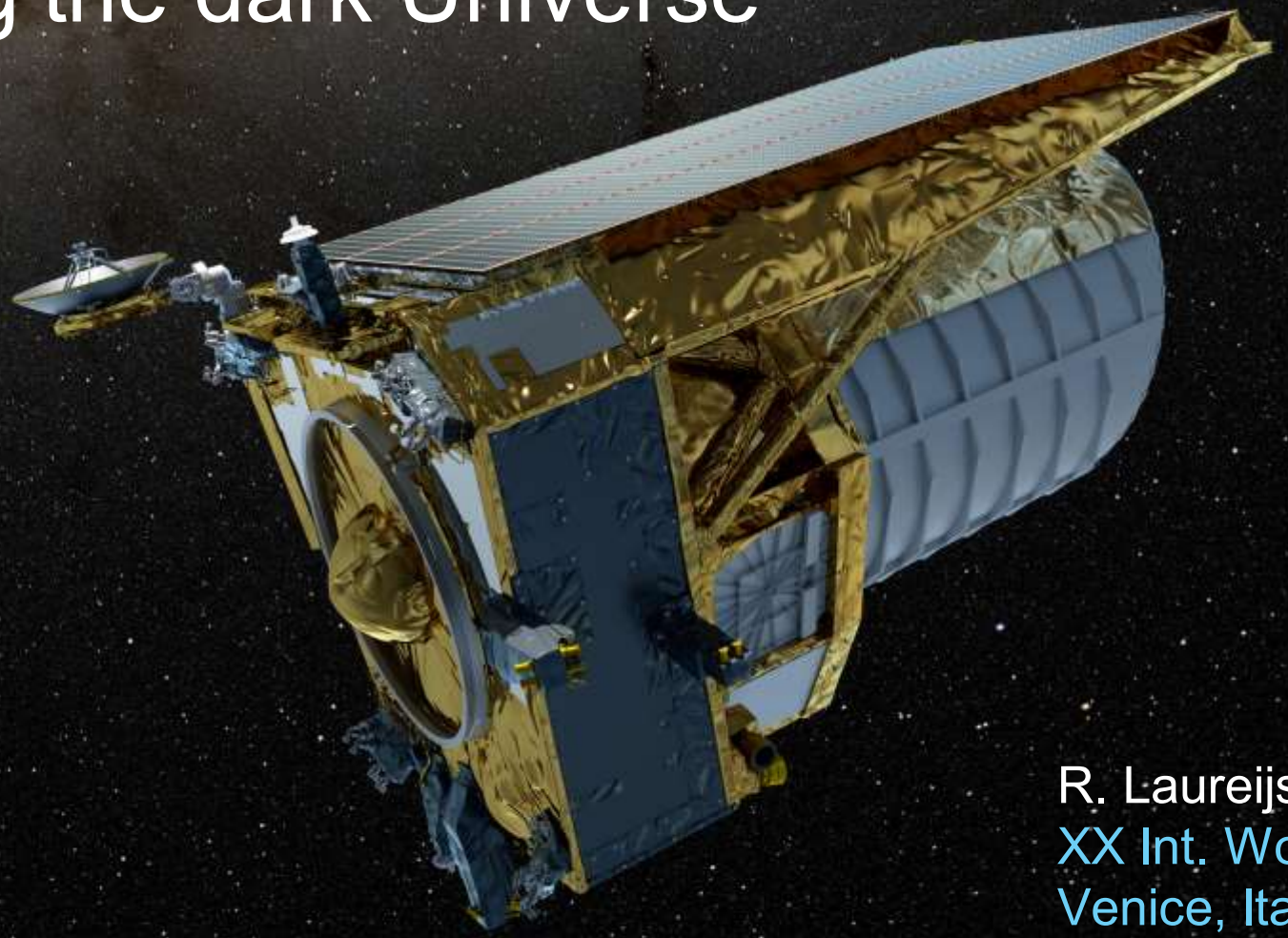
Euclid

exploring the dark Universe



R. Laureijs, ESA

XX Int. Workshop on Neutrino Telescopes

Venice, Italy

Euclid Launch
1 July 2023, 11:18 EDT
to its orbit in Lagrange 2

We were really close to the real thing!

Euclid Prime Science Objectives

Understand the nature of the *apparent acceleration of the Universe* and test *gravity on cosmological scales*

→ Measure the acceleration with a figure of merit of FoM>400

$$w(a) = w_p + w_a(a_p - a) \rightarrow FoM \sim 1/(\Delta w_p \, \Delta w_a) > 400$$

→ Test gravity by measuring the growth index γ for structures with an uncertainty of $\sigma(\gamma) < 0.02$.

For a Lambda Cold Dark Matter Universe:

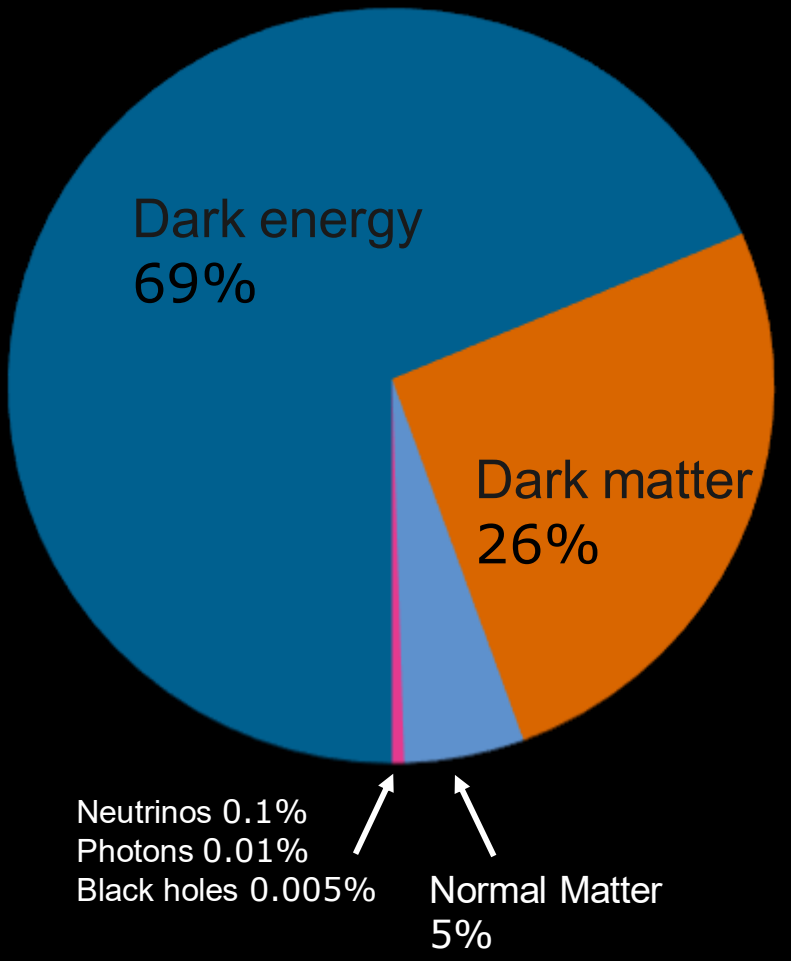
$w_p = -1$

$w_a = 0$

$\gamma = 0.55$

The Euclid results must be decisive onΛCDM!

The high value of FoM allows exploration of alternative theories.



Euclid will observe the evolution of structure in the Universe: obtain a 3D map (position, redshift) of the Universe optimised for two cosmological probes:

<u>Weak Lensing</u> – provides the total matter distribution

requires photo-z (griz+VIS+YJH) + morphometry of ~30 gal/arcmin2

<u>Galaxy Clustering</u> – provides the distribution of galaxies, the luminous matter

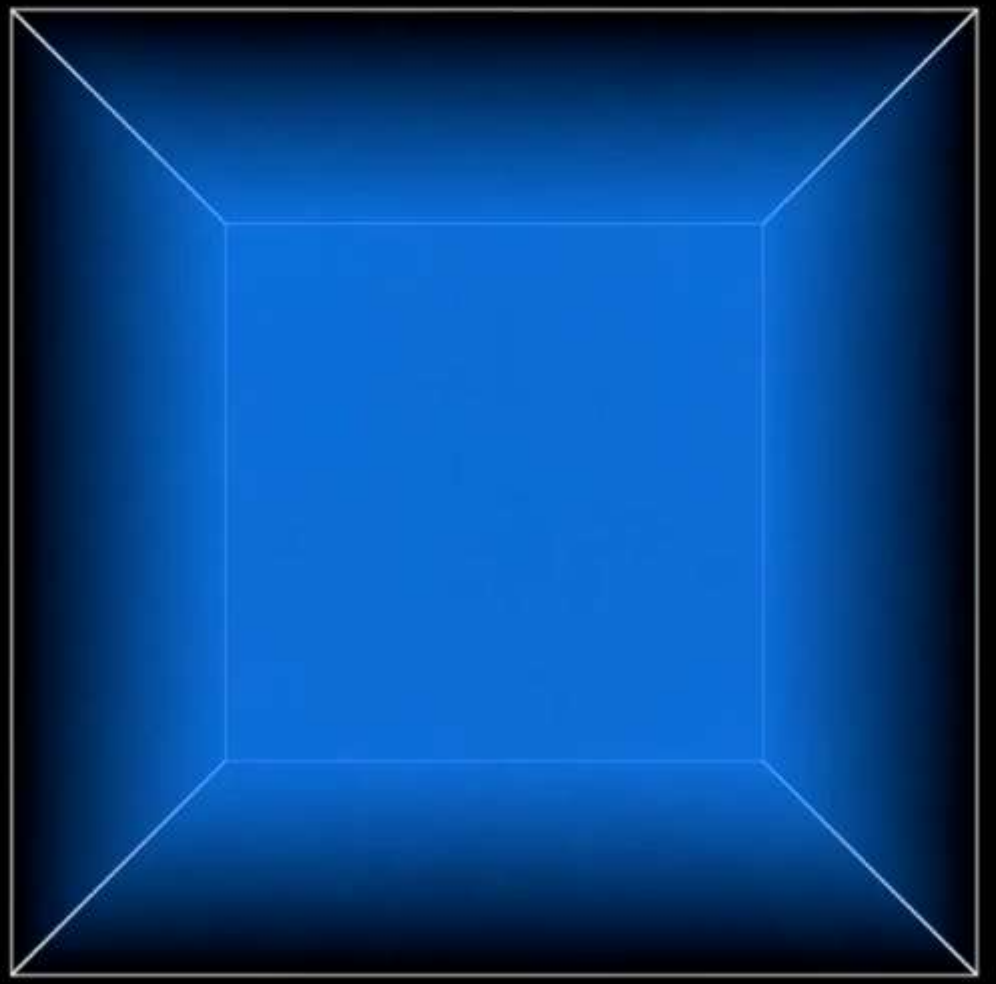
requires slitless spectroscopy dz/(z+1) ~0.001 of ~1700 gal/deg2

with 0.9 < z < 1.8

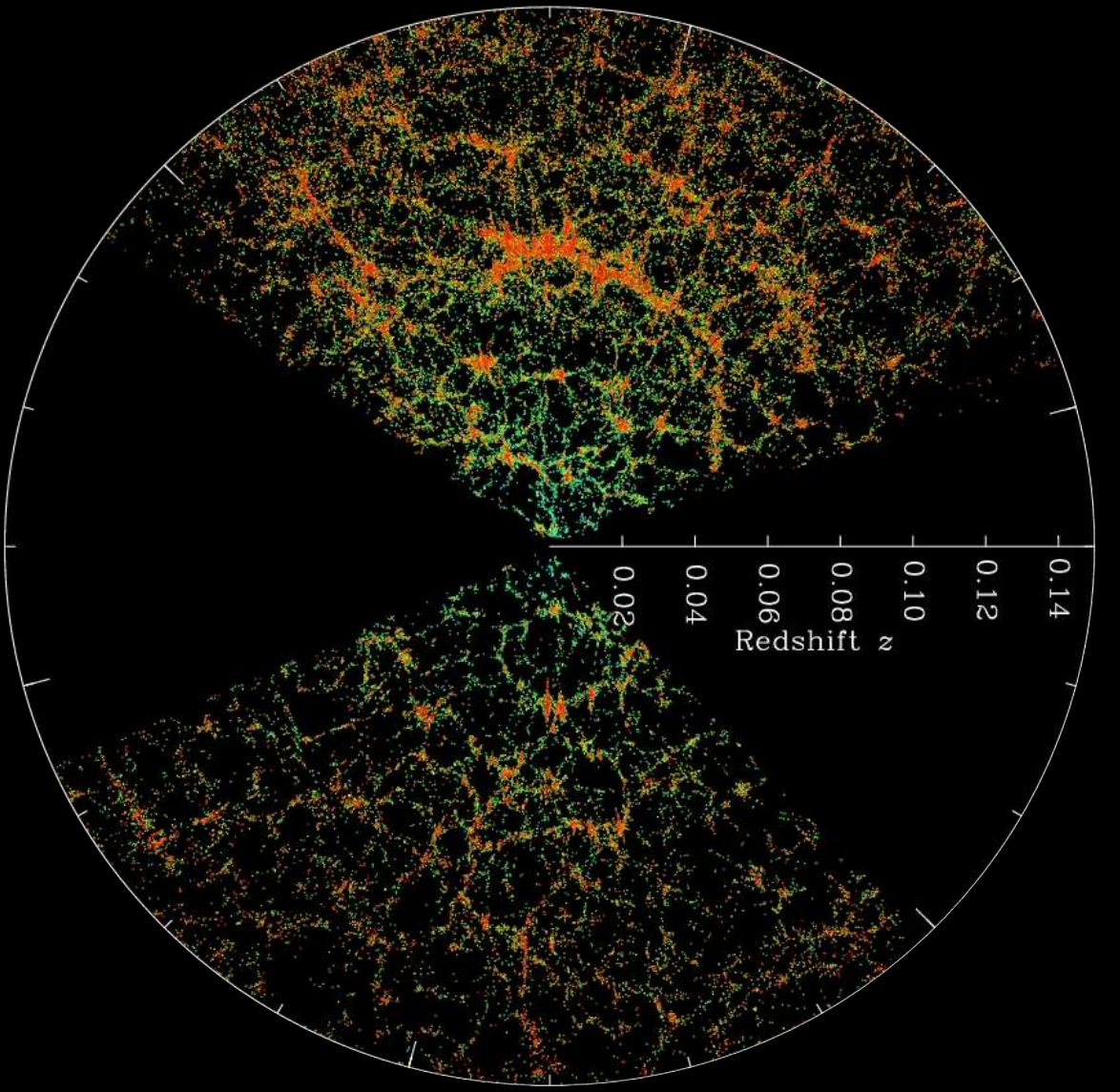
Out to a redshift of 2, or 10 billions years evolution,

For a sky area of ~15,000 deg2

Evolution of gas density from Big Bang to present day

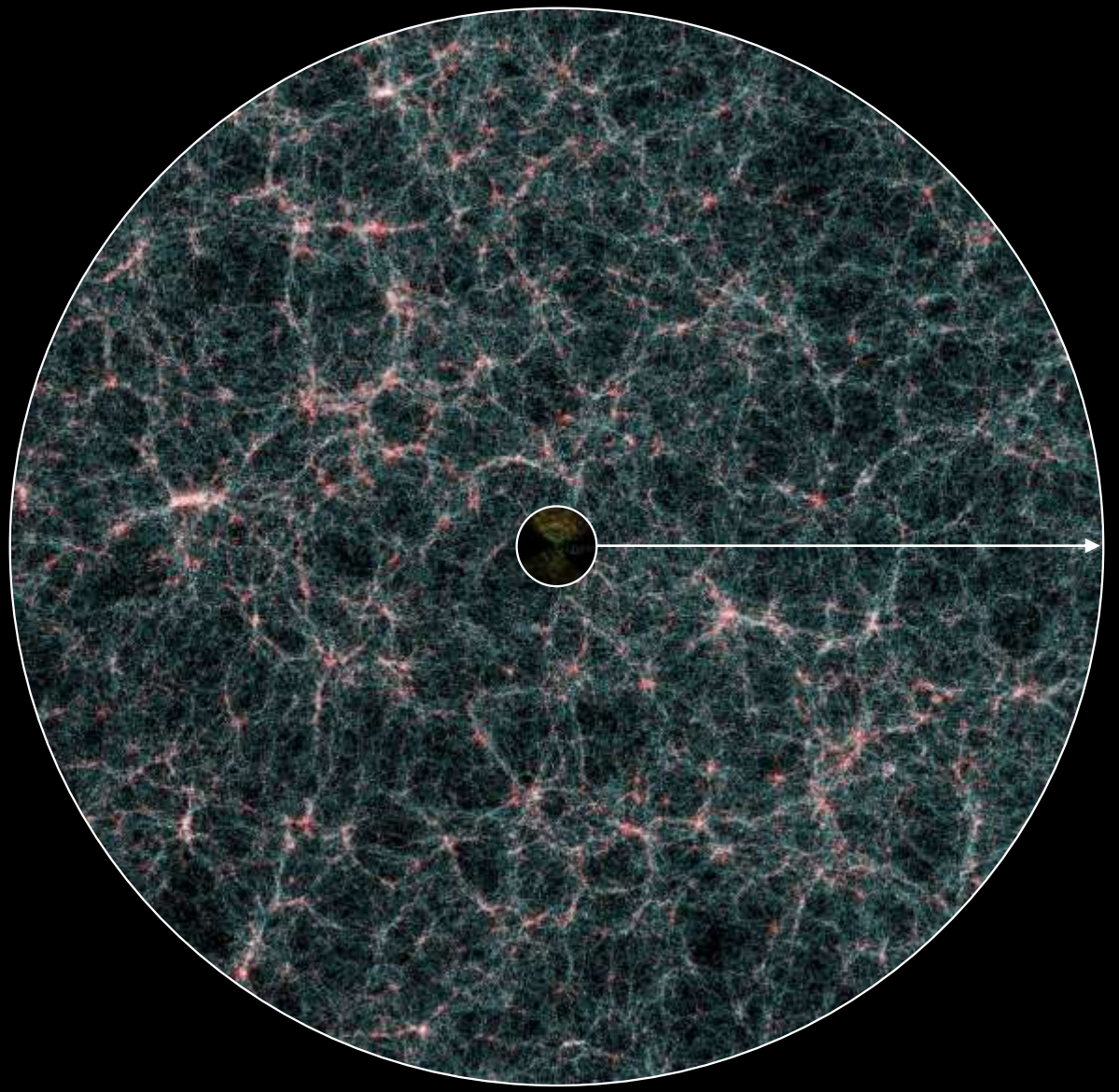


Mapping the cosmic web with redshift surveys



Simulation of the evolution of cosmic structure over lifetime of the universe / B Villasenor, UCSC

Sloan Digital Sky Survey galaxy map / M Blanton, SDSS



Euclid will survey galaxies out to redshift = 2,
3.3 billion years after the Big Bang

Euclid Consortium Flagship Simulation

Euclid will survey billions of galaxies in the universe over the past 10 billion years

Their positions, distances, & apparent shapes will map the distribution of Dark and Normal (baryonic) Matter

The evolution of structure will measure the accelerated expansion of the universe due to Dark Energy → w

The growth of structure will also test our understanding of gravity acting on cosmic scales over cosmic time → γ

Neutrino science with Euclid

Euclid Objective:

Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with a 1-sigma accuracy of a few hundredths of an eV

→ $\Delta m_\nu < 0.03$eV

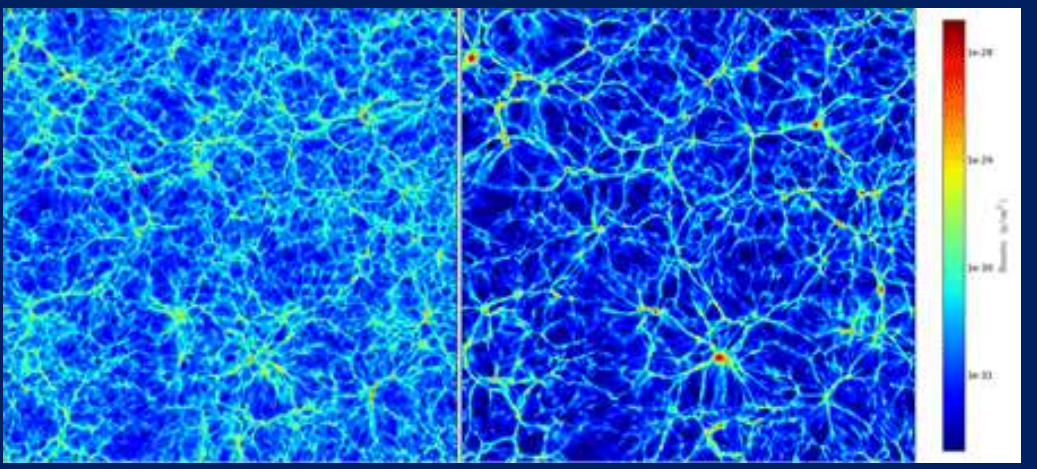
Such a measurement relies on precise modelling of the impact of neutrinos on structure formation, which can be studied with N-body simulations.

Comparison of theoretical predictions against cosmological data:

- Helps understanding the statistical analysis of the cosmological data → check data analysis
- Search for true biases between the two → new physics?

See also Euclid presentations on Wed and Thu, by De Caro and Passalacqua, resp.

M_ν =1.9 eV M_ν = 0



S. Agarwal and H. Feldman

Elements of the Euclid programme

Spacecraft
Prime: Thales Alenia Space Italy
Payload & telescope: Airbus D&S France

ESTRACK ground stations
Cebreros, New Norcia, Malargüe

Mission operations
ESOC, Darmstadt

Falcon 9 launcher
SpaceX

Euclid science team, Euclid consortium,
& wider academic community
Worldwide

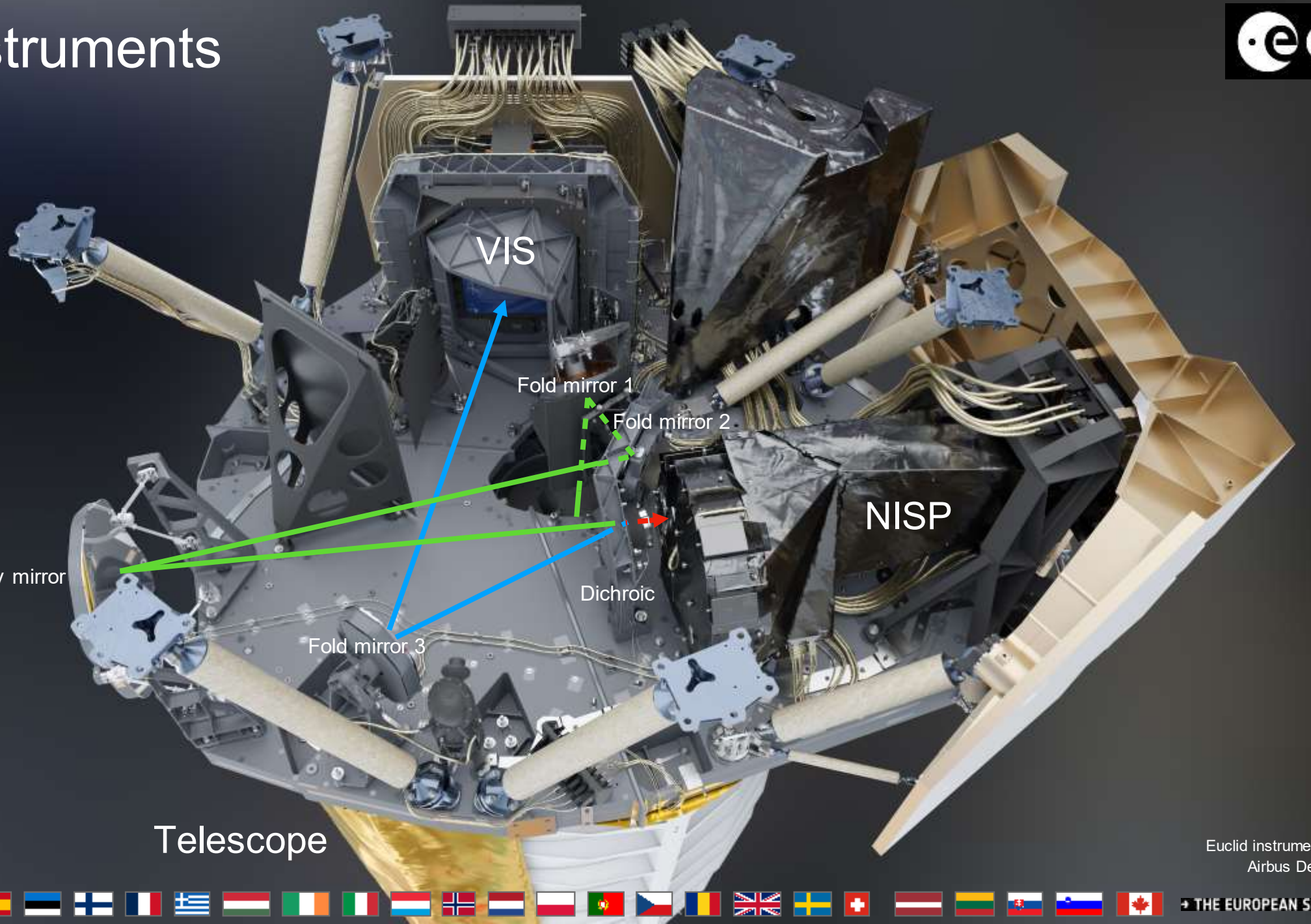
Science operations
ESAC, Villafranca

Telescope

- All silicon carbide 3-mirror Korsch anastigmat, with a 1.2 metre primary diameter
- Wide field-of-view & stable, diffraction-limited imaging

Euclid telescope in testing at CSL Liège
ESA, Airbus Defence & Space

Instruments

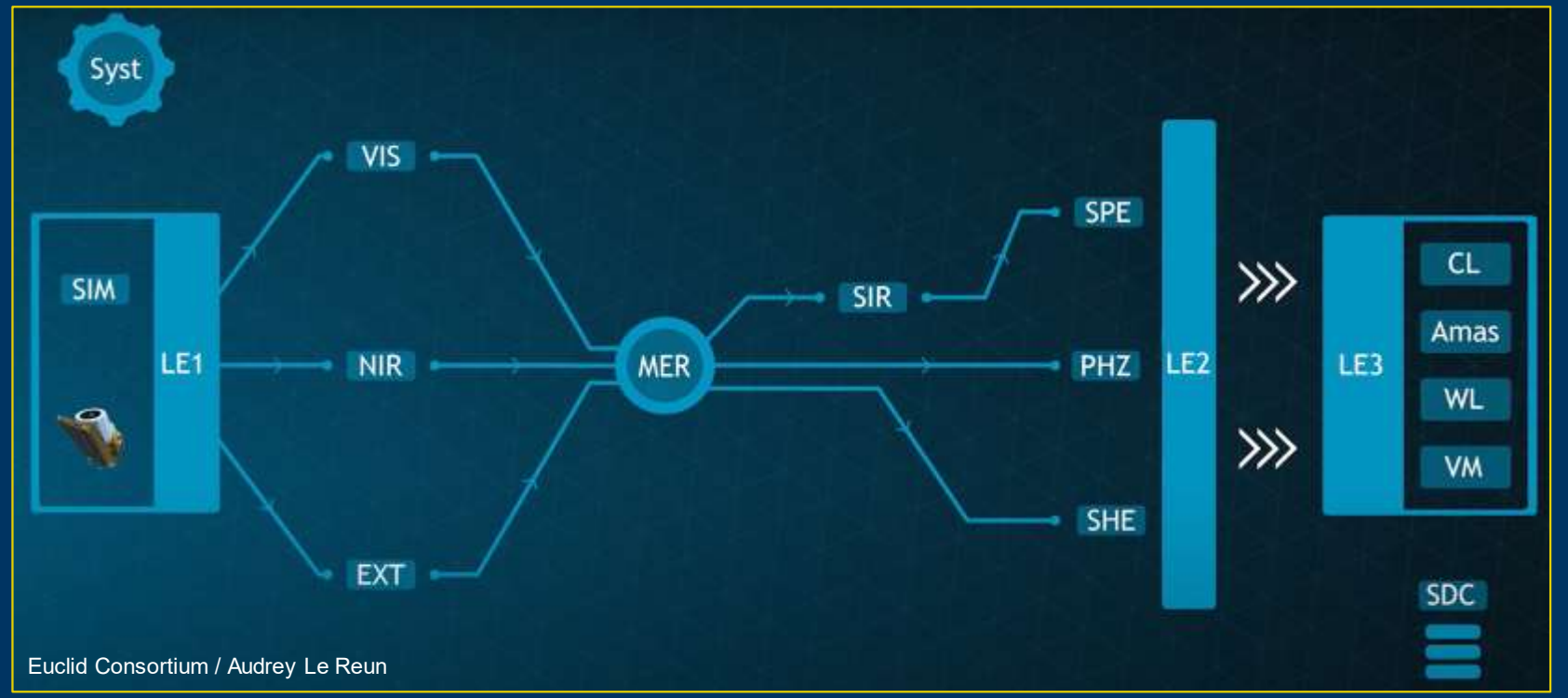


VIS and NISP instruments were provided by the Euclid Consortium

Telescope

Euclid instruments VIS & NISP
Airbus Defence & Space

Science data processing by Euclid Consortium



- Pipeline split across 9 Science Data Centres
- Each processing different patches of sky
- Products returned to central archive at ESAC

- Level 1 – raw data
- Level 2 – calibrated data products
- Level 3 – cosmology science-ready products

Total data volume: 170 petabytes (170,000,000 GB)

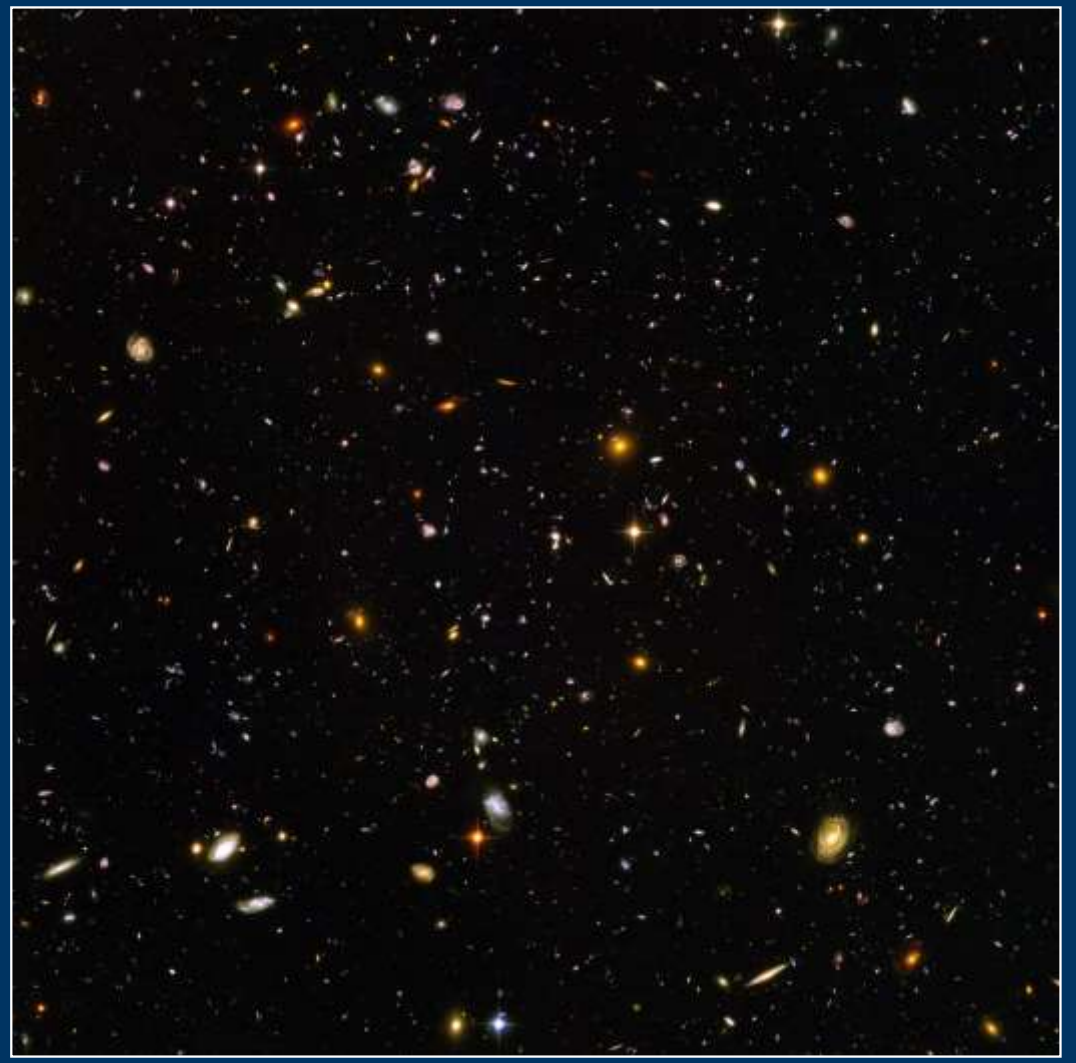
Key performances (1)

for a nominal mission of 6 years:

- **Telescope** delivers a **large field of view** with an **accurate point spread function**
  - Diffraction limited image quality requirements: ellipticity, FWHM and R2.
  - Optimised design for maximum suppression of straylight and ghosts.

- **Instruments** to cover the wide field with small pixels
  - VIS imaging: 600 Mpix for VIS (0.1×0.1 arcsec2) wide band [0.55-0.90] micron
  - NISP imaging photometer: 45 Mpix for NISP(0.3×0.3 arcsec2) Y, J, H
  - NISP Slitless spectroscopy using dedicated spectral decontamination strategy, by rotation over 4 angles

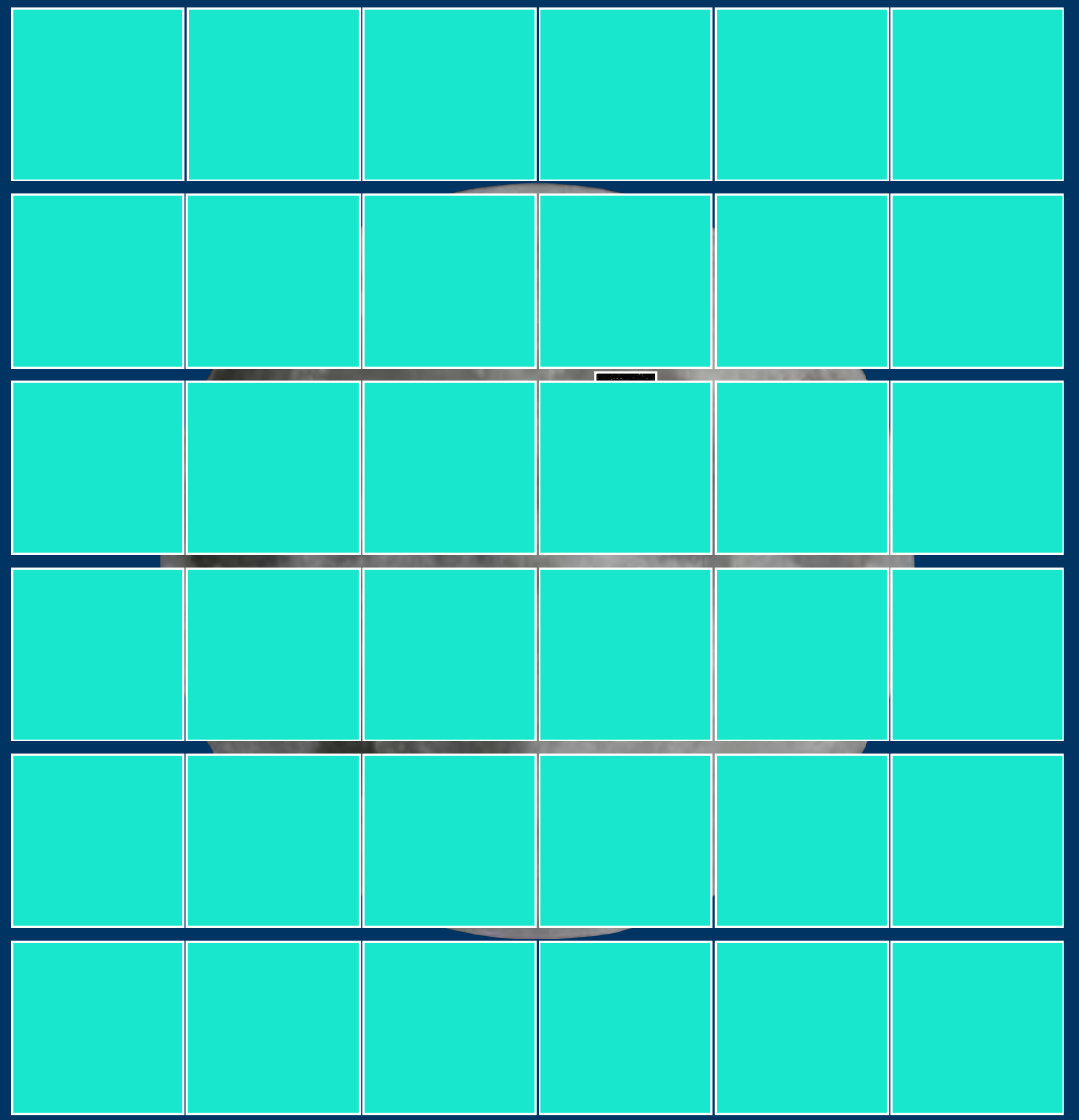
Optimised for wide-field imaging & spectroscopy



Hubble Ultra Deep Field in Fornax, 2.6 x 2.6 arcmin (29 AB mag)

NASA, ESA

Optimised for wide-field imaging & spectroscopy



Moon / Matt Wedel

Euclid field-of-view: 42 x 44 arcmin

VIS:

36 x 4096 x 4132 pixel Si CCDs, supplied by Teledyne e2v
0.1 arcsec/pixel, 0.53–0.92 μm wide-band imaging

NISP:

16 x 2048 x 2048 pixel HgCdTe arrays, supplied by Teledyne & key NASA contribution to Euclid
0.3 arcsec/pixel, 0.95–2.02 μm Y/J/H-band imaging & R > 400 slitless spectroscopy

Total of ~40,000 independent fields to be studied with imaging & spectroscopy with diffraction-limited resolution

Key performances (2)

for a nominal mission of 6 years need dedicated survey capabilities:

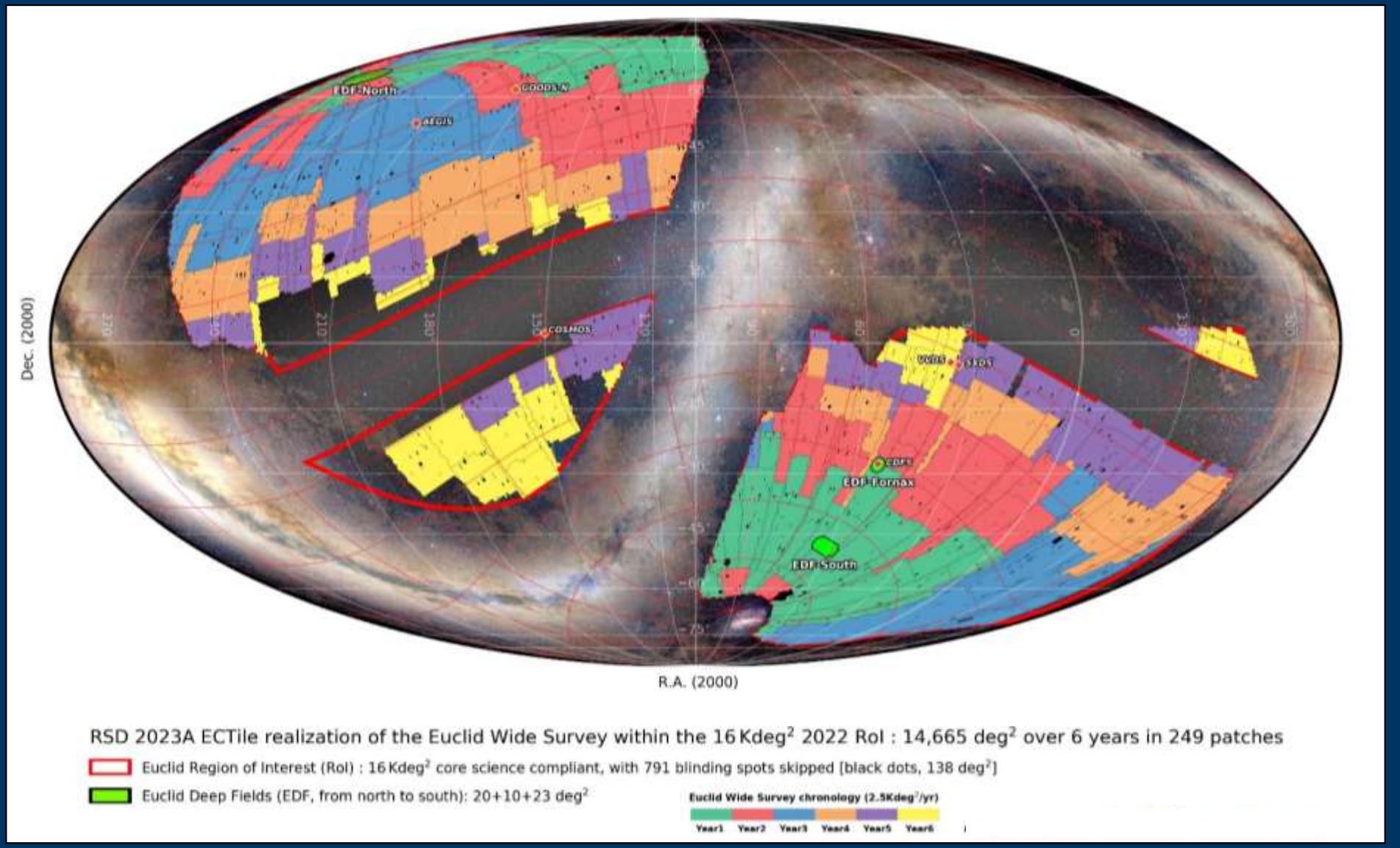
- **Spacecraft** is able to effectively survey the sky for over 40,000 fields, with very demanding guiding stability and minimum overheads due to slewing

  → Fine Guidance Sensor using telescope as star tracker, cold gas actuation

  →Step and stare strategy, with many pointing constraints

- **Spacecraft and ground segment** to cope with the high daily data rate of ~100 Gbyte of raw compressed data

Surveying 36% of the sky in 6 years (pre-launch)



Background image: Euclid Consortium, Planck collaboration, A Mellinger

Euclid Consortium, ESA, J-C Cuillandre, D Stern, ECSURV & COG groups

The Euclid legacy – a large extragalactic sky atlas

Wide Survey

Entire extra-galactic sky away from the galactic plane & zodiacal light
Almost 15,000 deg^2 (~1/3 of the sky) in the VIS, Y, J, & H bands over 6 years

Diffraction-limited imaging (0.18” in VIS) to 24.5 AB mag in VIS, 24 AB mag in Y, J, H
Slitless spectroscopy of all VIS sources (from 0.93–1.89μm in two bands)

Images & photometric redshifts for 1.5 billion galaxies
Photometry for hundreds of millions of stars
Near-infrared spectra, including precision redshifts, for tens of millions of sources

Deep Survey

10% of mission time spent covering 53 deg^2 (> 250 full Moons) in three fields
Each revisited 40–52 times, going 2 magnitudes deeper in background-limited imaging

Auxiliary Fields

Six well-known cosmology survey fields (e.g. GOODS-N, VVDS-Deep) + self-calibration field
Probed 4–8 x deeper than wide survey for photometric redshift & colour gradient calibration

In orbit performances status

Confirmed so far:

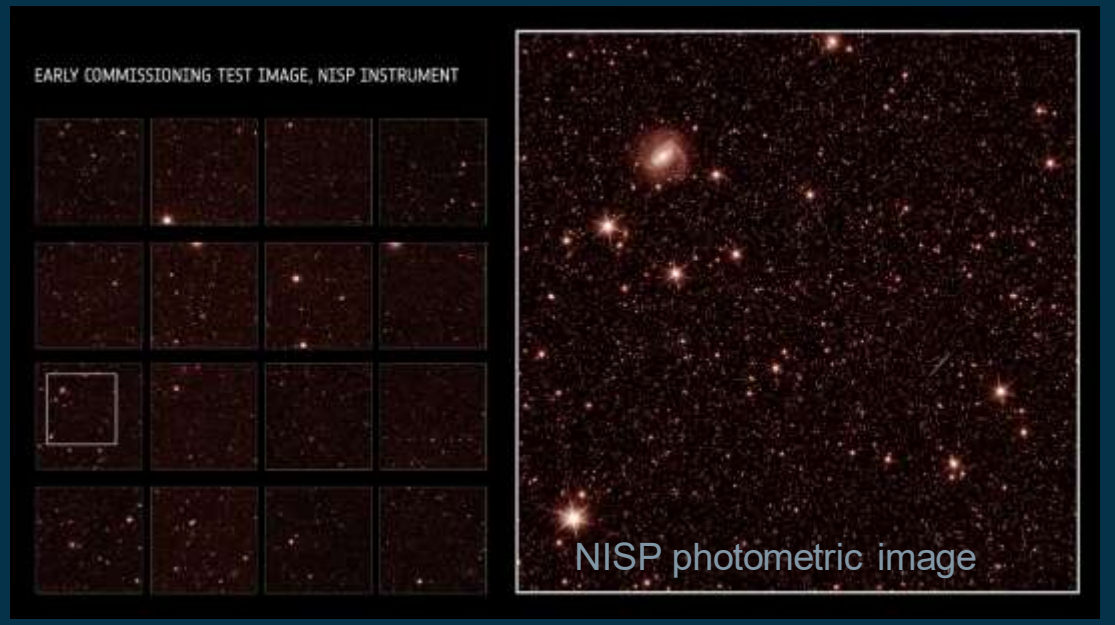
- **Successful launch** with SpaceX Falcon9, delivering Euclid to L2 orbit.
- **Telescope image quality**: as required, found deviations from fiducial model
- **VIS and NISP instruments**: working nominally with all sensors available
- **Spacecraft:** all hardware elements are working as required

….but anomalies were found:

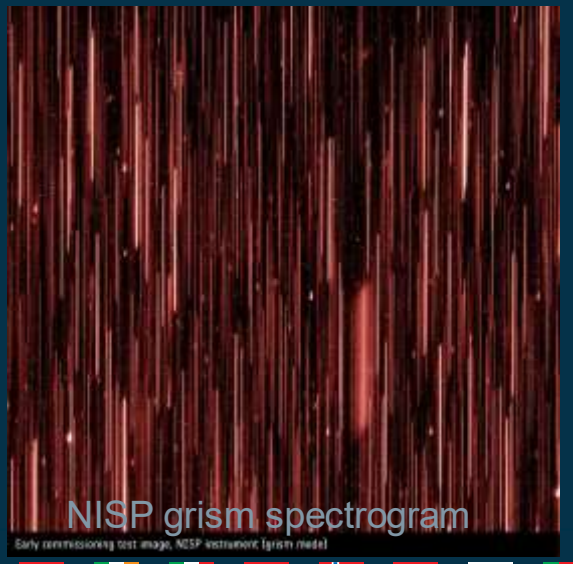
- Fine Guidance Sensor anomalies – solved! new software uploaded and being tested
- Parasitic straylight – restricting the available azimuth angles

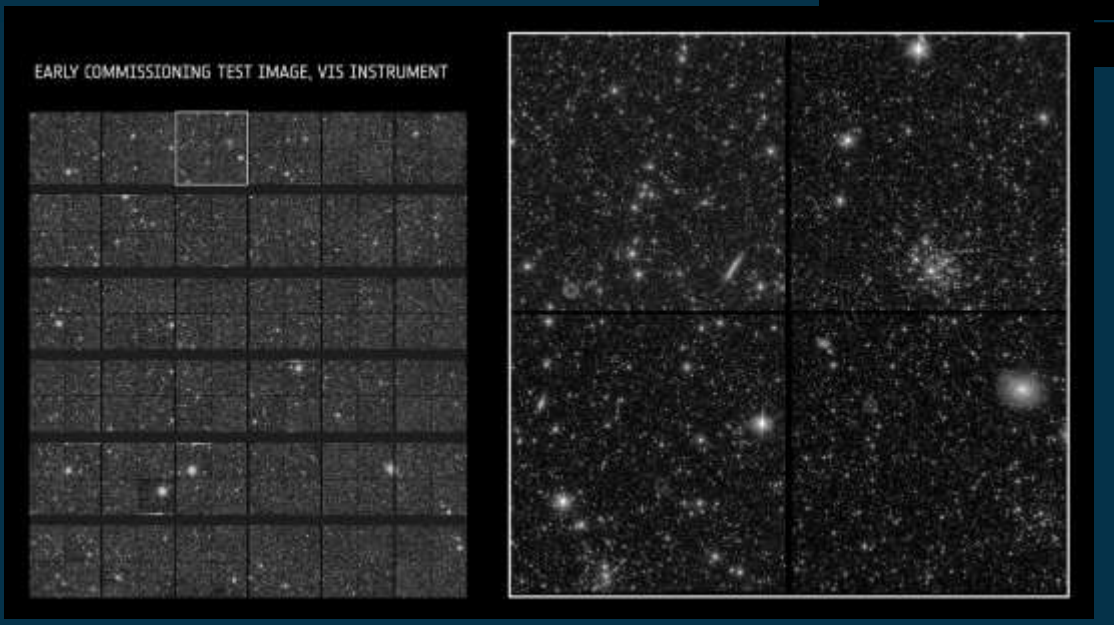
  → reprogramming of the nominal survey, ~10% loss of survey efficiency
- Sporadic Solar X-rays - invalidating 30% of the VIS array (worst case)

First test images



Focal Plane Array
16 H2RG 2k × 2k





Focal Plane Array
36 CCDs 4k × 4k

One CCD sensor

VIS Instrument Imaging

NISP photometry (Y,J,H) + VIS Imaging → Weak Lensing
NISP spectroscopy → Galaxy Clustering

Outlook

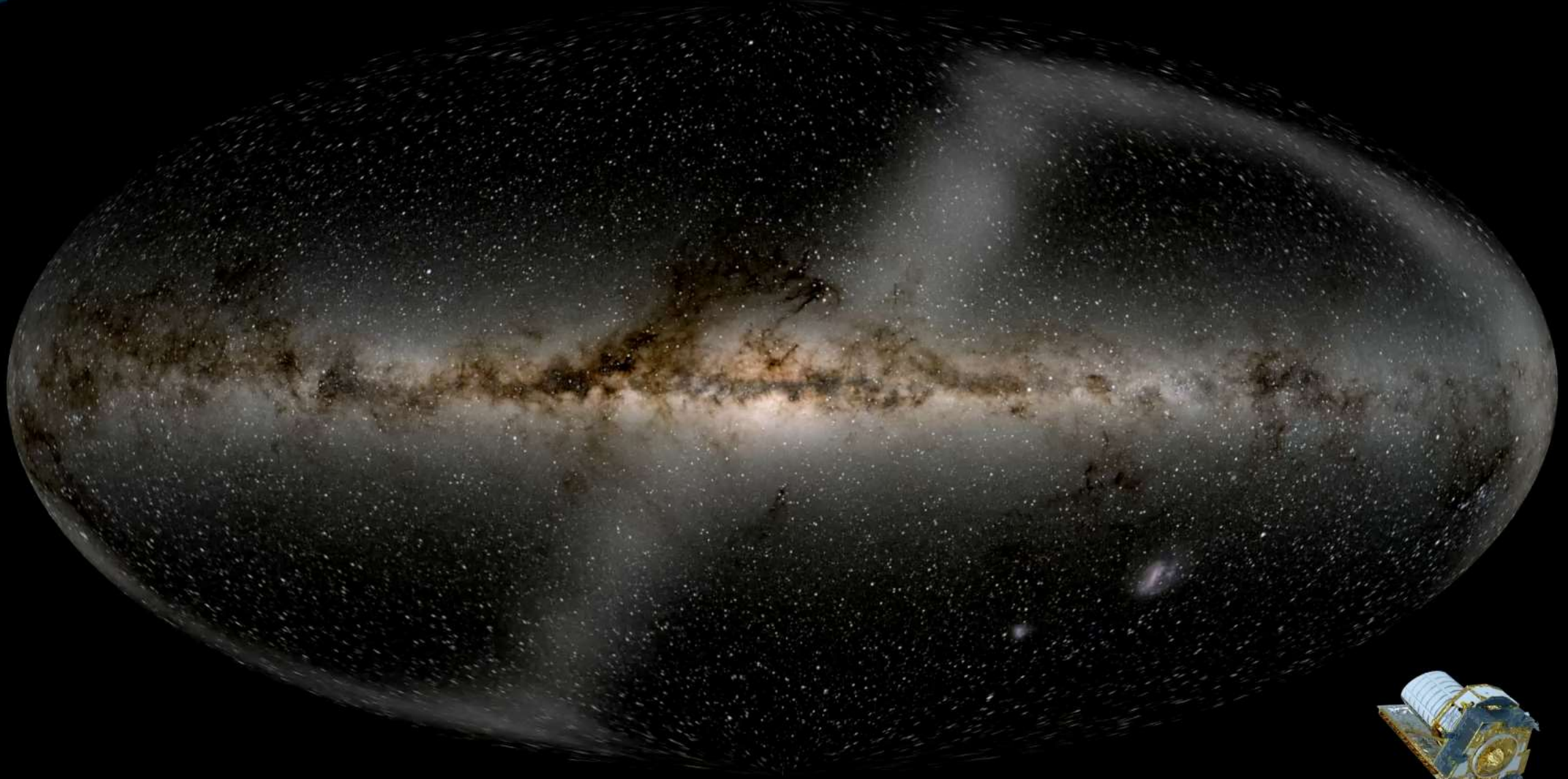
The teams are busy with the (scientific) performance verification, this phase includes calibrations and characterisations.

Post-launch milestones

Dec 2023	Start of nominal mission, with telescope wavefront error retrieval campaign for a detailed model of the point-spread function
Feb 2024	Start of the Euclid Sky Survey
Feb 2025	Q1 - First “Quick”release (area > 50 deg2)
Feb 2026	DR1 – first data release (~2000-2500 deg2, first year of survey data)

Thanks for your attention

Surveying 36% of the sky in 6 years



Galaxies and AGN Evolution with Euclid

Scientific aims for a nominal mission of 6 years:

- Provide distance measurements that allow a reliable conversion of the observed galaxy properties to key physical parameters like stellar mass and star formation rate well beyond the redshift where the integrated star formation rate in the Universe peaks.

- Measure redshifts for over 70 million star forming galaxies out to z~2 and a large number of AGN over a wide redshift range, including a sizable number of quasars at *z*>6-7.

- Establishing the co-evolution of galactic morphology, star-formation and AGN activity as a function of mass and environment.

Euclid Science Objectives

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% for several redshift bins from $z = 0.7$ to $z = 2$. • Look for deviations from $w = -1$, indicating a dynamical dark energy. • Euclid *alone* to give $FoM_{DE} \geq 400$ (roughly corresponding to 1-sigma errors on w_p, & w_a of 0.02 and 0.1 respectively)
Test of Gravity	• Measure the growth index, γ, with a precision better a 1-sigma error of 0.02 • Measure the growth rate to better than a 1-sigma error of 0.05 for several redshift bins between $z = 0.5$ and $z = 2$ • Separately constrain the two relativistic potentials Ψ and 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 a 1-sigma 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 with respect to Planck alone by a factor 2. • Measure the non-Gaussianity parameter f_{NL} for local-type models with a 1-sigma error better than 2.

Euclid by numbers

Countries involved: 21

Science institutions: 300

Science personnel: ~2500

Survey duration: 6 yrs

Area of sky: 15,000 deg^2

Number of galaxies: 1.5 billion

Companies involved: 80

Industry contracts: 140

Industry personnel: ~2000

Mission cost: ~ € 1.4 billion

Distance from Earth: 1.5 million km

Data download: 106 GB/day

Spacecraft mass: 2.2 tonnes

Telescope temperature: –140ºC

Number of pixels: 676 million

More information:

www.esa.int/euclid