The Euclid Mission

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Euclid Consortium

• Merger of DUNE (French led WL) and Space (Italian led BAO)
  • Dune was Vis/NIR imaging
  • Space was NIR spectroscopy
  • Recently NIR instruments were merged into NISP

• Consortium Lead Alexandre Refregier (France)

• 200+ Consortium members (very inclusive)

• Current European member countries: Austria, France, Germany, Italy, Netherlands, Norway, Spain, Switzerland, UK
Outstanding Questions in cosmology

→ Euclid’s Primary Science Objectives
Nature of the Dark Energy
Nature of the Dark Matter
Initial conditions (Inflation Physics)
Modifications to Gravity

→ Secondary Science Objectives
Legacy science (NIR)
Microlensing/planet finding enabled
Euclid concept

- **High-precision survey mission** to map the geometry of the Dark Universe
- **Optimized** for two complementary cosmological probes
  - Weak Gravitational Lensing
  - Baryonic Acoustic Oscillations
  - Additional probes enabled with same data: clusters, redshift space distortions, ISW
- **Full extragalactic sky survey** with 1.2m telescope at L2:
  - Imaging:
    - High precision imaging at visible wavelengths
    - Photometry/Imaging in the near-infrared
  - Near Infrared Spectroscopy
- **Ground/Space synergy** to minimize costs and maximize science
- **Legacy science** for a wide range of areas in astronomy
- Yellow Book for more information http://xxx.lanl.gov/abs/0912.0914
Weak Gravitational Lensing

**Weak Lensing:**
- Map the 3D distribution of Dark Matter in the Universe
- Measures the mass without assumptions in relation between mass and light
- Very sensitive to Dark Energy through both geometry and growth
  → Need measurements of *galaxy shape* and photometric *redshifts*

**COSMOS Dark Matter Map over 2 deg²**

**Dark matter power spectrum in 2 redshift bins**

Massey et al. 2007
Requirements for Weak Lensing

**Statistics:** optimal survey geometry: wide rather than deep for a fixed survey time, → need 20,000 deg² to reach ~1% precision on w

**Redshift bins:** good photo-z for redshift binning and intrinsic alignments → need deep NIR photometry

**Systematics:** must gain 2 orders of magnitude in systematic residual variance → need about 50 bright stars to calibrate PSF

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Photo-z errors with and without NIR imaging

Abdalla et al. 2008
Baryonic Acoustic Oscillations

- $H(z)$ (radial)
- $D_A(z)$ (tangential)
- $H(z)$ & $D_A(z)$ depend on $w(z)$

CMB ($z \approx 1000$)

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Galaxy Clustering Survey

- Need large volumes ($V_{\text{eff}} \approx 19 h^{-3} \text{ Gpc}^3 \approx 75x$ larger than SDSS)
- Need to probe redshifts $0<z<2$
- Use galaxy spectroscopic survey to measure: BAO, full galaxy power spectrum $P(k)$ and redshift space distortions to constrain Dark Energy and Modified Gravity

![Graph showing redshift distortions](image)

only 20% of the survey
Mission elements:
• L2 Orbit
• 4 -5 year mission (still being optimized)
• Telescope: three mirror astigmat (TMA) with 1.2 m primary
• Instruments:
  – VIS: Visible imaging channel: 0.5 deg², 0.10” pixels, 0.18” PSF FWHM, broad band R+I+Z (0.55-0.92μm), 36 CCD detectors, galaxy shapes
  – NISP: NIR channel: 0.5 deg², 16 HgCdTe detectors, 1-2μm (2.5 μm cutoff devices)
    • Photometry: 0.3” pixels, 3 bands Y,J,H, photo-z’s
    • Spectroscopy: R=500, slitless, redshifts
Euclid Focal Planes

Vis exposure time leaves margin (possibly for second filter)
Euclid Surveys

Wide Survey: 20,000 deg$^2$

- Visible: Galaxy shape measurements for $2 \times 10^9$ galaxies to $RIZ_{AB} \leq 24.5$ (AB, 10σ) at 0.16” FWHM, yielding 30-40 resolved galaxies/amin$^2$, with a median redshift $z \sim 0.9$

- NIR photometry: Y, J, H $\leq 24$ (AB, 5σ PS), yielding photo-z’s errors of 0.03-0.05(1+<z> with ground based complement (PanStarrs-2, DES, LSST, etc)

- Spectroscopy: redshifts for $40 \times 10^6$ galaxies with emission line fluxes $>4 \times 10^{-16}$ ergs/cm$^2$/s at $0<z<2$ (slitless)

Deep Survey: 40 deg$^2$ deg$^2$ 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

Possible additional Galactic surveys (enabled beyond 4 years):
- Short exposure Galactic plane
- High cadence microlensing extra-solar planet surveys

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• Only do from space what must be done from space due to backgrounds or systematics
• To achieve photometric redshift precision, combine Euclid visible/NIR photometry with visible photometry from the ground
• DES+Pan-STARRS2 will meet requirements for depth and sky coverage. LSST+PS4 will provide even better photo-z’s
• Collaborations engaged with DES and PS projects
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 prior)

**Dark Matter:** test of CDM paradigm, precision of 0.04eV on sum of neutrino masses (with Planck)

**Initial Conditions:** constrain shape of primordial power spectrum, primordial non-gaussianity

**Gravity:** test GR by reaching a precision of 2% on the growth exponent $\gamma$ ($d\ln \delta_m / d\ln a \propto \Omega_m^{\gamma}$)

→ Uncover new physics and map LSS at 0<z<2: Low redshift counterpart to CMB surveys like Planck
Euclid

- **Unique legacy survey**: 2 billion galaxies imaged in optical/NIR to mag 24, 40 Million NIR galaxy spectra, full extragalactic sky coverage, Galactic sources
- Unique dataset for **various fields in astronomy**: galaxy evolution, search for high-z objects, clusters, strong lensing, brown dwarfs, exo-planets, etc
- **Synergies with other facilities**: JWST, Planck, GAIA, DES, Pan-STARRSS, LSST, etc
- All data **publicly available** through a legacy archive
Search for Exo-Planets

Enabled in a possible extended mission

**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

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**Image**

- **Equation:** $M_{lens} = 1.00M_\odot$, $M_{planet} = 1.0M_\odot$, $a = 1.0$AU

- **Graphs:**
  - Days vs. magnification
  - DUNE photometry

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**Diagram**

- **Graph:** Exoplanet Discovery Potential
- **Axes:** Mass (Earth masses) vs. semi-major axis (AU)
- **Legend:**
  - Doppler
  - Ground-based microlensing
  - Kepler
  - DUNE-ML
  - Free floating planets

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• **Euclid** is a high-precision wide-field survey mission to map the geometry of the Dark Universe

• Euclid will provide unprecedented accuracy on all sectors of the cosmological model: Dark Energy, Dark Matter, Initial Conditions, Gravity

• Euclid will also provide unique legacy science from its all sky legacy archive and additional surveys

• Complementary and analogous to CMB measurement of Large-Scale Structure at matter-radiation transition epoch: Euclid will provide high-precision map of LSS at matter-DE transition epoch: 3D, non-gaussian, multi-probe
Current status of Dark Energy

Dark Energy:
• Affects cosmic geometry and structure growth
• Parameterized by equation of state parameter:
  \[ w(z)=\frac{\rho}{p}, \text{ constant } w=-1 \text{ for cosmological constant} \]

Current constraints: 10% error on constant \( w \)

For definite answers on DE: need to reach a precision of 1% on (varying) \( w \) and 10% on \( w_a=\frac{dw}{da} \)

→ Objective for Euclid
Advantages of Space

Space observations provide:

- small and stable PSF: larger number density of resolved galaxies, small systematics for Weak Lensing
- deep NIR photometry: better photometric redshifts
- NIR spectroscopy: galaxy redshifts at $z > 1$

Abdalla et al. 2008
2DF redshift survey

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