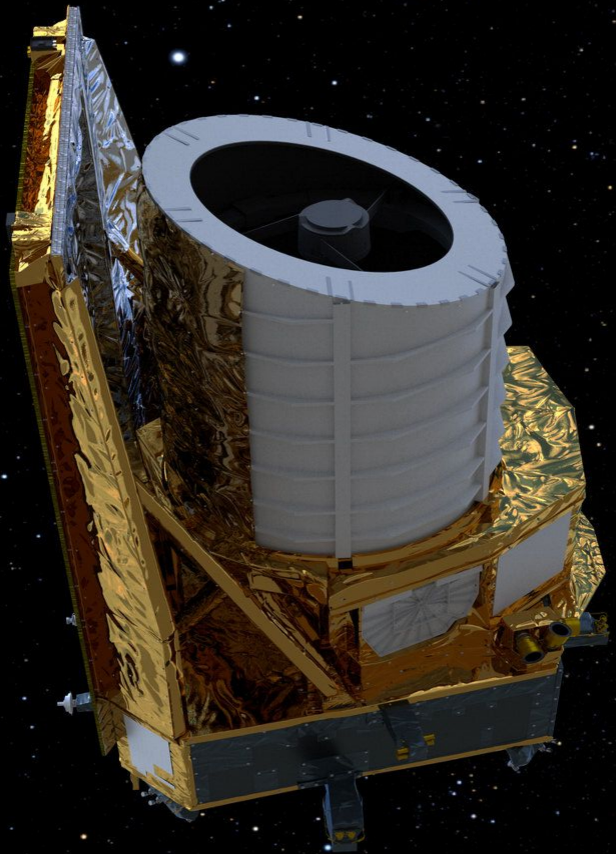


Overview of the Euclid mission and cosmological implications

Mario Ballardini
University of Ferrara

INFN Istituto Nazionale di Fisica Nucleare

Euclid consortium

Università degli Studi di Ferrara

Outline

- Euclid mission overview
  - What is Euclid and what does Euclid observe?
  - ERO, Q1 and Q2 data releases
- Cosmological forecasts
  - Dark energy and modified gravity
  - Neutrino parameters
  - Initial conditions
- Conclusions

Euclid Consortium

The Euclid Consortium

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

More than 2000 registered active member

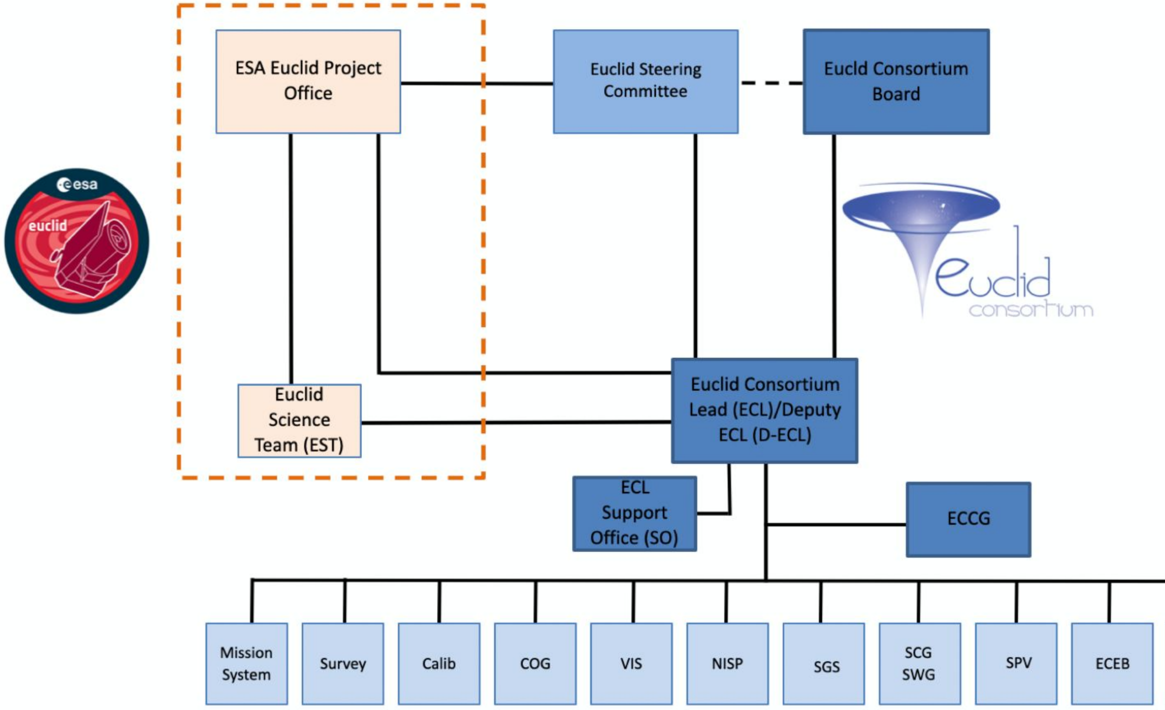
15 European countries
+ USA + Canada + Japan

Responsible of the Euclid instruments and the exploitation of the data

The Euclid Consortium

Euclid Consortium meeting in Barcelona, May 2026

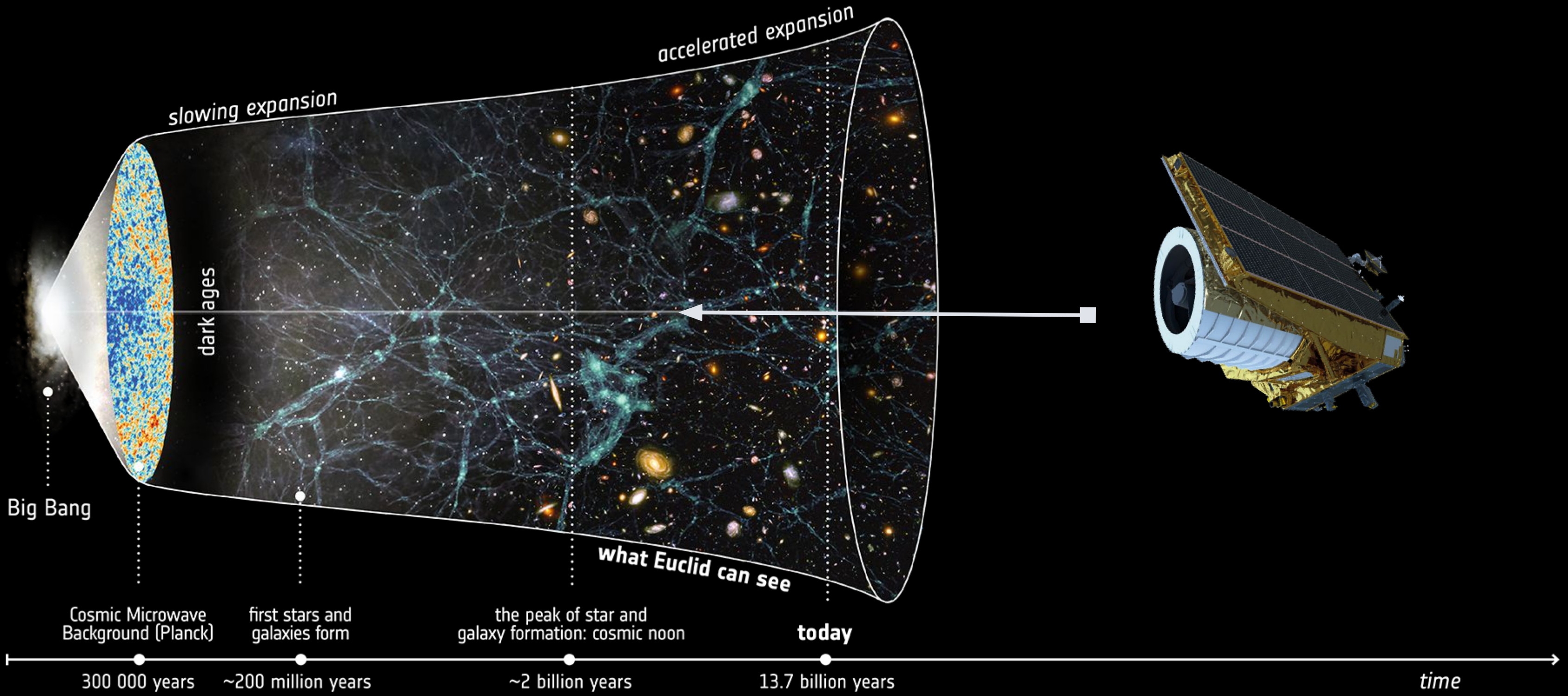
The Euclid Consortium & ESA Euclid



ECCG: Euclid Consortium Coordination Group
COG: Complementary Observations Group
SPV: Science Performance Verification
SCG: Science Coordination Group
SGS Science Ground Segment
SWG: Science Working Group
ECEB: Euclid Consortium Editorial Board
ECDC: Euclid Consortium Diversity Committee
COM: Communication group

Primary Science

Timeline of the Universe



Credit: ESA/ATG

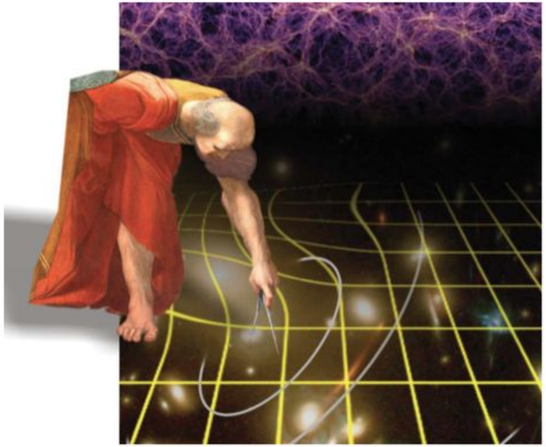
Main Objectives

esa

ESA/SRE(2011)12
July 2011

Euclid

Mapping the geometry of the dark Universe



Definition Study Report

Table 1: Euclid Primary Science Objectives – see RD10 for a full description.

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% for several redshift bins from $z = 0.7$ to $z = 2$. • Look for deviations from $w = -1$, indicating a dynamical dark energy. • Euclid *alone* to give $\mathrm{FoM}_{DE} \geq 400$ (roughly corresponding to 1-sigma errors on w_p, & w_a of 0.02 and 0.1 respectively)
Test of Gravity	• Measure the growth index, γ, to a precision better than 0.02 • Measure the growth rate to better than 0.05 for several redshift bins between $z = 0.5$ and $z = 2$ • Separately constrain the two relativistic potentials φ and ψ • Test the cosmological principle
Dark Matter	• Detect dark matter halos on a mass scale between 10^8 and $>10^{15}$ M_{Sun} • Measure the dark matter mass profiles on cluster and galactic scales. • Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with an accuracy of a few hundredths of an eV
Initial Conditions	• Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n_s to 0.01. • For extended models, improve constraints on n_s and α with respect to Planck alone by a factor 2. • Measure the non-Gaussianity parameter f_{NL} for local-type models with an error better than $\pm$ 2.

Credit: ESA Euclid Definition Study report

Spacecraft & Instruments

Spacecraft

4.7m tall
3.7m total diameter
1.2m diameter main mirror
2 tonnes

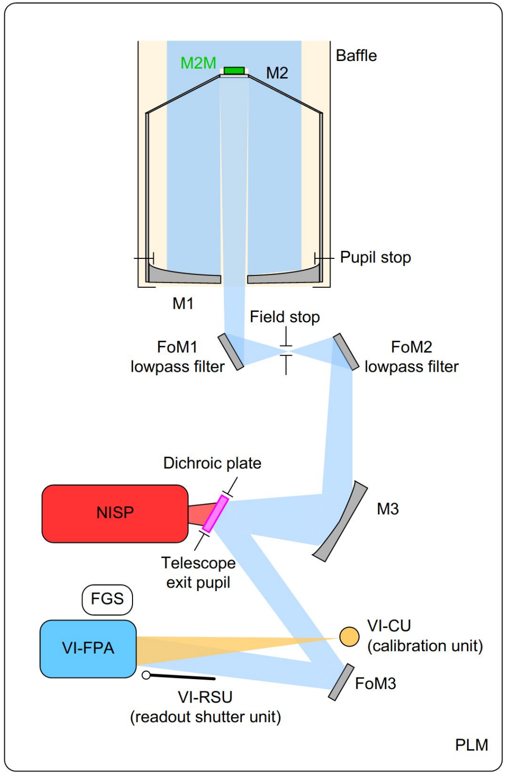
Sunshield

Solar panels

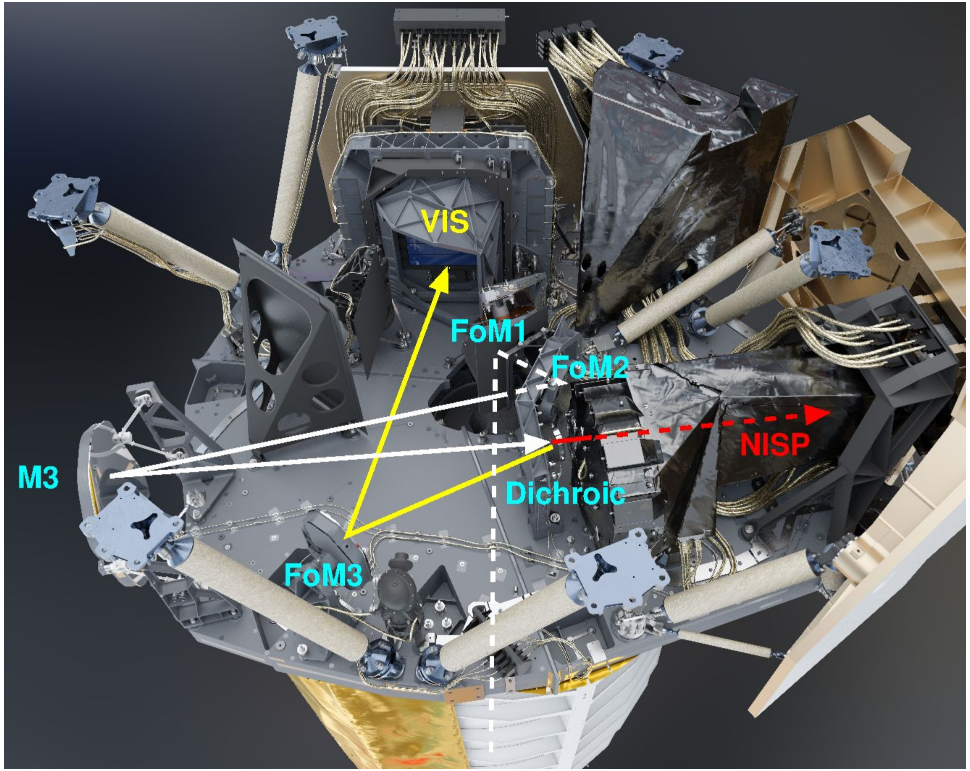
Service module

VIS and NISP

Payload Module: Optical path and instruments



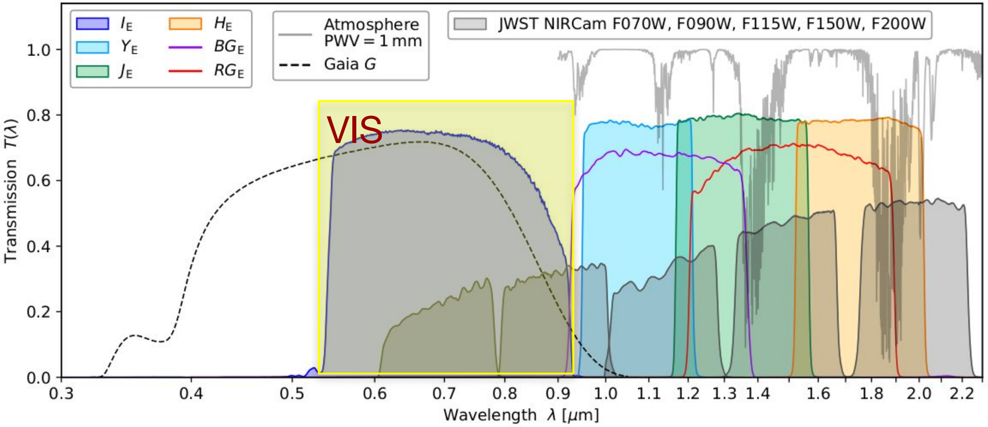
Optical layout
Credit: Airbus Defence and Space

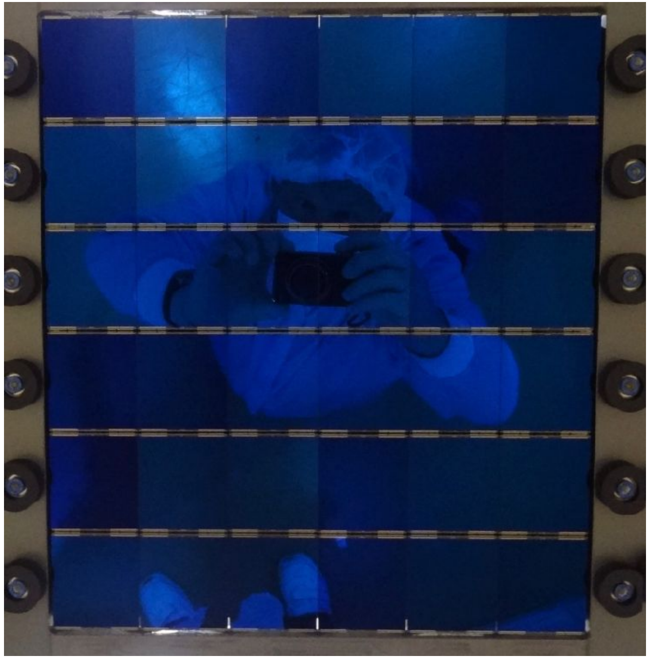


Layout of the instruments. The telescope is below, observing downwards.
Credit: Airbus Defence and Space; annotations by EC

VIS (VISible Instrument)

- Focal-plane instrument, no fore-optics
- 36 4k x 4k CCDs, 0.1” / pixel
- Readout time 72 seconds
- 530–920 nm wavelength range defined by coated mirrors, detectors, and dichroic beamsplitter
- Blade shutter
- Calibration lamp (6 wavelengths)
- Depth: 26.2 AB mag (5σ point source)

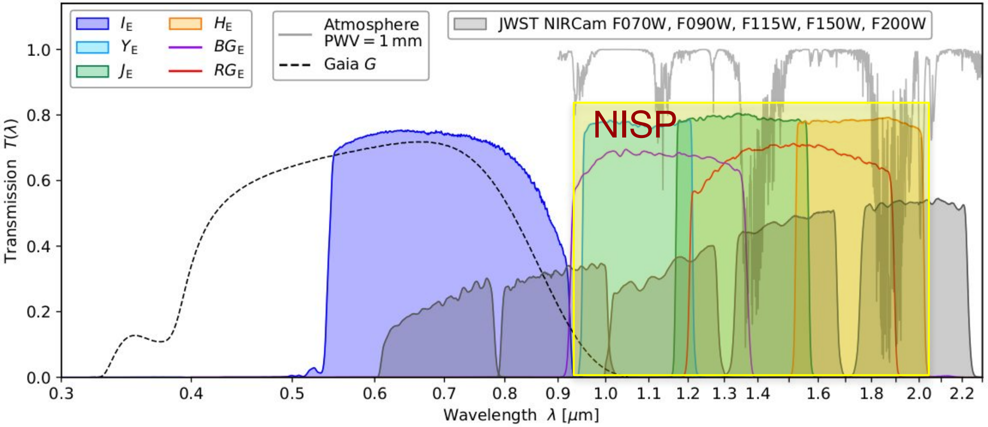


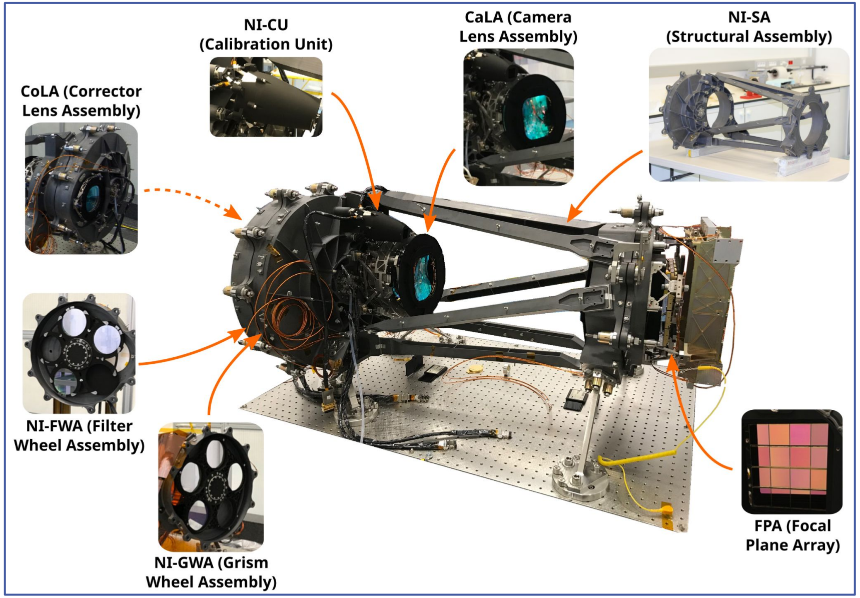


VIS instrument
Credit: EC VIS team

NISP (Near Infrared Spectrometer and Photometer)

- 16 detectors, 0.3” / pixel
- 3 photometric bands
- 2 spectroscopic bands
- Spectral resolution: R~480
- Calibration lamp (5 wavelengths)
- Depths:
  24.5 AB mag (5σ point source)
  2 10^{-16} erg/s/cm^2 (line flux)



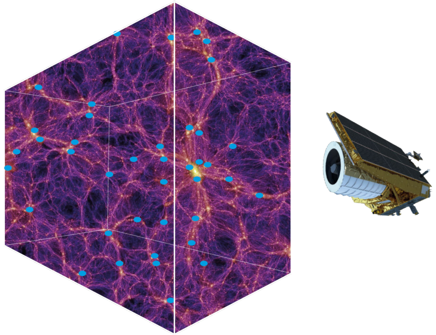


Credit: Euclid collaboration: Jahnke et al. (2024)
https://ui.adsabs.harvard.edu/abs/2024arXiv240513493E/abstract

Primary Probes

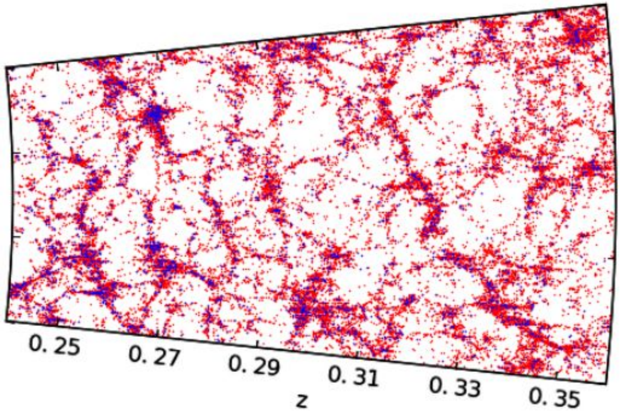
Two primary probes of the LSS

Galaxy clustering



Credit: Springel+ (2005) (Background) ESA/ATG medialab (spacecraft)

Spectroscopic



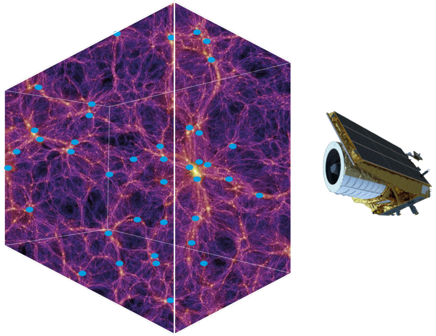
Stothert+ (2018)

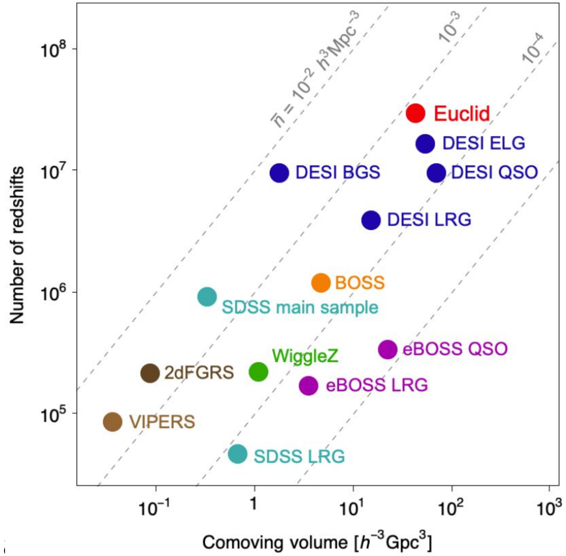
3-D position measurements of galaxies over $0.9 < z < 1.8$

- Probes expansion rate of the Universe (BAO) and growth of structure induced by gravity (RSD); expansion history, ψ potential
- Need high precision 3-D distribution of galaxies with spectroscopic redshifts
- 25M spectroscopic redshifts with 0.001 (1+z) accuracy over 14,000 deg^2

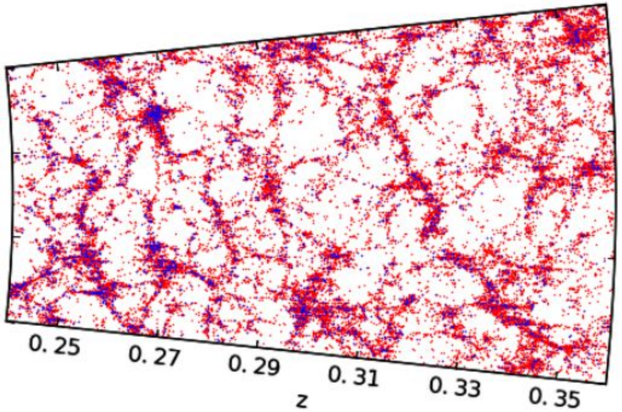
Two primary probes of the LSS

Galaxy clustering





Spectroscopic



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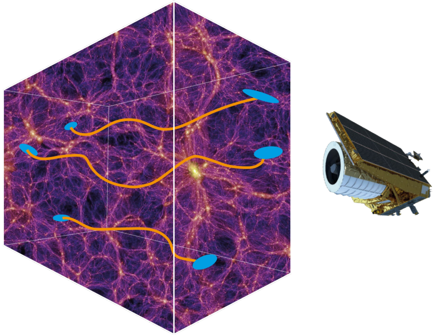
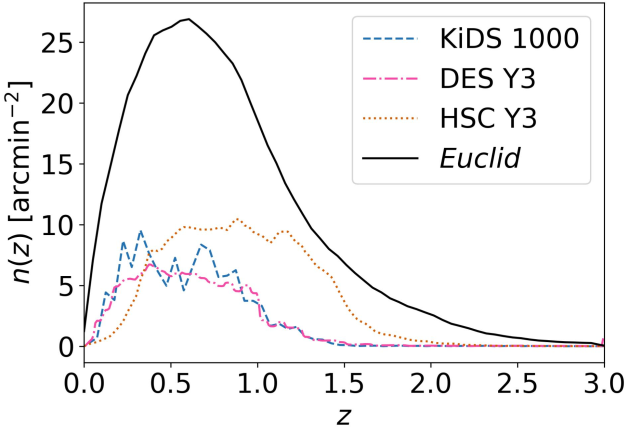
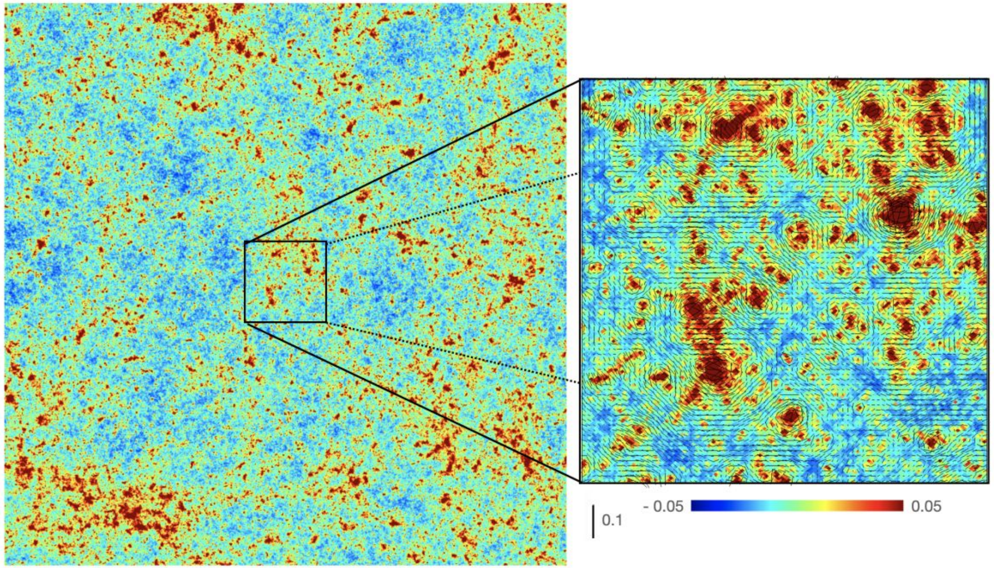
Two primary probes of the LSS

Cosmic shear





Galaxy shapes trace the L.O.S. mass distribution

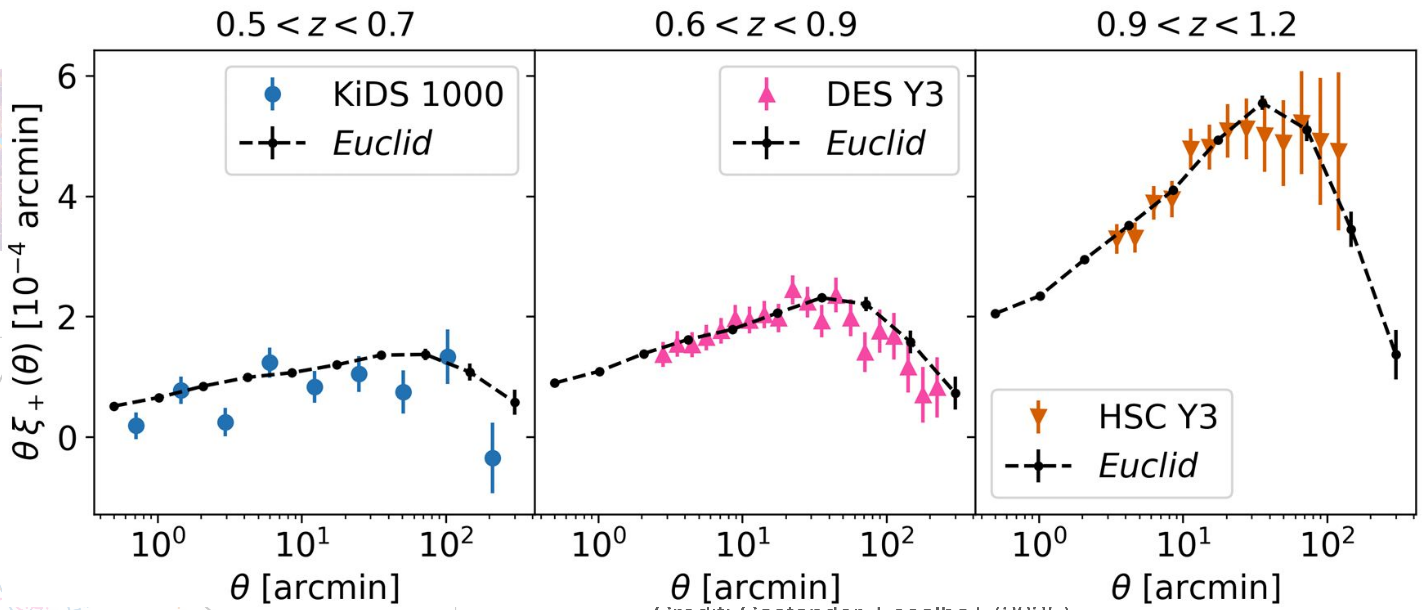


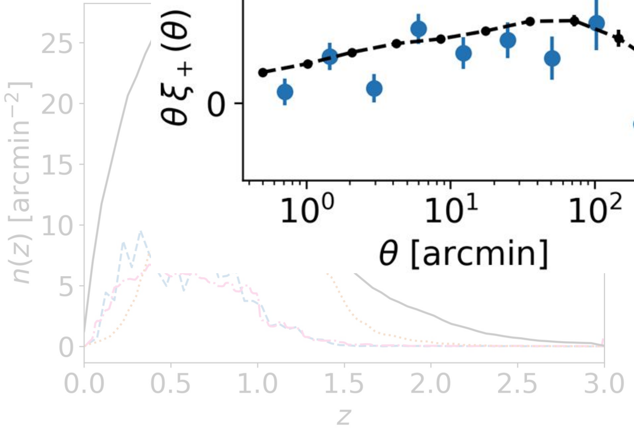
Credit: Castander, Fosalba+ (2025)

Two primary probes of the LSS

Cosmic shear

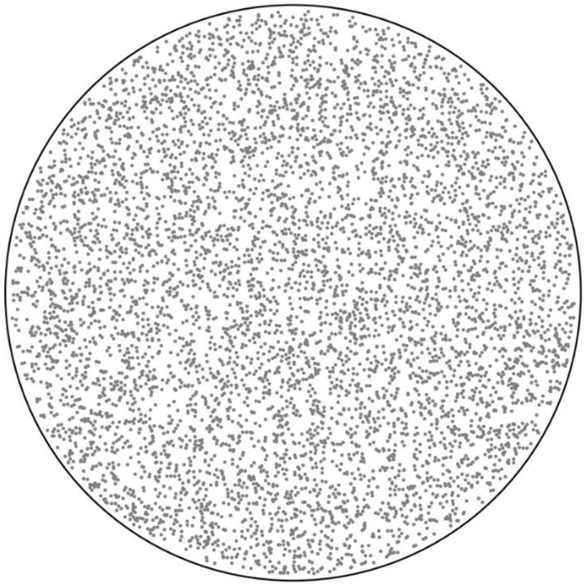
Galaxy shapes trace the L.O.S. mass distribution



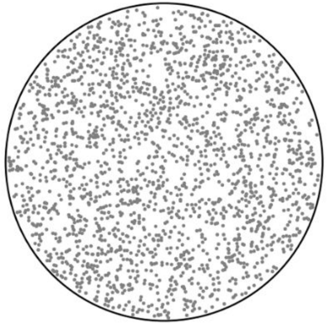


Credit: Castander, Fosalba+ (2025)

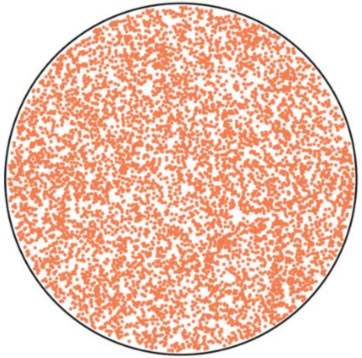
Cosmic shear: state of the art



DES Y6
4422 deg2
8.22 gal / arcmin2
152M galaxies



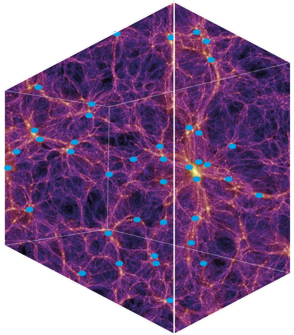
KiDS-Legacy
1347 deg2
8.79 gal / arcmin2
41M galaxies

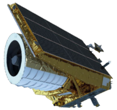


***Euclid* DR1**
1650 deg2
24.5 gal / arcmin2
150M galaxies

Two primary probes of the LSS

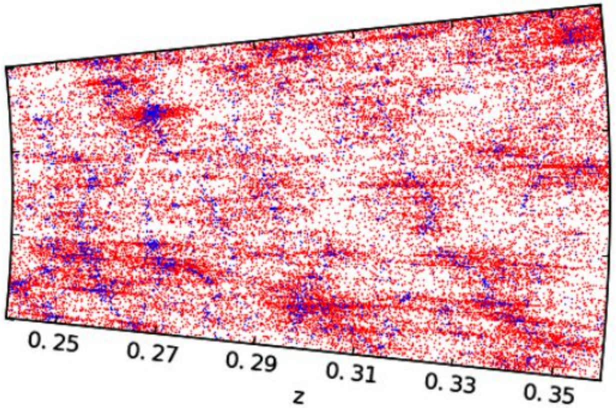
Galaxy clustering



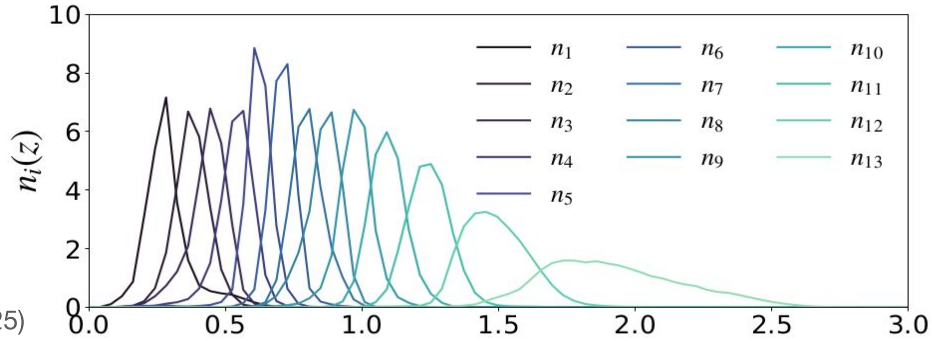


Photometric

$\sigma(z) < 0.05\,(1 + z)$

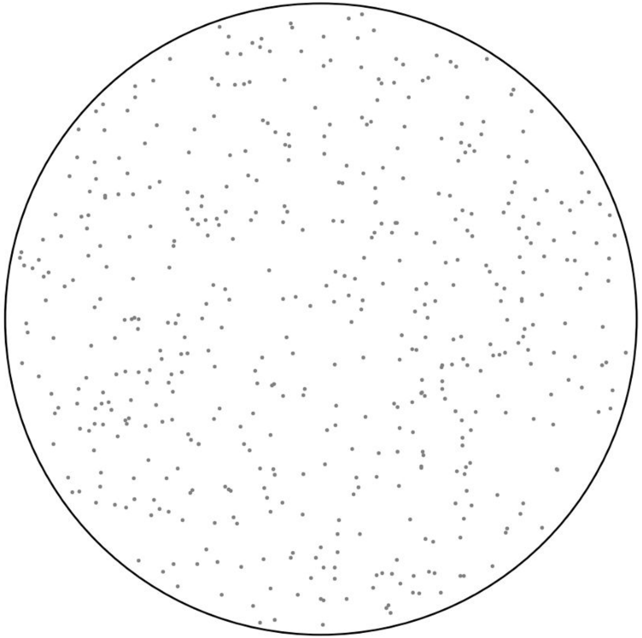


2D angular distribution in tomographic bins

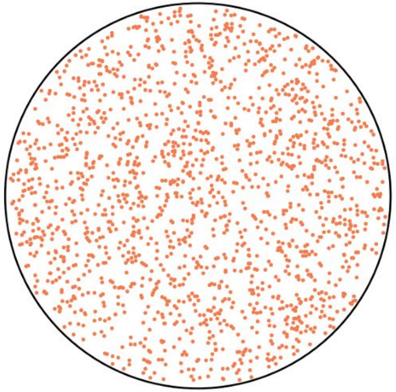


Credit: Mellier+ (2025)

Photo-z clustering: state of the art



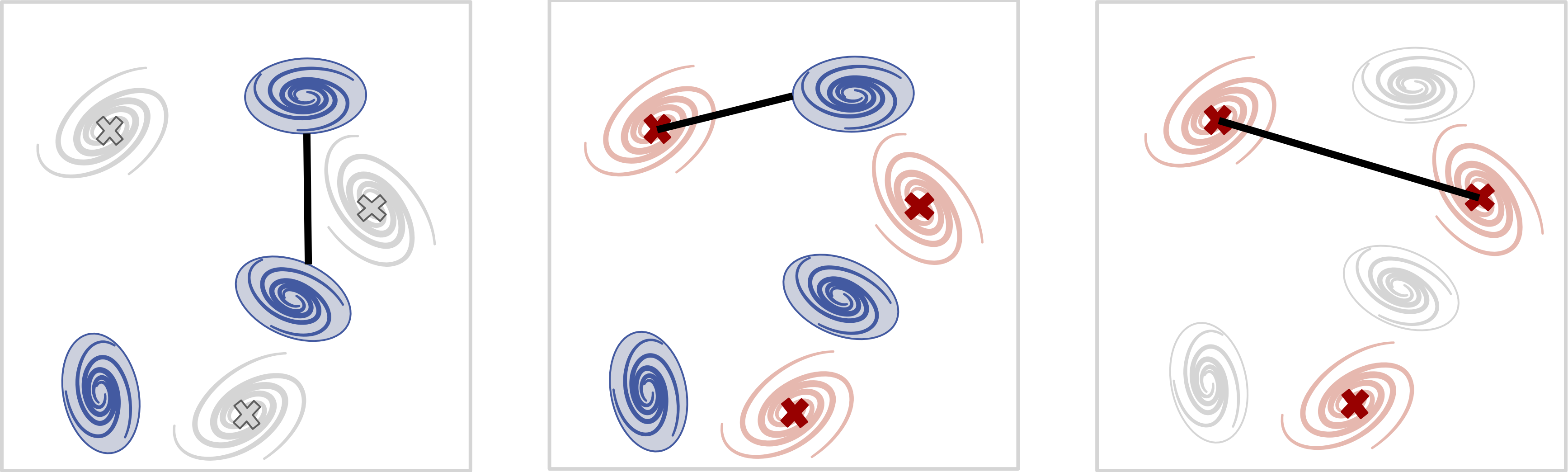
DES Y6 MagLim++
4422 deg2
0.63 gal / arcmin2
10M galaxies



***Euclid* DR1**
1650 deg2
5.7 gal / arcmin2
35M galaxies

3 x 2-pt analyses

Shape-Shape	**Position-Shape**	**Position-Position**
'Cosmic shear'	*'Galaxy-galaxy-lensing'*	*'Angular clustering'*



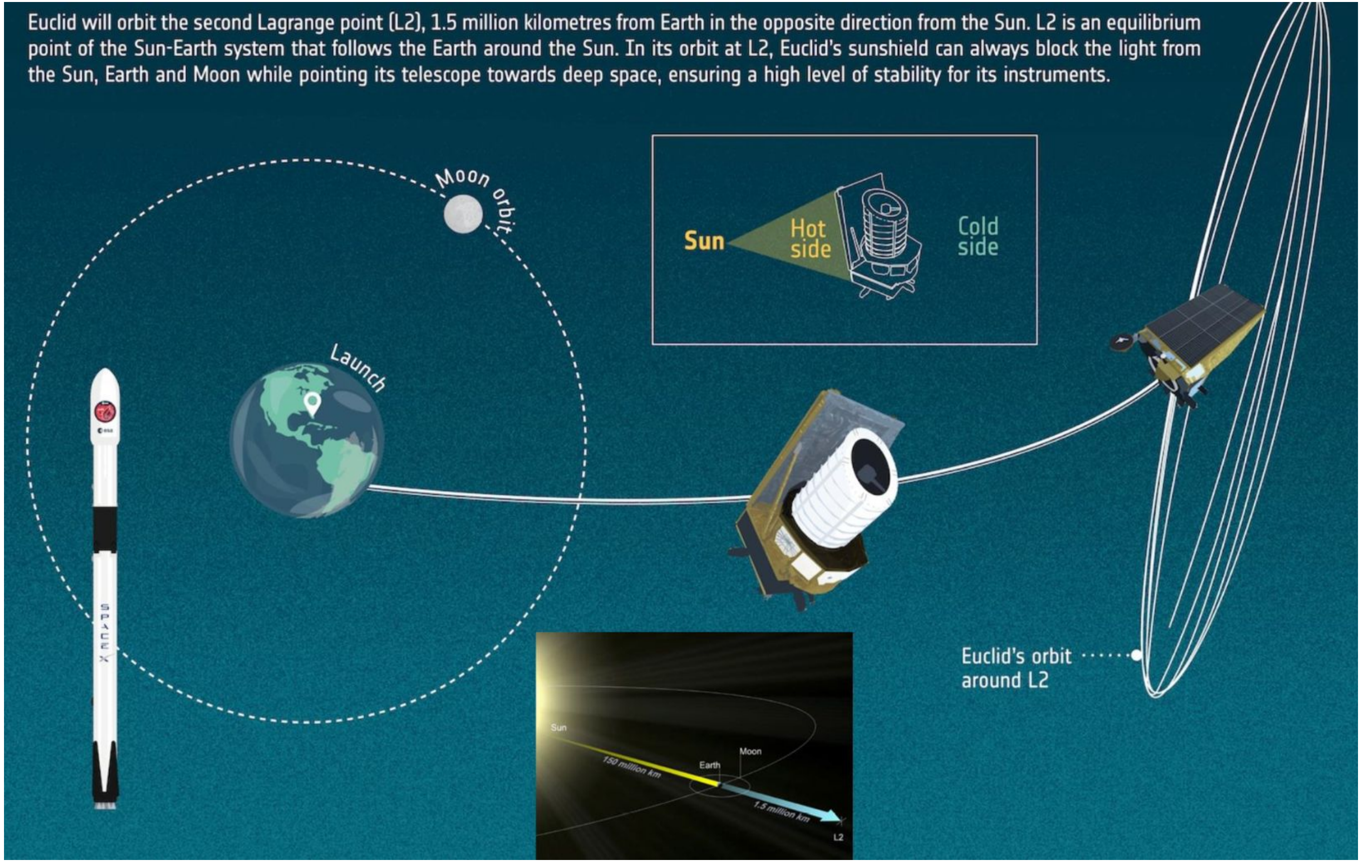
We combine **3** types of **2-pt correlations** to optimally **constrain cosmology from the photometric galaxy sample**

Launch

Euclid Launch

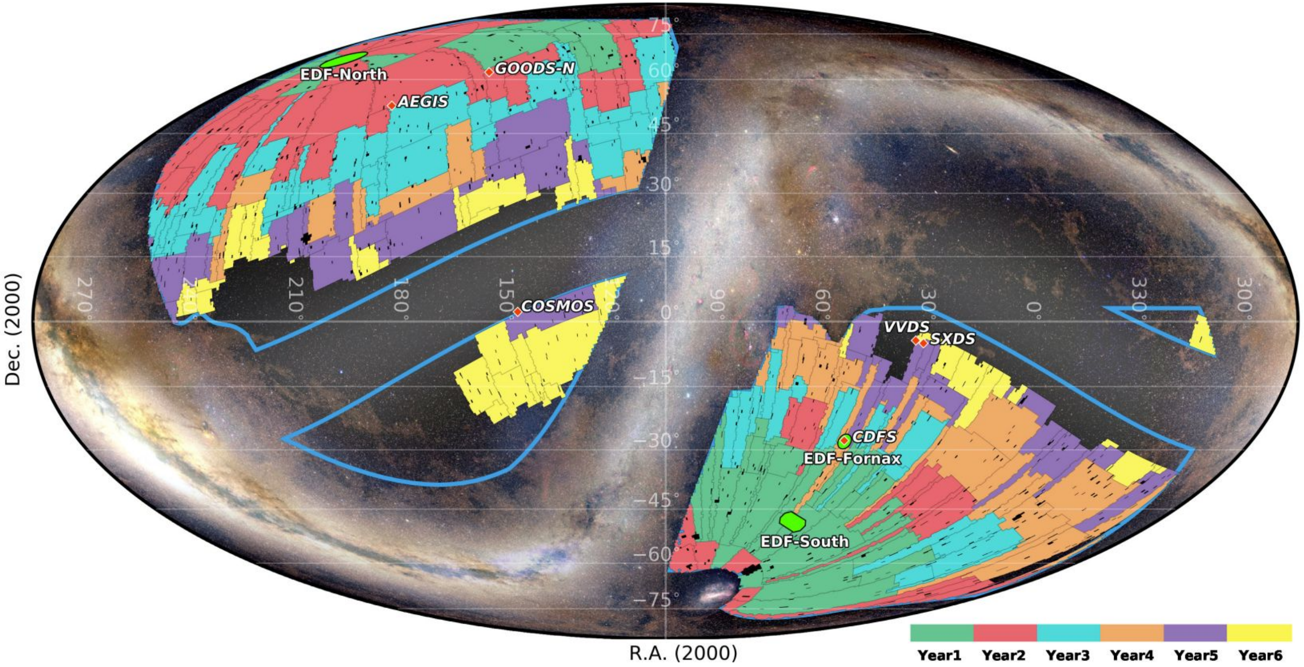
Euclid launched on a Falcon 9, SpaceX, on **1st July 2023**, from Cape Canaveral. Credit: ESA

Euclid Journey to L2



Survey

Euclid Wide Survey



- Duration: 6 years survey
- Euclid will observe 10 deg^2/day of the Euclid Wide Survey
- 12% of Euclid time is spent on Euclid Deep Survey

Euclid Wide Survey

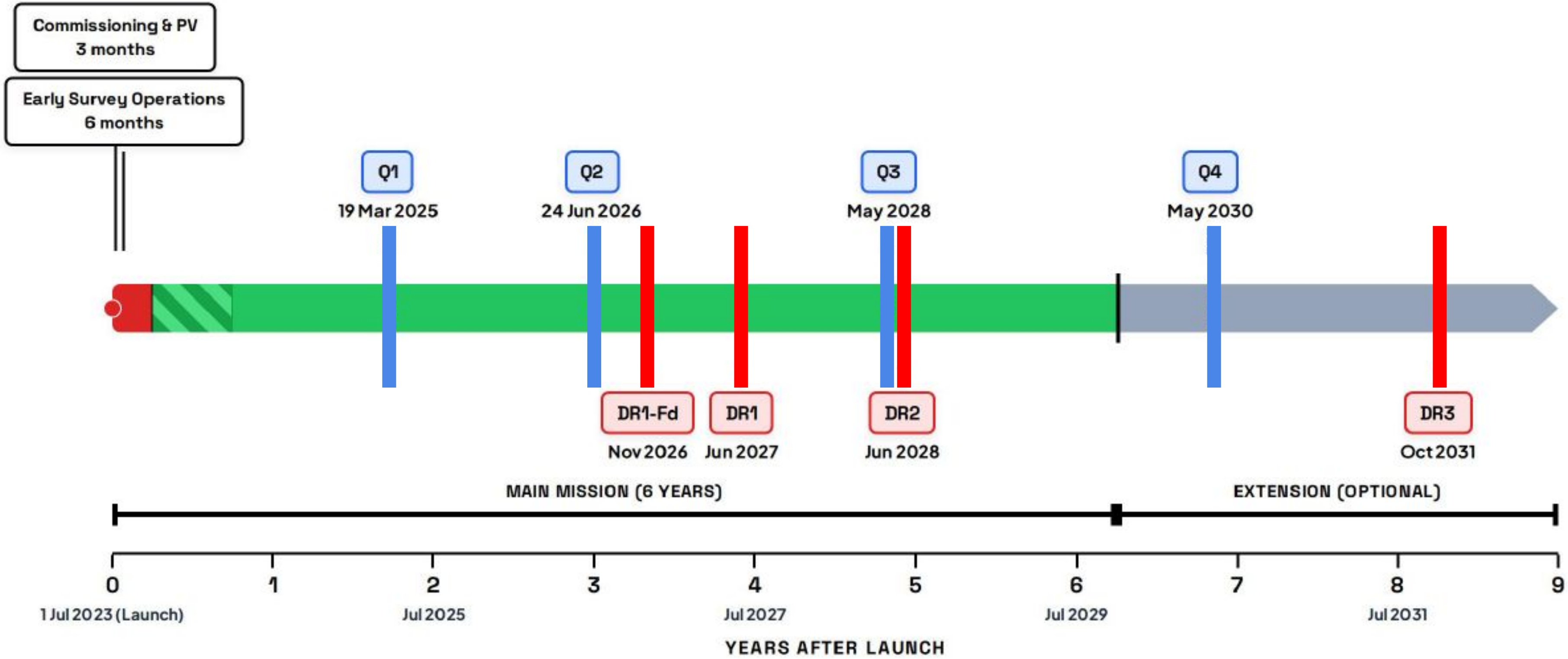
- 14000 deg^2
- 1.5B gal with photometric redshift and shape measurement (n_g = 30 gal/arcmin^2)
- 25M of galaxies with spectroscopic redshift

Euclid Deep Survey

- n_g = 50 gal/arcmin^2
- 3 fields
  - EDF-N: 23 deg^2
  - EDF-S: 28 deg^2
  - EDF-F: 12 deg^2

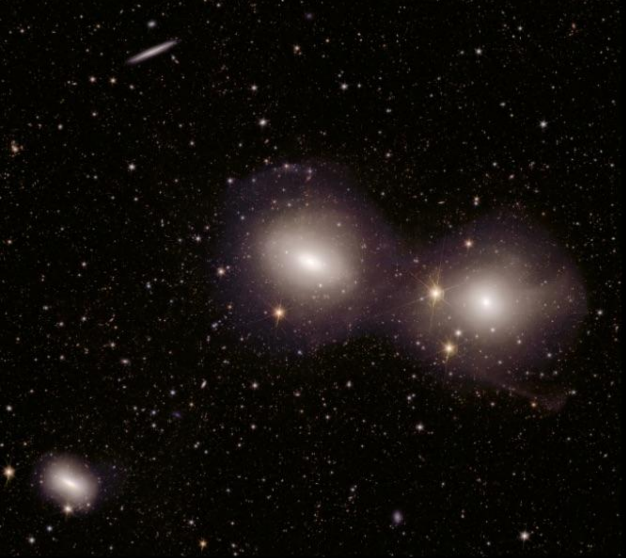
Euclid collaboration: Scaramella+, A&A 2022

Euclid Satellite Mission Timeschedule



Early Release Observations


Teaser images released in November 2023





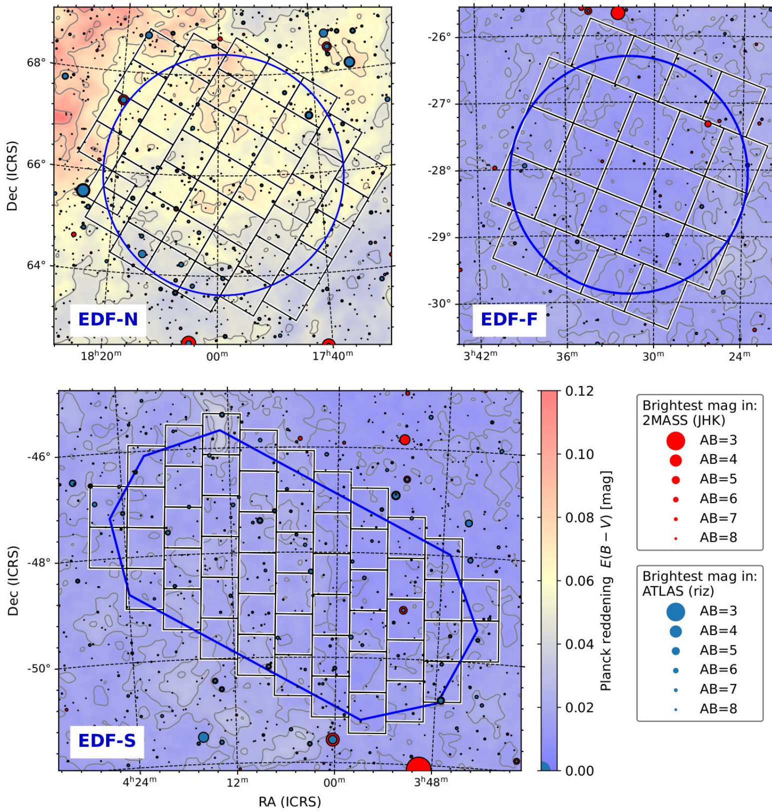
More images released in May 2024, along with a set of Early Release Observations papers

https://www.cosmos.esa.int/web/euclid/ero-papers

Q1 Data Release

Euclid Quick data release 1

- 63.1 deg²
- Approximately 26 million detections
- The release primarily aimed at a variety of astrophysical studies, providing VIS and NISP images, NISP spectroscopy, external ground-based data, catalogues, and masks
- Overview of the content of the release in “Euclid Collaboration: Aussel+, 2025”



https://www.euclid-ec.org/science/q1/

Q2 Data Release

Euclid Quick data release 2

- Euclid Bulge Galactic Survey
- 4.8 deg² over nine adjoining fields
- This dataset is an unprecedented deep, wide-field, high-resolution view of the inner bulge region of our Milky Way galaxy.
- Overview of the content of the release in “Euclid Collaboration: Beaulieu+, 2026”

https://www.euclid-ec.org/science/q2/

Cosmology with Euclid

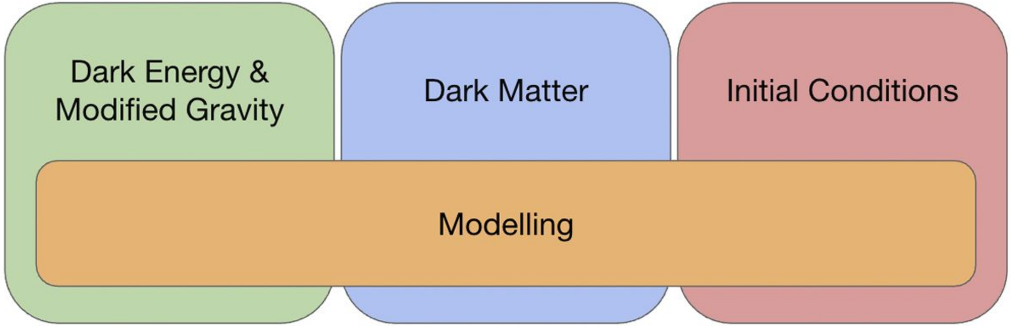
Science Working Group structure

Primary Probes SWGs (galaxy clustering and weak lensing):

- Responsible for the core measurements: cosmic shear and photometric/spectroscopic galaxy clustering.
- They deliver *Euclid* constraints on ΛCDM model and simplest extensions.

The Theory Working Group (TWG)

- Delivering *Euclid* constraints on extended cosmological models, beyond the standard ΛCDM baseline.



https://github.com/cloe-org

Constraints on DE and MG

Dynamical Dark energy

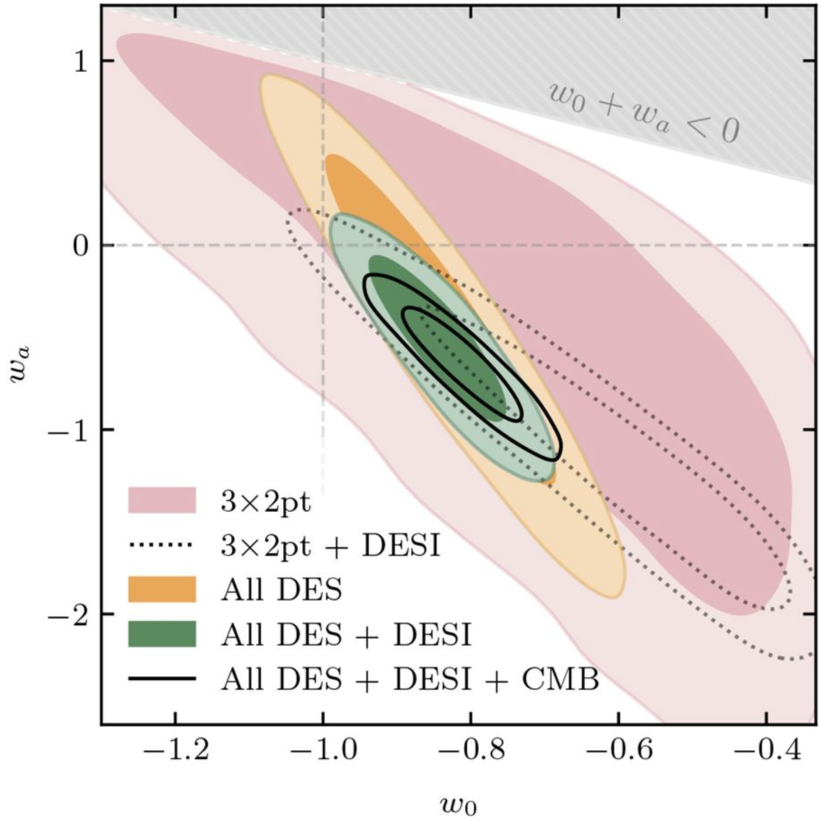
The dark energy component might not be a cosmological constant Λ:

$$w(z) \equiv \frac{\mathcal{P}}{\rho} = w_o + w_a \frac{z}{1+z}$$

Individual datasets are well fitted by ΛCDM but their combination shows hints of departure. In particular a non statistical evidence for inconsistency between low-z probes and CMB.

The evidence for w0waCDM is now less significant, up to ≲ 3-3.4 sigma.

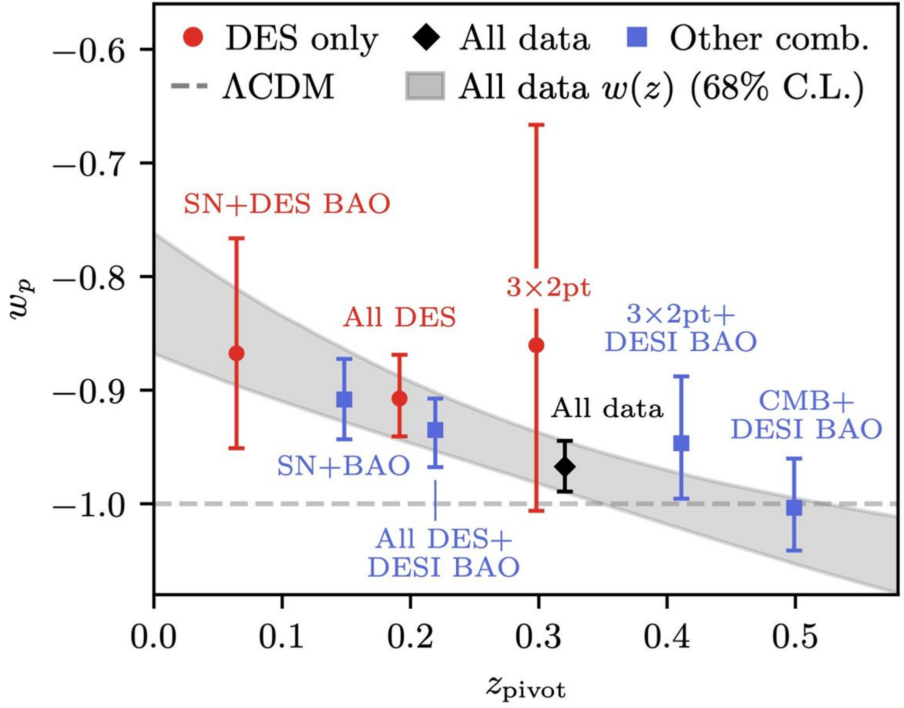
DESY6, arXiv:2605.27221



Dynamical Dark energy

DESY6, arXiv:2605.27221

Datasets	Distance to ΛCDM (σ)	$\Delta\chi^2$ (σ)	FoM
3×2pt	1.0	1.0	6
SN + DES BAO	1.5	1.6	11
All DES (3×2pt + SN + DES BAO)	2.2	2.0	48
All data (All DES + DESI BAO + CMB)	3.0	3.0	222
SN + BAO	2.4	2.3	61
3×2pt + DESI BAO	1.7	1.5	32
CMB + DESI BAO	2.9	2.9	61
All DES + DESI BAO (All except CMB)	2.3	2.2	110
SN + BAO + CMB (All except 3×2pt)	3.2	3.3	202
3×2pt + BAO + CMB (All except SN)	2.6	2.5	66
3×2pt + SN + CMB (All except BAO)	2.4	2.4	96
All DES + CMB (All except DESI BAO)	2.8	2.8	102

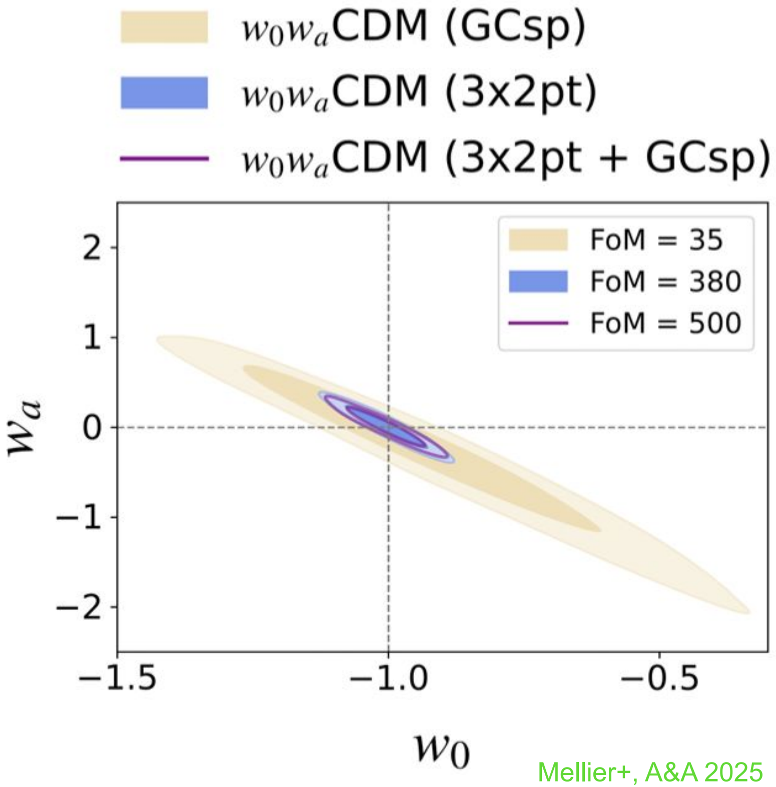


Dynamical Dark energy

Very precise constraints on the nature of dark energy:

- *Euclid* alone will be two times more precise than combined current constraints

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



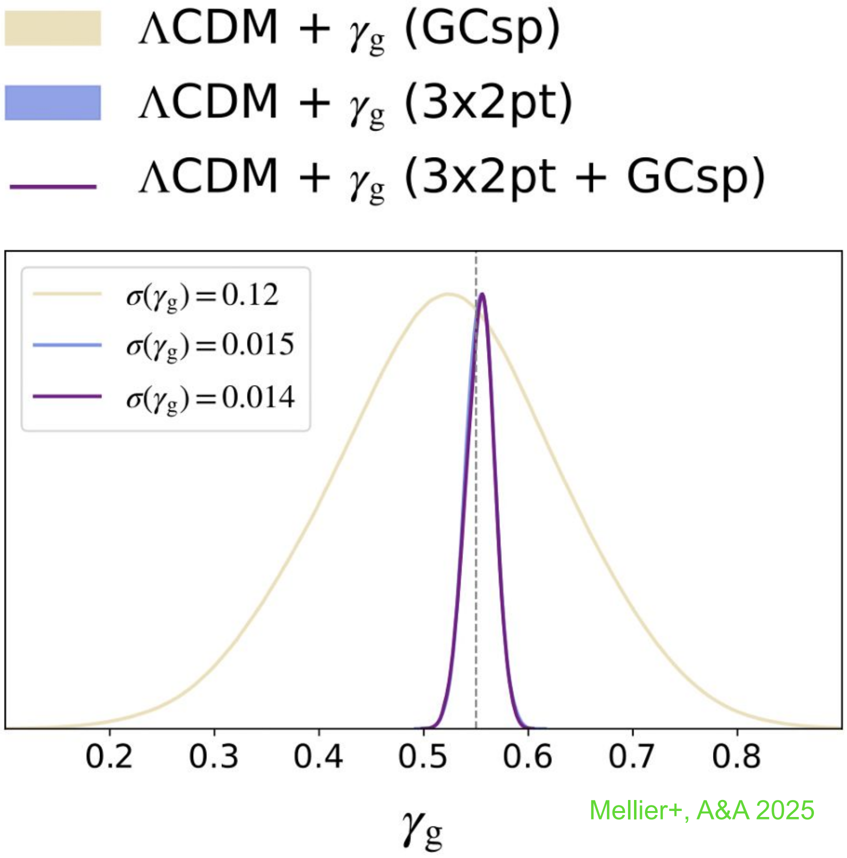
Mellier+, A&A 2025

Modified Gravity

Euclid will allow us to constrain modified gravity:

- Linear growth rate of matter perturbations

$$f_{\mathrm{g}}(z) \equiv \frac{\mathrm{d}\ln g_+(z)}{\mathrm{d}\ln a} \simeq [\Omega_{\mathrm{m}}(z)]^{\gamma_{\mathrm{g}}}$$



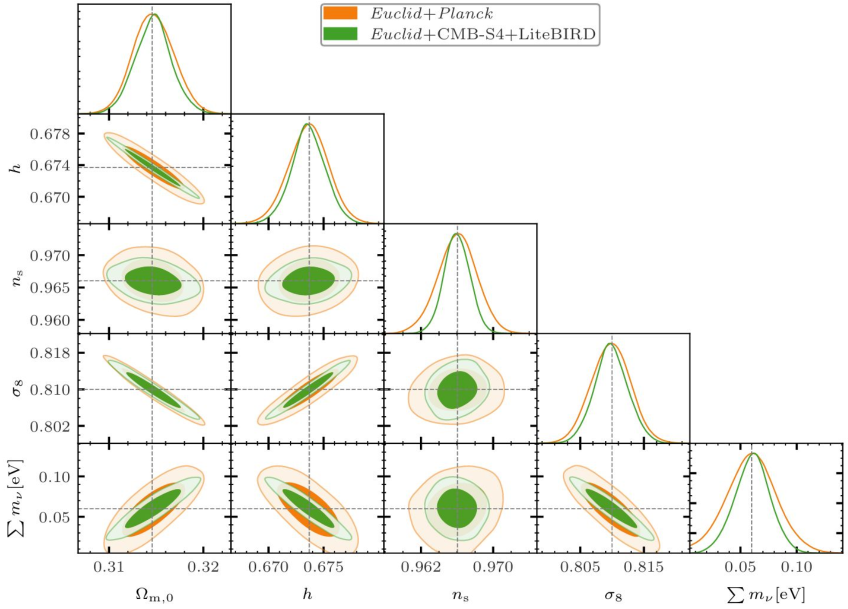
Mellier+, A&A 2025

Constraints on Particle Cosmology

Sensitivity to Neutrino Parameters

Euclid will also help us test neutrinos and other particles beyond the standard model:

- Neutrino sensitivity of *Euclid* alone: 56 meV (in ΛCDM)
  - *Euclid* + *Planck*: 23 meV
  - Evidence for a non-zero neutrino mass at 2.6 sigma (4 sigma with future data)



Euclid Collaboration: Archidiacono+, A&A 2025

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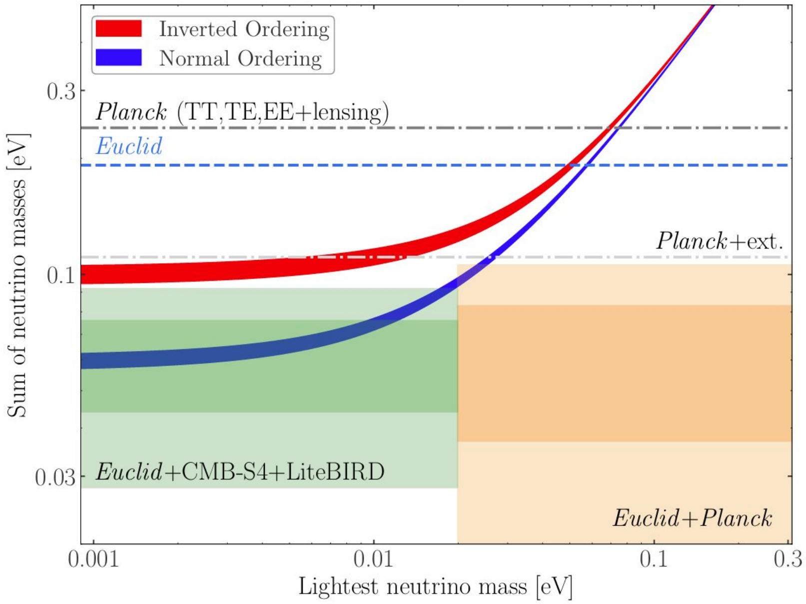
- If the true sum of neutrino masses is 0.06 eV (normal ordering), *Euclid* + future CMB data will rule out inverted ordering at 2.5 sigma



Euclid Collaboration: Archidiacono+, A&A 2025

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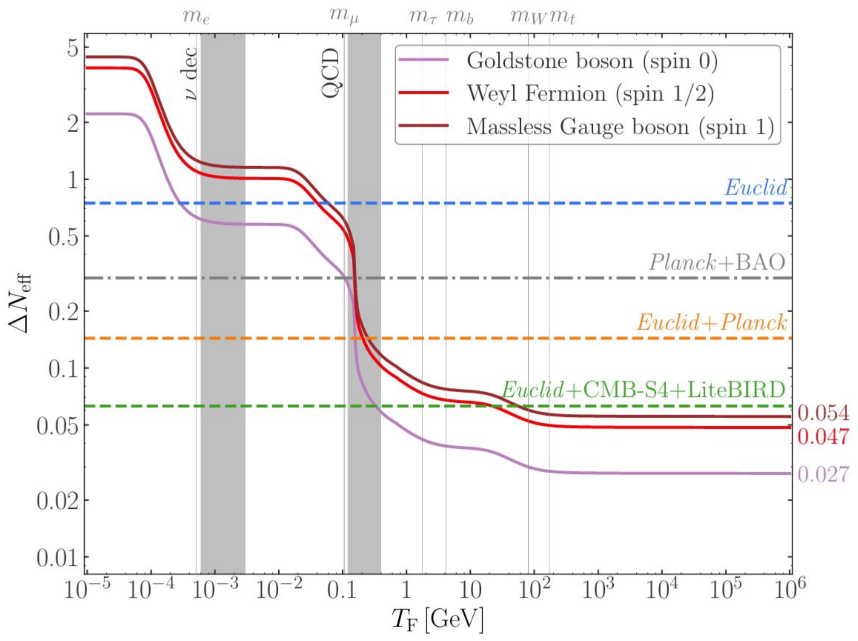
    - *Euclid* + *Planck*: 23 meV
    - Evidence for a non-zero neutrino mass at 2.6 sigma (4 sigma with future data)
- If the true sum of neutrino masses is 0.06 eV (normal ordering), *Euclid* + future CMB data will rule out inverted ordering at 2.5 sigma
- Adding *Euclid* improves the current limit on the presence of new light particles by more than a factor 2



Euclid Collaboration: Archidiacono+, A&A 2025

Constraints on Initial Conditions

Primordial Power Spectrum

Single-field slow-roll inflation predicts an almost scale-invariant power spectrum:

$$\mathcal{P}_{\mathcal{R}}(k) \equiv \frac{k^3}{2\pi^2}|\mathcal{R}(k)|^2 = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1}$$

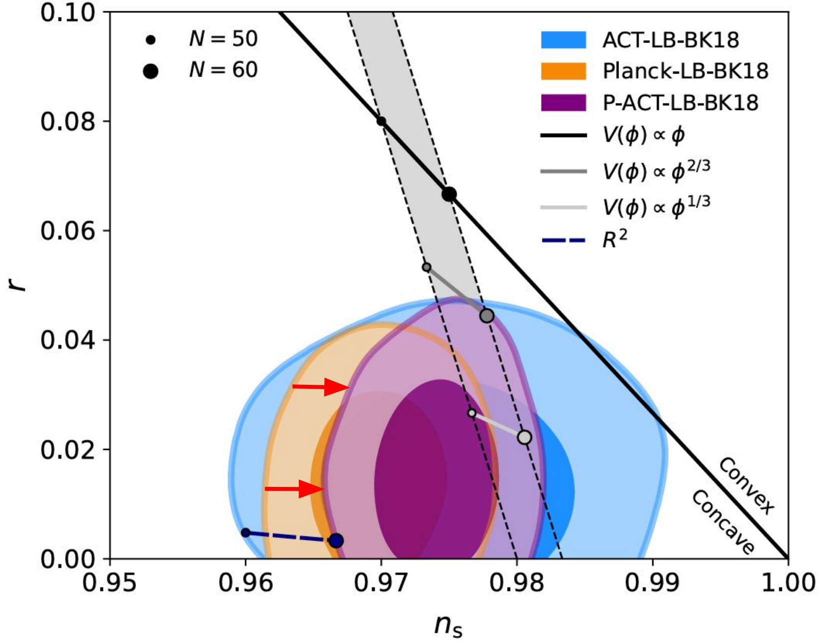
$$n_s = 0.9743 \pm 0.0034$$

[68% CL, *Planck*+ACT+DESI]

The results from *Planck* + BICEP/Keck, when combined with ACT and/or DESI BAO, suggest a larger value for the scalar spectral index

Ferreira+, PRD 2026

ACT Collaboration, JCAP 2025



Primordial Power Spectrum

Single-field slow-roll inflation predicts an almost scale-invariant power spectrum:

$$\boxed{\mathcal{P}_{\mathcal{R}}(k) \equiv \frac{k^3}{2\pi^2}|\mathcal{R}(k)|^2 = A_s\left(\frac{k}{k_*}\right)^{n_s-1}}$$

$$\ln(10^{10}A_s) = 3.044 \pm 0.014$$
$$n_s = 0.9649 \pm 0.0042$$

[68% CL, *Planck*]

Euclid Collaboration: Blanchard+, A&A 2020

All probe combination GC_s+WL+GC_{ph}+$XC^{(GC_{ph},WL)}$									
Setting	$\Omega_{m,0}$	$\Omega_{b,0}$	$\Omega_{DE,0}$	w_0	w_a	h	n_s	σ_8	γ
ΛCDM flat									
Pessimistic	0.0067	0.025	–	–	–	0.0036	0.0049	0.0031	–
Optimistic	0.0025	0.011	–	–	–	0.0011	0.0015	0.0012	–
w_0, w_a flat									
Pessimistic	0.0110	0.035	–	0.036	0.15	0.0053	0.0053	0.0049	–
Optimistic	0.0060	0.015	–	0.025	0.091	0.0015	0.0019	0.0022	–

- The forecasted uncertainties correspond to 0.0051–0.0014
- Reduced by factors of 2 (1.3) and 2.7 (1.5) when combined with *Planck* or SO

Euclid Collaboration: Ilic+, A&A 2022

Primordial Power Spectrum - Running

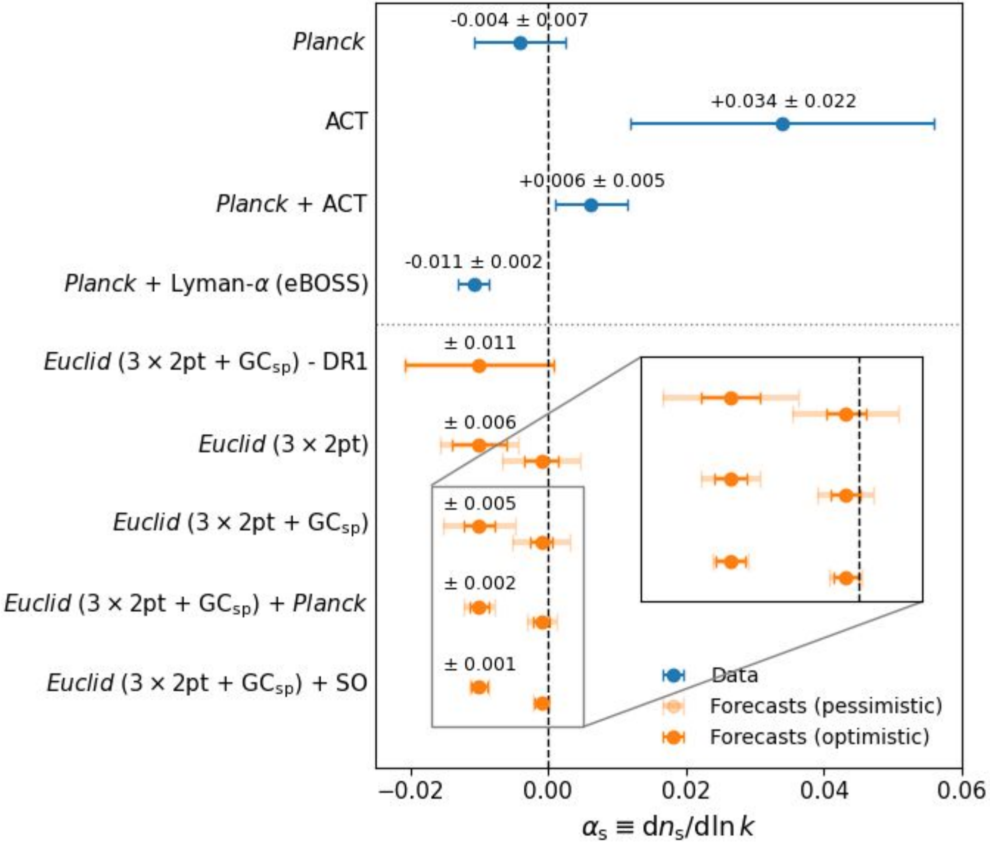
$$\boxed{\mathcal{P}_{\mathcal{R}}(k) = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1+\frac{1}{2}\alpha_{\rm s}\ln(k/k_*)}}$$

$$\alpha_{\rm s} \simeq -\epsilon_2(2\epsilon_1 + \epsilon_3)$$

Single-field slow-roll inflationary models (in agreement with cosmological data) have a precise prediction for the running of the scalar spectral index:

$$|\alpha_{\rm s}| \sim 10^{-4}\text{–}10^{-3}$$

Martin, Ringeval, Vennin, EPL 2024



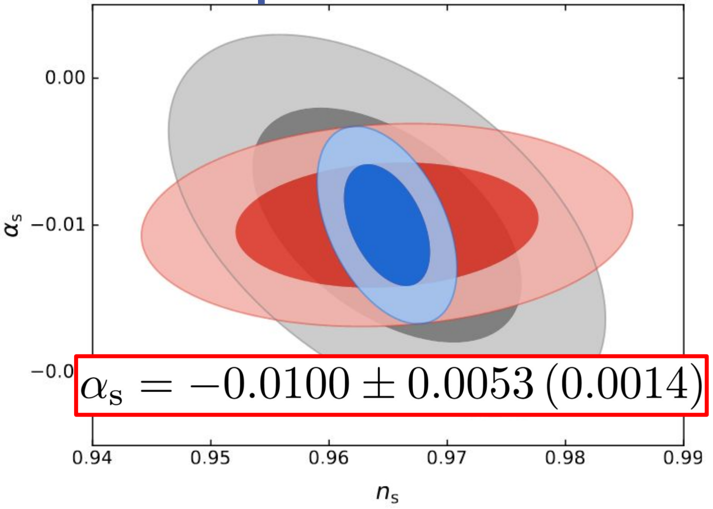
Primordial Power Spectrum - Running

$$\boxed{\mathcal{P}_{\mathcal{R}}(k) = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1+\frac{1}{2}\alpha_{\rm s}\ln(k/k_*)}}$$

$$n_s = 0.9659 \pm 0.0040$$
$$\mathrm{d}n_s/\mathrm{d}\ln k = -0.0041 \pm 0.0067$$

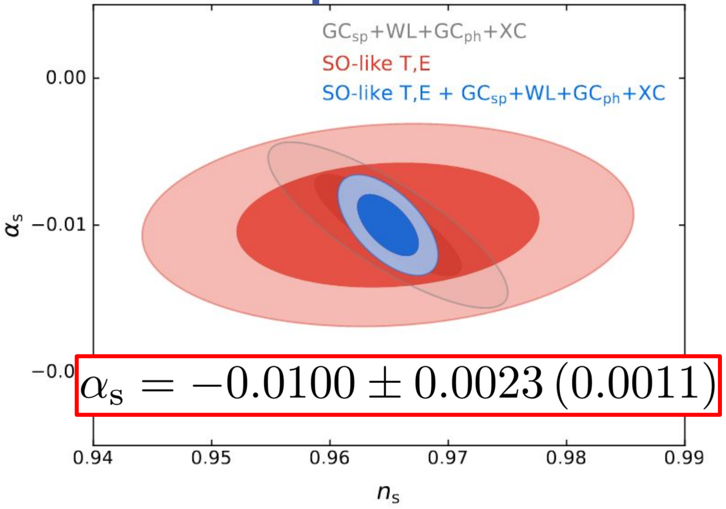
[68% CL, *Planck*]

pessimistic



$$\boxed{\alpha_{\rm s} = -0.0100 \pm 0.0053\,(0.0014)}$$

optimistic



$$\boxed{\alpha_{\rm s} = -0.0100 \pm 0.0023\,(0.0011)}$$

Euclid Collaboration: Finelli+, 2025

Features in the Primordial Power Spectrum

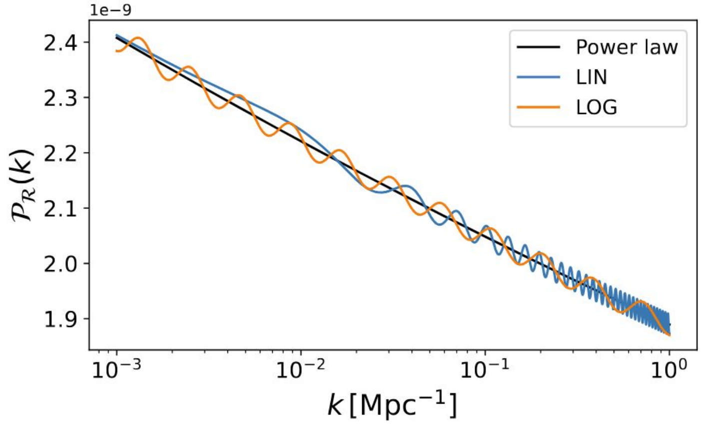
For a single clock:

- Excitations in time (changing equation-of-state during inflation at fixed time or speed of sound change) lead to linear oscillations (also known as sharp feature).
  Starobinsky, SJETPL 1992
  Adams, Cresswell, Easther, PRD 2001
  Chen, Easther, Lim, JCAP 2007
  Achucarro+, JCAP 2011

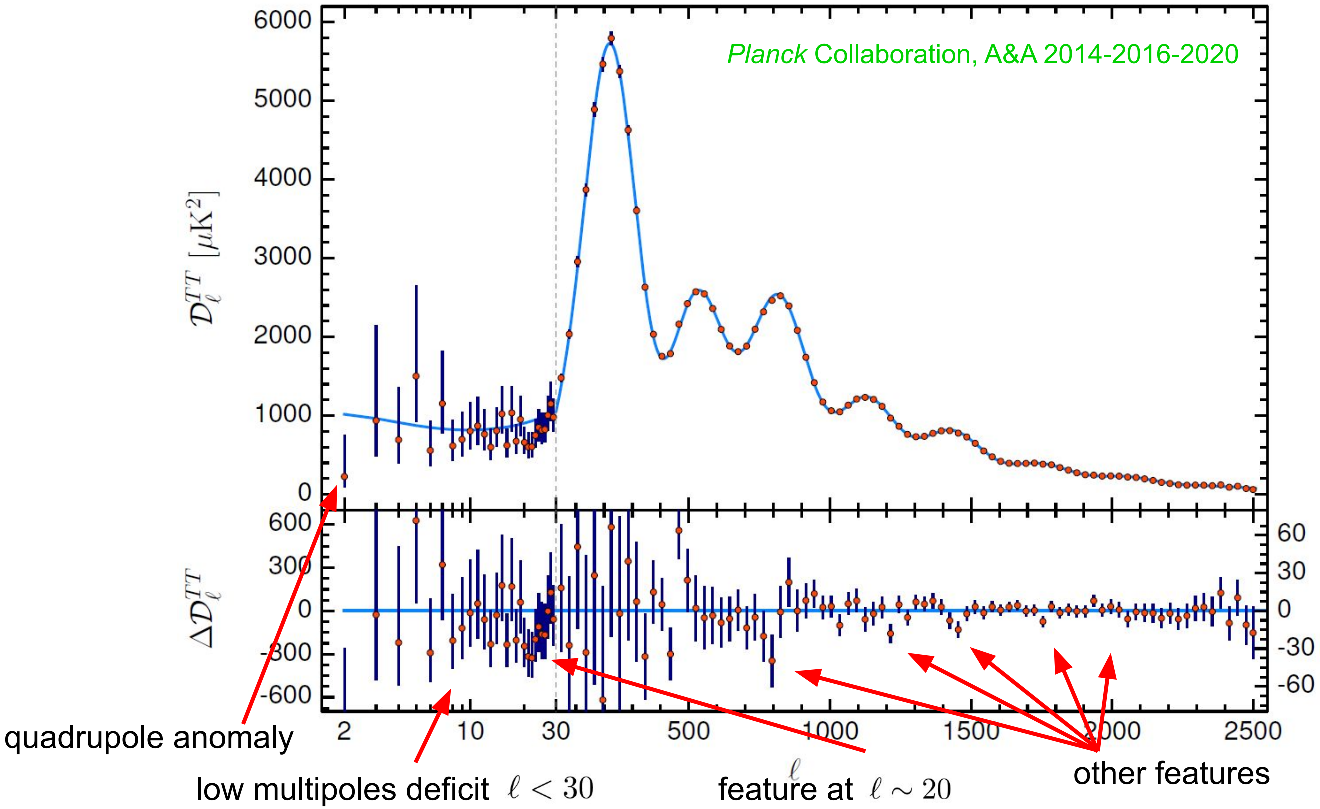
- Excitations in scale (oscillatory potential or initial state modifications at some fixed scale) lead to logarithmic oscillations (also known as resonant model).
  Chen, Easther, Lim, JCAP 2008
  Chen, JCAP 2012

$$\mathcal{P}_{\mathcal{R}}(k) = \mathcal{P}_{\mathcal{R},0}(k)\left[1 + \delta P^{\mathrm{X}}(k)\right]$$

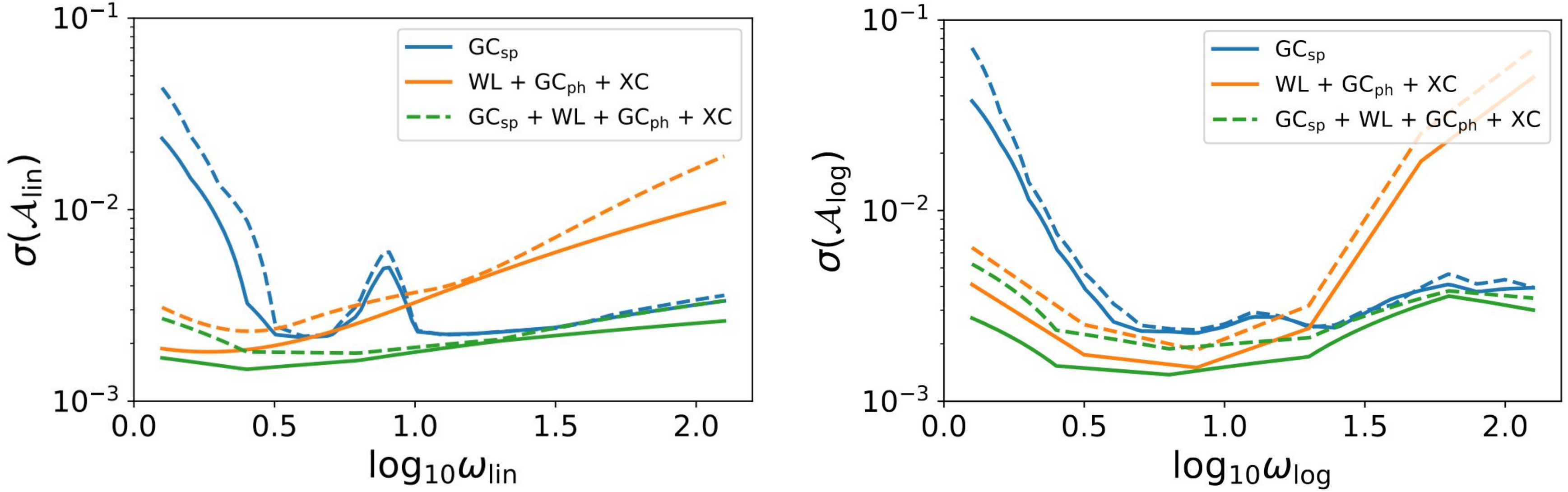
$$\boxed{\delta P^{\mathrm{X}}(k) = \mathcal{A}_{\mathrm{X}} \sin\left(\omega_{\mathrm{X}} \Xi_{\mathrm{X}} + 2\pi\phi_{\mathrm{X}}\right)}$$



Features in the CMB temperature APS

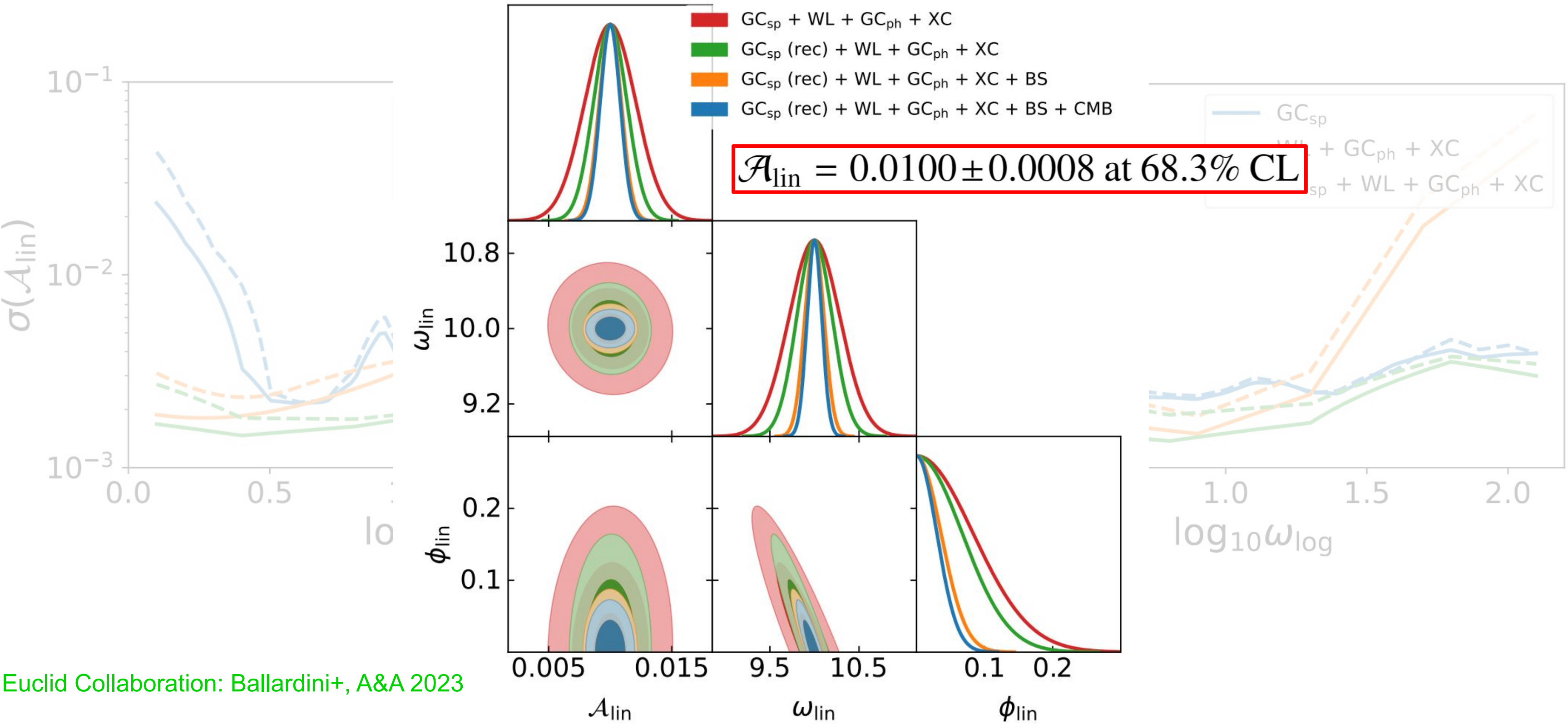


Forecasts for oscillatory features



Euclid Collaboration: Ballardini+, A&A 2023

Forecasts for linear features



Euclid Collaboration: Ballardini+, A&A 2023

Conclusions & outlook

Conclusions and outlook

Euclid launched on July 1st 2023, operates from L2, and is currently surveying 10 deg^2 per day

The goal is to map one third of the sky (14000 deg^2), first data release in June 2027 (1900 deg^2)

Euclid aims to unveil the nature of Dark Matter and Dark Energy by using weak gravitational lensing and galaxy clustering but will also be fundamental to improve our understanding on scalar initial conditions

DR1 is a demonstration: we can improve on the state of the art today.
DR2 and DR3 are where we break new ground

Euclid
consortium