Euclid-WFIRST complementarity

Y. Mellier & J. Rhodes

On behalf of the Euclid Consortium
Euclid Primary Objectives: the Dark Universe

- Understand the origin of the Universe’s accelerating expansion
- Probe the properties and nature of Dark Energy and Gravity,

- Probe the effects of Dark Energy, Dark Matter and Gravity by:
  - Using at least 2 independent but complementary probes (5)
  - Tracking their observational signatures on the
    - Geometry of the universe: Weak Lensing (WL), Galaxy Clustering (GC)
    - Cosmic history of structure formation: WL, Redshift-Space Distortion (RSD), Clusters of Galaxies (CL)
  - Controlling systematics to an unprecedented level of accuracy.
Euclid will explore the dark universe and the DM-dominated / DE-dominated transition period

Plot inspired by the BOSS collaboration

Community Astrophysics with WFIRST, Pasadena, 29 Feb 2016
The ESA Euclid space mission

Soyuz@Kourou
Launch date: Dec 2020

PLM+SVM: 2010-2020

Surveys: 2010-2028 (Survey WG)
Survey duration: 6 yrs
15,000 deg²
Commissioning – SV

Euclid opération:
5.5 yrs: Euclid Wide+Deep
+: SNIa, mu-lens, MW?

NIR spectro-imaging
2010-2020 (NISP team)

VIS imaging: 2010-2020
(VIS team)

~100 PB data processing (EC-SGS team)

commisionning – SV

~100 PB data processing (EC-SGS team)

Science analyses
VIS and NISP

VIS
Courtesy: S. Pottinger, M. Cropper and the VIS team

- FoV: 0.55deg²
- Mass: 159 kg
- Telemetry: < 290 Gbt/day
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky
- Limiting mag, wide survey AB: 24 (5σ)
- 3 Filters: Y, J, H
- 4 grisms: 1B (920 – 1250), 3R (1250 – 1850)

NISP
Courtesy: T. Maciaszek and the NISP team

- FoV: 0.54deg²
- Mass: 133 kg
- Telemetry: < 520 Gbt/day
- 36 4kx4K E2V CCDs, 12 micron pixels
- 0.1 arcsec pixel on sky
- Limiting mag, wide survey AB: 24.5 (10σ)
- 1 Filter: Y(R+I+Y): band pass 550-900nm
Euclid Legacy value

- **Euclid Wide:**
  - 15000 deg$^2$ outside the galactic and ecliptic planes
  - 12 billion sources (3-sigma)
  - 1.5 billion galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z, (R+I+Z) AB=24.5, 10.0 $\sigma$ +
    - NIR photometry: Y, J, H AB = 24.0, 5.0$\sigma$
    - Photometric redshifts with 0.05(1+z) accuracy
  - 35 million spectroscopic redshifts of emission line galaxies with
    - 0.001 accuracy
    - Halpha galaxies within 0.7 < z <1.85
  - Flux line: $2 \times 10^{-16}$ erg.cm$^{-2}$.s$^{-1}$; 3.5$\sigma$
Euclid Legacy value

- **Euclid Deep:**
  - 2x20 deg$^2$ at ecliptic poles
  - 10 million sources (3-sigma)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z, (R+I+Z) $AB=26.5$, $10.0\,\sigma$ +
    - NIR photometry: Y, J, H $AB = 26.0$, $5.0\sigma$
    - Photometric redshifts with $0.05(1+z)$ accuracy
  - 150000 spectroscopic redshifts of emission line galaxies with
    - 0.001 accuracy
    - Halpha galaxies within $0.7 < z < 1.85$
    - Flux line: $5 \times 10^{-17}$ erg.cm$^{-2}.s^{-1}$; $3.5\sigma$
Calibration sequence over 6 years (ecliptic coordinates, Mollweide projection) → All calibration fields are shown, including HST targets and the EDFS and EDFN near the ecliptic poles. The ecliptic is shown as a vertical line, jagged lines show background level contour E(B-V)=0.08
## Euclid Post-Planck Forecast for the Primary Program

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Modified Gravity</th>
<th>Dark Matter</th>
<th>Initial Conditions</th>
<th>Dark Energy</th>
<th>FoM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref: Euclid RB arXiv:</td>
<td>γ</td>
<td>$m_\nu$ /eV</td>
<td>$f_{NL}$</td>
<td>$w_p$</td>
<td>$w_a$</td>
</tr>
<tr>
<td>1110.3193</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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>
<td>0.150</td>
</tr>
<tr>
<td>EuclidAll (clusters,ISW)</td>
<td>0.009</td>
<td>0.020</td>
<td>2.0</td>
<td>0.013</td>
<td>0.048</td>
</tr>
<tr>
<td>Euclid+Planck</td>
<td>0.007</td>
<td>0.019</td>
<td>2.0</td>
<td>0.007</td>
<td>0.035</td>
</tr>
<tr>
<td>Current (2009)</td>
<td>0.200</td>
<td>0.580</td>
<td>100</td>
<td>0.100</td>
<td>1.500</td>
</tr>
<tr>
<td>Improvement Factor</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>&gt;10</td>
<td>&gt;40</td>
</tr>
</tbody>
</table>

DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p-a)$

From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p) > 400 \rightarrow \sim 1\%$ precision on w’s.

Growth rate of structure formation: $f \sim \Omega^\gamma$.

Notice neutrino constraints -> minimal mass possible $\sim 0.05$ eV.
Euclid:
contributing to the next generation wide field VIS/NIR surveys for the whole scientific community

- Very large samples
  → Diversity of populations
  → Distribution functions
  → ~50,000 clusters of galaxies
- Huge volumes and numbers
  → Rare sources, probing the extremes
- Exquisite imaging of galaxies
  → Morphologies, mergers, galaxy-scale lenses
  → Observations of $10^6$ dwarf galaxies
- Strong and Weak Lensing
  → Galaxy evolution as function of halo properties
  → Galaxy alignment
  → 5000 clusters with giant arcs
- NIR Spectroscopy
  → Metals, star formation@ z>1
  → Cool stars
  → Very high-z QSOs

From J. Brinchmann 2013

HST in 15 yrs
15, 000 deg2

Euclid in 5 yrs
10, 000 deg2

Astrophysics with WFIRST, Pasadena, 29 Feb 2016
Legacy Science Working Groups

- Extra-solar planets
- Milky way and Resolved Stellar populations
- Local Universe
- Galaxies and AGN evolution
- Primeval Universe
- Clusters of galaxies
- Strong lensing
- CMB Cross-correlations
- Cosmological Theory
- Cosmological simulations
- Supernovae and transients
Legacy Science Working Groups

- Extra-solar planets
- Milky way and Resolved Stellar populations
- Local Universe
- Galaxies and AGN evolution
- Primeval Universe
- Clusters of galaxies
- Strong lensing
- CMB Cross-correlations
- Cosmological Theory
- Cosmological simulations
- Supernovae and transients
Clusters of galaxies with Euclid

- Probe of peaks in density distribution
- Nb density of high mass, high redshift clusters very sensitive to
  - primordial non-Gaussianity and
  - deviations from standard DE models
- Euclid data will get for free:
  - $\Lambda$-CDM: all clusters with $M>210^{14}$ Msol detected at $3-\sigma$ up to $z=2$
    - $60,000$ clusters with $0.2<z<2$
    - $1.8 \times 10^4$ at $z>1$.
  - $\sim 5000$ giant gravitational arcs
    - very accurate masses for the whole sample of clusters (WL)
    - dark matter density profiles on scales $>100$ kpc

Synergy with Planck and eROSITA
Expected precision on the mean mass of clusters with gravitational shear in bin of $\Delta \log(M_{200})=0.2$ and $\Delta z=0.1$

- Survey of 15,000 deg$^2$
- $\Lambda$-CDM Planck cosmology
- Tinker mass function
- Shape noise of 0.3

Euclid has the potential to calibrate the mean mass, and hence the scaling relations, to 1% out to $z=1.0$ and to 10% out to $z=1.6$

Sartoris et al 2015
Legacy Science Working Groups

- Extra-solar planets
- Milky way and Resolved Stellar populations
- Local Universe
- Galaxies and AGN evolution
- Primeval Universe

- Clusters of galaxies
- Strong lensing
- CMB Cross-correlations
- Cosmological Theory
- Cosmological simulations
- Supernovae and transients
Strong lenses seen with Euclid:

- Galaxy-galaxy lensing
- Galaxy-QSO lensing
- Gravitational arcs
- Compound lenses
- Multiple images in clusters
- Exotic lenses

Giant arcs in clusters (Boldrin et al 2015)

- 1300 arcs with L/w > 10
- 8000 arcs with L/w > 5

Galaxy-galaxy lensing (Collett 2015)

- 140,000 lenses in the wide survey
- 650 double source plane lenses
Euclid VIS Legacy: after 2 months
(66 months planned)
Legacy Science Working Groups

- Extra-solar planets
- Milky way and Resolved Stellar populations
- Local Universe
- Galaxies and AGN evolution
- Primeval Universe
- Clusters of galaxies
- Strong lensing
- CMB Cross-correlations
- Cosmological Theory
- Cosmological simulations
- Supernovae and transients
Euclid will get the resolution of SDSS but at $z=1$ instead of $z=0.05$.

Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey
35 million spectra with at least 3 exposures taken with 3 different orientations and a total exposure time of 4000 sec.

From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. zoubian
Galaxy evolution with Euclid: physical parameters

From Pozzetti & Bolzonella

Accuracy on physical parameters from SED fits on Euclid AGNs, emission lines galaxies

$\sigma_{\text{Mass}}$ worse by 0.1-0.2 dex and $\sigma_{\text{SFR}}$ worse by 0.3 dex relative to COSMOS
Galaxy evolution with Euclid: local environments

Will Euclid data have enough spatial resolutions to characterise local environments?

From Cucciati

[Diagram showing PHOT. CAT. and ZADE-LIKE method results]

Communit

Yes
Measuring absorption lines on Euclid spectra

From Quai, Moresco, Cimatti, Pozetti,

age=0.5 Gyr  
z=1.5
Prospect for detecting high-z Ly-a emitters


Detectable by Euclid at z~7

Community Astrophysics with WFIRST, Pasadena, 29 Feb 2016
Legacy Science Working Groups

- Extra-solar planets
- Milky way and Resolved Stellar populations
- Local Universe
- Galaxies and AGN evolution
- Primeval Universe

- Clusters of galaxies
- Strong lensing
- CMB Cross-correlations
- Cosmological Theory
- Cosmological simulations
- Supernovae and transients
Microlensing survey?

3 fields observed every 17mn in H, every 12 hours in VIS, J and Y

- Mini-survey during commissioning (24h),
- then 4x1 months survey
- Measuring cold Earth abundance and mass function
  - 35 planets/months (5 Earth/month, 15 Neptune/month)
- Getting constraints on free-floating planets
  - 15 free floating planets/month

Euclid will complement the parameter space probed by RV and Kepler

- Measuring the cold planet mass function below 1 Earth mass

Possibility of simultaneous Euclid-WFIRST in the extended mission 2026+: parallax between Euclid and WFIRST to measure masses of Earth mass free floaters)? → still valid with the new WFIRST orbit in L2?
Microlensing survey?

From Beaulieu and Penny et al 2013
WFIRST and Euclid are Complementary

- Understanding dark energy will require tight control of systematics and multiple cross checks

**WFIRST-AFTA**
- Is deep, infrared over 2000 square degrees
- Multiple shape measurements in 2-3 well-sampled bands
- Higher resolution and source density (2.5 times as many as Euclid)
- High quality survey of >2000 SN using a dedicated IFU
- Redshift survey for galaxy clustering extends to z=3

**Euclid**
- Measures shapes in single optical band but with CCD detectors very well known for WL. Different systematics than WFIRST-AFTA, lower redundancy and internal cross-checks.
- Much wider (15,000 deg$^2$) but shallower
- No SN
- Lower redshift range for galaxy clustering
- Launch in 2020, survey completed by 2026: 2500 deg$^2$ public in 2023, 7500 deg$^2$ in 2025, final 2027.

**Euclid-WFIRST data processing synergy:** lessons learned from Euclid (H2RG detectors, Grisms), tens of scientists and engineers involved in both surveys

The best constraints on DE and Legacy in the 2020s will come from a combination of Euclid, WFIRST and ground-based (LSST, Subaru) data