Imaging the Dark Universe with Euclid

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on behalf of
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for the Euclid Imaging Consortium
Euclid Science Objectives

Outstanding questions in cosmology:
• the nature of the Dark Energy
• the nature of the Dark Matter
• the initial conditions (Inflation Physics)
• modifications to Gravity

→ Euclid’s primary science objectives
→ Secondary objectives: Legacy Science
Primary Science objectives

EUCLID concept = all-sky \((2\pi \text{ sr})\) Vis+NIR imaging and spectroscopic survey

Primary EUCLID cosmological probes
• Weak Lensing Tomography
• Baryonic Accoustic Oscillations

Additional EUCLID cosmological probes:
• Cluster Counts
• Integrated Sachs-Wolfe Effect (correlation with CMB)
• Redshift space distortions
Weak Lensing Shear Measurement

Distortion matrix:

\[ \Psi_{ij} = \frac{\partial \delta \theta_i}{\partial \theta_j} = \int dz \, g(z) \frac{\partial^2 \Phi}{\partial \theta_i \partial \theta_j} \]

lensed background galaxies

mass and shear distribution

⇒ correlated image distortions on sky produce WL power spectrum \( C_1(\theta, z) \)
Weak Lensing Tomography

Lensing signal $C_l(\theta, z)$ depends on:
- shape of total matter density fluctuation spectrum
- angular diameter distance in lensing equation for lensing amplitude
- angular diameter distance for angular scale of density spectrum
- growth factor $g(z)$ of dark matter density fluctuations

WL tomography addresses all sectors of Dark Cosmology

Example: WL power spectrum for each of two $z$-bins

$z > 1$

$z < 1$

$\Omega_m = 0.30, w = -1.0$

$\Omega_m = 0.35, w = -1.0$

$\Omega_m = 0.30, w = -0.7$
Weak Lensing Tomography

COSMOS 1.7 deg\(^2\) HST/ACS imaging as a prototype for Euclid with 1/10,000 of area

COSMOS Dark Matter Map compared with (visible) galaxy distribution

WL tomography measurements:
COMBO17: Bacon et al. 2005
CFHTLS: Sembolini et al. 2006
COSMOS/HST: Massey et al. 2007b

Massey et al. 2007a, Nature

\(z \sim 0.6\)
\(z \sim 1.2\)
\(z \sim 2.0\)

Massey et al. 2007b
Weak Lensing Tomography

New analysis of public COSMOS data

Agreement with WMAP5 on $\sigma_8$ and $\Omega_m$

Evidence for acceleration

COSMOS alone
Euclid alone
10,000 larger
Current DE Constraints from Weak Lensing

Current constraints: 10% on constant $w$

For definite answers on DE: need to reach a precision of 1% on (varying) $w$ and 10% on $w'$

→ Objective for Euclid WL

Comparison with Other Probes

Astier et al. 2005

Jarvis et al. 2006

CTIO-LS

75 deg$^2$
Requirements for precision Weak Lensing

(1) **Statistics**: optimal survey geometry (in a fixed survey time) is "wide rather than deep"

→ need 20,000 deg$^2$ to reach 1% precision on $w$

(2) **Systematics**: must reduce the systematics in shear measurement by *almost two orders of magnitude*

→ highly stable PSF spatially and temporally enabling 50 bright stars to calibrate PSF plus a PSF < typical ground-based seeing to use small faint galaxies

*This requires access to space*
Shear Measurement

**Space:**

- Stable PSF $\rightarrow$ lower residual systematics from better calibration with finite number of available stars

**Ground:**

- Smaller PSF $\rightarrow$ better resolved small galaxies $\rightarrow$ less "deconvolution"

Ground PSF calibration and deconvolution
(3) **Photo-z:** need redshifts $z$ to make bins for tomography (and deal with intrinsic alignment effects) $\rightarrow \sigma_z < 0.05(1+z)$.

- must be photo-z for 2 billion+ galaxies
- need photometry ($AB \geq 24$ from visible to near-IR). Visible can be done from ground (at substantial cost savings), but the essential near-IR at this depth over the whole sky **requires access to the low near-IR background of space.**

Abdalla et al. 2007
Euclid Imaging Survey(s)

**Wide Survey**: Extragalactic sky (20,000 deg² = 2π sr)

- Visible: Galaxy shape measurements to $RIZ_{AB} \leq 24.5$ (AB, 10σ) at 0.18 arcsec FWHM, yielding 35 resolved galaxies/arcmin², with a median redshift $<z> \sim 0.9$, for primary weak lensing tomography experiment.

- NIR photometry: Y, J, H ≤ 24 (AB, 5σ PS), yielding photometric redshifts 0.05(1+z) together with ground based complement (e.g. PanStarrs-2, DES)

**Deep Survey**: approx 30 deg² at ecliptic poles

- Monitoring of PSF drift (40 repeats at different orientations over life of mission

- Produces +2 magnitude in depth for both visible and NIR imaging data.

**Possible additional Galactic surveys:**

Short exposure Galactic plane and high cadence microlensing extra-solar planet surveys could be easily added within Euclid mission architecture.
Complementary probes within the Euclid Imaging Survey

- Cluster counts (with eRosita, Planck and other SZ surveys)
- Integrated Sachs-Wolfe effect (ISW)
- BAO/P(k) large scale structure with photo-z

Excellent complementarity with ENIS spectroscopic surveys (CAT)

- Determination of visible-DM bias $b$
- Calibration of photo-z
- Independent and better BAO/P(k) from spectroscopy
- Complementary growth of structure through redshift space distortions
Euclid will challenge all sectors of the cosmological model:

- **Dark Energy**: $w_p$ and $w_a$ with an error of 2% and 13% respectively (no priors)
- **Dark Matter**: test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)
- **Primordial Initial Conditions**: constrain amplitude, slope and higher order parameters of primordial power spectrum, constrain primordial non-gaussianity
- **Gravity**: Distinguish GR from simplest modified Gravity theories by reaching a precision of 2% on the growth exponent $\gamma \left( \frac{d \ln \delta_m}{d \ln a} \propto \Omega_m^{\gamma} \right)$
Euclid Imaging Legacy: Imaging the Universe

- Dark Matter
- Visible Matter
Imaging Legacy Science

- **Map the relation between Galaxy Mass and Light**: correlation of WL mass map with galaxy distribution and properties
- **Constrain the physical drivers of star formation**: galaxy morphologies and masses; SNe rate (Detection of ~3000 Type Ia and Type II supernovae in deep survey)
- **High-z objects**: Using the Ly-dropout technique in MD survey, detect $10^3-4$ star forming galaxies at $z \sim 8$, $10^{2-3}$ at $z \sim 10$, maybe $\sim 10$ at $z \sim 12$; also detect $10^{2-4}$ quasars at $z \sim 7$, and $10^{1-3}$ at $z \sim 9$. These will be the brightest in sky for follow-up.
- **Galaxy clusters**: Mass-detection of 40,000 clusters at $0.3 < z < 0.7$, well-matched to Planck SZ and eRosita cluster sample, and NIR detection of $10^{2-3}$ Virgo-like clusters and $10^{3-4} 10^{13}M_\odot$ at $z > 2$,
- **Strong-lensing systems**: $\sim 10^5$ galaxy-galaxy lenses, $\sim 10^3$ galaxy-quasar lenses, 5000 strong lensing arcs in clusters.

The "Genome Project" of the observable Universe?
Add-on? Search for Planets with Microlensing  

**Microlensing survey:** 4 deg$^2$ in the bulge, visited every 20 minutes over 3 months (Y,J,H ~ 22 per visit), monitor 2x10$^8$ stars

→ Detect ~30 Jupiters, and ~5 Earth Mass planets in the habitable zone
Euclid Mission Baseline

Mission elements:

- L2 Orbit
- 4-5 year mission
- Telescope: three mirror astigmat (TMA) with 1.2 m primary
- Instruments:
  - Imaging:
    - Visible imaging channel: 0.5 deg$^2$, 0.10 arcsec pixels, 0.18 arcsec PSF FWHM, single broad RIZ (0.55-0.92 $\mu$m), CCD detectors → galaxy shapes
    - NIR photometry channel: 0.5 deg$^2$, 0.3 arcsec pixels, 3 bands Y, J, H (1.0-1.7 $\mu$m), HgCdTe detectors, → photometry, photo-z’s
  - Spectroscopy: NIR Spectroscopic channel: 0.5 deg$^2$, R=200-600, 0.9-1.7 $\mu$m, → redshifts
    - baseline: slitless
    - option: multi-object slit-based with Digital Micro-Devices (DMD)
Euclid Imaging Instrument

EIC delivered data pack:
Design, Development Plan, Management & Cost + supporting Documents, EIC Science Requirements, Radiometric and NIP documents, joint EIC-ENIS ground segment document
EIC Organisation

130 people in 25 institutes in 7 countries

EIC PI

Co-PI Group

Co-I Group & Science Working Groups

EIC Instrument Scientists

System Lead

System Group

Project Manager

NPM Group

QA Lead

QA Group

D/H Grnd. Segment

AIV Lead

AIV Team

Integration

Qualification

Tests

Calibration

Therm-mech

Shutter

Fold Mirror

Dichroic

Calib Source

PMCU

COMA Lead

Project Office & AIV

Vis Chan. Lead

Project Office & AIV

NIP Chan. Lead

Project Office & AIV

PDHU Lead

Project Office & AIV

PDHU H/W

PDHU S/W

Det. Sub. Ass.

Readout Elect

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Fold Mirror

Lense Ass.

FWA

CCU

Calib Source

Electronics S/W

Groups

EIC Project Level

EIC Organisation

Euclid

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Groups
Ground Segment

Integrated ground segment and data handling
• Intimate connection between instrument knowledge and science analysis.
• Redundant data streams for multi-point cross checking.

see EIC-ENIS Ground Segment Document
### Other related EIC talks

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Summary

• **The Euclid concept**: a high-precision cosmological survey of imaging and spectroscopy, aimed at Weak Lensing and BAO, over $2\pi$ sr, with simultaneous matched survey speeds within a 5-year M-class mission envelope.

• **Euclid Imaging Survey** is optimised to achieve definitive constraints on Dark Energy through weak lensing tomography, addressing all sectors of the cosmological model analogous to CMB for the late-epoch DE dominated Universe $0 < z < 2$.

• **Euclid Imaging Consortium** maintains a strong link between science and instrumentation, and tight control of systematics that are essential for success in weak lensing.

• **Ground-based photometric surveys** offer cost-effective route to photo-$z$ performance

• **Euclid ENIS spectroscopy** provides strong synergy and complementarity for both cosmological probes and photo-$z$ calibration.

• **Euclid Legacy Surveys** from the "all-sky" and "deep" VIS/NIR imaging survey provide breakthrough resource for galaxy evolution, high-$z$ objects, clusters, strong lensing and the Galactic halo, with potential survey extensions, also exoplanets and the Milky Way disk.