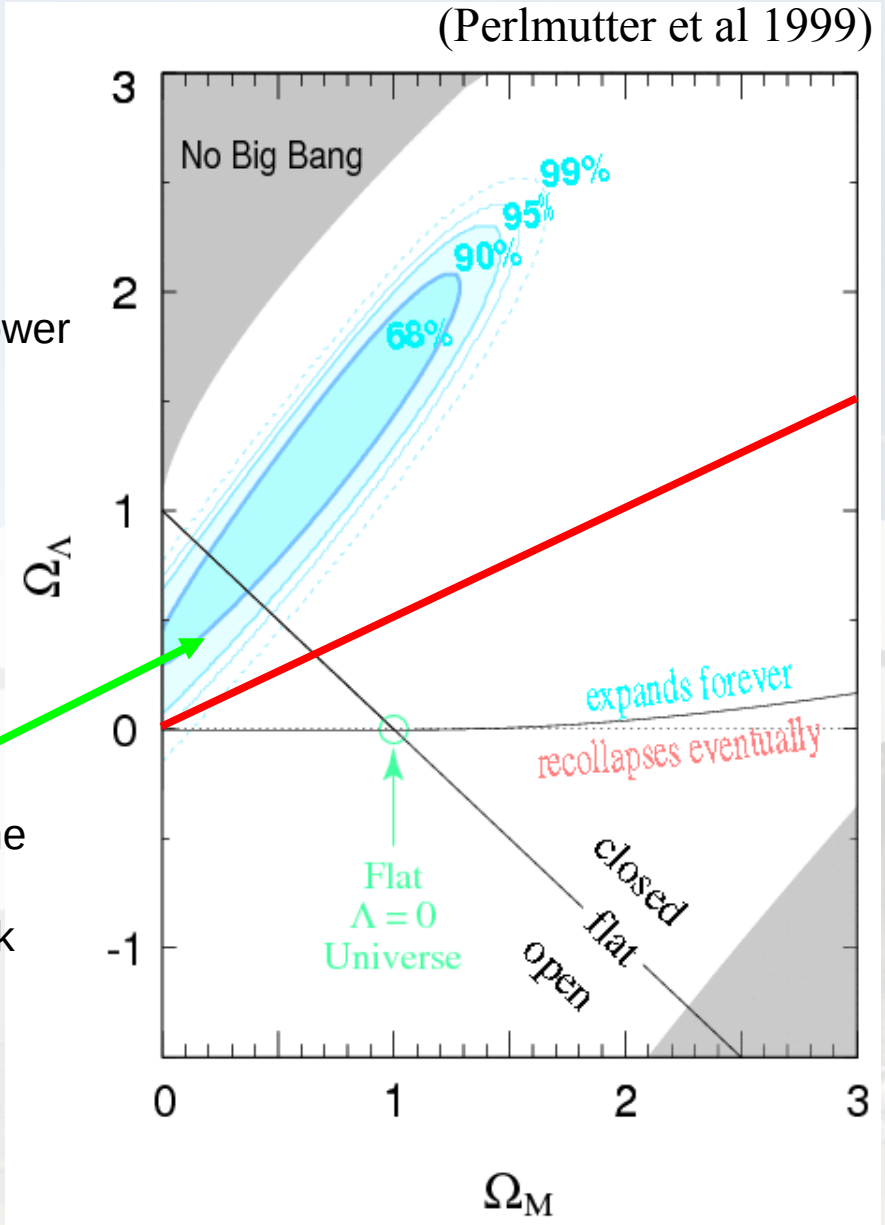
Cosmology with the

Emmanuel Gangler – LPC – Clermont-Ferrand (France)

Dark Energy : 1998-2014 … 16 years !

Evidence in 1998 that distant TypeIa have lower recession velocity expected

(Perlmutter et al 1999)



Smoking gun that the expansion is accelerating : a Dark Energy is at work !


Photo: U. Montan
Saul Perlmutter


Photo: U. Montan
Brian P. Schmidt

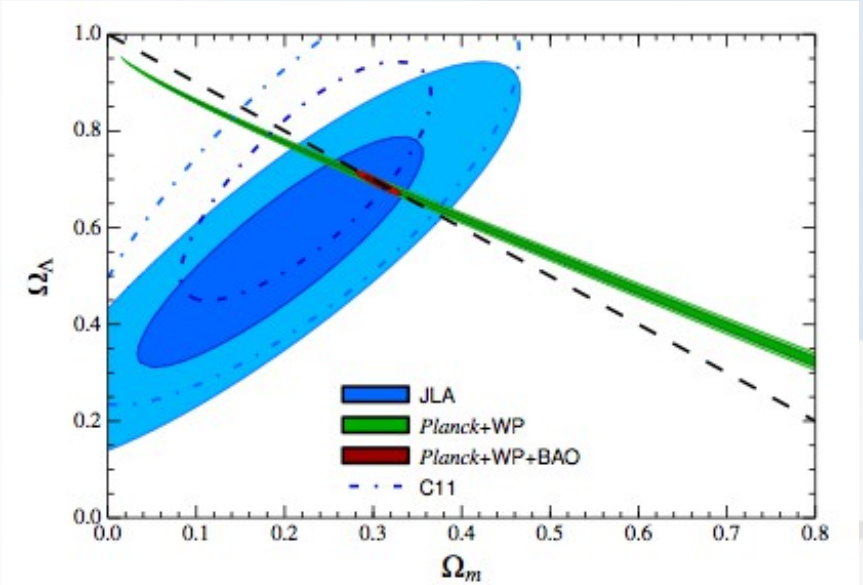

Photo: U. Montan
Adam G. Riess

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"*.

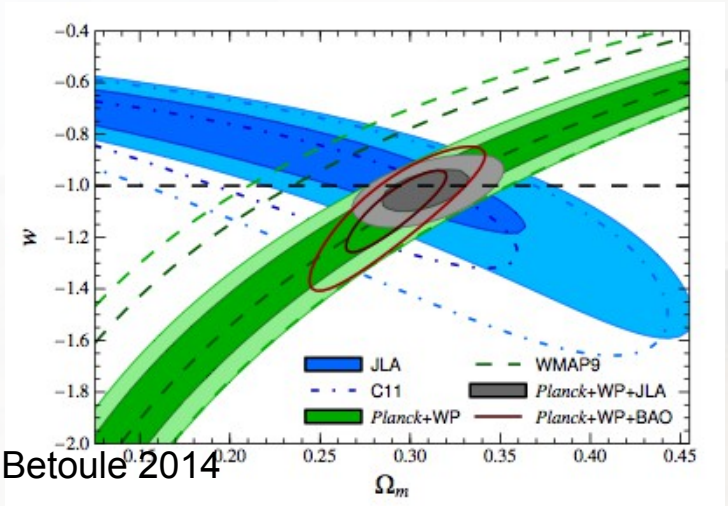
Nobel 1991

Dark Energy : 1998-2014 … 16 years and still there

Supernovae : senstive to expansion rate evolution → dark energy equation of state

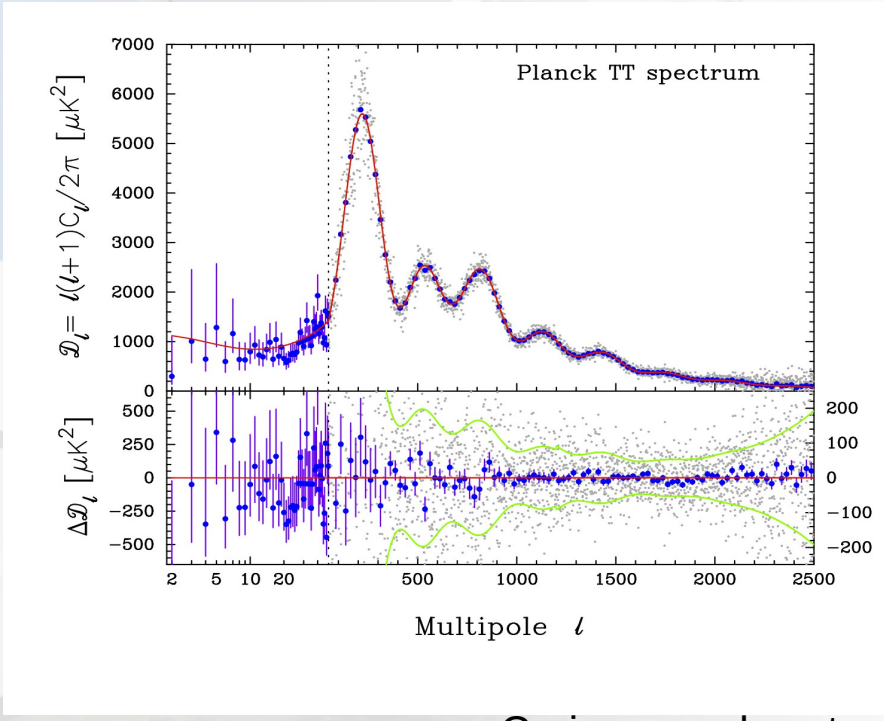


Equation of state $P = w\,\rho = [w_0 + w_a(1-a)]\,\rho$



Betoule 2014

CMB, BAO : scale parameter evolution → sensitive to Ωtot et power spectrum



Croissance des structures → sensible à Ω_M

→ Concordance model (flat-)ΛCDM quite robust … so far ?

… Energie Noire ???? Le point de vue des théoriciens

- **Une constante cosmologique (le terme « standard » de l'équation d'Einstein)**
  - **Peut-on ignorer le reste du XX ième siècle ? : Energie du Vide … Plus que 120 ordres de grandeur à pomper !**

- **Le principe anthropique**
  - **Le « dégrippant » de la physique théorique : quand ça « coince » un peu de principe anthropique et ça repart …**

- **Quintessence**
  - **Un bon vieux champ scalaire = « scotch » de la physique théorique , ou comment « fixer » un problème …. Méthode qui a fait ses « preuves » …**

- **Relativité générale modifié, extra dimension …**
  - **A chaque changement de Relativité Générale …penser à vérifier les fusibles …**

- **Back Reaction (pas de nouvelle physique) : La formation de structure induit une accélération moyenne apparente (densité non uniforme)**
  - **C'est ce qu'il faut étudier aujourd'hui… si si … hum … non... Quelle amplitude au fait ?**

Le couteau suisse de l'observateur : w0, wa / FLRW

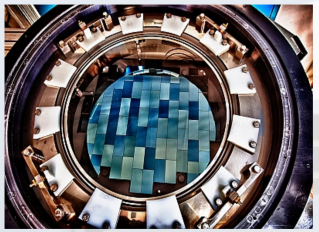
Thx Pierre;)

An quick panorama of sky surveys

2000 2010 2020

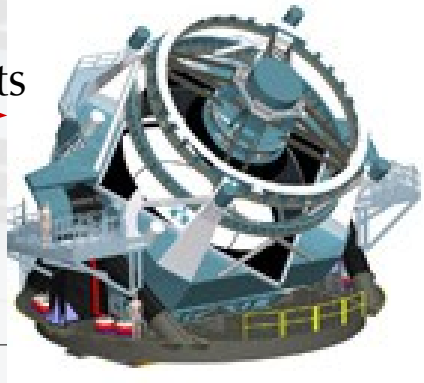
« SCP »

CFHTLS
157□
r'~25



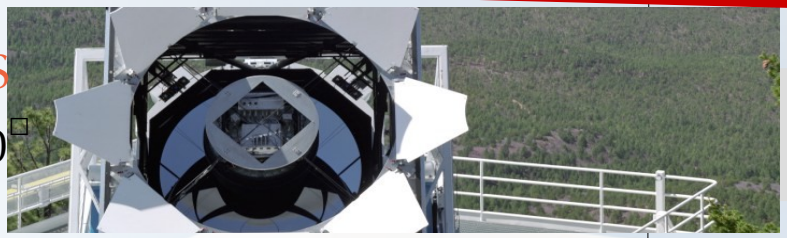
DES
5000□
i~24
~10 visits

LSST
18000□
r~24 / visit
~800 visits



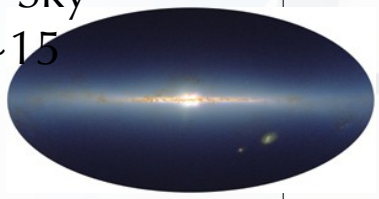
DSS
All-sky
Plate scan
B~22

SDSS
8400□
r~22

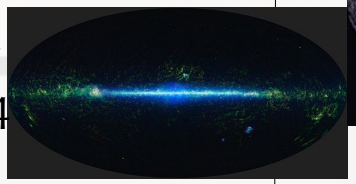


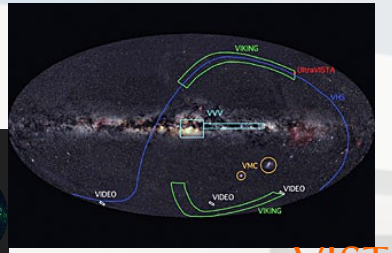
+Others (PTF, HSC, GAIA …)

2MASS
All-Sky
H~15

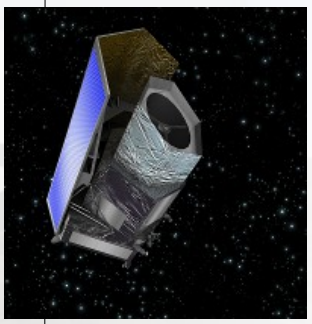


WISE
All-Sky
W1~14

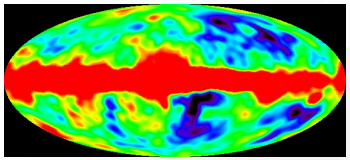




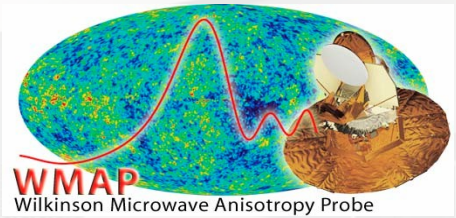
VISTA
Half-Sky
H~19

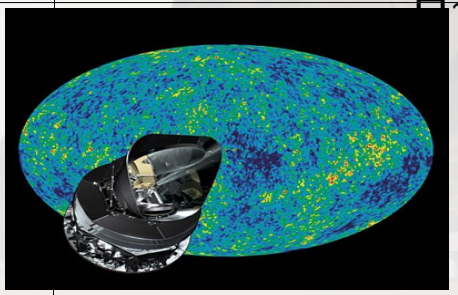


Euclid
15000□
Vis~24.5



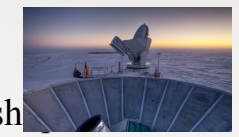
COBE





Planck

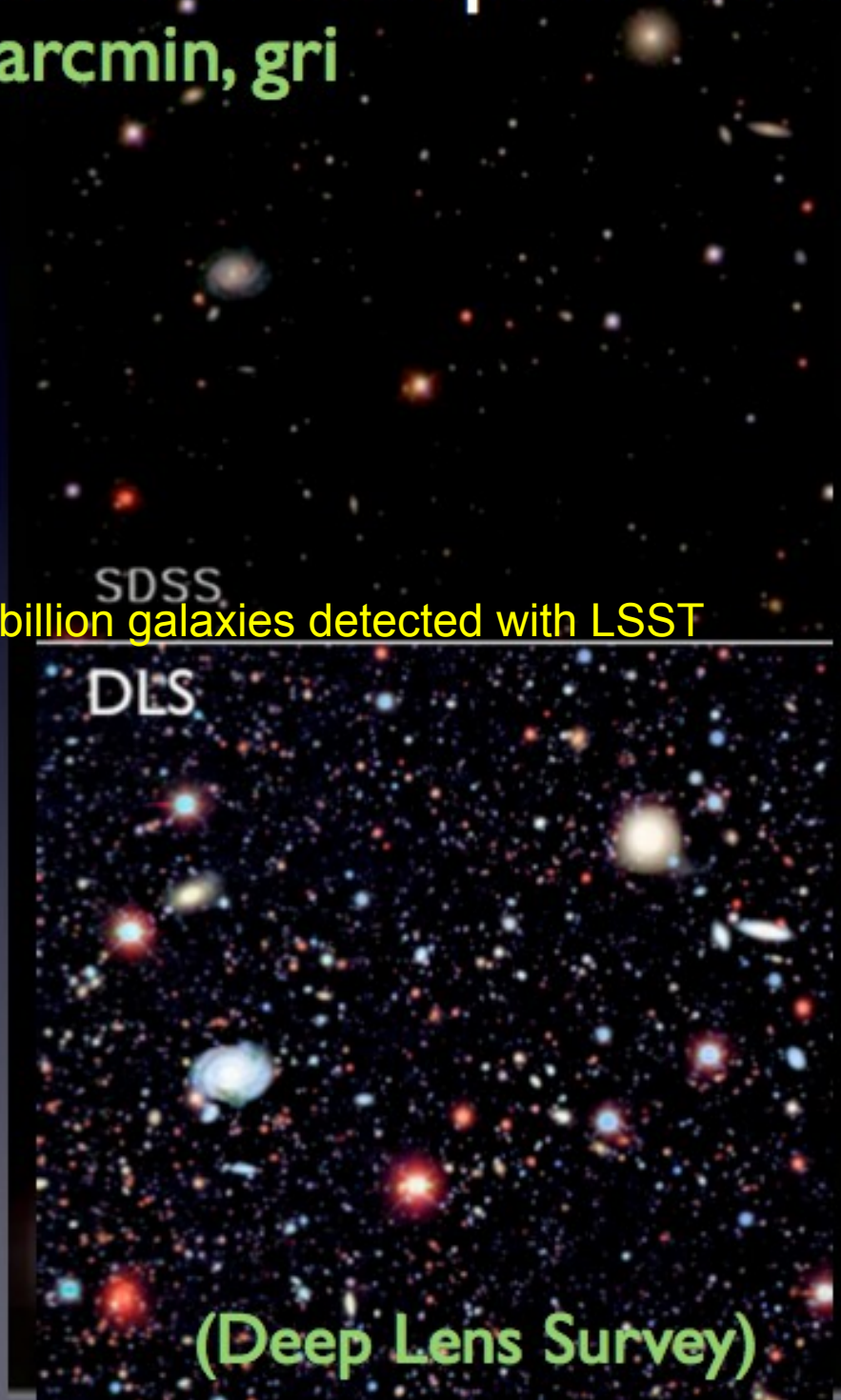
+South pole



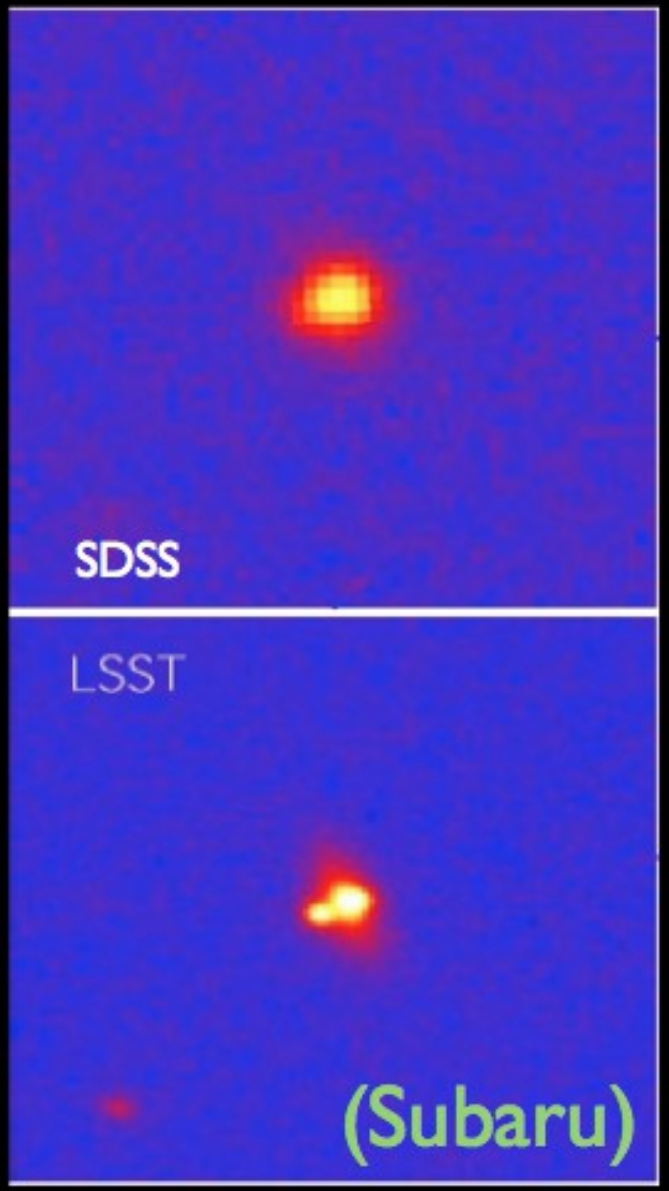
…

SDSS-LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

7x7 arcmin, gri



→ 10's billion galaxies detected with LSST



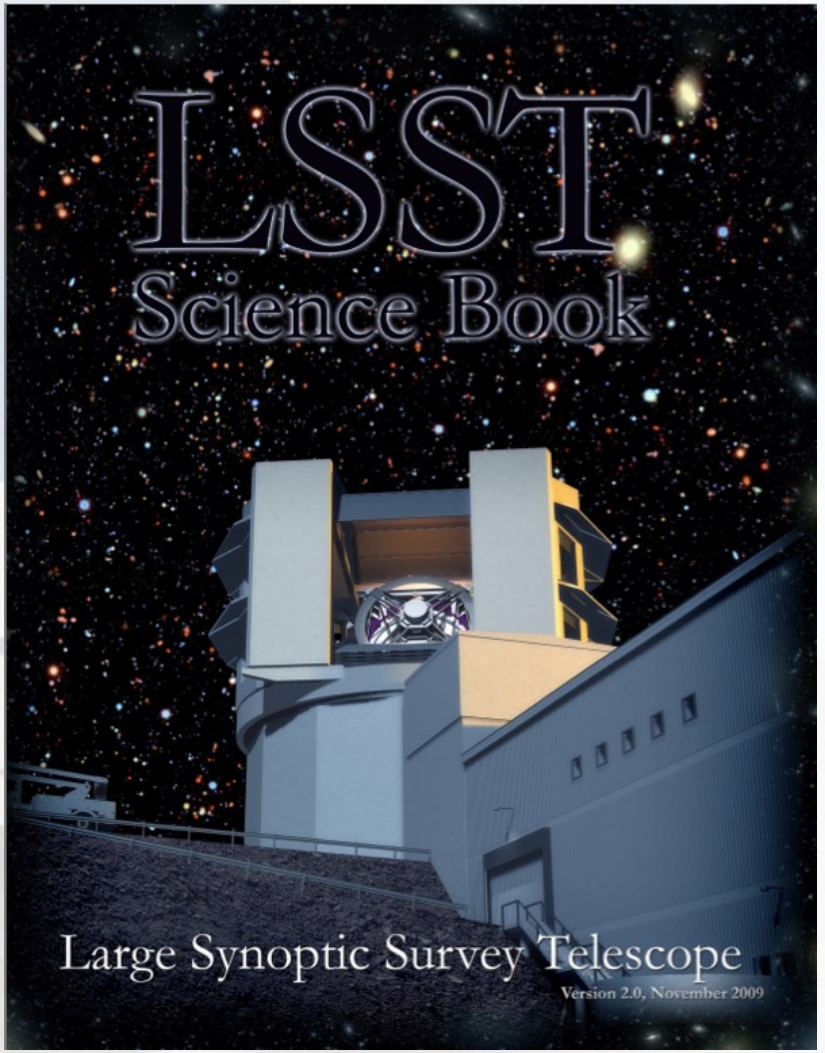
Slide from Izevic

The LSST science book

- 4 major themes
  - Dark Energy, Dark matter
  - Mapping Milky Way
  - Transient optical sky
  - Solar system
- 11 science collaborations
  - Weak Lensing
  - BAO
  - Supernovae
  - Strong lensing
  - Galaxies
  - AGN
  - Milky way and the local volume structure
  - Stellar populations
  - Transient/variable stars
  - Solar system
  - Informatics and statistics

LSST DESC Dark Energy Science Collaboration

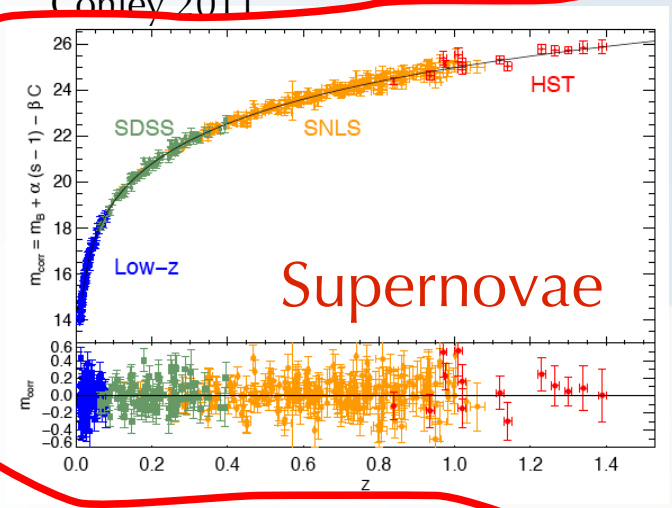
ArXiv 1211.0310



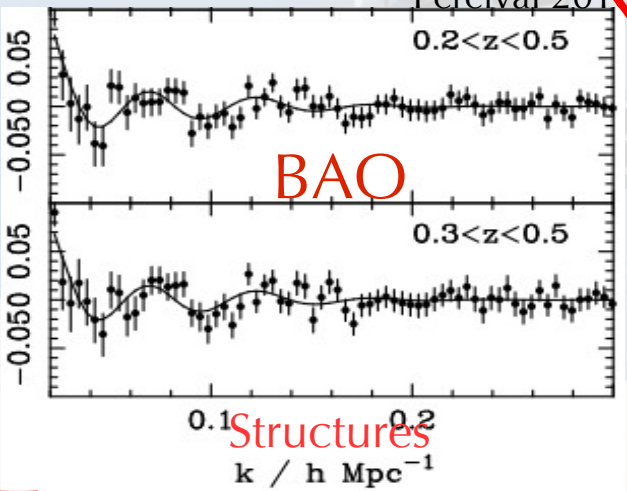
arXiv:0912.0201

LSST DESC Dark Energy Science Collaboration at a glance

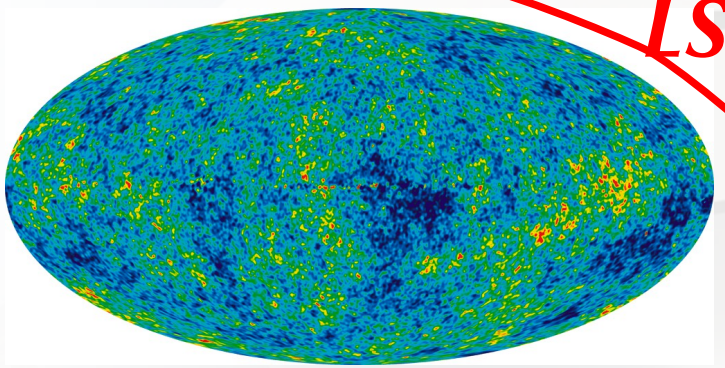
Copley 2011



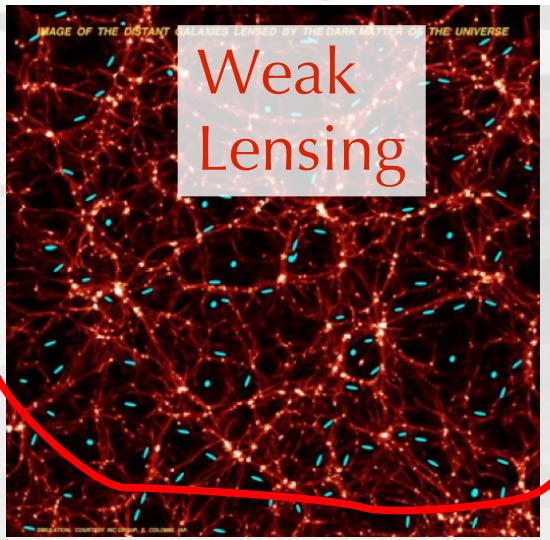
Percival 2010



LSST



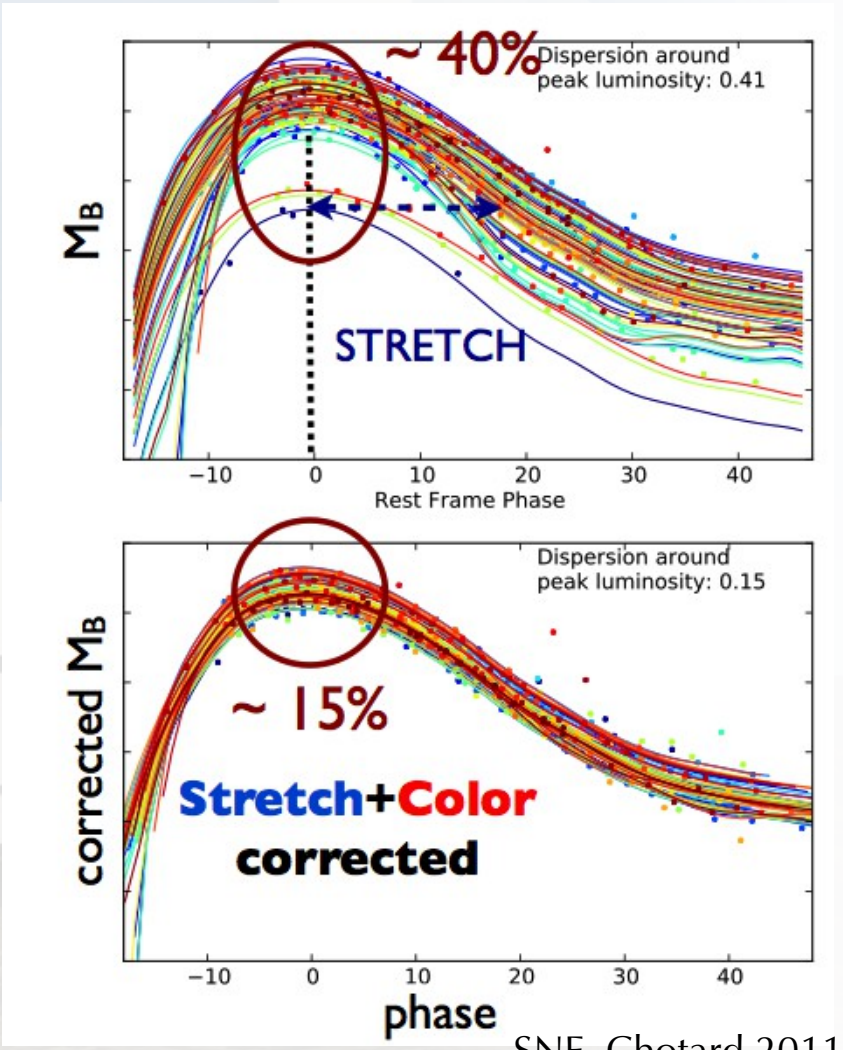
CMB



\+
LSS
Clusters
Strong lenses
Probes Combination

Why SNIa ?

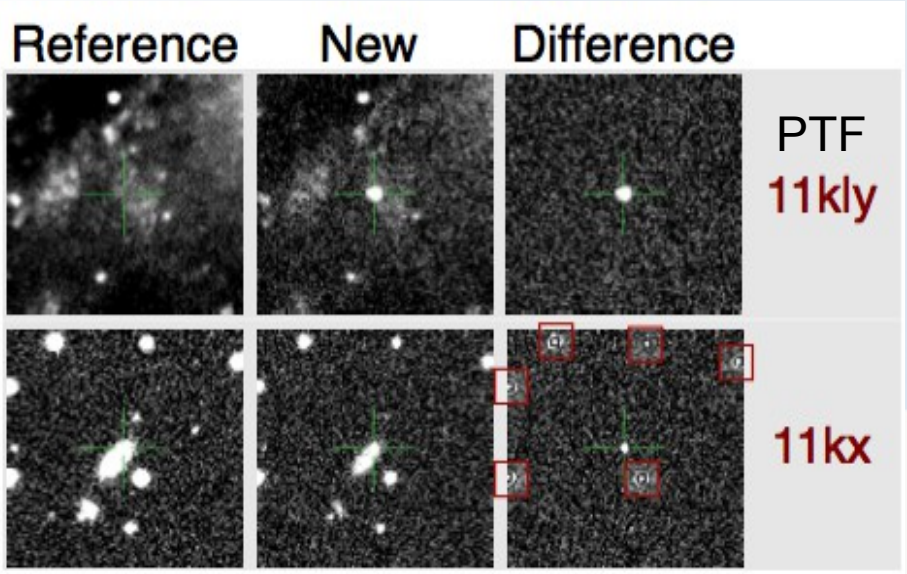
- Luminous M_B=-19.3
- Standard Candle ~0.40 mag (in B)
- Correction needed:
  - Extrinsic: (ISM)
    - **Color** correction
  - Intrinsic:
    - **Stretch** (^{56}Ni mass, or...)
    - Others expected
      - 2 parameter model insufficient
- **Empirical** corrections
- Accuracy after standardization ~ 0.12 mag



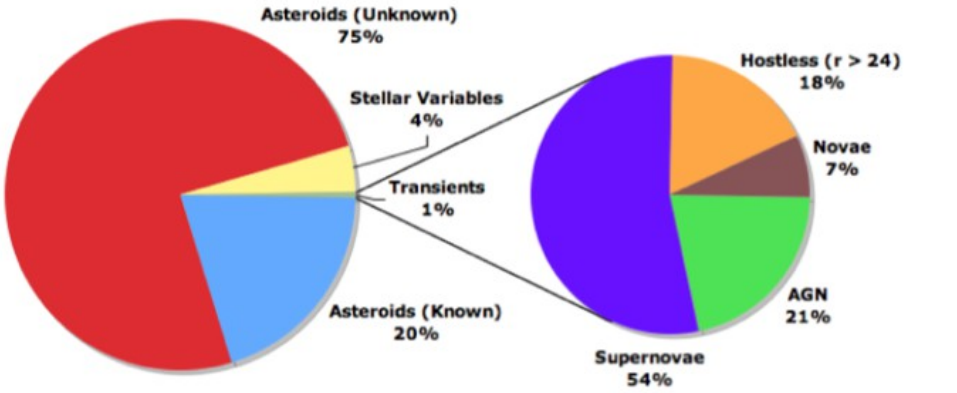
SNF, Chotard 2011

Hunting transients

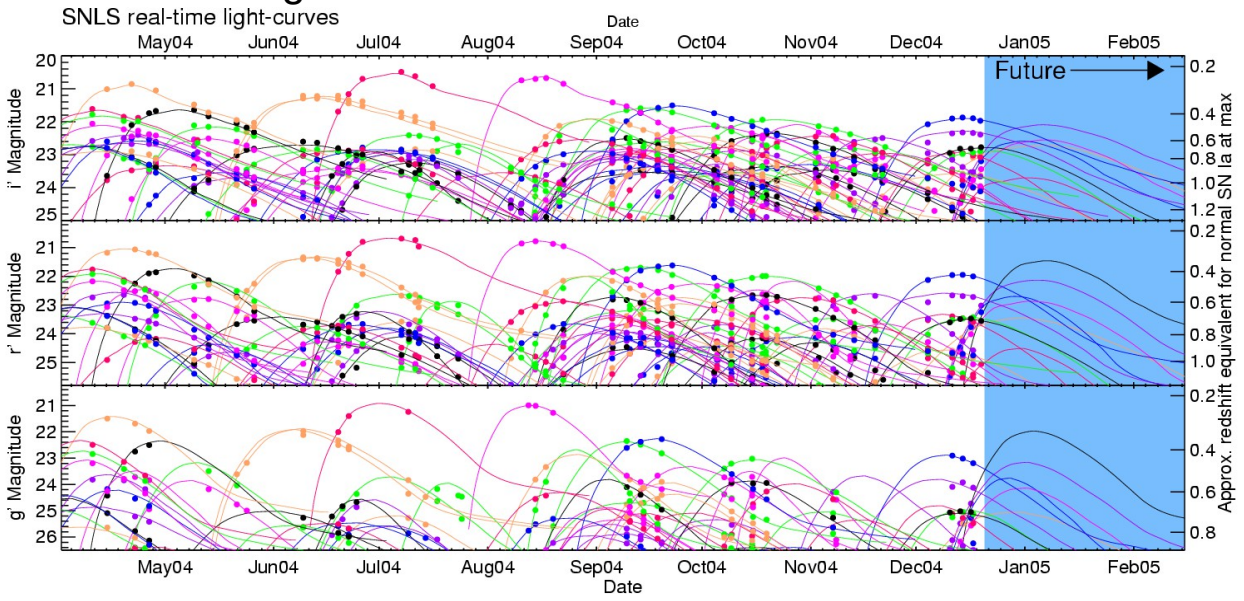
From a reference map, search detections by differential photometry.



In LSST : ~1 000 000 alerts / night !
< 1/100 of them will be Ia
Most of Ia will be useless (cadence)



→ use Rolling search



In CHFTLS : spectroscopic identification
Follow-up in LSST ?

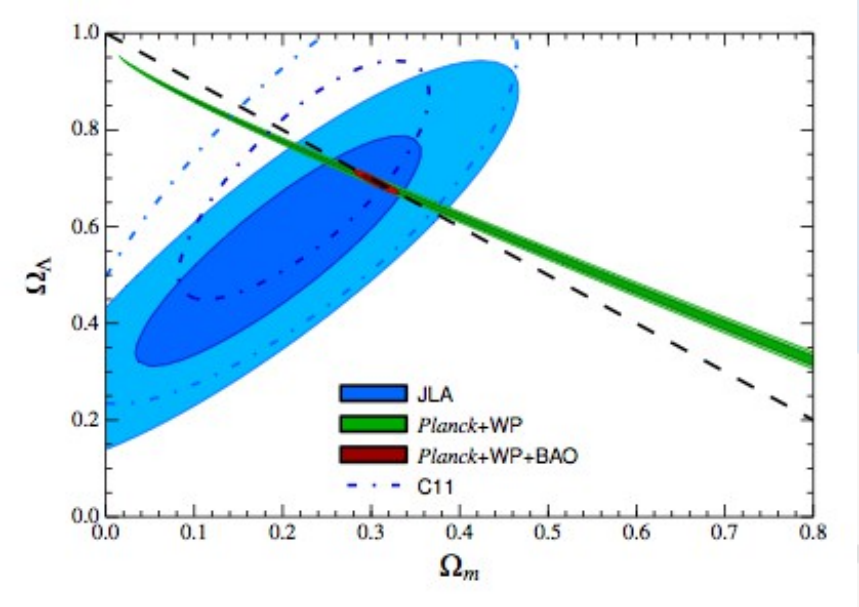
LSST expects/year

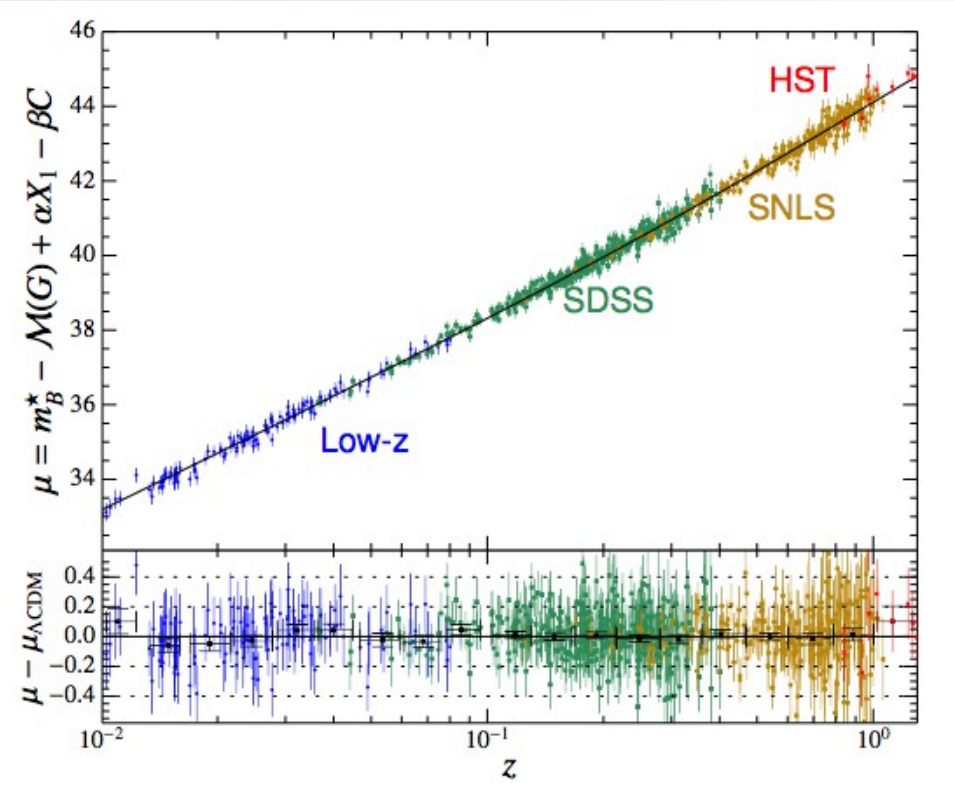
- 150 000 SNIa in wide
- 10 000 SNIa in deep field

Statistics are not the limit.

State of the art

Bétoule 2014 : 720 SNIa
Joint Light-Curve Analysis





Flat-ΛCDM model with SN alone:

uncertainties on Ω_M : 0.034

Stat: 0.018

Calibration: 0.20

Other syst: 0.12

This term to be negligible with LSST

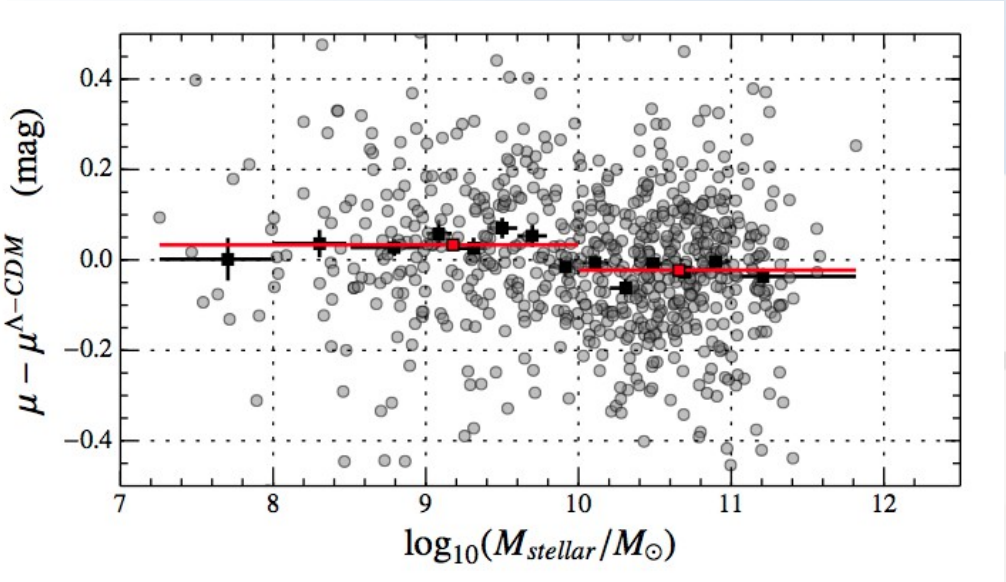
This is (already) precision cosmology !

Improving the correction ?

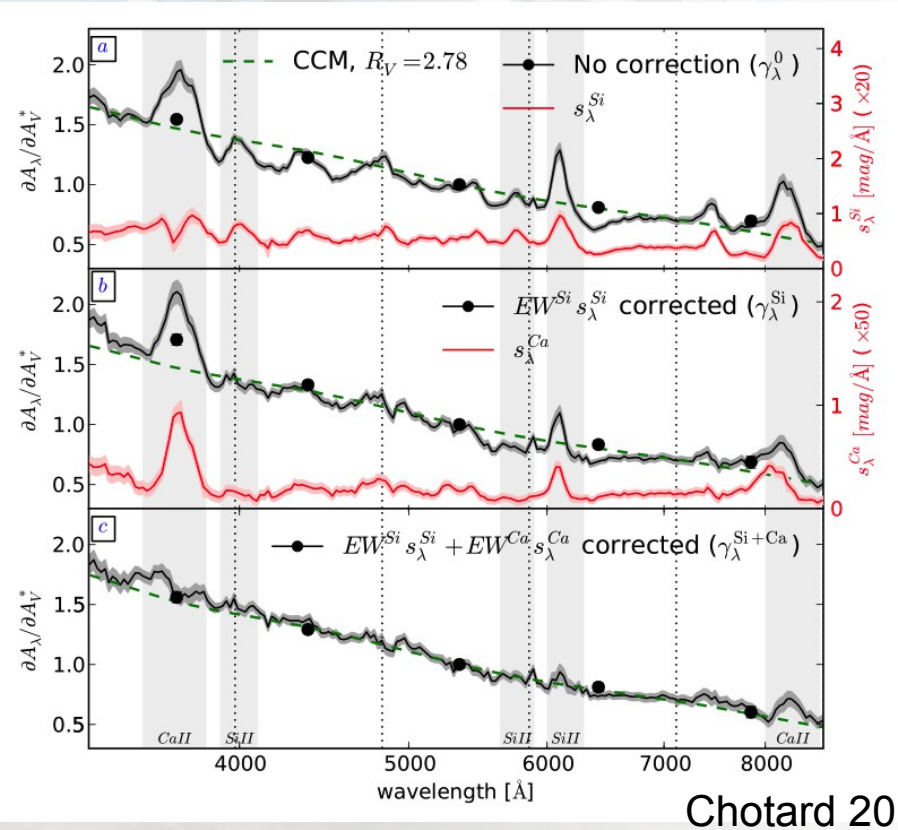
- Extrapolation of the correction in z □ potential bias
- Mass step

→ 0.06 mag step / host mass

Can be fitted out



- Additional sources of variability

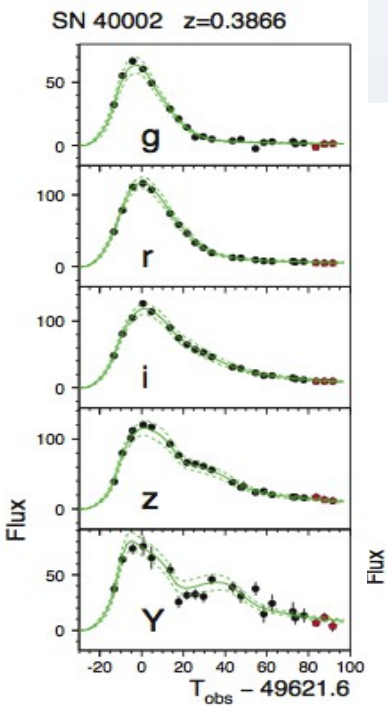


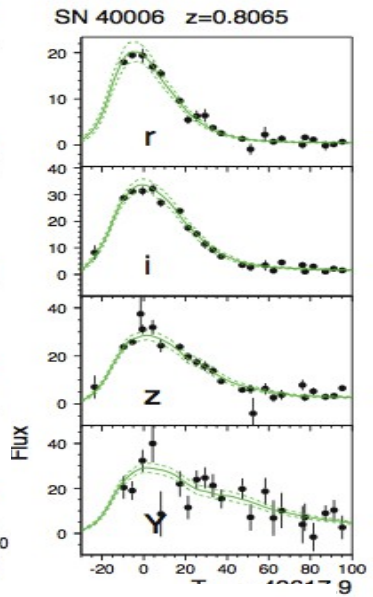
Chotard 2011

Overall impact is small

Beating 0.08 mag dispersion is difficult

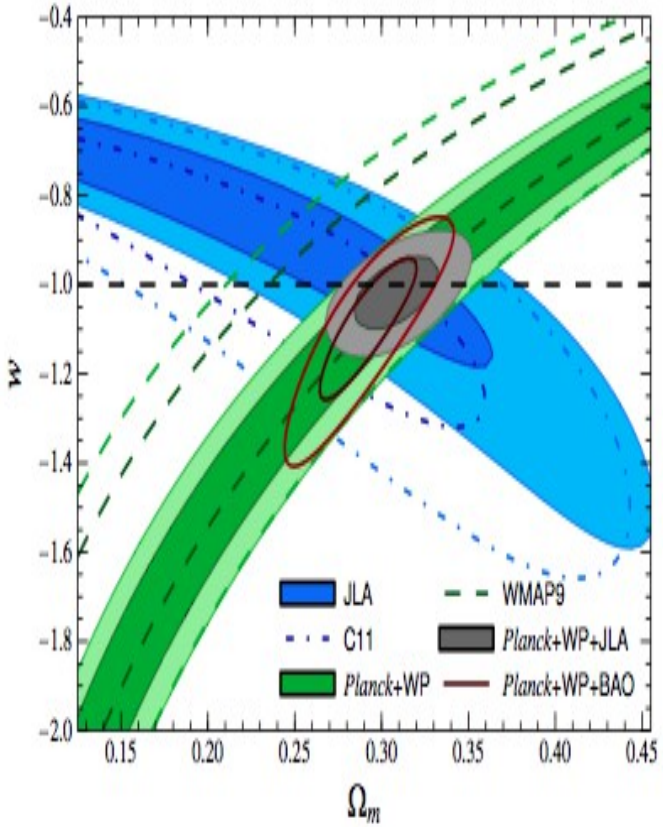
SN in LSST

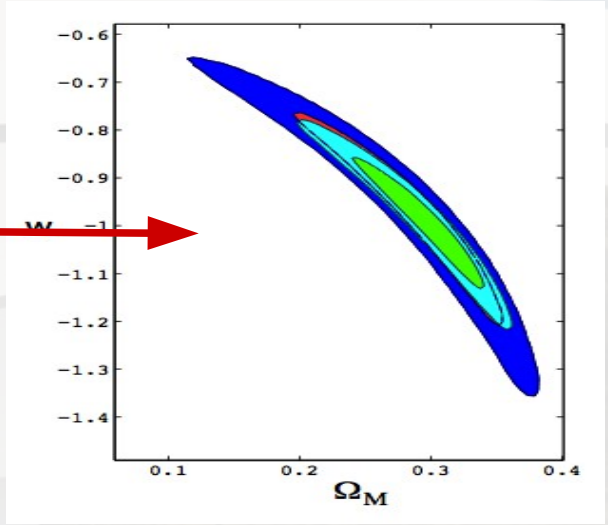




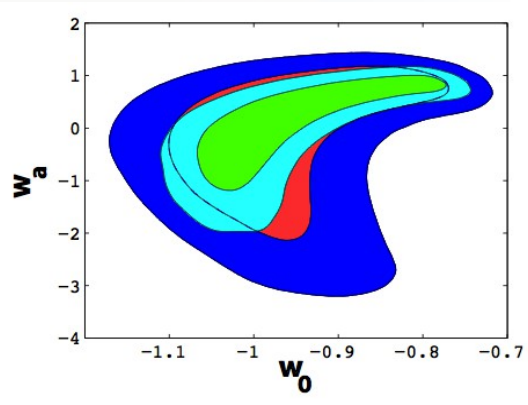
- *10 000 well sampled SN/year*
- Systematics dominated (short in IR)
- No spectroscopy (for now…)
- Redshift from external measurement

Huge improvement still !





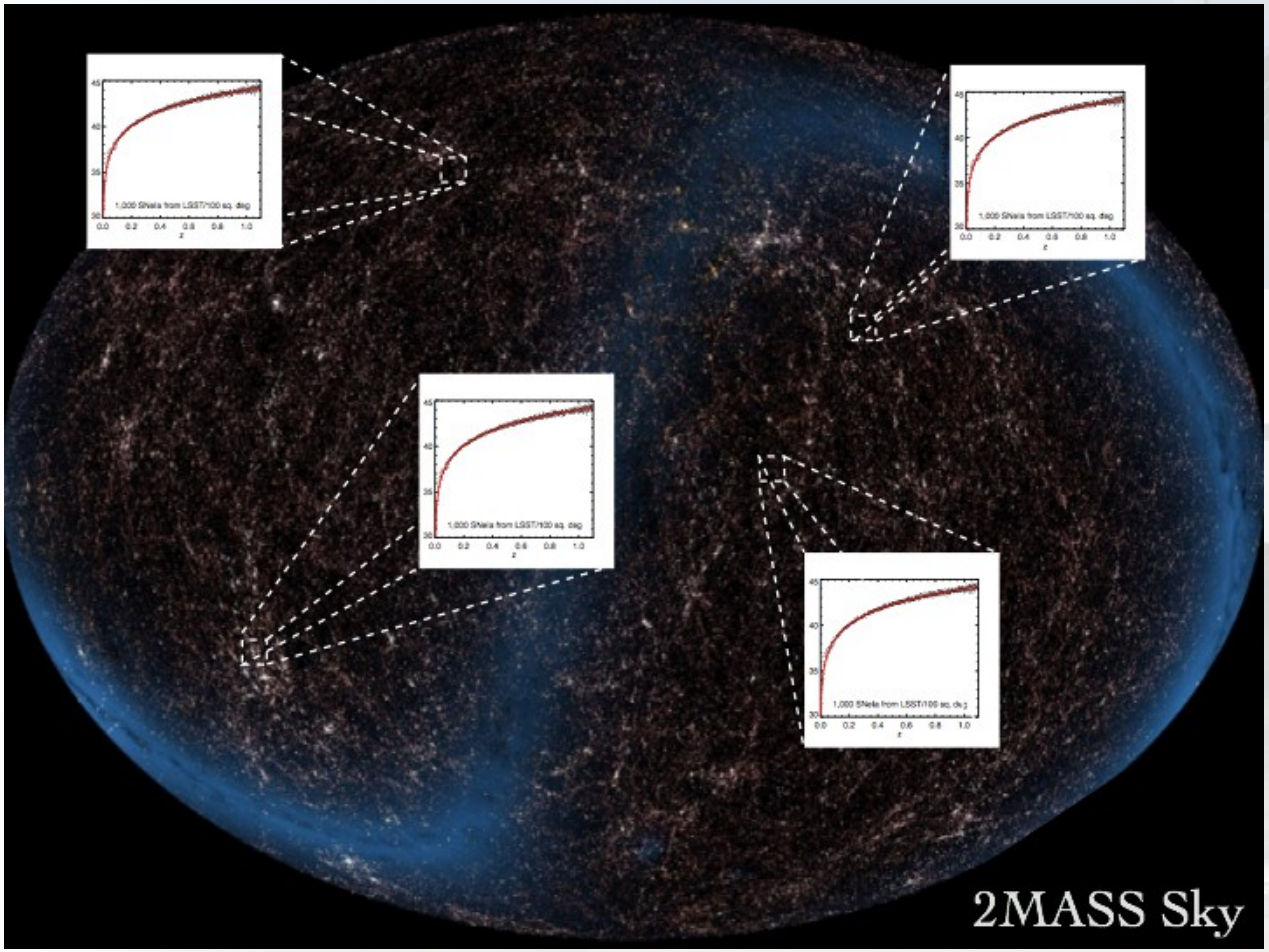
LSST 10 000 SN



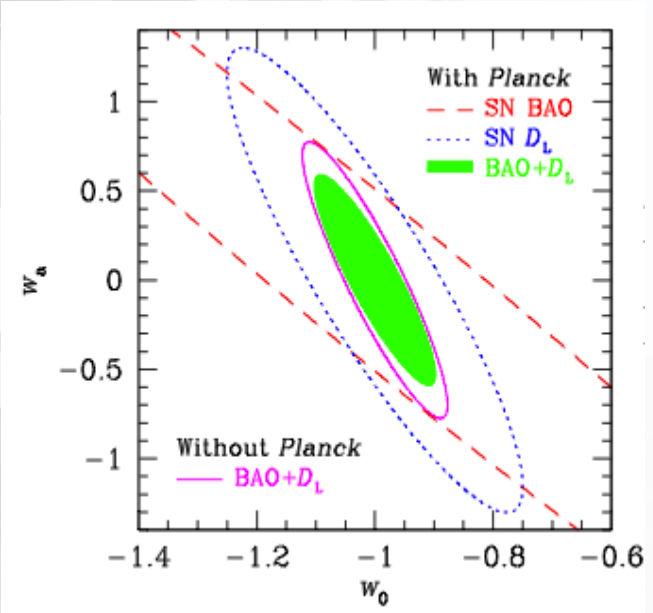
LSST 50 000 SN

Massive SN set :

- $10^{5\text{-}6}$ supernovae spatial repartition
- Homogeneity, isotropy

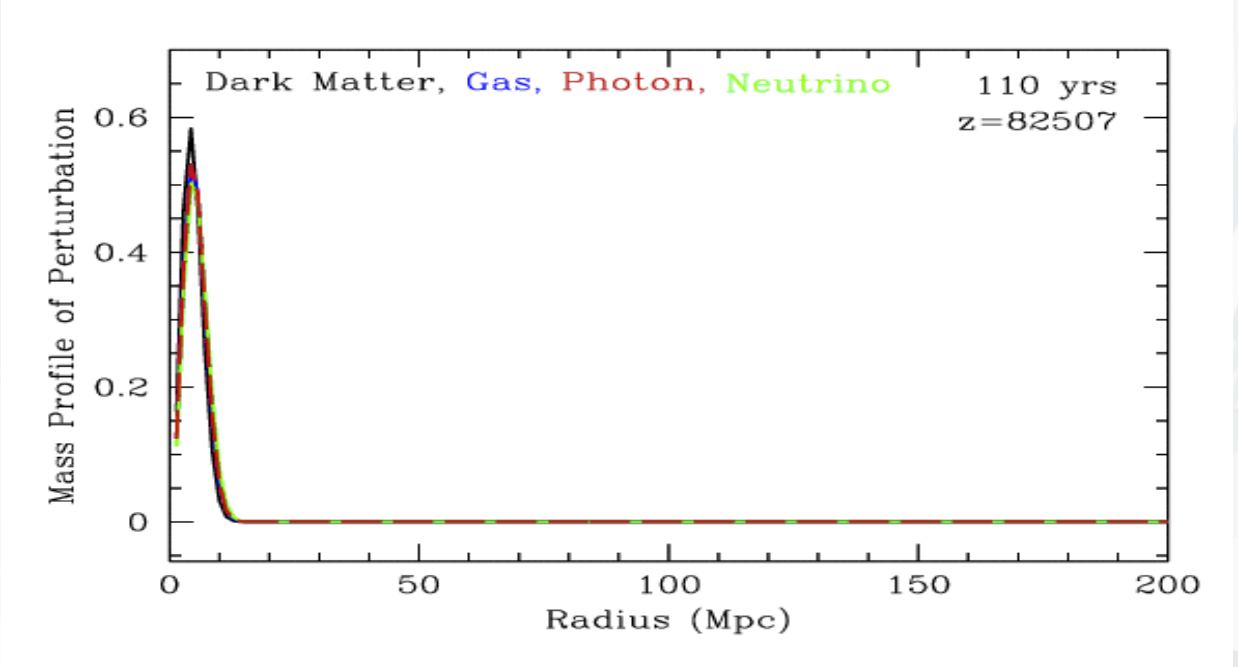


- BAO with SNIa



- + SN II, ...

BAO 101



- Life of a primordial dirac perturbation:

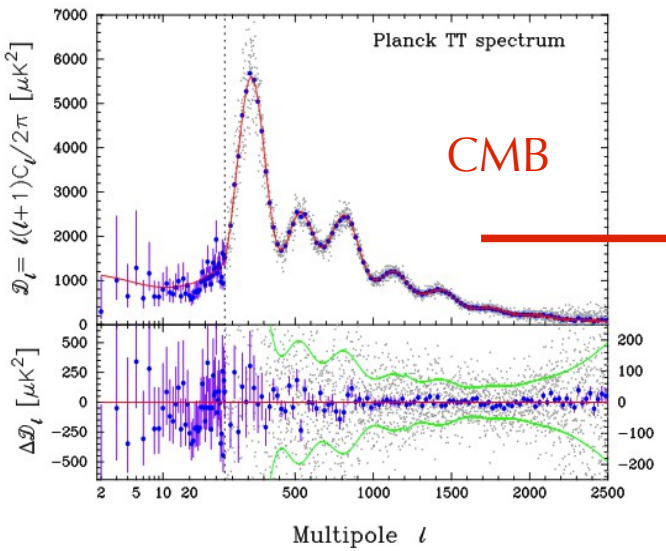
  1) Spherical acoustic wave ; baryons coupled to photons ; neutrinos escape

  2) Decoupling : sound speed vanished ; baryon carry the footprint of fluctuations ; photon escape (CMB)

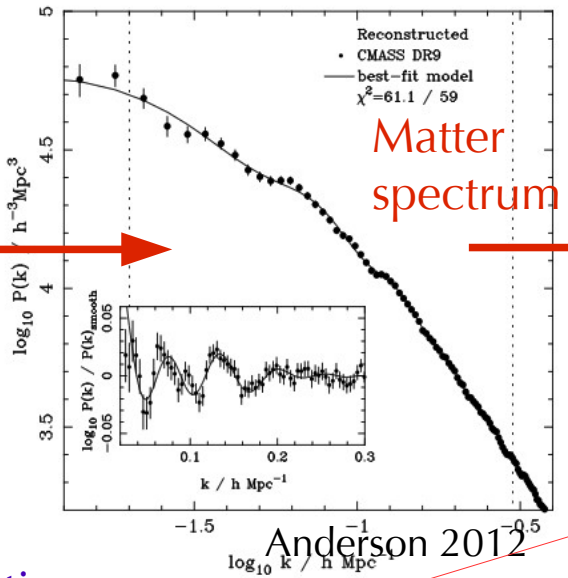
  3) DM and baryons coupled by gravitation

Cosmology with BAO

Standard ruler approach

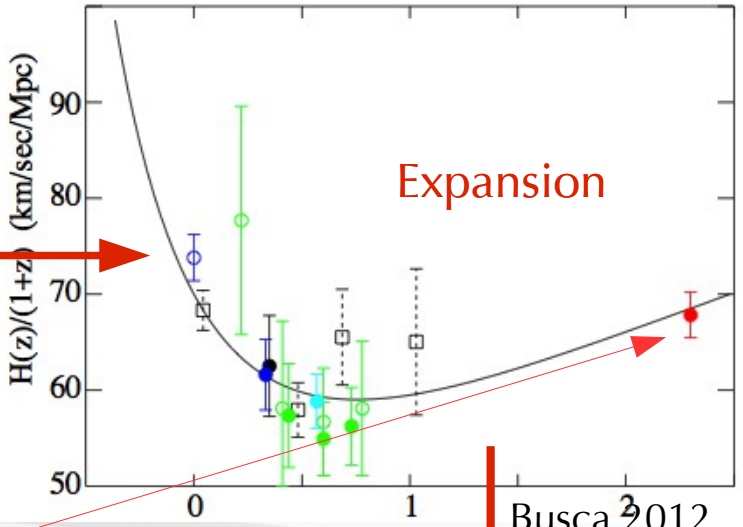


CMB



Matter spectrum

Anderson 2012



Expansion

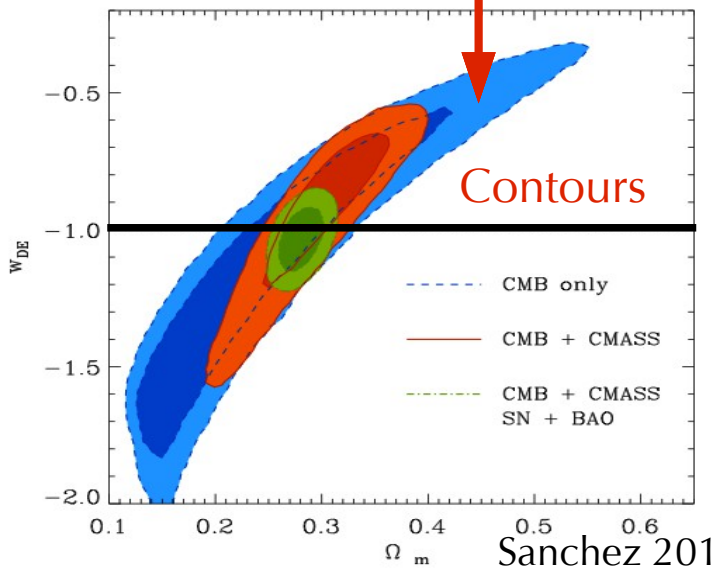
Busca 2012

Compute the correlation function
- Of galaxies (10^6)
- Quasar's Ly-α forest

Première détection 2005

Derniers résultats 2012 (BOSS)

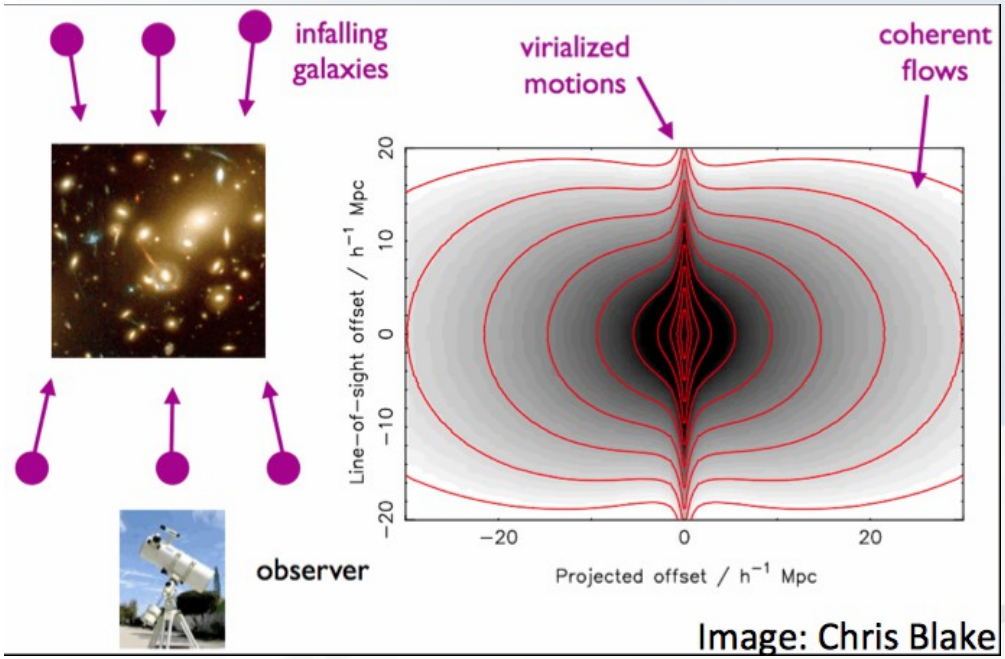
Difficulties :
- Redshift determination (spectro/photo)
- Statistics not an issue with ***LSST***
- Tacer of matter density

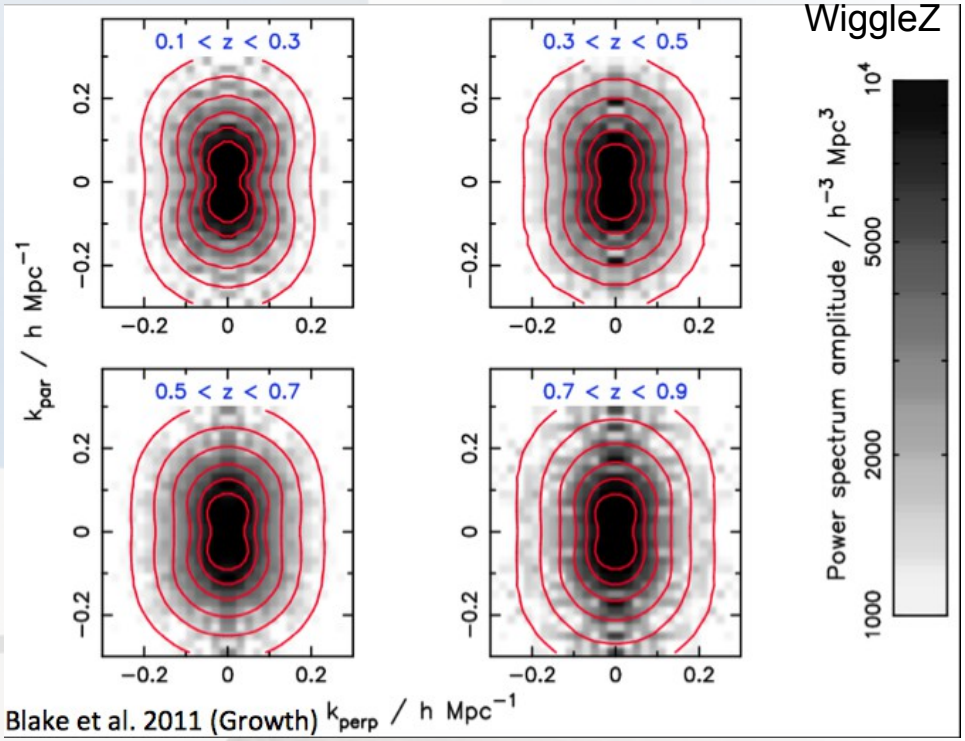


Contours

Sanchez 2012

Redshift distortions:

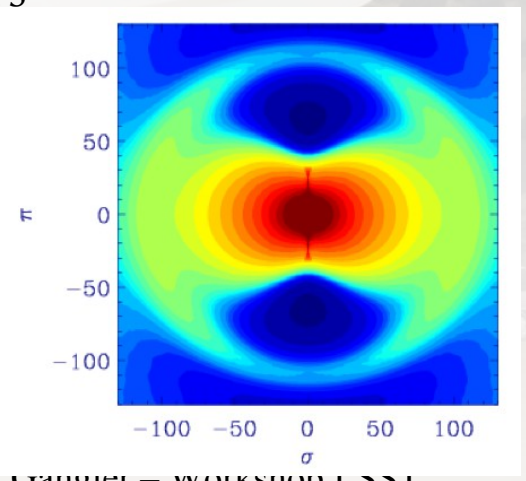


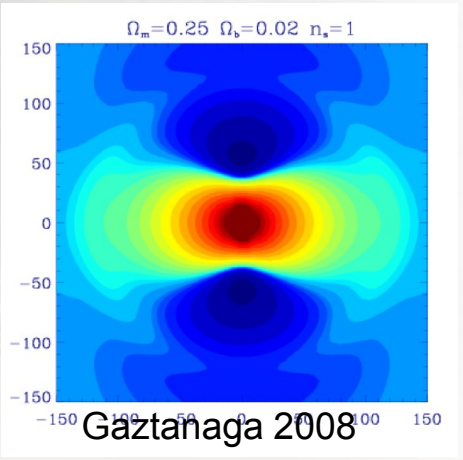


Fingers of god = central part of clusters

Coherent flow

- Sensitive to cosmological parameter
- Tomography growth of structure



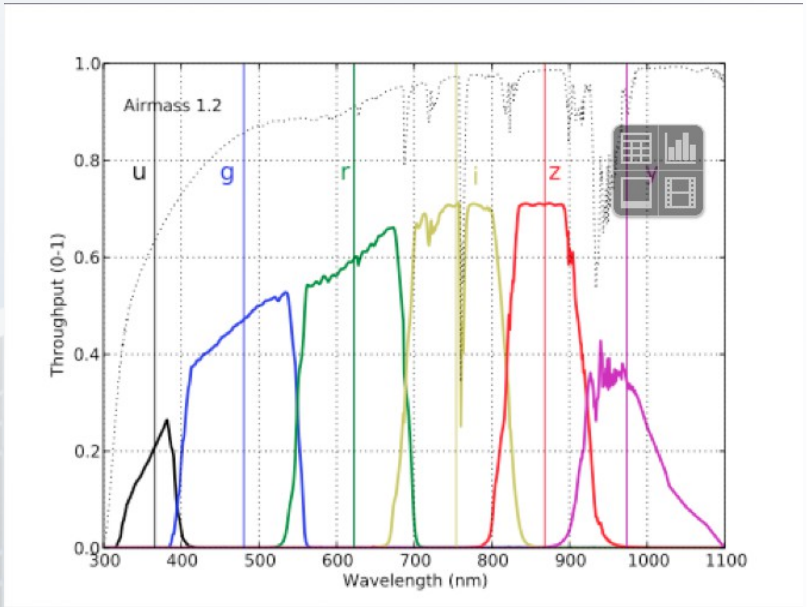


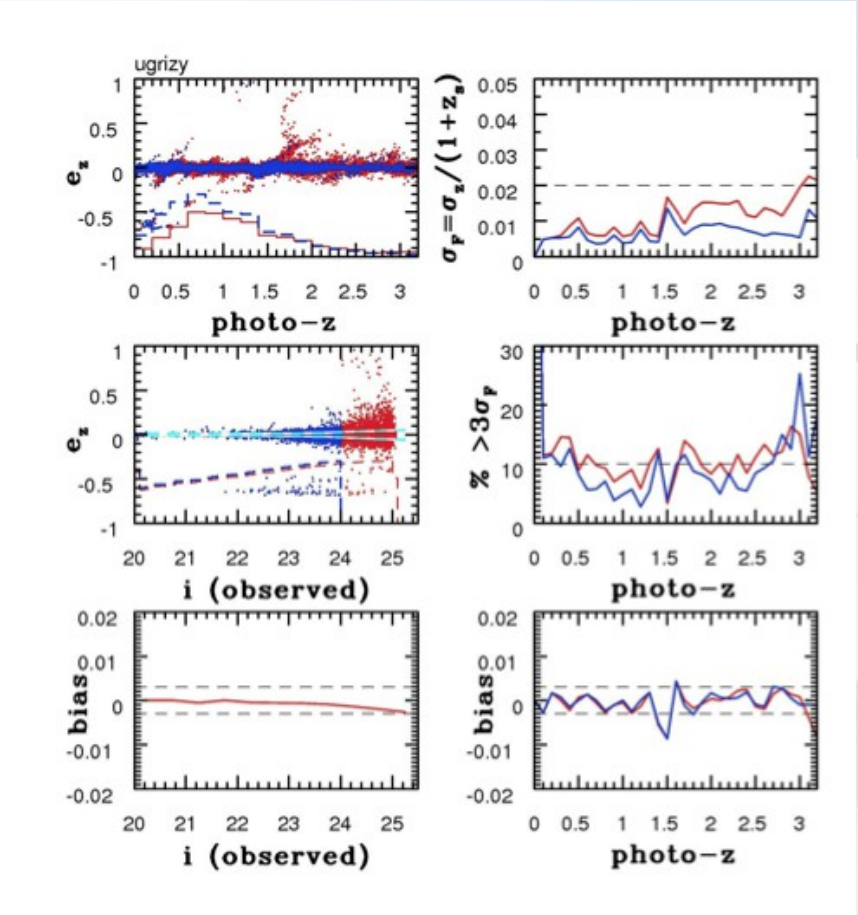
Gaztanaga 2008

Photo-z

LSST requirements on 1+z

- 0.02 random error
- <0.003 bias
- <10% 3-σ outliers





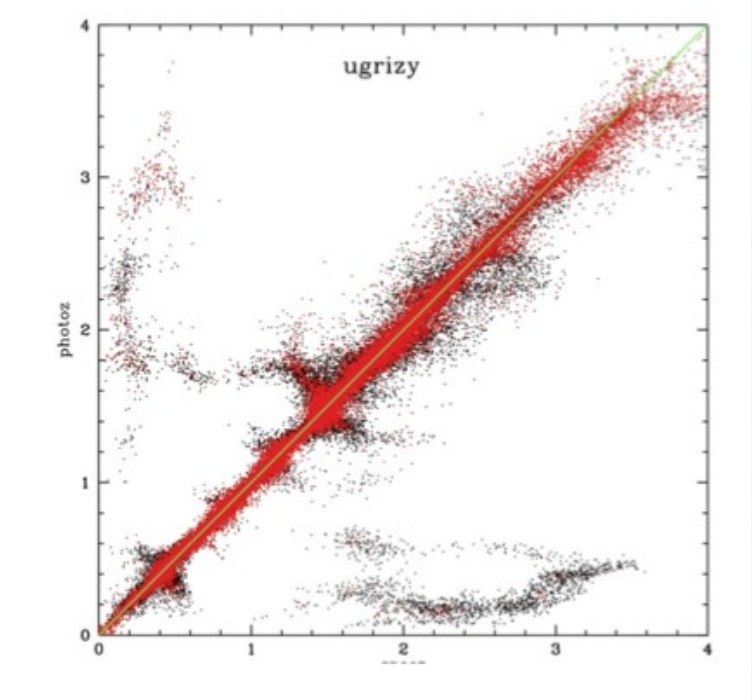
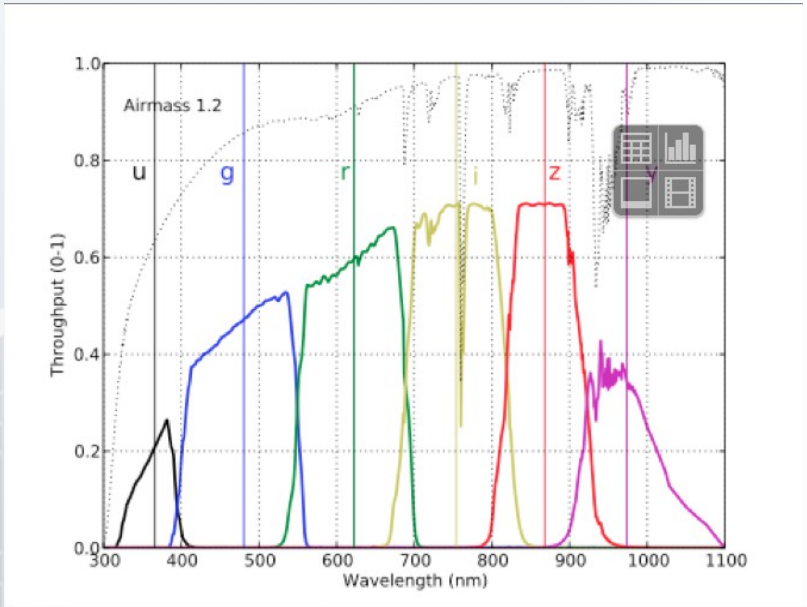
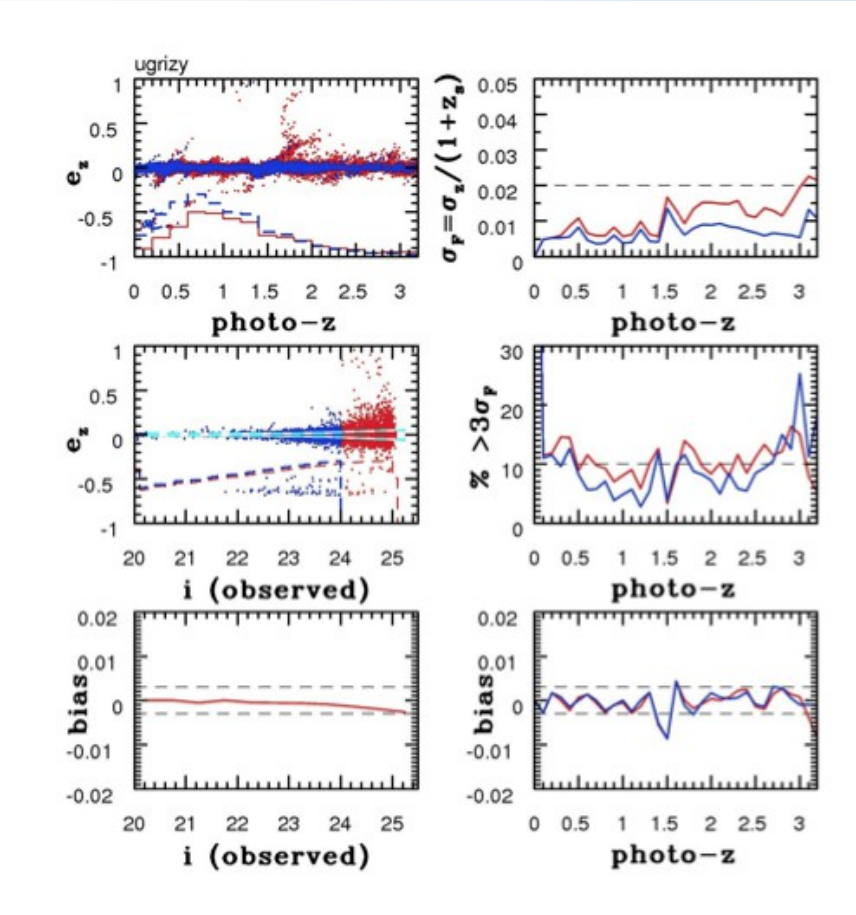


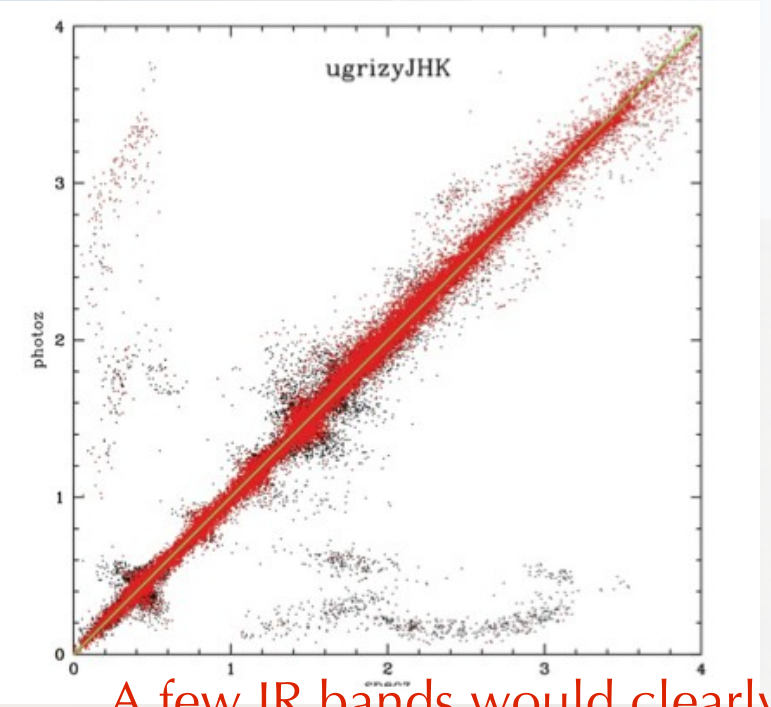
Photo-z

LSST requirements on 1+z

- 0.02 random error
- <0.003 bias
- <10% 3-σ outliers



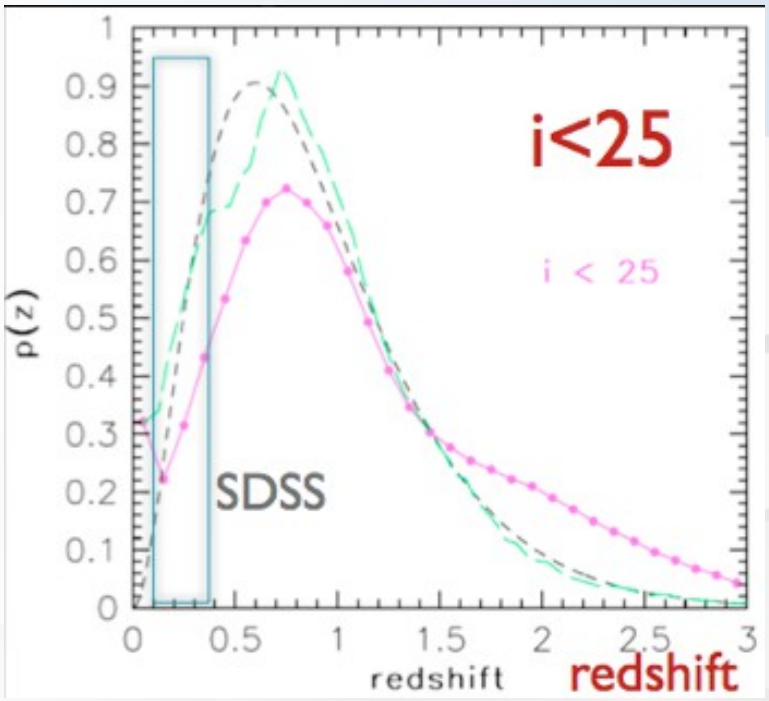


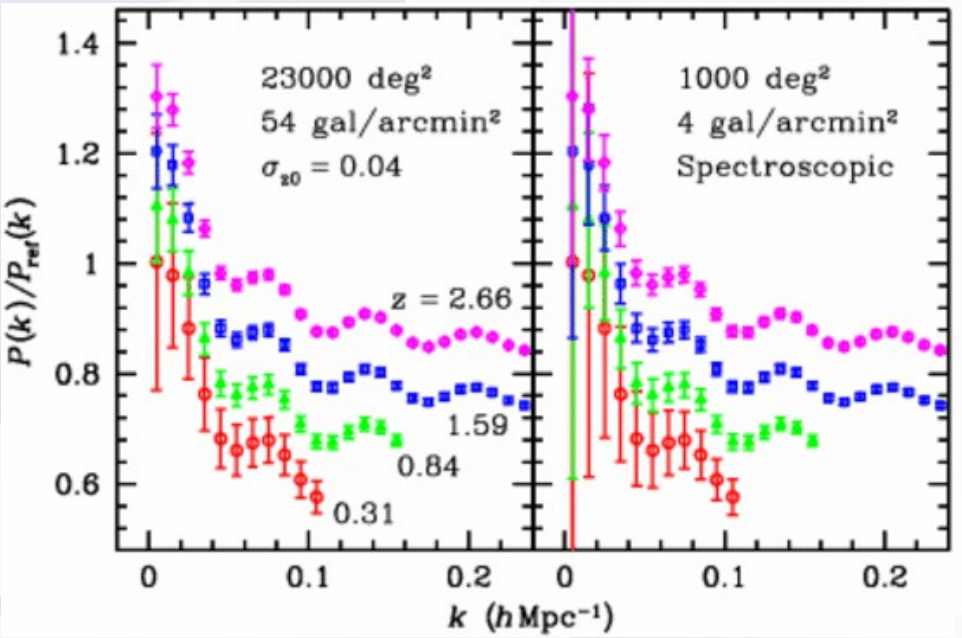


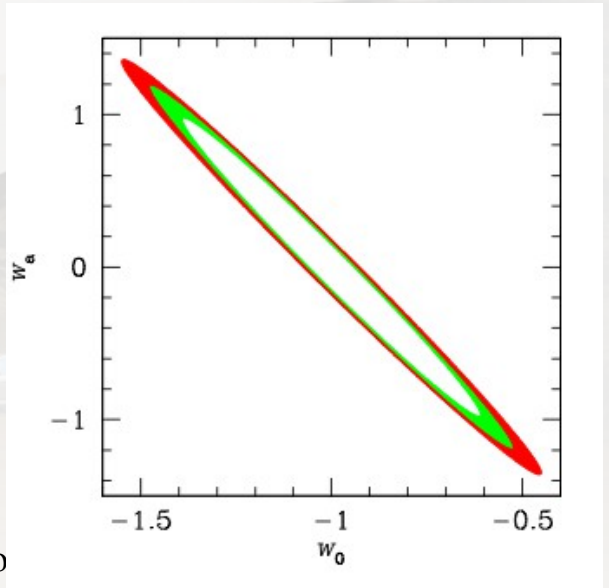
A few IR bands would clearly be of some help !

LSST BAO sensitivity :

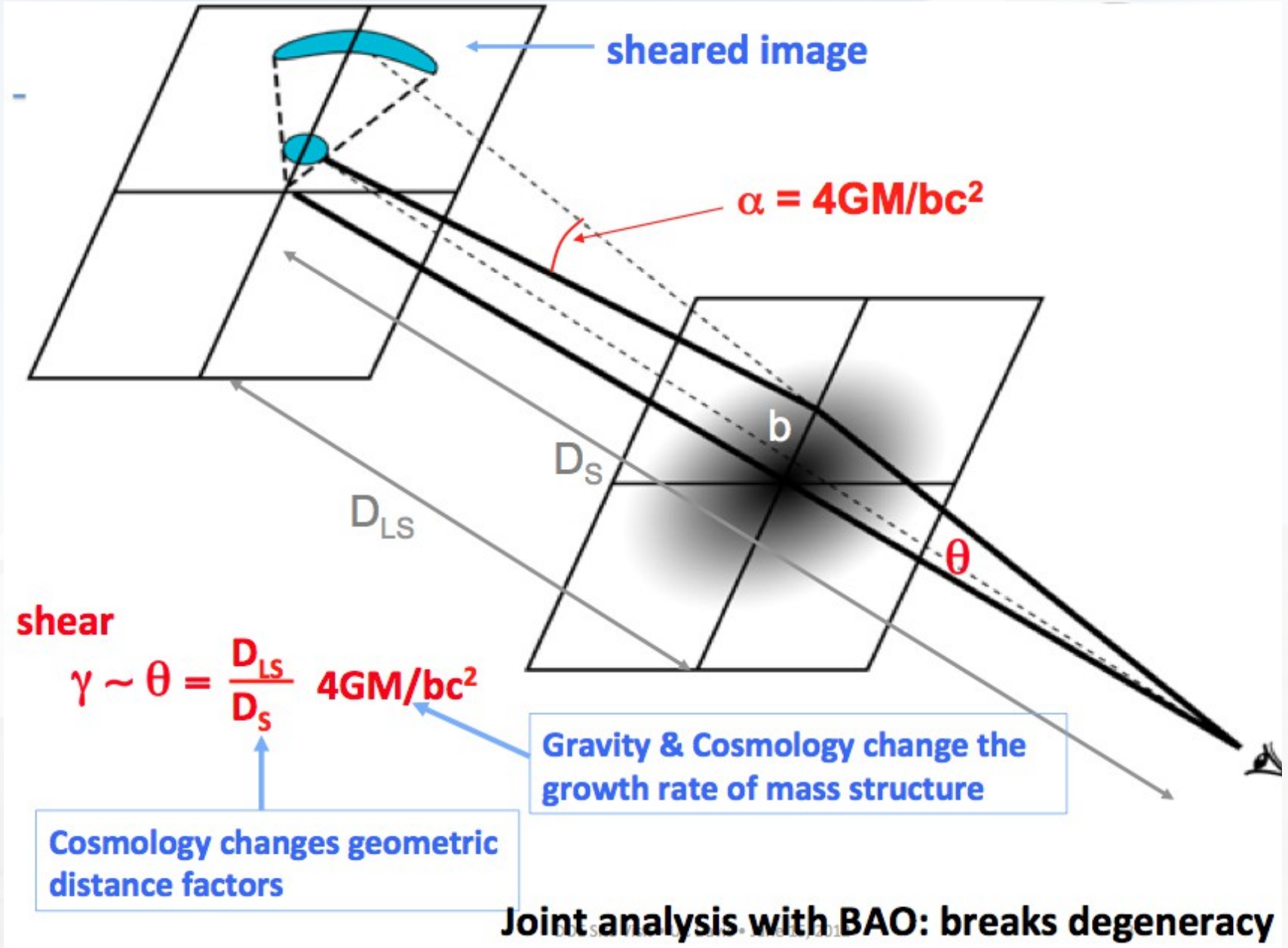
- 10 B galaxies in 20000□
  - 4B in gold sample (i<25.3)
  - Up to z < 2.5





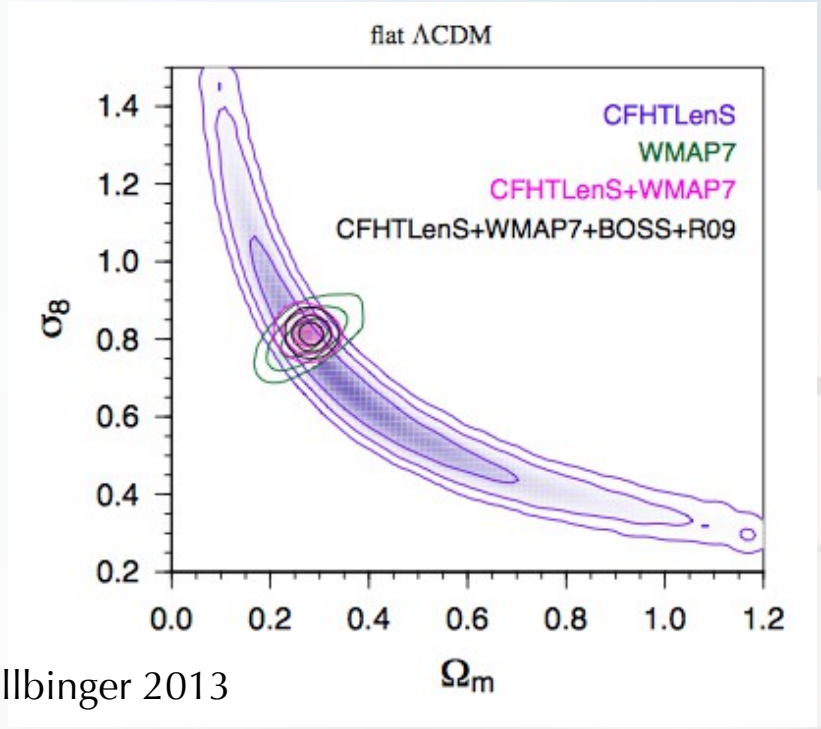


Weak Shear

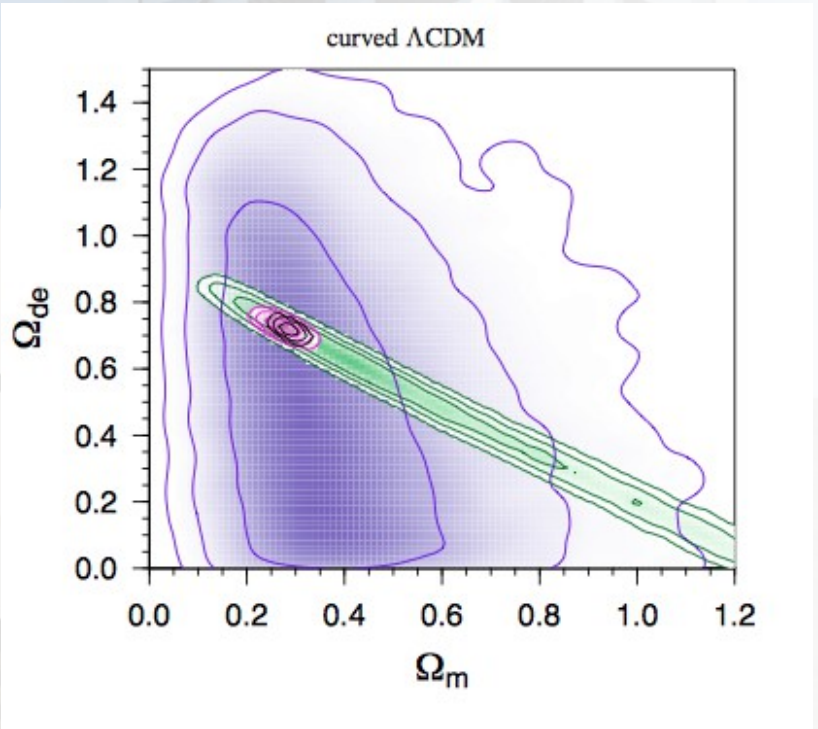

sheared image
α = 4GM/bc²
b
D_S
D_LS
θ
shear
γ ~ θ = D_LS / D_S 4GM/bc²
Gravity & Cosmology change the growth rate of mass structure
Cosmology changes geometric distance factors
Joint analysis with BAO: breaks degeneracy

Cosmology with WL

- Correlation function sensitive to $\Omega_m^{\alpha \sim 1.2}\, \sigma_8$
- Galaxy-galaxy lensing bring additional information



Killbinger 2013



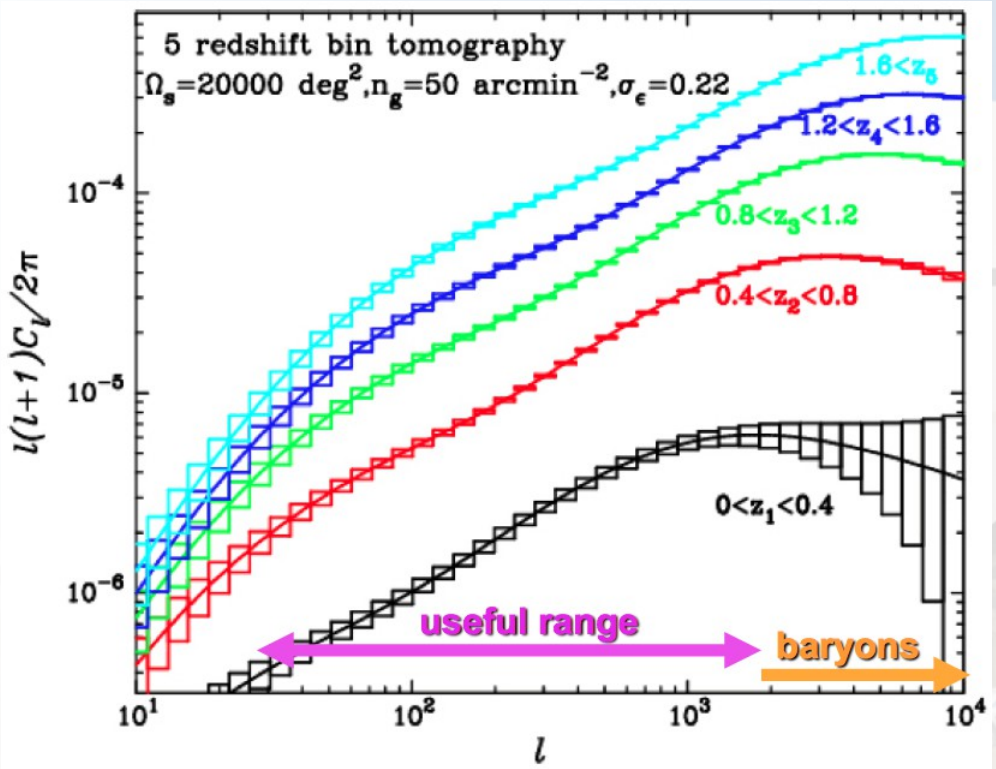
- Expected to be most precise probe with LSST

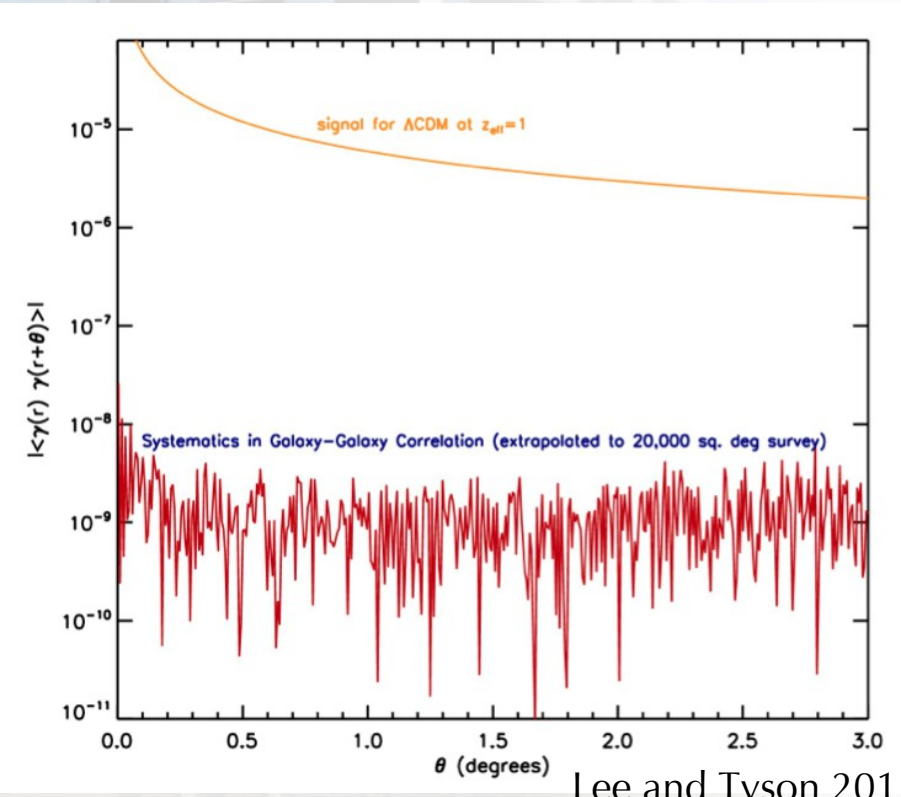
Lensing with LSST

Lensing is sensitive to all dark matter components, including neutrinos

10 redshift bins: 55 auto and cross-spectra

~100 visits will reduce the systematic shear correlations below the shot noise

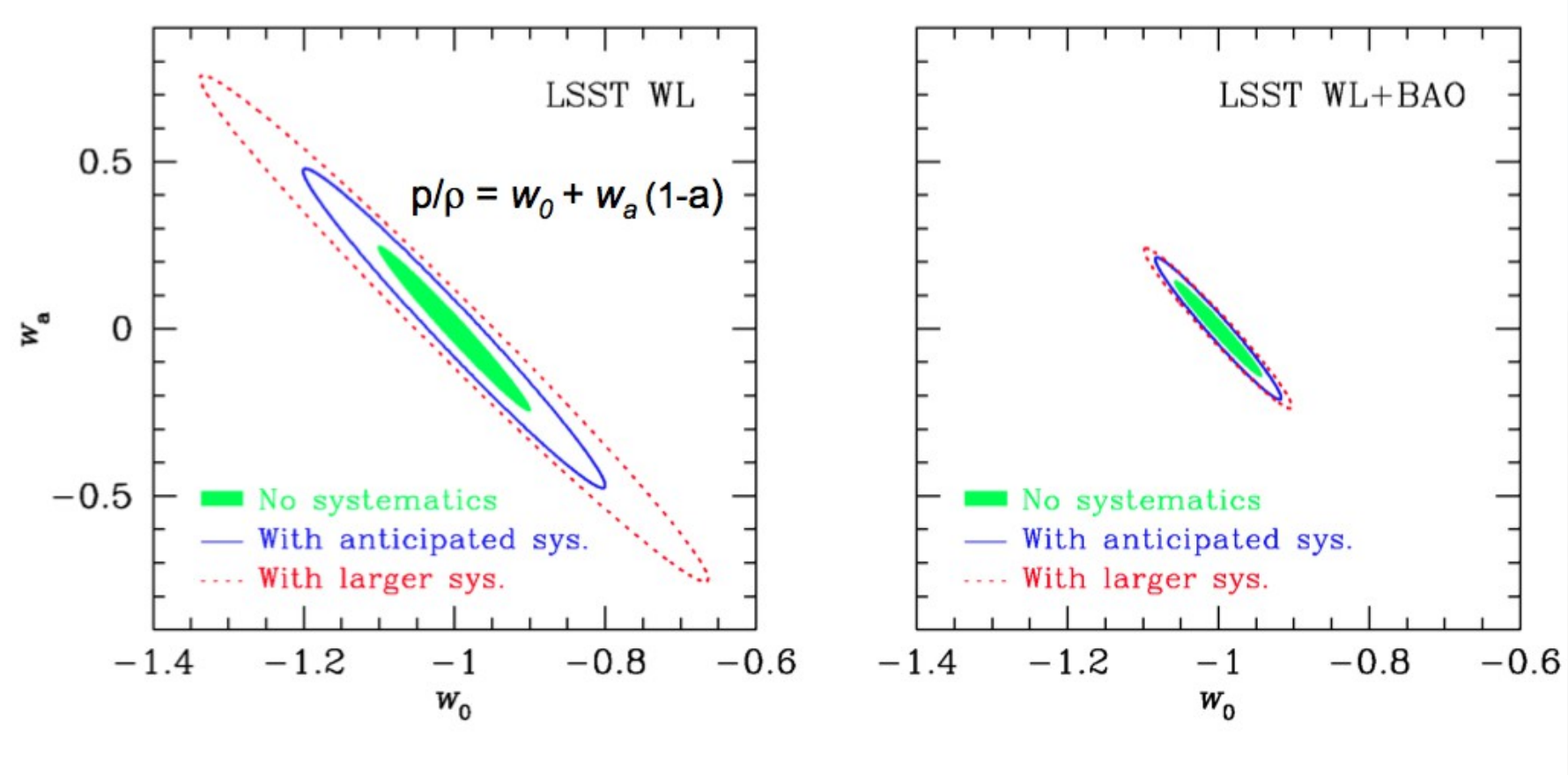




Lee and Tyson 2011

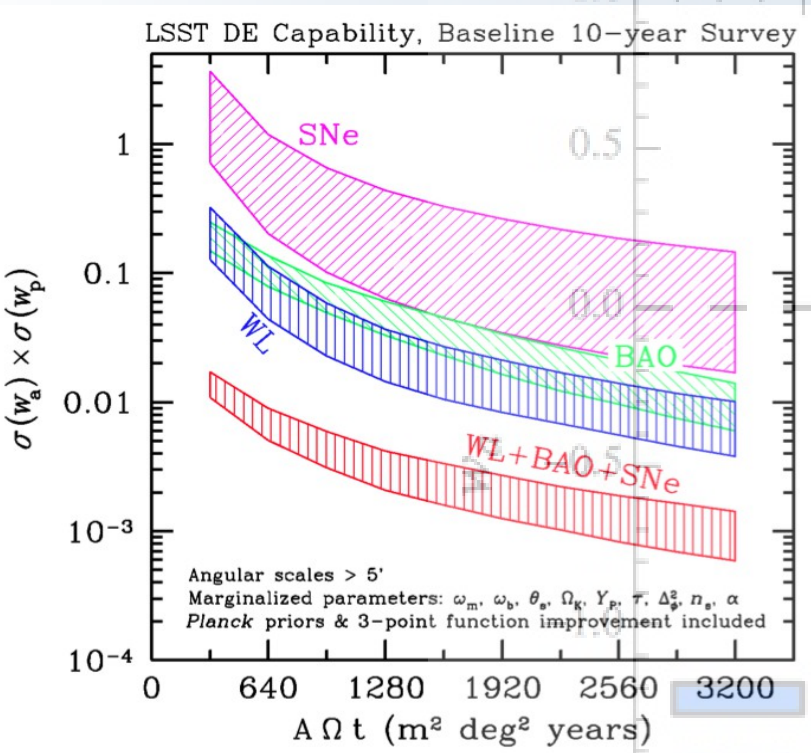
Probe combination is the key

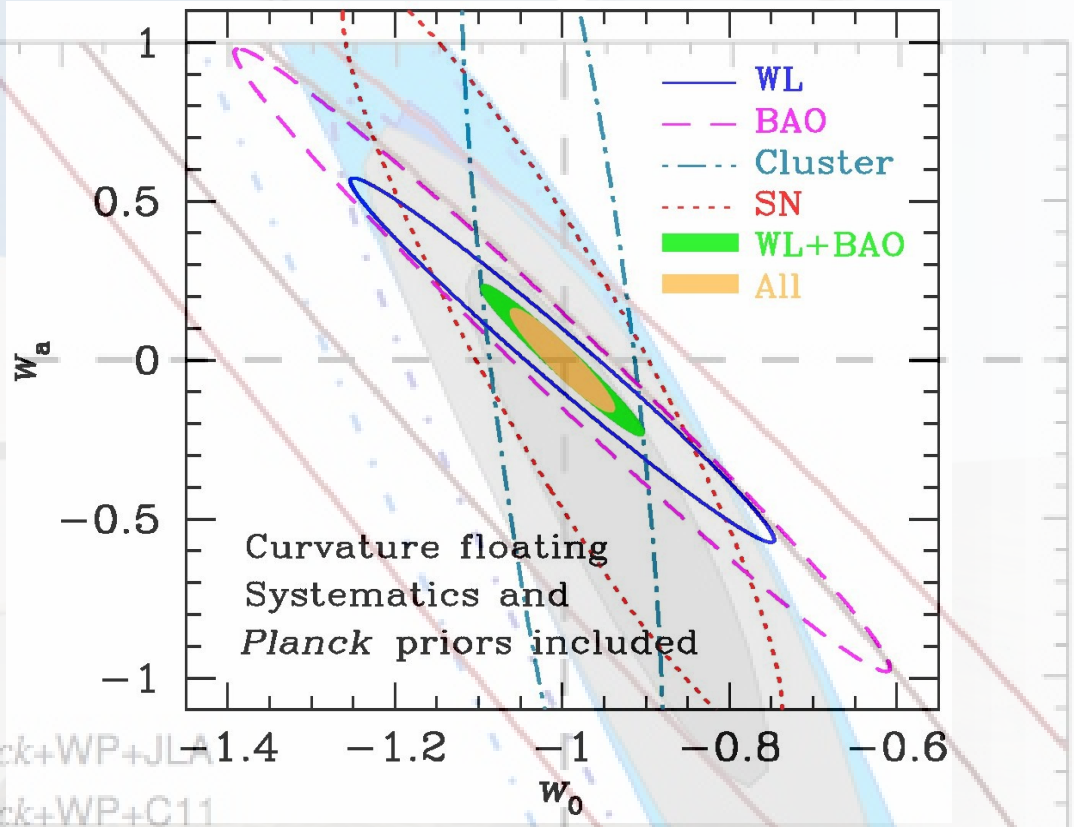
Combining WL and BAO breaks degeneracies
Joint analysis WL and BAO is far less affected by systematics



LSST Dark Energy constraints

Multi-probe approach precise determination of equation of state.
Sensitivity : WL>BAO>SN

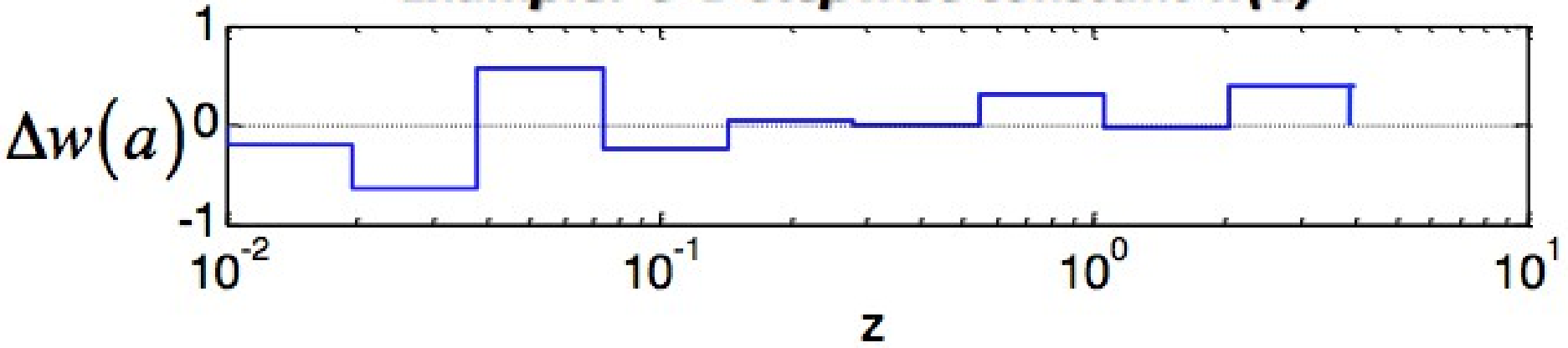




Errors will be systematics dominated !

Beyond w_o w_a

Example: 9-D stepwise constant w(a)



$$w(a) = -1 + \Delta w(a) = -1 + \sum_{i=1}^{9} \Delta w_i T(a_i, a_{i+1})$$

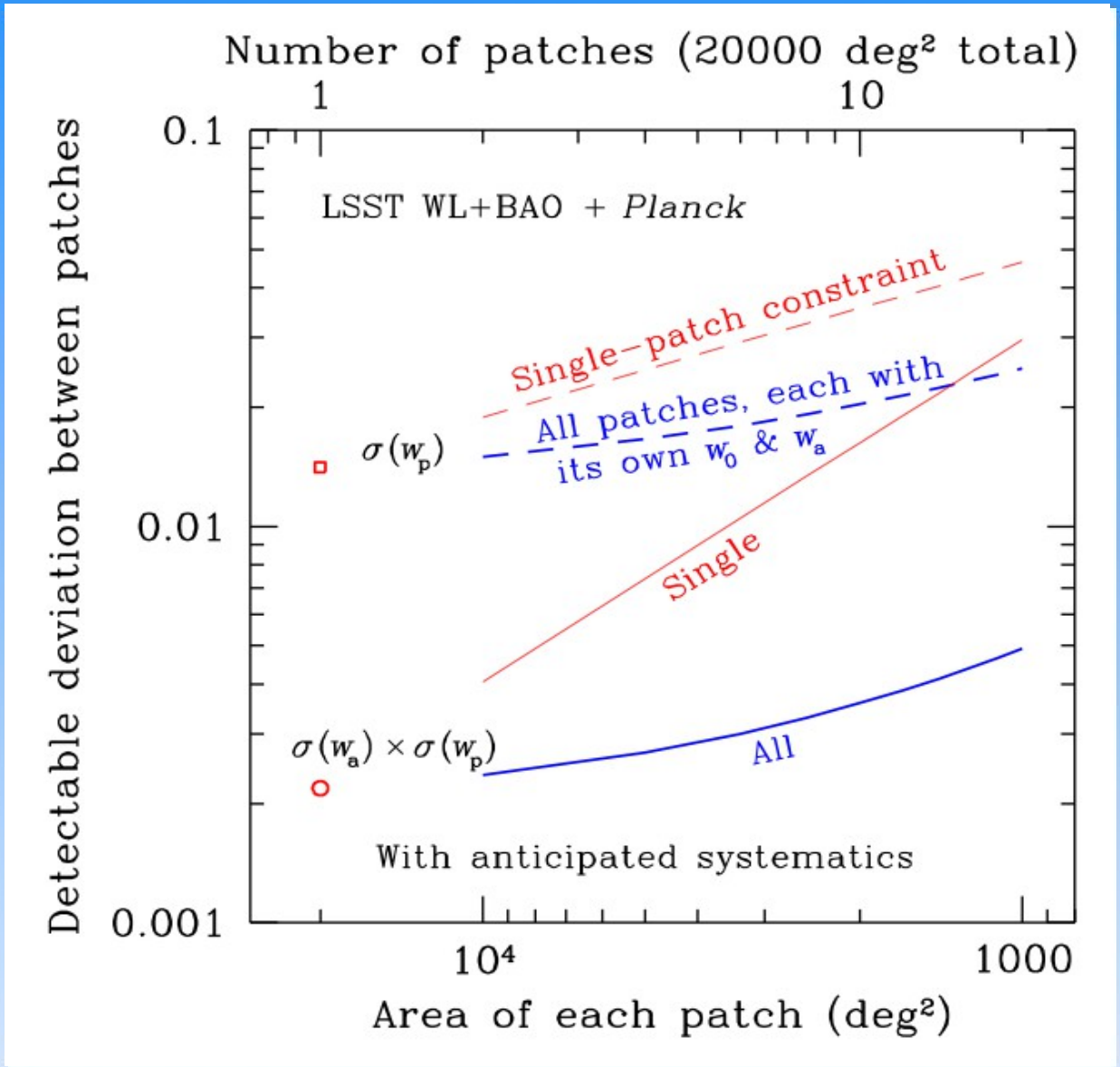
9 parameters are coefficients of the "top hat functions" $T(a_i, a_{i+1})$

Albrecht & Bernstein 2006

+ General models of Dark Energy

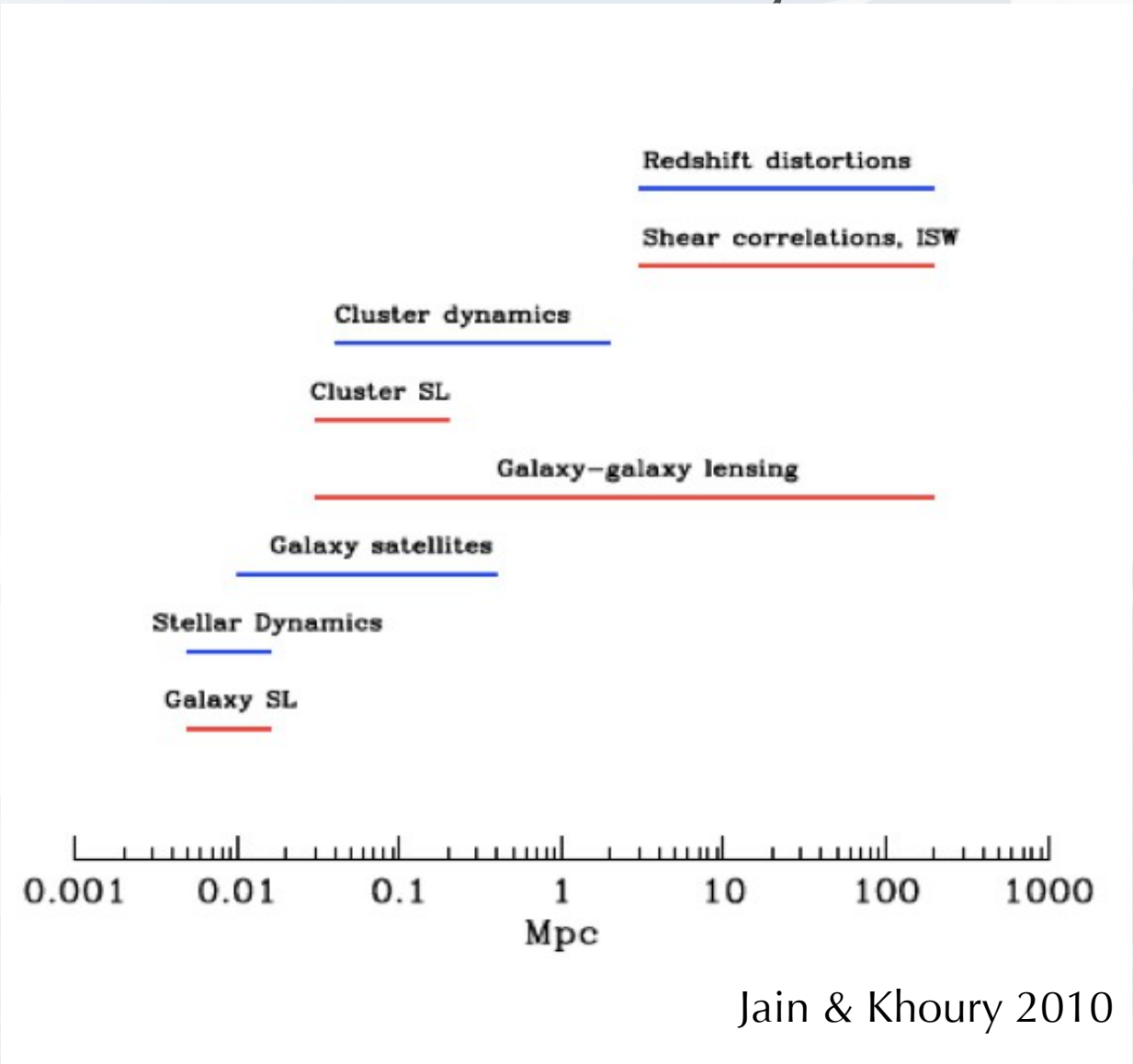
Is dark energy isotropic?

- Incorporating all-sky fits for other cosmology parameters, an LSST search for anisotropy in the EoS is quite sensitive.
- Shown is the sensitivity to deviation of dark energy EoS and DETF error product over the sky in patches of area A.
- This can separately be done with SNe



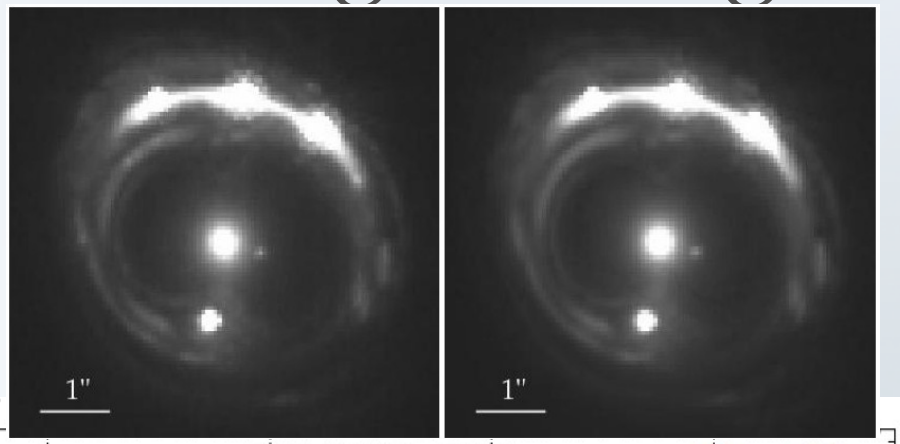
Science Book Ch. 15.4

Cosmological tests of general relativity

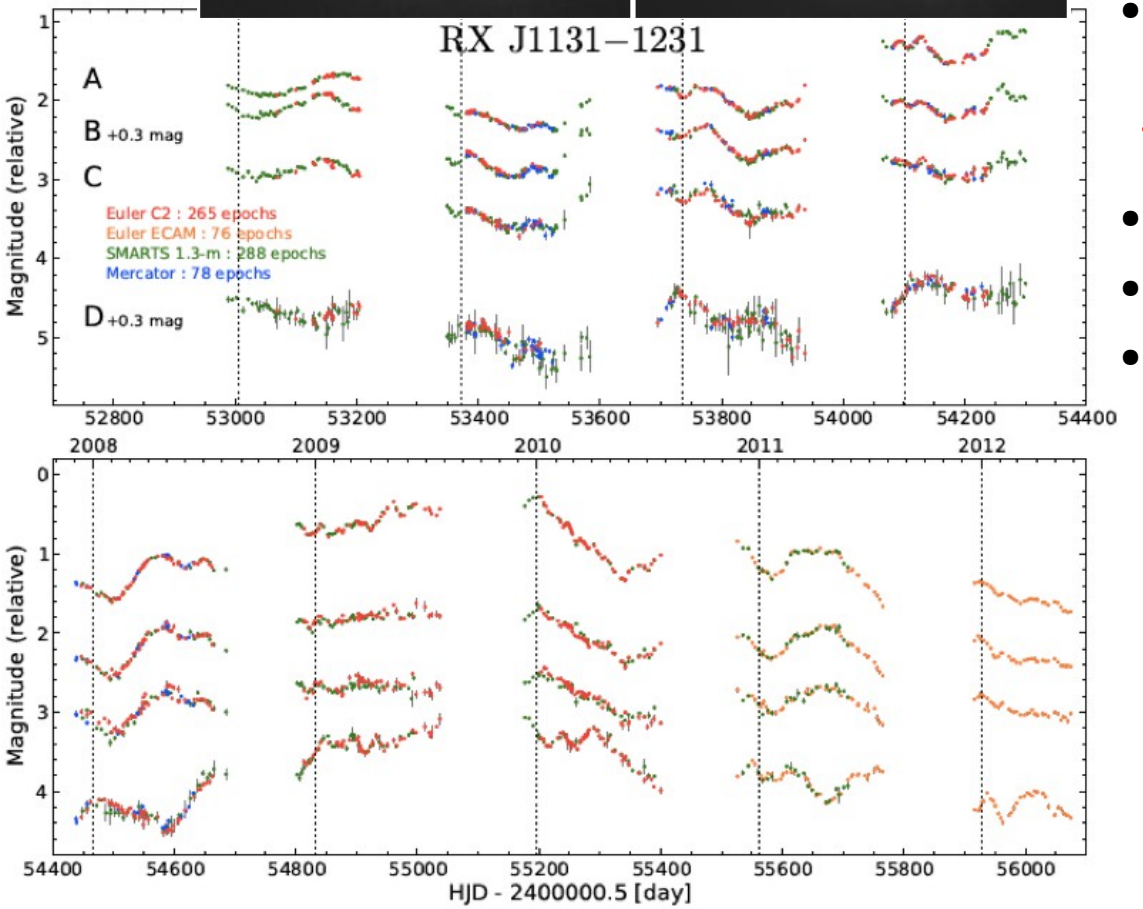


Jain & Khoury 2010

Strong lensing time delays



Treu 2013



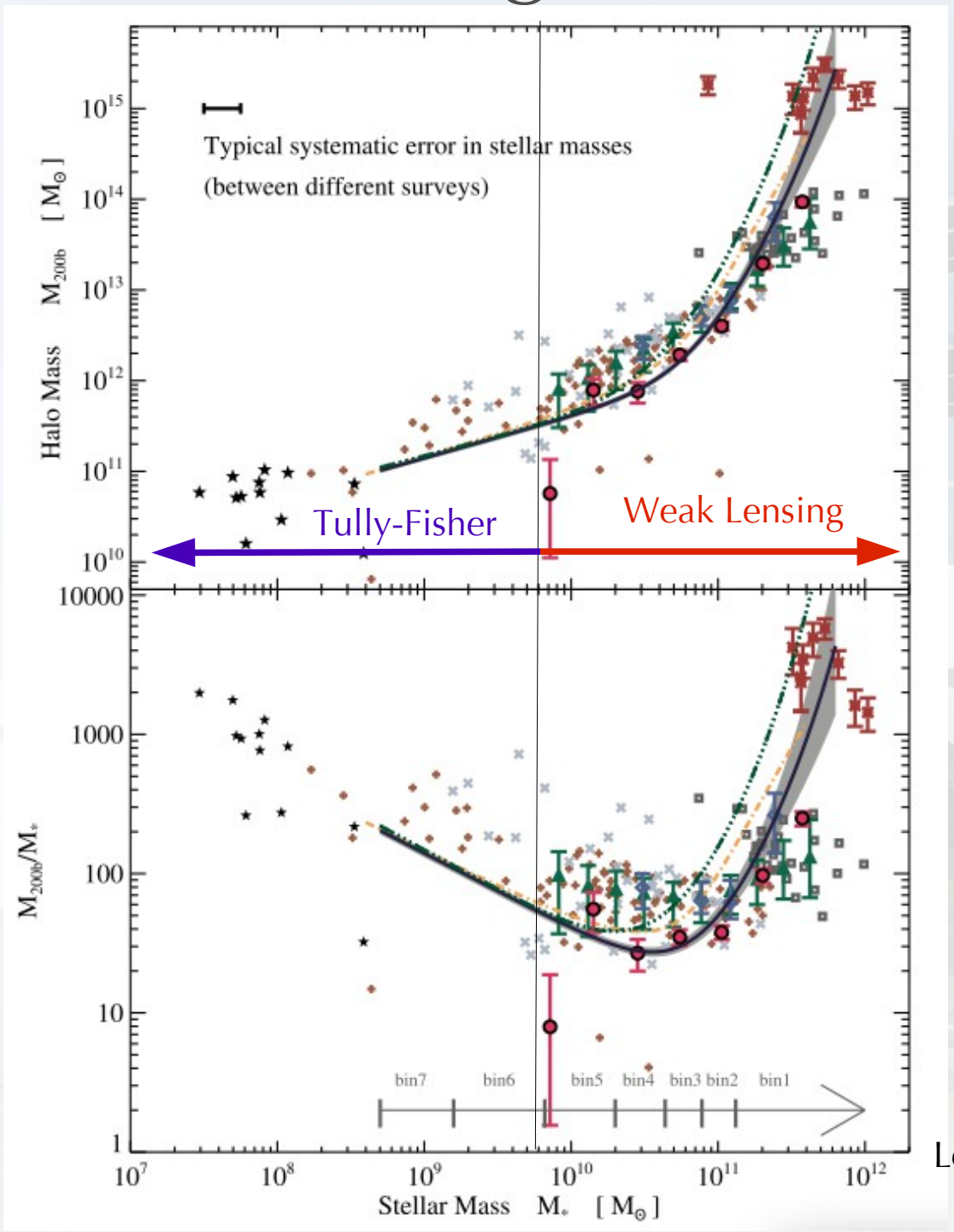
LSST expects strong lensend variable sources

- ~2500 quasars
- ~300 SN (100 Ia)

Time delay gives access to

- measure of H0
- DE EoS
- GR consistency

Probing dark matter



LSST/WL provides halo masses

… and evolution with z

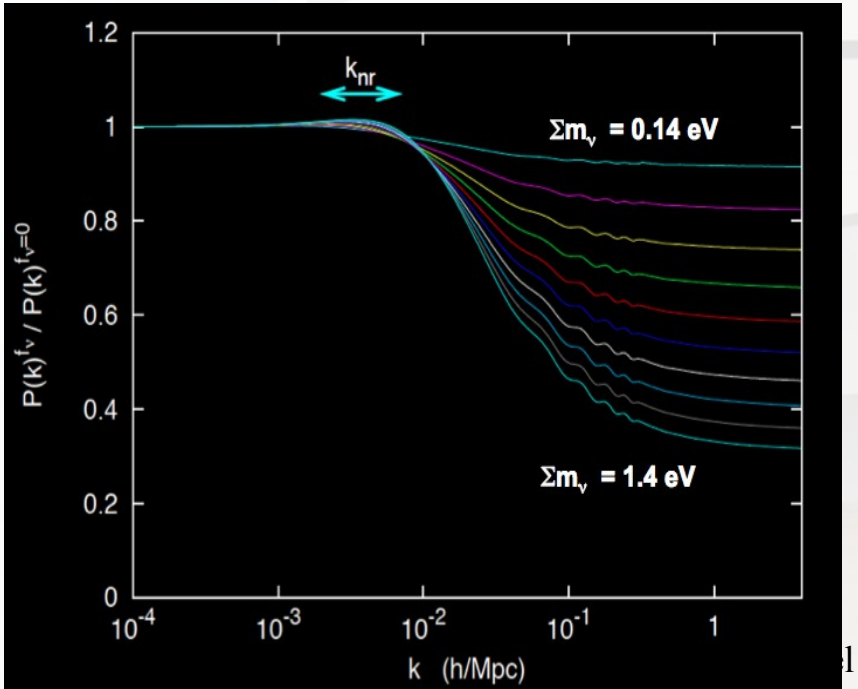
Leauthaud 2012

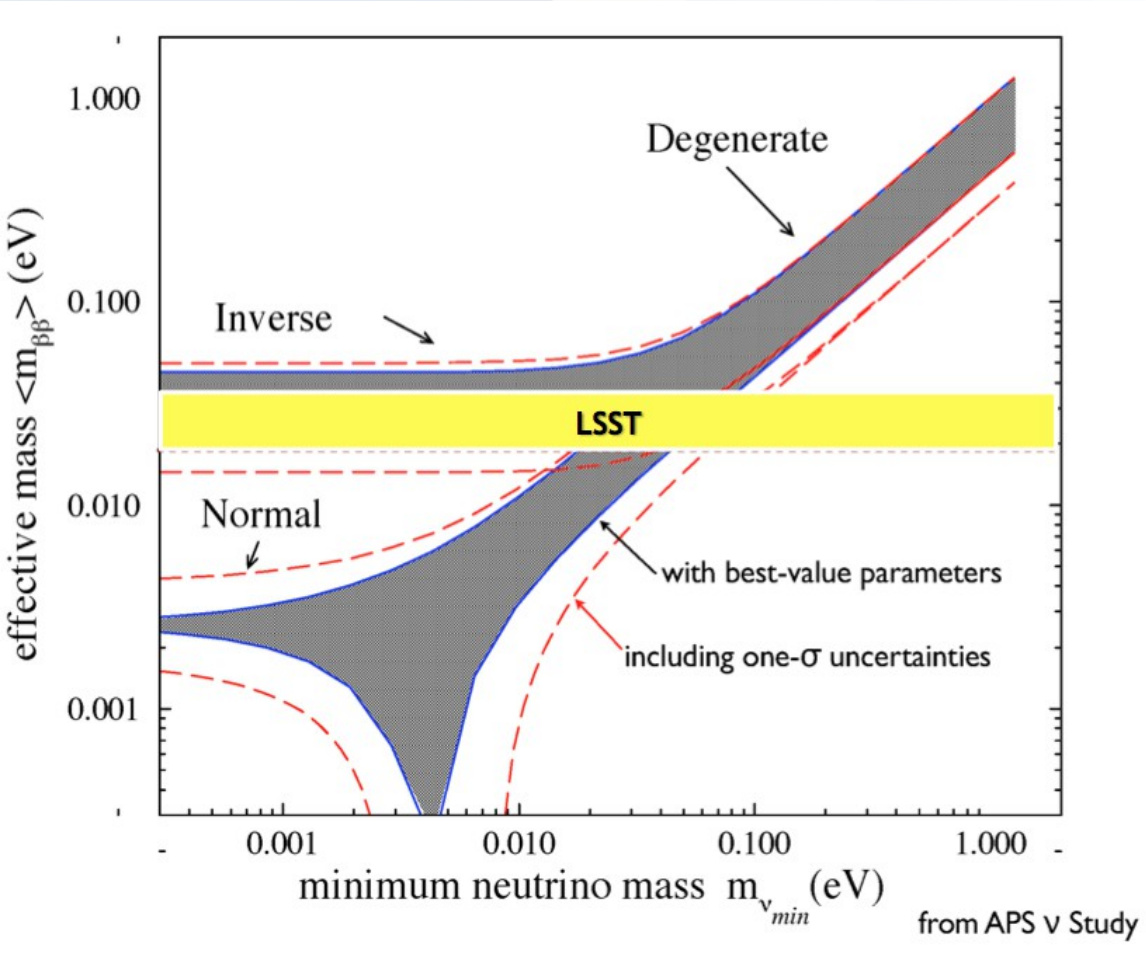
Neutrino mass

Neutrino suppress growth of structures

Smaller mass
- longer relativistic
- suppress growth on larger scales

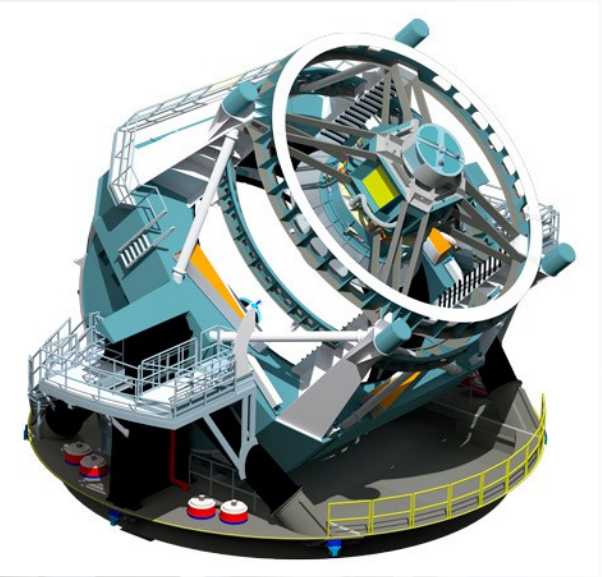
Abazajian



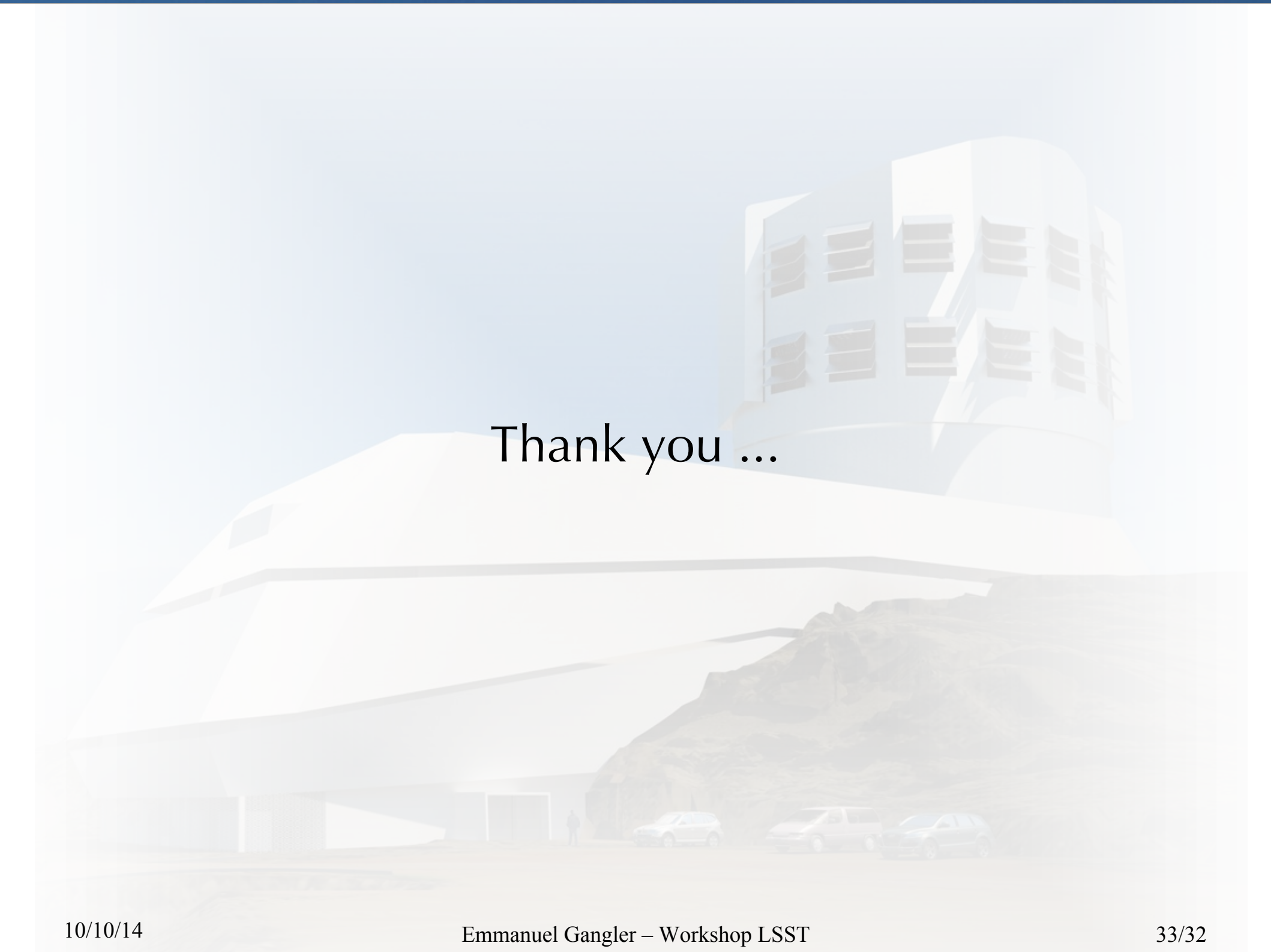


Expected 0.03 eV sensitivity

Conclusions



- **LSST will provide unprecedented data**
  - Opens up time domain
  - … and a LOT of scientific opportunities
- **Probe combination is the key for cosmology**
  - WL, BAO and SN addressed within the same survey
  - Precision cosmology may unveil the nature of dark energy
- **Combining data with other survey is a win-win**
  - **IR survey** is a natural complement
    - Photo-z, other combined analysis …
  - **Spectroscopy** surveys too
    - Photo-z calibration
    - Transient follow-up


Thank you ...