Effect of the cosmological model on LIV constraints from GRB Time-Delays datasets

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Time delays - overview

- **Classical** TD from interaction between gravity and particles and fields

  -- **Observed** in Shapiro delay, graviational and cosmological redshift

  -- Independent of the energy of the photons

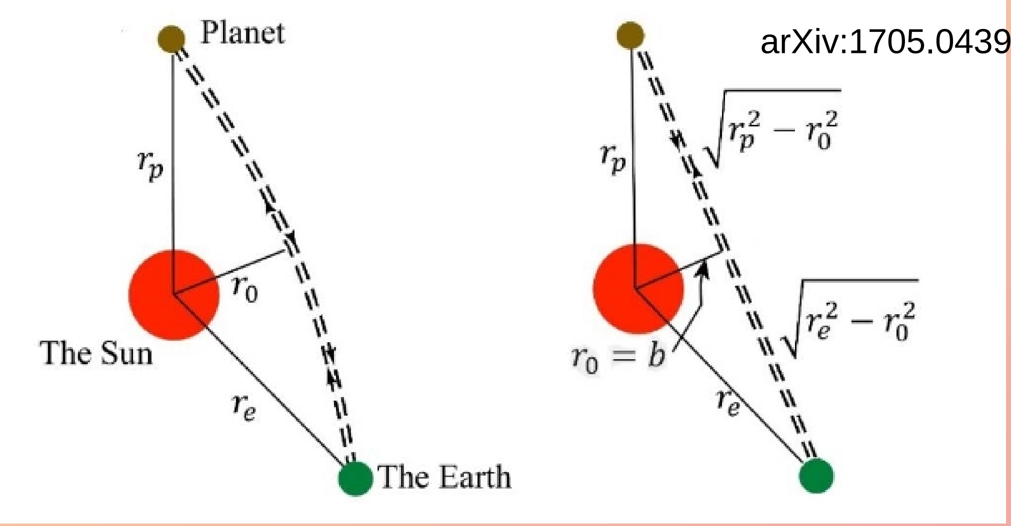
- **Quantum** Gravity TD from String theory, Loop QG, etc

  -- modified dispersion relations, i.e. dependent of the energy of the photon

  -- should affect all messengers (neutrino, GW, photons)

- -- **Strict constraints from GRBs (E_{QG}>7xE_{Pl}, Vasileiou et al 2013, E_{QG}>0.5xE_{Pl} Acciari et al 2020)**

$$E^2 = p^2c^2\left[1 - s_{\pm}\left(\frac{E}{\xi_n E_{QG}}\right)^n\right],$$



arXiv:1705.0439

Time delays in GRBs

Gamma-Ray Bursts

-- high energies ($E_{iso}>10^{52}$erg)

-- high redshifts (z~9)

-- numerous observations

A perfect probe for TD but a lot of difficulties

-- Progenitor model vs GRB light curve

-- Intrinsic vs propagational effects

-- What about the cosmology?

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

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

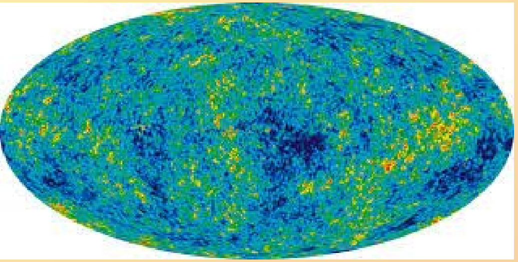
$$K \equiv \frac{1}{1+z} \int_0^z \frac{(1+\tilde{z})\, d\tilde{z}}{h(\tilde{z})} \,.$$

$$a_{LIV} \equiv \Delta E / (H_0 E_{QG})$$

$$\Delta t_{\rm obs} = \Delta t_{\rm int} + \Delta t_{\rm QG} + \Delta t_{\rm spec} + \Delta t_{\rm DM} + \Delta t_{\rm gra}$$

To investigate cosmology, we combine combine GRB TD data with other astrophysical sources

CMB



NASA/WMAP

z~1100

GRB

Cruz deWilde / Swift / NASA

z~6

BAO

BOSS

z~2

SN

NASA/ESA/CSA WEBB

z~2

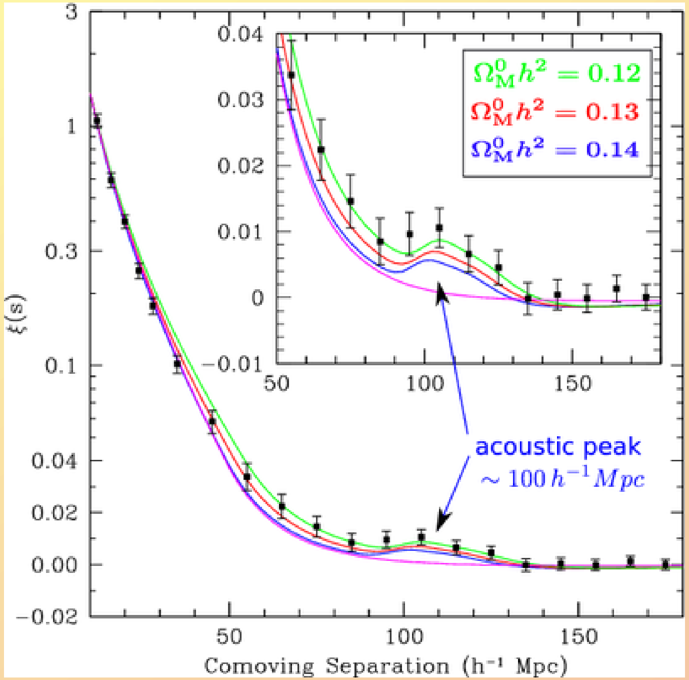
For all, we solve the Friedmann equations:

$$H(z)/H_0 = E(z) \qquad E(z)^2 = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_k(1+z)^2 + \Omega_{DE}(z),$$

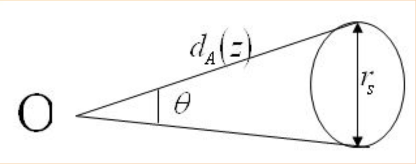
The DDE models we consider

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	$\frac{1-\tanh(\bar{\Delta}\log_{10}(\frac{1+z}{1+z_t}))}{1+\tanh(\bar{\Delta}\log_{10}(1+z_t))}$	$-\frac{(1+\tanh[\log_{10}(1+z)])}{3\ln 10}-1$

BAO – „standard ruler“ in cosmology



- Baryonic acoustic oscilations are 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 (Planck 2018: r_d=147.5 Mpc, z_d=1059, z_*=1100)
- Measured by looking at the large scale structure of matter



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

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

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

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

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

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

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

The quantities we use

- SN/GRB

$$\mu_B(z) - M_B = 5\log_{10}\left[d_L(z)\right] + 25\,,$$

- CMB distance priors

$$l_A = (1+z_*)\frac{\pi D_A(z_*)}{r_s(z_*)},$$

$$R \equiv (1+z_*)\frac{D_A(z_*)\sqrt{\Omega_m}H_0}{c},$$

- BAO

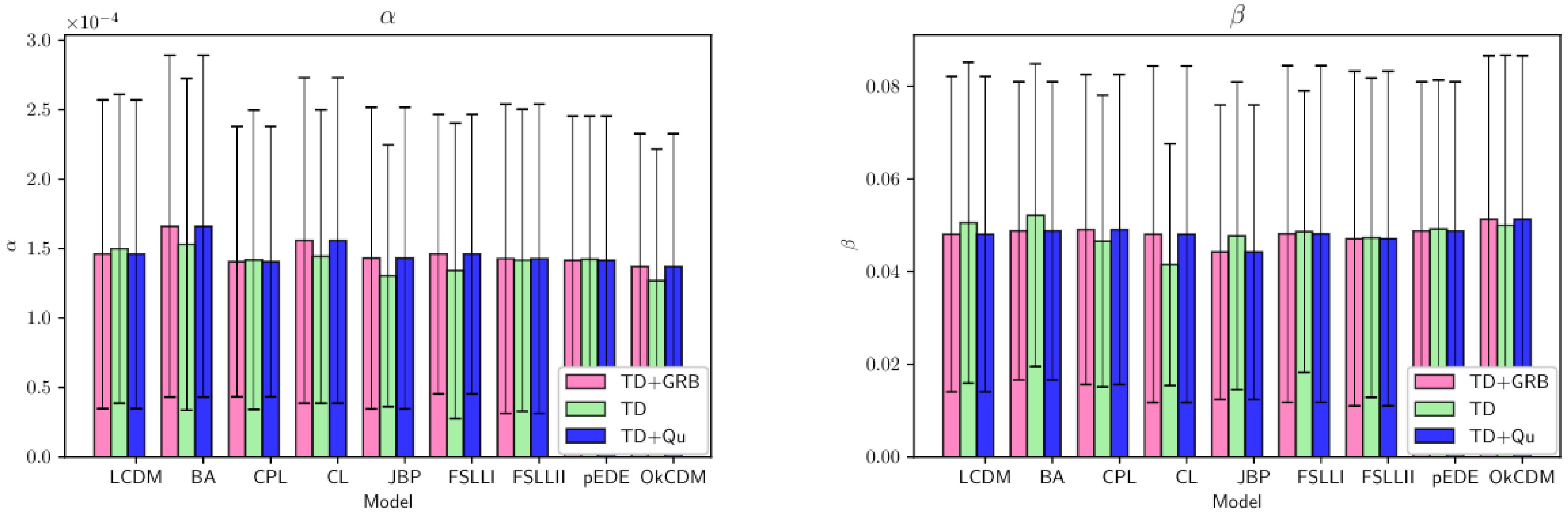
$$D_A = \frac{c}{(1+z)H_0\sqrt{|\Omega_k|}}\mathrm{sinn}\left[|\Omega_k|^{1/2}\int_0^z \frac{dz'}{E(z')}\right]$$

where

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

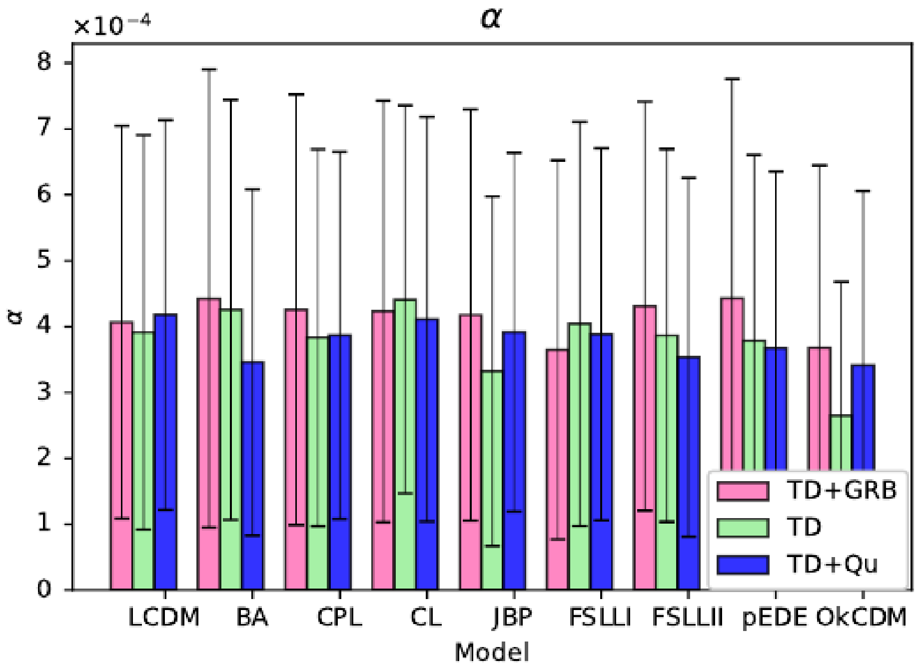
All depend on c/H_0r_d so we take it as 1 factor!

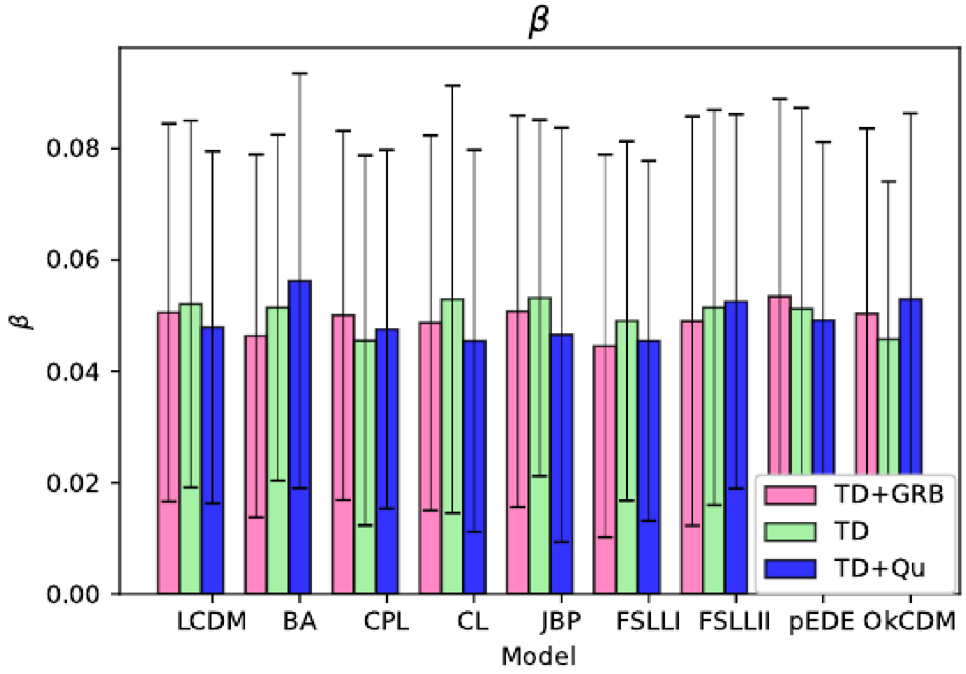
The results - TD1



Ellis et al. 2006,
35 GRBs,
wavelet method

The results - TD2

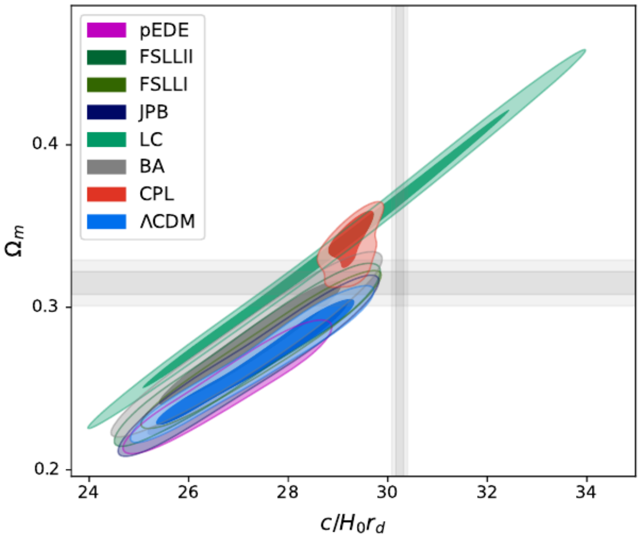


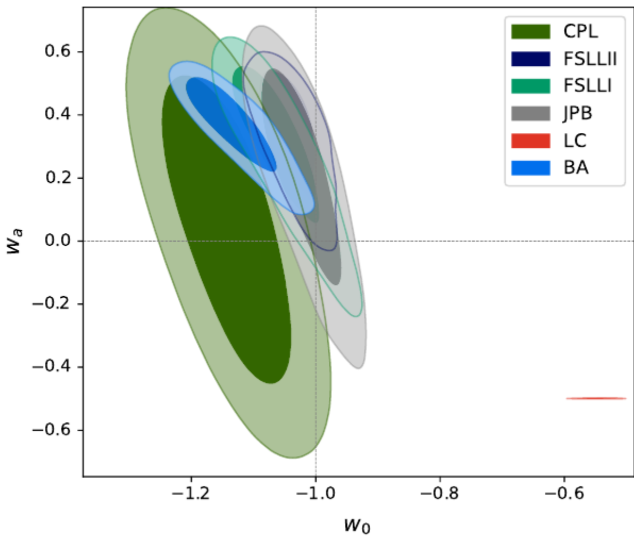


Vardanyan et al. 2022,
49 GRBs,
descrete CCF

In both cases - we see deviations between DE models

TD1

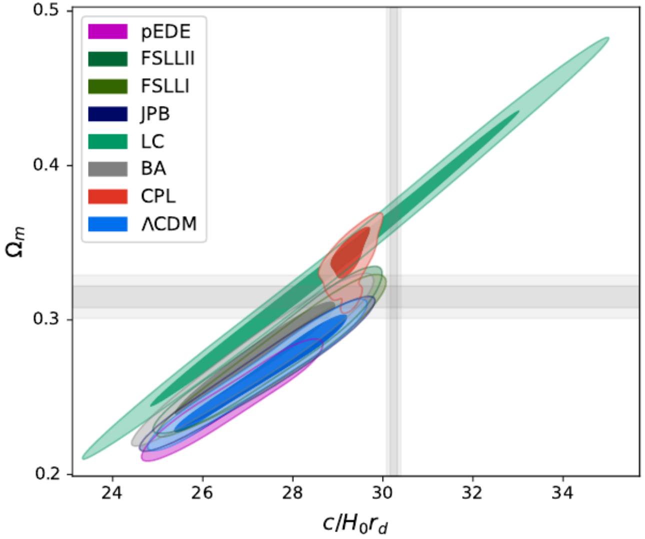


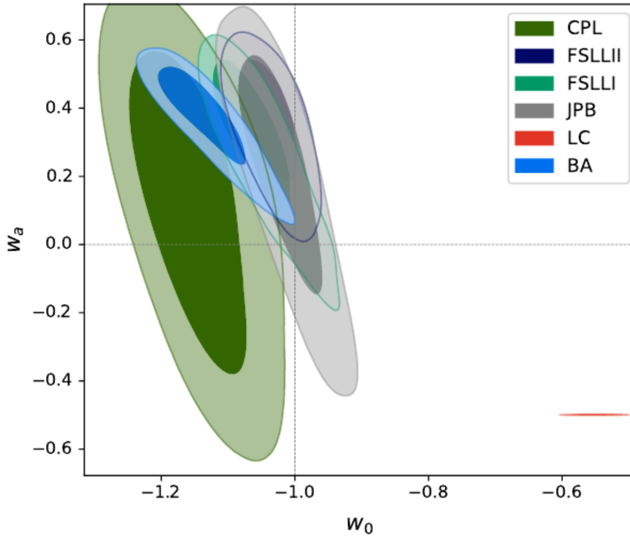


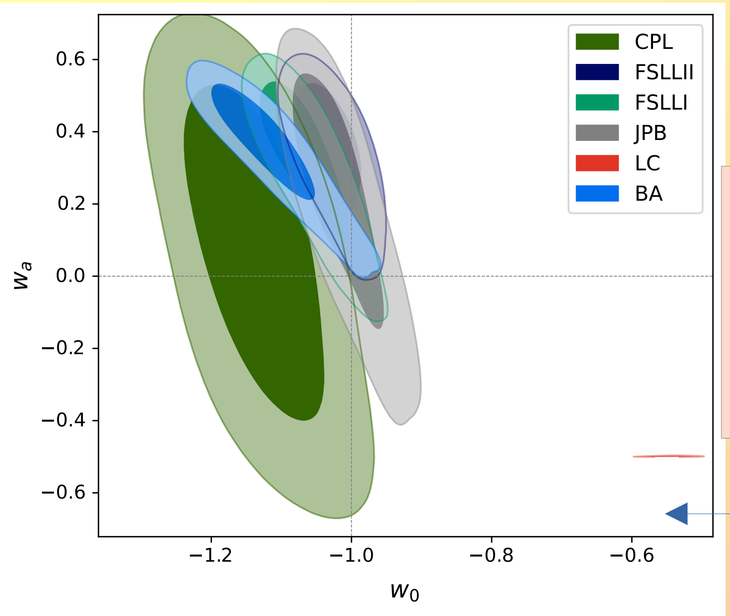
The cosmology
TD1 and TD2 look very similar)

In both cases c/H_0r_d~28!!!

TD2



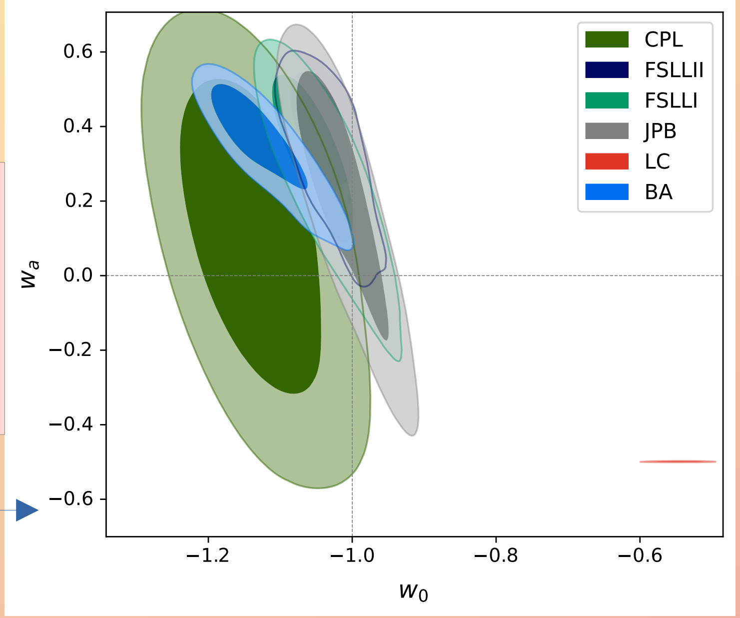


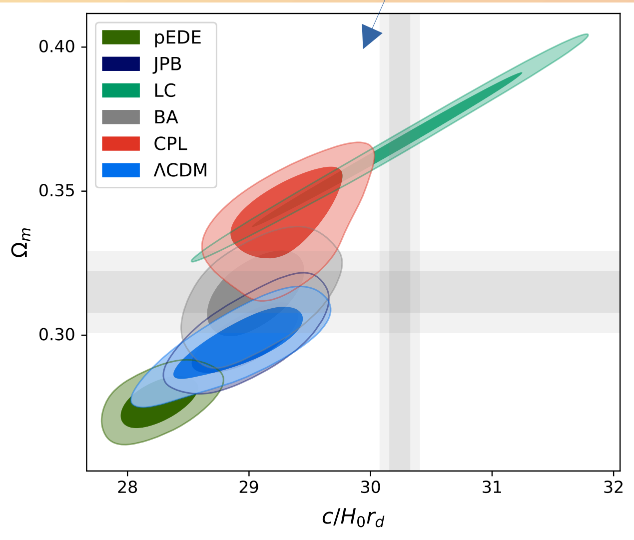


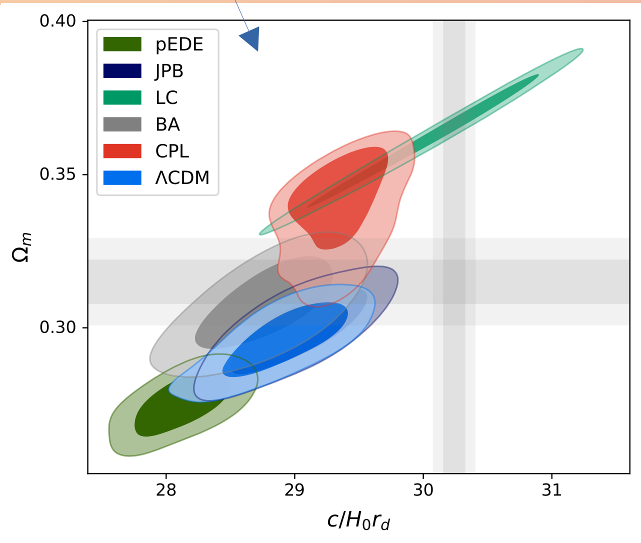
If we fix cosmology to c/H_0r_d~30

TD1

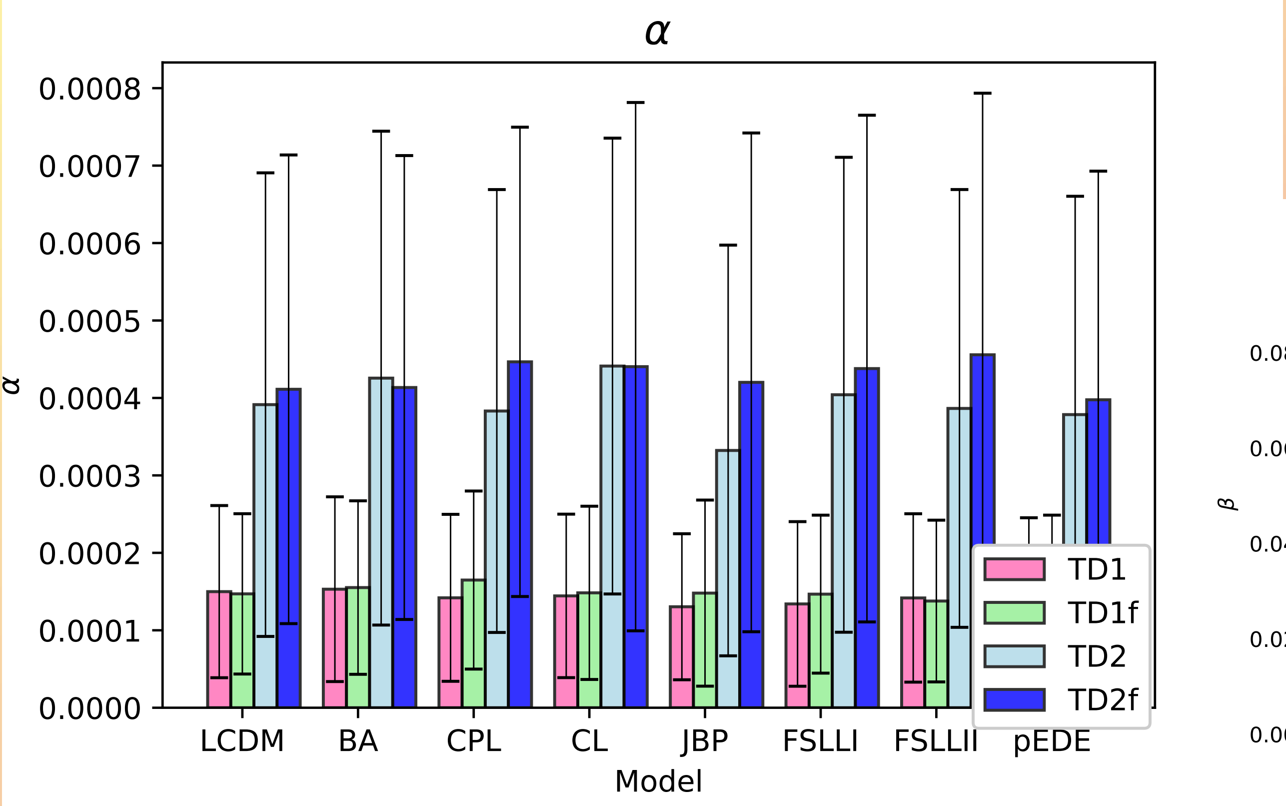
TD2

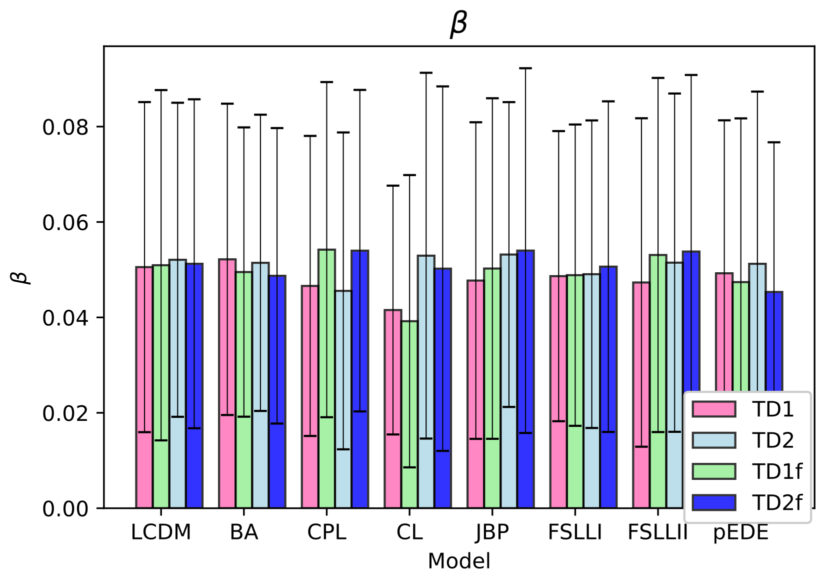




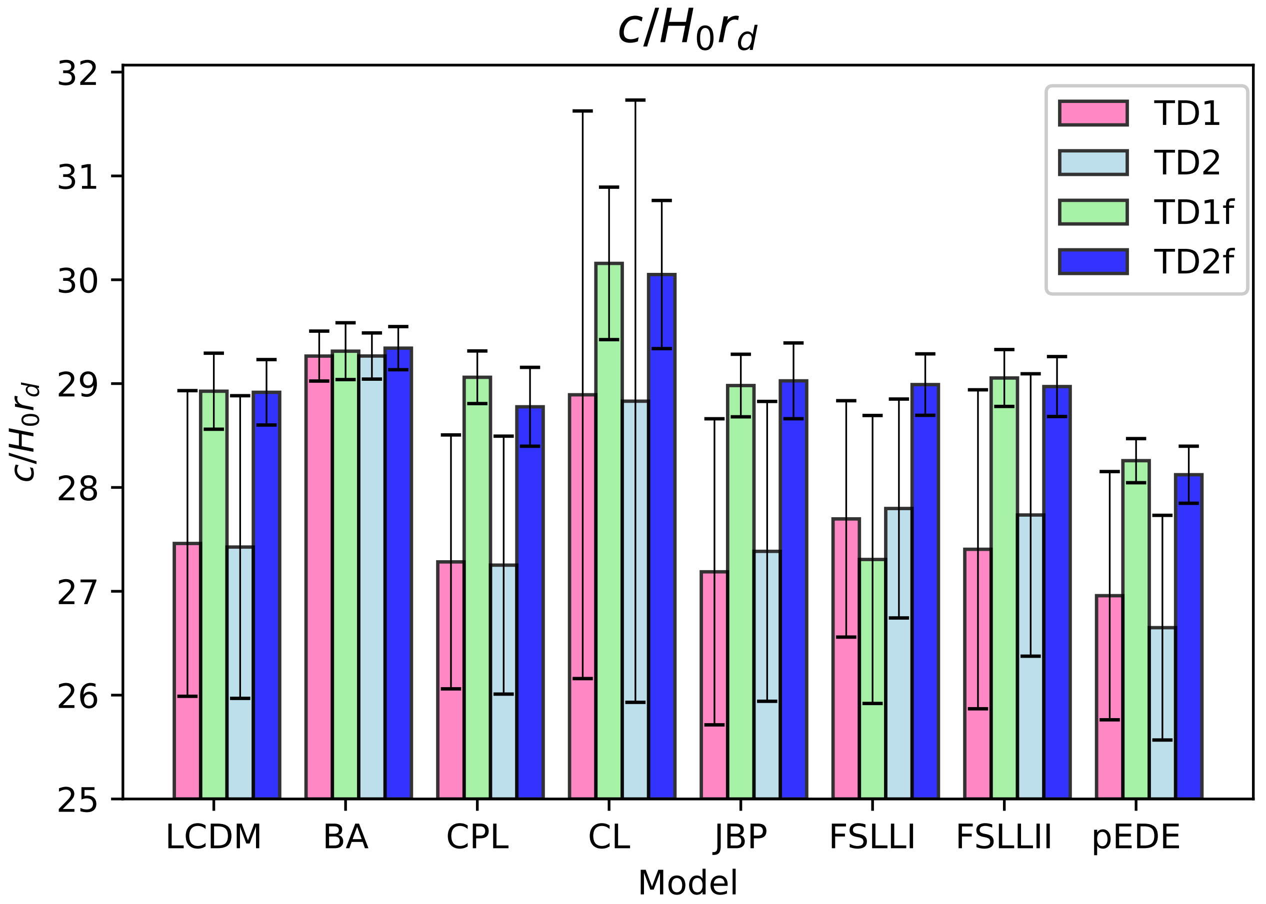


Or if we compare fixed cosmology with non-fixed cosmology...





The c/H_0r_d parameter



Conclusions:

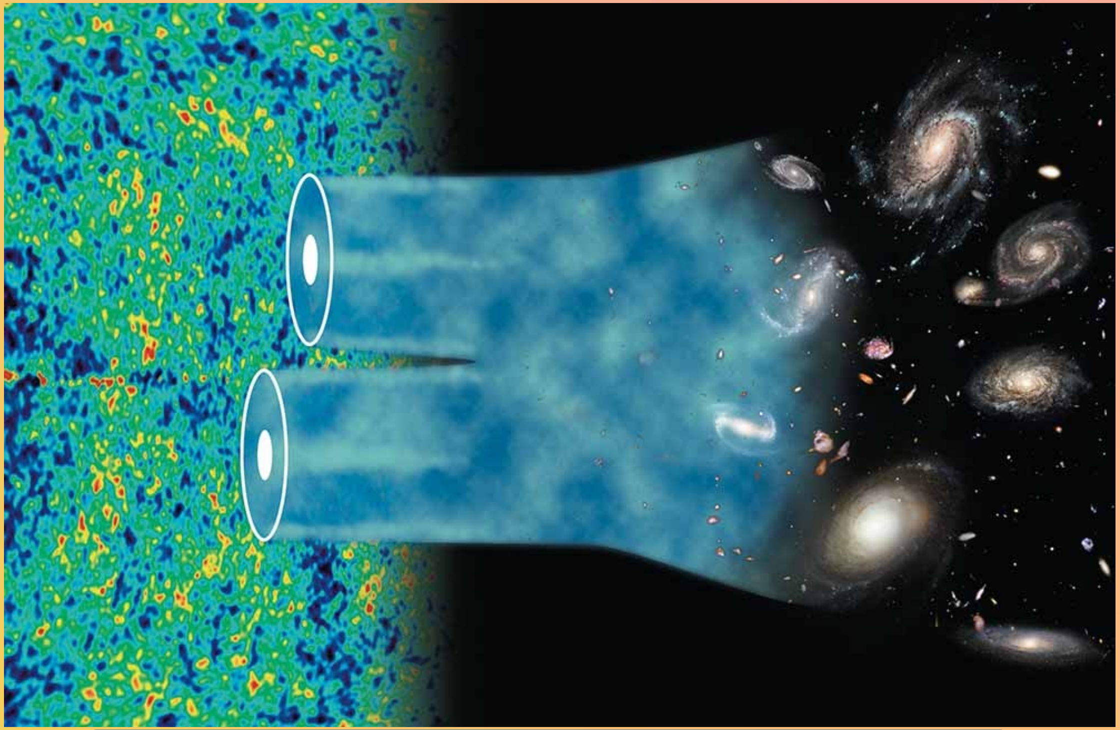
Variation within the model larger than variation between models!
Cosmology can account for at least 10% of any constraint on LIV effects!
We need better understanding of intrinsic effects!

- c/H_0r_d~27 – lower than pure DDE c/H_0r_d~30
- Lower than Planck's matter density
- Similar DDE parameters
- Some limited preference for CPL, BA, FSLLII
- TD1 $E_{QG} > 5 \times 10^{17}$ GeV
- TD2 $E_{QG} > 1.1 \times 10^{17}$ GeV

- 20%-60% deviation due to cosmology
- Consistent with previous results

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

Thank you for your attention!



Thanks to COST CA18108 for the   the financial support and the **inspiration!**

Datasets/Methods

- Two GRB TD datasets (TD1 – 35 pts, TD2 – 49 pts)
- CMB distance prior (2 pts)
- BAO (15 pts)
- SN (40 binned pts)
- GRB/Quasars (162/24 pts)

- MCMC with Polychord
- Marginalized SN and GRB
- DDE models
- We remove H_0 and r_d!

$$\tilde{\chi}^2_{SN,GRB} = D - \frac{E^2}{F} + \ln\frac{F}{2\pi}$$

$$D = \sum_i \left(\Delta\mu\, C^{-1}_{cov}\, \Delta\mu^T\right)^2,$$

$$E = \sum_i \left(\Delta\mu\, C^{-1}_{cov}\, E\right),$$

$$F = \sum_i C^{-1}_{cov},$$

$$\chi^2_{BAO} = \sum_i \frac{\left(\vec{v}_{obs} - \vec{v}_{model}\right)^2}{\sigma^2},$$

$$\chi^2_{TD} = \sum_i \frac{\left(\vec{\Delta t}_{obs} - \vec{\Delta t}_{model}\right)^2}{\sigma^2},$$

$$\chi^2 = \chi^2_{BAO} + \chi^2_{CMB} + \chi^2_{SN} + \chi^2_{TD}(+\chi^2_{GRB})(+\chi^2_{Qua}).$$