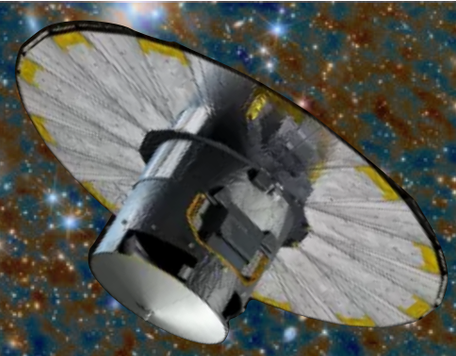
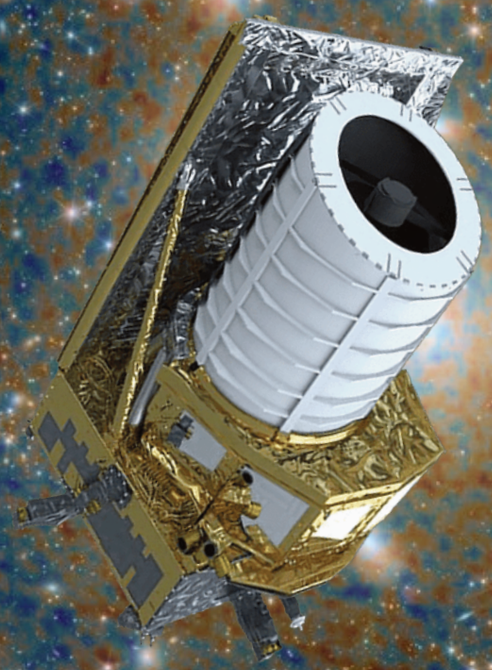


Cosmology from CMB and galaxy surveys from space: status and prospects.



Giulio Fabbian

Institut d'Astrophysique Spatiale

université PARIS-SACLAY

cnrs

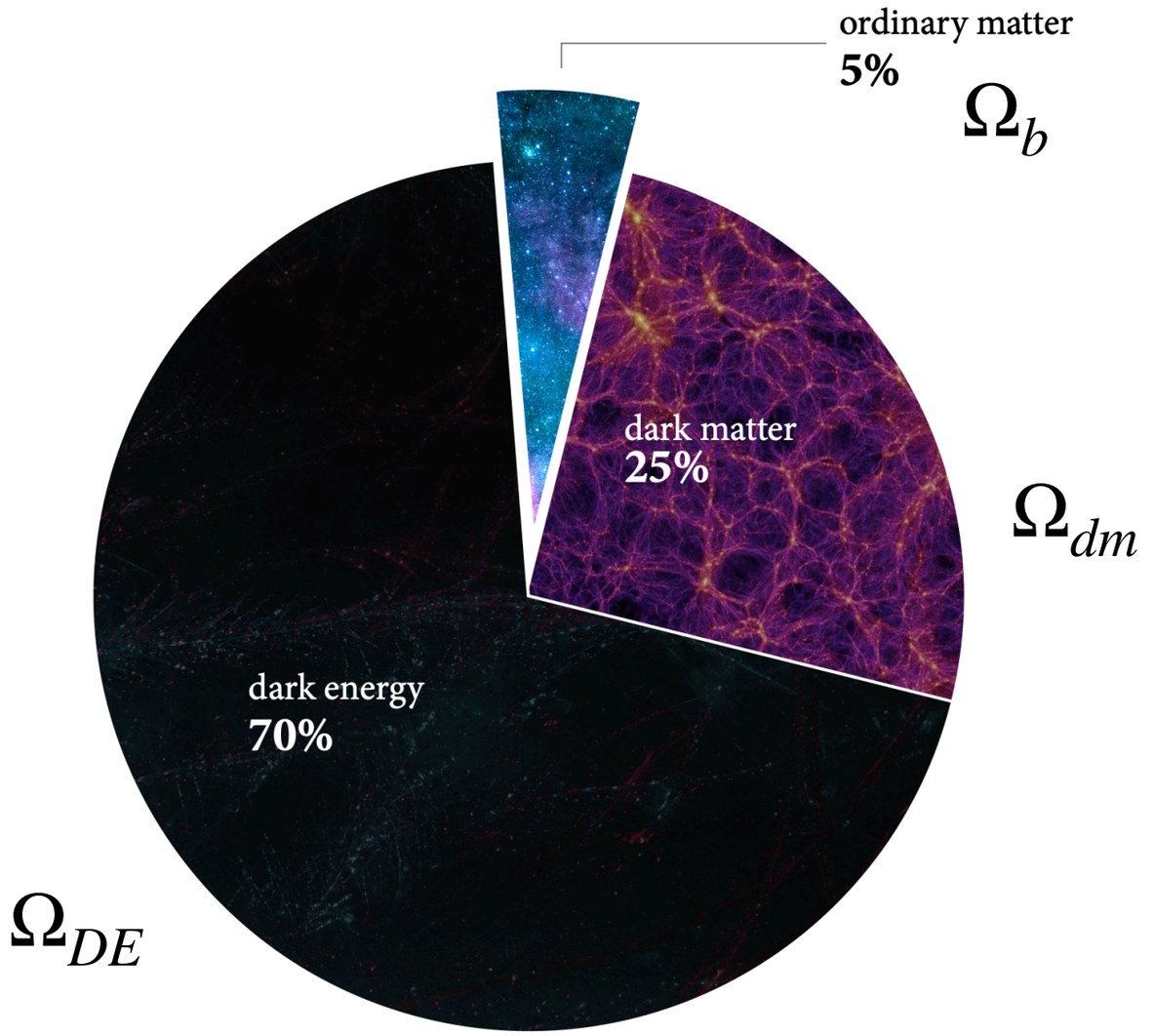
IAS Institut d'Astrophysique Spatiale Orsay

Outline (optimistic)

- Some general intro on CMB, LSS and cross-correlation cosmology.
- The Euclid mission
  - (Preliminary) cosmological results with Q1 data release
  - Status and prospects for DR1
- Cosmology and astrophysics with Gaia QSOs
  - Summary of past work and prospects for DR4.
- Conclusions

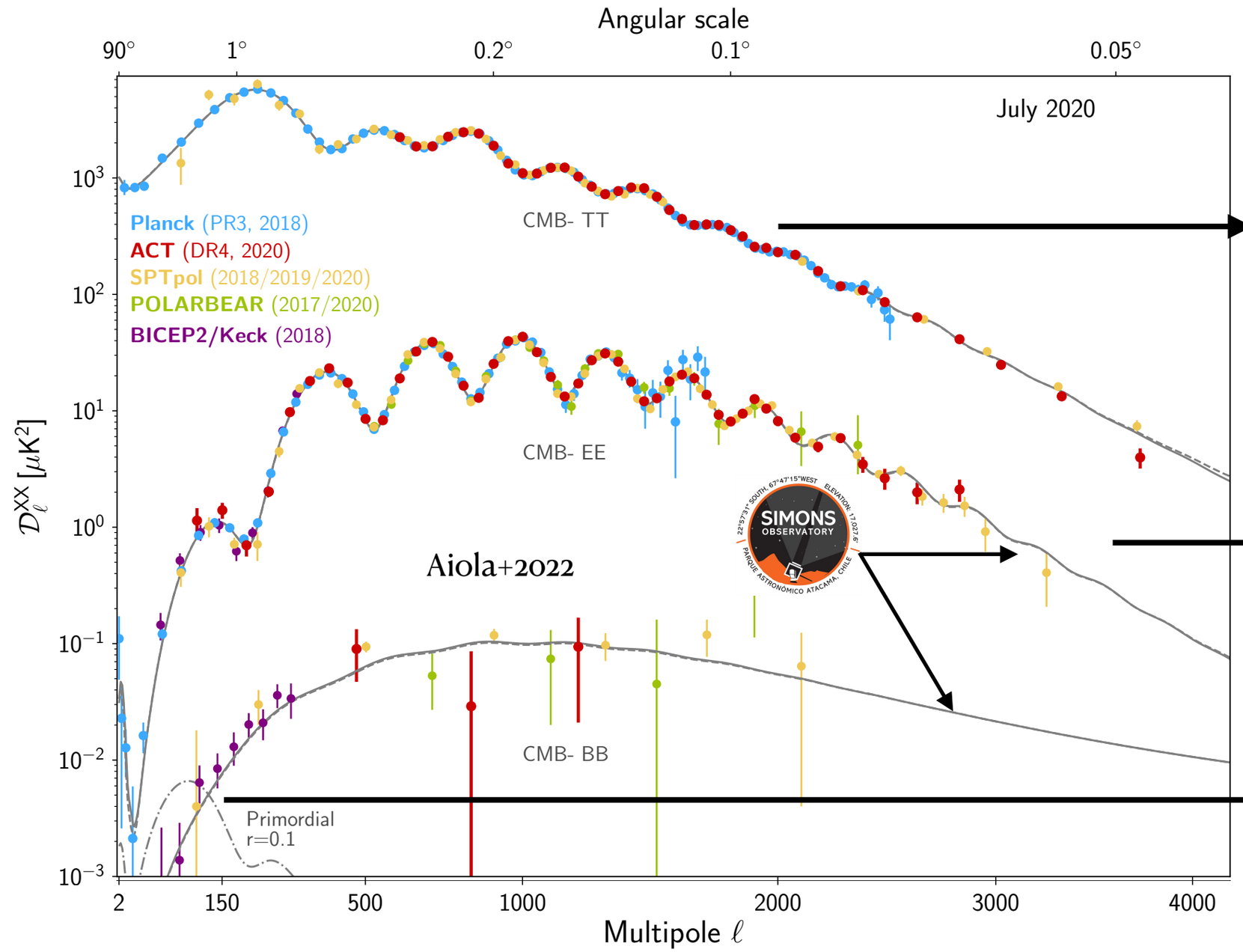


Open questions in cosmology as of 2026



- What is **dark matter**? Do **massive neutrinos** contribute?
- What is the nature of **dark energy**?
- Which mechanism driving primordial **inflation**?

Cosmological probes: CMB



$\Omega_b, \Omega_m, \Omega_\Lambda, \Omega_k, n_s, A_s, \alpha_s$

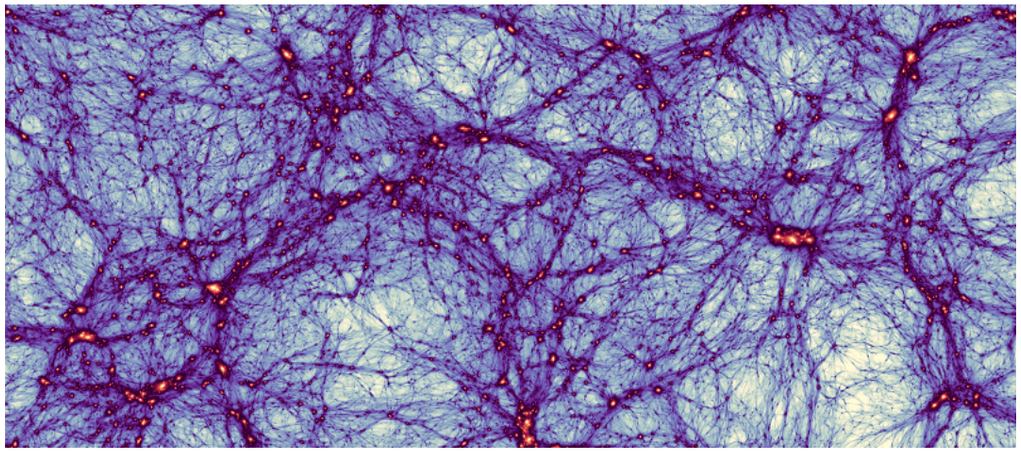
τ, N_{eff}

$r, n_T,$ inflation energy scale

- CMB temperature information saturated by Planck, now moving to polarization (ACT, SPT…)
- Major improvements on $\sum m_\nu$ from new polarization measurements.

Beyond CMB observations

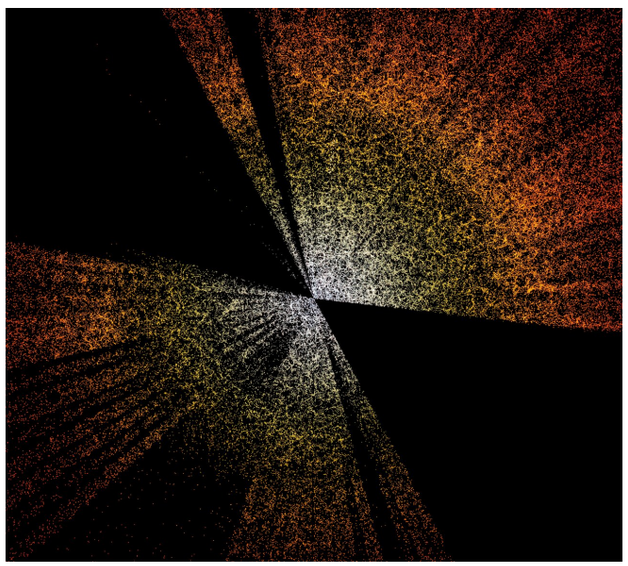
- Observing matter distributions as it grows: we need proxies

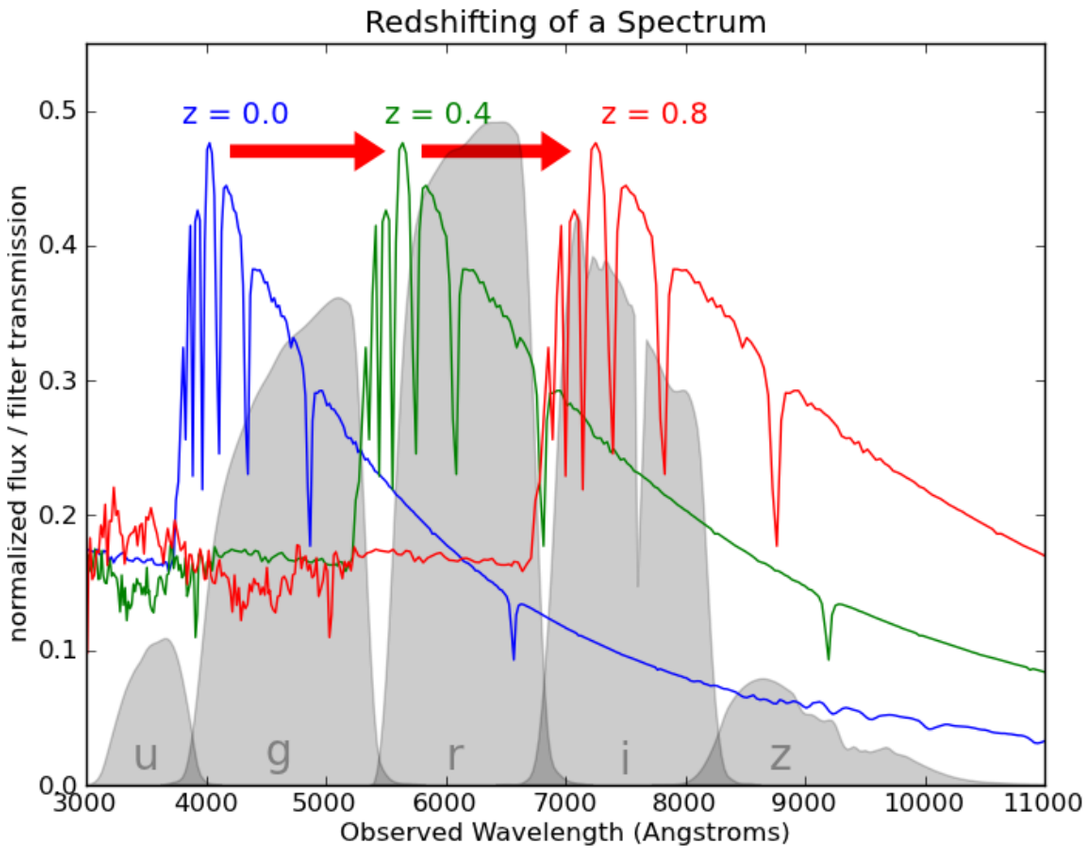


$f[\delta_m]$



- Spectroscopic surveys (e.g. DESI)



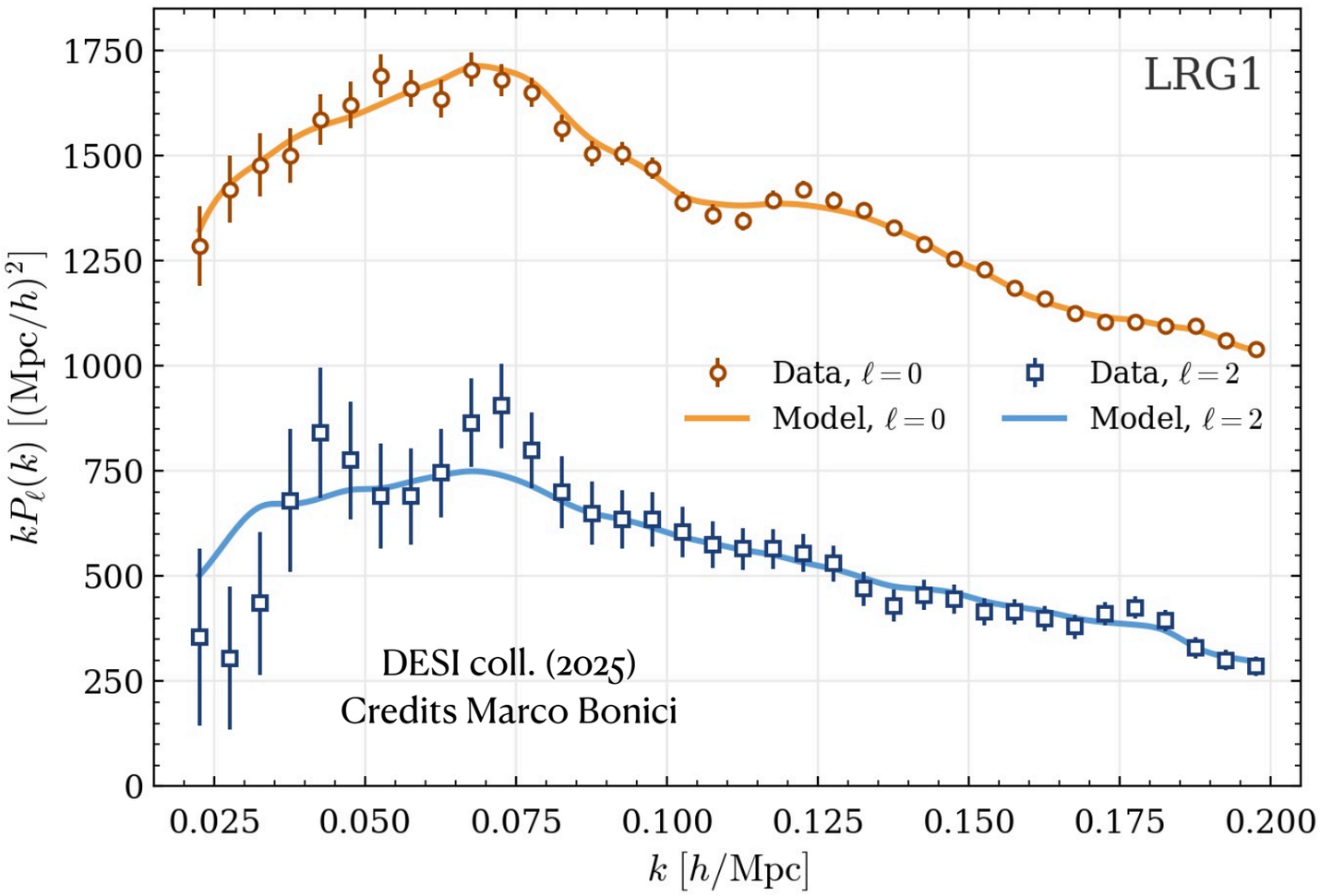


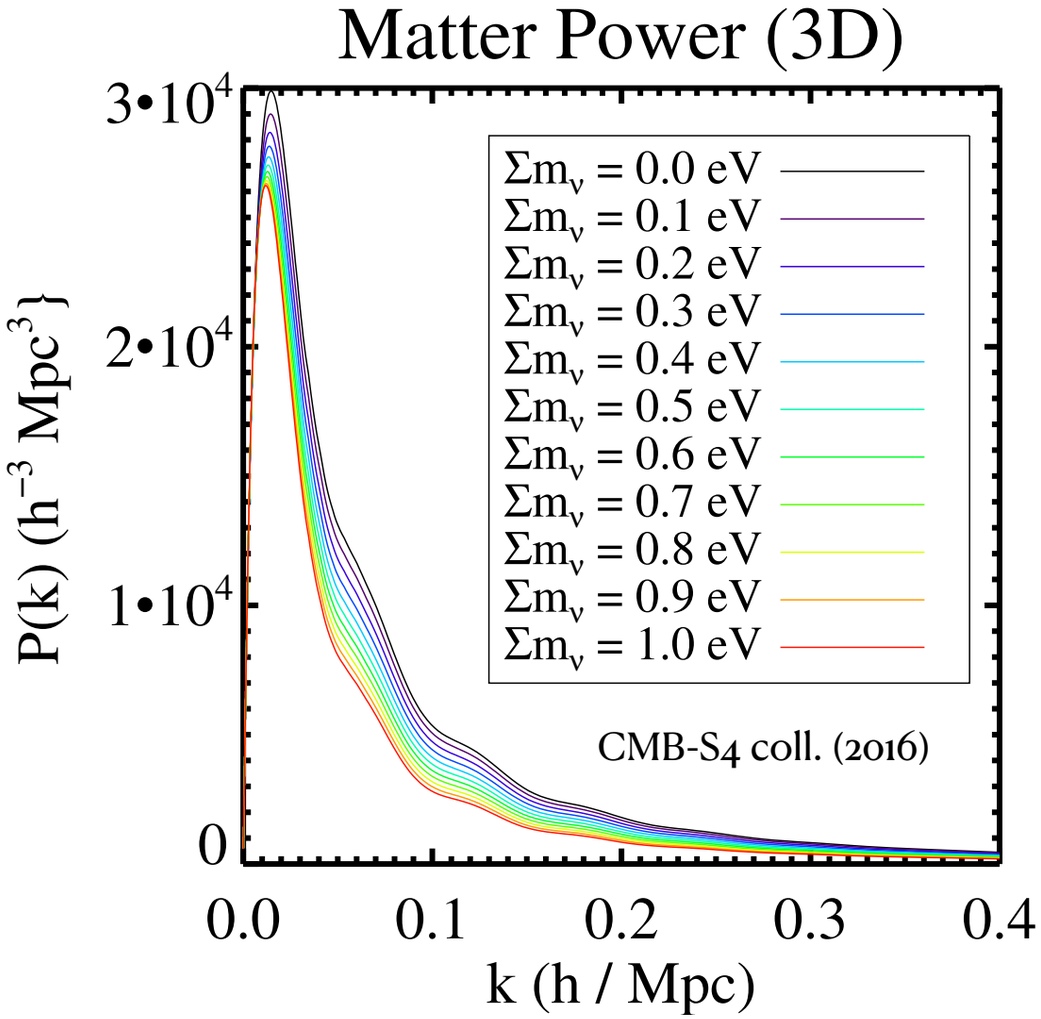
- Photometric surveys (e.g. Rubin)



Cosmological probes: galaxy clustering

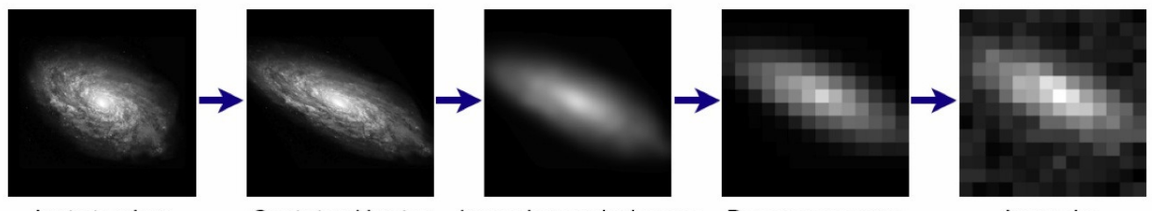
- To test LCDM model large-scale structures (LSS) offer invaluable tomographic help!
- More sensitive to parameters governing recent growth (dark energy, neutrinos)
  - 3D $P(k,z)$ with shape and BAO, 2D C_ℓ^{gg}
  - Challenges: galaxy bias $P(k,z) \approx b_g^2(z,k) P_{mm}(k,z)$



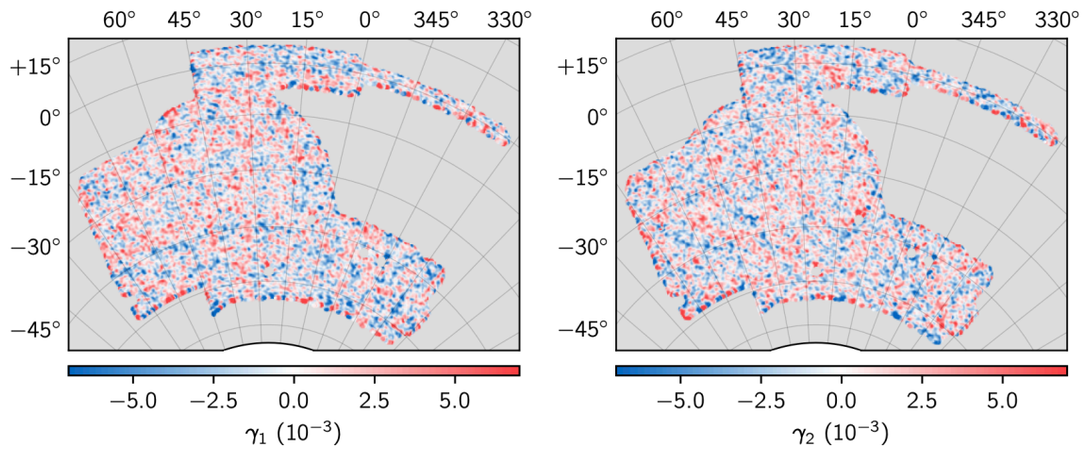


Cosmological probes: weak lensing

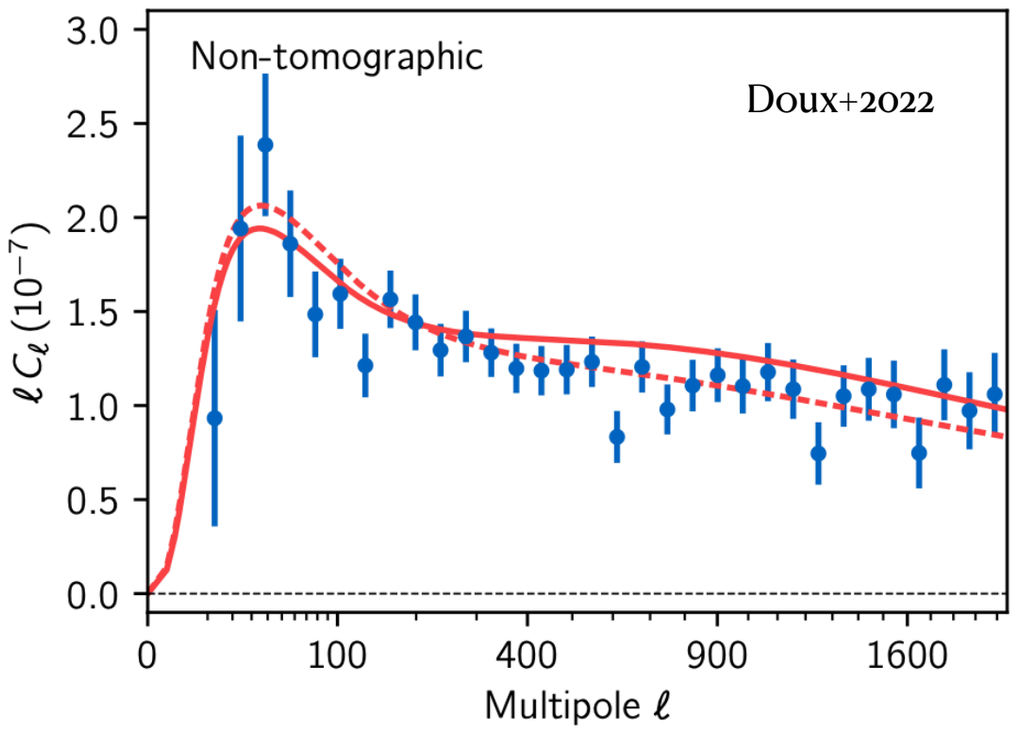
- Galaxy shape/ellipticity is correlated by the presence of dark matter through lensing.



$$\gamma = e_1 + ie_2$$



$$C_\ell^{\gamma\gamma} \approx P_{mm}(k, z_i)\frac{\chi - \chi_{z_i}}{\chi\chi_{z_i}}\frac{dN}{dz}j_\ell(k\chi)$$

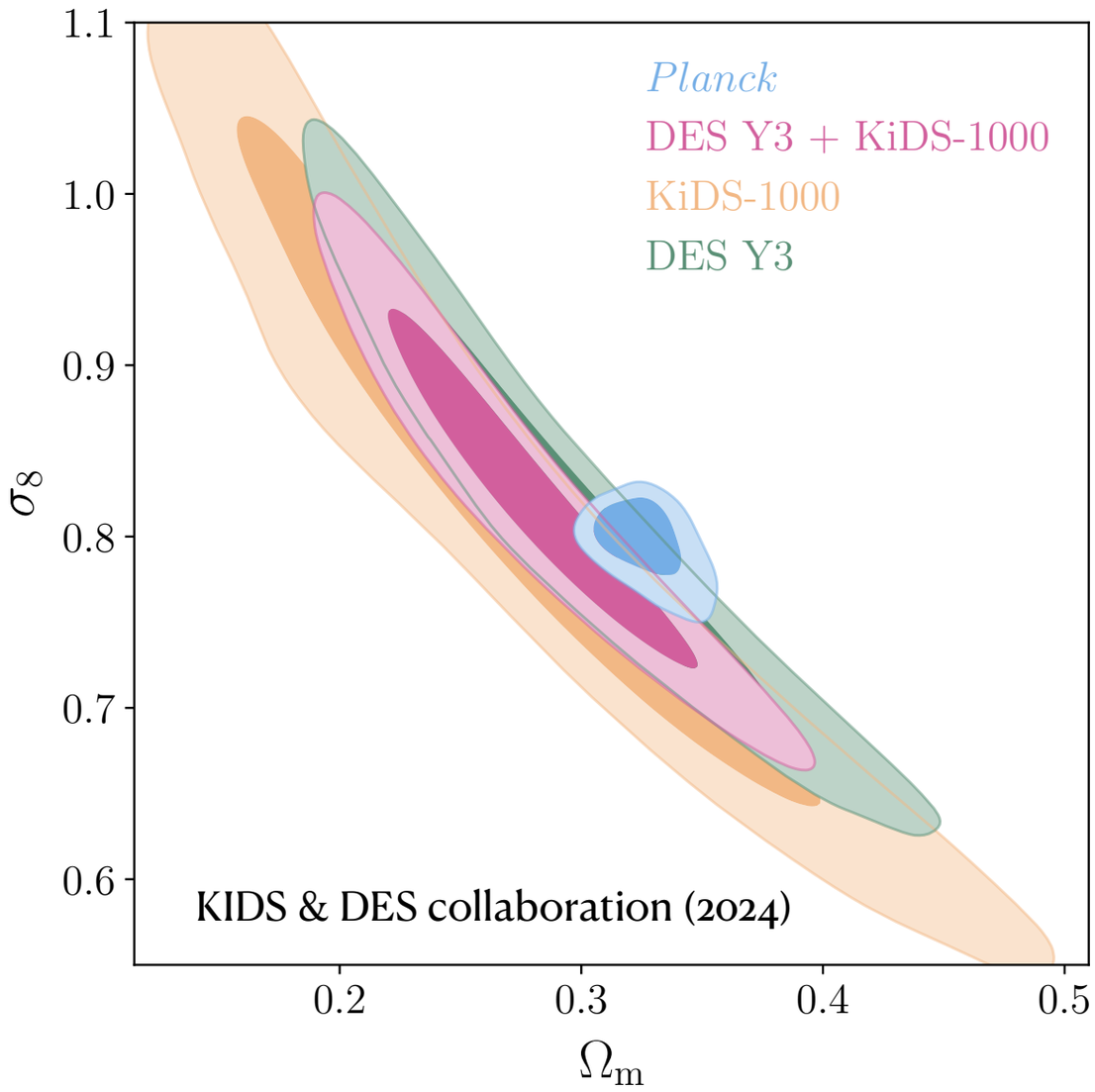


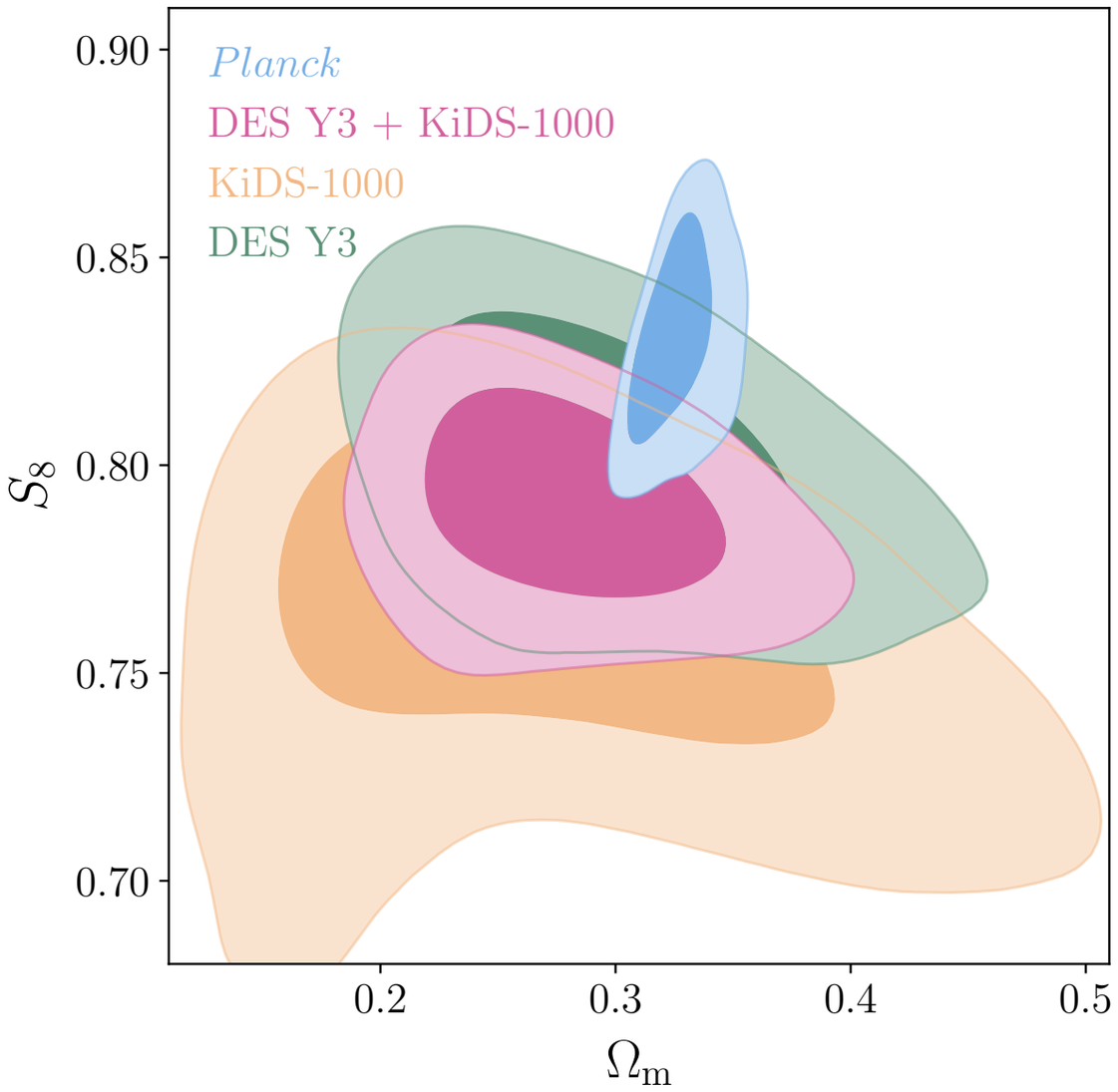
- Galaxy intrinsic alignment: $\langle\hat{\gamma}\hat{\gamma}\rangle = \langle\gamma\gamma\rangle + \langle\epsilon^s\epsilon^s\rangle + \langle\gamma\epsilon^s\rangle$

- PSF, noise and lensed galaxies' distribution: $\hat{\gamma} = (1+m)\gamma + \mathbf{n}$

Cosmic 3x2pt

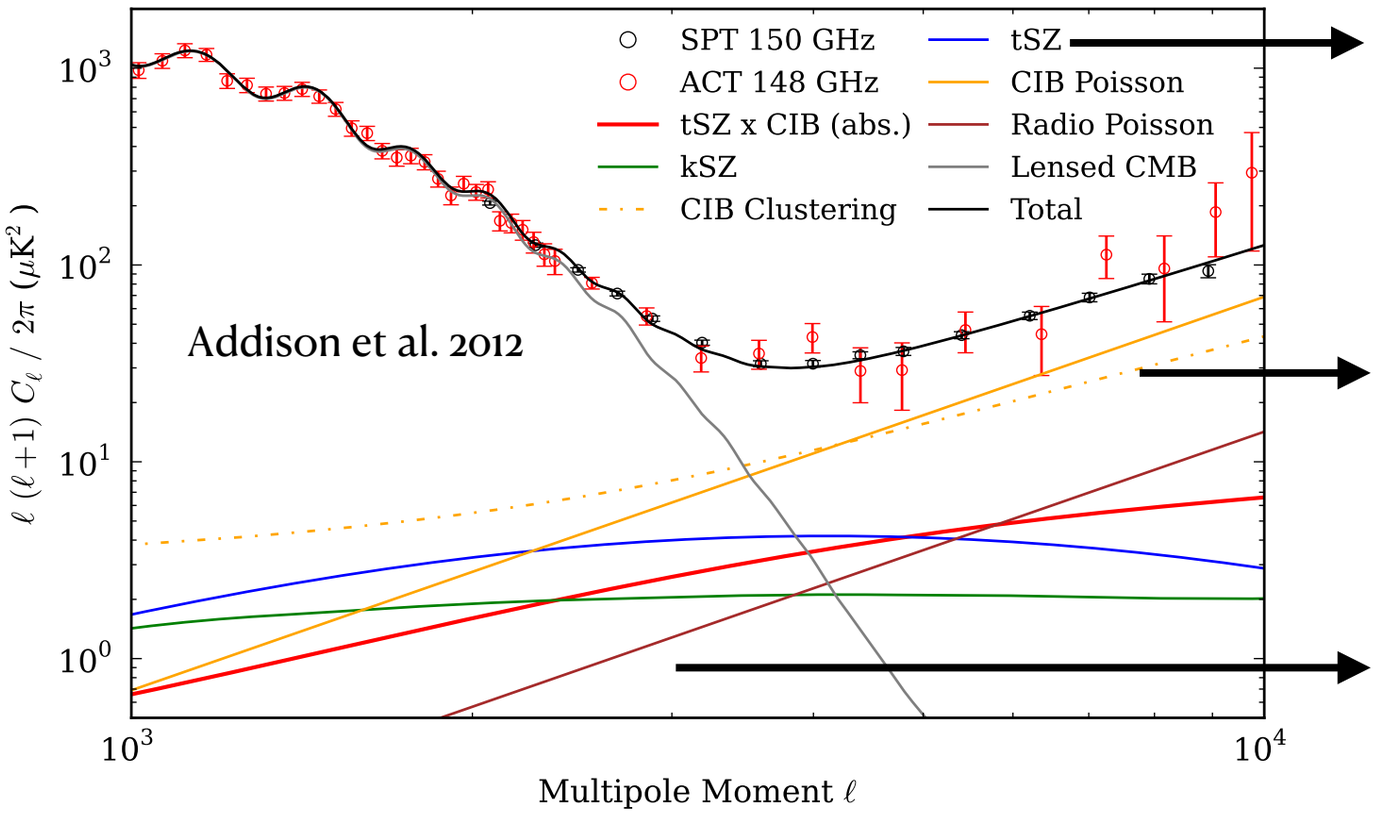
- Galaxy clustering: local, growth rate $C_\ell^{gg} \propto b_g^2 \sigma_8^2$ Matter RMS over 8 Mpc radius
- Weak lensing / cosmicshear: LOS integrated, sensitive to amplitude $S_8 = \sigma_8 \sqrt{\Omega_m / 0.3}$
- Shear + galaxy-shear: sensitive to $\partial C_\ell / \partial P(k), C_\ell^{g\gamma} \propto b_g \sigma_8^2$

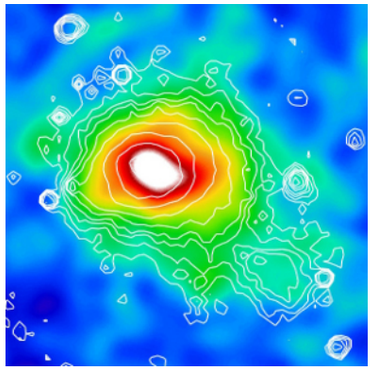




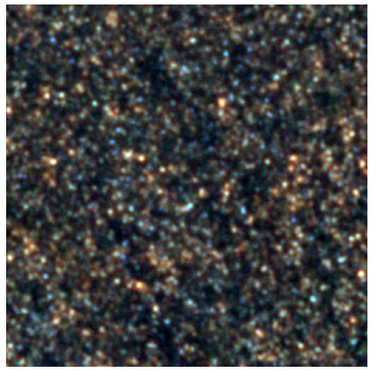
Is CMB "the" CMB?

- CMB is a snapshot of the universe at z ~1100.... plus lots of other things!
  - Galactic foreground emissions (dust, synchrotron, free-free, AME)
  - Imprint of astrophysical objects / late time physics

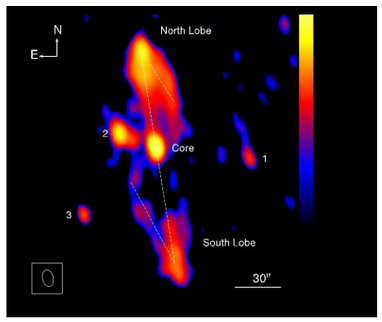




- ICM gastrophysics, cosmology (tSZ/kSZ)



- Star formation, cosmology (CIB)

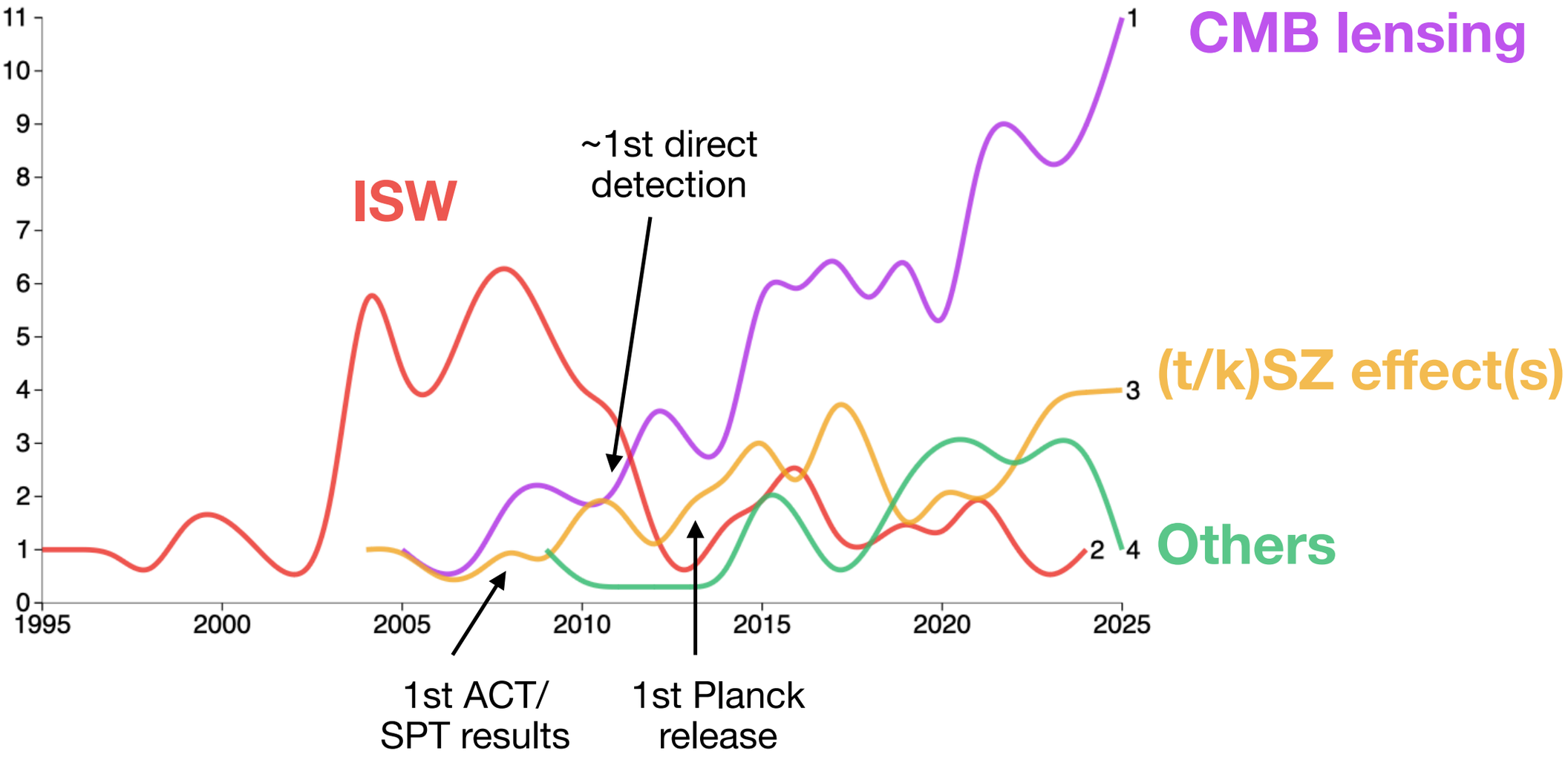


- Extragalactic astronomy, Galaxy evolution

State of the art of the CMB secondaries

- ISW "oldest" probe, becoming less competitive because of limited achievable precision (cosmic variance…)
- CMB lensing hints in early 2000s, first detections 2010, now booming!
- tSZ picking up after first Planck data release, regaining momentum with kSZ

Ignore units



CMB and gravitational lensing

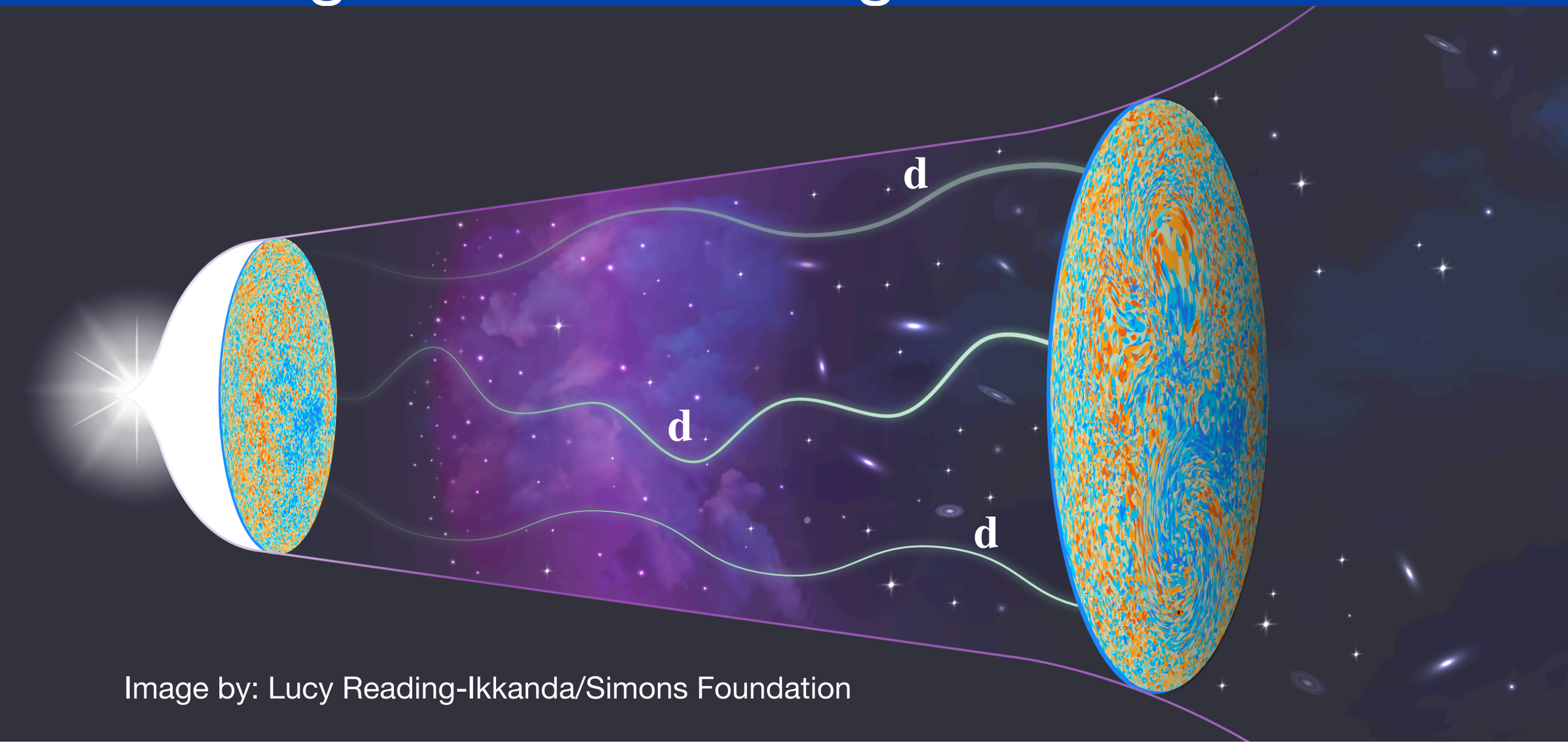


Image by: Lucy Reading-Ikkanda/Simons Foundation

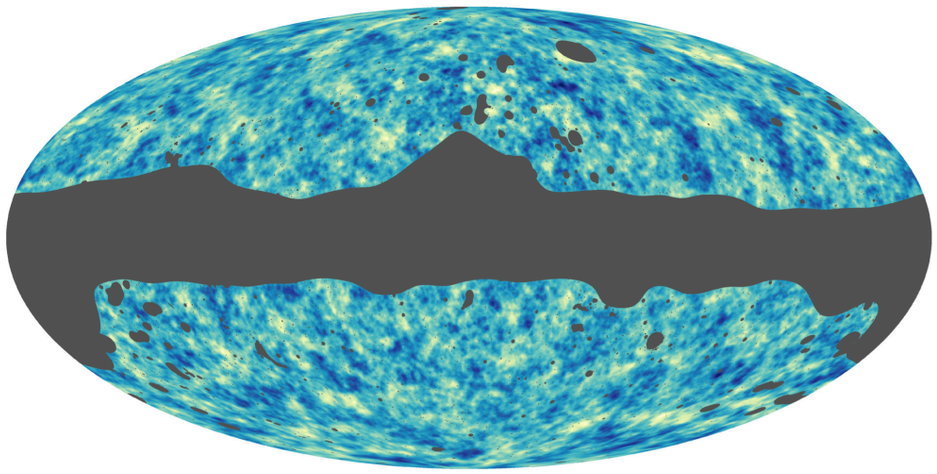
- CMB is the most distant light: photons cross potential wells of LSS as they form.

- The properties of lensing are encoded in the deflection field: can we estimate this? Yes!

$$\mathbf{d} = \nabla\phi \longrightarrow \hat{\phi}(\mathbf{L}) \sim \int \mathrm{d}^2\mathbf{l}\, T(\mathbf{l}) T^*(\mathbf{l}-\mathbf{L})$$

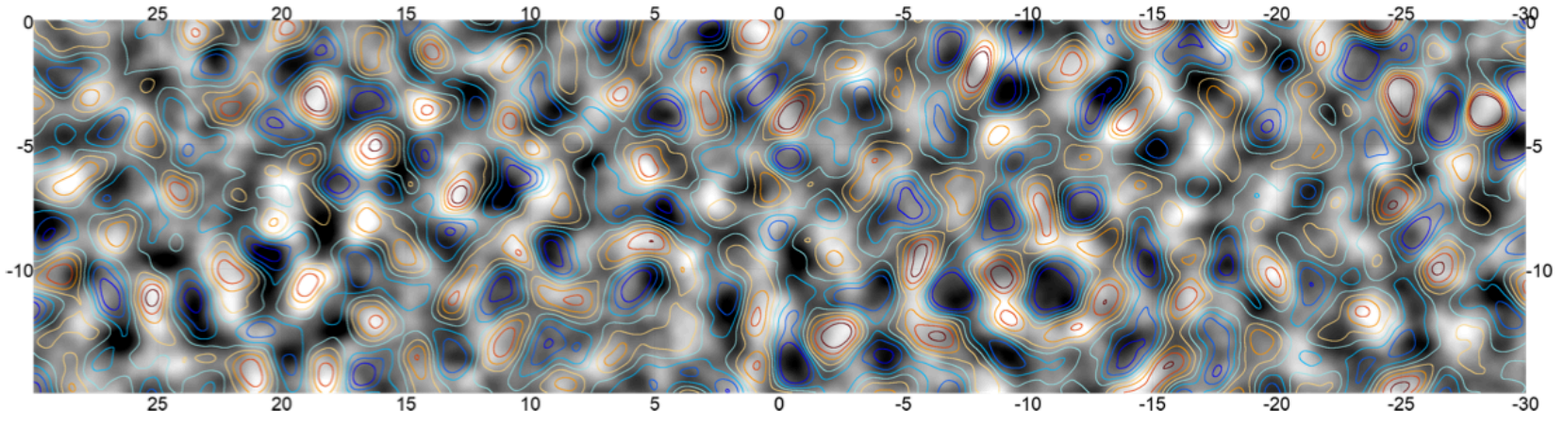
CMB lensing state of the art

Planck DR4 $|\mathbf{d}| = |\nabla\phi|$



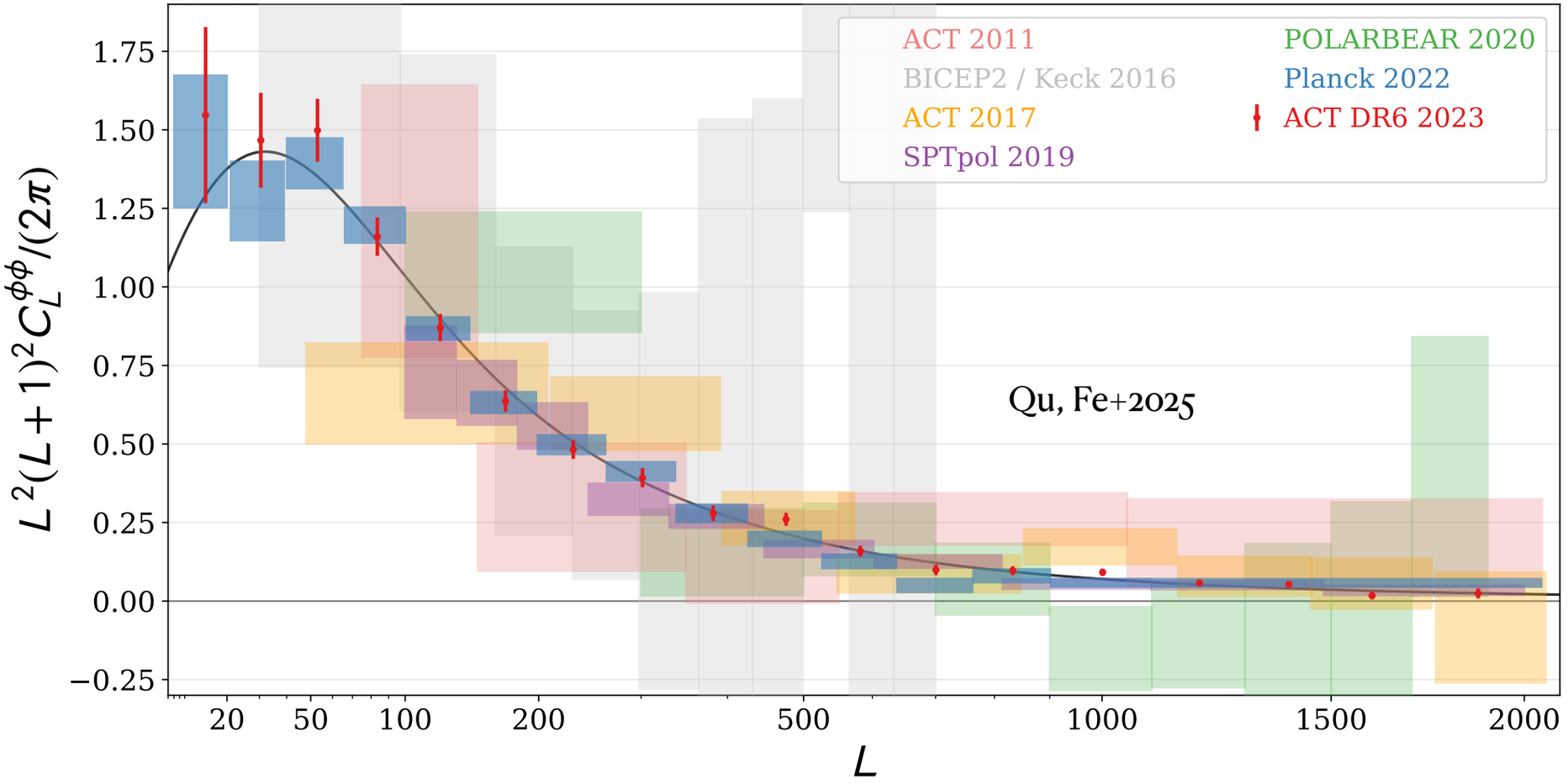
Planck (2018), Carron+(2022)

ACT (~40% sky, $\kappa \propto \nabla^2\phi$)



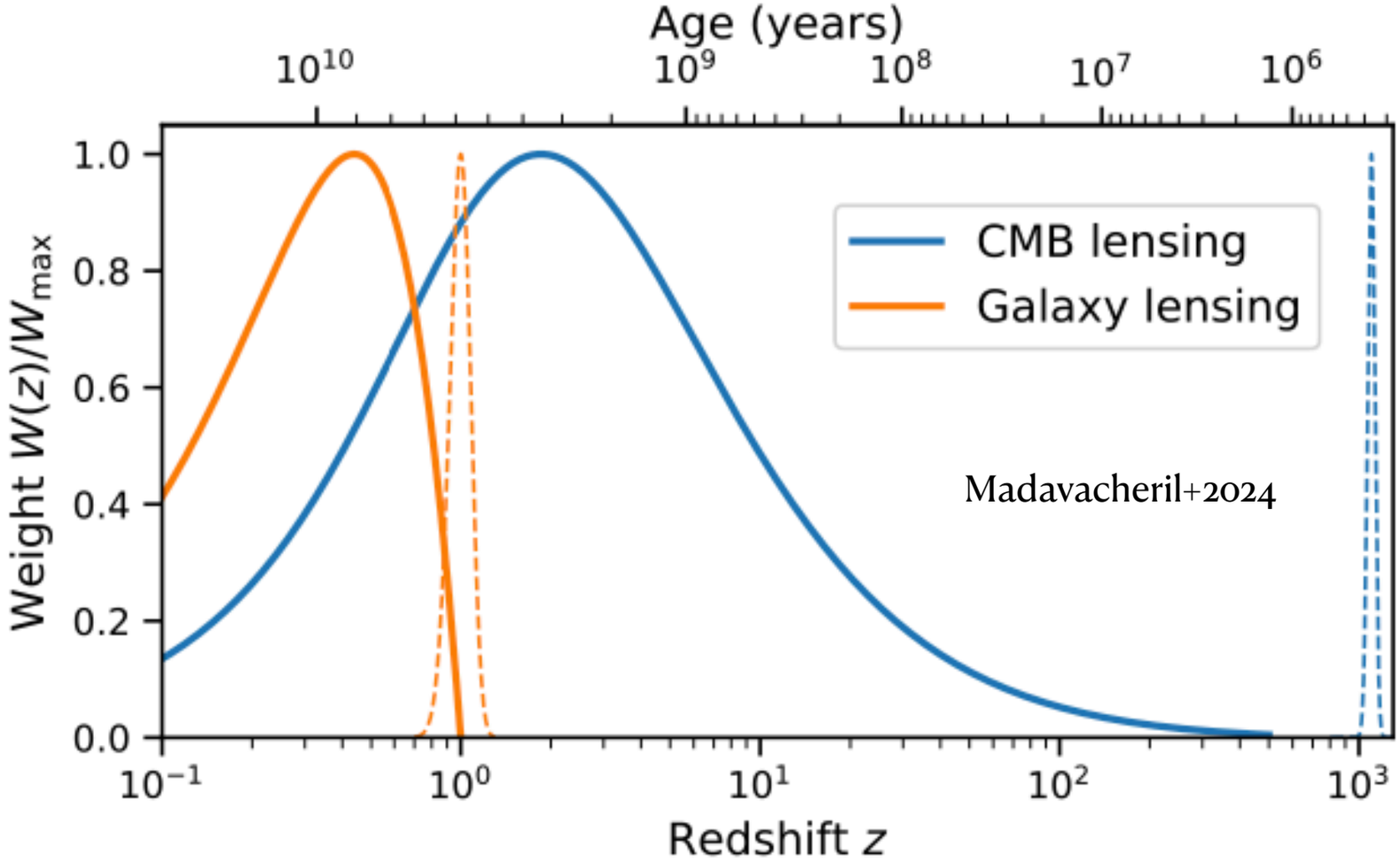
ACT: Madhavacheril+(2024), Qu+(2024).
Fe, Millea+(2024), Omori+ (2026) for SPT on 1500deg2

~40σ detection



CMB probes and cross-correlation

- CMB lensing: integrated, 2D projected, unbiased, mostly linear matter probe at z~2.
  - Applies also to SZ maps, CIB maps, temperature maps….
- Overlaps with anything connected to LSS (broad kernels):
  - synergies and complementarity with LSS probes.



Cross-correlation basis and examples

$$C_L^{AB} \approx \int \frac{d\chi}{\chi^2} W_A(\chi) W_B(\chi) P_\delta \left(k = \frac{L+1/2}{\chi}, z(\chi) \right)$$

CMB lensing

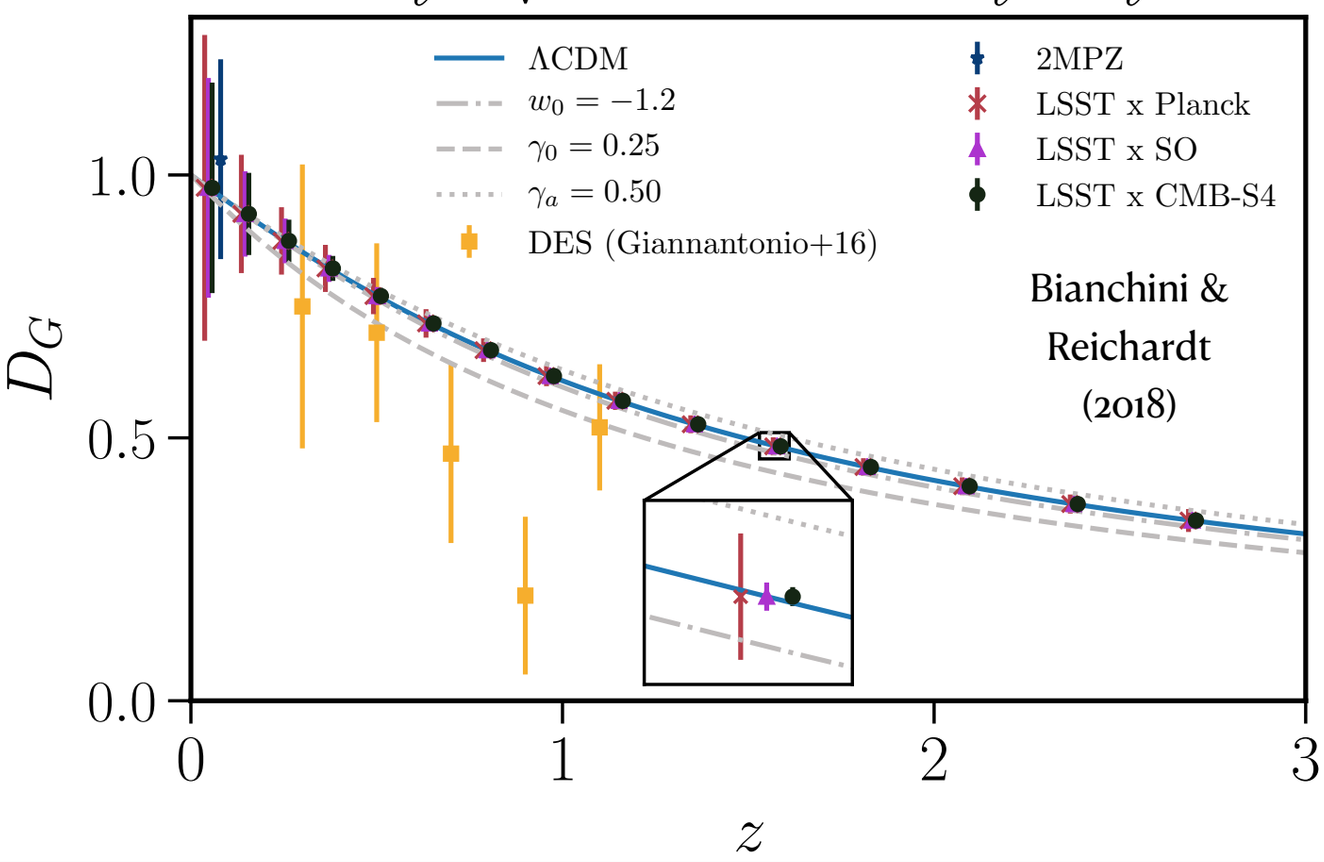
Galaxy clustering

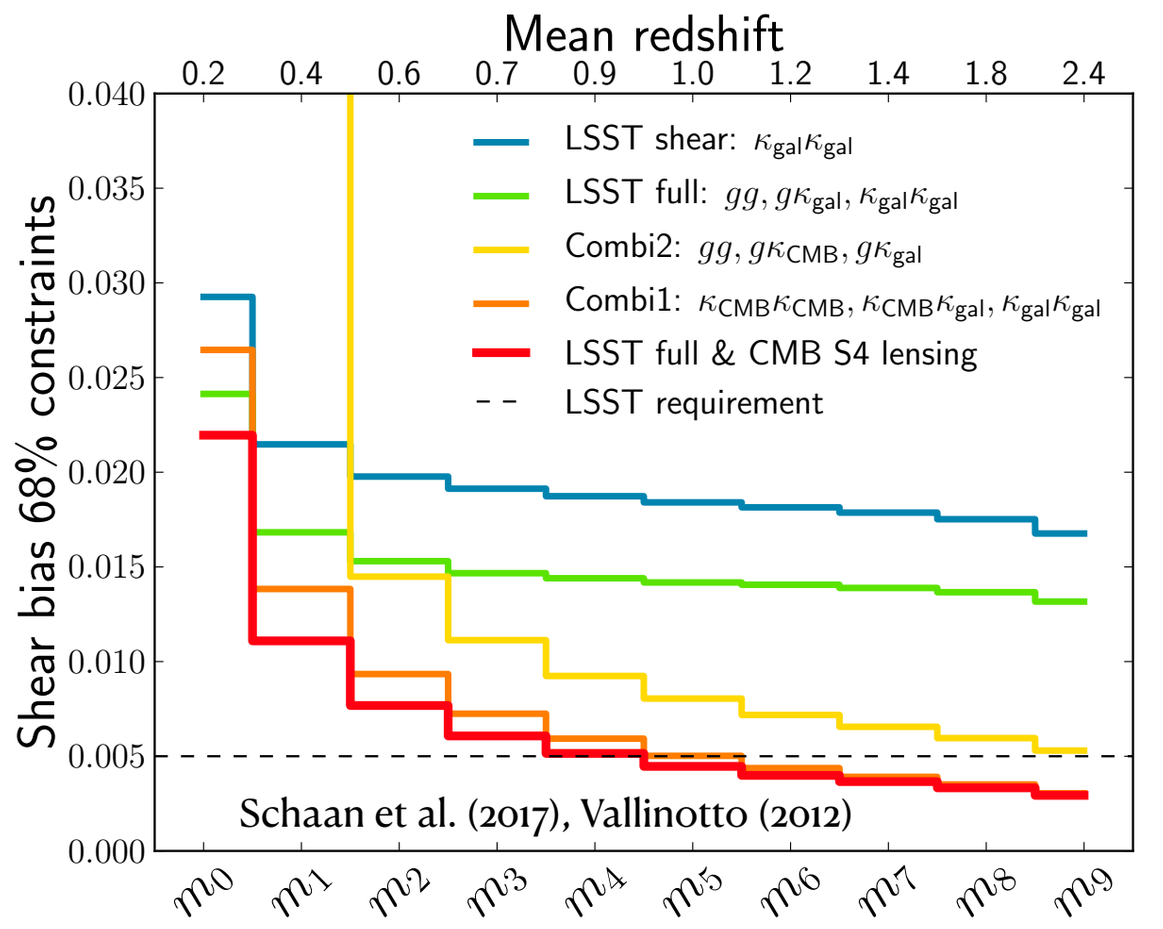
$$W_g(\chi) = b_g(z) \frac{1}{n} \frac{dn}{dz} \frac{dz}{d\chi}$$

Galaxy lensing

$$W_\kappa(\chi, \chi_s) = \gamma(\chi) \chi^2 \left(\frac{1}{\chi} - \frac{1}{\chi_s} \right) \Theta(\chi_s - \chi)$$

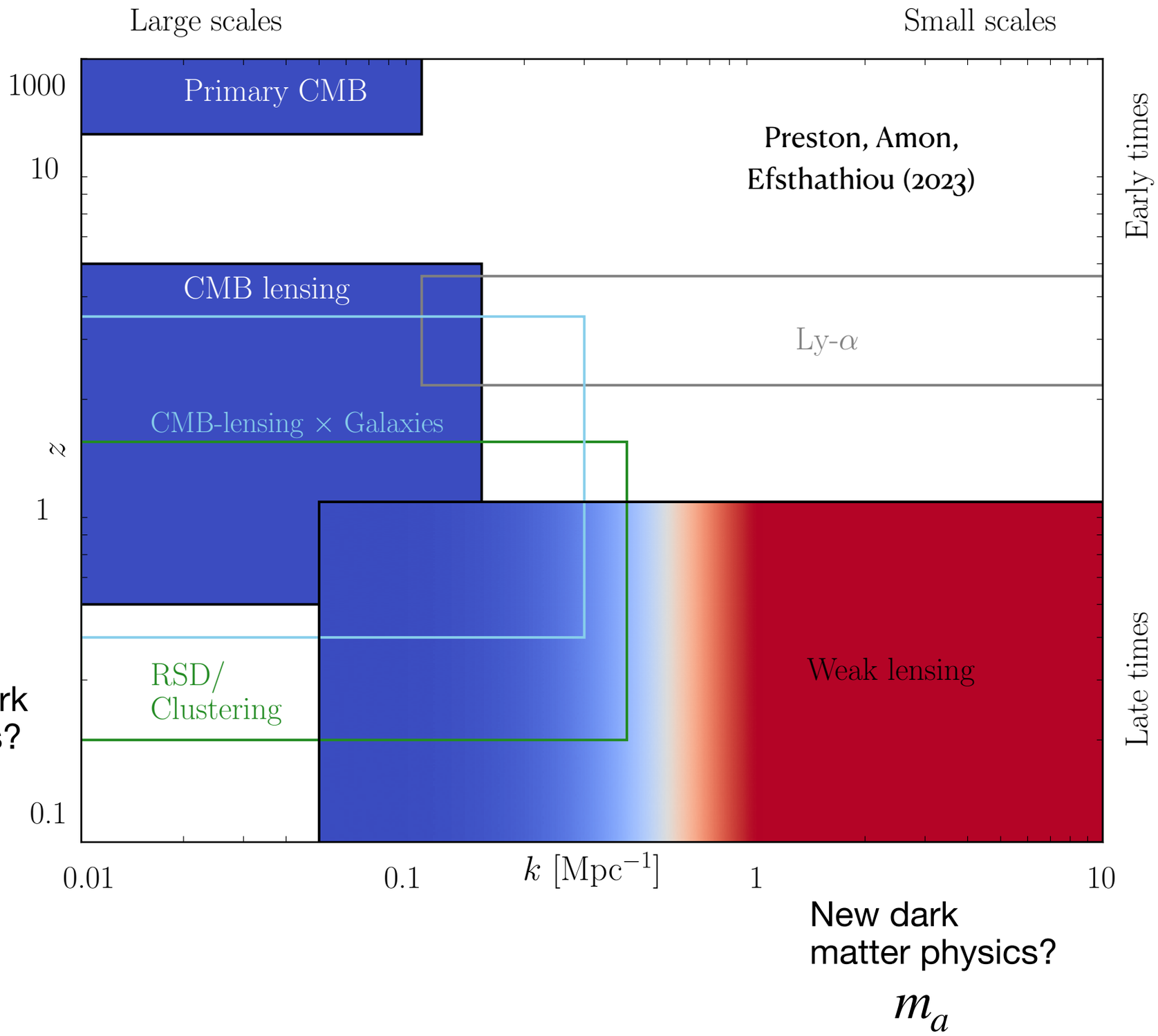
$$D_G \approx C_\ell^{\kappa g} / \sqrt{C_\ell^{gg}} \approx \hat{\boldsymbol{\theta}} \in \{C_\ell^{\kappa g}, C_\ell^{gg}\}$$





Cosmological probes and cross-correlations

- Test redshift and scale dependence of any new physics in a robust way.



Low-z: new dark energy physics?

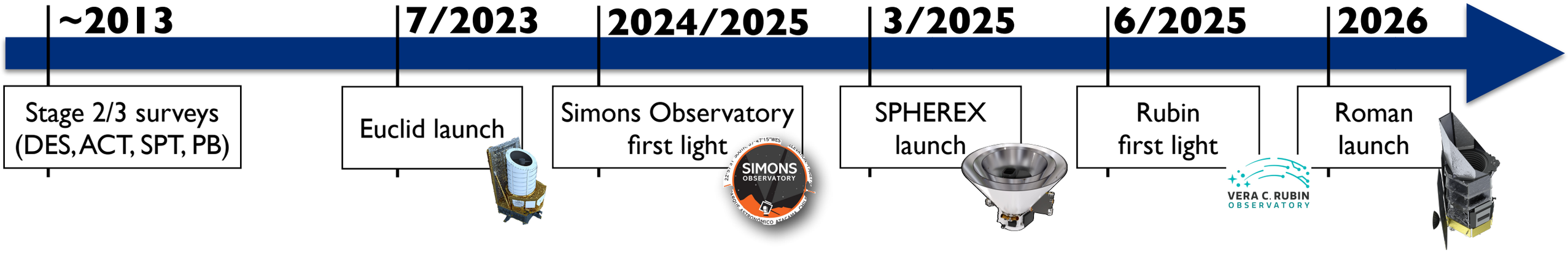
New dark matter physics?

m_a

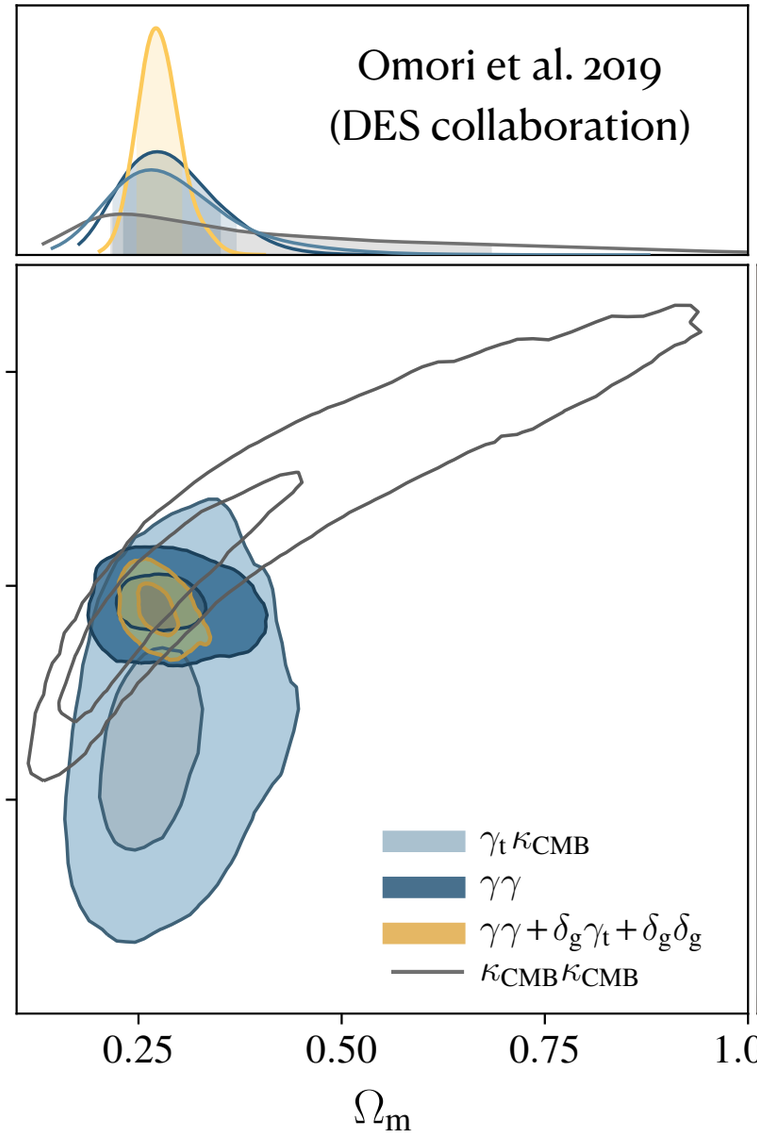
Messy baryonic physics?



CMB cross-correlations for cosmology



- Current data:
  - marginalizing systematics at limited cost.
    - Already some additional constraining power!
- Situation bound to change very soon:
  - New CMB data on sky!
  - New galaxy surveys on sky!



What to expect: synergies between surveys

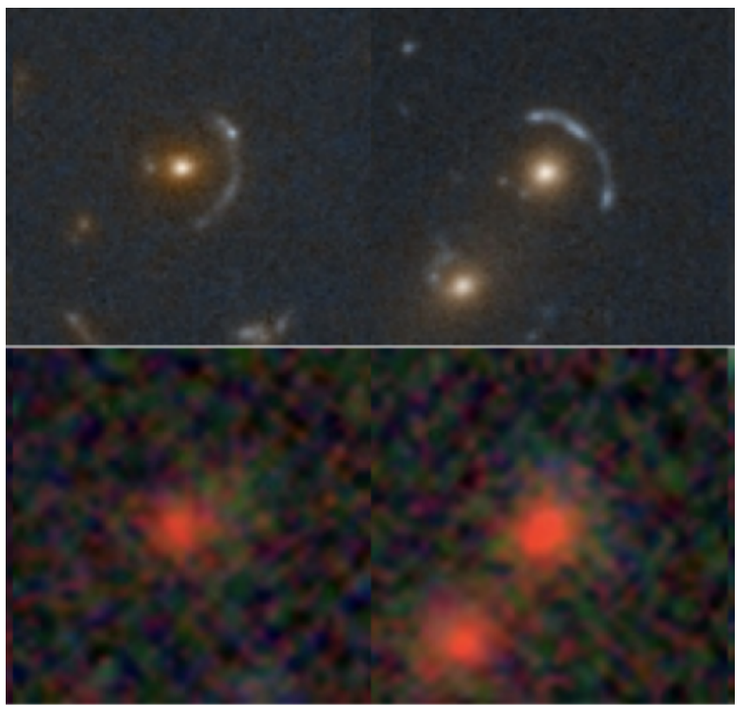


Euclid Early Release Observation image



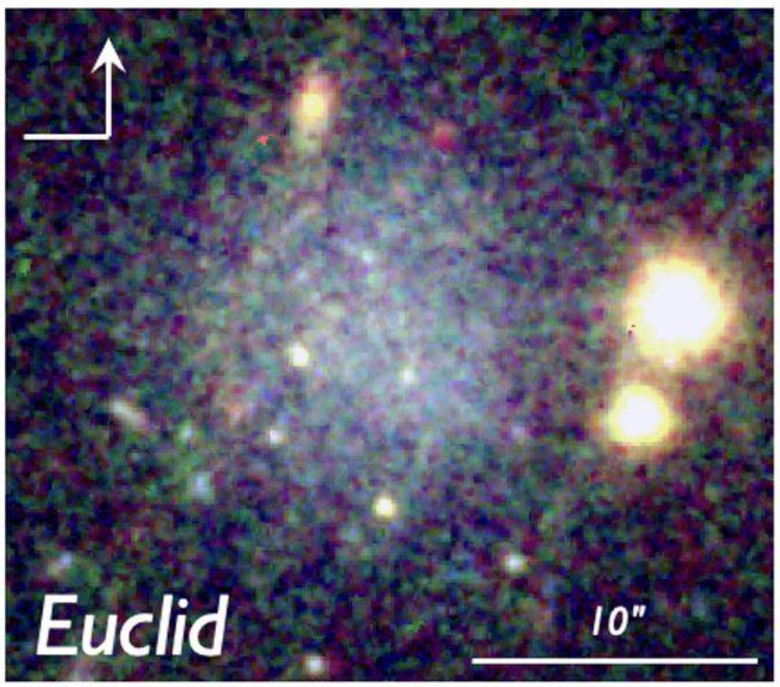
Rubin 1st wide image

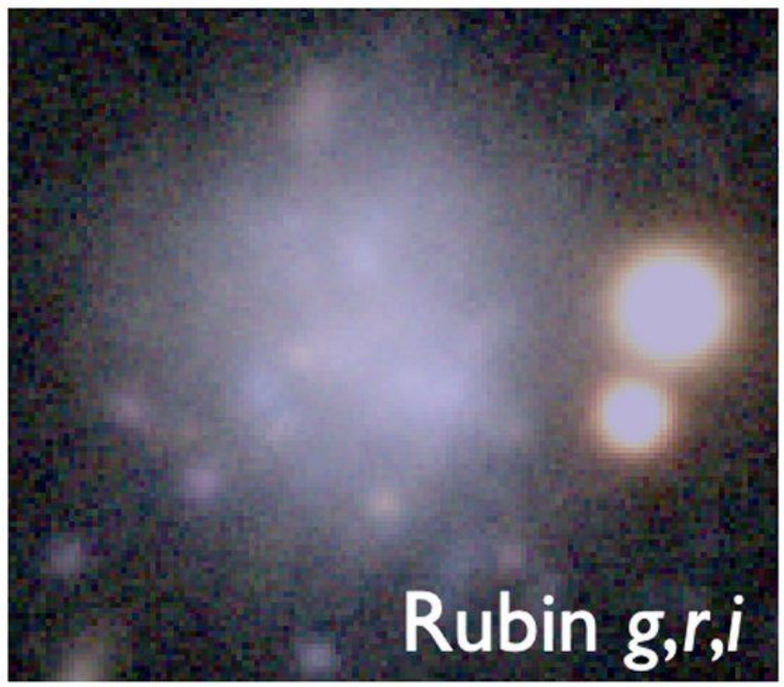
Euclid Q1 release



DESI Legacy Imaging Survey

Romanowsky+(2025)





EUCLID

LAUNCH



Euclid **launched on 1st July 2023** from Florida aboard a Falcon 9 launcher.

The Euclid consortium

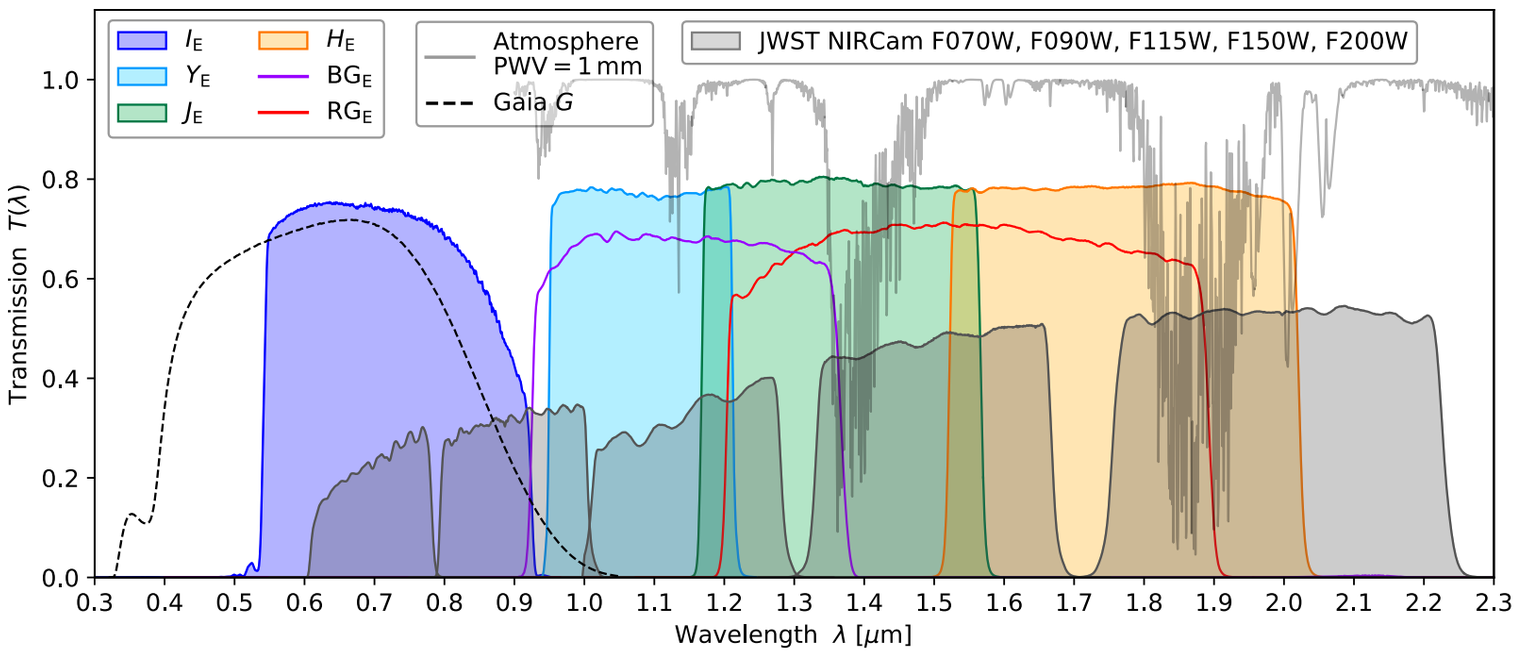
- 14 European countries (Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Portugal, Romania, Spain, Switzerland, UK) + USA, Canada, Japan.

- 2600 members, ~200 institutes covering cosmology, astrophysics, particle physics.

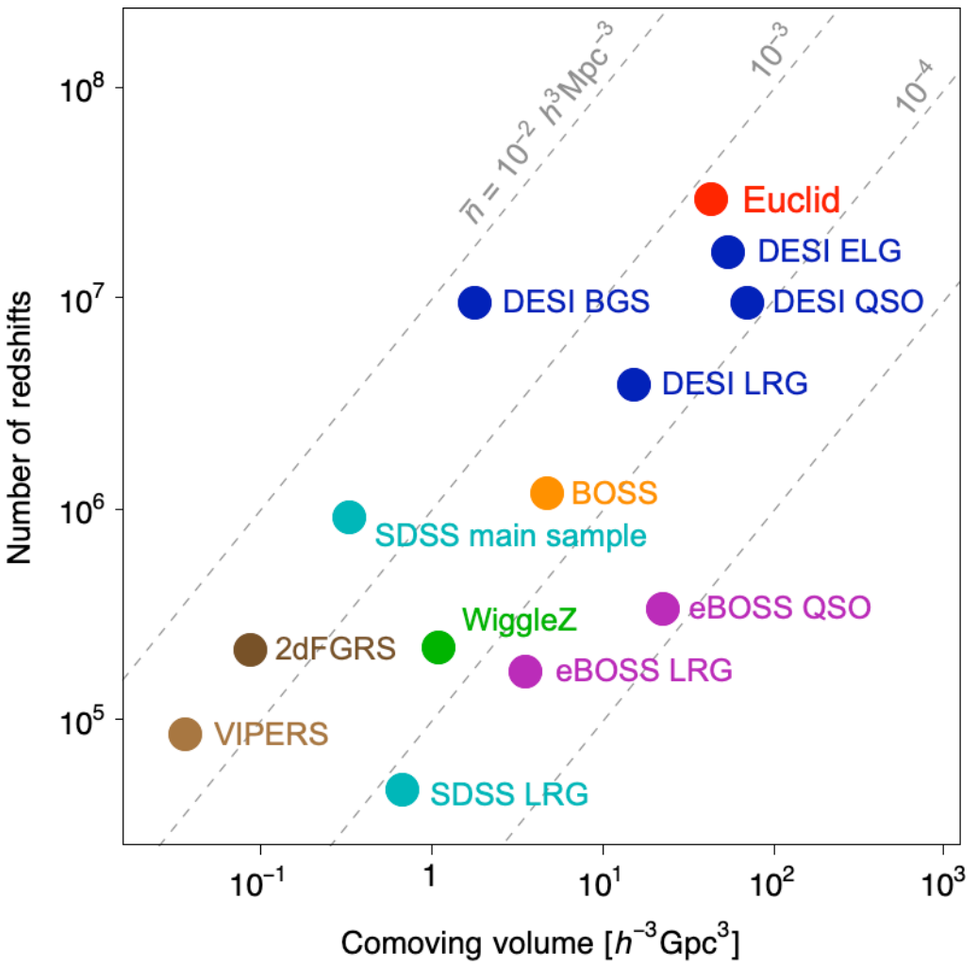


The Euclid instrument

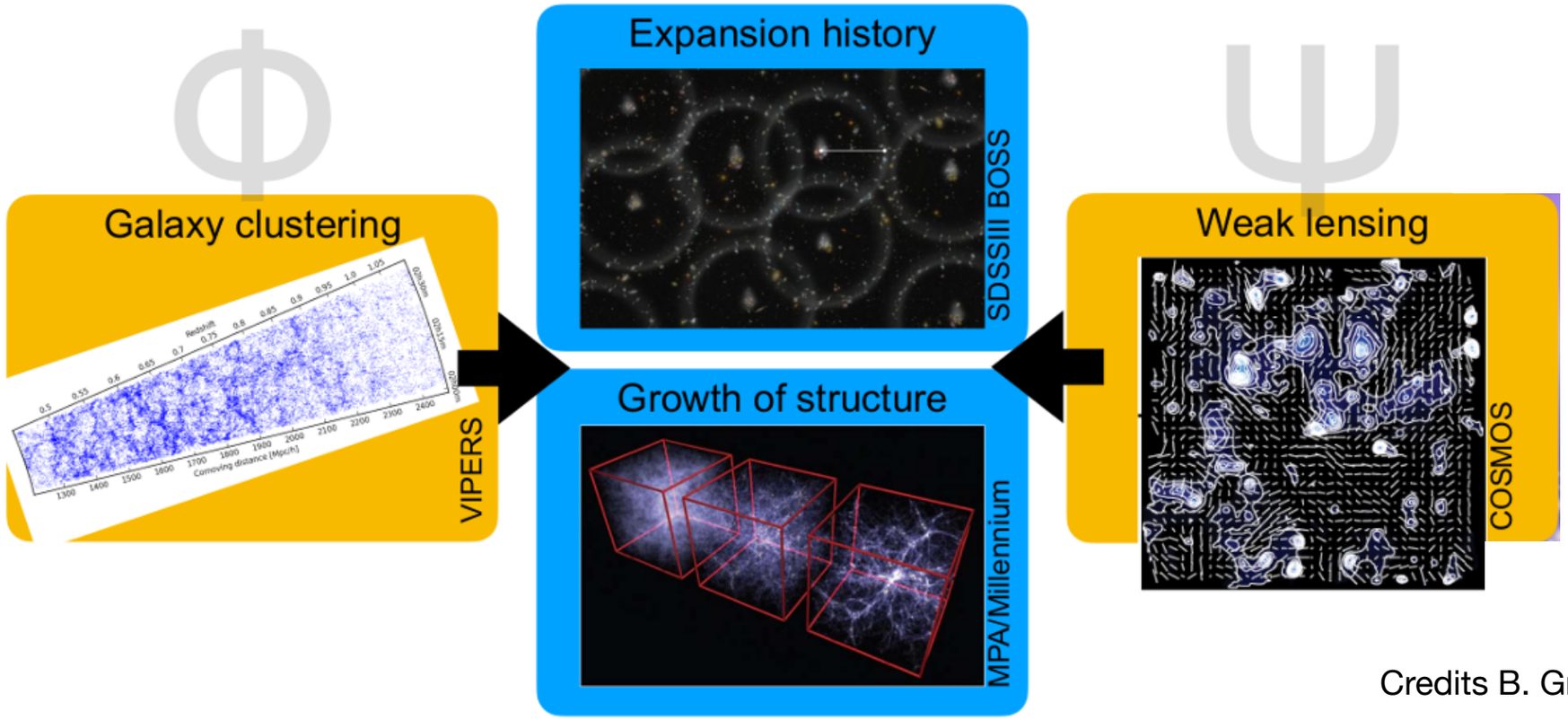
- Covers 30 years of Hubble operation every ~5 days (FoV ~ 0.57 deg^2), 0.2" PSF.
- 2 set of instrument working simultaneously:
  - VIS: visible band, 25 AB mag. limit at SNR ~10 (objects detected down to 29!).
  - NISP: near IR, 24.5 AB mag. limit at SNR ~5.
  - Slitless spectra with R~400 (DESI R~2000).



Euclid mission overview (Mellier+2024)



Euclid concept and targets



Credits B. Granett

Clusters

CMB cross-correlations

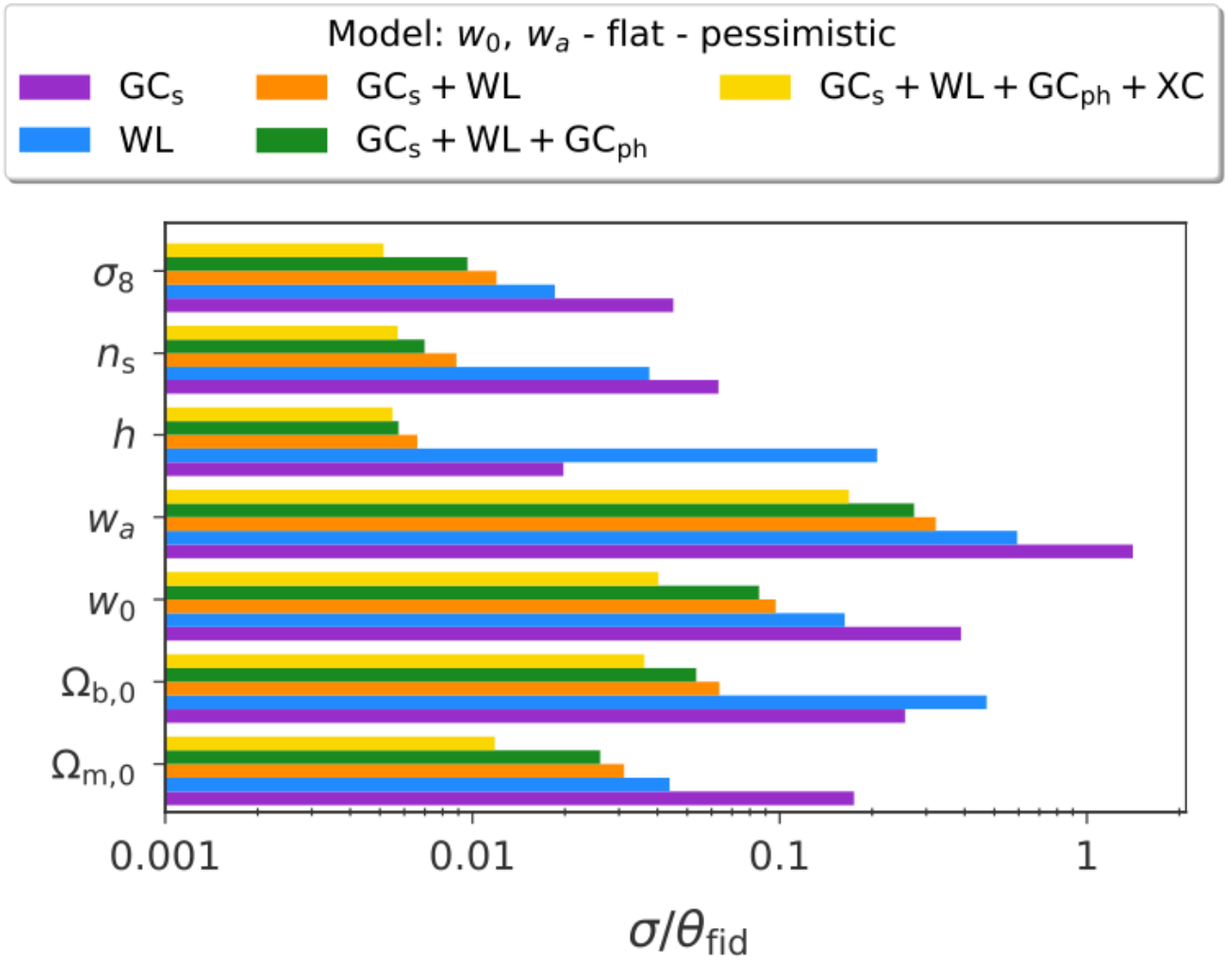
Strong lensing

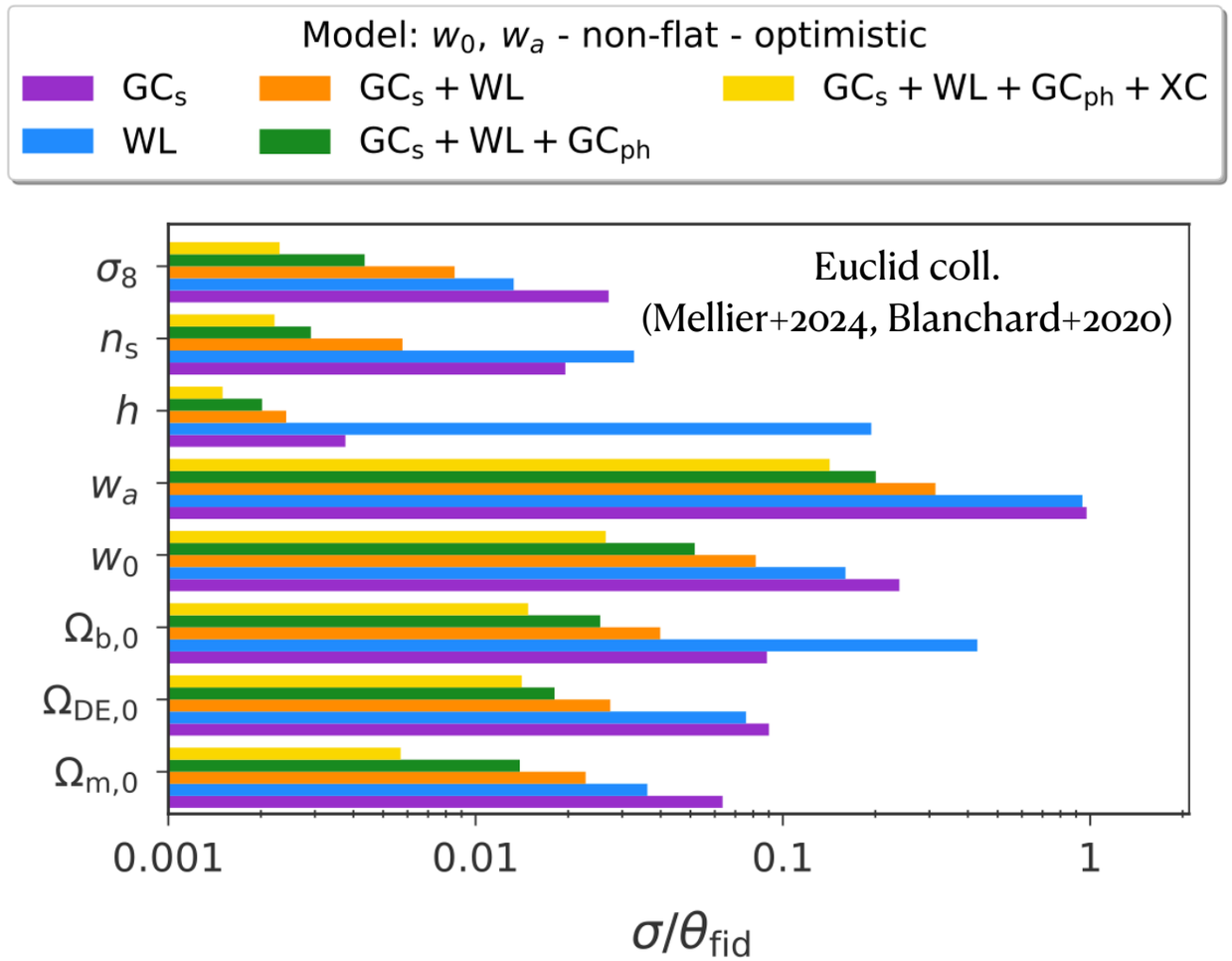
… and more

Euclid coll.
(Mellier+2024, Blanchard+2020)

- Probe dark energy EOS $w(a) = w_0 + w_a(1-a) \quad \sigma(w_0) = 0.02,\ \sigma(w_a) = 0.1$
- Test gravity $f \approx \Omega_m^{\gamma} \quad \sigma(\gamma) = 0.02, \quad \sigma(f) \approx 0.02 \quad 0.9 < z < 1.9$
- Probe dark mater and IC: $\sigma(\sigma_8) = 0.01,\ \sigma\left(\sum m_\nu\right) = 0.03eV$, 2x better n_s, α_s

Predictions and forecasts: main probes

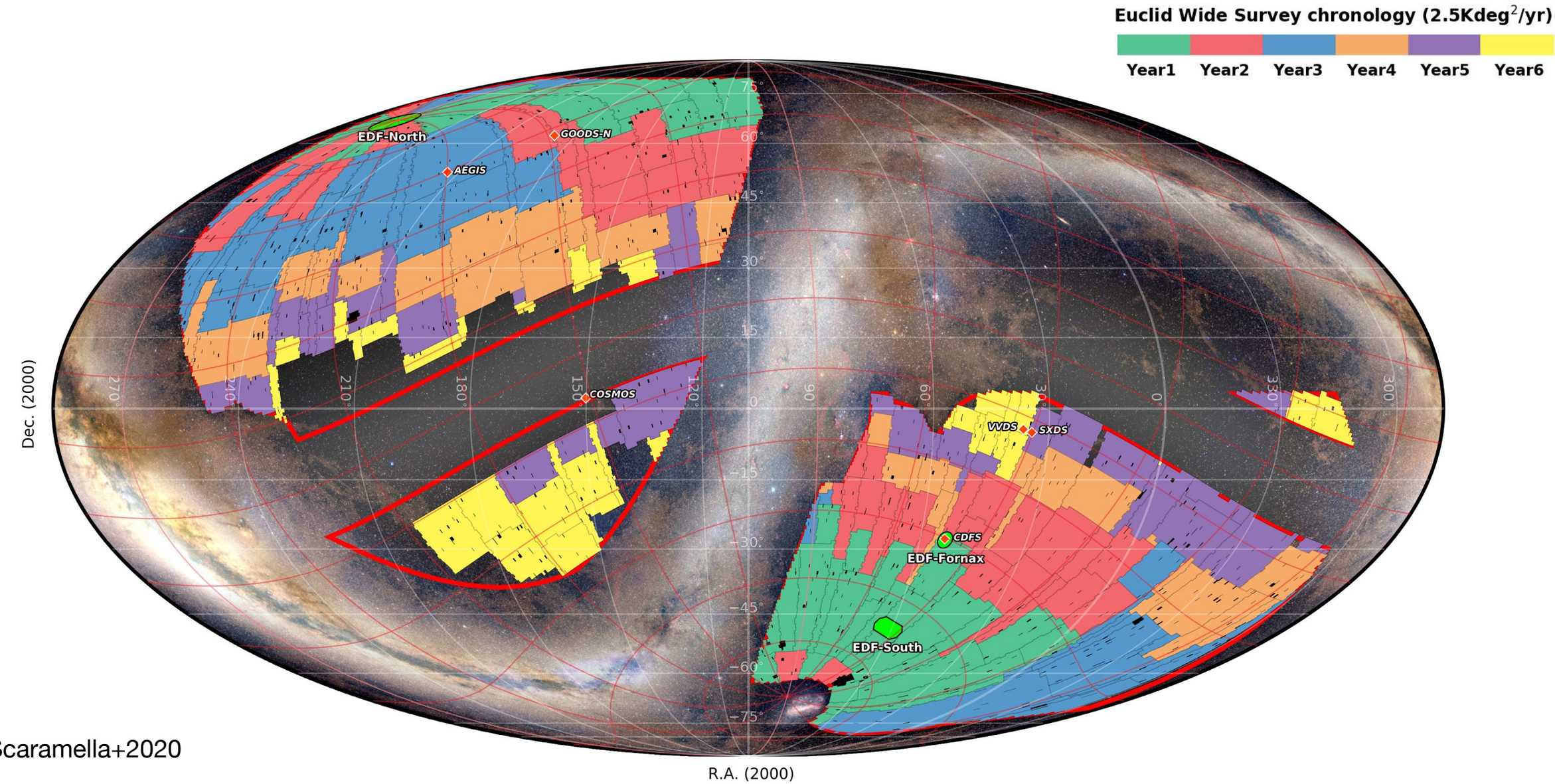




- None of the probes alone satisfies the science goals!
- Combination is crucial to reach targets, even more so for beyond LCDM models.
- Higher-order statistics can shrink by 50% (Ajani+2023)
- Others to be added: voids ~20% better, RSD…

WIDE survey

- 15000 deg^2 covered over 6 years of data acquisition. 4 visits with ~700s exposure.
- Optimized for low background (1/100 of Zodiacal + Galactic background).
- 1st full cosmology release expected ~ soon.

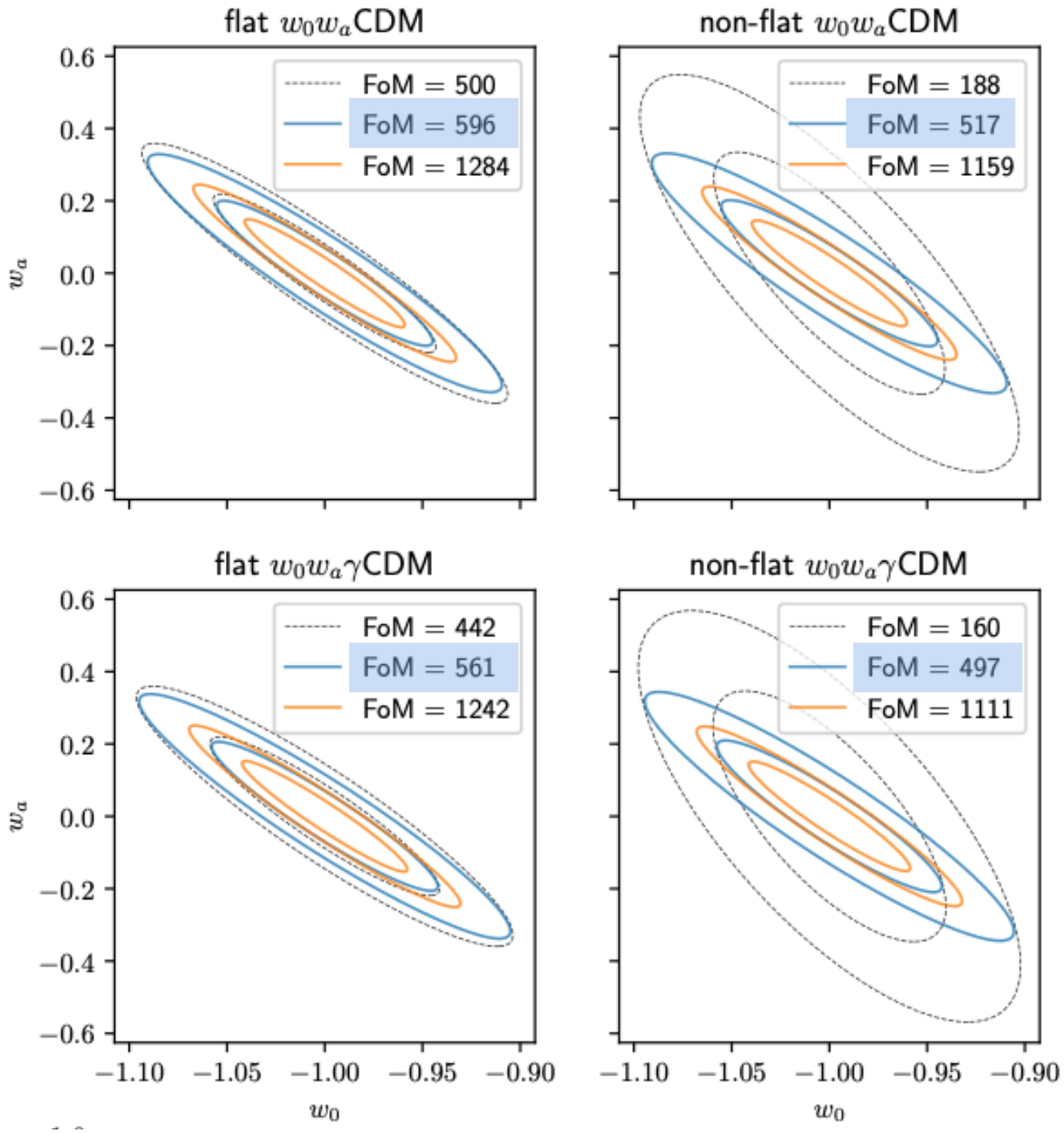


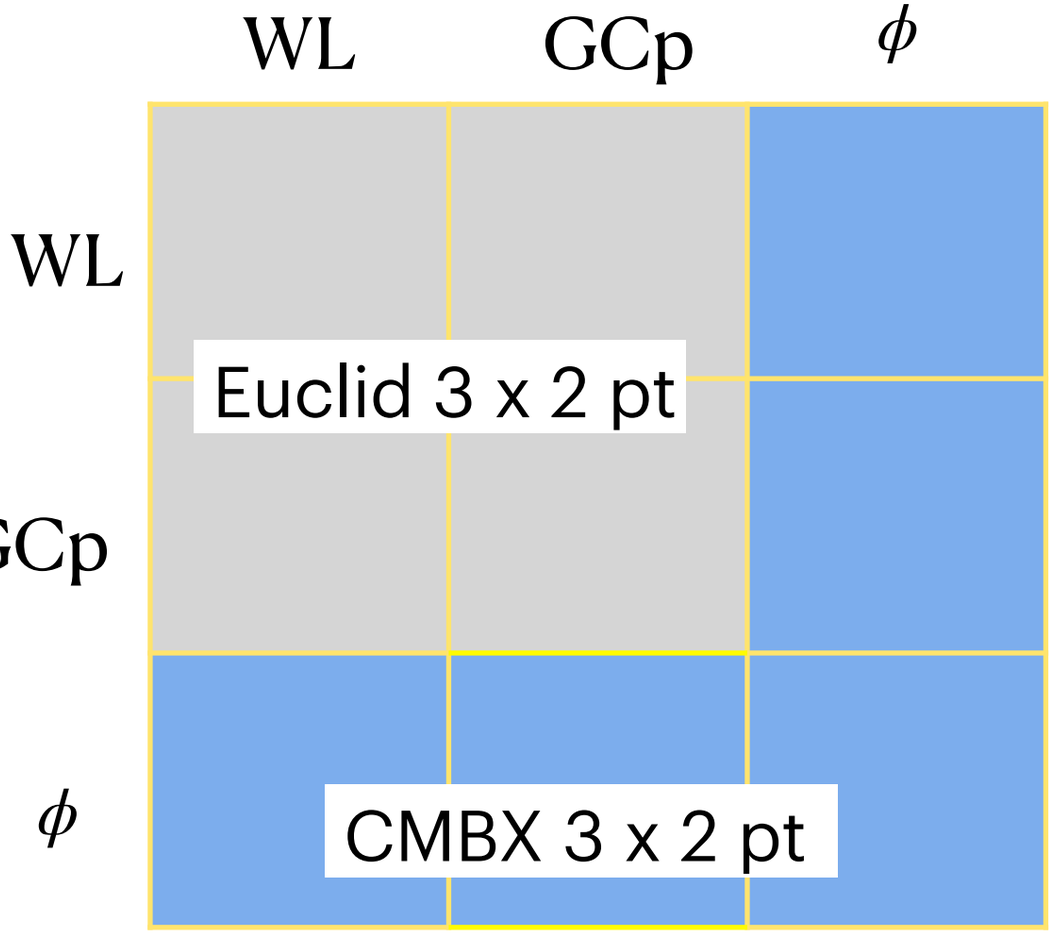
Scaramella+2020

Forecast for 6x2pt analysis end of mission

- Assumes pessimistic Euclid survey in ~5 tomographic redshift bins, $z_{max} = 1$

- SO-like CMB lensing: 4-10x improvements in dark energy / modified gravity constraints.





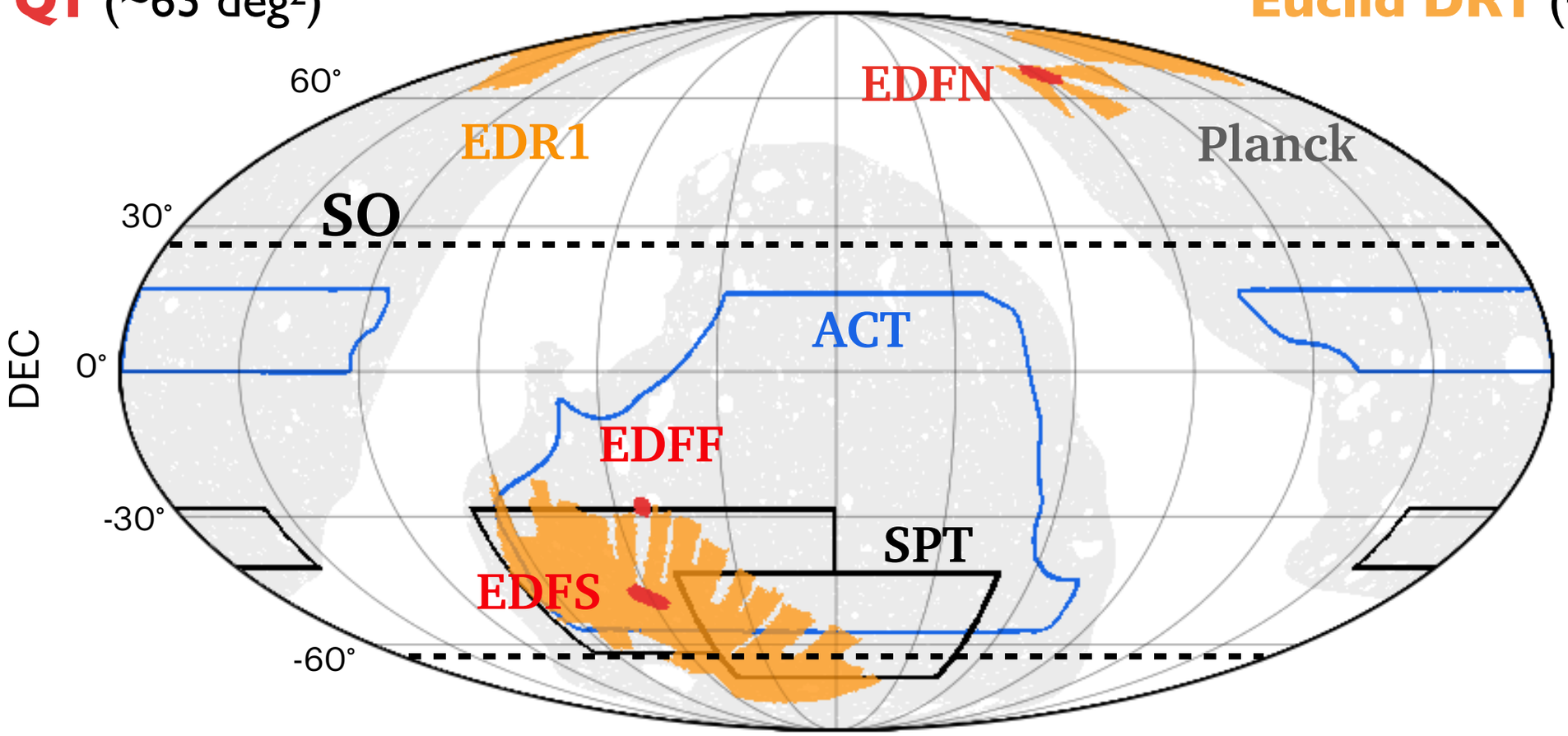
Euclid collab. (Blanchard+19)

Euclid collab. (Ilic+21, CMBX SWG)

Towards DR1: the Q1 data release

Euclid Q1 (~63 deg²)

Euclid DR1 (~1800 deg²)



- Initial release with 1st quarter of data (Q1) ~63 deg² using "pre-launch" pipeline.
  - Ideal for cross-correlation, end-to-end validation!
  - CMB data: Planck for Northern sky, ACT and SPT in the Southern sky.

Fabbian, Legrand, Pagano, Lembo, Piccirilli, Kou, Benabed, D'Assignies, Gouyou Beauchamps, Hartley, Tessore, Tutusaus + (to appear soon)

Meet the Euclid CMBX core team



Emma Ayçoberry



Cail Daley



Léa Dumilly



Margherita Lembo



Vilasini Tinnaneri Sreekanth



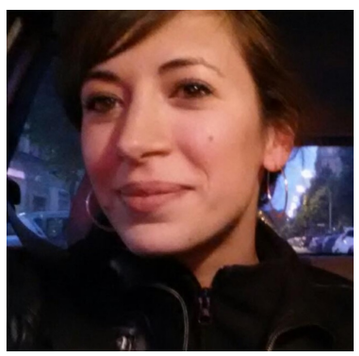
Tanguy Dusserre



Matteo Peronaci



Nabila Aghanim



Laura Salvati

université PARIS-SACLAY

+





Raphaël Kou (IRAP Toulouse)



Louis Legrand (IAS & CBPF)



Luca Pagano (U. Ferrara)



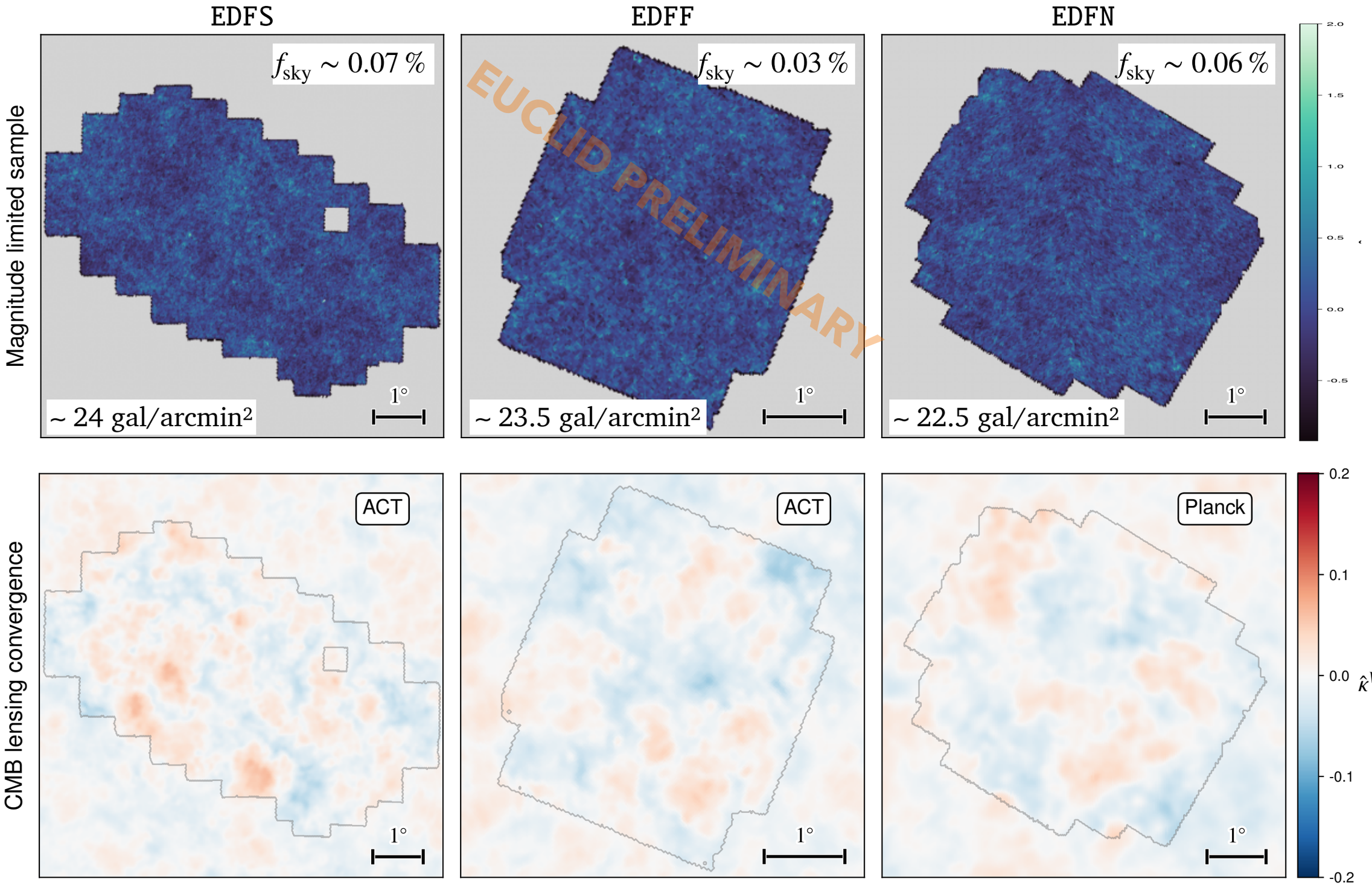
Giulia Piccirilli (U. Rome Tor Vergata)



Davide Luchina (U. Milan)

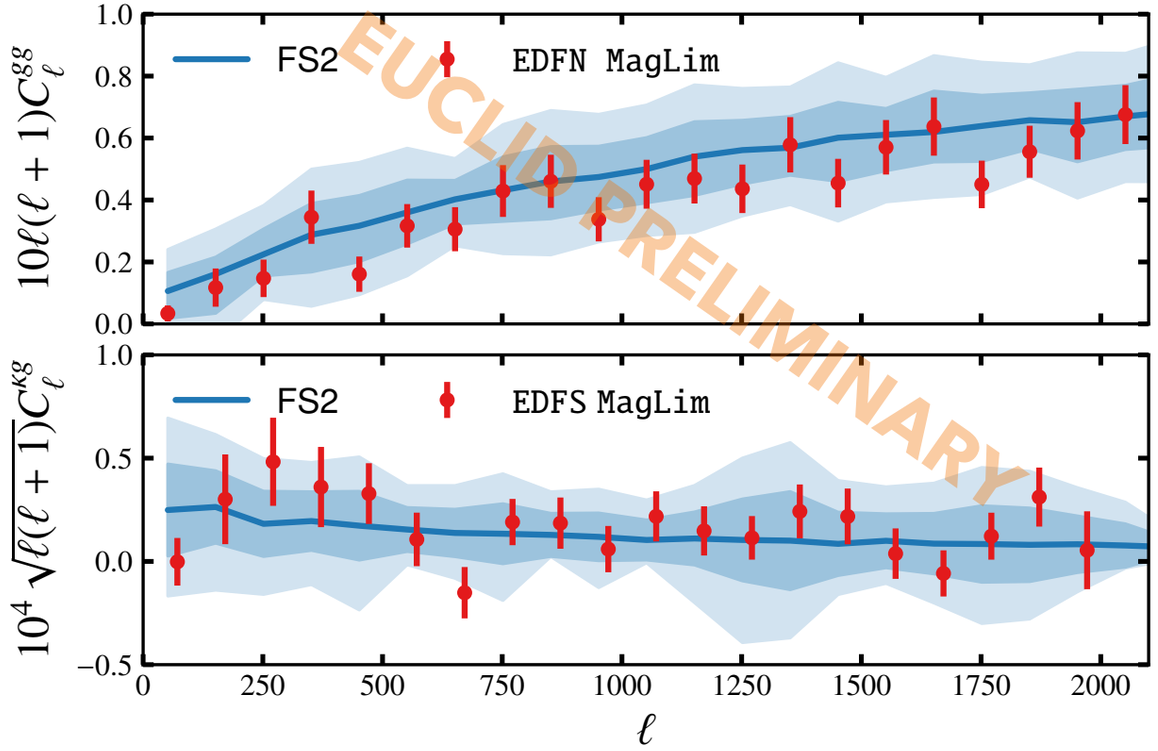
Towards DR1: the Q1 data release

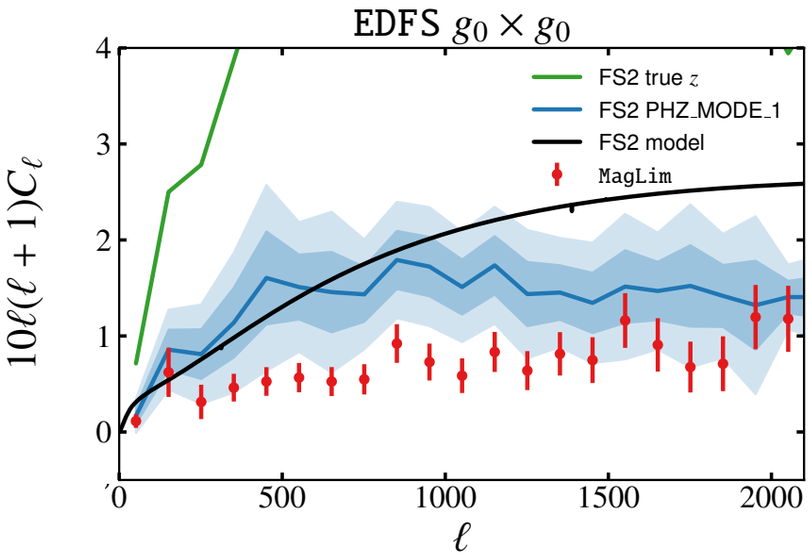
- Magnitude limited sample with ~20/arcmin², $z \lesssim 2.5$ after star/galaxy separation.

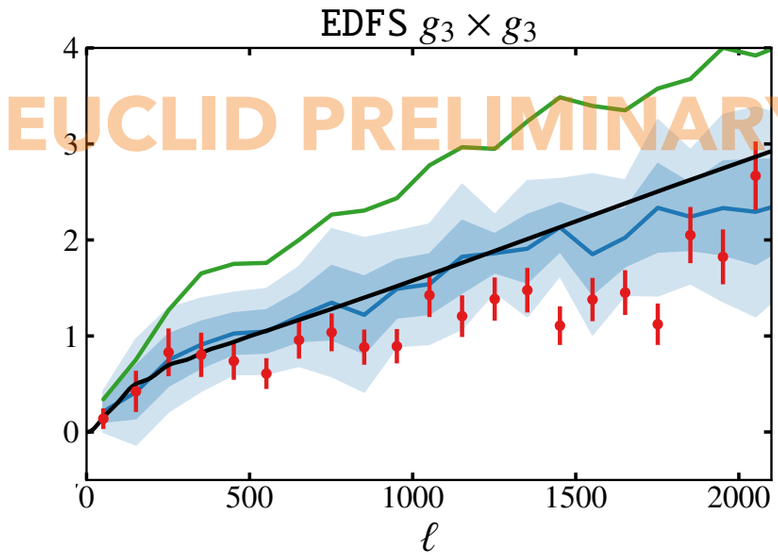


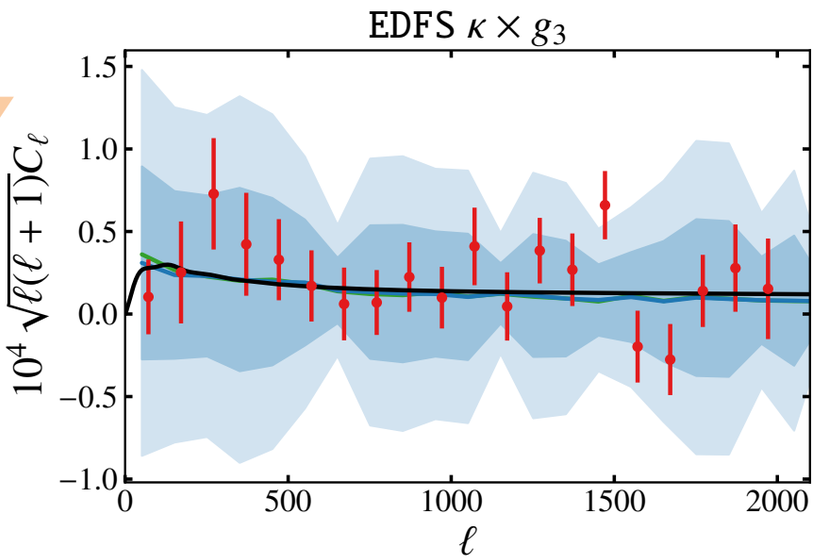
Towards DR1: the Q1 data release

- 1 bin: properties consistent across fields
- In agreement with "uncalibrated" Flagship 2 simulation (PTE>0.08)
- Tomography: we adopt "model-independent" data cuts based on jackknife consistency and Flagship 2 simulation.

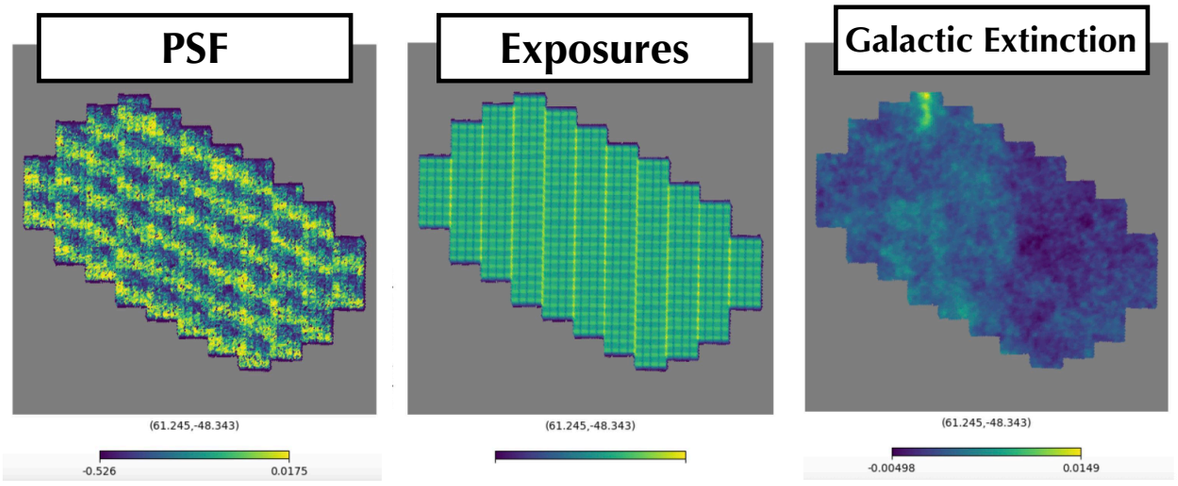






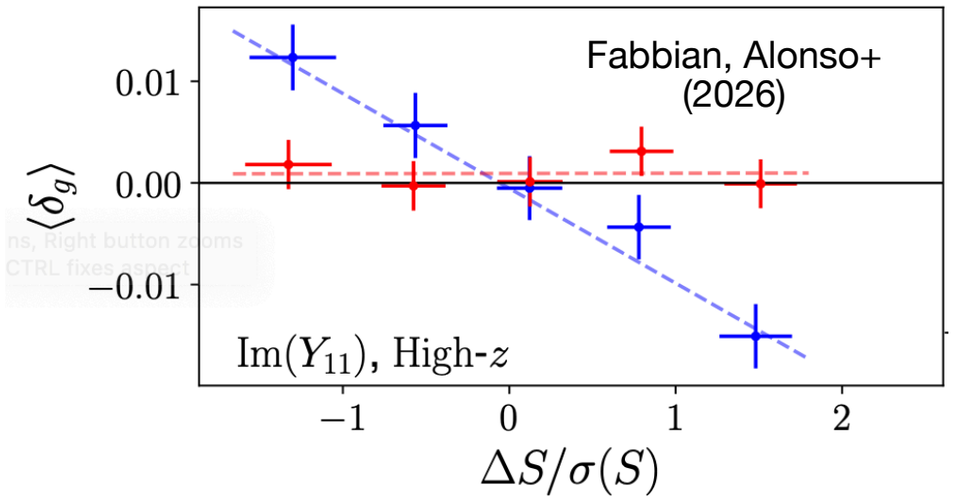


Imaging systematics treatment

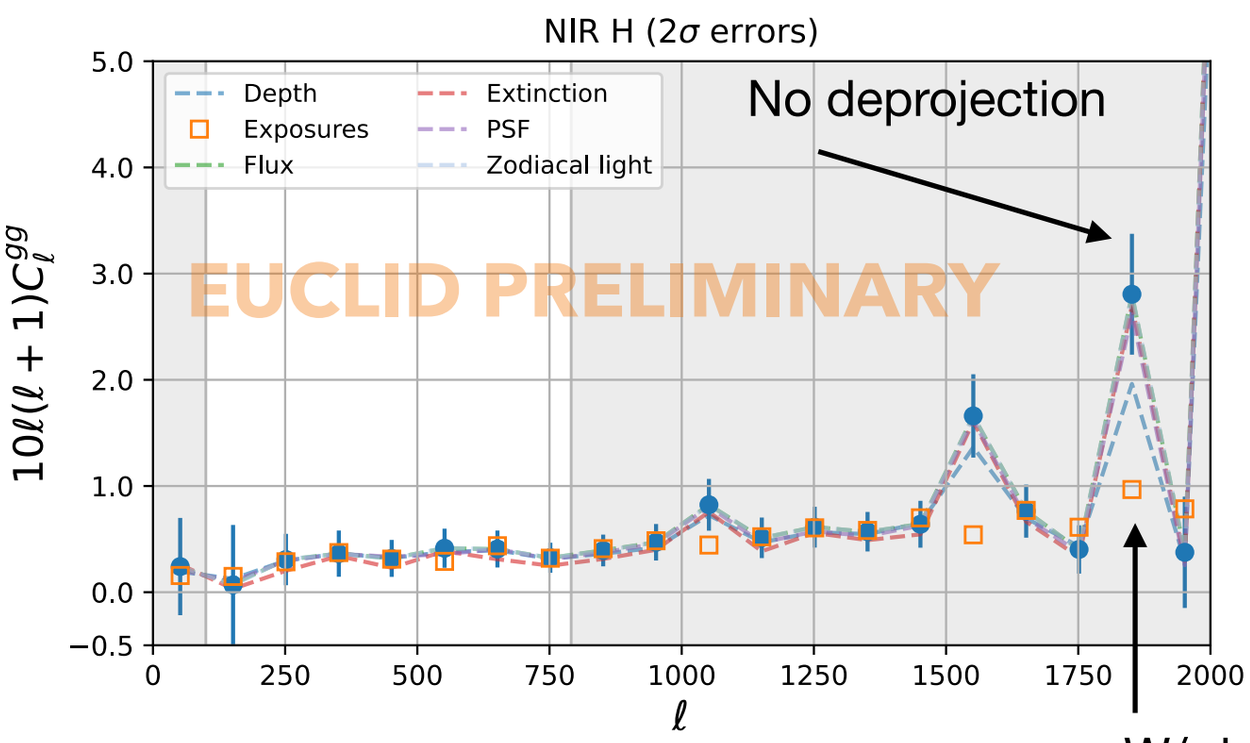


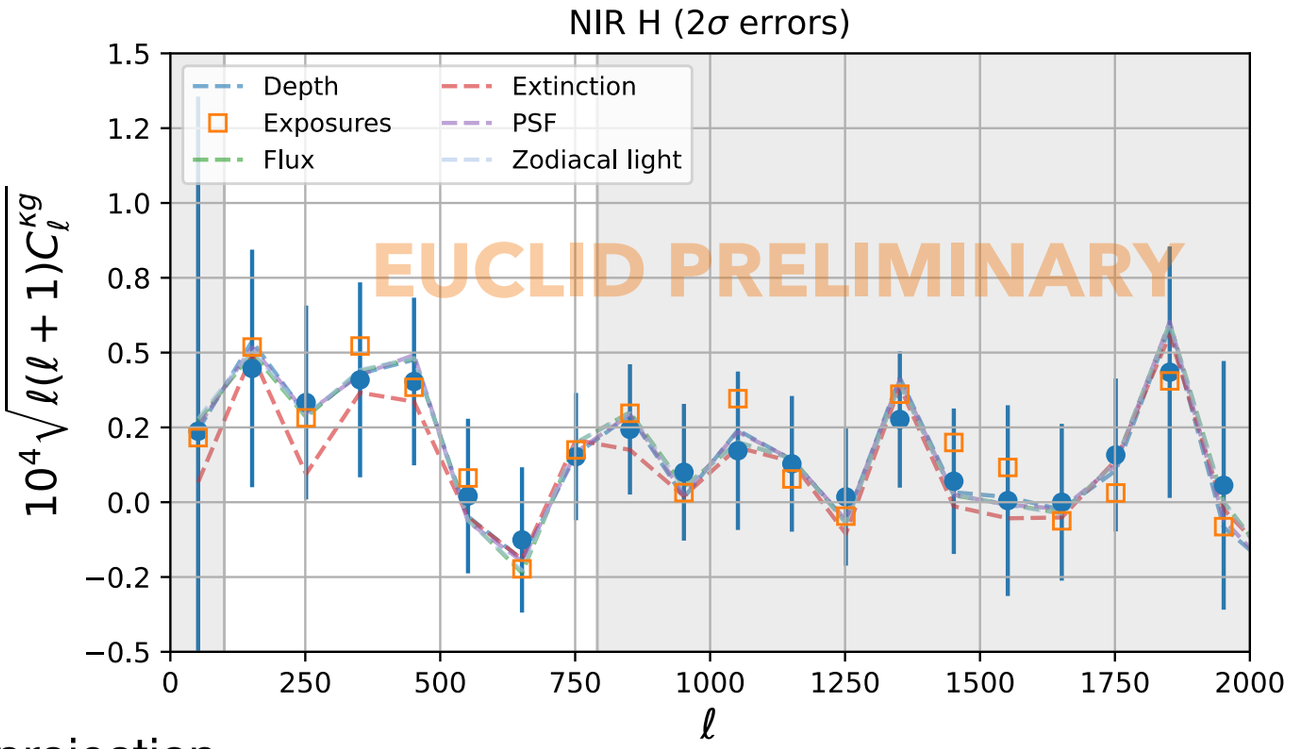
Linear deprojection

+12 others

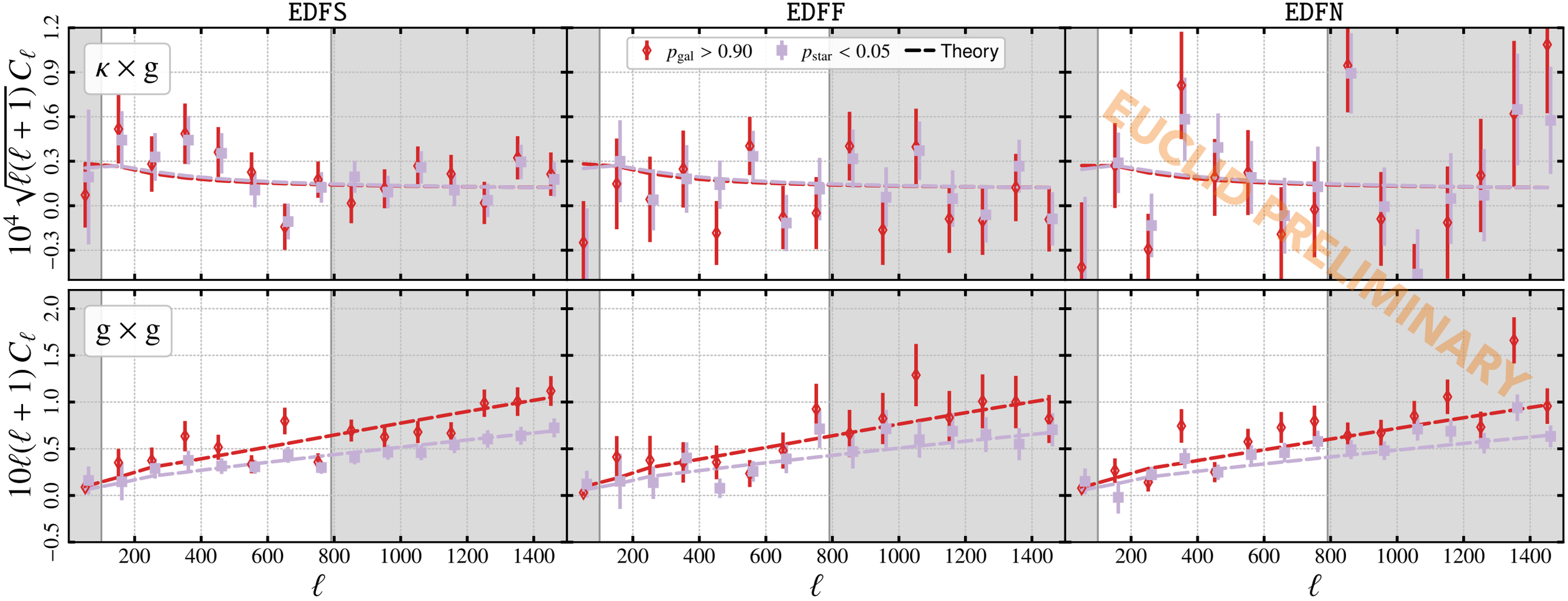


- Minor effects in the science band on well defined scales, no effect on cross-correlation





Power spectra measurements



- WARNING: theory lines are not fits!
  - Planck 2018 + estimated $n(z)$ + fiducial Flagship calibrated galaxy bias model.
  - **TLDR**: good $\tilde{\chi}^2$ (w/ RSD, magnification bias matching expectations).
  - Tomography case more complicated at face value: need to account for redshift errors.

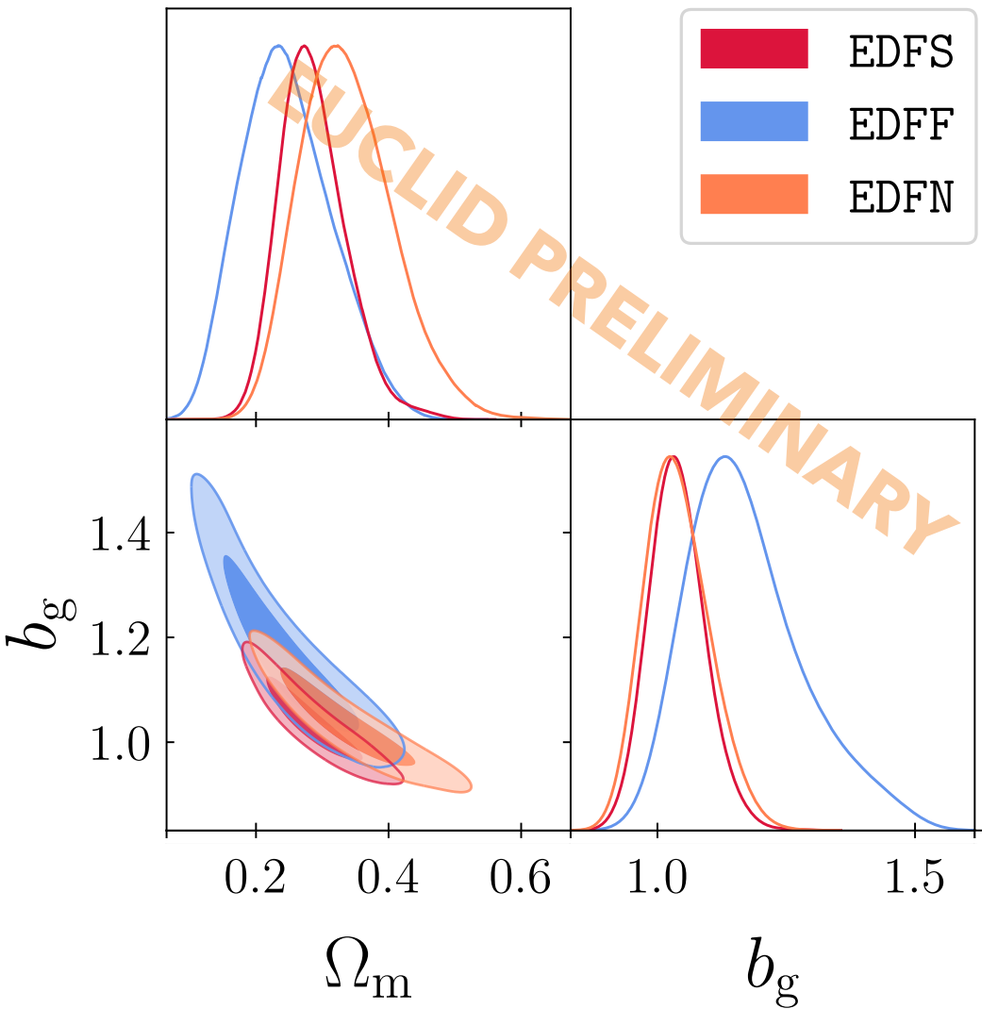
Towards a full cosmological inference pt I

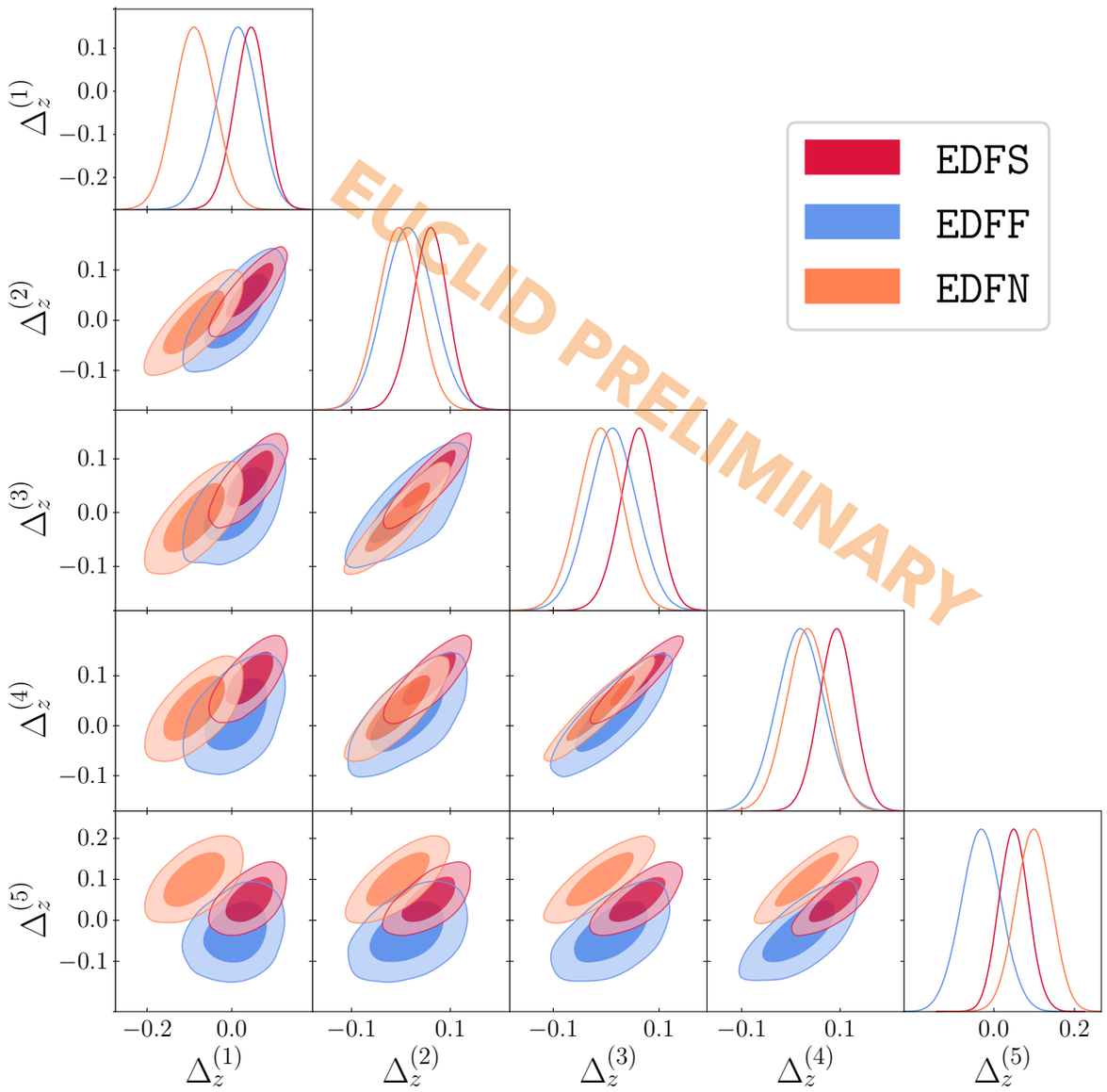
- Eulerian PT bias model at second order for $k_{\rm max} = 0.5\,h{\rm Mpc}^{-1}$ calibrated on Flagship 2

$$g = b_g\, b_1^{\rm fid}\,\delta_m + b_g^{nl}\frac{b_2^{\rm fid}}{2}\delta_m^2 + \frac{b_s}{2}s^2 + \frac{b_{3\rm nl}}{2}\psi_{\rm nl} + \frac{b_{k2}}{2}\nabla^2\delta_m \qquad b_s = -\frac{4}{7}(b_g\, b_1^{\rm fid} - 1)$$

Saito+2014; Gil-Marín+2015; Pandey+2020

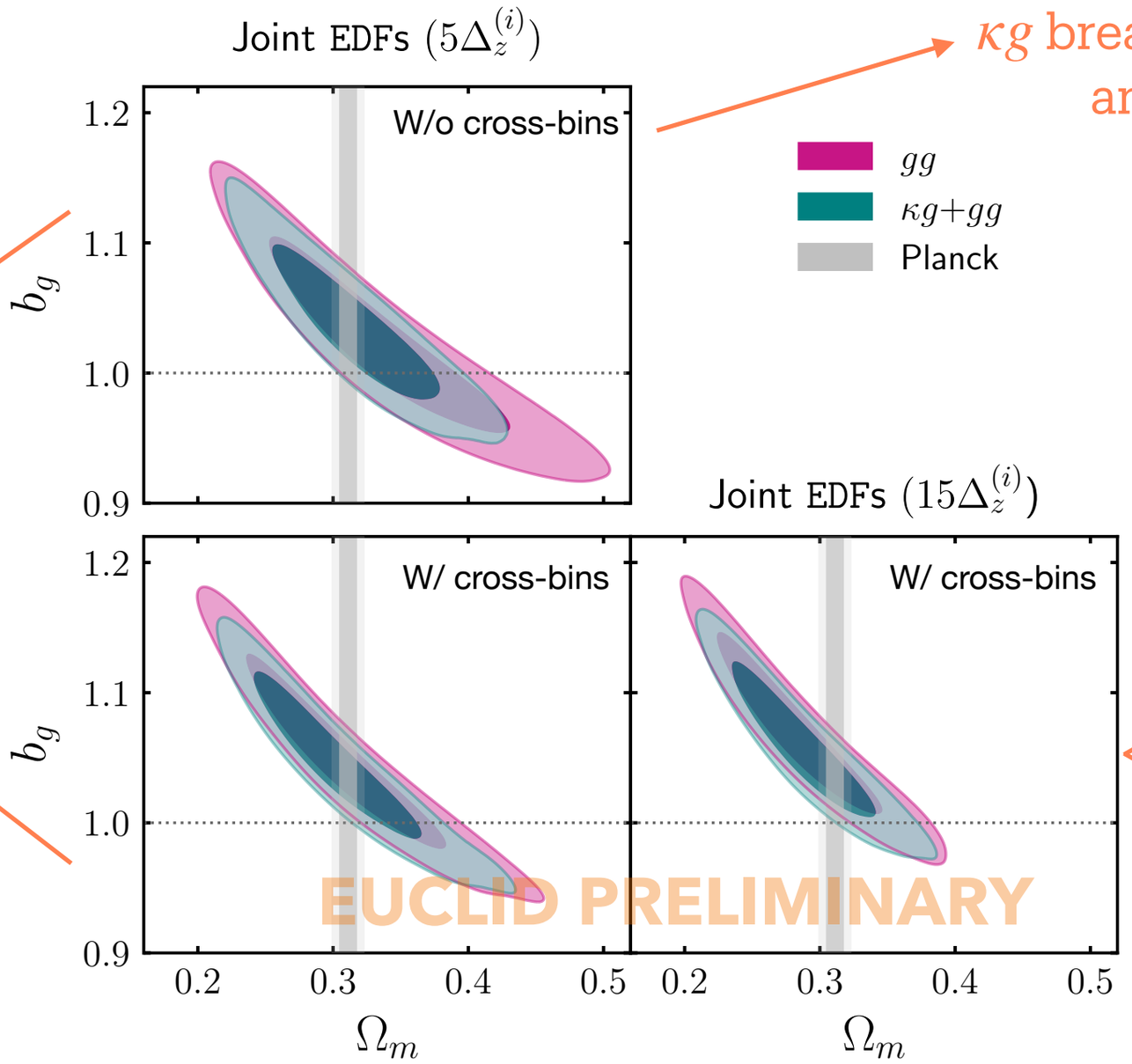
- Consistency across EDFs for cosmological parameters and differences in $\Delta_z^{(i)}$





Towards a full cosmological inference pt II

- Can we describe a single set of redshift error parameters?
- κg improves goodness of fit: $\sigma(\Omega_m) \sim 0.036, \sigma(b_{\rm g}) \sim 0.043$, robust to leave-one-out tests.



κg breaks degeneracies with bias and photo-z parameters ~30% improvement

$\kappa g + gg$: equally good with or w/o cross bins

Better photo-z errors handling: 20% tighter constraints

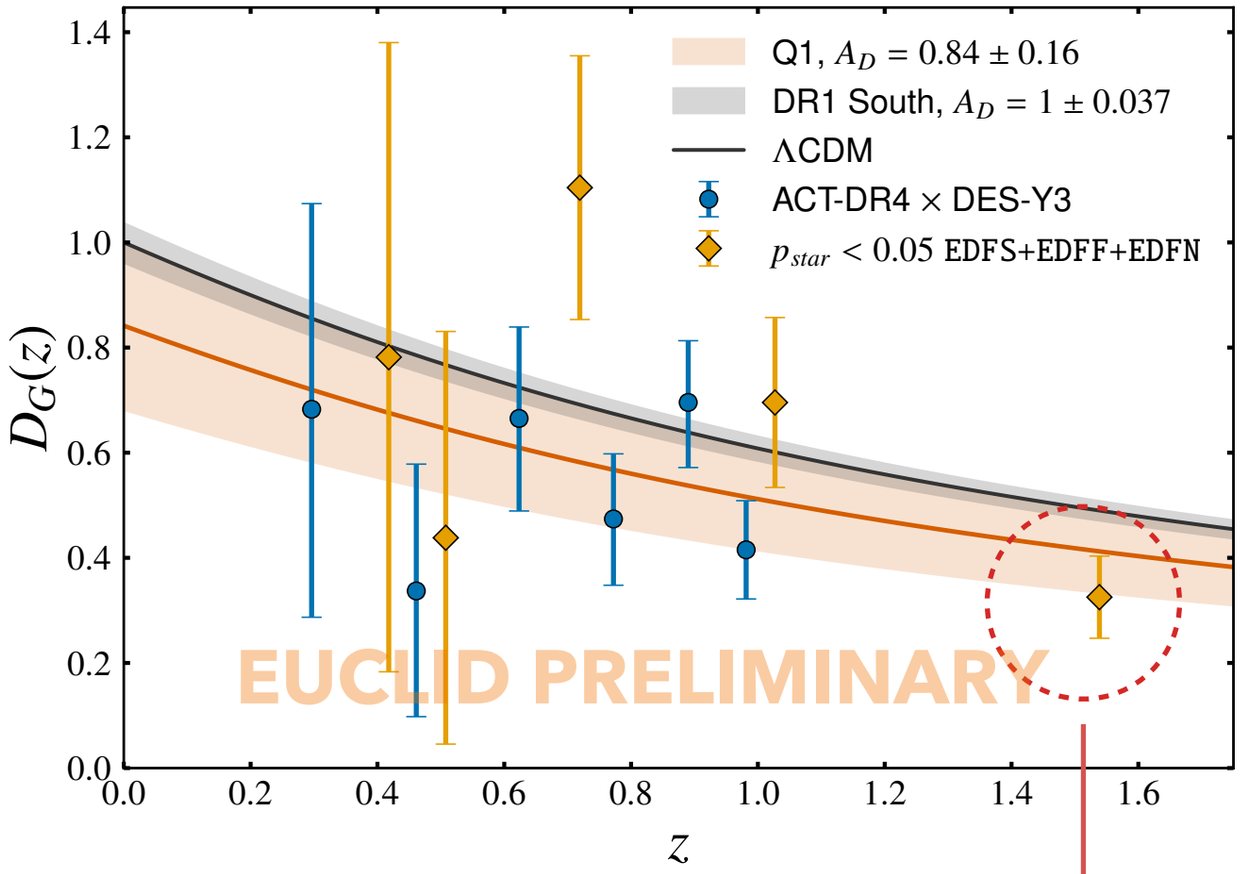
Better PTEs and better gg description

Comparison with state of the art

- Linear growth factor $D_G(z) \sim C_\ell^{\kappa g}/\sqrt{C_\ell^{gg}} \sim b_g D^2(z)/\sqrt{b_g^2 D^2(z)} = A_D D_{\rm fid}(z)$

  - Removes naturally redshift and bias modeling uncertainties.

  - Comparable to DES Y3 x ACT with ~10x less sky area.

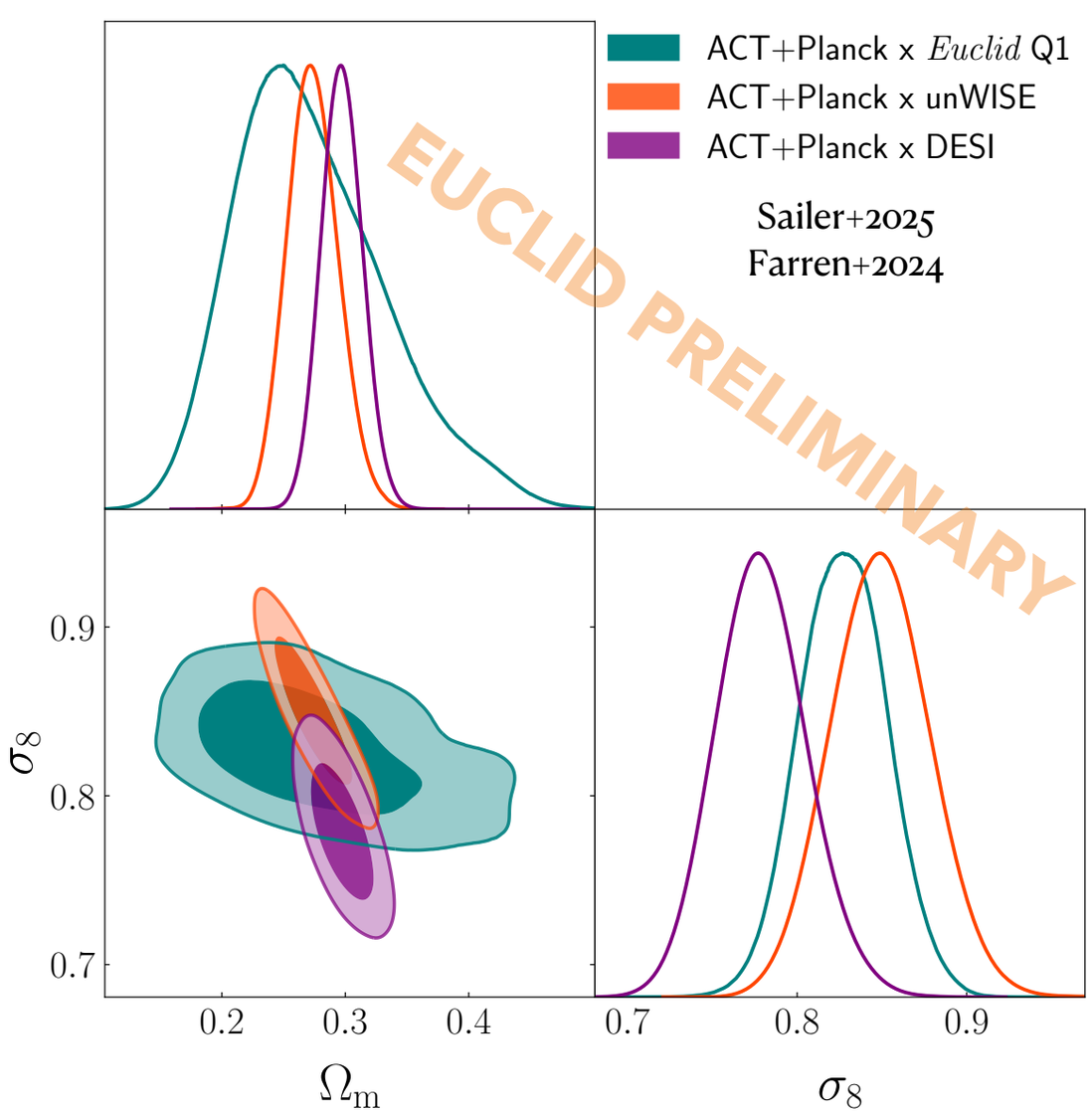


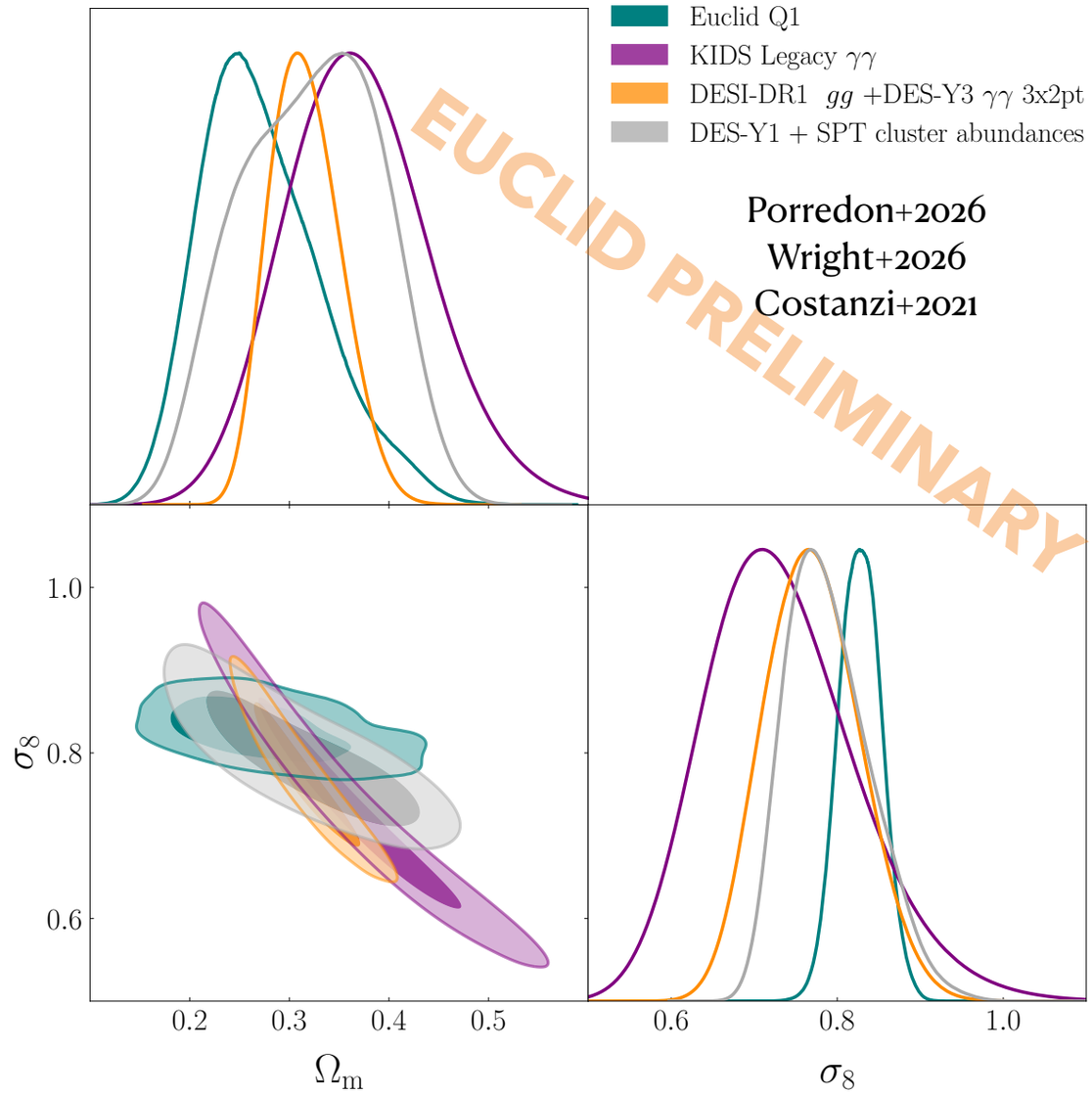
Marques+2024;
Bianchini+2018
Giannantonio+2016;

Higher redshift

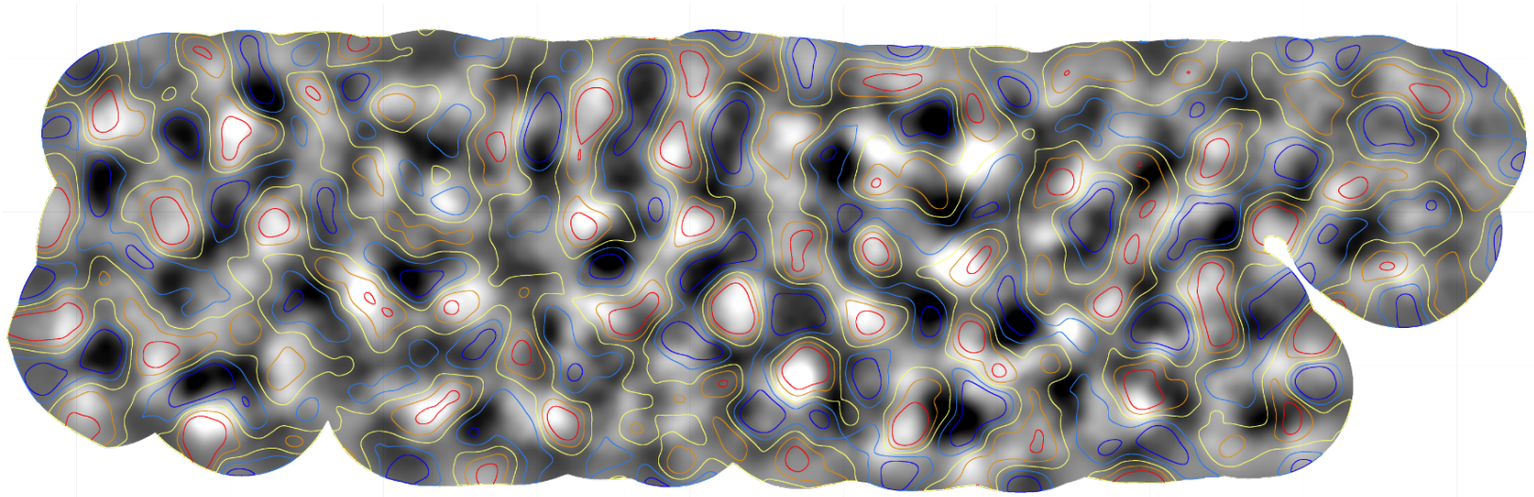
Comparison with state of the art II

- Adopting galaxy bias (conservative) priors from Flagship 2 for 2x2-pt : $\sigma(\sigma_8) \sim 0.028$
  - Comparable of full unWISE/DESI x ACT+Planck using ~10 000 deg^2
  - $S_8 = 0.79^{+0.07}_{-0.09}$, comparable with current $\sigma\left(S_8\right) \sim 0.02$ accounting for sky coverage.



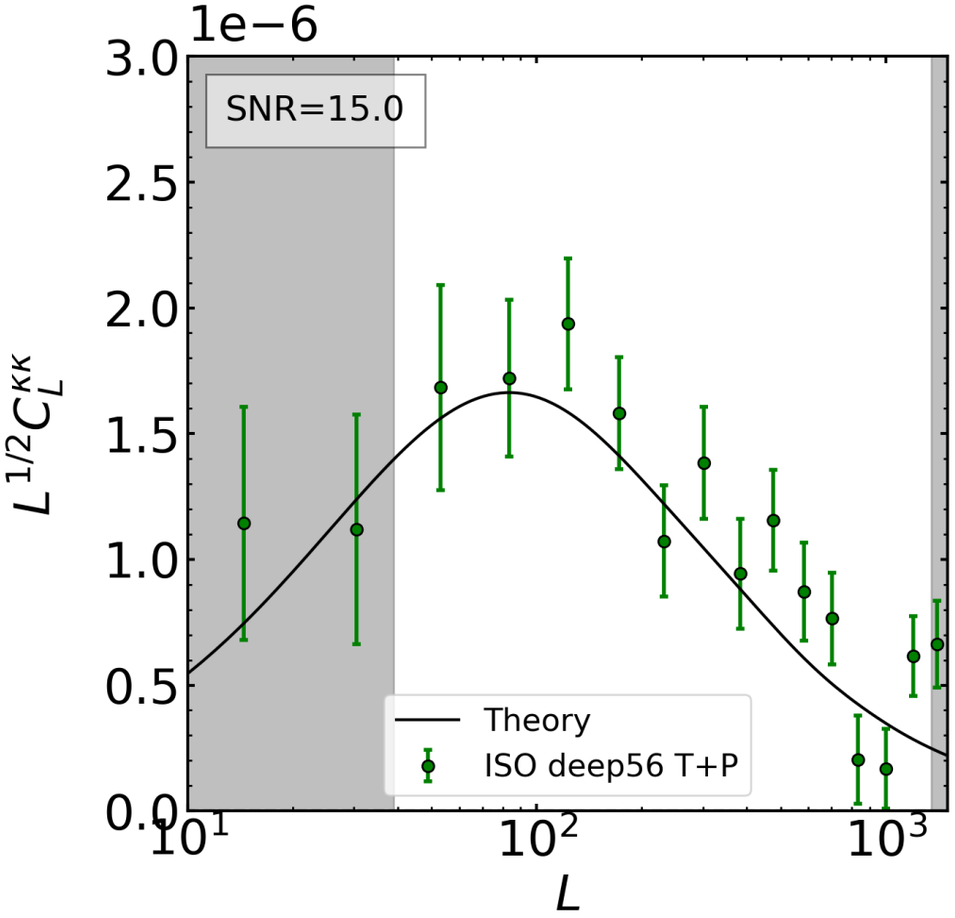


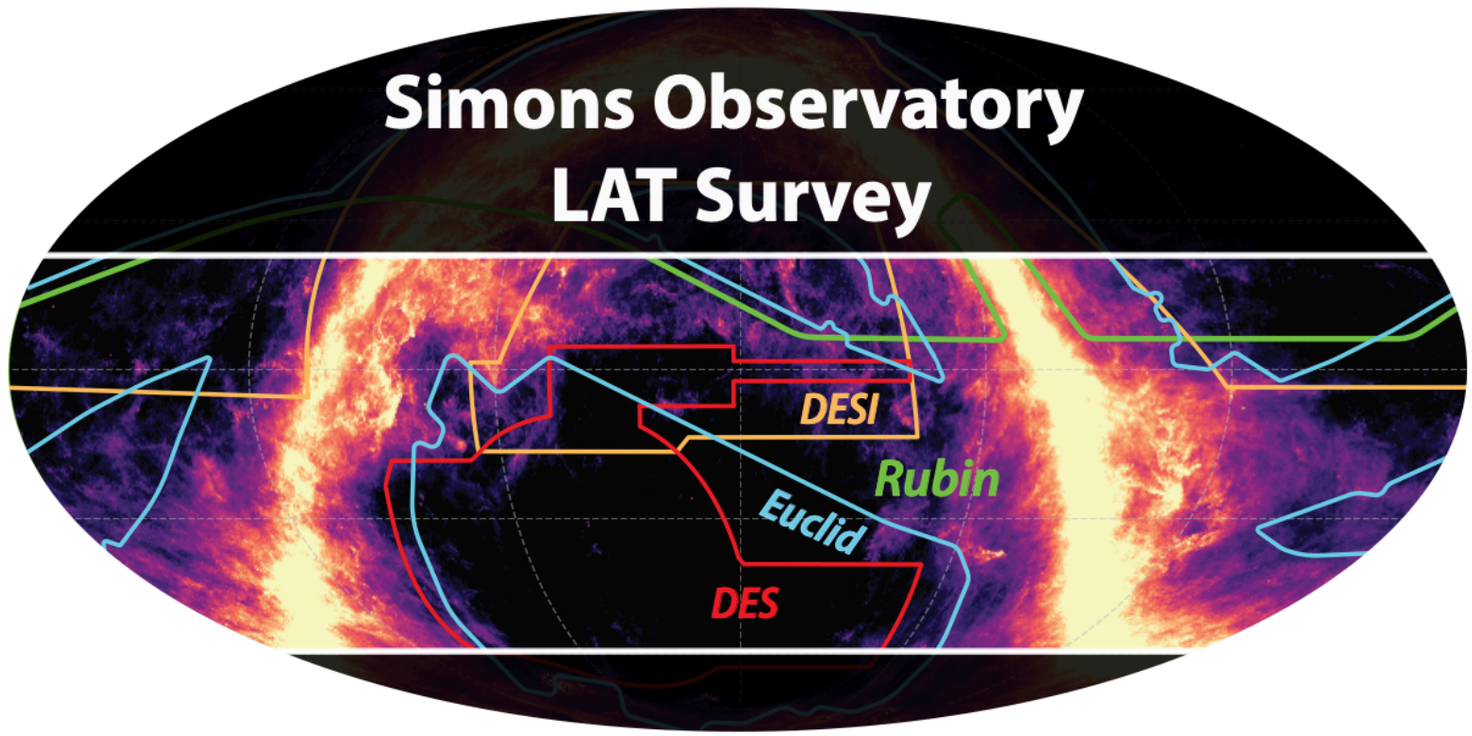
Simons Observatory CMB lensing status



Credits Ola Kusiak (KICC), **Karen Perez Sarmiento (IAS)** and SO collaboration

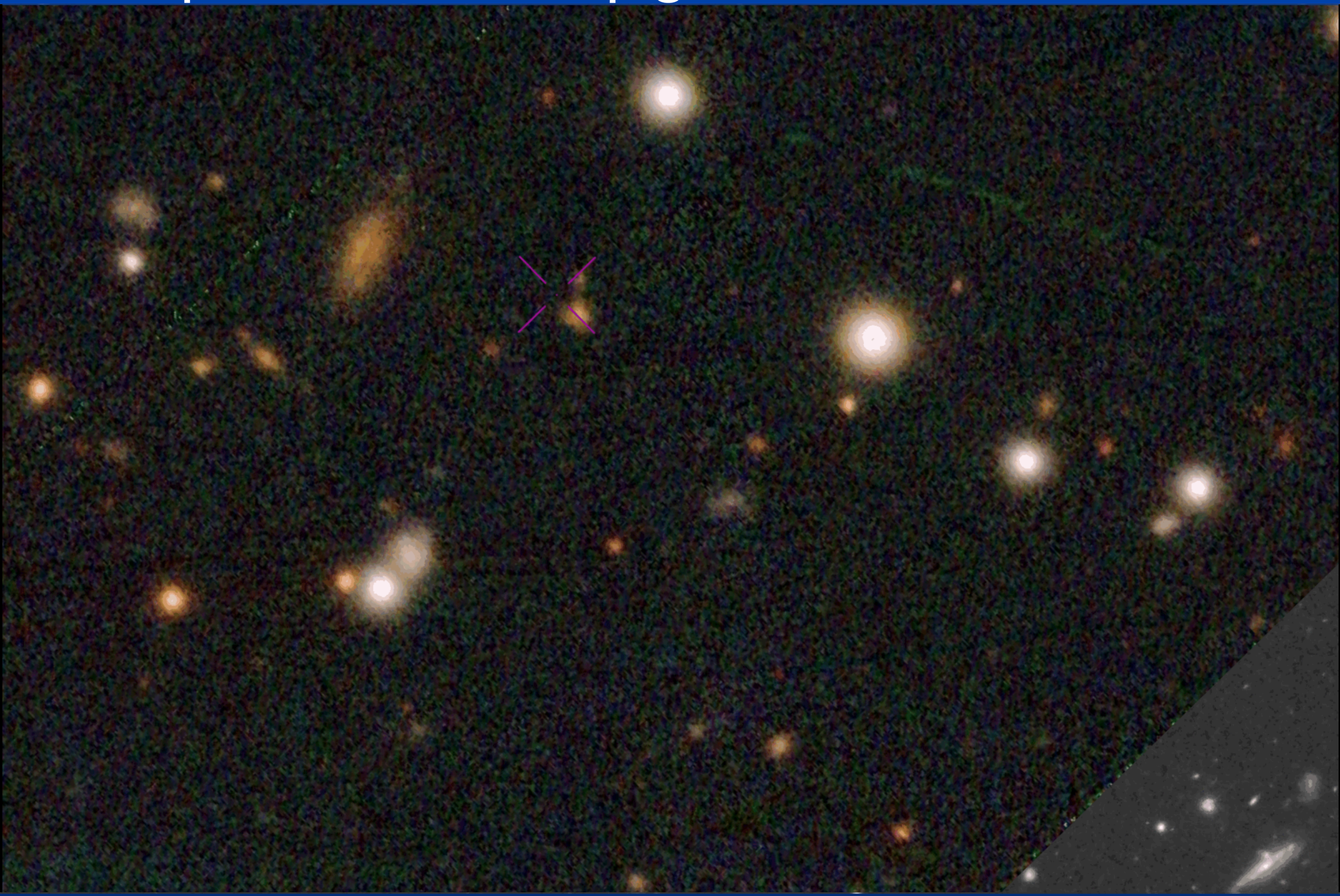






Simons Observatory coll. (2025)

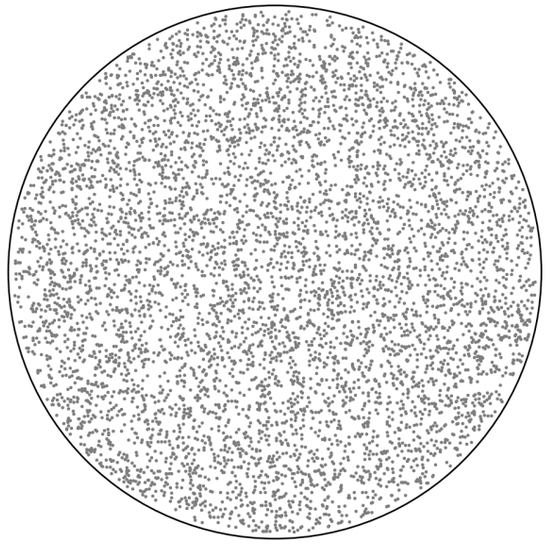
A comparison with deep ground-based data…



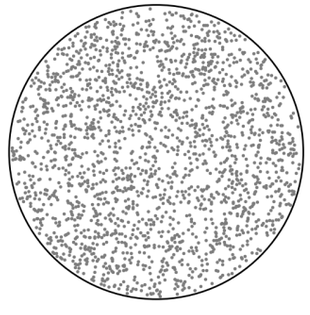
A comparison with deep ground-based data…



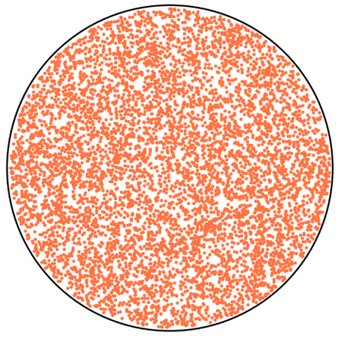
Cosmic shear cross-correlation status



DES Y6
4422 deg2
8.22 gal / arcmin2
152M galaxies

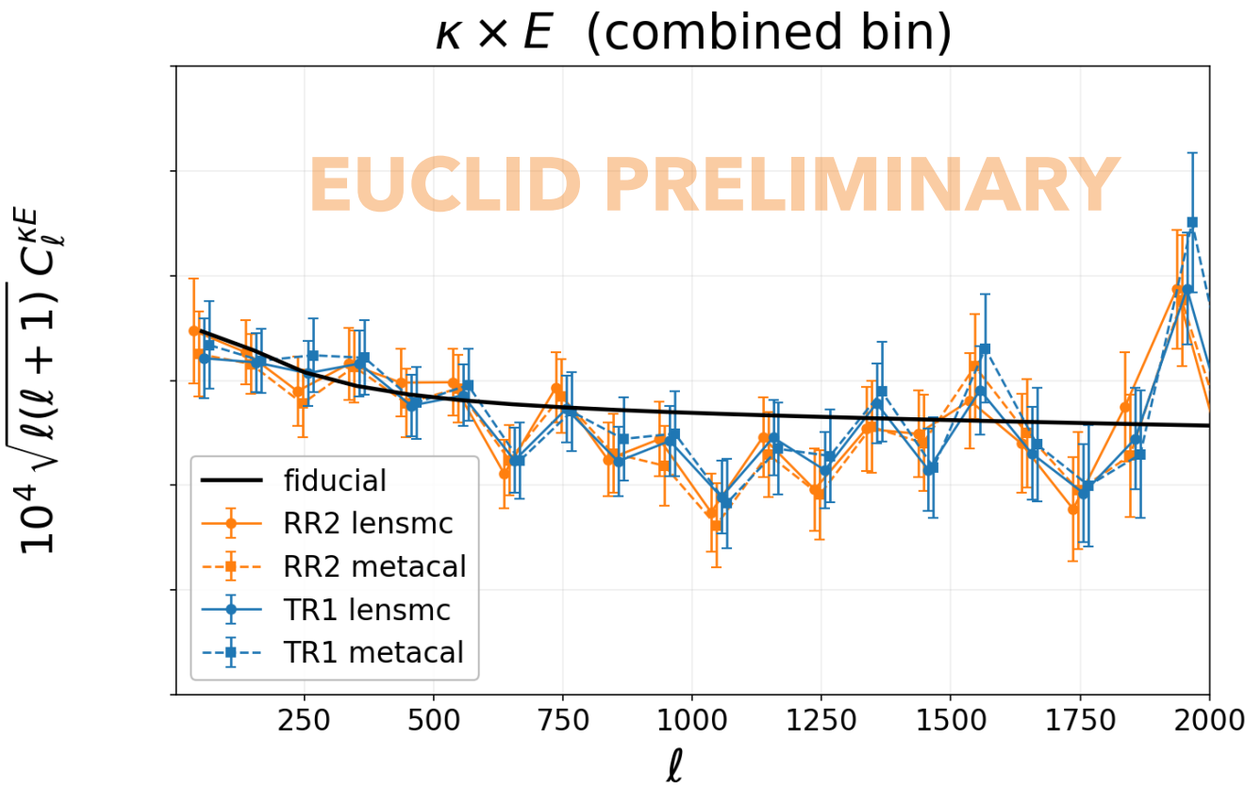


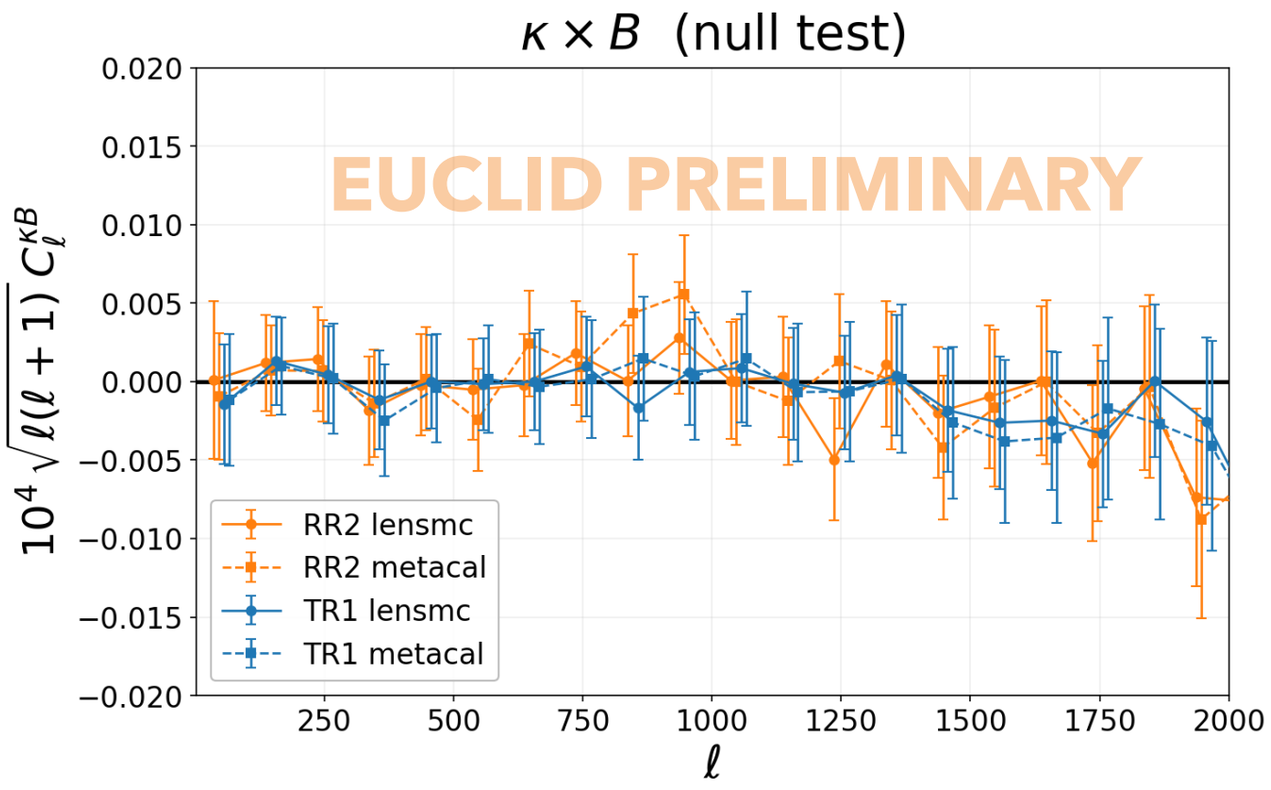
KiDS-Legacy
1347 deg2
8.79 gal / arcmin2
41M galaxies



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

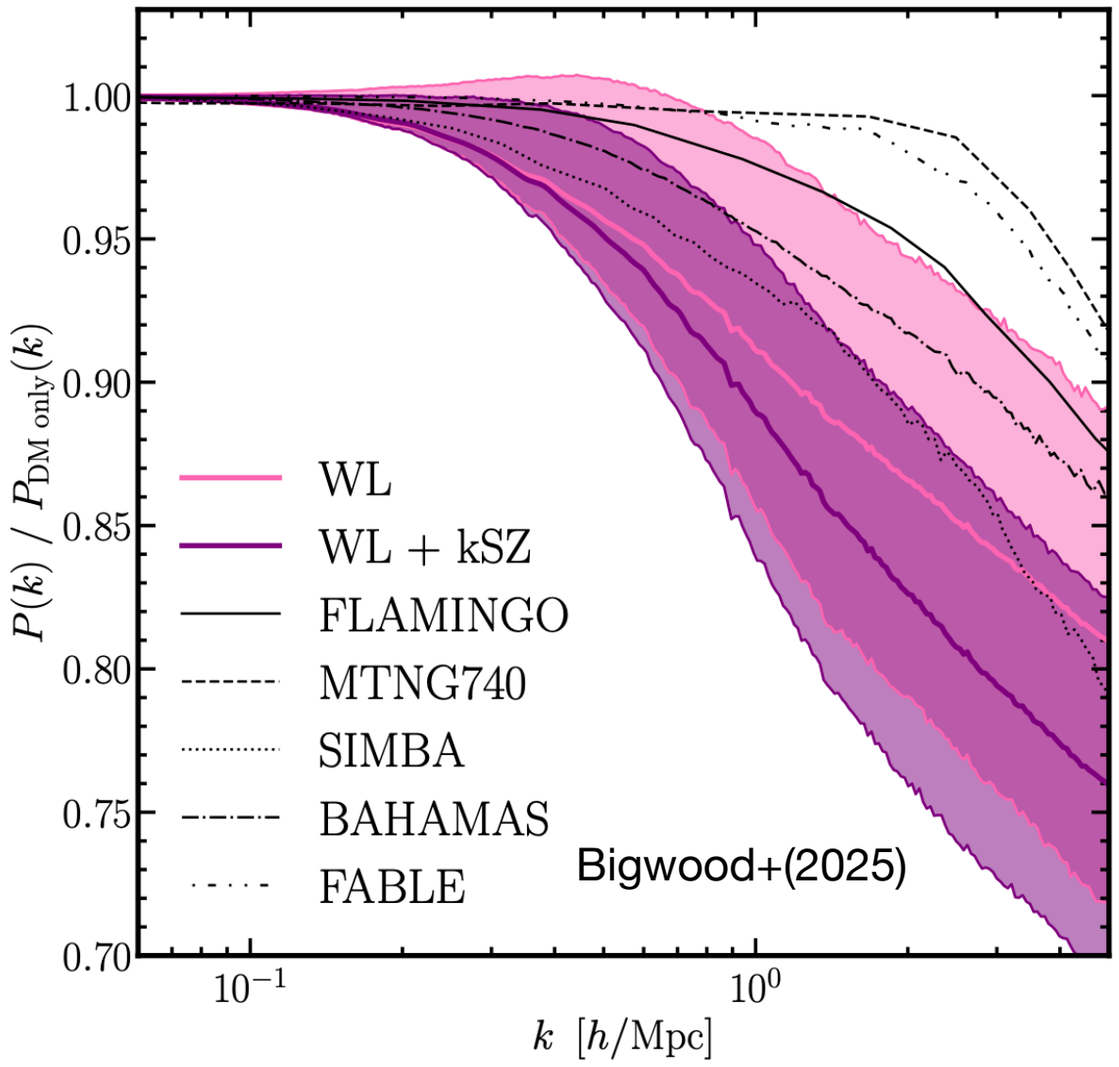
Tomographic $\kappa \times \gamma$ SNR~13 on ~200 deg^2, highest to date.

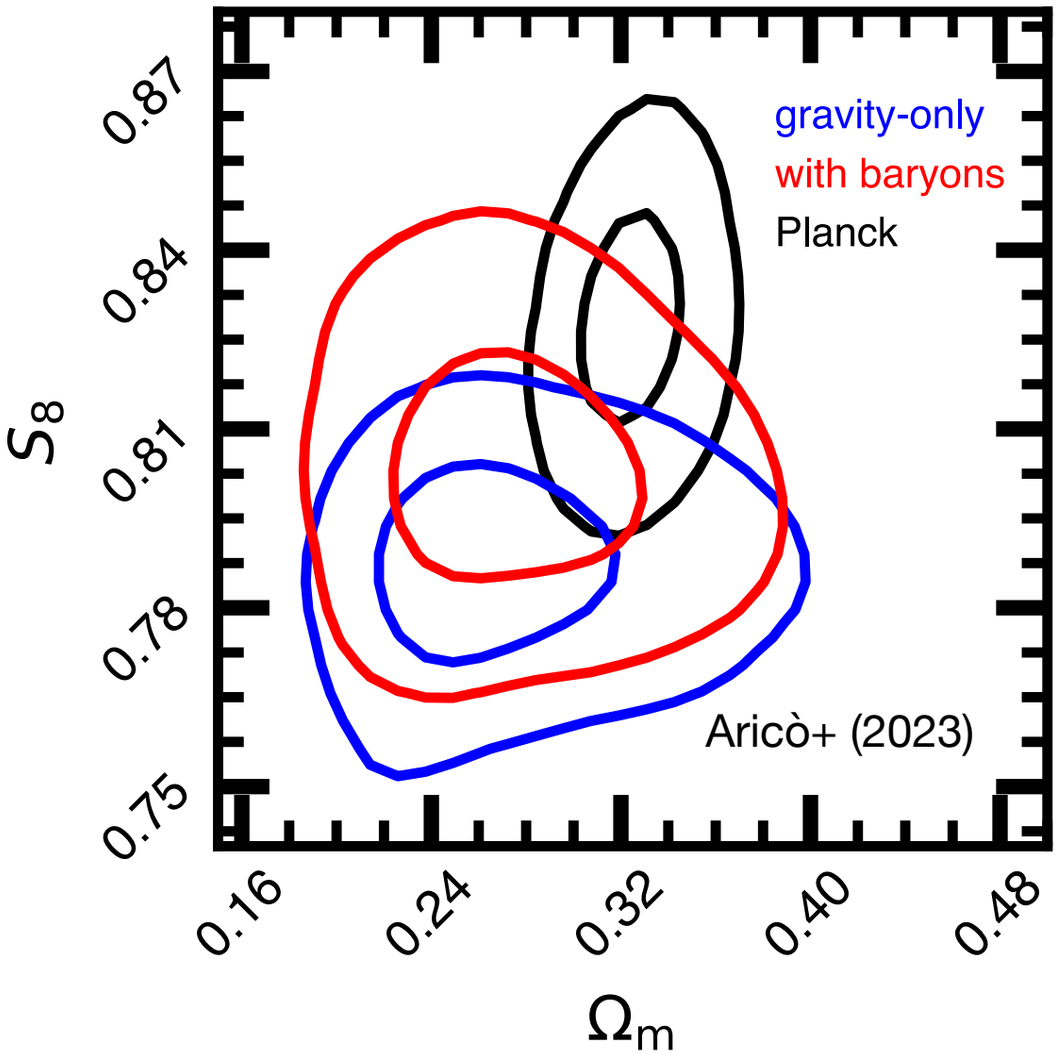




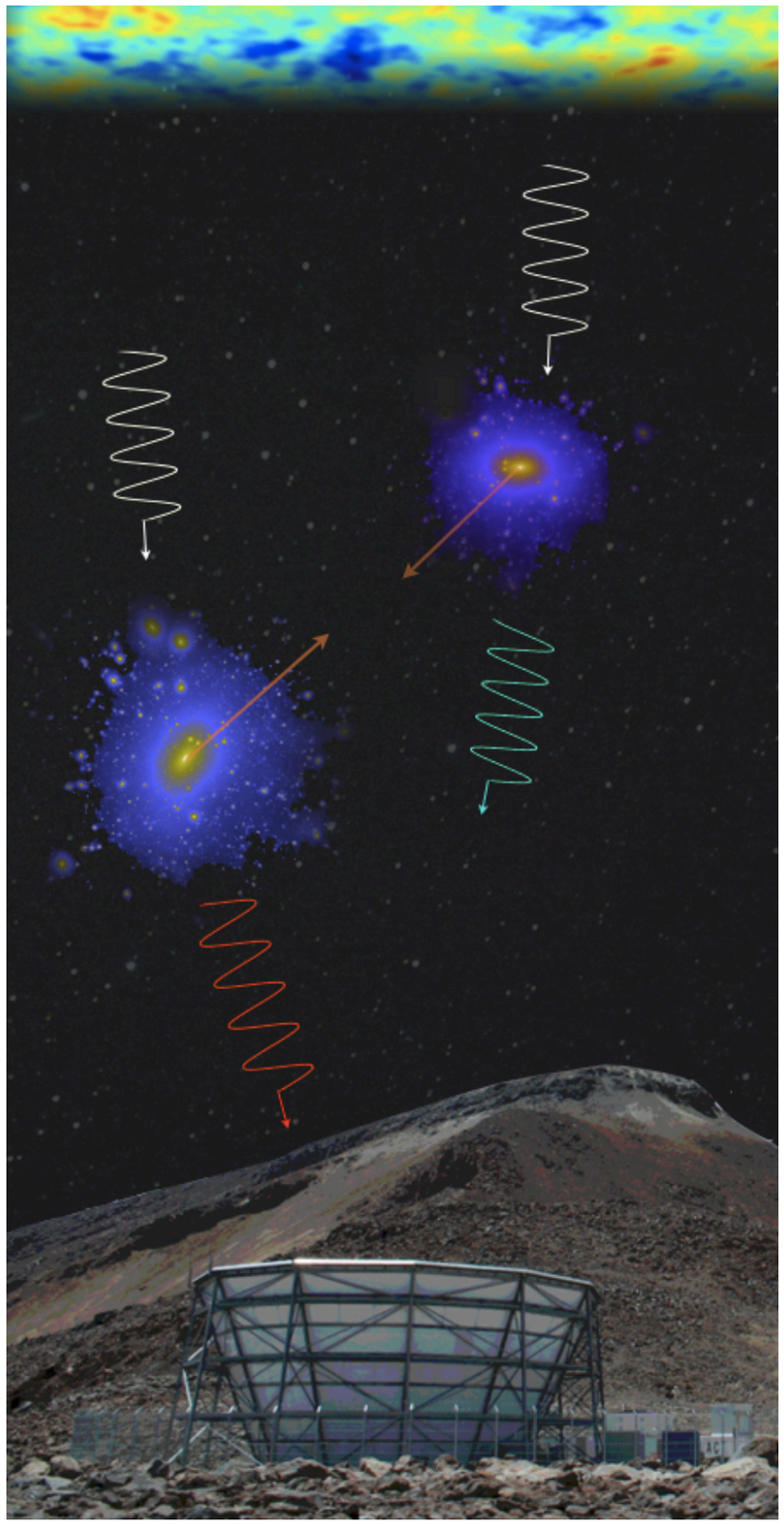
S8 tension and baryonic suppression

- Galaxy lensing drives the S_8 tension: large uncertainties on matter distribution at small scales.
  - Can reconcile current measurements with proper model of baryons.
  - Can perform a joint fit with other direct probe of gas distribution e.g. SZ effects

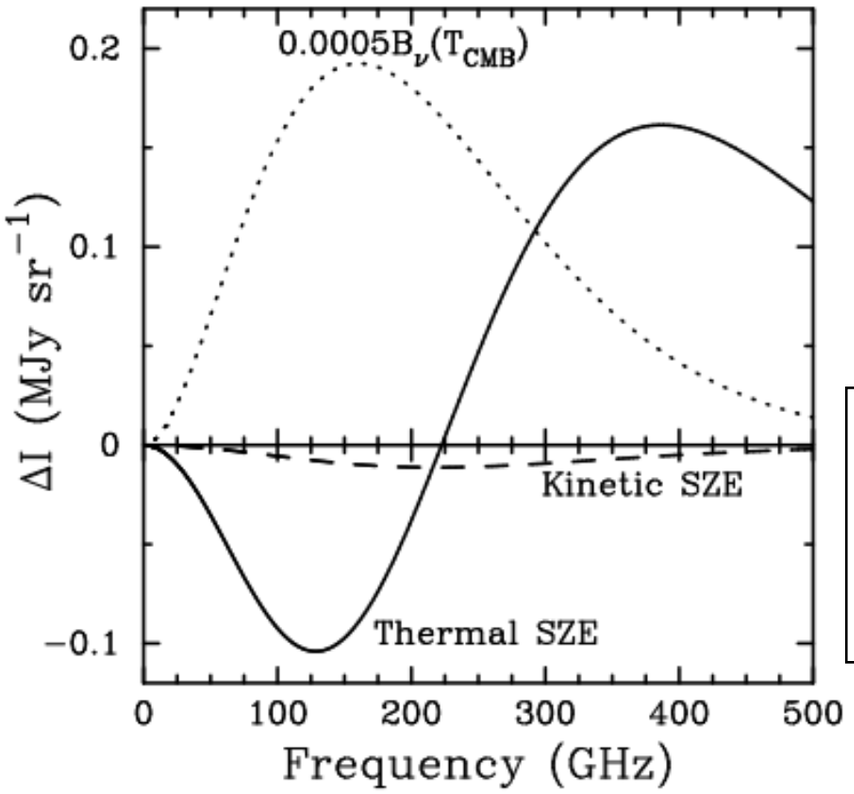




The Sunyaev - Zeldovich effect



- Compton-scattering of CMB photons off free electrons with non-zero line-of-sight bulk velocity.
- Direct probe of **gas momentum and gas abundance!**
- Cosmological information through velocity field, gas properties through optical depth.



$$\Delta T_{kSZ} \sim -\tau_e \frac{v_{los}}{c}$$

$$\tau_e = \int dl n_e \sigma_T$$

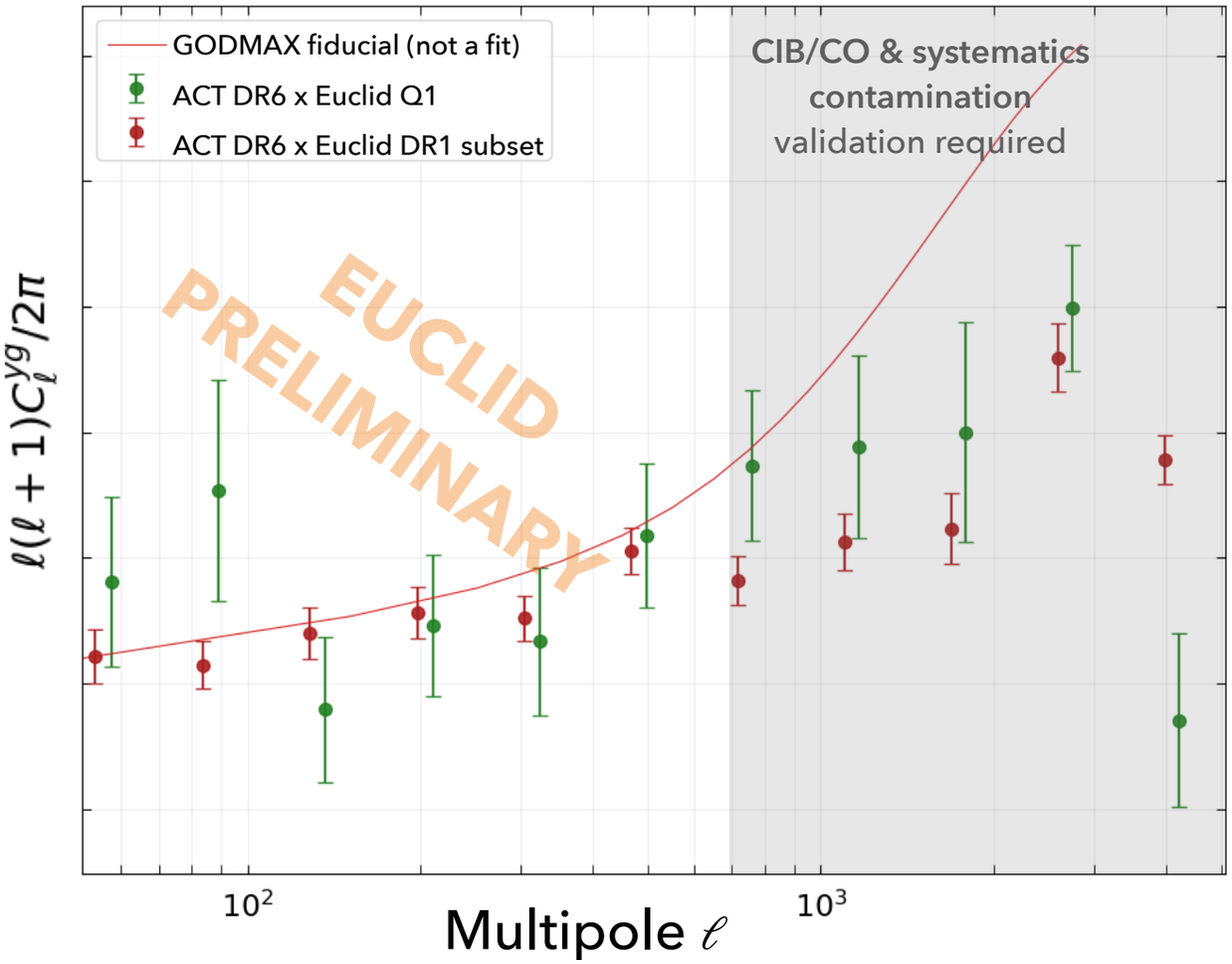
$$y(\hat{\mathbf{n}}) = \int n_{\mathrm{e}} \frac{k_{\mathrm{B}} T_{\mathrm{e}}}{m_{\mathrm{e}} c^2} \sigma_{\mathrm{T}} \, ds$$

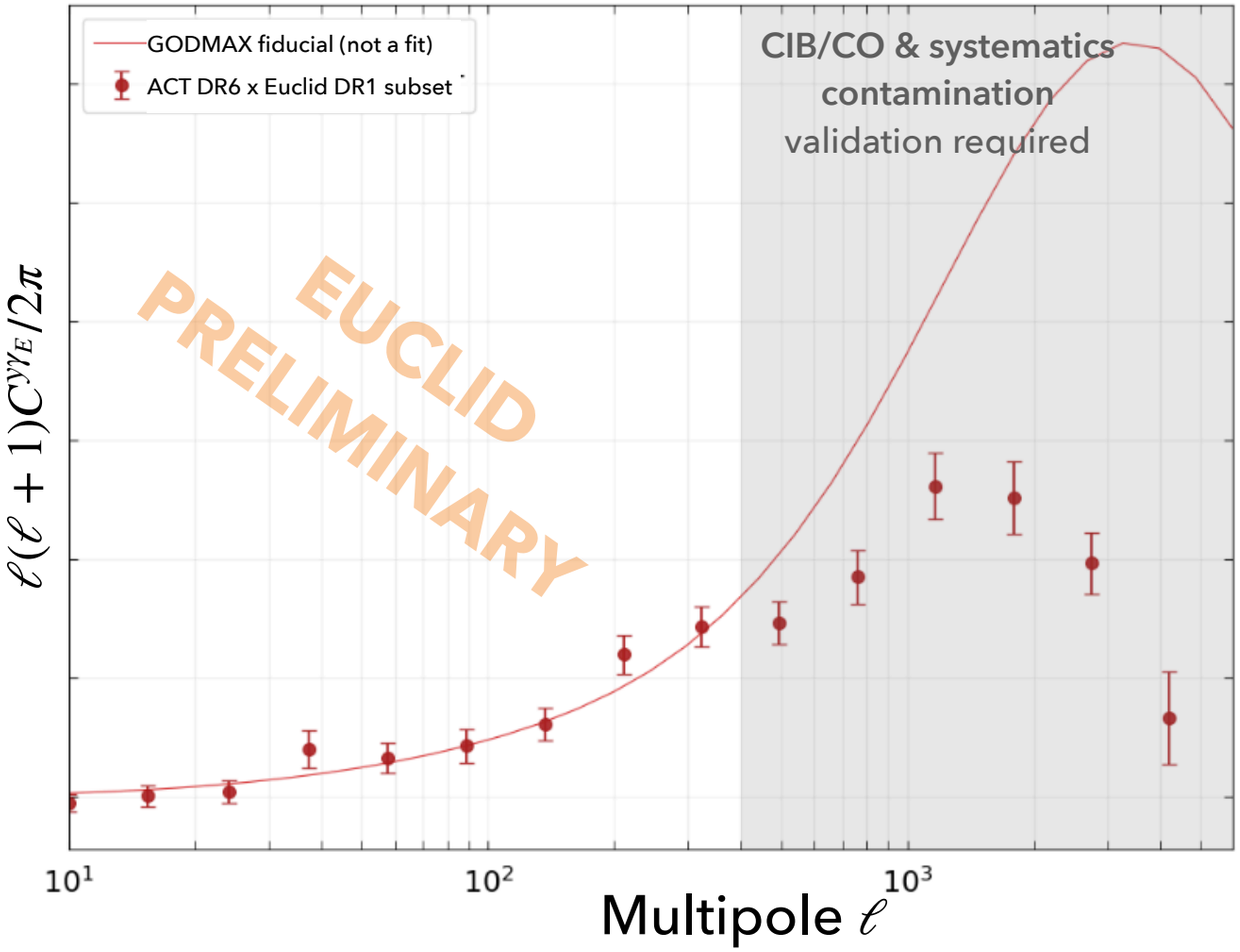
SZ cross-correlation with Euclid

- Shear x tSZ SNR ~13 Comparable to current best measurements with DES x ACT DR6.
- Galaxy clustering x tSZ: SNR ~18, should beat unWISE x ACT+Planck already in DR1.
- kSZ detected with spectroscopic sample…

Pandey+(2024)
Kusiak+(2024)

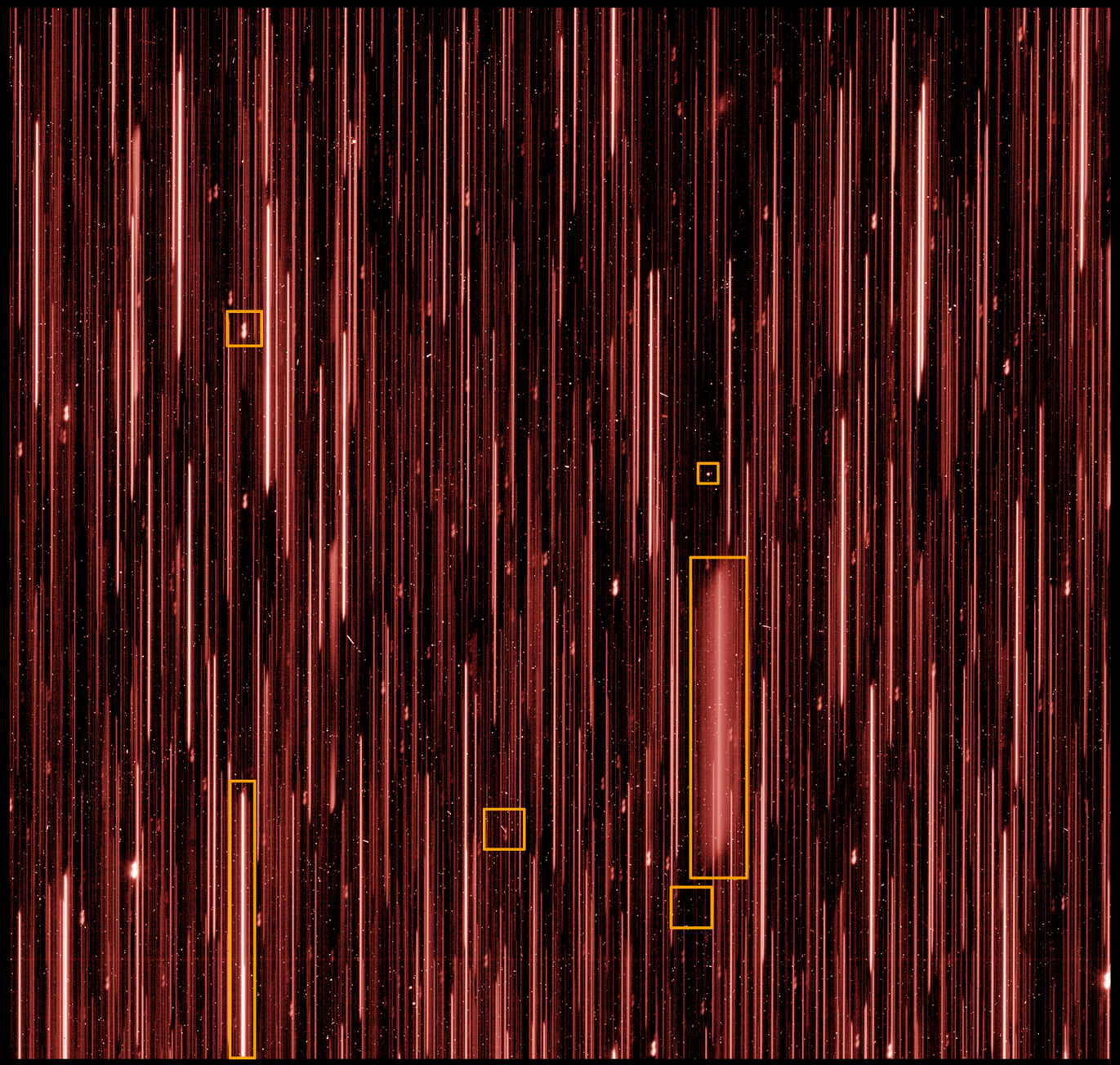
- Internal, self consistent constraints on gas physics (also to inform cosmological inference).





EUCLID

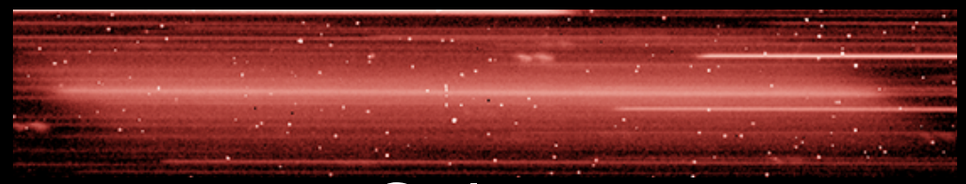
RESULTS SO FAR



Early commissioning test image, NISP instrument (grism mode)

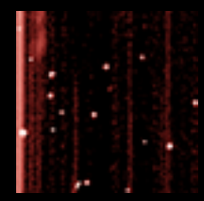


Stars

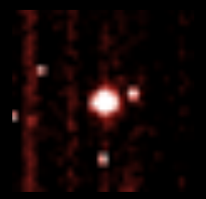


Galaxy





Cosmic ray / artifacts

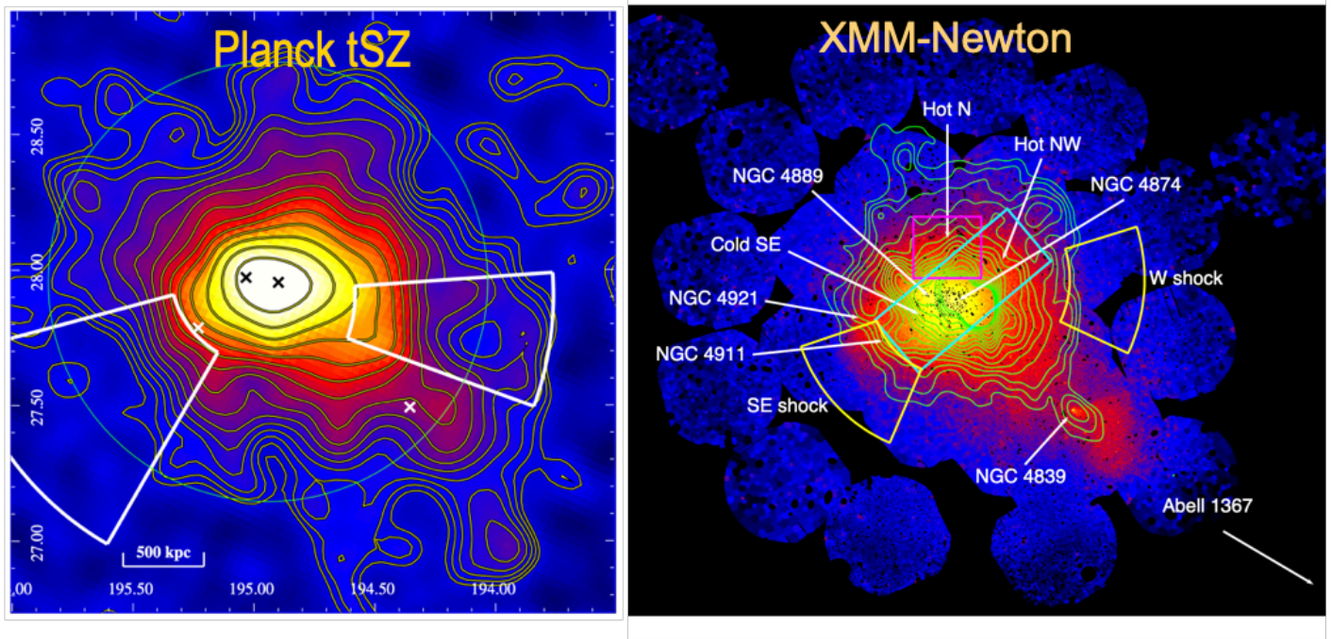


Snowball / muon

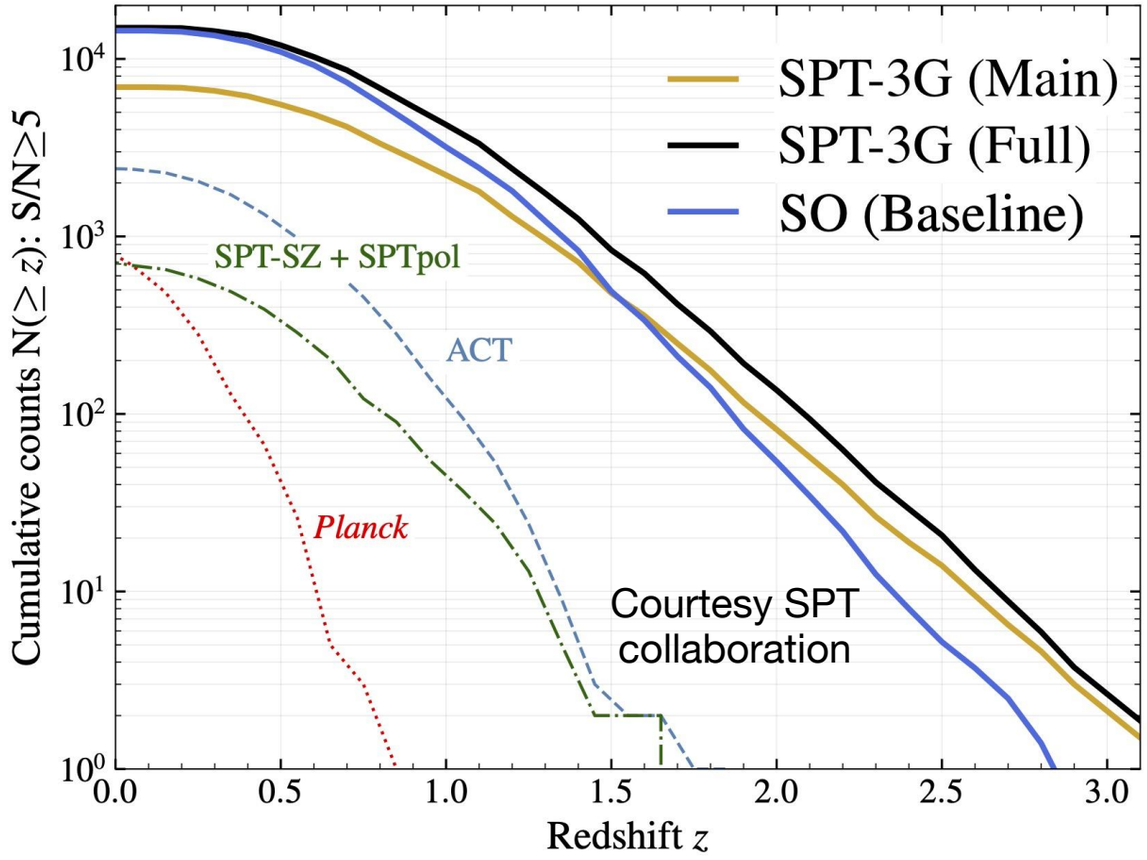
Credit: ESA/Euclid/Euclid Consortium/NASA

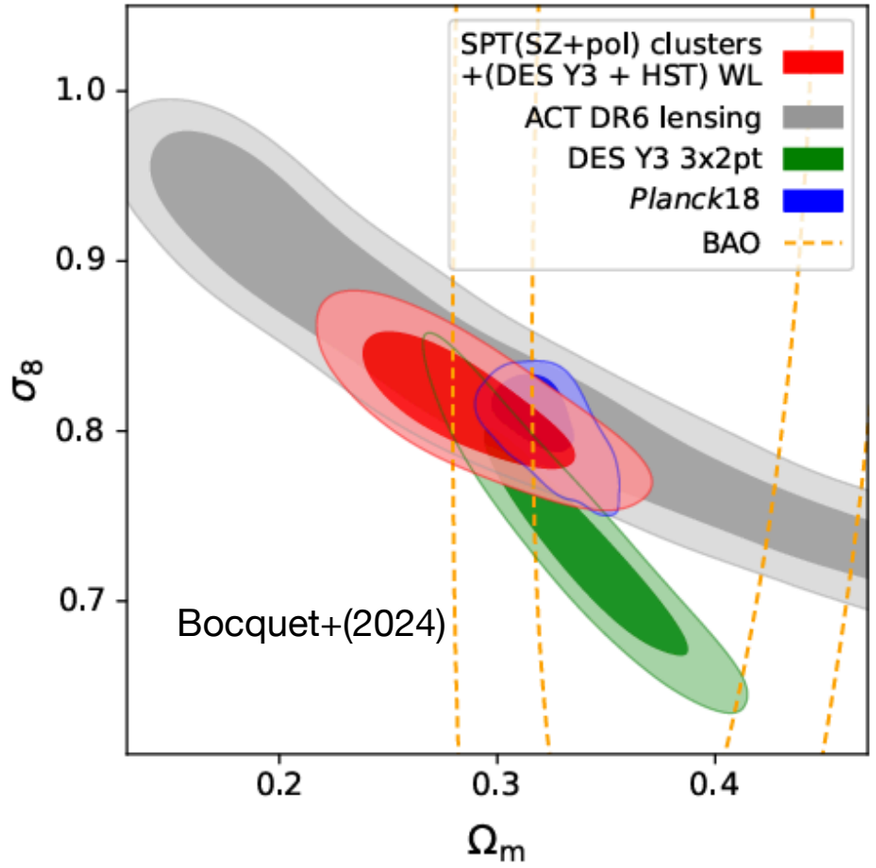
Cluster cosmology

- Number counts sensitive to dark energy (now ~1000s)
  - tSZ flux limit ~ mass limit!
  - Complementarity / synergies with X-ray and lensing surveys



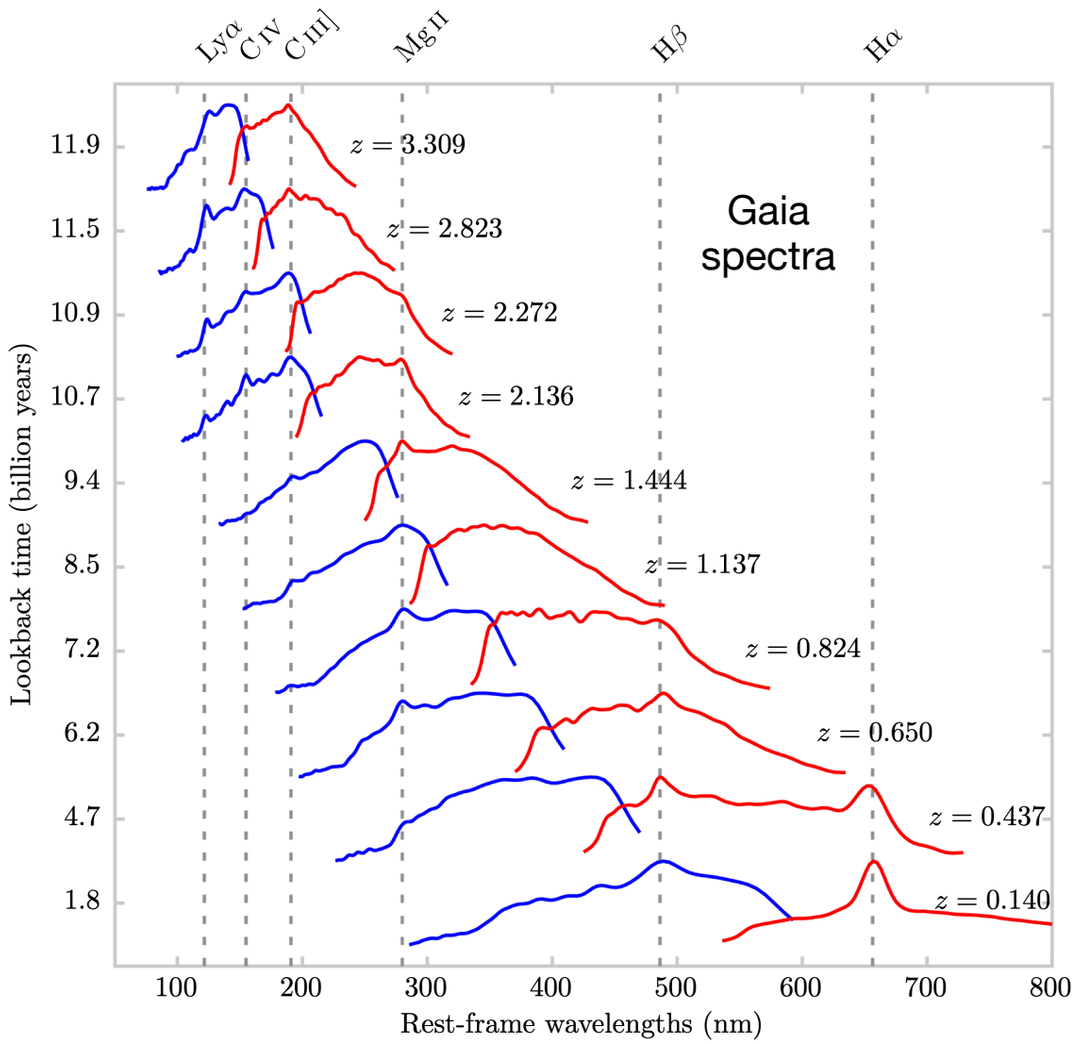
Coma cluster (Planck coll. 2015, Mirakhor+2020)

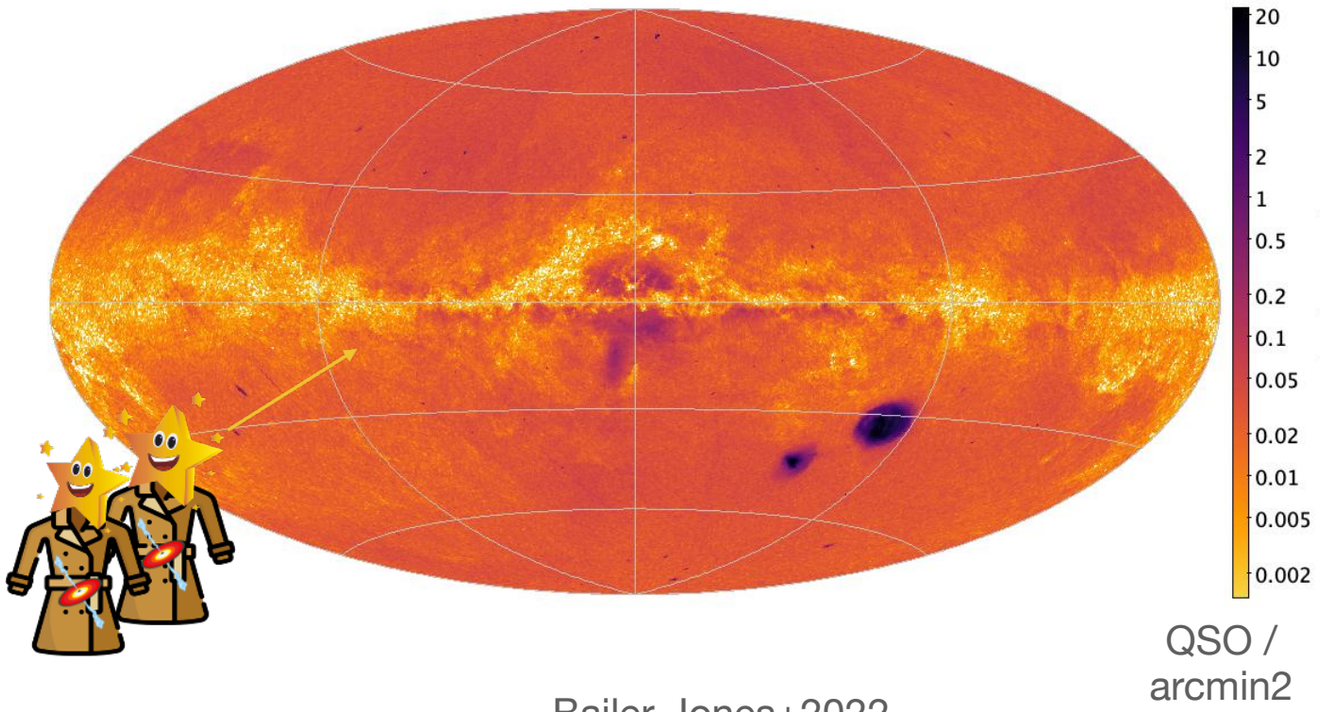




In the meantime… Gaia!

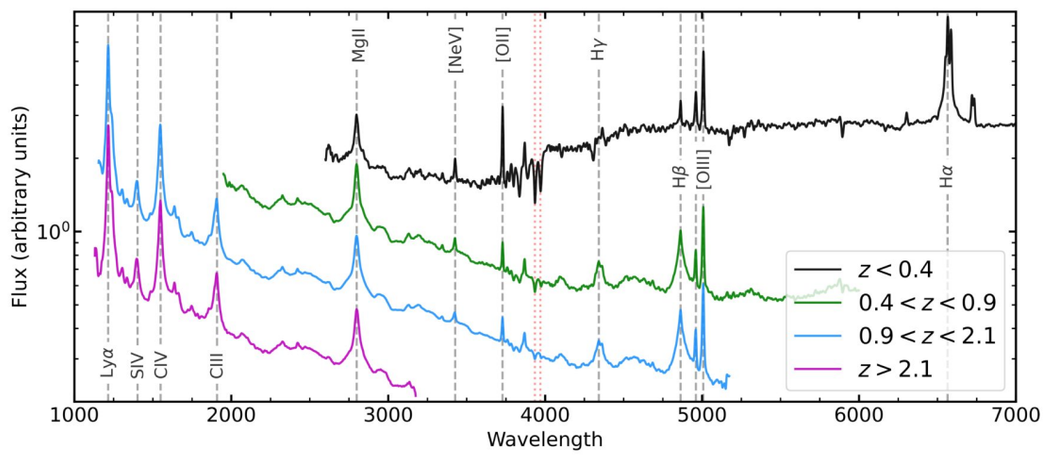
- Gaia: photometry, astrometry, slitless spectroscopy with $30 \leq \lambda/\Delta\lambda \leq 100$
- DR3 released 6.6 million quasar candidates.
  - Cleaner selection, omplete but low purity: many stars masquerading as QSO :/
- **DR4 expected in 2 months!**





Bailer-Jones+2022

DESI spectra (DESI coll.)



How it compares?



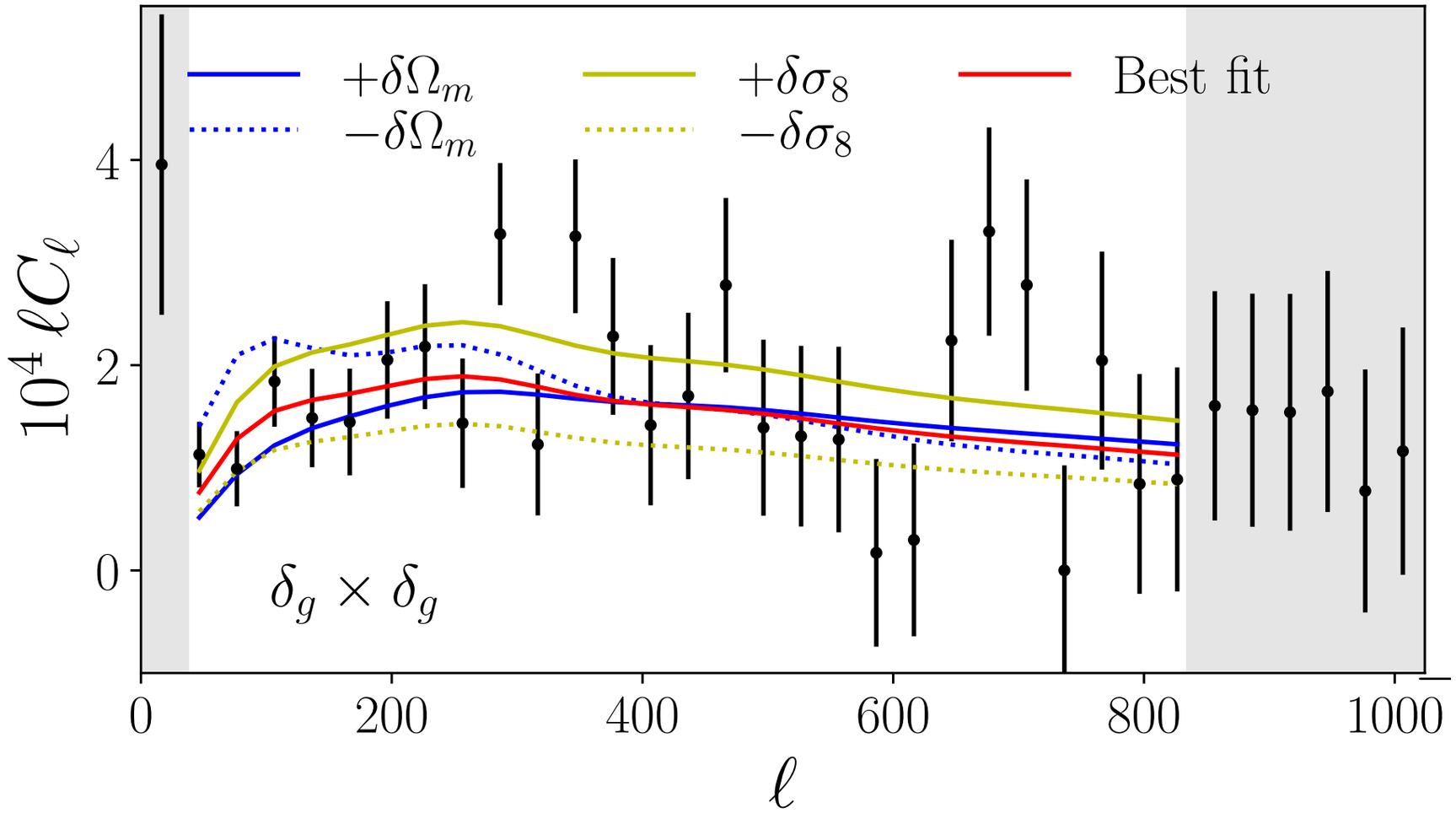
Credits Kate Storey-Fisher

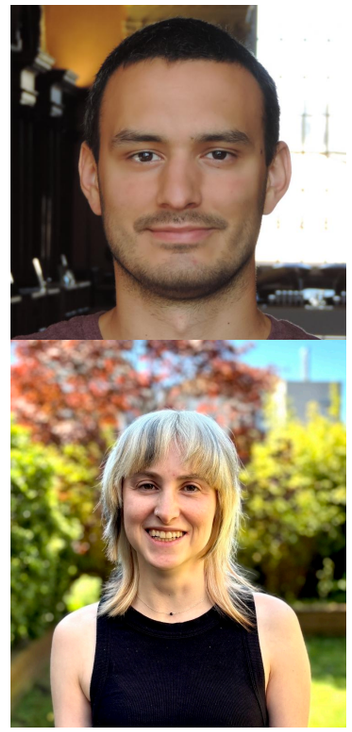
	N	$f_{\rm sky}$	$\bar{n}$, $\deg^{-2}$	$V_{\rm span}$, $(h^{-1}\,{\rm Gpc})^3$	$V_{\rm eff}$, $(h^{-1}\,{\rm Gpc})^3$	$z_{\rm med}$	$f(\lvert\delta z\rvert < 0.01)$	$f(\lvert\delta z\rvert < 0.1)$
Quaia	**1,234,715**	**0.73**	**40.78**	**143.78**	**7.08**	**1.48**	**0.63**	**0.84**
Gaia Purer	1,647,311	0.73	54.42	143.76	9.24	1.63	0.53	0.62
WISE-PS1	2,386,121	0.56	103.89	109.08	20.88	1.38	0.11	0.71
SDSS DR16Q	637,371	0.26	60.18	50.30	4.16	1.77	∼1	∼1
eBOSS Clustering	409,286	0.14	72.52	26.80	3.21	1.60	∼1	∼1

NB: after DESI, still largest QSO sample (slightly) and ~2.5x spanning volume

What Quaia can do for cosmology?

- Large sky coverage means capability to measure large angular scales.
- Towards non-degenerate σ_8, Ω_m measurements

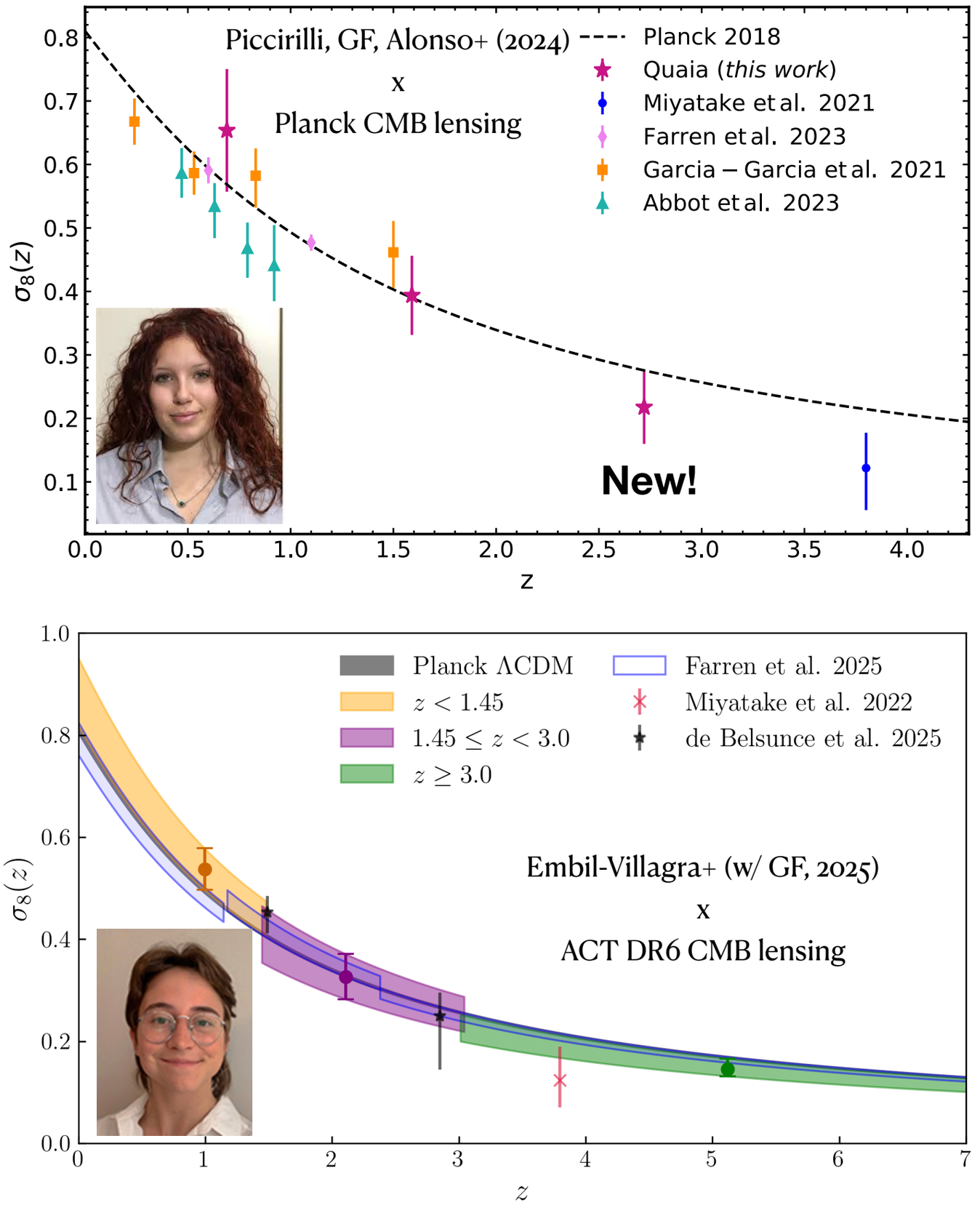




Alonso, Fabbian, Storey-Fisher+(2023)

Cosmology from Quaia x CMB lensing

- Tomographic $C_\ell^{gg}, C_\ell^{\kappa g}$ with Planck lensing
  - New high-z σ_8 constraints.
  - Careful foreground assessments.

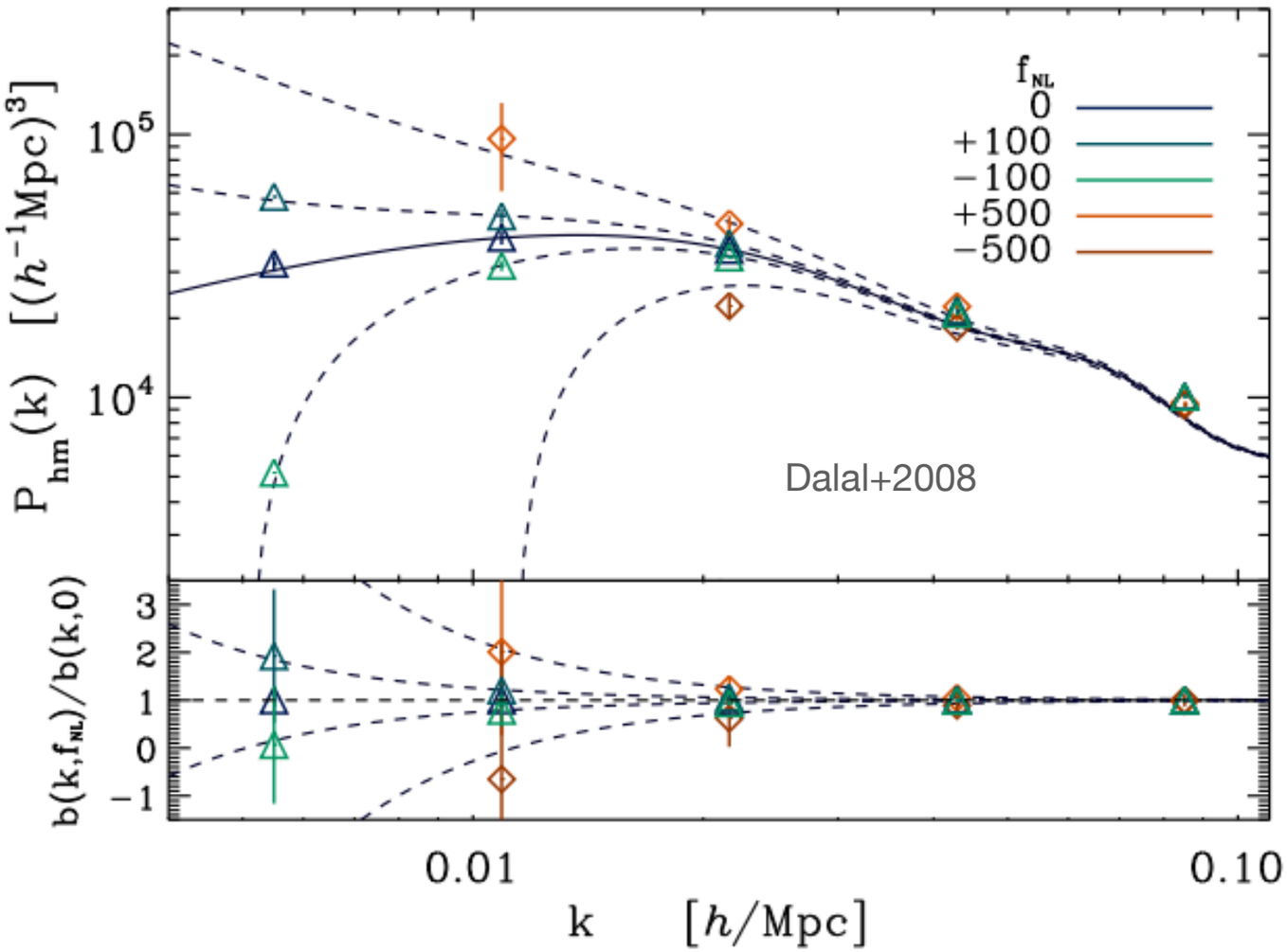


- Tomographic 3x2pt $C_\ell^{gg}, C_\ell^{\kappa g}, C_\ell^{\kappa\kappa}$ with ACT CMB lensing
  - Constraints on $\sigma_8(z = 5.1)$

Non-Gaussianities and scale dependent bias

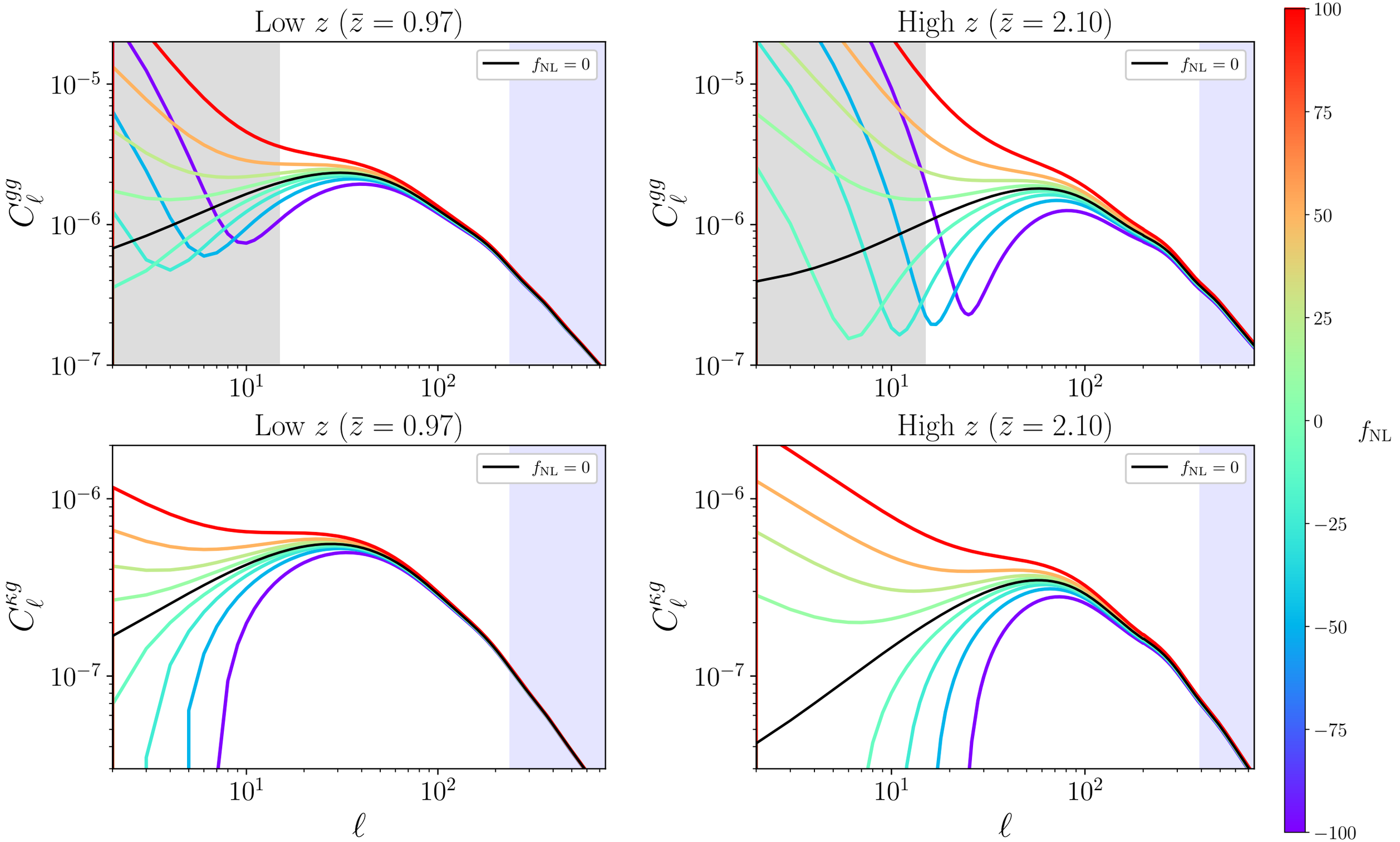
$$\Phi(\mathbf{x})_{\rm NG} = \Phi(\mathbf{x}) + f_{\rm NL}\left(\Phi^2(\mathbf{x}) - \langle\Phi^2\rangle\right)$$

$$\Delta b_1 \propto \frac{f_{\rm NL} b_1 b_\phi}{k^2 T(k)}$$



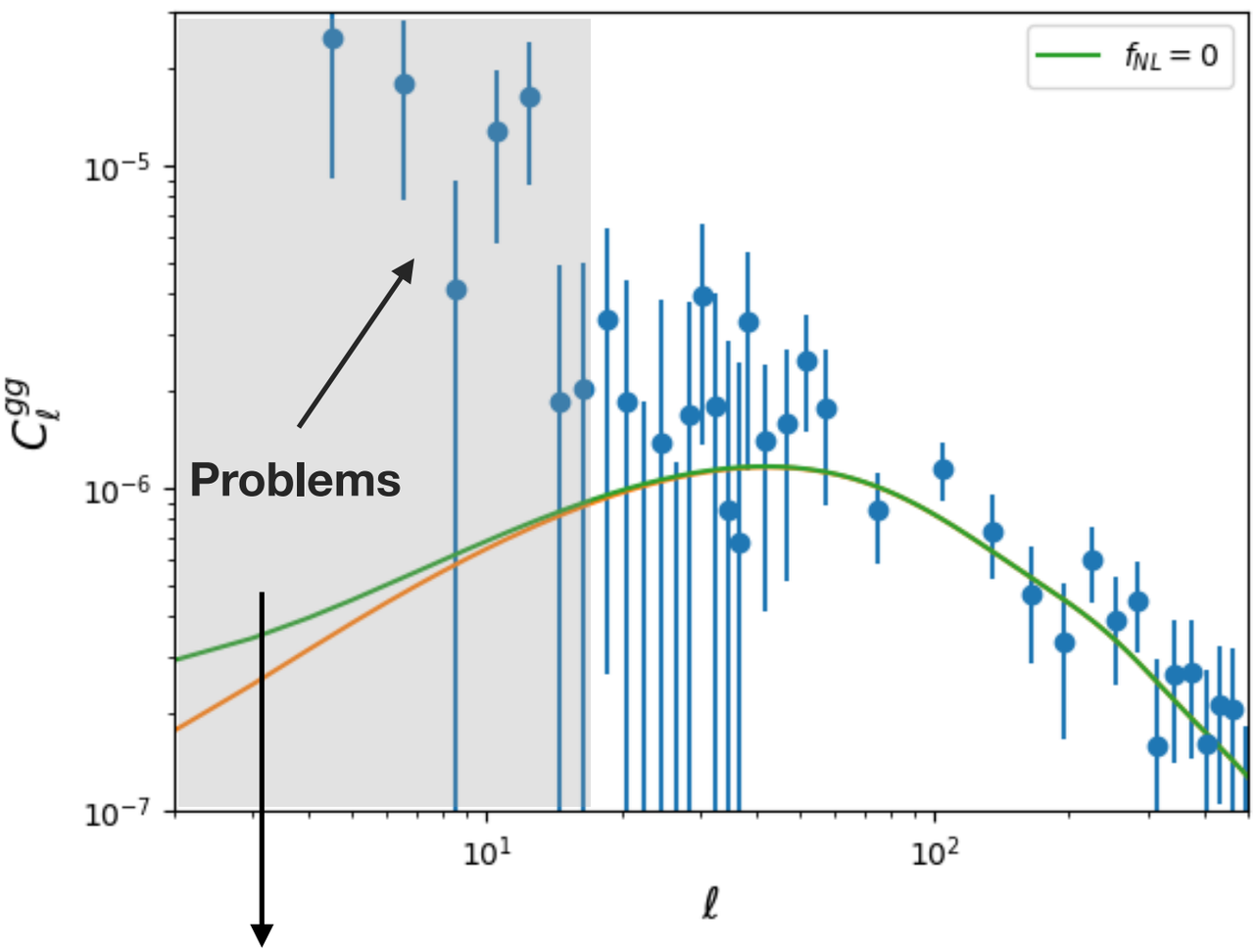
- Huge volume and high bias tracers is required to enhance detection.
- Quasars: detectable at high z thanks to bright AGNs, ~linear scales, ideal for f_{NL} studies.
- Galactic extinction, stellar contamination, seeing, survey depth inhomogeneity cause large scale variations / power excess in clustering measurements…

Signature of f_{NL} for projected statistics

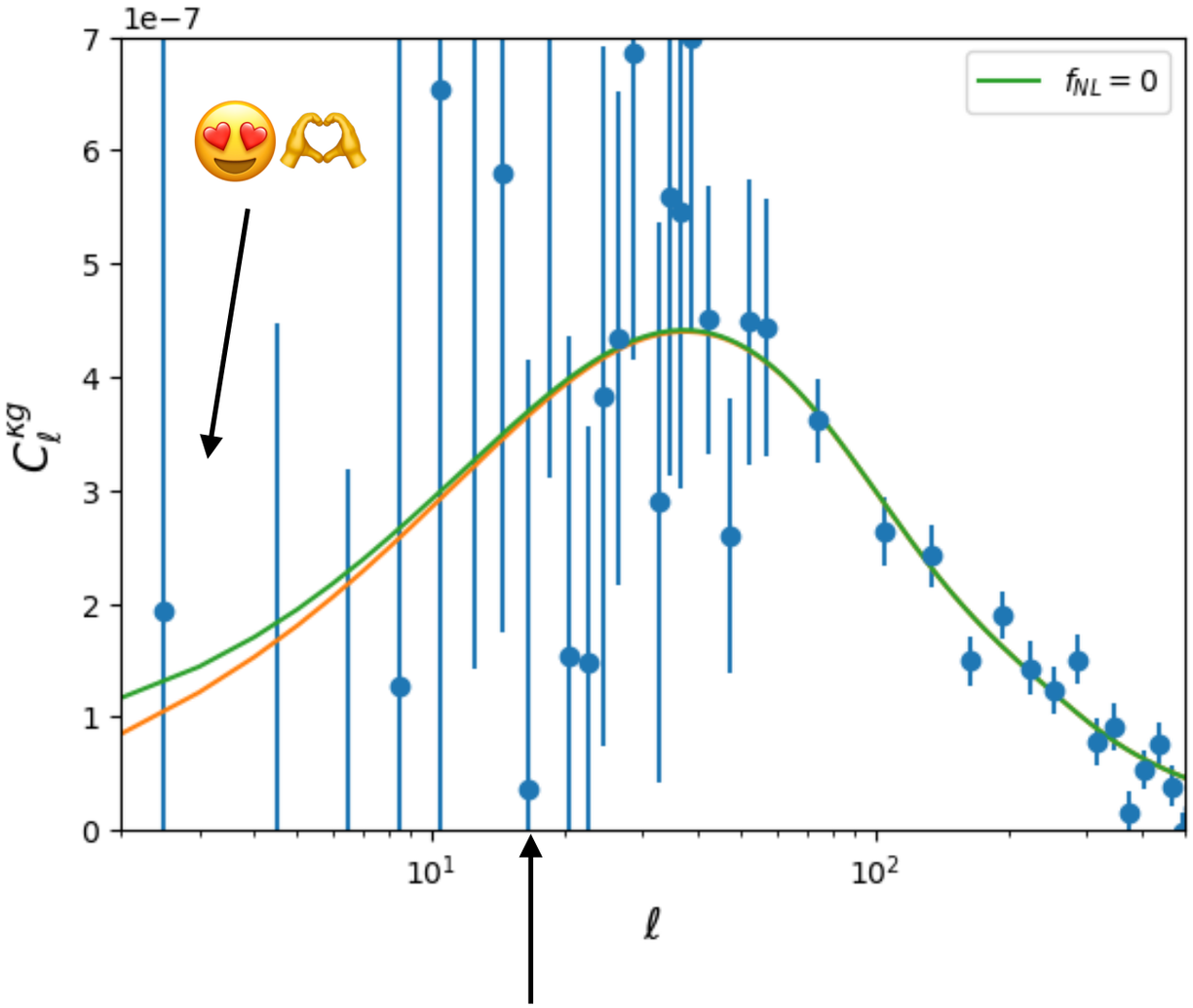


Fabbian, Alonso, Storey-Fisher+(2026)

Constraints on f_{NL}



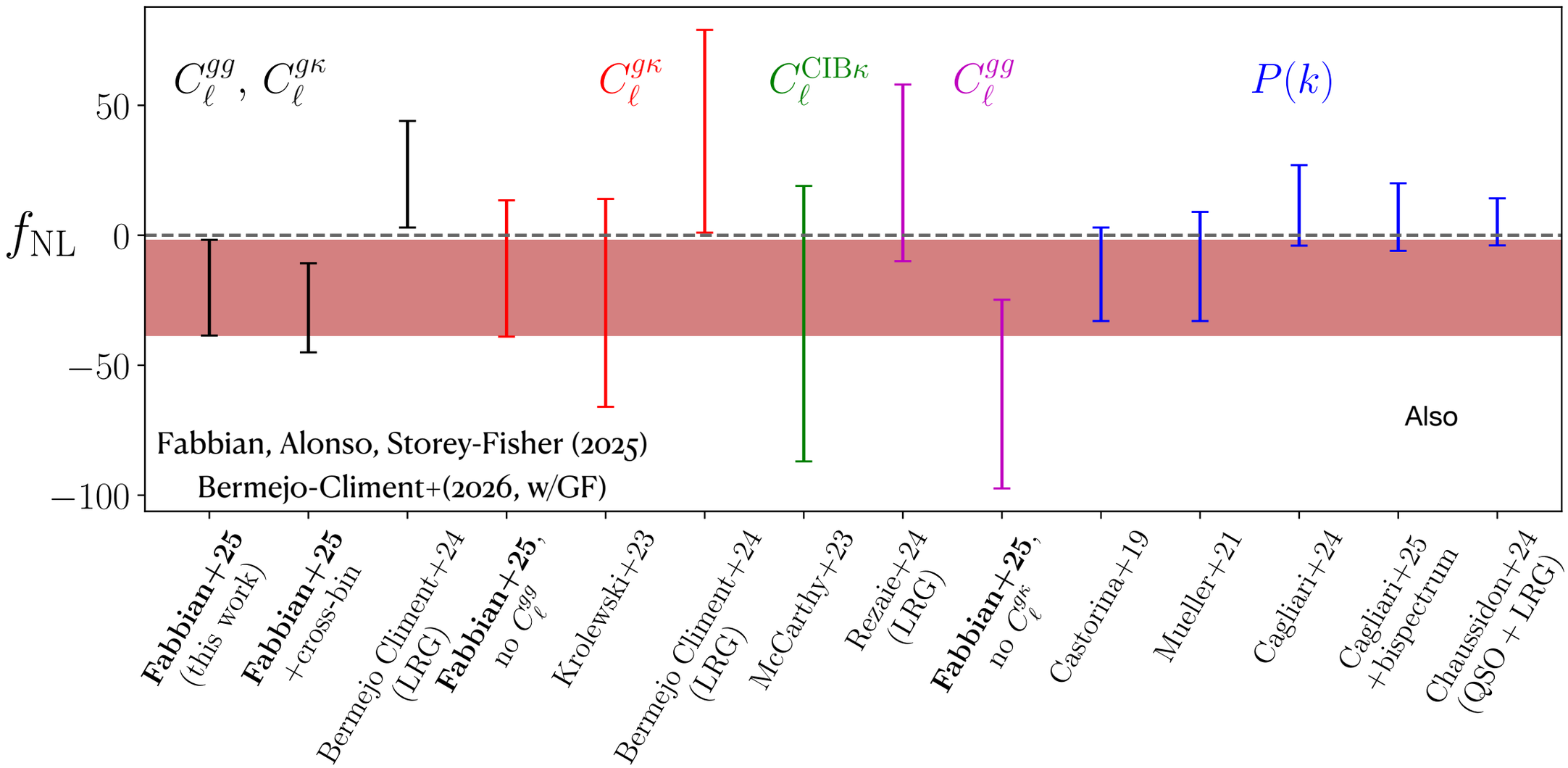
Aggressive systematics subtraction:
~3x degradation of results
(Rezeie+2025)



Scale cuts from ground-based surveys
(Krolewski+2023)

- Cross-correlation can reach the largest scales with no systematics contamination!
- $\sigma(f_{\rm NL})$: worse than expectations due to residual systematics $\Delta C_\ell^{\kappa g} \propto \sqrt{C_\ell^{\kappa\kappa} C_\ell^{gg}}$

Robustness tests and perspectives

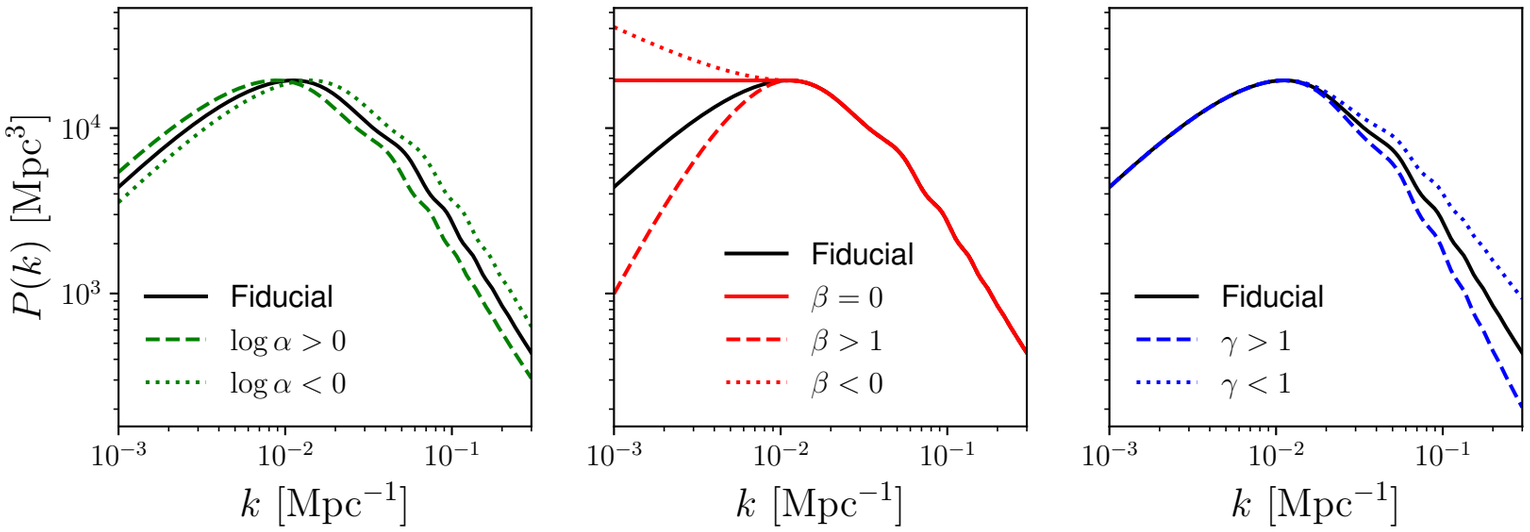


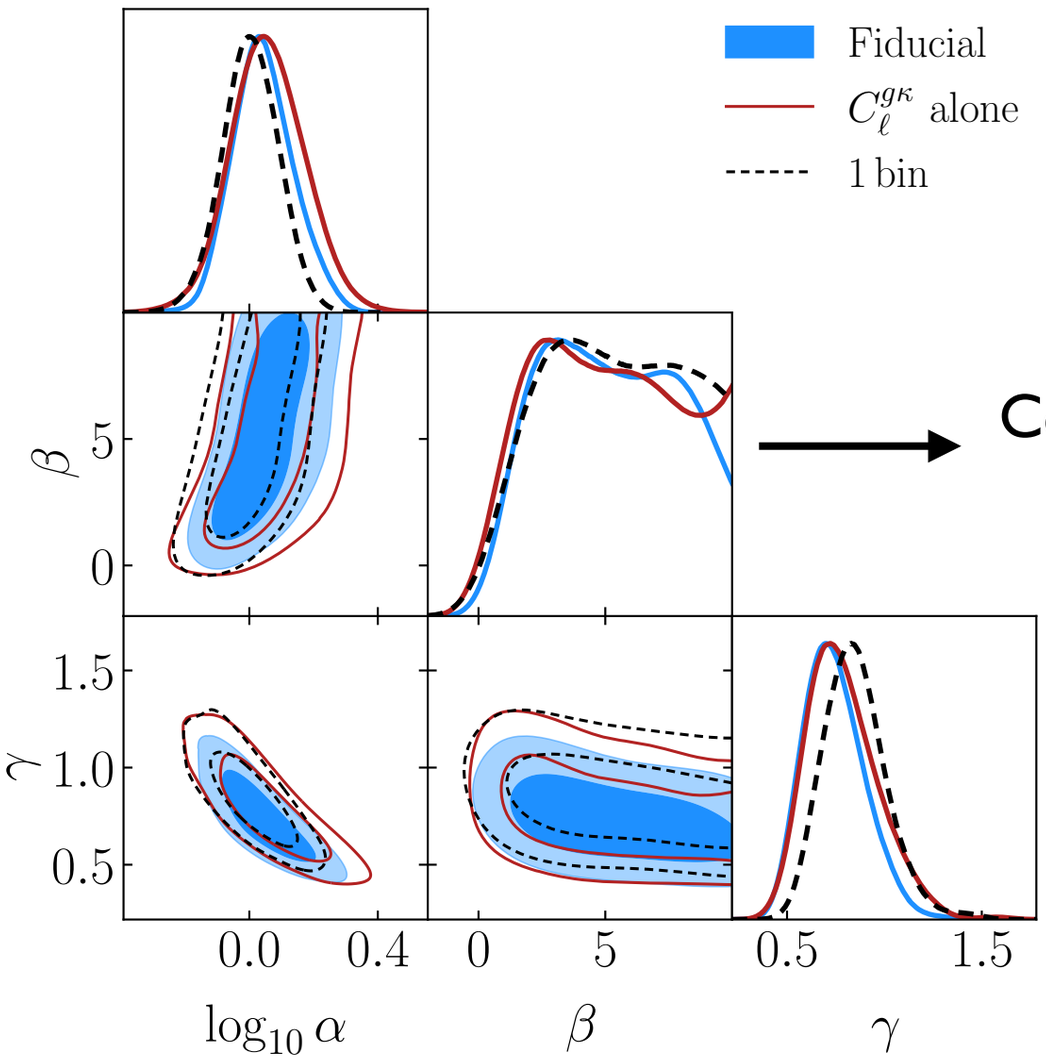
- $\sigma(f_{NL}) \sim 14 - 17$ approaching spectroscopic galaxy surveys in 3D $\sigma(f_{NL}) \sim 11$ $(b_\phi = 1)$
- With new Gaia DR4 $\sigma(f_{NL}) < 9$ within reach even with same number density
  - Synergies with new SPHEREX, DESI…

Chaussidon+2025
Chiarenza+2026

1st k_{eq} measurement from cross-correlation

$$P_{mm}(k) = A\,P_{\rm fid}(\alpha k)\left(\frac{P^{\rm LS}_{\rm flat}(\alpha k)}{P_{\rm fid}(\alpha k)}\right)^{1-\beta}\left(\frac{P^{\rm SS}_{\rm flat}(\alpha k)}{P_{\rm fid}(\alpha k)}\right)^{1-\gamma}$$





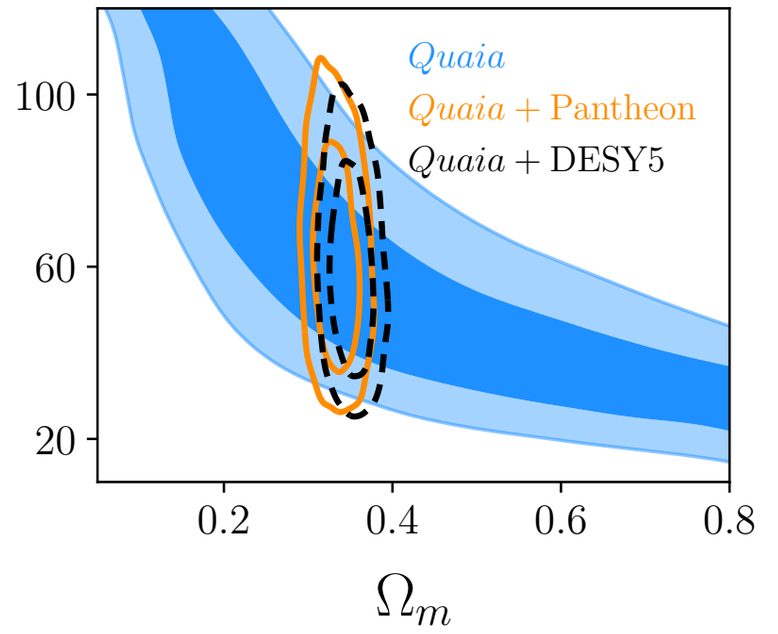
Detection of turnaround!

Cosmology from α

k_{eq} consistent with Planck within 0.5σ

Sound-horizon independent

See Bahr-Kalus+(2025) for 3D DESI QSO+LRGs



$H_0 \sim 63 \pm 16$km/s/Mpc

Alonso, Hetmansev, Fabbian+ (2025)

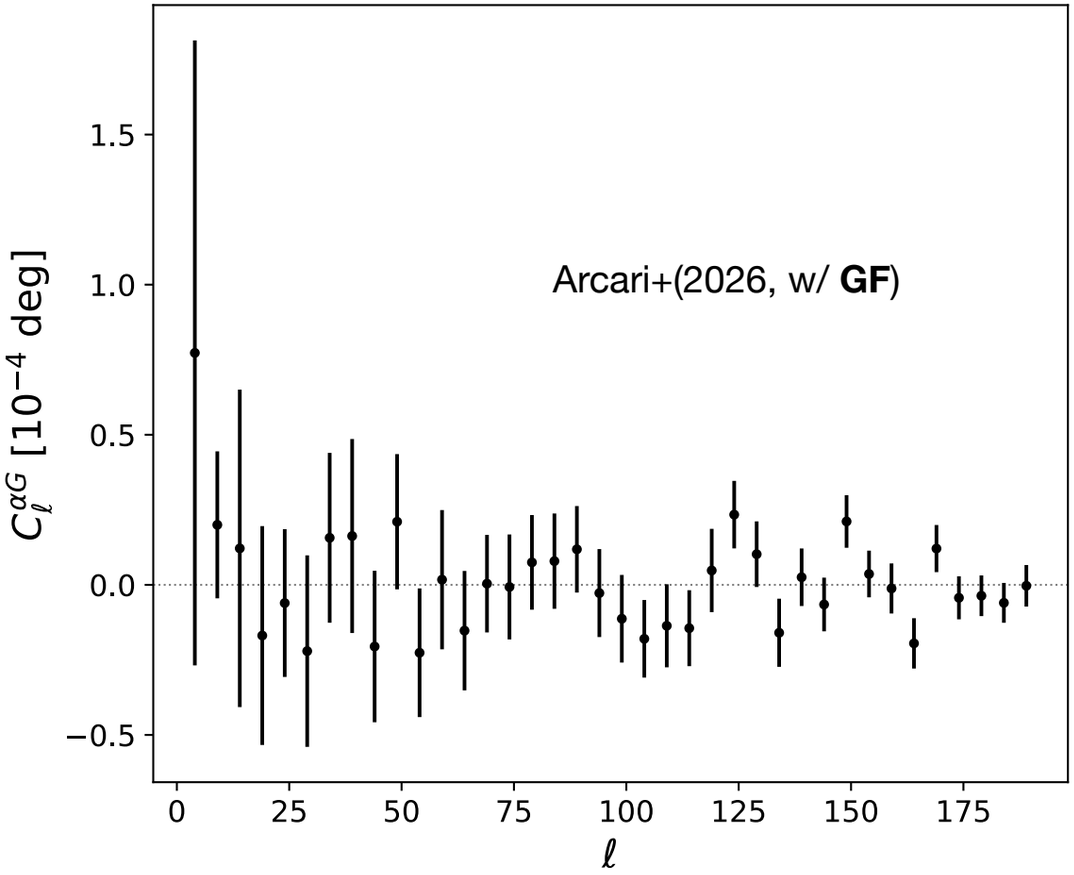
Cross-correlation with cosmic birefringence

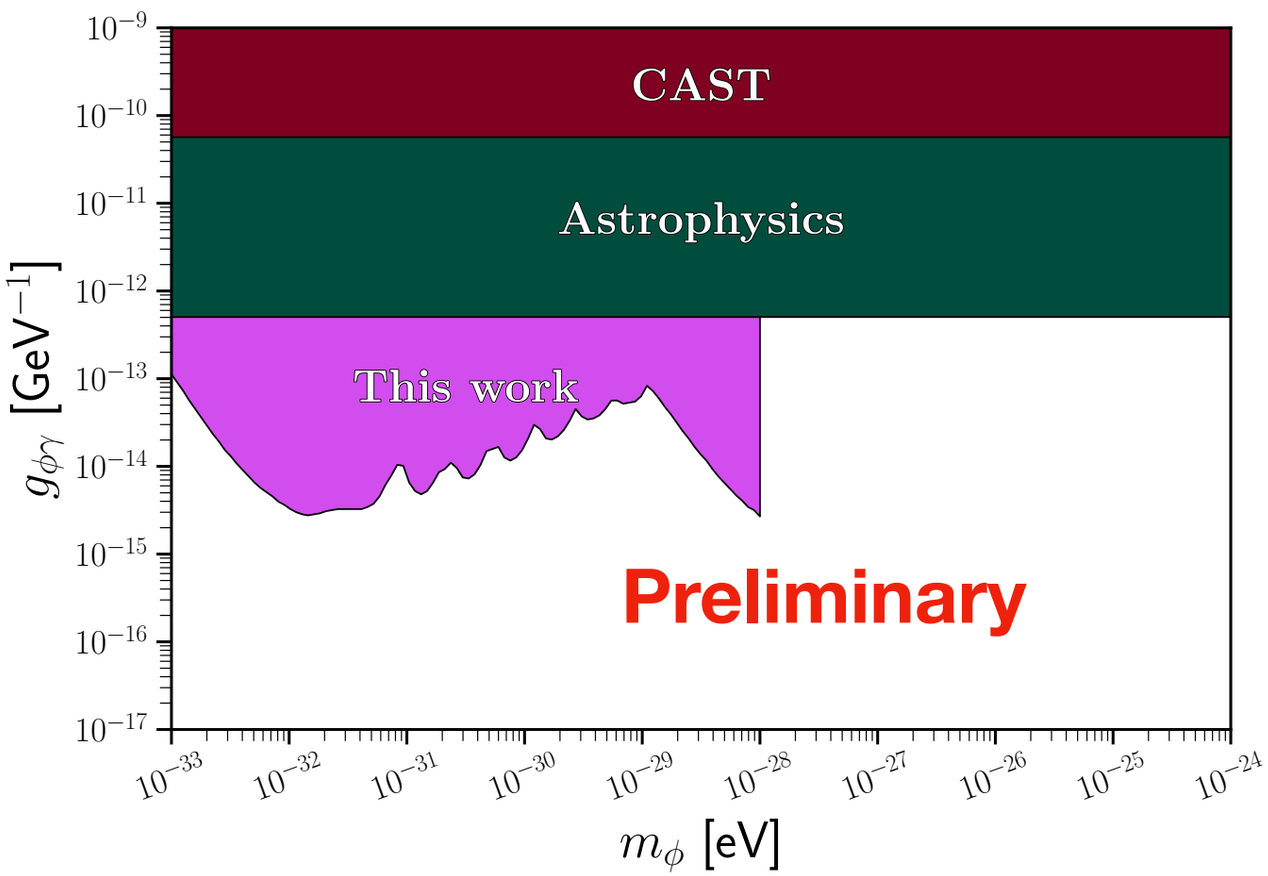
- Presence of axion like coupling can generate cosmic birefringence

$$\mathscr{L} \supset -\frac{1}{2} g^{\mu\nu} \partial_\mu \phi \, \partial_\nu \phi - V(\phi) - \frac{1}{4} g_{\phi\gamma} \, \phi \, F_{\mu\nu} \tilde{F}^{\mu\nu} \quad \longrightarrow \quad Q \pm iU \to e^{\mp 2i\alpha(\hat{\mathbf{n}})} (Q \pm iU)$$

- $\alpha(\hat{\mathbf{n}})$ can be reconstructed with quadratic estimators and correlated with matter tracers.

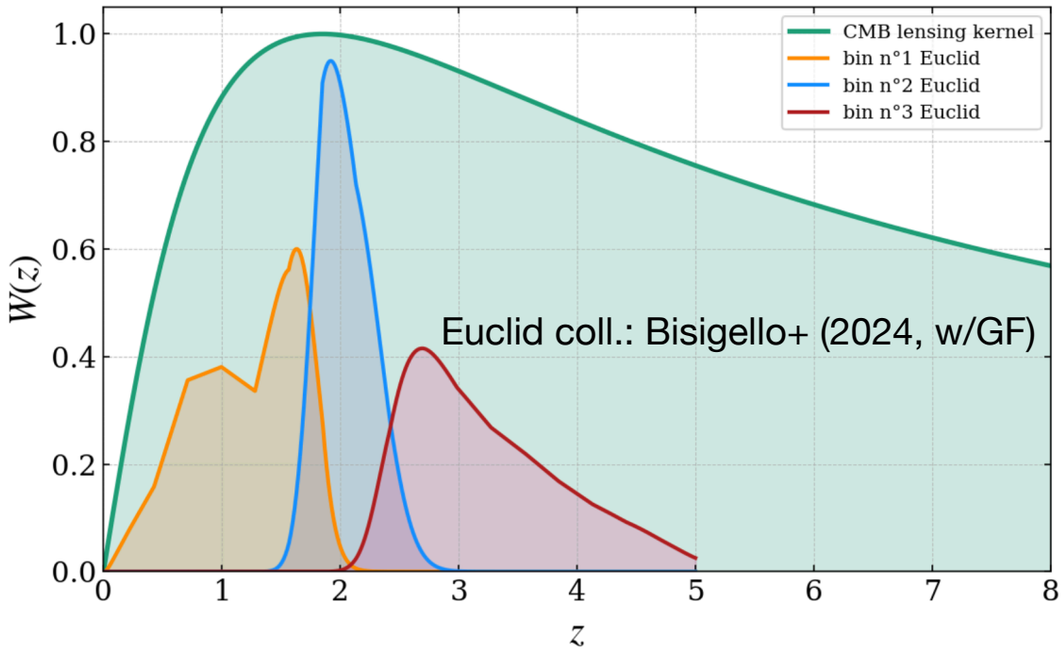
$$\delta\phi'' + 2\mathscr{H}\,\delta\phi' + \left(k^2 + a^2 \frac{d^2V}{d\bar{\phi}^2}\right)\delta\phi = -\frac{1}{2} h' \bar{\phi}' \qquad \Delta^{\alpha}_{\ell}(k) = g_{\phi\gamma} \int_0^{\tau_0} \mathrm{d}\tau \; g(\tau) T_{\delta\phi}(\tau, k) j_\ell \left[k(\tau_0 - \tau)\right]$$

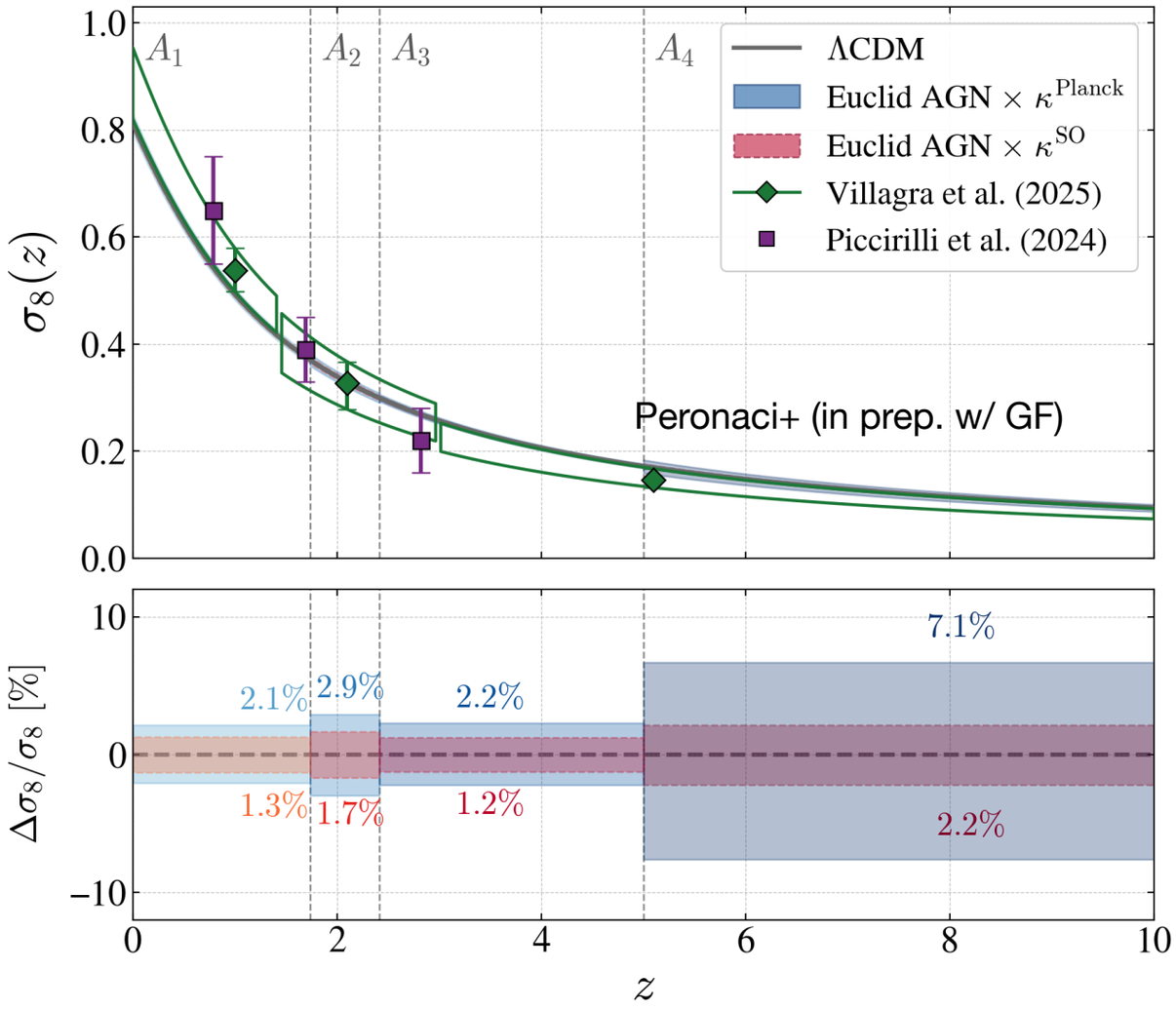


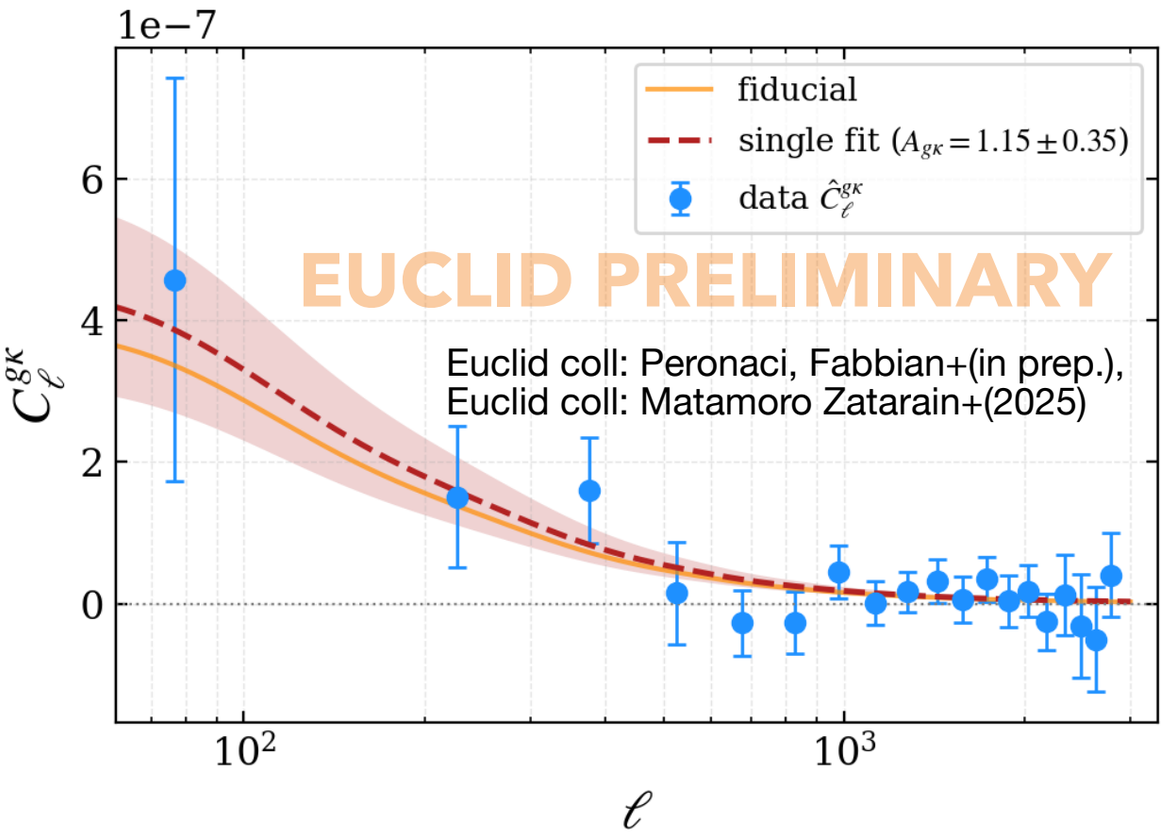


Euclid as synergy machine: QSOs

- Photometric AGN/QSOs (30M expected DR3):
  - $\sigma_8(z=7)$ at 2% w/ $\kappa g + gg + \kappa\kappa$
  - $\sigma(f_{\rm NL}) \sim 2$
- $\kappa g + gg$ from Q1 AGNs: signal detected ad $3-4\sigma$!

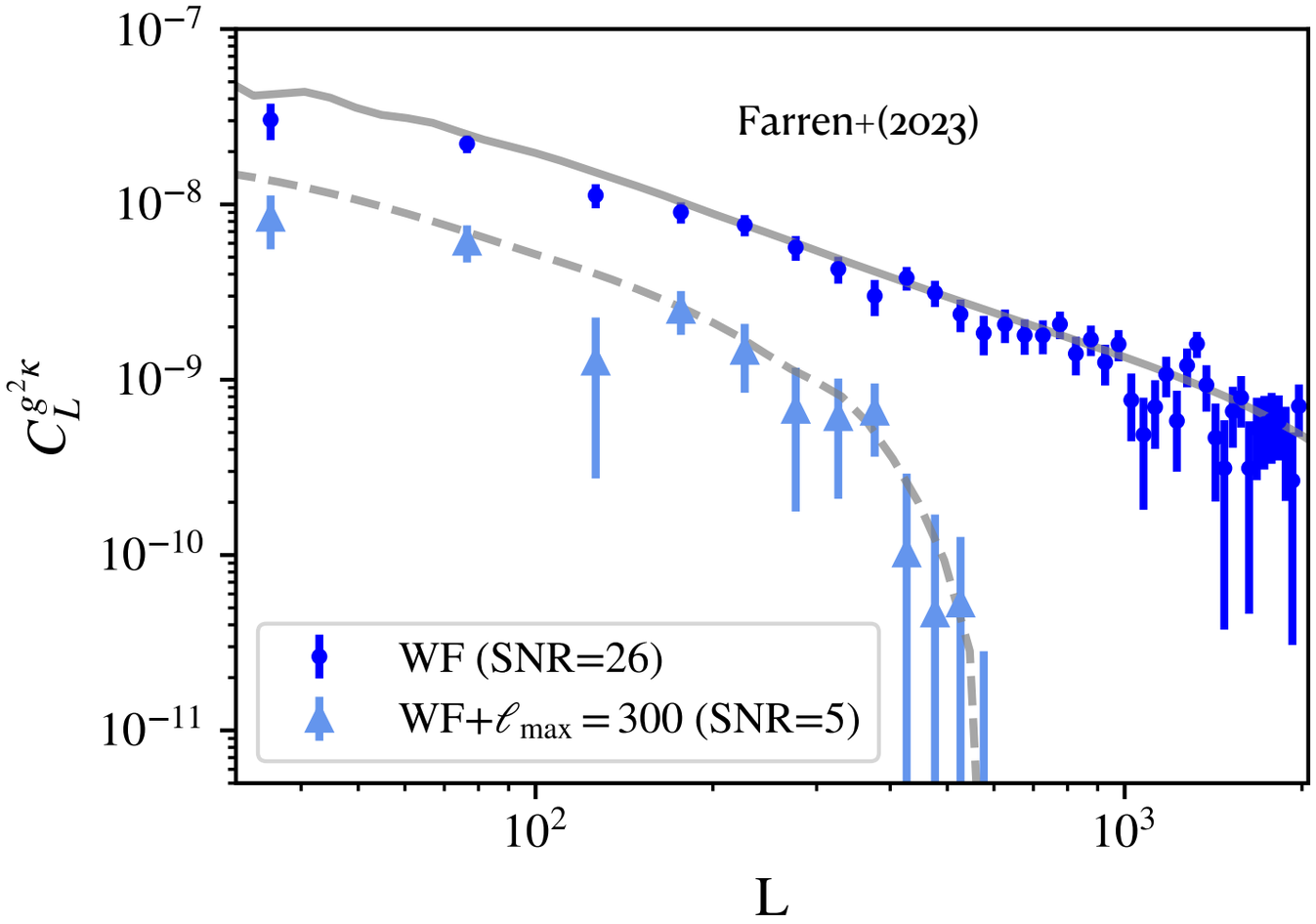


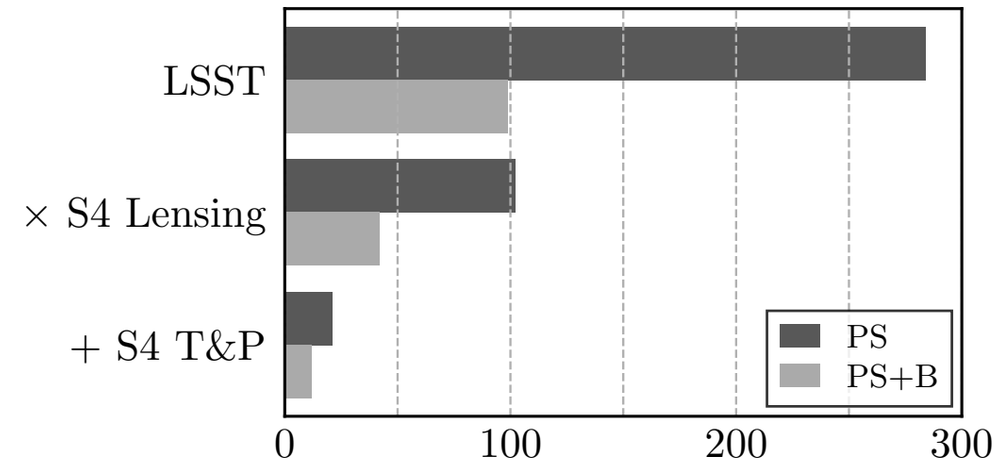


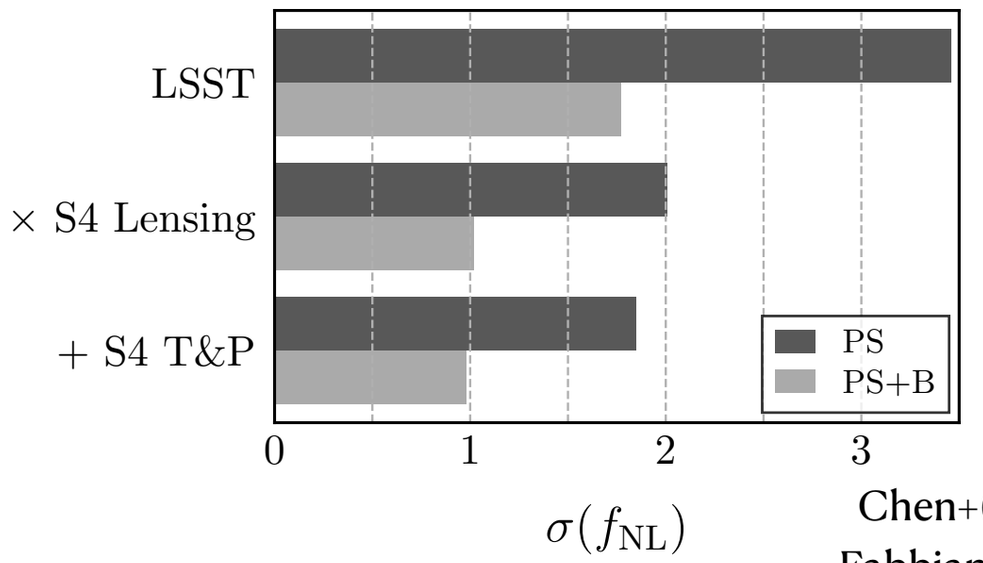


Higher-order cross-correlation

- Why limit to 2-point correlation functions….
- $\langle \kappa\kappa g \rangle$, $\langle \kappa g g \rangle$: great tools to reduce errors due to galaxy bias uncertainties.
- High-significant detections appeared very recently, hard to model…







Chen+(2023), Fabbian+(2019)

Conclusions

- Euclid is is a fantastic synergy machine.
- Exciting prospects for Euclid X CMB probes:
  - Promising cosmology results achieved in Q1.
  - With large number density and area come great responsibility: **A TON OF SALT** needed.
  - Ask me about kSZ if interested.
  - Upcoming DR1 will have >30σ C_ℓ^{kg} alone! BAO detection already has competitive results…
- Looking forward to Gaia DR4
  - New exciting constraints on primordial and late-time cosmology (and astrophysics).
- Stay tuned!



