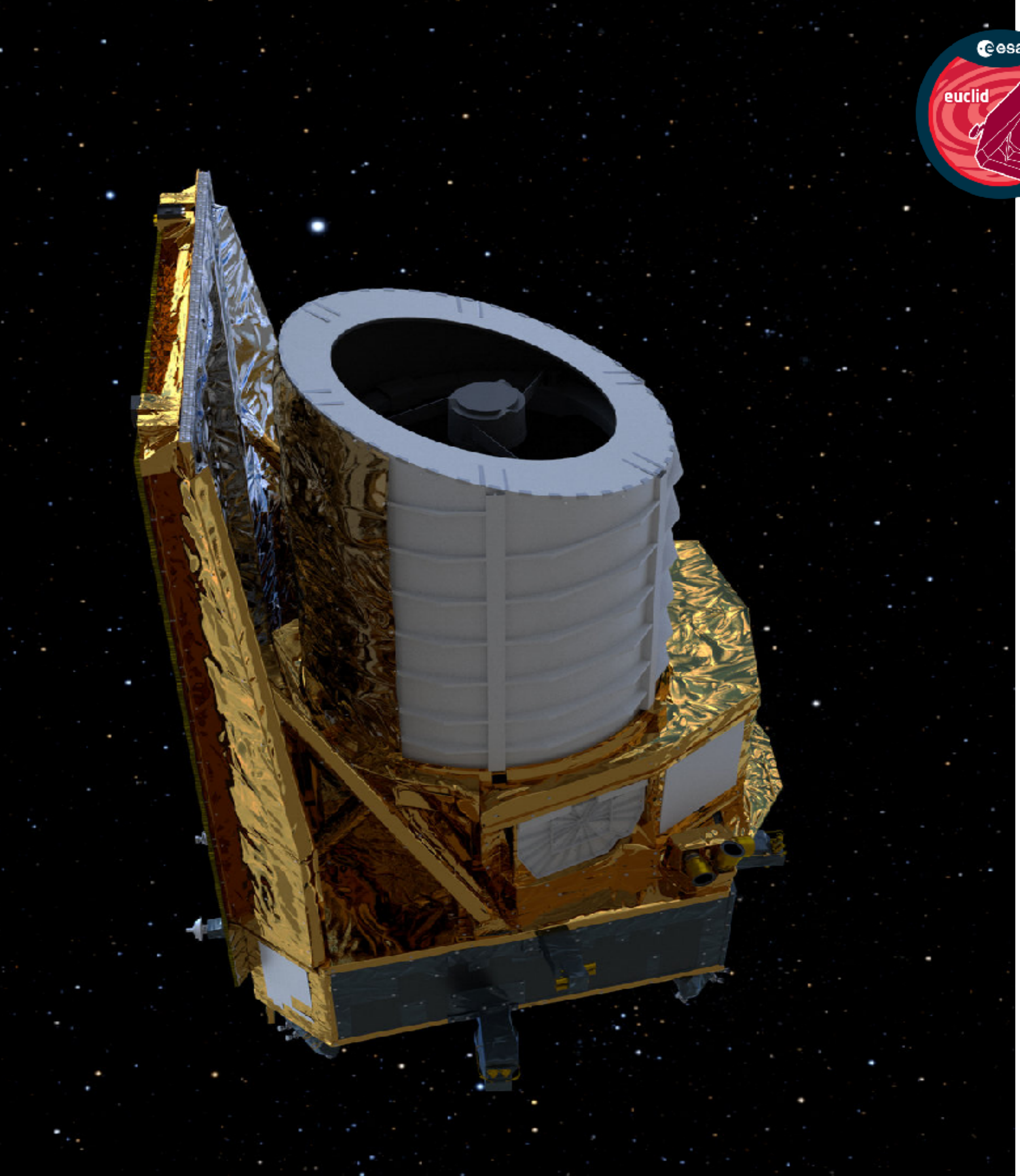


The Euclid mission and the quest for dark energy

Francis Bernardeau

Institut de Physique Théorique, CEA

presentation based to a large extent on :

Euclid. I. Overview of the Euclid mission
Mellier et al. (2024)
(https://arxiv.org/abs/2405.13491)

Euclid Q1 accompanying papers

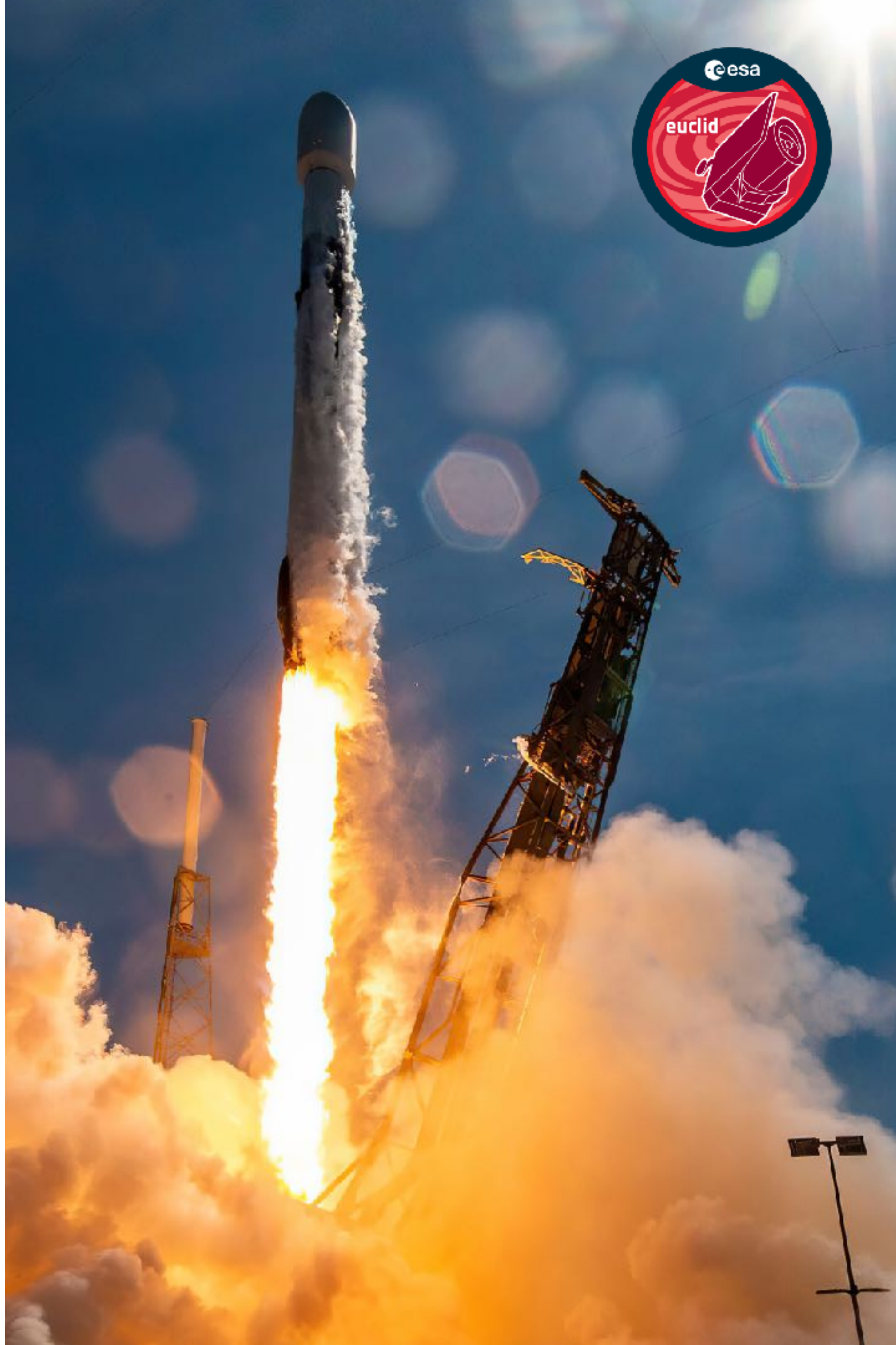
IPhT
Institut de Physique Théorique
DRF-INP UMR 3681

Physics of the Two Infinities, 18 Nov. 2025

Euclid is an ESA Medium Class mission of the Cosmic Vision program: it is the merger of two proposals, SPACE & DUNE. Visible imager and infrared spectro-imager aiming to survey 15,000 degrees^2 over a 6-year period;

Successful launch on July 1st, 2023 from Cape Canaveral. Now operating from L2.

After Performance and Verification phase, the Science survey started Feb 15th 2024



The Euclid Consortium

The mission is supported by the Euclid Consortium (EC) that comprises over 2500 members in more than 200 laboratories in 18 countries, EC Lead: Yannick Mellier (IAP)

The main goal of the EUCLID project

Unveiling the origin of the acceleration of the expansion of the Universe

see also : "Mapping the Dark Universe: Prospects for Dark Matter Science with Euclid", by Linda Blot on Friday 21th

The main goal of the EUCLID project

Unveiling the origin of the acceleration of the expansion of the Universe

A cosmological constant

The simplest explanation for dark energy is that it is an intrinsic, energy density of space-time, a cosmological constant, with an effective equation of state (EoS),

$$w = \frac{P}{\rho} = -1$$

A late time inflation like field

Such inflation phase differs from the cosmological constant in that it vary in space, but only at super-horizon scales, and in time, with in effects a time dependent EoS.

$$w > -1$$

Modified gravity models

Models where other degrees of freedom than metric that contribute to gravity: a "fifth" force is introduced in addition to gravity. Generically they change the growth rate, induce a scale dependent growth, and/or induce a non-zero effective anisotropic stress.

Probing the DE with Euclid, angular distances (BAO) and **gravitational growth**

Grav. Instabilities in one equation:

time variation of the local expansion

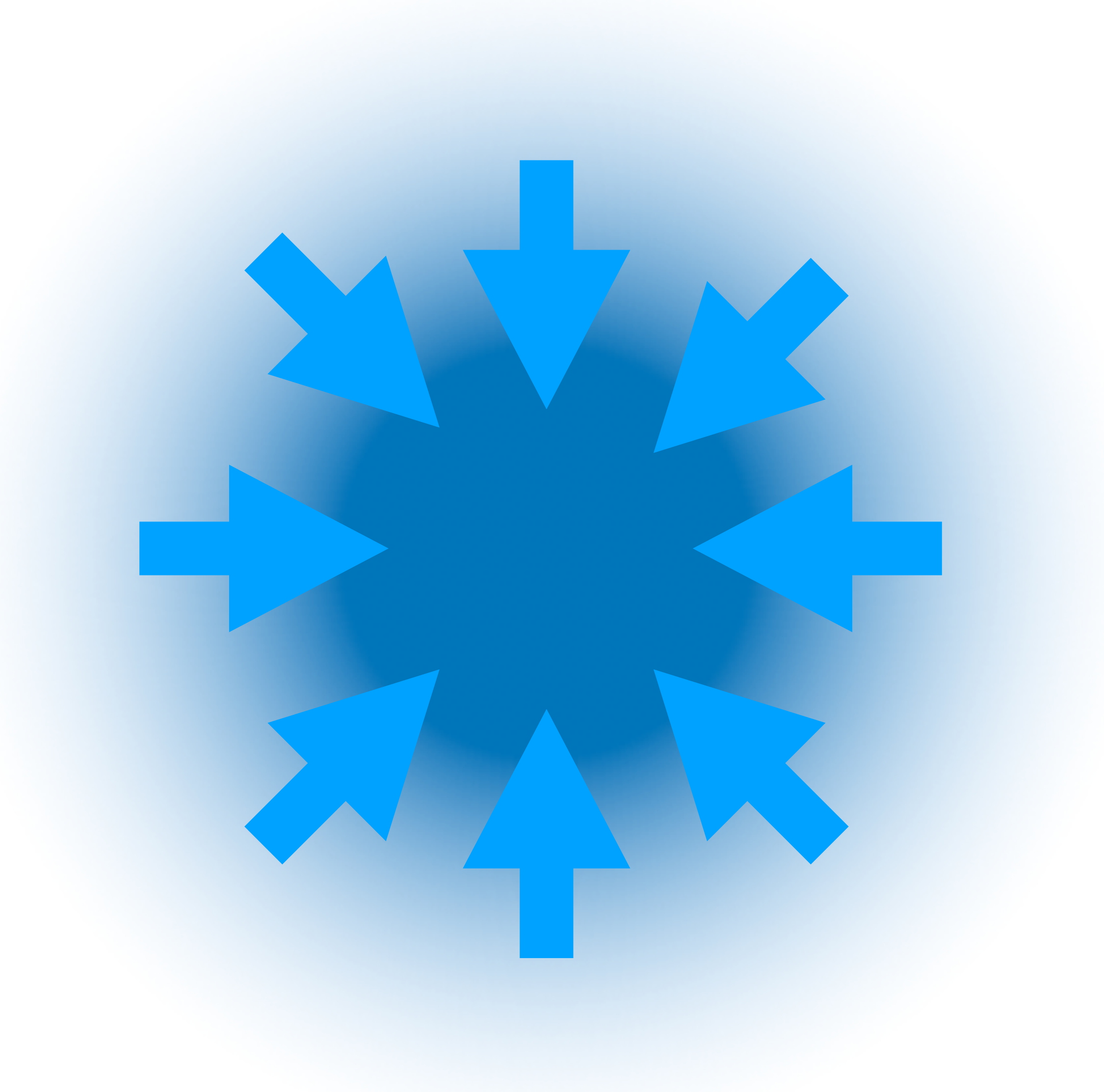
source of grav. instabilities = NR matter

Modified Gravity terms

$$\frac{\partial\theta}{\partial t} + 2H\theta = 4\pi G(\rho_m - \overline{\rho}_m) + \mathrm{Pressure} + \mathrm{M.G.\ terms}$$

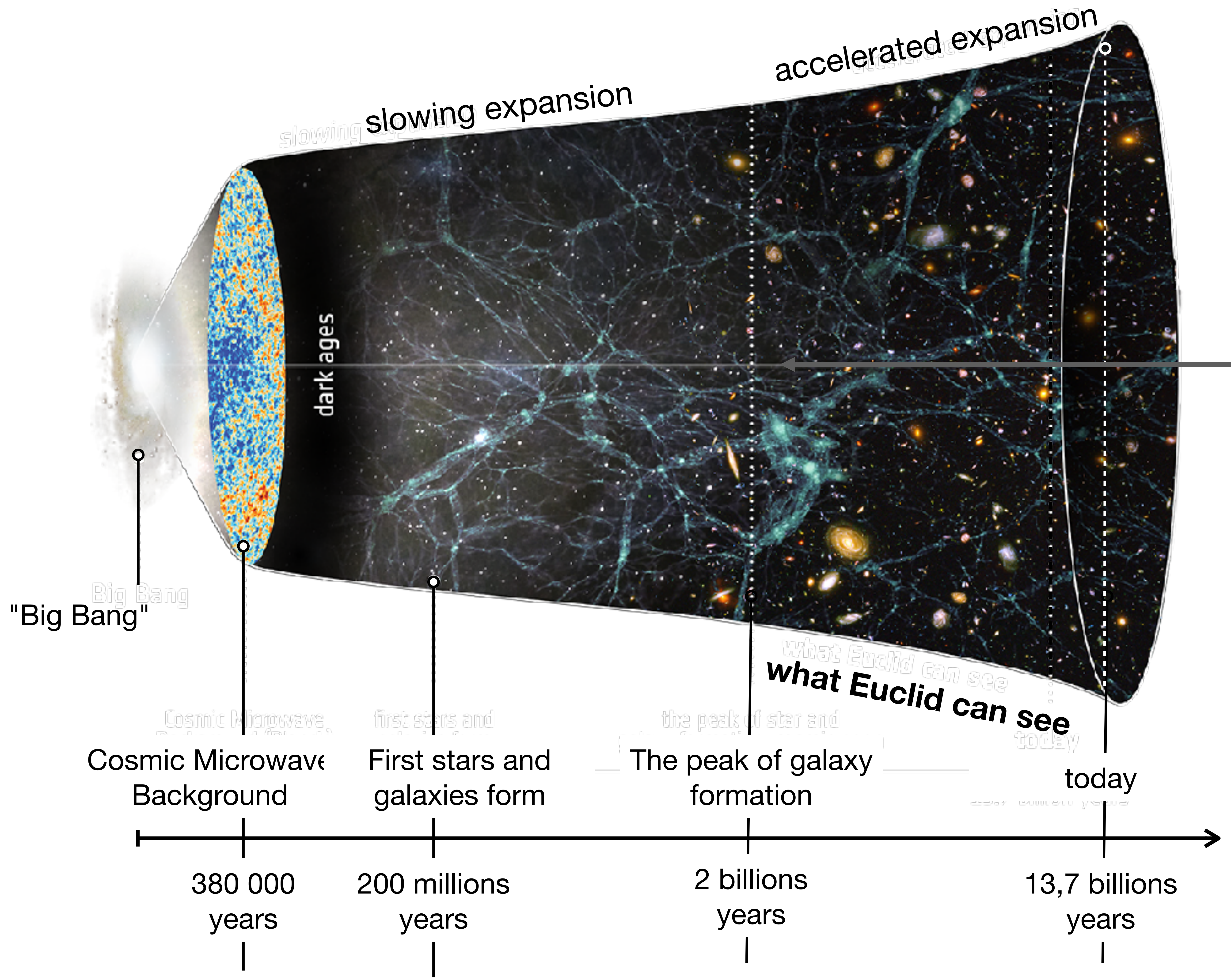
dilution due to expansion, depends on DE behavior

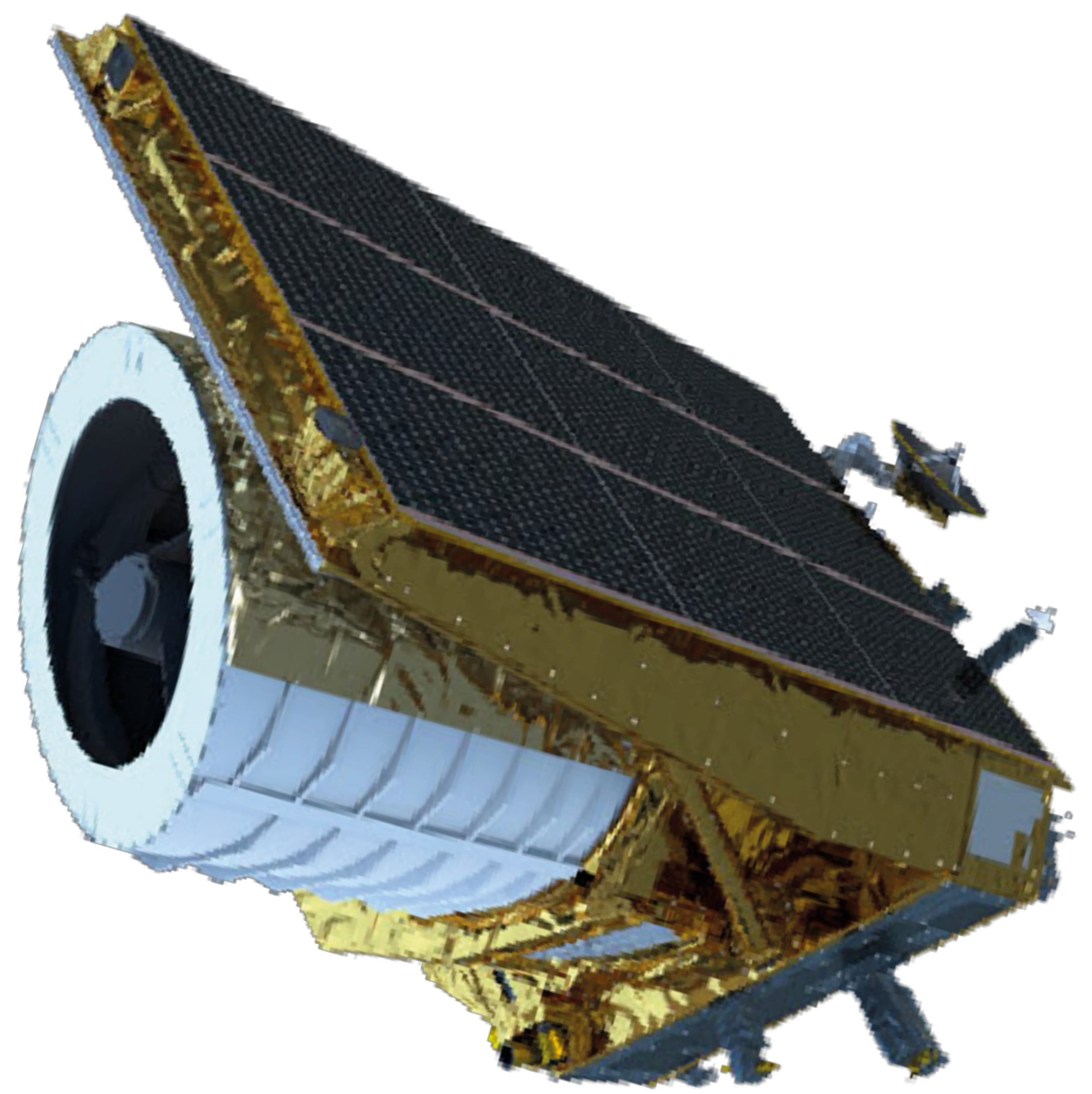
Pressure term for Relativistic matter (e.g. neutrinos)



LSS provides a rich view of the dark sector !

Timeline of the Universe

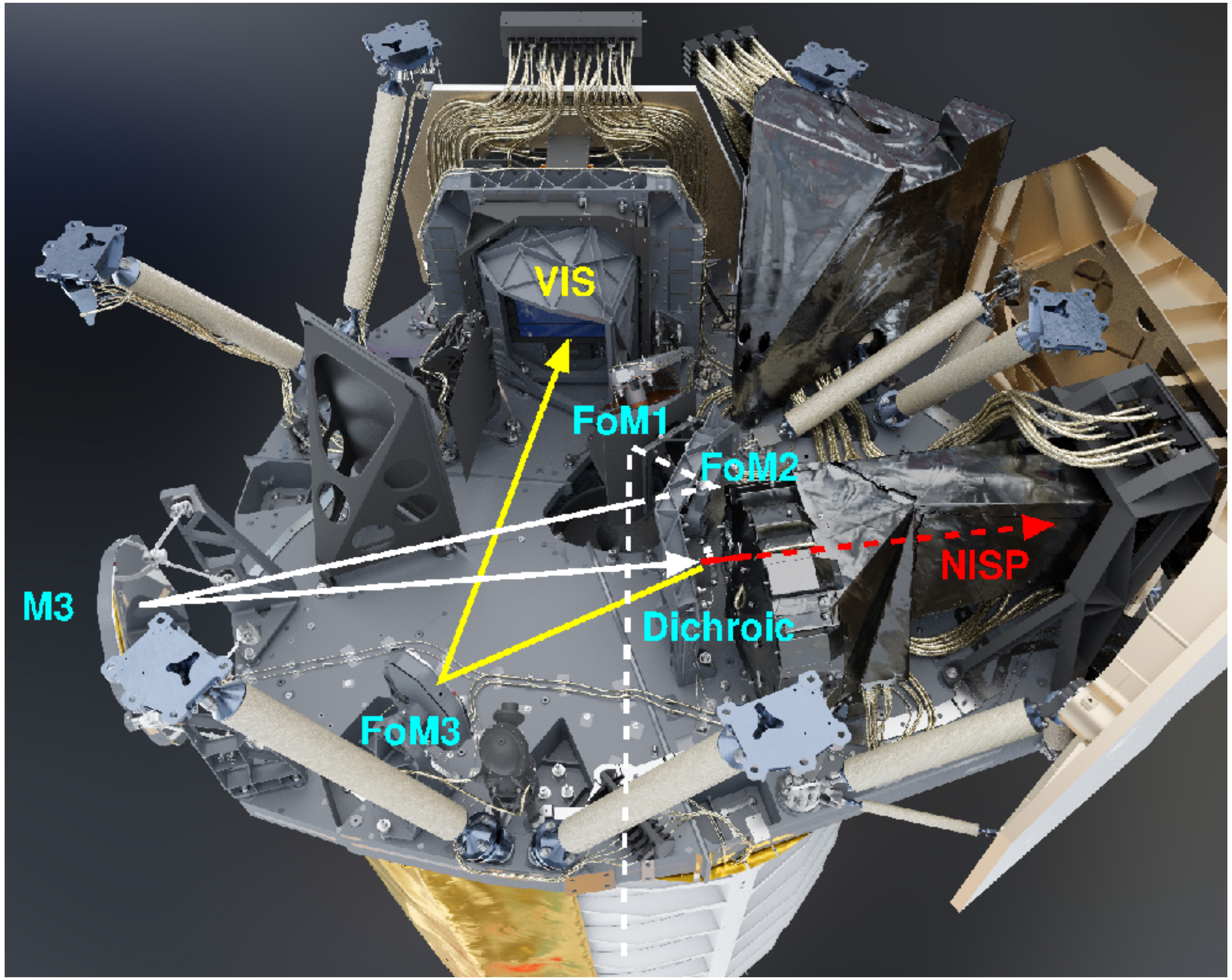




Dark Energy is a recent phenomenon in the history of the universe (z<2). Euclid will probe the universe at redshift between 0.5 and 2.5.

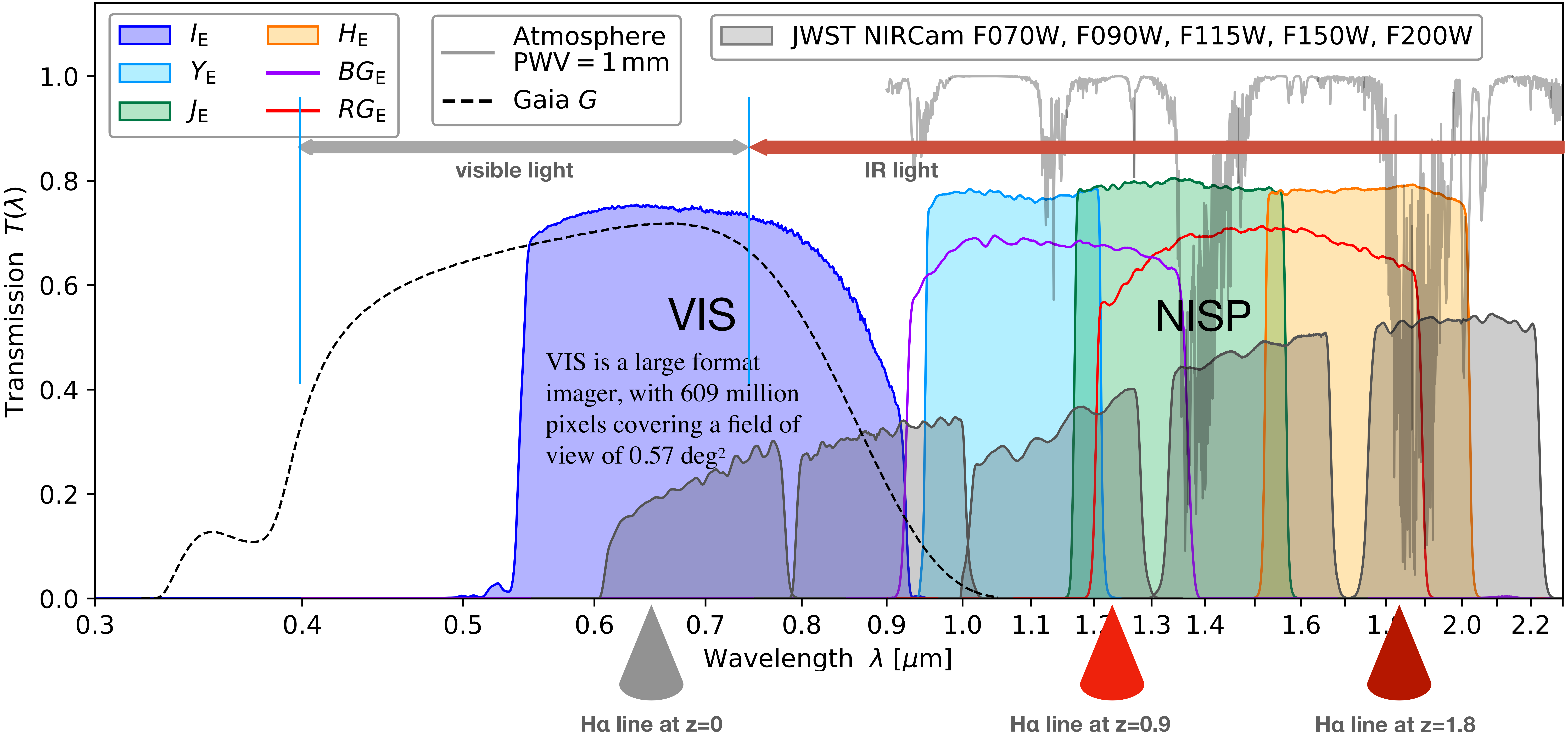
The concept

Payload Module: Optical system and instruments



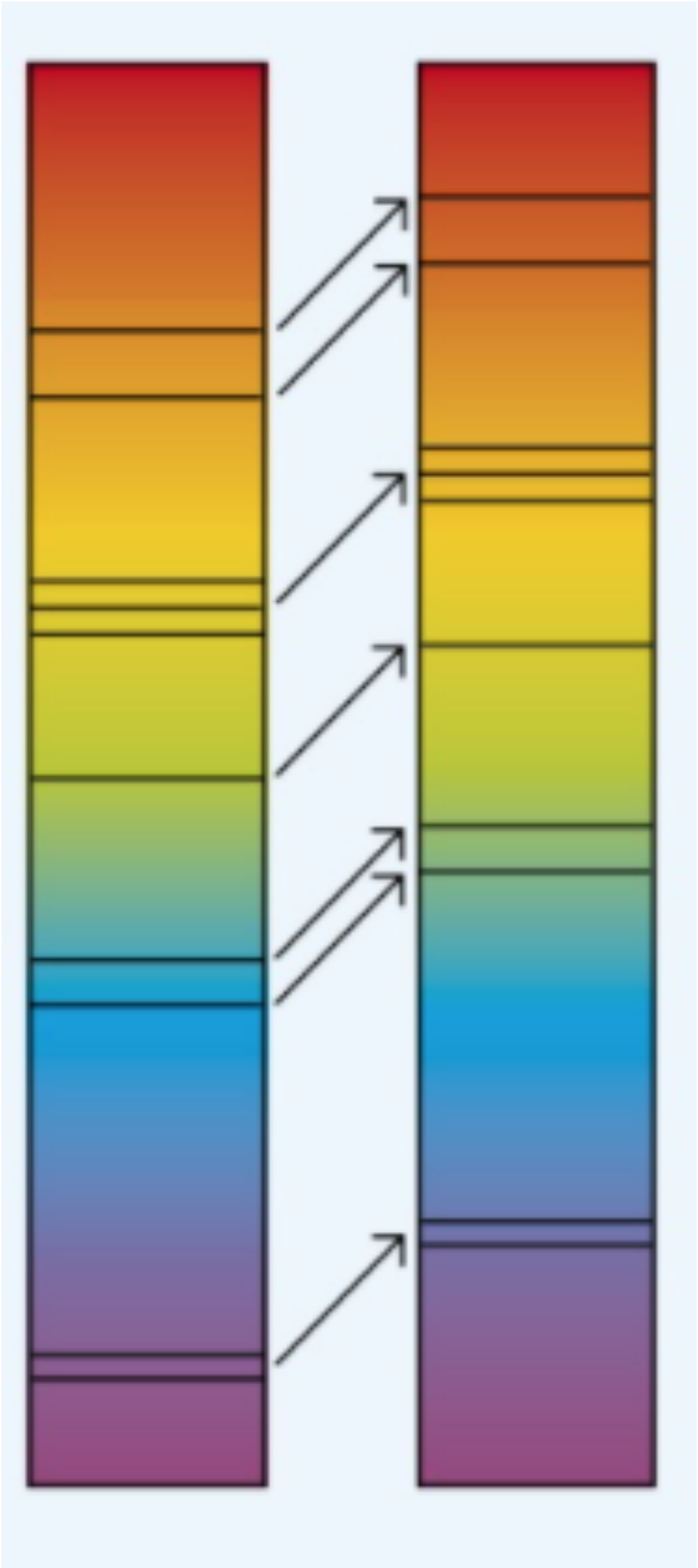
Layout of the instruments. The telescope is below, observing downwards.
Credit: Airbus Defence and Space; annotations by EC

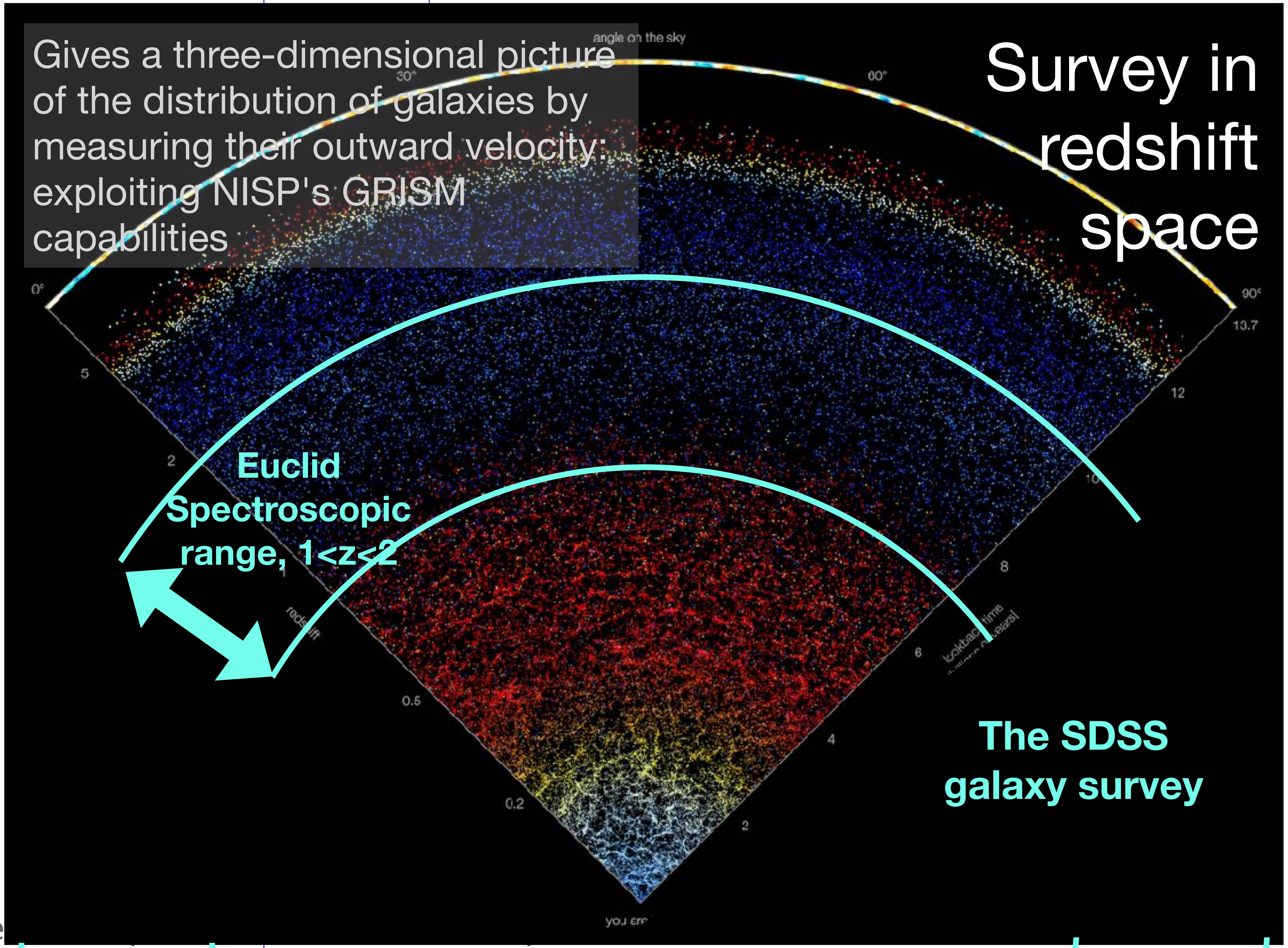
Spectral coverage of Euclid



Dark Energy, Euclid probes

Euclid: 35 million spectroscopic redshifts, in emission Hα line

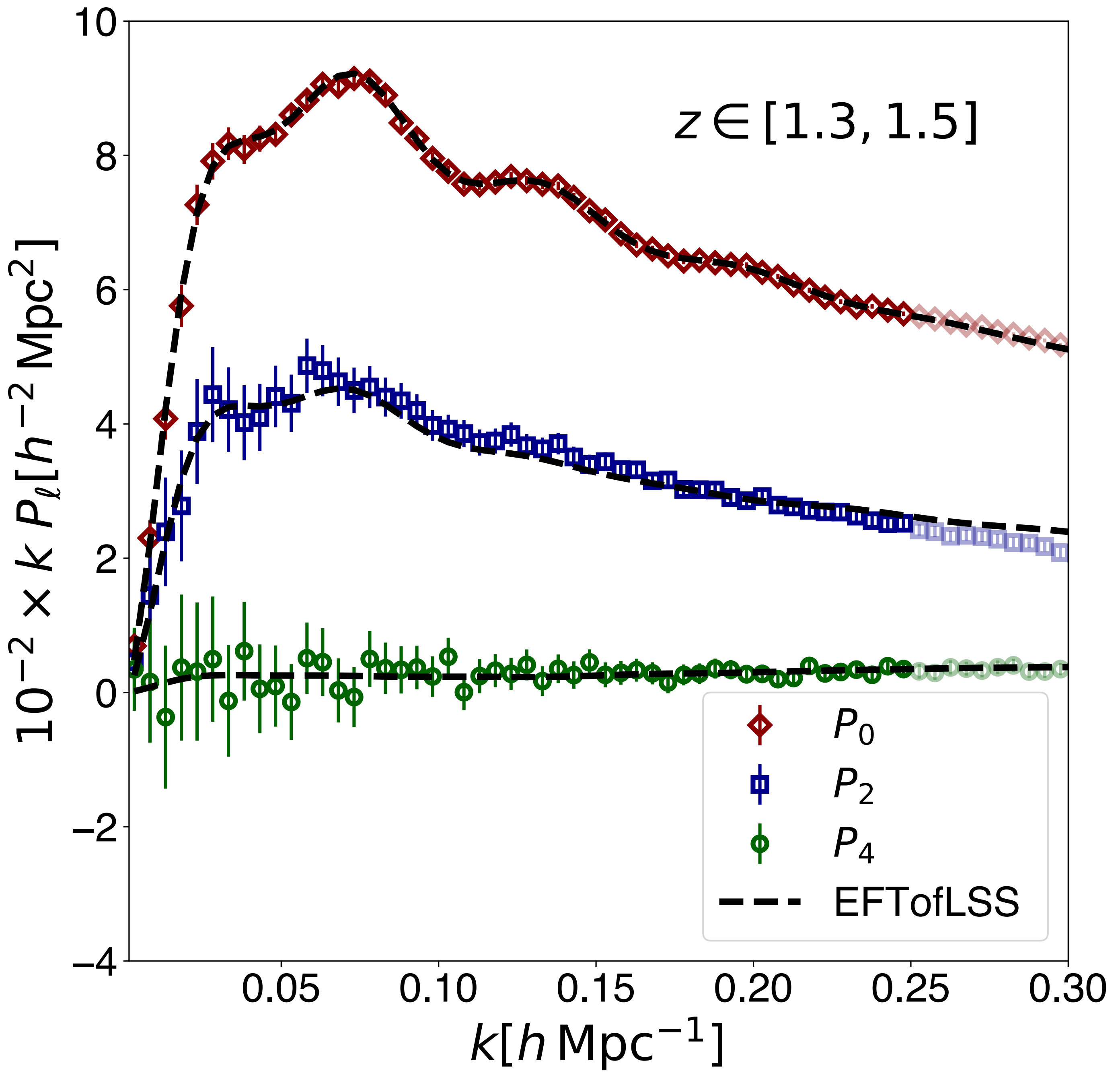




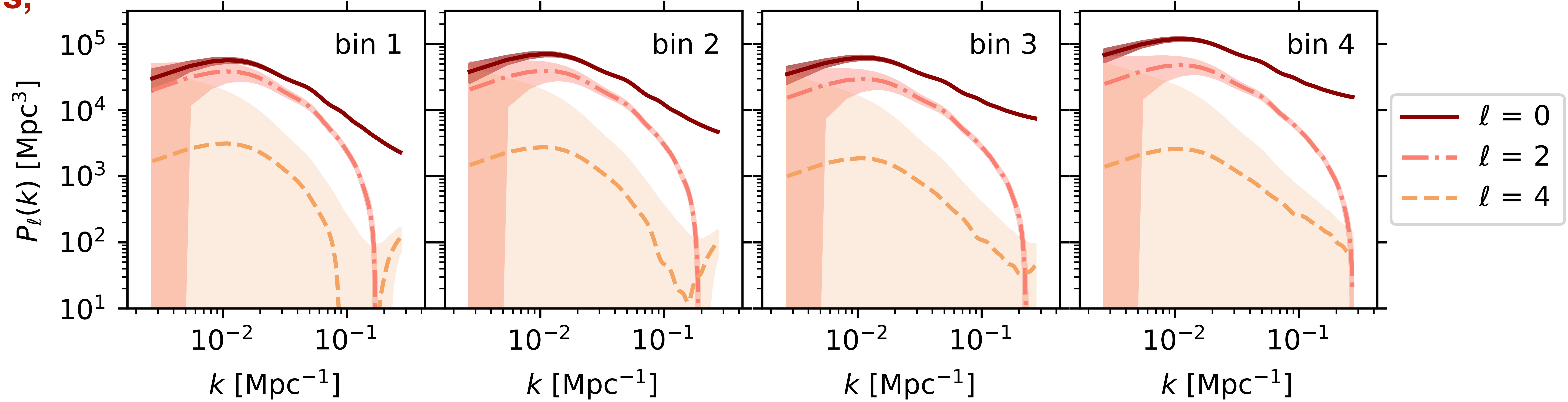
Galaxy density power spectra

Unprecedented precision for the determination of the BAO position for this z range: direct measurement of the expansion rate of the universe

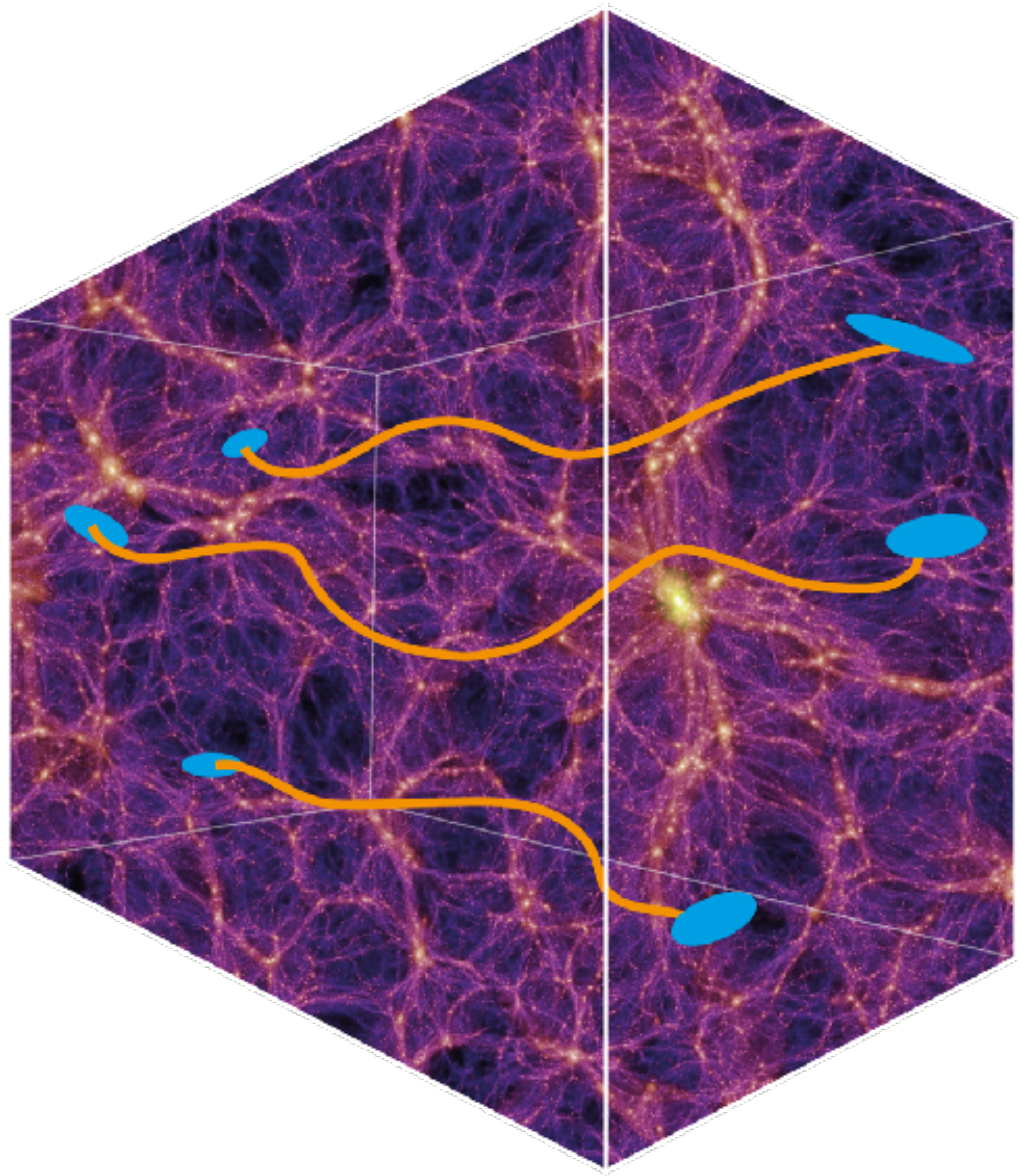
Very good statistical power for determining the relative amplitude of the multipoles: growth rate of fluctuations throughout cosmic time.

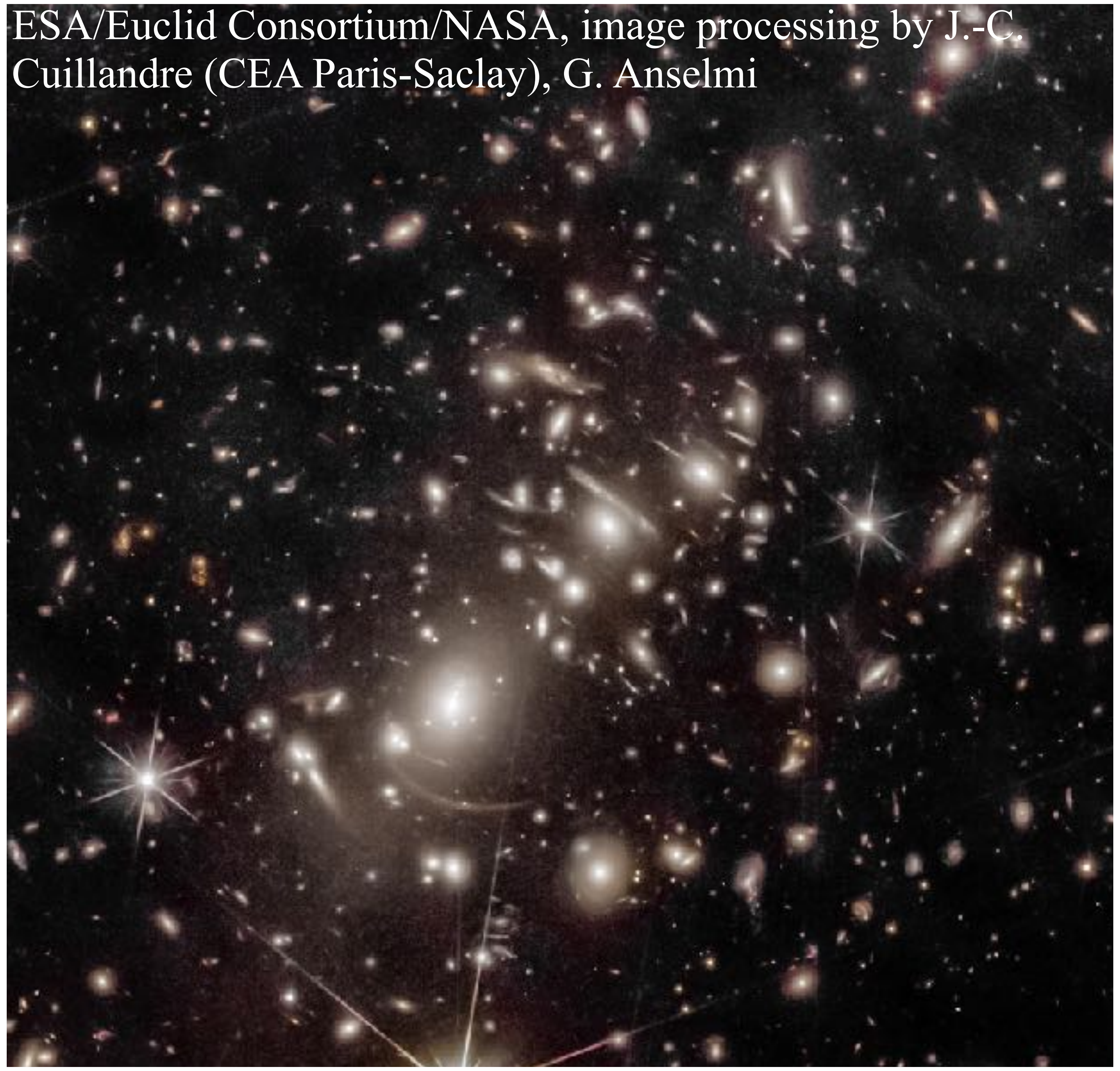


The reference four z-bins,

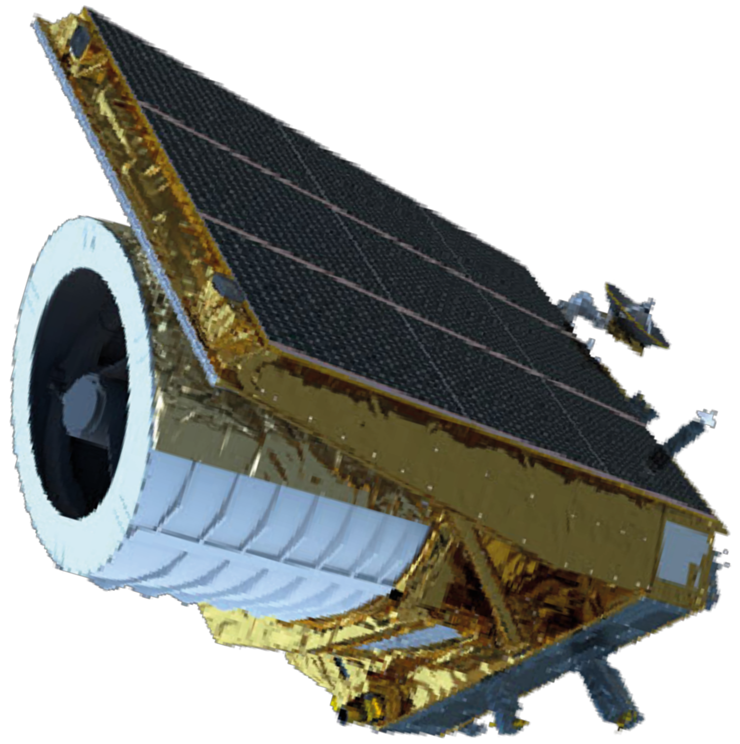


Cosmic shear observations = apparent angular shape correlation induced by lensing effect due to matter fluctuations along the lines of sight; first detection in 2000.





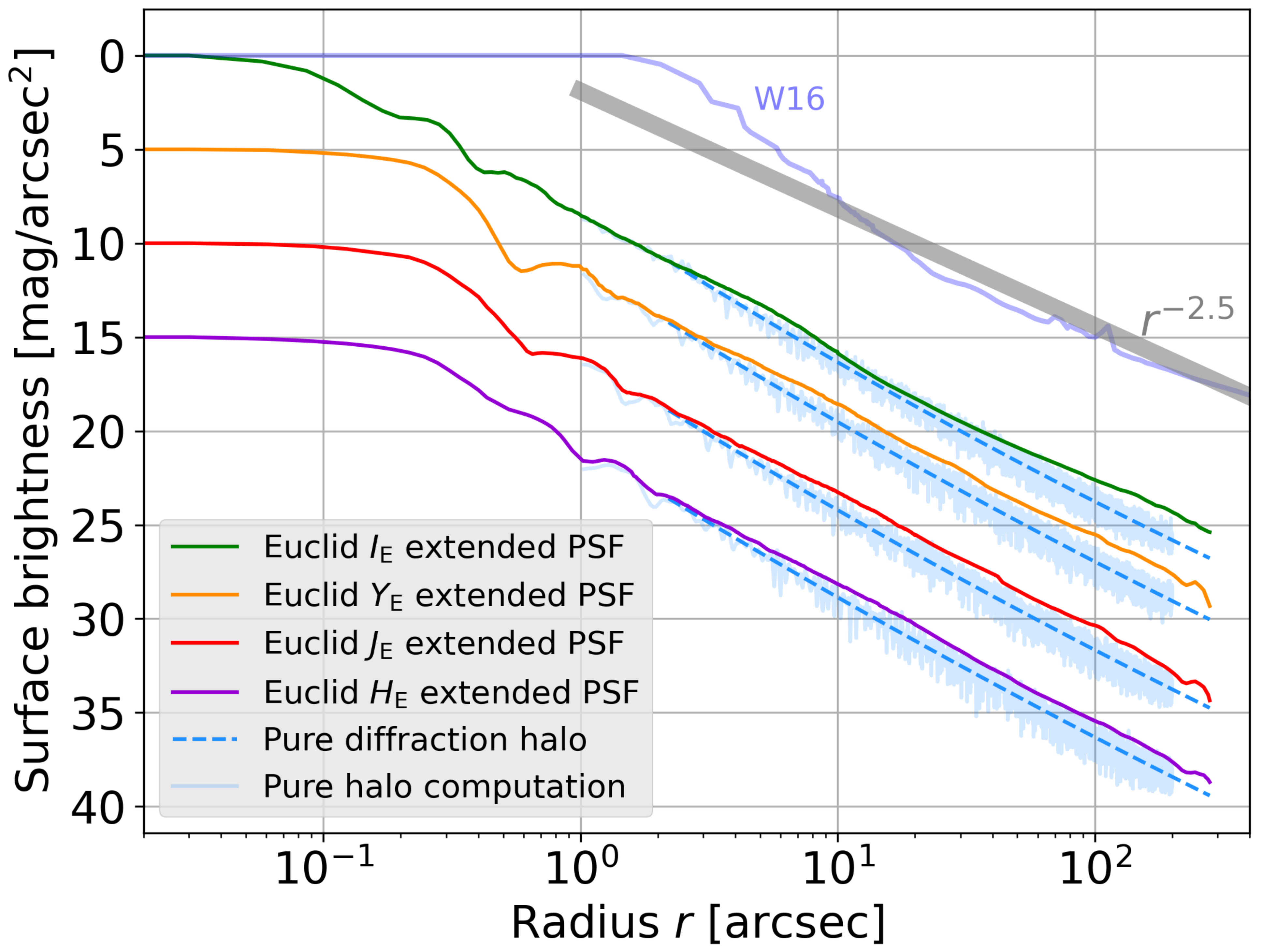
Cosmic shear is a 2-3 % effects that should be measured at percent level!



Euclid is a machine designed to measure galaxy ellipticities with accurate control on systematics (optical, instrumental, astrophysical, etc.)

Euclid performances from the ERO images, Nov 2023

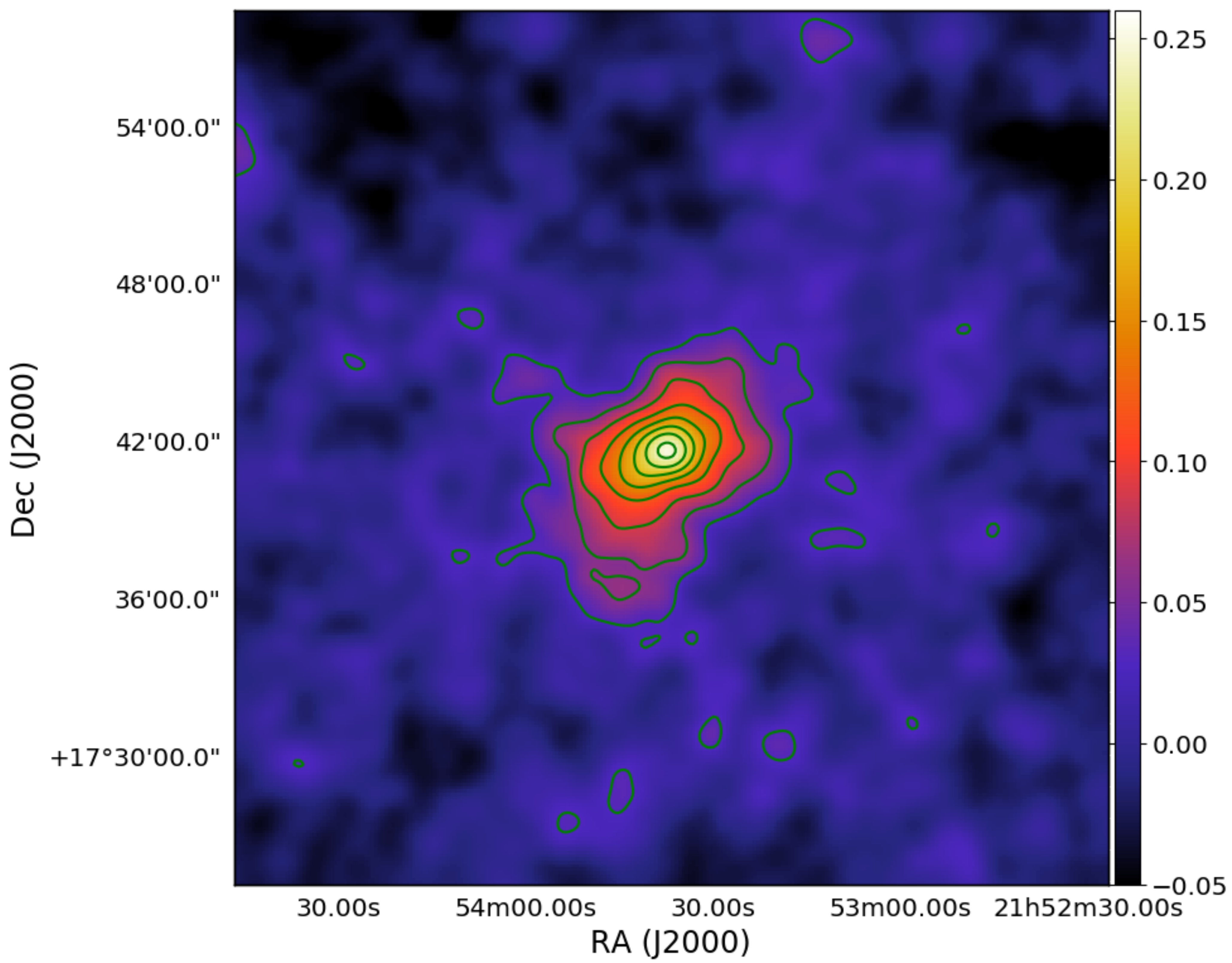
lessons from ERO (Cuillandre et al 2024)



- Very sharp PSF (in particular at large angular scale) allowing Low Surface Brightness galaxy exploration

Atek et al. 2024

Reconstructed mass map of Abell 2390 at z=0.23



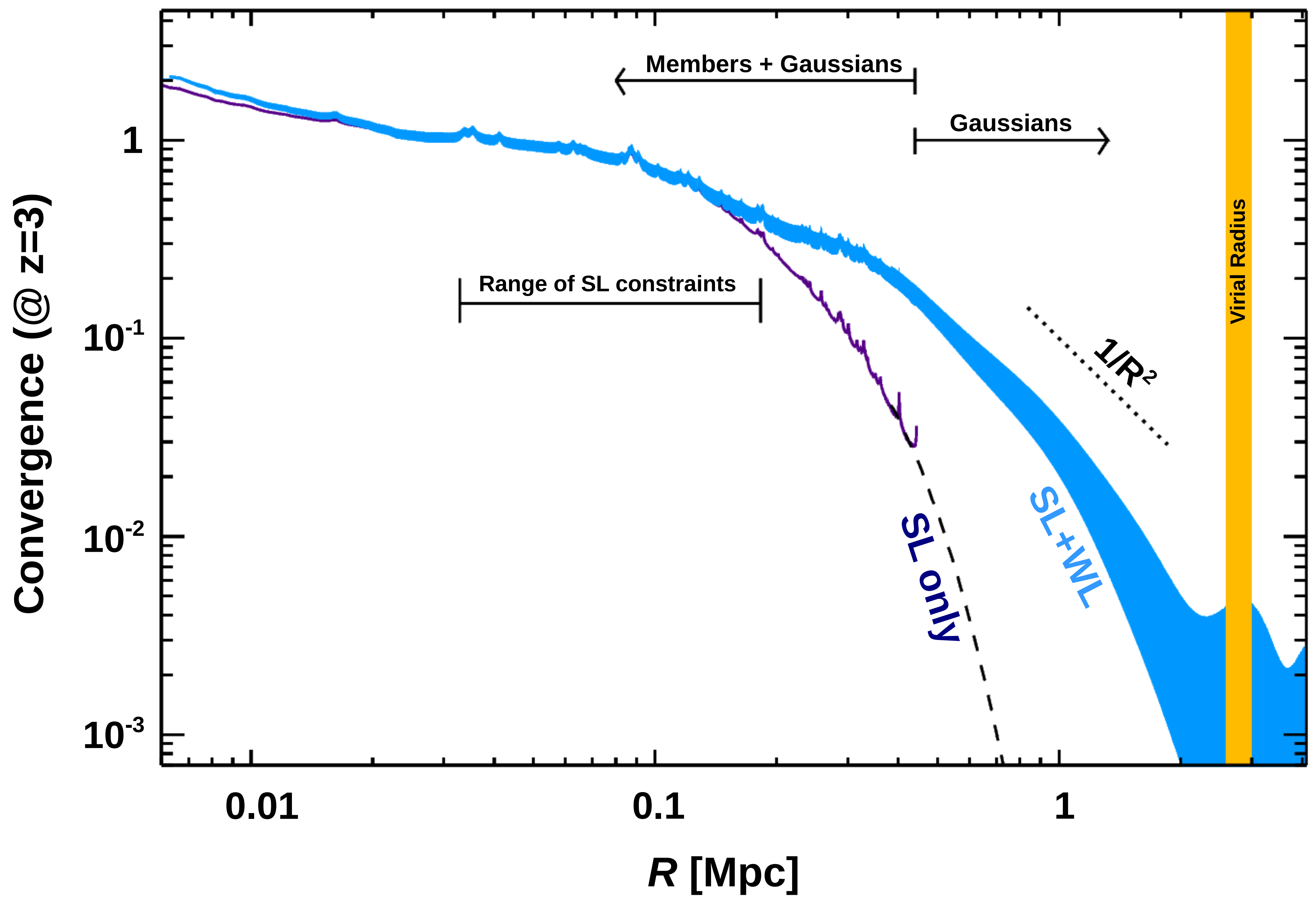
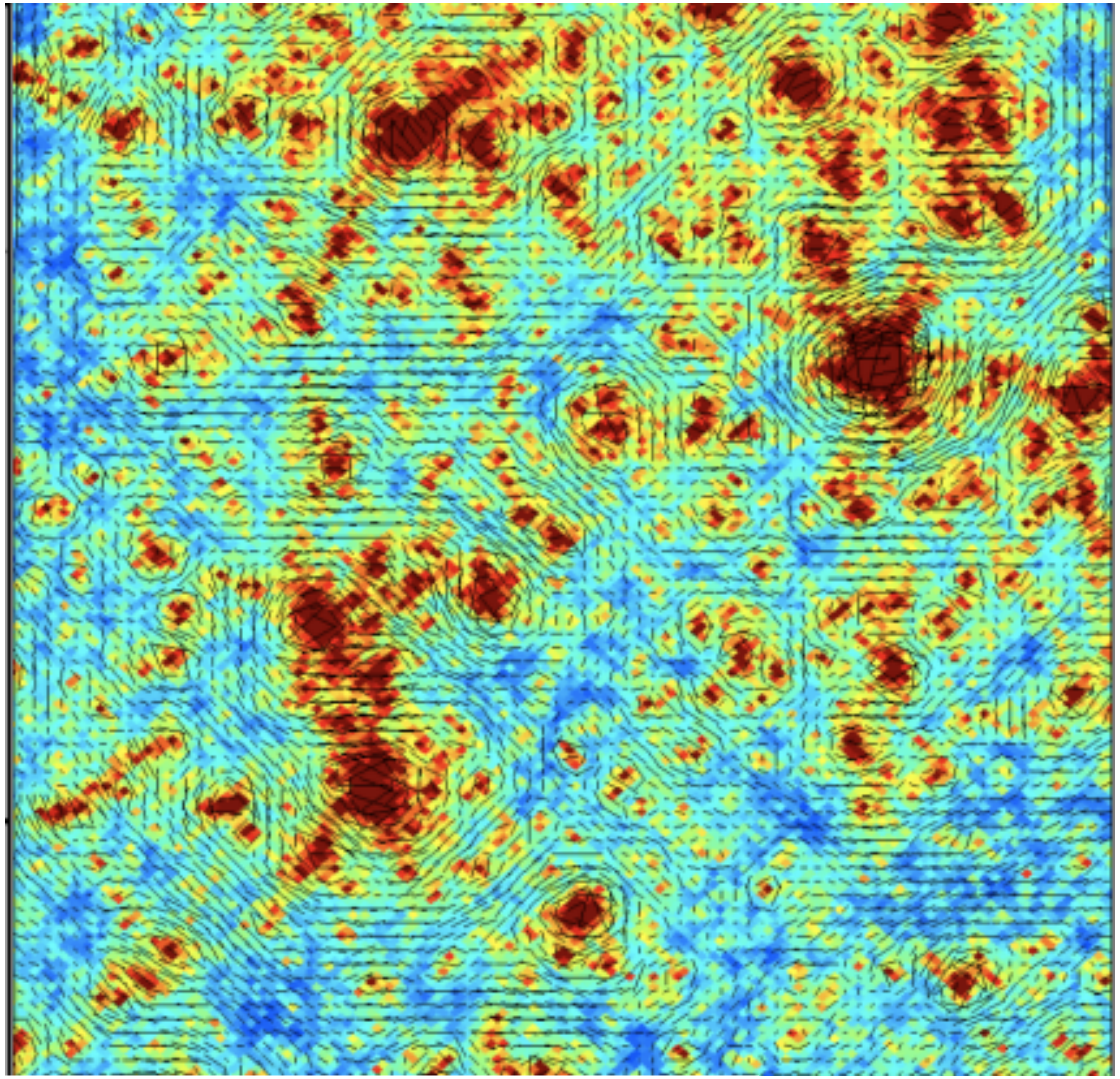
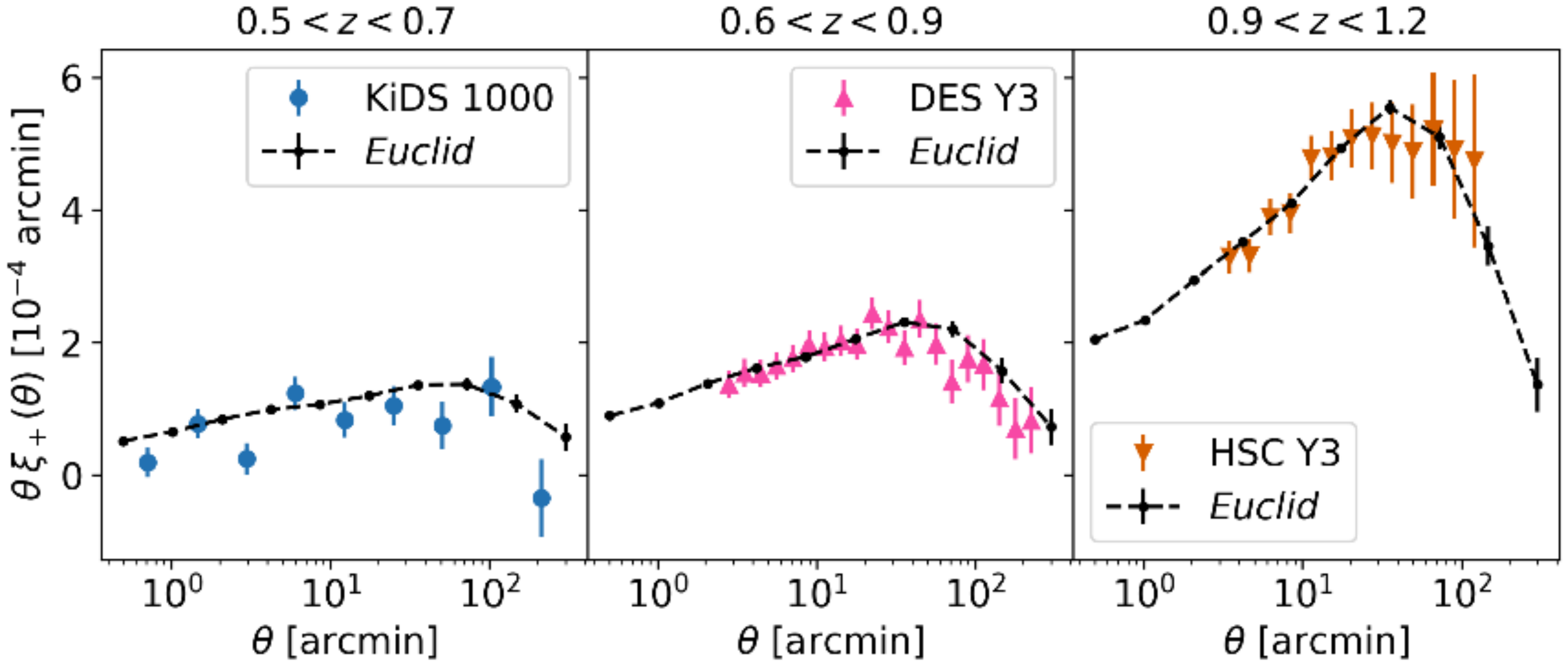


Fig. 9. Mass profile of A2390 from an SL-only analysis and a joint SL+WL analysis. The two regions that include members+Gaussians ($R \lesssim 0.44$ Mpc) in the lens model or only Gaussian functions are indicated. We also show the range of distances covered by the SL constraints

Cosmic Shear from 1.5 billions galaxies

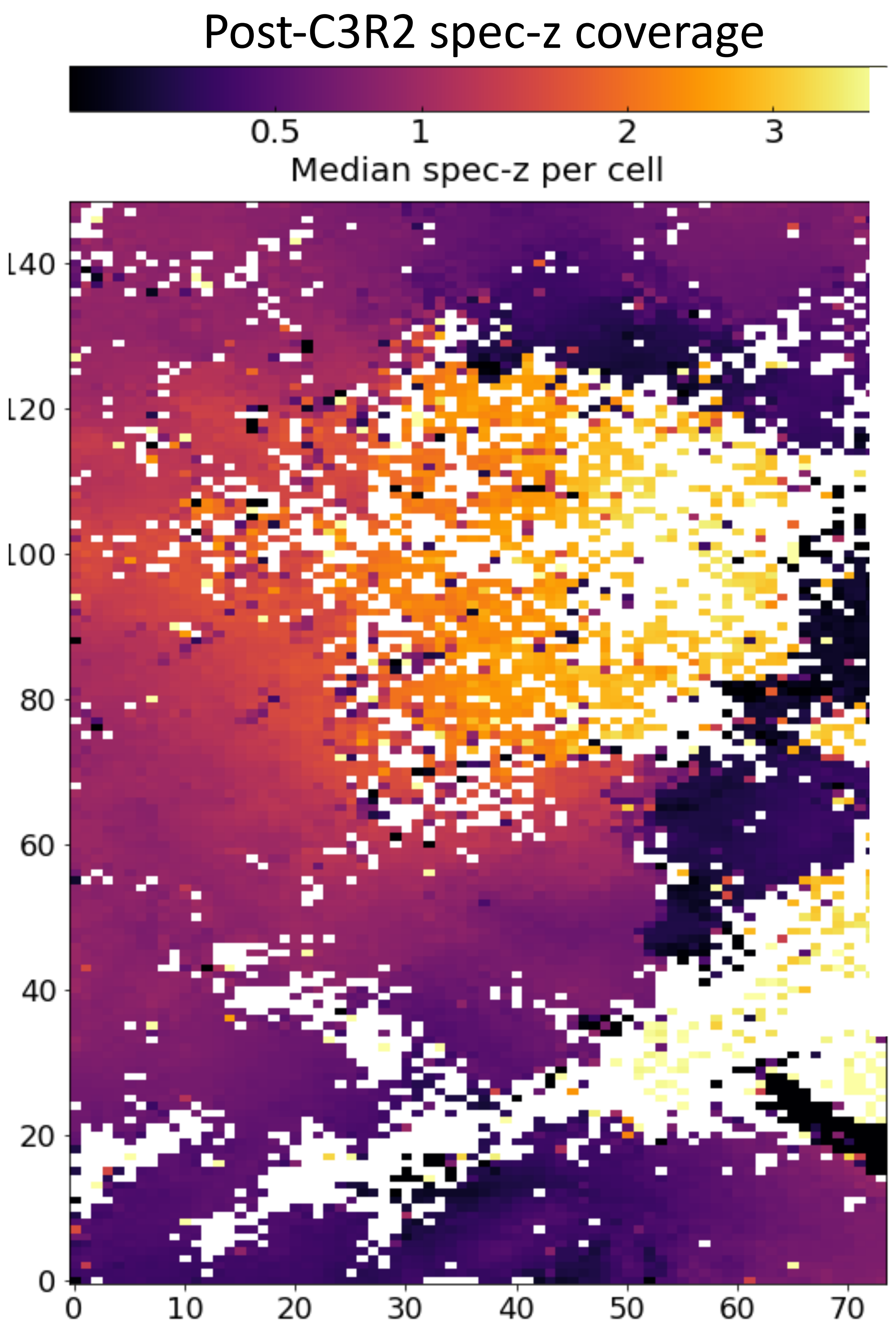


Credit: Euclid Collaboration: Castander+ (2024)

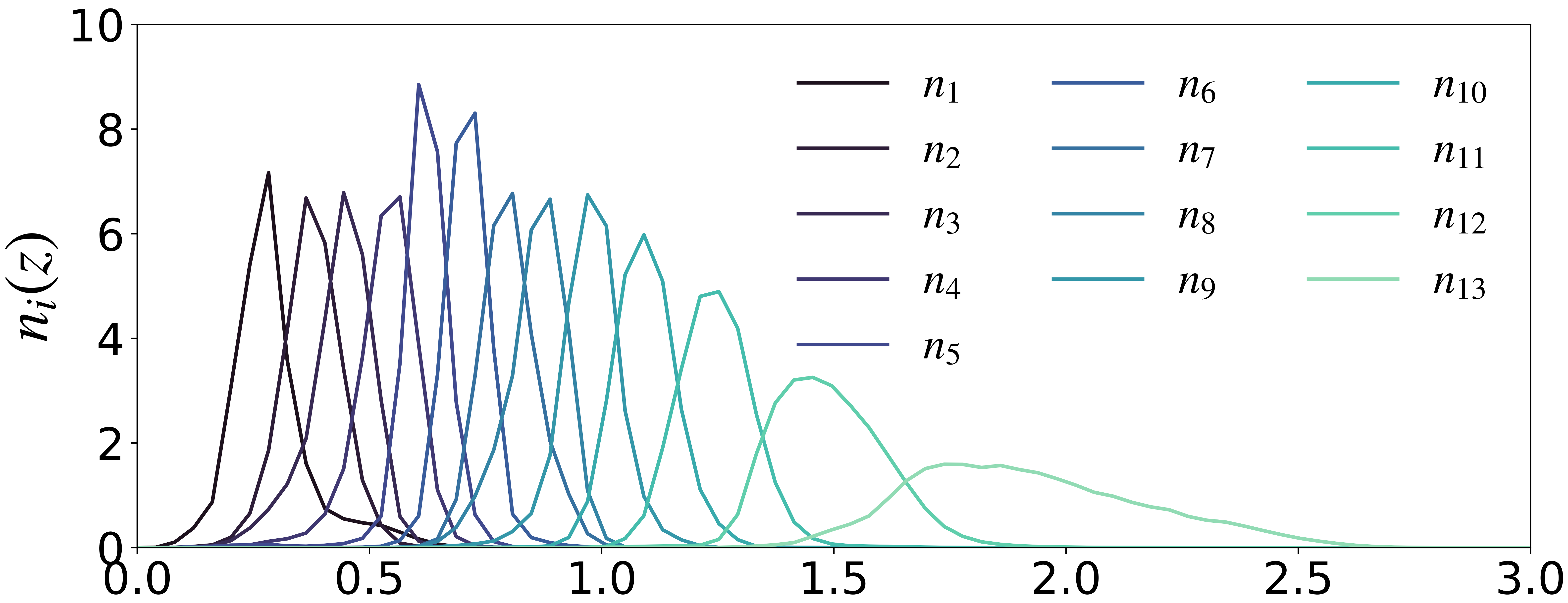


Order-of-magnitude increase in S/N
compared to Stage III survey with galaxies following the same redshift distribution!

Expected key performances in z-phot:



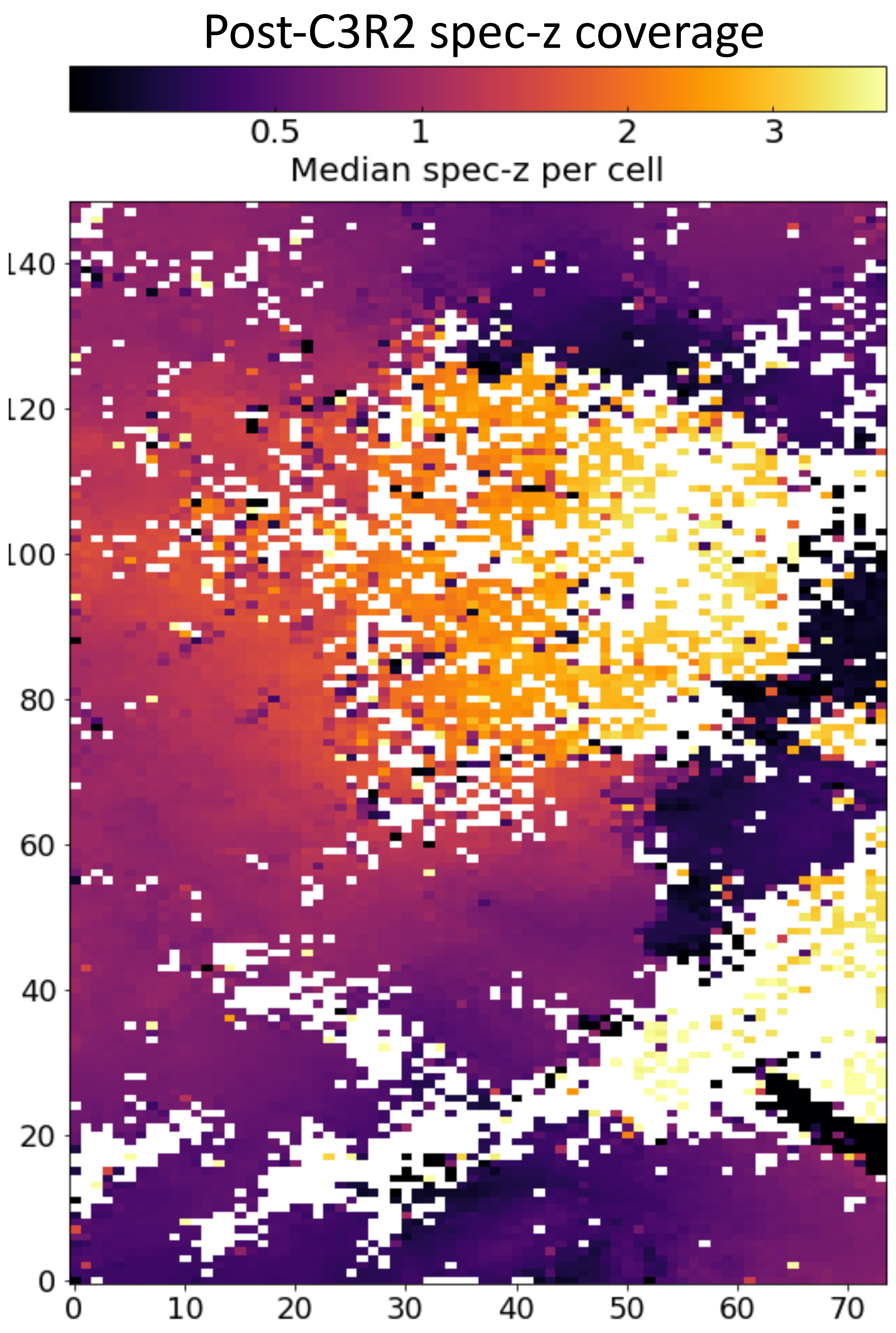
Spectroscopic calibration data in Self Organizing Map



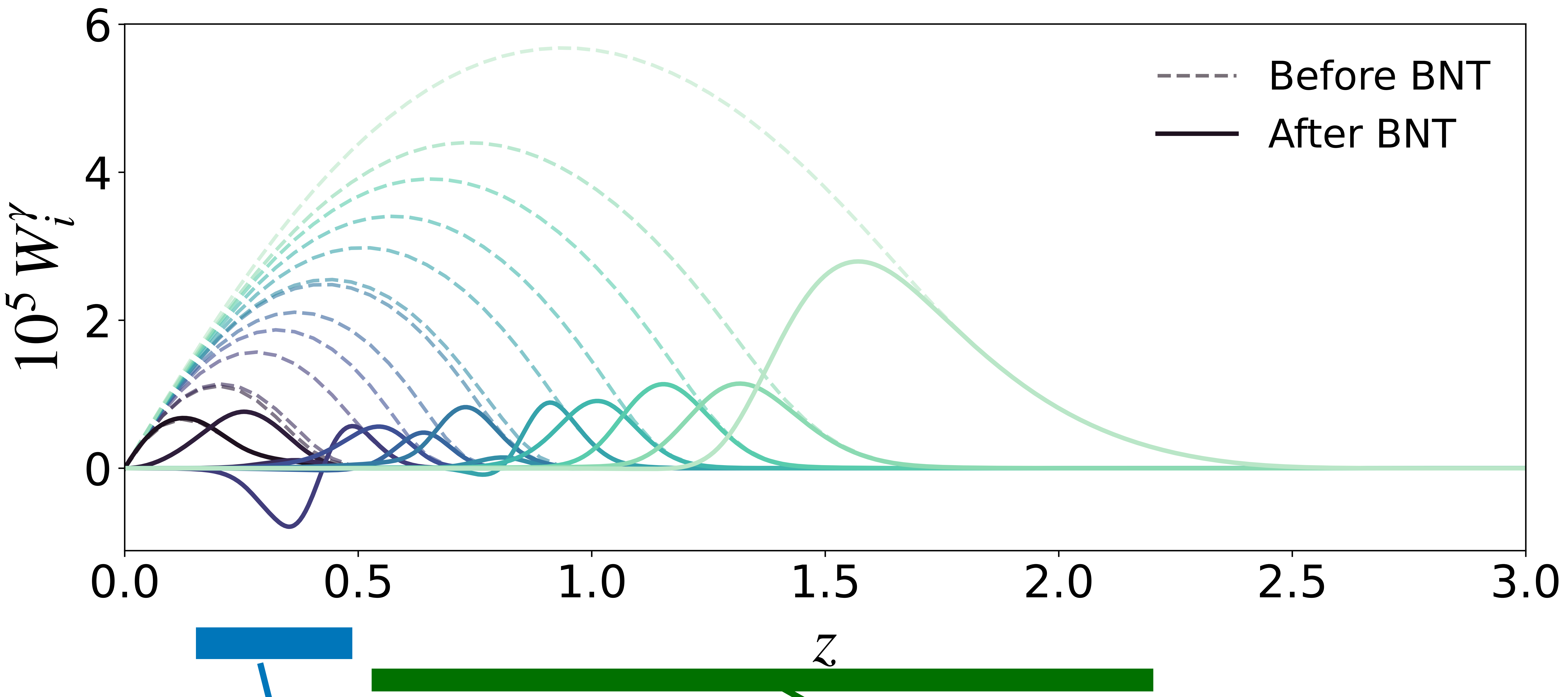
number of bins and their z-distribution as derived from **OU-PHZ PF** applied to **FS2.1 (Rubin Obs. EXT data quality)**

External data (DES, CFHT, Pan-STARRS, HSC-SSP, Rubin) are crucial here to reach full capabilities of the Euclid cosmic shear data.

Expected key performances in z-phot:



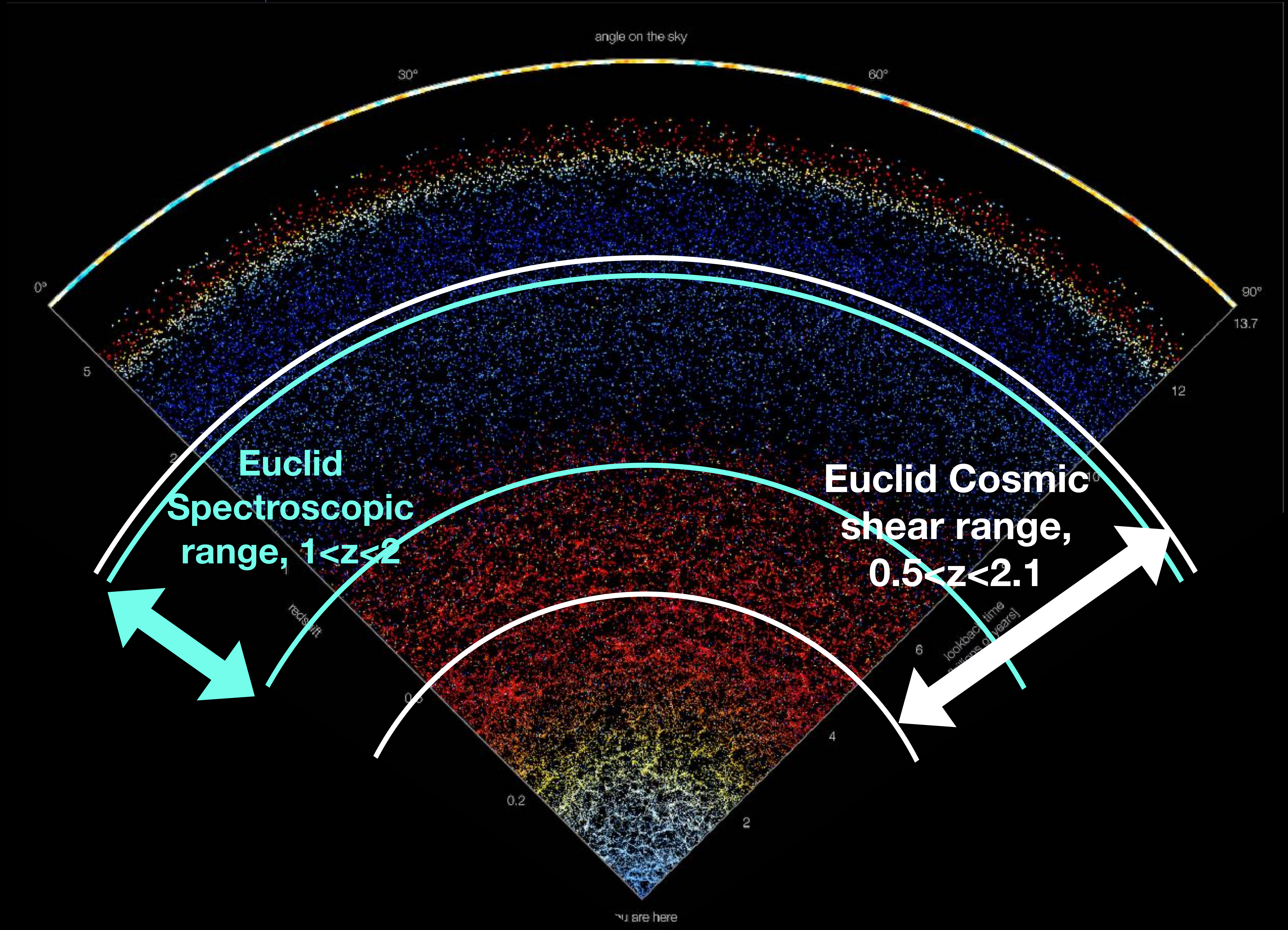
Spectroscopic calibration data in Self Organizing Map



Intrinsic alignment

WL tomographic information, growth rate and geometrical constraints

Dark Energy, Euclid probes



- **BAO scales and RSD power spectra for 1<z<2**
- **Growth of structure and geometrical constraints in 0.5<z<2.1**
- **density - velocity relation and constraints on 1<z<2**

The expected science performances

The Survey

Current 6 year nominal survey (13416 deg^2)

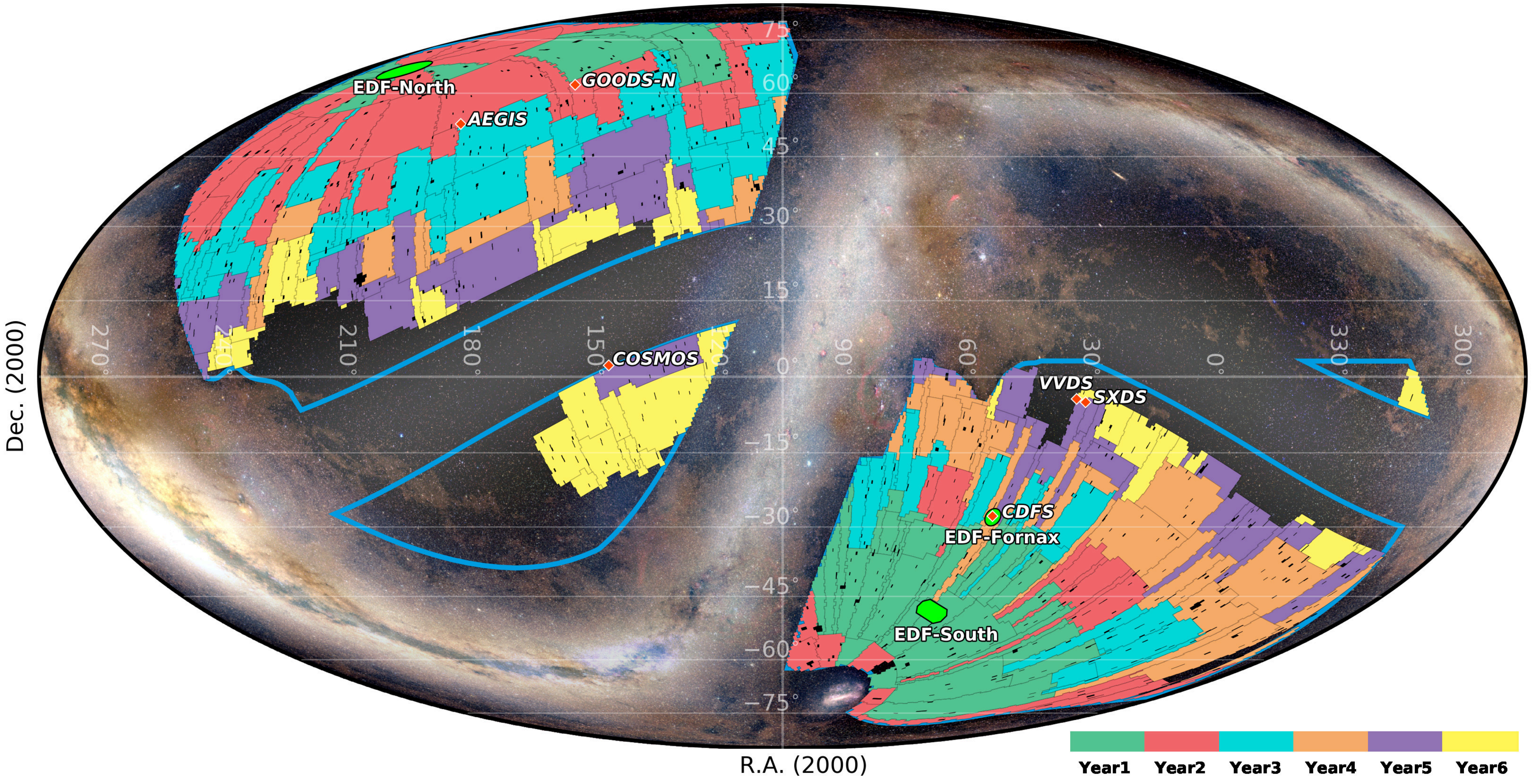


Fig. 25. EWS coverage and colour-coded yearly progress in an all-sky Mollweide projection. The blue borders enclose the 16 000 deg^2 RoI that contains the 13 416 deg^2 observed sky of the EWS. Small dark regions within the EWS are masks for stars brighter than 4 AB mag.

Wide survey

12 billion sources (3-σ)

1.5 billion galaxies (30 gal/ arcmin2)

- Accurate morphological information (WL)
- z-phot with an accuracy of 0.05(1+z)

35 million spectroscopic redshifts of Hα emission line galaxies

- accuracy of 0.001 z
- magnitude 21
- range 0.9 < z < 1.9

Survey started 15 Feb 2024

Performances with baseline model

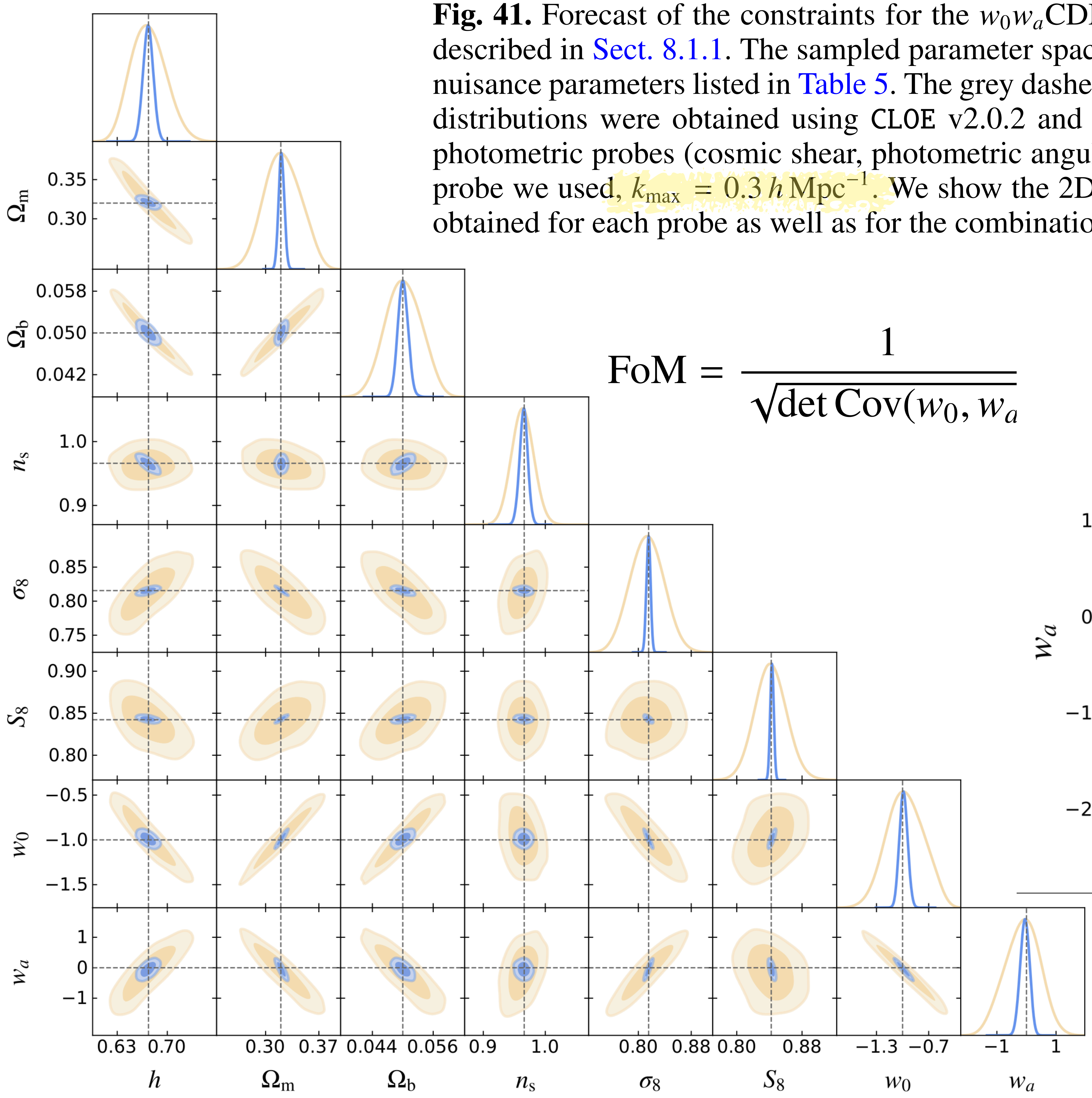
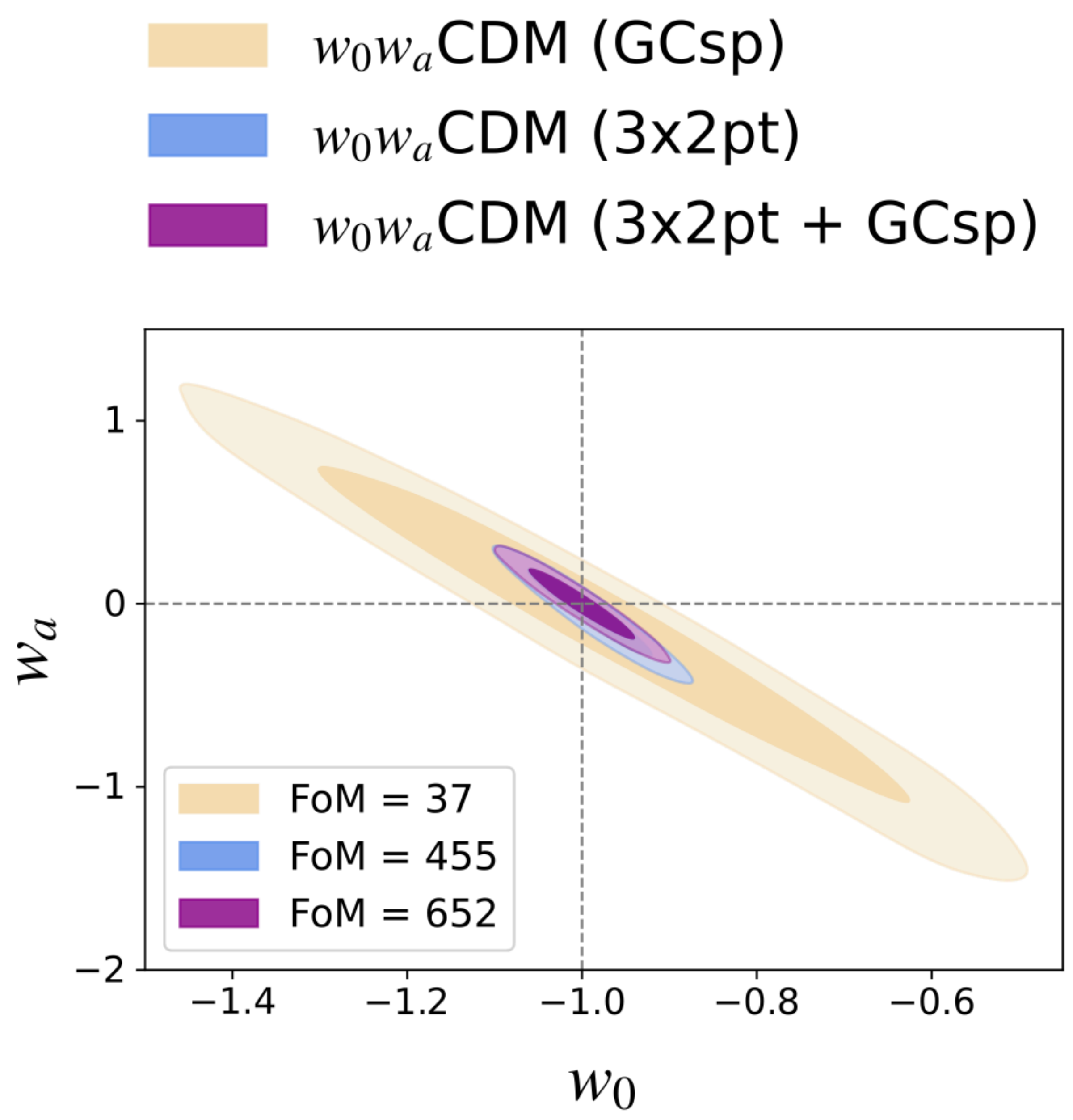
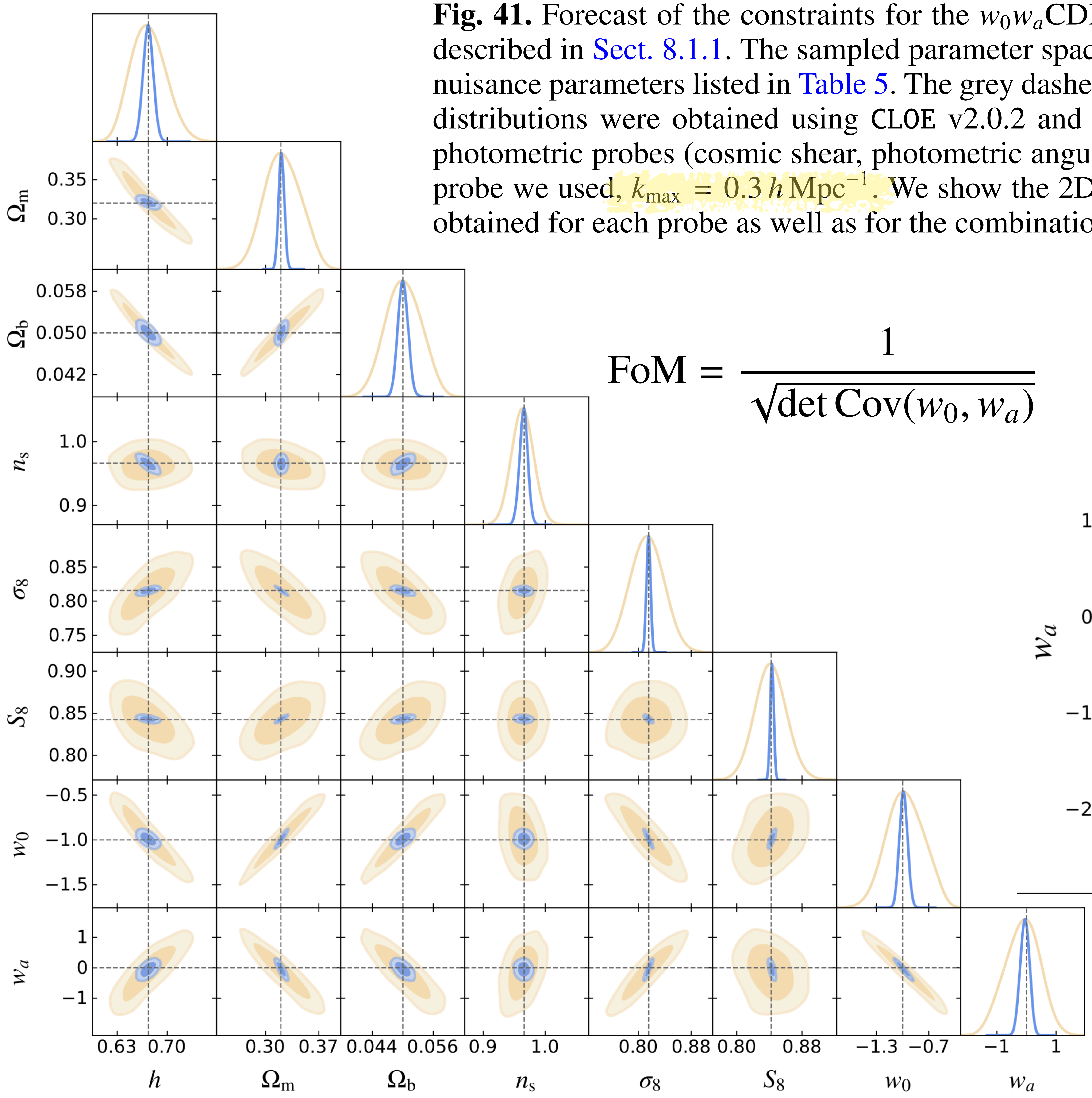


Fig. 41. Forecast of the constraints for the w_0w_aCDM cosmological model (adopting a flat geometry) using only the *Euclid* primary probes, as described in Sect. 8.1.1. The sampled parameter space also included the cosmological parameters ($\Omega_b h^2$, $\Omega_c h^2$, H_0, n_s, A_s, w_0 and w_a) and several nuisance parameters listed in Table 5. The grey dashed lines show the fiducial values of the parameters, that are also listed in Table 5. The posterior distributions were obtained using `CLOE` v2.0.2 and the sampler `Polychord`, with 800 live points and 0.01 as the precision criterion. For the photometric probes (cosmic shear, photometric angular clustering, and galaxy-galaxy-lensing), we used $\ell_{max} = 3000$, while for the spectroscopic probe we used, $k_{max} = 0.3\,h\,\mathrm{Mpc}^{-1}$. We show the 2D-posterior distribution for the parameters w_0 and w_a in detail, citing the corresponding FoM obtained for each probe as well as for the combination of both.

$$\mathrm{FoM} = \frac{1}{\sqrt{\det \mathrm{Cov}(w_0, w_a)}}$$



Performances with baseline model



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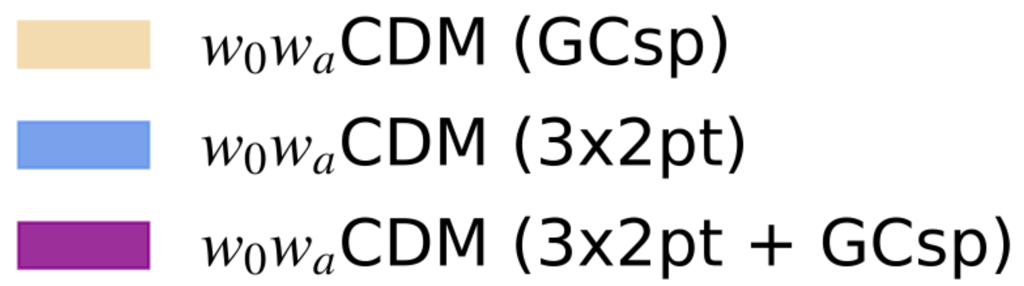
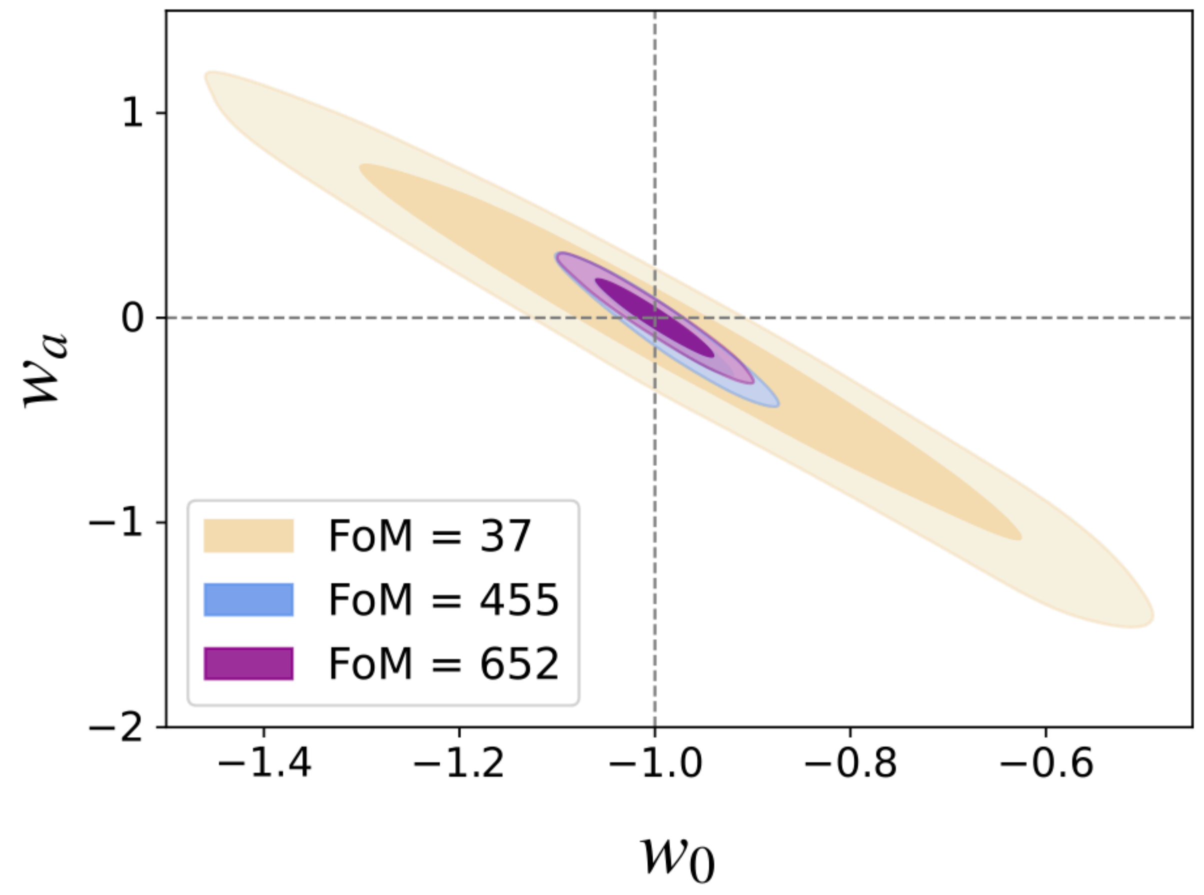
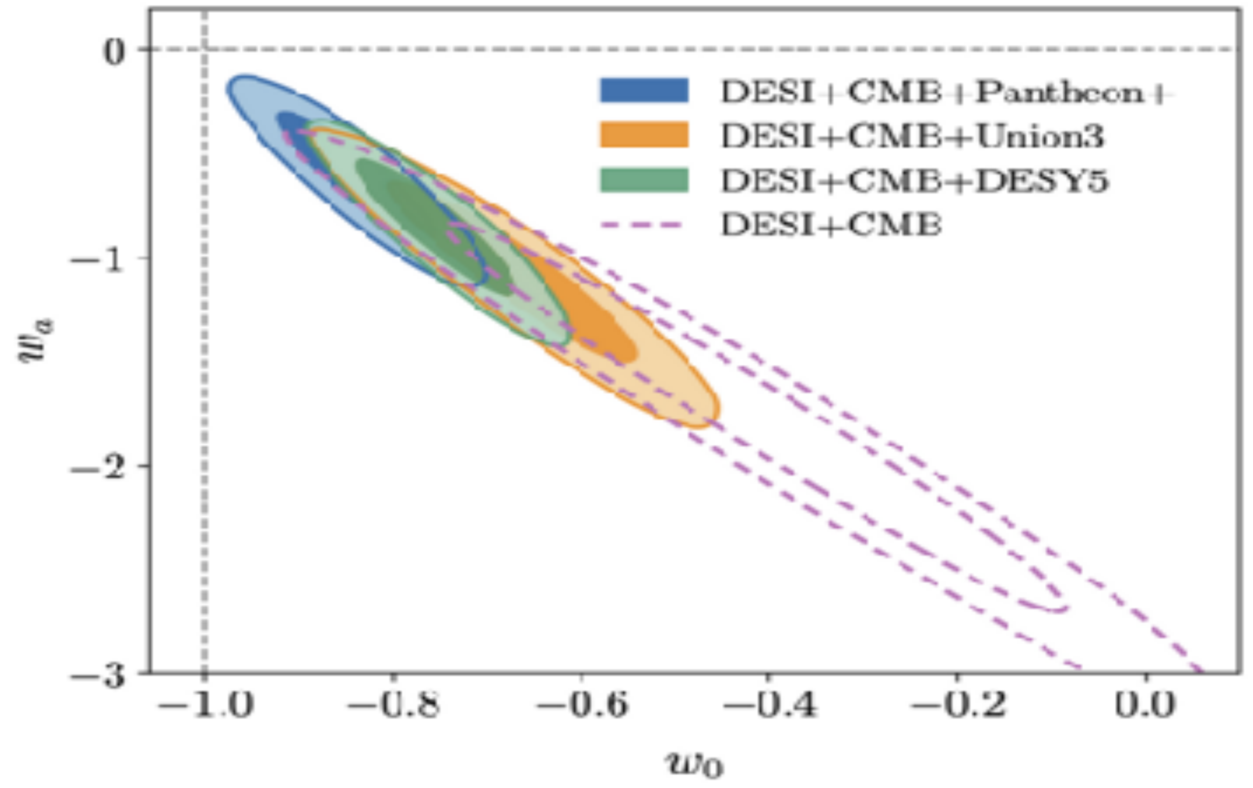




DESI DR2 Results II: *Measurements of Baryon Acoustic Oscillations and Cosmological Constraints*, arXiv: 2503.14738

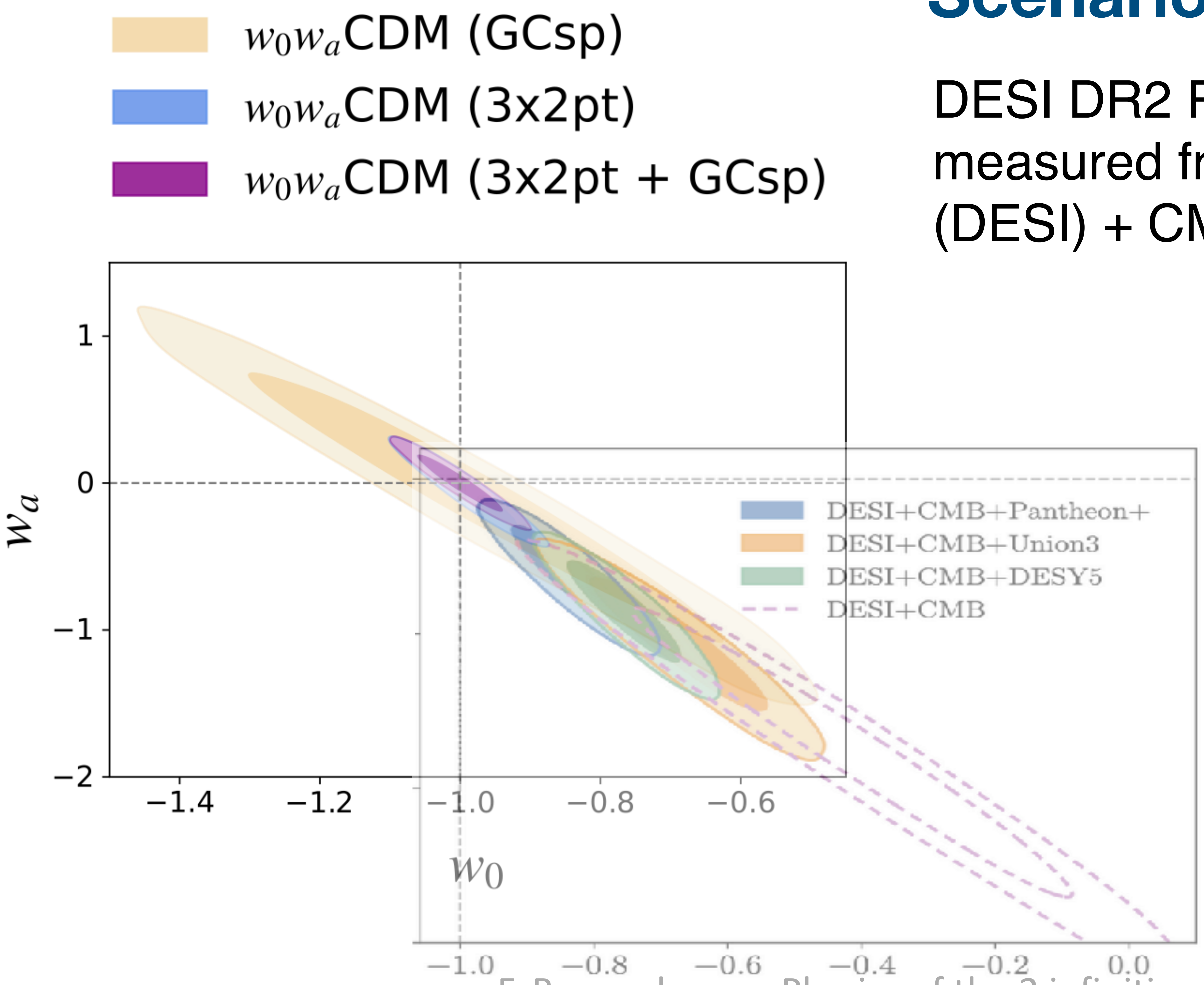


Constraints on the dark energy equation of state from fits of the w_0w_aCDM model to DESI DR2 in combination with CMB alone and CMB with three supernovae datasets.

a redshift

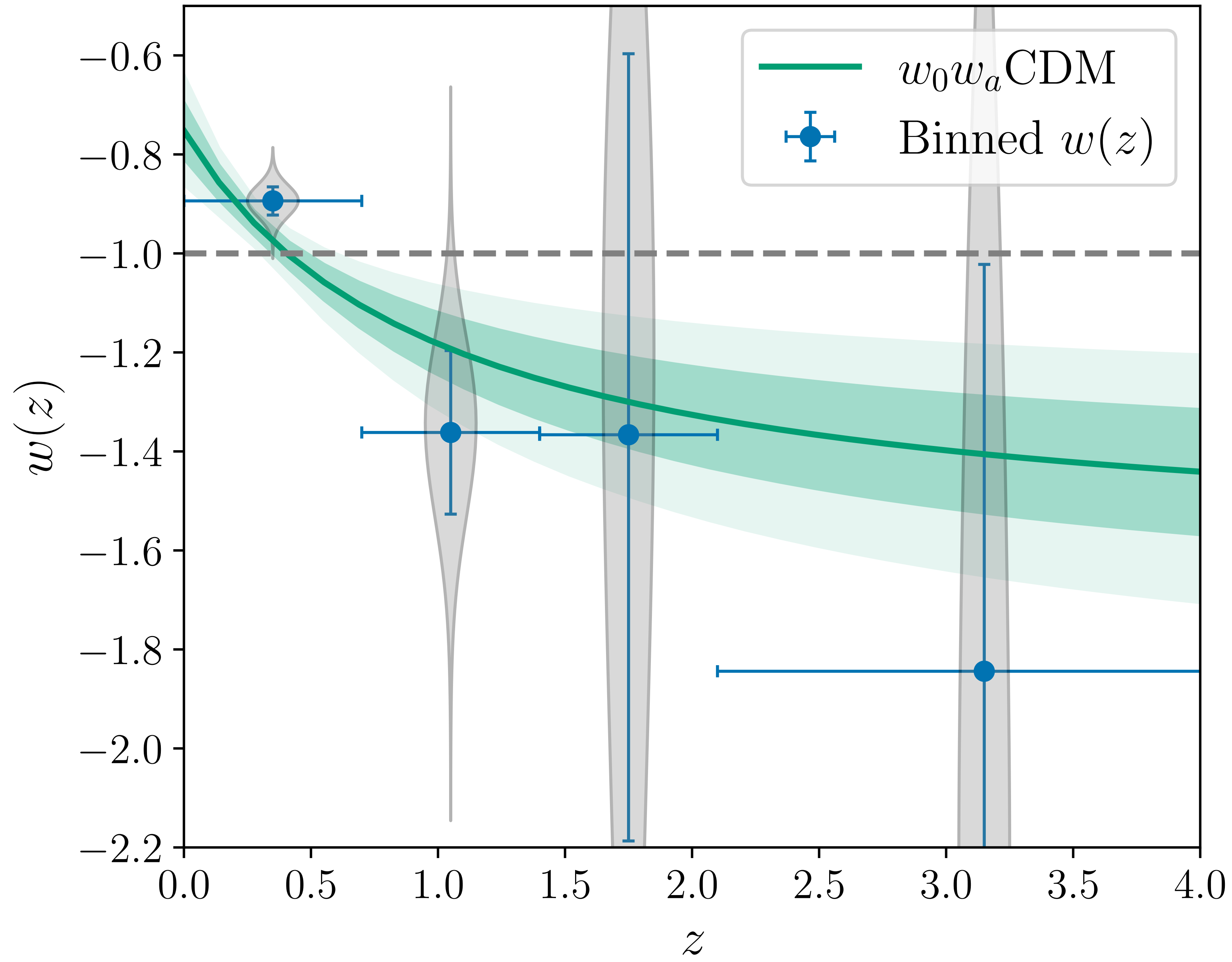
Expected Euclid-only performances

Cosmological constant or new form of energy



Scenario 2+ with DESI ?

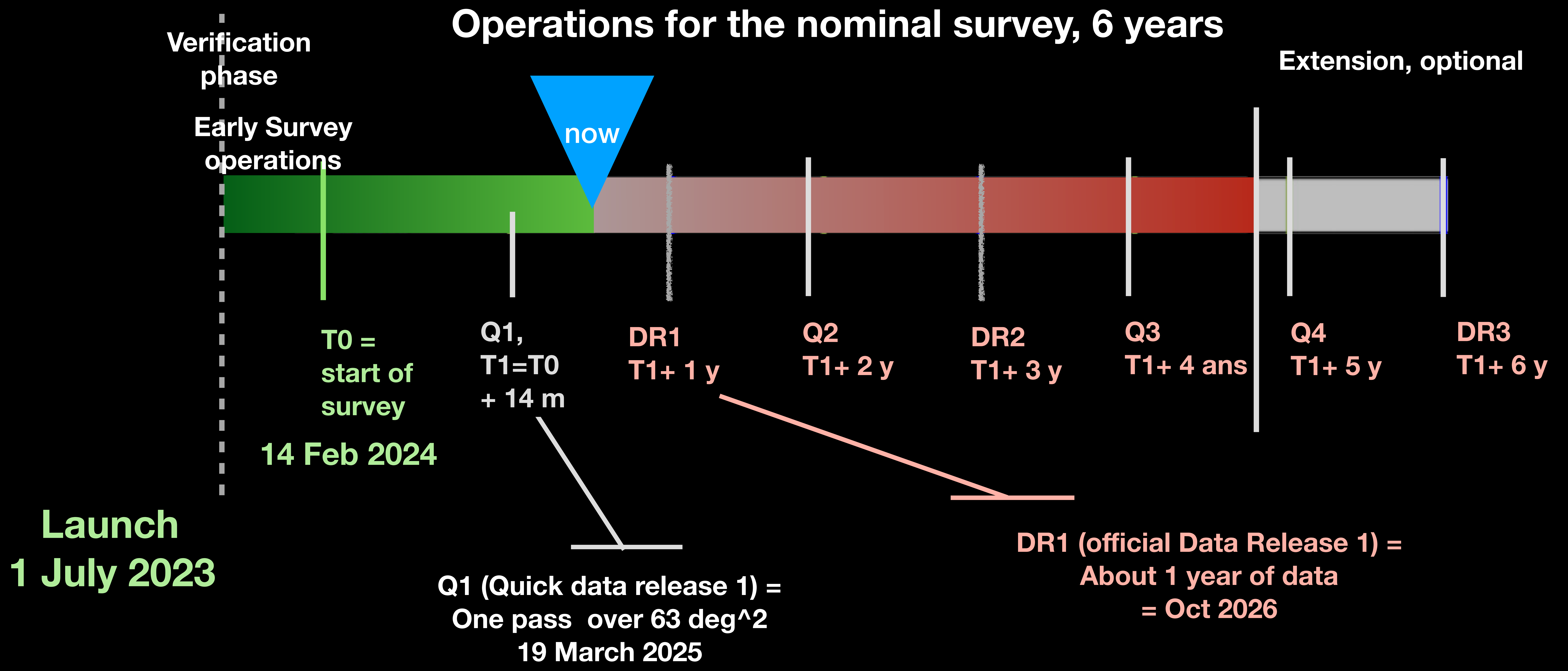
DESI DR2 Results II: DE equation of state as measured from the position of the BAO peaks (DESI) + CMB + DES Y5



Λ-CDM

a redshift

Calendar of Data Releases




About 500 gravitational arcs at galactic scales, Euclid Collaboration,
M. Walmsley et al. through deep learning searches and Citizen
Science inspections

About 500 gravitational arcs at galactic scales, Euclid Collaboration, M. Walmsley et al. through deep learning searches and Citizen Science inspections

Thank you for your attention

https://www.euclid-ec.org/euclid-anniversary/

52 weeks of Euclid in space

first year of a big journey to new physics

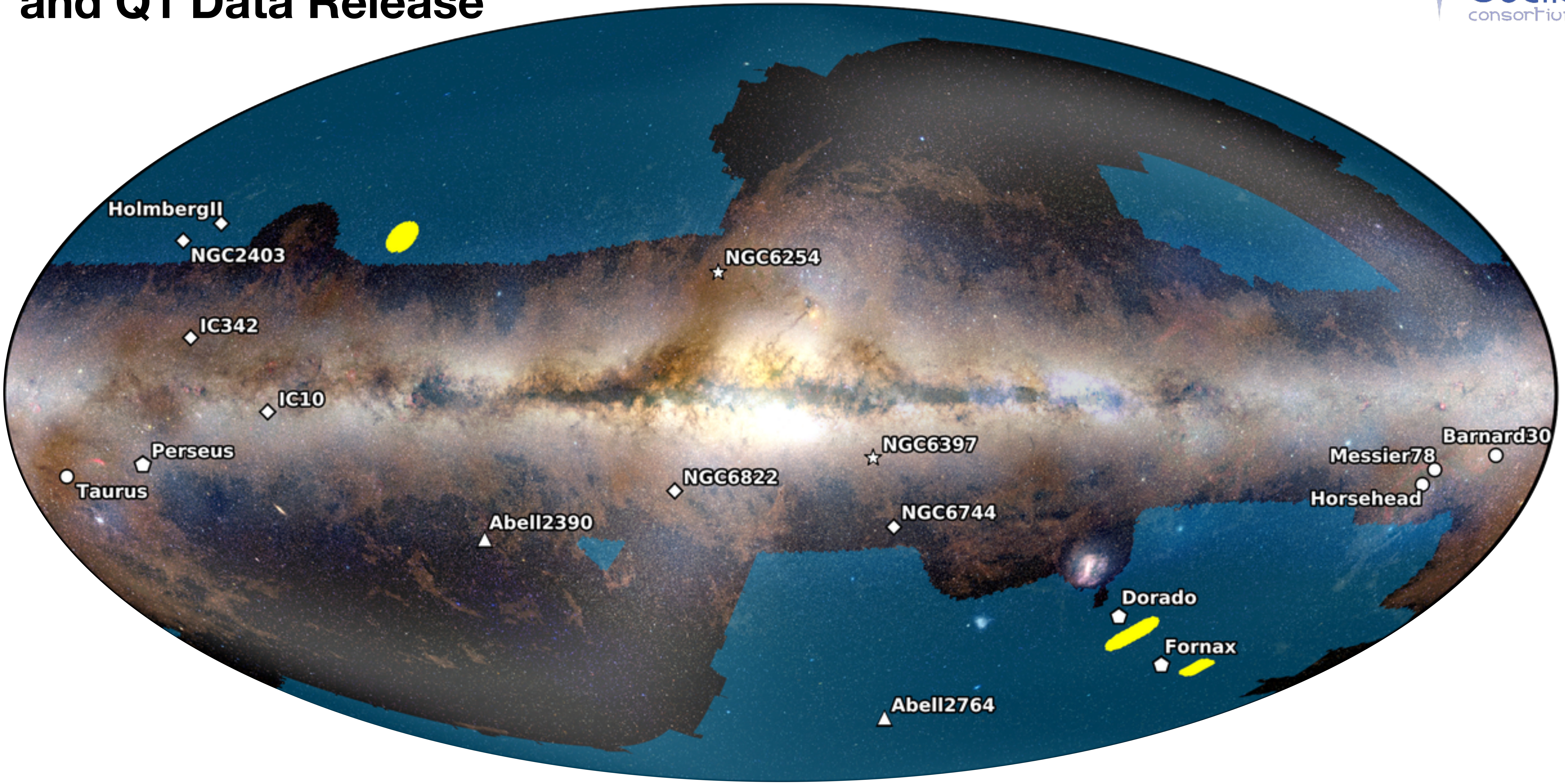
esa
euclid

AIRBUS
DEFENCE & SPACE

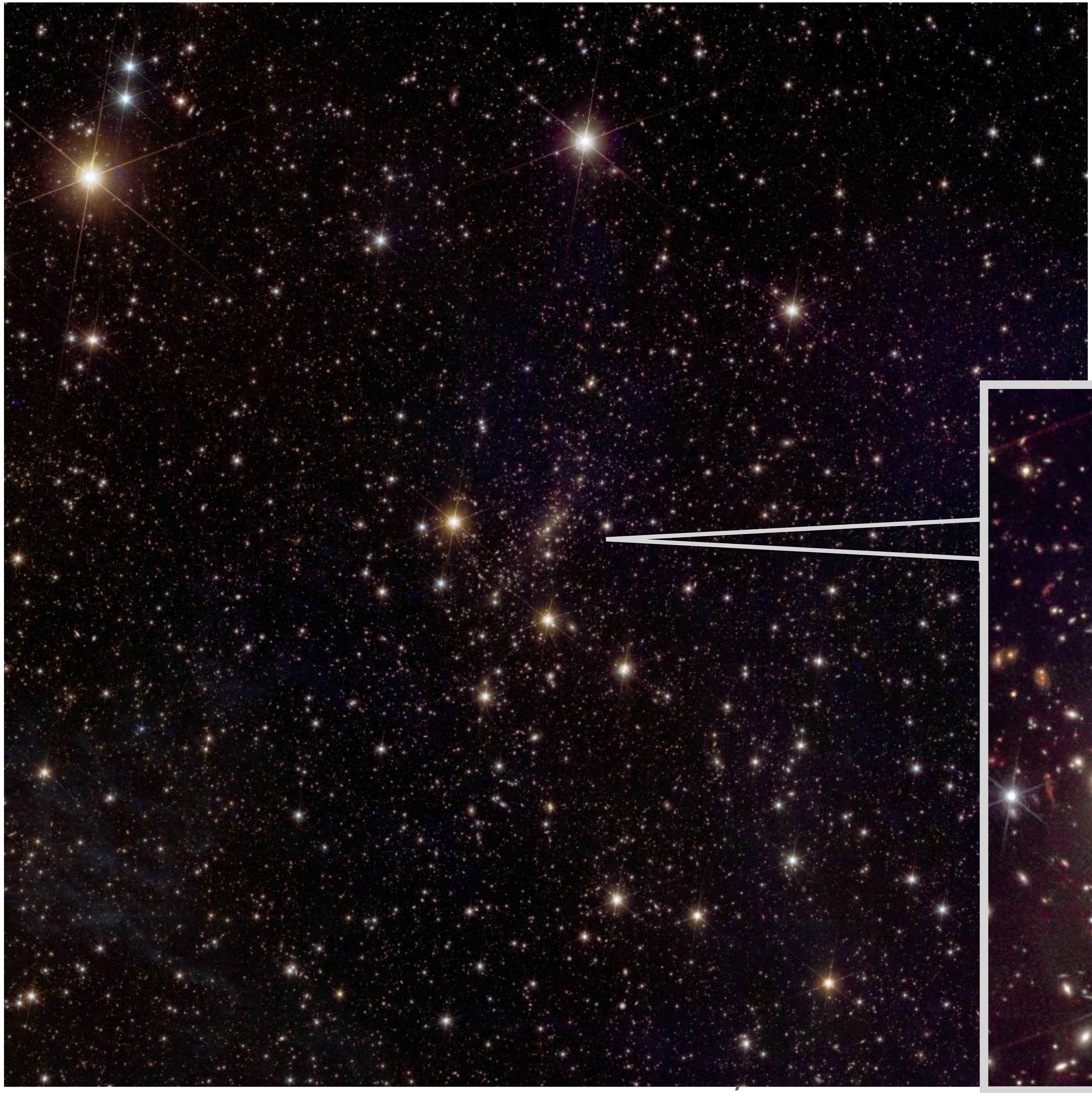
Euclid consortium

ThalesAlenia Space
a Thales / Leonardo company

The Early Release Observations and Q1 Data Release

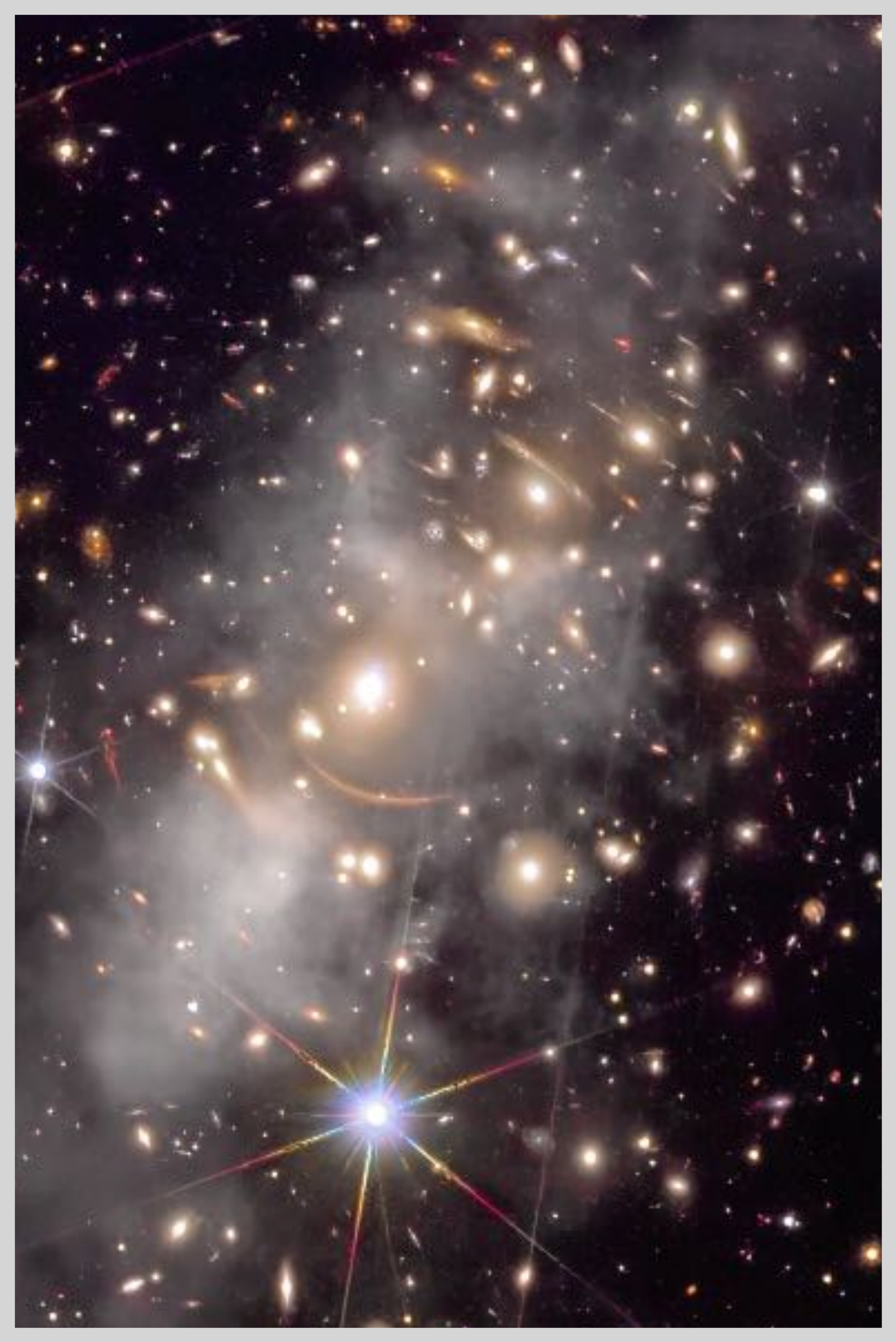


Euclid new image of galaxy cluster Abell 2390 at z=0.23



with arcs ...

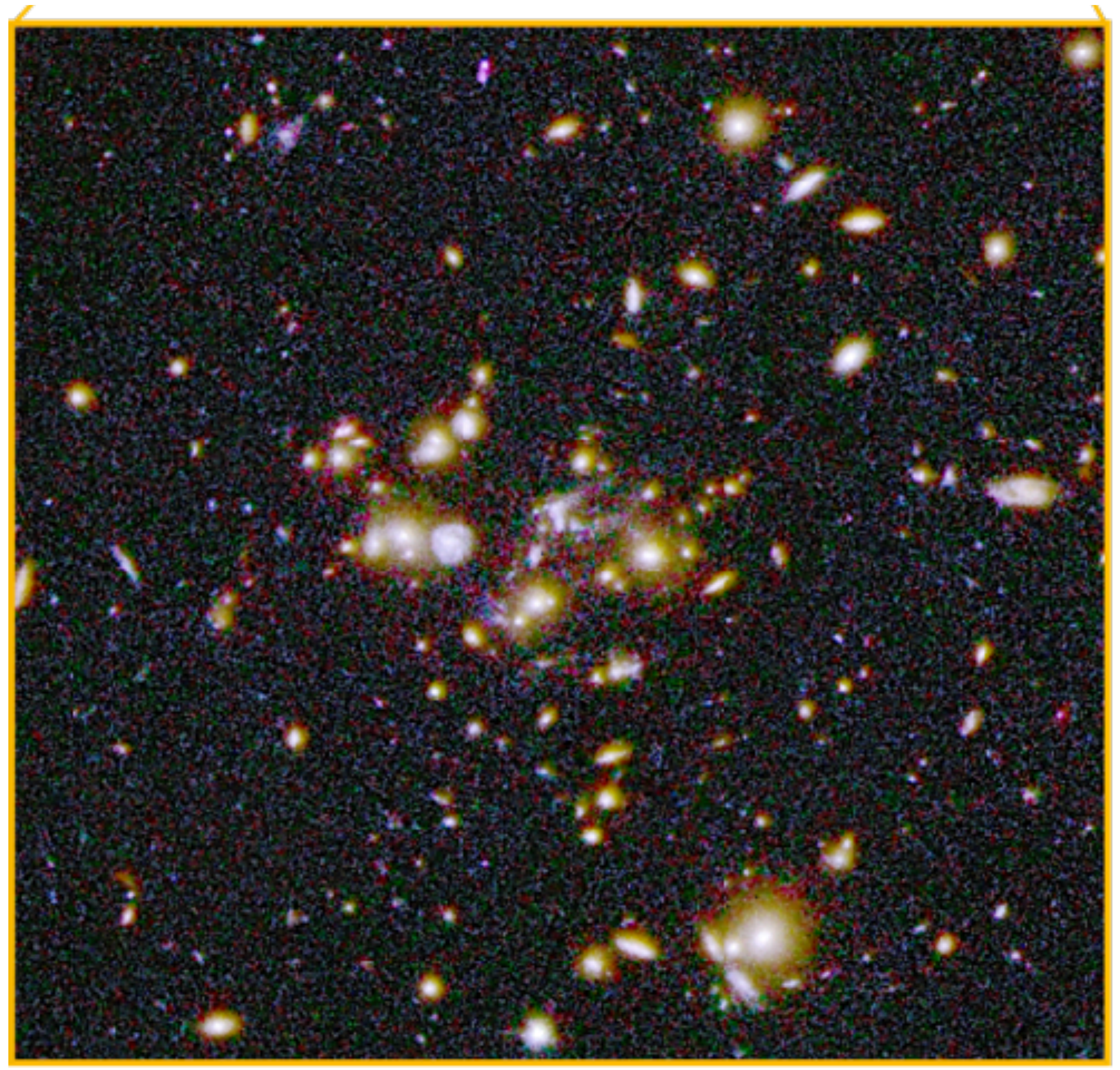
and intra-cluster light



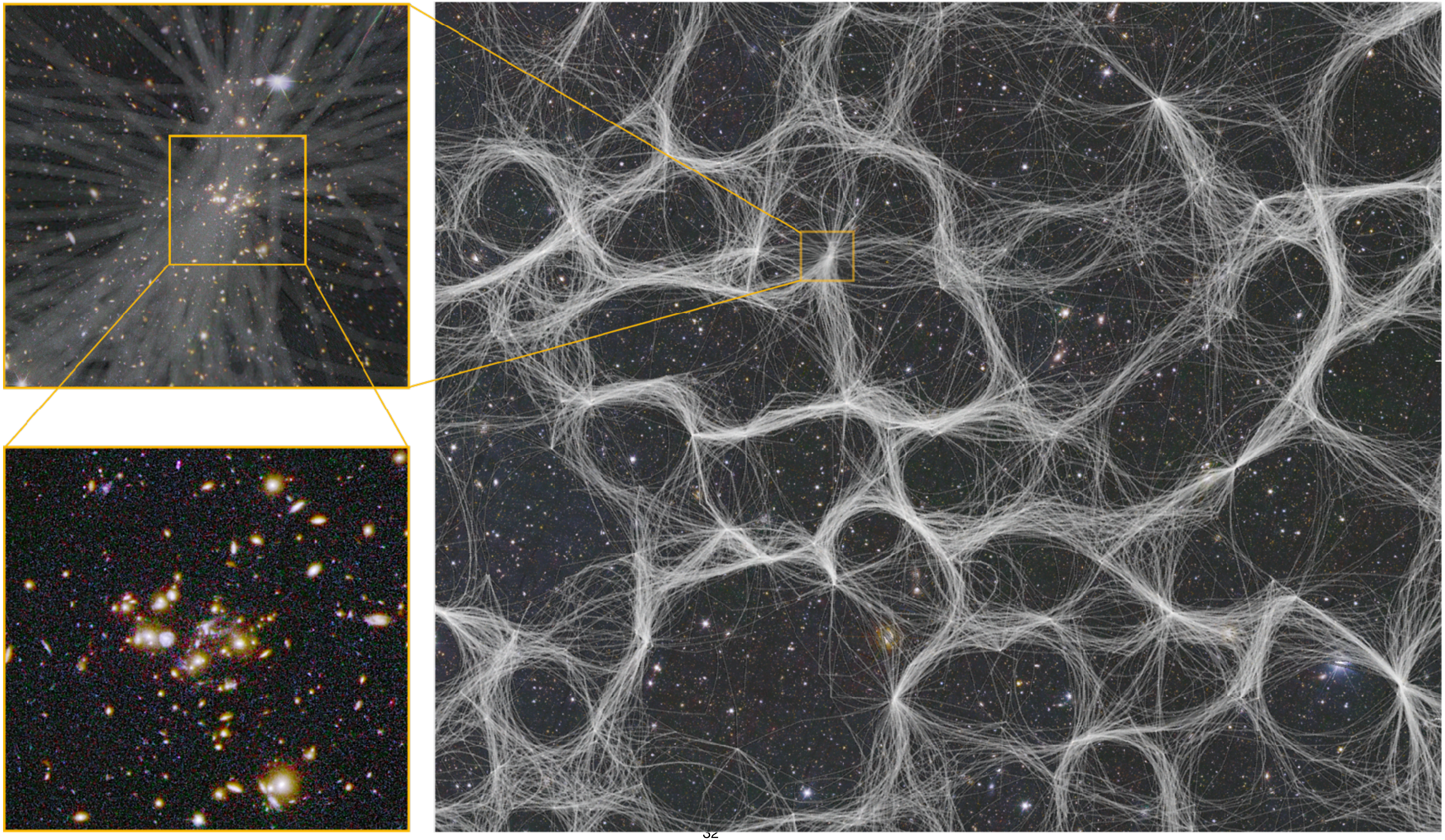
Euclid Q1: Galaxy shapes and alignments in the cosmic web

Euclid collaboration: Clotilde Laigle

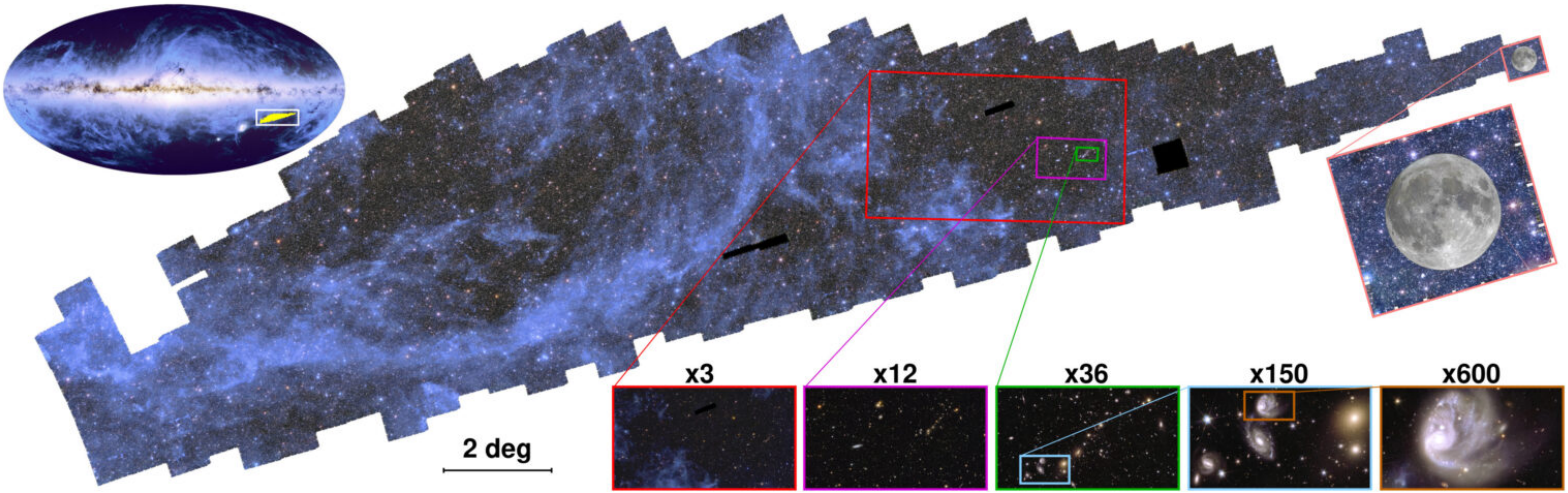
C. Gouin, F. Sarron, L. Quilley, C. Pichon, K. Kraljic, F. Durret, N. E. Chisari, U. Kuchner, N. Malavasi, M. Magliocchetti, H. J. McCracken, J. G. Sorce, Y. Kang, C. J. R. McPartland, S. Toft, et al.



C. Laigle, ESLAB Euclid Symposium 2025 Leiden



ESA unveils zoom into Euclid's first large piece of the sky



Compilation of the 132 deg² skypatch (center), its location on the sky compared to an all-sky Planck dust map (top left), comparison to the size of the Moon (top right), and successive zoom-in. (Image credits: ESA/Euclid/Euclid Consortium/NASA, CEA Paris-Saclay, image processing by J.-C. Cuillandre, E. Bertin, G. Anselmi; ESA/Gaia/DPAC; ESA/Planck Collaboration, CC BY-SA 3.0 IGO)

October 15, 2024

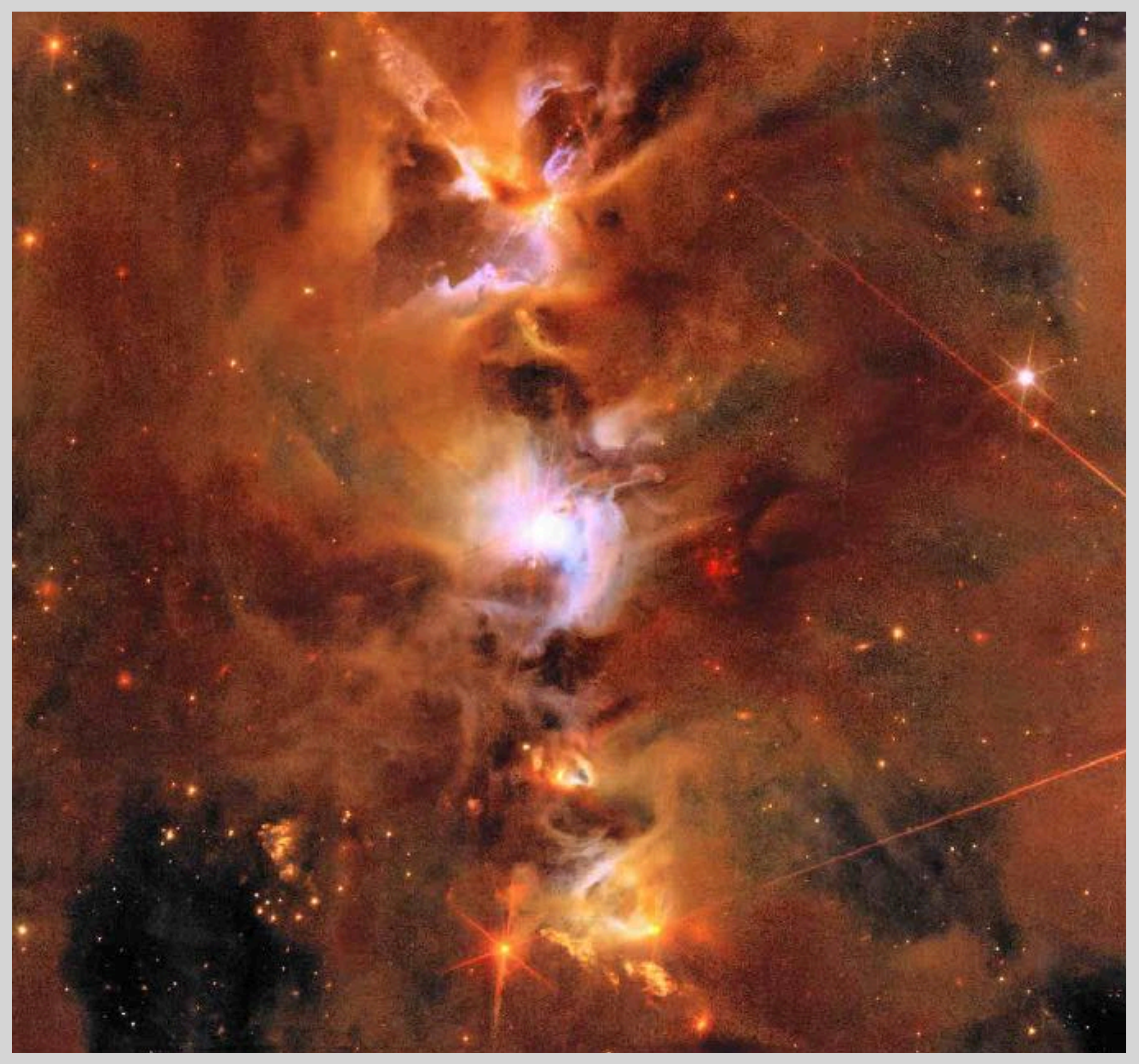
ESA unveils zoom into Euclid’s first large piece of the sky

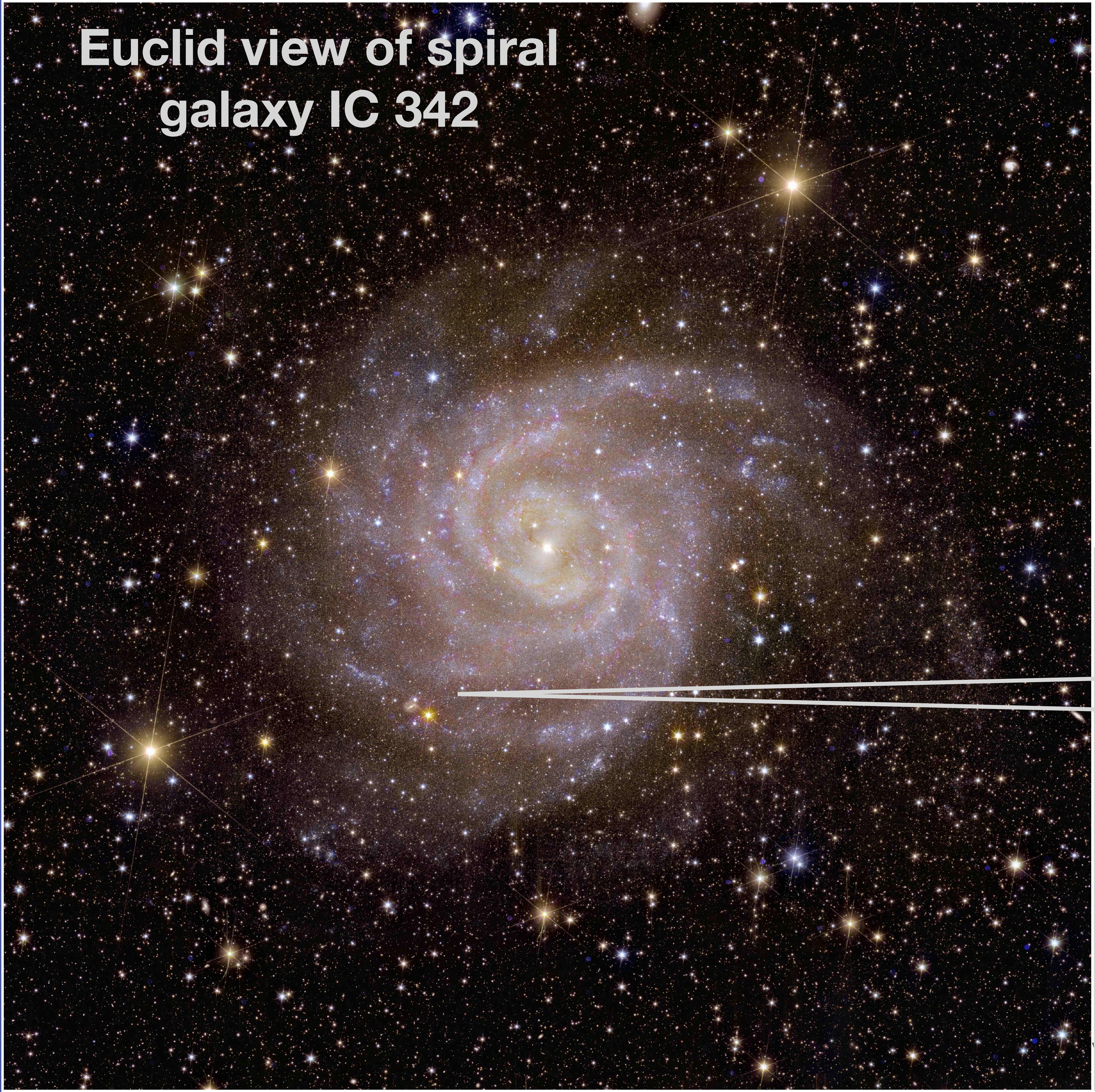
Zoom level x36: The galaxy cluster, some fainter, more distant galaxies behind it, two interacting galaxies to the left in front of it, and some bright stars (showing “spikes”) in our own galaxy in the foreground.

Zoom level x150: Massive elliptical galaxies in Abell 3381 on the right, and two interacting piral galaxies on the left belonging to a different cluster 420 million light years from us.

Zoom level x600: High-resolution image of a disturbed spiral galaxy. The asymmetry stems from interactions with other galaxies in the cluster, triggering fresh star formation.

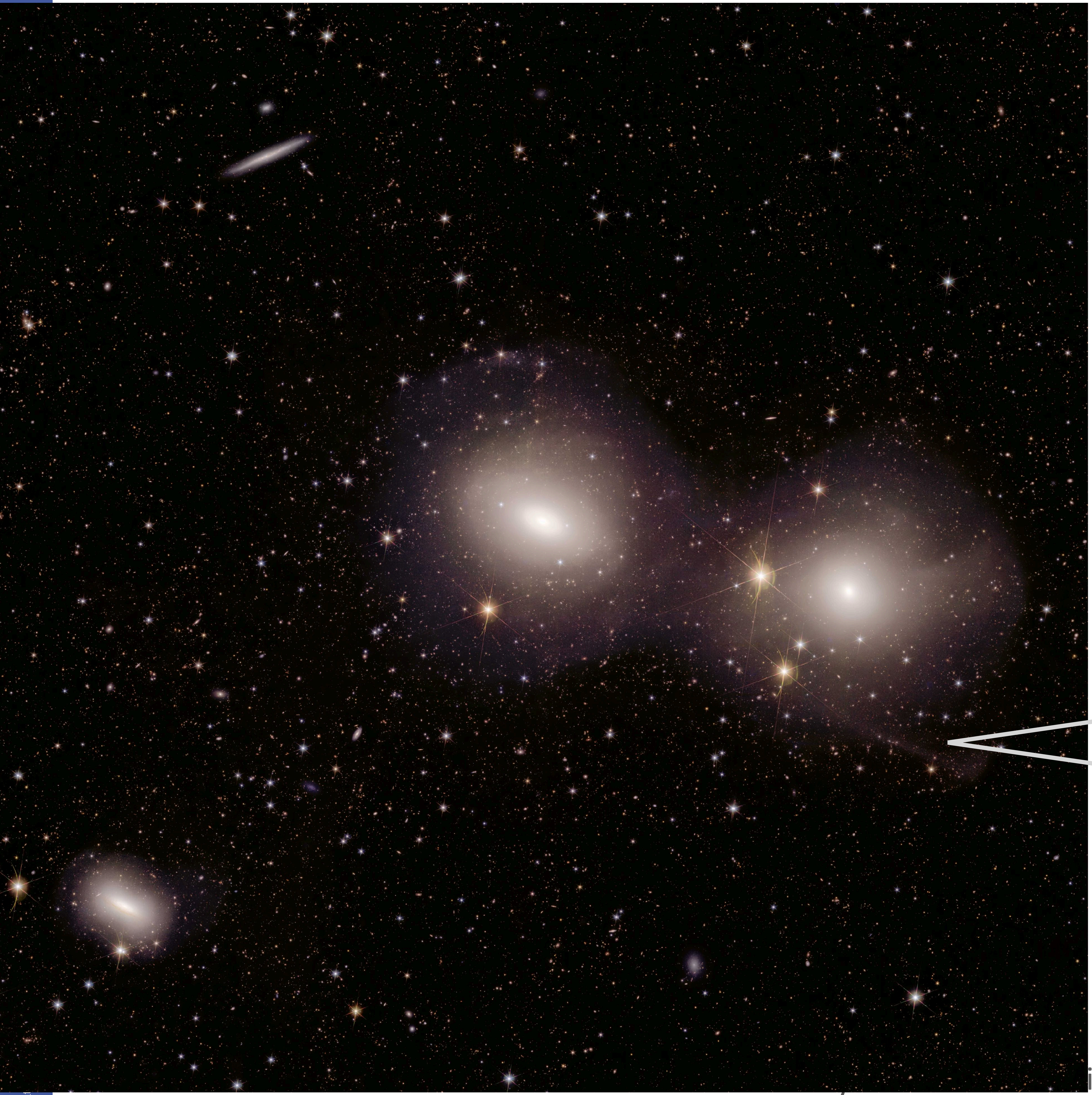
Euclid new image of star forming region Messier 78



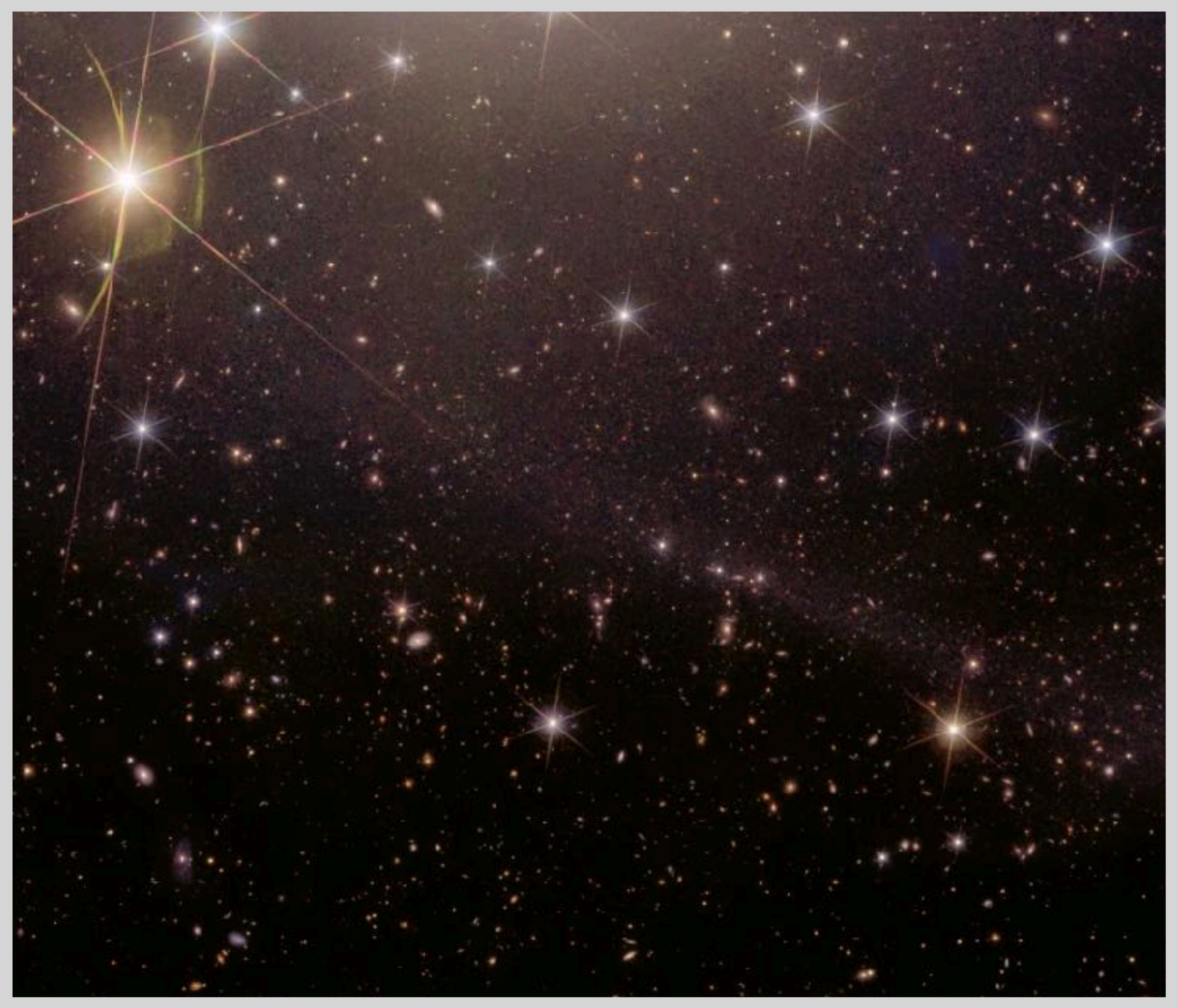


Euclid: **Early Release Observations – Deep anatomy of nearby galaxies**

L. K. Hunt et al., 2024

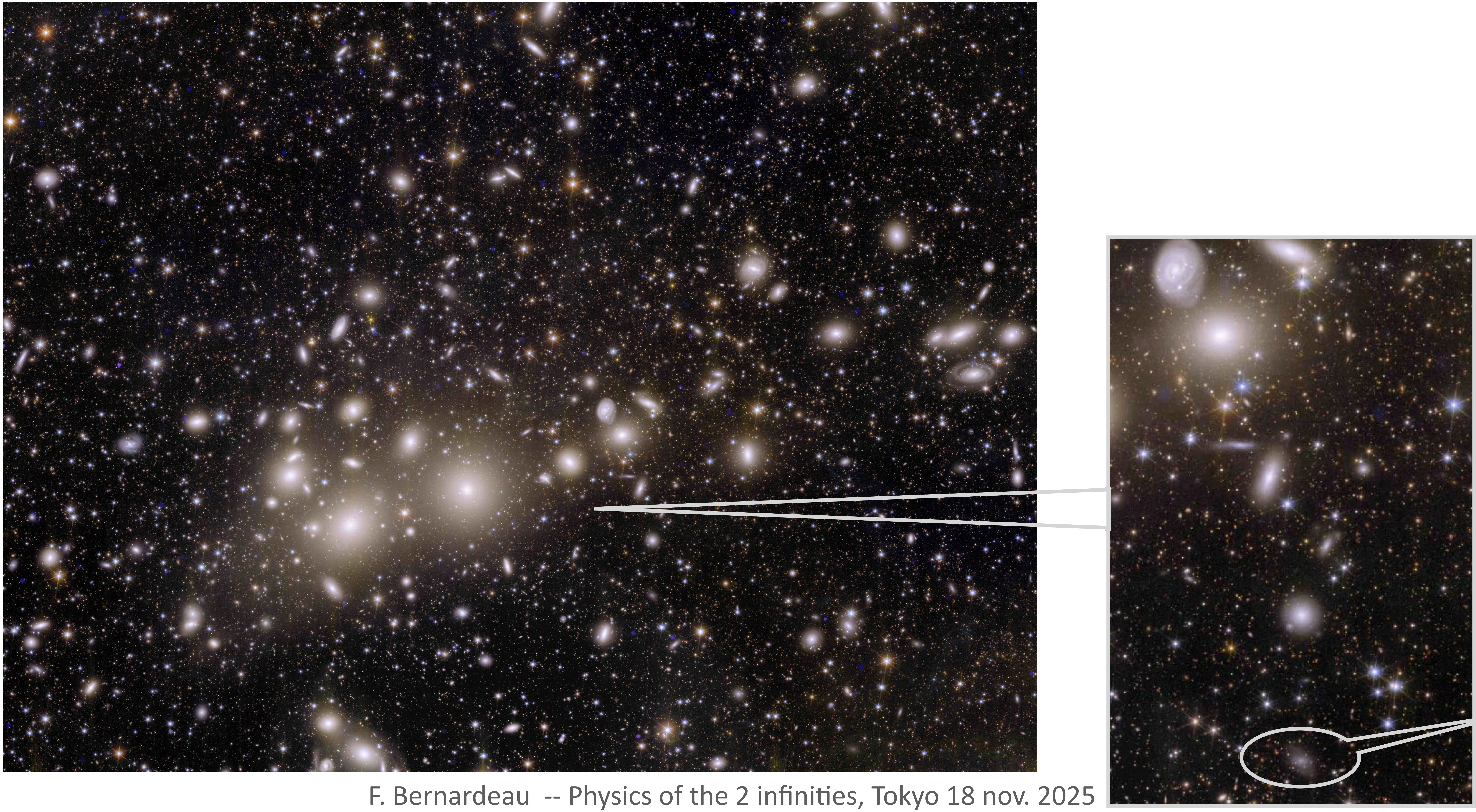


Euclid new image of the Dorado group of galaxies



Euclid view of the Perseus cluster of galaxies

Euclid view of the Perseus cluster of galaxies



dwarf galaxy

Euclid: Early Release Observations – Dwarf galaxies in the Perseus galaxy cluster ⋆

Marleau et al. 2024

1100 dwarf galaxies have been detected

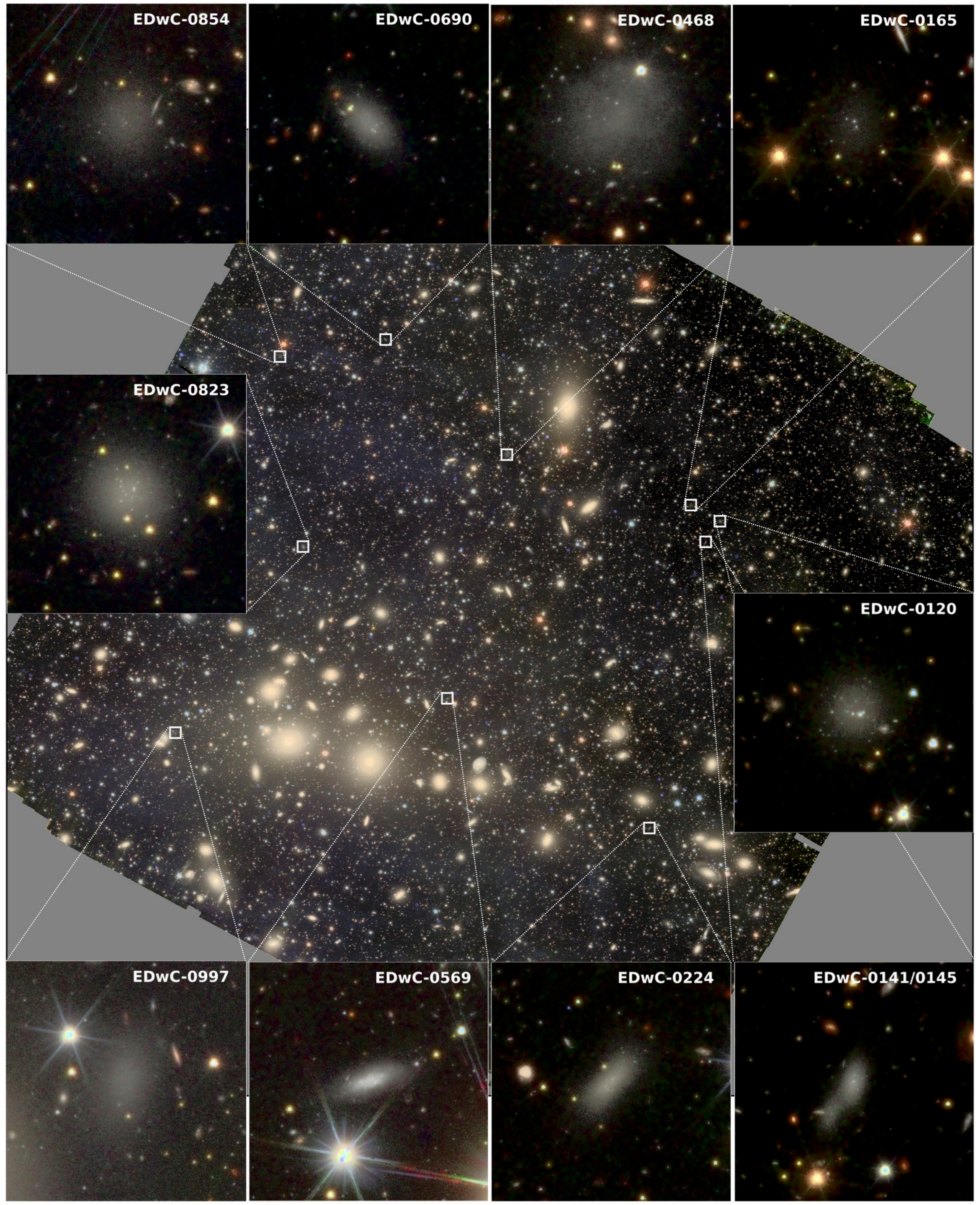


Fig. 4: VIS-NISP colour image of the Perseus galaxy cluster. The full FoV of $0\overset{\circ}{.}84 \times 0\overset{\circ}{.}84$ is shown, with north up and east to the left. Examples of dwarf galaxy candidates are shown in the individual cutouts of size $40'' \times 40''$. The galaxies EDwC-0854, EDwC-0468, EDwC-0165, and EDwC-0997 are newly identified UDG candidates. The system composed of EDwC-0141 and EDwC-0145 (*bottom right cutout*) show one example of two newly identified dwarfs that appear to be interacting.

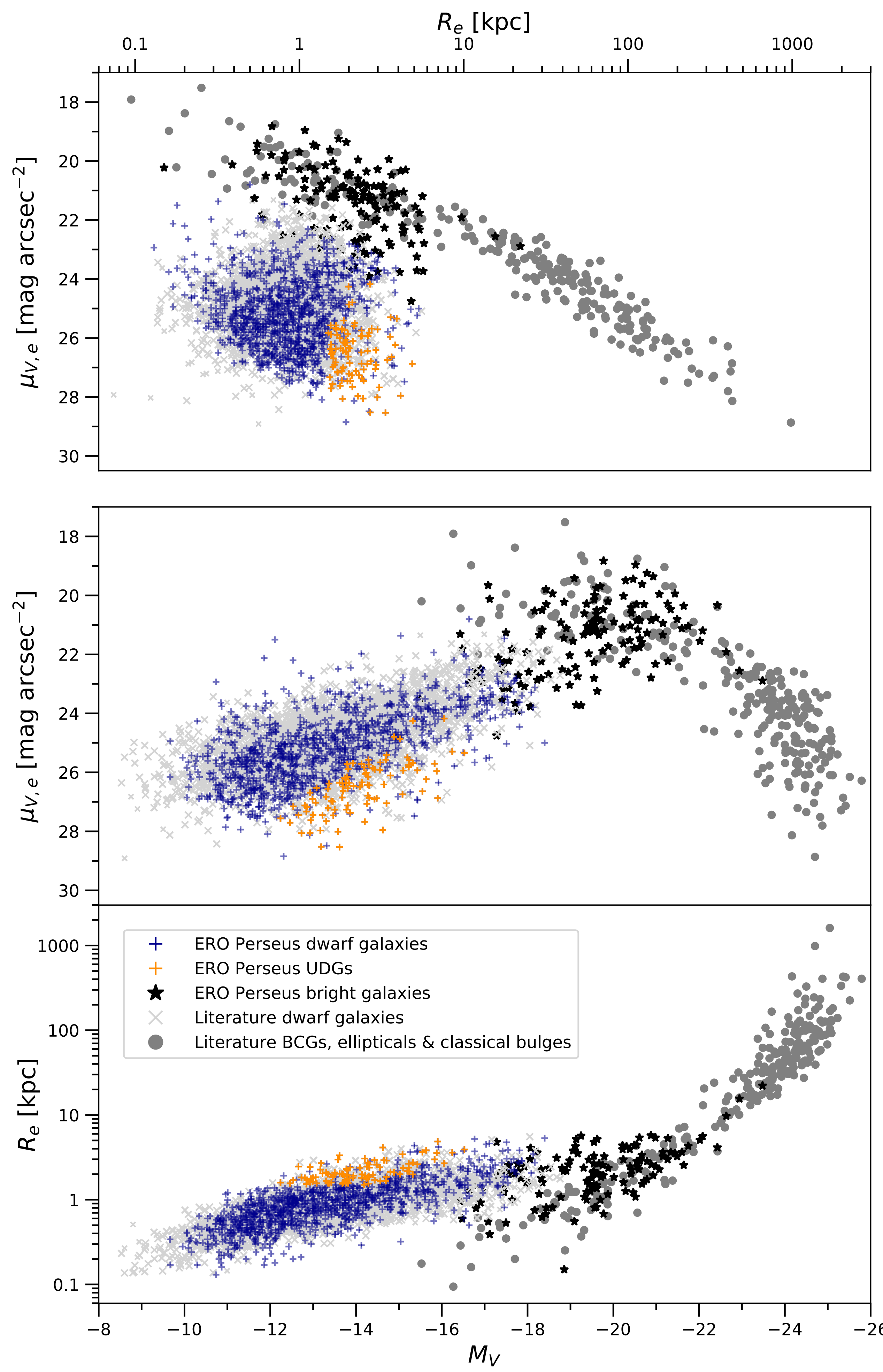


Fig. 12: Comparison between M_V, R_e, and $\mu_{V,e}$ scaling relations of the ERO Perseus dwarf sample (violet-blue), including UDGs (orange) from this work, and bright galaxies (black) from Cuillandre et al. (2024b). The basis for this plot is Figure 37 in Kormendy et al. (2009) with updates from Kormendy & Bender (2012), Bender et al. (2015), Kluge et al. (2020), Marleau et al. (2021) and Zöller et al. (2024), including brightest cluster galaxies (BCGs), ellipticals, and classical bulges (dark grey), as well as dwarf galaxies including UDGs (light grey). For the sake of clarity, we do not show errorbars. The uncertainties vary significant between the different galaxies.