The Euclid survey: a new window on the last 10 billion years of cosmic history

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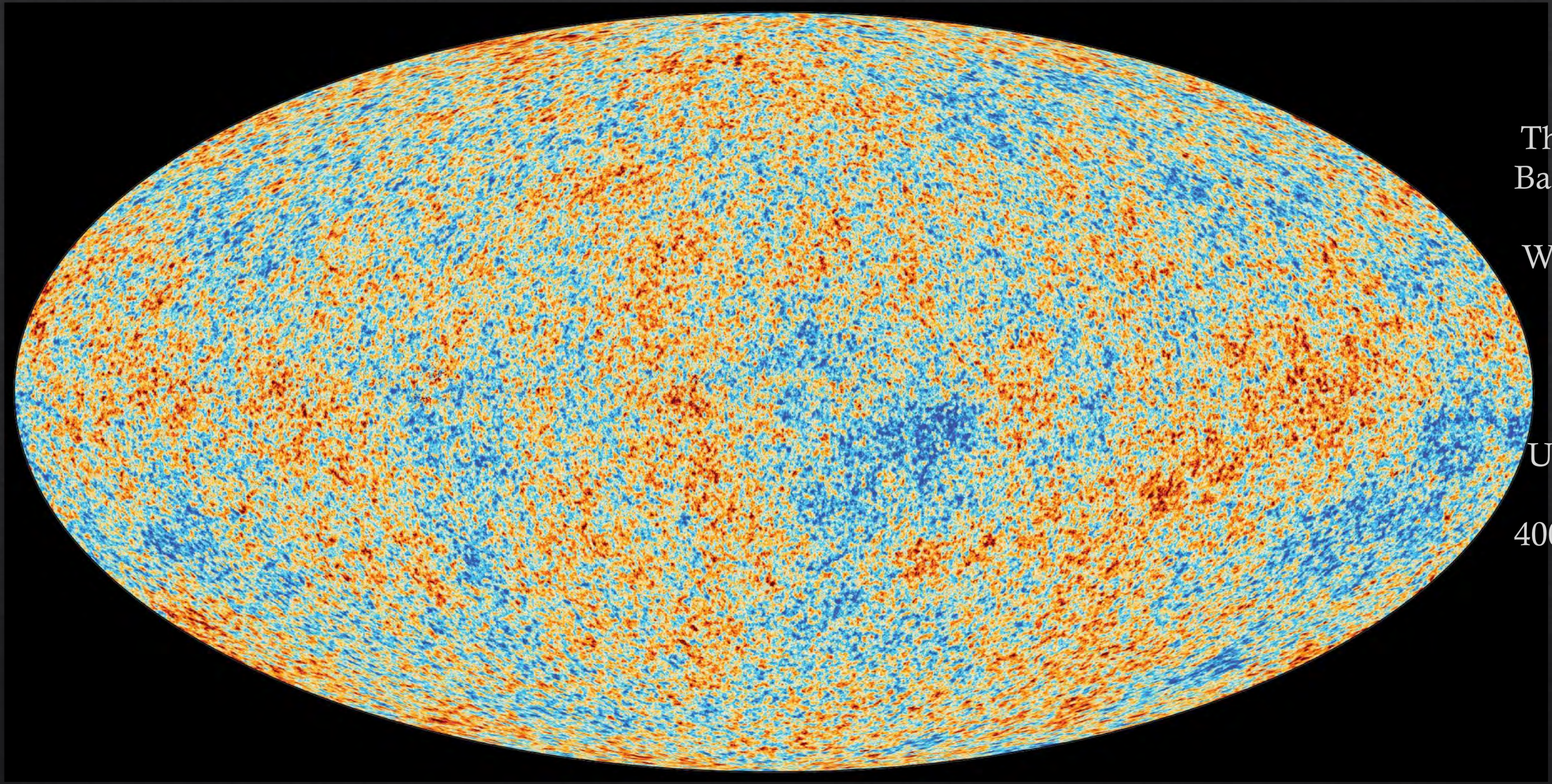
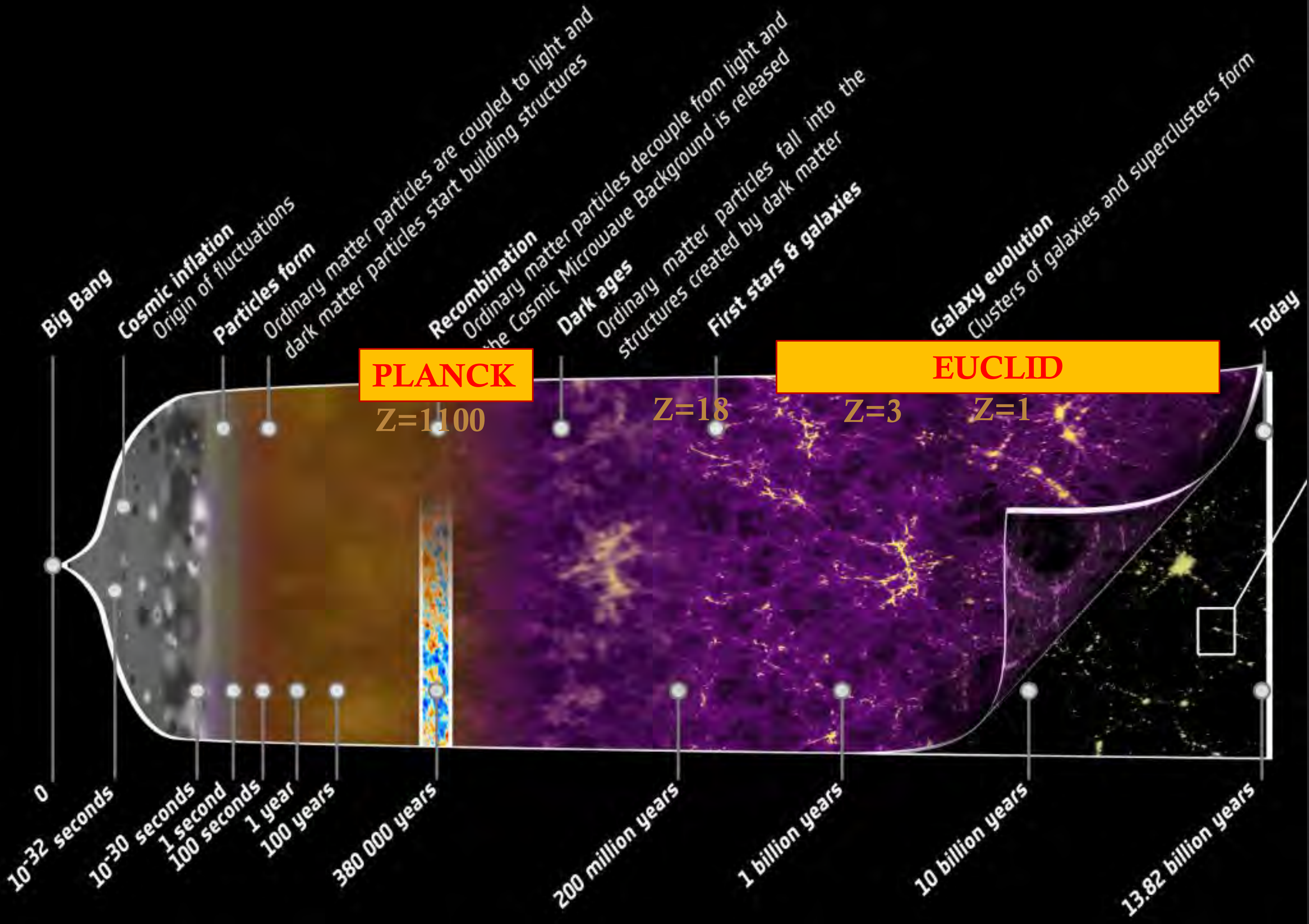
Introduction

- Observational cosmology has made incredible progress in the last couple of decades
- Thanks to, notably, very precise observations of the Cosmic Microwave Background fluctuations, supernovae, galaxy clusters and large galaxy surveys
- We live in an ever-expanding, accelerating Universe, spatially very close to flat
- The main cosmological parameters have been determined with accuracy
- However, the "elephant in the room" of this picture-perfect Universe is the massive presence of unknowns: Dark Matter and Dark Energy (or vacuum energy), together accounting for ~95% of the energy content of the present-day Universe.



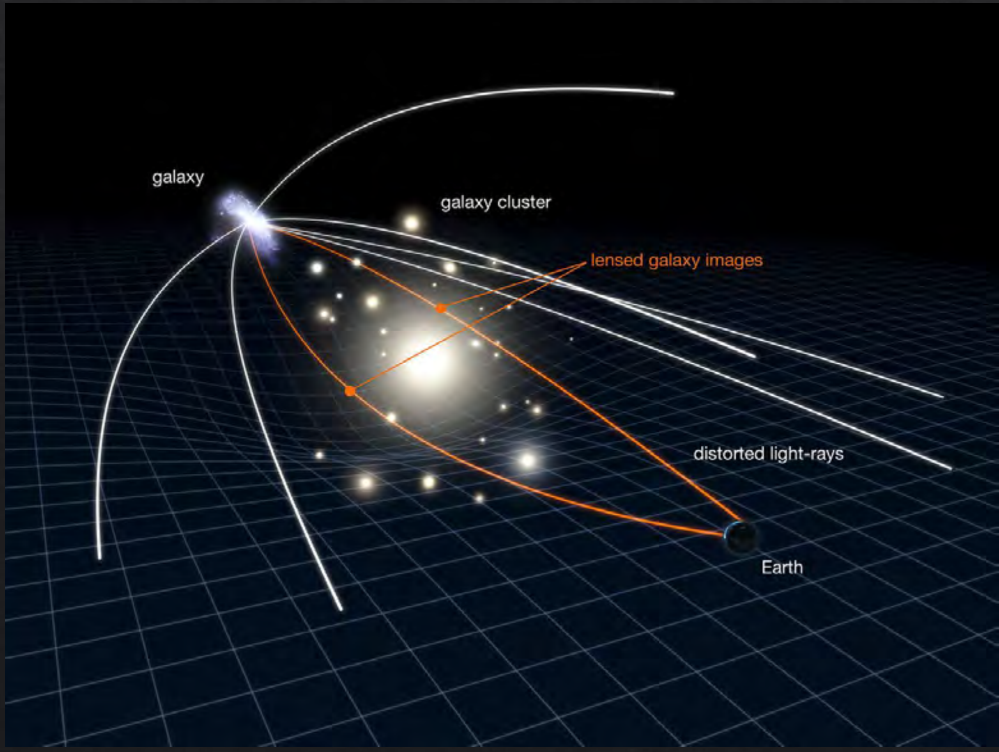
The Cosmic Microwave Background temperature fluctuations
Whole sky – Mollweide projection
Planck coll. 2018

The hot and dense Universe at the time of atom formation
400000 years > Big Bang
13.8 Gyr ago



Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
PLANCK
EUCLID
Z=1100
Z=18
Z=3
Z=1
0
10-32 seconds
10-30 seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

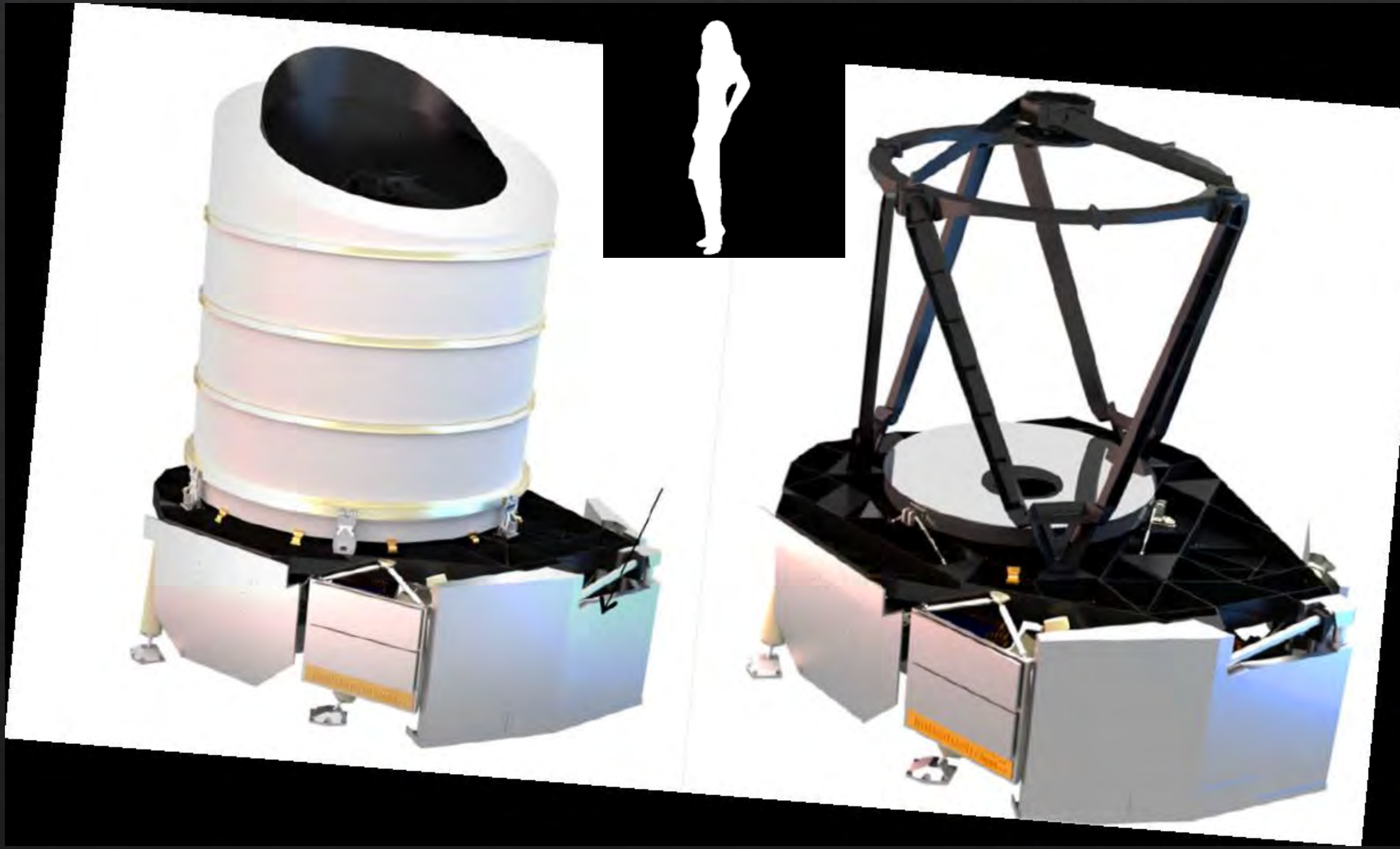
- Gravitational lensing
- Due to foreground large clump of Dark Matter (e.g. galaxy cluster), lensing light from background galaxy
- Hubble Space Telecope image on the left
- Drawing below from L. Calçada



- Galaxies gather into larger structures like clusters, filaments and super-clusters
- These large-scale structures evolved from the over-densities (over-temperatures) present in the early Universe (themselves having evolved from earliest quantum fluctuations)
- Hubble Space Telescope image of a galaxy cluster

The Euclid mission

- In order to better understand these DM and DE, the European Space Agency is implementing the Euclid mission
- 1.2 m space telescope with two focal instruments: Visual Imaging channel (VIS) and the Near-Infrared Spectrometer and Photometer (NISP).
- Each field of view is a 0.8 x 0.7 deg. tile with four dithers, with each dither in turn split into VIS imaging, NISP imaging and NISP spectrometry observations.
- Euclid will be launched in 2022 by Soyuz from Kourou, French Guiana, to the Sun-Earth L2 point.

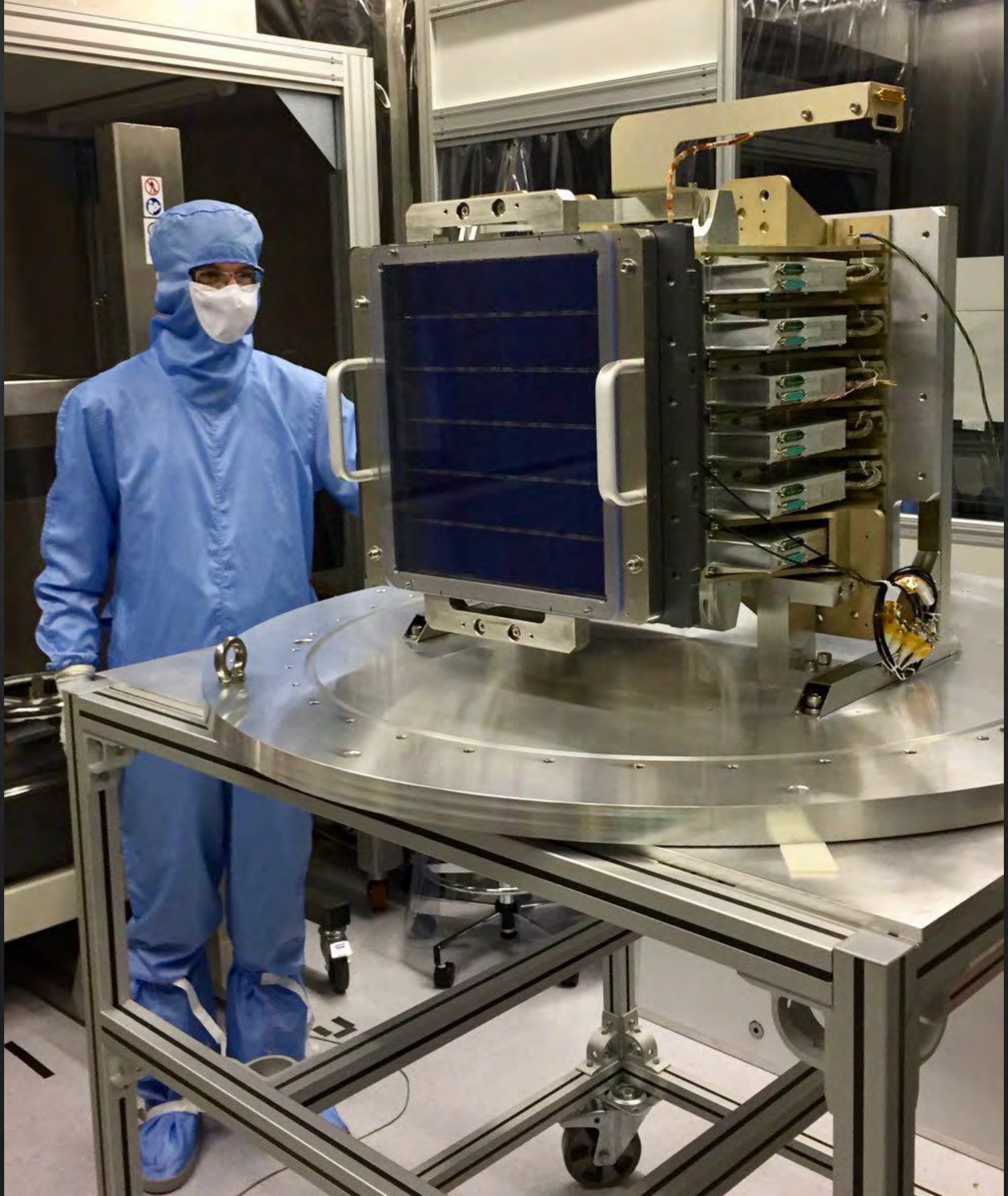


VIS instrument

- Visible wide-band imager
- 0.1”pix: precision galaxy shape measurement

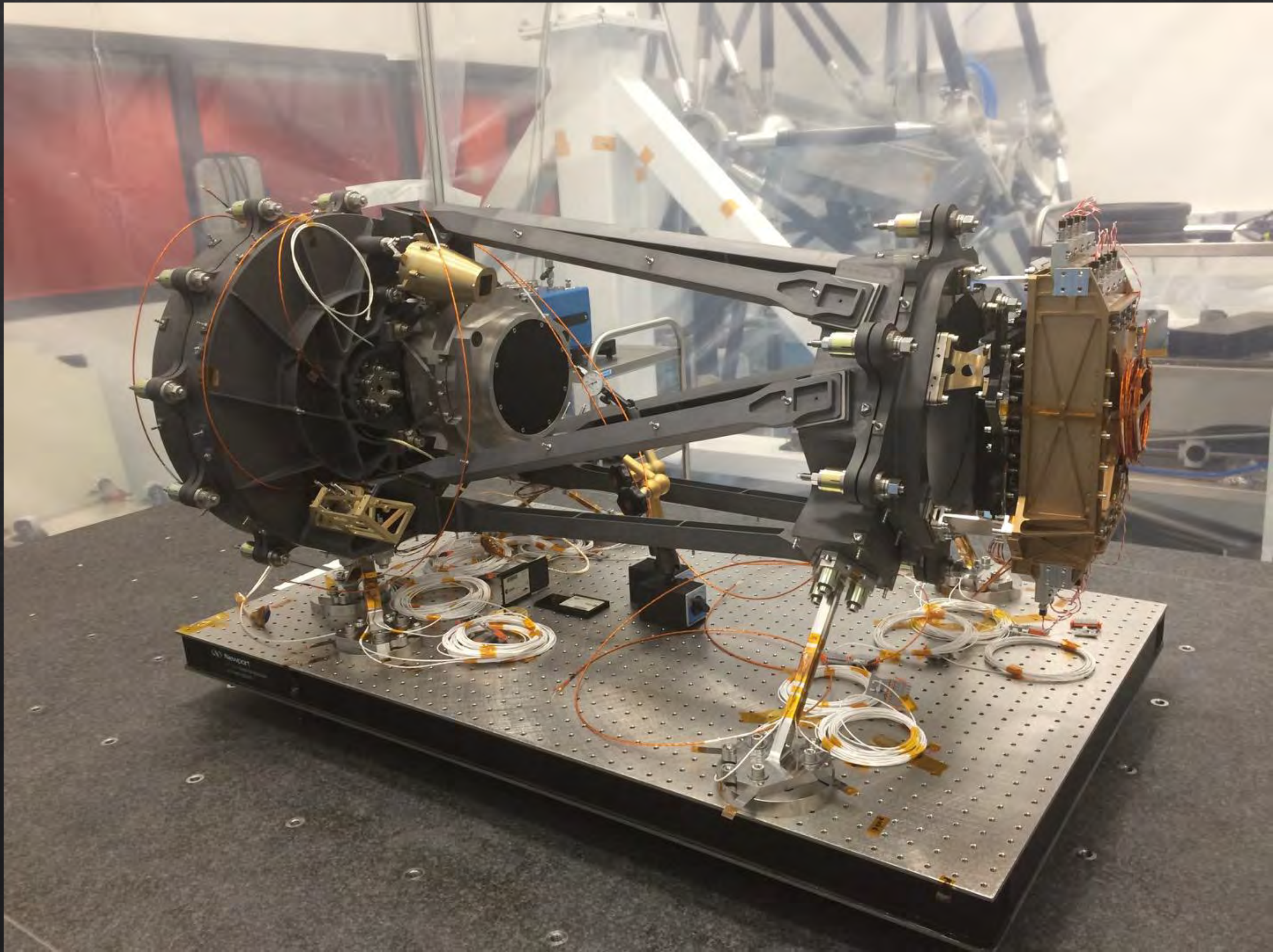
- VIS observes in a large unique visible band (0.55 – 0.9 μm) with a 24.5 mag (10 σ ext.) sensitivity thanks to 36 4kx4k CCD arrays, and reaches a pixel size of about 0.1”

- UK led, MSSL



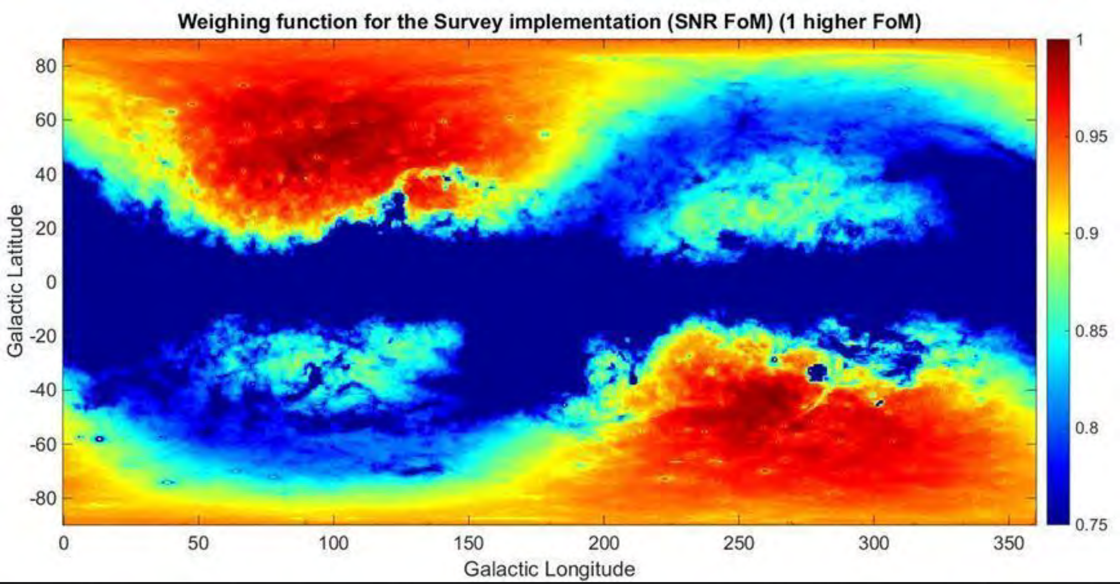
NISP instrument

- Near Infrared spectrometer & photometer
- NISP photometry consists of three wide near-infrared bands (Y: 0.9 – 1.1 μm, J: 1.1 – 1.4 μm, H: 1.4 – 2 μm) with a sensitivity of 24 mag (5 σ point source) and 0.3” pixel size.
- The NISP slit-less spectrometer works in the 1.1 – 1.85 μm range with a spectral resolution > 380 assuming a 0.5” aperture.
- Accurate measurement of galaxy redshifts
- France led, CNES/LAM



The Euclid survey

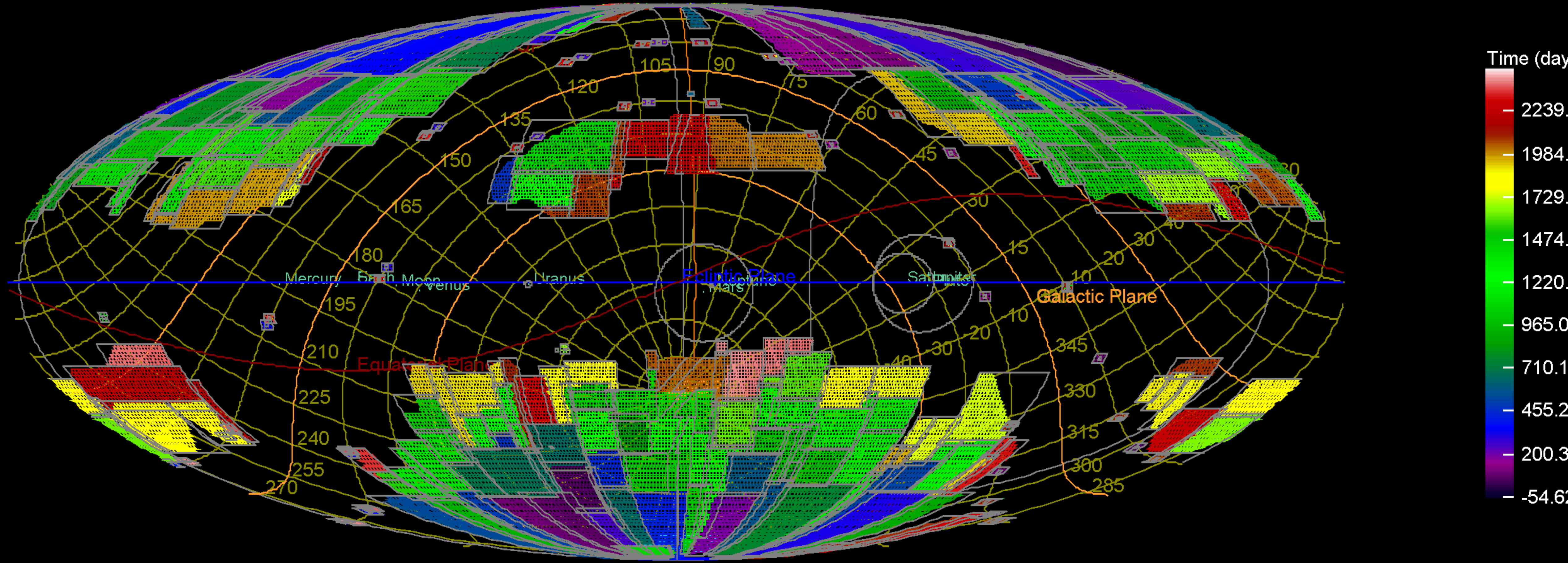
- Wide survey coverage: **15,000 deg2**
- Depth: **24.5mag**
- **30 galaxies** per arcmin2
- Wide survey: low-frequency grism only
- Avoid Ecliptic plane & low Galactic latitudes (< 30°)
- Exact footprint of the wide survey depends on the Figure-of-Merit map (on the right)



- Calibration fields along Galactic plane
- 16 large slews / month

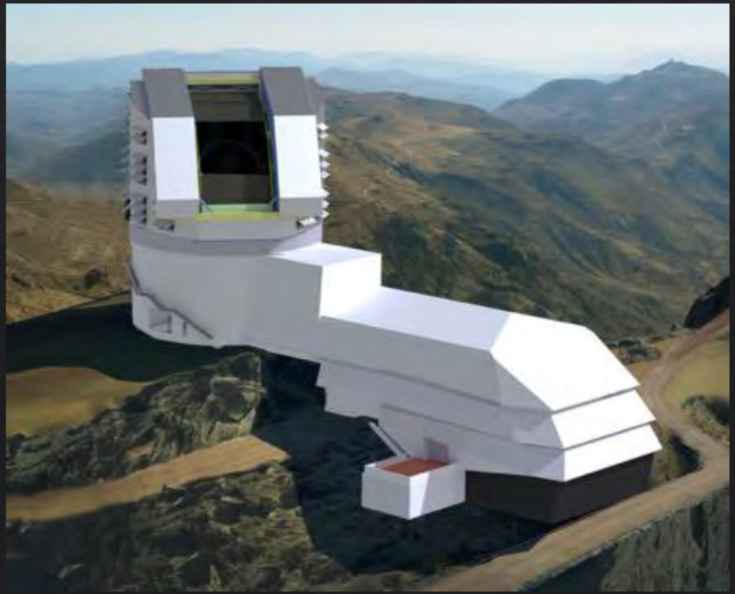
- Three deep fields, 40 sq. deg. in total:
- One near the North Ecliptic pole
- One near the South Ecliptic pole
- One in Fornax coinciding with the Chandra Deep Field
- It is required that the deep fields are at least 2 magnitudes deeper than the wide survey
- High-redshift cosmology (z > 2)

The Euclid survey (6 years)



Synergies

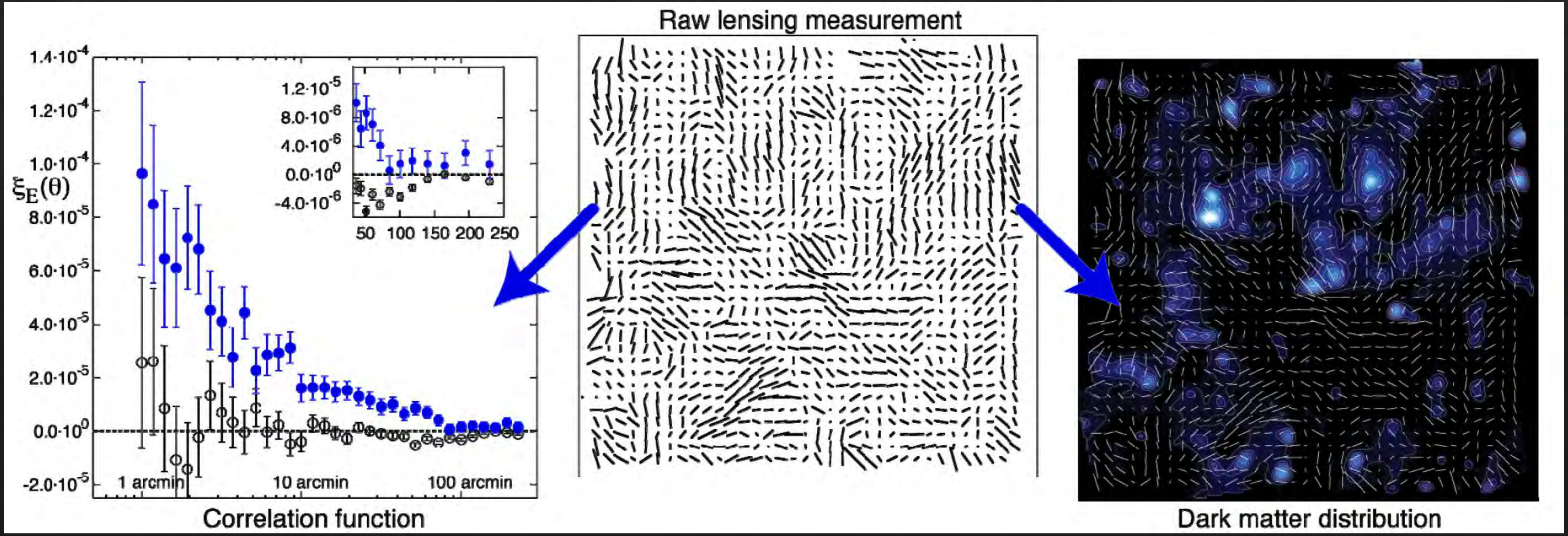
- Additional **4 band** (u)griz photometry: Pan-starrs, Subaru, CFHT
- Needed for photometric redshift and PSF modelling for individual galaxies
- LSST: 8.4m telescope (~2023)
- Volume of additional external data >> Euclid data



Weak-lensing probe with Euclid

- Weak-lensing measurements of > 1 billion galaxies
- Measuring the correlations in the shapes of these galaxies
  → determine the distribution of dark matter

Plots from Euclid Redbook, HST observations Massey et al. 2007



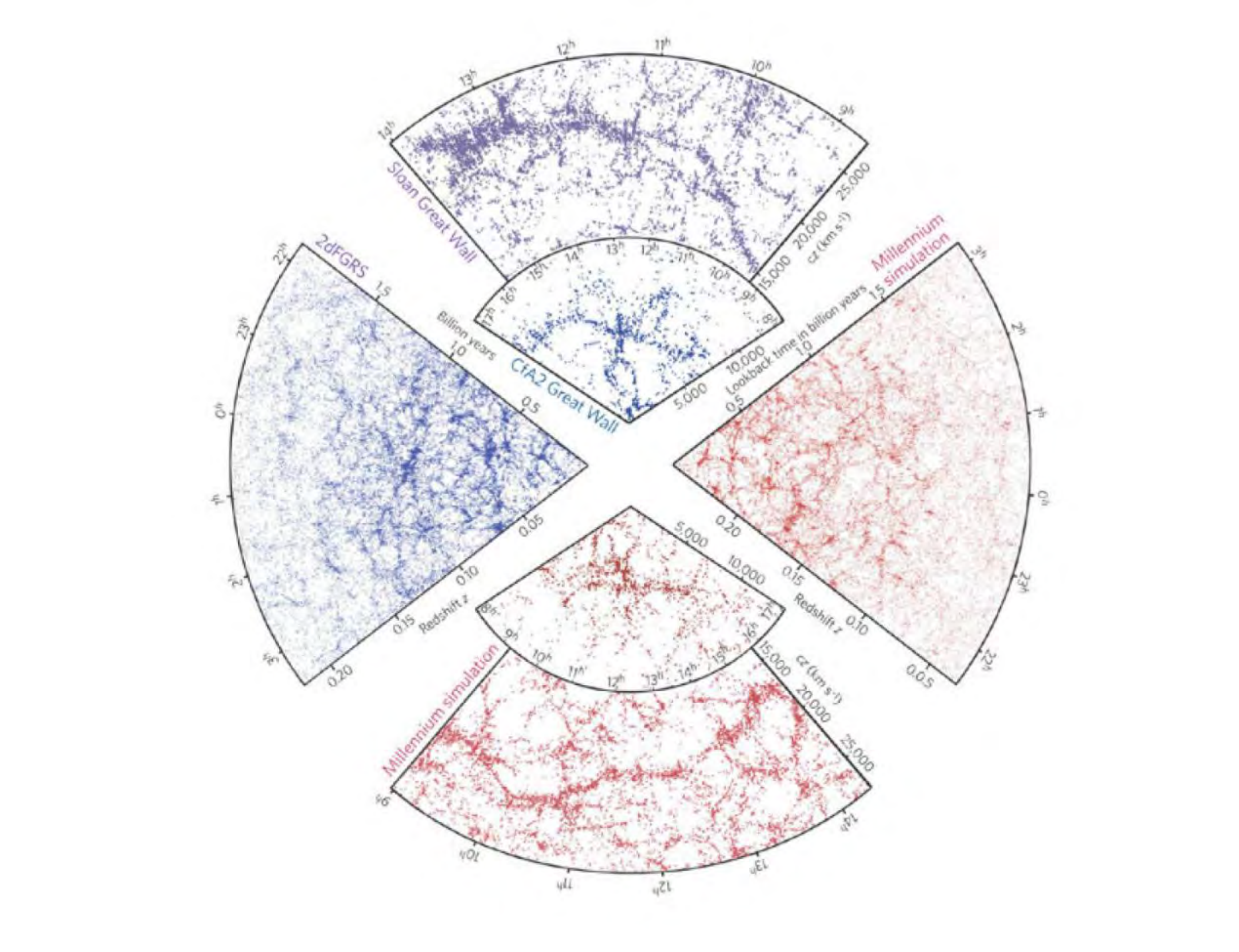
Weak-lensing probe

- With Euclid we also get photometric redshifts, so it is possible to study the matter distribution in 3D (***weak-lensing tomography***)
- The required accuracy on photometric redshift cannot be achieved from broadband Euclid data alone → additional (ground-based) data are required (visible bands)
- Weak lensing also constrains the expansion history of the Universe, through a combination of angular diameter distances to the lensed galaxies

Galaxy clustering probe with Euclid

- Baryonic Acoustic Oscillations (BAO) are wiggle patterns imprinted in the clustering of galaxies
- They provide a standard ruler to measure the rate of expansion of the Universe
- The properties of these wiggles are derived from accurate distance measurements of galaxies
- By measuring the spectroscopic redshifts of 50 million galaxies in the redshift range $0.7<z<2.1$, the *three dimensional* galaxy distribution of the Universe can be mapped to high precision
- 3-D galaxy distribution can be quantified in terms of power spectrum (or correlation function) within several redshift bins over time interval when Dark Energy becomes dynamically important
- The amplitude, shape and anisotropy of these statistics contain crucial information on the expansion and structure growth histories of the Universe
- Dark Energy influences the way galaxies cluster in this time interval, so measurements of galaxy clustering provide a powerful probe to infer DE properties

Galaxy Clustering with Euclid



Galaxy distribution in the Sloan, 2dFGRS and CfA2 Great Wall, compared to simulated distributions from the Millennium Run (*Springel et al. 2005*)

See Euclid Redbook for more details

Combining both probes:
Weak Lensing and Galaxy Clustering

- The unique feature of Euclid is that it will measure *both* the power spectrum of the galaxy distribution through its redshift survey, and that of the underlying matter distribution through its weak lensing survey

- The key benefit comes from the full combination of a deep imaging survey and an extensive redshift survey *over the same area of sky*

- As a result, the relationship between the distribution of luminous objects and the mass density field can be reconstructed

- This also allows to test gravity on cosmological scales

- Control of systematic effects is key to achieve Euclid cosmological goals

Expected performance on Dark Energy parameters

- Dark Energy equation of state

  $\mathbf{w} = \frac{p}{\rho}$

- Dark Energy equation of state, parametrized

  $\mathbf{w(a) = w_p + w_a\,(a_p - a)}$

  where the pivot scale factor a_p is chosen to have uncorrelated statistical errors on both parameters

- When p is present day we simply have:

  $\mathbf{w(a) = w_0 + w_a\,(1\text{-}a)}$

- Euclid+Planck expected performance on both parameters:

  0.007 on w_p

  0.035 on w_a

  (1σ predicted errors marginalised over all other parameters, Ω_m: 0.25, Ω_Λ: 0.75, Ω_b: 0.0445, σ_8: 0.8, n_s: 1.0, h: 0.7)

Euclid consortium

- 1500 scientists & engineers
- 15 countries
- 120 institutes
- Europe & USA
- Responsible for most of data-processing (Level 2 and up) and scientific analysis of Euclid data

Euclid Consortium 2018

ESA Euclid Science Operations Centre

Photo B. Altieri

SOC responsibilities

- Level 1 processing of Euclid data
- Quick-Look Analysis of Euclid data
- Survey strategy support
- Survey operations (see next slide)
- Operations, liaison to Mission Operations Centre
- Instrument support role
- Euclid Helpdesk
- Communication, web pages…
- …

SOC responsibilities for the Euclid survey

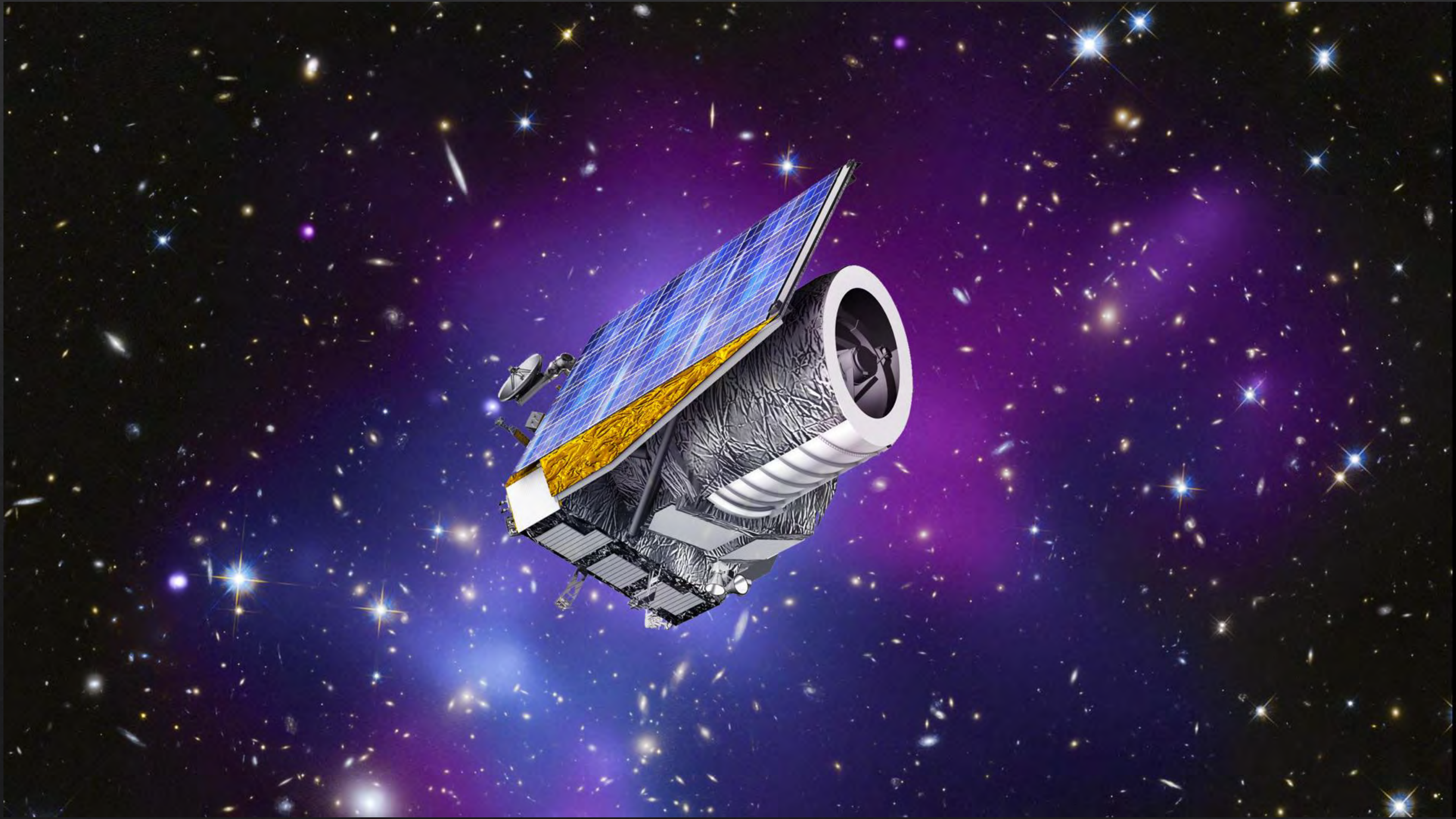
- **SOC responsibilities for survey operations:**

- Verification of the Reference Survey Definition: **integrity checks**
- Verification of the RSD: **compliance checks** (celestial constraints, consumables…)
- **survey performance verification** (RSD)

- Making and maintaining the Operational Sky Survey from the RSD
- Operating the survey in case of contingencies and change requests
- Leading the Euclid survey CCB for any change in the survey
- Issuing Survey Schedule Requests to MOC

- Monitoring of the survey
- Reporting on the state of the survey

- Launch foreseen early 2022
- Kourou, French Guiana
- Launch vehicle: Soyuz ST 2.1B



Thank you for your attention

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Final thoughts

- Que guarda Darth Vader en su nevera ?
- Helado oscuro