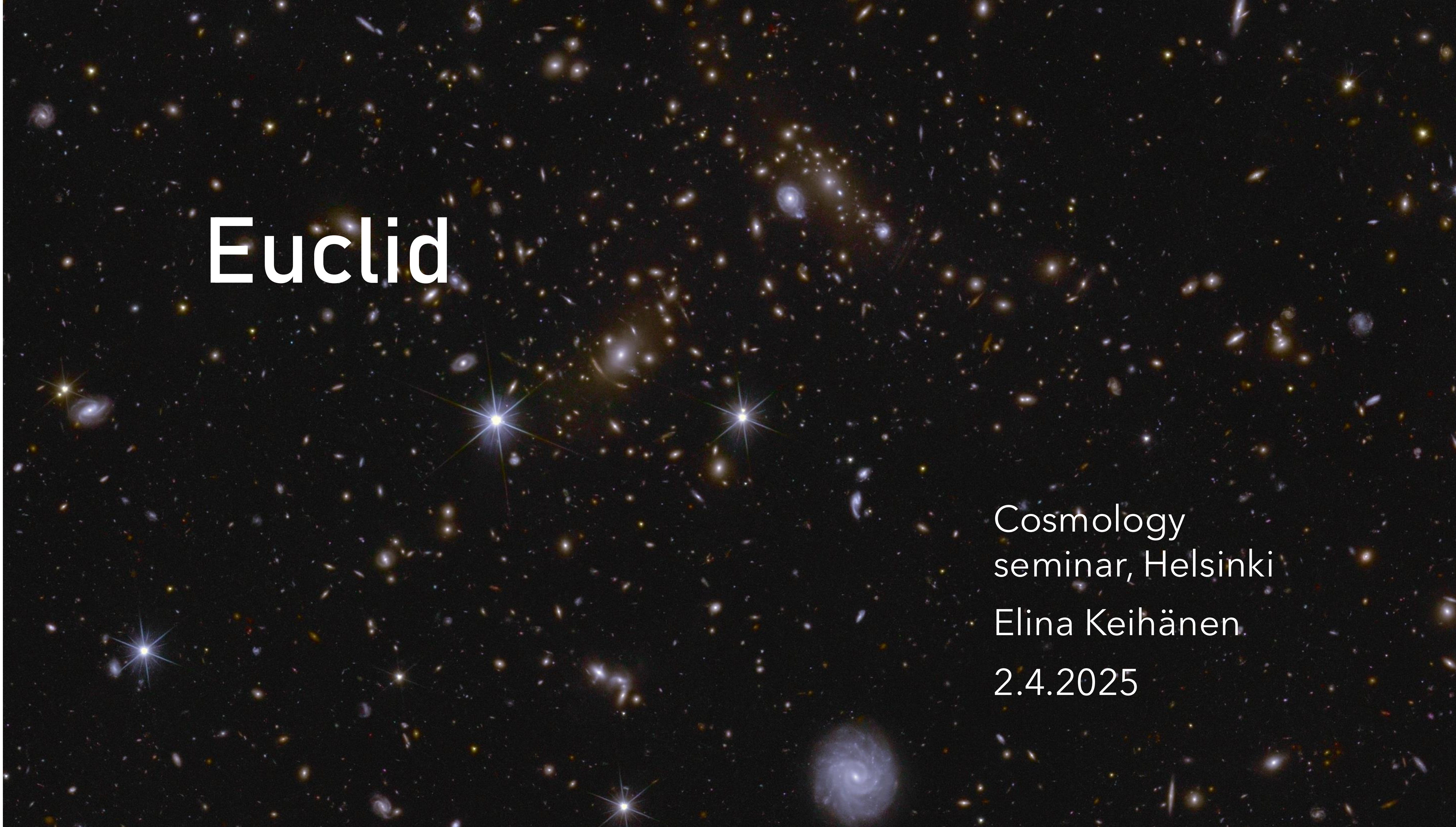


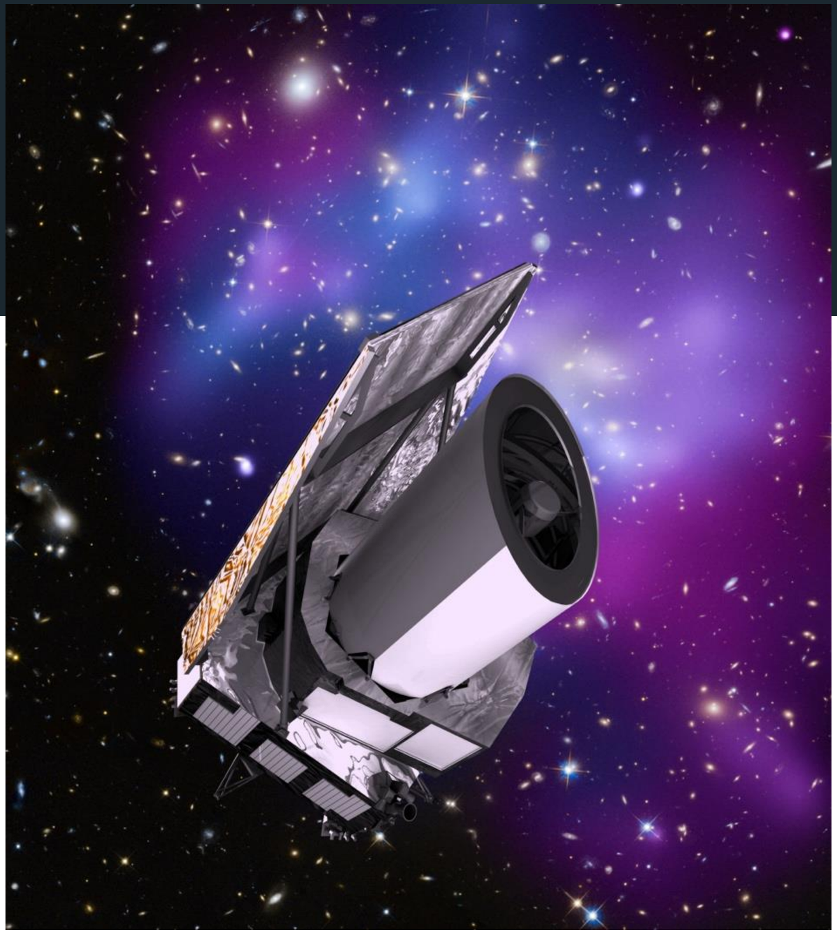
Euclid

Cosmology seminar, Helsinki

Elina Keihänen

2.4.2025

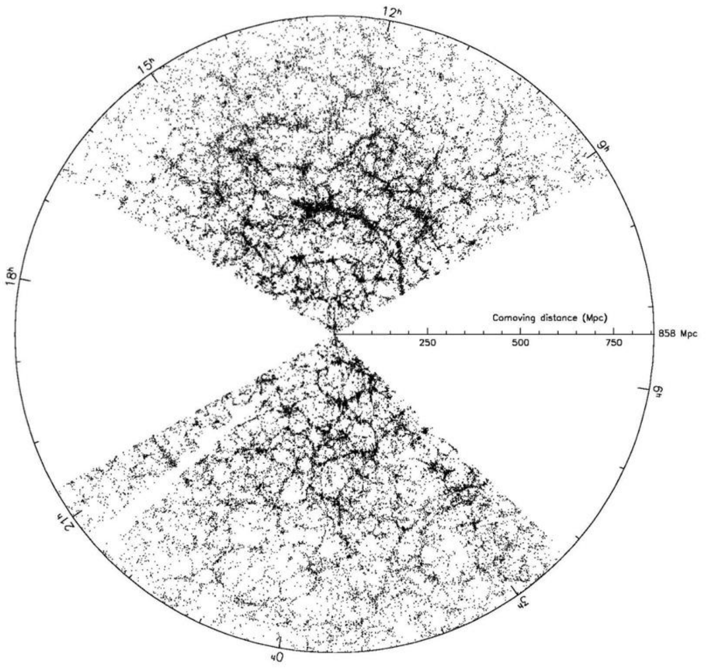
Euclid



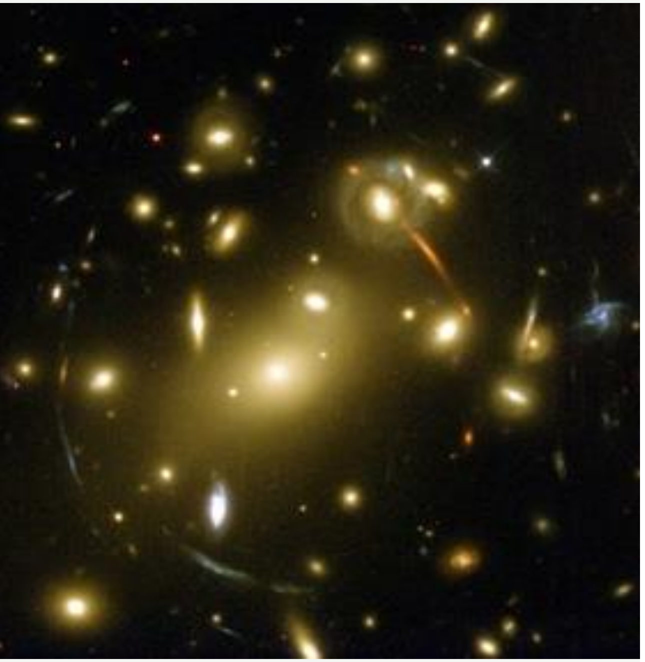
- ESA (European Space Agency) satellite mission
- Launched in July 2023
- Goal: solve the **mystery of dark energy**, why is the expansion of the universe accelerating.
- Two probes:
  - Galaxy survey
  - Gravitational lensing
- Together these two probes will map the **large-scale structure** and the **expansion history** of the universe.
- The unique strength of Euclid is the combination of these two probes.

Why study galaxy surveys

- Galaxy surveys reveal how galaxies are distributed on cosmic scales. These structures reflect the initial density fluctuations in the early universe.
- By measuring how galaxy clustering changes with redshift, we get information about the **growth history of cosmic structures**.
- This depends on the amount of matter, and the influence of dark energy.
- Features like **Baryon Acoustic Oscillations (BAO) scale** act as a standard ruler to measure cosmic distances.
- Track the expansion history of the universe, insight into the nature of **dark energy**.



Why study gravitational lensing?



- Deflection only depends on the strength of the gravitational field, regardless of what is sourcing it (visible or dark matter).
- Powerful tool to map the structure of the gravitational field - ––> **dark matter**
- Observations of sources at different distances –> 3D mapping
- Dark energy is homogeneous –> causes no lensing, however affects the expansion of the universe and affects observations indirectly.
- Gravitational lensing tests **Einstein’s theory of general relativity at large scales**.

A combined image of VIS and NISP images

Euclid instruments

- Euclid carries two instruments:
  - VIS (optical imaging)
  - NISP (Infrared imaging and spectrograph)
- Field-of-view 0.57 deg^2.
- VIS will take pictures of 3000 million galaxies (up to z=2) and measure their distortion due to **gravitational lensing** –> 3D mapping of the gravitational field.
- NISP spectrograph is used for a **galaxy survey**: It will measure the exact redshifts and locations of tens of millions of galaxies –> 3D map of the large-scale structure of the universe.
- Infrared images from NISP are needed for the interpretation the VIS measurements.

EXT data

- VIS band is too wide to allow for the determination of photometric redshifts.
- VIS data is complemented by ground-based observations from large-area surveys.
  - Southern sky: DES (Q1), Vera C. Rubin
  - Northern sky: CFIS, Pan-STARRS. HSC, WHIGS, WISHES
- External data is recalibrated and put into Euclid format (Oulu, A. Venhola & group)
- EXT is the “third Euclid survey”
- Together, the space- and ground-based data form the Euclid mission data set.

Launch and first steps

- Launched on July 1st 2023 from Florida (Kennedy Space Center, Cape Canaveral)
  - Falcon 9 of SpaceX
- Early issues:
  - Fine-guidance sensor not working right (software issue, fixed)
  - Straylight from the Sun entering the detectors (survey strategy redesigned)
  - Ice accumulating on the detectors (two de-icing periods March/June 2024)
- Since June 2024 the instruments have been working flawlessly.
- Collecting of scientific data began in Feb 2024.

VIS image of Messier 78

Early Release observations were published in May 2024.

SDC-FI

- SDC-FI: Euclid Science Data Center Finland
- One of the 9 Euclid data processing centers
- All 9 SDCs have the same software and are able to run the same processing steps.
- Since 2024 SDC-FI operates as part of CDC-FI, Cosmology Data Center Finland, shared resources with LISA.
- Hosted by CSC in Kajaani, operated from Helsinki (main system manager Valtteri Lindholm).
- Will process 5% of Euclid data.

Data release timeline

1. July 2023	Launch
Nov 2023	First images of astronomical objects published
Feb 2024	Survey begins
May 2024	Second set of Early Release Observations (ERO).
19. March 2025	Q1, First Quick Release
Feb 2024 – May 2025	Collecting data for DR1
Oct 2026	DR1, First Data Release, first cosmological results
June 2028	DR2
June 2031	DR3

Q1, First Quick Release

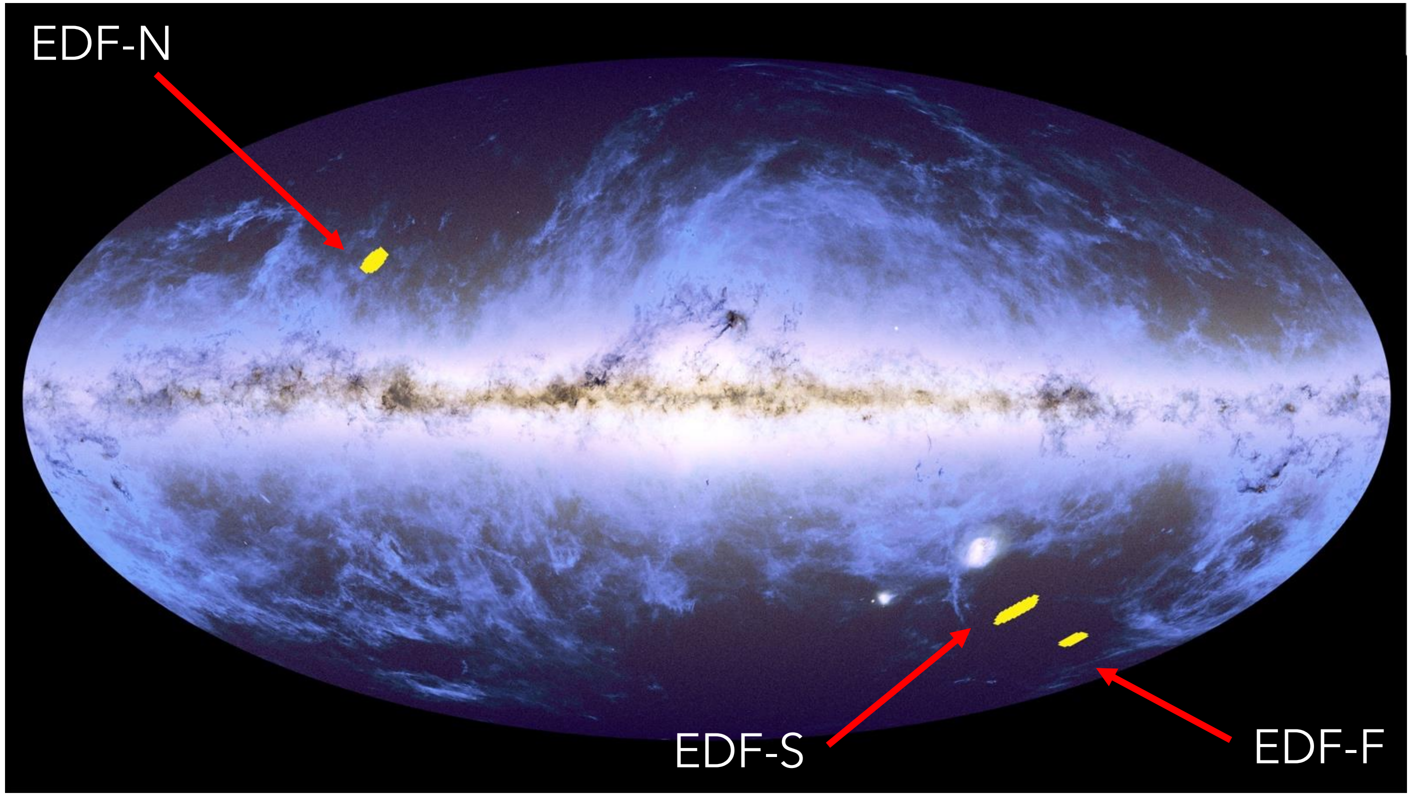
- Publication date: March 19th 2025
- Scientific results, not just images

Purpose of Q1

- Demonstrate the data to be expected in DR1.
- Give the non-Euclid community the chance to prepare their analysis tools for the actual DR1.
- Survey area not large enough for estimation of cosmological parameters.
- No cosmology yet, astronomical observations.
- “The Q products are suitable for most purposes in astronomy except for the core cosmology objectives of Euclid.”

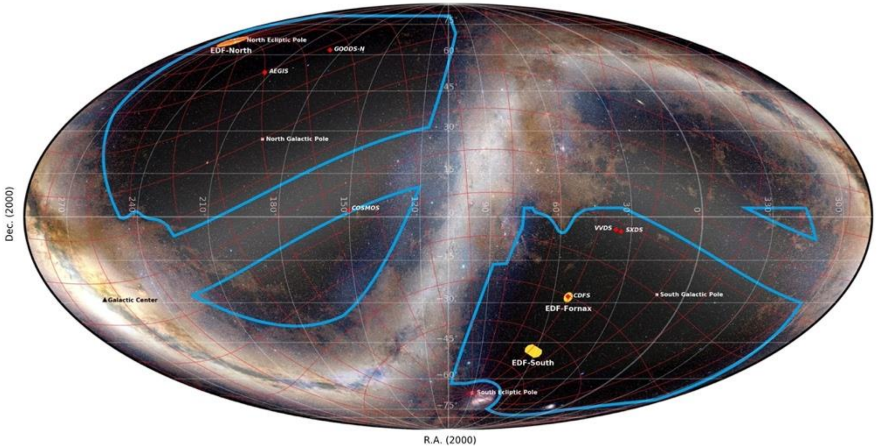
Q1 Sky areas

- Single visits over the **Euclid Deep Fields** (EDFs):
  - 20 deg^2 of the EDF North (EDF-N)
  - 10 deg^2 of the EDF Fornax (EDF-F)
  - 23 deg^2 of the EDF South (EDF-S)
- 63 deg^2 total (EDFs+margin)
- 0.45% of full Euclid survey (14 000 deg^2)



Euclid wide survey and deep surveys

- **Euclid wide survey** (EWS) covers 14 000 deg^2 (full sky is 41 253 deg^2)
    - Covered in 6 years
    - Magnitude limit I_E<24.5
    - Galactic plane and the Solar system plane excluded
- **Euclid deep surveys** (EDS) cover 53 deg^2
    - Visited tens of times times during the survey.
    - Will reach 2 magnitudes deeper than EWS.
- **Q1** covers EDS areas to EWS depth:



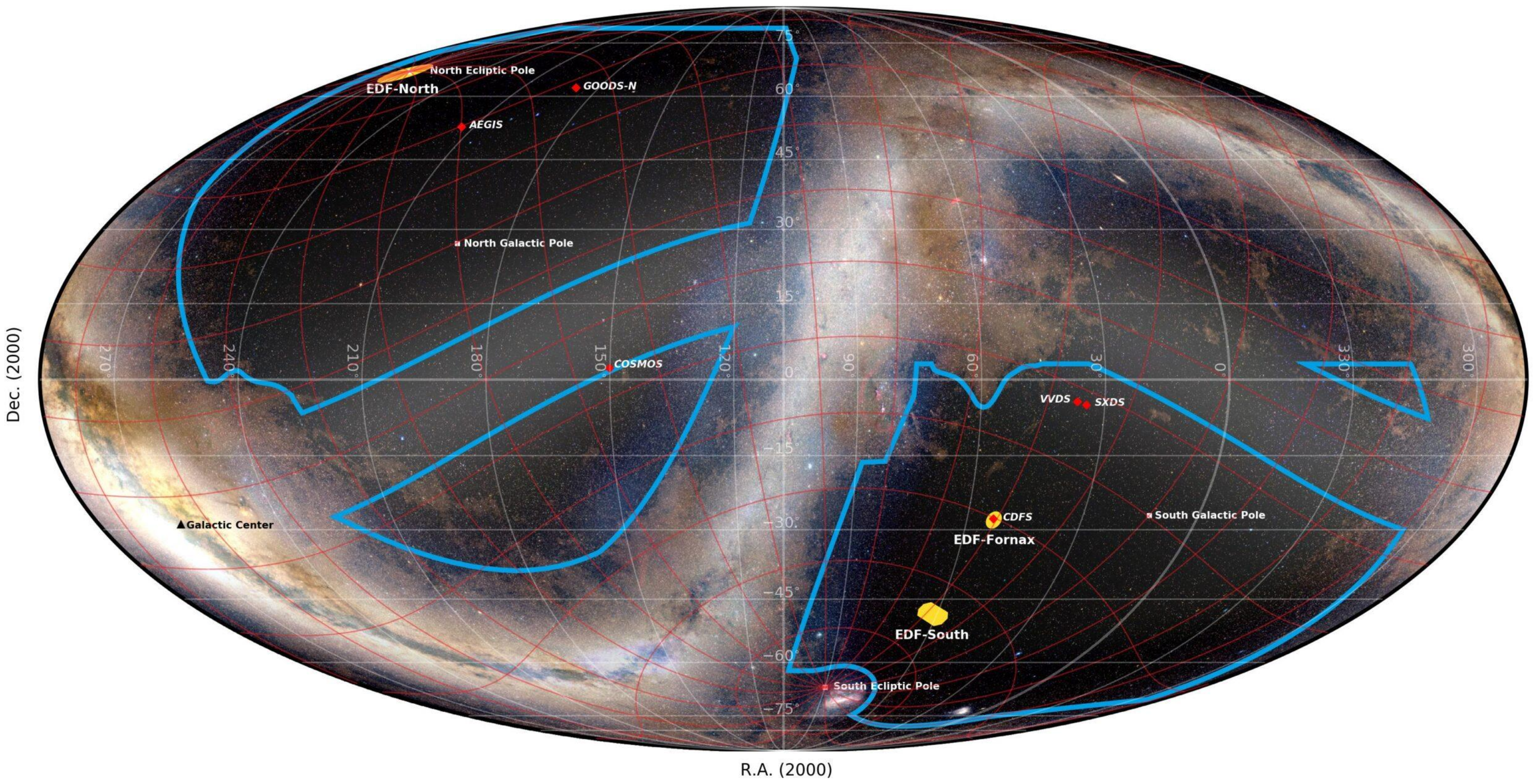
The 15,000 deg.^{2} Euclid Wide Survey, the 53 deg.^{2} Euclid Deep Survey, and the 6 deep auxiliary fields (6.5 deg.^{2}) [Mollweide Celestial]

Euclid Wide Survey region of interest : 16 Kdeg.^{2} compliant with a 15 Kdeg.^{2} survey

Euclid Deep Fields : North=20 deg.^{2}, Fornax=10 deg.^{2}, South=23 deg.^{2}

Euclid deep auxiliary fields (GOODSN=0.5, AEGIS=1, COSMOS=2, VVDS=0.5, SXDX=2, CDFS=0.5 deg.^{2})

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



The 15,000 deg.^{2} Euclid Wide Survey, the 53 deg.^{2} Euclid Deep Survey, and the 6 deep auxiliary fields (6.5 deg.^{2}) [Mollweide Celestial]

Euclid Wide Survey region of interest : 16 Kdeg.^{2} compliant with a 15 Kdeg.^{2} survey

Euclid Deep Fields : North=20 deg.^{2}, Fornax=10 deg.^{2}, South=23 deg.^{2}

Euclid deep auxiliary fields (GOODSN=0.5, AEGIS=1, COSMOS=2, VVDS=0.5, SXDX=2, CDFS=0.5 deg.^{2})

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

Q1 data selection

- Q1 aims at demonstrating the data to be expected from the Wide Survey
- Covers the deep survey areas to the wide survey depth = single sweeps
- EDF-N has been scanned six times so far
  - One scan lost to high solar activity
  - One suffered from ice contamination
  - From the remaining four, the one with least data loss due to cosmic rays was selected for Q1
- EDF-S has been scanned three times
  - The one with least solar activity was selected for Q1
- EDF-F had two passes, one selected for Q1

Self-calibration field

EDF-N includes the Euclid self-calibration field:
Will be observed hundreds of times.

Close-up of the Einstein ring around galaxy NGC 650 in the self-calibration field:

What is included in Q1?

- Three areas, 63 deg^2 coverage
- Euclid dark cloud
- 7 days of Euclid observations
- 30 million objects: galaxies, stars, quasars, brown dwarfs, solar system objects
- VIS and NISP images
- EXT data
- Catalogs of objects
- Available at the public Euclid science archive hosted at ESAC (see Q1 overview paper for details)

Euclid dark cloud

Star forming area in Orion, observed in September 2023 to test and optimize the fine-guidance sensor

Fig. 3. Small cutout of the NISP dark-cloud image. Shown near the centre is HOPS 221, a YSO with prominent outflows that can be traced across the image and beyond. North is up, east is to the left, and the field is 7′ wide.

Comparison to Hubble Space Telescope

How does HST sky coverage compare to Euclid?

- Field-of-view (Ω):
  - Euclid 0.57 deg^2
  - HST 0.0031 deg^2
- Etendue ($A\Omega$):
  - Euclid 0.57m^2deg^2
  - HST 0.0126 m^2deg^2

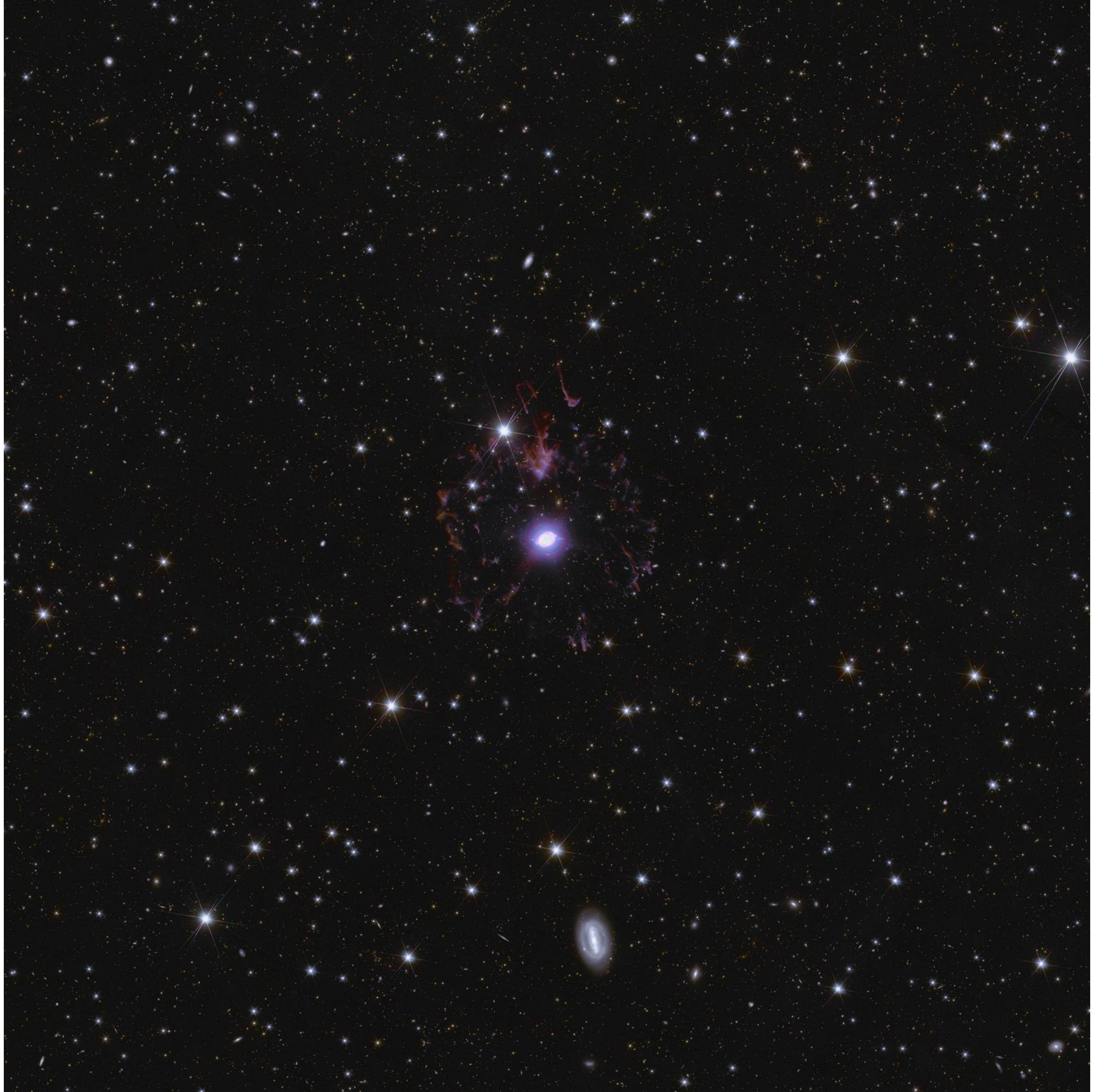
- Full HST survey area:
  - One estimate: 0.8% of full sky ≈ 320 deg^2
  - Q1 overview paper (H. Aussel et al):

2.3. Target populations

With 63.1 deg^2, the Q1 area coverage is likely to be comparable within a factor of a few to that of HST since its launch[1]. While

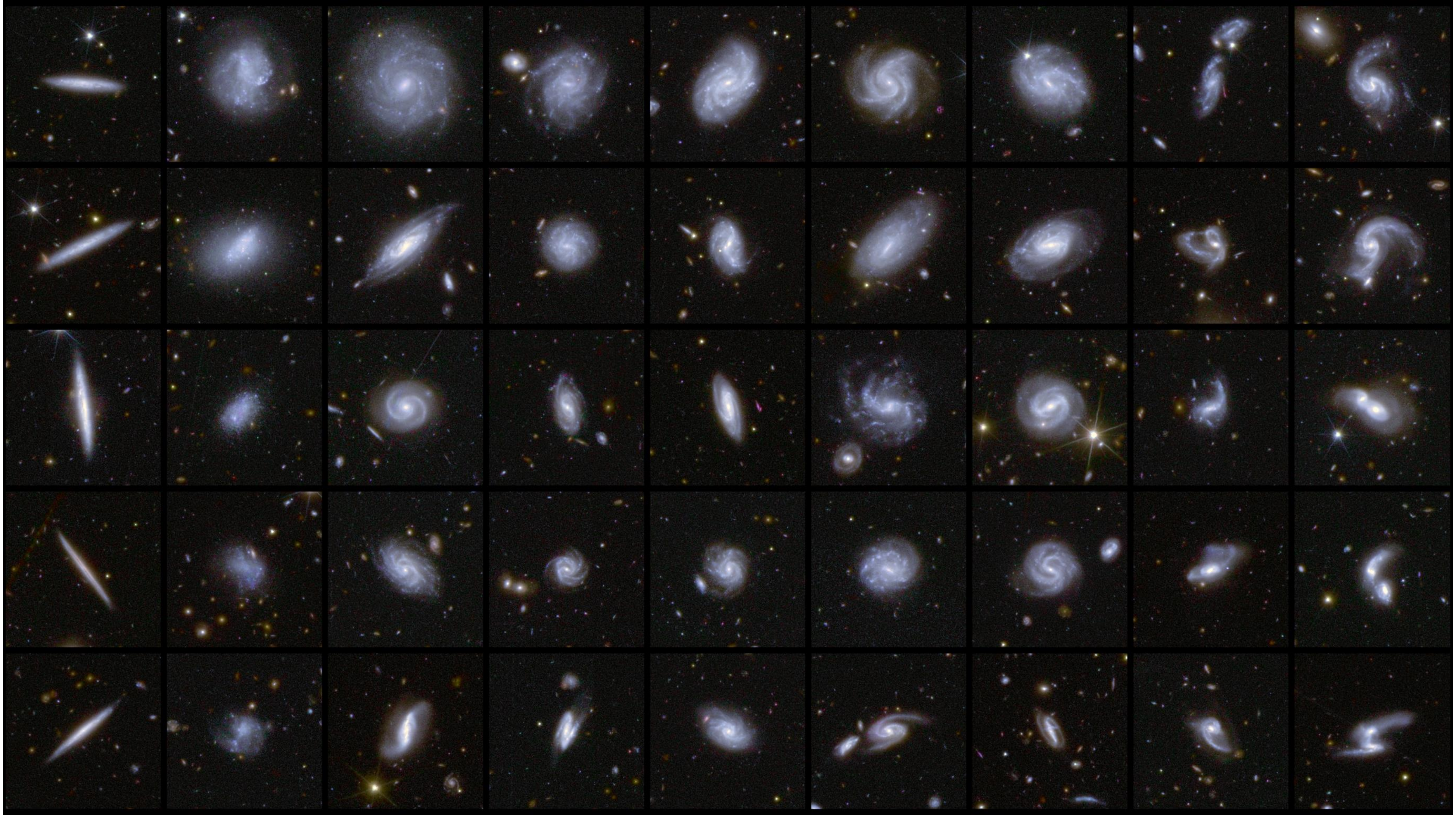
[1] The actual HST sky coverage is difficult to determine, due to overlapping observations and parallel fields. We did not attempt to make an accurate estimate.

Examples of images



Cat's Eye nebula

Euclid deep field South (70x zoom)



Galaxies seen by Euclid

Strong gravitational lensing

- Most galaxy-scale strong lenses are expected to have have Einstein radii smaller than 1′′ (arcsec), below the resolution of ground-based surveys
- Euclid can resolve Einstein radii to 0.6 arcsec
- Q1 release contains a catalog of 497 strong lenses, doubling the number of known strong lensing candidates with space-based imaging
- Extrapolation to EWS → 100 000 strong lensing candidates

Strong lensing candidates detected by Euclid

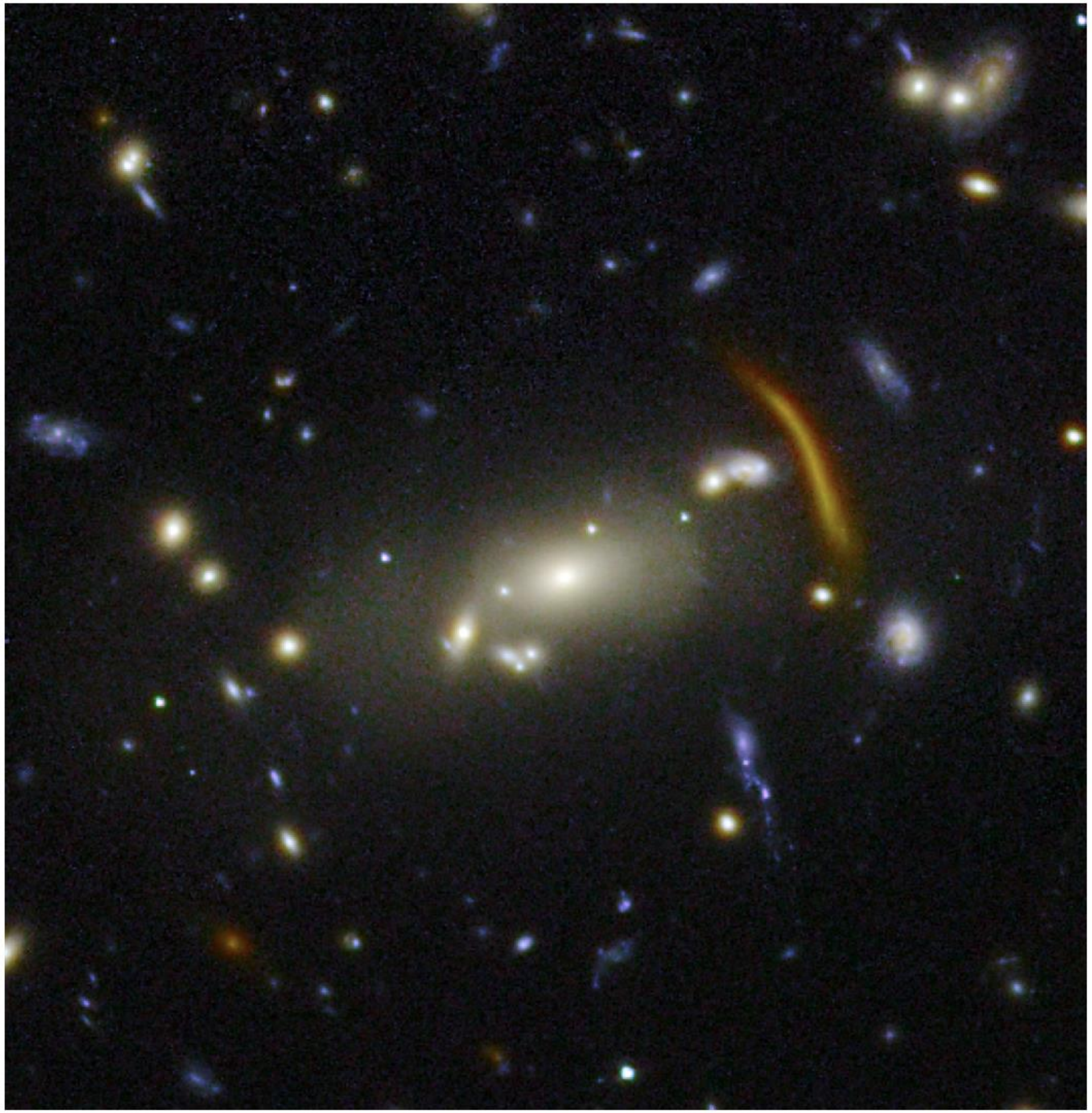


Fig. 11. The strong-lensing cluster Abell 2280 in the EDF-N Q1 area. This image is at the full VIS resolution, $52'' \times 52''$ wide, using VIS and all NISP photometric images for colour information.

Q1 publications

27 scientific publications
+7 describing the data processing

Available in Euclid portal or at arXiv

~10 more internal reviewing

Coordinated Release "Quick Data Release (Q1)," March 2025

- Euclid Collaboration: Aussel et al., 2025, *"Euclid Quick Data Release (Q1). Data release overview"*
- Euclid Collaboration: McCracken et al., 2025, *"Euclid Quick Data Release (Q1). VIS processing and data products"*
- Euclid Collaboration: Polenta et al., 2025, *"Euclid Quick Data Release (Q1). NIR processing and data products"*
- Euclid Collaboration: Romelli et al., 2025, *"Euclid Quick Data Release (Q1). From images to multiwavelength catalogues: the Euclid MERge Processing Function"*
- Euclid Collaboration: Tucci et al., 2025, *"Euclid Quick Data Release (Q1). Photometric redshifts and physical properties of galaxies through the PHZ processing function"*
- Euclid Collaboration: Copin et al., 2025, *"Euclid Quick Data Release (Q1). From spectrograms to spectra: the SIR spectroscopic Processing Function"*
- Euclid Collaboration: Le Brun et al., 2025, *"Euclid Quick Data Release (Q1). Characteristics and limitations of the redshift measurements"*
- Euclid Collaboration: Quilley et al., 2025, *"Euclid Quick Data Release (Q1). Exploring galaxy morphology across cosmic time through Sersic fits"*
- Euclid Collaboration: Walmsley et al., 2025, *"Euclid Quick Data Release (Q1). First visual morphology catalogue"*
- Euclid Collaboration: Huertas-Company et al., 2025, *"Euclid Quick Data Release (Q1). A first look at the fraction of bars in massive galaxies at z<1"*
- Euclid Collaboration: Siudek et al., 2025, *"Euclid Quick Data Release (Q1). Exploring galaxy properties with a multimodal foundation model"*
- Euclid Collaboration: Cleland et al., 2025, *"Euclid Quick Data Release (Q1). The evolution of the passive-density and morphology-density relations between z = 0.25 and z = 1"*
- Euclid Collaboration: Enia et al., 2025, *"Euclid Quick Data Release (Q1): A first view of the star-forming main sequence in the Euclid Deep Fields"*
- Euclid Collaboration: Corcho-Caballero et al., 2025, *"Euclid Quick Data Release (Q1). A probabilistic classification of quenched galaxies"*
- Euclid Collaboration: Roster et al., 2025, *"Euclid Quick Data Release (Q1). Optical and near-infrared*

TeX

Data processing

- Half of the scientific Q1 papers make use of AI in some form (find and classify AGNs, characterization of gravitational lenses...)
- Calaxy classification used a neural network trained within Zooniverse project: Human volunteers classified by eye galaxies in HST and JWST images.

DR1 = First Data Release

- Public release in **October 2026**
- First cosmological data release
- Includes the data collected between Feb 2024 and May 2025
- Sky coverage 1900 deg^2 (1/7 of the full Euclid survey)
  - 1400 deg^2 in Southern sky
  - 500 deg^2 in Northern sky
- Cosmological results!