EUCLID
Mapping the geometry of the dark Universe

Conseil scientifique IN2P3
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A.Ealet (CPPM/IN2P3)
• EUCLID is a space mission dedicated to understand the origin of the acceleration of the Universe

• Euclid was selected by ESA in Oct. 2011, Adopted in June 2012 in the cosmic vision program as the M2 mission to be launched in 2020

• EUCLID will measure the expansion history $H(z)$ to unprecedented accuracy, as to detect any deviation in observational signatures in geometry/structure from dark matter/energy with full control of systematic effects:
The Euclid scientific strategy

Distinguish between interpretations:

- **DE models** ➞ *Is there a variation in time of Λ?* \( w(a) = w_0 + w_a(1-a) \)

- **Gravity** ➞ *Verify that growth of structure \( f(z) \) consistent with \( \Lambda CDM \)

*Is the gravity law that causes structure formation consistent with the law that governs the expansion of the Universe?*

⇒ *Observations of both expansion \( H(z) \) and growth of structure \( f(z) \)*

**Strategy:** use a multi probes approach sensitive to \( H(z) \) and \( f(z) \)

⇒ Reduce statistical errors by a full sky coverage ➞ wide field instruments

⇒ Control systematical errors using space advantages:
  ⇒ High image quality
  ⇒ High PSF stability
  ⇒ Infrared access (high redshift)
  ⇒ Low sky background

⇒ Need large simulation of structure formation with different
Galaxy clustering (GC): BAO, RSD, AP..

3-D position measurements:
0.9<z<2
→ 3-D distribution of galaxies from spectroscopy in NIR range.
→ 50 millions of spectroscopic redshifts

Weak lensing (WL):

-3-D cosmic shear measurements: 0<z<2
→ Shape measurement and photo-z’s from optical and NIR data;
→ 1.5 Billions of galaxies
3-D position measurements of galaxies over $0.9 < z < 2$
- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); $\psi, H(z)$.
- Need high precision 3-D distribution of galaxies with spectroscopic redshifts.

**Euclid:**

50 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg$^2$
Primary probe 1: Euclid Redshift Survey

What is the expansion rate of the Universe?

How does structure form within this background?

What are the neutrino masses, matter density?

What is $f_{nl}$, which quantifies non-Gaussianity? GR-horizon effects

Does the potential change along line-of-sight to CMB

Understanding Dark Energy

Understanding energy-density, gravity

Understanding energy-density

Understanding Inflation, GR

Understanding DE, GR
The galaxy power spectrum: SDSS forecast.

**SDSS (BOSS) today**

$0.15 < z < 0.5$

**EUCLID expected**

One of the 5 redshift slice $(0.9 < z < 2)$
Redshift space distortion

Probing the growth rate of structure

\[ f = \frac{d\ln D}{d\ln a} \]

(Credit: V. Springel)
RSD constraints modified gravity

Current and EUCLID measurements of the growth rate $f$

(BOSS, Reid et al. 2012)

(EUCLID forecast, Majerotto et al. 2012)
Primary probe 2: Weak Lensing

Cosmic shear over 0<z<2

$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2} \int_0^\omega f_K(\omega - \omega') f_K(\omega') \delta [f_K(\omega') \theta; \omega'] d\omega'$$

- Probes distribution of matter (Dark + Luminous): expansion history, lensing potential $\varphi + \psi$.
- **Shapes+distance of galaxies:** shear amplitude, and bin the Universe into slices.
- “Photometric redshifts” sufficient for distances: optical+NIR data.

Euclid:

WL with 1.5 billion galaxies over 15,000 deg$^2$
What is the expansion rate of the Universe?

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Understanding DE, GR
Euclid: Combining WL and GC data

- Tomographic WL shear cross-power spectrum for $0.5 < z < 1.0$ and $1.0 < z < 1.5$ bins.
- Percentage difference [expected – measured] power spectrum: recovered to 1%.

- $V_{\text{eff}} = 19 h^3 \text{Gpc}^3 = 75x$ larger than SDSS
- Redshifts $0.9 < z < 1.9$

- Percentage difference [expected – measured] power spectrum: recovered to 1%.
$f \sim \Omega^\gamma; \quad \gamma = 0.55$? As predicted by GR

The growth rate well described by $f(z) = \Omega_m(z)^\gamma$. 

23/10/2015 The Euclid mission
# EUCLID forecasts...

Assume systematic errors are under control

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Modified Gravity</th>
<th>Dark Matter /eV</th>
<th>Initial Conditions</th>
<th>Dark Energy</th>
</tr>
</thead>
<tbody>
<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>
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<tr>
<td>Euclid+Planck</td>
<td>0.007</td>
<td>0.019</td>
<td>2.0</td>
<td>0.007</td>
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<tr>
<td>Current (2009)</td>
<td>0.200</td>
<td>0.580</td>
<td>100</td>
<td>0.100</td>
</tr>
<tr>
<td>Improvement Factor</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

- DE equation of state: \( P/p = w \), and \( w(a) = w_p + w_a(a_p - a) \)
- Growth rate of structure formation: \( f \sim \Omega \tau \)
- From Euclid data alone, get FoM=\( 1/ (\Delta w_a \times \Delta w_p) > 400 \rightarrow \sim 1\% \) precision on \( w \)'s.
Ade et al. (2013), these combined probes produce an upper limit $P_m < 0.23$ eV (95% confidence) when assuming zero curvature.
EUCLID

The mission
Euclid Survey Machine: 15,000 deg$^2$ + 40 deg$^2$ deep

**External Photometry and External Spectroscopy**

**Space Euclid VIS and NIR observer of stars and galaxies**
- **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**
  - $2 \times 10^{-16}$ erg.cm$^{-2}$.s$^{-1}$; $3.5\sigma$
  - $5 \times 10^{-17}$ erg.cm$^{-2}$.s$^{-1}$; $3.5\sigma$

**Other Euclid probes**
**Cosmic Shear survey**
**Galaxy Redshift survey**

**Cosmological explorer of gravity, dark matter, dark energy and inflation**

**Legacy Science**

**External Photometry**

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**Legacy Science**

**External Photometry and External Spectroscopy**

**Planck, eROSITA, ...**

**Cosmo. Simul.**
Euclid is an ESA mission with a strong scientific consortium.

ESA provides the telescope and detectors (via industry), the satellite, launch and operation centers.

Countries provide the 2 instruments (VIS and NISP) and the ground segment (SGS).

Euclid will do a wide survey of 15000 deg² and a deep survey of 40 deg².
Euclid – Spacecraft Configuration

From Thales Alenia Italy, Airbus DS, ESA Project office and Euclid Consortium

- Total mass satellite: 2200 kg
- Dimensions 4.5 m x 3 m x 3 m

Télescope 1.2 m; FoV: 0.54 deg²
Mirror in Silicon Carbide = ultra-stable
Temp.: -150 deg. Stability ±: 0.05 deg.
The instruments

36 CCDs, 4kx4k, 12 micron pixels
0.1 arcsec pixel on sky
1 filter Y(R+I+Y)
Bandpass 550-900 nm
Data volume 520 Gbit/day
Mass 135 Kg

23/10/2015

The Euclid mission

16 2kx2k, H2RG, 18 micron pixels
0.3 arcsec pixel on sky
3 filters Y, J, H
4 grisms 1B(920-1350), 3 R(1250-1850)
Data Volume 290 Gbit/day
Mass 159 Kg
The consortium is responsible of the production of the scientific data at all levels

- Processing of the VIS et NISP instrument raw data up to cosmological analyses
- Add external data if needed in adequate format
- Simulations
- Produce data catalogs to be delivered to the community

The final interpretation and cosmological analysis is under the responsibility of the science groups

The ground segment is identified as challenging because of the size of the survey, the level of systematic errors and the complexity of the data chain production and distribution
SDC : infrastructure for pipeline, production
Ous : (organizational Unit): prototypes of algorithms
The mission PDR has just end up. No major issues. CDR expected in 2016.
Ground based + Euclid imaging data: plans

- **Year -3**: Start ground based observations (<2017)
  - T-3 start ground based observations
  - All Euclid pointings set

- **Yr -1 Ground DR1 ready (2500 deg²)**

- **Yr +1 Ground DR2 ready (7500 deg²)**

- **Yr +3 Ground DR3 ready (15000 deg²)**

- **T-0 start Euclid nominal mission (2020)**

- **Year 1**
  - Q1: ~ 50 deg²

- **Year 2**
  - DR1: ~ 2500 deg²

- **Year 3**
  - Q2: + ~ 50 deg²
  - DR2: + ~ 5000 deg²; Total ~7500 deg²

- **Year 4**
  - Q3: + ~ 50 deg²

- **Year 5**
  - Q4: + ~ 50 deg²

- **Year 6**
  - DR3: + ~ 7500 deg²; Total ~15000 deg²

Mission timeline
The Euclid mission

Euclid : The organisation

The scientific consortium: 120 laboratories, > 1200 members

France is a main actor with 30% of the country contributions
> 250 french members, INSU, IN2P3 and IRFU.

- **Very high level of responsibilities:**
  - Lead consortium (Y. Mellier, INSU)
  - EST, ECB members (Y. Mellier, O. Le fevre, A. Ealet)
  - Lead NISP instrument (CNES, INSU, IN2P3)
  - Lead of VIS focal plan (IRFU)
  - Scientist of the ground segment (IRFU)
  - Lead of the SGS system team (CNES)

- **More than 10 laboratories**
  - INSU: IAP, IAS, LAM, IRAP, Lagrange
  - IN2P3: APC, CPPM, IPNL, LPSC, LPNHE
  - IRFU
  - CC IN2P3

- **A strong CNES support and participation**
French Responsibilities
Euclid Consortium

Points marquants IN2P3 2015
-NISP Instrument scientist (A.Ealet/CPPM)
-NISP Detector scientist (R.Barbier/IPNL)

IN2P3 responsibilities:

- Reception of the 16 flight detectors from NASA (CNES/CPPM)
- Characterisation (CPPM/IPNL)
- Radiation tests (APC/LPSC)
- Integration and test of the full focal plan (NI-DS) (CPPM)

CPPM : develop test facilities for flight detectors reception (clean room)
+ do the detector characterisation
+ deliver the Ni-DS product ~ 1 FTE

IPNL : develop software et analyses ~ 5 FTE

APC /LPSC : radiation tests : 2015-2017 ~ 3 FTE

Full size Demonstrator with 4 representative Euclid detectors Tested in 2015
IN2P3 contribution in OUs

• External data and photo-z production (OU-EXT-OU-MER-OU-PHZ) (APC)
  • Preparation of photo-z catalogs, using the full chain of data and external data such as CFHT, DES, LSST (under agreement)

• Euclid image simulation (OUSIM) (CPPM, IPNL)
  • Co lead
  • Production of prototypes for NISP pixel simulator
  • Test and integration at SDC level
  • Preparation of data challenge
  • Performance validation

• NISP level 1 and 2 data (OUSIR and SPE) (IPNL, CPPM)
  • Co lead (new)
  • Development of calibration and feature extraction

• Level 3 (OULE3) (APC, CPPM, LPSC)
  • Production of tools for scientific analysis for the cluster analysis
  • Validation of catalogs
APC Arago center is a meso-center for pipeline development and is the software development platform for Euclid

CC-IN2P3 is the SDC- France and is in charge of the Euclid data production for France

Large increase of activities expected in 2016-2020

IN2P3 strongly supports the production of EUCLID data:
Agreement CNES and IN2P3 to produce the first data release (DR1=30% of data)
- French effort is monitored through an inter-organism committee (CIO) (CNRS, IRFU, CNES)

- French contribution is managed by a CNES project manager (R. Clédassou/CNES)

- CNES is providing the funding for all technical and SGS activities (AP, CDD) through conventions with CNRS and IRFU.

- Computing in France is provided by the CC-IN2P3 infrastructure and CNES CDD support ((K. Ganga/IN2P3, M. Poncet /CNES)

- Currently the estimation is of ~ 900 FTE for the investment (2012-2020), 80% CNRS/IRFU
The science is developed under science working groups SWG (~ 15 groups)
- The participation to SWG is based on the individual willing: Euclid members can propose to participate or to lead a work package (WP).
- The SWG Euclid groups WP lead are based on existing expertise: need to be an expert and to dedicate enough time to have a visibility!

Today, IN2P3 scientists are members in Clustering, Supernovae and CMB/clusters SWGs
IN2P3 is pushing to include SN in the cosmology probes too.

- There a deficit of French scientists in SWGs and of leads !!
Euclid French community has decided to promote a French Euclid coordination group to prepare a scientific roadmap and develop the French expertise. This is based on 3 science priorities:
  1- Cosmological probes: WL, Clustering, Clusters
  2. Combinaison of probes: in Euclid, but also with external data as CMB, SNe etc..
  3. Formation and galaxy evolution

The French group will present the roadmap and the scientific priorities to CNRS, CNES and IRFU. IN2P3 will participate strongly in point 1 and 2.
EUCLID

External data
Photometric redshifts needed for Euclid

• Weak Lensing: redshifts of $1.5 \times 10^9$ sources to
  - Slice the universe
  - Control contamination by intrinsic alignments of galaxies

• Redshifts of Euclid clusters: (60,000 clusters, 5,000 giant arcs)
  → synergy with Planck, Nika, and eROSITA

• Redshifts of sources and lenses: needed at least in the range $0.2 < z < 2$

→ Photo-z needed with VIS+NIR data
Ground based imaging data for photo-z

Current best options:

- South:
  DES (5000 deg²), LSST

- North:
  CFHT: 2-3 bands ?
  proposal in progress
  WHT: William-Hershel telescope
  1-2 band

(Es-PAU proposal)

Subaru?

LSST+EUCLID
photo-z, SEDs for PSF, source identification, classification, many complementarities
need official agreement
• ESA has selected the only space mission dedicated to understand the acceleration of the expansion of the Universe.

• Euclid is a large consortium (more than 1000 members!) where France takes the leadership.

• Euclid includes a strong contribution of all national agencies IN2P3, INSU, IRFU and is supported by the space agency CNES making France the biggest contributor to the mission.

• Euclid has finalized the conceptual and design phases and start to build the instruments.

• IN2P3 contribution is based on the expertise of the institute on detectors and on data processing and provide support and large computing infrastructure used in particle physics.

The science preparation is starting and need to build a strong expertise and a good organisation prior to the launch.
Euclid and LSST = fantastic projects for the next generation of scientists

We need to prepare the scientific return of such an investment by building the scientific expertise of the next generation

This is mandatory to be prepared to explore DE in the next decade
SPARES
Curvature from radial & transverse BAO

$w(z)$ from SN-Ia, BAO directly (and contained in most other probes)

In addition 5 quantities, e.g. $\phi$, $\psi$, bias, $\delta_m$, $V_m$

Need 3 probes (since 2 cons eq for DM)
e.g. 3 power spectra: lensing, galaxy, velocity

Lensing probes $\phi + \psi$

Velocity probes $\psi$ (z-space distortions?)

And galaxy $P(k)$ then gives bias

($\rightarrow$ Euclid 😊)
Assuming:

- DE equation of state: \( \frac{P}{\rho} = w \), and \( w(a) = w_p + w_a(a_p - a) \)
- Growth rate of structure formation: \( f \sim \Omega \gamma \)
- **Nature of dark energy**
  - Distinguish effects of \( \Lambda \) and dynamical DE: Measure \( w(a) \rightarrow \) slices in redshift
  - From Euclid data alone, get \( \text{FoM} = 1/(\Delta w_a \times \Delta w_p) > 400 \rightarrow \sim 1\% \) precision on w’s.
    \( \rightarrow \) if data consistent with \( \Lambda \), and \( \text{FoM} > 400 \) : \( \Lambda \) favoured with odds of more than 100:1 = a “decisive” statistical evidence.
- **Nature of gravity on cosmological scales**
  - Probe growth of structure \( \rightarrow \) slices in redshift ,
  - Separately constrain the metrics potentials \( (\Psi, \Phi) \) as function of scale and time
  - Distinguish effects of GR from MG models with very high confidence level:
    \( \rightarrow \) absolute 1-\( \sigma \) of 0.02 on the growth index, \( \gamma \), from Euclid data alone.
    \( \rightarrow \) WL and RSD are differently sensitive to \( \Psi, \Phi \): \( \Psi + \Phi \) (WL); \( \Phi \) (GC, RSD)
Challenges of Euclid

• **EC Management**: 1250 persons, 120 labs, 14 countries:
• **Data management and processing**: huge volume, multi-wavelength data, ground + space, NIR+VIS, 10 SDCs, archive → data, algorithm and hardware challenges
• **Shape measurements/systematics**
  • Control multiplicative and additive biases, shape measurement algorithms
• **Photometric redshifts**:
  • Ground based photometry in 4 bands: 15,000 deg$^2$ (i.e. north and south)
• **Numerical simulations** with power spectrum to a 1% accuracy:
  • Underlying physics: e.g. numerical simulations with baryons
  • Numerical simulations of a large number of DE, GR models
  • $10^3$ to $10^5$ simulations to estimate covariance matrices

• **End-to-End performances**
• **Spectroscopic surveys to**:
  • Calibrate deep photo-z and understand BAO and RSD samples
next generation wide field cosmic shear surveys
GR: evolution of Universe contents of Universe

\[ \Omega_b = 4.92 \pm 0.13\% \]

Planck 2015 what makes up 95% of the Universe?!
3D mapping of the position of galaxies

Distribution of galaxies (SDSS)

Size of the Horizon: mass-radiation equilibrium

non-gaussian initial fluctuations

Dark Energy: Baryonic Acoustic Oscillation

Dark Matter Warm Cold

Neutrinos Masses

Galaxy halo occupation distribution (HOD)

Growth of structure

A refaire
Ultimately…need to combine all probes….
A worldwide synergy

[Diagram with various labels and connections, including MSE, MOONS, PFS, 4MOST, DESI, Euclid Tel., DES, CFHT, LSST, GAIA, Virtual Universes, Planck, eROSITA, ESA Euclid Tel. archive, + national SDCs, processing + EC archive, Euclid Core, EuclidSurvey, JWST, ALMA, E-ELT, Targets, MSE, SKA.]
Euclid+ground: photo-z of 1.5 billion galaxies

Critical: need ground based imaging over 15,000 deg$^2$ in 4 bands

Requirements:
- get photo-z for ~all WL galaxies
- cover the whole Euclid sky (15000 deg$^2$)
- accuracy = 0.05x(1+z)

$\rightarrow$ 4 optical bands needed

Visible data obtained from ground based telescopes