EUCLID

Mapping the geometry
of the dark Universe

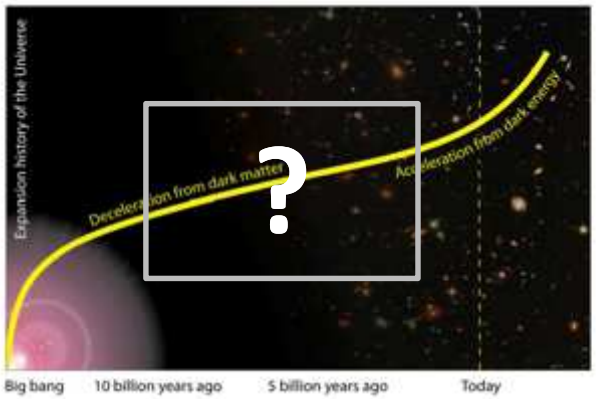
Conseil scientifique IN2P3

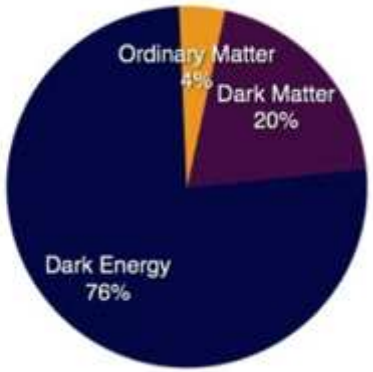
22 Octobre 2015

A.Ealet (CPPM/IN2P3)

Euclid : the objectives

- 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 ΛCDM

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

=> *Observations of both expension 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

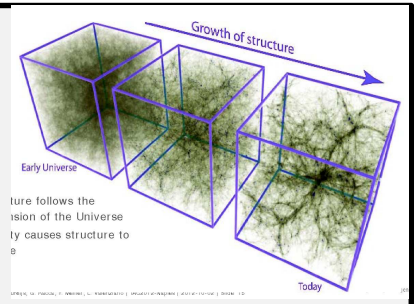
⇒ Control systematical errors using space advantages :

- ⇒ High image quality
- ⇒ High PSF stability
- ⇒ Infrared access (high redshift)
- ⇒ Low sky background

⇒ Need large simulation of structure formation with different

Main cosmological probes in Euclid

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

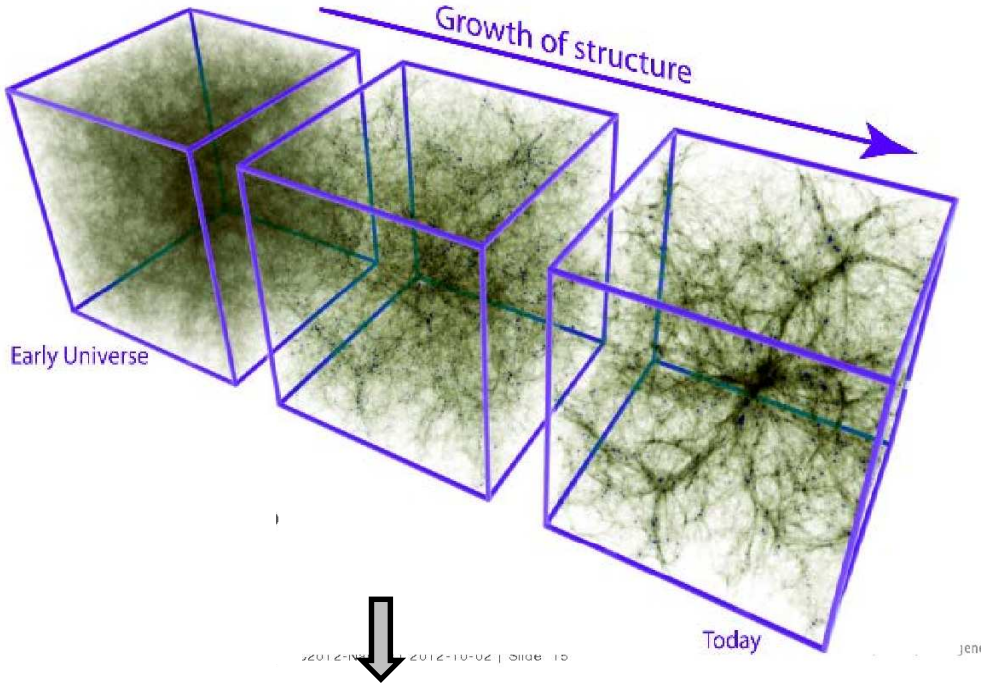
Primary: Galaxy Clustering: BAO + RSD

Euclid Consortium

3-D position measurements
of galaxies over 0.9<z<2

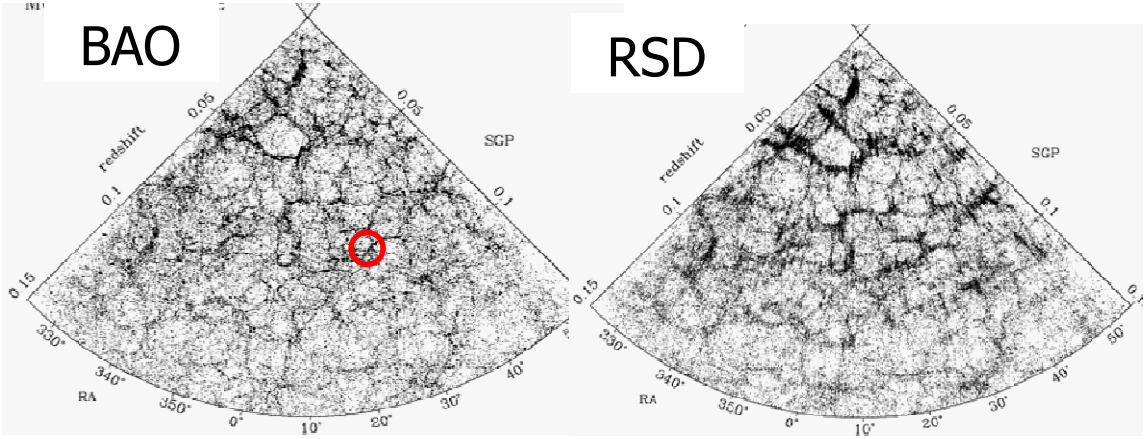
- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); ψ, $H(z)$.

- Need high precision 3-D distribution of galaxies with spectroscopic redshifts.

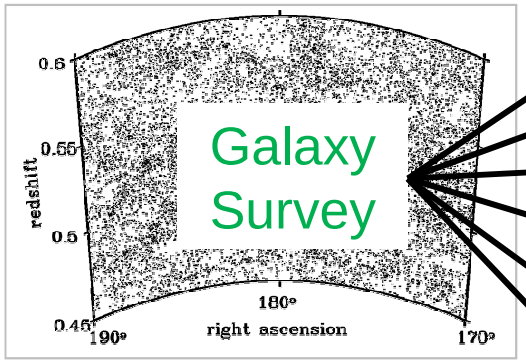


Euclid:

50 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg^2



Primary probe 1: Euclid Redshift Survey



Baryon Acoustic Oscillations → What is the expansion rate of the Universe?

Alcock-Paczynski effect → What is the expansion rate of the Universe?

Redshift-Space Distortions → How does structure form within this background?

Comoving clustering → What are the neutrino masses, matter density?

Large-scale shape → What is f_{nl}, which quantifies non-Gaussianity? GR-horizon effects

ISW effect → Does the potential change along line-of-sight to CMB

Understanding Dark Energy

Understanding energy-density, gravity

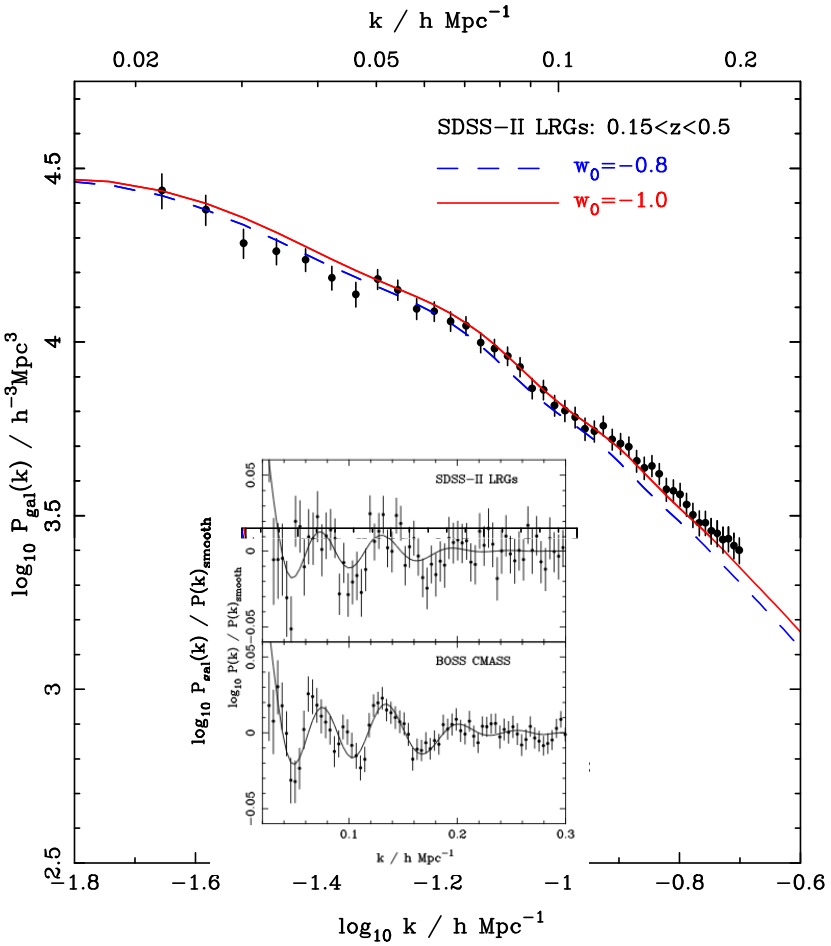
Understanding energy-density

Understanding Inflation, GR

Understanding DE, GR

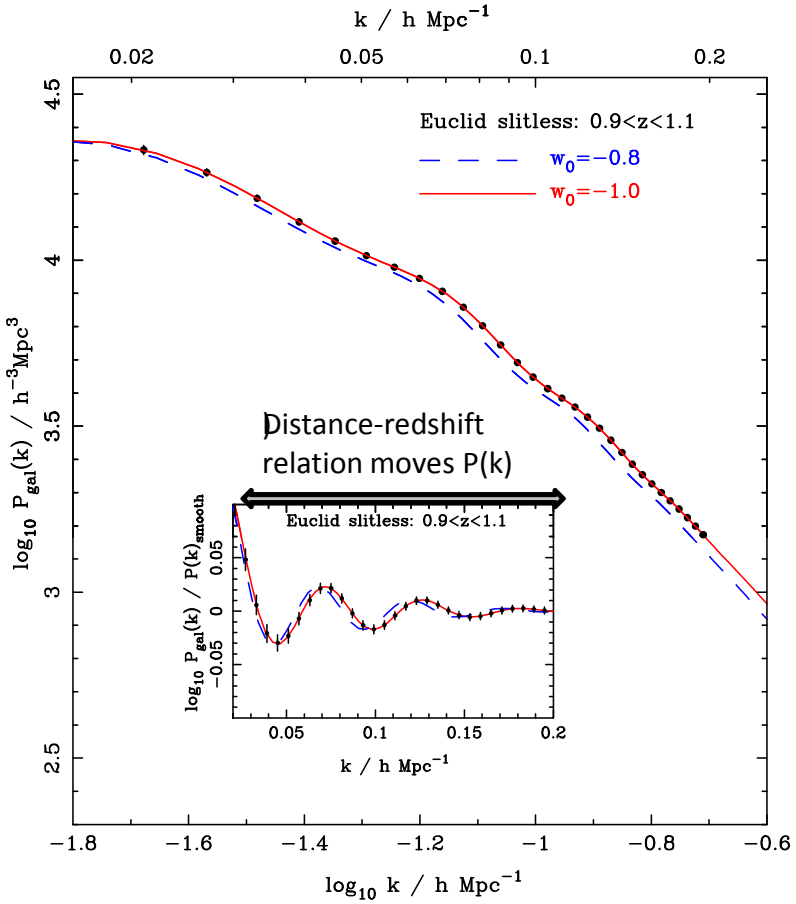
The galaxy power spectrum : SDSS / forcast

Euclid Consortium



SDSS (BOSS) today

0.15<z<0.5

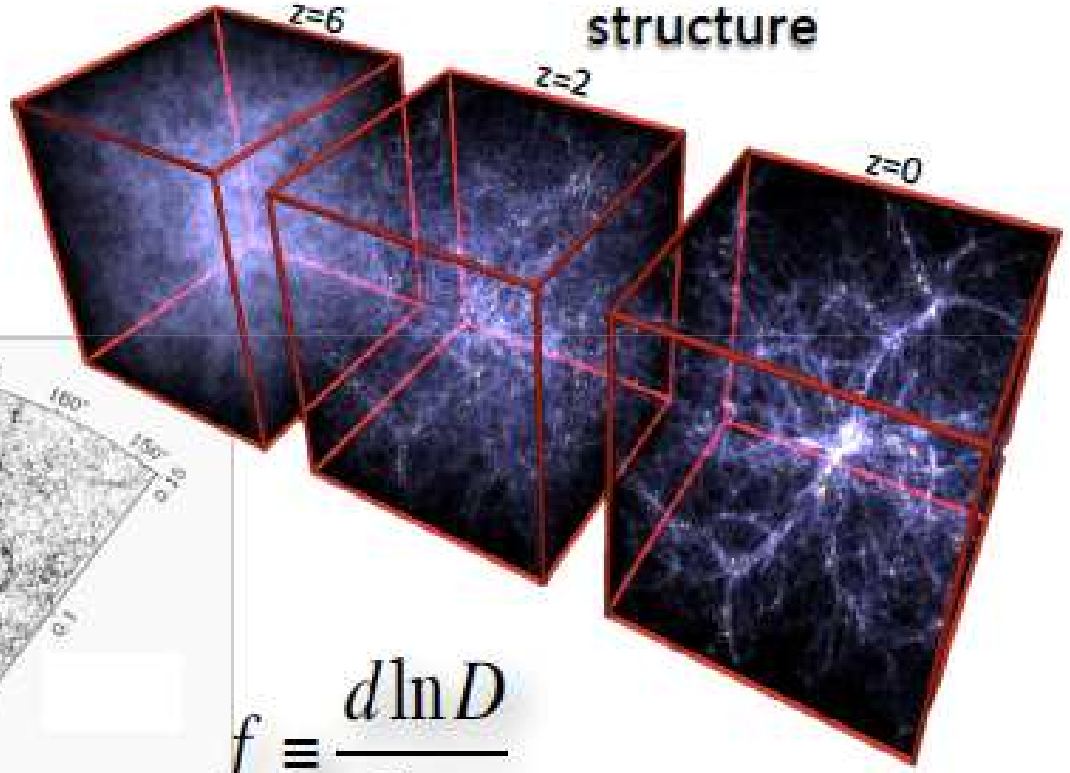


EUCLID expected

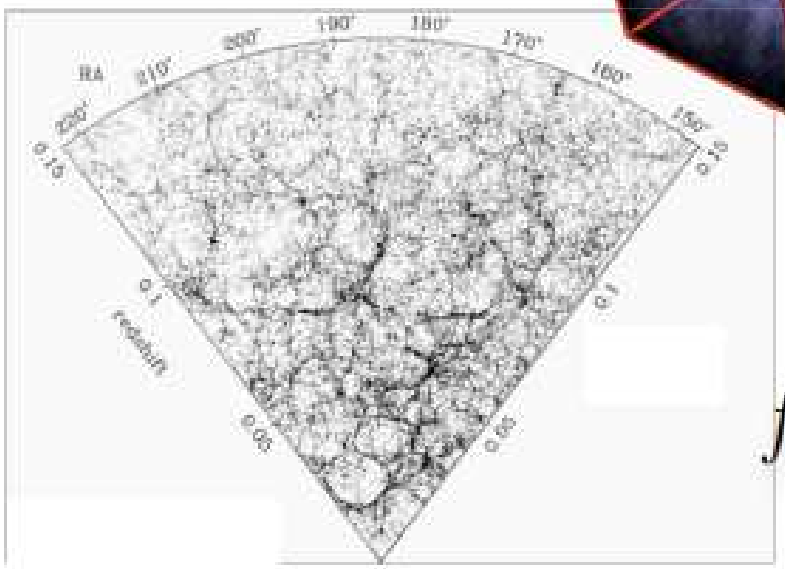
One of the 5 redshift slice (0,9<z<2)

Redshift space distorsion

Probing the growth rate of structure



Real space



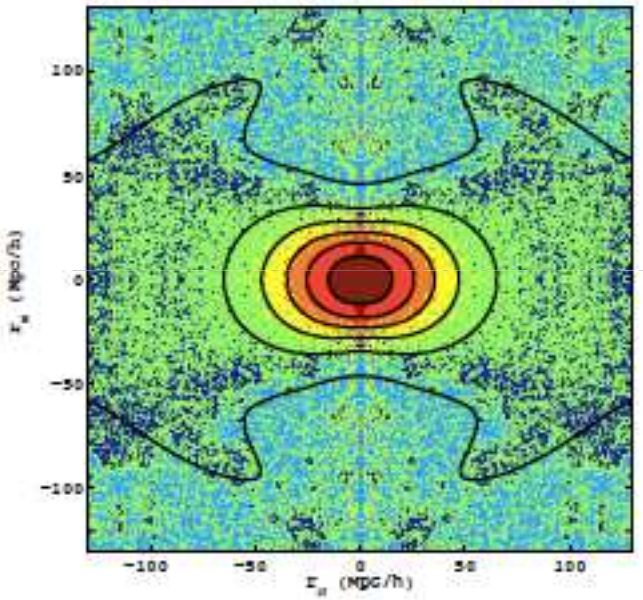
$$f \equiv \frac{d\ln D}{d\ln a}$$

(Credit: V. Springel)

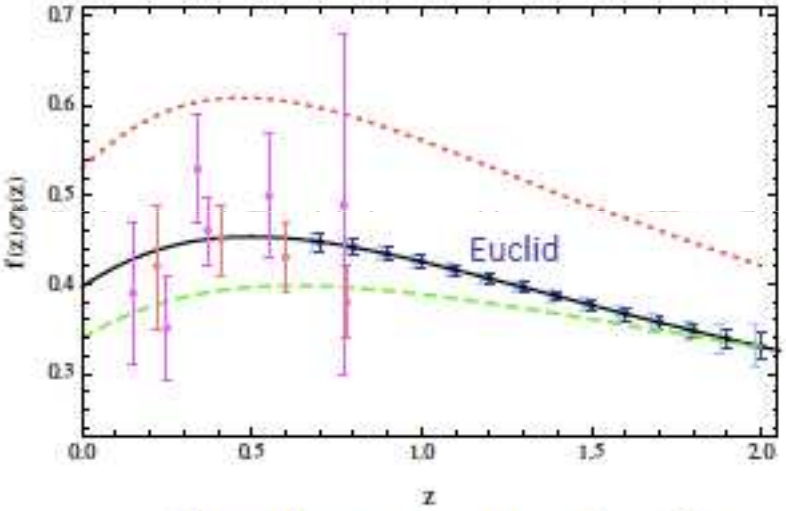
Beyond BAO

RSD constraints modified gravity

Current and EUCLID measurements of the growth rate *f*



(BOSS, Reid et al. 2012)

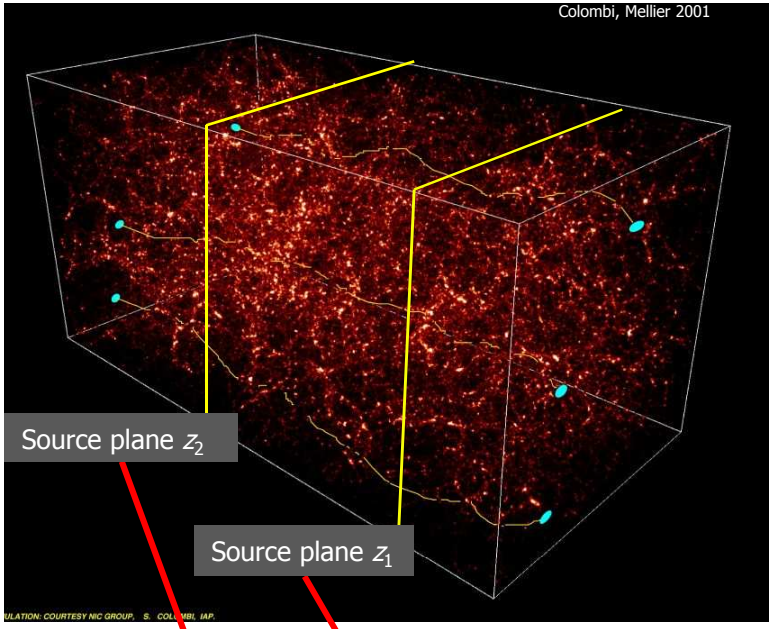


(EUCLID forecast, Majerotto et al. 2012)

Primary probe 2: Weak Lensing

Cosmic shear over 0<z<2

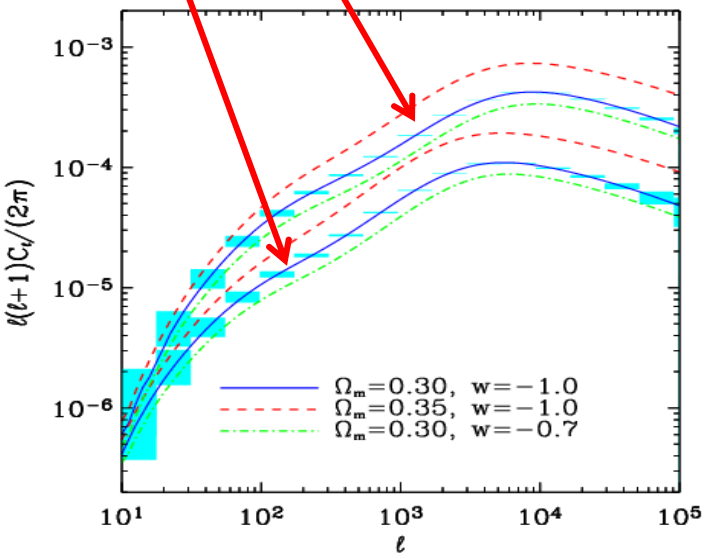
$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega}\frac{f_K(\omega-\omega')\,f_K(\omega')}{f_K(\omega)}\frac{\delta\left[f_K(\omega')\,\boldsymbol{\theta};\omega'\right]}{a(\omega')}\mathrm{d}\omega'$$



•Probes distribution of matter (Dark +Luminous): expansion history, lensing potential φ+ψ.

→ Shapes+distance of galaxies: shear amplitude, and bin the Universe into slices.

→ "Photometric redshifts" sufficient for distances: optical+NIR data.

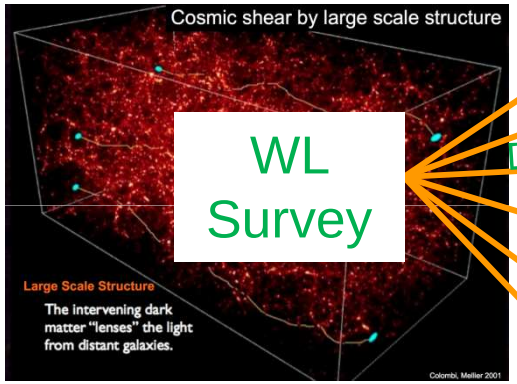


Euclid:

WL with 1.5 billion galaxies over 15,000 deg^2

Cosmology Weak Lensing survey

Euclid Consortium



DM power spectrum, tomography

Peak stat, Clusters Mass Func

DM power spectrum, tomogr

DM power spectrum

3-pt statistics , Halos

ISW effect

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

Understanding Dark Energy

Understanding energy-density, gravity

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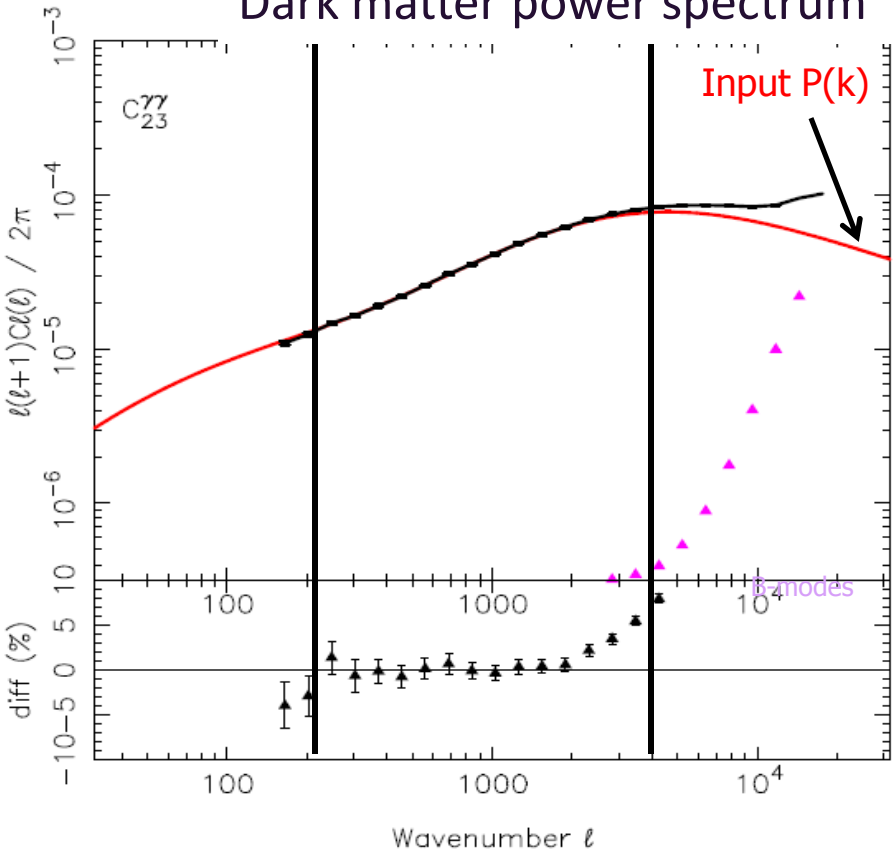
Understanding DE, GR

Euclid: Combining WL and GC data

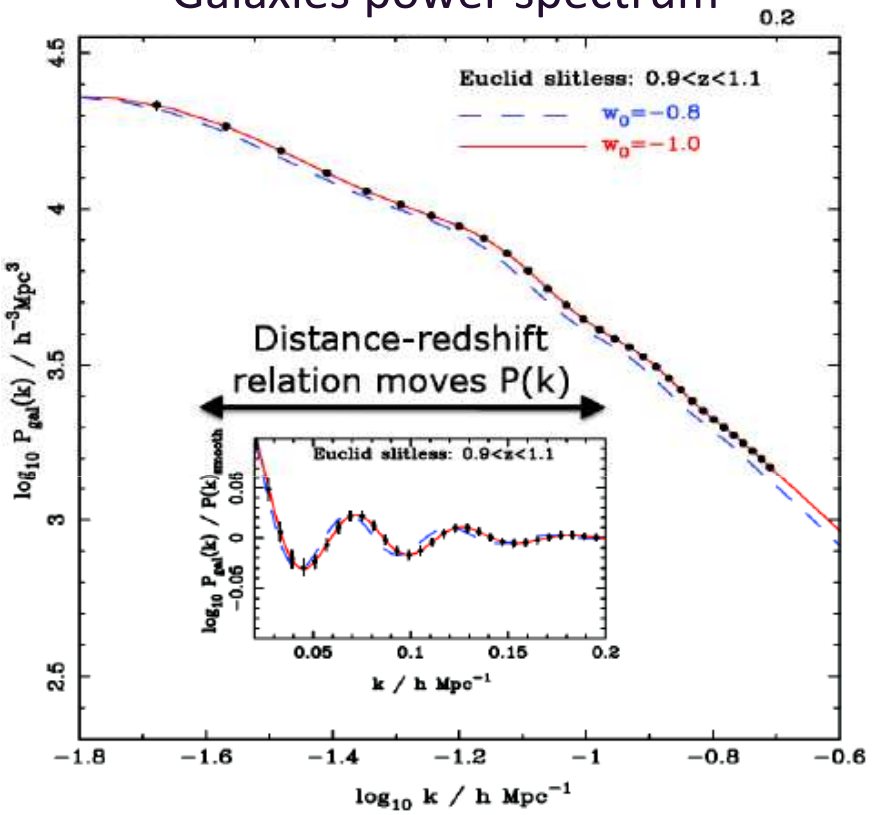
Euclid Consortium

Dark matter power spectrum



- 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% .

Galaxies power spectrum



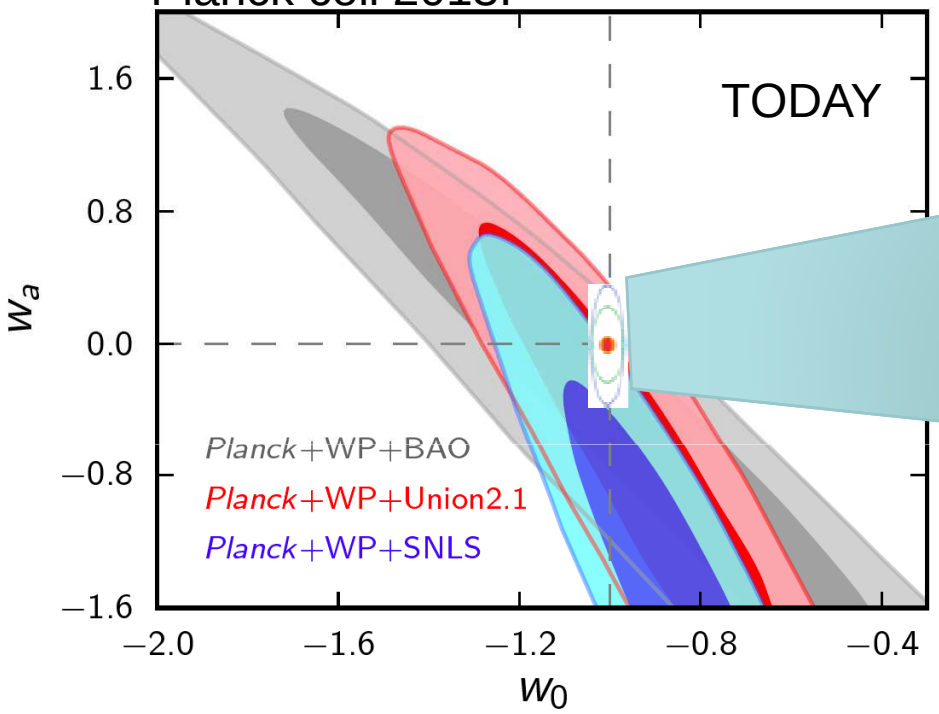
- $V_{eff} \approx 19\ h^{-3}\ Gpc^3 \approx$ 75x larger than SDSS
- Redshifts 0.9<z<1.9

- Percentage difference [*expected* – *measured*] power spectrum: recovered to 1% .

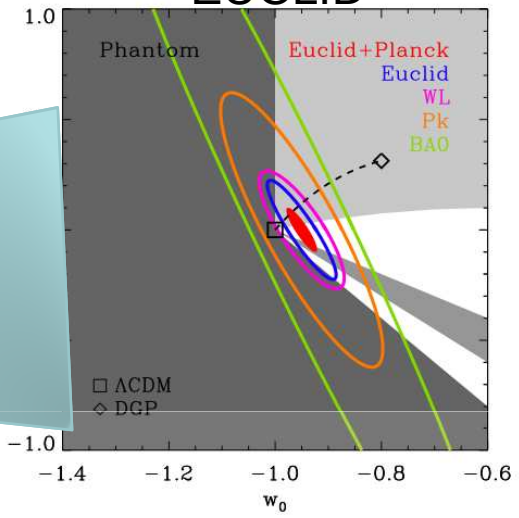
Combining probes for Dark Energy

Euclid Consortium

Planck coll 2013.

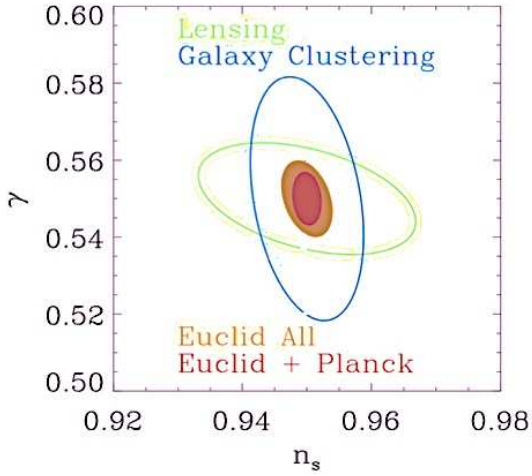


EUCLID



$f \sim \Omega^{\gamma}$; $\gamma = 0.55$? As predicted by GR

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



EUCLID forcasts…

Euclid Consortium

Assume systematic errors are under control

Ref: Euclid RB arXiv: 1110.3193	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	**FoM** $=1/(\Delta w_p \times \Delta w_a)$
Euclid primary(WL+GC)	0.010	0.027	5.5	0.015	0.150	430
EuclidAll (clusters,ISW)	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	6000
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

- DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$
- Growth rate of structure formation: $f \sim \Omega^\gamma$;
- From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p) > 400$ → ~1% precision on w's.

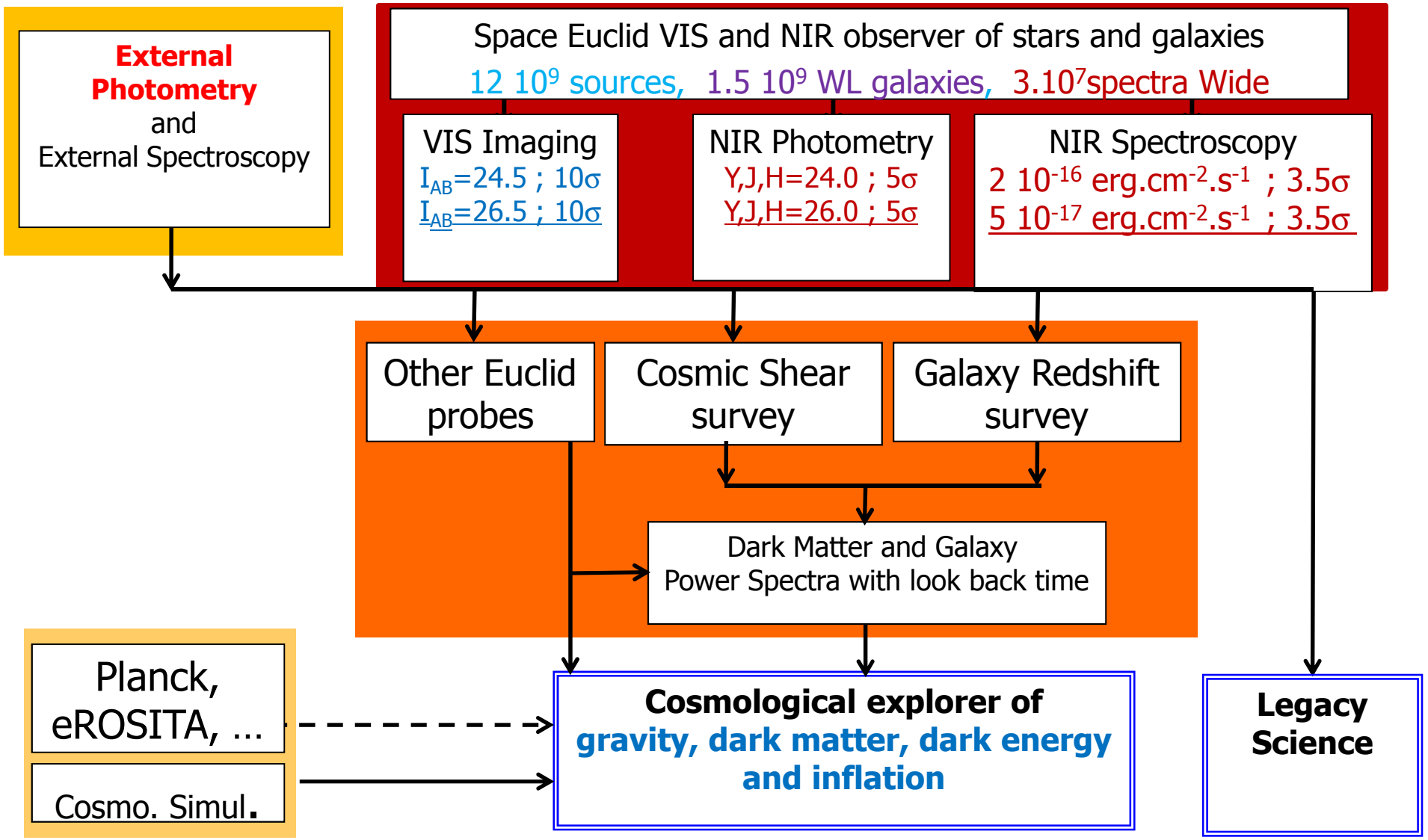
7 Ade et al. (2013), these combined probes
produce an upper limit Pm < 0.23 eV (95% confidence) when assuming zero curvatur
Anne Ealet; 30/05/2013

EUCLID

The mission

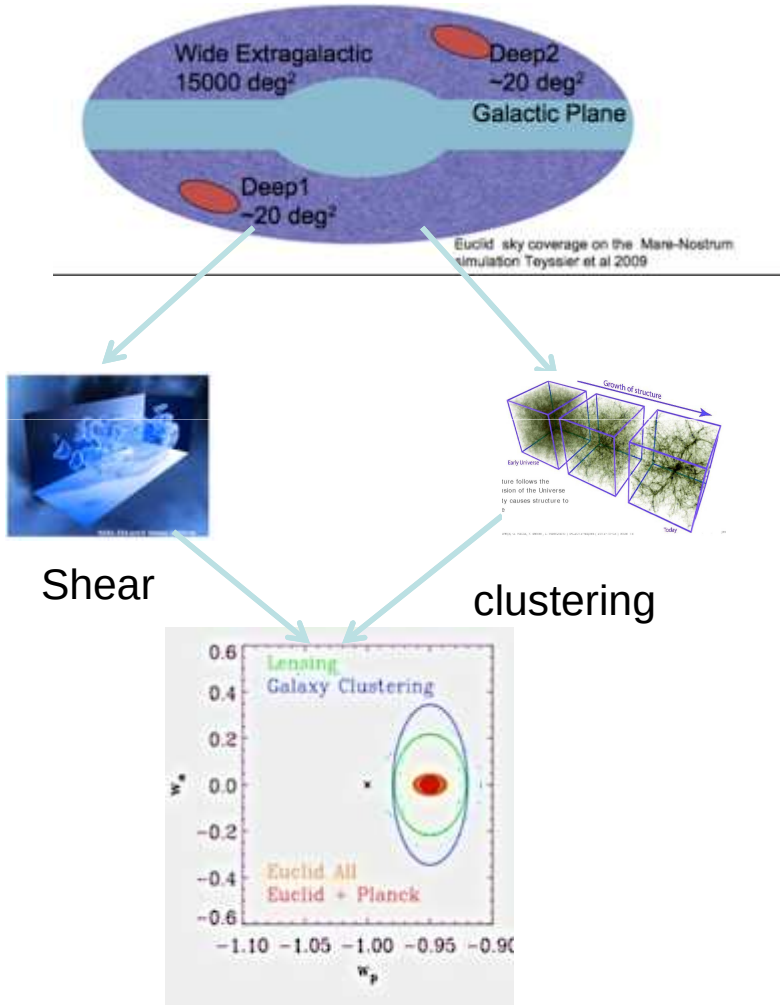
Euclid Survey Machine: 15,000 deg^2 + 40 deg^2 deep

Euclid Consortium



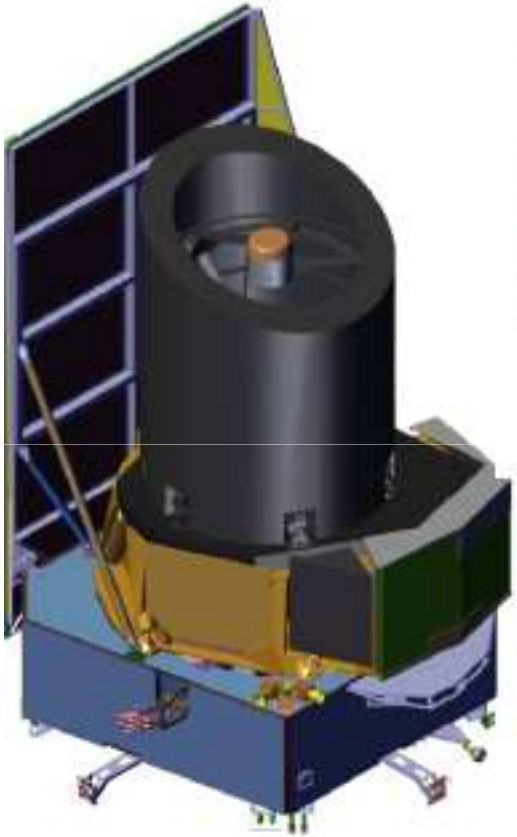
Euclid: an ESA space mission

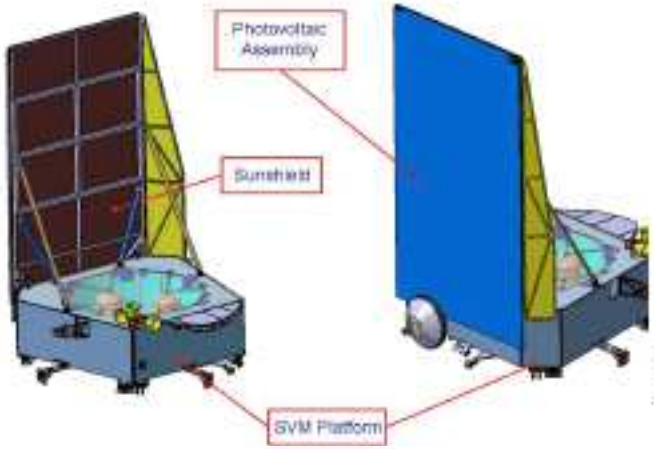
- Euclid is an ESA mission with a strong scientific consortium
- ESA provides the telescope and detectors (via industry), the satellite, launch and operation centers
- Countries provide the 2 instruments (VIS and NISP) and the ground segment (SGS)
- Euclid will do a wide survey of 15000 deg2 and a deep survey of 40 deg2

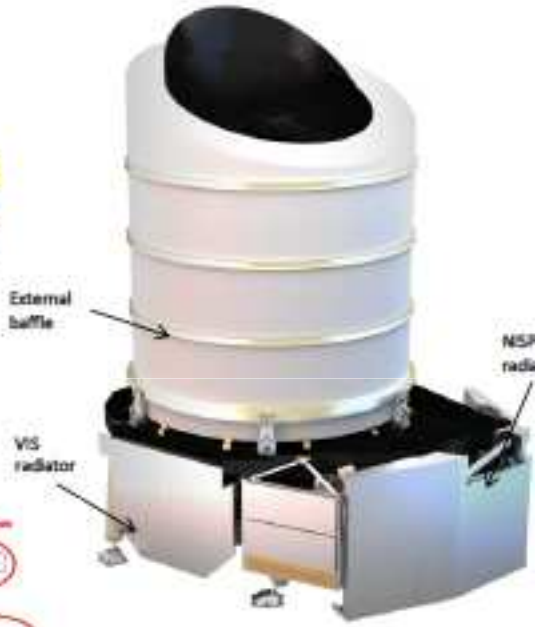


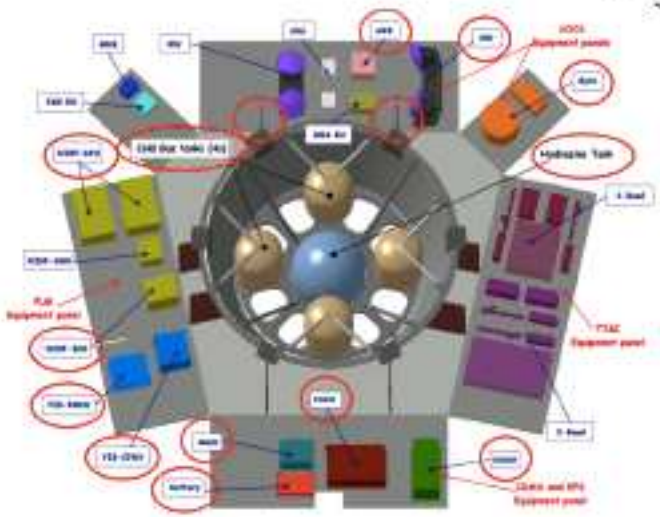
Euclid – Spacecraft Configuration

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









- Télescope 1,2 m: FoV: 0.54 deg^2
- Miror in Silicon Carbide= ultra-stable:

Temp.: -150 deg. Stability +:- 0.05 deg.

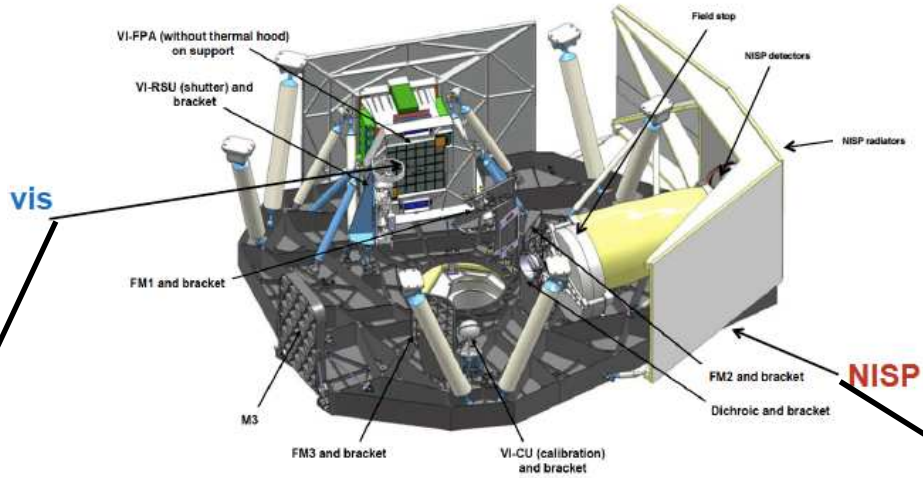
- Total mass satellite :

2 200 kg

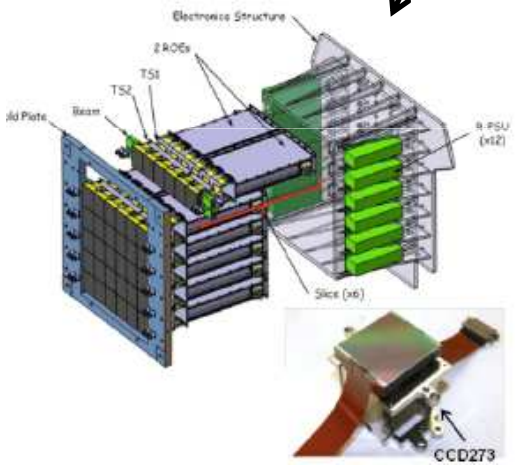
- Dimensions

4,5 m x 3m x 3 m

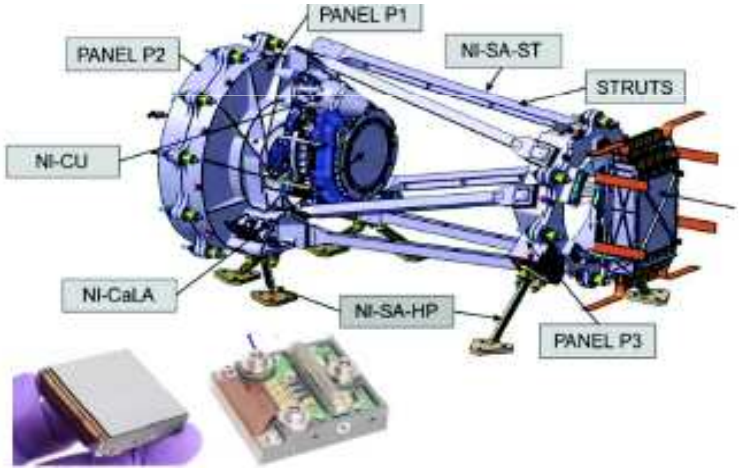
The instruments



Common VIS and NIR FoV = 0.54 deg²



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



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 Ground segment

- 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 adequat format
  - ✓ Simulations
  - ✓ Produce data catalogs to be delivered to the community
- The final interpretation and cosmological analysis is under the responsability 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

les OUS et les SDC

SDC : infrastructure for pipeline, production
Ous : (organizational Unit): prototypes of algorithms

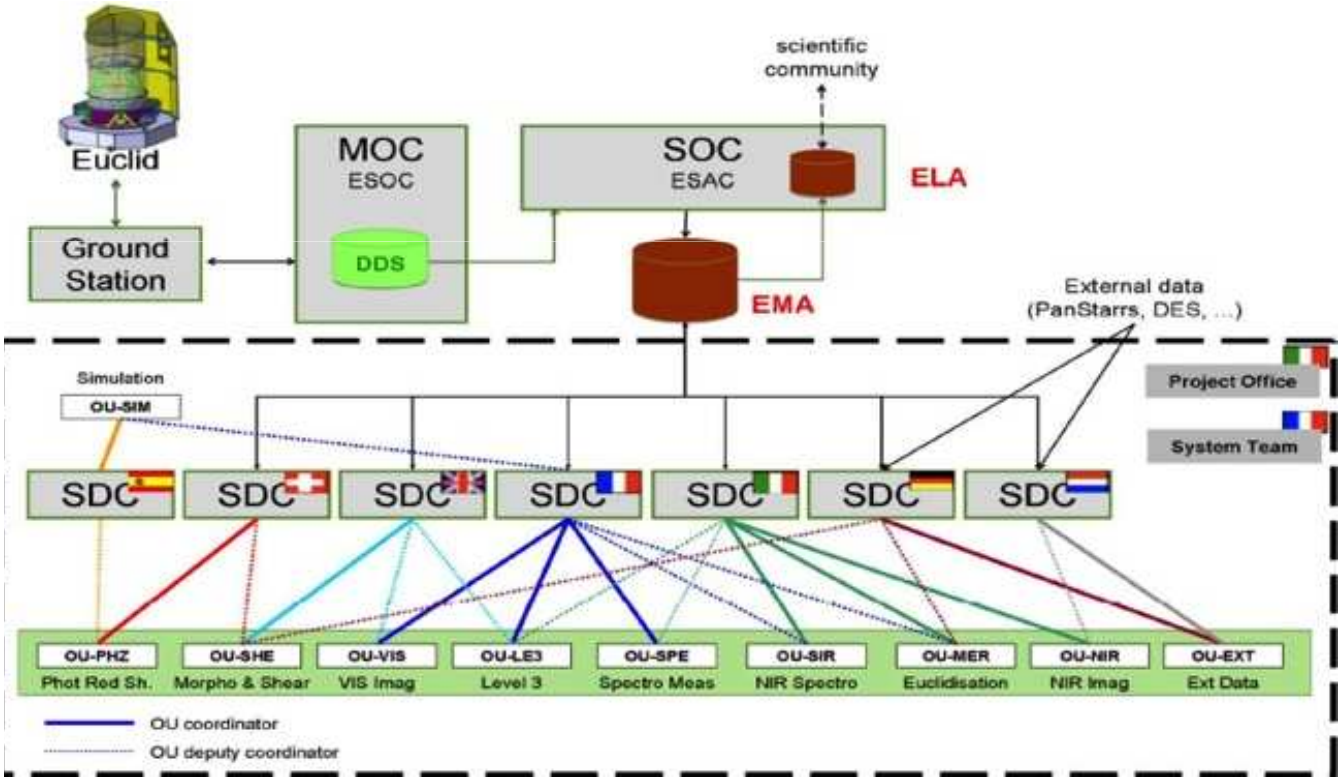
Complex organisation:

- 10 Organisation Units
- 7 Science Data Centers
- Data centric processing architecture and archive/ distribution

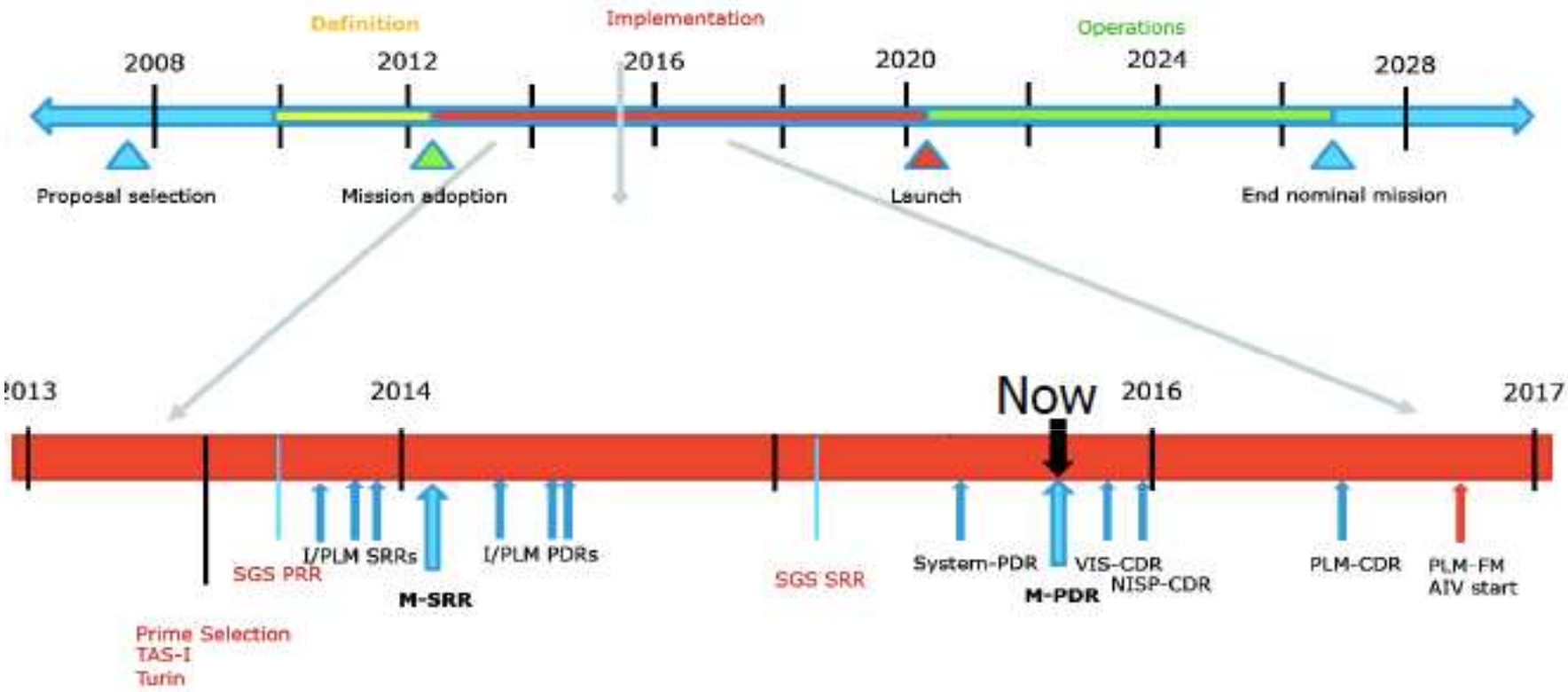
Data: huge volumes, heterogeneous data sets

- VIS+NIR imagery and morphometry, photometry , spectroscopy
- data from ground and space
- >30 Pbytes
- 1+ million big images
- > 10^{10} sources (>3-sigmas)

Cost SGS: 50% of Euclid Consortium contributions.



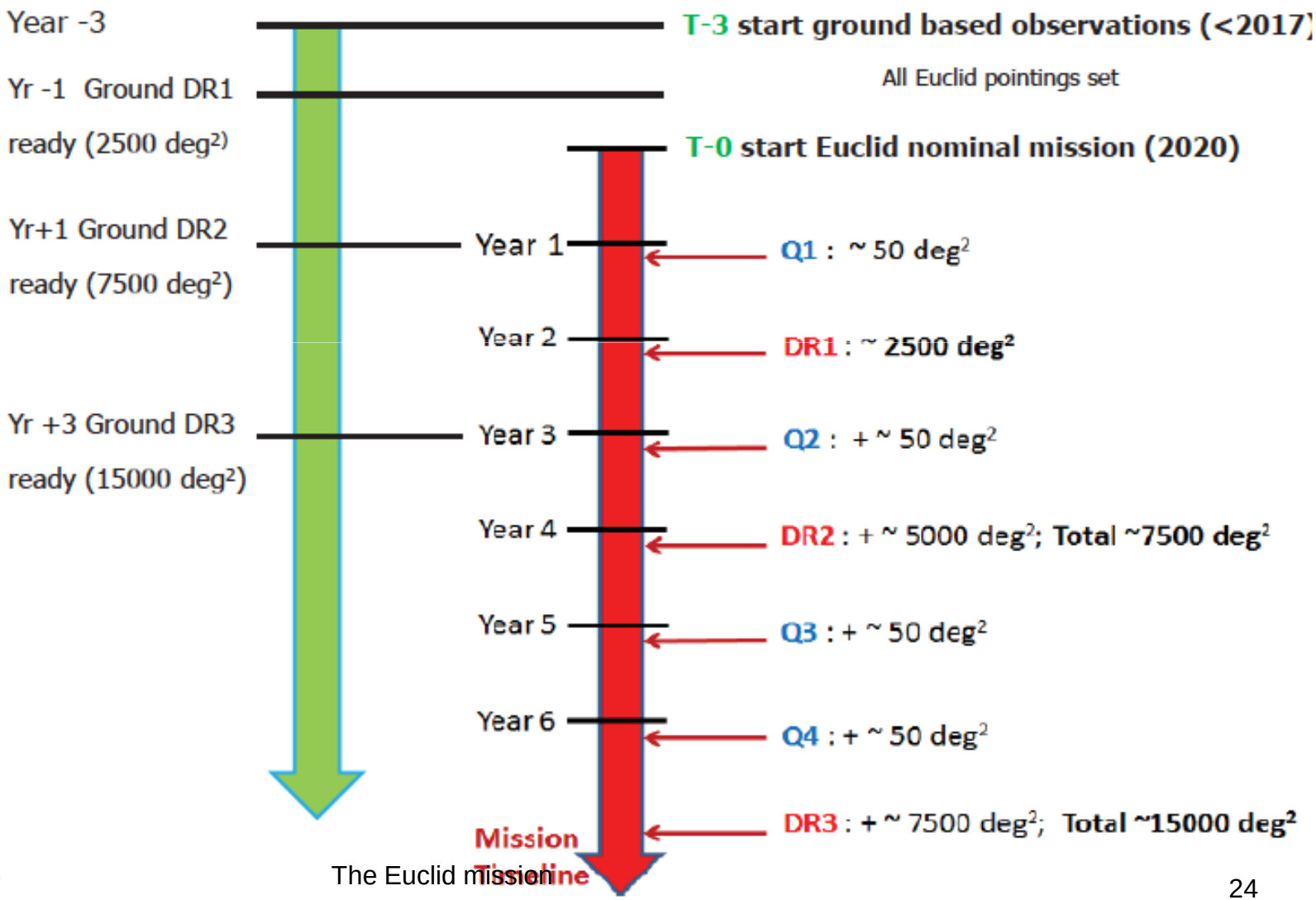
Euclid schedule



The mission PDR has just end up. No major issues. CDR expected in 2016.

Schedule for data release

Ground based + Euclid imaging data: plans



Euclid : The organisation

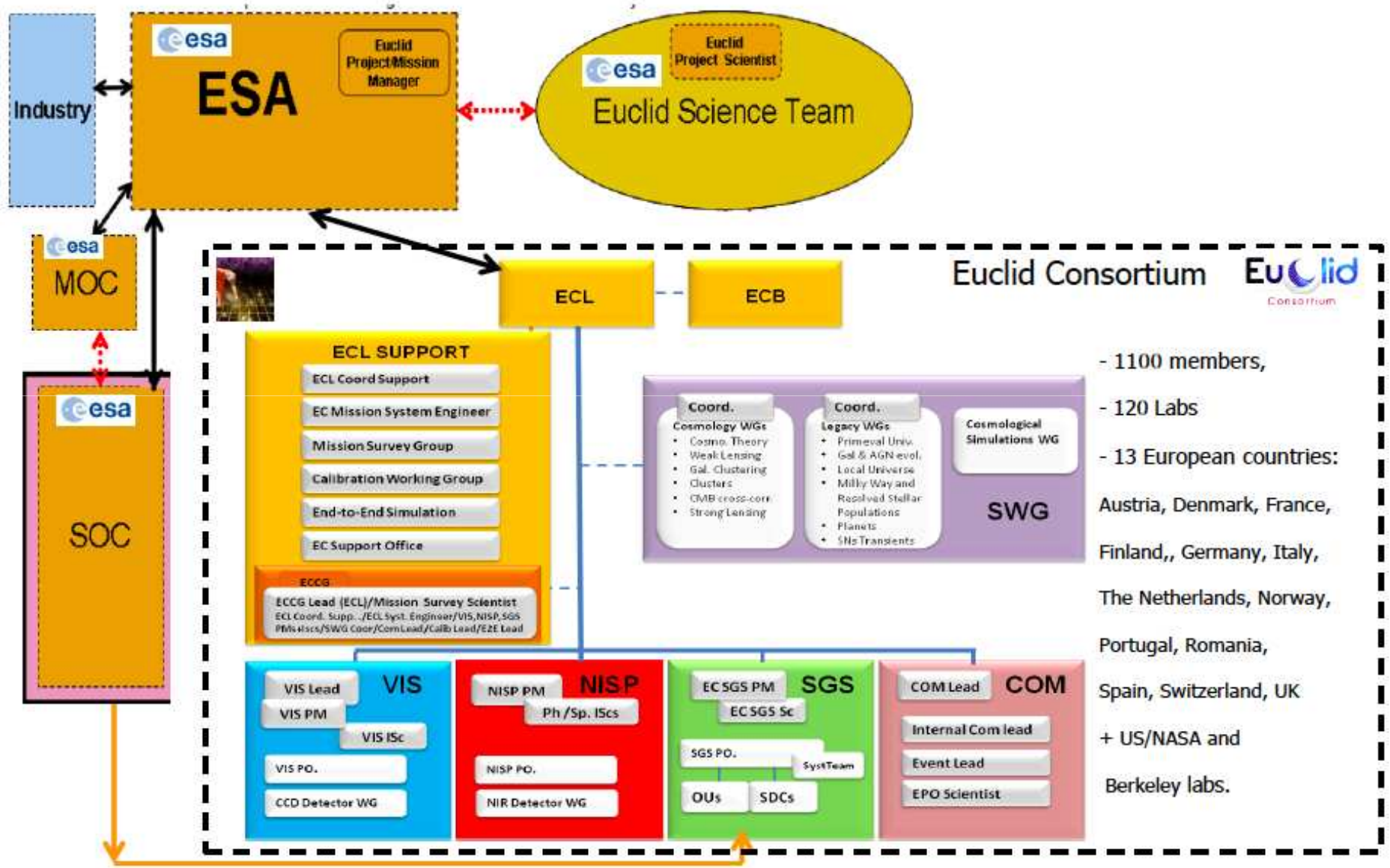
The scientific consortium : 120 laboratories, > 1200 members

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

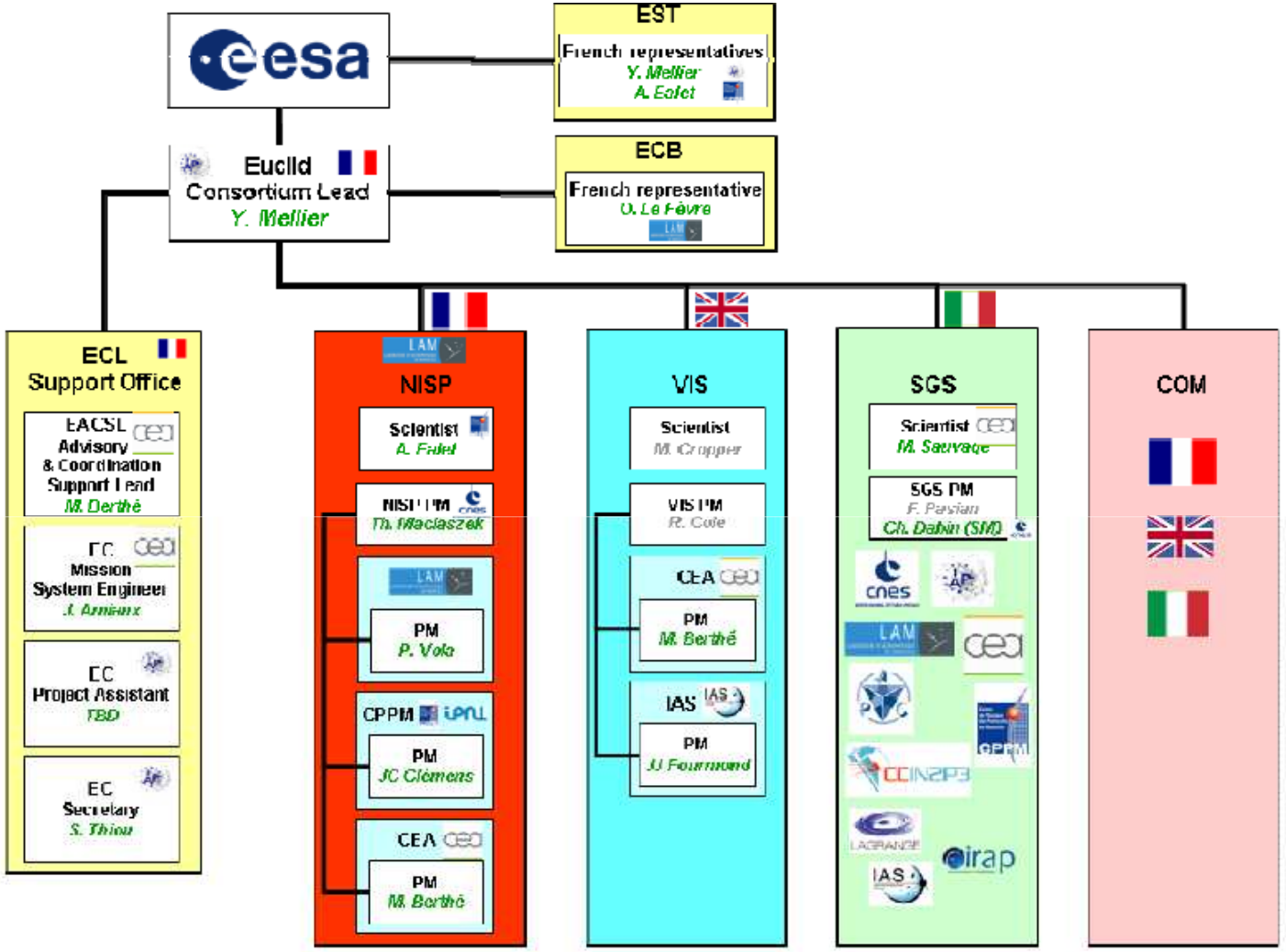
- Very high level of responsabilities:
  - ✓ Lead consortium (Y.Mellier, INSU)
  - ✓ EST ,ECB members (Y.Mellier, O.Le fevre, A,Ealet)
  - ✓ Lead NISP instrument (CNES,INSU,IN2P3)
  - ✓ Lead of VIS focal plan (IRFU)
  - ✓ Scientist of the ground sgment (IRFU)
  - ✓ Lead of the SGS system team (CNES)
- More than 10 laboratories
  - ✓ INSU: IAP, IAS, LAM, IRAP, Lagrange
  - ✓ IN2P3: APC, CPPM, IPNL, LPSC, LPNHE
  - ✓ IRFU
  - ✓ CC IN2P3

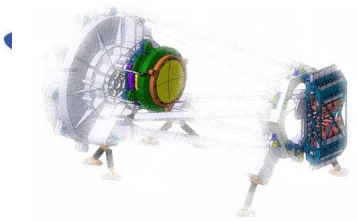
- A strong CNES support and participation

Euclid: organisation



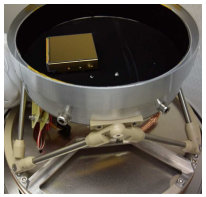
French Responsabilities

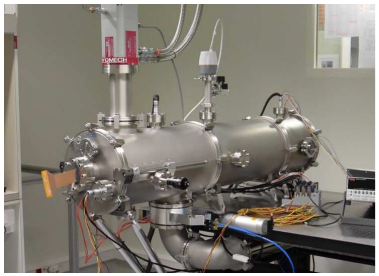




NISP focal plan : IN2P3 contribution

Euclid Consortium





-NISP Instrument scientist (A.Ealet/CPPM)
-NISP Detector scientist (R.Barbier/IPNL)

IN2P3 responsabilities:

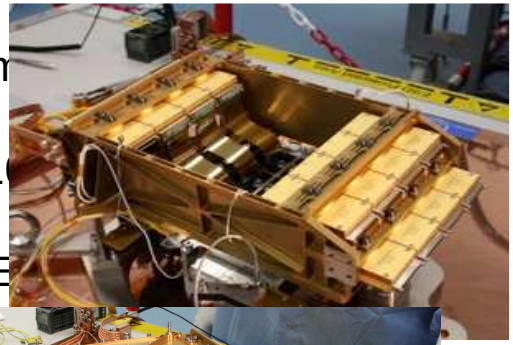
TELEDYN

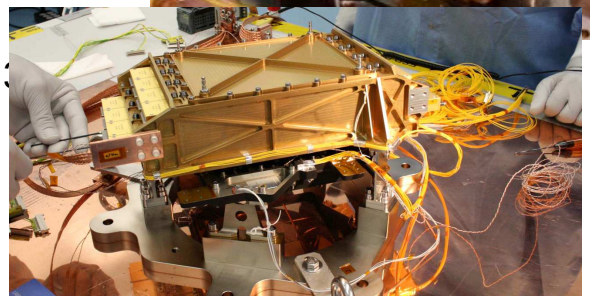
- Reception of the 16 flight detectors from NASA (CNES/CPPM)
- Characterisation (CPPM /IPNL)
- Radiation tests (APC/LPSC)
- Integration and test of the full focal plan (NI-DS) (CPPM)

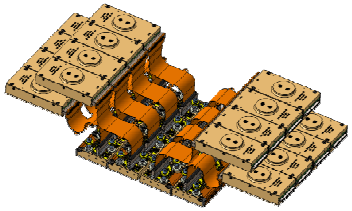
CPPM : develop test facilities for flight detectors reception (clean room
+ do the detector characterisation
+ deliver the Ni-DS product ~ 1

IPNL : develop software et analyses ~ 5 FTE

APC /LPSC : radiation tests : 2015-2017 ~







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

~ 20 FTE In2P3
Included scientists

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

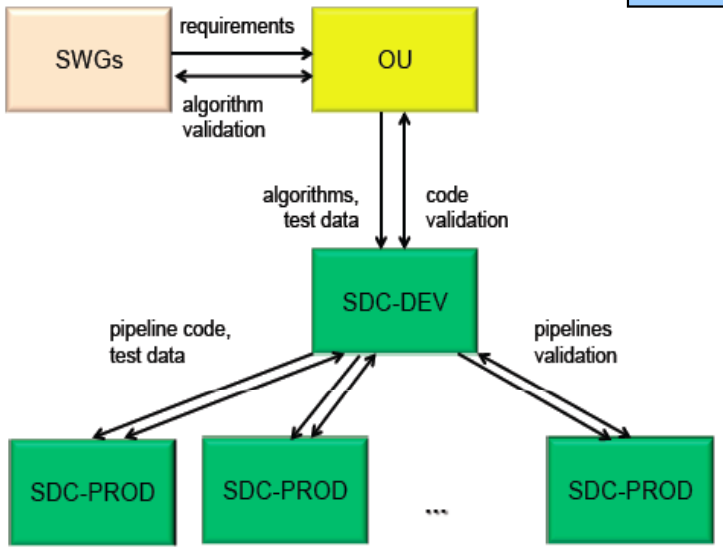
- Level 3 (OULE3) (APC,CPPM, LPSC)
  - Production of tools for scientific analysis for the cluster analysis
  - Validation of catalogs

SDC France and CC-IN2P3

Euclid Consortium

SDC-FR (K.Ganga (IN2P3) /M.Poncet CNES)

SDC-DEV (APC)	SDC-PROD (CCIN2P3)



APC Arago center is a meso-center for pipeline development and is the software development platform for Euclid

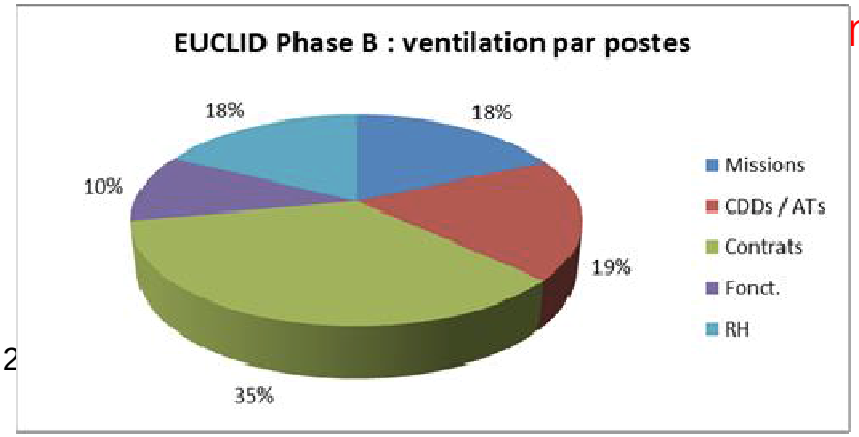
CC-IN2P3 is the SDC- France and is in charge of the Euclid data production for France

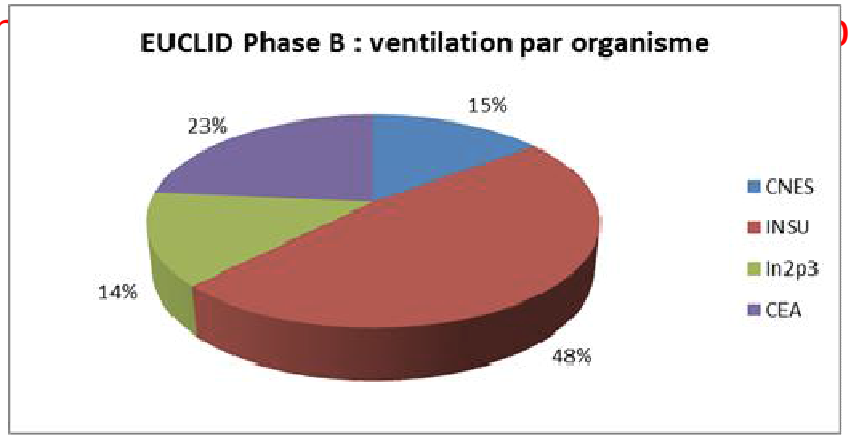
Large increase of activities expected in 2016-2020

IN2P3 strongly supports the production of EUCLID data :
Agreement CNES and IN2P3 to produce the first data release (DR1=30% of data)

The French organisation

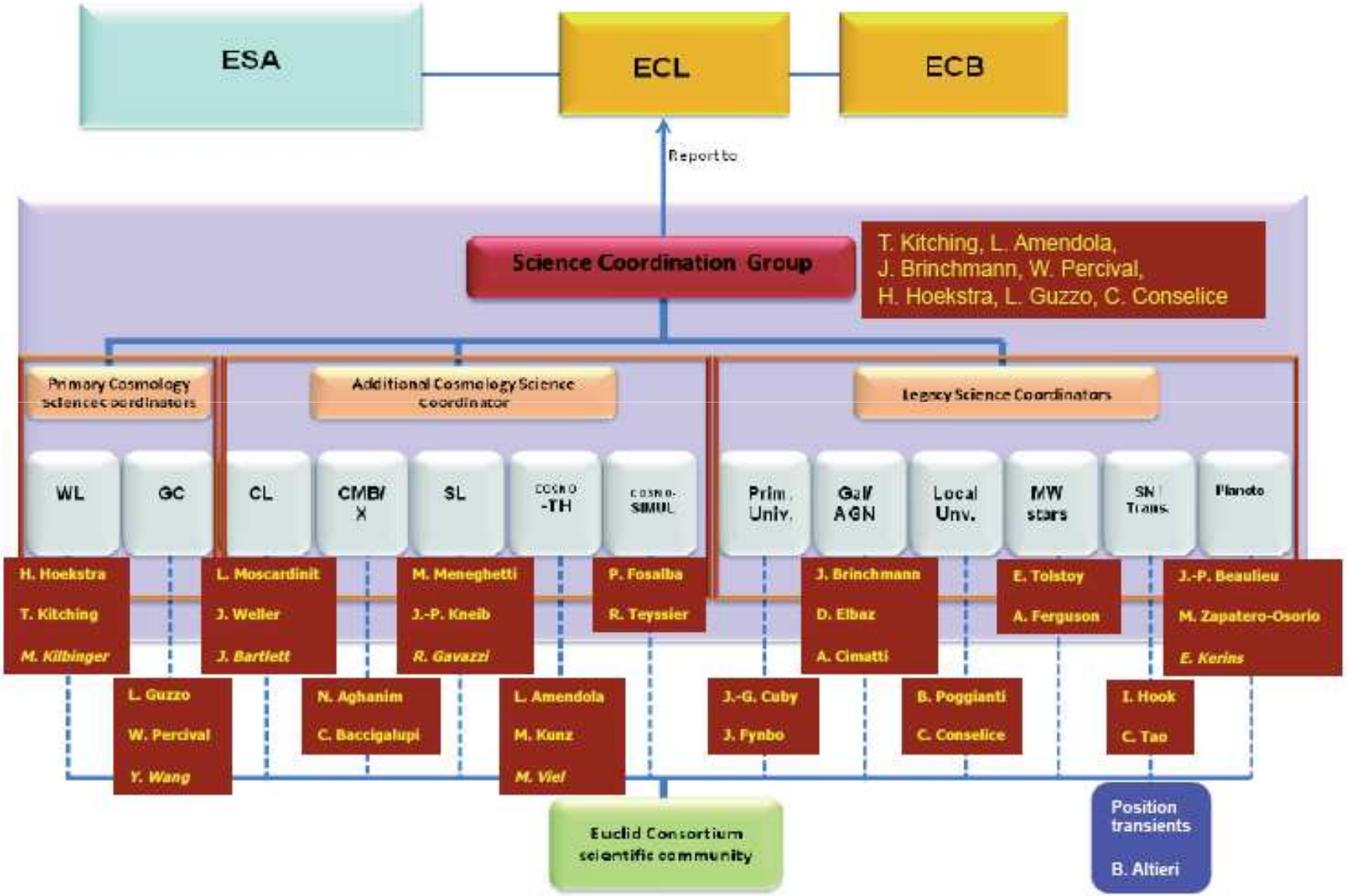
- French effort is monitored through an inter-organism committee (CIO) (CNRS,IRFU,CNES)
- French contribution is managed by a CNES project manager (R.Clédassou/CNES)
- CNES is providing the funding for all technical and SGS activities (AP, CDD) through conventions with CNRS and IRFU .
- Computing in France is provided by the CC-IN2P3 infrastructure and CNES CDD support ((K.Ganga/IN2P3, M.Poncet /CNES)
- Currenly the estimation is of ~ 900 FTE for the investment (2012-2020) , 80 % CNRS/IRFU
- r …n a





The Euclid science organization

Euclid Consortium



French scientific organisation

-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.

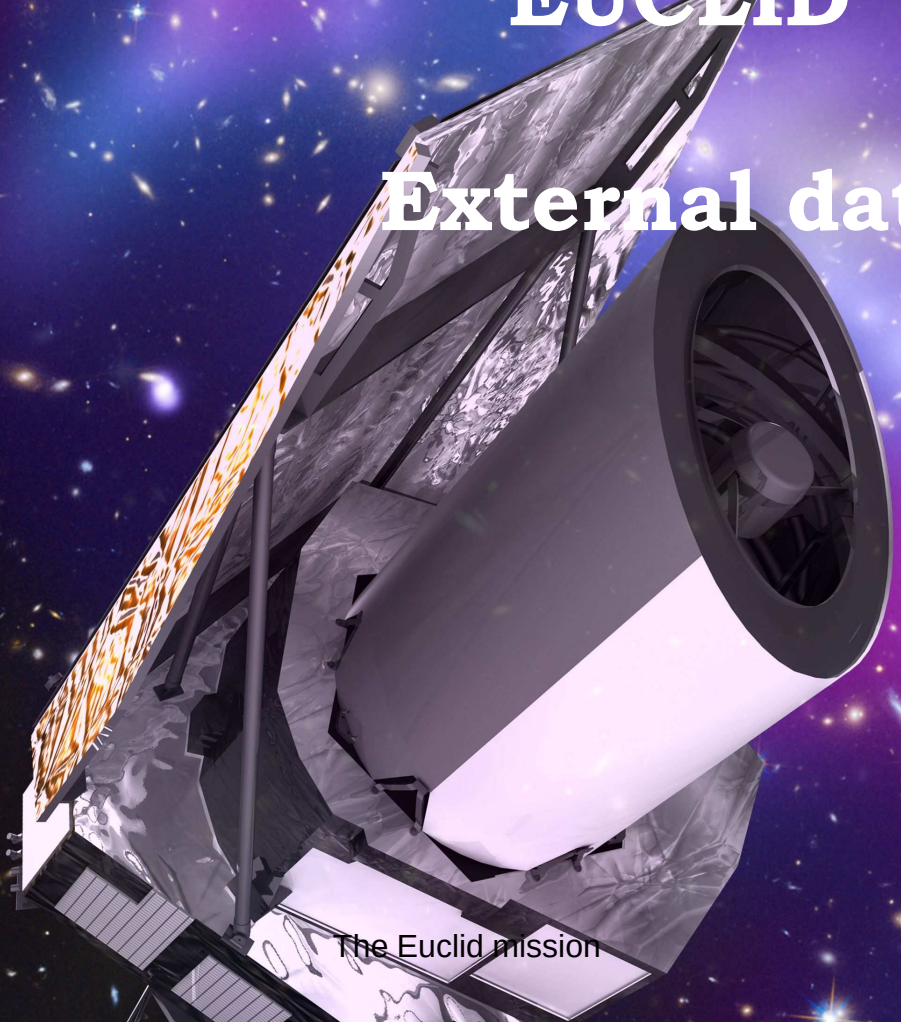
-There a deficit of French scientists in SWGs and of leads !!
Euclid French community has decided to promote a a French Euclid coordination group to prepare a scientific roadmap and develop the French expertise. This is based on 3 science priorities:

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

Euclid Consortium

- Weak Lensing : redshifts of 1.5 x10^9 sources to
  - o Slice the universe
  - o Control contamination by intrinsic alignments of galaxies

HST/ACS credit NASA/ESA

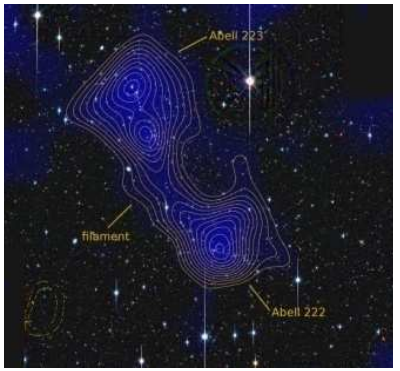
Galaxy halos

HST/ACS; credit NASA/ESA

Clusters of galaxies

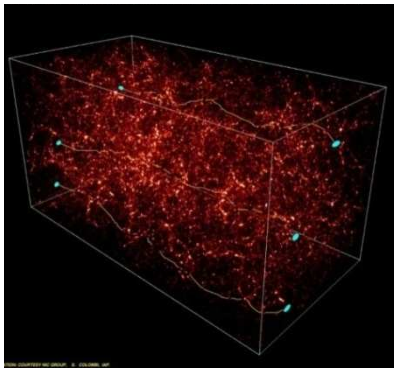
- Redshifts of Euclid clusters: (60,000 clusters, 5,000 giant arcs)
  → synergy with Planck,Nika and eROSITA

Dietrich et al 2012



Filaments between clusters

Colombi/Mellier



Cosmic shear

- 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

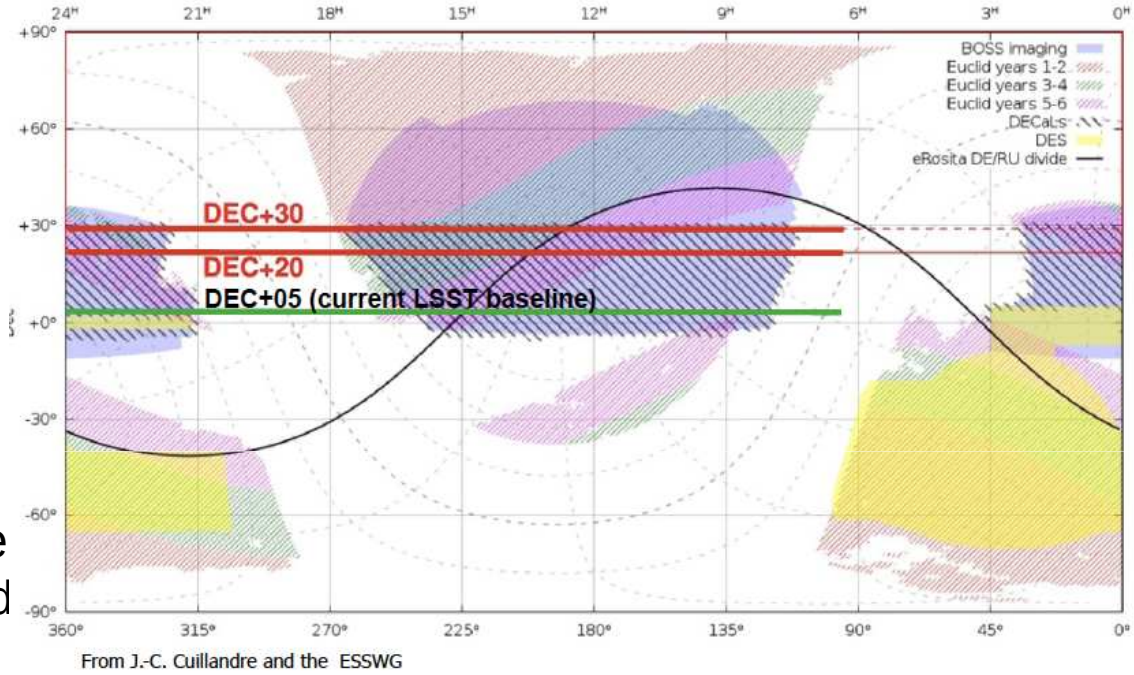
Current best options:

- South:
  DES (5000 deg2), LSST

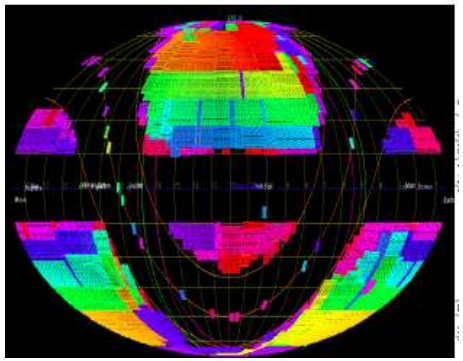
- North:
  CFHT: 2-3 bands ?
  proposal in progress
  WHT : William-Hershel telescope
  1-2 band

(Es-PAUproposal)

Subaru2



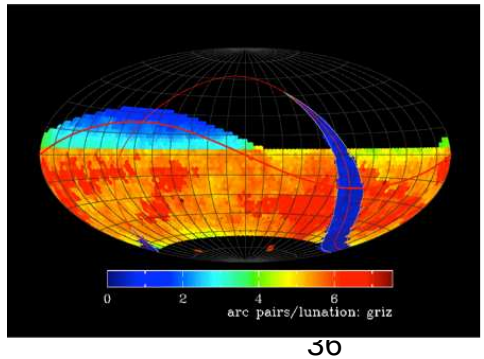
From J.-C. Cuillandre and the ESSWG



LSST+EUCLID

photo-z, SEDs for PSF, source identification, classification, many complementarities

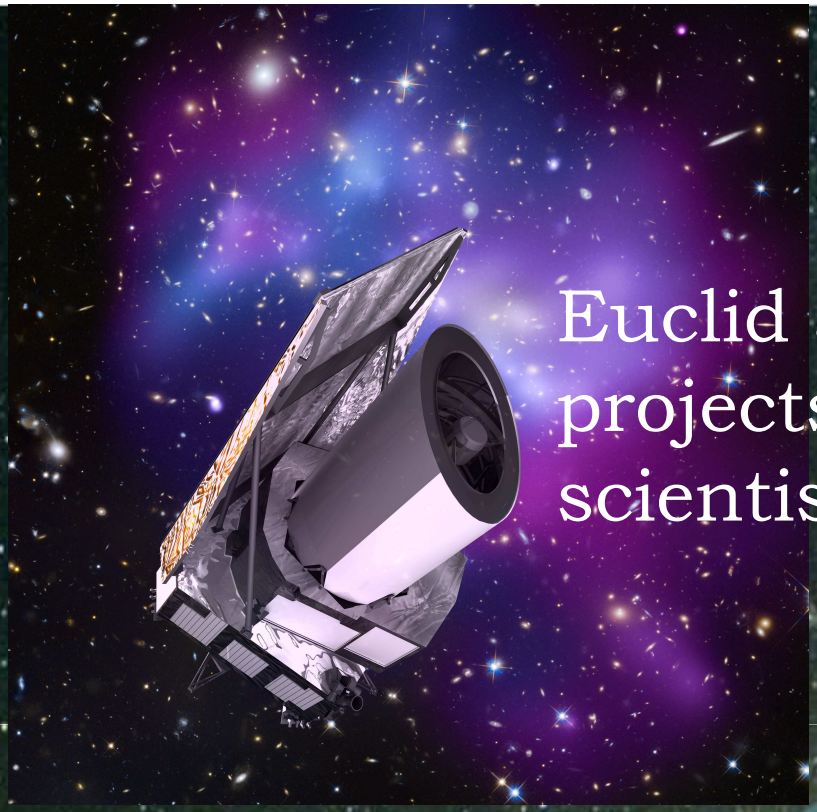
need official agreement



Summary

- 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 buiding 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. ϕ, ψ, bias, δ_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 ψ (z-space distortions?)
And galaxy P(k) then gives bias
(-> Euclid ☺)

Distinguishing *decisively*

Assuming:

- DE equation of state: $P/\rho = w$, 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 Λ and dynamical DE: Measure $w(a)$ → slices in redshift
  - From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p) > 400$ → ~1% precision on w's.

    → if data consistent with Λ, and FoM > 400 : Λ favoured with odds of more than 100:1 = a "decisive" statistical evidence.
- Nature of gravity on cosmological scales
  - Probe growth of structure → slices in redshift ,
  - Separately constrain the metrics potentials (Ψ,Φ) as function of scale and time
  - Distinguish effects of GR from MG models with very high confidence level:

    → absolute 1-σ of 0.02 on the growth index, γ, from Euclid data alone.

→ → WL and RSD are differently sensitive to Ψ, Φ: $\Psi + \Phi$ (WL) ; Φ (GC, RSD)

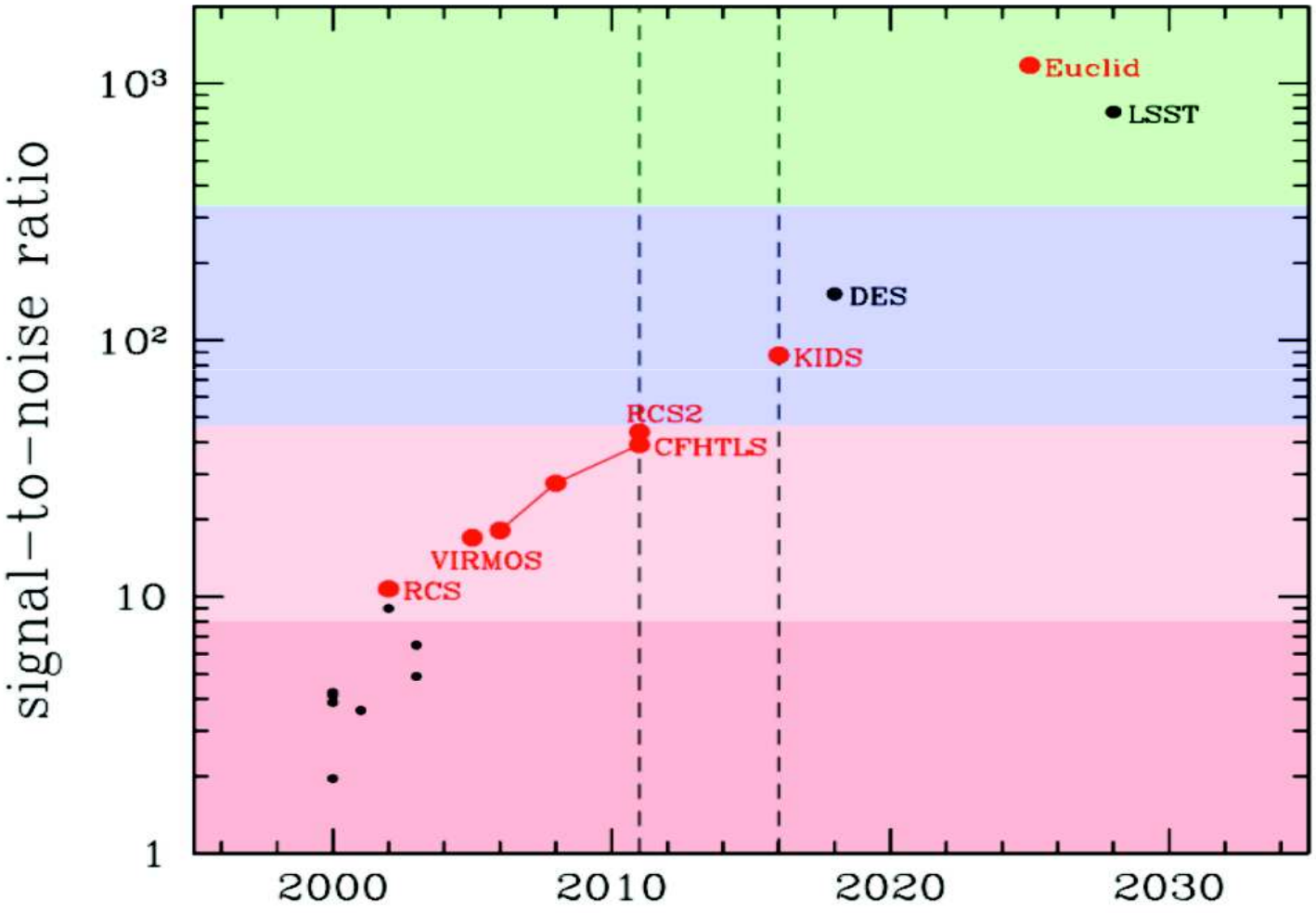
Challenges of Euclid

- **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

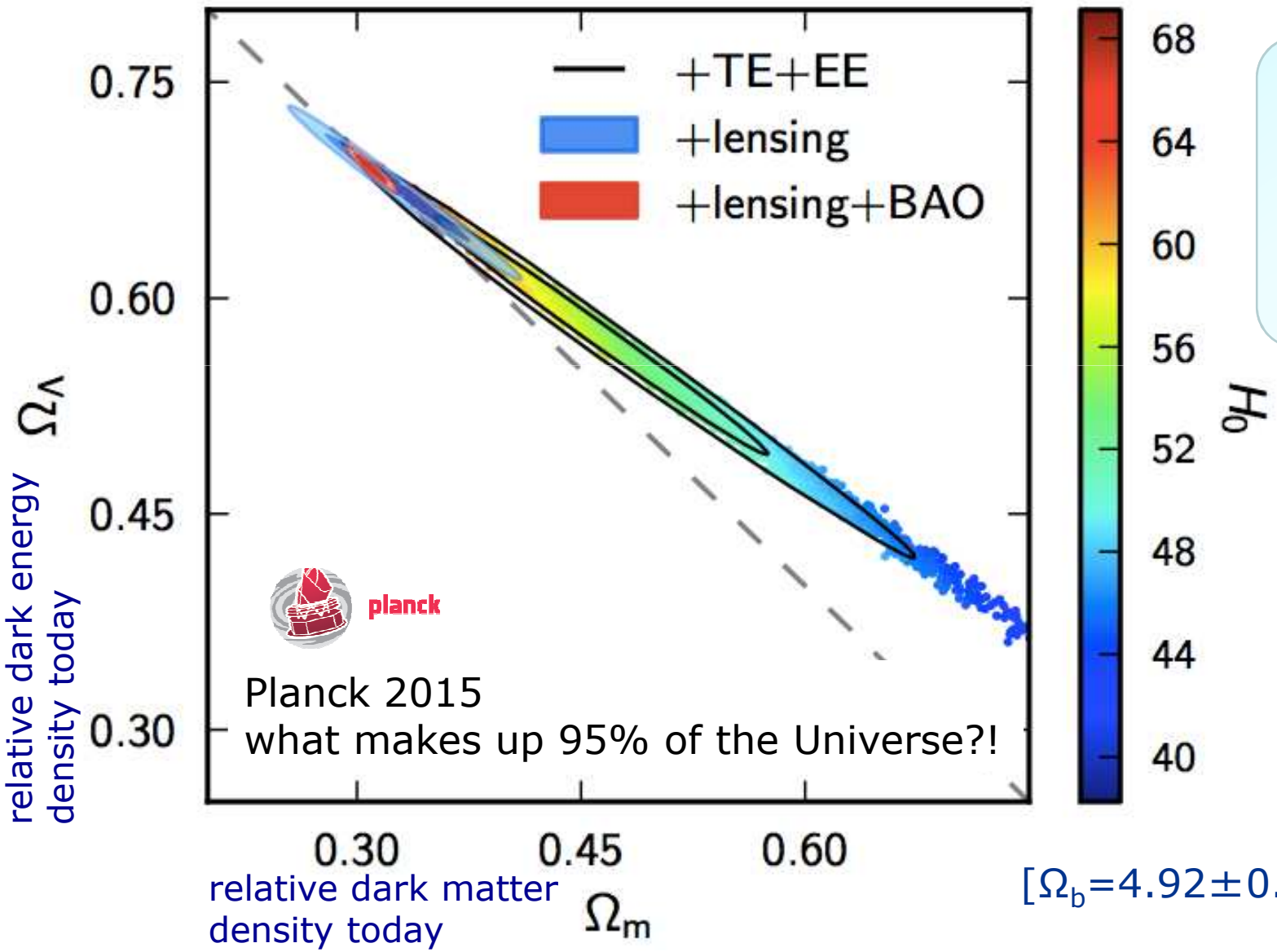
- **End-to-End performances**
- **Spectroscopic surveys to**:
  - Calibrate deep photo-z and understand BAO and RSD samples

next generation wide field cosmic

Euclid Consortium



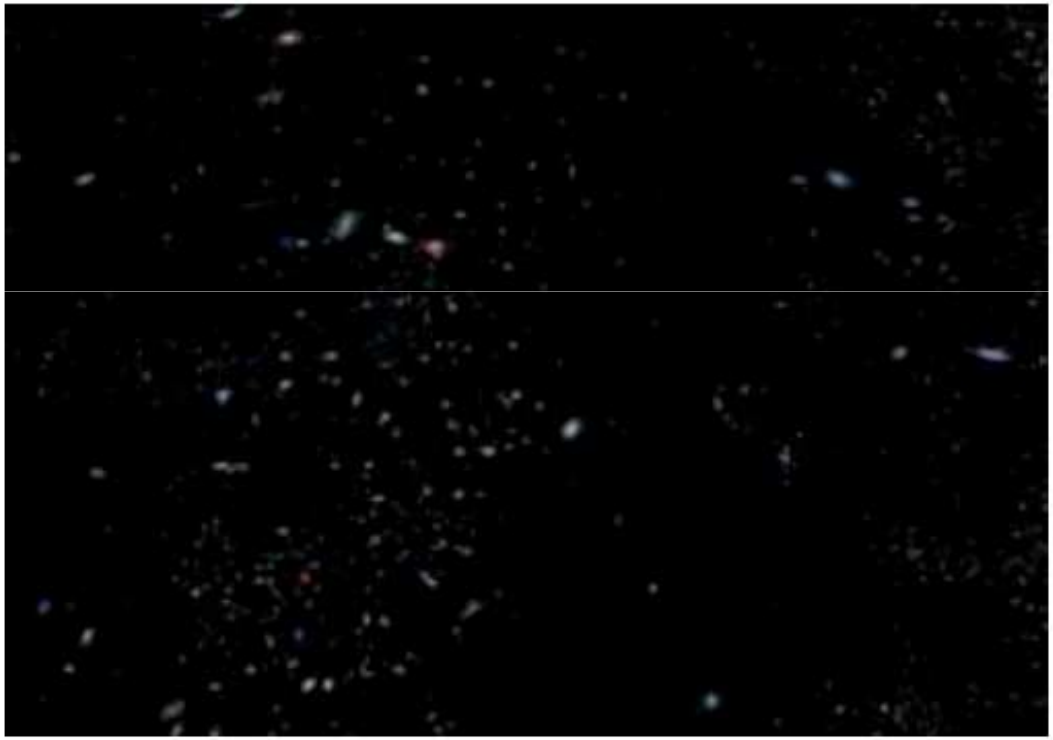
the dark universe today



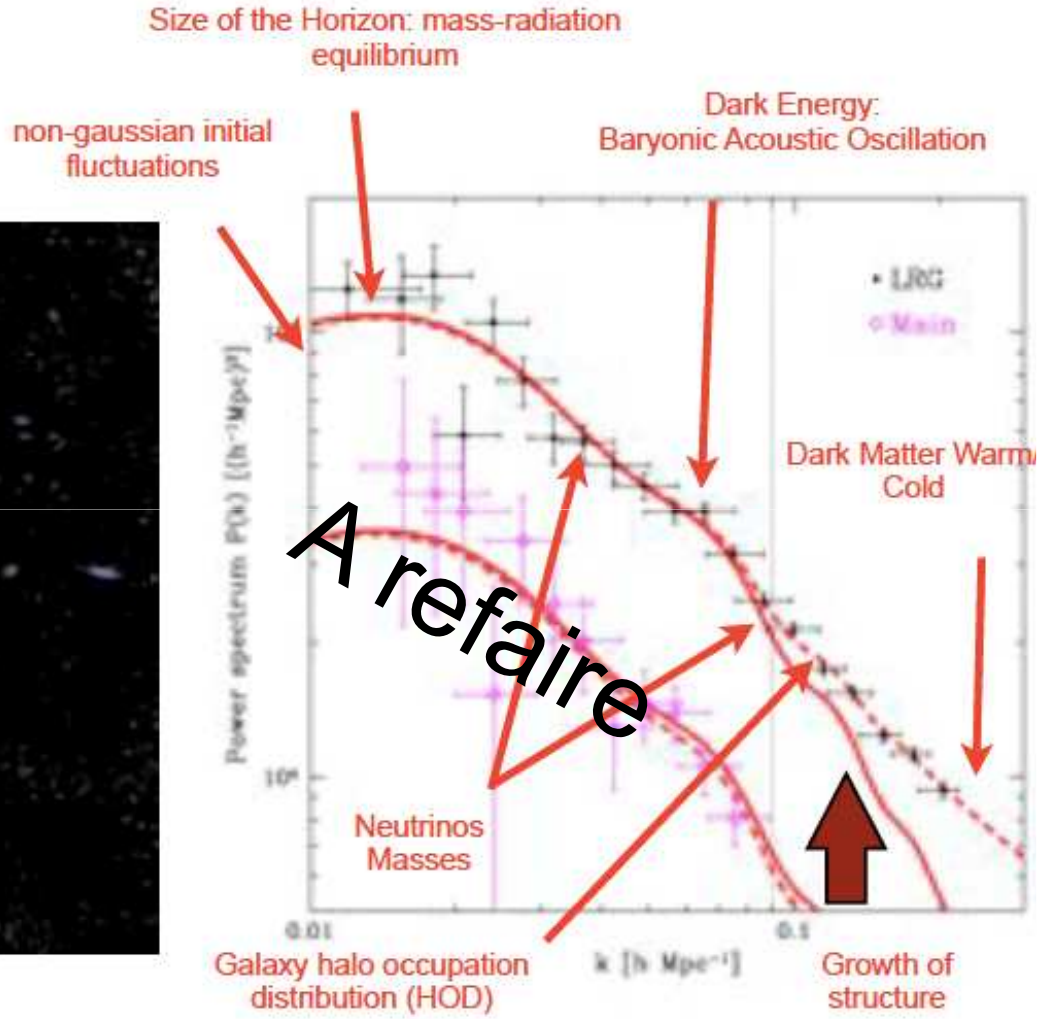
GR:
evolution of Universe
↕
contents of Universe

[Ω_b=4.92±0.13%]

3D mapping of the position of galaxies

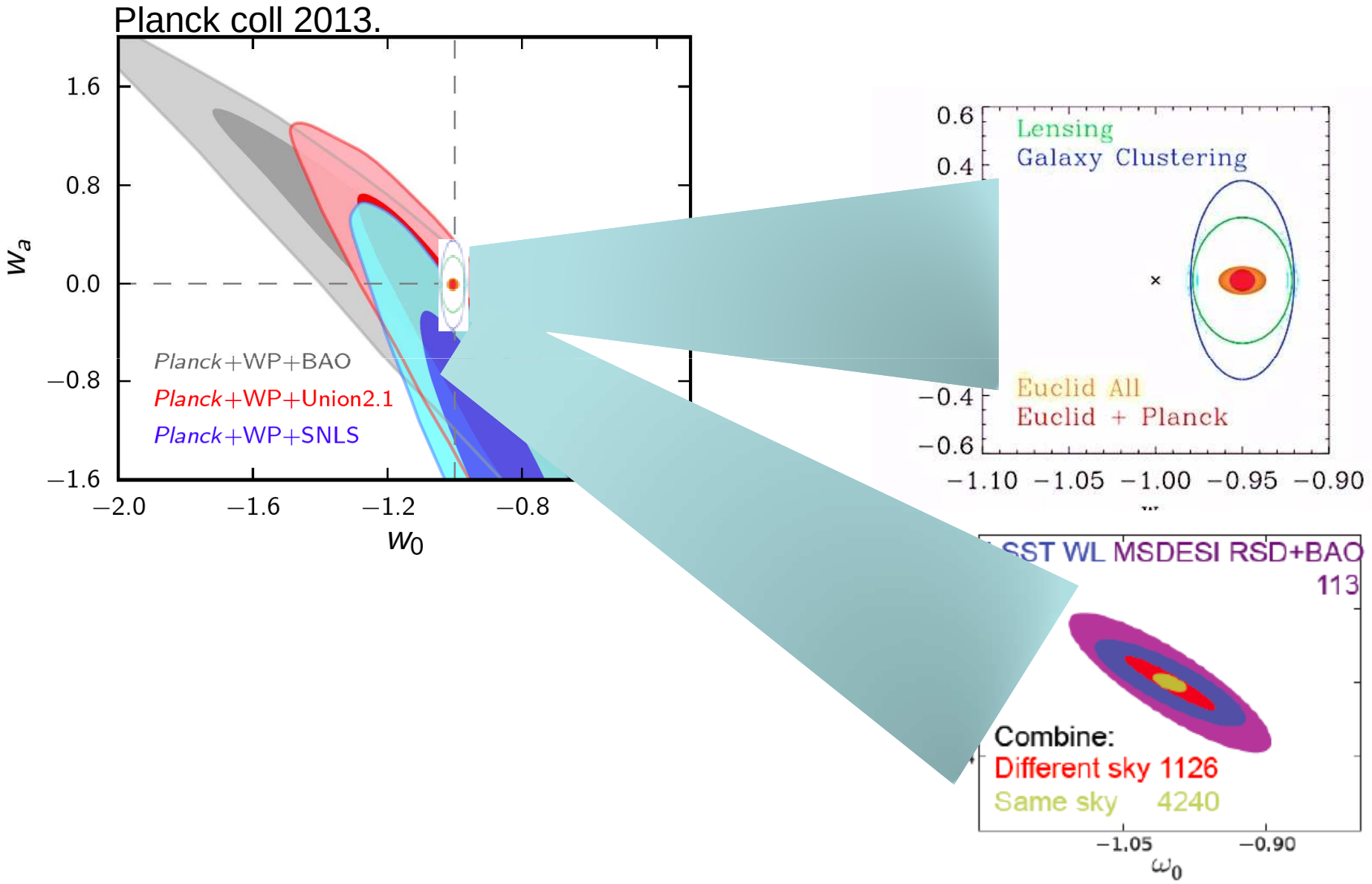


Distribution of galaxies (SDSS)

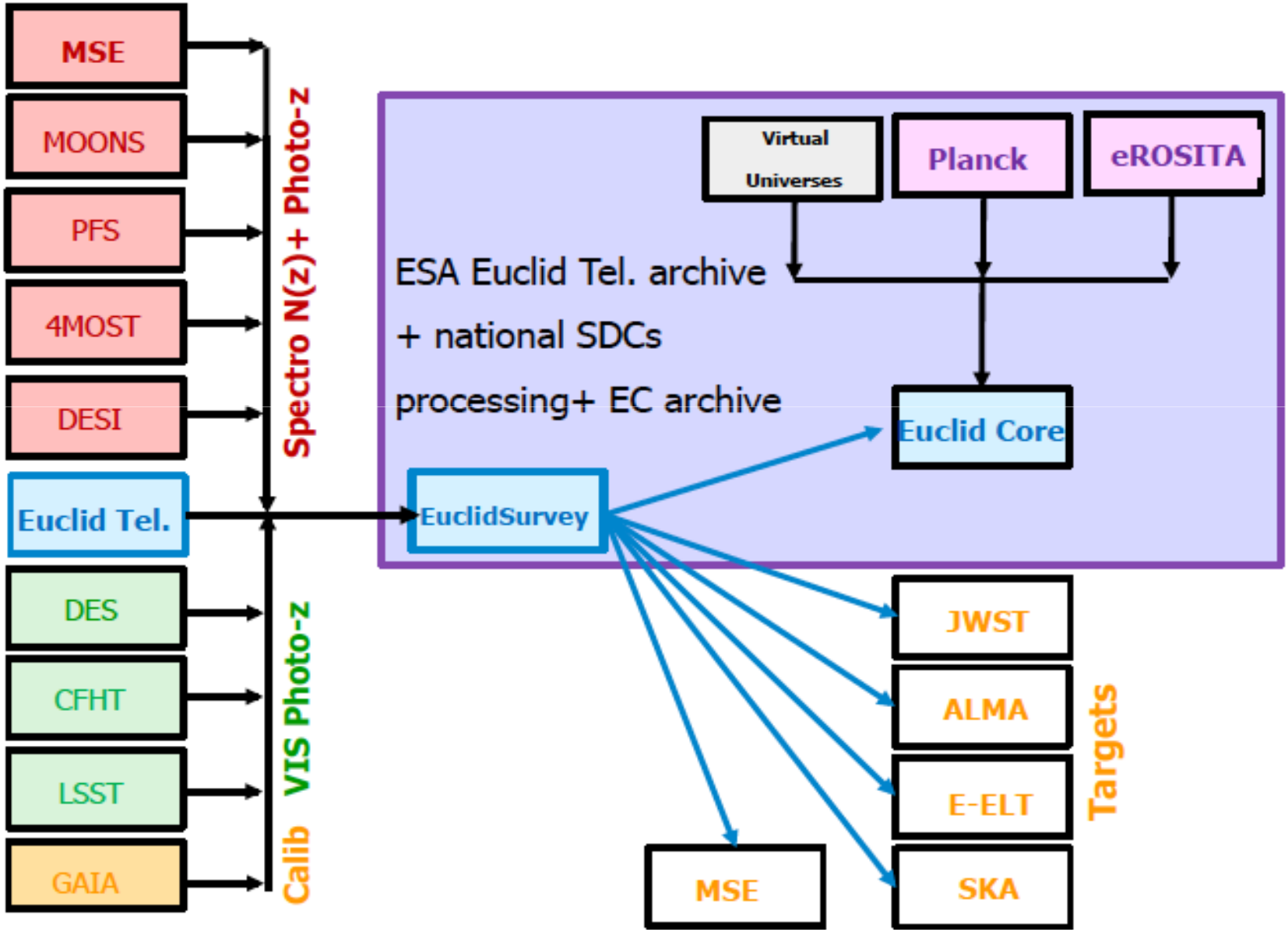


Ultimately…need to combine all probes….

Euclid Consortium



A wordwide synergy



Euclid+ground: photo-z of 1.5 billion galaxies

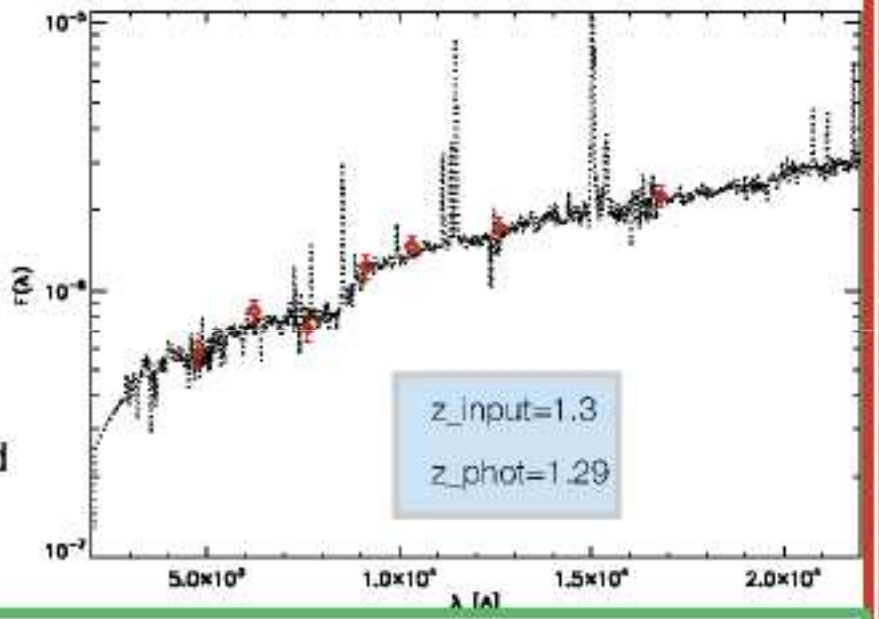
Critical: need ground based imaging over 15,0000 deg^2 in 4 bands

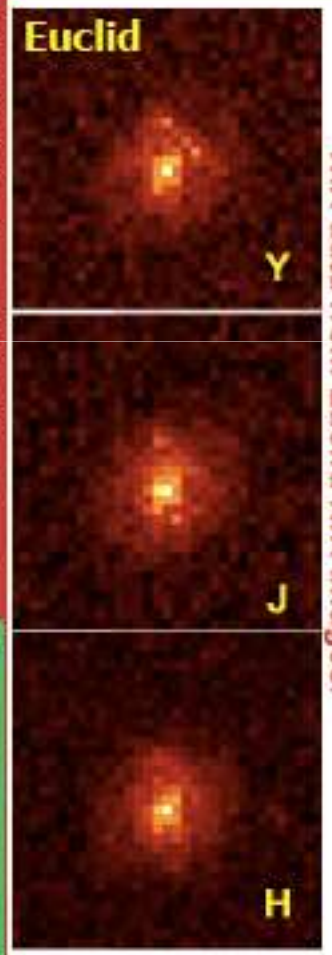
Courtesy Euclid SWG Photo-z and OU-PHZ

Requirements:

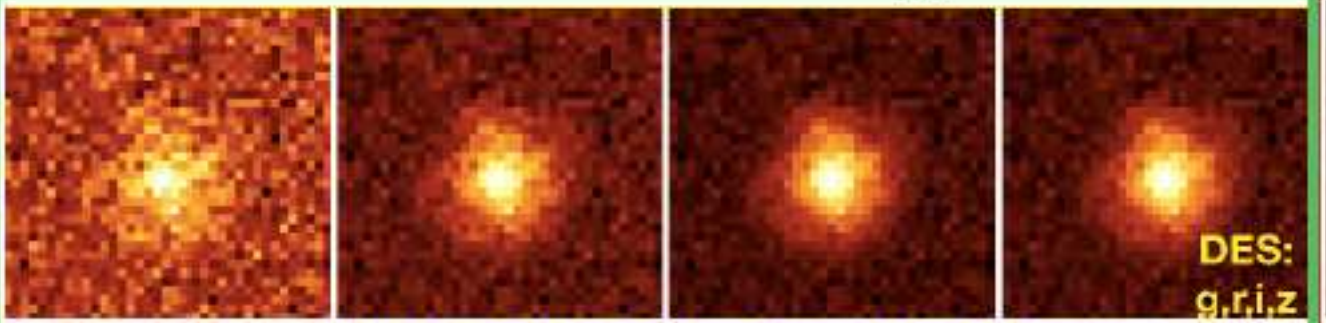
- get photo-z for ~all WL galaxies
- cover the whole Euclid sky (15000 deg^2)
- accuracy = 0.05x(1+z)

→ 4 optical bands needed





NIR data from Euclid NIR images.



Visible data obtained from ground based telescopes