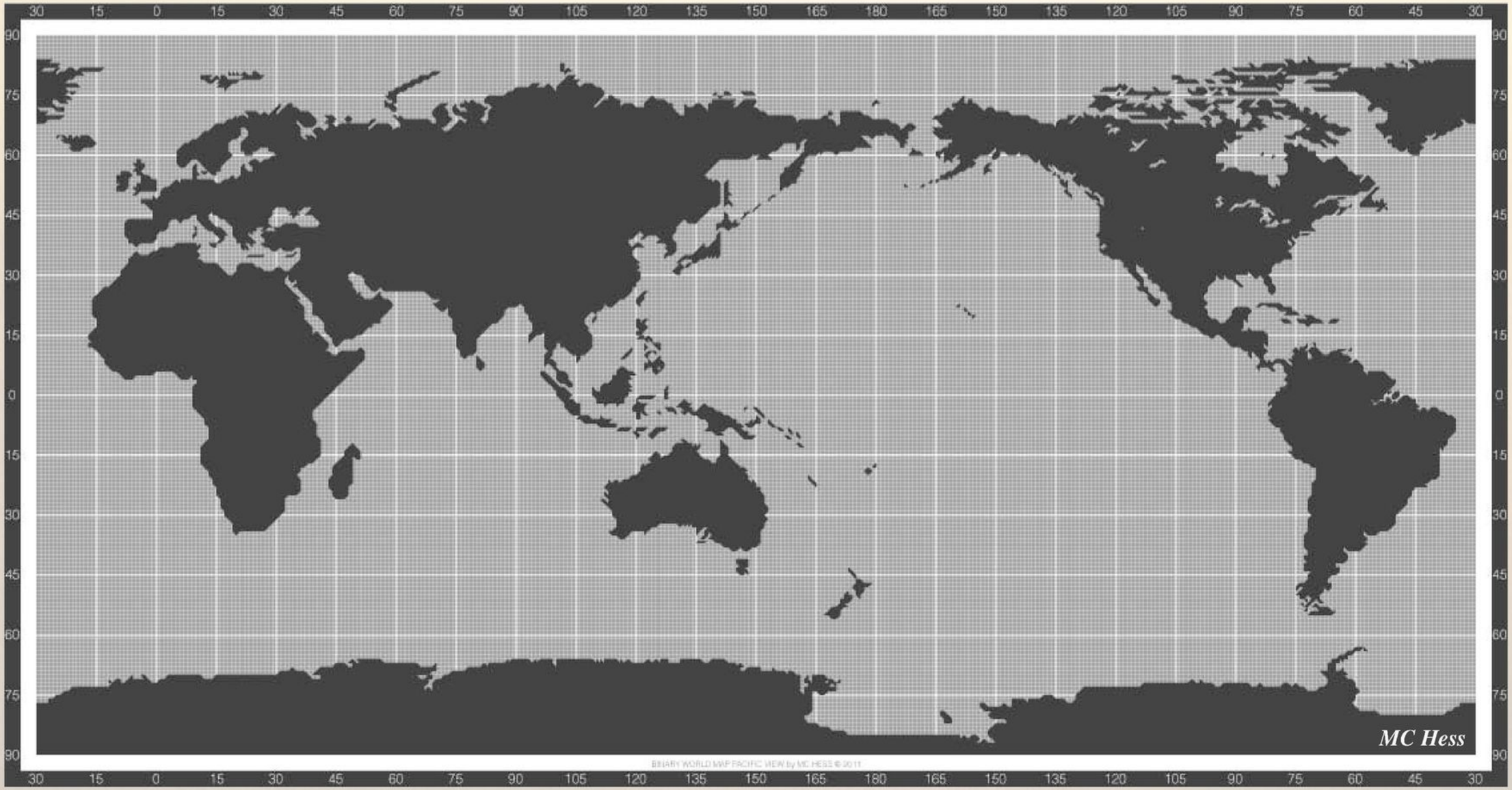
# Euclid Complementary Observations


## Jean–Charles Cuillandre, Konrad Kuijken, Peter Capak

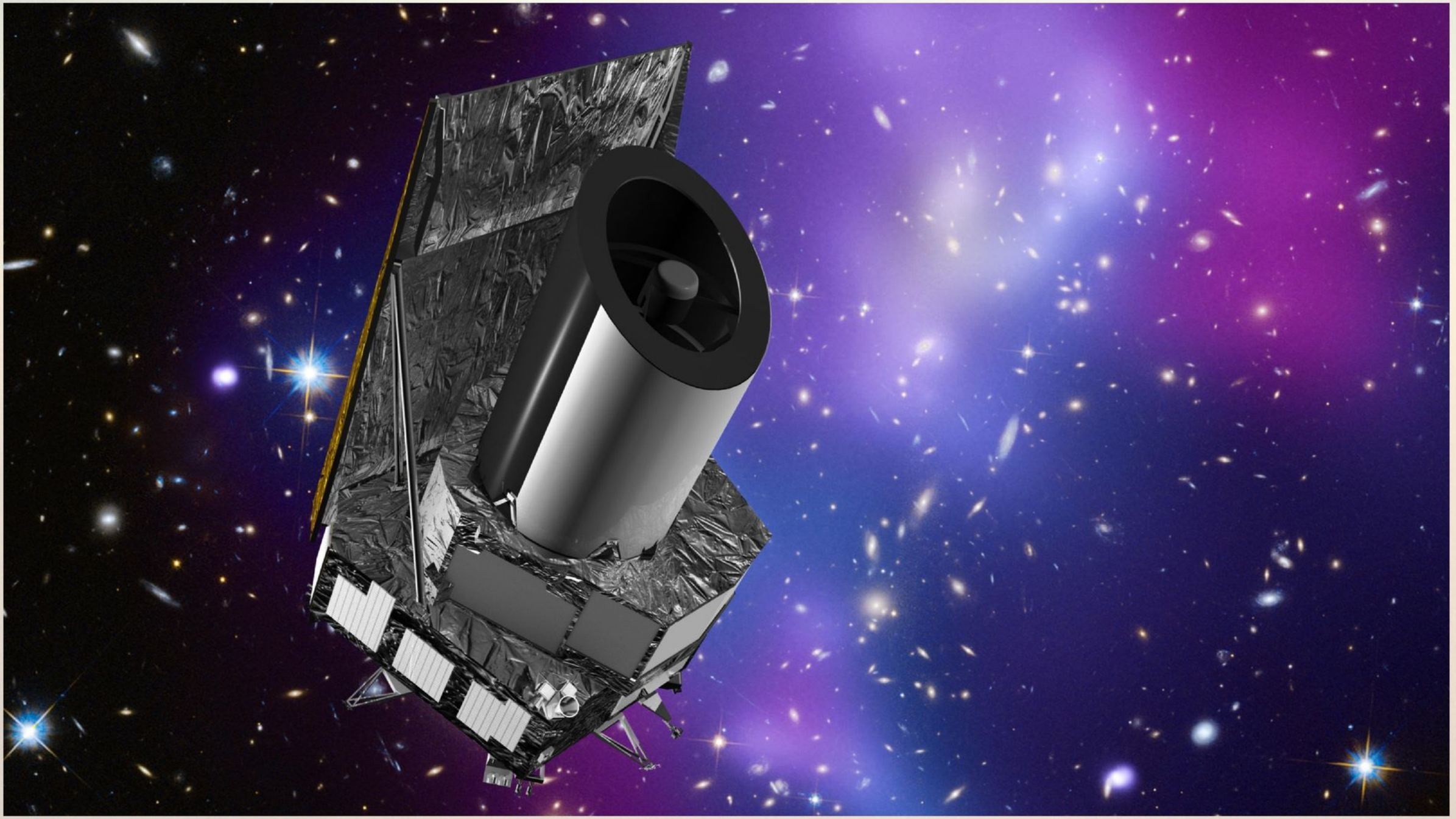
*CEA–Saclay / Observatoire de Paris* *Leiden Observatory* *Caltech*

*with contributions from Yannick Mellier (IAP) and Gijs Verdoes Kleijn (University of Groningen)*


*SCIOPS, Oct. 2017, ESAC, Spain*

# Mapping the geometry of the dark Universe



*How most people perceive the Euclid mission*

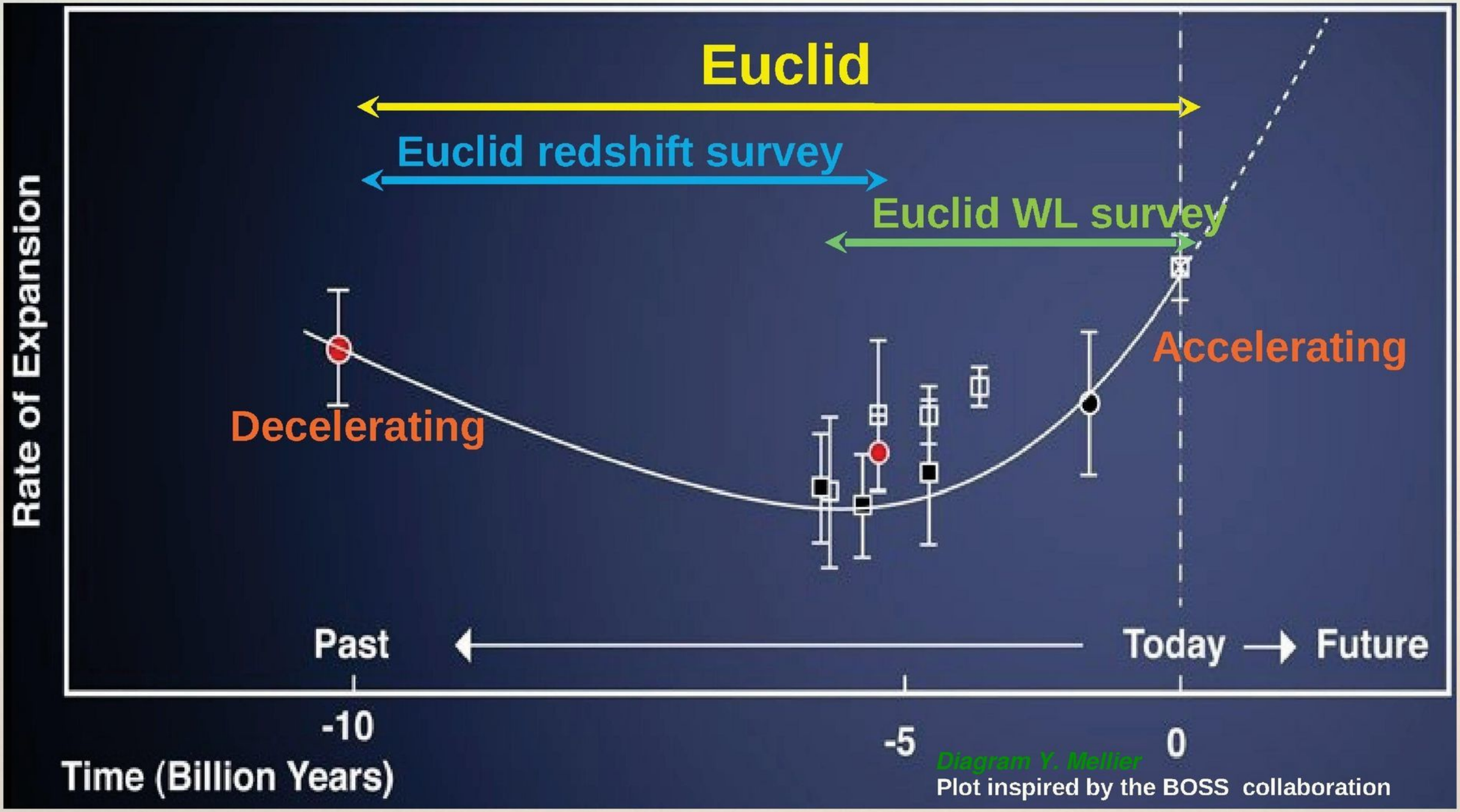
# How people should perceive the Euclid mission


– The ESA mission, 6 years non–stop of space observations

– Plus 1,000 nights across 8 world–class ground–based telescopes

– A combo critical to reach the mission core science goals on dark energy

# Probing the DM vs DE universe dominated transition



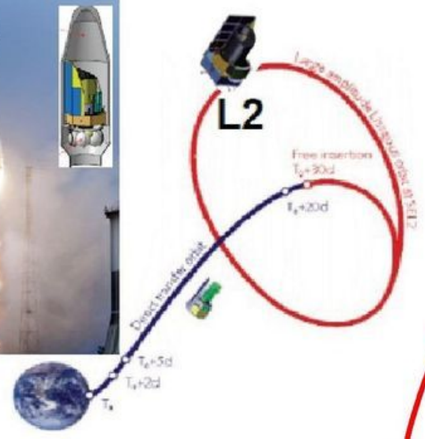

– Dark matter once dominated the Universe expansion versus dark energy

– Euclid is a calibration mission aimed at high precision cosmology

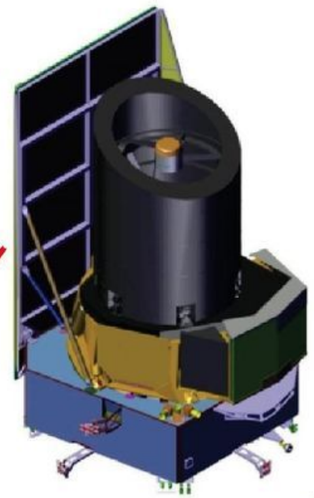
# The ESA Euclid mission in a nutshell

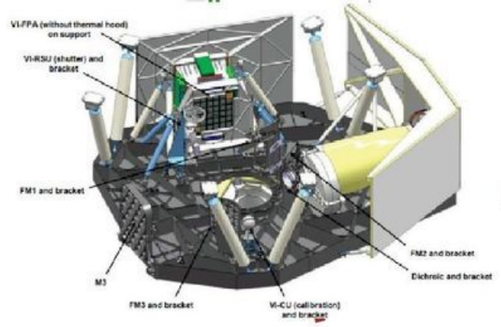
**Soyuz in Kourou:**

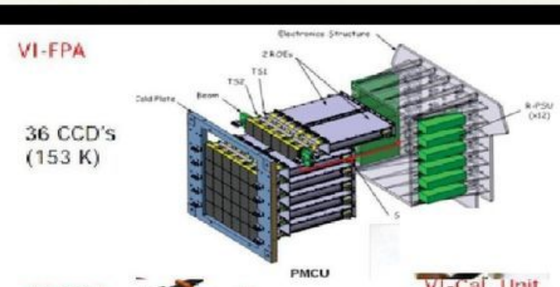
**2021**




**PLM+SVM: 2010-2020 (ESA)**

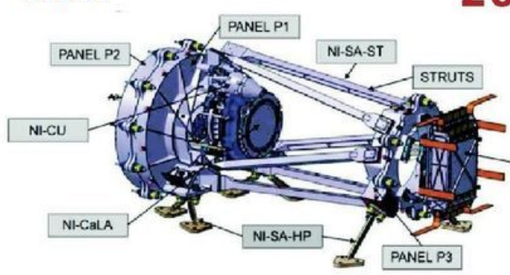




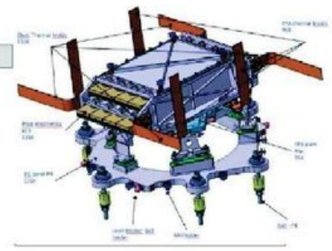




**VIS imaging:**
**2010-2020**
**(EC VIS)**

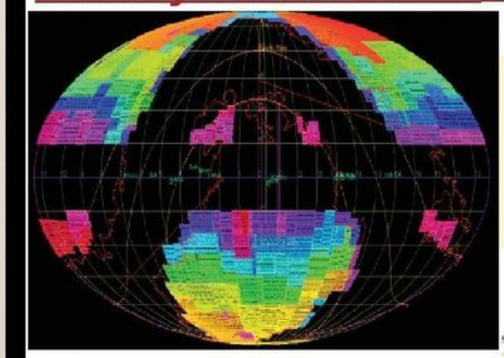
**NIR spectroscopy-imaging:**

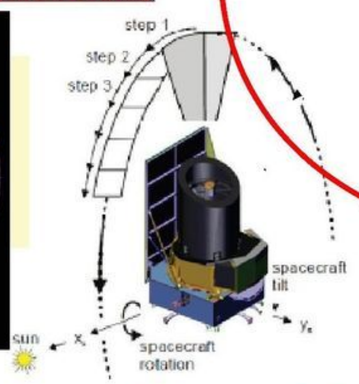



**2010-2020 (EC NISP)**



**Survey: 2021-2028 (EC+ESA)**





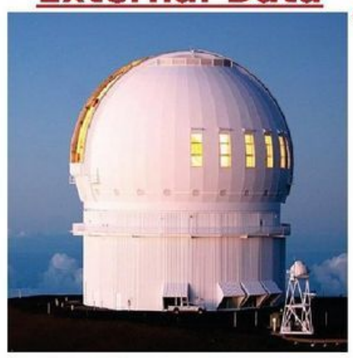

**Survey: 6 years**

**Wide = 15,000deg²**

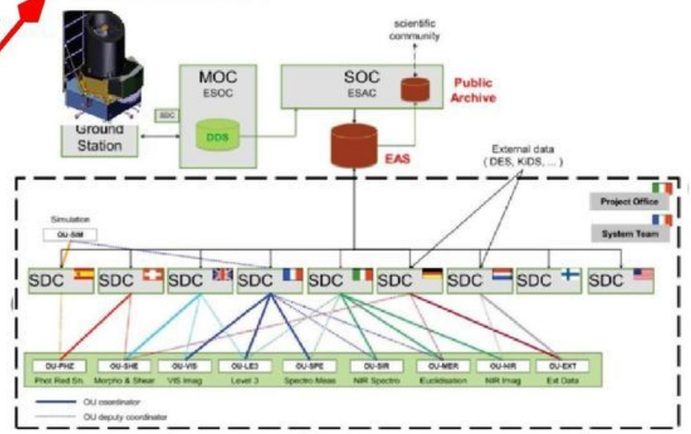
**Deep = 40deg²**

**Calibrations = 10 deg²**

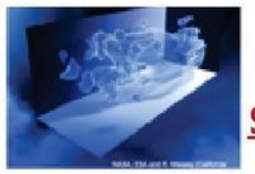
**External Data**



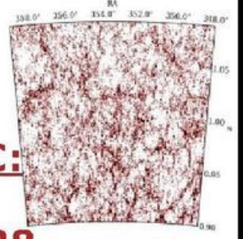
**SGS EC: 2010-2028**



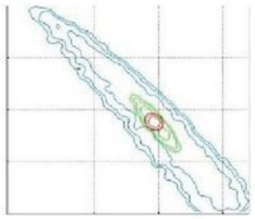

**~100 PB data processing**



**SWG EC:**




**2019-2028**



**Science analysis**

*Slide by Y. Mellier*

# Two worlds apart: a gap in the funding


– Space mission: ~$1B (ESA + Euclid Consortium)

– Ground surveys: $0 (Euclid Consortium)

– Ground surveys are spawned from various scientific communities

# Sources of input for the reference survey

**Wide survey + Deep survey + Calibrations**

**Mission Operation Concept (MOCD–A)**

**+**

**Calibration Concept Document (CalCD–B)**

**+**

**Euclid Science Teams**

**+**

**ECSURV group & ESA's Euclid Sky Survey Working Group**

# The Euclid reference survey: 3 distinct components

**Wide survey + Deep survey + Calibrations**

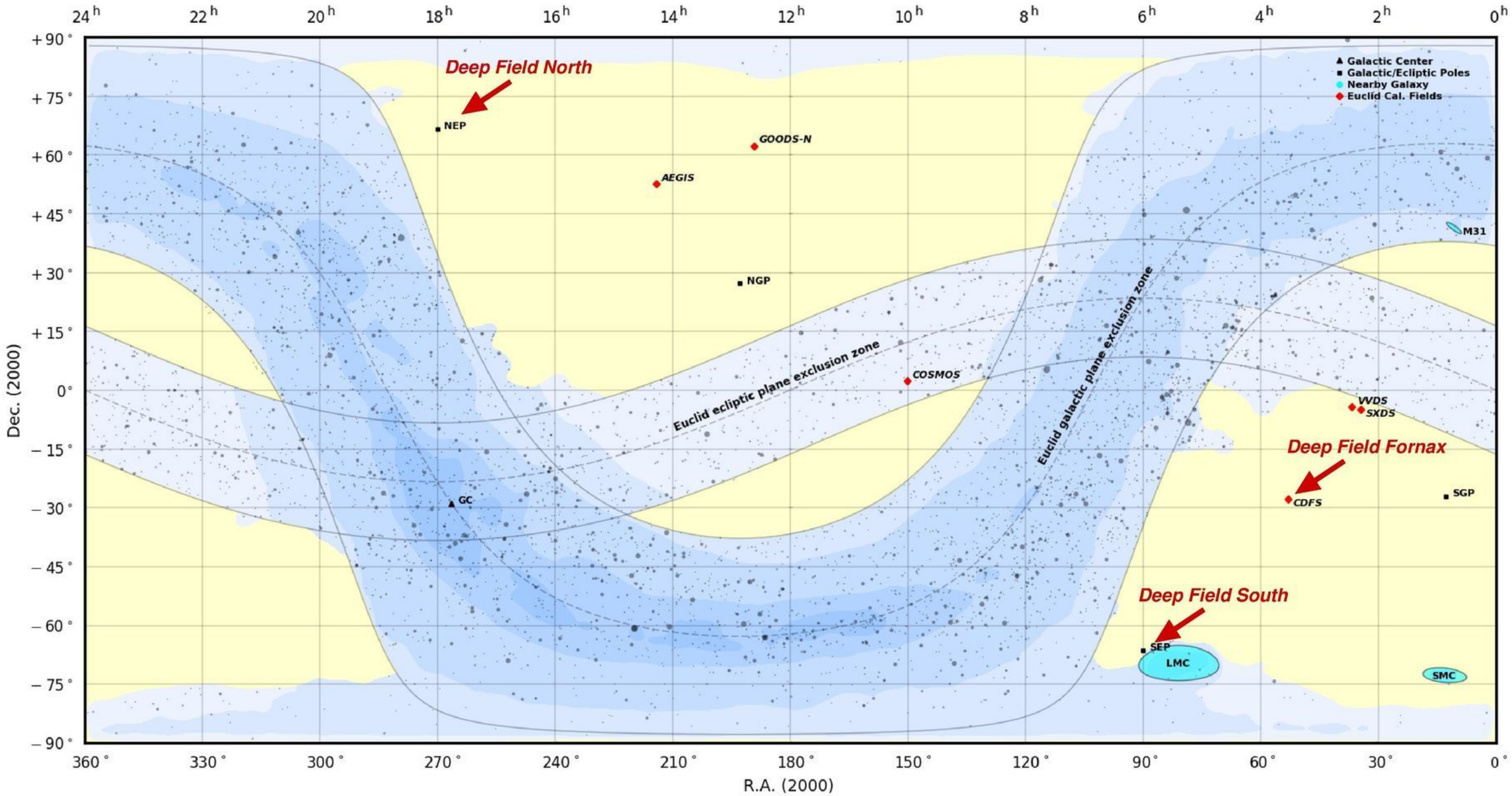
**15,000 sq.deg.**

**40 sq.deg. in 3 split fields**
**+**
**Time constraints**

**Misc. locations, many repeats**
**+**
**Time constraints**

**Scheduling priorities: 1) Calibrations, then 2) Deep, and then 3) Wide**

# The Euclid reference survey




The Euclid Wide Survey (Red Book clippings) in equatorial coordinates on an equirectangular projection

Euclid exclusion zone : 26,000 deg.$^2$ [galactic+ecliptic planes]

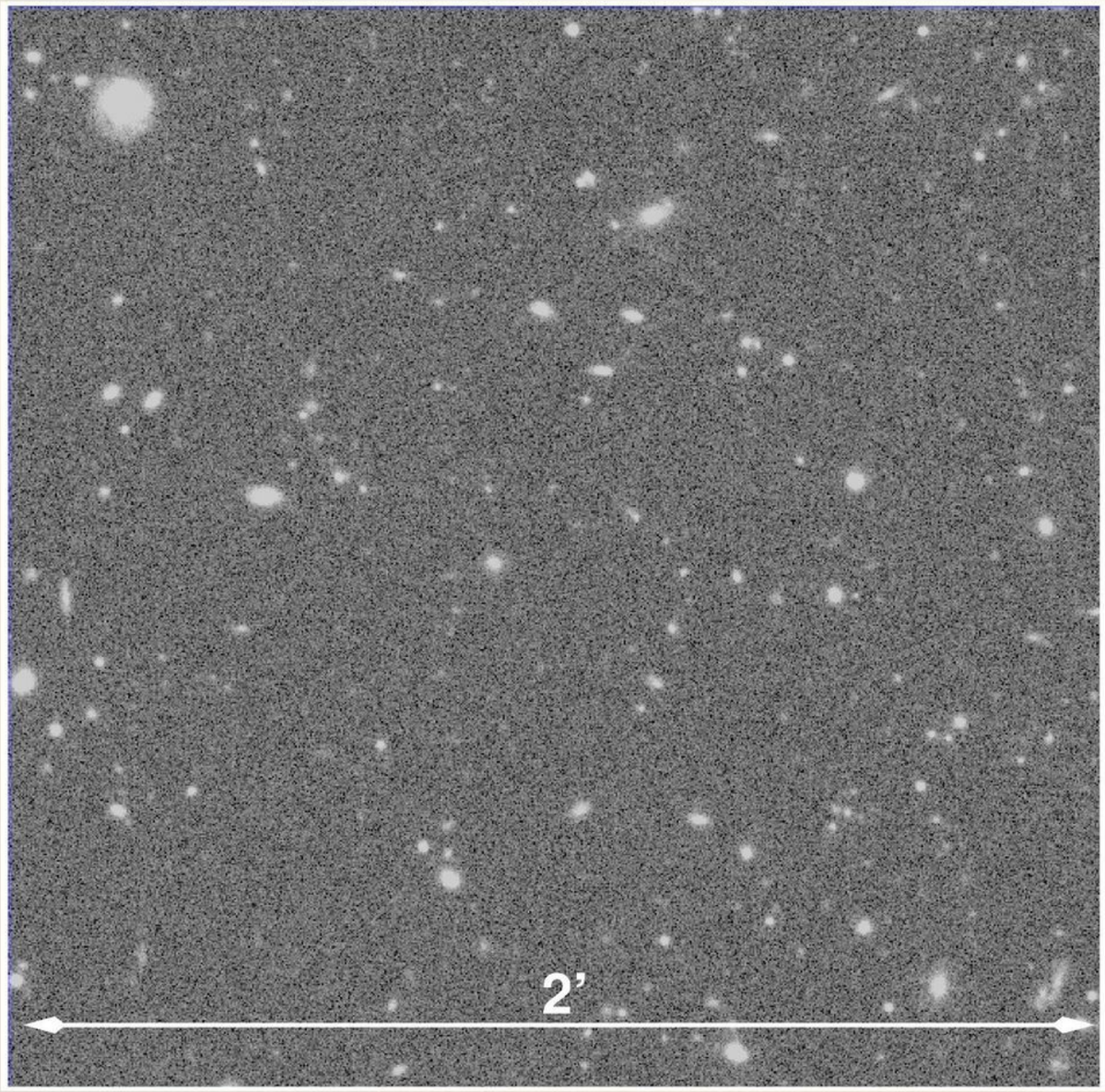
Euclid Wide Survey : 15,000 deg.$^2$ [with E(B−V)<0.08, up to 0.15 to avoid holes/islands]

– The Euclid reference survey is a work in progress but the big picture remains

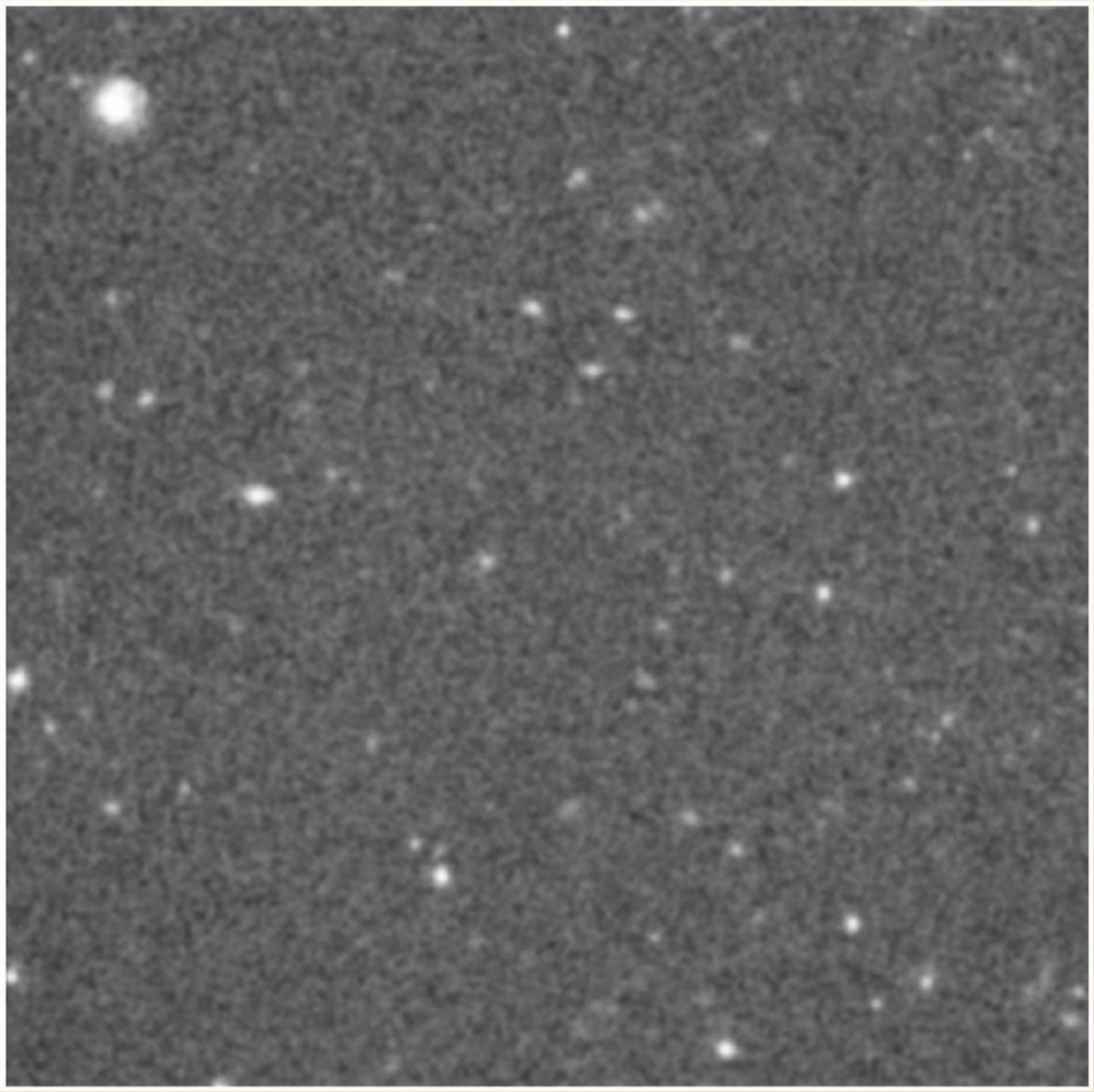
– Euclid needs broad–band (Sloan) filters photometry and deep spectroscopy

# Euclid data are deep, a challenge to match from the ground

## Wide survey example: 2x2 sq. arcmin = 1/13,500,000 of the total survey area




*VIS depth: ~30 "Euclid" galaxies/arcmin2 (ACS, i)*



*Sought ground–based data (CFHT, r)*

– Euclid will measure the shape of nearly 2 billion galaxies

– Wide survey depths can be reached with high etendue 2 to 4–m class telescopes

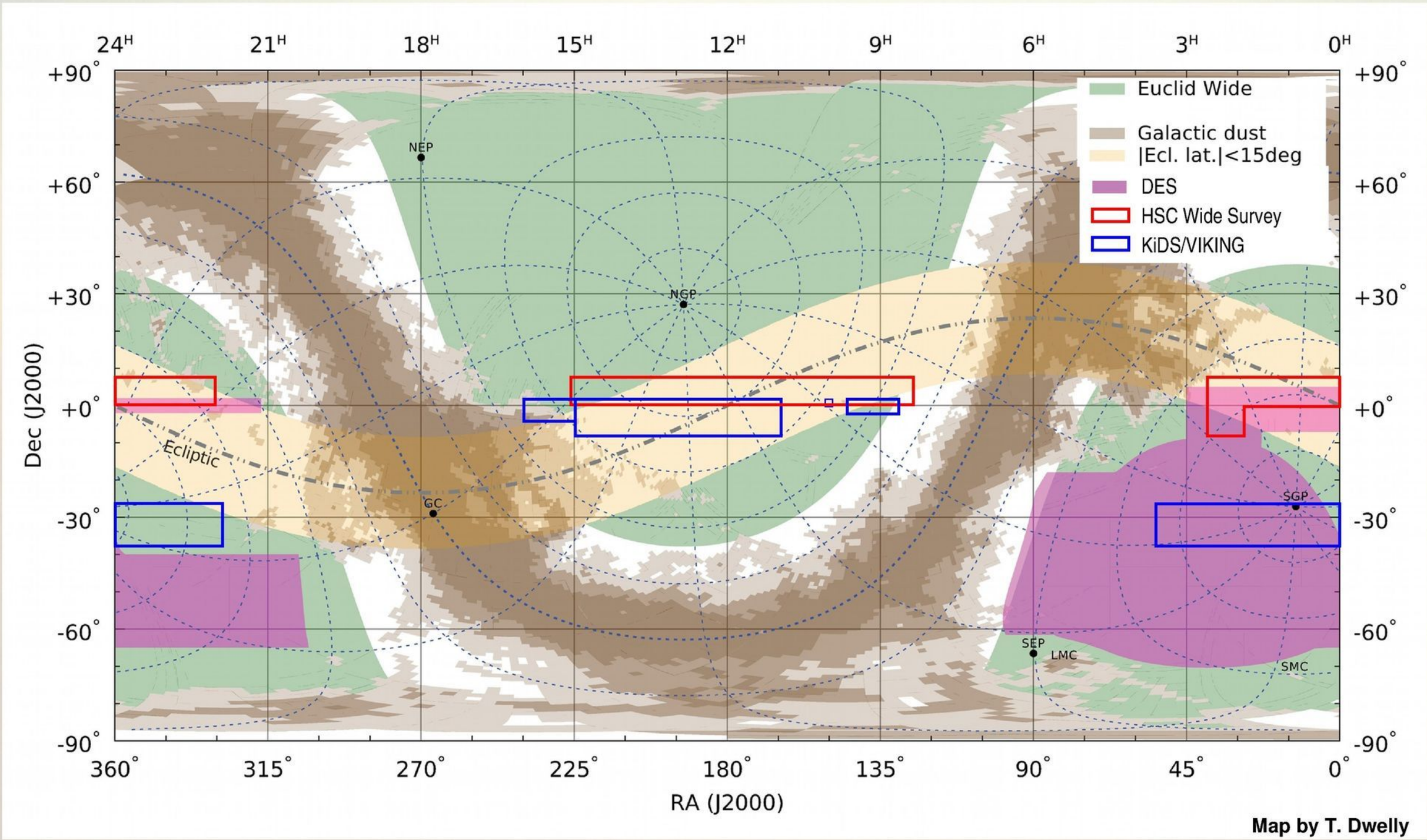
– The Euclid deep fields are 2 magnitudes deeper: 8–m class telescopes needed

# Present and upcoming wide–field imagers relevant to Euclid


| Facility | Year | Aper. | FOV | IQ | CCD class | Type | Hemisphere |
|---|---|---|---|---|---|---|---|
| LSST | 2021 | 6.6m | 9.6 sq.deg. | 0.8" | Deep depletion | Surveyor | South |
| Subaru | 2013 | 8.2m | 1.8 sq.deg. | 0.6" | Fully depleted | Observatory | North |
| Blanco | 2013 | 4.0m | 3.0 sq.deg. | 0.9" | Fully depleted | Observatory | South |
| JST | 2018 | 2.5m | 4.8 sq.deg. | 0.7" | Deep depletion | Surveyor | North |
| CFHT | 2003 | 3.6m | 1.0 sq.deg. | 0.6" | EPI | Observatory | North |
| PS1 | 2008 | 1.5m | 7.0 sq.deg. | 1.0" | Fully depleted | Surveyor | North |

Etendue

# Euclid inherits sub–optimal unrelated surveys




Map by T. Dwelly

– The Subaru HSC Wide Survey is mostly useless: ~1,400deg2 very deep on the ecliptic plane

– KiDS/VIKING has limited overlap in u,g,r,i,z (~800deg2) and is too shallow in the red bands (i,z)

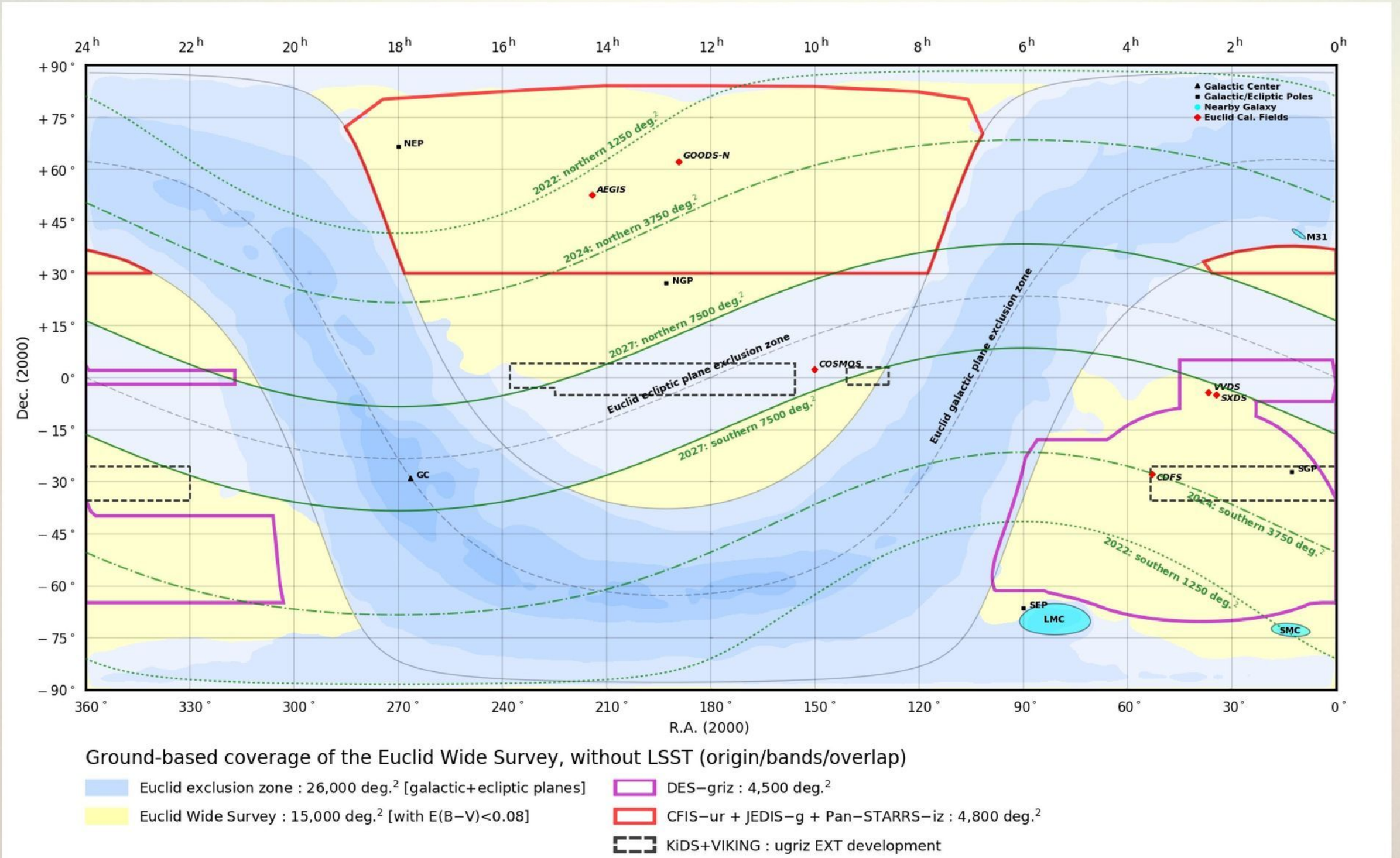
– DES has excellent overlap (~4,500deg2) in g,r,i,z but is too shallow in the red bands (i,z)

# Ground based observatories and space missions needs

– CFHT is a startling example of the tension imposed by space missions

– Observatories' currency is observing time, not signal as Euclid needs it

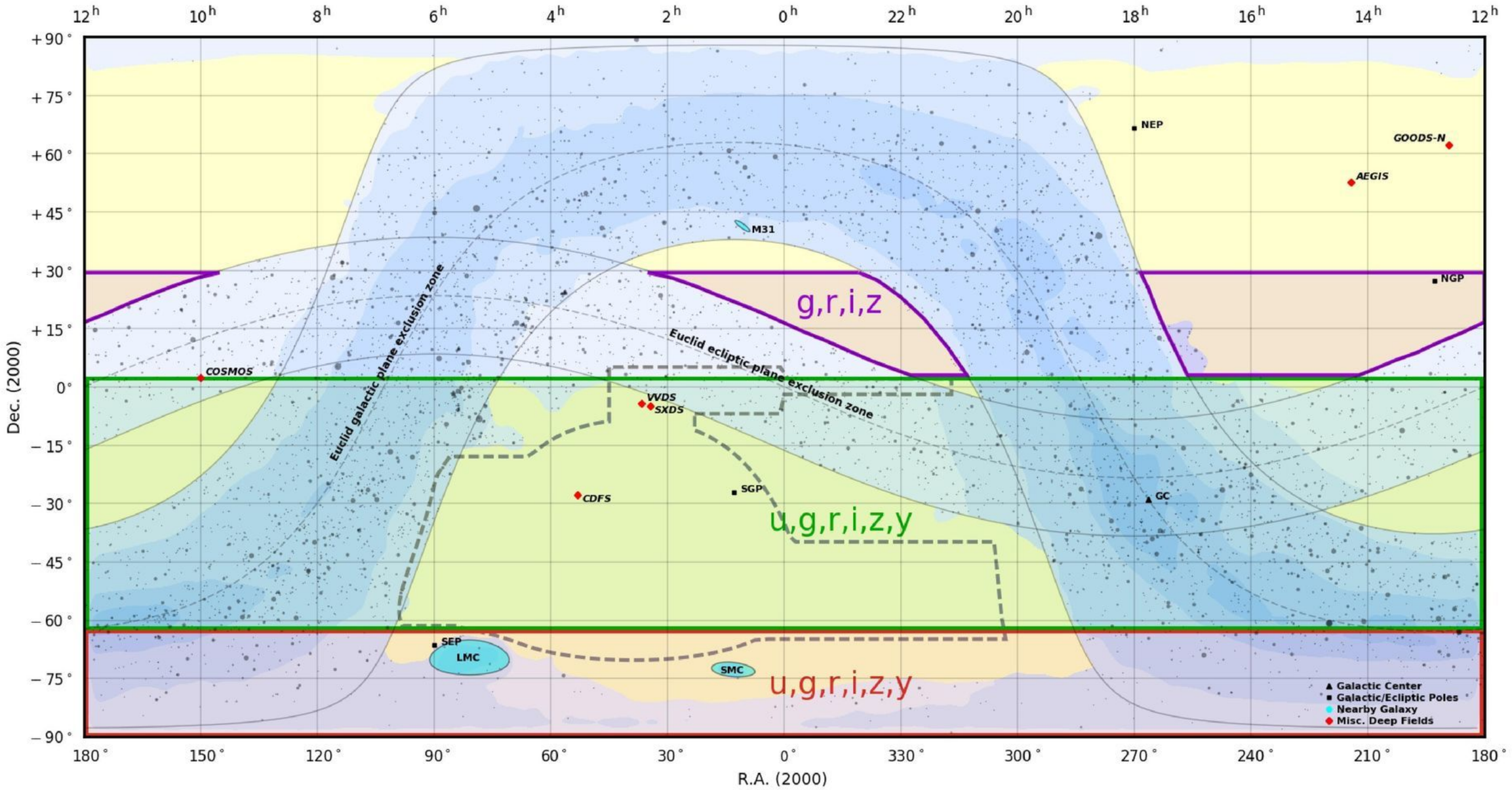
# The Euclid Wide survey before LSST: Euclid North & DES




– The Euclid Consortium has now secured a plan for DR1 (2023)

– Euclid North will be used for DR2 (2026) and DR3 (2029)

# Euclid & LSST synergy: 2/3 of Euclid Wide + 2 Deep fields



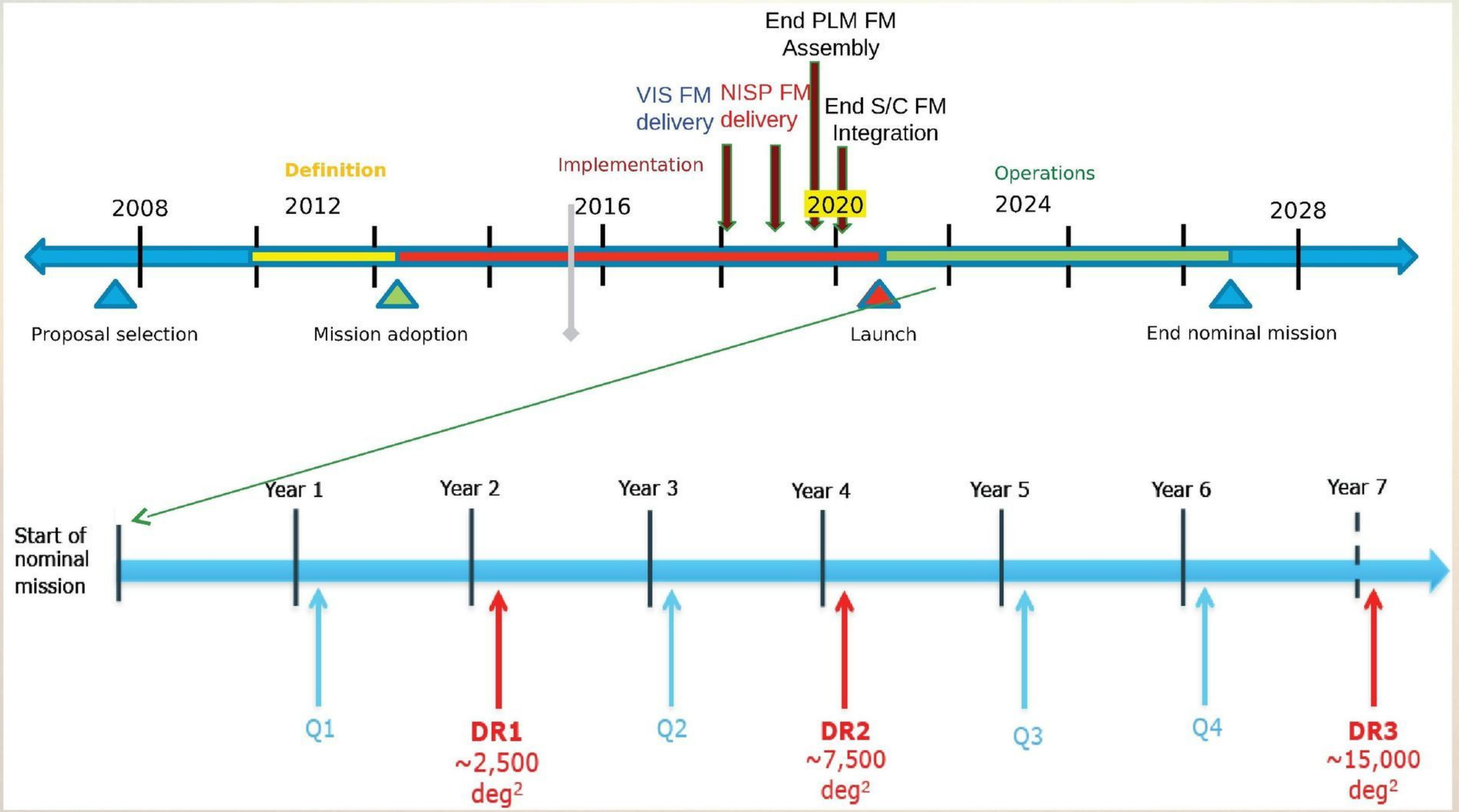

LSST main survey and extensions : complementarity with the Euclid Wide Survey

- Euclid exclusion zone : 26,000 deg.$^2$ [galactic+ecliptic planes]
- Euclid Wide Survey : 15,000 deg.$^2$ [with E(B−V)<0.08]
- DES : 4,500 deg.$^2$ Euclid overlap in g,r,i,z
- LSST main survey : 7,000 deg.$^2$ Euclid overlap in u,g,r,i,z,y
- LSST south extension : 1,000 deg.$^2$ Euclid overlap in u,g,r,i,z,y
- LSST Euclid extension : 3,000 deg.$^2$ in g,r,i,z specific to Euclid (depths/coverage)

– Advanced discussions between the Euclid Consortium and LSST have started

– The "LSST and Euclid Synergy" White Paper out this month (Rhodes et al.)

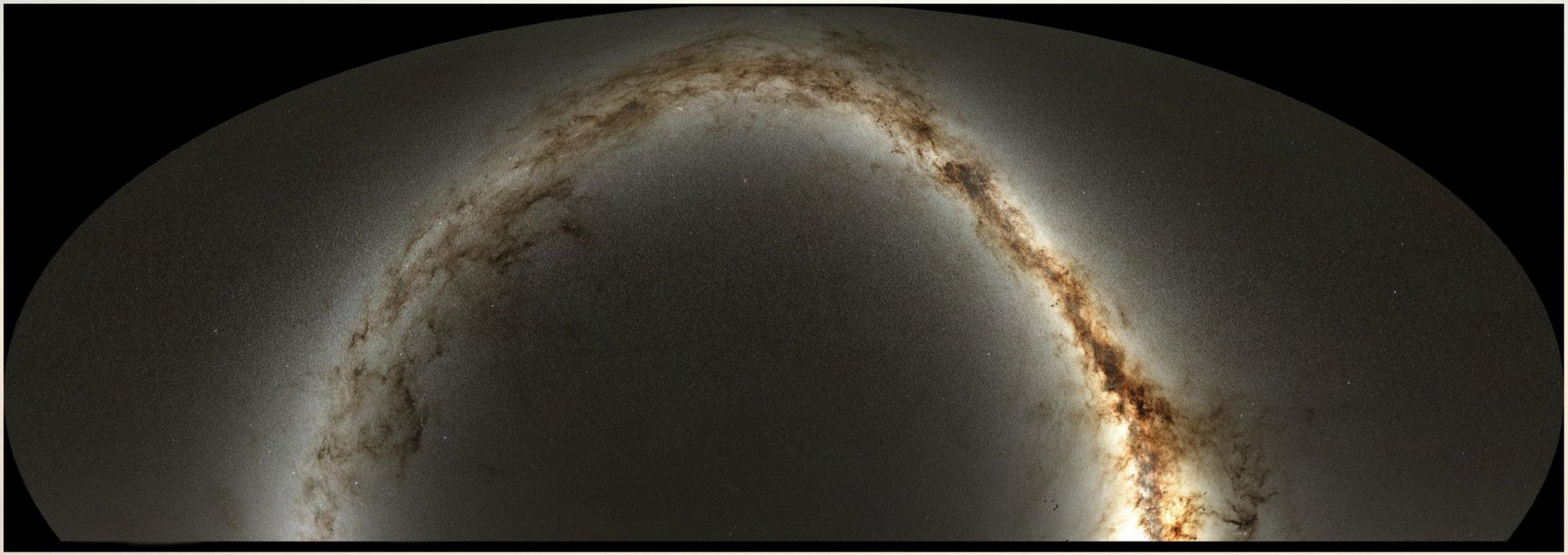
# Euclid schedule & Data Releases



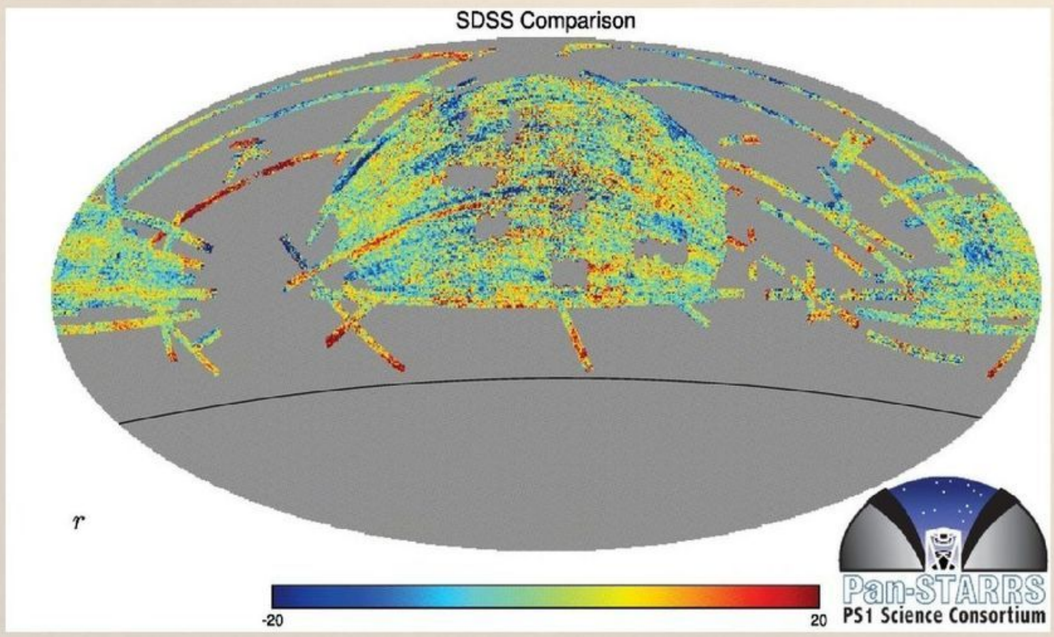

– Ground surveys will take years to build: MOUs stretch up to 5 years from now

– The Euclid Consortium needs the ground data one year ahead of the space data

# Pan–STARRS 3Pi: 30,000 deg2 in g,r,i,z at 4mmag. accuracy



*D. Farrow, N. Metcalfe and the PS1 Builders, 2016*

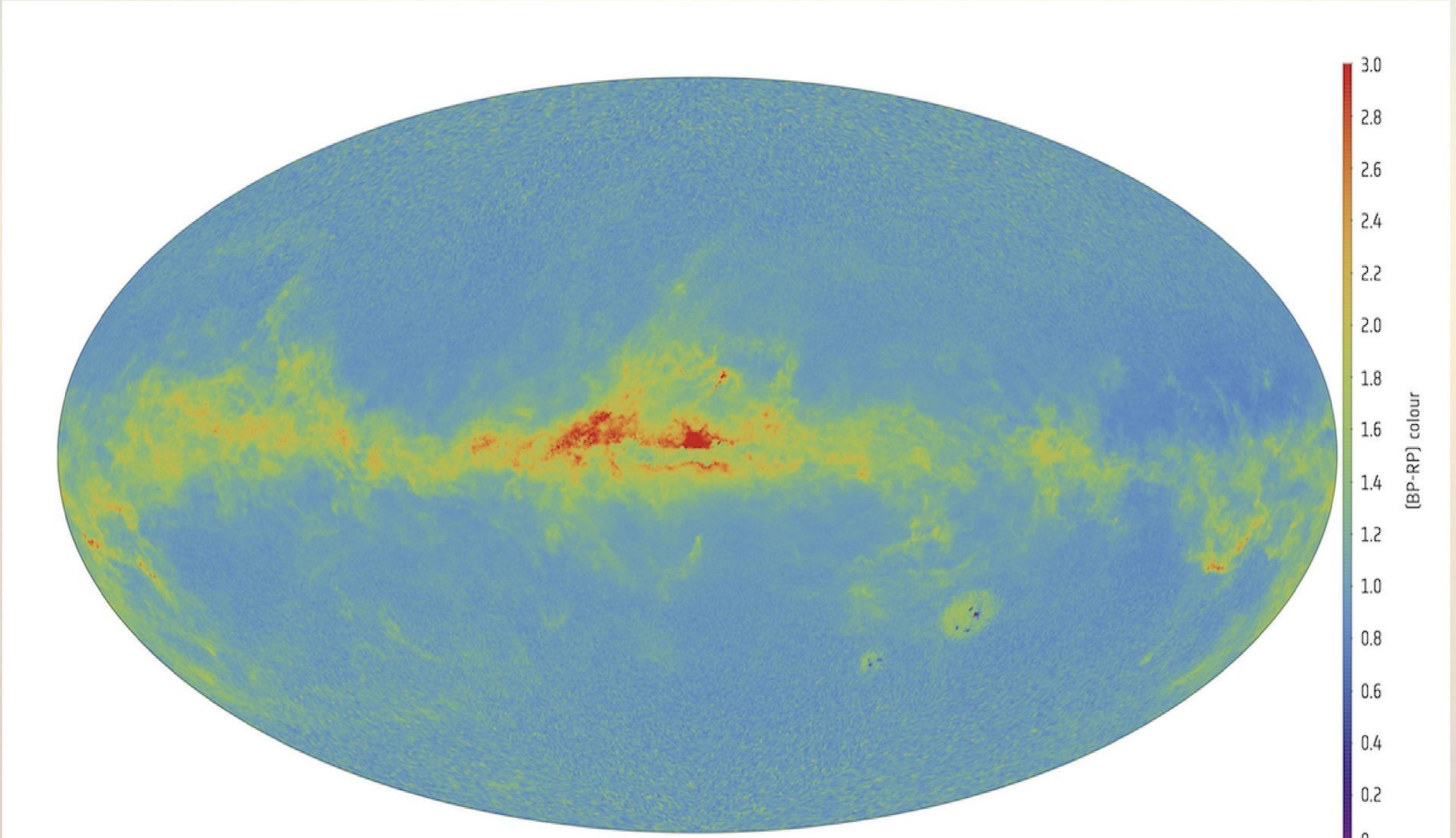



*E. Magnier, 2015*

**– Covers the declination range from –30 to +90 deg. in g,r,i,z,Y (30,000 deg2) at the 4 mmag. abs. level**

**– Photometric stars catalog released fall 2016 : used for the CFIS (CFHT Euclid r–band) until...**

# Gaia: a new paradigm for astrometry & optical photometry




*Gaia's first full-colour all-sky map (2017)*

**– All sky astrometry reference, path forward for the best absolute photometry in the optical (g,r,i,z)**

**– DR2 (2018) dramatically improved over DR1: 2 mmag. absolute in reach (BP/RP to Sloan, DR3)**

## Matching the space and ground data: the "Euclidization"

- Photometry & Astrometry
  - Common reference system Euclid and EXT
  - Photometry kept in native passband system
- Detailed PSF modelling, keep native sampling
- VIS-forced photometry
- Common data model between VIS, EXT, NIR

| Consistency for: | VIS | External Surveys |
|---|---|---|
| **Photometry** | - Gaia-G | - VIS+Gaia for EXT-r<br>- Stellar Locus + Gaia for EXT-giz |
| **Intrinsic light distribution** | - PSF model | - PSF model |
| **Astrometry** | - Gaia-G | - VIS |

*Slide by Gijs Verdoes Kleijn*

**– Euclidization now means anchoring to a common reference + adopting similar quality control tools**

**– The responsibility for calibration now falls onto the data provider, de facto in the Euclid Consortium**

# The volume of external data exceeds the Euclid dataset


– Some Euclid–EXT dataset (e.g. Pan–STARRS > 1PB) impose a new paradigm:

*"If you can't get to Euclid, Euclid will come to you"*

– Modern forced photometry on individual frames only needs Euclid morphometry

# Euclid Complementary Observations

- The Euclid primary mission relies on essential non–spacecraft data
    - Photometric redshifts for tomography
    - Galaxy colors for chromatic PSF correction to lensing
    - Spectroscopy for photo–z calibration
    - HST imaging (archive) for galaxy shape calibration

- Unlike any previous astronomy space mission really
- The Euclid legacy science is also tremendously enhanced
- These massive surveys are a consortium/community effort
- Today’s autonomous science belongs to those bringing the dataset, not Euclid

# Euclid Complementary Observations: types

- Four types of data:
  - **Complementary**
    - essential to the core science case
  - **Enhancing**
    - data that improve FoM but not essential
  - **Ancillary**
    - Amplify multiple legacy science cases
  - **Tertiary**
    - More limited in scope

Ground-based colours
Spec-z surveys

Extra bands for phot-z
Further spec-z

MoU's

FIR, Radio, X-ray maps

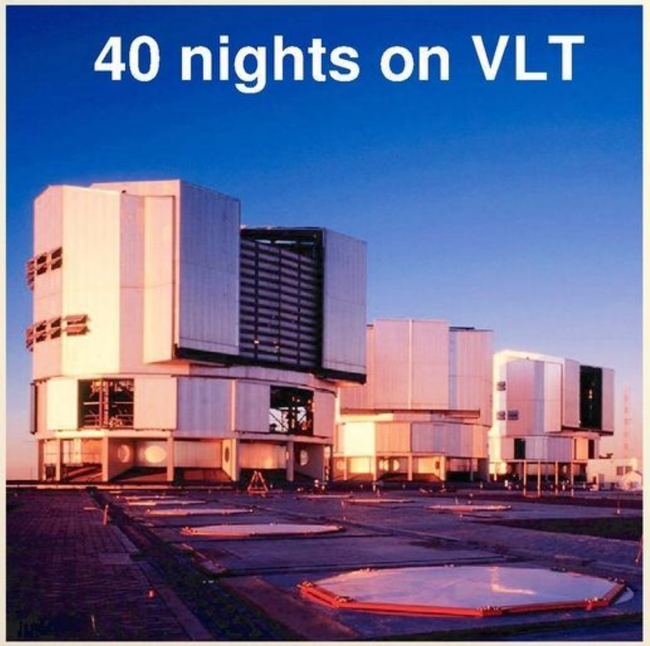
Stellar spectroscopy

**– COG = new oversight group now in place within the Euclid Consortium (2017)**

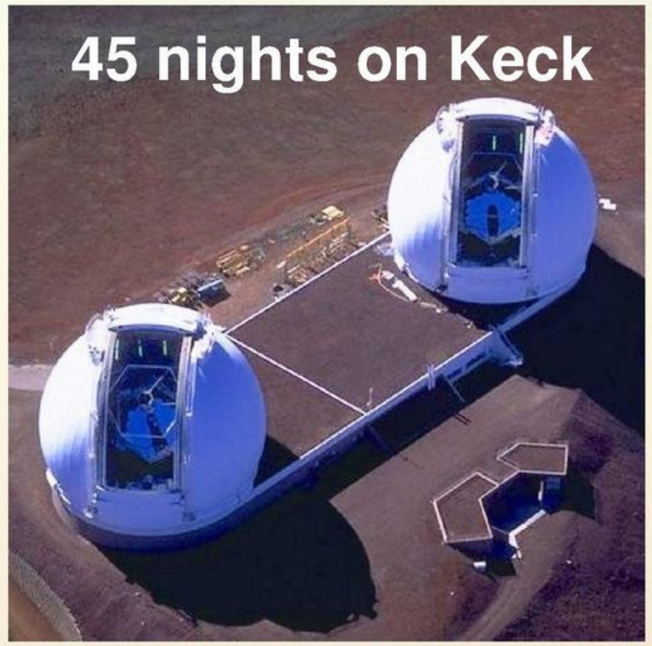
**– The Complementary Observations Group (COG) is Kuijken/Capak/Cuillandre**

# Euclid Complementary Observations: on–going highlights

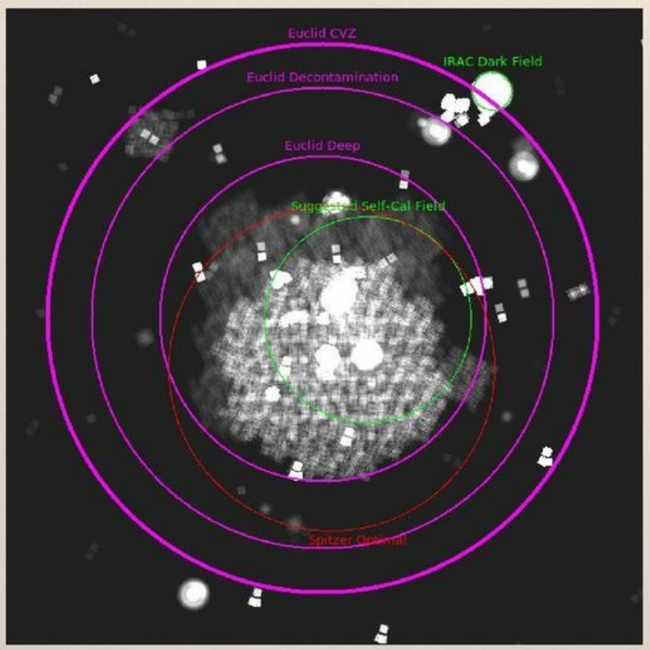
– Spectroscopy for photo–z calibration: on the Euclid calibration fields




COMPLEMENTARY
Photo–z calibration

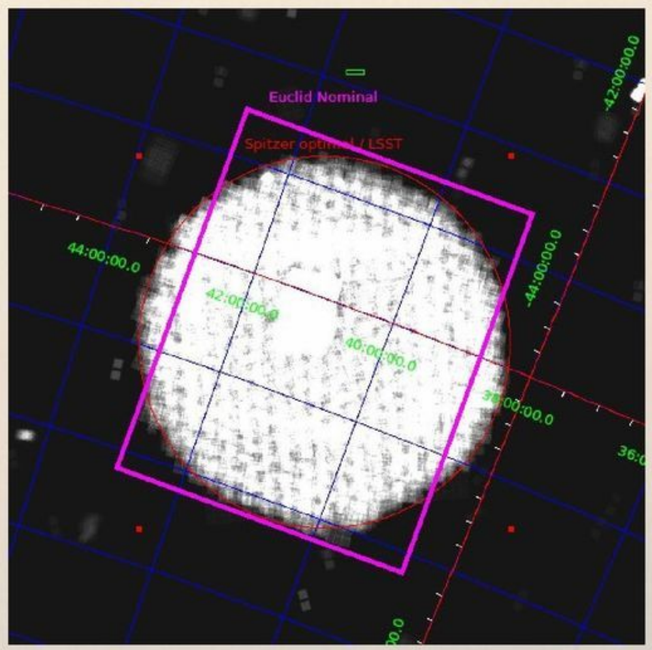



– The Spitzer Extragalactic Legacy Survey: 5,300 hours (PI P. Capak)



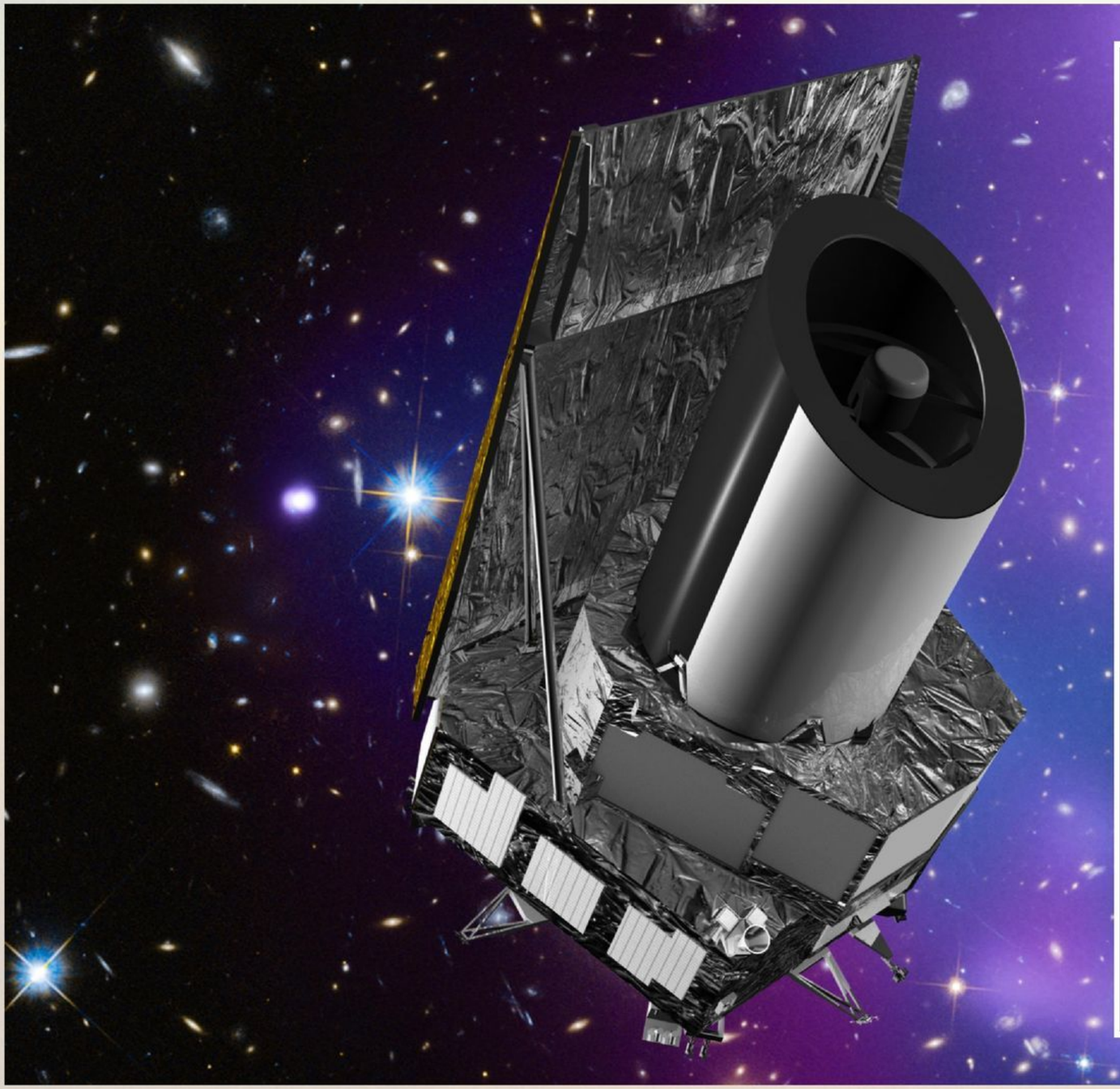

10 sq.deg. on EDF–N

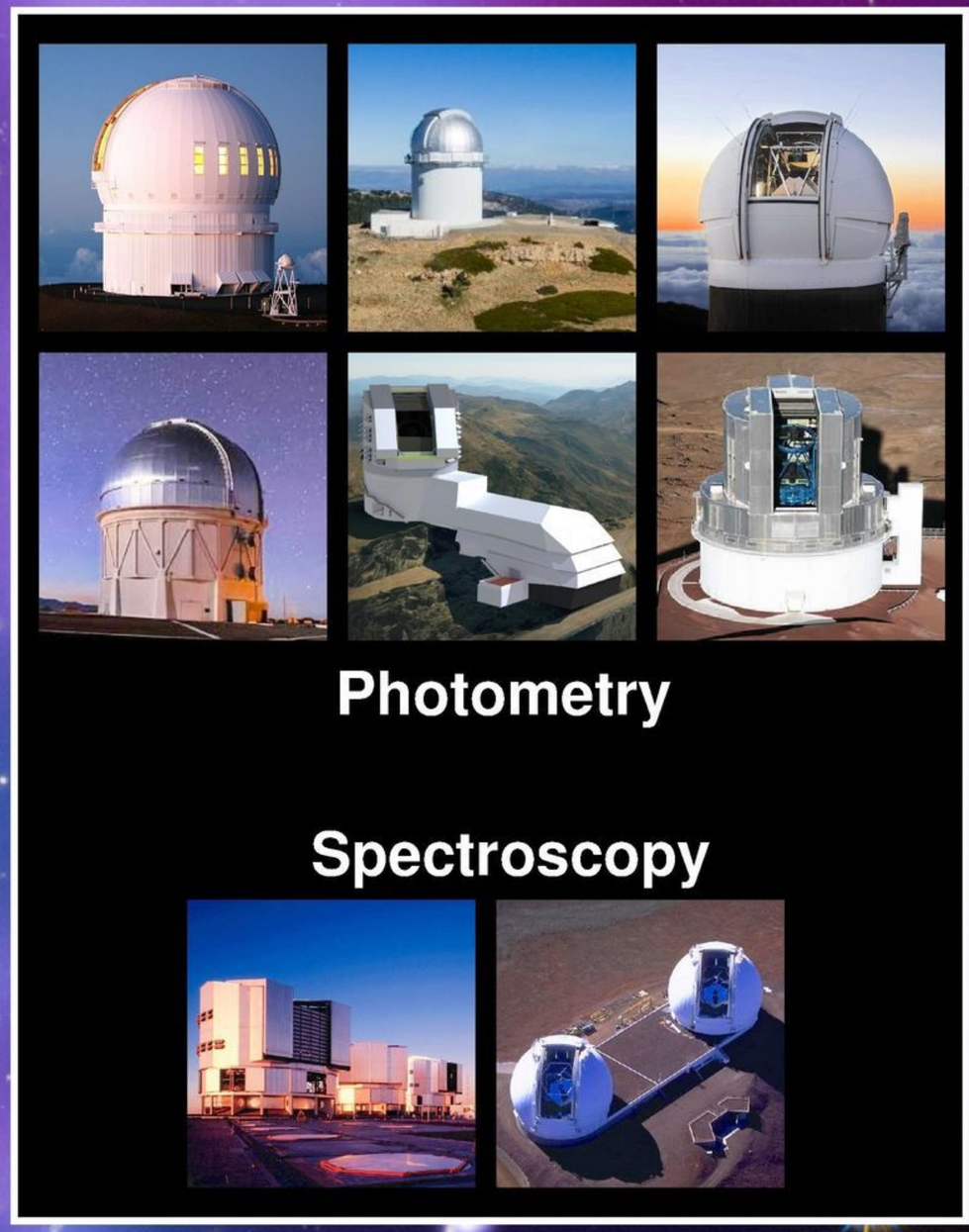
ANCILLARY
Groundbreaking legacy science




10 sq.deg. on EDF–F

# Euclid Complementary Observations : conclusions





Photometry

Spectroscopy