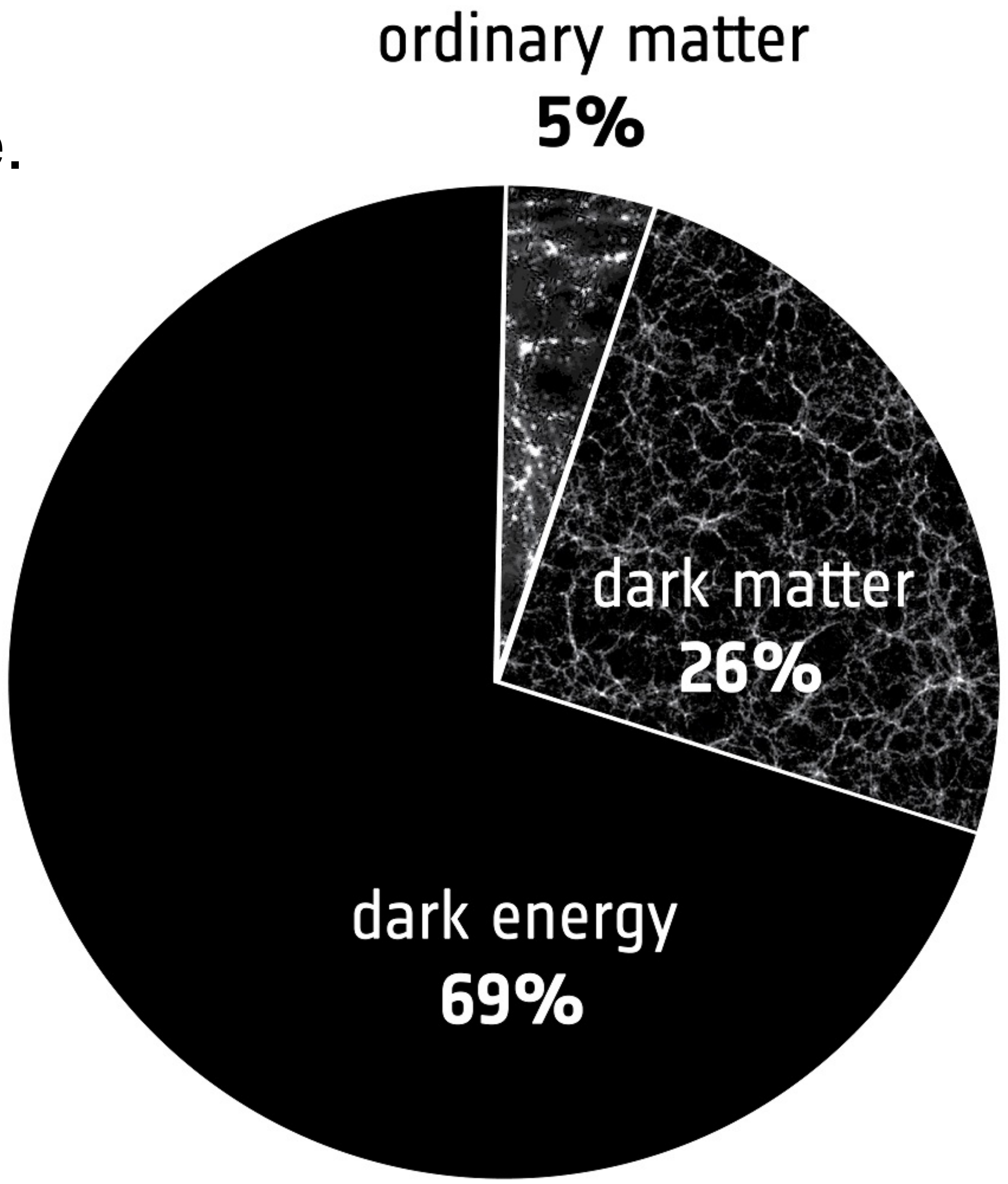
Euclid mission

Status and scientific goals

Alfonso Veropalumbo, on behalf of Euclid Consortium - Cosmology 2023 at Miramare - 28/08/2023

The cosmological model

- Probes of the primordial Universe gave us an accurate description of our Universe.
- Many questions are left open:
  - What is the nature of the **dark matter** component?
  - What is the nature of the **dark energy**?
  - What is the **origin of the large-scale structures**?



Credits: ESA

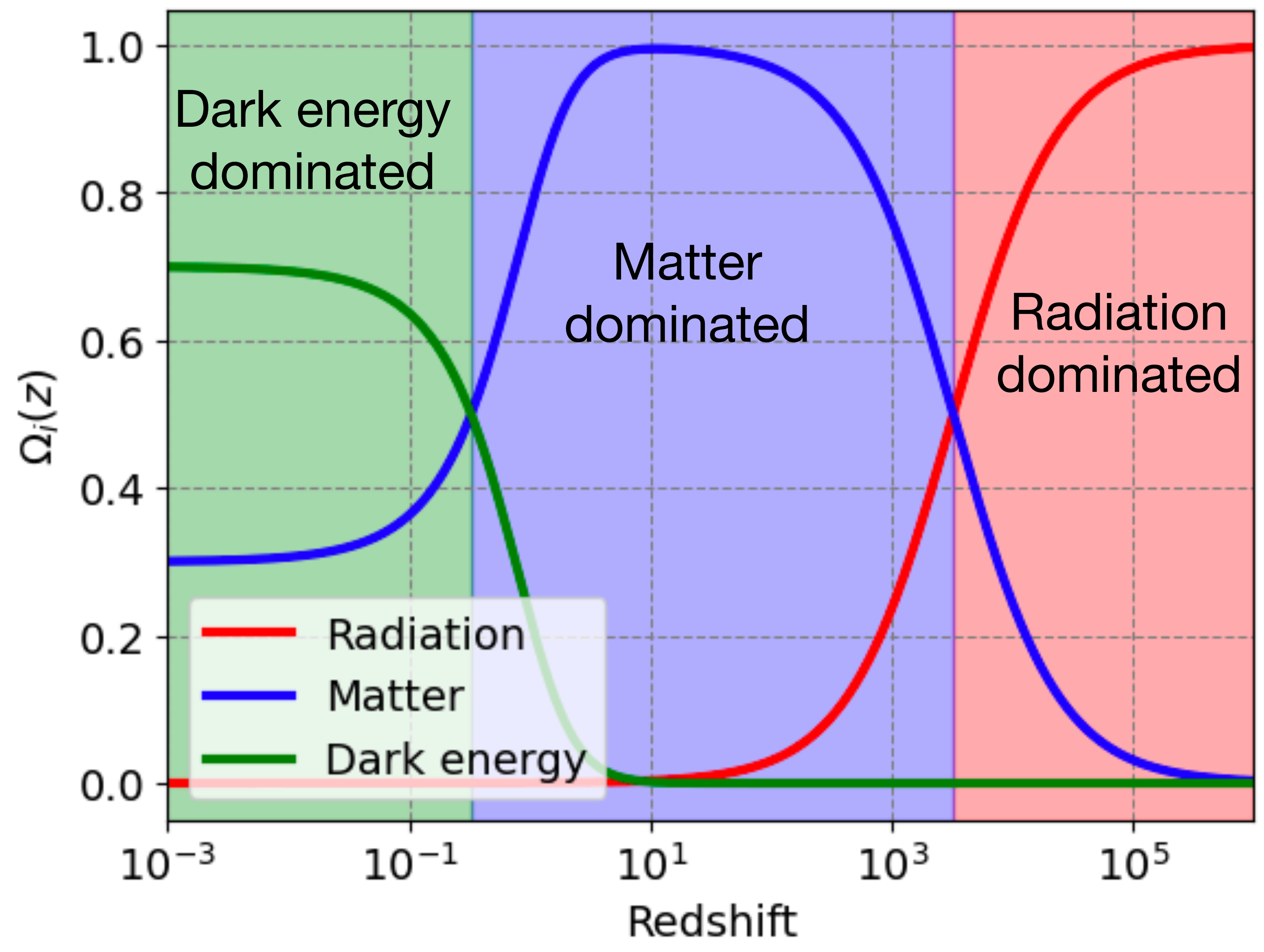
Dark energy

- Current knowledge points to a cosmological constant (Λ) dark energy model ($w_0 = -1, w_a = 0$).

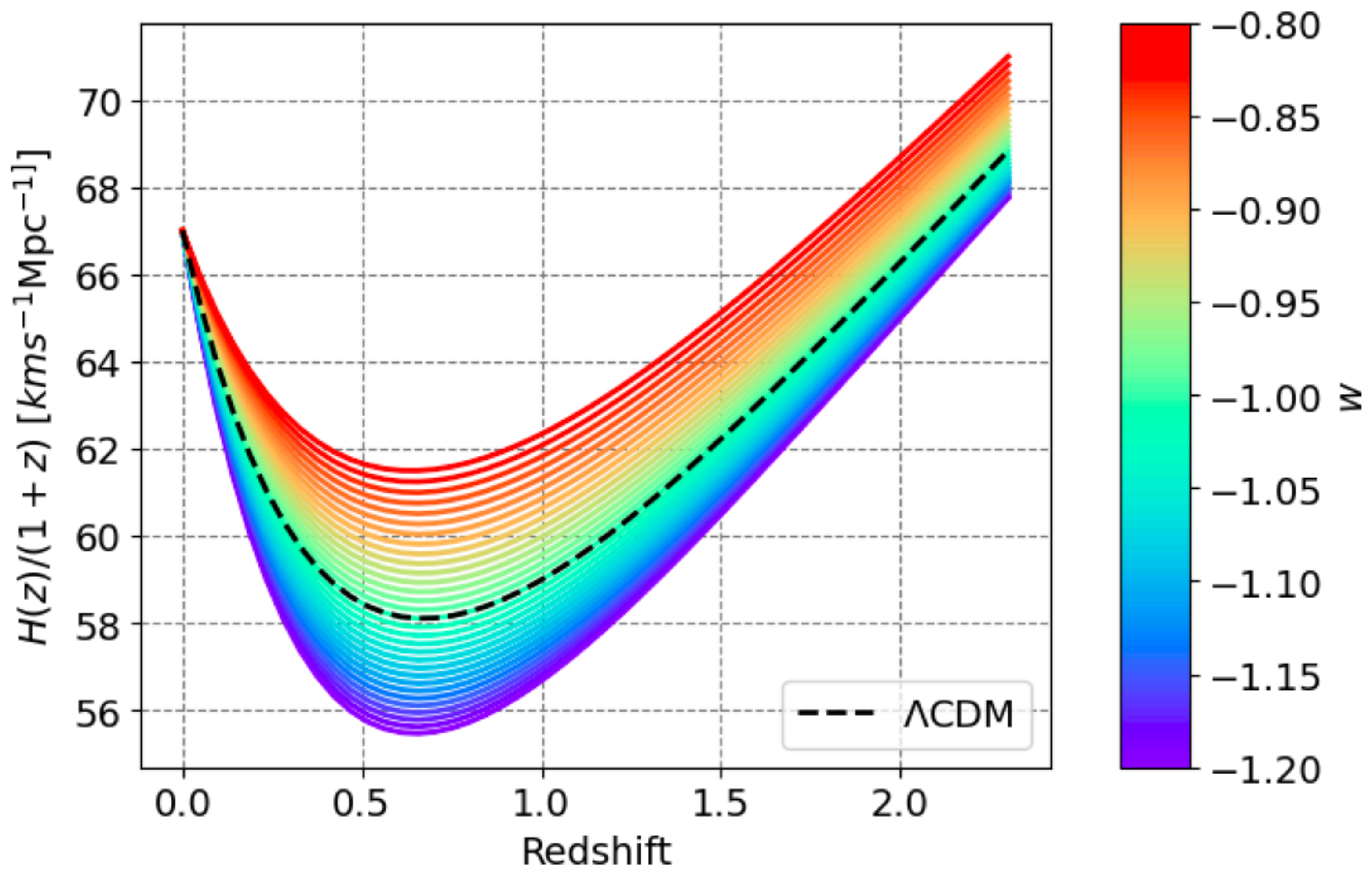
$$\rho_{\rm DE}(z) = \rho_{\rm DE,0}(1+z)^{3(1+w_0+w_a)}\exp\left[-3w_a\frac{z}{1+z}\right]$$

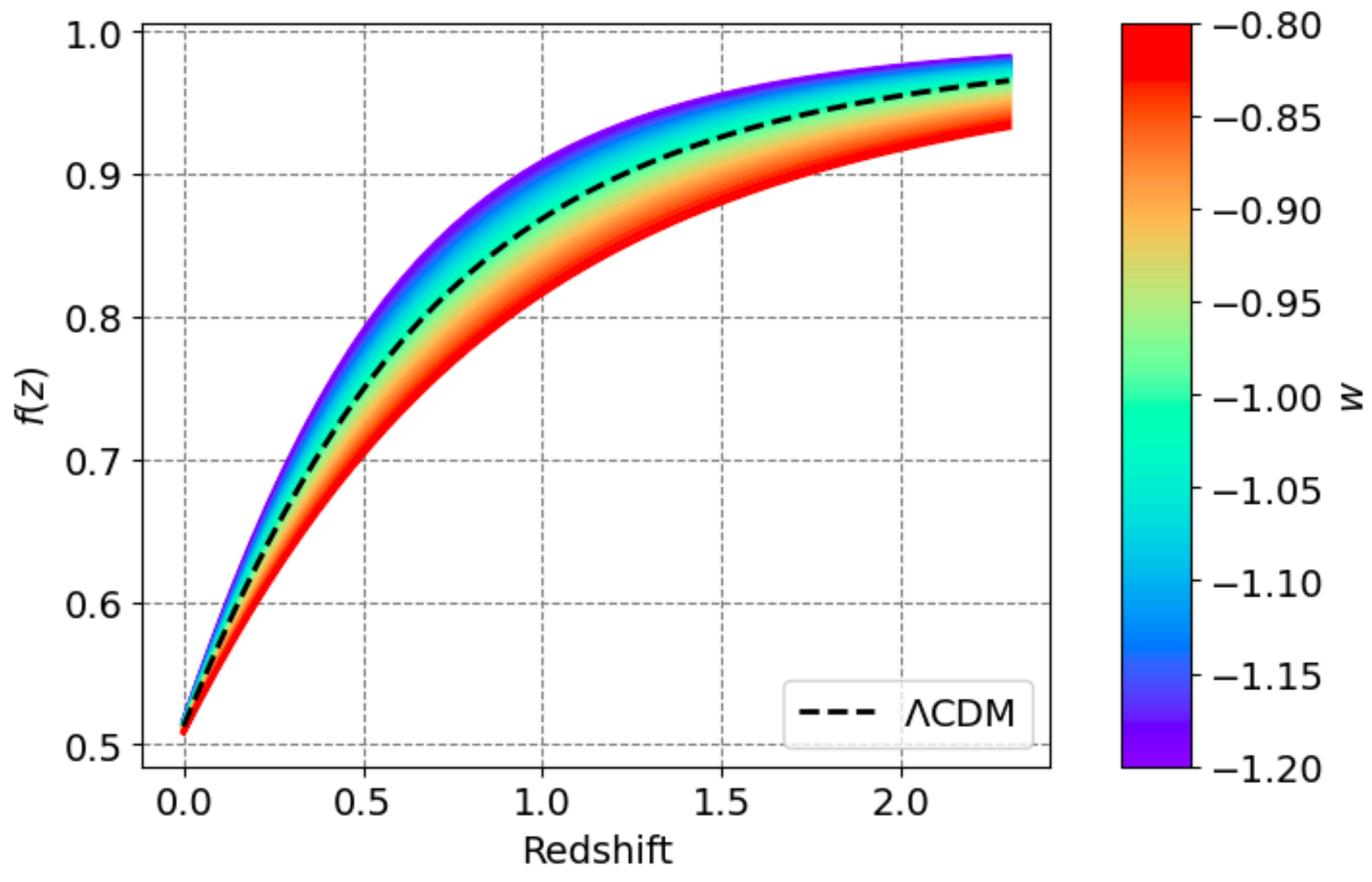
- Responsible for the accelerated expansion of the Universe.

- Impact on the growth of structures.



Late time probes are needed!

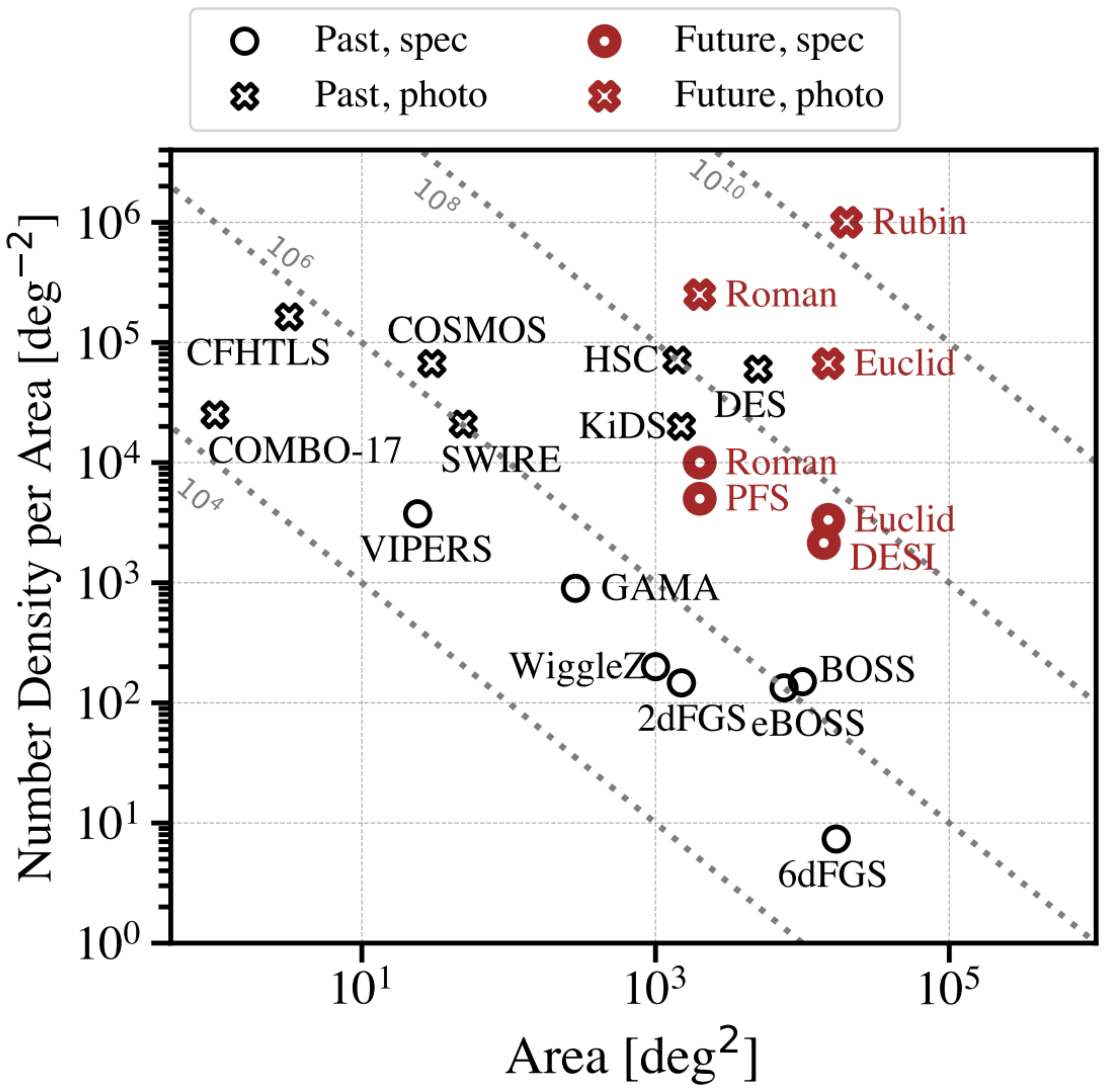




Cosmological surveys

- The **matter density field** is full of **cosmology-relevant information**
- By looking at different redshifts, we probe **different epochs**.
- Key tool to probe the Universe at late time.
- As statistical errors go down, future surveys must put particolar attention to **systematic effects.**

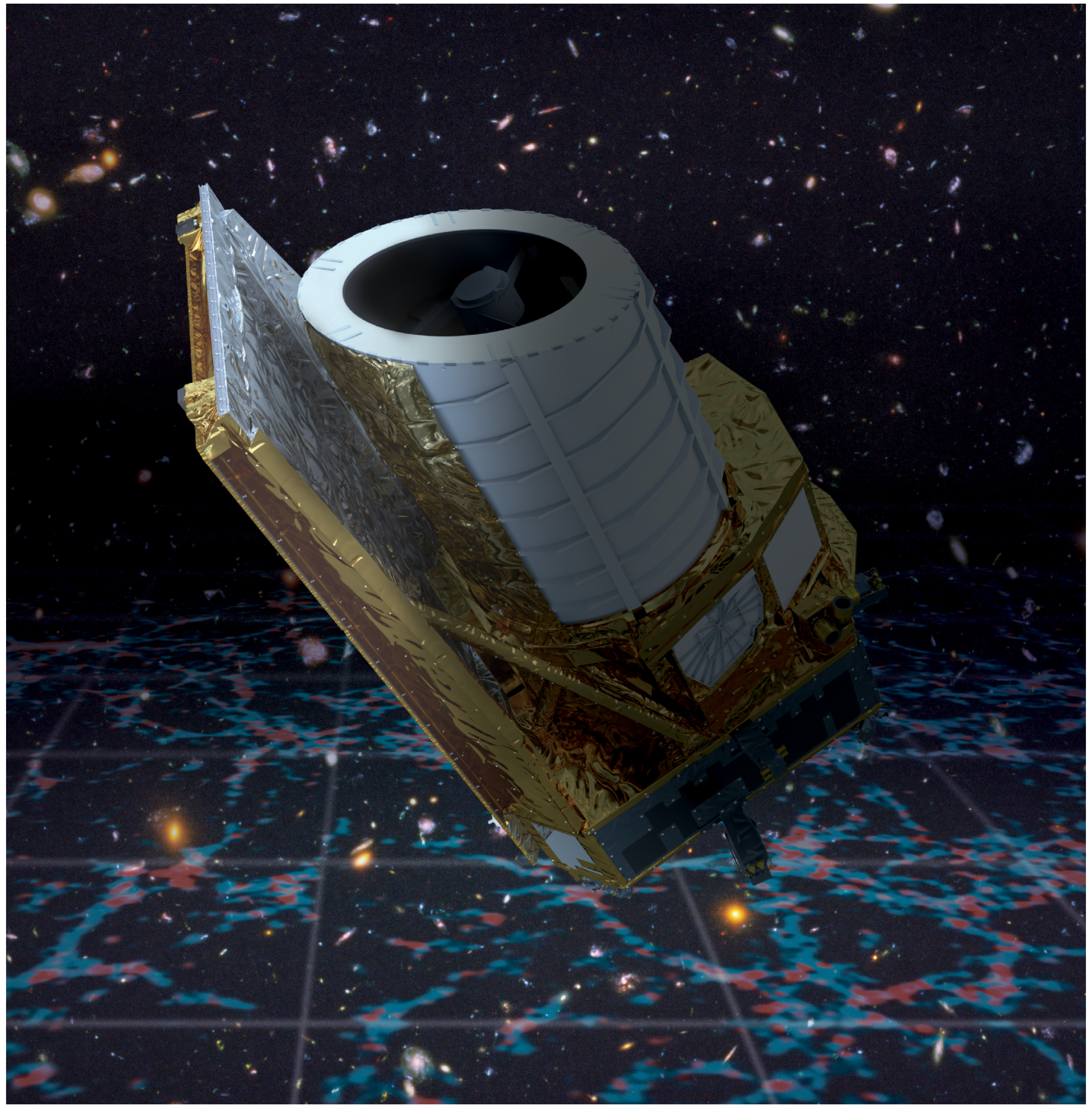
Stage IV is happening now!



Surveys in the Area - number density plane, Hou et al 2023

The Euclid mission

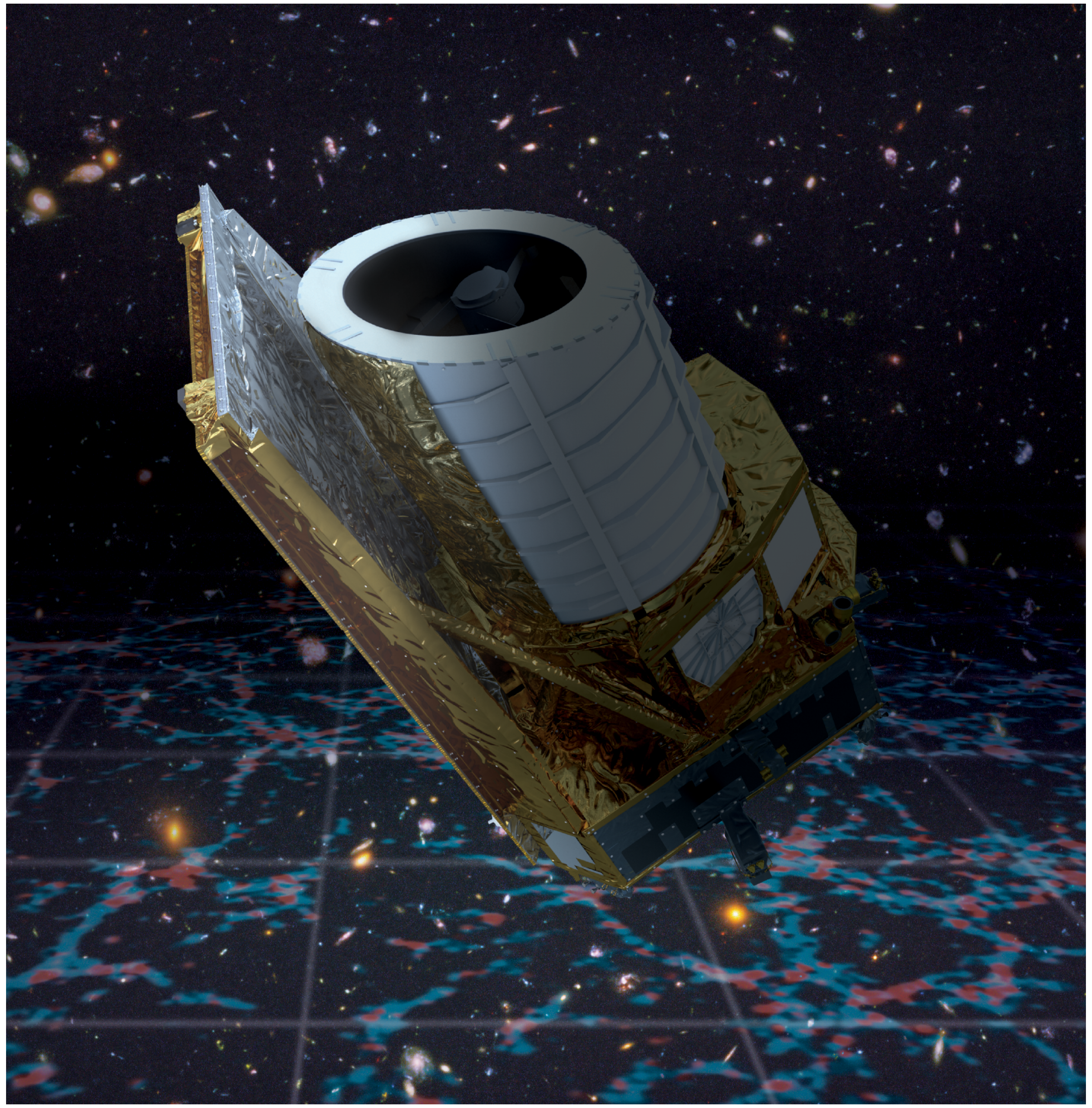
- Euclid is an **ESA mission** with extra contribution by national agencies (instrument development, Science Ground Segment, survey and data analysis preparation → **Euclid Consortium**)
- The primary goal is the exploration of the **dark Universe.**
- It will produce an **unprecedently large 3D map** of the Universe
- Core science: **Cosmology**
    - **Weak lensing, galaxy clustering,** additional probes (e.g. galaxy clusters, cosmic voids, CMB cross-correlations, strong lensing …).
- Legacy science: Galaxy & AGN evolution, Local Universe …



Artist impression of the Euclid mission in space - ESA/Euclid/Euclid Consortium/NASA

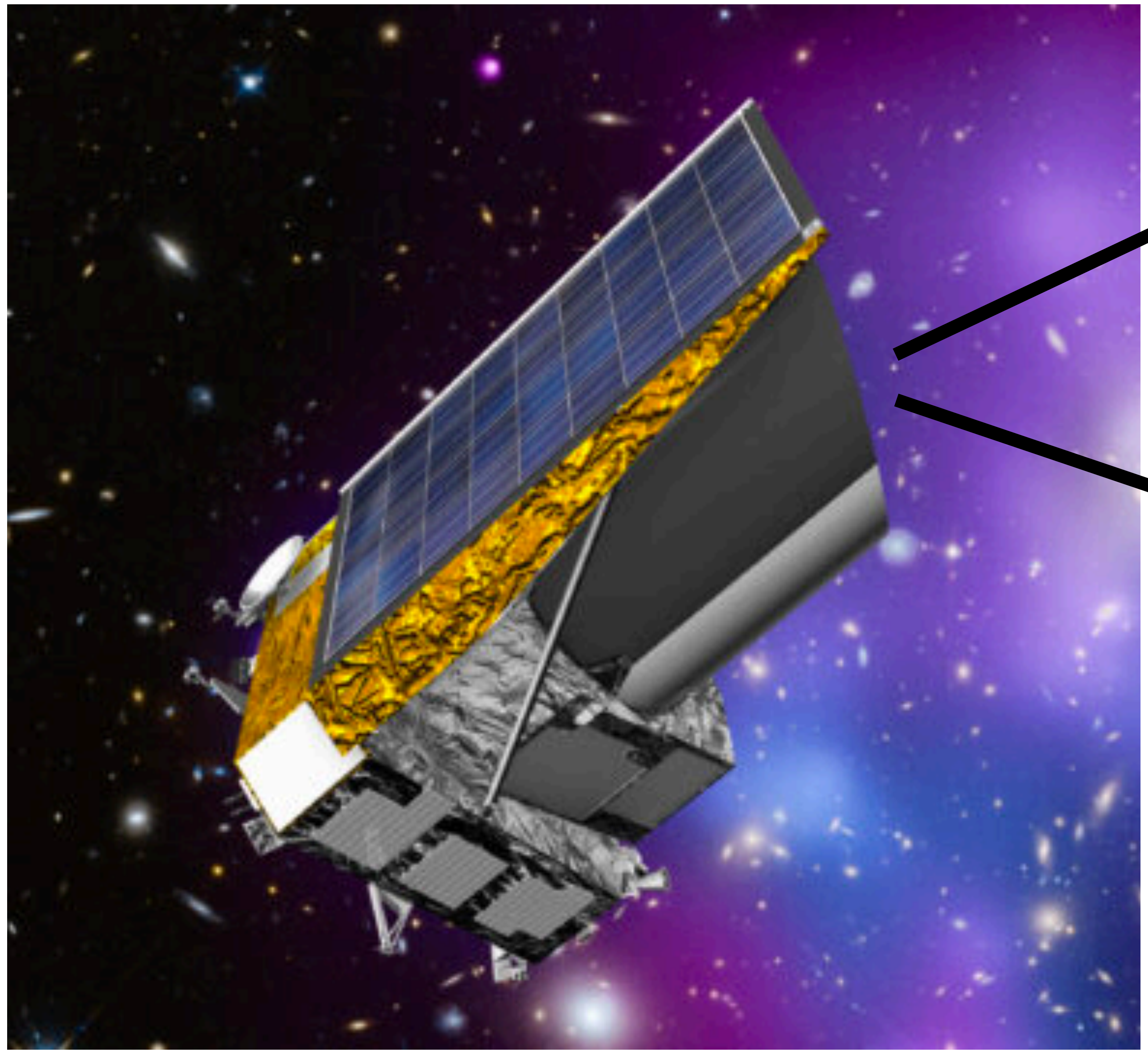
The Euclid mission

- **Large collaboration!**
  - Satellite and operations under the responsibility of **ESA**,
  - The **Euclid consortium** (more than 2000 scientists from 13 European countries, US, Canada, Japan) is responsible for the scientific instruments and data analysis.

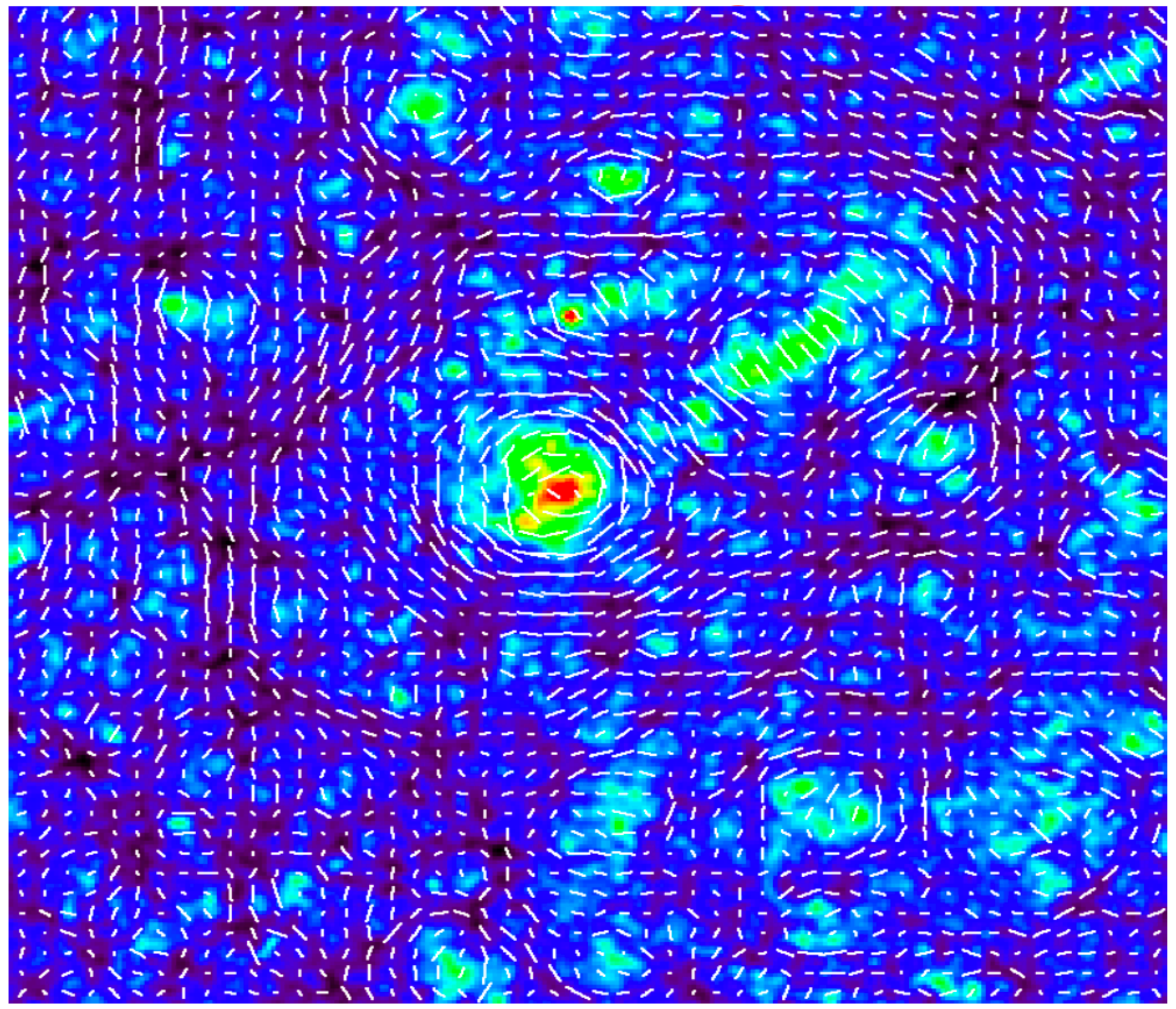


Artist impression of the Euclid mission in space - ESA/Euclid/Euclid Consortium/NASA

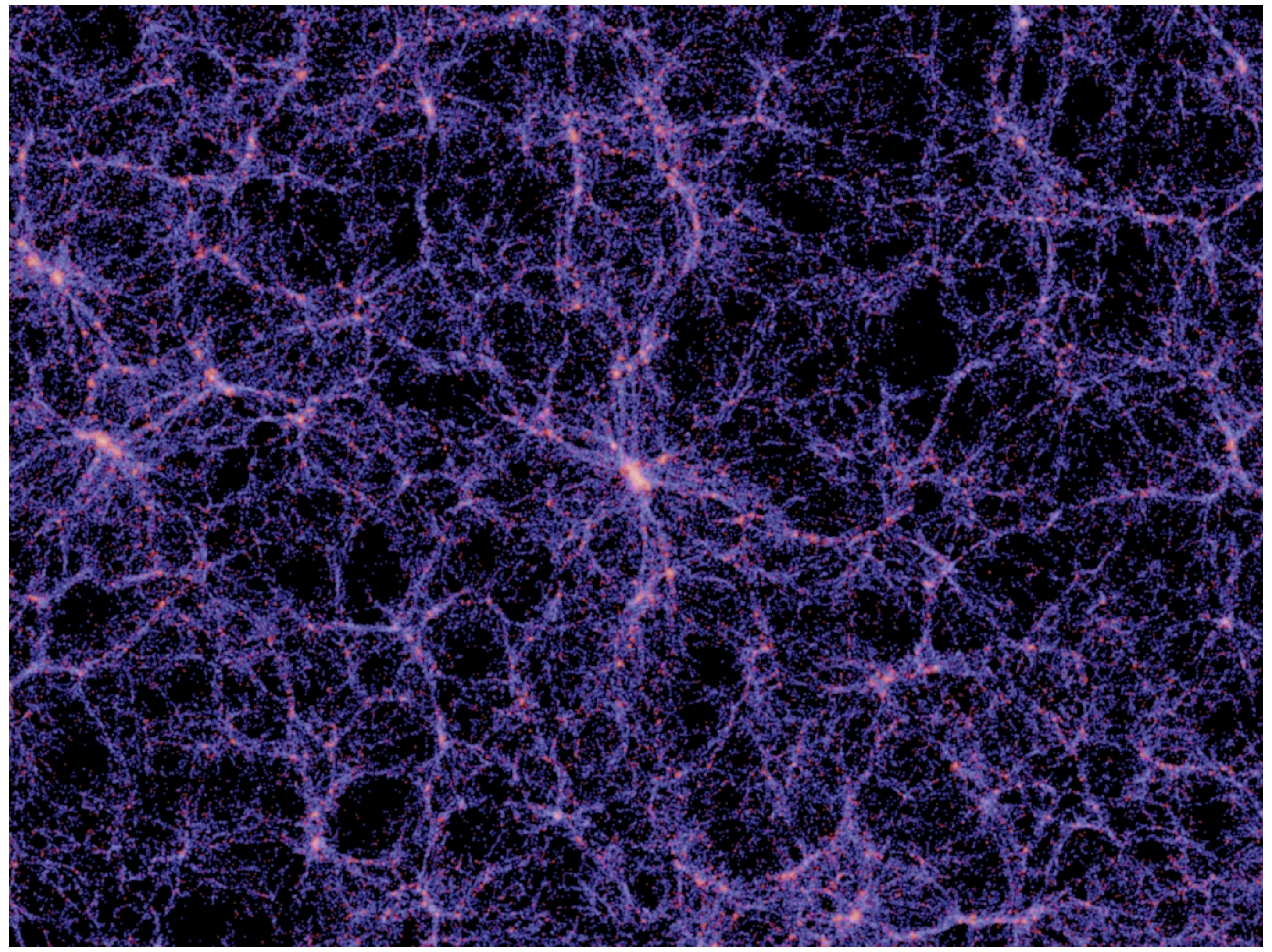
Euclid: Core Science



Weak lensing

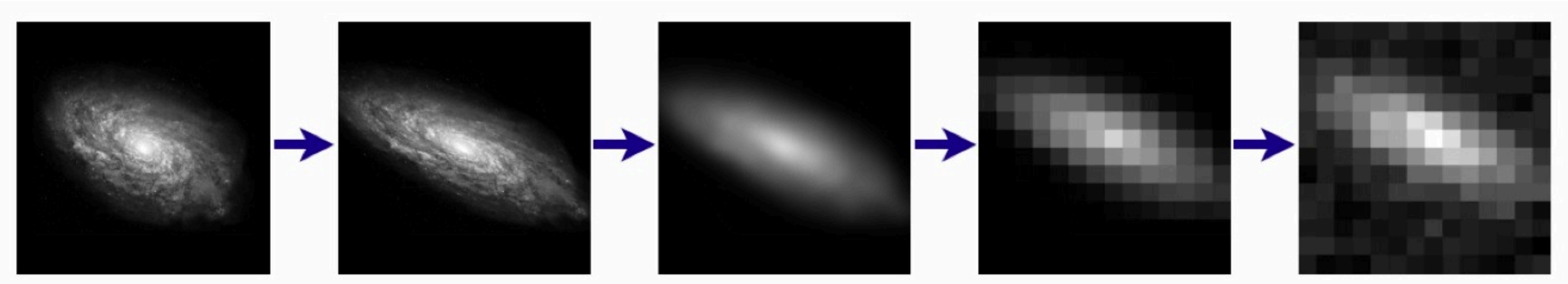


Galaxy clustering



Weak lensing

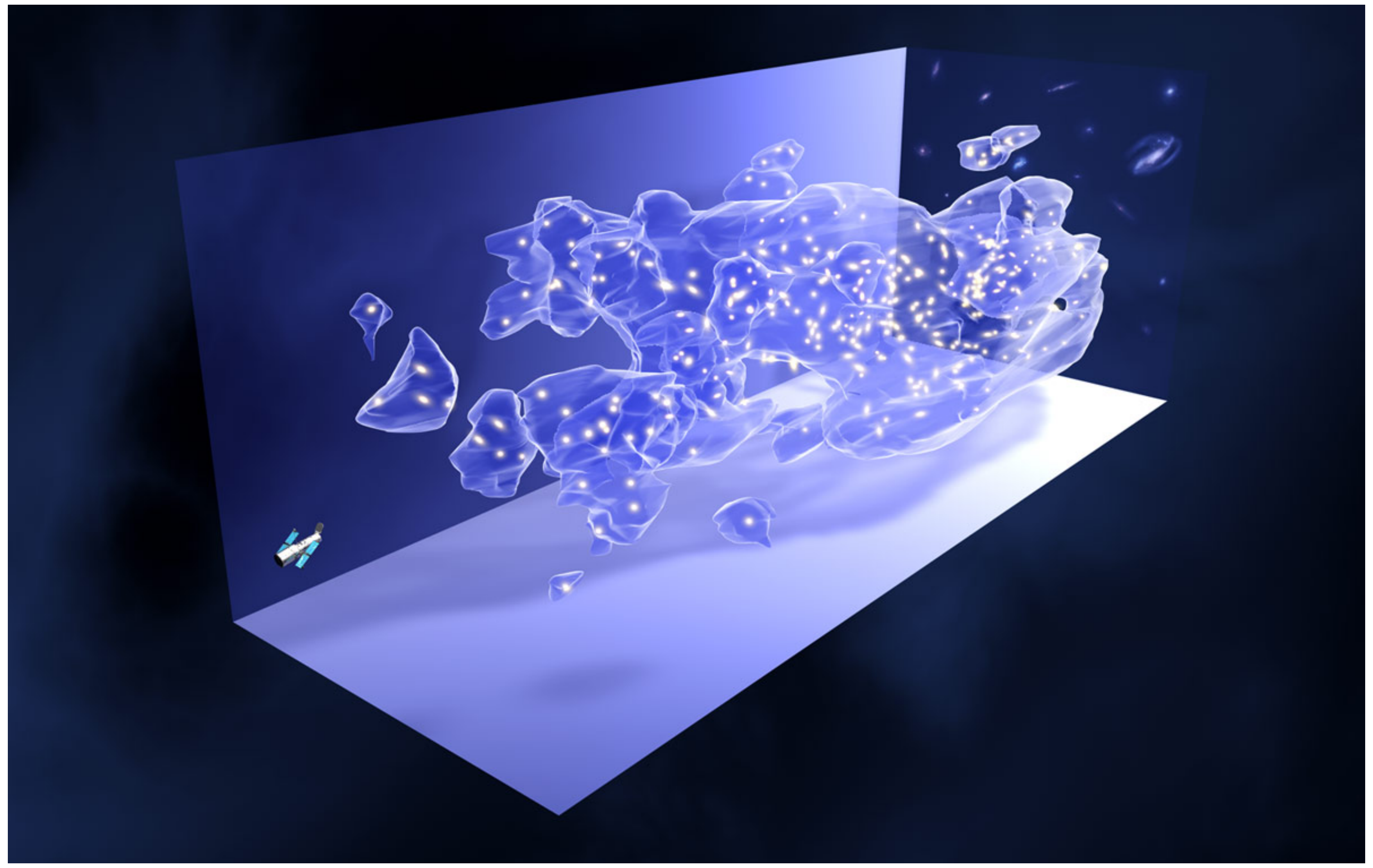
- The **matter** structure **distorts** the observed **shape** of far-away objects.
- The distortions encode how much matter the light rays encountered on their way to us.
- **Accurate calibrations** of the instrument are required to control observational systematics carefully.
- A sharp PSF is not enough: we need to **correlate the shapes of millions of galaxies** to measure the cosmological signal (~10^{-3} in ellipticity).

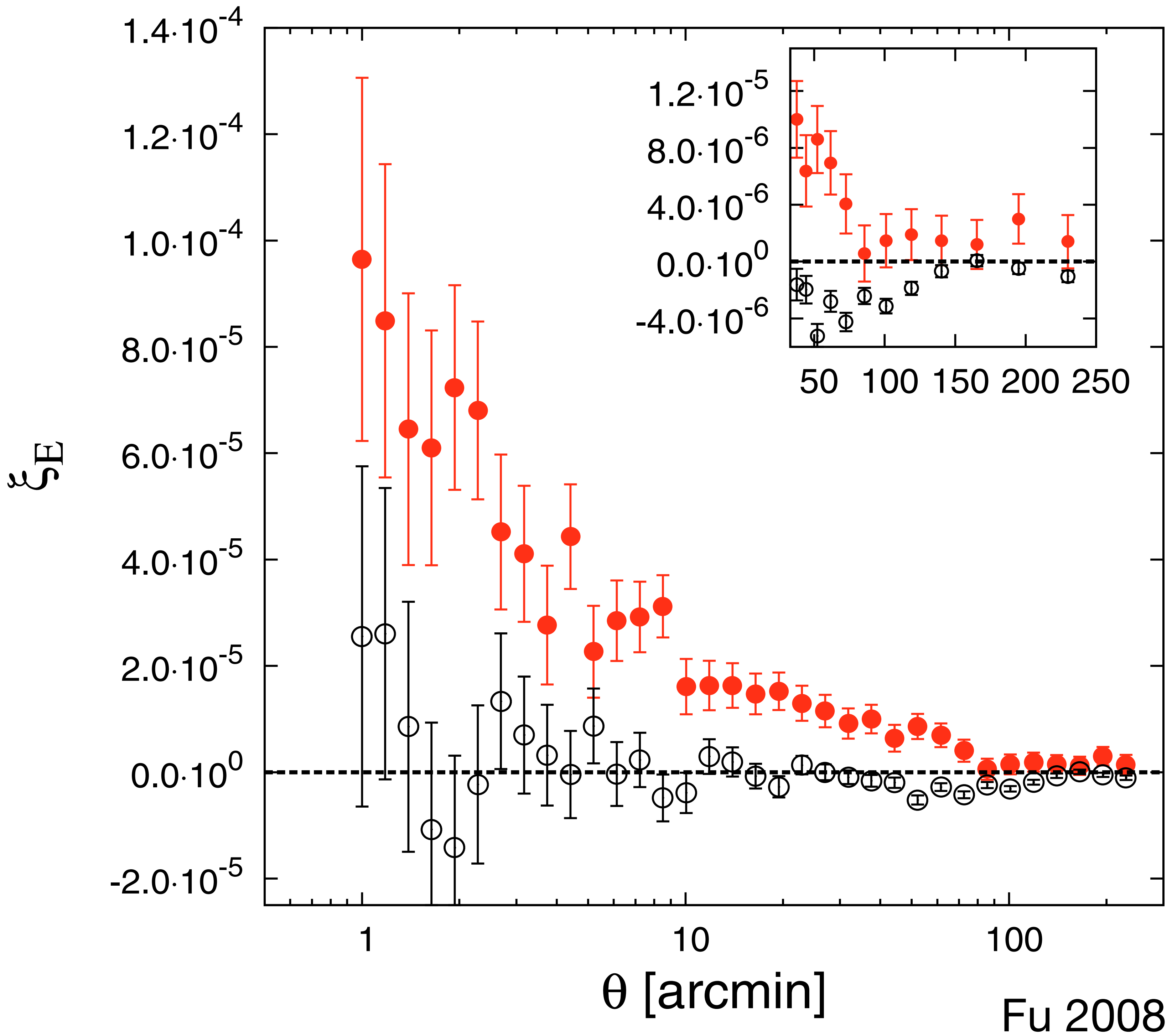


Original galaxy Lensed galaxy Telescope convolution Detector sampling Image noise

Adapted from Bridle et al 2011

- The signal is integrated over redshift: need for a **tomographic approach**.
- **Photometric redshift distributions** are to be estimated with the addition of ground-based photometry.
- The signal in the reconstructed map is compressed in summary statistics (C_l).
- **Systematic biases** need to be accounted for:
    - **Color-dependence of PSF**: PSF correlates with SED type and redshift; even colour gradients in galaxies can bias results.
    - The primordial tidal field induces **intrinsic alignments** between galaxies.

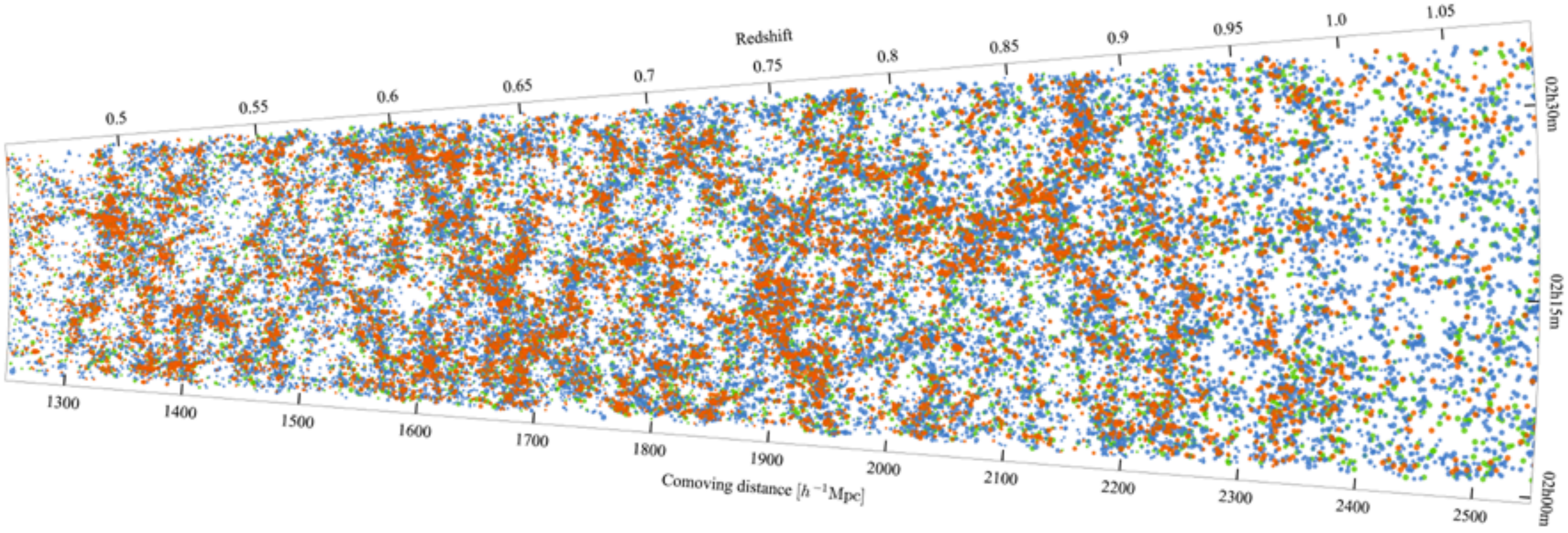




Fu 2008

Galaxy clustering

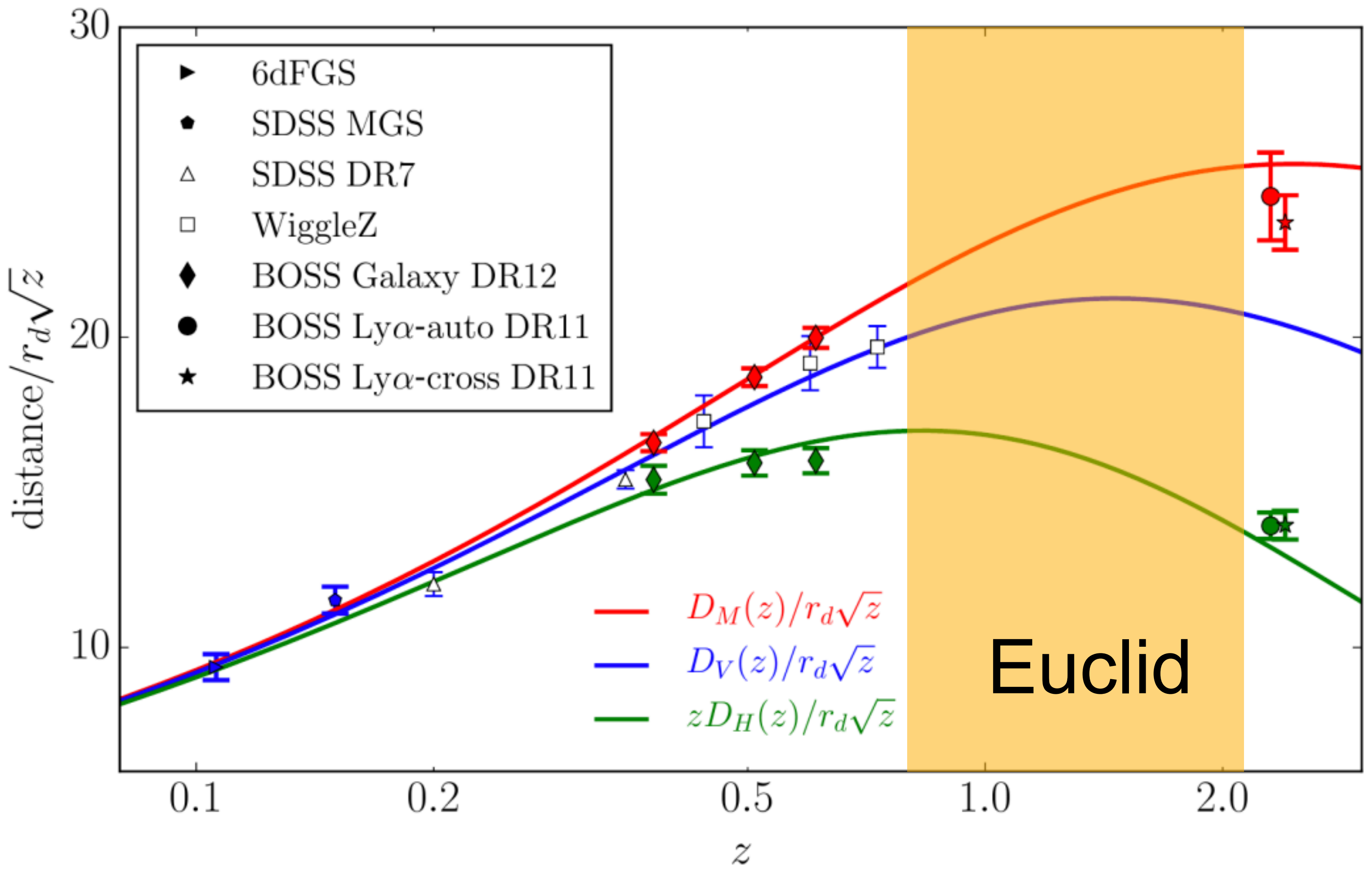
- We trace the underlying dark matter density field by observing galaxies.
- **Statistical description of the Large-Scale structure of the Universe (N-point correlation functions).**
- Exploiting s**pectroscopic information**, we get a **precise** determination of the source **distance**.



Credits: VIPERS collaboration

Baryon acoustic oscillations

- Early-time photon-baryon coupling left imprinted in the matter distribution.
- Excess of pairs at a specific separation (Sound horizon $r_s \approx 145\,\mathrm{Mpc}$).
- **BAO is a standard ruler**, allowing us to determine the distance corresponding to the survey redshift.
- **BAO signal is enhanced using Reconstruction techniques.**



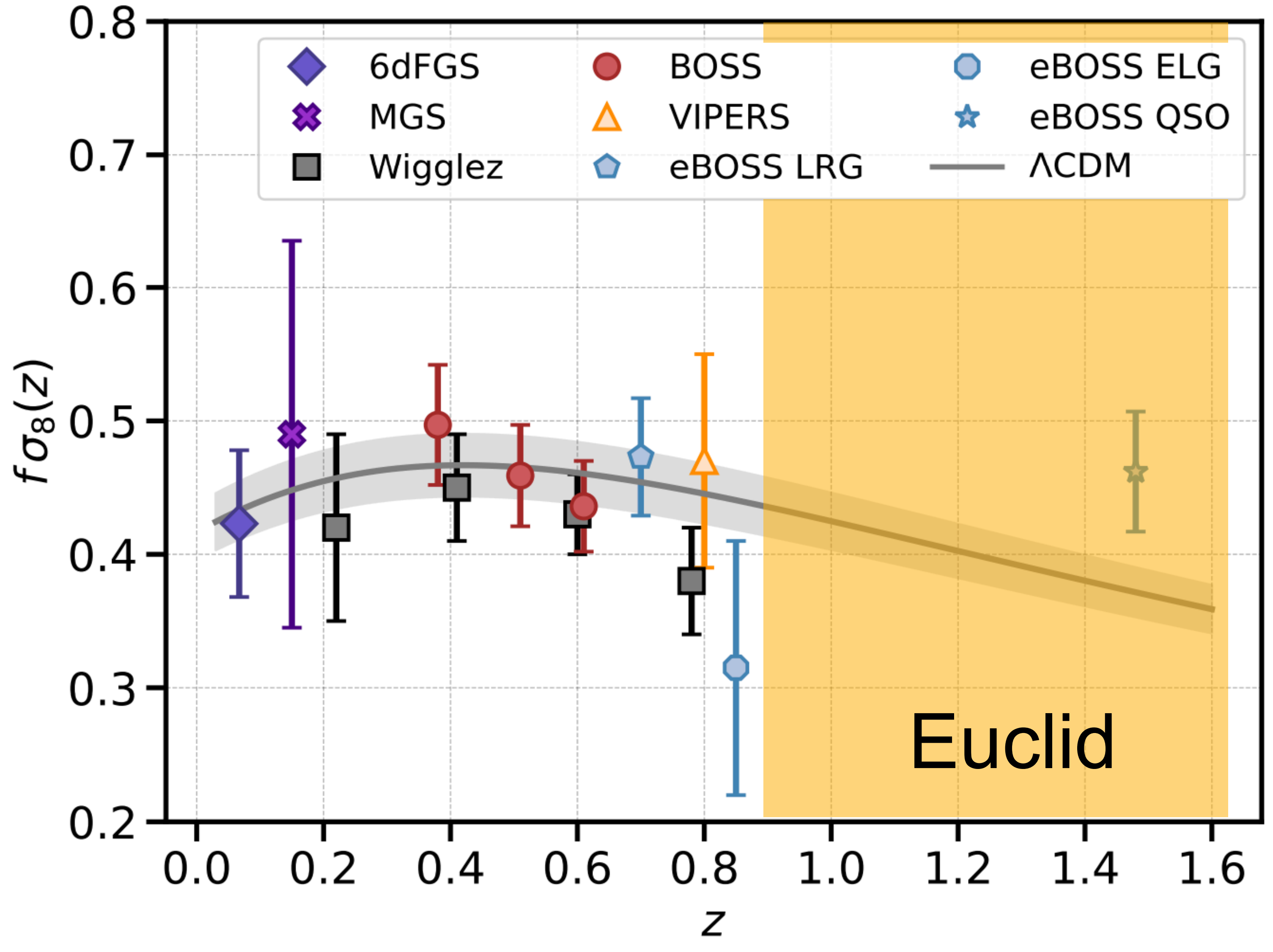
Distance constraints from BAO - Alam et al. 2016

Redshift-Space distortions

- Large-scale velocity fields are linked to the density field
- Redshift from spectroscopy encodes information **on both position and peculiar velocity**

$$z_{obs} = z_c + \frac{v_p}{c}(1 + z_c) + \sigma_z.$$

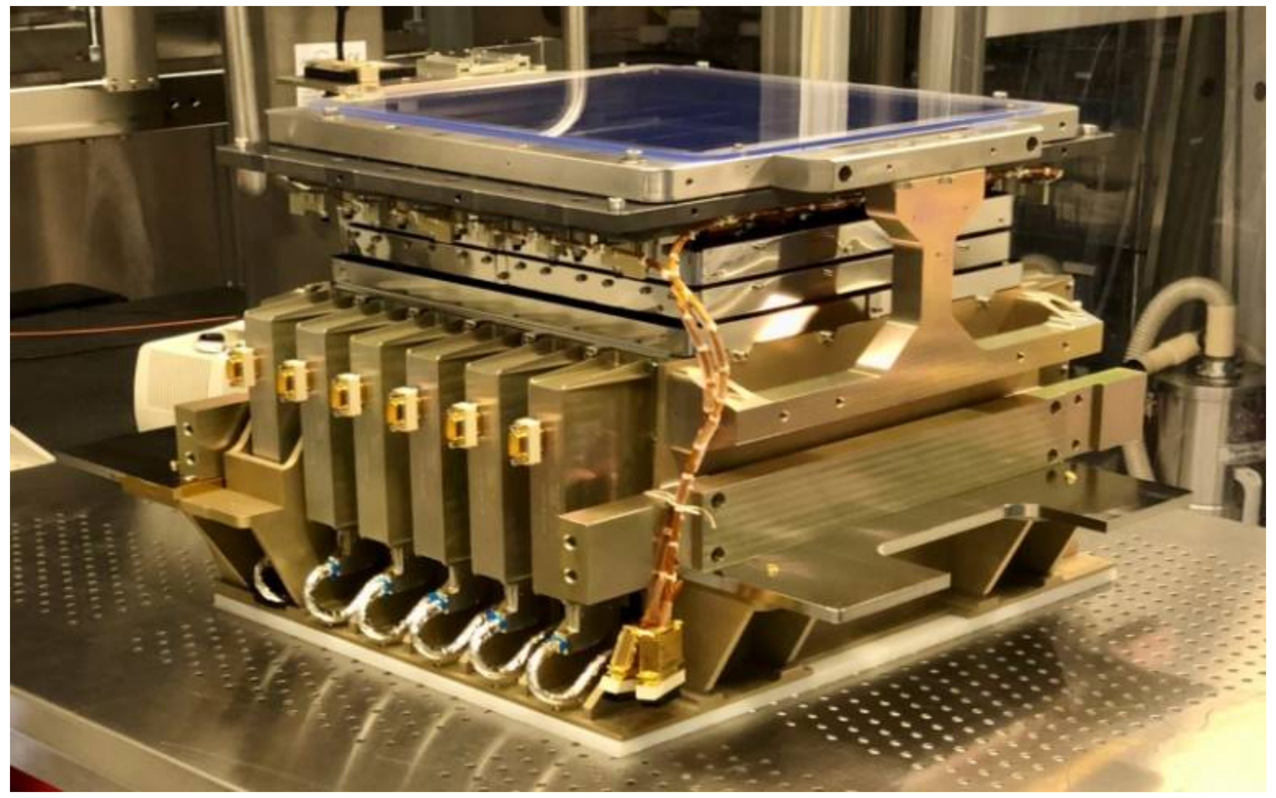
- **Peculiar velocities distort distances** along the line of sight, changing the shape of clustering statistics.



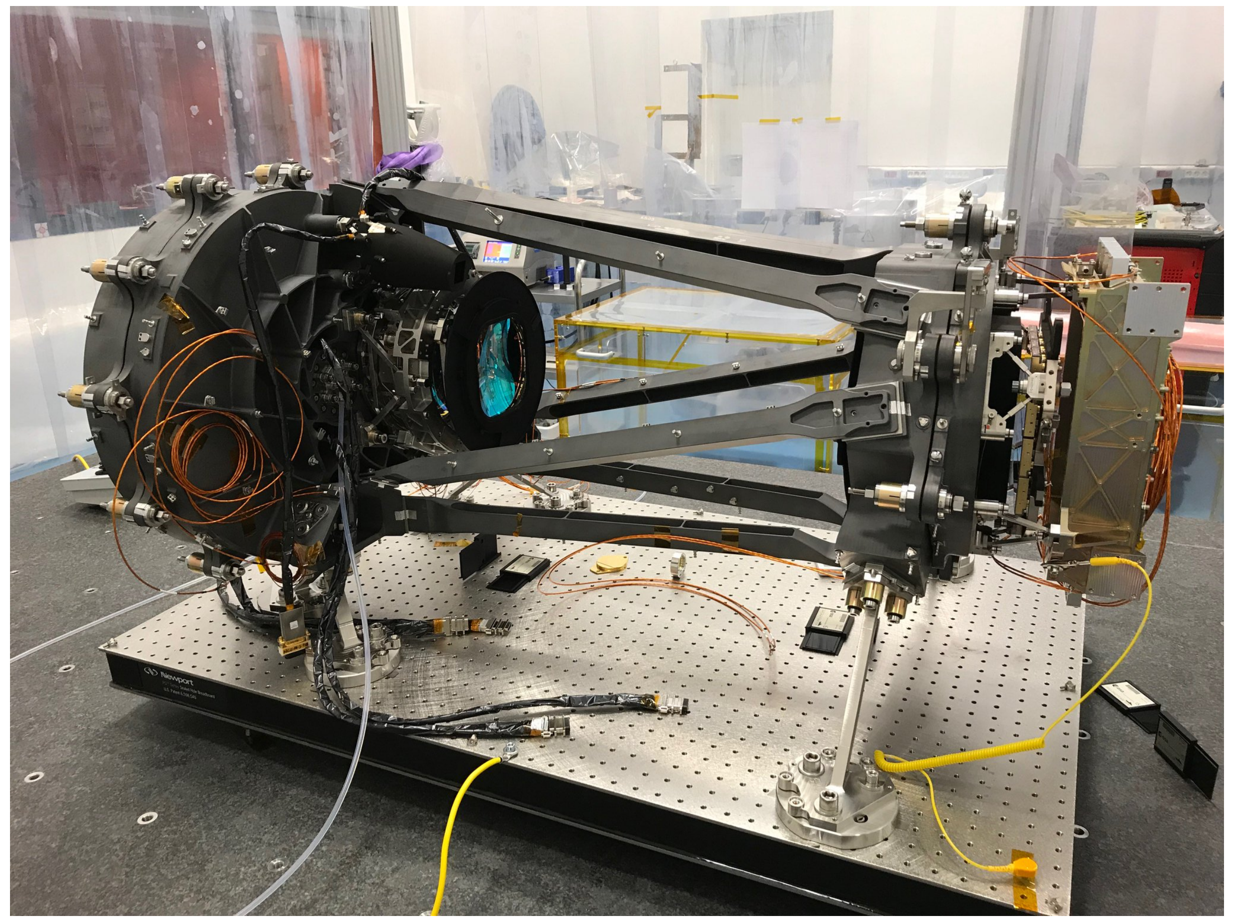
Collection of $f\sigma_8(z)$ measurements, Hou et al 2023

Euclid: Design and survey

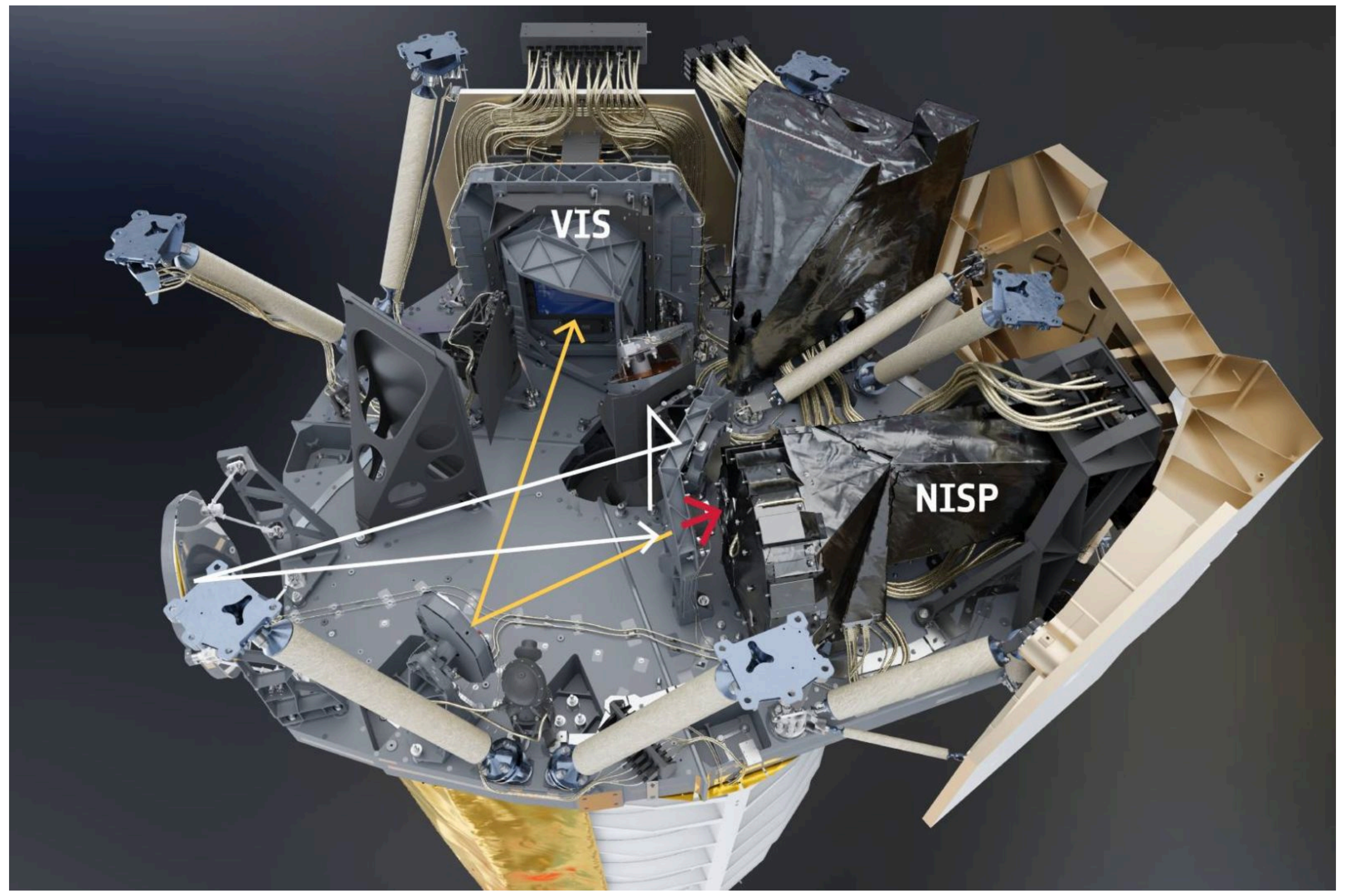
- Euclid satellite is designed to observe the sky in visual and near-infrared bands efficiently.
- The **VIS instrument** fulfils the requirement in terms of source number density and PSF size to achieve weak lensing goals.
- The **Near-Infrared Spectrometer and Photometer** (NISP) will collect spectroscopic information for precise redshift determination.
- Fundamental role of simulation in verifying instrument performances.



The Integrated VIS Focal Plane Assembly



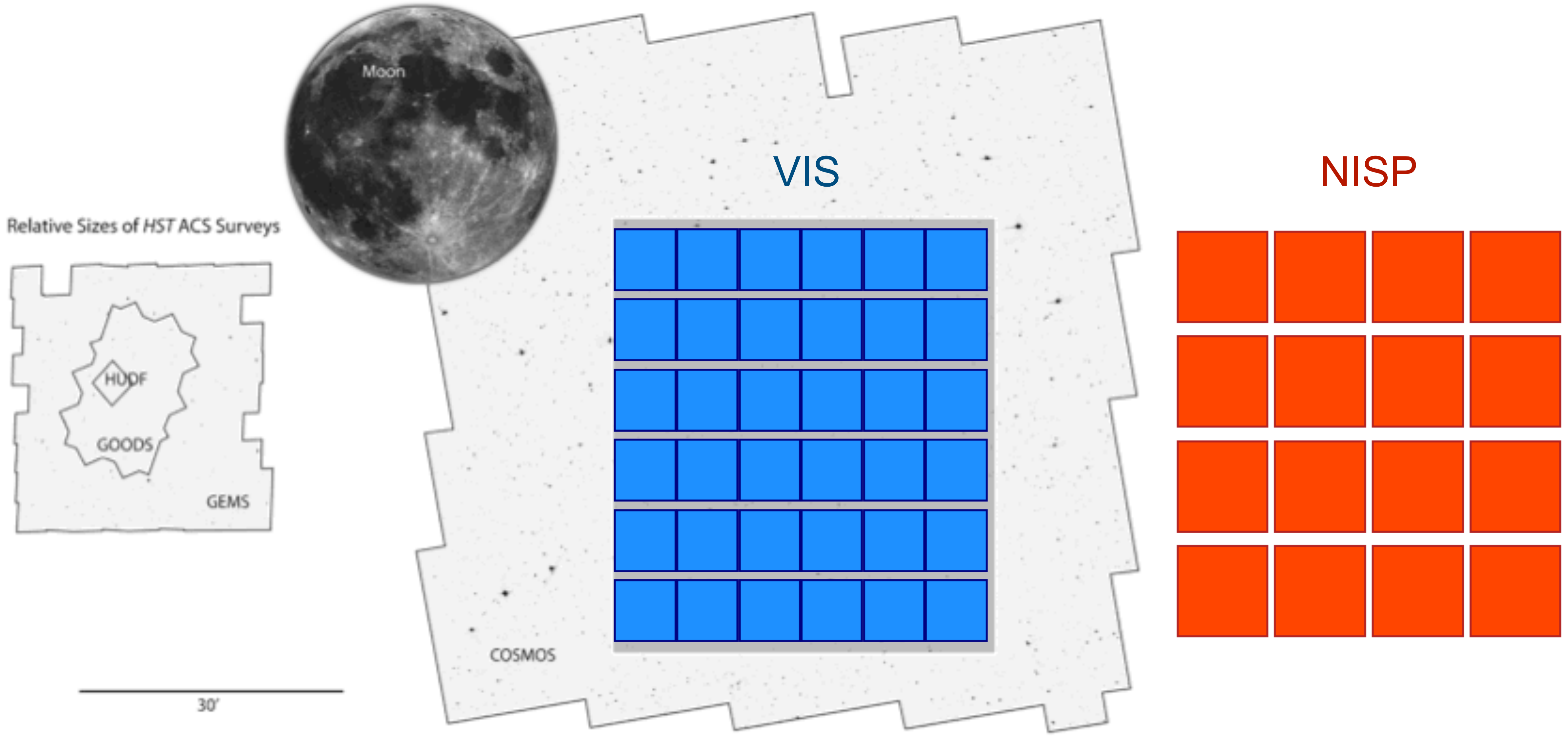
NISP instrument.
Credits: NISP Instrument team/ LAM



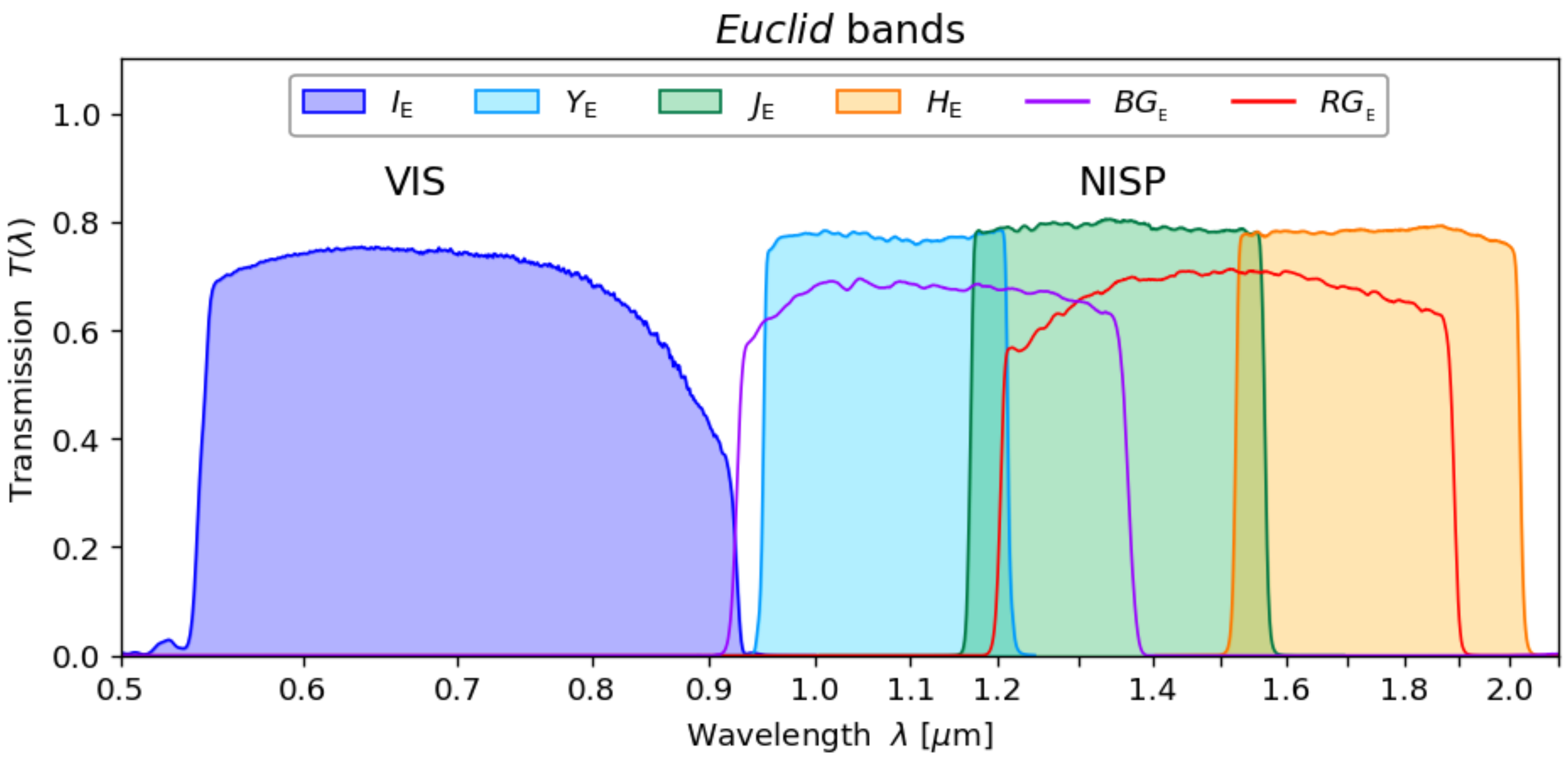
Credits ESA

A Large field of view!

Euclid field of view, compared to HST/ACS surveys



Euclid photometric band and spectroscopic range

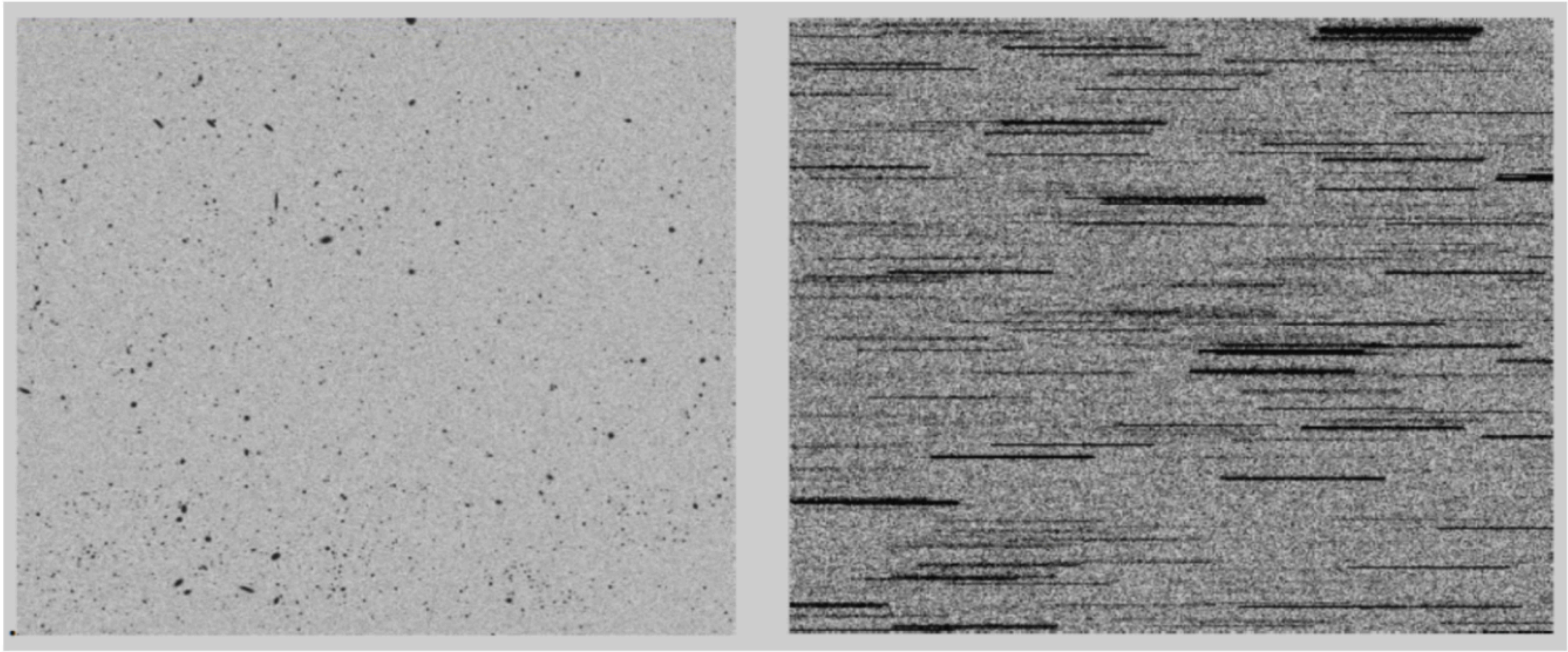


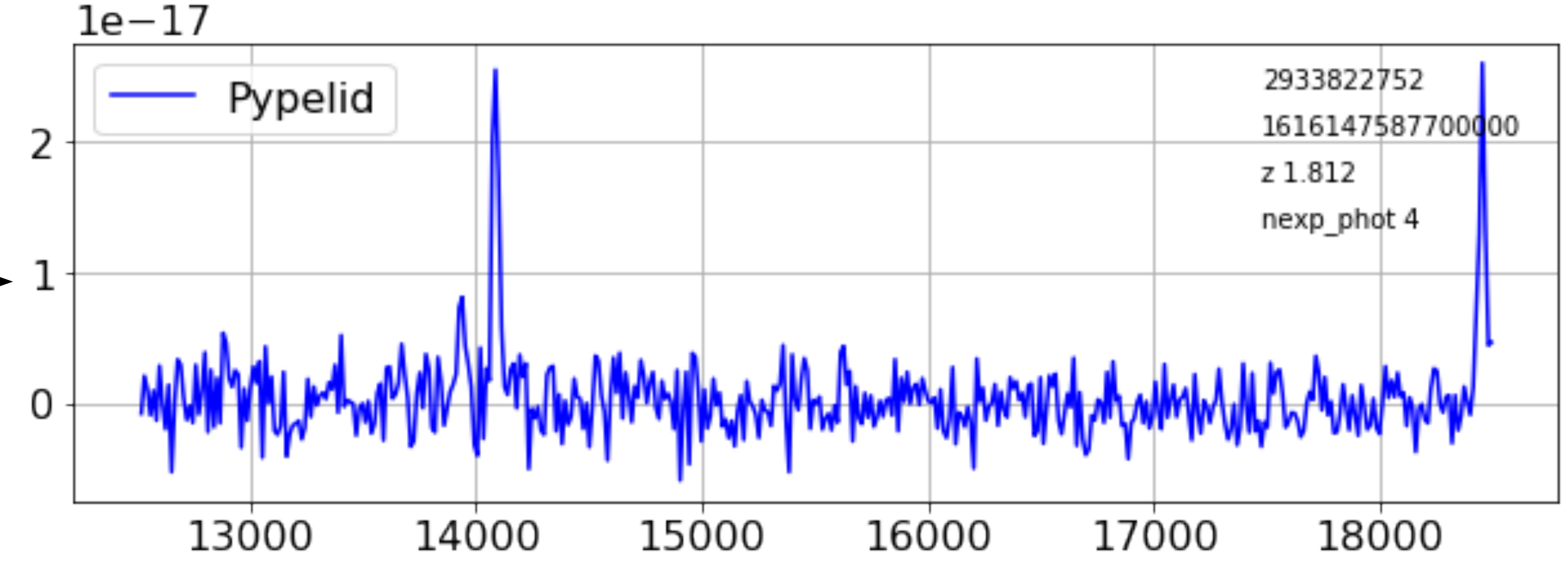
Multi-wavelength approach

Original slide courtesy of B. Granett

Euclid: Spectroscopy

- Slitless spectroscopy: no targeting, no fiber-collision
- 2D spectra will be collected at different grism orientations to allow field decontamination.
- Possible misidentification from OIII, OII (higher redshift) and SIII (lower redshift) when a single line is detected
- $\mathrm{H}\alpha$ emitting galaxies are the primary target.
- Target $\Delta z_{sp} = 0.001(1+z)$.





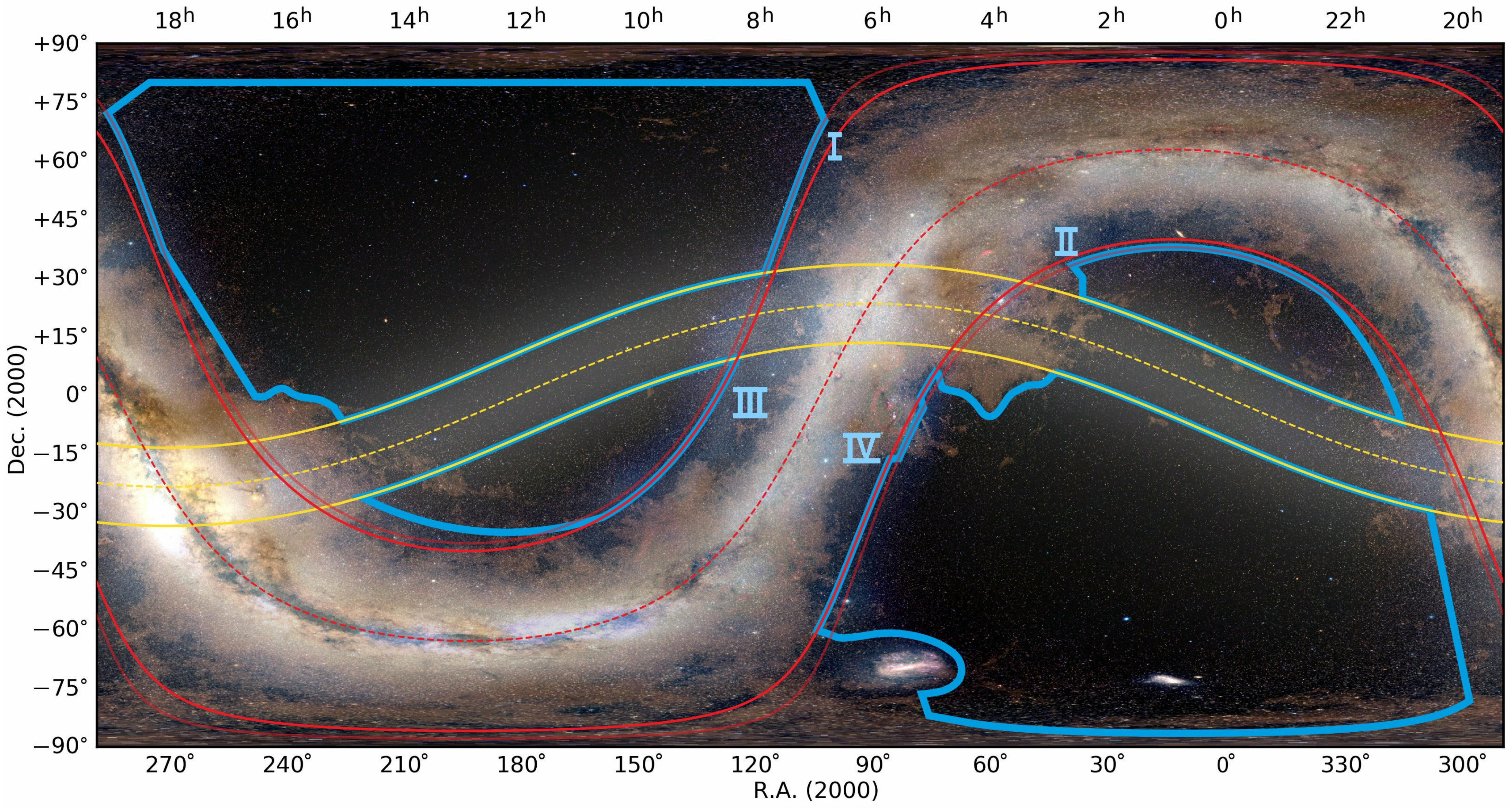
Credits: Granett & Euclid GC end-to-end group

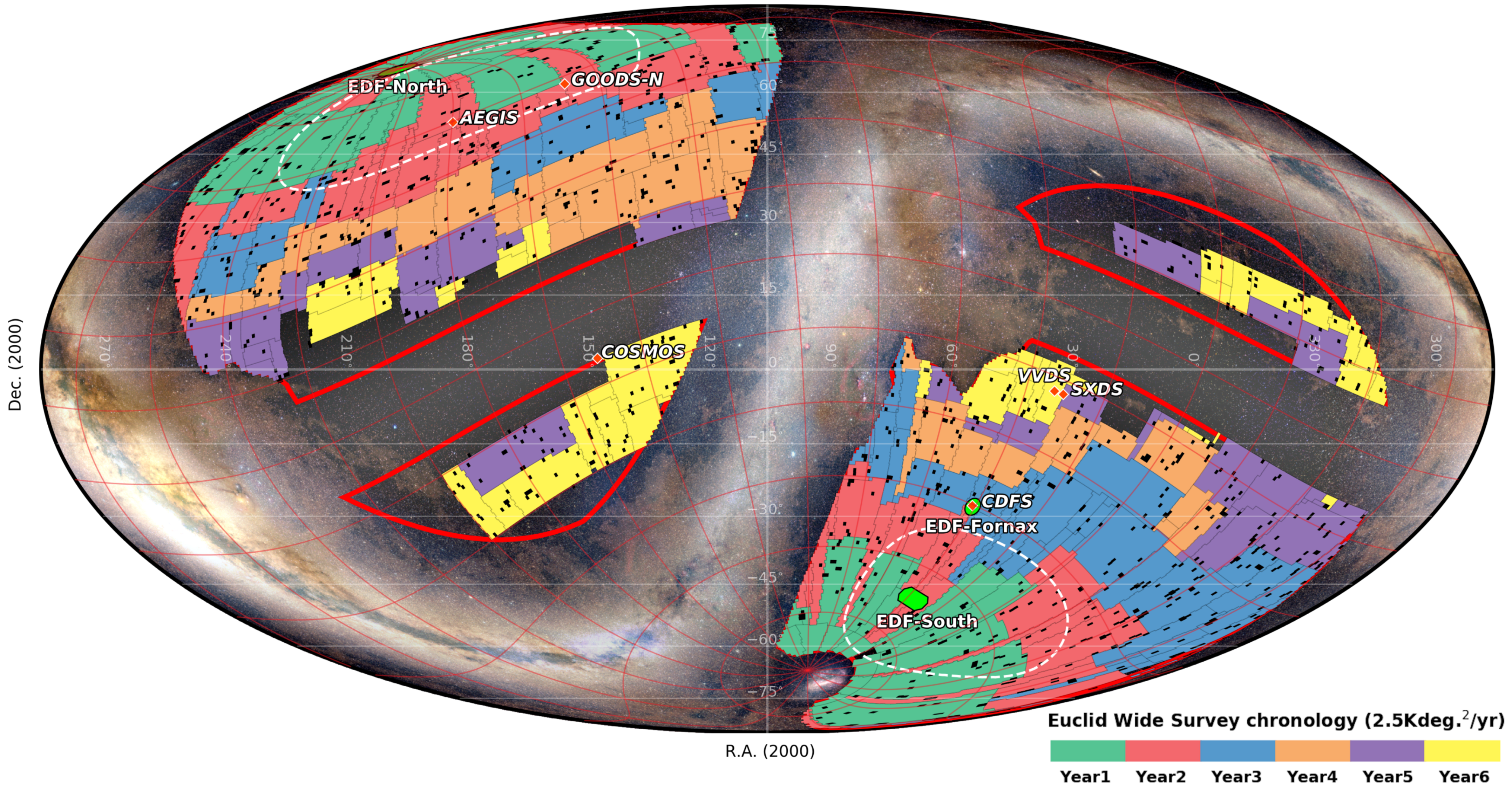
Euclid: Wide Survey

Euclid preparation: I. The Euclid Wide Survey
[Scaramella et al. 2021, arXiv:2108.01201]

At the end of the six-year of operation, Euclid will observe:

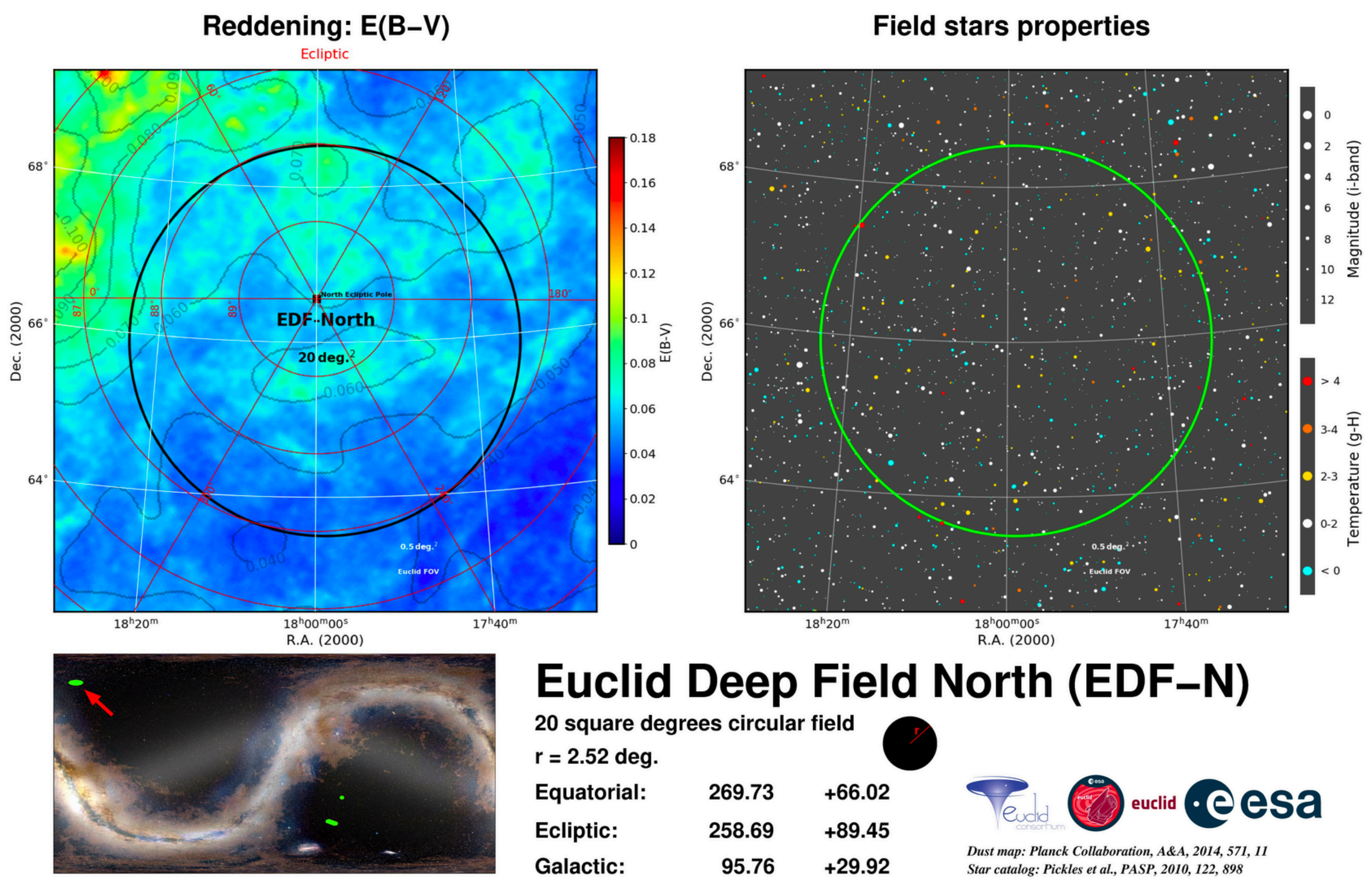
- 15000 deg^2 (1/3 of the sky)
- 1.5 billion photometric galaxies ($n_{gal} \approx 30 \text{ arcmin}^{-2}$)
- ~30 million spectra in the range $0.9 < z < 1.8$.
- Photometric depth [AB magnitude]:
  - $I_E = 26.2$ Visible Band
  - $Y_E = 24.3$
  - $J_E = 24.5$ NIR Band
  - $H_E = 24.4$
- Hα Line flux limit: $2 \times 10^{-16} \text{erg}^{-1} \text{cm}^{-2} \text{s}^{-1}$ at 1600 nm.

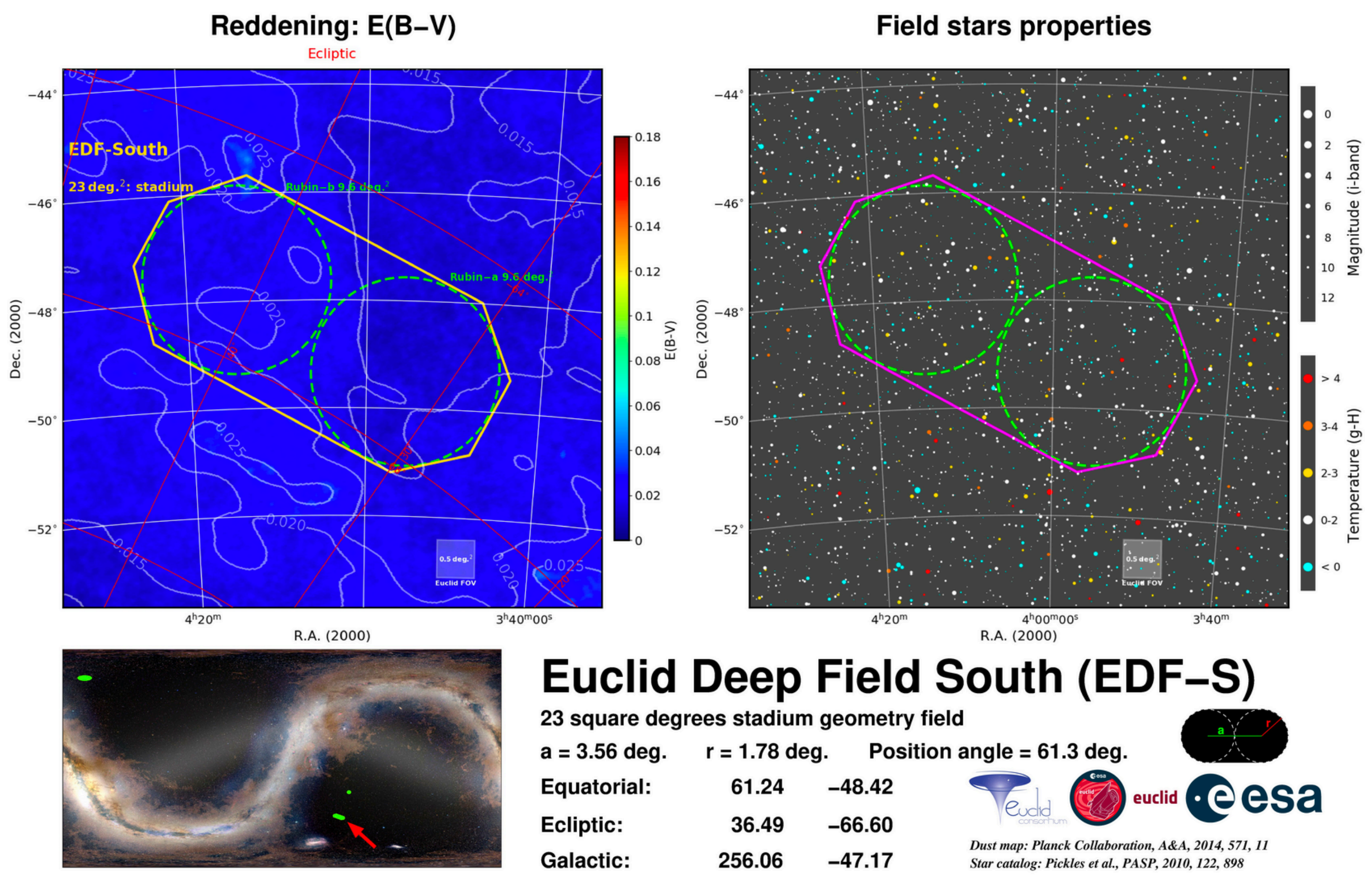


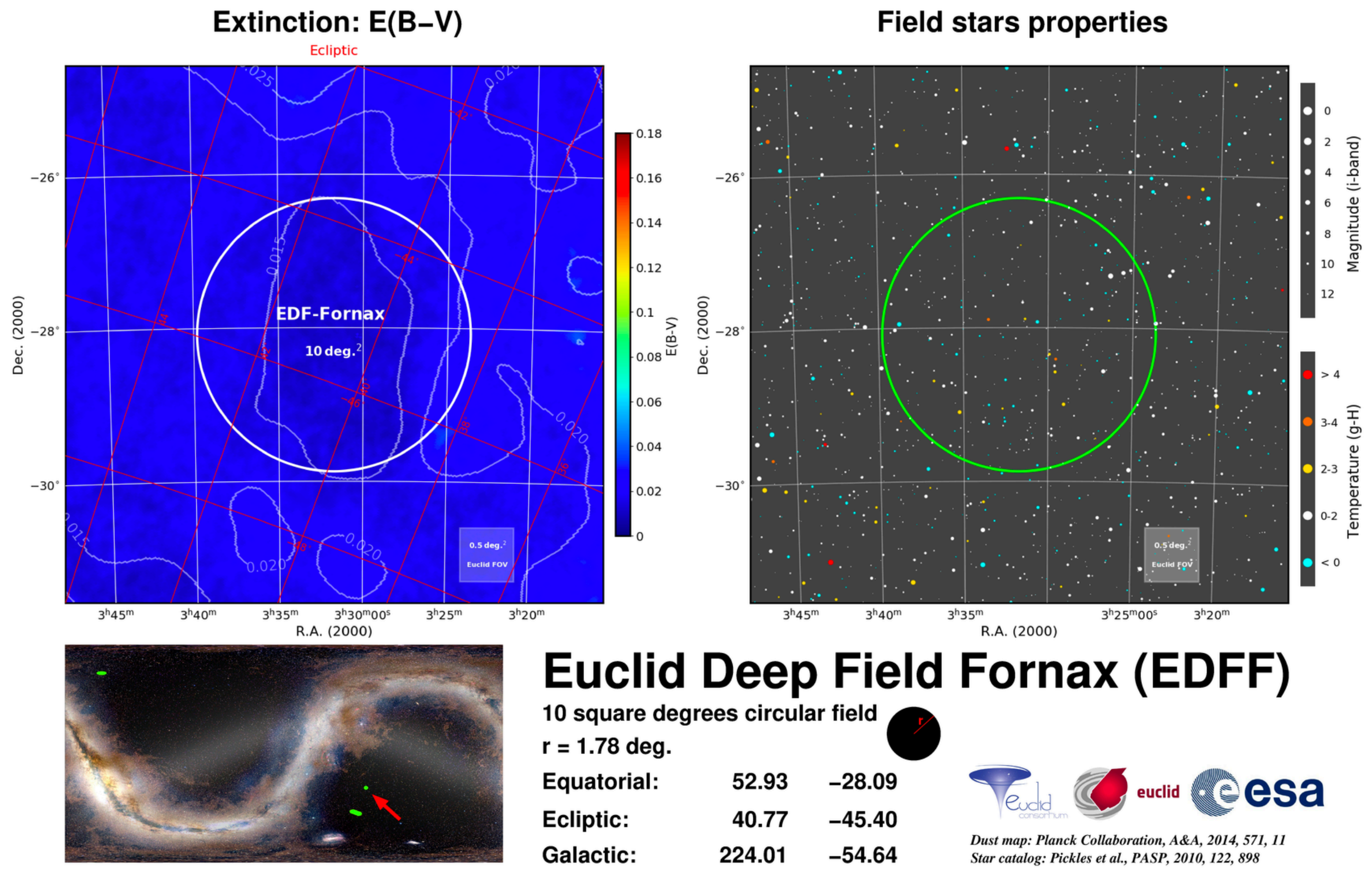


Euclid: Deep Survey

- 3 Fields. Total Area: $53\,\mathrm{deg}^2$.
- **Each pointing will be covered with 15 observations Wide-like with Red Grism + 25 with Blue Grism.**
- The **deep fields will be crucial to assess the purity and completeness of the wide survey.** This will be obtained thanks to the higher SNR, a large number of grism orientations and complementary "Blue" grism coverage of the 0.9-1.4 micron range.



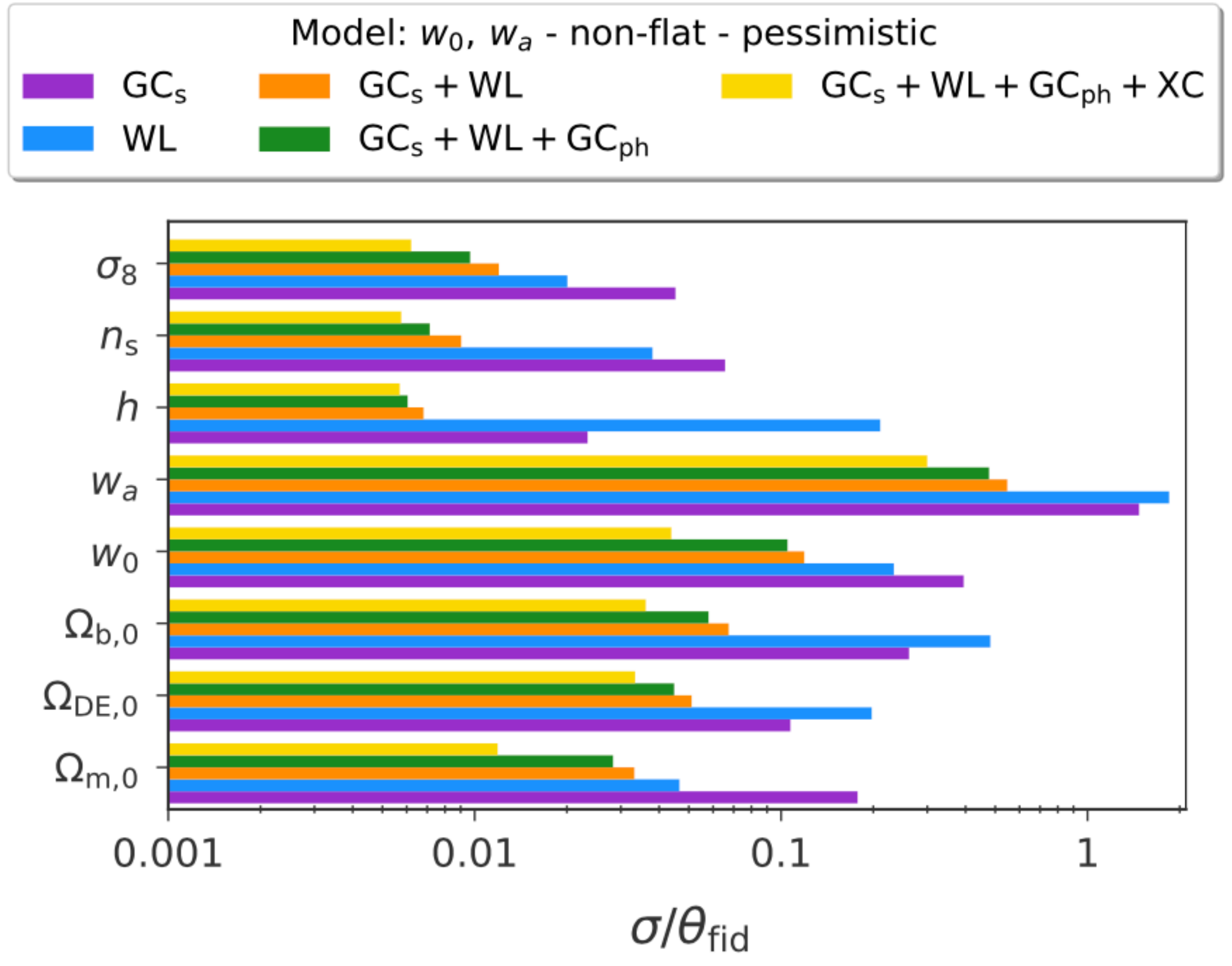


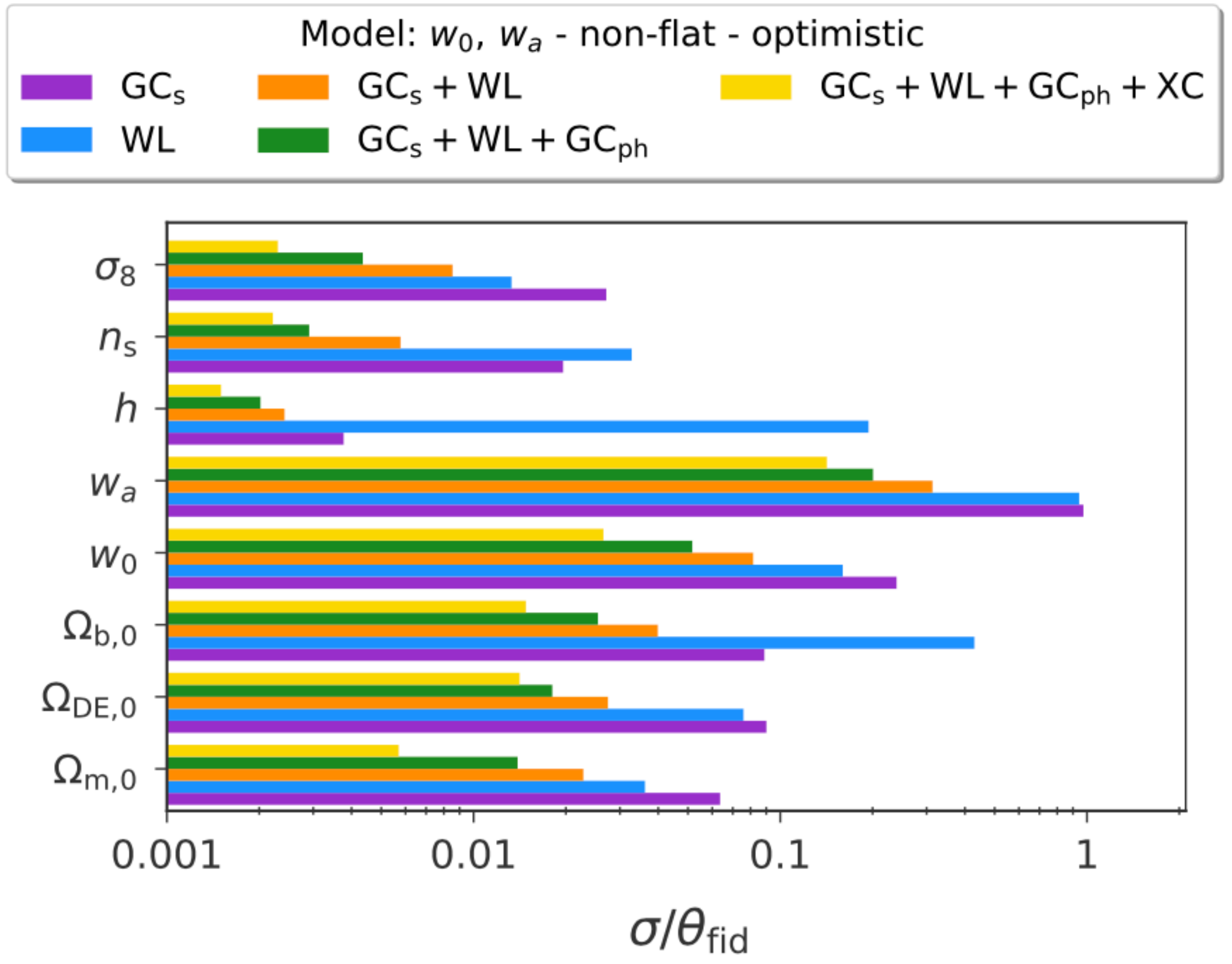


Euclid: Forecast

Euclid Preparation: VII. Forecast validation for Euclid cosmological probes
[Blanchard et al 2020, arXiv:1910.09273]

w_0, w_a FoM	Flat	Non-flat
Linear setting		
GC_s	40	19
Pessimistic setting		
GC_s	14	10
WL	23	5
GC_s+WL	99	40
GC_{ph}+WL	64	14
GC_s+WL+GC_{ph}	123	49
WL+GC_{ph}+$XC^{(GC_{ph},WL)}$	367	59
GC_s+WL+GC_{ph}+$XC^{(GC_{ph},WL)}$	377	128
Optimistic setting		
GC_s	55	19
WL	44	12
GC_s+WL	157	87
GC_{ph}+WL	235	129
GC_s+WL+GC_{ph}	398	218
WL+GC_{ph}+$XC^{(GC_{ph},WL)}$	1033	326
GC_s+WL+GC_{ph}+$XC^{(GC_{ph},WL)}$	1257	500





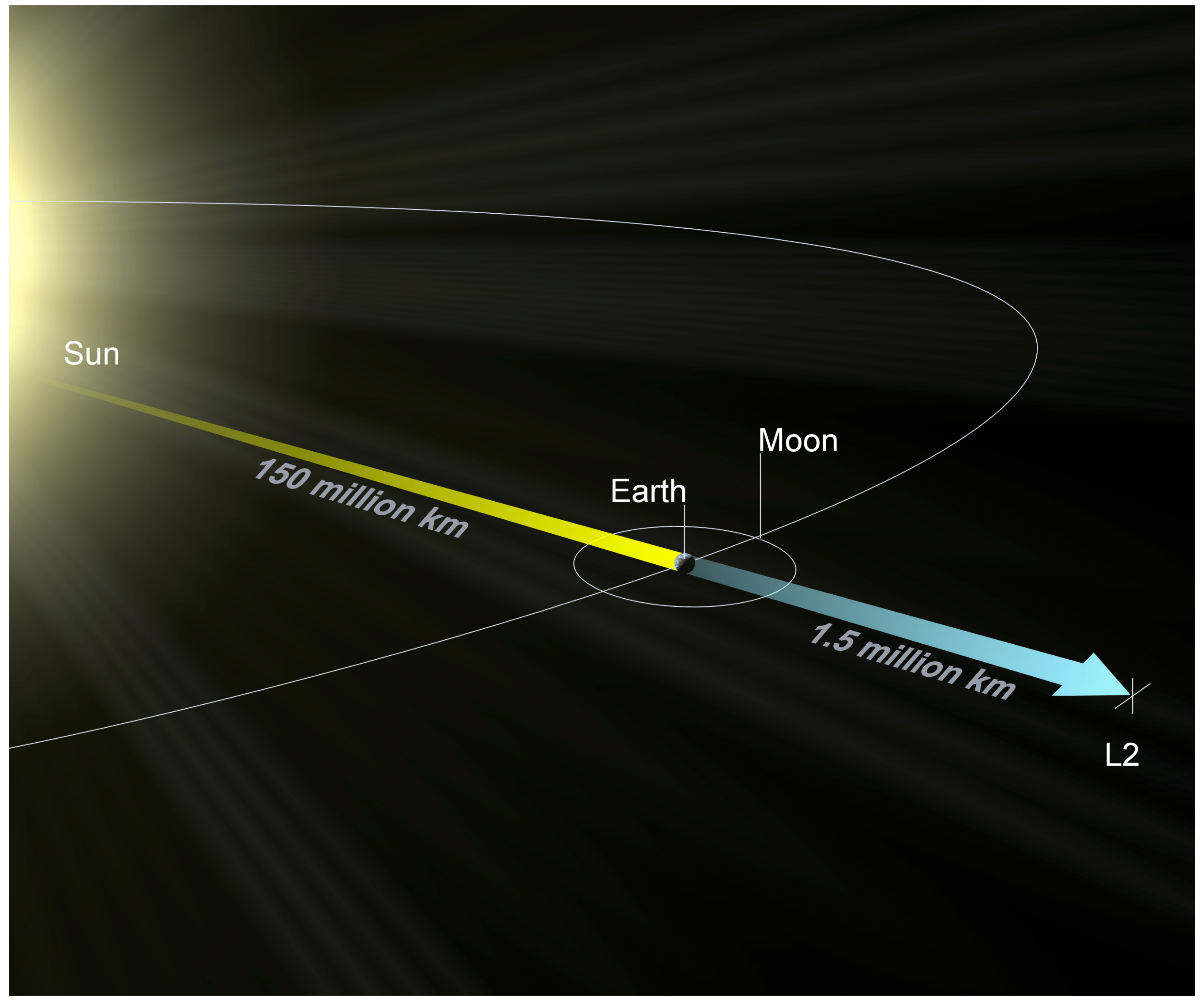
The beginning of the journey

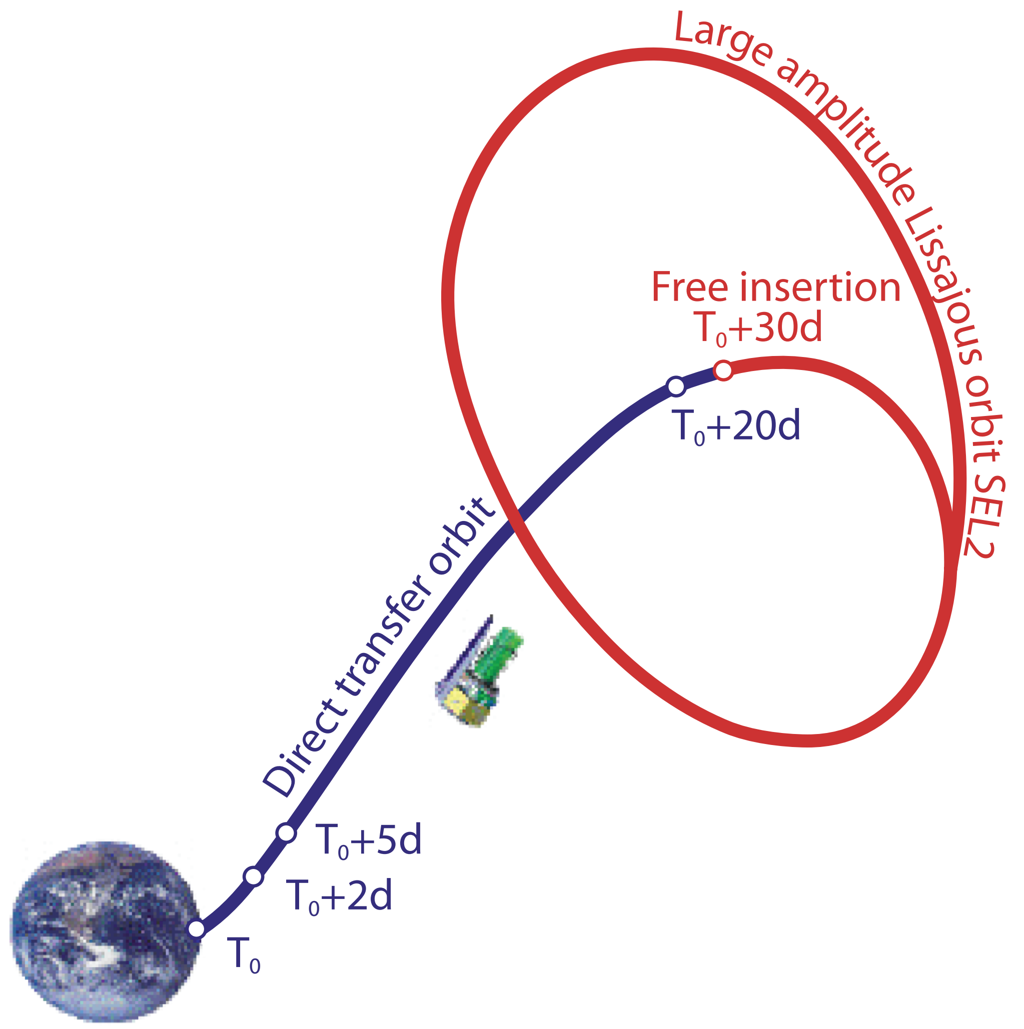
Launch: 1 July 2023

Launch location: Cape Canaveral, Florida, USA

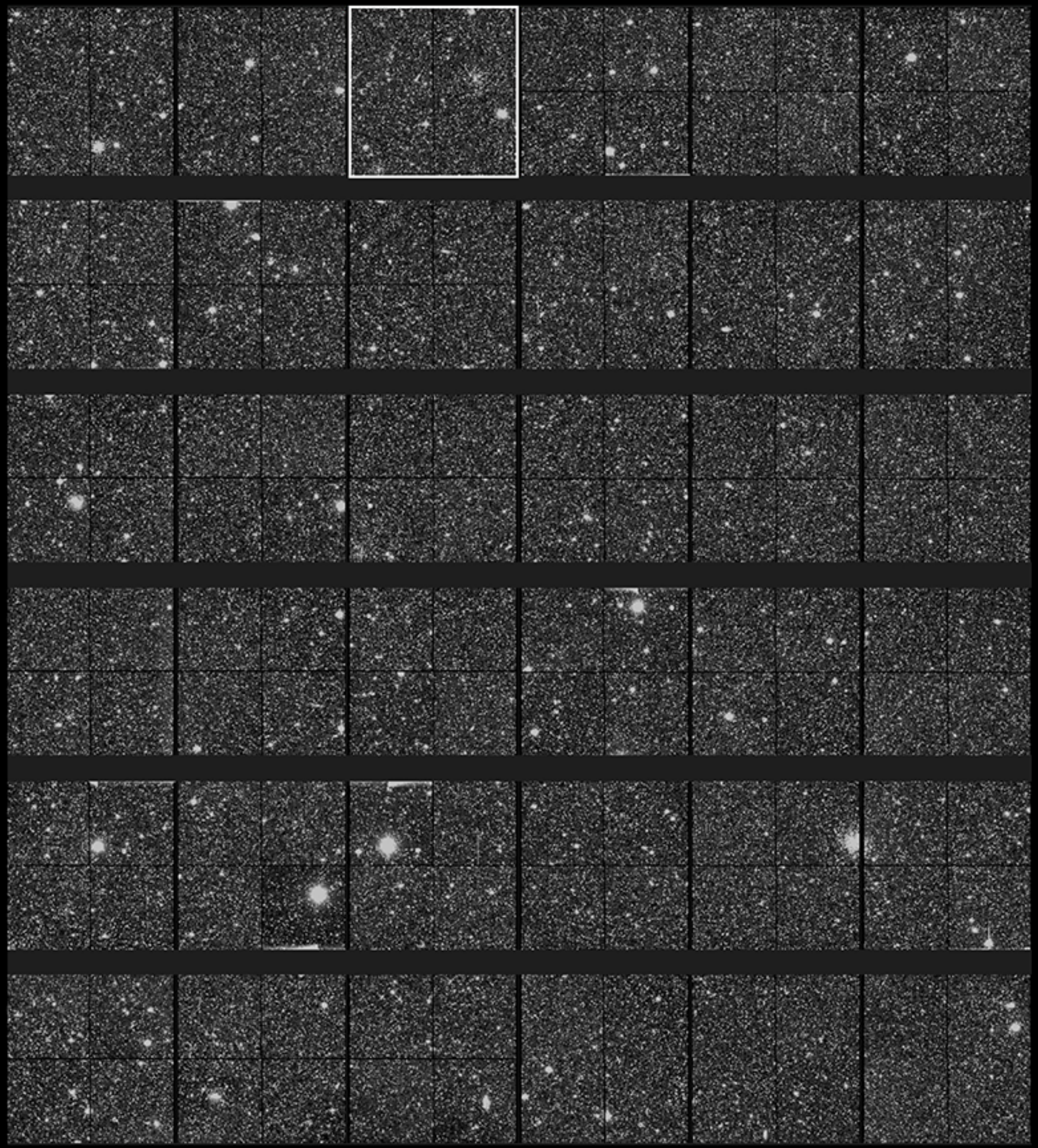
Launch vehicle: SpaceX Falcon 9

Destination: Sun-Earth Lagrange point 2, 1.5 million km from Earth



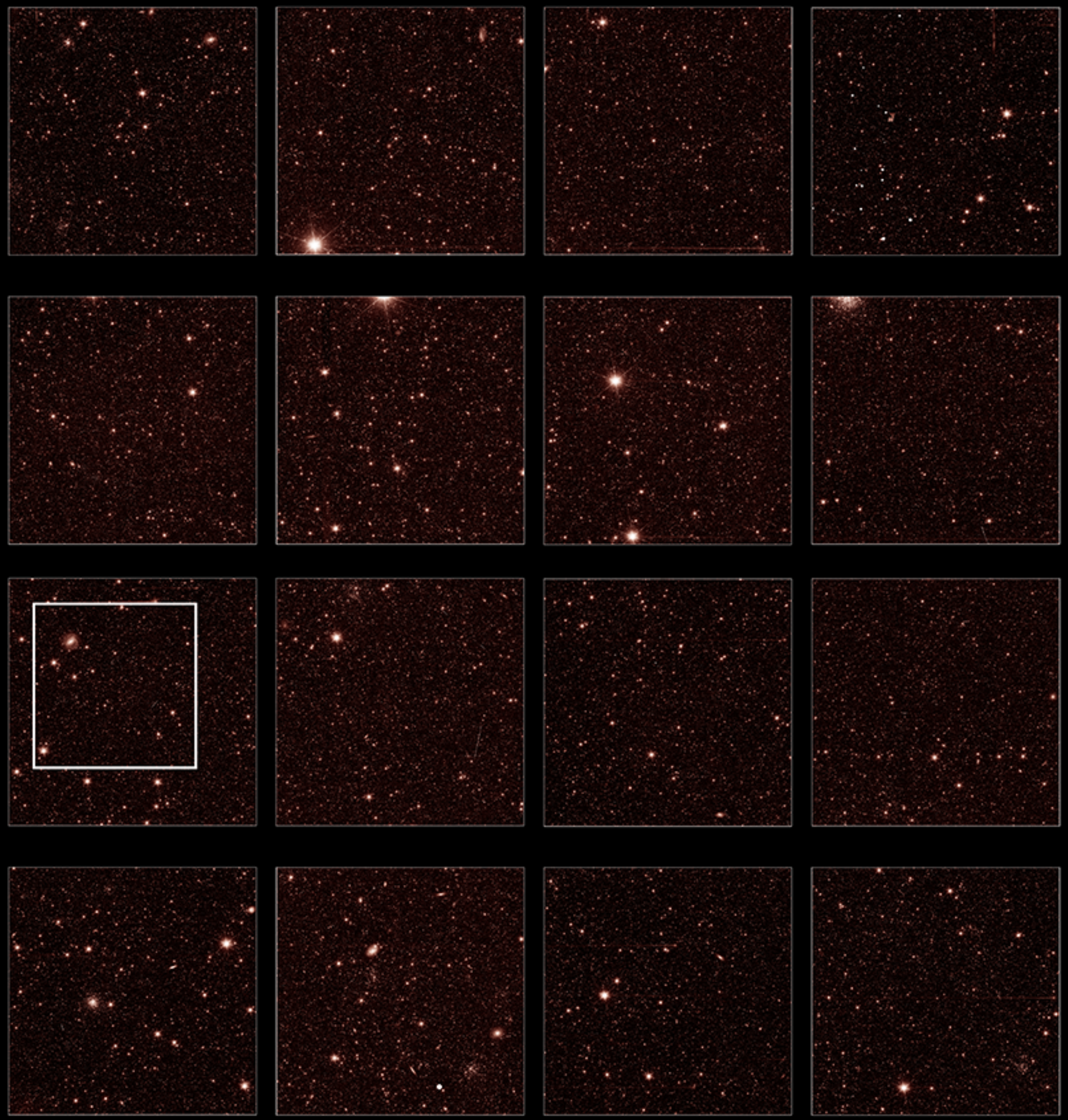


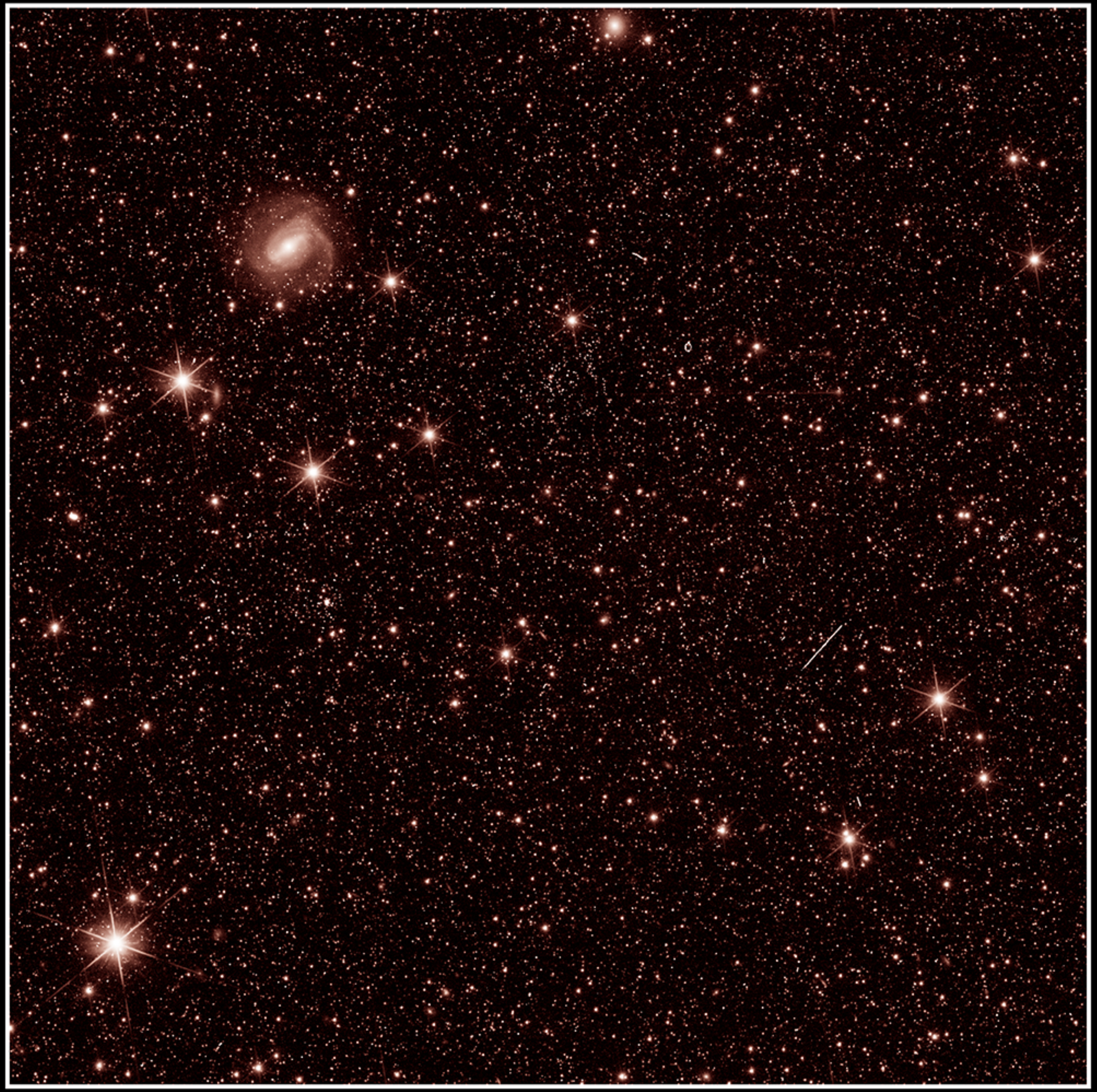
EARLY COMMISSIONING TEST IMAGE, VIS INSTRUMENT



Credits: ESA/Euclid/Euclid Consortium/NASA

EARLY COMMISSIONING TEST IMAGE, NISP INSTRUMENT





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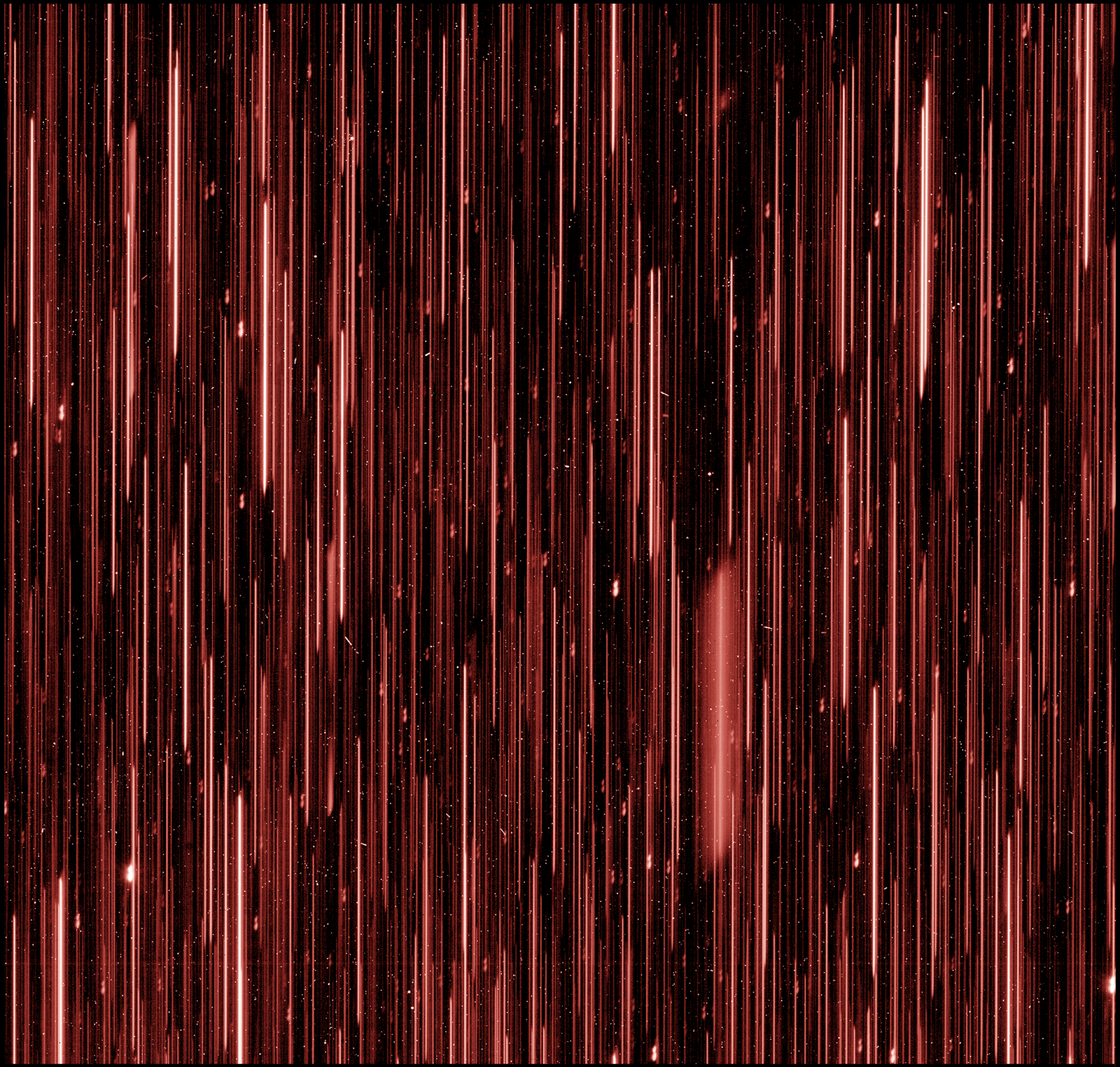
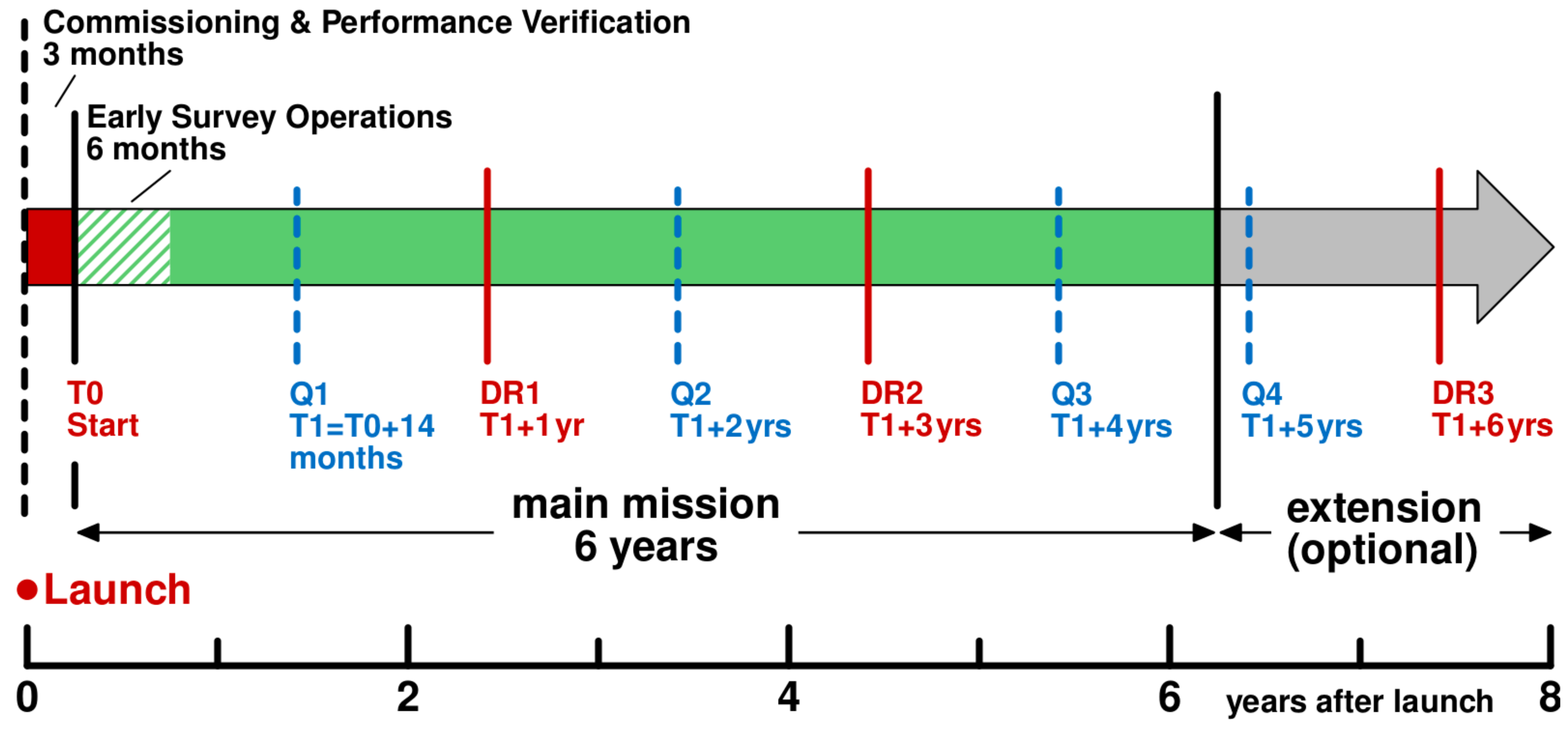


Early commissioning test image, NISP instrument (grism mode)

What's next?



- Currently **troubleshooting the fine guidance sensor (FGS).**
- At the end of performance verification, the survey operations will officially start
- Three public data releases, with an increasing fraction of the survey:
  - DR1: ~ mid 2025 (1/6 of the survey)
  - DR2: ~ 2027 (1/2 of the survey)
  - DR3: ~ 2031 (full survey)
- Each Data Release will be coupled with papers containing results from the official analysis.

This is just the beginning, stay tuned for more!