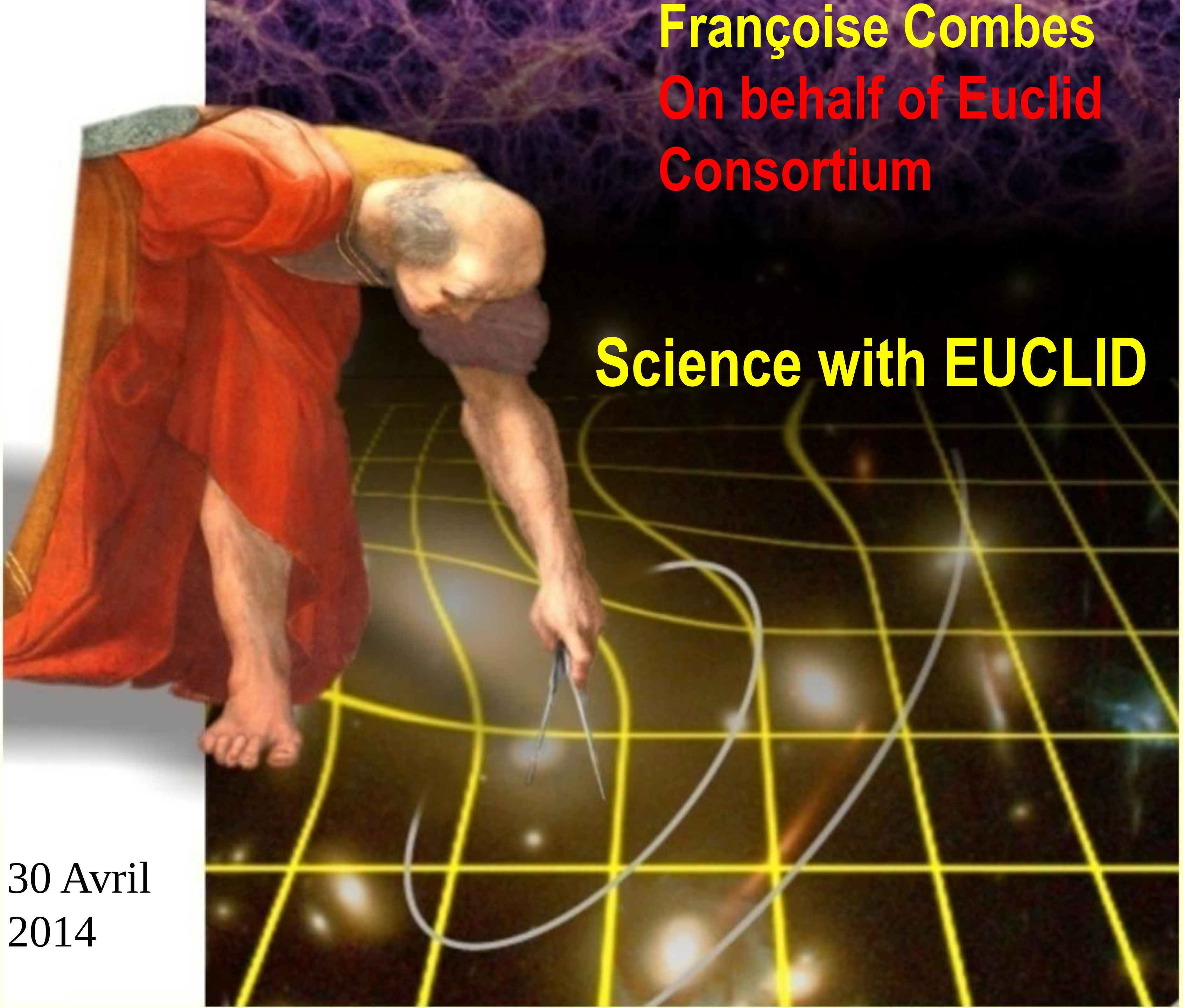


Françoise Combes

On behalf of Euclid Consortium

Science with EUCLID

30 Avril
2014

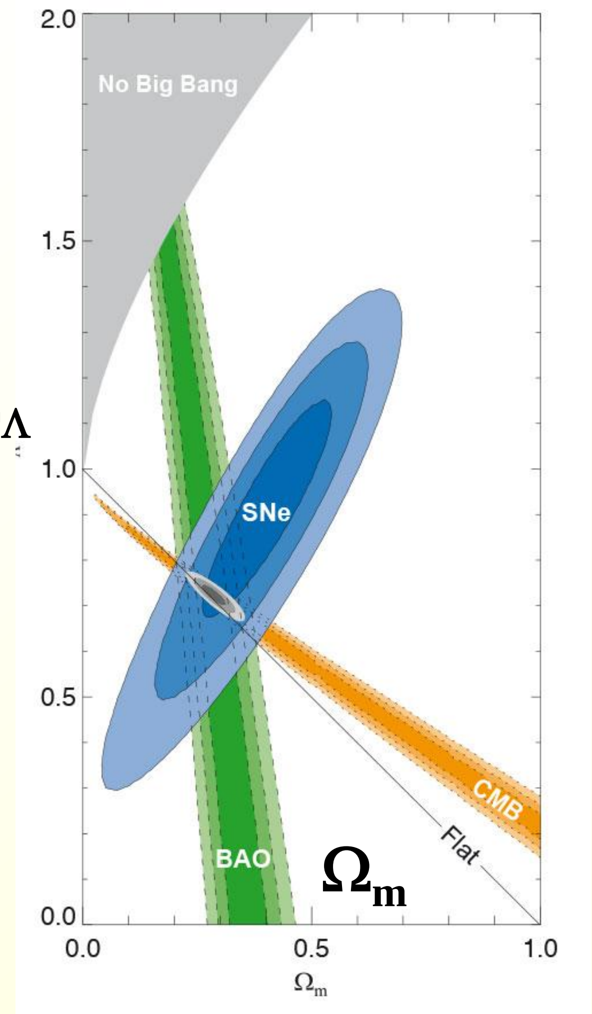
Cosmology, Dark energy

Kowalski et al 2008

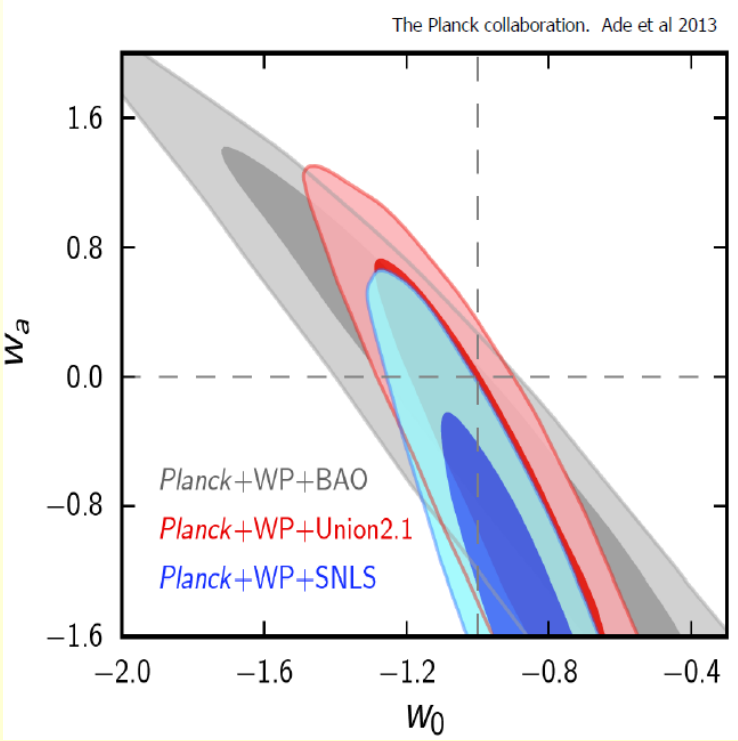
Concordance model, between CMB, Supernovae Ia, Large-scale structure (weak lensing, BAO..)

$P = w\,\rho$ $w(a) = w0 + wa\,(1-a)$

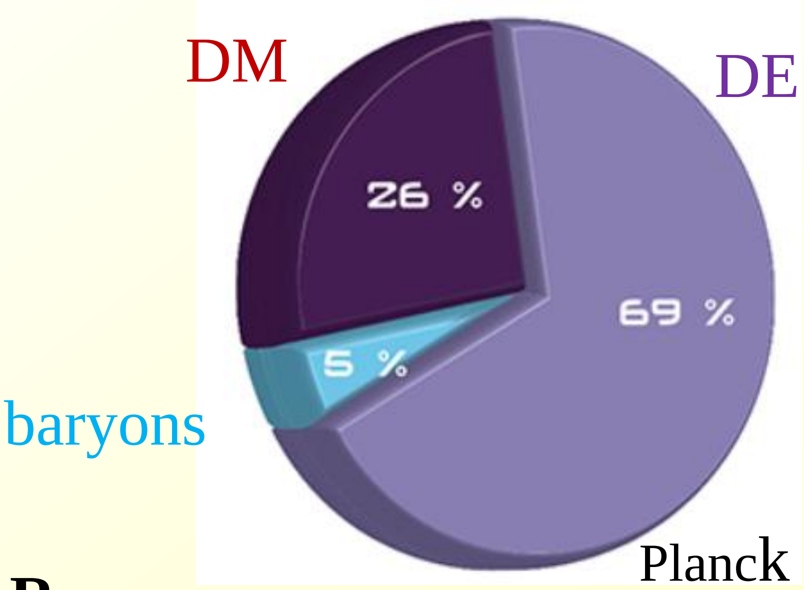
Ω_Λ



wo~-1
wa~0



Main questions in cosmology



Matter in the Universe

Dark matter/visible matter vs z

Dark energy:

Is it varying with time?

How is the Universe re-ionized?

End of the dark age: cosmic dawn, EoR

How do baryons assemble into the large-scale structures?

Galaxy formation and evolution (mergers, cold accretion)

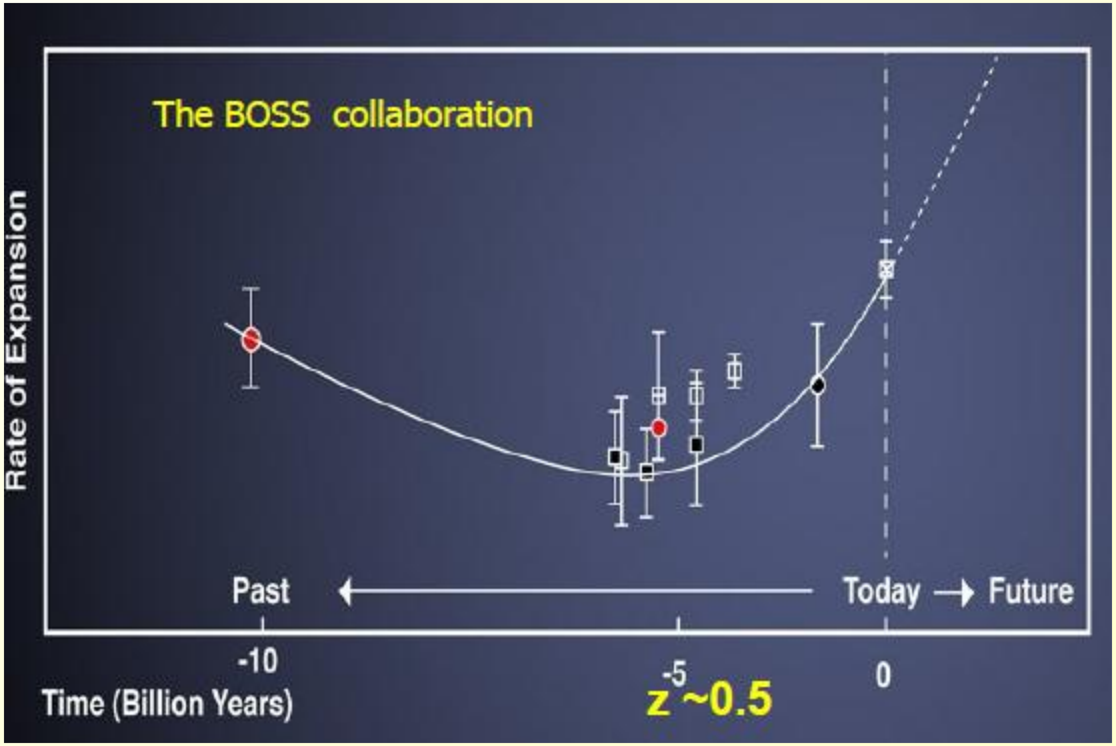
Star formation history, quenching

Environment: groups and galaxy clusters

Transition between DM and DE

The DE was not significative until very recently,
At z ~ 1 or less

The transition is very close and we are able to see it in optical and near infrared



➔ Domain of Euclid

Translation into Main Parameters

1-What is dark energy: w   P= w ρ

Equation of state and nature of DE, through expansion and growth rates, 5 tools: Weak Lensing, BAO, RSD, Clusters, ISW

2-Gravity beyond Einstein: γ

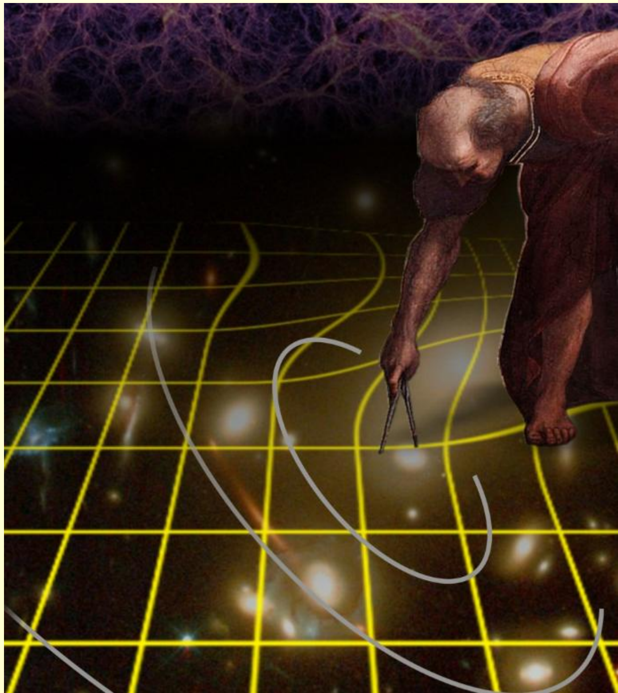
Testing modified gravity, by measuring growth rate exponent γ

3-The nature of dark matter, m_ν

Testing the CDM theory, and measuring neutrino mass

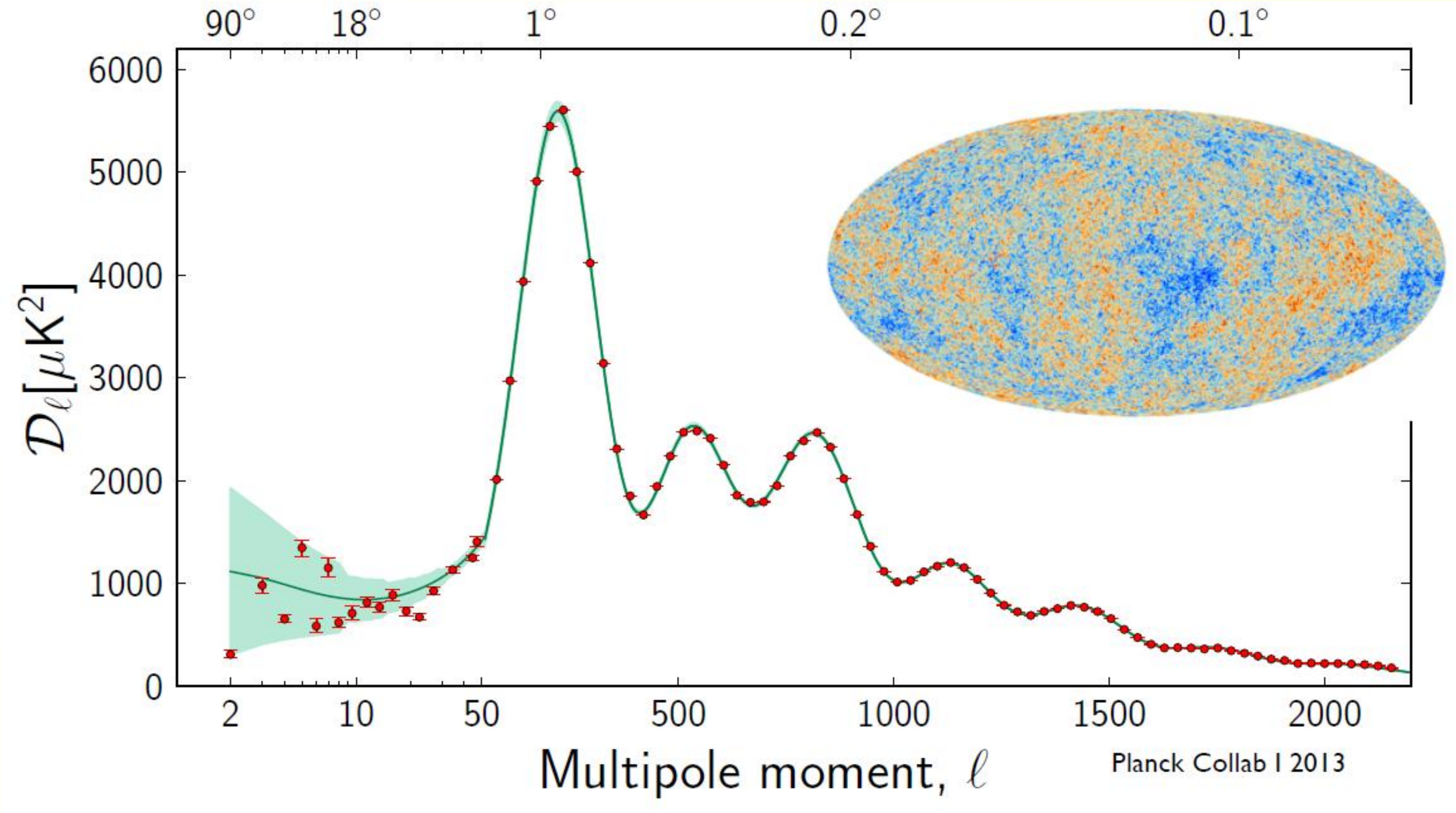
4- The seeds of cosmic structures

Improve by a factor 20, n= spectral index,
σ_8=amplitude of power spectrum,
f_{NL}= non-gaussiantities



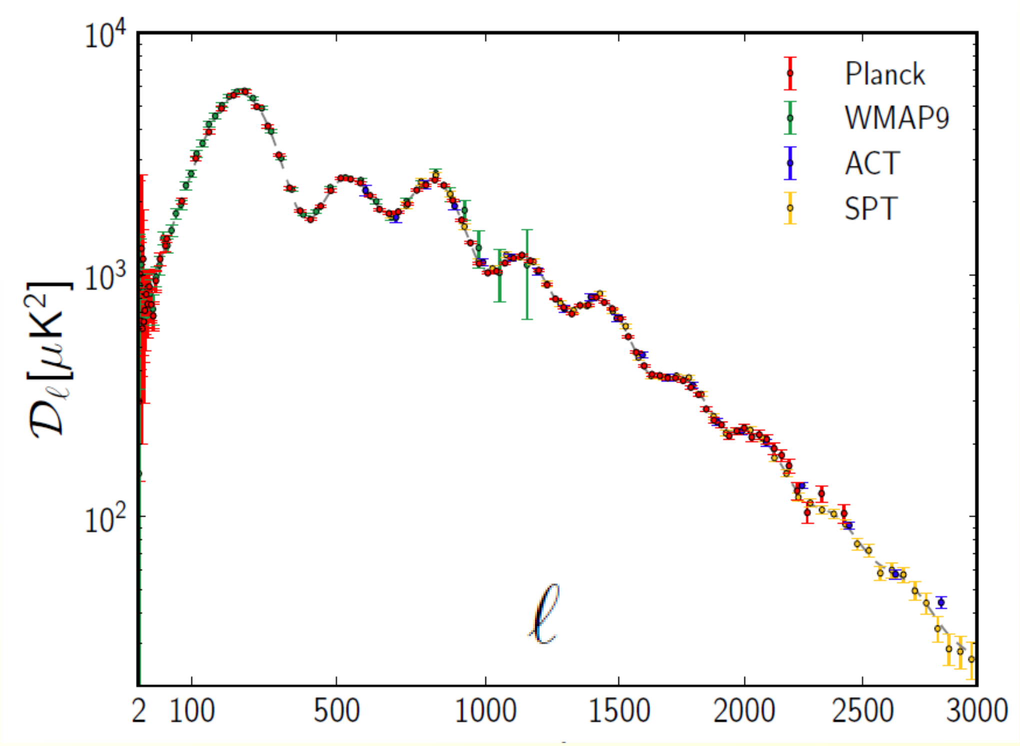
What do we know with CMB

Planck Large Scales -- Not enough power at low-*l*



Ωb, Ωc, Peak position➔ flatness - Amplitude σ8 (at 8Mpc/^{6}h)

CMB anisotropies



Small scales with ACT
Atacama Cosmology Tel
(Das et al 2013)

and South Pole Telescope
SPT (Story et al 2012)

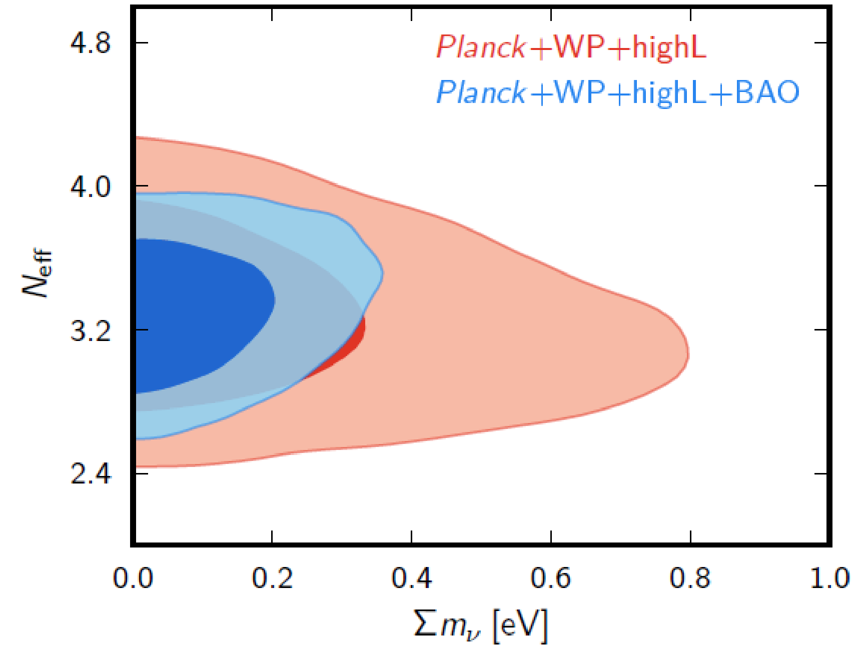
No detection of f_{nl} (non Gaussianity)

Slope of power-spectrum, ns, departure from scale-invariant
ns= 0.960 ± 0.0070 ➔ inflation

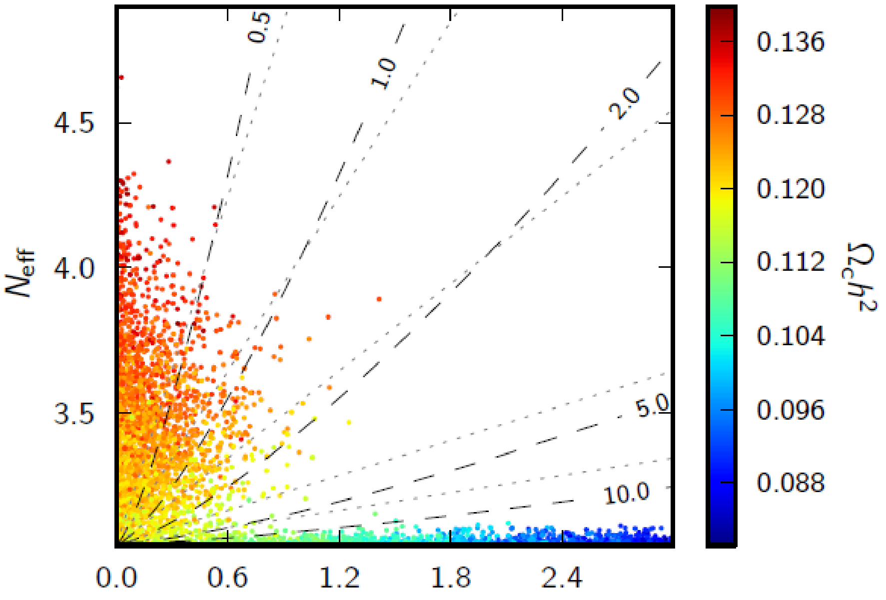
z(reion)= 11.1 $\pm$ 1.1 optical depth $\tau = 0.091 \pm 0.01$

Mass and number of neutrinos

With extra mass-less neutrinos



with one sterile massive neutrino



-- thermal mass

Planck coll (2013) Paper XVI

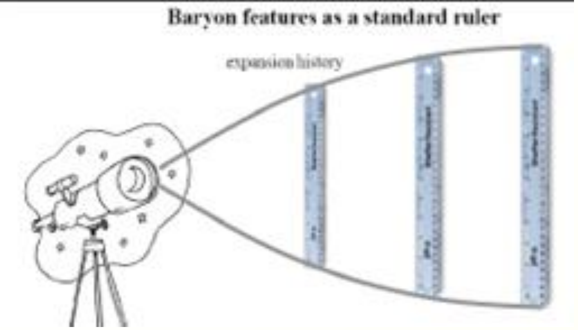
Neutrino mass constraint from power-spectrum (free-streaming)

$N_{\rm eff}$ could be higher due to lepton asymmetry

or the existence of a sterile neutrino

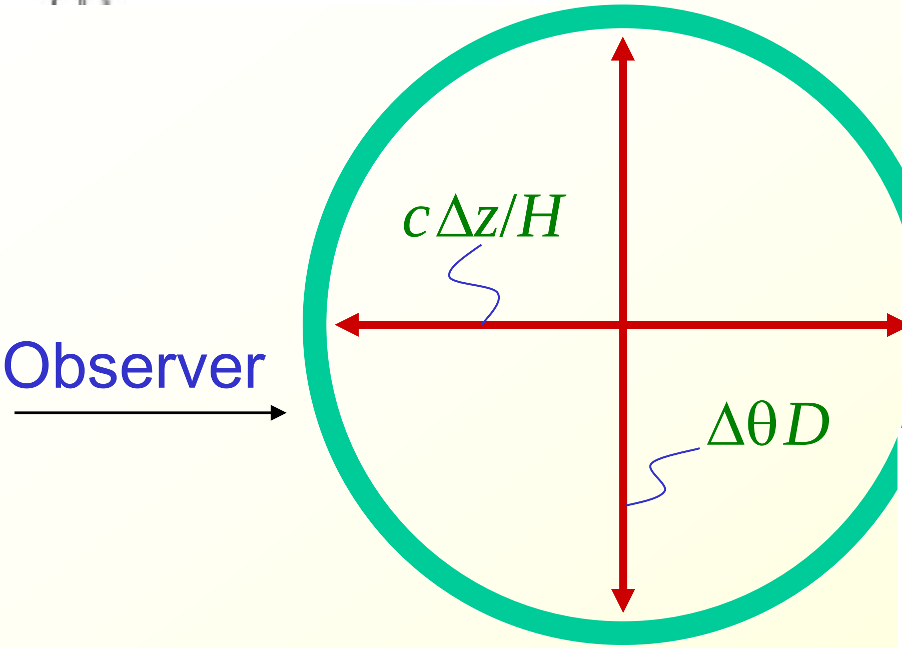
With Euclid ➔ σ (M_ν) = 0.03 eV, $\sigma(N_{\rm eff})$ = 0.02

BAO: Standard Ruler



Alcock & Paczynski (1979)
Test of cosmological cst

Could test the bias b
Or $\beta = \Omega_m^{0.6}/b$



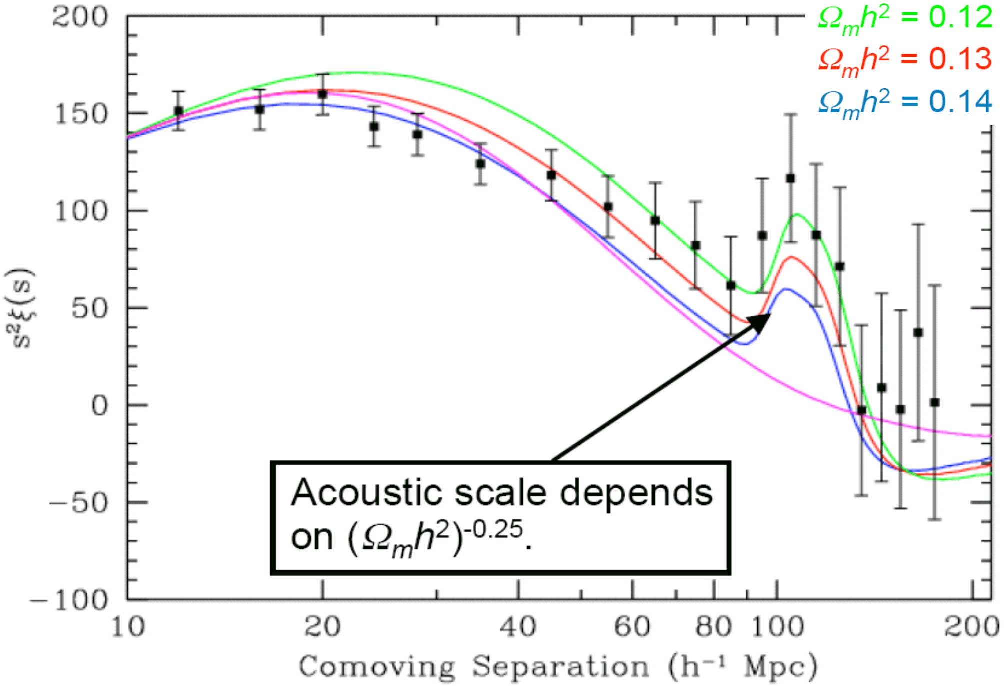
$c\Delta z/H$

$\Delta\theta D$

Observer

$$c\Delta z/H = \Delta\theta D$$

Eisenstein et al. (2005)
50 000 galaxies SDSS

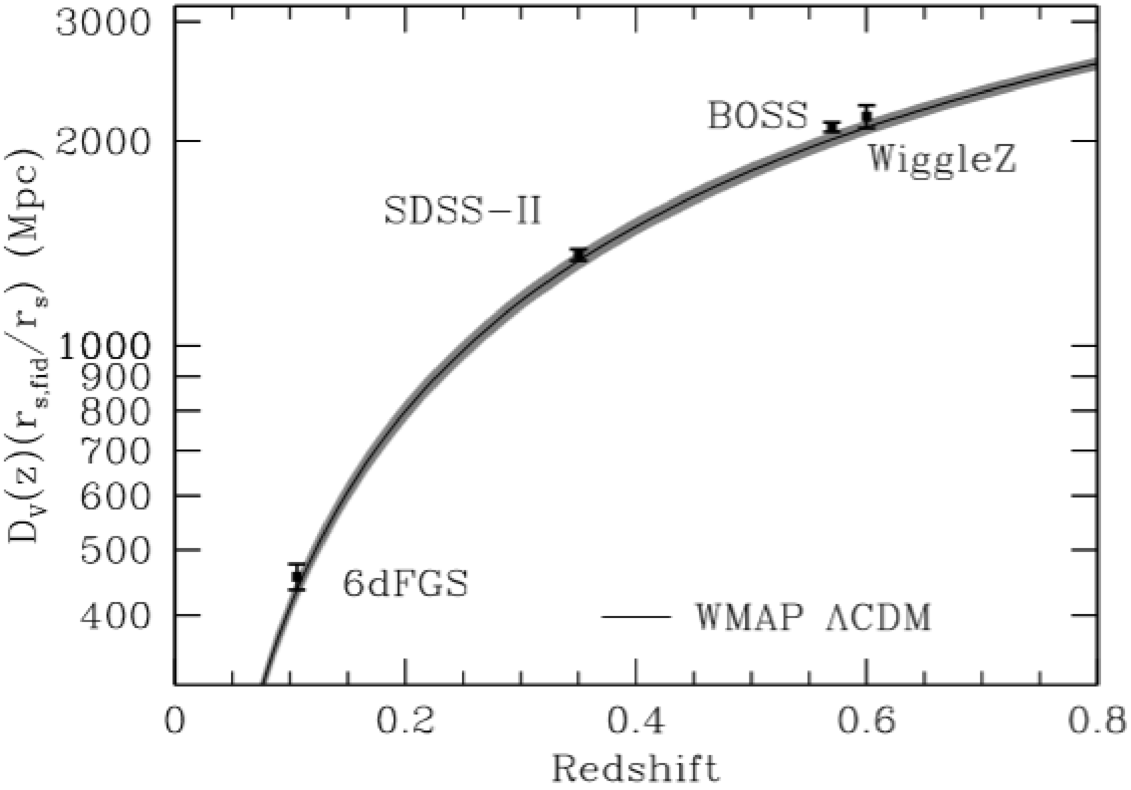


Acoustic scale depends on $(\Omega_m h^2)^{-0.25}$.

➔Possibility to determine H(z)

Recent BAO spectro-z data

$$D_V(z) = \left[(1+z)^2 D_A^2(z) \frac{cz}{H(z)}\right]^{1/3}$$



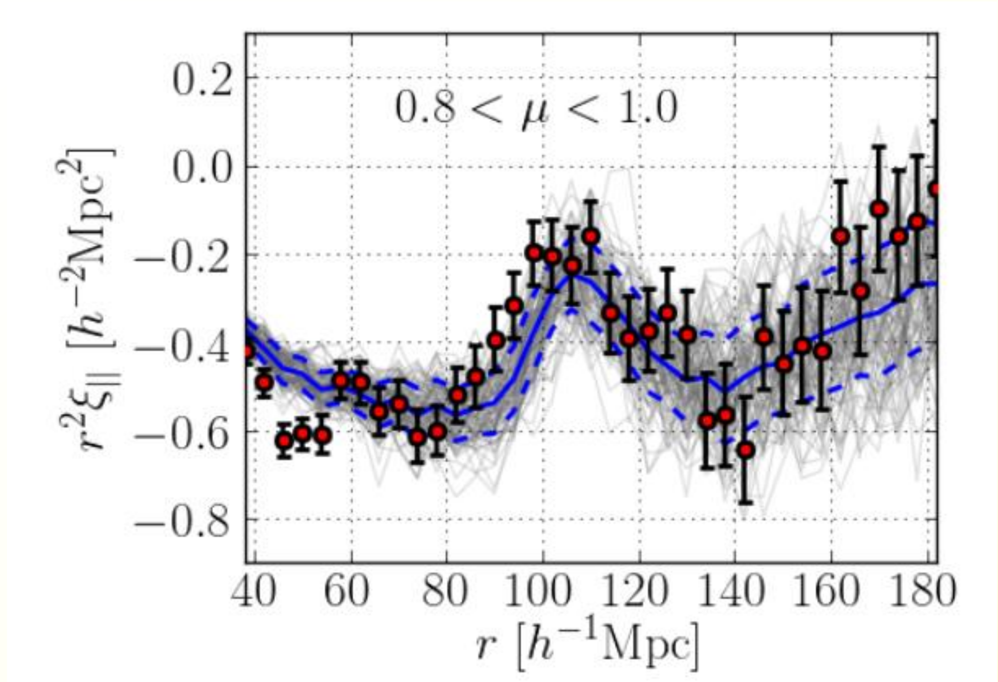
Excellent agreement
With ΛCDM (grey)

D_V (2.34) = 4628 Mpc

Slosar et al 2013
Delubac et al 2014

Anderson et al 2012

BAO in the Lyα forest at z=2.3



137 000 BOSS quasars

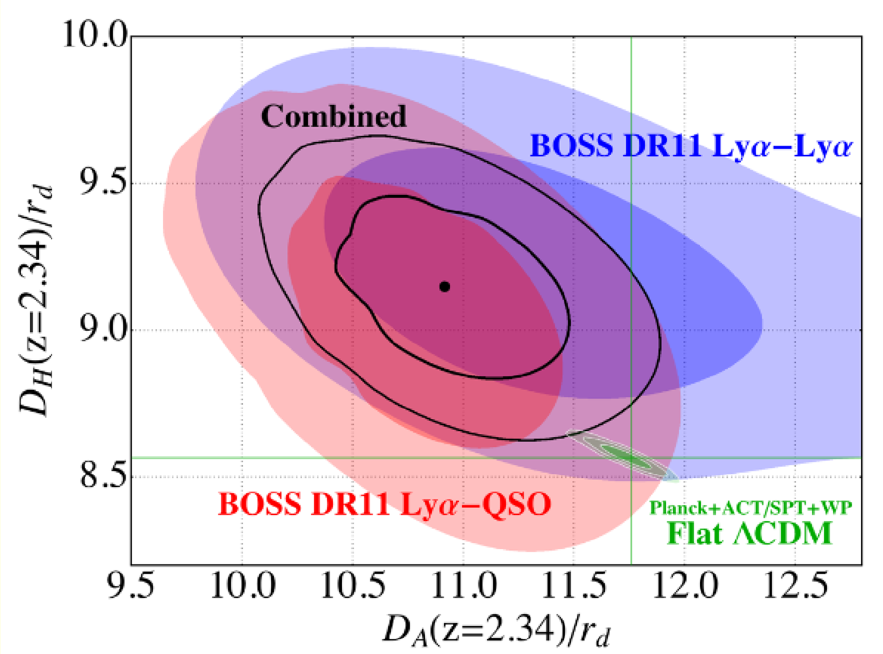
$2.1 < z < 3.5$

Blue Lyα autocorrelation

Red: Quasar-Lyα cross-correl

(Font-Ribera et al 2013)

Black: combined



Delubac et al 2014

Red data points compared to the

Mock quasar simulations (grey)

rd Sound horizon at the drag epoch

D_A angular dist, D_H= c /H

Tension with Planck at 2.5σ

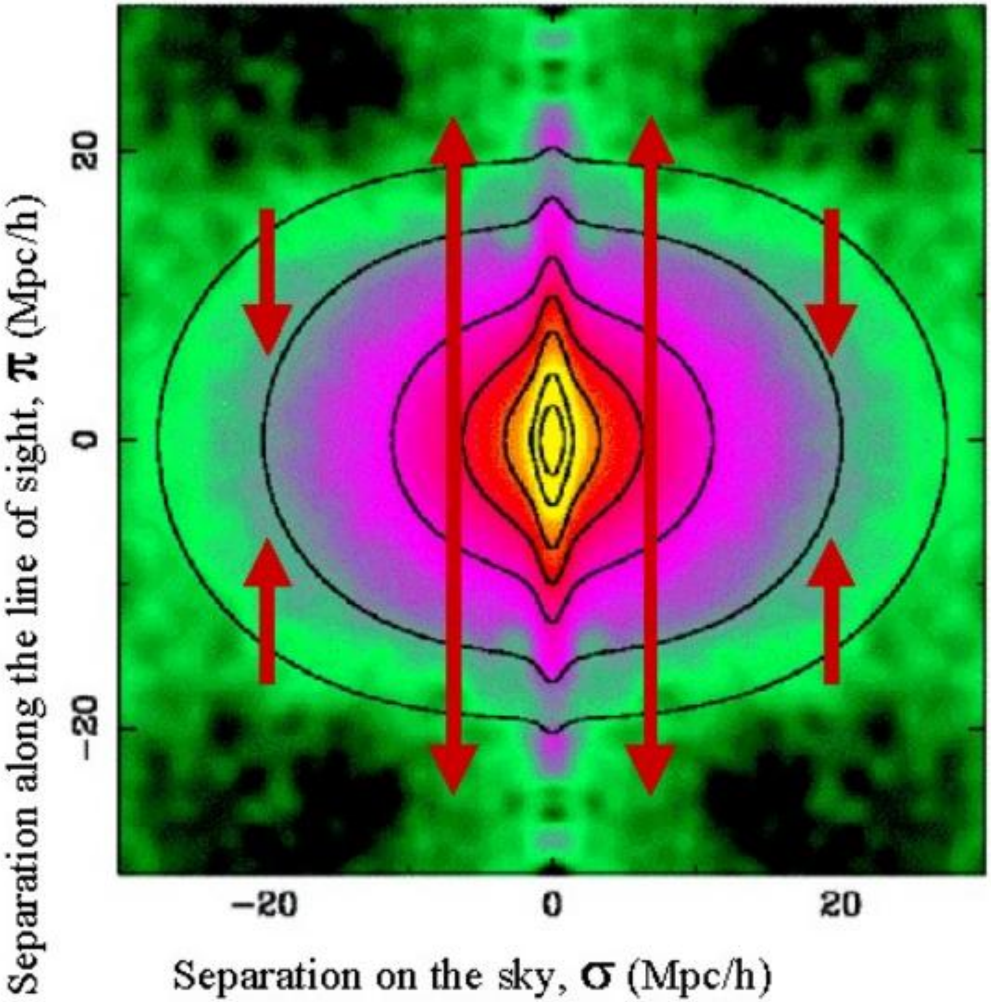
RSD Redshift space distortions

Distortions due to peculiar velocities on the line of sight (fingers of god!)

Kaiser effect in clusters
Systematic infall

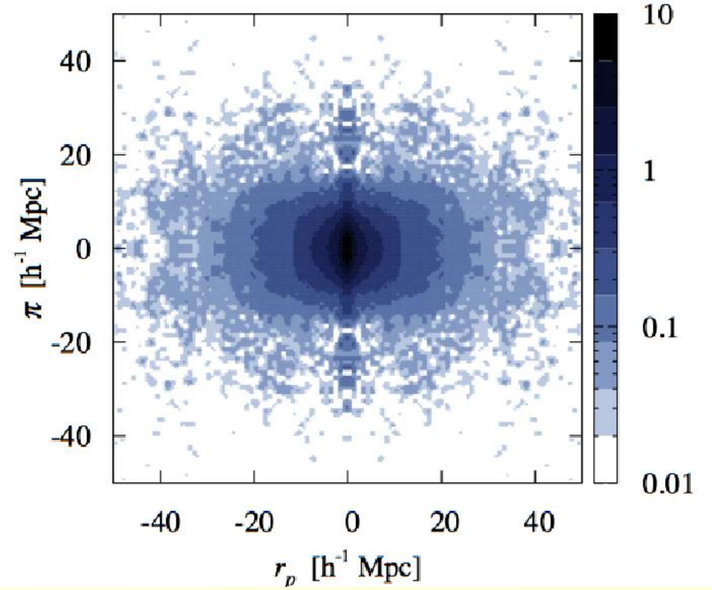
More than random allows to determine

$\beta = \Omega_m^{0.6}/b$
bias $\delta_{galaxies} = b\ (\delta_{mass})$
and σ_{gal}

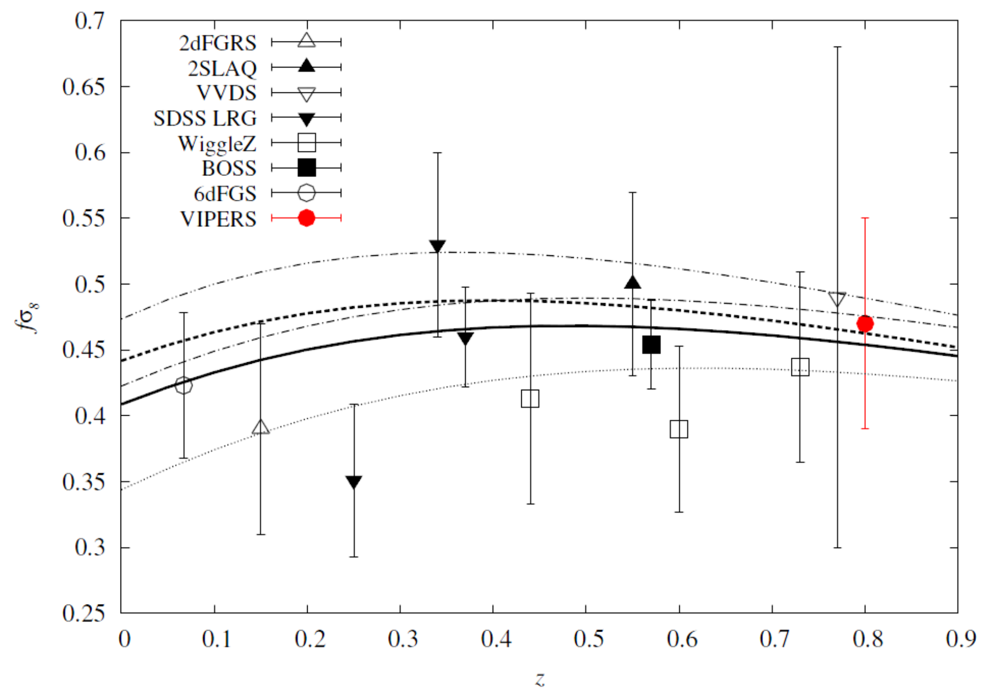


The 2dF Galaxy Redshift Survey Team (2001)

Status of RSD measures



Various galaxy surveys
VIPERS, de la Torre et al
2013



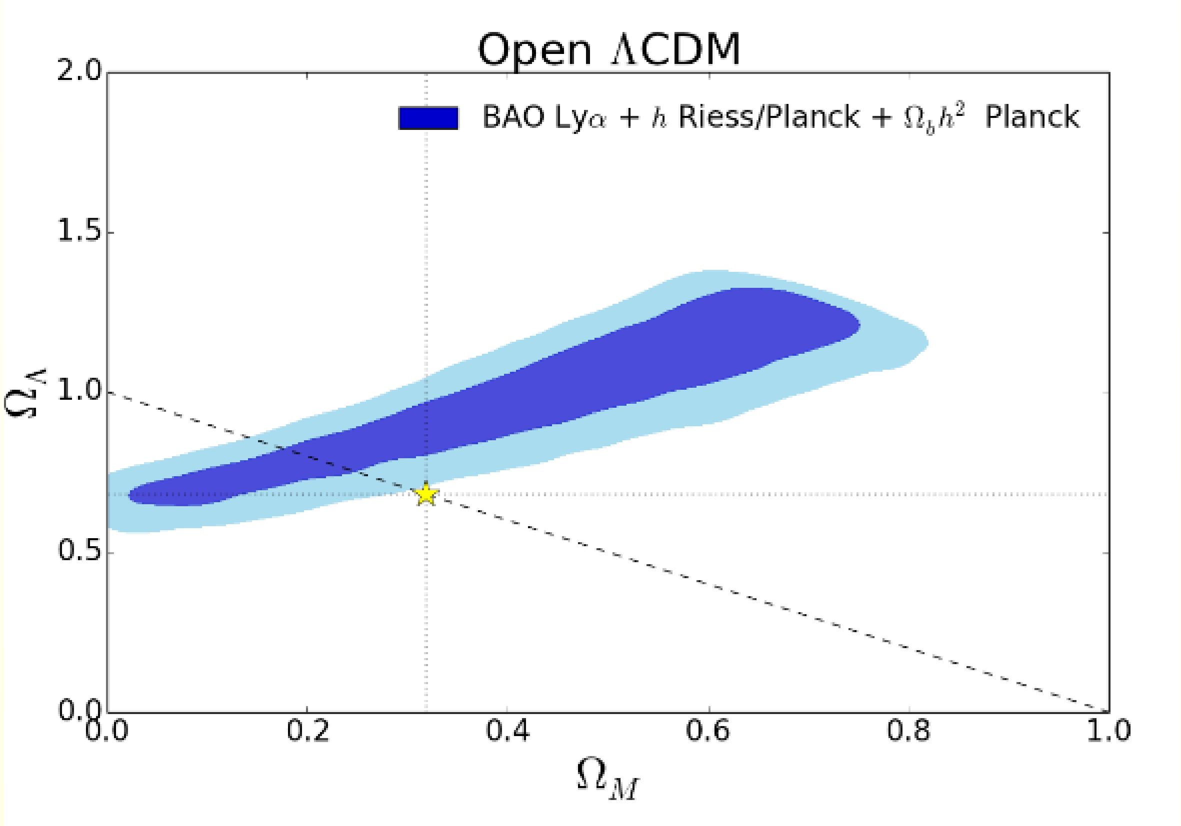
Thick line: GR gravity

Dahed or dotted lines
Modified gravity
DGP (Dvali et al 2010
f(R) models, etc..

Tension between Planck, Cepheids, BAO …

BAO at 68 and 95% confidence level (blue)

Ho (Cepheids) = 74km/s/Mpc, while Planck favors 67 km/s/Mpc



Planck

Delubac et al 2014

Independent cosmology probes

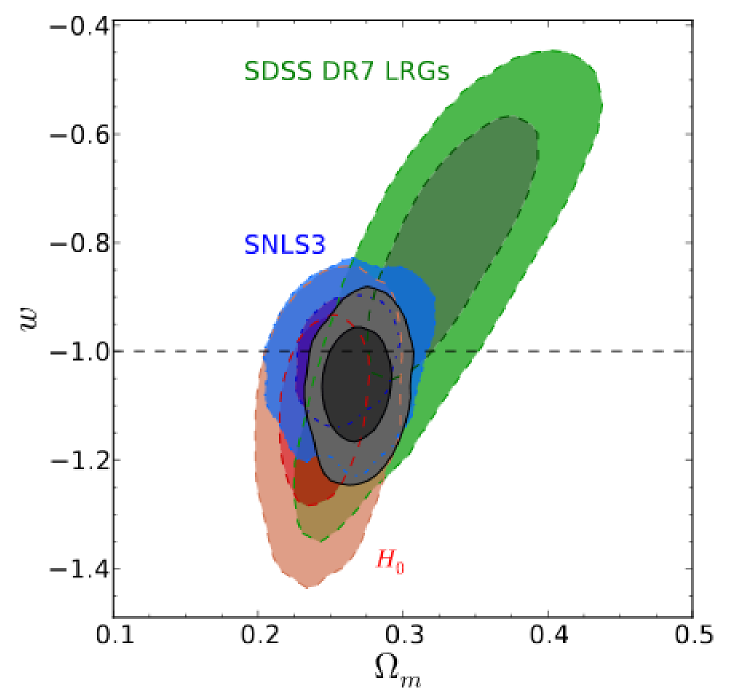
Hubble constant measured through cosmic distance ladder
73.8 ± 2.4 km/s/Mpc (Riess et al 2011) 3% precision
➔***Tension with Planck = 67.3 ± 2.5 km/s/Mpc***

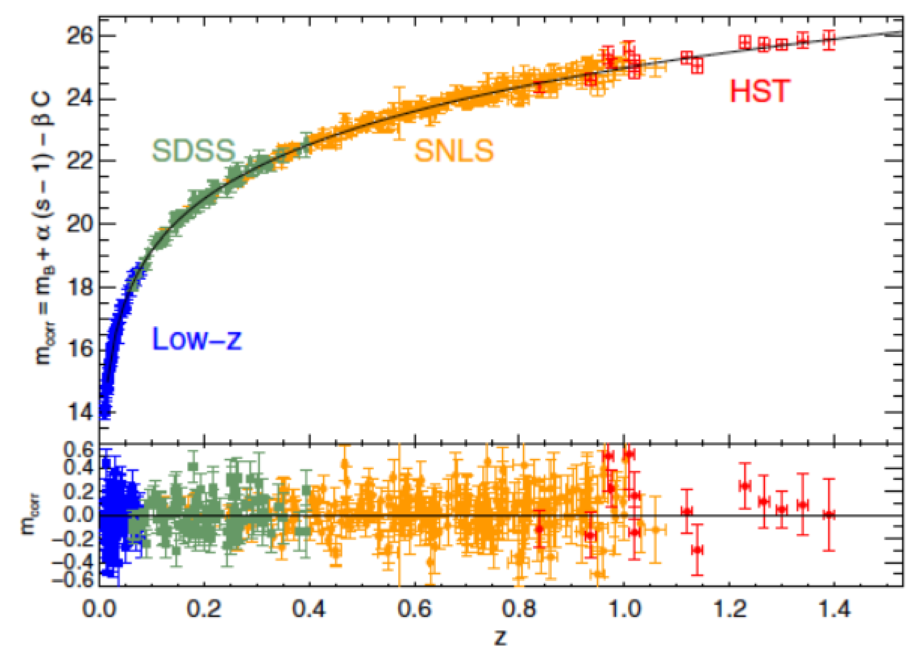
600 Cepheids in NIR, including hosts of SNIa, with WFC3 on HST
Also host NGC 4258 (Dist known with H_2O masers)

Type Ia supernova
SNLS (Conley et al 2011, Sullivan et al 2011)
5-yr survey: 500 new SNIa spectra and light-curves $0.2 < z < 1.0$
Imaging with CFHT-Megacam, Spectra with 8_10 m Keck-VLT

Accelerating universe from SNIa

2003-2008 SNLS survey, French-Canadian collaboration



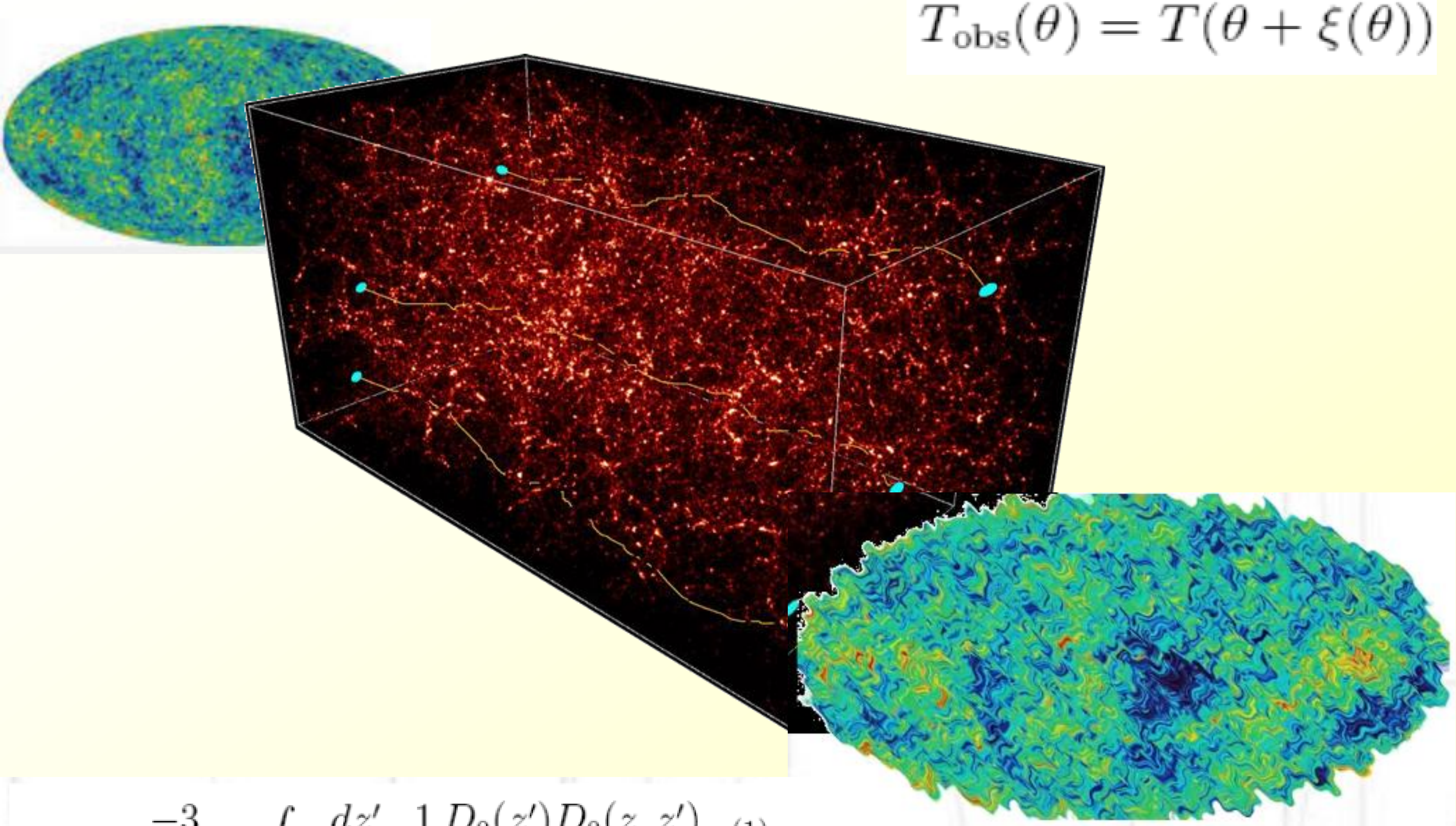


Sullivan et al 2011
Assuming flat universe

Conley et al 2011

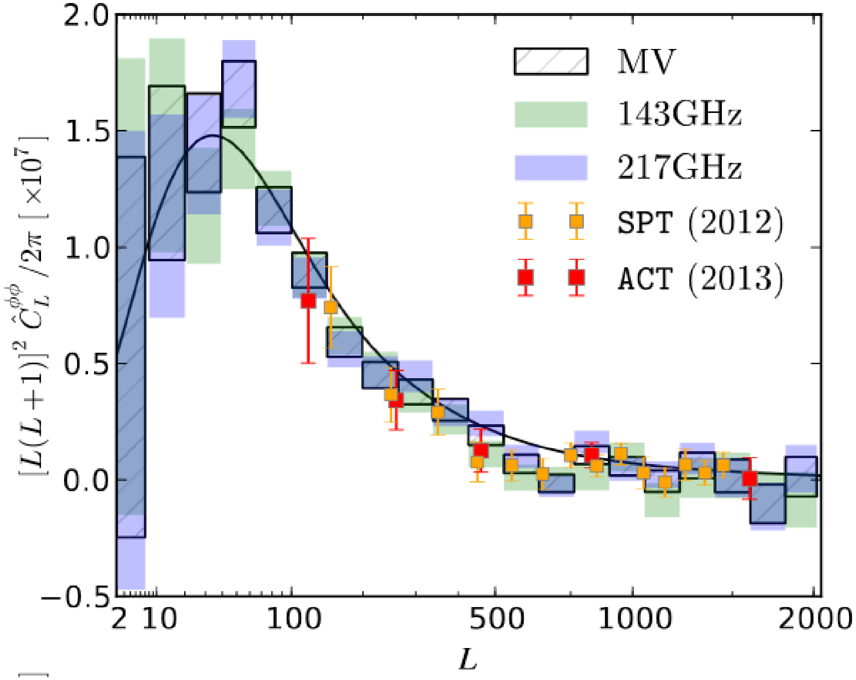
CMB Lensing tool

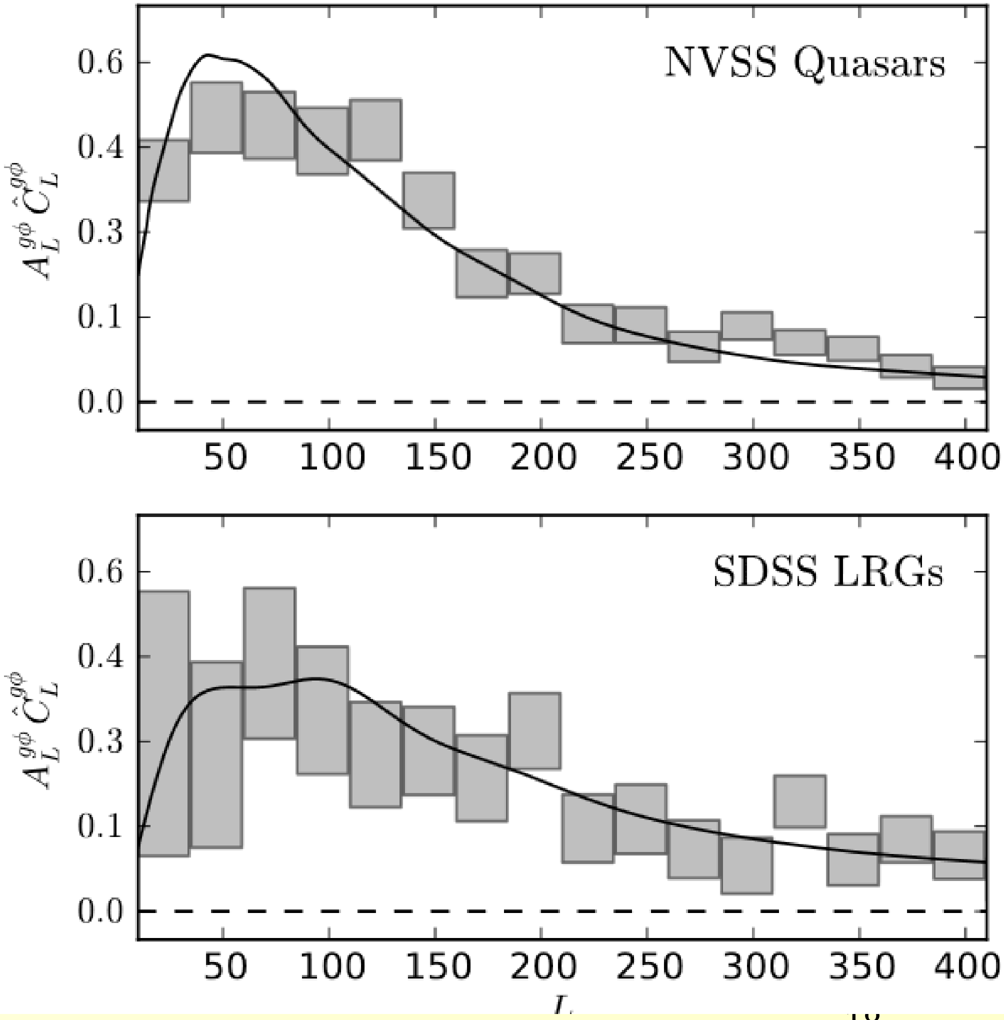
$$T_{\mathrm{obs}}(\theta) = T(\theta + \xi(\theta))$$



$$\xi_i(\theta) = \frac{-3}{2}\Omega_0 \int \frac{dz'}{H(z')}\frac{1}{a}\frac{D_0(z')D_0(z,z')}{D_0(z)}\varphi^{(1)}_{,i}(\theta, z)$$

CMB lensing





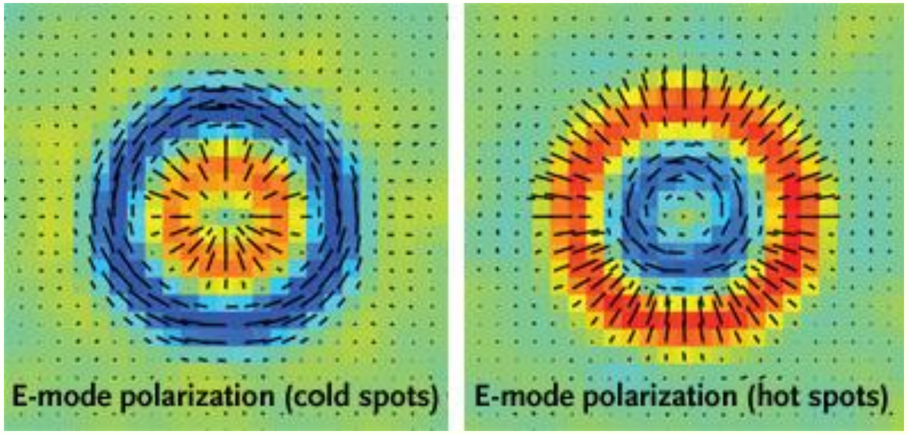
Measure of the curvature
Constraint Amplitude σ8

Correlation with LSS
along the line of sight

Planck Coll paper XVII (2013)

CMB polarisation: E-mode and B-mode

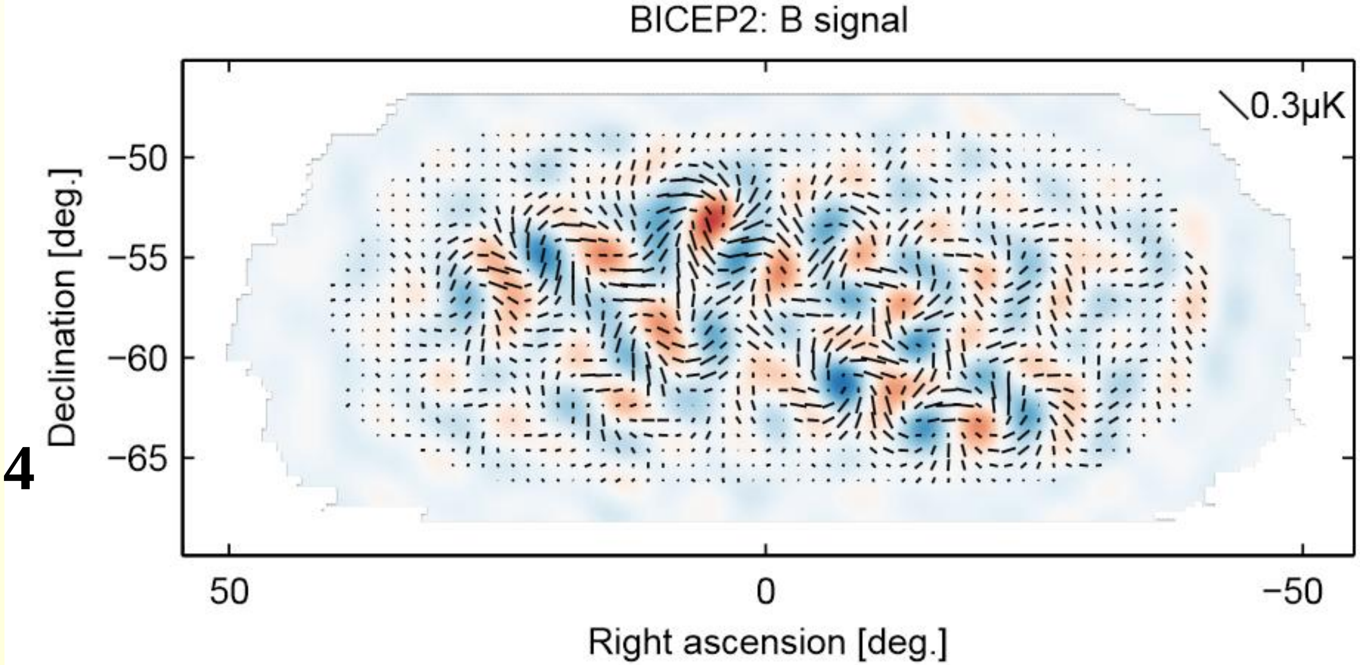
Planck: E-mode, stack of 10^4 hot and cold spots



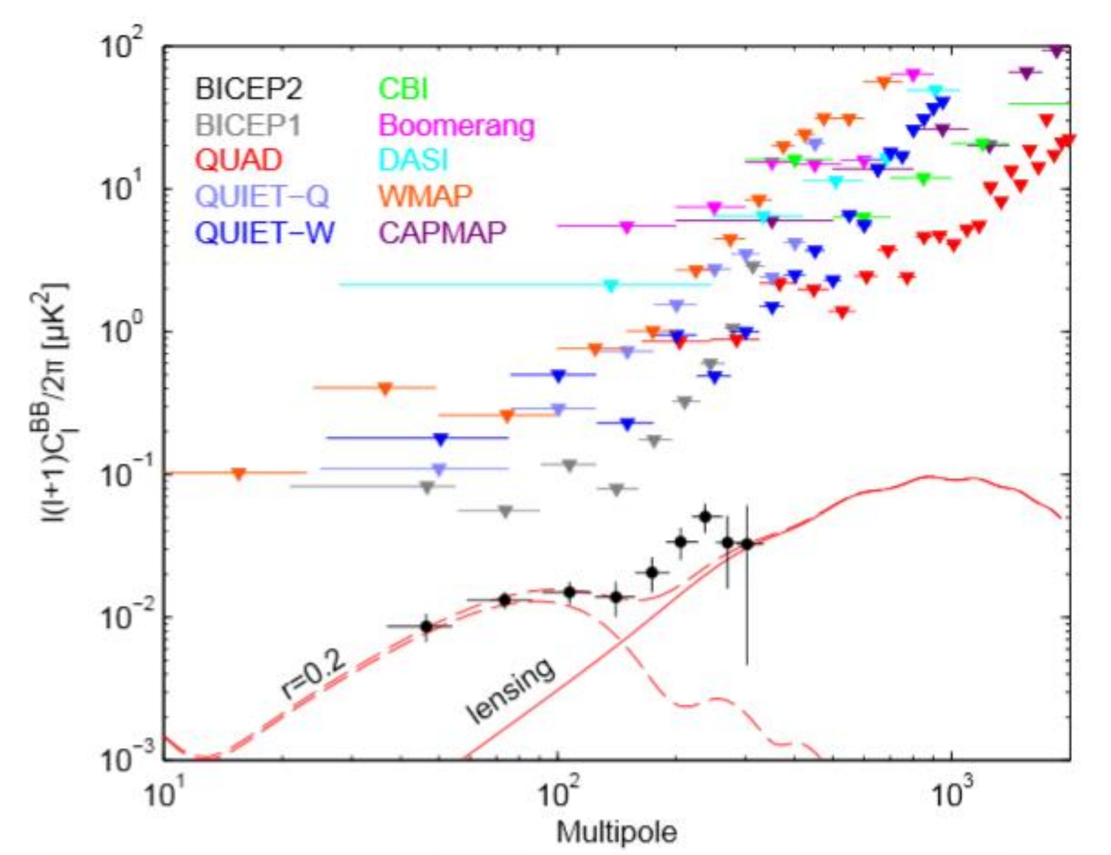
In perfect agreement
With ΛCDM

First detection of
B-mode

BICEP2 March 2014



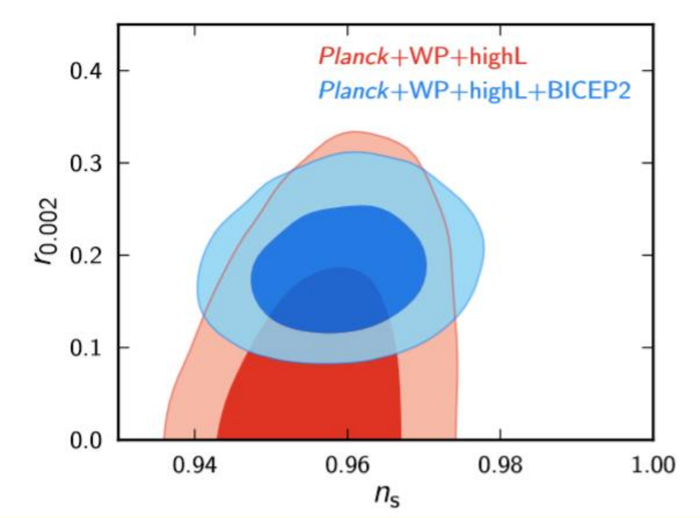
Comparison with previous data



Detection at the level of r=0.2

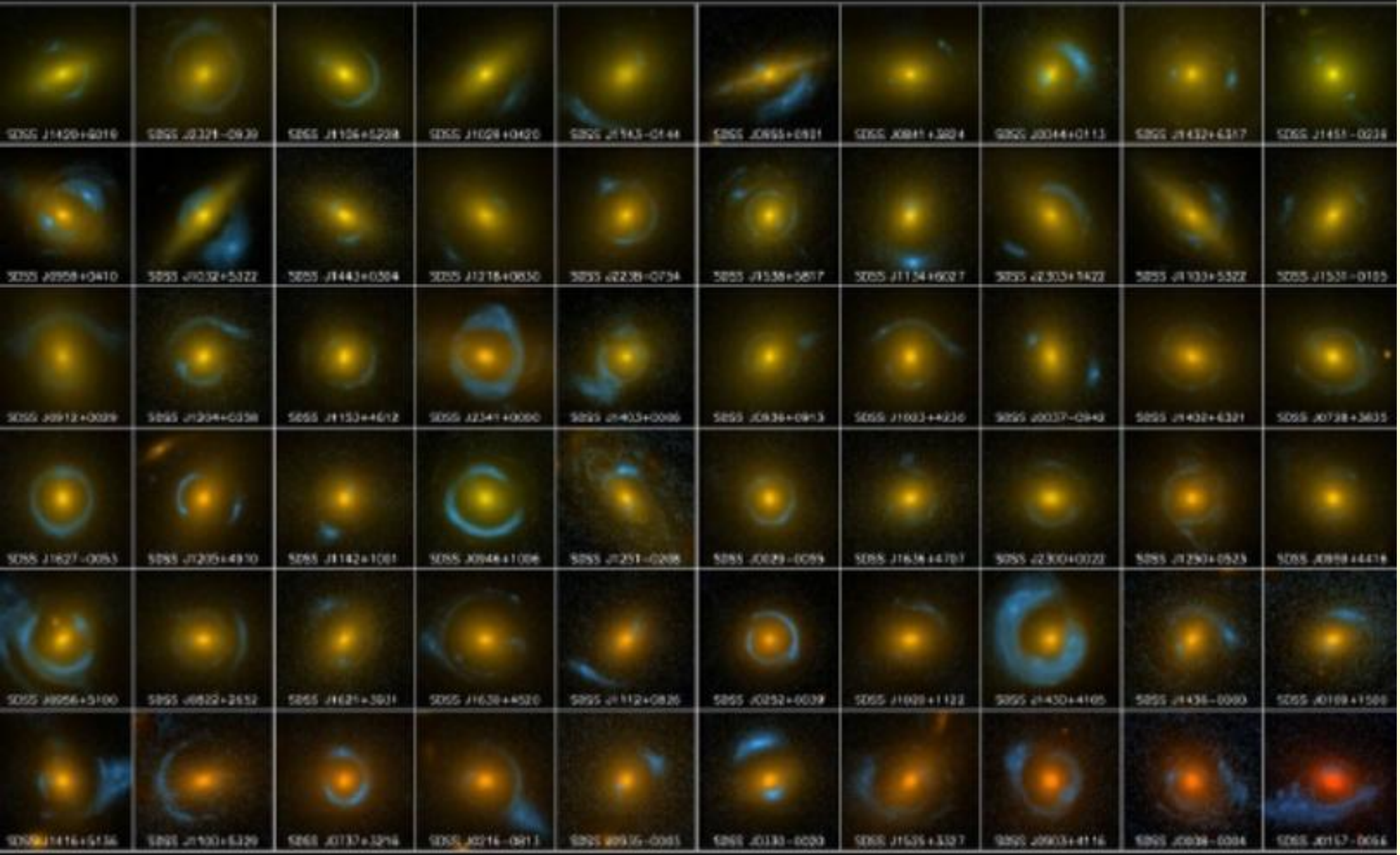
Ratio tensor/scalar, signature of gravitational wave in inflation

Higher than the upper limit from Planck



Strong Lensing

SLACS (~2010 - HST)



SLACS: The Sloan Lens ACS Survey

www.SLACS.org

A. Bolton (U. Hawai'i IfA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

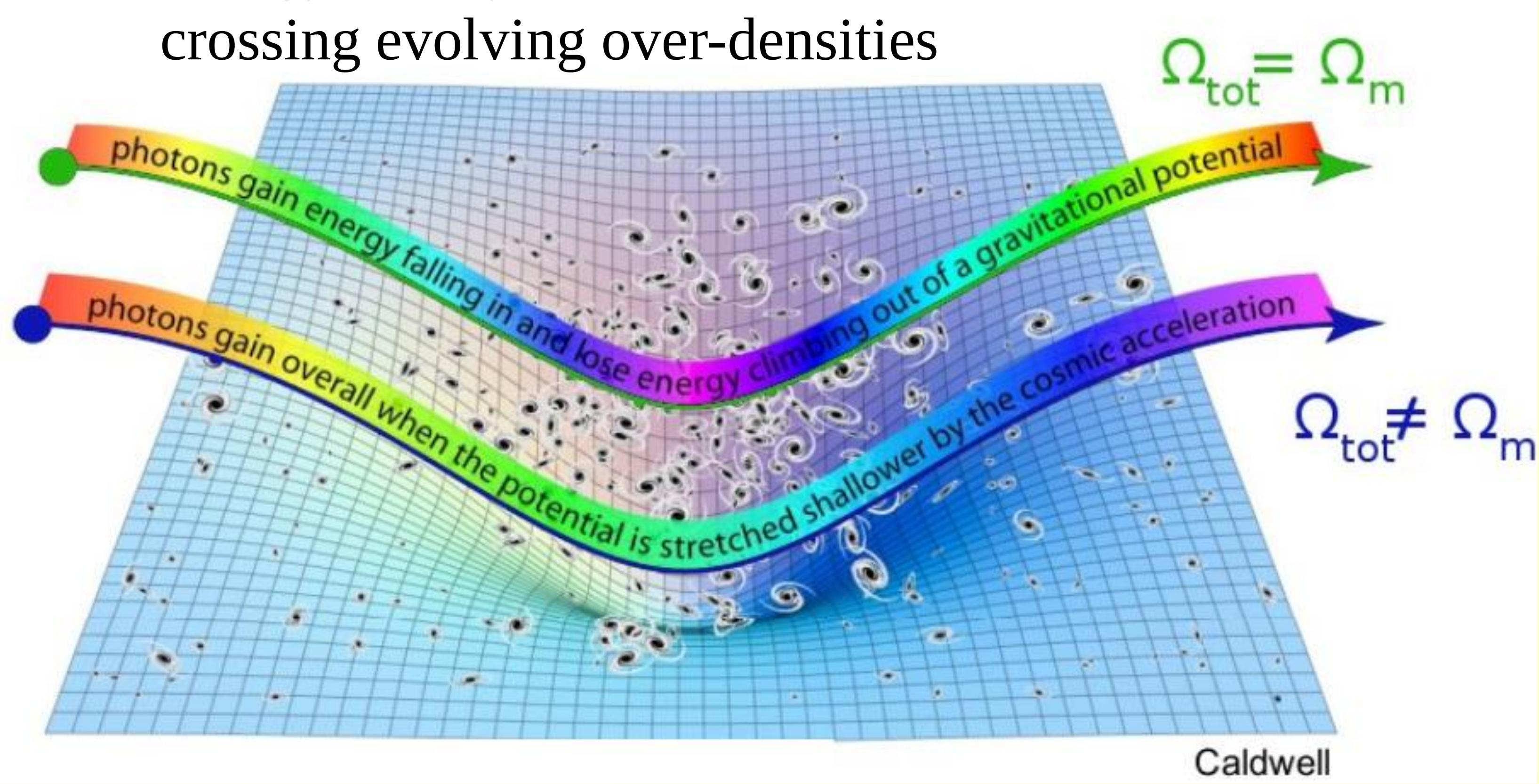
Will become an industry

Substructure study; high-z normal galaxies… **Dark matter studies**

➔ Similar number per unit surface with SKA 100 000

ISW Integrated Sachs-Wolf

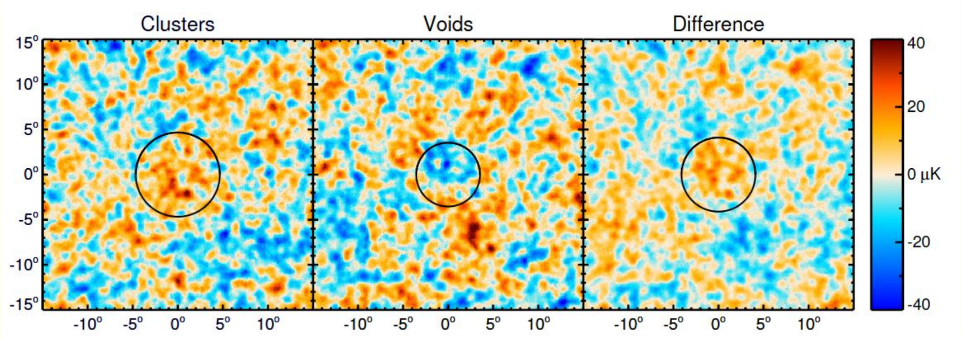
Energy loss by CMB photons while crossing evolving over-densities



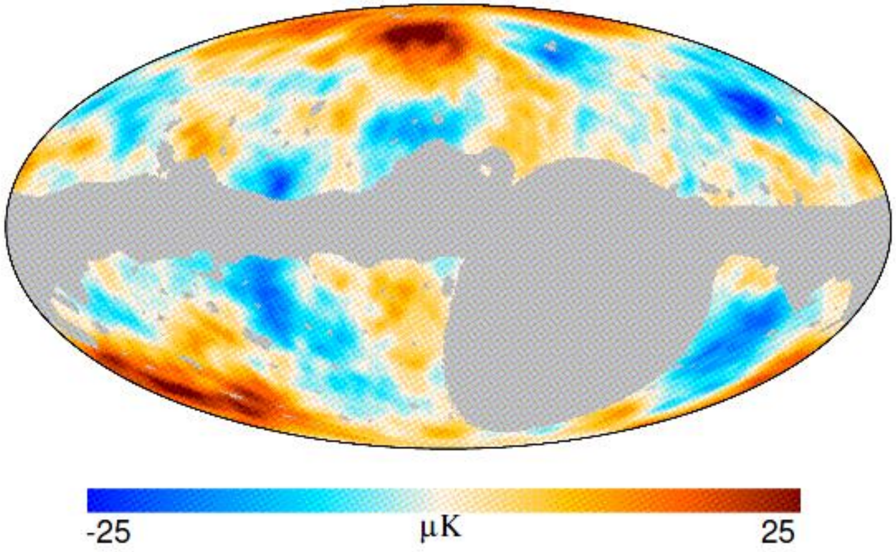
Amplitude of the effect: information on the amount of DE also growth of structures, and modifications of GR

Correlation CMB-LSS (NVSS, SDSS)

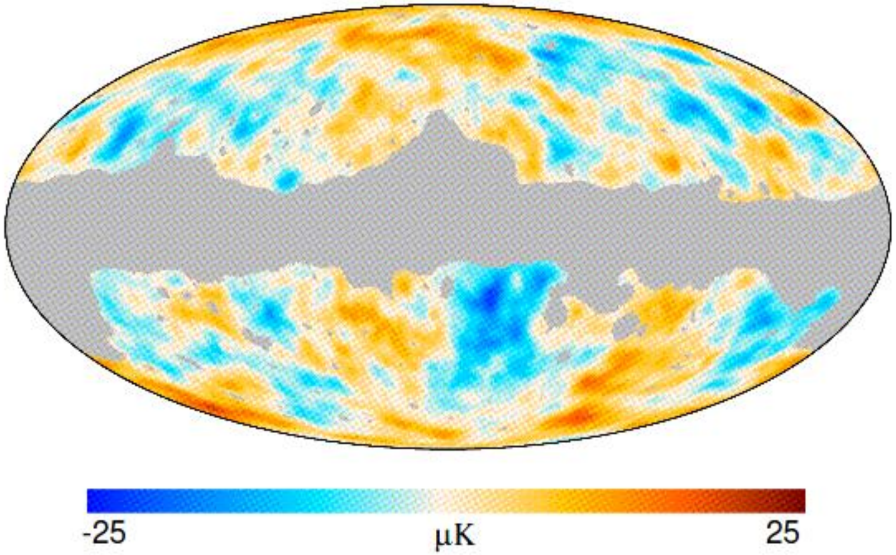
Detected at 2.5σ with Planck
Stacking 50 voids,
50 super-clusters



NVSS radio sources+CMB

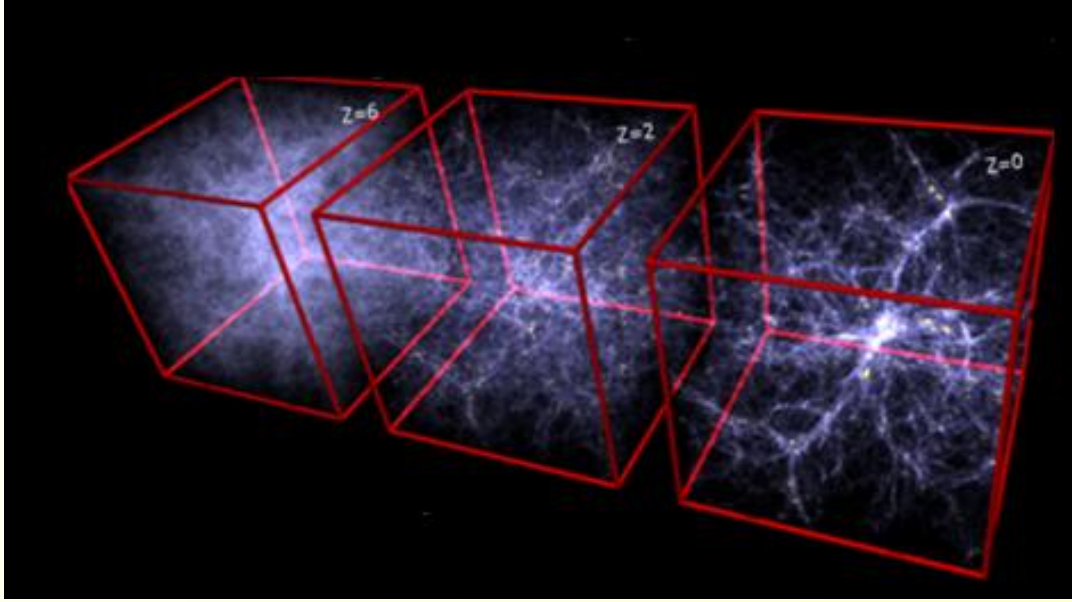


lensing +CMB



Maps of the ISW: Blue= over-densities
Red= under-densities

Growth rate as test of gravity

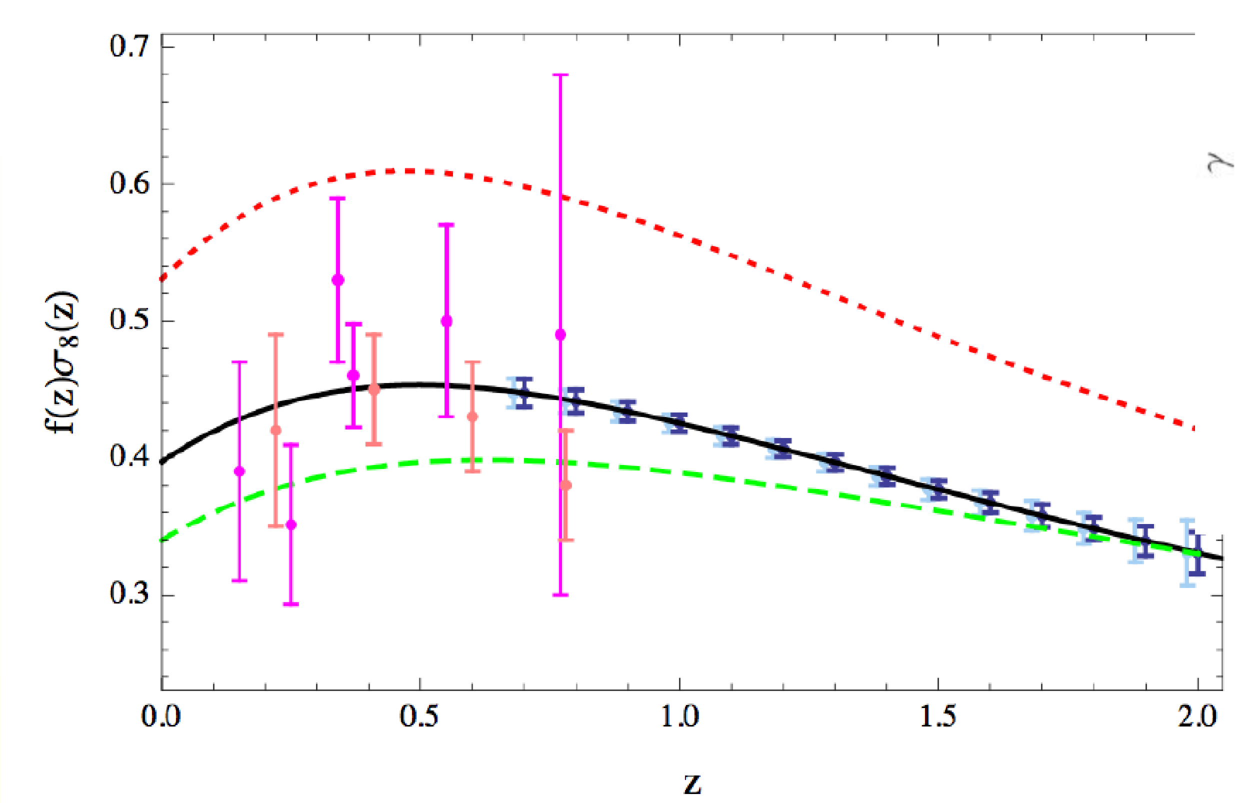


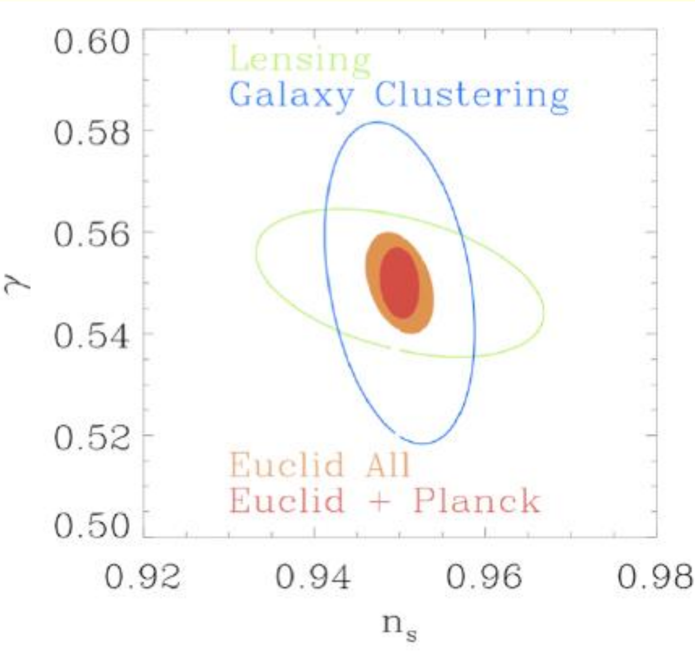
$$\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G\langle\rho\rangle\delta$$

Growth rate γ = dlog (δ) /dlog (a)
Growth produces peculiar motions ➔ RSD

The growth-rate will be measured through
1- Weak Lensing (WL) Tomography
2- Clustering redshift-space distortions (RSD)

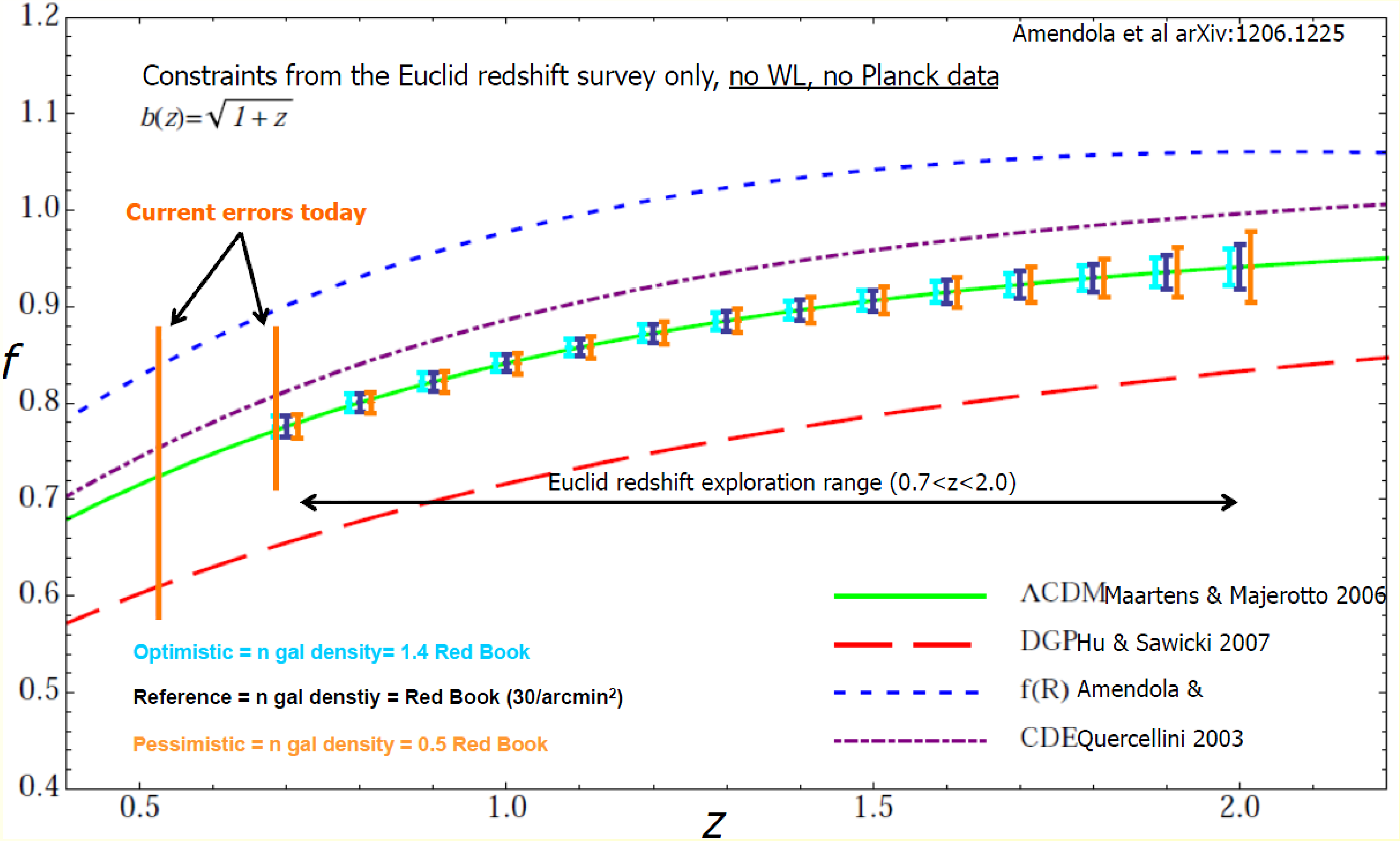
Euclid redbook, predictions





Majerotto et al 2012

Exploration of DE models with Euclid (redshifts only no WL data)



Amendola et al arXiv:1206.1225

Constraints from the Euclid redshift survey only, no WL, no Planck data

$b(z)=\sqrt{1+z}$

Current errors today

Euclid redshift exploration range (0.7<z<2.0)

Optimistic = n gal density= 1.4 Red Book

Reference = n gal denstiy = Red Book (30/arcmin^2)

Pessimistic = n gal density = 0.5 Red Book

Maartens & Majerotto 2006

Hu & Sawicki 2007

Amendola &

Quercellini 2003

EUCLID Legacy

Wide survey 15 000 deg^2
Deep survey 40 deg^2 (+2mag)

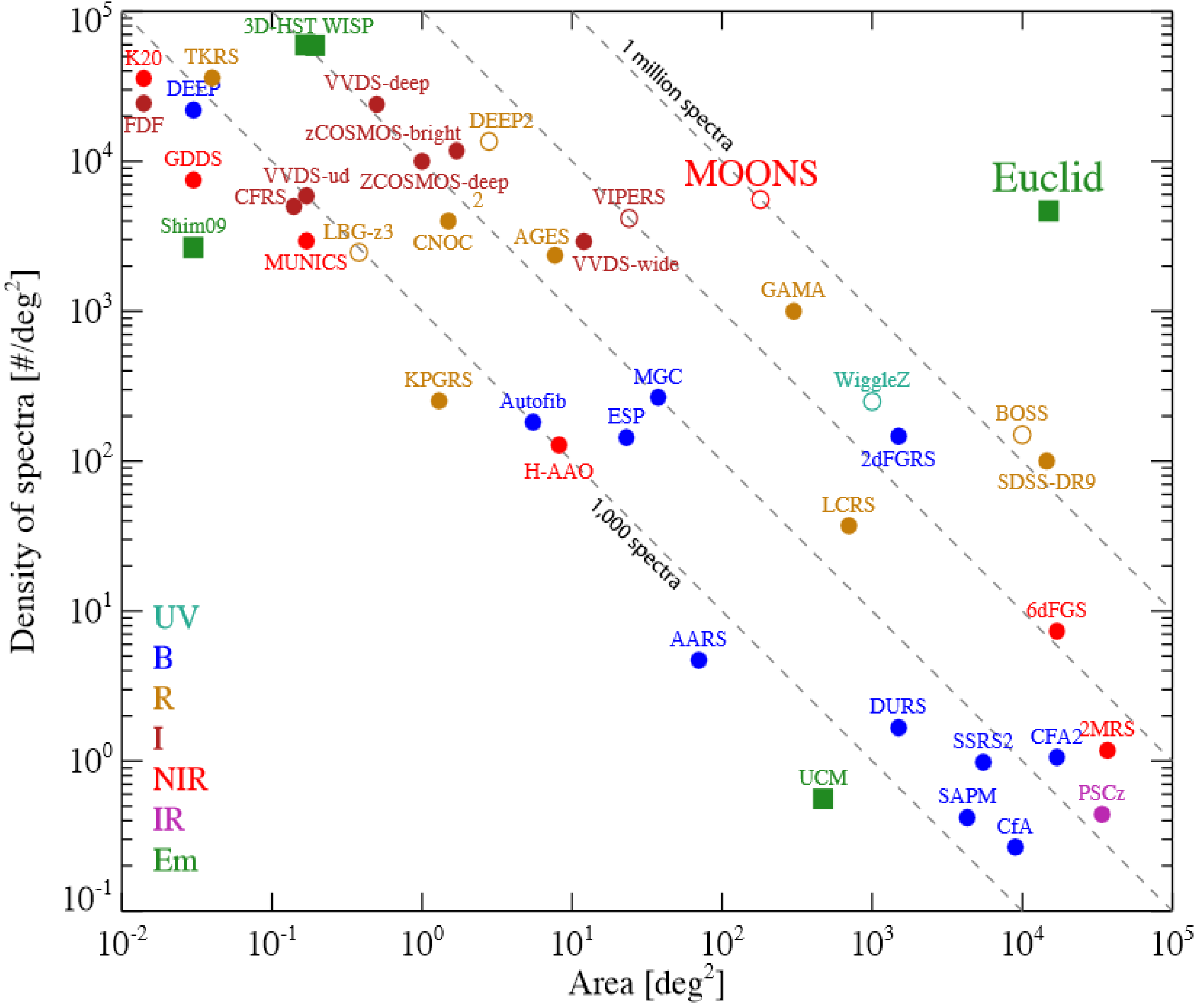
12 billion sources (3σ)

50 million redshifts

A reservoir of targets
for JWST,GAIA, ELT
ALMA, Subaru, VLT, etc

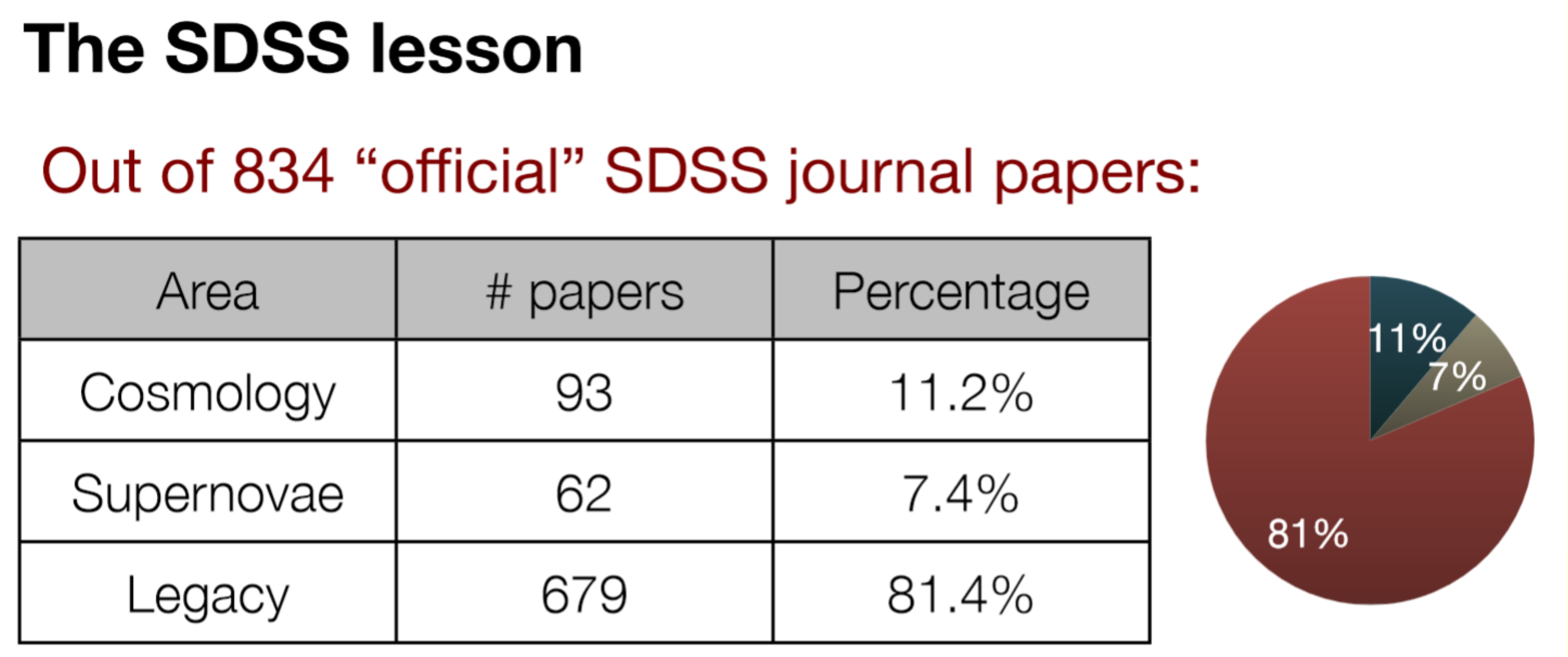
Objects	Euclid	Before Euclid
Galaxies at 1<z<3 with precise mass measurement	~2x10^8	~5x10^6
Massive galaxies (1<z<3))	Few hundreds	Few tenss
Hα Emitters with metal abundance measurements at z~2-3	~4x10^7/10^4	~10^4/~10^2 ?
Galaxies in clusters of galaxies at z>1	~2x10^4	~10^3 ?
Active Galactic Nuclei galaxies (0.7<z<2)	~10^4	<10^3
Dwarf galaxies	~10^5	
T_{eff} ~400K Y dwarfs	~few 10^2	<10
Lensing galaxies with arc and rings	~300,000	~10-100
Quasars at z > 8	~30	None

Comparison with other surveys



Based on a compilation by I. Baldry

Other domains: Galaxy evolution



The SDSS lesson

Out of 834 “official” SDSS journal papers:

Area	# papers	Percentage
Cosmology	93	11.2%
Supernovae	62	7.4%
Legacy	679	81.4%

➔ **Most papers could come from outside the Core Science**

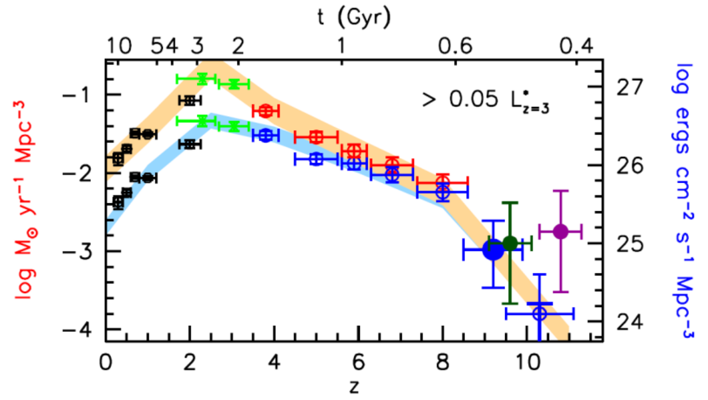
Main issues, synergies: JWST, ELT, SKA

Galaxy formation and evolution, physics and dynamics

Surveys of galaxies at high and intermediate redshifts
Mass assembly and star formation, mergers, cold accretion
Quenching: supernovae and AGN feedback

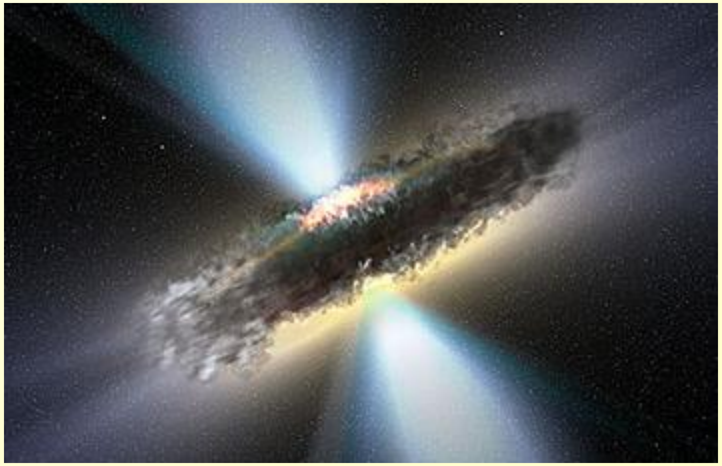
Epoch of reionization

Early galaxies and black holes z=10-6
Absorption in front of QSO, GRB
IGM

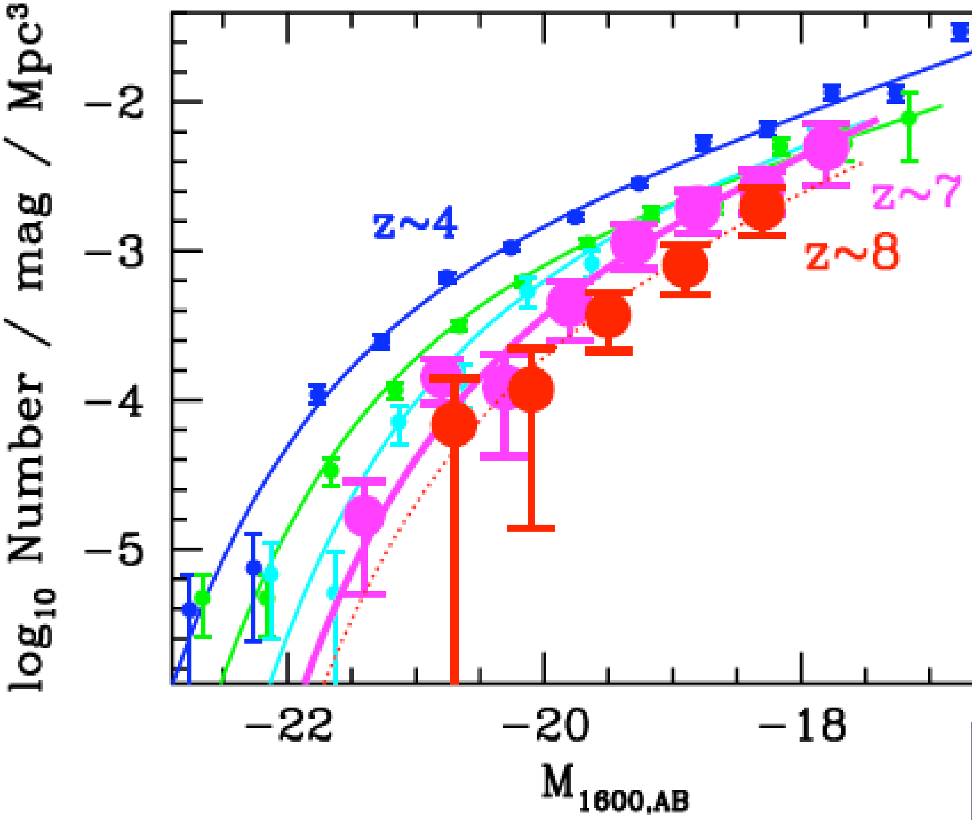


AGN and super-massive BH

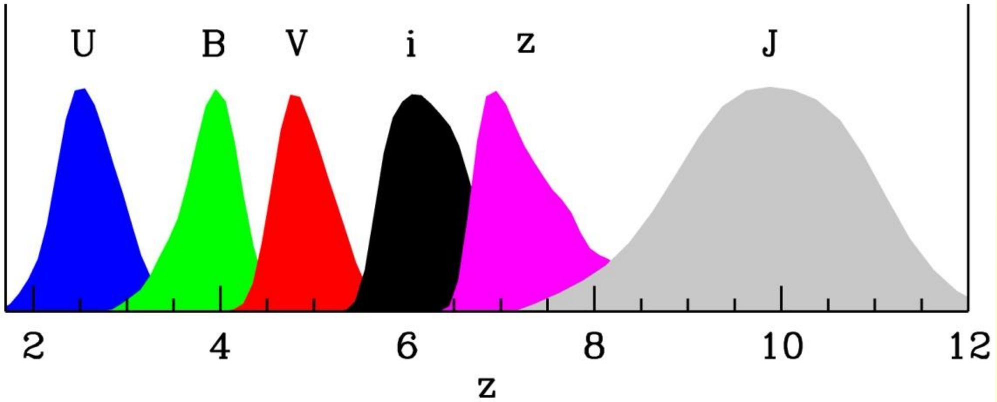
Symbiotic growth with galaxies
Physics of accretion

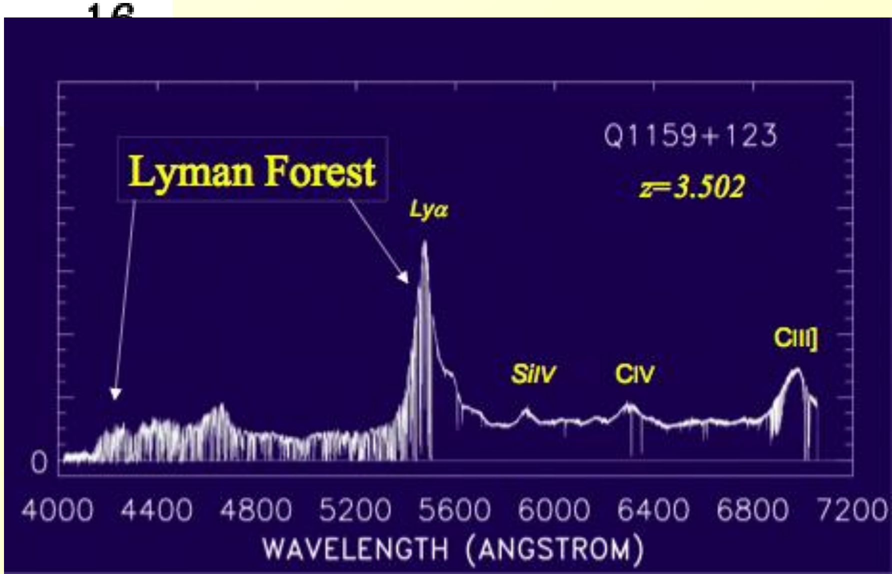


Are galaxies at z=7-10 able to re-ionize?



Nbre of galaxies
mag^{-1} Mpc^{-3}





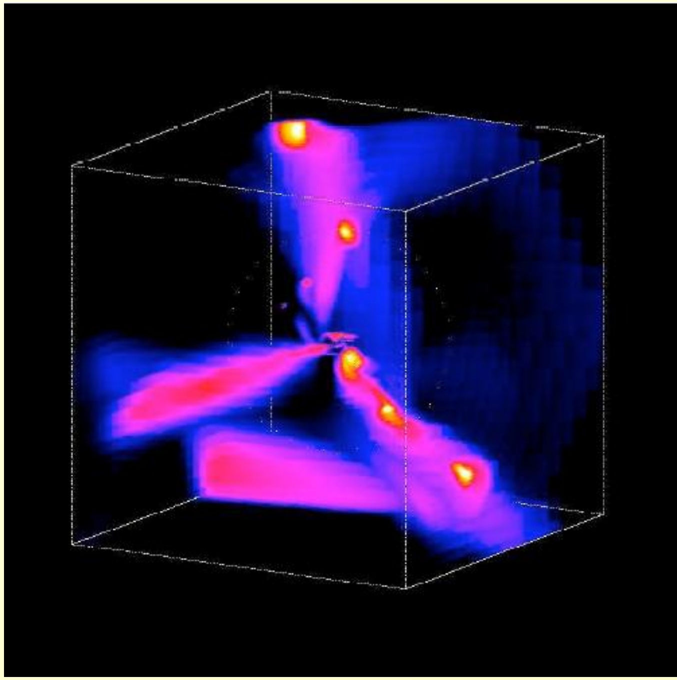
Galaxy formation and evolution

How galaxies assemble their mass?

How much mass assembled in mergers?

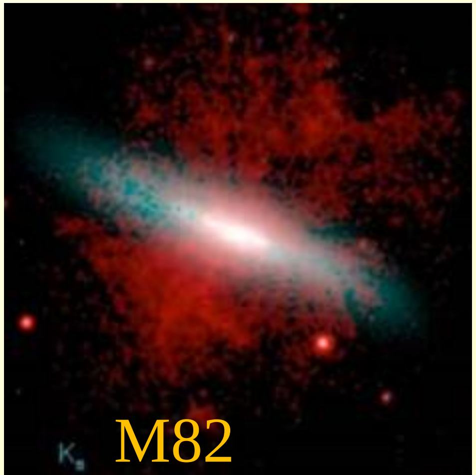
How much through gas accretion and secular evolution?

Star formation modes; main sequence,
Starburst, mergers?



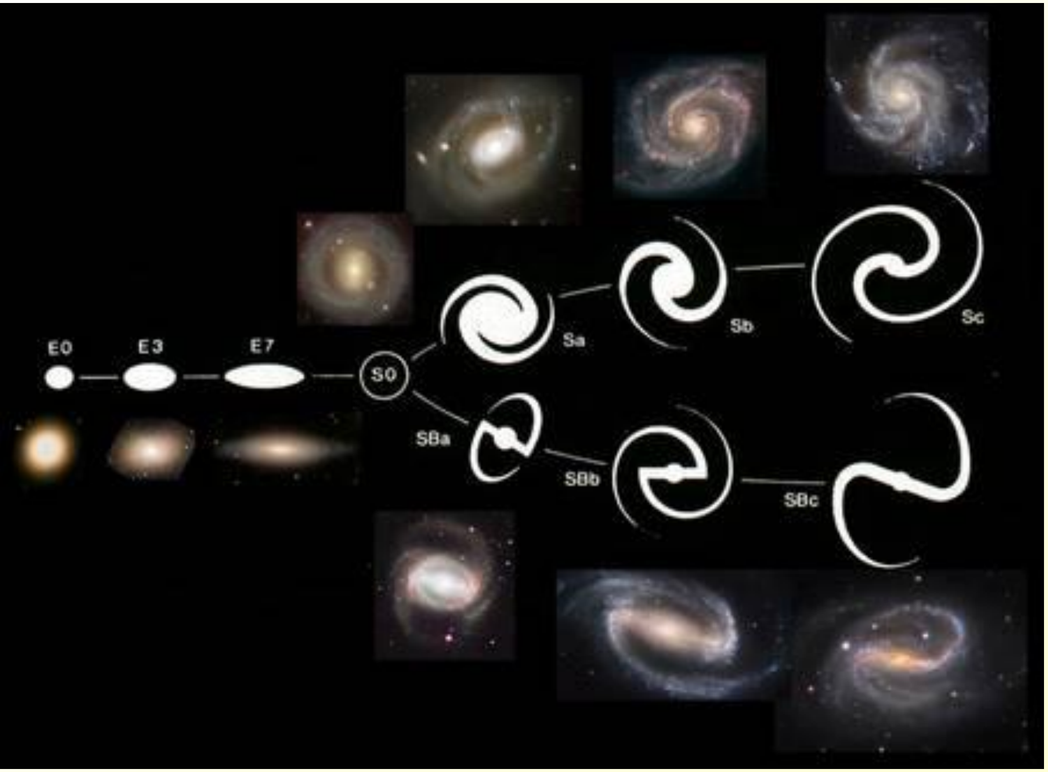
Modes of Quenching

SF and AGN feedback

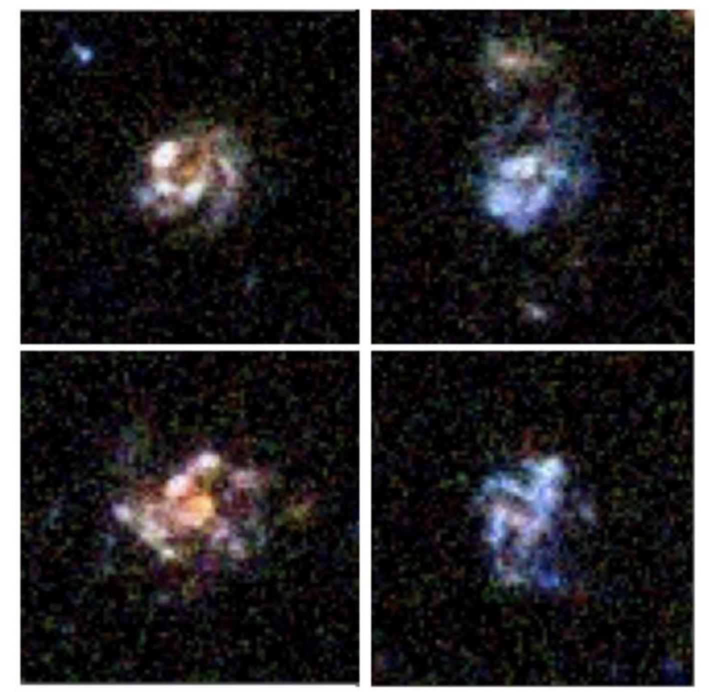


How the Hubble sequence sets in?

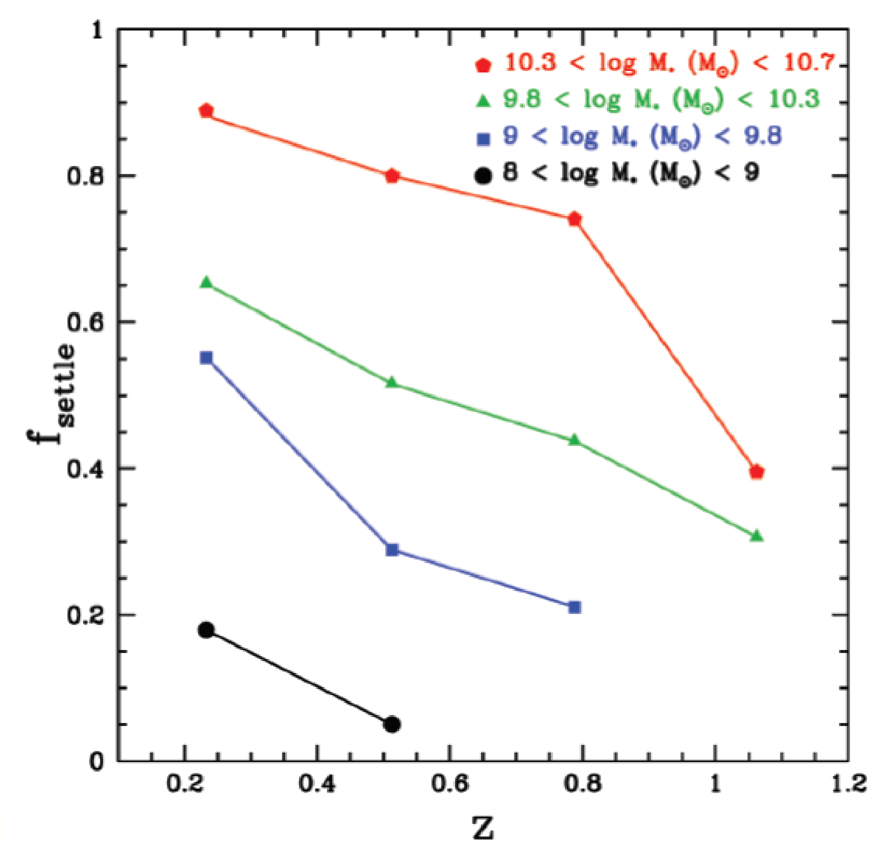
Galaxies today



In the first half of the Universe age



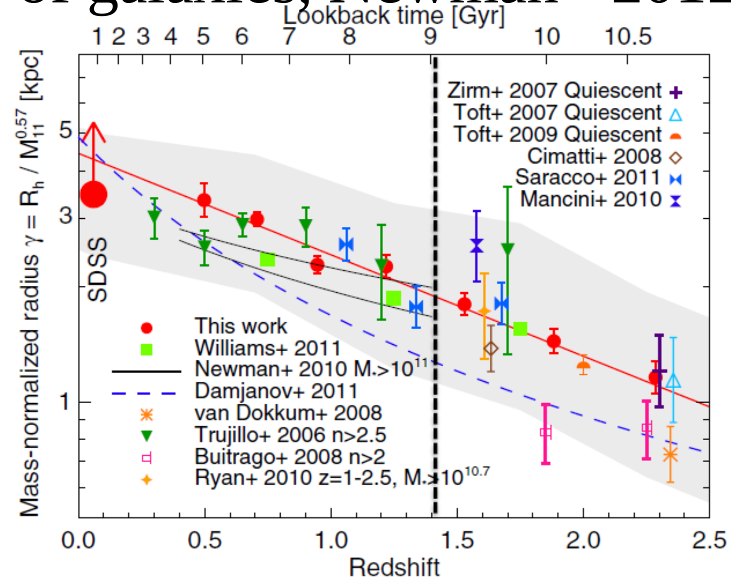
When star formation declines, the Hubble sequence sets in



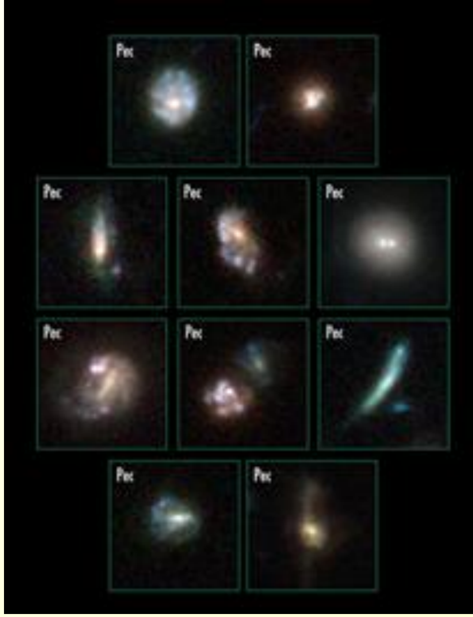
Kassin +2013

Fraction of disks which have settled i.e. V/σ > 3

Size of galaxies, Newman +2012



The main questions



When does the Hubble sequence turn on?

➔ **More perturbed systems at high redshift**

Disks appear thick, or dispersion dominated

Clumpy galaxies? Or transient stages after mergers?

➔**The Elliptical galaxies appears surprisingly early**

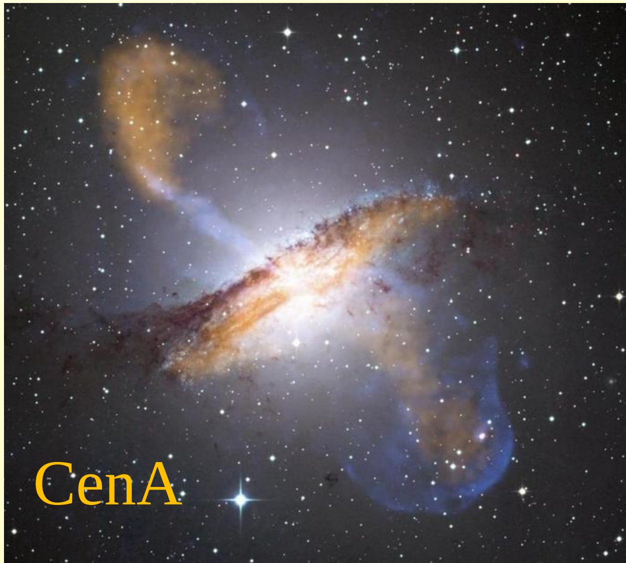
Downsizing? Anto-hierarchical

➔**When and where most of the stars formed?**

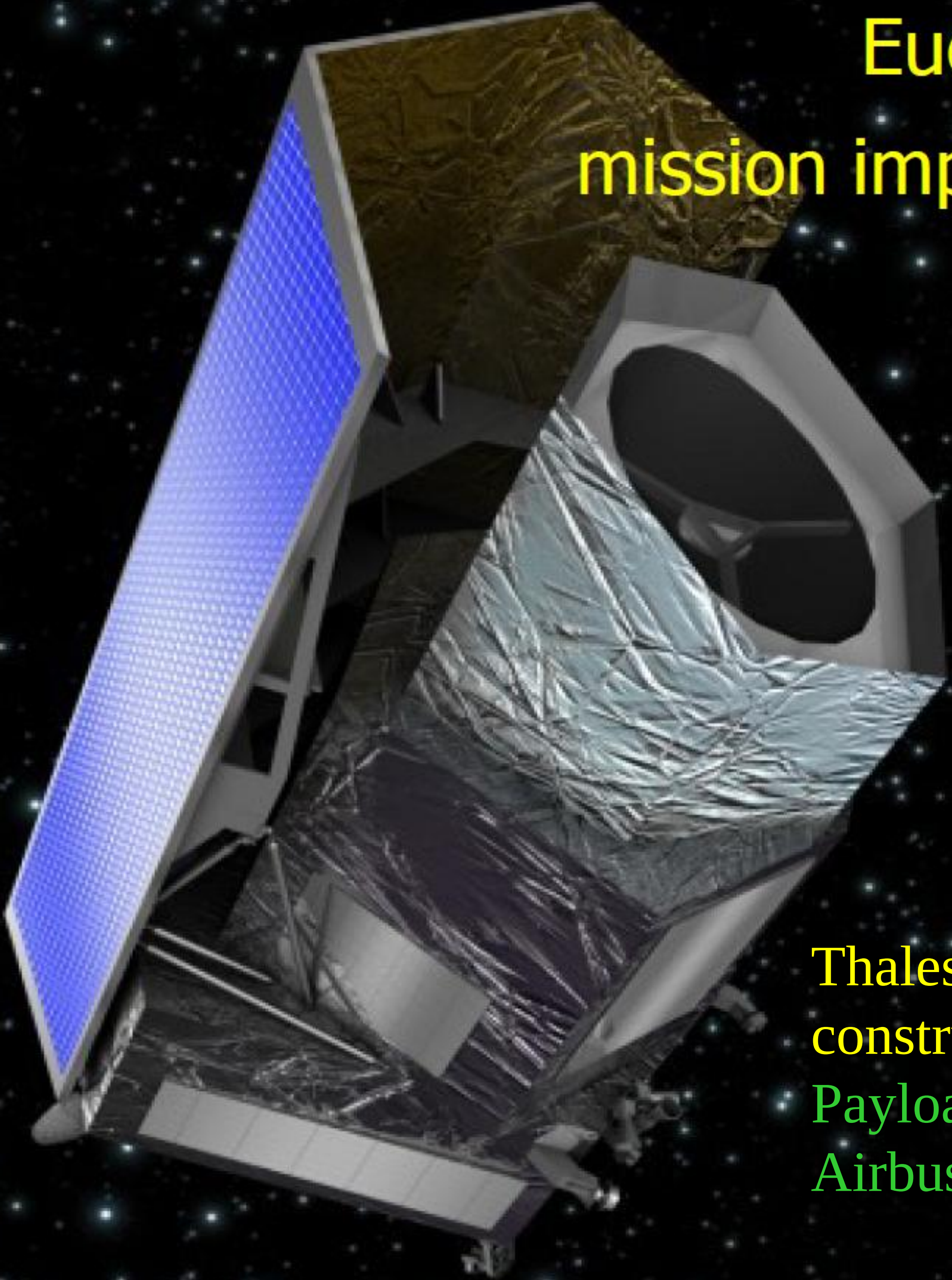
➔**Mass assembly: how and when?**

➔**Environment effects**

➔**AGN and bulge growths**



Euclid:
mission implementation

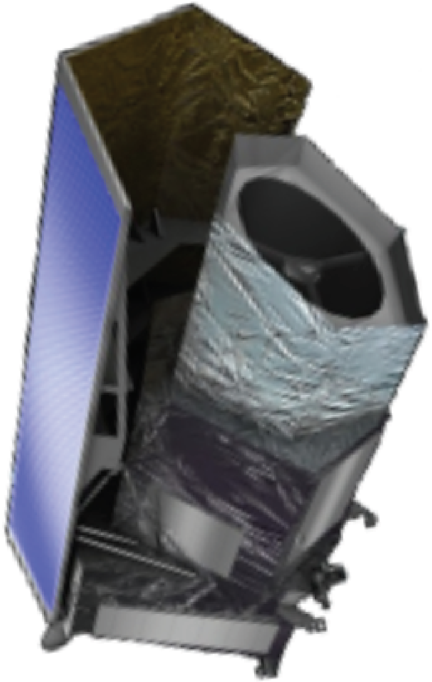


Thales Alenia Space begins construction in 2013

Payload Module: Astrium

Airbus Defense and Space

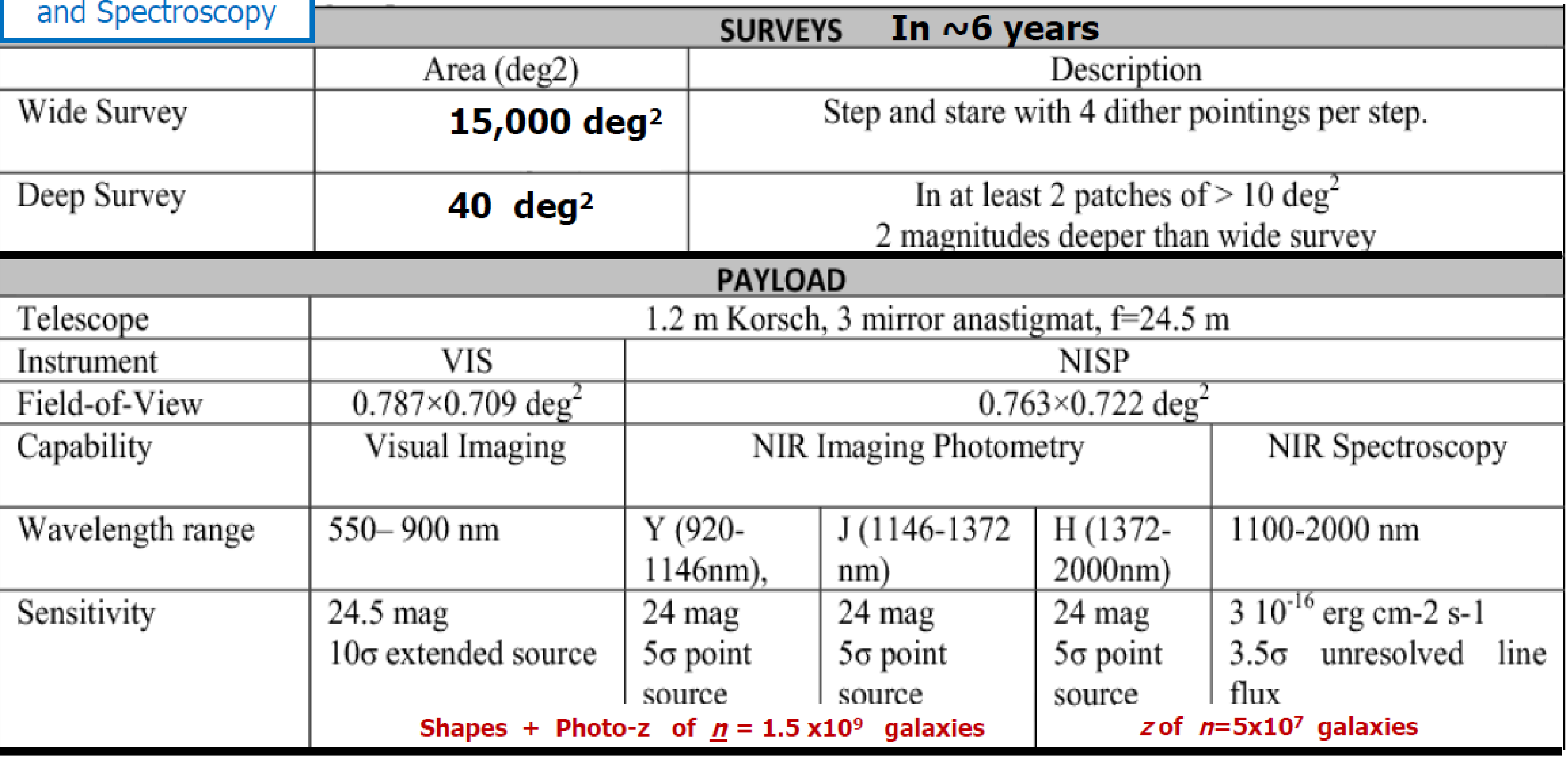
Euclid Concept



- ESA-led mission
- Selected in Oct. 2011 - Fully funded
- Phase B2 close to completion
- Telescope –
  - 1.2m aperture primary
  - 3 mirror anastigmat
- Overall Mass – ~2020 kg
- Power – 1710 W
- Cost: ~ 850 Meuros
- Instrument – Two channels
  - Wide field instrument, VIS: 36 e2v 4kx4k CCDs
  - 576 M pixels, 0.11 arcsec/pix, 0.53 deg^2 FoV
  - Photom.+spectrom.: 16 H2RG HgCdTe detectors;
  - 64 Mpixels, 0.30 arcsec/pix, 0.53 deg^2 FoV (=VIS)
  - Grism slitless spectro
- Downlink Rate – X/X + K-band to Ground Station 55 Mbits/s. 850 Gbit/day to transfer 4hr/day.
- L2 orbit
- Launch Vehicle – Soyuz-Fregat
- Launch date 2020
- 6.25 years mission+additional surveys (exopl, SN)
- Main surveys: 15,000 deg^2+40 deg^2 2 mag. deeper
- Science drivers: DE

EUCLID mission: launch in 2020

Photo-z: Ground based Photometry and Spectroscopy



<table>
<tr><th colspan="6">SURVEYS **In ~6 years**</th></tr>
<tr><td></td><td>Area (deg2)</td><td colspan="4">Description</td></tr>
<tr><td>Wide Survey</td><td>**15,000 deg²**</td><td colspan="4">Step and stare with 4 dither pointings per step.</td></tr>
<tr><td>Deep Survey</td><td>**40 deg²**</td><td colspan="4">In at least 2 patches of > 10 deg^2
2 magnitudes deeper than wide survey</td></tr>
<tr><th colspan="6">PAYLOAD</th></tr>
<tr><td>Telescope</td><td colspan="5">1.2 m Korsch, 3 mirror anastigmat, f=24.5 m</td></tr>
<tr><td>Instrument</td><td>VIS</td><td colspan="4">NISP</td></tr>
<tr><td>Field-of-View</td><td>0.787×0.709 deg^2</td><td colspan="4">0.763×0.722 deg^2</td></tr>
<tr><td>Capability</td><td>Visual Imaging</td><td colspan="3">NIR Imaging Photometry</td><td>NIR Spectroscopy</td></tr>
<tr><td>Wavelength range</td><td>550– 900 nm</td><td>Y (920-1146nm),</td><td>J (1146-1372 nm)</td><td>H (1372-2000nm)</td><td>1100-2000 nm</td></tr>
<tr><td>Sensitivity</td><td>24.5 mag
10σ extended source</td><td>24 mag
5σ point source</td><td>24 mag
5σ point source</td><td>24 mag
5σ point source</td><td>3 10^{-16} erg cm-2 s-1
3.5σ unresolved line flux</td></tr>
<tr><td></td><td colspan="3">**Shapes + Photo-z of *n* = 1.5 x10^9 galaxies**</td><td colspan="2">***z* of *n*=5x10^7 galaxies**</td></tr>
</table>

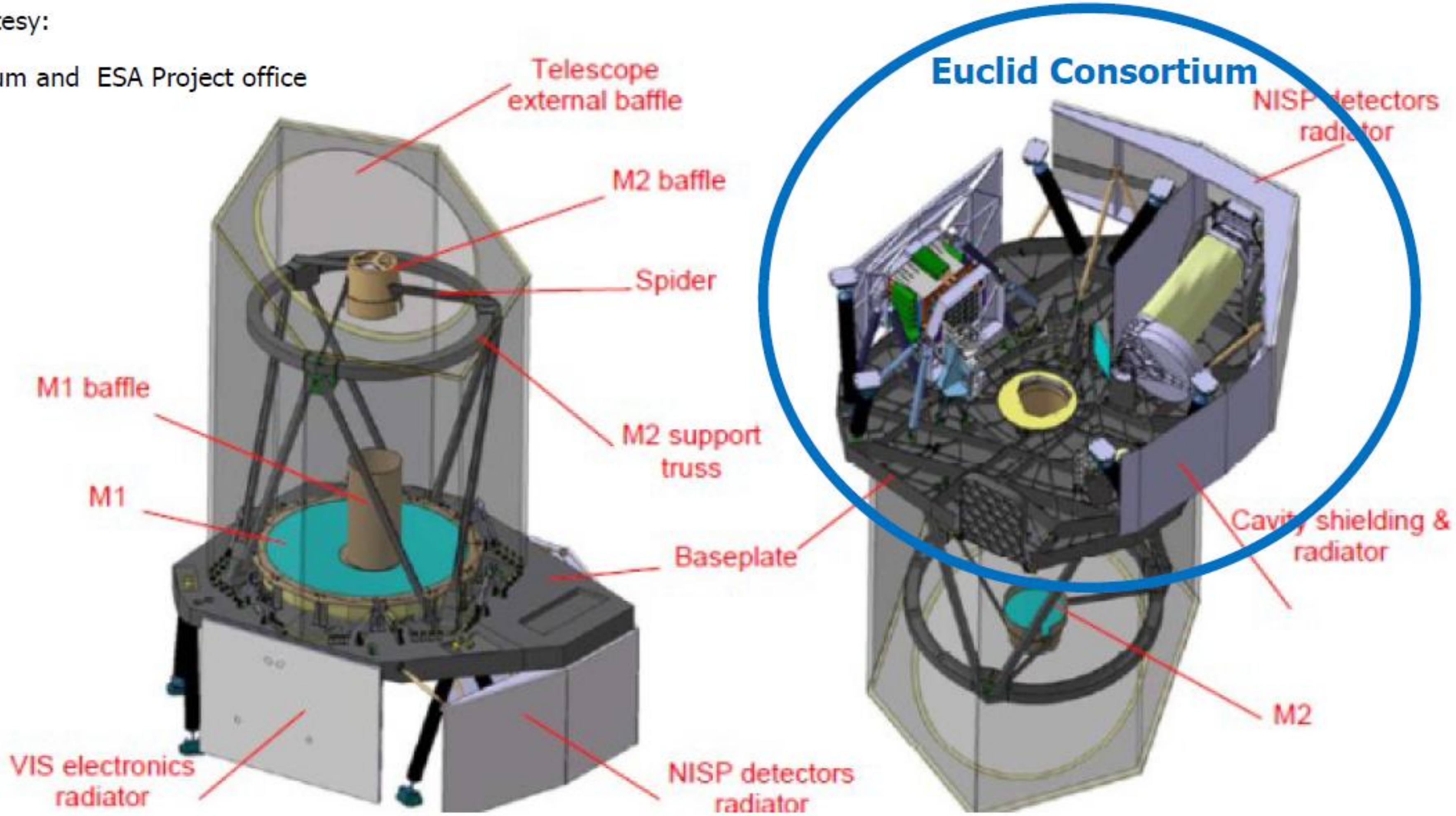
Possibility other surveys: SN and/or μ-lens surveys, Milky Way ?

Ref: Euclid RB Laureijs et al arXiv:1110.3193

EUCLID: scientific instruments, VIS, NISP

Courtesy:

Astrium and ESA Project office



- Stabilisation: Pointing error along the x,y axes= 25mas over a period 700 s.
- FoV: Common visible and NIR Fov = 0.54 deg^2

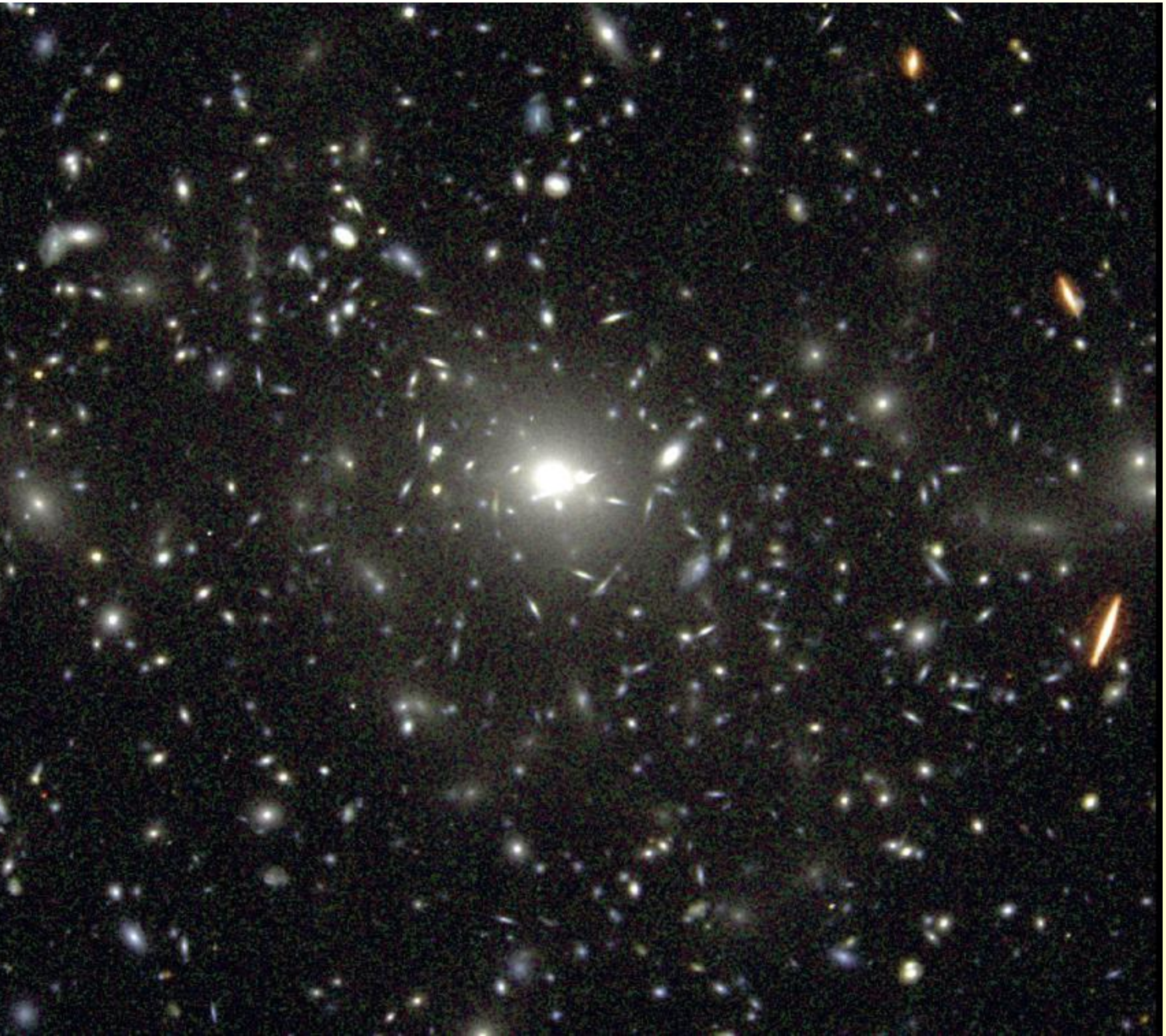
Simulation with VIS instrument

Messier 51 galaxy at z~0.1 and 0.7:

Euclid will get the resolution of Sloan Digital Sky Survey but at z=1 instead of z=0.05.

Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

Euclid simulation VIS+NISP



YJH image
z~0.3 cluster of galaxies

Ground base data for photo-z

- South

o DES data deep enough in g,r,i,z . Suits Euclid needs

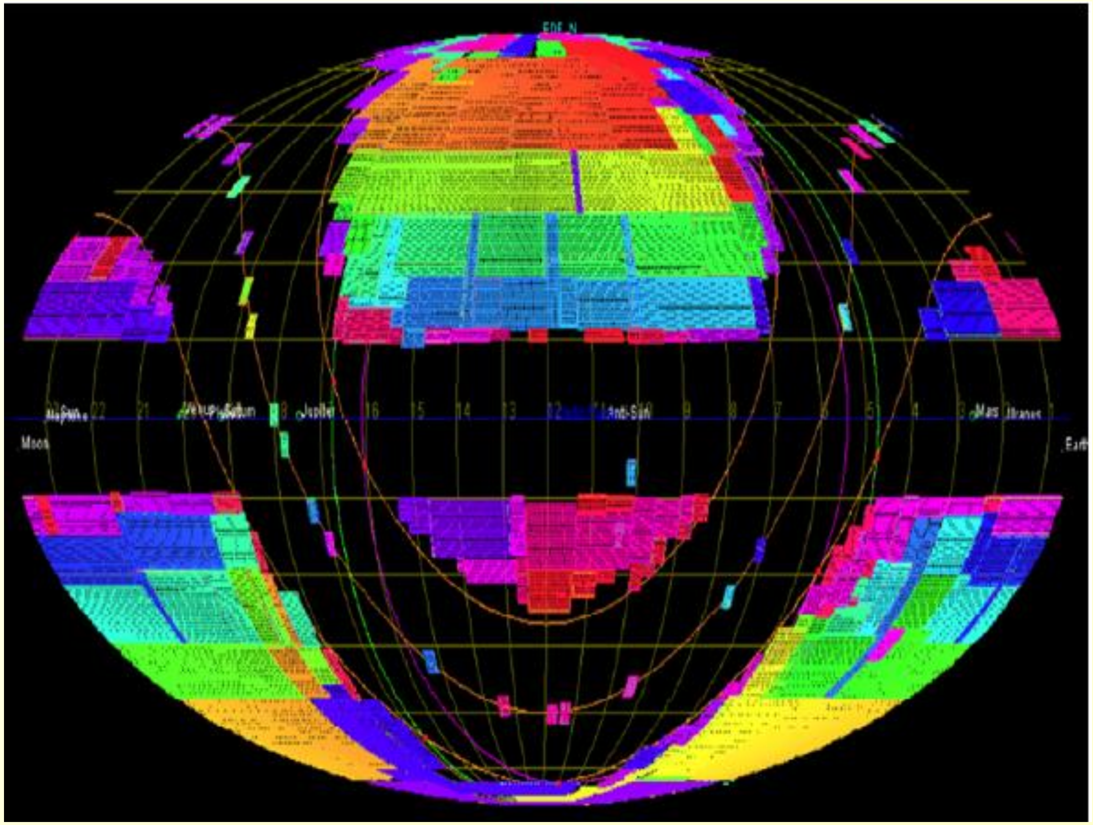
o Part of south with LSST?

- North:

o MegaCam-RED at CFHT + WHT (WEAVE survey)

o HSC/Subaru

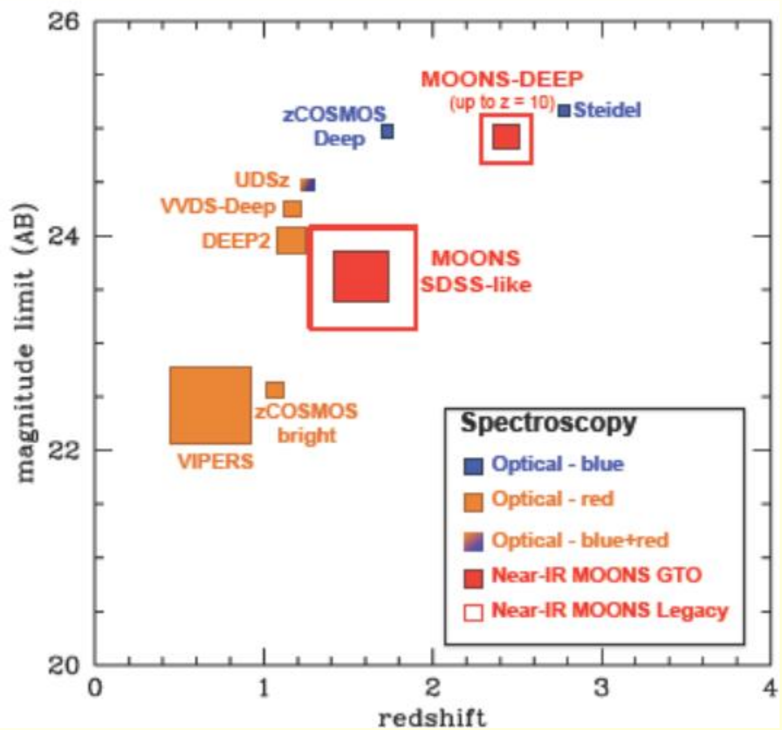
o LSST south-north?



Ground spectroscopy in synergy

HI spectroscopy will provide spectro-z catalogs for Euclid
Ultimately 1 billion HI spectro-z (SKA2)
With SKA-1 ~ 10% of SKA2

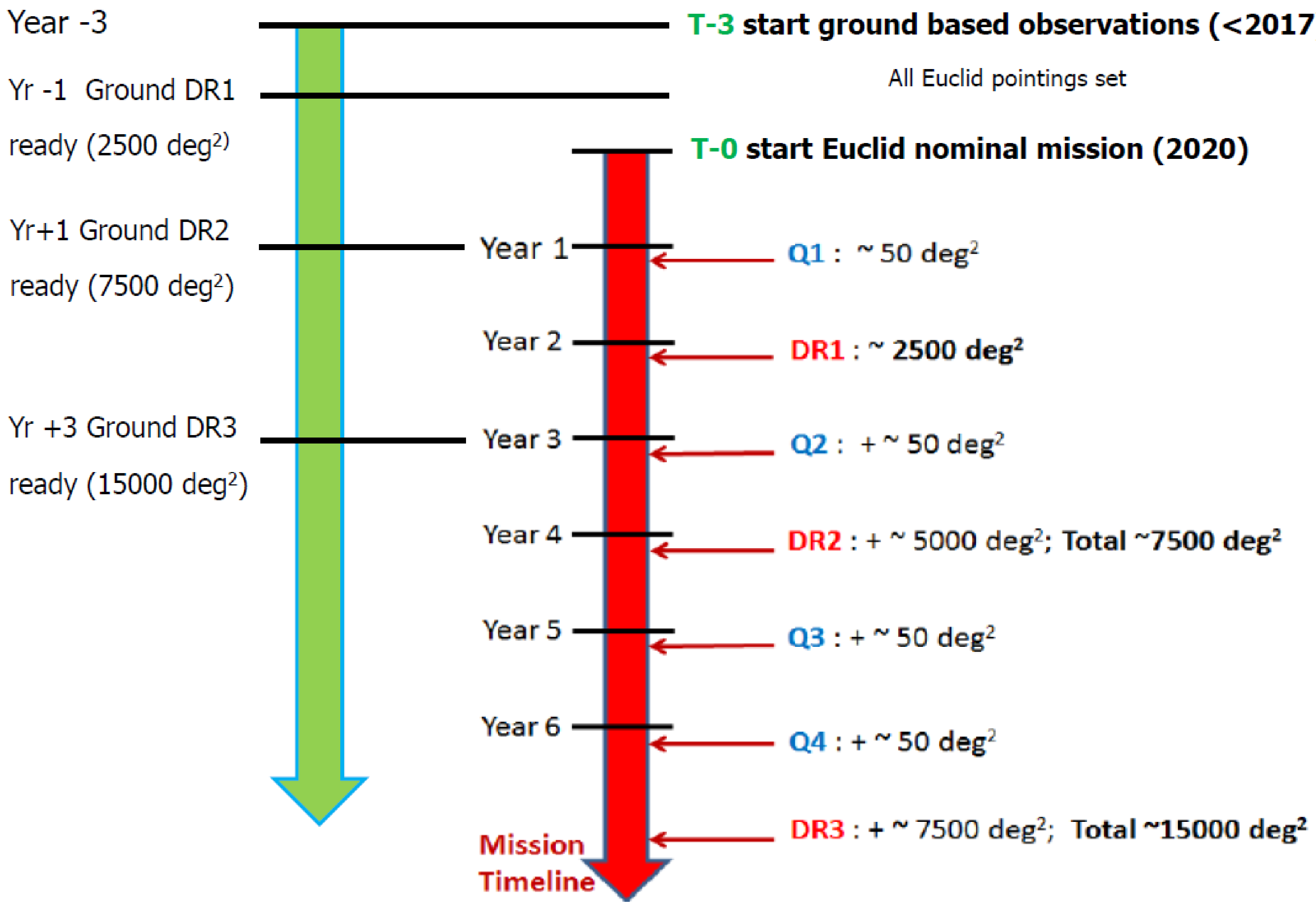
MOONS is ideal to provide the control sample for Euclid
Euclid is ideal to provide deep near-IR photometry for MOONS



In addition to the ground photo-z Survey, with CFHT in the North DES, LSST in the South

E-ELT: very small FOV
Will make follow-up of SKA and Euclid sources, with high resolution
Complementary in science goals

Data release: ground based + Euclid



Year -3

T-3 start ground based observations (<2017

Yr -1 Ground DR1

ready (2500 deg$^{2)}$

All Euclid pointings set

T-0 start Euclid nominal mission (2020)

Yr+1 Ground DR2

ready (7500 deg^2)

Year 1

Q1 : ~ 50 deg^2

Year 2

DR1 : ~ 2500 deg^2

Yr +3 Ground DR3

ready (15000 deg^2)

Year 3

Q2 : + ~ 50 deg^2

Year 4

DR2 : + ~ 5000 deg^2; **Total ~7500 deg^2**

Year 5

Q3 : + ~ 50 deg^2

Year 6

Q4 : + ~ 50 deg^2

DR3 : + ~ 7500 deg^2; **Total ~15000 deg^2**

Mission Timeline

Summary

The Euclid mission is now in implementation phase

- Euclid = 5 cosmological probes: WL, RSD, BAO, CL, ISW *with 2 independent methods: geometry and growth rate*
- Europe is leading one of the most fascinating and challenging question of modern physics and cosmology

- **Euclid Legacy = 12 billion sources, 50 million redshifts**
  - A mine of images and spectra for the community for several decades;
  - Synergy with LSST, e-ROSITA, SKA
  - A reservoir of targets for JWST, GAIA, VLT, E-ELT, TMT, ALMA, etc..