Inferring cosmological parameters from Baryon Acoustic Oscillations datasets

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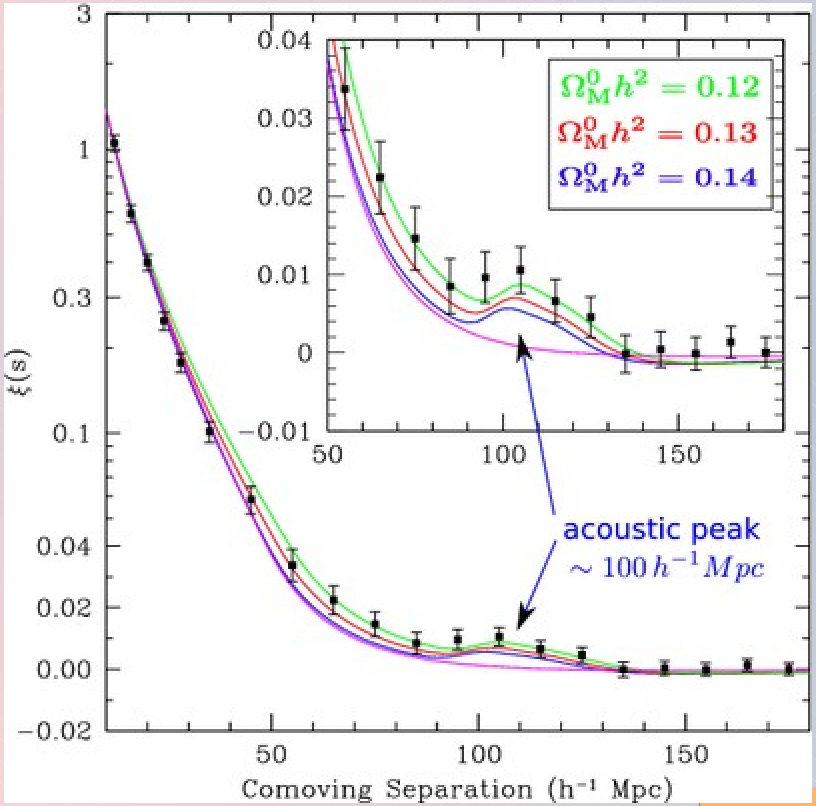
Based on works with D. Benisty, J. Mifsud, J. Levi Said

Tensions in Cosmology – Corfu, 7-12.09.2022

BAO – „standard ruler“ in cosmology



- Baryonic acoustic oscilations are regular, periodic fluctuations in the density of the visible baryonic matter of the universe.
- Created by the intrerplay 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

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

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

Planck 2018:

r_d=147.5 Mpc,
z_d=1059, z_*=1100.

Credit: Eisenstein et al., 2005; Cole et al., 2005

Inferring cosmological parameters from BAO:

We measure the projections:

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

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

→

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

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

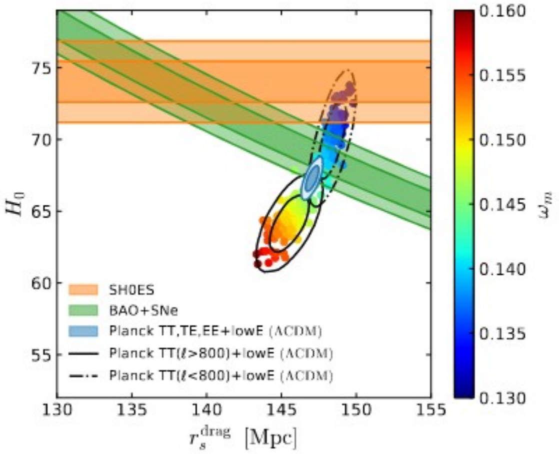
Both quantities $\sim r_d H_0/c$!

To get the parameters, we solve the Friedmann equations:

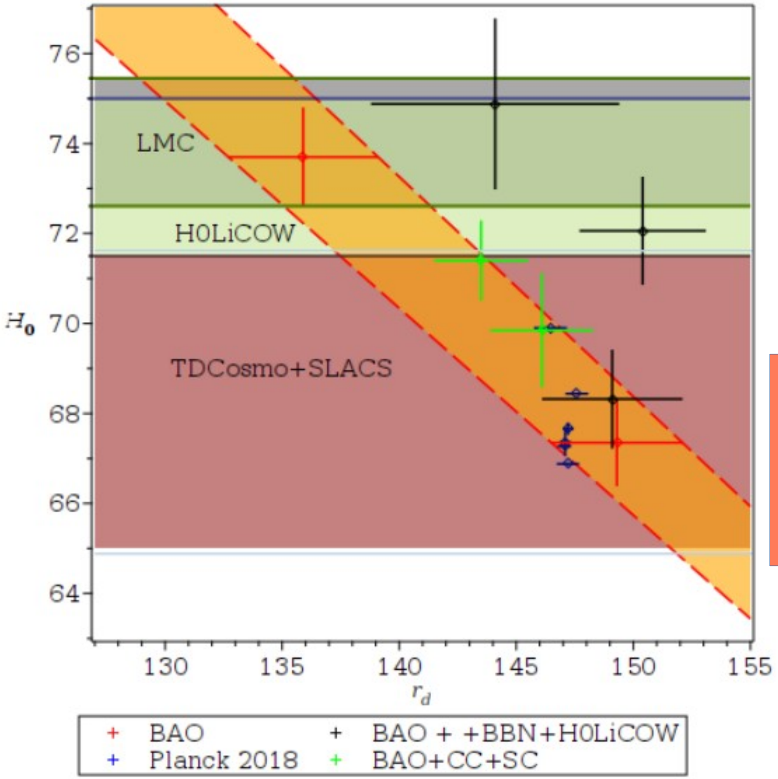
$$H(z)/H_0 = E(z)$$

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

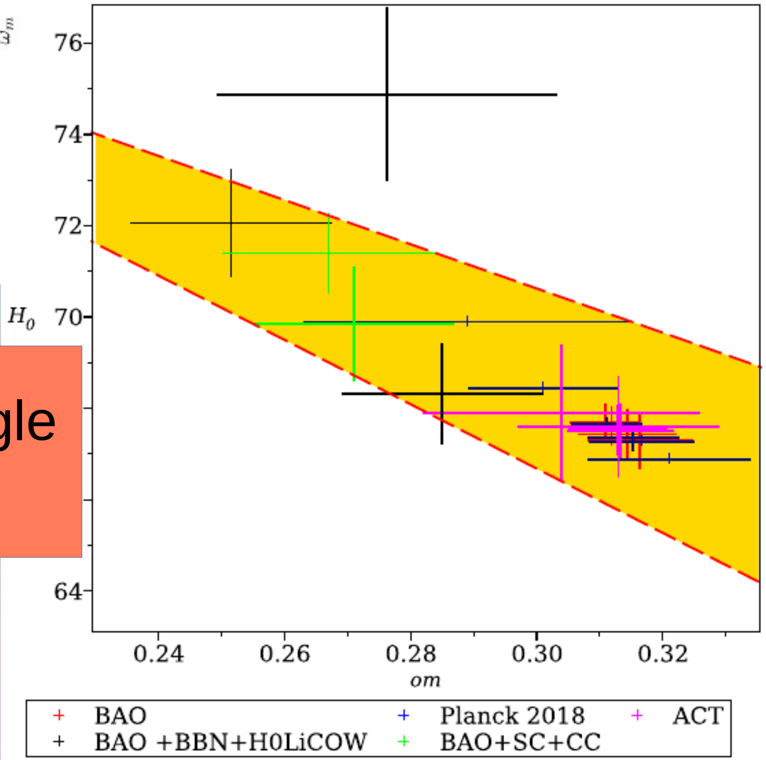
The problem: r_d, H_0 and Ω_m are coupled!



Knox & Millea (2020)
PRD 101, 043533



We need to disentangle them somehow!



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

Where + and + are from D.B&D.S. A&A 647, A38 (2021)

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 $\tilde{\chi}^2 = \tilde{\chi}^2_{BAO} + \tilde{\chi}^2_{SN}.$
- We use them to constrain DE models (CPL, pEDE, gEDE)

$$\tilde{\chi}^2 = C - \frac{B^2}{A} + \log\left(\frac{A}{2\pi}\right),$$

where

$$A = f^j(z_i) C_{ij} f^i(z_i),$$

$$B = \frac{f^j(z_i) C_{ij} v^i_{model}(z_i) + v^j_{model}(z_i) C_{ij} f^i(z_i)}{2},$$

$$C = v_j^{model} C_{ij} v_i^{model}.$$

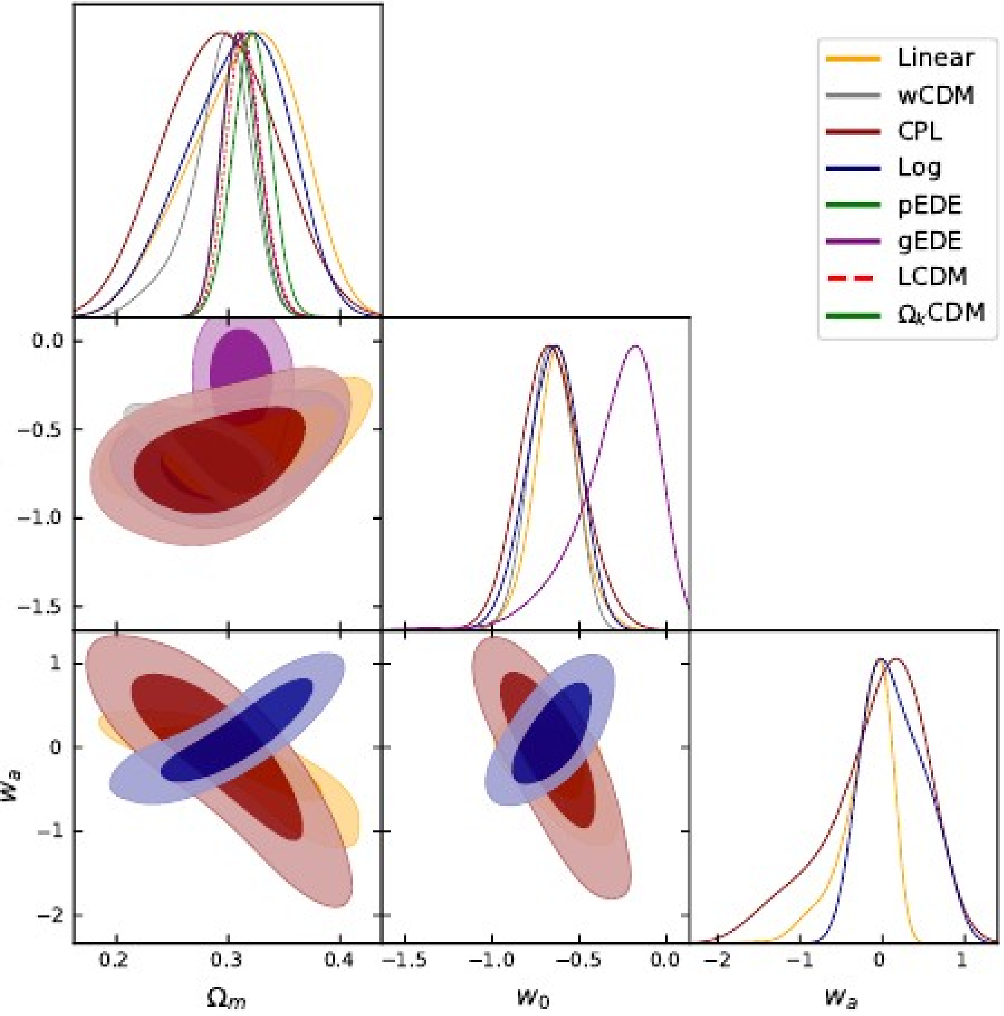
and

$$f(z) = \frac{1}{(1+z)\sqrt{|\Omega_K|}} \mathrm{sinn}\left[|\Omega_K|^{1/2} \int \frac{dz'}{E(z')}\right].$$

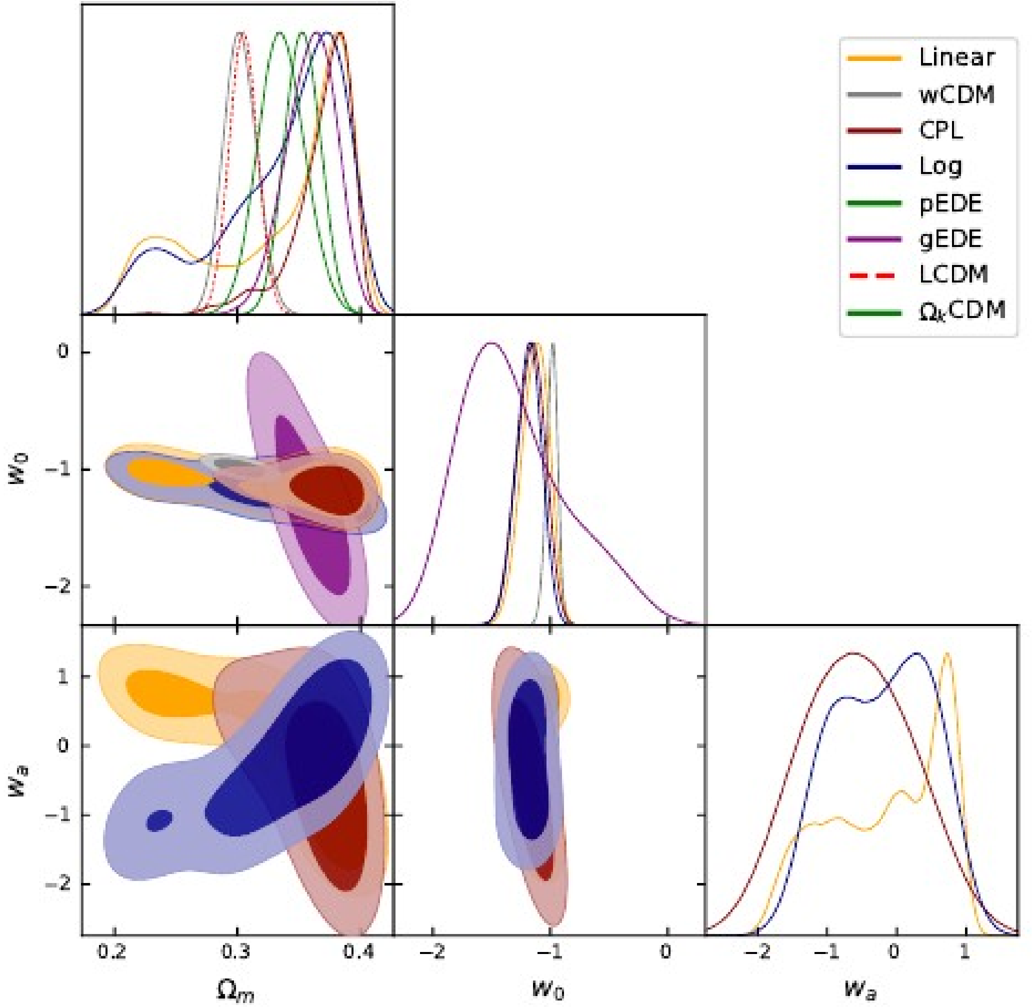
$$w(z) = \begin{cases} w_0 + w_a z & \text{Linear} \\ w_0 + w_a \frac{z}{z+1} & \text{CPL} \\ w_0 - w_a \log(z+1) & \text{Log} \end{cases}$$

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

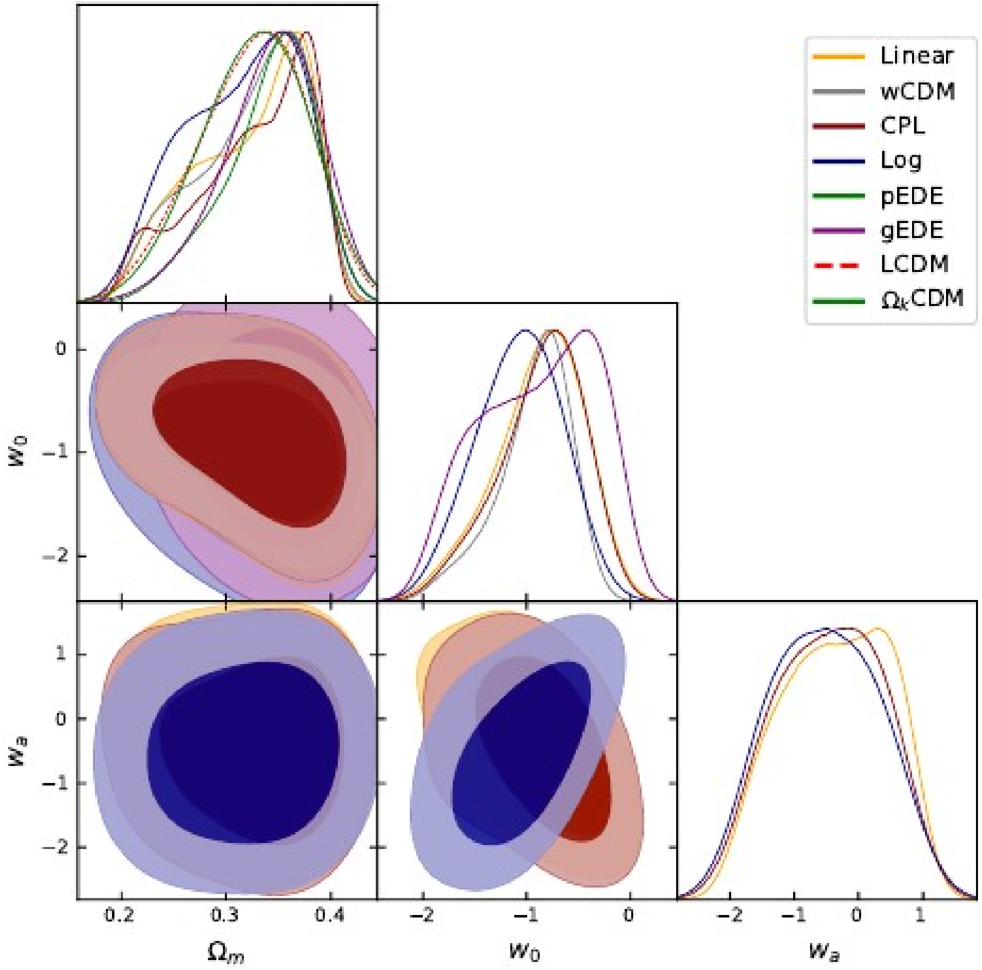
Angular BAO



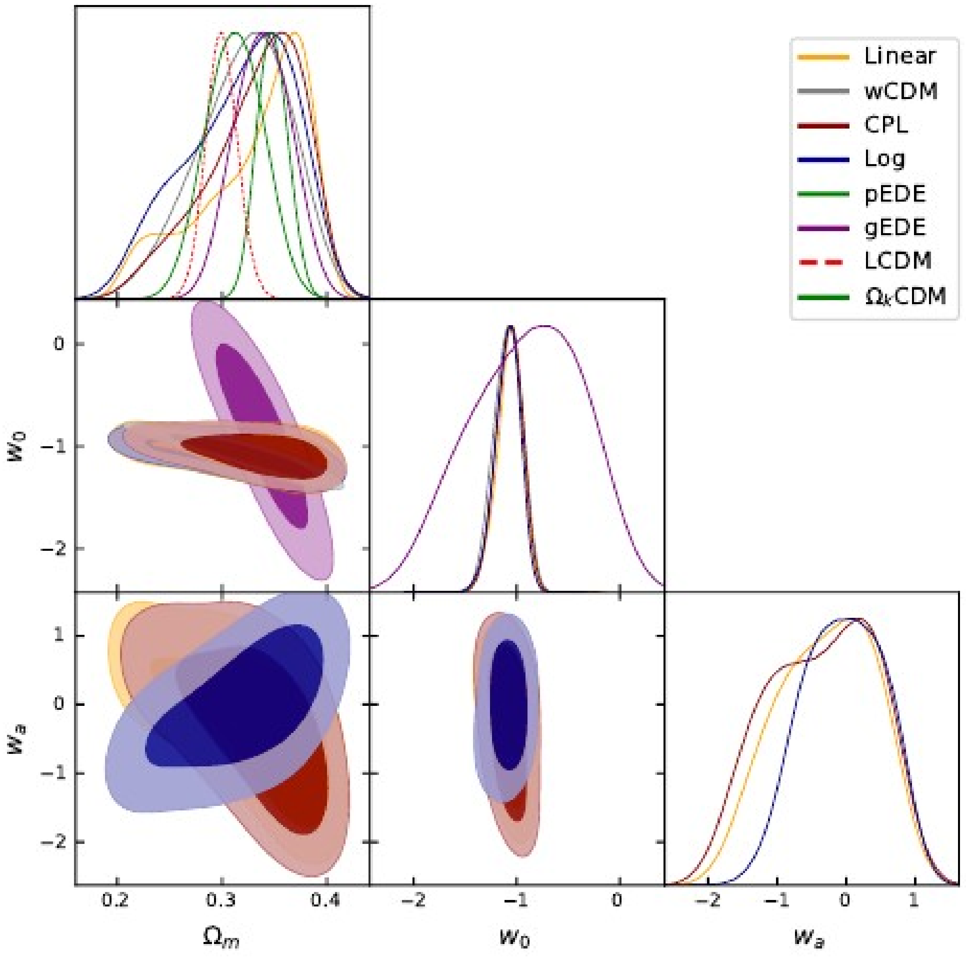
Angular BAO+SN



BAO


Linear
wCDM
CPL
Log
pEDE
gEDE
LCDM
ΩkCDM
w0
wa
Ωm
0.2
0.3
0.4
−2
−1
0
1

BAO+SN


Linear
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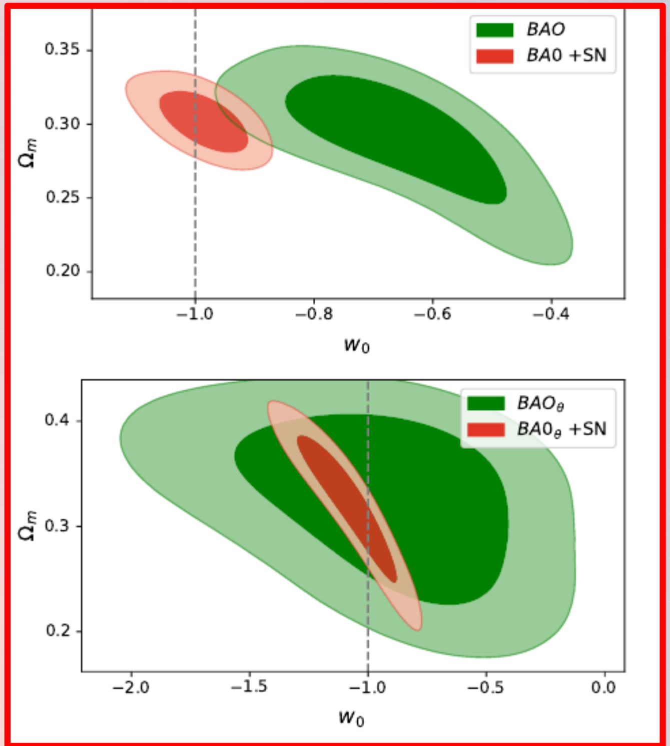
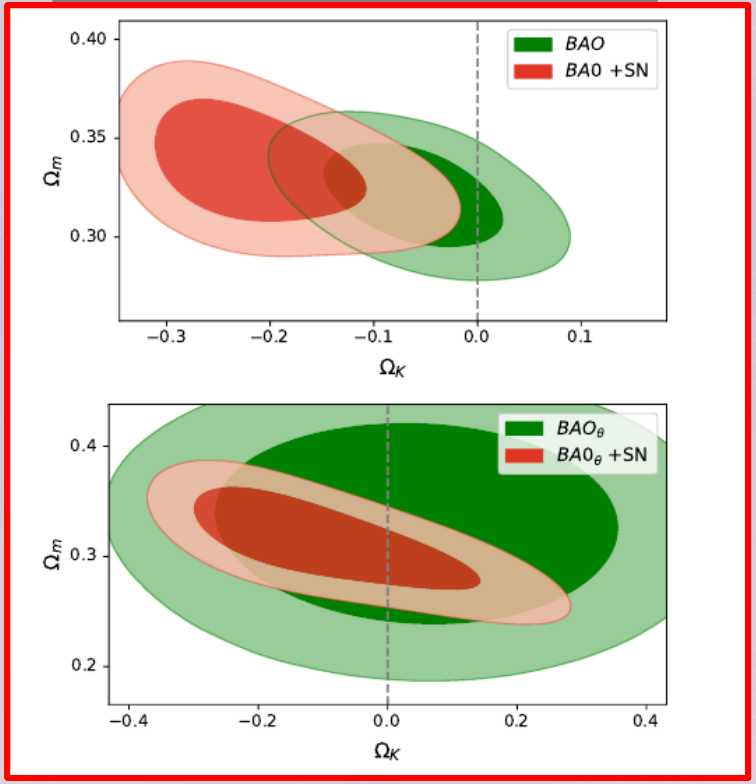
Different datasets, different models

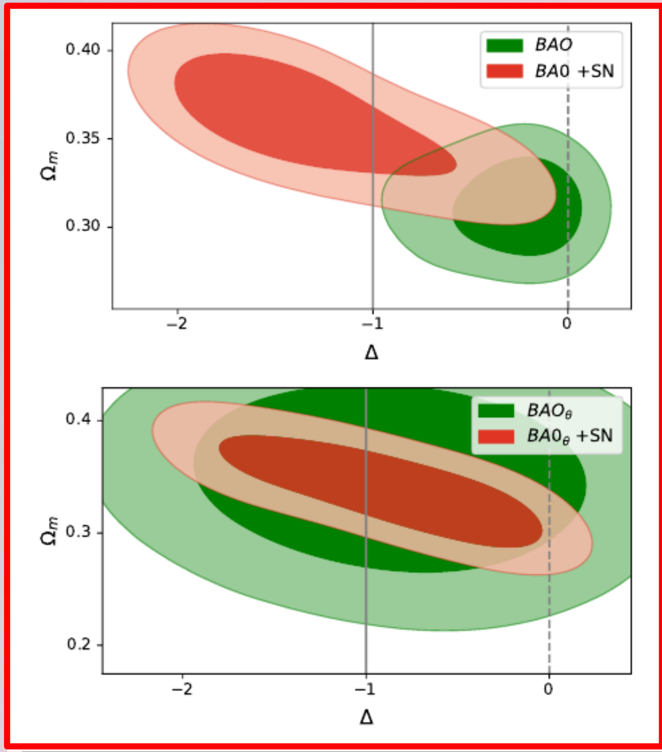
OkLCDM

wCDM

gEDE







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

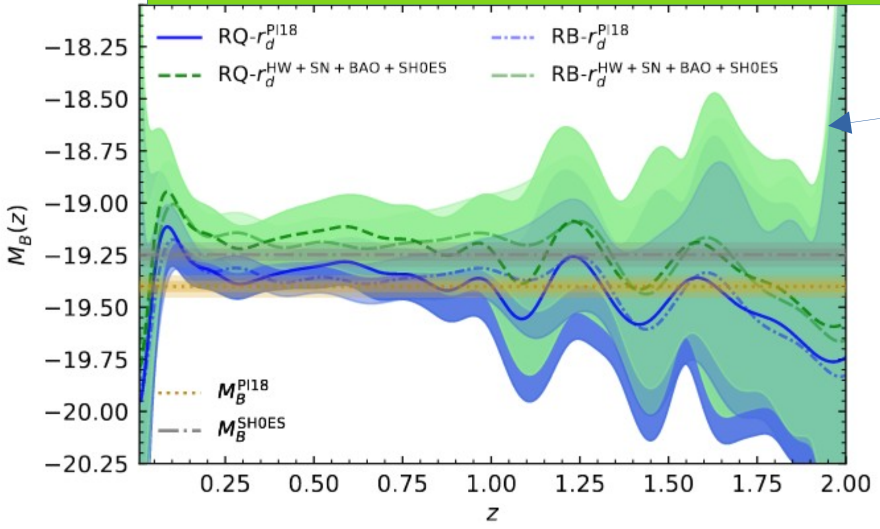
Numbers are compatible with earlier results:

- BAO + SN:
- w=-0.986 ± 0.045
- w_0=-1.18±0.139, w_a=-0.367± 0.672
- BAO$_\theta$+SN
- w=-1.08 ±0.14 S
- w_0=-1.09±0.09, w_a=-0.31±0.74
- **BAO + SN prefers a closed universe (Ω_k=-0.21±0.07)**
- **BAO$_\theta$+SN prefers a flat one (Ω_k=-0.09±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

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



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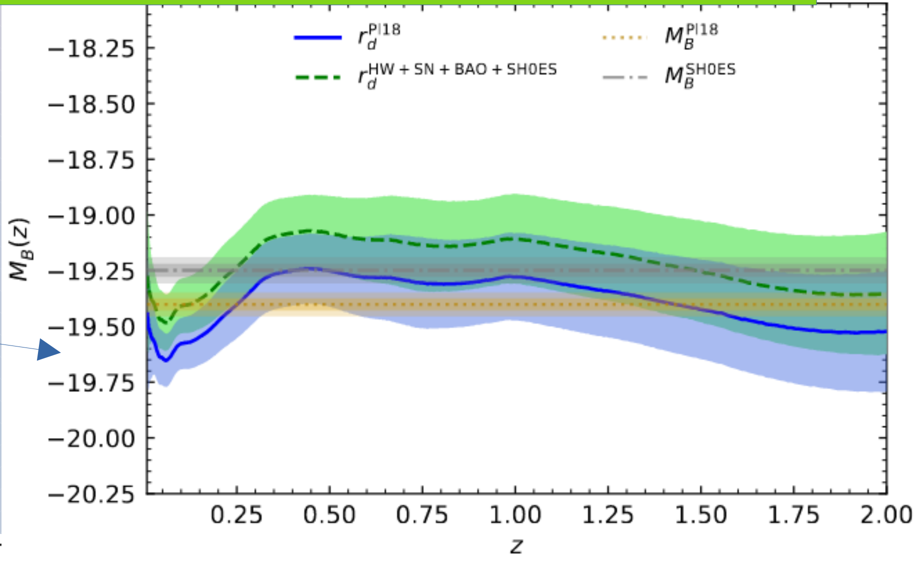
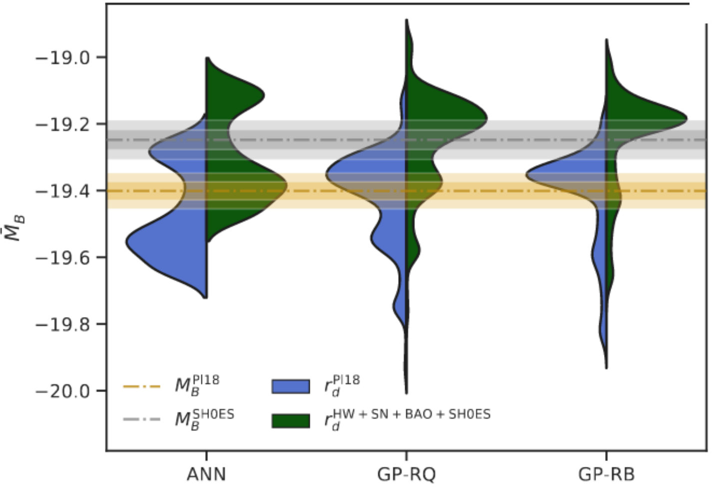




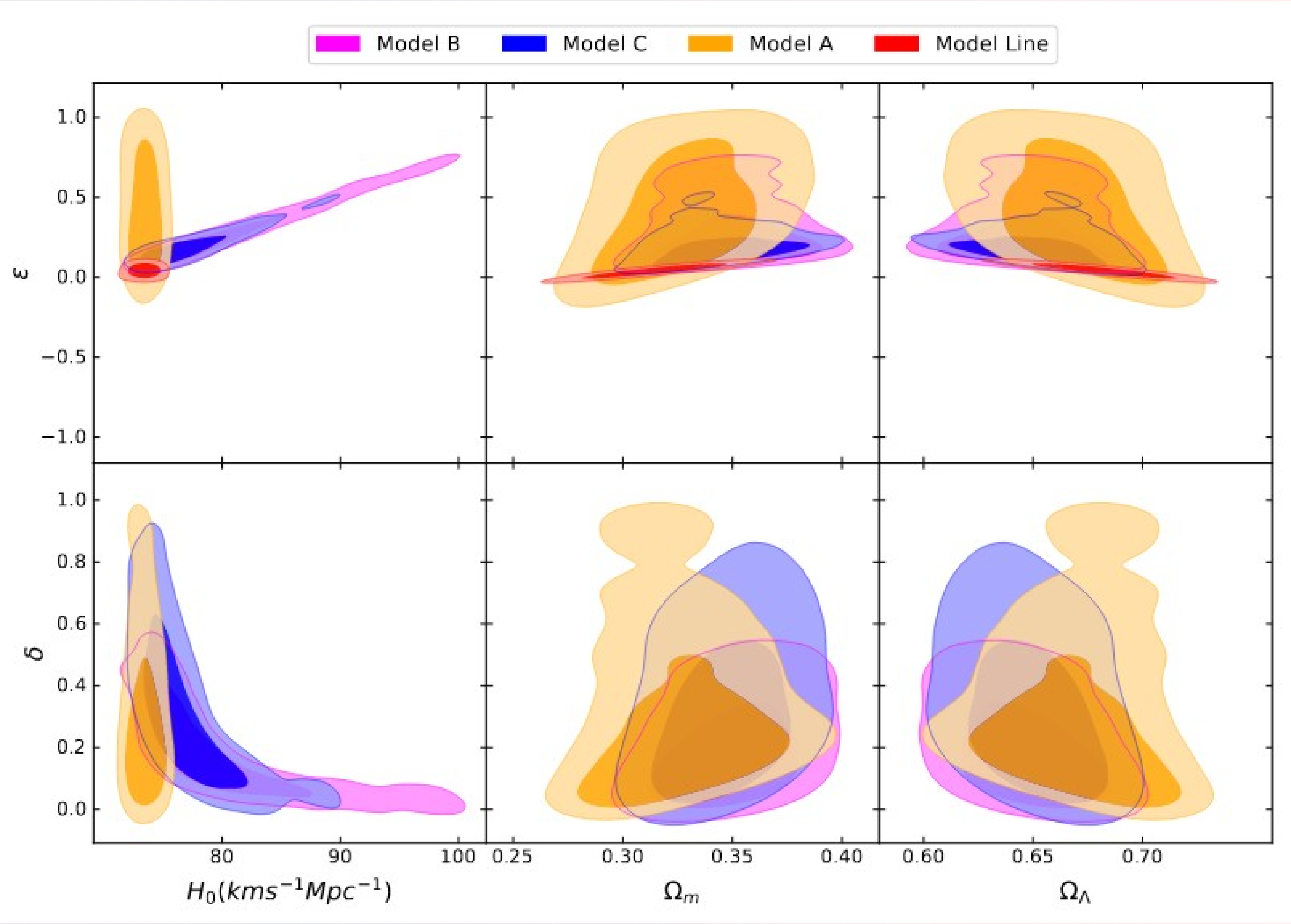
$$M_B = \mu_{Ia} - 5\log_{10}\left[(1+z)^2\left(\frac{D_A}{r_d}\right)_{\rm BAO}\cdot r_d\right] - 25\,, \quad (3a)$$

which gives uncertainties

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

We tested known models for the nuissance parameter

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

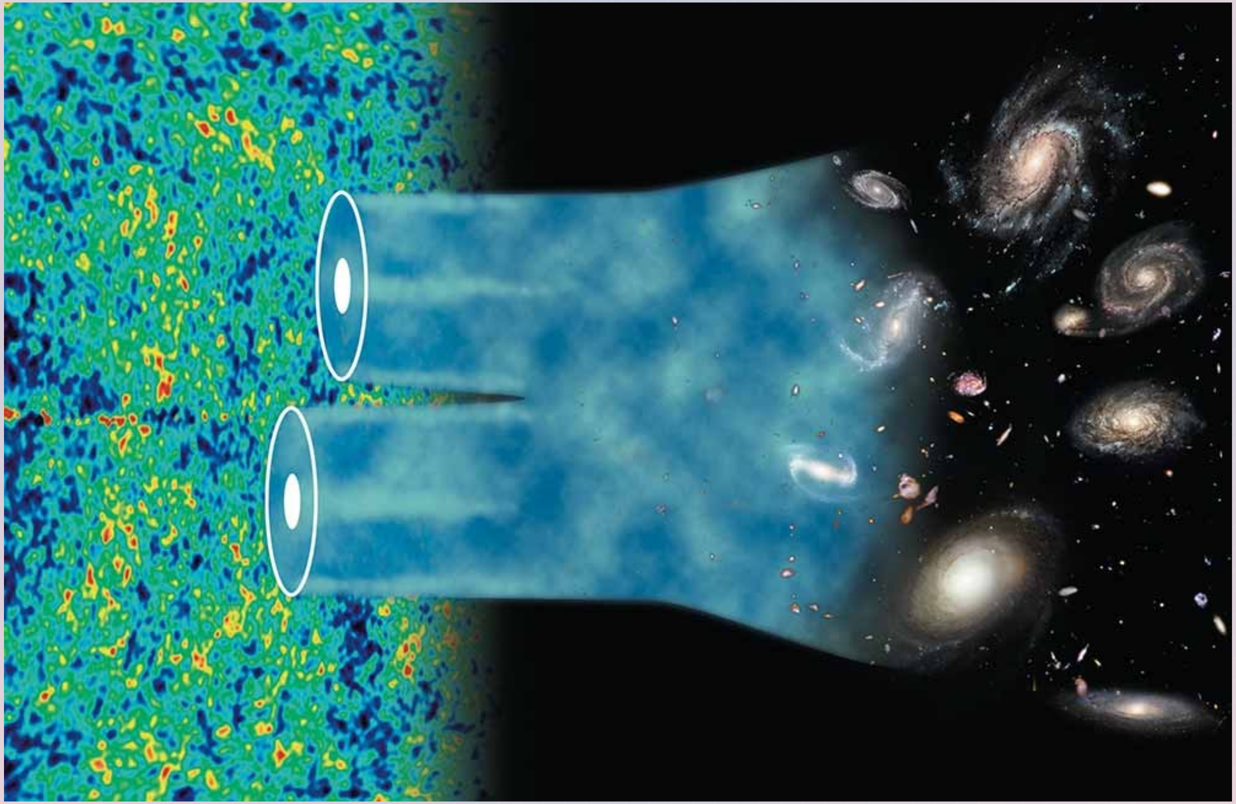


Conclusions:

- **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**

arXiv:2202.04677

Thank you for your attention!



Supported by grant KP-06-N 38/11