The Euclid mission: scientific forecast, overview and status

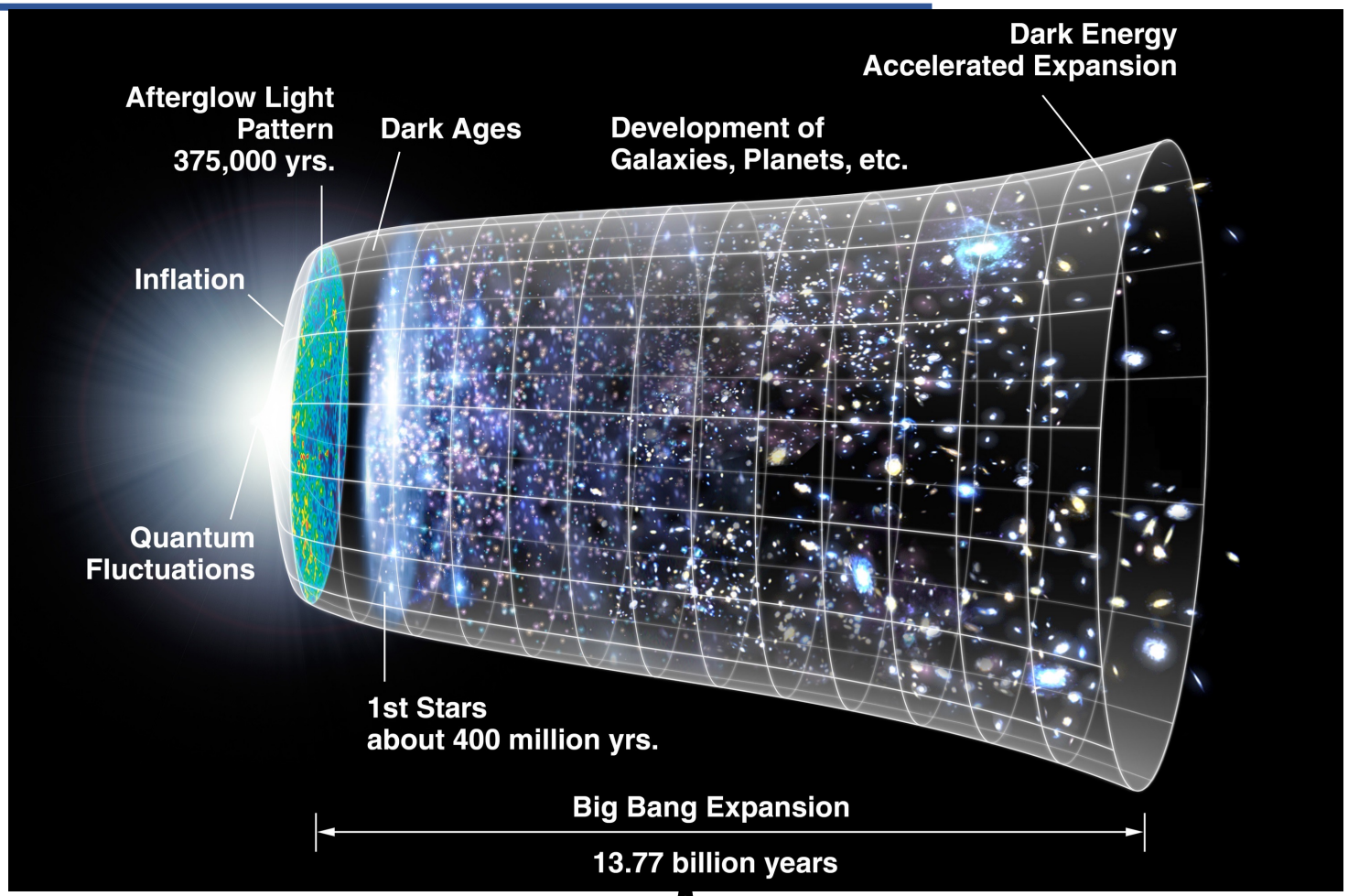
Cristobal Padilla

ICHEP 2024, Prague

July 18th, 2024

On behalf of the Euclid Consortium

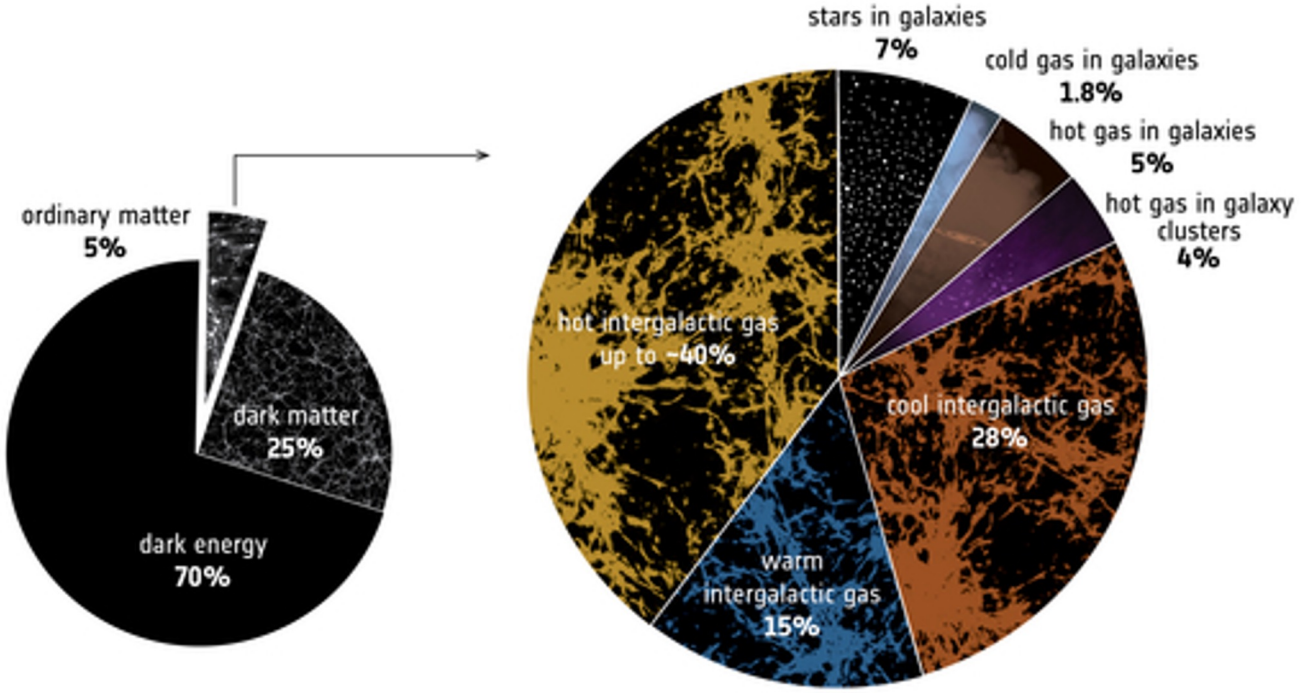
Present model of our Universe



H_0	Ω_m	Ω_b	Ω_Λ	σ_8	n_s
Current expansion rate	Matter density	Baryon density	Dark Energy density	„Clumpiness“	Scale index of initial density fluctuations

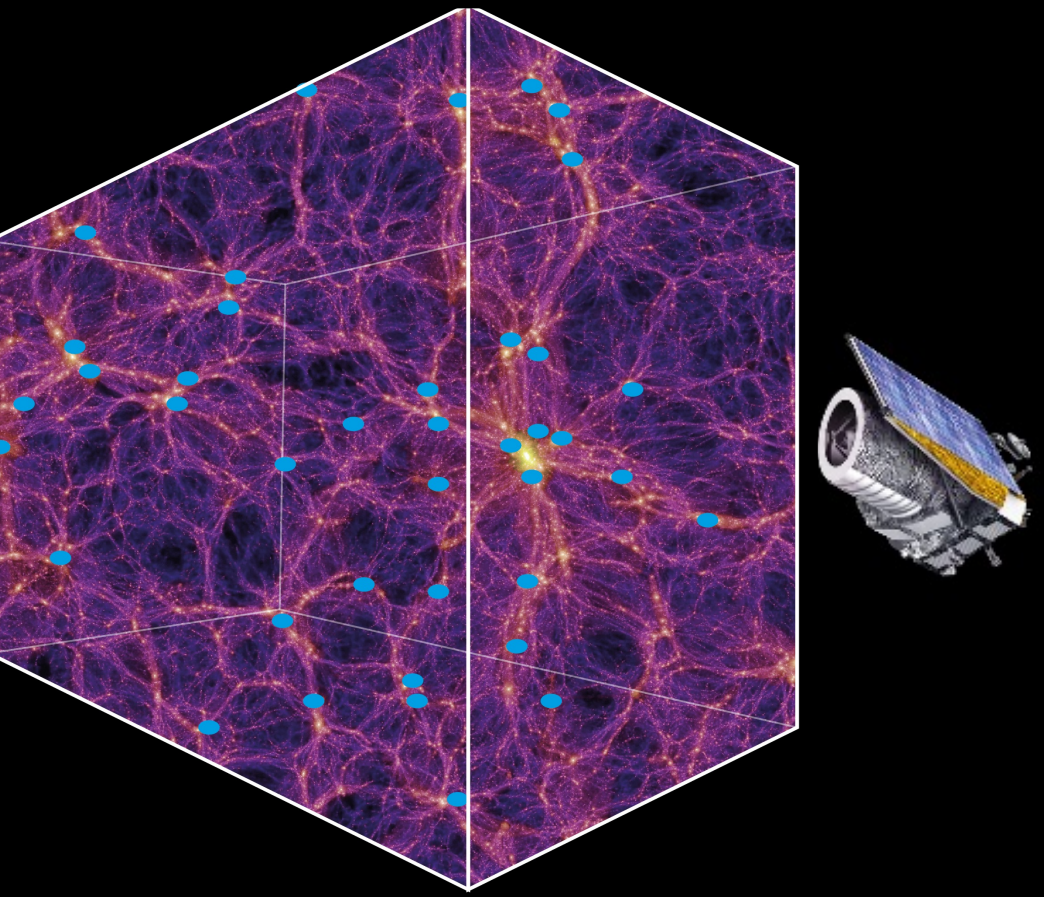
Present model of our Universe

- We only observe 5% of our universe
- We know that there is a lot of matter we do not see
  - Galaxies rotate too fast
  - Galaxies move too fast inside its cumulus
- LHC has “only” discovered the Higgs up to now
- Neutrinos mass, hierarchy?
- We know that the Universe is not stopping its expansion
  - In fact, the expansion is accelerating



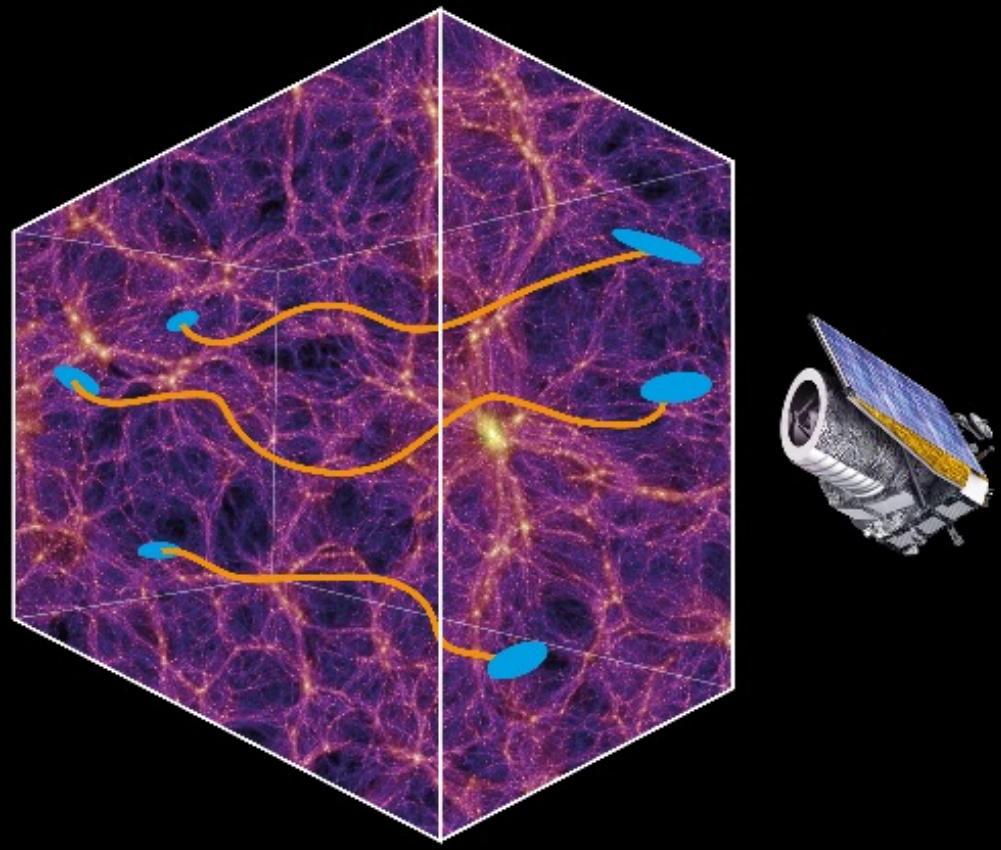
Two primary probes

Galaxy clustering

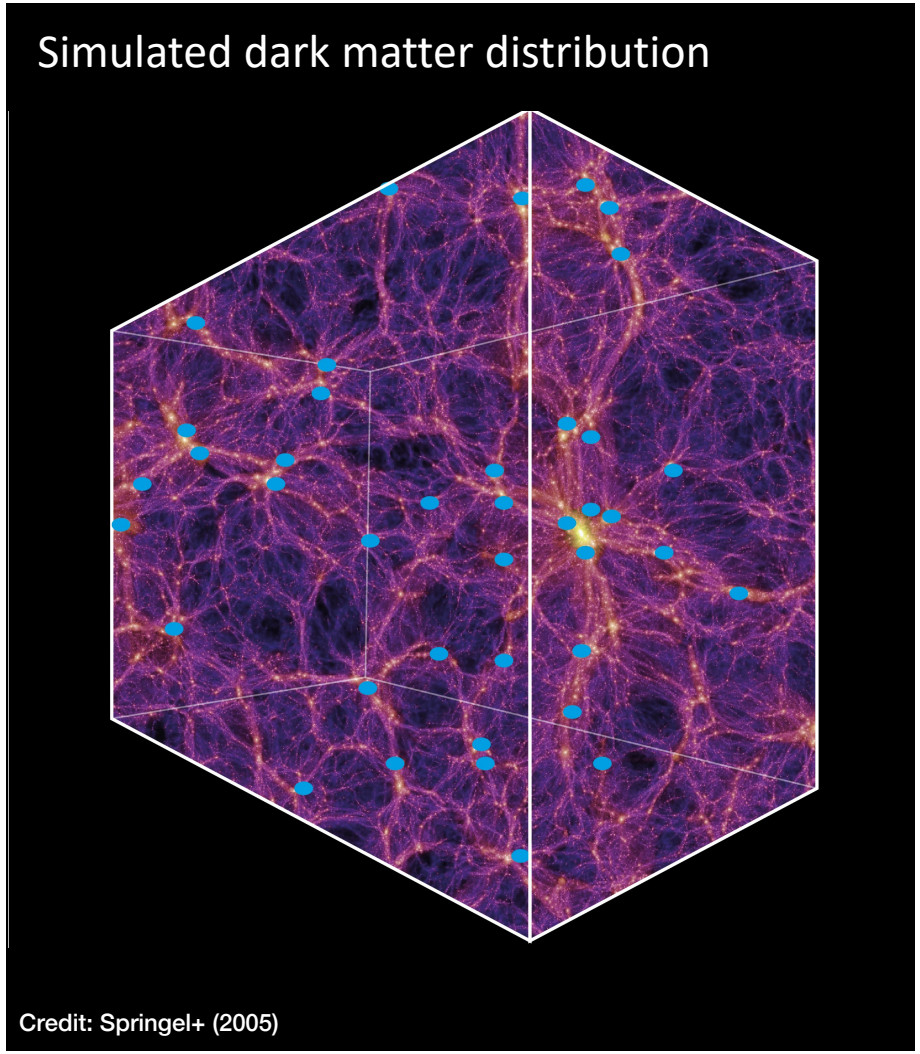


Credit: Springel+ (2005) (Background) ESA/ATG medialab (spacecraft)

Cosmic Shear



Cosmology from Large Scale Structures



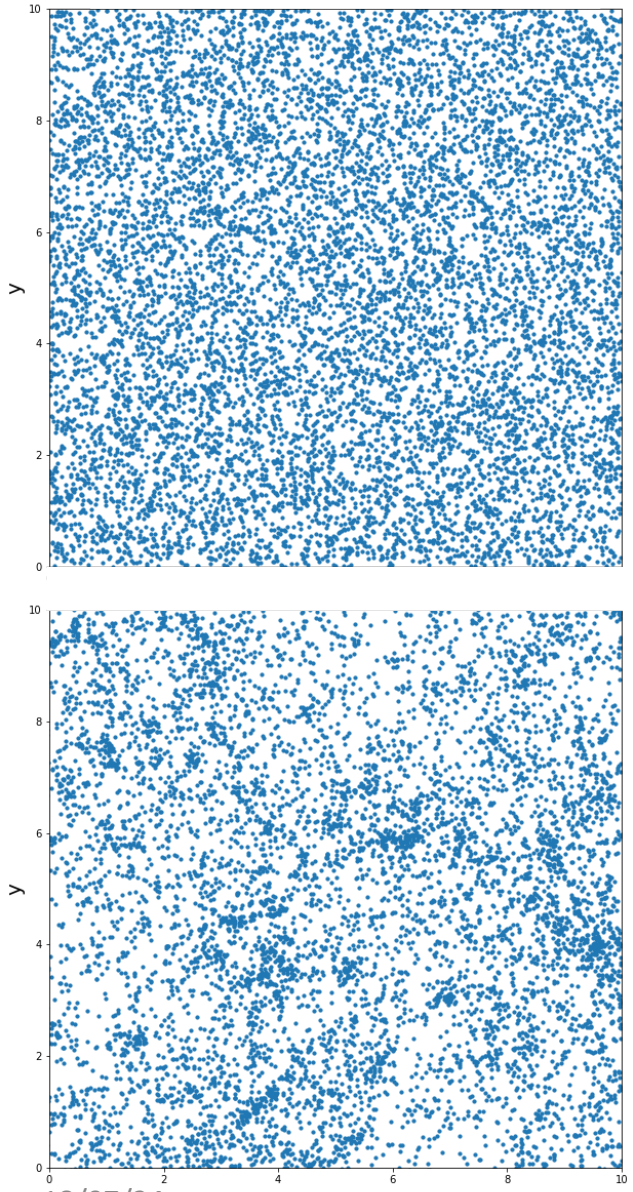
Dependance of size and distribution of structures

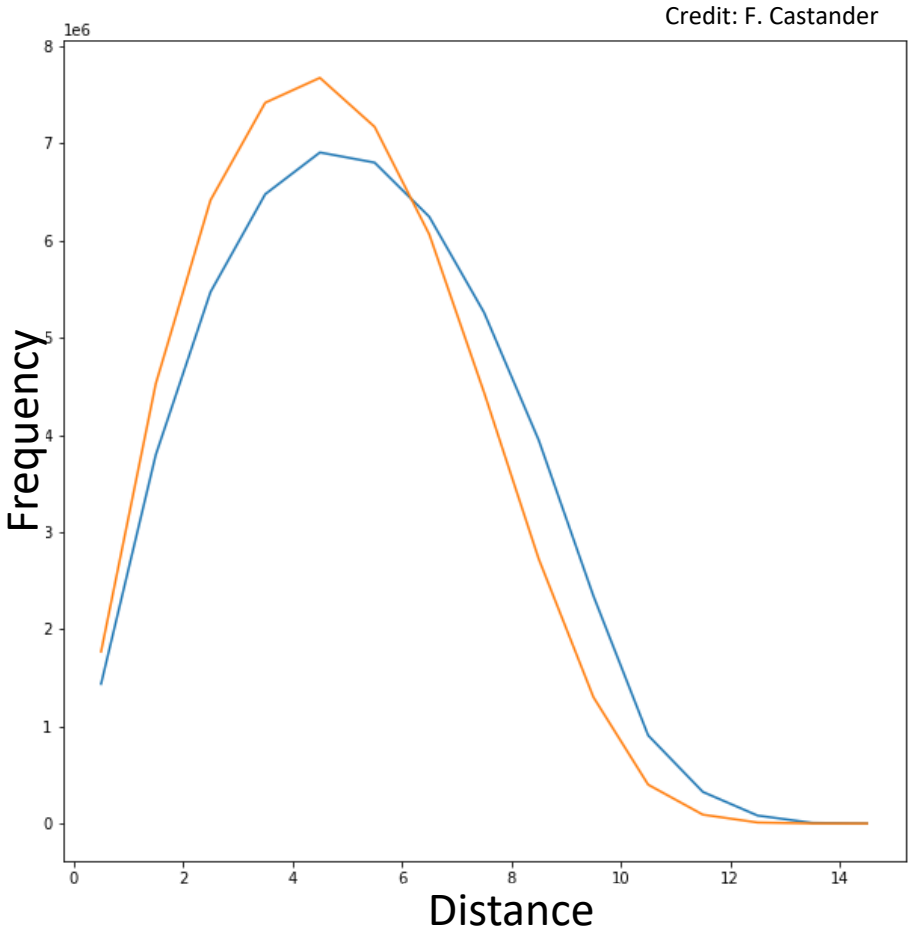
Amount of matter and clustering → Ω_m , σ_8

Expansion of Universe at different distances → w, Ω_Λ

We cannot directly observe dark matter

Measurement Galaxy Clustering

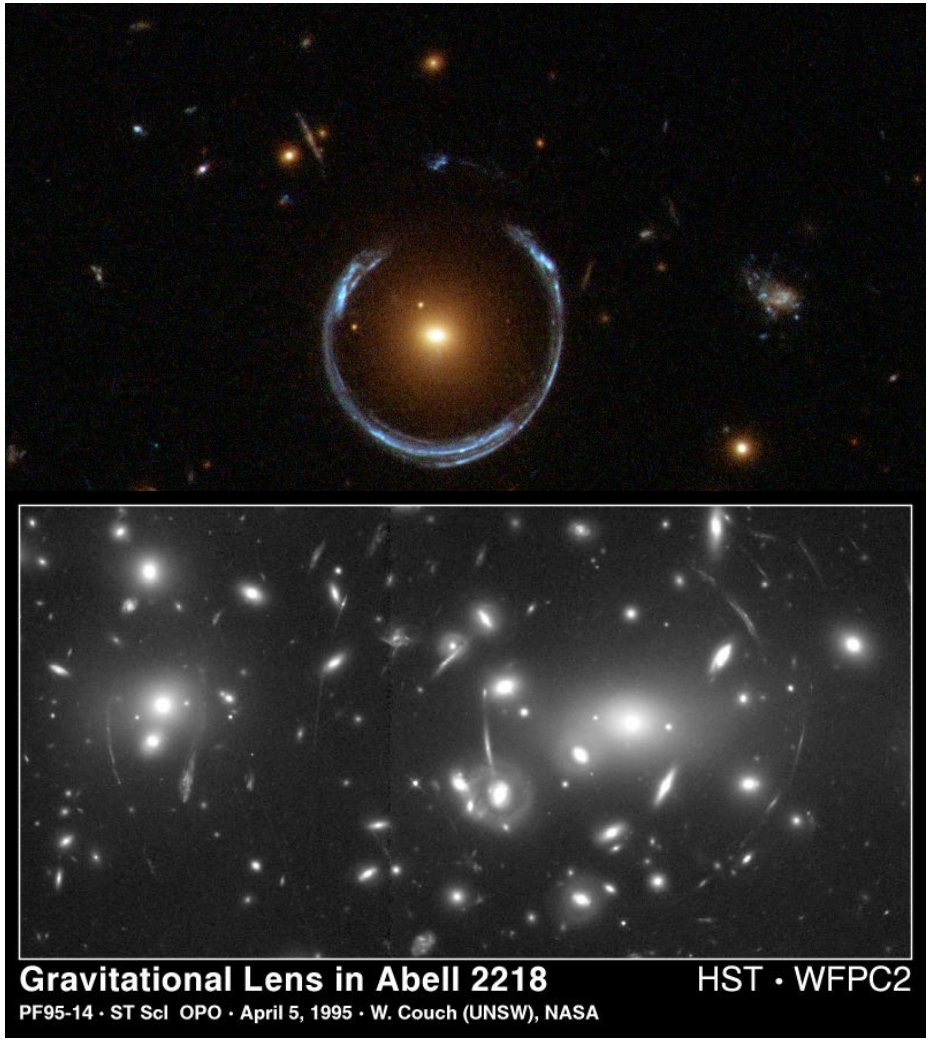




- Make the histogram of the distances of galaxies
- Difference between random positioning of galaxies and with the gravitational effects
  - Clustering
  - Depends on distribution of Dark Matter

Gravitational Lensing

Strong Lensing



Gravitational Lensing

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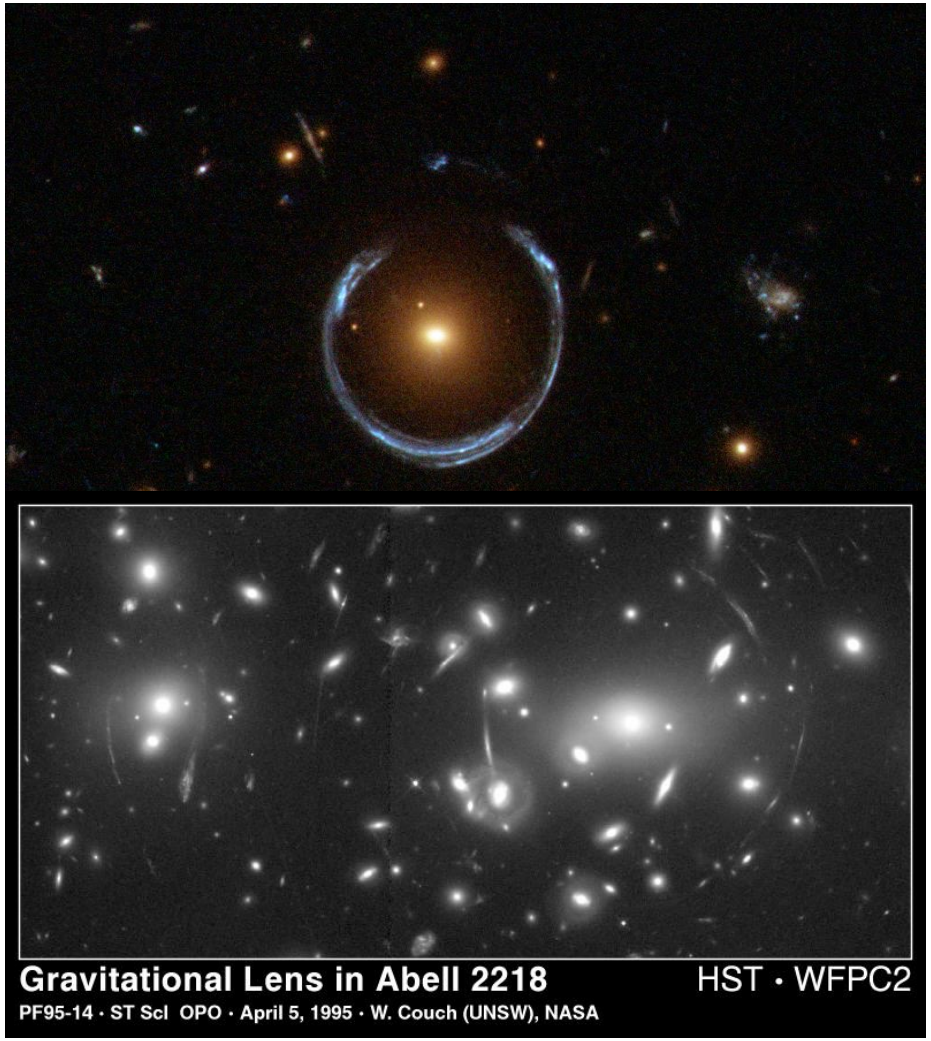
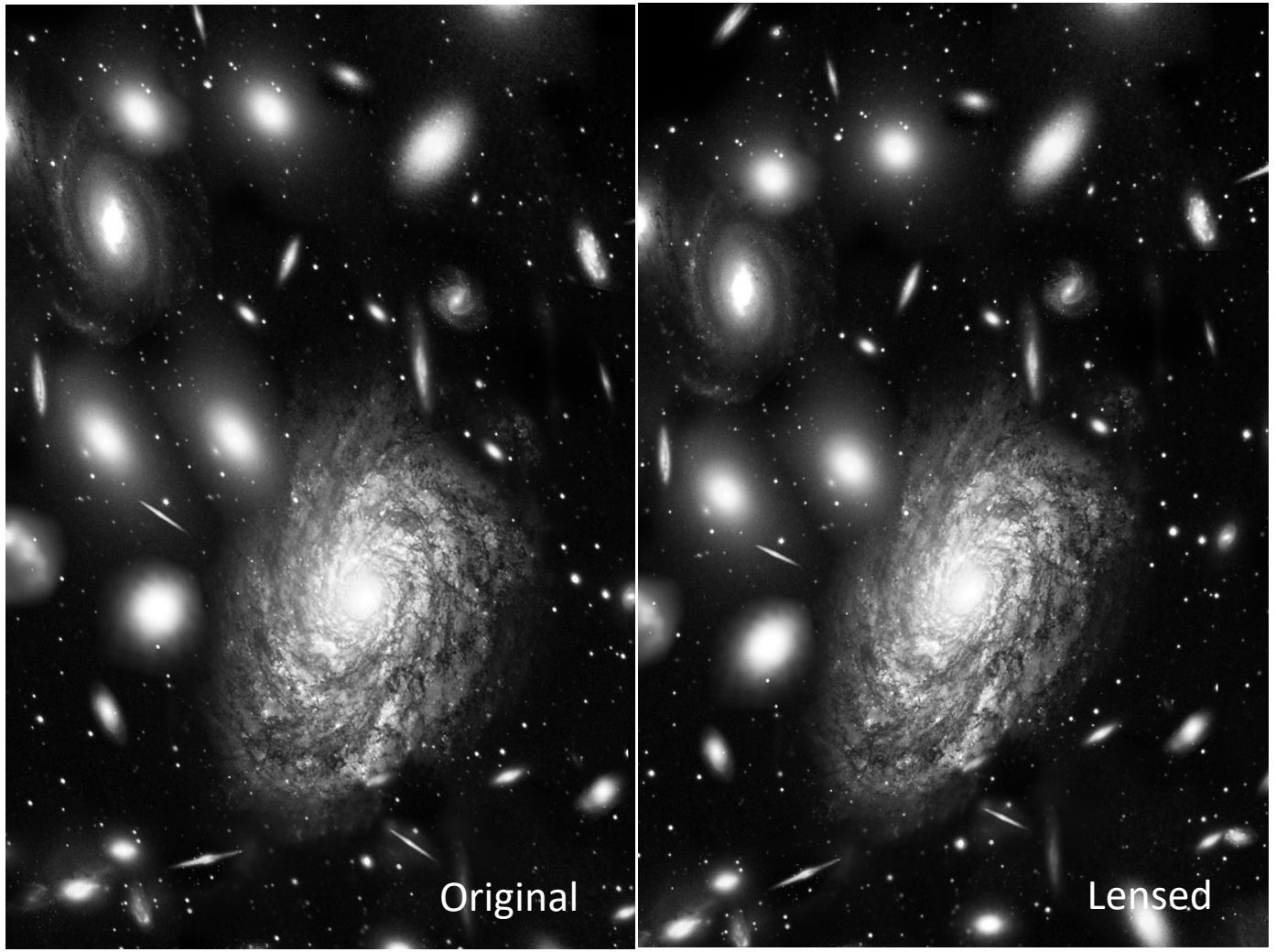
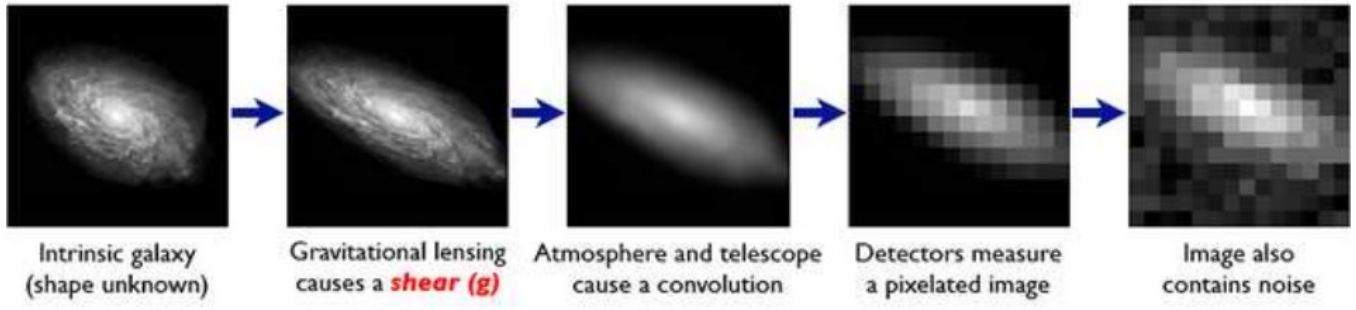


Weak Lensing



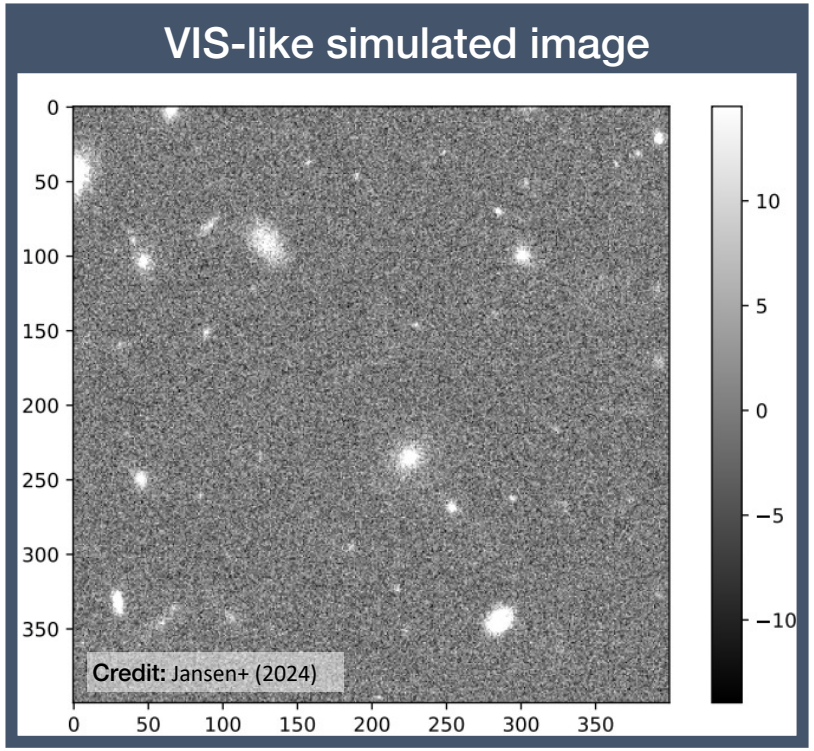
Shape Measurements challenge



Credit: Bridle+ (2006)

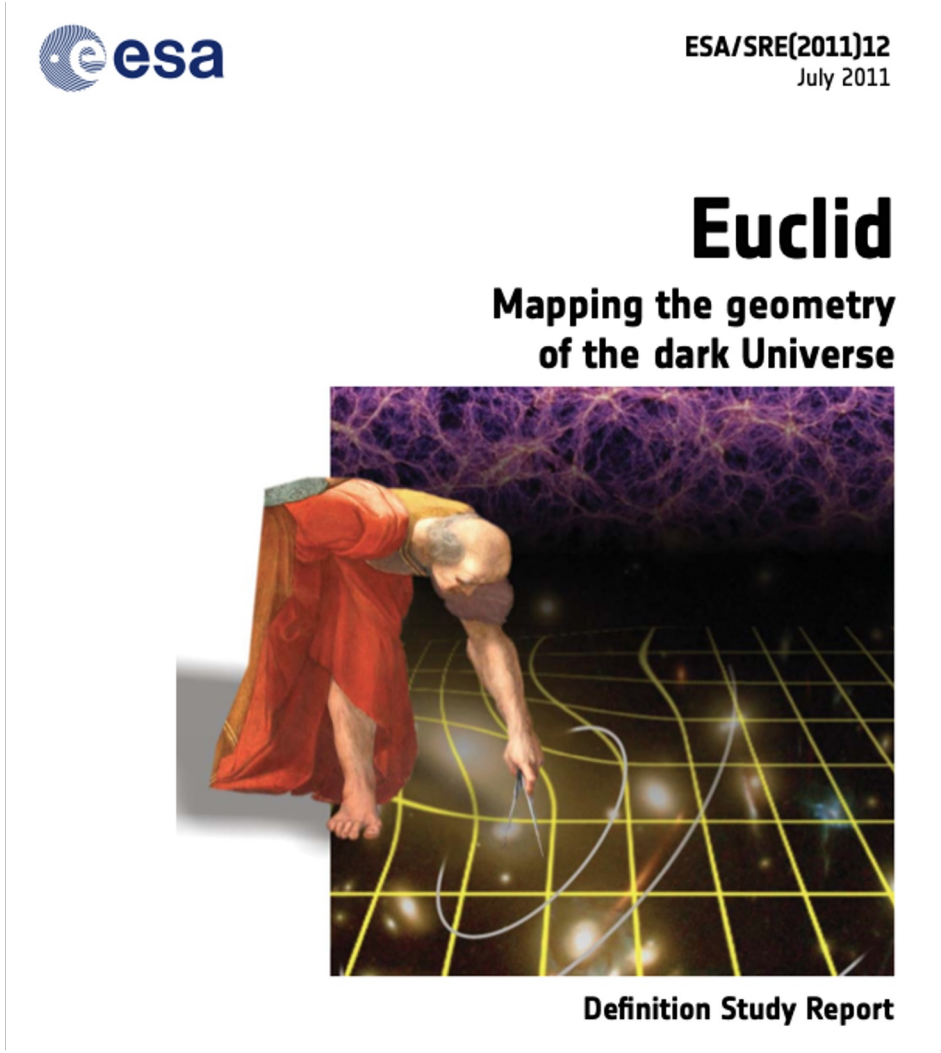
Shape measurements are very difficult:

- PSF Convolution
- Pixelization
- Image Noise
- Detection Probabilities and blending



Realistic image simulations are used to test, validate and calibrate measurement methods

Main objectives



Euclid is designed to understand the **nature** of **Dark Energy and Dark Matter**

Reach a dark energy *FoM* > 400 using only Euclid primary probes

Measure the exponent of the growth factor with a 1 sigma precision < 0.02

Measure the sum of the neutrino masses with a 1 sigma precision better than 0.03 eV.

Constrain the spectral index and measure non-Gaussianity of initial conditions

Credit: ESA Euclid Definition Study report

Main objectives

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g only

factor with

Measure the sum of the neutrino masses with a 1 sigma precision better than 0.03 eV.

Constrain the spectral index and measure non-Gaussianity of initial conditions

Needs telescope in space with exquisite control of instrumental and optical effects

Credit: ESA Euclid Definition Study report

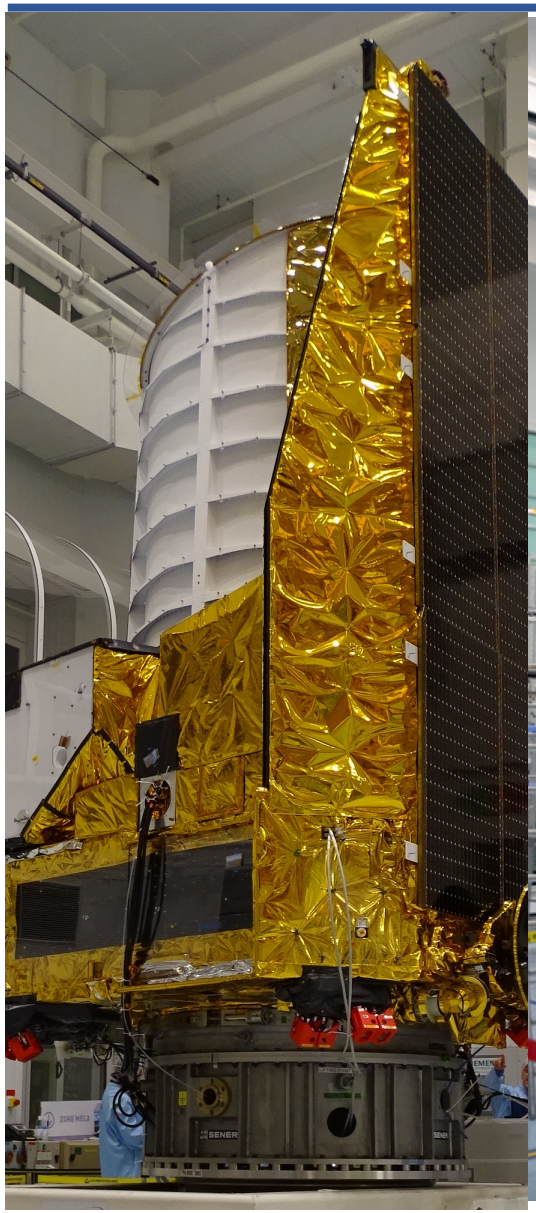
The Euclid Consortium

More than 2700 registered scientists

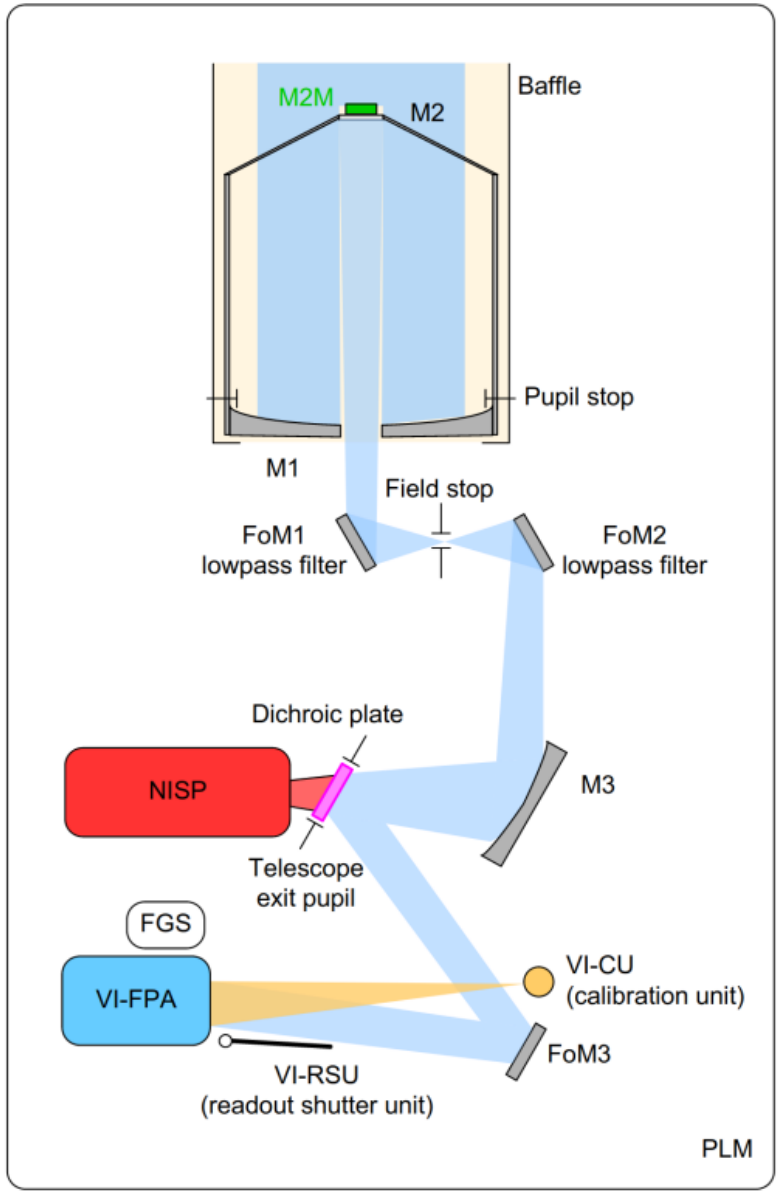
14 European countries + USA + Canada + Japan

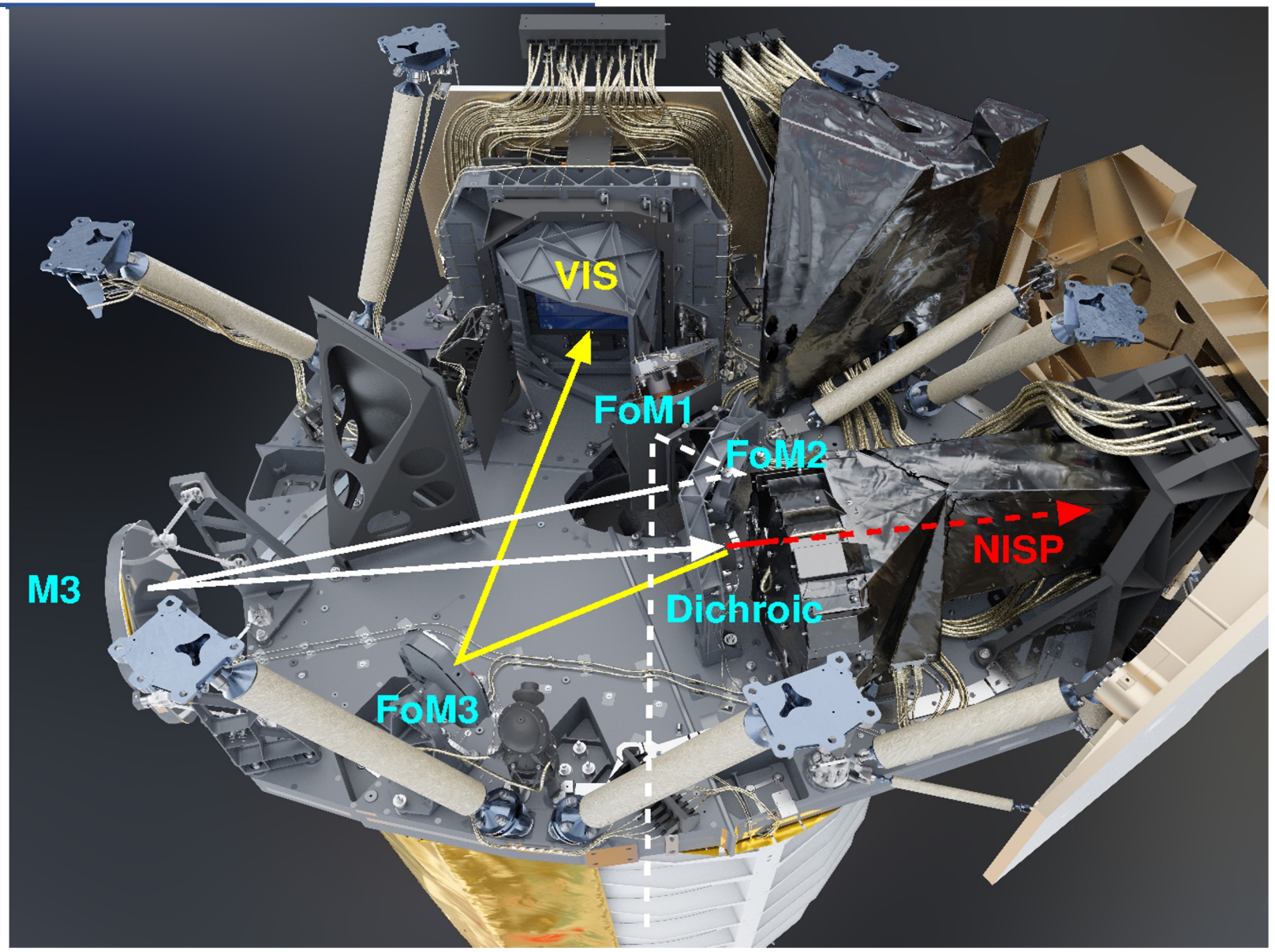
Responsible for the two Euclid instruments and the reduction and analysis of the data (Science Ground Segment)

Euclid Satelite

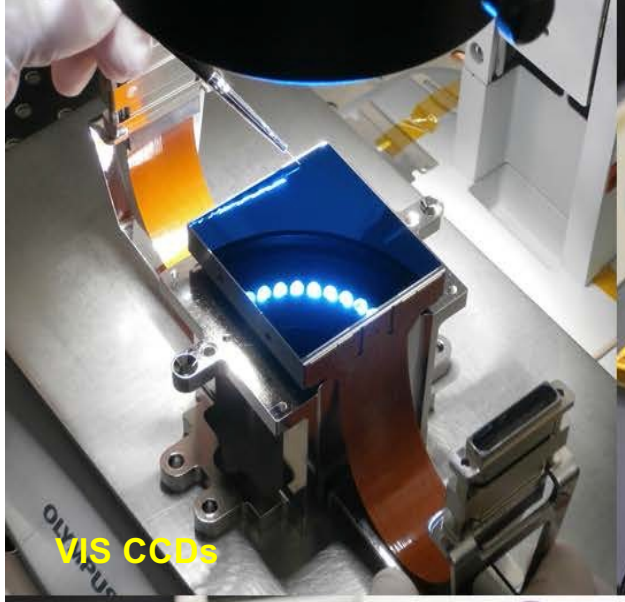


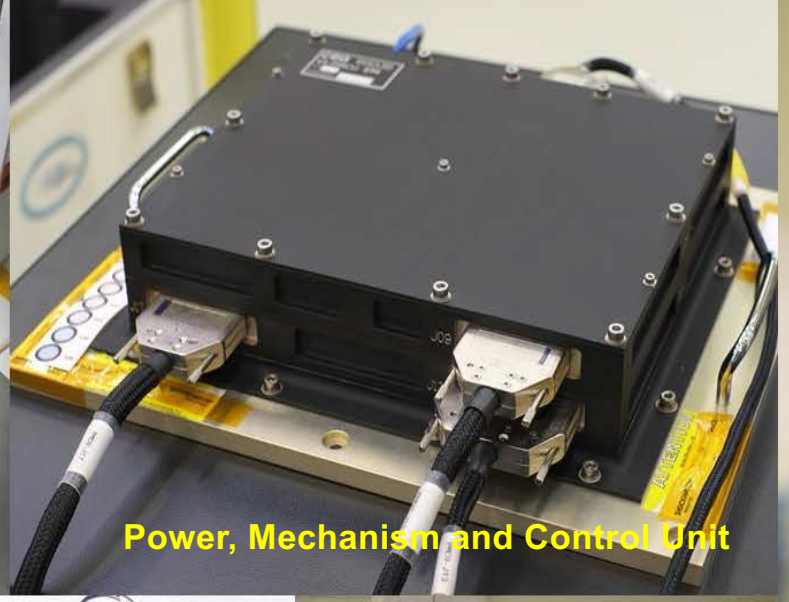
Euclid Telescope and instruments





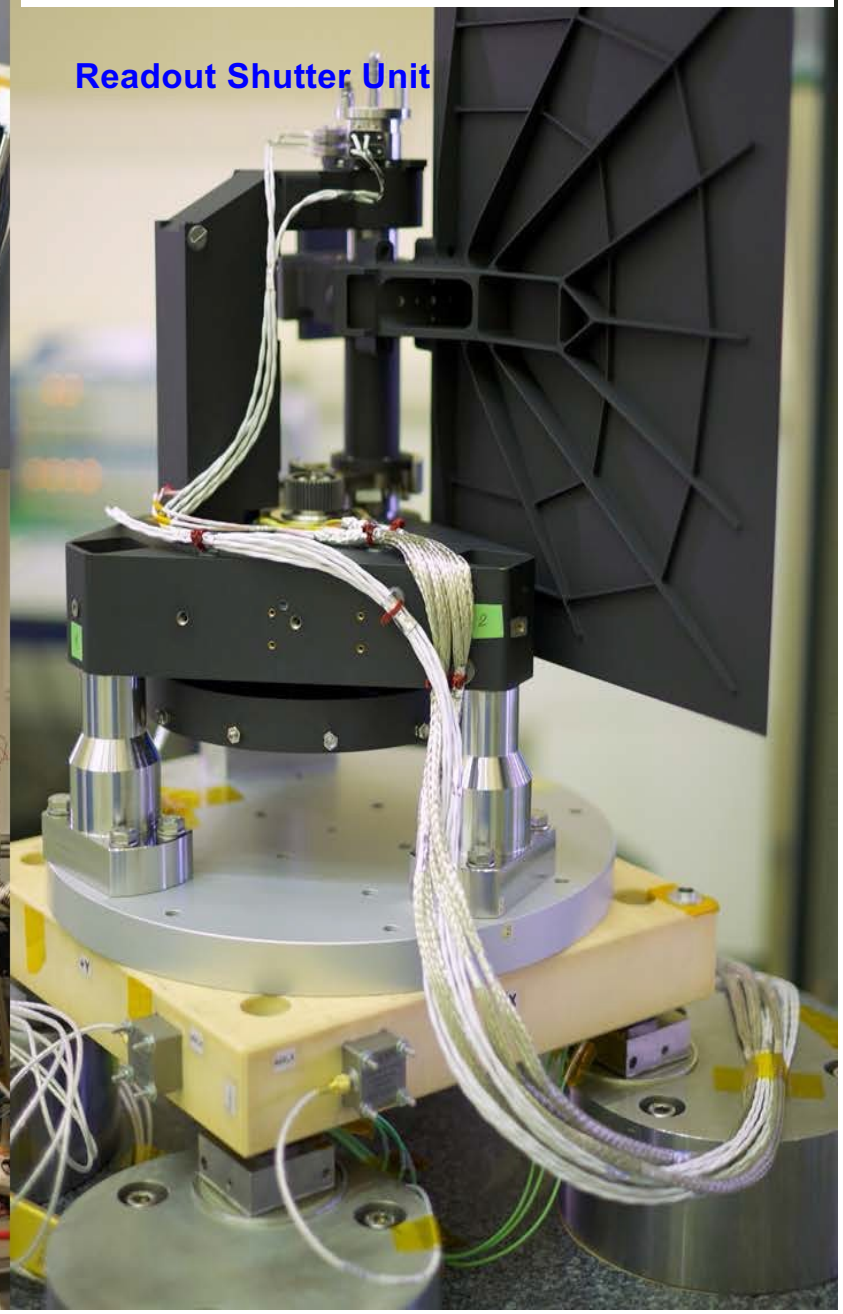
VIS Instrument


VIS CCDs

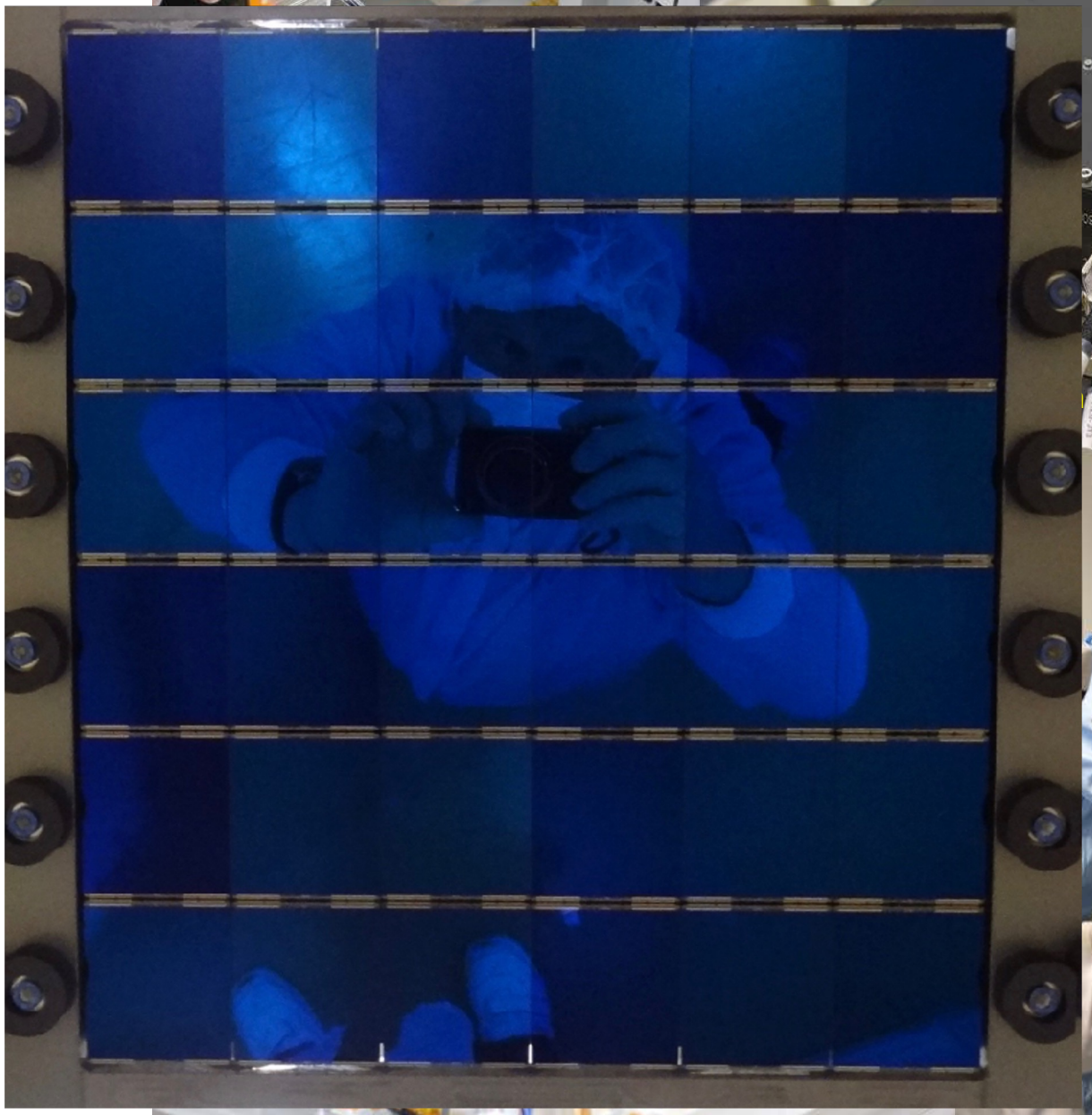

Power, Mechanism and Control Unit


Focal Plane Assembly


VIS CCD testing


Readout Shutter Unit

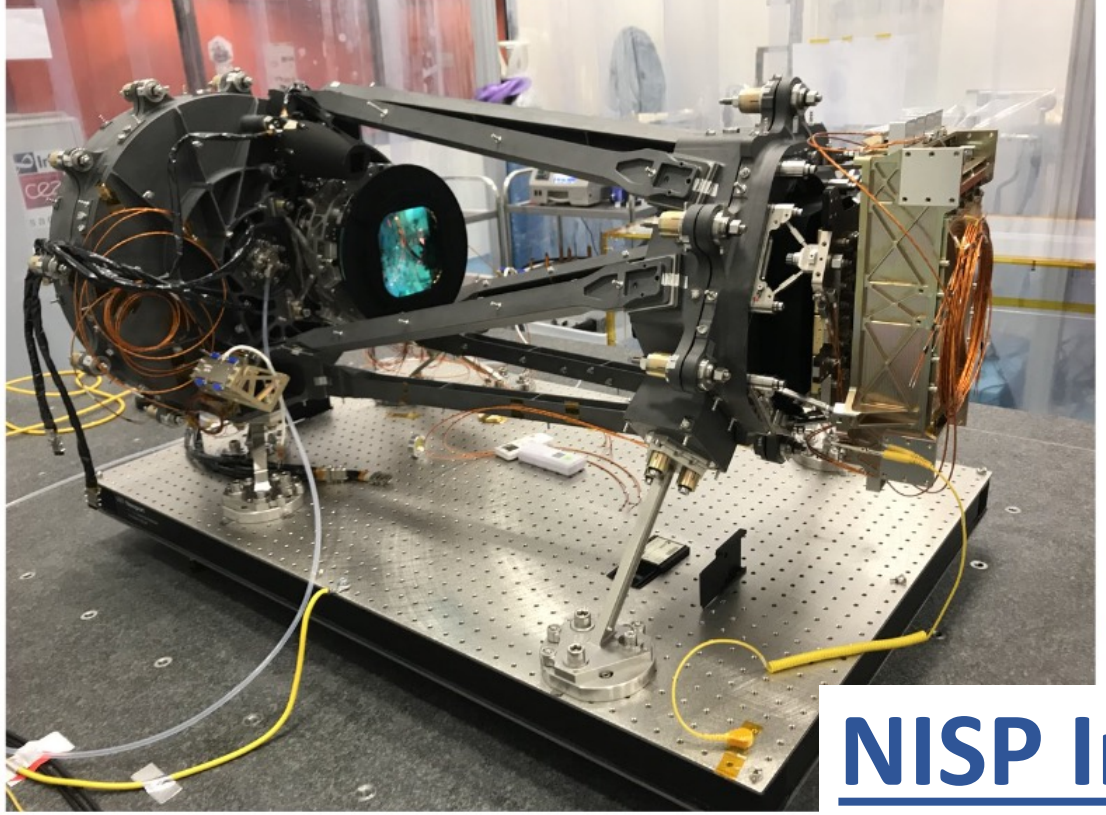
VIS Instrument



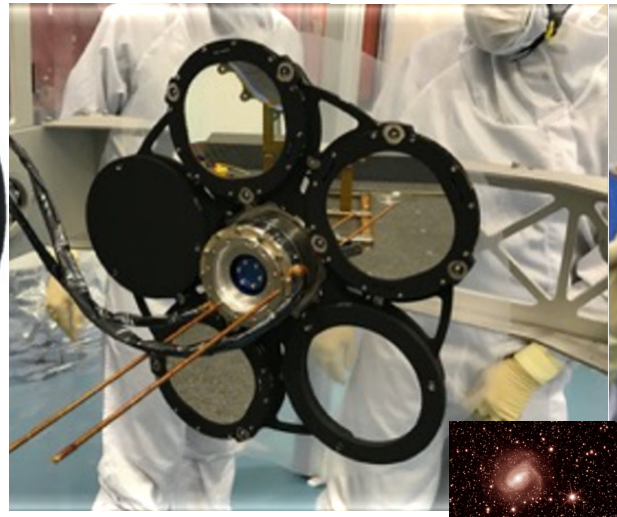
Focal Plane Assembly

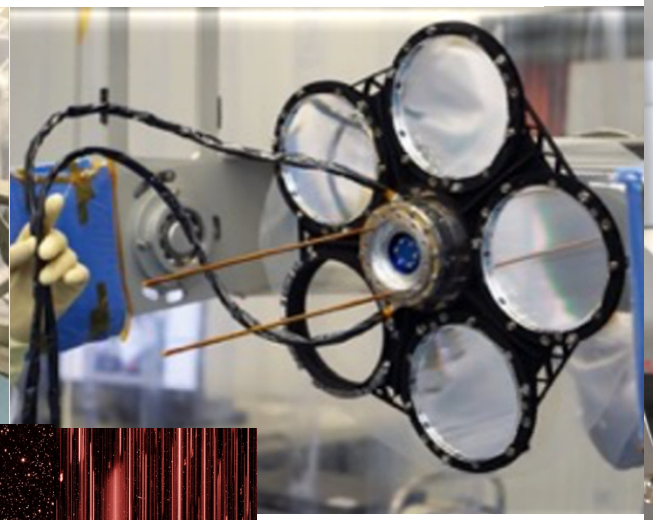
Readout Shutter Unit

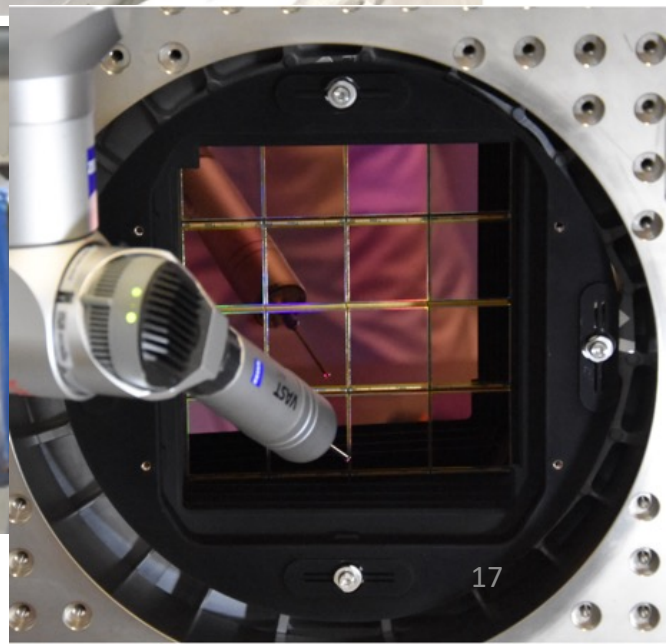
- Focal-plane instrument, no fore-optics
- 36 4k x 4k CCDs, 0.1” / pixel
- Readout time 72 seconds
- 530-920 nm wavelength range defined by coated mirrors, detectors, and dichroic beamsplitter
- Blade shutter
- Calibration lamp (6 wavelengths)
- Depth: 26.2 AB mag (5σ point source)

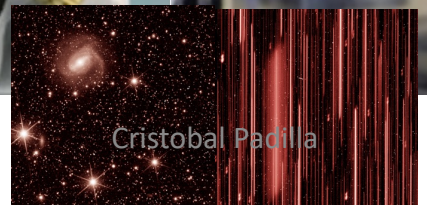


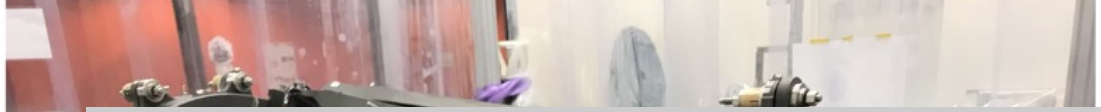
NISP Instrument

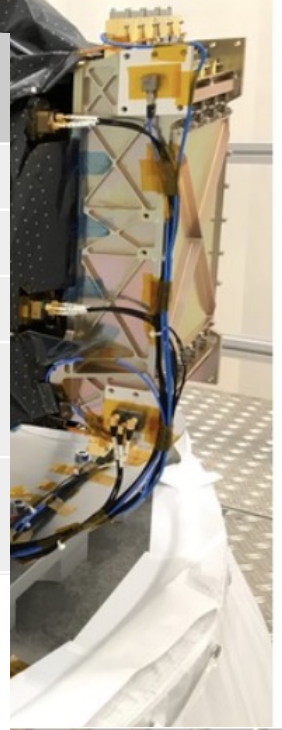








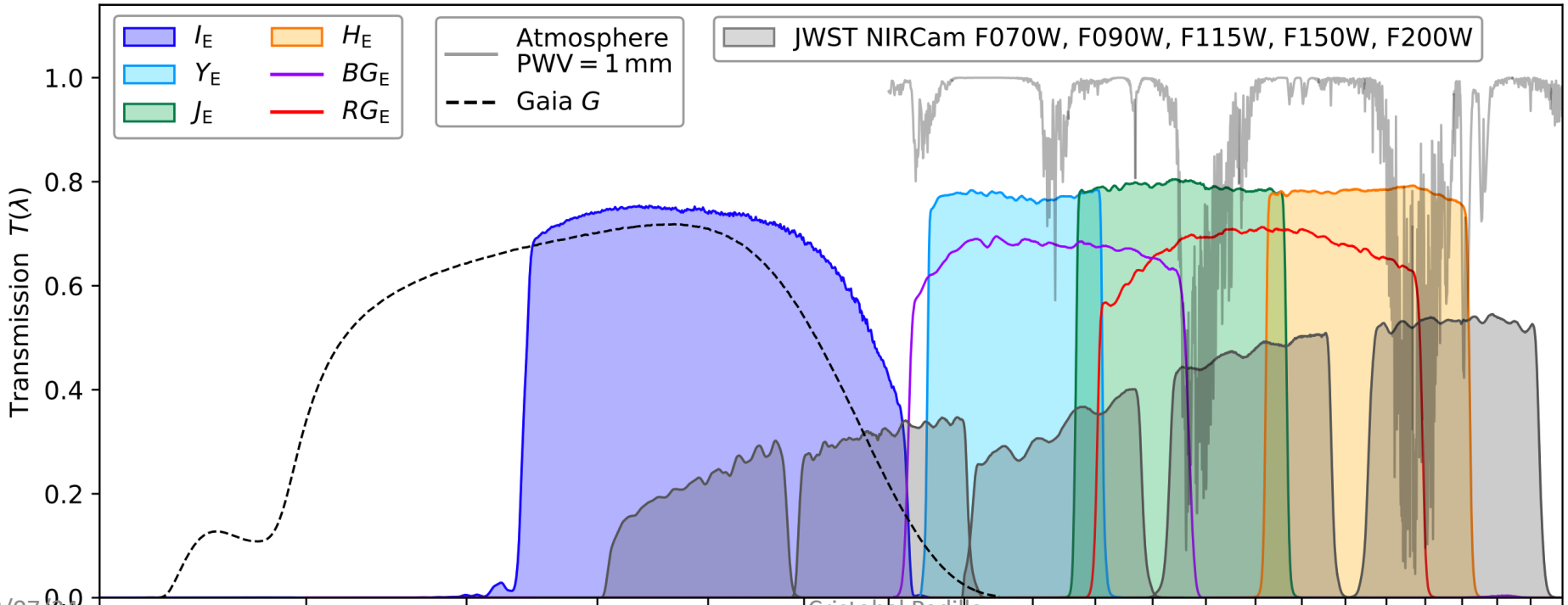


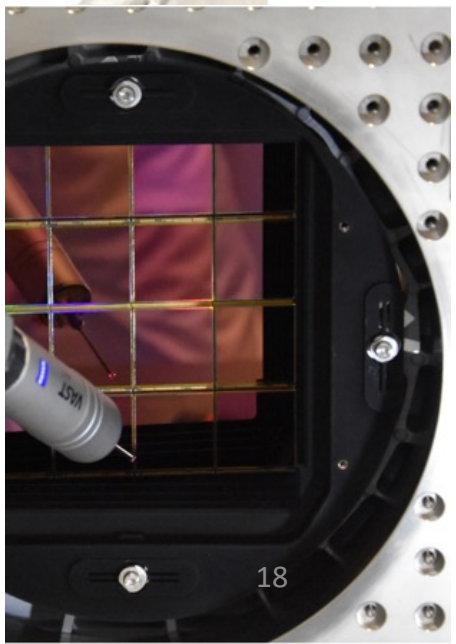


Instrument characteristics

Near-infrared spectrometer and photometer (NISP)

Field-of-view	0.763 deg × 0.722 deg			
Capability	Near-infrared imaging photometry			Near-infrared spectroscopy
Wavelength range	Y (920 - 1146 nm)	J (1146 - 1372 nm)	H (1372 - 2000 nm)	1100 - 2000 nm
Sensitivity	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
Detector Technology	16 arrays 2k × 2k near-infrared sensitive HgCdTe detectors			



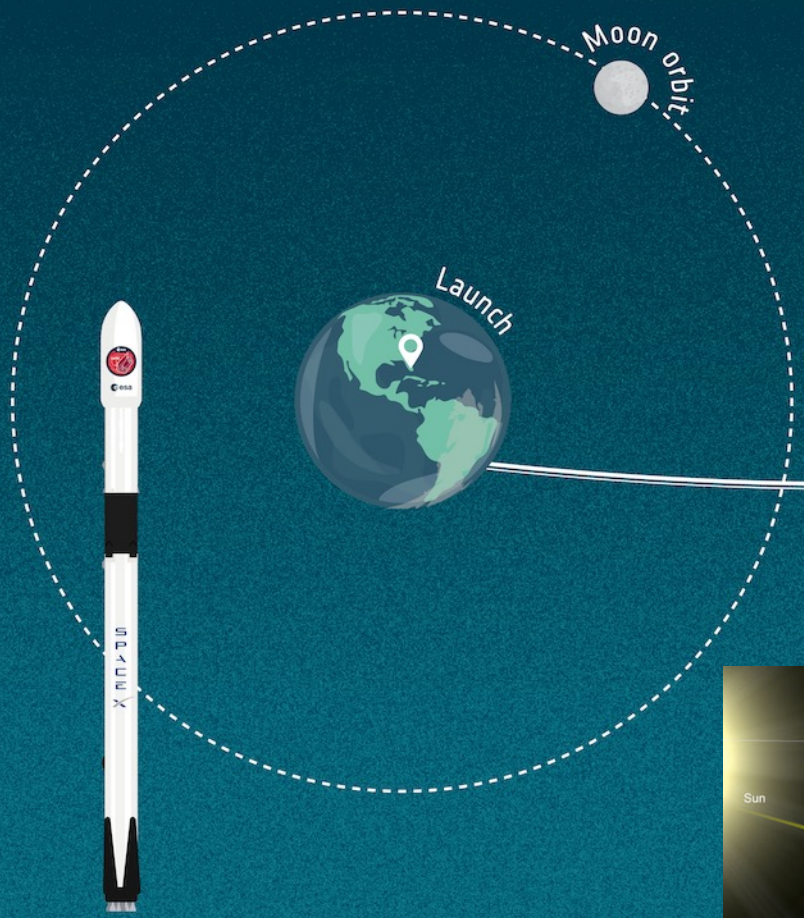


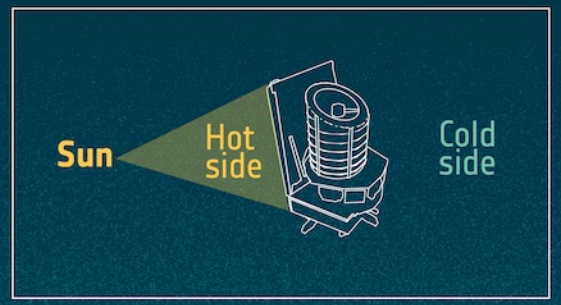
Successful Launch on July 1st,2023

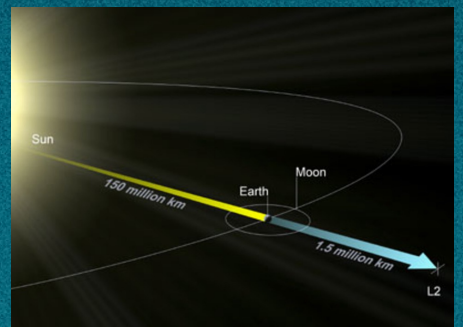
Euclid launched on a Falcon 9 on 1st July 2023, from Cape Canaveral. (Credits: ESA, NASA & Space-X)

EUCLID'S JOURNEY TO L2

Euclid will orbit the second Lagrange point (L2), 1.5 million kilometres from Earth in the opposite direction from the Sun. L2 is an equilibrium point of the Sun-Earth system that follows the Earth around the Sun. In its orbit at L2, Euclid's sunshield can always block the light from the Sun, Earth and Moon while pointing its telescope towards deep space, ensuring a high level of stability for its instruments.







Launch (L)

L+2 days:

Euclid is on its way to L2

L+2 weeks:

Euclid cool-down is complete

L+4 weeks:

Euclid in orbit around L2

L+4 weeks:

Telescope aligned and all instruments turned on

L+1–3 months:

Testing of scientific performance and readiness for science

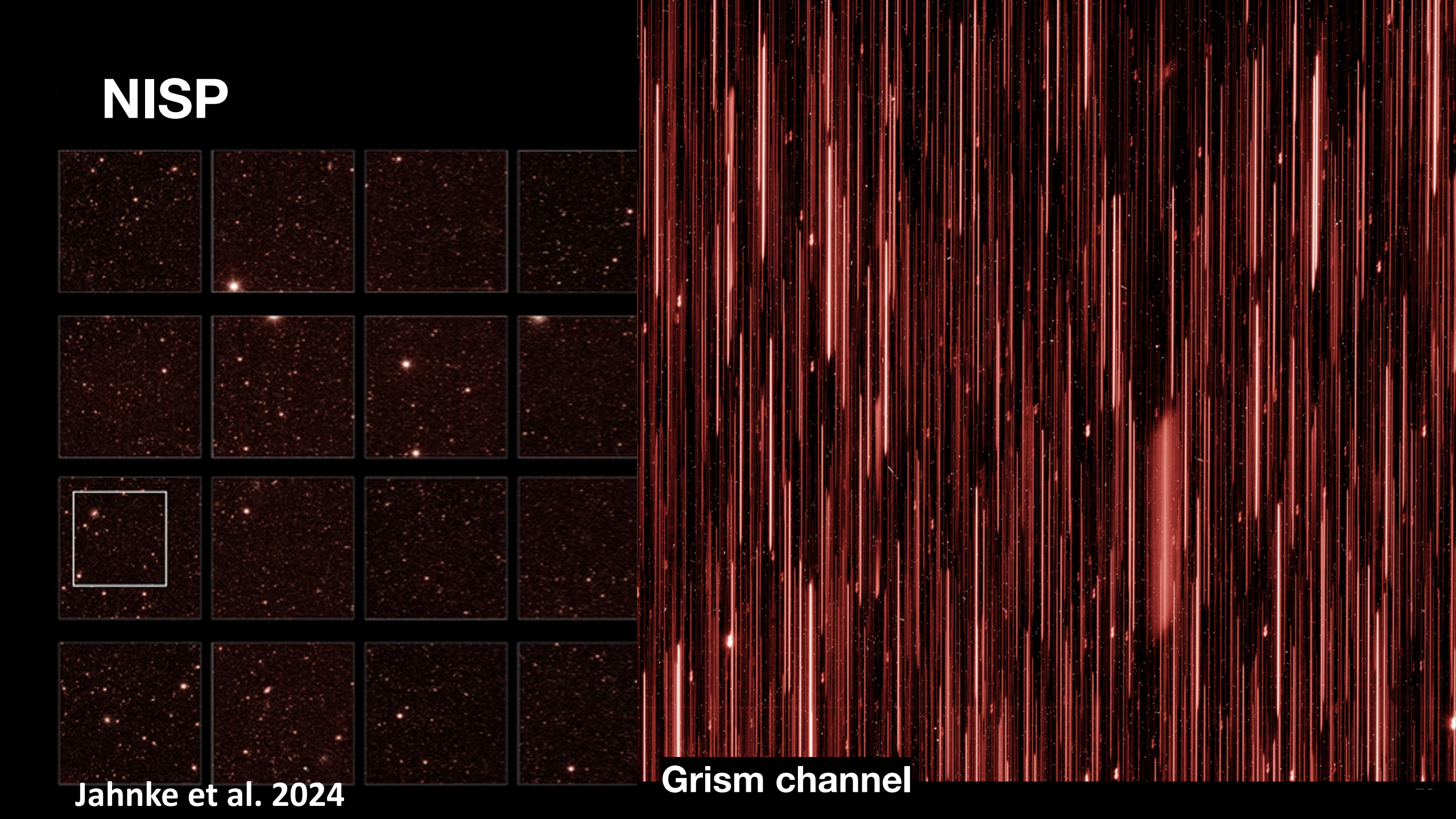
L+3 months:

Euclid begins its survey

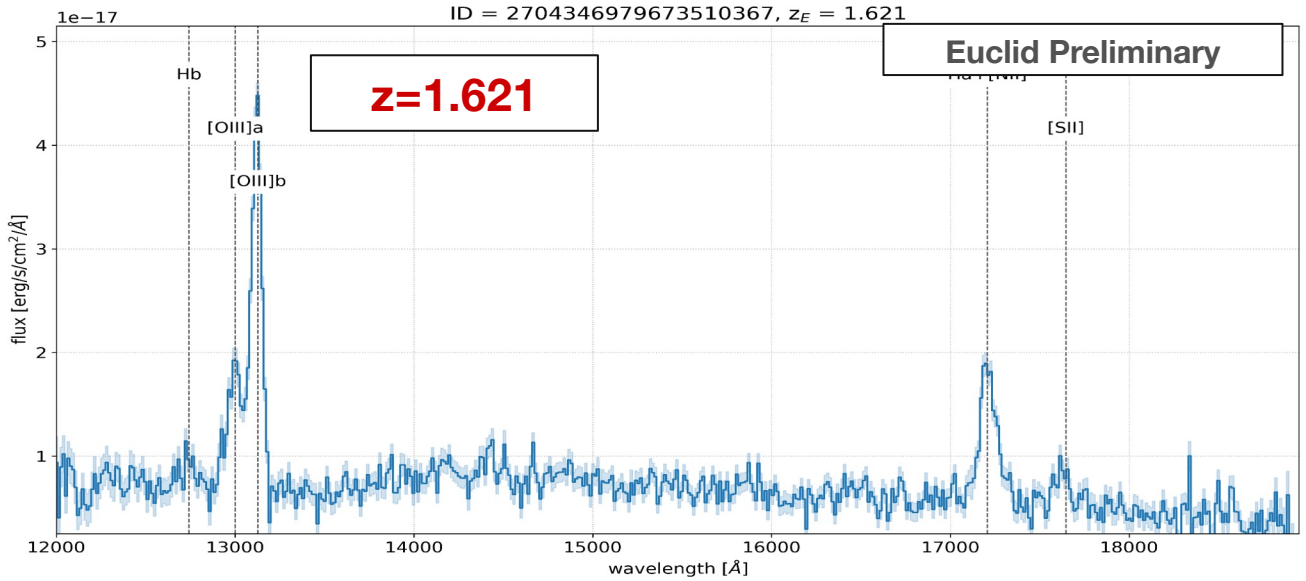

Horsehead Nebula (1375 ly)
Spiral Galaxy IC342 (11 mly)
Globular Cumulus NGC 6397 (7.8 kly)
Euclid First Images
Supernova
Explosions
Irregular Galaxy NGC 6822 (1.6 mly)
Perseus Galaxy Cumulus (240 mly)

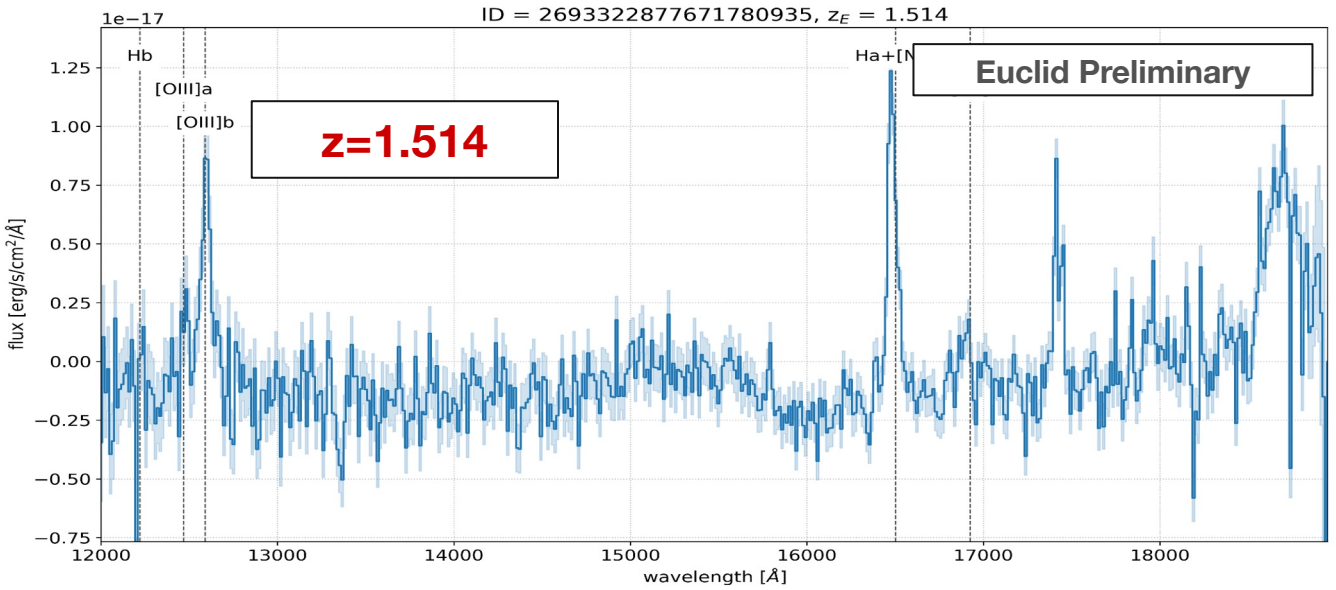
Chris Pattison

This is a single Hubble pointing at the same scale.


NISP
Grism channel
Jahnke et al. 2024

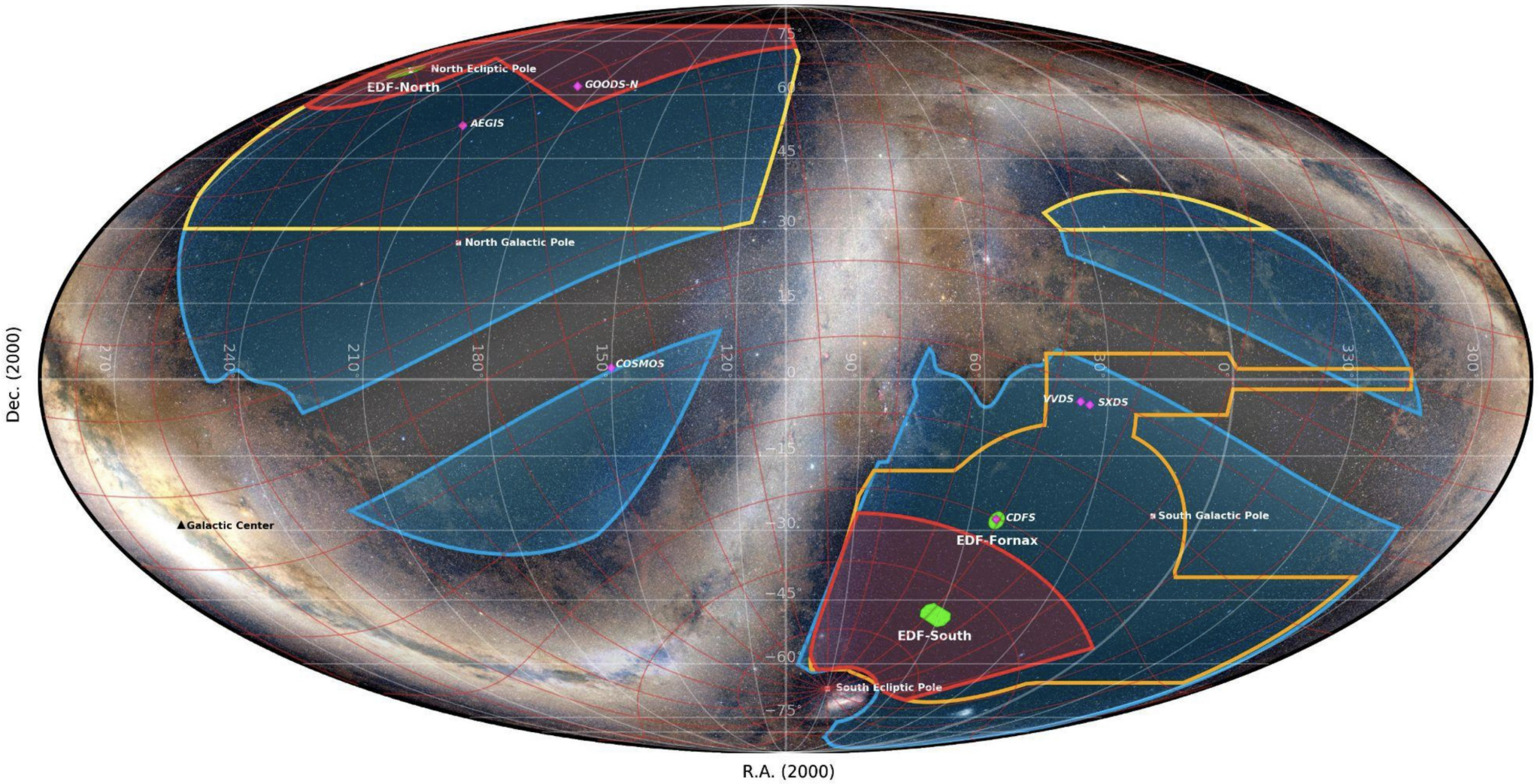
Examples of high SNR spectra





strong emission line galaxy, with multiple lines

Euclid Survey



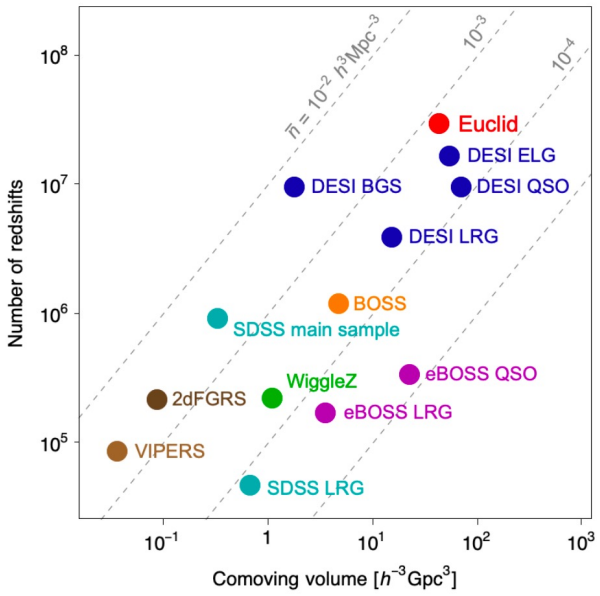
Euclid observes ~10 deg²/day in the wide survey

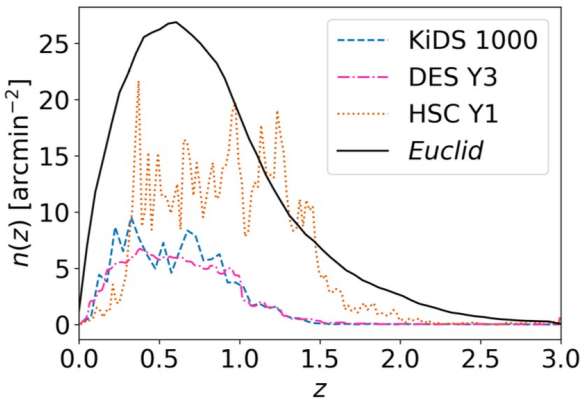
The Euclid Wide Survey DR1 area maximizing the overlap with DES : North = 821 deg², South = 1657 deg² [Mollweide Celestial]

- Euclid Wide Survey region of interest : 17,354 deg²
- DES, griz, 2013−19 : 4500 deg² overlap with the region of interest
- UNIONS [CFIS / JEDIS−g / Pan−STARRS / WISHES], ugriz, 2017−27 : 4800 deg²
- Euclid DR1 area, 2023 : 2500 deg²
- Euclid Deep Fields [total 43 deg²]

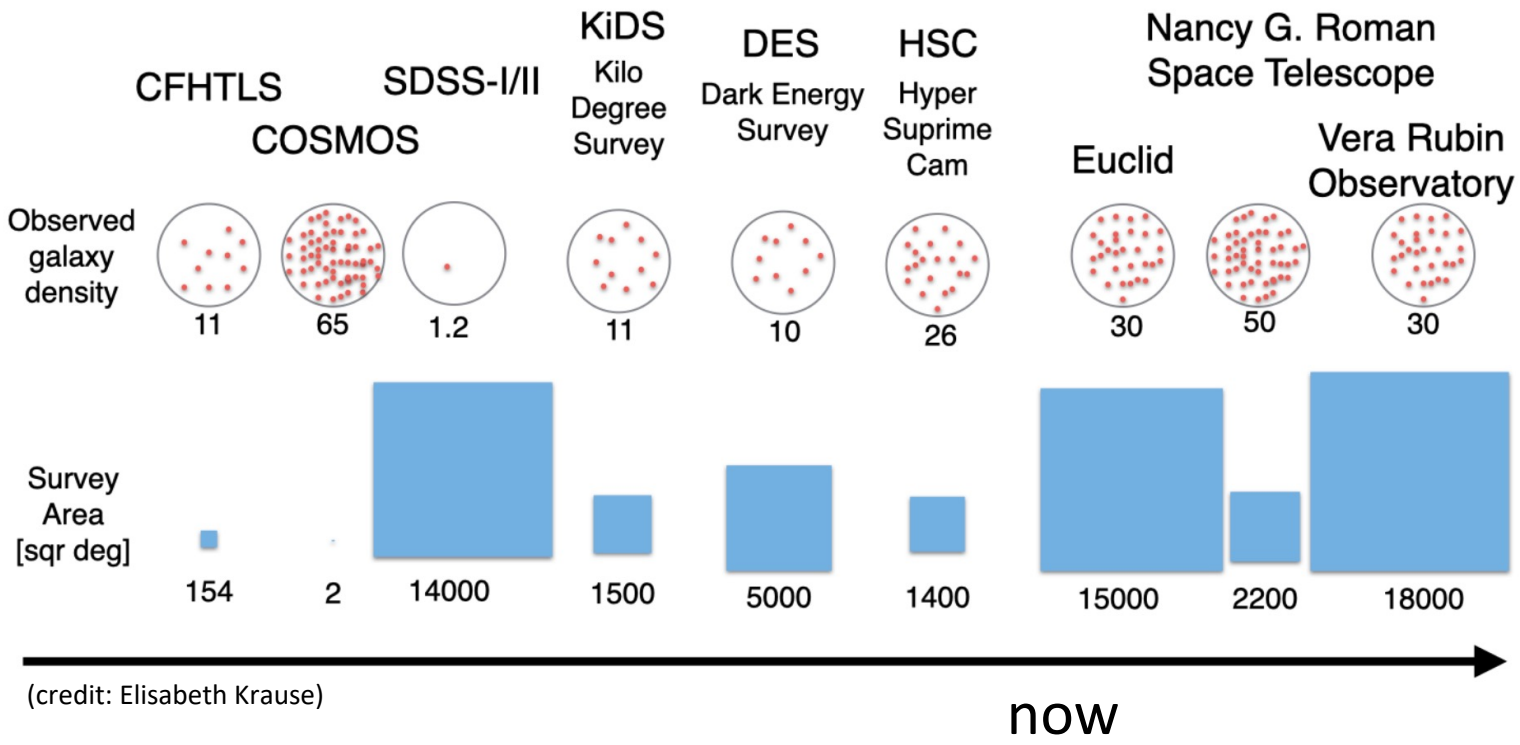
Background image: Euclid Consortium / Planck Collaboration / A. Mellinger

The Euclid Survey in Context





Euclid WL vs. Stage III & IV experiments



(credit: Elisabeth Krause)

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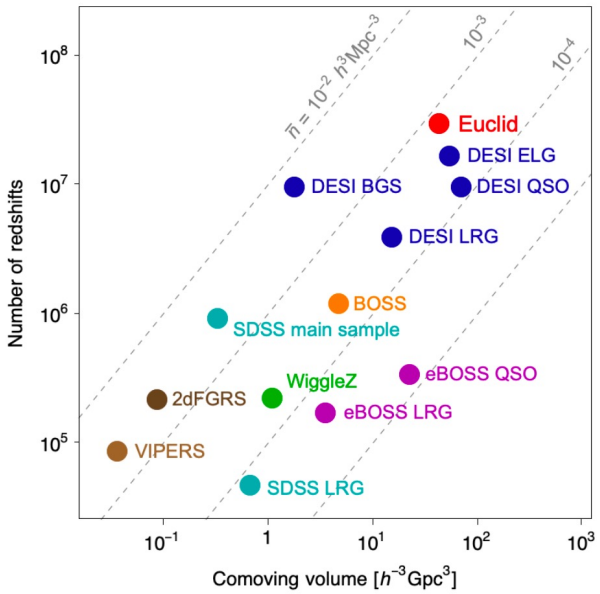

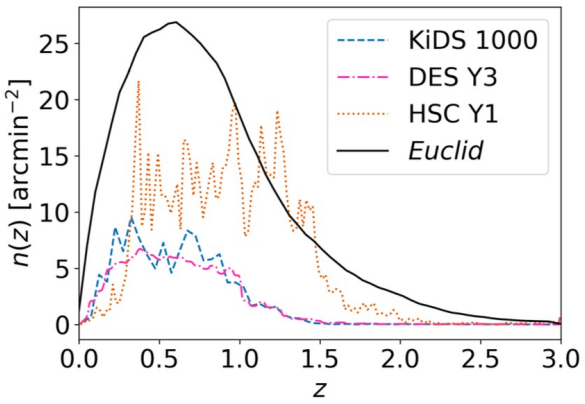

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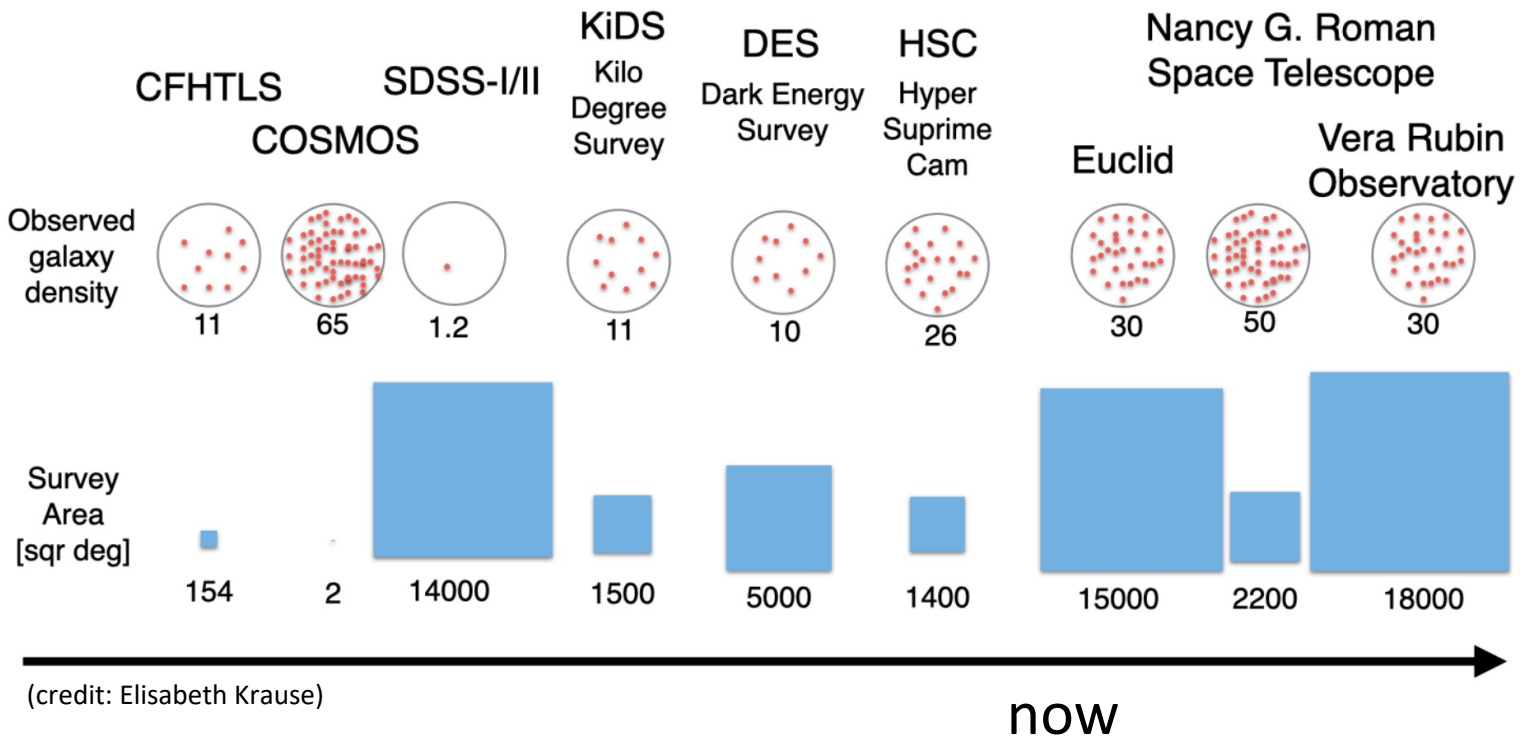
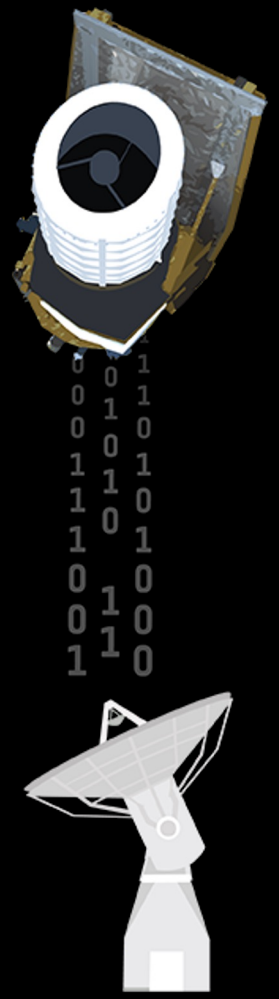


(credit: Elisabeth Krause)

Unprecedented volume coverage with objects up to redshift 2

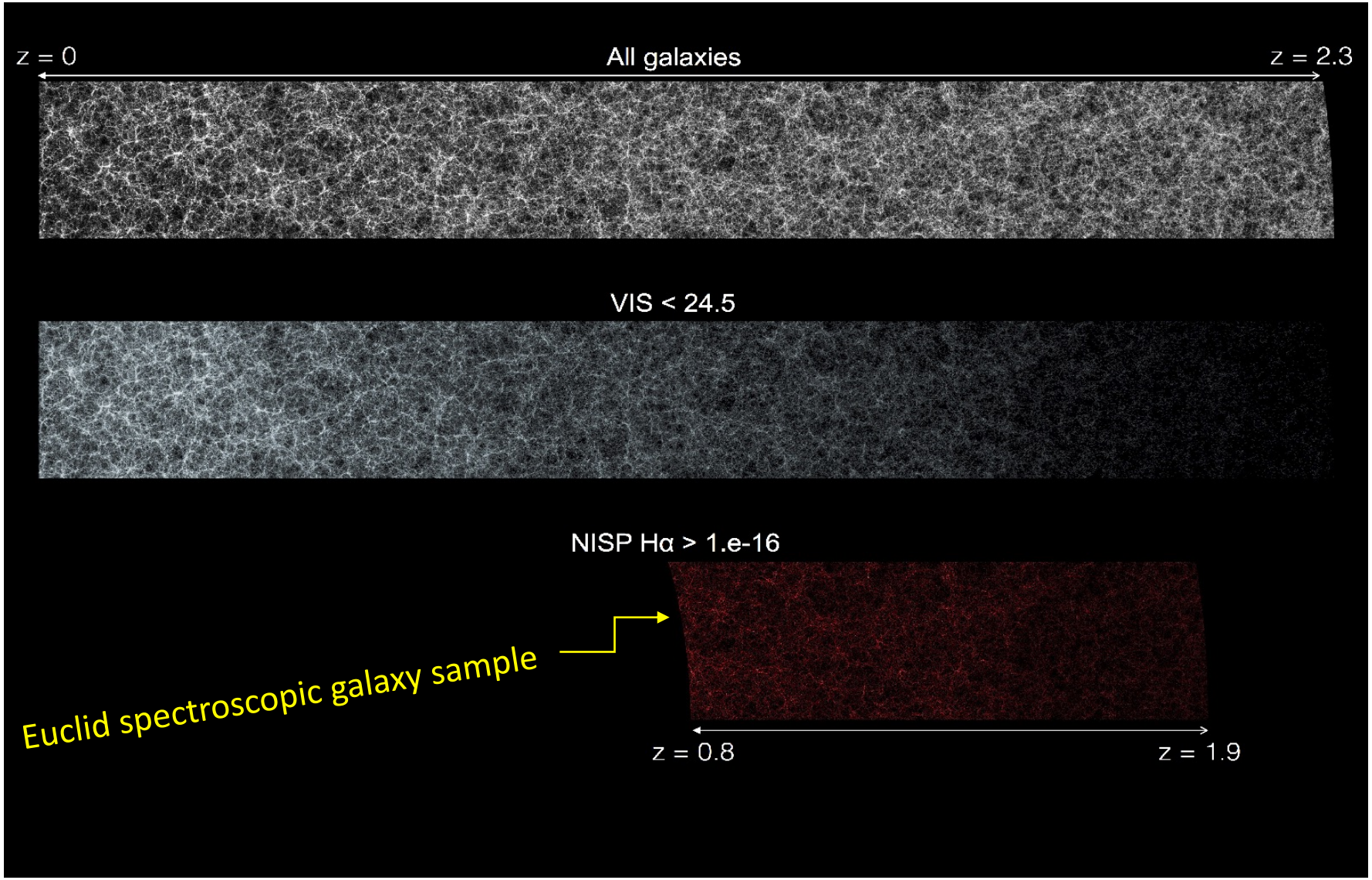
Data transfer



- Collecting 30 Petabytes of unprocessed data
- Communications from L2, to ESOC (Germany), to ESAC (Madrid), once per day
- Distribution along 9 dedicated data centres

Credit: ESA/ATG

Euclid Flagship Simulations



Simulations are crucial to achieve Euclid's scientific goals:

- Instrumental effects
- Analysis biases
- ….

Just cannot simulate multiple universes….

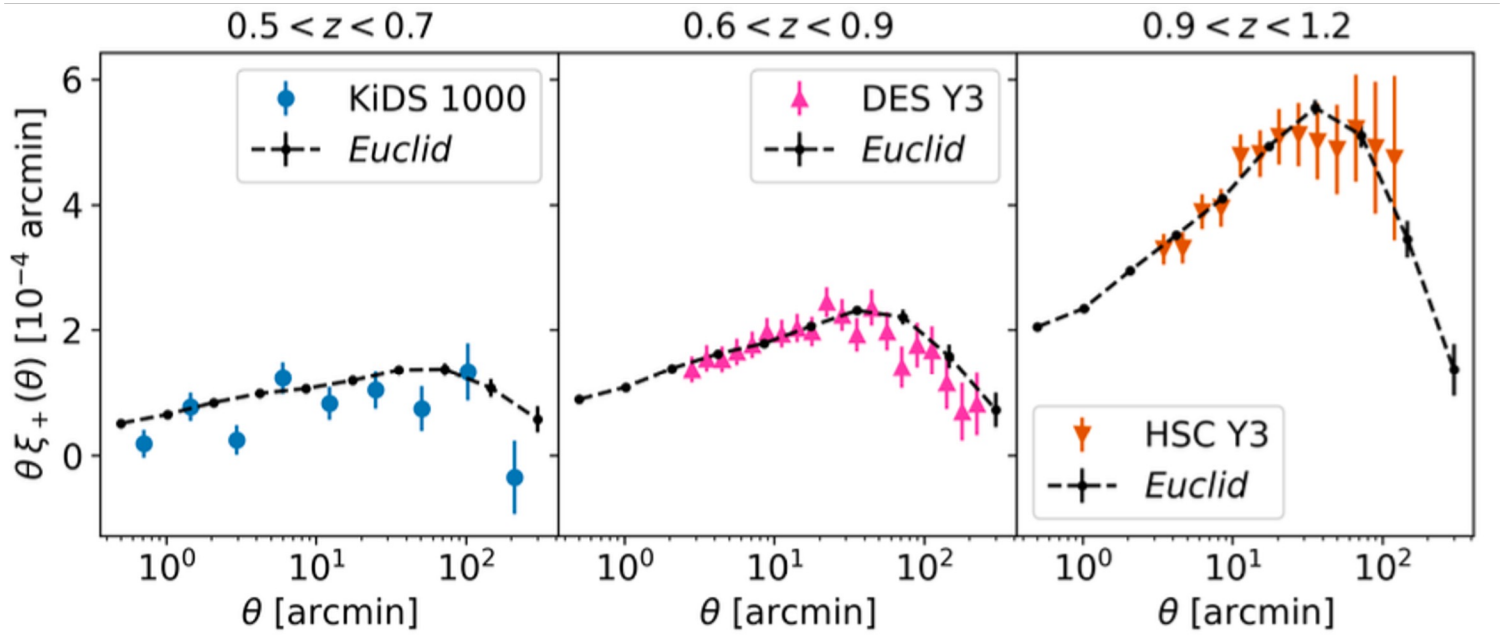
Cosmology with Euclid: combined probes (weak lensing & galaxy clustering)

The so-called "3x2pt" analysis combines:

- Angular auto-correlation functions (galaxy positions);
- Shear auto-correlation functions (galaxy ellipticities);
- Cross-correlations between positions and ellipticities.

Sensitive to the matter distribution along the line-of-sight, and the history of structure formation.

Forecast shear auto-correlation functions (with the highest S/N for every survey)



(Mellier et al 2024)

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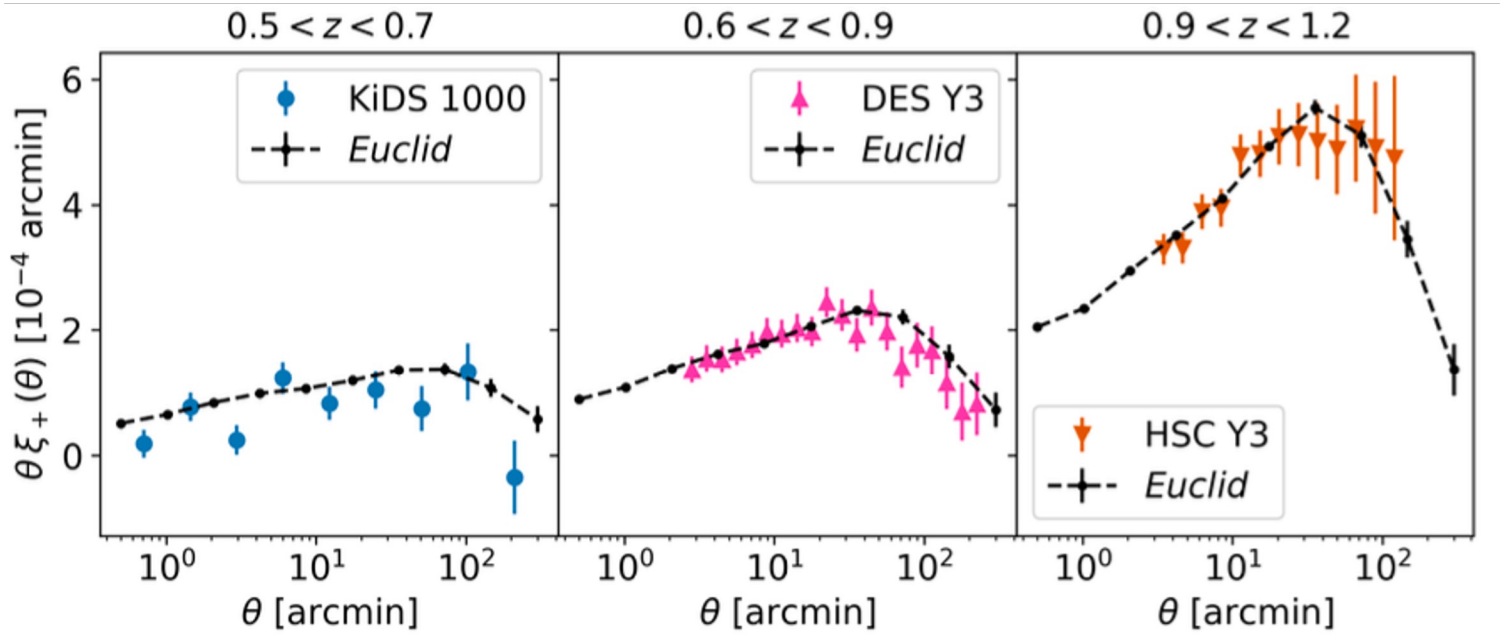


(Mellier et al 2024)

Euclid S/N an order of magnitude higher than other surveys

Cosmological inference: overview

Theoretical Predictions

COMPUTE EUCLID PRIMARY OBSERVABLES ACCORDING TO THE THEORY

Non-linear cosmology

MODEL NON-LINEAR SCALES FOR POWER SPECTRA

Euclid data as input

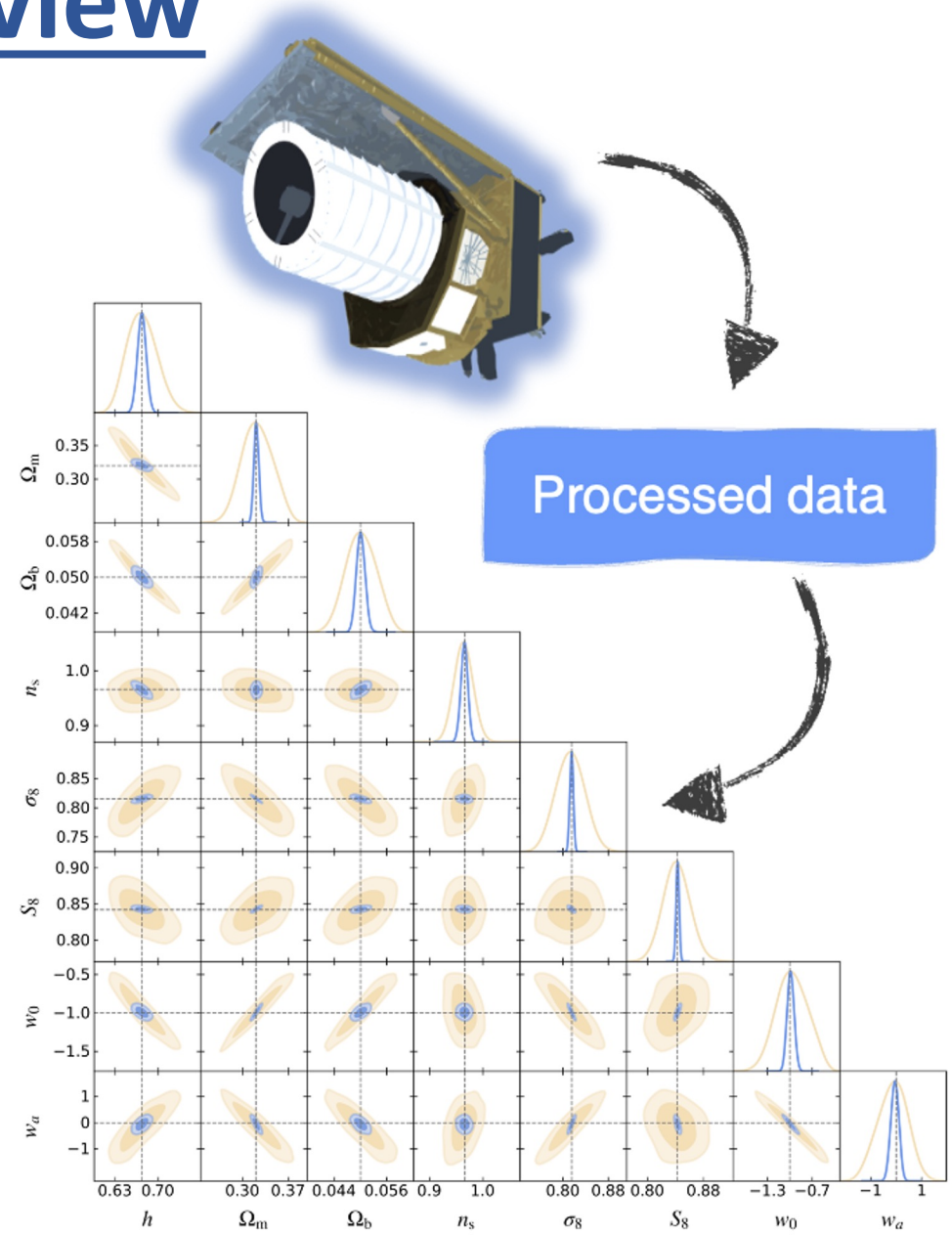
DATA VECTORS ARE PROVIDED BY THE EUCLID SCIENCE GROUND SEGMENT

Likelihood computation

WE COMPARE THEORY AGAINST DATA DOING A STATISTICAL ANALYSIS

Cosmological parameters

PRODUCE THE BAYESIAN STATISTICAL ANALYSIS TO OBTAIN CONSTRAINTS ON COSMOLOGICAL PARAMETERS

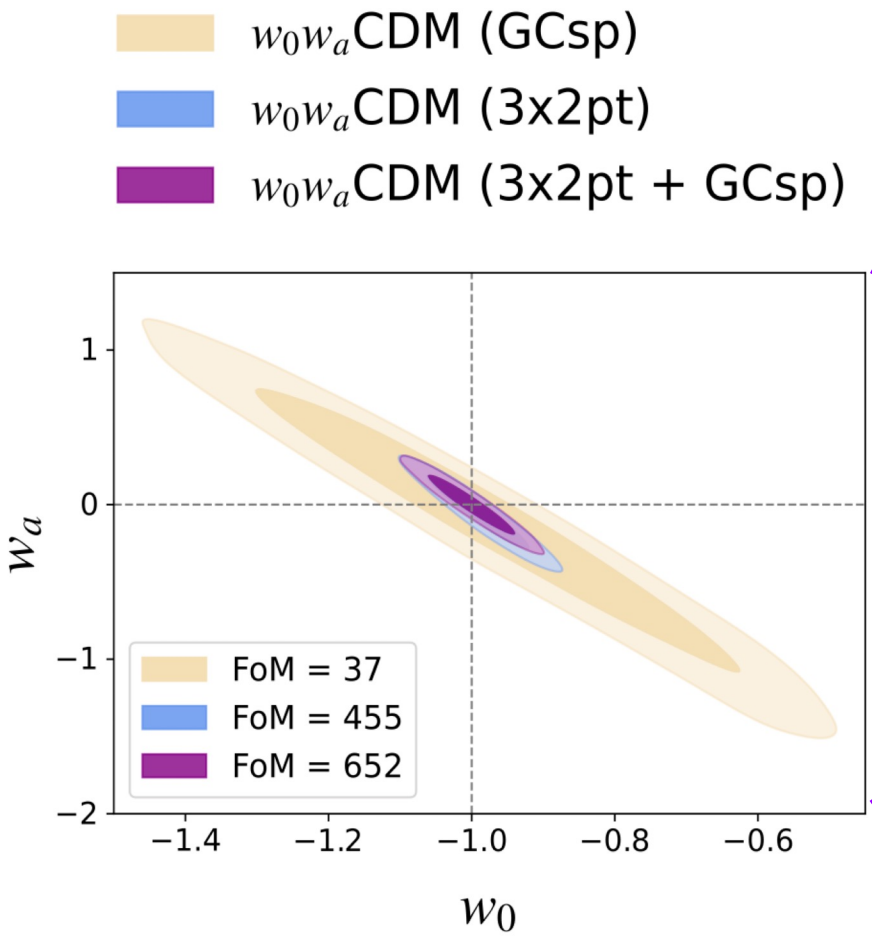


Euclid: the physics of cosmic acceleration

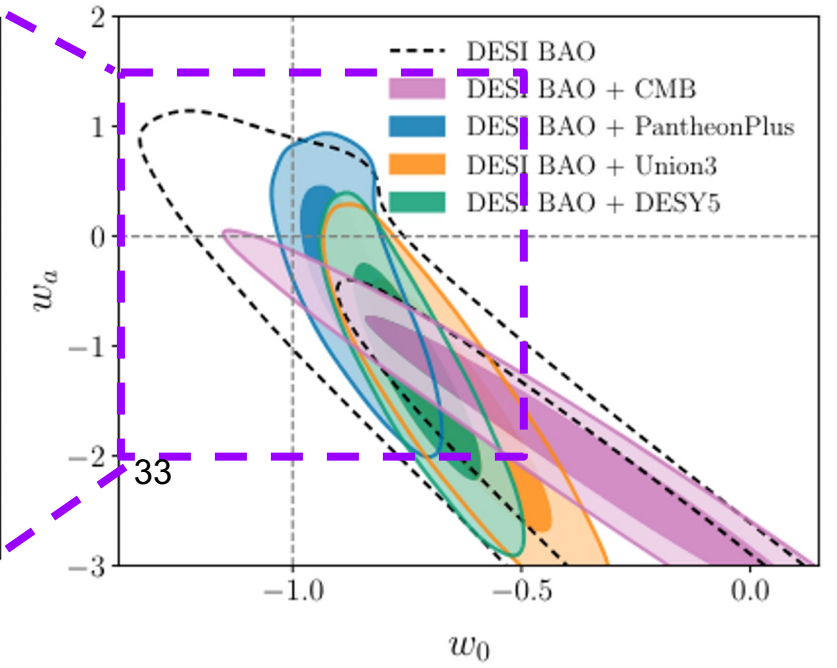
The dark energy equation of state $w \neq -1$ indicates a departure from the cosmological constant, requiring a dynamical dark energy scenario.

Parameterized evolution of $w(z)$:

$$w(z) = w_0 + w_a \frac{z}{1+z}$$



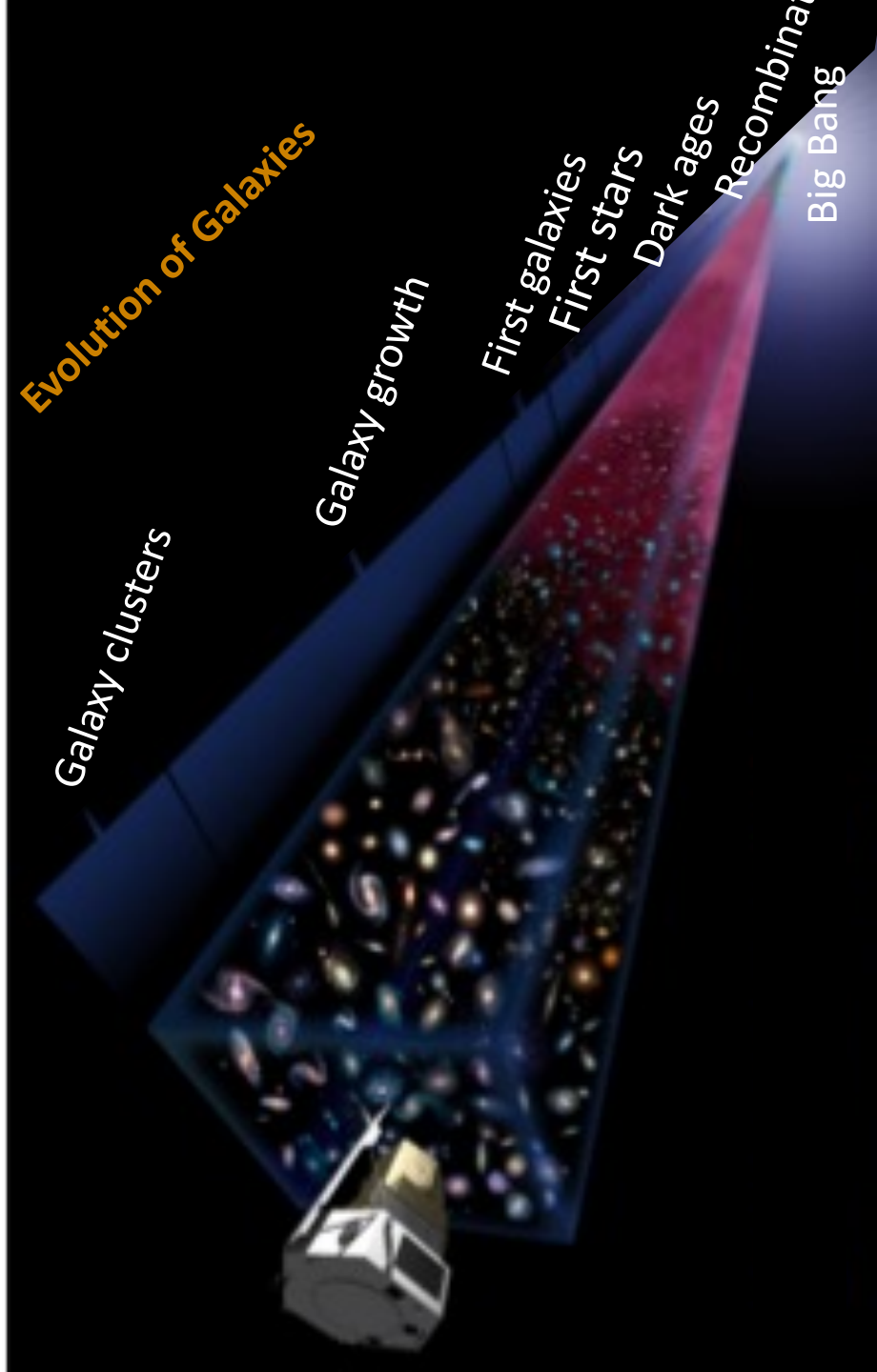
Euclid Forecast
(Mellier et al 2024)



DESI Collaboration 2024

Euclid Additional Science

- 10^5 **galaxy clusters**
- **Cosmic Voids**
- **Cross-correlations with CMB** temperature and lensing
- 10^5 **strong gravitational lenses**
- Transients in Deep fields
  - ~50 **Super-luminous SNe** / year (Inserra+17)
- Galaxy formation and evolution
  - Census of **AGN** at $1 < z < 3$
  - Galaxy **morphologies** at $z > 1$
  - **Lyman break galaxies** at $z > 7$
  - High-z **quasars**
- Milky Way
  - Census of **brown dwarf** stars
  - **Satellites & environs**



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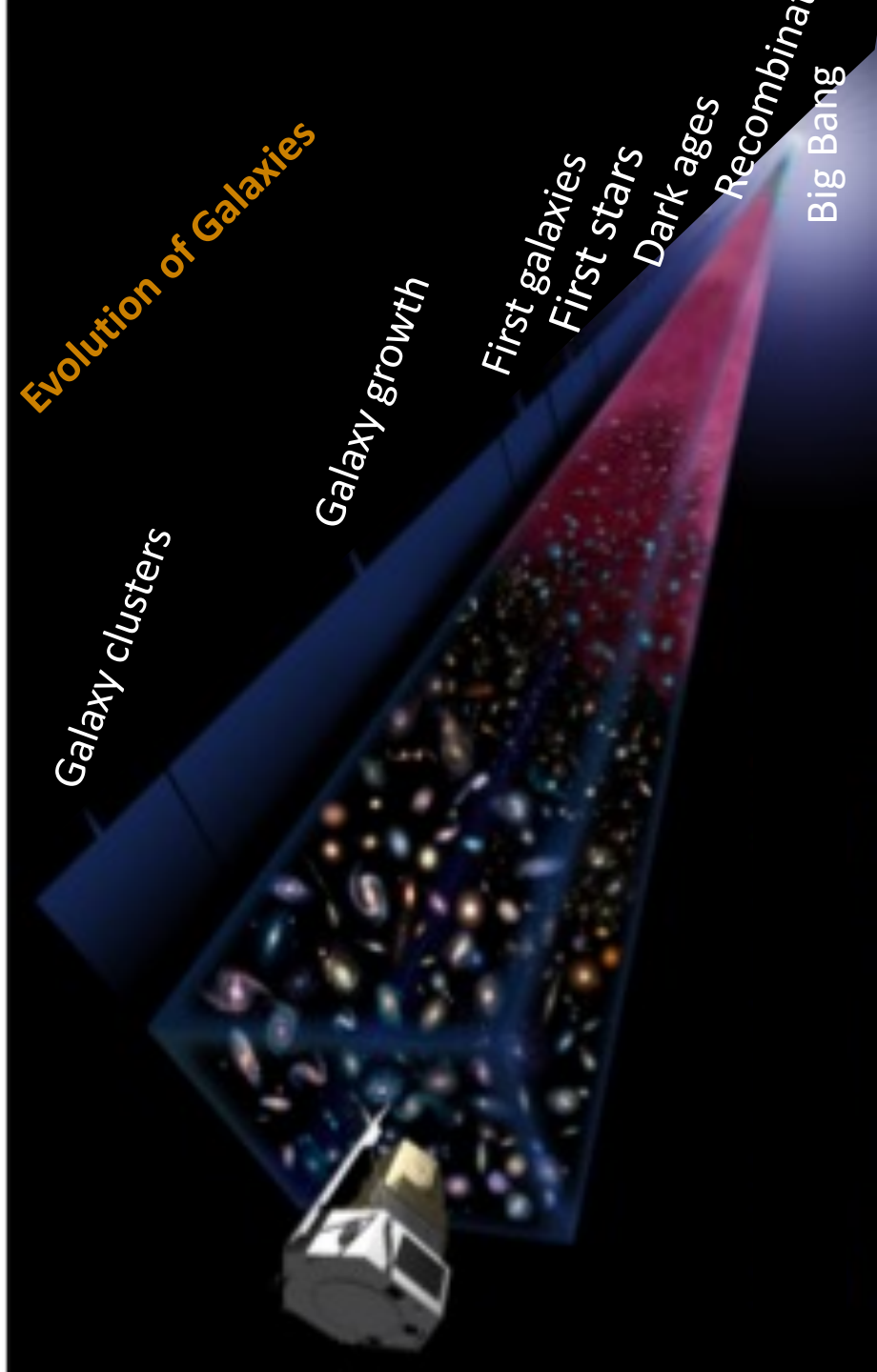
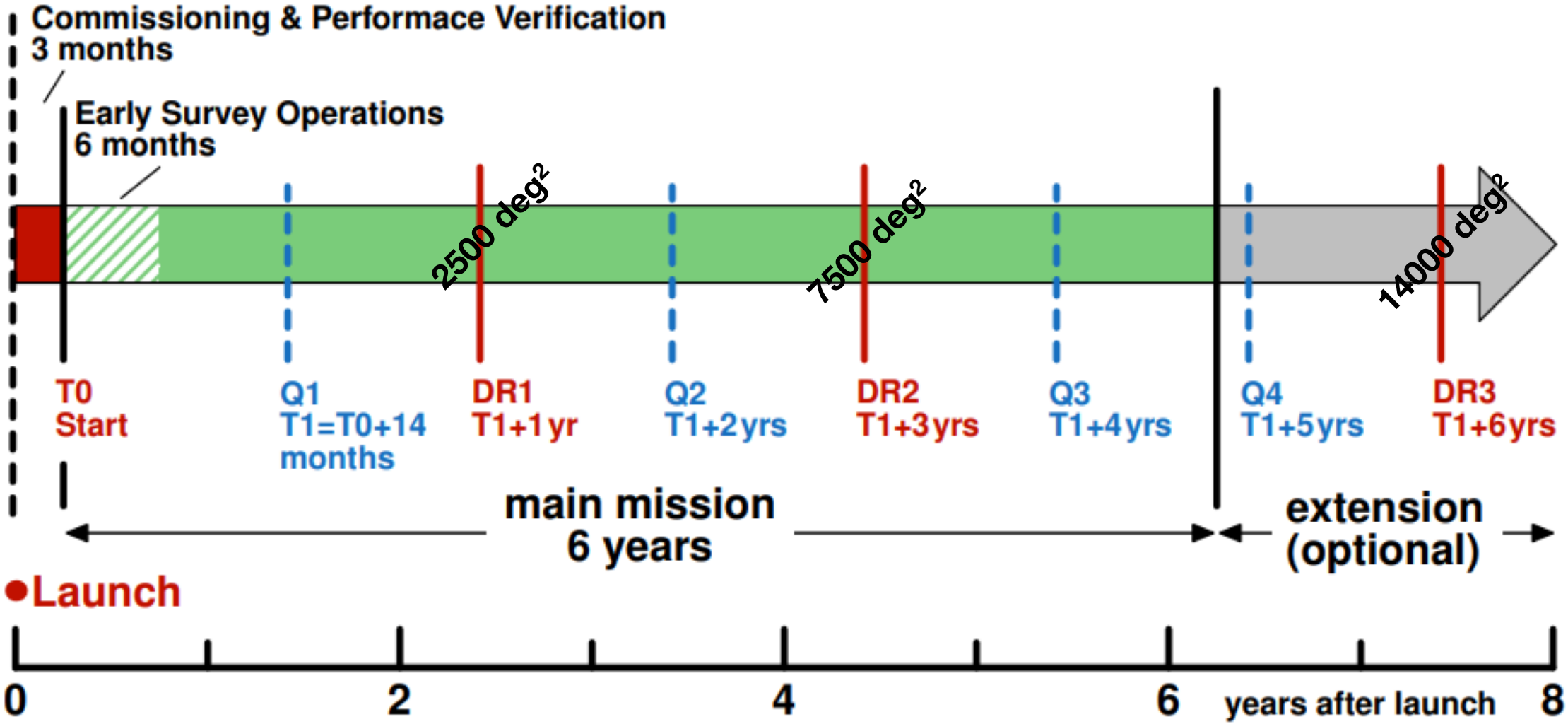
x10 in number of sources compared to previous surveys in most cases



The Euclid Data Releases



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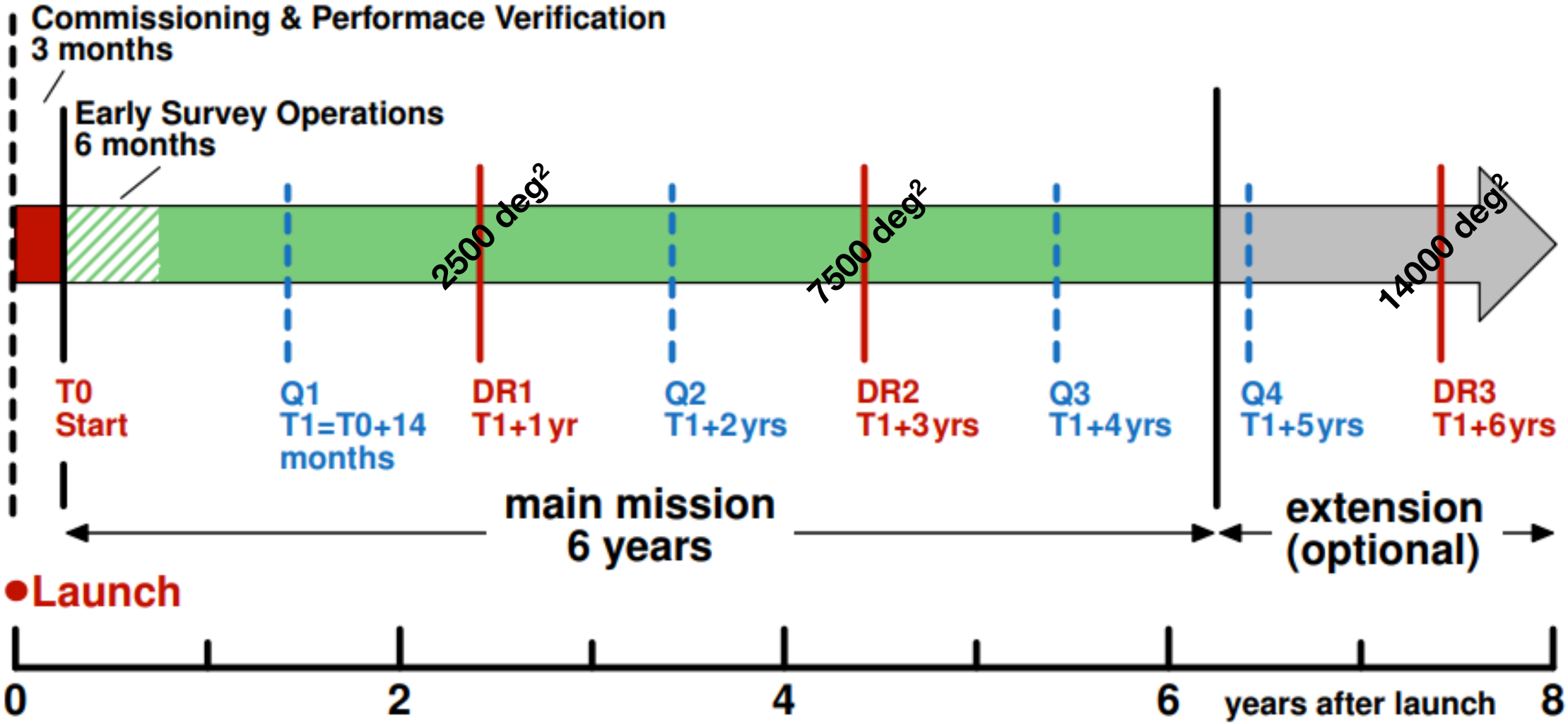

First Cosmology results in 2026 and several public releases afterwards that will continue to produce interesting physics results

Summary

- **Euclid** will observe **1/3 of sky at redshifts up to 2**
  - Currently observing ~10 deg^2/day
- The results will provide high precision results in the **Dark Energy Equation of state** and other cosmological parameters
- Spacecraft, system and instruments **work as expected**
  - Early issues (guiding system, stray light) solved brilliantly
  - X-ray flares and ice deposition are handled successfully on a regular basis
- Legacy data will also help understanding key fundamental issues in **non-cosmological science**
  - We just released the Early Release Observation papers

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Euclid aims to map 2 billion years of cosmic history to understand the nature of Dark Energy and Dark Matter, creating the largest 3D catalogue ever built of the Universe's Large Scale Structure

List of Early Release Observation papers

- Euclid: Early Release Observations – Programme overview and pipeline for compact- and diffuse-emission photometry, *Cuillandre et al.*
- Euclid: Early Release Observations – A glance at free-floating new-born planets in the σ Orionis cluster, *Martin et al.*
- Euclid: Early Release Observations – Unveiling the morphology of two Milky Way globular clusters out to their periphery, *Massari et al.*
- Euclid: Early Release Observations – Deep anatomy of nearby galaxies, *Hunt et al.*
- Euclid: Early Release Observations – Globular clusters in the Fornax galaxy cluster, from dwarf galaxies to the intracluster field, *Saifollahi et al.*
- Euclid: Early Release Observations – Overview of the Perseus cluster and analysis of its luminosity & stellar mass functions, *Cuillandre et al.*
- Euclid: Early Release Observations – Dwarf galaxies in the Perseus galaxy cluster, *Marleau et al.*
- Euclid: Early Release Observations – The intracluster light and intracluster globular clusters of the Perseus cluster, *Kluge et al.*
- Euclid: Early Release Observations – A preview of the Euclid era through a magnifying lens, *Atek et al.*
- Euclid: Early Release Observations – NISP-only sources and the search for luminous z = 6 – 8 galaxies, *Weaver et al.*

Credits

All Euclid material shown here on behalf of (and approved by) the *Euclid Consortium* and ESA

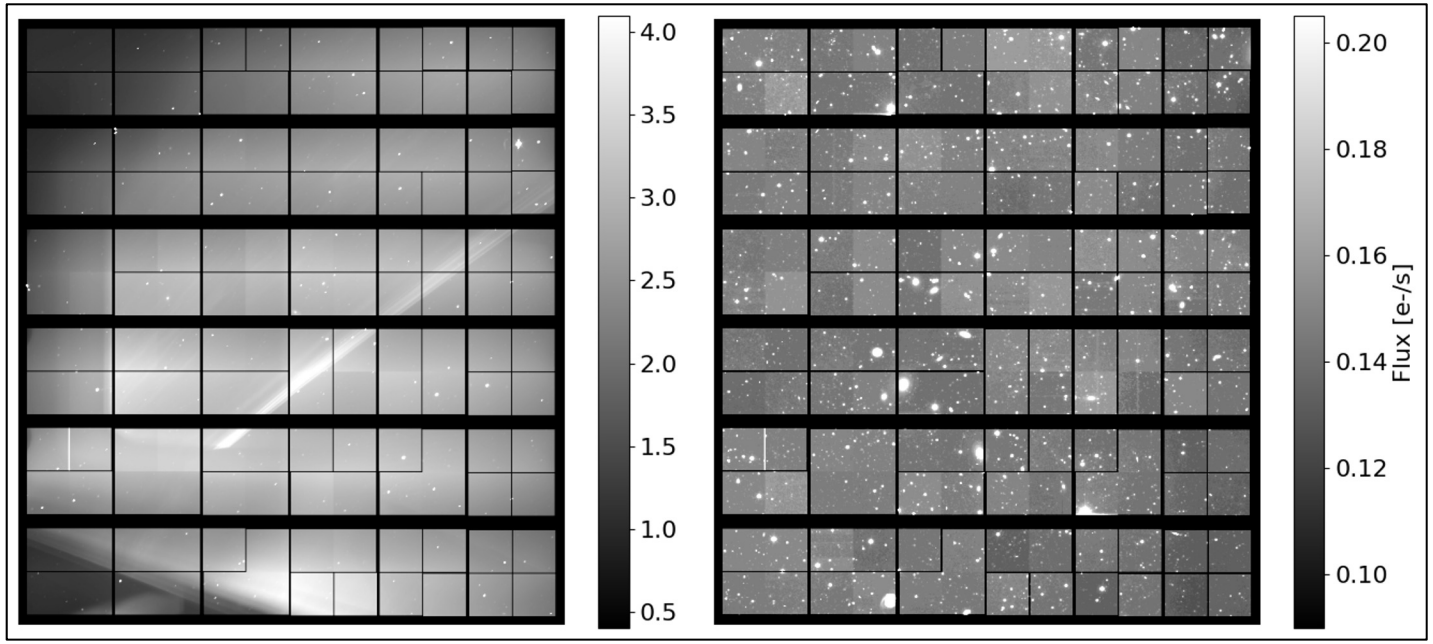
For more information and proper credit to national space agencies and funding organisations: https://www.euclid-ec.org/

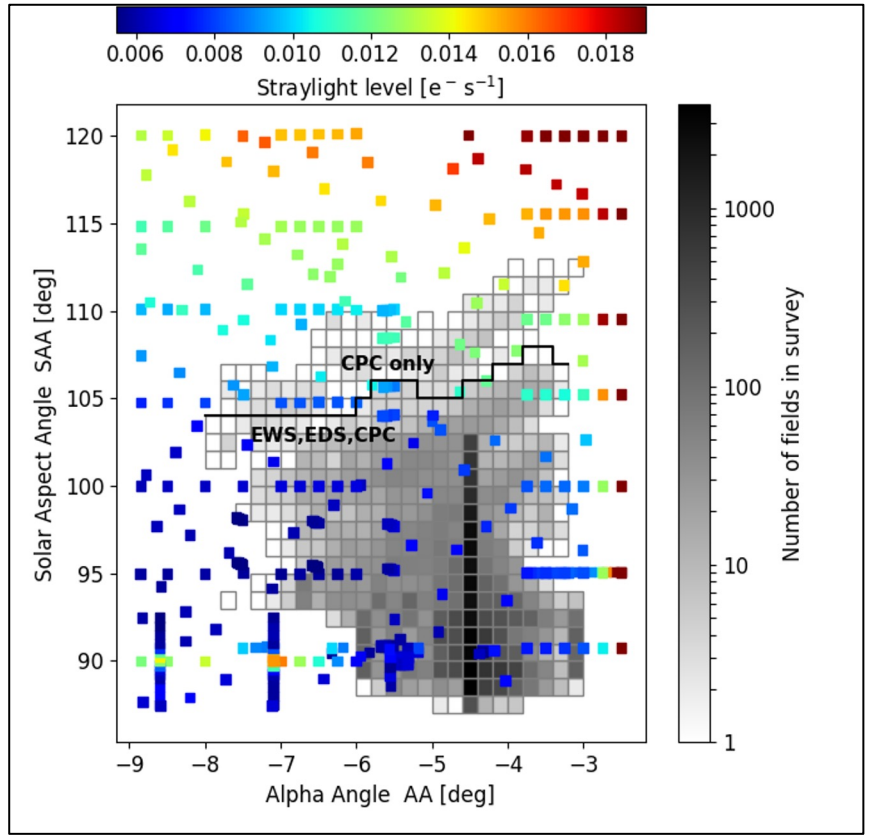
Pictures and movies:
https://www.esa.int/Science_Exploration/Space_Science/Euclid


euclid
consortium

EXTRA SLIDES

Internal straylight





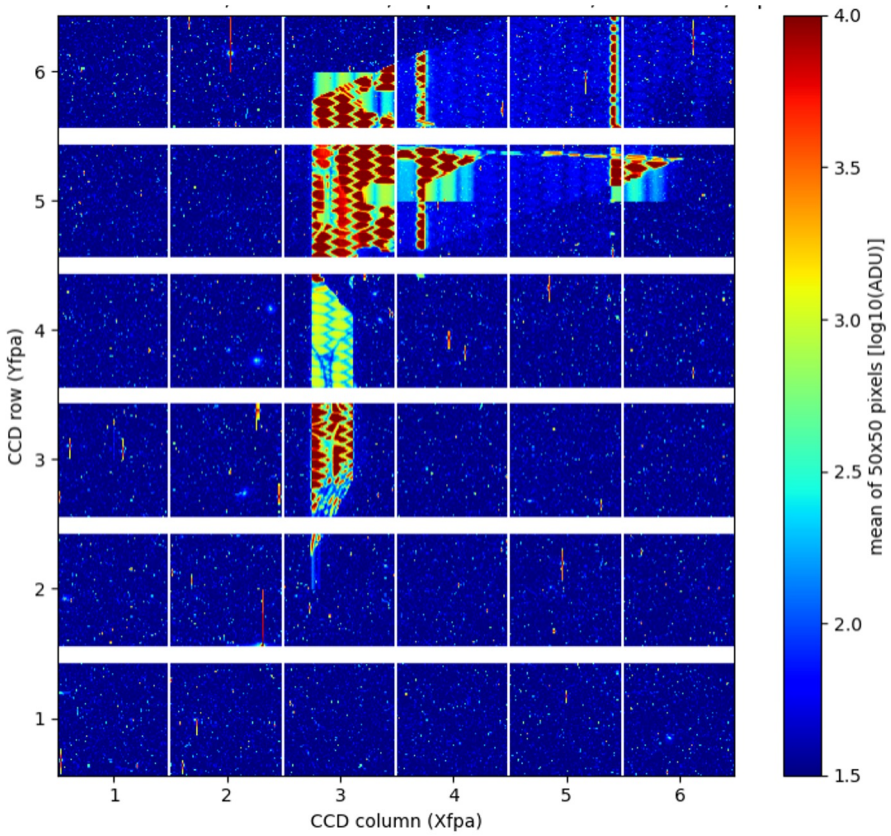
Left: Sunlight hitting a thruster nozzle reaches VIS detectors. NISP is unaffected.

Middle: Straylight is largely avoided by orienting Euclid so that nozzle is in shadow

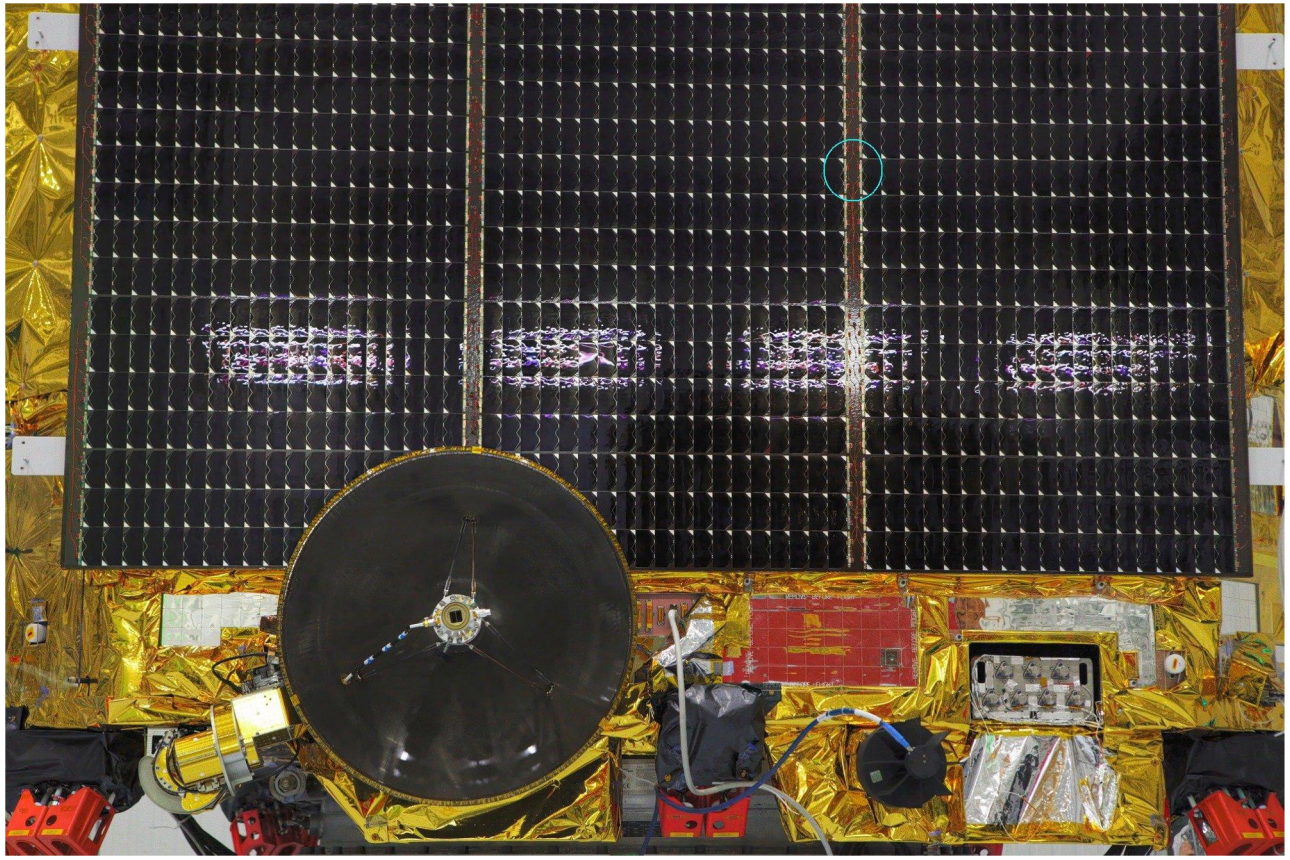
Right: The survey was fine-tuned to select low-straylight conditions, only.

X-ray contamination

X-rays from Solar flares penetrate sunshield and reach VIS. Average area loss during Solar maximum: 3-4%



VIS image taken during an X-class flare. Weak flares cause isolated cosmics. Strong flares result in contiguous area loss.



X-rays enter through the major gaps between solar cells.

Credit: J.-C. Cuillandre