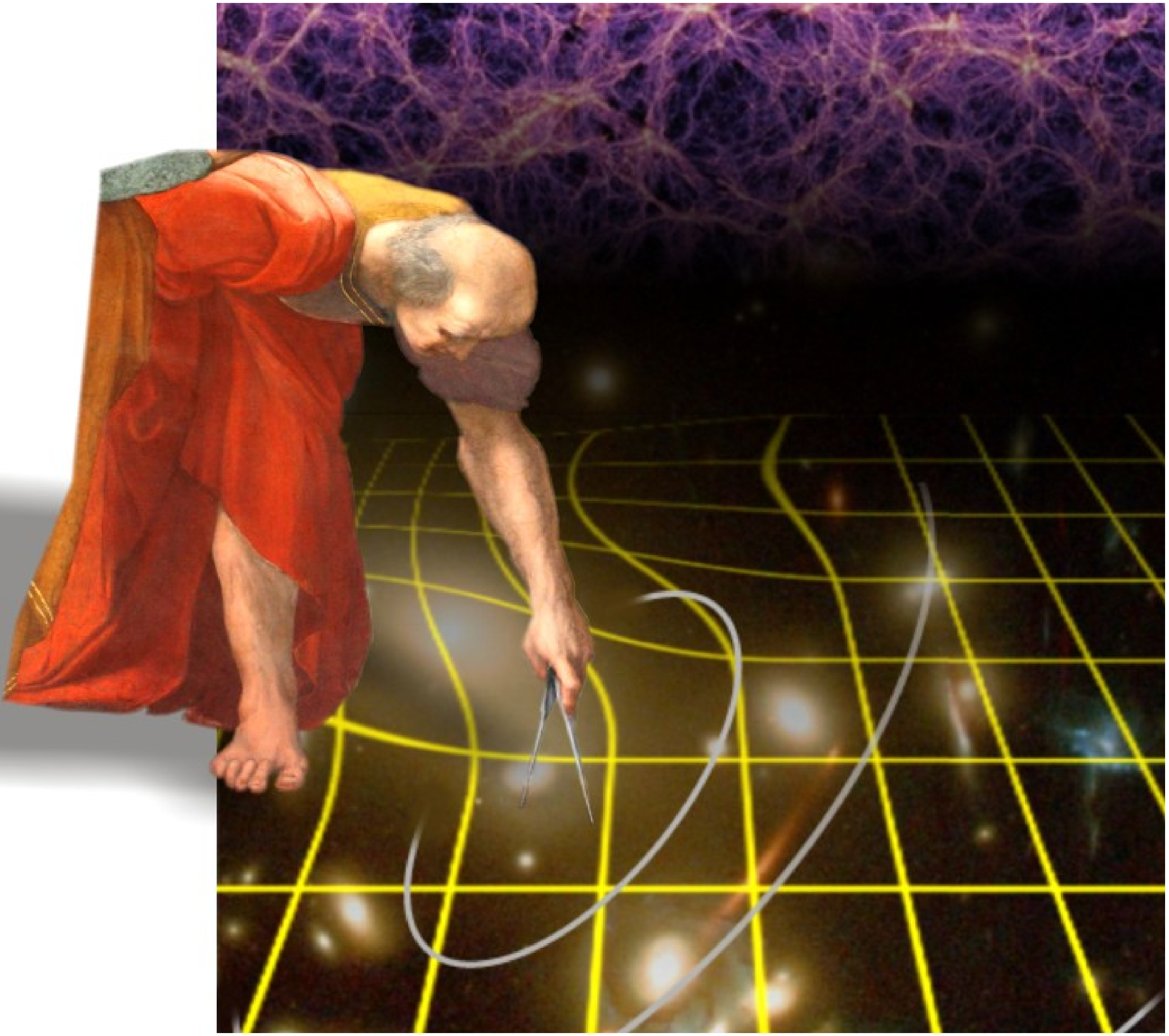


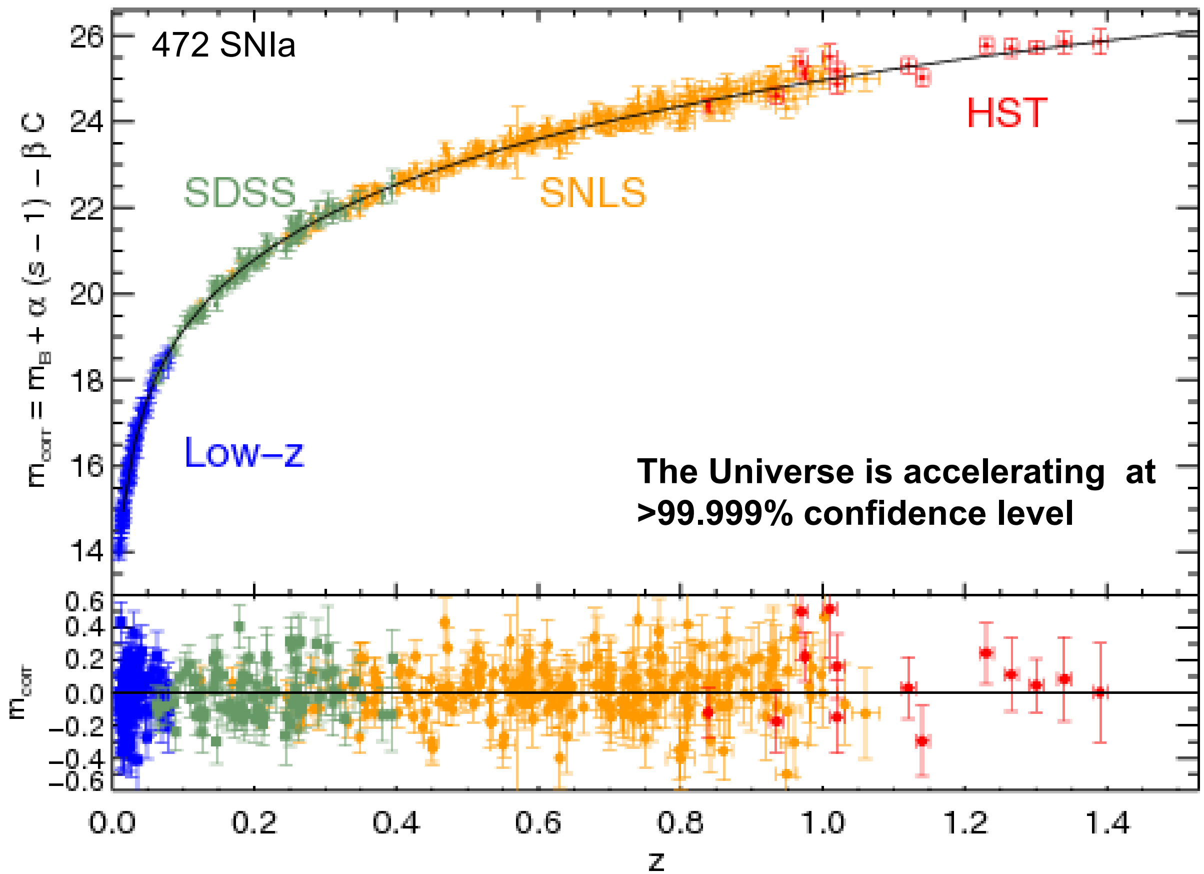
Probing the Dark Universe with the Euclid Space Mission

Y. Mellier
on behalf of the
Euclid Collaboration

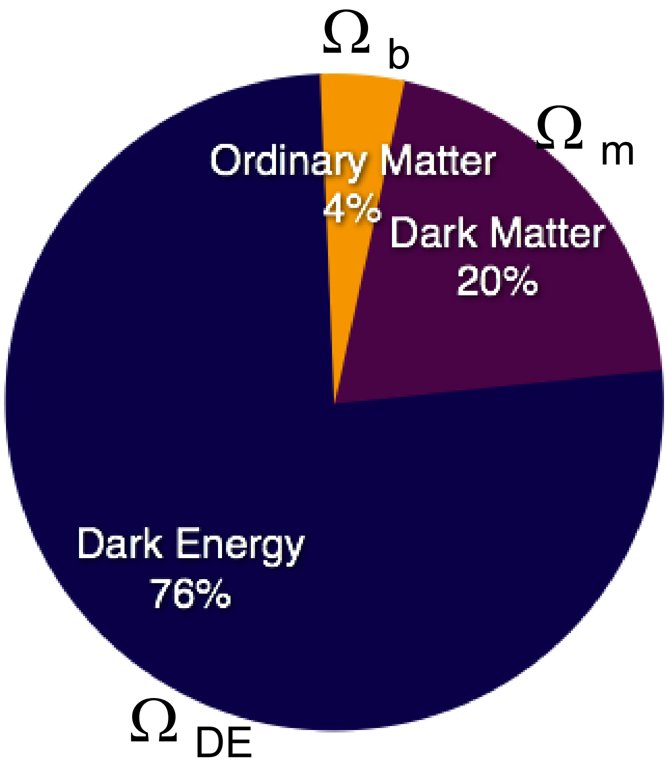
http://www.euclid-ec.org

Scientific objectives

An accelerating universe dominated by DE

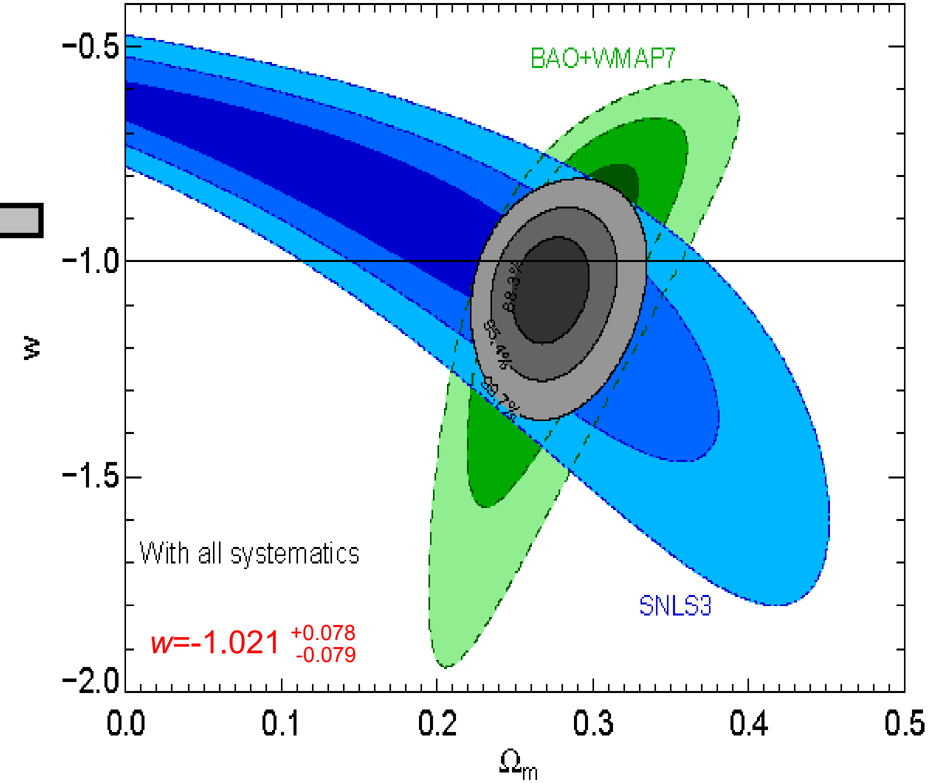


Conley et al 2011



Is Λ the source of the acceleration?

- If $w_X = P/\rho =$ cte
→ w_X ~ -1… But how close?



- Need higher precision data:
  - is w_X = -1.00 → Λ ?
  - exploring non-constant w_X :
    «dynamical dark energy» or…
  - deviation to General Relativity at cosmological scale? or…
  - ?

The ESA Euclid mission: scientific objectives

Euclid Consortium

Understand the origin of the Universe's accelerating expansion

- Constrain parameters that characterise properties of a broad range of dark energy (DE) and modified gravity (MG) models

- Design surveys that can distinguish DE, MG, DM effects by… :
    - using at least 2 independent, complementary probes (***5 probes***)
    - tracking their observational signatures on the
        - geometry of the Universe:
            - Weak Lensing (WL), Baryon Acoustic Oscillations(BAO),
        - cosmic history of structure formation:
            - WL, Redshift-Space Distortion, Clusters of Galaxies
    - <u>controlling systematic residuals</u> to a very high level of accuracy.

Distinguishing « Dark Energy » hypotheses

Relevant parameters… 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: $f \sim \Omega_m(a)^\gamma$ ($\gamma = 0.55$ GR)

⇩

1. Is the acceleration of expansion produced by a cosmological constant?

- Distinguish effects of Λ and dynamical dark energy → Measure *w(a)* → slices in redshift
- From Euclid data alone, get $FoM = 1/(\Delta w_a \times \Delta w_p) > 400$:

  If data consistent with Λ, and ***FoM* > 400** then :

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

2. Can we observe deviation from GR on cosmological scales?

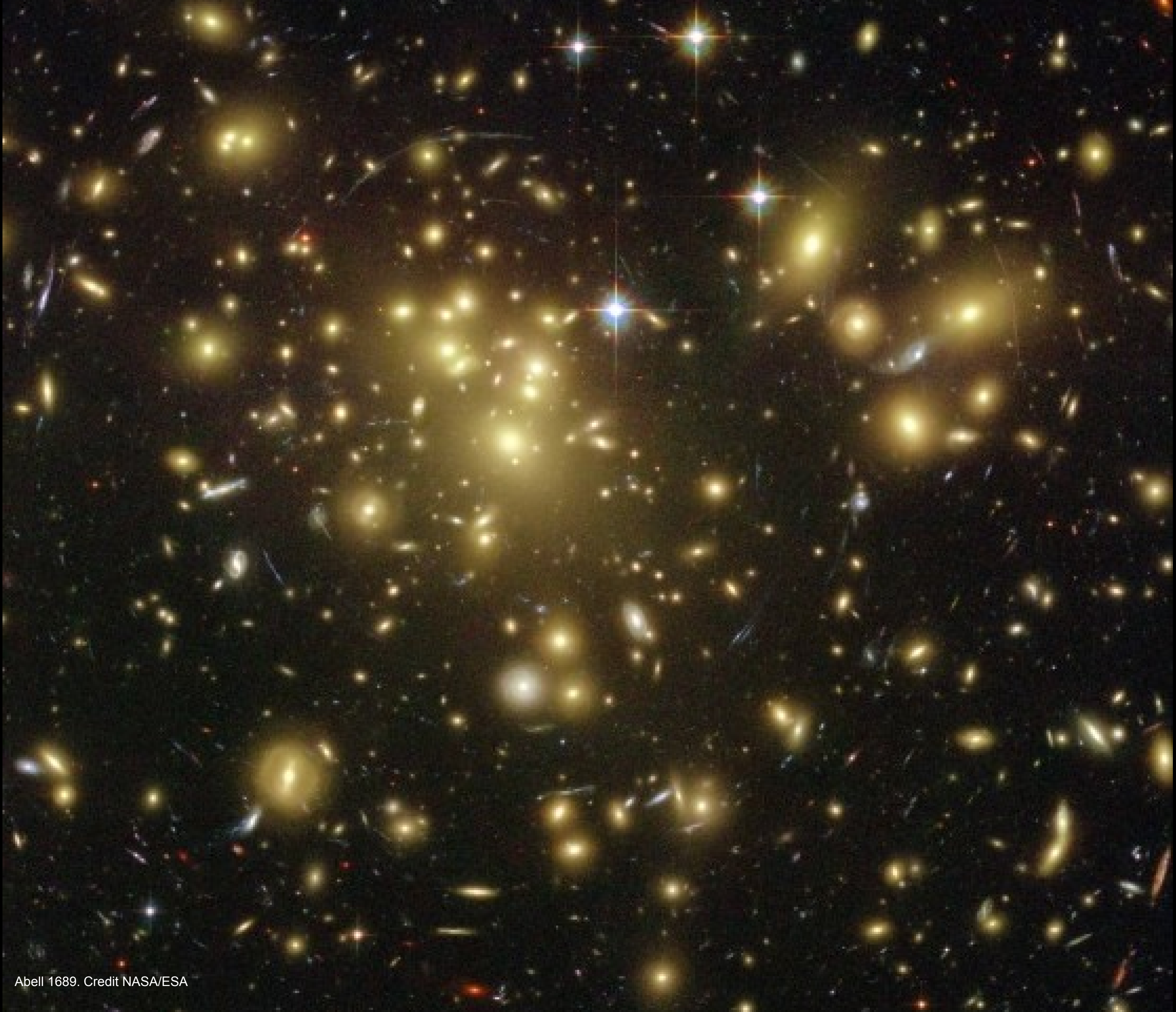
- Probe growth of structure → slices in redshift ,
- Distinguish effects of GR from MG models with very high confidence level:

  → 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?

- **Weak gravitational Lensing (WL):**

gravitational distortion (shear)


Abell 1689. Credit NASA/ESA

Weak Lensing: tomography of dark matter

Euclid Consortium

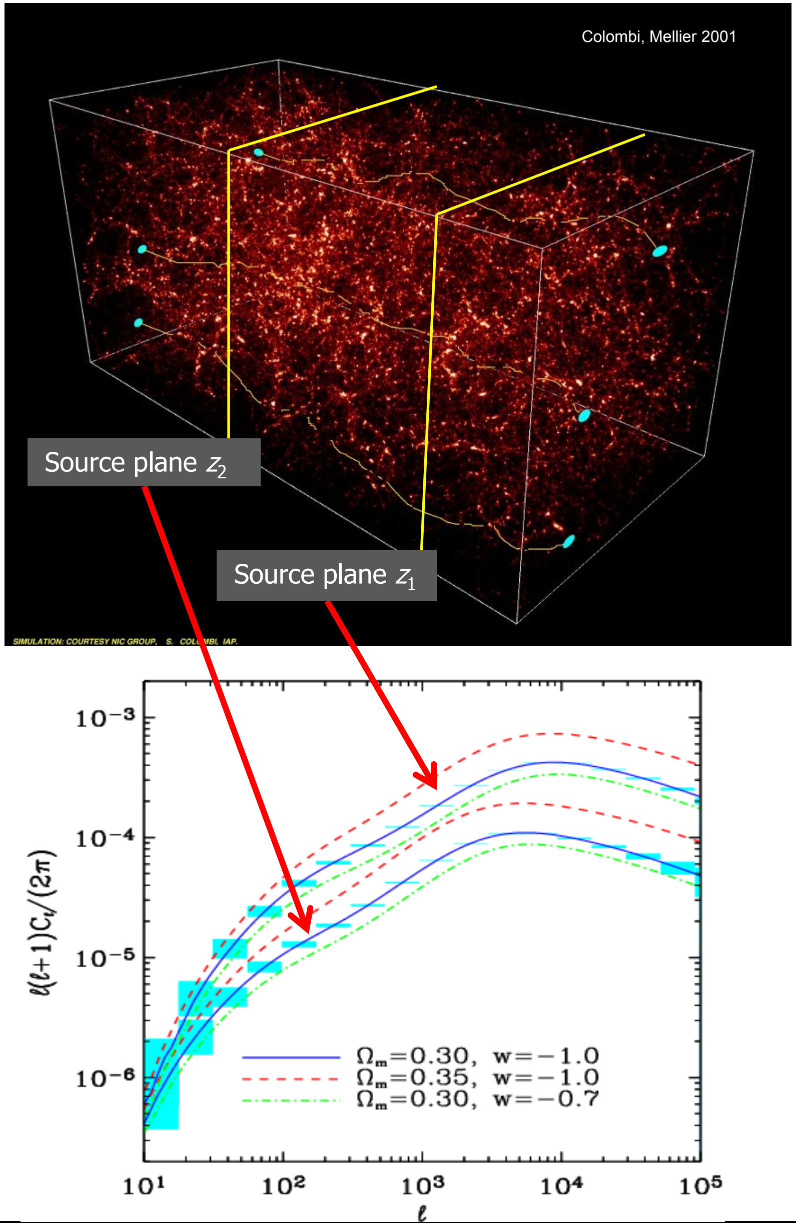
- **Weak Lensing (WL), very wide field:**

3-D cosmic shear measurements (tomography) over 0<z<2

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

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

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

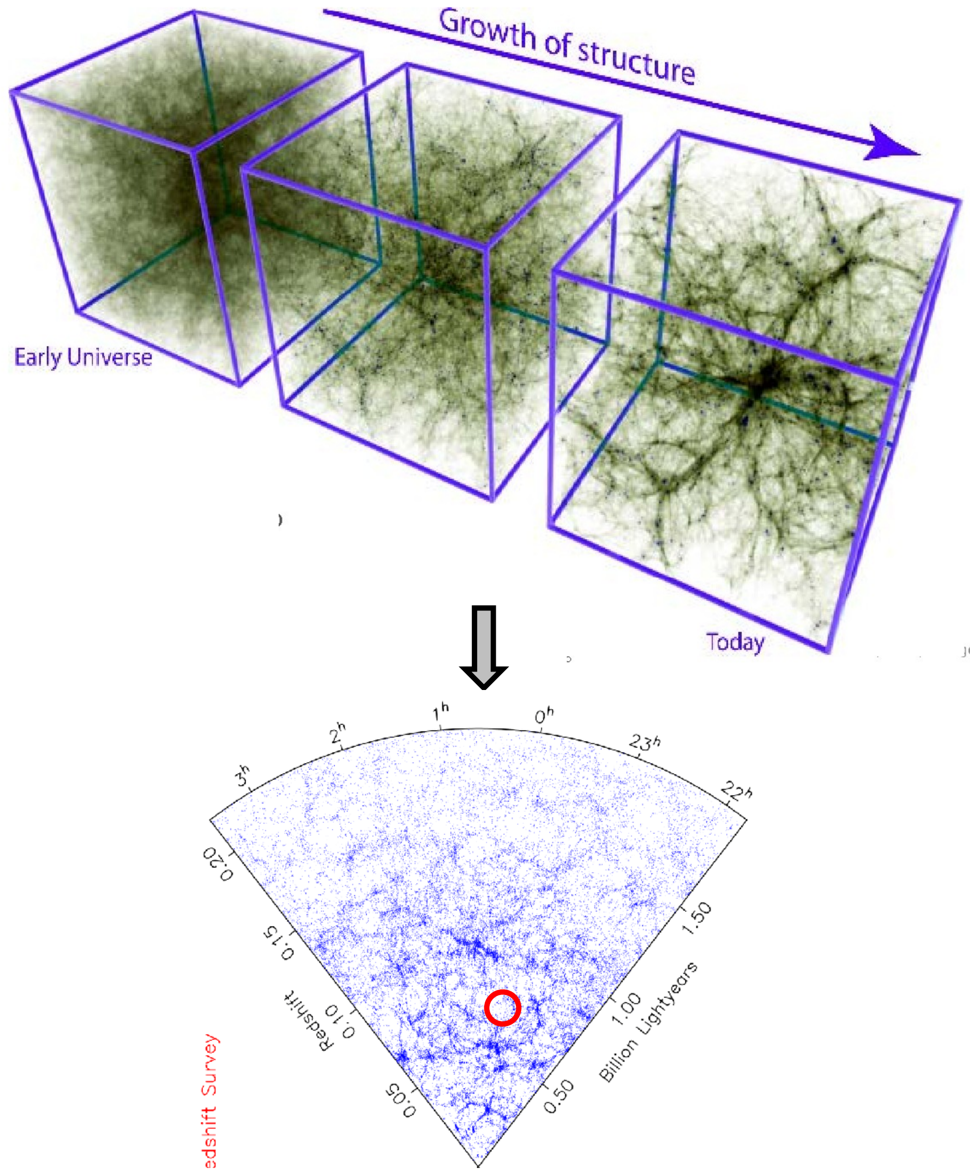


• **Galaxy Clustering (GC), very wide field:**

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.



A joint (WL+GC) survey is optimal

- **GC <u>and</u> WL:**
  - Use the same survey (minimise complexity and cost)
  - Use different data, complementary physical effects
  → different and decoupled systematics

  - Provide huge outstanding VIS imaging, NIR photometry and spectroscopy data with considerable Legacy value, beside the core program

- **CG and WL are *P*(*k*,z) explorers:**
  - Both probe power spectra
  → contain also imprints of dark matter (neutrino) and inflation (non-Gaussianity and f_{NL}) on the galaxy and dark matter power spectra

4th Euclid probe: Clusters of galaxies

- **Clusters of galaxies**:
  - probe of peaks in density distribution
  - number 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)

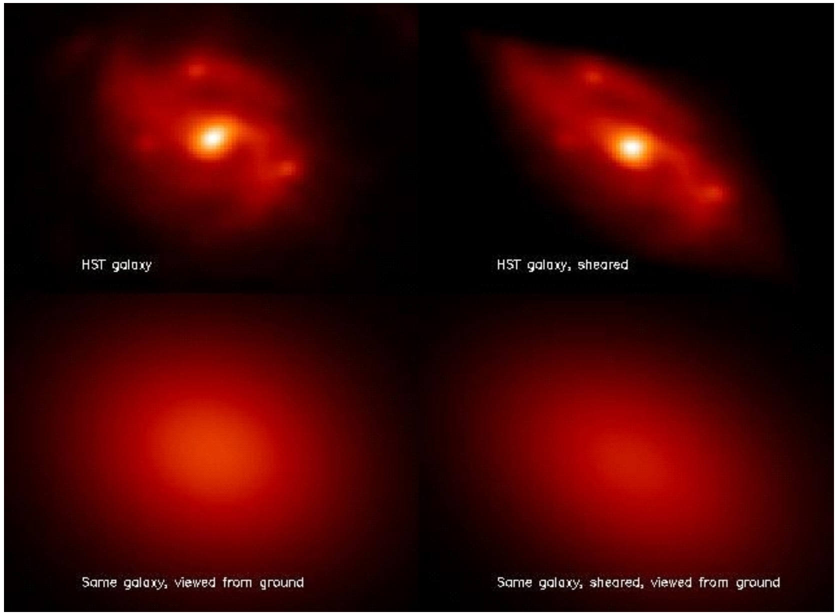
  → very accurate masses for the whole sample of clusters (WL)

  → dark matter density profiles on scales >100 kpc

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

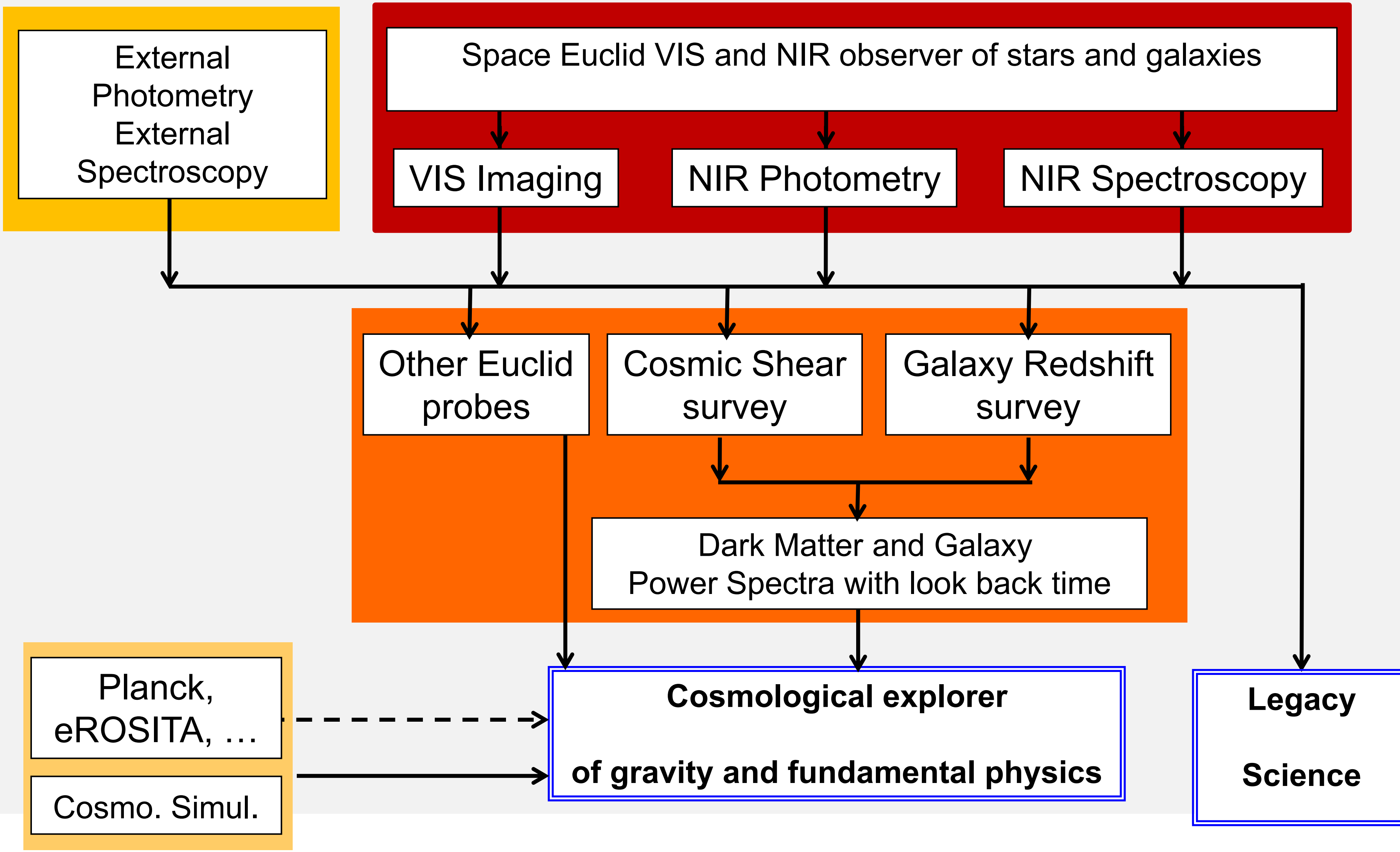
Why a space mission?

- **Shape measurement easier**:
  - No degradation of the PSF and images by atmospheric effects (seeing, atmospheric refraction)
  - PSF very stable
  - Shapes of faint galaxies better resolved →systematics much lower and easier to control



- **NIR data more stable and deeper**:
  - In the range 1.2< z < 2.5 redshifts cannot be measured without NIR data
  - NIR background x1000 fainter than from the ground: deep NIR photometry possible : with ESO/VISTA: 640 years
  - NIR observing conditions much more stable than from the ground

The Euclid Machine



The Euclid Mission: baseline and options

SURVEYS In ~5.5 years

	Area (deg2)	Description
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg^2**	In at least 2 patches of > 10 deg^2 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 deg^2	0.763×0.722 deg^2			
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**	
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

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

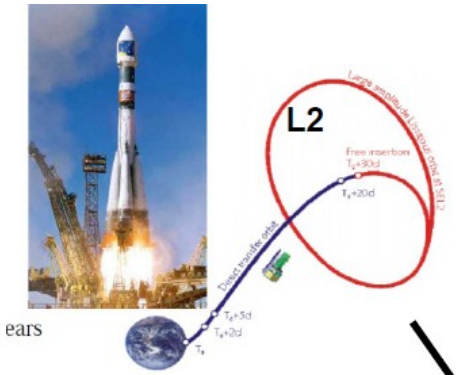
Ref: Euclid RB arXiv:1110.3193

Mission Implementation

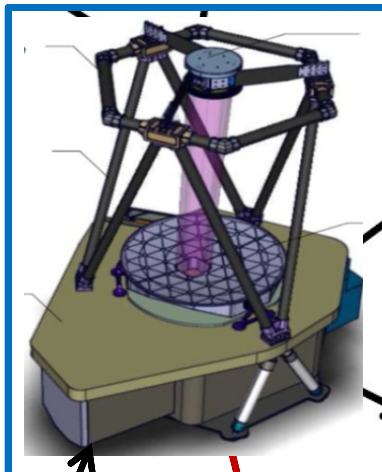
The Euclid mission… in one slide

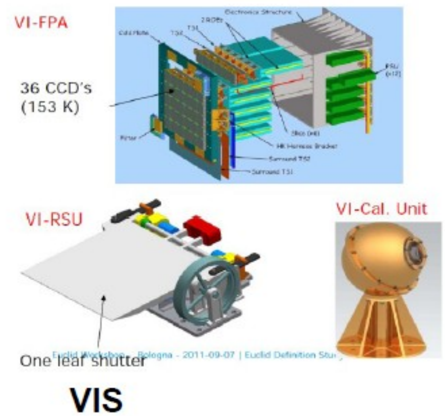
Euclid Consortium

Soyuz@Kourou
Q2 2020



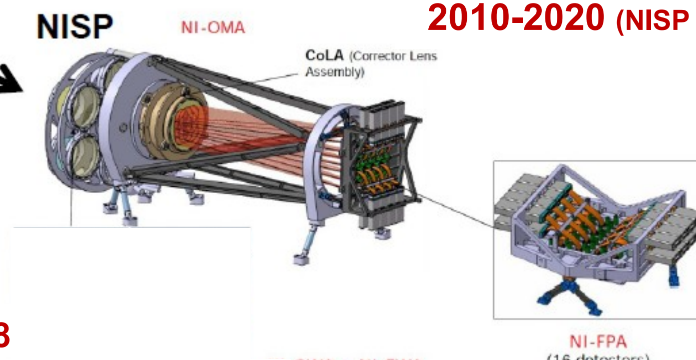
PLM+SVM: 2010-2019



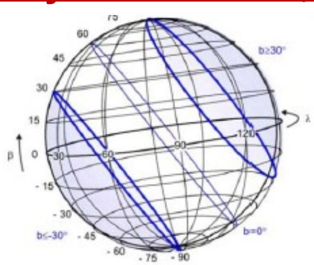


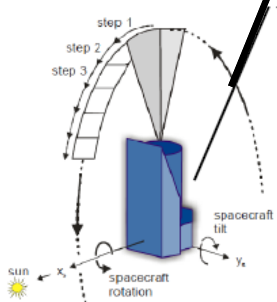
VIS imaging: 2010-2020 (VIS team)

NIR spectro-imaging 2010-2020 (NISP team)



Surveys: 2010-2028 (Survey WG)

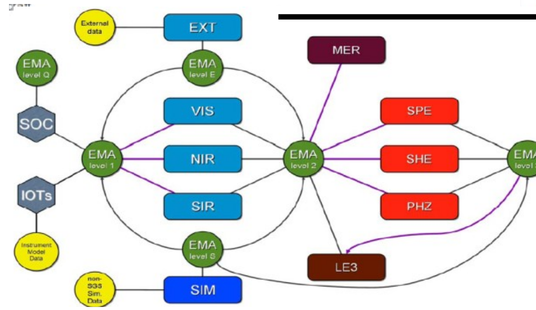


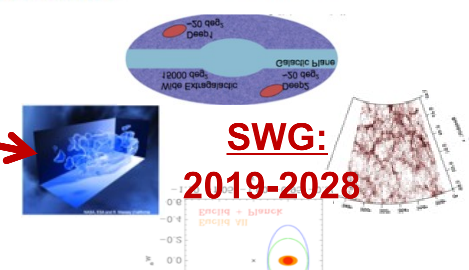


6 yrs mission

- Commisionning – Sc. Verif.
- Euclid nominal in opération: 5.5 yrs of Euclid Wide+Deep
- Euclid+: Additional surveys: SNIa, mu-lens, Milky Way?

SGS: 2010-2028

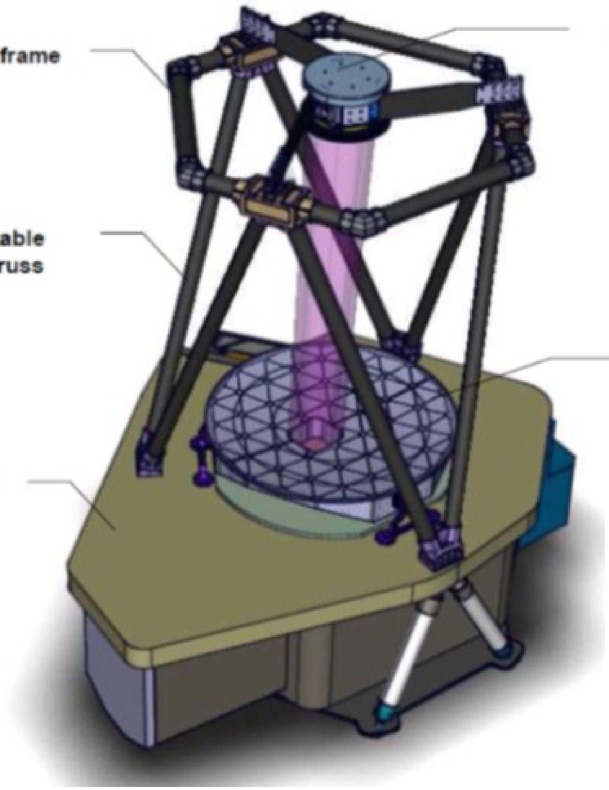




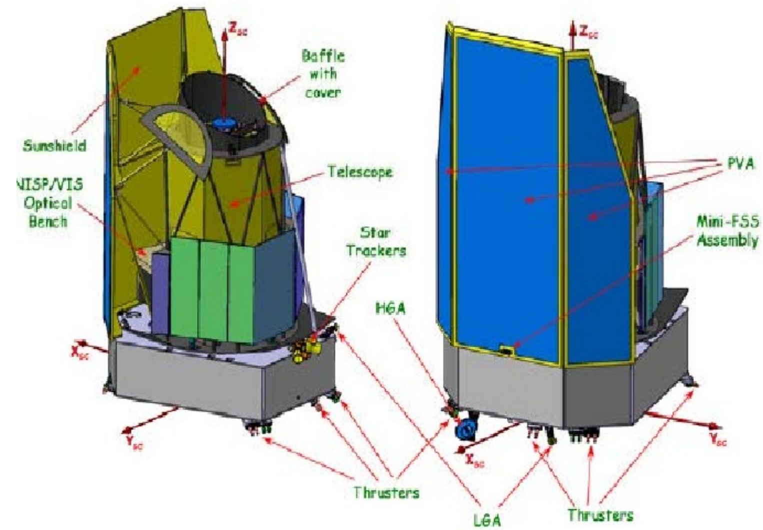
SWG: 2019-2028

20-30 PB data processing (EC-SGS team) – Science analyses

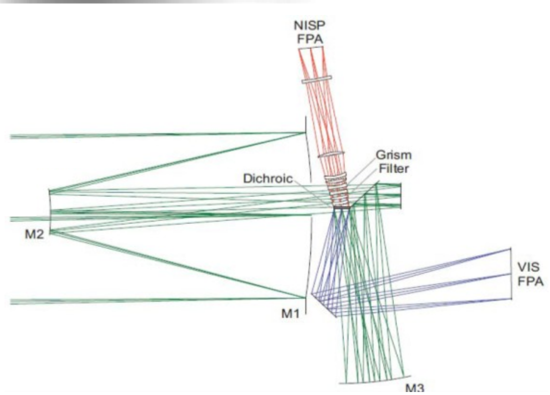
Telescope and payload module

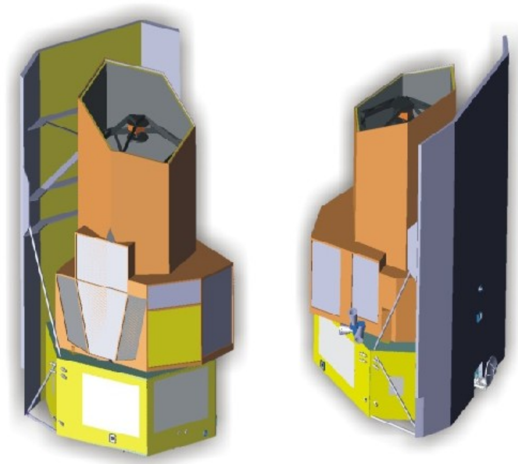


- 1.2 m Korsch
- 3 mirror anastigmat
- 0.45 deg. off-axis field
- f=24.5m
- Pointing stability in (x,y):25 mas over 600 s



Thales-Alenia Space design





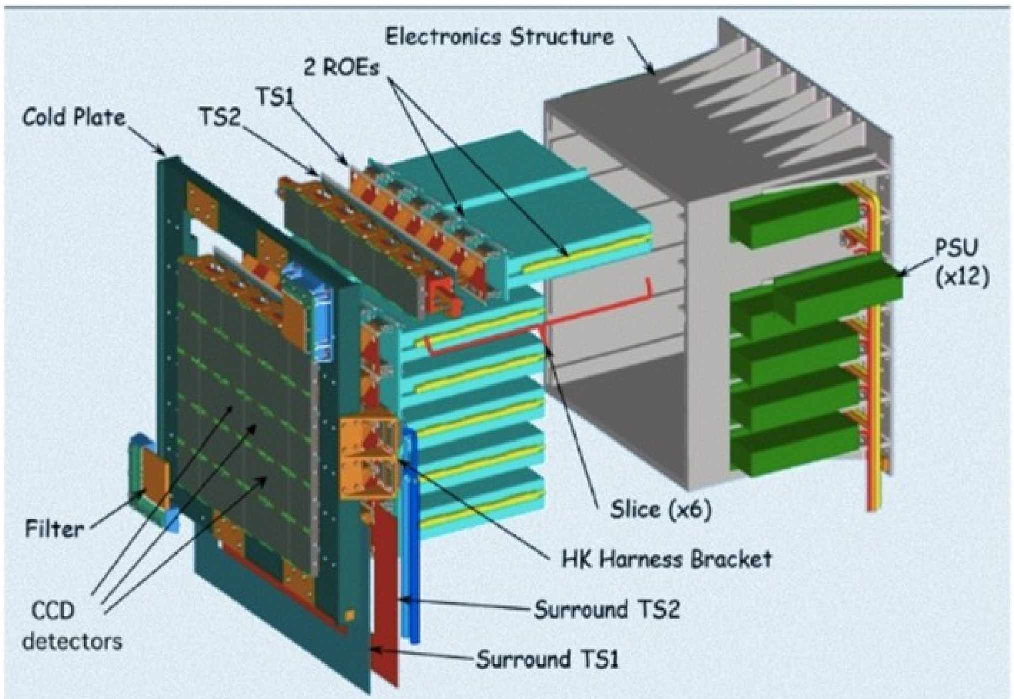
Astrium design

VIS and NISP: share the same FoV (0.54 deg^2)
Dichroic beam splitter at exit pupil

VIS Instrument

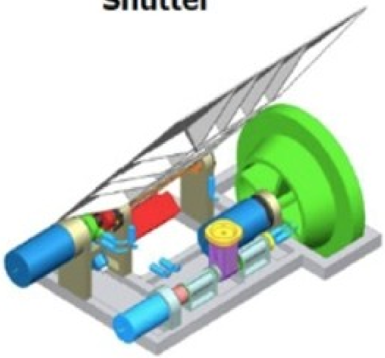
- Large area imager: a « shape measurement machine »
- 36 4kx4k E2V CCDs, 12 micron pixels
- 0.1 arcsec/pixel on sky
- Bandpass 550-900 nm
- Limiting magn.for wide survey : AB 24.5, 10 σ extended
- Data volume 520 Gbit/day

COLD

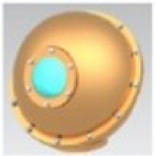


Focal Plane Assembly

Shutter

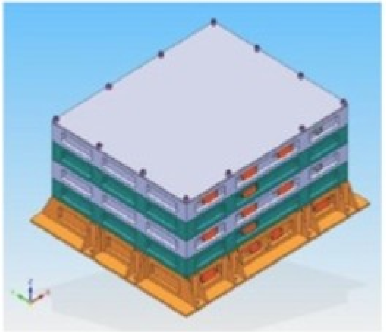


Cal Unit

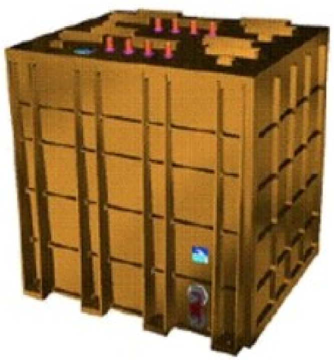


WARM

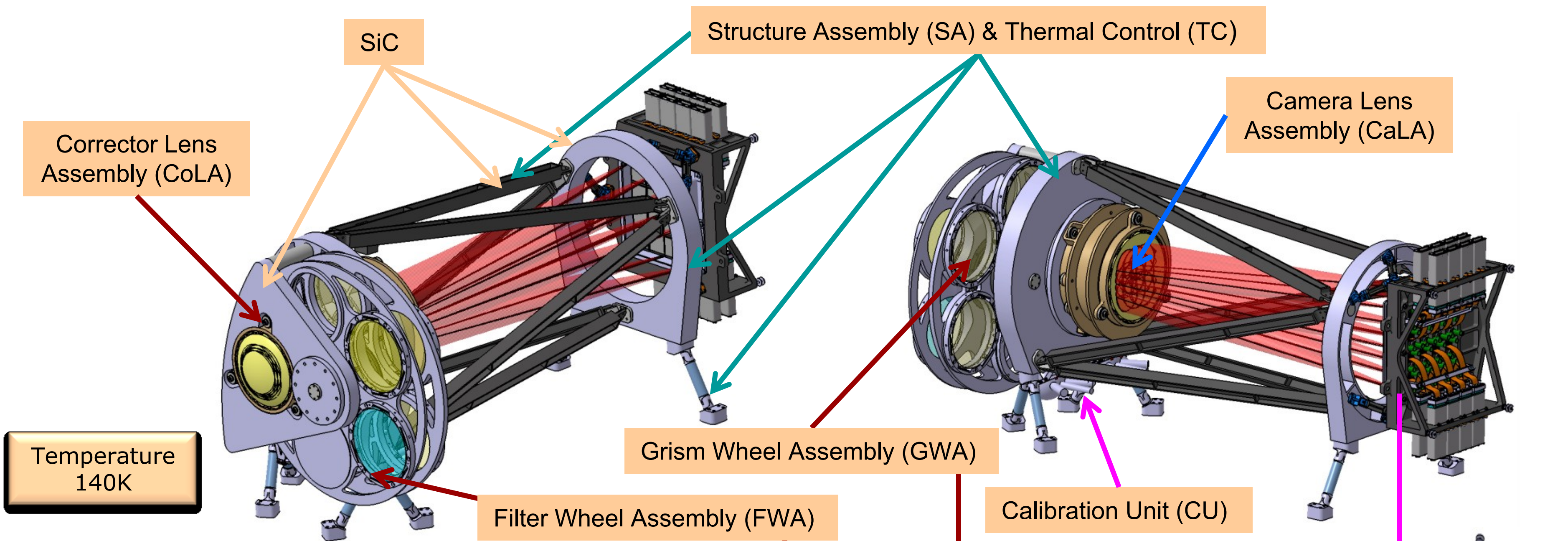
Power and Mechanisms Control Unit

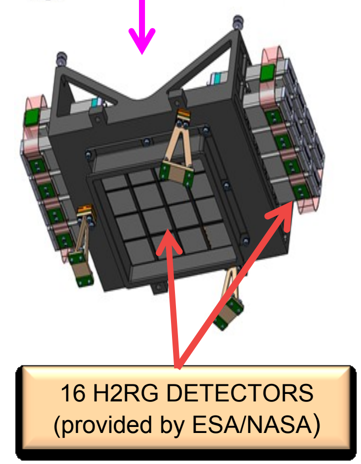


Command and Data Processing Unit

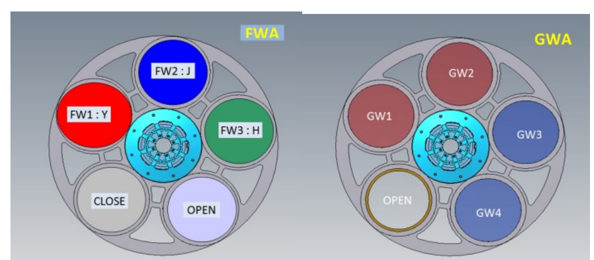


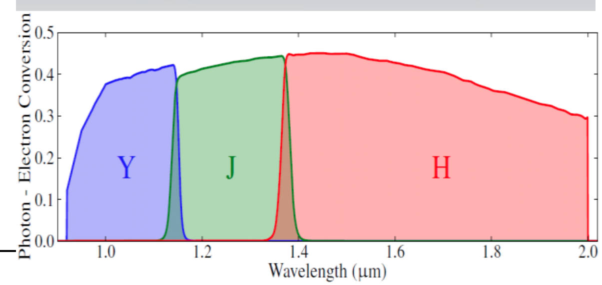
NISP instrument





- Large area NIR imager and slitess spectrograph
- 16 2kx2k H2GR NIR detectors
- 0.3 arcsec/pixel on sky
- 3 NIR filters: H,J,H,
- 4 Grisms (2 « blue », 2 « red »)
- Limiting magn.for wide survey : AB 24.0, 5 σ point source
- Data volume 180 Gbit/day

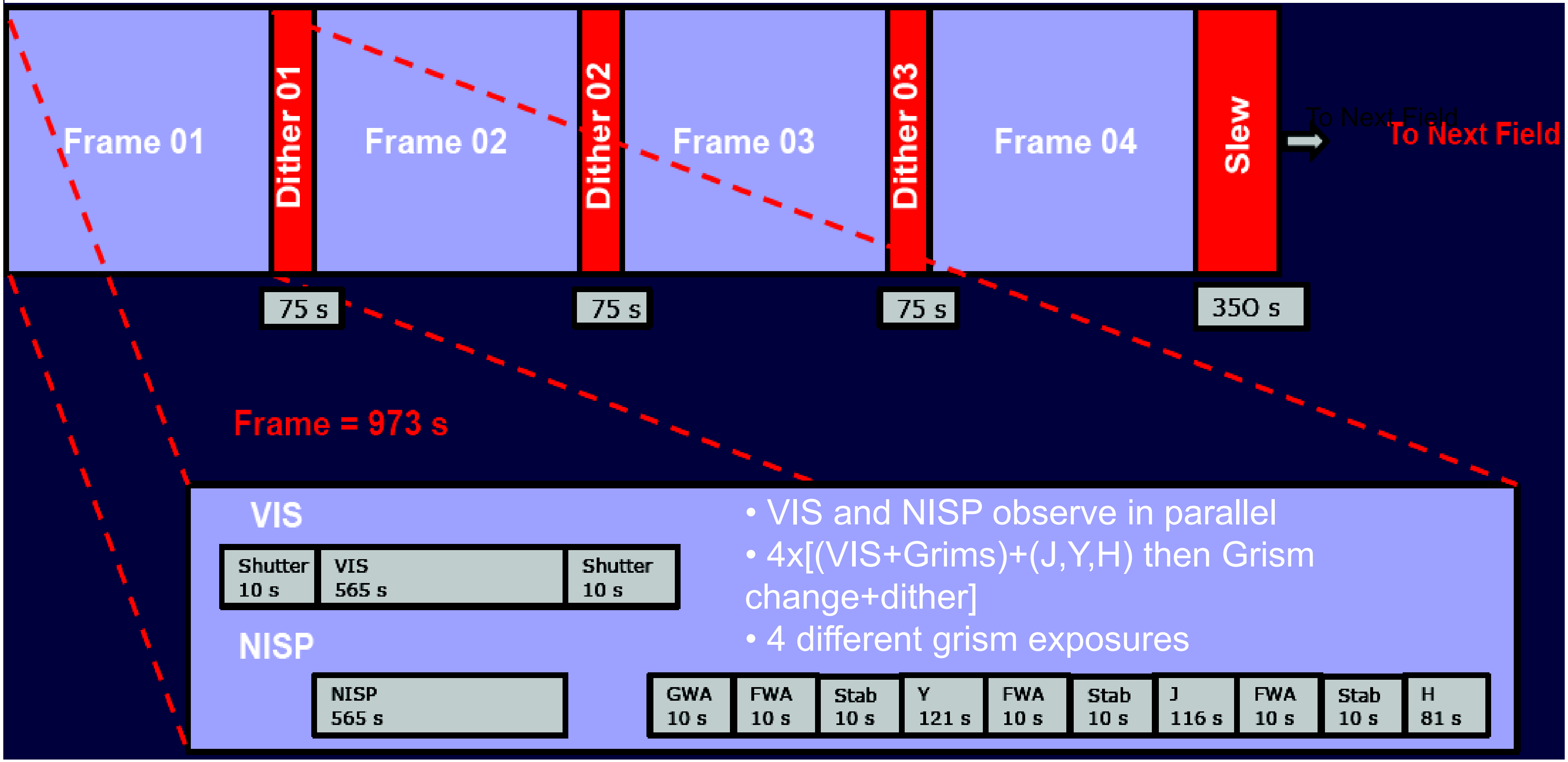




NISP+VIS field observing sequence

Total Field of View observation time (time between 2 fields observations):

•Reference Case = 4 x 973 s + 3 x 75 s + 350 s = 4467 s ⇒ **Reference Field Sequence = 4500 s**

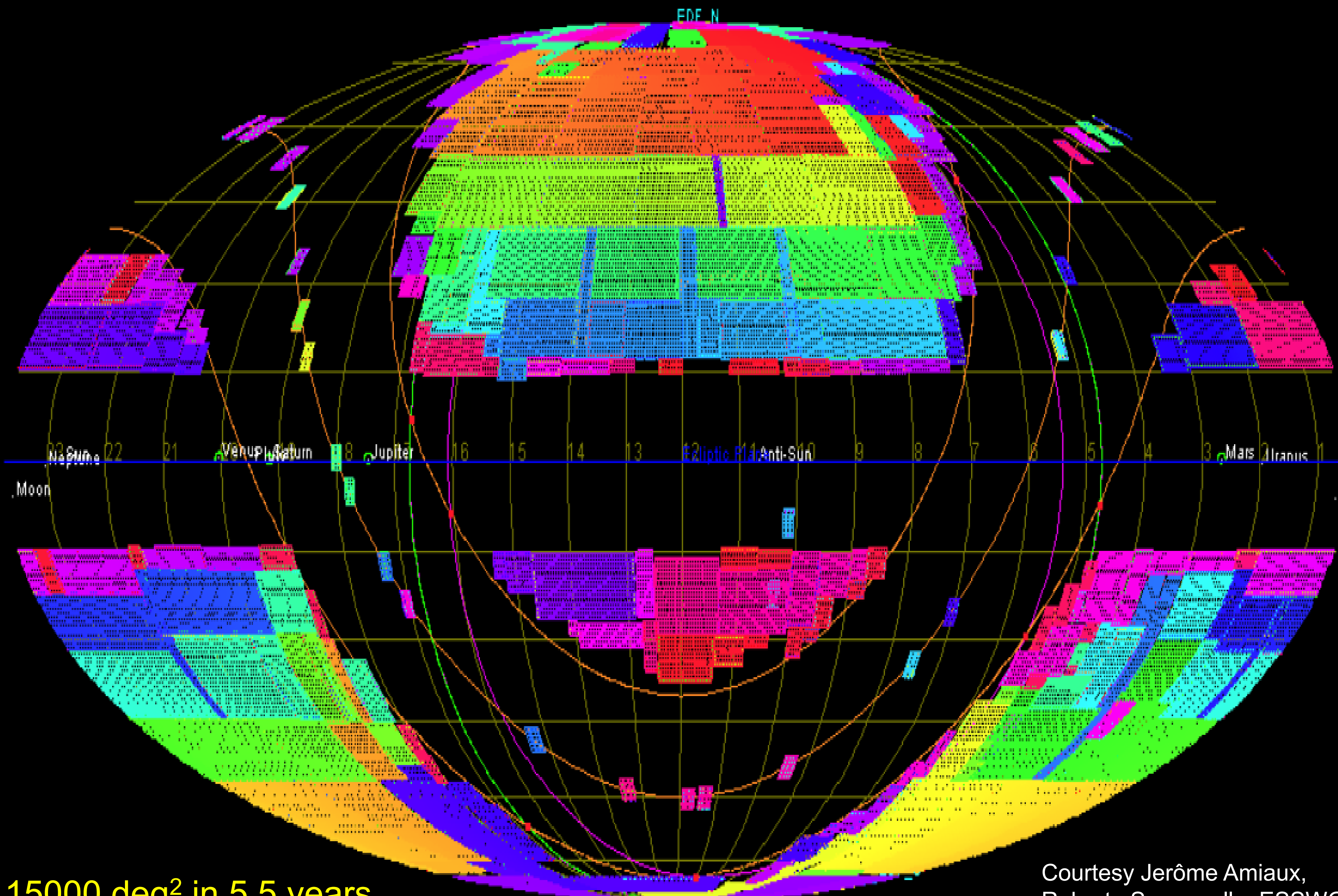


Courtesy Jerôme Amiaux, ESSWG

Data transfer to Earth: 4 hours/day

Euclid Deep+Wide survey model

Euclid Consortium



15000 deg^2 in 5.5 years

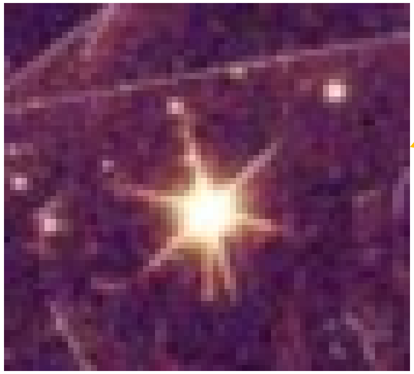
Courtesy Jerôme Amiaux,
Roberto Scaramella, ESSWG

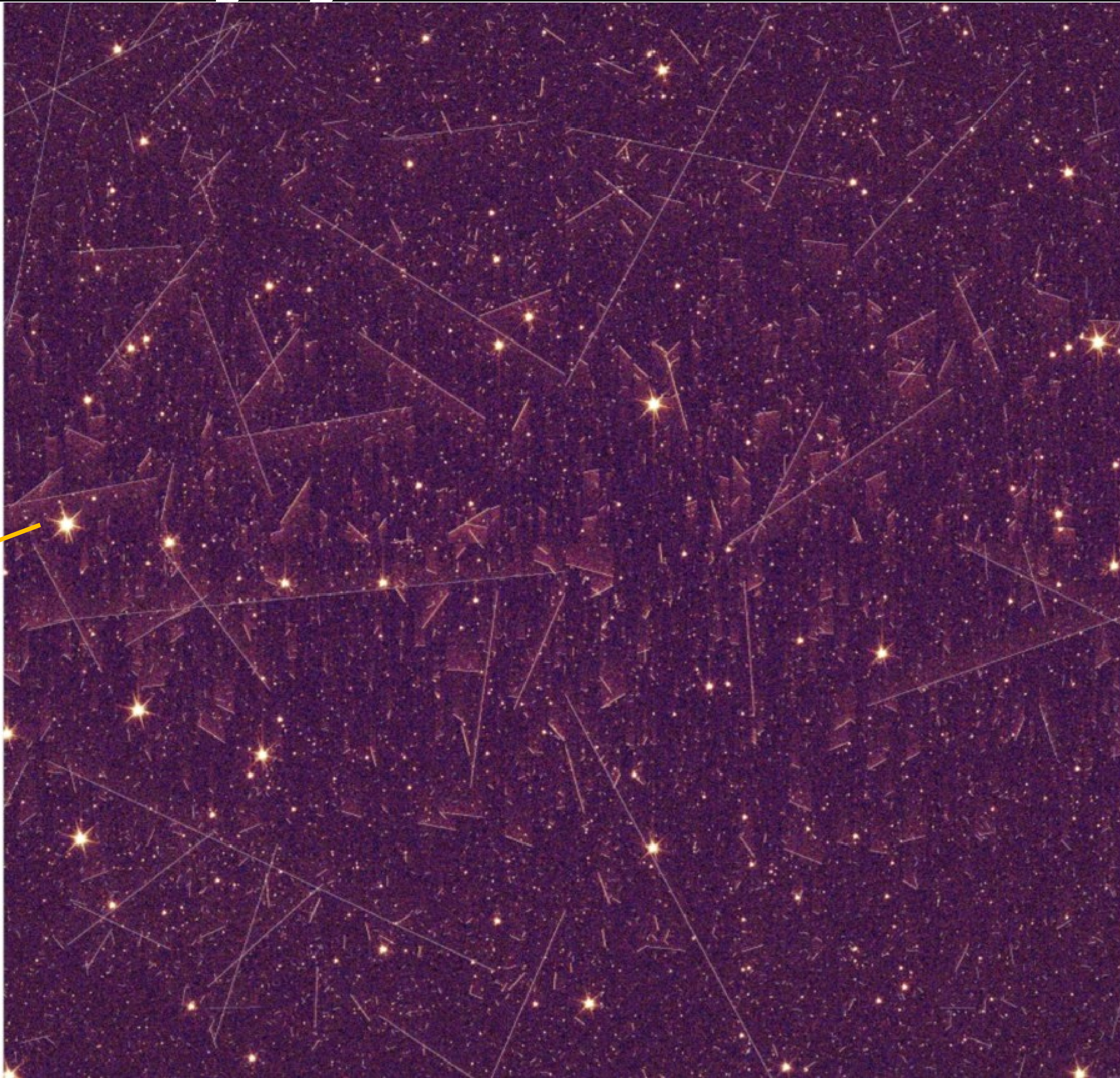
Performances

VIS performance:imaging

A 4kx4k view of the Euclid sky

VIS image: cuts made to highlight artefacts





Courtesy Mark Cropper,
Sami M. Niemi

Euclid:optimised for shape measurements

Euclid Consortium

M51

Courtesy Jarle Brinchmann, Steve Warren

SDSS @ z=0.1 | Euclid @ z=0.1 | Euclid @ z=0.7

- Euclid images of z~1 galaxies: same resolution as SDSS images at z~0.05 and at least 3 magnitudes deeper.
- Space imaging of Euclid will outperform any other surveys of weak lensing.

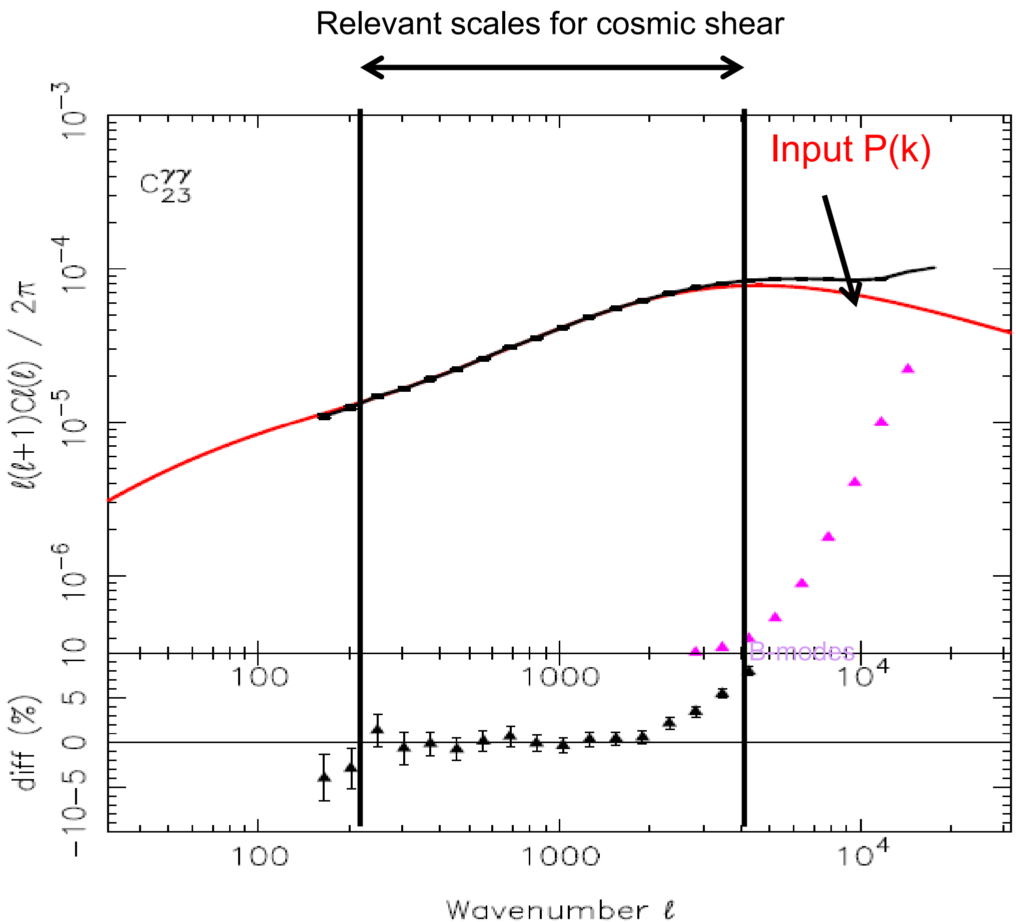
Cluster with Euclid VIS+NIS imaging

Euclid combined VIS+Y+J+H images of a simulated cluster

Courtesy Massimo Meneghetti

Euclid: DM reconstructed P(k)

Courtesy
Henk Hoekstra,
Tom Kitching



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

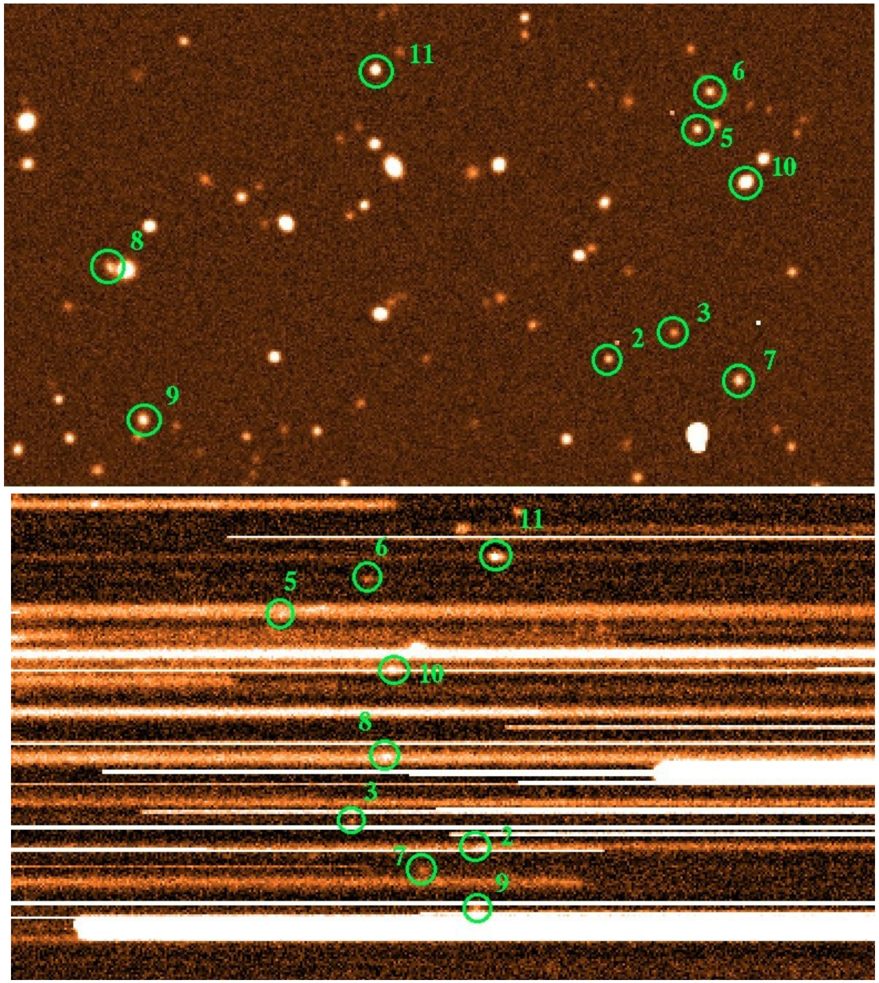
• Percentage difference [*expected* – *measured*] power spectrum: recovered to 1% .

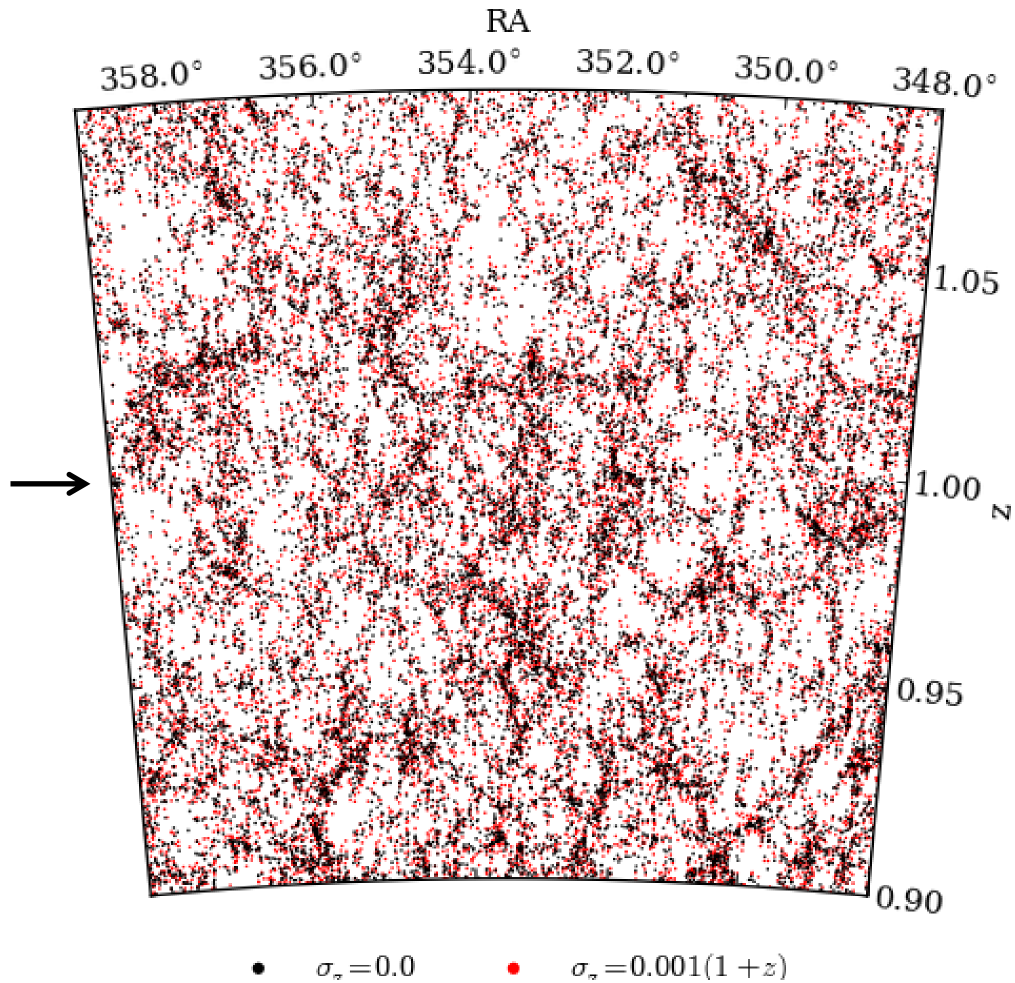
Laureijs et al 2011,
Euclid RB
arXiv:1110.3193 from
Euclid SWGs

NISP Performance: images/spectra/redshifts

Euclid Consortium

Courtesy Anne Ealet, Knud Jahnke, Bianca Garilli, Will Percival, Luigi Guzzo



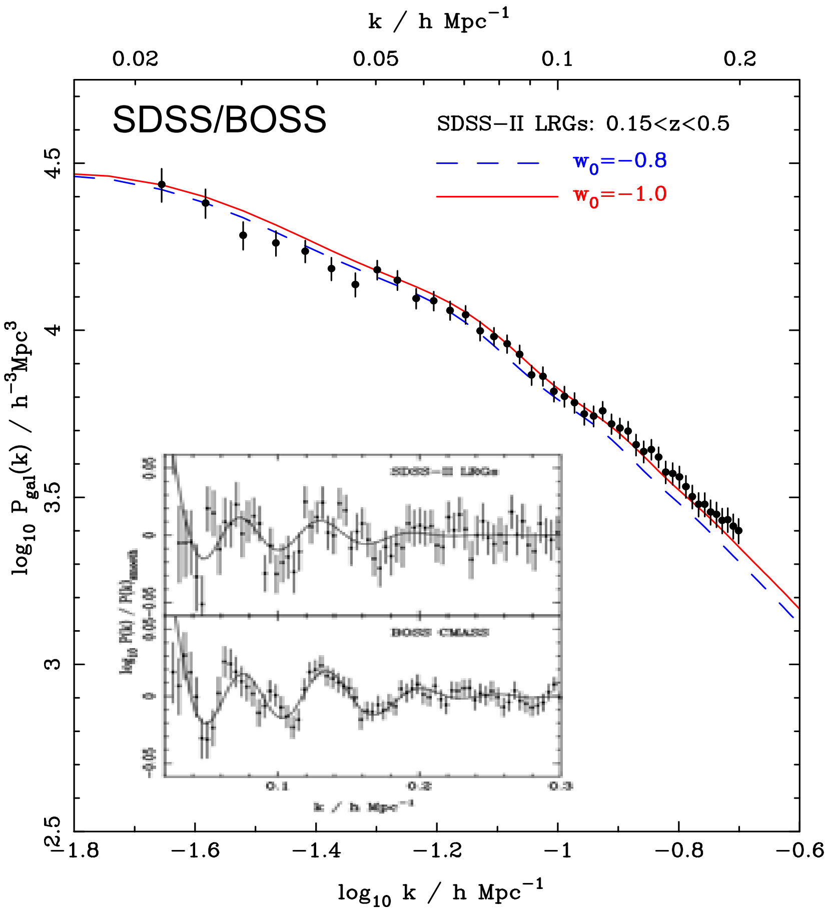


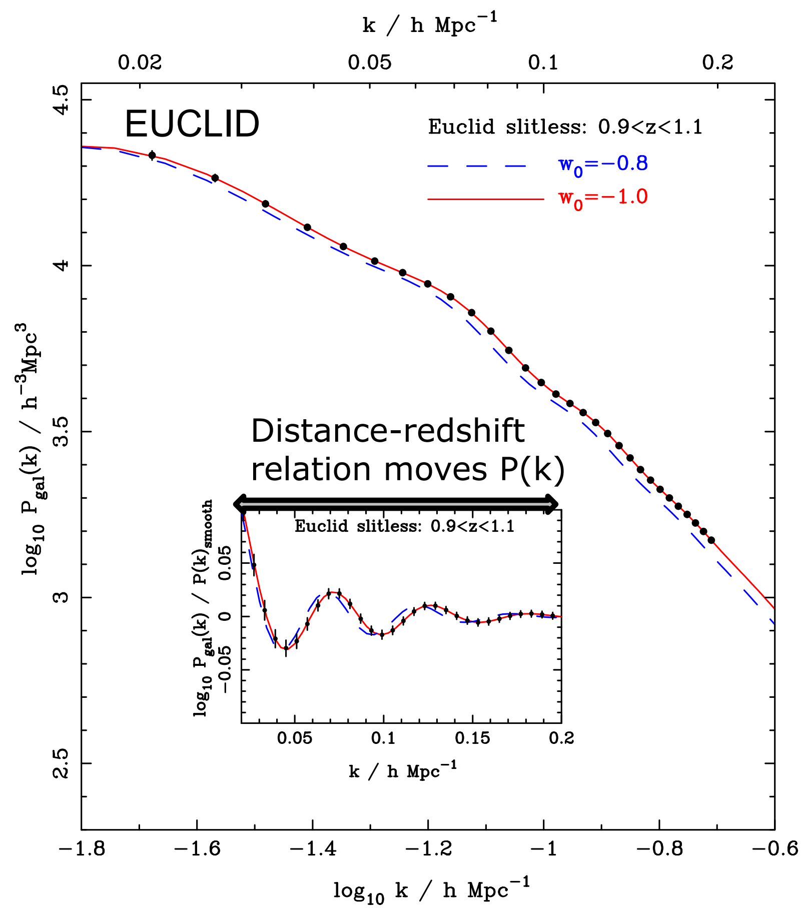
- 1 deg2 of the sky simulated and propagated through end-2-end Euclid spectroscopic simulation
- Shows can meet the required n(z), completeness and purity

True vs. measured redshift

BAO : SDSS, BOSSS vs Euclid

Euclid Consortium





0.15<z<0.5

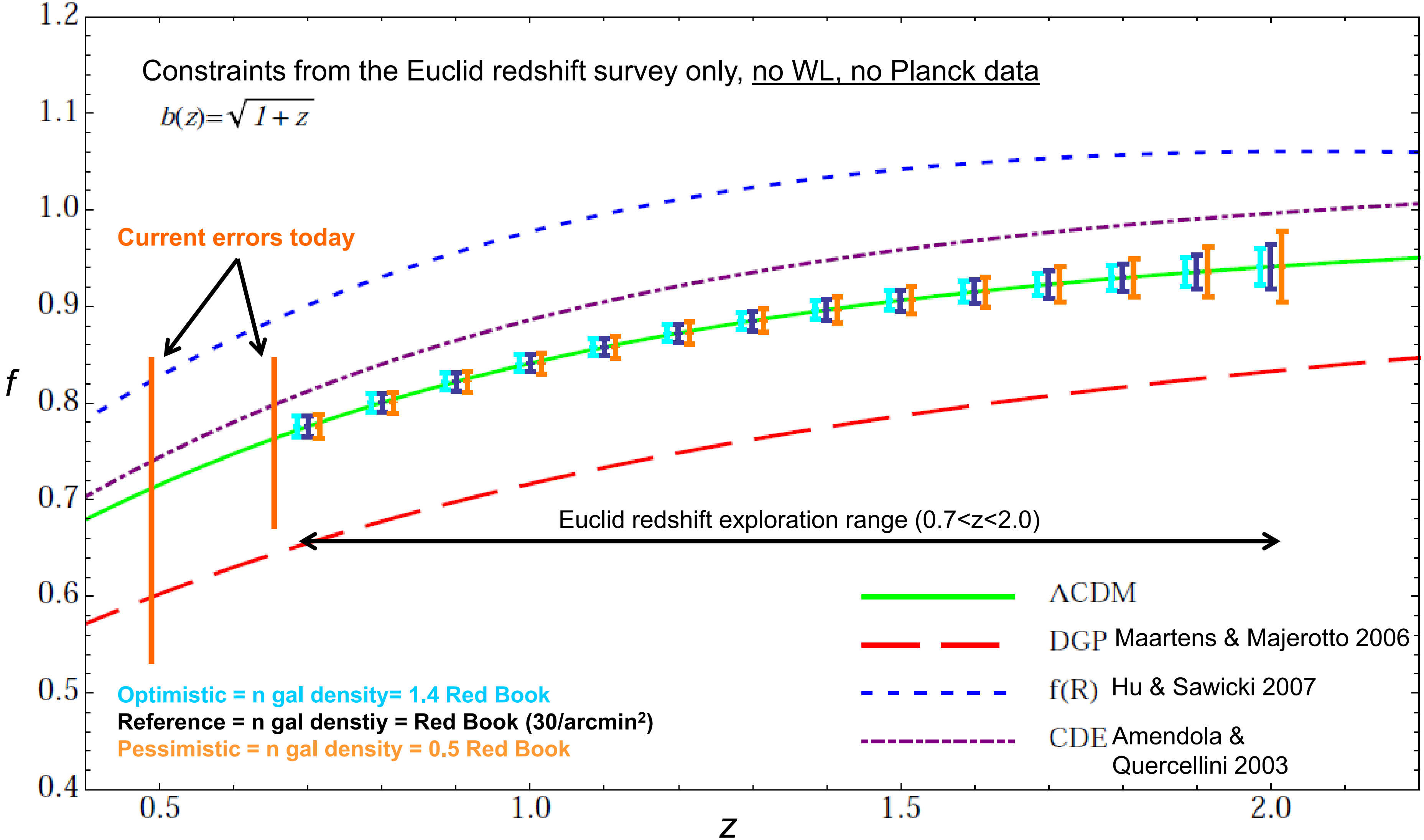
- $V_{eff} \approx 19\ h^{-3}\ Gpc^3$ ≈ 75x larger than SDSS
- Redshifts 0<z<2
- Percentage difference [*expected* – *measured*] power spectrum: recovered to 1% .

Ref: Euclid RB arXiv:1110.3193 from Euclid SWGs

Exploration of DE models with GC only

Euclid Consortium

See Amendola et al 2012 for a comprehensive of model exploration with Euclid

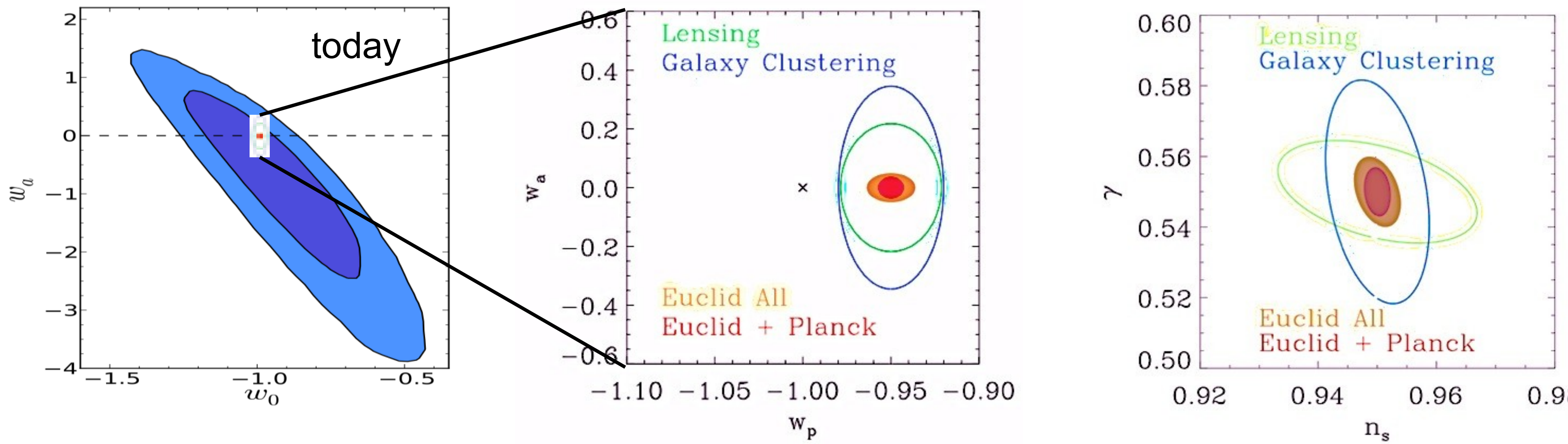


Amendola et al arXiv:1206.1225

Euclid(WL+GC)+Planck: predicted performances

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**

Laureijs et al 2011, Euclid RB arXiv:1110.3193 from Euclid SWG
Amendola et al arXiv:1206.1225

Assume systematic errors are under control

Importance of redshifts

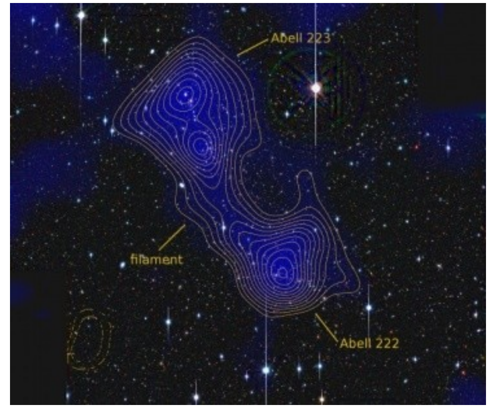
HST/ACS credit NASA/ESA

Galaxy halos

HST/ACS; credit NASA/ESA

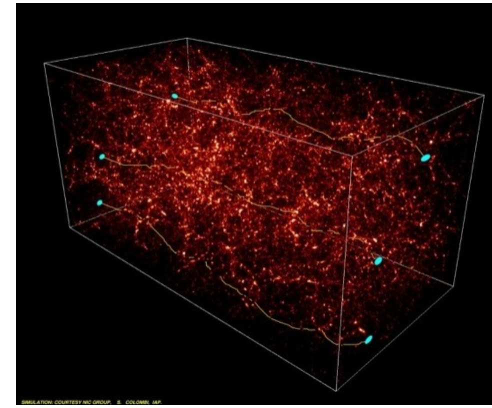
Clusters of galaxies

Dietrich et al 2012



Filaments between clusters

Colombi/Mellier



Cosmic shear

$$\vec{\alpha} = \frac{2}{c^2} \cdot \frac{D_{LS}}{D_{OS}} \vec{\nabla}_{\vec{\theta}_I} \phi_N^{2D}$$

Redshifts of sources and lenses are needed

Cosmic shear tomography redshifts are also needed to

- Slice the universe
- Clean contamination by intrinsic alignements of galaxies

Problem: unfeasible to get 2.10^9 spectroscopic redshifts

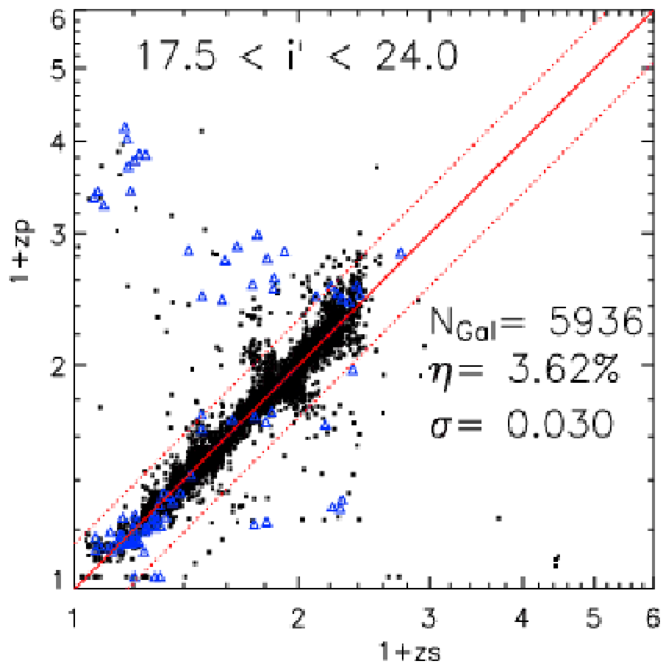
Photo-z with Euclid: need VIS and NIR data

Euclid weak lensing will probe the lensed universe between redshift 0.2 and 3…

Photo-z vs. Spectro-z (deep optical)

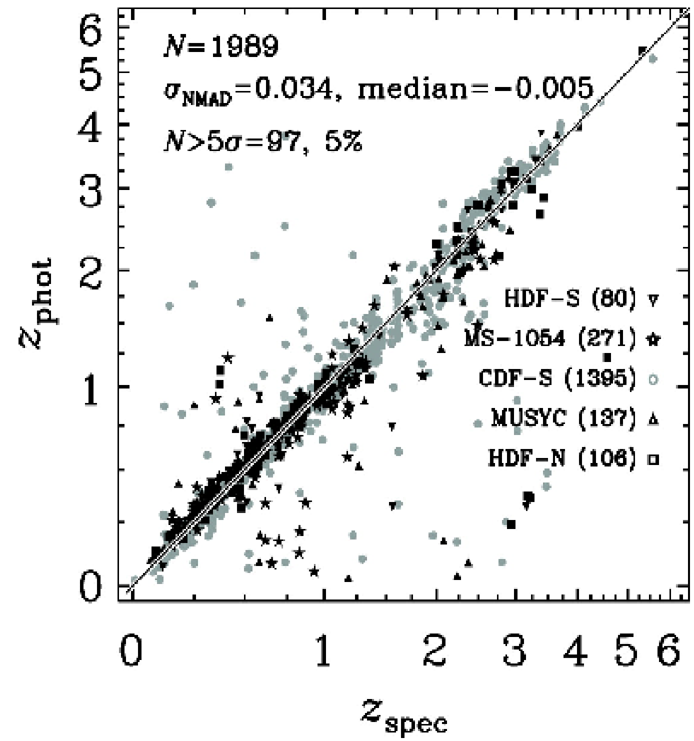
Courtesy:

H. Hildebrandt



Coupon et al 2008

Photo-z vs. Spectro-z (deep optical+NIR)



Brammer et al 2008

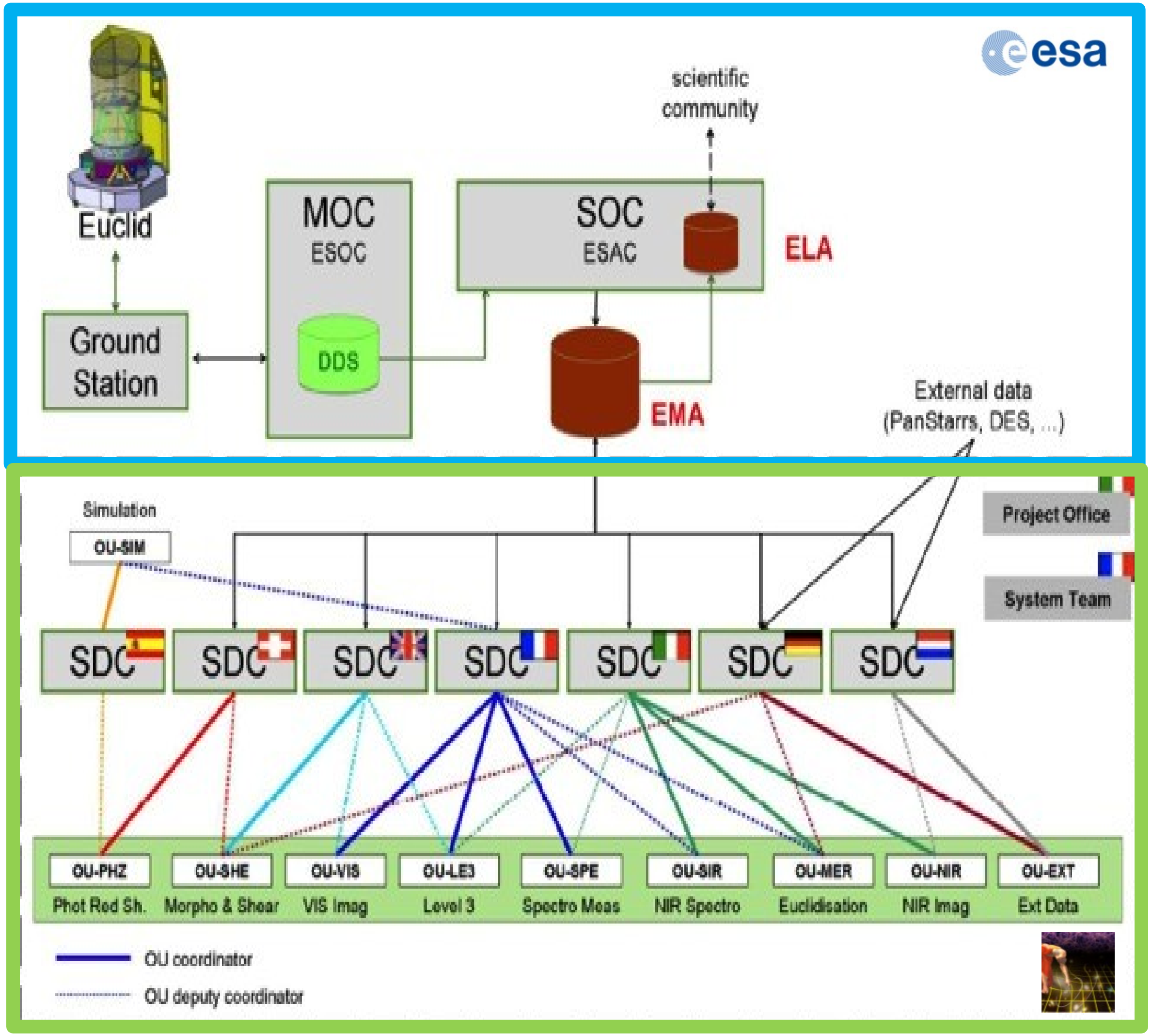
Redshifts needed with only an accuracy of 0.05(1+z)

→ Photometric redshifts: need 4 visible band and 3 NIR band photometry

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

Ground Segment, data processing

Ground segment organisation : SDCs and OUs



Challenges:

- Data quantity
- Level of quality
- 26 Pbytes /cycle/year
- 10^{10} objects/year

First Level 3 release:
26 months after the beginning of the surveys . Then yearly.

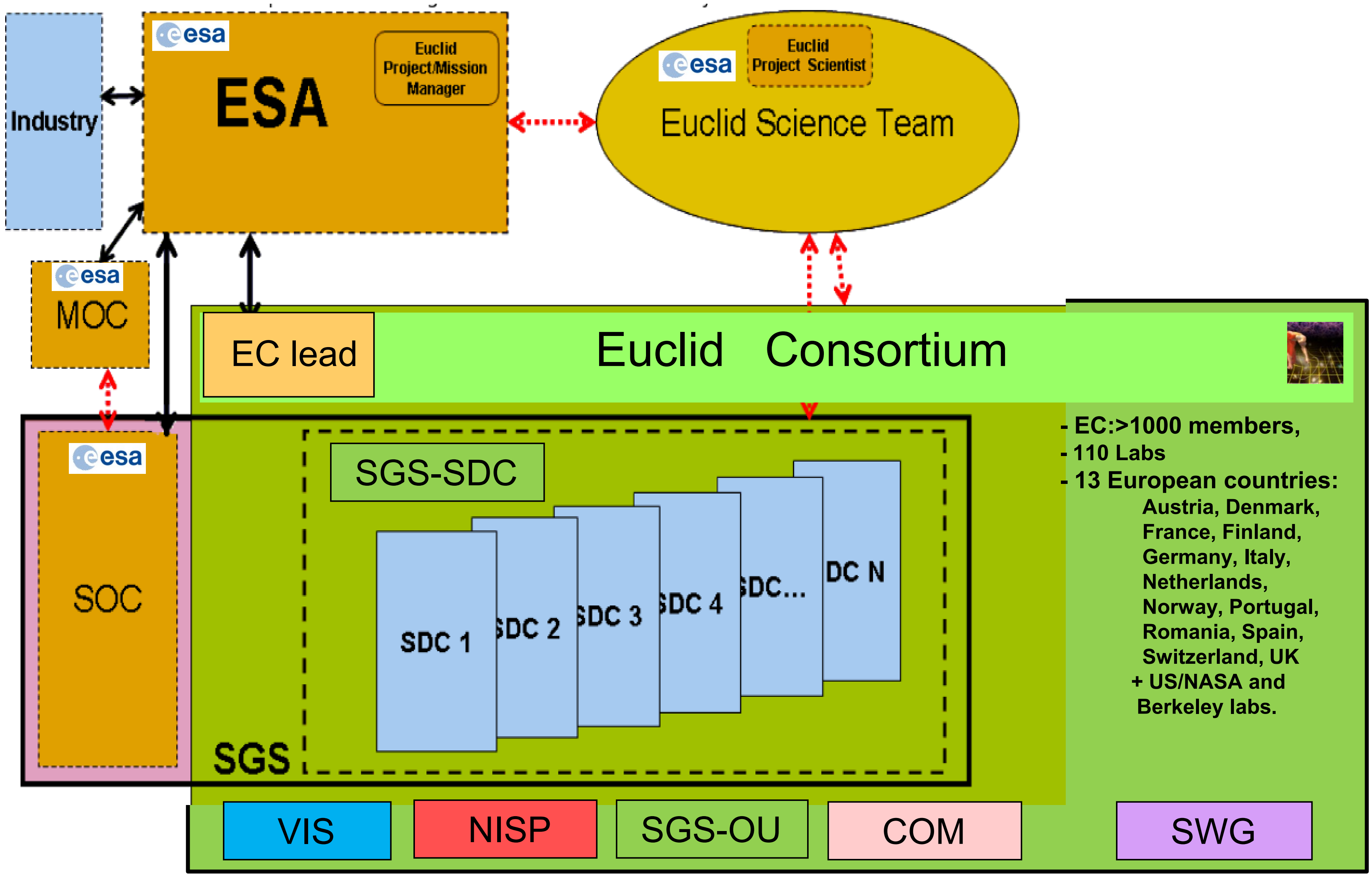
Complexity:
Science Data Centers (SDC) in each country should ensure the production of Euclid data

Very complex chain of data production to meet the precision and accuracy requirements

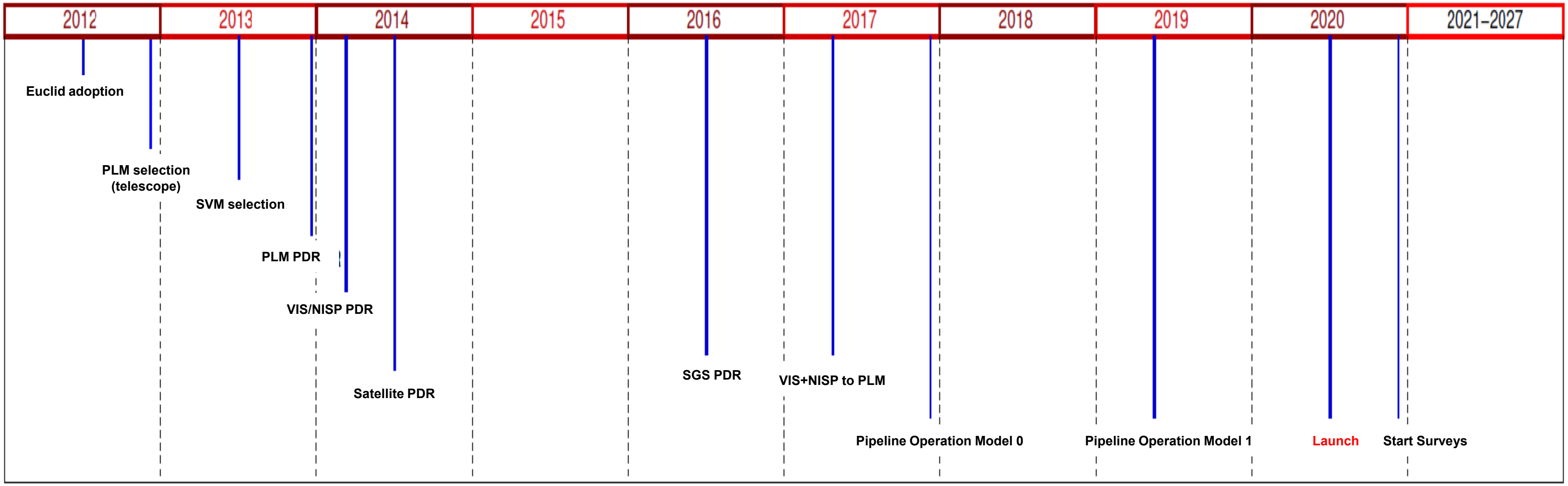
Organisation

Euclid Collaboration: organisation

Euclid Consortium



Schedule



Launch date: Q2 2020

Summary

- ESA is preparing the only space mission designed to understand the origin of the accelerating universe;
- Euclid will use 5 probes to provide:
  - tight constraints over the broadest range of DE; MG models ever explored,
  - unrivalled legacy value of VIS/NISP images and spectra;
- Put Europe at the forefront of a fundamental question in physics/ cosmology for the next decades;
- Eucid is entering in implementation phase. Stay tuned until 2020…
- Hope Euclid will do as well as LHC and Planck…