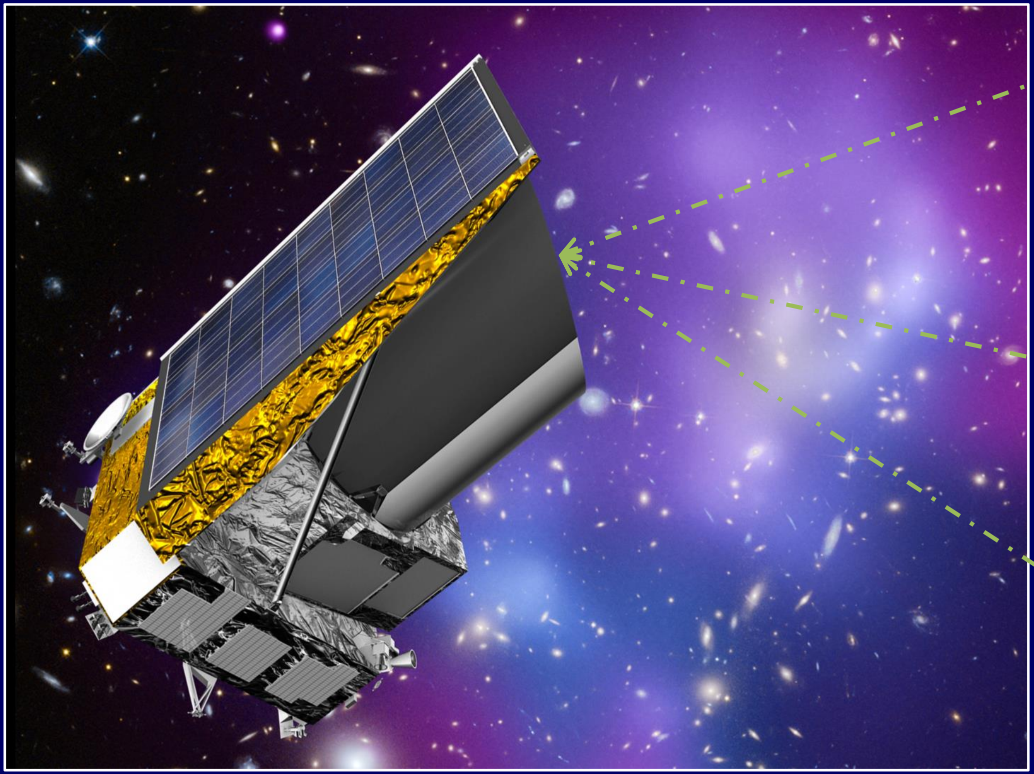
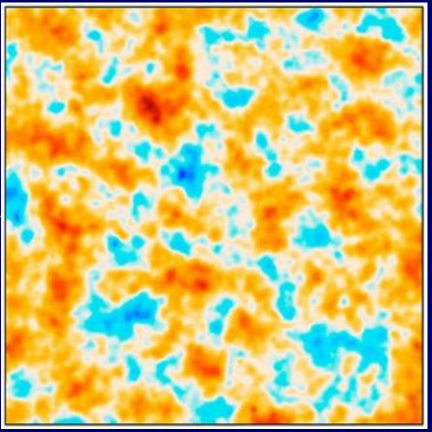
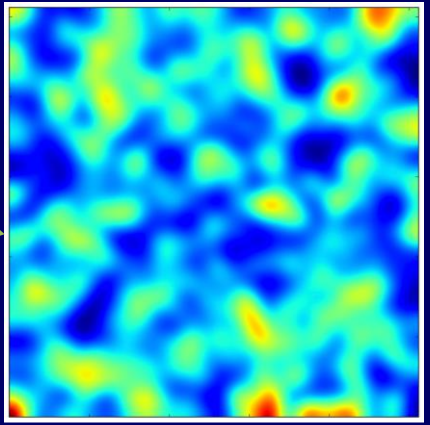
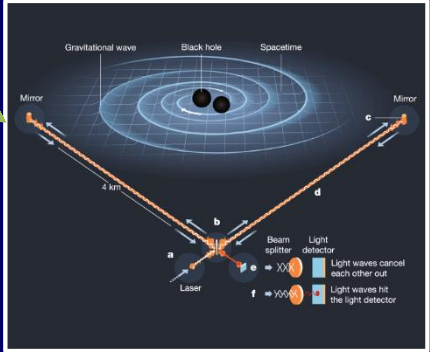
Multiprobe Cosmology in the Euclid Era









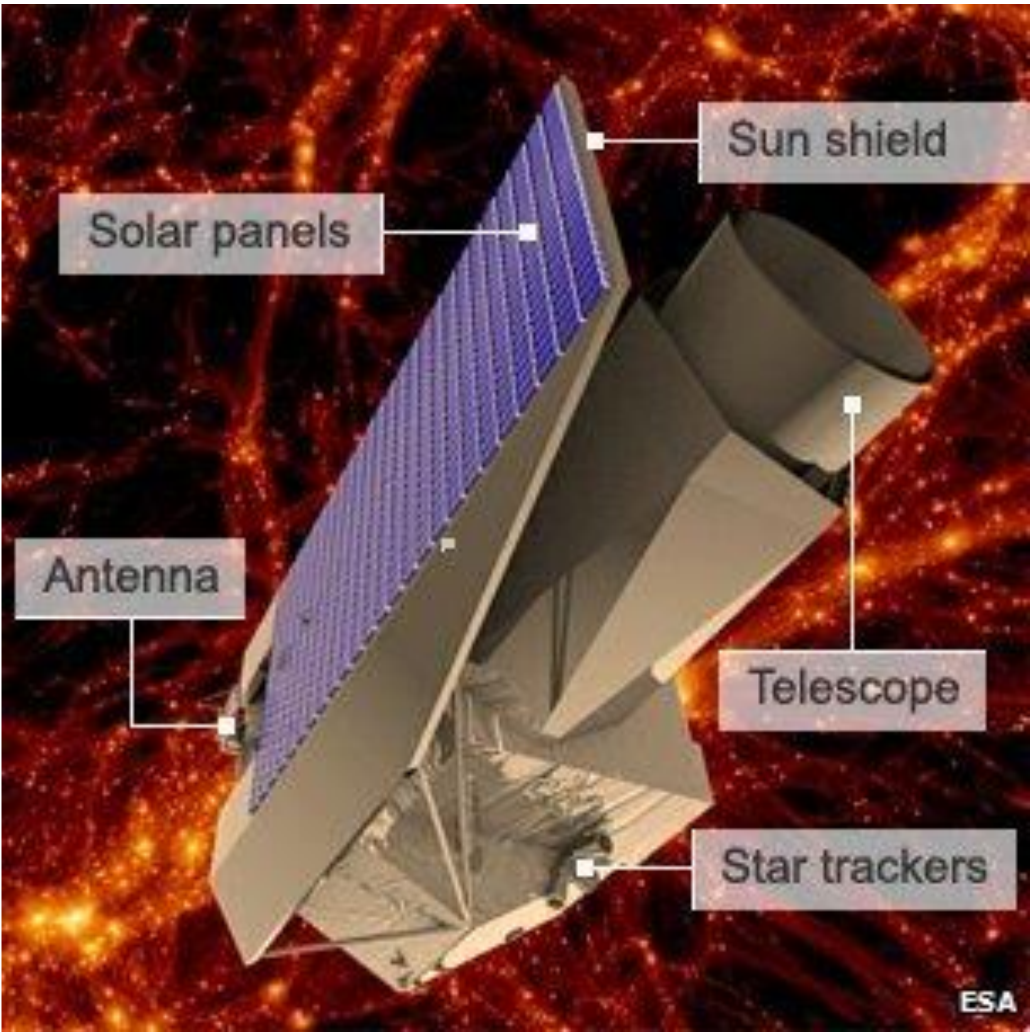
Carmelita Carbone
INAF – IASF Milan

Giornate INAF, 3rd May 2023, Napoli

Contributors:

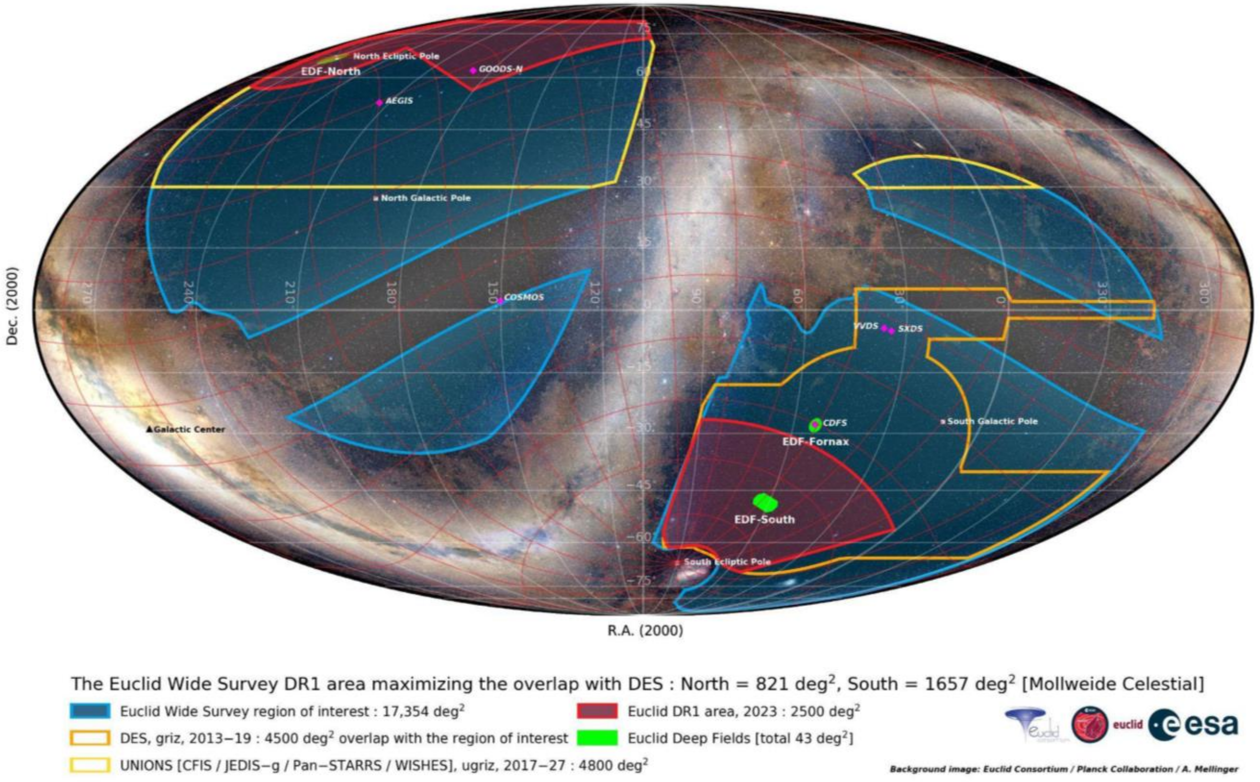
Carlo Baccigalupi (SISSA), Stefano Camera (UniTO), Vincenzo Cardone (INAF-OAR), Fabio Finelli (INAF-OAS), Luigi Guzzo (UniMI), Alessandro Gruppuso (INAF-OAS), Matteo Martinelli (INAF-OAR), Marina Migliaccio (UniToV), Michele Moresco (UniBO), Lauro Moscardini (UniBO), Daniela Paoletti (INAF-OAS), Alvise Raccanelli (UniPD), Angelo Ricciardone (UniPI) &… *all my hard worker Euclid-colleagues*!

The Euclid Mission

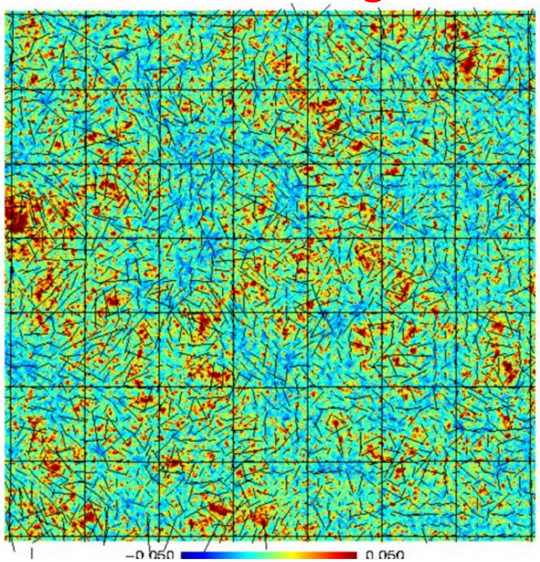


- Medium-class ESA mission
- 1.2m mirror telescope
- Optical imager (R+I+Z) (VIS)
- NIR-photometer (Y, J, H) (NISP-P)
- NIR-spectrograph slitless (NISP-S)
- **Launch 1-7 July 2023**, Orbit L2
- Mission duration 6 years
- **Cosmology**
  - **Galaxy Clustering**
  - **Cosmic shear**
  - **Galaxy Clusters**
  - **Cosmic Voids**
  - **CMBX**
  - **Strong Lensing**
- **Legacy Science**

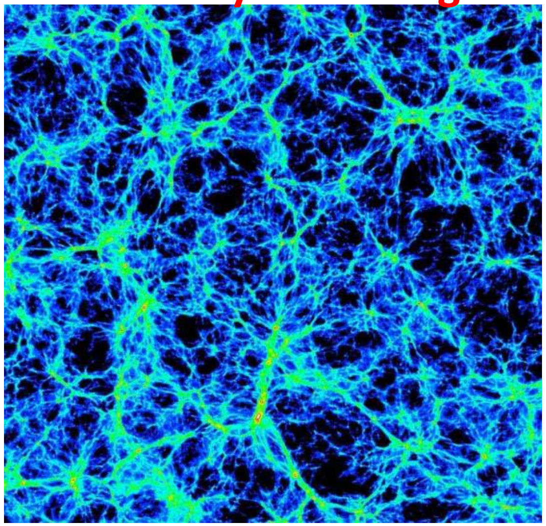
Unveiling dark energy and gravity with the Euclid probe combination approach to the dark sector



Weak lensing



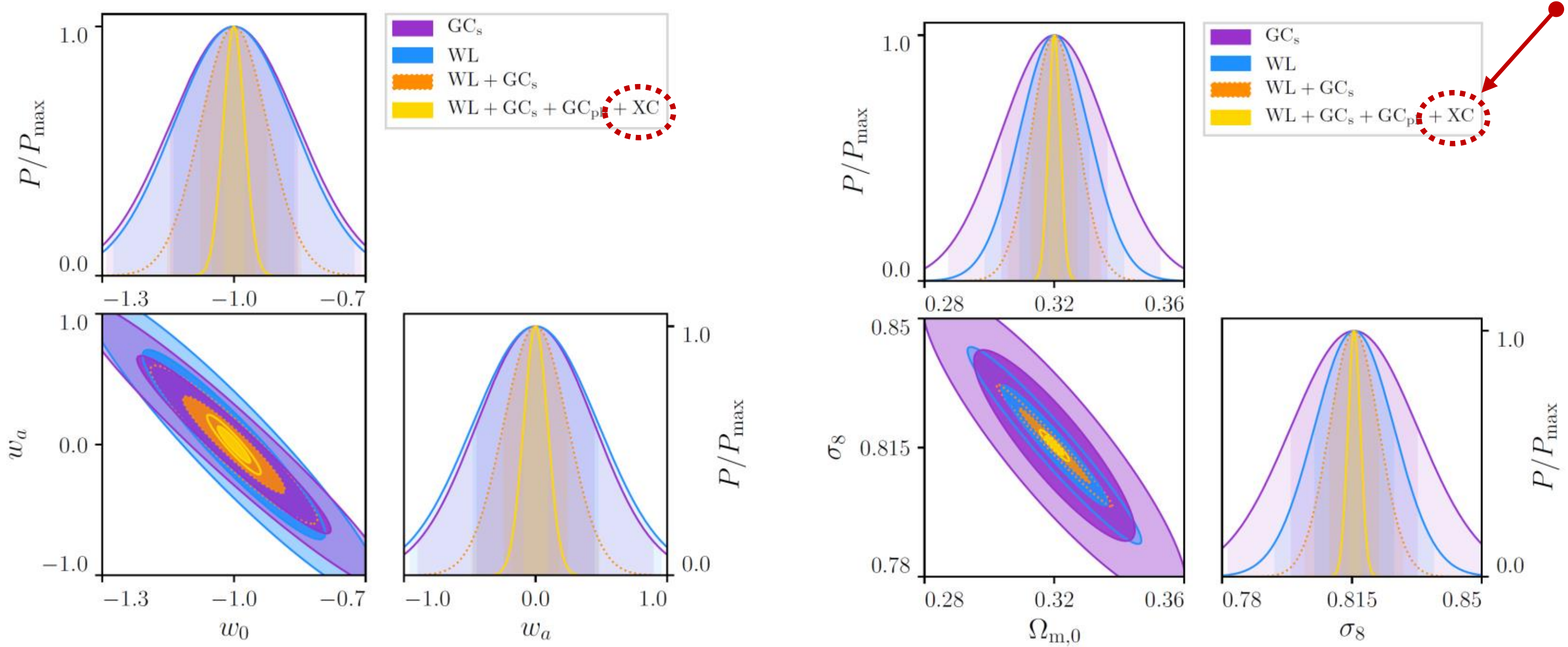
Galaxy Clustering



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

Probe combination is key to high precision and accuracy

REFERENCE PAPER: Euclid Consortium, Blanchard etal 2020 (arXiv:1910.09273)



All probe combination $\mathrm{GC_s}$+WL+$\mathrm{GC_{ph}}$+$\mathrm{XC^{(GC_{ph},WL)}}$								
Setting	$\Omega_{\mathrm{m},0}$	$\Omega_{\mathrm{b},0}$	$\Omega_{\mathrm{DE},0}$	w_0	w_a	h	n_s	σ_8
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

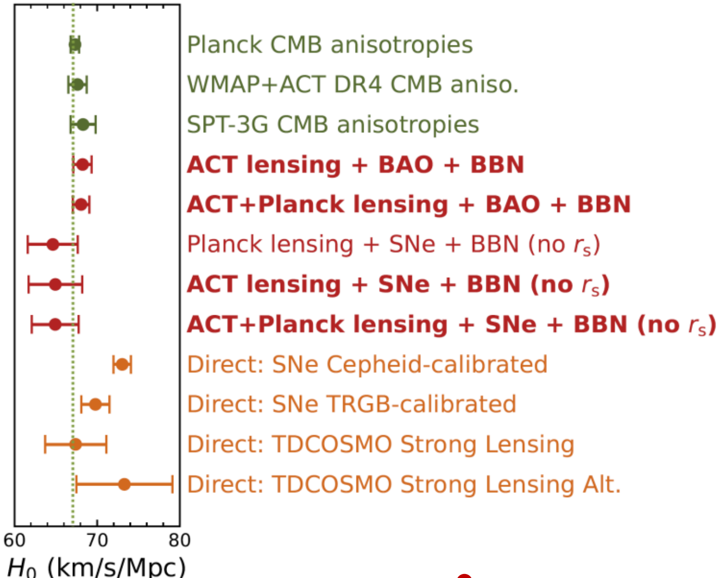
Big questions in cosmology

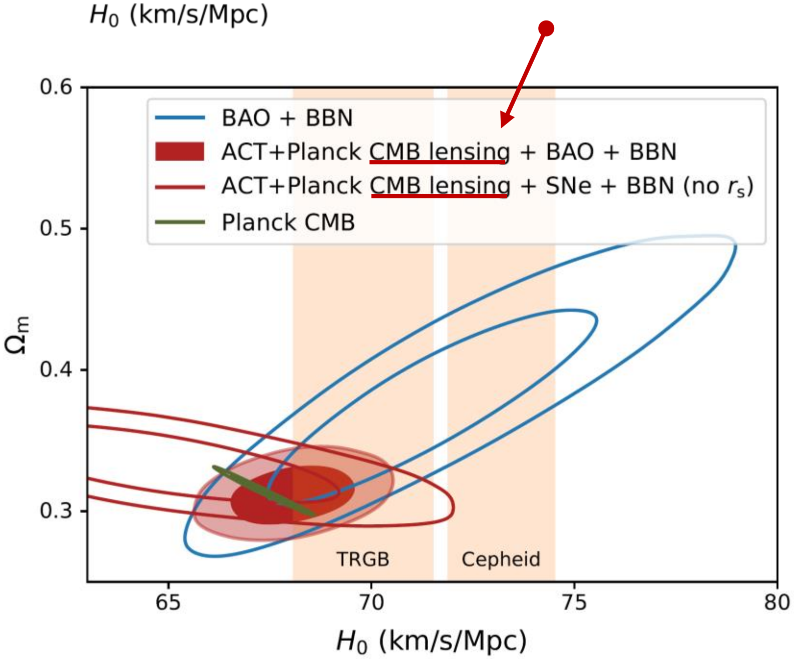
- H_0 & S_8 tensions
- Origin of the late accelerated expansion (dark energy, MG…)
- Neutrino mass
- Universe initial conditions (primordial non-Gaussianity…)
- Dark matter
- Etc…

Will Euclid give an answer?

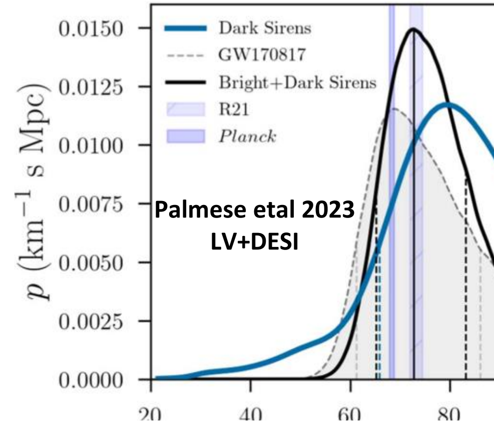
Probably not alone… cross-correlation with external probes is needed!

H_0 tension: current status

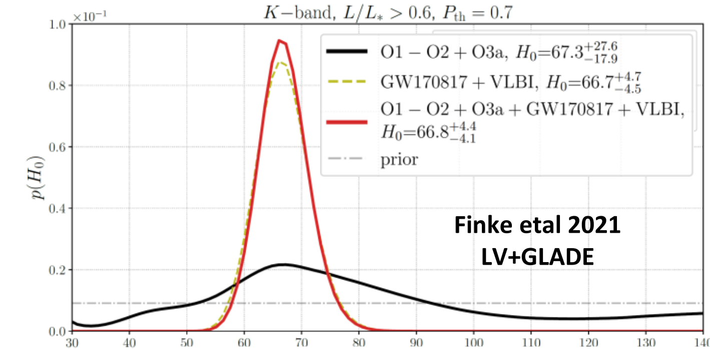




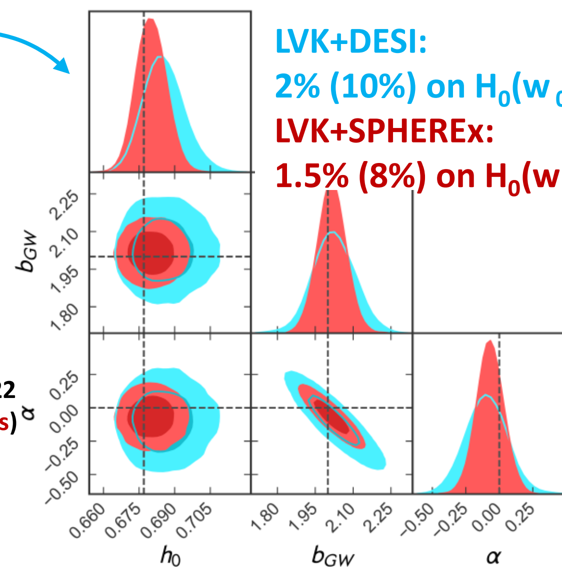
Madhavacheril etal 2023



GW170817:
$H_0=70.0_{-8}^{+12}$
8 Dark GWs:
$H_0=79.8_{-12.8}^{+19.1}$



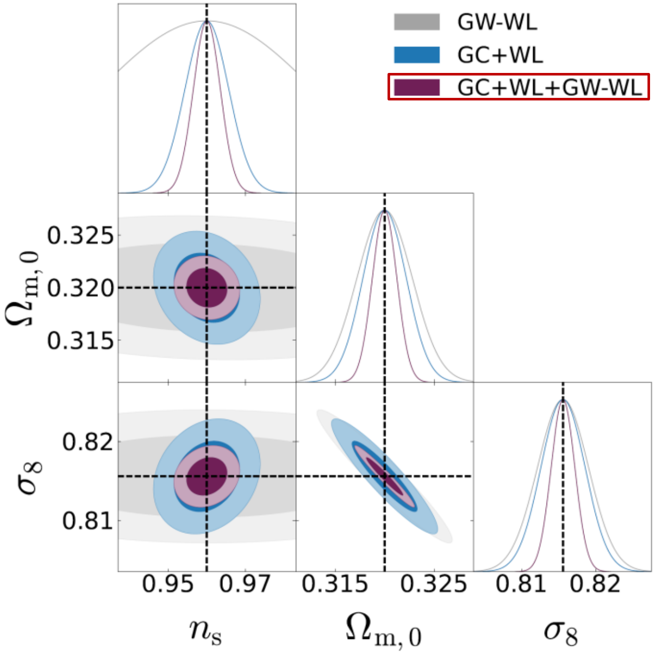
Exploit the spatial clustering between spectro-galaxies and GW sources

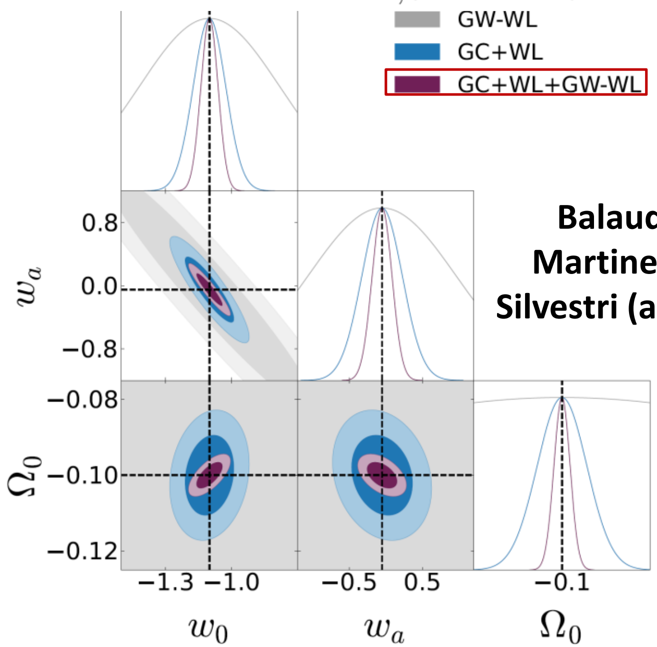


LVK+DESI:
2% (10%) on $H_0(w_0)$
LVK+SPHEREx:
1.5% (8%) on $H_0(w_0)$

Cigarran Diaz & Mukherjee 2022
LVK+galaxy (forecasts on mocks)

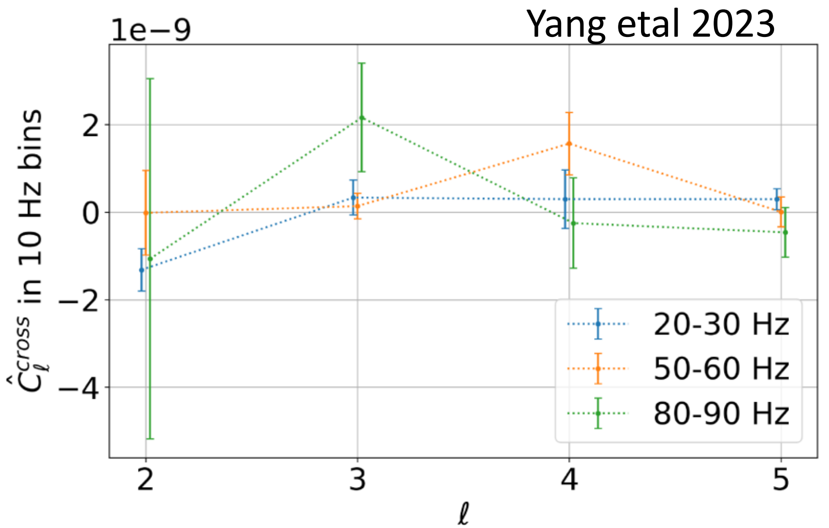
GW×Euclid: forecasts

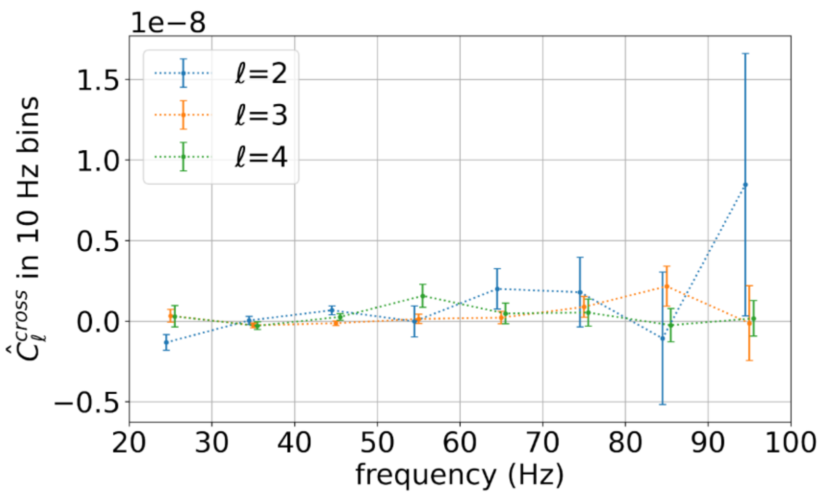




Balaudo, Garoffolo, Martinelli, Mukherjee, Silvestri (arXiv:2210.06398)

SGWB×SDSS: observations

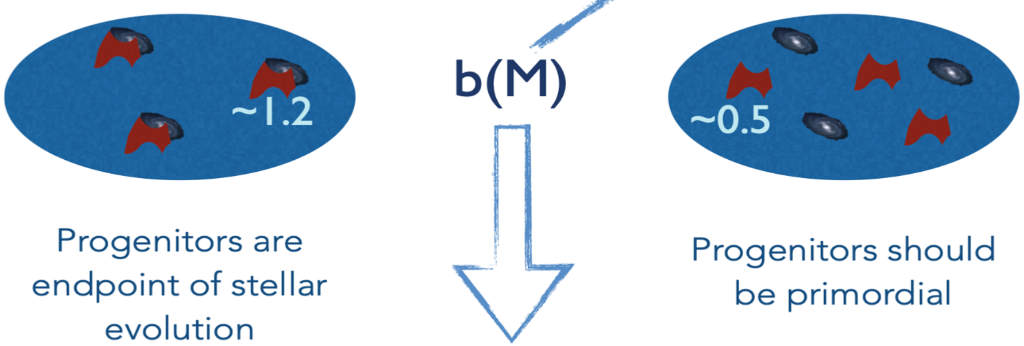




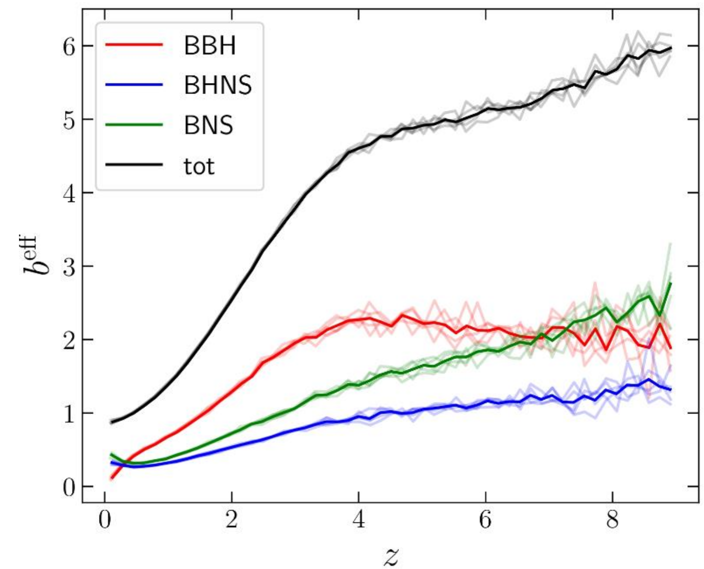
Cross-correlation of the anisotropic SGWB measurements using data from aLIGO (O3) and SDSS

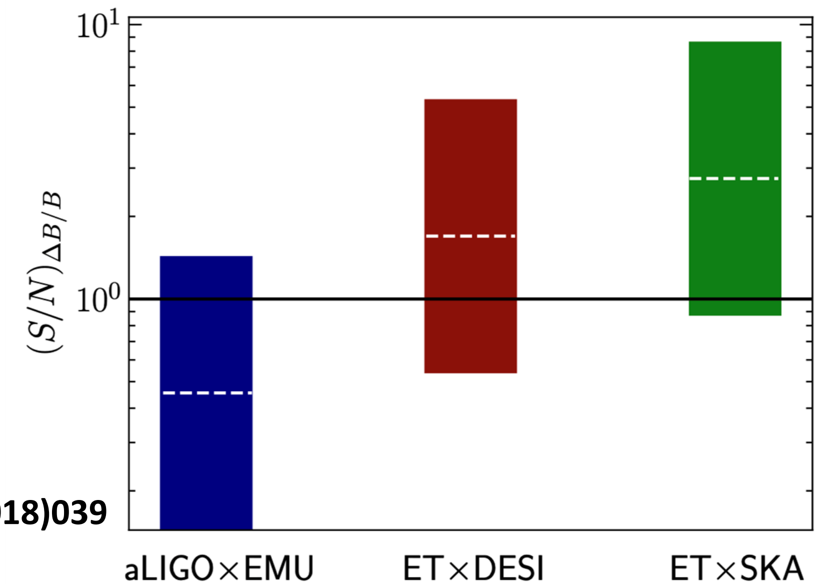
GW×LSS: forecasts
chasing the progenitors of merging binary black holes

$$C_\ell \propto \int k^2 P(k)dk \int W_\ell^g b^g(z) j_\ell(k\chi_1)d\chi_1 \int W_\ell^{GW} b^{GW}(z) j_\ell(k\chi_2)d\chi_2$$



info is in amplitude of Cls
Measure of bias of host of BBH merger





Pieroni, M., et al *Sci.Rep.* 12 (2022) 1, 17940

Bellomo, N., et al JCAP 06 (2022) 030

G. Scelfo, N. Bellomo, A. Raccanelli, S. Matarrese, L. Verde JCAP09(2018)039

Maximising the scientific return of GW as standard sirens

N. Borghi (UniBo, PhD), M. Moresco (UniBo), A. Cimatti (UniBo), M. Mancarella (UniMiB), F. Iacovelli (UniMiB, UniGe), M. Maggiore (UniGe)

Aim: expand current GW codes to perform a **joint analysis** of cosmological (H_0) & astrophysical (BBH rate and mass distribution) parameters

Applications:

(i) forecast on H_0 and population parameters for LVK O4, LVKI O5 (+ code release, Borghi, Moresco et al., in prep 2023a)

(ii) forecasts on GW as dark sirens from ET x Euclid (Borghi, Moresco et al., in prep 2023b)

Other improvements w.r.t. previous codes:

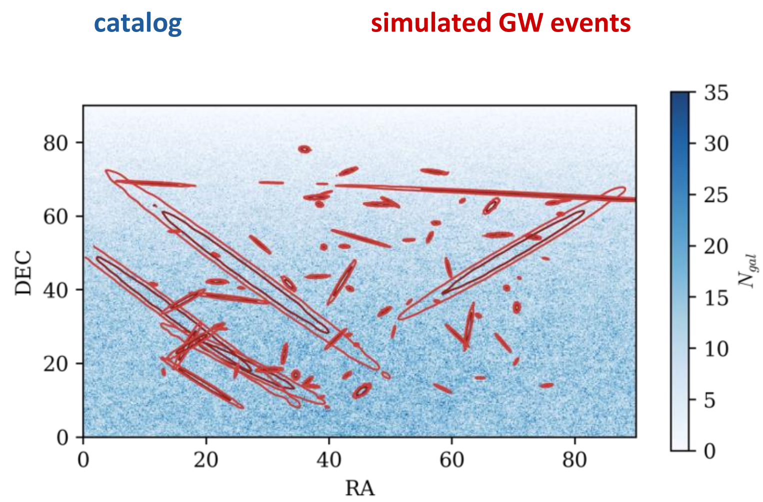
- Pixelated approach (see Gray et al. 2023)
- KDE approximation of GW data

Current activities:

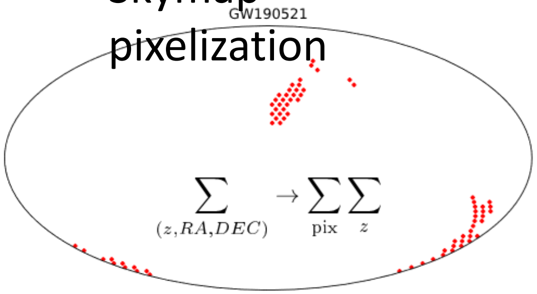
- generated mock catalog of potential host galaxies (MICEv2; Fosalba et al. 2015) and associated GW events (simulated with GWFast; Iacovelli et al. 2022)
- Code verification and validation

Contribution:

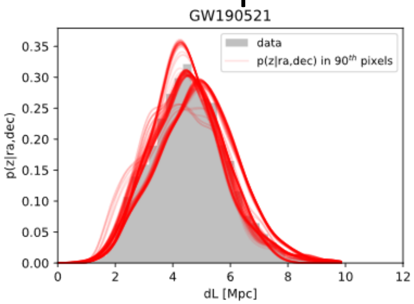
activity lead by Unibo (and Bologna, BoET Research unit in Einstein Telescope collaboration) + UniMiB and UniGe



Skymap pixelization



KDE interpolation



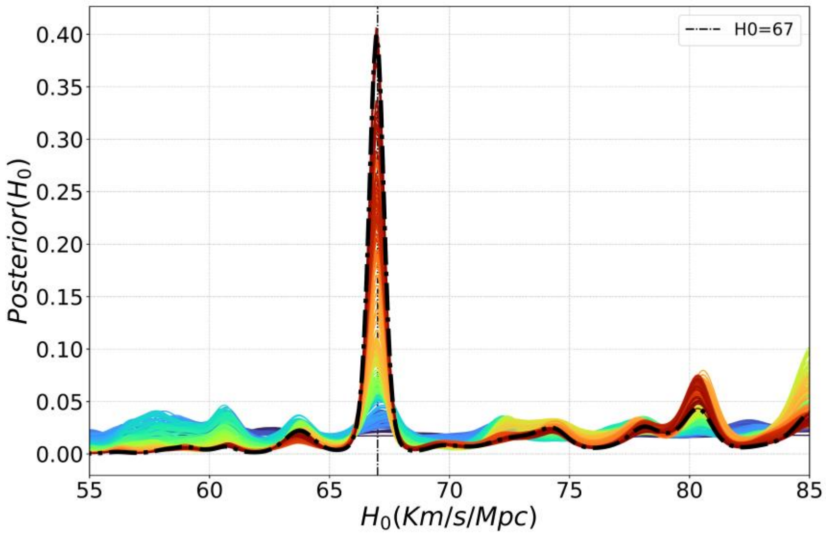
Combining the Euclid spectroscopic sample with the Dark Siren catalogue of the Einstein Telescope

R. Ciancarella (PhD Roma3), E. Branchini (UniGE), C. Carbone (IASF-MI), M. Bonici (IASF-MI)

Euclid Galaxy Survey: synthetic Euclid spectroscopic catalogue form the Flagship simulation. A total of 20M galaxies over 15000 deg^2 in the redshift range z= [0.9; 1.8]

Einstein Telescope: synthetic DS catalogue observed by a detector matching the specification of the Einstein Telescope.

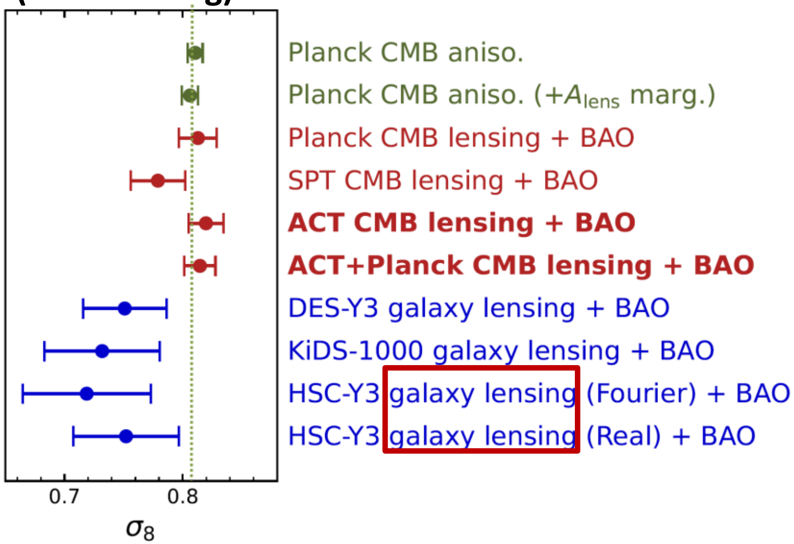
We follow the approach of Finke et al 2021, extended to the high redshift covered by Euclid and ET.

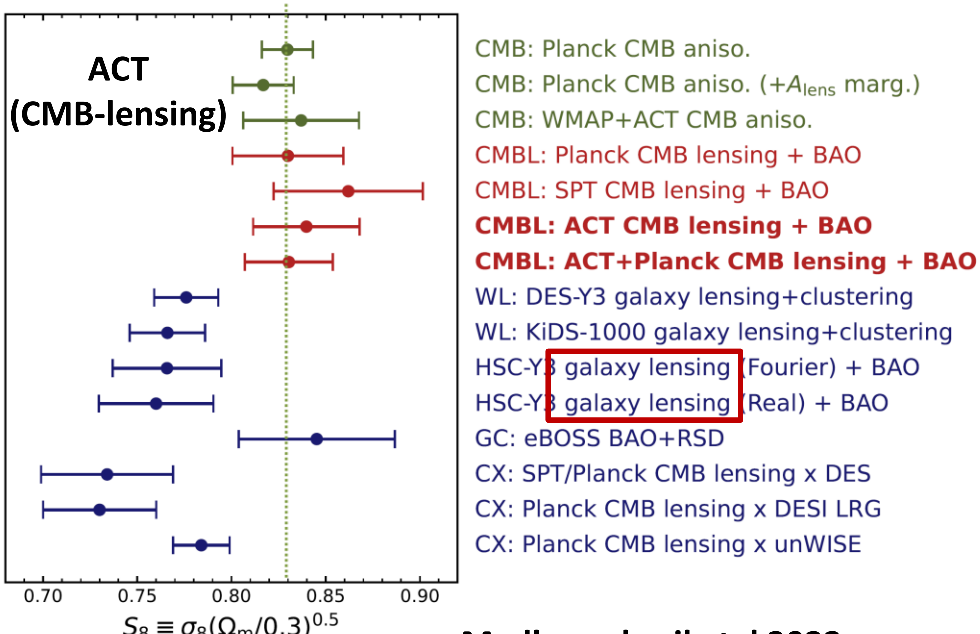


Test made on a uniform catalogue of hosts and a set of sirens whose distances are measured with a few % precision and angular position determined to within 10 squared degrees.

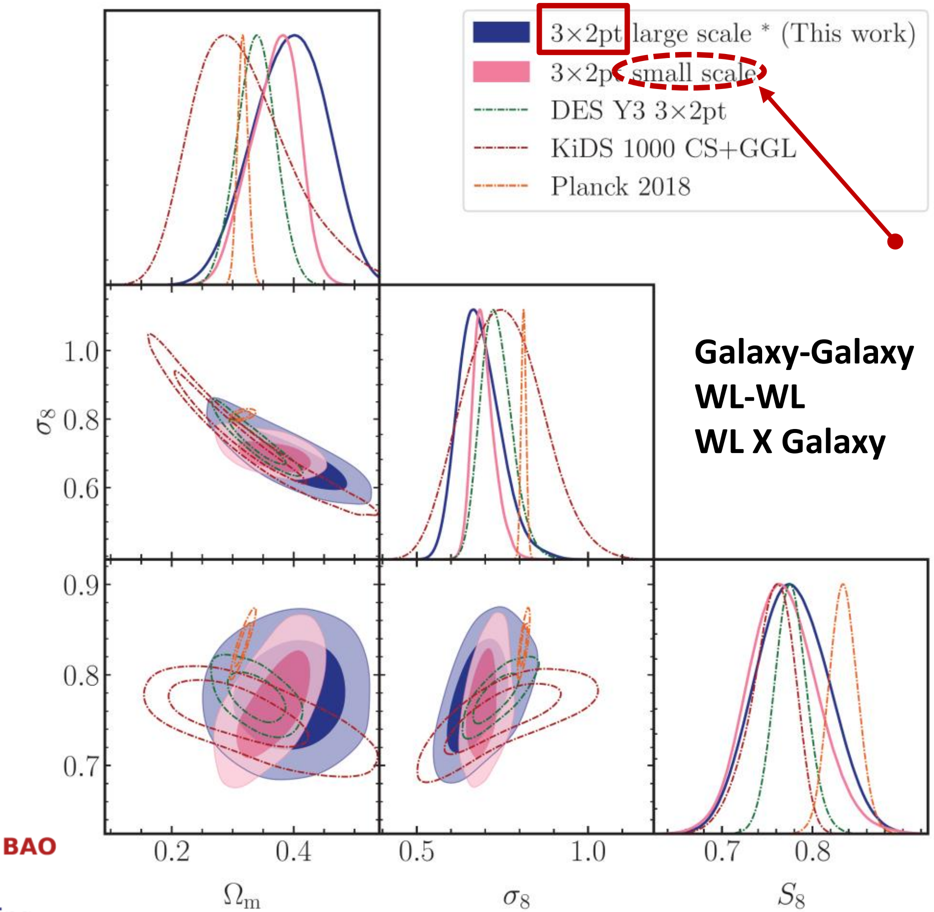
S_8 tension: current status

ACT (CMB-lensing)





Madhavacheril etal 2023



Hyper Suprime-Cam Year 3

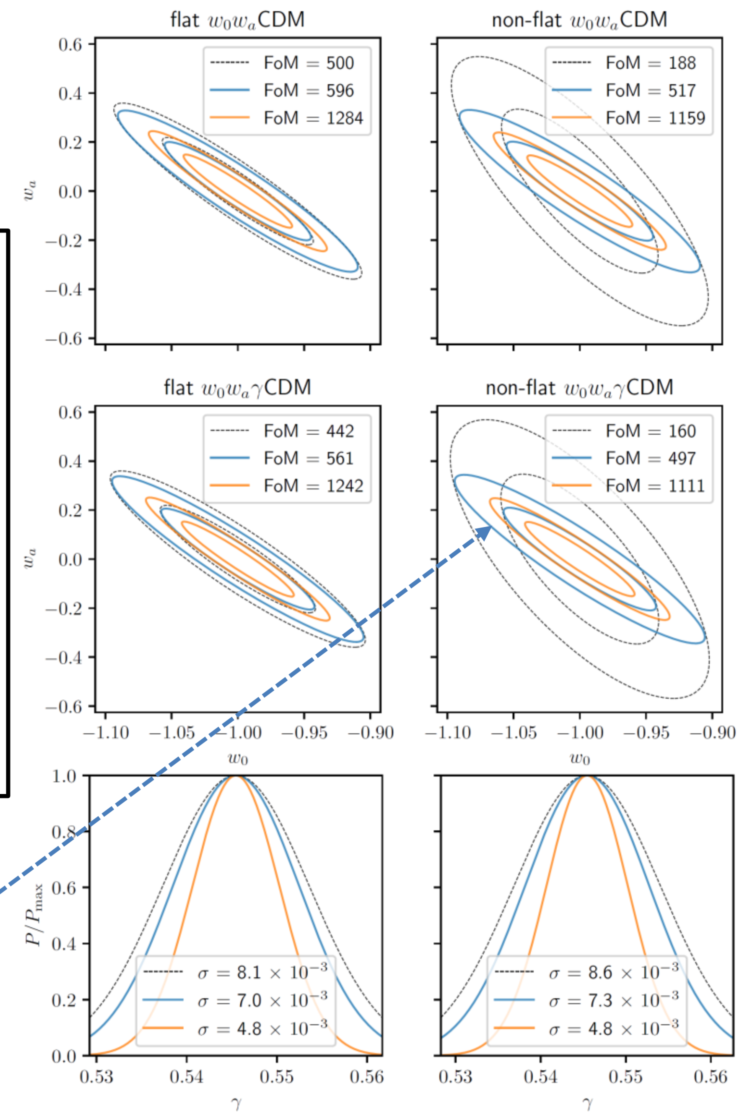
2.5-σ tension with Planck!

Sugiyama etal 2023

Euclid X CMB-lensing to constrain DE and MG

REFERENCE PAPER: Euclid Consortium, Ilic etal 2021 (arXiv:2106.08346)

Complementary to forecasts from primary probes (GC_{sp}+3x2pt)



Pessimistic Euclid + SO

Key figures:

- 3 LSS probes: GC_{ph}, GC_{sp}, WL
- 3 CMB probes: T, E, ϕ
- 6 XC signals: GC_{ph}XT, GC_{ph}XE, GC_{ph}Xϕ, WLXT, WLXE, WLXϕ
- 6 cosmological models (incl. w_0/w_a, Ω_k, γ)
- 2 Euclid scenarii (pessimistic/optimistic)
- 3 CMB setups (Planck-like, SO, CMB-S4)
- 2 scientific cases:
  - Euclid + CMB ϕ (all "matter probes")
  - Euclid + full CMB

Euclid only

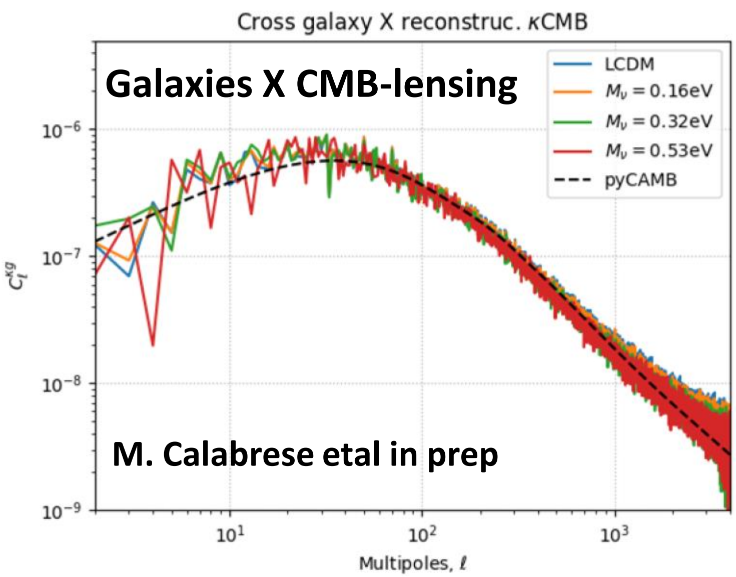
Euclid + CMB ϕ

Euclid + full CMB

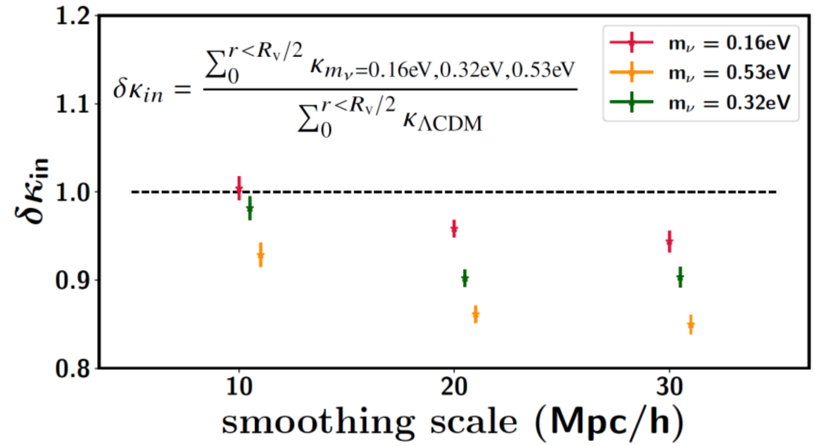
w_0w_a FoM including CMBX >1100

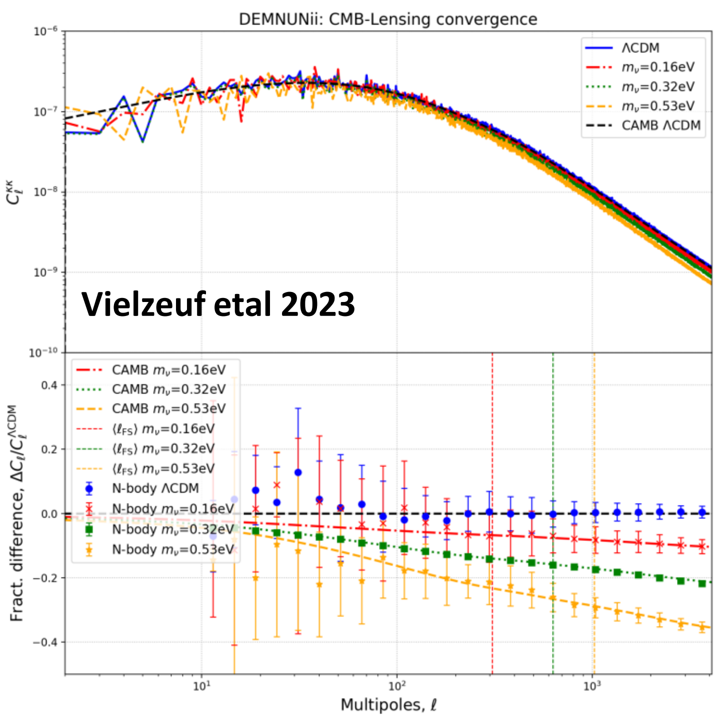
Error on γ almost halved

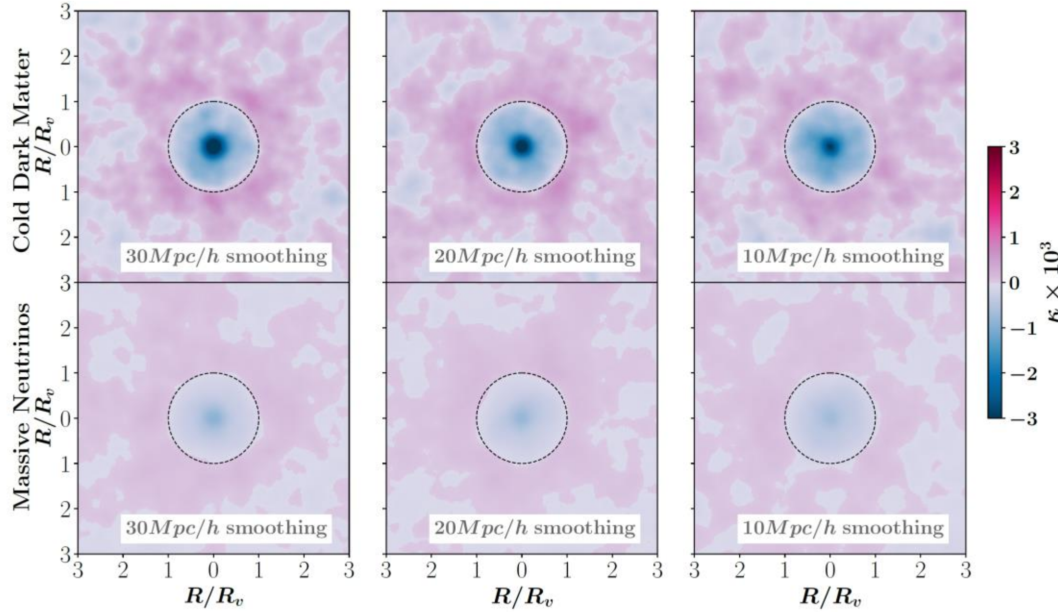
Euclid X CMB-lensing to constrain the neutrino mass



Voids X CMB-lensing







Vielzeuf etal 2023

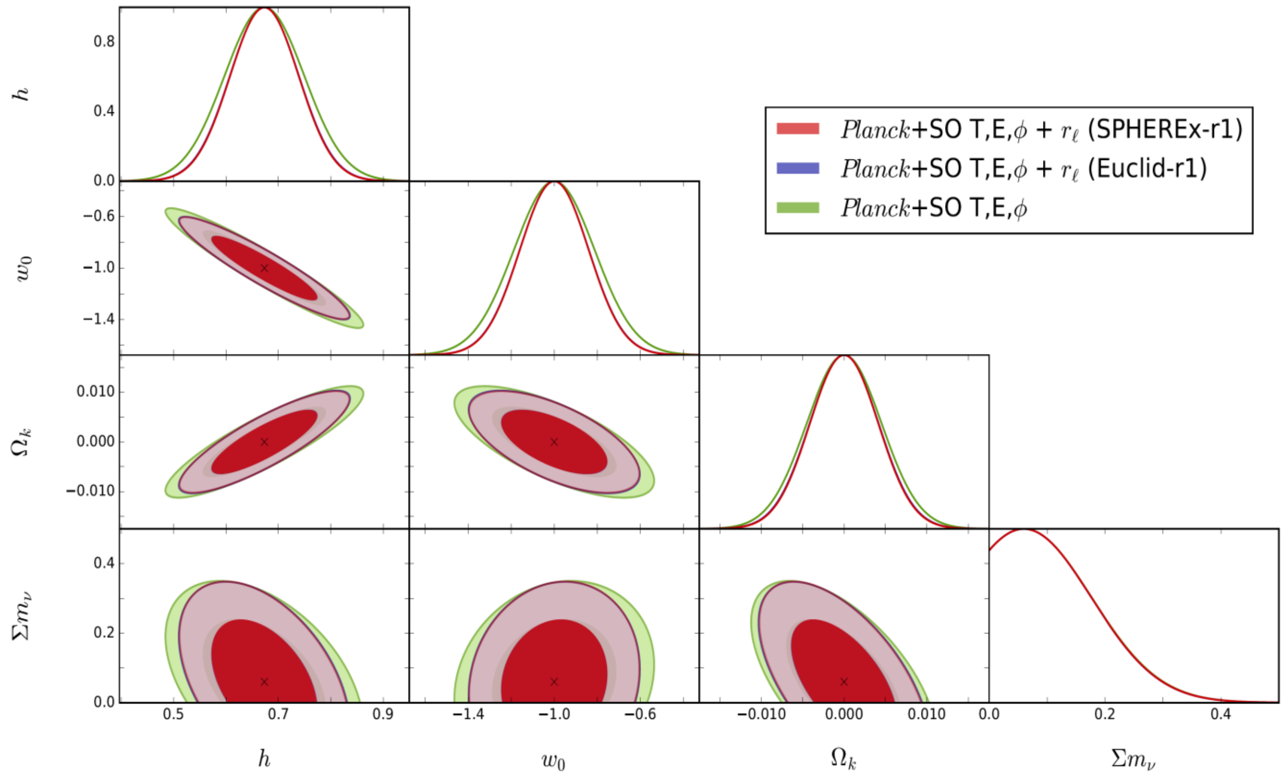
Euclid X CMB-lensing: lensing ratios

$$r_\ell \equiv \frac{C_\ell^{\kappa_{\rm CMB} G}}{C_\ell^{\kappa_{\rm gal} G}}$$

Lensing ratios - shear ratios between the galaxy - CMB lensing and galaxy - galaxy lensing cross-correlations are useful as “cosmographic” distance estimators (Das & Spergel 2009), mostly independent on bias.

Euclid in combination with CMB lensing is an ideal experiment for the lensing ratio: it will provide measurements of galaxy lenses (spectroscopic survey) and sources (photometric survey)

~5% measurement with Planck lensing, ~2% with SO (Bermejo-Climent etal (2020)
Current measurement is ~17% with DES+SPT

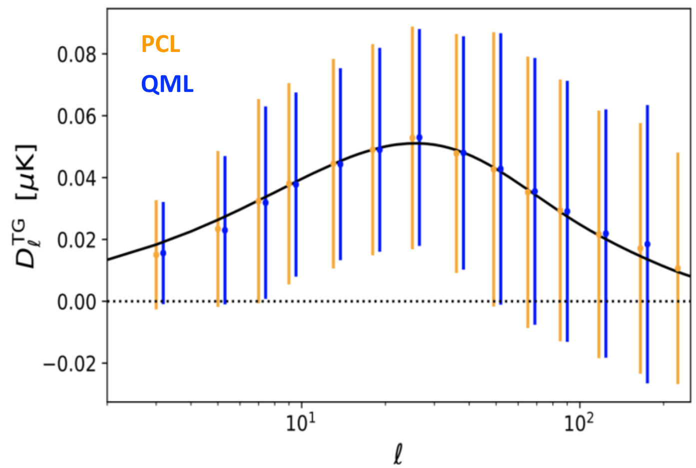


J. R. Bermejo-Climent et al. Phys. Rev. D (2020)

Euclid X CMB-ISW: constraining DE and primordial non-Gaussianity

(Gruppuso, Migliaccio, Cuozzo…)

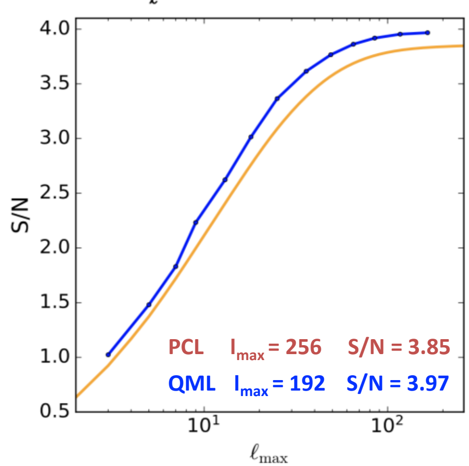
Comparison between PCL and QML on CMB and Euclid photometric survey simulations

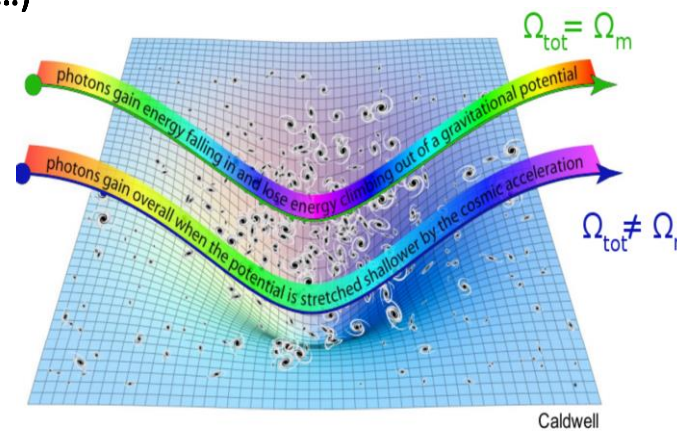


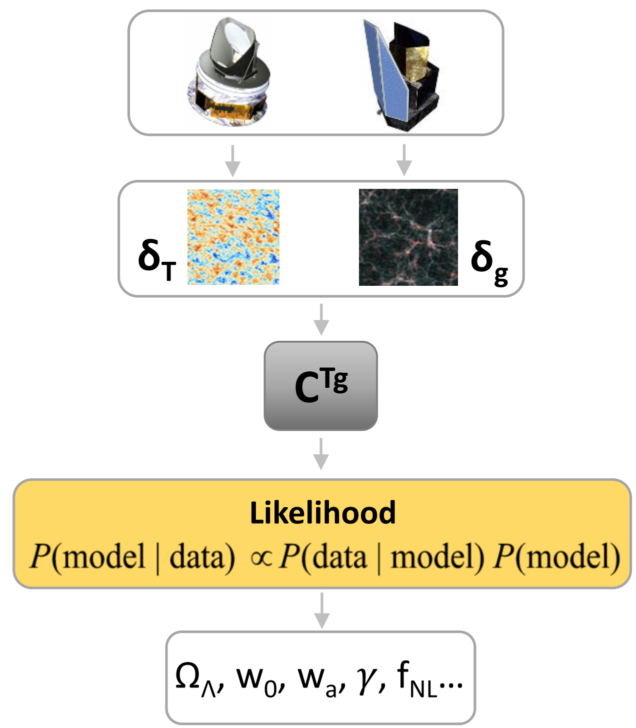
preliminary results

PCL= pesudo-CL etimators

QML=Quadratic Maximum likelihood estimators







Euclid X CMB-ISW: constraining DE and primordial non-Gaussianity

(Gruppuso, Migliaccio, Cuozzo…)

$\Omega_\Lambda \longrightarrow$ $$\boxed{\chi^2(\Omega_\Lambda) = \left[\hat{C}^{TG} - C^{TG}(\Omega_\Lambda)\right]^T Cov^{-1}\left[\hat{C}^{TG} - C^{TG}(\Omega_\Lambda)\right]}$$

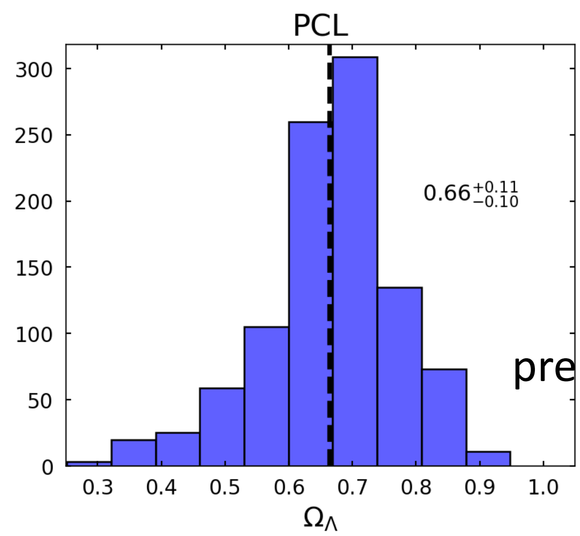
→ Assuming Fiducial Gaussian Likelihood with the PCL analytic covariance matrix

- $\widehat{C}^{TG}$: PCL estimates for 1000 simulations using the new survey RSD_2022G mask
- $C^{TG}(\Omega_\Lambda)$: grid of model C^{TG}

Mean bestfit of the Ω_Λ parameter:

$\Omega_\Lambda = 0.66^{+0.11}_{-0.10}$

[$\Omega_\Lambda^{\mathrm{Fiducial}} = 0.68$]

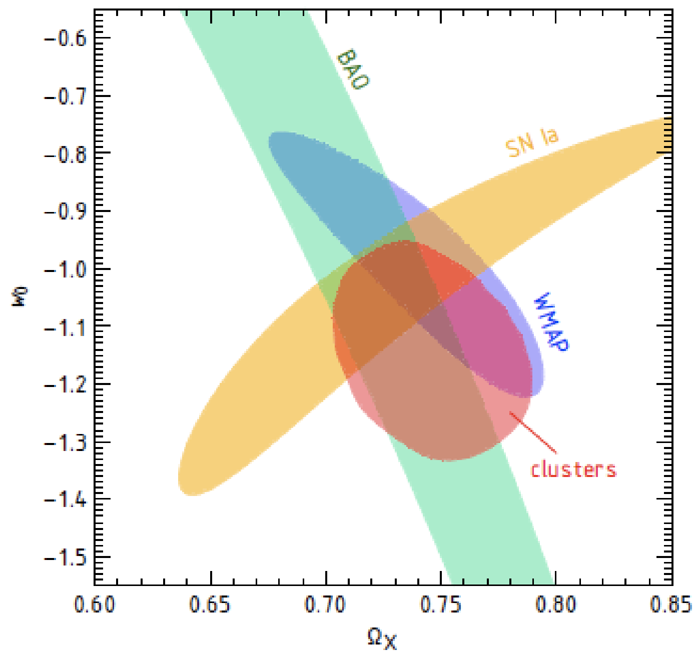


preliminary results

Galaxy-clusters X CMB: alternative ISW detection

Compared to CMB, SNe, Galaxy Clustering & Lensing, both **degeneracies and systematics** are different: **complementarity**

Two Euclid cluster probes: abundances & clustering



Vikhlinin et al. 2009

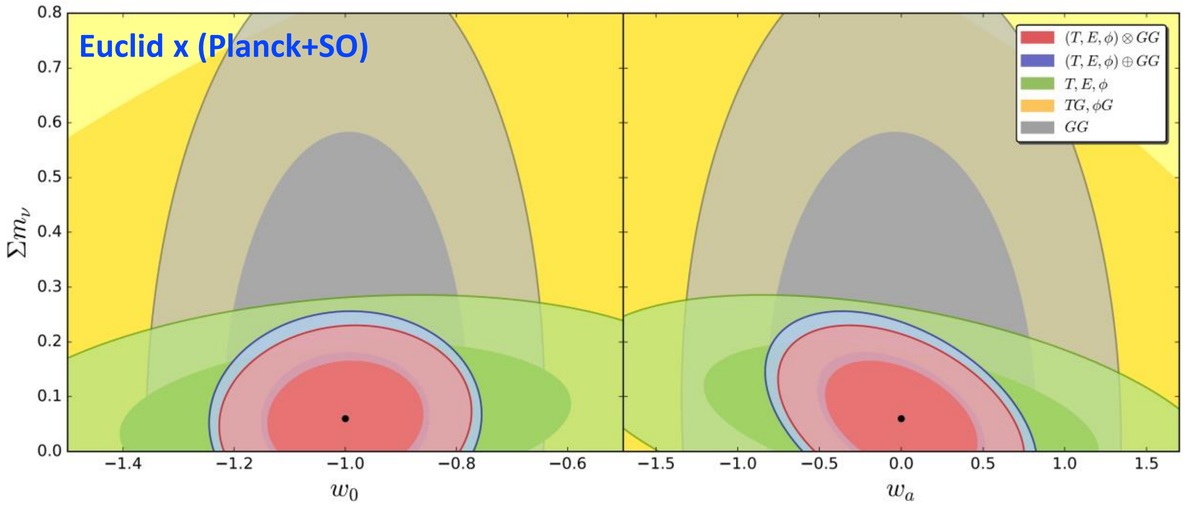
- with Euclid or eRosita you can detect ISW not only by cross-correlation with galaxies, but also with clusters of galaxies!

- 2 < S/N < 3 with current single galaxy survey.
- We find S/N ~ 4 for the expected Euclid cluster catalogue (Sartoris et al. 2016):

	eR_cl	Eu_cl_opt	Eu_cl_con	Eu_gal_sp	Eu_gal_ph
T	2.5	3.5	3.3	2.2	3.7
T,E	3.0	4.1	3.9	2.5	4.3

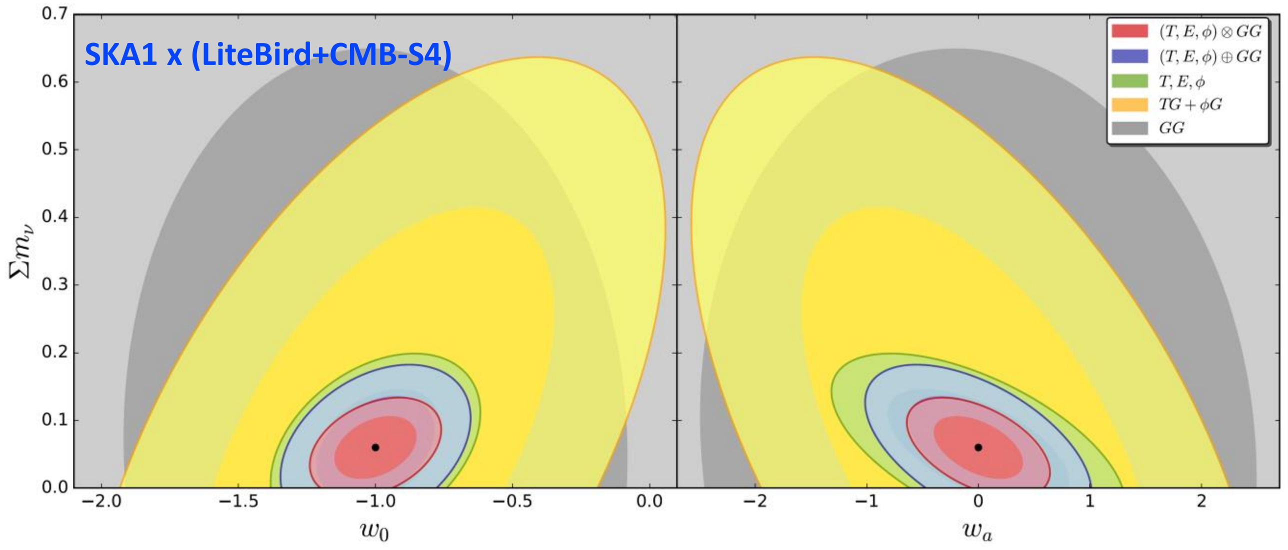
Ballardini, Paoletti, Finelli, Moscardini, Sartoris, MNRAS 482 (2019)

Euclid X ISW+CMB-lensing: constraining DE & neutrino mass



J. R. Bermejo-Climent etal (2021)

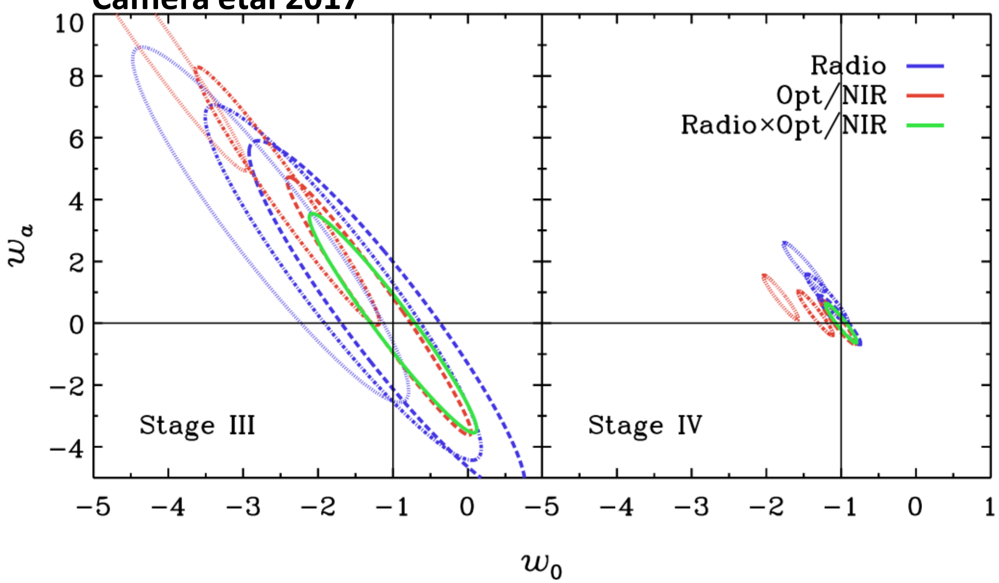
See also:
J. R. Bermejo-Climent Ph.D. thesis (2021),
supported by INAF-Spain fellowship.



Euclid X SKA: DE and primordial non-Gaussianity

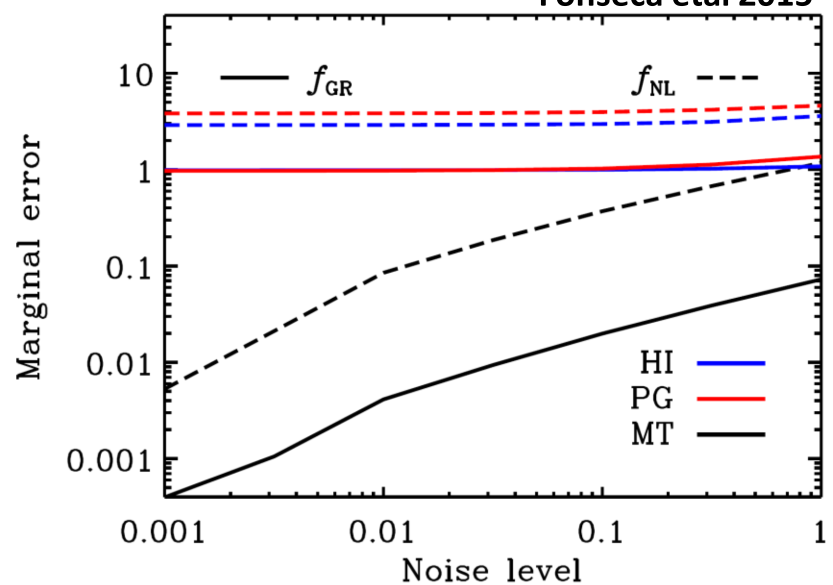
- SKA 21cm surveys would provide an independent redshift sample over large part of the wide Euclid survey, to further control systematic effects
- Combination of Euclid- and SKA-selected samples OVER THE SAME VOLUME will add extra power to clustering analysis: use of multiple tracers reduces statistical errors (Mc Donald & Seljak 2009)

Camera etal 2017



All contours but those for the cross-correlation are biased (i.e. they are not centred on the black cross) due to the presence of residual, additive experimental systematics.

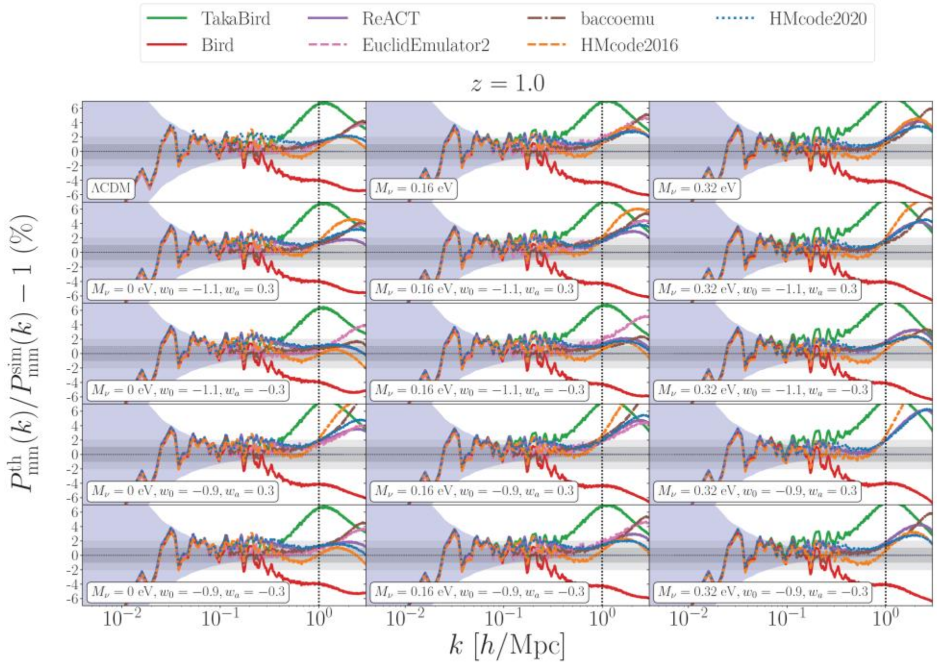
Fonseca etal 2015



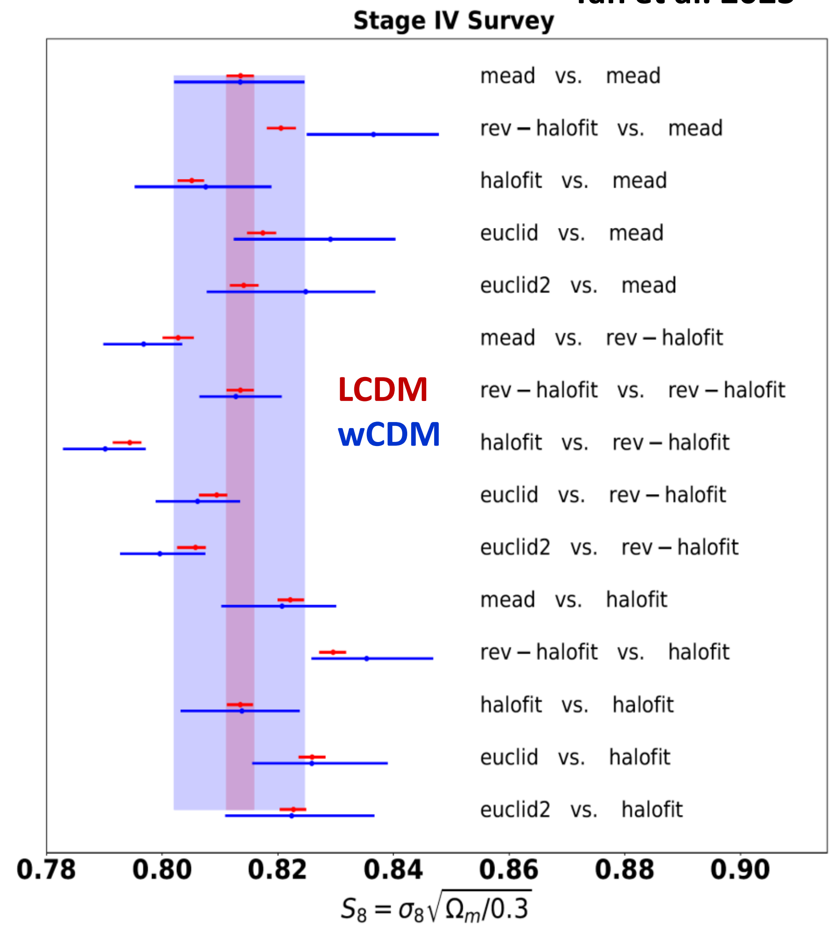
Multi-tracer technique applied to SKA1 X Euclid-photo dramatically reduce the statistical errors

Improving non-linear modelling…

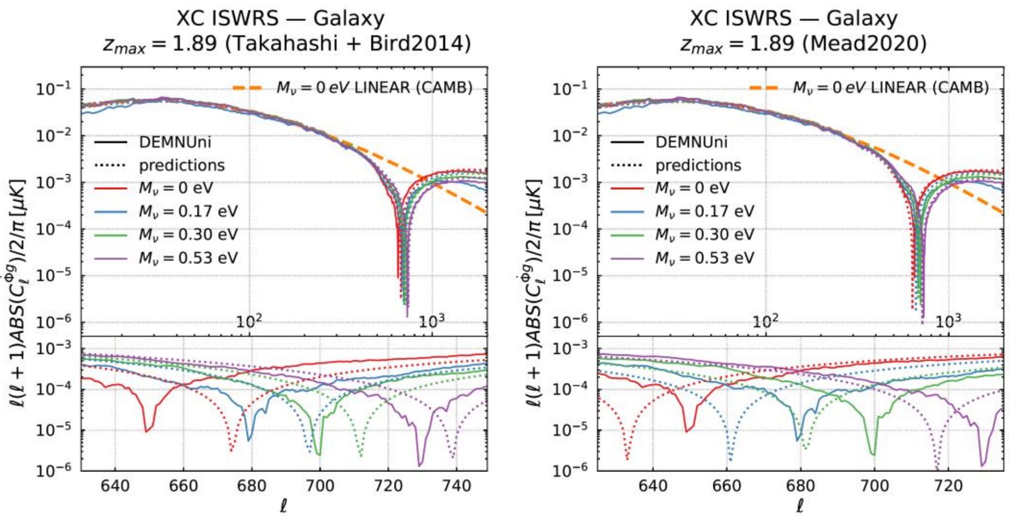
Parimbelli etal 2022



Tan et al. 2023

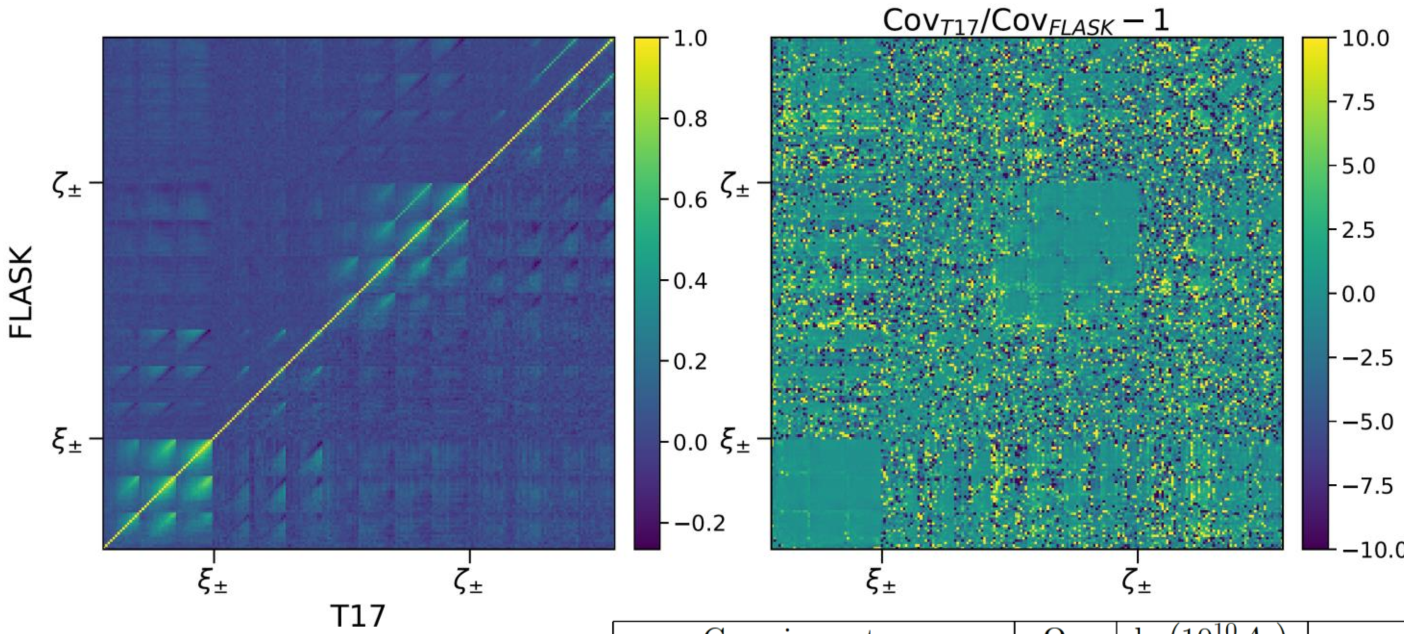


Weak-lensing alone



Cuozzo etal in prep

…implies investing in computational resources AND develop alternative strategies via ML/DL



Gong et al. 2023

Covariance type	Ω_m	$\ln\left(10^{10}A_s\right)$	w_0	c_min
FLASK (lognormal)	3.7%	20.2%	38.4%	15.1%
T17 (N-body simulations)	3.5%	8.8%	26.1%	8.7%

- Machine Learning for Observational Cosmology (arXiv:2303.15794)
- Jax-cosmo: an end-to-end differentiable and gpu accelerated cosmology library (arXiv:2302.05163)
- Cosmology with Galaxy Cluster Properties using Machine Learning (arXiv:2304.09142)
- Improving cosmological covariance matrices with machine learning (arXiv:2205.10881)
- Dedicated KP in Euclid GC-SWG WP:Likelihood (Bonici etal in prep)
- ….

Suggested future strategies

- Combine and cross-correlate sight (photons) and hearing (gravitons) as you do in your day life: maybe a possible solution to the H_0-tension.
- Improve nonlinear modelling: maybe a possible mitigation to the S_8 tension (needs big investment in computing resources).
- Data will be too huge for traditional techniques: invest in deep learning techniques (PNRR-CN1 only a starting point)
- Invest in (especially high-z) multi-wavelength and multi-tracers (SKA, Euclid, JWST…) cosmology: possible solution to calibration/systematics.