Constraining modified gravity with gravitational wave distance measurements

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Modified gravity cosmology

- The background and linear perturbations are completely specified by a tuple of time-dependent functions

$$(\alpha_K, \alpha_B, \alpha_M, \alpha_T, H)$$

Bellini and Sawicki, JCAP 07 2014 050

- Include all Horndeski theories and some of its extensions
- All alpha's are zero in GR

Gravitational waves in modified gravity

- GW amplitude propagates following

$$h''_P + (2 + \alpha_M)Hh'_P + (1 + \alpha_T)k^2 h_P = \Pi_P$$

- From GWs, we infer the luminosity distance of binary systems

$$h_P \sim \frac{1}{\mathcal{D}_L^{gw}}$$

- It is modified to

$$\mathcal{D}_L^{gw}(z) = \mathcal{D}_L^{em}(z) \exp\left\{\frac{1}{2}\int_0^z \frac{\alpha_M(\tilde{z})}{1+\tilde{z}} d\tilde{z}\right\}$$

Einstein Telescope forecasts

- Simulations of 1000 BNS mergers detected by the Einstein Telescope (ET) for 0.5 < z < 2
- Redshifts from gamma ray bursts
- Errors in D_L^{gw}

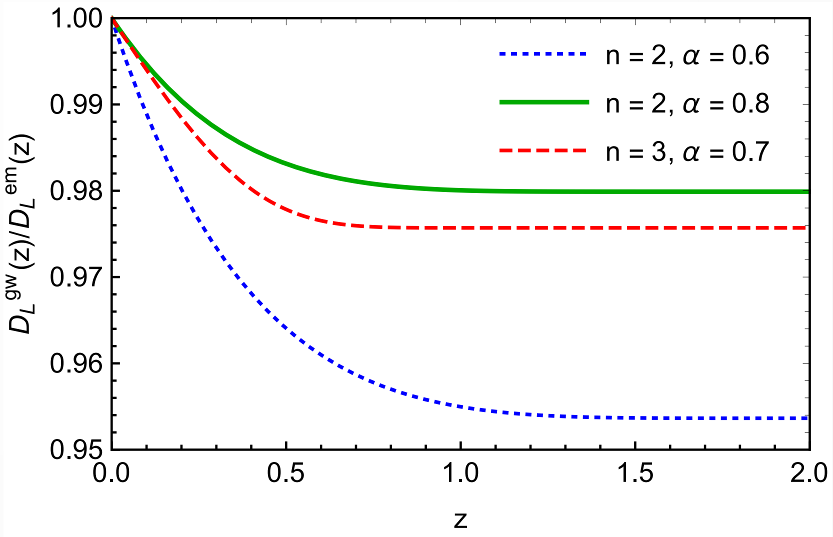
$$\sigma^2 = \sigma^2_{\rm lens} + \left(\frac{2\mathcal{D}_L^{gw}}{\rm SNR}\right)^2$$

Matos, I. S., Calvão M. O. and Waga, I., PRD 103, 104059 (2021)

In f(R)

- For a Lagrangian of the form $\mathcal{L} = R + f(R)$

$$\mathcal{D}_L^{gw} = \mathcal{D}_L^{em} \sqrt{\frac{1+f_{R0}}{1+f_R}}$$



γ gravity models

- Asymptoticaly goes to

$$1 + \frac{f_{R0}}{2}$$

- Assuming a LCDM background, ET provides

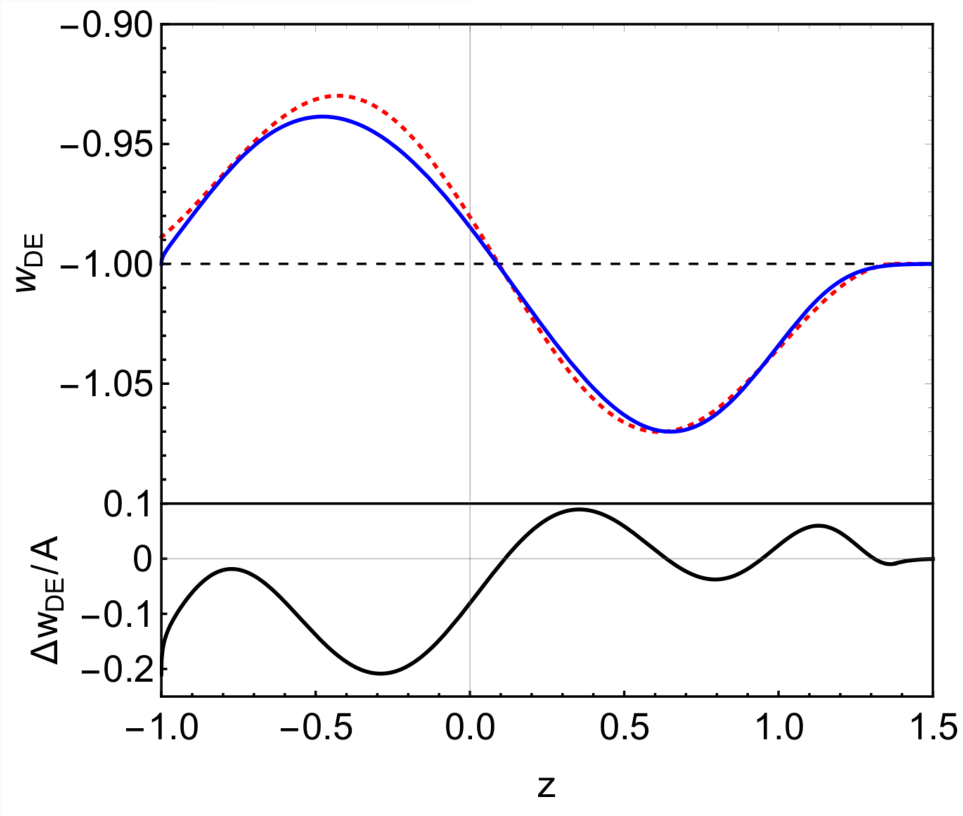
$$|f_{R0}| \lesssim 2 \times 10^{-2}$$

Parametrizing the background evolution

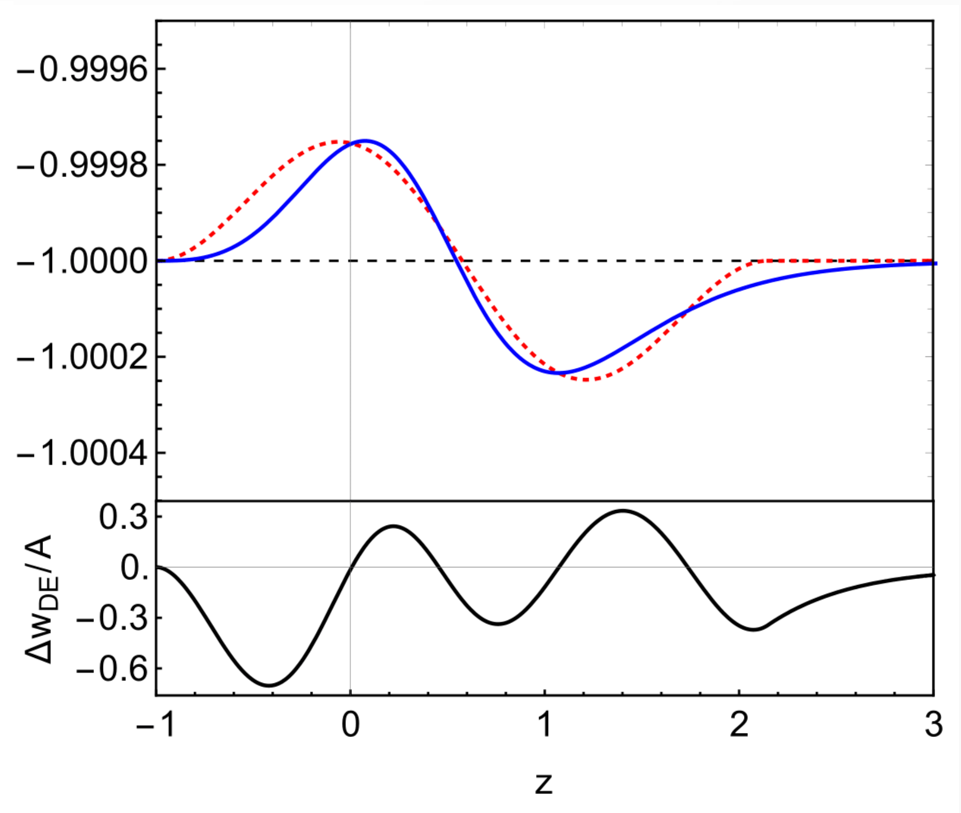
$$w_{\rm DE}(z, A, z_t, z_f) = -1 - A(z - z_f)(z_t - z)\sin\left[\frac{2\pi z - \pi(z_f + z_t)}{z_t - z_f}\right]$$

$$z_f < z < z_t$$

γ gravity

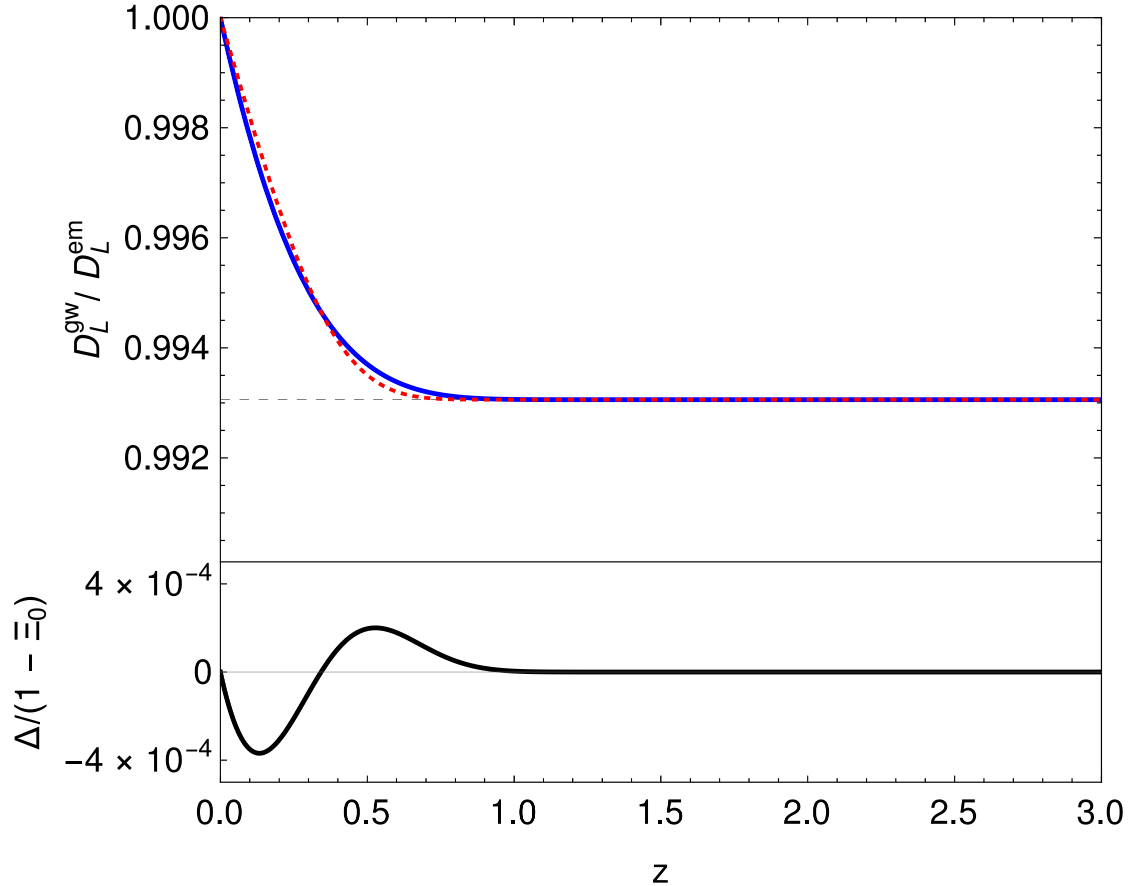


Hu-Sawicki



Parametrizing the ratio of distances

$$\Xi(z, \Xi_0, \nu) = \Xi_0 + (1 - \Xi_0)e^{1-(1+z)^{\nu}}$$



- Asymptote

  $\to \Xi_0$

- GR is recovered

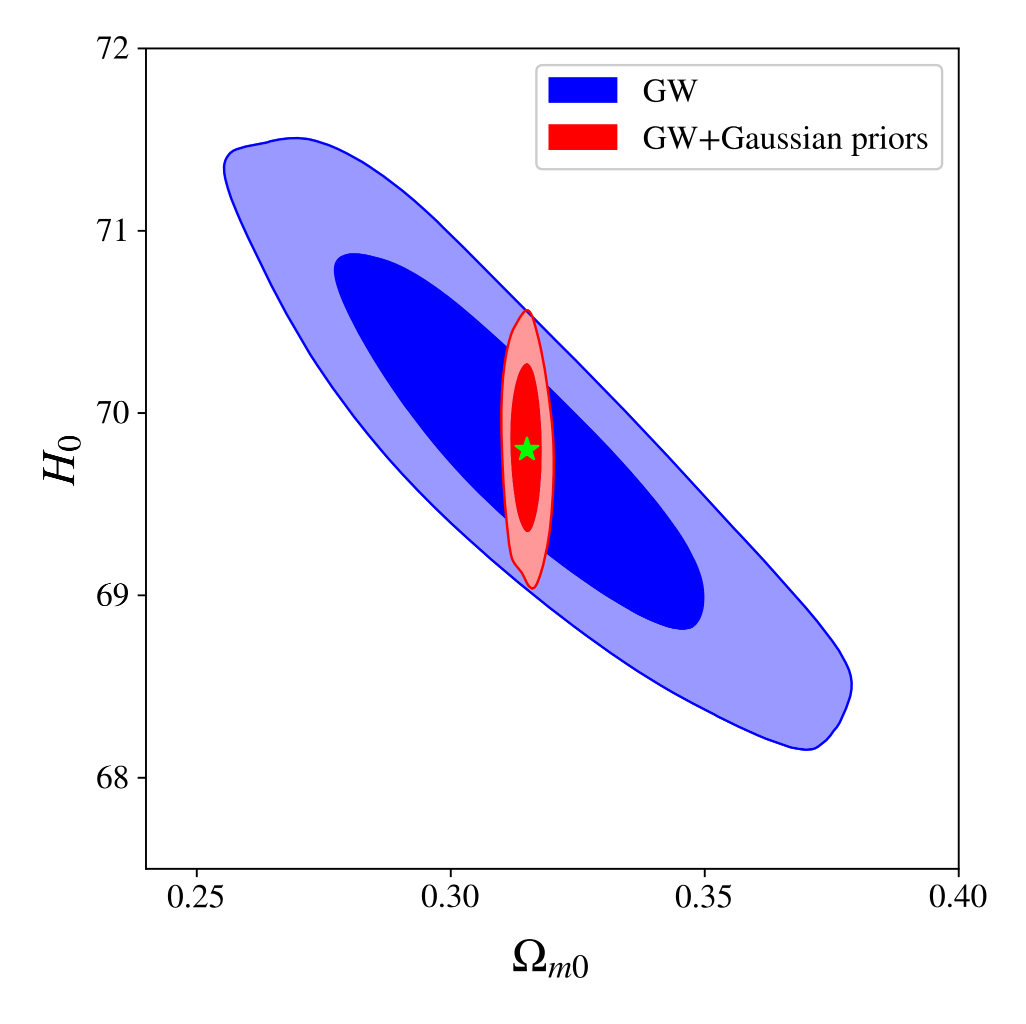
  $\Xi_0 = 1$ or $\nu = 0$

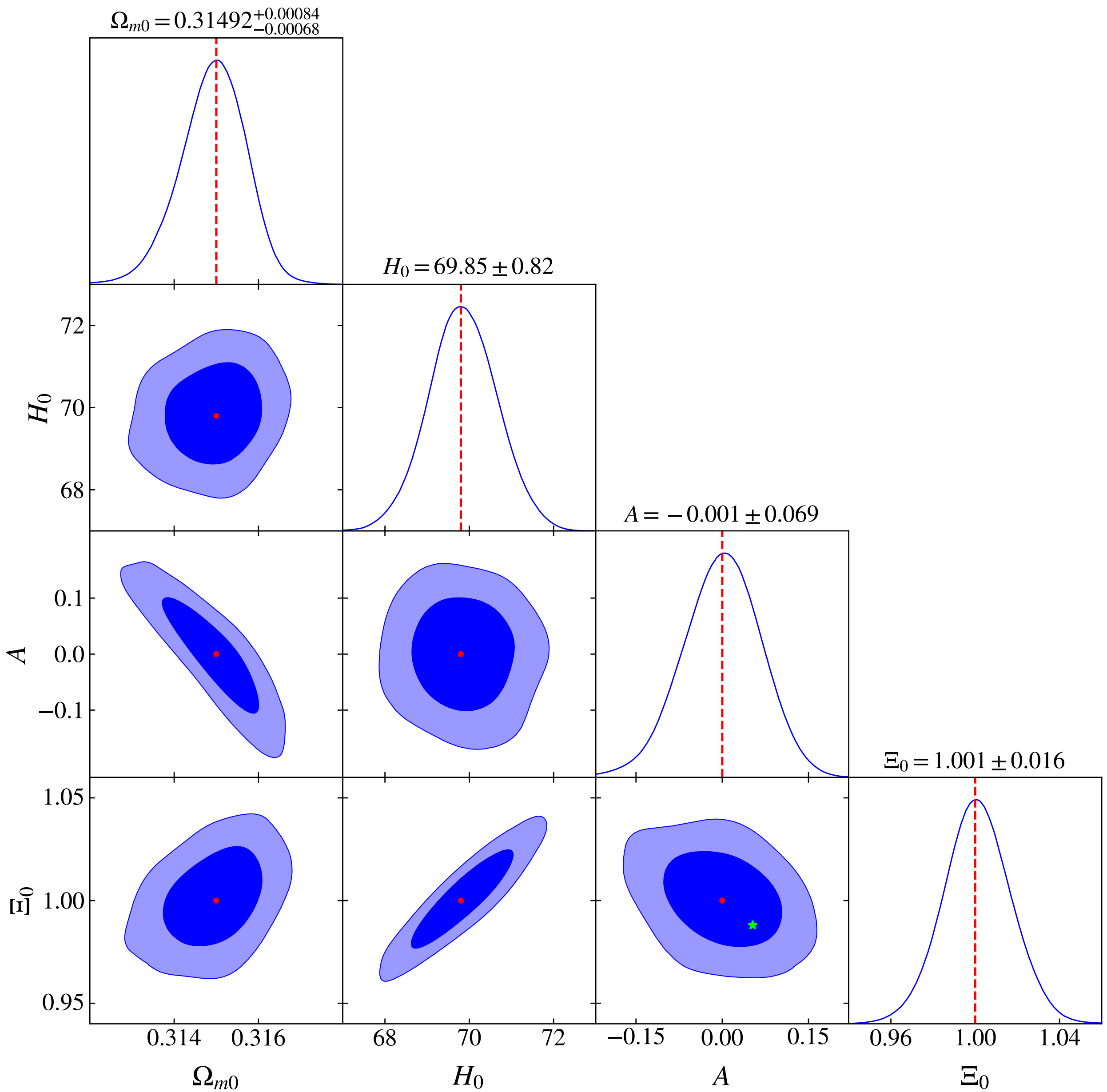
  $A = 0$

Results for LCDM

- Simulations of 1000 GW events from BNS mergers (0.01 < z < 2)

$$\frac{\Delta H_0}{H_0} \sim 0.97\% \qquad \frac{\Delta \Omega_{m0}}{\Omega_{m0}} \sim 7.6\%$$





Fiducial model is ΛCDM

Gaussian priors

$H_0 \rightarrow$ N(69.8, 1.9)

A → N(0, 0.14)

$\Omega_{m0} \rightarrow$ N(0.315, 0.007)

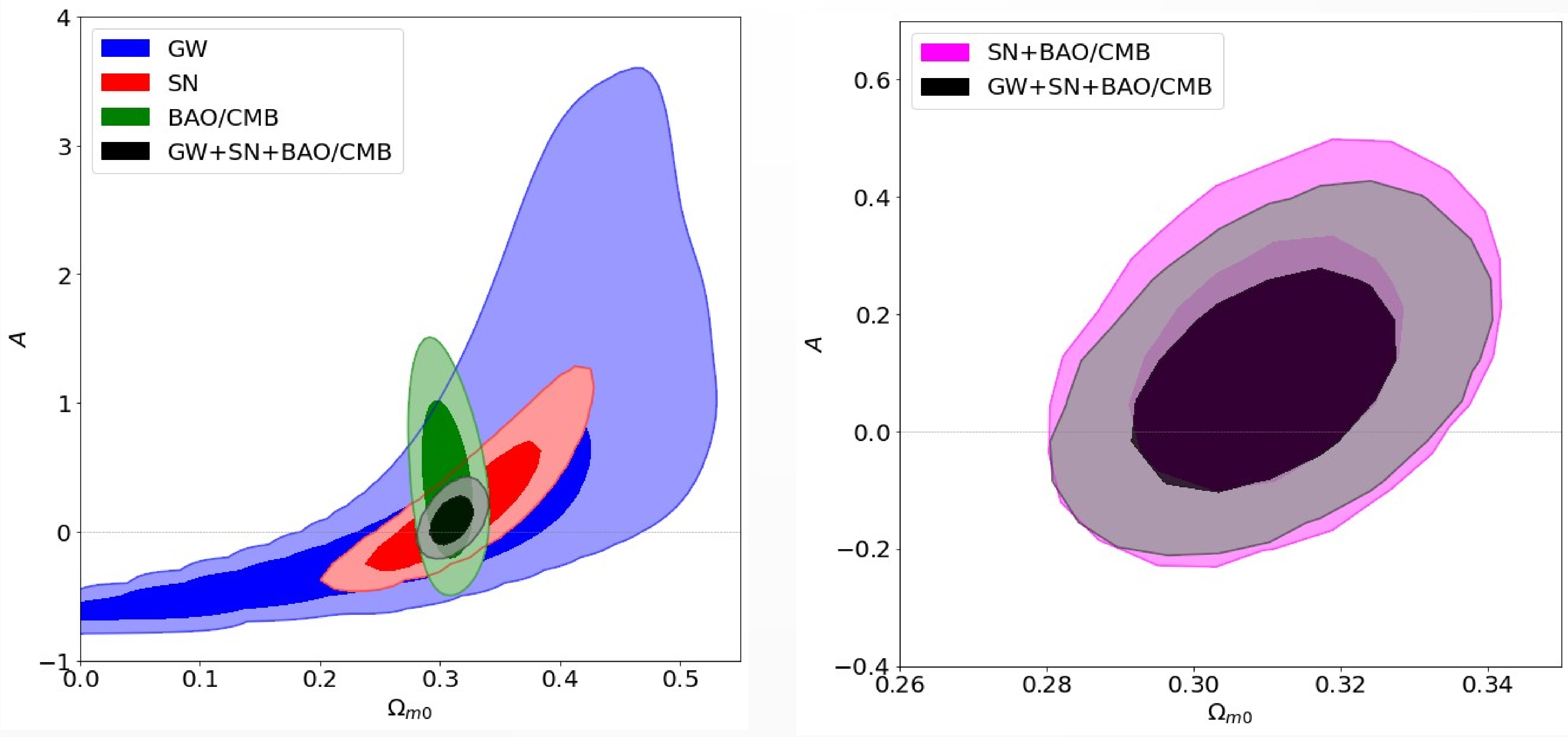
Fixed: ν, z_t, z_f

Markers

γ-gravity with

n=2 and α=0.9

Combination with actual data from other observables



Next steps: slip

- The running of the Planck mass does not affect only the GW friction, but also the scalar perturbations

$$\Psi - (1 + \alpha_T)\Phi + (\alpha_M - \alpha_T)H\frac{\delta\phi}{\dot{\phi}} = \Pi$$