Euclid: a survey space telescope led by European Space Agency (ESA) and the Euclid Consortium

Prime Science Objectives: quantify Dark Energy \([w(a)]\), Modified Gravity \([\gamma]\), Dark Matter \([m_\nu]\), and the Universe’s Initial Conditions \([f_{NL}]\)

make a decisive measurement of the accelerated expansion of the Universe

Euclid Leadership:
Rene Laureijs- ESA PS
Giuseppe Racca- ESA PM
Yannick Mellier- Euclid Consortium Lead
Euclid is designed to measure two cosmological probes:

- Weak Lensing (WL)
Euclid is designed to measure two cosmological probes:

- Galaxy Clustering (GC, including Baryon Acoustic Oscillations and Redshift Space Distortions)

Credit: NASA GSFC
Euclid Primary Probes

BAO, RSD and WL over 15,000 deg$^2$

50 million galaxies with redshifts

1.5 billion sources with shapes, 10 slices

Source plane $z_2$

Source plane $z_1$

$\Omega_m = 0.30$, $w = -1.0$

$\Omega_m = 0.35$, $w = -1.0$

$\Omega_m = 0.30$, $w = -0.7$
Combining probes

From Y. Mellier
Euclid legacy science - some examples

Cool brown dwarfs - both in spectroscopy and imaging

Euclid NIR imaging: detection of giant branch stars out of 5 Mpc - streams, galaxy halos

2-3 orders of magnitude more strong galaxy lenses than before Euclid (1.5 SLACS/week)

Galaxy morphologies across the whole extragalactic sky (>10³xHST)

Rare objects galore - massive, passive galaxies with spectra to H~23, the brightest z>7 Ly-a emitters, …

Euclid will find the sources to follow-up for years to come

<table>
<thead>
<tr>
<th>What</th>
<th>Euclid</th>
<th>Per deg²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxies at 1&lt;z&lt;3 with good mass estimates and morph.</td>
<td>~2x10⁸</td>
<td>~10⁴</td>
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<tr>
<td>Massive galaxies (1&lt;z&lt;3) w/spectra</td>
<td>~few x 10³</td>
<td>~0.2</td>
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<tr>
<td>Hα emitters/metal abundance at z~2-3</td>
<td>~4x10⁷/10⁵</td>
<td><del>10⁹</del>10</td>
</tr>
<tr>
<td>Galaxies in massive clusters at z&gt;1</td>
<td>~(2-4)x10⁴</td>
<td>~40 (per cluster, HAB&lt;22.5)</td>
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<tr>
<td>Type 2 AGN (0.7&lt;z&lt;2)</td>
<td>~10⁴</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Galaxy mergers</td>
<td><del>10⁵</del>few x 10⁶</td>
<td>1-100</td>
</tr>
<tr>
<td>Strongly lensed galaxy-scale lenses</td>
<td>~200,000</td>
<td>1-10</td>
</tr>
<tr>
<td>z &gt; 7 Ly-a emitters</td>
<td>~few 10³</td>
<td>&lt;&lt;1</td>
</tr>
<tr>
<td>Resolved stellar populations</td>
<td>~13? with Mabs &lt; -19</td>
<td>&lt;&lt;1</td>
</tr>
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courtesy Tranin, Cimatti, Moresco, Pozzetti, Ealet, Zoubian et al
<table>
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<tr>
<th>Proposed lifetime</th>
<th>2023 - 2033</th>
<th>2022 - 2030</th>
<th>2026 - 2031</th>
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<tr>
<td>Mirror size (m)</td>
<td>6.5 (effective diameter)</td>
<td>1.2</td>
<td>2.4</td>
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<td>Survey size (sq deg)</td>
<td>~20,000</td>
<td>15,000</td>
<td>2,227</td>
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<td>Median z (WL)</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
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<td>Depth (5σ AB mag point source)</td>
<td>~27</td>
<td>~24 (NIR)</td>
<td>~27</td>
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<td>FoV (sq deg)</td>
<td>9.6</td>
<td>0.5 (Vis) 0.5 (NIR)</td>
<td>0.28</td>
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<td>Filters</td>
<td>u-g-r-i-z-y</td>
<td>Y-J-H-Vis</td>
<td>Y-J-H-F184</td>
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<tr>
<td>PSF Size</td>
<td>~0.7”</td>
<td>~0.2” (Vis)</td>
<td>~0.2” (NIR)</td>
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<tr>
<td>Mode</td>
<td>Photometry</td>
<td>Photometry/Grism</td>
<td>Photometry/Grism</td>
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</table>
Launch: on Soyuz from Kourou, No earlier than Oct. 2022

Mission Lifetime: 6+ years @ L2

Aperture: 1.2m

Near-Infrared Spectrometer and Photometer (NISP)
- FOV: 0.78 x 0.73 deg
- 16 H2RGs
- 0.3” / pixel

Visual Imager (VIS)
- FOV: 0.79 x 0.70 deg
- 36 4kx4k e2v CCDs
- 0.1” / pixel

1 Blue Grism: 0.92-1.3 µm
3 Red Grisms: 1.25-1.85 µm
US Science Participation – selected by NASA through peer review

- “Constraining Dark Energy and Gravity with Euclid”, PI Rhodes (JPL)
  - To measure dark energy and how mass is distributed on the largest cosmic scales, through weak lensing (distortions of galaxy shape), baryon acoustic oscillations (galaxy clustering), and supernova explosions; to study how galaxies form by observing the most youthful (high-redshift) objects

- “Looking at Infrared Background Radiation Anisotropies with Euclid”, PI Kashlinsky (at GSFC)
  - To study unresolved infrared background light from the earliest galaxies, to infer the pace of early star formation.

- “Precision Studies of Galaxy Growth and Cosmology Enabled Through a Physical Model for Nebular Emission”, PI Chary (Caltech)
  - To study the effect of dust and glowing gas on galaxy spectra, to obtain better distance (redshift) estimates from the measured colors.

- Jason Rhodes - member of Euclid Consortium Board and ESA Euclid Science Team

- Michael Seiffert - Project Scientist and participant in Euclid Consortium
Near Infrared Spectrometer – Photometer (NISP) Detector System

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

- 2.3 um cutoff HgCdTe detectors
- SIDECAR ASIC detector readout
- Cold cables

JPL led, with GSFC testing support

All NASA provided hardware has been successfully integrated with the NISP instrument and shows good performance.
Euclid mission status

• Payload (telescope + two instruments) has completed thermal vacuum test
• Spacecraft integration and test underway
• Launch no earlier than Oct 2022

Spacecraft I&T at TAS-I

Integrated payload prior to thermal vac test; May ‘21
Euclid Survey

Expected ground–based coverage of the Euclid Wide Survey for DR1/2/3 (2.5/7.5/15 Kdeg.²) [origin/bands/calendar/overlap]

- Euclid Wide Survey: 17 Kdeg.² compliant with a 15 Kdeg.² survey
- Rubin LSST WFD, ugriz, 2023: 8 Kdeg.² overlap
- DES, griz, 2019: 4.5 Kdeg.² overlap
- LSST southern extension, griz, 2027: 1 Kdeg.² overlap
- UNIONS (CFHT/STP–STARRS/Subaru), ugriz, 2027, 5 Kdeg.²
- LSST northern extension, griz, 2027: 3 Kdeg.² overlap
- Best 2600 deg.² SNR areas
Nominal Euclid Survey Exptimes

**Pointing 1**

- **VIS**
  - Shutter: 3 s
  - VIS: 570 s
  - Shutter: 3 s

- **NISP**
  - FWA: 10 s
  - Stab: 10 s
  - NISP-S: 574 s
  - RGS000: 108 s

**Pointings 2, 3**

- **VIS**
  - Shutter: 3 s
  - VIS: 570 s
  - Shutter: 3 s

- **NISP**
  - NISP-S: 574 s
  - RGS180_rot (Dither 2): 108 s
  - RGS000_rot (Dither 3): 108 s

**Pointing 4**

- **VIS**
  - Shutter: 3 s
  - VIS: 570 s
  - Shutter: 3 s

- **NISP**
  - NISP-S: 574 s
  - RGS180: 10 s

- **Flat Field**
  - 8 s
Science Driven Rubin-Euclid Derived Data Products (DDPs)

The DDPs will maximize the science output of both projects independently by generating products shared openly across the two consortia, all the while protecting science that is truly unique to each individual project.

Rubin and Euclid can have a large sky area in common.

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.
Euclid NASA Science Center at IPAC

- US Node of a distributed (across all Euclid countries) ‘Science Ground Segment’
- Each SGS node is developing specific parts of Euclid pipeline
- ENSCI role is centered on US expertise and NIR detectors (will provide lessons learned to Roman)
• NASA has established the **Euclid NASA Science Center at IPAC (ENSCI)** in order to support US-based investigations using Euclid data.

• **ENSCI primary tasks:**
  – T1: US Community Support
  – T2: Detector Characterization Data Archive
  – T3: Contribute/Gain expertise in pipelines
    • Participation in NISP algorithm/software design and high level calibration tasks
    • Develop production software in our role as SDC-US-Dev
  – T4: Establish and operate SDC-US [production side]
    • data processing, storage, and access
    • Node in distributed processing system
  – T5: Work closely with SOC on Data Quick Look Analysis (DQLA)
    • Gain insight into operations, advocate for US community needs
  – T6: Mission Verification working group
    • Insight into the big picture of science mission design

• For more details, see [http://euclid.caltech.edu](http://euclid.caltech.edu)
ENSCI and the US Community

• Web presence
  – Help desk (ensci-support@ipac.caltech.edu)
  – Documents and tutorials

• Support for US Science Teams
  – Meetings, telecons,
  – developer advice; calibration docs/files

• Contact with archival community
  – Conferences/AAS and Workshops
  – Push info to community: newsletters, AAS bulletin, social media, etc.
  – User Panel (starting 1 year before launch)

• Support US research with Euclid
  – Documents
  – Data tools
  – Work with IRSA

• ENSCI support prioritizes US users but is open to all;
  • European researchers will have access to mission knowledge from national centers
ENSCI and the Euclid Archive

• 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)
  – ENSCI is working with IRSA on archive design

• Euclid will be “big data”
  – Petabyte-scale data products acquired from spacecraft
  – Significant ground-based supporting optical imaging data (release policy is TBD)

• Expect a flood of proposals after first public data release
  – Spitzer and WISE were each ~40% of ADAP in their first year

About 3 months after launch
Euclid Structures - how to join

- Euclid Consortium (EC) >2000 members
  - 114 active members from US
  - ~10 science working groups
  - 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 and will be Chair 2022-2023

- ESA Euclid Science Team (EST), 13 member ESA body that ‘safeguards’ science requirements, ensures mission success, defines additional surveys
  - Jason.d.rhodes@jpl.nasa.gov is US rep
Thanks to ESA and the Euclid Consortium for many slides in this presentation
Euclid Timeline

Overview mission timeline

- **2008**: Proposal selection
- **2012**: Mission adoption
- **Definition**
- **2016**: Implementation
- **2020**: Operations
- **2024**: Launch
- **End nominal mission**

**NOW!**

- **2021**: PLM TVAC
- **2022**: Satellite Integration and test
- **S/C QR MKP**
- **GSRR**
- **FAR**
- **MCRR 20/01/23**

**Launch Oct 22**

- **End Early survey Ops Phase**
- **Q1 release**

**Survey and Calibrations Operations Review**

- **NISP-FM Delivery IQAR**
- **GSIR KO**
- **GS ORR OGS only**
### Rubin Euclid Data Release Timeline

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<th>Survey</th>
<th>Data Release</th>
<th>2022</th>
<th>2023</th>
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#### Assumptions:

- **October 2022**: Euclid mission launch date
- **October 2023**: LSST survey start

#### Key:
- Observing
- Processing
- Proprietary Access
- Public Access

#### Notes:

(a) Euclid launch and LSST survey start may both slip by ~6 months.
(b) LSST data release dates may move by ~3 months as the operations team adapts to circumstances.
(c) Euclid plan additional quick releases containing specific featured data products made with the Y2 (*Q2*), Y4 (*Q4*) and Y6 (*Q6*, TBC) data. The data from these years will be available to the consortium to use while they are being processed, there just won't be an internal release of a full data release dataset.
(d) The overlap between Euclid Y1 and LSST Y5 is potentially quite small, because Rubin commissioning observations are needed at a wide range of latitude (and the best calibration pre-cursor data tends to be closer to equator). The SIT-Com team's field selection is not yet determined.
(e) LSST Y2 is when the survey depths become matched, which is important for photo-z estimation: the double lined box shows the ensuing joint photo-z era.

DDPs exchange should start as early as 2023 in an investigative manner (limited overlap) in order to be mature in time for the main effort in 2025: Euclid DR2 + LSST Y1.
Microlensing with *Euclid* & *WFIRST*: Masses of Free-Floating Planets

**Projected Einstein radius:**

\[
\tilde{r}_E \approx 3 \times 10^6 \text{ km} \sqrt{\frac{M}{M_{\text{Earth}}}}
\]

\[
\pi_E = \frac{\text{AU}}{\tilde{r}_E}
\]

- Can measure parallaxes for a wide range of events
- Expect ~1 FFP parallax for every 6 days of Euclid observations (Bachelet & Penny 2019)
- Expect ~1 bound-planet parallax for every 1 day of Euclid observations
- Euclid and WFIRST will see measurably different lightcurves for bound and free-floating planets
- Needs high-cadence Euclid observations (~30 min) simultaneous with WFIRST

**Left plot:** Free-floating planet

**Right plot:** Earth-sized bound planet at 1 AU around a 0.1M sun star

Bachelet et al., 2021, submitted

\[
\pi_E = 61.8 \pm 19.3
\]

\[
\theta_E = 6.6 \pm 1.3 \mu\text{as}
\]

\[
M = \frac{\theta_E}{\kappa \pi_E}
\]

\[
M = 0.44 \pm 0.16 M_{\text{Earth}}
\]
Euclid Collecting Information

- Euclid carries two types of sensors
  - 36 CCDs (4kx4k pixels) – visible channel
  - 16 HgCdTe CMOS (2kx2k pixels) – infrared channels (NASA contribution)

- One block observation gives consists of 4 dithers of
  - 1 VIS exposure – 36 x 16 Mpix
  - 1 Spectroscopy field – 16 x 4 Mpix
  - 3 imaging photometry (Y,J,H) – 3 x 16 x 4 Mpix

- Survey Speed: 20-22 block observations per day
ENSCI in the distributed Euclid data processing system