UNIVERSITÉ DE GENÈVE

FNSNF SWISS NATIONAL SCIENCE FOUNDATION

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Legrand et al. 2020 A&A, 646 (2021) A109

Angular redshift fluctuations,

A new statistic to probe the dark sector

GALAXIES TRACE DARK MATTER

- Galaxies are biased tracers:

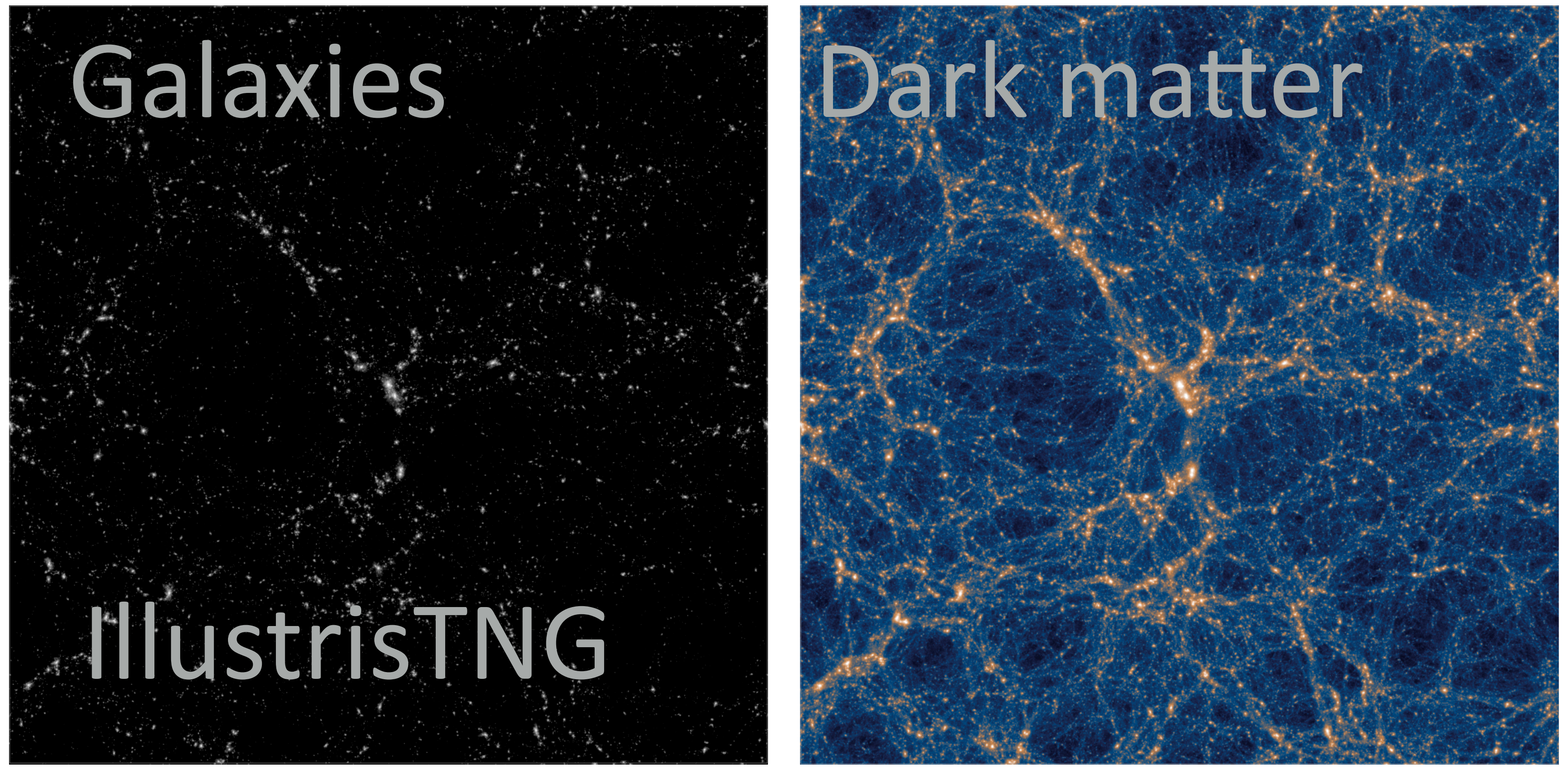
$$P_{\rm g}(k,z) = b_{\rm g}(z)\,P_{\rm m}(k,z)$$

- Observed redshift of galaxies:

$$z_{\rm obs}(z,\hat{\boldsymbol{n}}) = z + (1+z)\,\frac{\mathbf{v}(z,\hat{\boldsymbol{n}})\cdot\hat{\boldsymbol{n}}}{c}$$

Cosmological redshift (Hubble expansion)

Peculiar velocity (Doppler)

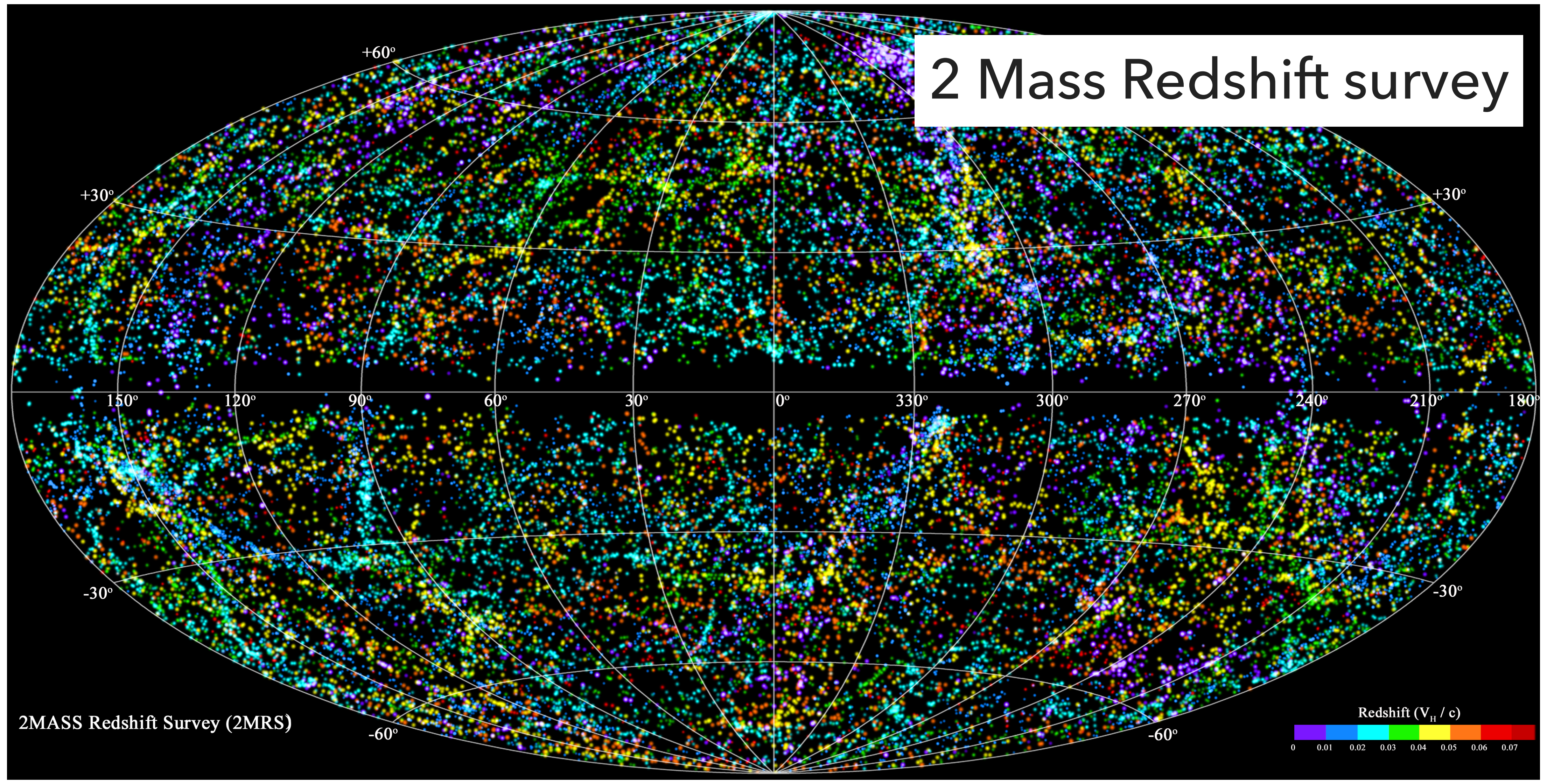


- Peculiar velocity:
  - Linked to the time derivative of the density field
  - Contains information about the growth of structures

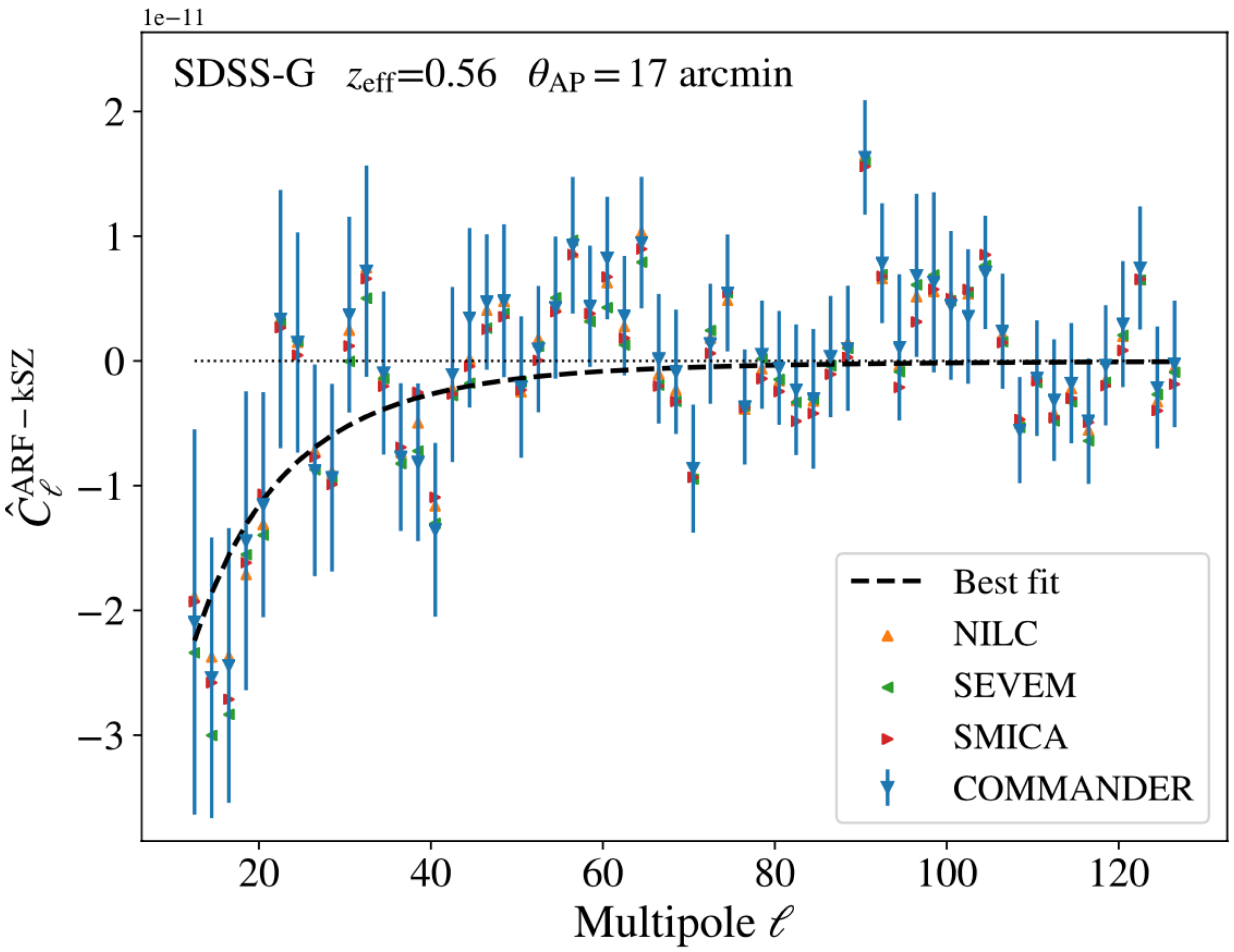
$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = 0$$

ANGULAR REDSHIFT FLUCTUATIONS

- Angular galaxy clustering (AGC):
  - Project 3D galaxy **density** field on a 2D map
- Angular redshift fluctuations (ARF):
  - Project 3D galaxy **redshift** field on a 2D map



CROSS CORRELATION OF ARF WITH KINETIC SZ



Chaves-Montero et al. 2019
arXiv:1911.10690

- Cross-correlates ARF from SDSS galaxies with Planck CMB maps
- 10 σ detection

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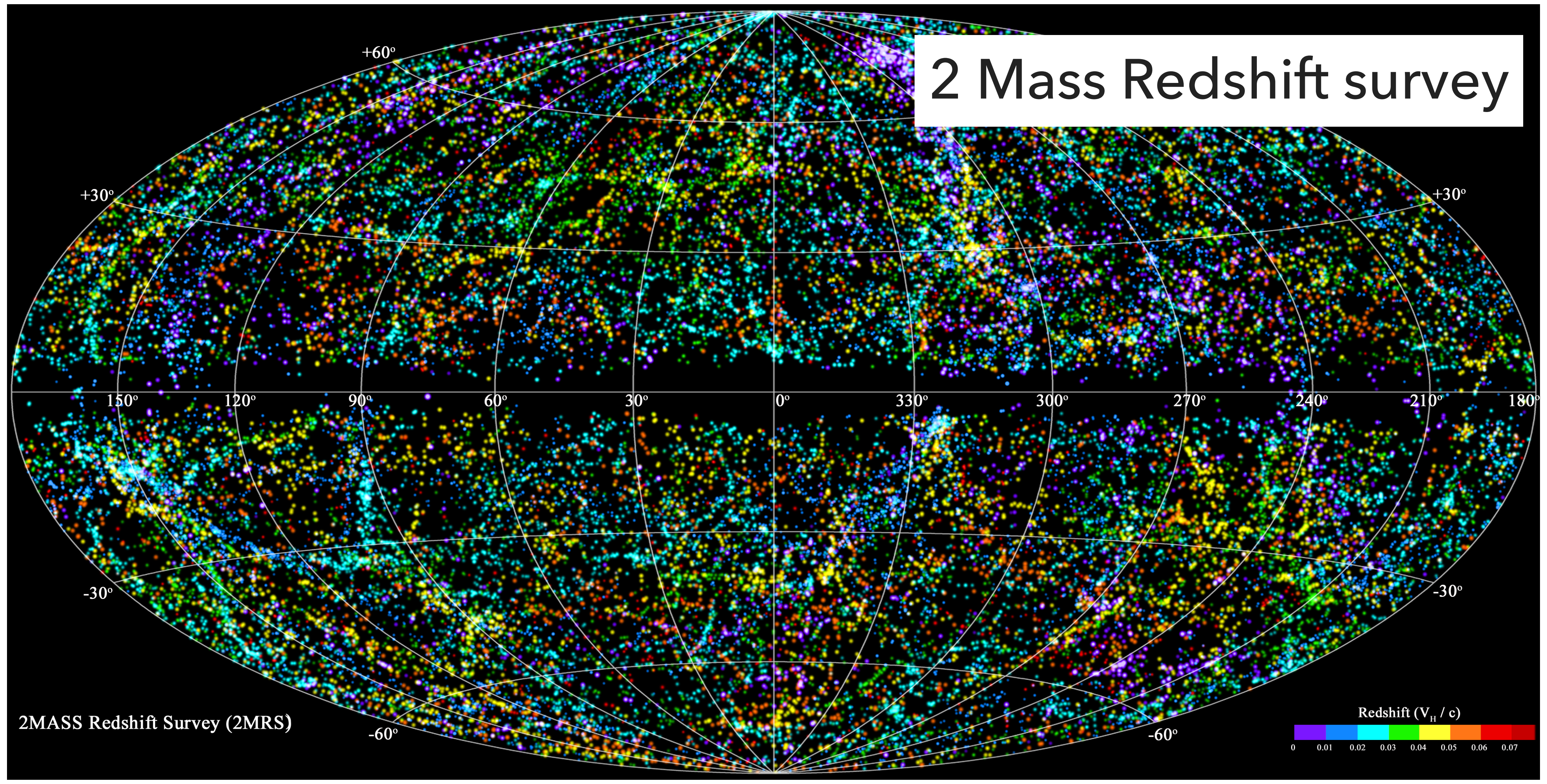


What are the advantages of combining AGC with ARF for cosmological analyses?

INTEREST OF PROBE COMBINATION

- Each probe has specific:
  - Cosmological degeneracies
  - Astrophysical degeneracies
  - Systematics uncertainties
- Combination
  - Breaks degeneracies
  - Decreases systematic uncertainties

Cross angular power spectrum is modelled by

$$C_\ell^{\alpha,\beta} = \frac{2}{\pi}\int_0^\infty dk k^2 P_{\rm m}(k)\Delta_\ell^\alpha(k)\Delta_\ell^\beta(k),$$

Matter power spectrum

Kernels specific to each observable

MODELLING THE ARF POWER SPECTRUM

Hernandez-Monteagudo et al. 2019
arXiv:1911.12056

Angular power spectrum: $C_\ell^{\alpha,\beta} = \frac{2}{\pi}\int_0^\infty dk k^2 P_{\mathrm{m}}(k)\Delta_\ell^\alpha(k)\Delta_\ell^\beta(k)$

Kernels, sum of density and peculiar velocity contributions : $\Delta_\ell^{\delta_z} = \Delta_\ell^{\delta_z}|_{\delta_m} + \Delta_\ell^{\delta_z}|_{v_{los}}$

No Limber approximation

galaxy bias   growth factor

density: $\Delta_\ell^z|_\delta(k) = \frac{1}{N}\int \mathrm{d}V\, \bar{n}_{\mathrm{g}}(z)\, W(z)\, b_{\mathrm{g}}(z)\, D(z)\, (z-\bar{z})\, j_\ell(k\, r(z))$

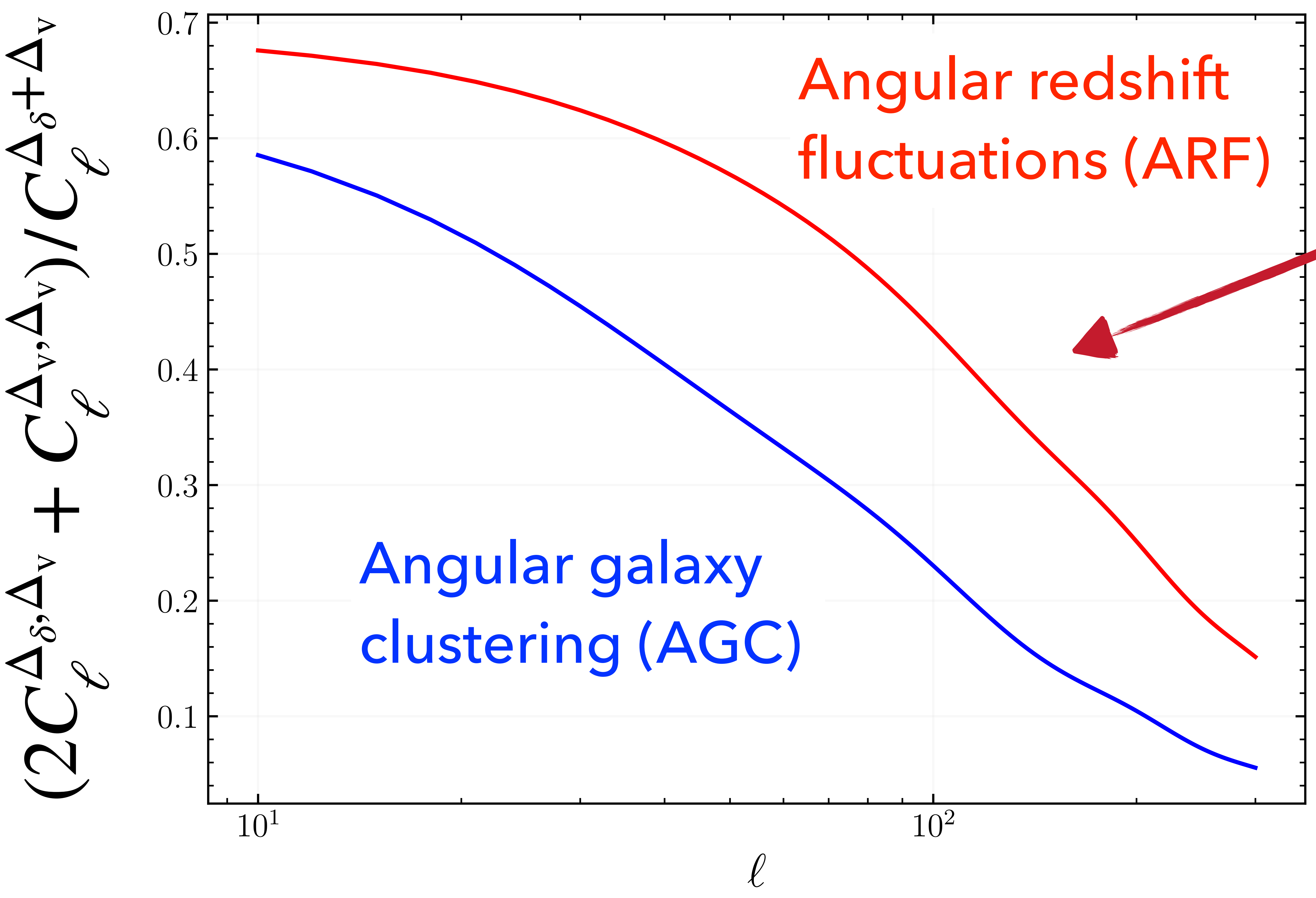
Terms specific to ARF

velocity: $\Delta_\ell^z|_{\mathrm{v}}(k) = \frac{1}{N}\int \mathrm{d}V\, \bar{n}_{\mathrm{g}}(z)\, W(z)\, (1+z)\, H(z)\frac{\mathrm{d}D}{\mathrm{d}z}\left[1 + (z-\bar{z})\frac{\mathrm{d}\ln W}{\mathrm{d}z}\right]\frac{j_\ell'(k\, r(z))}{k}$

No galaxy bias

SENSITIVITY TO PECULIAR VELOCITIES

$$C_\ell = C_\ell^{\Delta_\delta + \Delta_\mathrm{v}} = C_\ell^{\Delta_\delta, \Delta_\delta} + 2C_\ell^{\Delta_\delta, \Delta_\mathrm{v}} + C_\ell^{\Delta_\mathrm{v}, \Delta_\mathrm{v}}$$

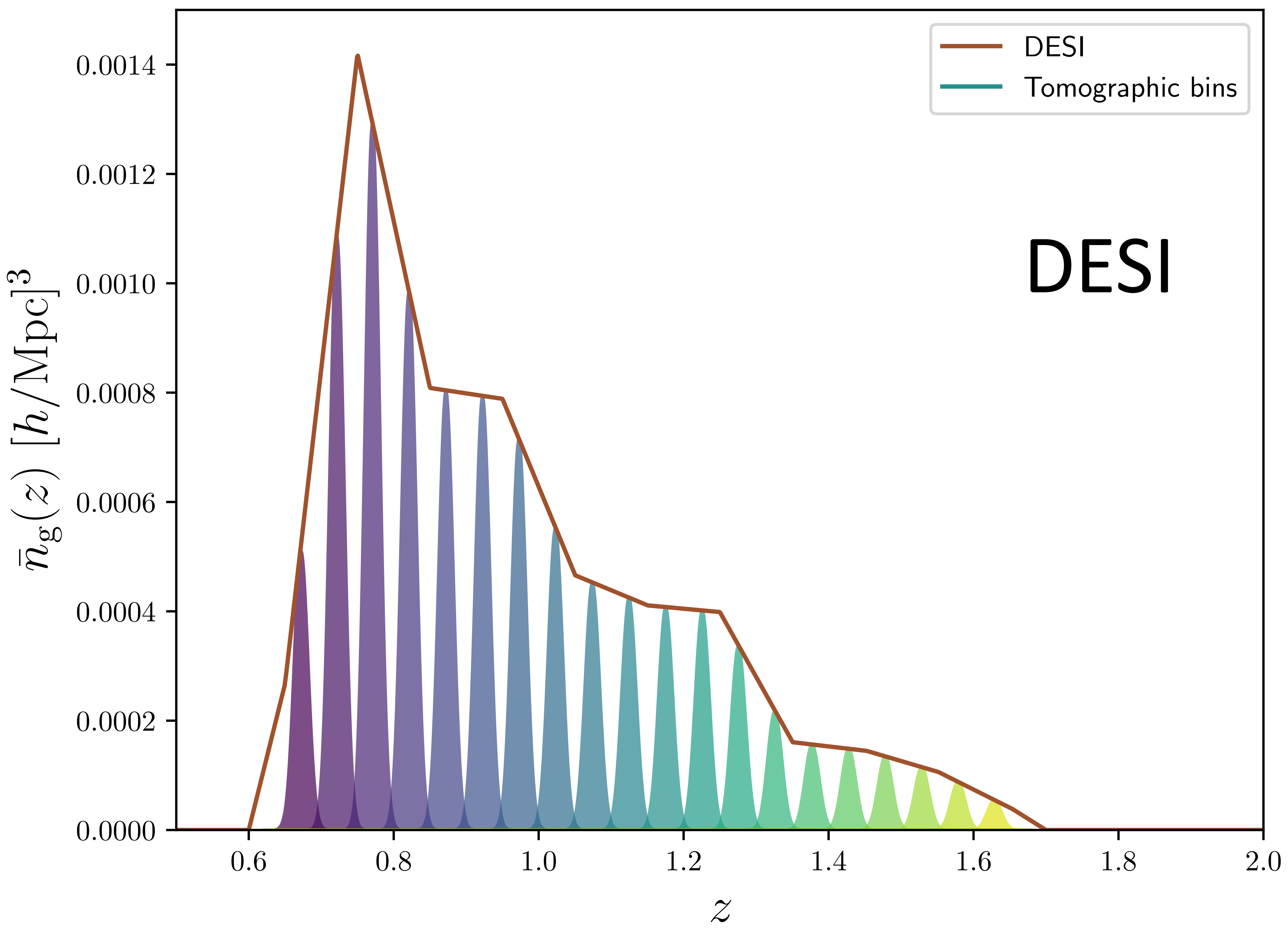


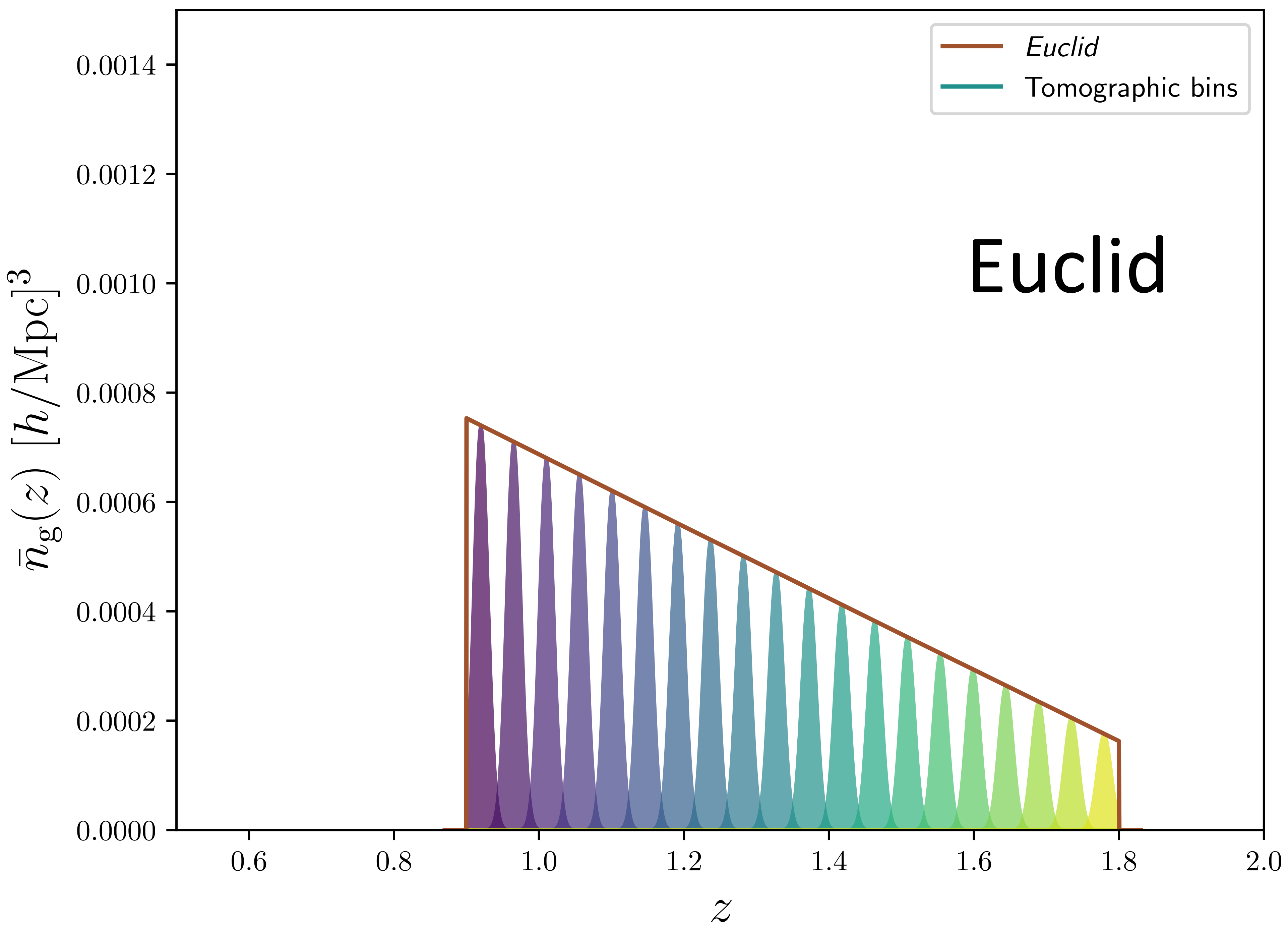
ARF and AGC have a different sensitivity to peculiar velocities

COSMOLOGICAL FORECASTS

Legrand et al. 2020 [A&A, 646 (2021) A109]

- Fisher forecast for two spectroscopic surveys: DESI and Euclid
- Tomographic analysis with 20 redshift bins with $\sigma_z = 0.01$
- Marginalise on 20 galaxy bias parameters (one for each bin)





FISHER FORMALISM

- Fisher formalism
  - Likelihood of parameters is a multivariate Gaussian
  - Survey properties (sky fraction, noise resolution, redshift distribution)
- Assume gaussian covariance between the probes:

$$\mathrm{Cov}_\ell\left(C_\ell^{\alpha,\beta}, C_\ell^{\gamma,\delta}\right) = \frac{1}{(2\ell+1)f_{\mathrm{sky}}} \times \left[\left(C_\ell^{\alpha,\gamma} + \delta_\gamma^\alpha N_\ell^\alpha\right)\left(C_\ell^{\beta,\delta} + \delta_\delta^\beta N_\ell^\beta\right)\left(C_\ell^{\alpha,\delta} + \delta_\delta^\alpha N_\ell^\alpha\right)\left(C_\ell^{\beta,\gamma} + \delta_\gamma^\beta N_\ell^\beta\right)\right]$$

- Assume each multipole is independent

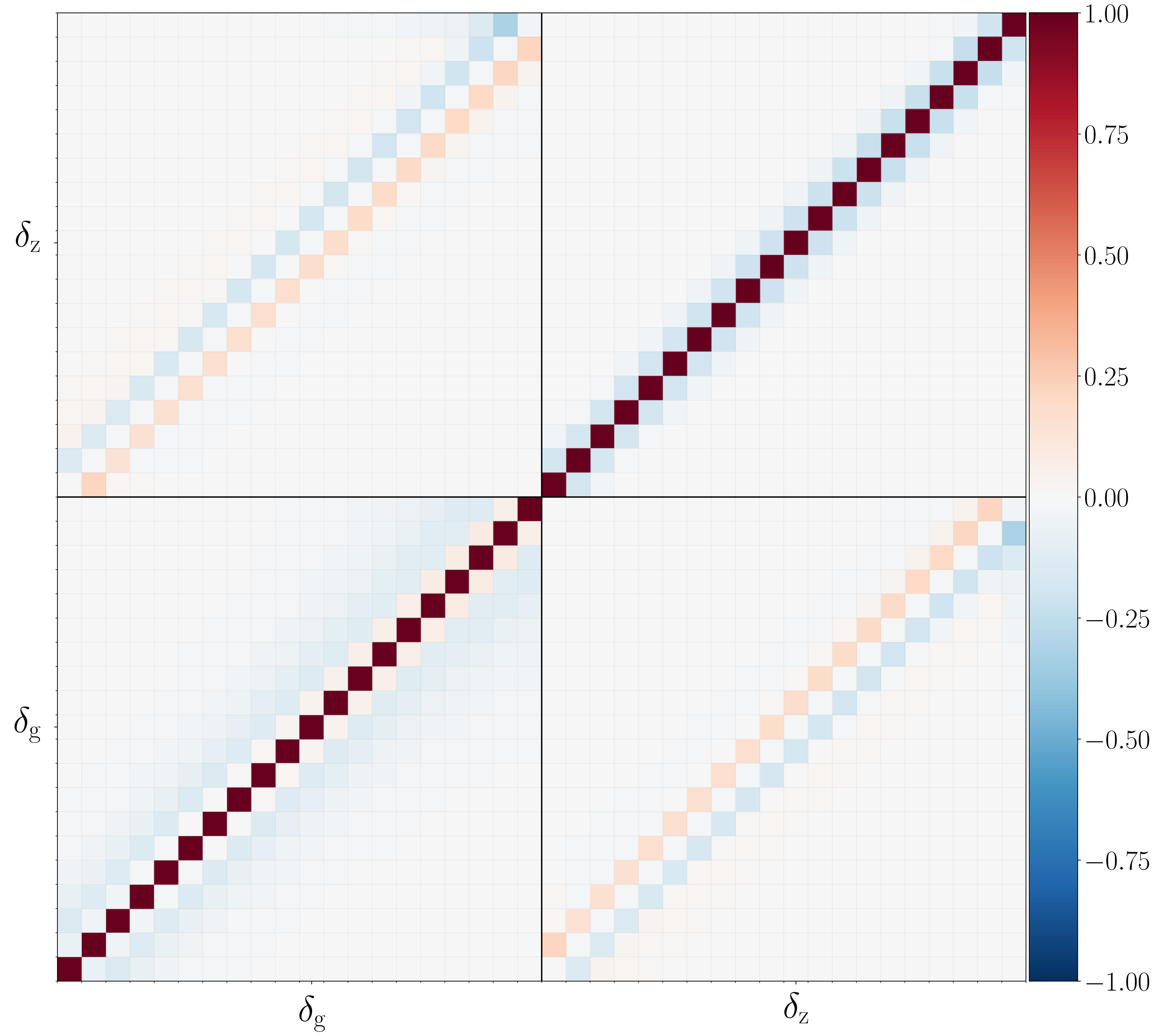
$$F_{i,j} = \sum_\ell \frac{\partial C_\ell}{\partial \lambda_i} \mathrm{Cov}_\ell^{-1} \frac{\partial C_\ell}{\partial \lambda_j}$$

Parameters of the model

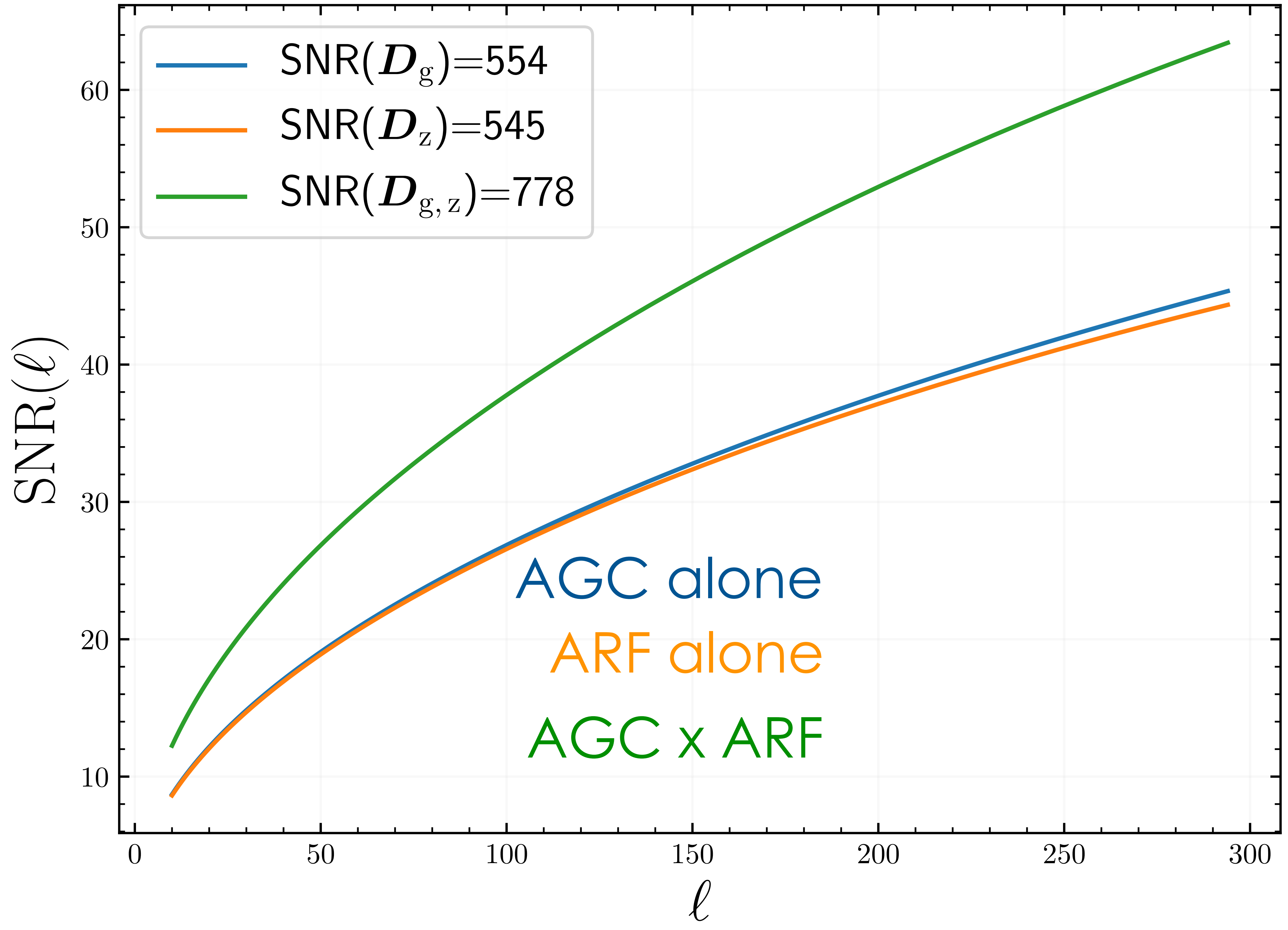
CORRELATION BETWEEN ARF AND AGC

ARF

AGC



AGC ARF

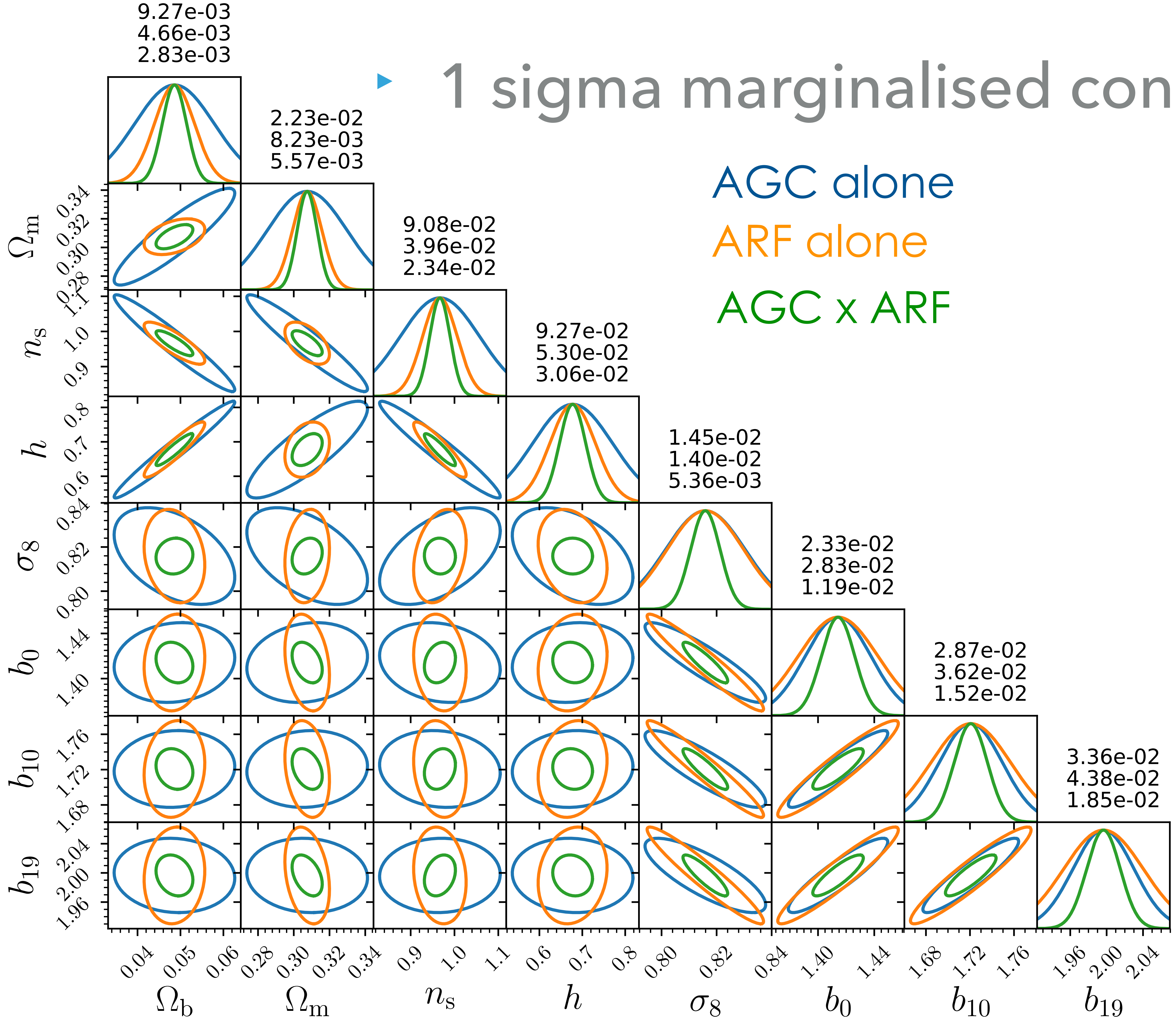


$$\mathrm{SNR}(\ell) = \sqrt{C_\ell \, \mathrm{Cov}_\ell^{-1} \, C_\ell}$$

Correlation matrix in a Euclid-like survey at ell=10

MARGINALISED CONSTRAINTS

Legrand et al. 2020 A&A, 646 (2021) A109



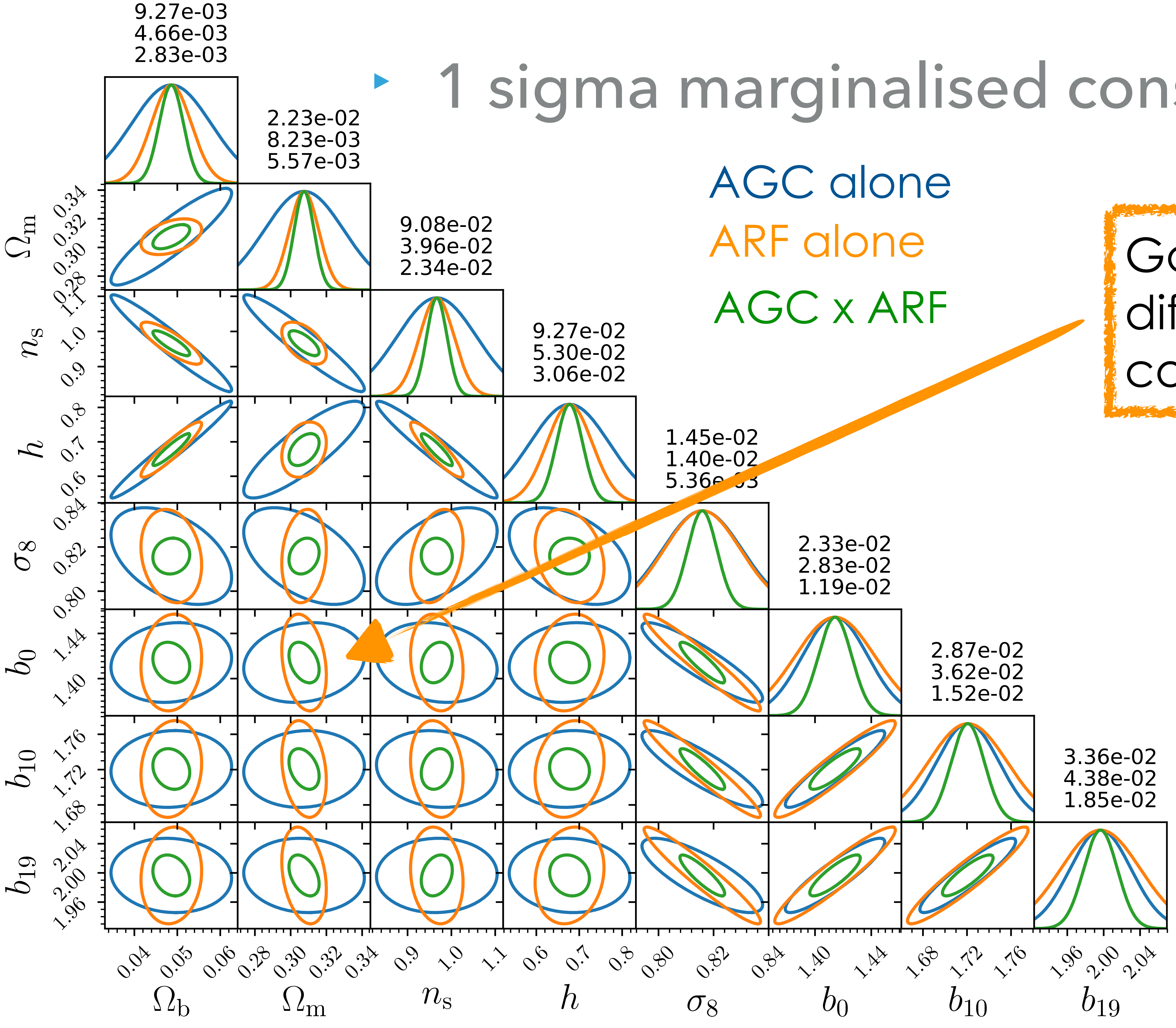
- 1 sigma marginalised constraints for a Euclid like survey

AGC alone

ARF alone

AGC x ARF

MARGINALISED CONSTRAINTS



- 1 sigma marginalised constraints for a Euclid like survey

AGC alone

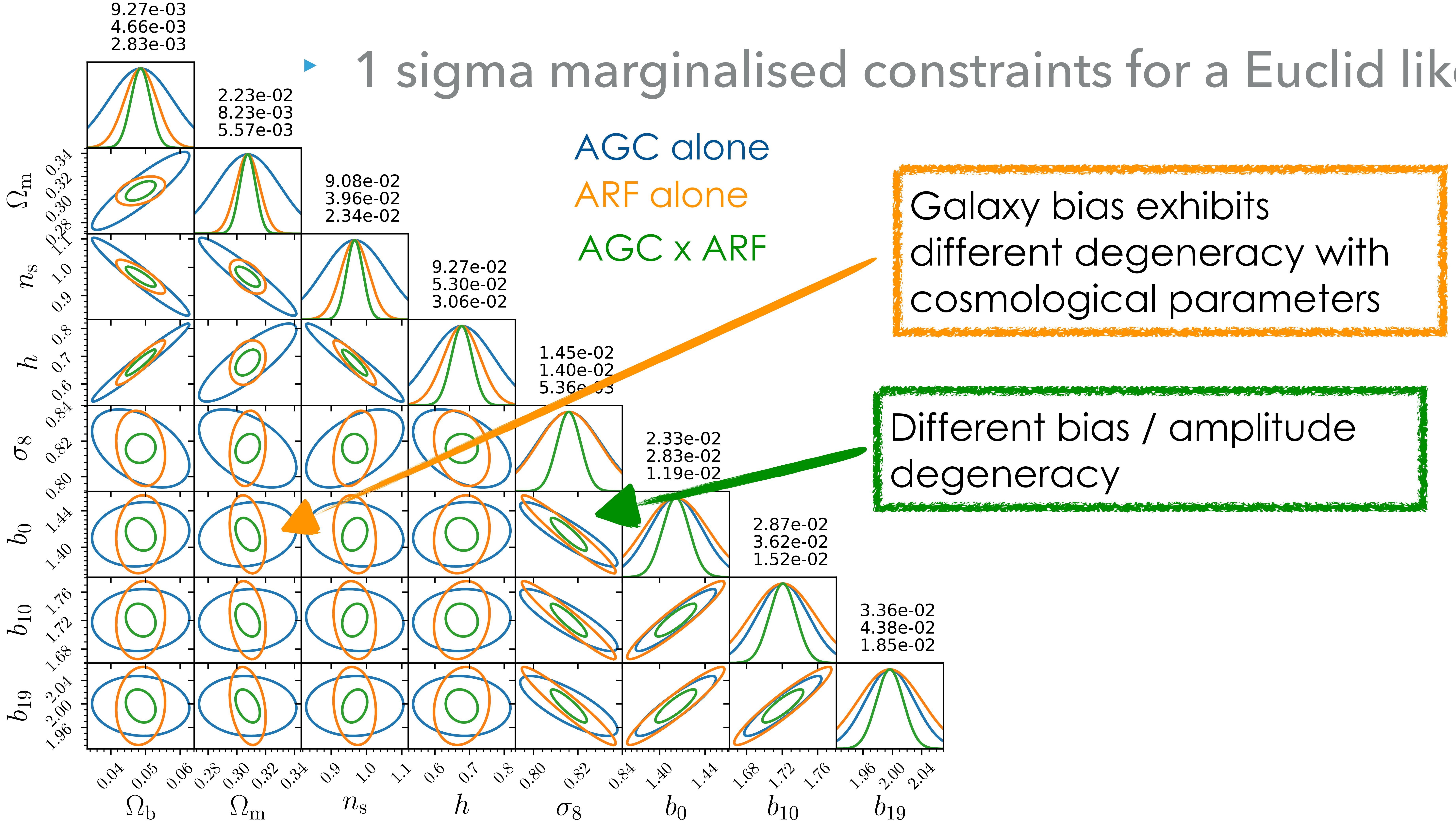
ARF alone

AGC x ARF

Galaxy bias exhibits different degeneracy with cosmological parameters

MARGINALISED CONSTRAINTS

- 1 sigma marginalised constraints for a Euclid like survey



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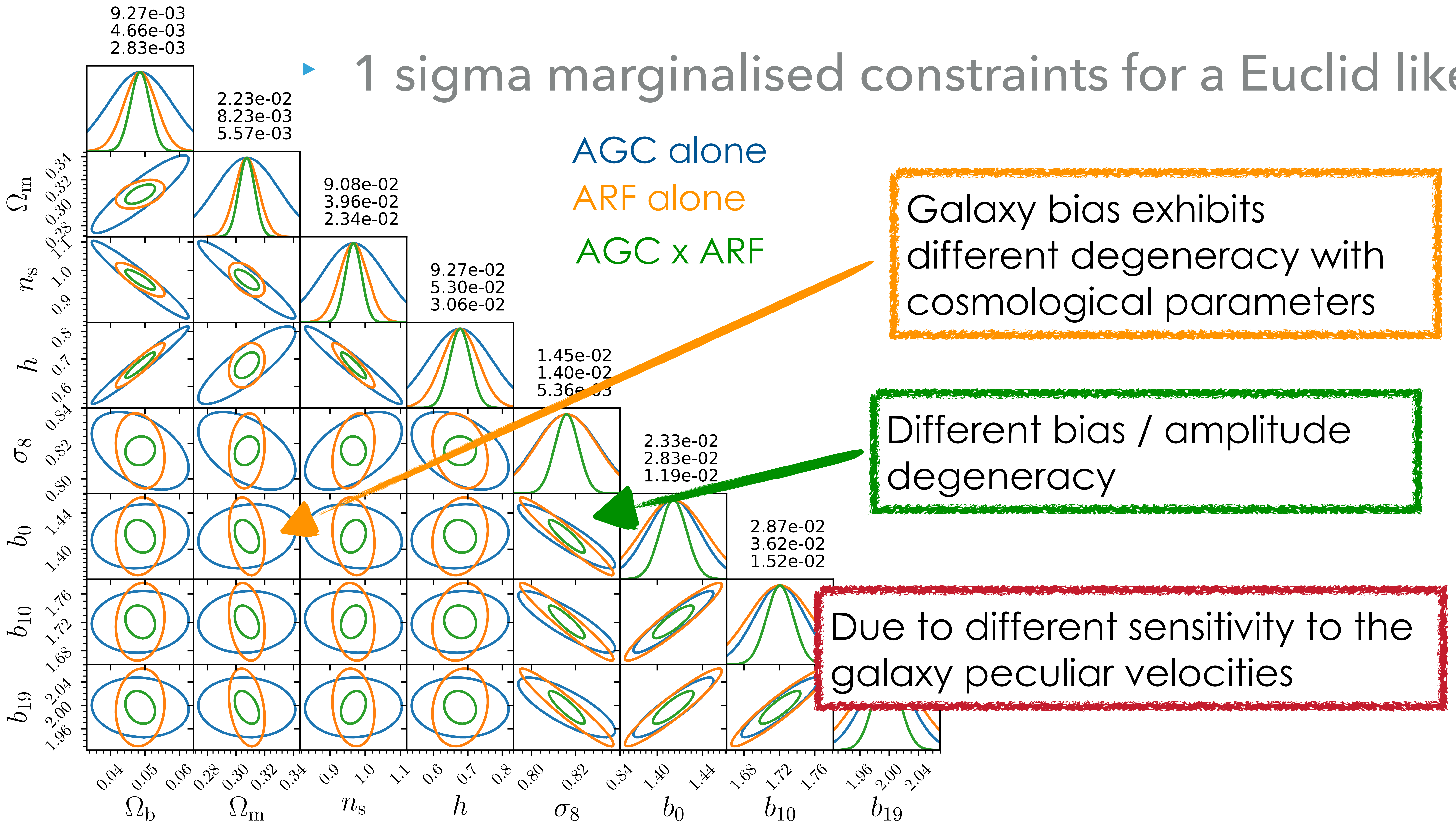
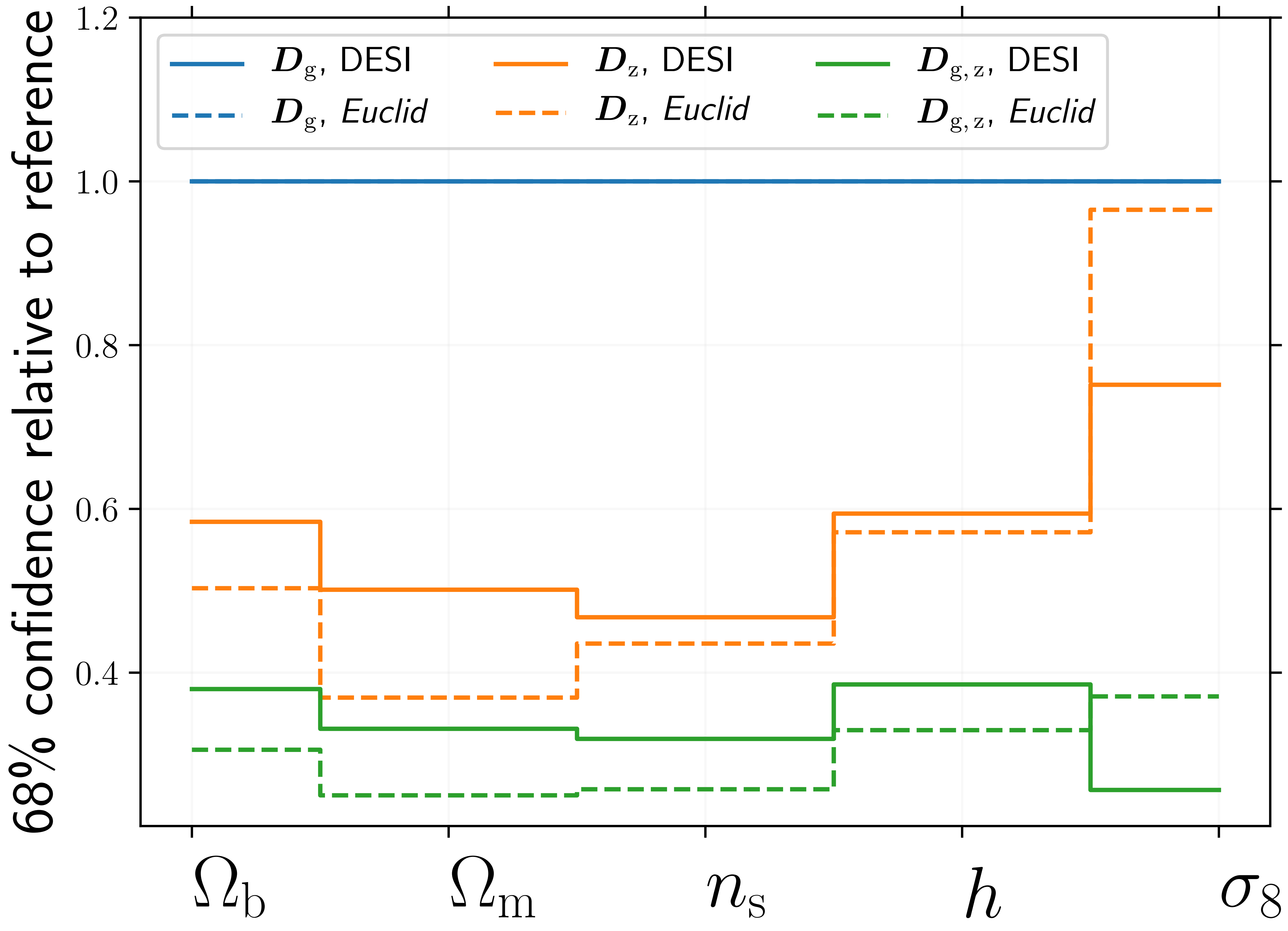


IMPROVEMENT OF CONSTRAINTS



AGC

ARF

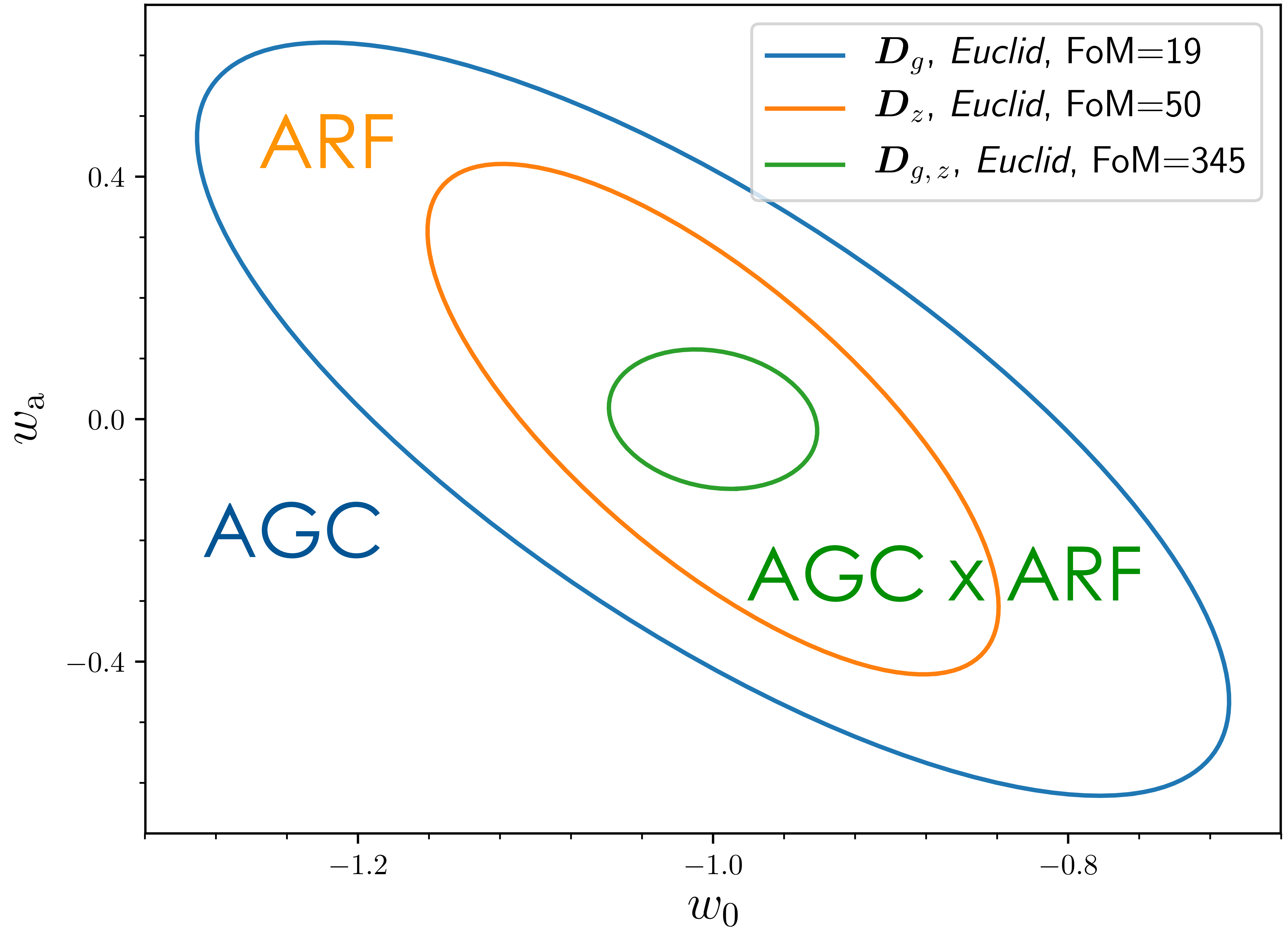
AGC x ARF

Factor 2.5 improvement

Legrand et al. 2020 arXiv:2007.14412

DARK ENERGY EQUATION OF STATE EVOLVE WITH TIME

- Assuming CPL parametrisation: $w(z) = w_0 + \frac{z}{1+z} w_a$



Factor 4 improvement on each DE parameters

Legrand et al. 2020 arXiv:2007.14412

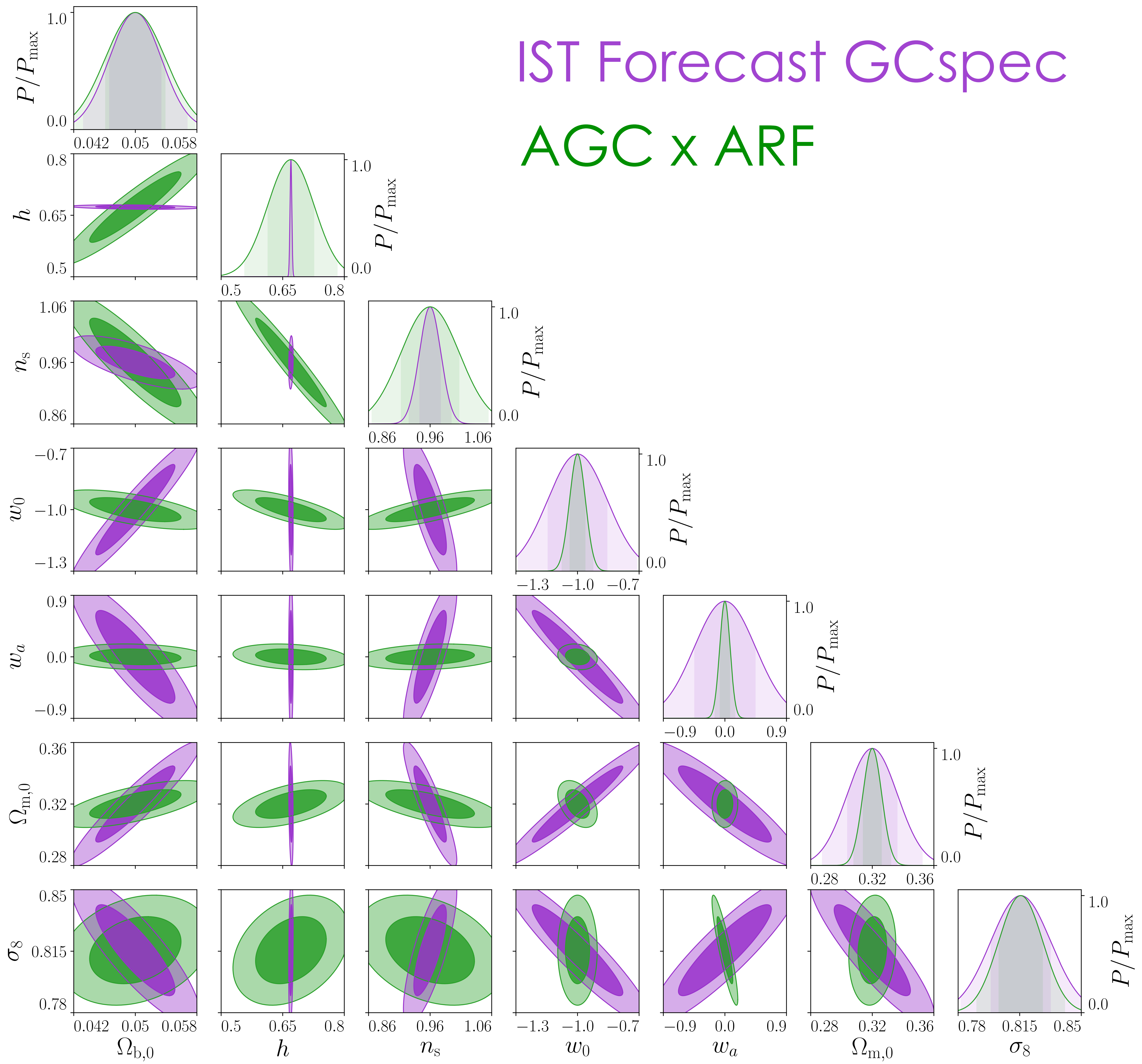
COMPARING TO GC SPECTROSCOPIC

Euclid collaboration et al 2020, arXiv:1910.09273

- Euclid IST:Forecast Fisher matrix
- GC spectroscopic
- Rough comparison (not same scale cuts, non-linear modelling, not same marginalised parameters…)

- P(k) much better to measure H0
- ARFxAGC better at constraining w0-wa
- Similar constraints on other parameters

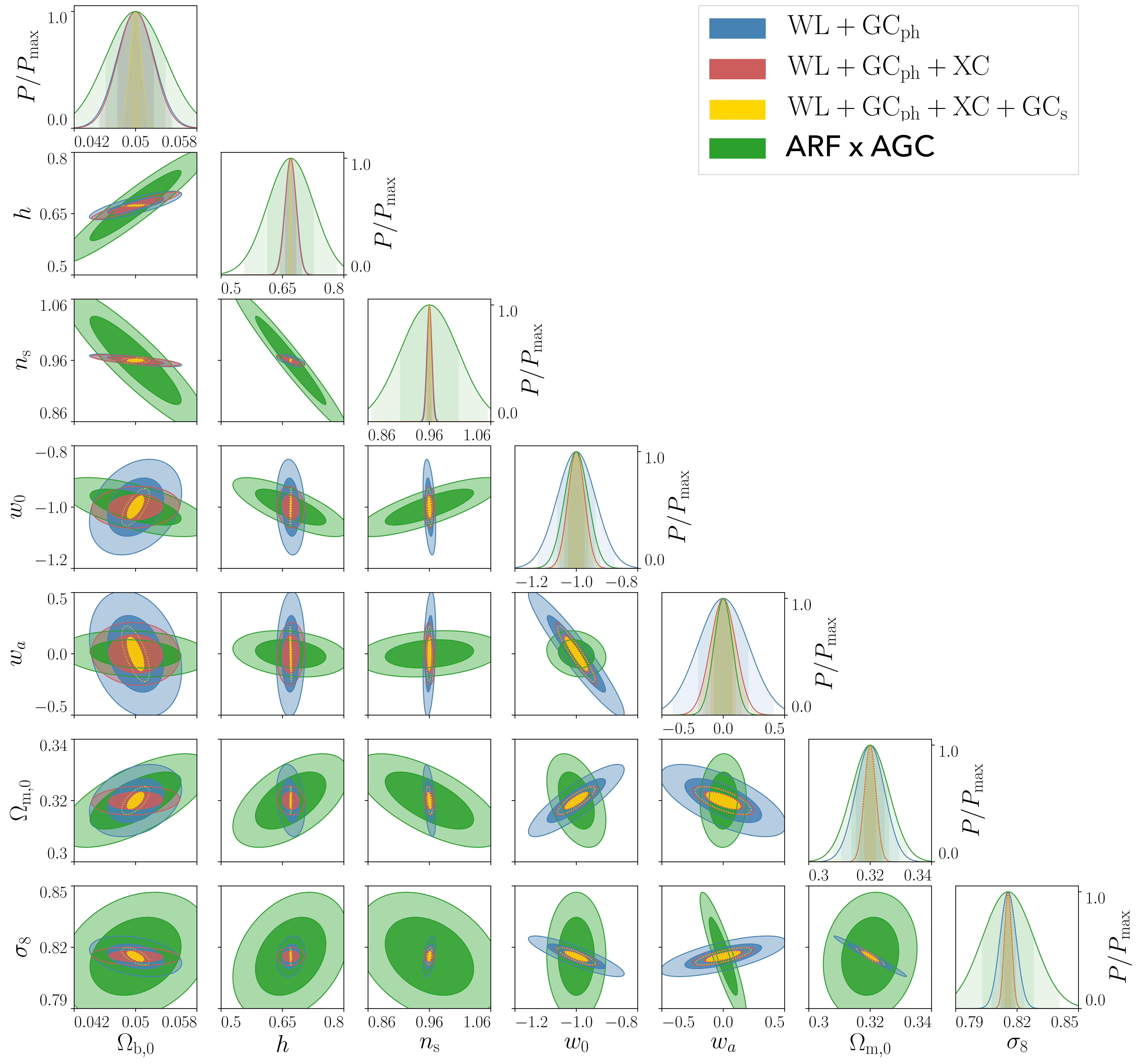
- Starting point to combine galaxy spectroscopic and photometric sample



COMPARING TO WL

- Euclid forecast analysis, WL + GCph + XC
- Neglecting correlations between spectroscopic and photometric samples

- ARFx AGC only on spectroscopic sample
- Seems we can break degeneracies for w0-wa by combining with WL and GCphot



SUMMARY

- Angular redshift fluctuations:
  - Different sensitivity to peculiar velocities than AGC
  - Different degeneracies with galaxy bias parameters
  - Degeneracies broken when combined with AGC
  - Improve constraints by a factor 2.5, and up to 5 on DE EoS parameters
- Next steps:
  - Extended models: Massive neutrinos, modified gravity models
  - Fair comparison with Euclid forecasts, including cross correlation with WL and GC phot to
  - Could help to solve issue of combining spectro and photo samples
  - More realistic framework:
    - non linearities
    - higher order covariances
    - more systematics parameters