



Cosmology and the Euclid Dark Energy Mission

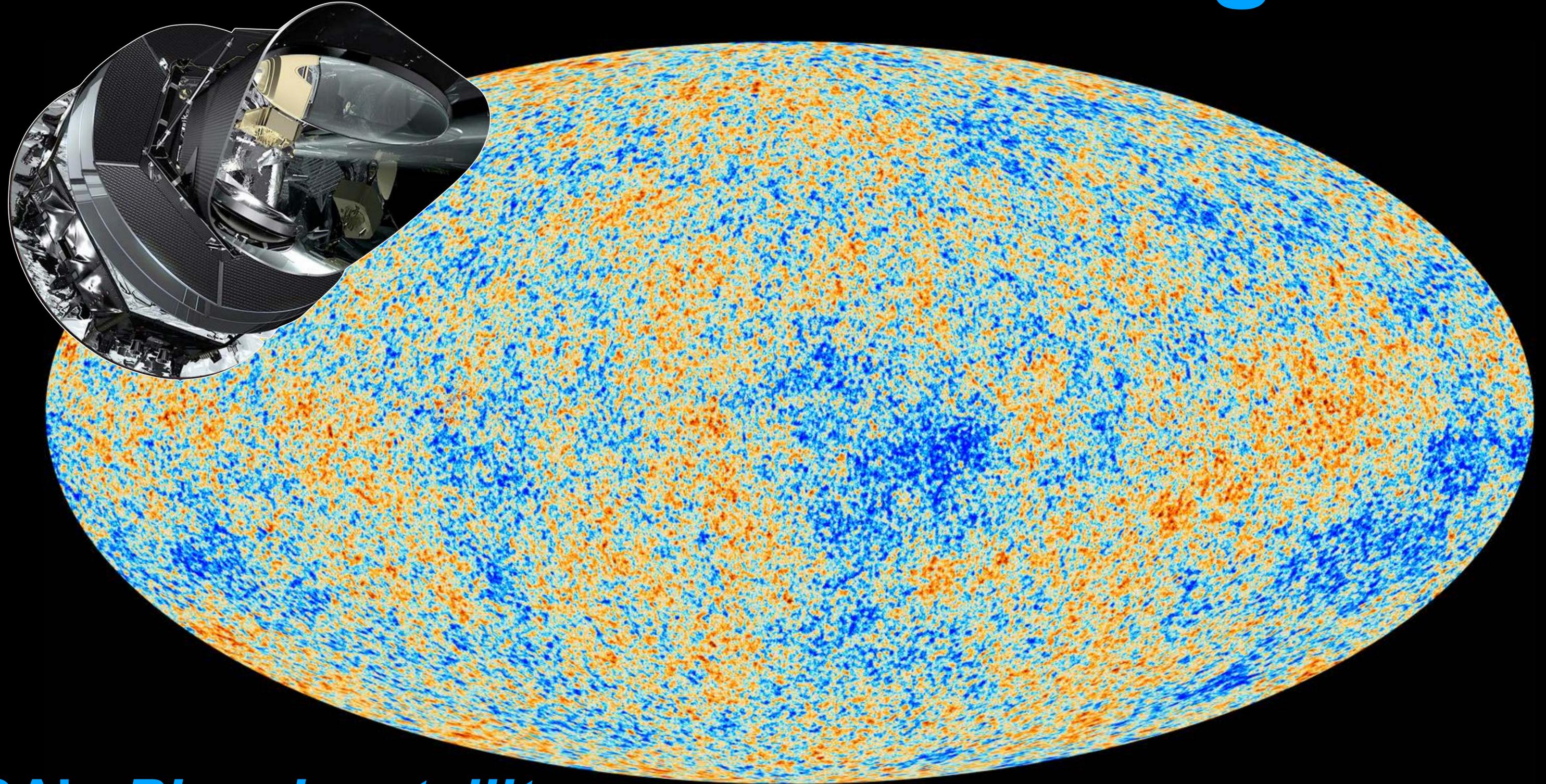
Andy Taylor

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Royal Observatory Edinburgh
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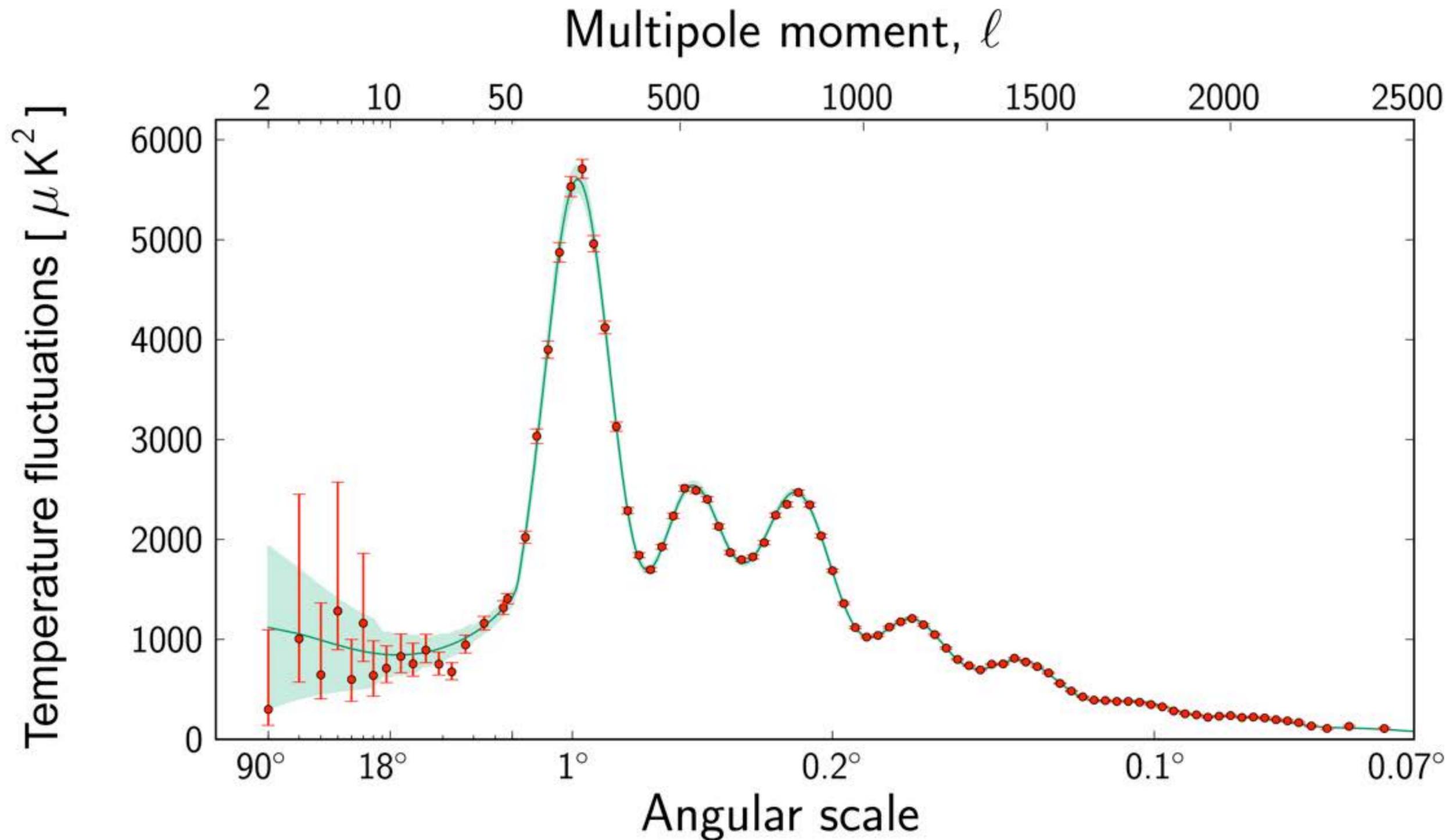
KMI Symposium, Nagoya, Japan, 5-7 March 2025

Cosmic Microwave Background



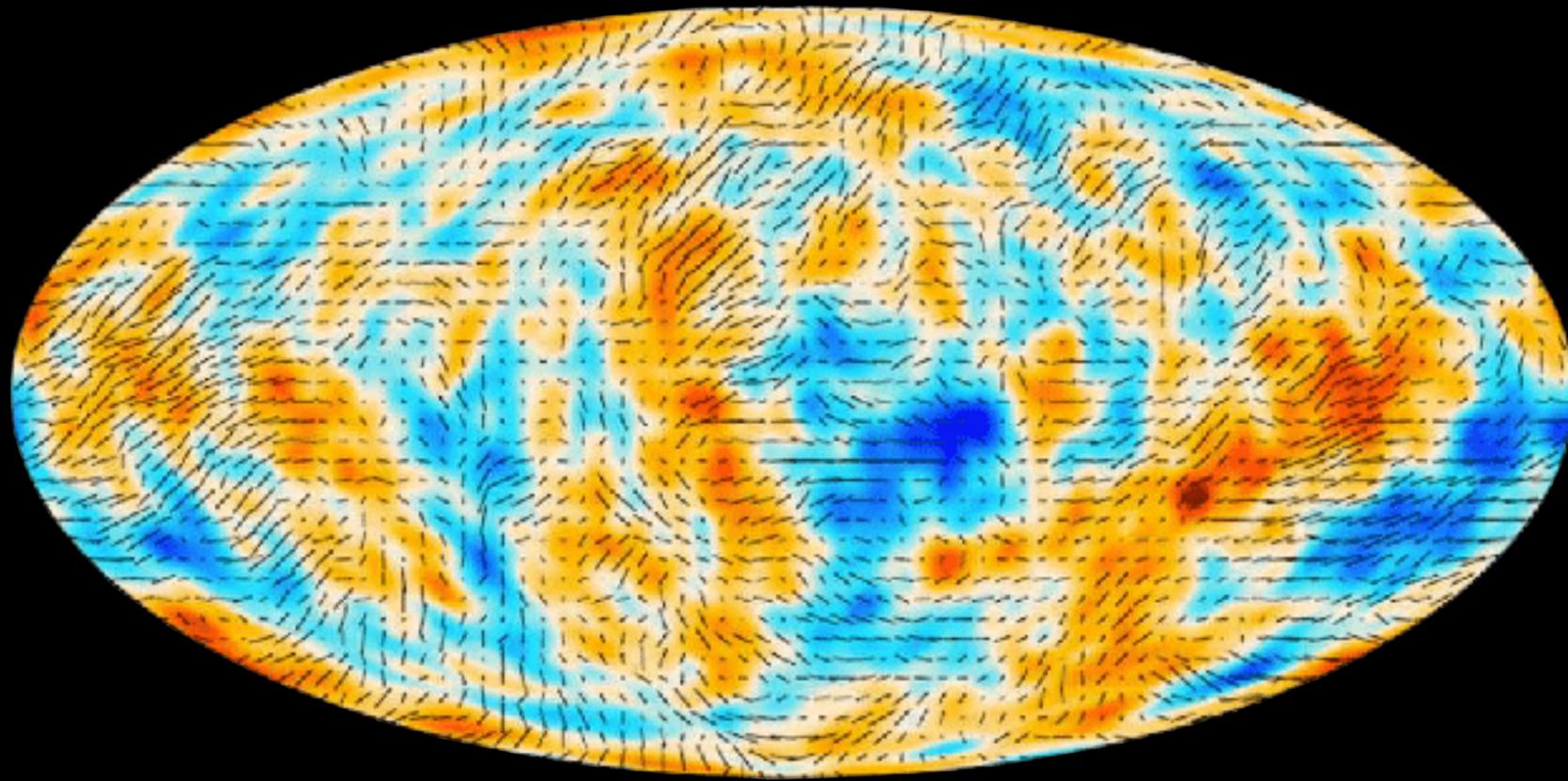
ESA's *Planck* satellite

Cosmic Microwave Background

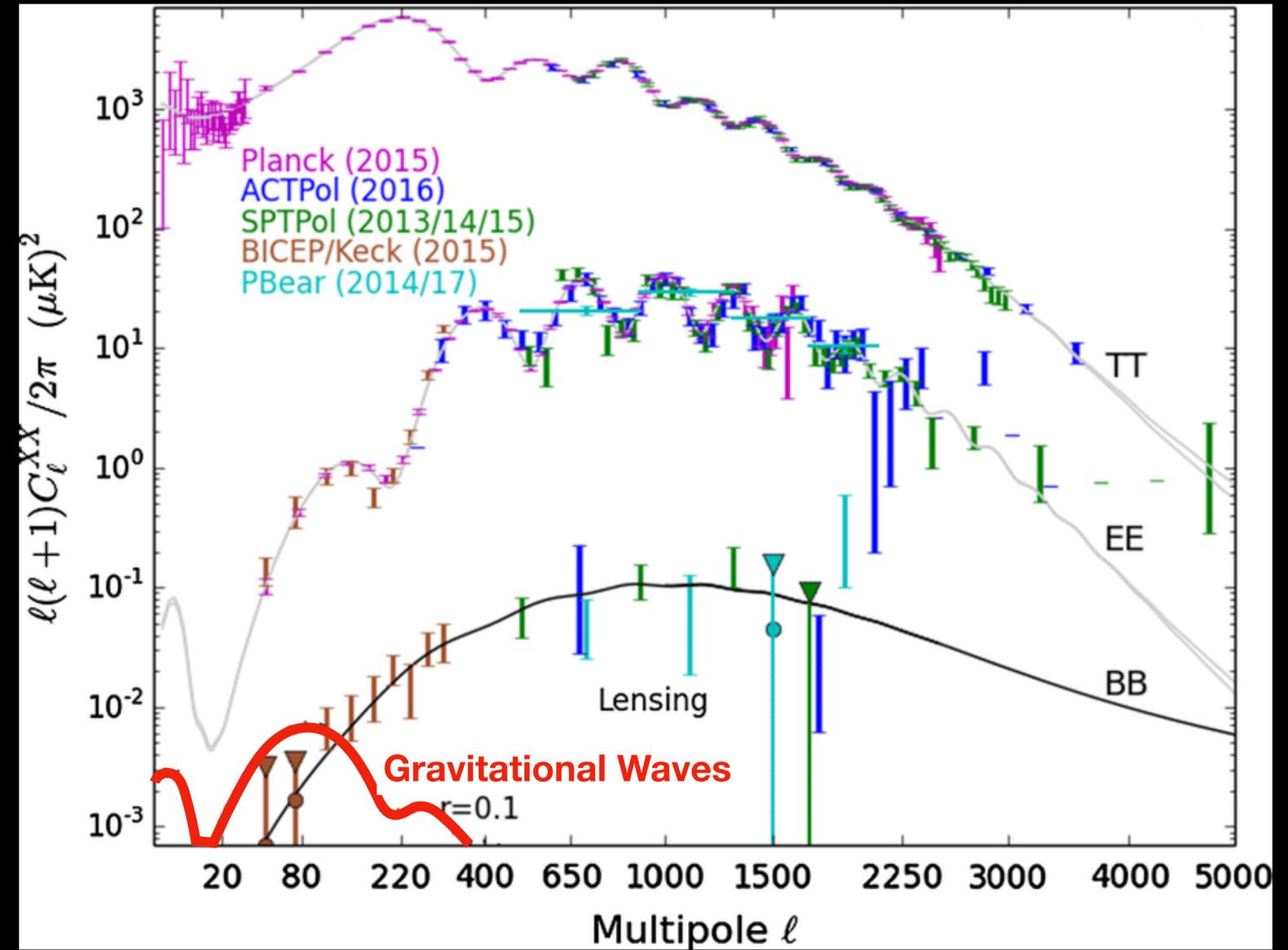


ESA's *Planck* satellite

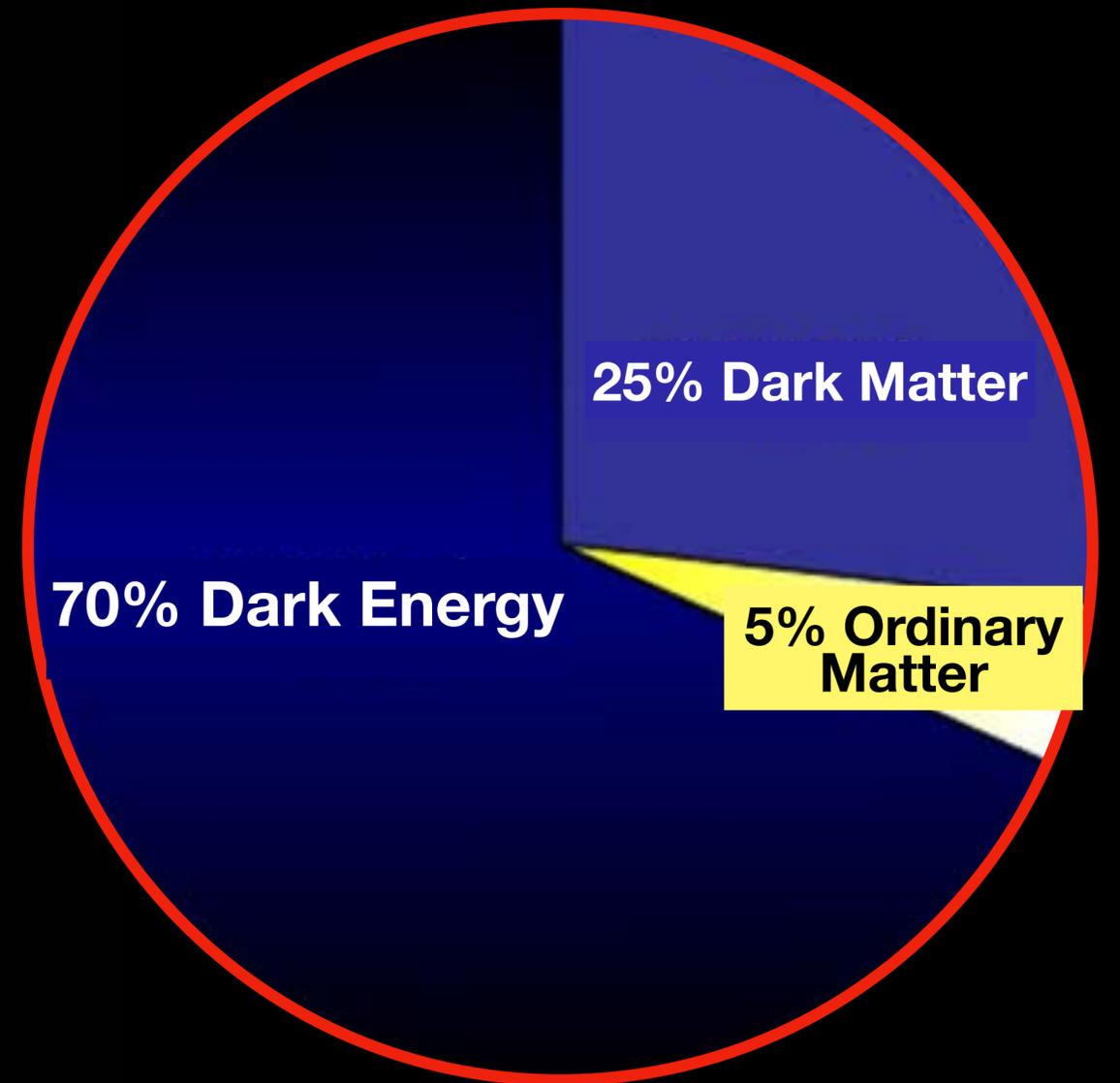
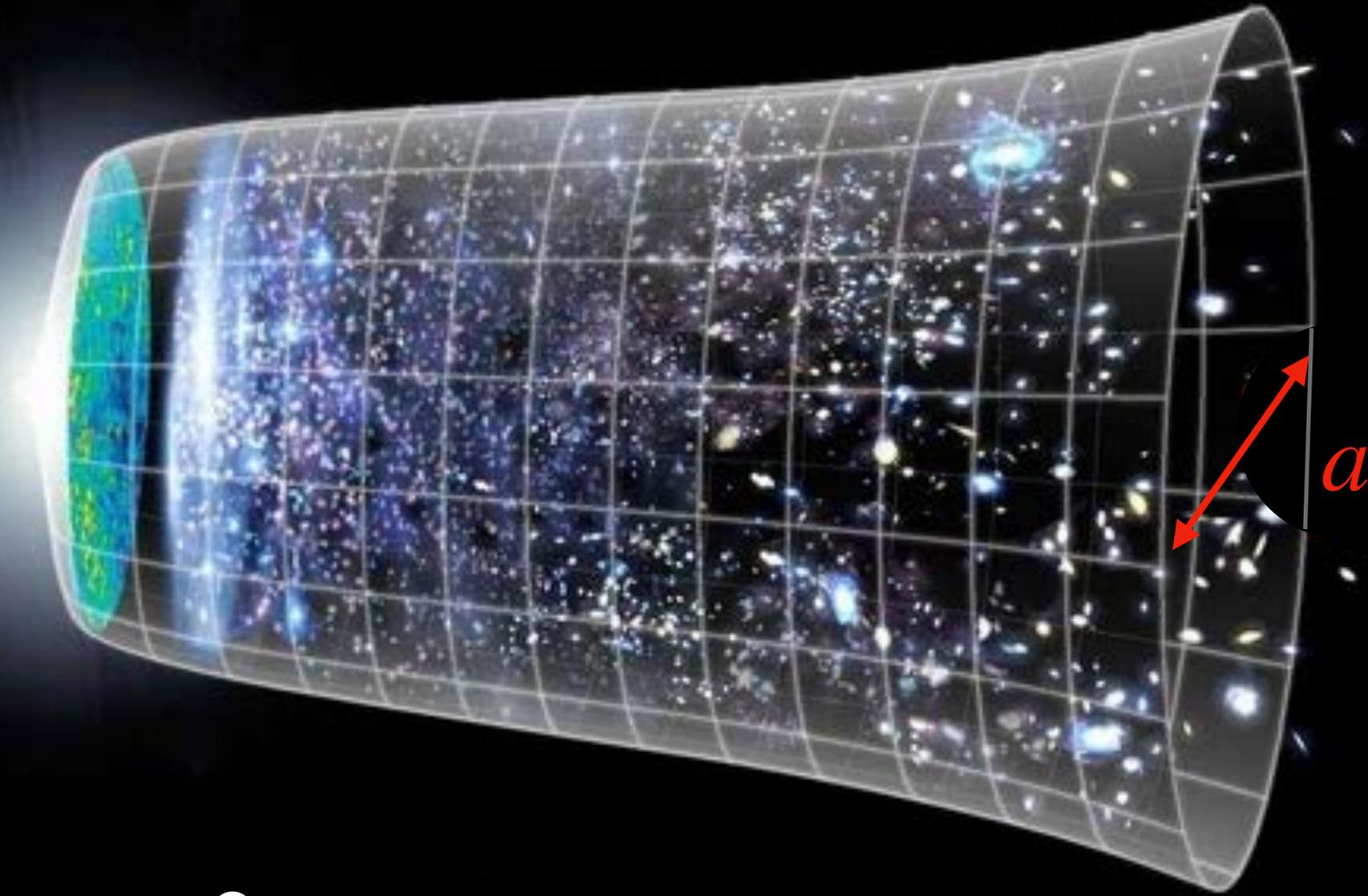
CMB Polarisation



Planck

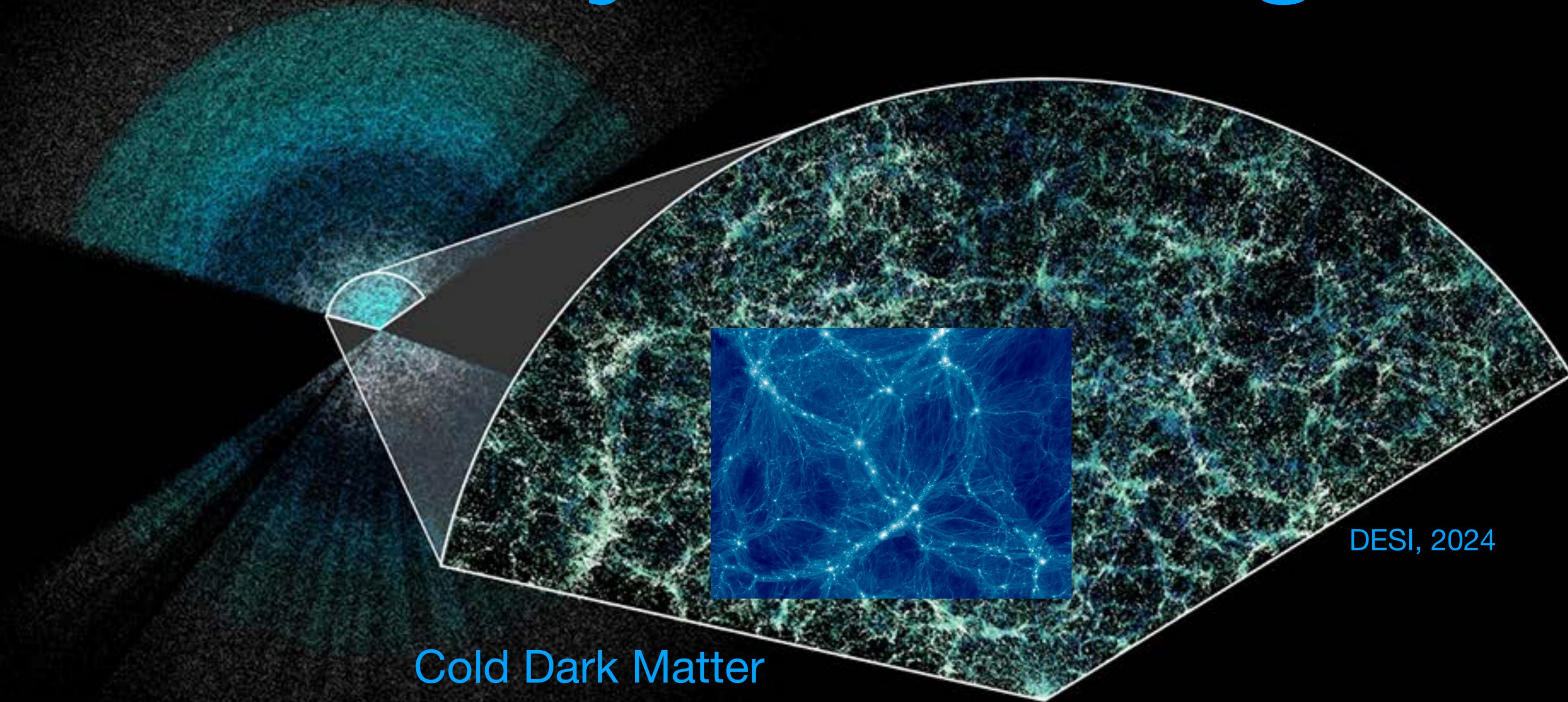


Standard Cosmological Model



$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = H_0^2 \left(\Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_\Lambda\right)$$

Galaxy Clustering

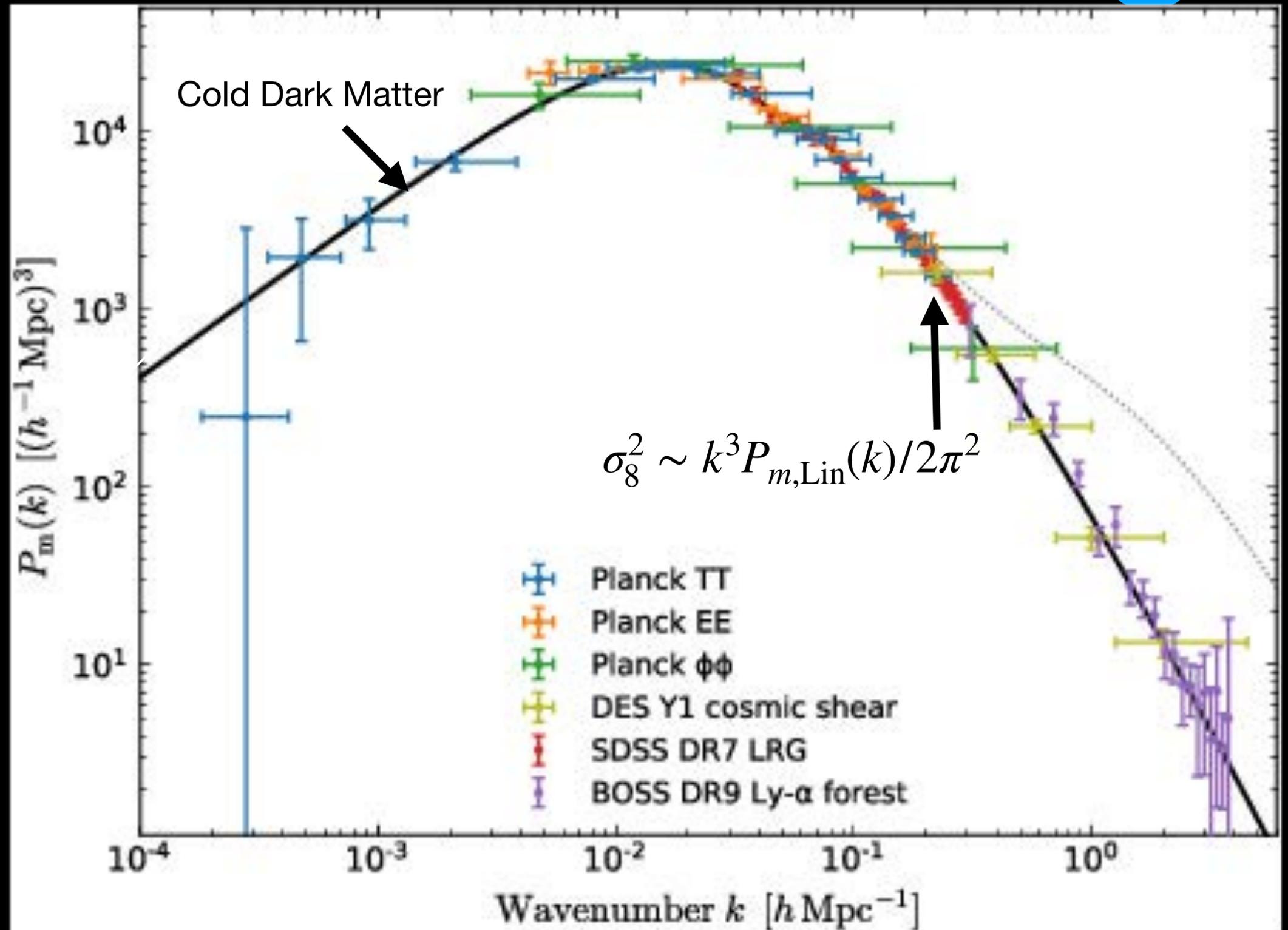
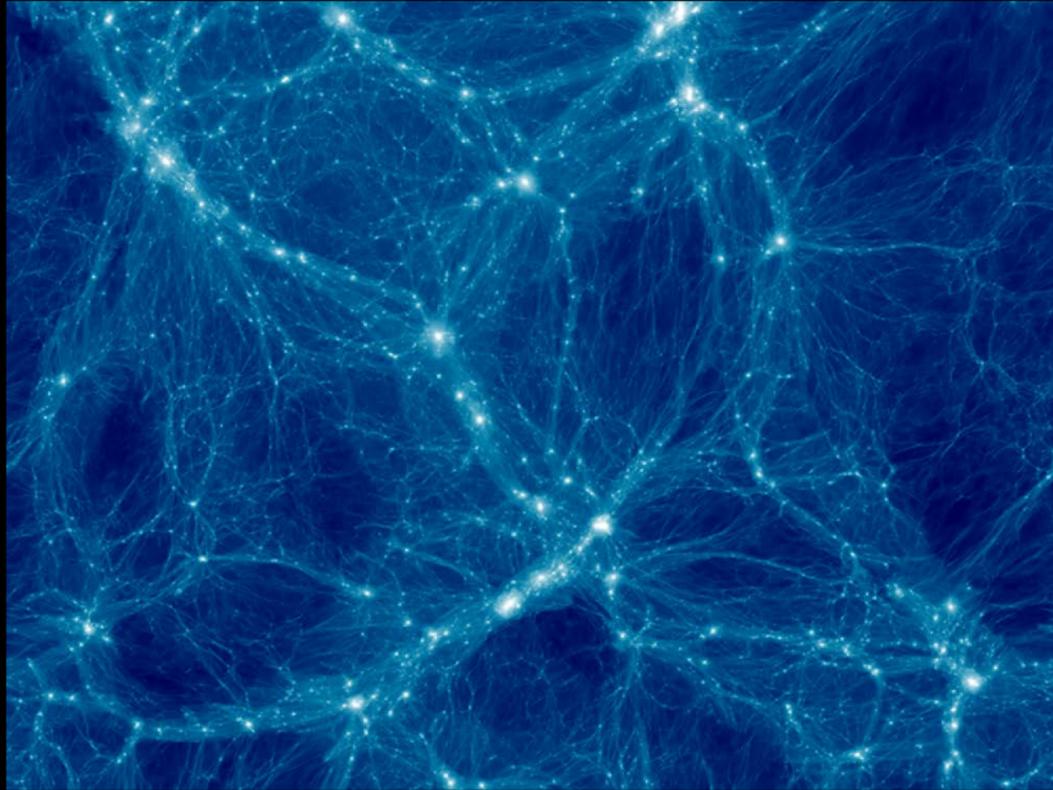


DESI, 2024

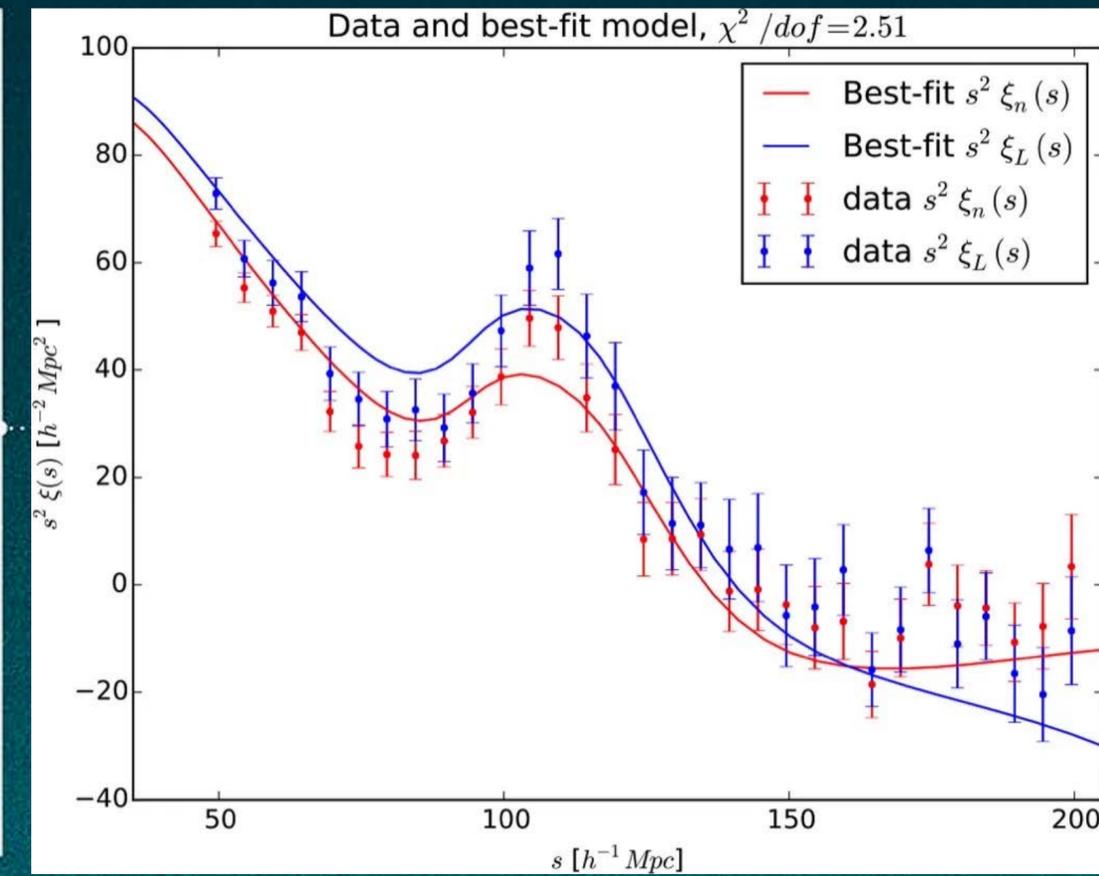
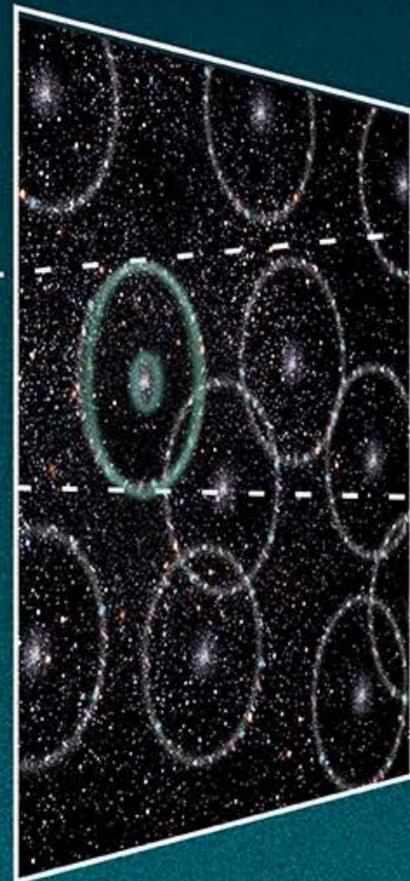
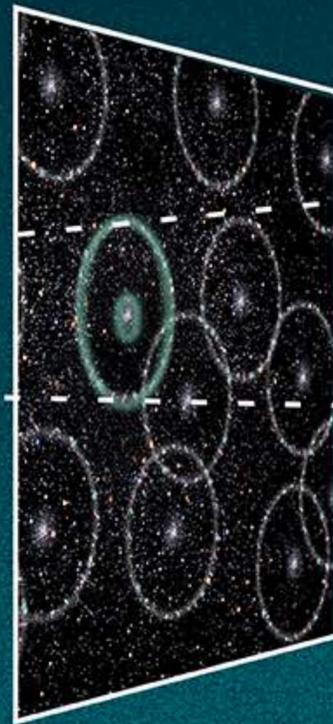
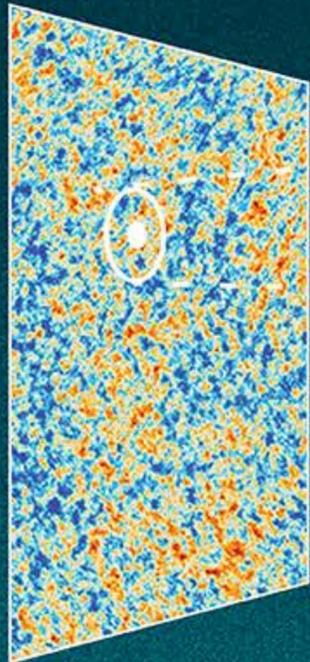
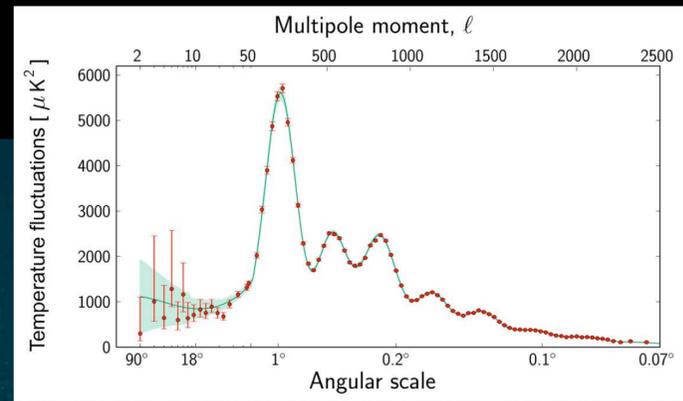
Cold Dark Matter

Dark Matter Clustering

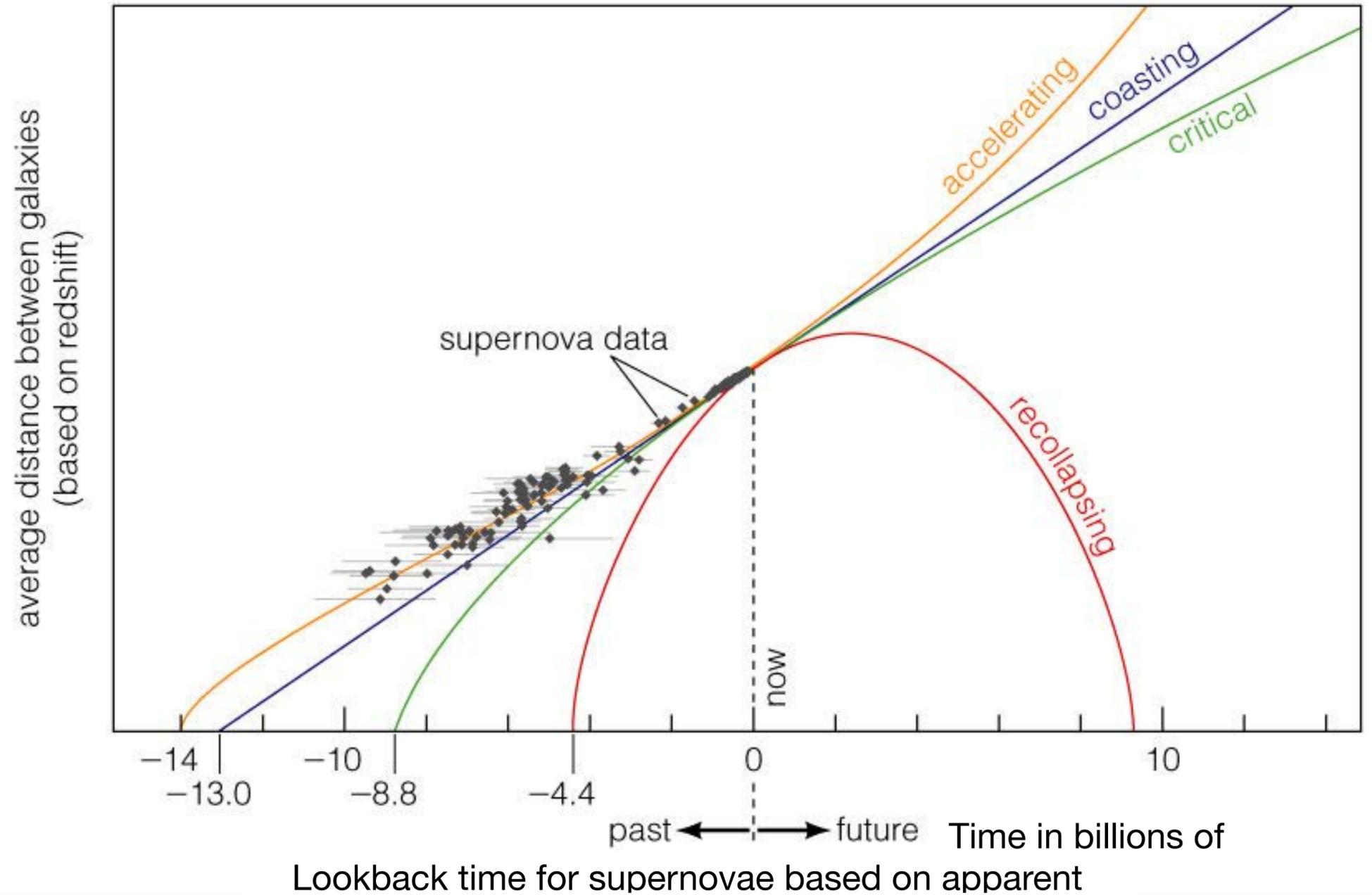
$$P_{m,\text{Lin}}(k) = A_s T^2(k, \theta_{\text{cosmo}}) k^{n_s}$$



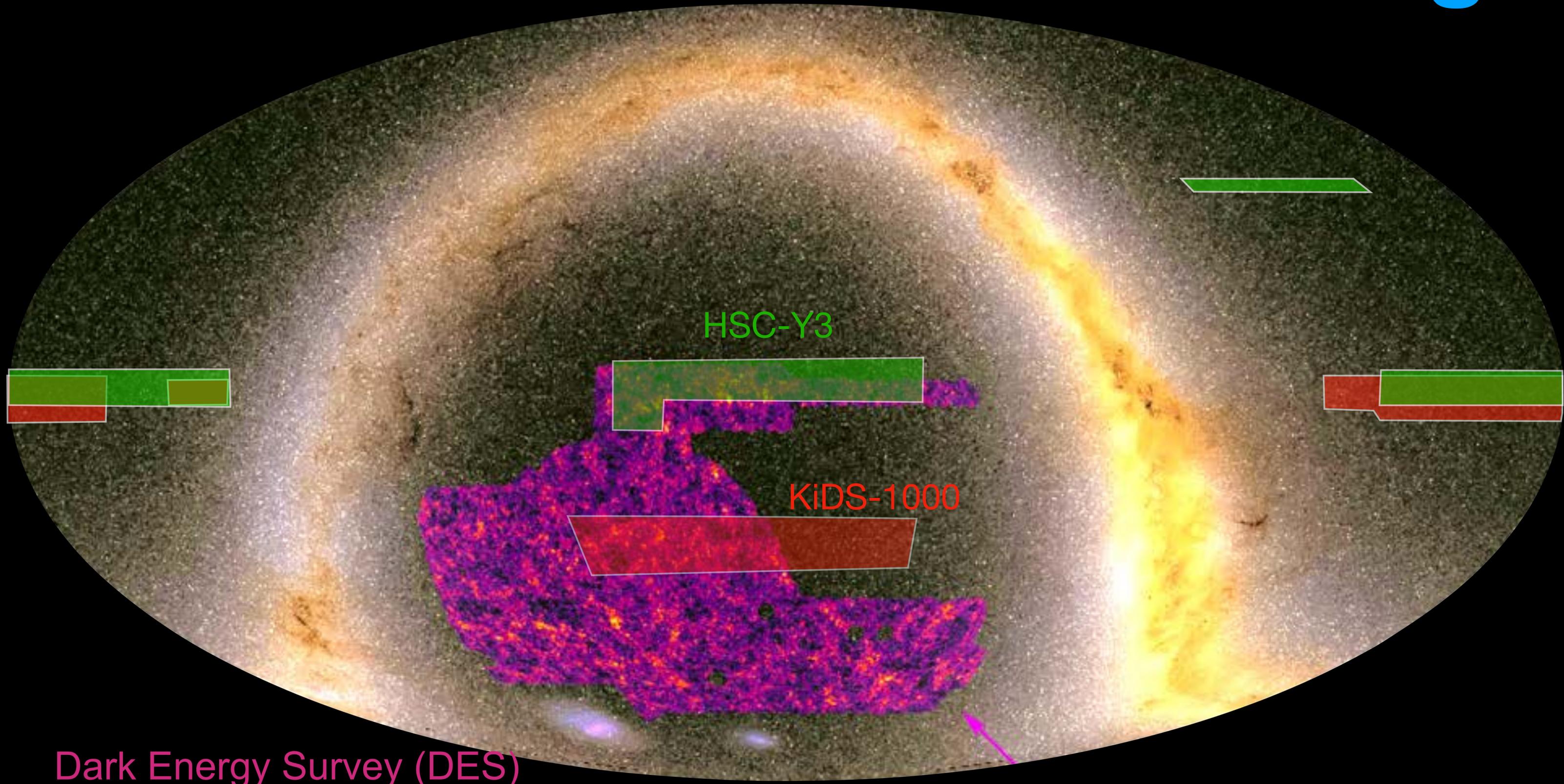
Baryonic Acoustic Oscillations (BAO)



Supernova Type Ia



Weak Gravitational Lensing



Dark Energy Survey (DES)

Sigma-8 'Tension'

Amplitude of matter clustering

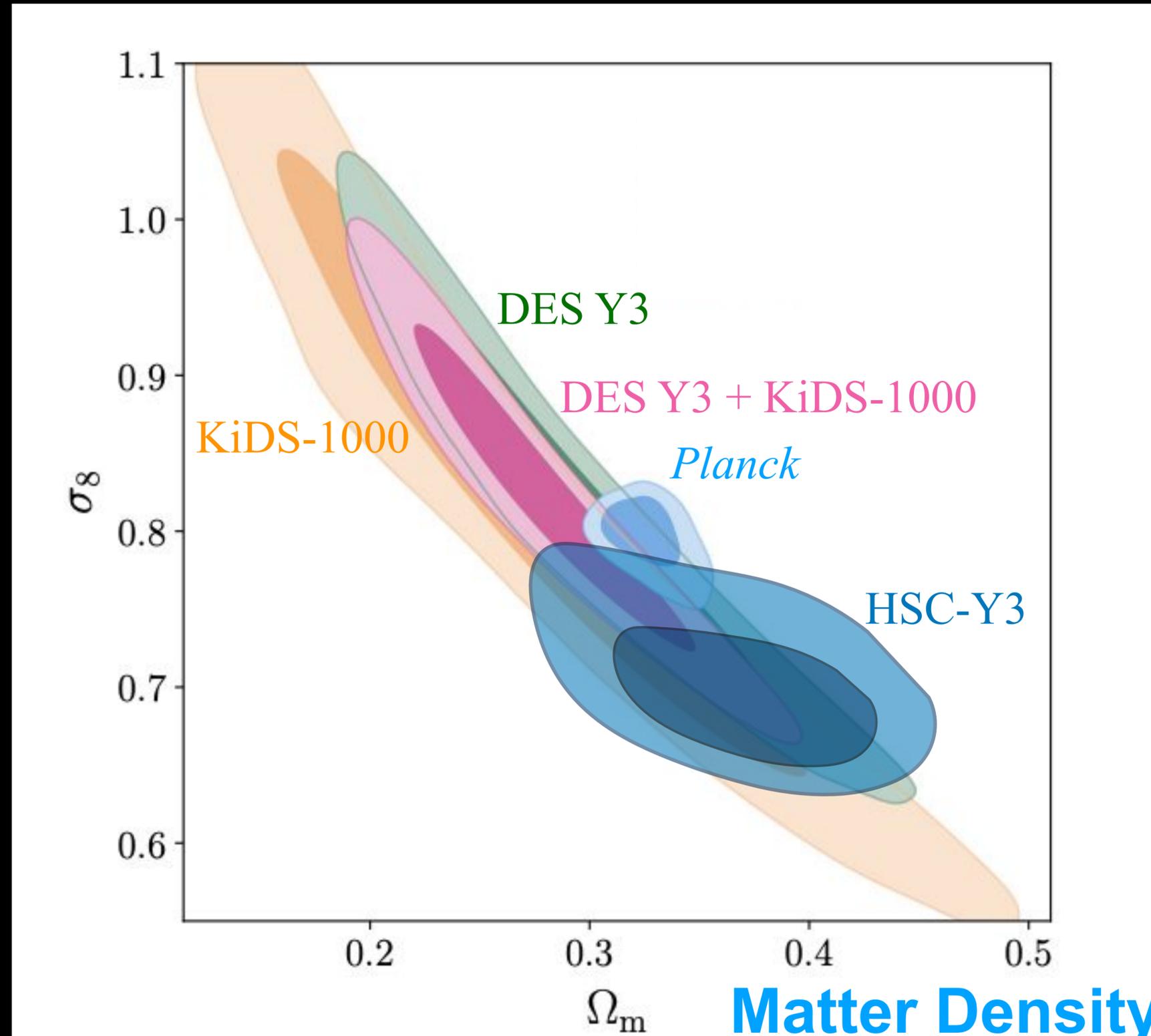
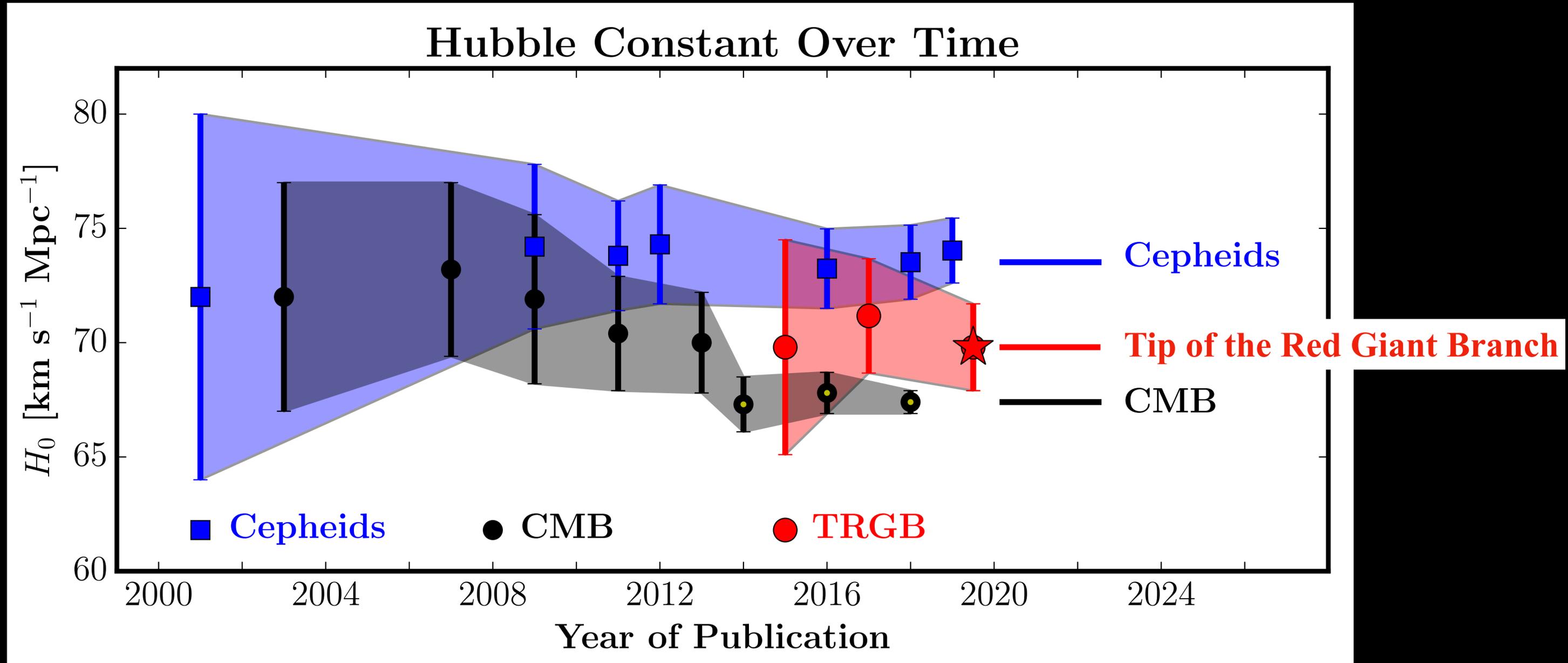


Figure adapted from
DES+KiDS Abbott et al 2023,
HSC-Y3 Miyatake et al 2024

Matter Density Parameter

Hubble Trouble

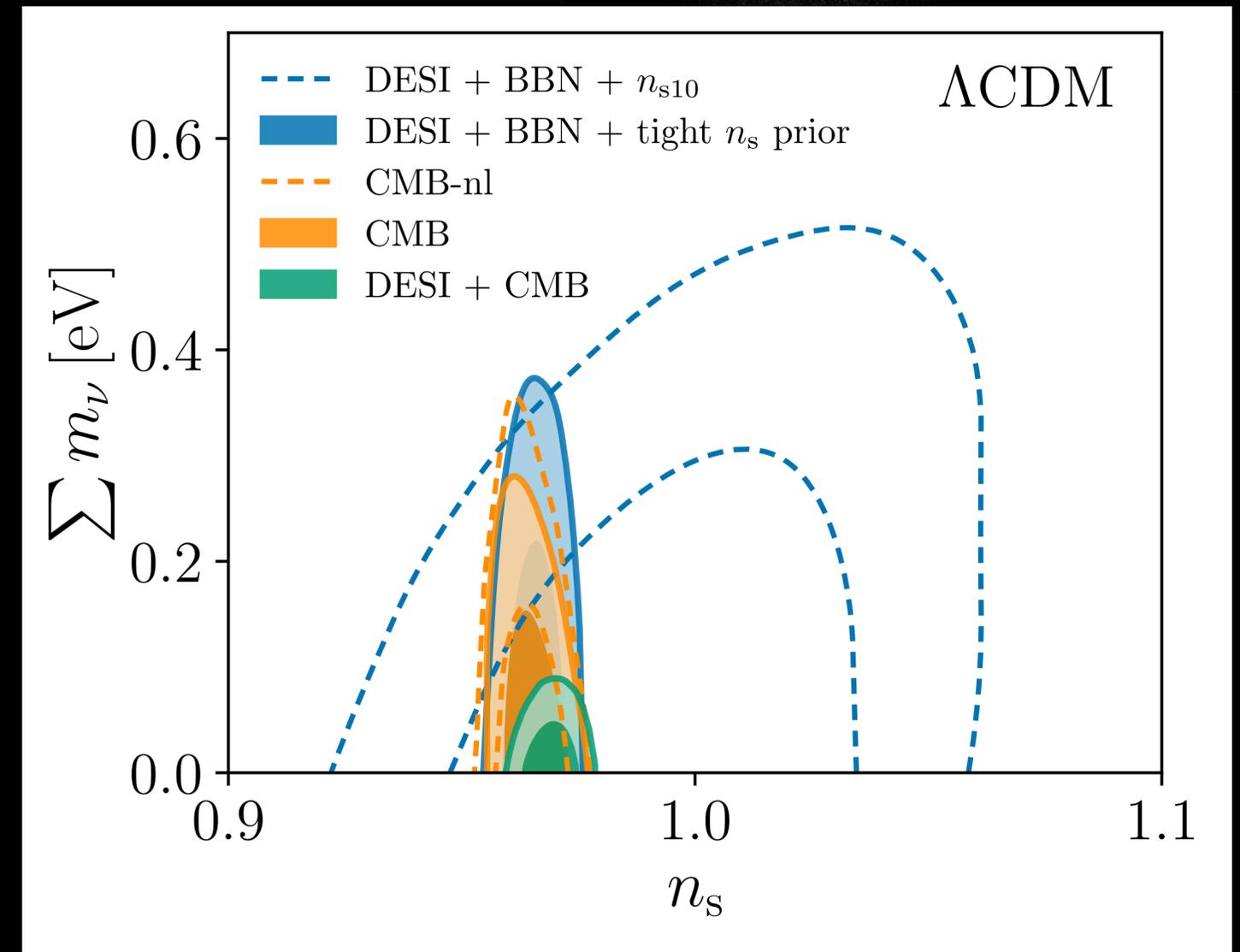
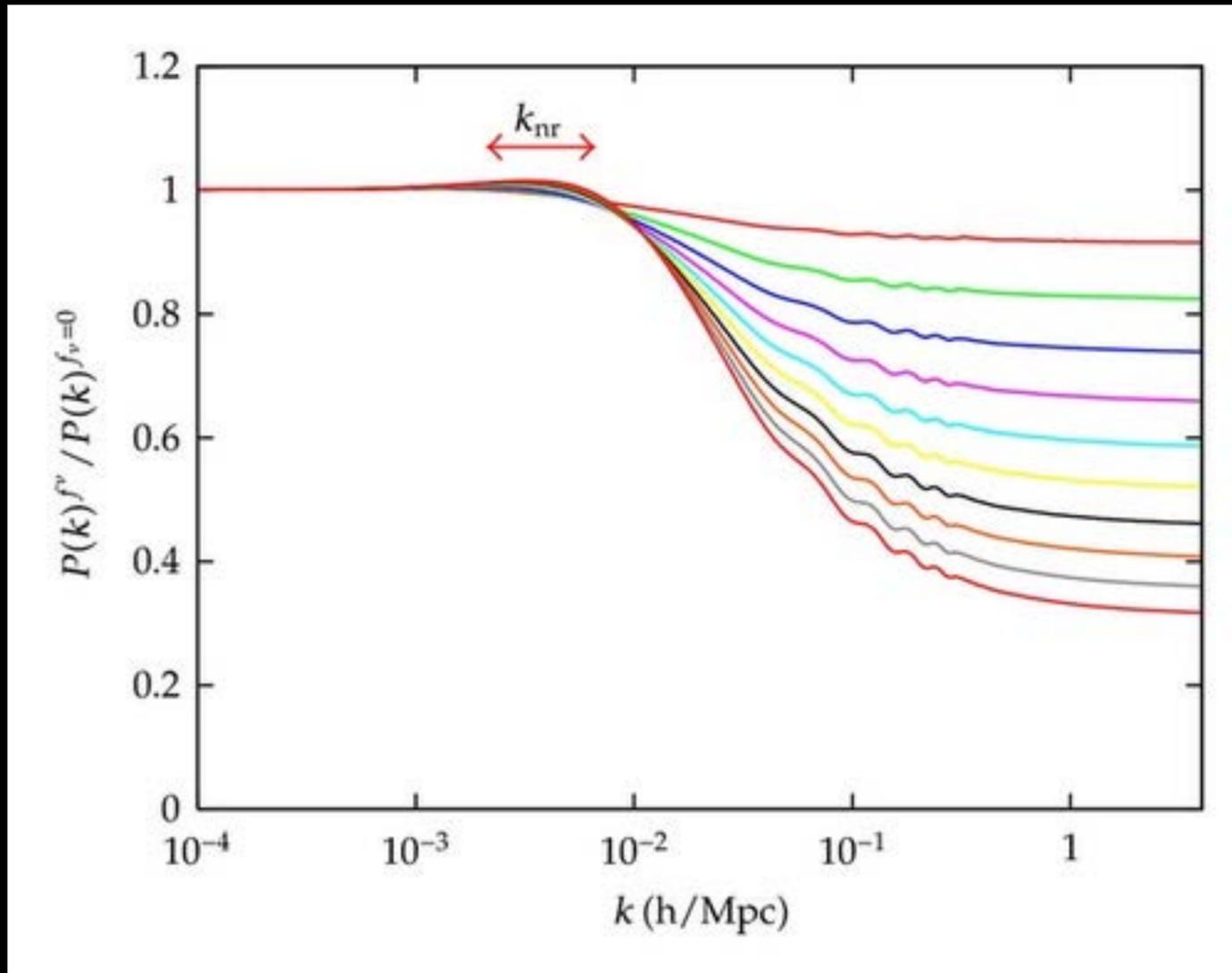
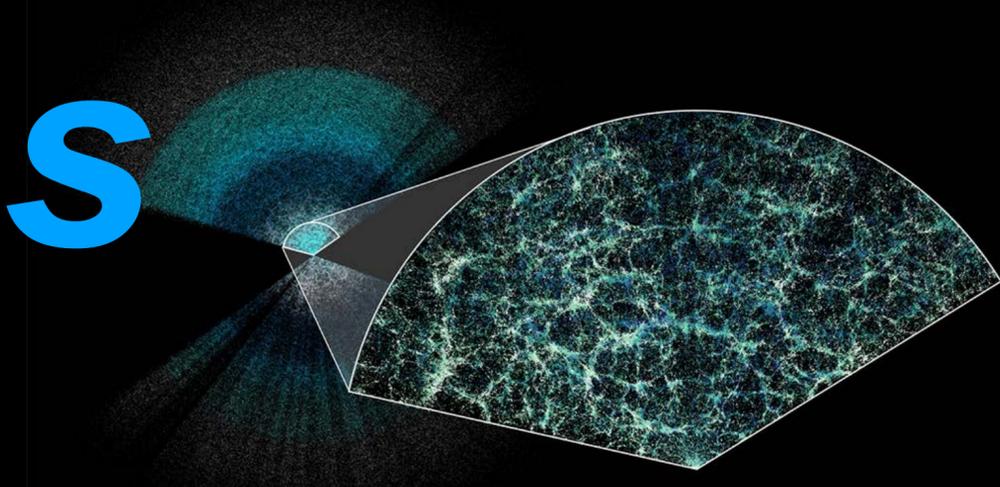
$$H(a)^2 = H_0^2 (\Omega_r a^{-4} + \Omega_m a^{-3} + \Omega_\Lambda)$$



Freedman et al 2019

Massive Neutrinos

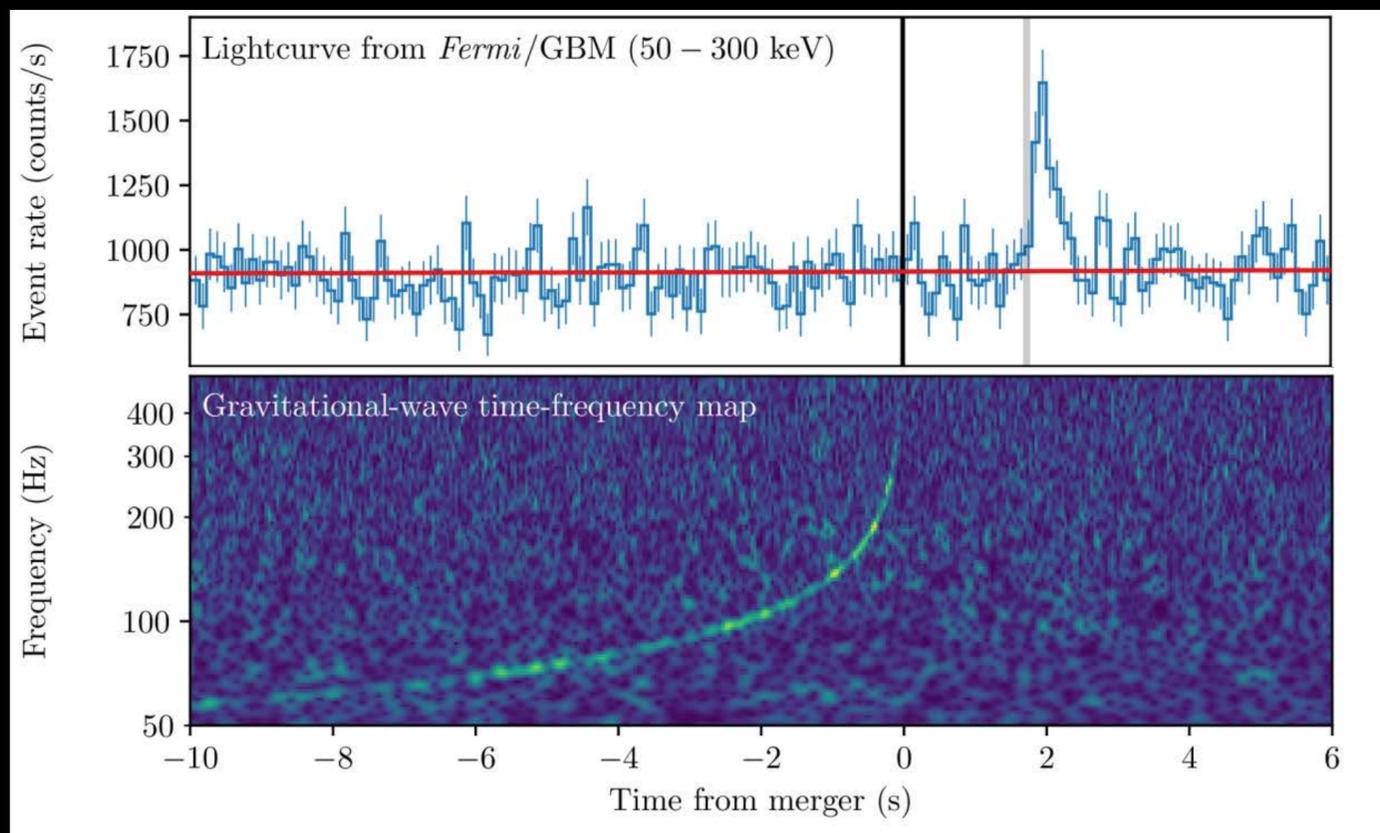
- Massive neutrinos damp smaller-scale clustering.



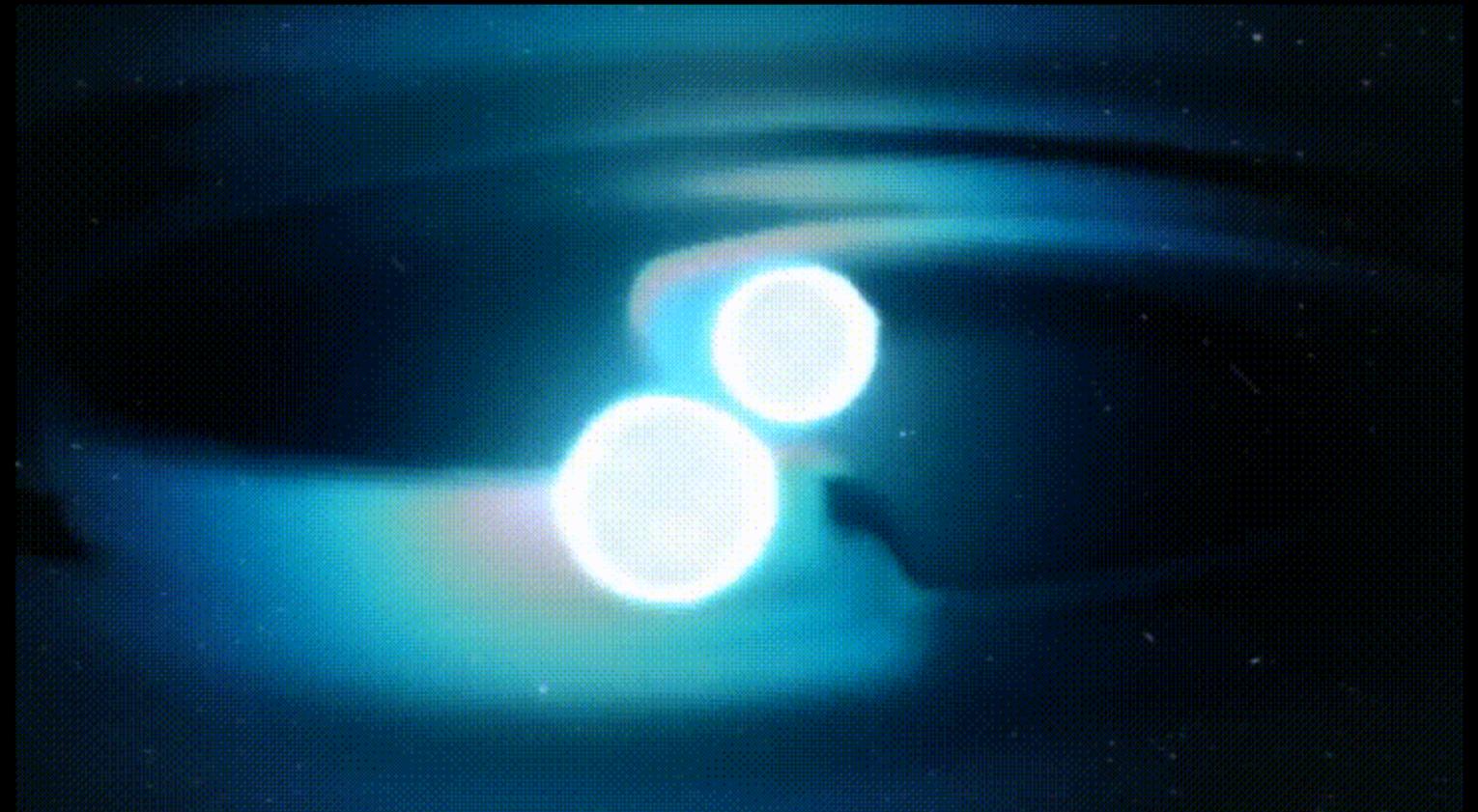
- But data seems to prefer negative values - enhanced compare to LCDM?

Gravitational Waves

- Speed of GWs changes in many Modified Gravity models.
- Measure GW speed relative to EM from Neutron Star / Neutron Star merger.



GW and EM wave detection from GW170817



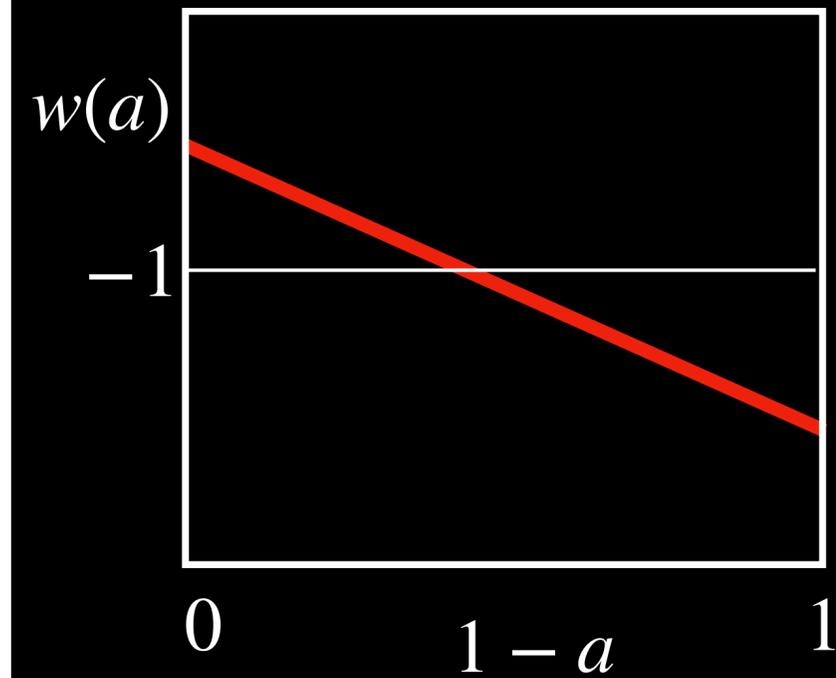
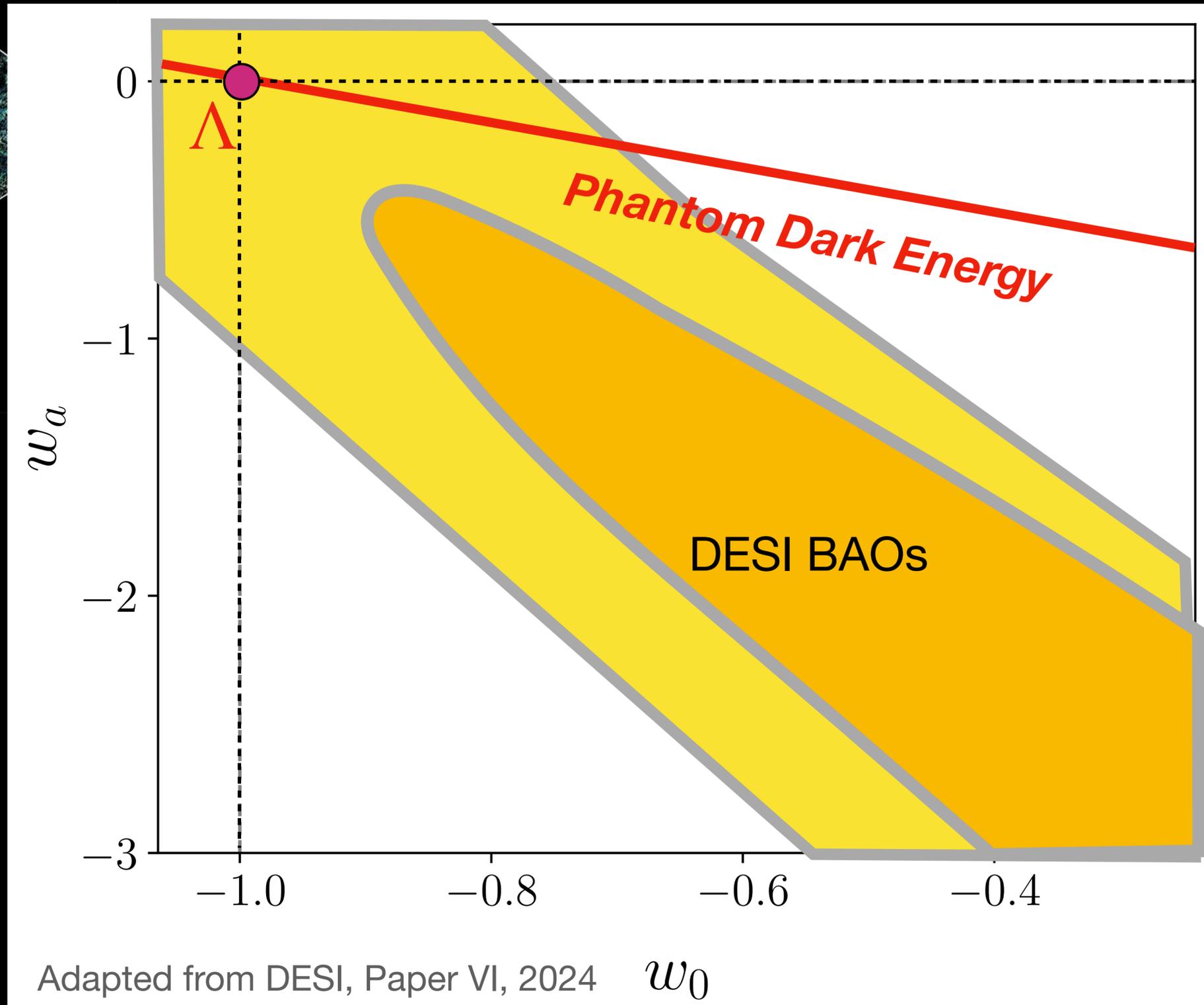
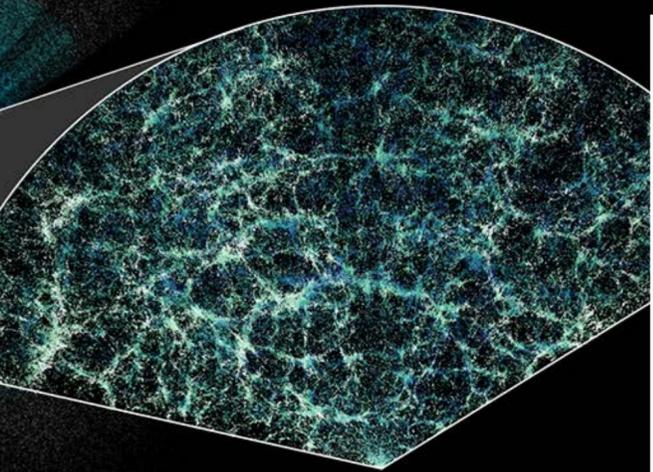
Neutron Star - Neutron Star merger

- Difference of $(v_{\text{GW}} - c)/c \leq 10^{-15}$ rules out many Mod Grav models.

Dynamical Dark Energy

$$w(a) = -1 + \frac{1}{3} \frac{d \ln \rho_{DE}}{d \ln a}$$

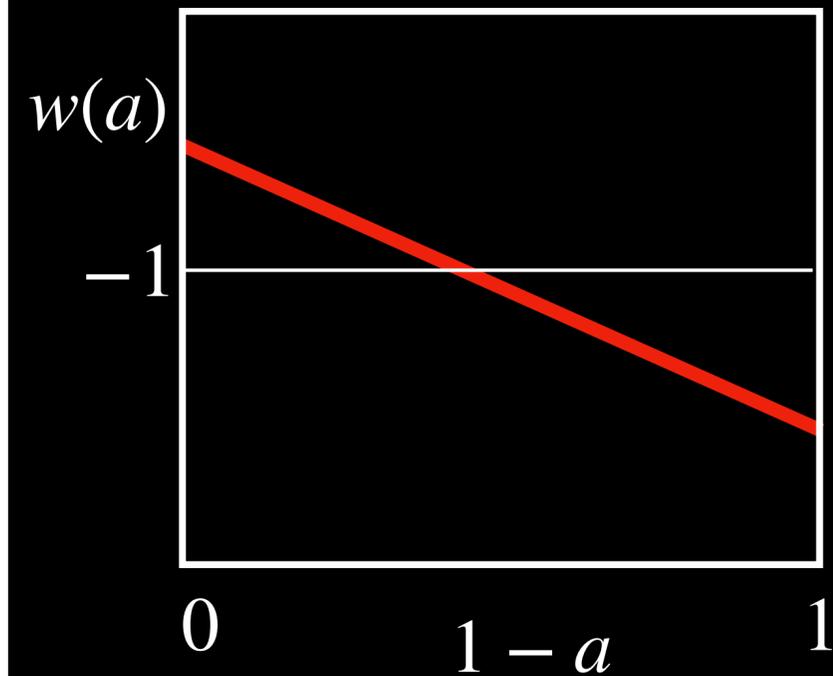
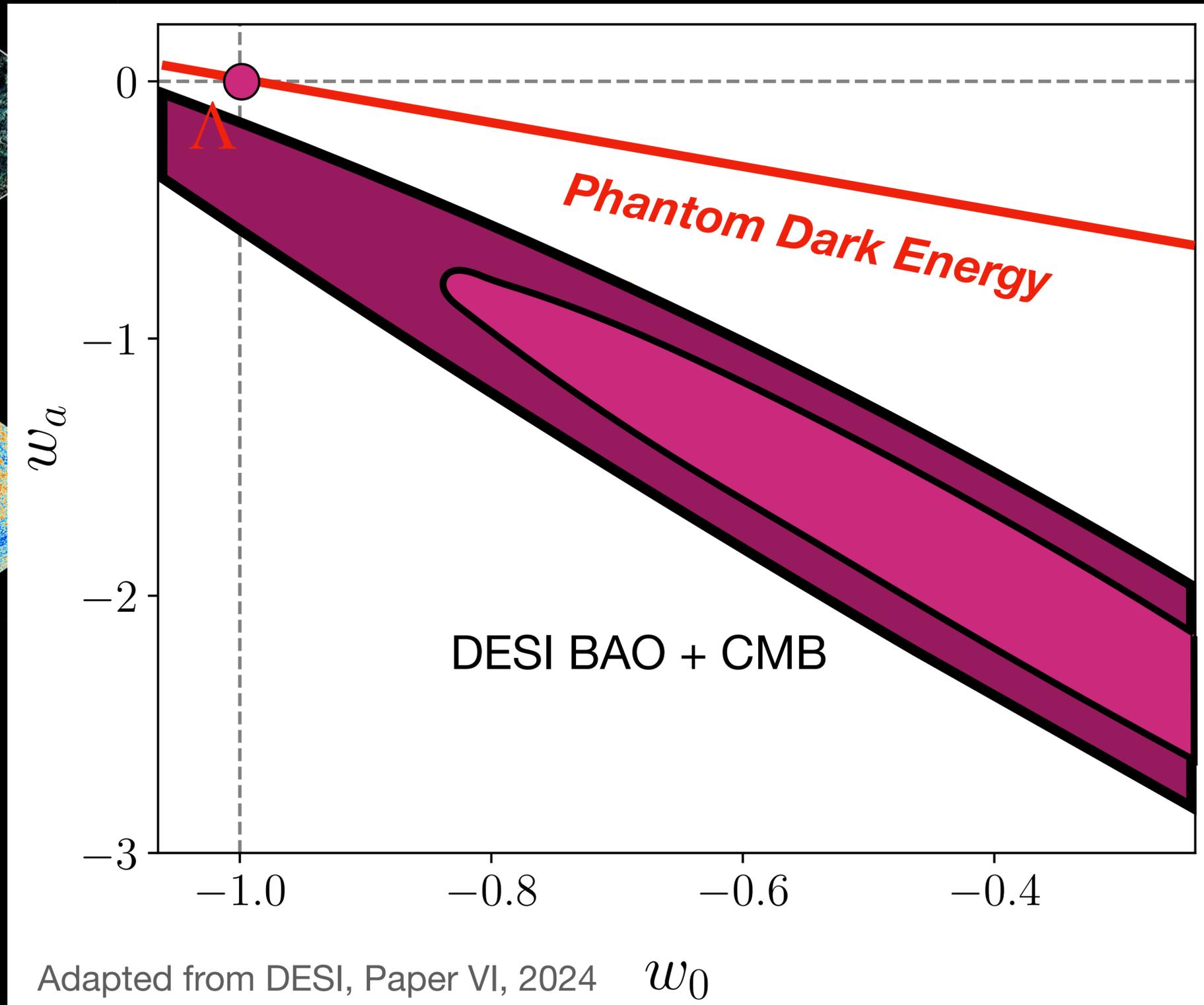
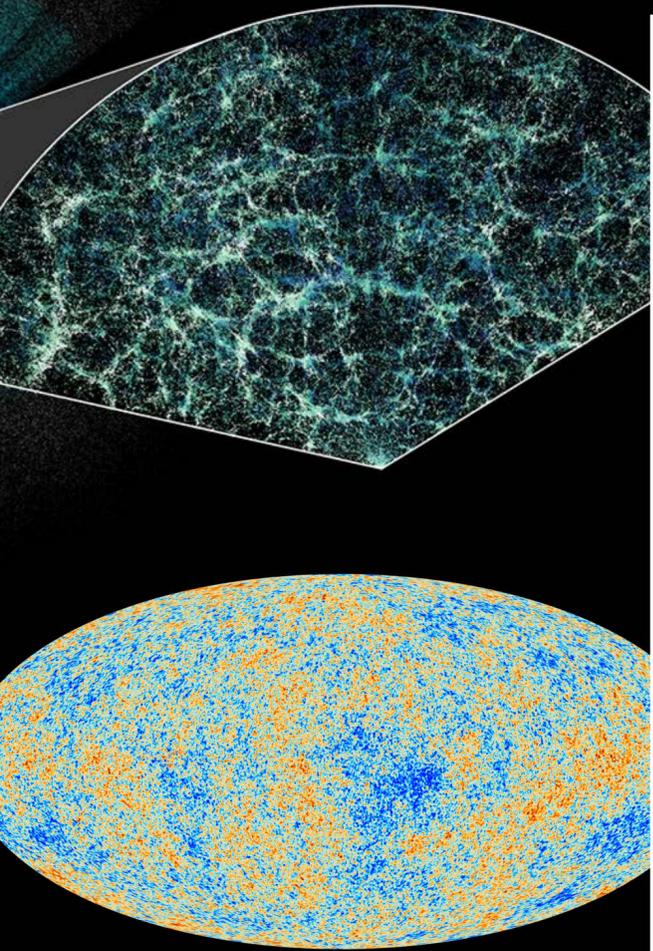
$$\approx w_0 + w_a(1 - a)$$



Dynamical Dark Energy

$$w(a) = -1 + \frac{1}{3} \frac{d \ln \rho_{DE}}{d \ln a}$$

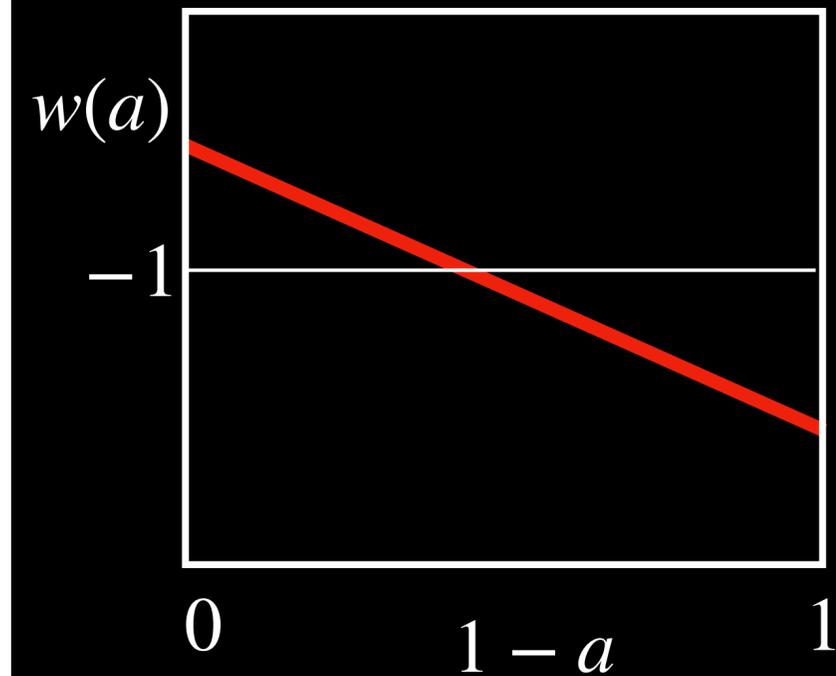
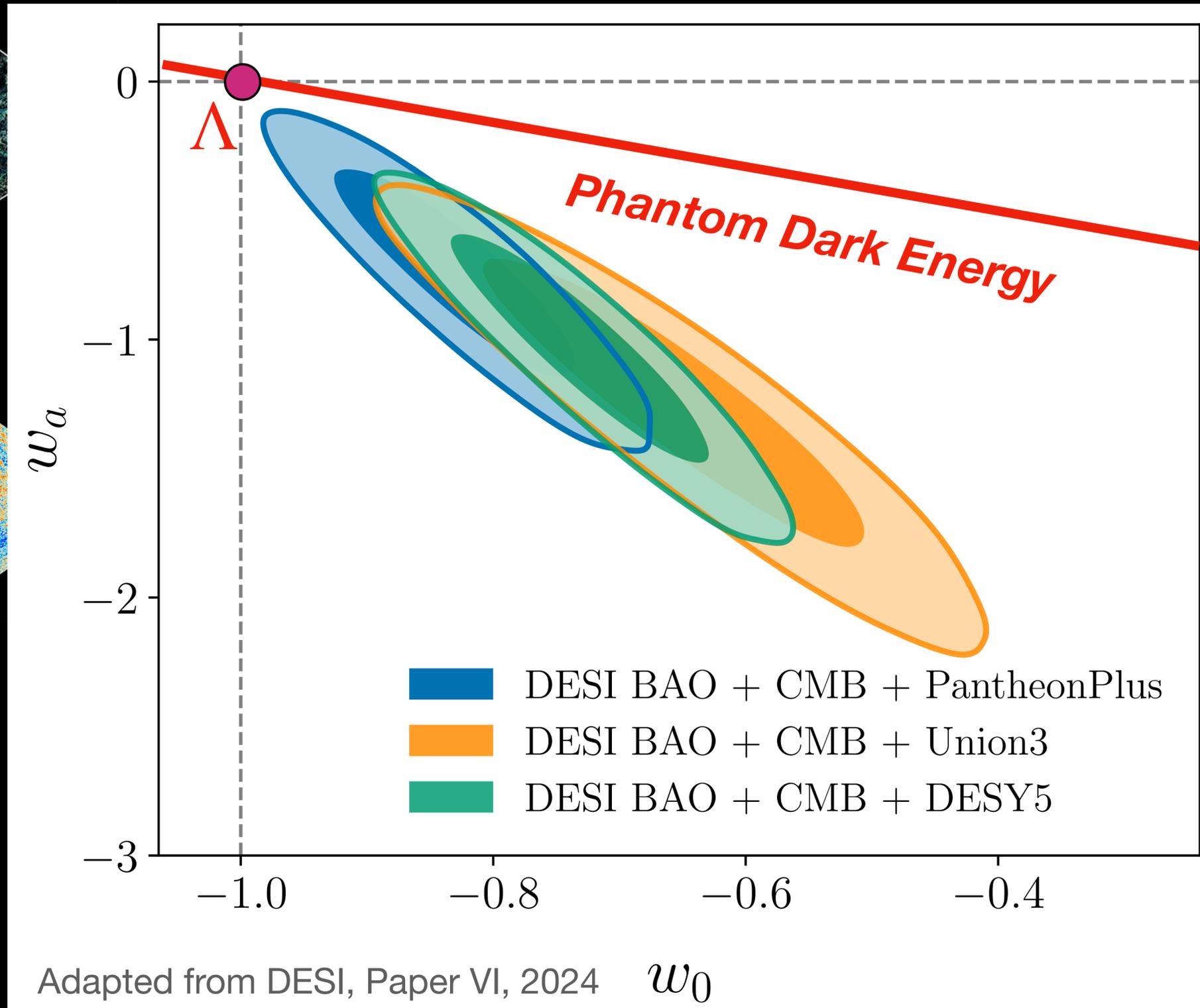
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Dynamical Dark Energy

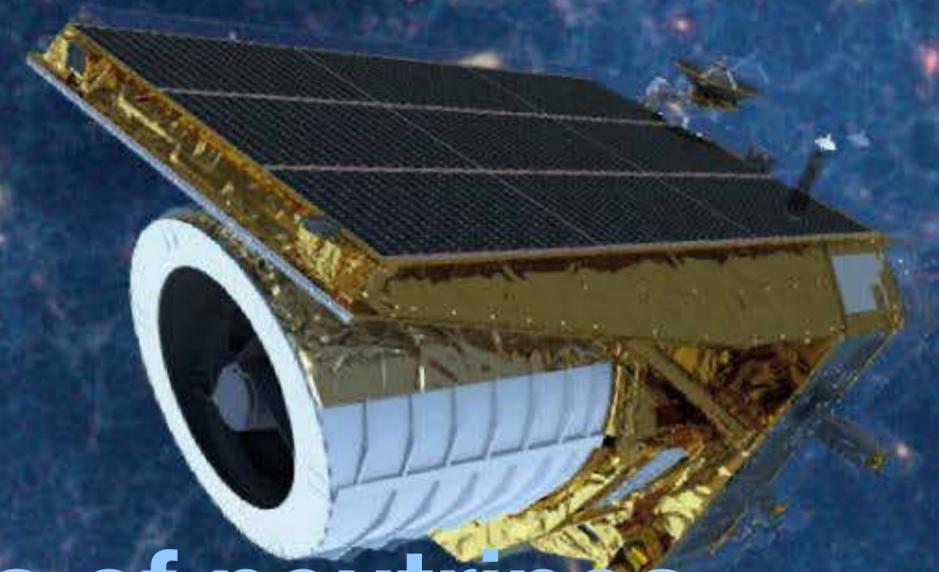
$$w(a) = -1 + \frac{1}{3} \frac{d \ln \rho_{DE}}{d \ln a}$$

$$\approx w_0 + w_a(1 - a)$$



Euclid's Mission

- Measure the properties of **Dark Energy**.
- Probe **Dark Matter** and measure the **mass of neutrinos**.
- **Test Einstein's Theory of Gravity** on the largest scales.
- Probe the **very earliest moments** of the Universe.



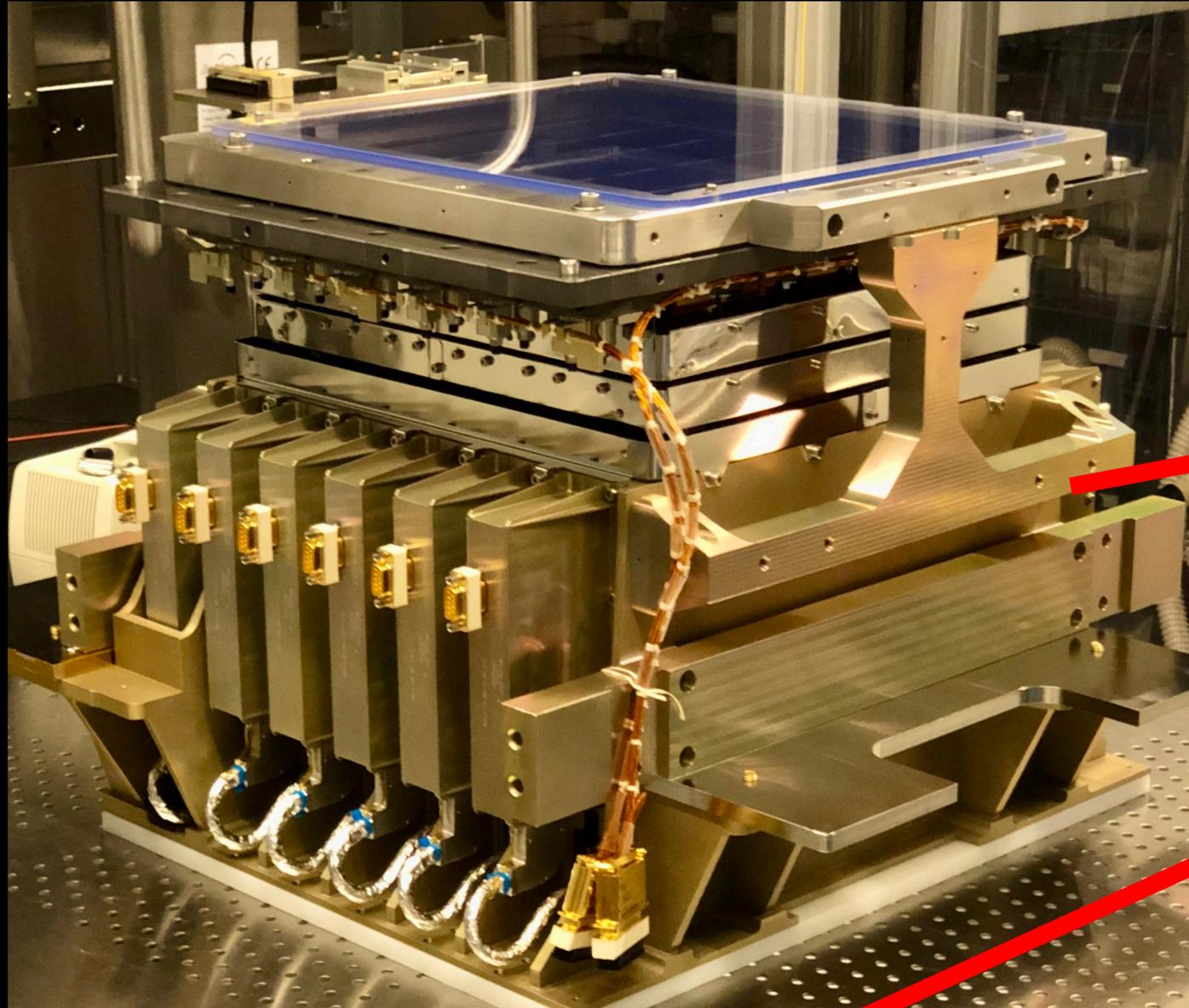
Sending Euclid on its way



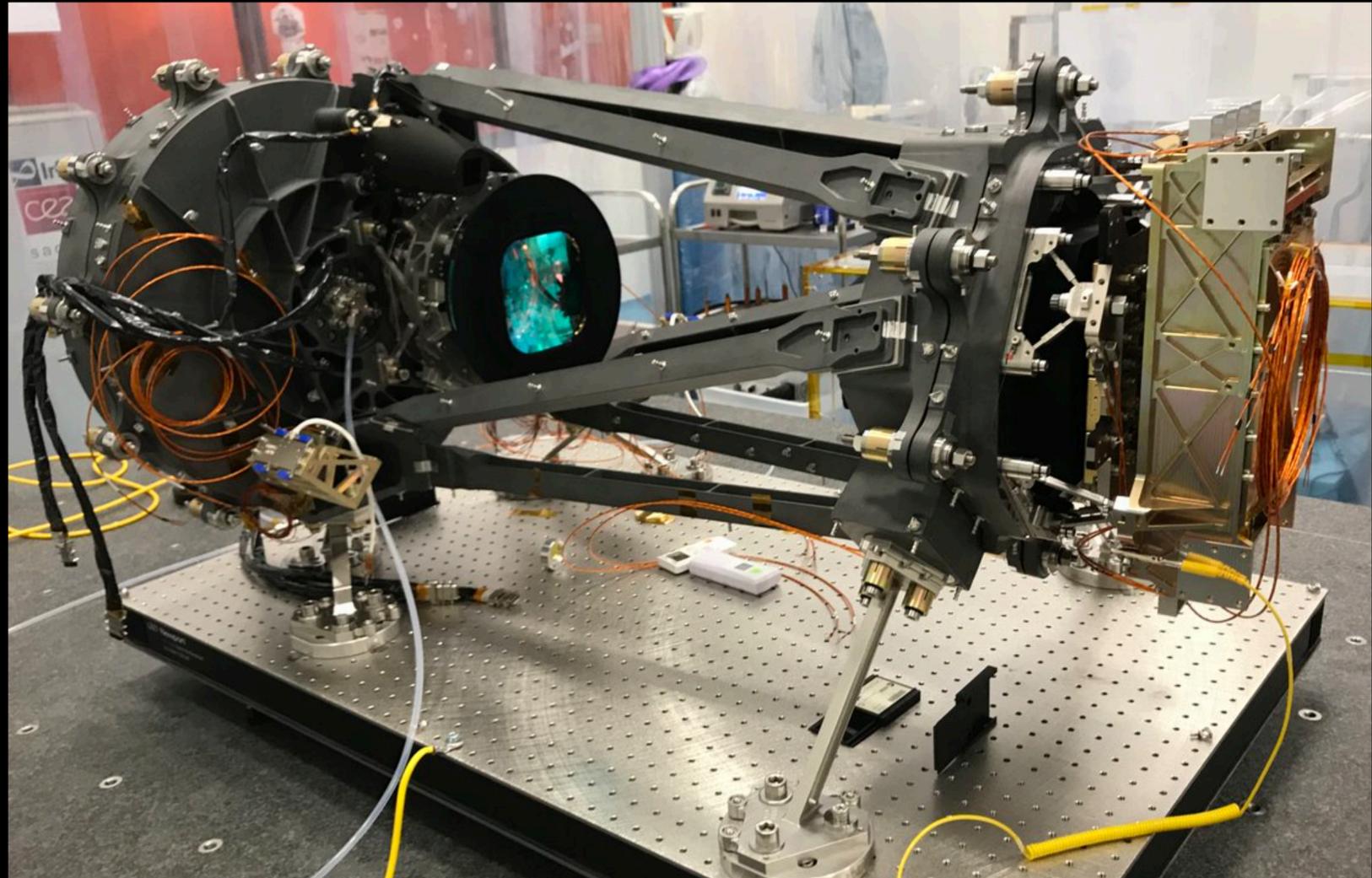
Credits: Thales-Alenia

Euclid's Instruments

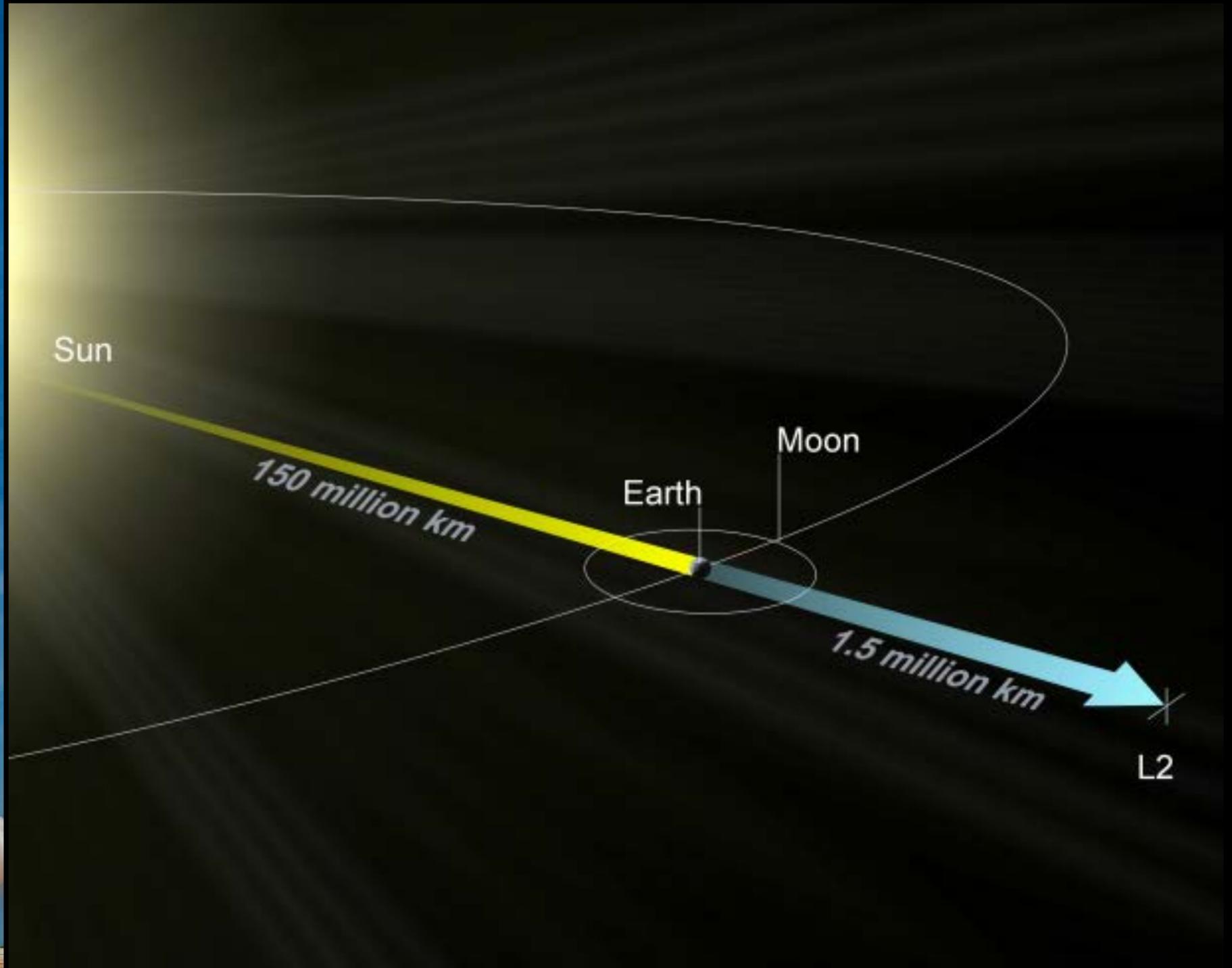
UK-led Optical Camera (VIS)



Italy-led Near Infrared Camera (NISP)

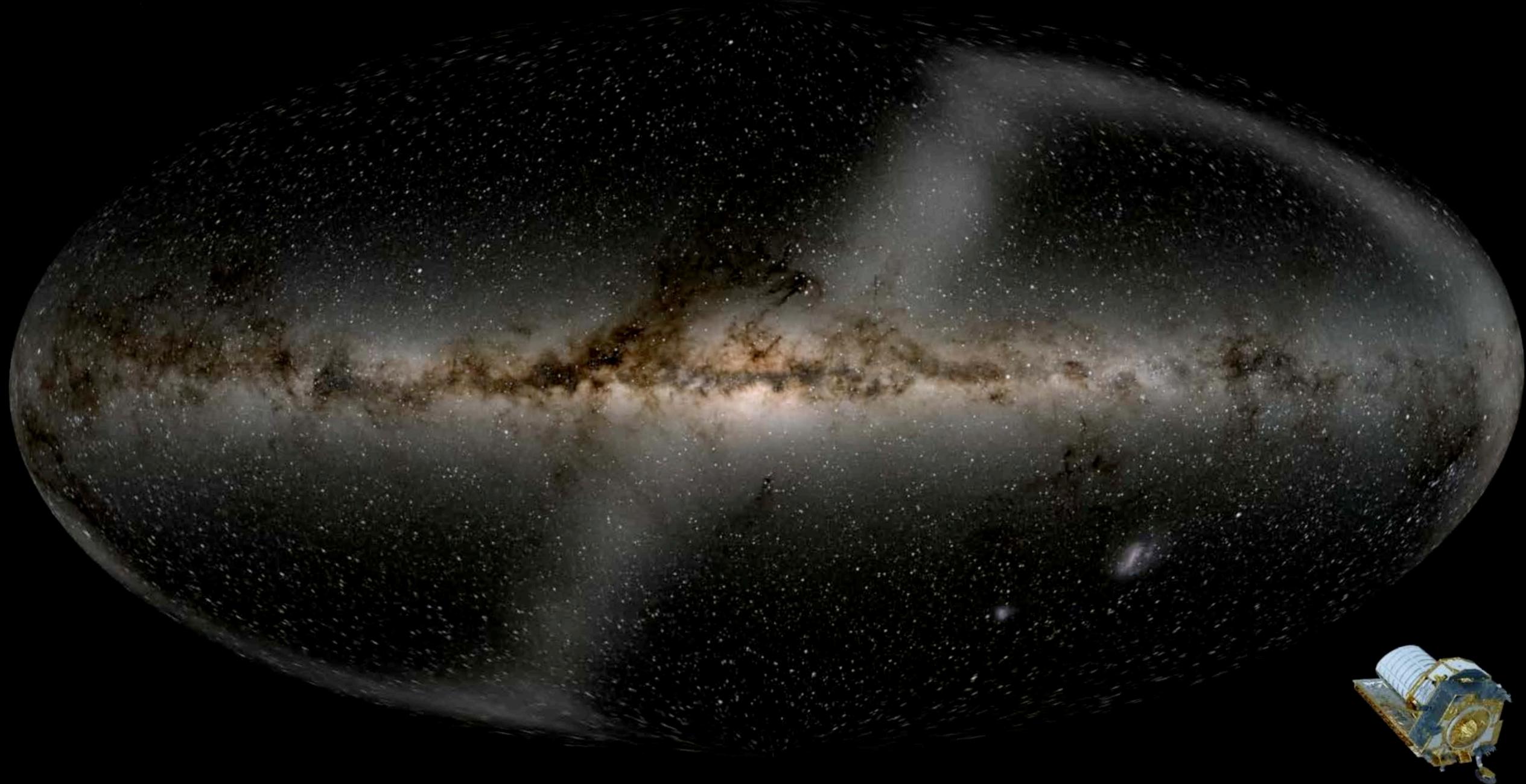


Launch and Journey to L2

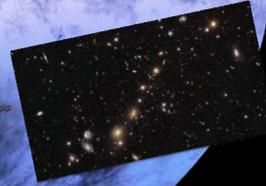
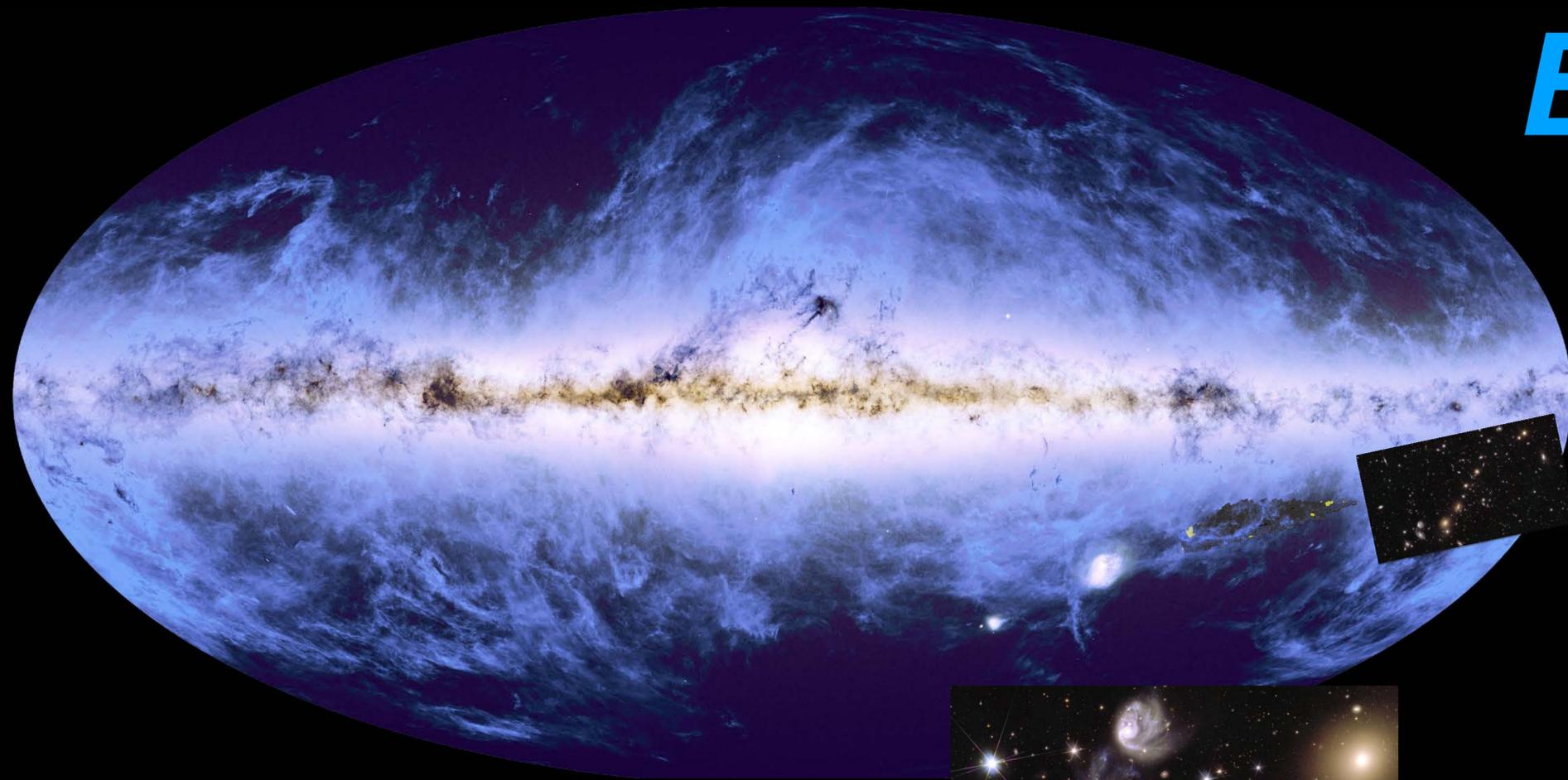


Euclid's Dark Energy Survey

- 1/3rd of the sky mapped over 6 years.
- 1.5 Billion galaxies with high-quality optical images & 8 colours.
- 35 Million galaxies with spectroscopic redshifts.

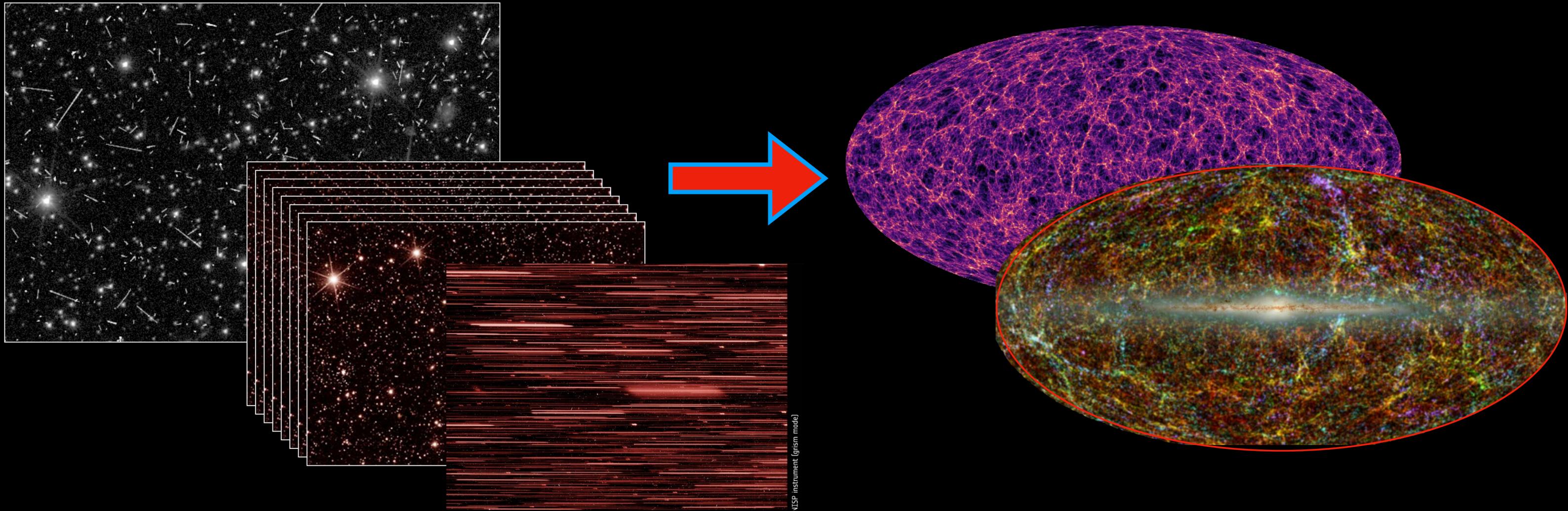


Euclid Images



Euclid's Data Processing Challenge

- Euclid's **Science Ground Segment** will process 100s Pbs of VIS and NISP photometric and spectroscopic data, along with ground-based data.

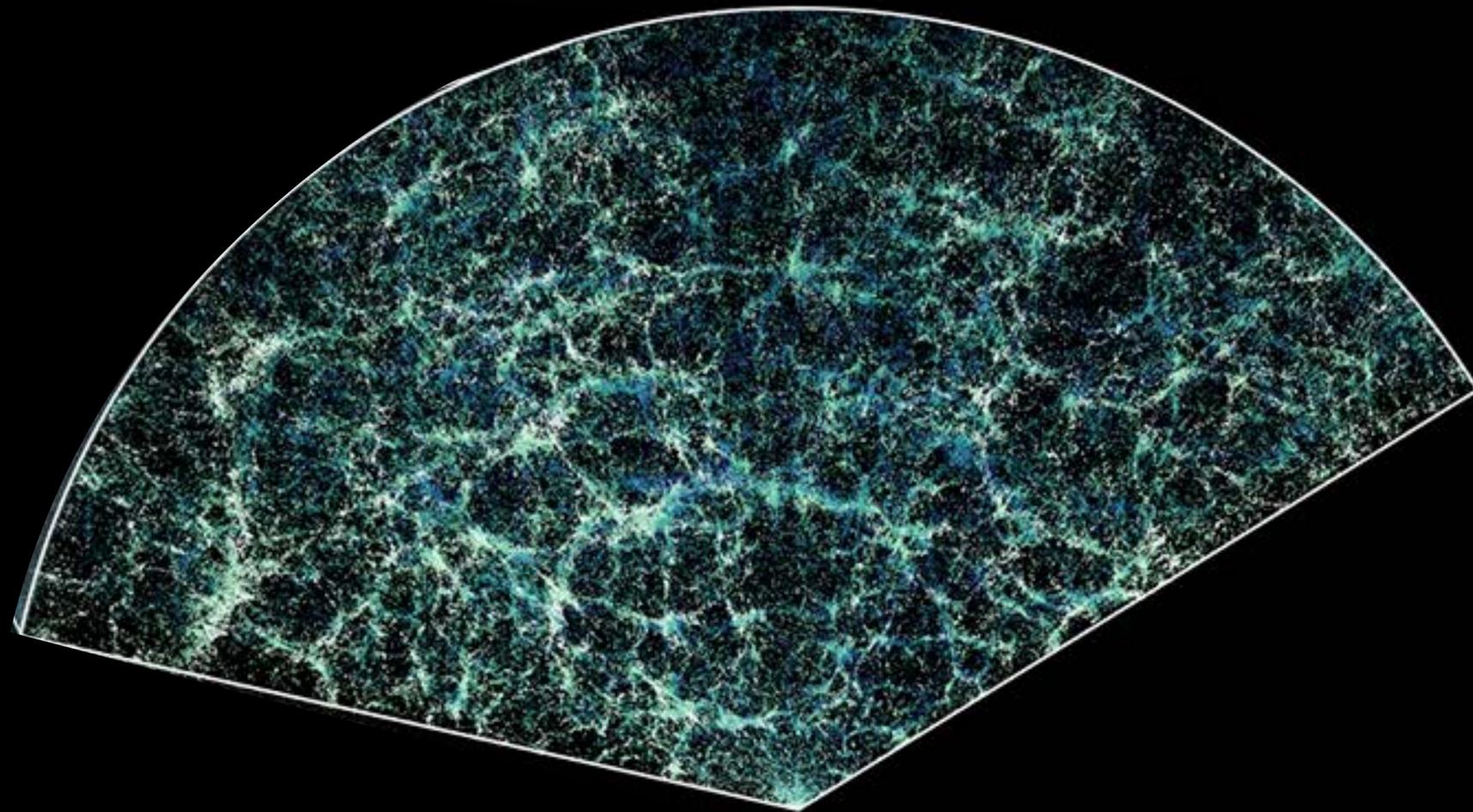
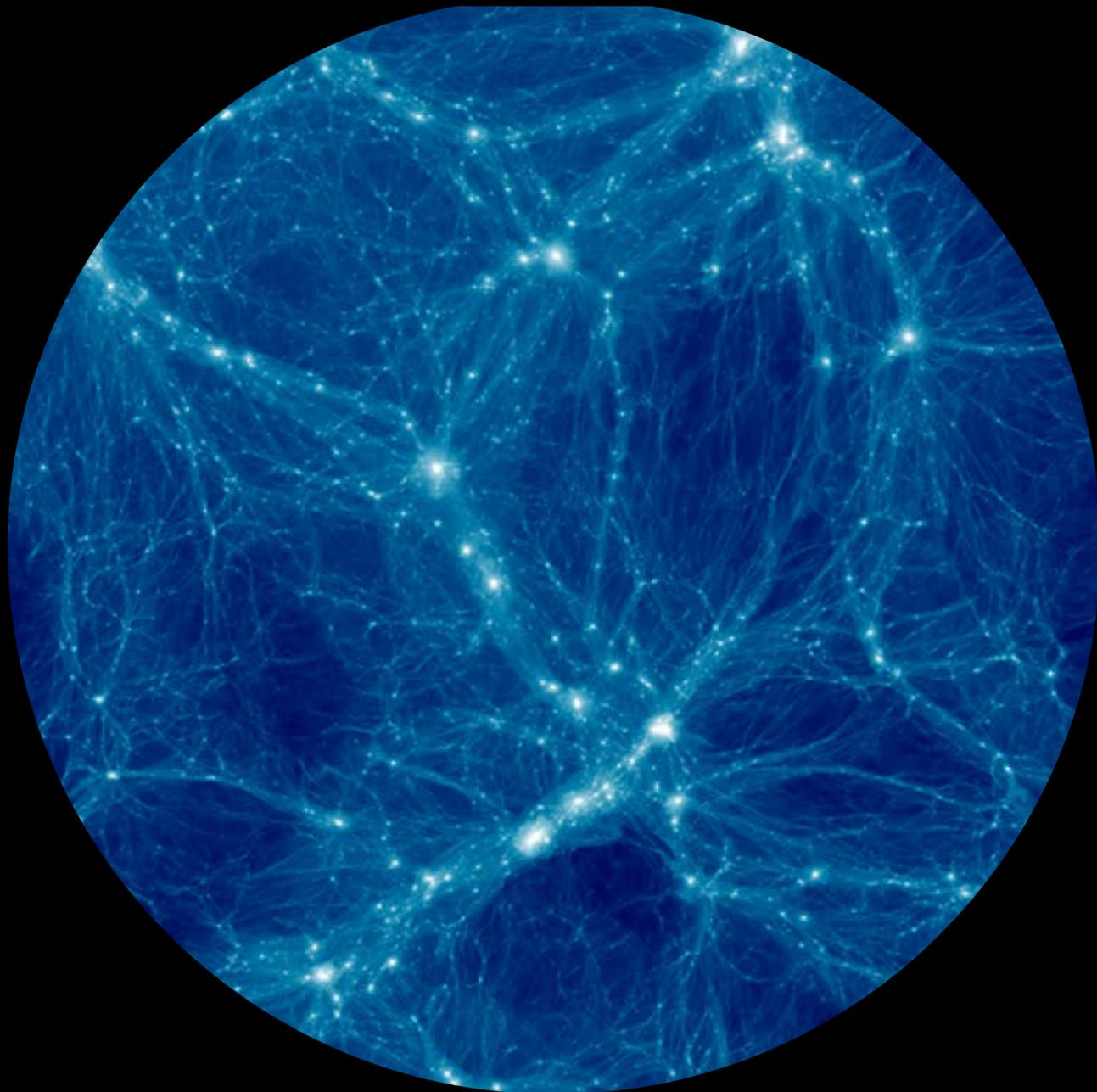


- Output shear, photo-z, spec-z catalogues, calibration parameters, maps, 2-point statistics, noise covariances and visibility masks.

Euclid Maps the Universe

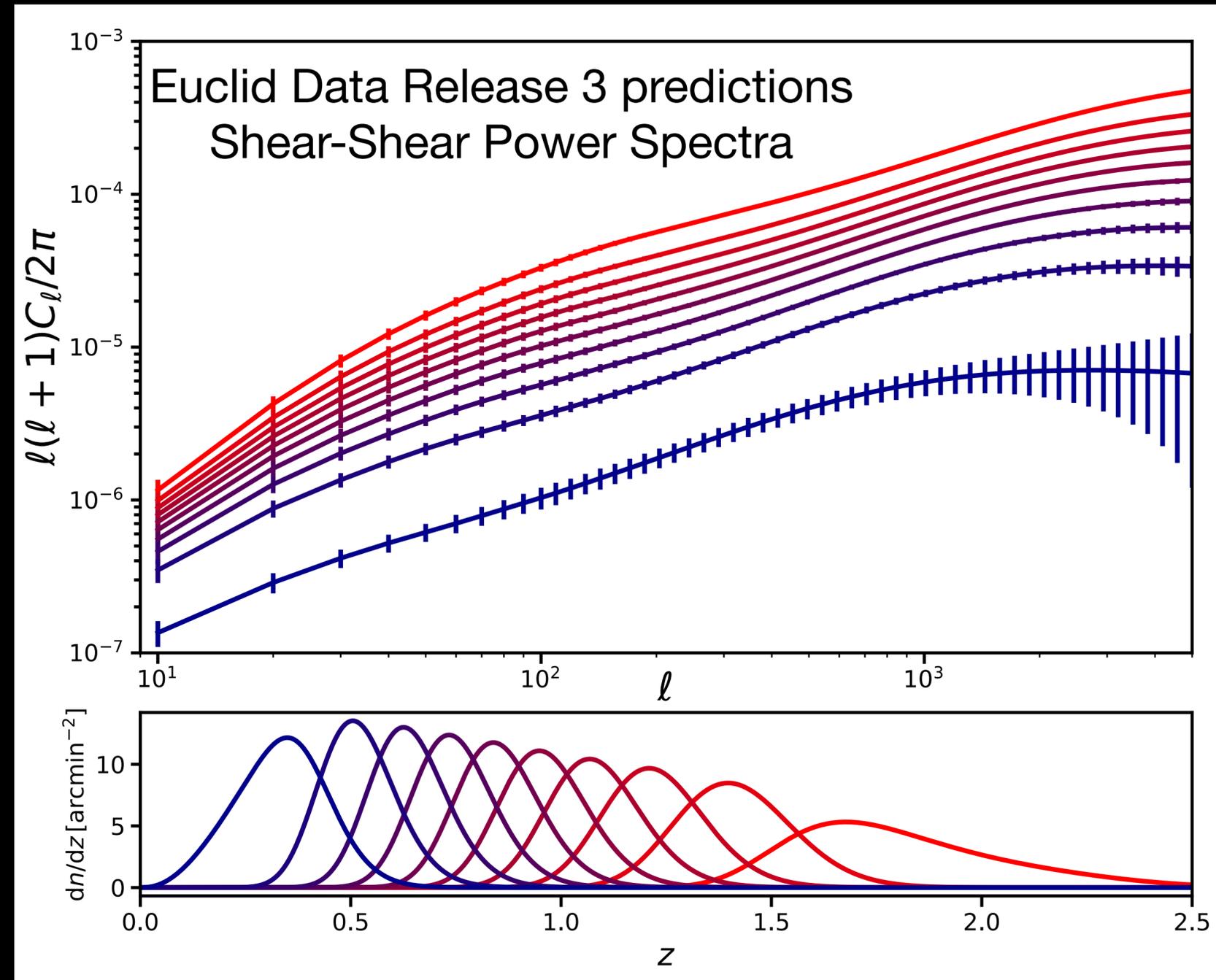
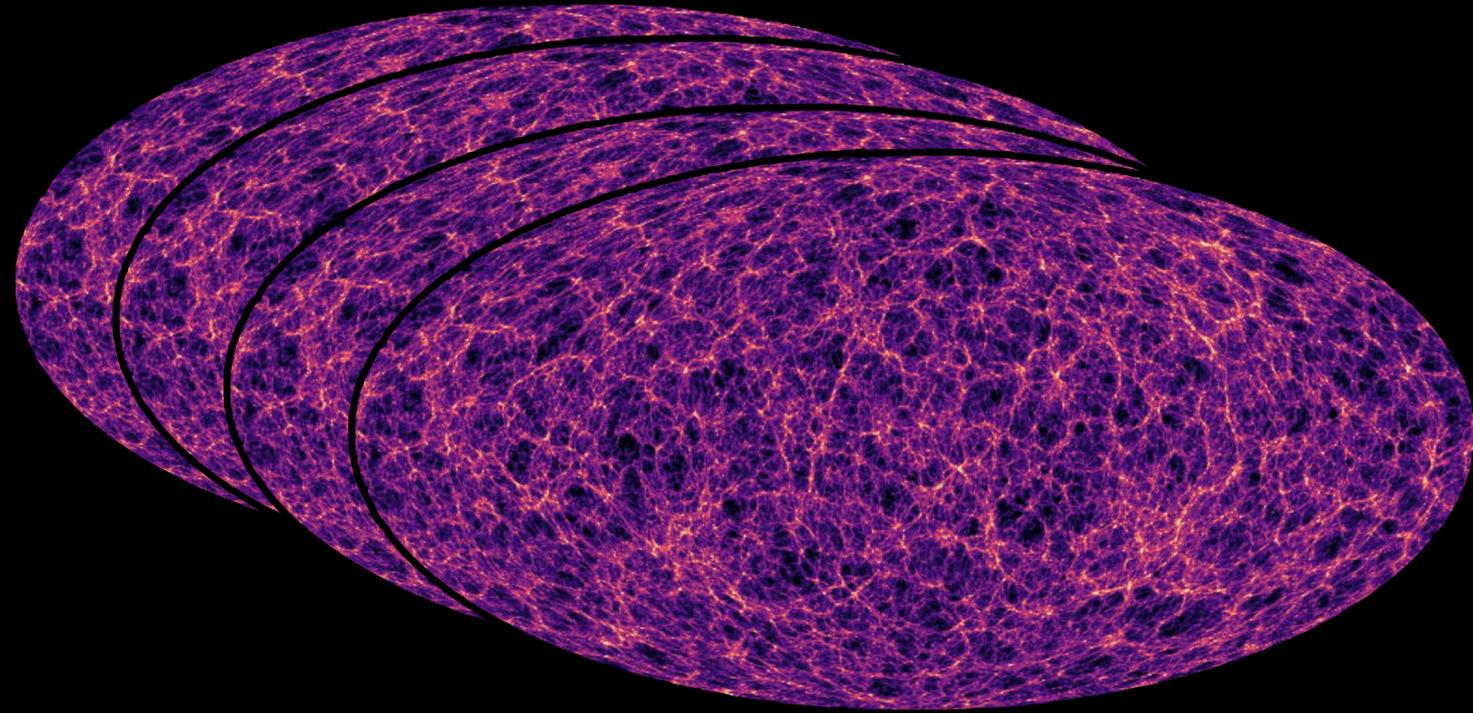
- Dark Matter with Weak Gravitational Lensing

- The distribution of galaxies



Euclid's Shear Power

- Weak Lensing shear-shear power spectra for 10 redshift bins.



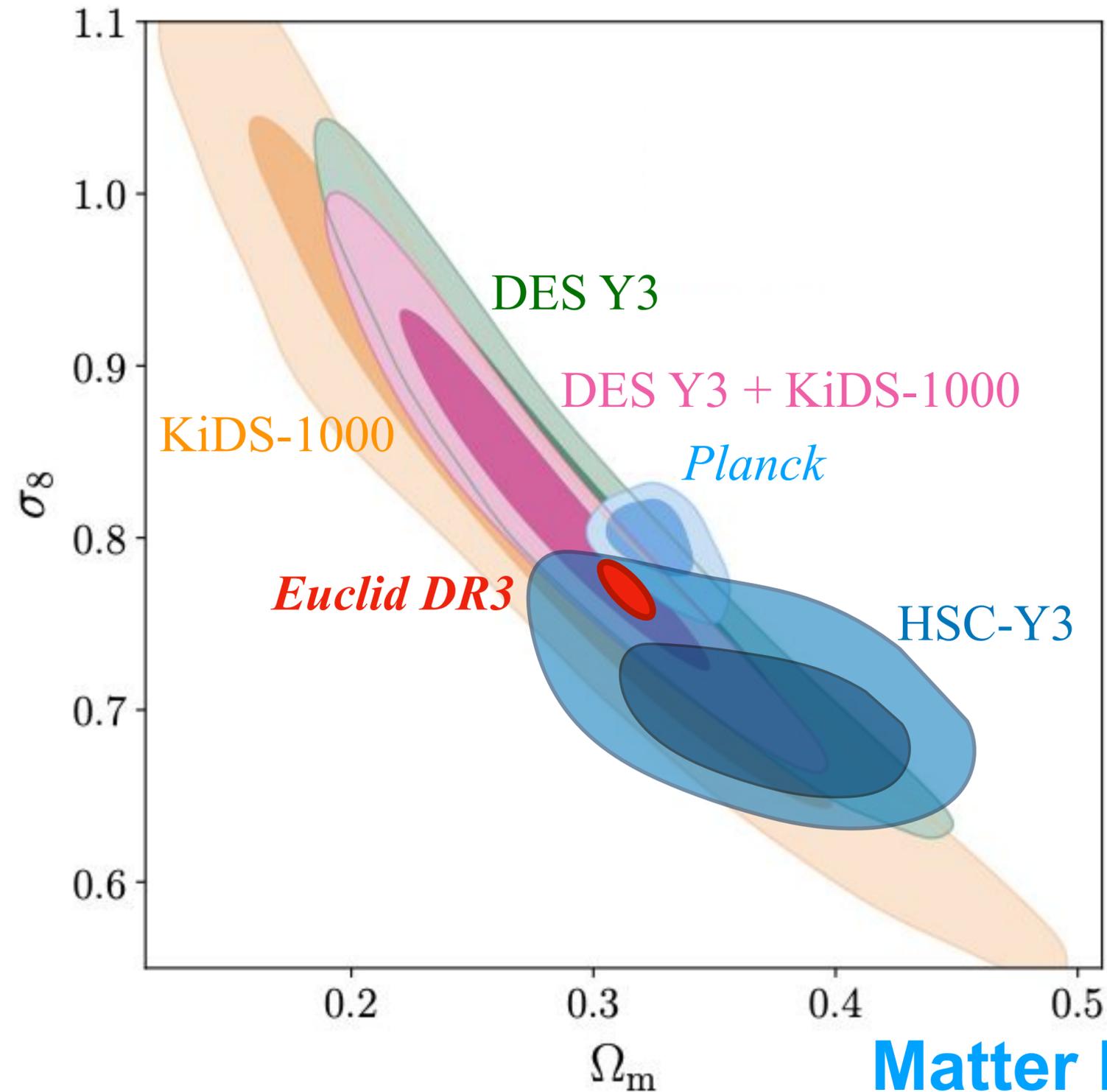
- >330 shear-shear, position-position, shear-position power spectra.

+ Spectroscopic Redshift Survey power spectra.

Figure: Hall & ANT 2024

Matter Density and Clustering

Amplitude of mass clustering



Euclid Collabn: Blanchard et al 2020
Copeland, ANT & Hall, 2020

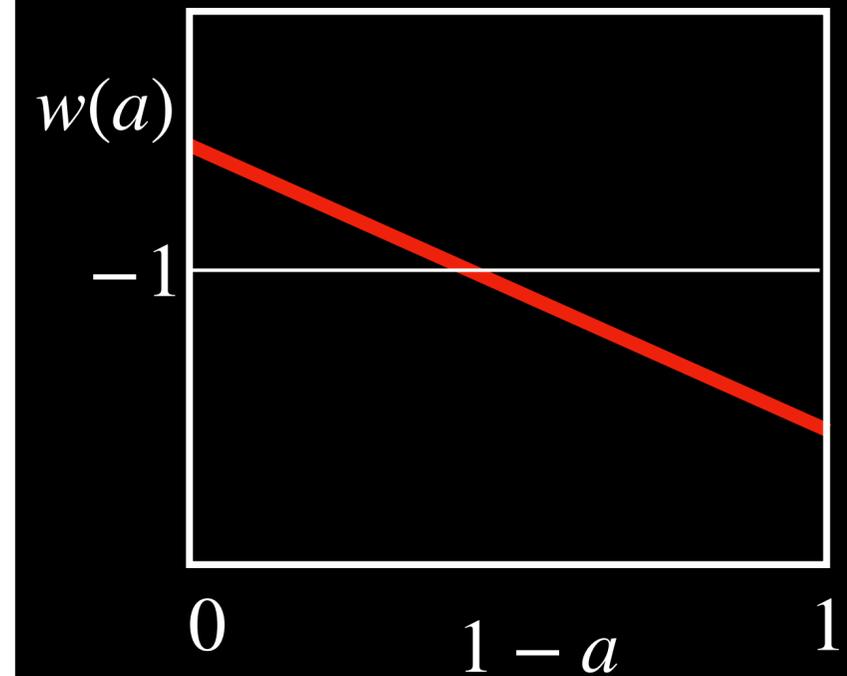
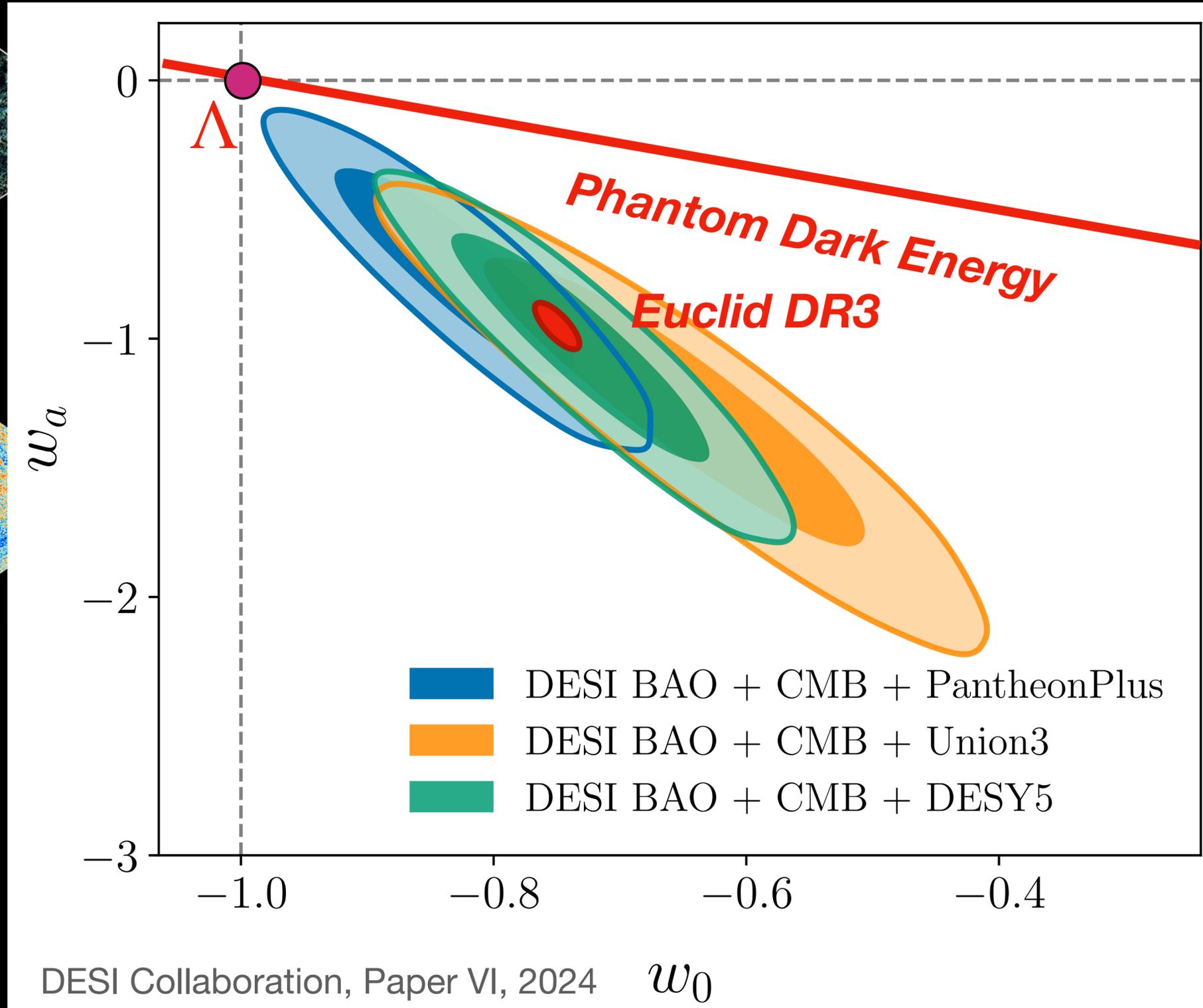
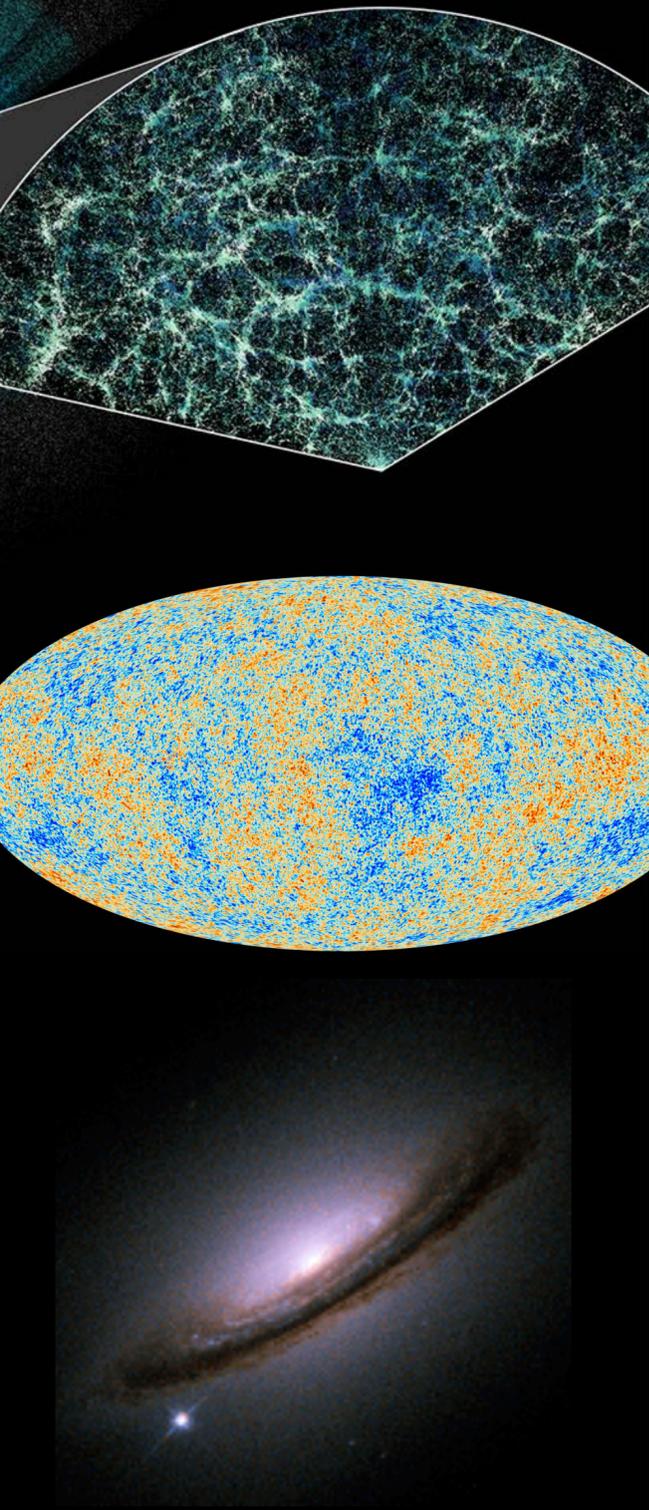
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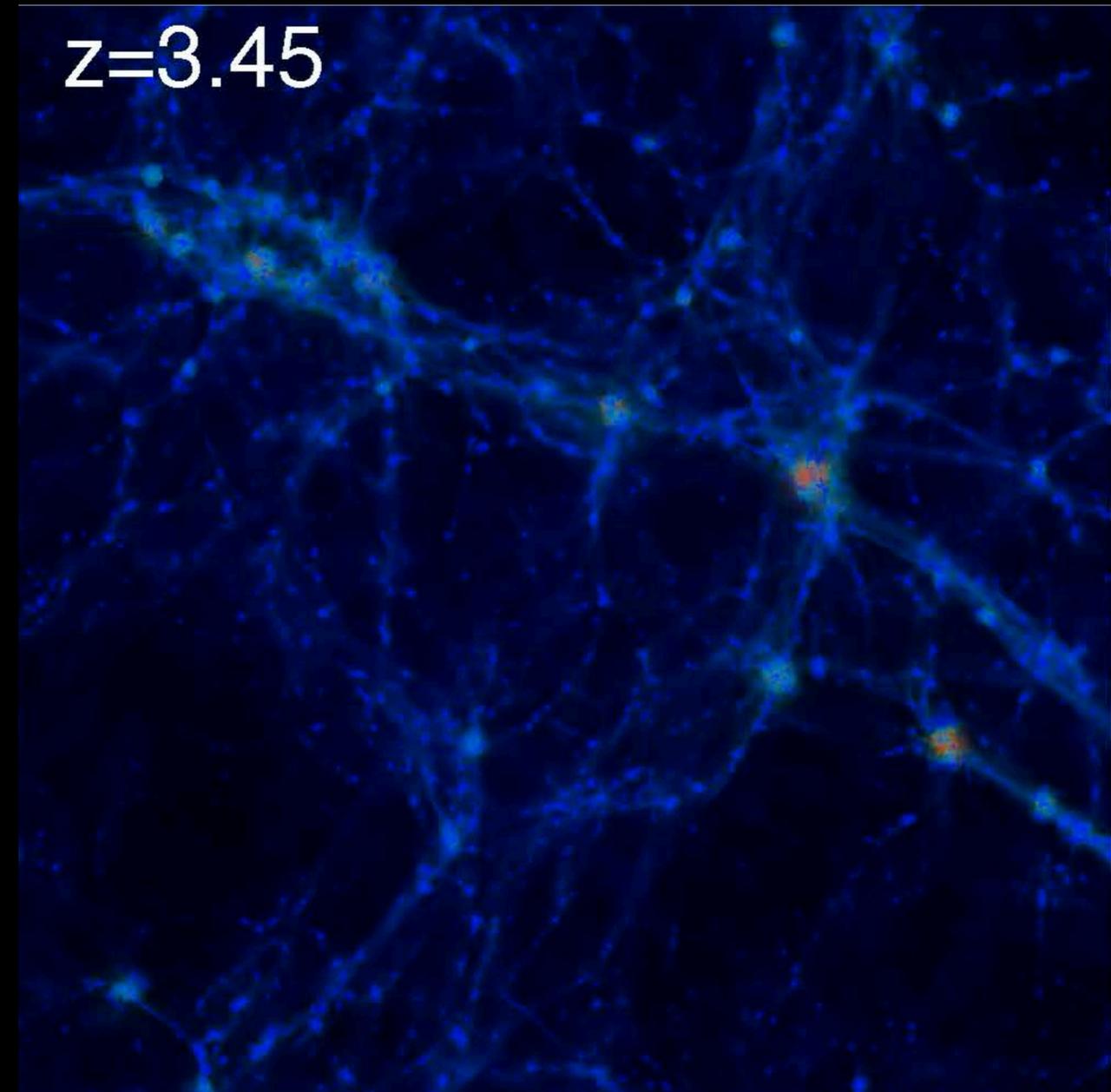
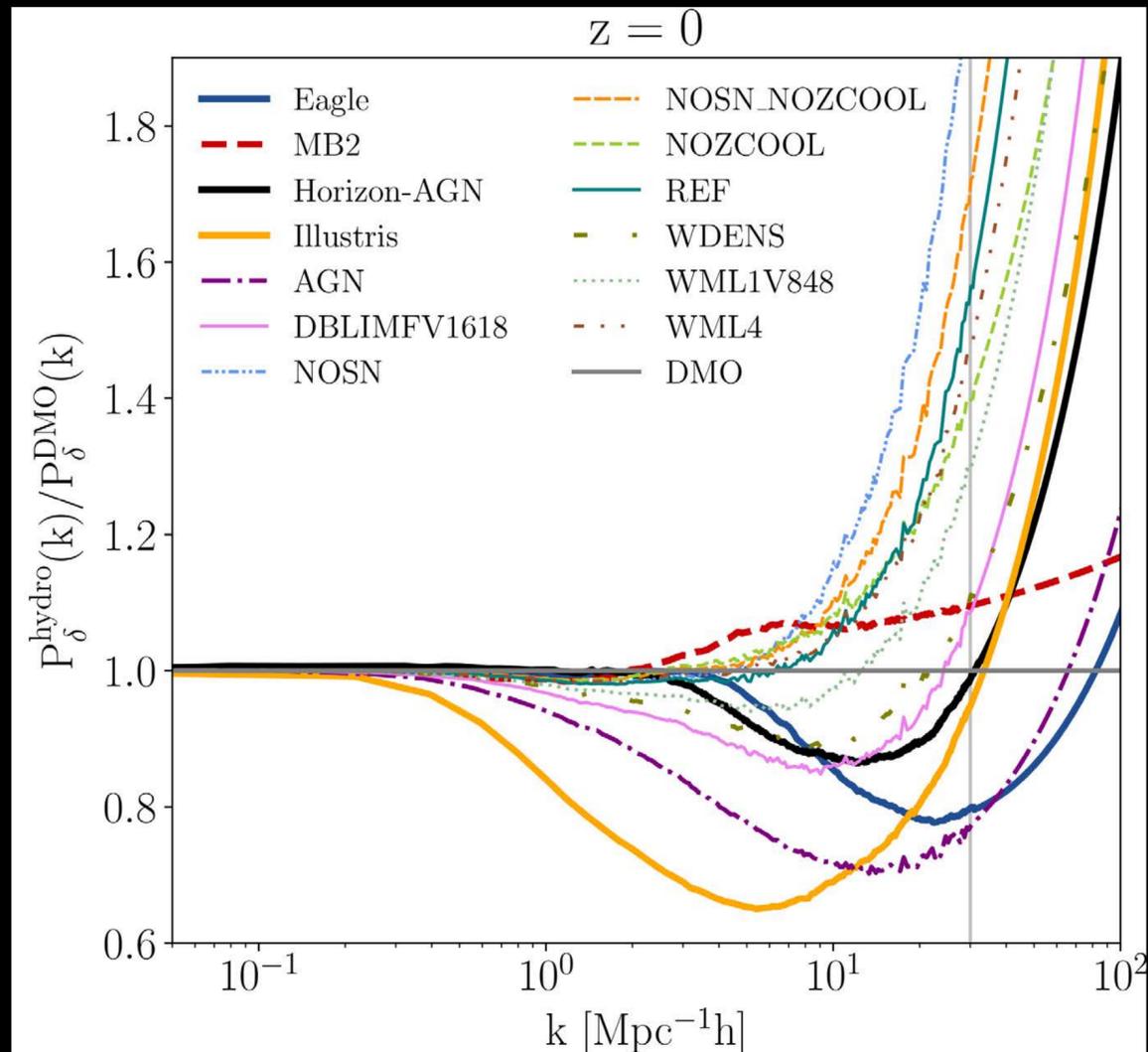
$$\approx w_0 + w_a(1 - a)$$



Euclid Collabn: Blanchard et al 2020
Copeland, ANT & Hall, 2020

Challenges: Modelling Baryon Feedback

- Change in matter power spectrum
- Gas Temperature changes due to AGN feedback



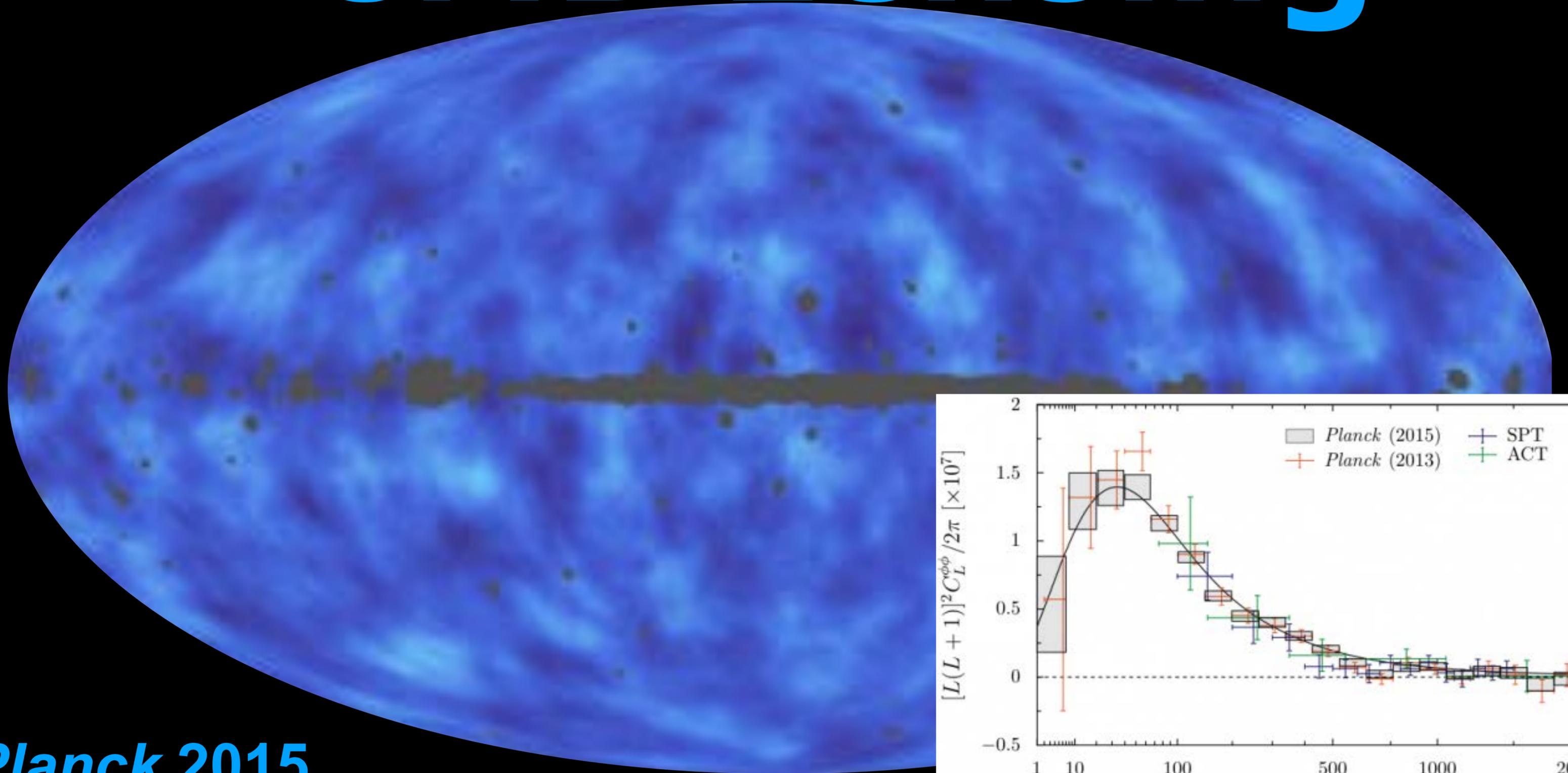
Simulation Credit: Illustris Collaboration

Summary

- A Golden Age for Cosmology with DESI, *Euclid*, Rubin, and more, turning the Universe into a vast laboratory.
- Exciting indications that the Standard Cosmological Model is breaking down, leading to new physics !
- Expect major scientific breakthroughs in Cosmology over the next few years - *Euclid* is well placed.
- *First 'Quick-Look' Science Results from Euclid released on 19th March 2025, internal DR1 Oct 2025 !!*

END

CMB Lensing



Planck 2015

