

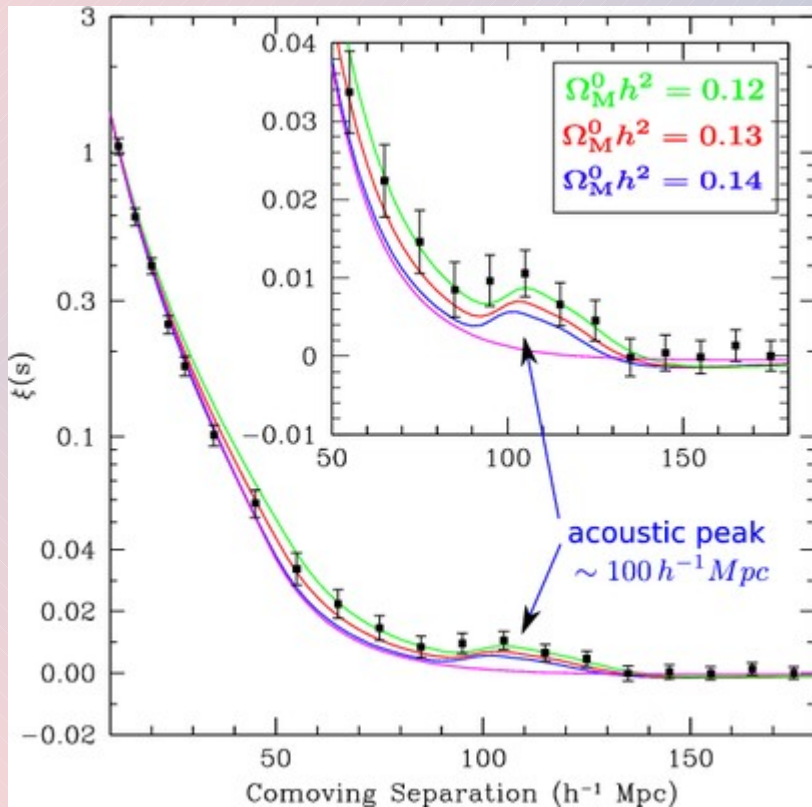
Tensions in Baryon Acoustic Oscillations dataset

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Based on works with D. Benisty, J. Mifsud, J. Levi Said

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BAO – „standard ruler“ in cosmology



- Baryonic acoustic oscillations are regular, periodic fluctuations in the density of the visible baryonic matter of the universe.
- Created by the interplay of gravity, radiative pressure and the expansion of the universe
- The distance at which plasma waves induced by radiation pressure froze at recombination the sound horizon, r_d
- Measured by looking at the large scale structure of matter

Planck
2018: $r_d=147.5$
Mpc, $z_d=1059$,
 $z_*=1100$.

$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz$$

$$c_s(z) = \frac{c}{\sqrt{3 \left(1 + \frac{3\Omega_b}{4\Omega_\gamma} \frac{1}{1+z} \right)}}$$

Inferring cosmological parameters from BAO:

We measure the projections:

$$\Delta z = r_d H(z) / c$$

$$\Delta\theta = \frac{r_d}{(1+z)D_A(z)}$$



**Both
~ $r_d H_0 / c$!**

And we calculate the distances:

$$D_M = \frac{c}{H_0} S_k \left(\int_0^z \frac{dz'}{E(z')} \right)$$

$$D_A = D_M / (1+z)$$

with

$$S_k(x) = \begin{cases} \frac{1}{\sqrt{\Omega_k}} \sinh(\sqrt{\Omega_k} x) & \text{if } \Omega_k > 0 \\ x & \text{if } \Omega_k = 0 \\ \frac{1}{\sqrt{-\Omega_k}} \sin(\sqrt{-\Omega_k} x) & \text{if } \Omega_k < 0 \end{cases}$$

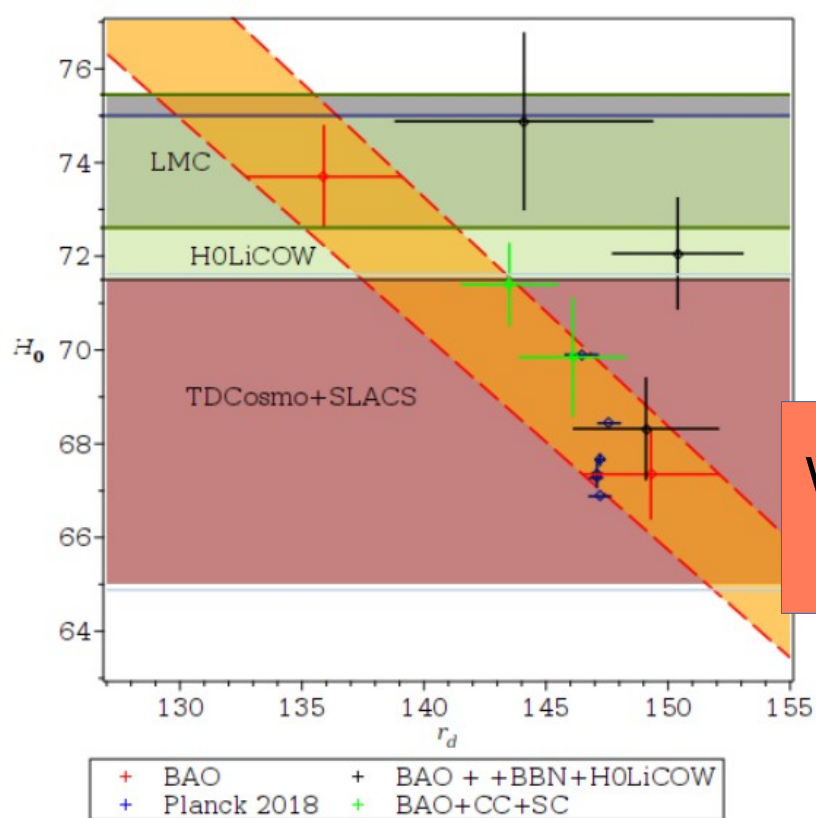
To get the parameters, we solve the Friedmann equations

$$H(z)/H_0 = E(z)$$

$$E(z)^2 = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\Lambda$$

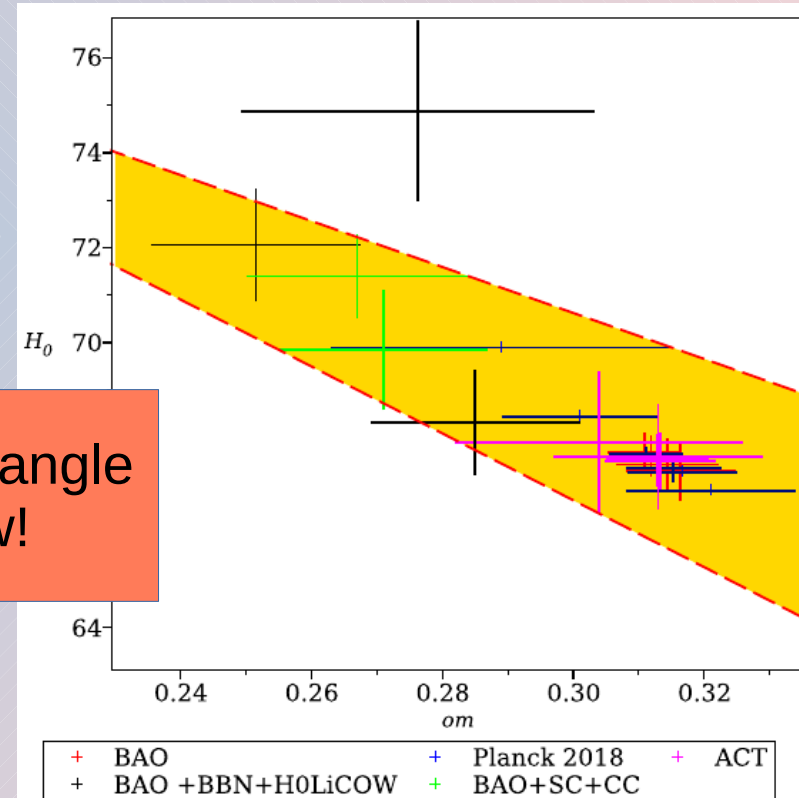
The problem:

r_d , H_0 and Ω_m are coupled!



We need to disentangle them somehow!

D.S., MG-16 proc,
arXiv:2111.07907



So we marginalise over $H_0 r_d$

- We redefine the χ^2 to integrate over $H_0 r_d$
- We take two BAO datasets:
 - uncorrelated angular BAO
 - a mix of radial + angular BAO + covariances
- To which we add the Pantheon binned SN with the covariances
- We use them to constrain DE models (CPL, pEDE, gEDE)

$$\chi_{\theta,BAO}^2 = \left(\frac{H_0 r_d}{c}\right)^2 A_{\theta} - 2B_{\theta} \left(\frac{H_0 r_d}{c}\right) + C,$$

$$A_{\theta} = \sum_{i=1}^N \frac{h(z_i)^2}{\sigma_i^2},$$

$$B_{\theta} = \sum_{i=1}^N \frac{\theta_D^i h(z_i)}{\sigma_i^2},$$

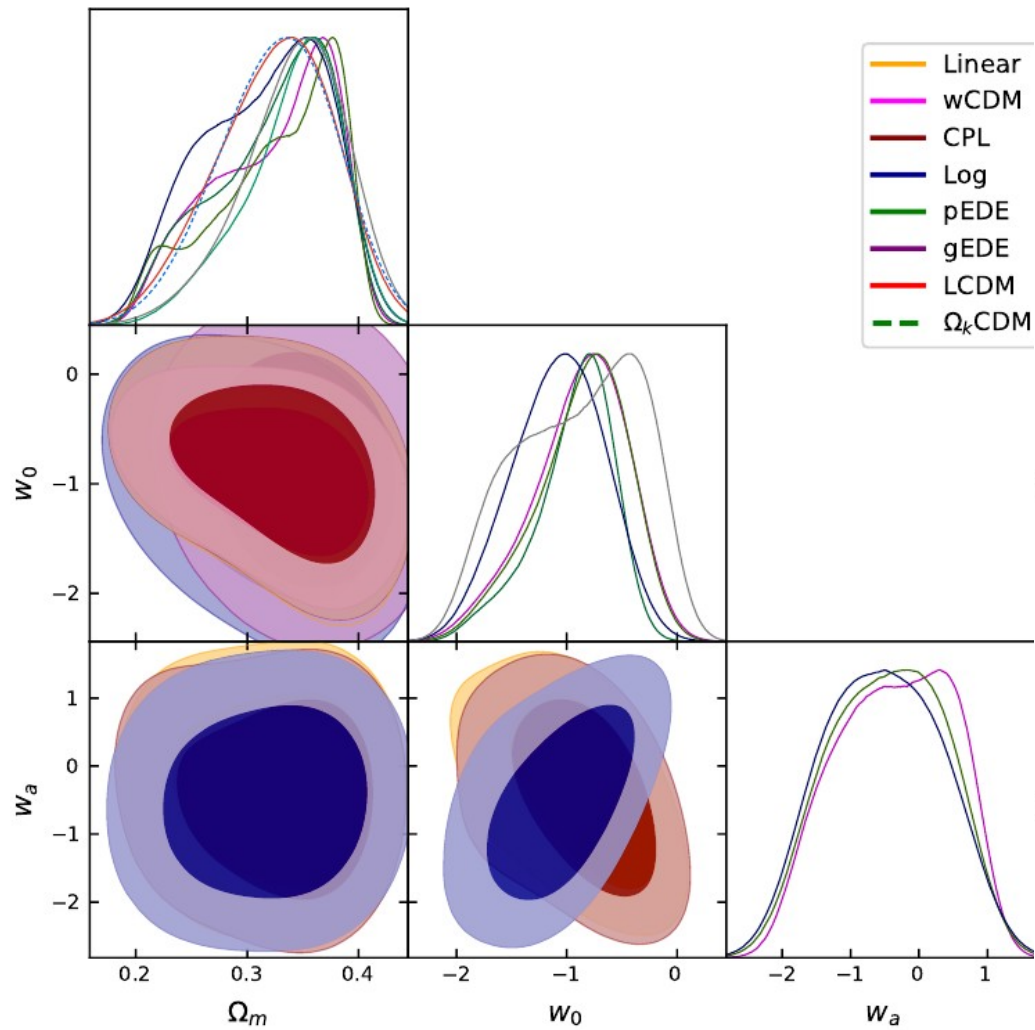
$$\tilde{\chi}^2 = \tilde{\chi}_{BAO}^2 + \tilde{\chi}_{SN}^2.$$

$$C_{\theta} = \sum_{i=1}^N \frac{(\theta_D^i)^2}{\sigma_i^2}.$$

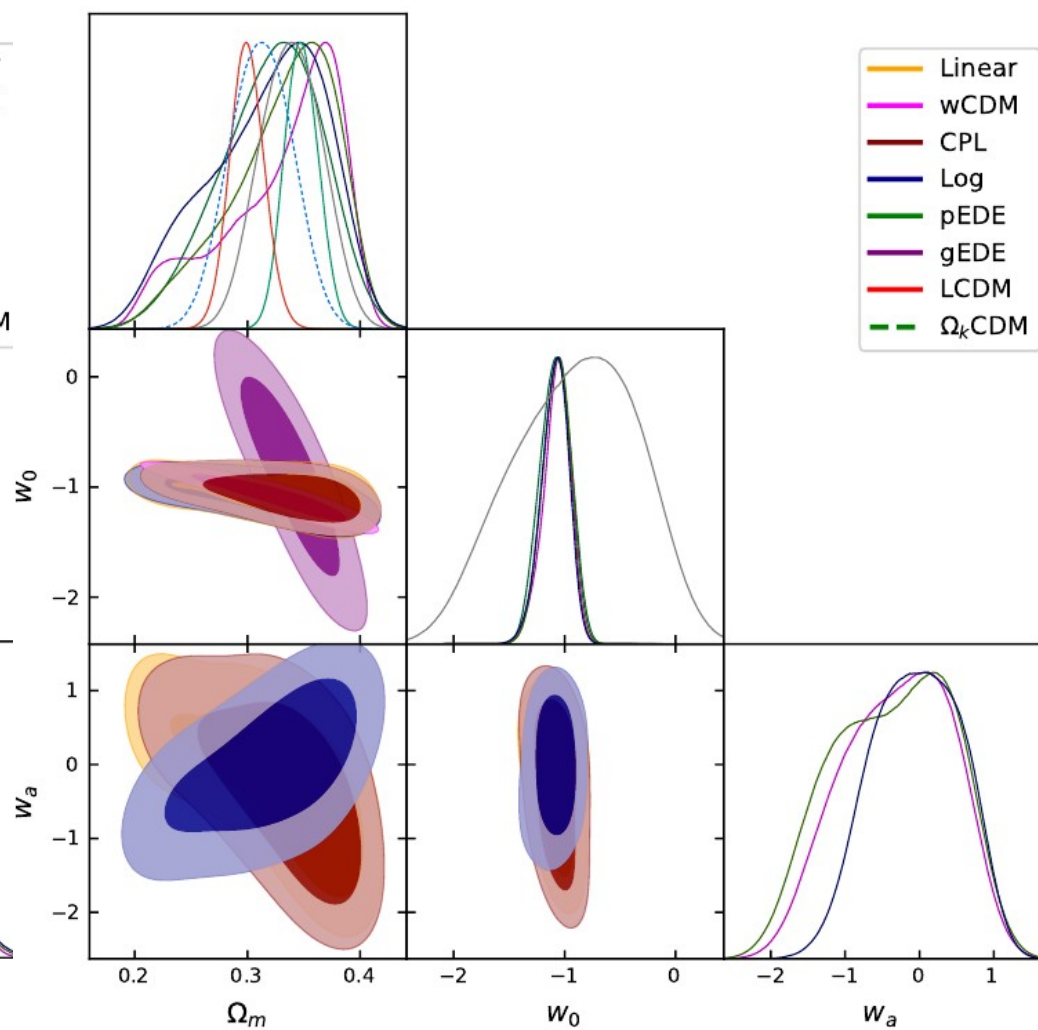
$$w(z) = \begin{cases} w_0 + w_a z & \text{Linear} \\ w_0 + w_a \frac{z}{z+1} & \text{CPL} \\ w_0 - w_a \log(z+1) & \text{Log} \end{cases}$$

$$\Omega_{DE}(z) = \Omega_{\Lambda} \frac{1 - \tanh(\Delta \log_{10}(\frac{1+z}{1+z_t}))}{1 + \tanh(\Delta \log_{10}(1+z_t))}$$

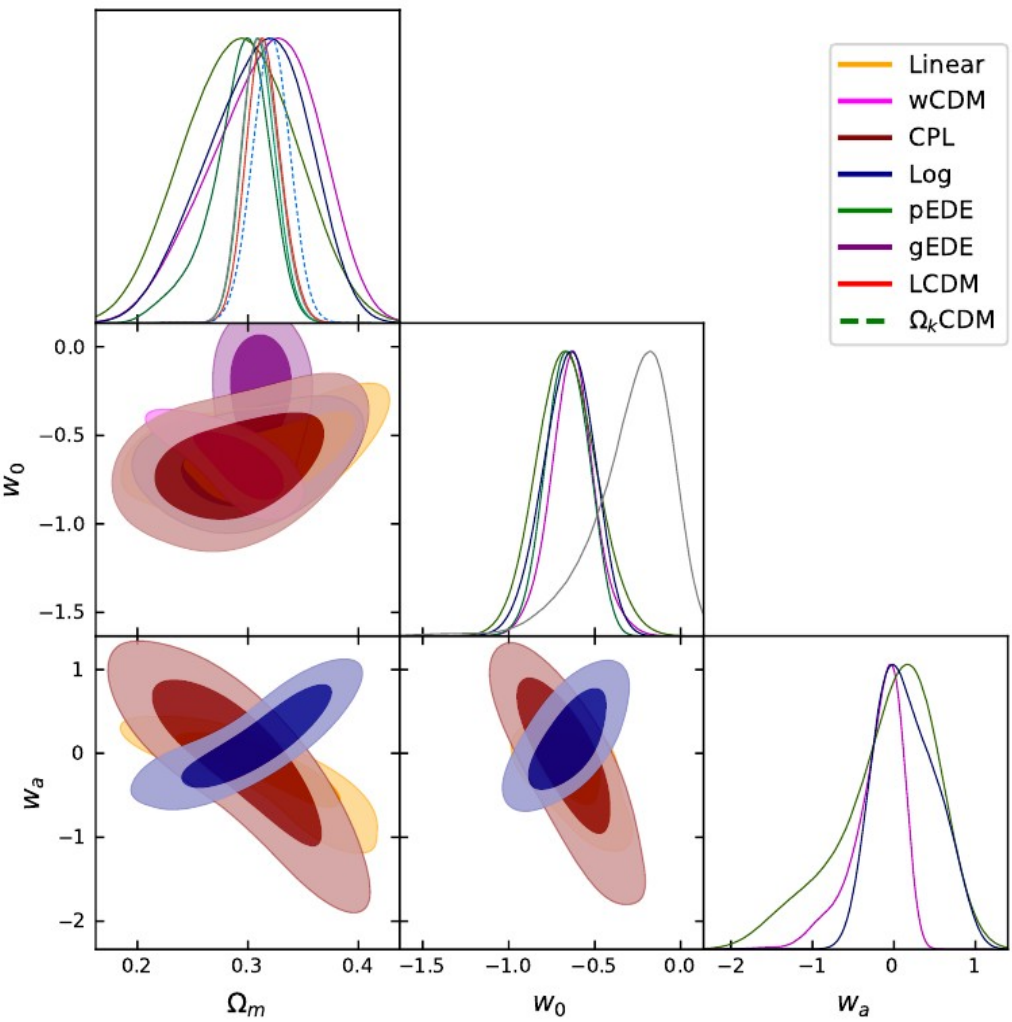
Angular BAO



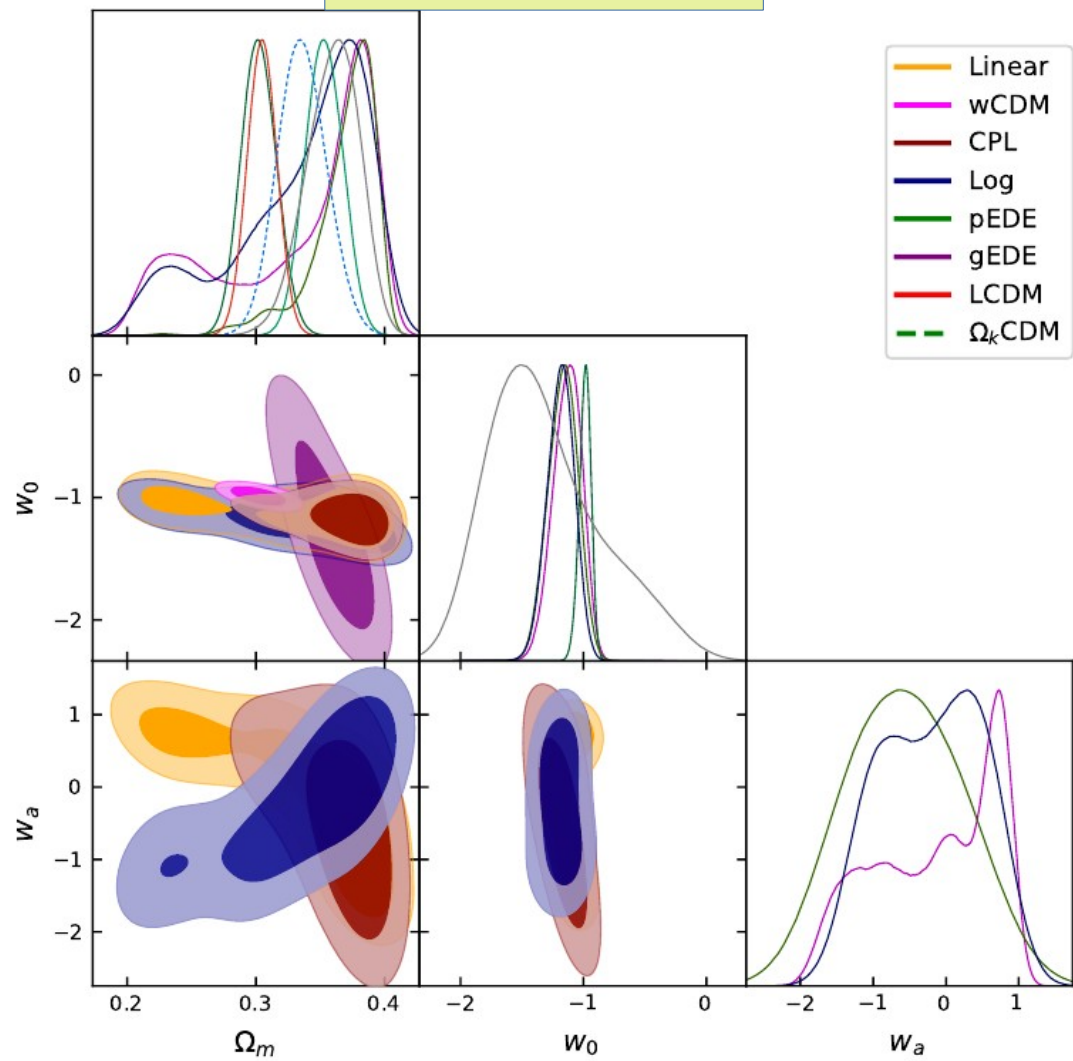
Angular BAO+SN



BAO



BAO+SN



Conclusions:

- BAO alone are not able to constrain DE models
- Adding SN decreases the errors significantly
- The **angular** BAO dataset and the **mixed one** do not favor the same models (wCDM vs LCDM)
- The marginalization is able to produce interesting results on the cost of bigger error

Numbers are compatible with earlier results:

- BAO + SN:
- $w = -0.986 \pm 0.045$
- $w_0 = -1.18 \pm 0.139$, $w_a = -0.367 \pm 0.672$
- BAO_θ+SN
- $w = -1.08 \pm 0.14$
- $w_0 = -1.09 \pm 0.09$, $w_a = -0.31 \pm 0.74$
- BAO + SN prefers a closed universe ($\Omega_k = -0.21 \pm 0.07$),
- BAO_θ+SN prefers a flat one ($\Omega_k = -0.09 \pm 0.15$).

Constraining the dark energy models using the BAO data:

An approach independent of $H_0 \cdot r_d$

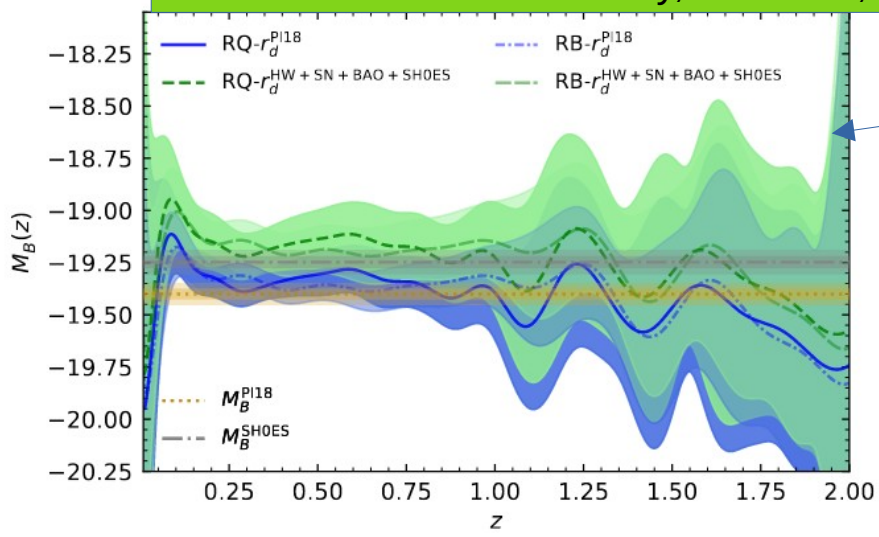
Benisty, Staicova

arXiv:2107.14129 [astro-ph.CO]

On the Robustness of the Constancy of the Supernova Absolute Magnitude: Non-parametric Reconstruction & Bayesian approaches

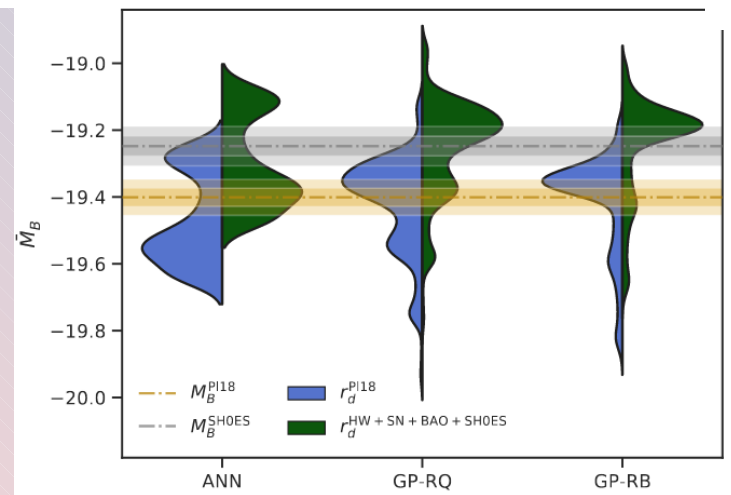
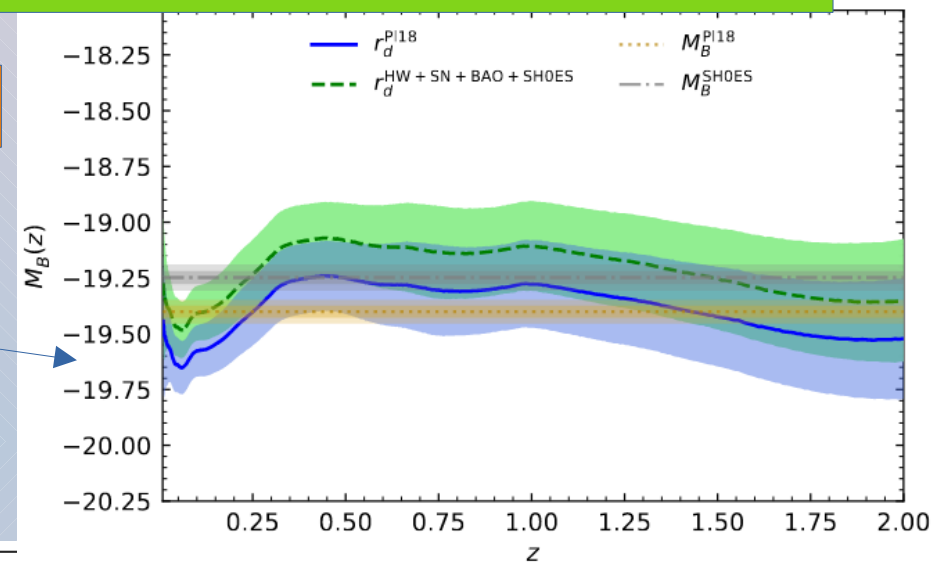
Non-parametric Reconstruction & Bayesian approaches

D. Benisty, J. Mifsud, J. Levi Said, D. Staicova arXiv:2202.04677



GP

ANN



$$M_B = \mu_{Ia} - 5 \log_{10} \left[(1+z)^2 \left(\frac{D_A}{r_d} \right)_{BAO} \cdot r_d \right] - 25, \quad (3a)$$

which gives uncertainties

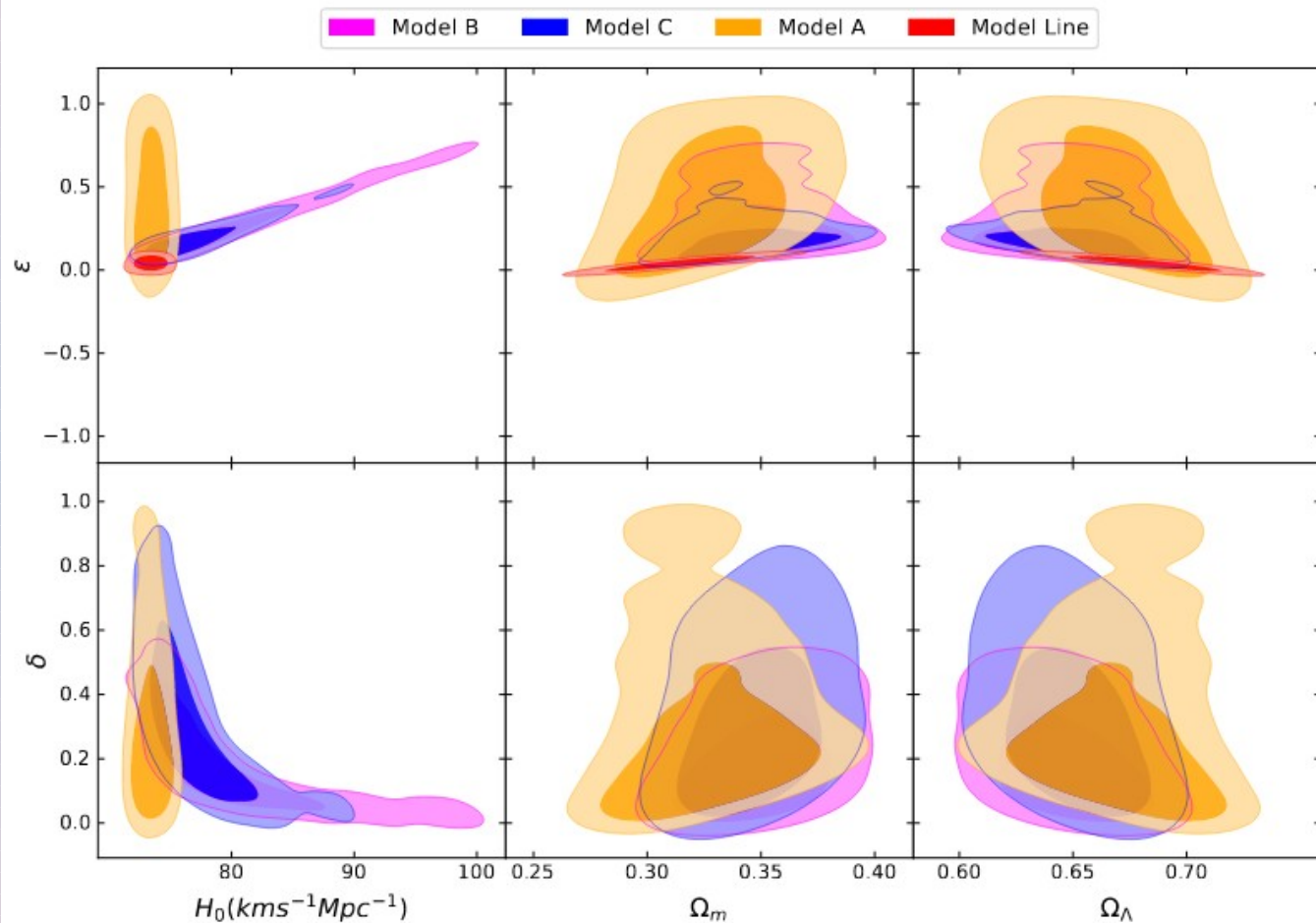
$$\Delta M_B = \Delta \mu_{Ia} + \frac{5}{\ln 10} \left[\frac{\Delta r_d}{r_d} + \frac{\Delta (D_A/r_d)_{BAO}}{(D_A/r_d)_{BAO}} \right]. \quad (3b)$$

We tested known models for the nuisance parameter

$$\delta M_B(z) = \begin{cases} \epsilon z & \text{Model Line} \\ \epsilon [(1+z)^\delta - 1] & \text{Model A} \\ \epsilon z^\delta & \text{Model B} \\ \epsilon [\ln(1+z)]^\delta & \text{Model C} \end{cases}$$

Conclusions:

- The constancy of M_B is at level of 1σ .
- The MCMC do not prefer any of the tested non-constant model significantly.
- We exchange the tension in H_0 - r_d with a tension in the M_B - r_d plane



Thank you for your attention!



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