DE Models with Combined H0 · rd from BAO and CMB Dataset and Friends

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Based on A&A 668, A135 (2022), Universe 2022, 8(12), 631;
arXiv:2303.11271

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ИЯИЯЕ INRNE

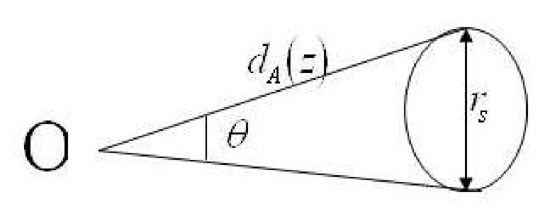
БЪЛГАРСКА АКАДЕМИЯ на НАУКИТЕ 1869

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 quantities ~ $r_d H_0/c$!

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

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

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

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

Then we solve the Friedmann equations:

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

$$E(z)^2 = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_{DE}(z),$$

How to avoid the degeneracy between H_0 and r_d

Add a prior on either or both

Integrate $H_0 r_d$ from the χ^2

Take $H_0 r_d$ as one common factor

Callibrate with early or late universe

- CMB
- SN
- Quasars
- GRBs

Advantage: the marginalization procedure removes $\mathbf{r_d}$ and $\mathbf{H_0}$ from our equations

Disadvantage: **one cannot discuss the tensions**

"Constraining the dark energy models using Baryon Acoustic Oscillations: An approach independent of $H_0 \cdot r_d$"   D. S., David Benisty, A&A 668, A135 (2022)

"Model selection results from different BAO datasets -- DE models and Ω_KCDM" ,D.S., Proc. of the "Corfu Summer Institute 2022

Advantage: simpler to understand and preserves some information about $\mathbf{r_d}$ and $\mathbf{H_0}$, so that one can at least check how close to the expected the solution is

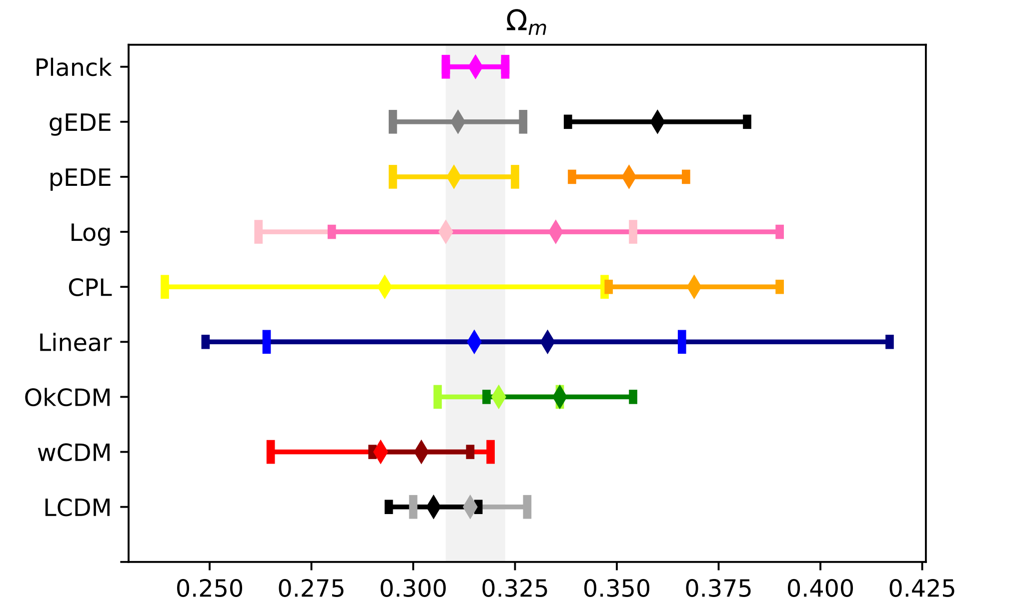
Disadvantage: not new, but still useful

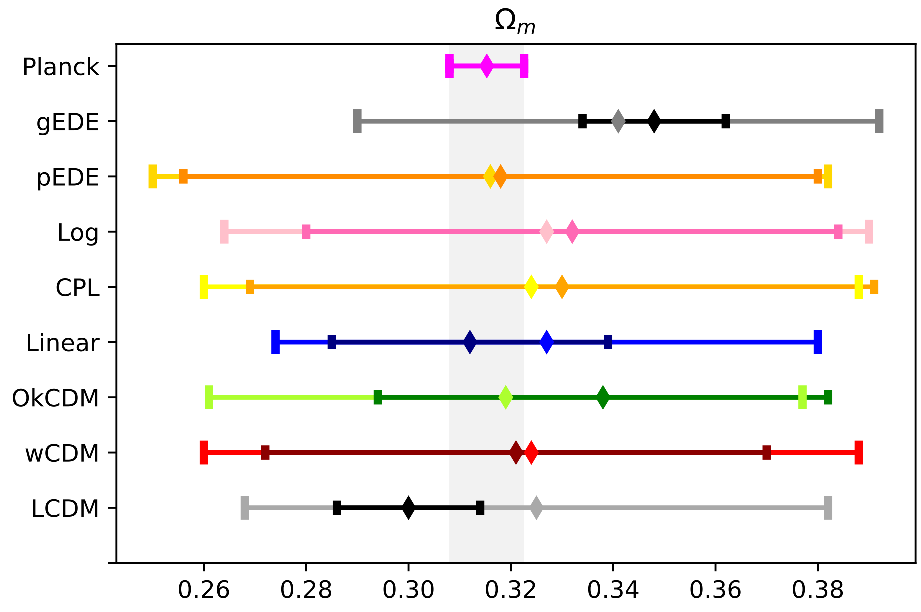
“DE models with combined $H_0 \cdot r_d$ from BAO and CMB dataset and friends” D.S., Universe 2022, 8(12), 631;

The DE models we consider (+GEDE)

Model	$\Omega_{DE}(z) = \Omega_\Lambda \times$	$w(z)$
CPL	$\exp\left[\int_0^z \frac{3(1+w(z'))dz'}{1+z'}\right]$	$w_0 + w_a \frac{z}{z+1}$
BA	$(1+z)^{3(1+w_0)}(1+z^2)^{\frac{3w_1}{2}}$	$w_0 + z\frac{1+z}{1+z^2}w_1$
LC	$(1+z)^{(3(1-2w_0+3wa))}e^{\frac{9(w_0-wa)z}{(1+z))}}$	$\frac{(-z+z_c)w_0+z(1+z_c)w_c}{(1+z)z_c}$
JPB	$(1+z)^{3(1+w_0)}e^{\frac{3w_1z^2}{2(1+z)^2}}$	$w_0 + w_1\frac{z}{(1+z)^2}$
FSLLI	$(1+z)^{3(1+w_0)}e^{\frac{3w_1}{2}\arctan(z)}(1+z^2)^{\frac{3w_1}{4}}(1+z)^{-\frac{3}{2}w_1}$	$w_0 + w_1\frac{z}{1+z^2}$
FSLLII	$(1+z)^{3(1+w_0)}e^{-\frac{3w_1}{2}\arctan(z)}(1+z^2)^{\frac{3w_1}{4}}(1+z)^{+\frac{3}{2}w_1}$	$w_0 + w_1\frac{z^2}{1+z^2}$
PEDE	$\frac{1-\tanh(\bar{\Delta}\log_{10}(\frac{1+z}{1+z_t}))}{1+\tanh(\bar{\Delta}\log_{10}(1+z_t)}$	$-\frac{(1+\tanh[\log_{10}(1+z)])}{3\ln 10}-1$

If we remove H_0 and r_d, we can compare only Ω_m





3d BAO and BAO+SN

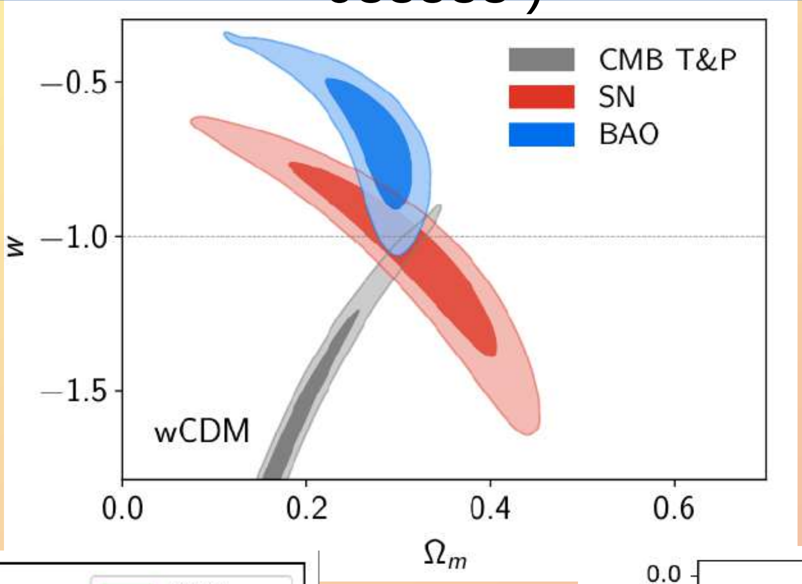
The lighter colors are BAO, the darker ones are the BAO+SN

2d BAO and BAO+SN

SDSS IV → $\Omega_m \sim 0.25 - 0.31$

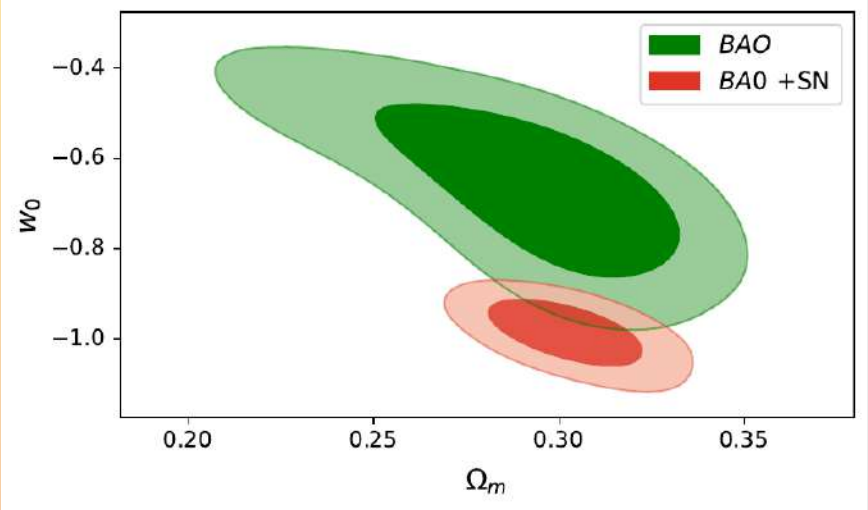
$\Omega_m \sim 0.23 - 0.29$ ← Nunes et al., MNRAS, 497,2, 2020

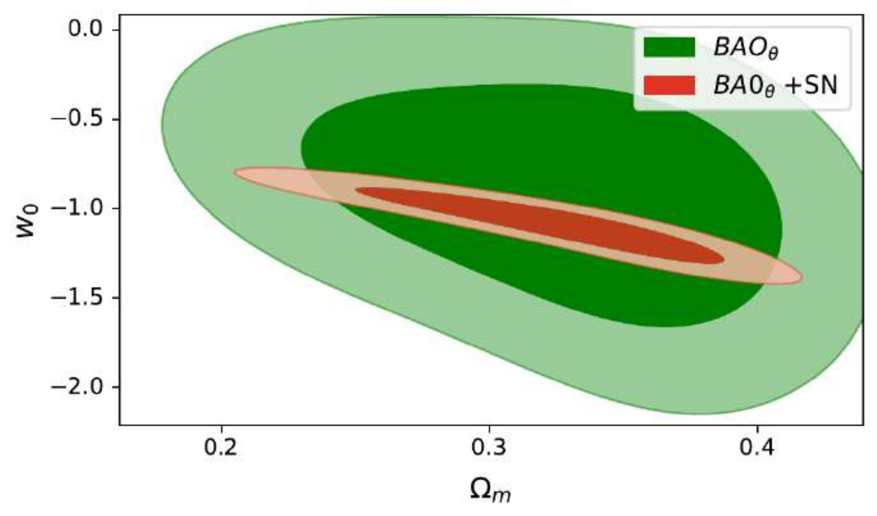
Comparison with SDSS IV (Alam et al., Phys.Rev.D 103 (2021) 8, 083533)



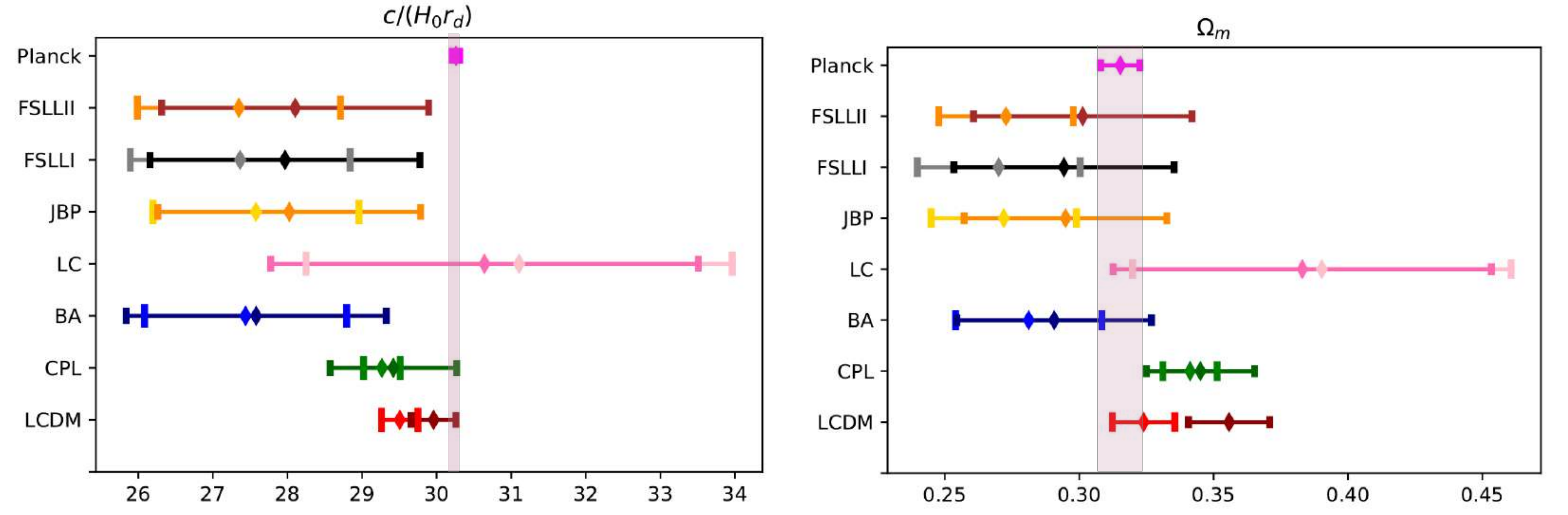
BAO

BAO$_\theta$



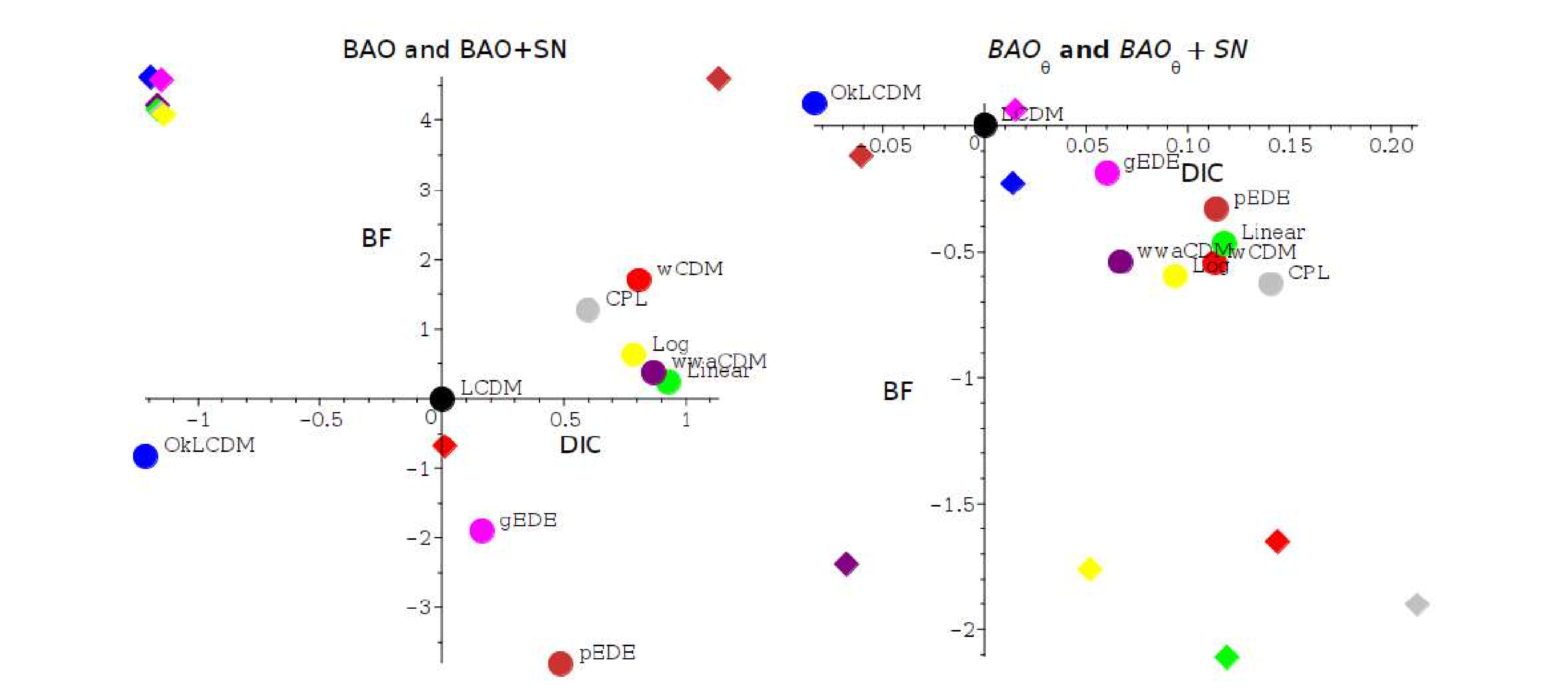


If we use H_0r_d as a common factor:



BAO+CMB (darker) and
BAO+CMB+SN+GRB(lighter)

Model selection (the dataset effect):

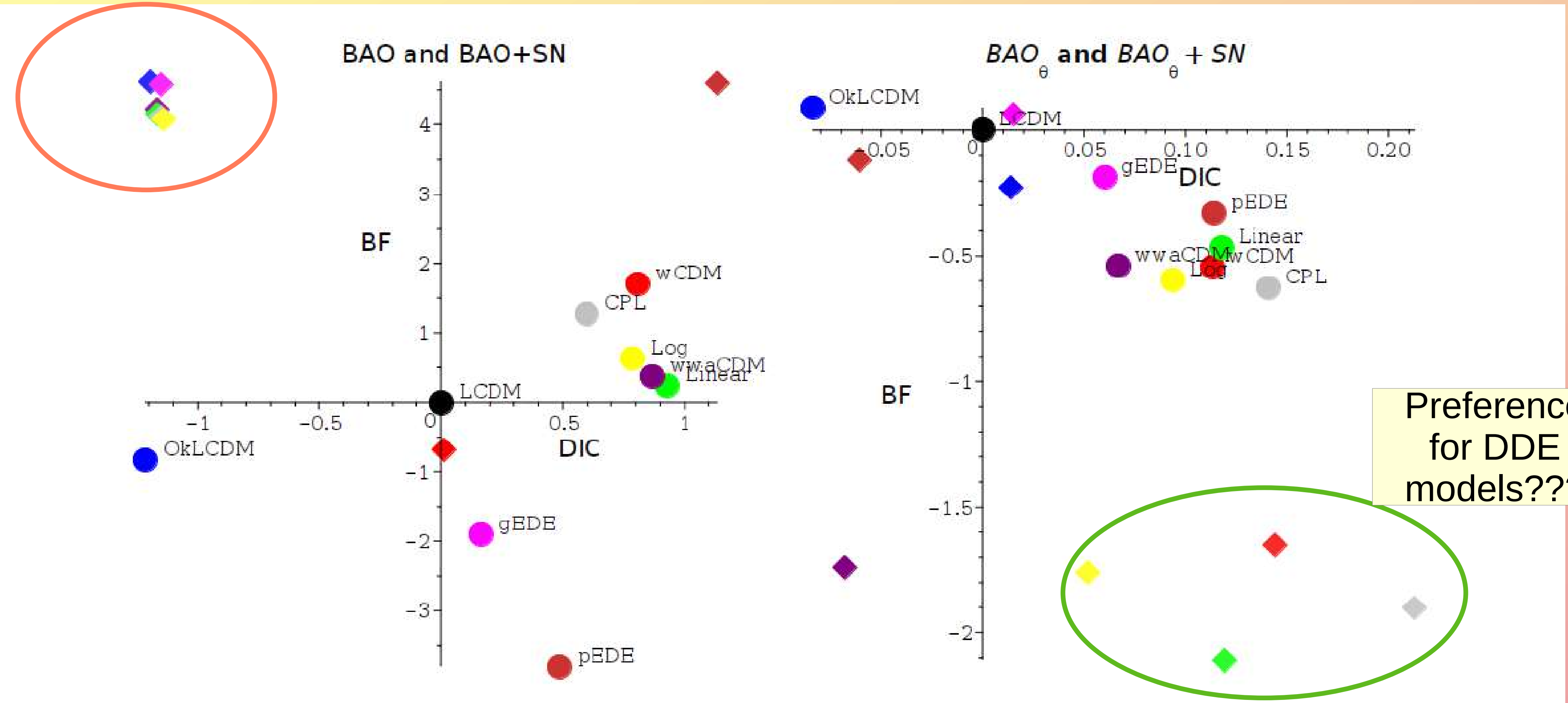


BAO
BAO+SN

$$B_{ij} = \frac{p(d|M_i)}{p(d|M_j)}$$

$$\mathrm{DIC} = 2\overline{(D(\theta))} - D(\bar{\theta})$$

Preference for LCDM



Preference for DDE models???

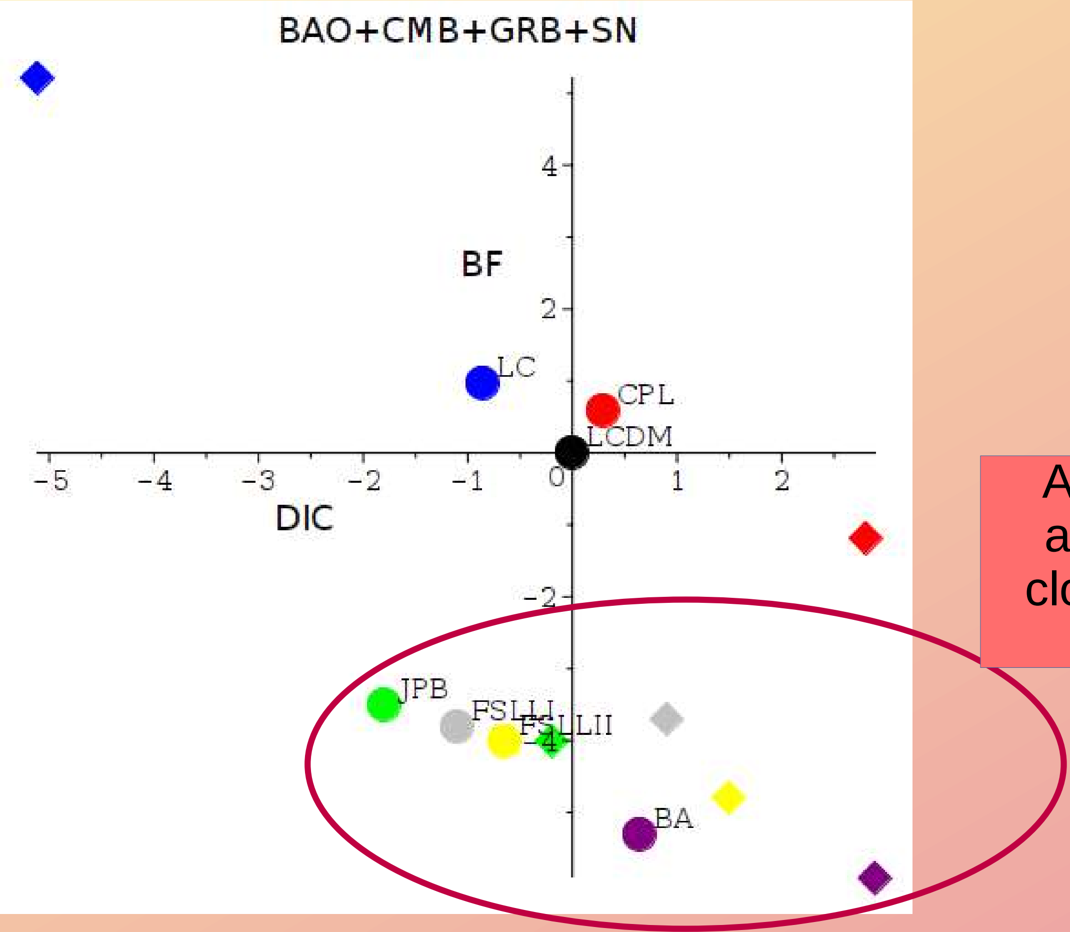
BAO
BAO+SN

$$B_{ij} = \frac{p(d|M_i)}{p(d|M_j)}$$

$$\mathrm{DIC} = 2\overline{D(\theta)} - D(\bar{\theta})$$

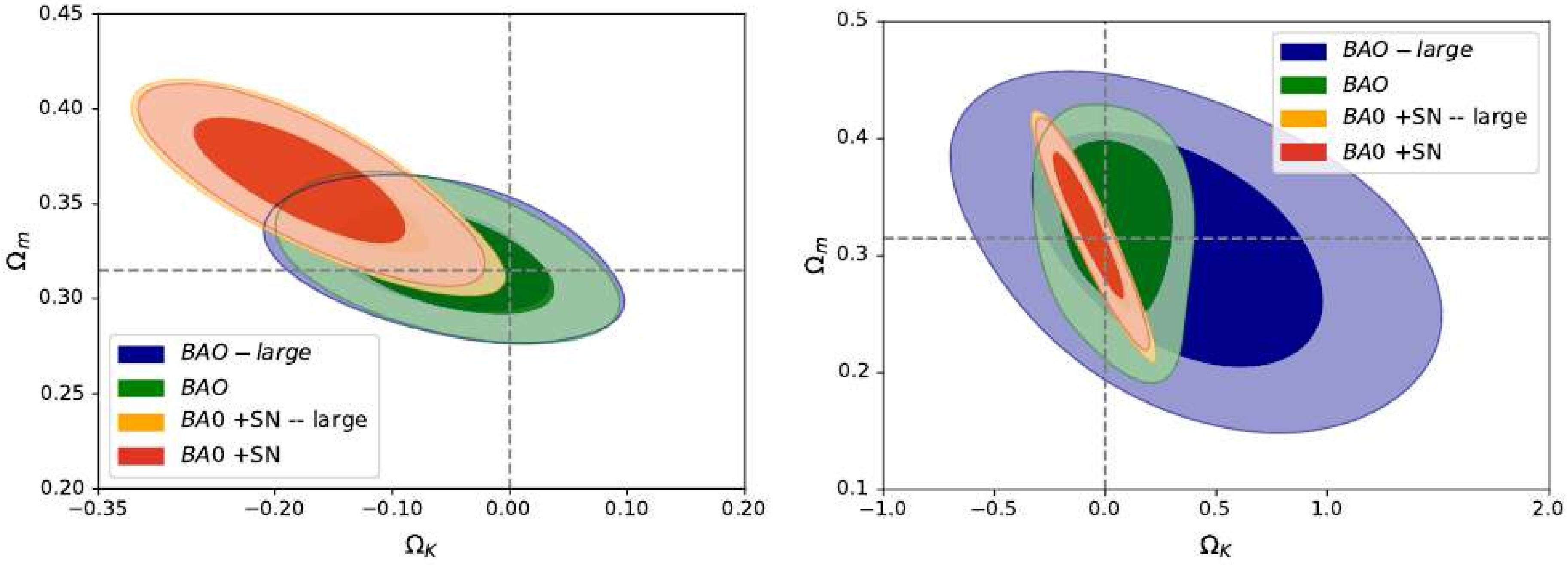
$$\Delta\mathrm{IC}_{\mathrm{model}} = \mathrm{IC}_{\Lambda\mathrm{CDM}} - \mathrm{IC}_{\mathrm{model}}$$

Model selection (the dataset effect) :



All models but LC and CPL are very close or better than LCDM

The curvature question



BAO

Different sensitivity for Ω_K

BAO_θ

Conclusions:

- BAO alone are not able to constrain DE models
- Adding "Friends" decreases the errors
- The tensions remain! Now it transfers to Ω_m!
- The curvature Ω_K and the preference for LCDM/DE differ between the two datasets

- Numbers are compatible with earlier results:
- BAO + SN:
- $w=-0.986 \pm 0.045$
- $w_0=-1.18\pm0.139$, $w_a=-0.367\pm 0.672$
- BAO_θ+SN
- $w=-1.08 \pm0.14$
- $w_0=-1.09\pm0.09$, $w_a=-0.31\pm0.74$
- **BAO + SN prefers a closed universe ($\Omega_k=-0.21\pm0.07$)**
- **BAO_θ+SN prefers a flat one ($\Omega_k=-0.09\pm0.15$)**

Main conclusion: the H_0 tensions is not here by design, but now we see differences in Ω_m between transversal vs. mixed BAO datasets and between BAO and BAO+SN

Another use of BAO – time delays

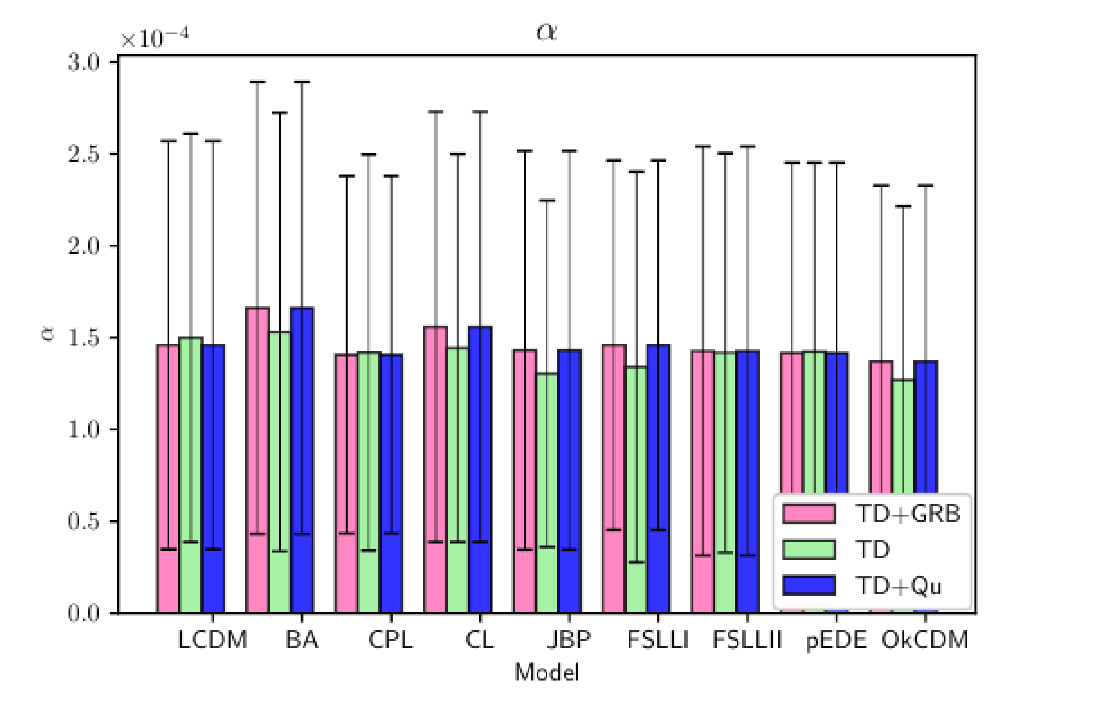
Measuring TD could be a signature for QG on E<E_{Pl}

$$\Delta t_{LIV} = \frac{\Delta E}{E_{QG}} \int_0^z (1+z') \frac{dz'}{H(z')}$$

$$\frac{\Delta t_{obs}}{1+z} = a_{LIV} K + \beta \,,$$

$$K \equiv \frac{1}{1+z} \int_0^z \frac{(1+\tilde{z})\, d\tilde{z}}{h(\tilde{z})} \,.$$

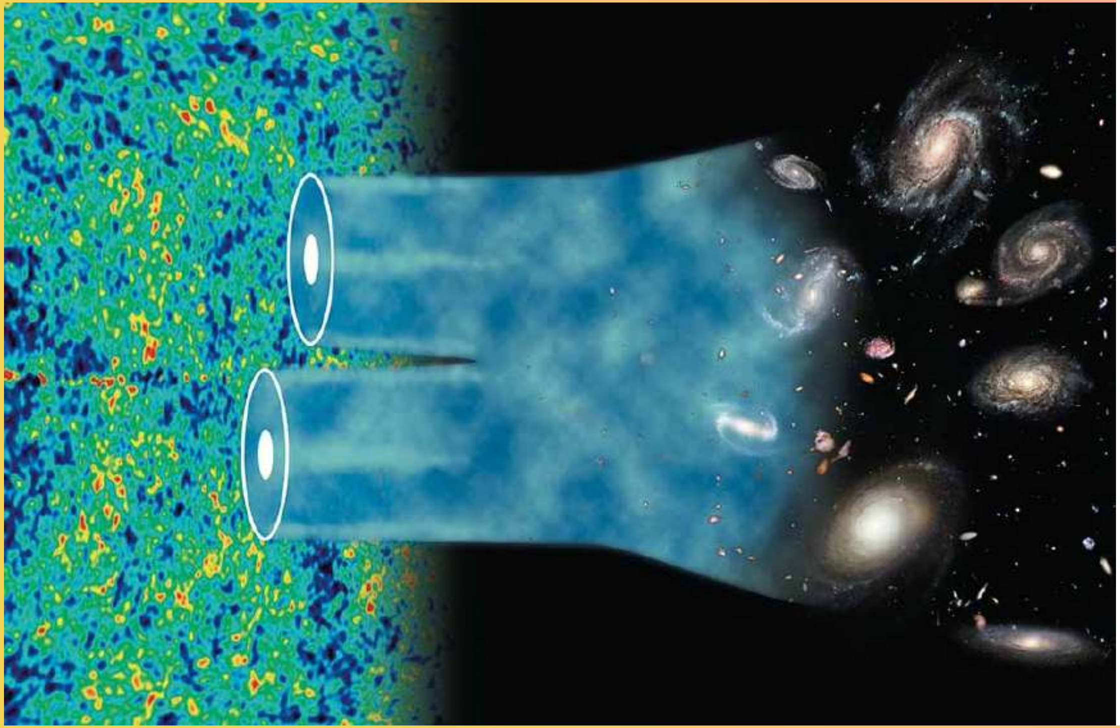
BAO+TD+CMB+SN+GRB/Qua



- Cosmology is stable
- LIV effects depend on cosmology ~ 10%

„Effect of the cosmological model on LIV constraints from GRB Time-Delays datasets„ DS, arXiv:2305.06504

Thank you for your attention!



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