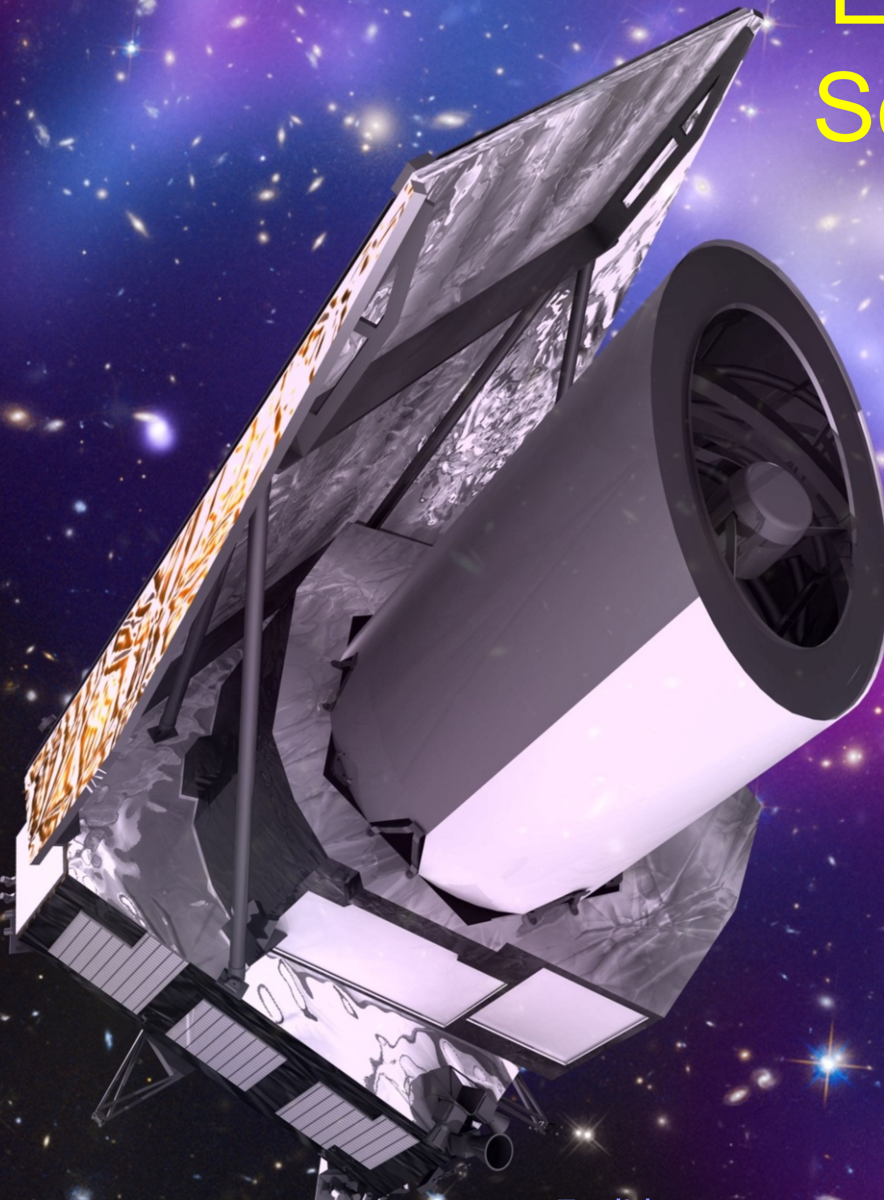
Exploring Large Scale Structures with *Euclid*



Y. Mellier
on behalf of the Euclid Consortium

www.euclid-ec.org

Euclid Mission Overview

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 and expansion history 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 is designed to probe large scale structures

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):

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

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

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

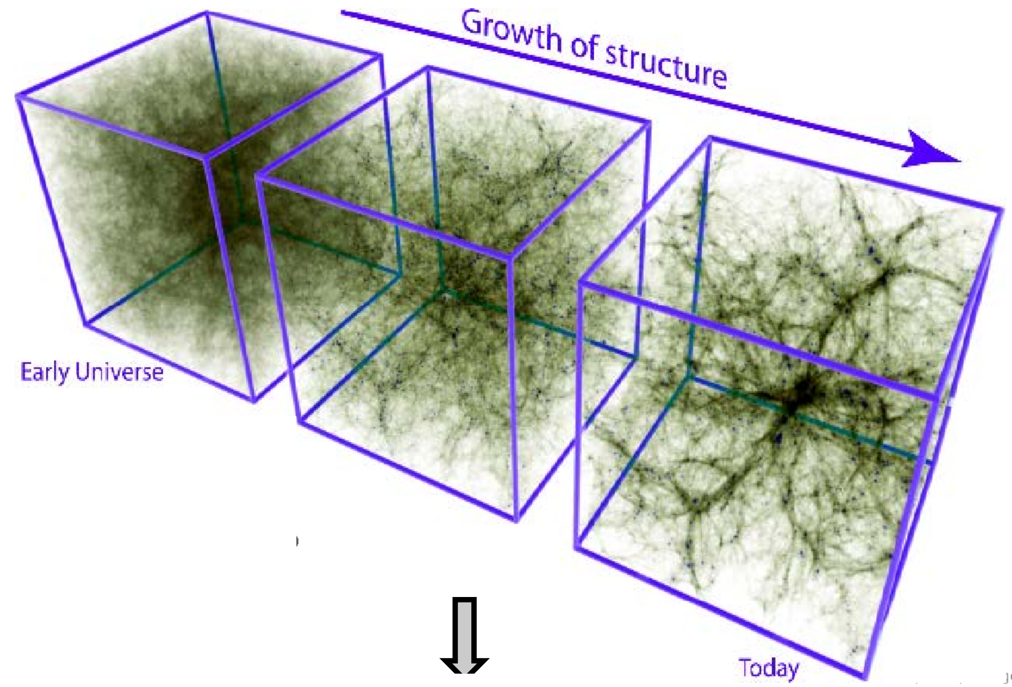
$$ds^2 = -(1 + 2\psi)\, dt^2 + (1 - 2\phi)\, a^2(t)\, dx^2$$

Euclid consortium

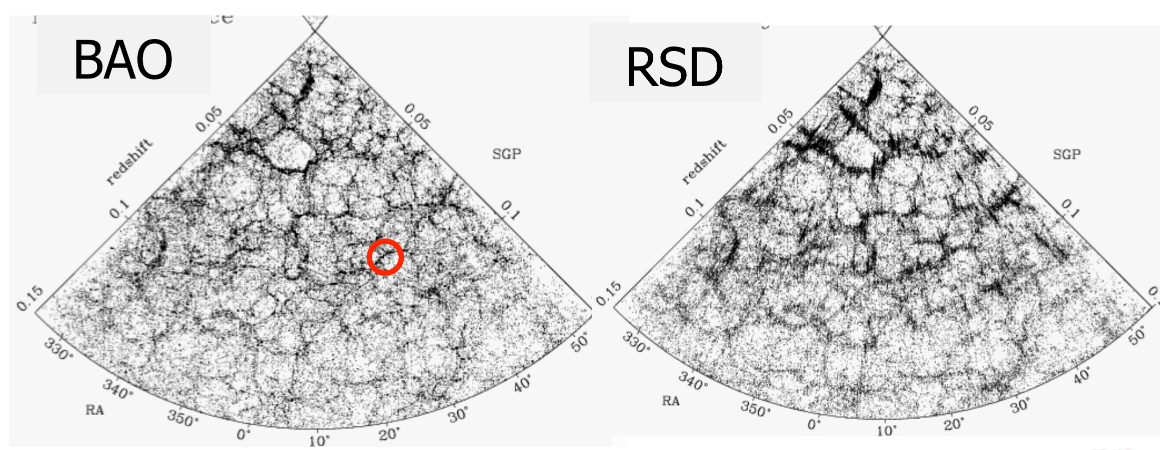
Primary Probe 1 : Galaxy Clustering: BAO + RSD

3-D position measurements of galaxies over 0.7 < z < 1.8

- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); $H(z)$, ψ



→ Need high precision 3-D distribution of galaxies and an estimate of peculiar velocities of galaxies with spectroscopic redshifts.



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

Primary probe 2: Dark matter in the Universe

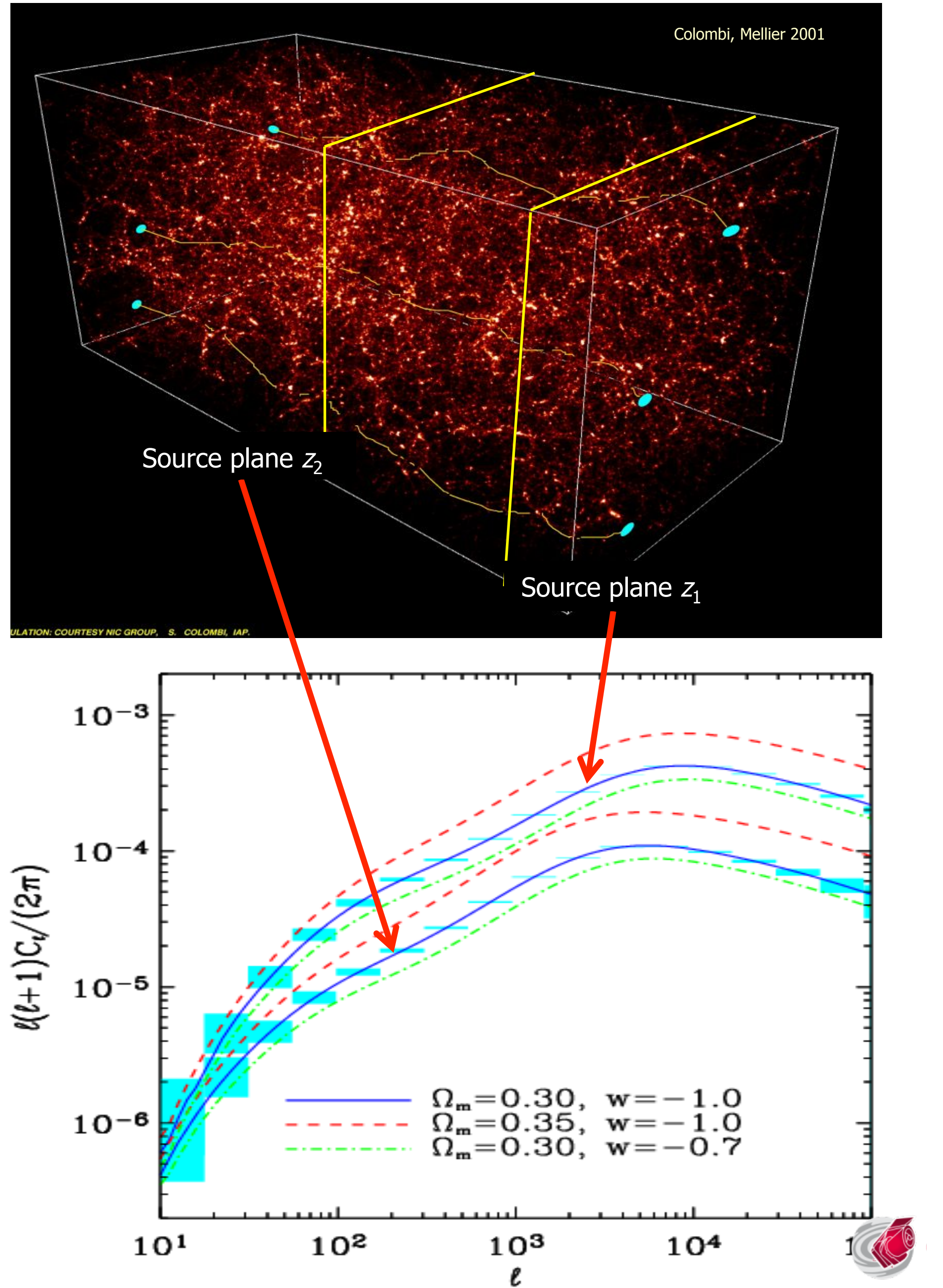
Cosmic shear over 0 < z < 2

- Probes distribution of (Dark +Luminous) matter with Weak Lensing (WL): expansion history, lensing potential $\psi + \phi$.

→ Shapes+distance of galaxies: shear amplitude, and binning the Universe into redshift slices.

→ "Photometric redshifts" sufficient for distance ratios and intrinsic alignement of galaxies: need optical +NIR data.

1.5 billion galaxies shapes, shear and photometric redshifts with 0.05 (1+z) accuracy over 15,000 deg^2



Distinguishing *decisively*

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

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

- **Nature of dark energy**
  - Distinguish effects of Λ and dynamical DE: $w(a)$ → slices in redshift
  - From Euclid data alone, get FoM=1/(Δw_a x Δw_p) > 400→ ~1% precision on *w*'s.

    → if (data consistent with Λ+FoM > 400) → Λ favoured with odds of more than 100:1 = a "decisive" statistical evidence.
- **Nature of gravity on cosmological scales**
  - Probe growth of structure → slices in redshift ,
  - **Study of 3 power spectra**: lensing, galaxy, velocity → biasing
  - Separately constrain the potentials (ψ,ϕ) as function of scale and time
  - Distinguish effects of GR from MG models with high confidence level:

    → Absolute 1-σ of 0.02 on the growth index, γ , from Euclid data alone.

    → Use WL and RSD → differently sensitive to ψ and ϕ

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

Photometric redshifts: : External Photometry

and

External Spectroscopy

Space Euclid VIS and NIR observer of stars and galaxies

12.0 10^9 sources, 1.5 10^9 WL galaxies, 3.5 10^7 spectra Wide

VIS Imaging

I_{AB}=24.5 ; 10σ

I_{AB}=26.5 ; 10σ

NIR Photometry

Y,J,H=24.0 ; 5σ

Y,J,H=26.0 ; 5σ

NIR Spectroscopy

2 10^{-16} erg.cm^{-2}.s^{-1} ; 3.5σ

5 10^{-17} erg.cm^{-2}.s^{-1} ; 3.5σ

Other Euclid probes

Tomographic WL survey

Galaxy Redshift survey

Dark Matter + Galaxy Power Spectra as function of look back time

Planck, eROSITA, …

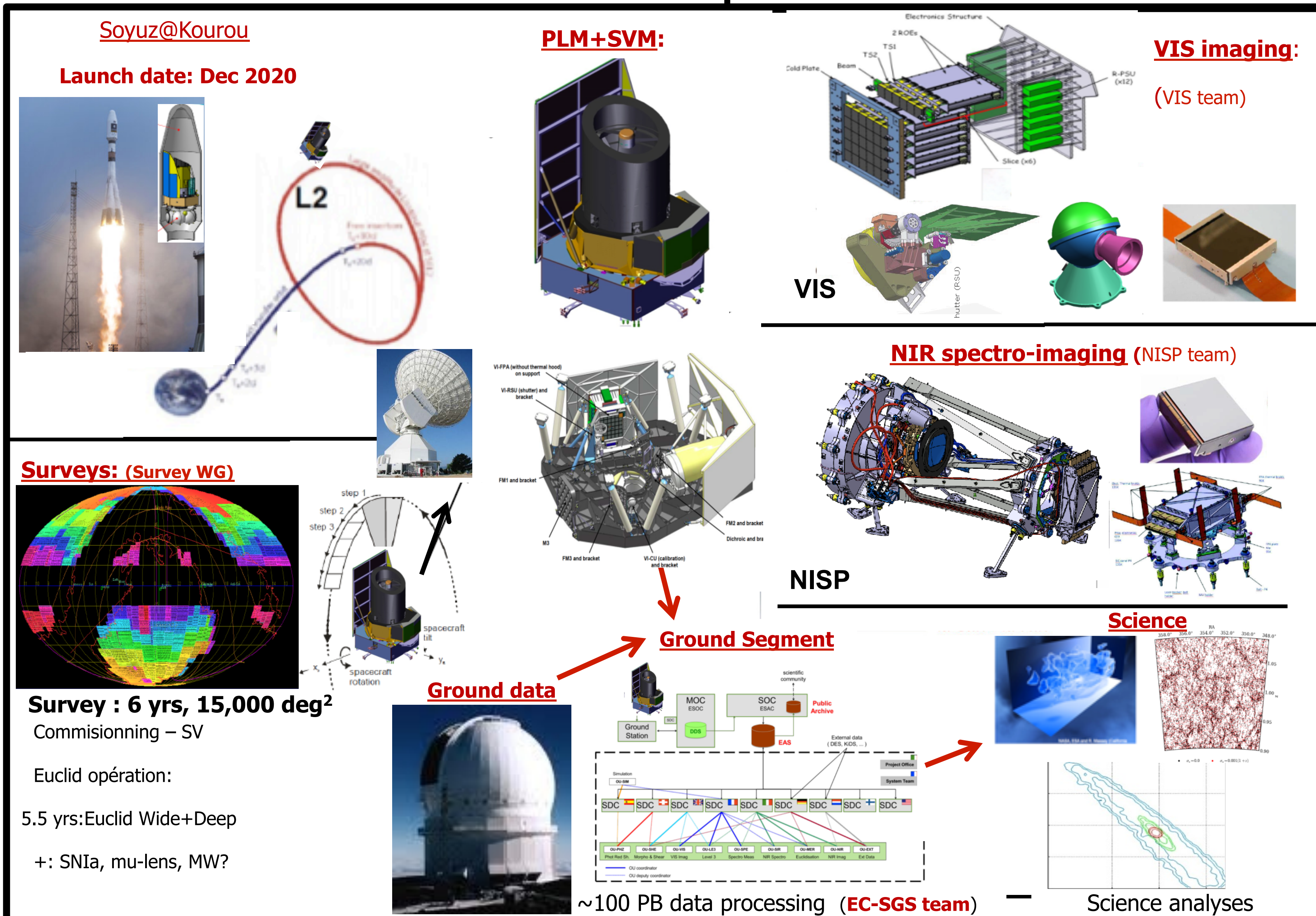
Cosmo. Simul.

Cosmological explorer of

gravity, dark matter, dark energy and inflation

Legacy Science

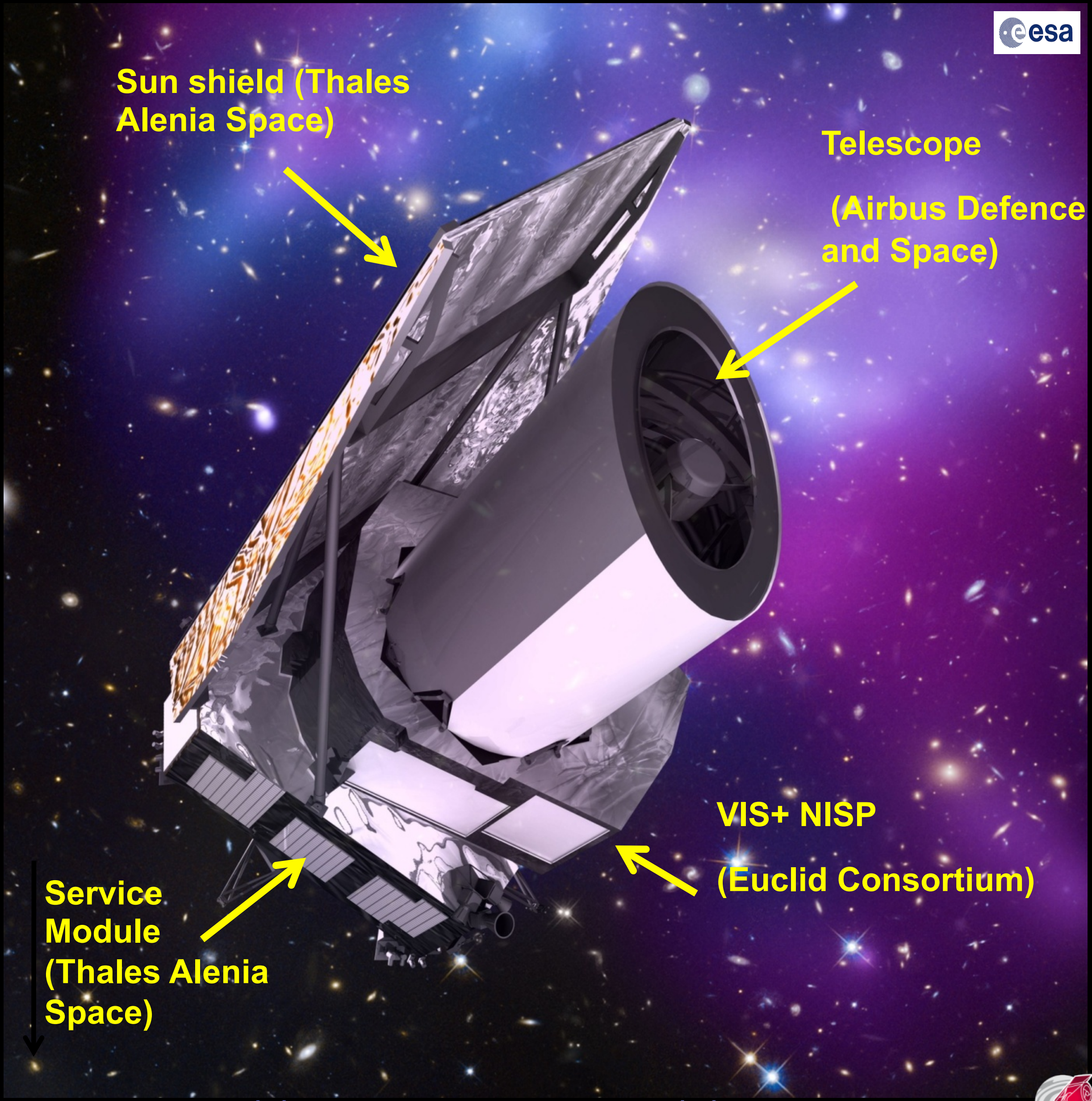
The ESA Euclid space mission



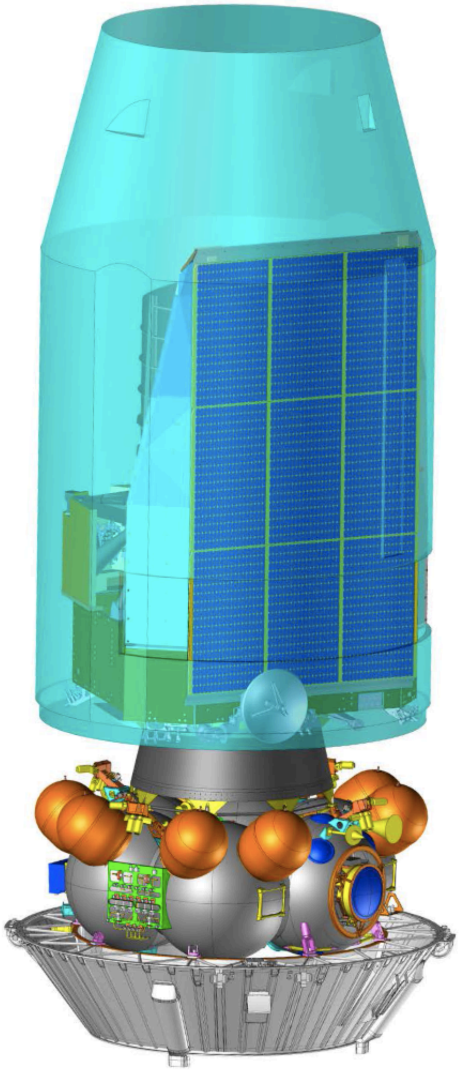
ESA Euclid mission

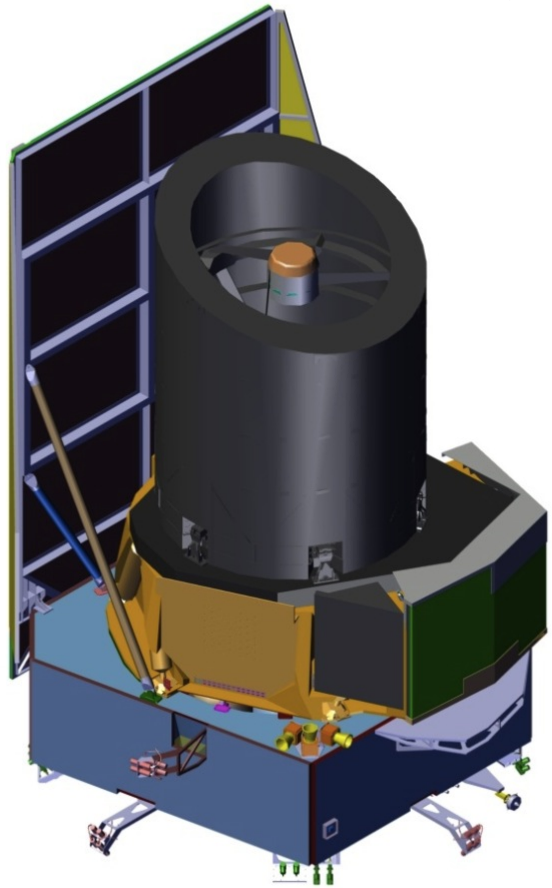
- - Total mass satellite :
- 2200 kg

- - Dimensions:
- 4,5 m x 3 m

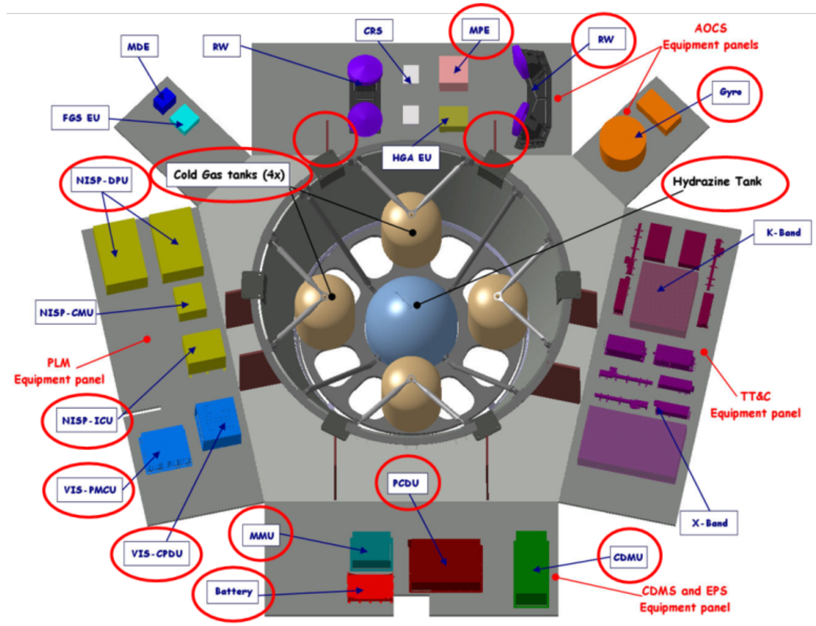


Spacecraft Configuration





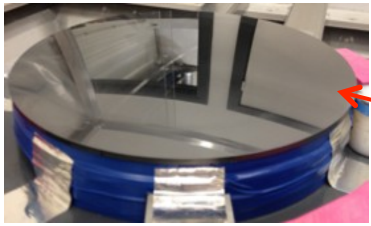
- Telescope 1,2 m: FoV: 0.54 deg^2
- Mirror in Silicon Carbide = ultra-stable:
  - Temp.: -150 °C
  - Stability: +/- 0.05 °C

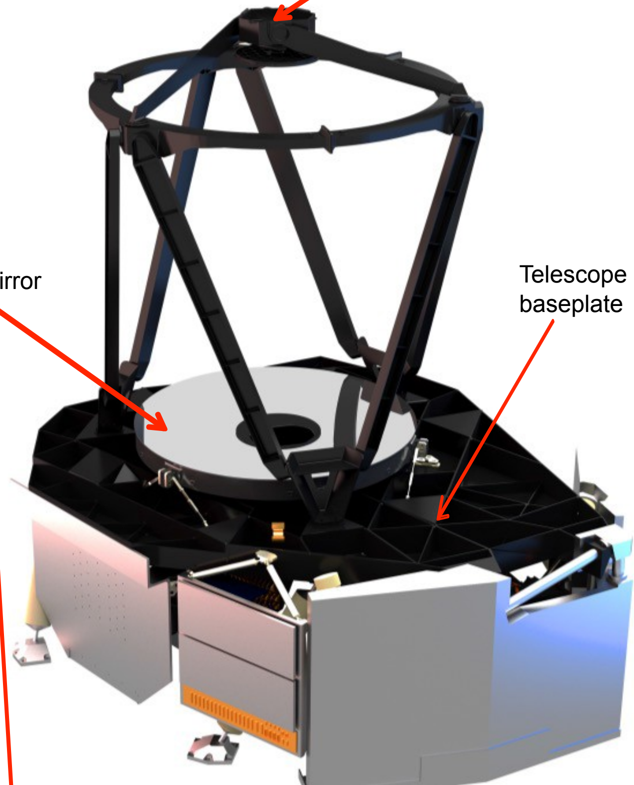


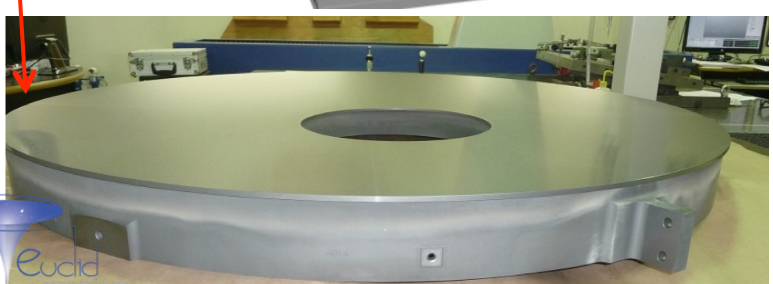
From Thales Alenia Italy, Airbus DS, ESA Project office and Euclid Consortium

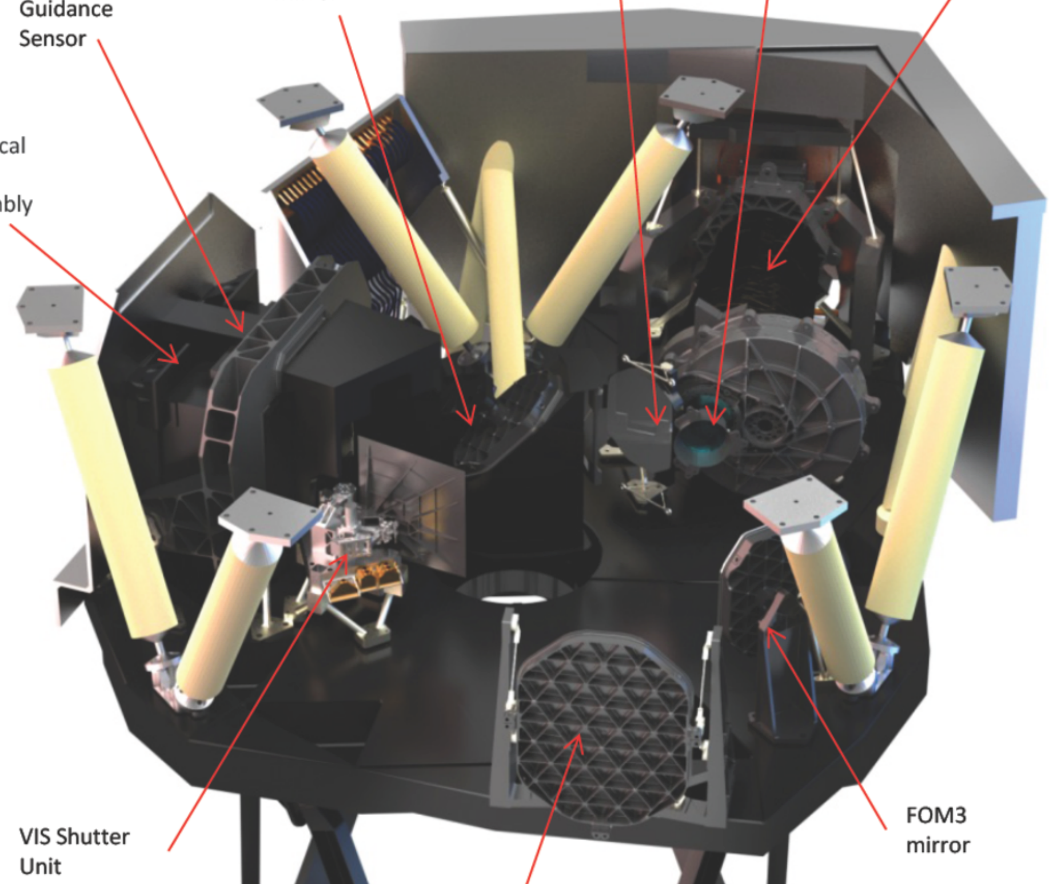
PLM, flight hardware, scientific instruments

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







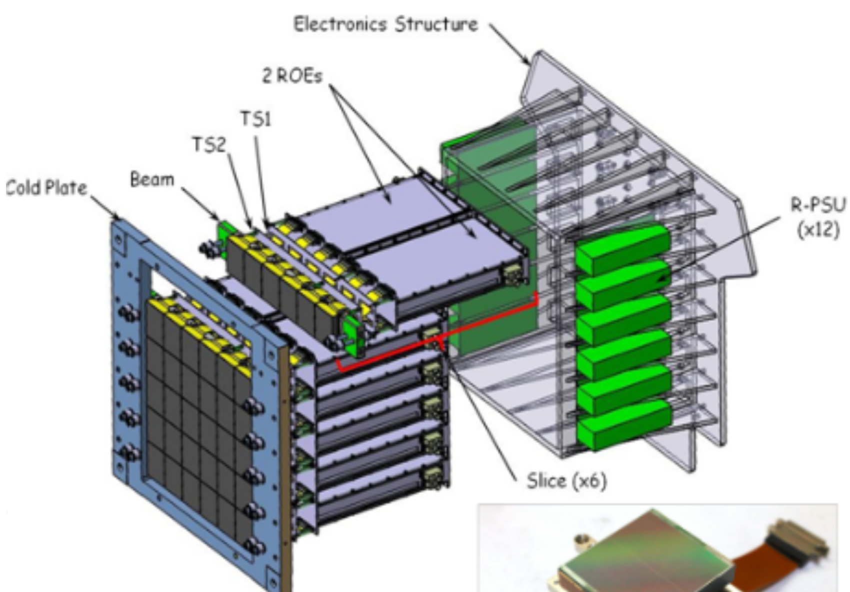


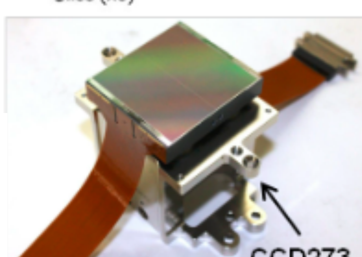
VIS and NISP

VIS

Courtesy: S. Pottinger, M. Cropper and the VIS team

- FoV: 0.54deg^2
- Mass : 133 kg
- Telemetry: < 520 Gbt/day
- 36 4kx4K E2V CCDs, 12 micron pixels
- 0.1 arcsec pixel on sky
- Limiting mag, wide survey AB : 24.5 (10 σ)
- **1 Filter**: Y(R+I+Y): band pass 550-900nm

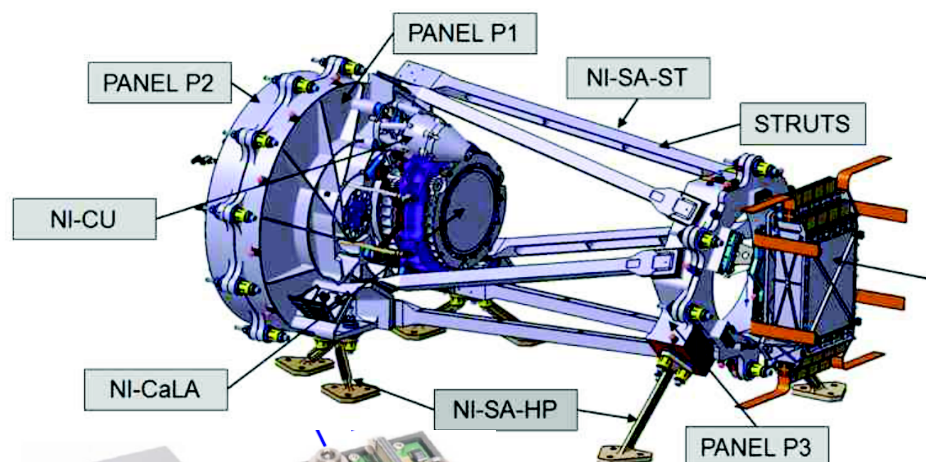




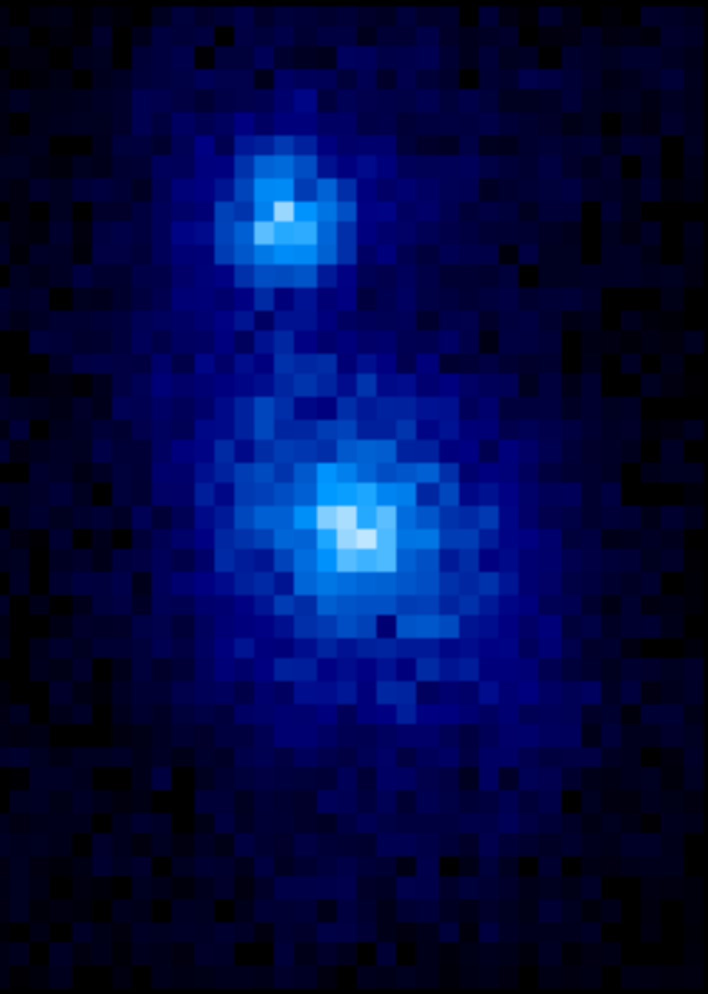
NISP

Courtesy: T. Maciaszek and the NISP team

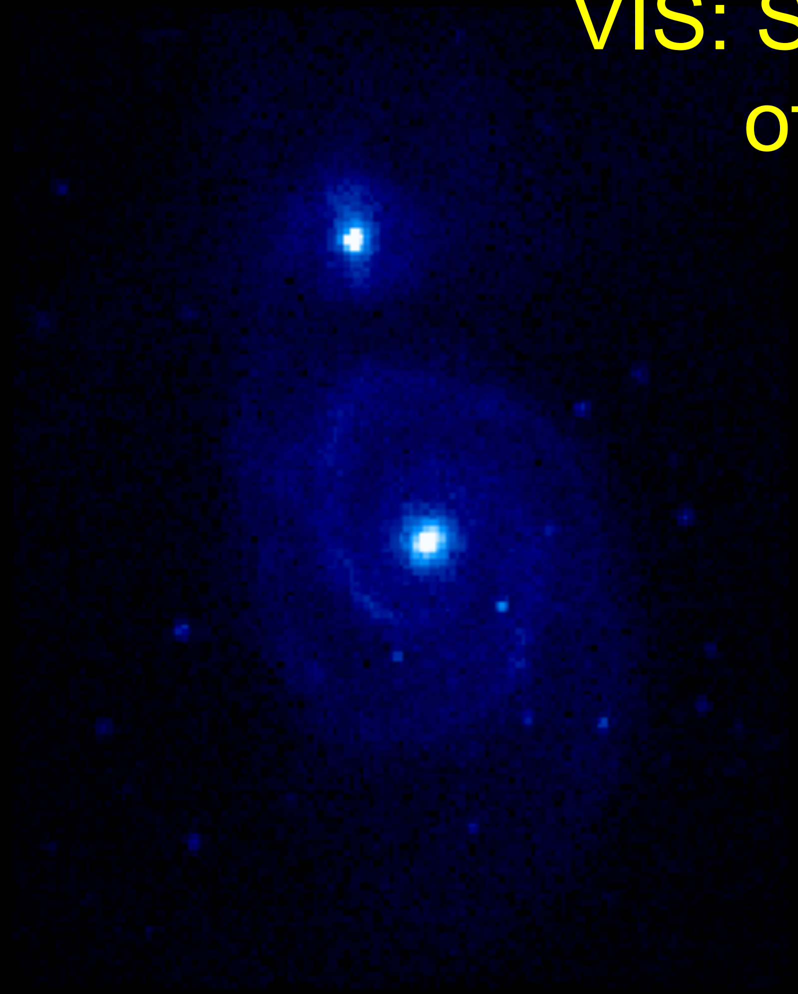
- FoV: 0.55 deg^2
- Mass : 159 kg
- Telemetry: < 290 Gbt/day
- Size: 1m x 0.5 m x 0.5 m
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky
- Limiting mag, wide survey AB : 24 (5 σ)
- **3 Filters**: Y, J, H
- **4 grisms**: 1B (920 – 1250) ,3R (1250 – 1850)



VIS: Simulation of M51



2.4m SDSS-like @ z=0.1

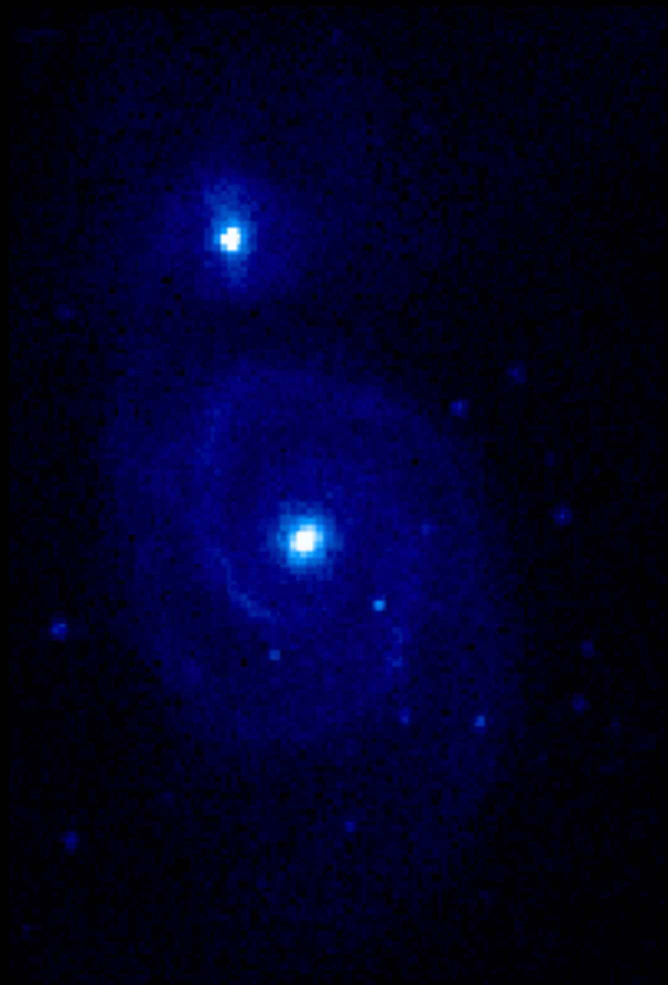


Euclid @ z=0.1

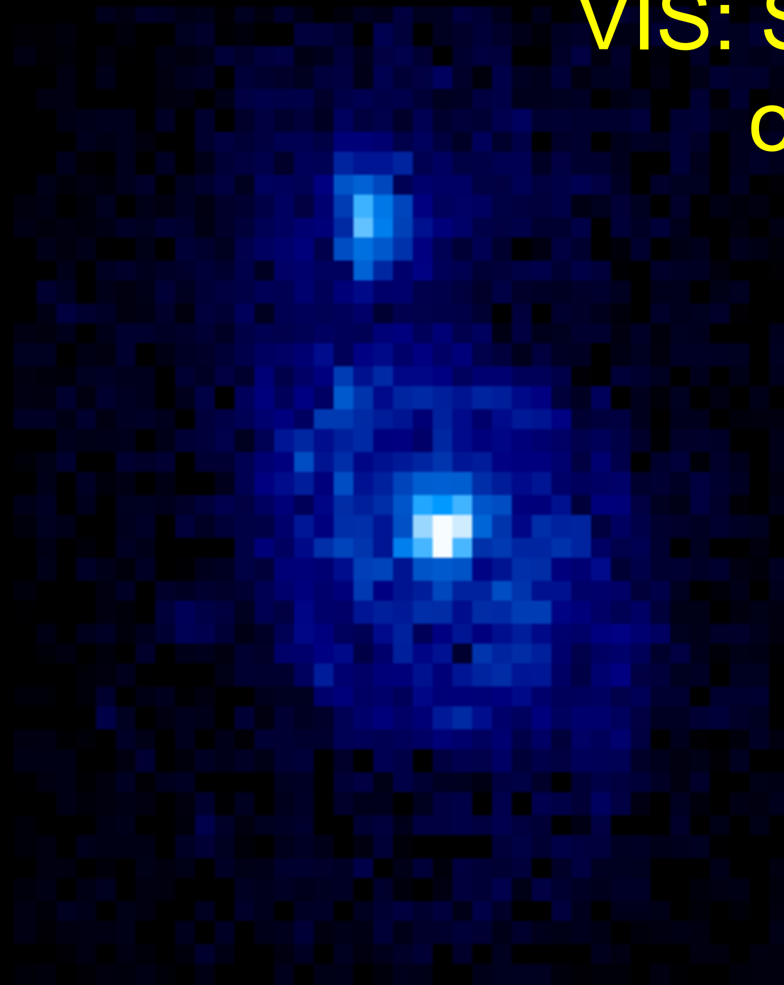
Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.

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

VIS: Simulation of M51



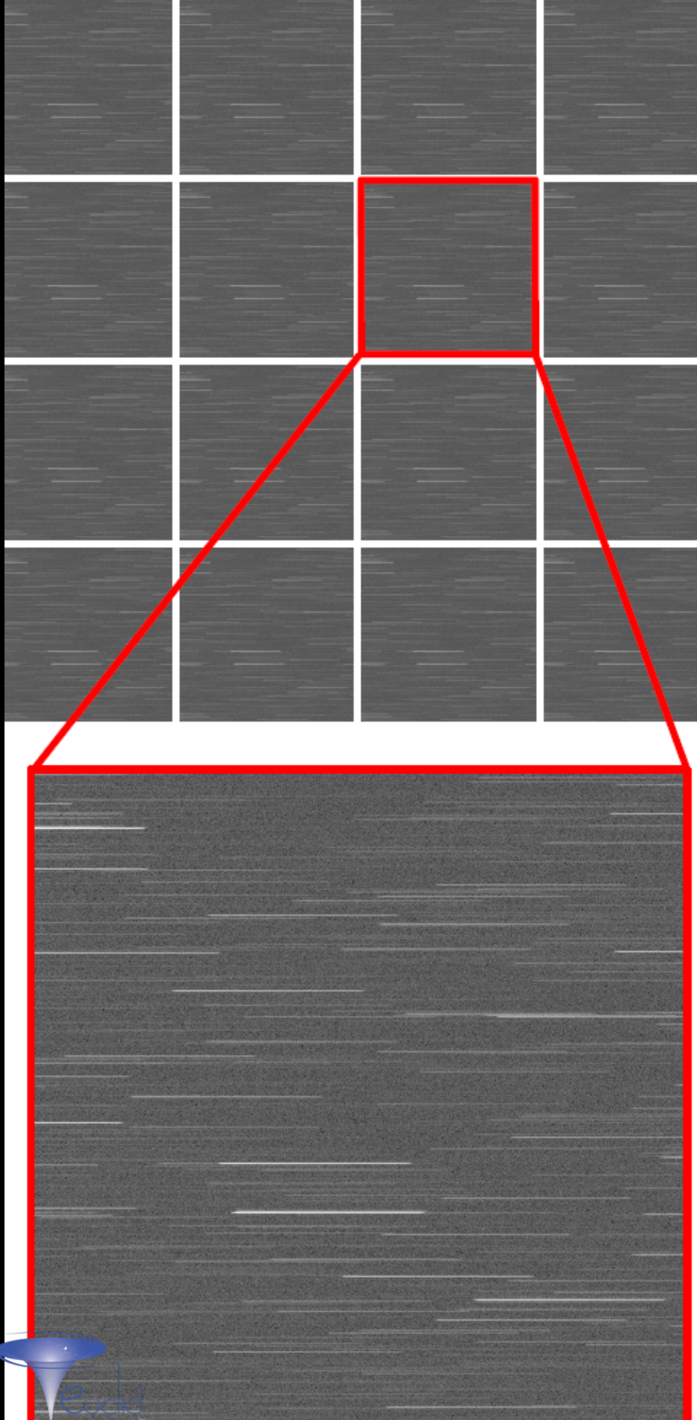
Euclid @ z=0.1



Euclid @ z=0.7

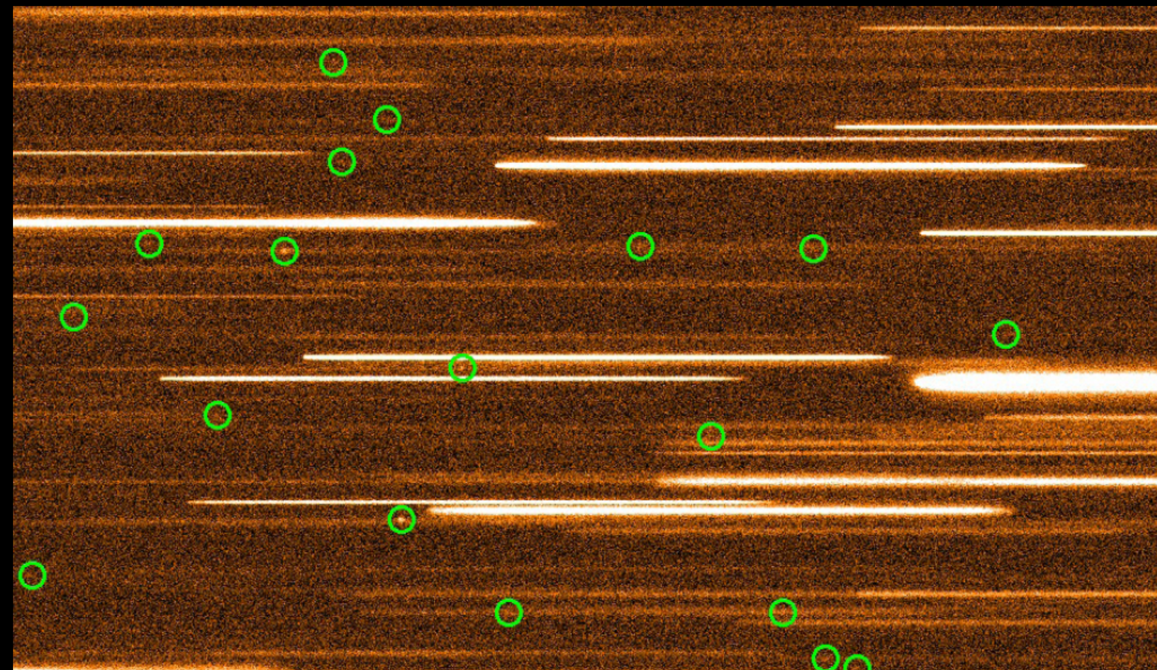
Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.

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



NISP-spectroscopy for Euclid (2015)

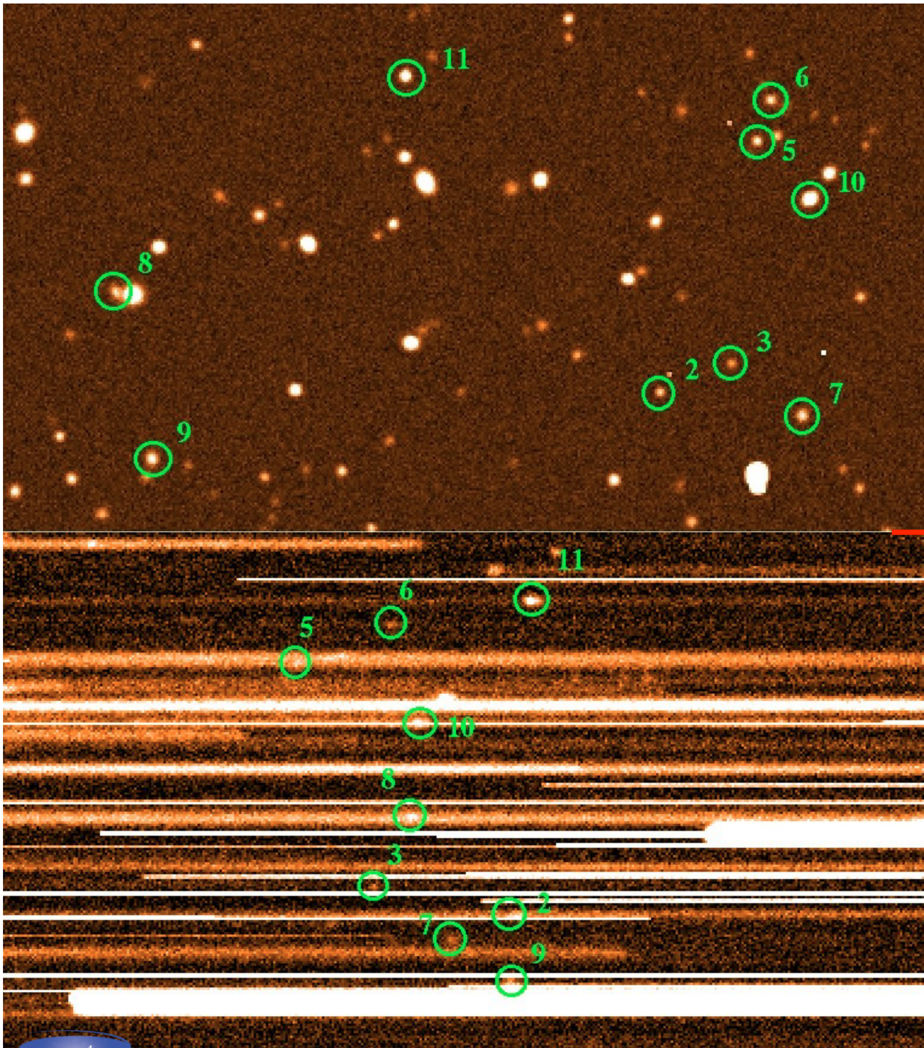
From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. zoubian

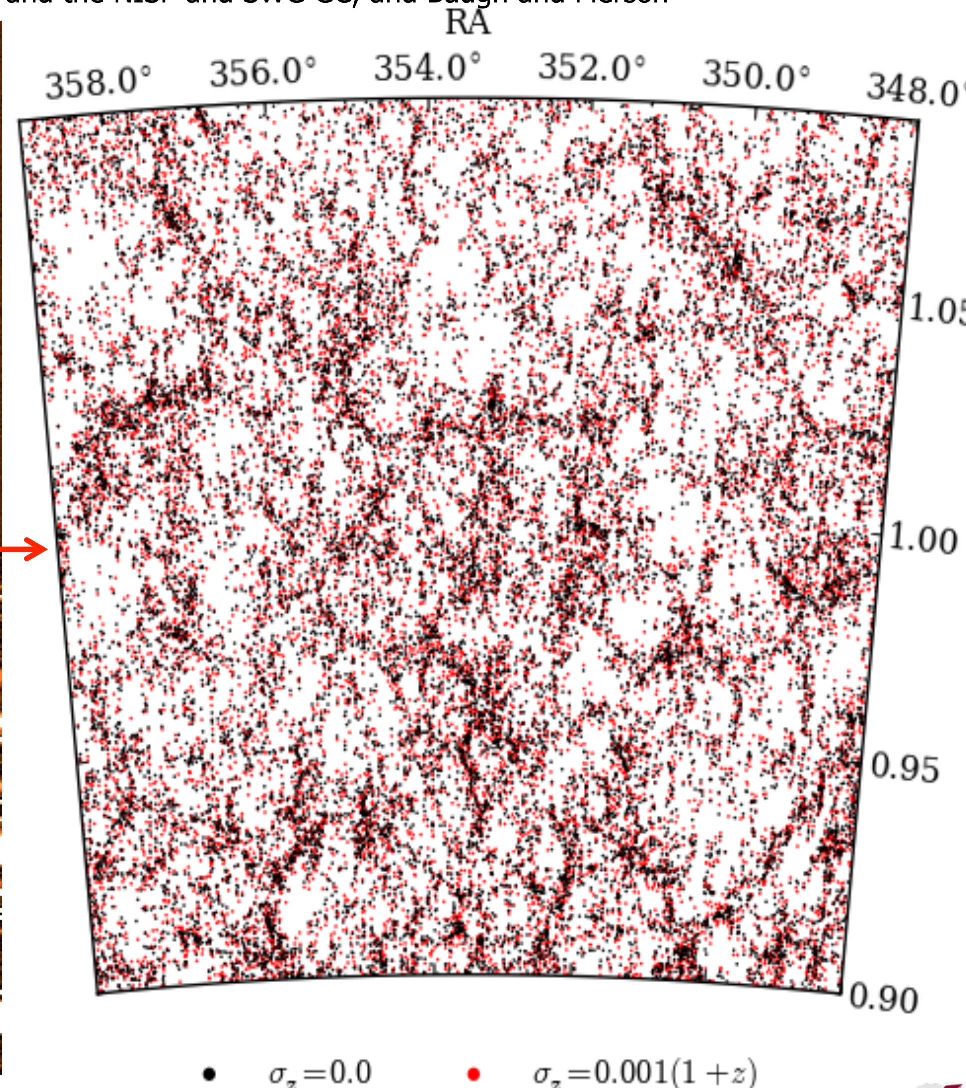


35 million spectra with at least 3 exposures taken with 3 different orientations and a total exposure time of 4000 sec.

From Euclid NISP spectral images to redshifts

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





Euclid True vs. Measured redshift

Technical Performance Measure		Requirement	CBE
Image Quality			
VIS Channel	FWHM (@ 800nm)	180 mas	163 mas
	ellipticity	15.0%	5.9%
	R2 (@ 800 nm)	0.0576	0.0530
	ellipticity stability σ(εi)	2.00E-04	2.00E-04
	R2 stability σ(R2)/<R2>	1.00E-03	1.00E-03
	Plate scale	0.10 "	0.10 "
	Out-of-band avg red side	1.00E-03	1.13E-05
	Out-of-band avg blue side	1.00E-03	2.12E-04
	Slope red side	35 nm	15 nm
	Slope blue side	25 nm	8 nm
NISP Channel	rEE50 (@1486nm)	400 mas	217 mas
	rEE80 (@1486nm)	700 mas	583 mas
	Plate scale	0.30 "	0.30 "
Sensitivity			
VIS SNR (for mAB = 24.5 sources)		10	17.1
NISP-S SNR (@ 1.6um for 2xe-16 erg cm-2 s-1 source)		3.5	4.87
NISP- P SNR (for mAB = 24 sources)	Y-band	5	5.78
	J-band	5	6.69
	H-band	5	5.35
NISP-S Performance			
Purity		80%	72%
Completeness		45%	0.52
Survey			
Wide Survey Coverage		15,000 deg2	15,000
Survey length [years]		5.5	5.4

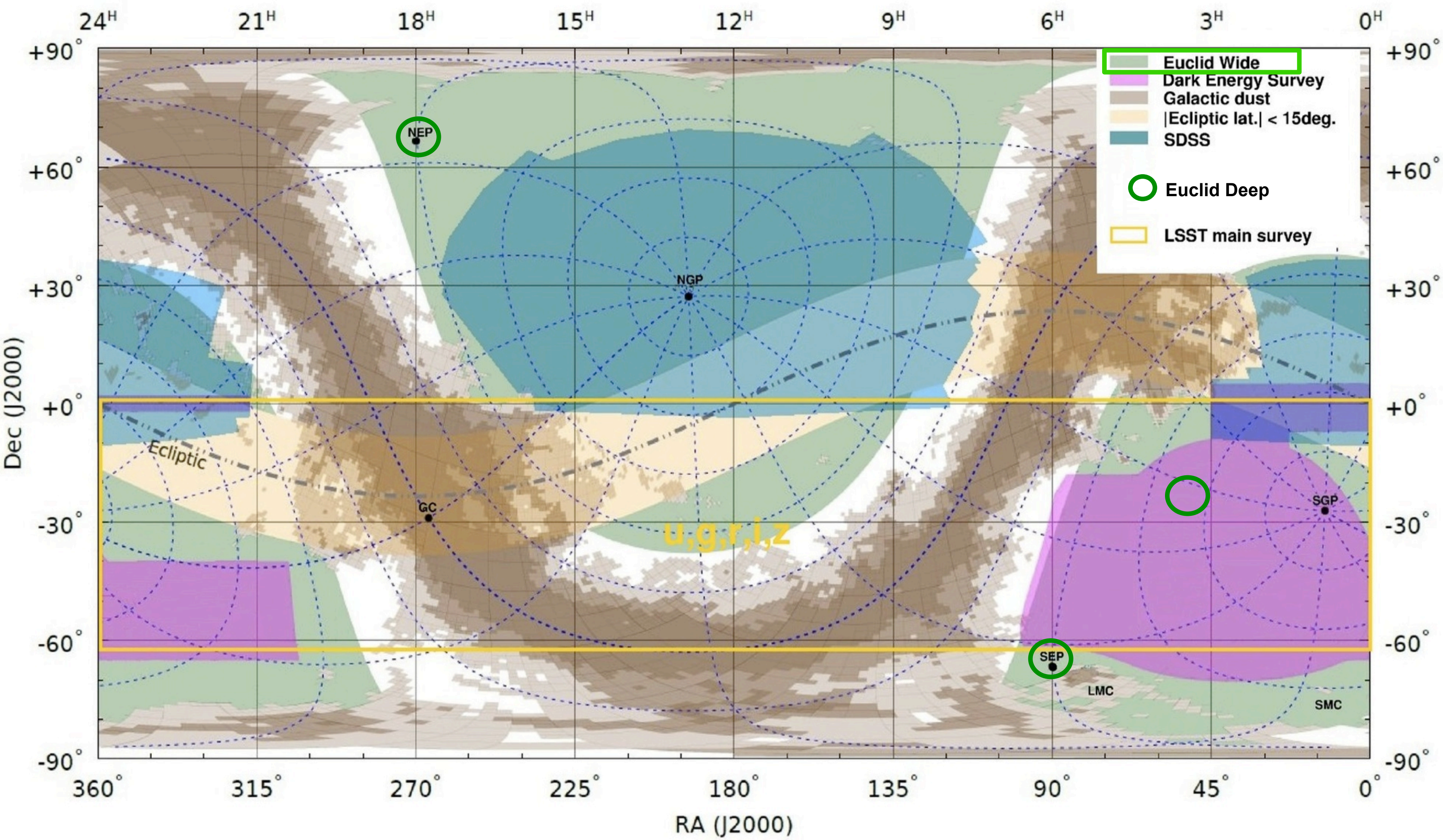
ESA Mission PDR October 2015 successful:

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).

Science with Euclid Data

Euclid Wide and Deep Surveys



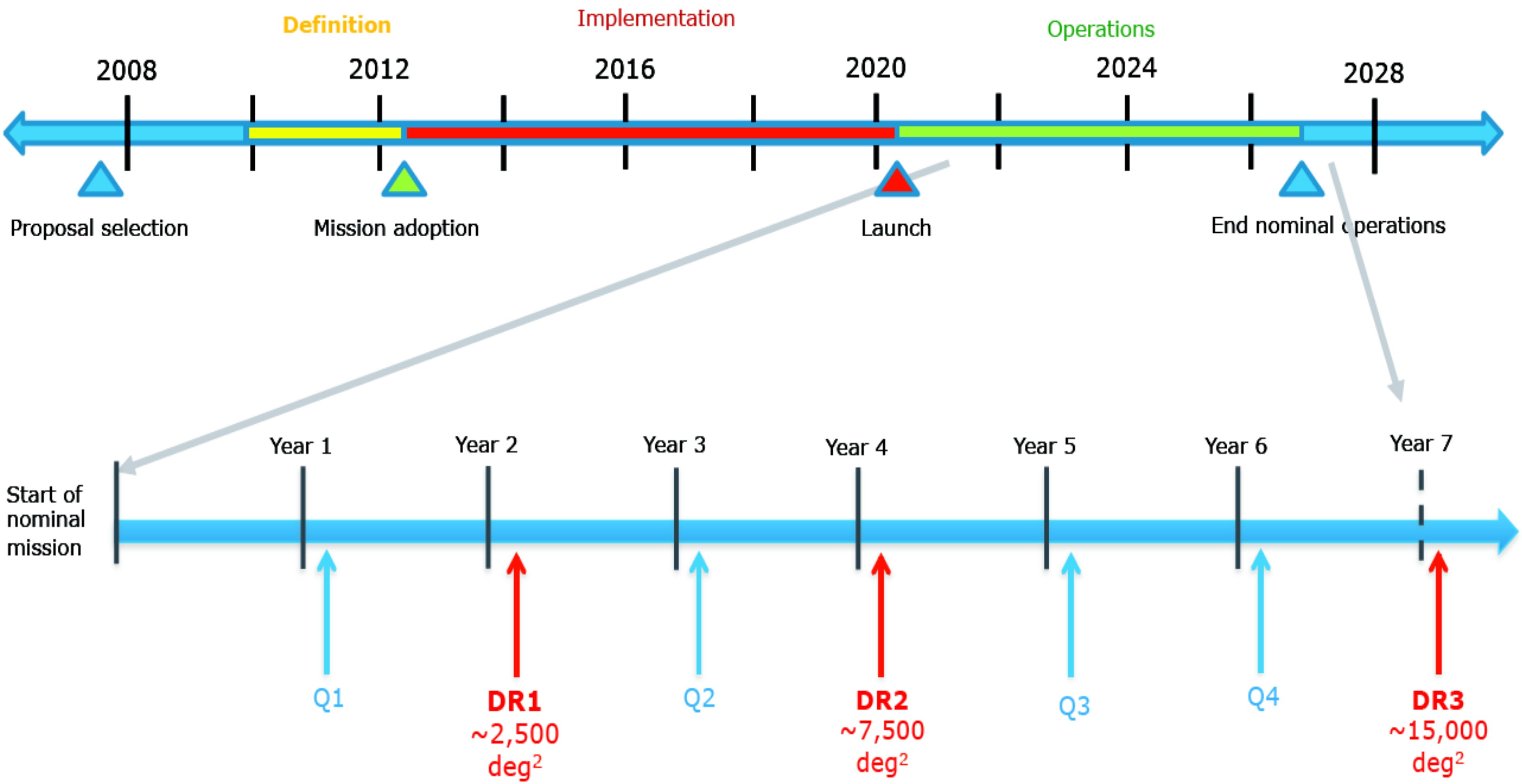
Euclid Wide and Deep Surveys

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

- **Euclid Deep:**
  - 1x10 deg^2 at North Ecliptic pole + 1x20 deg^2 at South Ecliptic pole

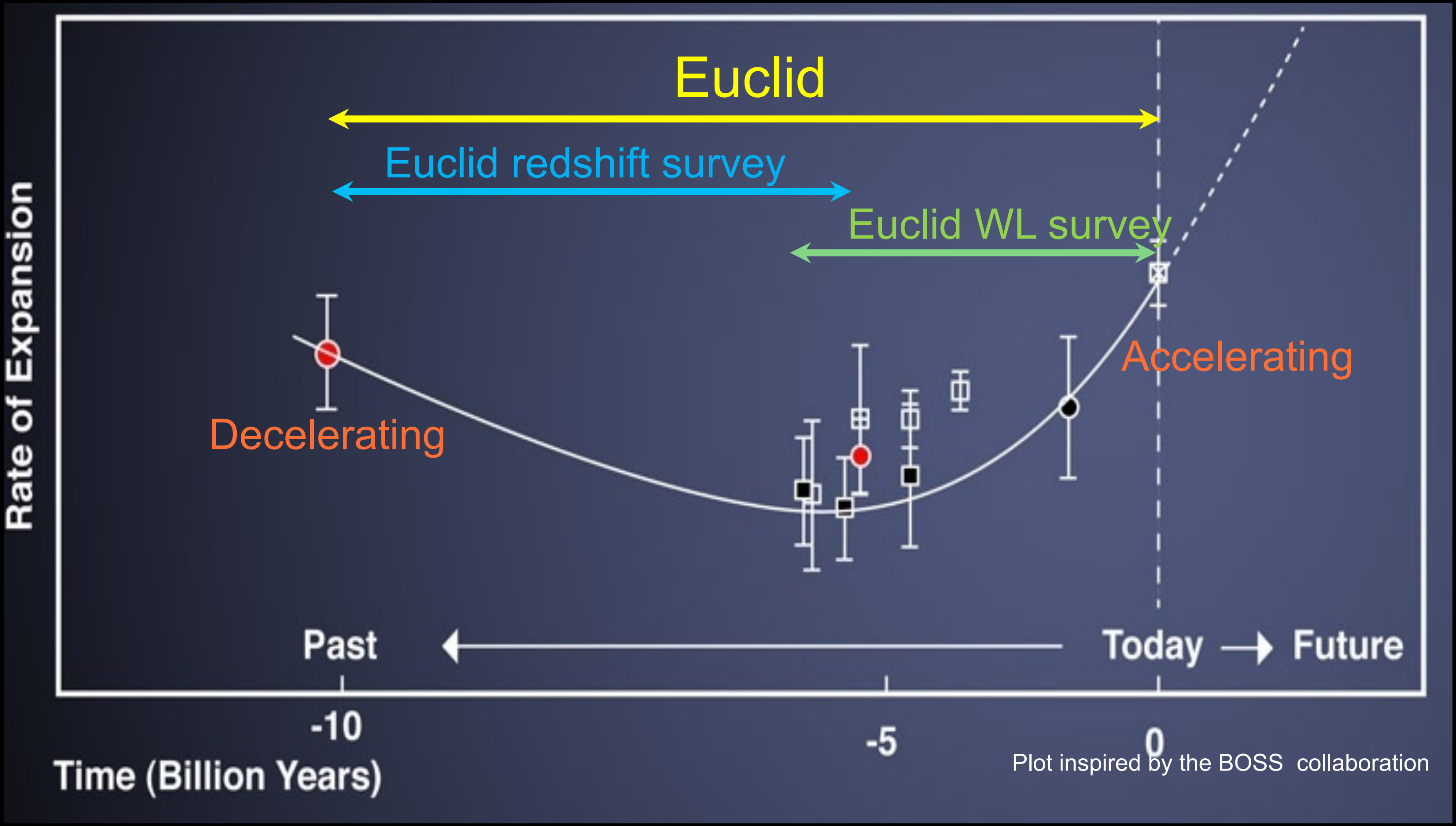
    + 1x10 deg^2 South Equatorial field
  - 10 million sources (3-σ)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R +I+Z) AB=26.5, 10.0 σ +
    - NIR photometry : Y, J, H AB = 26.0, 5.0σ
    - Photometric redshifts with 0.05(1+z)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

Data release



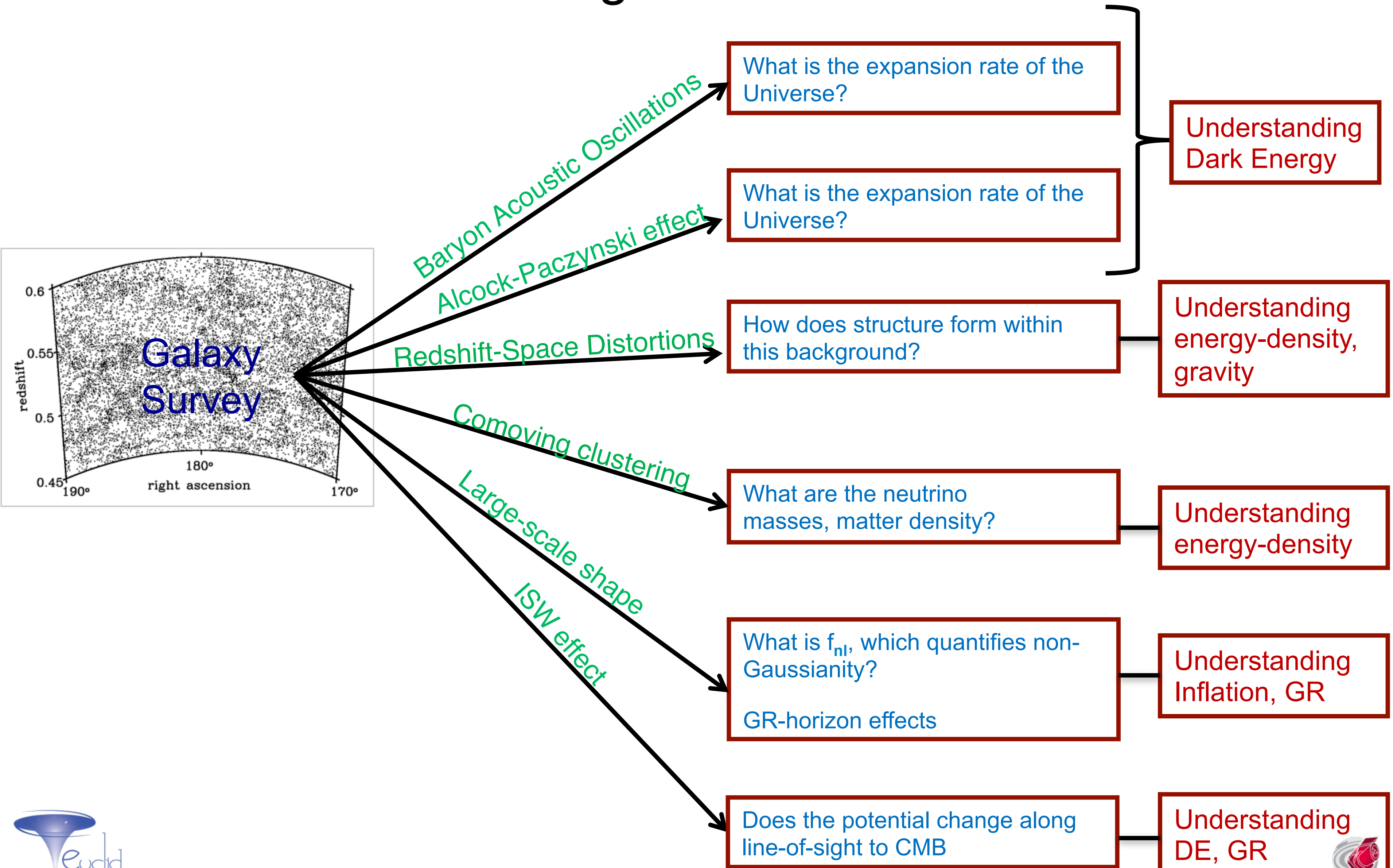
Science with Euclid will start in 2022 with Q1 and in 2023 with DR1

Euclid and the DM-dominated / DE-dominated transition period



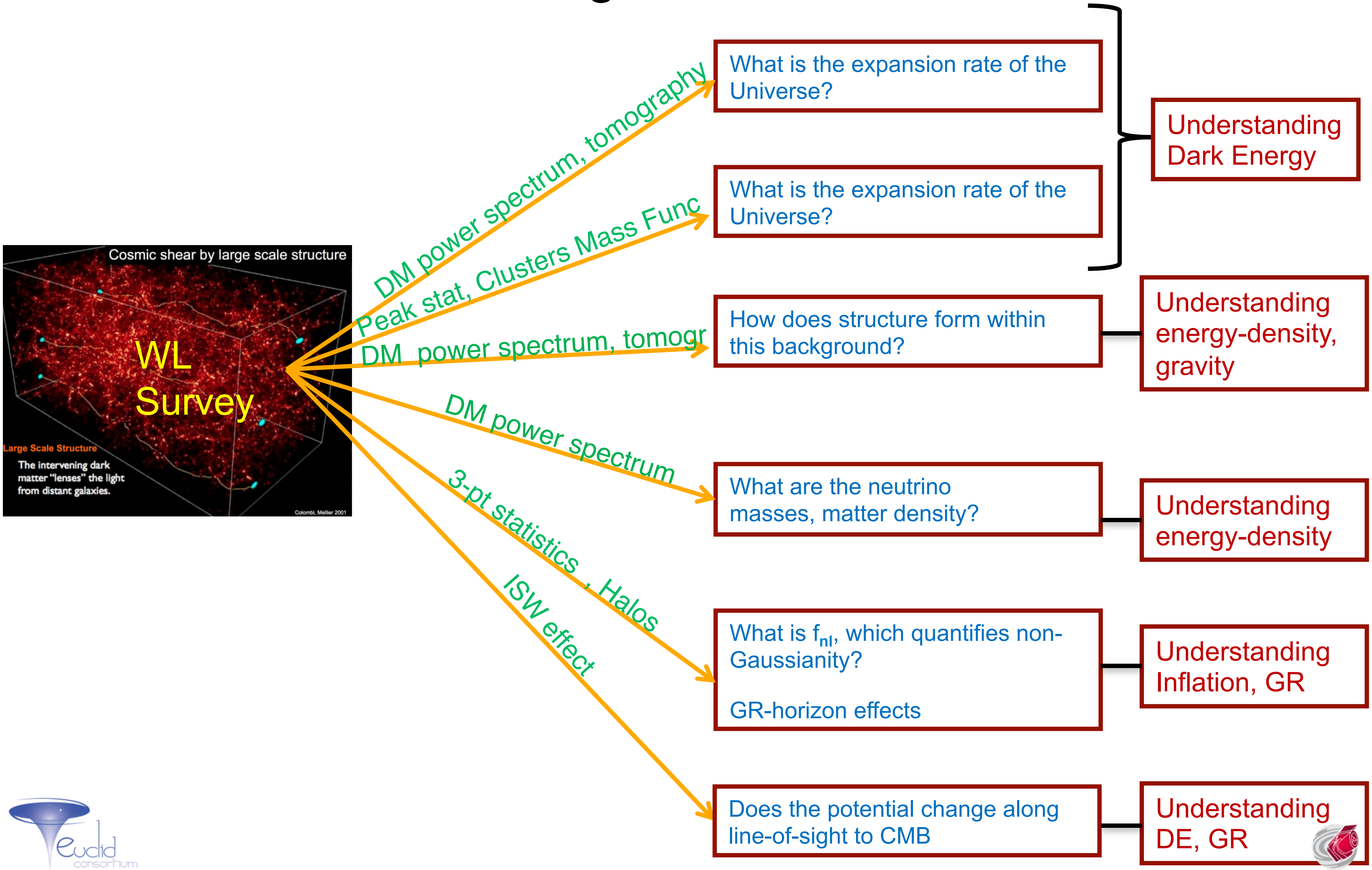
Euclid Redshift Survey:

from observational signatures to the dark universe



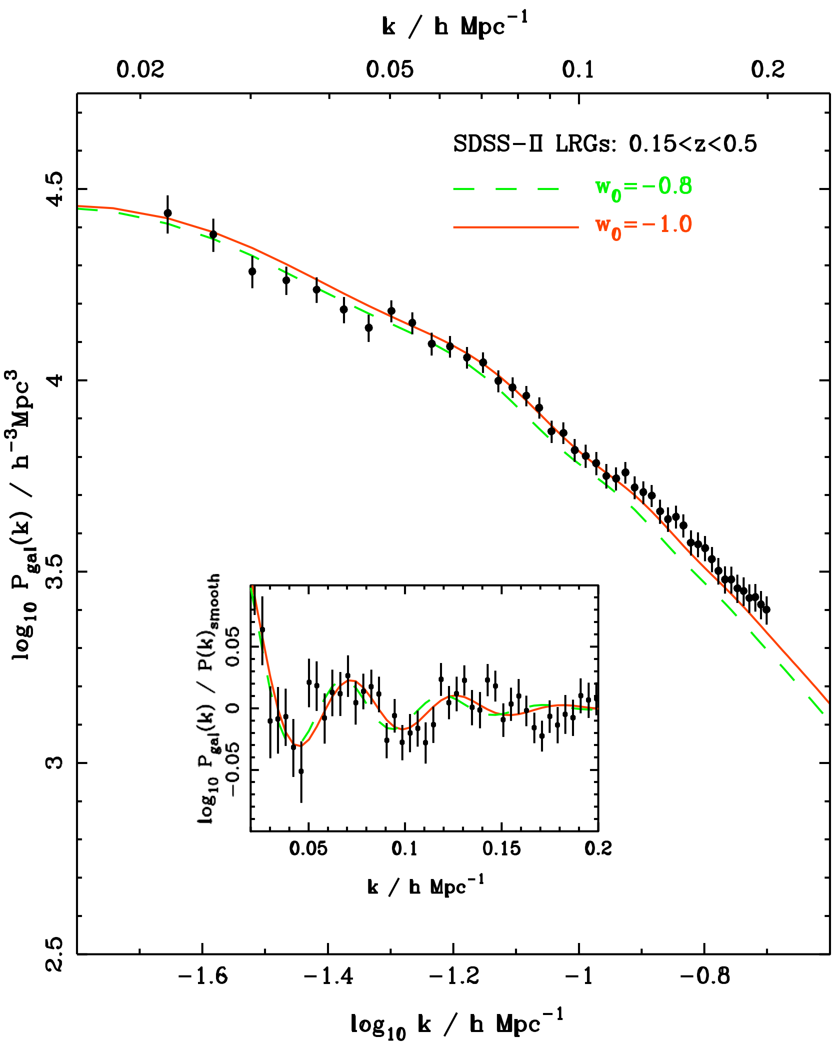
Euclid Weak Lensing Survey:

from observational signatures to the dark universe



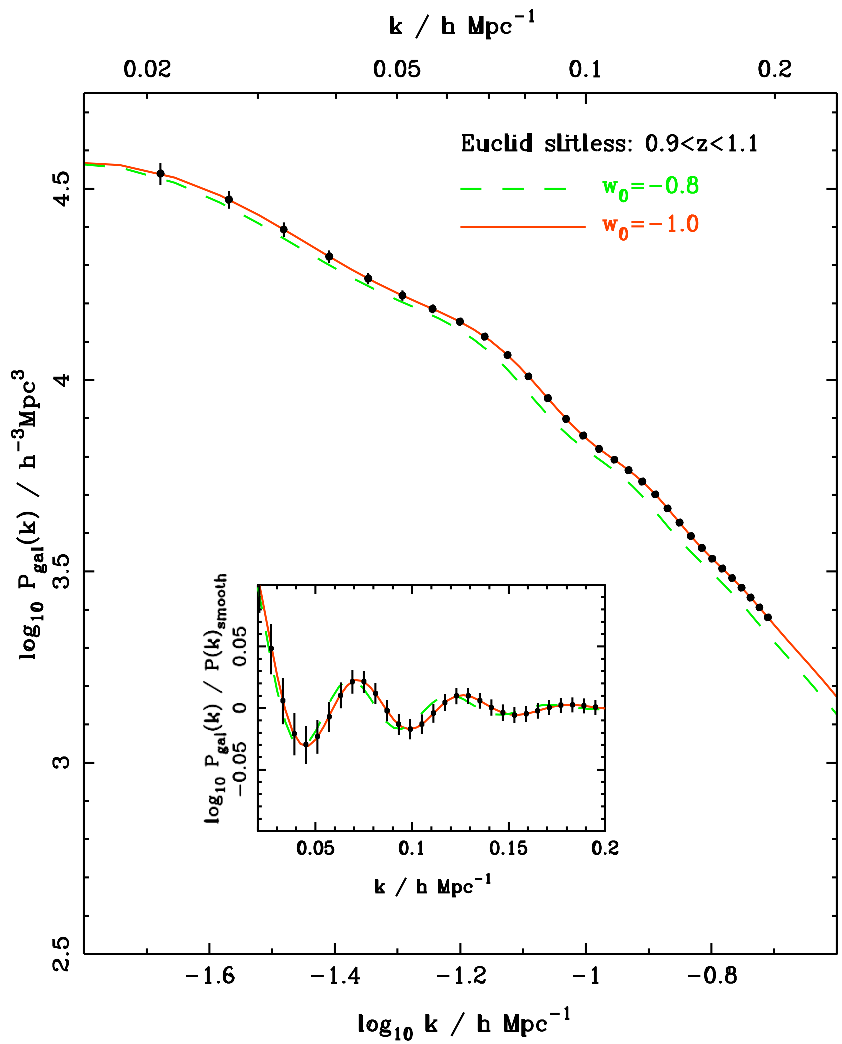
Euclid vs SDSS : BAO

SDSS today



0.15<z<0.5

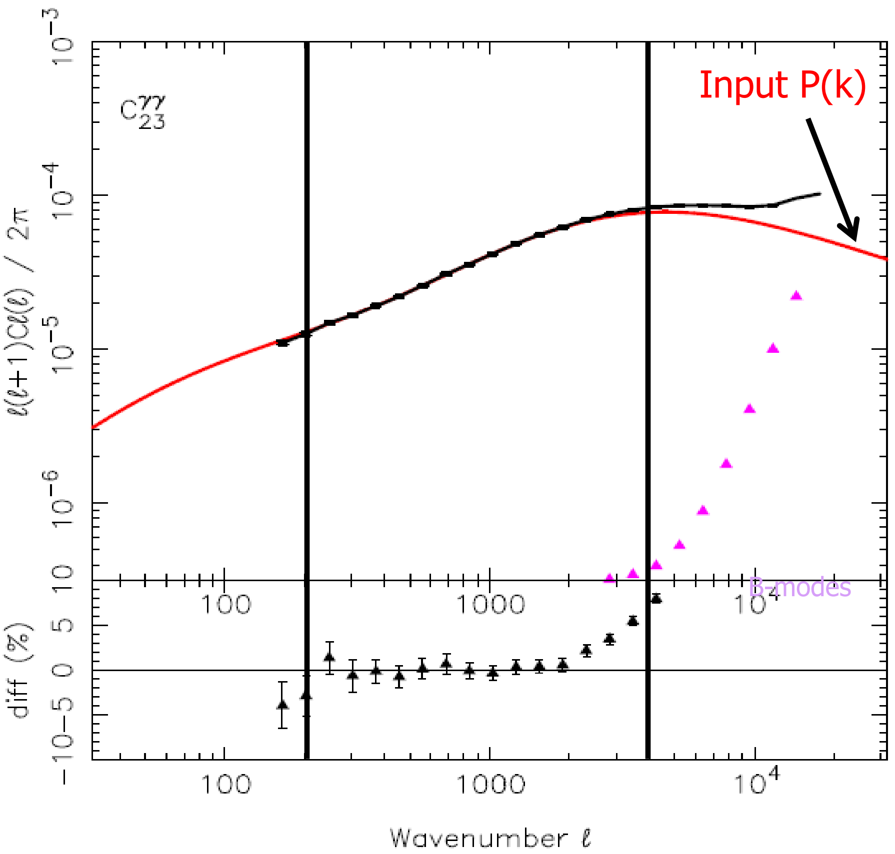
Euclid expected (20% of Euclid data)



0.7<z<2.0

Euclid: combining WL and GC data

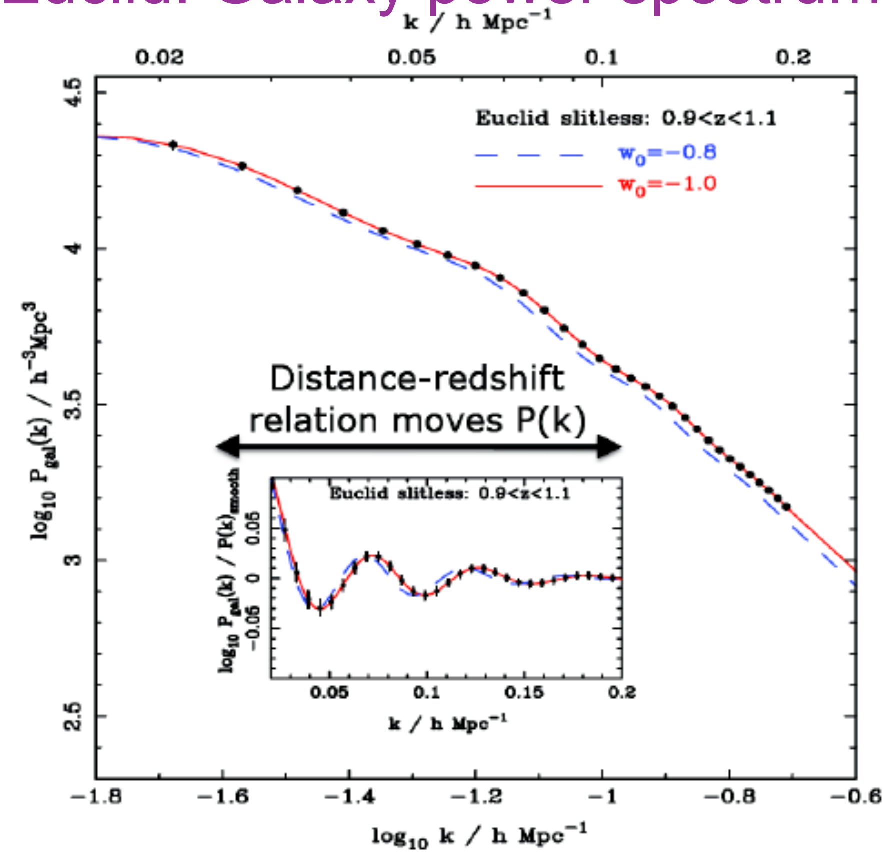
Euclid : DM power spectrum



• Tomographic WL shear cross-power spectrum for 0.5 < z < 1.0 and 1.0 < z < 1.5 bins.

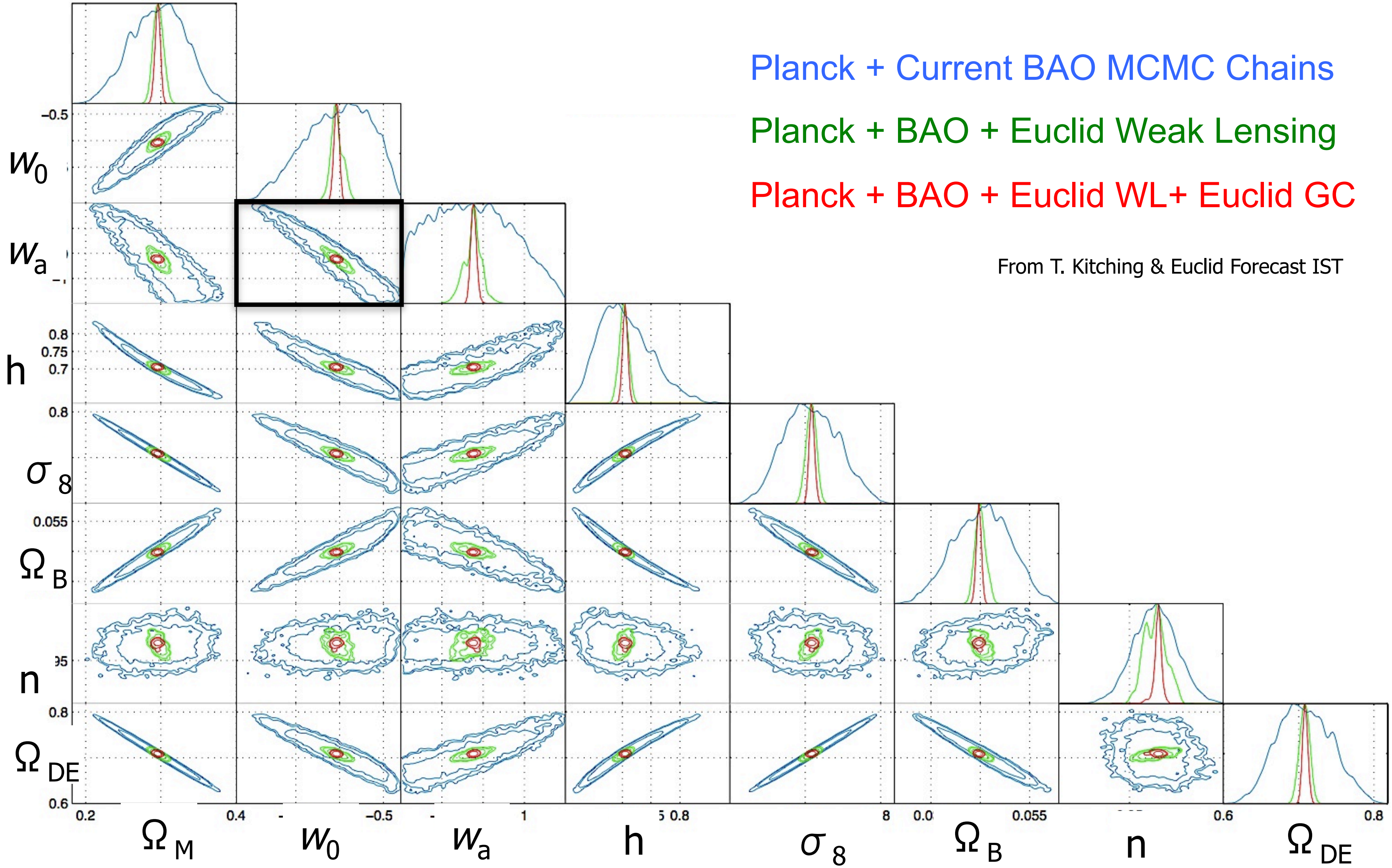
• Percentage difference [*expected – measured*] power spectrum: recovered to 1% .

Euclid: Galaxy power spectrum

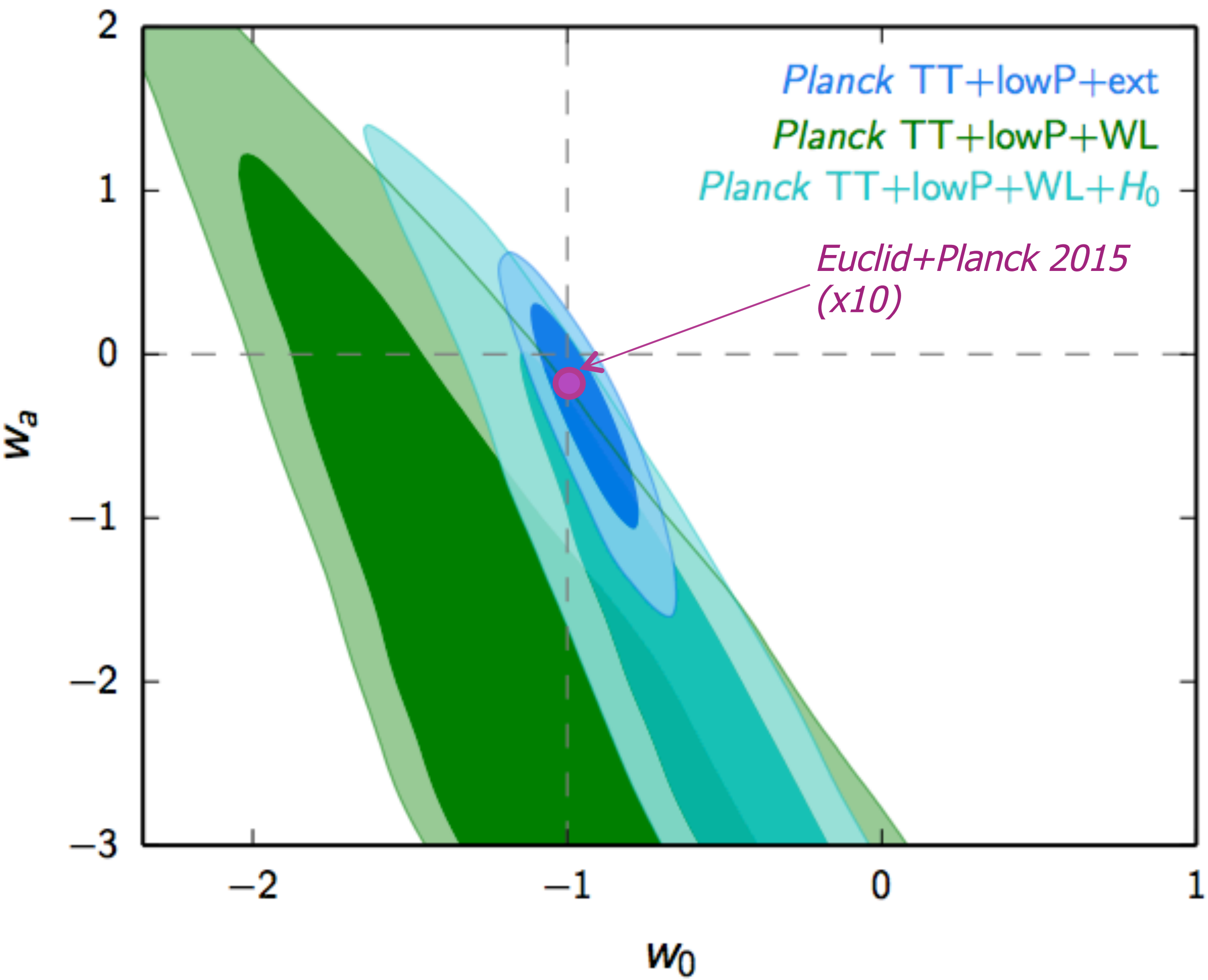


- $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx 75$x larger than SDSS
- Redshifts 0.7<*z*<1.85
- Percentage difference [*expected – measured*] power spectrum: recovered to 1% .

Euclid Forecast



Euclid Post-Planck Forecast for the Primary Program



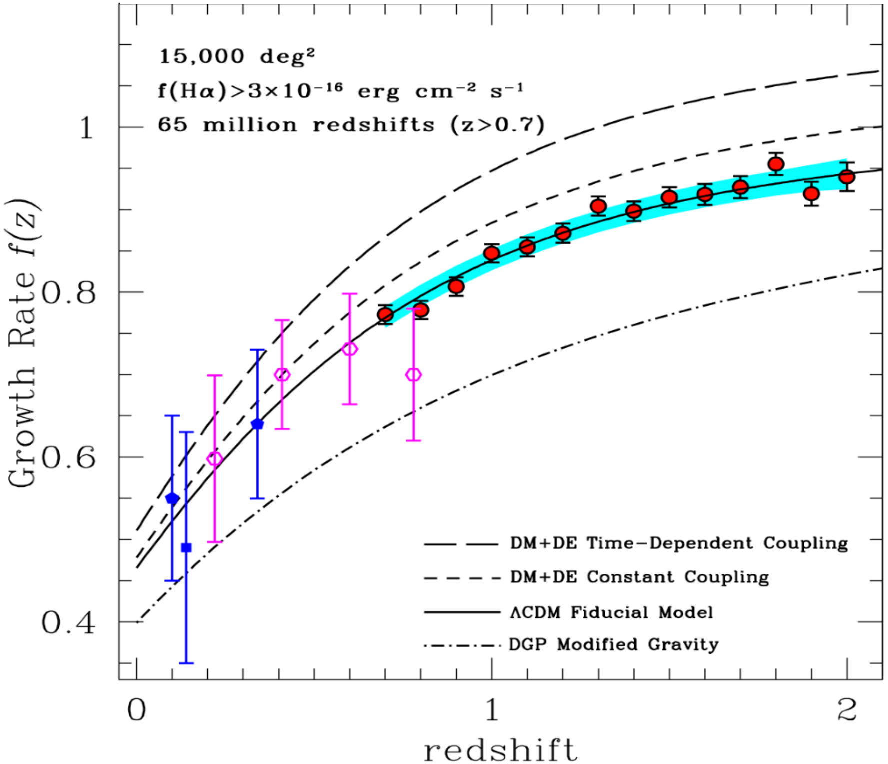
Dark Energy		
w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
0.015	0.150	430
0.013	0.048	1540
0.007	0.035	6000
0.100	1.500	~10
>10	>40	>400

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

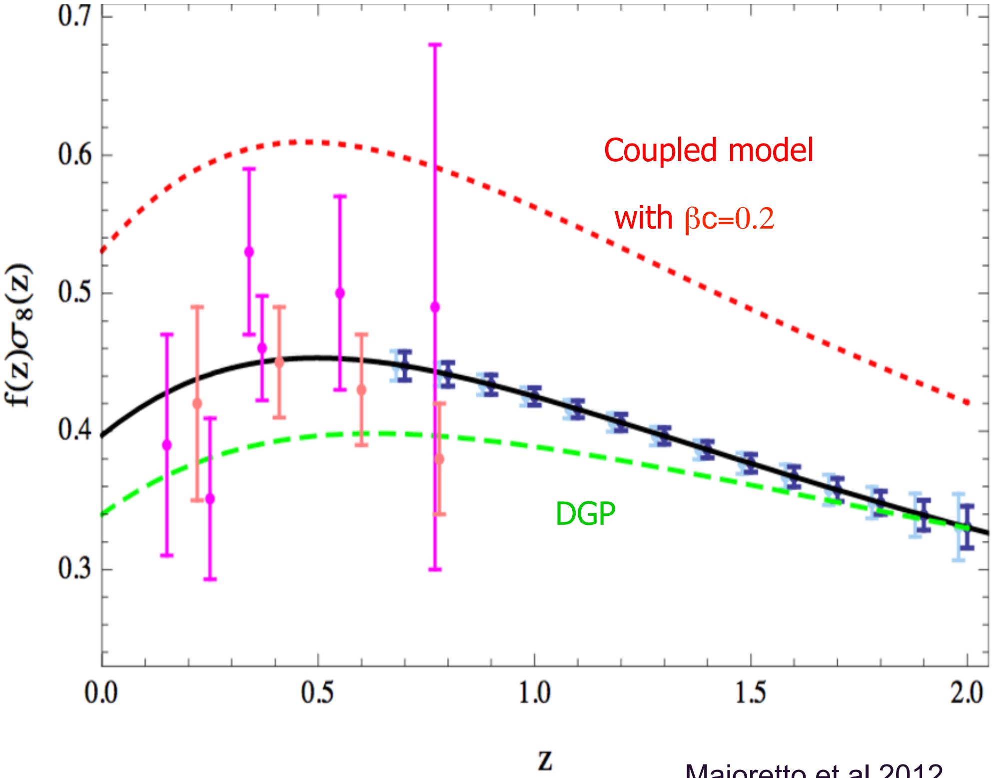
From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p) > 400$→ ~1% precision on w's.

Exploration of DE models with Euclid (redshifts only)

Euclid RSD alone



Euclid: combined RSD and amplitude of GC



Majoretto et al 2012

Euclid Post-Planck Forecast for the Primary Program

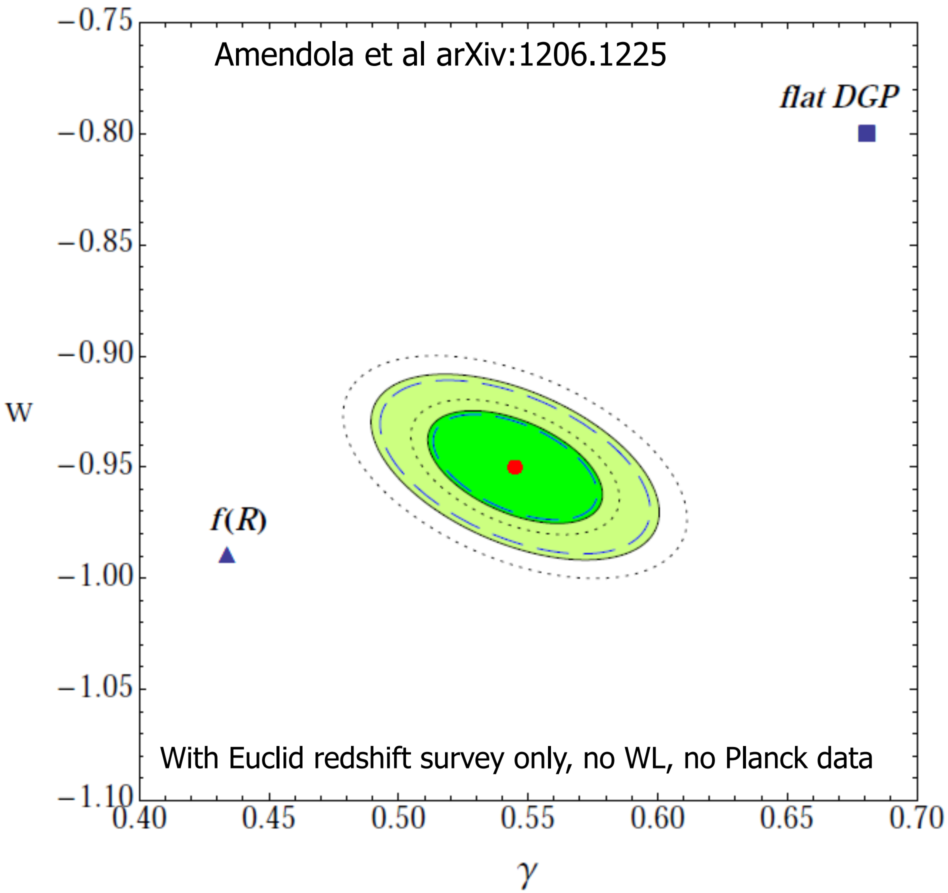
Ref: Euclid RB arXiv: 1110.3193	Modified Gravity	Dark Matter	Initial Conditions
Parameter	γ	m_ν /eV	f_{NL}
Euclid primary (WL+GC)	0.010	0.027	5.5
EuclidAll (clusters,ISW)	**0.009**	**0.020**	**2.0**
Euclid+Planck	0.007	0.019	2.0
Current (2009)	**0.200**	**0.580**	**100**
Improvement Factor	**30**	**30**	**50**

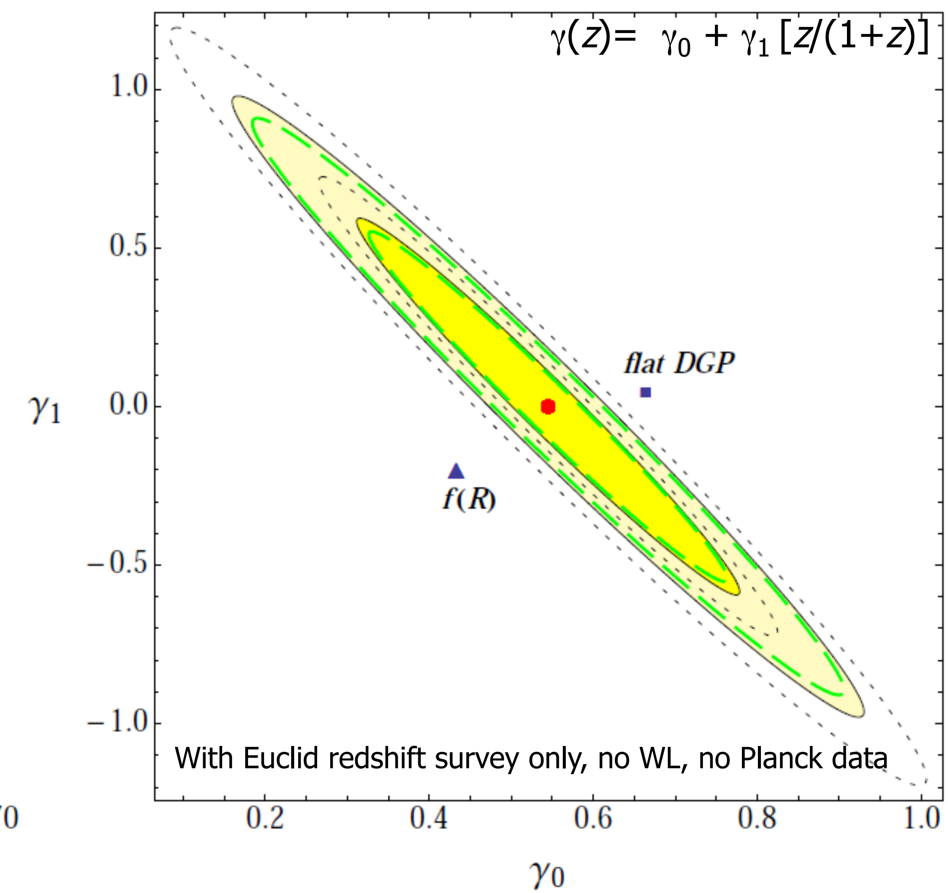
Assume systematic errors are under control

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

Notice: neutrino constraints → minimal mass possible ~ 0.05 eV!

Euclid: predicted performances from GC





$1/2-\sigma$ marginalised probability regions, constant γ and *w*

Reference = green regions

Optimistic = blue long-dashed ellipses

Pessimistic= black short-dashed ellipses

$1-\sigma$, $2-\sigma$ marginalised probability regions for γ_0 and γ_1

Reference = yellow regions

Optimistic = green long-dashed ellipses

Pessimistic= black doted ellipses

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

[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.

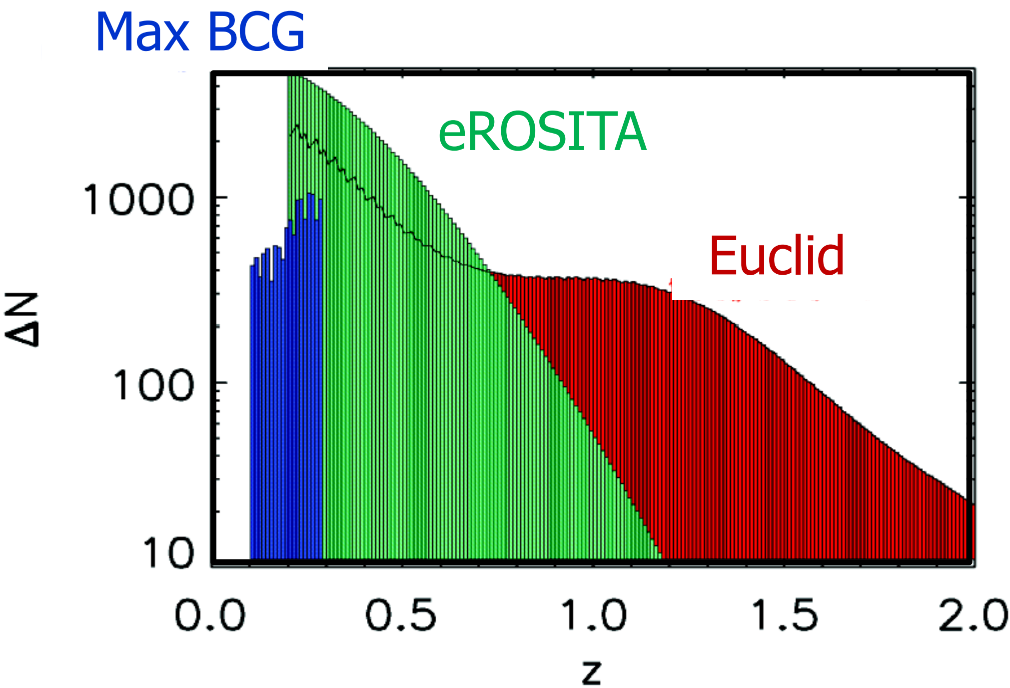
- **If Σ <0.1 eV**

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

Clusters of galaxies with Euclid

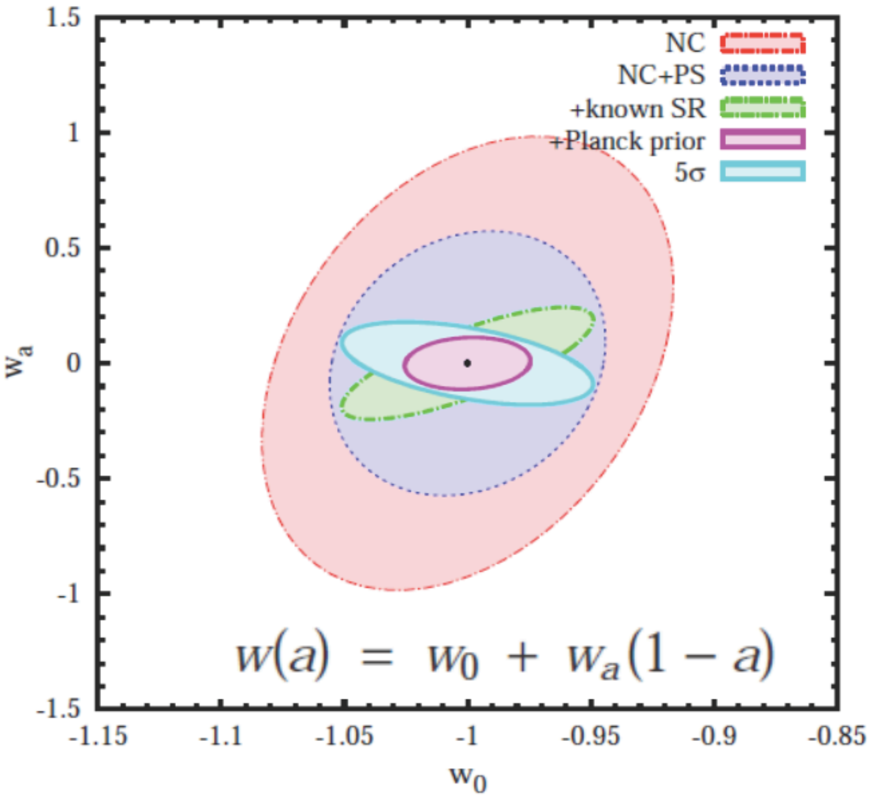
- Probe of peaks in density distribution
- Nb density of high mass, high redshift clusters very sensitive to
  - primordial non-Gaussianity and
  - deviations from standard DE models
- Euclid data will get for free:
  - Λ-CDM: all clusters with M>2 .10^{14} Msol detected at 3-σ up to z=2
    - → 60,000 clusters with 0.2<z<2 ,
    - → 1.8 10^4 clusters at z > 1.
  - ~ 5000 giant gravitational arcs
    - → accurate masses for the whole sample of clusters
    - → dark matter density profiles on scales >100 kpc

→ Synergy with Planck and eROSITA

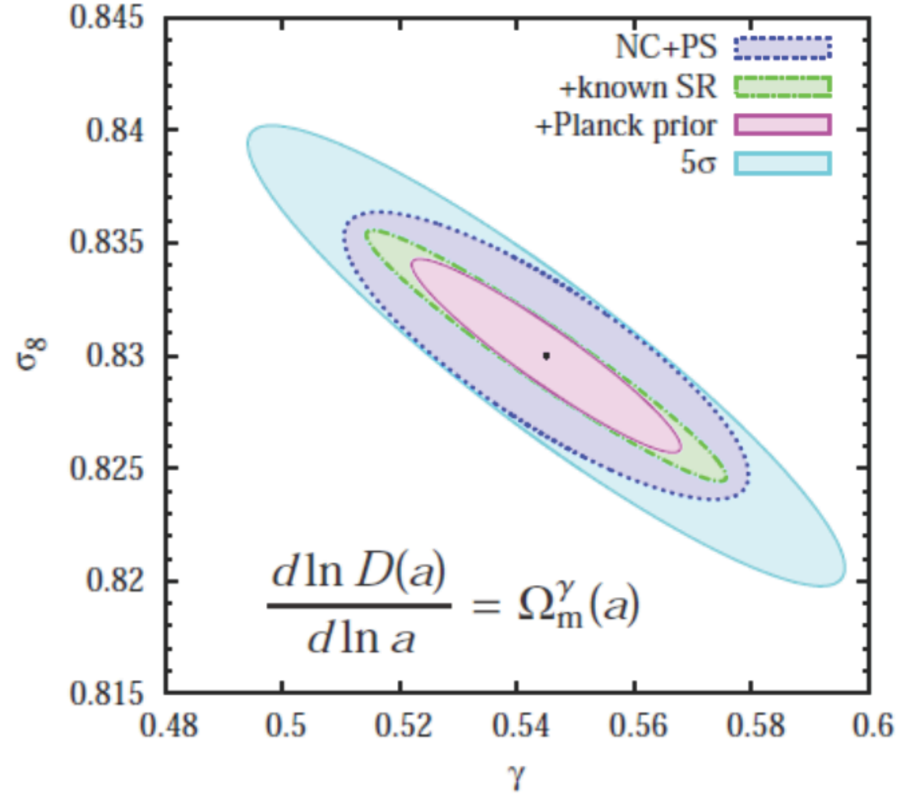


Cosmology with Euclid Clusters of Galaxies

Constraints on homogeneous dark energy



Constraints on fluctuations and growth rate

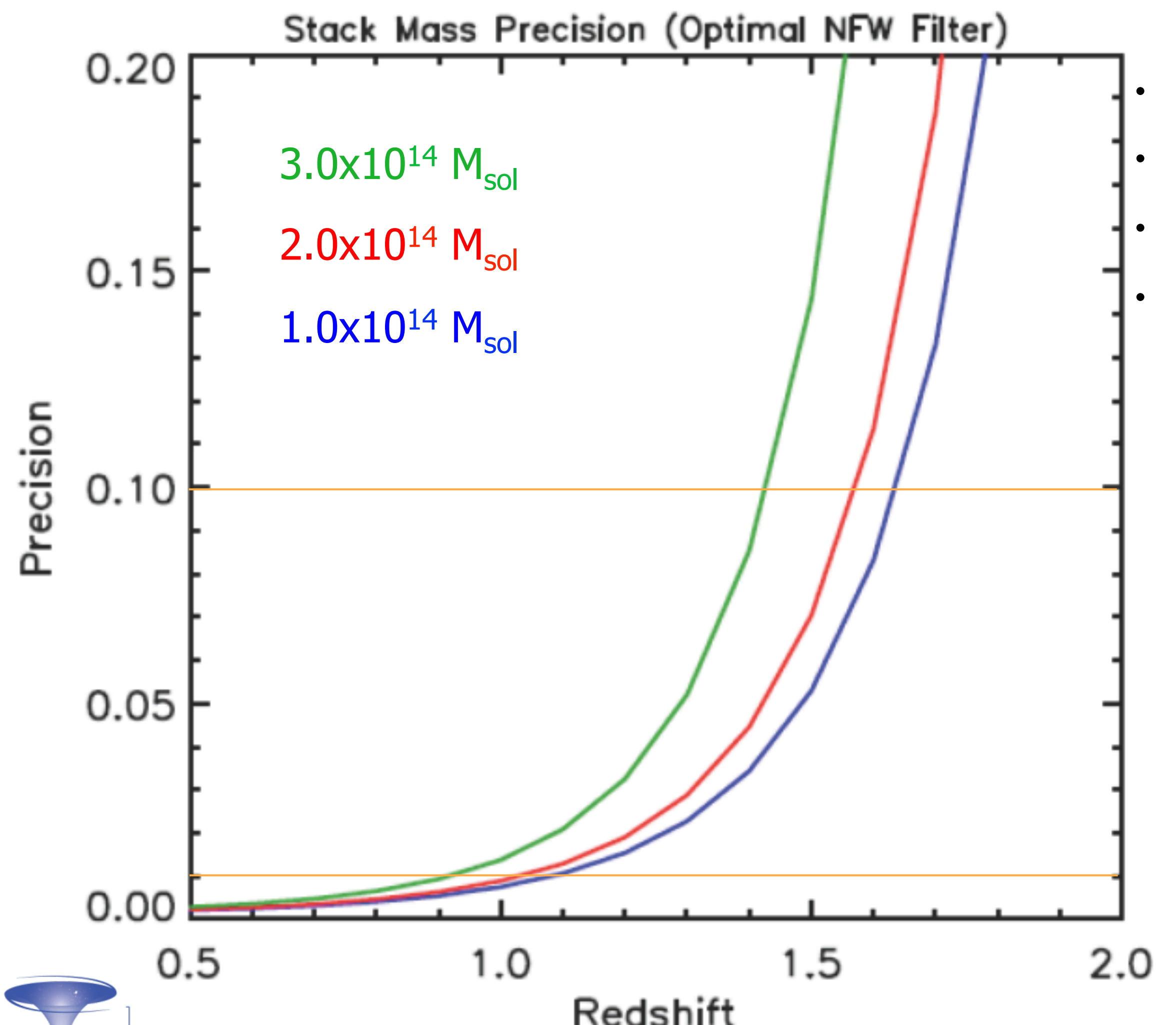


Sartoris et al. 2015 arXiv:1505.02165

NC: Cluster Number counts ; **PS**: Cluster Power Spectrum, **SR**: Cluster Scaling Relation

Scaling relations with Euclid Clusters

Expected precision on the mean mass of clusters with gravitational shear in bin of Δlog(M200)=0.2 and Δz=0.1



- Survey of 15,000 deg^2
- Λ-CDM Planck cosmology
- Tinker mass function
- Shape noise of 0.3

Euclid will calibrate the mean mass, and the scaling relations, to

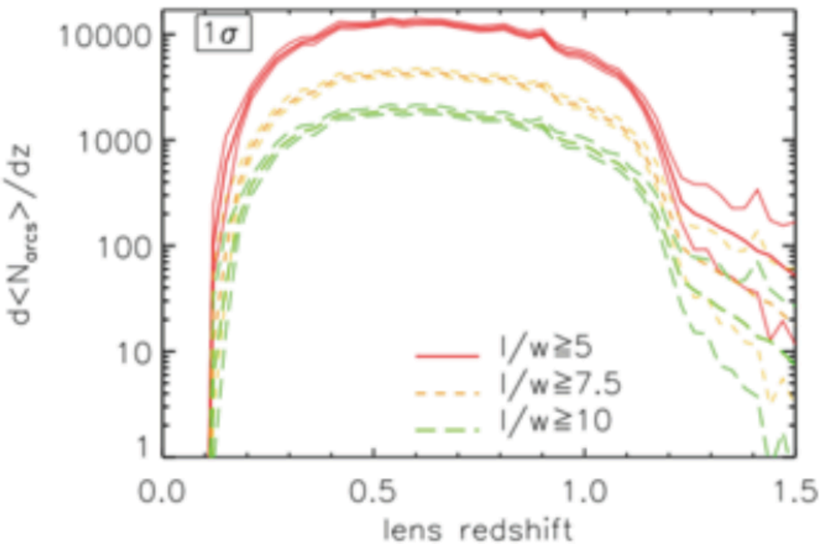
- 1% out to z=1.0
- 10% out to z=1.6

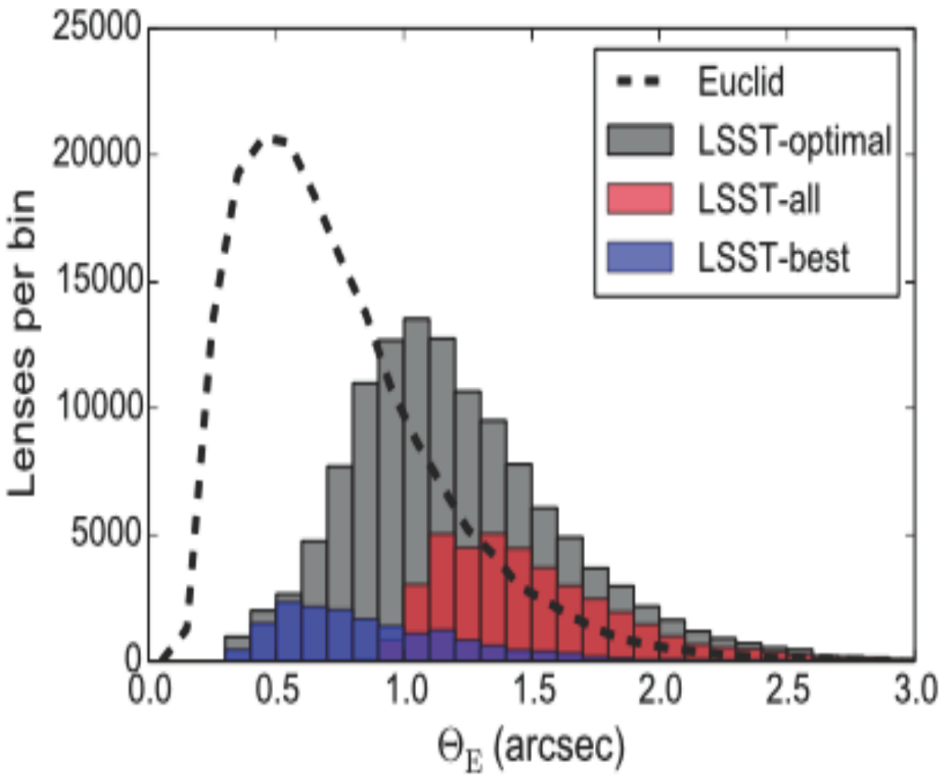
Sartoris et al 2015

Probing haloes with strong lensing

Strong lenses with Euclid:

- Galaxy-galaxy lensing
- Galaxy-QSO lensing
- Gravitational arcs
- Multiple images in clusters





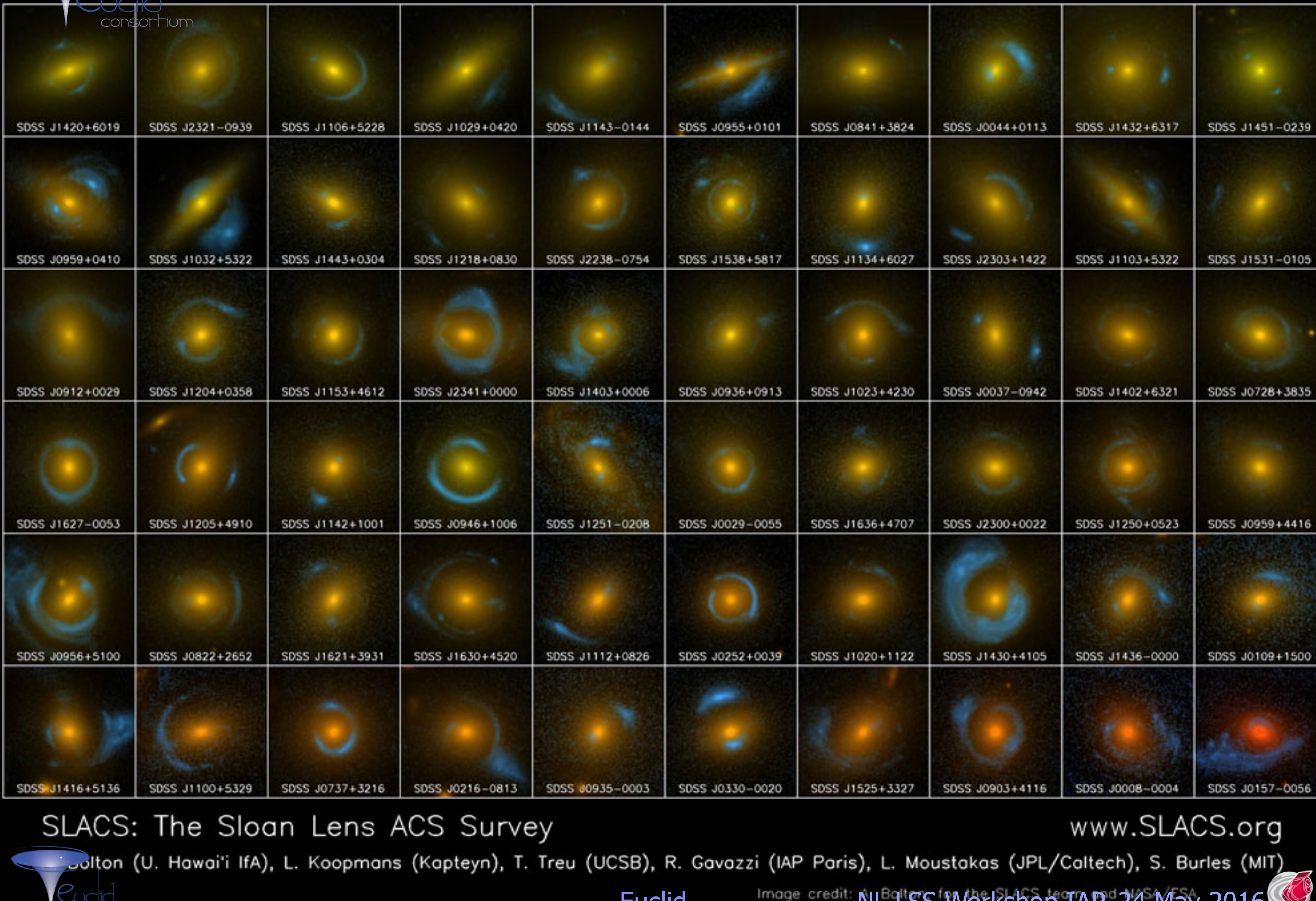
Giant arcs in clusters (Boldrin et al 2015)

- 1300 arcs wit L/w >10
- 8000 arcs with L/w > 5

Galaxy-galaxy lensing (Collett 2015)

- 140,000 lenses in the wide survey
- 650 double source plane lenses

SLACS (~2010 - HST)



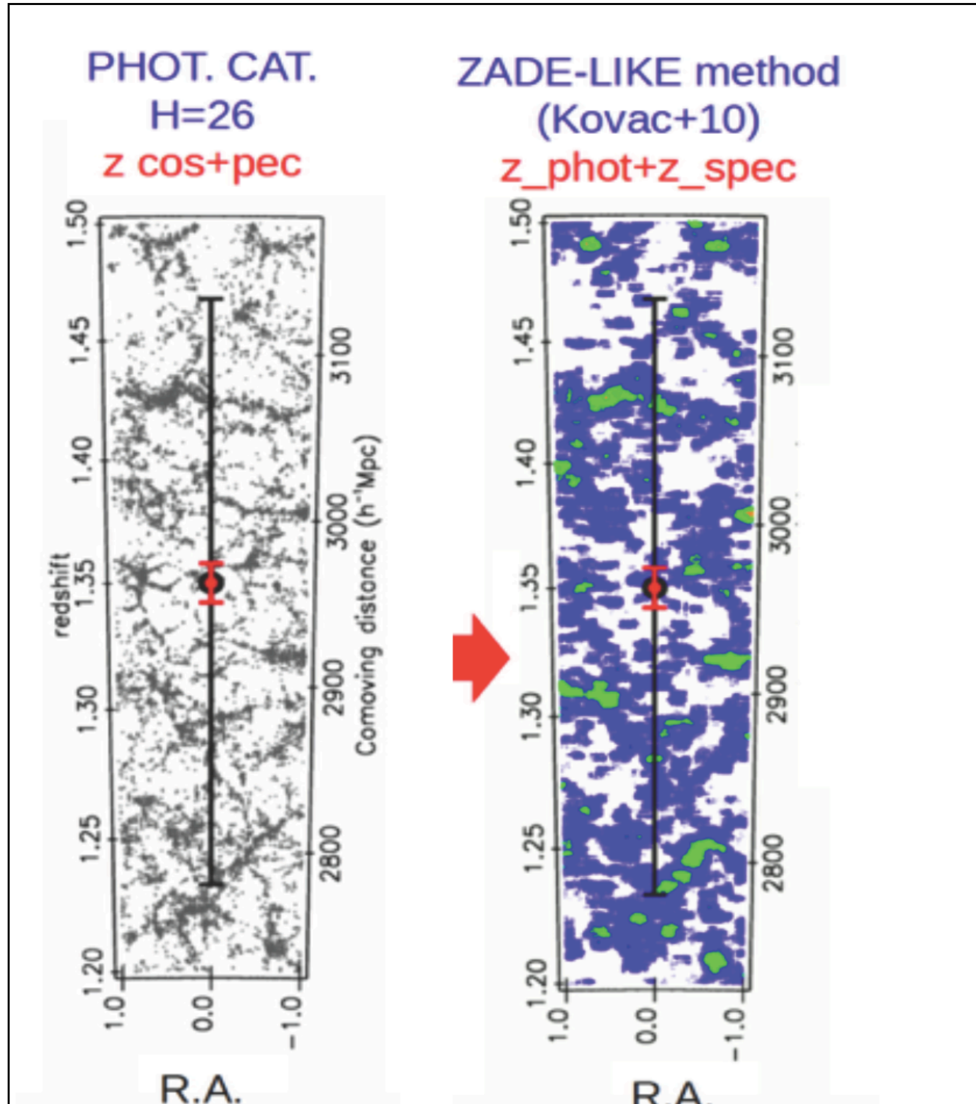

SLACS
Euclid VIS Legacy : after 2 months
(66 months planned)

Galaxy clustering and local environment with Euclid photo-z

Euclid has enough spatial resolution to

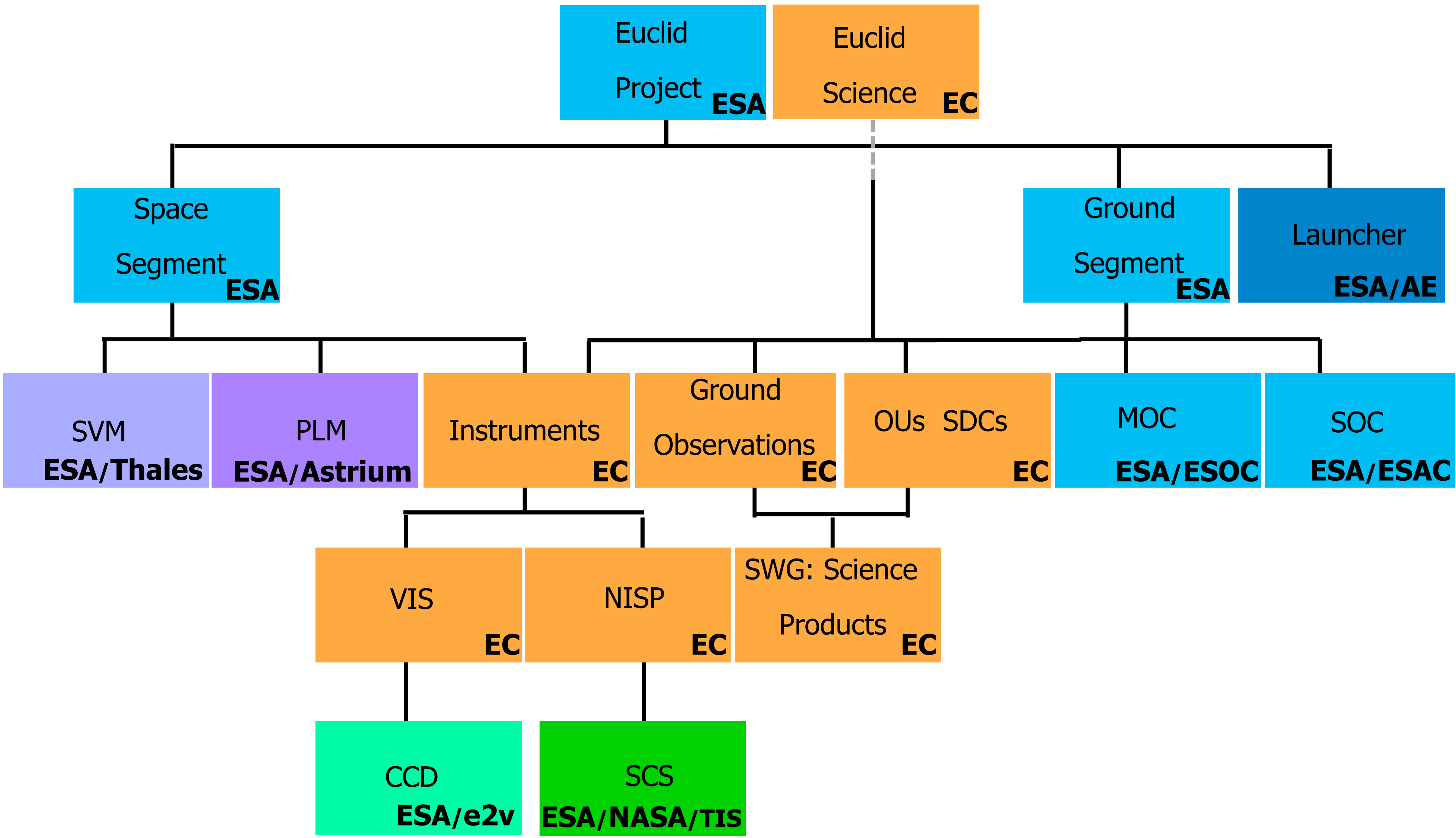
- characterise local environments,
- explore galaxy clustering with photometric redshifts.

From Cucciati

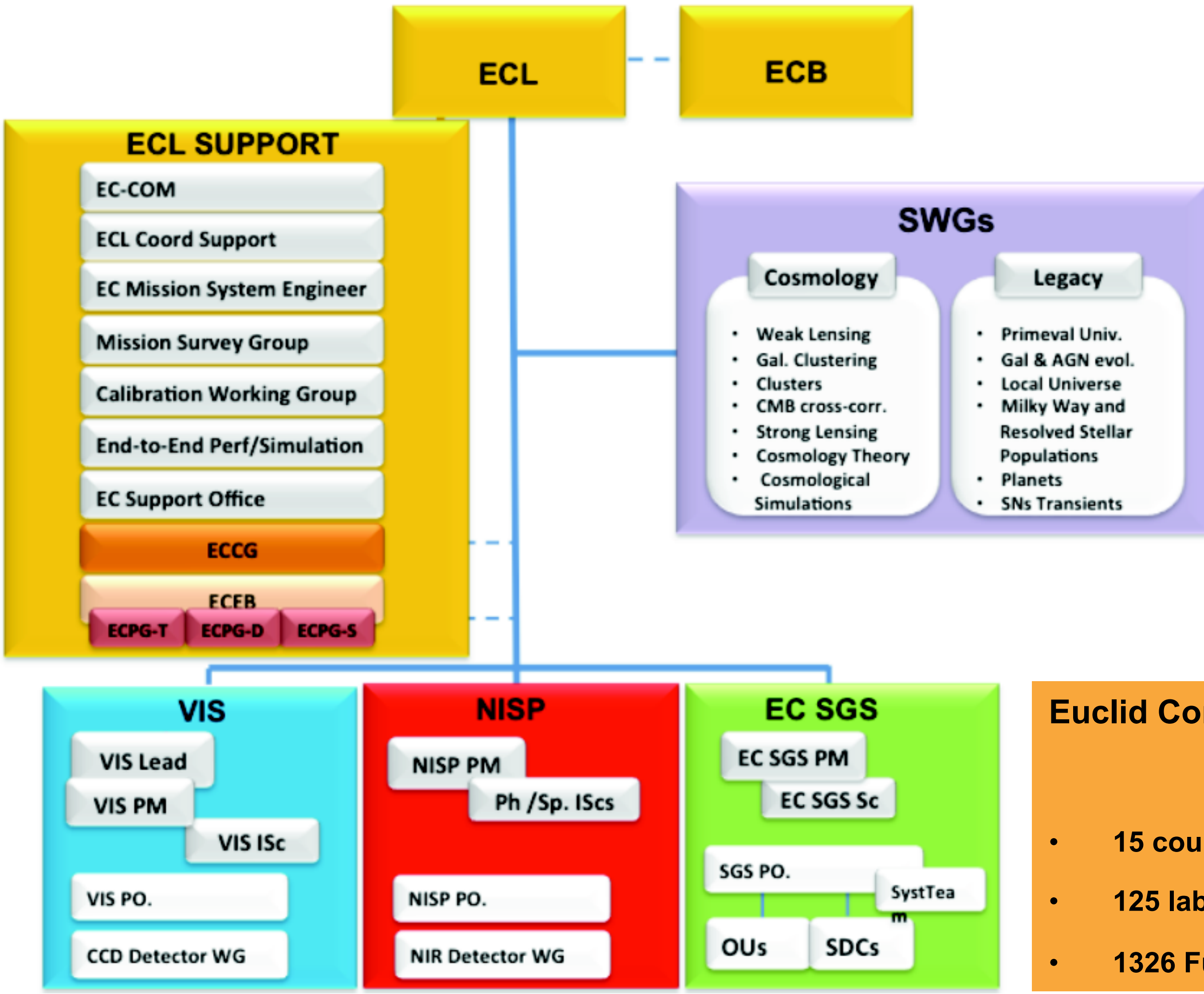


Euclid Organisation
and
Schedule

Euclid Collaboration



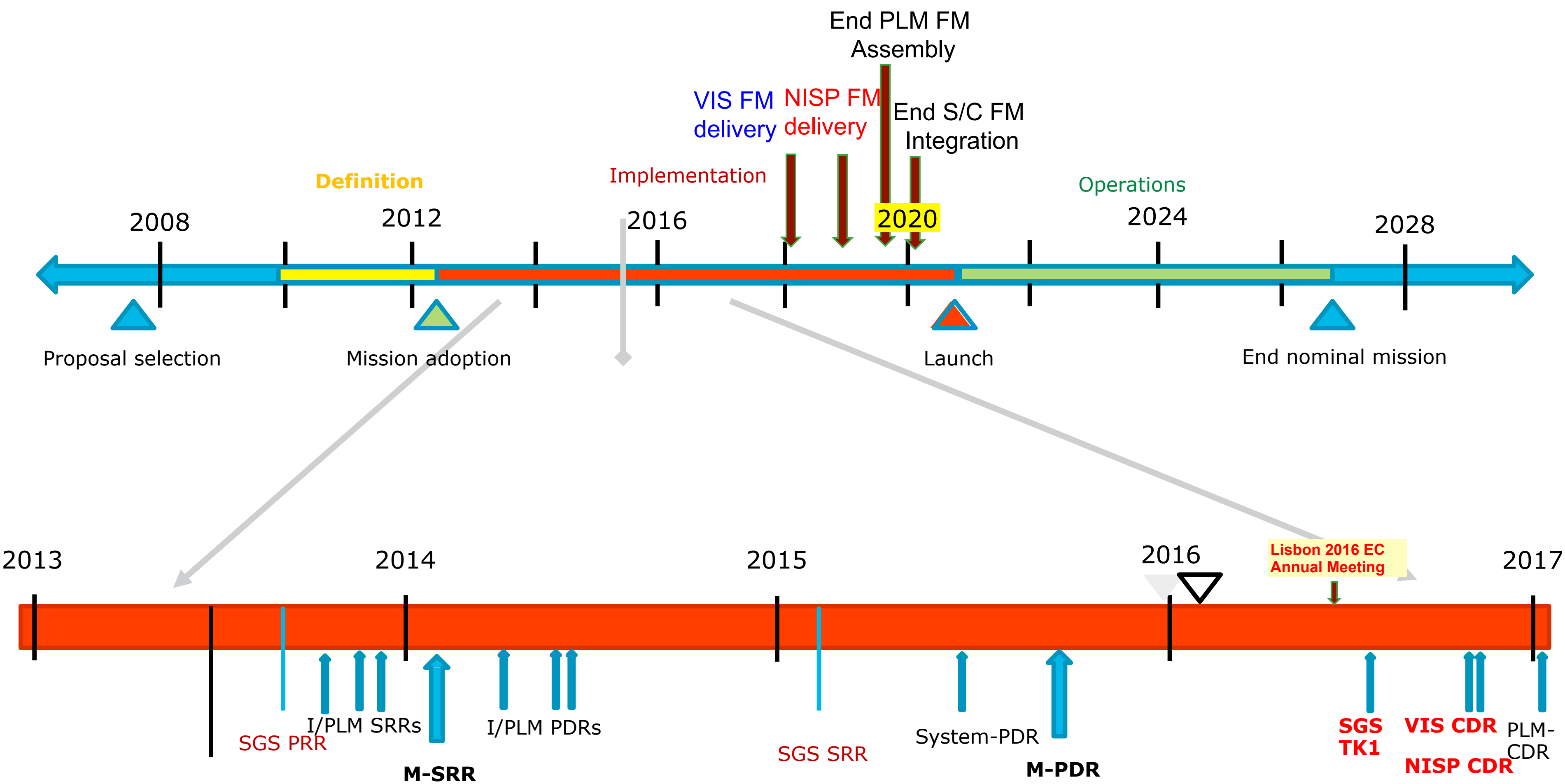
Euclid Consortium (May 2016)



Euclid Consortium May 21 2015

- **15 countries**
- **125 labs**
- **1326 Full members**

Overview mission timeline



Summary

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.

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

Euclid: a space mission to probe LSS

- Euclid cosmology core program:
  - Use 5 cosmological probes, with at least 2 independent, and 3 power spectra
  - Explore the dark universe: DE, DM (neutrinos), MG, inflation, biasing
  - Explore the transition DM-to-DE-dominated universe periods
  - Get the percent precision on w and the growth factor γ
  - Perfect complementarity with Planck: probes and data, cosmic periods
  - Synergy with New Gen wide field surveys: LSST, WFIRST, e-ROSITA, SKA
  - Provide 150,000 strong lenses → propoerties of DM haloes at 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 in 2020, survey completed by 2026: 2500 deg^2 public in 2023, 7500 deg^2 in 2025, final 2027