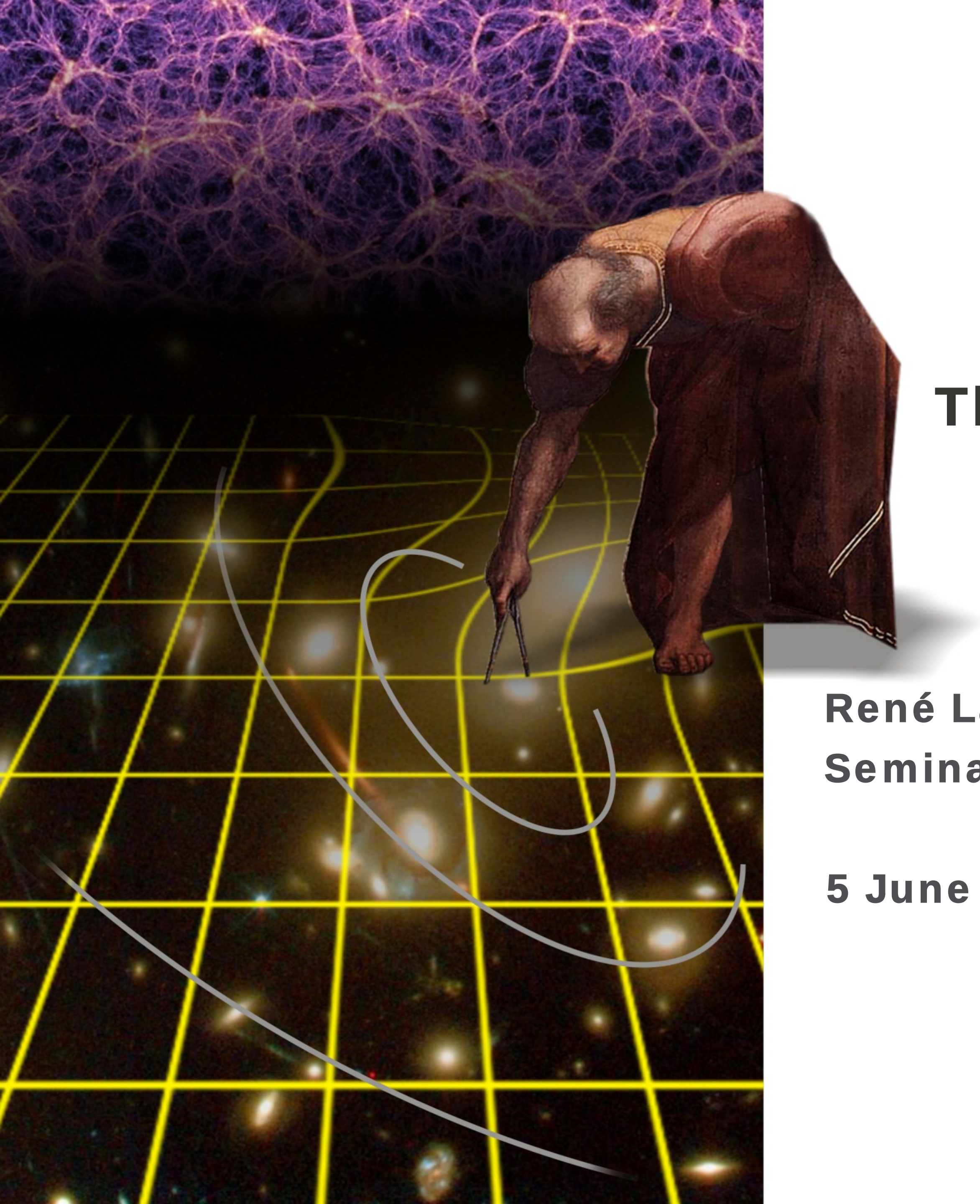


The Euclid Mission

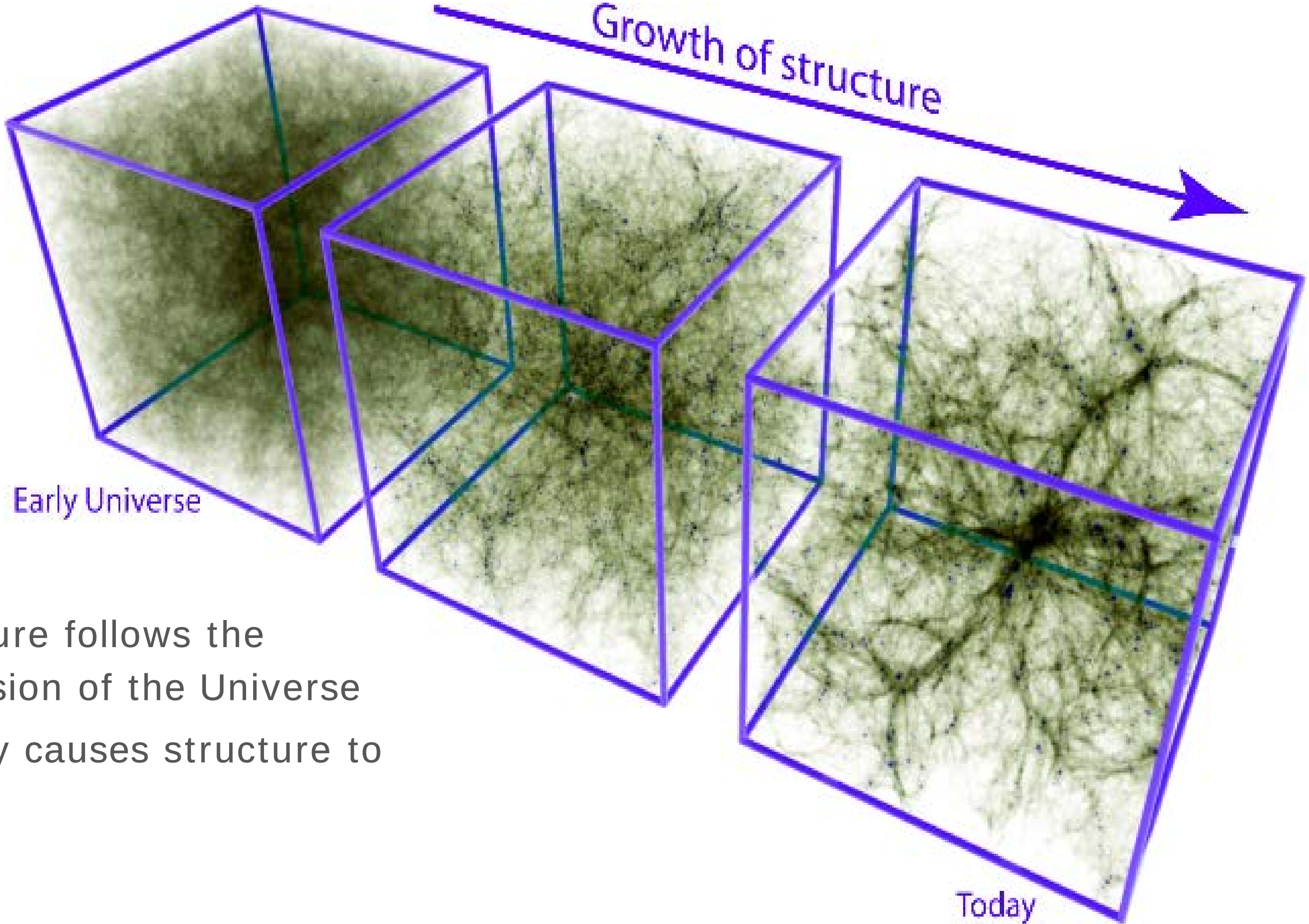
René Laureijs
Seminar at ESAC

5 June 2014

Outline

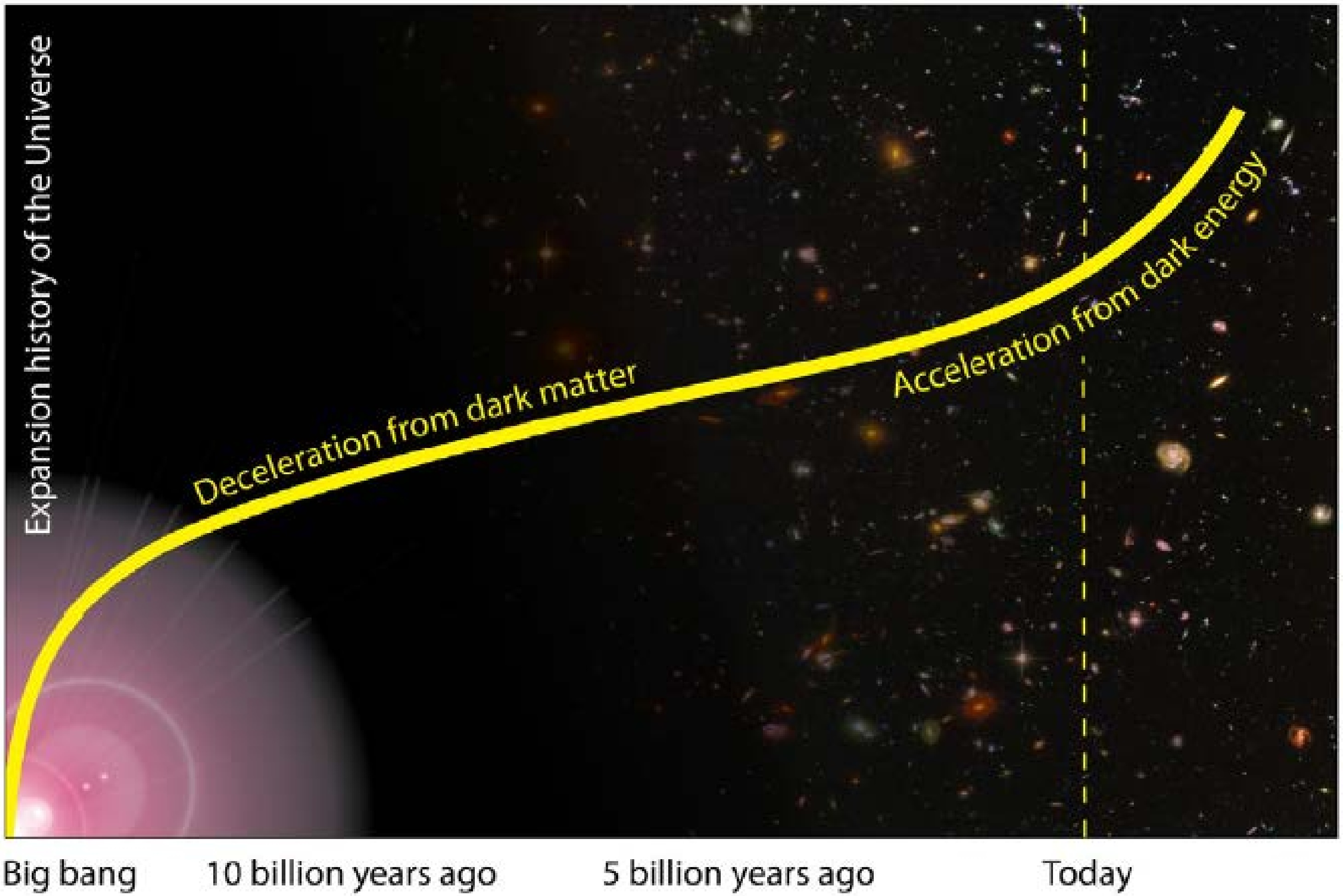
- Science Context
- Cosmological Probes for Euclid
- Science objectives and driving requirements
- Mission Implementation
- Euclid surveys and data.....
- Outlook and Conclusions

Evolution of mass distribution

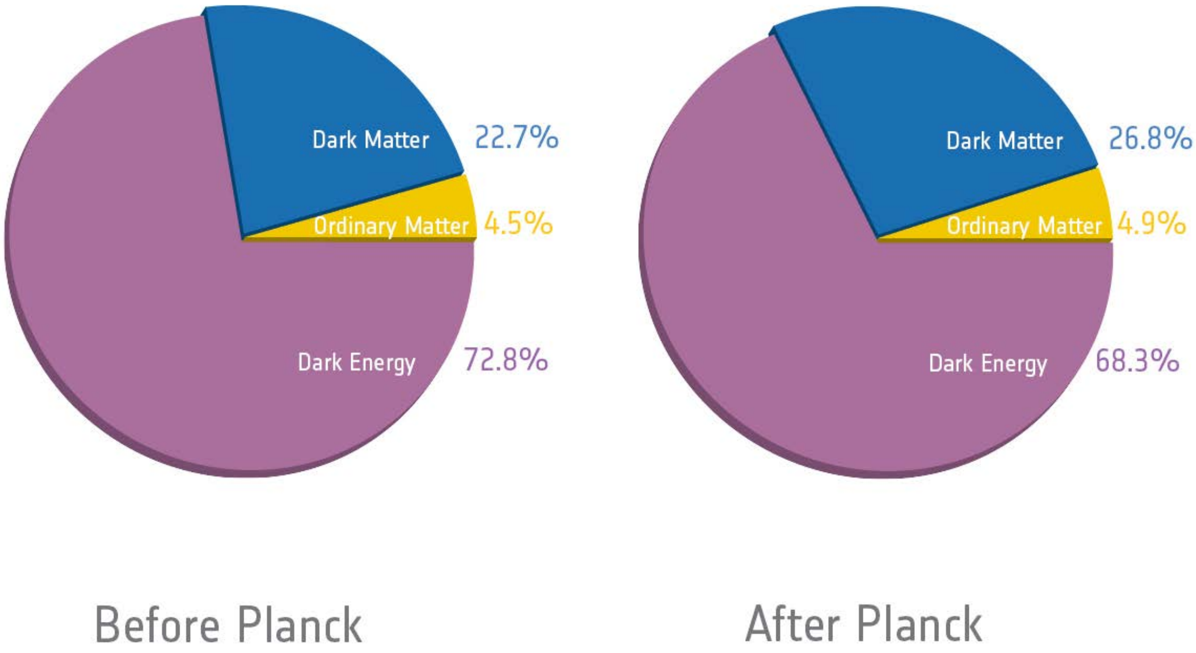


- Structure follows the expansion of the Universe
- Gravity causes structure to evolve

Expansion history



What is the Universe made of?



Assuming the framework of ΛCDM!

…. so far…ΛCDM nicely fits the observations but does not give a satisfactory explanation in terms of fundamental physics….

→ **Euclid will explore the dark sectors**

If we want to know more about dark energy…
then determine the acceleration and its effects (very) accurately

The signature of the acceleration is locked up in:

- **The geometry of the universe**
  - Distance as a function of redshift
- **Growth of density perturbations**
  - Evolution of structure as a function of cosmic time, *growth rate*

Most promising techniques, the *cosmological probes:*

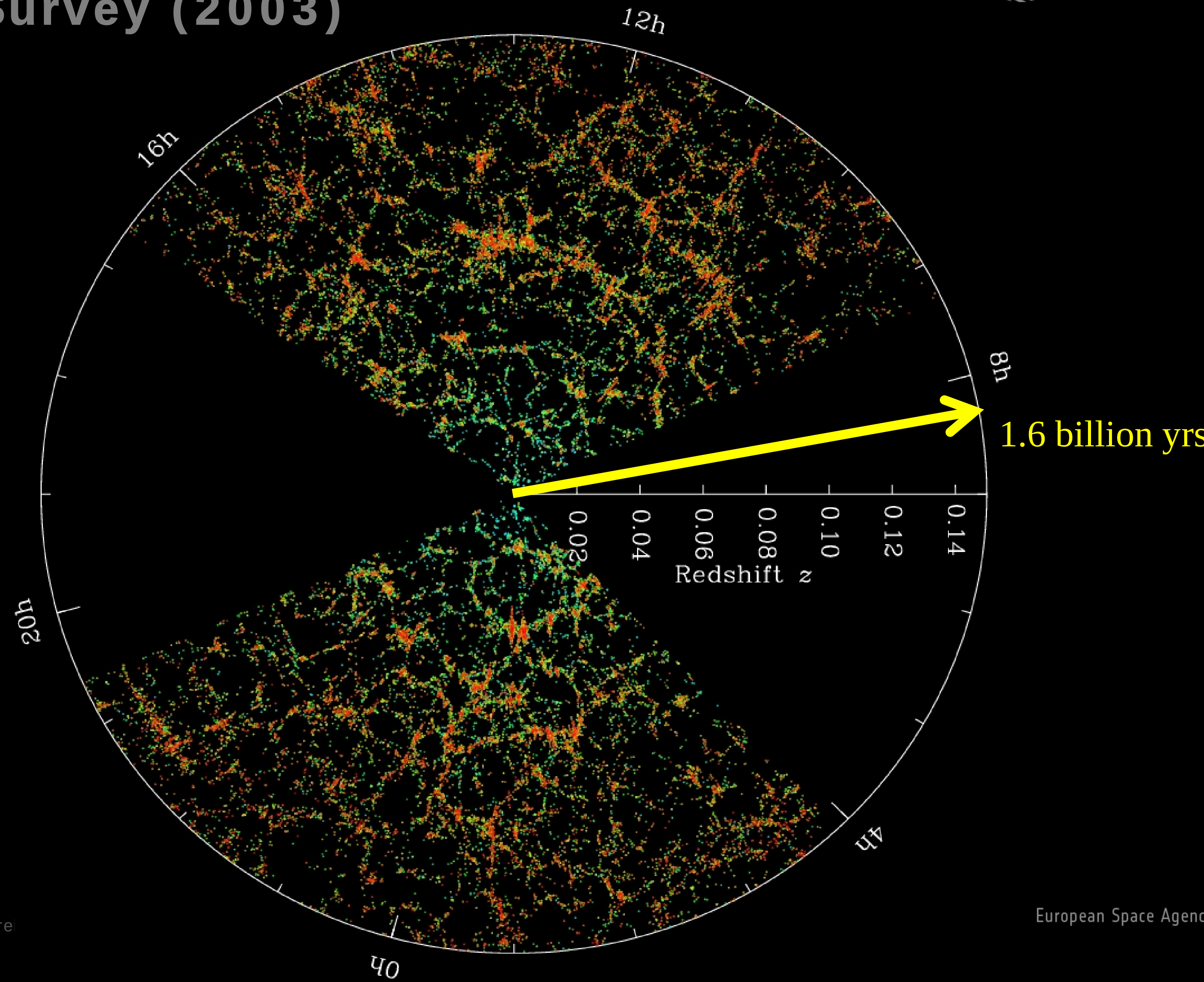
- Type 1a Supernovae
- **Galaxy Clustering**
  - **Baryon Acoustic Oscillations**
  - **z-space distortions**
- **Weak Gravitational Lensing**

Euclid primary probes

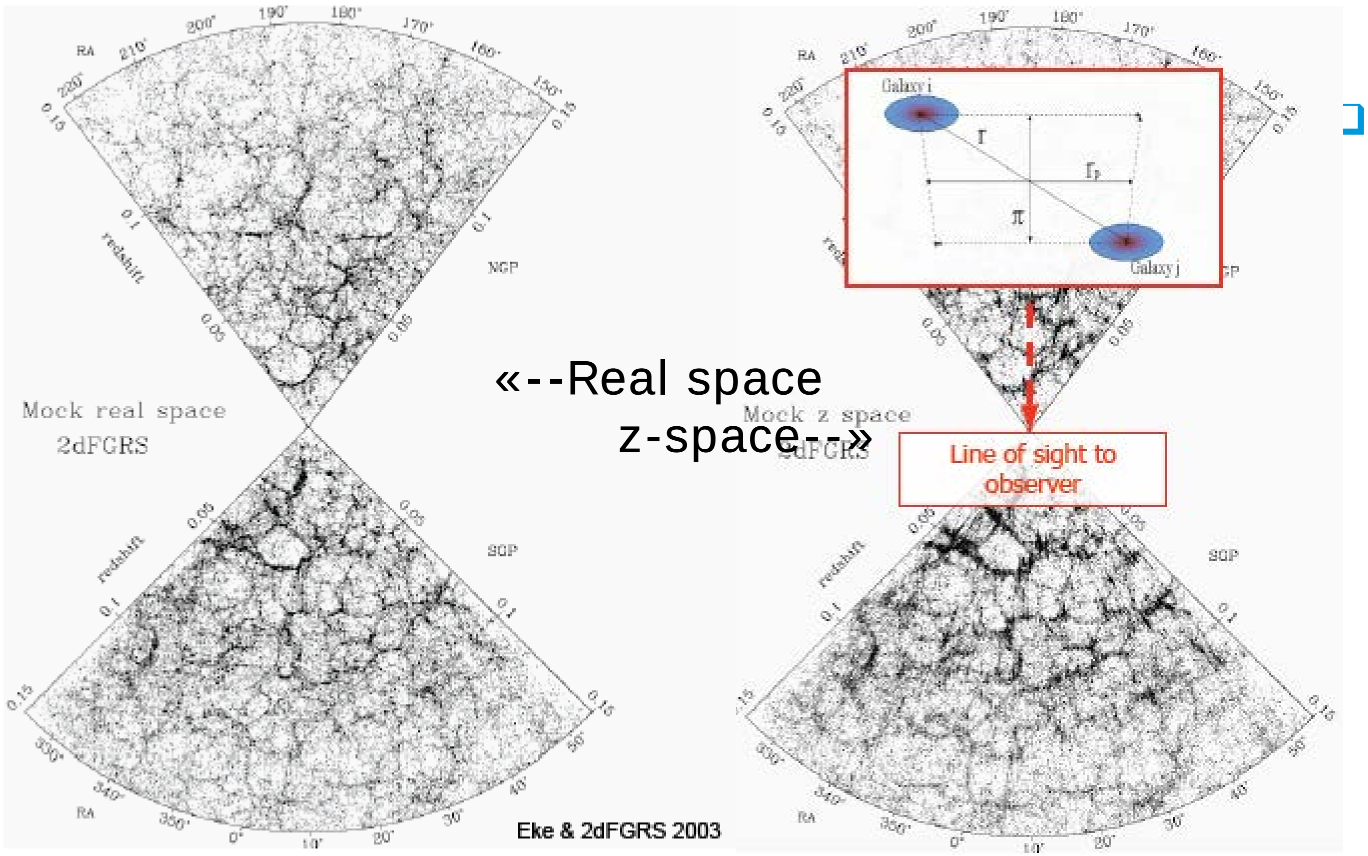
euclid

European Space Agency

2dF Survey (2003)



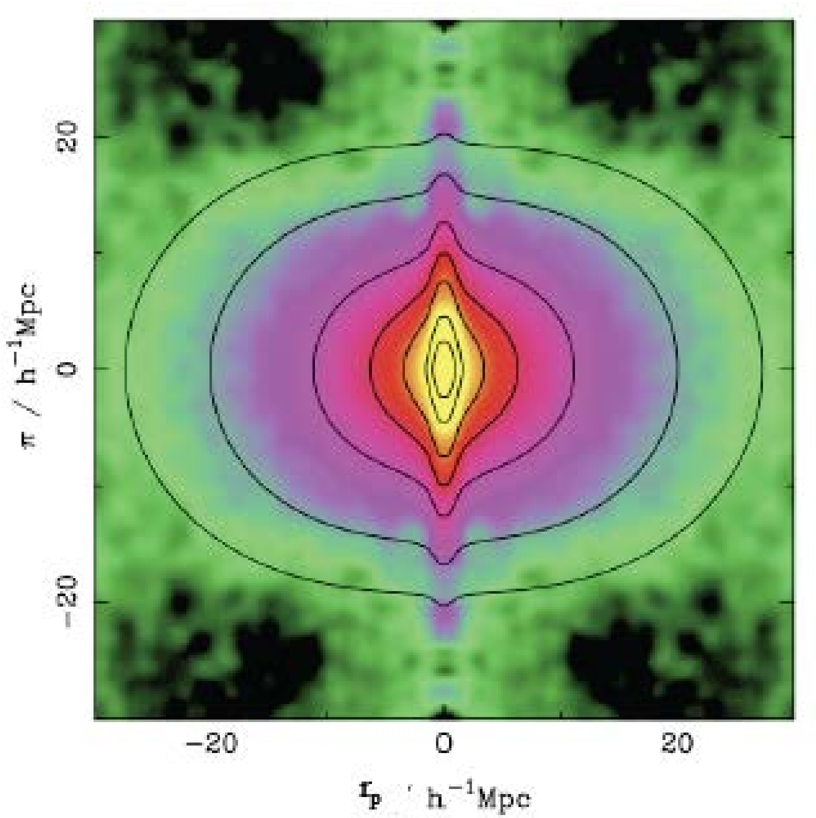
Redshift Space Distortions



- Peculiar velocities cause redshift-space distortions

European Space Agency

Growth Rate



Guzzo, 2009

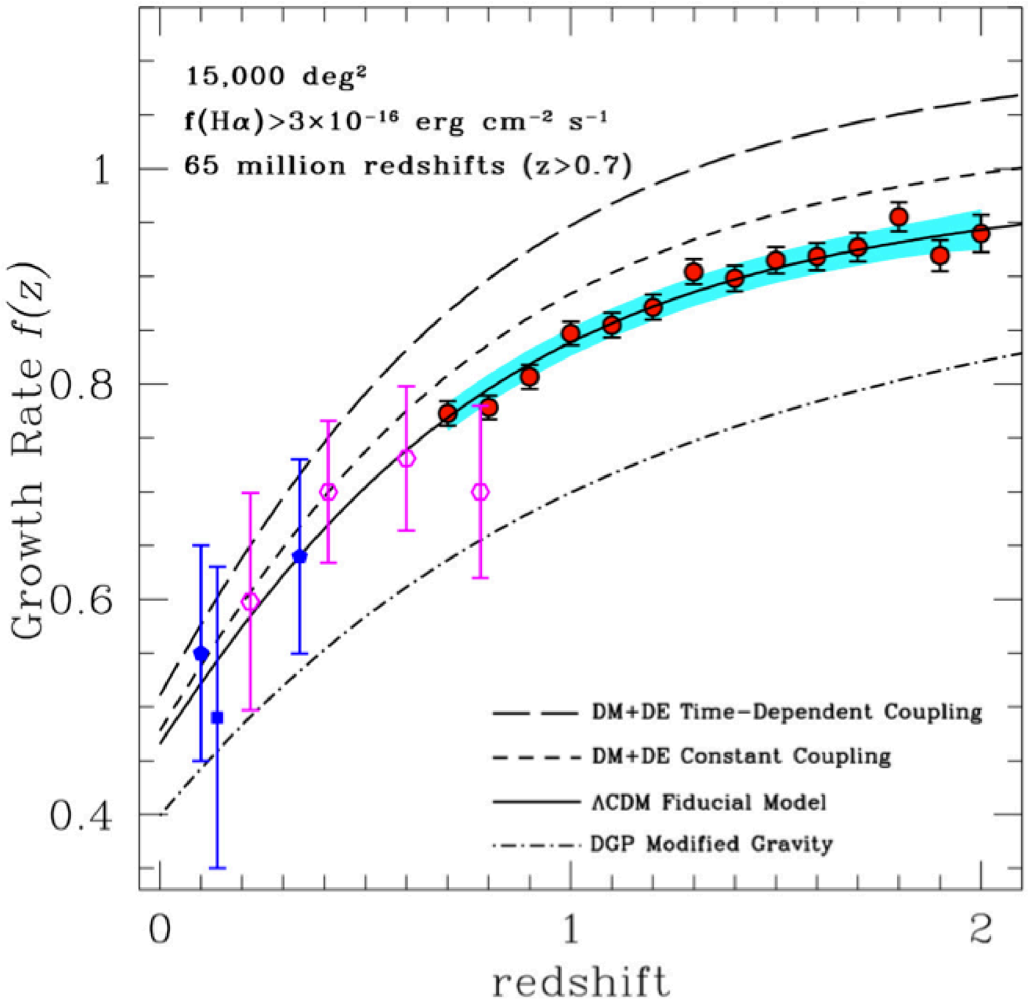
Z-space distortions reveal the growth rate of structure:

- Measure redshift and position of galaxies
- Determine the growth rate f(z) for a given redshift bin

$f(z)=[\Omega_m(z)]^\gamma$

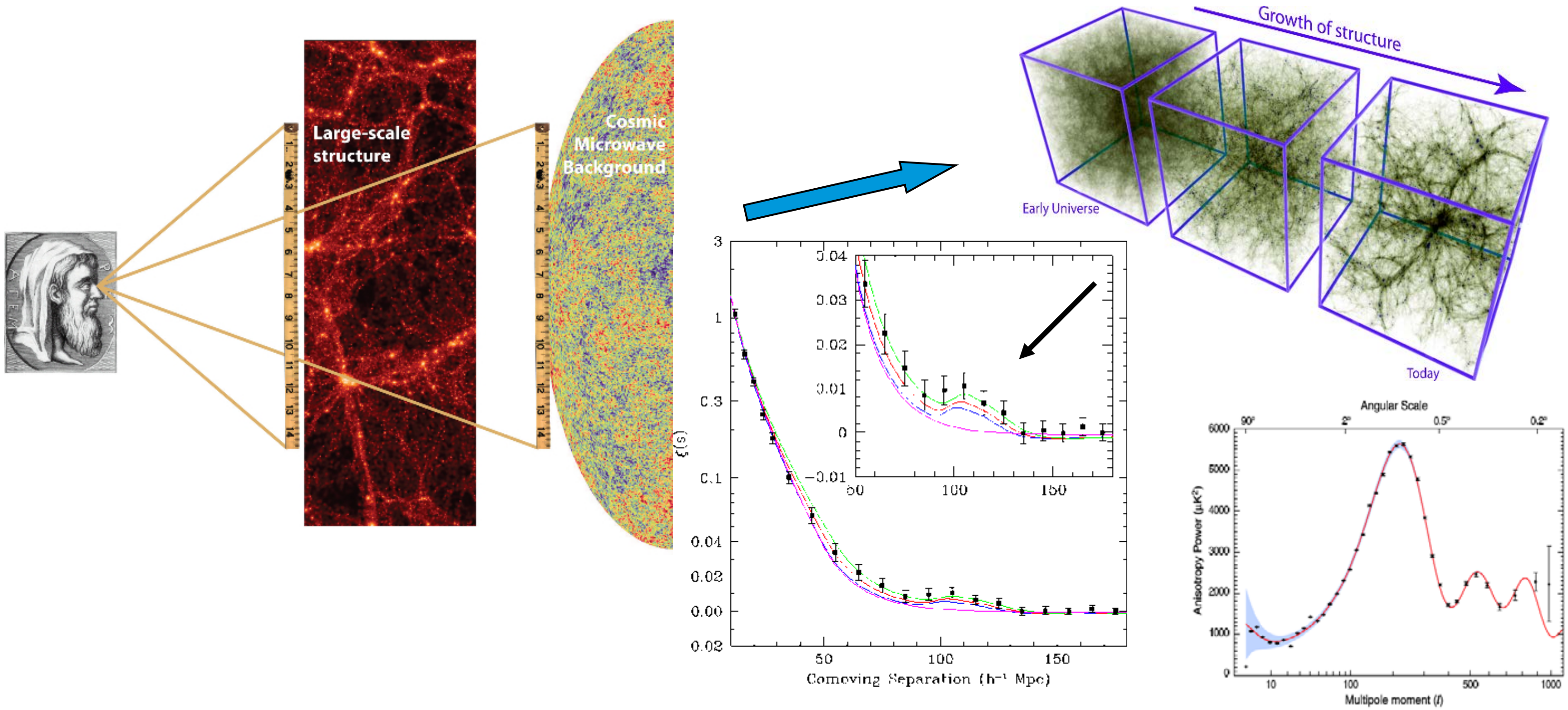
- Determine the growth factor γ:
γ=0.55 for standard Λ
γ=0.68 for DGP braneworld

Euclid – RSD improvements



- Percival, 2012

Baryon Acoustic Oscillations

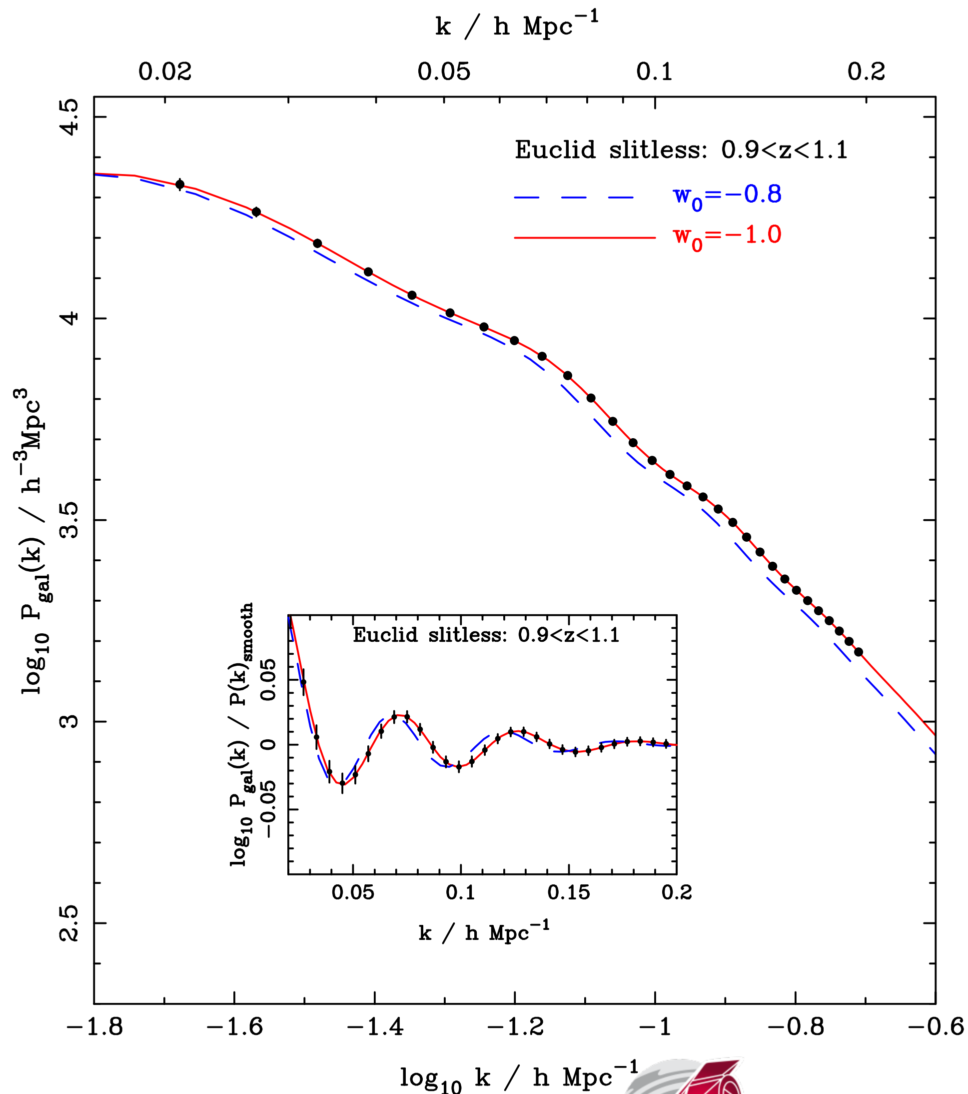


Z=1100 from WMAP

BAO reveals the geometry of the luminous matter:

- Measure redshifts of galaxies over a large volume
- Obtain the power spectrum for a given redshift bin
- Determine the "wiggles" – the acoustic peaks
- The peaks correspond to a typical scale length

Predicted Euclid Result



Redshift Slice
$0.9 < z < 1.1$

Total Effective volume (of Euclid)
$V_{eff} = 19.7\ Gpc^3h$

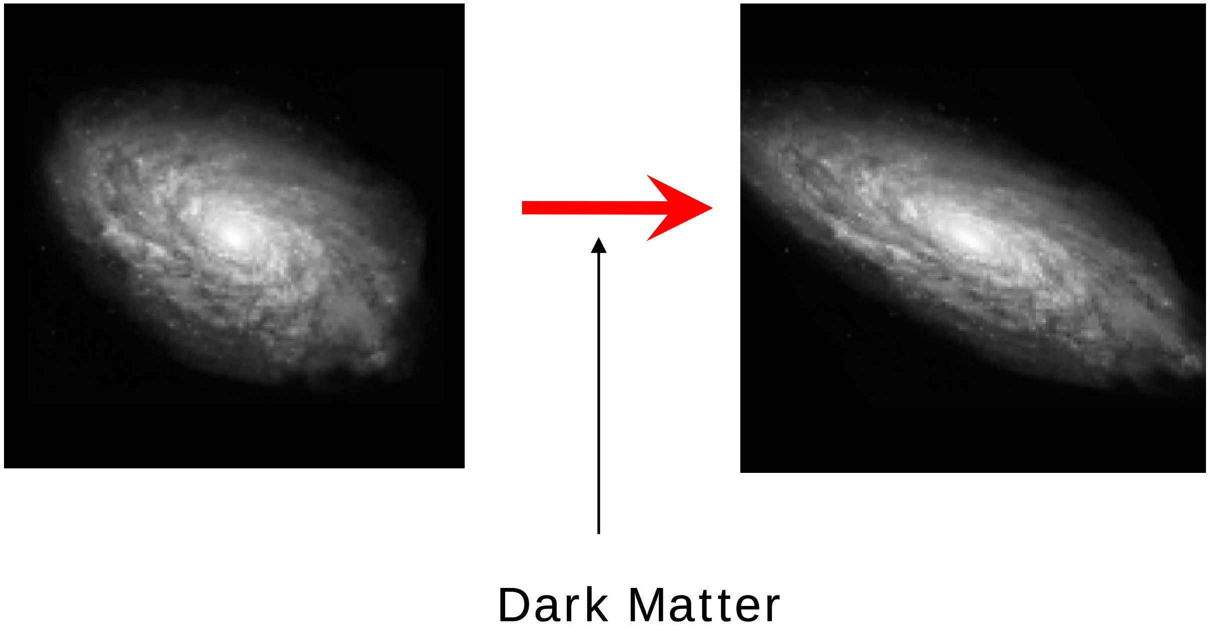
Weak Lensing

Studying the distortions in galaxy shapes caused by Dark Matter

euclid European Space Agency

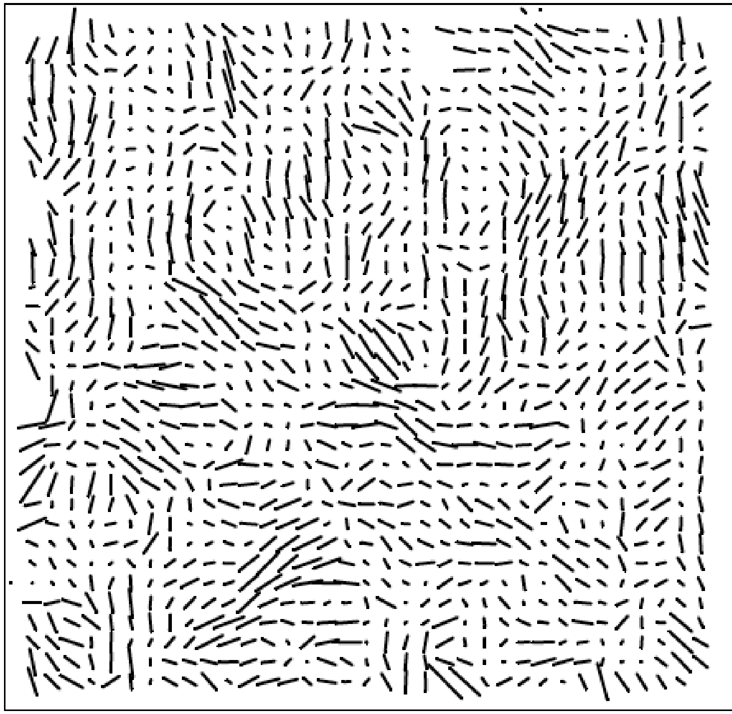
Weak Lensing (2)

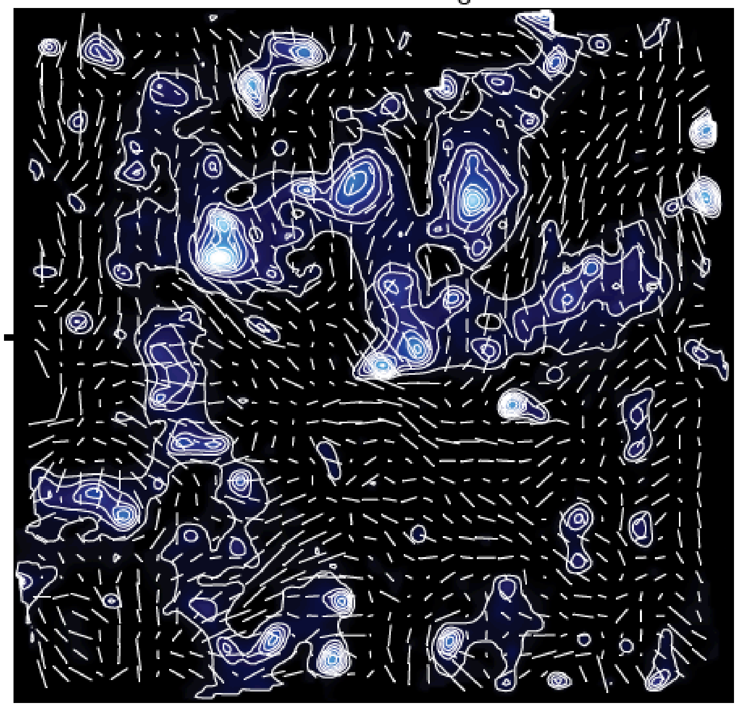
- The weak lensing distortion is simply a (very small) change in ellipticity and position angle of a galaxy



Euclid WL galaxies are ≥0.3 arcsec

From shear to distribution

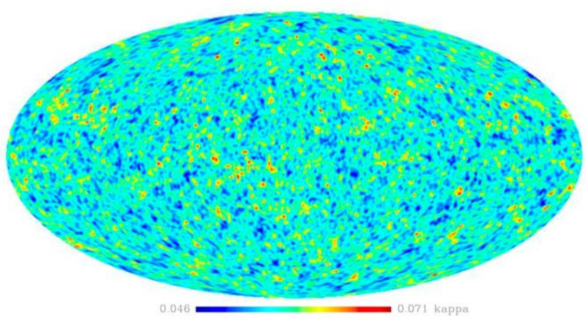




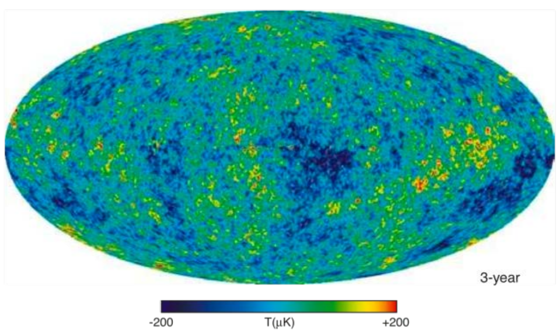
Weak Lensing method

WL reveals the geometry using the dark matter:

- ❑ Measure shapes of galaxies over a large volume
- ❑ Obtain the shear power spectrum for a given redshift bin
- ❑ Determine the changes of the power spectrum as a function of redshift → **cosmic acceleration**
- ❑ Determine also the **growth factor** γ



Weak Lensing result:
Simulated DM distribution at z=2



WMAP CMB
Structure at z=1100

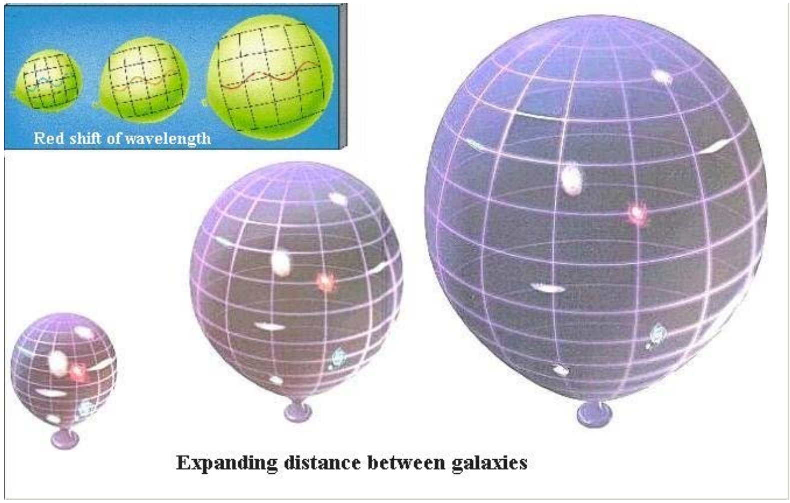
Some Cosmology.....

- Scale factor a(t)
- Redshift z

$$a = \frac{1}{1+z}$$

$$z = H_0 \mathrm{r}$$

$$H = \frac{\dot{a}}{a}$$



Remember Einstein….

Friedman
Equation of expansion

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p)$$

Conservation of Energy

$$d(V\rho) = -pdV$$

Cosmological constant:

$$p_\Lambda = -\rho_\Lambda$$

$$w = -1$$

Dark Energy – equation of state

$$p = w(a)\rho$$

$$w(a) < -\frac{1}{3}$$

$$w(a) = w_p + w_a(1-a)$$

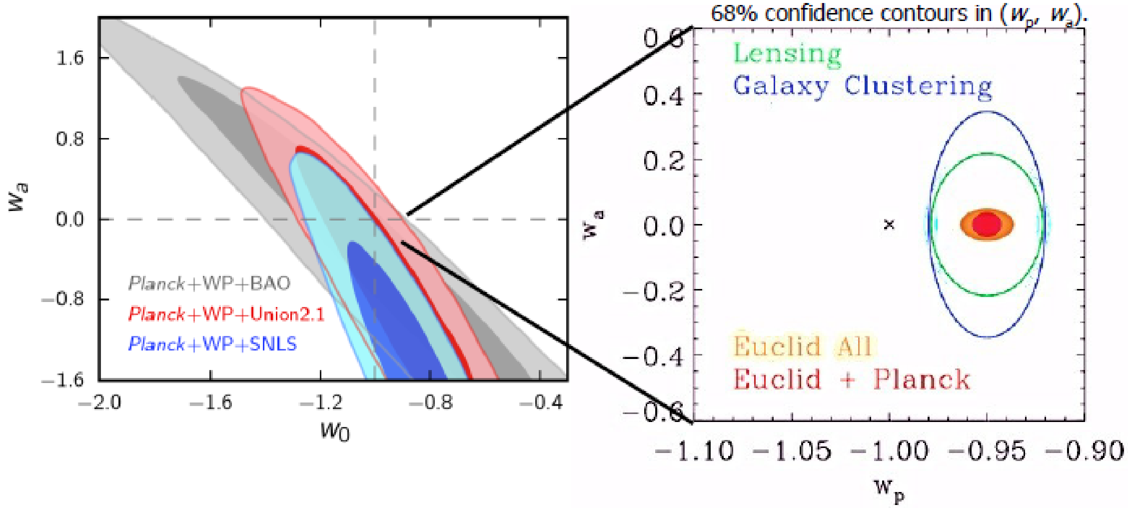
Euclid Scientific Objectives

Issue	Euclid's Targets
What is Dark Energy: *w*	Measure the DE equation of state parameters w_p and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Beyond Einstein's Gravity: γ	Distinguish General Relativity from modified-gravity theories, by measuring the growth rate exponent γ with a precision of 2%.
The nature of dark matter: m_ν	Test the Cold Dark Matter paradigm for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.
The seeds of cosmic structure: f_{NL}	Improve by a factor of 20 the determination of the initial condition parameters compared to Planck alone. n (spectral index), σ_8 (power spectrum amplitude), f_{NL} (non-gaussianity)

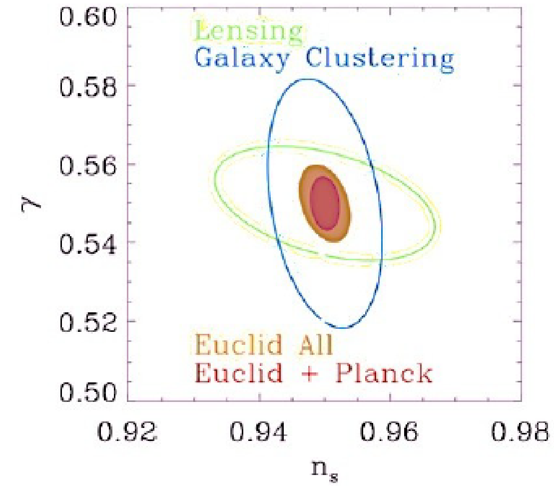
Forecast

The Planck Collaboration. Ade et al 2013

DE constraints from Euclid:



Constraints on γ and n_s. Errors marginalised over all other parameters.



	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	***γ***	***m ν /eV***	f_{NL}	w_p	w_a	***FoM***
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current (2011)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Ref: Euclid RB arXiv:1110.3193

Assume systematic errors are under control

Mission Implementation

Euclid Scientific Requirements

- Optimize the mission for two complementary dark energy probes: galaxy clustering and weak lensing;
- Minimum survey area of 15,000 deg^2 (36% of the total sky)

  → 6 year nominal mission

Weak Lensing: → VIS imager + NIR imaging-photometer

- Shapes and shear of galaxies with a density of >30 galaxies/arcmin^2.
- Minimum Systematics $\sigma^2_{sys} < 10^{-7}$
  - Very high image quality, high stability
- Redshift range 0<z<~2, accuracy dz/(z+1) ~ 0.05

Galaxy clustering → NIR slitless spectrometer

- Redshifts for >1700 galaxies/deg^2
- Redshift range 0.9< z <1.8, accuracy dz/(z+1) < 0.001
- Same area as WL→ line Flux limit < 2 10^{-16} erg cm^{-2}s^{-1} .

Ground based data

- Euclid cannot meet the photo-z requirement $dz/(z+1) \sim 0.05$ without ground based data. The availability of ground based data is an essential part of meeting the science objectives:
    - 4-band (g,r,i,z) imaging photometry down to ~24.5 mag
    - Same coverage as the Euclid survey (15,000 deg^2)

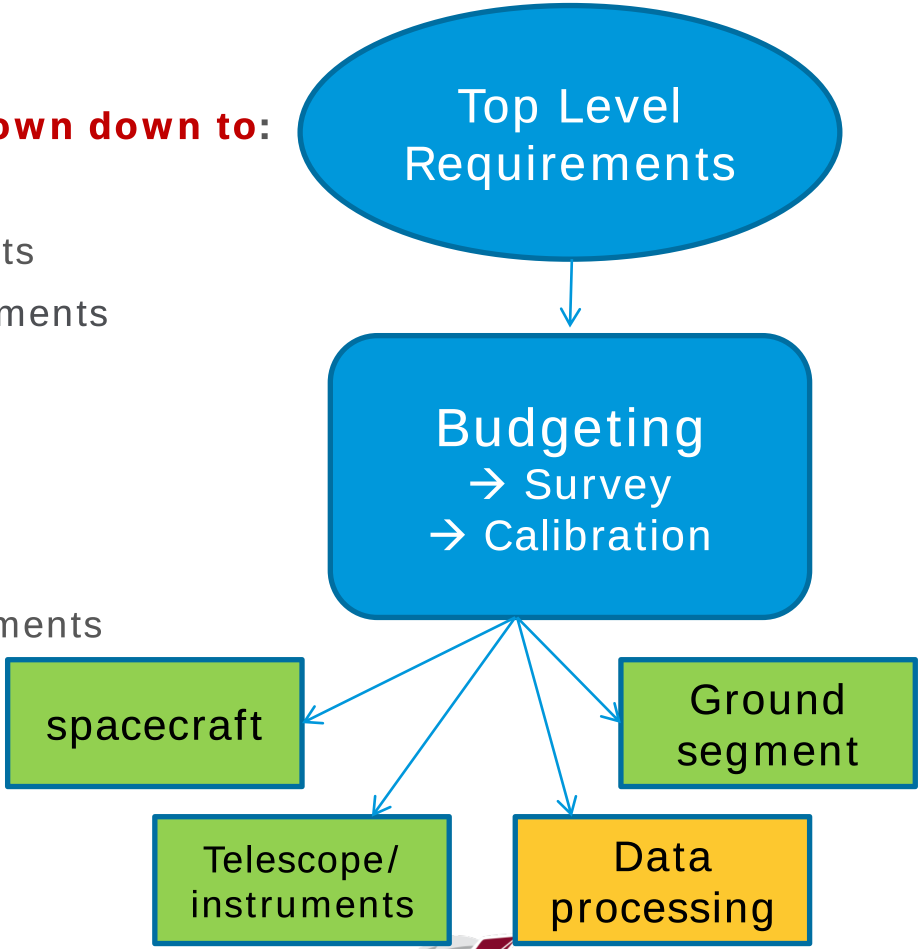
- Status
    - Southern hemisphere: DES data
    - Northern Hemisphere: negotiations in progress

Requirements flow-down

The top level requirements are flown down to the main sub-systems, with a traceable and justifiable budgeting

- **Top level science requirements are flown down to:**
  - Spacecraft requirements
  - Payload/Instrument requirements
  - Ground data processing requirements
  - Ground Segment requirements

- **The budgeting includes**
  - Control of margins
  - Operational constraints/requirements
  - Calibration requirements

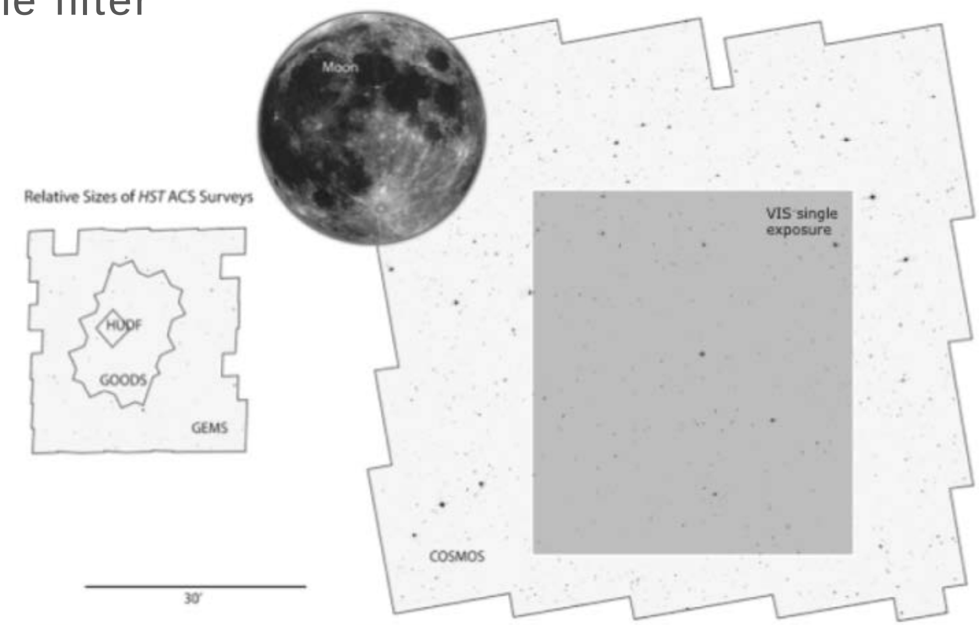


Euclid Payload

- Korsch 3-mirror anastigmat (TMA) telescope, 1.2 m primary, FoV ~0.54 deg^2
- Optical bench and payload cavity are passively cooled down to 150 K; with two instruments:
  - **NISP:** Spectrometer/Photo-imager - $0.92 < \lambda < 2.0$ micron

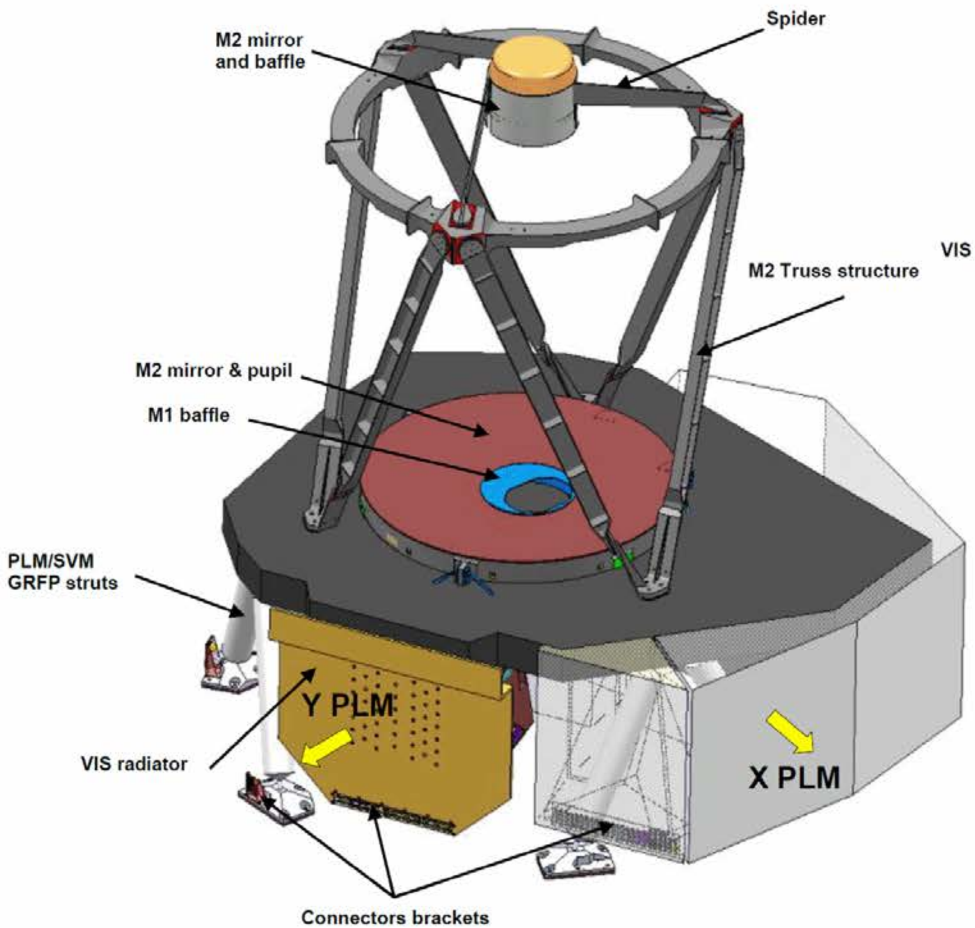
    16 (2kx2k) HgCdTe (HAWAII-2RG) detectors operating at 90-100 K
  - **VIS:** Visual imager - $0.55 < \lambda < 0.92$ micron

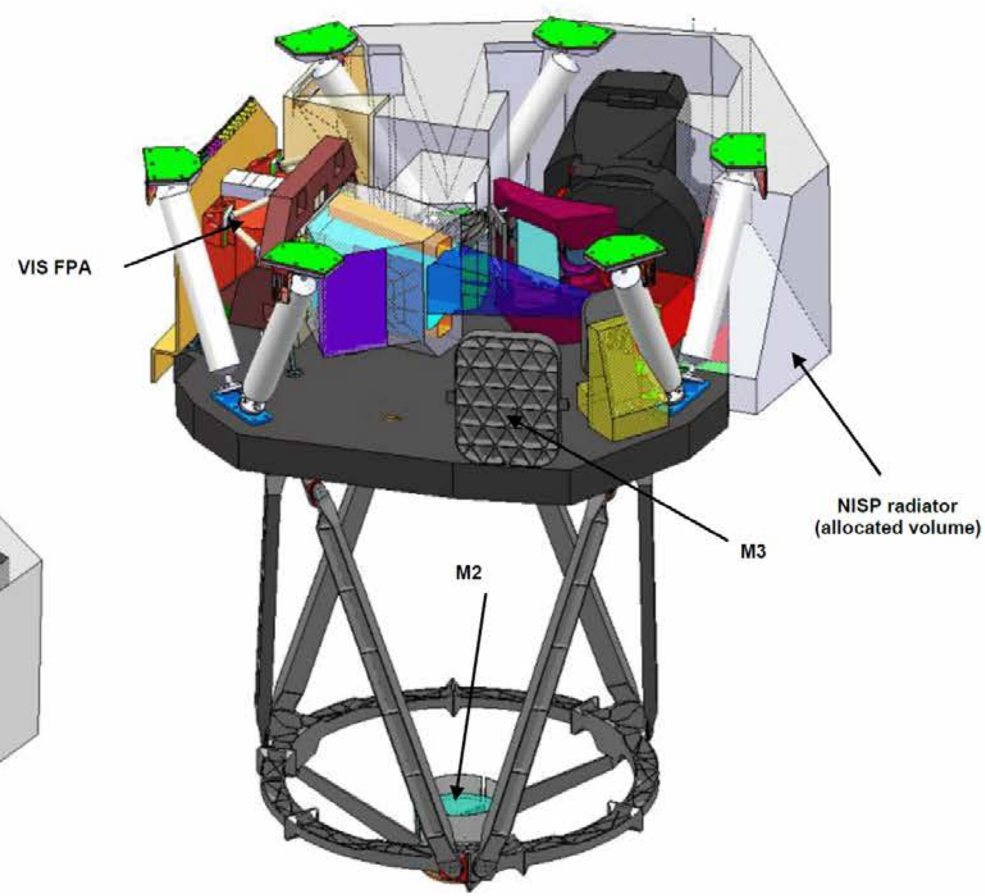
    36 (4kx4k) CCDs, single filter
- Sensors are optimised for Euclid
- PLM industrial contractor:
  Airbus DS - Toulouse



Credit: Space Telescope Science Institute/Nick Scoville (Caltech)

Euclid Payload





Euclid Mission and Spacecraft

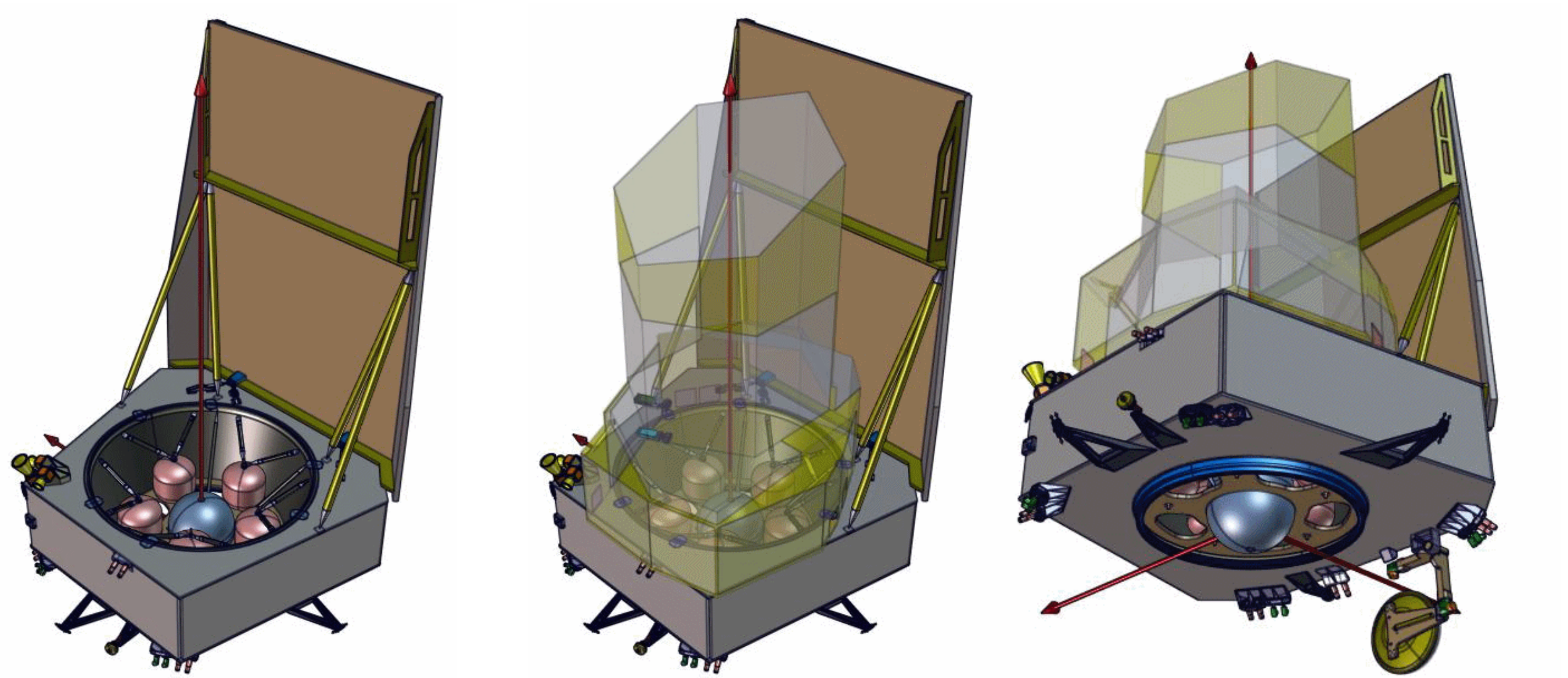
Mission

- Soyouz-Fregat ST-2.1B carrier, ~2150 kg spacecraft mass to L2, with line of sight nearly 90 degrees from Sun, to ensure **thermal stability**
- Mission is scoped to a nominal lifetime of 6 years + cruise + commissioning

Spacecraft

- Attitude and Orbit Control System includes a **Fine Guidance Sensor** near the (visual) instrument's focal plane; pointing stability < 25 mas during > 700 s.
- 4 hours daily communication window with **K-band** to receive **850 Gbit/day** compressed science telemetry

Euclid Spacecraft



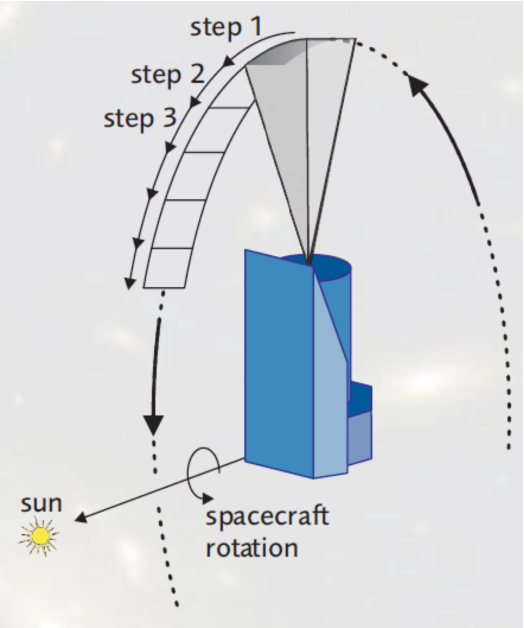
- ❑ Reaction wheels operated in "Stop and go"
- ❑ Cold gas for fine pointing actuation
- ❑ Spacecraft Prime Contractor: Thales-Alenia Space, Turin

Euclid Surveys

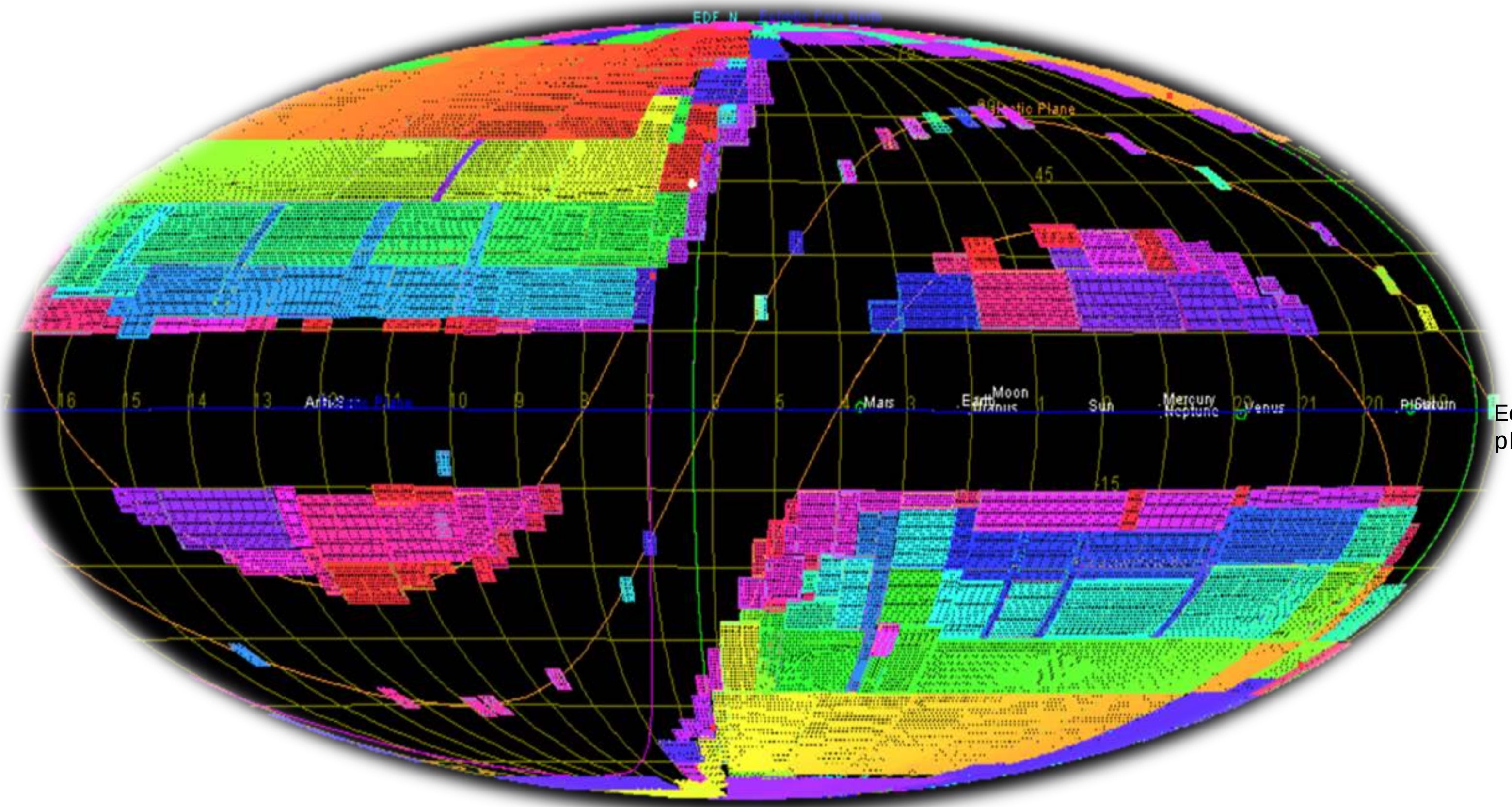
- **Wide Survey**:
  Euclid's primary *wide survey* aims at covering 15,000 deg^2, i.e. most of the extragalactic sky.

- **Deep Survey**:
  Euclid's additional *deep survey* covers ~40 square degrees. This survey is 2 mag deeper than the wide survey → AB > 26.5 mag.

- **Additional Surveys**
  The Euclid instrument and pointing capabilities offer the possibility to carry out additional surveys, during or after the nominal mission.

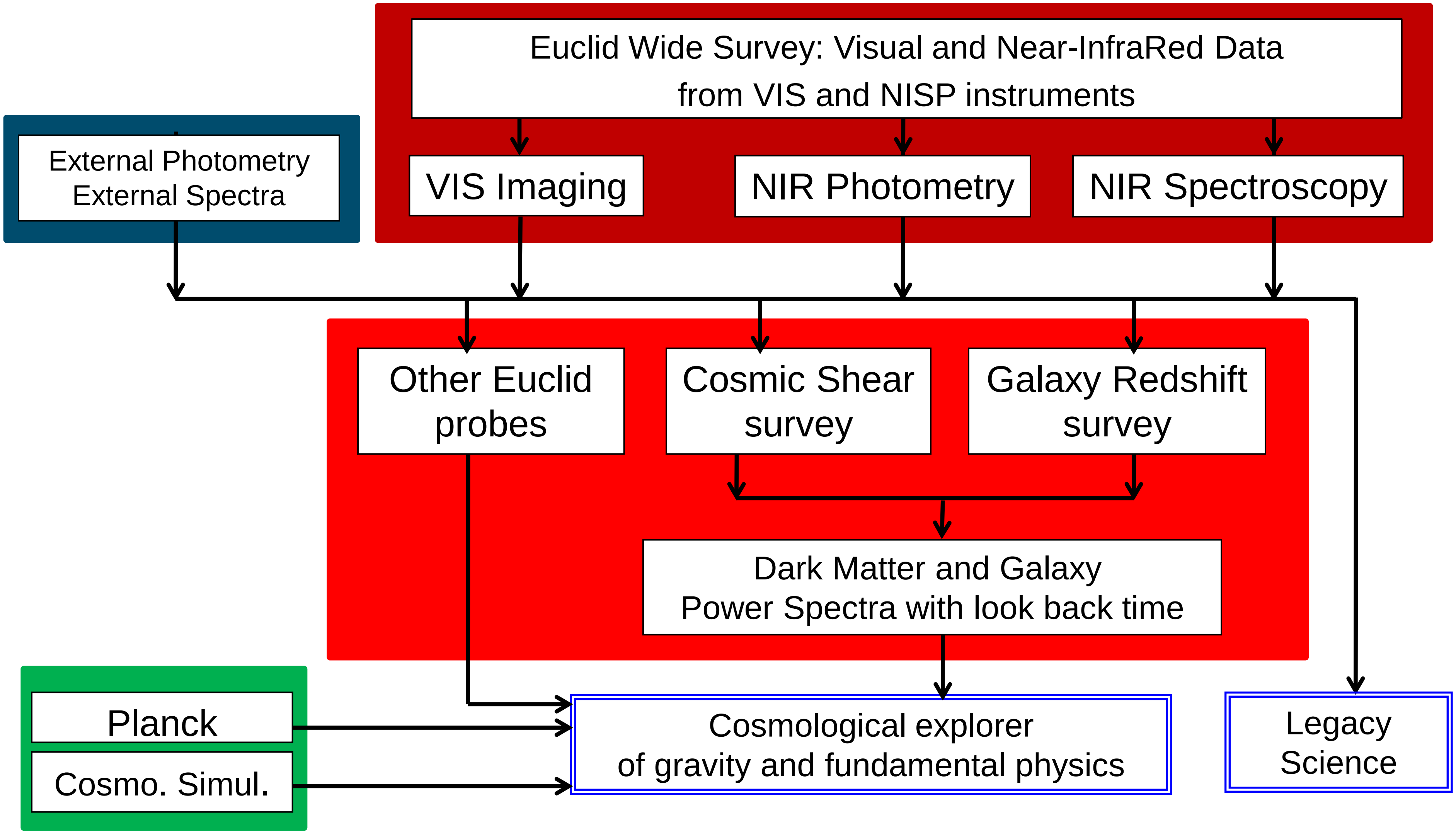


Euclid reference survey



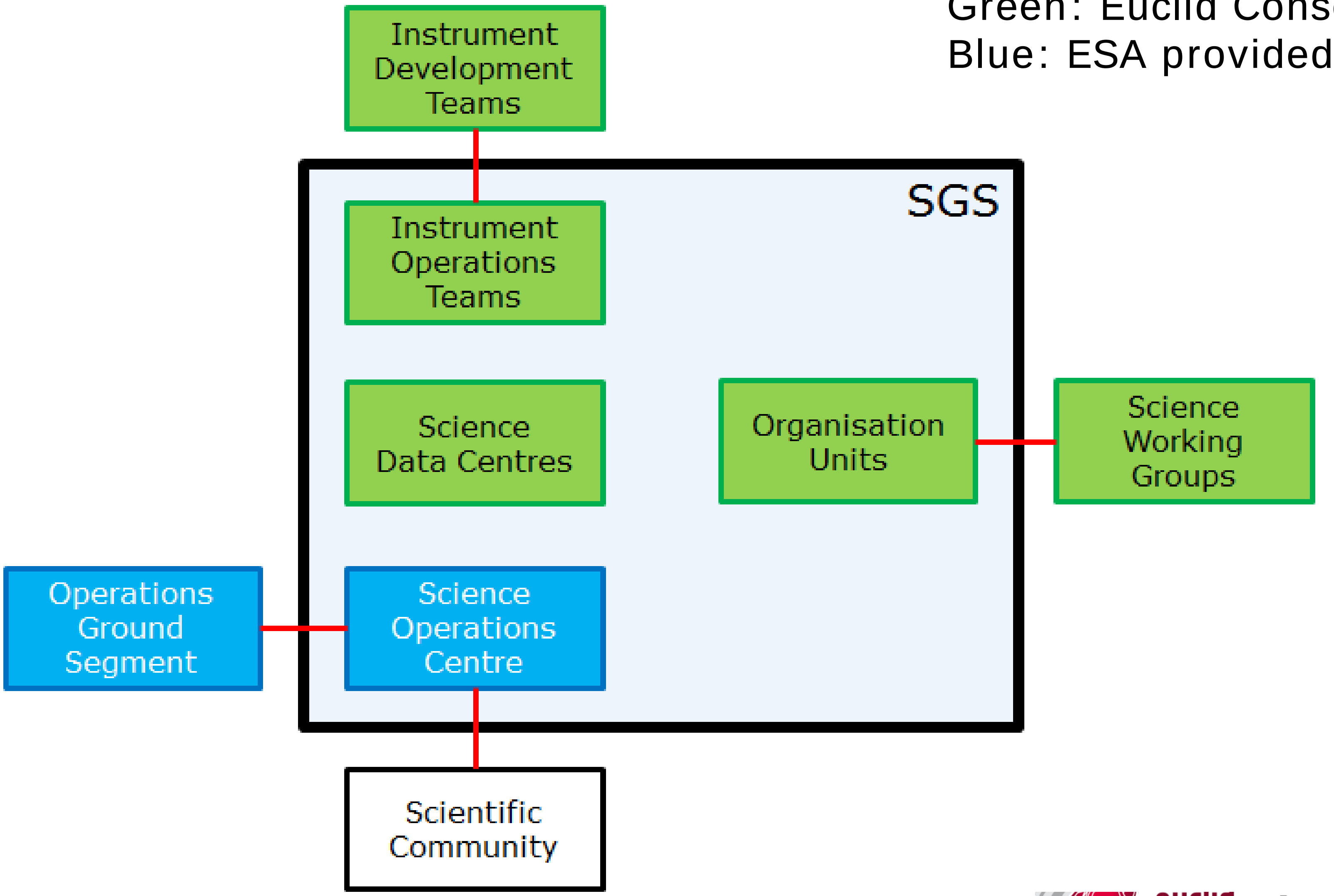
- Avoided: Ecliptic plane (zodiacal light) and low (<30 deg) galactic latitudes
- Different colours indicate different survey years
- Calibration fields along the galactic plane

Euclid Machinery

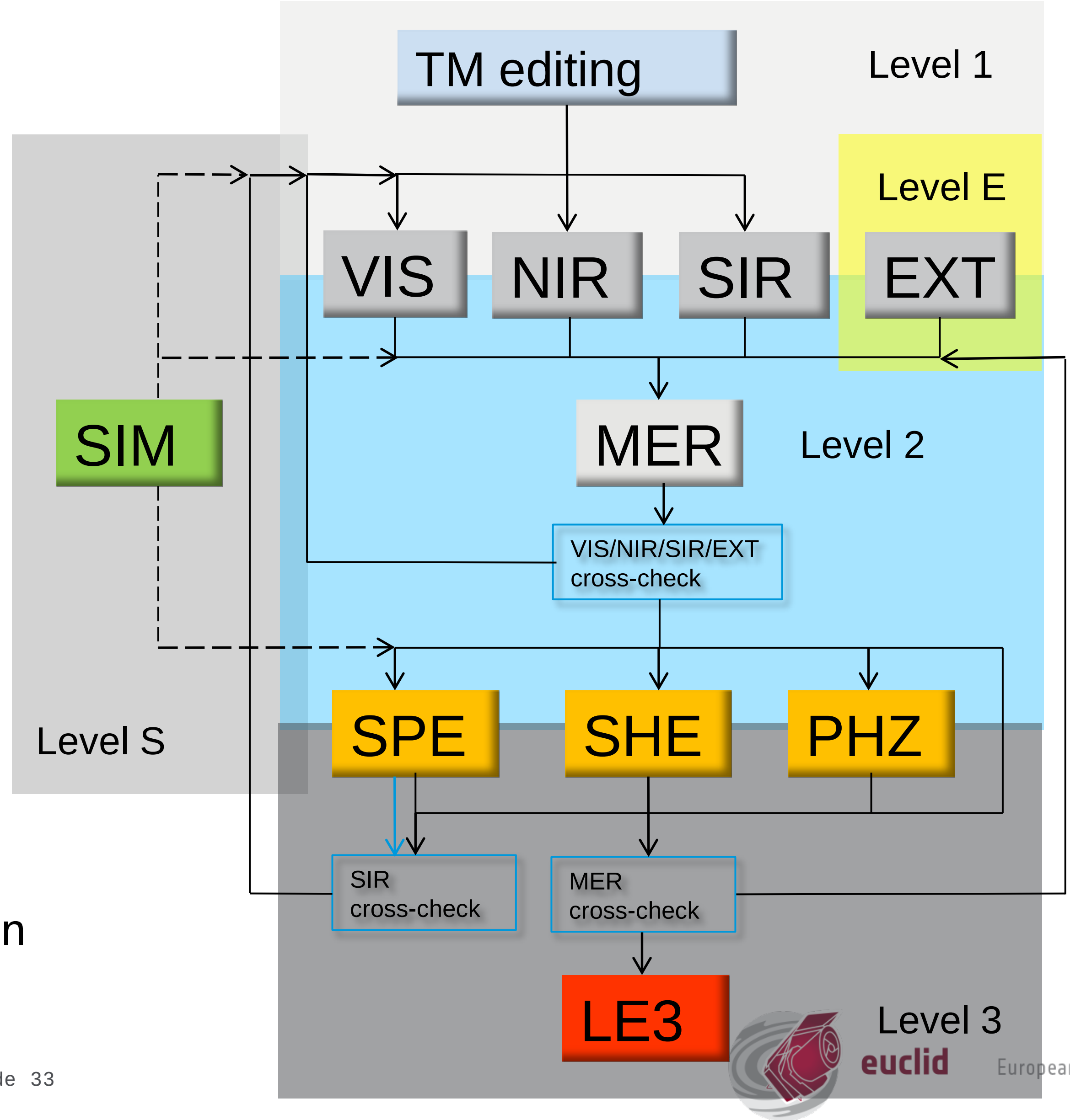


Science Ground Segment (SGS)

Green: Euclid Consortium
Blue: ESA provided

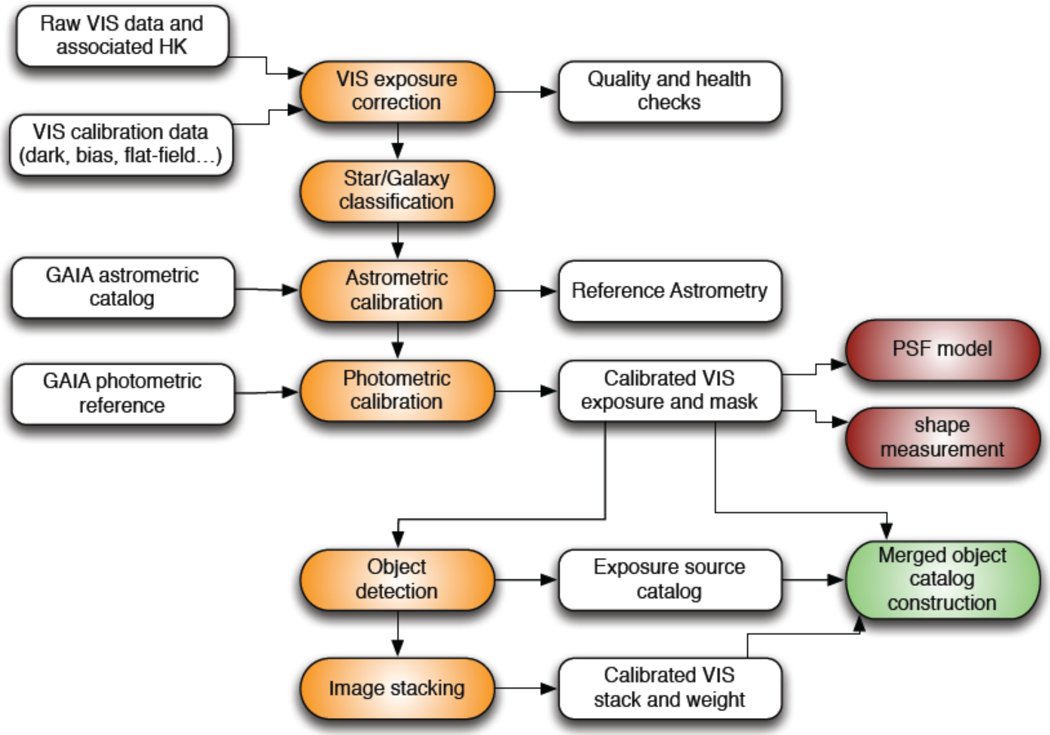


Data Processing Flow



Courtesy: F. Pasian

Example: VIS pipeline



Object type	Typical size	Number produced	Input or Output
Scientific exposure	1 GB	170000	I
Calibration exposure	1 GB	80000	I
Calibrated exposure and mask	3 GB	170000	O
Calibrated stack and mask	*n* x 3 GB	30000-40000	O
Exposure catalog	60000 sources per field		O

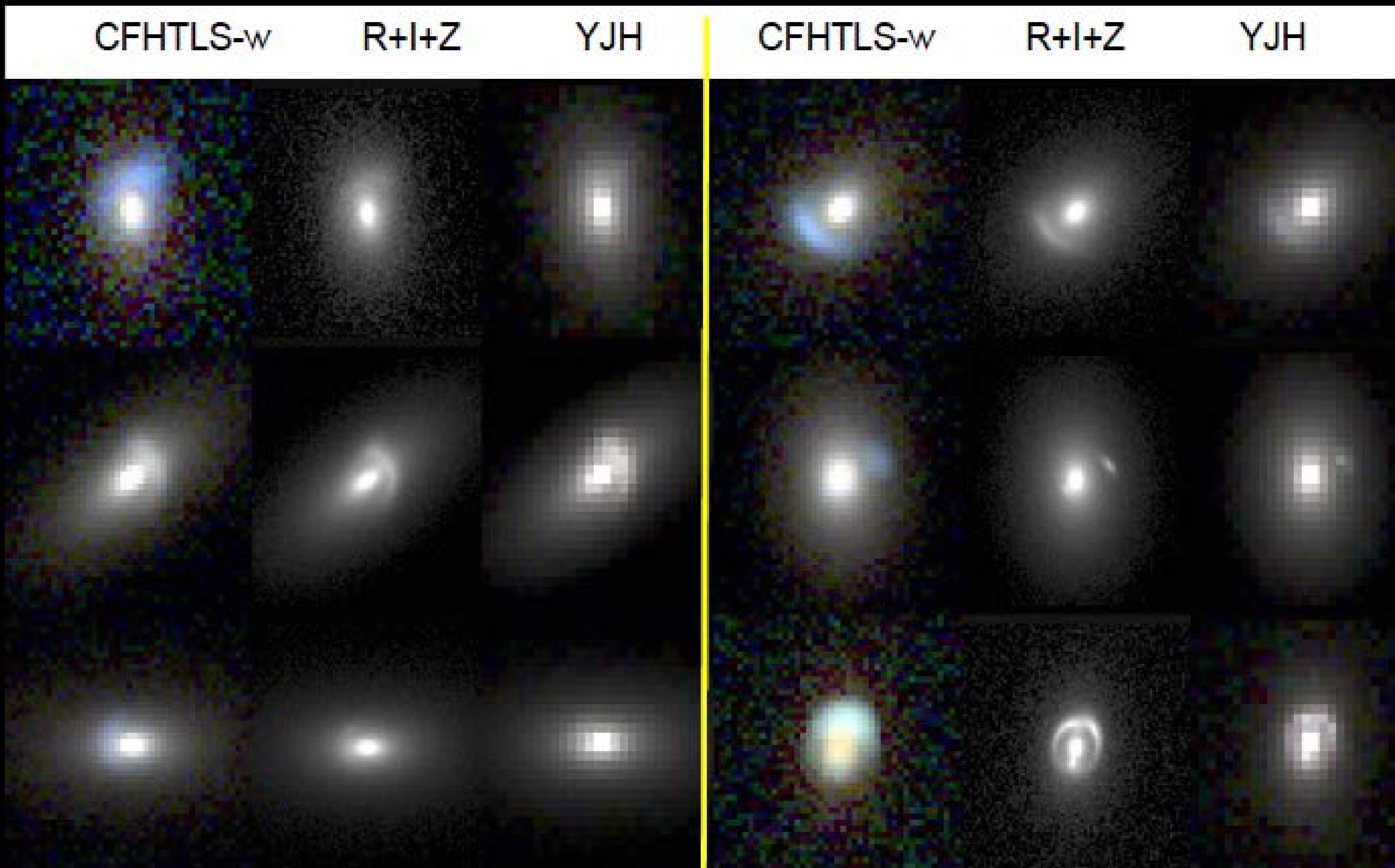
n = oversampling

Euclid Legacy

- Billions of stars and galaxies
  - statistics: Euclid = a SDSS survey for the $1<z<3$ universe
  - rare objects
- The Euclid surveys feature:
  - High resolution imaging,
  - NIR: access to cool, obscured and high redshift sources
    - Wide survey 15,000 deg^2 $YJH_{AB}=24$: 680 years with VISTA
    - Deep survey 40 deg^2 $YJH_{AB}=26$: 72 years with VISTA
- Synergy with LSST (a NIR LSST), GAIA, e-ROSITA, Planck
- Targets for JWST, ELT's, ALMA

Legacy Euclid surveys add hugely to scientific return from the mission

Simulations of gravitational arcs and Einstein rings with Euclid



SLACS (~2010 - HST)

SLACS: The Sloan Lens ACS Survey

www.SLACS.org

A. Bolton (U. Hawai'i IfA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

Image credit: A. Bolton, for the SLACS team and NASA/ESA

Courtesy: L. Koopmans

Summary

- Euclid is an ESA mission with an immense scientific value: Cosmology, Fundamental Physics, and Legacy for all Astronomy
  - 12 billion sources, 50 million redshifts
- It will measure complementary cosmological probes
- Euclid is a feasible mission: no technical (high TRL) and programmatic show stoppers – *but* there are still challenges.
- The Euclid Consortium consists of more than 100 European institutes and is well organised. It is fully equipped to support the mission and its science return
- Approved in June 2012, Launch in 2020 – 6 year nominal operations.

ESA Scientists

- According to SMP, ESA scientists can have 5% of the proprietary papers
- ESA scientists will not be members of the consortium but have the same publication rights
- We are in the process defining project for ESA scientists
- E.g. – solar system transients, extended emission, ...

Thanks for your attention!