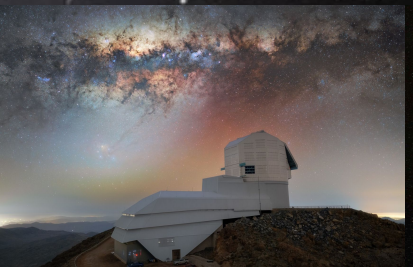
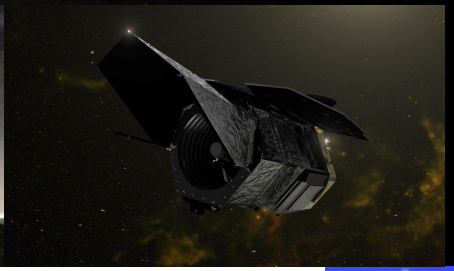
Weak lensing: what's next?

Isaac Tutusaus (Institute of Space Sciences, Barcelona)

GGI workshop: Exploring New Frontiers in Cosmology, July 2026





euclid consortium

CSIC Consejo Superior de Investigaciones Científicas | Institute of Space Sciences | Excelencia María de Maeztu | MaX Marco de Autoevaluación de la Excelencia | IEEC | irap astrophysique & planétologie | Ministerio de Ciencia, Innovación y Universidades | Cofinanciado por la Unión Europea | Agencia Estatal de Investigación

Outline

- Introduction
- Weak lensing and probe combination in *Euclid*
- Weak lensing and probe combination in *Rubin* and *Roman*
- Joint analysis of stage-IV data
- From *Euclid*'s launch to the first data release
- Conclusions

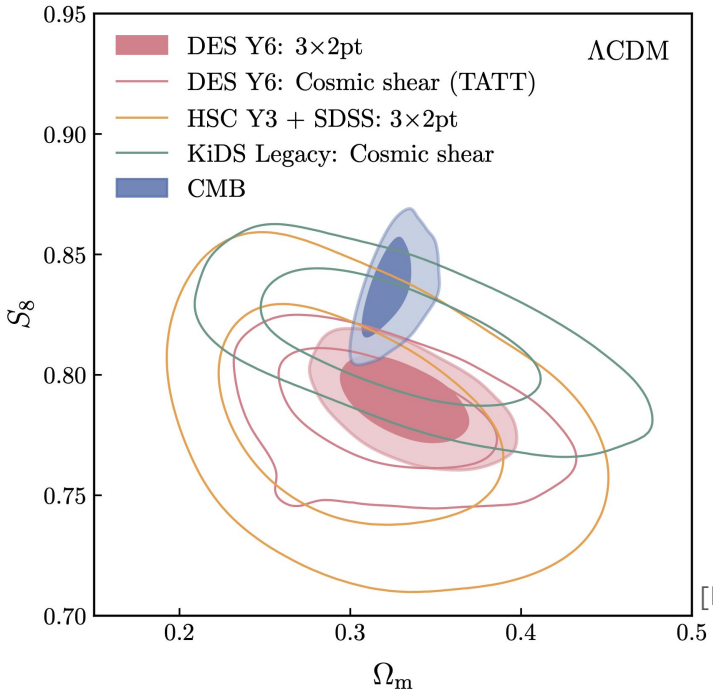
Introduction

- The **concordance model** in cosmology, LCDM, has been accurately reproducing the **main cosmological observations** for several decades

- But:
  - The **nature** of its main components, dark energy and dark matter, remains **unknown**
  - Some **tensions** start to appear
  - The latest data show preference for an **evolving dark energy**

Introduction

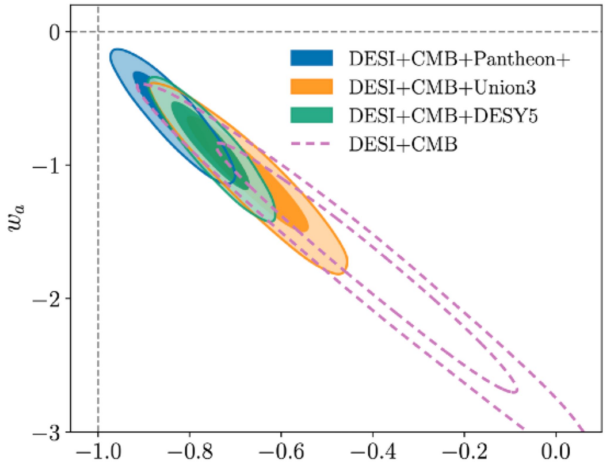
- **S8 tension**: ~2 sigma discrepancy between weak gravitational lensing and cosmic microwave background estimates



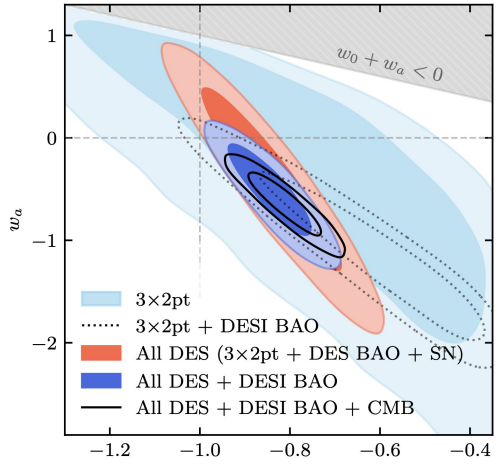
[DES Collaboration: Abbott et al. 2026]

Introduction

- **Evolving dark energy**:
  - Phenomenological approach: treat dark energy as a fluid
  - Parameterizing its equation of state parameter as $w(z) = w_0 + w_a \frac{z}{1+z}$
  - 3-4 sigma preference for evolving dark energy with the latest observations:



[DESI Collaboration: Abdul-Karim et al. 2025]



[DES Collaboration: Abbott et al. 2026]

Introduction

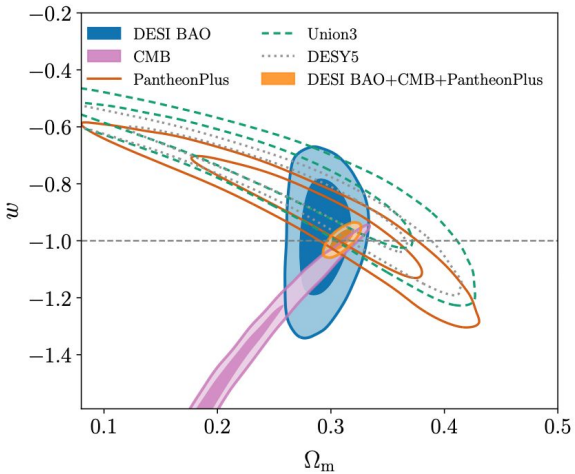
- In the coming years **observational cosmology** will reap the benefits from the **investment in large projects** to better understand the Universe

- *Euclid*:
  - Largest European project with important contributions from Canada, Japan, USA
  - Exquisite measurements to shed new light on the dark components and test gravity
  - Different cosmological probes are considered


[ESA]

Introduction

- **Combining** different **probes** is one of the most powerful ways to **constrain a cosmological model**:
  - ➢ Sensitive to different aspects of how **gravity** acts in the cosmos
  - ➢ Different **degeneracies** and **systematic** effects
- Example:



[DESI Collaboration: Adame et al. 2025]

Introduction

- In the coming years **observational cosmology** will reap the benefits from the **investment in large projects** to better understand the Universe

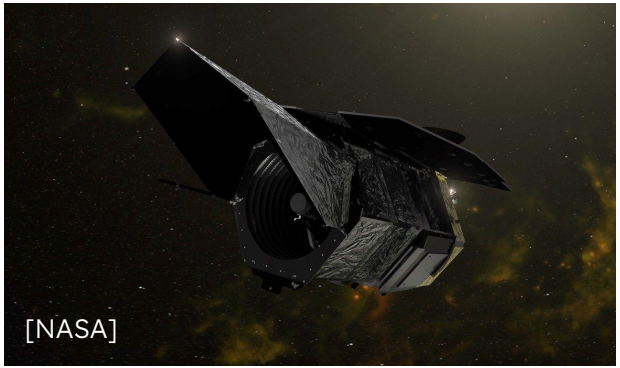
- *Vera C. Rubin* Observatory – The Legacy Survey of Space and Time:
  - Exquisite measurements to probe the dark components, the Solar System, transients, and the Milky Way
  - Main cosmological probes: galaxy clustering, weak lensing, supernovae, galaxy clusters


[NSF–DOE Vera C. Rubin Observatory/NOIRLab/SLAC/AURA/H. Stockebrand]

Introduction

- In the coming years **observational cosmology** will reap the benefits from the **investment in large projects** to better understand the Universe

- *Nancy Grace Roman* Space Telescope:
  - Exquisite measurements to probe the expansion and structure growth in the Universe, exoplanets, general astrophysics surveys
  - Main cosmological probes: galaxy clustering, weak lensing, supernovae, galaxy clusters


[NASA]

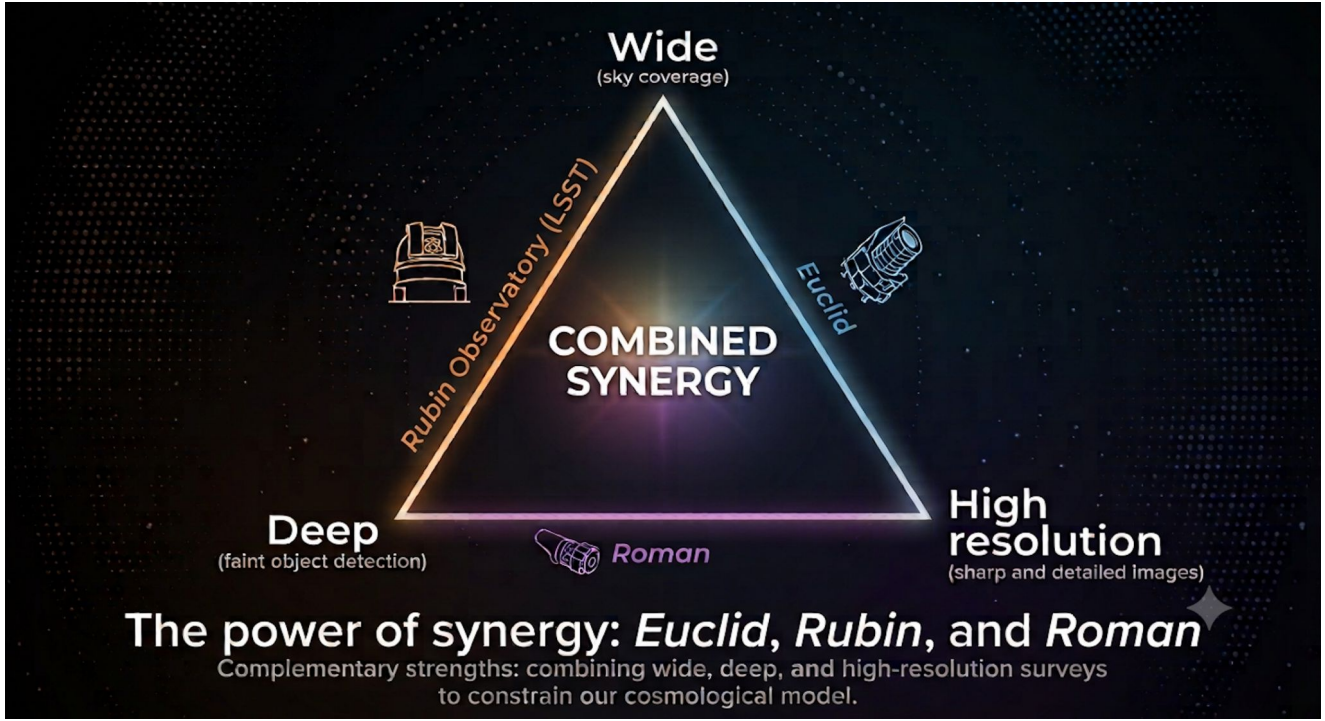
Introduction

	Rubin (LSST)	*Euclid*	*Roman*
Proposed lifetime	2026–2036	2023–2030	2026–2032
Mirror size (m)	6.5 (effective diameter)	1.2	2.4
Survey area (deg²)	~18,000	14,000	5,100
Median redshift (WL)	0.9	0.9	1.2
Depth (5σ AB mag, point source)	~27	~24 (NIR)~26 (VIS)	~27
Field of view (deg²)	9.6	0.5 (VIS)0.5 (NIR)	0.28
Filters	*u, g, r, i, z, y*	*IE, YE, JE, HE*	*F062, F087, F106, F129, F158, F184, F213, F146*
PSF size	~0.7″	~0.2″ (VIS)	~0.2″ (NIR)
Observing mode	Photometry	Photometry + Grism	Photometry + Grism

Note: Values should only be taken as indicative and may still change

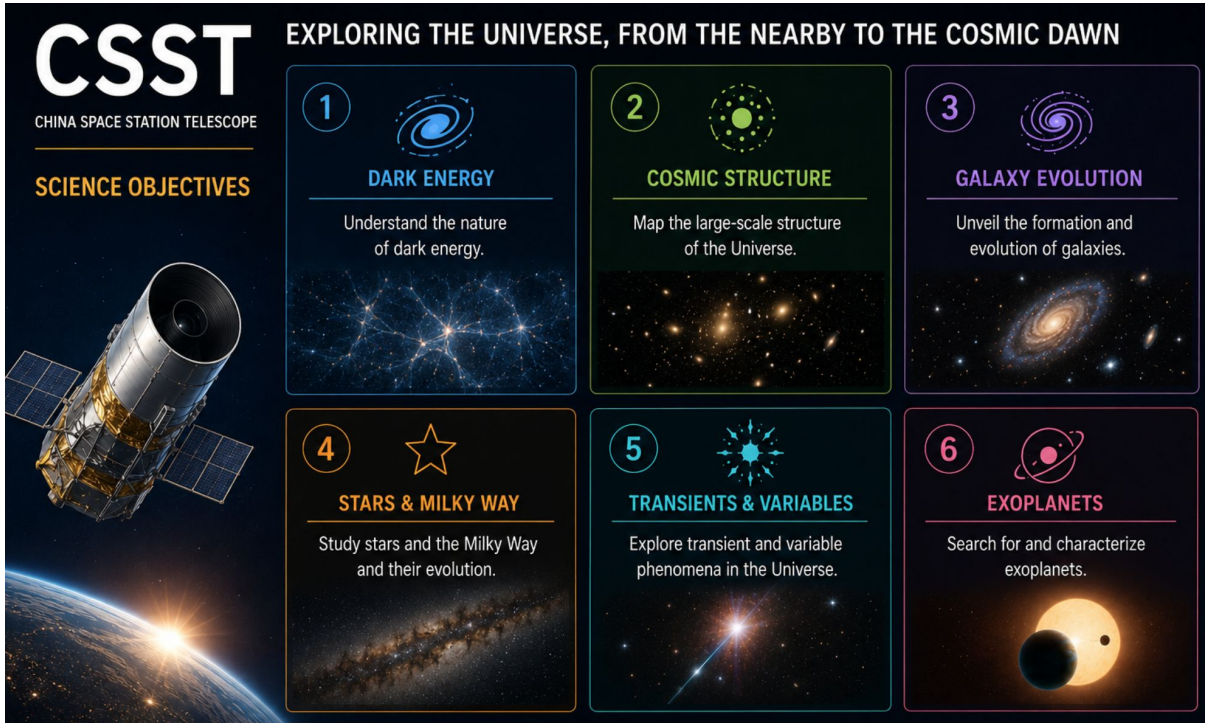
Introduction

- Stage-IV photometric galaxy survey trifecta:



Introduction

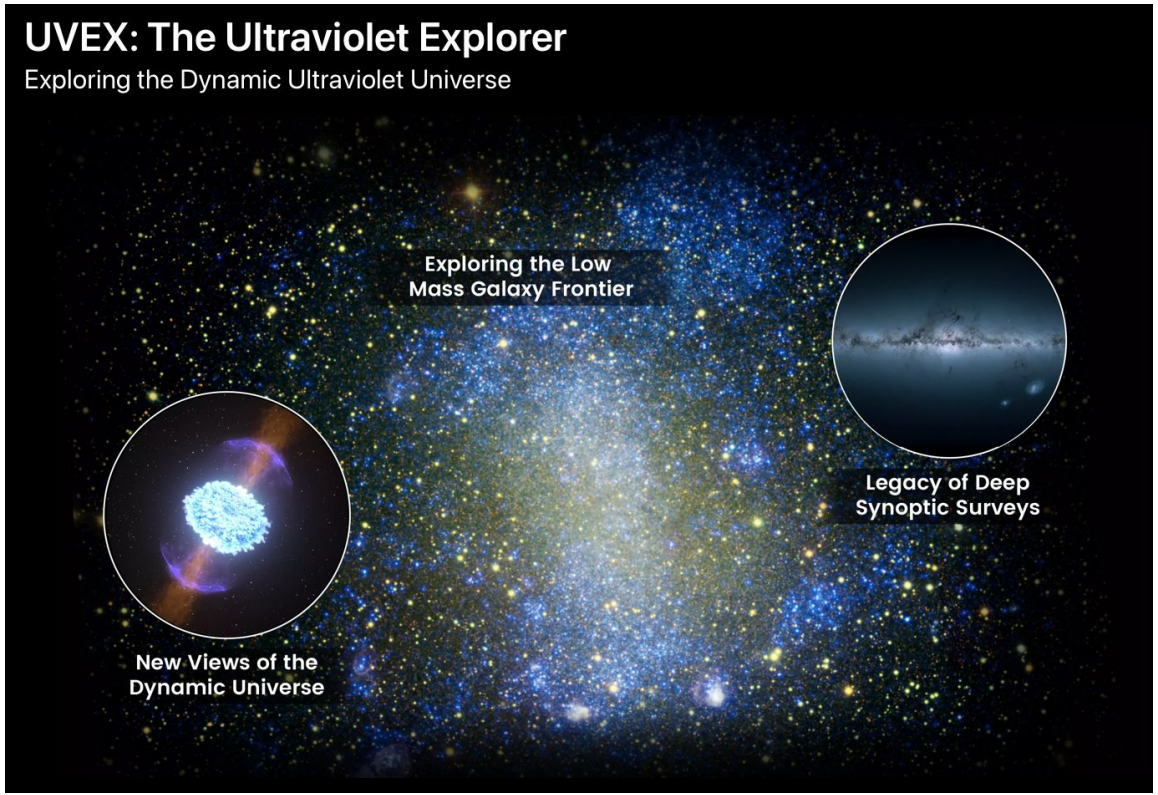
- And more are coming:



Proposed Lifetime	~2027—2037
Mirror Size	2 m
Survey Area	$17,500\ \mathrm{deg}^2$
Depth (5σ AB mag)	**Photometric:** 24.4 – 26.3 **Spectroscopic:** 23.2 – 23.4
Field of View (FoV)	$1.1\ \mathrm{deg}^2$
Filters	NUV, u, g, r, i, z, y, J, H
PSF Size	~0.15''
Observing Mode	Photometry + Grism

Introduction

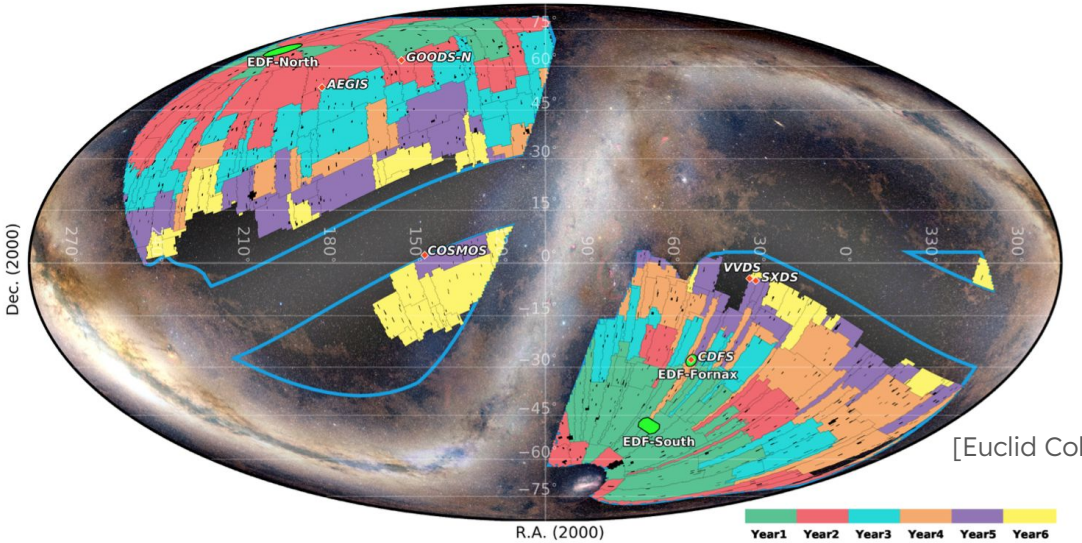
- And more are coming:



- Approved NASA Mid-Sized Explorer
- Planned launch date: 2030
- All-sky survey
- ~25.8 mag in FUV and NUV
- Photometry + spectrometer

Weak lensing and probe combination in *Euclid*

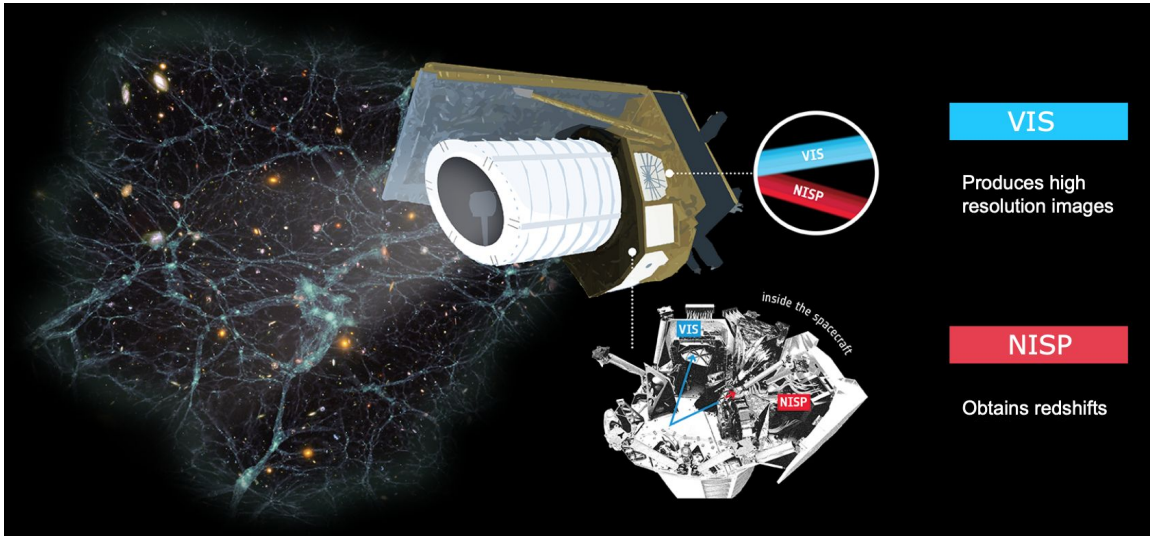
- *Euclid*:
  - **Survey** started on Feb 14th, 2024 – 1st stage-IV weak lensing survey **in operations**
  - It will cover about **14 000 sq deg** of extragalactic sky in **6 years**



[Euclid Collaboration: Mellier et al. 2025]

Weak lensing and probe combination in *Euclid*

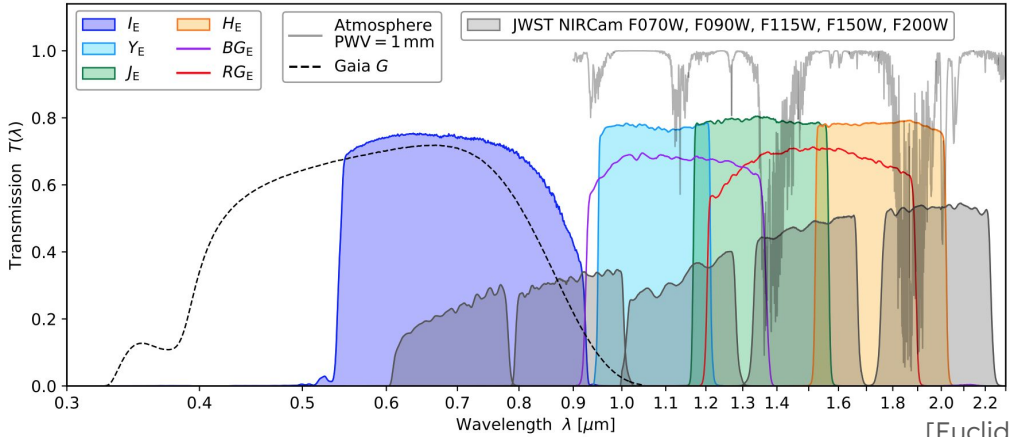
- *Euclid* contains 2 instruments onboard:
  - Visible instrument (VIS) – **imaging**
  - Near Infrared Spectrometer and Photometer (NISP) – **imaging** and **spectroscopy**



[ESA/ATG]

Weak lensing and probe combination in *Euclid*

- *Euclid* alone cannot provide measurements in different optical bands:
  - ➢ Necessary to combine with **ground-based data** for photometric redshifts

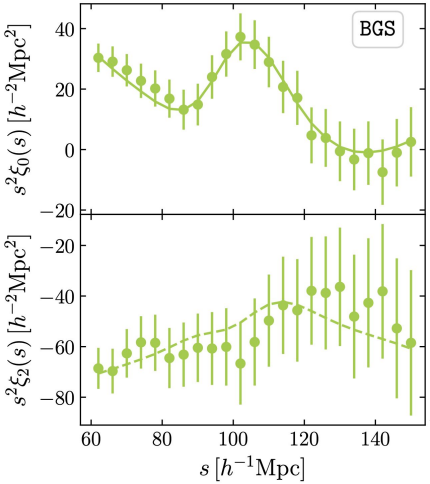


[Euclid Collaboration: Mellier et al. 2025]

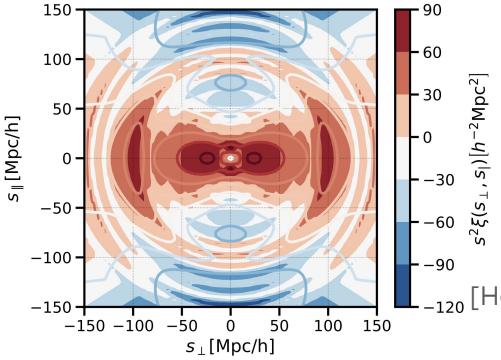
- **Combination of probes** (and data) is a **key ingredient** in *Euclid*'s analysis

Weak lensing and probe combination in *Euclid*

- **Core science** – (Spectroscopic) **galaxy clustering** (GC)
- Baryon acoustic oscillations:
  - ➢ Provide a **cosmic ruler**
  - ➢ Sensitive to the **expansion** history and the angular-diameter **distance**
- Redshift-space distortions
  - ➢ Sensitive to the **growth rate** of structures
  - ➢ Tests of modified gravity



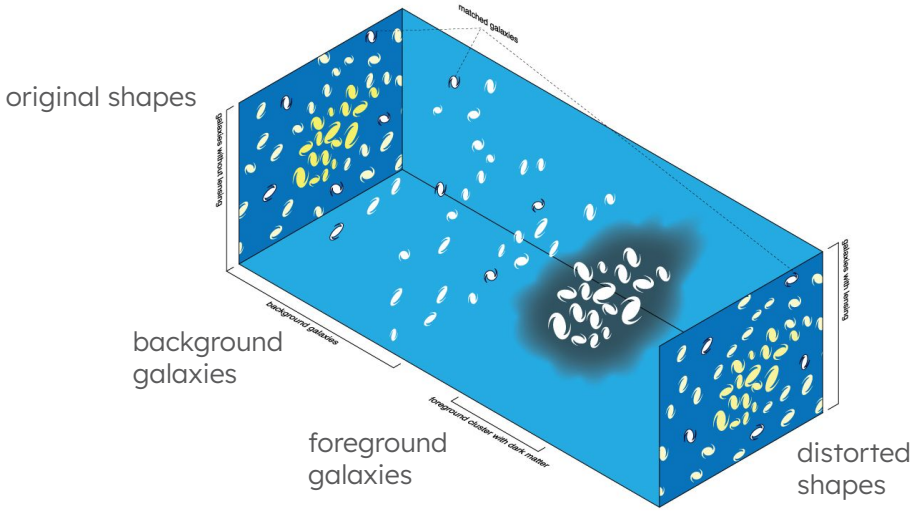
[DESI Collaboration: Abdul-Karim et al. 2025]



[Hou et al. 2021]

Weak lensing and probe combination in *Euclid*

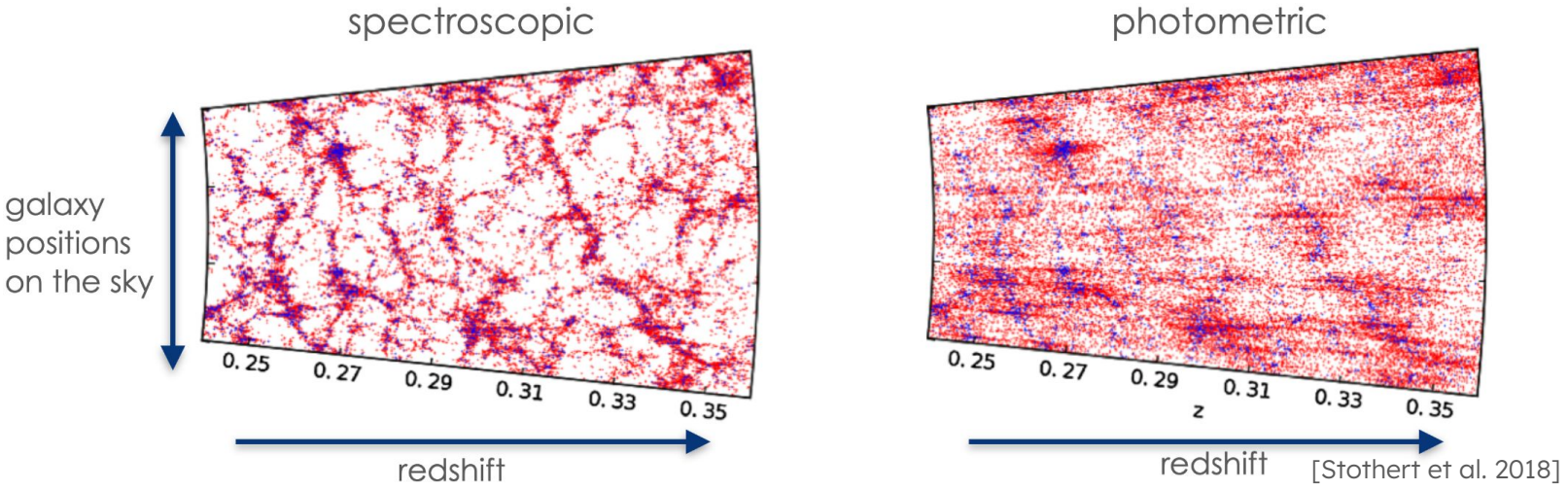
- **Core science** – (Photometric) **weak lensing** (WL):
  - Information about **mass distribution** imprinted on galaxy images
  - Sensitive to **matter density**, initial conditions, and **growth of structures**



[M. Sachs]

Weak lensing and probe combination in *Euclid*

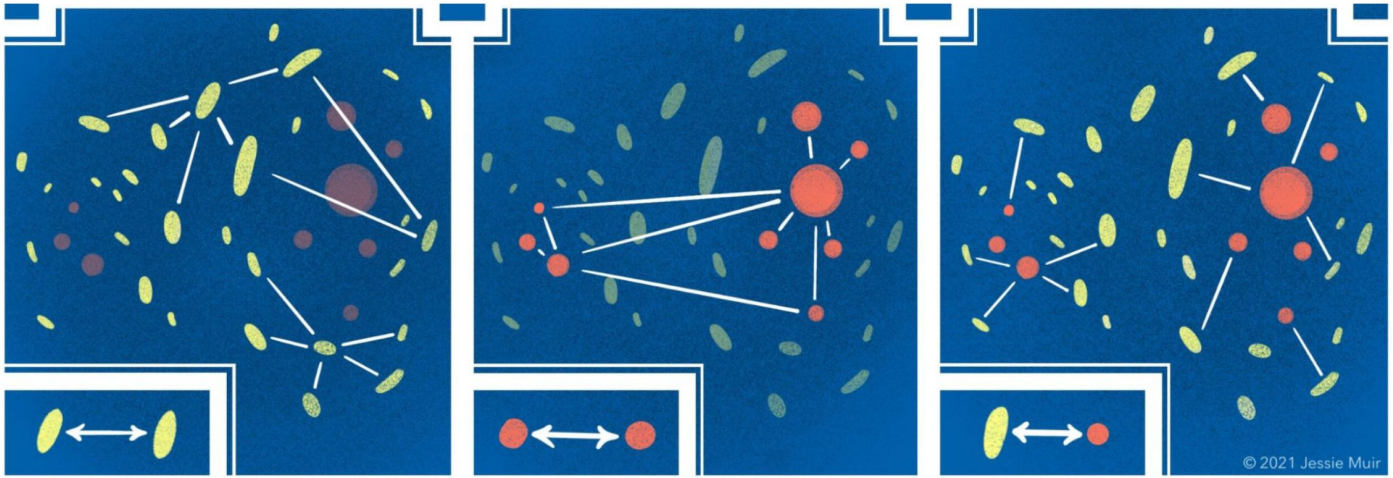
- **Core science** – (Photometric) **galaxy clustering**:
  - Loss of radial information
  - Higher number density & different systematic uncertainties
  - Source of cosmological information



[Stothert et al. 2018]

Weak lensing and probe combination in *Euclid*

- **Core science** – Combined **3x2pt** analysis from **photometric** data:



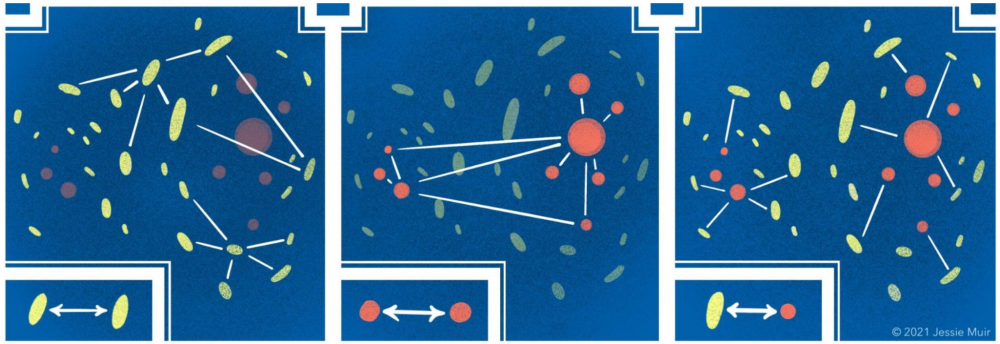
[J. Muir]

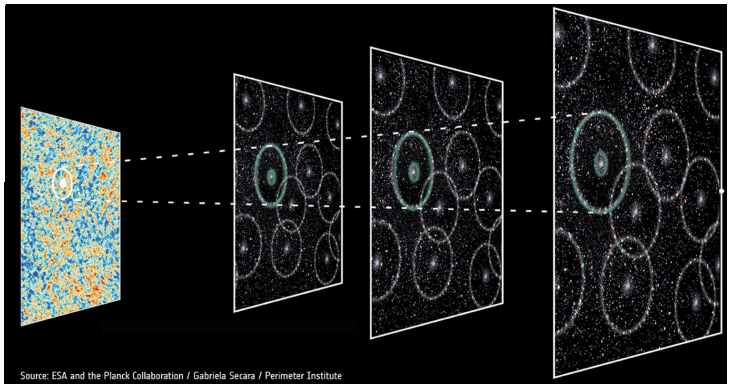
WL | Photometric galaxy clustering | Galaxy-galaxy lensing

Weak lensing and probe combination in *Euclid*

- *Euclid* has been designed to perform both a **photometric** and a **spectroscopic** survey
- **Baseline** analysis: 3x2pt from the photometric data + spectroscopic galaxy clustering

  (~negligible cross-covariance)



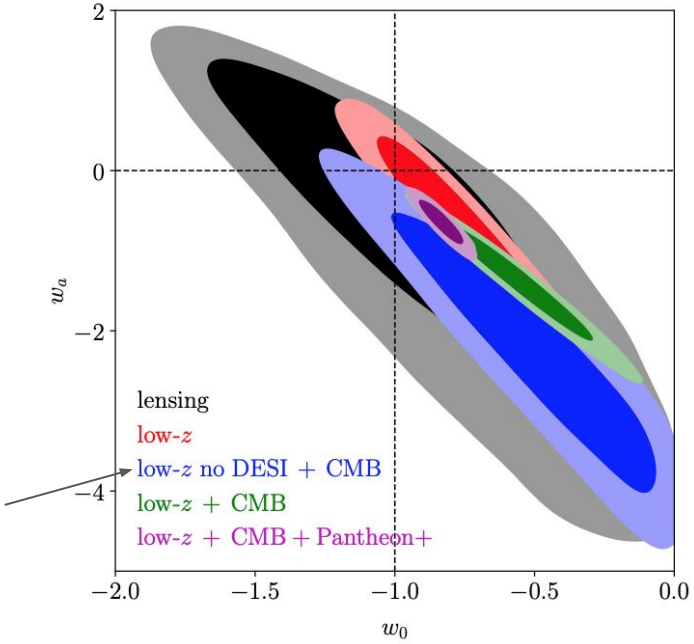


Weak lensing and probe combination in *Euclid*

- **Cross-covariance** between spectroscopic galaxy clustering and 3x2pt:
  - **High-redshift** spectroscopic sample vs **low-redshift** weak lensing kernel
  - **Different modes** probed by spectroscopic vs photometric probes (Taylor & Markovic 2022 – see also Euclid Collaboration: Paganin et al. 2024)
  - Similar conclusions from **configuration space** analyses (Semenaite et al. 2026)
  - **Negligible** for **DESI DR1** combined with **stage-III WL** surveys (Semenaite et al. 2026)
  - Currently estimating the cross-covariance for *Euclid* DR1
- Can we gain **information** by adding cross-correlations as an **additional data vector**?

Weak lensing and probe combination in *Euclid*

- Weak lensing and probe combination with **stage-III** galaxy surveys:



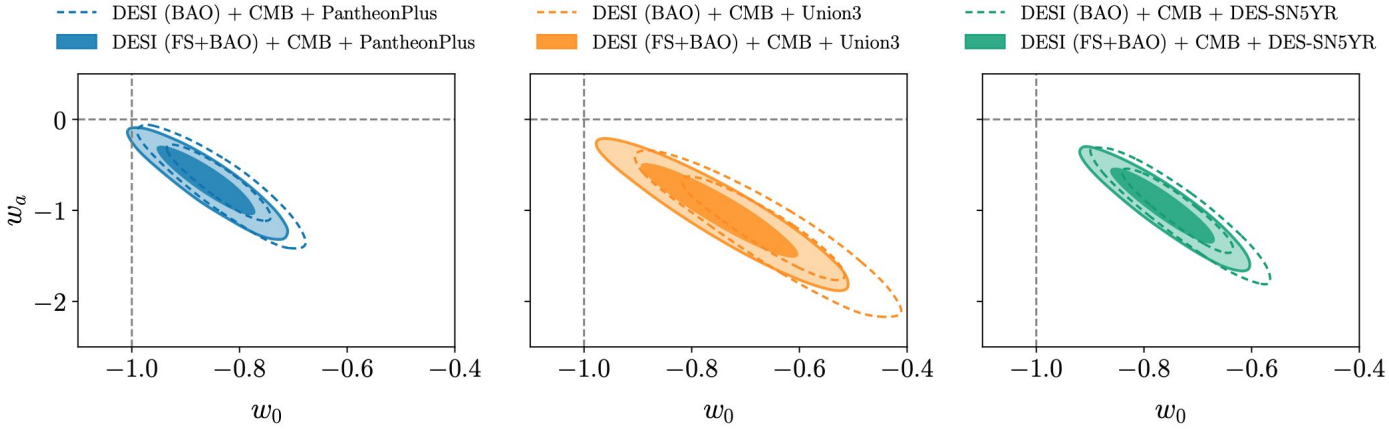
name	data set
KiDS	KiDS DR5 cosmic shear catalogue
CMB	SPT 3G D1 + ACT DR6 + Planck 2018 lensing and primary (also known as SPA)
lensing	KiDS + DES Y3 + CMBlensing
low-z	KiDS + DES Y3 + DESI DR2 BAO + eBOSS DR16 RSD

[Reischke et al. 2026]

- ~0.32 uncertainty on w_0 and ~1.15 uncertainty on w_a

Weak lensing and probe combination in *Euclid*

- First spectroscopic **stage-IV** data: Dark Energy Spectroscopic Instrument DR1

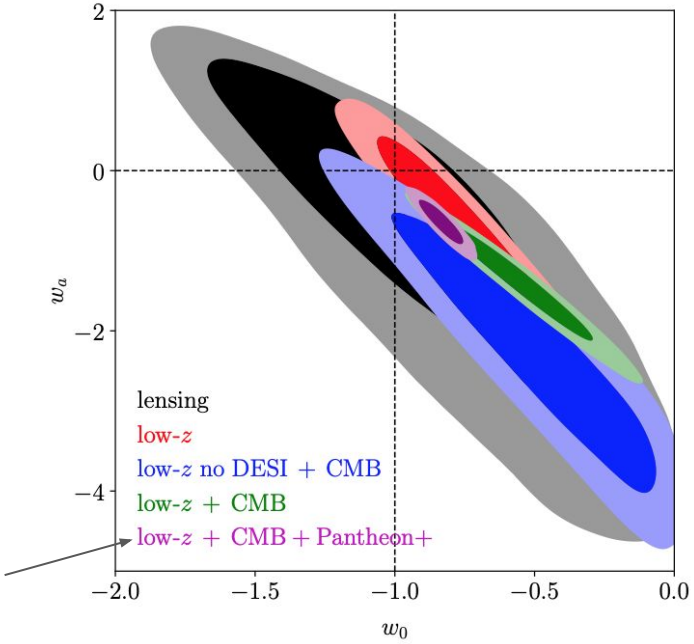


[DESI Collaboration: Adame et al. 2025]

- ~0.06 uncertainty on w_0 and ~0.3 uncertainty on w_a – improved with DR2

Weak lensing and probe combination in *Euclid*

- Weak lensing and probe combination with **stage-IV** galaxy surveys:



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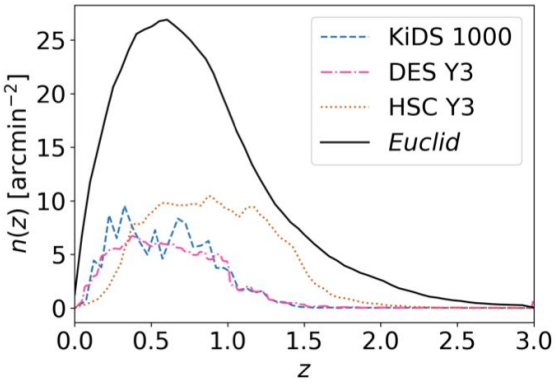
lensing	KiDS + DES Y3 + CMBlensing
low-z	KiDS + DES Y3 + DESI DR2 BAO + eBOSS DR16 RSD

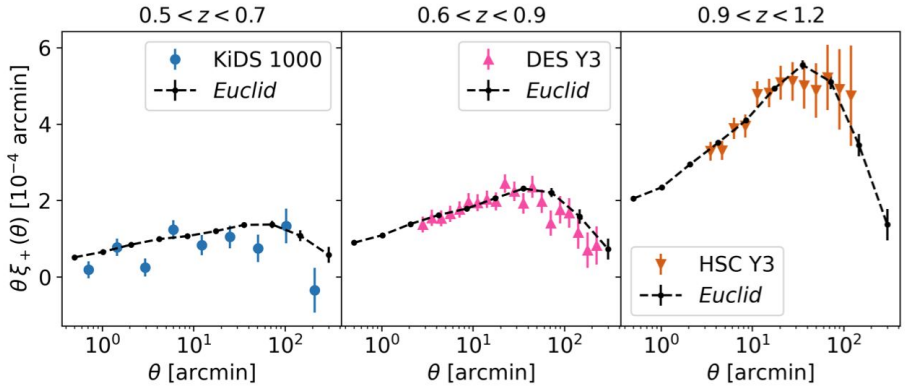
[Reischke et al. 2026]

- ~0.052 uncertainty on w_0 and ~0.19 uncertainty on w_a – similar to All DES + DESI BAO + CMB [DES Collaboration: Abbott et al. 2026]

Weak lensing and probe combination in *Euclid*

- How will *Euclid* compare to current surveys?
  - ➢ Weak lensing:
    - More than 10^9 shapes of galaxies up to high redshift

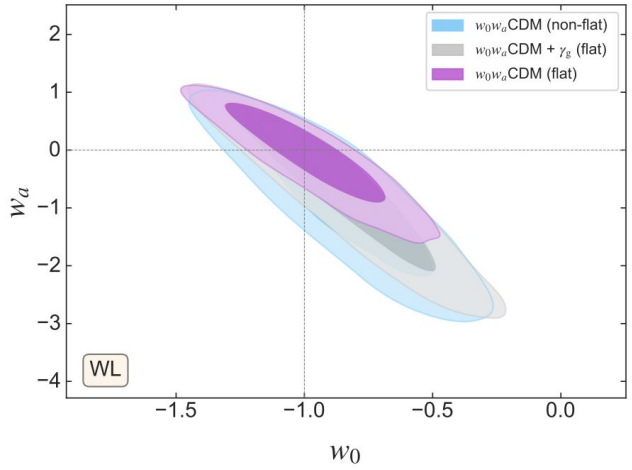


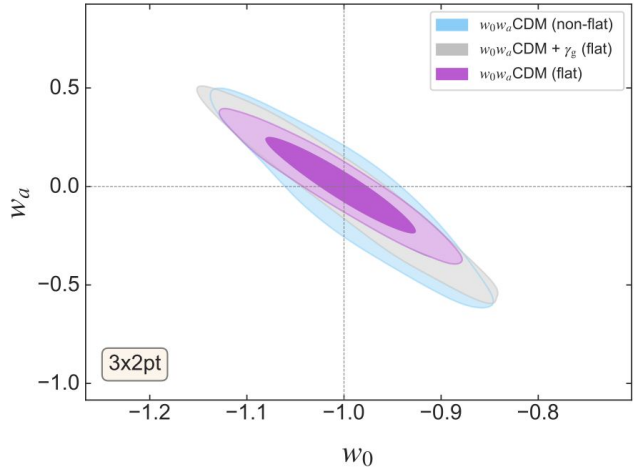


[Euclid Collaboration: Mellier et al. 2025]

Weak lensing and probe combination in *Euclid*

- Very **precise constraints** on the nature of **dark energy**



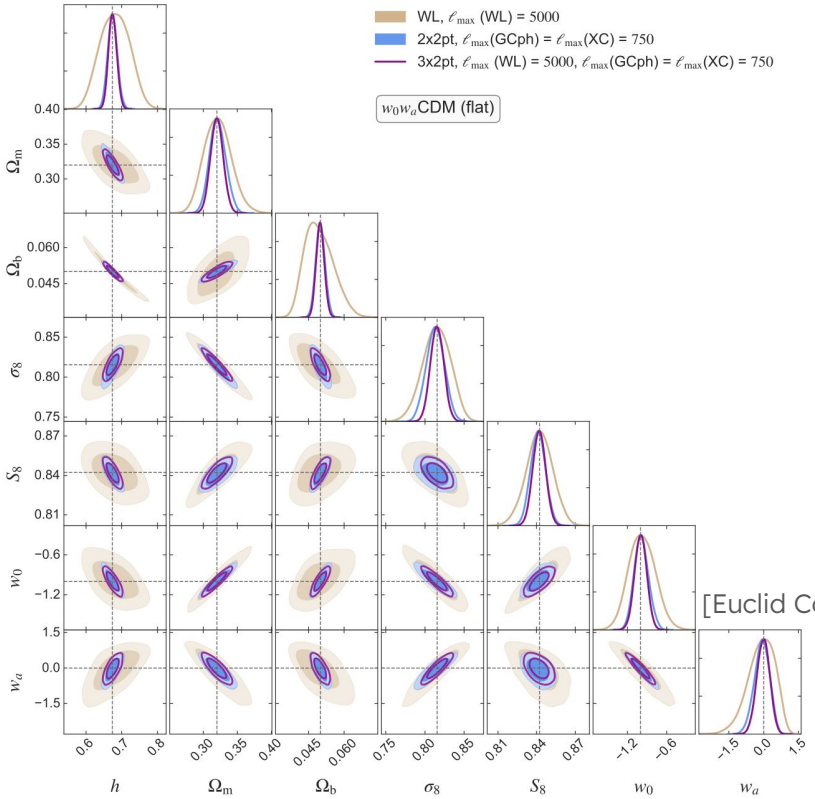


[Euclid Collaboration: Cañas-Herrera et al. 2026]

- ~0.046 uncertainty on w_0 and ~0.13 uncertainty on w_a – 3x2pt + GCsp
- More precise than combined current constraints with *Euclid* main probes **alone**

Weak lensing and probe combination in *Euclid*

- Also very **precise constraints** on the other parameters of the standard model

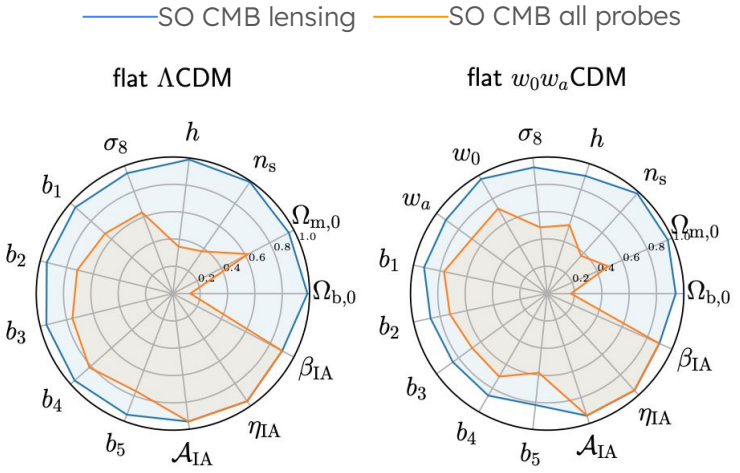


[Euclid Collaboration: Cañas-Herrera et al. 2026]

Weak lensing and probe combination in *Euclid*

- Several **other cosmological probes** can be combined to extract even more information:
  - Cross-correlations with the cosmic microwave background
  - Galaxy clusters
  - Voids

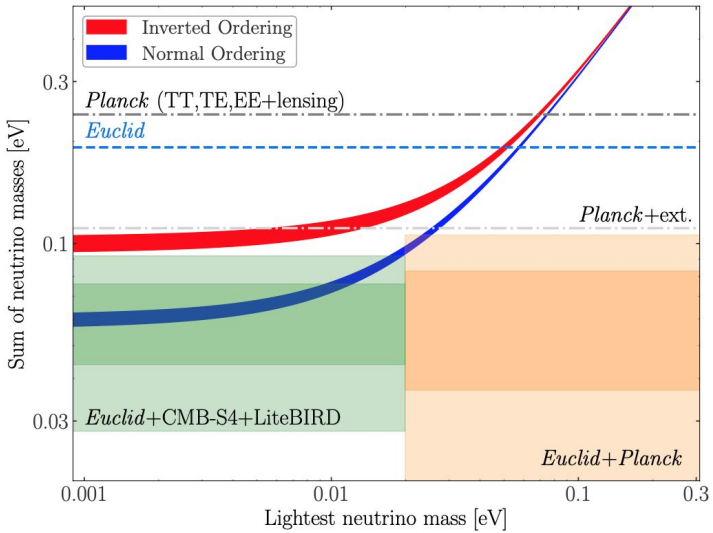
- Also combinations with **higher-order statistics**
  - 2pt + 3pt statistics
  - Simulation-based inference
  - Field-level inference



[Euclid Collaboration: Ilic et al. 2022]

Weak lensing and probe combination in *Euclid*

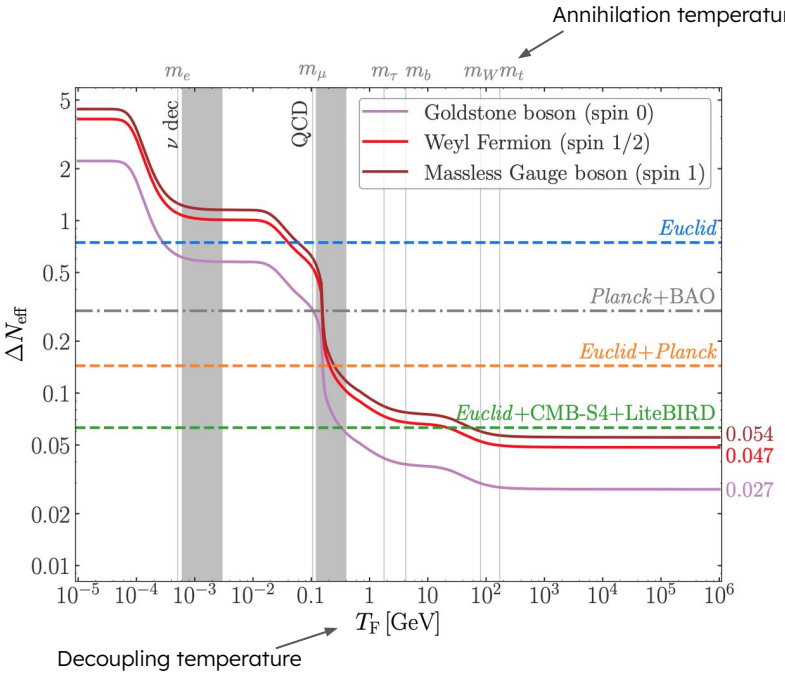
- Thanks to probe combination, *Euclid* will also help us test **neutrinos** and other particles beyond the standard model:
  - If the true sum of neutrino masses is 0.06 eV (normal ordering), *Euclid* + future CMB data can rule out inverted ordering at 2.5 sigma



[Euclid Collaboration: Archidiacono et al. 2025]

Weak lensing and probe combination in *Euclid*

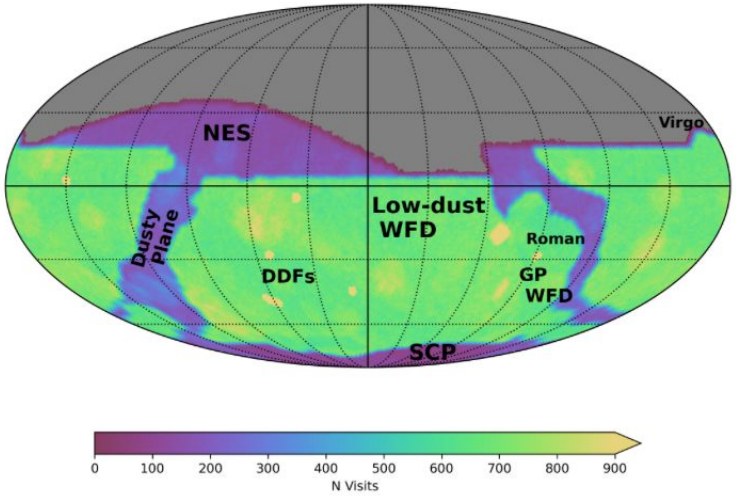
- Thanks to probe combination, *Euclid* will also help us test neutrinos and **other particles** beyond the standard model:
  - Adding *Euclid* improves the current limit on the presence of new light particles by more than a factor 2



[Euclid Collaboration: Archidiacono et al. 2025]

Weak lensing and probe combination in *Rubin* and *Roman*

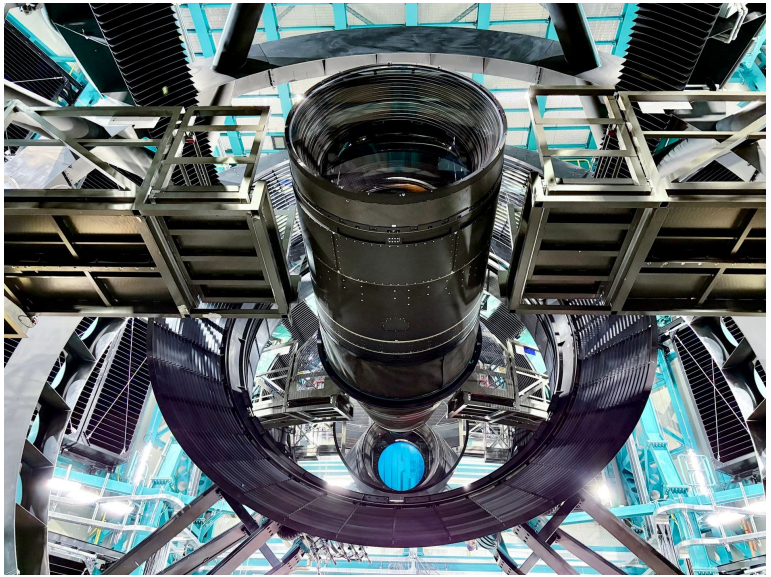
- *Rubin*:
  - **Survey** started on Jun 30th, 2026
  - It will cover about **18 000 sq deg** of sky during **10 years** with **800 visits** per pointing



[*Rubin* (LSST)]

Weak lensing and probe combination in *Rubin* and *Roman*

- *Rubin* uses the LSST Camera:
  - **Imaging** in 6 filters (only 2 minutes to swap filters – 3000 kg camera)
  - 3.6 GPix in ~10 sq. deg. An image every ~40 s



[RubinObs/NSF/DOE/NOIRLab/SLAC/ AURA/T. Lange]

Weak lensing and probe combination in *Rubin* and *Roman*

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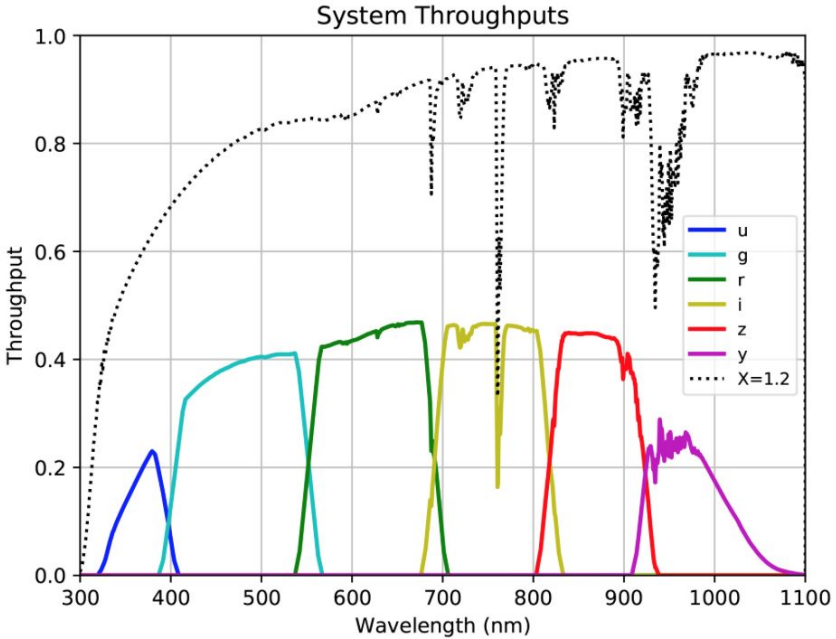
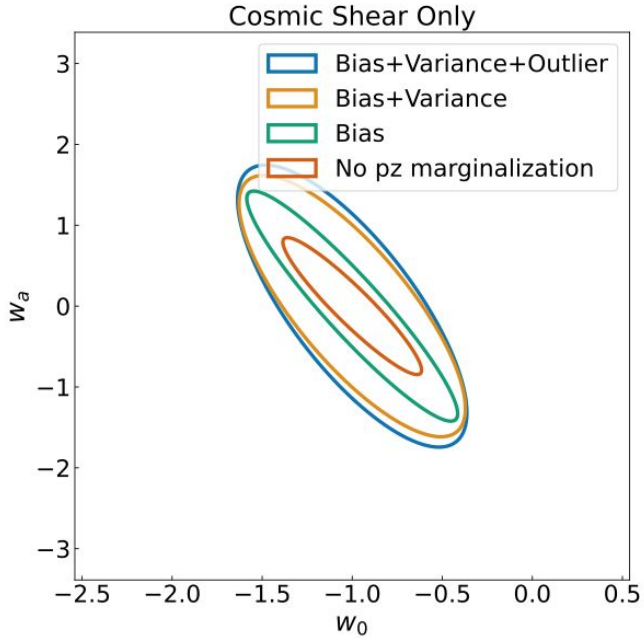
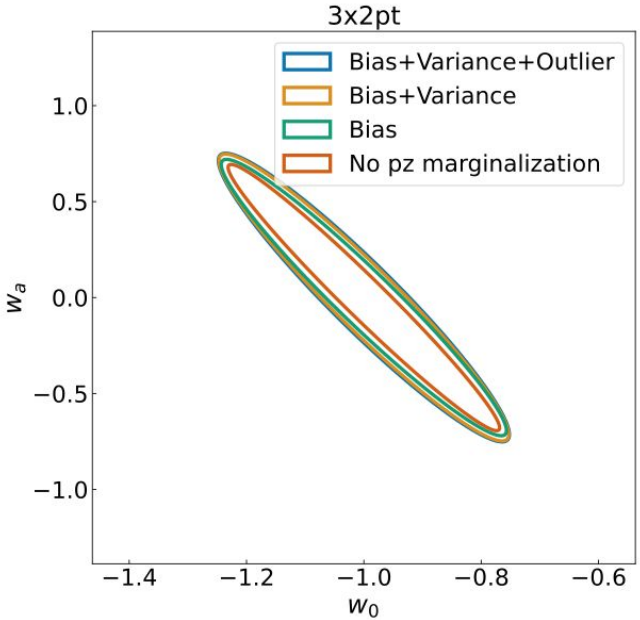


[Ivezic et al. 2019]

Weak lensing and probe combination in *Rubin* and *Roman*

- *Rubin* will provide exquisite constraints on dark energy



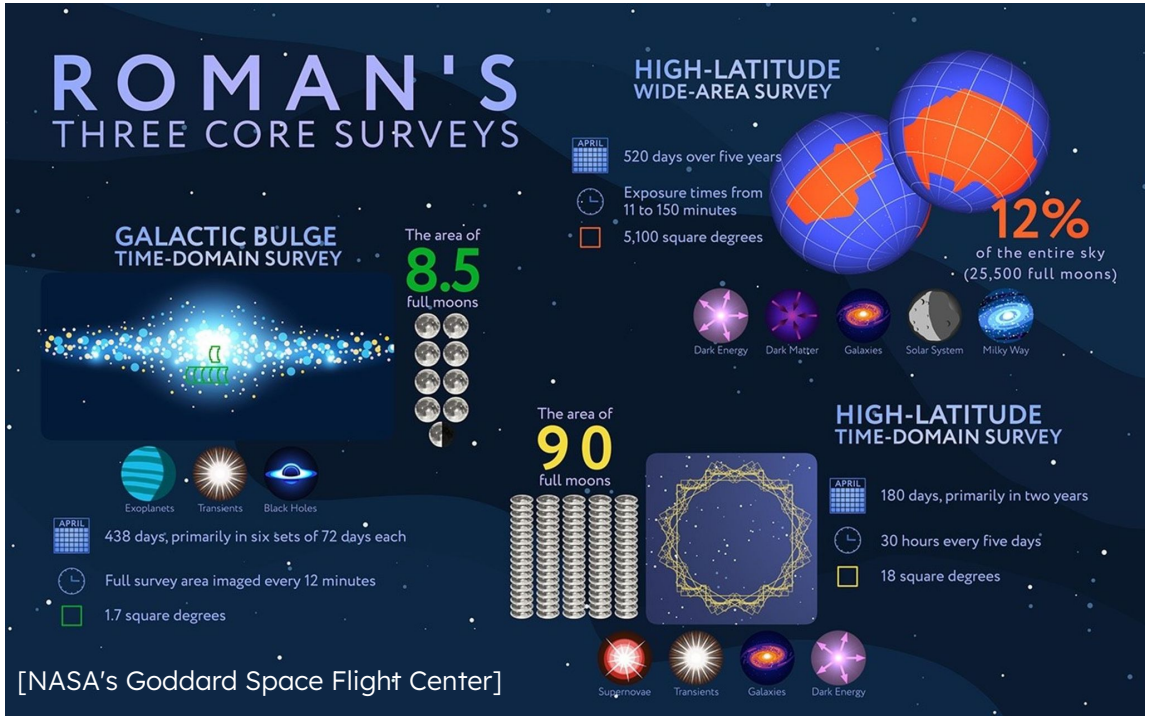


Note: **2σ** Fisher contours. Lens galaxy distributions perfectly known

[The LSST Dark Energy Science Collaboration: Zhang et al. 2025]

Weak lensing and probe combination in *Rubin* and *Roman*

- *Roman*:
  - Official launch date: **Aug 30th, 2026**



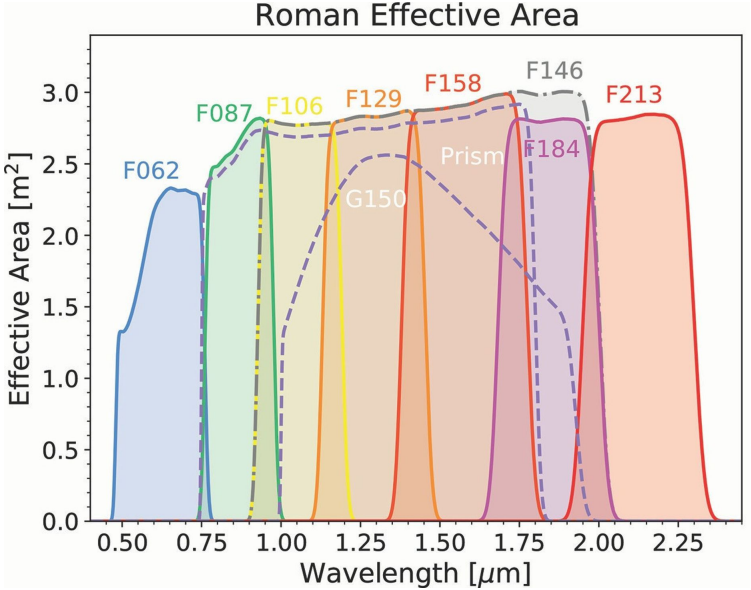
Weak lensing and probe combination in *Rubin* and *Roman*

- *Roman* contains 2 instruments onboard:
  - Wide Field Instrument (WFI) for science
  - Coronagraph Instrument – Technology demonstration
  - 25% of time for guest observer surveys

[NASA]

Weak lensing and probe combination in *Rubin* and *Roman*

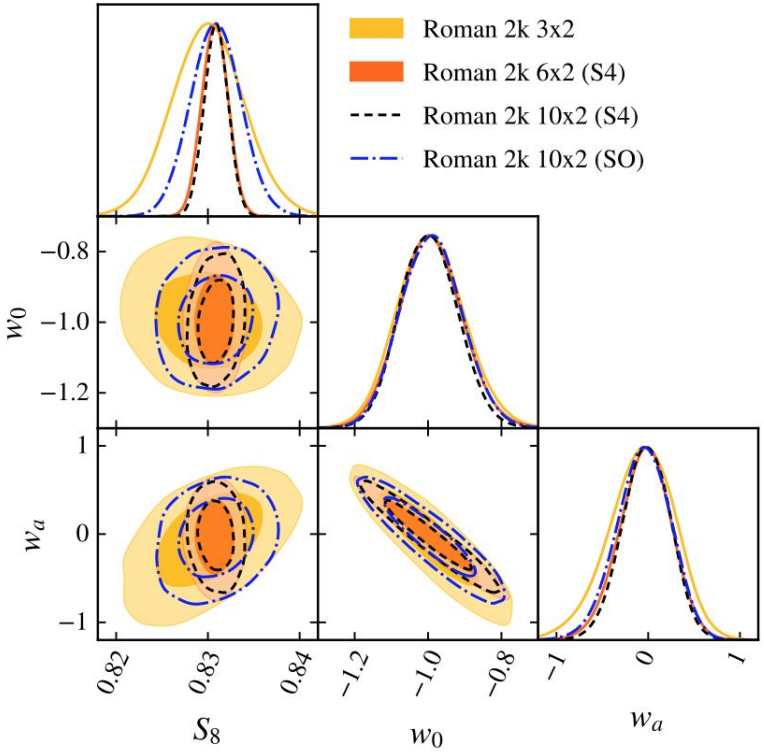
- *Roman*:
  - **Imaging** in 8 optical and NIR filters
  - **Spectroscopy** with 1 prism and 1 grism



[NASA]

Weak lensing and probe combination in *Rubin* and *Roman*

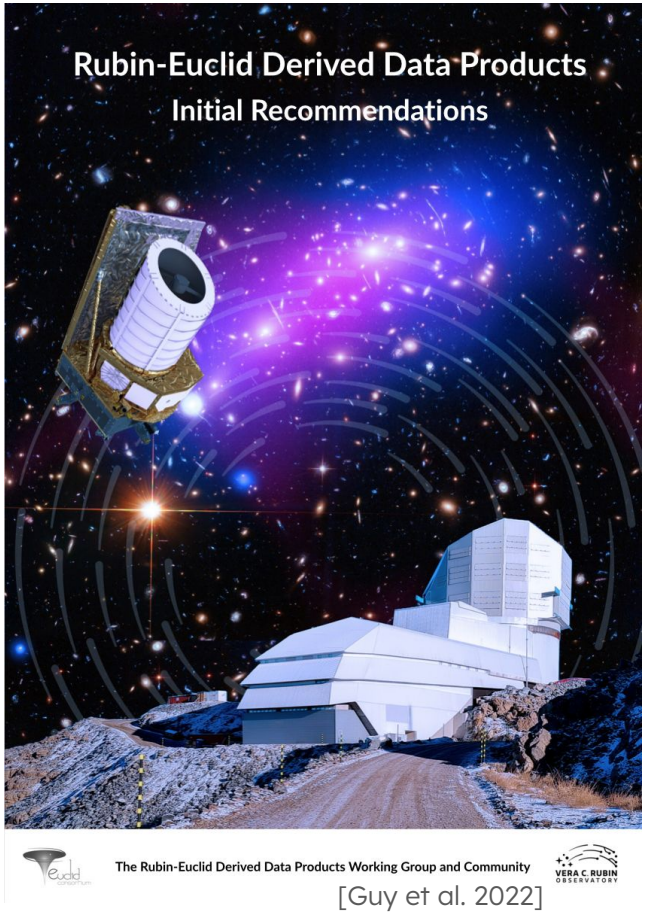
- *Roman* will provide exquisite constraints on dark energy



[Eifler et al. 2024]

Joint analysis of stage-IV data

- Joint derived data products (DDPs):
  - Maximise science generating products shared between the consortia, while protecting the individual unique science
  - Combining *Euclid*'s high spatial resolution with *Rubin*'s density will enhance the science yield of both surveys
  - Tiered approach from catalogue merging up to joint pixel processing
  - Pathfinder for Rubin-Euclid-Roman DDPs (see also Chary et al. 2020)



[Guy et al. 2022]

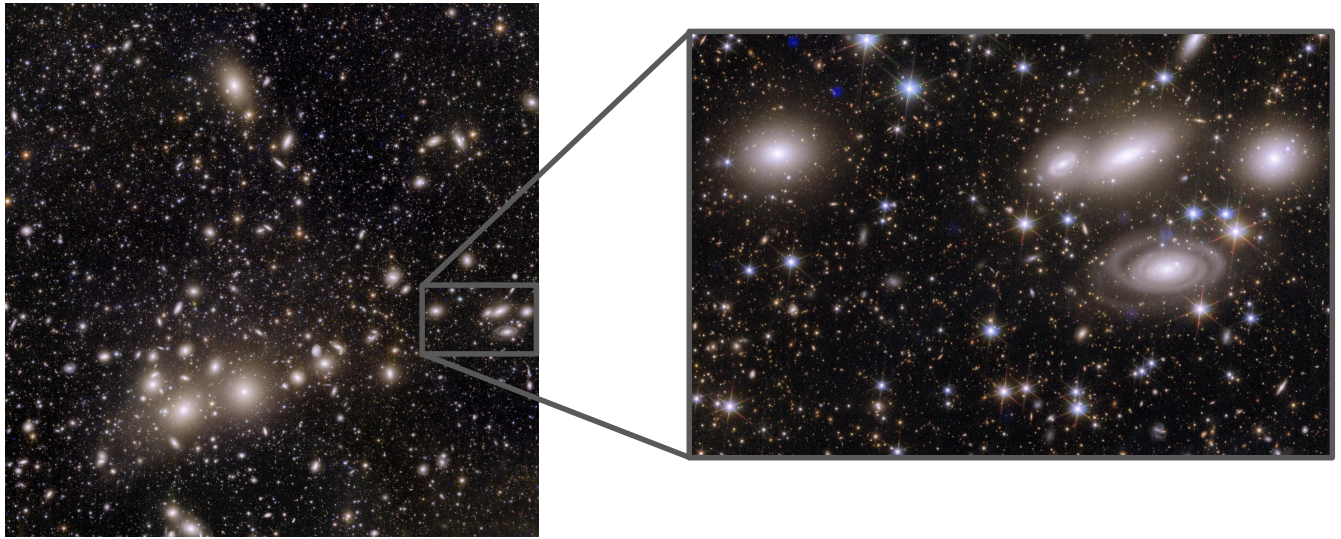
From *Euclid*'s launch to the first data release

- **Launch** Jul 1st, 2023:
  - Cape Canaveral, Florida, USA with a Space X Falcon 9
  - Destination: 2nd Lagrange point

[Space X; ESA]

From *Euclid*'s launch to the first data release

- **Early Release Observations** Nov 2023 & May 2024:
  - 24h of observations of allocated targets
  - 10 images – first scientific results



[Perseus cluster – ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre (CEA Paris-Saclay), G. Anselmi]

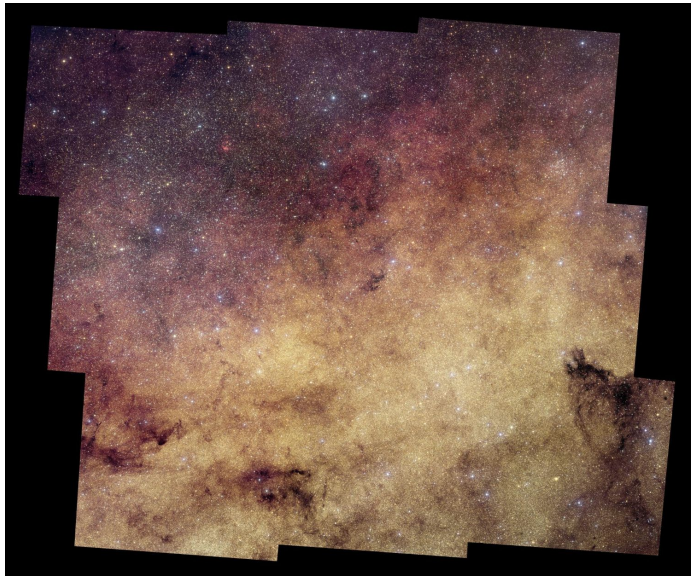
From *Euclid*'s launch to the first data release

- **Quick data release 1** (Q1) Mar 19th, 2025:
  - First glimpse of *Euclid*'s cosmological survey ~63 sq deg
  - 50+ scientific papers
  - Non-cosmological science for the moment (e.g., Milky Way, galaxy morphology, proto-clusters)

[Euclid Deep Field South x70 – ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre, E. Bertin, G. Anselmi]

From *Euclid*'s launch to the first data release

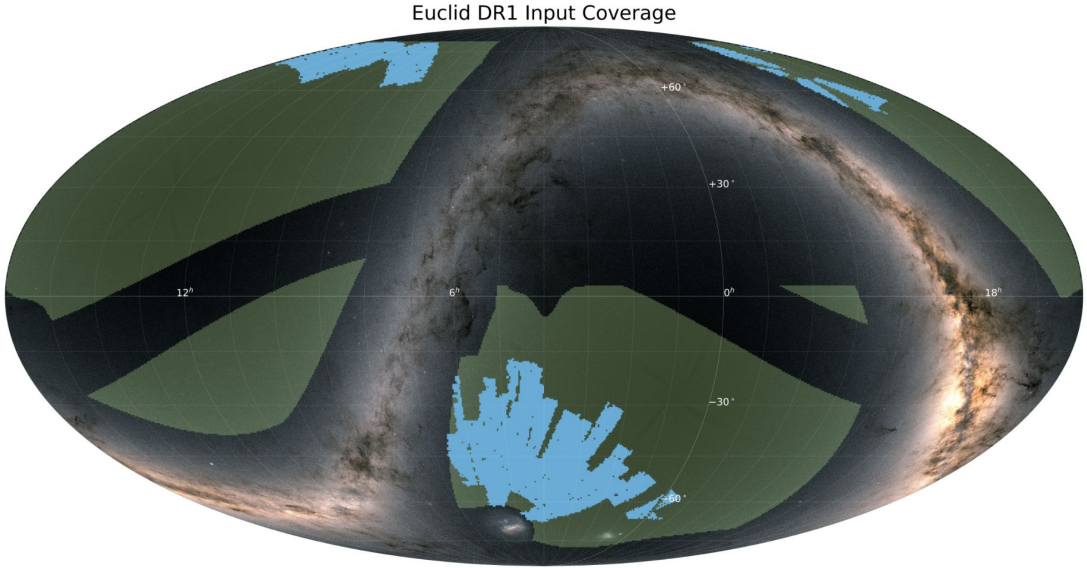
- **Quick data release 2** (Q2) Jun 24th, 2026:
  - *Euclid* Galactic Bulge Survey: 4.8 sq deg over 9 adjoining fields
  - Unprecedented deep, wide-field, high-resolution view of the inner bulge region of the Milky Way



[Galactic bulge – ESA/Euclid/Euclid Consortium/NASA, CFHT, image processing by J.-C. Cuillandre and E. Bertin (CEA Paris-Saclay)]

From *Euclid*'s launch to the first data release

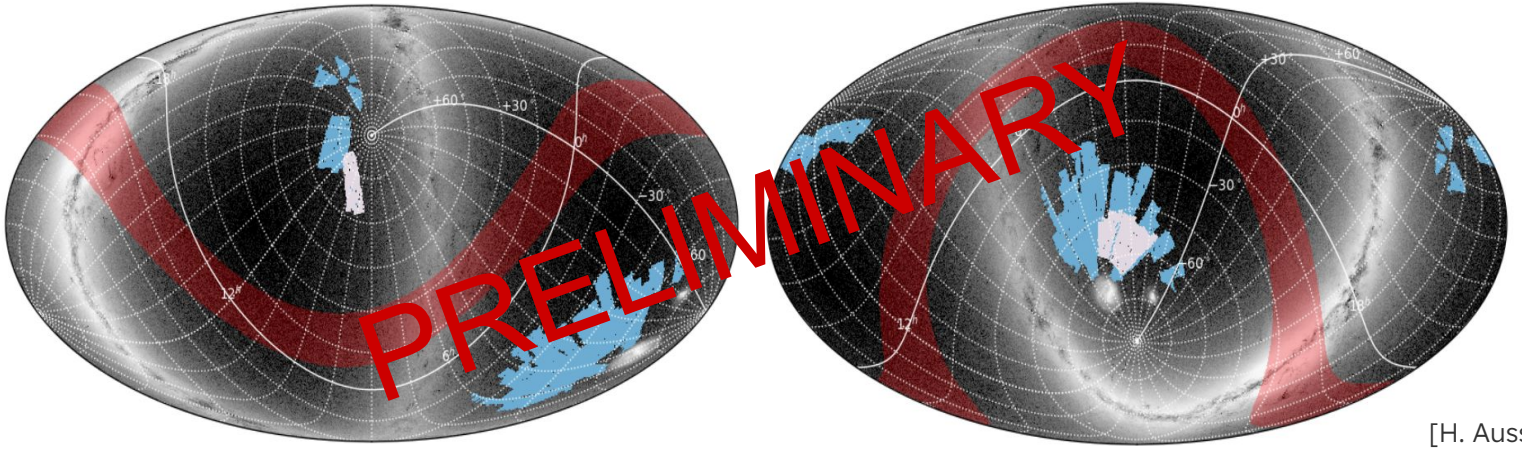
- Towards **Data Release 1** (DR1) mid 2027 (Nov 2026 for DR1-Foundation):
  - First *Euclid*'s cosmological results
  - Expectation: around 1900 sq deg



[H. Aussel/ESA/Euclid/Euclid Consortium/NASA; ESA/Gaia/DPAC. Acknowledgement: A. Moitinho]

From *Euclid*'s launch to the first data release

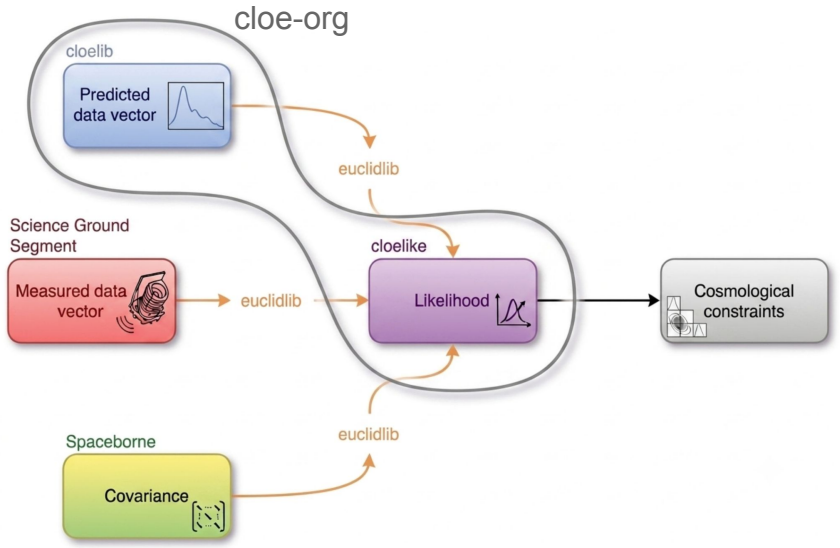
- Currently performing **data validation** with TR1:
  - Subset of DR1 (152 sq deg North, 368 sq deg South)
  - Compatible with the blinding policy



[H. Aussel]

From *Euclid*'s launch to the first data release

- Stress-testing the **inference pipeline** and discussing **modelling** and **analysis choices**:
  - Within the Consortium key projects, in particular the Joint Cosmology (C. Carbone, M. Crocce, I. Tutusaus)

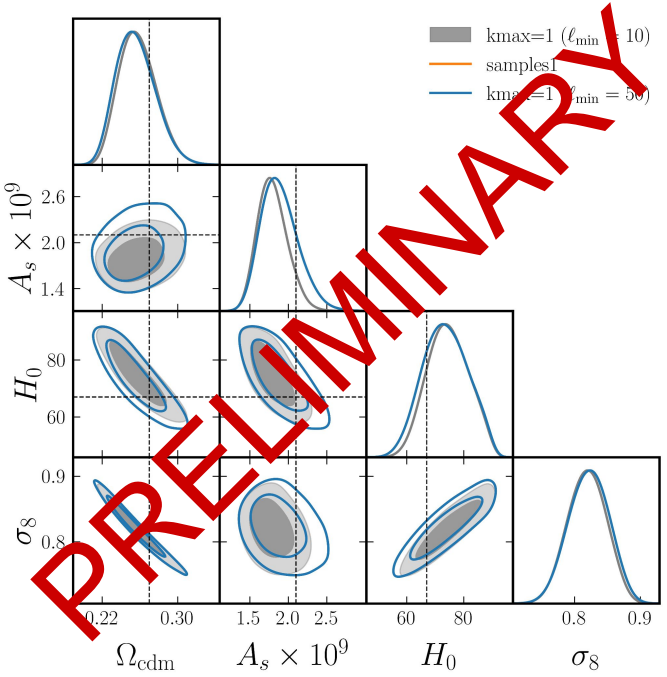


[euclidlib](#) (G. Cañas-Herrera et al.)
[Spaceborne](#) (D. Sciotti et al.)

  - [cloe-org](#) (Maintainers: M. Bonici, G. Cañas-Herrera, P. Carrilho, S. Casas, C. Moretti, A. Pezzotta – 50+ Contributors) – [cloelib](#), [cloelike](#)

From *Euclid*'s launch to the first data release

- Stress-testing the **inference pipeline** and discussing **modelling** and **analysis choices**:
  - Example: weak lensing analysis with ~2500 sq deg of the Flagship 2 simulation (Euclid Collaboration: Castander et al. 2025)
    - Measurements: heracles (Euclid Collaboration: Tessore et al. 2025)
    - Predictions: cloelib
    - Covariance: Spaceborne
    - Likelihood: cloelike



[J. Coloma, S. Gouyou-Beauchamps, M. Crocce et al.]

Conclusions

- Some tensions start to appear within LCDM and the nature of the dark components remains unknown
- Stage-IV photometric galaxy surveys will provide exquisite measurements to perform weak lensing and joint analyses that will shed light on the dark sectors of the Universe
- The different stage-IV surveys are complementary and exploiting their synergies will provide the best science possible
- *Euclid*'s DR1 analyses are ongoing, *Rubin* recently started the LSST, and *Roman* will be launched soon
- Stay tuned for the weak lensing results that will come out of this golden era!