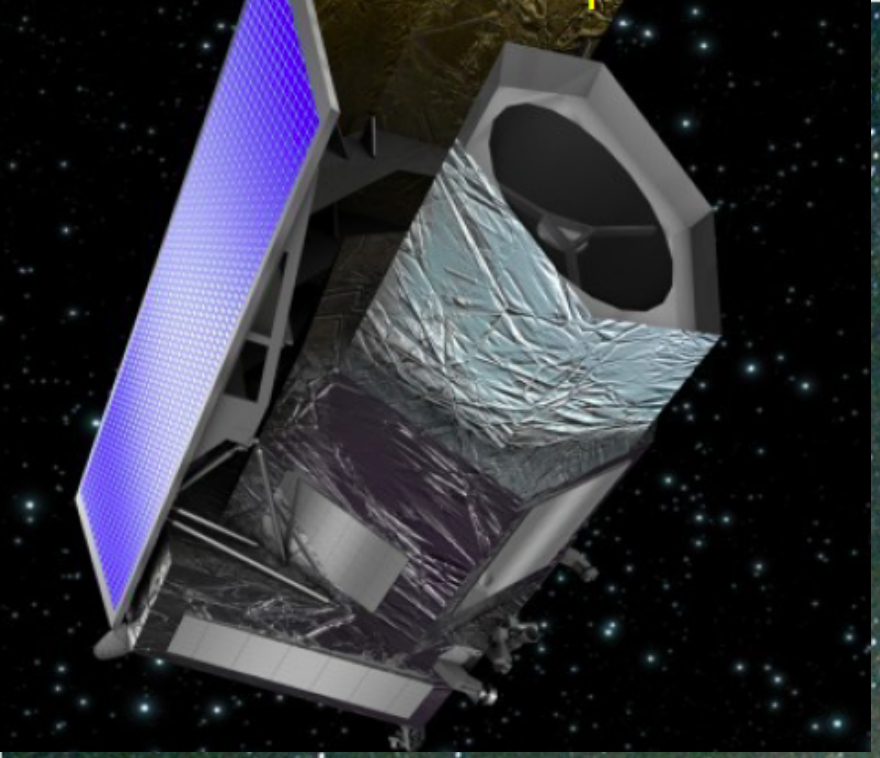
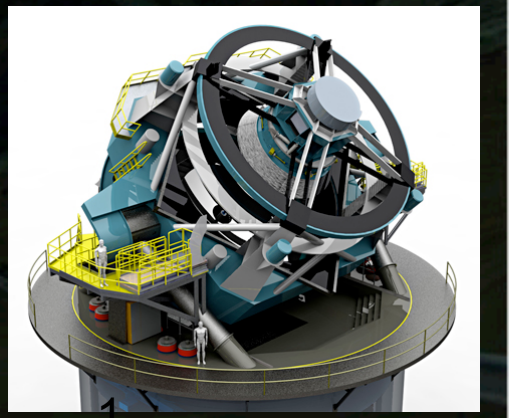


Cosmology with wide field imagers

An overview

A.Ealet
CPPM/IN2p3/France



Overview

ΛCDM .. The current status

- ΛCDM confirmation with Planck
- Status of cosmological probes:
  - Supernovae observation
  - BAO (Baryonic Acoustic Oscillation) as a standard ruler

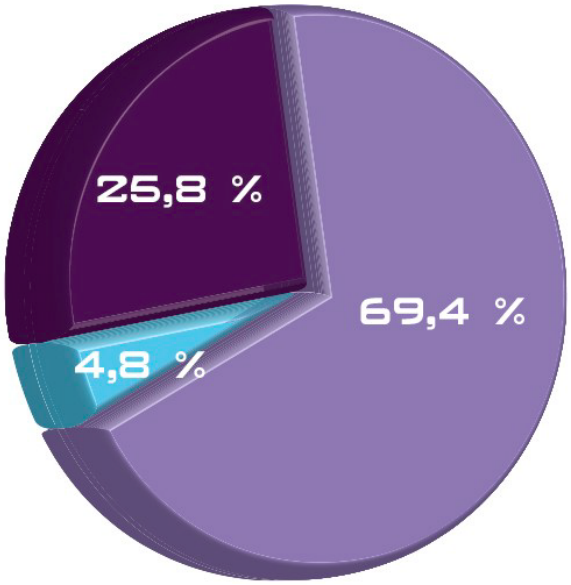
What to do next ? Testing the nature of dark energy

- Future probes
- Future dedicated 'wide imagers' in ground and space
  LSST and Euclid

ΛCDM evidence

New Universe composition after Planck

- **69.4 % dark energy (72.8 % before)**
- **25.8 % dark matter (23 % before)**
- **4.8 % baryons (4.3 % before)**



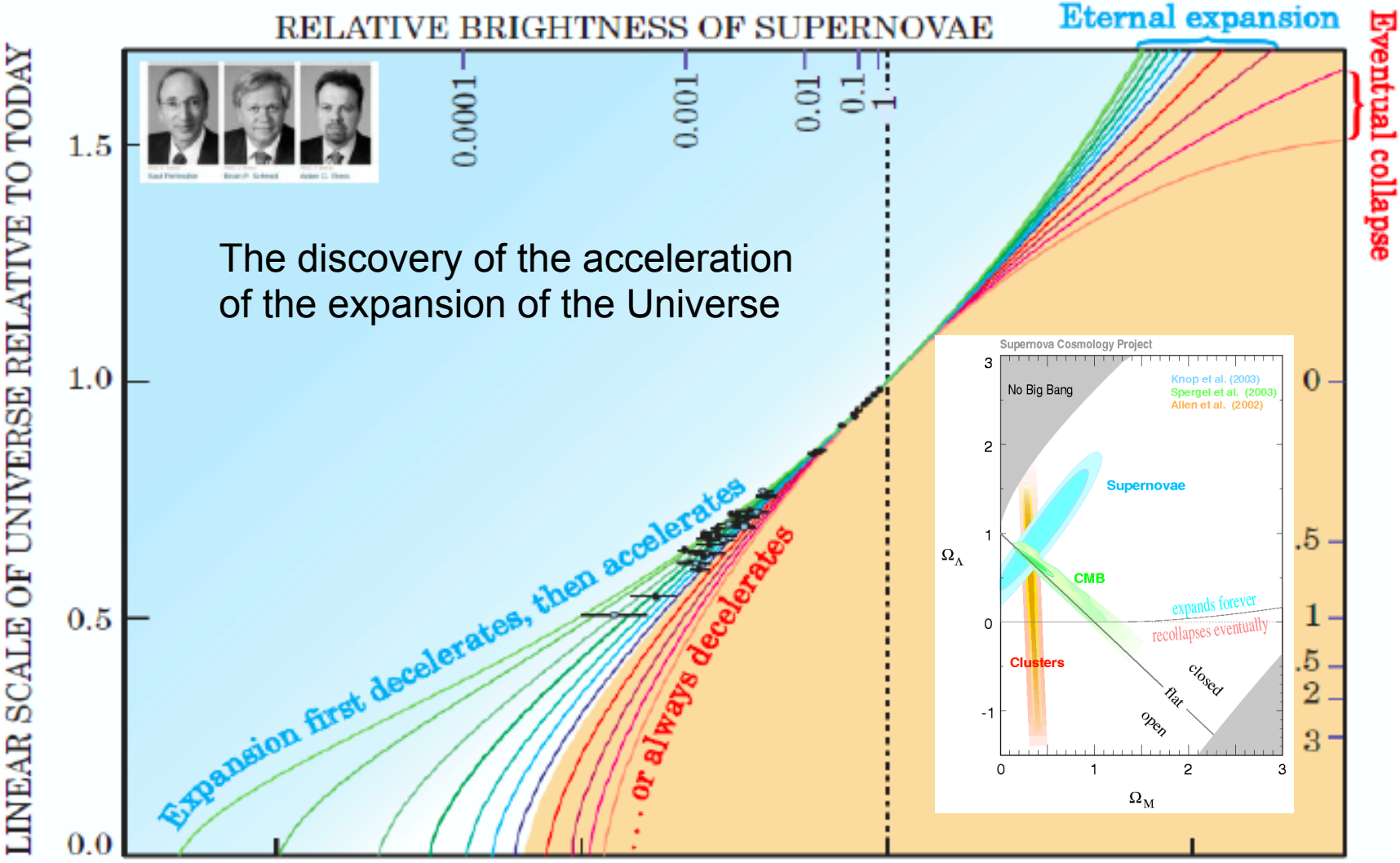
⇒ Ω_Λ **: clear evidence from CMB (WMAP and now Planck)**
and also from supernovae and baryonic acoustic oscillation

ΛCDM is confirmed…. BUT what is Dark Energy ??

⇒Beyond the scope of the Planck mission..

⇒What impact on fundamental physics and post Planck

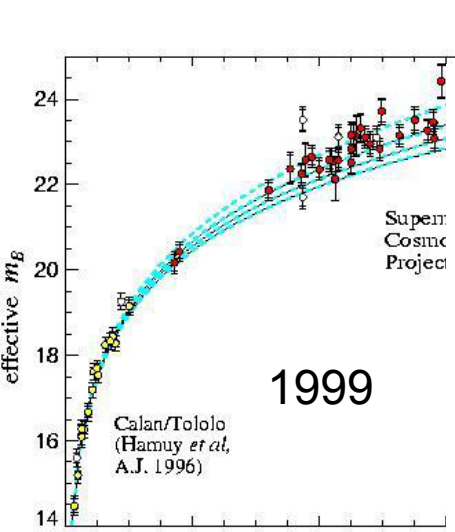
Acceleration and dark energy: Supernovae

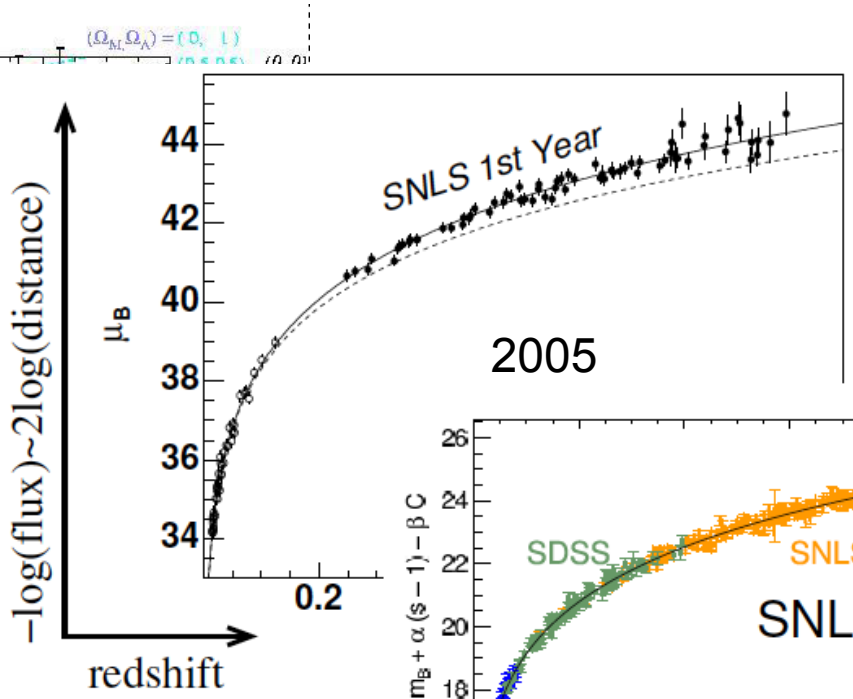


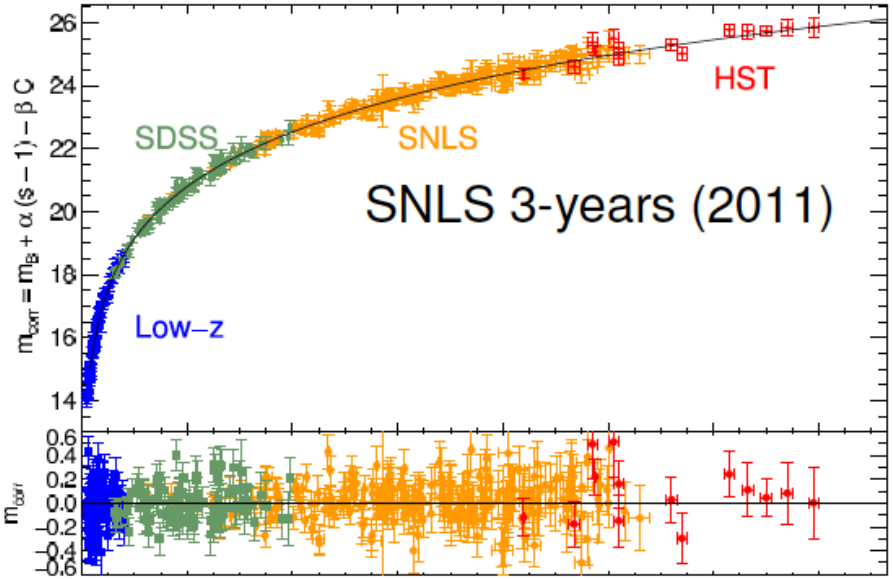
Supernovae (Sn factory, SDSS, SNLS) ….Hubble diagrams

Supernovae : improvement in quantity and quality

- direct evidence of the acceleration of the expansion of the Universe in 1999
- since then.. SN factory, SNLS, SDSS..
- main limitation: systematics and calibration







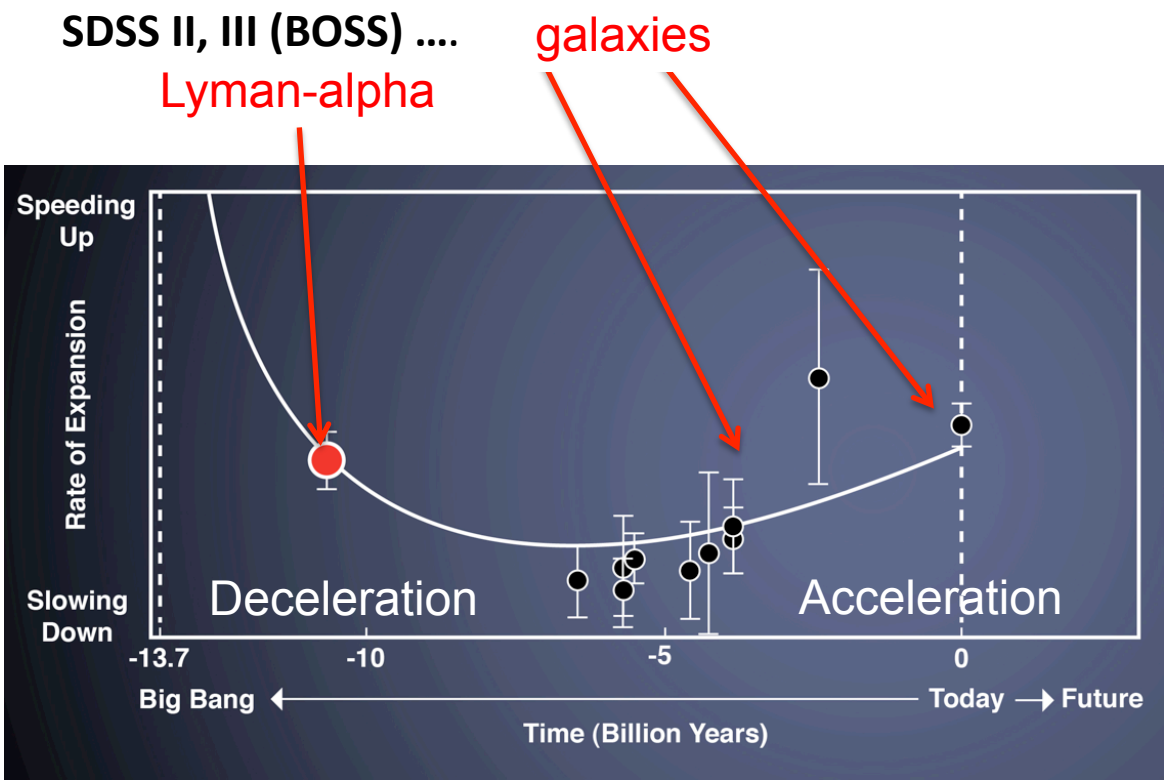
Acceleration and Dark Energy (DE) : BAO

Baryonic Acoustic Oscillation (BAO) …..progressing :

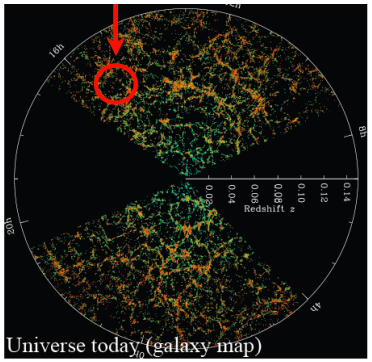
-A peak in the matter correlation fonction
-Relic of the sound waves in the primordial plasma
-Used as a distance ruler

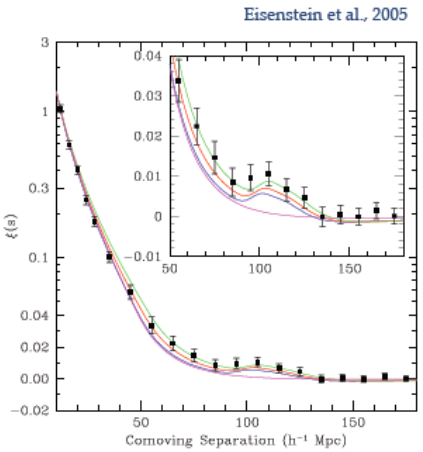
SDSS I, discovery in 2006

SDSS II, III (BOSS) ….



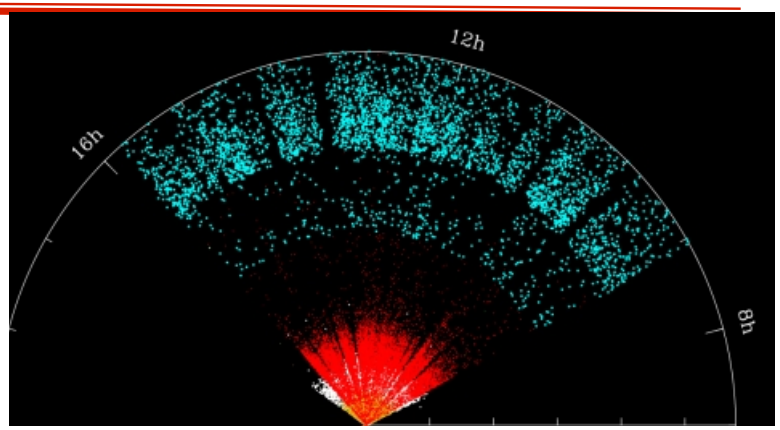
Primordial fluctuation today





BAO a standard ruler… started in 2006 !..

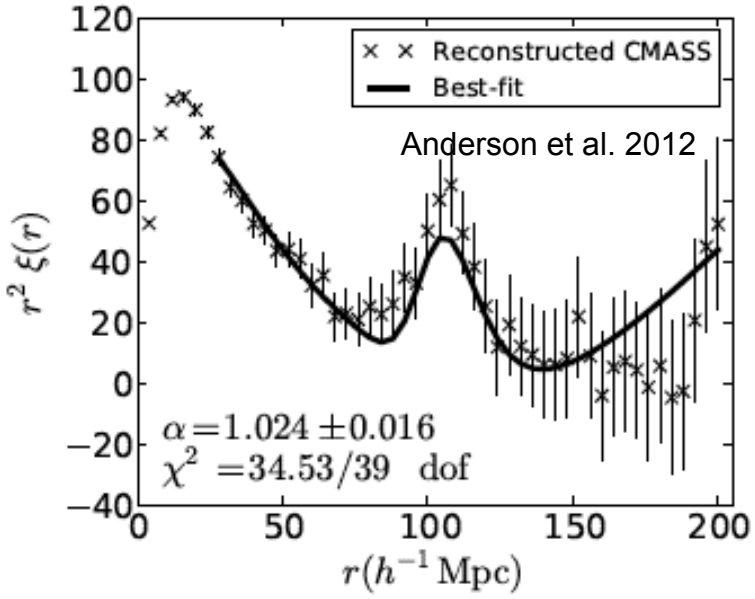
From SDSS I to SDSS III/BOSS ….. running!



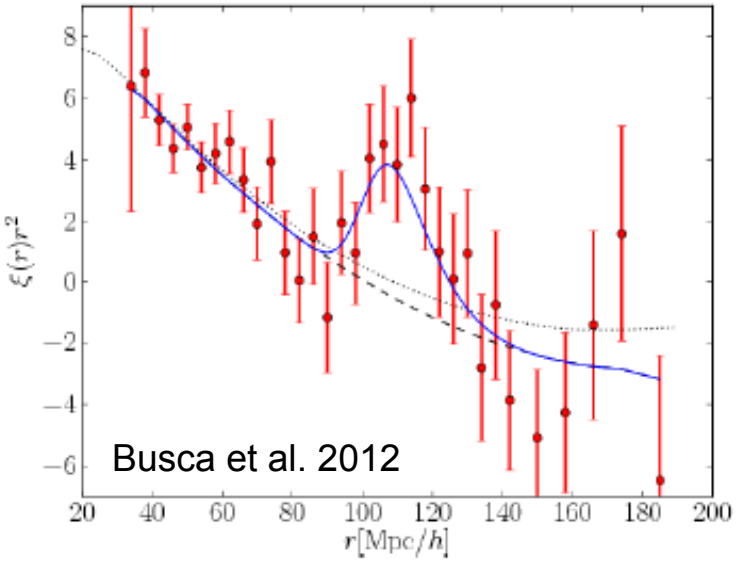
The Baryon Oscillations Spectroscopic Survey is the main survey of SDSS-III and targets BAO with

1.5 M luminous red galaxies

160k z>2 quasars (Lyman-α forest)



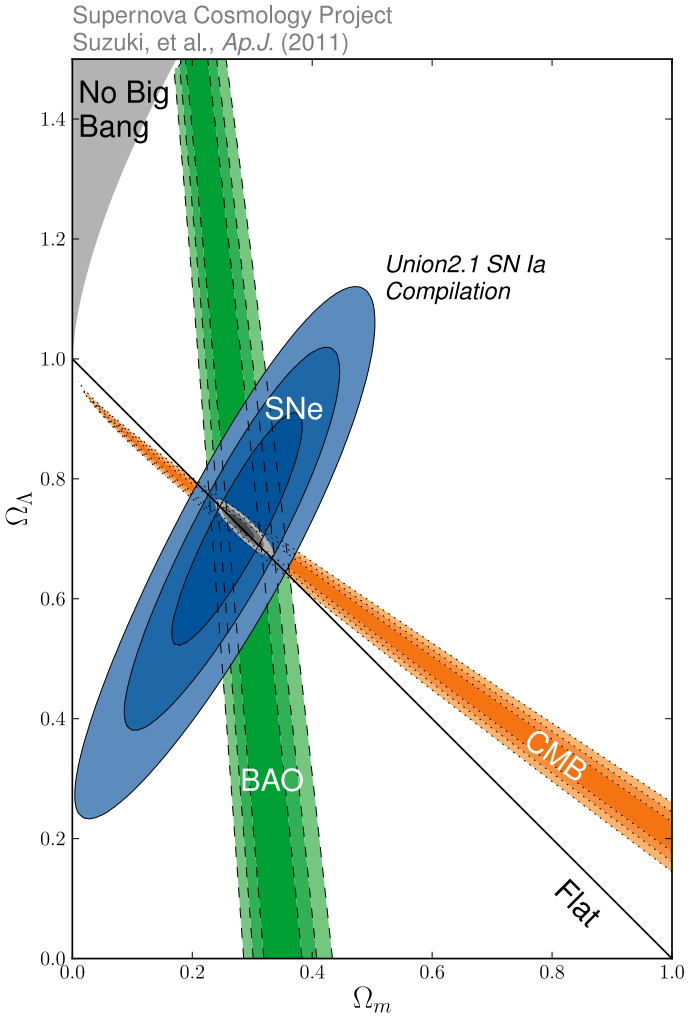
DR9 $0.43 < z < 0.7$ galaxy sample

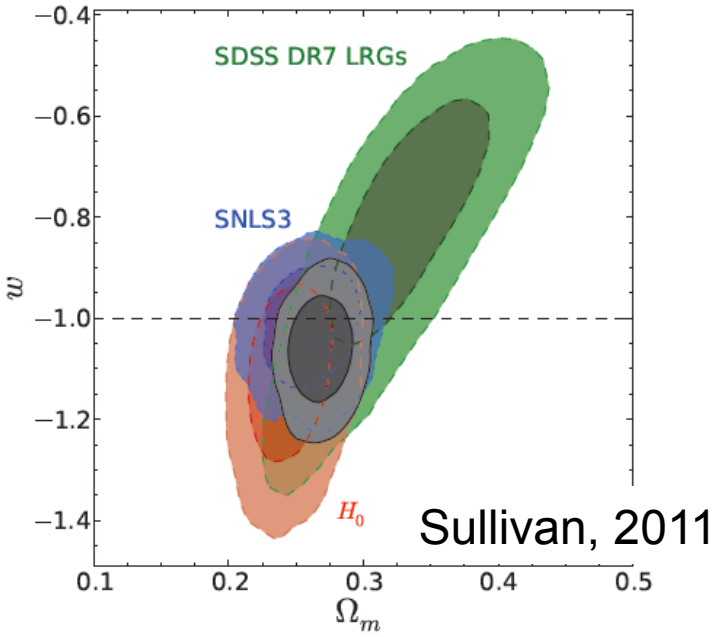


DR9 BOSS Ly-α quasars

Cosmological constraints …. progressing evidence

…





Sullivan, 2011

ΛCDM is validated:
Dark energy equation of state:

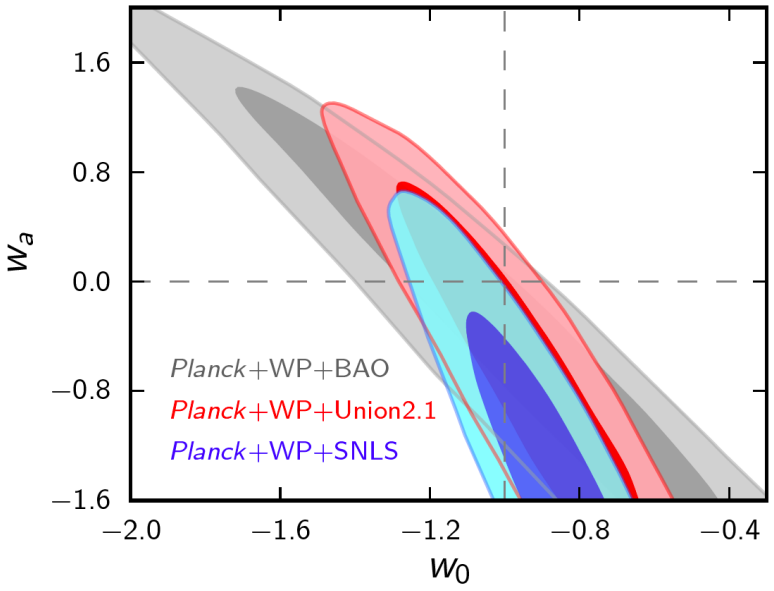
w = p/ ρ = -1 < 10 % accuracy
a cosmological constant is well confirmed

What to do next ?

Search any deviations from ΛCDM

e.g time variation of ρΛ; non zero curvature etc….

The Planck collaboration. Ade et al 2013



Equation of state : $w(a) = w_0 + w_a(1 - a)$

- w_a gives a sensitivity to any deviation, dynamical (as quintessence) or other type (as modification of gravity)
- quantify the sensitivity , it is admitted to use the figure of Merit (FoM) :

FoM = $1 / \sigma_{w0} \times \sigma_{wa}$

Today : FoM ~ 12 !!!!

to test a deviation to ΛCDM ➔ we want FoM > 400 !!!!

The next generation

FoM > 400 :Distinguish different interpretations of Dark Energy

Test DE models = > Equation of state : $w(a) = w_0 + w_a(1 - a)$
Is there a variation in time?
Test gravity => Verify that growth of structure consistent with ΛCDM
Is the gravity law that causes structure formation consistent with the law that gouverns the expansion of the Univers??
By product: more physics as constraint on neutrino mass

-Need more precision

-Need more probes

-Need combination of probes

-Need large set of data

= > large multi probes surveys -> wide field instruments

Step 1 …..improving SN and BAO

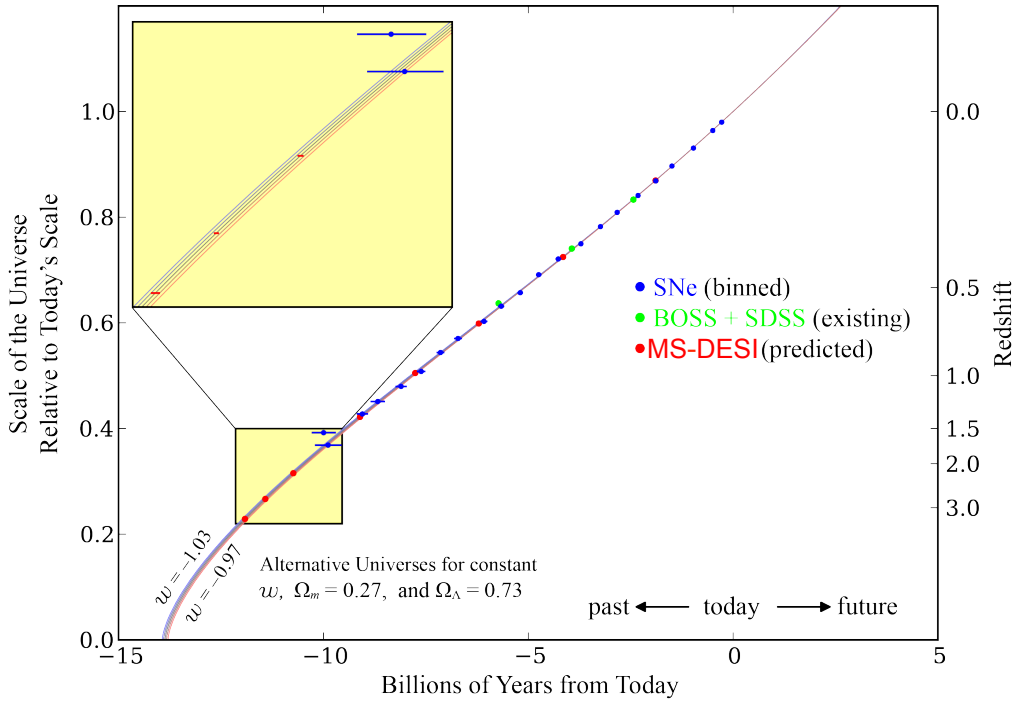
-for SN :

✓ Need a better understanding of SN systematics + more data
DES (2013)…… LSST(2020), WFIRST (>2024?)

-for BAO :

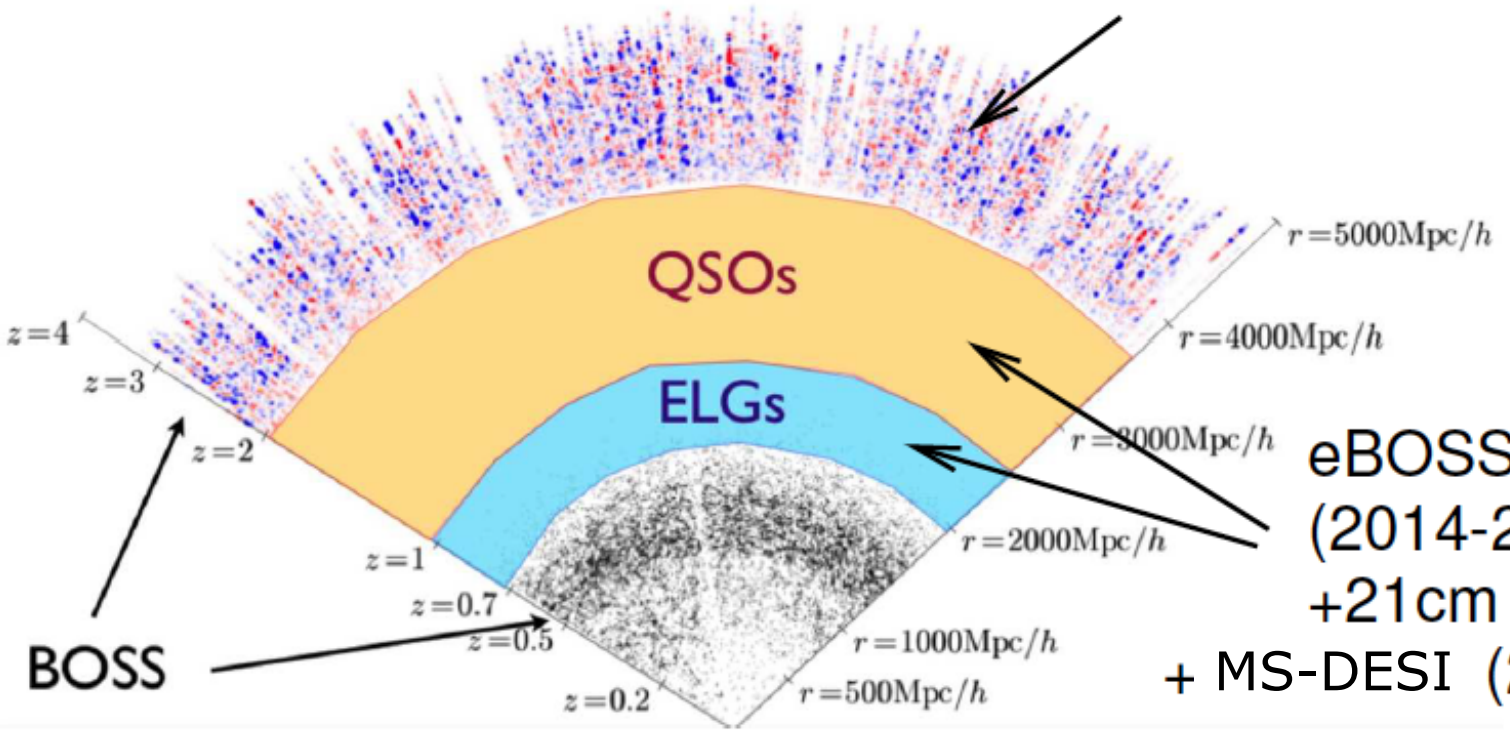
✓ Better BAO Hubble diagrams i.e.

✓ eBOSS (2014), 21 cm surveys(?), MS-DESI (2018), ….. EUCLID(2020)



BAO…more redshift surveys on ground .

map redshift range $0 < z < 4.$ (half way to horizon)



MS-DESI : a large new spectroscopic survey

- Merging BigBoss and DESpec propositions of large spectroscopic surveys in US
- Scale up BOSS to a massively parallel fiber-fed spectrometer at a 4-meter telescope.
- Site selection done (Mayall telescope)
- CD-1 late this year.
- CD-2 should be around June 2014.
- Delivery of instrument 4 years after CD-2 (2018)

Reference concept

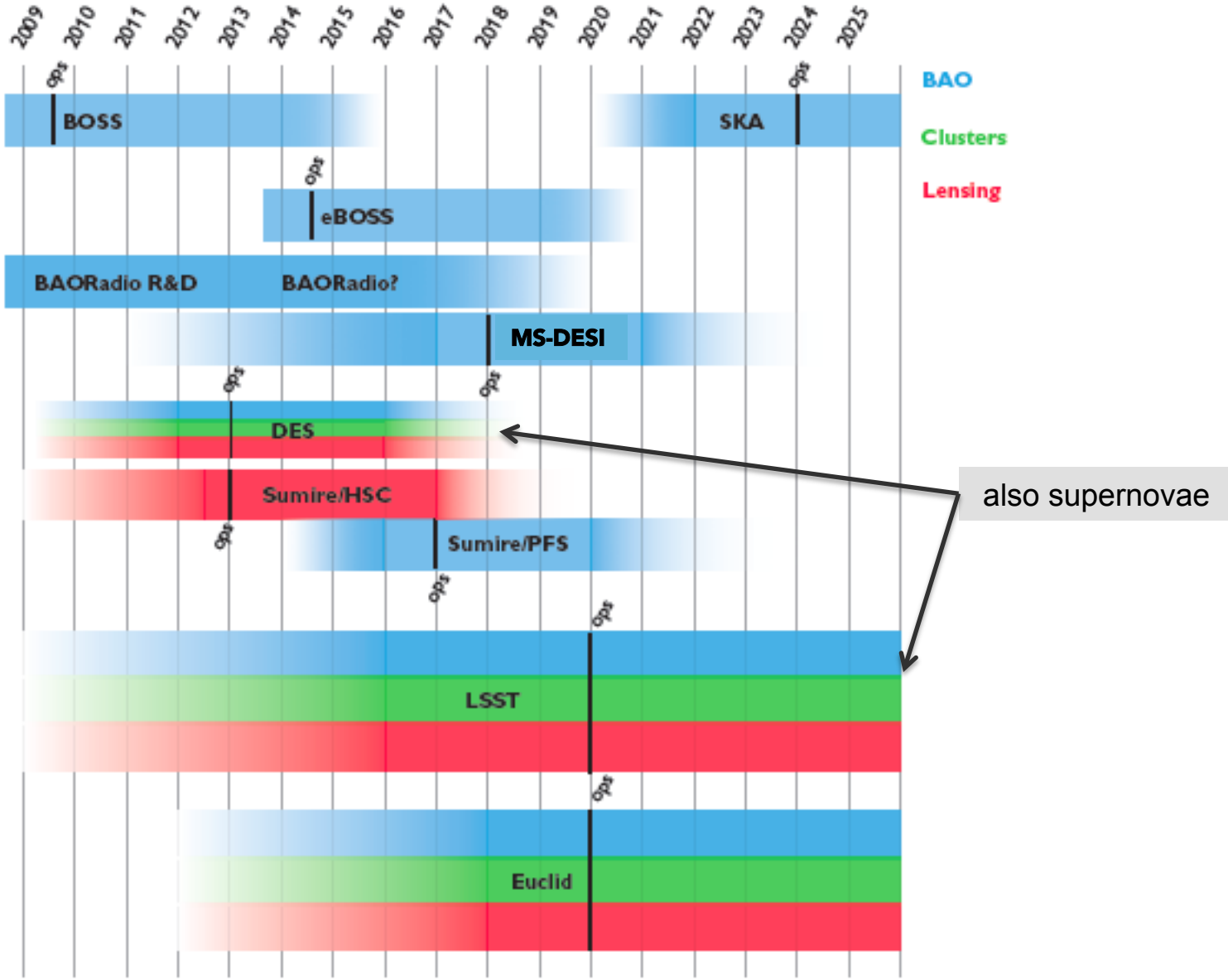
- Broad range of target classes: LRG's, ELG's, QSO's
- Broad redshift range: $0.5 < z < 1.6$, $2.2 < z < 3.5$
- Sky area: 14,000 – 18,000 square degrees
- Number of redshifts: 20 – 35 million
- Medium resolution spectroscopy, R ~ 3000 – 5000
- Spectroscopy from blue to far-red

Step 2: Combining probes

FOM > 400 => combining probes on dedicated projects 'all' sky" and choose the 'most powerful combination of probes'

- *Weak gravitational shear..*
  precise imaging, most promising..BUT.. difficult
- *Matter power spectrum (clustering, BA0, RSD…)*
  Spectroscopy, redshift surveys ,a lot of physic
- *Galaxy cluster*
  Need better mass-luminosity relations
  Need better simulation of structure formation
- *Supernovae*
  now limited by systematics

Overview of wide surveys (bias view toward DE studies …)



Euclid & LSST : two large selected projects for 2020

Goal ➔ -reduce by 1 order of magnitude the errors on DE equation of state.

-give constraint on modified gravity

Remark : give also constraint on neutrino mass

Method ➔ Large sky Survey (1/3-1/5 of total sky) & deep (24-27 mag)

Key issue ➔ Systematic Errors

➔ combining probes

Observables ➔

- Weak Lensing : growth of structure
- Galaxy Clustering : growth of structure (RSD)
- Baryon Acoustic Oscillations : standard ruler
- SuperNovae : standard candle
- Galaxy cluster

A large europeen space Project selected: EUCLID

A large US ground project selected: LSST

Weak Lensing tomography and 3D lensing

cosmic shear over 0<z<2

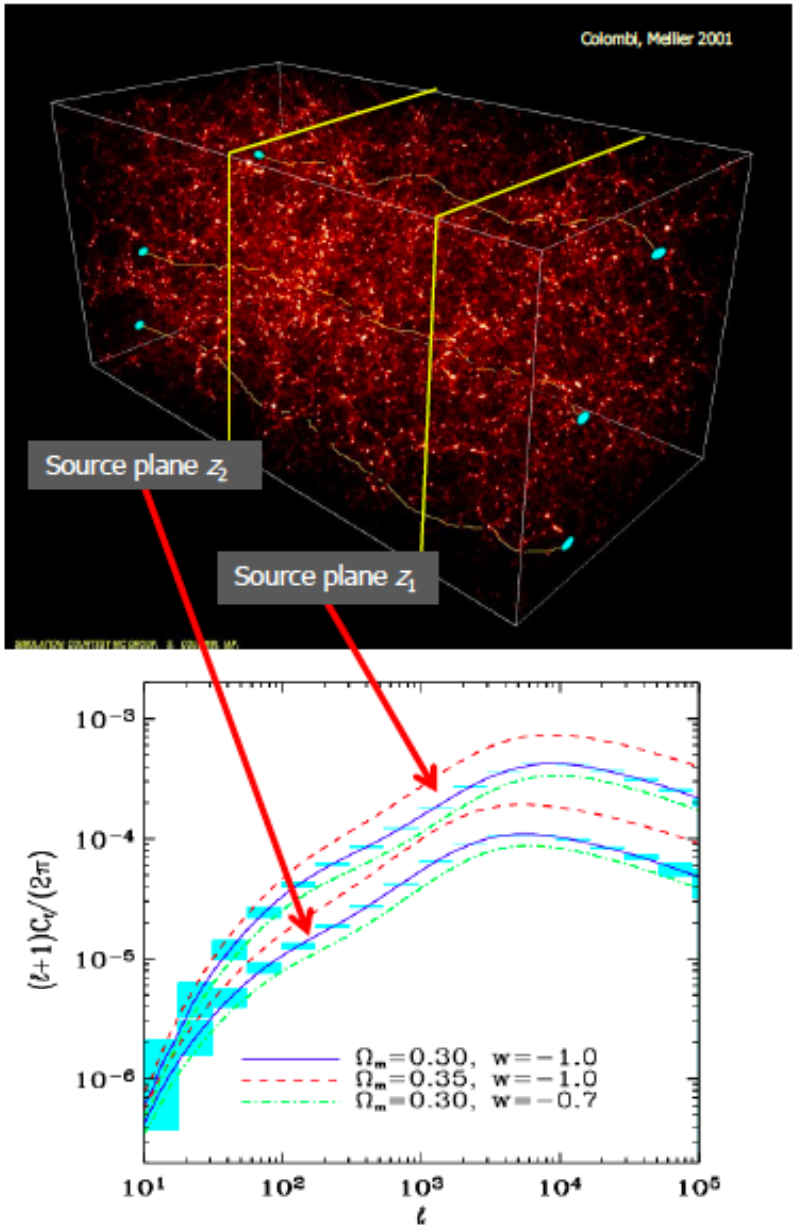
$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega}\frac{f_K(\omega-\omega')\,f_K(\omega')}{f_K(\omega)}\frac{\delta\left[f_K(\omega')\,\boldsymbol{\theta};\omega'\right]}{a(\omega')}\mathrm{d}\omega'$$

- Probes distribribution of matter (Dark+Luminous): expansion history, growth rate of structure formation.

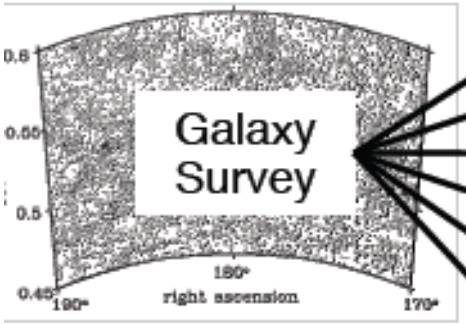
→ Shapes+distance of galaxies: shear amplitude, and bin the universe into slices.

→ Photo-z sufficient, but with optical and NIR data.

- > precise shape measurements need image in visible with very precise optical quality



Galaxy clustering and redshift surveys



Baryon Acoustic Oscillations

Alcock-Paczynski effect

Redshift-Space Distortions

Comoving clustering

large-scale shape

ISW effect

What is the expansion rate of the Universe?
e.g. Anderson et al (2012)

What is the expansion rate of the Universe?
e.g. Samushia et al (2012)

How does structure form within this background?
e.g. Reid et al (2012)

What are the neutrino masses, matter density?
e.g. Zhao et al (2012)

What is f_{nl}, which quantifies non-Gaussianity?
GR-horizon effects
e.g. Ross et al. (2013)

Does the potential change along line-of-sight to CMB
e.g. Giannantonio et al (2013)

Understanding Dark Energy

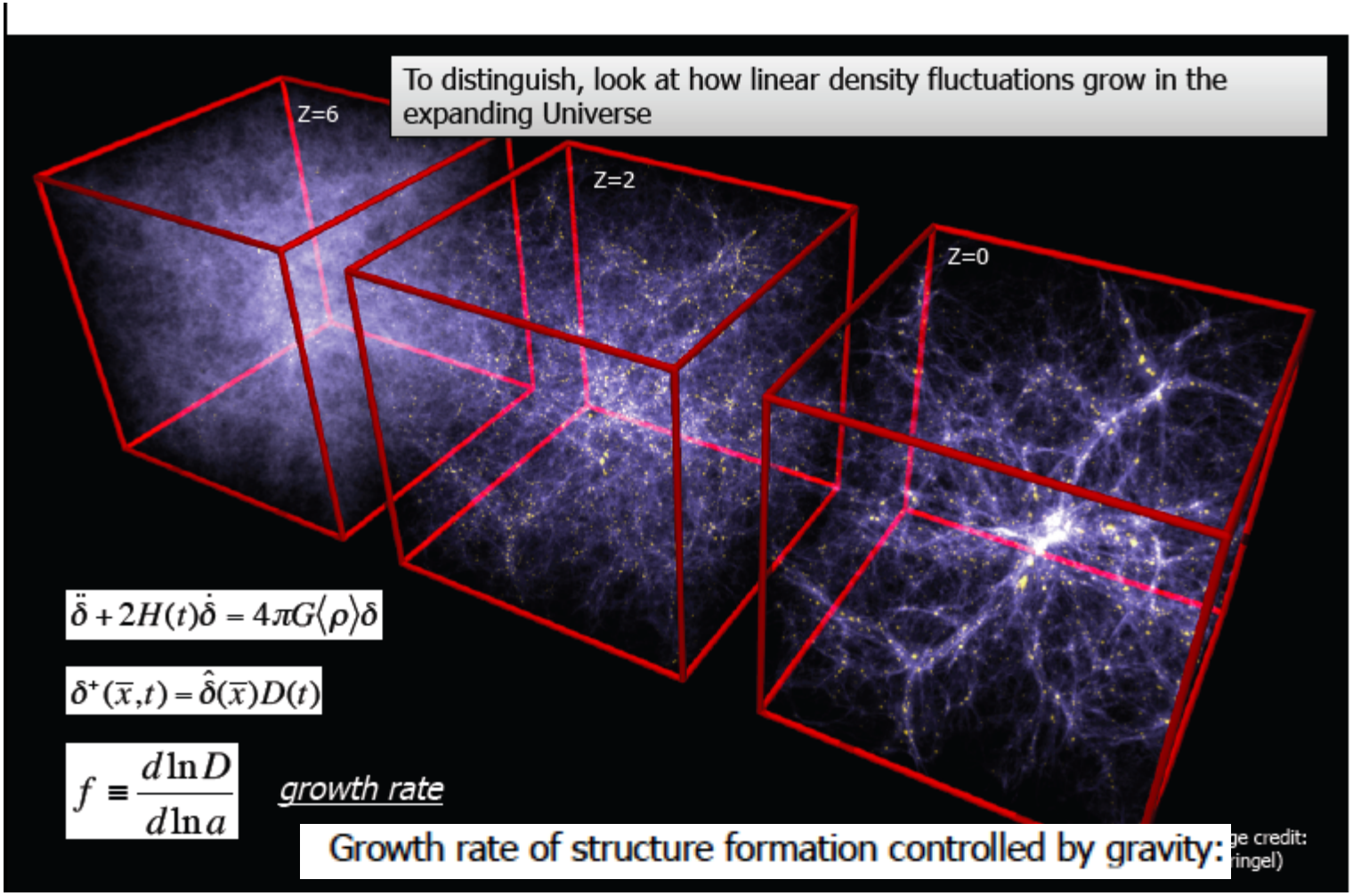
Understanding energy-density, gravity

Understanding energy-density

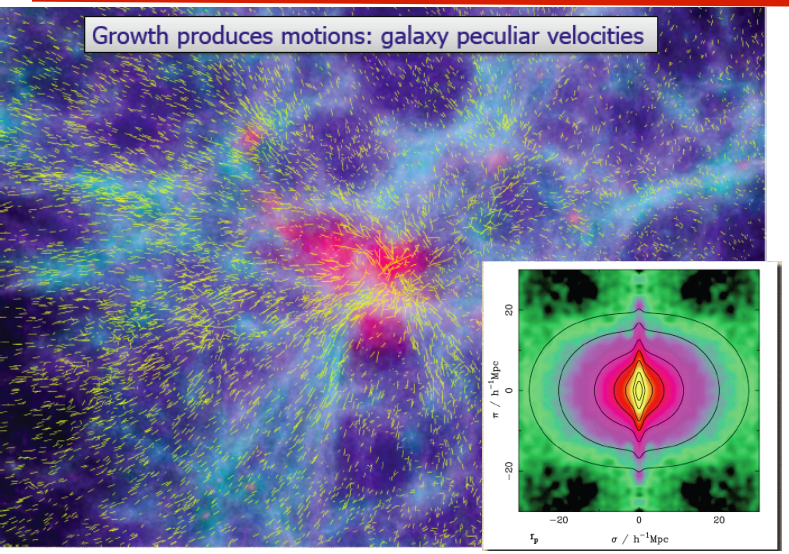
Understanding Inflation, GR

Understanding DE, GR

Growth of structure



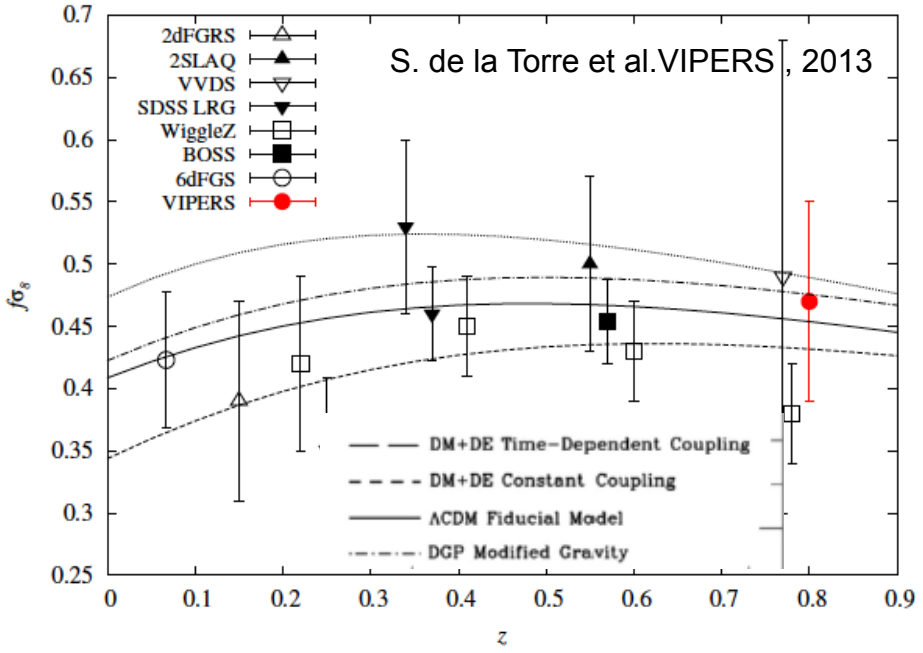
Growth rate and redshift space distorsion



In galaxy redshift surveys:
Peculiar velocity manifest themselves as redshift-space distorsion (RSD)
-predicted (Kaiser 1987)
-measured in current surveys

The growth factor or growth rate f(z) quantifies the efficiency with which cosmological structures can be build

$$f(z)\sigma_8(z) \propto \frac{dG}{d\log a}$$



Main characteristics of EUCLID and LSST

Euclid Consortium

FoM ~ 1500 , -4000 (all)

Main probes: WL & Galaxie clustering (BAO,RSD) (spectro))

European lead project / ESA

Participation of NASA

~ 1000 members

Space telescope / 1.2 m mirror

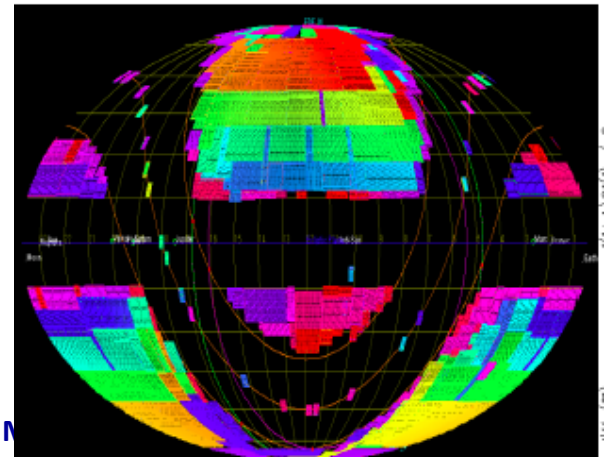
Launch : 2020

Mission length : 6 years

1 exposure depth : 24 mag

Survey Area : 15 000 sq deg (.36 sky)

Filters : 1 Visible(550-900nm)+ 3 IR (920-2000 nm) + NIR spectroscopy (1100 – 2000 nm)



LSST Large Synoptic Survey Telescope

FoM > 800

Main probes : WL,SN , BAO(photo),

US lead project / NSF-DOE

Participation of France/In2P3

~ 450 Core members + 450 to come

Ground Telescope / 6.5 m effective mirror

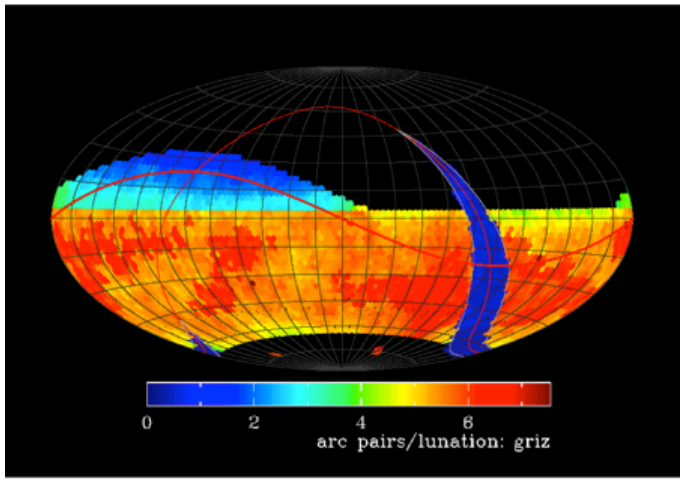
1st light : 2020

Observation length : 10 years

1 exposure depth : 24 mag (i)

Survey Area : 20 000 sq dg (.48 sky)

Filters : 6 filters (320-1070 nm)



- **LSST : a large dedicated telescope on ground**
- **LSST selected by « Astro2010 » as The ground project for next decade**
- **In 2012 , a HEP like collaboration has been set LSST DESC (Dark Energy Science Collaboration)**

•LSST is in the "In FY 2014 President's budget" , the agencies will start the LSST construction in 2014.

• LSST calendar :

–Telescope first light 2019

–Camera delivered at summit 2020

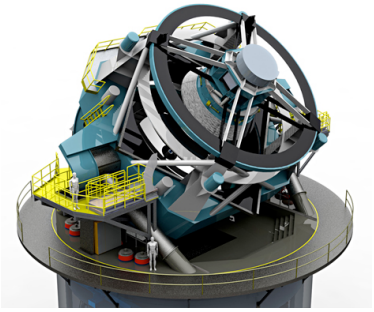
– mid 2021 Start of the LSST "Science Verification survey"

– May 2022 "LSST delivery" / start of 10 years survey

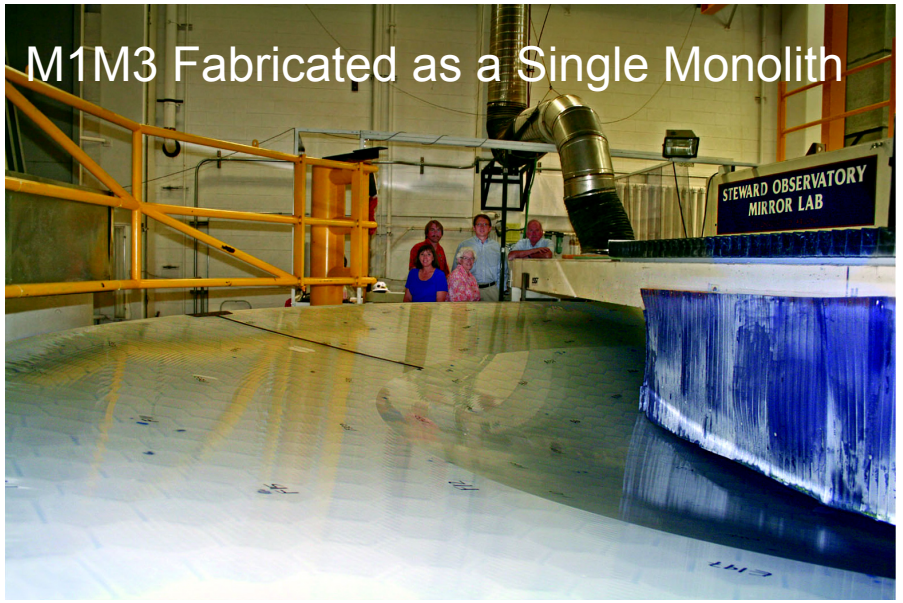
• 20 billions of objects !

•10 millions of SNs

•>100 000 well measured



After ~4,000 kg of explosives and ~12,500 m^3 of rock removal, Stage I of the El Peñón summit leveling is completed.

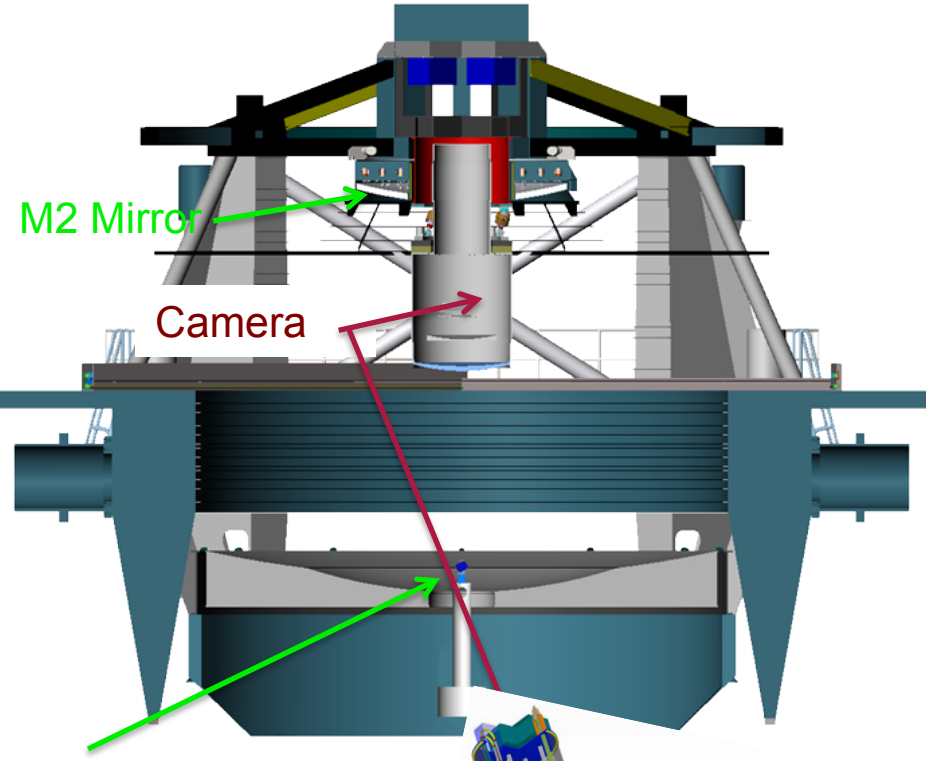


LSST : Wide , Deep and Fast

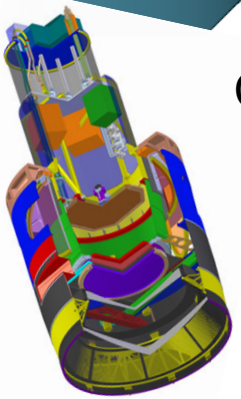
Field of view :

3.5 deg (9.6 deg^2 =.023% sky sphere)

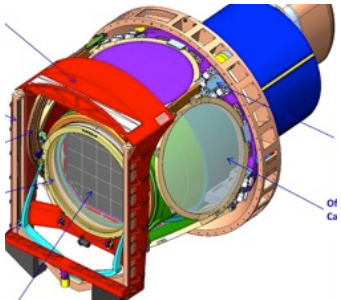
Full moon = 0.5 deg = 4.8 10^{-6} of sky sphere



M1M3 primary (8.4m) & Tertiary mirrors

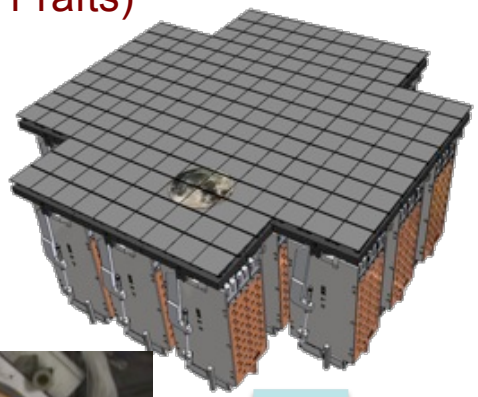


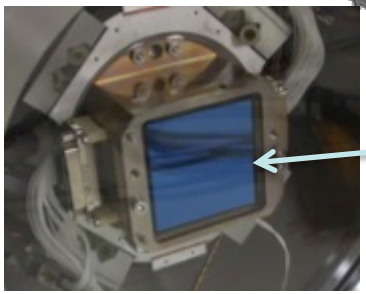
Camera 3 m filters u,g,r,i,z,y

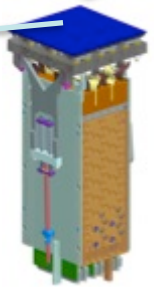


Focal plane diameter : 64 cm
189 science CCD (21 rafts)
3024 Channels
>3 10^9 pixels
Readout: 2s

PSF<0,4"
Seeing = 0,6"





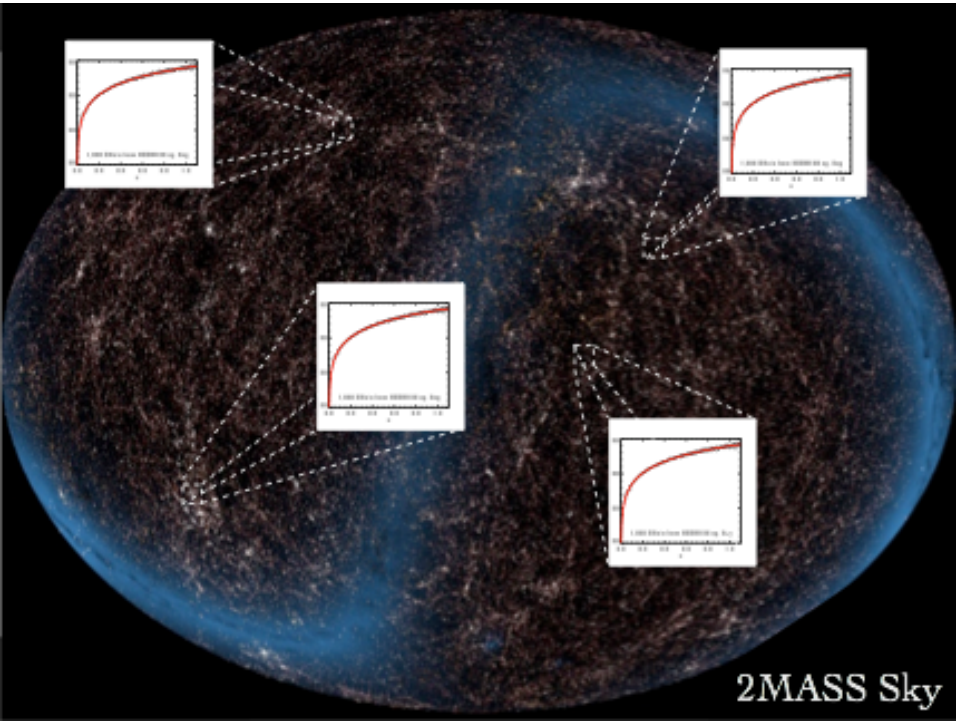


E2v CCD 250 ,
4kx4k , 10 µm pixels
100 µm deep depleted
UV to IR sensitive
16 channels output
Designed by Dedicated R&D for LSST

1 raft = 3x3 CCD
150 M pixels
(1/2 Megacam)

LSST : examples of high statistic DE science with SN Ia

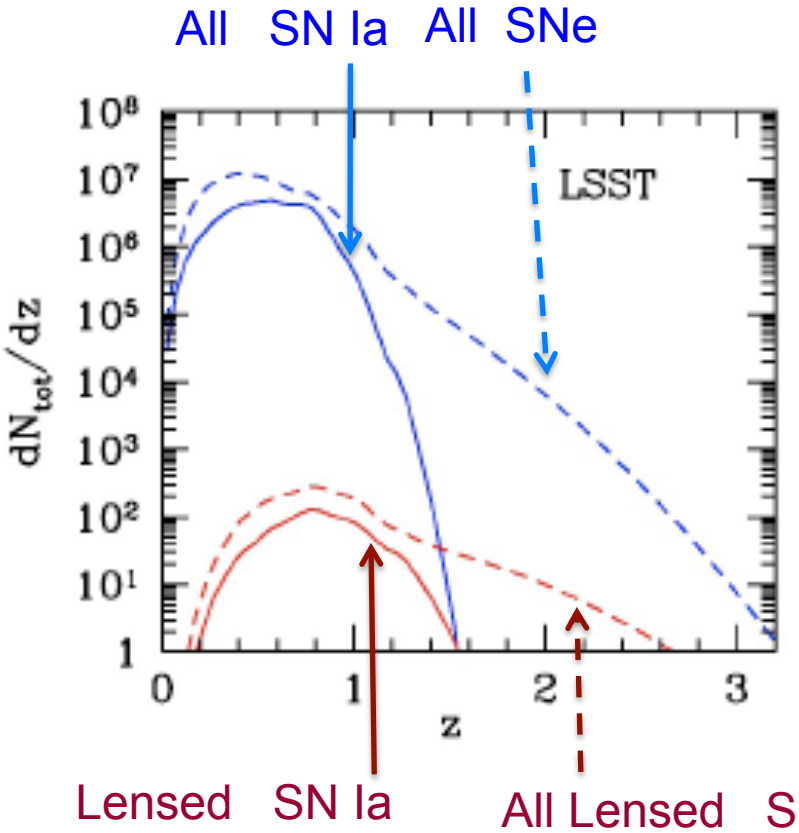
LSST will be able to probe the isotropy of the Dark Energy properties . For example the large SNIa statistic will allow to build SNIa hubble diagram for different directions in the sky.



LSST will provide time-dependent imaging of an unprecedented sample of rare strong gravitational lensing events.

➔Strong lensed SN Ia

= sensitive to H(z) at the lens location



- **EUCLID is an europeen space mission with visible and Infrared observations of all sky, both in photometry and spectroscopy**

- Euclid was selected by ESA in Oct. 2011, Adopted in June 2012 in the cosmic vision program as the M2 mission to be launch in 2020

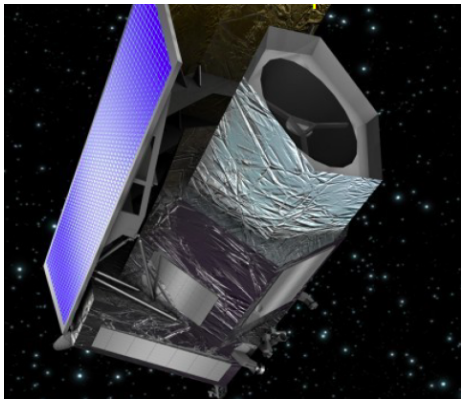
- Euclid is an ESA M mission with in-kind Member States contribution (MS)
- The MS contribution is provided through a scientific consortium

- ESA provides the telescope and detectors (via industry), the satellite, the launch by a Soyouz ST-2.1B and operation centers

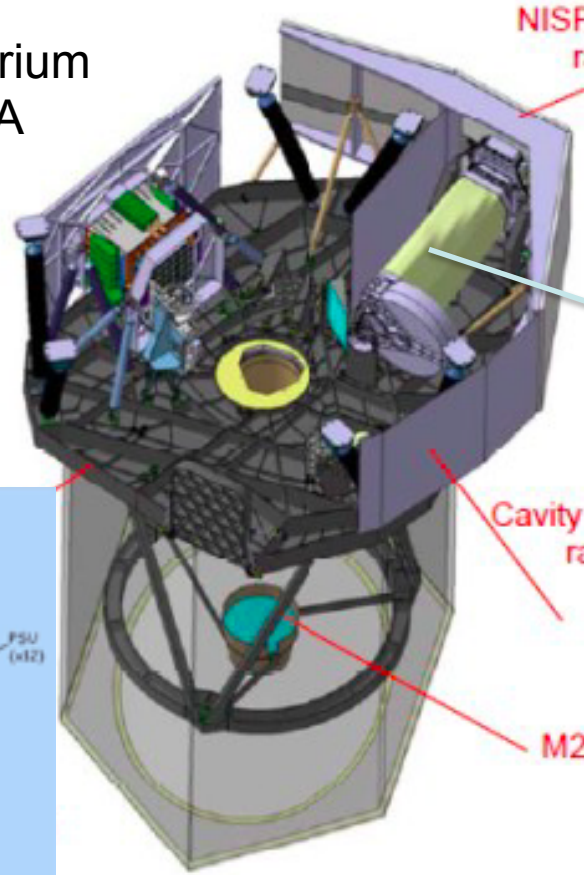
- The consortium provides the 2 instruments (VIS and NISP) and the ground segment (data processing)

- The scientific consortium = 117 Eu laboratories, 18 countries +NASA/US

- expected 2 billions of galaxies and more than 50 millions of redshift

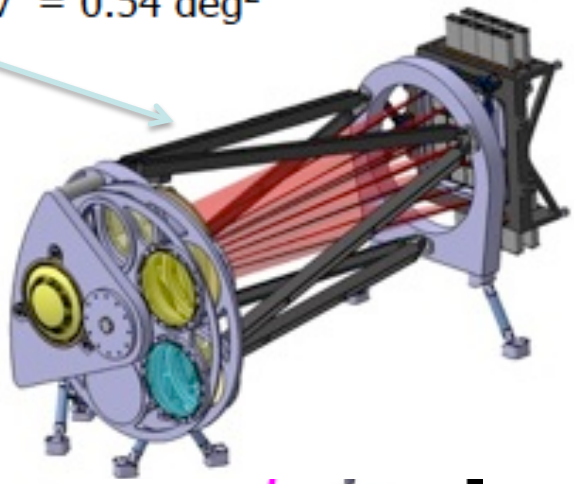


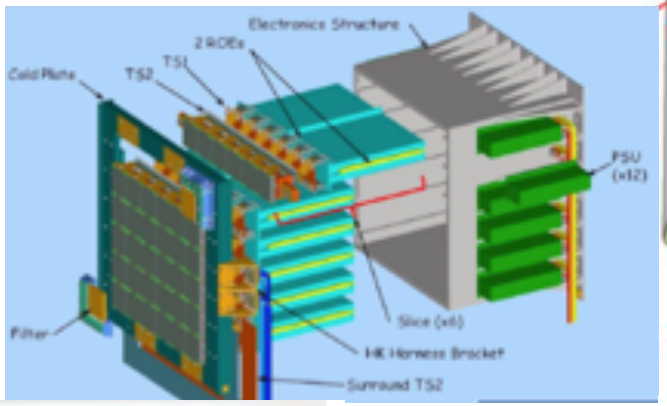
Astrium
ESA



Euclid Consortium

Common visible and NIR
Fov = 0.54 deg^2



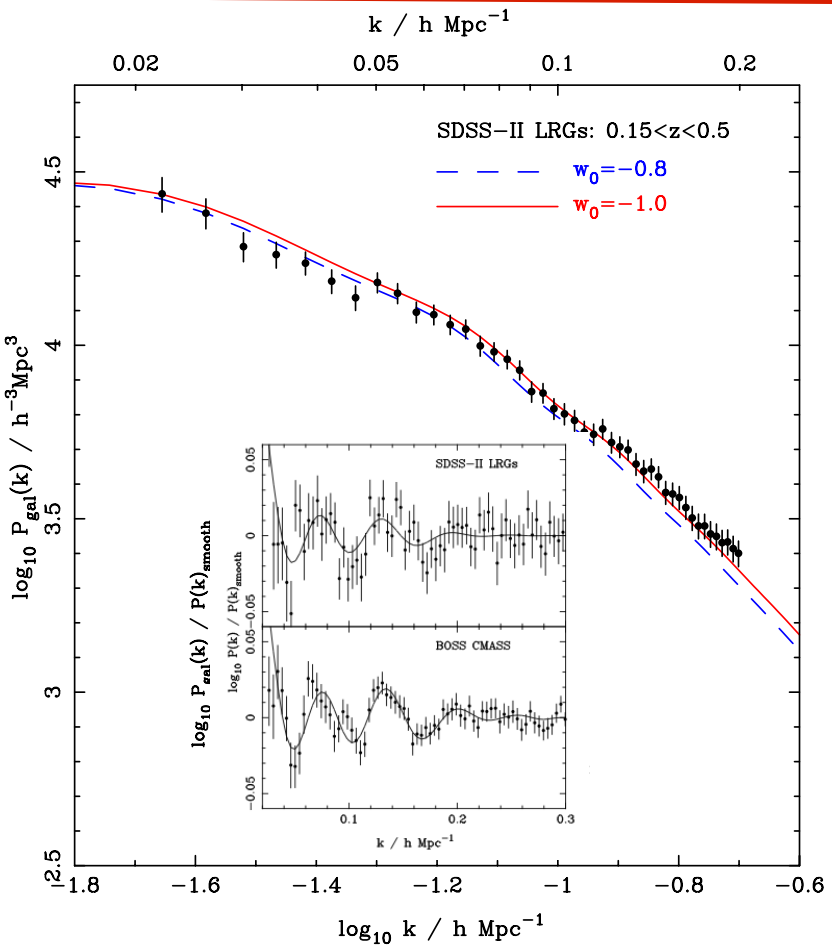


Pointing error along the x,y axes= 25mas over a period 700 s.

The Visible imager (VIS)
36 E2V CCD
0,1''PSF
1 broad band R+I+Z (550-900nm)

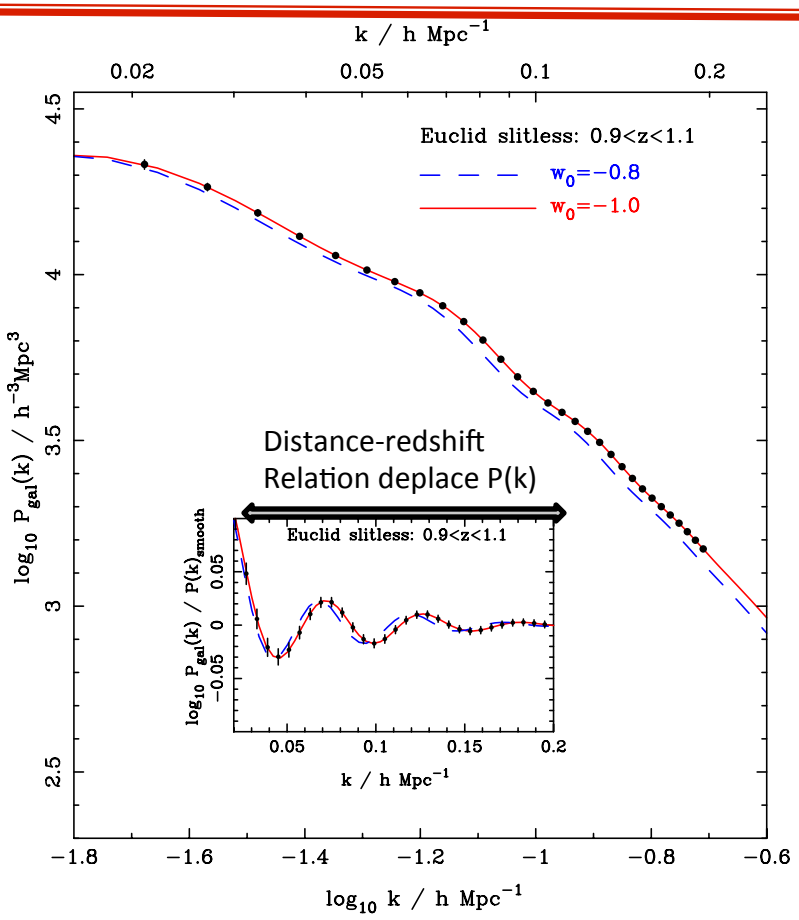
The Infrared spectro/photometer (NISP)
16 H2Rg infra red pixel detectors
0,3'' PSF, 3 IR bands Y,J,H (920-2000 nm)
NIR slitless spectroscopy (1100 – 2000 nm) R ~ 350

Expected BAO improvement



SDSS (BOSS) today

0.4<z<0.7



EUCLID expected

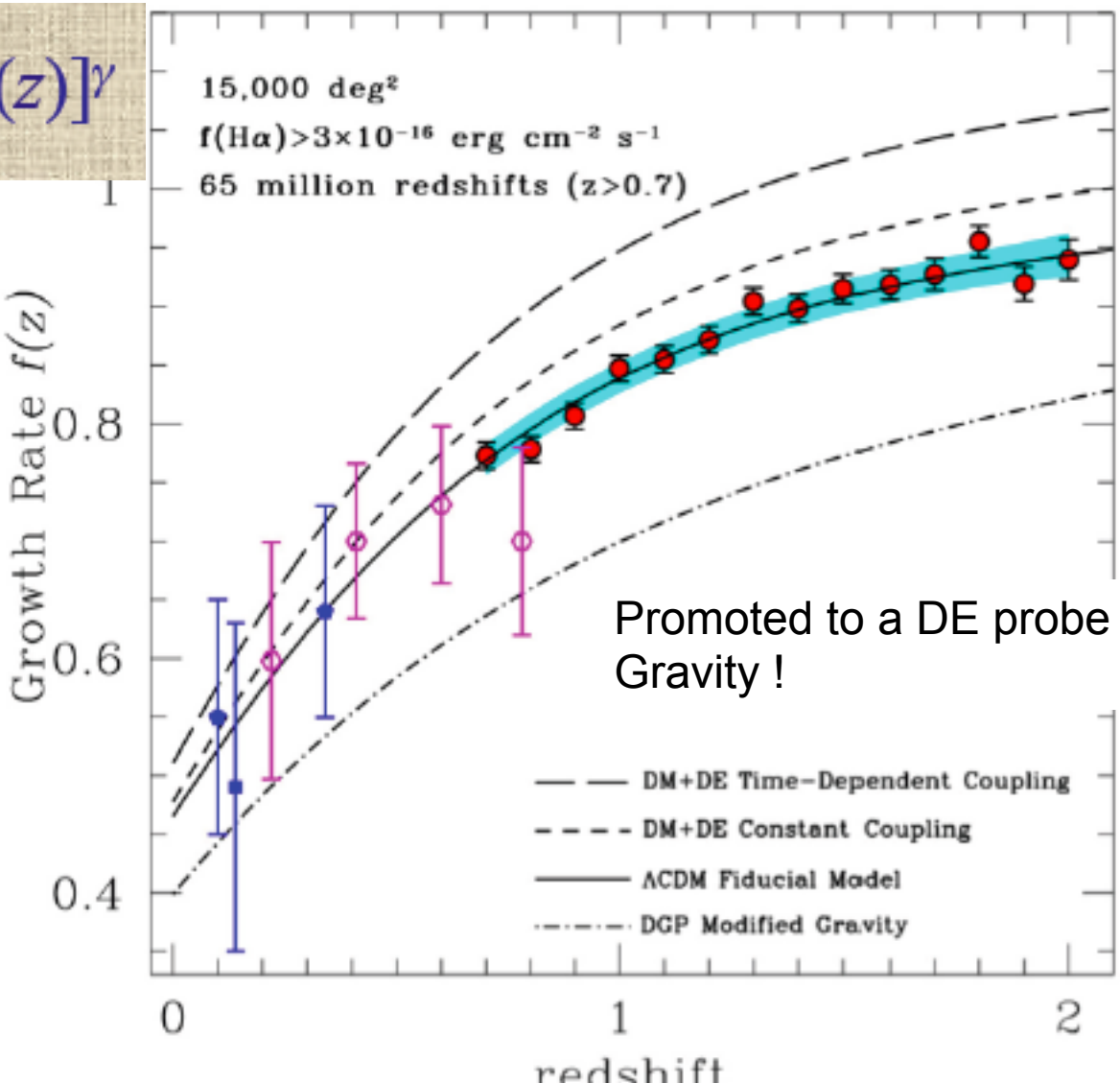
One of five redshift slices (0,7<z<2)
assuming slitless baseline in one slice z~1

The growth rate…

Euclid – RSD improvements

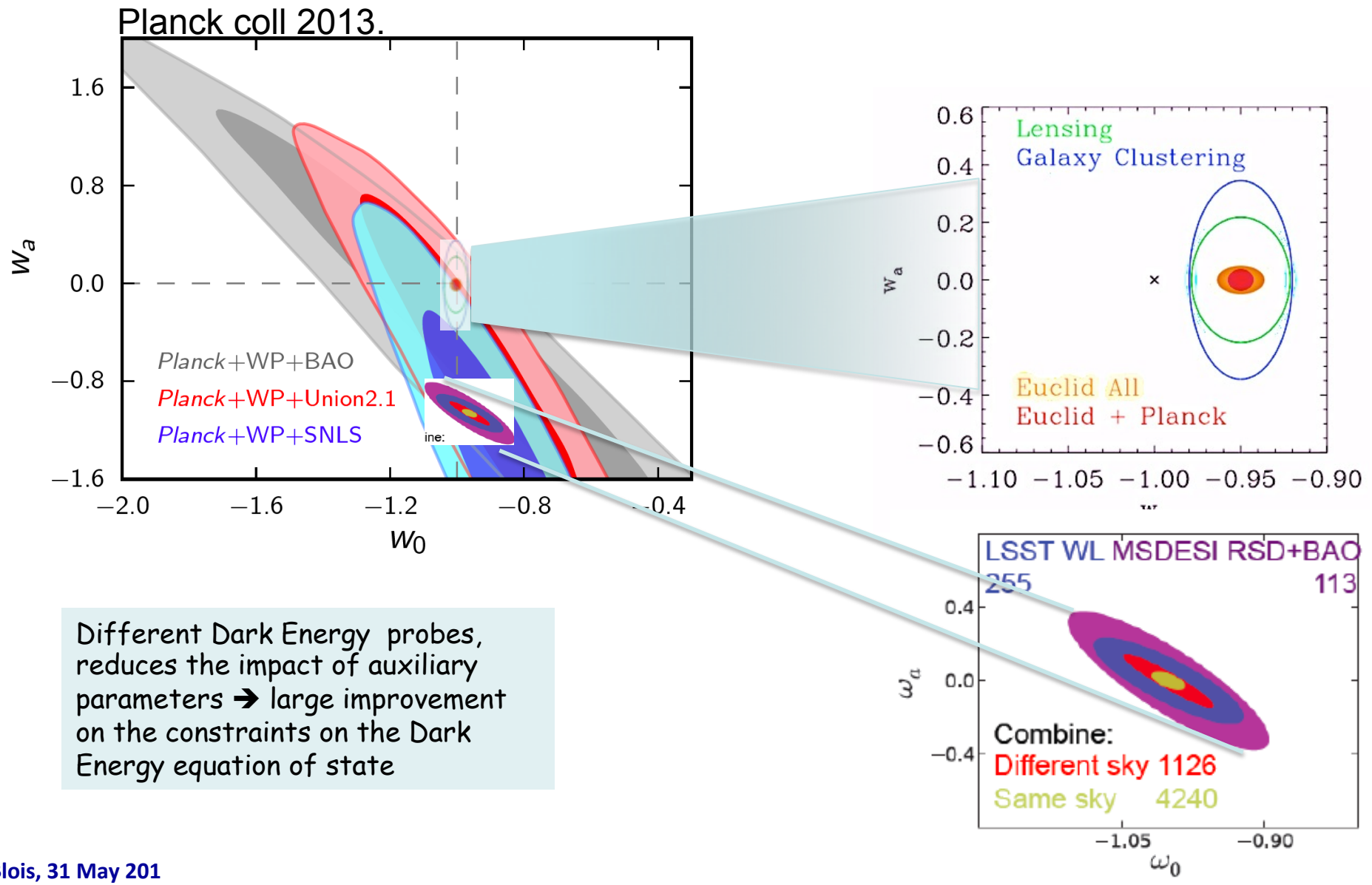
$f(z)=[\Omega_m(z)]^\gamma$

$\gamma = 0.55$?



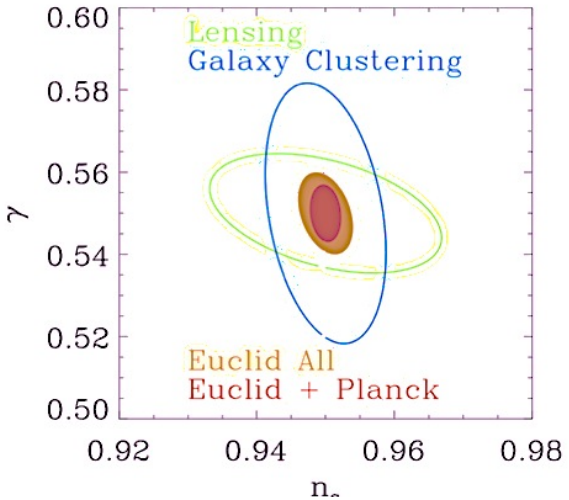
Promoted to a DE probe in Euclid to test Gravity !

Ultimately…need to combine all probes….



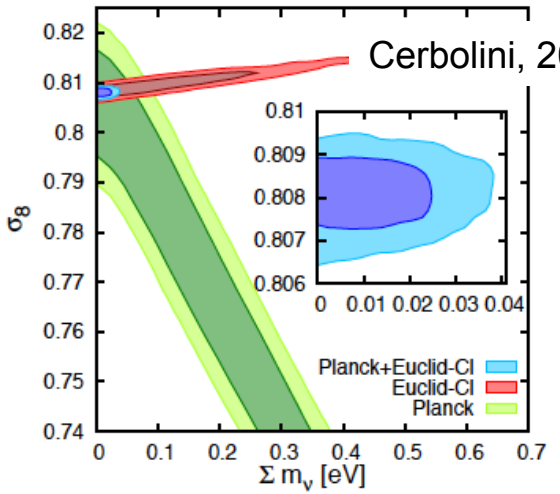
Different Dark Energy probes, reduces the impact of auxiliary parameters ➔ large improvement on the constraints on the Dark Energy equation of state

Combining WL +GC – example of other tests…



The growth rate well described by $f(z)=\Omega_m(z)^{\gamma}$.

$f \sim \Omega^{\gamma}$; $\gamma = 0.55$?



Neutrinos mass

	Dark energy			neutrinos	Initial conditions	Modified gravity
Parameter	**w_p**	**w_a**	**FOM**	**mν (eV)**	**F_{NL}**	**γ**
EUCLID +Planck	**0.007**	**0.035**	**4020**	**0.019**	**2.0**	**0.007**
Current (2009)	**0.1**	**1.5**	**~10**	**0.58**	**100**	**0.2**
Improve factor	**>10**	**>50**	**>400**	**30**	**50**	**30**

These numbers have a meaning only if we can control the systematic errors

Conclusion

- ΛCDM a cosmological model well confirmed by current data (CMB, SN, BAO)

- No evidence today of any deviation
- Not enough sensitivity to understand what is dark energy…

- The next generation of wide field instruments:

  - Improve our knowledge (wider, faster, better)
  - Dedicated projects to understand dark energy
    - Multi probe approach (WL, (BAO and RSD), SN, Cluster)
    - Full sky survey
    - Imaging AND spectroscopy

- Two big projects have been selected to tackle the DE investigation :
  - a space mission in Europe: Euclid
  - a ground telescope in US: LSST

Toward a definitive answer of the nature of dark energy…
…Waiting now for 2020

spare