Énergie noire
Formation des structures

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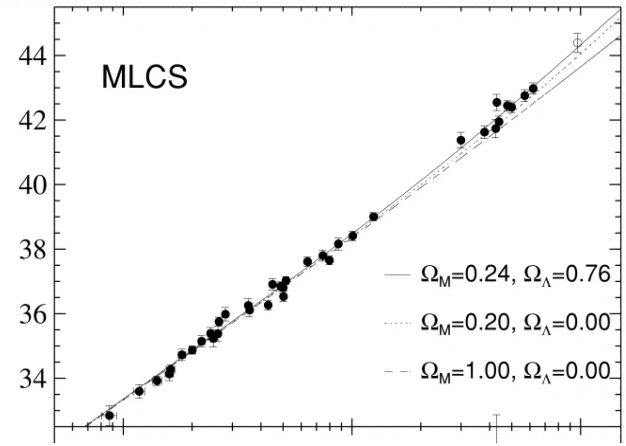
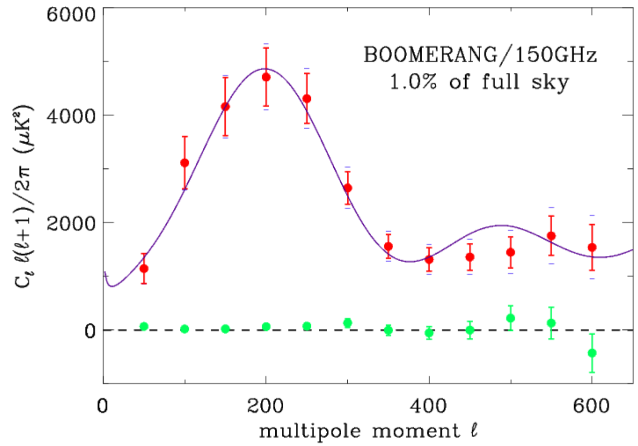
Outline

- Overview of DE probes (and recent highlights)
  - Hubble Diagram of supernovae (JLA)
  - Baryon accoustic oscillations (BOSS)
  - Lensing (CFHTLS)
  - Matter clustering (VIPERS, BOSS)
- The next decade
  - Large imaging surveys: Euclid, LSST (and CFIS !)
  - Massive spectroscopic surveys: DESI, 4MOST
  - ...
- Conclusion

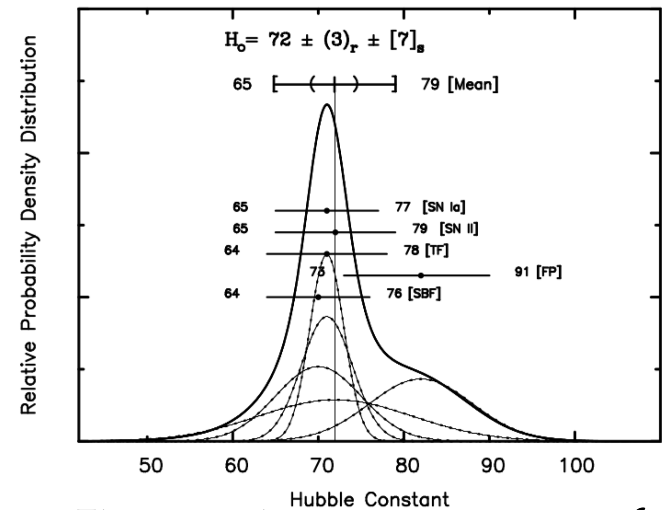
At the turn of the century ...



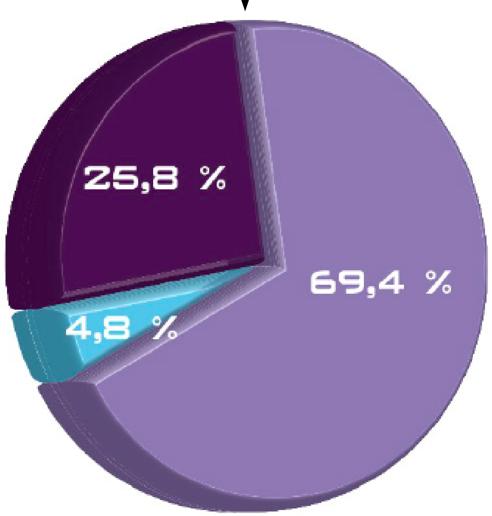
First convincing evidence for acceleration (e.g. Riess et al 1998, Perlmutter et al, 1999)



First precise measurements of CMB accoustic peak (e.g. de Bernardis et al, 2000)



First precise measurement of H0 (Freedman et al, 2000)



BTW: If you have read Nielsen et al [1506.01354], be sure to read also Rubin & Hayden (2016) [1610.08972]

An accelerated Euclidian Universe, dominated by Cold Dark Matter and Dark Energy (Λ)

Nature of “dark energy” ?

- Cosmological constant / fluid of unknown nature ?
  - Measure its equation of state $w = \frac{p}{\rho}$
  - with potentially :

$$w(a) = w_p + w_a(a_p - a)$$

$$\Lambda \Rightarrow w = -1$$

- Something wrong with GR at cosmological scales ?
  - Then, expect a different phenomenology
  - e.g. growth of structure should be different

$\longrightarrow$ Precision test of GR

$$f \propto \Omega_m^{\gamma}$$

Growth rate

GR predicts γ ~ 0.55

Dark Energy Probes

- The smooth Universe
  - Type Ia Supernovae
  - Baryon acoustic oscillations

"0th order cosmology"
Kinematic probes

- Inhomogeneities
  - Lensing by Large scale structures
  - Redshift space distorsions
  - Clusters

"1st order cosmology"
Dynamical probes

Note that ΛCDM (6 parameters)

$\Omega_b h^2$

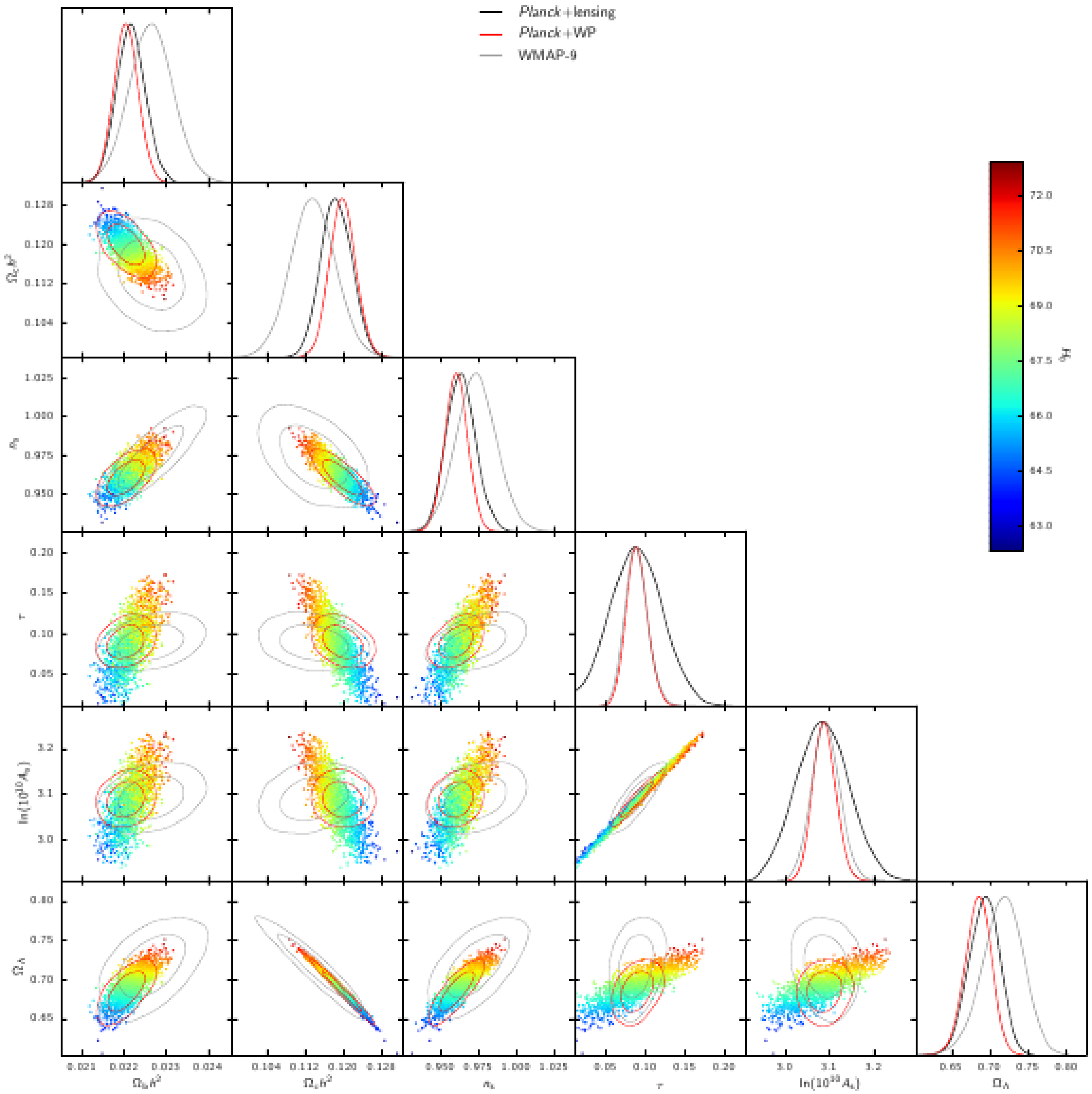
$\Omega_c h^2$

n_s

τ

$\ln\left(10^{10} A_s\right)$

Ω_Λ



(Planck collaboration XVI)

+ extensions (w, Ω_K, ...)

... is a very good fit to the data ...

A much more extensive investigation of models of dark energy and also models of modified gravity can be found in Planck Collaboration XIV (2015). The main conclusions of that analysis are as follows:

- an investigation of more general time-variations of the equation of state shows a high degree of consistency with $w = -1$;
- a study of several dark energy and modified gravity models either finds compatibility with base ΛCDM, or mild tensions, which are driven mainly by external data sets.

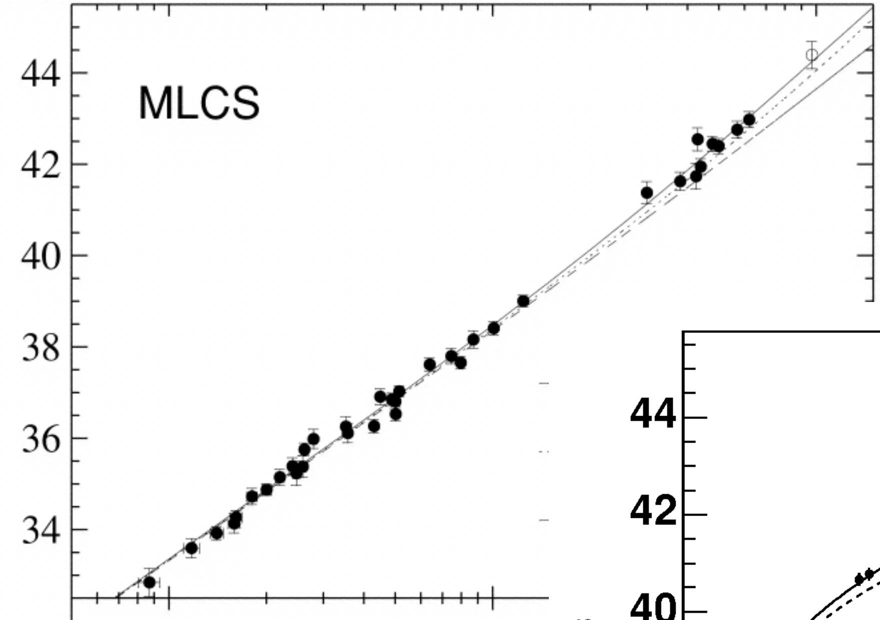
7. Conclusions[37]

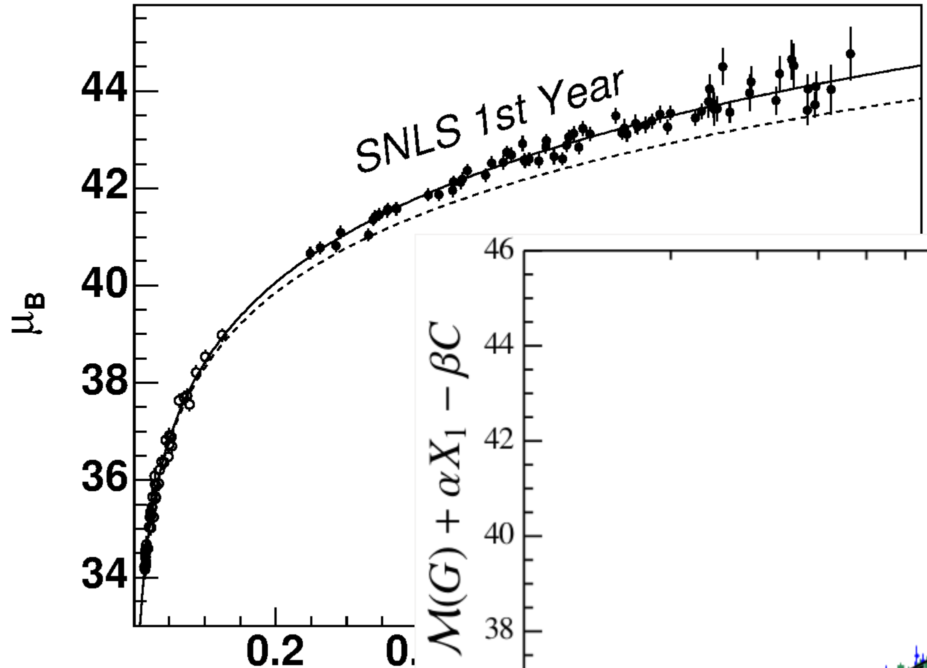
(1) The six-parameter base ΛCDM model continues to provide a very good match to the more extensive 2015 *Planck* data, including polarization. This is the most important conclusion of this paper.

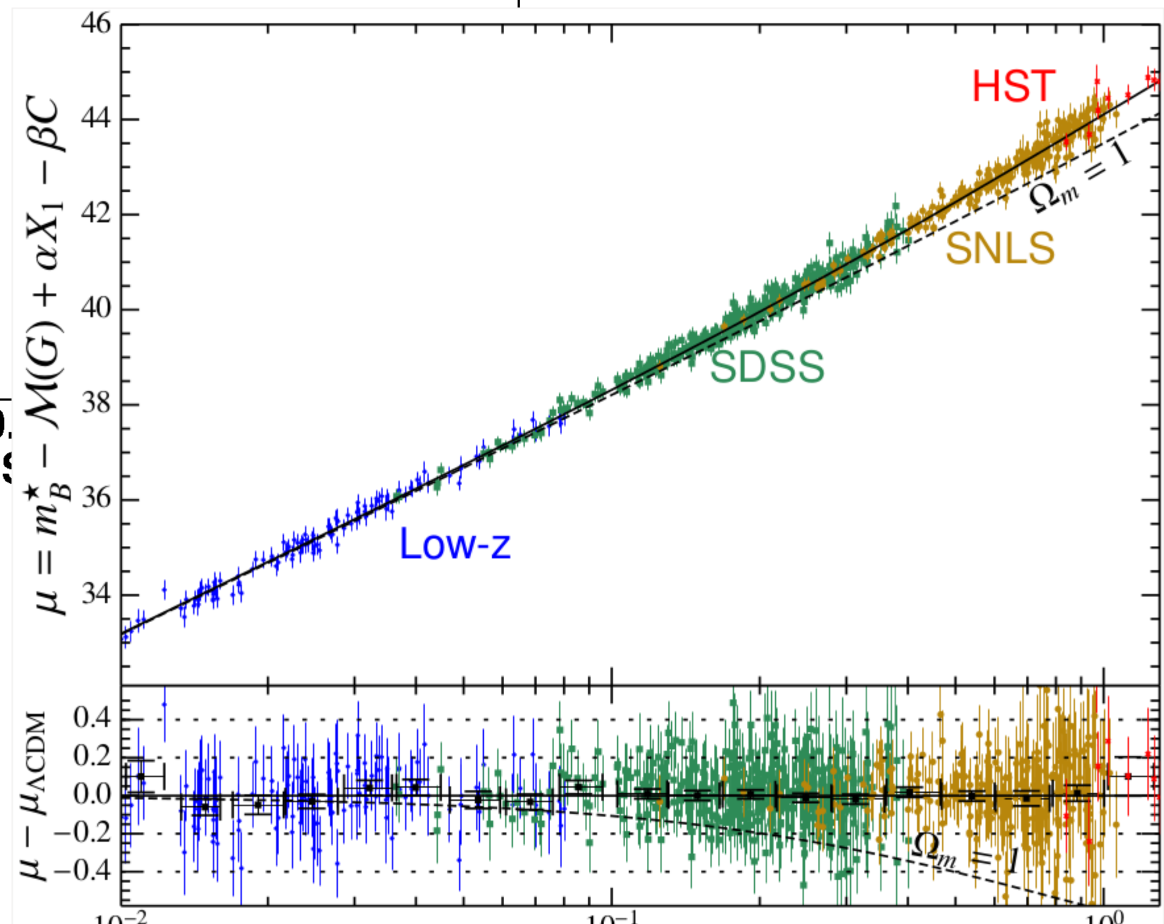
Planck Coll. XIII (2015)

Probes of the smooth Universe

Supernovae





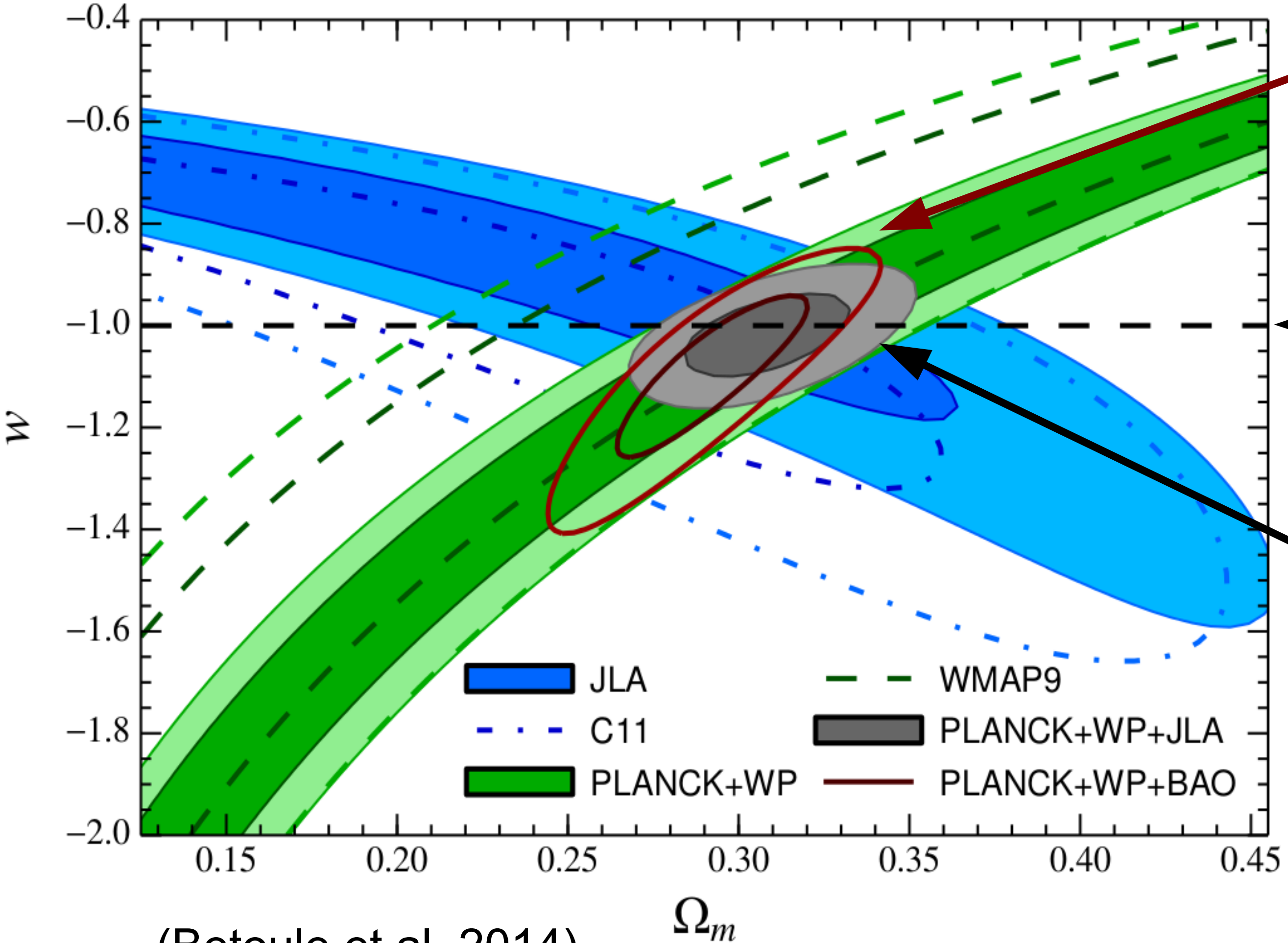


(Betoule et al, 2014)

- 1998 : O(50) SNe
- 2005 : O(100) SNe
- 2014 : O(1000) Sne

(x 20 in statistics)

Flat wCDM



Planck + BAO

w = -1.01 ± 0.08

Λ

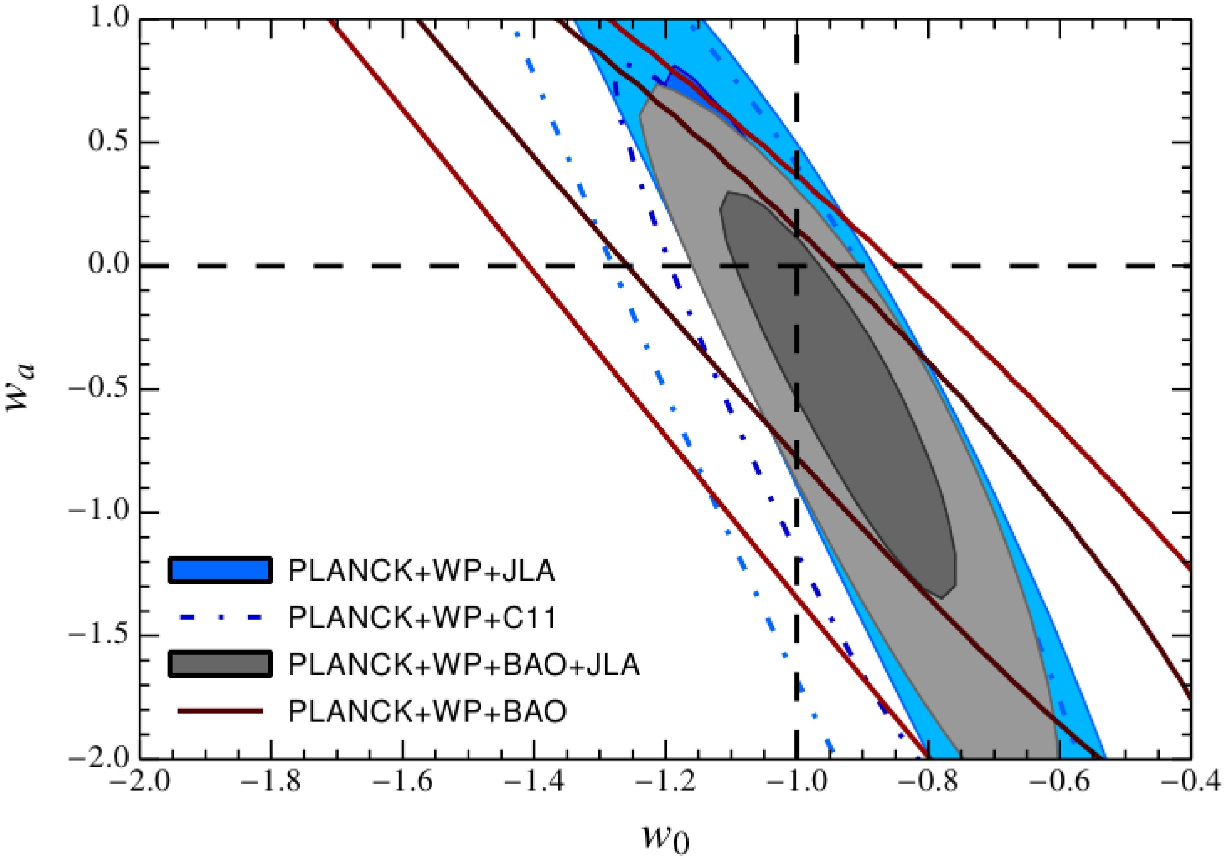
Planck + SNe

w = -1.018 ± 0.057

(Betoule et al, 2014)

(see also Suzuki et al '12,
Rest et al '13, Scolnic et al '13...)

Marginal constraints on (w_p, w_a)



DETF FoM ~ 15

Ingredients

- Large SDSS dataset
- Calibration accuracy
- Better CMB + BAO

$$FoM = \frac{1}{\sigma(w_p) \times \sigma(w_a)}$$

DETF : Albrecht et al '06
See also: Peacock et al '06

Goals for next decade:
FoM > 400

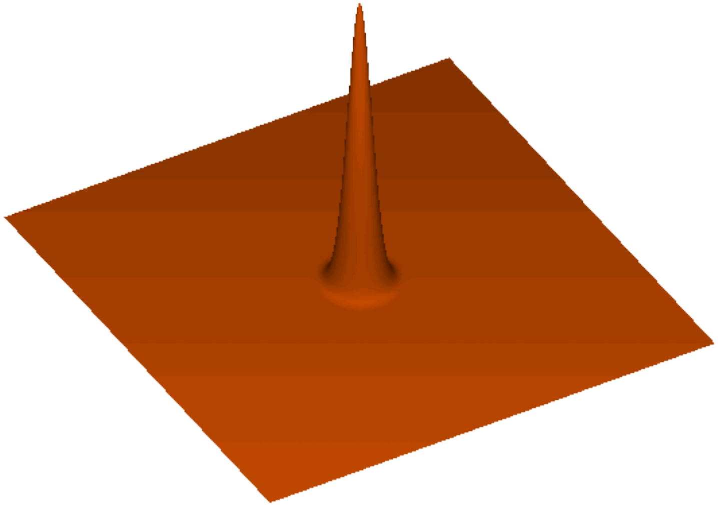
Baryon accoustic oscillations

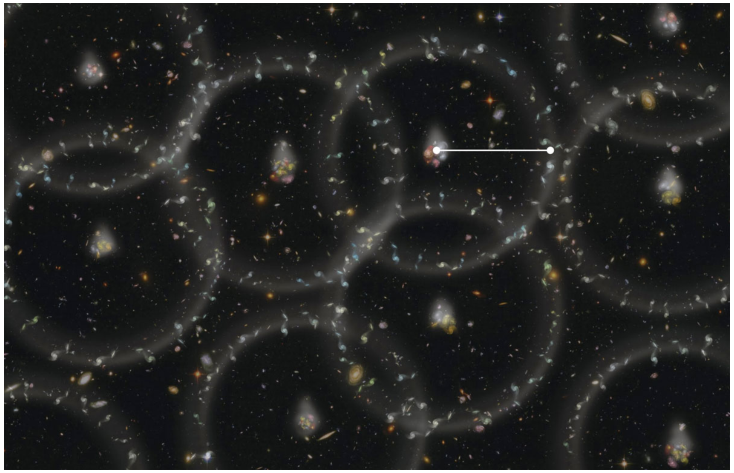
- Oscillations in primordial plasma

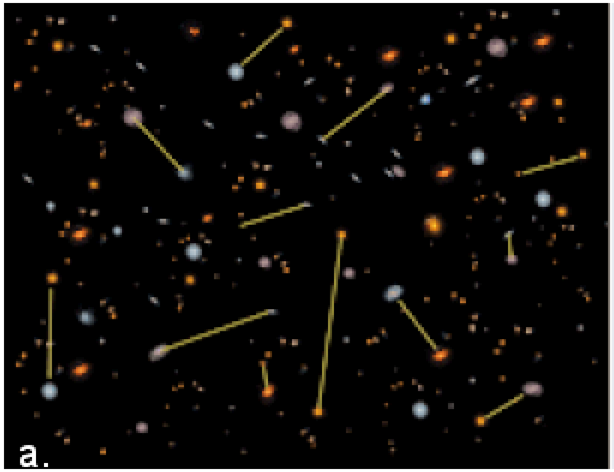
$$r_s = \int_0^{t_\star} \frac{c_s(t)}{a(t)} dt$$ = 147.5 ± 0.6 Mpc

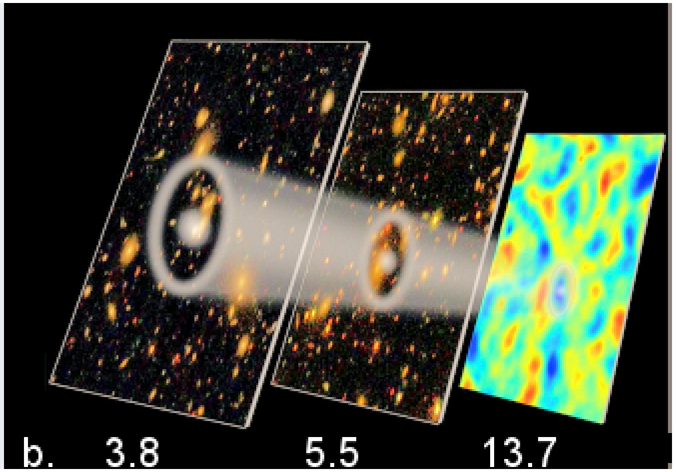
(Planck Coll XVI)

Simple, linear physics



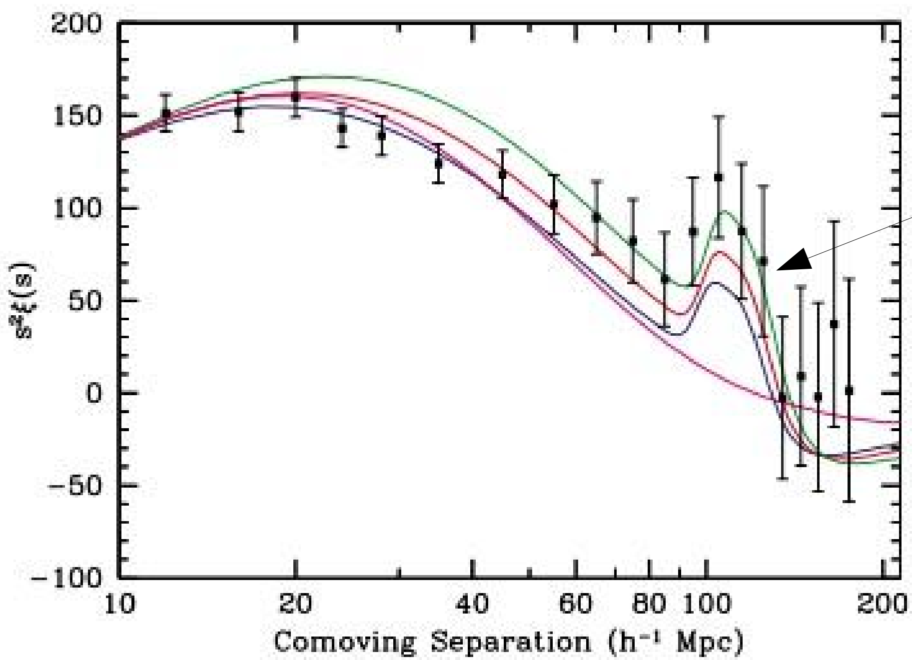






Baryon accoustic oscillations

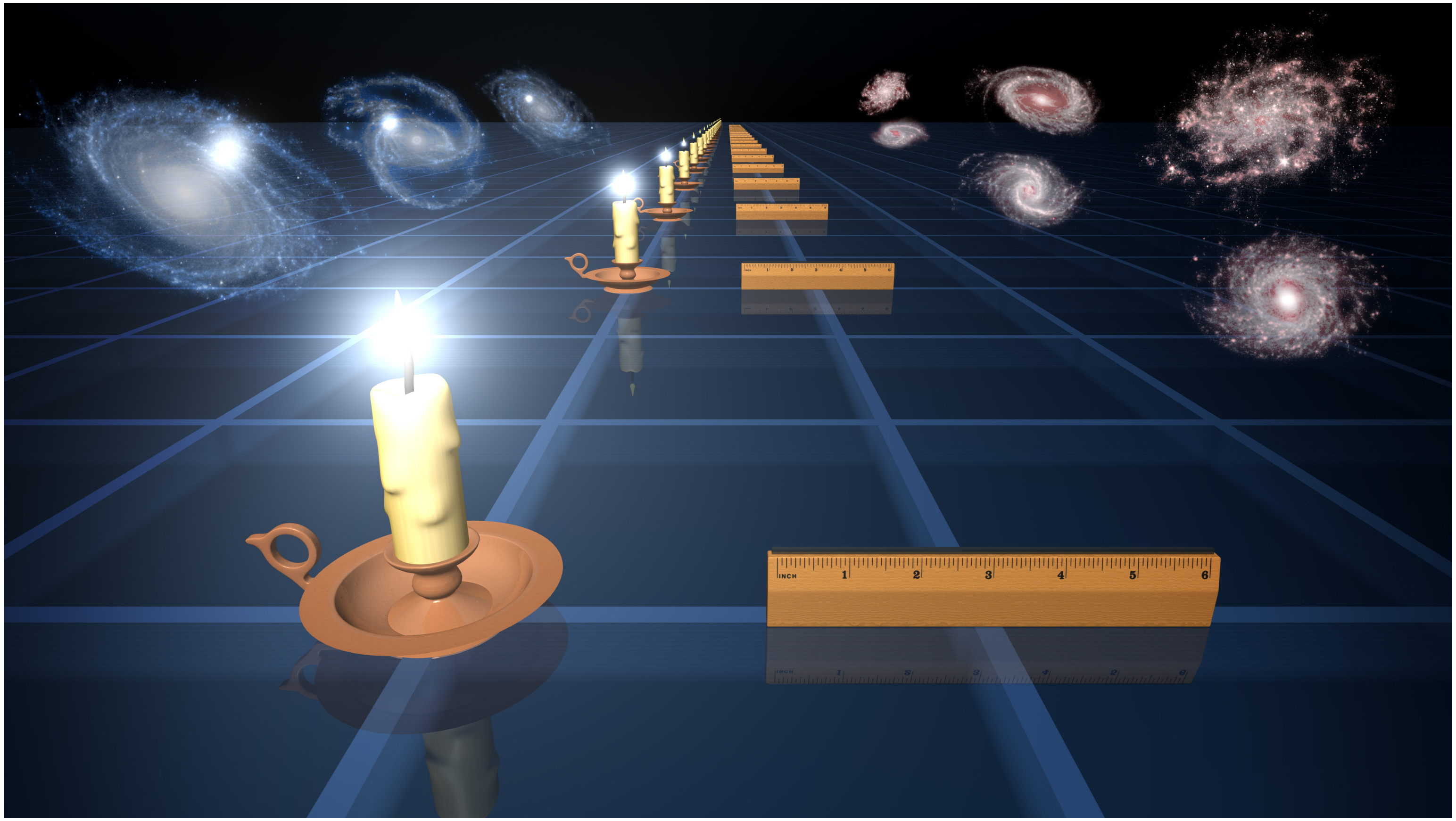
- With a massive spectroscopy survey, one can measure the positions (θ, φ, z) of enough (~10^5 – 10^6) galaxies and histogram their distances :



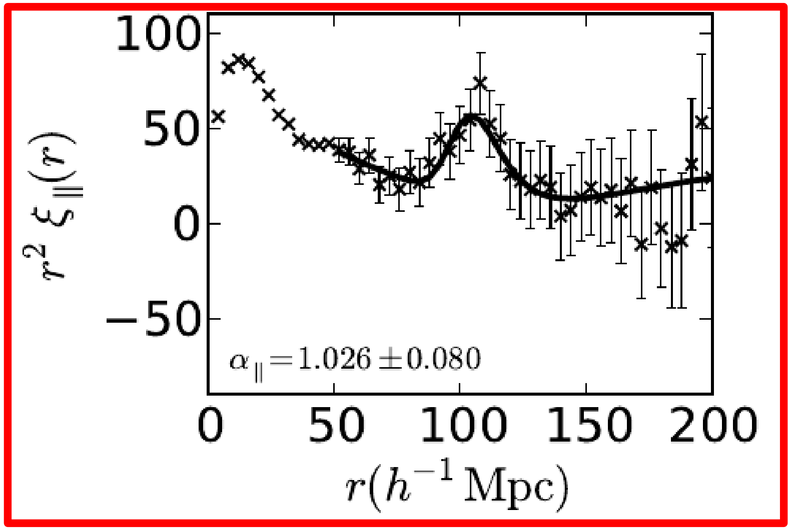
Baryon accoustic peak !

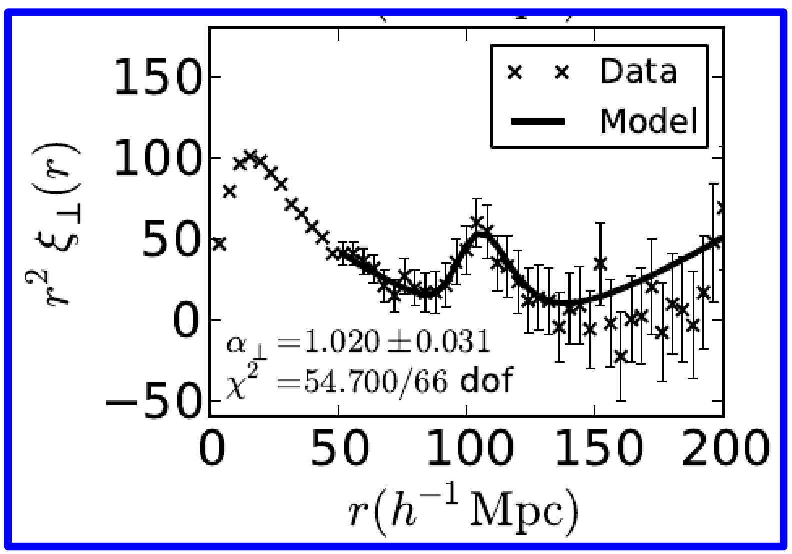
(Eisenstein et al, '05   Cole et al '05)

Angular distance Hubble diagram

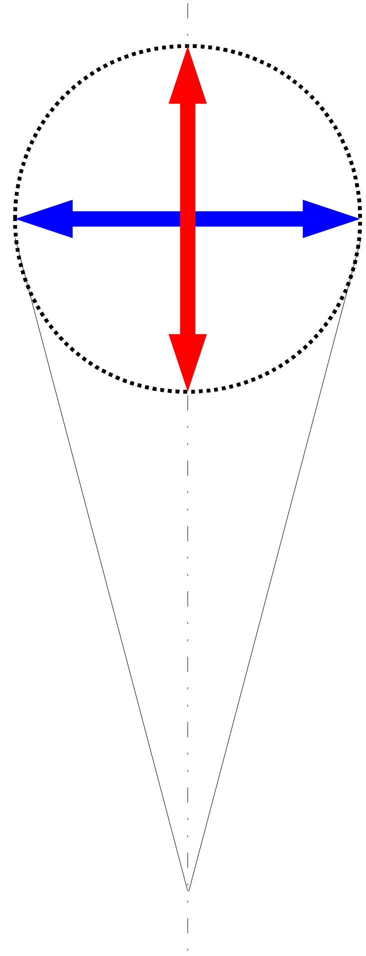


Can do even better...





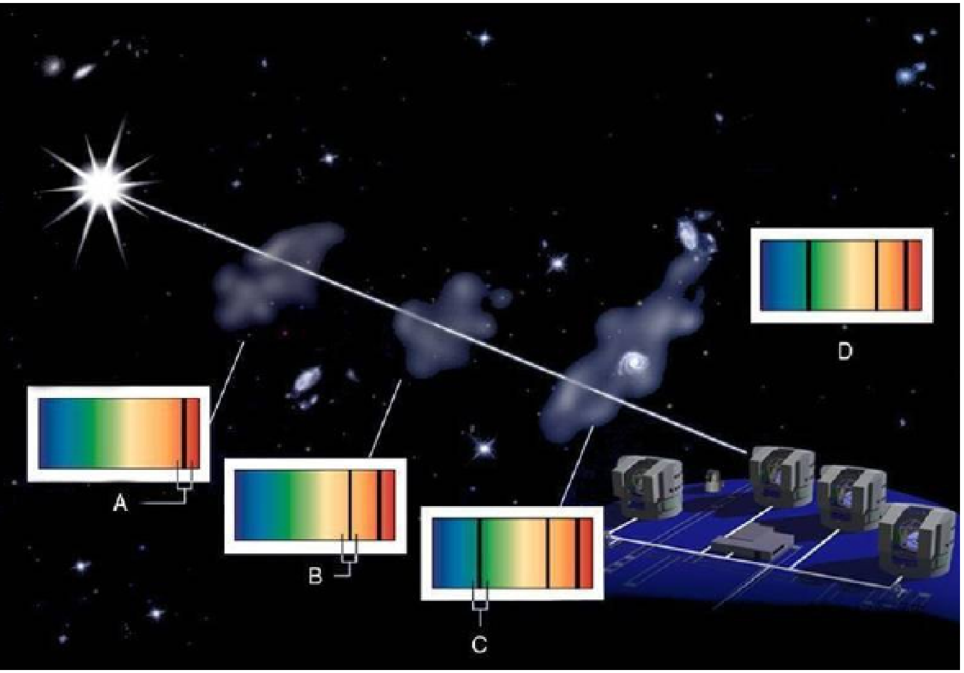
$$\delta r_{\parallel} = \frac{c}{H(z)}\Delta z$$



$$\delta r_{\perp} = D_A \delta\theta$$

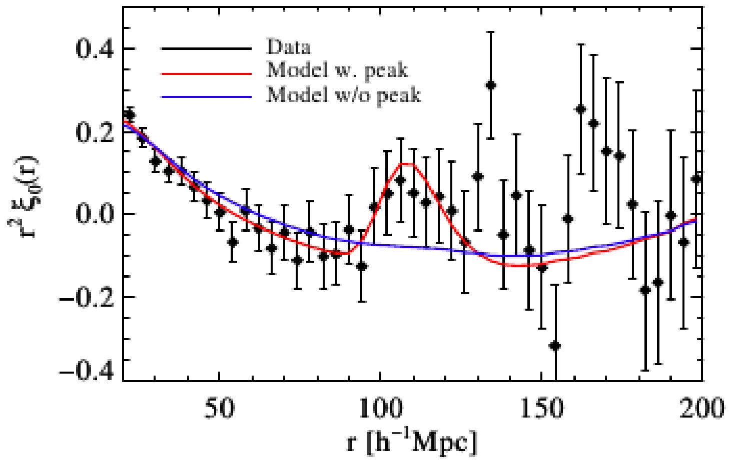
$$\propto \int \frac{dz}{H(z)}$$

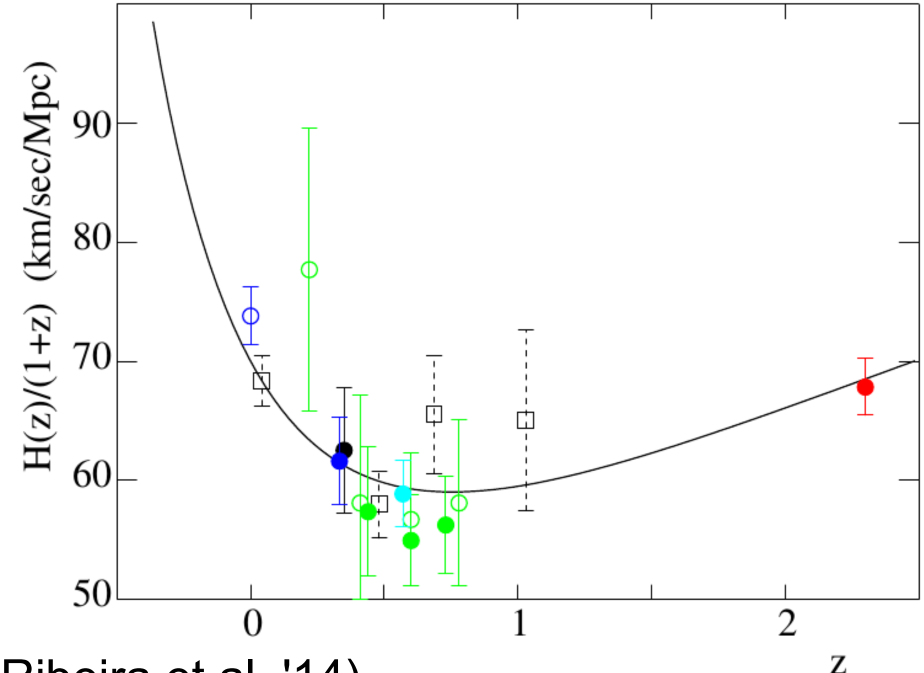
BAO in the Ly-α Forest



- Background quasars
- Light travels through the intergalactic medium (ionized H)
- Ly-α, absorption line

$\lambda = 1215Å$





(See e.g. Busca et al, '12, Delubac et al, '15, Font Ribeira et al, '14)

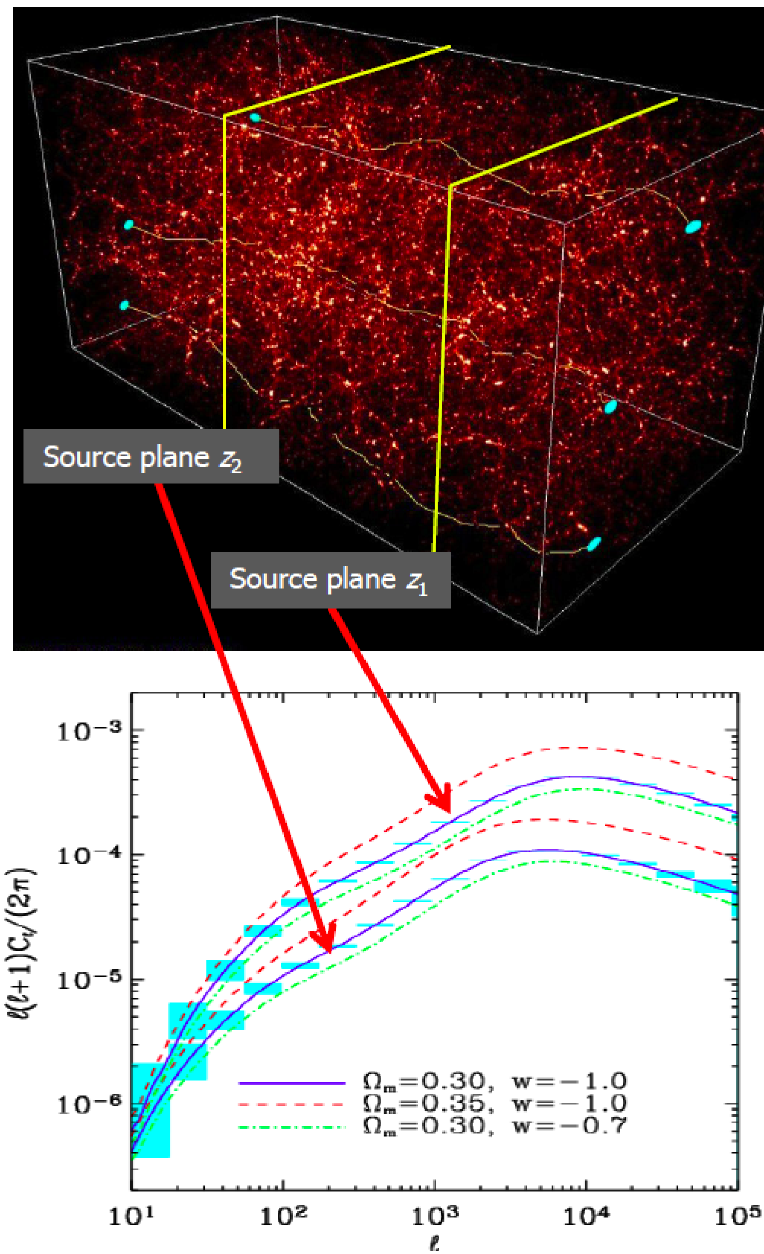
Baryon acoustic oscillations

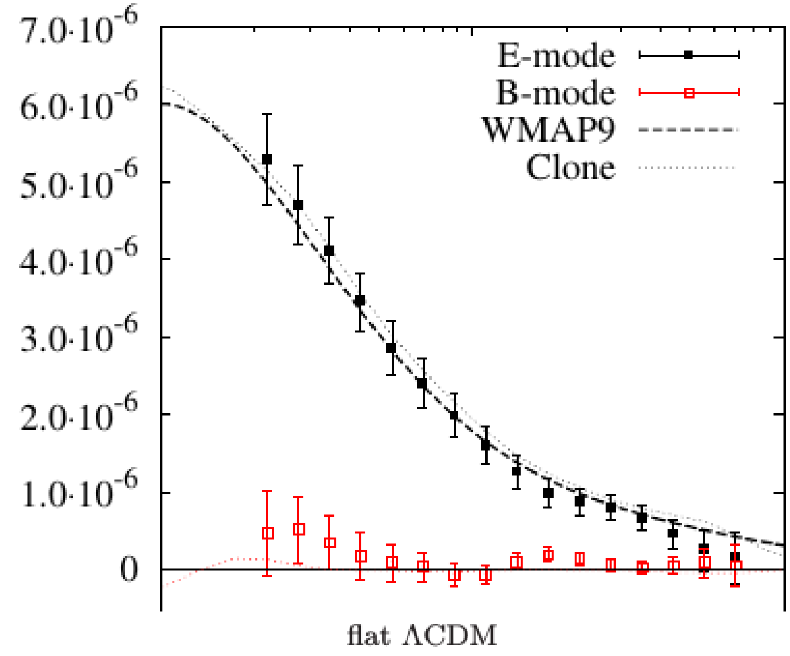
- Geometric measurement
- *Absolute* angular distances (r_s is known)
- Sensitivity to H(z)
- Measurable wherever there are baryons
  - (Galaxies, Ly-α forest, quasars…)
- Expensive probe : millions of redshifts needed
- Cosmic variance at low redshift
- Target selection : photometric catalog needed before the survey starts !
- Strong implication FR community (BOSS/eBOSS/DESI/4MOST)

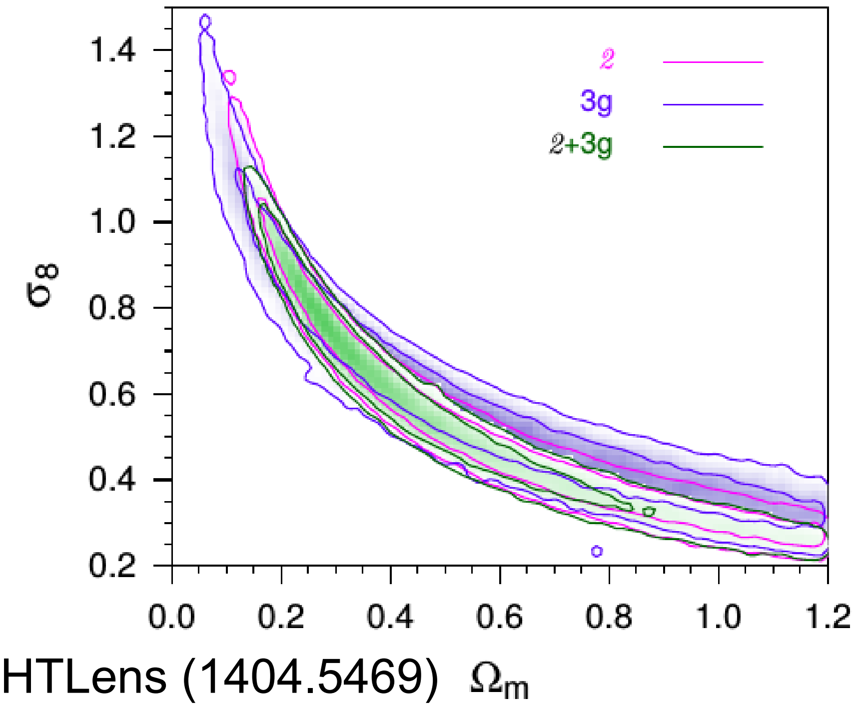
Probes of the inhomogeneous Universe

Weak lensing

1.5 billion sources with shapes, 10 slices







CFHTLens (1404.5469)

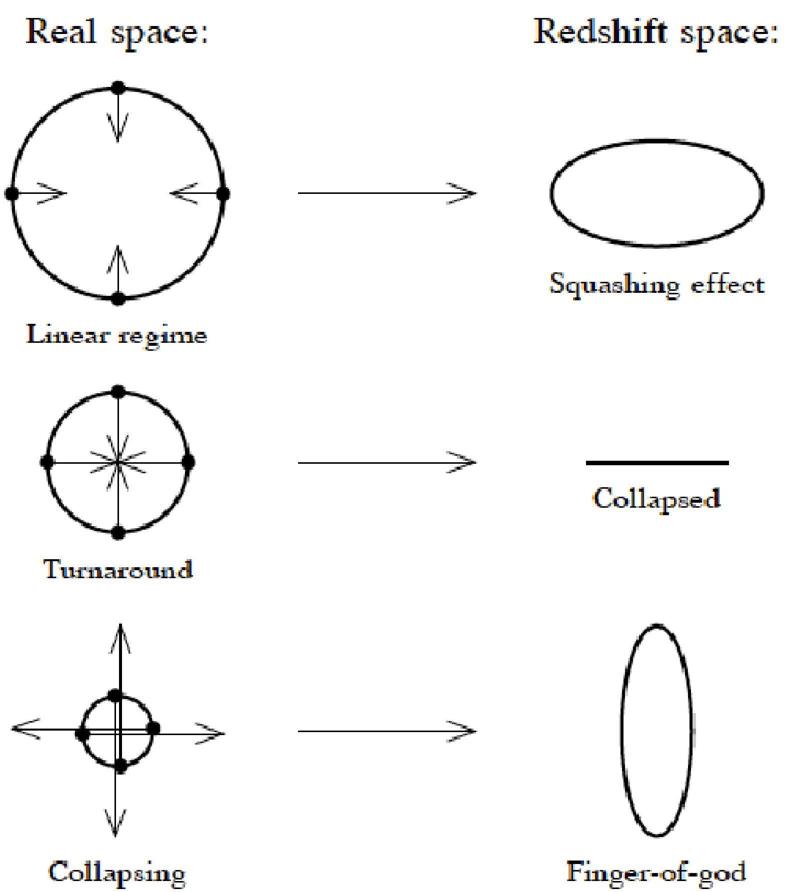
Weak lensing

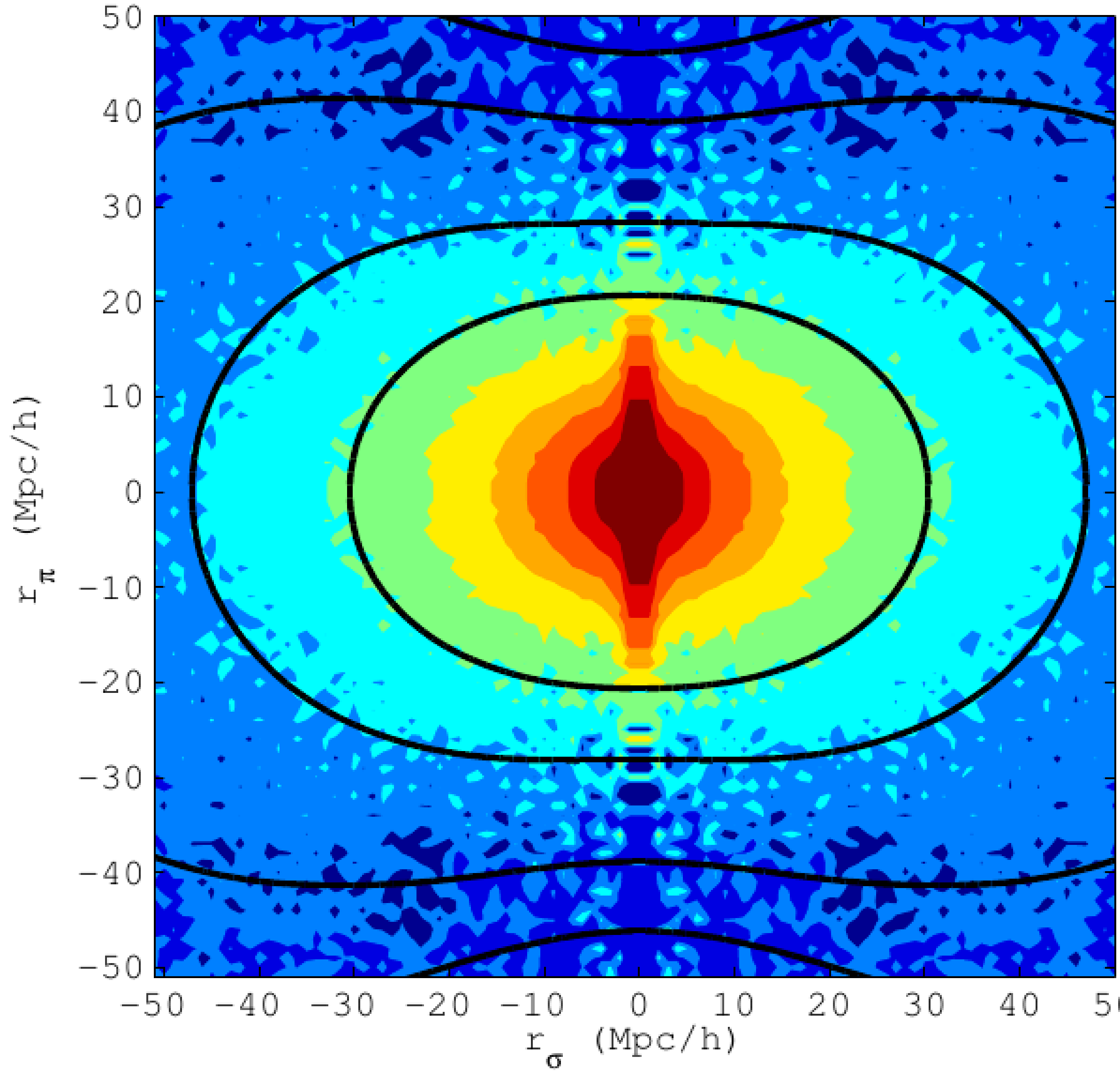
- Direct probe of dark matter *and* baryonic matter

  → No need to model a "visible-to-dark" bias

  → need to model baryons at small scales though
- Sensitive to geometry *and* growth of structure
- Very demanding measurement
  - PSF stability / modeling
  - Accurate modeling of baryon physics at small scales
- State of the art: analysis of the CFHTLS-Wide (strong implication of the FR community)
- Note: France not in DES / Subaru (current active surveys)

Redshift space distorsions

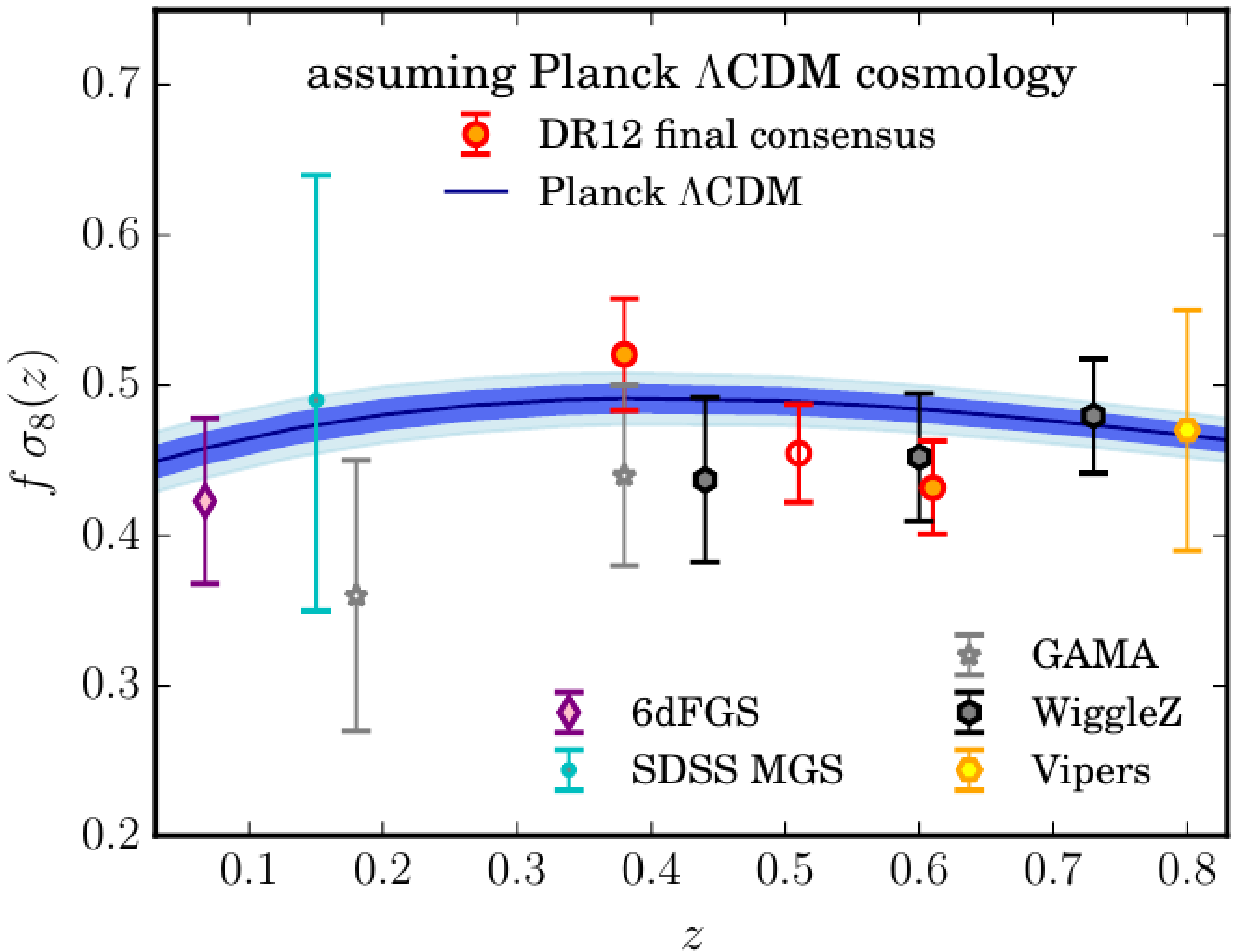




(Reid et al, '12)

- RSD ⟶ f (in fact $f\sigma_8$)
- Alcock-Paczynski test ⟶ F(z) = (1+z) D_A(z) H(z) (quadrupoles)

Recent constraints on growth rate



Alam et al, 2016 [1607.03155]

(see also de la Torre et al, 2014 (VIPERS))

21-cm BAO surveys

- Same program, with HI high-redshifts
  - Intensity mapping ⟶ BAO @ z ~ 2-3
  - Hardware developpement (correlators)
  - Demonstrators in Nancay (observations of clusters)
  - Discussion with 21-cm projects (CHIME, Tianlai, HIRAX)

Outline

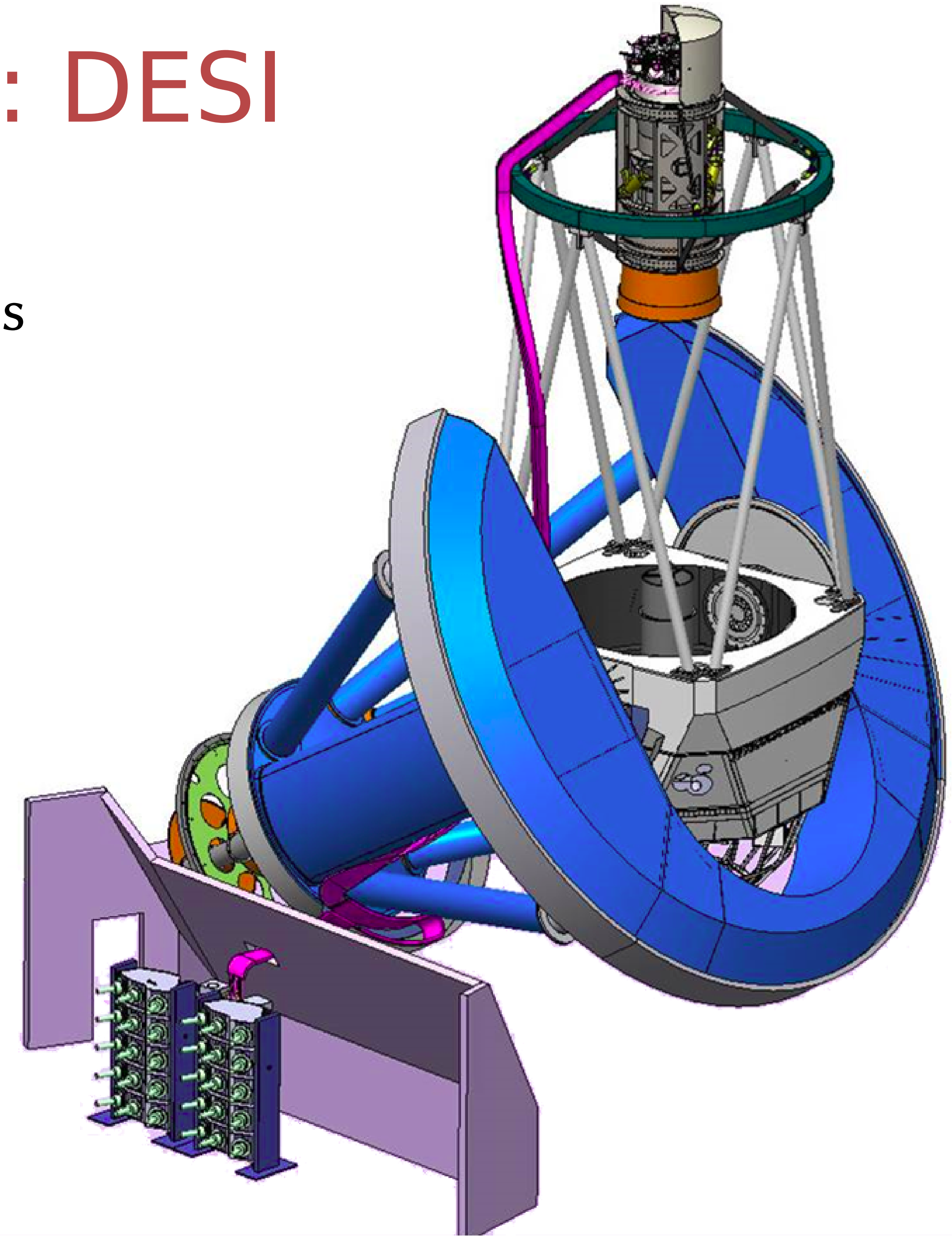
- Overview of DE probes (and recent highlights)
  - Hubble Diagram of supernovae (JLA)
  - Baryon accoustic oscillations (BOSS)
  - Lensing (CFHTLS)
  - Matter clustering (VIPERS, BOSS)
- The next decade
  - Large imaging surveys: Euclid, LSST (and CFIS !)
  - Massive spectroscopic surveys: DESI, 4MOST
  - ...
- Conclusion

In the north: DESI

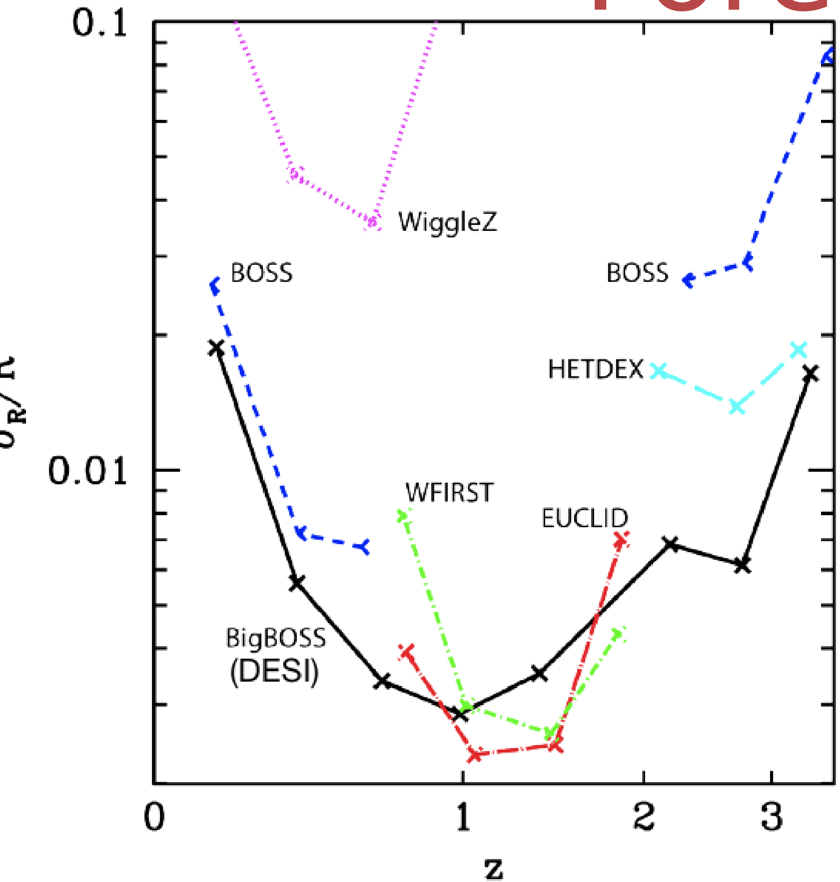
- 5,000 fibers
- 10 500-fiber spectrographs
- 4-m telescope (Mayall)
- 14,000 deg^2
- 50 h^{-3} Gpc^3
- First light in 2019

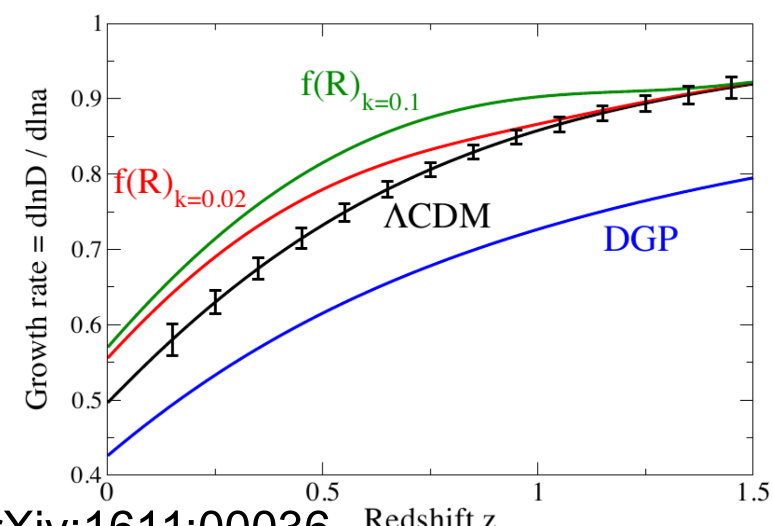
- Target selection
  - South : DECals, DES
  - North : Bok (2.3-m) + ?

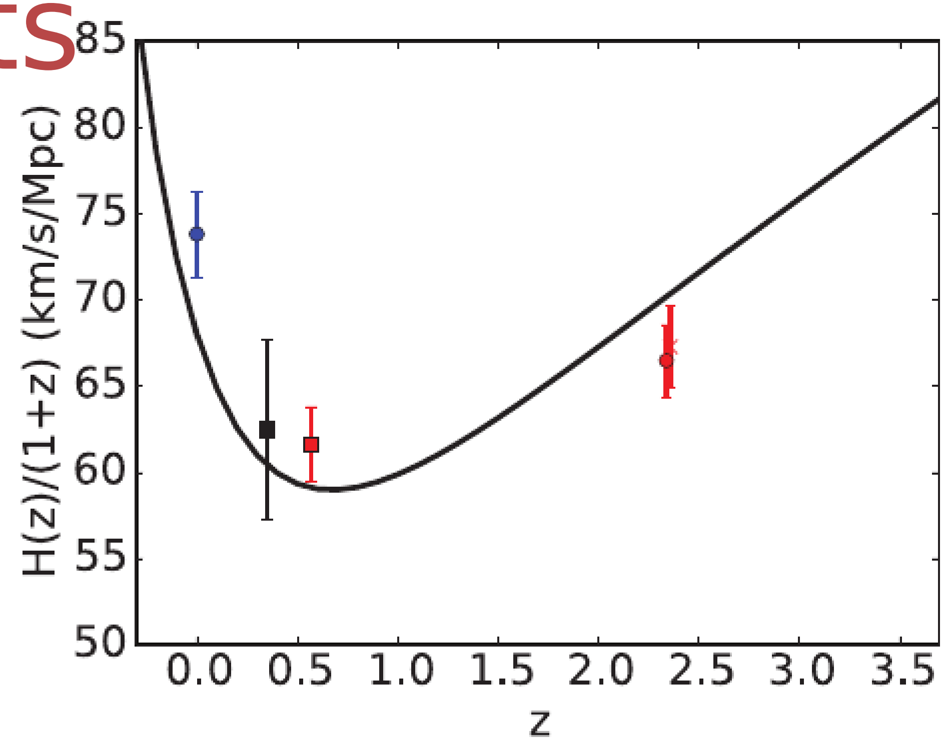
French consortium, with hardware contributions
- INSU, CEA, IN2P3

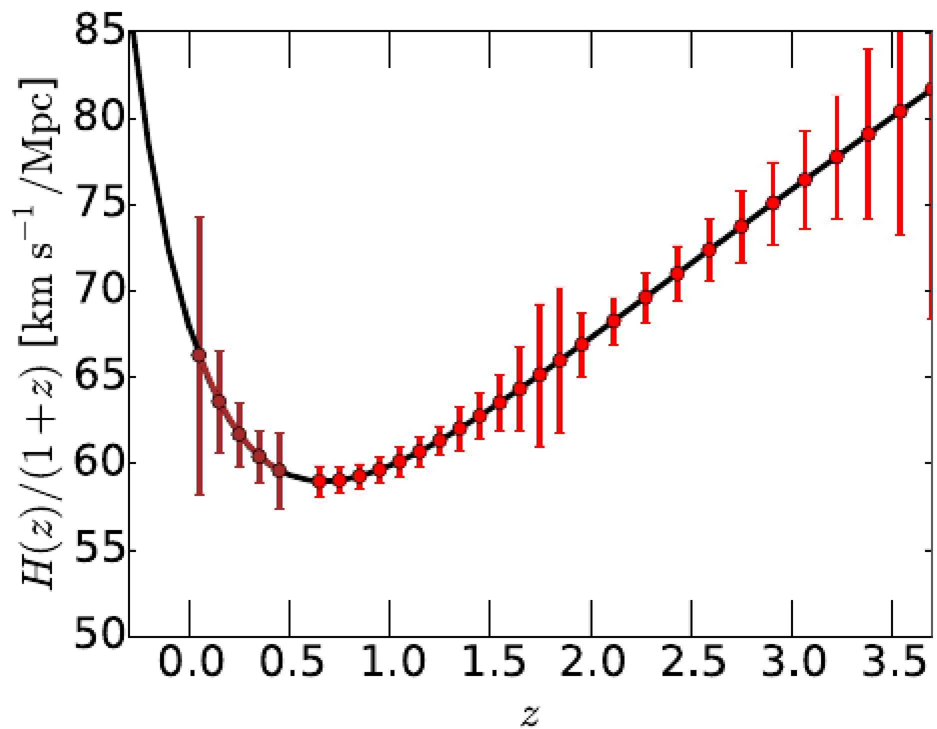


Forecasts





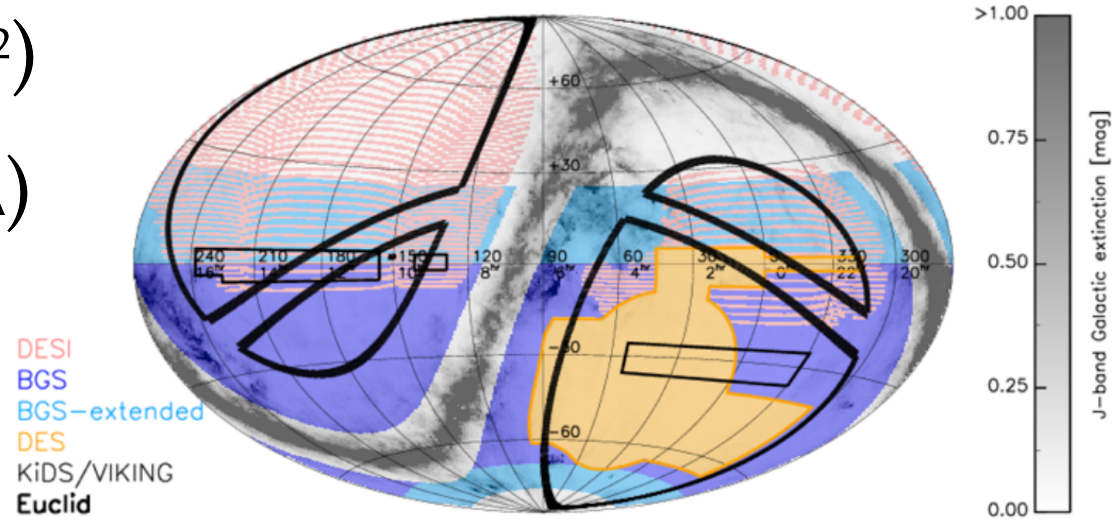




arXiv:1611:00036

In the south : 4MOST

- ~ 2500 fibers (4.1 deg²)
- 4-m telescope (VISTA)
- First light in 2022
- 9 science surveys
  - Milky way (x4)
  - Galaxy clusters, AGN, Magellanic clouds…
  - Cosmology redshift survey (PIs: Richard, Kneib)
- Target selection from DES (and potential synergy with LSST)



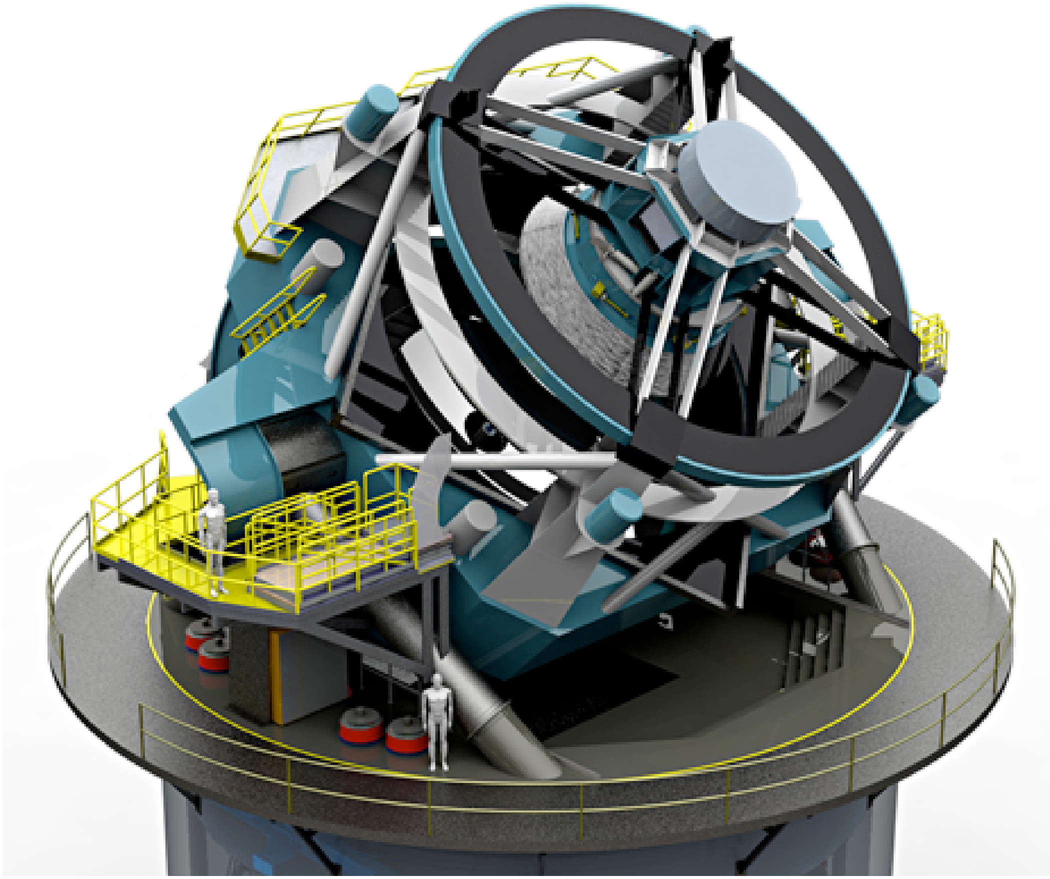
(J. Richard)

LSST

- 8.4 m (6-m equivalent)
- 9.6 deg^2 (ugrizY)
- 3 Gigapixels
- Fast readout~ 2s
- Slew $\longrightarrow$ adjacent field : 4-s

- All sky survey (20,000 deg^2)

- Dark energy probes
  - Weak & strong lensing
  - Supernovae @ low & high z
  - BAO (photo-z's)
  - Galactic structure
  - Transients
  - …



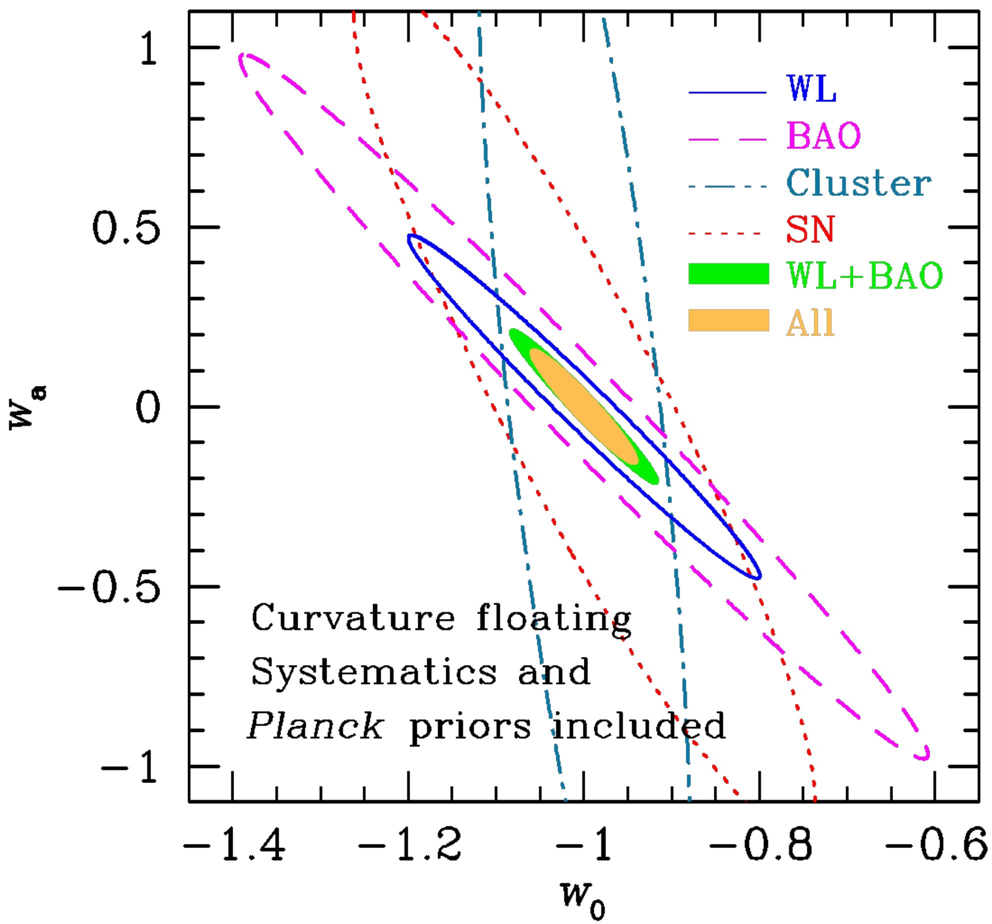
Recouvrement tres fort avec
Tous les themes du PNCG

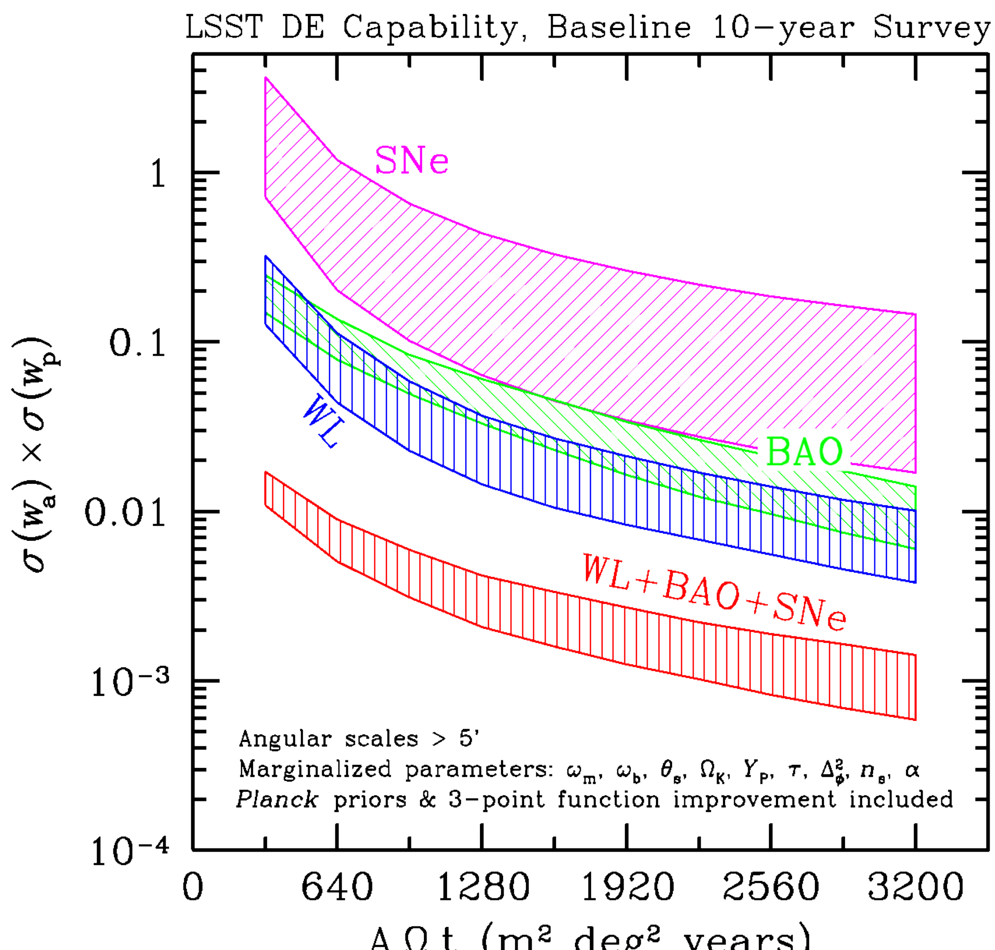
LSST: Stage IV Dark Energy Experiment

LSST complementary techniques to constrain Dark Energy :

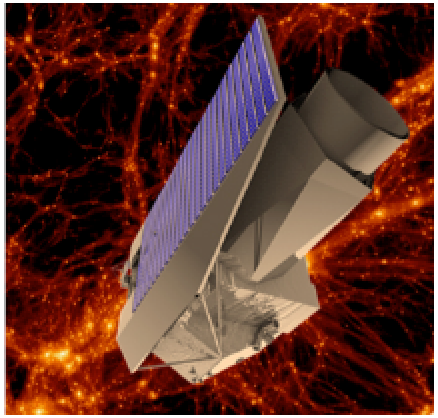
Weak gravitational lensing
Baryon acoustic oscillations
Type 1a supernovae
Statistics of clusters of galaxies

- Remark : LSST Key properties to remove instrumental/atmospheric signature : > 800 exposures of each field
- Stage IV criterion defined in terms of the inverse of the error ellipse in the w_a-w plane.





Euclid

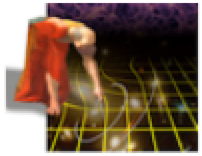


- ESA "M" mission (100+ labs, 14 countries)
- Primarily goal: constrain properties of DM and DE
- Main probes:
  - Weak lensing
  - Galaxy clustering (BAO, RSD)
  - Cluster counts
  - x-correlations with CMB
- 1.2-m telescope
- VIS + IR Photometry
  - 0.5 deg^2 in the visible (1 band)
  - 0.5 deg^2 in the infrared (3 bands)
  - 15,000 deg^2 (0.36 sky)

- Pi: Y. Mellier (IAP)
- O. Le Fevre member of the Euclid Consortium Board)

- Strong French participation
  - ~ 300 from INSU, CEA, IN2P3

Complementarity LSST-Euclid

Euclid 

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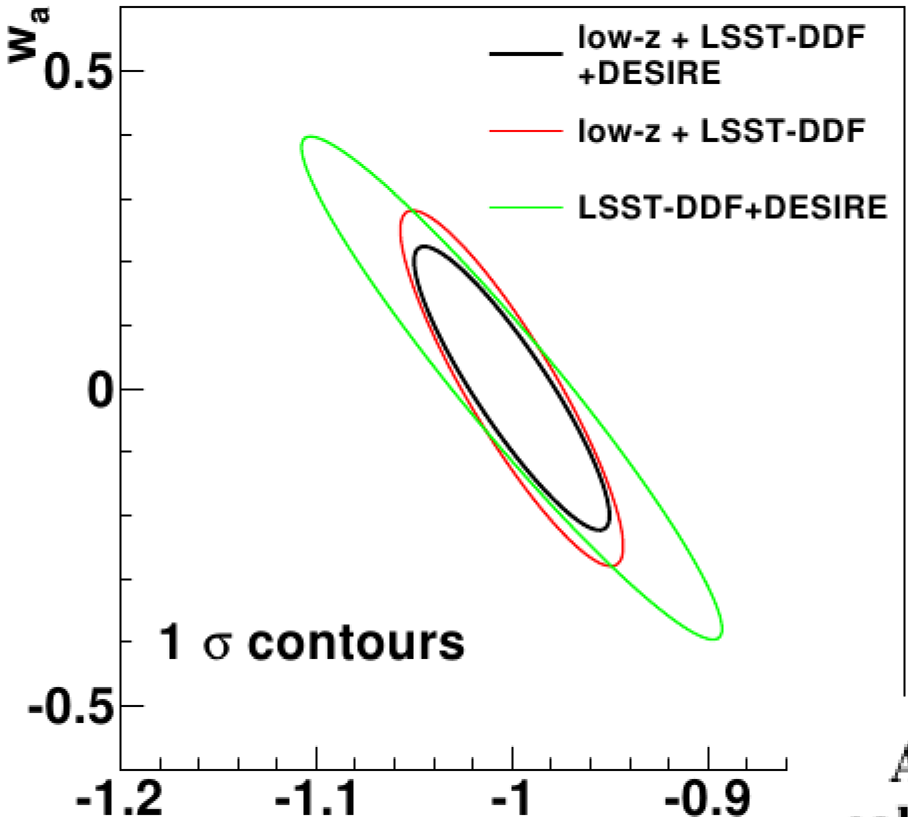
LSST

FoM ~ 1500(WL&Galaxie)-4000 (all)
~ 900 members
European lead project / ESA
Space telescope / 1.2 m mirror
Launch : 2019
Mission length : 6 years
1 exposure depth : 24 mag
Survey Area : 15 000 square degrees (.36 sky)
Filters : 1 Visible(550-900nm)+ 3 IR(920-2000 nm)
+ NIR spectroscopy (1100 – 2000 nm)

FoM > 800 (WL,BAO, SN)
~ 450 Core members + 450 to come
US lead project / NSF-DOE
Ground Telescope / 6.5 m effective mirror
1st light : 2019
Observation length : 10 years
1 exposure depth : 24 mag (i) (~27 in 10 years)
Survey Area : 20 000 square degrees (.48 sky)
Filters : 6 filters (320-1070 nm)

→2 complementary approaches to address the question of the acceleration of the Universe and the nature of the Dark Energy in the next decade.

Another example



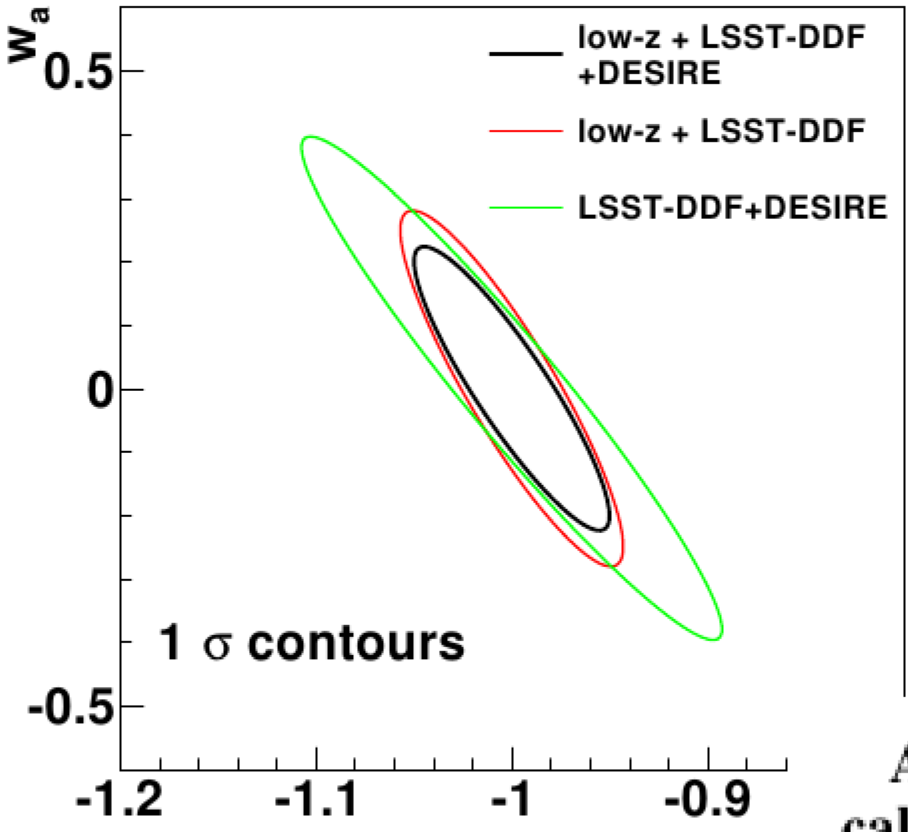
LSST + Euclid, 1409.8562

- Combined SN survey :
  - → ground based observations (visible)
  - → space based follow (IR)
- May be LSST + Euclid or LSST + WFIRST
- Demonstrator : Subaru + HST

Note : requires acquiring redshifts

Assumptions						
cal	evo	train	$\sigma(w_a)$	z_p	$\sigma(w_p)$	FoM
n	n	n	0.15	0.30	0.016	418
y	n	n	0.18	0.30	0.016	339
n	y	n	0.18	0.25	0.018	315
y	y	n	0.20	0.27	0.019	266
y	n	y	0.21	0.28	0.020	238
y	y	y	0.22	0.25	0.022	203

LSST + Euclid : expected constraints



(Astier et al, in prep)

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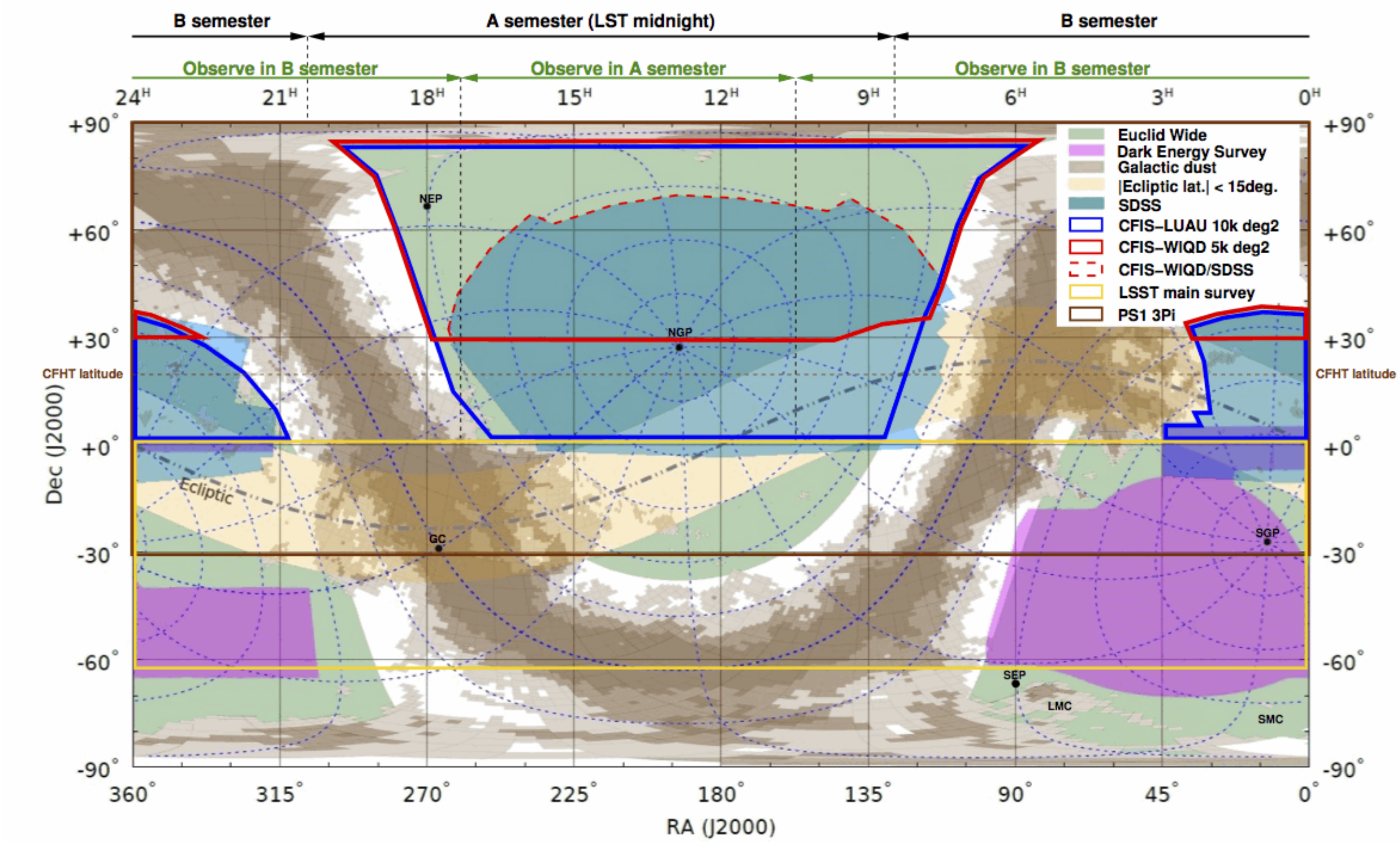


CFIS

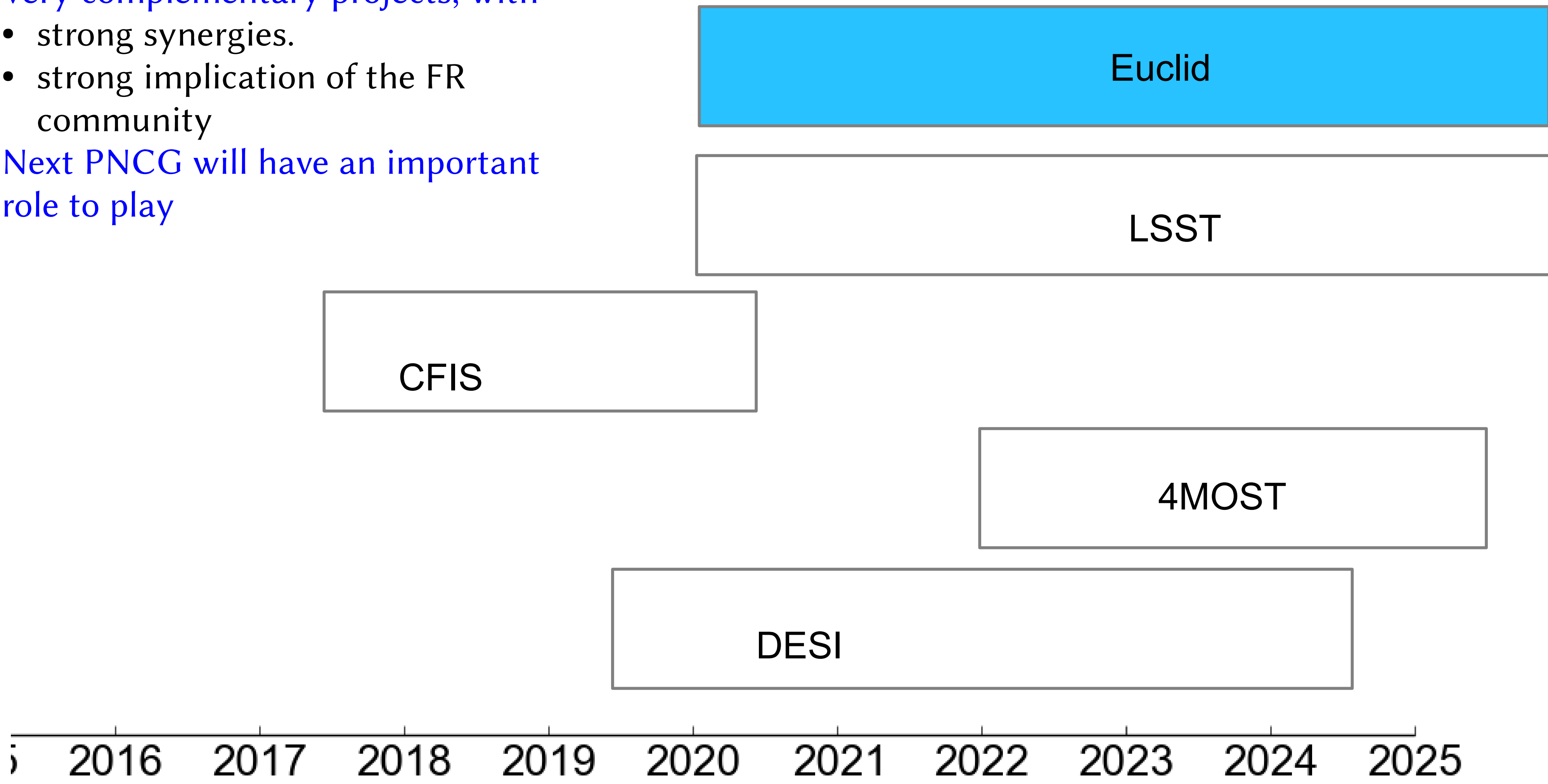
CFIS Science:

- Weak lensing
- Galactic archaelogy
- …
- Photo-z's ⟶ Euclid
- Target selection for BAO surveys (u great for QSO detection)

- Large program 2017-2019 – 271 nights
- PI's: J.-Ch. Cuillandre and A. McConnachie
- Two programs in one:
  - u-band extension of LUAU to 10,000 deg^2
  - r-band, integration 3x200s, *r=24.8* (point source 5σ), ~5,000 deg^2 north of ↱=+30

Conclusion

- Very complementary projects, with
  - strong synergies.
  - strong implication of the FR community
- Next PNCG will have an important role to play



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