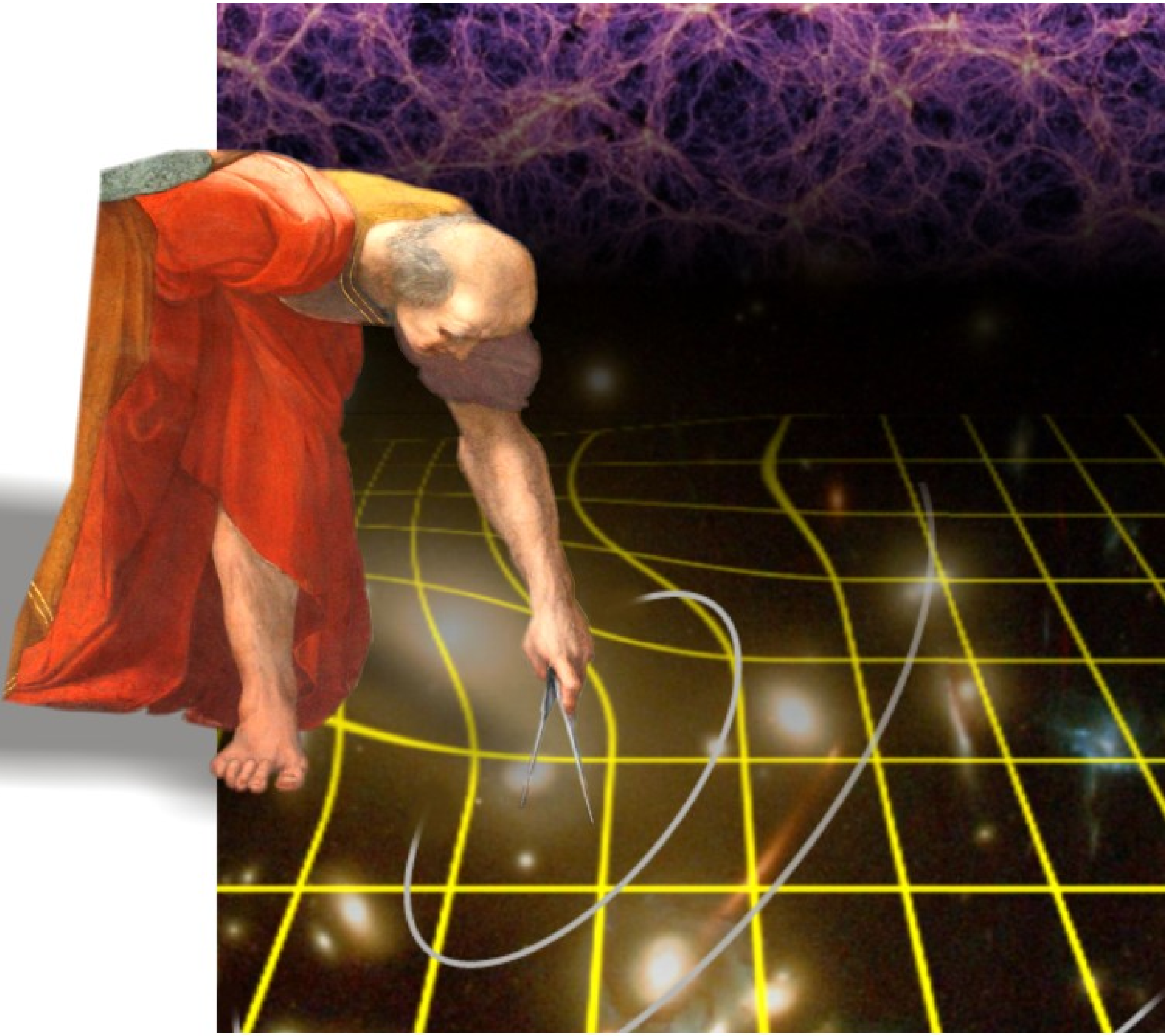


Dark Energy with the Euclid Space Mission

Y. Mellier
On behalf of the Euclid Consortium

http://www.euclid-ec.org

Objective of the Euclid Mission

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 systematic residuals</u> to a very high level of accuracy.

Distinguishing effect *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: $f \sim \Omega^{\gamma}$, with $\gamma = 0.55$ for general relativity … if different, then GR not valid

1. Nature of the apparent acceleration
   - 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. Effects of gravity on cosmological scales
   - Probe growth of structure → slices in redshift ,
   - Separately constrain the metrics potentials (Ψ, Φ) as function of both scale and time
   - 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.) set the primary objectives of Euclid → how can Euclid achieve this?

WL and GC: optimal primary probes for Euclid

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

3-D cosmic shear measurements (tomography) over 0<z<2
→ probes distrib. of matter (D+L), expansion history, growth factor , $\Psi+\Phi$.
→ shapes+distance of galaxies: shear amplitude, and bin the universe into slices. For 0<z<2 photo-z sufficient, but with optical and NIR data.

- **Galaxy Clustering (GC), wide field:**

3-D position measurements over 0<z<2
→ probes clustering history of galaxies induced by gravity, Ψ , γ, $H(z)$.
→ 3-D distribution of galaxies, but spectroscopic redshifts needed.

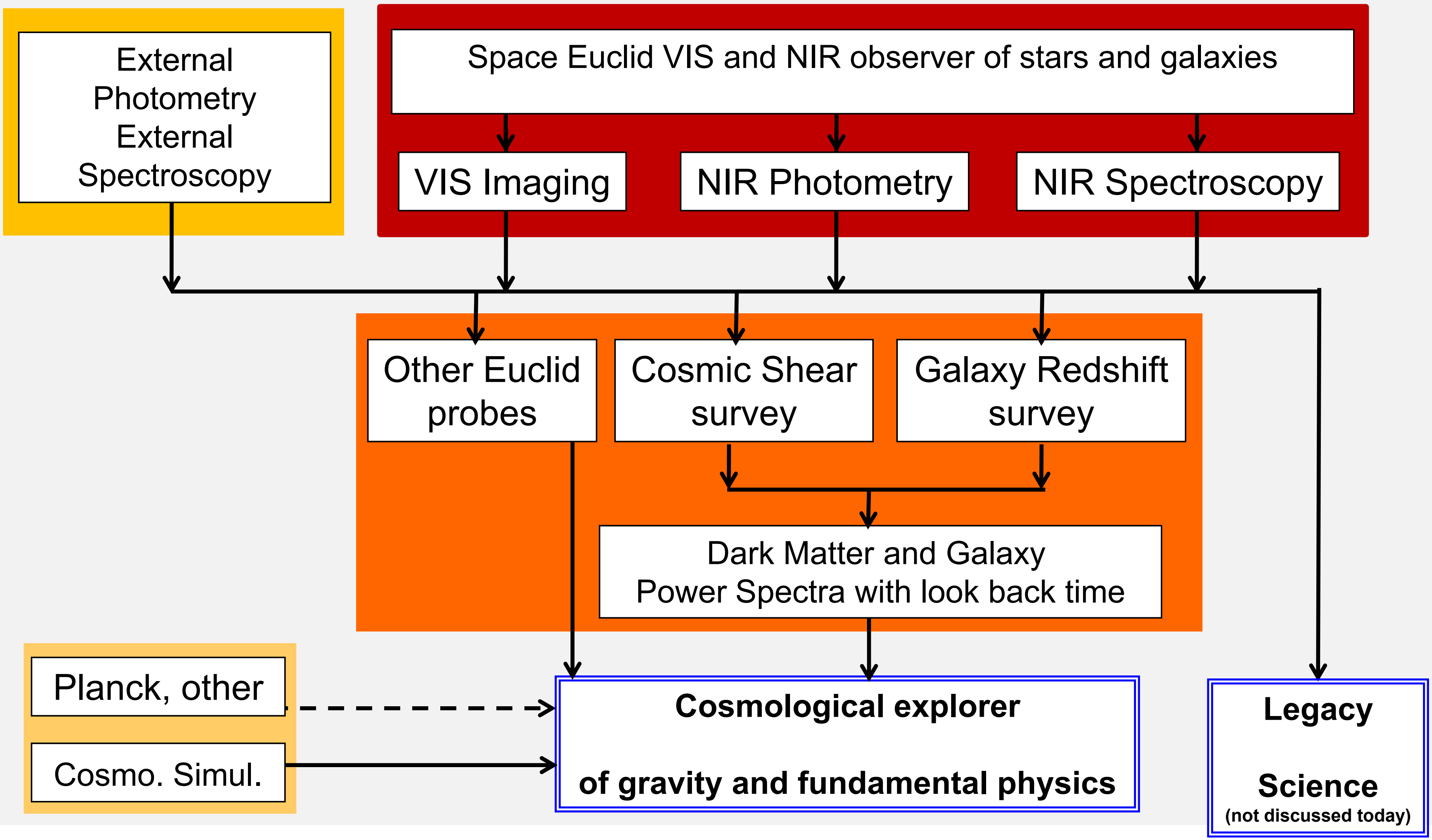
- **GC <u>and</u> WL:**

use the same survey (minimise complexity and cost)
use different data, complementary physical effects → different systematics

- **CG and WL are *P*(*k*,z) explorers:**

both probe power spectra → can be used also to probe dark matter (neutrino) and inflation (non-Gaussianity and f_{NL})

The Euclid Machine



The Euclid Mission: baseline and options

SURVEYS In ~5.5 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 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 x10⁹ galaxies ?				***z* of *n*=5x10⁷ 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 to propose other surveys: SN and/or μ-lens surveys, Milky Way ?

Ref: Euclid RB arXiv:1110.3193

Euclid:optimised for shape measurements

Euclid Consortium

M51

- 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.

Third 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 =
  - 60,000 clusters with a S/N>3 between $0.2<z<2$ (obtained for free).
  - more than 10^4 of these will be 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

  → direct constraints on numerical simulations.

→ 300000 strong galaxy lensing + 5000 giant arcs

  → test of CDM : probe substructure and small scale density profile.

Cluster with Euclid VIS+NIS imaging

Euclid Consortium

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

Telescope and instruments

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 WL systematics

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

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

→ $m < 2\times10^{-3}$: multiplicative bias

$\sigma_{sys}^2 \approx \langle c^2\rangle < 10^{-7}$: additive bias

→ Small PSF
→ Knowledge of the PSF size
→ Knowledge of distortion
→ Stability in time
→ External visible photometry for photo-z accurary: 0.05x(1+z)

- GC and GC systematics

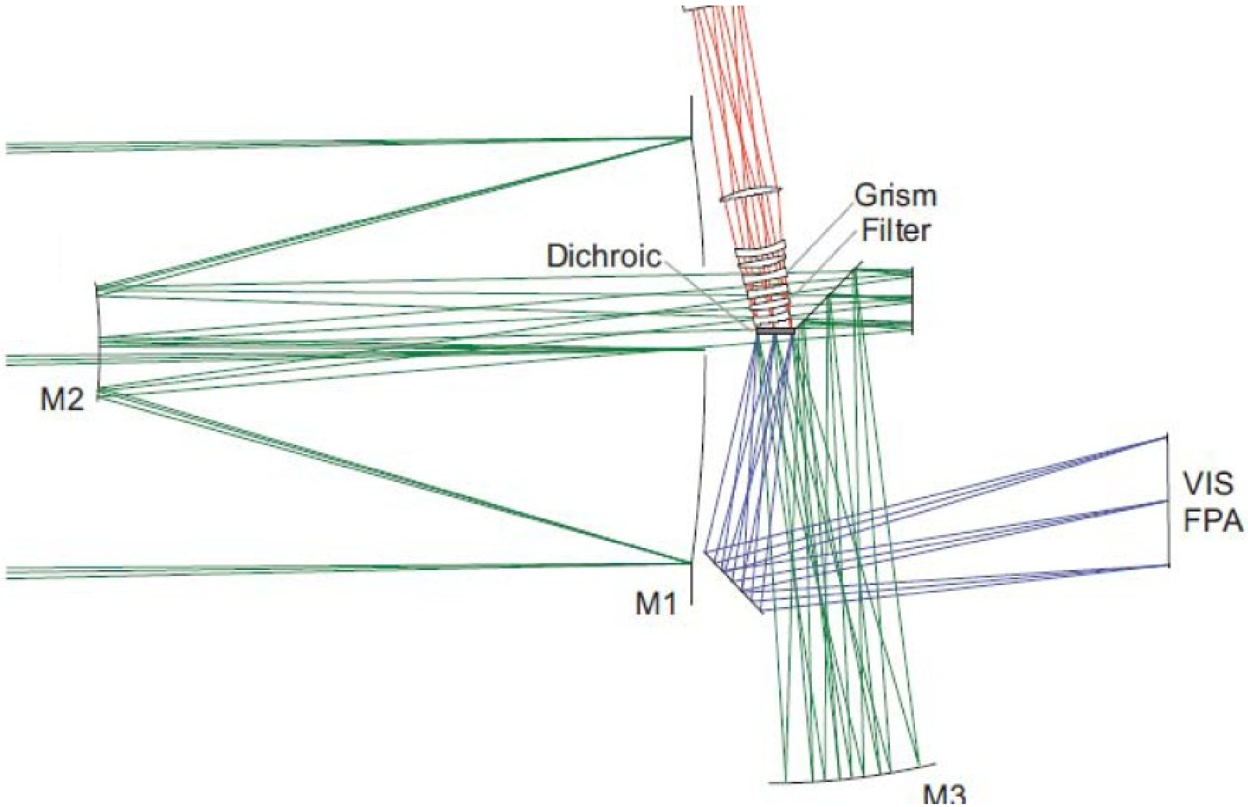
→ Catastrophic z < 10%
→ <z>/(1+z)<0.002
→ Understand selection→Deep field
  - Completeness
  - Purity

Current optical design

Telescope:

1.2 m Korsch , 3 mirror anastigmat, with a 0.45 deg. off-axis field , f=24.5m

Optically corrected and unvignetted FoV : 0.79 x1.16 deg^2

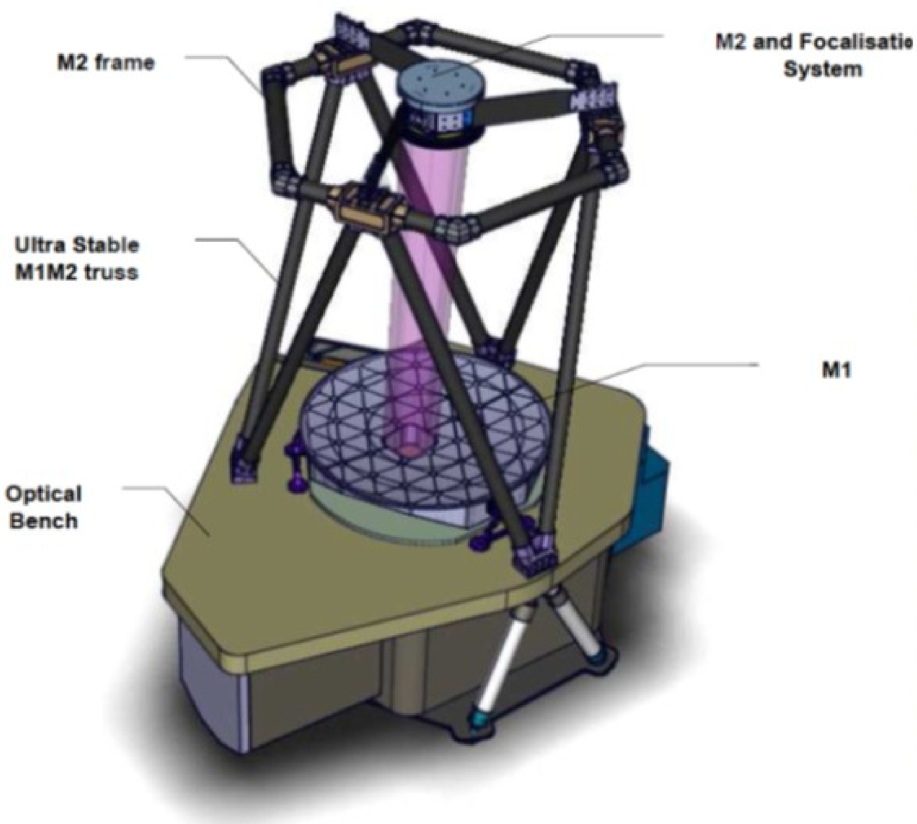


VIS and NISP: share the same FoV (0.54 deg^2)

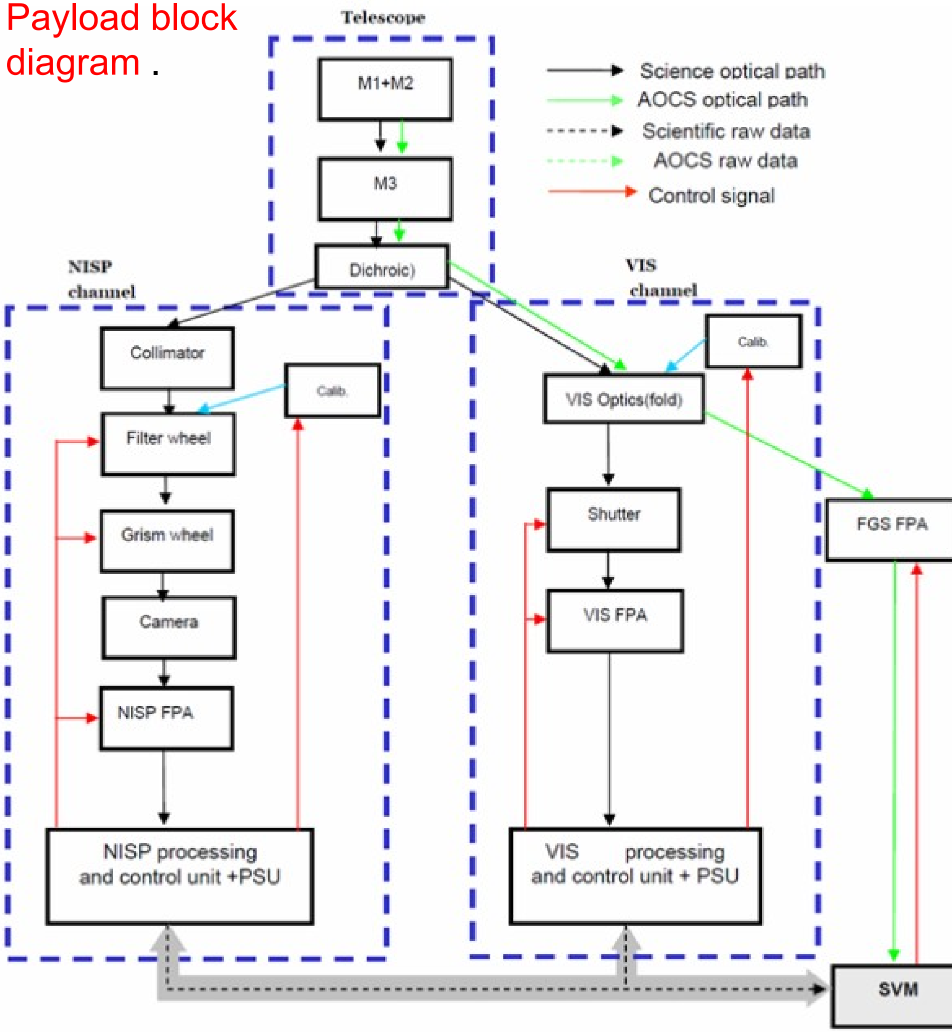
Dichroic beam splitter at exit pupil : Visible and Near Infrared observations in parallel

Telescope and payload module

Typical telescope mechanical architecture



Payload block diagram .



Note: pointing error in spacecraft x,y direction = 25mas over 600 s.

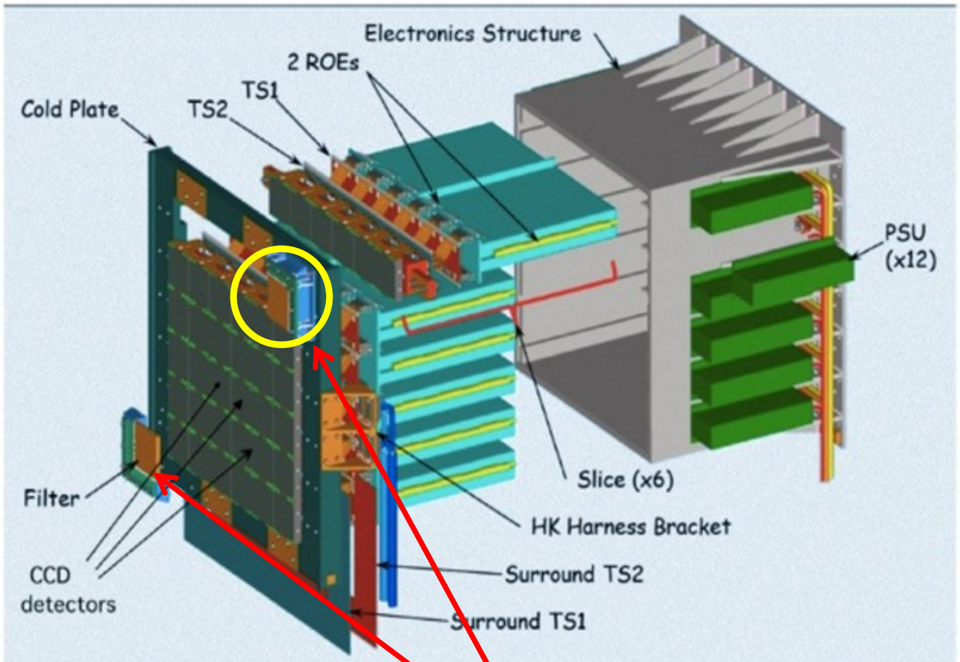
Reference: Laureijs et al 2012. SPIE.

FGS FPA = Fine Guidance Focal Plane Array: mounted on the VIS FPA and part of the Attitude and Control Orbit System (AOCS)

VIS Instrument

Euclid Consortium

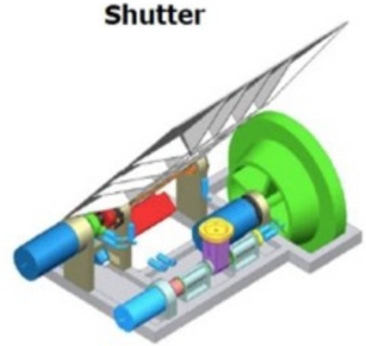
- large area imager – a 'shape measurement machine'
- 36 4kx4k CCDs with 12 micron pixels
- 0.1 arcsec pixels on sky
- bandpass 550-900 nm –
- limiting magnitude for wide survey of magAB = 24.5 for 10σ (extended)
- data volume – 520Gbit/day



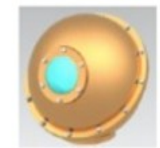
Focal Plane Assembly

Narrow band filters (color gradient) → Suppressed .

Shutter

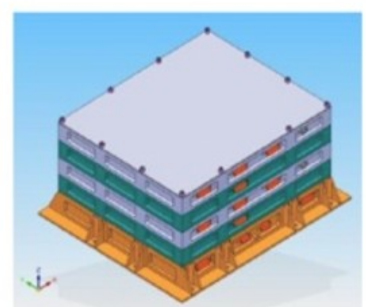


Cal Unit



WARM

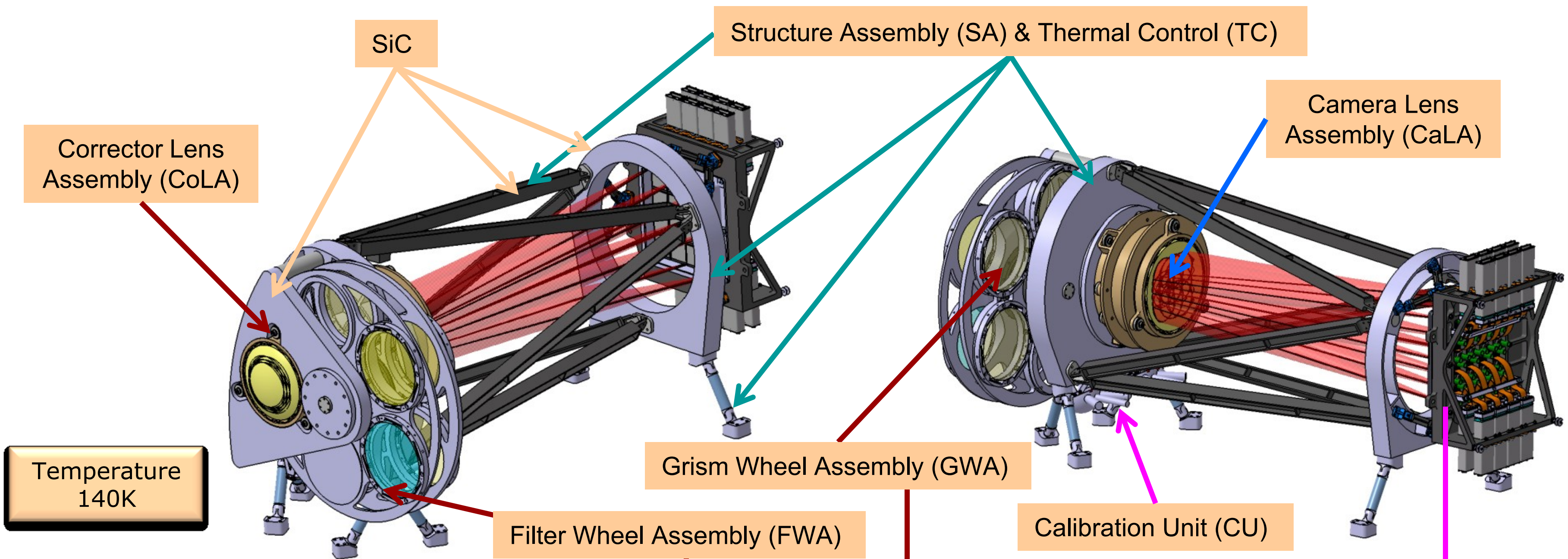
Power and Mechanisms Control Unit



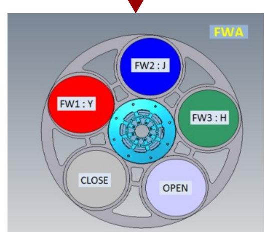
Command and Data Processing Unit

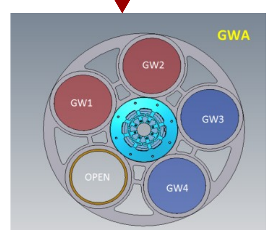
NISP instrument

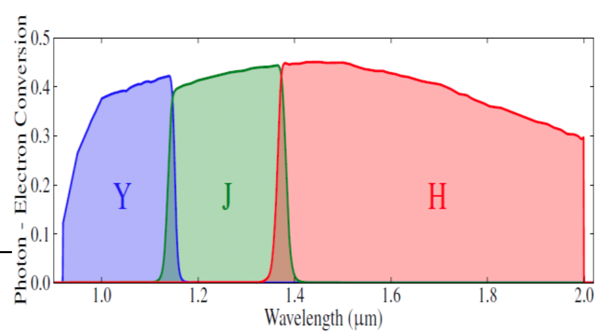
Euclid Consortium

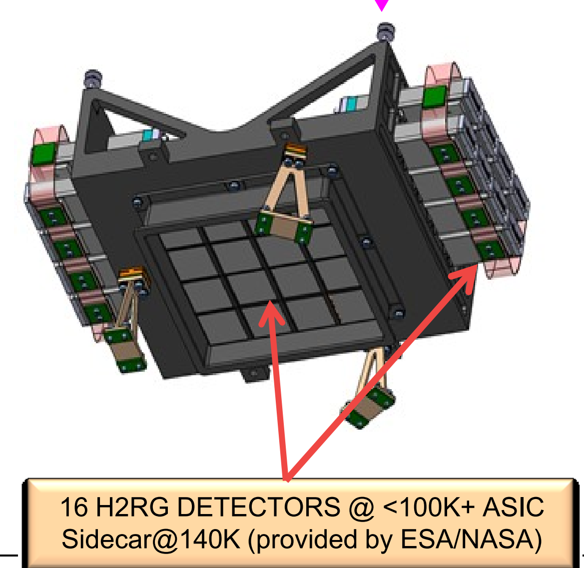


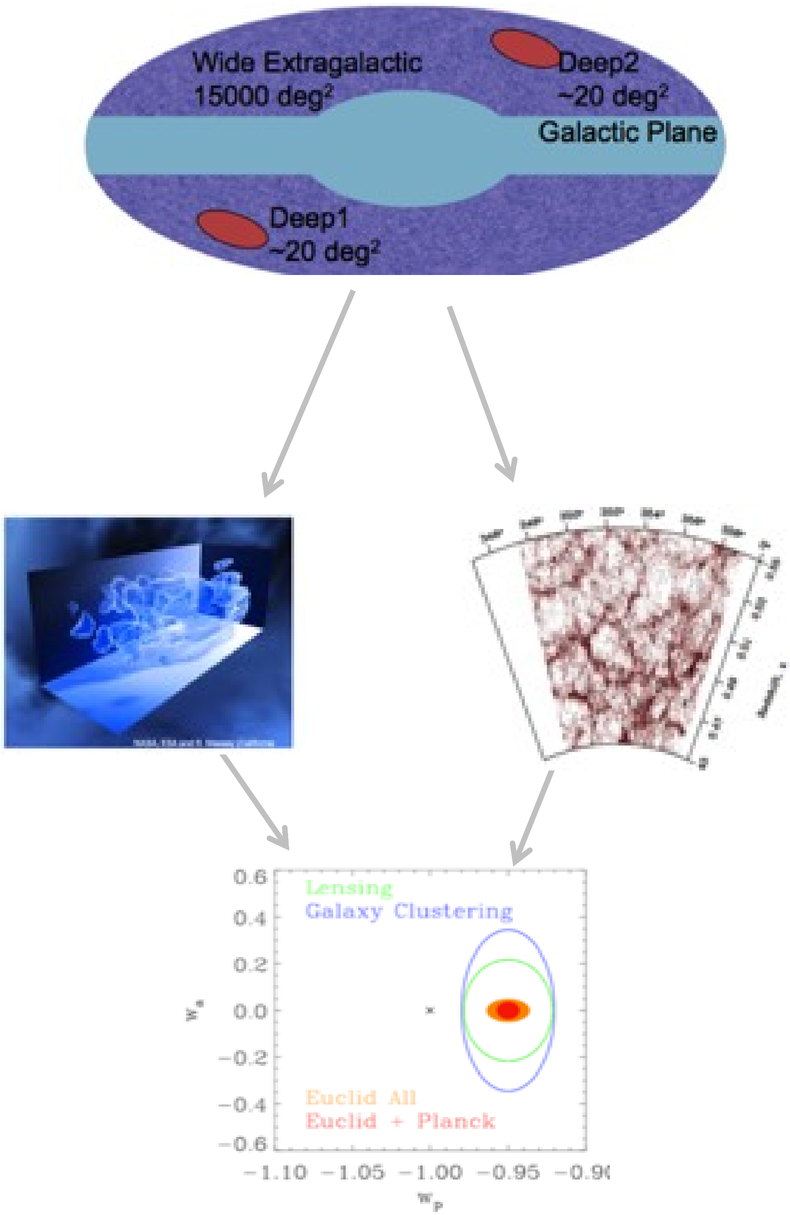
- 16 NIR 2kx2k H2RG detectors
- 0.3 arc/pixel
- 4 Grisms (2 blue, 2 red, rotated by 90 deg.) ;
- 3 NIR filters: Y, J H
- Telemetry= 180 Gbit/day











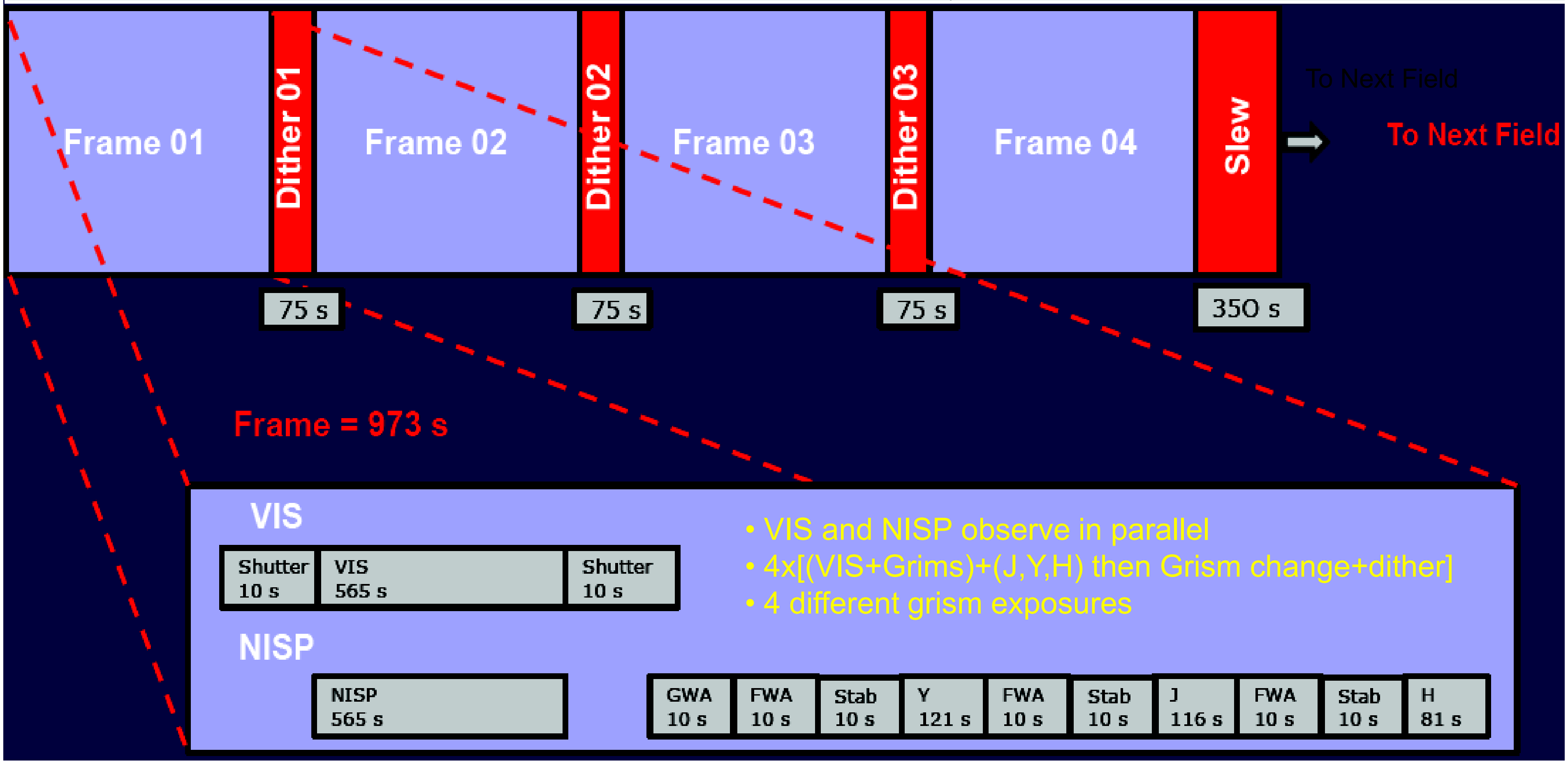
Performances:

- Survey,
- Images,and observables
- Cosmology

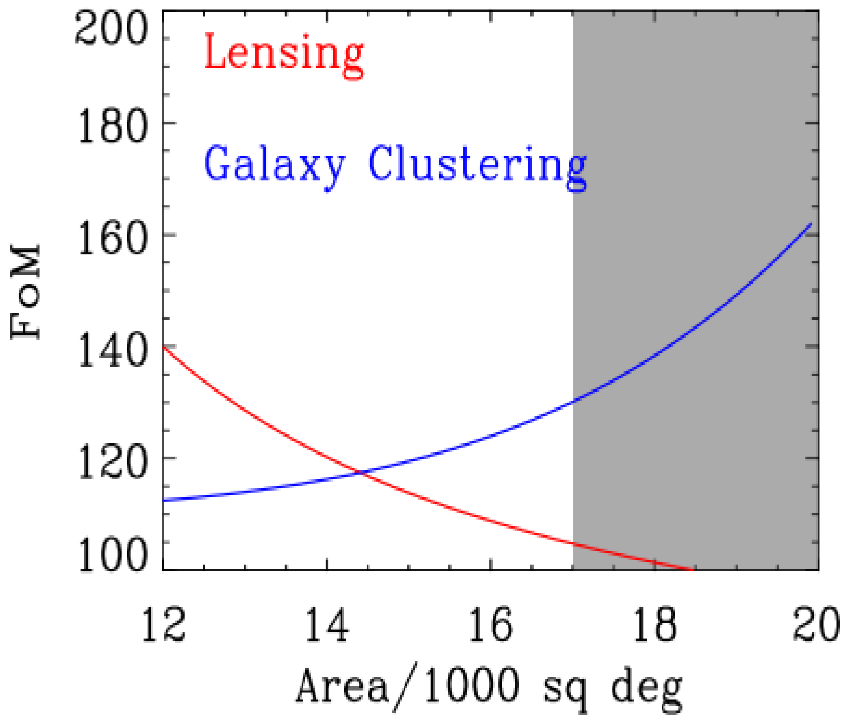
NISP+VIS field observing sequence

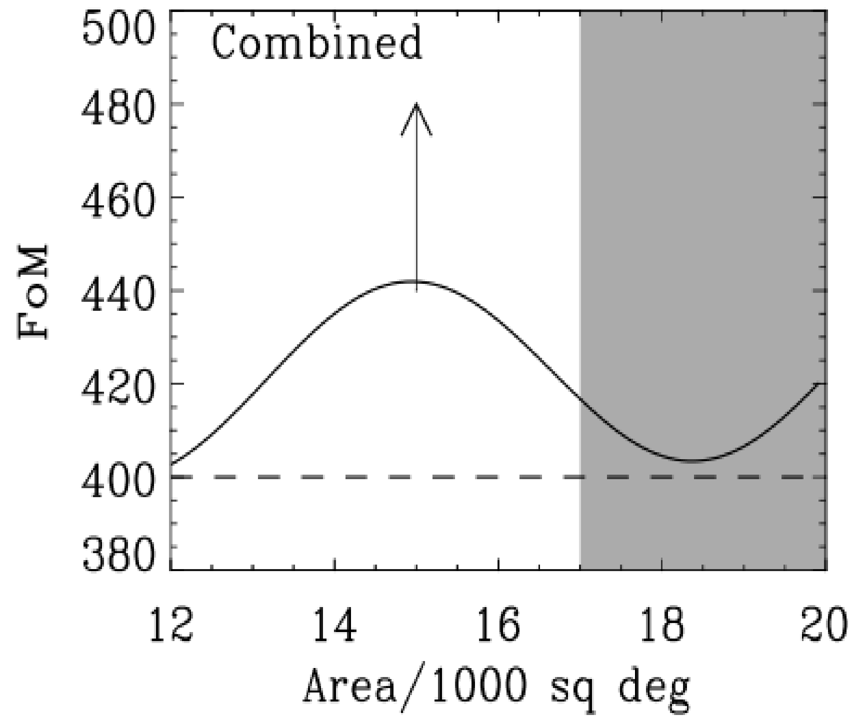
Total Field of View observation time (time between 2 fields observations):

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



Optimal sky coverage for a fixed-length survey

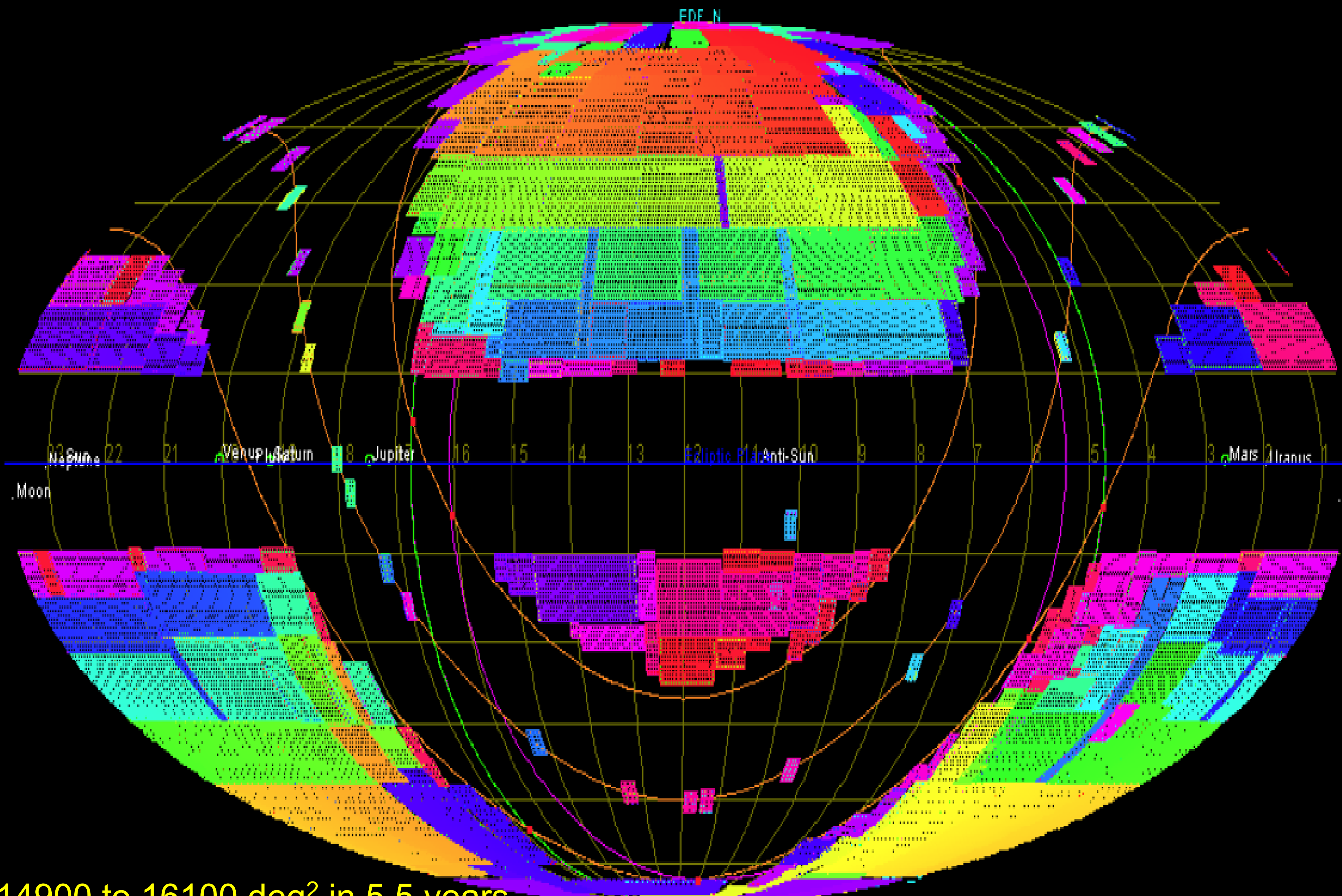




- With 15,000 deg^2 for for GC and WL: optimisation for a fixed time survey.
- Allows Euclid to do WL and GC simultaneously on the same area.

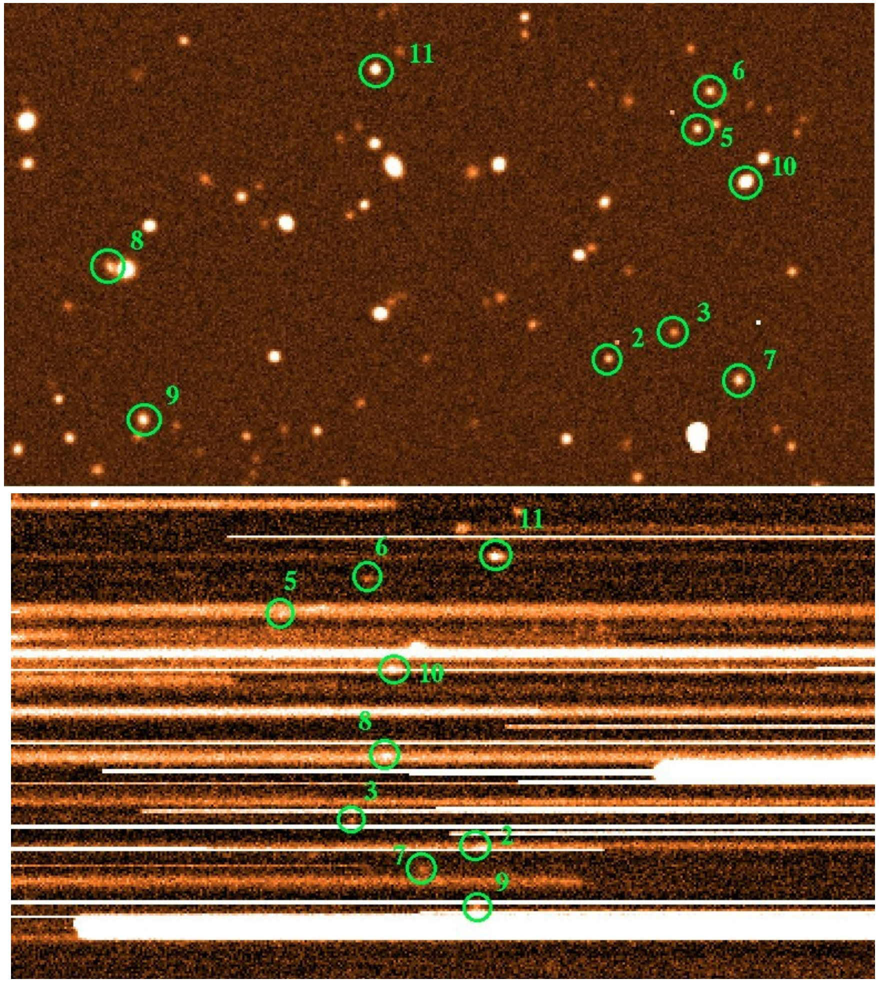
Euclid Deep+Wide surveys feasible in 5.5 years

Euclid Consortium

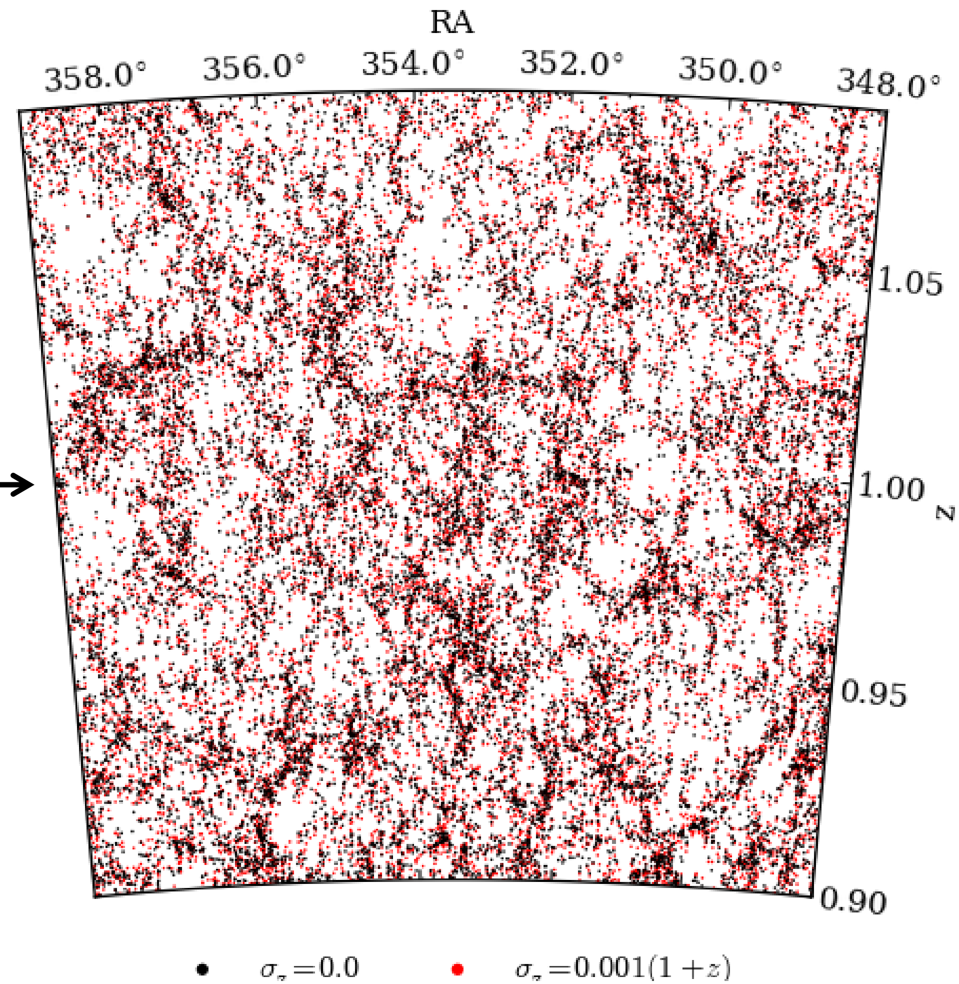


14900 to 16100 deg^2 in 5.5 years

NISP Performance: images/spectra/redshifts



- 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

All performances have been verified at image simulation level

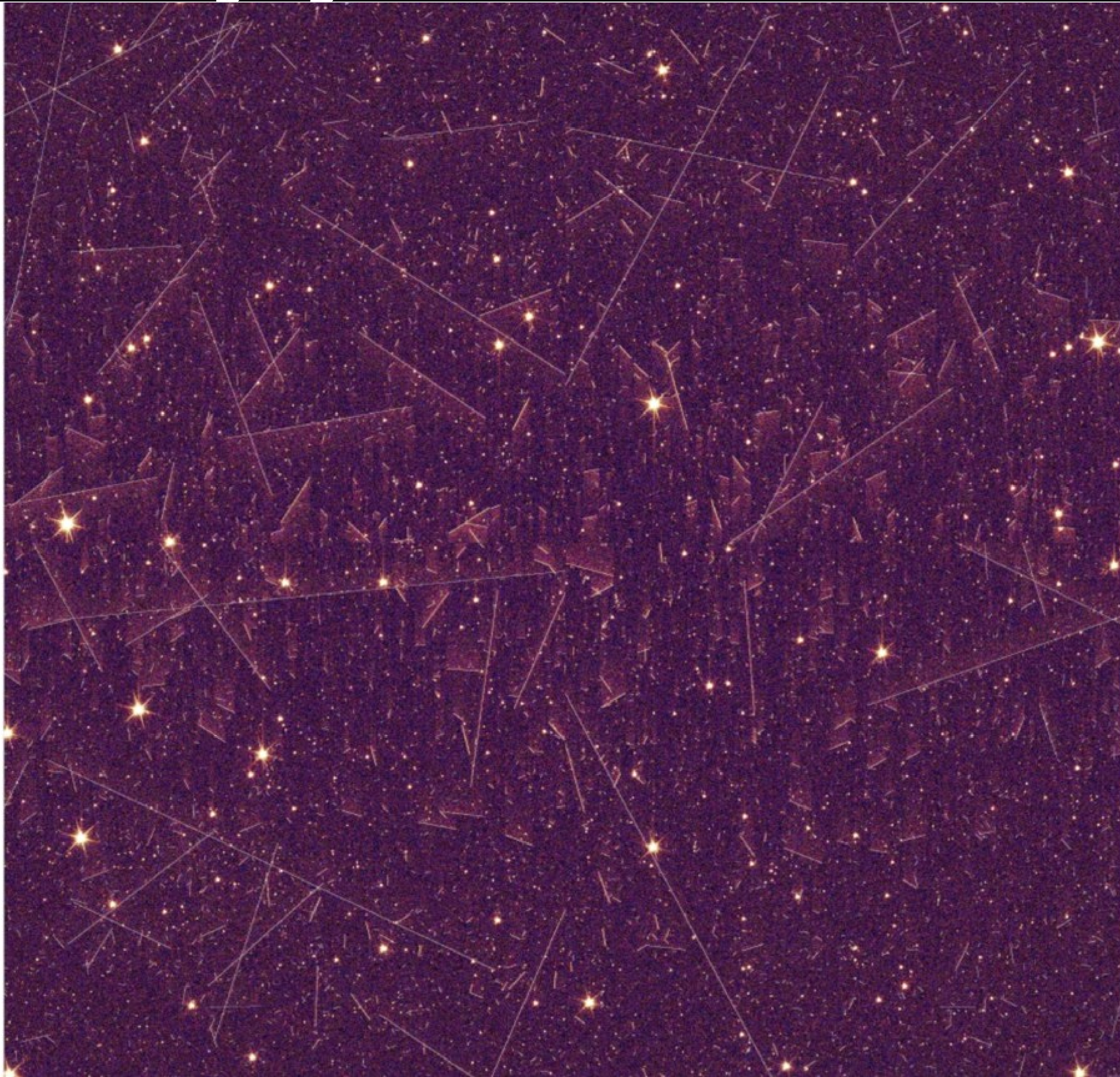
VIS performance:imaging

A 4kx4k view of the Euclid sky

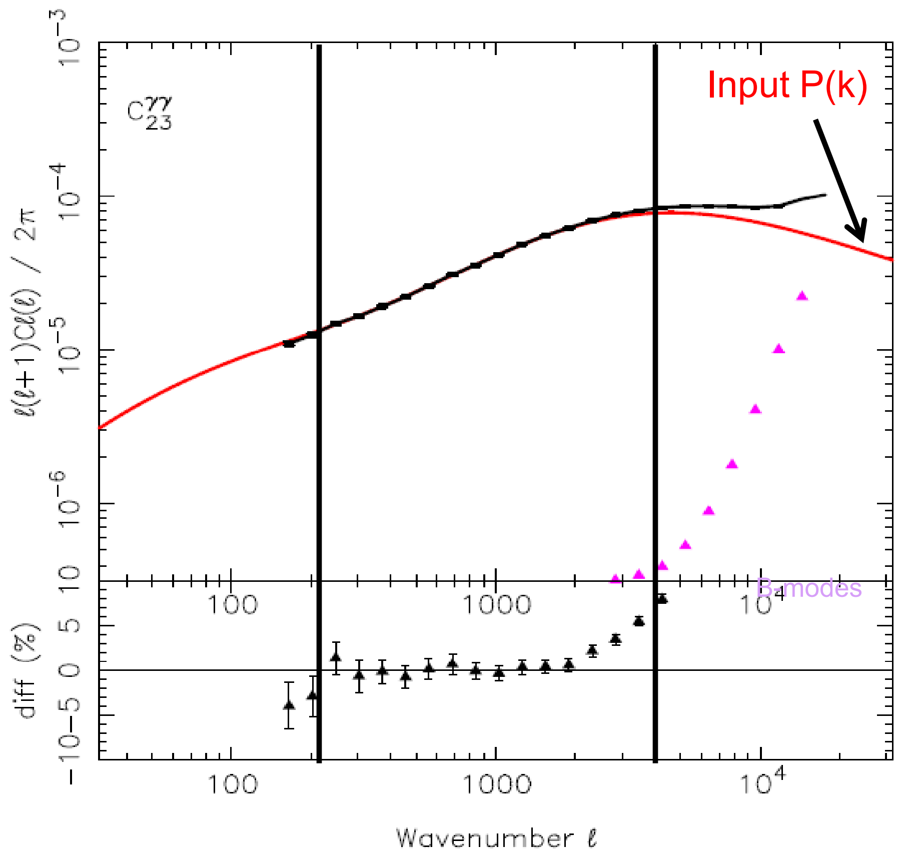
VIS image: cuts made to highlight artefacts

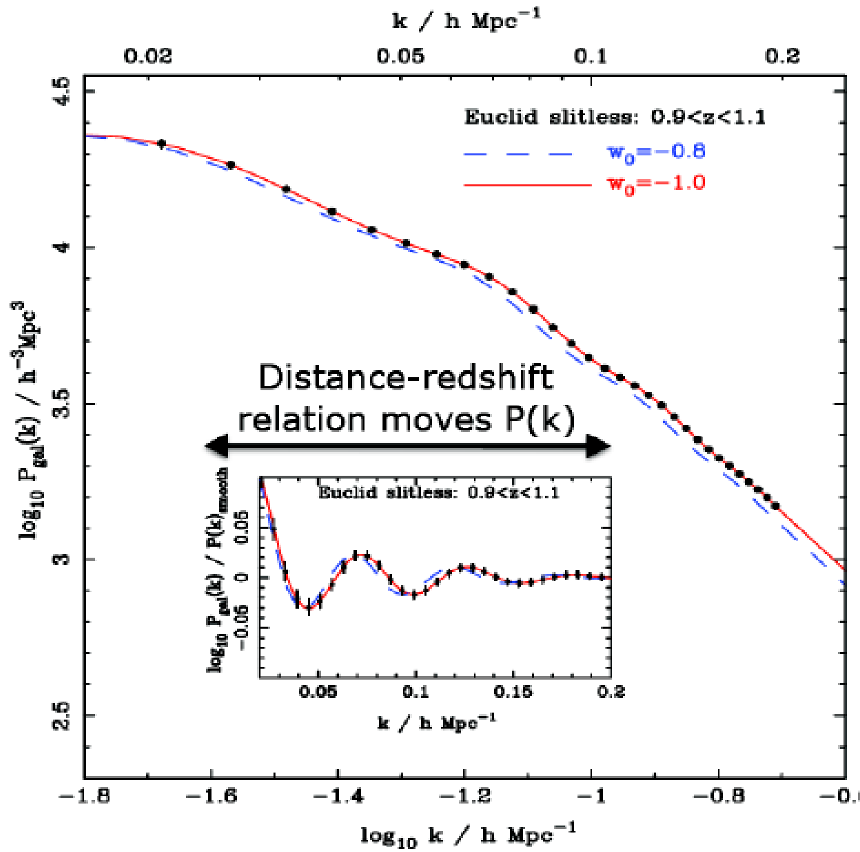
• Charge Transfer Inefficiency (CTI) of CCDs increases due to cosmic rays.
Can be corrected to the required level of accuracy.

• EC analysis: CTI has NO impact on the P(k) and the cosmology core program



Euclid WL GC: DM and GC reconstructed P(k)





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

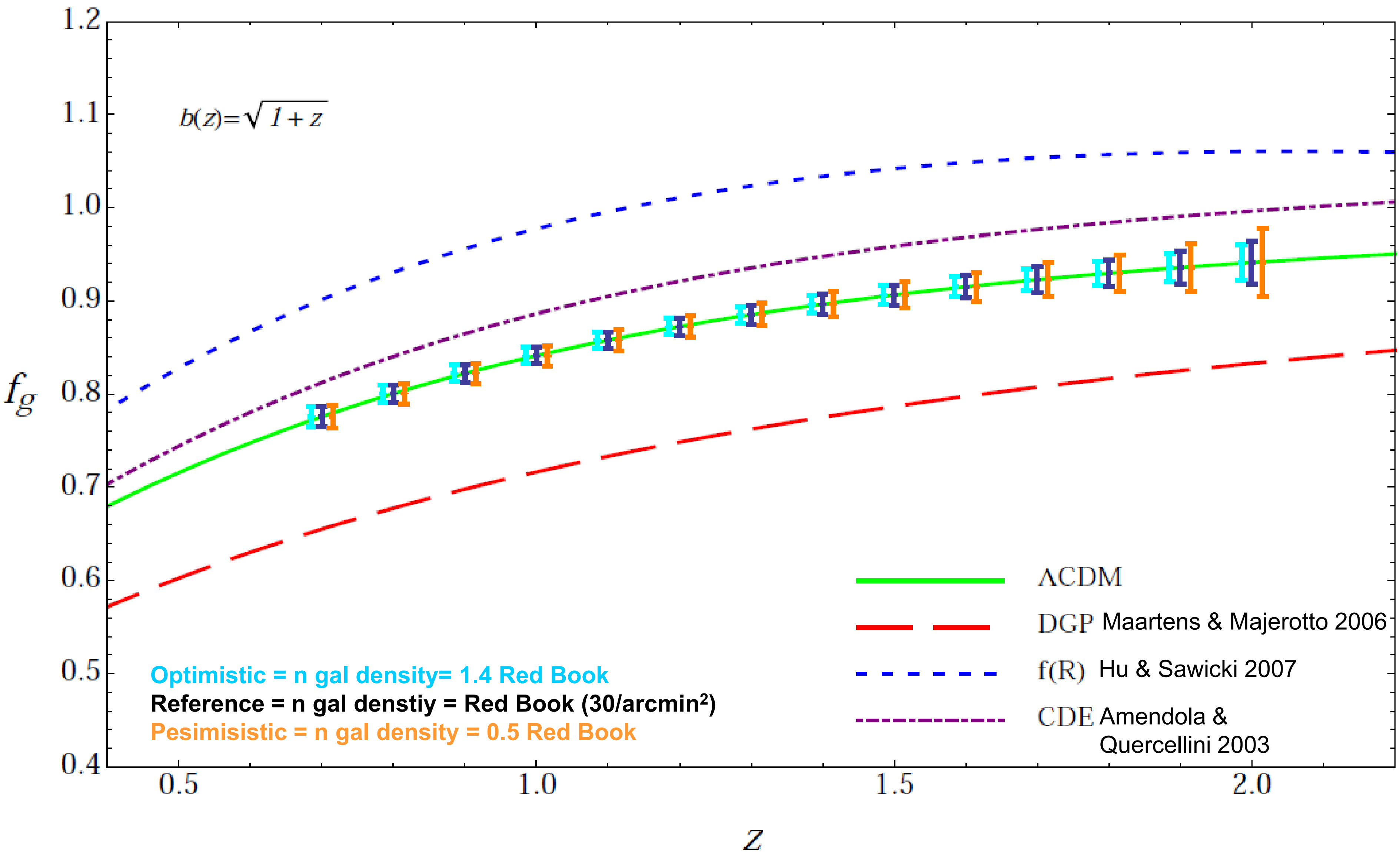
- Percentage difference [*expected* – *measured*] power spectrum: recovered to 1% .

- $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx$ 75x larger than SDSS
- Redshifts 0<*z*<2

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

Ref: Euclid RB arXiv:1110.3193

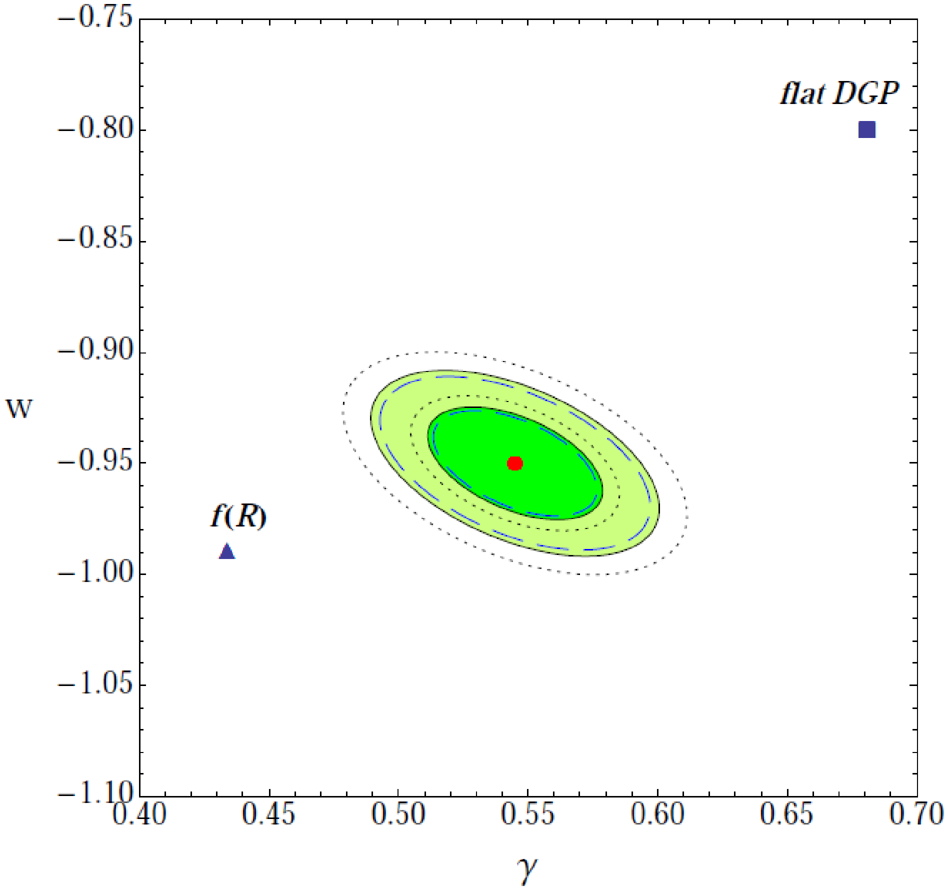
Biasing and Growth rate



Amendola et al arXiv:1206.1225

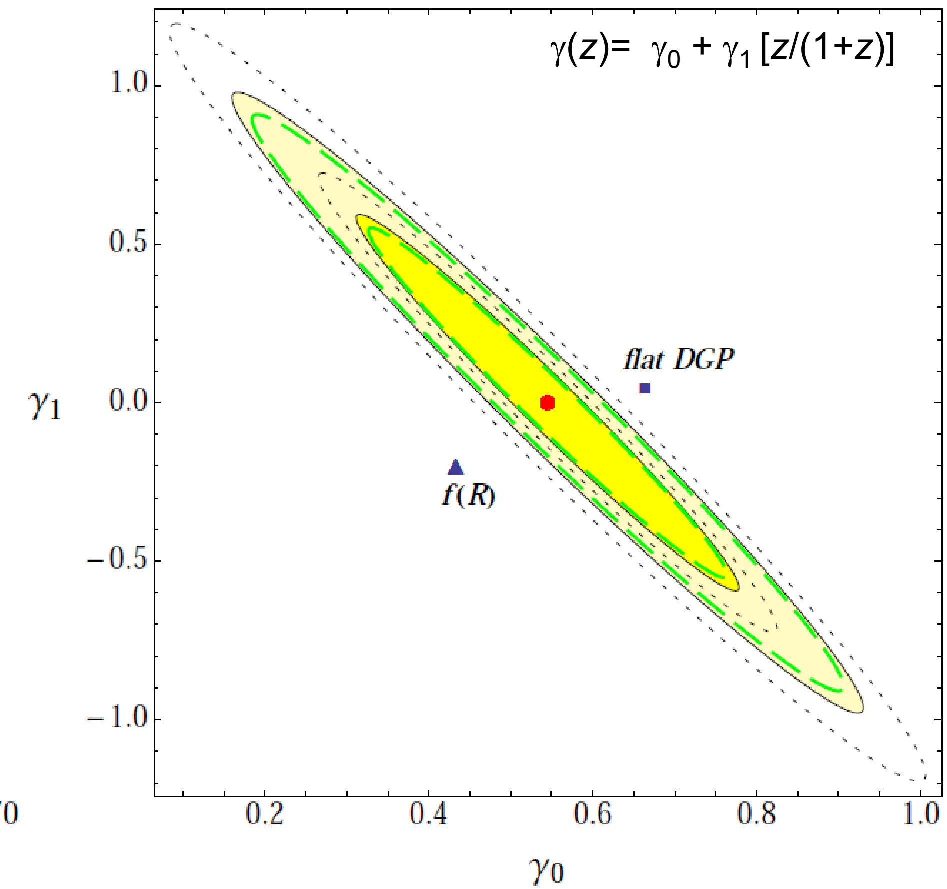
Euclid Cosmo predicted performances

Euclid Consortium



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

Reference = green regions
Optimistic = blue long-dashed ellipses
Pessimistic= black short-dashed ellipses



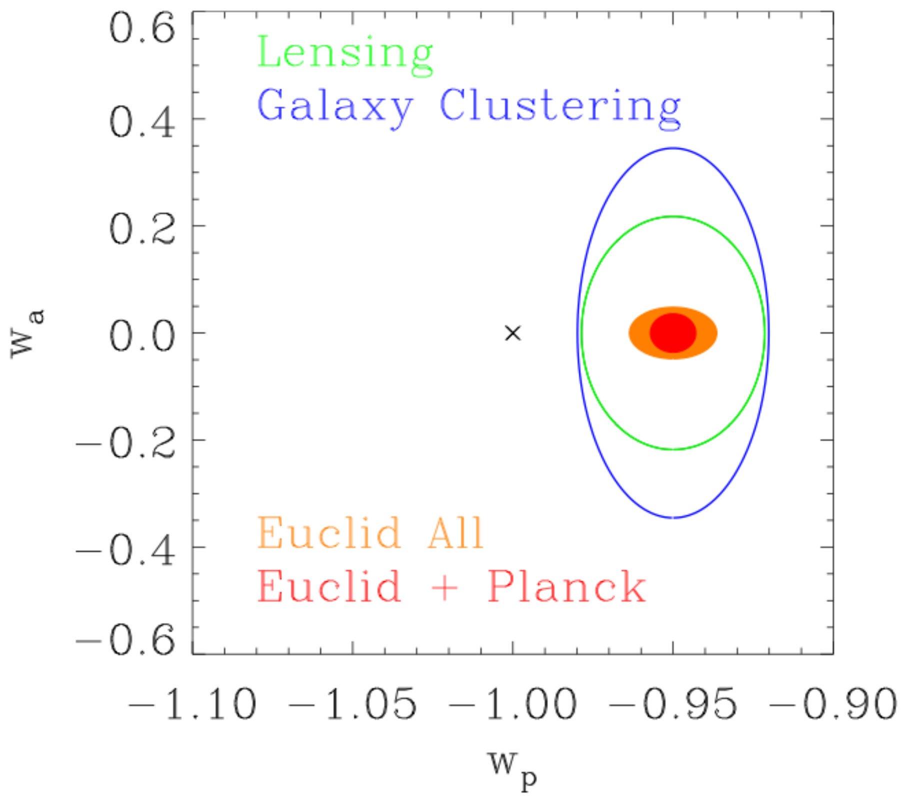
$1-\sigma$, $2-\sigma$ marginalised probability regions for γ_0 and γ_1

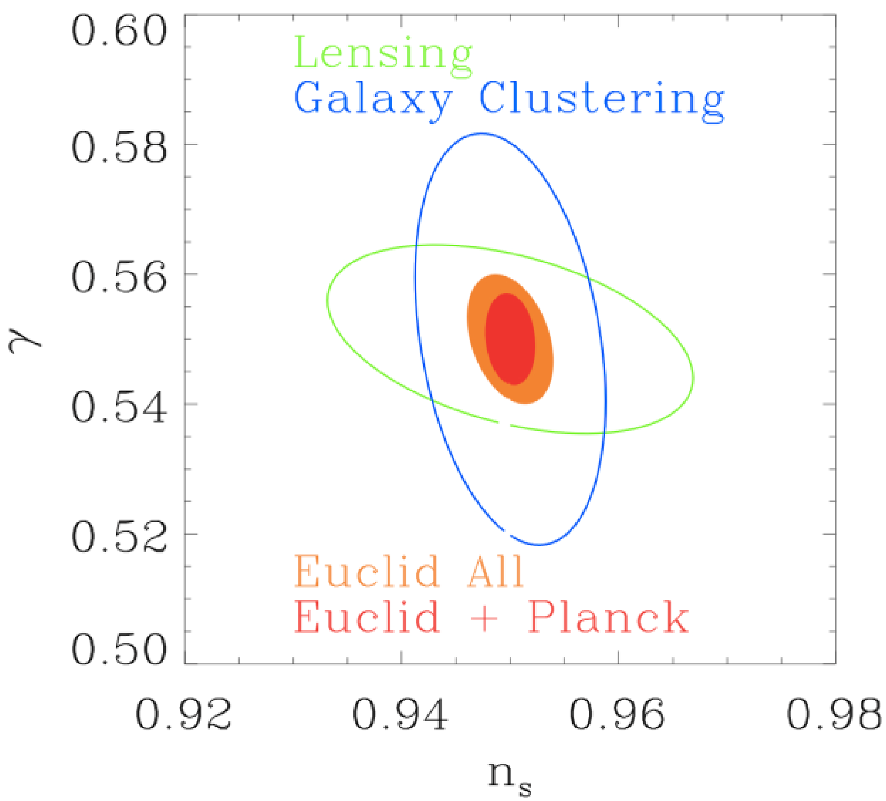
Reference = yellow regions
Optimistic = green long-dashed ellipses
Pessimistic= black doted ellipses

Amendola et al arXiv:1206.1225

Euclid combined: Cosmo predicted performances

Euclid Consortium





DE constraints from Euclid: 68% confidence contours in the (w_p, w_a).

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

Ref: Euclid RB arXiv:1110.3193

Predicted FoM of the Euclid mission

	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
More detailled forecasts given in Amendola et al arXiv:1206.1225

Organisation, data and schedule

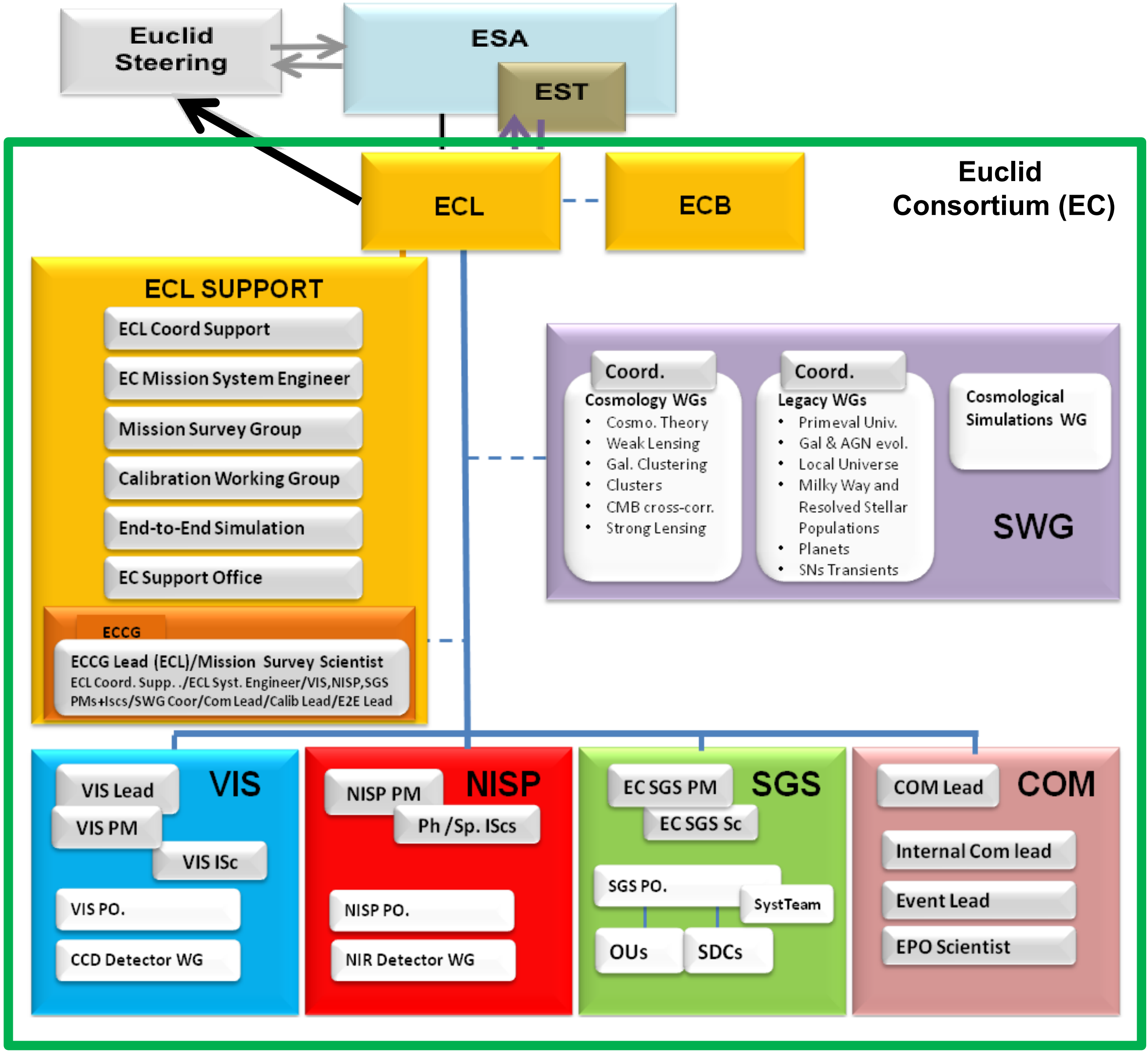
Euclid and Euclid Consortium organisations

EC:~950 members, 110 Labs

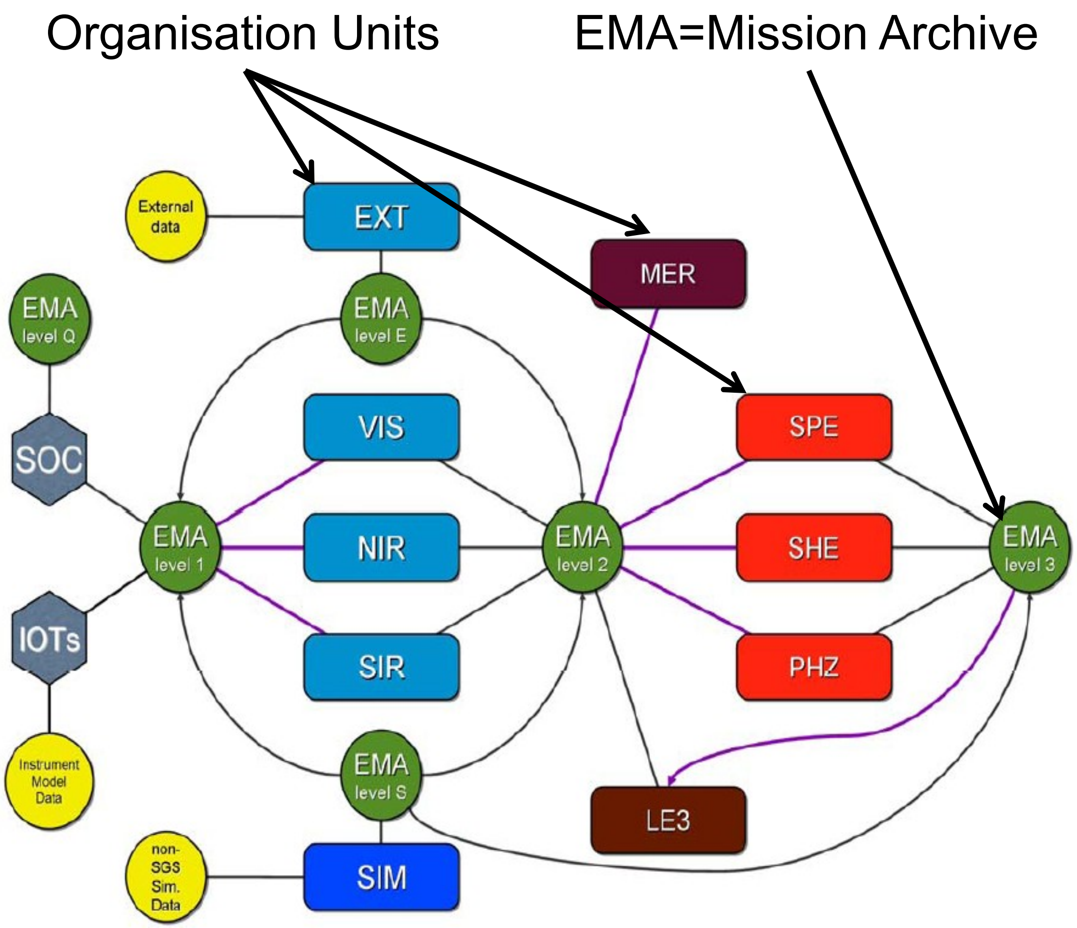
13 European countries

- Austria, Denmark, France, Finland, Germany, Italy, Netherlands, Norway, Portugal, Romania, Spain, Switzerland, UK
  + Contributions from Berkeley labs.
- Discussions: US/NASA , Canada/CSA, Belgium, Sweden

EC contribution: ~1/3 of the cost of the mission



Euclid/SGS flow and Organisation Units



- ESA Mission Operation Center
- ESA Science Operation Center

- Science Working Groups: 13 SWGs
  - Science objectives
  - Requirements: pipeline products
  - Requirements: pipeline performances
  - Verify that the requirements are met
  - Final science analyses

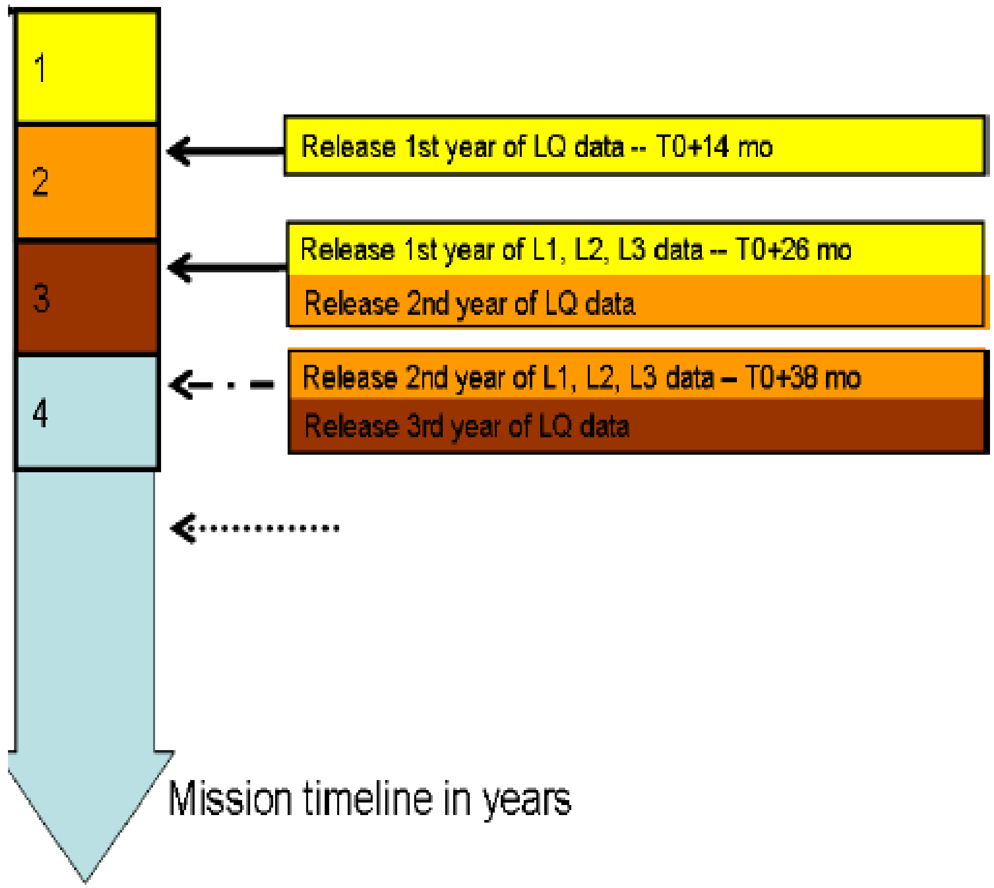
- Organisation Units: 10 OUs
  - Algorithmic definition of the processing
  - Validating the implementation
  - →OU scientists are from the SWGs

- Science Data Centers: 8 SDCs
  - Implementing pipelines
  - Procuring local H/W and S/W resources
  - SDC-DEV: algorithms → robust codes
  - SDC-PROD:integration on local infrastructure, production runs of pipelines

- Total: ~ < 2PB of Euclid data (~ 10^6 images) + >10 PB of external data.
- Data volume for simulations may be much larger

Data products and releases

- First release Level Q (Quick) data release: 14 months after the start of the survey (TBC)
-
- First complete data release: 26 months after the start of the survey
- Then yearly releases



Schedule

- October 4, 2011 : Euclid selected as ESA M2 Cosmic Vision
- Spring 2012 : Completion of the Definition phase (A/B1)

- June 20, 2012 ? : Adoption for the Implem. Phase (B2/C/D/E1)
- July 2012 : ITT release for PLM
- November 2012 : KO PLM contract
- December 2012 : ITT release for SVM
- June 2013 : KO SVM contract

- Q1 2014 : Instrument PDR
- Q3/Q4 2017 : Flight Model delivery

- Q2 2020 : Launch (L)
- <(L+6 months) : Start Routine Phase
- L+7 yrs : End of Nominal Mission
- L+9 yrs : End of Active Archive Phase

Summary: Euclid

- ESA has selected the only space mission designed to understand the origin of the accelerating universe;
- Put Europe at the forefront of one of the most fascinating question of physics/cosmology of the next decades;
- Euclid will provide:
  - tight constraints over the broadest range of DE; MG models ever explored,
  - unrivalled legacy value of VIS/NISP images and spectra;

- Extensive simulations have demonstrated it is feasible;
- Entering in implementation phase. Stay tuned until 2020…