
Image courtesy of ESA

UNIVERSITÀ DEGLI STUDI DI TRIESTE

Dipartimento di Fisica

Dipartimento d'Eccellenza 2023-2027

# Euclid: a space mission to map the dark Universe

**Pierluigi Monaco**

on behalf of the Euclid Collaboration

(Trieste University, INAF, INFN, IFPU, ICSC)

Neutrino telescopes

29 September 2025, Padova

euclid consortium

esa euclid

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

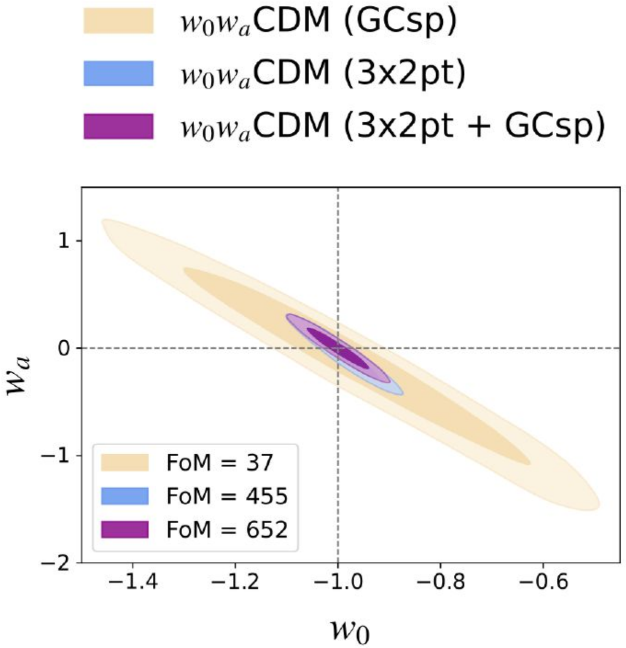
ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

# Euclid (2023 - 2029+)

Satellite mission led by ESA, Launched July 1, 2023
EC: Mellier et al 2025, A&A 697, id.A1

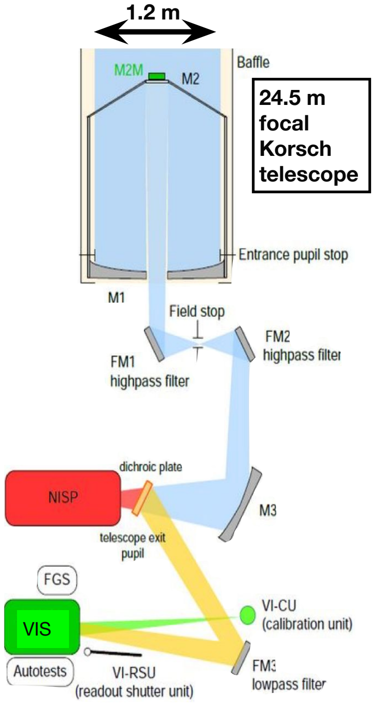
cosmology:
**galaxy weak lensing**
**galaxy clustering**
clusters of galaxies
galaxy voids
cross-correlation with CMB
strong lensing

**formal goal:**
**FoM($w_0$,$w_a$)> 400**

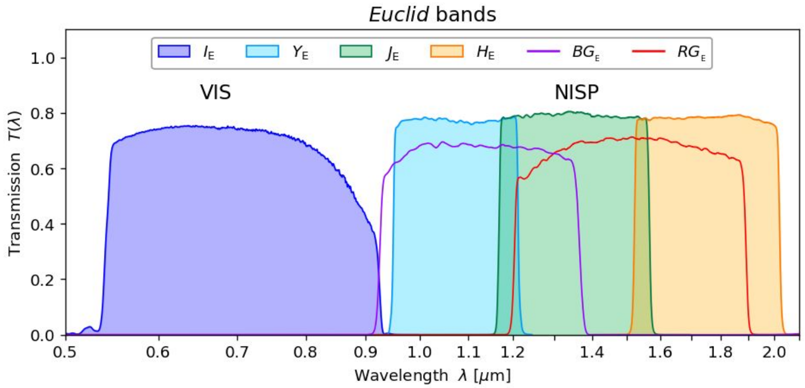


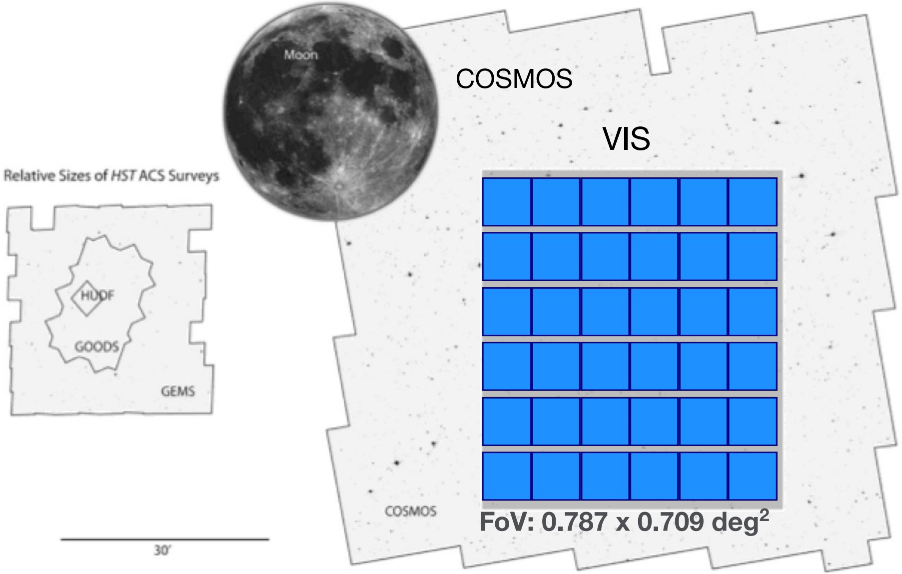

and **legacy science**:
galaxy evolution, primeval Universe, local Universe, Solar System objects...

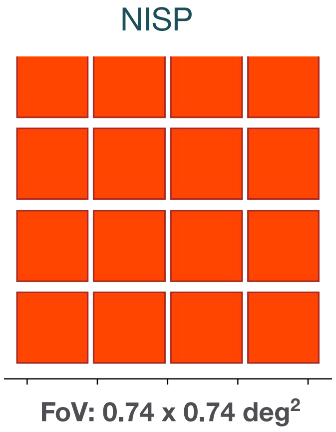
# A dual wide-field imager




Overview of the PLM sub-systems – Courtesy Airbus Defence and Space.



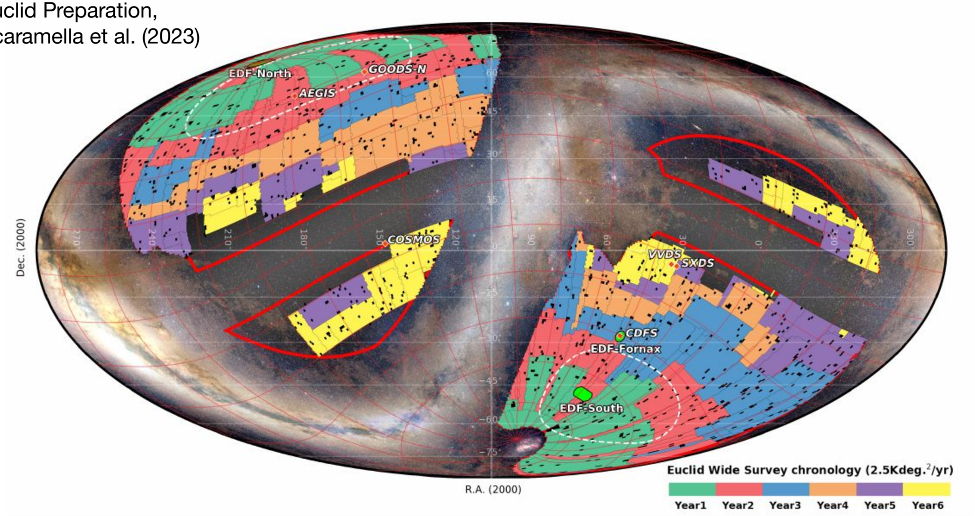

*Credit: Space Telescope Science Institute/Nick Scoville (Caltech)*

# Deep and wide fields in Euclid

Wide survey:

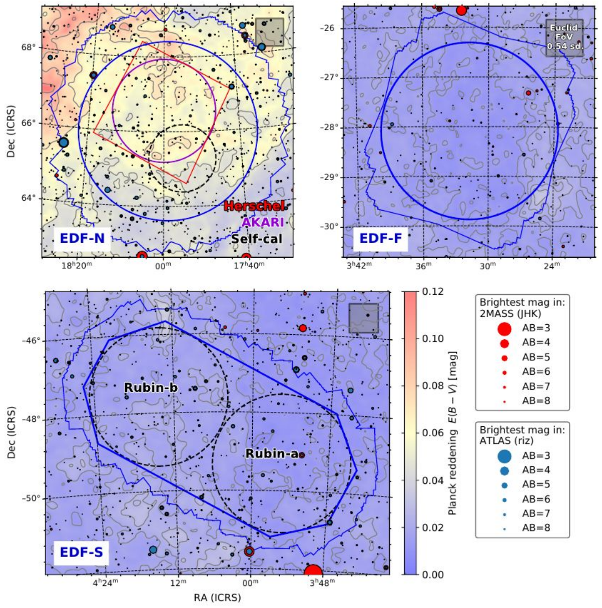
- 14,000 deg$^2$
- VIS and NIR photometry
- slitless spectroscopy

Euclid Preparation,
Scaramella et al. (2023)

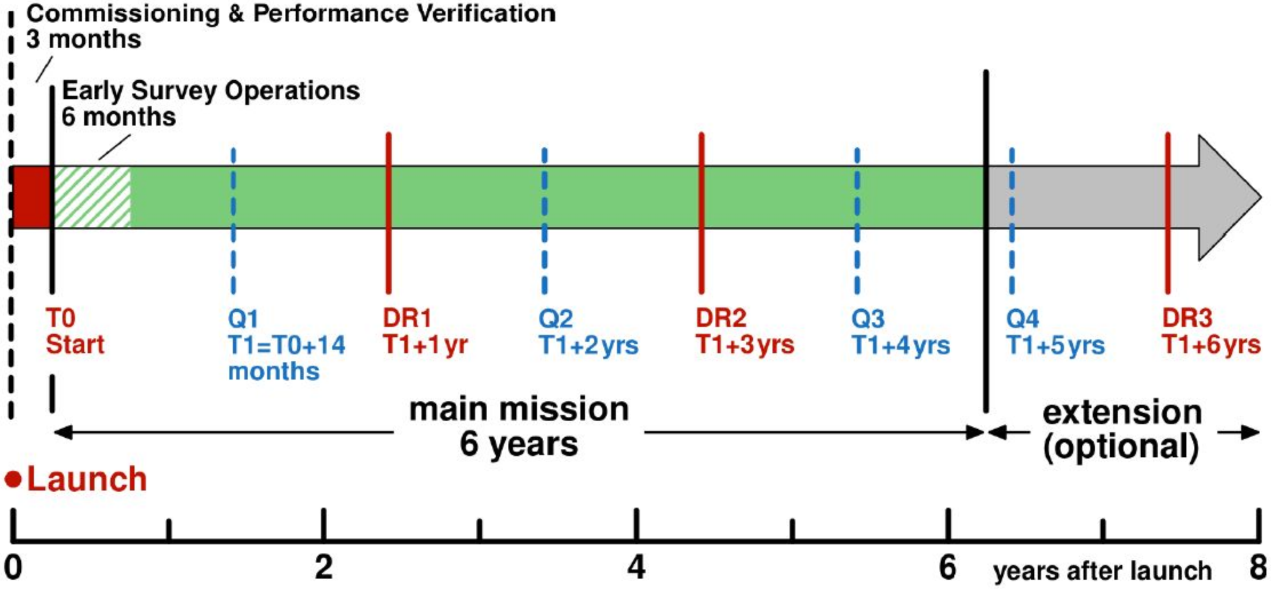



Deep survey:

- 53 deg$^2$
- 15 wide-like passes (red grism)
- 25 with blue grism

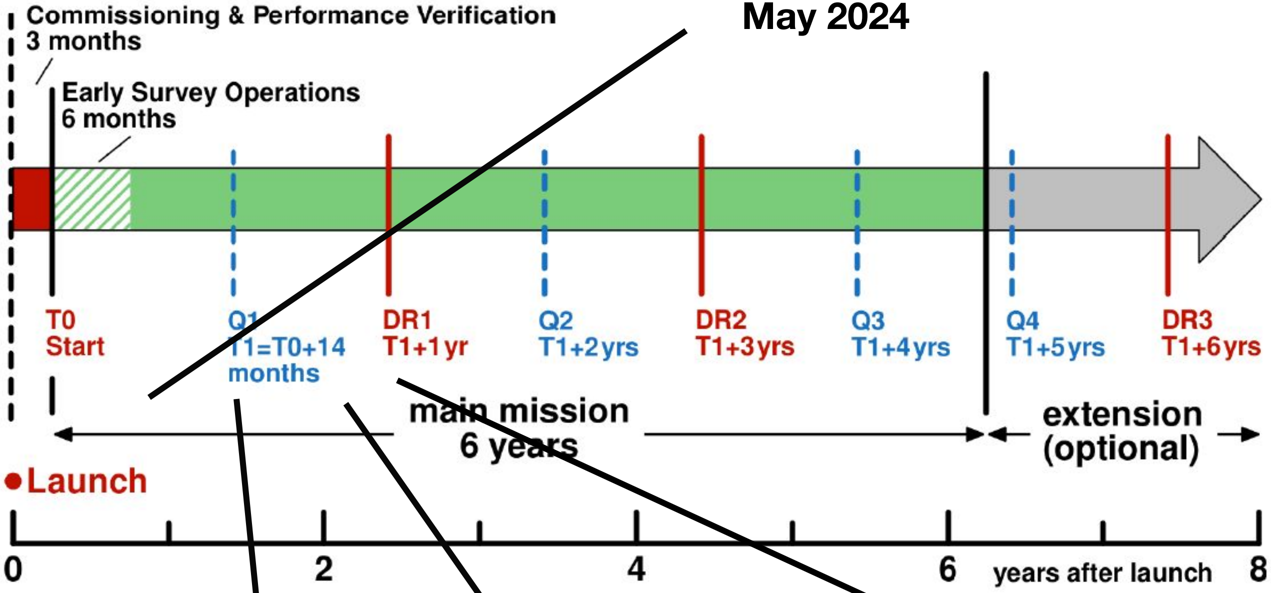


# Timeline




1 July 2023

# Timeline




Early Release Observations: May 2024

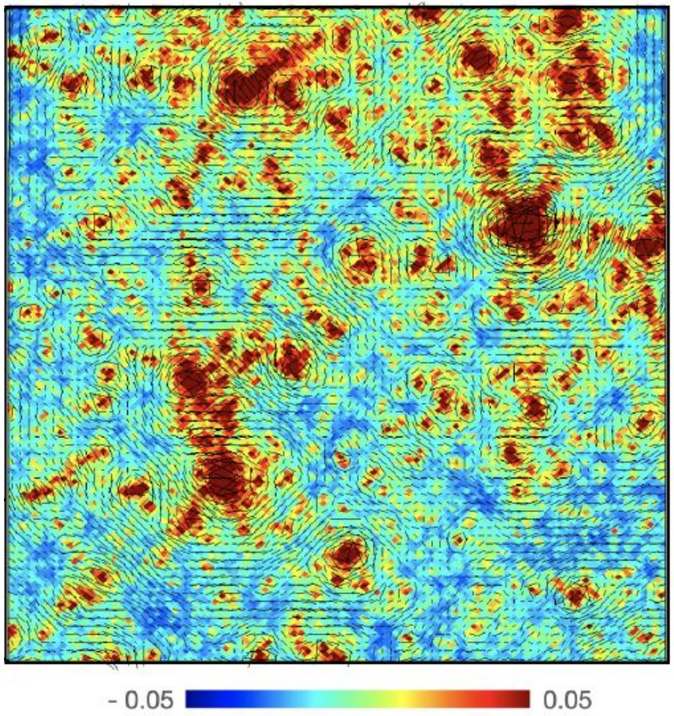
1 July 2023

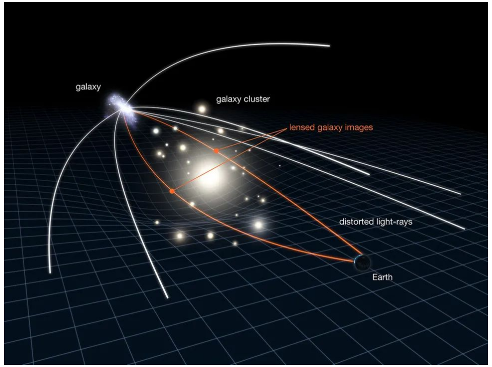
Q1: March 2025

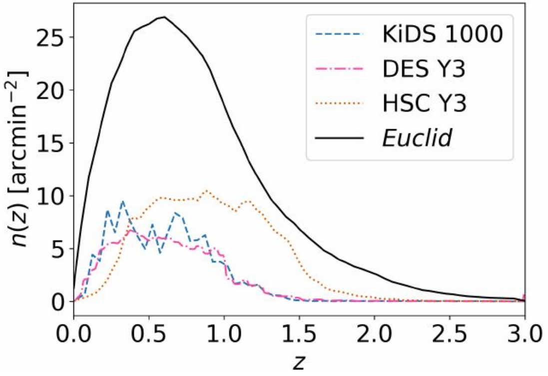
DR1 released to EC: March 2026

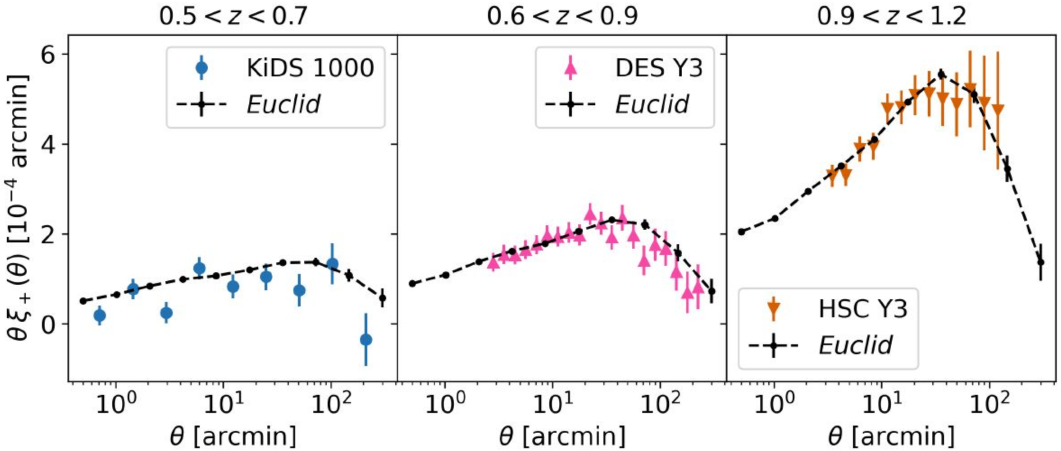
DR1 public
October 2026
~2000 sq deg

# Photometry: galaxy weak lensing

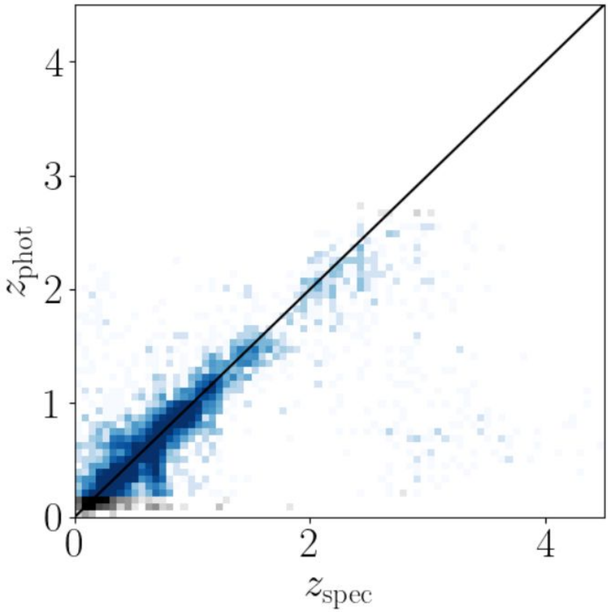


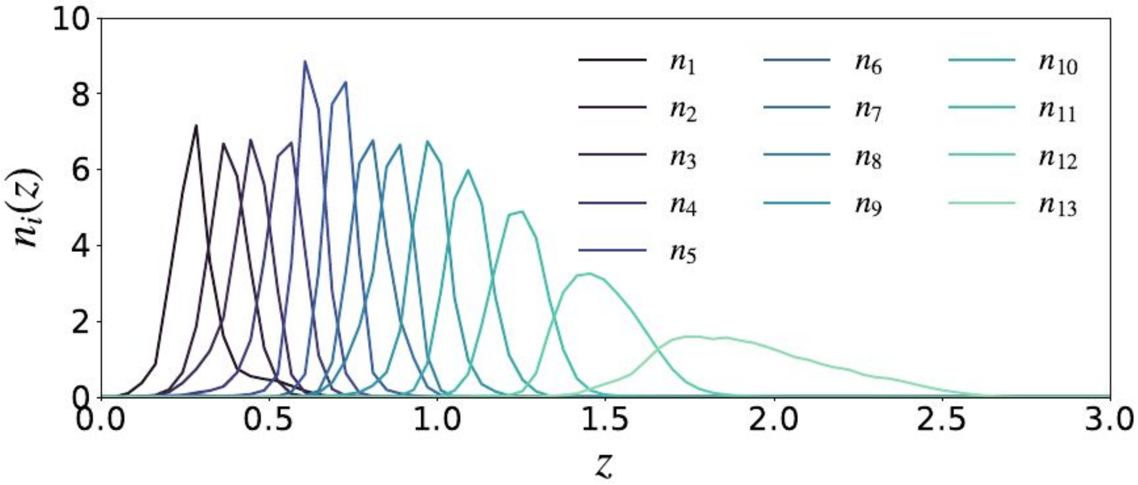



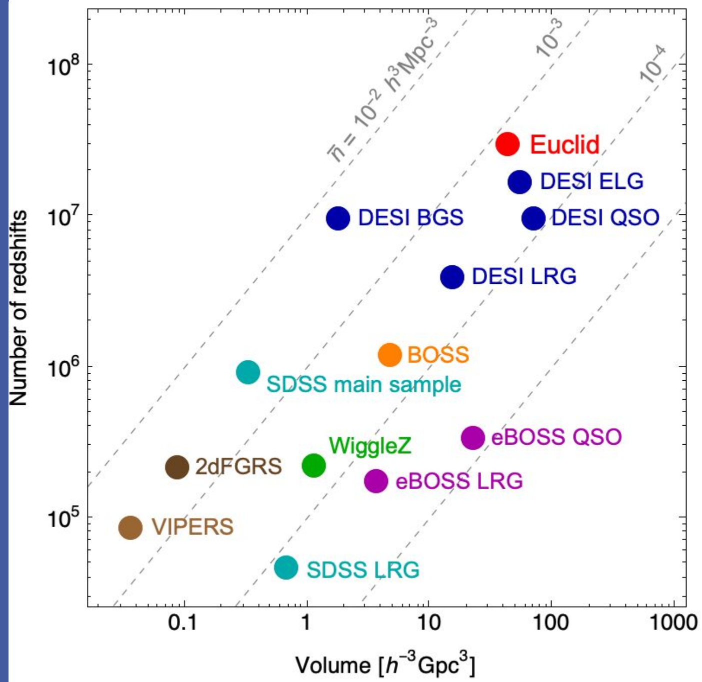



# Photometry: galaxy clustering

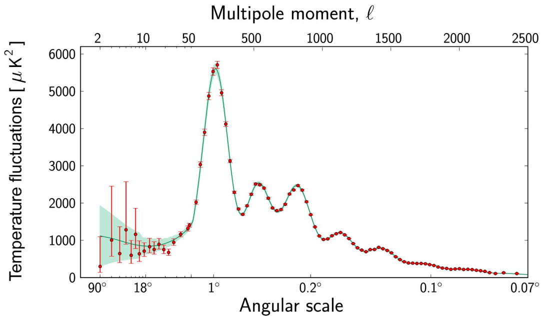


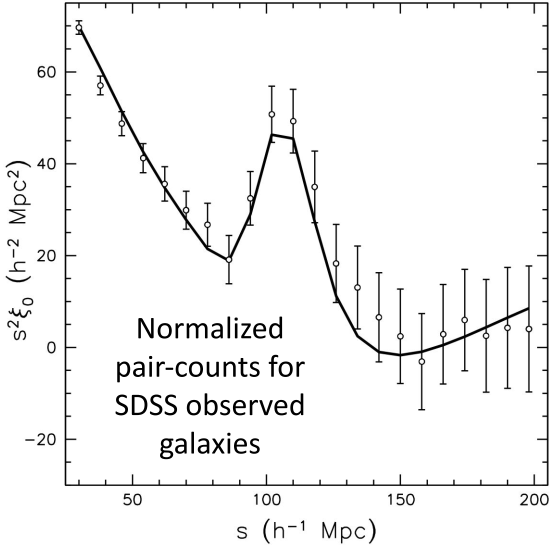
# Spectroscopy: galaxy clustering



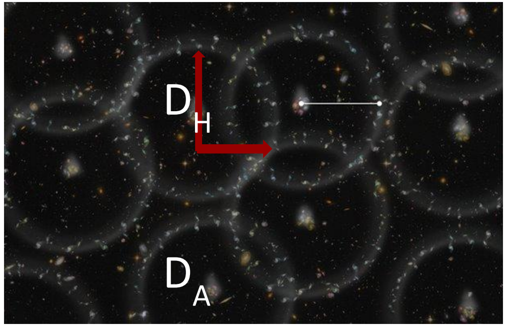
# BAO as a standard ruler




Acoustic waves move material in the early (<300,000 years) universe



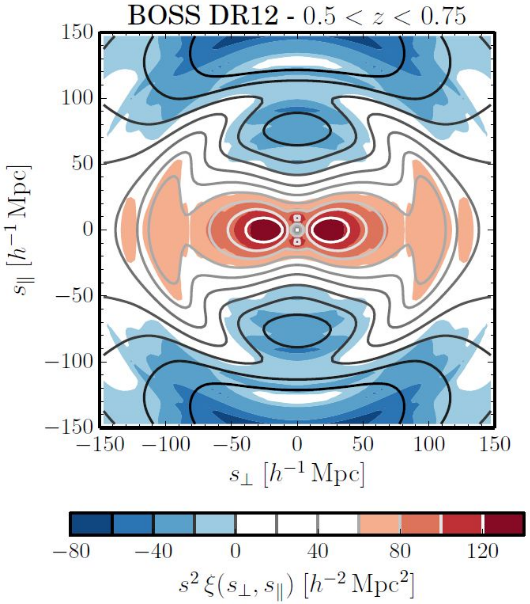

Galaxies form concentrations of mass; we see the imprint of the acoustic waves in the galaxy distribution

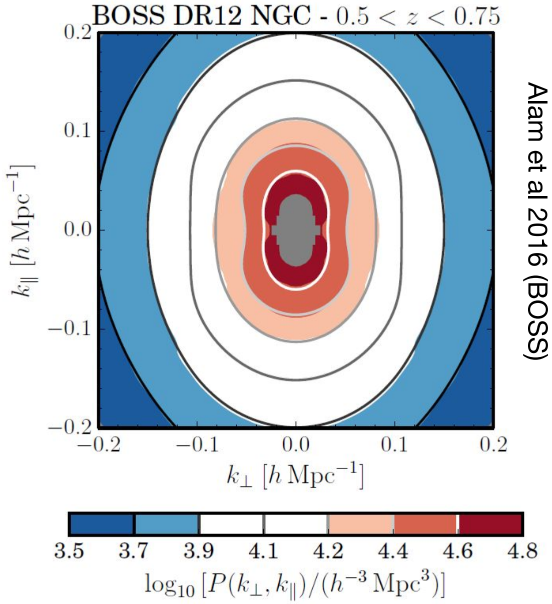



The projected scale of the acoustic waves gives a standard ruler with which to measure the universe

# RSD in 2-point clustering

$\xi(r_p,\pi)$



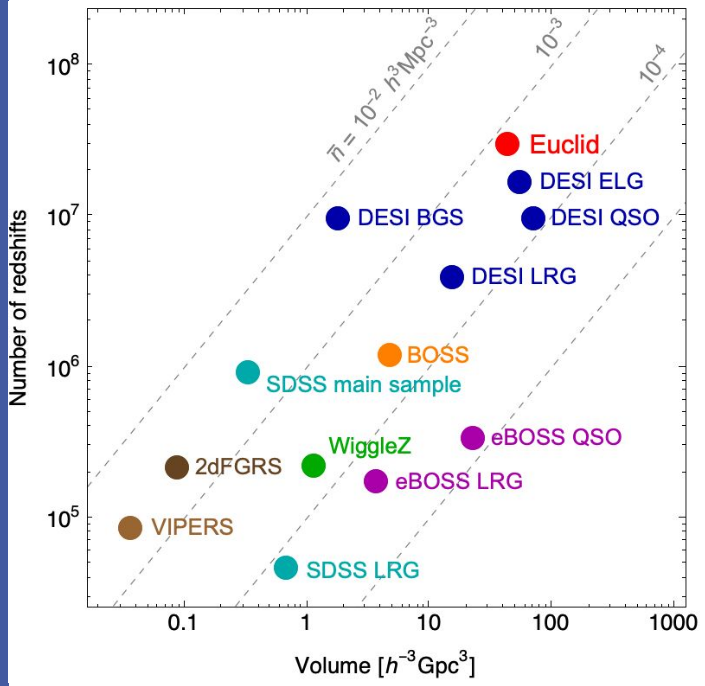



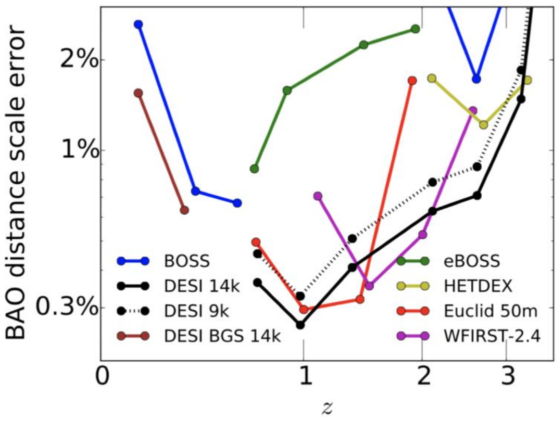

Alam et al 2016 (BOSS)

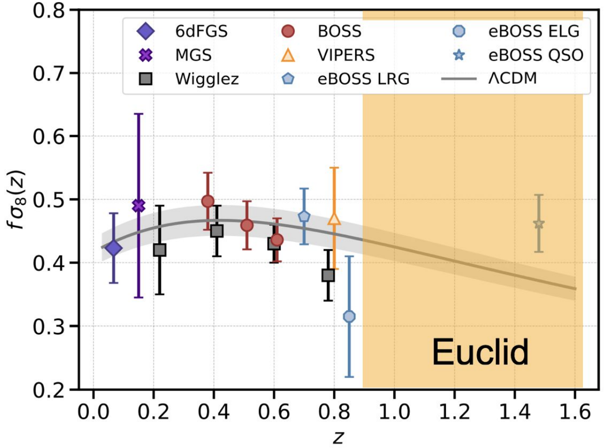
$P(k,\mu)$

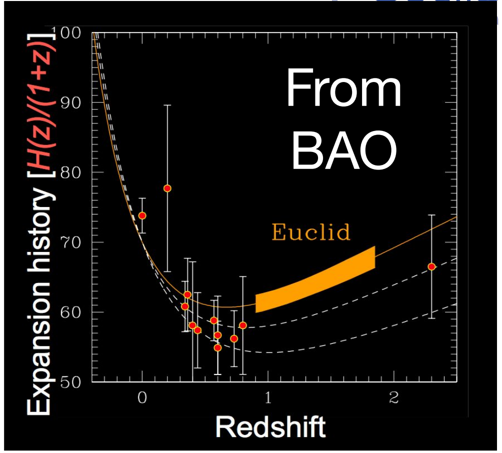
The measured pre-reconstruction correlation function (left) and power spectrum (middle) in the directions perpendicular and parallel to the line of sight

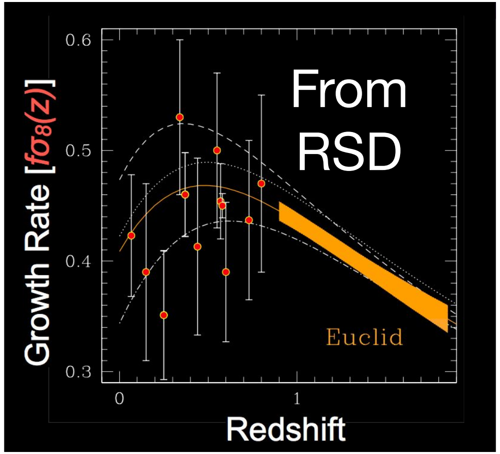
# Spectroscopy: galaxy clustering



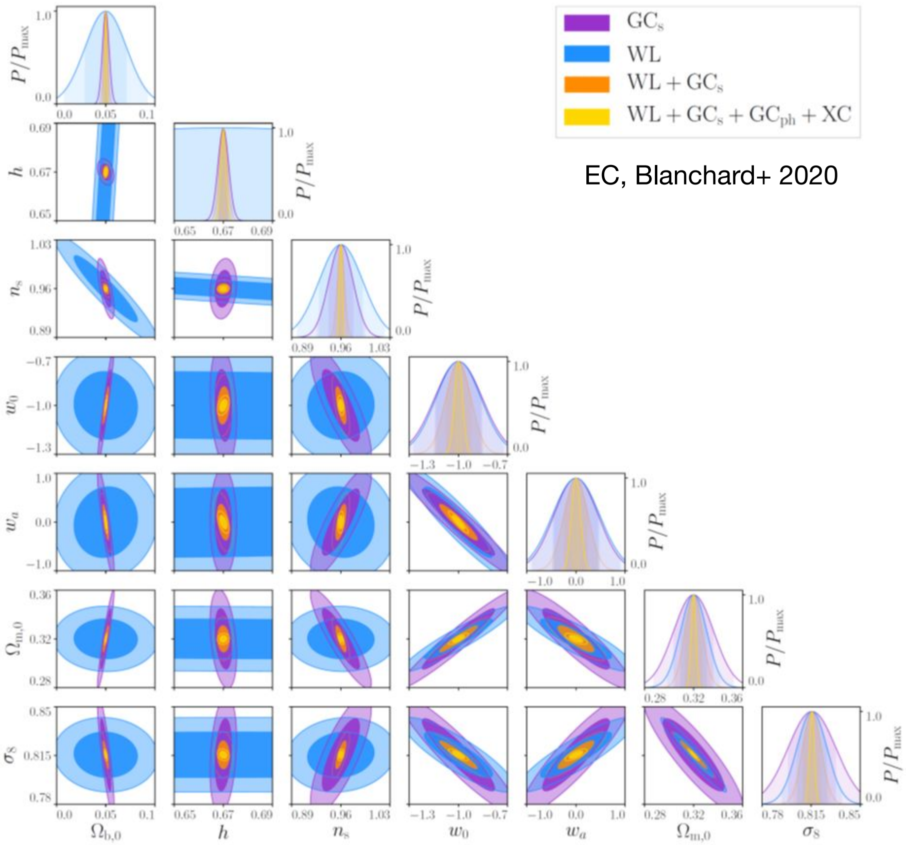
# Probe combination

**Galaxy weak lensing**:
is a probe of integrated matter density
does not rely on assumptions on galaxy bias
it can be combined with photometric clustering
=> **3x2pt**
main systematics:

- galaxy intrinsic alignments
- effect of baryons on small scales

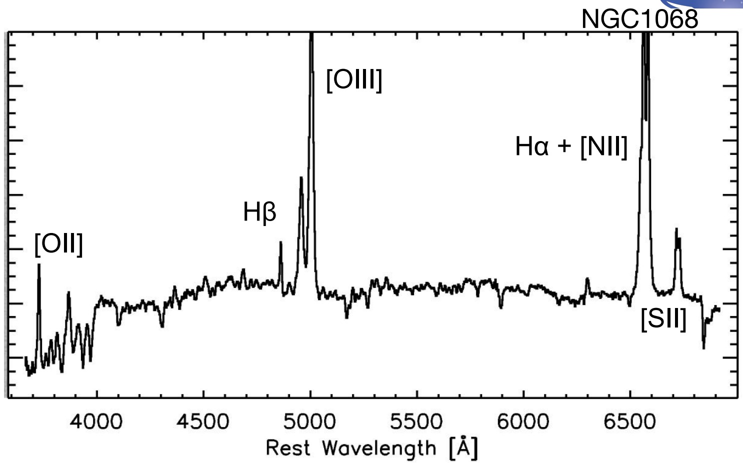
**Spectroscopic clustering**:
BAO + RSD are powerful complementary probes
galaxy bias is a theoretical nuisance
main systematics:

- angular fluctuations of survey depth
- redshift errors



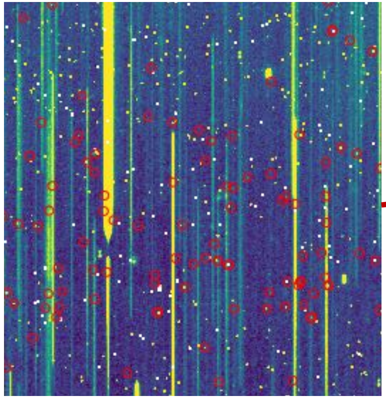

EC, Blanchard+ 2020

# Slitless spectroscopy

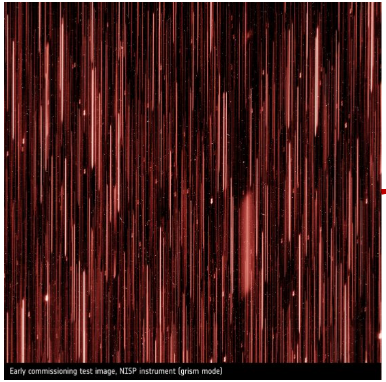



Credits: B. Granett

simulated



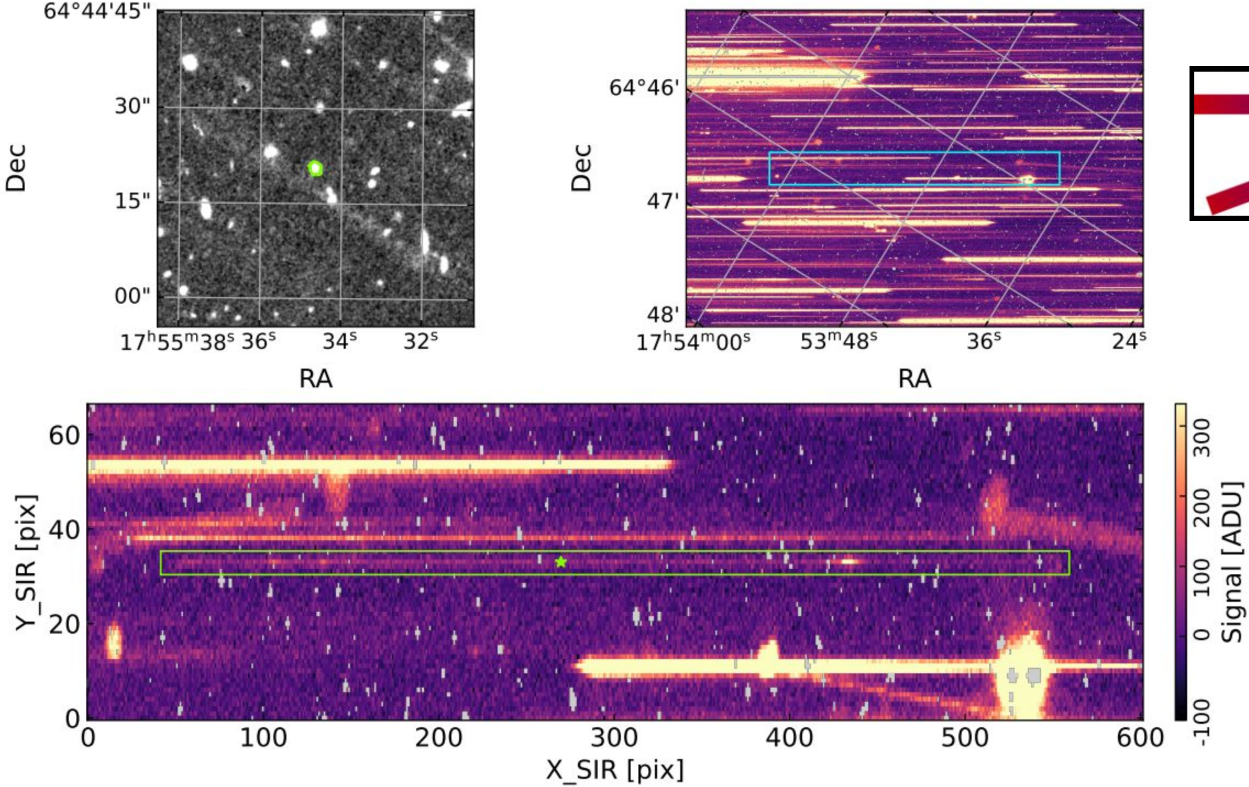
real

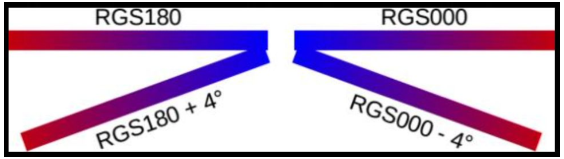



- All photons pass the grism (no slits or fibers)
  - Emission line galaxies are the main target
  - **No photometric selection required**
  - Efficiency loss due to higher background
- Euclid is the **first large-scale application** of this technique
- Slitless spectroscopy is technically simpler (no fibers), but the resulting **selection function** is complex
- Low signal-to-noise needed to have a dense sample
  => **high level of redshift errors**

# Slitless spectroscopy

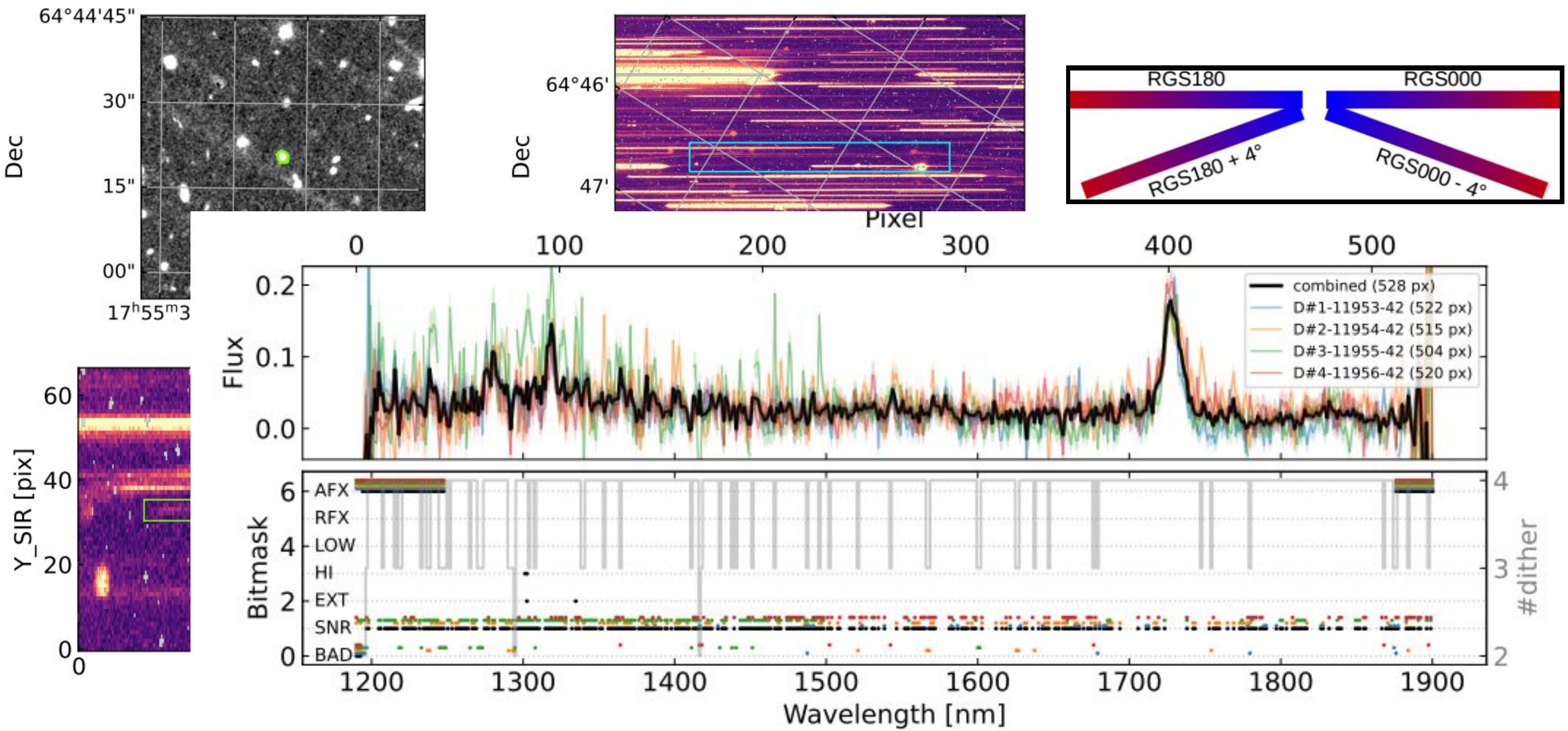
EC-Q1, Copin et al., arXiv:2503.15307



# Slitless spectroscopy

EC-Q1, Copin et al., arXiv:2503.15307



# Purity and completeness

Due to the high background, the fraction of galaxies with a correct redshift is not expected to be very high.

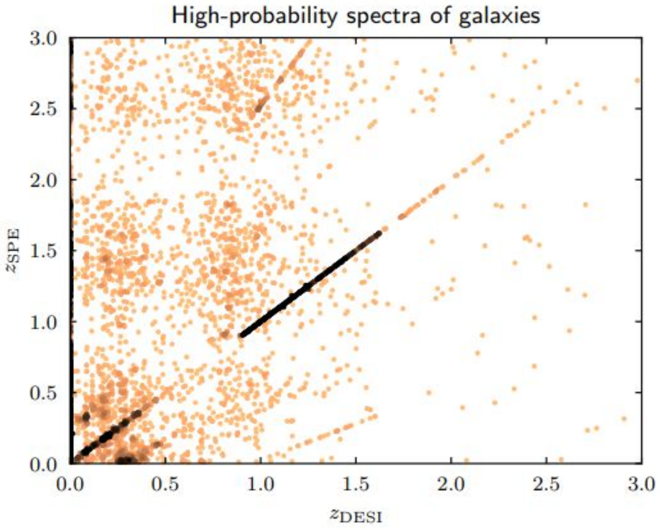
In Q1 data the fraction of correct redshifts (purity) was still low, due to a large number of bad redshifts.

We expect:

- **line interlopers**: galaxies with a detected line that is misinterpreted as an Halpha line
- **noise interlopers**: galaxies without prominent lines, where a noise fluctuation or a detector feature not perfectly removed is interpreted as a line.

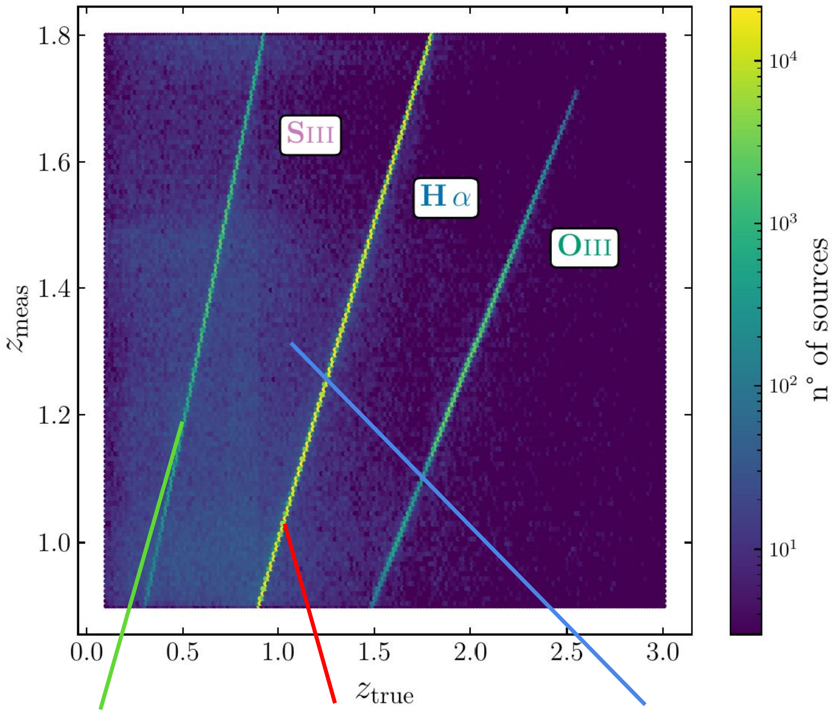
We aim at a purity of 80% for a sample with a galaxy density of at least 1700 deg$^{-2}$

| sources in NISP | Number |
|---|---|
| $H_E < 24$ galaxies | 100 000 |
| $H_E < 20$ galaxies with continuum | 1900 |
| H$\alpha$+[N II] | 2100 |
| [O III] | 200 |
| [S III] | 80 |
| tot. ELGs | 2380 |
| stars | 5000–15 000 |




EC-Q1, Le Brun et al., arXiv:2503.15308

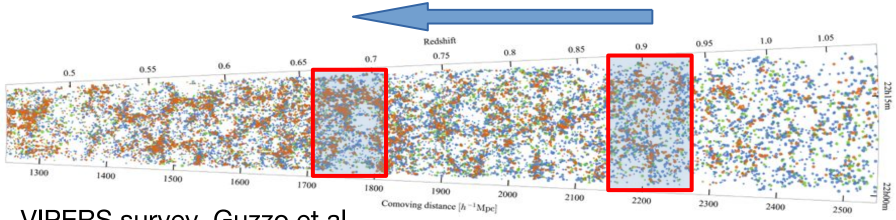
# Line and noise interlopers



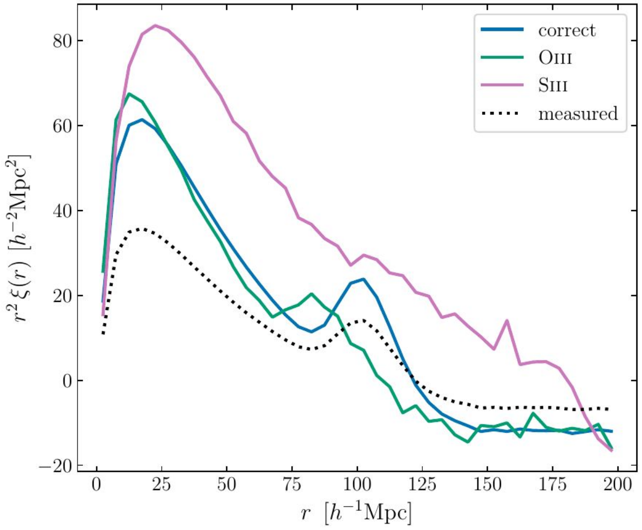

**line** interlopers ~10%

**correct** galaxies ~80%

**noise** interlopers ~10%




VIPERS survey, Guzzo et al.



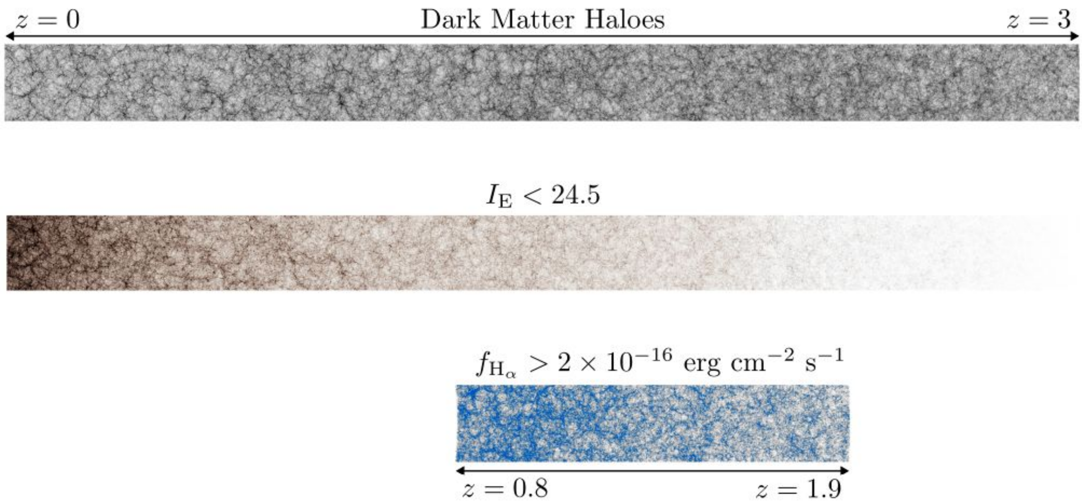

EC: Risso et al, arXiv:2505.04688

# A Flagship mock galaxy catalogue

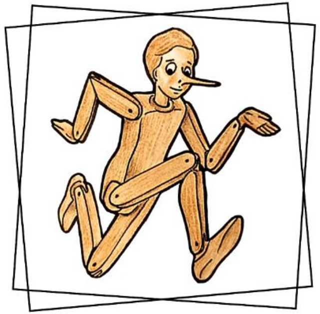
Simulation box of **3600 Mpc/h**
**$16000^3$ particles**
particle mass of $10^9$ Msun/h
output on the past light cone to z=3
~1 000 000 node hours on 4000 node of Piz Daint, ~68 000 000 core hours

Data public con [cosmohub.pic.es](cosmohub.pic.es)

Euclid Collaboration: Castander, F. J., et al.: A&A, 697, A5 (2025)



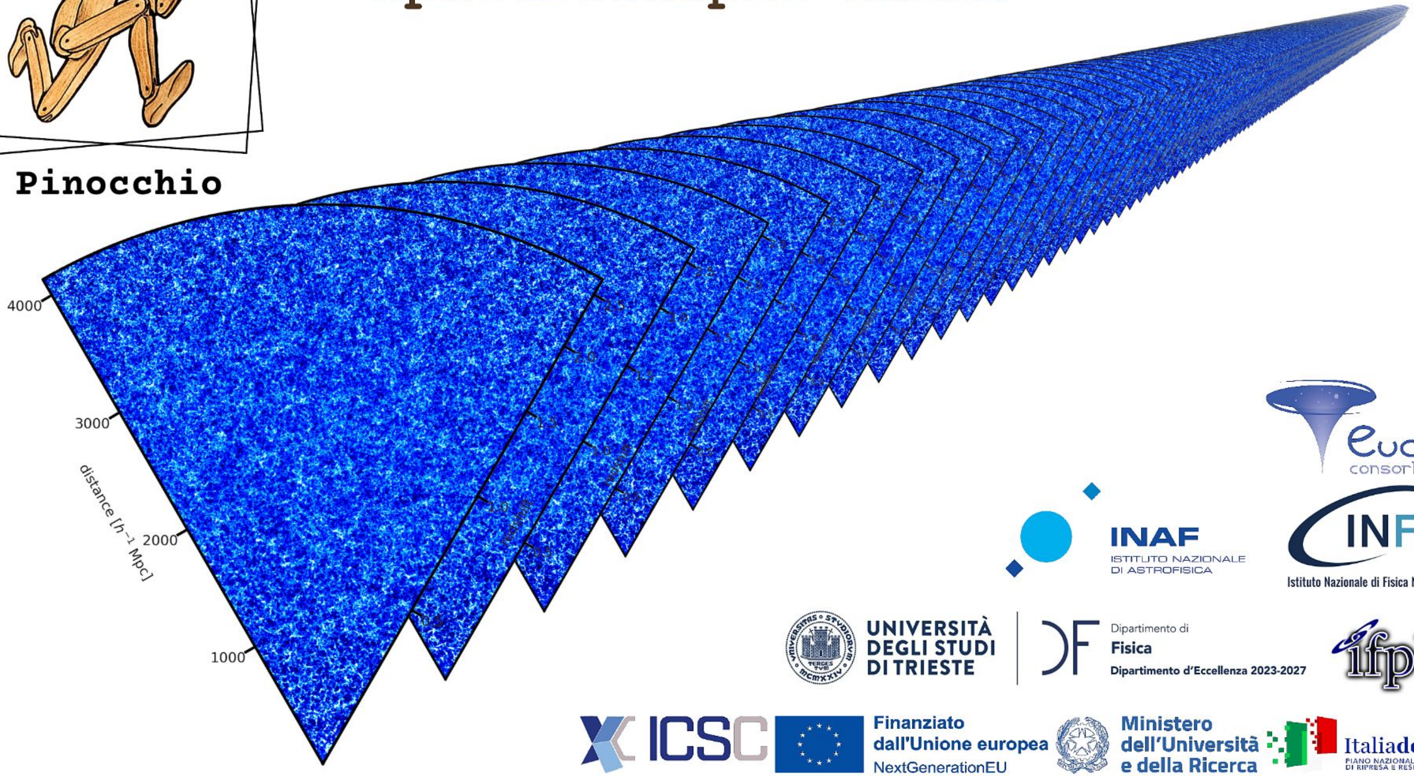
Euclid consortium



Pinocchio

# Thousands of Euclid spectroscopic skies

EC, Monaco et al., arXiv:2507.12116




Euclid consortium

INAF ISTITUTO NAZIONALE DI ASTROFISICA

INFN Istituto Nazionale di Fisica Nucleare

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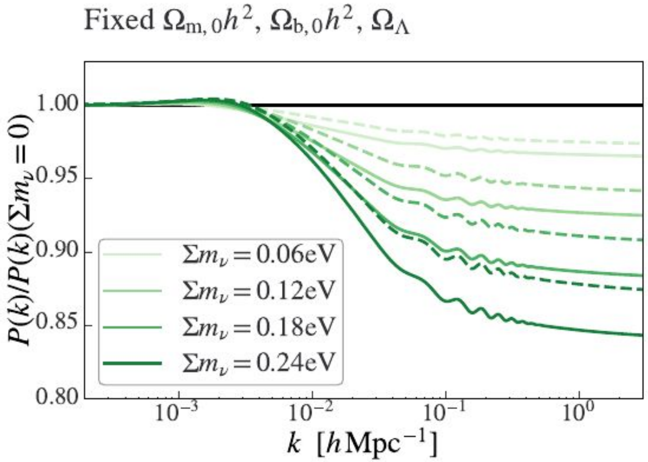
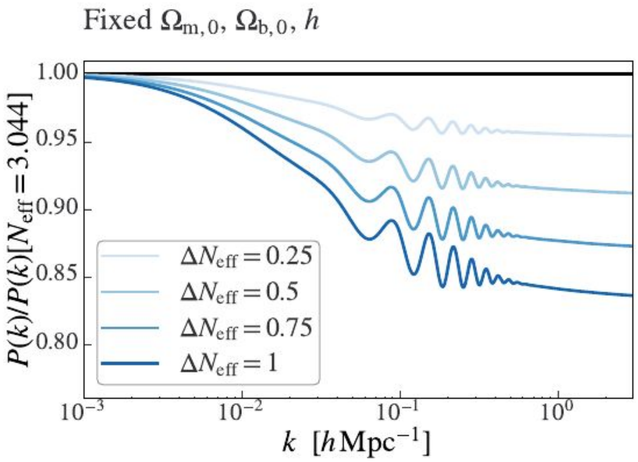
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

# Massive neutrinos

Massive neutrinos make the growth of structure **scale-dependent**, leaving imprints on the matter power spectrum.

This enables us to measure the sum of neutrino masses, whose effect is similar to that of the effective number of relativistic degrees of freedom



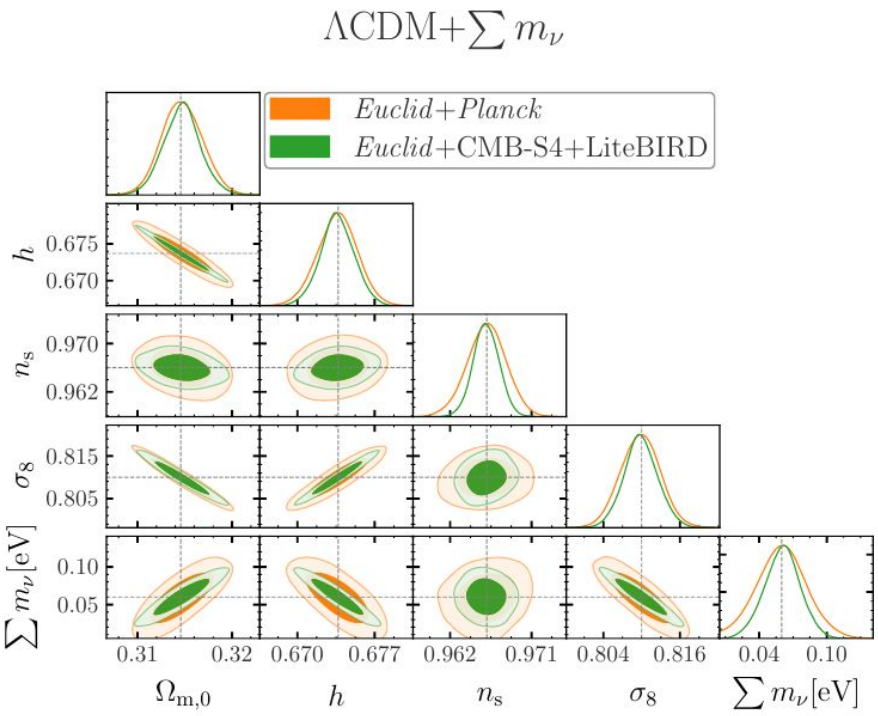

EC, Archidiacono et al., 2025, A&A 693, id.A58

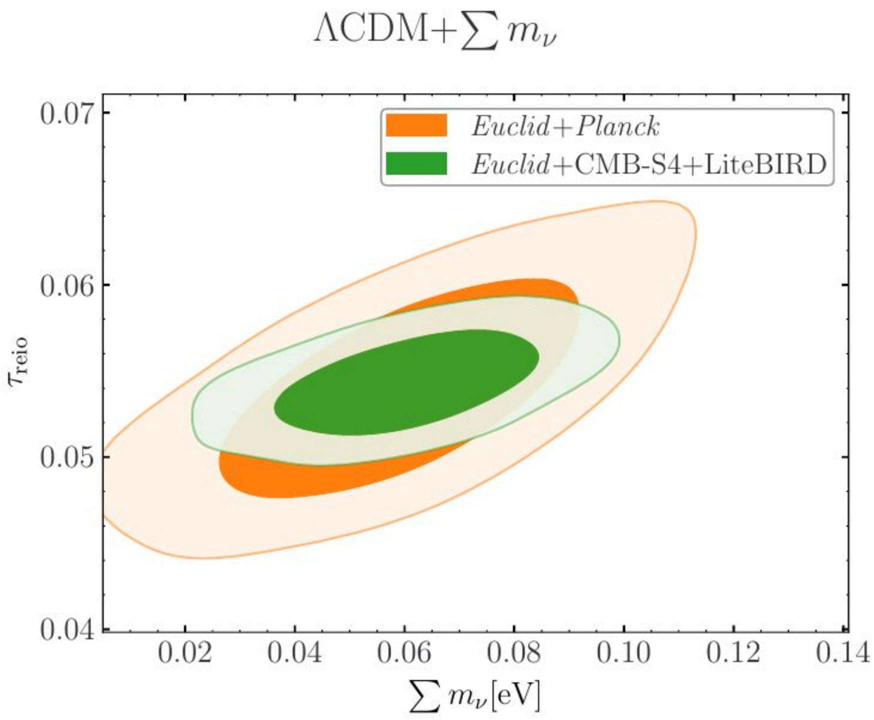
# Massive neutrinos

| $\Lambda\mathrm{CDM} + \sum m_\nu$ | $\Omega_{\mathrm{m},0}$ | $100\,\Omega_{\mathrm{b},0}$ | $h$ | $n_\mathrm{s}$ | $\sigma_8$ | $\sum m_\nu$[meV] | |
|---|---|---|---|---|---|---|---|
| *Euclid*-only | | | | | | | |
| $\mathrm{GC_{sp}}$ | 0.0068 | 0.37 | 0.033 | 0.029 | 0.0077 | $< 320$ | |
| $\mathrm{WL+GC_{ph}+XC_{ph}}$ | 0.0032 | 0.36 | 0.035 | 0.017 | 0.0047 | $< 260$ | |
| $\mathrm{WL+GC_{ph}+XC_{ph}+GC_{sp}}$ | 0.0026 | 0.24 | 0.022 | 0.013 | 0.0039 | 56 | |
| $\mathrm{WL+GC_{ph}+XC_{ph}+GC_{sp}+CC}$ | 0.0025 | 0.24 | 0.022 | 0.012 | 0.0037 | 53 | |
| *Euclid*+CMB | | | | | | | |
| *Euclid*+*Planck* | 0.0023 | 0.033 | 0.0021 | 0.0022 | 0.0033 | 23 | |
| *Euclid*+CMB-S4+LiteBIRD | 0.0021 | 0.024 | 0.0016 | 0.0014 | 0.0028 | 16 | |
| $\Lambda\mathrm{CDM} + \sum m_\nu + \Delta N_\mathrm{eff}$ | $\Omega_{\mathrm{m},0}$ | $100\,\Omega_{\mathrm{b},0}$ | $h$ | $n_\mathrm{s}$ | $\sigma_8$ | $\sum m_\nu$[meV] | $\Delta N_\mathrm{eff}$ |
| *Euclid*-only | | | | | | | |
| $\mathrm{WL+GC_{ph}+XC_{ph}+GC_{sp}}$ | 0.0026 | 0.19 | 0.023 | 0.012 | 0.0039 | $< 220$ | $< 0.746$ |
| *Euclid*+CMB | | | | | | | |
| *Euclid*+*Planck* | 0.0022 | 0.037 | 0.0028 | 0.0021 | 0.0031 | 25 | $< 0.144$ |
| *Euclid*+CMB-S4+LiteBIRD | 0.0019 | 0.025 | 0.0018 | 0.0016 | 0.0025 | 16 | $< 0.063$ |

EC, Archidiacono et al., 2025, A&A 693, id.A58

# Massive neutrinos: Euclid + CMB

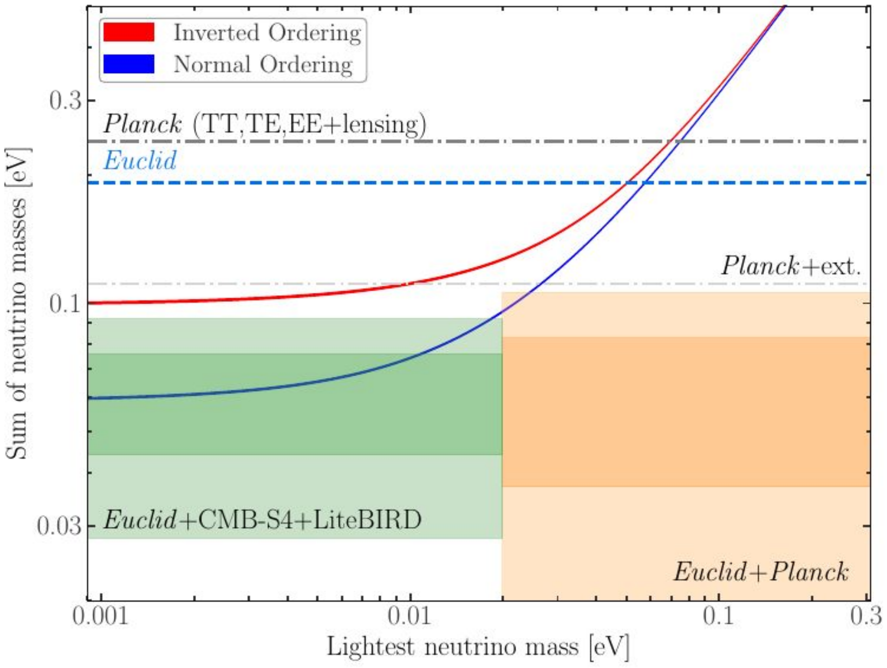


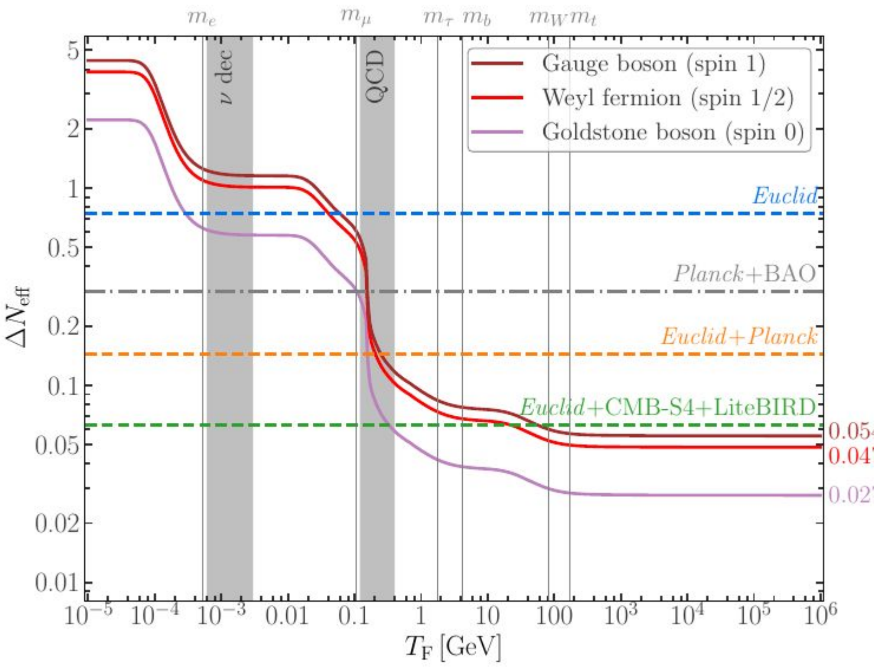

EC, Archidiacono et al., 2025, A&A 693, id.A58

# Massive neutrinos and $N_{eff}$

normal/inverted neutrino mass hierarchy




further relativistic degrees of freedom

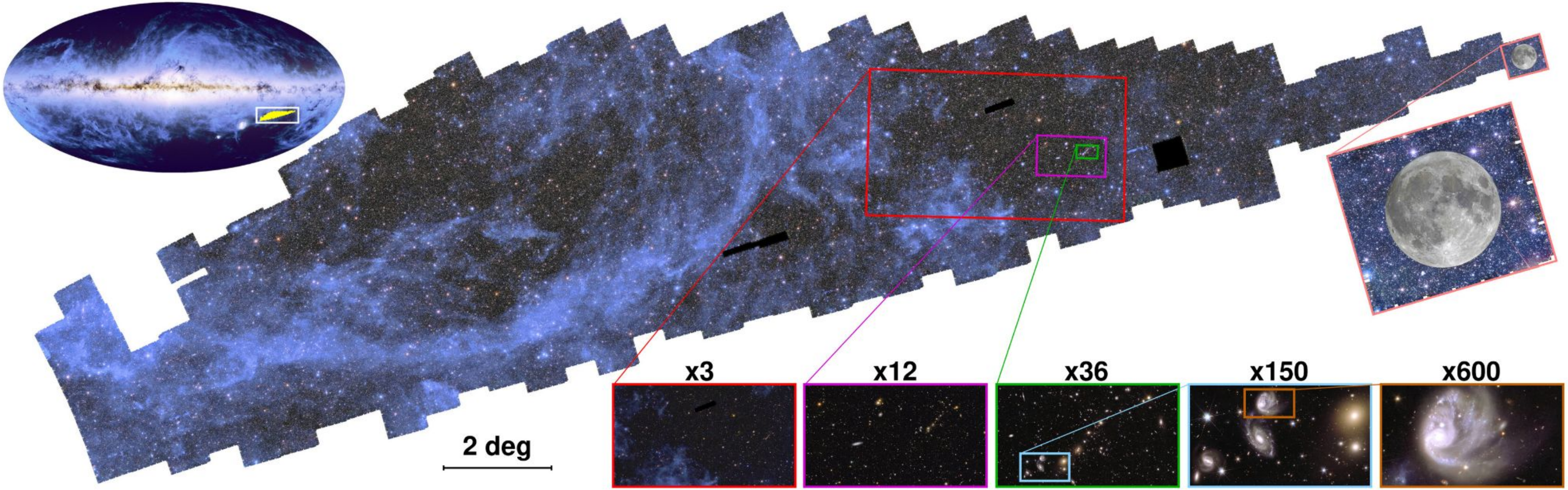



EC, Archidiacono et al., 2025, A&A 693, id.A58

# Conclusions

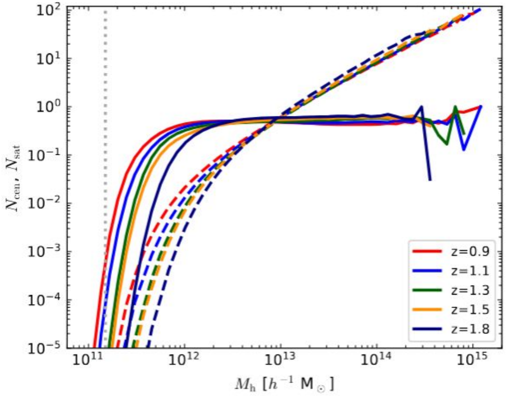
Bright times ahead with **Euclid**, DESI, Roman, Rubin-LSST, SKA...

A measurement of the **neutrino mass** from large-scale structure may be behind the corner

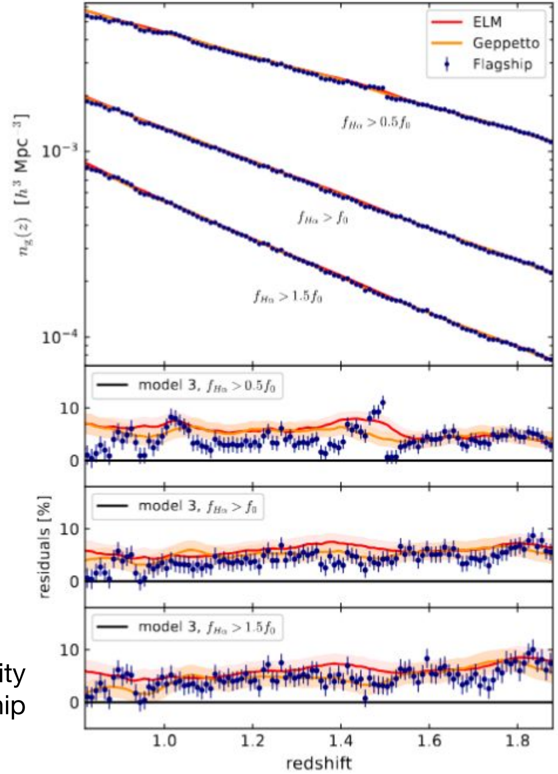


# backup slides

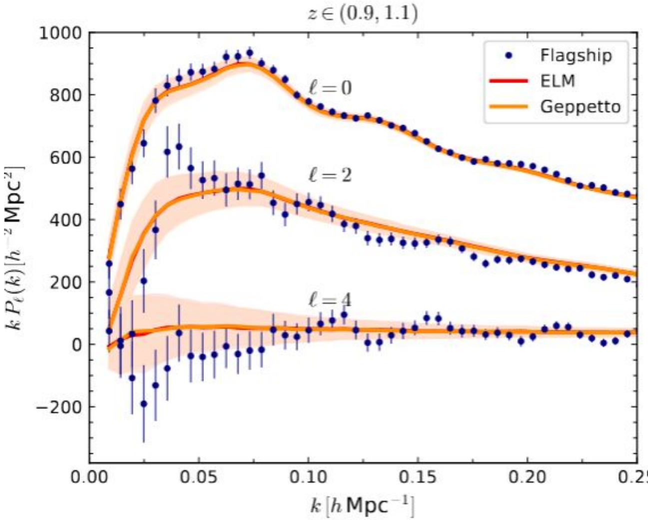
# Calibrated on Flagship mock




HOD curves $N_{cen}(M_h,z)$ and $N_{sat}(M_h,z)$



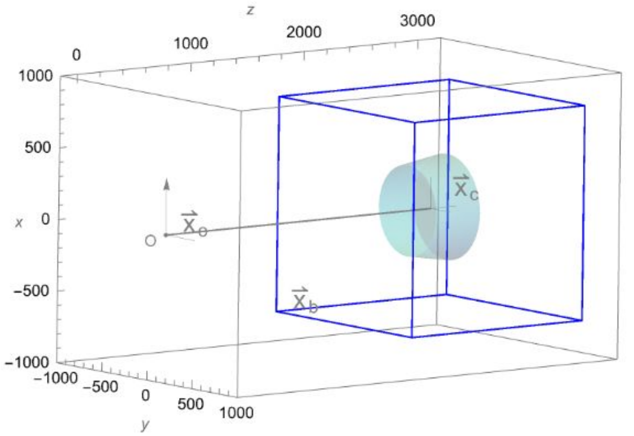

number density
vs Flagship




**galaxy power spectrum** vs Flagship

EC, Monaco et al., arXiv:2507.12116

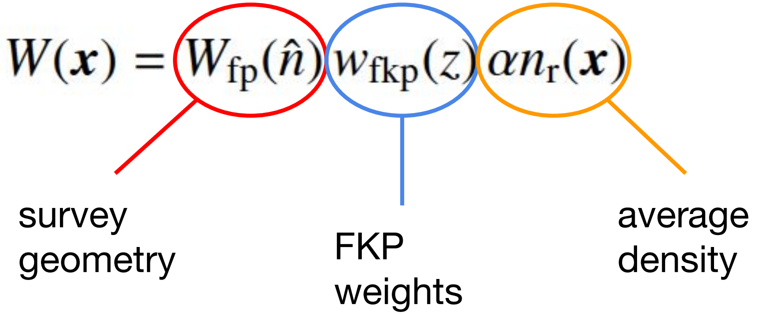
# Measuring the galaxy power spectrum




J. Salvalaggio, E. Sefusatti, A. Eggemeier, K. Pardede, F. Rizzo et al., in prep.

With a survey geometry you are measuring the **convolution** of the galaxy power spectrum with a window function

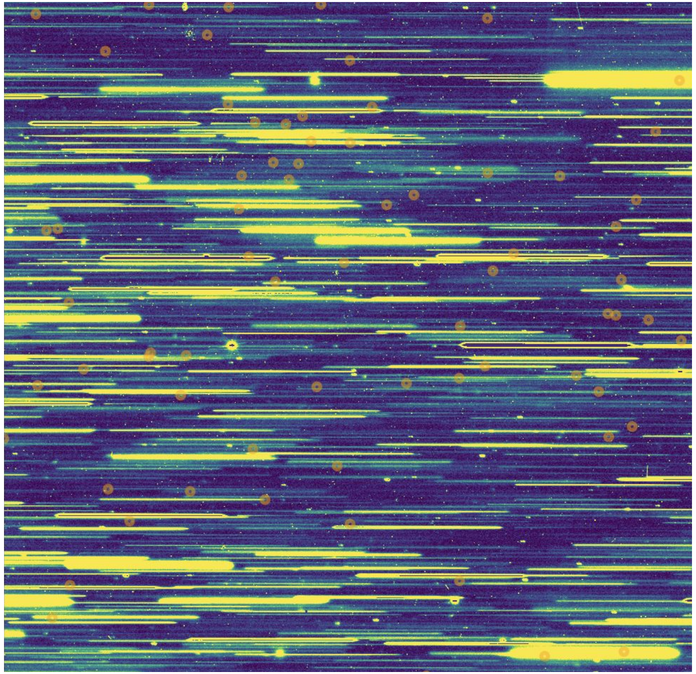
$$\tilde{P}_\ell(k) = \sum_{\ell'} \int \mathrm{d}^3k' \, \mathcal{W}_{\ell\ell'}(k,k') P_{\ell'}(k')$$




The window function and its mixing matrix are obtained by taking the Fourier transform of the **random catalog**

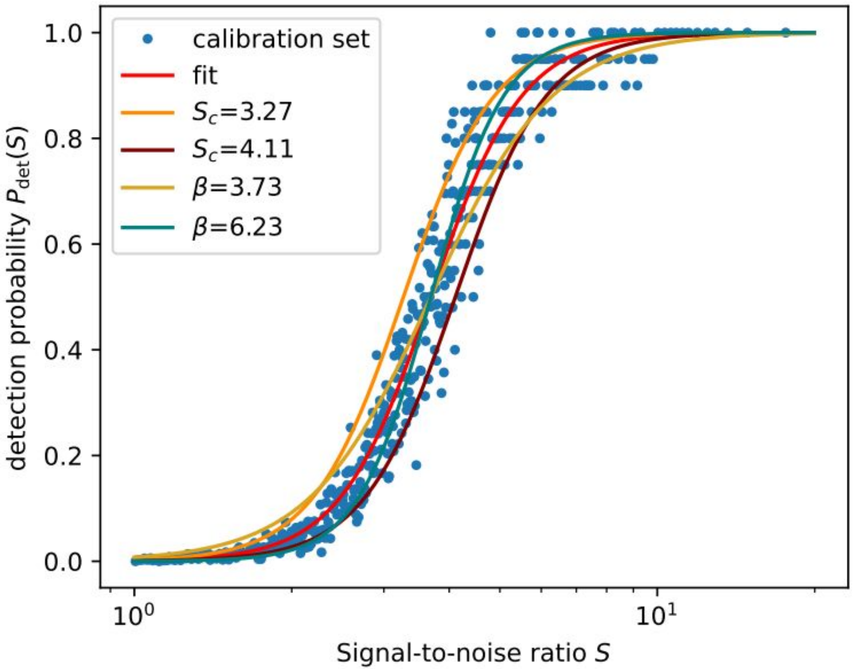
# A forward model of systematics

circles denote the location of Hα line



EC: Monaco et al., in prep.

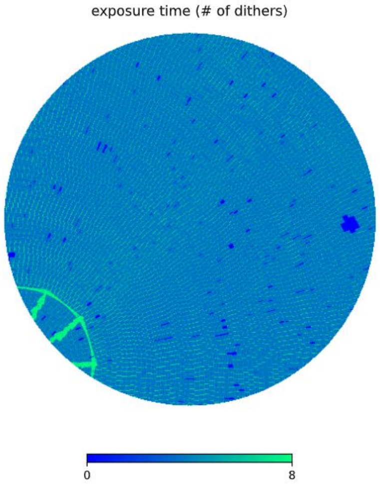
Detection probability is expected to be a function of SNR at the location of emission lines



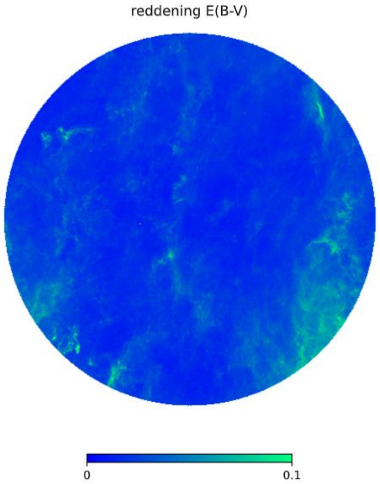
# Nuisance maps

$$S = \kappa_1 f \mathcal{E} \sqrt{\frac{\mathcal{T}}{\mathcal{N}}}$$

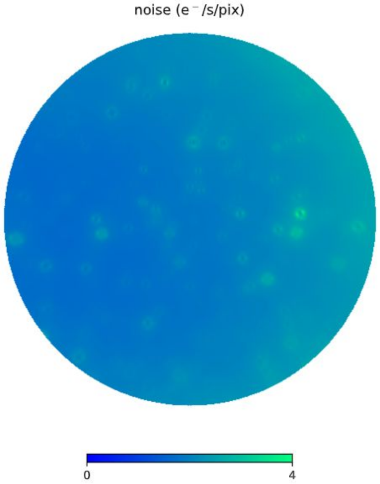
**tiling** of the survey

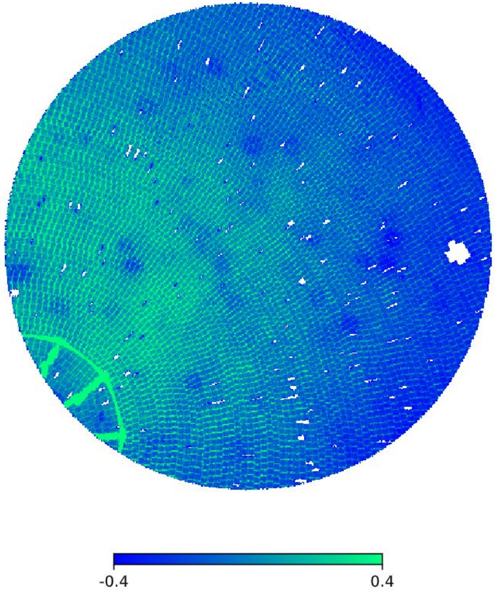



Milky Way **extinction**




(simple) background **noise**




The **random** catalog
represents angular systematics

EC: Monaco et al., in prep.

# No bias when the window is known

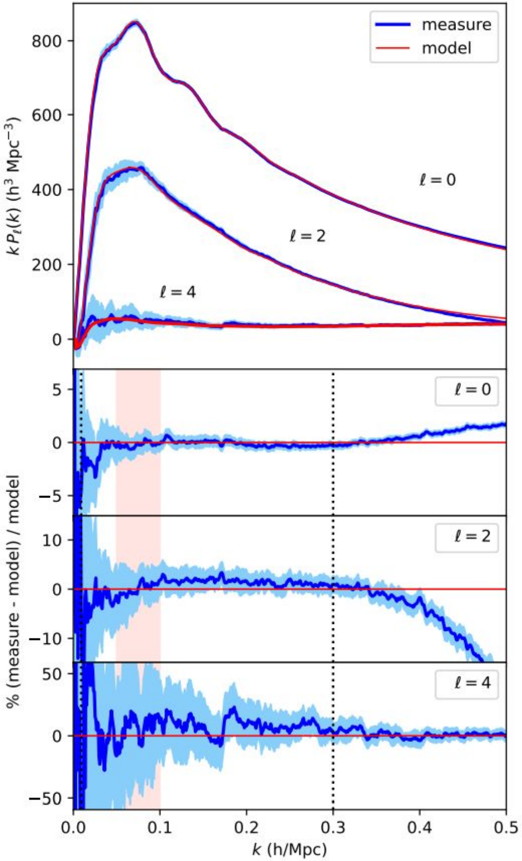
we use **50 mocks**, averaging over groups of 5 - so we have 10 DR3-sized realizations

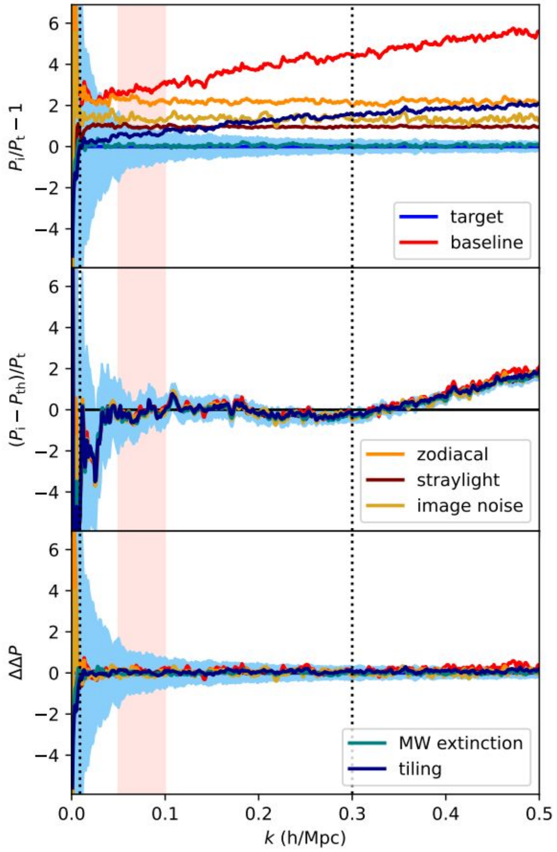
we use four **redshift bins** [0.9,1.1,1.3,1.5,1.8]

we fit the no-systematics case with **VDG** model

using the same model, we **convolve** it with different window functions and compare it with measurements

thanks to Y. Elkhashab, J. Salvalaggio, E. Sefusatti

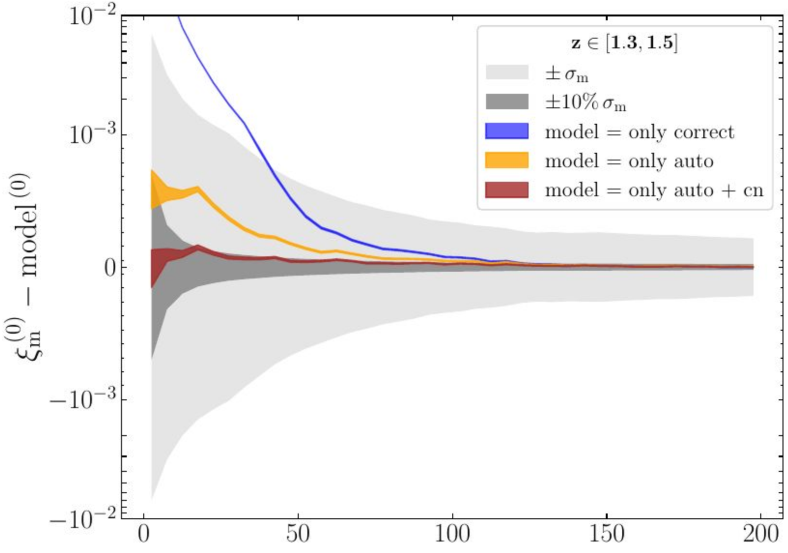


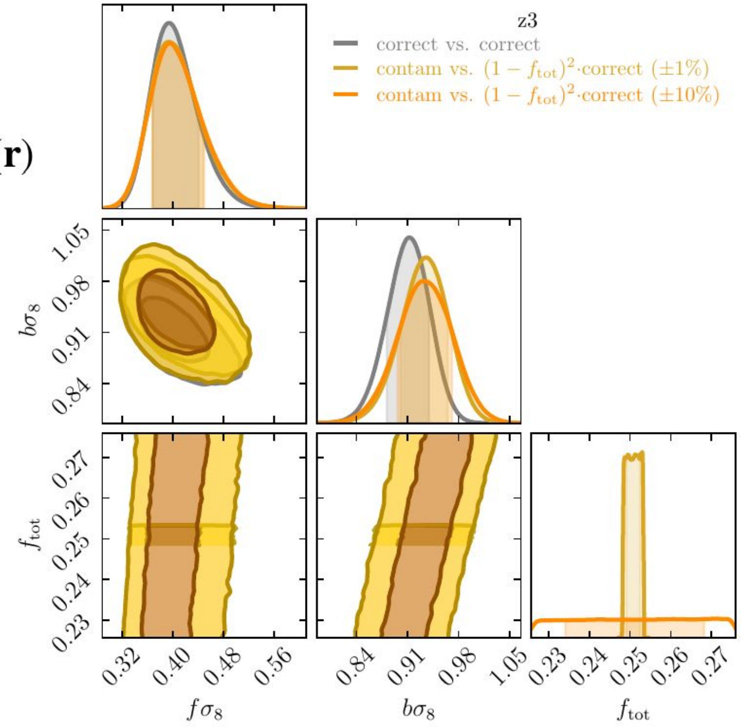




EC: Monaco et al., in prep.

# The role of interlopers

$$\xi_{\rm m}(\mathbf{r}) = (1 - f_{\rm tot})^2\, \xi_{\rm cc}(\mathbf{r}) + f_\ell^2\, \xi_{\ell\ell}(\mathbf{r}) + f_{\rm n}^2\, \xi_{\rm nn}(\mathbf{r}) + 2 f_\ell (1 - f_{\rm tot})\, \xi_{{\rm c}\ell}(\mathbf{r}) + 2 f_{\rm n}(1 - f_{\rm tot})\, \xi_{\rm cn}(\mathbf{r}) + 2 f_\ell f_{\rm n}\, \xi_{\ell{\rm n}}(\mathbf{r})$$




At this level of contamination **a simple $(1\text{-}f_{\rm tot})^2$ correction** seems to be adequate