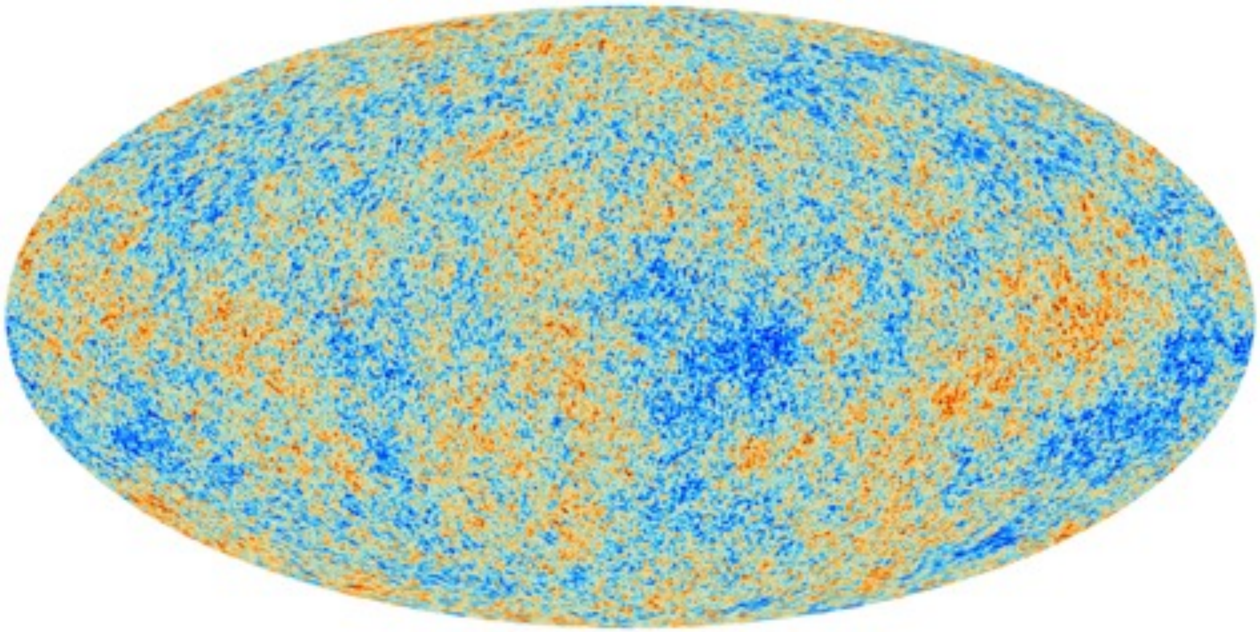
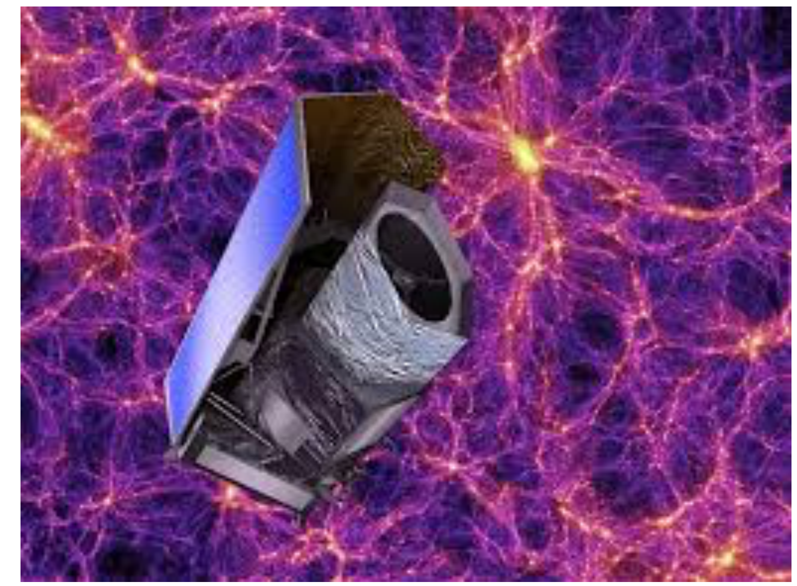
Update on cosmological parameters forecasts from a joint 2D tomographic analysis of CMB and galaxy clustering and beyond





J. R. Bermejo-Climent, M. Ballardini, F. Finelli, D. Paoletti

INAF OAS Bologna
INFN Bologna

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INAF ISTITUTO NAZIONALE DI ASTROFISICA
OSSERVATORIO DI ASTROFISICA E SCIENZA DELLO SPAZIO DI BOLOGNA

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Aims

Methodological research project based on the standard Fisher approach with two main aims:

- Which cosmological parameters constraints one can obtain from CMBXC with galaxy clustering

- What CMBXC can add to the combination of CMB in terms of cosmological constraints in a 2D tomographic approach

CMB includes lensing (S/N much larger than TG, EG)

Room to limit ourselves to galaxy clustering as matter fields as a first step, galaxy shear could be inserted as a second step (a lot of work already done in this direction).

Timeline

Application to CMB surveys completed or ongoing or in preparation or concepts rather than completely idealistic specifications.

After the contribution to IST forecasts this project took some shape

- Specifications for Planck-like survey inherited from our work for IST *
- (Some) Extended cosmological models identified
- First application to Euclid spectroscopic and photometric surveys
- First snapshot of preliminary results (separately for spectroscopic and photometric Euclid surveys) presented last year in the Orsay meeting
- Update and consolidation of results presented in Ferrara last October including the extension to non-Euclid galaxy surveys
- Results successfully compared with previous ones on the literature

* We are not part of the IST forecast paper

Cosmological models

- So far, three 2-parameter ΛCDM extensions have been preliminarily considered. These are studied separately and jointly
  - Dynamical dark energy (w_0, w_a)
  - Neutrino physics (Σm_ν, $N_{\rm eff}$)
  - Primordial universe ($d\, n_s/d \ln k$, $f_{\rm NL}$)

CMB surveys

- **Planck-like**: we readapt the specifications of the 143 GHz channel in order to mimic the Planck 2018 TT+TE+EE constraints for the ΛCDM model. We inflate the noise in EE for $\ell < 30$ by a factor 8. We use $\ell_{max} = 1500$ for T,E.
  For lensing we use $8 < \ell < 400$ for $\phi\phi$, cut T and E according to the Planck real likelihood and reconstruct the noise using the 143 GHz and 217 GHz channels.

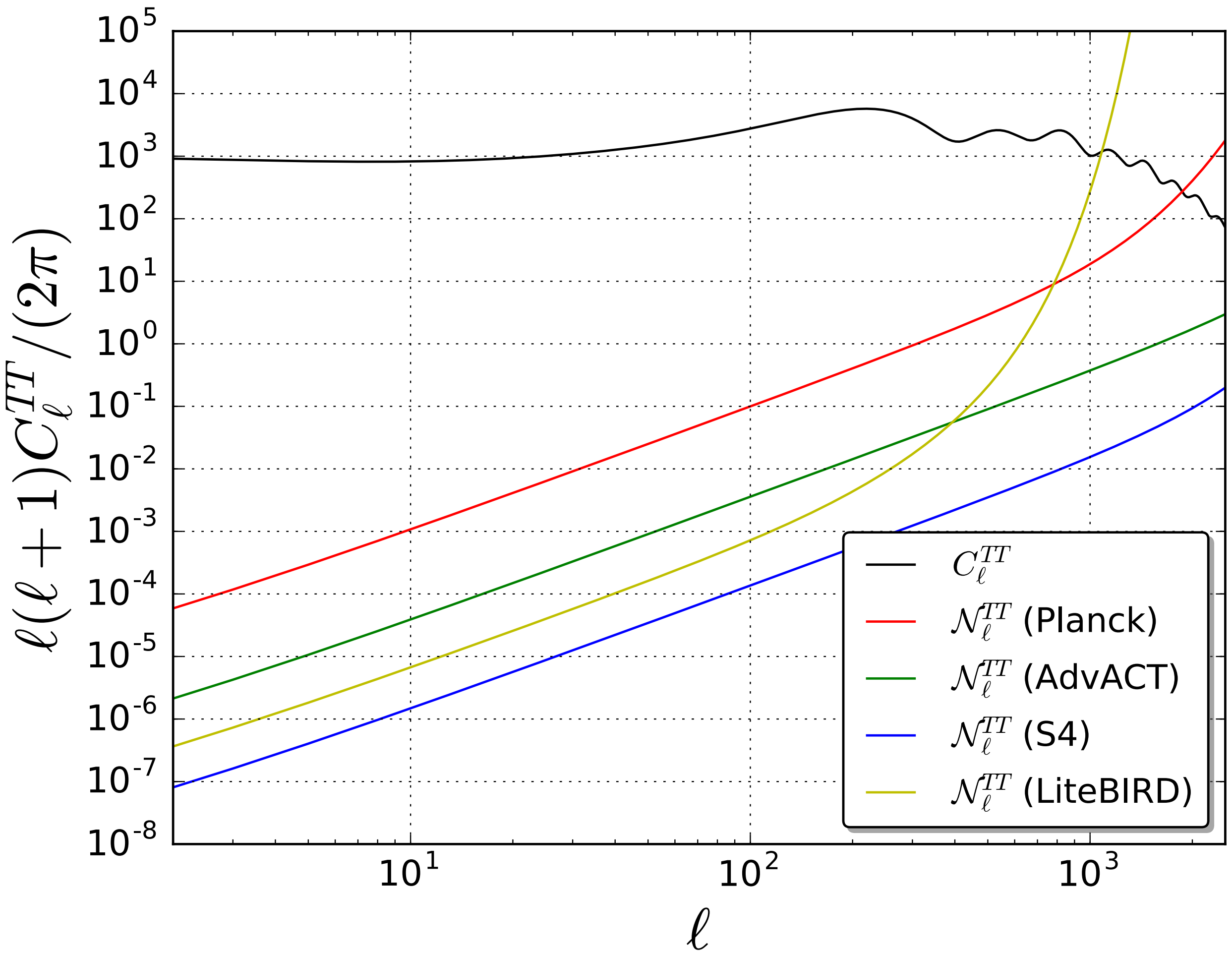
- **Advanced ACTpol (AdvACT)**, following the specifications by Henderson et al. (2015)

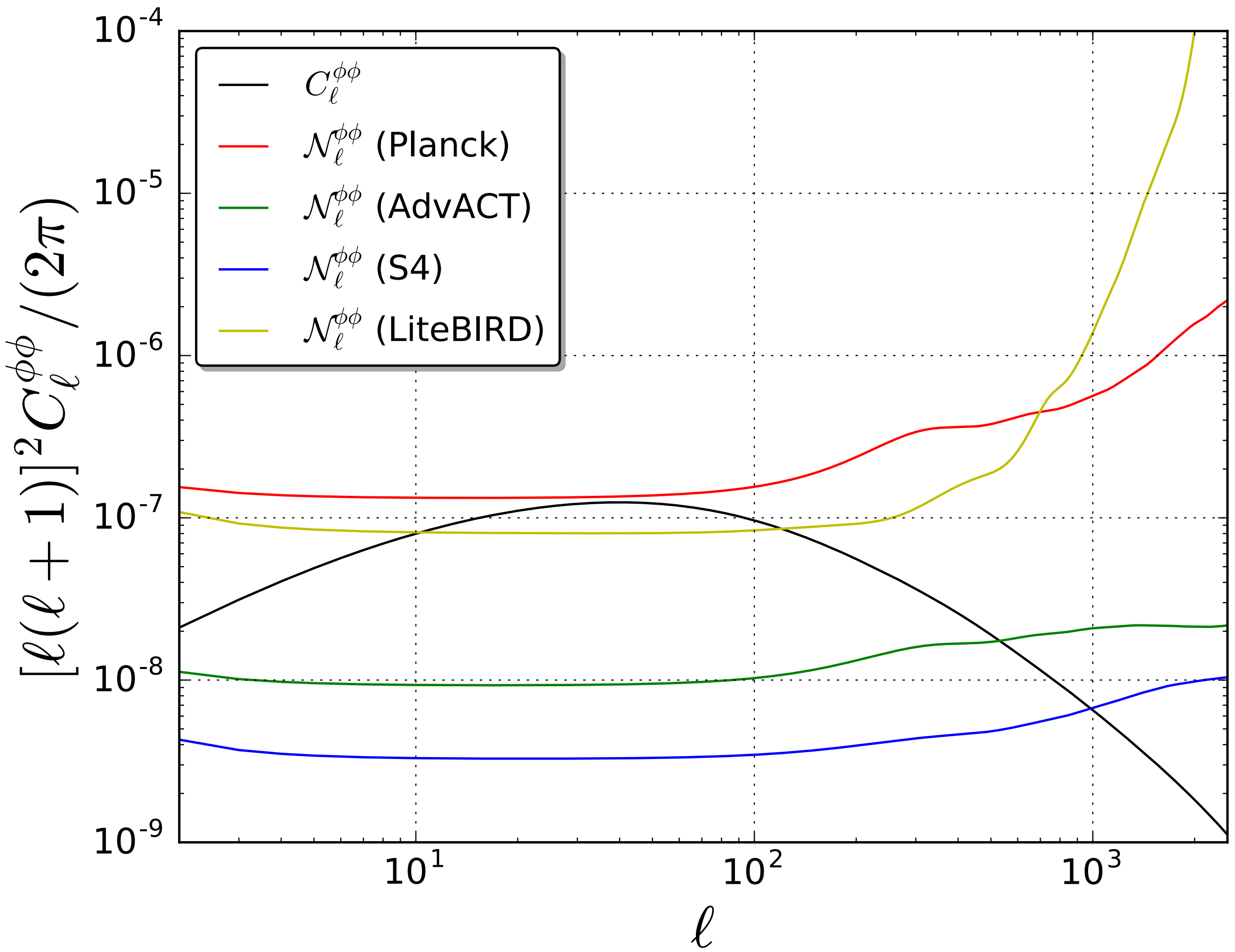
- **CMB Stage-4 (S4)**, following the specifications by CMB-S4 Science Book, Abazajian et al. (2016)

- For both AdvACT and S4, since they are ground-based we use $\ell_{min} = 30$, $\ell_{max} = 3000$ ($\ell_{max} = 1000$ for $\phi\phi$). For for $\ell < 30$ we add:
  - the Planck information to AdvACT
  - the LiteBird information to S4, following the specifications in Finelli et al. (2018)

CMB surveys

- We reconstruct the CMB lensing noise basing on the Okamoto & Hu (2003) algorithm and using the public code *quicklens*





LSS surveys

- We consider the following surveys:
  - **Euclid**: photometric and spectroscopic surveys
  - **LSST**
  - **SPHEREx**
  - **EMU** and **SKA** (radio continuum surveys)
- We use and modify CAMB_sources to obtain the power spectra
  Relativistic corrections are considered
  Non-linear correction recipe: Takahashi halofit
- We limit the analysis to quasi-linear scales: we consider the GG spectra up to k_{max} = 0.1 h/Mpc, with the corresponding ℓ_{max}^{GG} different in each bin:

$$\ell_{\mathrm{max}} = \chi(\bar{z}) k_{\mathrm{max}} - 1/2$$

For each ϕG bin we adopt $\ell_{max}^{\Phi G} = (\ell_{max}^{\Phi\Phi} \ell_{max}^{GG})^{1/2}$

LSS surveys: Euclid photometric

- We parametrize the number density of sources following:

$$\frac{\mathrm{d}N}{\mathrm{d}z} = \frac{1}{\Gamma\left(\frac{\alpha+1}{\beta}\right)}\beta\frac{z^{\alpha}}{z_0^{\alpha+1}}\exp\left[-\left(\frac{z}{z_0}\right)^{\beta}\right] \qquad \alpha = 2,\ \beta = 1.5,\ z_0 = 0.64$$

- Tomography: we convolve the dN/dz with a gaussian photo-z distribution

$$\frac{\mathrm{d}n^{i}_{\mathrm{gal}}}{\mathrm{d}z} = \frac{\mathrm{d}N}{\mathrm{d}z}\int_{z_{\min}}^{z_{\max}} \mathrm{d}z_m p(z_m|z) \qquad p(z_m|z) = \frac{1}{\sqrt{2\pi}\sigma_z}e^{-\frac{1}{2}(z_m-z)^2/\sigma_z^2}$$

- We integrate the redshift evolution of the bias
  The galaxy bias follows $b_G = b_0\,(1+z)^{1/2}$
  We study fNL through the induction of a scale-dependent bias:

$$b(k,z) = b_G(z) + \Delta b(k,z) = b_G(z) + [b_G(z)-1]f_{\mathrm{NL}}^{\mathrm{loc}}\delta_c\frac{3\Omega_m H_0}{c^2k^2T(k)D(z)}$$

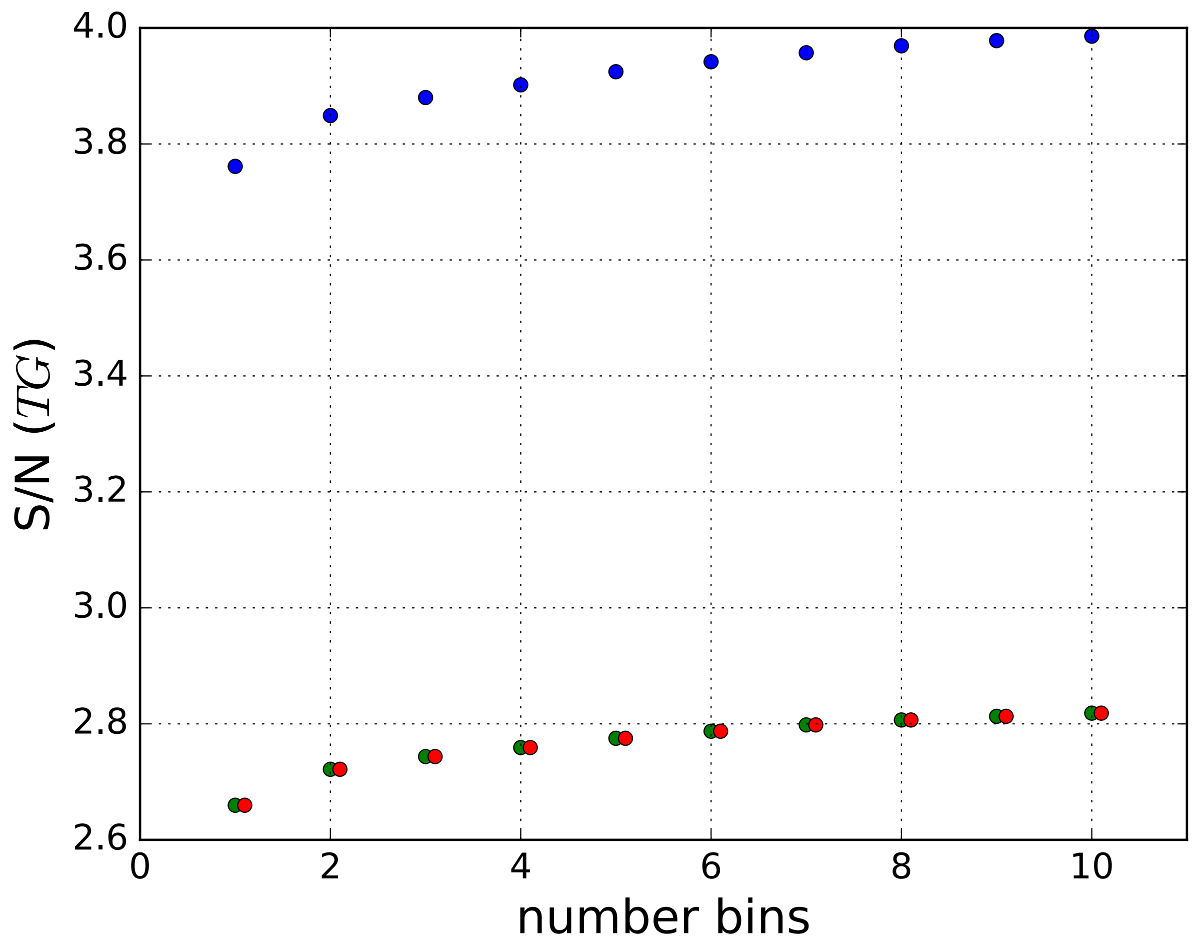
- N_{bin}+1 nuisance parameters: z_0, b_0

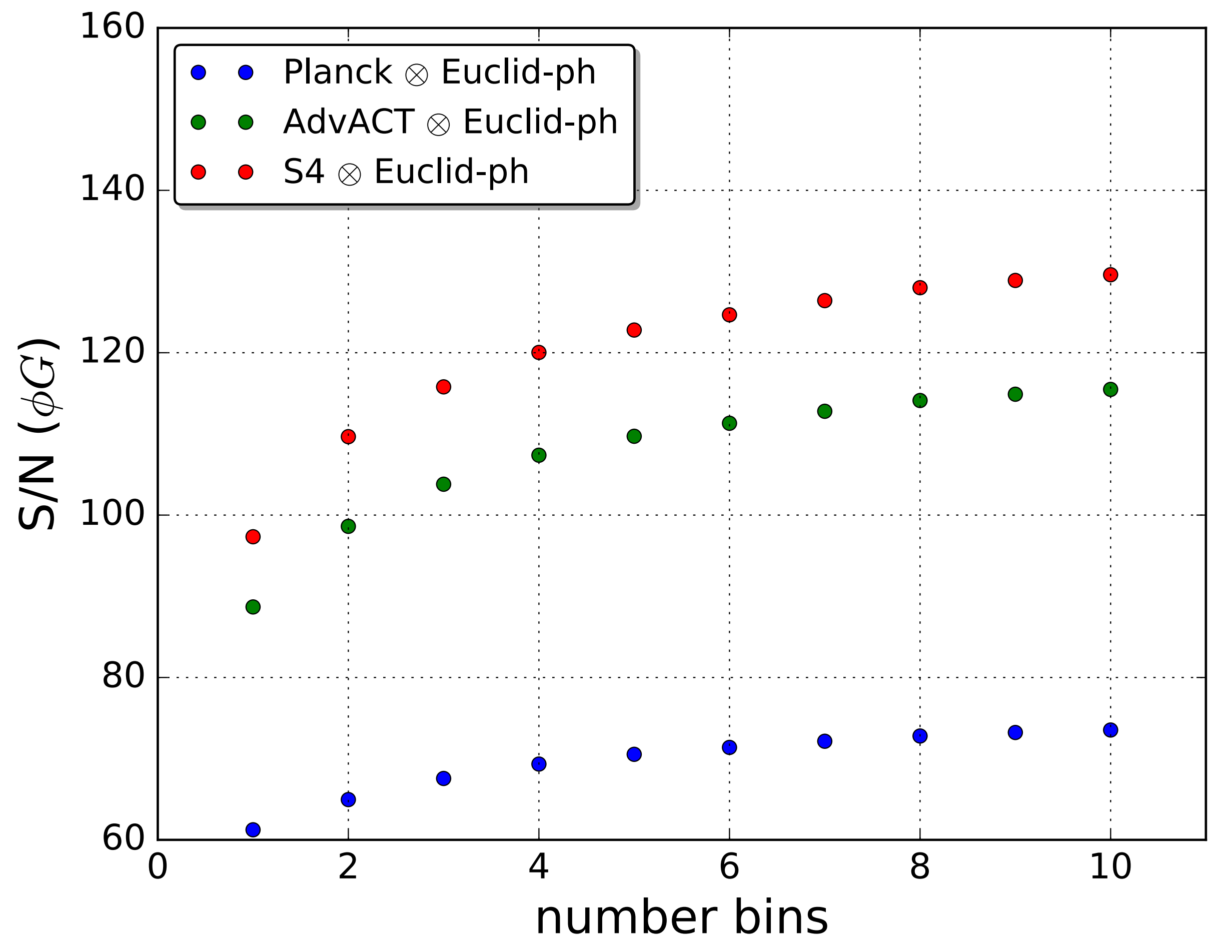
Signal-to-noise analysis

We compute the tomographic signal-to-noise (SNR) of *TG* and ϕ*G* as a function of the number of bins

$$\left(\frac{S}{N}\right)^2 = \sum_{i,j}\sum_{\ell=2}^{\ell_{\max}}(2\ell+1)f_{\rm sky}^{XG}C_\ell^{XG}(z_i)[{\rm Cov}_\ell^{-1}]_{ij}C_\ell^{XG}(z_j)$$

$$[{\rm Cov}_\ell]_{ij} = \bar{C}_\ell^{GG}(z_i,z_j)\bar{C}_\ell^{XX} + C_\ell^{XG}(z_i)C_\ell^{XG}(z_j)$$





Fisher formalism

Joint Fisher matrix for CMB and galaxy clustering:

$$\mathcal{F}_{\alpha\beta} = \sum_{\ell_{\min}}^{\ell_{\max}} \sum_{abcd} \frac{2\ell+1}{2} f_{\rm sky}^{abcd} \frac{\partial C_\ell^{ab}}{\partial \theta_\alpha} (\mathcal{C}^{-1})^{bc} \frac{\partial C_\ell^{cd}}{\partial \theta_\alpha} (\mathcal{C}^{-1})^{da}$$

$$abcd \in \{T, E, \phi, G_1, ..., G_N\} \qquad f_{\rm sky}^{abcd} \equiv \sqrt{f_{\rm sky}^{ab} f_{\rm sky}^{cd}}$$

Theoretical covariance matrix for the CMB x G case for N galaxy bins:

$$\mathcal{C} = \begin{bmatrix} \bar{C}_\ell^{TT} & C_\ell^{TE} & C_\ell^{T\phi} & C_\ell^{TG_1} & \dots & C_\ell^{TG_N} \\ C_\ell^{TE} & \bar{C}_\ell^{EE} & C_\ell^{E\phi} & C_\ell^{EG_1} & \dots & C_\ell^{EG_N} \\ C_\ell^{T\phi} & C_\ell^{E\phi} & \bar{C}_\ell^{\phi\phi} & C_\ell^{\phi G_1} & \dots & C_\ell^{\phi G_N} \\ C_\ell^{TG_1} & C_\ell^{EG_1} & C_\ell^{\phi G_1} & \bar{C}_\ell^{G_1 G_1} & \dots & C_\ell^{G_1 G_N} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ C_\ell^{TG_N} & C_\ell^{EG_N} & C_\ell^{\phi G_N} & C_\ell^{G_1 G_N} & \dots & \bar{C}_\ell^{G_N G_N} \end{bmatrix}$$

We adopt the **CMB basis** for the parameters: we use the Jacobian to project into sigma8

Figures of Merit (FoMs)

We calculate the Figure of Merit (FoM) for the 2 parameter extensions following the definition:

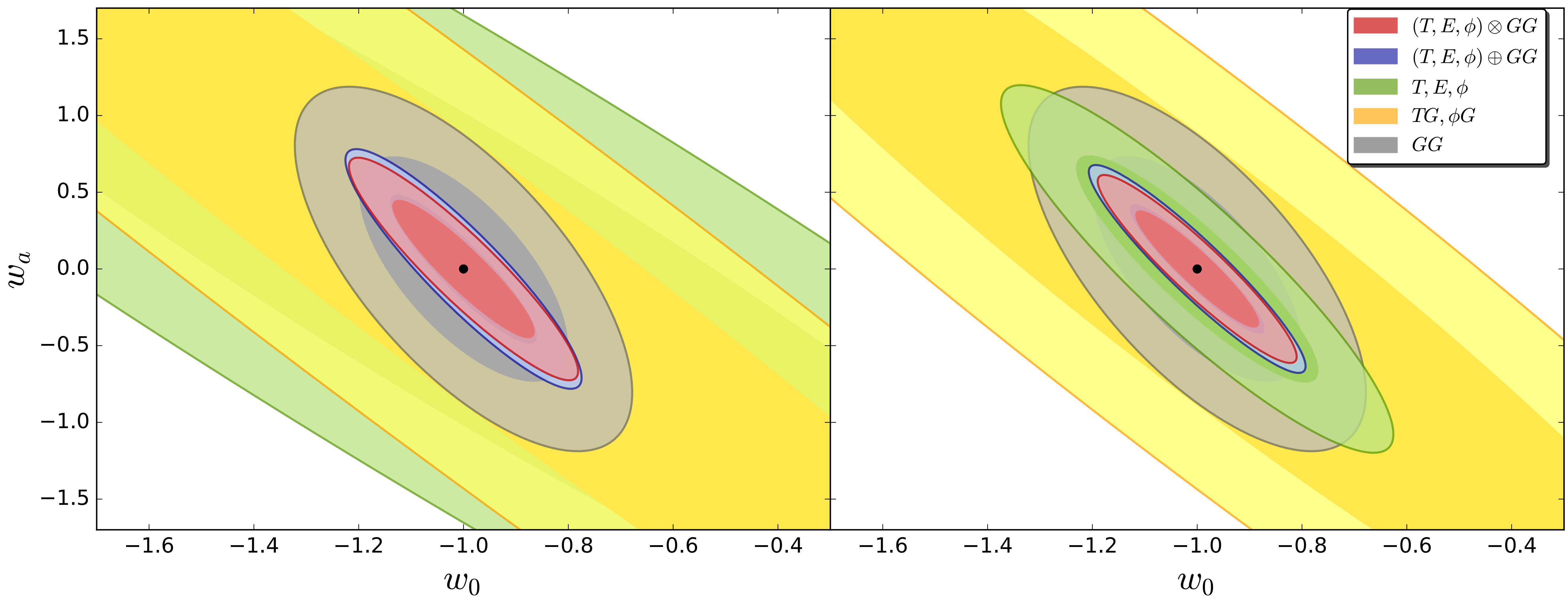
$$\mathrm{FoM}_{\alpha,\beta} = \frac{1}{\sqrt{\det(\mathcal{F}^{-1}_{\alpha,\beta})}}$$

Alternative definitions in the literature when more than two parameters are also considered:

$$\mathrm{FoM}_{\alpha_i} = \left[\frac{1}{\det(\mathcal{F}^{-1}_{\alpha_i})}\right]^{1/N}$$

Results: dark energy ($w_0 w_a$CDM)

Preliminary



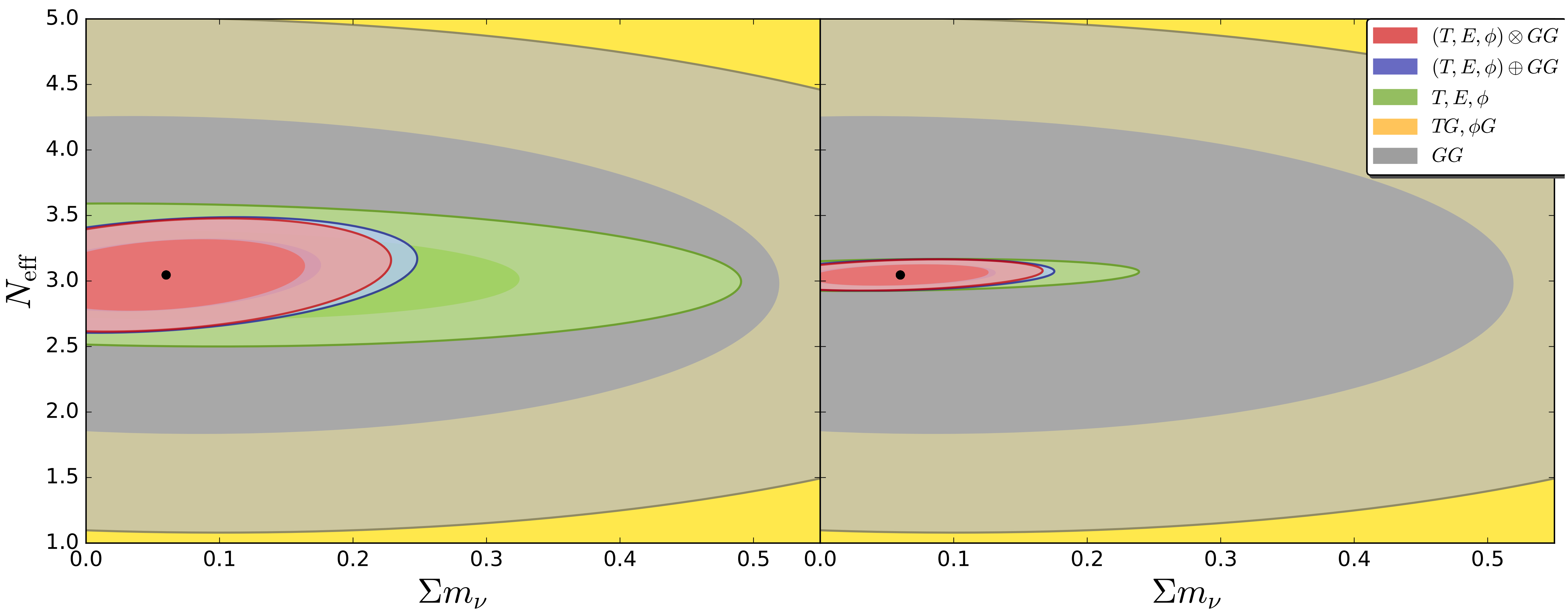
Planck + Euclid_ph **AdvACT + Euclid_ph**

Results: neutrino physics

N_{eff} mainly constrained by CMB

$\boldsymbol{\Sigma}$m$\boldsymbol{\nu}$ error can be improved with the inclusion of cross-correlation

Preliminary



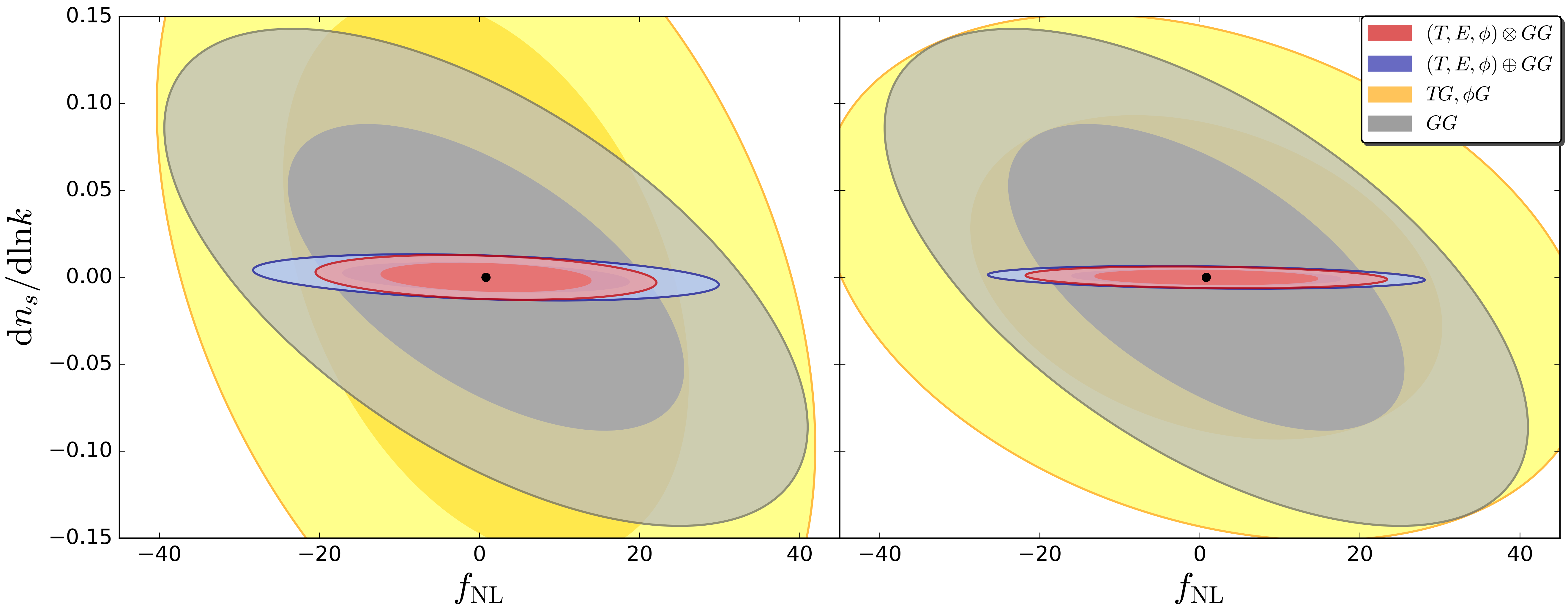
Planck + Euclid_ph **AdvACT + Euclid_ph**

Results: primordial universe

d n_s/d ln k mainly constrained by CMB

$f_{\rm NL}$ error can be improved with the inclusion of cross-correlation

Preliminary



Planck + Euclid_ph

AdvACT + Euclid_ph

Results: $w_0 w_a$CDM + Σm_ν

CMB-LSS cross-correlation can help in constraining parameters in extended models where there are degeneracies

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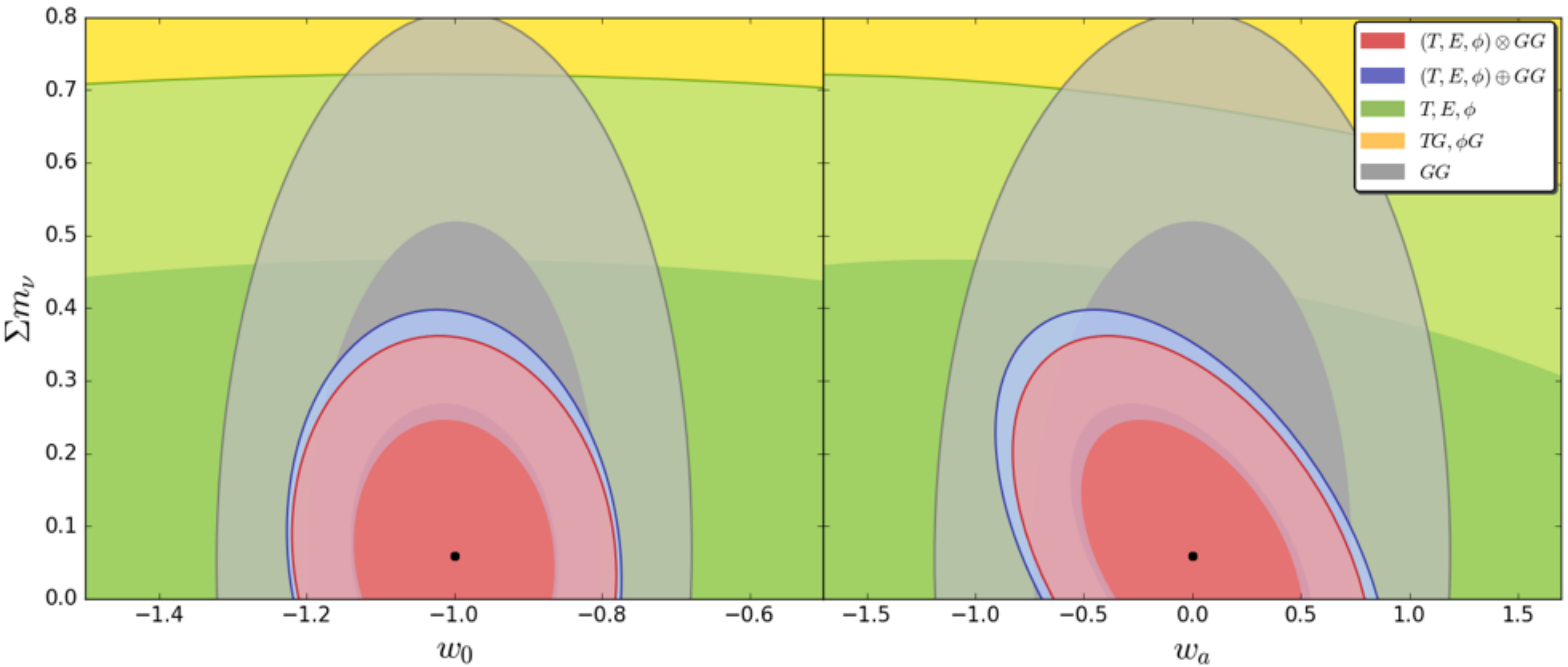

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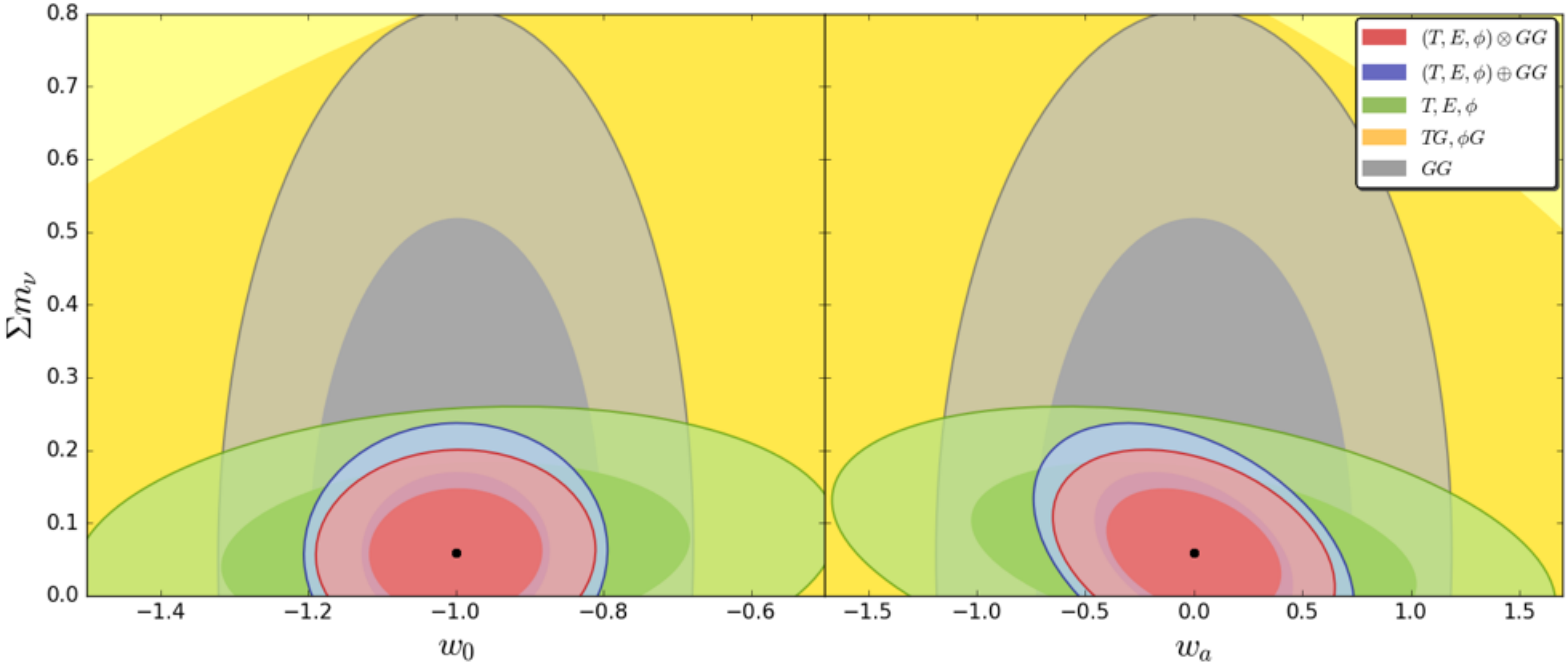

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