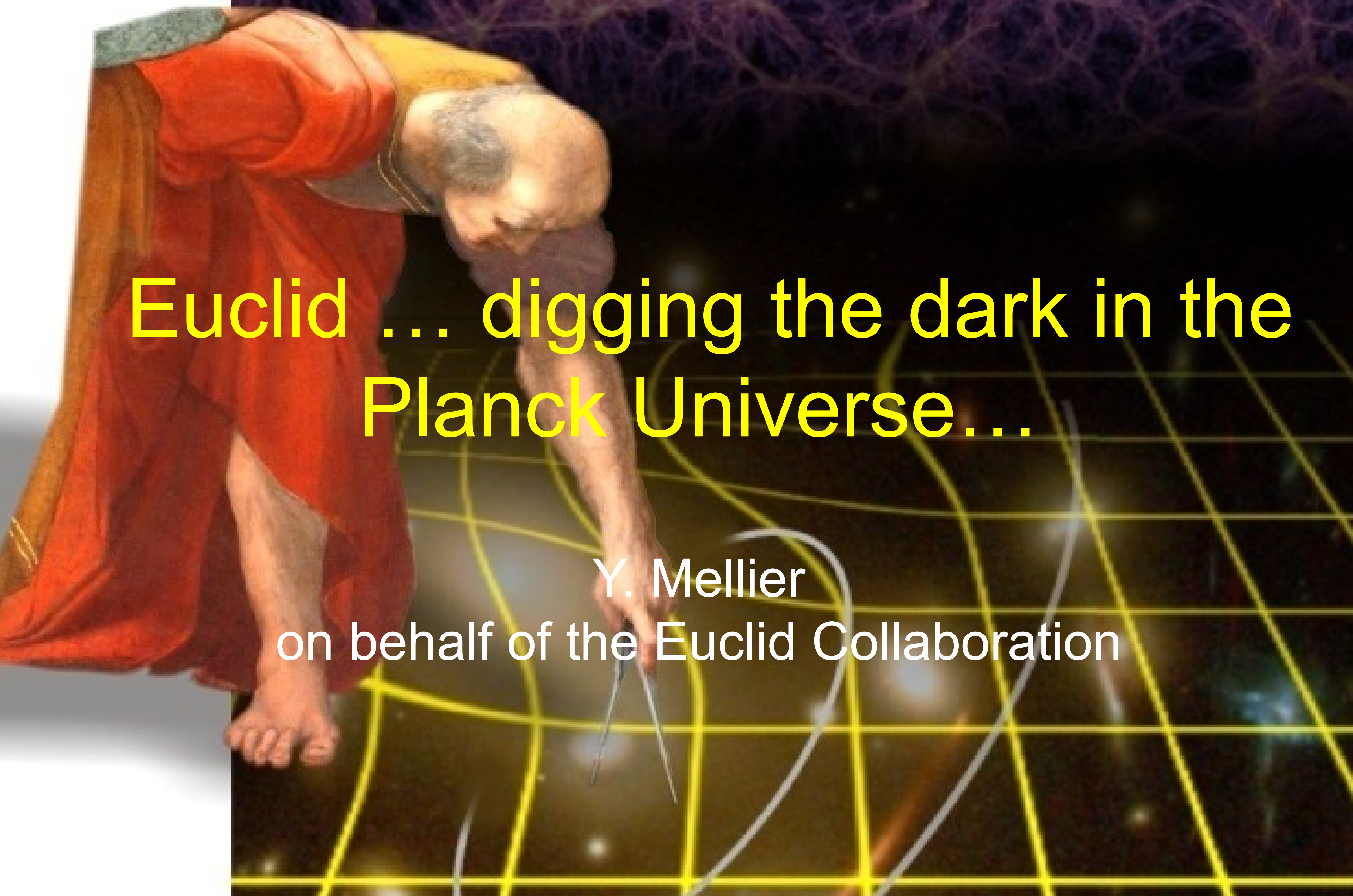
Euclid … digging the dark in the Planck Universe…

Y. Mellier
on behalf of the Euclid Collaboration

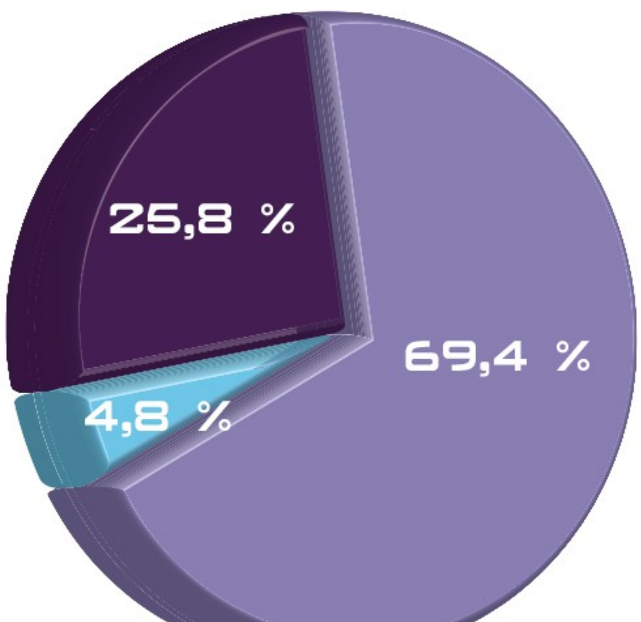


esa
Euclid Consortium

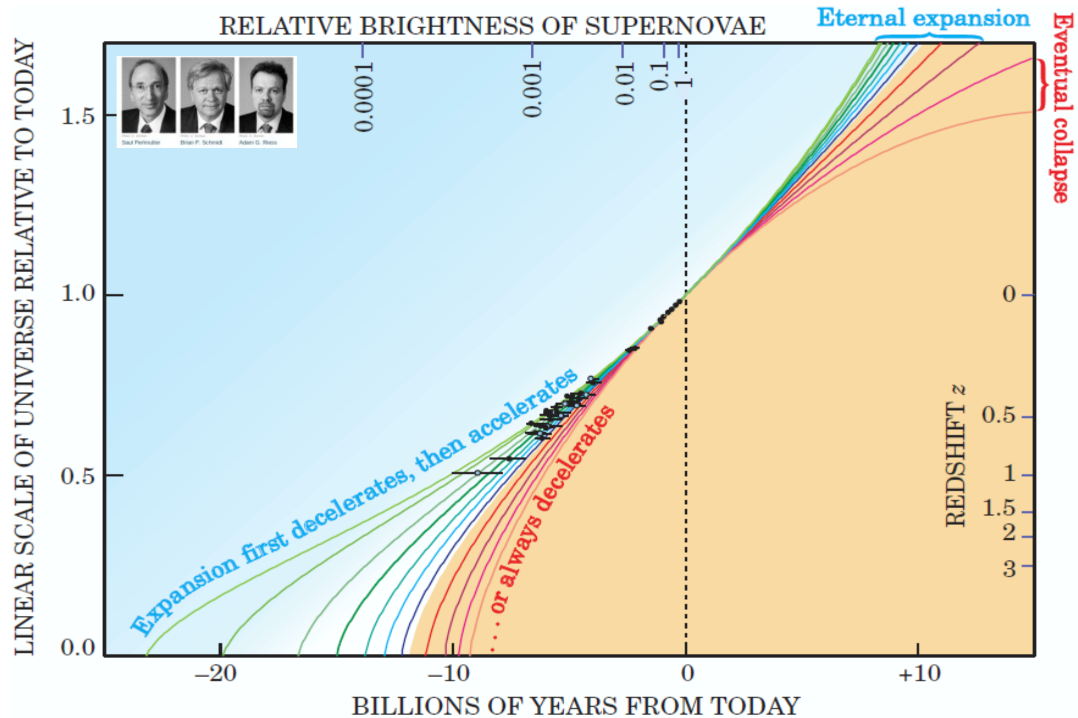
Why is the Universe accelerating?

- What is *dark energy*: Dark Energy (DE), modified gravity, other?
- When did it start dominating the matter-energy content of the Universe?
- What impact on fundamental physics and post-Planck cosmology?

… questions beyond the scope of the Planck mission…



The Planck collaboration.



The ESA Euclid mission: scientific objectives

- Understand the origin of the Universe's accelerating expansion
- Derive properties/nature of dark energy (DE), test gravity (MG)
- Distinguish DE, MG, DM effects *decisively* by… :
  - Using at least 2 independent but complementary probes
  - 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, Clusters of Galaxies
  - <u>Controlling systematics</u> to a very high level of accuracy.

Distinguishing « *decisively* »

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 controlled by gravity: $f \sim \Omega^\gamma$; $\gamma = 0.55$ GR

... ?

What do we know today, with Planck?

If $w_X = P/\rho = \text{cte}$

w_X still compatible with -1

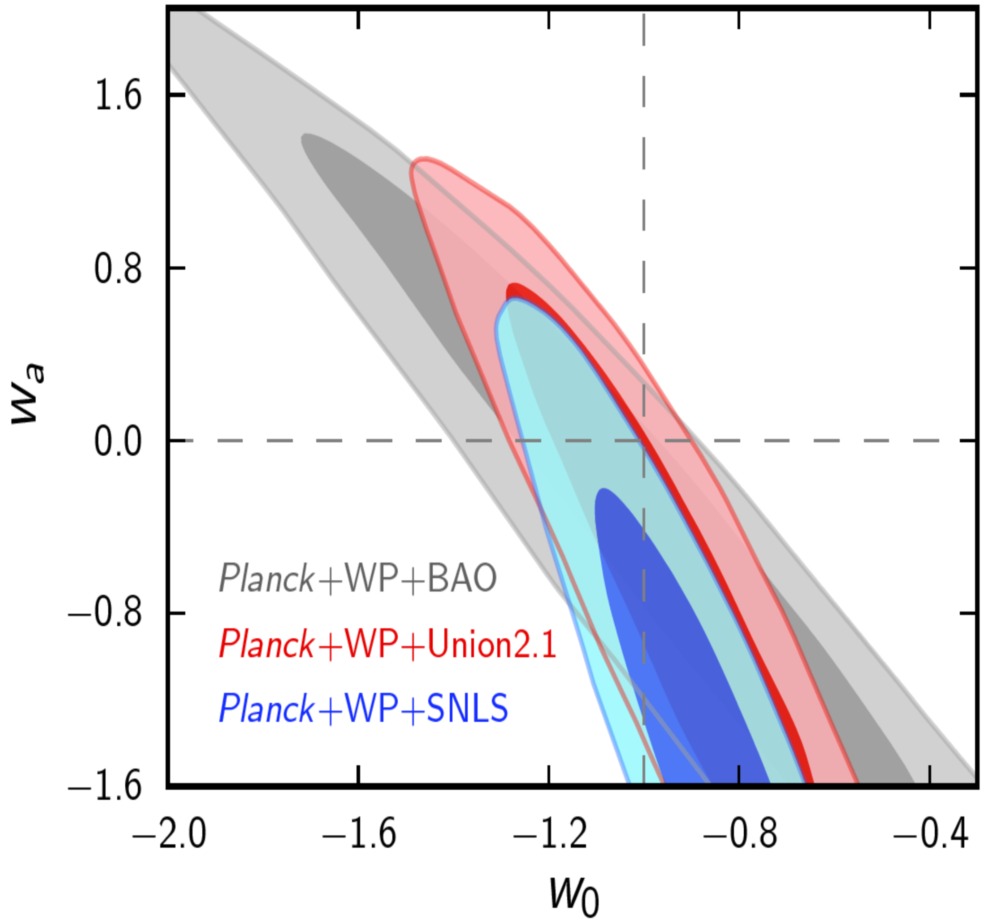
- Either *w* is constant and its value is very very close to -1

The source of the accelerating expansion is the Cosmological Constant first introduced by Einstein. But what is its origin?

- But Planck data leave open that *w* may not be -1 or may vary with time ...

→ Euclid can probe its effects and explore its very nature.

The Planck collaboration. Ade et al 2013



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Growth rate of structure formation controlled by gravity: $f \sim \Omega^{\gamma}$; $\gamma = 0.55$?

1. Nature of the apparent acceleration

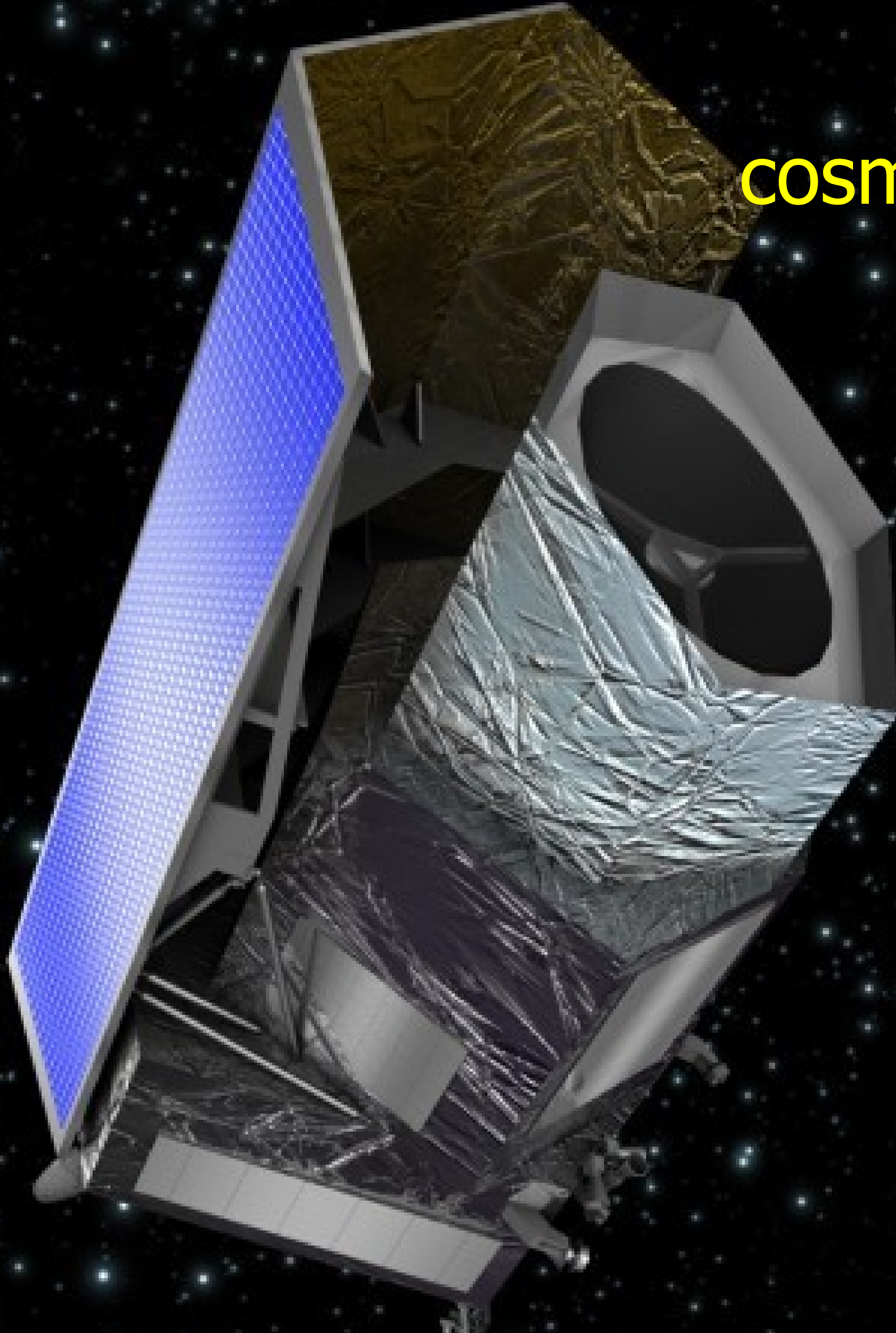
1. Distinguish effects of Λ and dynamical dark energy → Measure *w(a)* → slices in redshift
2. From Euclid data alone, get $FoM = 1/(\Delta w_a \times \Delta w_p) > 400$ (with Planck $\Delta w_a < 5\%$ $\Delta w_p < 1\%$)
   → if data consistent with Λ, and ***FoM* > 400** then
   Λ favoured with odds of more than 100:1 = a "decisive" statistical evidence

2. Effects of gravity on cosmological scales

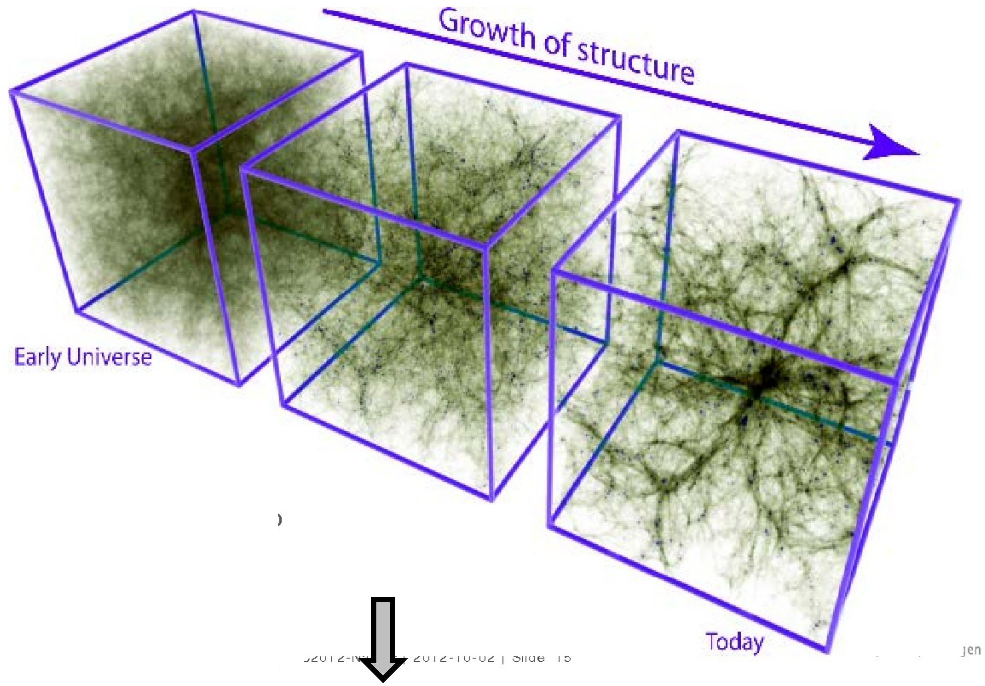
1. Probe growth of structure → slices in redshift ,
2. Separately constrain the metrics potentials (Ψ, Φ) as function of both scale and time
3. Distinguish effects of GR from MG models with very high confidence level (indicative):
   → absolute **1-σ precision of 0.02** on the growth index, γ, from Euclid data alone.

(1. + 2.) → primary objectives of Euclid → how can Euclid achieve this?

Euclid:
cosmological probes



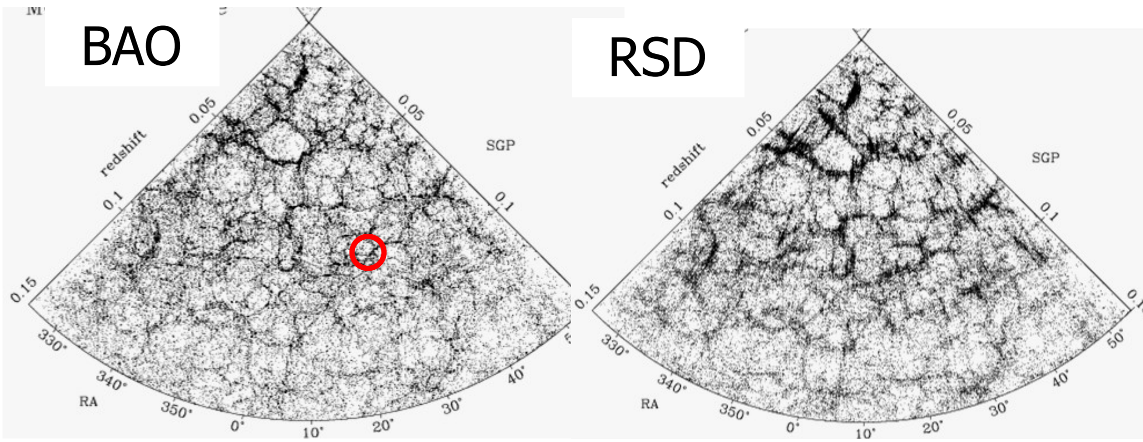
Galaxy Clustering: BAO + RSD



3-D position measurements of galaxies over 0<z<2

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

- Need high precision 3-D distribution of galaxies with spectroscopic redshifts.



Euclid:

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

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

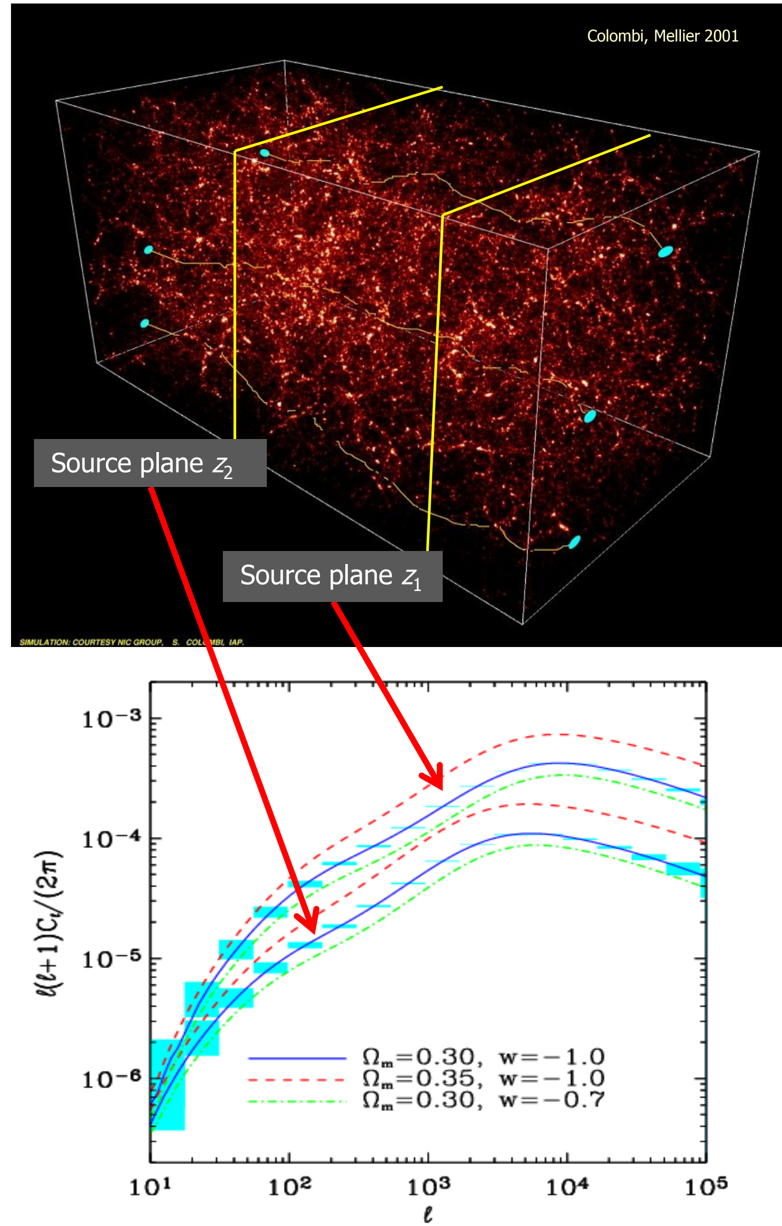
→ Shapes+distance of galaxies: shear amplitude, and bin the Universe into slices.

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

Euclid:

WL with 1.5 billion galaxies

over 15,000 deg^2



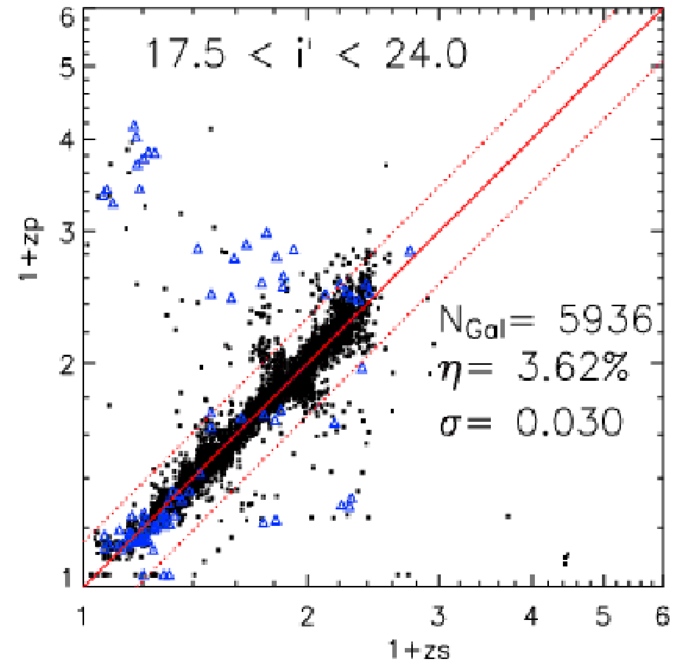
Redshifts measurements from “photometric redshifts”

• Redshifts for WL with only need an accuracy of 0.05(1+z) : primarily constrained by contamination of WL signal from intrinsic alignement

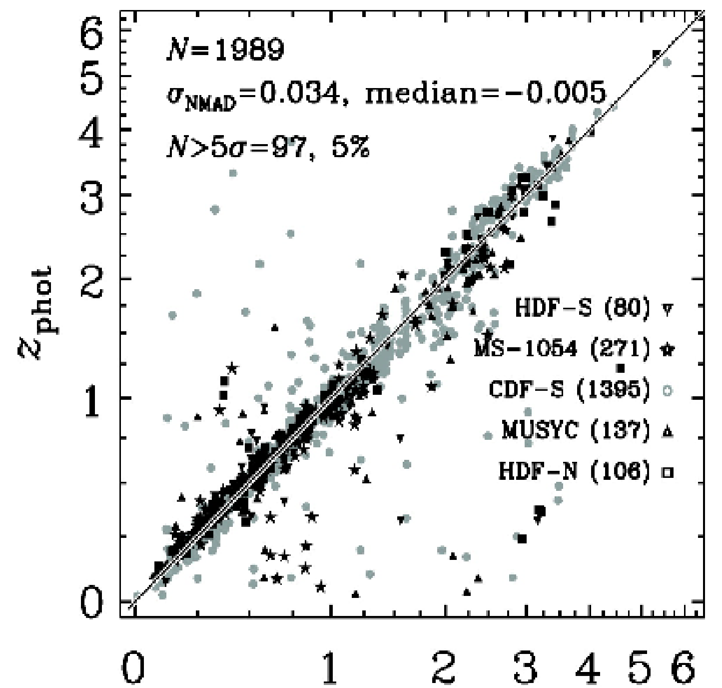
• Need to explore 0.7<z<2 → need 4 visible band and 3 NIR band photometry

→ Euclid + ground based visible data (DES,Pan-STARRS, KIDS, HSC, LSST, CFHT, WHT, etc…)

With deep visible data



With visibke and nera infrared data



Clusters of galaxies

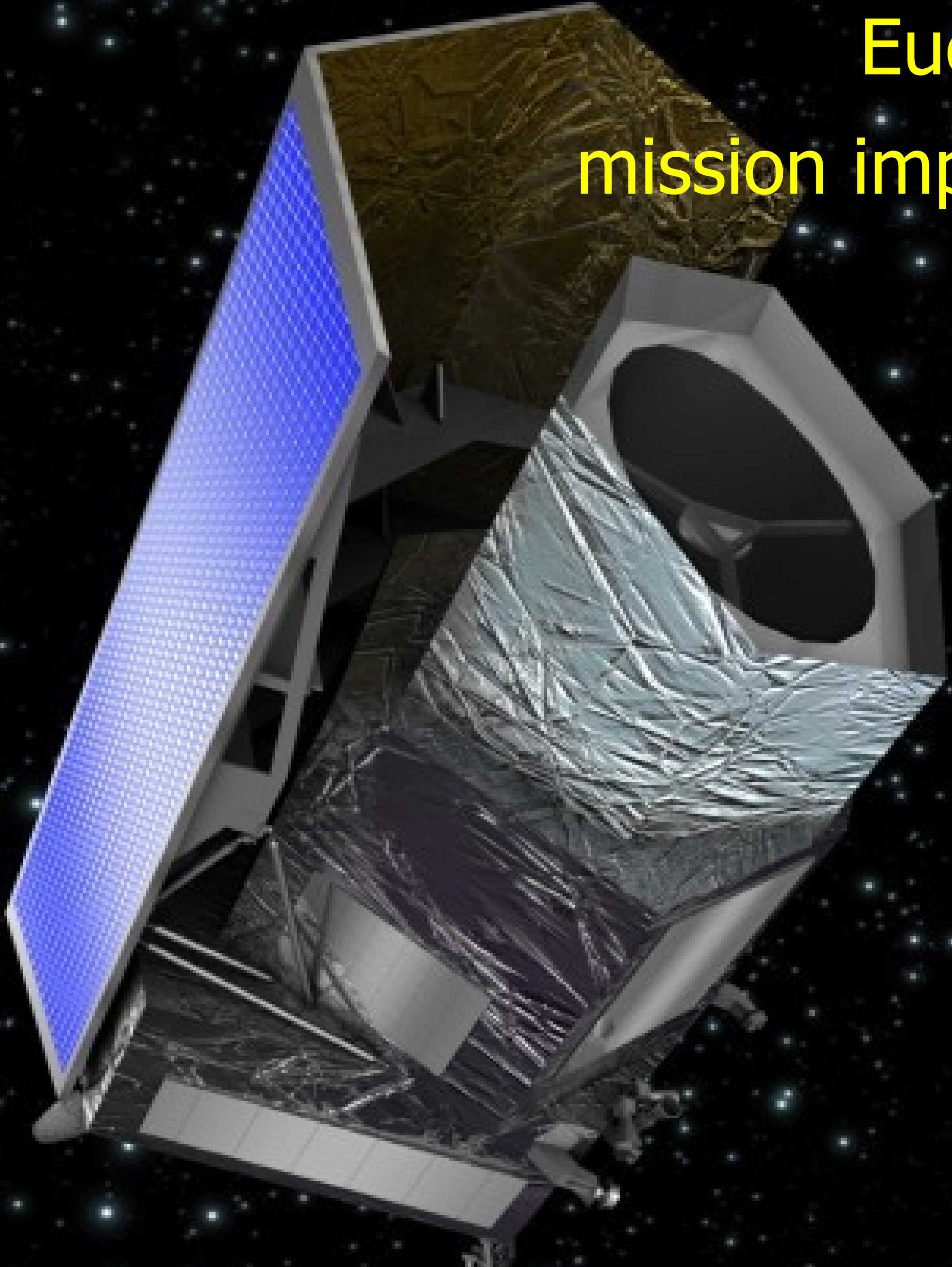
- Probe of peaks in density distribution
- Nb density of high mass, high redshift clusters very sensitive to
  - any primordial non-Gaussianity and
  - deviations from standard DE models
- Euclid data will get for free:
  - 60,000 clusters between $0.2<z<2$, 10^4 of these will be at $z>1$.
  - ~ 5000 giant gravitational arcs (→ SL+WL mass reconstruction)

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

  → dark matter density profiles on scales >100 kpc

Synergy with Planck (=5th Euclid probe: ISW) and eROSITA

Euclid:
mission implementation



Main 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

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

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

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

Completeness

Purity

The Euclid Mission: baseline and options

SURVEYS In ~6 years		
	Area (deg2)	Description
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey

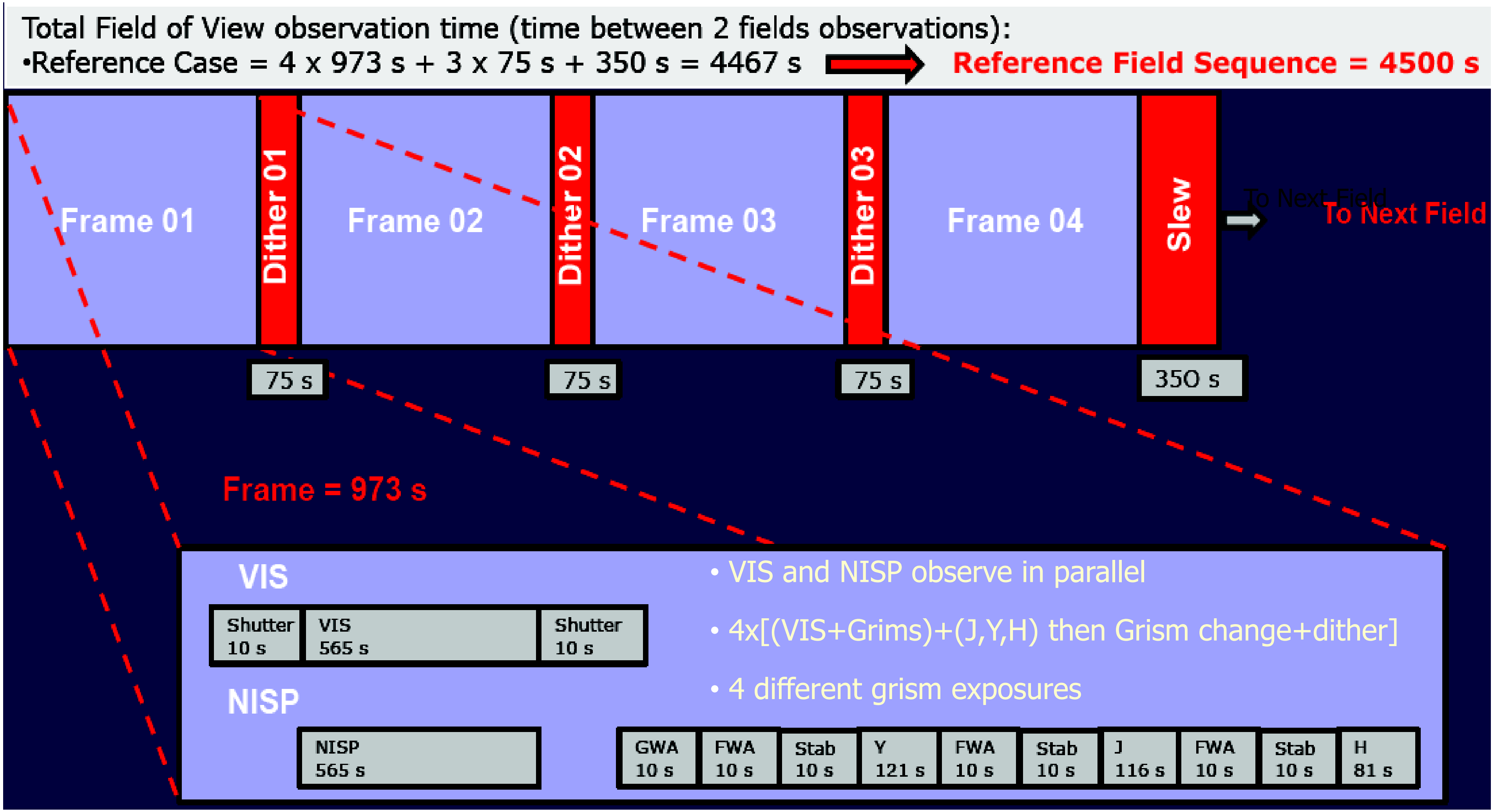
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg²	0.763×0.722 deg²			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of *n* = 1.5 x10^9 galaxies			*z* of *n*=5x10^7 galaxies	

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

Ref: Euclid RB Laureijs et al arXiv:1110.3193

Obs. sequence: 4 (VIS+NISP) frames/pointing

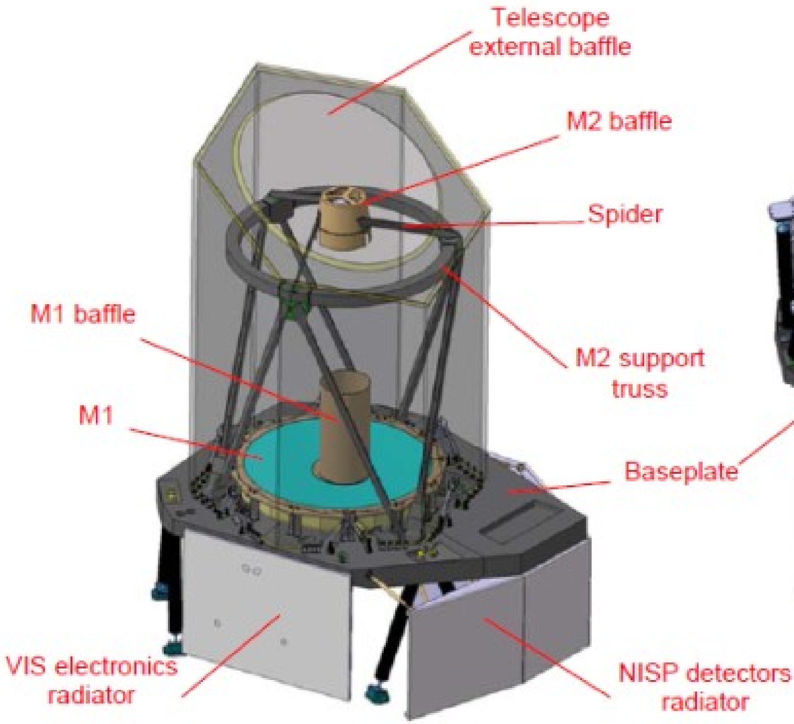
Courtesy J. Amiaux, ESSWG

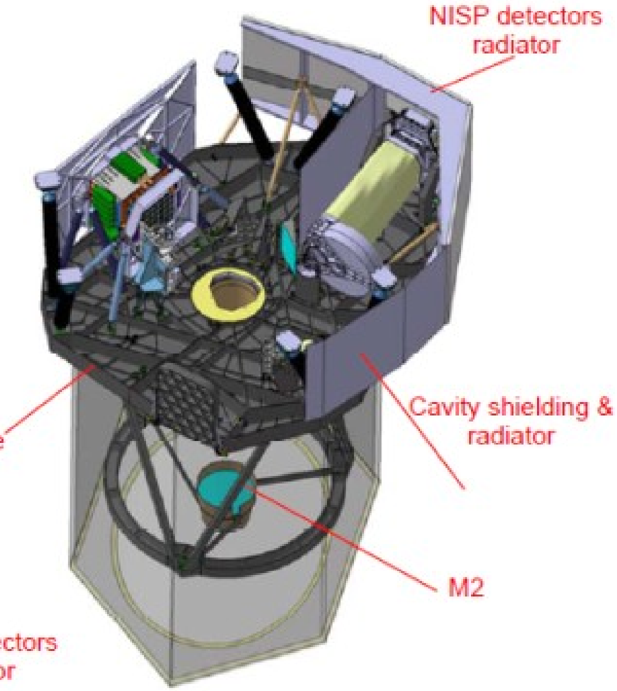


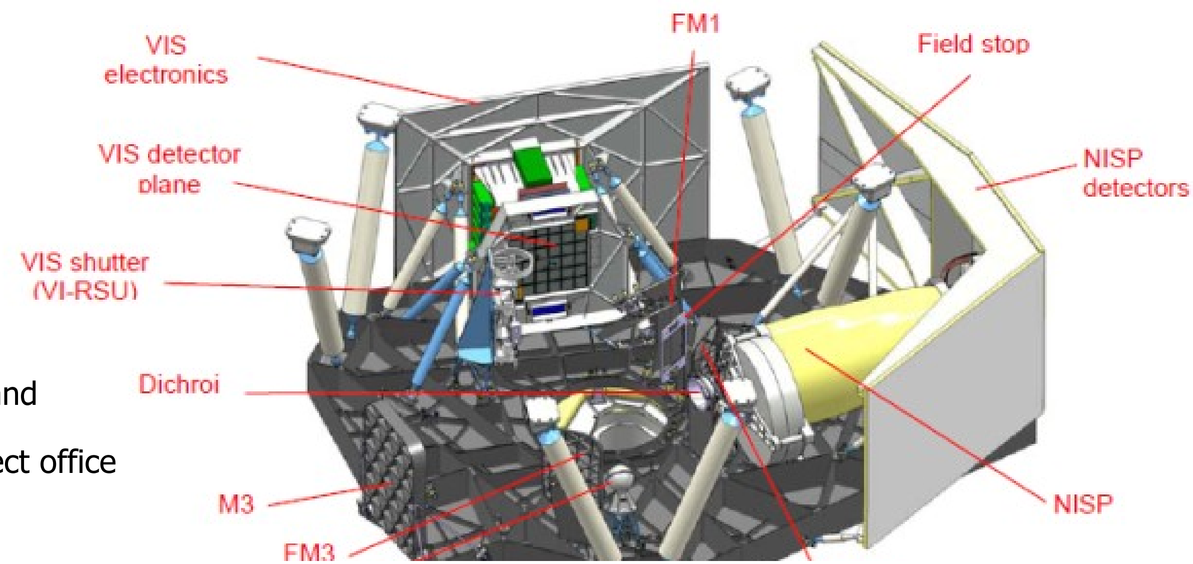
Data transfer to Earth: 4 hours/day

Euclid:

telescope and instruments







• Stabilisation:

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

• FoV:

Common visible and NIR Fov = 0.54 deg^2

Courtesy:

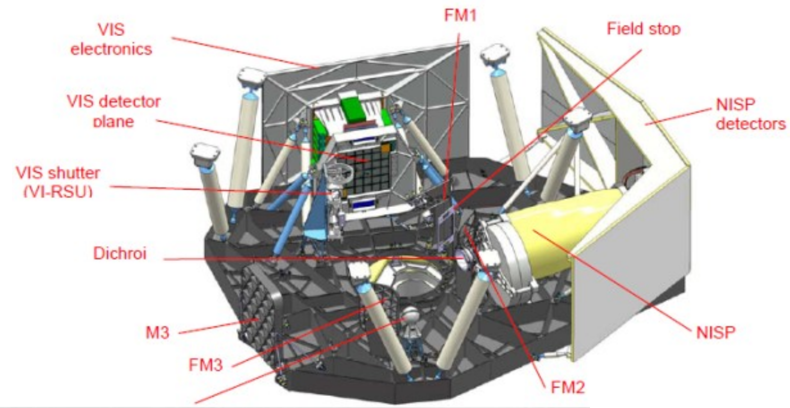
Astrium and

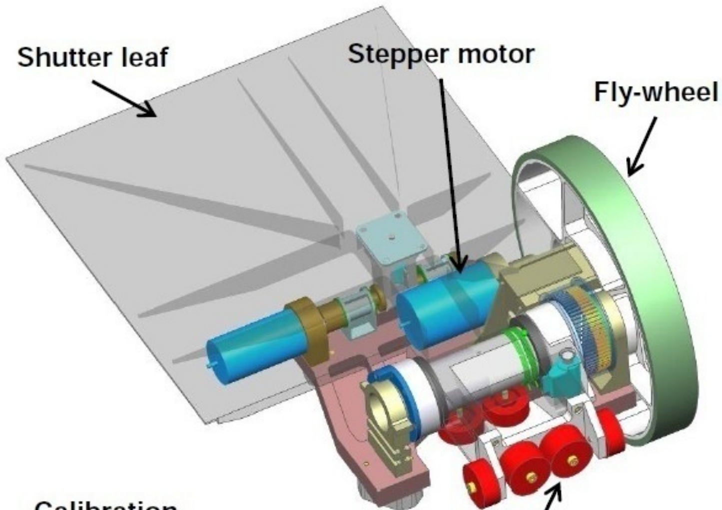
ESA Project office

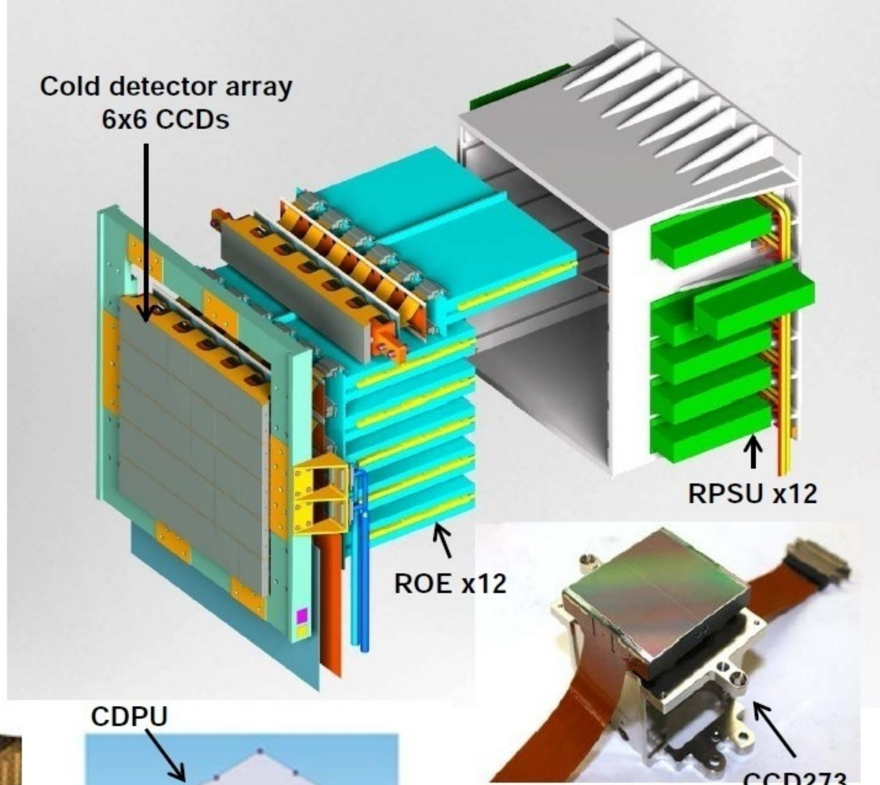
The VIS instrument

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

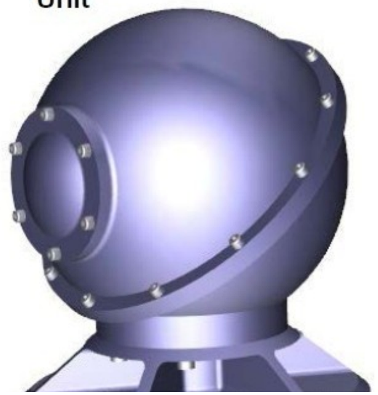
- large area imager – a 'shape measurement machine'
- 36 4kx4k CCDs with 12 micron pixels
- 0.1 arcsec pixels on sky
- bandpass 550-900 nm (wide band channel)
- limiting magnitude for wide survey of magAB = 24.5 for 10σ (extended)
- data volume – 520Gbit/day

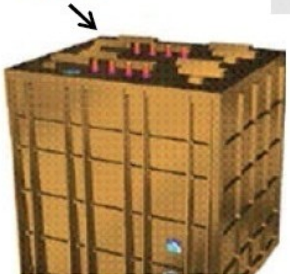


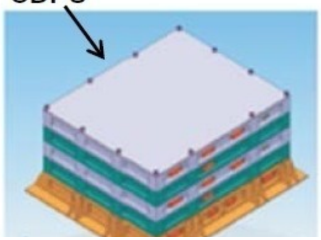


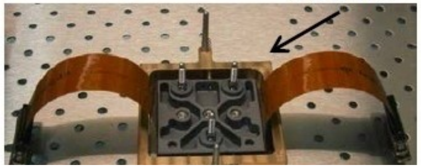


Calibration Unit



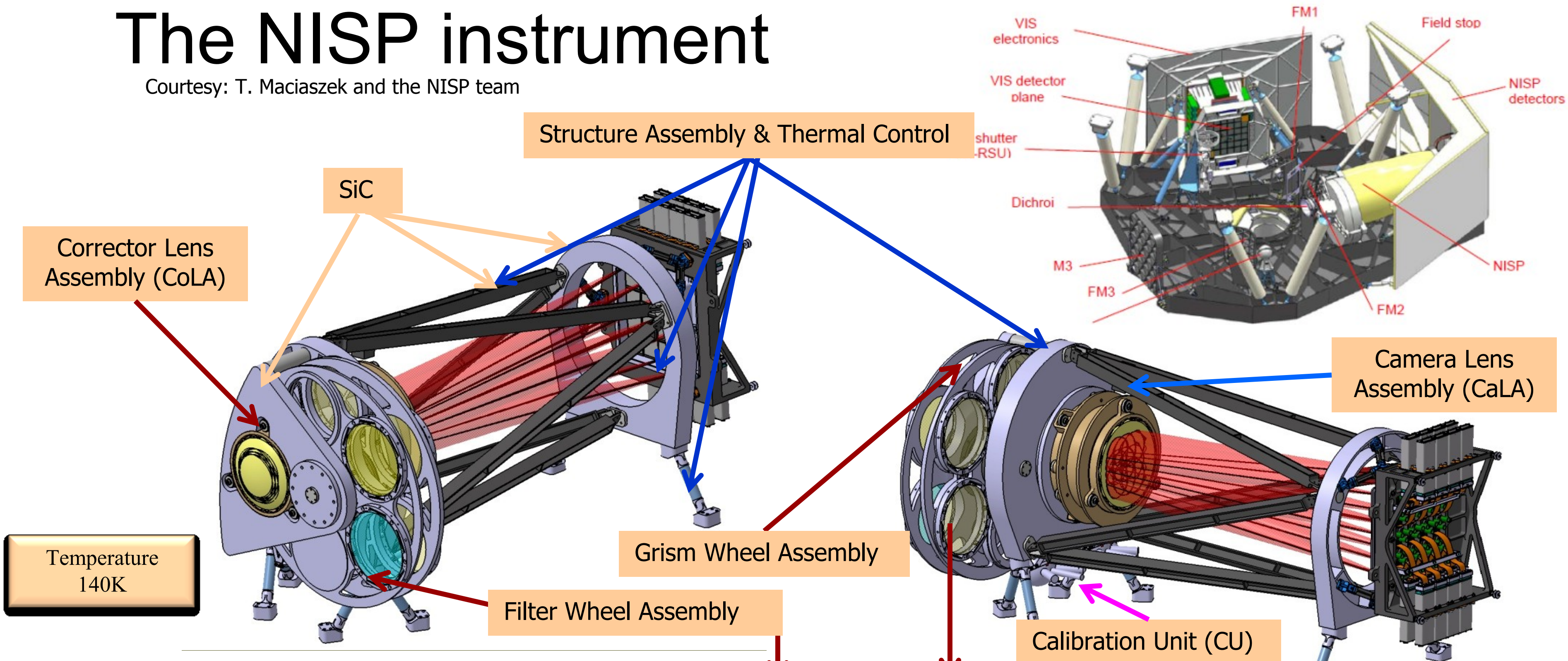






The NISP instrument

Courtesy: T. Maciaszek and the NISP team



16 2kx2k H2GR NIR detectors

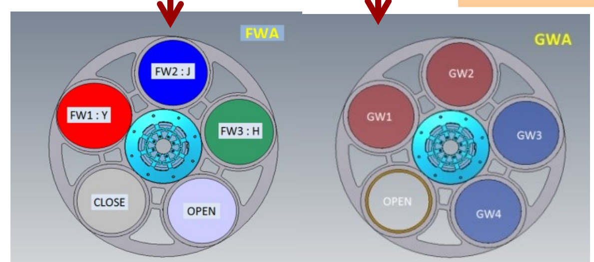
0.3 arcsec/pixel

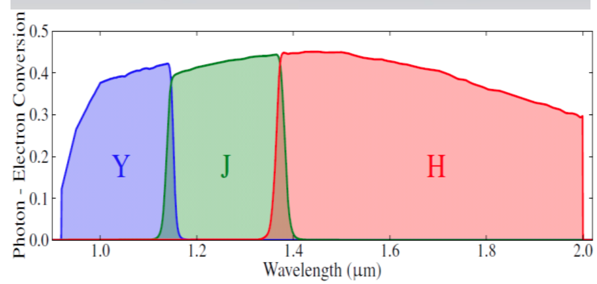
3 NIR filters: H,J,H,

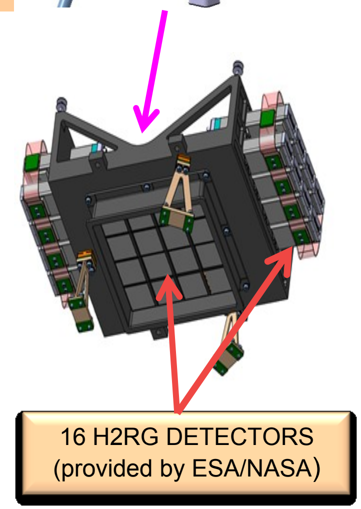
4 Grisms (2 « B»; 2 « R »)

Lim. mag: AB 24.0 ; 5 σ pt source

Data volume:180 Gbit/day

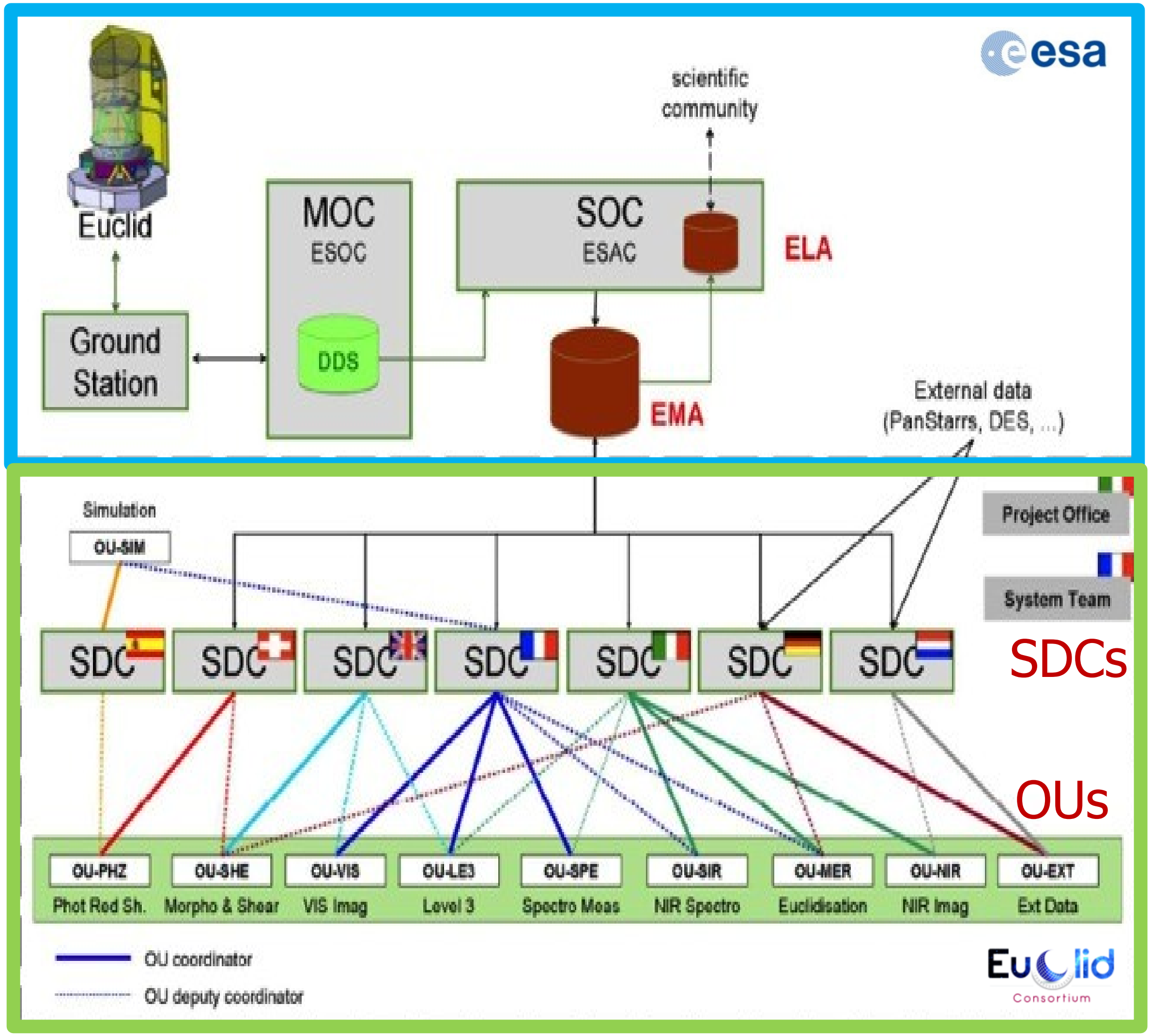






Science Ground Segment (SGS): production and data analysis

Courtesy: F. Pasian, M. Sauvage, EC SGS and ESAC



Complex organisation:

- 10 Organisation Units
- 7 Science Data Centers

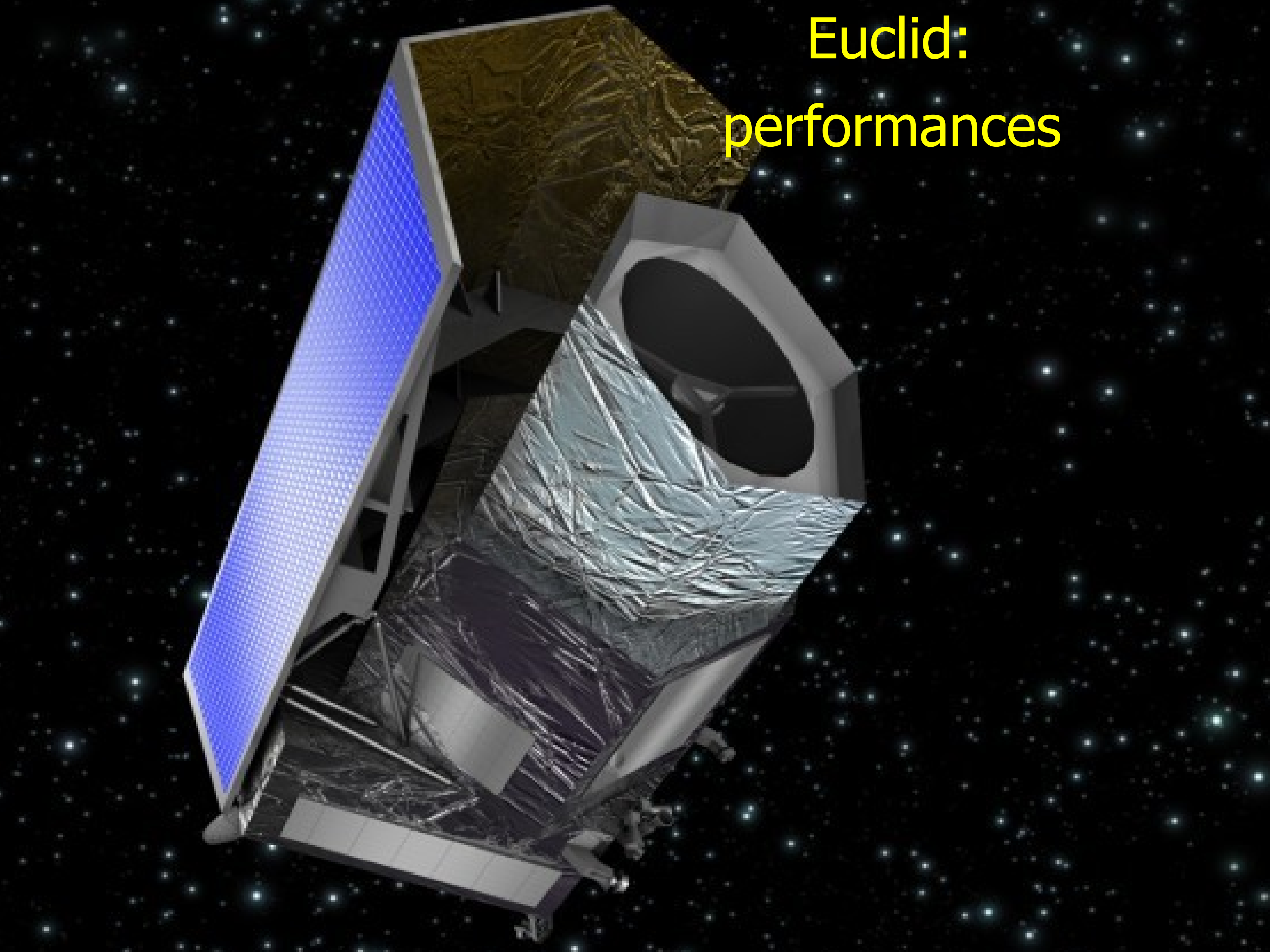
Data: huge volumes, heterogeneous data sets

- imagery and morphometry, photometry , spectroscopy
- data from ground and space
- 20-30 Pbytes
- > 10^{10} sources (>3-sigmas)

1st release Level-3: 26 months after the begining of the survey.

SGS = 50% of national agency contributions.

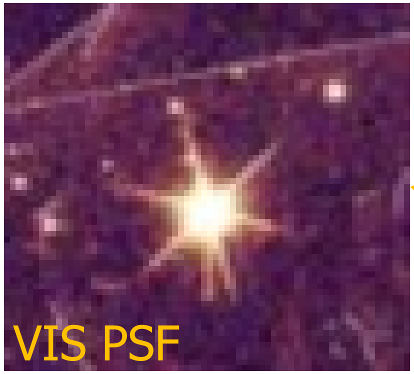
Euclid: performances

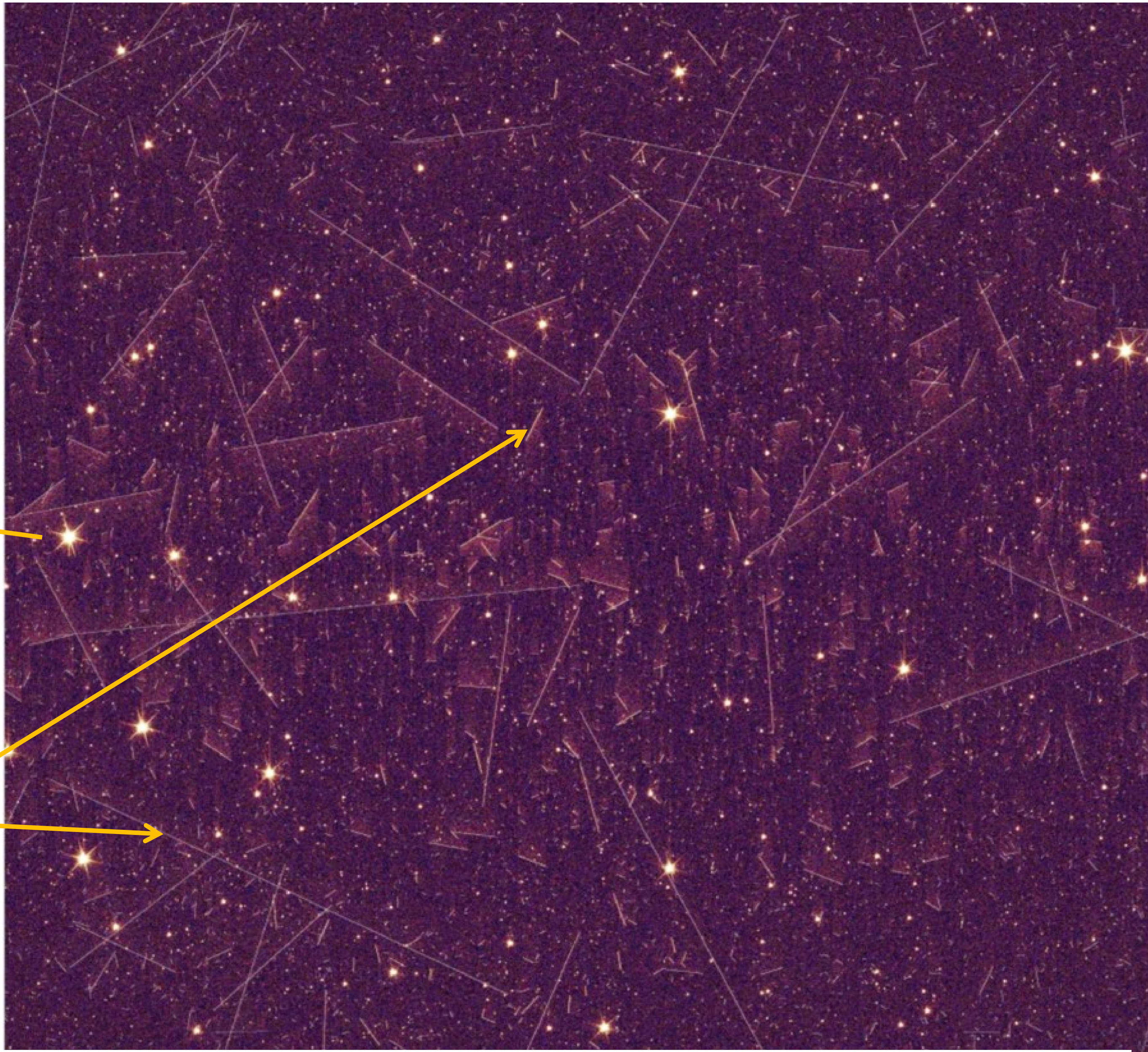


VIS performance:imaging

A 4kx4k view of the Euclid sky

VIS image: cuts made to highlight artefacts





Cosmic rays

Courtesy Mark Cropper,

Sami M. Niemi and the VIS team

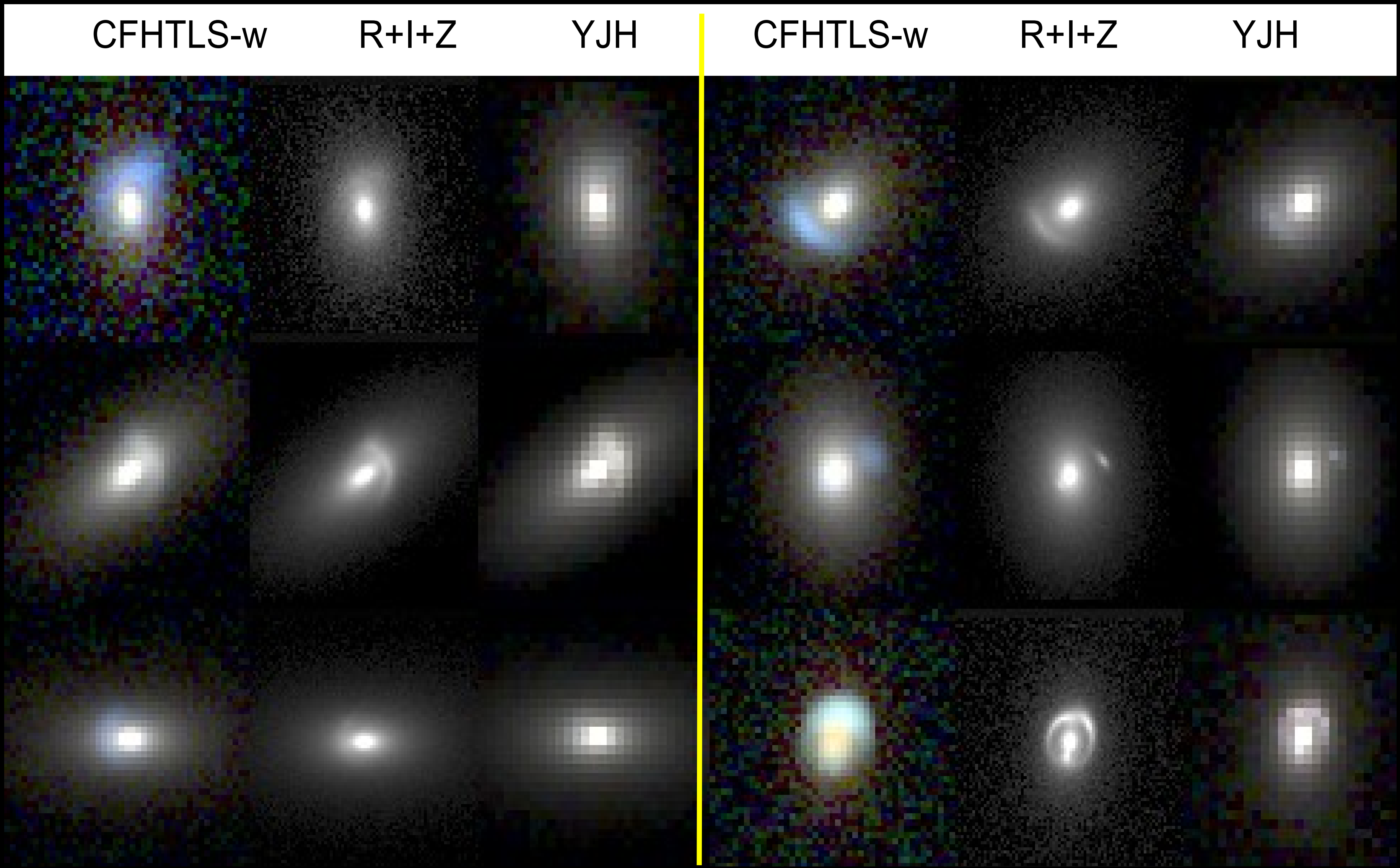
Simulation of M51 with VIS

Messier 51 galaxy at z~0.1 and 0.7:

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

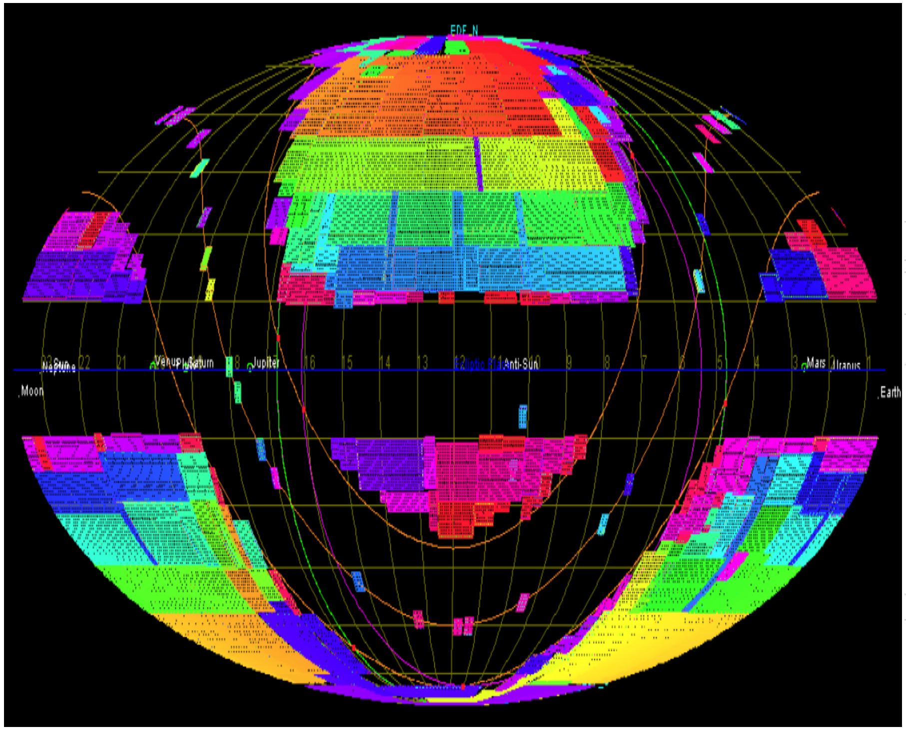
Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

Simulations and predictions of gravitational arcs and Einstein rings with Euclid



Euclid: DM reconstructed P(k): full wide survey

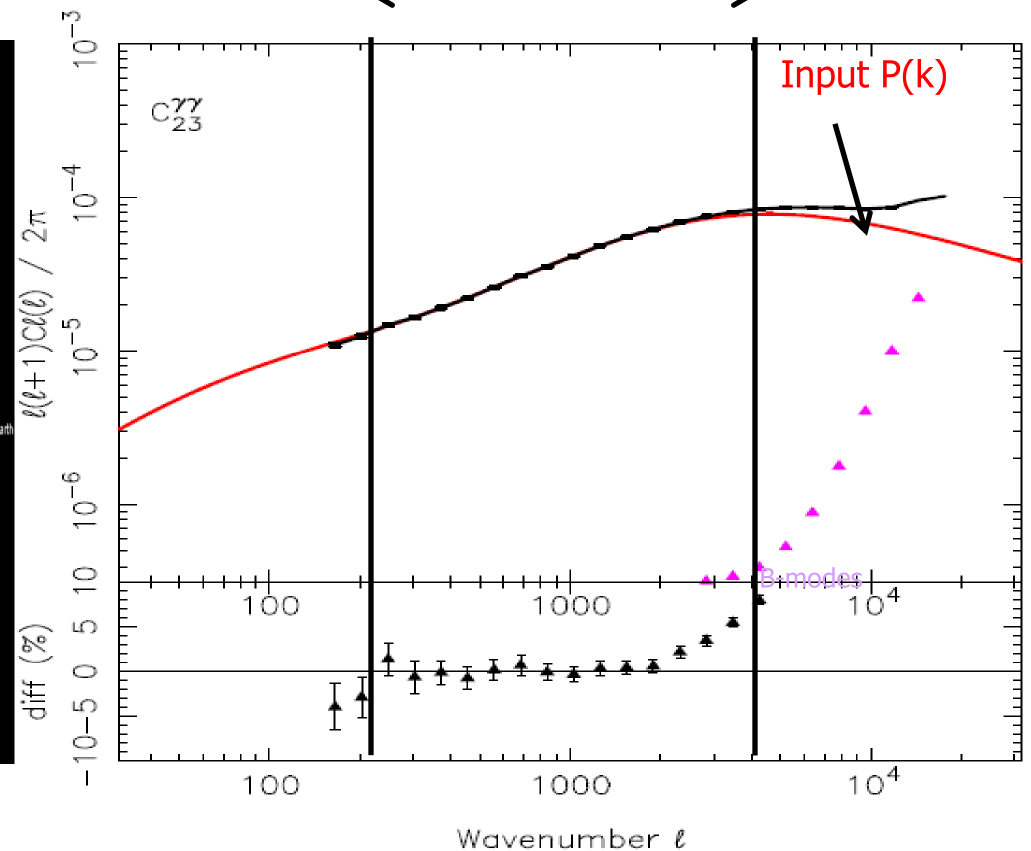
Laureijs et al 2011, Euclid RB arXiv:1110.3193 . Courtesy H. Hoekstra, T. Kitching and the WL SWG



15,000 deg^2 in 5.5 years

Courtesy J. Amiaux, R. Scaramella, and the ESSWG

Relevant scales for cosmic shear

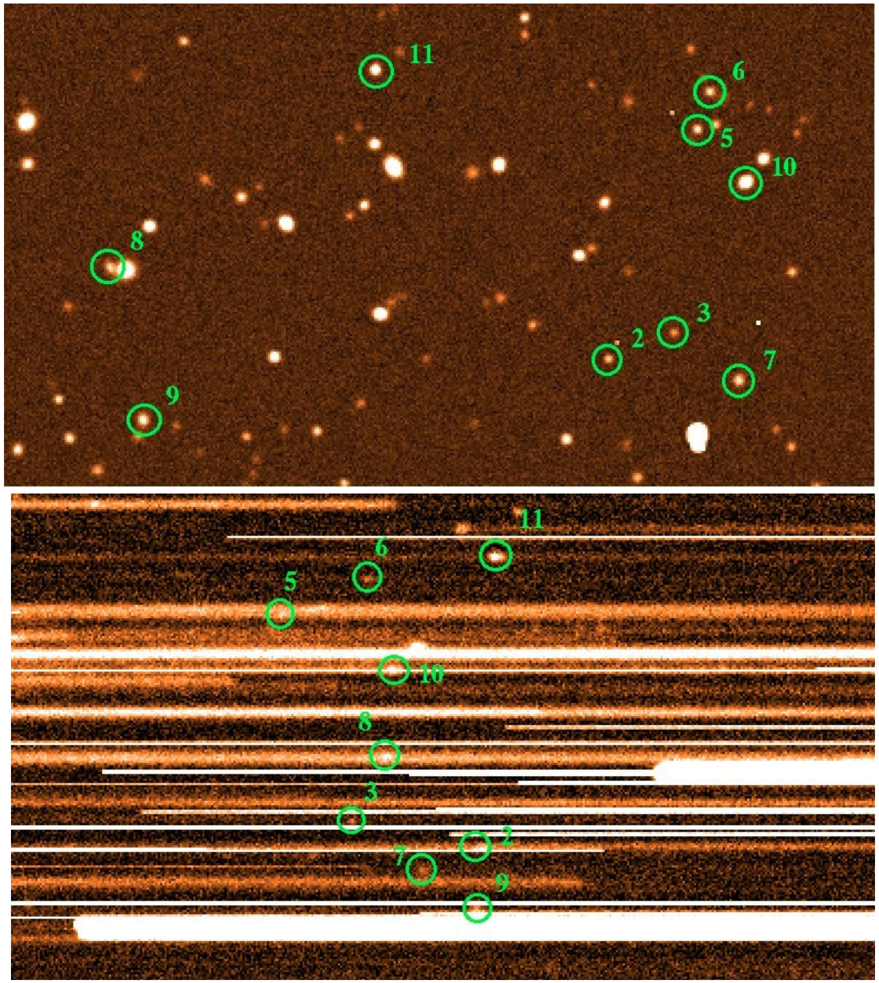


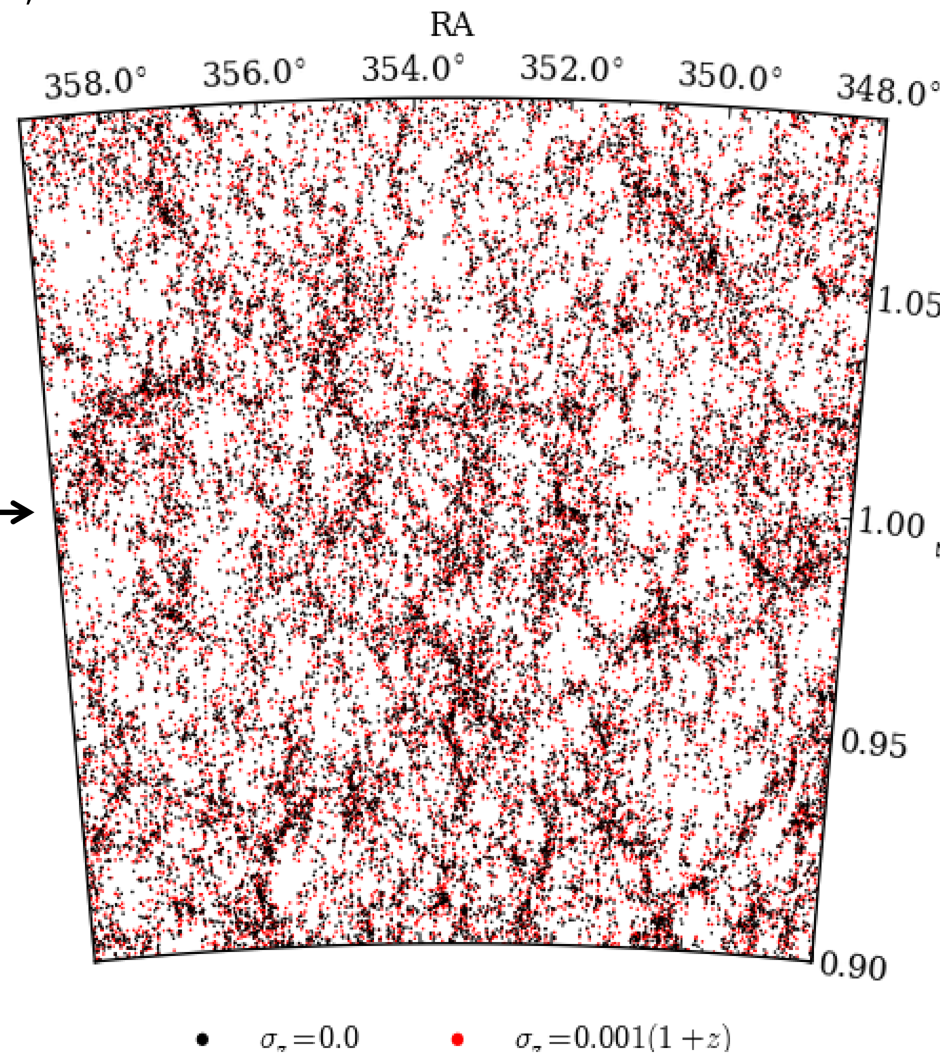
- Tomographic WL shear cross-power spectrum for 0.5 < z < 1.0 and 1.0 < z < 1.5 bins.

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

NISP Performance: images/spectra/redshifts

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



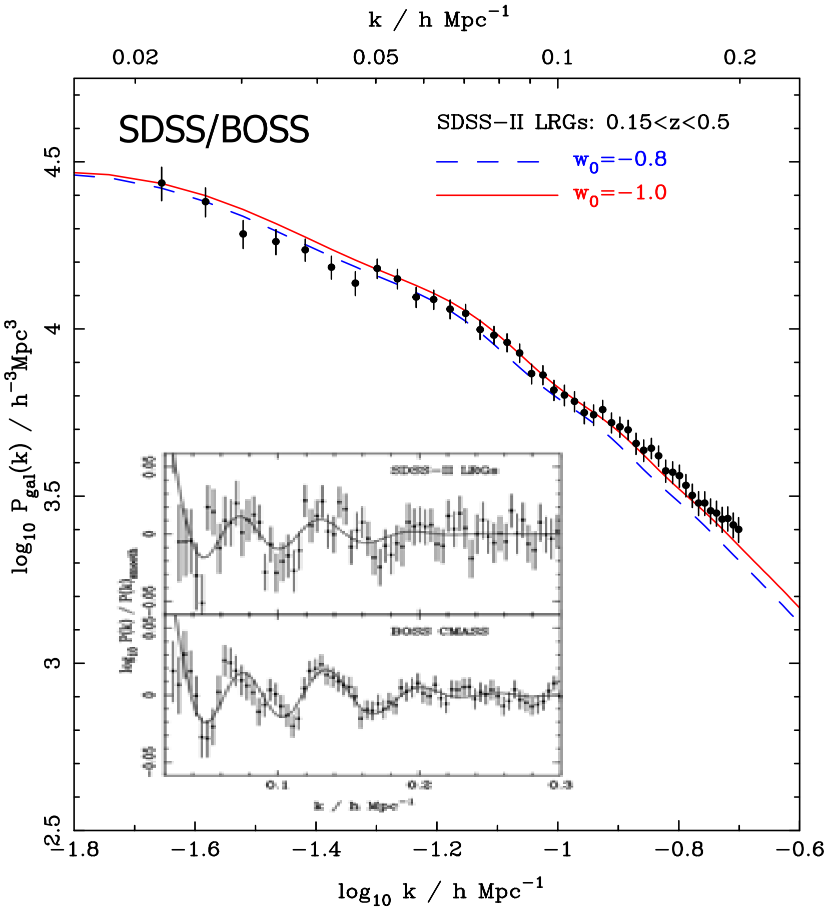


- 1 deg2 of the sky simulated and propagated through end-2-end Euclid spectroscopic simulation
- Shows can meet the required n(z), completeness and purity

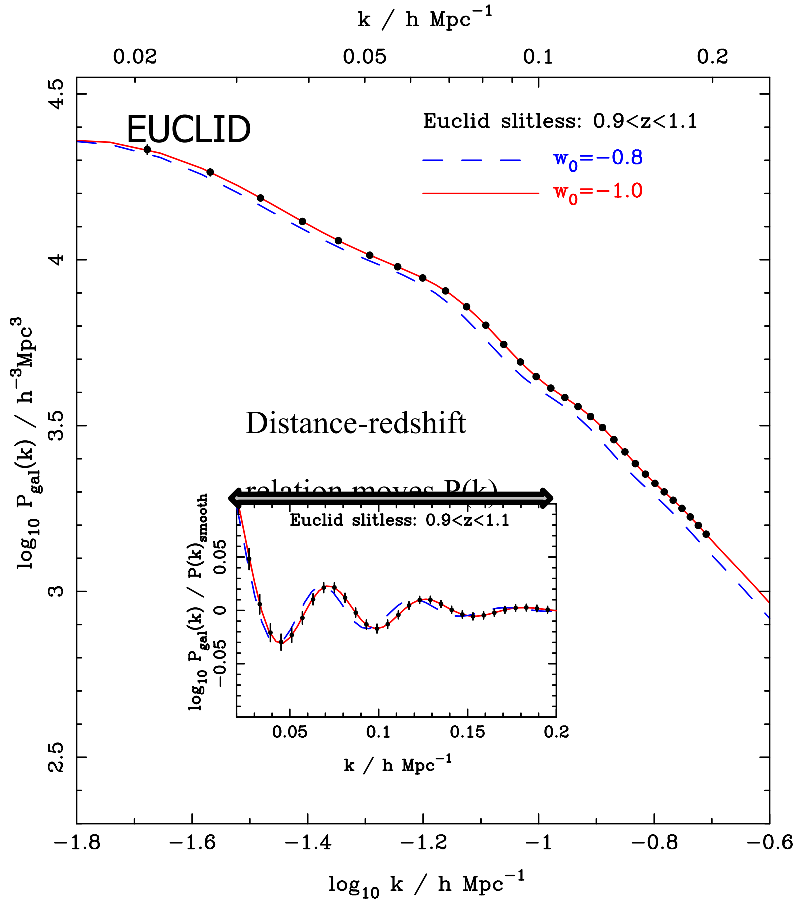
True vs. measured redshift

BAO : SDSS, BOSS vs Euclid

Courtesy W. Percivall, L. Guzzo and the Euclid GC SWG



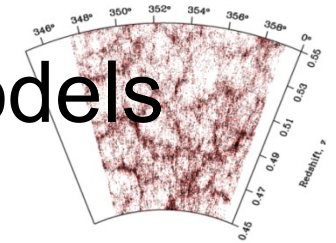
0.15<z<0.5



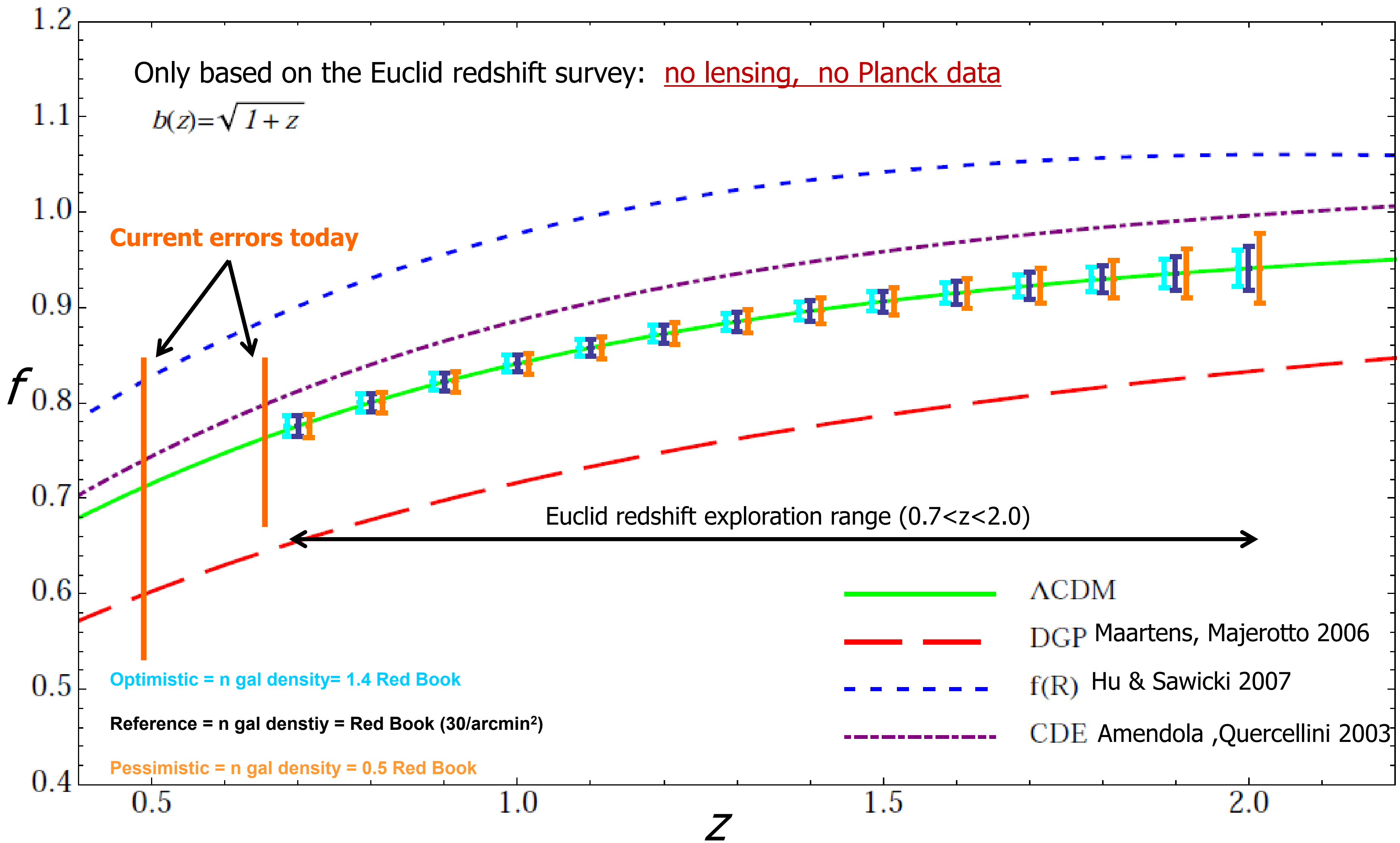
- $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx 75$x larger than SDSS

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

Euclid GC: constraints on dark energy models

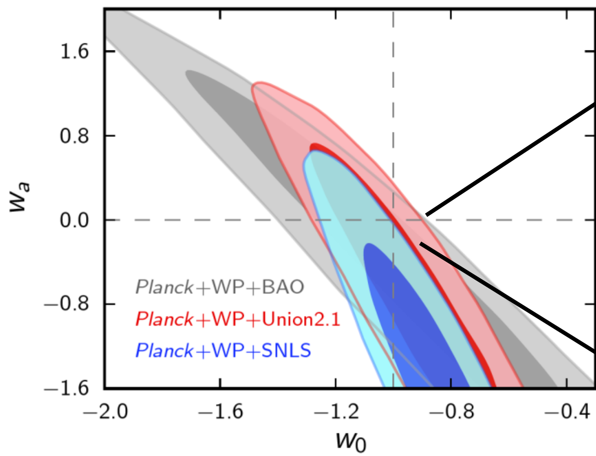


Amendola et al arXiv:1206.1225



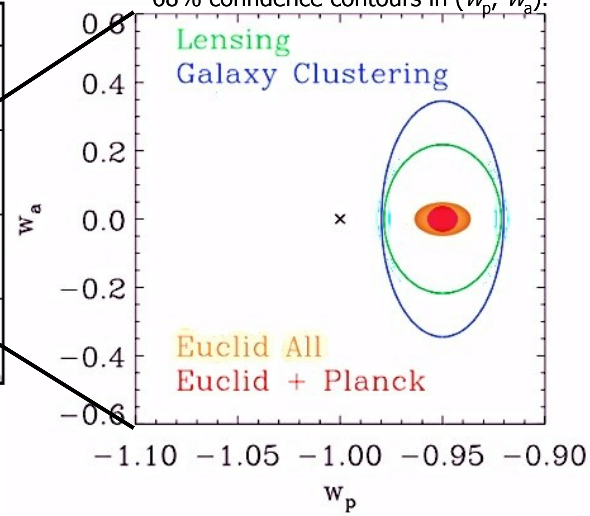
Forecasts for the primary cosmology programme of the Euclid mission

The Planck Collaboration. Ade et al 2013

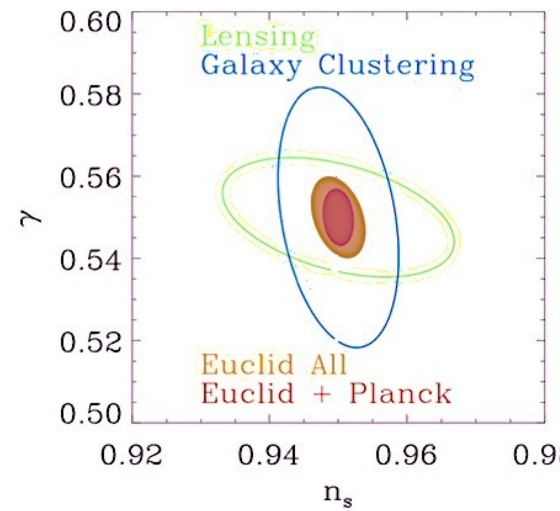


DE constraints from Euclid:

68% confidence contours in (w_p, w_a).



Constraints on γ and n_s. Errors marginalised over all other parameters.

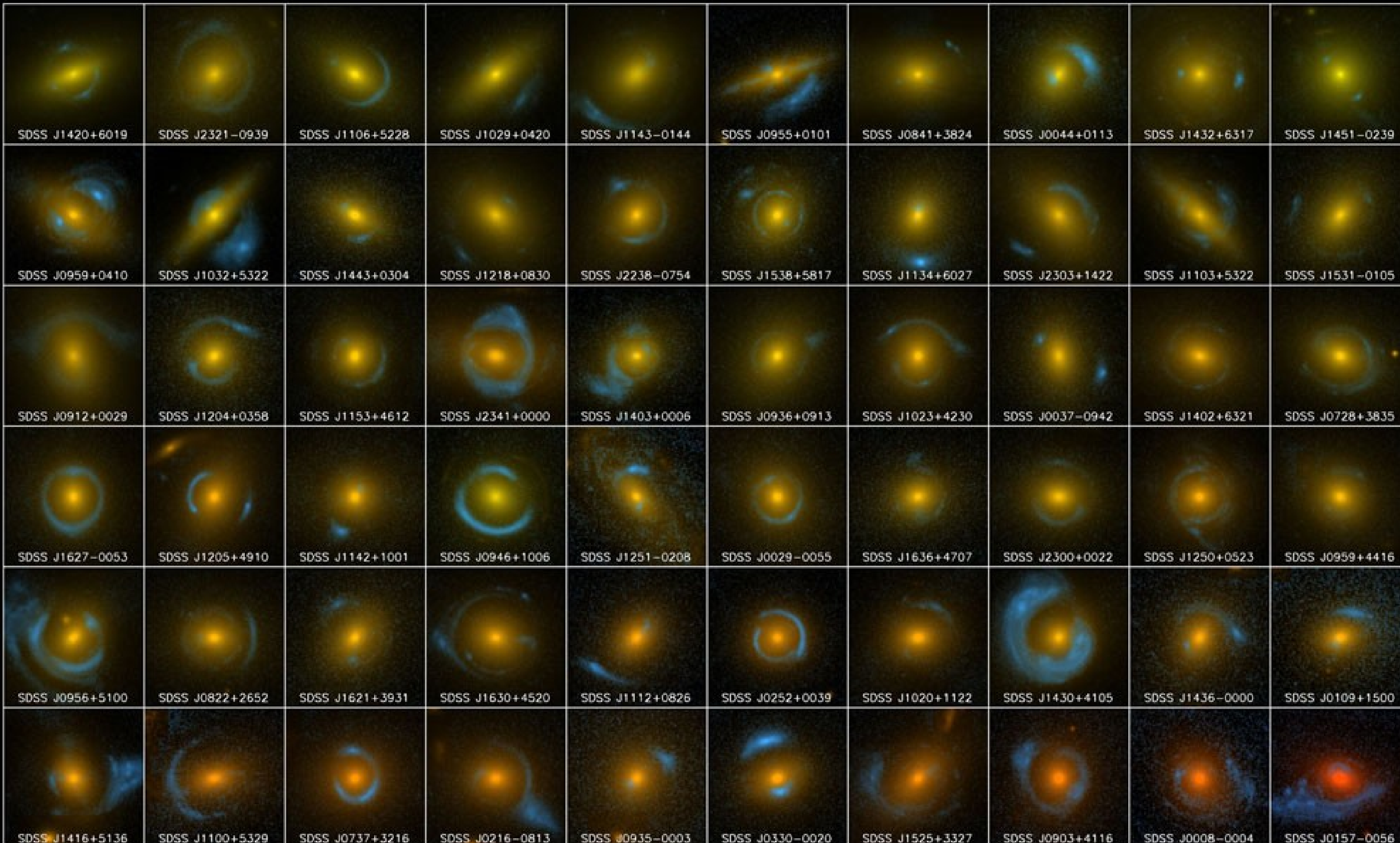


	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	FoM
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Ref: Euclid RB arXiv:1110.3193

Assume systematic errors are under control

SLACS (~2010 - HST)



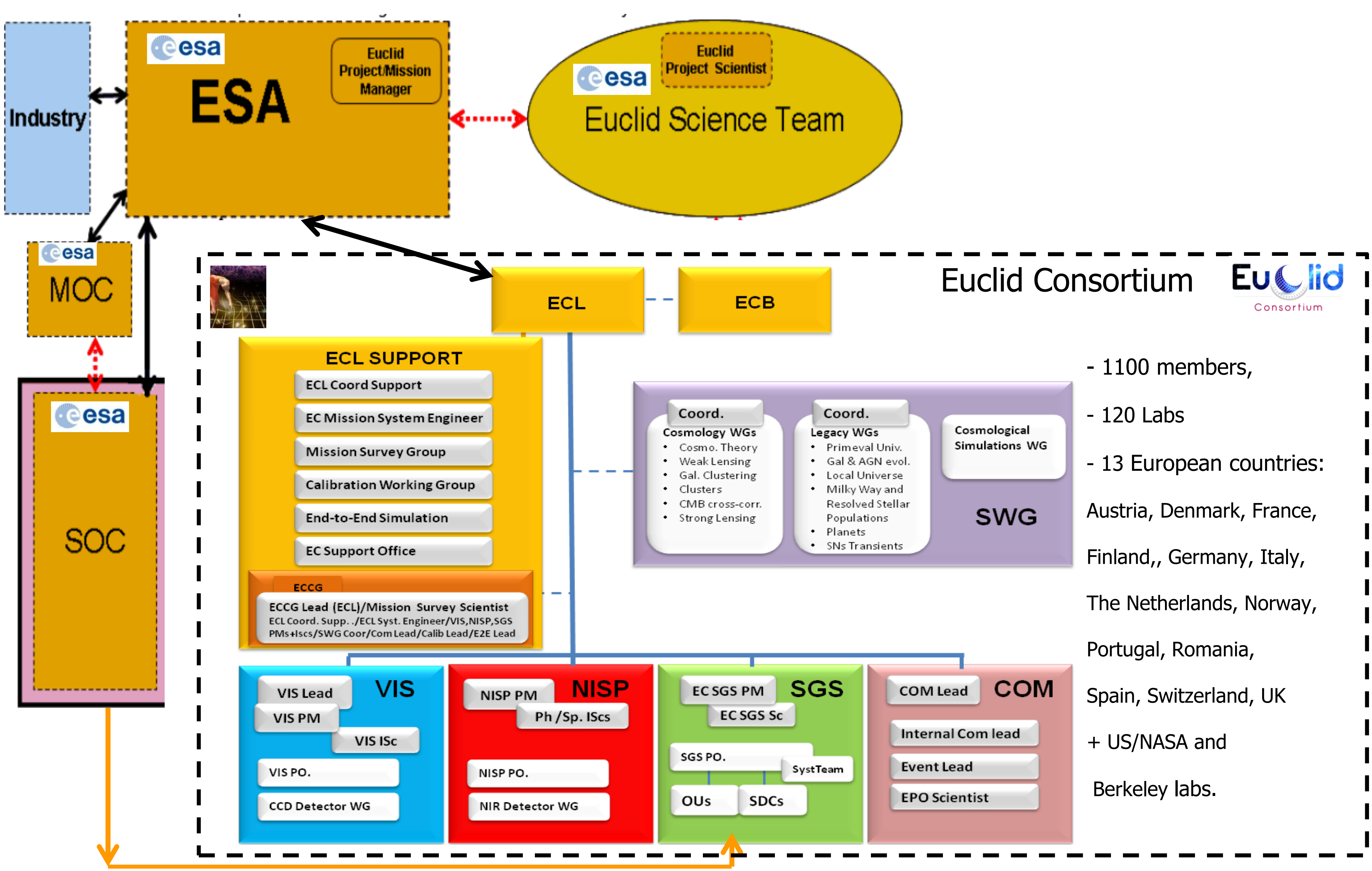
SLACS: The Sloan Lens ACS Survey www.SLACS.org

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

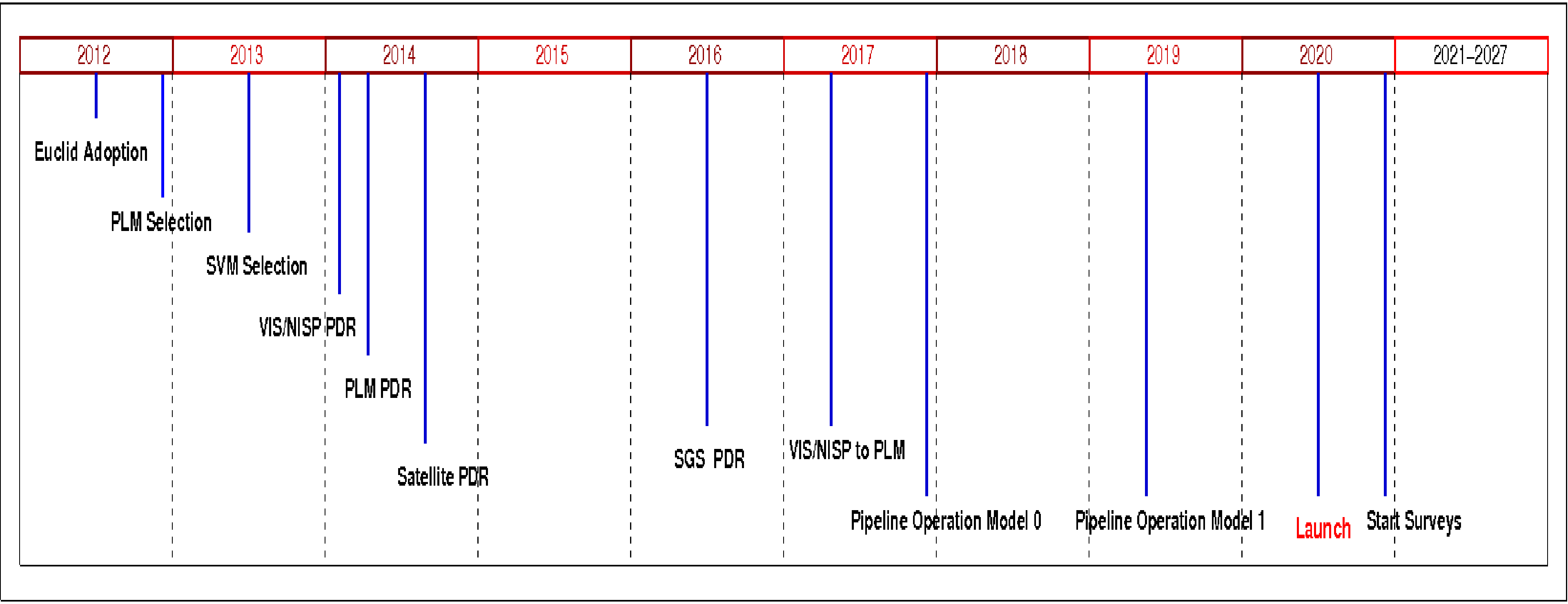
Image credit: A. Bolton, for the SLACS team and NASA/ESA


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

Euclid: organisation



Simple schedule



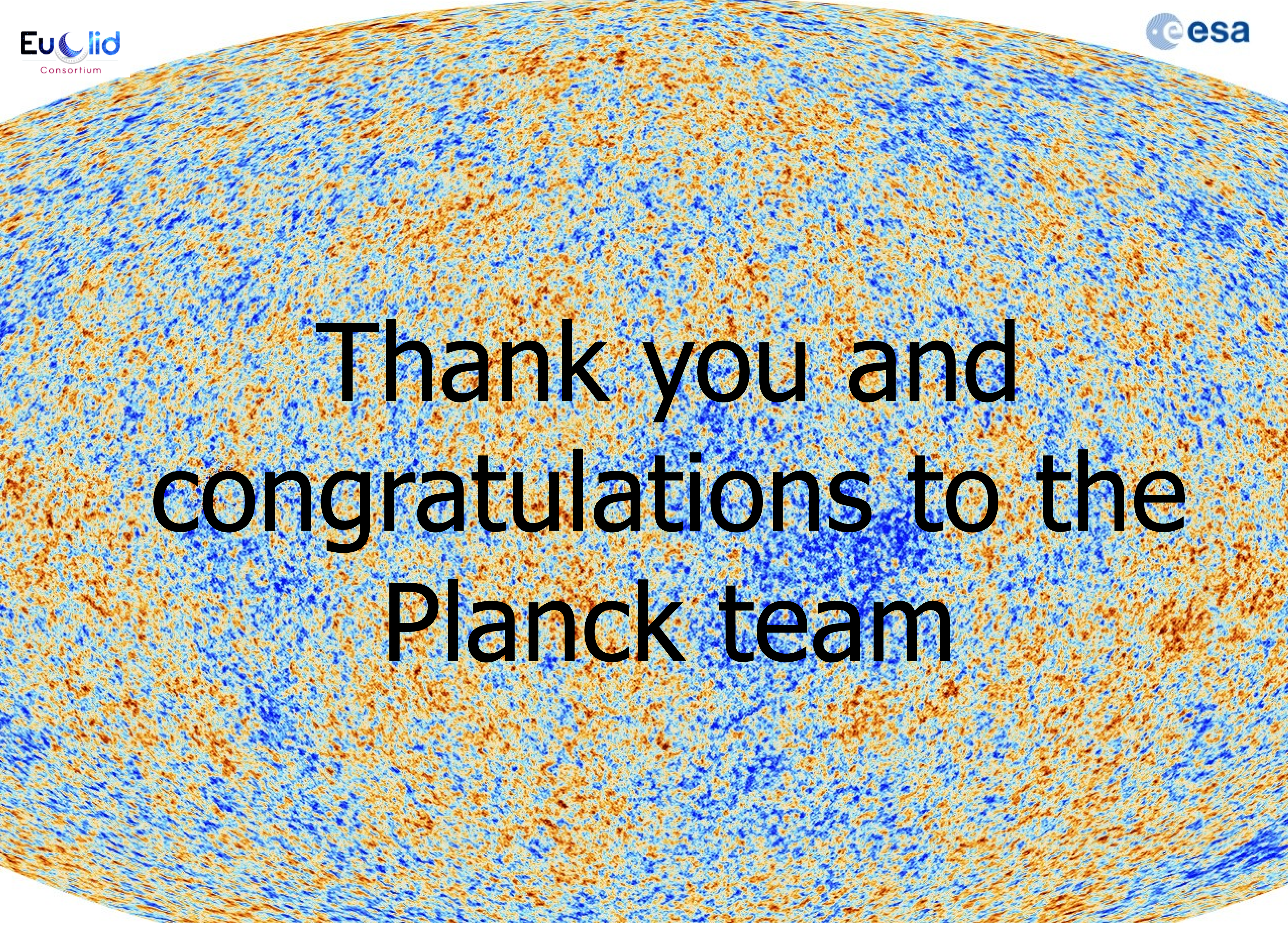
Launch date: Q1 2020

Summary

- ESA selected the only space mission designed to understand the origin of the accelerating expansion of the Universe;
- Euclid = 5 cosmological probes: WL, RSD, BAO, CL, ISW
- Put Europe at the forefront of one of the most fascinating and challenging question of modern physics and cosmology;

- Euclid Legacy = 12 billion sources, 50 million redshifts;
  - A mine of images and spectra for the community for several decades;
  - A reservoir of targets for JWST, GAIA, E-ELT, TMT, ALMA, VLT, SKA
  - Releases: +26 months then yearly (still debated)
- A formidable chance for young physicists and astrophysicists during the period 2020-2040

2020-2026: we hope that the Euclid mission will be as successful as the Planck mission!


Thank you and congratulations to the Planck team

Challenges for Euclid

Shape measurements/systematics

Control of both multiplicative and additive biases

Photometric redshifts:

Ground based photometry in 4 bands : 15,000 deg^2 (i.e. north and south)

Numerical simulations with power spectrum to a 1% accuracy :

Resolution

Underlying physics: e.g. numerical simulations with baryons

Numerical simulation of a large number of DE, GR models

10^3 to 10^5 simulations to estimate covariance matrices

High order statistics:

Potentials of high order statistics for DE science + Systematics

Need Spectroscopics surveys to

Calibrate deep photo-z and

Understand BAO and RSD samples