Euclid space mission

(a few whys and hows)

R. Scaramella (on behalf of Euclid Science Team and Euclid Consortium)

(Euclid Consortium, old timer, Mission Survey Scientist, member of the EC Board and EST)

Lots of figures and material courtesy of: EC&ESA (SciRD, CalWG, ECSURV, ESSWG, VIS, NISP, SWGs, OUs ...)

Red Book released in July 2011 (ESA web pages)

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1. Why

1. Dark Energy & Dark Matter (Cosmology) ; Legacy

2. How

2. Space imaging (morphology & NIR) + Spectra: Grav. Lensing & Clustering

3. When

3. 2022-2028+
Main Scientific Objectives

- Understand the nature of Dark Energy and Dark Matter by:
  - Reach a dark energy FoM > 400 using only weak lensing and galaxy clustering; this roughly corresponds to 1 sigma errors on $w_p$ and $w_a$ of 0.02 and 0.1, respectively.
  - Measure $\gamma$, the exponent of the growth factor, with a 1 sigma precision of < 0.02, sufficient to distinguish General Relativity and a wide range of modified-gravity theories.
  - Test the Cold Dark Matter paradigm for hierarchical structure formation, and measure the sum of the neutrino masses with a 1 sigma precision better than 0.03eV.
  - Constrain $n_s$, the spectral index of primordial power spectrum, to percent accuracy when combined with Planck, and to probe inflation models by measuring the non-Gaussianity of initial conditions parameterised by $f_{NL}$, to a 1 sigma precision of ~2.

### SURVEYS

<table>
<thead>
<tr>
<th>Area (deg²)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Survey</td>
<td>15,000 (required) 20,000 (goal) Step and stare with 4 dither pointings per step.</td>
</tr>
<tr>
<td>Deep Survey</td>
<td>40 In at least 2 patches of &gt; 10 deg² 2 magnitudes deeper than wide survey</td>
</tr>
</tbody>
</table>

### PAYLOAD

<table>
<thead>
<tr>
<th>Telescope</th>
<th>VIS 1.2 m Korsch, 3 mirror anastigmat, f=24.5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>NISP</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>0.787×0.709 deg² 0.763×0.722 deg²</td>
</tr>
<tr>
<td>Capability</td>
<td>Visual Imaging NIR Imaging Photometry NIR Spectroscopy</td>
</tr>
</tbody>
</table>

| Wavelength range | Y (920-1146nm), J (1146-1372 nm), H (1372-2000nm) 1100-2000 nm |
| Sensitivity | 24.5 mag 10σ extended source 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 | 36 arrays 4k×4k CCD 16 arrays 2k×2k NIR sensitive HgCdTe detectors |
| Pixel Size | 0.1 arcsec 0.3 arcsec 0.3 arcsec R=250 |
| Spectral resolution | |

### SPACECRAFT

| Launcher | Soyuz ST-2.1 B from Kourou |
| Orbit | Large Sun-Earth Lagrange point 2 (SEL2), free insertion orbit |
| Pointing | 25 mas relative pointing error over one dither duration 30 arcsec absolute pointing error |
| Observation mode | Step and stare, 4 dither frames per field, VIS and NISP common FoV = 0.54 deg² |
| Lifetime | 7 years |
| Operations | 4 hours per day contact, more than one groundstation to cope with seasonal visibility variations; |
| Communications | maximum science data rate of 850 Gbit/day downlink in K band (26GHz), steerable HGA |

### Budgets and Performance

<table>
<thead>
<tr>
<th>Industry</th>
<th>TAS Astrium TAS Astrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload Module</td>
<td>897 696 410 496</td>
</tr>
<tr>
<td>Service Module</td>
<td>786 835 647 692</td>
</tr>
<tr>
<td>Propellant</td>
<td>148 232 90 65</td>
</tr>
<tr>
<td>Adapter mass/Harness and PDU losses power</td>
<td>129 129 90 65</td>
</tr>
<tr>
<td>Total (including margin)</td>
<td>2160 1368 1690 1690</td>
</tr>
</tbody>
</table>

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All data you need to know (Red Book, some changes)

- **Wide Area (>10⁴ sq deg)**
- **Wide Field (FoV > 0.5 sq deg)**
- **Opt. imaging**
- **NIR photon**
- **NIR slitless**

Two instruments:

**VIS:** optical imager &
**NISP:** NIR imager + grisms
EUCLID Mission

- Launcher: Soyuz ST2-1B from Kourou
- Direct injection into transfer orbit
  - Transfer time: 30 days
  - Transfer orbit inclination: 5.3 deg
- Launch vehicle capacity:
  - 2160 kg (incl. adapter)
  - 3.86 m diameter fairing
- Launch ≈ 2022
- Mission duration: 6 years

For stability need to always observe orthogonally to the sun

region visibility: twice/yr at ecliptic plane (1deg/day), max at ecliptic poles (always).

spin 2 behaviour as in WL
4 dithers ~1 full Field -0.5 sq deg- / 1.25 hr  (≈10 sq deg/day)

Observing sequence for each field + move to next one ~4500 s

Frame 01  Dither 01  Frame 02  Dither 02  Frame 03  Dither 03  Frame 04  Slew

75 s  75 s  75 s  350 s

Frame = 973 s

Figure 5-4: Nominal Field Observation Sequence.

VIS
Shutter 10 s  VIS 565 s  Shutter 10 s

60%  40%

NISP
NISP 565 s

FWA 10 s  FWA 10 s  Stab 10 s  Y 121 s  FWA 10 s  Stab 10 s  J 116 s  FWA 10 s  Stab 10 s  H 81 s

Slitless: Red grism 1.25-1.8μ (Hα: 0.9<z<1.7)
4 exposures: directions 0, 90, 180 degs, then again once

Slitless: Blue grism 0.92-1.25μ (TBD) only in the Deep
Large sky regions are unsuitable or subpar for our $T_{\text{exp}}$.

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Figure 7.2.1 Euclid sky with best areas identified. Good areas $<< 15,000$ sq degs

Plots by J.C. Cuillandre
Euclid Deep Fields

Requirements

- cover at least 40 square degrees in two fields (one in Northern, one in Southern Emisphere)
- at least 2 magnitudes deeper (→ 40 visits)
- growth in time like the survey
- Completeness Purity Calibration files [CPC]: at least 40 square degrees of spectroscopy, 10 visits with large angular separation for spectral dispersion

CPC example:
Three Deep Fields

Proposal now approved by everybody

So now have:

- a two tier EDF-North [EDFN] (20 sq deg x 10 visits+ inner sq deg 10 x 30 visits more); + self-cal (4 sq deg, monthly visits, partial random cover)
- an EDF-Fornax [EDFF] (10 sq deg x 56 visits) comprising the Chandra Deep South
- an EDF-South [EDFS] (23 sq deg x 45 visits); collaboration with LSST

limiting AB mag 5σ pointlike: VIS ~27.5, NISP y, J, H ~26

Also ”blue” [0.92-1.25μ] grism can be used to observe the deep fields
Euclid Deep Field North (EDF–N)

R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

Wide view context:
- Reddening: E(B–V)
- Contamination: bright stars

Center is offset by ~1 deg from geometric NEP to maximise overlap with Spitzer
(P. Capak)

plot (and similar ones) by J.C. Cuillandre

Euclid Deep Field North (EDF–N)

R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

Wide view context:
- Optical: true image (RGB)
- Optical: stellar density (R)

good: several stars for PSF but not too many
Euclid Deep Field North (EDF–N)

R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

Equatorial: 269.73  +66.02
Ecliptic:    258.69  +89.45
Galactic:    95.76   +29.92

Center is offset by ~1 deg from geometric NEP to maximise overlap with Spitzer (P. Capak)
**EDF-Fornax**

4x5+1 fields, 56 visits (+16 compensate for larger <zodiacal>), no much smearing at borders

Change from rectangle (Euclid optimal) to a circle to better cover Spitzer (Capak) and LSST
Euclid Deep Field Fornax (EDF–F)


Wide view context:
• Reddening: E(B–V)
• Contamination: bright stars


This plot and similar ones by J.C. Cuillandre
Euclid Deep Field Fornax (EDF-F)


Wide view context:
- Optical: true image (RGB)
- Optical: stellar density (R)

Stellar density dataset: ESA/Gaia/DPAC

R. Scaramella-Big Eyes-Rome-9 September 2019
Euclid Deep Field Fornax (EDF–F)


Equatorial: 52.93 -28.09
Ecliptic: 40.77 -45.40
Galactic: 224.01 -54.64

Akari is not feasible because of the bright blue.

Tried to also fit some rectangular shapes for LSST.

Search area good for Euclid & LSST.

A 20 sq deg can be covered with 5x8 fields or 4x10. With not a square 20 sq degs can be covered with 45 fields.

Area circle = 20 —> radius 2.52 —> diameter 5.05 —> 7 fields.

With not a square 20 sq degs can be covered with 21 fields.

Area circle = 10 —> radius 1.78 —> diameter 3.56 —> 5 fields.

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Euclid Deep Field South (EDF–S)

Search area for the optimal contiguous 20 sq. deg.

Wide view context:
- Reddening: E(B–V)
- Contamination: bright stars

For Euclid a simple circle is best, covered with 43 tiles

LSST possible ways of covering 20 sq deg: spatially varying completeness

Since LSST goes much deeper than required by Euclid this solution would match well Euclid needs but it has too low efficiency for LSST

LSST prefers this binocular shape because it is optimal and has 100% efficiency for it

Need LSST ~33 hrs for Euclid photoz depth
From Euclid to present times, a well known concept...
To cover the LSST shape need 46 tiles instead of 43 (~ +7%)

“Stadium” shape (pill-like)

Radius, Perimeter, Area \[ R = 1.78^\circ \]

\[ P = 2R(2 + \pi) \]

\[ A = R^2(4 + \pi) \]

But need some more fields when tilted on the sky:

On average need ~51+ fields depending on covered fraction (~ + 19%)

Need to also add ~ +12% time for larger Zodiacal, i.e. from 40 to 45 visits. Total is ~ 102 days for a circle, in total add ~ 3 weeks for stadium shape ]. TBD
Extinction: $E(B-V)$

Contamination: bright stars

Euclid Deep Field South (EDFS)


23 sq. deg. stadium FOV

Wide context (1600 sq. deg.)

Optical: true image (RGB)

Looks fine for bright stars

Optical: stellar density (Gaia)

Euclid Deep Field South (EDFS)
23 sq. deg. stadium FOV
Wide context (1600 sq. deg.)

Stellar density dataset: ESA/Gaia/DPAC

R. Scaramella-Big Eyes-Rome-9 September 2019
Euclid Deep Field South (EDFS)

23 square degrees stadium geometry field

\[ a = 3.50 \text{ deg.} \quad r = 1.75 \text{ deg.} \quad \text{Position angle} = 61.3 \text{ deg.} \]

Eq 3.56 ial: \( 61.28 \quad -48.42 \)

Ecliptic: \( 36.56 \quad -66.60 \)

Galactic: \( 256.05 \quad -47.14 \)

Looks fine for extinction
Euclid Deep Field South (EDFS)

23 square degrees stadium geometry field

\[ a = 3.50 \, \text{deg.} \quad r = 1.78 \, \text{deg.} \quad \text{Position angle} = 61.3 \, \text{deg.} \]

Equatorial: \[ 61.28 \quad -48.42 \]

Ecliptic: \[ 36.56 \quad -66.60 \]

Galactic: \[ 256.05 \quad -47.14 \]

**Looks fine for bright stars and large objects**

**CHECKED ALSO ON WISE**

[Meisner, A.M., Lang, D., and Schlegel, D.J. (2017) "Deep Full-sky Coadds from Three Years of WISE and NEOWISE Observations"]
CPCs & EDFs coverage build up

After one year can have 1 visits (all red spectra) on CPC + EDFF = 50 sq deg for Q1 release

CPC visits are counted also as EDF visits
EDFs status 2019 (now frozen)

(square deg x visits; number of latters will be increased to compensate for larger zodiacal background)

- EDFN (20 x 10 + inner 10 x 30) = (1/2) CPC + (1/4) DEEP; offset 1 deg from NEP; observed by Spitzer
- EDFF (10 x 40) = (1/4) DEEP; Fornax region; observed by Spitzer
- EDFS (23 x 40) = (1/2) CPC + (1/2) DEEP; observations allocated for Spitzer; LSST optical coverage requested

75% synergy between CPCs and EDFs

Visibility from Ground facilities has increased enormously, enabling much more science to be done on EDFs

Details on ESA web pages
2019 Survey a great step ahead: polar caps, all calibrations up to date, all EDFs
Euclid Foregrounds (1/8): zodiacal light background level from Lagrangian2

- **Euclid Wide Survey**: $15,000\,\text{deg}^2$ [with $E(B-V)<0.08$, up to 0.15 to avoid holes & islands]
- **Euclid exclusion zone**: $26,000\,\text{deg}^2$ [galactic & ecliptic planes + reddening]
- **Euclid Deep Fields**: North = $10\,\text{deg}^2$, Fornax = $10\,\text{deg}^2$, South = $20\,\text{deg}^2$

**Zodiacal light level in the VIS band (Mjy/str & mag/arcsec^2)**

- 0.11
- 0.27
- 22.7
- 21.8

*The ecliptic referential is overplotted in light purple*
Euclid Foregrounds (2/8): reddening and galactic light reflection from interstellar cirrus

- **Euclid Wide Survey**: 15,000 deg.² [with E(B−V)<0.08, up to 0.15 to avoid holes & islands]
- **Euclid exclusion zone**: 26,000 deg.² [galactic + ecliptic planes + reddening]
- **Euclid Deep Fields**: North=10 deg.², Fornax=10 deg.², South=20 deg.²

Dust map: ESA / Planck Collaboration
Euclid Foregrounds (3/8): cumulated stellar brightness from the Galaxy

- Euclid Wide Survey: 15,000 deg.² (with E(B−V)<0.08, up to 0.15 to avoid holes and islands)
- Euclid exclusion zone: 26,000 deg.² (galactic- and ecliptic planes + reddening)
- Euclid Deep Fields: North=10 deg.², Fornax=10 deg.², South=20 deg.²
Euclid Foregrounds (4/8): bright stars from the visible to the near-infrared

- **Euclid Wide Survey**: 15,000 deg.$^2$ (with $E(B-V)<0.08$, up to 0.15 to avoid holes/islands)
- **Euclid exclusion zone**: 26,000 deg.$^2$ (galactic+ecliptic planes + reddening)
- **Euclid Deep Fields**: North=10 deg.$^2$, Fornax=10 deg.$^2$, South=20 deg.$^2$

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- $g$ or $H$ magnitude (AB):
  - $g$ band: Yale Bright Star Catalog (Hoffleit & Warren 1991)
  - $H$ band: The Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006)
Euclid Foregrounds (5/8): brightest extended galactic nebulae (Messier/NGC/IC)

- Yellow: Euclid Wide Survey: 15,000 deg.² [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]
- Light blue: Euclid exclusion zone: 26,000 deg.² [galactic+ecliptic planes + reddening]
- Green: Euclid Deep Fields: North=10 deg.², Fornax=10 deg.², South=20 deg.²

NGC/IC class:
- Red: Galactic nebula
- Orange: Open cluster
- Pink: Globular cluster

New General Catalogue of Nebulae & Clusters of Stars, Sulentic&Tiff 1973
Euclid Foregrounds (6/8): galaxies from the local group and the nearby universe (z<0.01)

- Euclid Wide Survey: 15,000 deg.$^2$ [with E(B-V)<0.08, up to 0.15 to avoid holes&islands]
- Euclid exclusion zone: 26,000 deg.$^2$ [galactic+ecliptic planes + reddening]
- Euclid Deep Fields: North=10 deg.$^2$, Fornax=10 deg.$^2$, South=20 deg.$^2$

Total K-band magnitude:

The supergalactic reference is overlaid in light purple

Galaxy catalog: The 2MASS Redshift Survey (2MRS), Huchra et al. 2012
Euclid Foregrounds (7/8): nearby galaxies beyond the local universe (0.01<z<0.06)

- **Euclid Wide Survey**: 15,000 deg.$^2$ [with $E(B-V)<0.08$, up to 0.15 to avoid holes&islands]
- **Euclid exclusion zone**: 26,000 deg.$^2$ [galactic+ecliptic planes + reddening]
- **Euclid Deep Fields**: North=10 deg.$^2$, Fornax=10 deg.$^2$, South=20 deg.$^2$

**Total K-band magnitude**: 3 5 7 9 11

*Galaxy catalog: The 2MASS Redshift Survey (2MRS), Huchra et al. 2012*
Euclid Foregrounds (8/8): distant clusters of galaxies (0.06<z<0.40)

- Euclid Wide Survey: 15,000 deg.² [with E(B-V)<0.08, up to 0.15 to avoid holes&islands]
- Euclid exclusion zone: 26,000 deg.² [galactic+ecliptic planes + reddening]
- Euclid Deep Fields: North=10 deg.², Fornax=10 deg.², South=20 deg.²

Cluster catalog: 2MASS+WISE+SuperCOSMOS, Wen et al. 2017
Expected coverage from the ground for WL photoz

Figure 7.1.2 Expected coverage from the ground for Euclid DR2/DR3
Public data releases:

Two kind:

Q’s = small area prerelease for the community to get acquainted

DR = data release (three DR of increasing areas: early -2500-, intermediate -7500-, final -15000 sq degs)

Q1: 14 months after start of the nominal mission
   — data released: one visit on the deep fields [50 sq deg]

DR1: one year after Q1
   — data released: 2500 sq deg

Stay tuned!!