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On behalf of the Euclid Consortium
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An accelerating $\Lambda$-dominated Universe: “concordance”, but with a few crucial open questions...

Amanullah et al. 2010 (Union supernovae)

Planck Collaboration 2015, paper XIII
**KQ1:** Is cosmic acceleration produced by a cosmological constant or by an evolving scalar field?

Evolving equation of state of DE:

\[ w(a) = w_0 + w_a (1 - a) \]

DETF (Albrecht et al. 2006): characterize experiments through a Figure of Merit in \((w_0, w_a)\) plane (or similar):

\[ \text{FoM} = 1/(\Delta w_0 \times \Delta w_a) \]

But this reflects chosen parameterization

\[ \Rightarrow \text{FoMs should be taken with a big grain of salt (e.g. NASA/DOE/ESA FoMSWG report, Albrecht et al. 2009): there is much more science in a galaxy survey} \]
KQ2: Is General Relativity valid on cosmological scales? Can we tell the difference between Dark Energy and Modified Gravity?

As a consequence, probing the expansion history of the Universe alone does not allow us to distinguish between a modified gravity (e.g. a $\Lambda$-term) and a Dark Energy.

$Lohav & Liddle, 2014$
Euclid goal is to measure these three quantities in a single experiment

This degeneracy can, at least partially, be lifted by considering perturbation in the cosmic density and velocity field and their evolution. A linearly perturbed FRW metric can be expressed as

\[ ds^2 = (1 + 2\Psi)dt^2 - a^2(t)(1 - 2\Phi)dx^2 \]

- Relativistic particles respond to the sum of the two scalar potential. Probed by e.g. gravitational lensing.
- Massive Particles respond to the Newtonian potential. Probed by e.g. peculiar velocities.
- Expansion history. Probed e.g. by BAO.

And more …
1. Measure the expansion history $H(z)$ to high accuracy, as to detect percent variations of DE equation of state $w(z)$ with robust control of systematics:

Achieve this through two probes:

A. Using the scale of Baryonic Acoustic Oscillations (BAO) in the clustering pattern of galaxies as a standard rod

B. Using shape distortions induced by Weak Gravitational Lensing

2. Measure at the same time the growth rate of structure from the same probes, to detect modifications of gravity:

A. Clustering redshift-space distortions (RSD)

B. Weak Lensing (WL) Tomography

→ These two probes are differently sensitive to the $\Psi$ and $\Phi$ potentials of the perturbed metric, i.e. to deformations of time and space

(Credit: V. Springel)
w(z) from BAO

Alam+16
SDSSIII BOSS

20% of the Euclid slitless data at z~1. Total effective volume (of Euclid) $V_{\text{eff}} = 19.7 \text{ Gpc}^3 h^{-3}$ (Euclid Red Book; credit: Percival, Guzzo & GC Working Group)
Weak Lensing tomography: get matter \( P(k,z) \)

- The lensing kernel is most sensitive to structure halfway between the observer and the source. But the kernel is broad: we do not need precise redshifts for the sources: photometric redshifts are fine.

- Also, since the kernel is broad the tomographic bins are very correlated. The gain saturates quickly with the number of bins: **not many z bins**

(Euclid Red Book; credit: Hoekstra, Kitching & WL Working Group)

\[
C_{ij}(\ell) = \int_0^{r_H} dr \, W_{ij}^{GG}(r) P_\delta \left( \frac{\ell}{S_k(r)}; r \right)
\]
Weak Lensing Probe

Light propagation through large-scale structure results in a lensed image

A sharp PSF is not enough: need to correlate shapes of millions of galaxies to measure the cosmological signal at $10^{-3}$ in ellipticity (+ Photometric redshifts + Color-corrected PSF + …)

Telescope
Detector

Unlensed stars used to measure instrumental effects.

(Hoekstra, Kitching & WL Working Group)
Anisotropy of 2pt correlation function (Pezzotta +, 2017)

The distortion of the correlation function is sensitive to the growth-rate of structure $f\sigma_8(z)$ and modifications of gravity theory.

(e.g. VIPERS: Scoddegio+, 2017)
Euclid will set new limits

(Credit: Guzzo, Percival & GC Working Group)
Euclid and DM

- Probing halo mass as a function of z (low-mass tail)
- Survey of clusters (combined with X-rays observations) -> high mass tail
- Galaxy-galaxy interactions (extending the bullet cluster study to 15KsqDeg) will set limits to DM self-interaction cross section (Massey, 2011)
- Euclid WL observations could constraint $m_{WDM} < 2$ keV (Markovic et al, 2010)
- Euclid cosmological constraints on neutrino properties are highly complementary to particle physics experiments (see M. Kuntz talk) - time-varying neutrino mass, sum of neutrino mass (galaxy power spectrum and weak lensing),…-
- DM-DE coupling, Unified Dark Matter, …

Euclid exquisite (in statistical terms) accuracy will allow disentangling between theoretical predictions and/or confirm direct detection

See Amendola +, 2016, arXiv:1606.00180v1
How to do this with Euclid

Ground-based observations
- griz imaging
- spectroscopy

Space-based observations with Euclid
- VIS imaging
- NIR imaging
- NIR spectroscopy

Other probes
- Clusters, ISWSNe
- Cosmic shear
- Redshift survey
- \( P(k;z) \)

Simulations
- Planck
- eRosita

Test of fundamental physics
- Legacy Science

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How to do this with Euclid

Ground-based observations

VIS
\[ I_{AB} = 24.5 \pm 10\sigma \]

NIR
\[ YJH = 24 \pm 5\sigma \]

NIR spectroscopy
\[ 2 \times 10^{-16} \text{erg cm}^{-2} \text{s}^{-1} \pm 3.5\sigma \]

Wide Field: 1.5 \(10^9\) WL galaxies, 3 \(10^7\) spectra + Deep Field for calibration

Griz imaging spectroscopy

Other probes

Cosmic shear

Redshift survey

Clusters, ISWSNe

P(k;z)

Other probes

Test of fundamental physics

Simulations

Planck

eRosita

Legacy Science

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The Euclid Consortium

- 16 countries +
- More than 120 institutes/labs
- More than 1200 members

www.euclid-ec.org
sci.esa.int/euclid

An artist view of the Euclid satellite – courtesy ESA

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• **ESA mission**

• Selected in Oct. 2011 - Fully funded
• Partners: ESA, TAS-I, Airbus DS, Euclid Consortium (EC)
• Overall mass: ~2020 kg, Power: 1920 W (E0L)
• Data rate: 850 Gbit/day
• Telescope (T=125K, passive):
  • 1.2m aperture primary, 3 mirror Korsch anastigmat
• 2 Instruments (VIS, NISP) – T = 100-140 K (passive)
  • Wide field instrument, VIS: 36 e2v 4kx4k CCDs 0.55<λ<0.92 μm, 576 M pixels, 0.11 arcsec/pix, 0.53 deg² FoV
  • Photom. (Y, J, H) + spectrom.: 16 H2GR HgCdTe detectors;
  • 64 Mpixels, 0.30 arcsec/pix, 0.53 deg² FoV (=VIS)
  • Grism slitless spectro (1B + 3R grisms) 0.92<λ<2.05 μm, R>250

• Downlink Rate: X/X + K-band to Ground Station 55 Mbits/s. 850 Gbit/day to transfer 4hr/day.
• Ground Segment: ESA (50%), EC (50%, EC leads science and external data): 1.5 billion galaxies for WL, 30 million redshifts, 12 billion sources (3sigma)
• L2 orbit
• Launch Vehicle – Soyuz-Fregat
• Launch date mid 2021, from Kourou space port
• 6.25 years mission + additional surveys (exopl, SN)
• Main surveys: 15,000 deg²+40 deg² 2 mag. deeper
• Science drivers: DE
• Science leads: Euclid Consortium
The Euclid Mission in one slide

Avoid Galaxy+Ecliptic

Surveys: 2010-2027+ (Survey WG)

6.25 yrs - 15,000 deg²
Commisionning – SV
Euclid opération:
>5.5 yrs: Euclid Wide+Deep

PLM+SVM: 2010-2027+

VIS imaging: 2010-2021
(VIS team)

NIR spectro-imaging
2010-2021 (NISP team)

SGS: 2010-2028+

Ground data

20-30 PB data processing (EC-SGS team)

SWG: 2019-2028+

Science analyses

Soyuz@Kourou 2021
Euclid is an experiment combining GC and WL: an unprecedented match of an imaging and redshift survey from space, building a sample of $>10^9$ galaxy shapes and $\sim5 \times 10^7$ galaxy distances (and much more).

Euclid results may well revolutionize our understanding of physics: for sure it will provide a huge database for unexpected discoveries (legacy).

Ideal complementarity to CMB observations and direct/indirect DM search.

Euclid is one of the most sophisticated scientific instruments ever launched: large cryo optics, large focal planes, the most powerful on-board data processing.
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