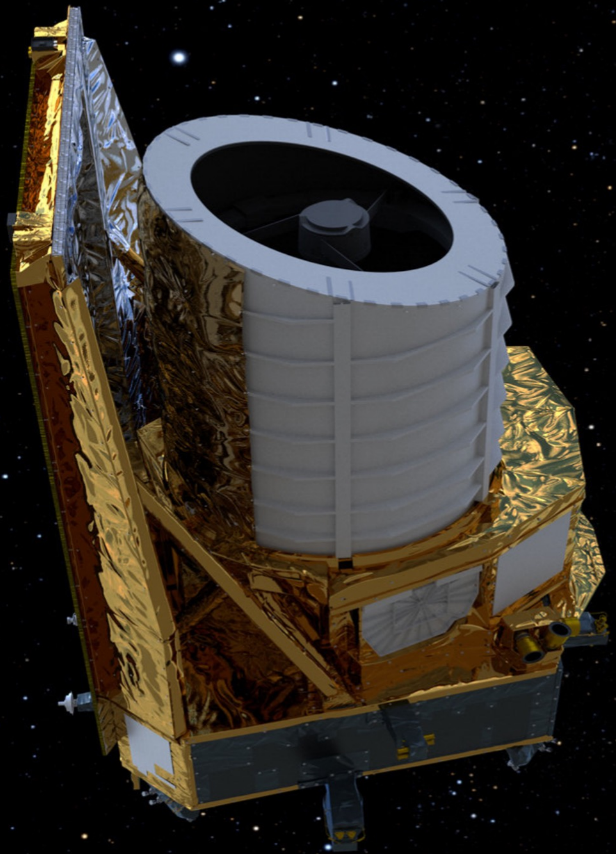


Euclid: performance on main cosmological parameter science

William d’Assignies D. (on behalf of the Euclid Consortium) - EPS HEP 8th July 2025

https://arxiv.org/abs/2405.13491

Euclid consortium

IFAE Institut de Física d’Altes Energies

EXCELENCIA SEVERO OCHOA

Standard model of cosmology

- **A compact and successful model !**
- **Which recently started to show some ‘tensions’**

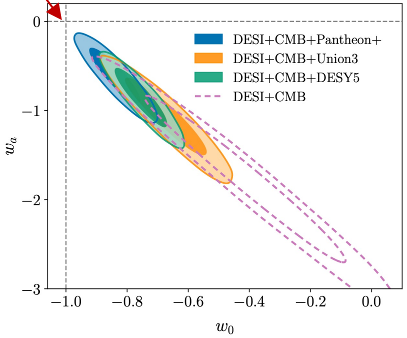
H_0	Ω_m	Ω_b	Ω_Λ	σ_8	n_s
Current expansion rate	Matter density	Baryon density	Dark Energy density	„Clumpiness“	Scale index of initial density fluctuations

$(+\sum m_\nu)$

Sum of individual neutrino masses

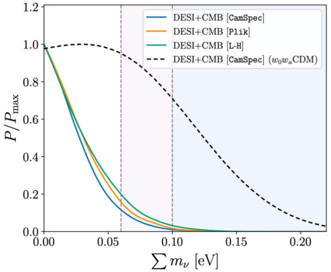
Preference for **DDE** for DESI+CMB+ SN 2.8 – 4.2σ

ΛCDM



Credit: DESI DR2 Results II (2025)

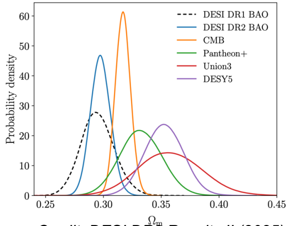
DESI and CMB 95% upper limit $\sum m_\nu < 0.064$ with ΛCDM



Credit: DESI DR2 Results II (2025)

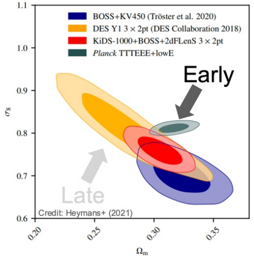
And many more:

$\boldsymbol{\Omega_m}$

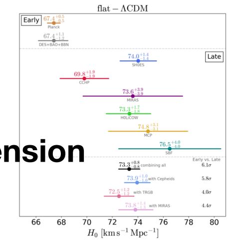


Credit: DESI DR2 Results II (2025)

$\boldsymbol{S_8}$ ‘tension’



$\boldsymbol{H_0}$ **tension**

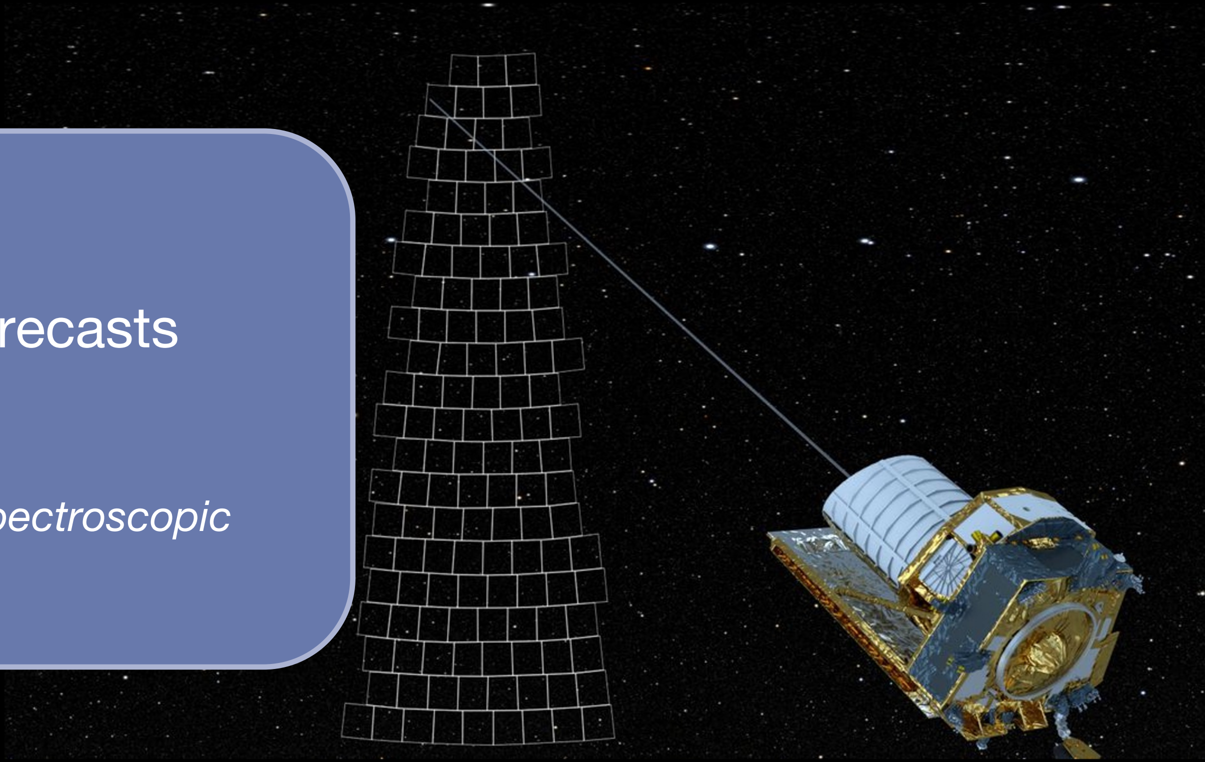


Credit: Verde+(2019)

Outline

- Euclid data
- Main probes and forecasts
- Systematics

For Euclid photometric and spectroscopic surveys.



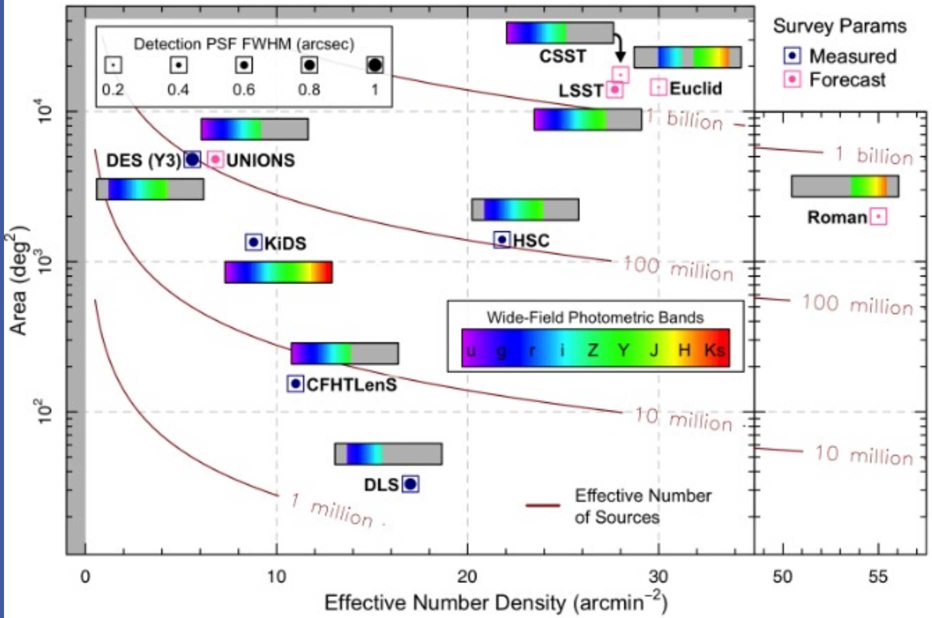
Credit: ESA

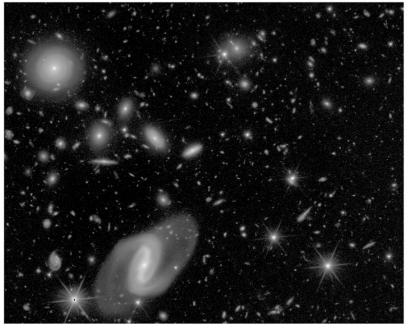
Euclid data
(cosmology perspective)

- Photometric samples
- Spectroscopic samples

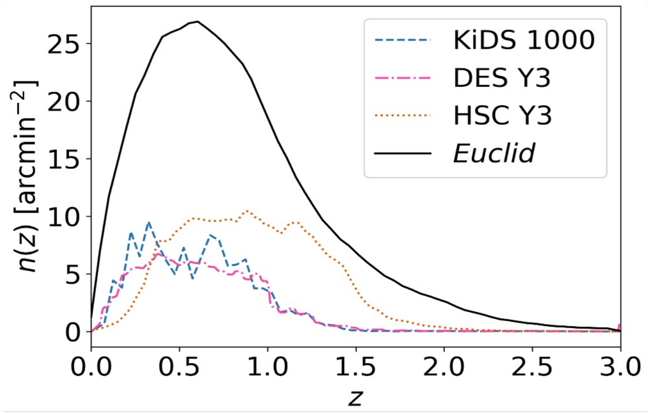
Photometric samples

Higher densities and higher redshifts





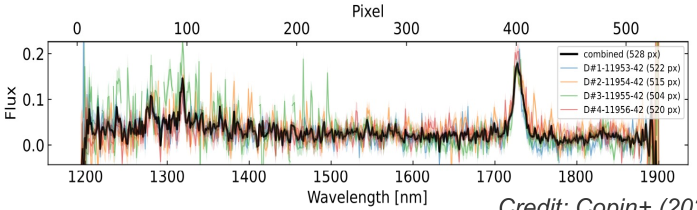
A VIS-processed stack using 42 exposures



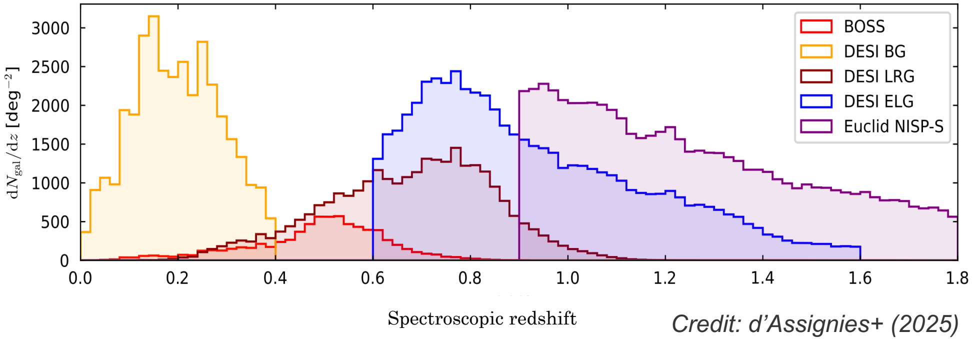
Euclid observes a **higher number density** of galaxies and many more sources at **higher redshifts** compared with Stage III surveys

Spectroscopic sample

- The redshifts the Hα emission line identification will cover is $0.9 < z < 1.8$ given the range of the instrument (red grism).

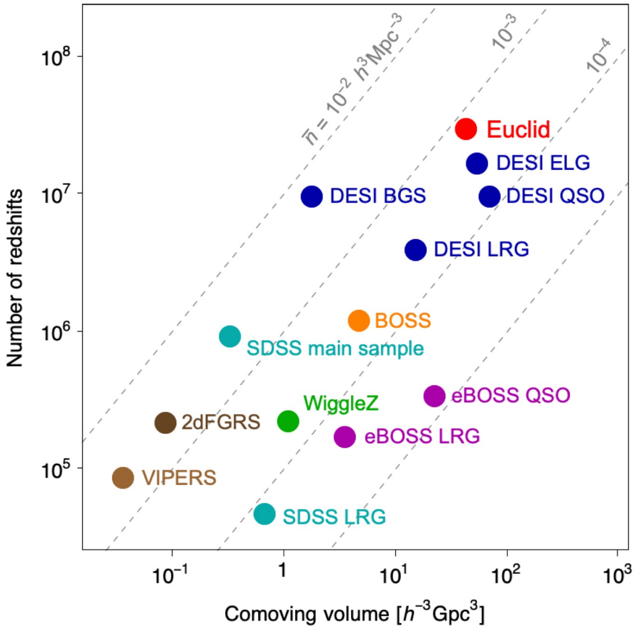


Credit: Copin+ (2025)

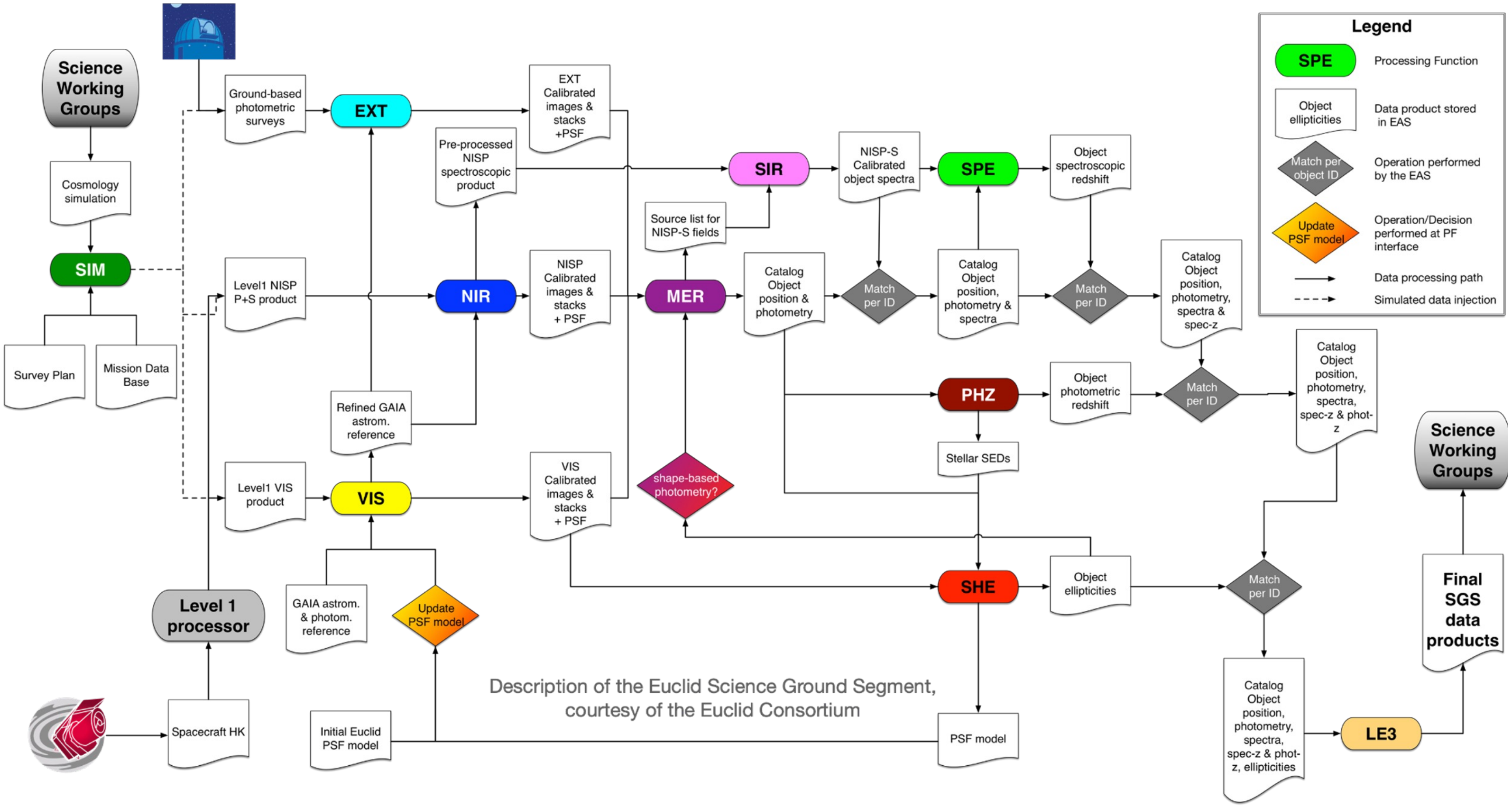


Credit: d'Assignies+ (2025)

Euclid will measure 30 million of such spectroscopic redshifts.



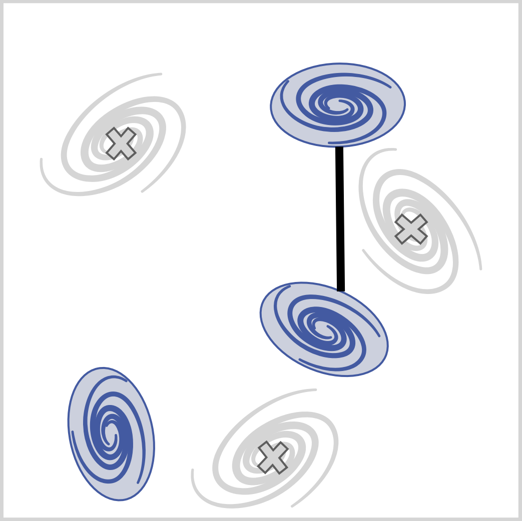
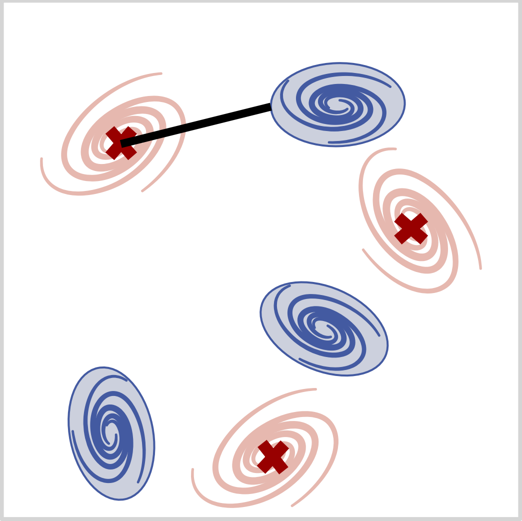
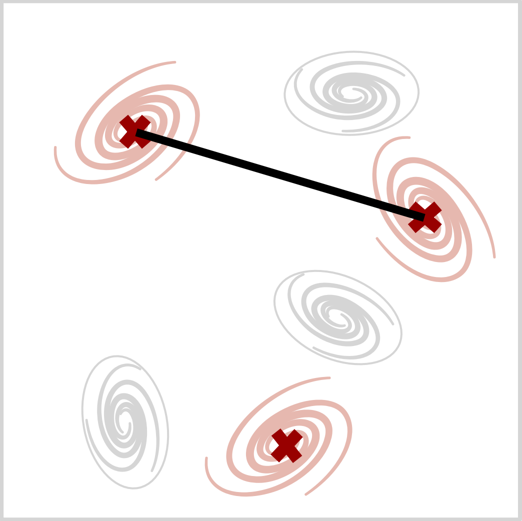
The Euclid Consortium Science Ground Segment



(Main) Probes

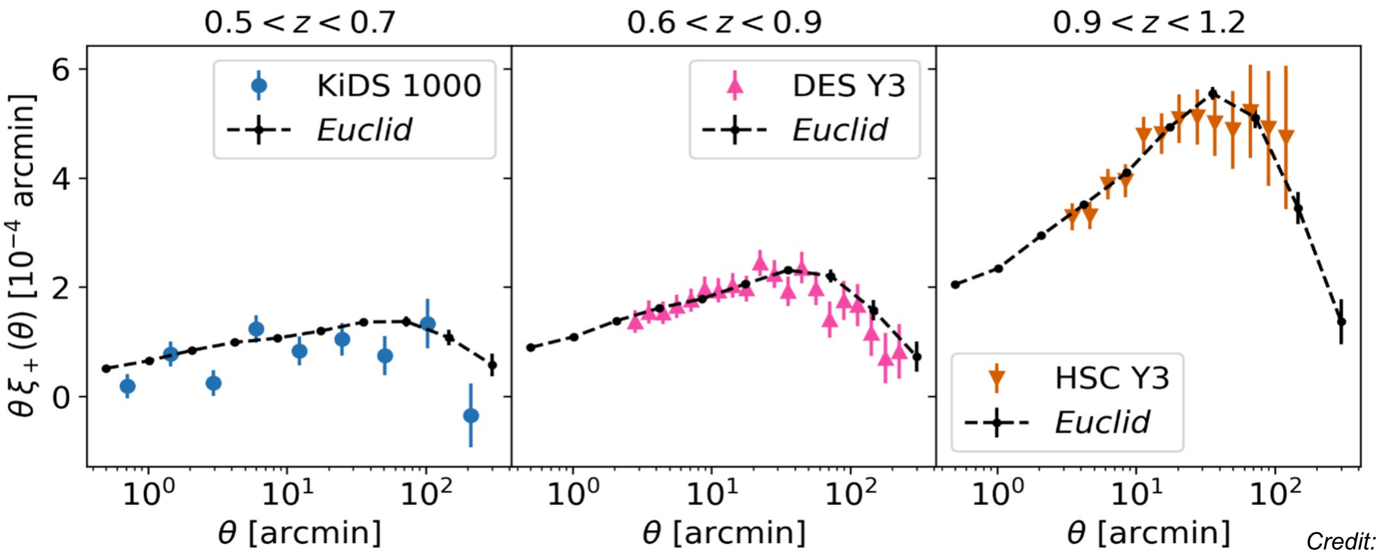
- Photometric survey: 3x2pt
- Spectroscopic survey: RSD and BAO
- Forecasts

Photometric : 3 x 2-pt analyses

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

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

Euclid’s statistical power *(photometric probes)*



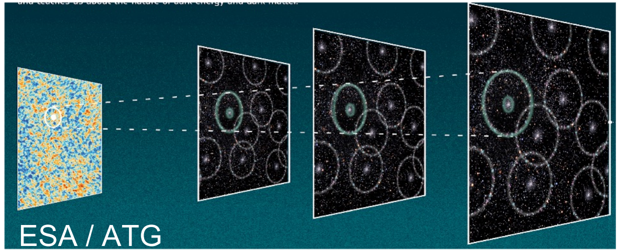
Credit: Mellier+ (2024)

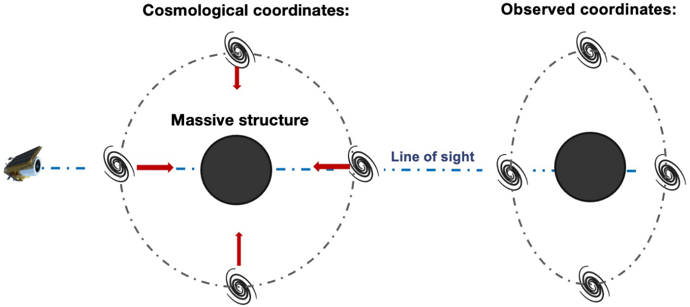
Order-of-magnitude increase in S/N compared to Stage III survey with galaxies following the same redshift distribution!

Spectroscopic: BAO and RSD

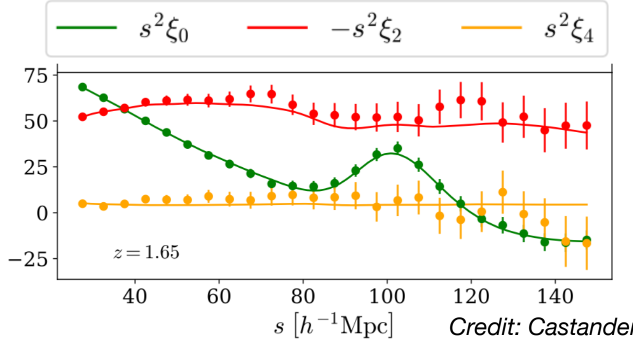
Sound horizon scale in CMB has become **BAO scale** in galaxy large-scale structure.

Spectroscopic redshift includes the velocity of the galaxies. This creates **anisotropies: RSD.**



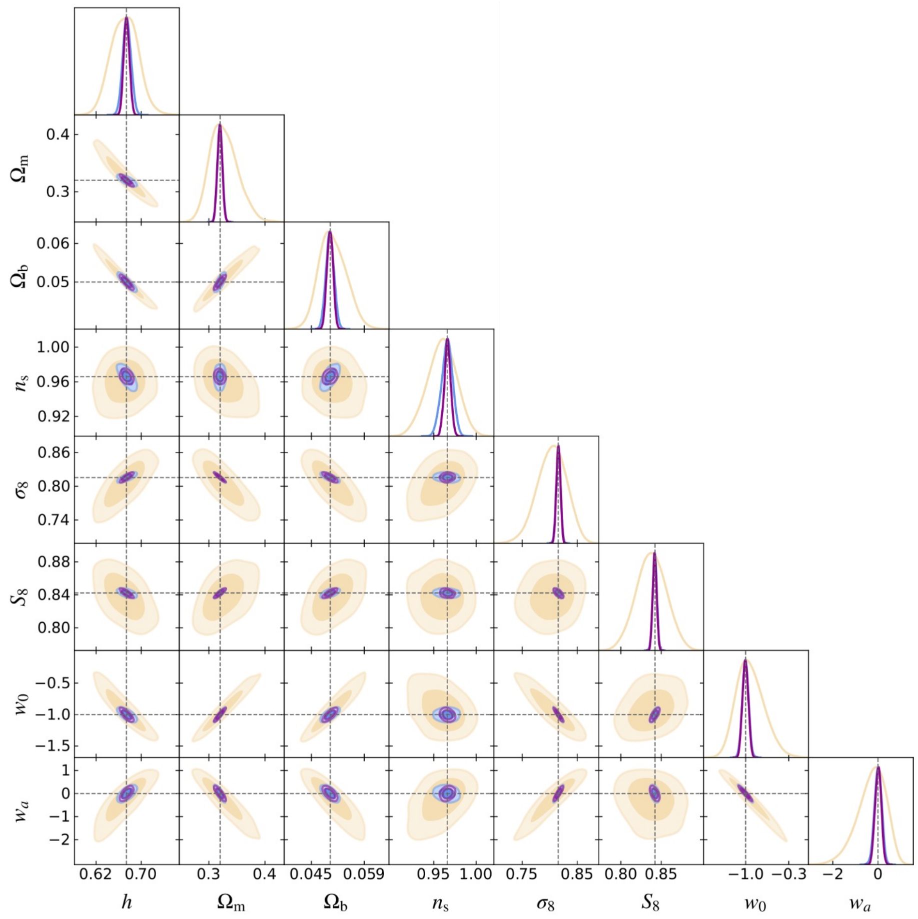


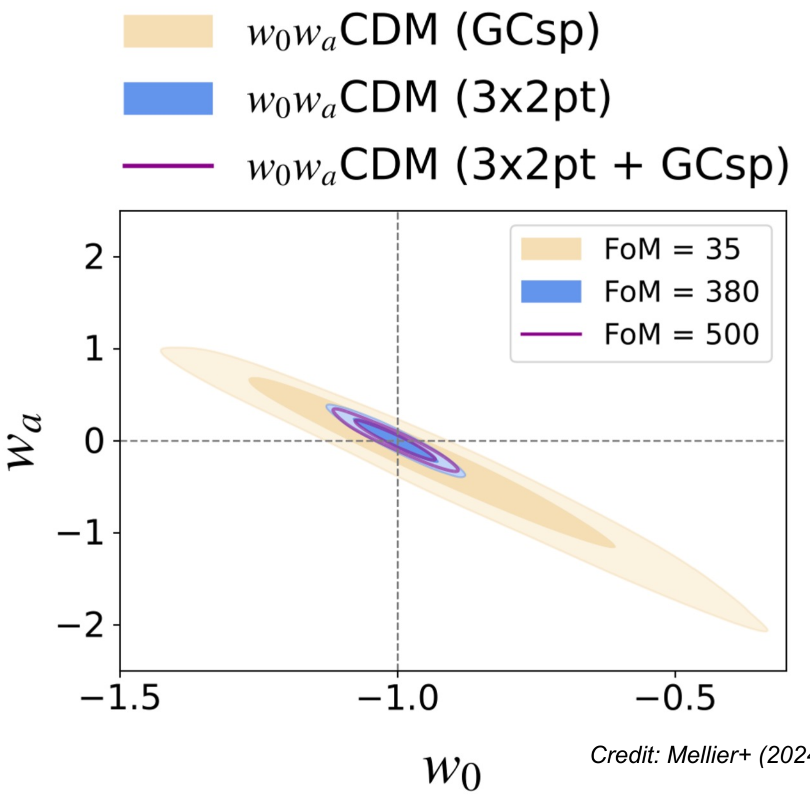
Redshift-space **two-point correlation function multipoles** of Hα galaxies in the Flagship simulation



Credit: Castander+ (2024)

Expected parameter constraints

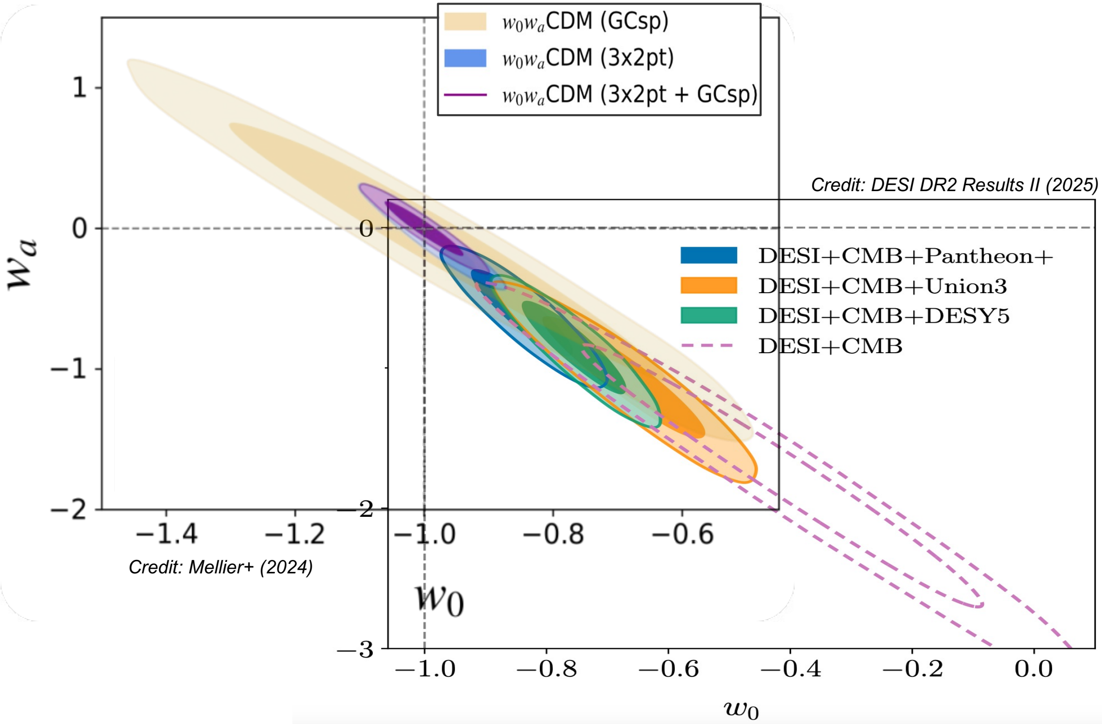




Credit: Mellier+ (2024)

Euclid Figure of Merit for dark energy

Euclid only probes projected to give tighter constraints than DESI+ CMB+SN.



Credit: DESI DR2 Results II (2025)

Credit: Mellier+ (2024)

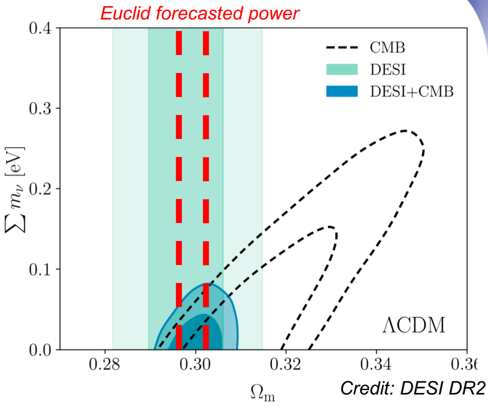
DE EOS. $\omega = P/c^2\rho$

$$\boxed{w(a) = w_0 + w_a(1-a)}$$

Forecasts: Neutrino

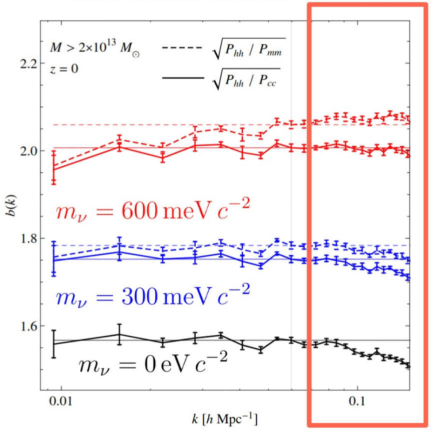
Two ways of constraining neutrino mass parameter:
- reducing CMB internal parameters degeneracies
- full shape analysis, measuring the scale dependant impact of massive neutrino (small scales)

Euclid forecasted power



Credit: DESI DR2 Results II (2025)

Non-linear scales



Emanuele Castorina et al. (2013)

DESI+CMB (2025): (peak at $\sum m_\nu$=0)

$$\sum m_\nu < 0.064\,\mathrm{eV} \quad (95\%,\ \mathrm{DESI{+}CMB}). \qquad (29)$$

Assuming normal hierarchy:
- Euclid alone: $\sigma(\sum m_\nu) \sim 0.053$ eV
- **Euclid + Planck will $\sigma(\sum m_\nu) \sim 0.023$ eV**

	$\sum m_\nu$[meV]
Euclid-only	
GC_{sp}	< 320
$WL+GC_{ph}+XC_{ph}$	< 260
$WL+GC_{ph}+XC_{ph}+GC_{sp}$	56
$WL+GC_{ph}+XC_{ph}+GC_{sp}+CC$	53
Euclid+CMB	
Euclid+*Planck*	23
Euclid+CMB-S4+LiteBIRD	16

Cf: Archidiacono+ (2024), arXiv 2405.06047

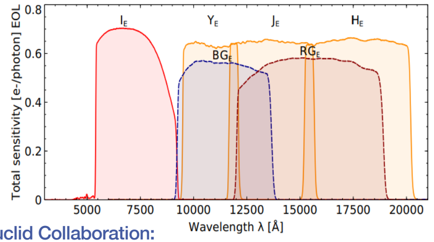
(some) Systematics

- Photometric sample: - External photometry
  - Redshift distribution

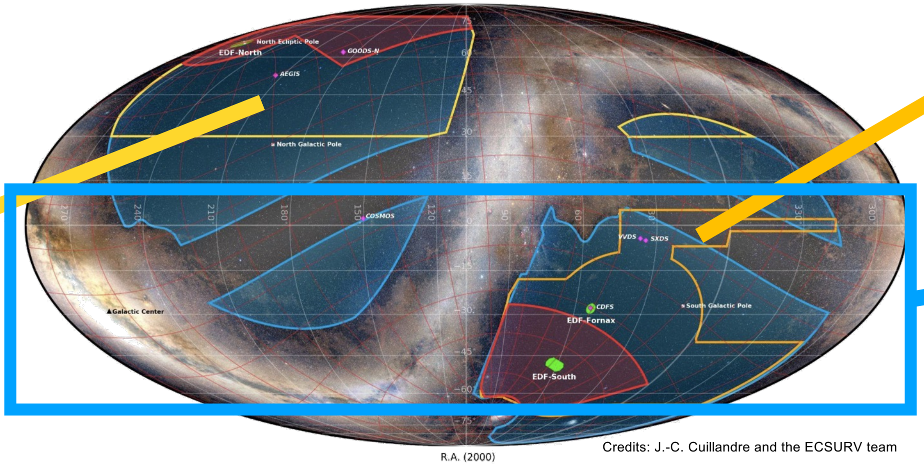
- Spectroscopic sample: - Interlopers

External photometry for photo-z and mask

- VIS and NISP **alone cannot** give us good photometric redshift. We need external photometry
- **We lose uniformity and need to split the data into 'regions'.**



Euclid Collaboration: Scaramella+ (2022)



Credits: J.-C. Cuillandre and the ECSURV team

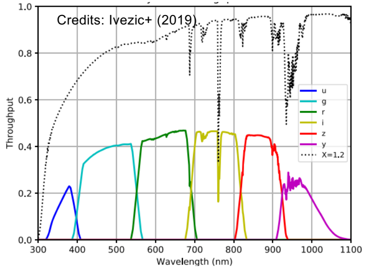
Euclid Wide Survey region of interest : 17,354 deg^2
DES, griz, 2013–19 : 4500 deg^2 overlap with the region of interest
UNIONS [CFIS / JEDIS–g / Pan–STARRS / WISHES], ugriz, 2017–27 : 4800 deg^2
Euclid DR1 area, 2023 : 2500 deg^2
Euclid Deep Fields [total 43 deg^2]

UNIONS

u&r by CFHT
i by PanSTARRS
g&z by Subaru

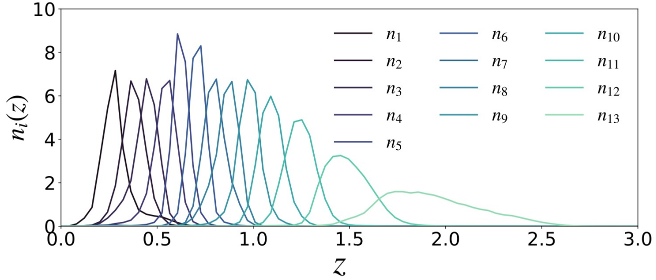
The Dark Energy Survey,
g, r, i, z, Y

VERA C. RUBIN OBSERVATORY



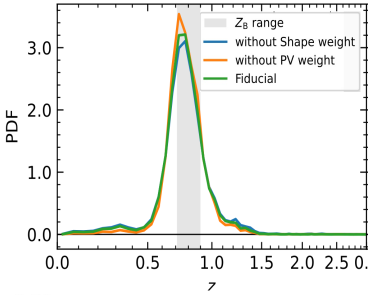
Photometric calibration of the redshift distributions

- Having photo-z estimates in hand, we can split our data sample into bins, with photo-z cuts

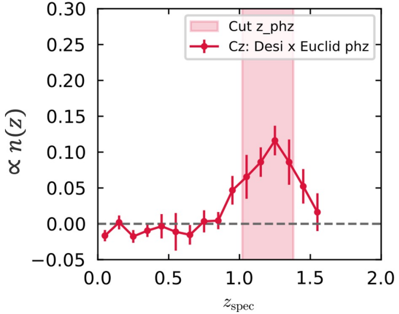


- The modelling requires an precise estimate of the redshift distribution of the bins.

Calibration with colour-based technique via a self-organising map.
Credit: Wright+ (2025)

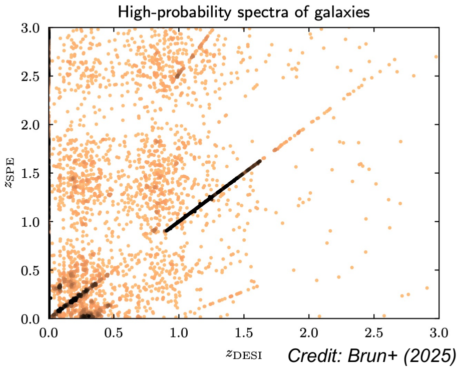


Calibration based on external spectroscopic cross-correlations
Credit: W. d'Assignies

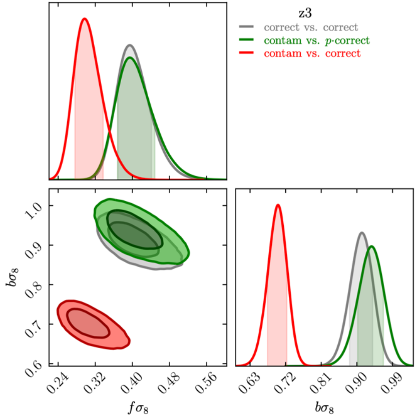


Interlopers in the spectroscopic sample

- Our **sample is contaminated by noise and lines interlopers.**



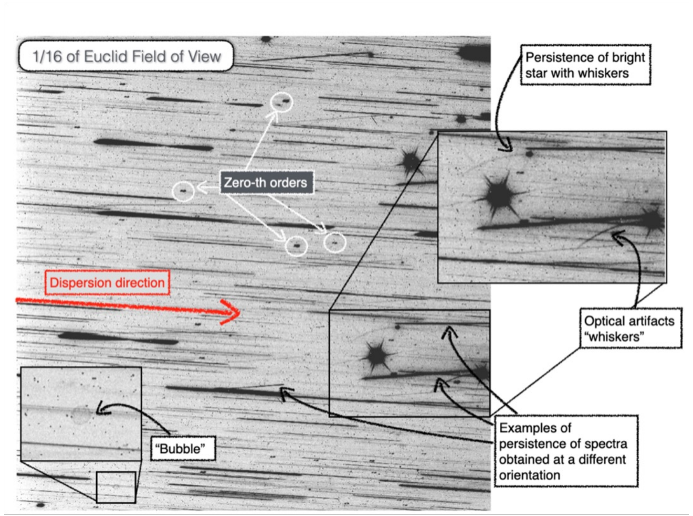
Credit: Brun+ (2025)



Credit: Risso+ (2025)

Reducing the interlopers contamination, and modelling their properties, we can still do cosmology.

- Various origins, and intensive work to 'clean' the sample, using preliminary Euclid data, for DR1.



Credit: C. Scarlata

And many more …

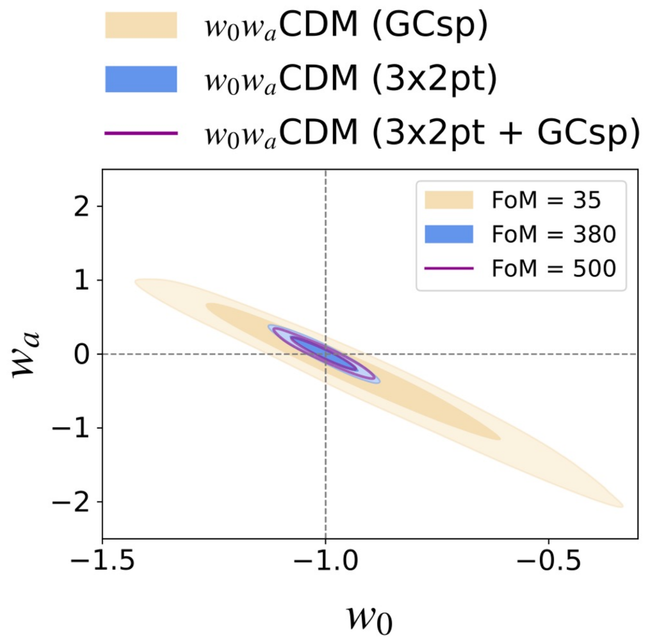
Conclusions & outlook

Outlook

Euclid is both a photometric and a spectroscopic survey. The goal is to map one third of the sky (14000 deg^2). First data release after one year of operations (2000 deg^2, mid-2026).

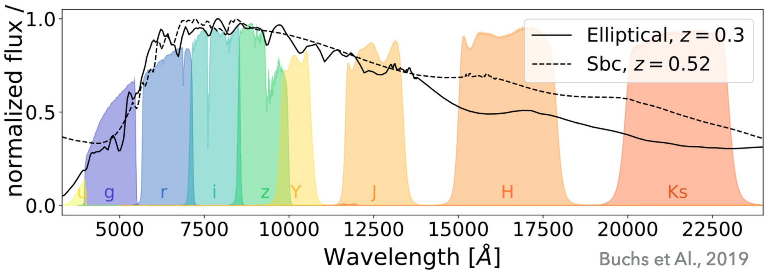
Euclid aims to unveil the nature Dark Energy by using weak gravitational lensing and galaxy clustering, and constrain **the standard model parameters, including the neutrino mass.**

Requires exquisite systematic understanding, control, and calibration. Being in space offers advantages, but requires new types of calibration and complex processing.

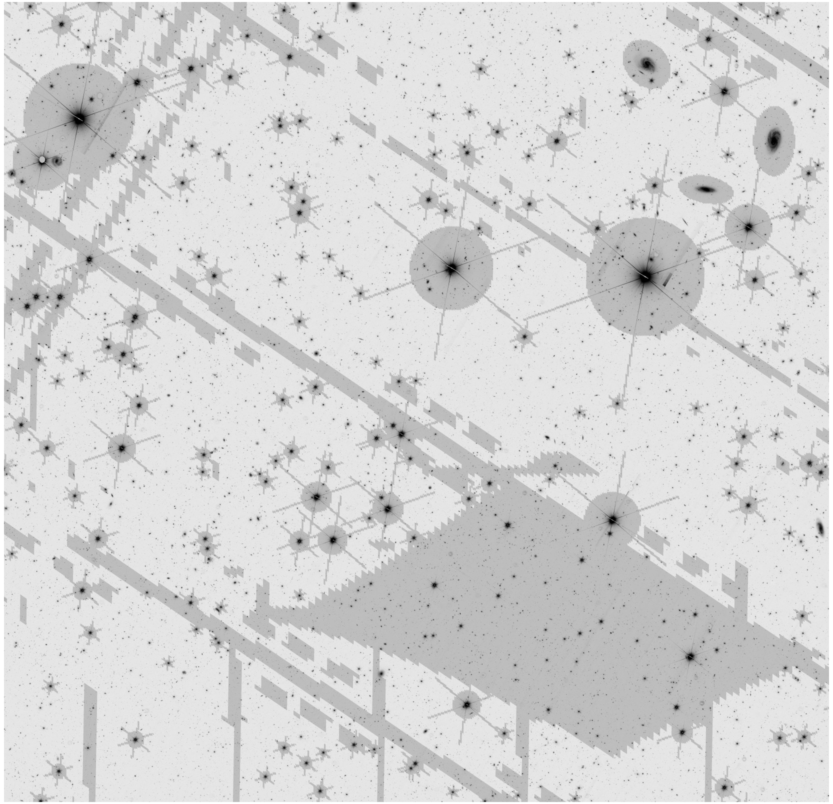


External photometry for photo-z and mask

- With more bands, we get better photo-z.

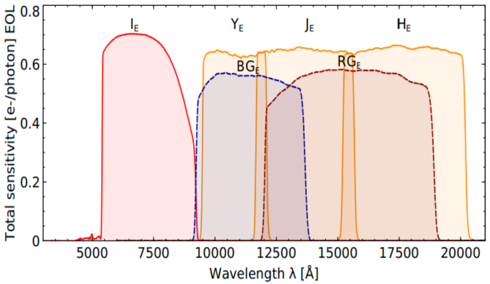


- Not only we need an **Euclid mask**, but we should combine with **ground based survey masks** as we are using their photometry !



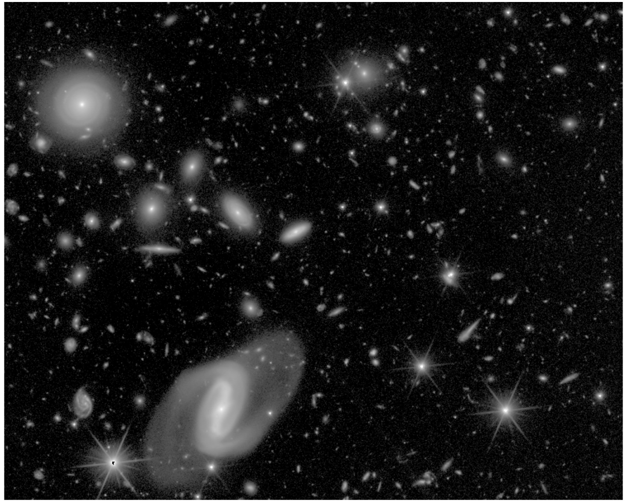
Credit: W. Hartley

Photometric samples

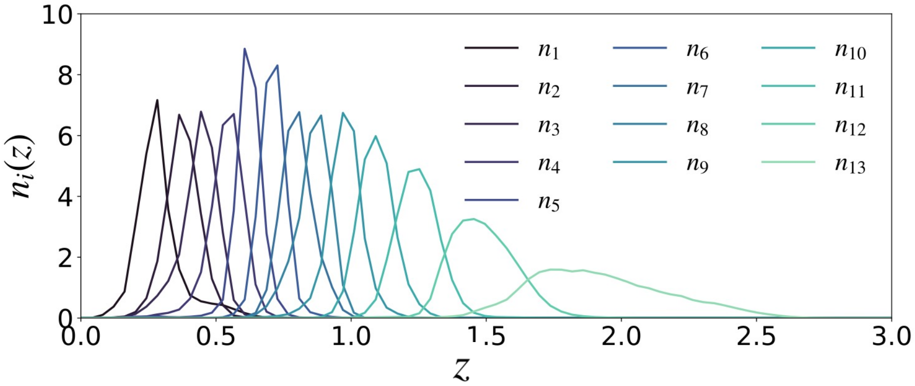


Euclid Collaboration: Scaramella+ (2022)

- Photometric samples: **angular positions**, **galaxy shapes**, and redshift estimates (the so called '**photo-z**').
- A VIS-processed stack using 42 exposures, or about 10 times the exposure time of the wide survey.

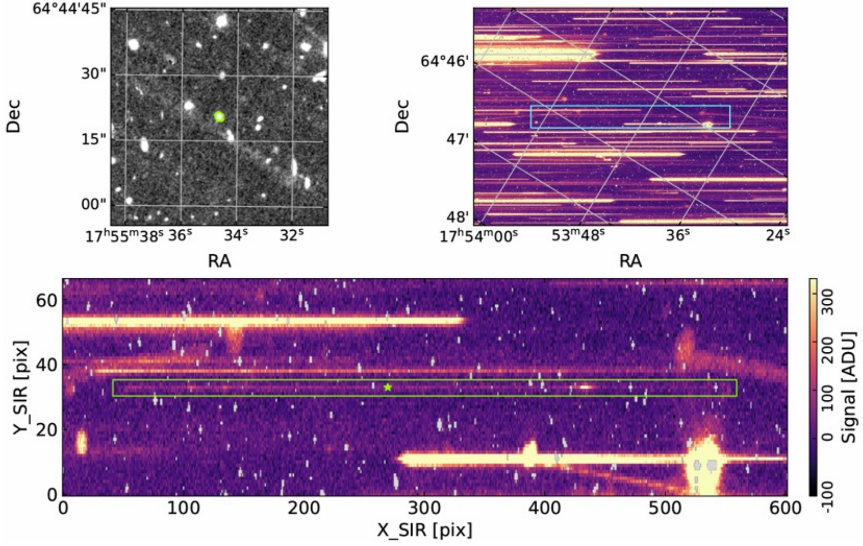


- Vis (I) AB magnitude limit of 24.5 (S/N of 10)
- NIR bands YJH in addition to VIS, AB magnitude limit of 24
- Photometric data are distributed into redshift bins (usually equipopulated), with photo-z cuts.



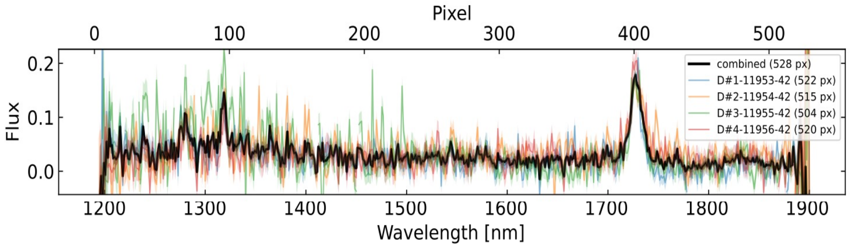
Spectroscopic sample: grism image

- Euclid uses the slitless spectroscopy technic.
- Top : A galaxy at z = 1.63 (green on the left) and a spectroscopic exposure.
- Bottom : Green box is the effective extraction window. Green star : location of
λ = 1504 nm reference.



Credit: Copin+ (2025)

- Combination of the *single-dither spectra* (black).
- We get: $\lambda_{obs}/\lambda_{H\alpha}$= 1730/656=1+1.63=1+z)



Credit: Copin+ (2025)

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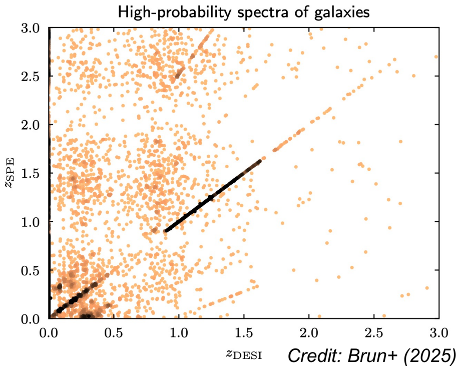
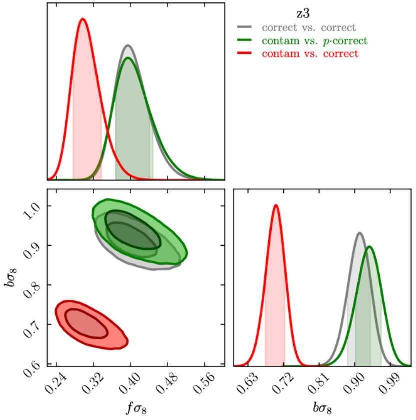


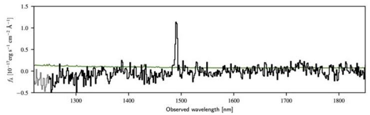
Credit: Brun+ (2025)



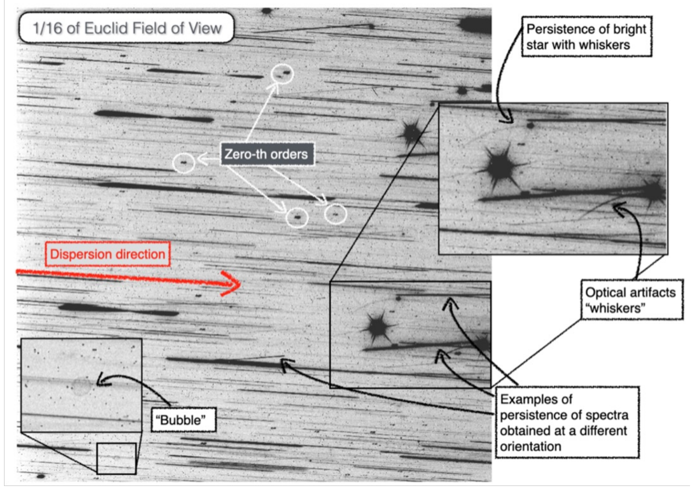
Credit: Risso+ (2025)

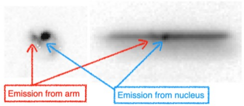
Reducing the interlopers contamination, and modelling their properties, we can still do cosmology.

- Various origins, and intensive work to 'clean' the sample, using preliminary Euclid data, for DR1.



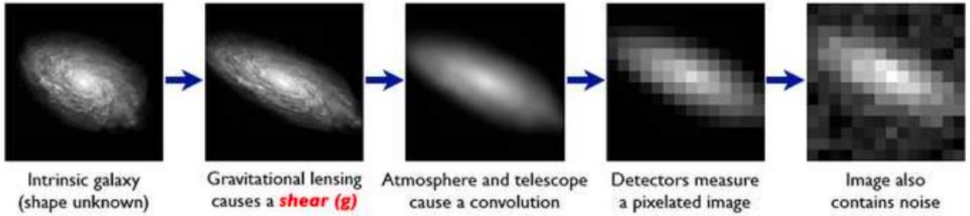
Credit: Brun+ (2025)





Credit: C. Scarlata

Galaxy shapes



Credit: Bridle+ (2006)

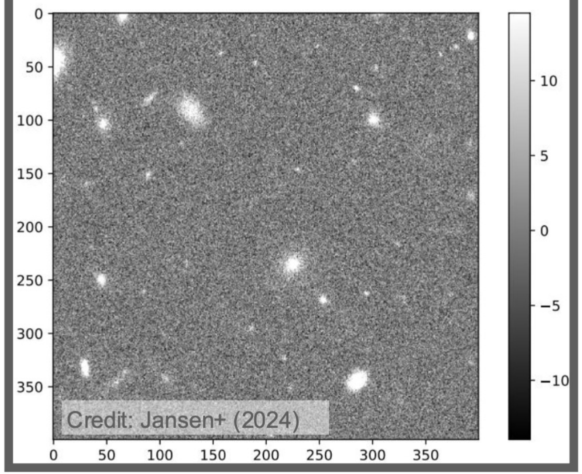
Shape measurements are difficult due to

- PSF convolution
- Pixelization
- Image noise
- Detection probabilities and blending

PSF is forward-modelled, but continously calibrated

Realistic image simulations are used to validate and calibrate shape measurement

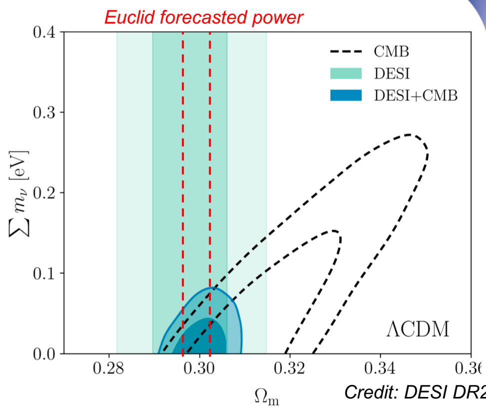
VIS-like simulated image



Forecasts: Neutrino

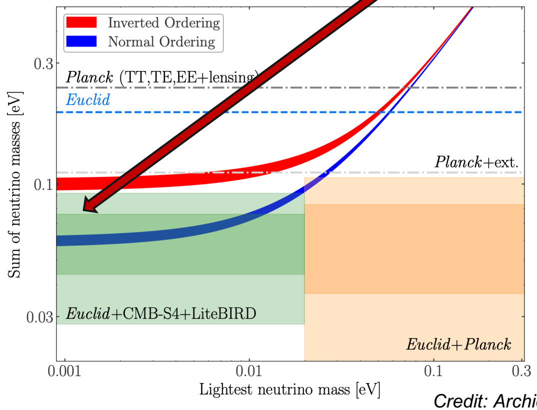
Two ways of constraining neutrino mass parameter:

- reducing CMB internal parameters degeneracies
- full shape analysis, measuring the scale dependant impact of massive neutrino (small scales)

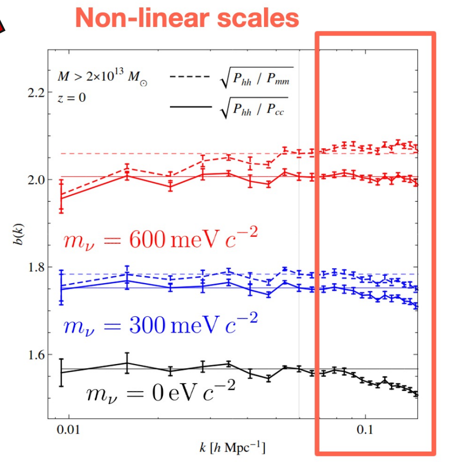


Credit: DESI DR2 Results II (2025)

Assuming minimal neutrino mass, **Euclid+CMB-S4+LiteBIRD will rule out the inverted ordering at 2.5σ level** (green vs red).



Credit: Archidiacono+ (2024)



Emanuele Castorina et al. (2013)

Parameter inference

CLOE: Cosmological Likelihood for Observables in Euclid

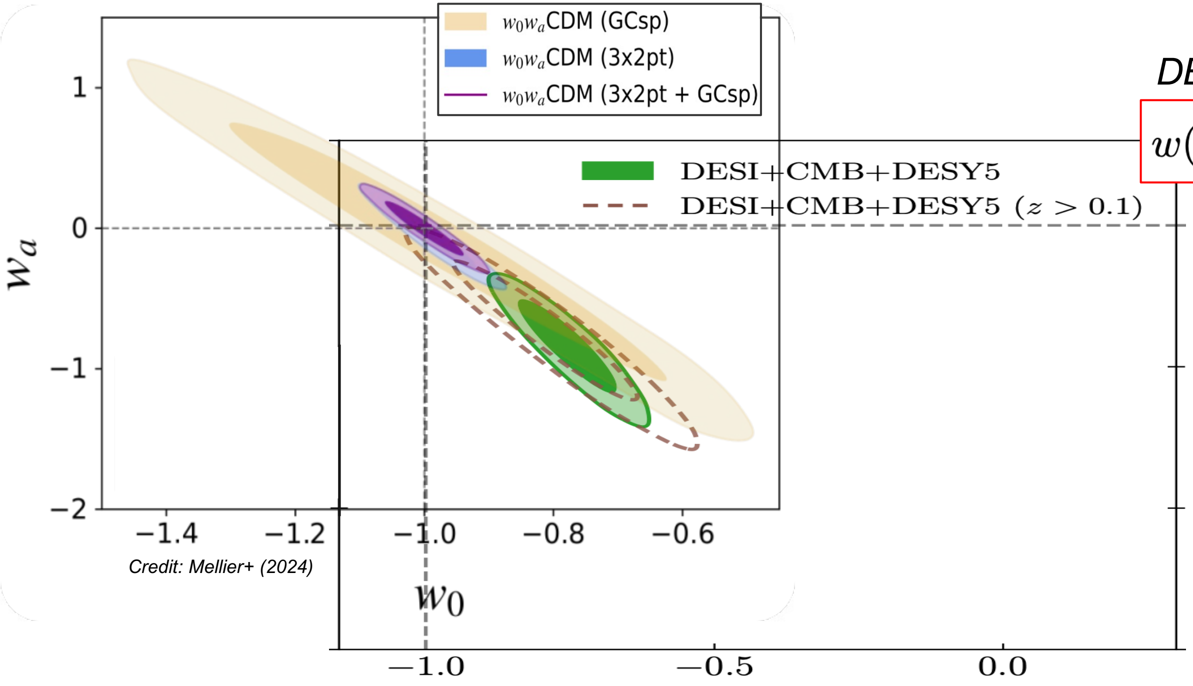
$$\underbrace{-2\log\mathcal{L}(\mathbf{d}\,|\,\theta)}_{\text{Likelihood}} = [\underbrace{\mathbf{t}(\theta)}_{\text{Theory vector}} - \underbrace{\mathbf{d}}_{\text{Data vector}}]^T\,\underbrace{C^{-1}}_{\text{Data covariance}}\,[\mathbf{t}(\theta) - \mathbf{d}]$$

- ‘Theory vector’ has to include systematics parameters for photometric and spectroscopic probes.
- Standard model parametrisation + extension (DE, gravity, neutrino,…).
- Modelling of physics at small scales, with variety of models.
- Data vector of single probes, or combinations, 1x2, 3x2, 3x2+ GCsp, …

Dark Energy

Euclid Figure of Merit for dark energy

Euclid only probes projected to give tighter constraints than DESI+ CMB+SN.



Credit: Mellier+ (2024)

Credit: DESI DR2 Results II (2025)

DE EOS. $\omega = P/c^2\rho$

$$\boxed{w(a) = w_0 + w_a(1-a)}$$