Jet Propulsion Laboratory
California Institute of Technology

euclid

Euclid Update

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On behalf of the NASA project and the Euclid Consortium

ipac ensci

euclid consortium

Euclid – mapping the geometry of the dark universe

A space-based survey telescope led by the European Space Agency (ESA) and the Euclid Consortium with contributions from NASA.

First space mission dedicated to the study of dark energy.

Measurements include the Dark Energy equation of state, $w(a)$, the growth of structure parameter, γ, the neutrino mass, m_ν, and the universe's initial conditions f_{NL}

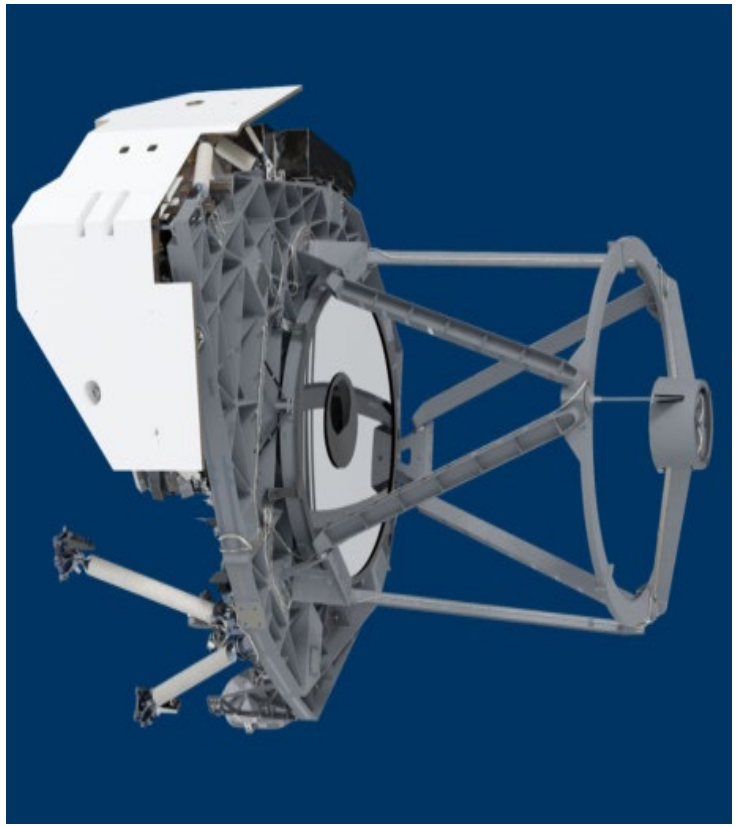
Image credit: SpaceX

Three NASA-provided elements:

- Hardware contribution to near-IR instrument
- Euclid NASA Science Center at IPAC (ENSCI)
- 3 Science teams selected through peer review:
  - Constraining Dark Energy and Gravity with Euclid (PI J. Rhodes, JPL)
  - Looking at Infrared Background Radiation Anisotropies with Euclid (PI A. Kashlinsky, GSFC)
  - Precision Studies of Galaxy Growth & Cosmology Enabled Through a Physical Model for Nebular Emission (PI R. Chary, UCLA)

Euclid – Telescope and Instruments

Telescope:
1.2 meter primary diameter
Silicon Carbide 3-mirror Korsch anastigmat



Two Instruments:
VIS – wide band visible imaging array instrument
NISP – near-IR spectrometer and photometer

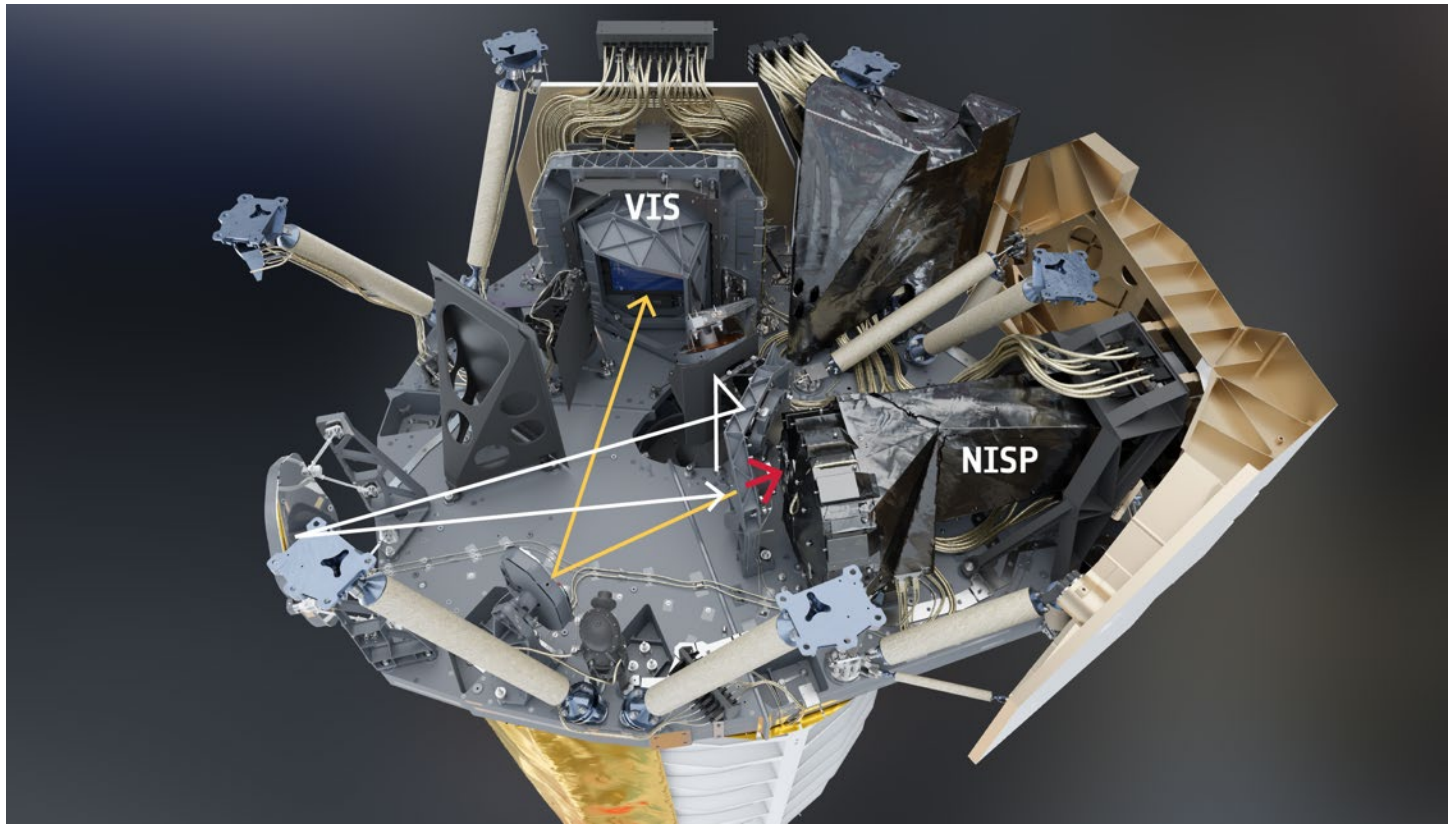


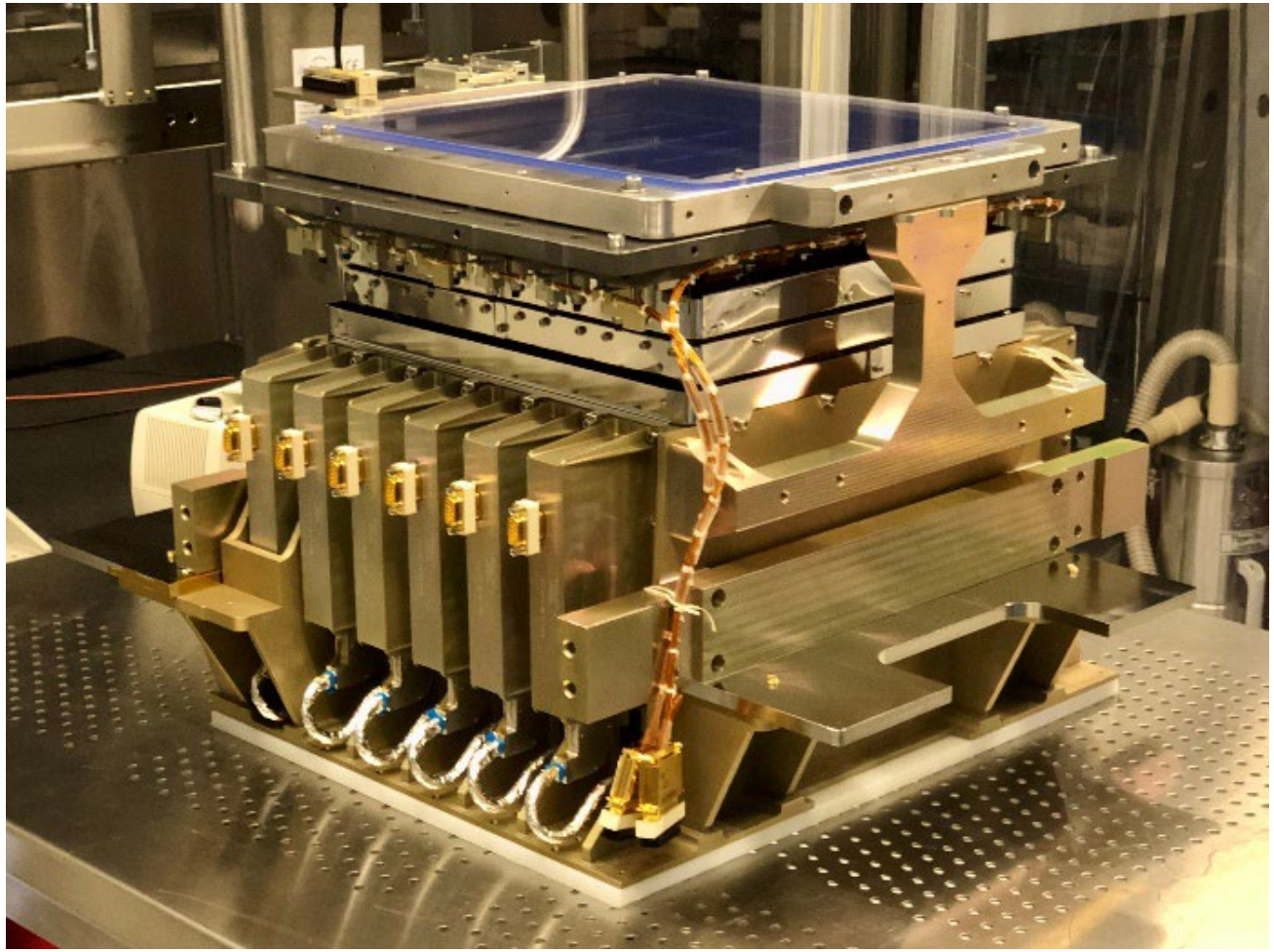
Image credit: Airbus Defense and Space / ESA

Euclid – Visible Instrument (VIS)

Focal Plane Array (FPA) 6 x 6 array
- 4096 x 4132 pixel Teledyne e2v Si CCDs
- 0.1 arcsec/pixel
- 0.53–0.92 µm wide-band imaging

Thermal Isolation Layer
- CCD/FPA = (**153** ± 7) K
- ROE = (**270** ± 20) K

Read Out Electronics (ROE)
- Signal amplifier & Analog to Digital Converter (ADC)
- FPGA for CCD operation



FPA with cover on top of CCDs for protection

Image: M. Cropper et al. *The* Euclid *Visible Camera VIS*

Euclid – Near-infrared Spectrometer and Photometer

- 16 x 2048 x 2048 pixel 2.3 um cutoff Teledyne HgCdTe arrays
- SIDECAR ASIC detector readout
- 0.3 arcsec/pixel
- 0.95–2.02 µm Y/J/H-band imaging
- R > 400 slitless spectroscopy

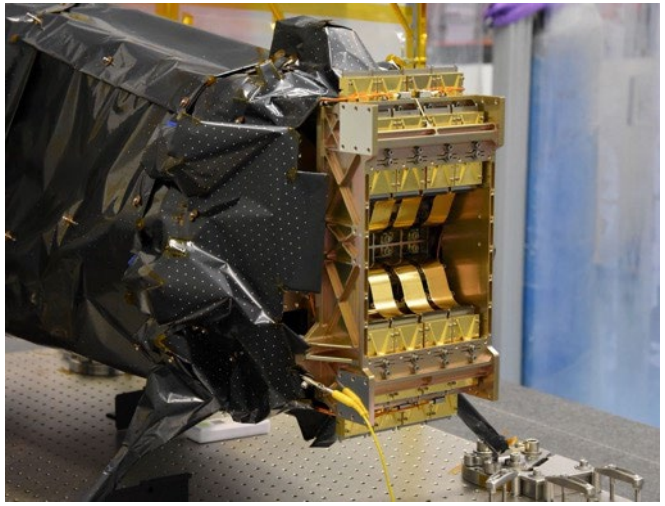


Image credit: Euclid Consortium/CPPM/LAM

NASA flight hardware consists of 16 flight units (+ 4 flight spares) of:

- Detectors
- Readout electronics
- Cryogenic cables

JPL led, with GSFC testing support

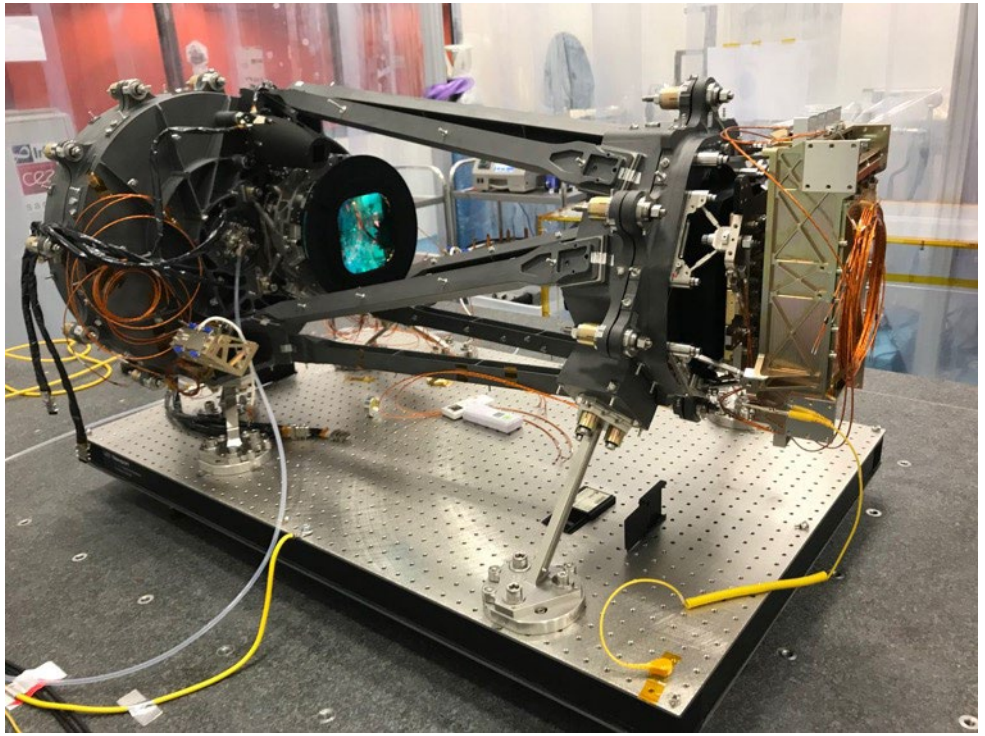


Image credit: Euclid Consortium & NISP instrument team

NISP flight model before being wrapped in Multi-Layer Insulation (MLI).

Euclid – Survey

Euclid was launched on July 1, 2023 from Cape Canaveral, FL on a SpaceX Falcon 9.

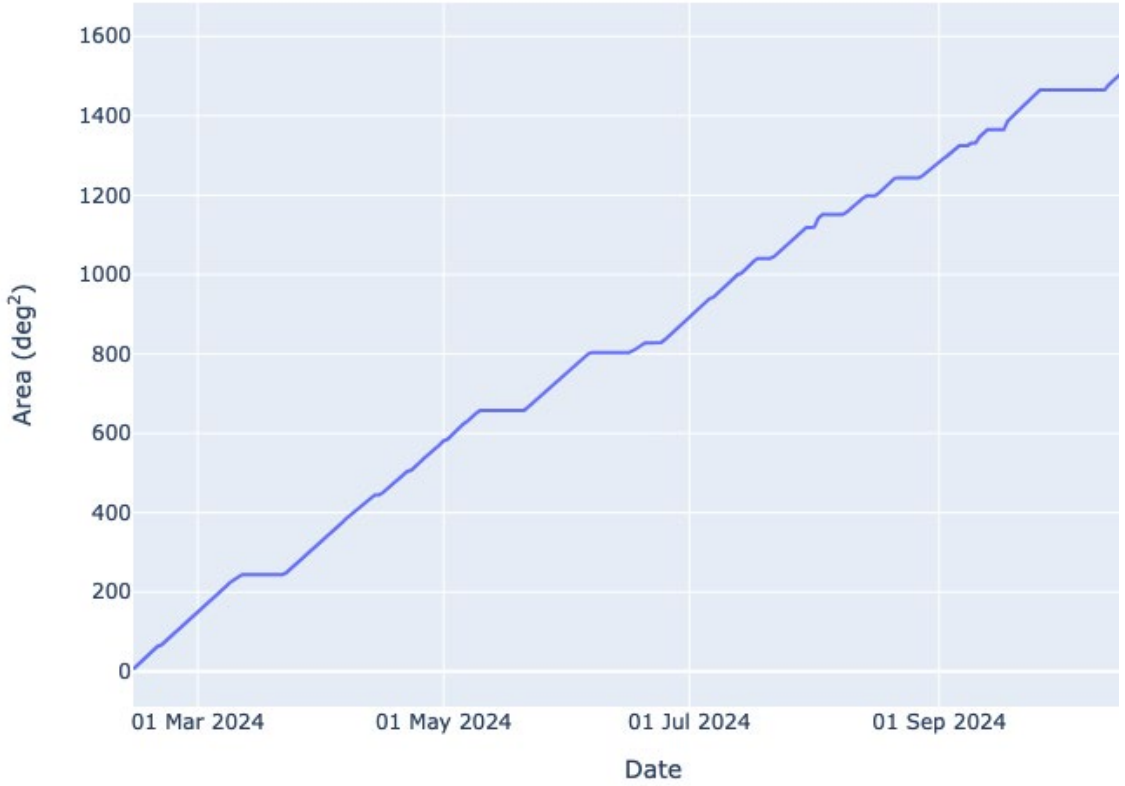
Euclid's primary science is accomplished through a wide (>14,000 square degrees) survey of the extragalactic sky. There are additional deep fields and calibration fields.

Early observations showed that Euclid is performing well.

A few areas of concern have been identified and mitigated:

- Unexpected straylight at specific spacecraft orientations
- Occasional X-rays from solar flares contaminates some VIS images
- Occasional loss of fine guidance tracking
- Ice contamination of VIS images

- Nominal survey began on Feb. 14, 2024
- Survey operations are continuing normally.



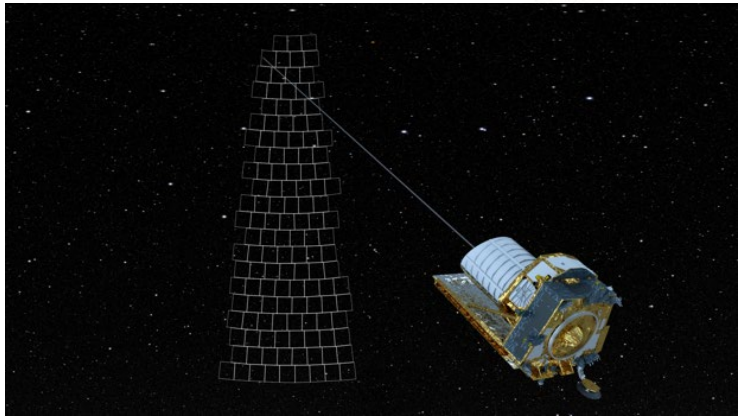
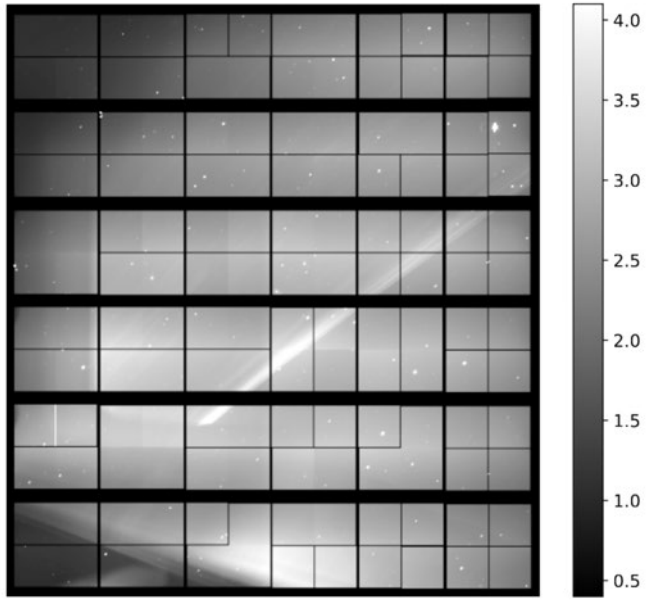


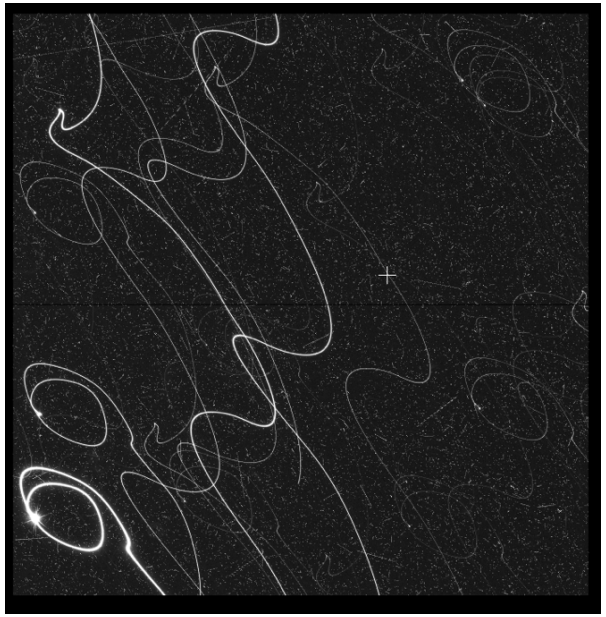
Image credit: ESA

Euclid Lessons Learned

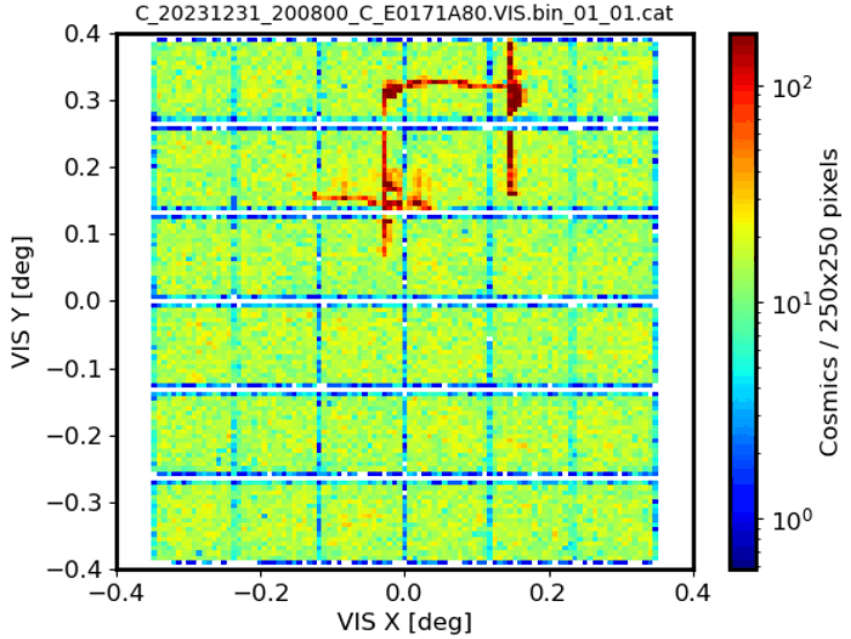
- ESA and NASA Euclid Projects jointly organized a series of three “Lessons Learned” virtual meetings for NASA missions in Spring 2024
  - Audience was Roman, CASE/ARIEL, IPAC/STScI, SPHEREx, UVEX, NEO Surveyor, HWO
  - Opened lines of communication and may be repeated
  - Peak attendance > 90 people
  - Topics covered included: Straylight, Fine Guidance System anomaly, Solar X-ray flare effects, PSF stability, icing and decontamination, calibration of H2RG (especially persistence), data processing, jitter performance



Straylight in VIS instrument. Euclid Collaboration: Y. Mellier et al. 2024

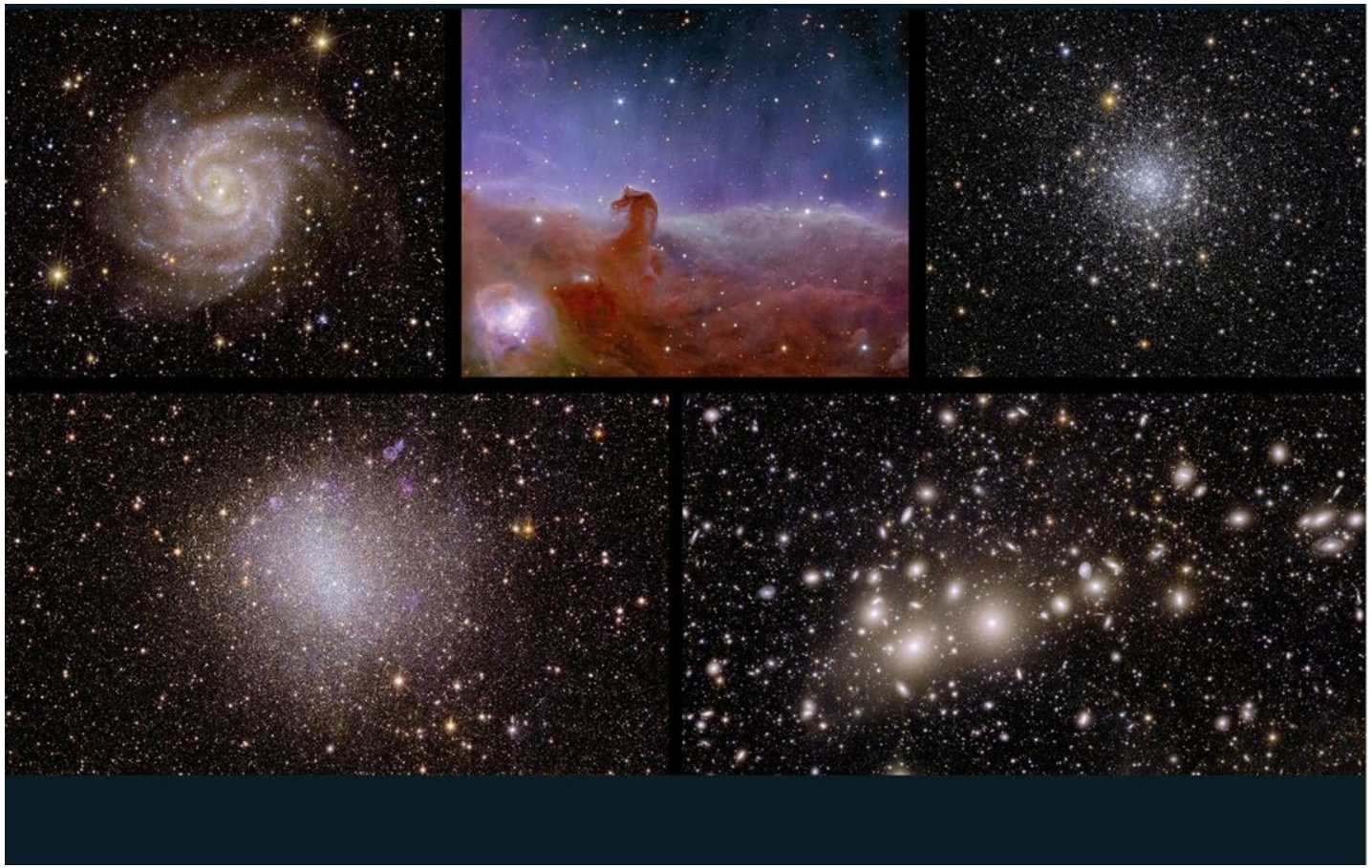


Intermittent loss of fine guidance. Image: ESA



Solar x-ray flare: Koen Kuijken / Euclid Consortium

Early Release Observations



SCIENCE & EXPLORATION

Euclid's first images: the dazzling edge of darkness

07/11/2023 48058 VIEWS 696 LIKES 484284 ID

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DETAILS RELATED

Today, ESA's Euclid space mission reveals its first full-colour images of the cosmos. Never before has a telescope been able to create such razor-sharp astronomical images across such a large patch of the sky, and looking so far into the distant Universe. These five images illustrate Euclid's full potential; they show that the telescope is ready to create the most extensive 3D map of the Universe yet, to uncover some of its hidden secrets.

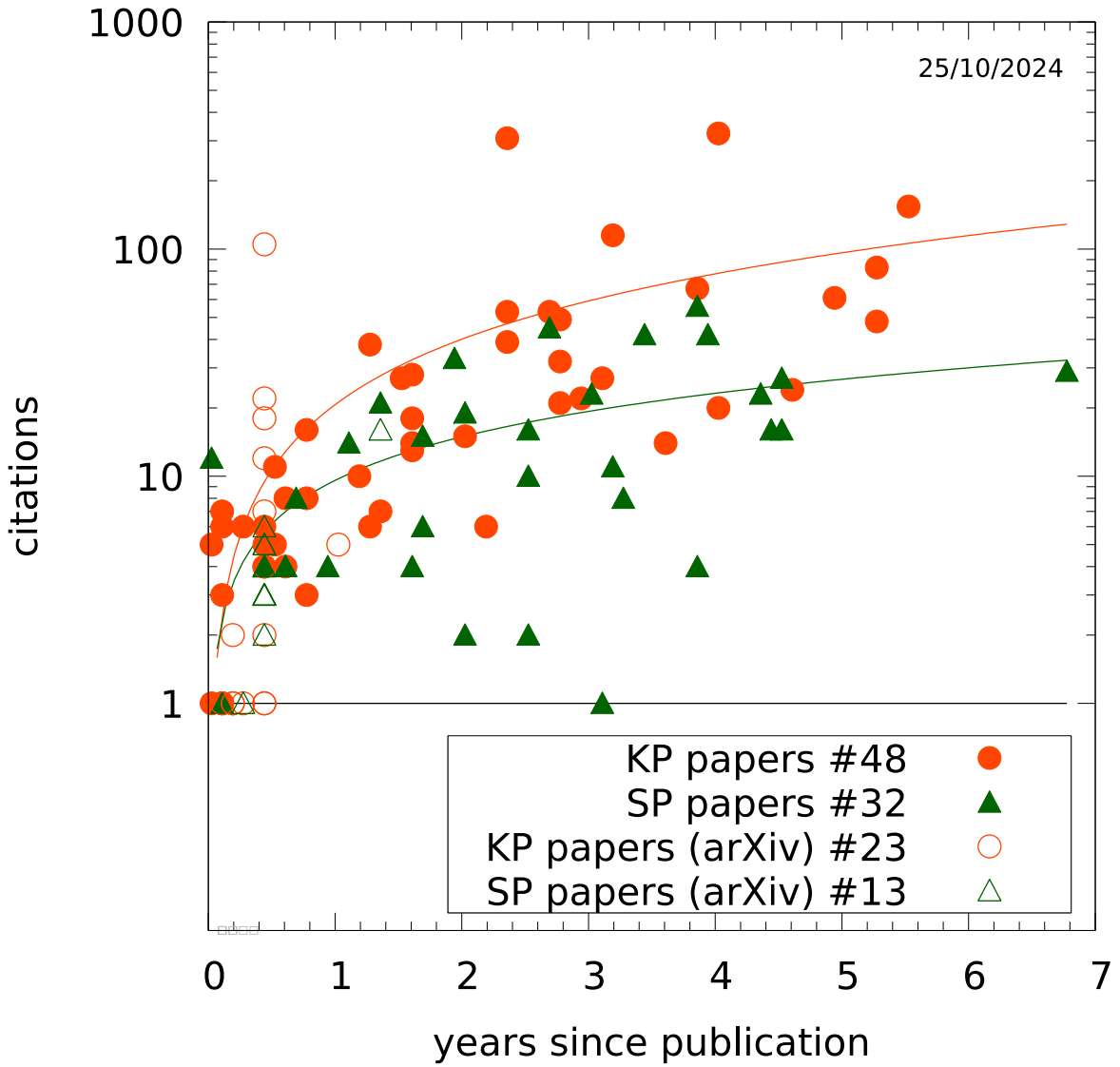
Read more about Euclid's first images and download the individual images here

- Early release observations chosen for visual impact and to demonstrate capability
- ~ 10 square degrees of visible an NIR imaging *taken in less than one day*
- Public relations splashes in Nov 2023 and May 2024 (with public data release) involved NASA
- Images covered by media outlets reaching over 2 Billion people

The Horsehead Nebula by Euclid

- ERO images accompanied by 14 refereed papers across a wide range of science areas
- Includes free floating planets in the Horsehead Nebula

Euclid Publications



- We are in the beginning stages of tracking the impact of Euclid publications. The figure shows *Euclid Consortium* publications with citations shown on a log scale.
- It is too early to gauge the scientific impact of Euclid – we will have a clearer picture after the release of the first cosmology results with Data Release 1 (DR1)

Primary mission reference :

Euclid. I. Overview of the Euclid mission, *Euclid Collaboration: Mellier et al.* 84 pages, > 1000 co-authors

- Primary cosmology probes
- Spacecraft and instruments
- Survey plans
- Early commissioning results
- Simulations
- Data products and processing
- Expected cosmology constraints from primary probes
- Additional cosmological probes
- Science beyond cosmology

Upcoming Publications

- **142** official Euclid Consortium (EC) publications so far with many more in prep
- Euclid publications are **Flagship** (very few, highest impact), **Key** papers (defined top down as priorities), and **Standard** papers (anything a Consortium member wants to use the data for in the proprietary period)
- US EC community has commensurate number of crucial Key Project leadership positions

- Euclid Consortium is planning papers around data releases including Q1 (March 2025) and DR1 (Summer 2026)
  - For **Q1, the EC has 82 planned papers** (mostly Key, but some Standard), number of Standard papers may grow
  - For **DR1, EC has 318 planned Key papers**, perhaps expect same order of magnitude Standard papers (not yet defined)
  - Not all of these papers will come to fruition, but majority will
- Euclid will have a huge impact in cosmology and beyond with planned EC papers
- We hope that the non-EC community exploits the Euclid data for decades to come

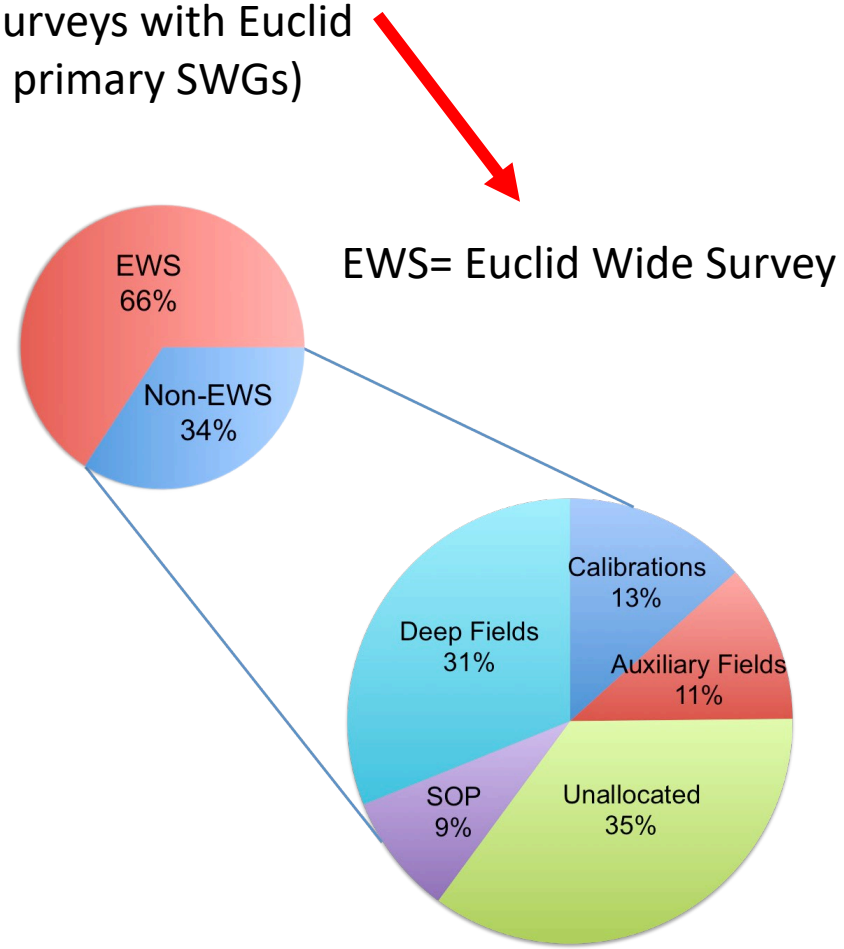
US Euclid Engagement

- 160 Full members of the Euclid Consortium (up from 54 at mission adoption in 2013)
- Key Leadership positions that leverage US strengths
  - Jason Rhodes chaired Euclid Consortium Board 2022-2024
  - Jason Rhodes on the ESA Euclid Science Team that will coordinate additional surveys with Euclid
  - Yun Wang is co lead of the Galaxy Clustering Science Working Group (one of 2 primary SWGs)
  - Claudia Scarlata is on the 7-person Science Coordination Group
  - Dida Markovic overhauled Euclid internal communications

- Key science deliveries include (all feed into Roman)
  - Photo-z algorithms and calibration data (e.g. Subaru and Keck)
  - Follow up opportunities on Keck/Palomar/other US facilities
  - Weak lensing shape measurement pipeline
  - Galaxy cluster detection algorithm

- Strong overlap with Roman High Latitude Imaging and Spectroscopic Project Infrastructure Teams

- Leadership on Euclid/Rubin/Roman coordination including (see next slides)
  - Joint Processing-Derived Data Products
  - Survey Coordination
  - Joint Simulations

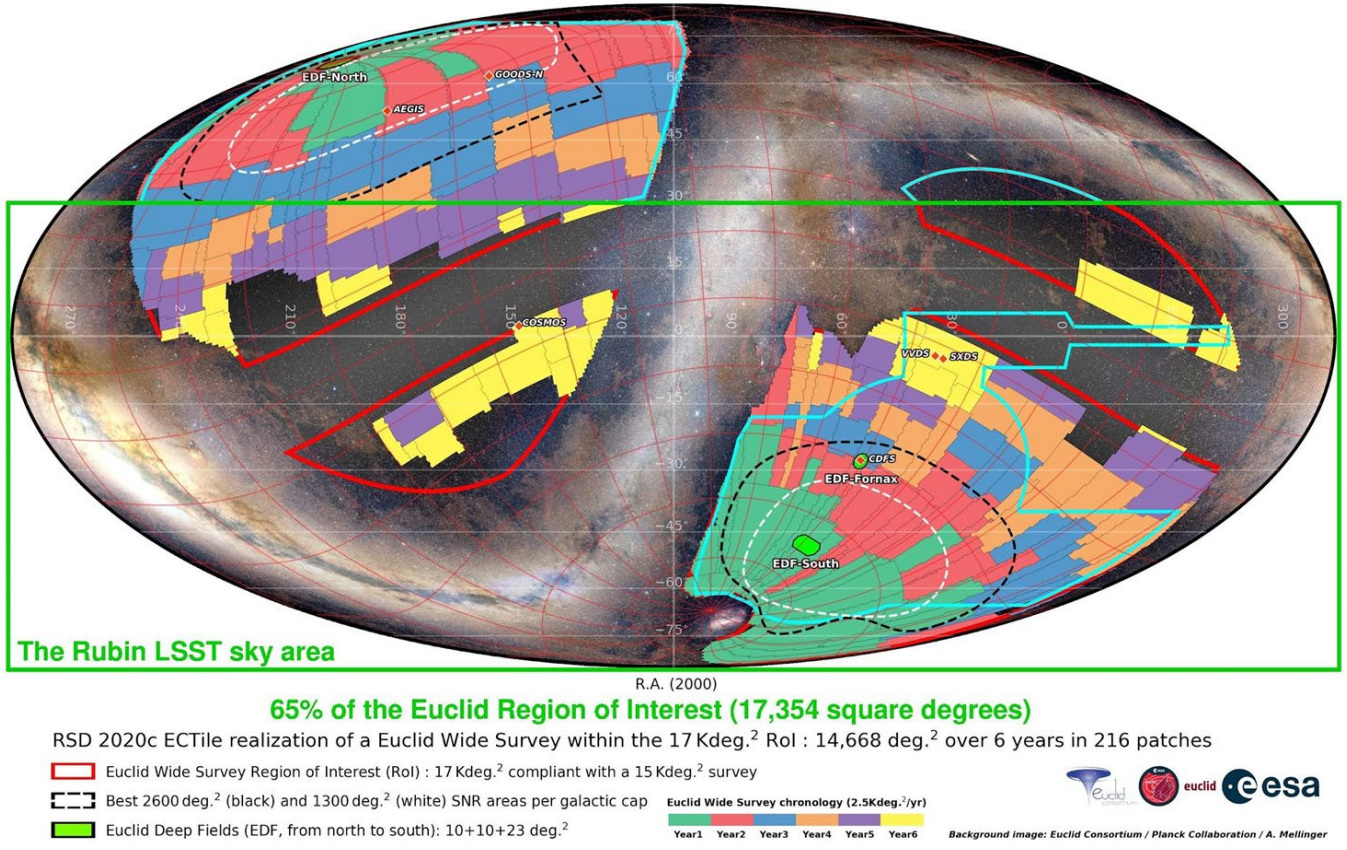


Euclid Structures- how to join/engage

- Euclid Consortium (EC) >2000 members
  - > 150 members from US
  - 14 science working groups coordinated by a 7-member Science Coordination Group
  - Defines Key projects and allows for Standard projects within proprietary period
  - Possible to join: compelling contribution to Euclid, support of science working group lead(s), sufficient funding to cover engagement
- Euclid Consortium Board (ECB), ~ 20 member governing body of EC appointed by national agencies ("ultimate authority within Euclid"). Jason.d.rhodes@jpl.nasa.gov is US rep
- ESA Euclid Science Team (EST), 13 member ESA body that 'safeguards' science requirements, ensures mission success, advises ESA on data releases, defines additional surveys. Jason.d.rhodes@jpl.nasa.gov is US rep

Joint Processing and Science Driven Rubin-Euclid Derived Data Products (DDPs)

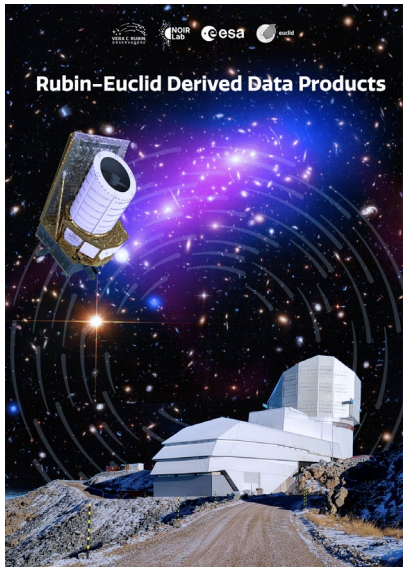
Effort to maximize science generating products shared openly across the two consortia, while protecting science each individual project's unique science



In 2024 a Joint Implementation Working Group co led out of NOIRLab and IPAC has made progress toward implementing the first steps. Roman/Rubin is kept in mind.

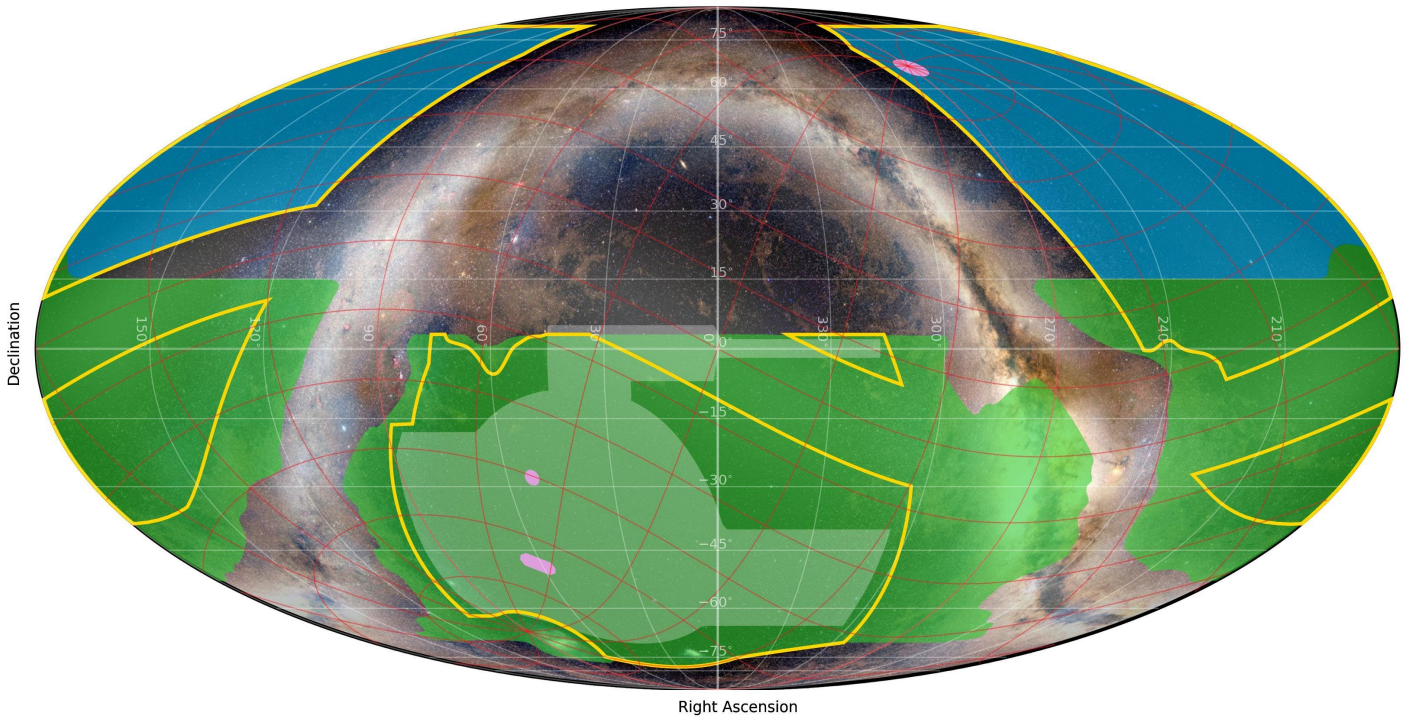
Science explored by the 350 Rubin and Euclid scientists during the open community 5-month long discussion on the forum:

- Solar System
- Milky Way
- Transients
- Nearby Universe
- AGN & Galaxy Evolution
- Clusters of Galaxies
- Galaxy Clustering
- Strong Lensing
- Weak Lensing
- Primeval Universe

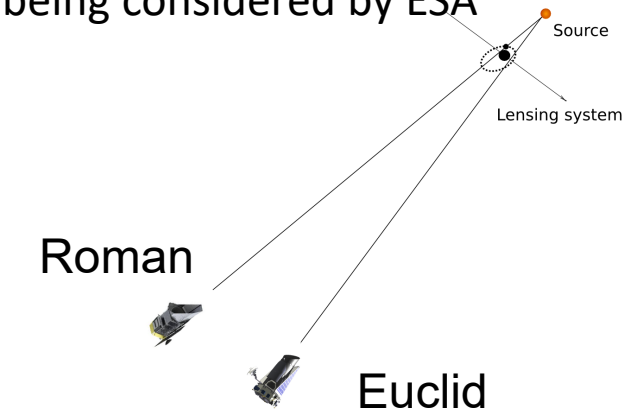


The great diversity in the complexity of the suggestions point to a tiered approach to developing DDPs : from simple catalog merging and cutouts exchange, enriching each side's catalog with provided algorithms, up to full blown joint pixel processing

Survey Coordination



- A potential Roman/Euclid joint microlensing survey would allow better bound planet mass estimates and the only way to get rogue planet masses
- Euclid precursor observations of Roman galactic bulge field being considered by ESA

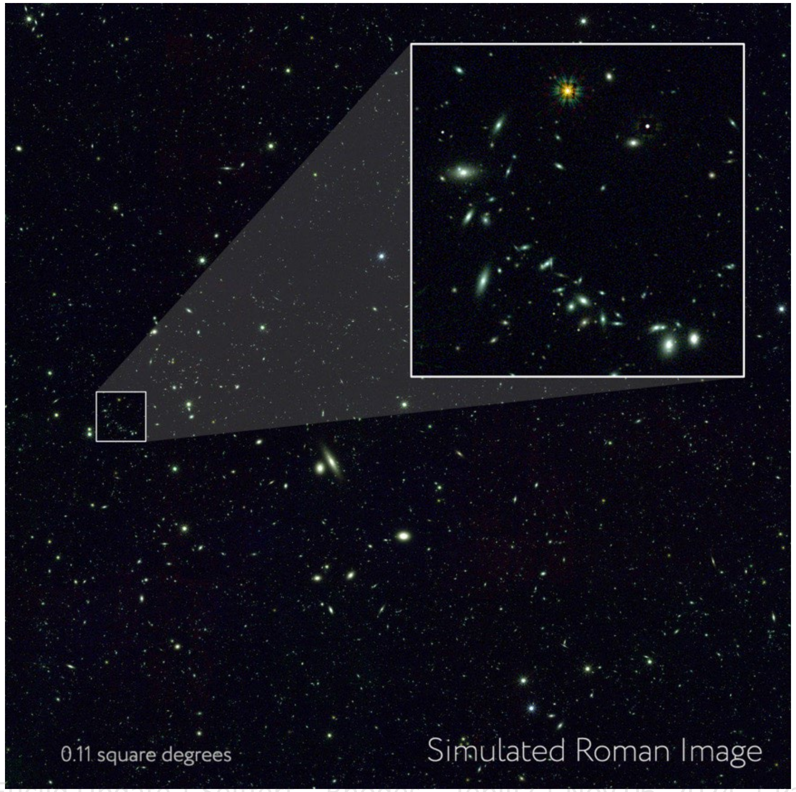


- Both Euclid and Rubin have tweaked survey footprints to maximize overlap
- Data sharing MOU signed for Euclid Deep Field South (EDF-S; helps with DDP planning)
- Rubin ComCAM early observations of EDF-S being explored (very soon)

OpenUniverse is a directly funded NASA effort that began in FY20.

- Resources are focused on coordinating mock galaxy catalogs, image simulations, and covariance matrix generation across cosmology surveys.
- All work must be relevant to two or more of the surveys.
- All simulation products are made publicly available for worldwide usage.
- Combines and builds upon expertise from NASA and DOE communities.

Alina Kiessling (JPL, PI)
Vandana Desai (IPAC, Archives Lead)
Andrew Hearin (ANL, Mocks Lead)
Bhuv Jain (UPenn, Covariances Lead)
Michael Troxel (Duke, Images Lead)



C. Hirata and K. Cao (OSU) and NASA's Goddard Space Flight Center

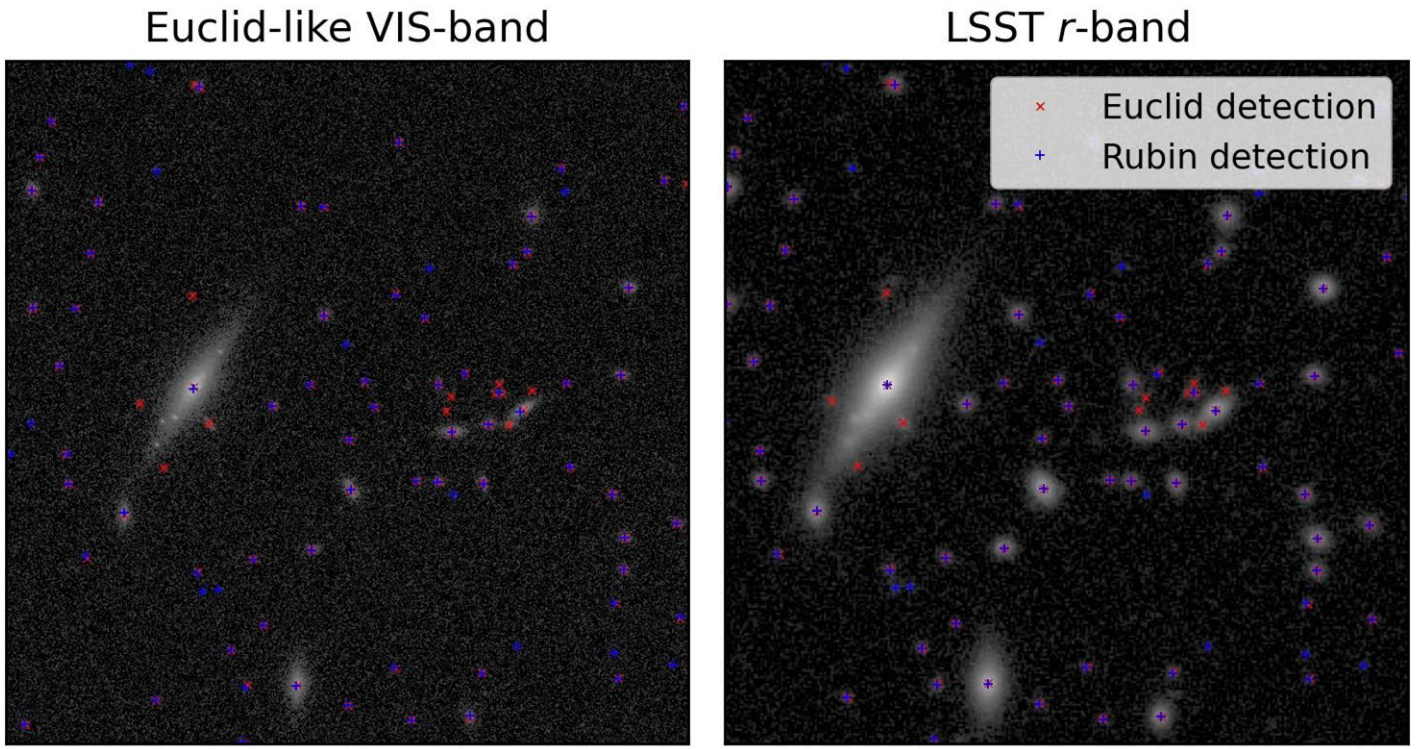
Same-sky Roman+Rubin+Euclid simulations

Team: Federico Berlfein (CMU), **Axel Guinot (CMU)**, Xiangchong Li (CMU), Andy Park (CMU), Rachel Mandelbaum (CMU), Jason Rhodes (JPL), Michael Troxel (Duke)

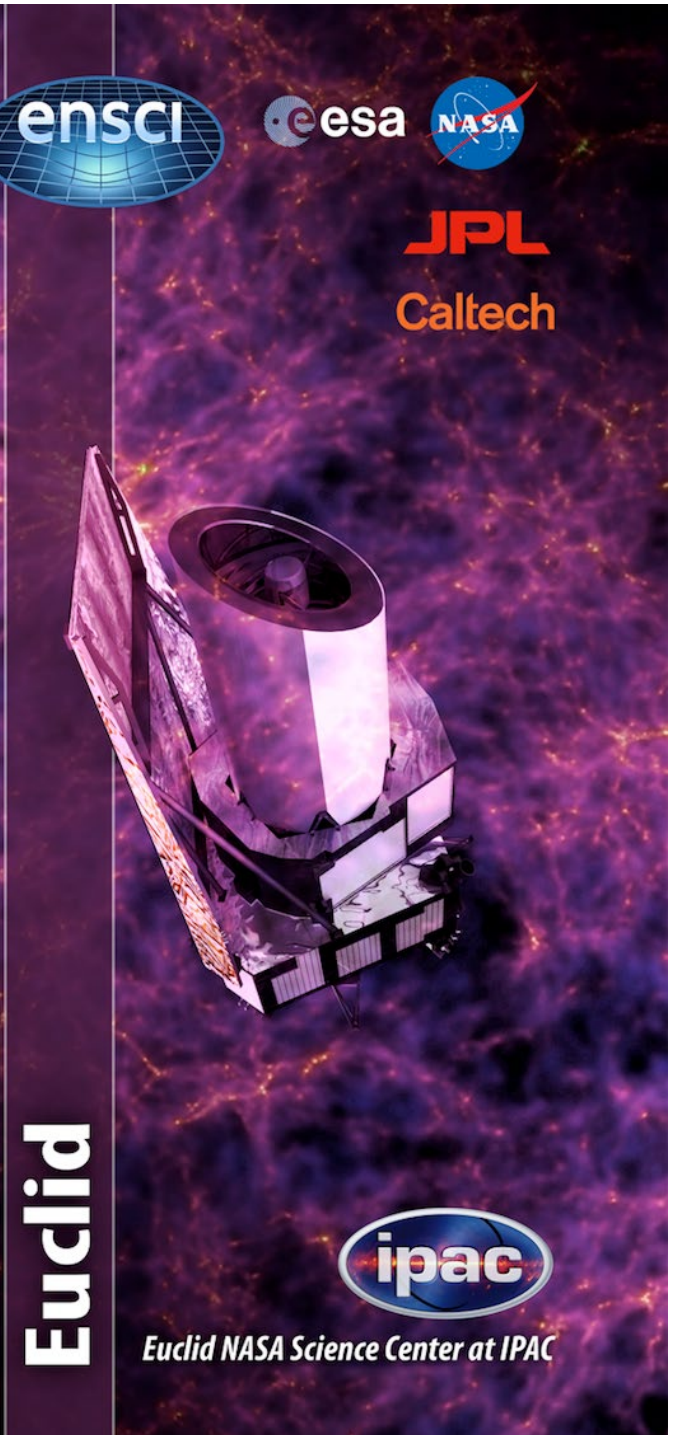
This work inherits from the huge effort on Roman+Rubin simulations and adds a Euclid-like component to make it Rubin+Roman+Euclid. Our goals:

- Provide same-sky public Euclid-like VIS image simulations & catalog-level NISP simulations
- Provide public tools to make Euclid-like VIS images
- Enable the broad community interested in studies of joint Rubin-Euclid processing and DDPs

Collaborations: Euclid OU-SIM (host for project), LSST DESC, OpenUniverse, Roman SN and WL PITs and SIM-WG

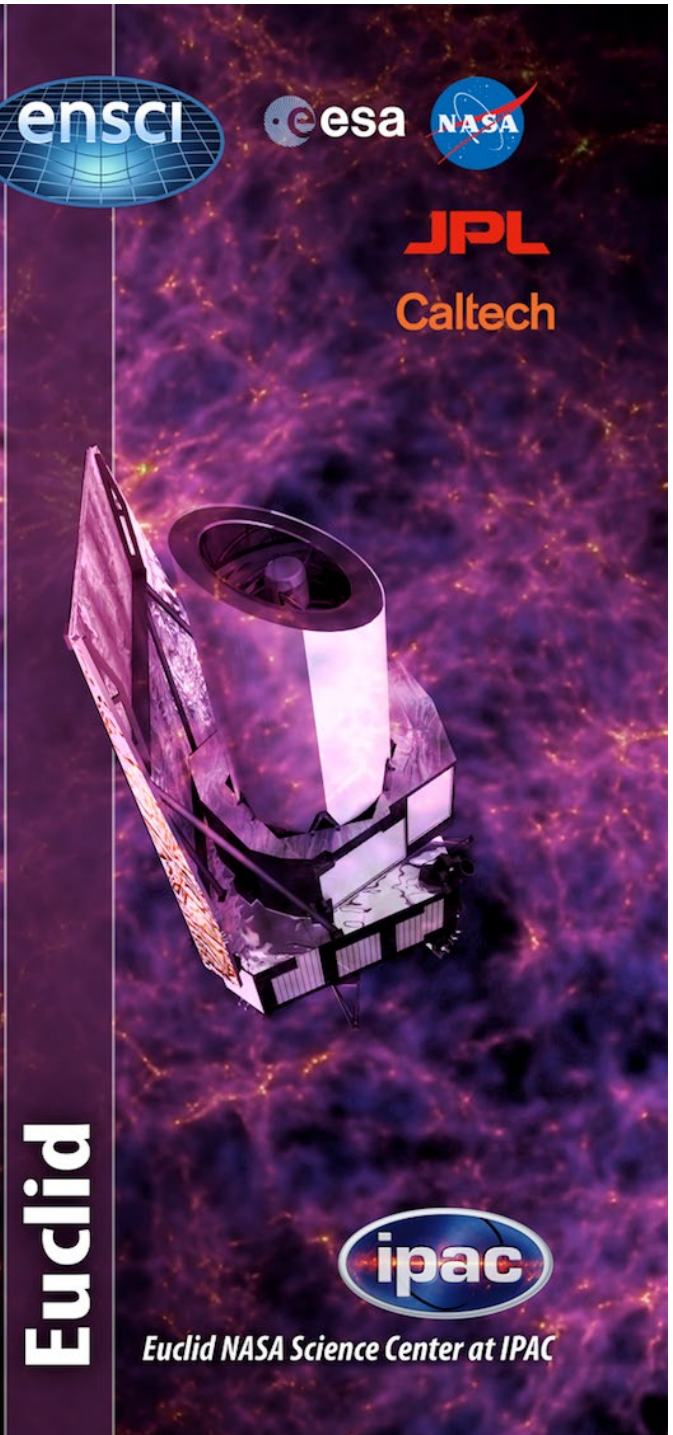


Preliminary detection comparison



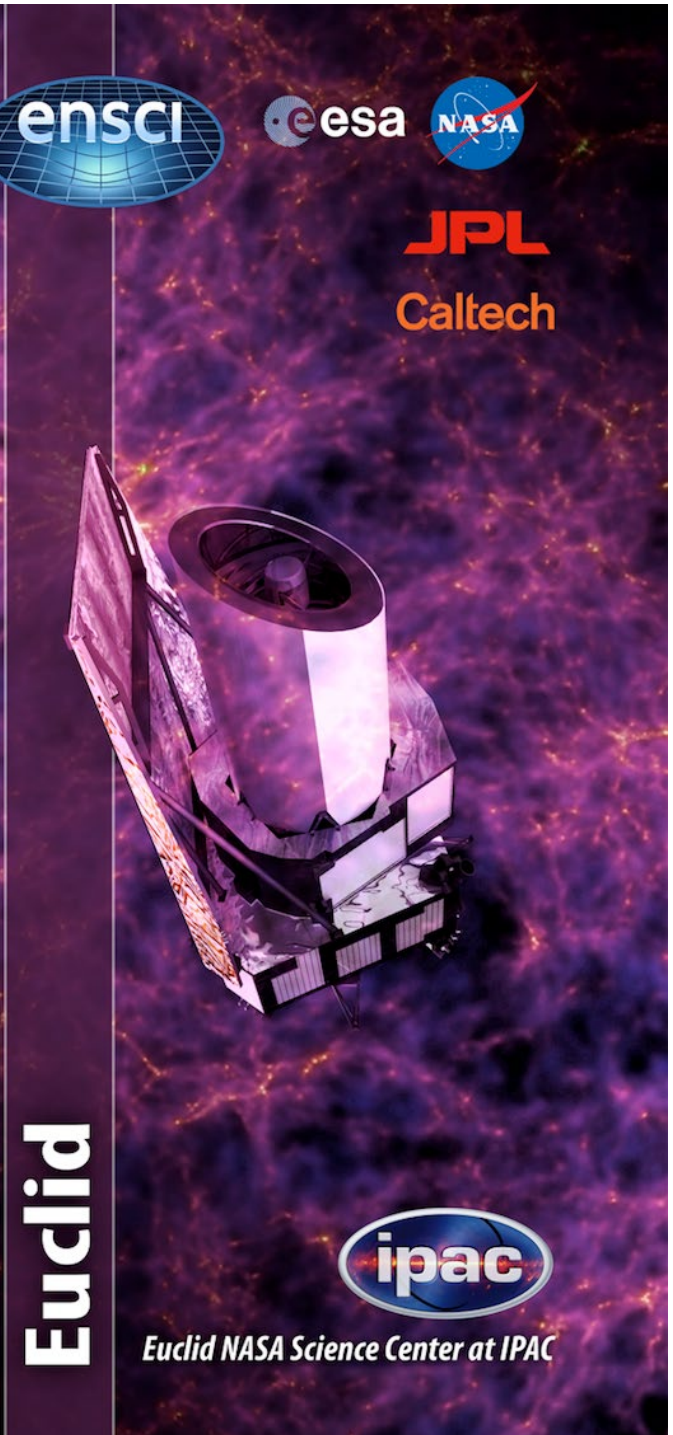
Euclid NASA Science Center at IPAC (ENSCI)

- Primary role is supporting US community science with Euclid data.
  - Website: http://euclid.caltech.edu
  - Helpdesk: ensci-support@ipac.caltech.edu
- US Node of a distributed (across all Euclid countries) 'Science Ground Segment' (SGS)
  - Each SGS node is developing specific parts of Euclid pipeline, and will process Euclid data
- ENSCI role is centered on US expertise and NIR detectors
  - Large impact on SGS development by small team
  - This provides valuable lessons learned to Roman



ENSCI Updates

- Daily Data Processing
  - Hundreds of “pipeline processing orders” per month from distributed system
- Software Development
  - Participation in Performance Verification period
  - Updating pipeline modules based on insight from flight data
- User Support
  - Opt-in mailing list – please sign up if interested in Euclid
  - FAQ pages on website
  - Will support IPAC booth at AAS in January and hyperwall talk on Euclid
- Support for US archive
  - NASA/IPAC Infrared Science Archive (IRSA) is hosting a complementary archive of public Euclid data, serving the same data released by ESA, but with user services optimized for the needs of the US community. Early Release Data are the first Euclid data in the IRSA archive.
  - ENSCI supporting development of archive services at IRSA
  - Developing python notebook tutorials for use of Euclid data



ENSCI User Panel

- ENSCI held the third meeting of the ENSCI User Panel online on August 12 and 14, 2024.
  - The Panel provides input on ENSCI priorities for community support.
  - Panel members represent a range of US institutions and research interests from the community that will use Euclid data, including both archival research and work by members of the Euclid Consortium (EC).
  - See: https://www.euclid.caltech.edu/page/ENSCI-User-Panel
- The Panel expressed confidence in ENSCI's user support plans and discussed several suggestions for additional ways to support the community.

Euclid Special Session at AAS in January, 2025

- **Title**: The Euclid Mission: First Results and Opportunities for Archival Research
- **Date/Time**: Tuesday, January 14, 2025 at 2:00 PM ET - 3:30 PM ET
- The session will feature talks about the mission, the Early Release Observations, data processing, and the archive.
- Speakers
  - Roland Vavreck (ESA)
  - Dida Markovic (JPL)
  - Hakim Atek (IAP)
  - Hervé Aussel (CEA)
  - Vandana Desai (Caltech/IPAC)

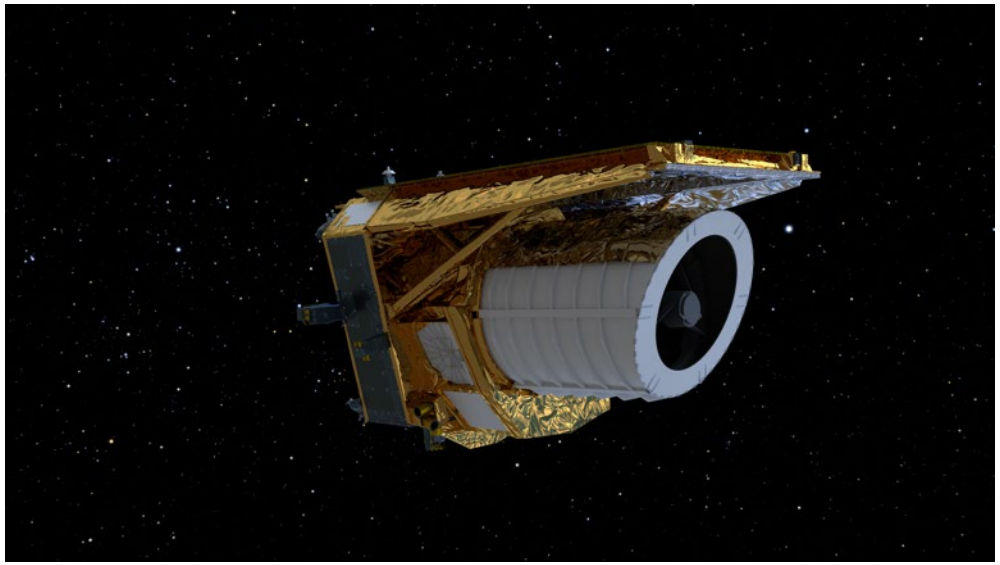


Image credit: ESA.

Euclid Data Quality

- **Data quality is excellent and shows that the survey can meet requirements**
  - Early Release Observation data provide examples for community

- Atek et al. (2024): https://arxiv.org/abs/2405.13504
  - PSF is sufficiently well behaved that it can be subtracted to a very low surface brightness level to reveal the intra cluster light (ICL)
- Marleau et al. (2024): https://arxiv.org/pdf/2405.13502
  - "The pristine PSF and high spatial resolution of Euclid provide the ability to distinguish dwarfs from other sources"
  - FWHM of 0.16, 0.48, 0.49, and 0.50 arcseconds (1.6, 1.6, 1.63, 1.67 pixels) in I_E, Y_E, J_E, and H_E, respectively (Cuillandre et al. 2024a).
- Massari et al. (2024): https://arxiv.org/abs/2405.13498
  - Final PSF models have an average ellipticity of 0.02 and a FWHM spatial variation of only 3%.

Euclid ERO image of galaxy cluster Abell 2390;
Credit: ESA/EC/NASA, image processing by J.-C. Cuillandre (CEA), G. Anselmi;

Euclid Data Quality (Technical Details)

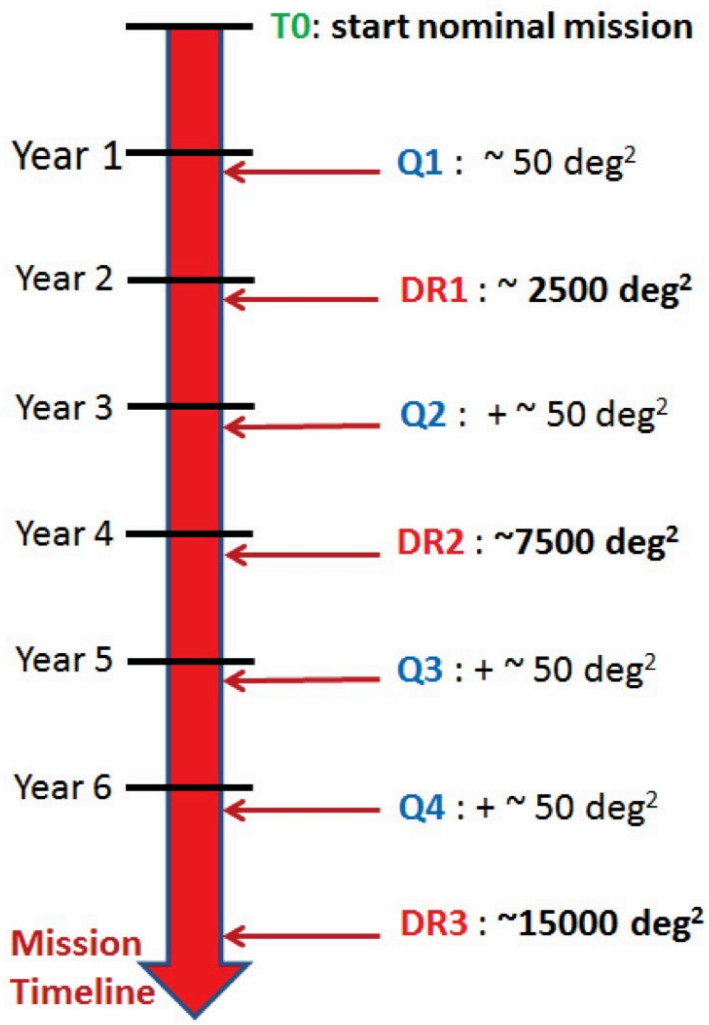
- VIS (https://arxiv.org/abs/2405.13492)
  - Expected to reach S/N = 5 for m_{AB} = 26.5 in four exposures for a 0.''6 diameter aperture with typical zodiacal light backgrounds (the dominant source of noise).
  - Expected to saturate on point sources for $m_{AB} \leq 18.0$ in a typical 566 s science exposure
- NISP (https://arxiv.org/abs/2405.13493)
  - Reaches S/N = 5 for mAB ~ 24.5 in three photometric exposures of about 100 s, for point sources.
  - For spectroscopy of a point-source S/N = 3.5 for emission line with flux ~2 *10−16 erg s−1 cm−2 integrated over two resolution elements of 13.4 Angstroms, in 3*560 s grism exposures at 1.6 µm (redshifted Hα)
- Additional details in Cuillandre et al. (2024) https://arxiv.org/pdf/2405.13496


Euclid ERO image of globular cluster NGC 6397;
Credit: ESA/EC/NASA,

Euclid Data Releases

- Data will be public within about 2 years of acquisition
- ESA will serve public Euclid data through the Euclid Science Archive System
- **The same data (or a subset) will also be available at the NASA/IPAC Infrared Science Archive (IRSA)**
- NASA is funding archival science
- Euclid will be “big data”
  - Petabyte-scale data products acquired from spacecraft
  - Significant ground-based supporting optical imaging data

Euclid Public Data Releases

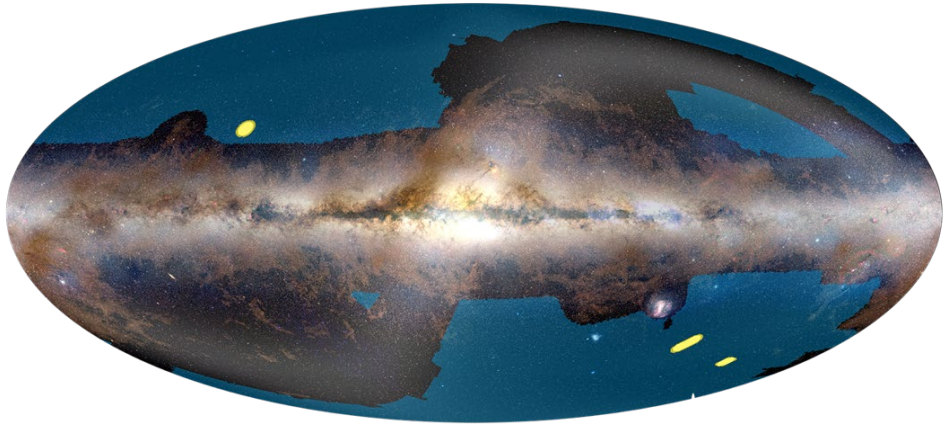


Quick Data Release #1 (Q1) – March 2025

- **A single visit over the Euclid Deep Fields (EDFs)** with RA/Dec:
  - EDFN (North) - 17:58:55.9 +66:01:03.7; (20 deg^2)
  - EDFS (South) - 04:04:57.84 -48:25:22.8; (23 deg^2)
  - EDFF (Fornax) - 03:31:43.6 -28:05:18.6; (10 deg^2)
  - https://www.cosmos.esa.int/web/euclid/euclid-survey

- Data products:
  - Level 1 – raw frames from VIS and NISP instruments
  - Level 2
    - Calibrated VIS & NISP images and catalogs
    - 2D grism exposures and combined 1D spectra
    - Merged mosaics and catalogs
    - Photometric redshift estimates
    - Line measurements and redshifts from spectra
  - Level 3 – visibility masks

- For Q1, the EC has 82 planned papers



Credit: ESA/Euclid/Euclid Consortium/NASA/Planck Collaboration/A. Mellinger

Data Release #1 (DR1) – June 2026

- **Approximately the first year of Euclid Survey data**

- Data products will be expanded from Q1 and may include (TBD by ESA):
  - Level 1 – raw frames from VIS and NISP instruments
  - Level 2
    - Calibrated VIS & NISP images and catalogs
    - 2D grism exposures and 1D spectra
    - Merged mosaics and catalogs for VIS, NISP, and ground-based data
    - Photometric redshift estimates
    - Line measurements and redshifts from spectra
    - Shear catalogs
  - Level 3
    - Cosmology catalogs
    - visibility masks
  - Calibration data

- DR1, EC has 318 planned Key papers