The Euclid Mission

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On behalf of the Euclid consortium – www.euclid-ec.org
Motivation - I

SNIa observations are pointing toward

a. An accelerated expansion of the Universe today

b. A late time acceleration: expansion was decelerating in the past during matter dominated era
Motivation - II

- CMB (Planck) + Geometry probes (SNIa, BAO) (mainly from Planck) point toward large contribution of DE at late time indiscernible from a cosmological constant
- No way from current probes to assess exact nature of the component
- It could be something different
- Even in the dynamical DE class, too many models

\[ w = P/\rho, \quad w(t) = w_0 + w_\alpha(t) + \ldots \]

- \( w = 0 \) - matter
- \( w = 1/3 \) - radiation
- \( w = -1 \) - cosmological constant
- \( w(t) > -1 \) \((dw/dz > 0)\) - quintessence
- \( w(t) > -1 \) \((dw/dz < 0)\) - k-essence
- \( w(t) < -1 \) - phantom
How to look for accelerated expansion?

**Geometry**

Look at how a known scale (from the observer or at fixed depth) is seen at different redshifts.

- Fix the Hubble radius at \( z=1100 \)

**Clustering evolution**

Look at how the clustering of matter evolves under the joint influence of gravity and expansion.

- Measure the amplitude and slope of fluctuation.
- Measure energy density of matter.

*Need CMB to break degeneracy and…*
Probes

Geometry

- SNIa
- Baryon acoustic oscillations

Clustering evolution

- Redshift space distortions
- Cluster counts
- Strong & weak cluster lensing
- Cosmological weak lensing
Comme on peut le constater sur ces projets (très préliminaires) d’affiches, la seule présence de la signature sur un visuel permet d’en identifier facilement la provenance, mais ce n’est pas tout …
Euclid

- A single survey providing data for 5 different probes of dark energy
  - Optimal use of a space observatory
  - Explore both geometry/expansion and clustering evolution/growth of structures
- Design allow for a single visit to acquire imaging and spectroscopy on wide fields
- Main probes are Weak Lensing and BAO/RSD surveys
  - **WL:** 1.5 $10^9$ galaxy shapes, shear & photo-z (u,g,r,i,z,Y,J,H, $\Delta z=0.05(1+z)$)
    - 15000 deg$^2$, up to z=2
  - **GC/RSD:** 35 $10^6$ spectroscopic redshifts ($\Delta z=0.001(1+z)$)
    - 15000 deg$^2$ probing 0.7<z<1.8
- Great for DE
- Fantastic for ancillary astrophysics!
Euclid surveys complementarity

Plot inspired by the BOSS collaboration
## Euclid Science Requirements

<table>
<thead>
<tr>
<th><strong>Sector</strong></th>
<th><strong>Euclid Targets</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dark Energy</strong></td>
<td>• Measure the cosmic expansion history to better than 10% in redshift bins (0.7 &lt; z &lt; 2).  &lt;br&gt;• Look for deviations from (w = -1), indicating a dynamical dark energy. &lt;br&gt;• Euclid alone to give (\text{FoM}_{\text{DE}} = 1/(\Delta w_p \Delta w_o) \geq 400) ((\Delta w_p = 0.02) &amp; (w_o = 0.1) marginals) i.e. % precision on (w_s)</td>
</tr>
<tr>
<td><strong>Test Gravity</strong></td>
<td>• Measure the growth index, (\Omega^\gamma), with (\Delta \gamma \leq 0.02) &lt;br&gt;• Measure the growth rate to better than 0.05 in redshift bins between (0.5 &lt; z &lt; 2). &lt;br&gt;• Separately constrain the two relativistic potentials. (\psi) and (\phi) &lt;br&gt;• Test the cosmological principle</td>
</tr>
<tr>
<td><strong>Dark Matter</strong></td>
<td>• Detect dark matter halos on a mass scale between (10^8) and (&gt;10^{15}) (M_{\text{Sun}}) &lt;br&gt;• Measure the dark matter mass profiles on cluster and galactic scales &lt;br&gt;• Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with an accuracy of a few hundredths of an eV</td>
</tr>
<tr>
<td><strong>Initial Conditions</strong></td>
<td>• Measure the matter power spectrum on a large range of scales in order to extract values for the parameters (\sigma_8) and (n) to a 1-sigma accuracy of 0.01. &lt;br&gt;• For extended models, improve constraints on (n) and (\alpha) wrt to Planck alone by a factor 2. &lt;br&gt;• Measure a non-Gaussianity parameter: (f_{NL}) for local-type models with an error (&lt; +/-2).</td>
</tr>
</tbody>
</table>
# Forecasts

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Modified Gravity</th>
<th>Dark Matter</th>
<th>Initial Conditions</th>
<th>Dark Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\gamma$</td>
<td>$m_\nu/eV$</td>
<td>$f_{NL}$</td>
<td>$w_p$</td>
</tr>
<tr>
<td>Current (2009 - WMAP)</td>
<td>0.200</td>
<td>0.580</td>
<td>100</td>
<td>0.100</td>
</tr>
<tr>
<td>Euclid primary (WL+GC)</td>
<td>0.010</td>
<td>0.027</td>
<td>5.5</td>
<td>0.015</td>
</tr>
<tr>
<td>EuclidAll (clusters,ISW)</td>
<td>0.009</td>
<td>0.020</td>
<td>2.0</td>
<td>0.013</td>
</tr>
<tr>
<td>Euclid+Planck</td>
<td>0.007</td>
<td>0.019</td>
<td>2.0</td>
<td>0.007</td>
</tr>
<tr>
<td><strong>Improvement Factor</strong></td>
<td><strong>30</strong></td>
<td><strong>30</strong></td>
<td><strong>50</strong></td>
<td><strong>&gt;10</strong></td>
</tr>
</tbody>
</table>

Laureijs et al 2011
Euclid Survey Machine

- Euclid mission
  - 2 surveys: wide: $15000\text{deg}^2$ & deep: $40\text{deg}^2$
  - 1 space borne observatory + numerous ground based ones
  - Synergy with numerous ancillary experiments (Planck, eRosita…)
  - Dark Energy/cosmology AND great legacy science

- Other Euclid probes
  - VIS Imaging
    - $I_{AB}=24.5 ; 10\sigma$
    - $I_{AB}=26.5 ; 10\sigma$
  - NIR Photometry
    - $Y,J,H=24.0 ; 5\sigma$
    - $Y,J,H=26.0 ; 5\sigma$
  - NIR Spectroscopy
    - $2 \times 10^{16} \text{erg.cm}^{-2}.\text{s}^{-1} ; 3.5\sigma$
    - $5 \times 10^{17} \text{erg.cm}^{-2}.\text{s}^{-1} ; 3.5\sigma$

- Galaxy Redshift survey
  - Vis and NIR observer of stars and galaxies
  - $12.0 \times 10^9$ sources, $1.5 \times 10^9$ WL galaxies, $3.5 \times 10^7$ spectra Wide

- Other Euclid probes
  - Legacy Science
  - Cosmo. Simul.
  - Planck, eROSITA, …

- Space Euclid VIS and NIR observer of stars and galaxies
  - Dark Matter + Galaxy Power Spectra as function of look back time
  - Cosmological explorer of
    - $\text{gravity, dark matter, dark energy and inflation}$
Surveys

- **Common features**
  - Very accurate morphology (VIS)
  - Visible ($u, g, r, i, z$) & NIR ($Y, J, H$) photometry, $\Delta z=0.05(1+z)$ probing up to $z=2$
  - Spectroscopy, $R: 260$, $\Delta z=0.001(1+z)$ probing H$_{\alpha}$ galaxies between $0.7<z<1.8$
  - 6 years survey

- **Wide**
  - 15000 deg$^2$ — 12 $10^9$ sources ($3\sigma$)
  - Photometry
    - 1.5 $10^9$ galaxies
    - Visible $I_{AB}=24.5$ ($10\sigma$)
    - NIR $I_{AB}=24.0$ ($5\sigma$)
  - Spectroscopy
    - 35 $10^6$ redshifts
    - 21 mag
    - Flux line: $2 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$ ($3.5\sigma$)

- **Deep**
  - 10 (NEP)+20 (SEP)+10 (CDFS) deg$^2$ — 10 $10^6$ sources ($3\sigma$)
  - Photometry
    - 1.5 $10^6$ galaxies
    - Visible $I_{AB}=26.5$ ($10\sigma$)
    - NIR $I_{AB}=26.0$ ($5\sigma$)
  - Spectroscopy
    - 15 $10^4$ redshifts
    - 23 mag
    - Flux line: $5 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$ ($3.5\sigma$)
Euclid Satellite

Launch begin 2021 by a Soyuz rocket from Kourou, orbit around L2 (sun/earth) for 6 years of survey

Operation ESA

Large international collaboration (including NASA)
16 countries, 220 labs, 1400 Full members

Sun shield and SVM by Thales Alenia Space

Instruments by Euclid Consortium

Telescope by Airbus Defence & Space
**Instruments**

Near Infrared spectroscopy and photometry

Visible broadband imager

**PLM design overview**
Table 1: VIS and weak lensing channel characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Spectral Band</td>
<td>550 – 900 nm</td>
</tr>
<tr>
<td>System Point Spread Function size</td>
<td>≤0.18 arcsec full width half maximum at 800 nm</td>
</tr>
<tr>
<td>System PSF ellipticity</td>
<td>≤15% using a quadrupole definition</td>
</tr>
<tr>
<td>Field of View</td>
<td>&gt;0.5 deg²</td>
</tr>
<tr>
<td>CCD pixel sampling</td>
<td>0.1 arcsec</td>
</tr>
<tr>
<td>Detector cosmetics including cosmic rays</td>
<td>≤3% of bad pixels per exposure</td>
</tr>
<tr>
<td>Linearity post calibration</td>
<td>≤0.01%</td>
</tr>
<tr>
<td>Distortion post calibration</td>
<td>≤0.005% on a scale of 4 arcmin</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$m_{AB} \geq 24.5$ at 100 in 3 exposures for galaxy size 0.3 arcsec</td>
</tr>
<tr>
<td>Straylight</td>
<td>≤20% of the Zodiacal light background at Ecliptic Poles</td>
</tr>
<tr>
<td>Survey area</td>
<td>15000 deg² over a nominal mission with 85% efficiency</td>
</tr>
<tr>
<td>Mission duration</td>
<td>6 years including commissioning</td>
</tr>
<tr>
<td>Shear systematic bias allocation</td>
<td>additive $\sigma_{sys} \leq 2 \times 10^{-7}$, multiplicative $\leq 2 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Euclid will get the resolution of SDSS but at $z=1$ instead of $z=0.05$.

Euclid will be 3 magnitudes deeper than SDSS
NISP

NISP CDR successful in Nov 2016

The Euclid Mission

Meeting Place, Date

• FoV: 0.55 deg²
• Mass: 159 kg
• Telemetry: < 290 Gbt/day
• Size: 1m x 0.5 m x 0.5 m
• 16 2kx2K H2GR detectors
• 0.3 arcsec pixel on sky
• Limiting mag, wide survey AB: 24 (5σ)

• 3 Filters:
  • Y (950-1192nm)
  • J (1192, 1544nm)
  • H (1544, 2000nm)

• 4 griisms:
  • 1B (920 – 1300), 1 orientation 0°
  • 3R (1250 – 1850), 3 orientations 0°, 90°, 180°
Euclid surveys complementary data

- 45 nights at Keck telescope: spectroscopy on Euclid Wide fields north
- 25 nights at VLT VMOS/KMOS: spectroscopy on Euclid Wide fields south
- 2 nights pilot program at GTC: preparation of a spectroscopic large program
- 5300 hrs of Spitzer satellite, period 13, priority 1 on 2 Euclid Deep field (20 deg2)
- DES+KIDS survey data
- 271 nights at CFHT u-, r- band data on Euclid Wide North
- 110 nights at JST/T250 g- band data on Euclid Wide North
- Discussions on going with other telescopes
Mission Timeline

Science with Euclid will start in 2022 with Q1 and in 2023 with DR1
Summary

- **Euclid Mission**
  - 2 surveys wide and deep, photometry and spectroscopy with optimal usage of space and ground based observatories
  - 1.2m primary space borne telescope with broadband imaging and NIR photometry and spectroscopy
  - Large international collaboration

- **Euclid cosmology core program**
  - Use 5 cosmological probes, with at least 2 independent test (geometery and growth of structures)
  - Percent error on DM power spectrum over a wide range of redshifts and scales
  - Perfect complementarity with Planck: probes and data, cosmic periods
  - Explore the dark universe: DE, DM (neutrinos), MG, inflation, biasing, baryons
  - Explore the transition DM-to-DE-dominated universe period
  - Get the percent precision on w and the growth factor $\gamma$
  - Synergy with New Gen wide field surveys: LSST, WFIRST, e-ROSITA, SKA
  - 140,000 strong lenses: DM haloes of galaxies, galaxies, groups, clusters

- **Euclid =12 billion sources, 35 million redshifts, 1.5 billion shapes/photo-z of galaxies**
  - A mine of images and spectra for the community for years
  - A reservoir of targets for JWST, E-ELT, TMT, ALMA, VLT
  - A set of astronomical catalogues useful until 2040+

- Big challenges ahead of us: data processing (100-300 Petabytes), cosmological simulations

- **Milestones**
  - Launch 2021
  - start 2022: 2500 deg2 public in 2023
  - 7500 deg2 in 2025
  - final 2027