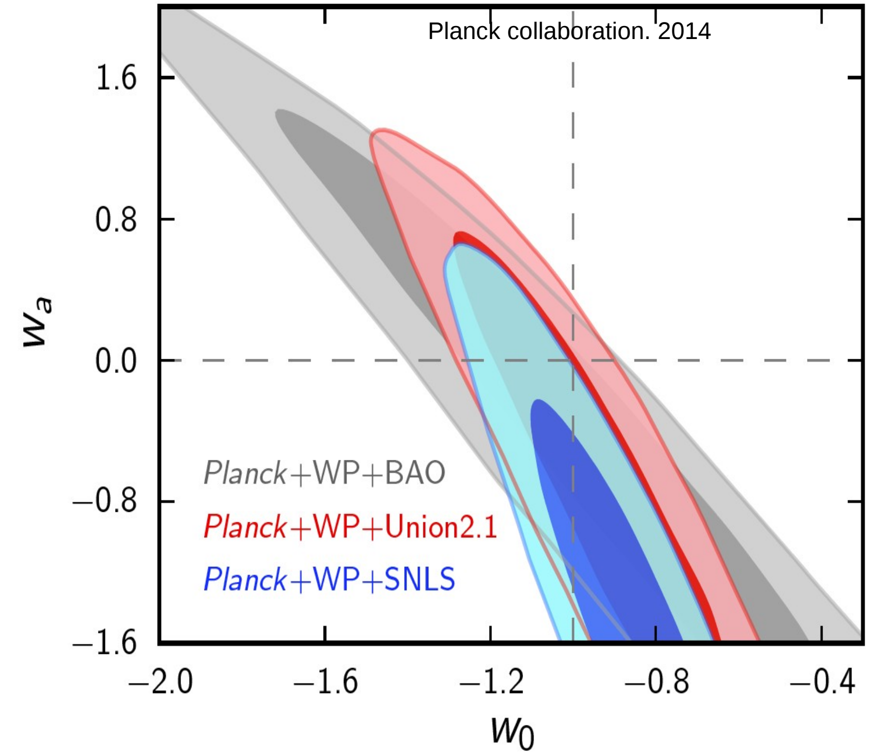
Cosmological surveys: from Planck to Euclid

Nabila Aghanim

Institut d'Astrophysique Spatiale
On behalf of the Euclid Consortium

The dark universe after Planck

A post-Planck concordance cosmology with two puzzling ingredients: dark matter & **dark energy** → acceleration of expansion



- Dark Energy: new component opposing gravitation on cosmological scales, as a negative pressure?
- Modified Gravity: Einstein's GR is not a good description of gravitation on cosmic scales?

Parameterising our ignorance:

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

Growth rate of structure formation: $f \sim \Omega^{\gamma}$; $\gamma = 0.55 = \mathrm{GR}$

- **After Planck:** *w* may be -1, may vary with time … (cf talk by Pettorino)

Planck cannot probe its nature/effects in detail → different cosmological probes:

- Expansion rate (BAO, Galaxy clustering)
- Distances (SN, BAO)
- Growth rate (Weak Lensing, clusters, iSW)

Primary Objectives of Euclid ESA mission: the Dark Universe

- Understand the origin of the accelerating expansion
- Probe the properties and nature of Dark Energy and Gravity
  - Distinguish effects of Λ and dynamical DE: Measure *w(a)* → slices in redshift
  - Probe the growth of structures and distinguish effects of GR from MG models → slices in redshift
  - Separately constrain the metrics potentials (Ψ,Φ) as function of scale and time

- Probe effects of Dark Energy, Dark Matter and Gravity by:
  - Using at least 2 independent but complementary probes : WL, GC (5 probes in total)
  - Tracking their observational signatures on the Geometry of the universe and Cosmic history of structure formation
  - Controling systematic residuals to an unprecedented level of accuracy

Requirements to design the mission

	Wide survey	**Deep survey**
Survey: 6 years		
size	15, 000 deg ^{2}	40 deg^2 N/S
VIS imaging		
Depth	n_{gal} > 30/arcmin^2 M_{AB} =24.5, 10σ for gal size 0.3 » → <z> ~0.9	M_{AB} = 26.5
PSF size knowledge	$\sigma[R^2]/R^2<10^{-3}$	
Multiplicative bias in shape	$\sigma[m]<2\ .10^{-3}$	
Additive bias in shape	$\sigma[c]<2\ .10^{-4}$	
Ellipticity RMS	$\sigma[e]<2\ .\ 10^{-4}$	
NIP photometry: YJH		
Depth	24 M_{AB}	26 M_{AB}
NIS spectroscopy: 4 R exp., 3 R orientations		
Flux limit (erg/cm^2/s)	2 10^{-16}	5 10^{-17}
Completness	> 45 %	>99%
Purity	>80%	>99%
Confusion	3 rotations	>12 rotations

WL and systematics

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

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

- Small PSF, Knowledge of the PSF size
- Knowledge of distortion
- Stability in time → space telescope
- Photo-z accurary: 0.05x(1+z) ; Catastrophic z < 10%

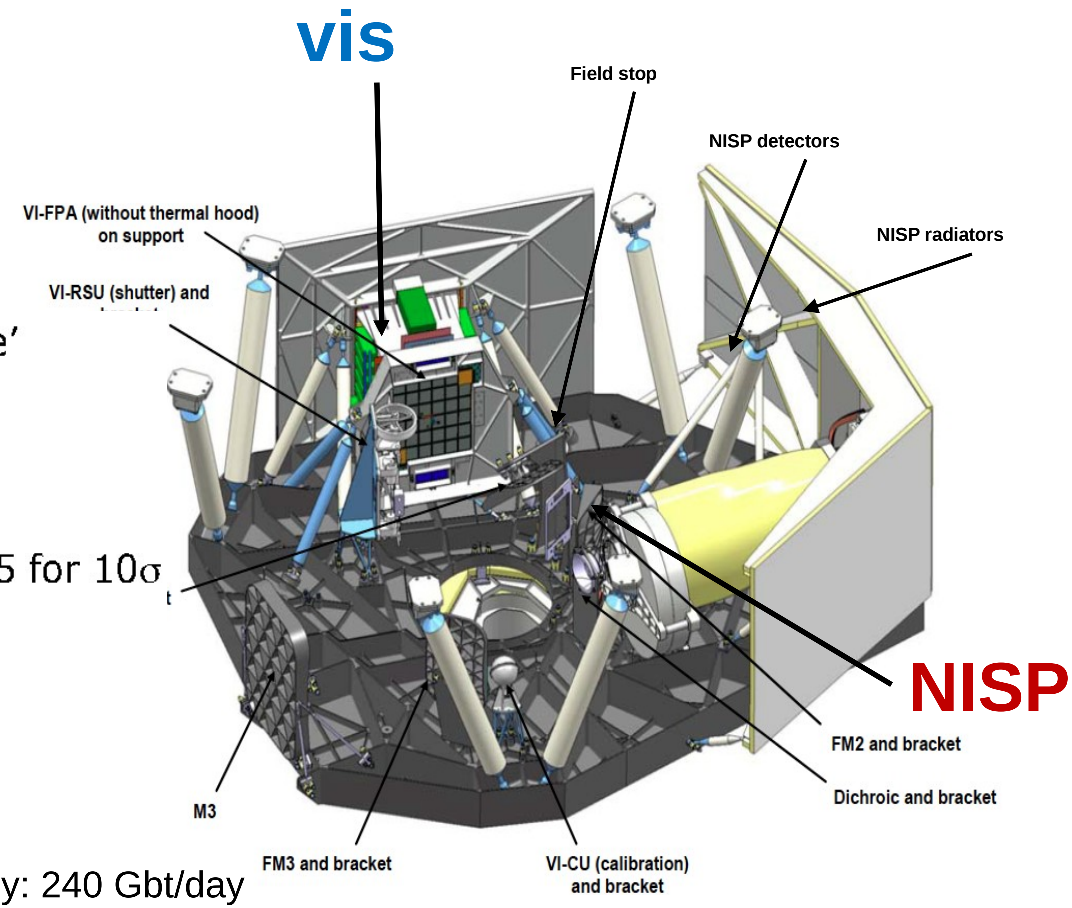
GC and systematics

- Correct for contaminated spectra ; confusion ...
- Understand selection → Deep field (photo+spectro)
  - Completeness
  - Purity

Euclid PLM and scientific instruments

From Thales Alenia Italy, Airbus DS, ESA Project office and Euclid Consortium

Launch Q1 2020 (Soyuz@Kourou)

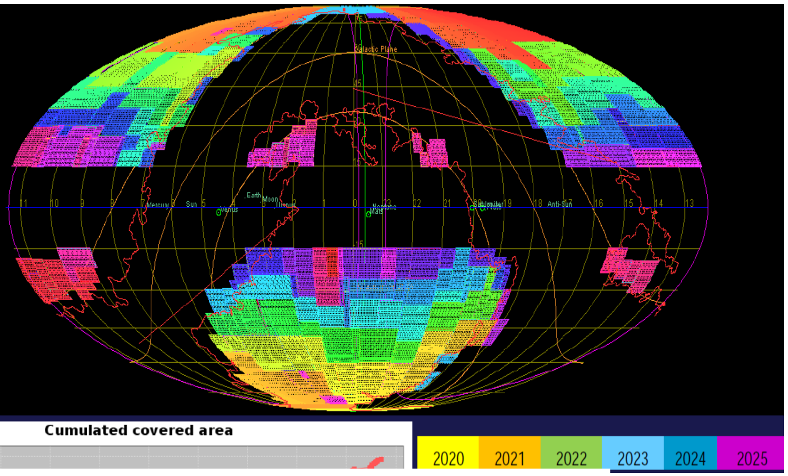


Common VIS and NIR FoV = 0.54 deg^2

VIS

- large area imager – a 'shape measurement machine'
- 36 4kx4k CCDs with 12 micron pixels
- 0.1 arcsec pixels on sky
- bandpass 550-900 nm – narrow band channel
- limiting magnitude for wide survey of magAB = 24.5 for 10σ
- data volume – 520Gbit/day

Survey in 6 years →15,000 deg^2



Courtesy J. Amiaux & survey WG

NISP

- Telemetry: 240 Gbt/day
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky (Wide survey only with R-grism)
- Limiting mag AB for wide survey of magAB 24 (5 °)
- NIR photometry 3 Filters: Y, J, H
- NIR slitless spectroscopy 4 grisms (1100 – 2000nm), 3×10^{-16}ergcm^{-2}s^{-1} 3.5σ line flux

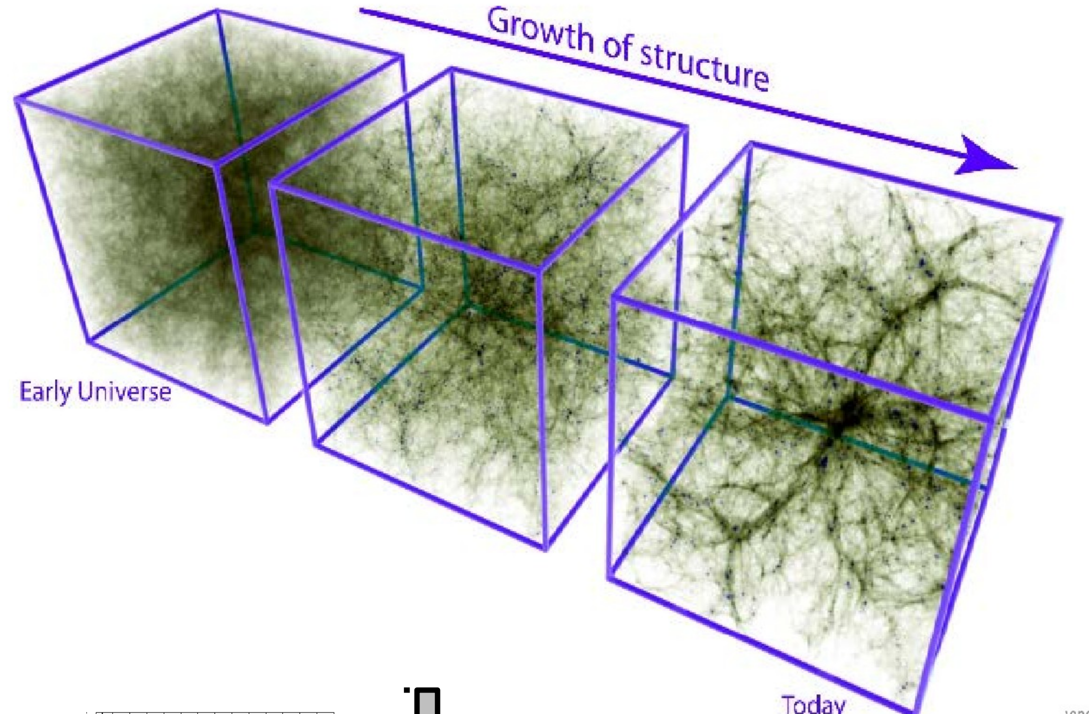
Galaxy Clustering: BAO + RSD

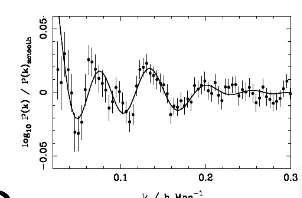
Euclid:

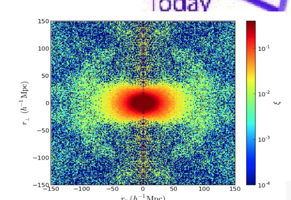
Over 15,000 deg^2 30 million spectroscopic redshifts with 0.001 (1+z) accuracy up to z~2

High precision 3D position distribution of galaxies with spectro-z over 0.7<z<1.8

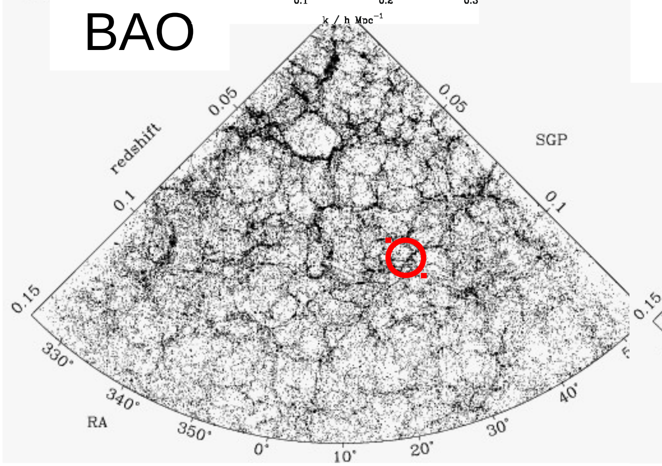
- Measure of BAO in galaxy power spectrum (standard ruler)probes **expansion rate** and of anisotropy of the correlation function (RSD) **clustering history** induced by gravity; $\gamma, H(z)$



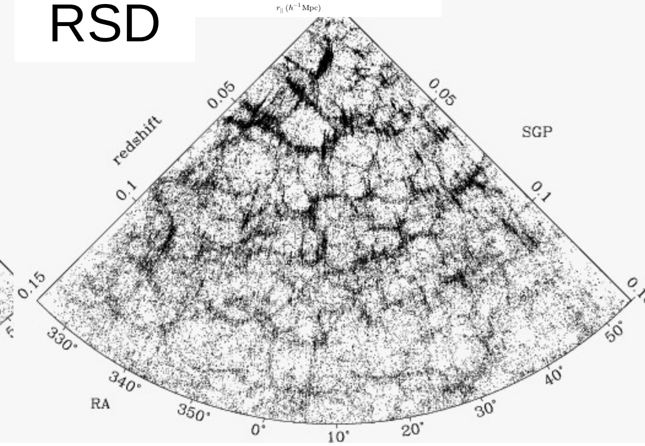




BAO

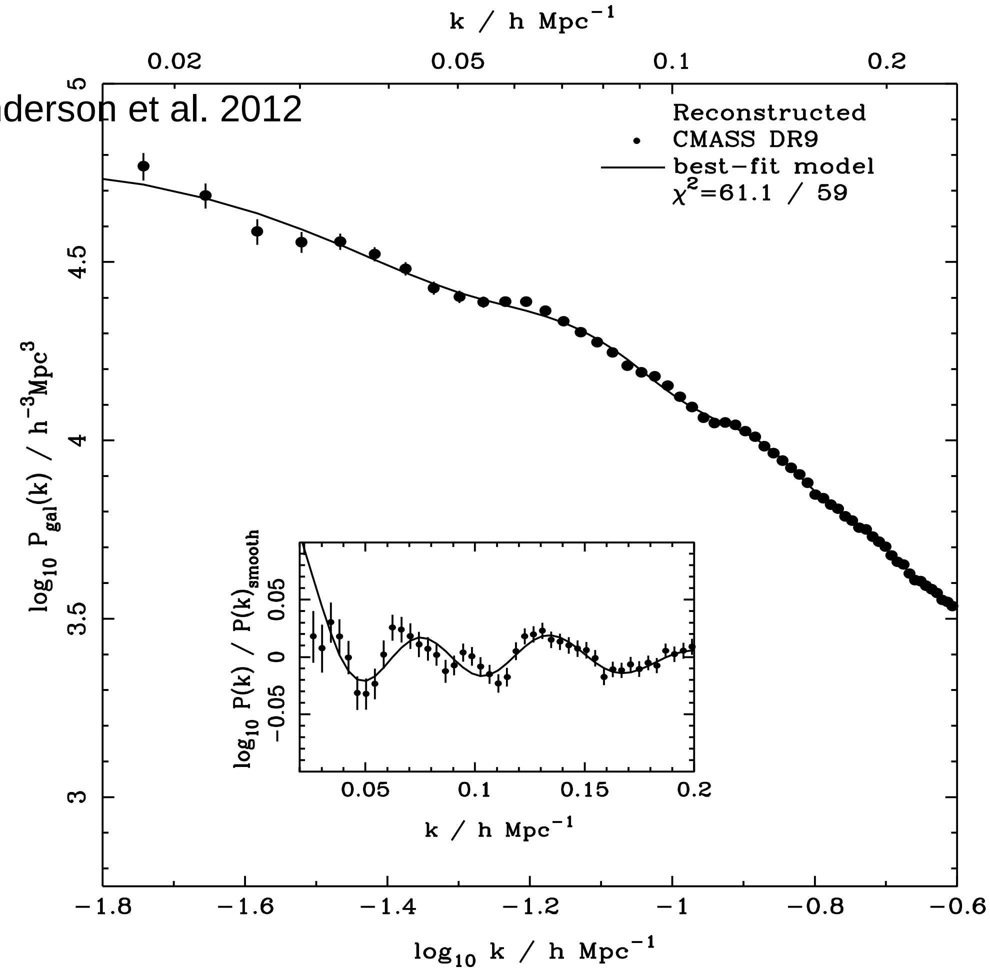


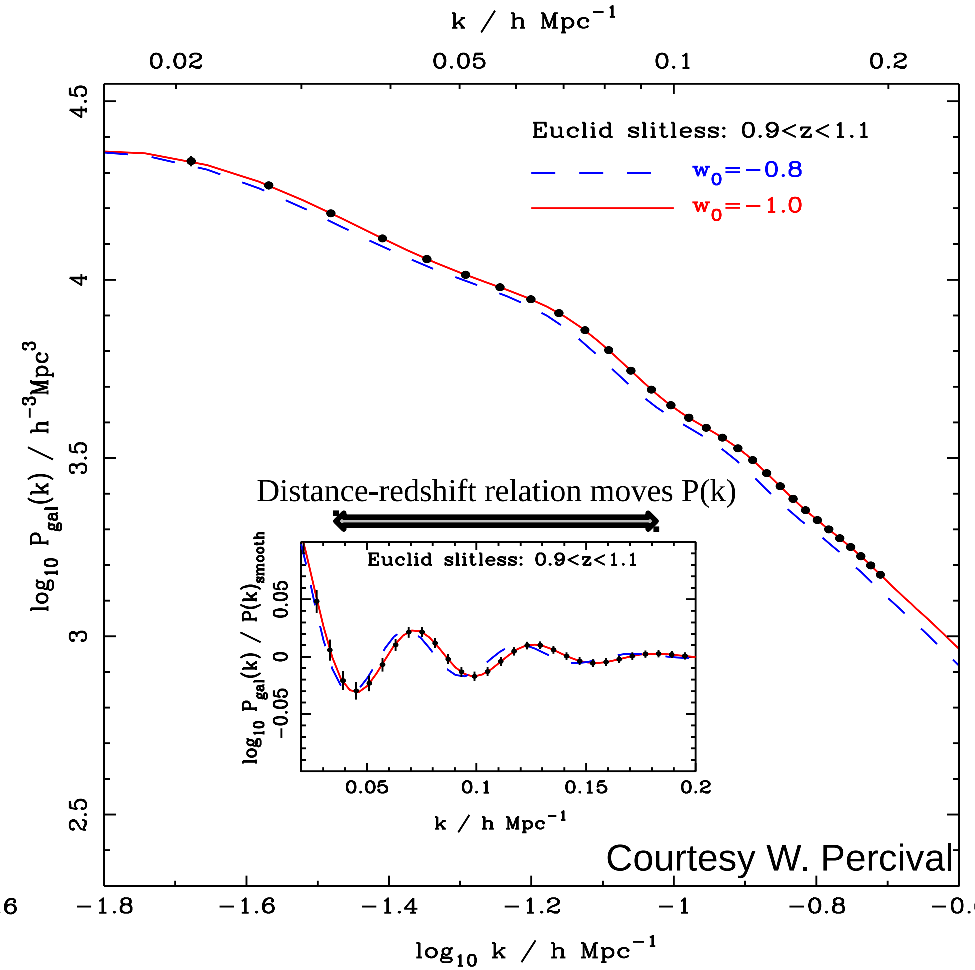
RSD



Galaxy clustering

Anderson et al. 2012





SDSS today

BOSS-CMASS galaxies z~0.57

Total effective volume

V_{eff} = 2.2 Gpc³

Euclid forecast (one redshift bin 0.2)

0.9 < z < 1.1

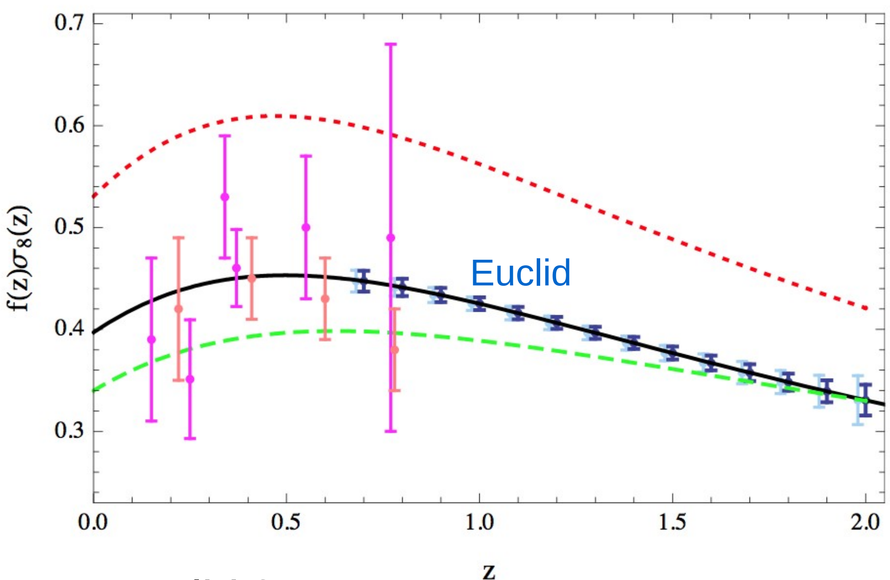
Total effective volume

V_{eff} = 57.4 Gpc³

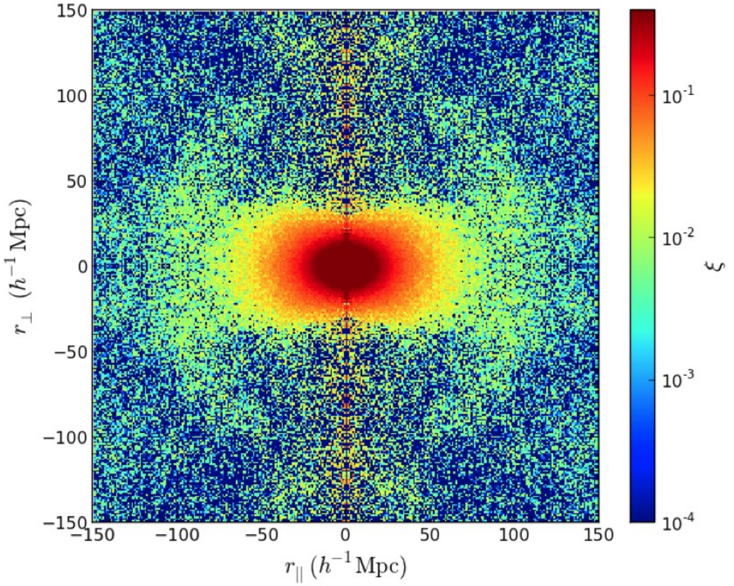
Dark matter power spectrum recovered to 1%

RSD from Euclid redshift survey

RSD as a measure of the growth rate of structure

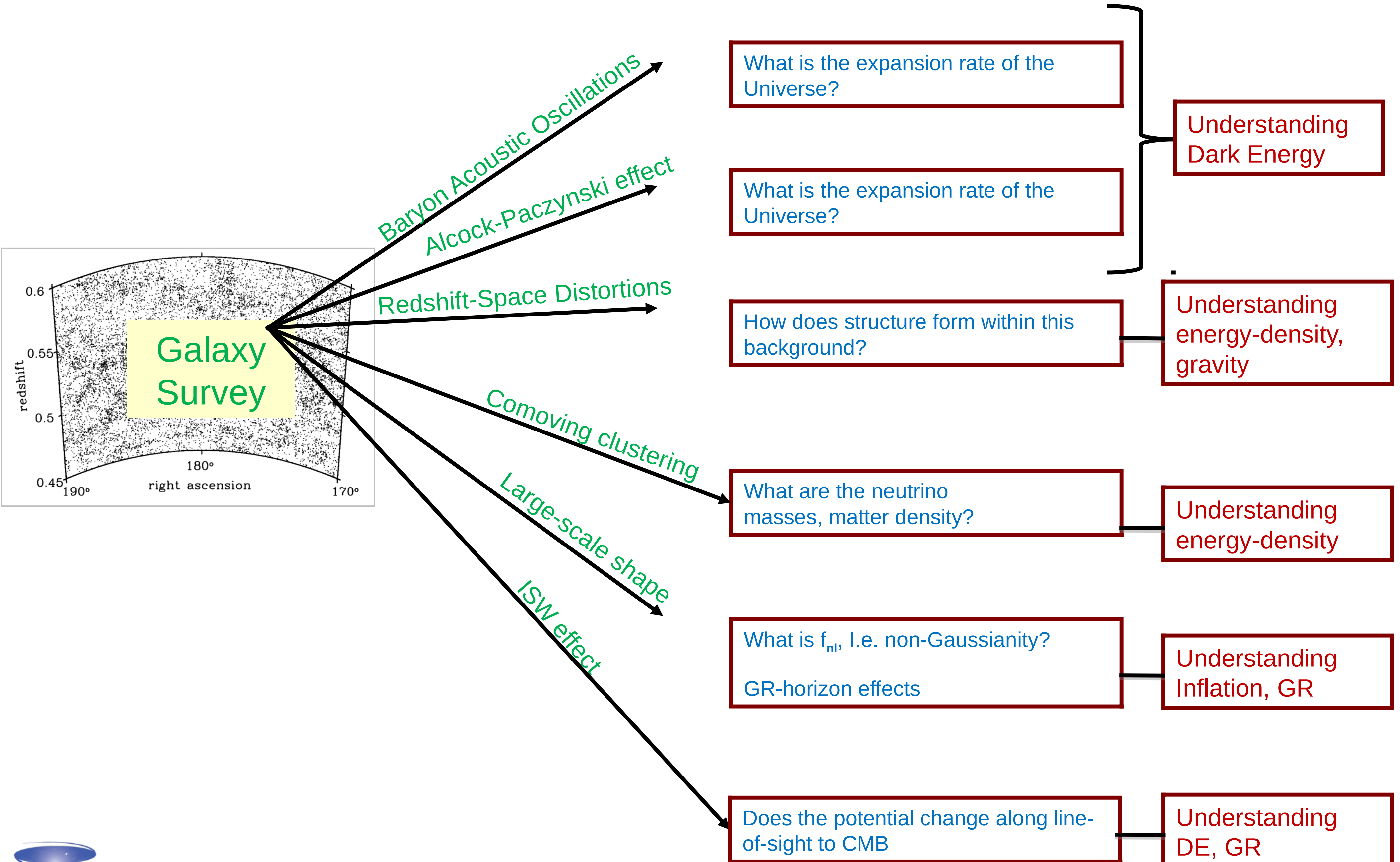


Euclid forecast (Majerotto et al. 2012)



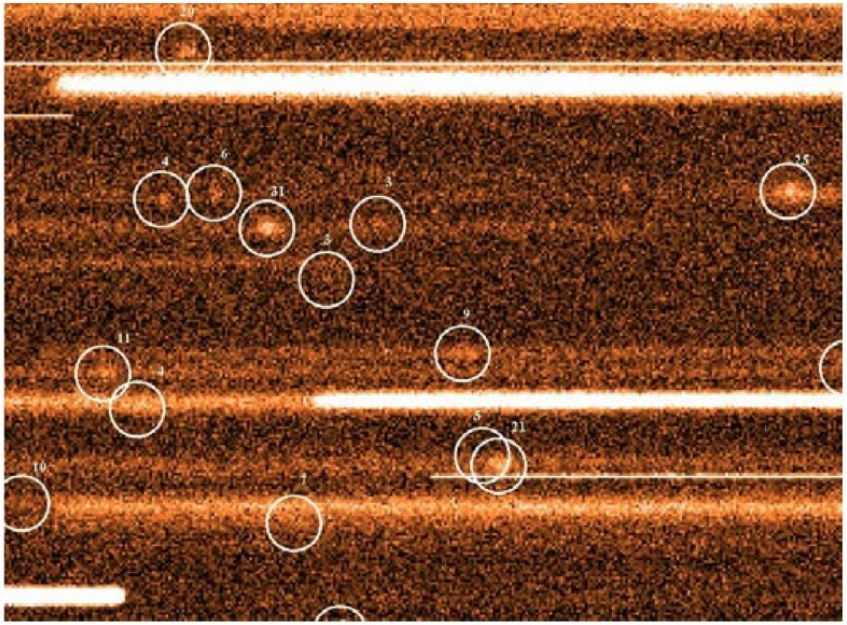
Successful combination of CMB & BAO demonstrated in the Planck analyses discussed in details (cf talk by Freedman)

Cosmology with the Euclid Redshift Survey

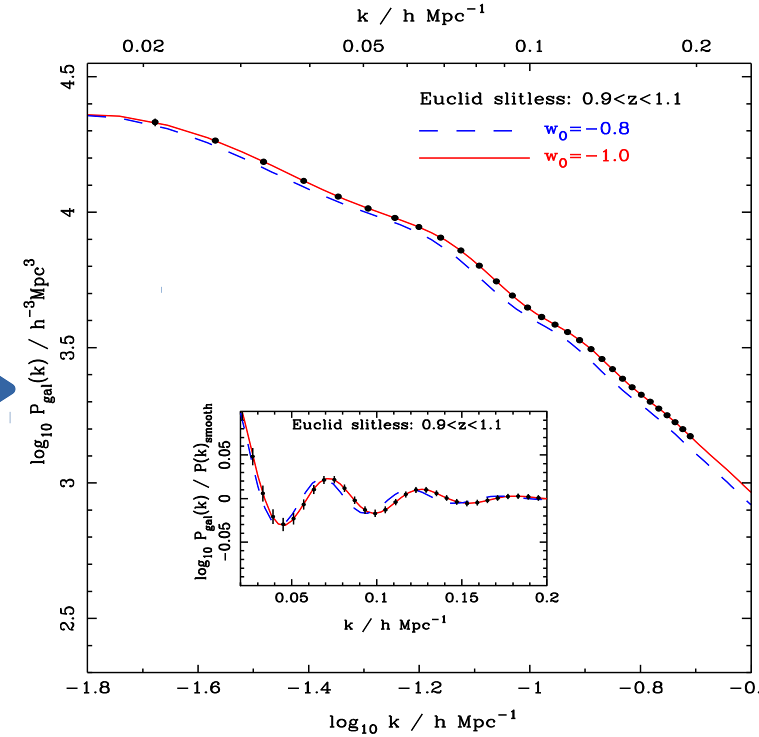


The long way from raw spectra to data

NISP spectroscopy (2015 simulations)



Courtesy P. Franzetti, B. Garilli, A. Ealet et al.



Slitless spectroscopy: Uniform sample but contaminated spectra

→simulations and deep survey are crucial to control systematics

Need to understand confusion, mis-identification, zero-point errors, etc.

Need to understand the populations (radial & angular completeness; radial & angular density variations, etc)

Weak Lensing tomography and 3D lensing

Euclid:

Over 15,000 deg^2 WL measurement with 1.5 x10^9 galaxies to slice the universe and control contamination by intrinsic alignments

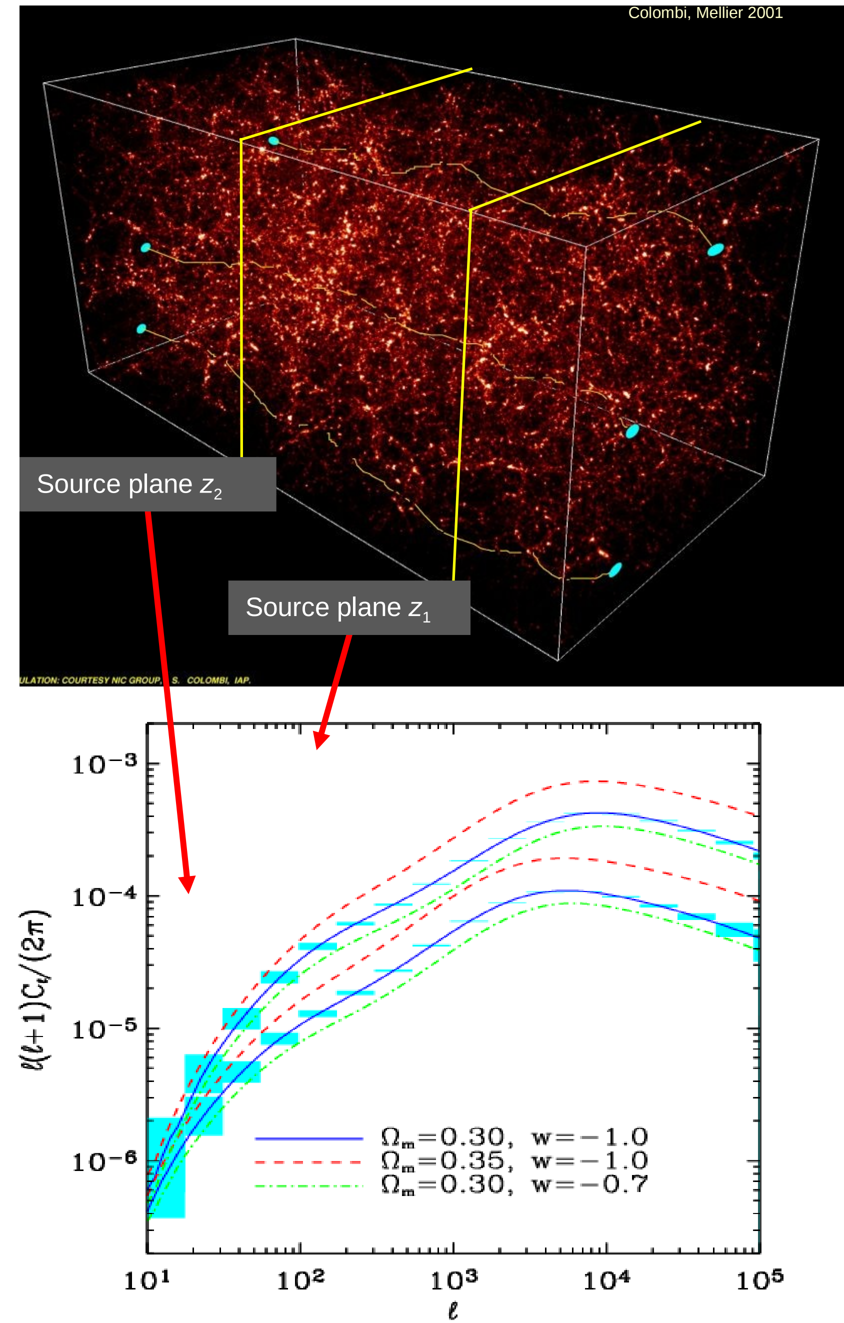
Cosmic shear over 0<z<2

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

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

→ Shapes+distance of galaxies: shear amplitude in redshift slices.

→ “Photometric redshifts” sufficient for distances: optical+NIR data.

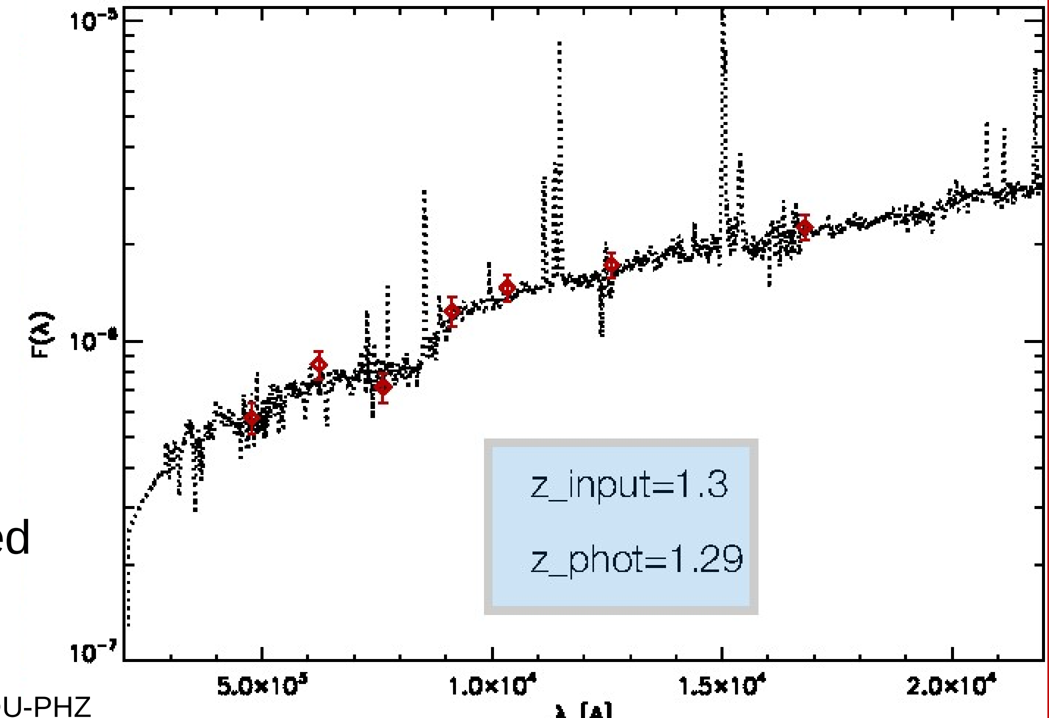


Euclid+ground: photo-z of 1.5 billion lensed galaxies

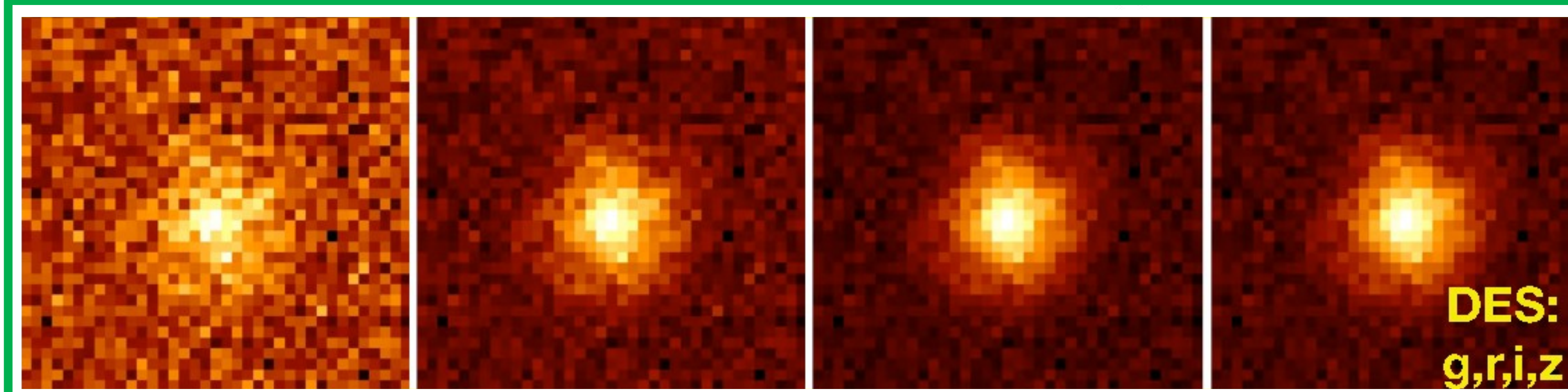
Requirements:

- photo-z for ~all WL galaxies
- cover the whole Euclid sky (15000 deg^2)
- accuracy = 0.05x(1+z)

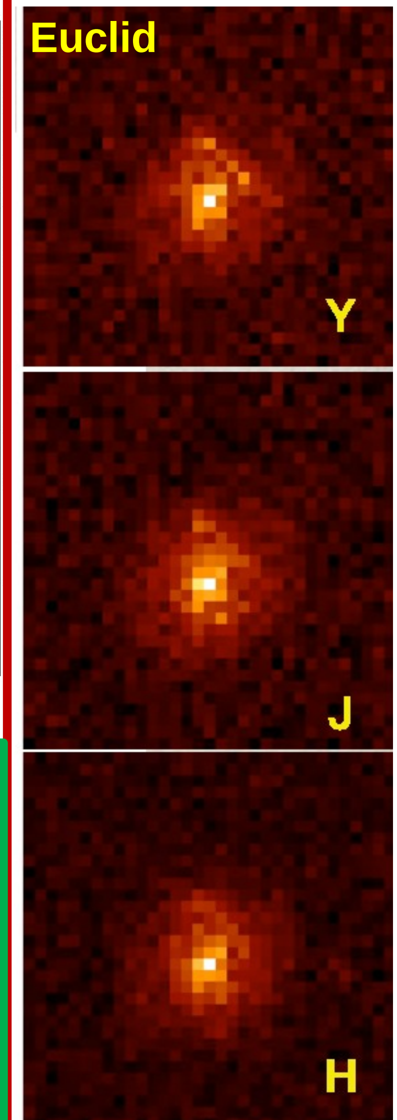
→ 4 optical bands needed



Courtesy Euclid SWG Photo-z and OU-PHZ



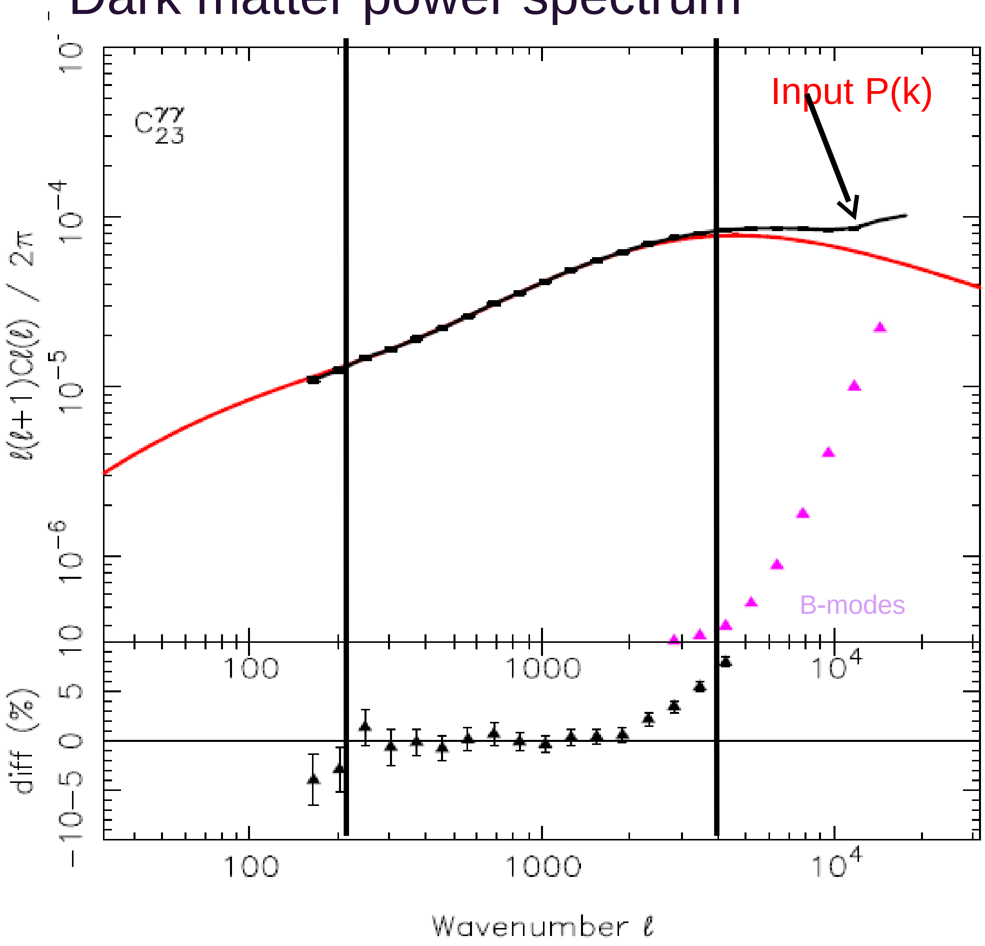
Visible data obtained from ground based telescopes



NIR data from Euclid NIR images.

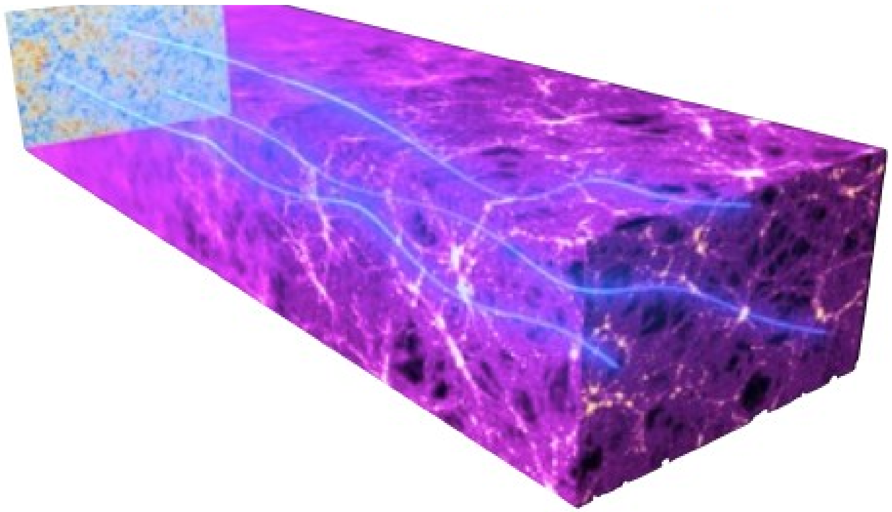
Euclid Weak Lensing

Dark matter power spectrum

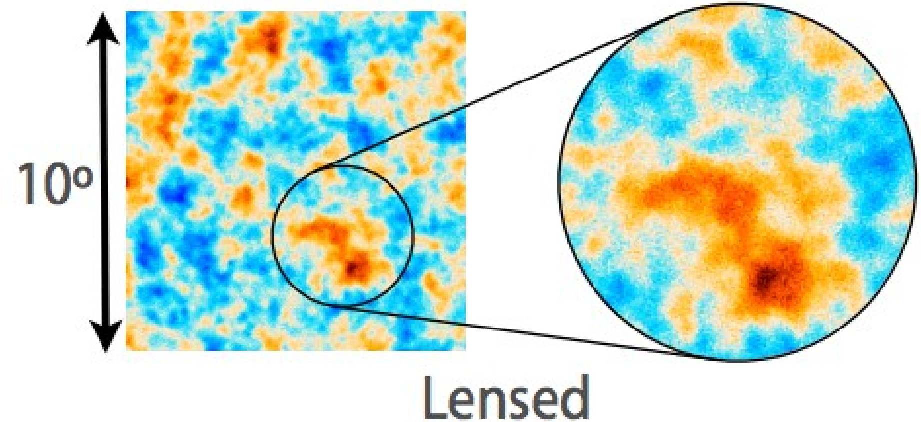


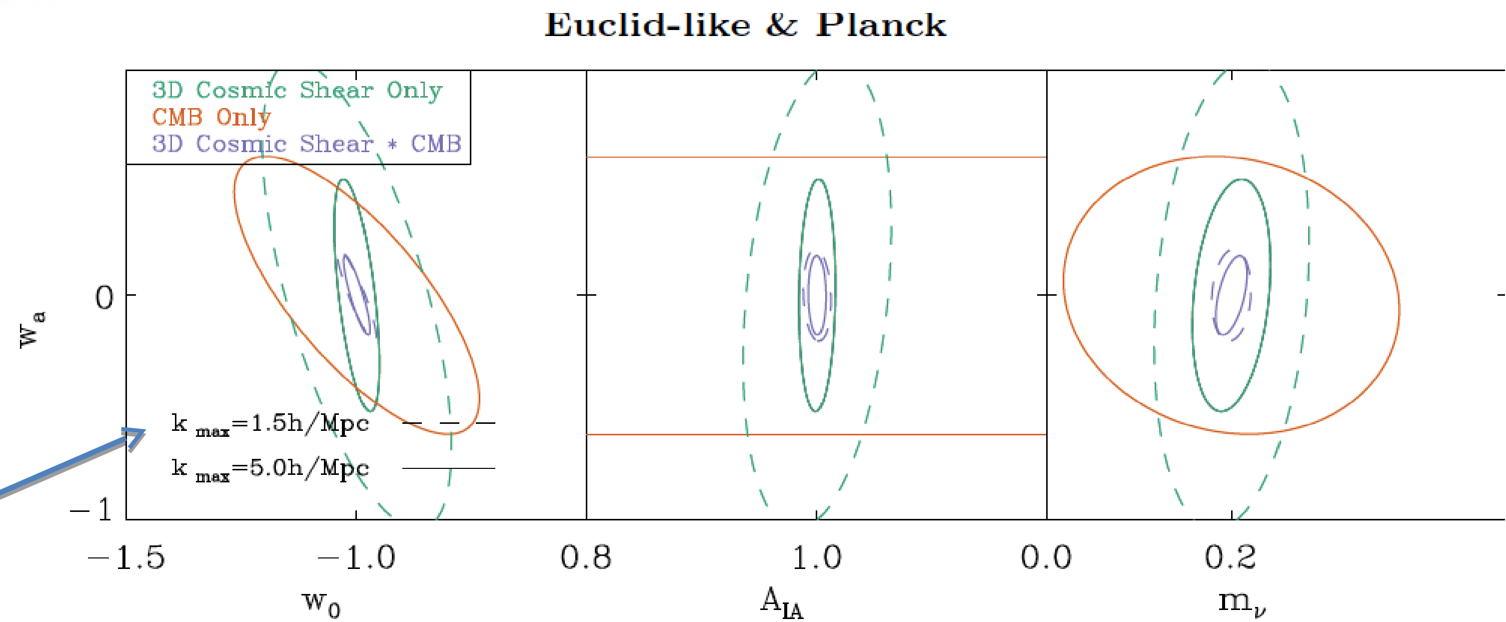
- Tomographic WL shear cross-power spectrum for bins 0.5 < z < 1.0 and 1.0 < z < 1.5
- Dark matter power spectrum recovered to 1%

Forecast for combined CMB & galaxy lensing



Planck collaboration 2014

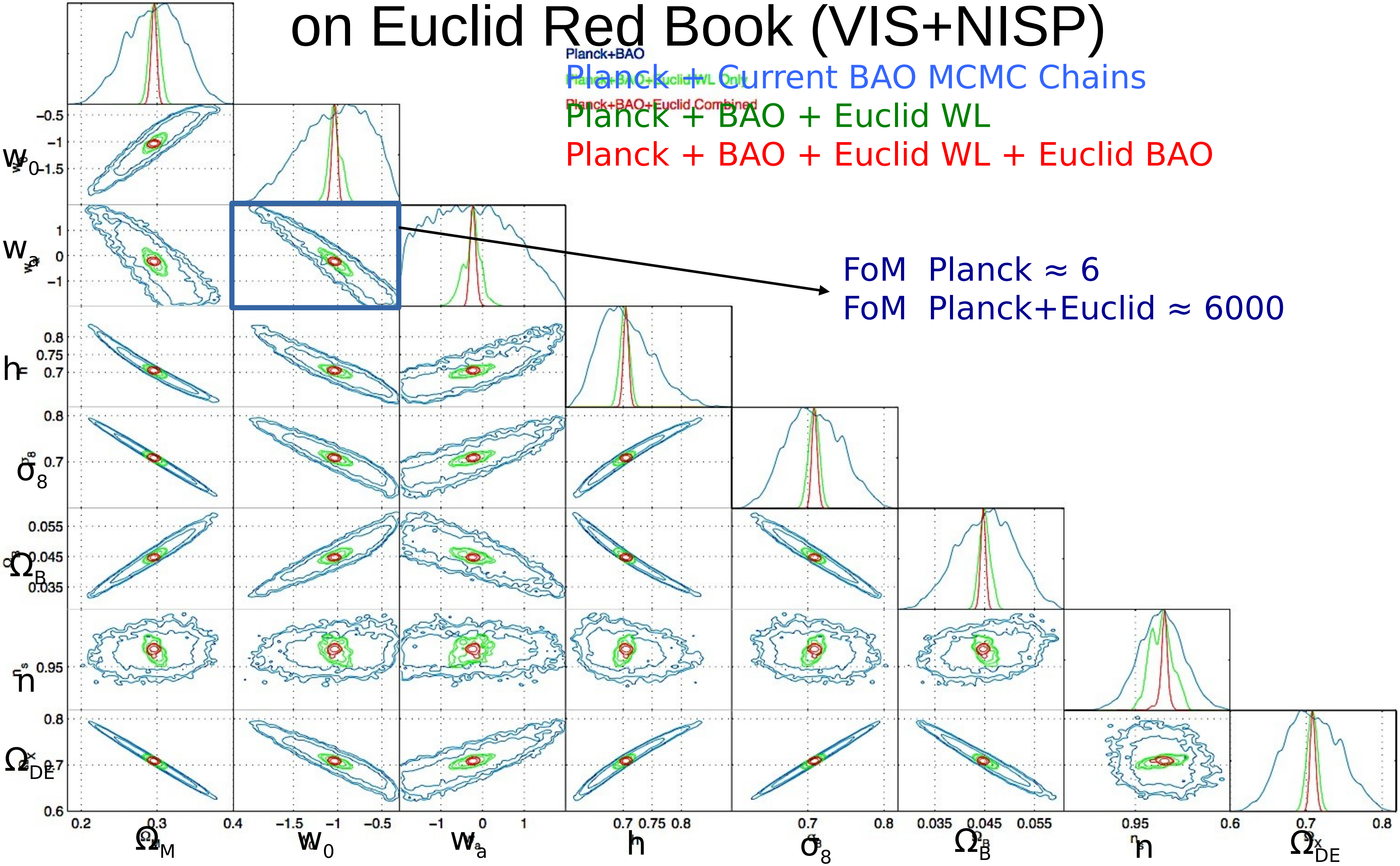




Linear & non-linear scales

CMB & galaxy lensing combination improves:
Dark energy, galaxy alignment measurements and neutrino mass

Constraints on w: Updates (post-Planck) on Euclid Red Book (VIS+NISP)



Planck + Current BAO MCMC Chains

Planck + BAO + Euclid WL

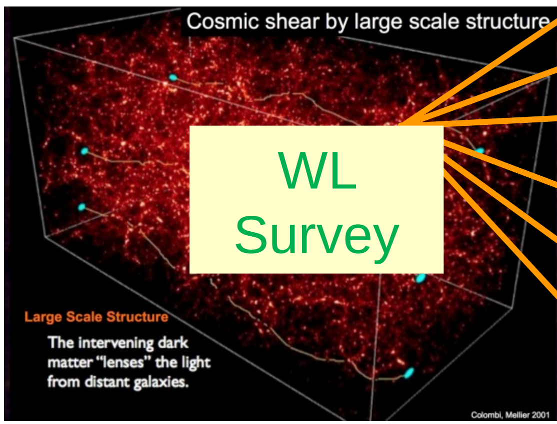
Planck + BAO + Euclid WL + Euclid BAO

FoM Planck ≈ 6

FoM Planck+Euclid ≈ 6000

Courtesy T. Kitching & Euclid Forecast IST

Cosmology with the Euclid Weak Lensing survey



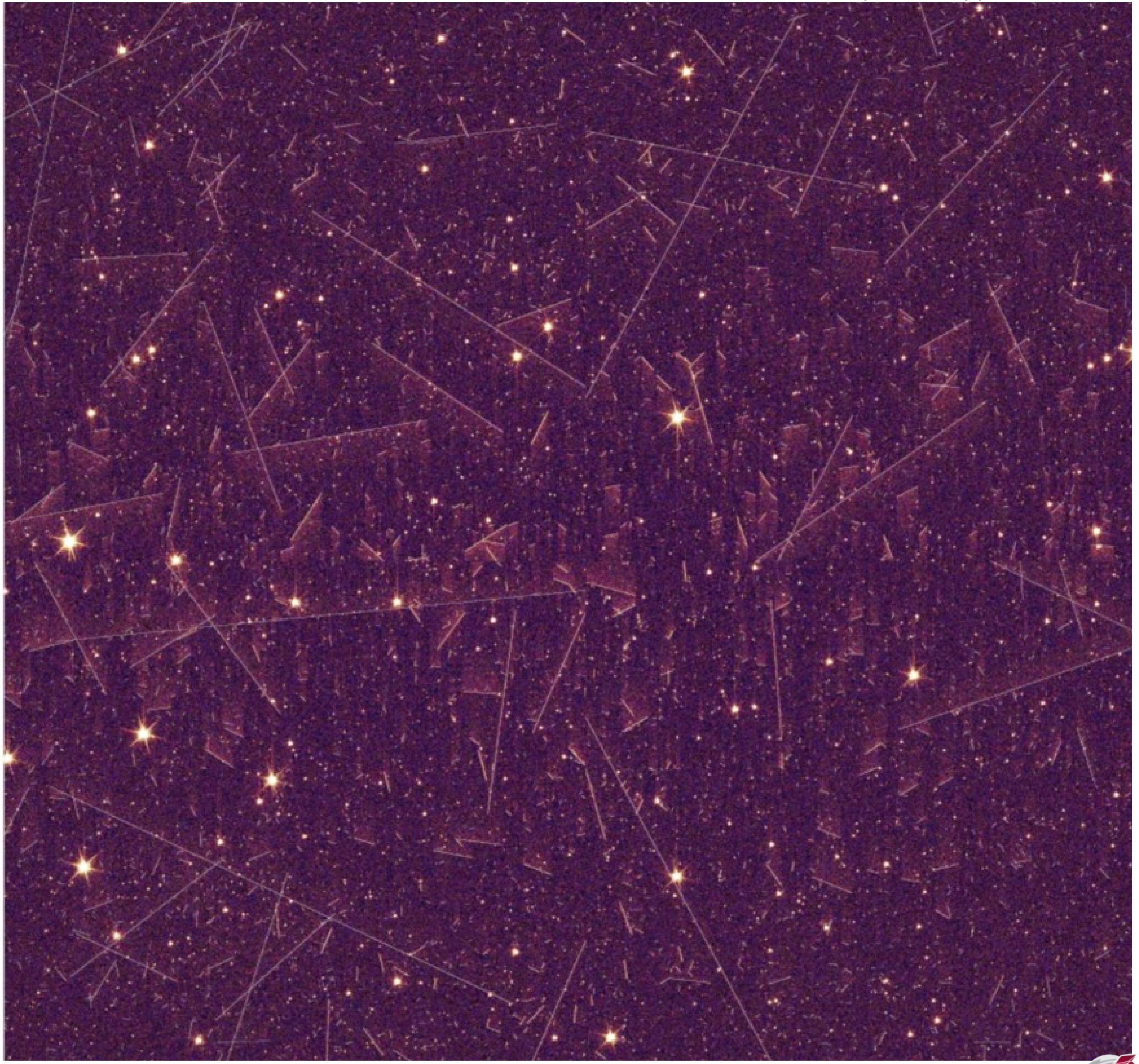
WL Survey →

- DM power spectrum, tomography → What is the expansion rate of the Universe?
- Peak stat, Clusters Mass Func → What is the expansion rate of the Universe?
  - → Understanding Dark Energy
- DM power spectrum, tomogr → How does structure form within this background? → Understanding energy-density, gravity
- DM power spectrum → What are the neutrino masses, matter density? → Understanding energy-density
- 3-pt statistics, Halos → What is f_{nl}, which quantifies non-Gaussianity? GR-horizon effects → Understanding Inflation, GR
- iSW effect → Does the potential change along line-of-sight to CMB → Understanding DE, GR

VIS performance: imaging

Courtesy M. Cropper, S. Niemi

A 4kx4k view of the Euclid sky



Cuts made to highlight artefacts due to Charge Transfer Inefficiency

- Tested in worse case
- Can be corrected to required accuracy with no impact on P(k) and cosmology core progr.

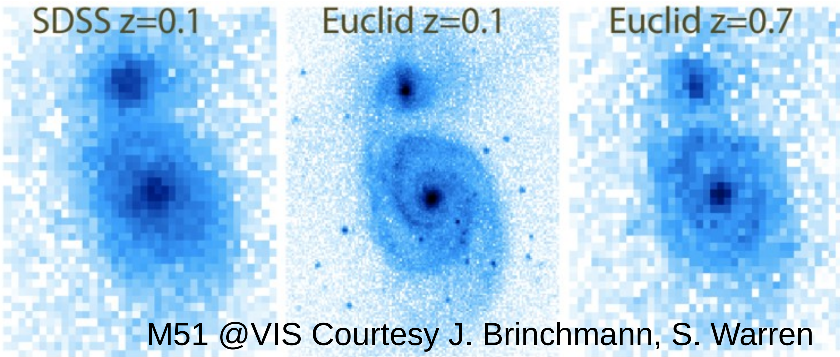
Euclid VIS+NISP Legacy

Very large samples of sources

→ Diversity of populations

Exquisite imaging of galaxies

→ Morphologies, mergers



M51 @VIS Courtesy J. Brinchmann, S. Warren

Strong and Weak Lensing

→ Galaxy evolution as function DM halo

→ Galaxy alignement

→ 5000 clusters with giant arcs, strong galaxy-scale lenses

Huge volumes and numbers

→ Rare/extreme sources

NIR Spectroscopy

→ Metals, star formation@ z>1

→ Very high-z QSOs

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

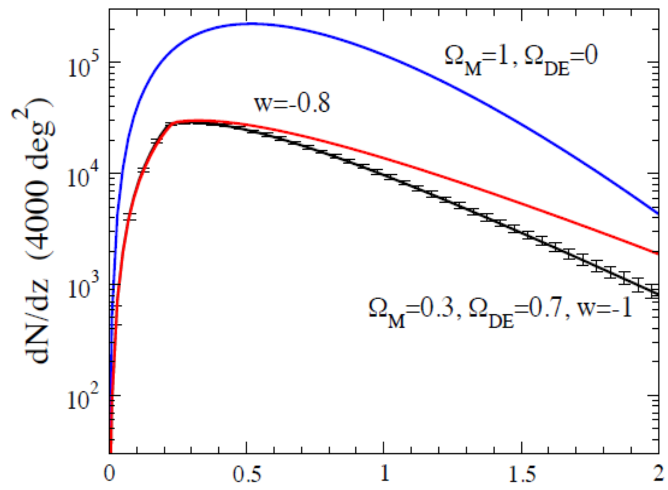
Clusters of galaxies

mass function; calibrated from simulations to ~10% accuracy

$$\frac{d^2N}{d\Omega\,dz} = n(z)\,\frac{r(z)^2}{H(z)}$$

$= dV / (d\Omega dz)$; exactly predictable given a cosmological model

observed



Euclid data will give “for free”:

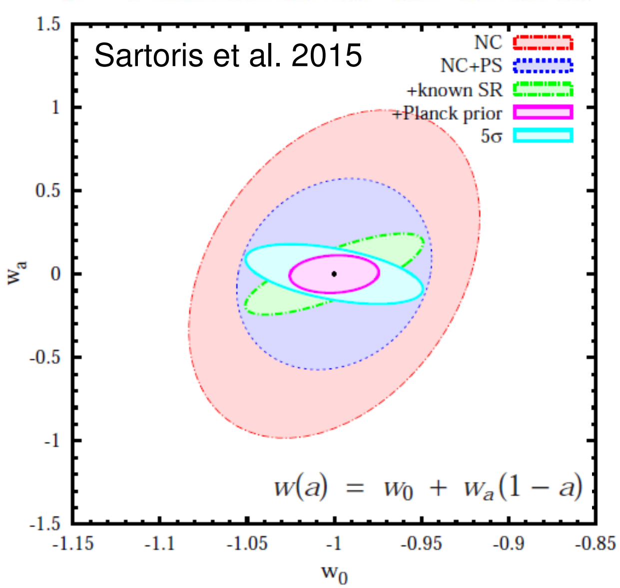
- ~200,000 clusters between $0.2<z<2$, ~40,000 at $z>1$
- ~ 5000 giant gravitational arcs (SL+WL mass)

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

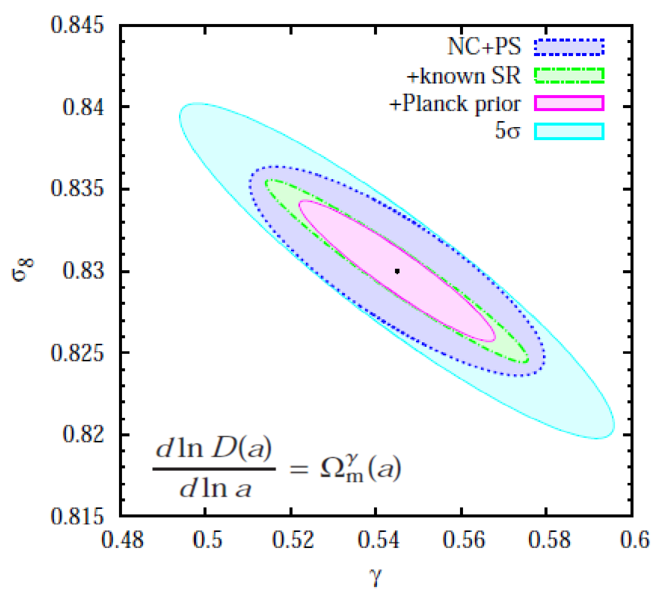
→ deviations from standard DE and GR models

→ dark matter density profiles on scales >100 kpc

$p = \{\Omega_m, \sigma_8, w_0, w_a, \Omega_k, \Omega_b, H_0, n_S\}$



$p = \{\Omega_m, \sigma_8, w_0, w_a, \Omega_k, \Omega_b, H_0, n_S, \gamma\}$



Synergy with Planck and eROSITA

Euclid Post-Planck Forecast for the Primary Program

Assume systematic errors are under control

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**
Improvement Factor	**30**			**>10**	**>40**	**>400**

From Euclid data alone if data consistent with Λ, and FoM > 400

→ Λ favoured with odds of more than 100:1 = a "decisive" statistical evidence.

Summary: the post-Planck cosmology mission

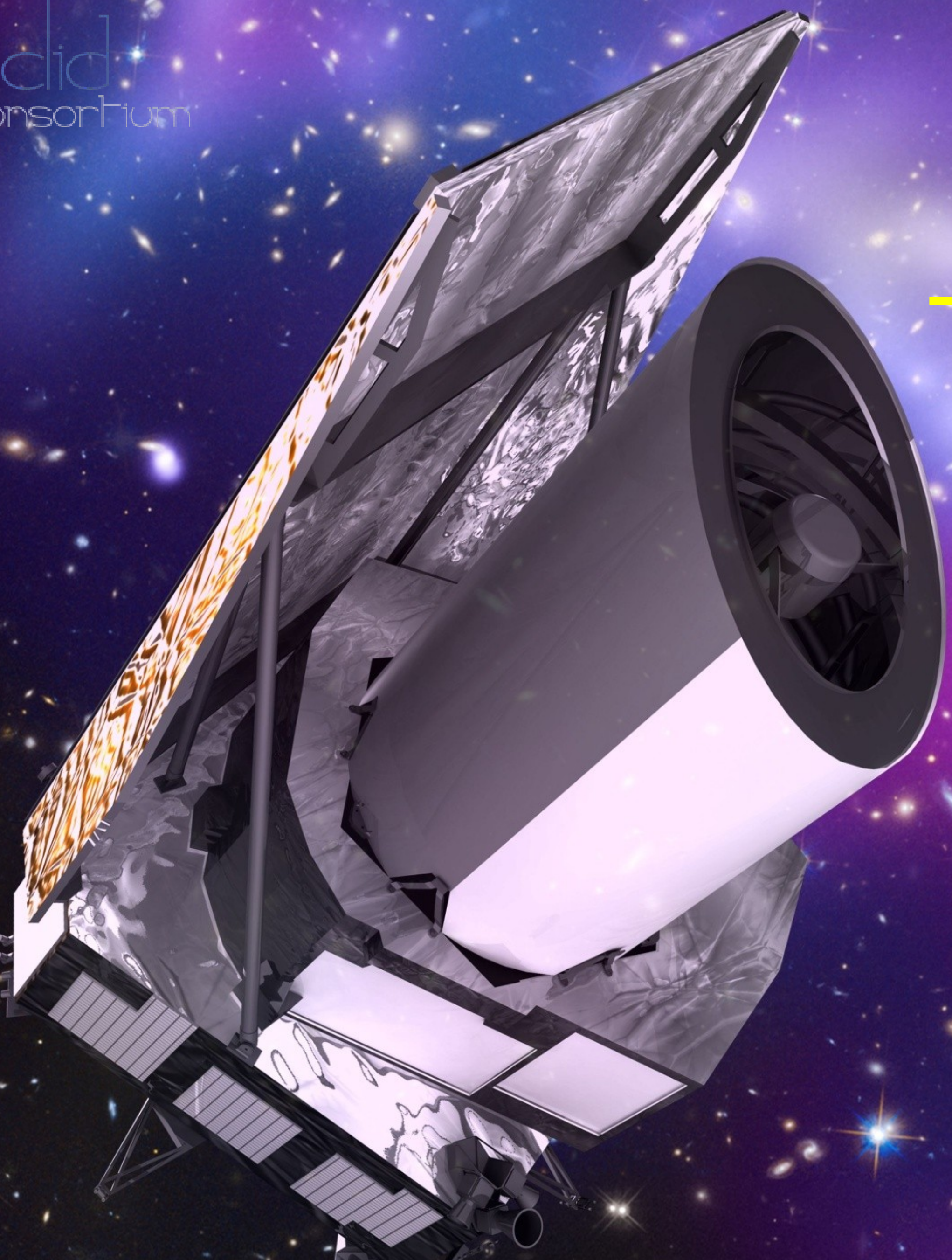
Euclid will

Explore the dark universe: DE, DM (in particular neutrinos), MG

- Use 5 cosmological probes, with at least 2 independent
- Get the percent precision on P(k), w and the growth factor
- A revolution for wide field VIS and NIR surveys

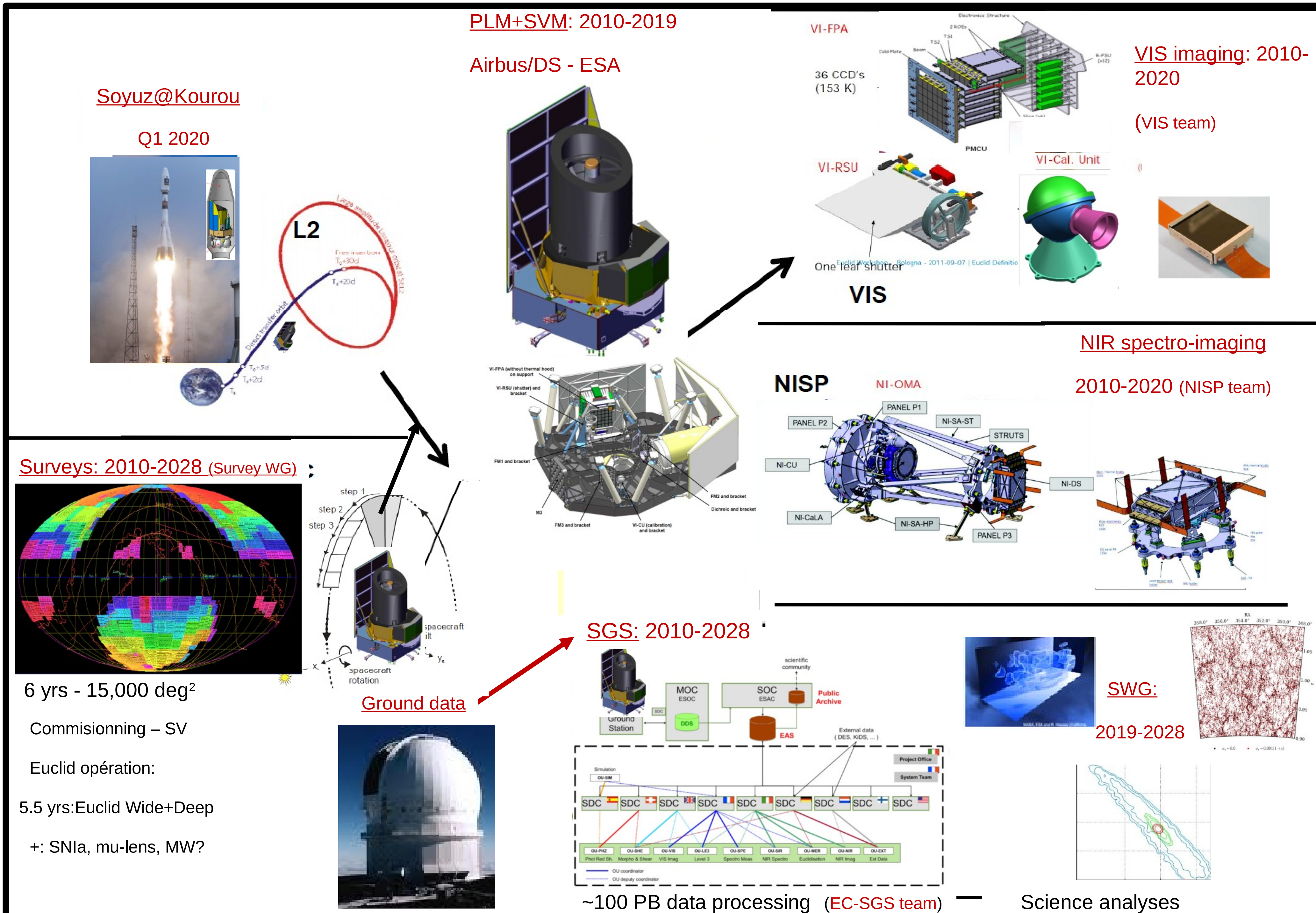
Euclid Legacy = 12 billion sources, >30 million redshifts;

- A mine of images and spectra for the community for years;
- A reservoir of targets for SUBARU, JWST, E-ELT, TMT, ALMA, VLT
- A set of astronomical catalogues useful until 2040+
- A synergy with wide field panchromatic all sky surveys: Planck, GAIA, LSST, WFIRST, e-ROSITA, SKA



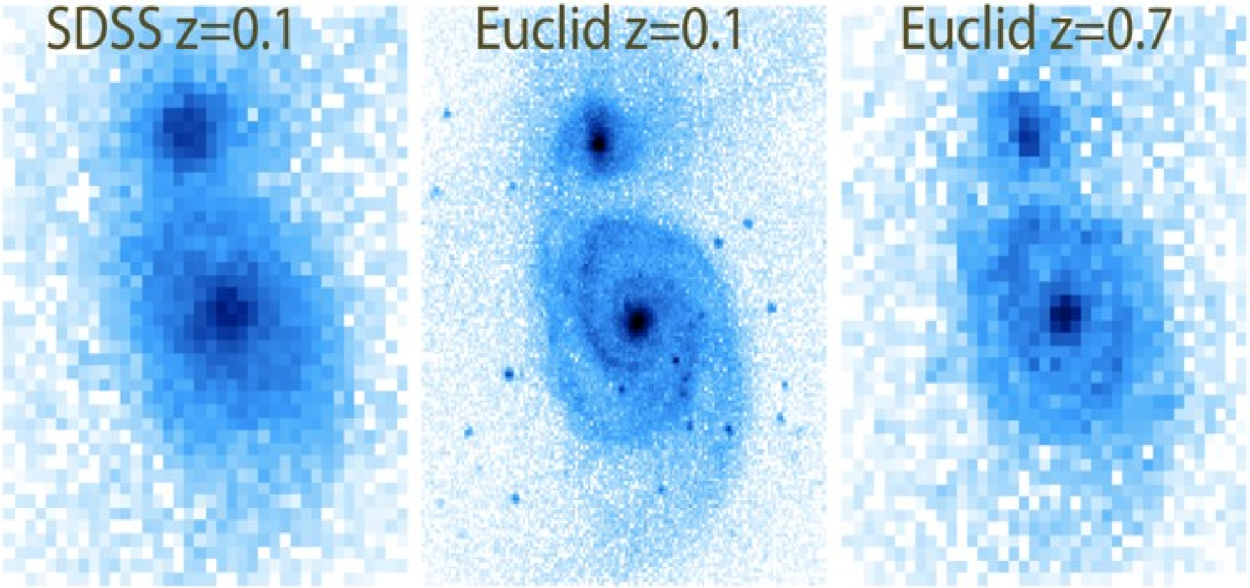
Thank you

The ESA Euclid space mission in a nutshell



A sharp view of the cosmos

Simulation of M51 with VIS



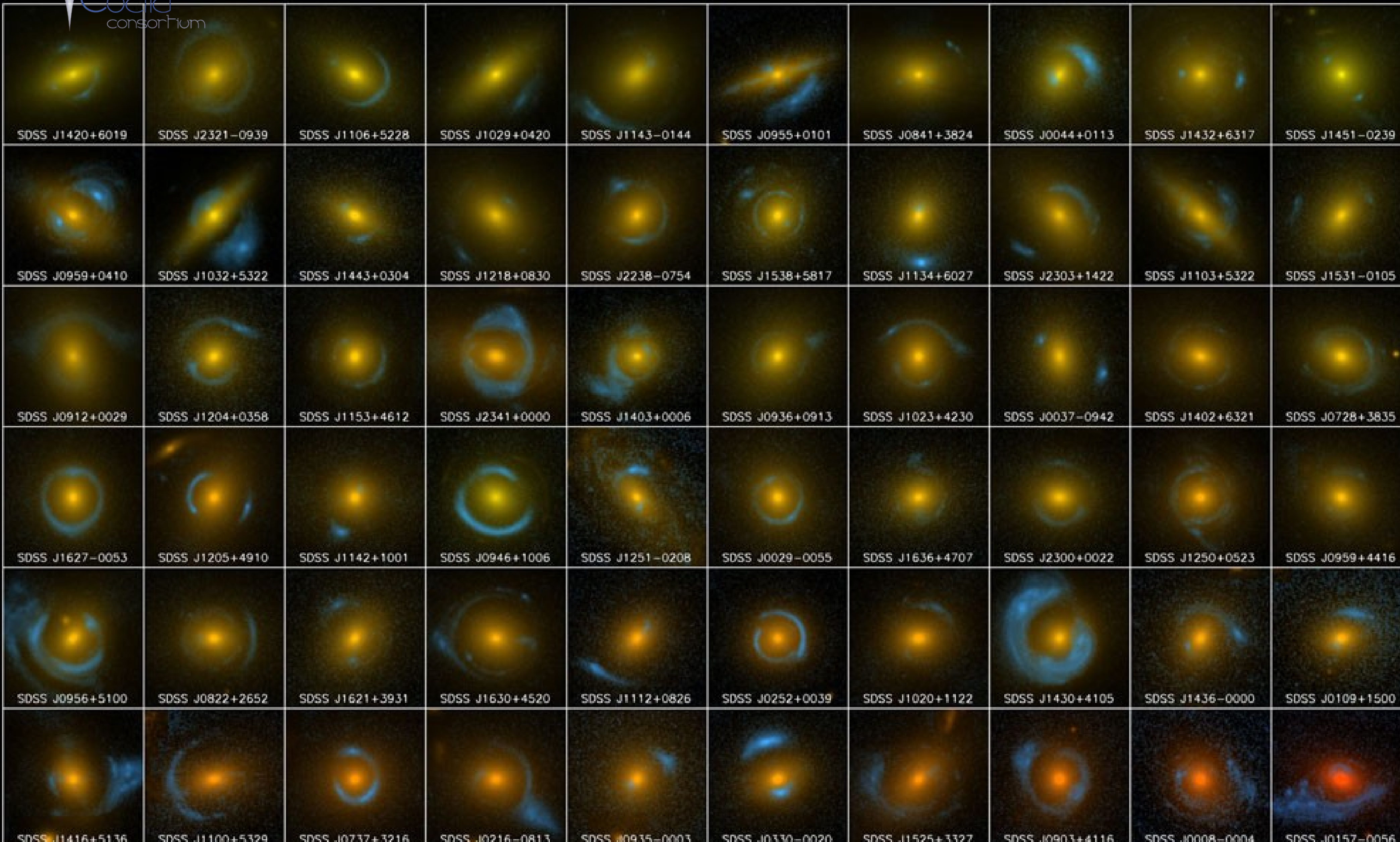
Courtesy J. Brinchmann, S. Warren

Near-HST resolution images across the sky will revolutionise several areas of galaxy evolution

1000 times more area with high resolution imaging = **3 orders of magnitude** increase in sample size (galaxy-galaxy lenses, galaxy mergers)

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

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)

Image credit: A. Bolton, for the SLACS team and NASA/ESA

Euclid Legacy : after 2 months
(66 months planned)