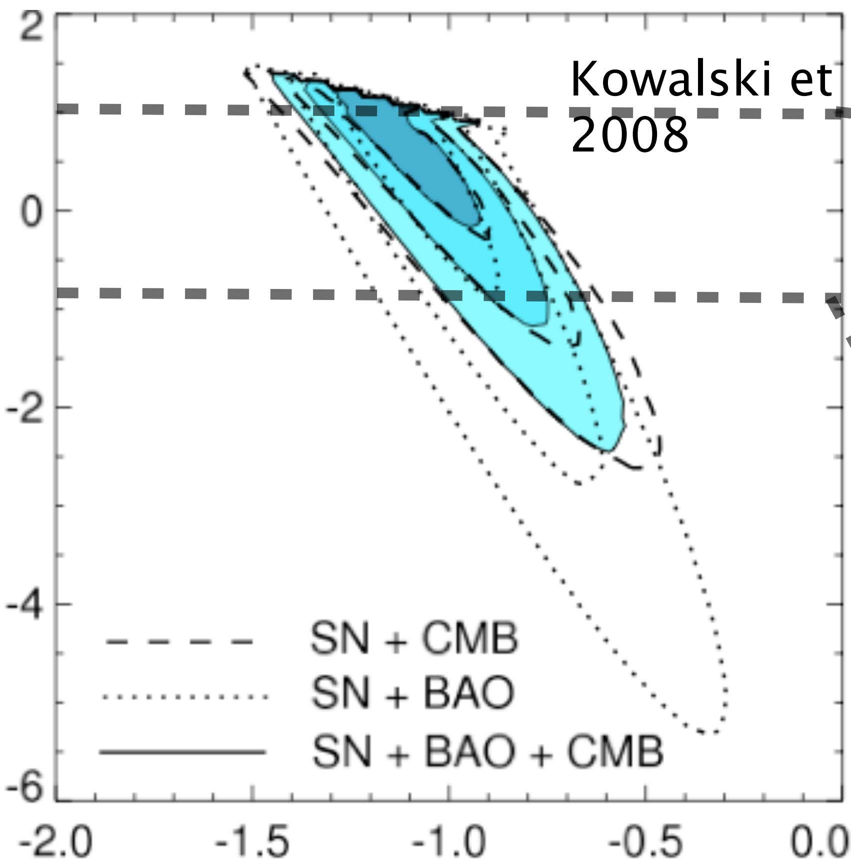
✓Very large effective volume for LSS,

✓Sufficiently large to select a «golden-sample» with high quality photometric redshift.

Prospective performances, some examples

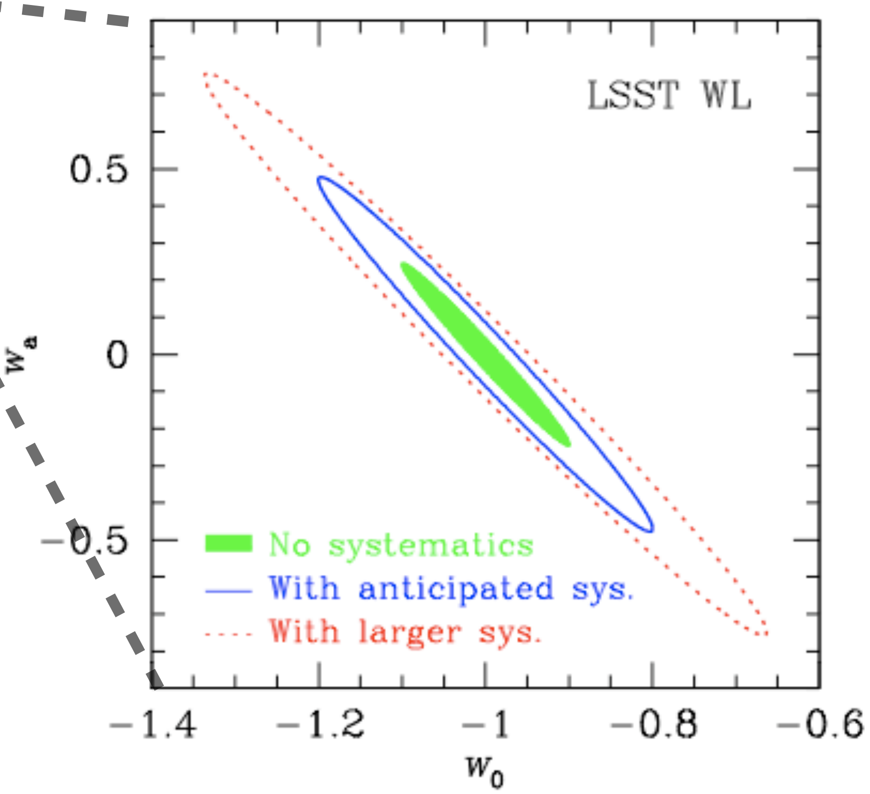


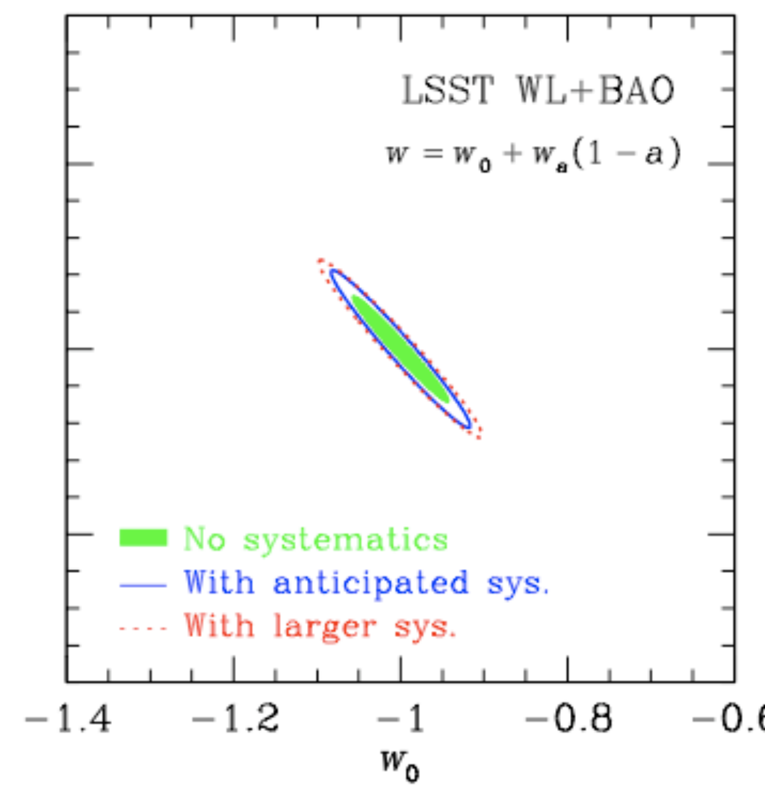
Kowalski et al 2008



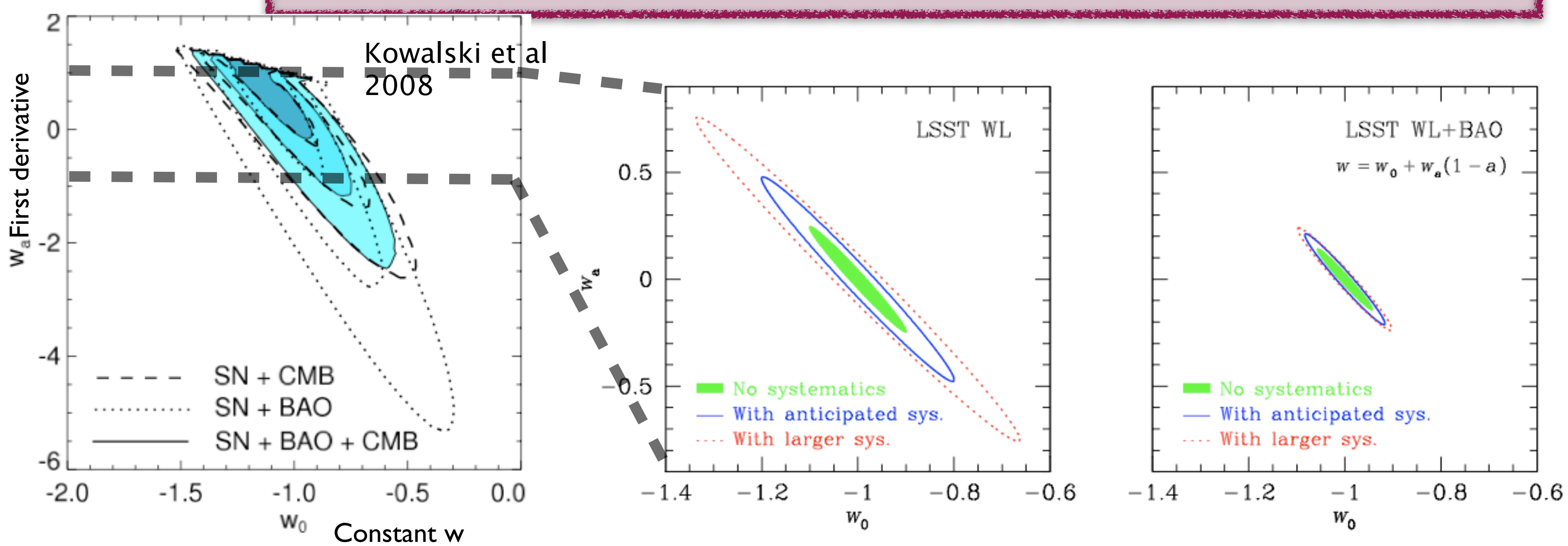
w_a First derivative

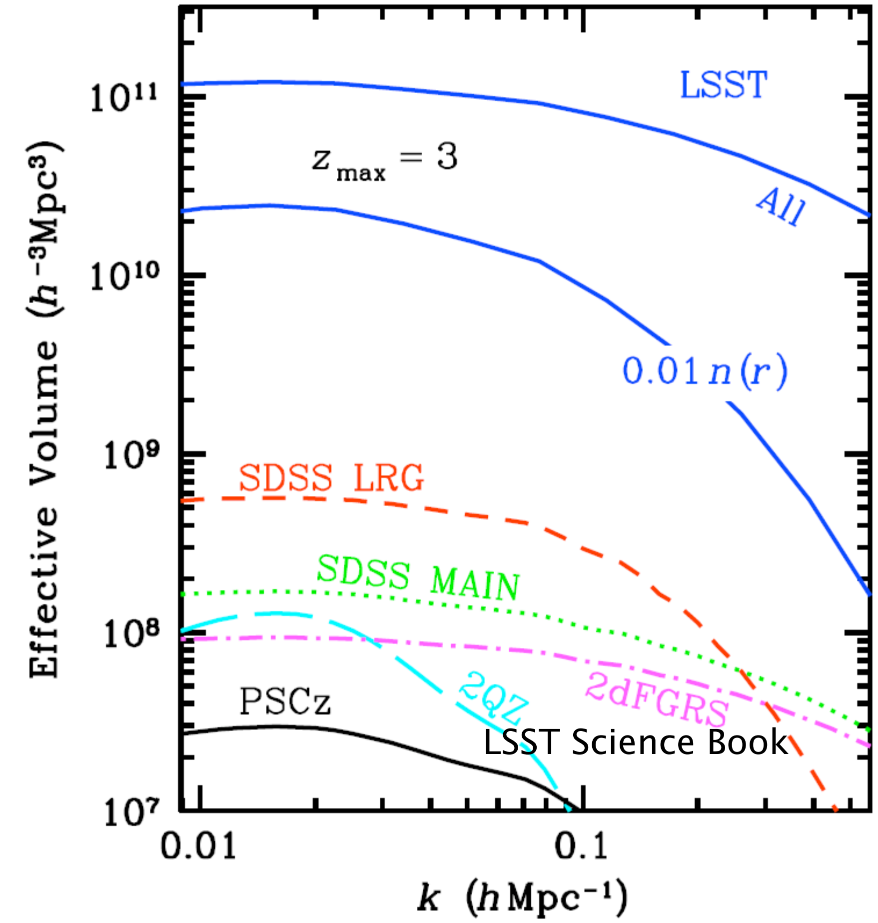
Constant w





Prospective performances, some examples





✓ Very large effective volume for LSS,

✓ Sufficiently large to select a «golden-sample» with high quality photometric redshift.

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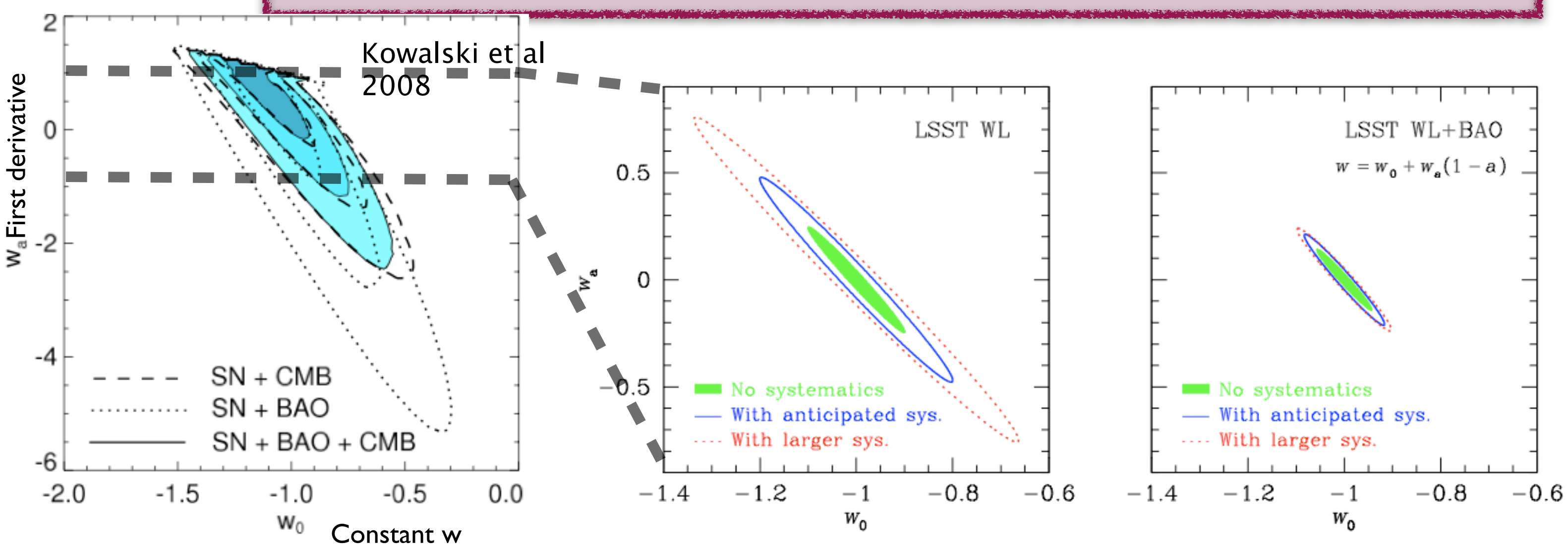

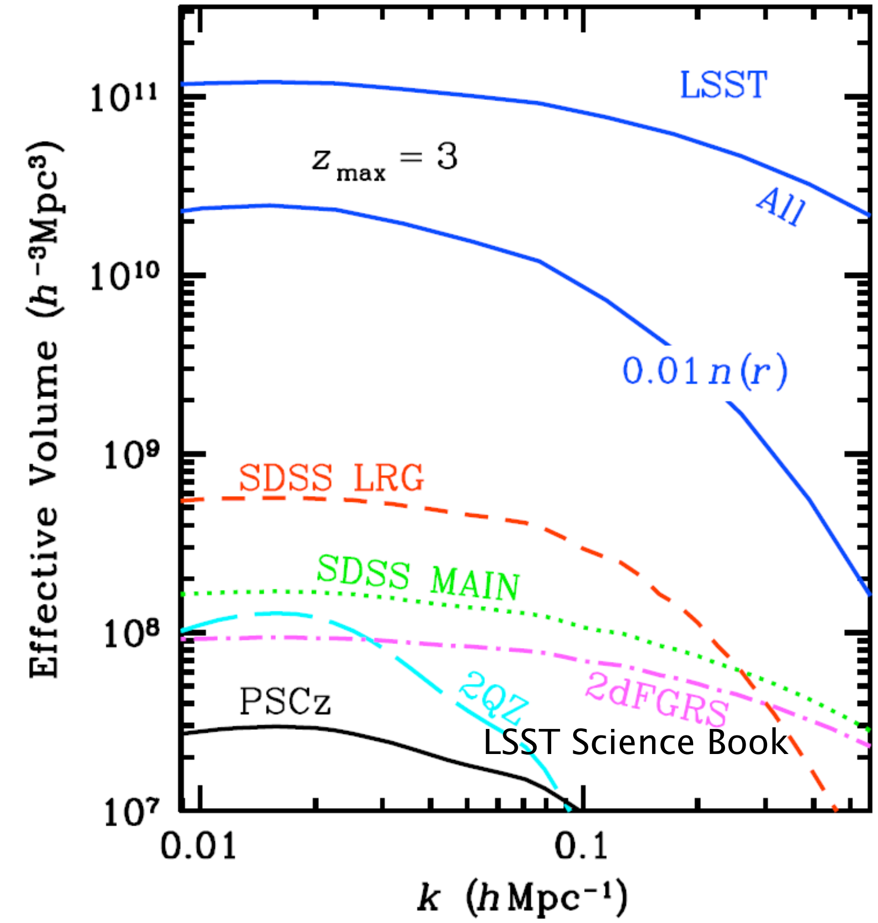

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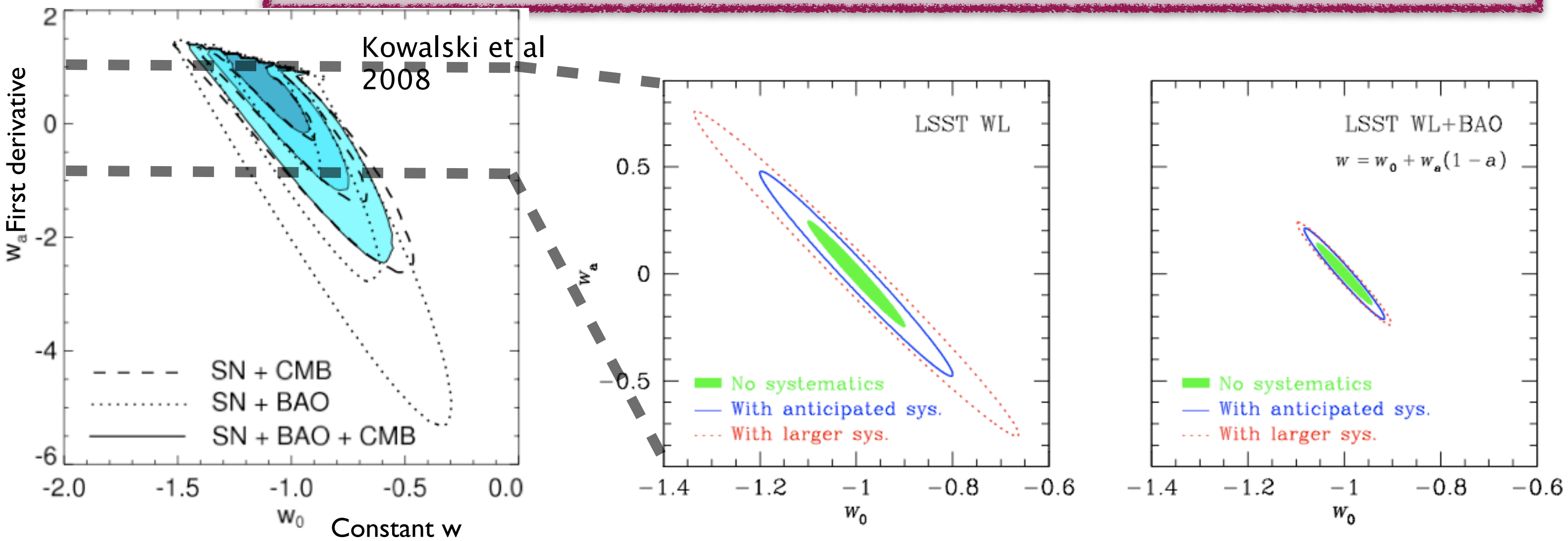

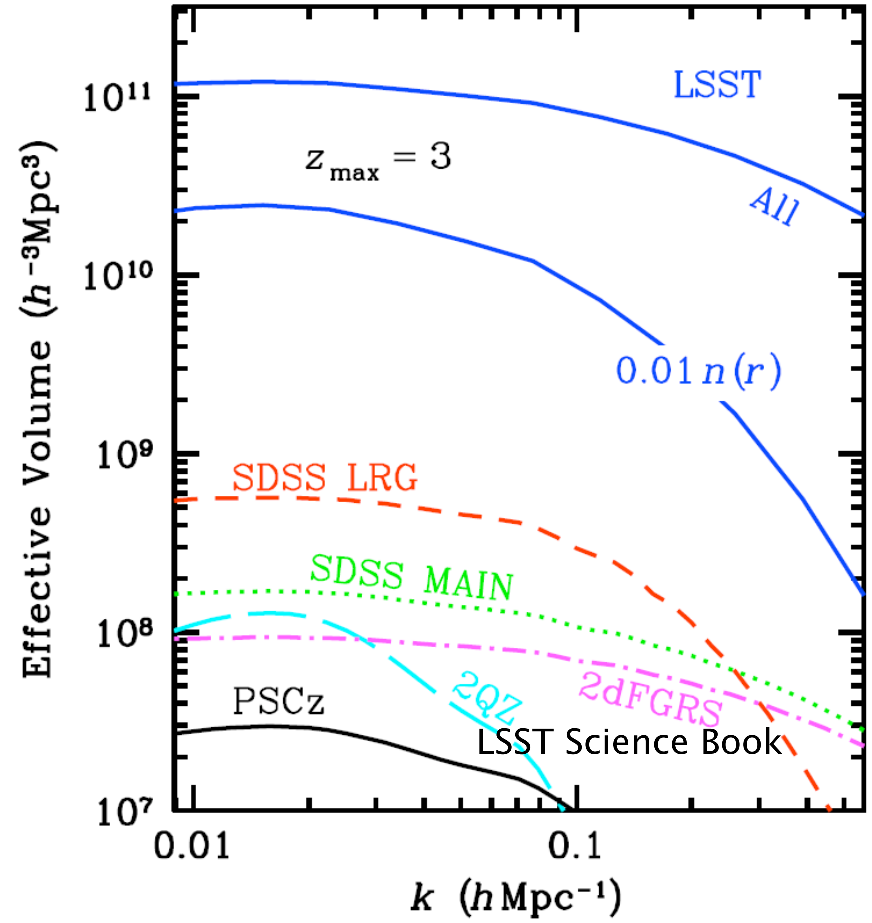

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DETF Stage-4: Improvement by a factor of 17 the figure of merit than current measurements.

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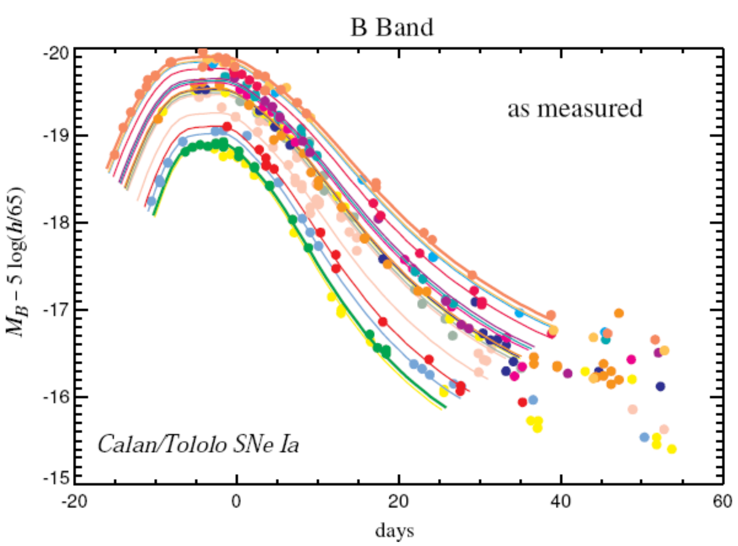
  - ✓ development of the LSST camera calibration optical bench (at LPSC)
- ✓ Photometric redshifts will be central:
  - ✓ Depend on the calibration training sample spectroscopic survey will necessary
  - ✓ Probable use of hybrid method (SED fitting and empirical method)
- ✓ Ongoing BAO simulation to predict uncertainty level on DE equation of state parameters (at LPSC and LAL)

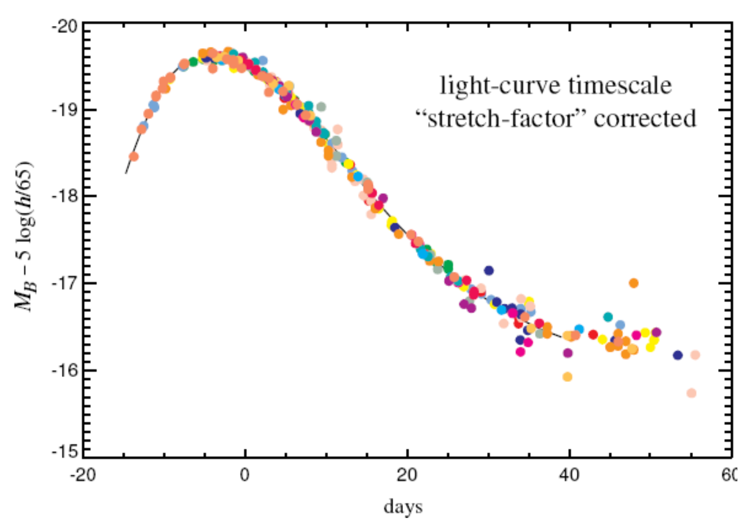
Thank you for your attention

Backup slides

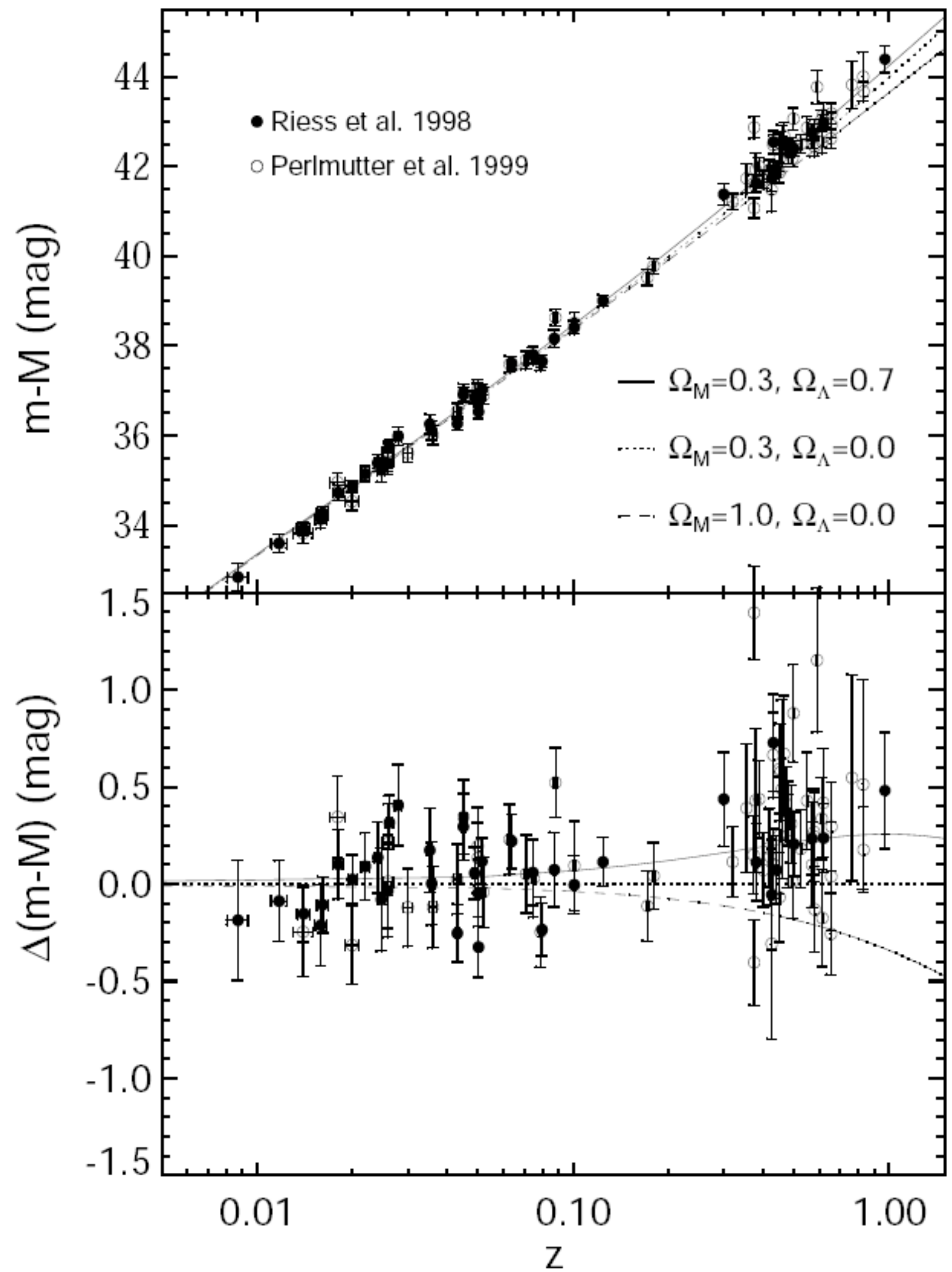
Probes of Dark Energy: Type Ia Supernovae

- Thermonuclear explosion of white dwarf of mass M: $$M = 1.4 M_\odot$$
- Why Type Ia are 'standard' candles: Ejection of a constant quantity of each element.
- The light curve (absolute magnitude vs. time) is calibrated.
- Probe: Evolution of the distance modulus with redshift: $$m - M = 5 \log\left(\frac{d_L(z)}{10(\mathrm{pc})}\right)$$
- But: Possible systematic effects from evolution of SN1a event





Kim 2004



Riess 2000

Probes of Dark Energy:Weak gravitational lensing

✓Convergence and shear parameters (κ, γ) are sensible to:

the **mass density profile** (growth of structure),

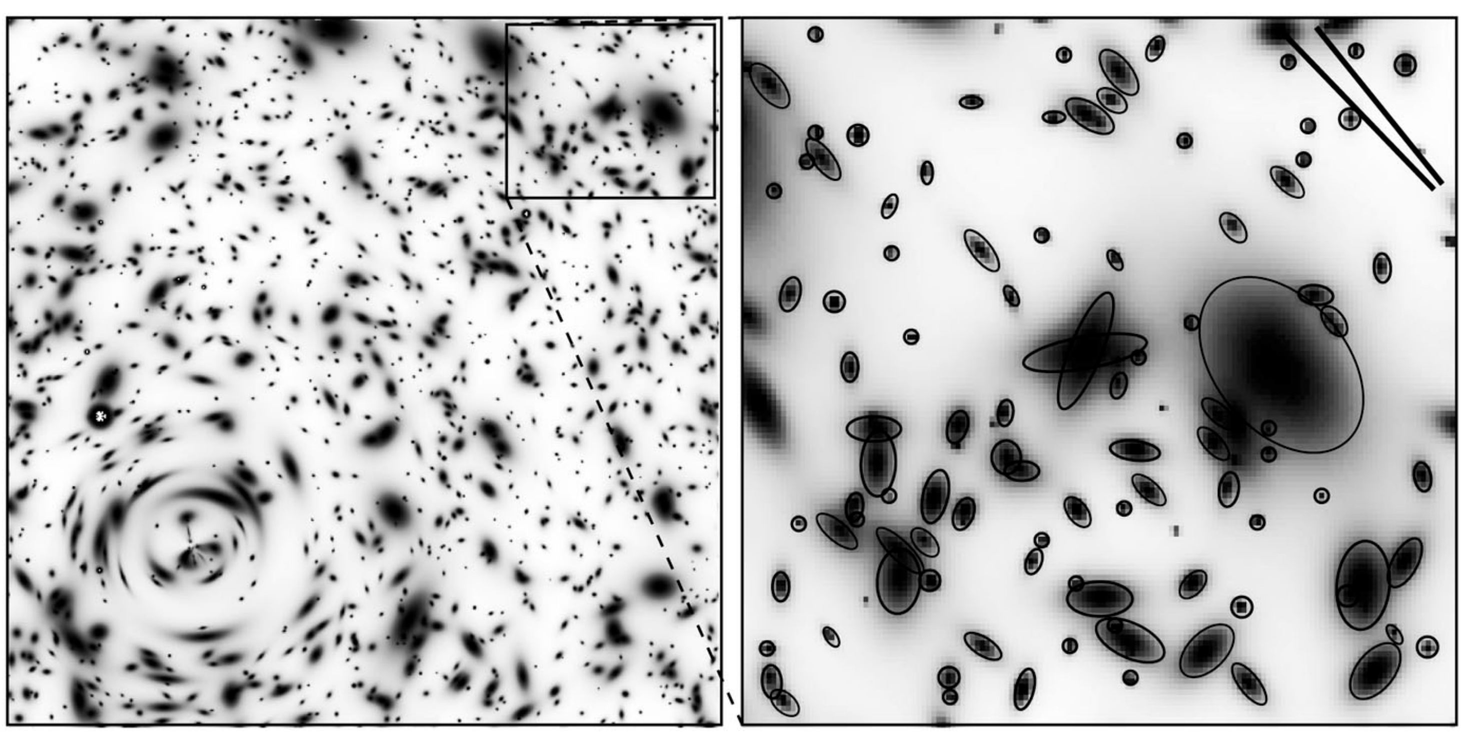
the **angular diameter distance** between, the observer the lens and the source.

✓<u>Probes:</u>

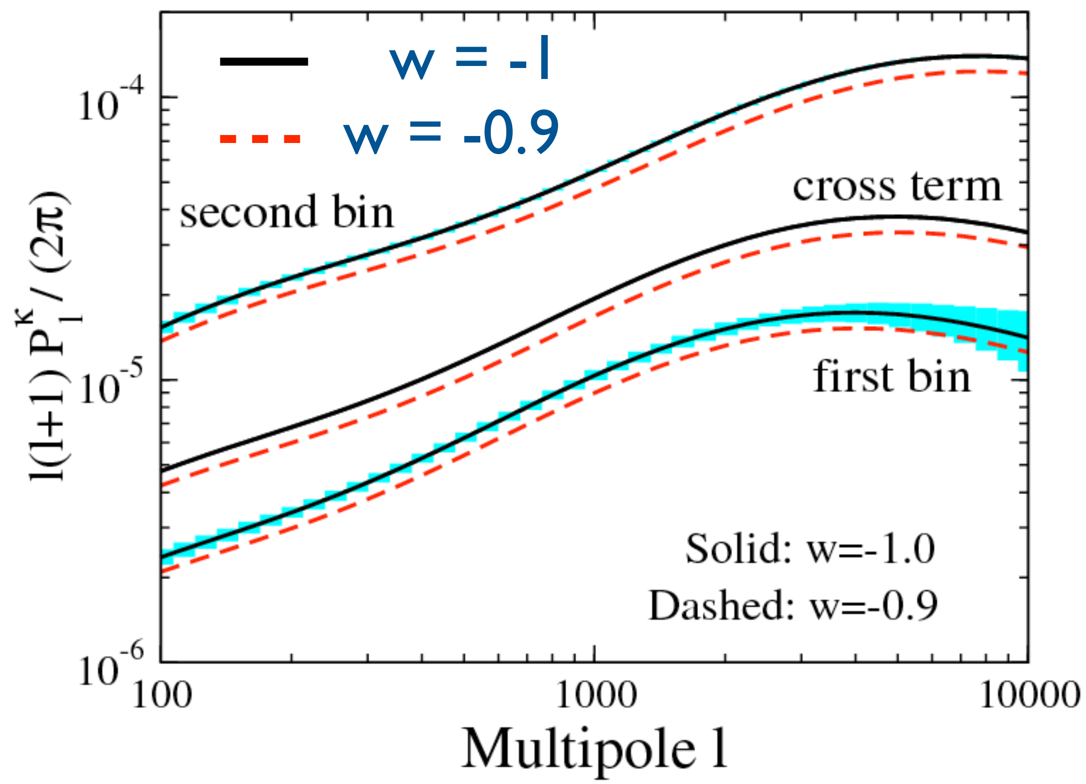
Convergence and shear correlation functions (⇔ power spectrum) between different redshift bin.

Multitude of statistics (power spectra, cross-spectra, bispectra) allow for internal checks

✓But: Systematic effects might be limiting



Mellier 1999



LSST Science Book 2009

Convergence angular power spectrum expected with LSST.

First bin: $z_s \in [0,1]$

Second bin: $z_s \in [1,3]$

Probes of Dark Energy: galaxy cluster count

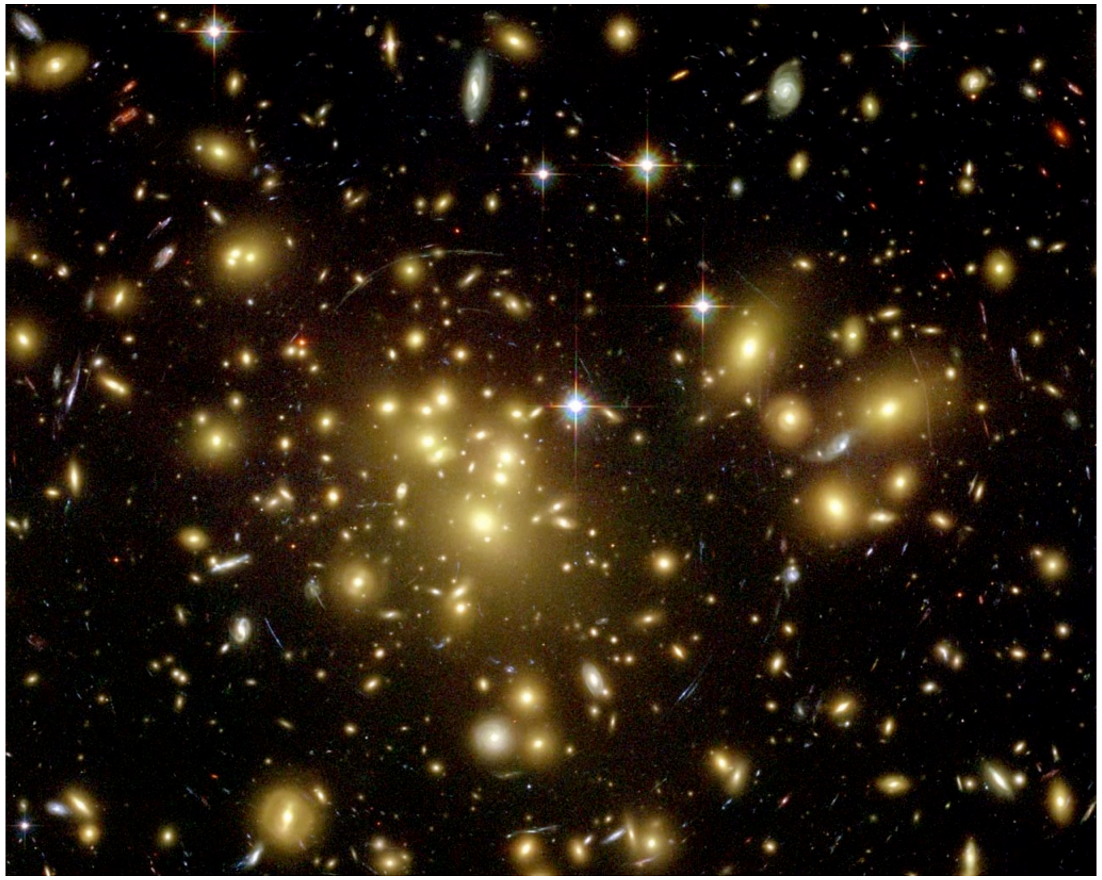
✓Identification of cluster:

Luminous Red Galaxies are often at the center of the cluster,

weak lensing gives the masse.

✓<u>Probe:</u> the change over time of the **galaxy number count of a given mass within a given volume**.

✓But:Still some uncertainties on the model of mass-observable relations



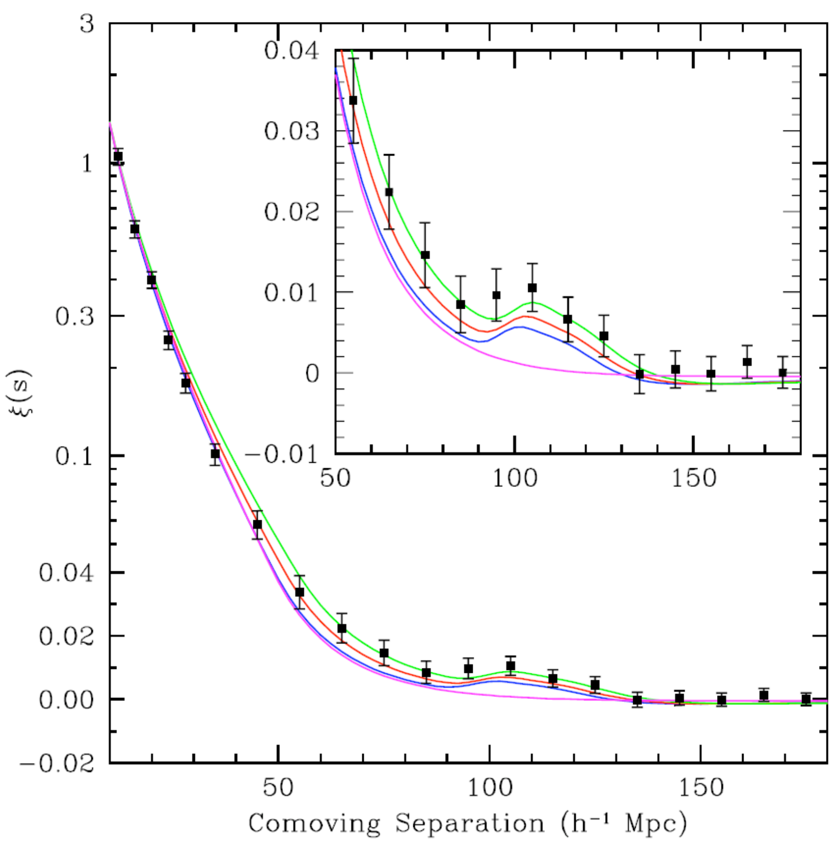
Abell 1689 (HST)

Volume sensible to the the DE parameters and other cosmological parameter

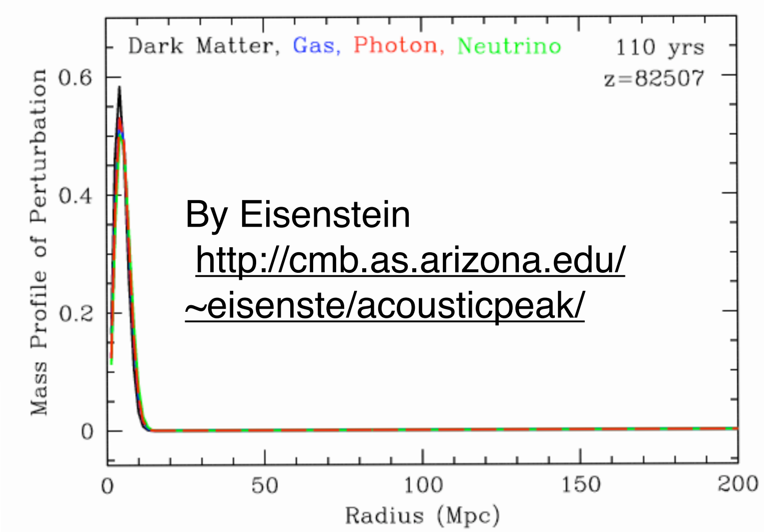
Mass sensible to the growth of structure

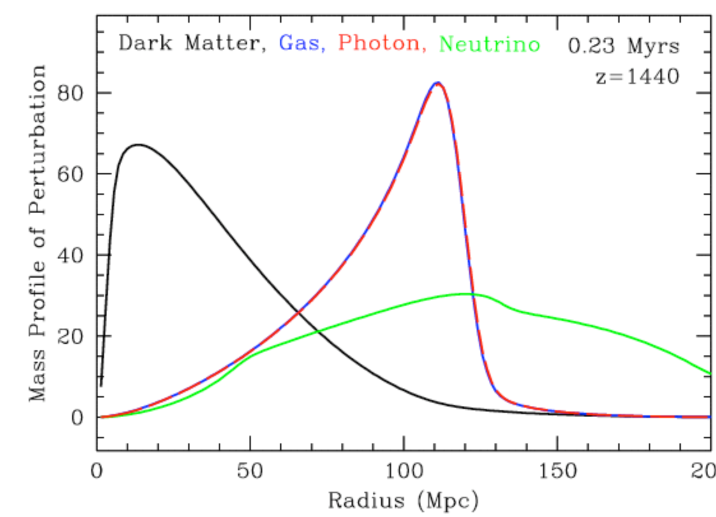
Probes of Dark Energy:Baryon acoustic oscillations

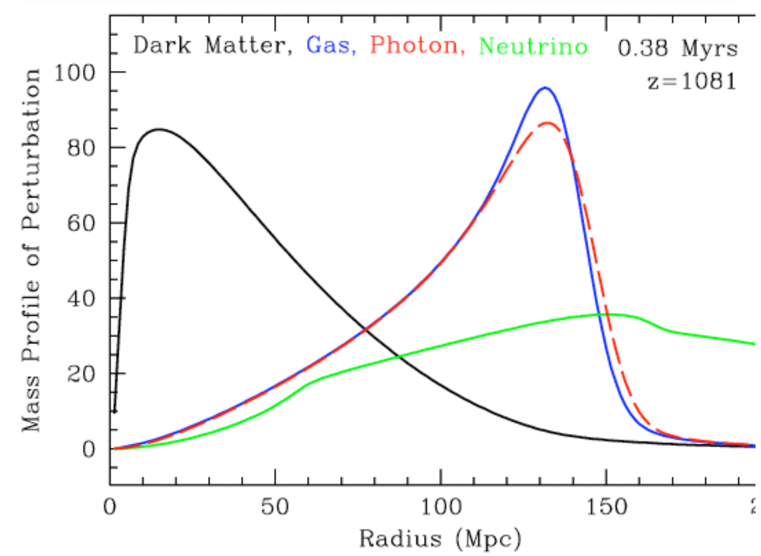
- ✓ Acoustic waves in the primordial plasma of baryons, electrons, dark matter and photons. Competition between the radiation pressure and the gravitational force caused by DM. Imprinted in both CMB (temperature anisotropies) and galaxies positions (over–density field).
- ✓ At decoupling ($z \approx 1100$), the shape of the wave is frozen.
- ✓ The size of the sound horizon which is a **standard ruler** then **follows the expansion of the Universe.** It is scaled with the temperature anisotropies of the CMB.
- ✓ <u>Probe:</u> Galaxy position correlation function peak (⇔ Power spectrum oscillations)
- ✓ But: only transverse BAO. Longitudinal BAO will affected by photoz

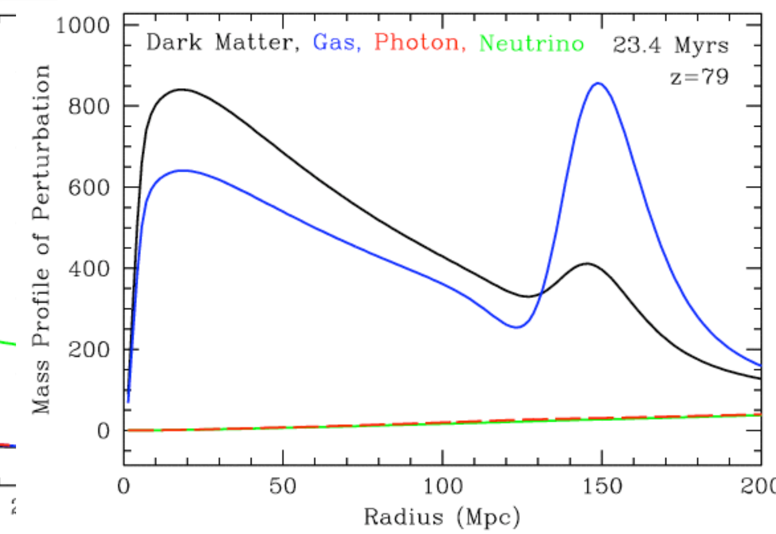


Eisenstein et al. 2005



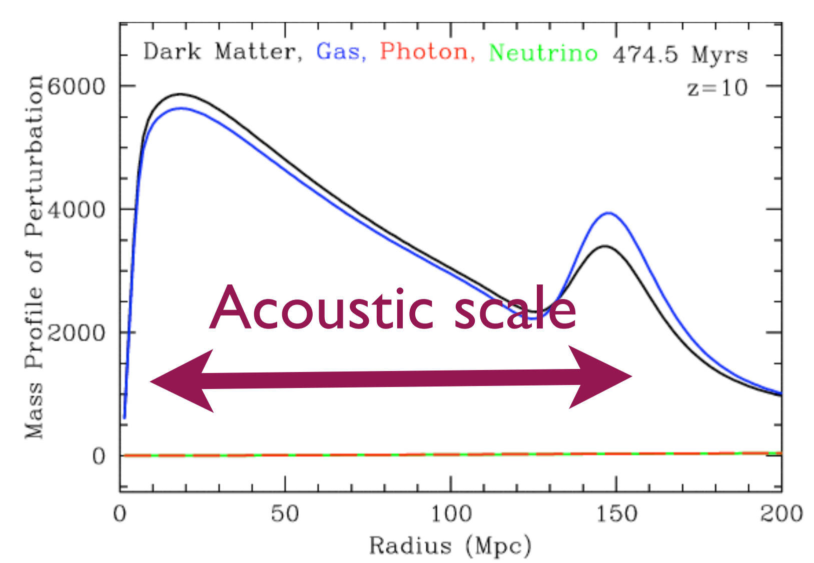






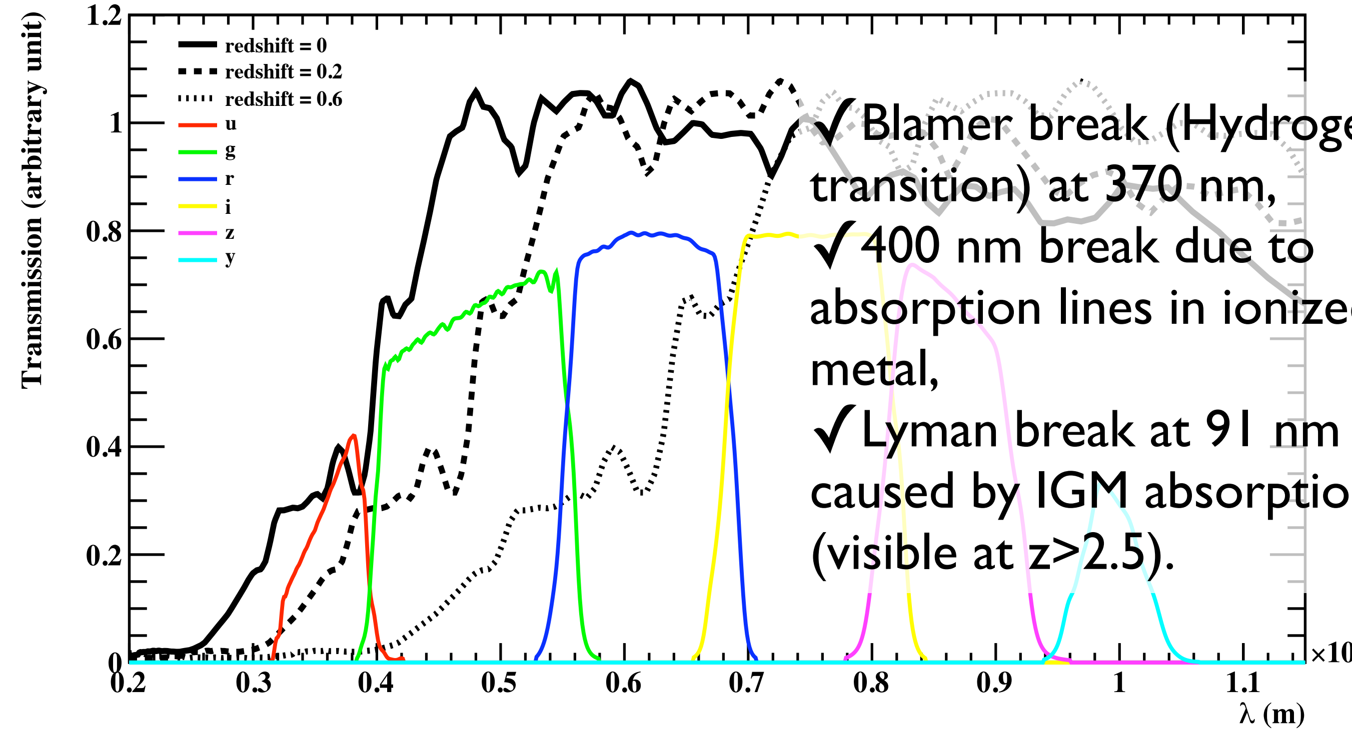
<u>In real space:</u> Peak at s = 150 Mpc ($100h^{-1}$Mpc)
<u>In Fourier space:</u> Wiggles of wavenumber
$\Delta k/h = 2\pi/100 = 0.06\ hMpc^{-1}$

($h = 0.7$ today)



Photometric redshifts

- ✓ Central to any dark energy science program,
- ✓ Evaluate the redshift of objects from 6 apparent magnitudes → Low resolution spectroscopy,
- ✓ Effects: smear the position of the galaxies.



✓Blamer break (Hydrogen transition) at 370 nm,
✓400 nm break due to absorption lines in ionized metal,
✓Lyman break at 91 nm caused by IGM absorption (visible at z>2.5).

Apparent magnitudes-redshift **empirical relation** from a training sample (like neural network):

Need a representative training sample of galaxies for which we know the spectroscopic redshift.

Spectral energy density (SED) **template fitting**:

T= SED type, E(B-V)= excess color, N= normalization, z= redshift.

Likelihood maximization:

posterior 2D, 1D probability density function (pdf)

parameter estimates.

likelihood profile