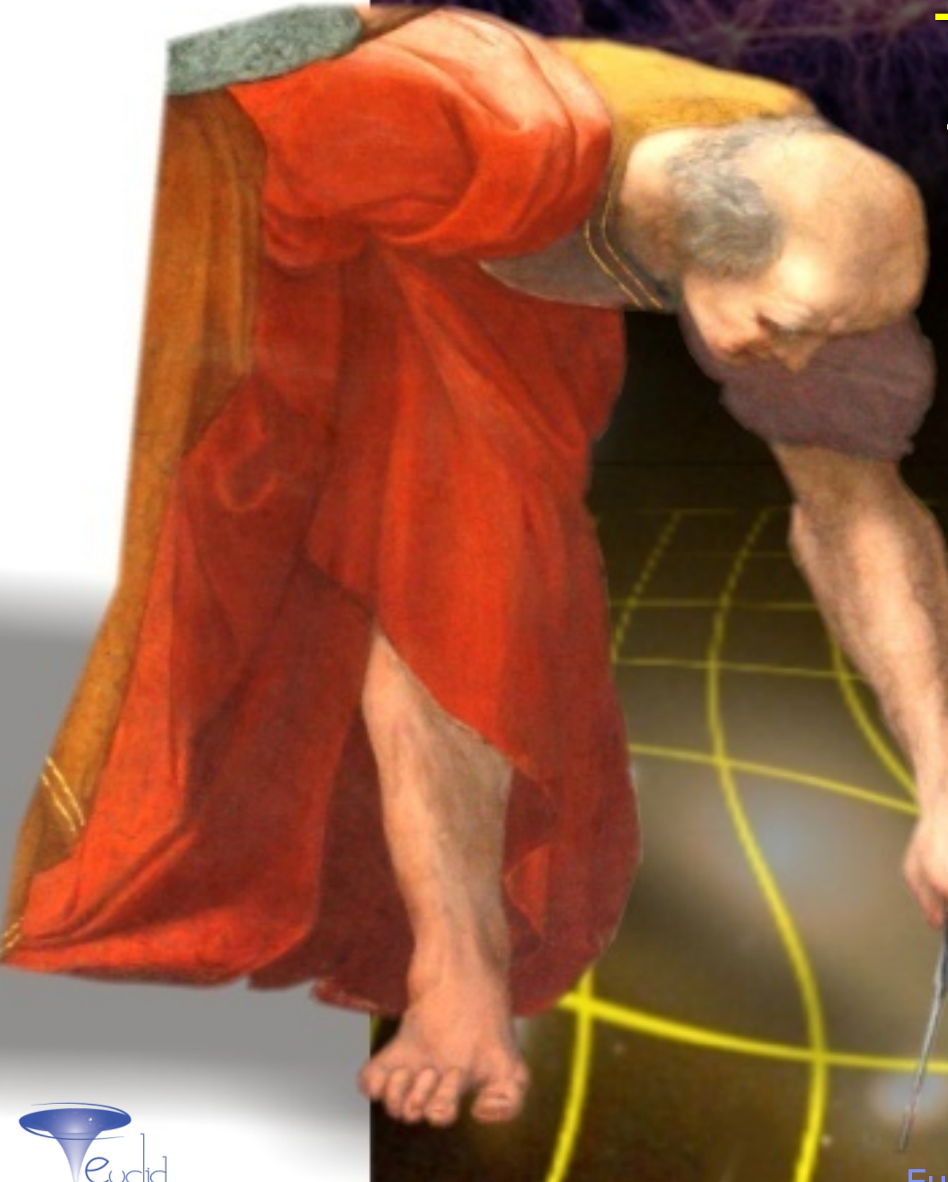
The Euclid space mission and the origin of the accelerating Universe



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On behalf of the Euclid Collaboration

The standard model of cosmology in the Planck era

Planck Cosmology

- Planck confirms that the following principles provide a very good framework to cosmological models:

  - The universe is homogeneous and isotropic
  - General relativity is a good description of gravitation at work in our Universe at all scales it can be probed

    → Friedmann Equations and cosmological models

  - The physics of the early universe can be described the by current theory of quantum/particle physics

Friedmann Equations

$$ds^2 = dt^2 - a^2(t)\left[dr^2 + S_k^2(r)(d\theta^2 + \sin^2\theta d\phi^2)\right]$$

$$S_k(r) = \begin{cases} \sin(r\sqrt{k})/\sqrt{k} & \mathrm{k} > 0 \\ \mathrm{r} & \mathrm{k} = 0 \\ \sinh(r\sqrt{|k|})/\sqrt{|k|} & \mathrm{k} < 0 \end{cases}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda c^2}{3}$$

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

$$\frac{H^2}{H_0^2} = \Omega_\Lambda + \frac{\Omega_k}{a^2} + \frac{\Omega_M}{a^3} + \frac{\Omega_r}{a^4}$$

- Scale factor
- Pressure : $p/\rho = w$
- Energy density
- Cosmological constant
- Curvature

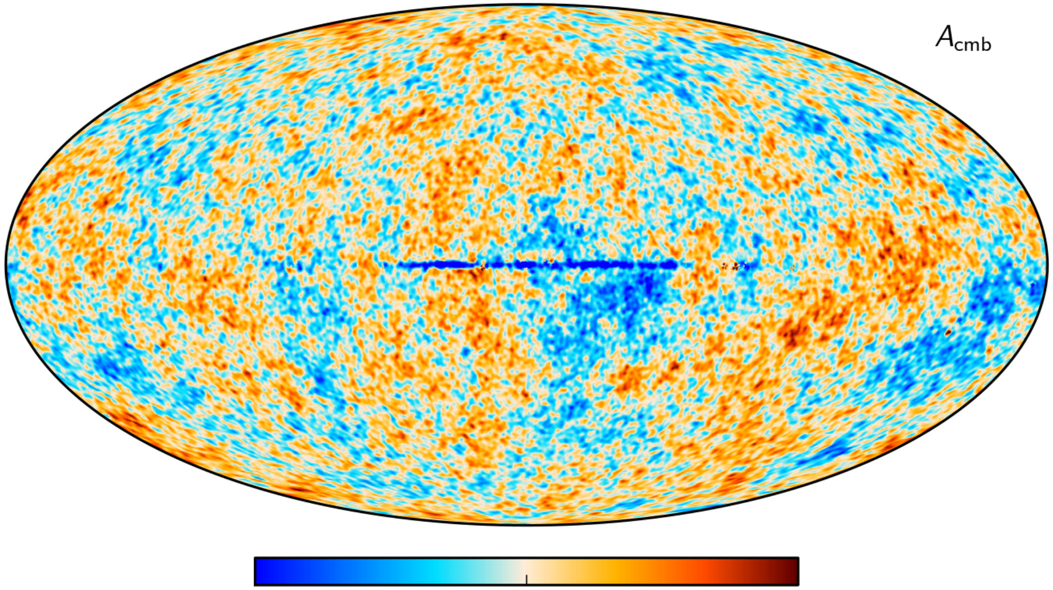
$H = \frac{\dot{a}}{a}$ Hubble parameter

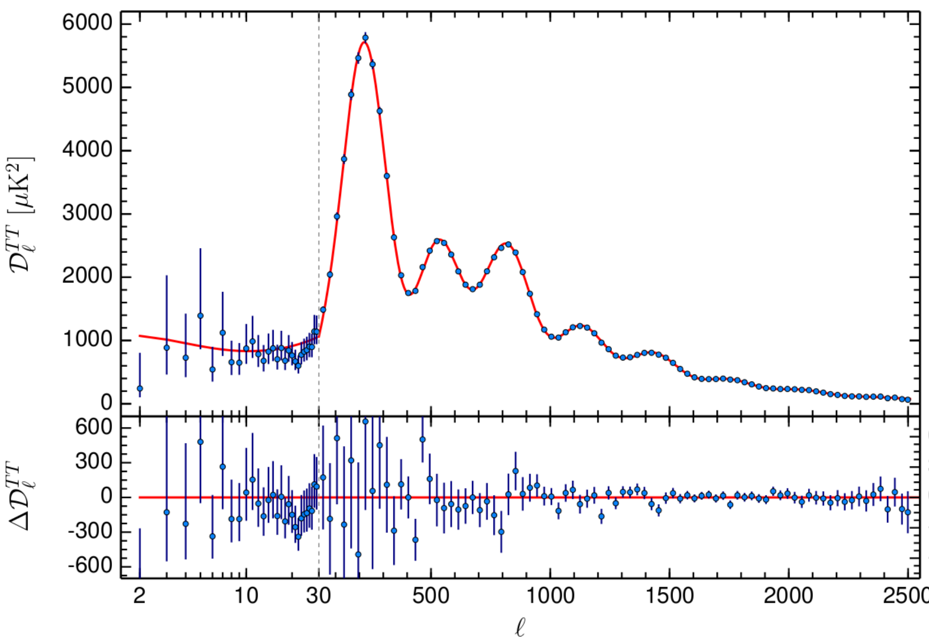
(expansion rate of the Universe)

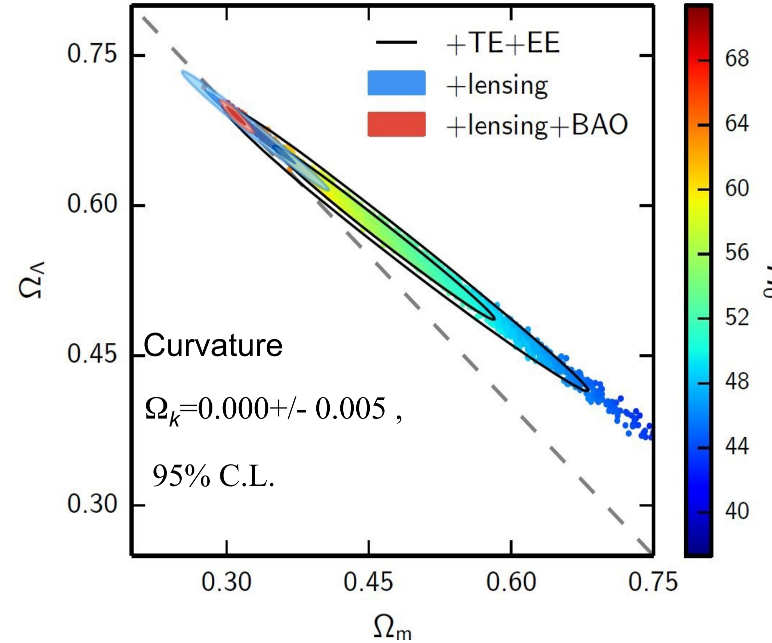
$\Omega_i = \frac{\rho_i}{\rho_c}$ Density parameters

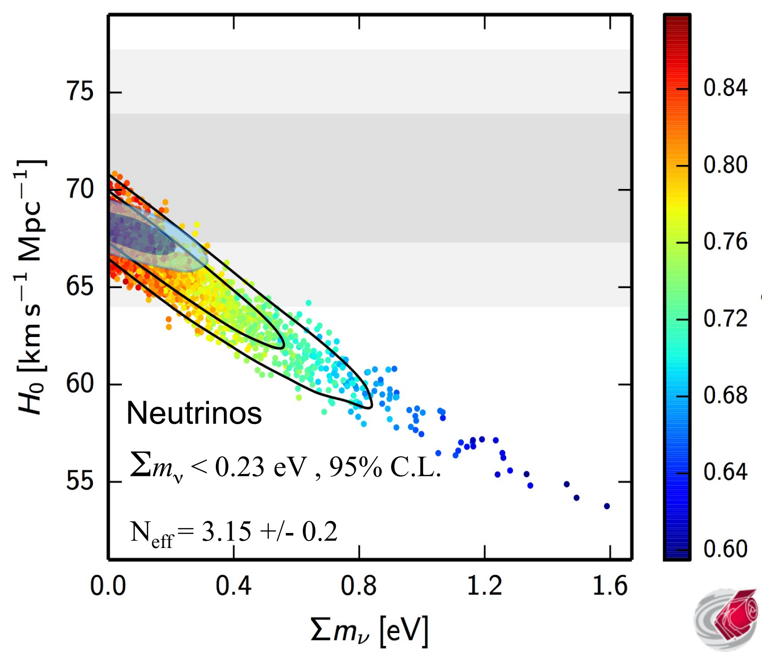
$\rho_c = \frac{3H_0^2}{8\pi G}$ Critical density

Planck-2015 Cosmology









Planck-2015: ΛCDM Cosmology

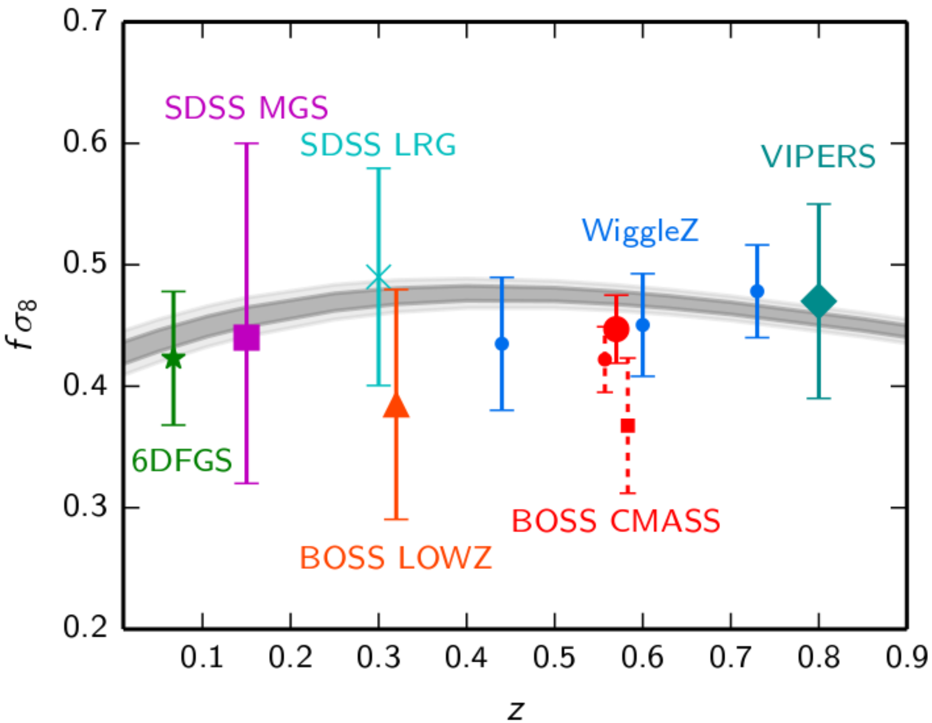
- Cosmic history of the Universe very well described by the hot big band paradigm with adiabatic expansion → CMB is a relic of the hot/dense period of the universe, primordial nuclosynthesis
- Our universe experienced an early inflation period
- The universe if (almost) flat
- The matter content of the unverse is dominated by a (cold) dark matter component of unknown nature
- Cosmic structures:
  - Formed from initial primordial (quantum) fluctuations that reached macroscopic scales during the inflation period and then grew by gravitational instabilities of dark matter perturbations.
  - Their statistical properties are characterised by a primordial power spectrum imprinted in the power spectrum of CMB primary anisotropies and the current power spectra of (dark) matter and galaxies power spectra observed today.

Planck-2015: ΛCDM Cosmology

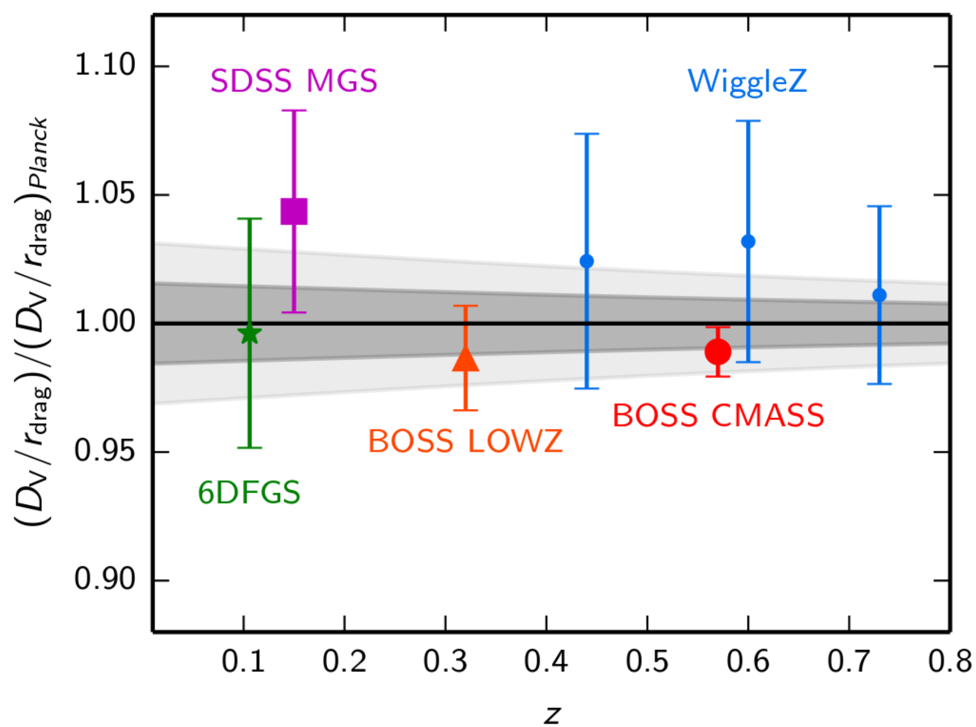
- The expansion of the Universe is accelerating
- If the universe is flat and accelerating then either its energy content must be dominated today by a new component (dark energy) or one must question our current understanding of gravity at cosmological scales:

  → Assuming DE is the cosmological constant Λ work remarkably well
- Our Universe experienced 3 cosmic periods that we can probe observationnally today: (1) radiation-, (2) matter-, (3) dark energy-dominated
- The acceleration period is recent
- The properties of the Universe are fully described by a set of « cosmological parameters » that are derived from astronomical observations of the Universe: CMB and other « cosmological probes »

ΛCDM is confirmed by several independent probes, beside CMB



Growth rate of structures at z<1



Baryon acoustic oscillations at z<1

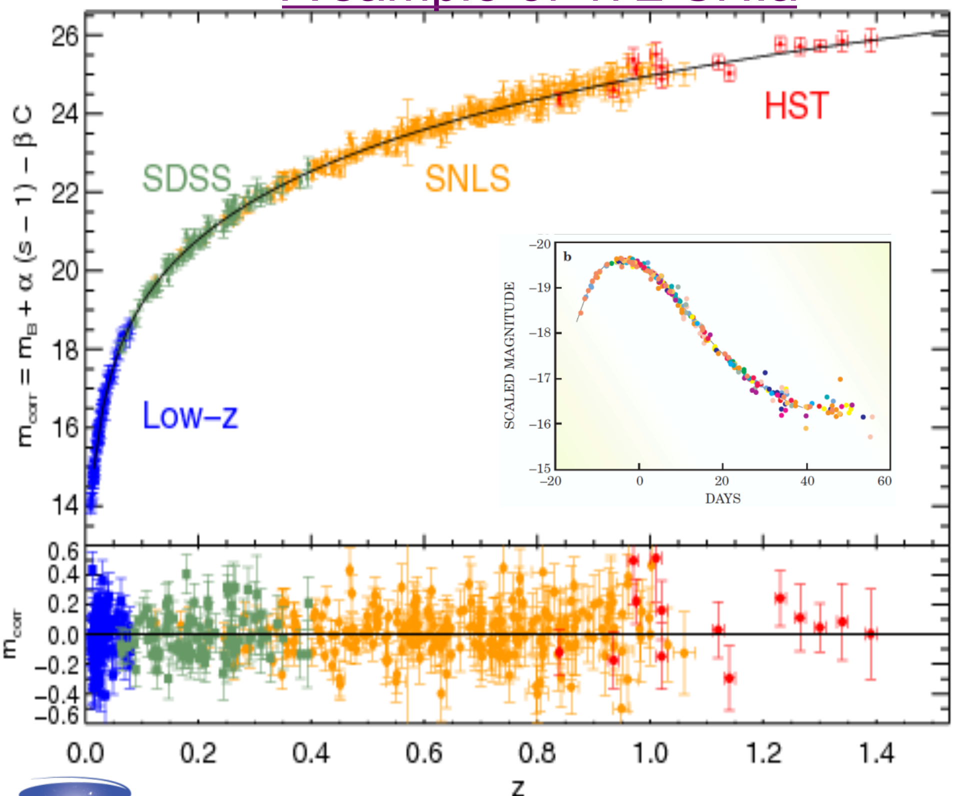
The expansion of the Universe is accelerating:

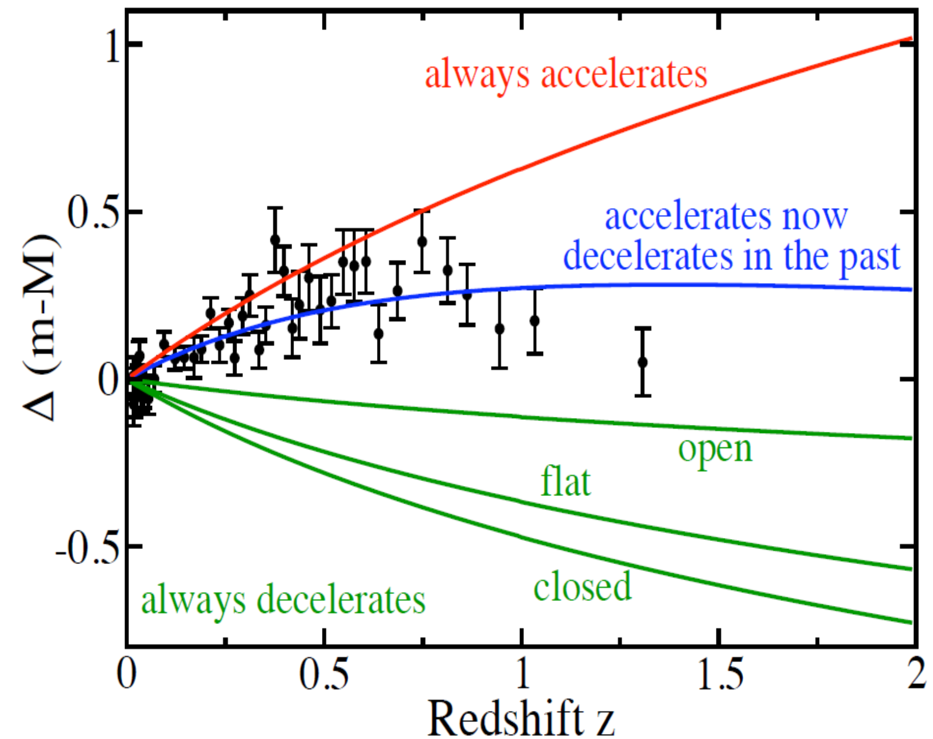
Confirmed today at a 99.999% confidence level

The acceleration of the expansion is recent:

in the past, expansion was decelerating: matter dominated era

A sample of 472 SNIa



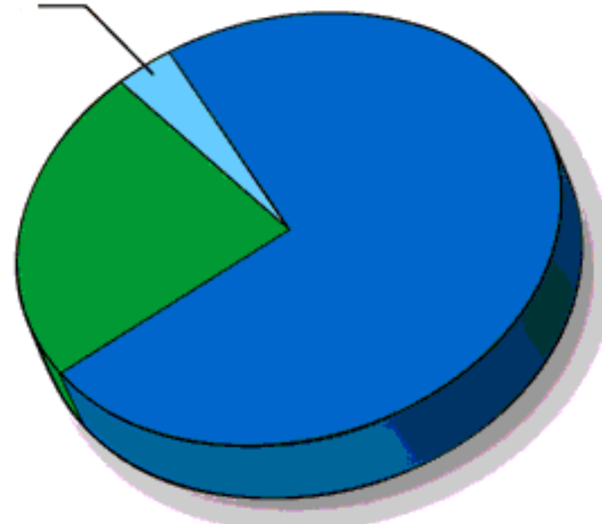


Cosmology in the dark universe after Planck

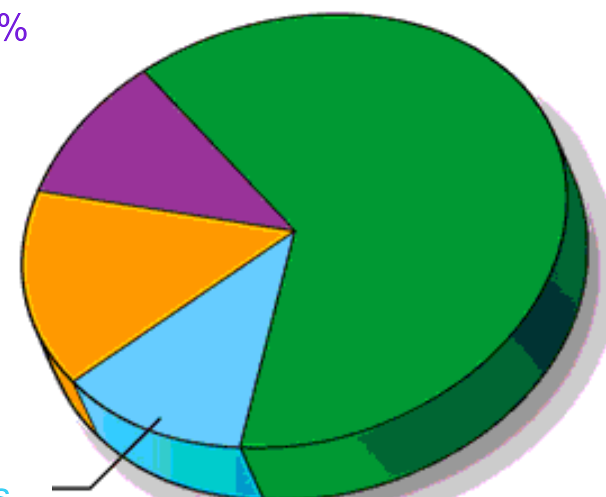
A Universe dominated today by a new component of unknown nature

- The origin of the acceleration
    - is totally unknown,
    - represents today 70% of the matter-energy content of our Universe.

Today (z=0)



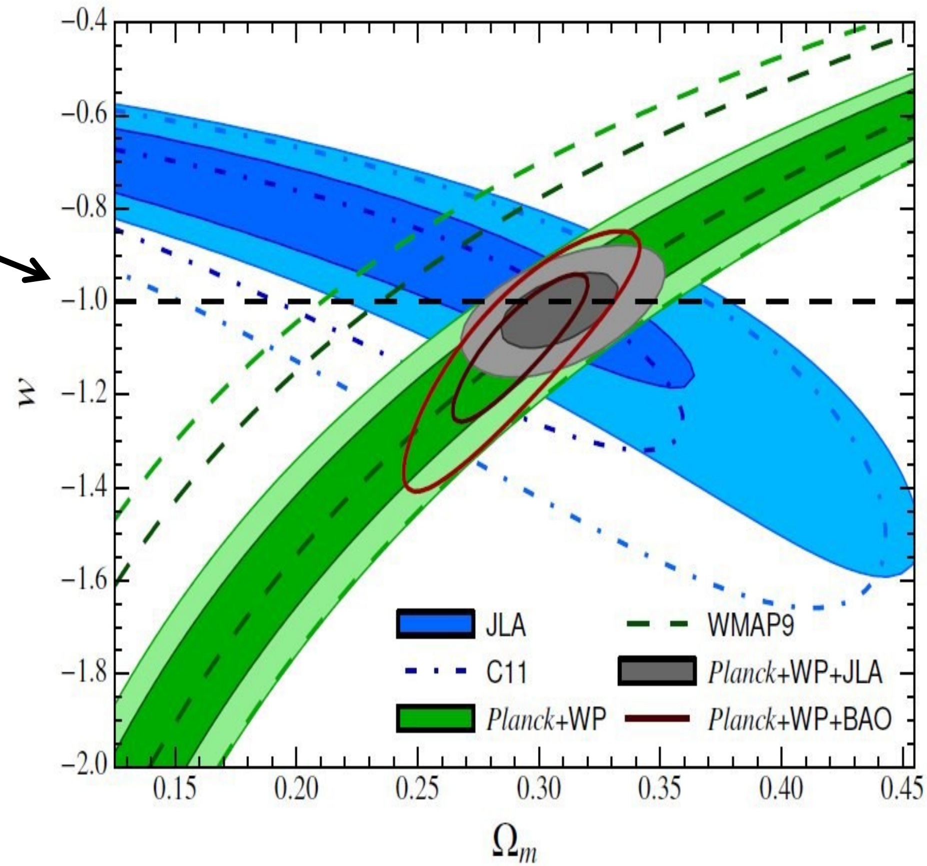
z=1000



→ The ΛCDM Universe is composed of 95% of dark matter + dark energy… both of unknown nature.

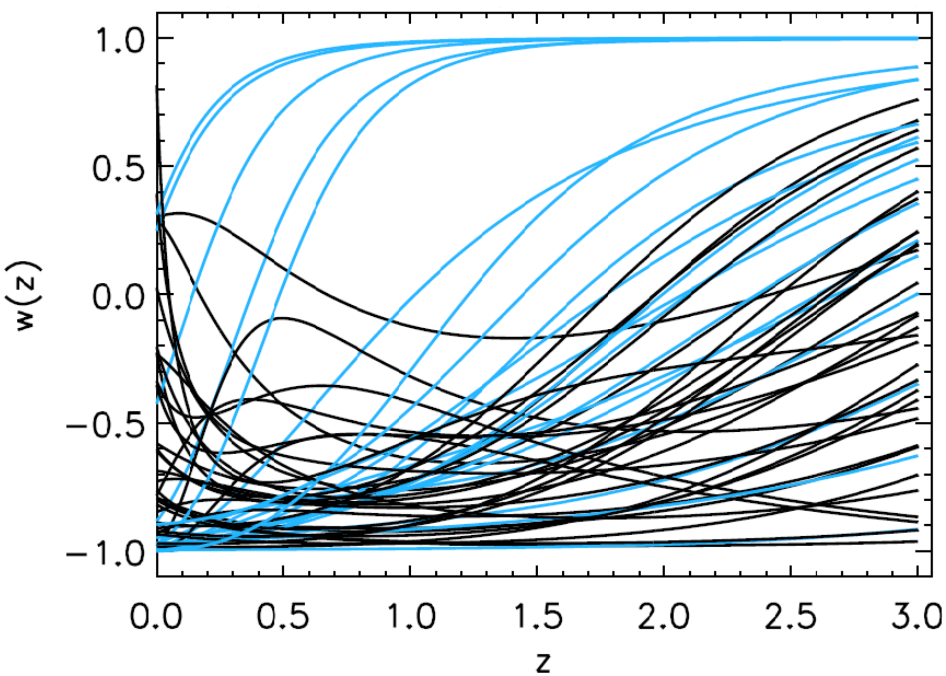
Post-Planck Cosmology: the dark universe

- Why the expansion of the universe is accelerating?
- Dark Energy
  - Planck w = -1.006 +/- 0.0045 : a cosmological constant to reconcile with particle physics
  - What is the nature of Dark Energy (DE)/Modified Gravtity (MG)
  - Dark Matter?
  - Other?
  - How observations can improve our knowledge on the nature of Dark Energy



Characterising *w*(*t*)

$w = P/\rho$ (w may slowy vary with time: $w(t) = w_0 + w_a\ (t)$)



$w_R = 1/3$ …. Radiation (photons)

$w_M = 0$ …. Non relativistic matter

$w_S = -1/3$ …. Cosmic string model

$w_W = -2/3$ …. Domain walls

$w_T = -1/3$ …. Textures

$w_Q(t) > -1 \quad (dw_Q/dz$ …. Quitessence

$w_K(t) > -1 \quad (dw_K/dz$ …. K-essences

$w_\Lambda = -1$ …. Cosmological constant

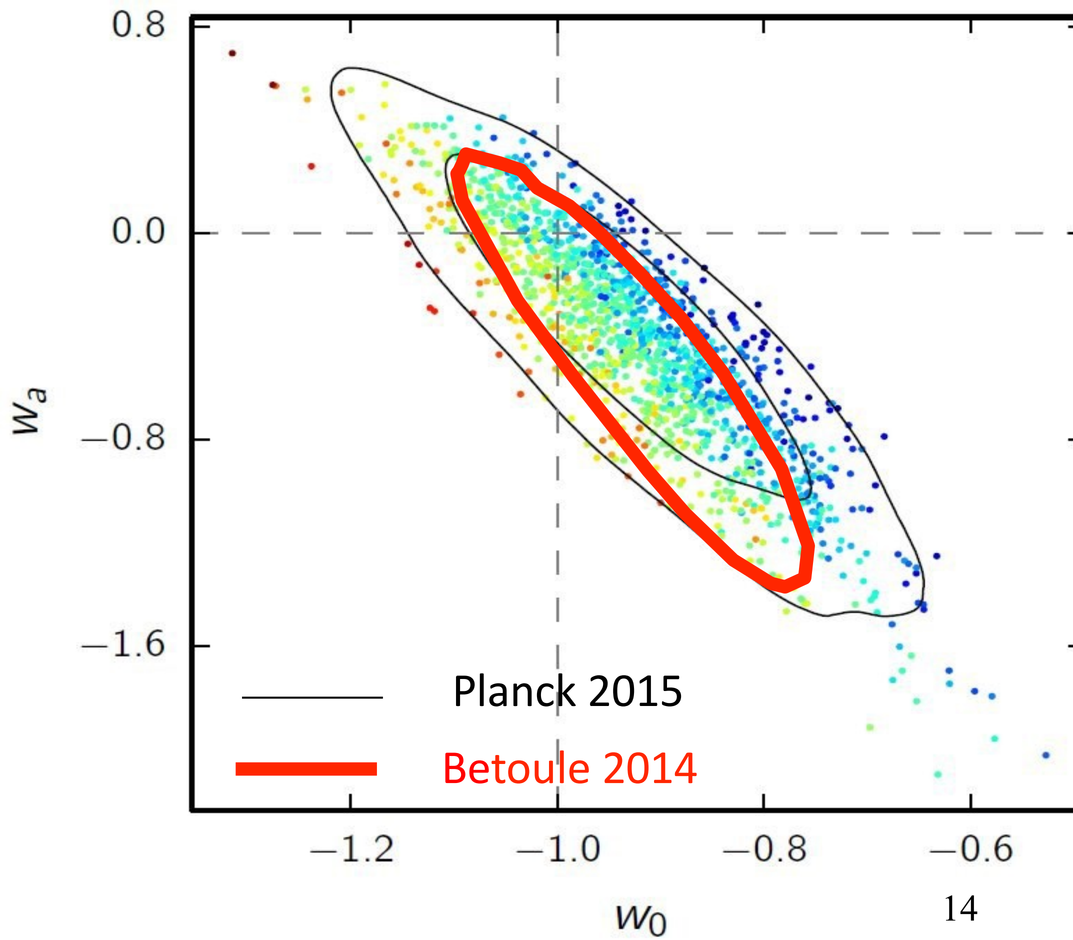
$w_{Ph}(t) < -1$ …. « Fantom » (→ Big Rip)

What do we know today with Planck?

w varies with time?...

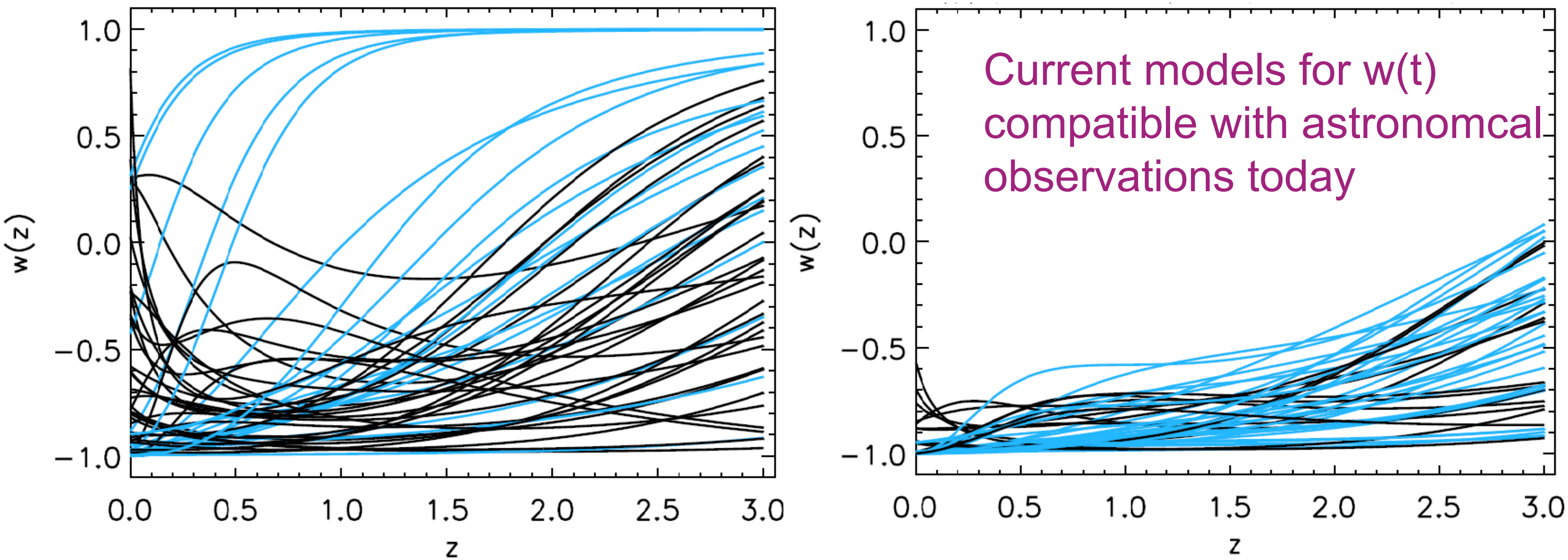
$w = w_p + w_a(t)$

→ need very a high precision experiment like Euclid to observe this variation and infer the very nature and its impact on fundamental physics.



$w(t)$: what do we know today?

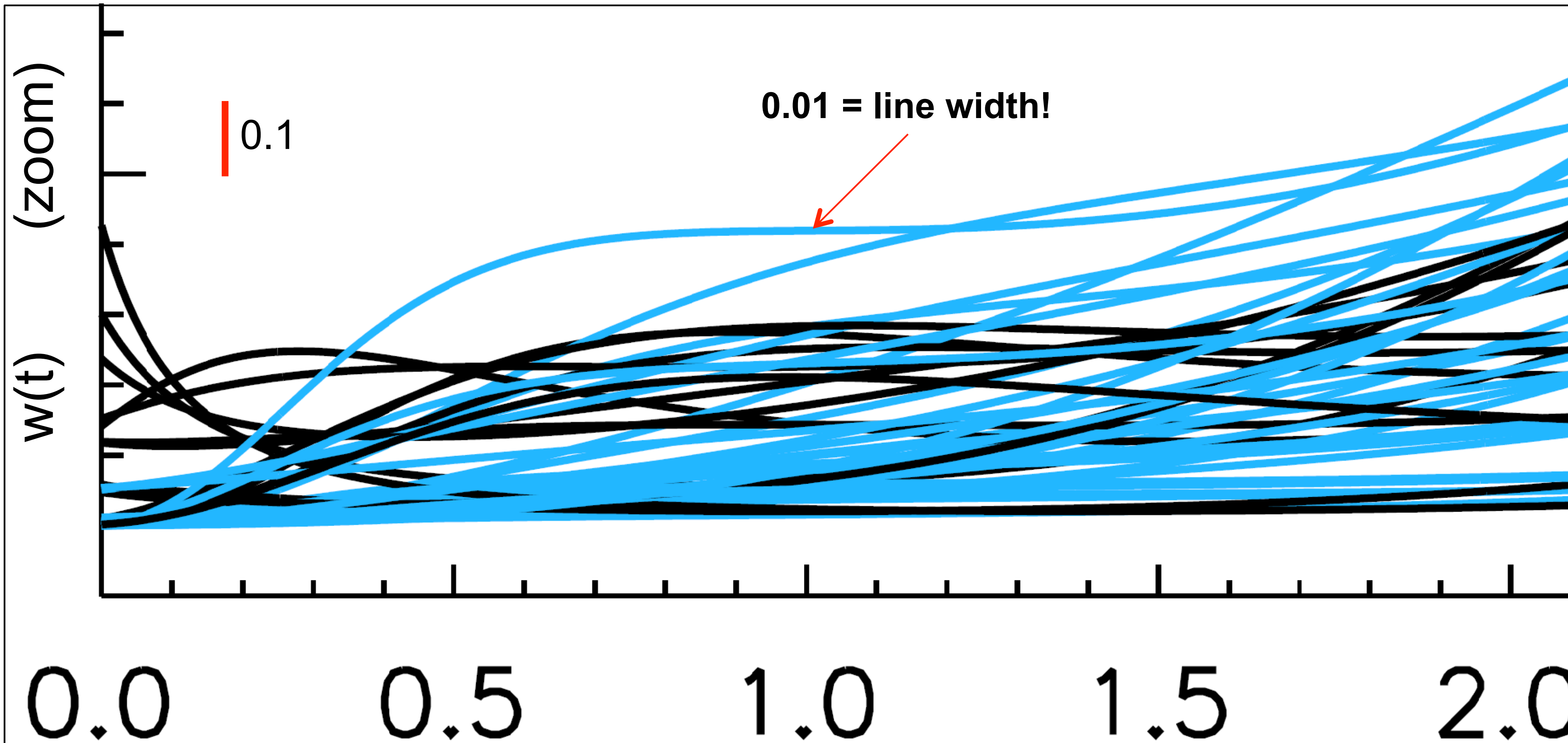
$w = P/\rho$ (w can depend on time: $w(t) = w_0 + w_a$ (t))



w(t): a challenge for precision cosmology

Tiny diffrences between models:

→ Need very accurate measurements of *w(t)* and measurements done at different ages of the Universe

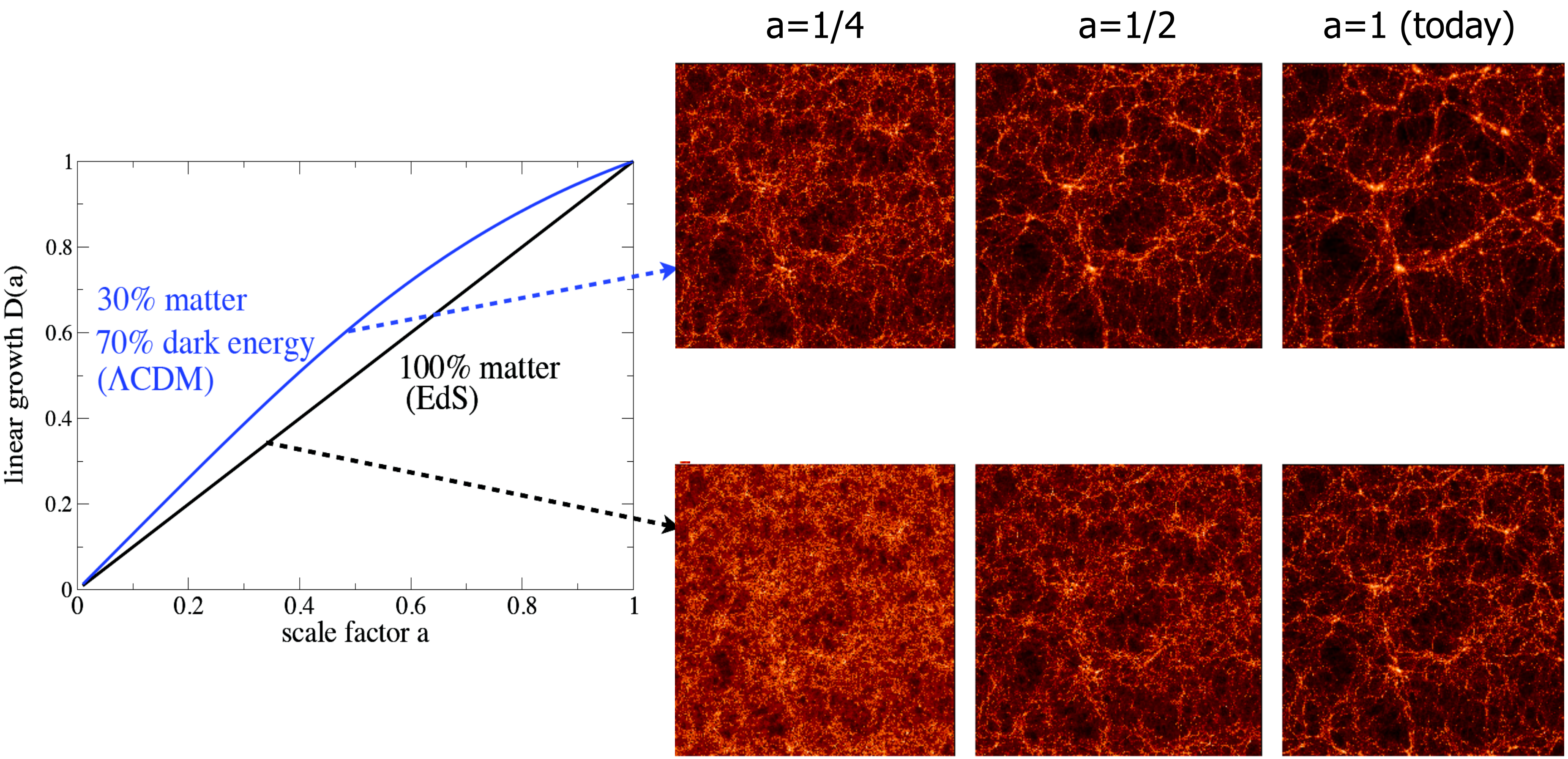


Dark energy or modified gravity : how can we answer using astronomical observations?

Dark energy and modified gravity can be separated by looking at their different effects on:

- The expansion history of the Universe;
- The history of structure formation in the Universe.

Dark energy and Dark Matter change the evolution of the Universe



Cosmological probes of dark energy

- Expansion Rate (BAO):

$$H(z) = H_0 \left[\Omega_{\rm M}(1+z)^3 + \Omega_{\rm DE} \frac{\rho_{\rm DE}(z)}{\rho_{\rm DE}(0)} + \Omega_{\rm K}(1+z)^2 \right]^{1/2}$$

- Distance (SN, BAO, CMB):

$$D(z) = \frac{1}{(|\Omega_{\rm K}|H_0^2)^{1/2}} S_{\rm K} \left[(|\Omega_{\rm K}|H_0^2)^{1/2} \int_0^z \frac{dz'}{H(z')} \right]$$

- Growth and growth rate (WL, Clusters, RSD):

$$G'' + \left(4 + \frac{H'}{H}\right) G' + \left[3 + \frac{H'}{H} - \frac{3}{2}\Omega_{\rm M}(z)\right] G = 0$$

$G = D_1/a$; $f = d \ln(D) / d \ln(a)$

- Effects the metrics: use probes that explore the 2 potentials

$$ds^2 = -(1+2\psi)\, dt^2 + (1-2\phi)\, a(t) d\vec{x}^2$$

Perturbed Einstein:

importance of probing effects of both potentials ψ and ϕ

- Small scalar perturbations:

$$ds^2 = -(1+2\psi)\,dt^2 + (1-2\phi)\,a(t)d\vec{x}^2$$

- Non relativistic particules are sensitive to: ψ
- Relativistic particules are sensitive to: $\psi + \phi$

- Standard GR + no anisotrotic stress: $\psi = \phi$

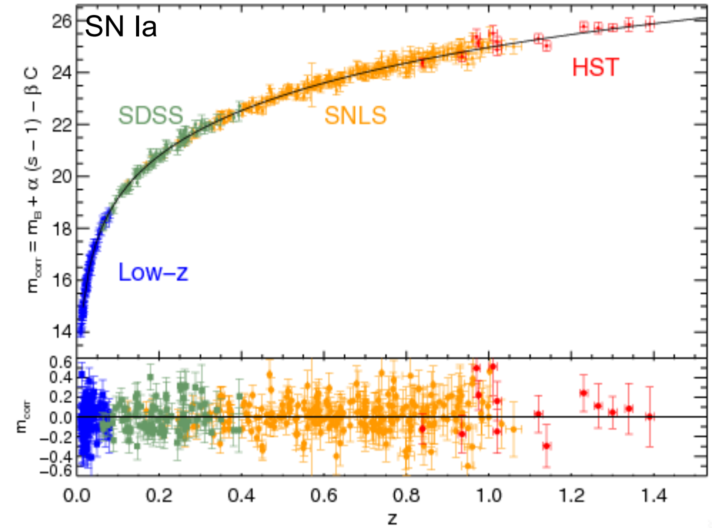
→ Poisson equation $k^2\phi = -4\pi G a^2 \sum \rho_i \Delta_i$

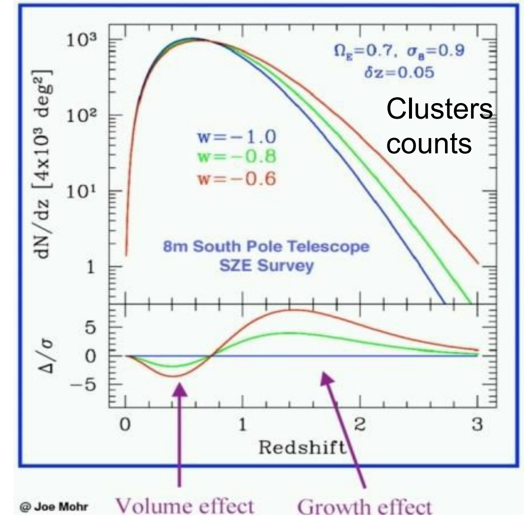
- Modified Gravity or Dynamical DE: $\psi = R\phi$

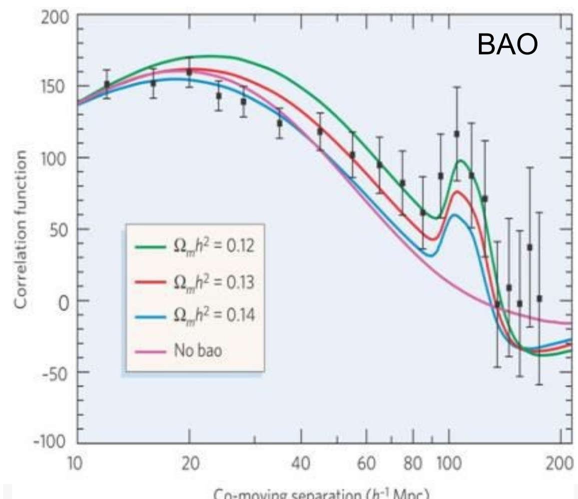
→ Poisson equation: $k^2\phi = -4\pi G Q a^2 \sum \rho_i \Delta_i$

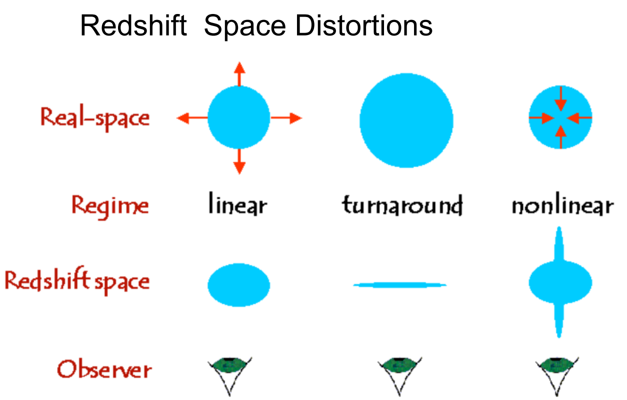
$Q(k,a)$, $R(k,a)$: imprints on clustering of DM, Gal and DE

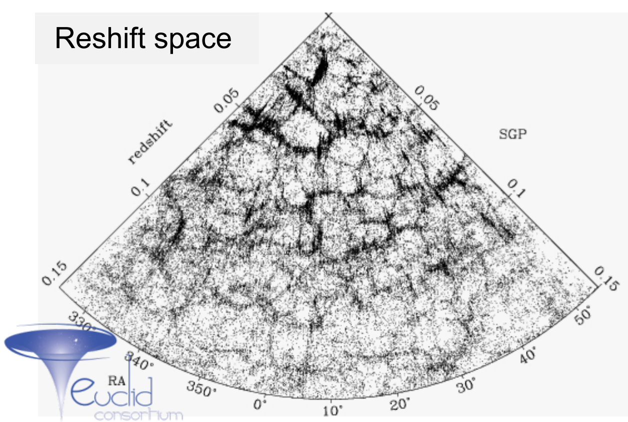
Observational probes of dark energy

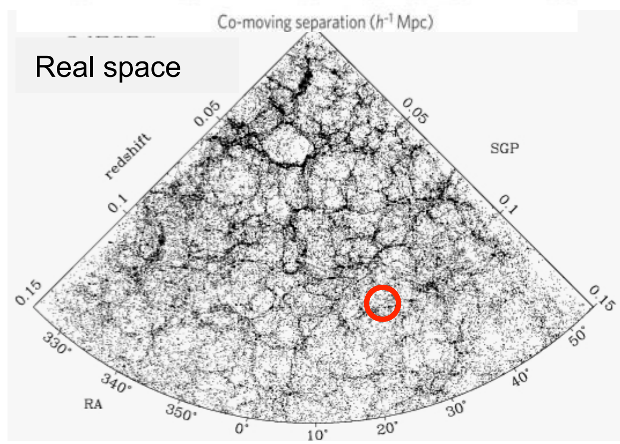


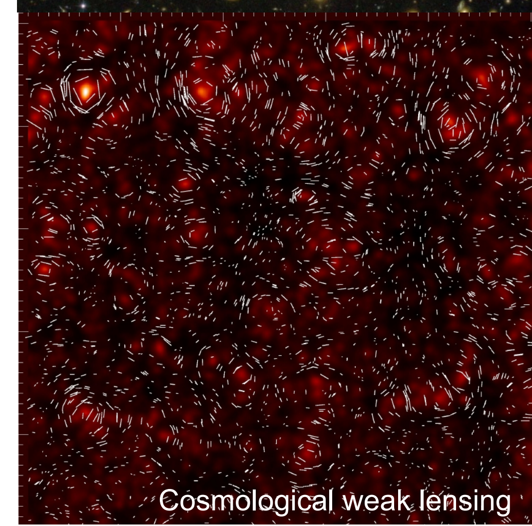




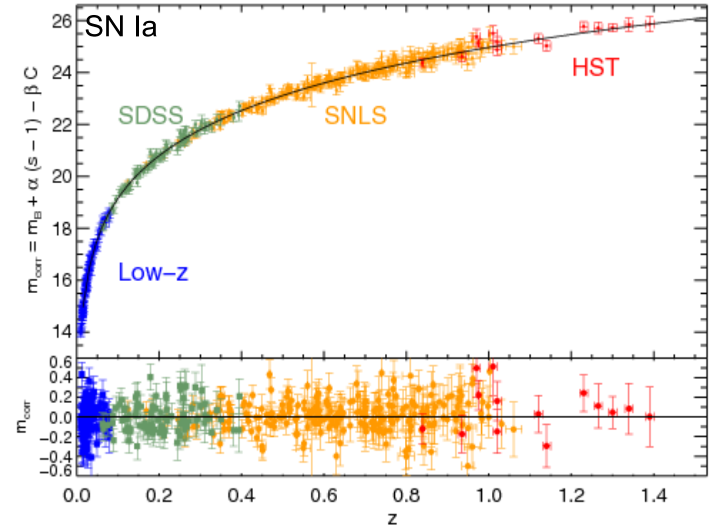


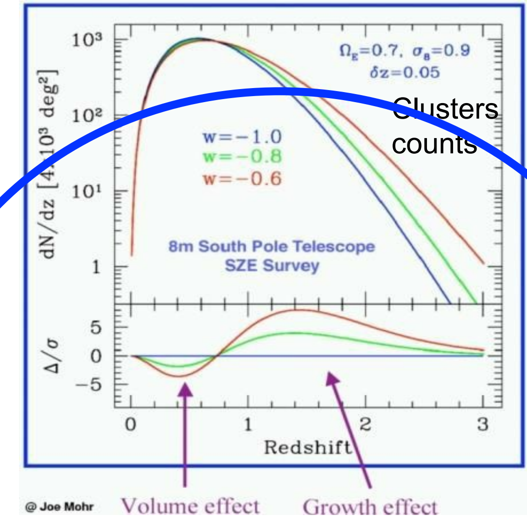


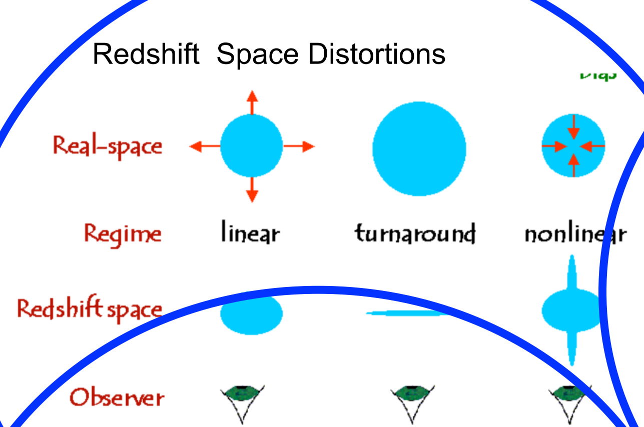


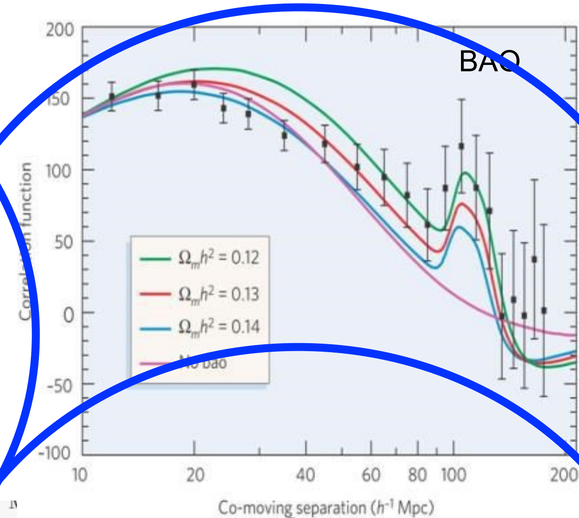


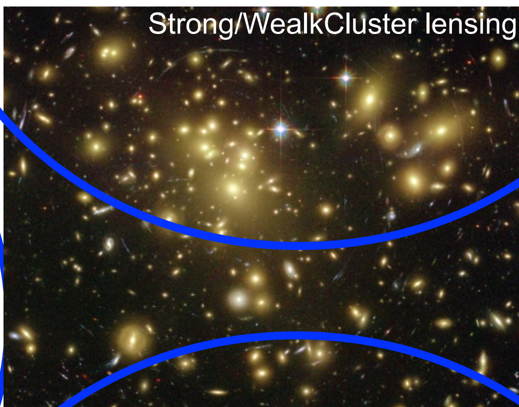
Euclid probes of dark energy

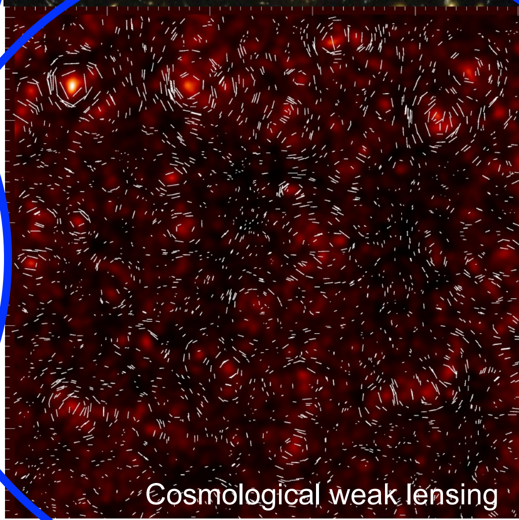


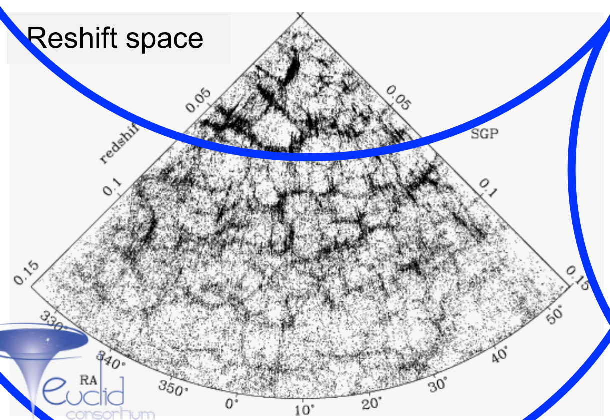


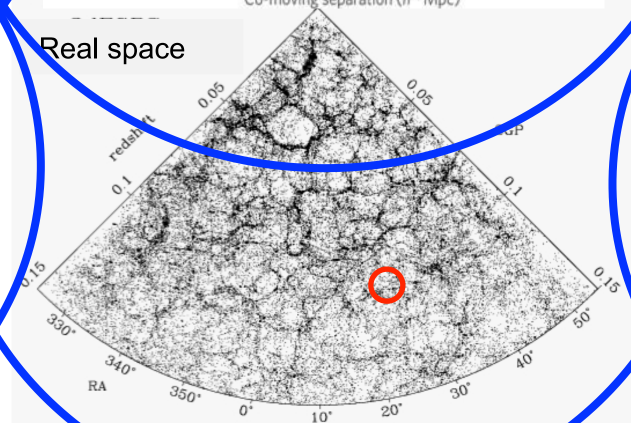




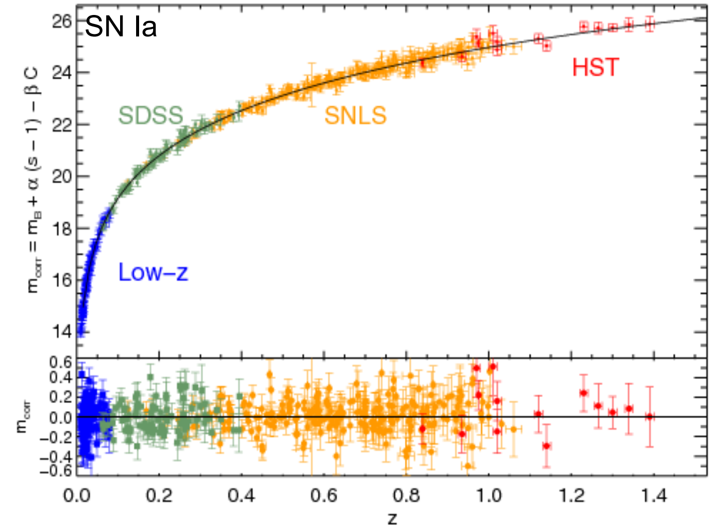


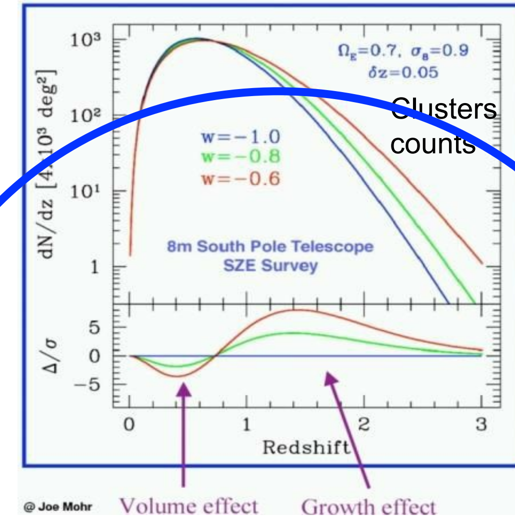


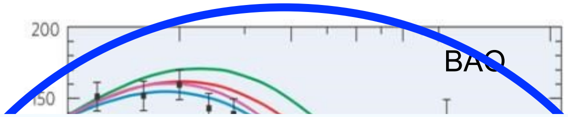


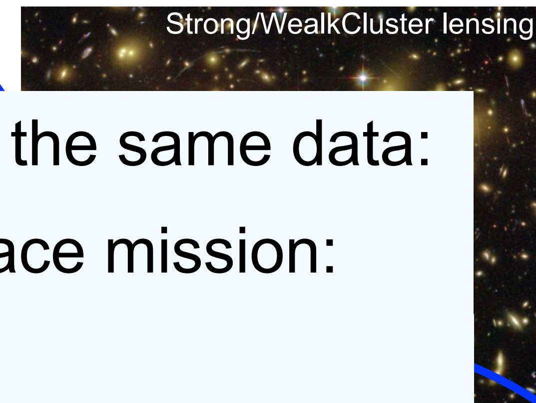


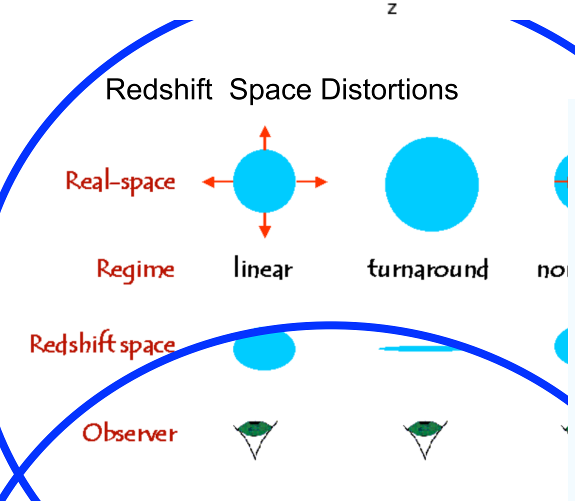
Euclid probes of dark energy

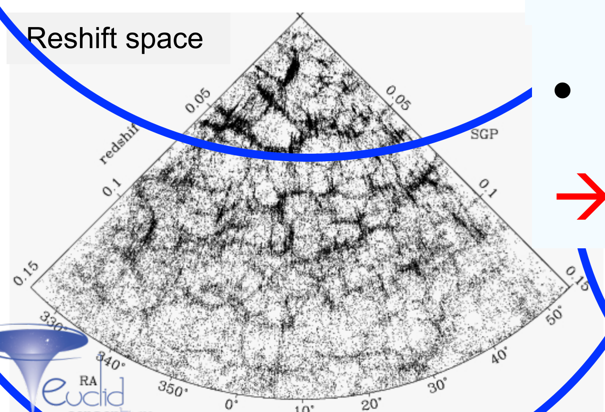


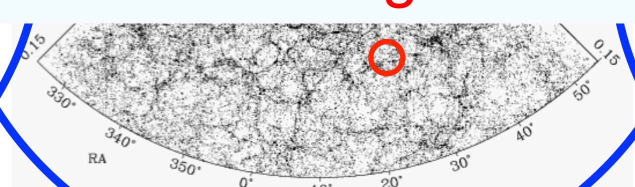


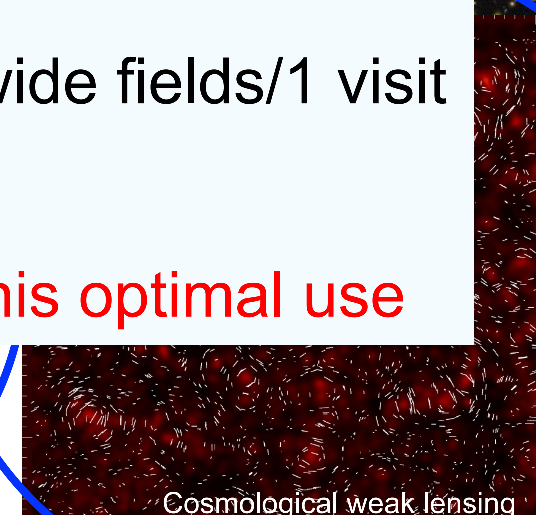












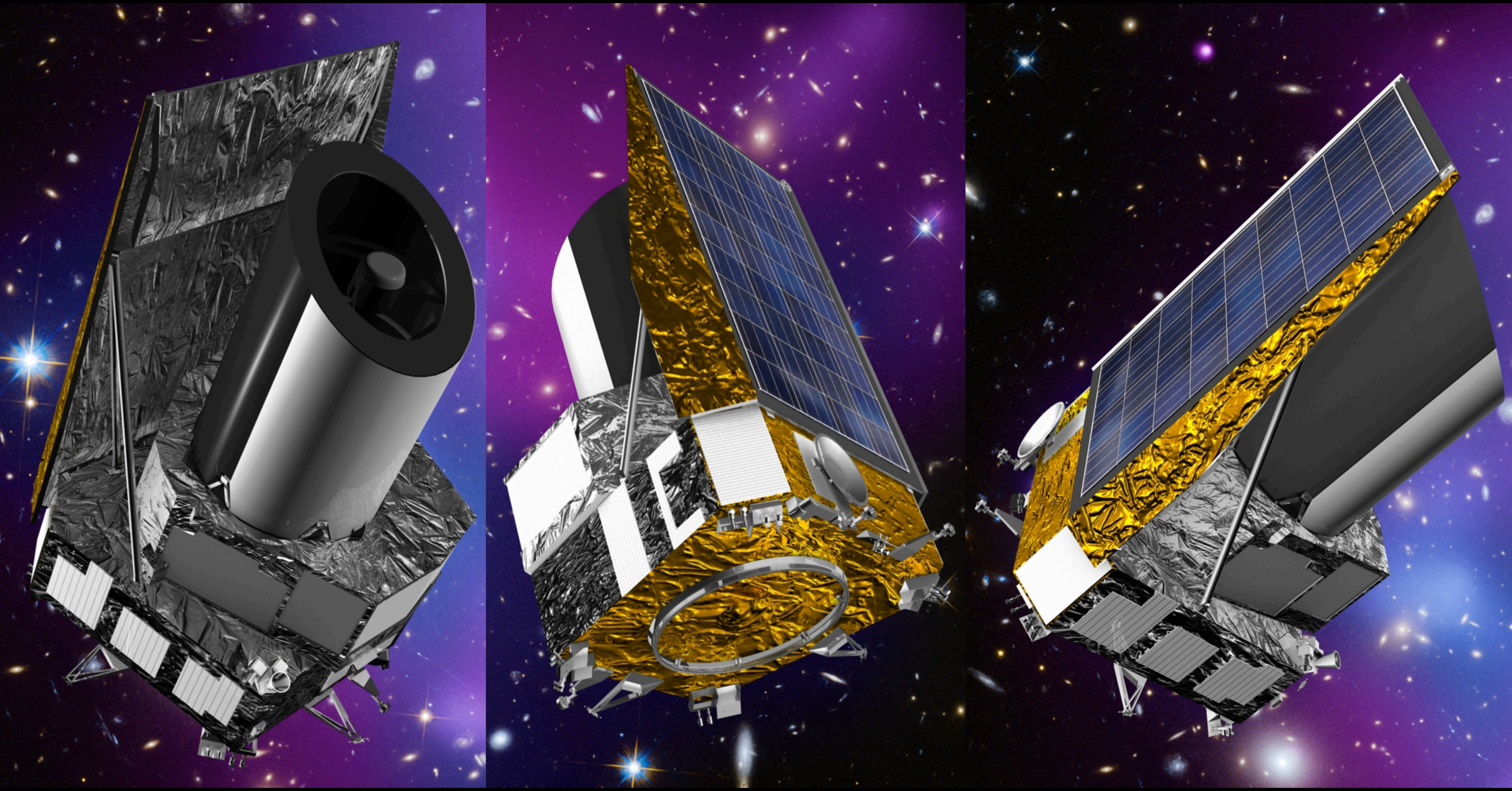
Use the same survey and the same data:

→ optimal use of a space mission:

- Imaging/spectroscopy/wide fields/1 visit
- Probes both ψ and ϕ

→ Euclid is designed for this optimal use

The quest of dark energy with the Euclid space mission



Euclid Primary Objectives: the Dark Universe

- **Understand**
  - The origin of the Universe's accelerating expansion
  - The properties and nature of Dark Energy and Gravity,

- **Probe the effects of Dark Energy, Dark Matter and Gravity by**:
  - Using at least 2 independent but complementary probes (5)
  - Tracking their observational signatures on the
    - Geometry of the universe: Weak Lensing (WL), Galaxy Clustering (GC)
    - Cosmic history of structure formation: WL, Redshift-Space Distortion (RSD), Clusters of Galaxies (CL)
  - Controling systematics to an unprecedented level of accuracy.

Euclid Top Level Science Requirements

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% in redshift bins $0.7 < z < 2$. • Look for deviations from $w = -1$, indicating a dynamical dark energy. • Euclid *alone* to give $FoM_{DE} \geq 400$ (1-sigma errors on w_p, & w_a of 0.02 and 0.1 respectively)
Test Gravity	• Measure the growth index, γ, with a precision better than 0.02 • Measure the growth rate to better than 0.05 in redshift bins between $0.5 < z < 2$. • Separately constrain the two relativistic potentials ψ , ϕ • Test the cosmological principle
Dark Matter	• Detect dark matter halos on a mass scale between 10^8 and $>10^{15}$ M_{Sun} • Measure the dark matter mass profiles on cluster and galactic scales • Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with an accuracy of a few hundredths of an eV
Initial Conditions	• Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n to a 1-sigma accuracy of 0.01. • For extended models, improve constraints on n and α wrt to Planck alone by a factor 2. • Measure a non-Gaussianity parameter : f_{NL} for local-type models with an error < +/-2.

Laureijs et al 2011

- DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$
- Growth rate of structure formation: $f \sim \Omega^{\gamma}$;
- FoM=$1/(\Delta w_a \times \Delta w_p) > 400$ → ~1% precision on w's.

Requirements to design the mission

	Wide survey	Deep survey
Survey		
size	15000 deg^2	40 deg^2 N/S
VIS imaging		
Depth	n_{gal} > 30/$arcmin^2$ → M_{AB} =24.5 → <z> ~0.9	M_{AB} = 26.5
PSF size knowledge	$\sigma[R^2]/R^2<10^{-3}$	
Multiplicative bias in shape	$\sigma[m]<2x10^{-3}$	
Additive bias in shape	$\sigma[c]<5x10^{-4}$	
Ellipticity RMS	$\sigma[e]<2x10^{-4}$	
NIP photometry		
Depth	24 M_{AB}	26 M_{AB}
NIS spectroscopy		
Flux limit (erg/cm^2/s)	3 10^{-16}	5 10^{-17}
Completness	> 45 %	>99%
Purity	>80%	>99%
Confusion	2 rotations	>12 rotations

WL and systematics

$$\gamma^{obs} = (1+m)\times\gamma^{true} + c$$

$$C_l^{true} \approx \left[1+2\langle m\rangle\right]\times C_l^{obs} \quad +\langle c^2\rangle$$

- Small PSF, Knowledge of the PSF size
- Knowledge of distortion
- Method to correct distortion
- Method to correct Non-convolutive PSF
- Stability in time → space telescope far best option!
- External visible photometry for photo-z accurary: 0.05x(1+z)
- Catastrophic z < 10%

GC and systematics

- Understand selection→Deep field (photo+spectro)
  - Completeness
  - Purity

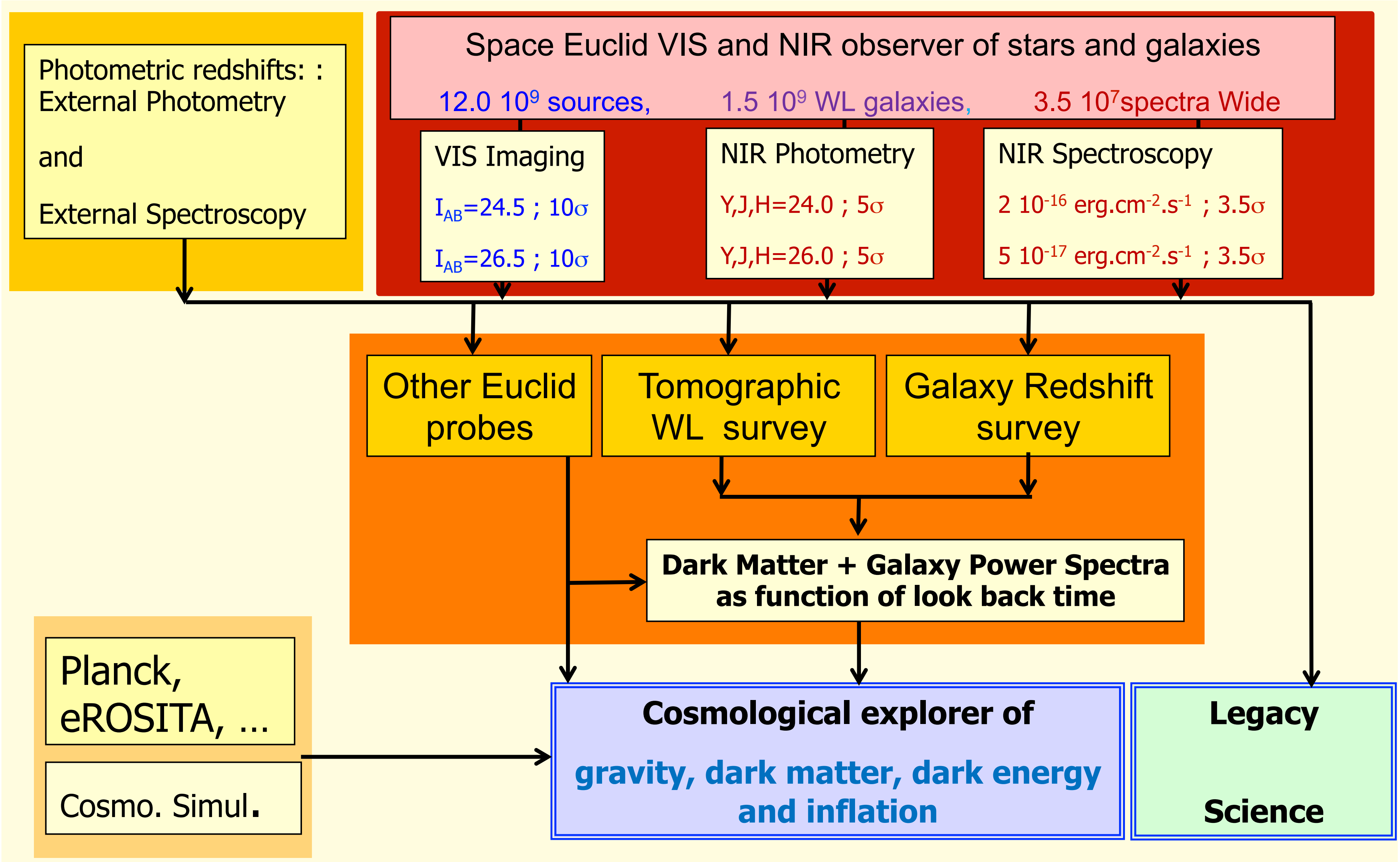
Why going to space?

- Measuring shapes of galaxies with a space telescope
    - No image degradation by atmospheric turbulense or chromatic atmospheric refractions
    - Ultra-stable telescope over the 6 years of the survey

- Mesuring distances in the infrared (needed to explore the universe in the redshift range $1<z<2$)
    - Thermal emission from sky 1000 times fainter than on ground based telescopes

    → Observing 15000 deg^2 to the Euclid depth with a NIR ground based telescope like ESO/VISTA (4 m diameter, field of view x2 bigger than Euclid)… → 640 years.

Euclid Survey Machine:15,000 deg^2 + 40 deg^2 deep

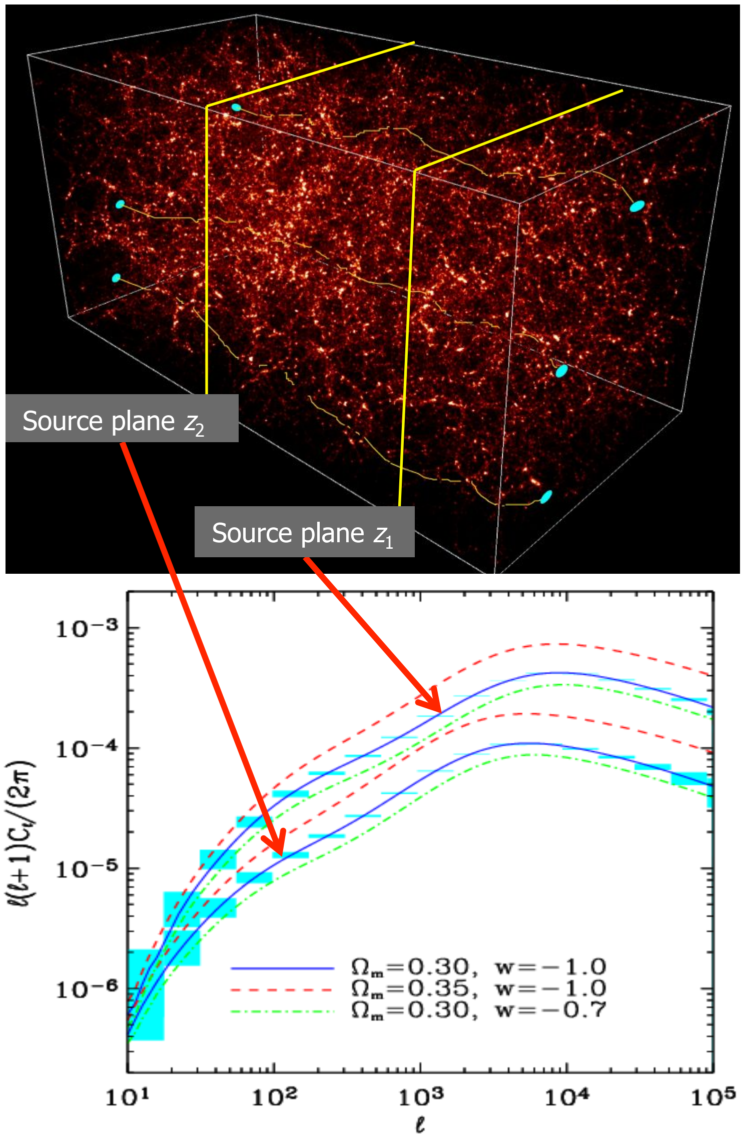


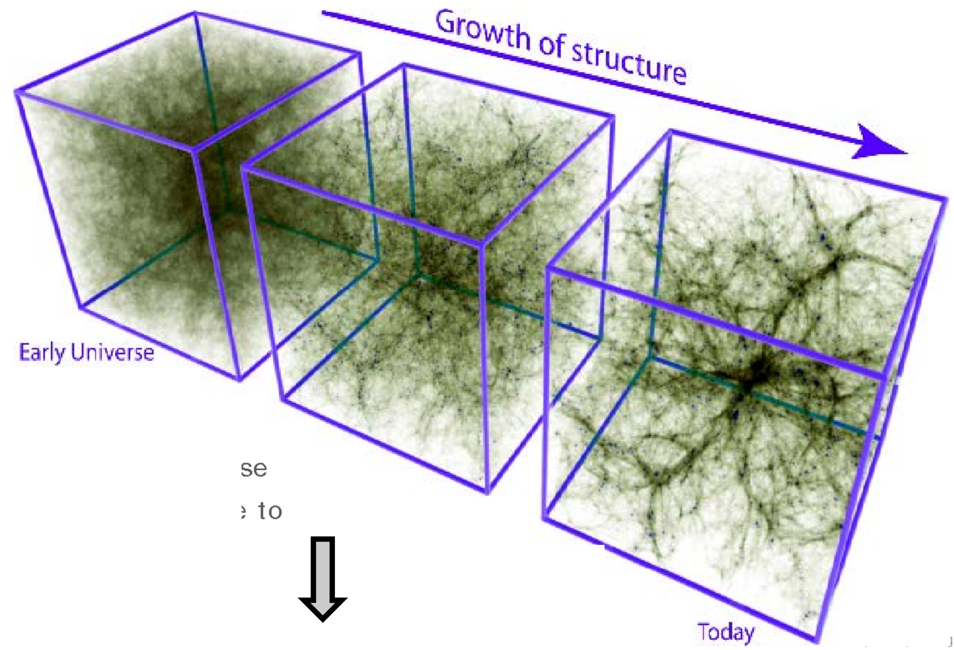
WL probe: Cosmic shear over 0<z<2 :

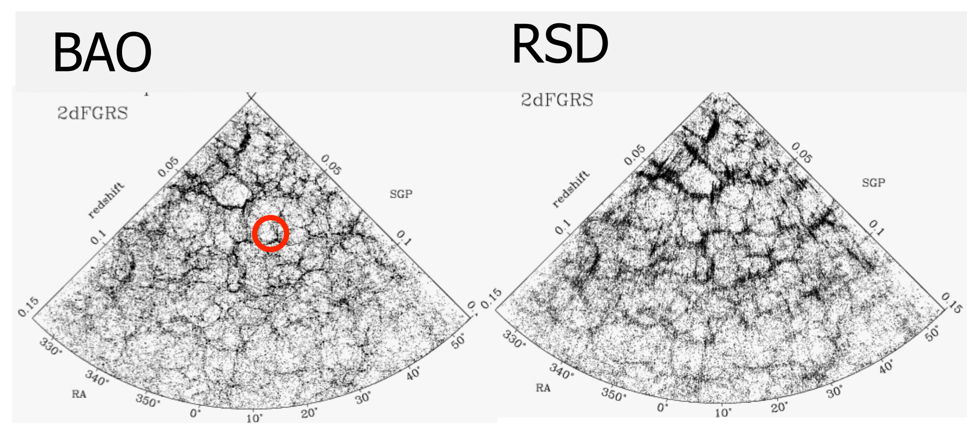
1.5 billion galaxies shapes, shear and phot-z (u,g, r,i,z,Y,J,H) with 0.05 (1+z) accuracy over 15,000 deg^2

GC; BAO, RSD probes: 3-D positions of galaxies over 0.7<z<1.8 :

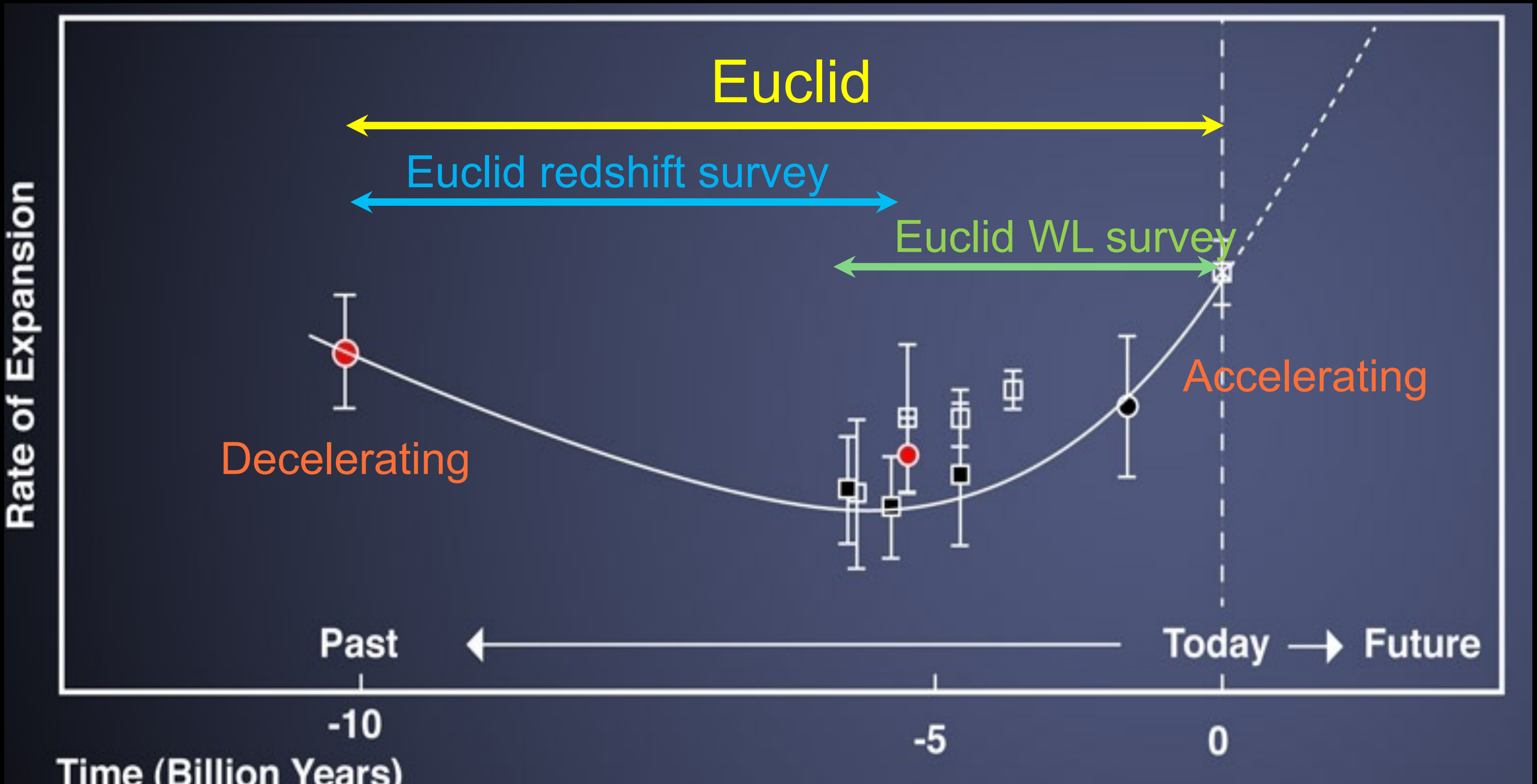
35 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg^2







Euclid will explore the dark universe and the DM-dominated / DE-dominated transition period



Plot inspired by the BOSS collaboration

Euclid+ground: photo-z of 1.5 billion galaxies

Critical: need ground based imaging over 15,0000 deg^2 in 4 bands

Courtesy Euclid SWG Photo-z and OU-PHZ

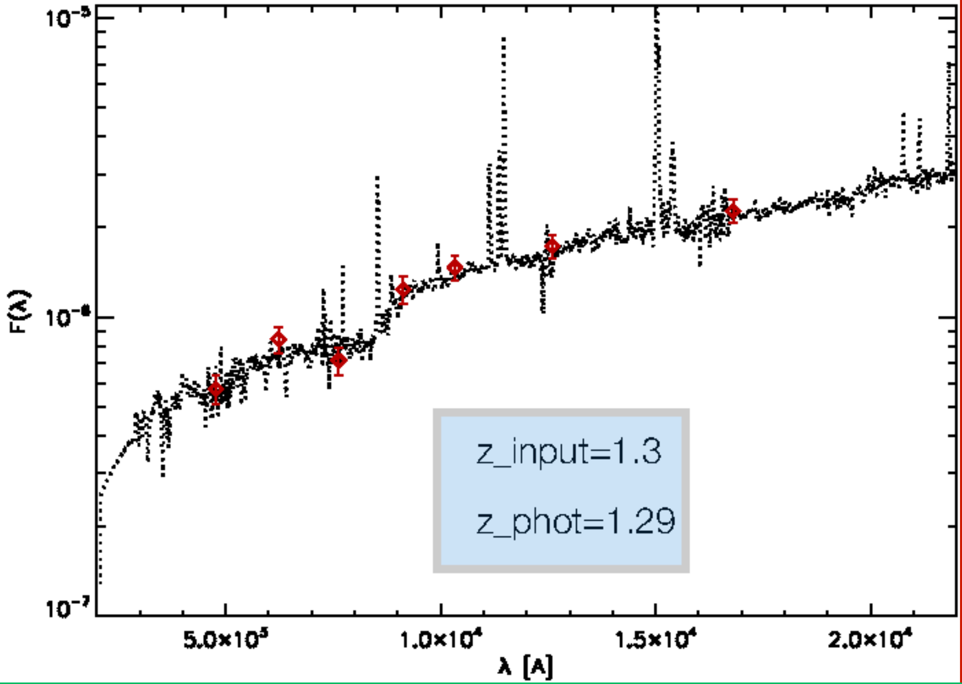
Requirements:

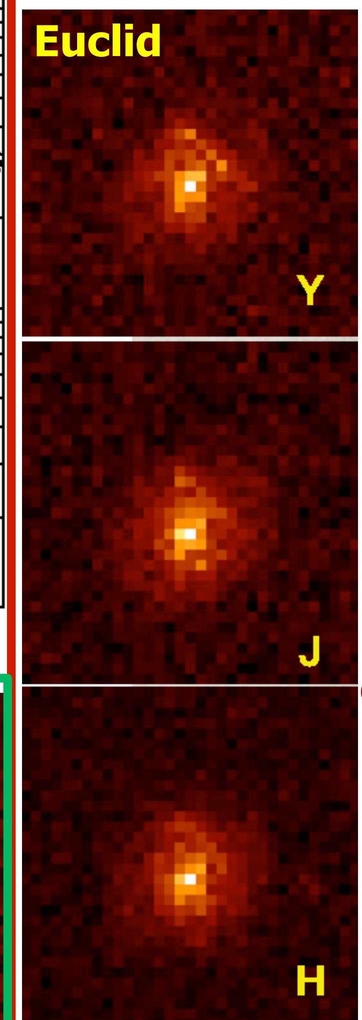
• get photo-z for ~all WL galaxies

• cover the whole Euclid sky (15000 deg^2)

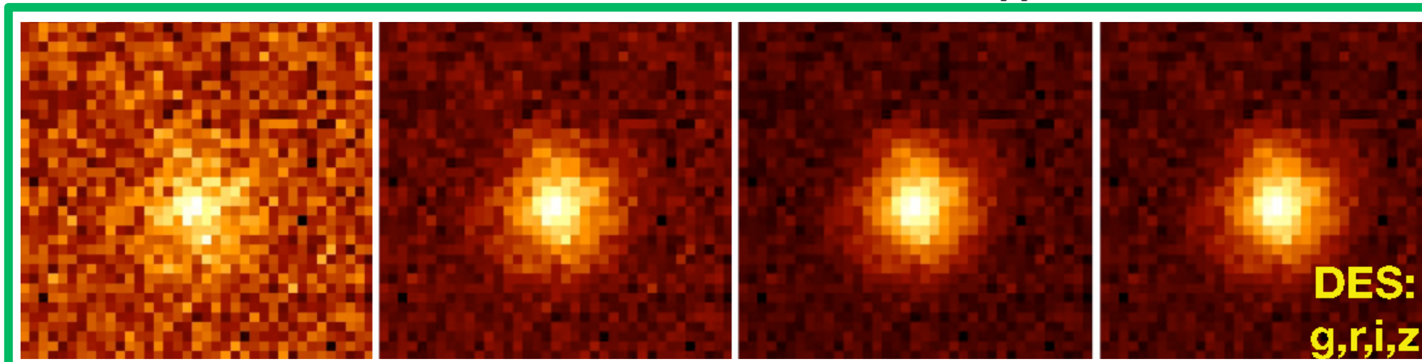
• accuracy: 0.05x(1+z)

→ 4 optical bands needed

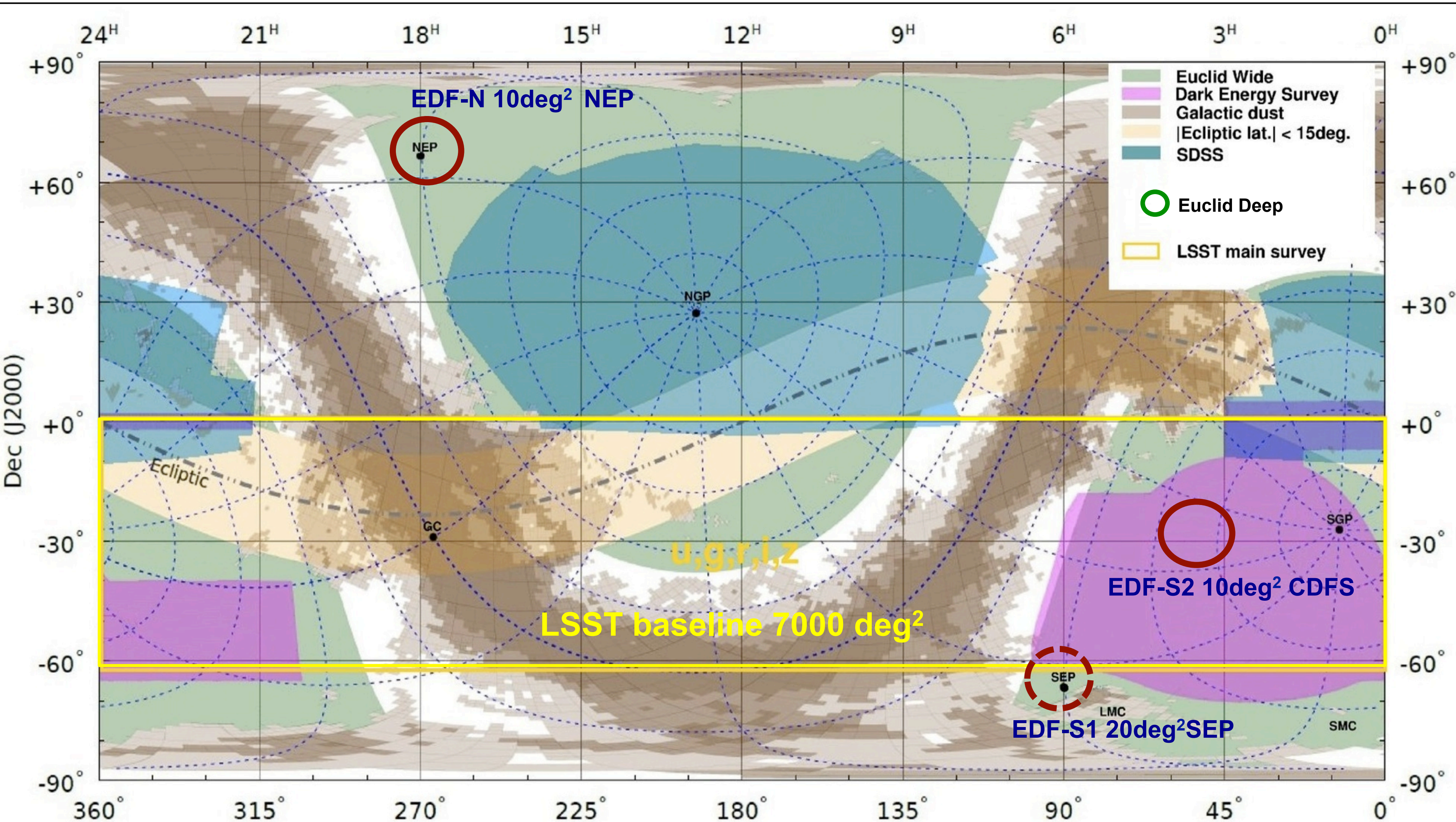




NIR data from Euclid NIR images.



Selection of *Euclid Deep Fields*



From J.-C. Cuillandre and the Survey WG

Euclid Wide+Deep Surveys

- **Euclid Wide:**
  - 15000 deg^2 outside the galactic and ecliptic planes
  - 12 billion sources (3-σ)
  - 1.5 billion galaxies (30 gal/$arcmin^2$) with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R +I+Z) AB=24.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 24.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 35 million spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - 21 mag
    - Hα galaxies within $0.7 < z < 1.85$
    - Flux line: 2 . 10^{-16} erg.cm^{-2}.s^{-1} ; 3.5σ

- **Euclid Deep:**
  - 1x10 deg^2 North Ecliptic pole (EDF-N) + 1x20 deg^2 South Ecliptic pole (EDF-S1)

  + 1x10 deg^2 at CDFS (EDF-S2)
  - 10 million sources (3-σ)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R +I+Z) AB=26.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 26.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 150 000 spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - 23 mag
    - Hα galaxies within $0.7 < z < 1.85$
    - Flux line: 5 . 10^{-17} erg.cm^{-2}.s^{-1} ; 3.5σ

Performances and forecasts

Performance Status on Dec 2016

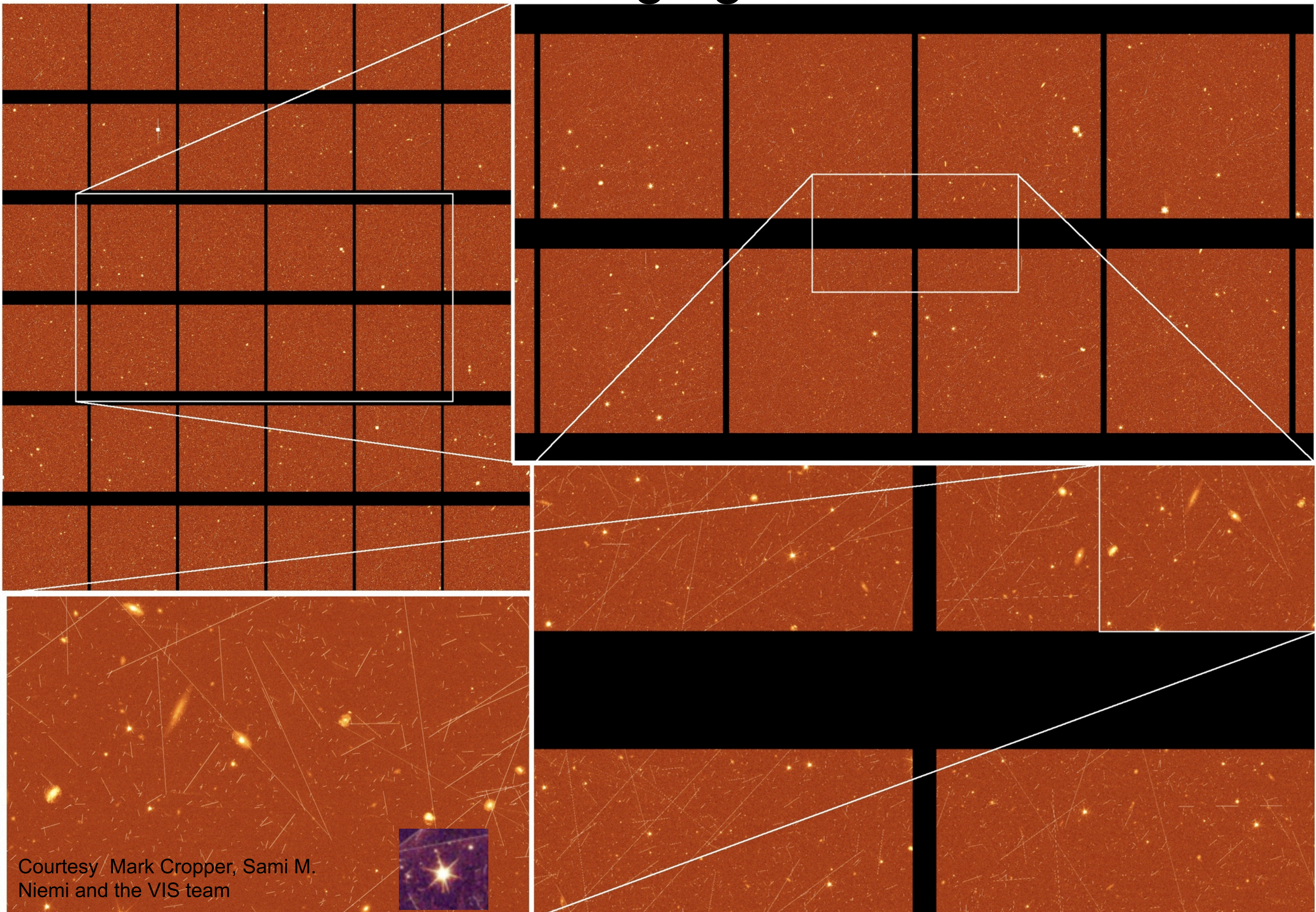
Technical Performance Measure		Requirement	CBE Current
Image Quality			
VIS Channel	FWHM (@ 800nm)	180 mas	160 mas
	ellipticity	15.0%	9.4%
	R2 (@ 800 nm)	0.0576	0.0551
	ellipticity stability σ(εi)	2.00E-04	1.90E-04
	R2 stability σ(R2)/<R2>	1.00E-03	1.00E-04
	Plate scale	0.10 "	0.100 "
NISP Channel	rEE50 (@1486nm)	400 mas	225 mas
	rEE80 (@1486nm)	700 mas	584 mas
	Plate scale	0.30 "	0.299 "
Sensitivity			
VIS SNR (for mAB = 24.5 sources)		10	16.99
NISP-S SNR (@ 1.6um for 2xe-16 erg cm-2		3.5	4.81
NISP- P SNR (for mAB = 24 sources)	Y-band	5	5.89
	J-band	5	6.69
	H-band	5	5.34
NISP-S Performance			
Purity		80%	72%
Completeness		45%	52%
Survey			
Wide Survey Coverage		15,000 deg2	15,000
Survey length [years]		5.5	5.4

Euclid performances meet the scientific and survey requirements

- Image quality of the system fully in line with needs.
- Ellipticity, R^2 stability and Non-convolutive errors performance dictated mainly by ground processing
- *Purity* not compliant with current data processing methods but expected to be recovered with Euclid specific algorithms (not yet installed at this stage).

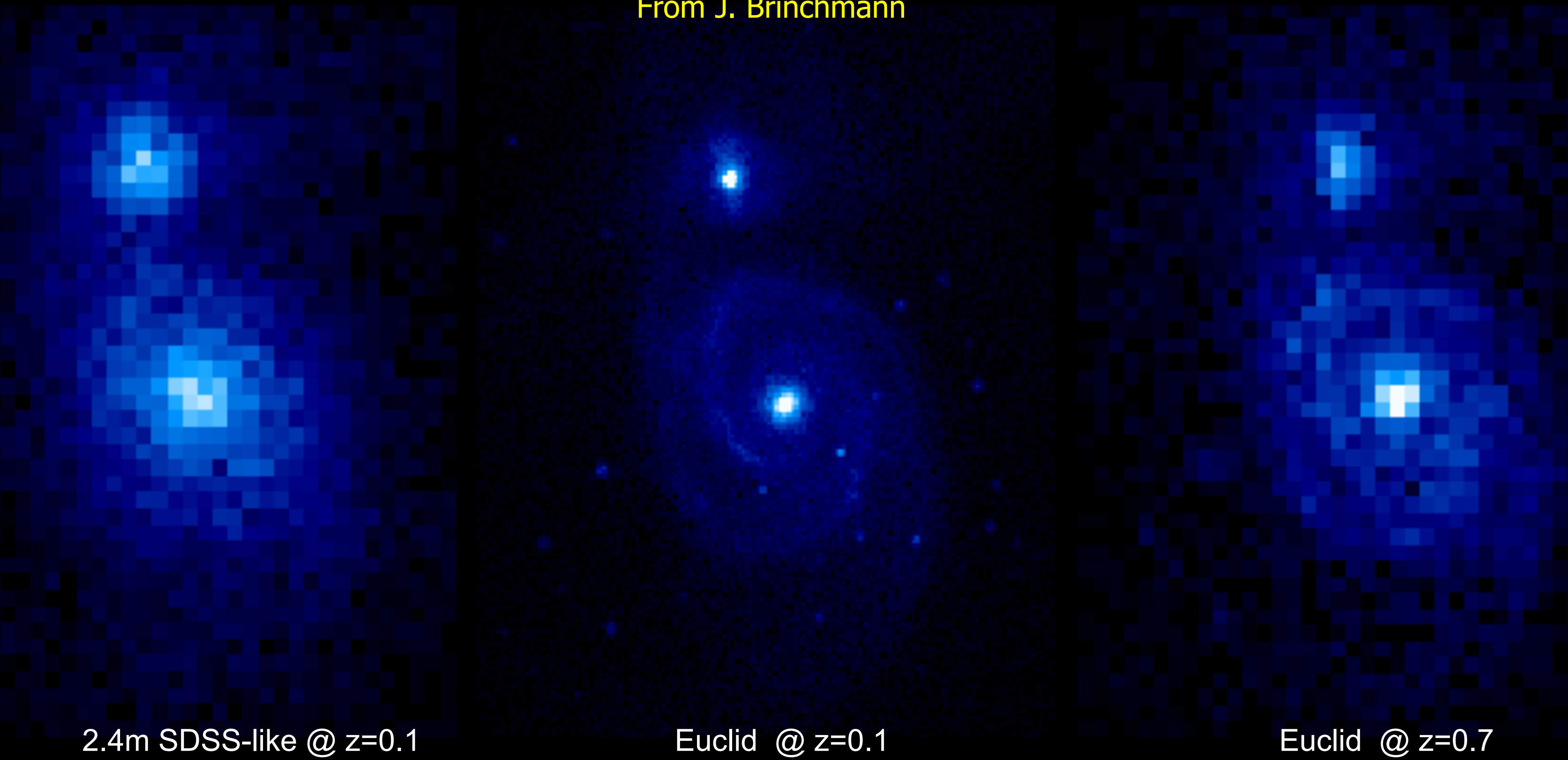
From R. Laureijs and ESA PO

Euclid : VIS imaging instrument



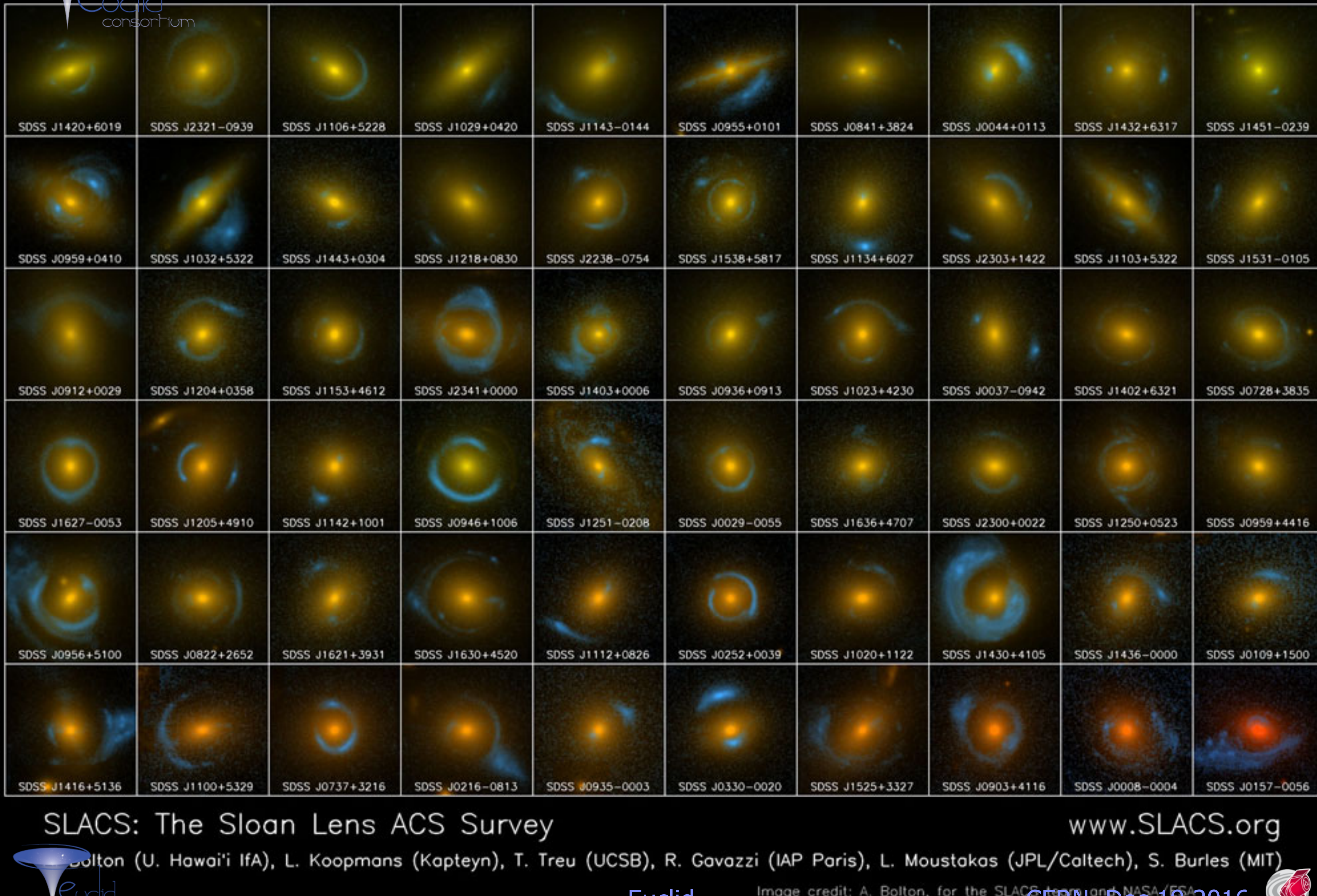
VIS: Simulation of M51

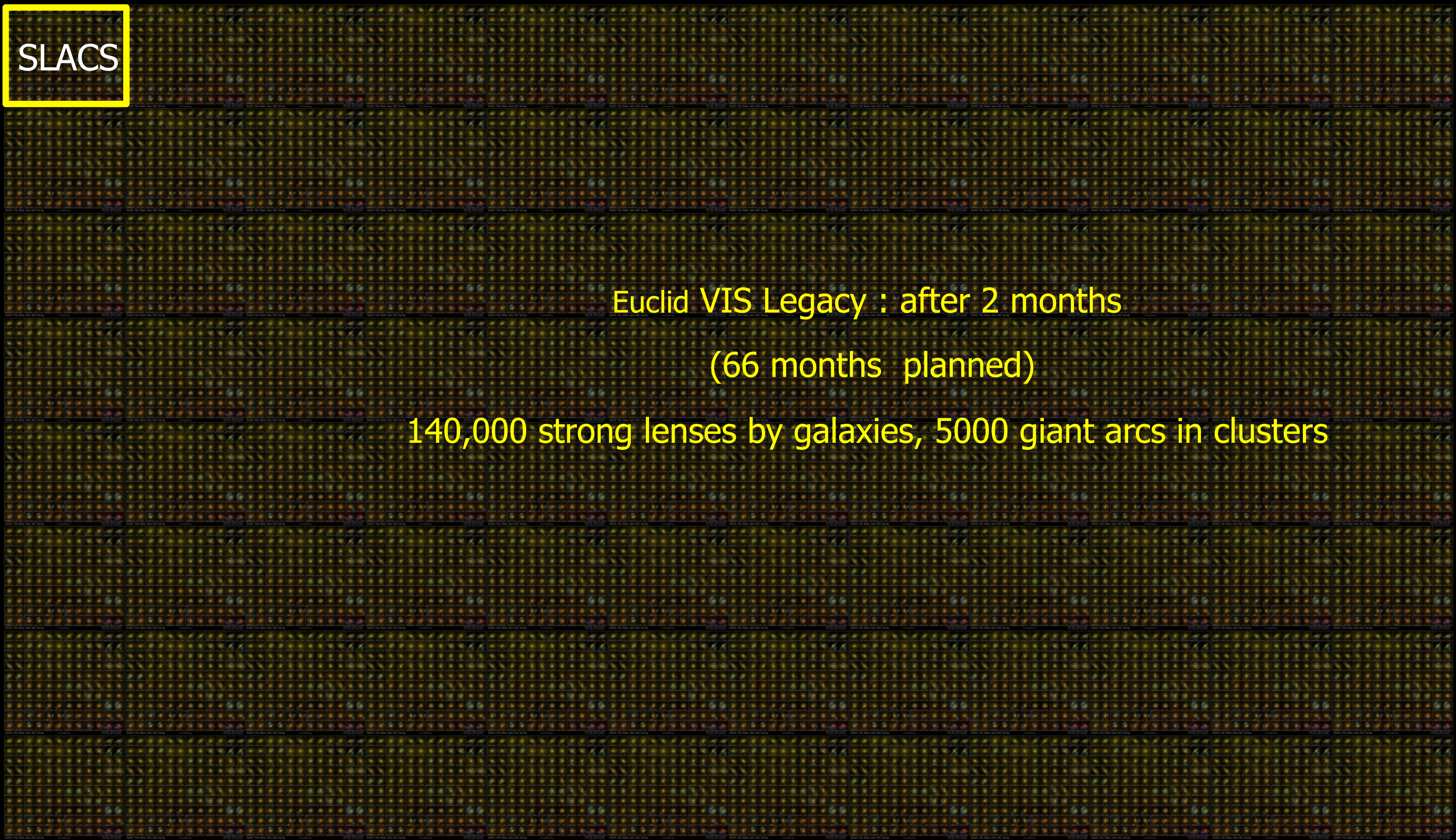
From J. Brinchmann



- Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.
- Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

SLACS (~2010 - HST): gravitational lensing by galaxies

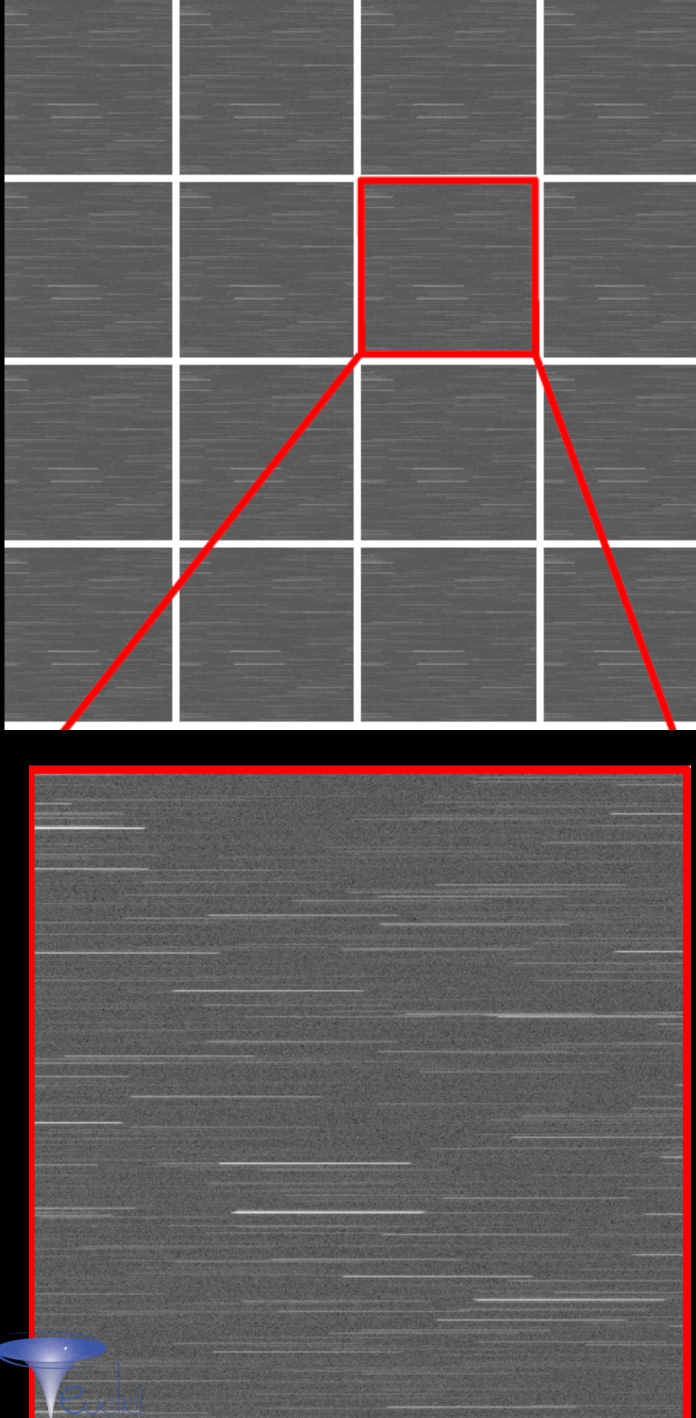




Euclid VIS Legacy : after 2 months

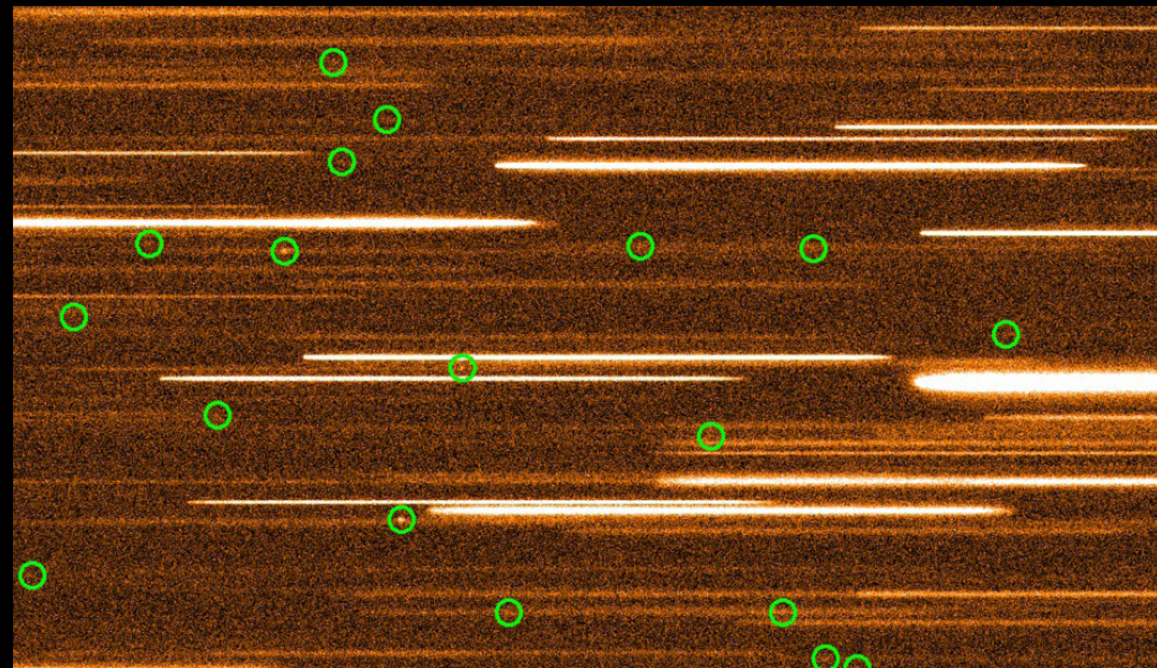
(66 months planned)

140,000 strong lenses by galaxies, 5000 giant arcs in clusters



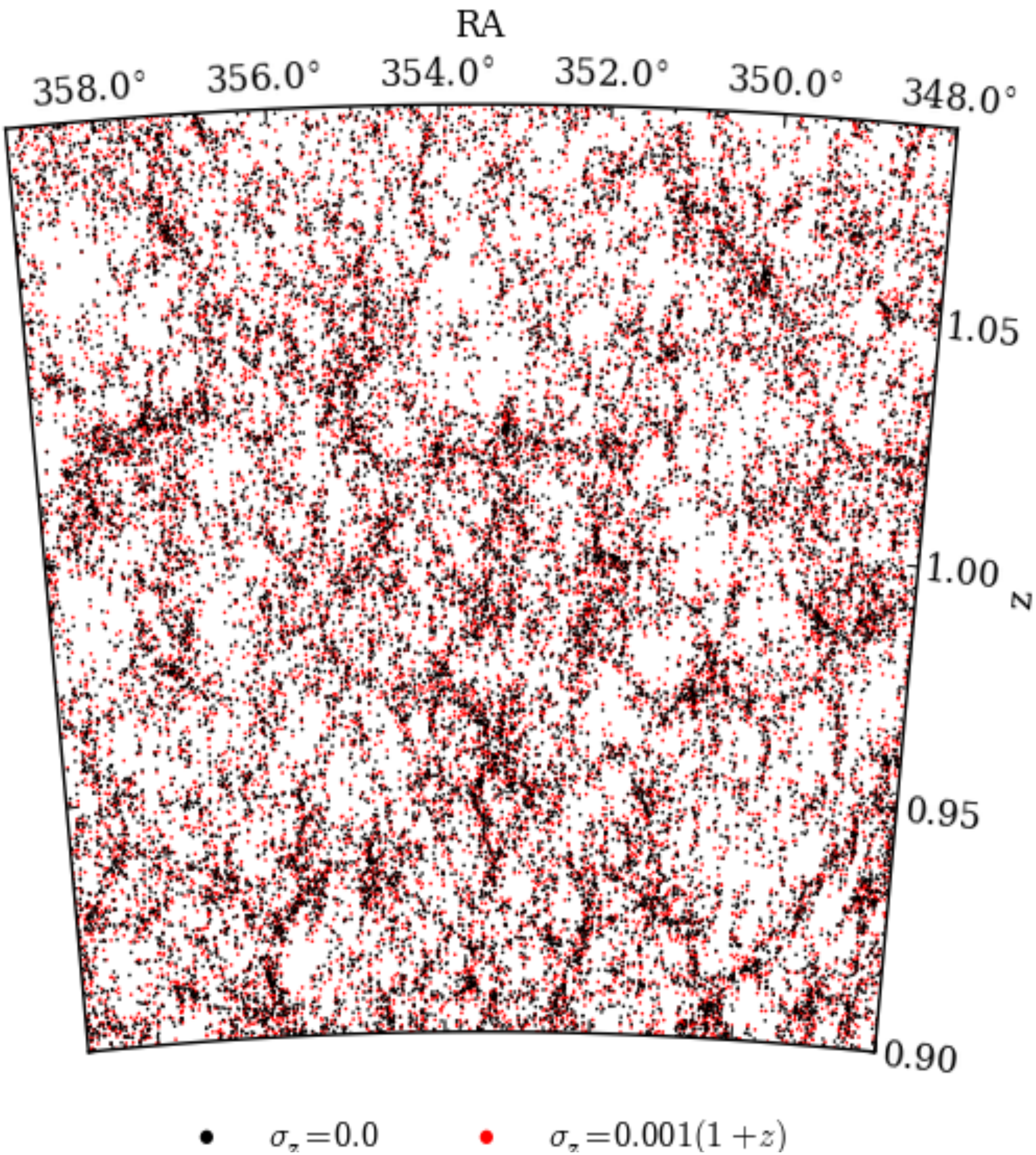
NISP-spectroscopy for Euclid (2015)

From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. Zoubian



35 million spectra with at least 3 exposures taken with 3 different orientations and a total exposure time of 4000 sec.

Euclid NISP: from original spectral images to redshifts

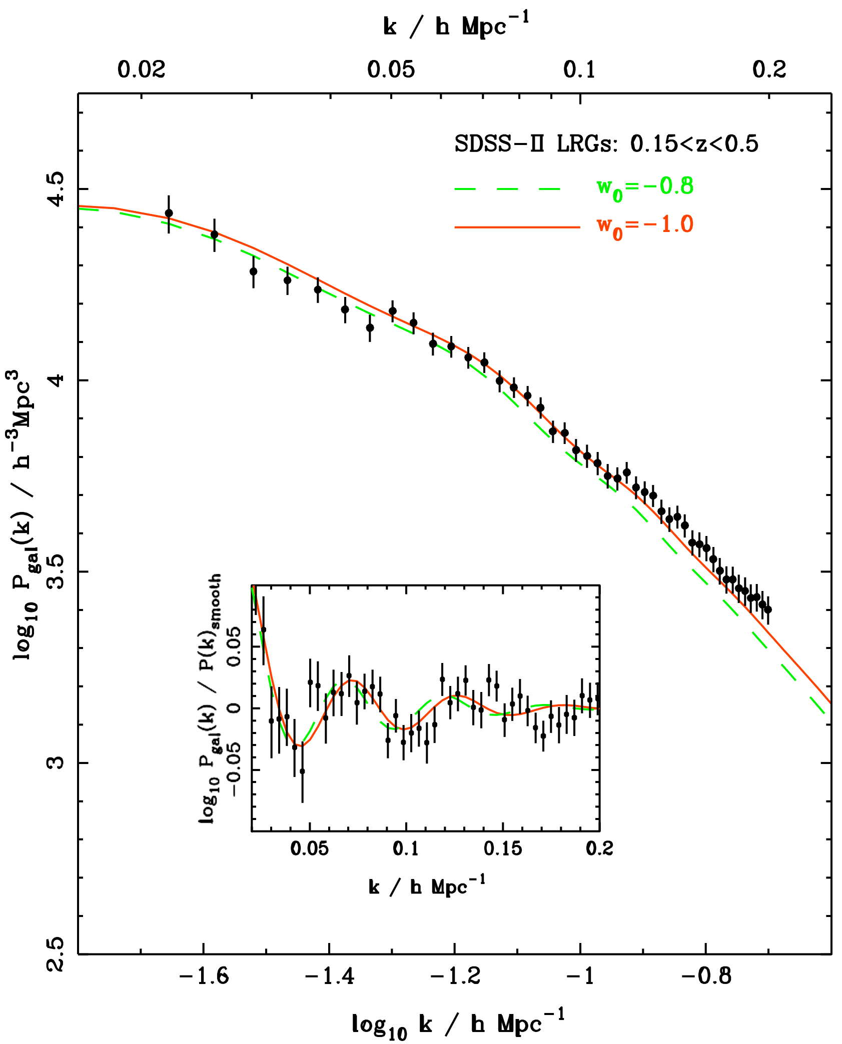


True vs. Measured redshift

From A. Ealet, B. Garilli, W. Percival, L. Guzzo and the NISP and SWG GC, and Baugh and Merson

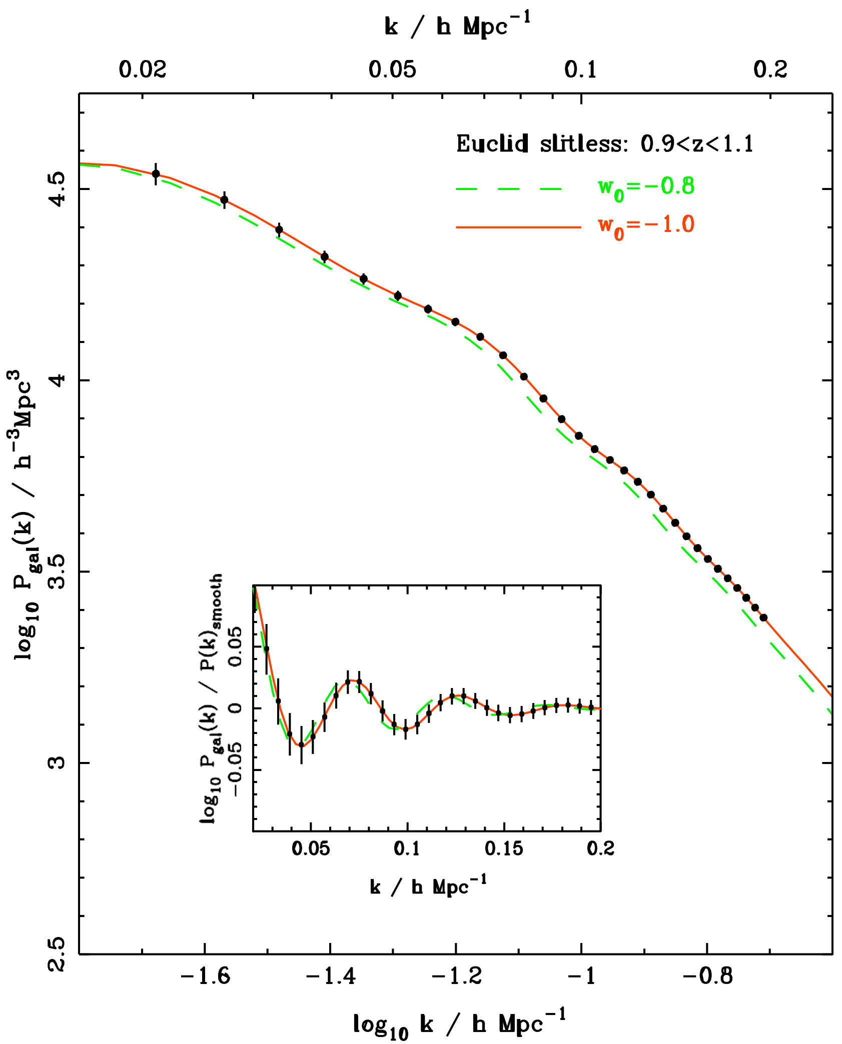
Euclid vs SDSS : BAO

SDSS today



0.15<z<0.5

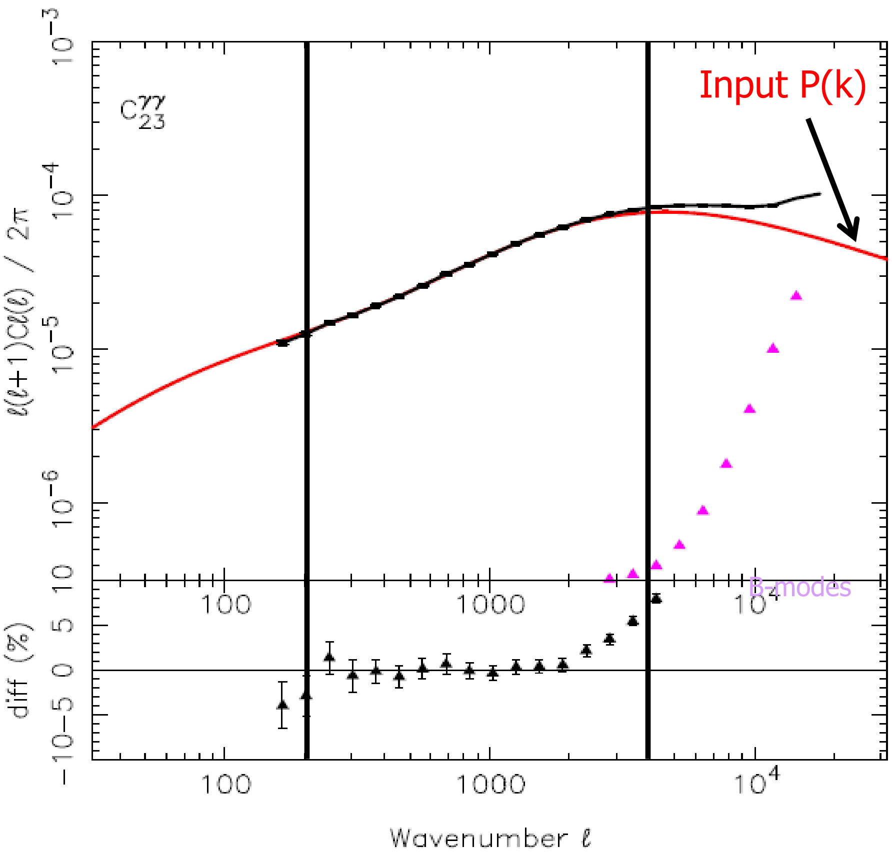
Euclid (20% of Euclid data)



0.7<z<2.0

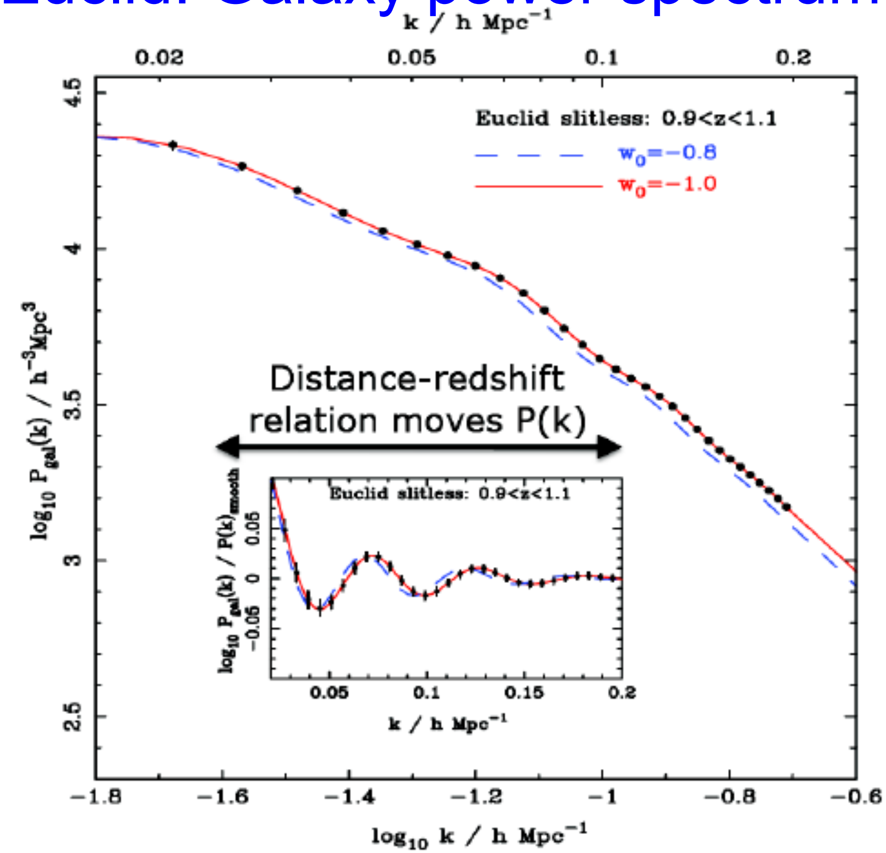
Euclid: combining WL and GC data

Euclid : DM power spectrum



- Tomographic WL shear cross-power spectrum for 0.5 < z < 1.0 and 1.0 < z < 1.5 bins.
- Percentage difference [*expected – measured*] power spectrum: recovered to 1% .

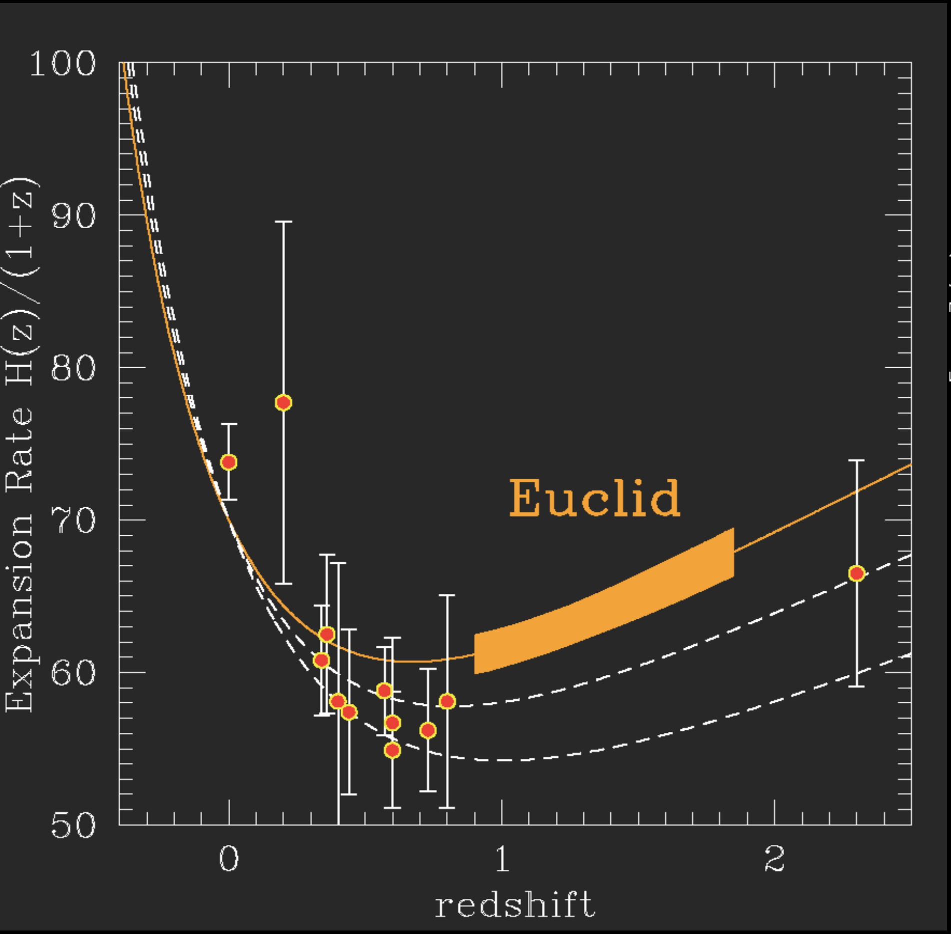
Euclid: Galaxy power spectrum

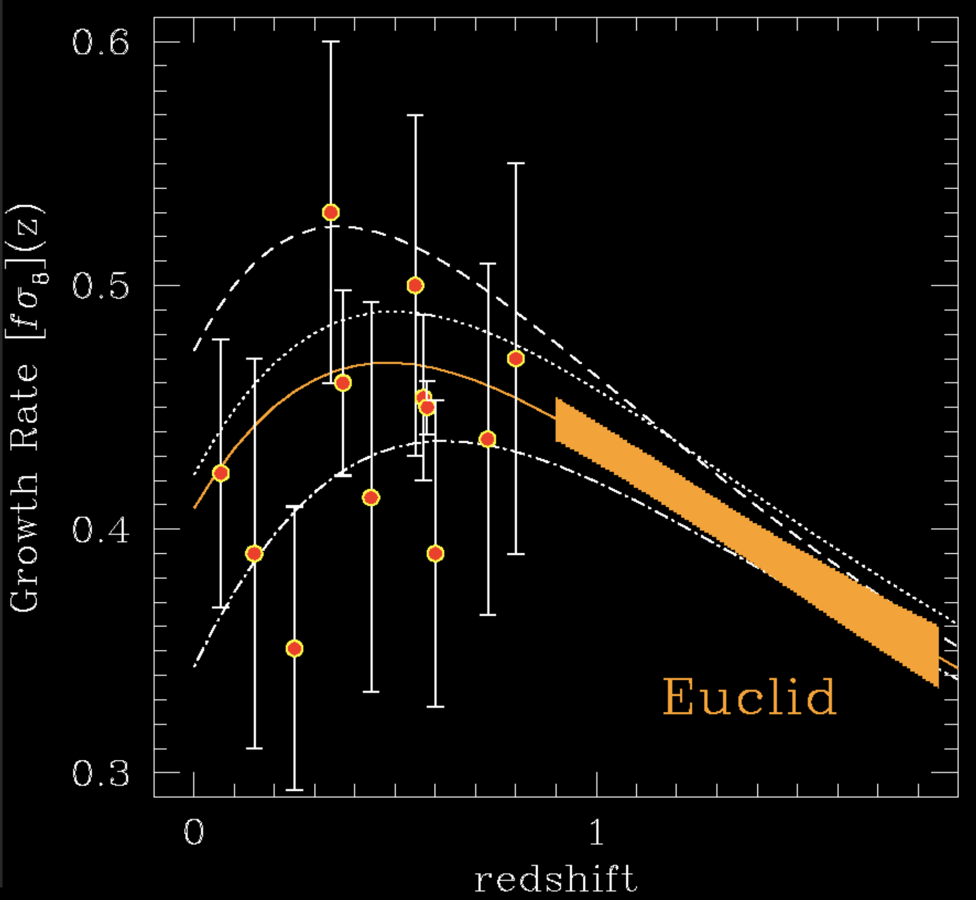


- $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx 75$x larger than SDSS
- Redshifts 0.7<*z*<1.85
- Percentage difference [*expected – measured*] power spectrum: recovered to 1% .

From the SWG-WL and SWG-GC groups

Exploration of DE models with Euclid (redshifts only)





From R. Guzzo and the SWG-GC group 2016

Clusters of galaxies with Euclid

- Probe of peaks in density distribution
- Nb density of high mass, high redshift clusters very sensitive to
  - primordial non-Gaussianity and
  - deviations from standard DE models
- Euclid data will get for free:
  - Λ-CDM: all clusters with M>2 10^{14} Msol detected at 3-σ up to z=2

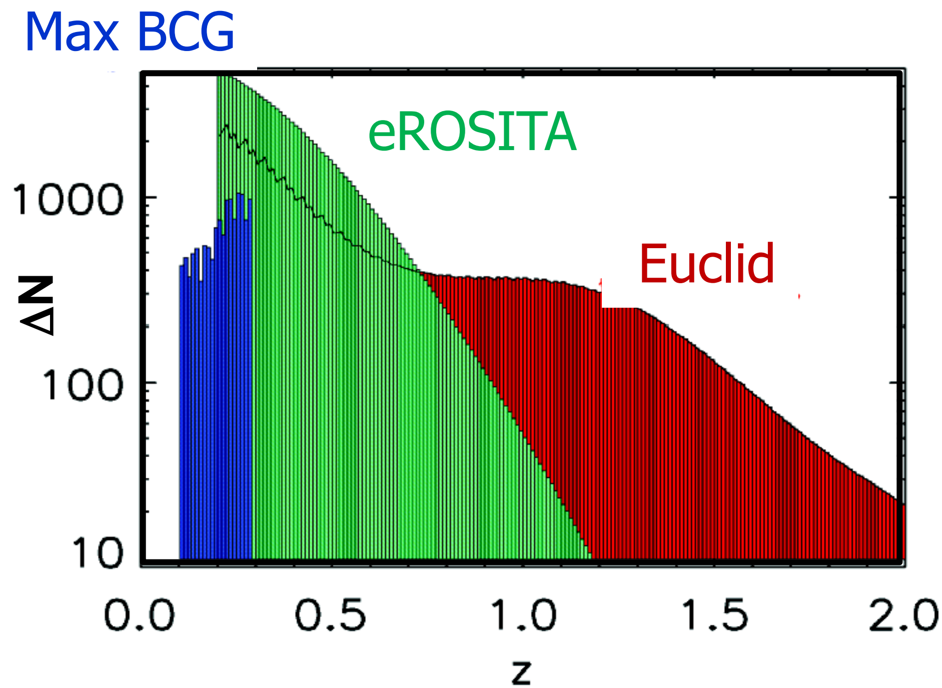
    → 60,000 clusters with 0.2<*z*<2 ,

    → 1.8 10^4 clusters at *z*>1.
  - ~ 5000 giant gravitational arcs

    → Very accurate masses for the whole sample of clusters (WL)

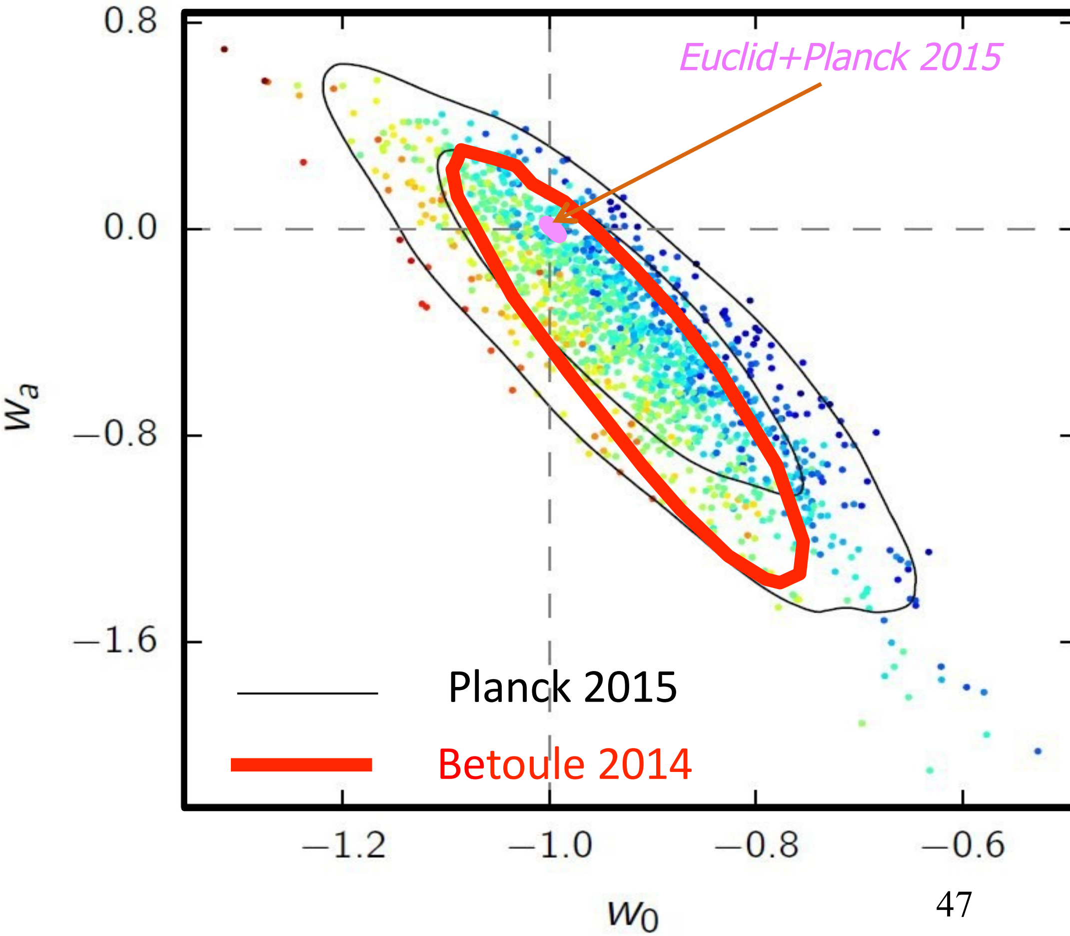
    → dark matter density profiles on scales >100 kpc

Synergy with Planck and eROSITA



Euclid Post-Planck :

Forecast for the Primary Program



Dark Energy		
w_p	w_a	FoM
0.015	0.150	430
0.013	0.048	1540
0.007	0.035	**6000**
0.100	1.500	~10
>10	>40	>400

Euclid Post-Planck Forecast for the Primary Program

Ref: Euclid RB arXiv: 1110.3193	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
EuclidAll (clusters,ISW)	**0.009**	**0.020**	**2.0**	**0.013**	**0.048**	**1540**
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	**6000**
Current (2009)	**0.200**	**0.580**	**100**	**0.100**	**1.500**	**~10**
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Laureijs et al 2011

DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$

From Euclid data alone, get FoM=1/(Δw_a x Δw_p) > 400→ ~1% precision on w's.

Growth rate of structure formation: $f \sim \Omega^{\gamma}$; .

Notice neutrino constraints -> minimal mass possible ~ 0.05 eV

Euclid forecast: neutrinos and relativistics species

Amendola et al 2013

	General cosmology					
fiducial →	$\Sigma = 0.3\,\mathrm{eV}^a$	$\Sigma = 0.2\,\mathrm{eV}^a$	$\Sigma = 0.125\,\mathrm{eV}^b$	$\Sigma = 0.125\,\mathrm{eV}^c$	$\Sigma = 0.05\,\mathrm{eV}^b$	$N_{\mathrm{eff}} = 3.04^d$
EUCLID+Planck	0.0361	0.0458	0.0322	0.0466	0.0563	0.0862
	ΛCDM cosmology					
EUCLID+Planck	0.0176	0.0198	0.0173	0.0218	0.0217	0.0224

Amendola et al 2016

^{a} for degenerate spectrum: $m_1 \approx m_2 \approx m_3$; ^{b} for normal hierarchy: $m_3 \neq 0$, $m_1 \approx m_2 \approx 0$
^{c} for inverted hierarchy: $m_1 \approx m_2$, $m_3 \approx 0$; ^{d} fiducial cosmology with massless neutrinos

- **If Σ >0.1 eV**

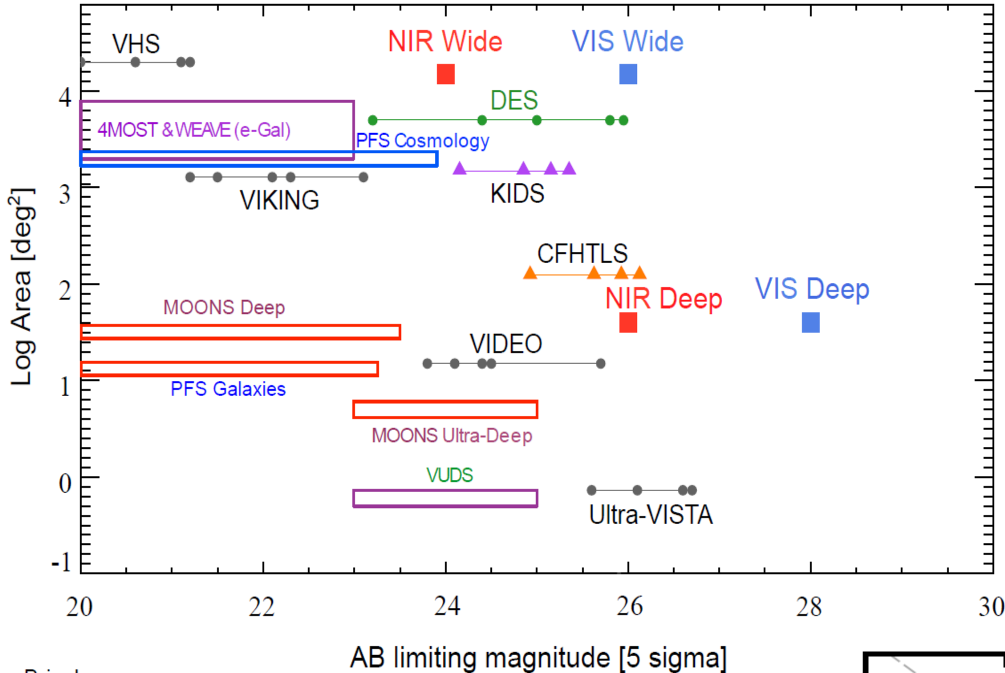
→ Euclid spectroscopic survey will be able to determine the neutrino mass scale independently of the model cosmology assumed.

- **If Σ <0.1 eV**

→ the sum of neutrino masses, and in particular the minimum neutrino mass required by neutrino oscillations, can be measured in the context of the ΛCDM

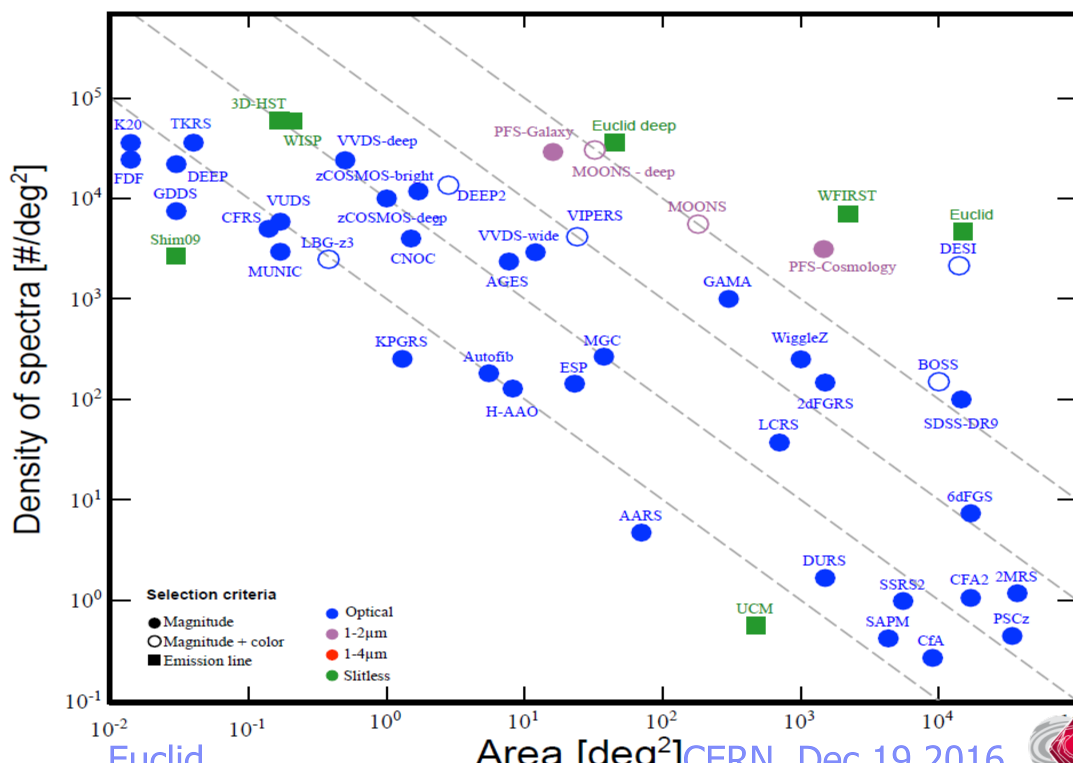
Euclid in the competition

Euclid and other surveys



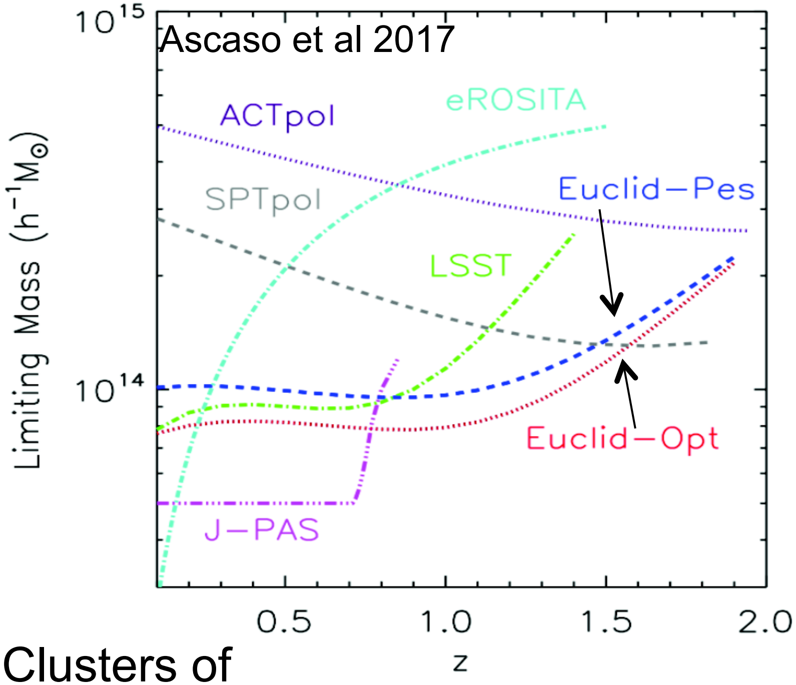
From Brinchmann

Imaging surveys



Spectroscopic surveys

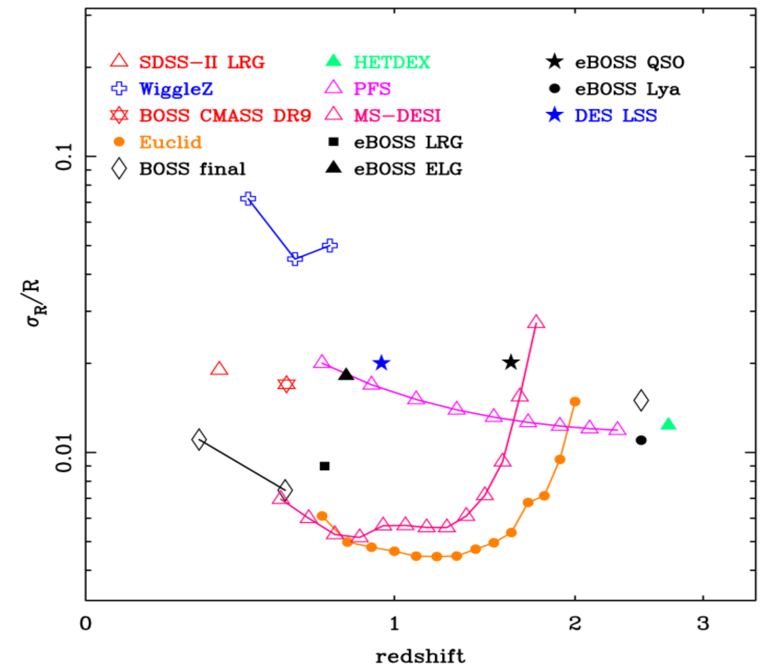
Euclid and competition



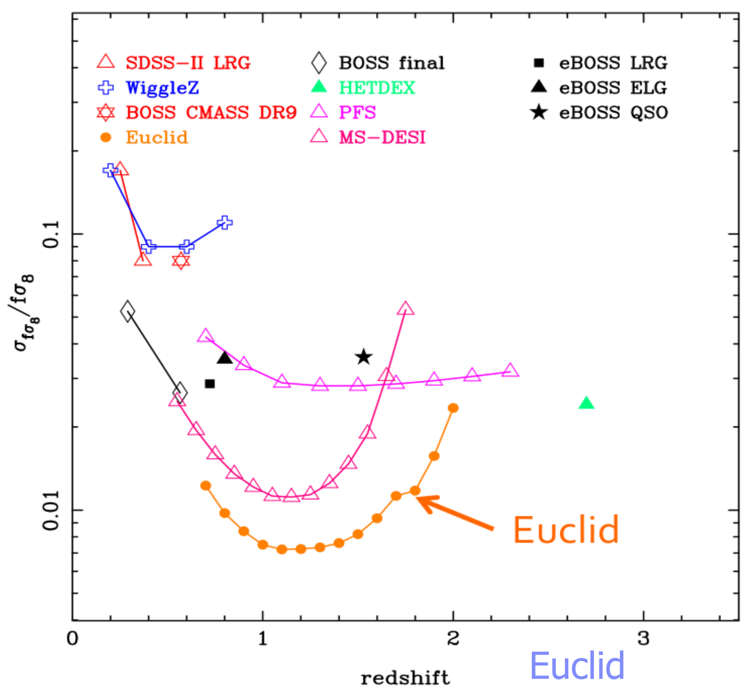
Clusters of galaxies:

WL masses

BAO: Euclid spectra

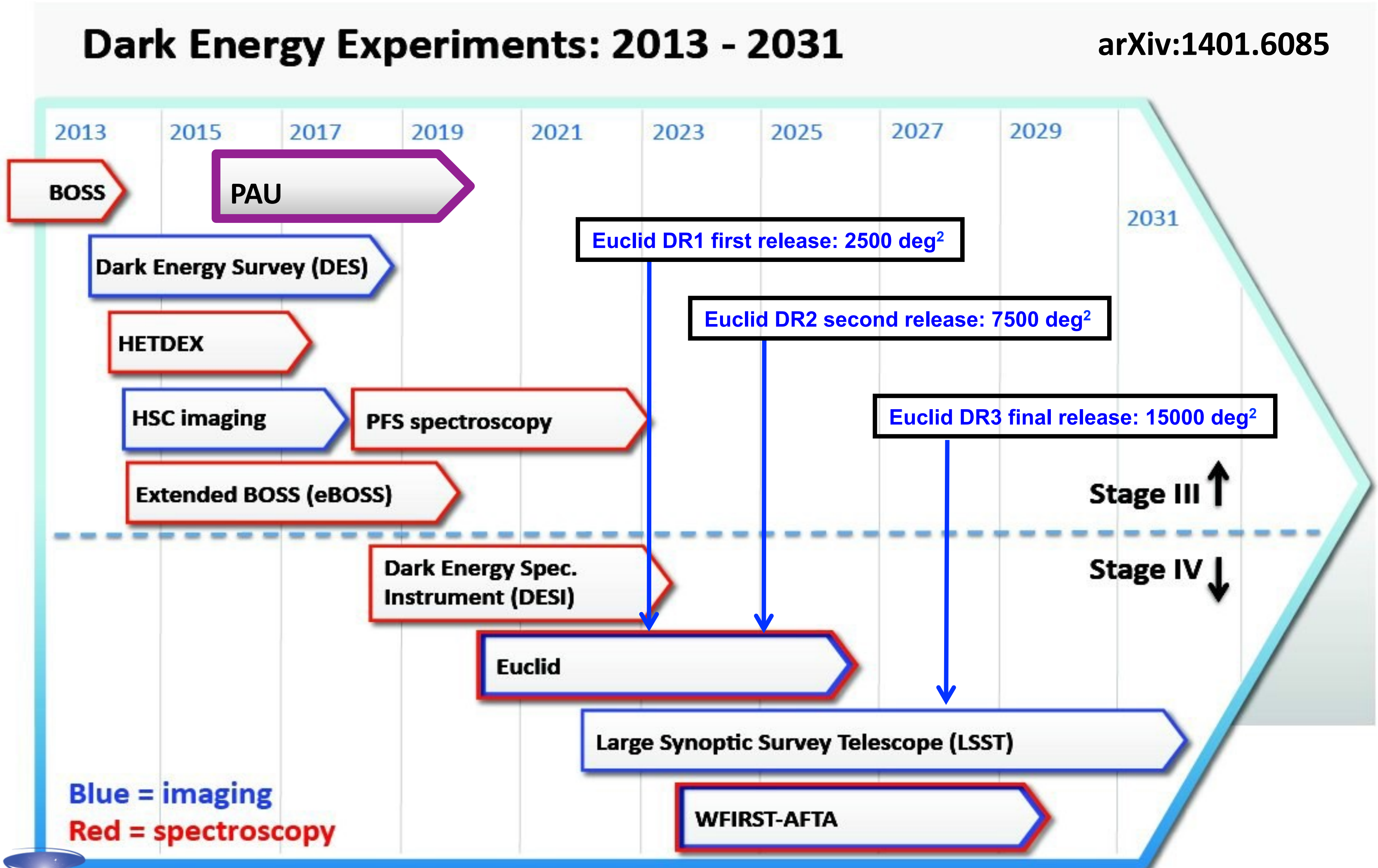


From Euclid SWG-GC group 2015



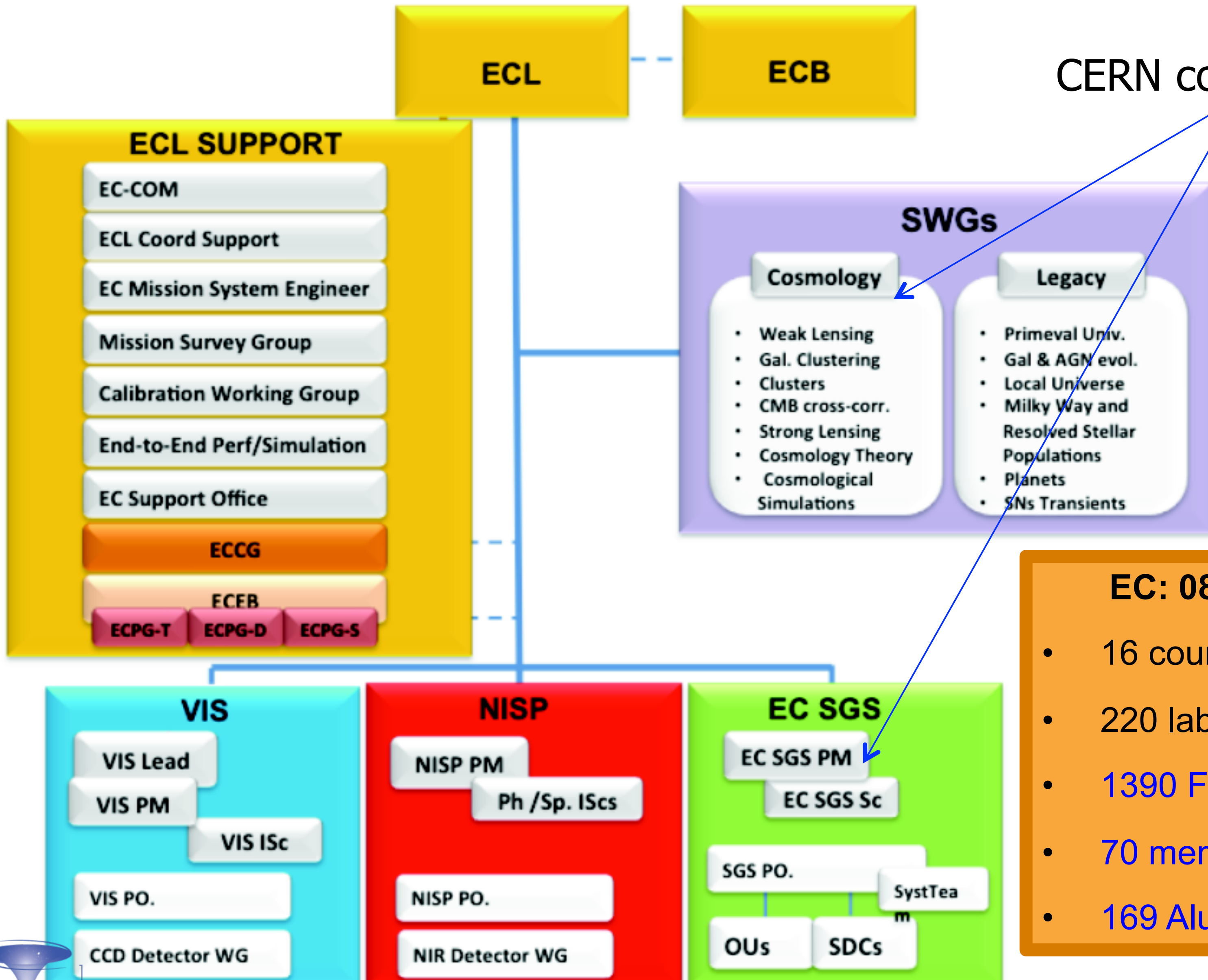
RSD: Euclid spectra

Current and future projects



Summary

Euclid Consortium Organisation



CERN contributions

EC: 08 Dec 2016:

- 16 countries (Canada)
- 220 labs (with CERN)
- 1390 Full members
- 70 member at Large
- 169 Alumni

Summary

- Euclid cosmology core program:
  - Use 5 cosmological probes, with at least 2 independent, and 3 power spectra
  - Perfect complementarity with Planck: probes and data, cosmic periods
  - Explore the dark universe: DE, DM (neutrinos), MG, inflation, biasing, baryons
  - Explore the transition DM-to-DE-dominated universe period
  - Get the percent precision on w and the growth factor γ
  - Synergy with New Gen wide field surveys: LSST, WFIRST, e-ROSITA, SKA
  - Provide 140,000 strong lenses → properties of DM haloes and dwarf galaxies, galaxies, groups, clusters of galaxies scales in the range of redshift $0. < z < 2$
- Euclid =12 billion sources, 35 million redshifts, 1.5 billion shapes/photo-z of galaxies;
  - A mine of images and spectra for the community for years;
  - A reservoir of targets for JWST, E-ELT, TMT, ALMA, VLT
  - A set of astronomical catalogues useful until 2040+
- Launch 2020, start 2021: **2500 deg^2 public in 2023**, 7500 deg^2 in 2025, final 2027


Thank You!