Late-time Accelerating Universe in Teleparallel Gravity

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Outline

- The H_0 **tension** problem
- The **Teleparallel Gravity** (TG) formalism
- Constraining parameters in **TG models** using **Markov Chain Monte Carlo (MCMC) technique** and the **updated version of Pantheon, Pantheon+ data set**
- Conclusion

Motivation

Tensions in the Hubble expansion

- The ΛCDM model has been called into question – due to open problems such as the H_0 tension

		H_0 [km s^{-1} Mpc^{-1}]
Indirect	P18	67.4 ± 0.5
	Atacama Cosmology Telescope	67.9 ± 1.5
	↕ **$\sim 5\sigma$ tension** ↕	
Direct	R22 (SH0ES Team)	73.04 ± 1.04
	H0LiCOW Collaboration	$73.3^{+1.7}_{-1.8}$

Theories beyond GR

Teleparallel Gravity

Einstein 1915: **General Relativity** (GR),

- Metric tensor ($g_{\mu\nu}$)
- **Levi-Civita Connection:** Curvature, Torsion-free
- Einstein-Hilbert action

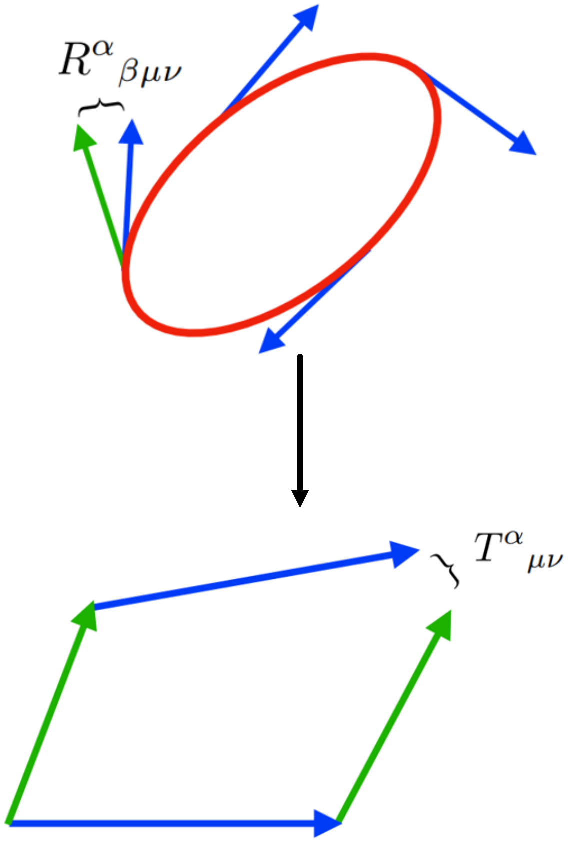
Einstein 1928: **Teleparallel Equivalent of GR**

- Tetrad ($e^a{}_\mu$): relates the tangent space
- **Weitzenböck Connection:** Curvatureless, Torsion

$$\boxed{S = -\frac{1}{16\pi G}\int d^4x\; e[T]}$$

T = Torsion Scalar

Beltran Jimenez et al. (2019)



Modified Teleparallel Gravity, *f*(*T*)

•Curvature-Torsion
Relation: $R = -T + B$

- Inspired by *f*(*R*) gravity: ***f*(*T*) gravity**

$f(T)$

$$\boxed{S = \frac{1}{16\pi G}\int d^4x\, e[-T + F(T)] + S_{\text{matter}}}$$

- Taking a flat FRLW cosmology
- Friedmann equations:

$$H^2 = \frac{8\pi \mathrm{G}}{3}\rho_m - \frac{\boldsymbol{F(T)}}{\boldsymbol{6}} + \frac{\boldsymbol{T}}{\boldsymbol{3}}\boldsymbol{F_T}$$

$$\dot{H} = -\frac{4\pi G(\rho_m + p_m)}{1 - \boldsymbol{F_T} - \boldsymbol{2TF_{TT}}}$$

$$\boxed{T \equiv -6H^2}$$

The Data

Observational Expansion Data Sets (*1*)

- Cosmic Chronometers (CC): Spectroscopic dating that depend on **stellar evolution** and **differential ageing** but **independent of cosmological models,** redshift range $z<2$
- Baryonic Acoustic Oscillations (BAO): 10 model dependent points up to redshift $z < 2.4$

Observational Expansion Data Sets (2)

- Type Ia Supernovae (SNe Ia)
  - **Pantheon Compilation (SN)**:
    - ❖ 1048 data points with redshift range, $0.01 < z < 2.3$
  - **Pantheon+ Compilation (SN+)**: A successor of the original Pantheon
    - ❖ 1701 data points with redshift range, $0.001 < z < 2.3$
  - **Pantheon+SH0ES Compilation (SN+ & SH0ES):**
    - ❖ Uses the Pantheon+ compilations and includes SH0ES Cepheids (i.e constraints on H_0 with R22)

Our work

Probe ***f*(*T*) gravity** – Use recent observational **Hubble data**

– In conjunction with **Markov Chain Monte Carlo** (MCMC) algorithm

↓

Explore **two** models in $f(T)$ gravity by constraining the model parameters

↓

Analyse the **impact** of different data sets and **compare** results with ΛCDM model

Power Law Model

$$S = \frac{1}{16\pi G}\int d^4x\, e\left[-T + \overset{\boldsymbol{f(T)}\,\swarrow}{F(T)}\right] + S_{\text{matter}}$$

f_1 – Power Law Model

$$\boxed{F(T) = \alpha_1 T^{b_1}}$$

- To obtain α_1 – evaluate the Friedmann equation at current times

$$\boxed{\alpha_1 = (6H_0^2)^{1-b_1}\frac{1-\Omega_{m_0}-\Omega_{r_0}}{2b_1-1}}$$

- Thus, the Friedmann equation for this model could be written as

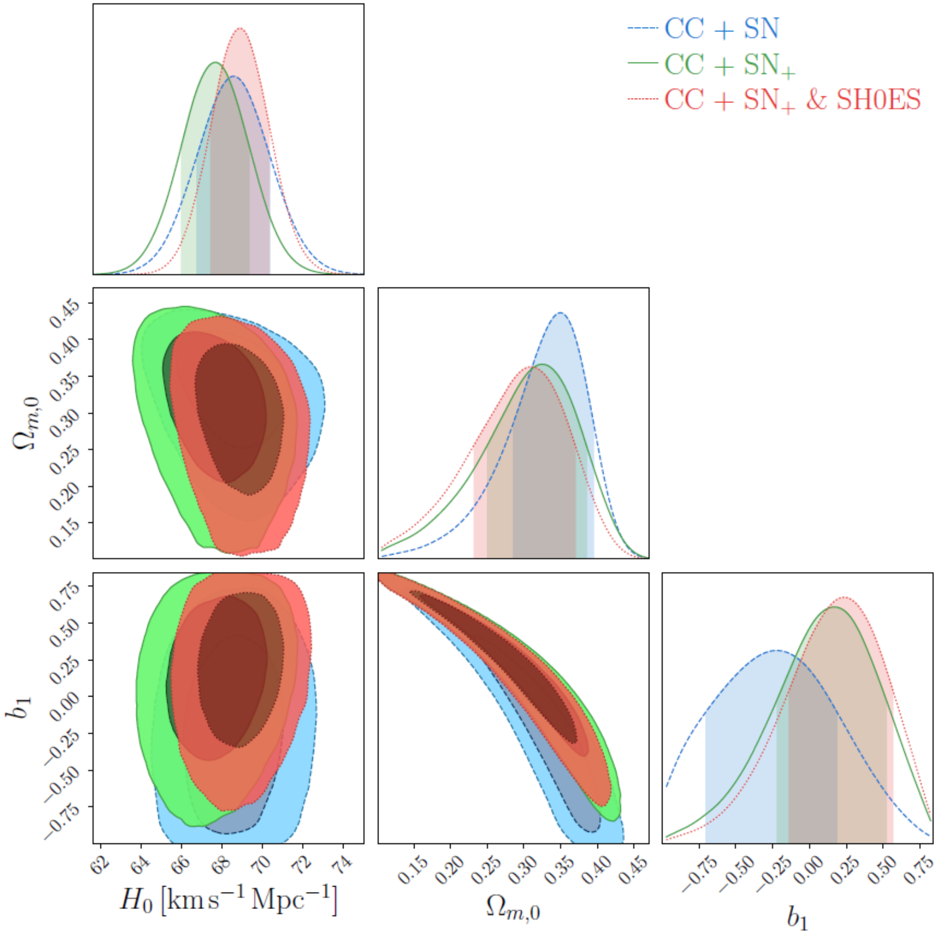
$$\boxed{\boldsymbol{E^2(z) = \Omega_{m_0}(1+z)^3+\Omega_r(1+z)^4+\left(1-\Omega_{m_0}-\Omega_{r_0}\right)E^{2b_1}(z)}}$$

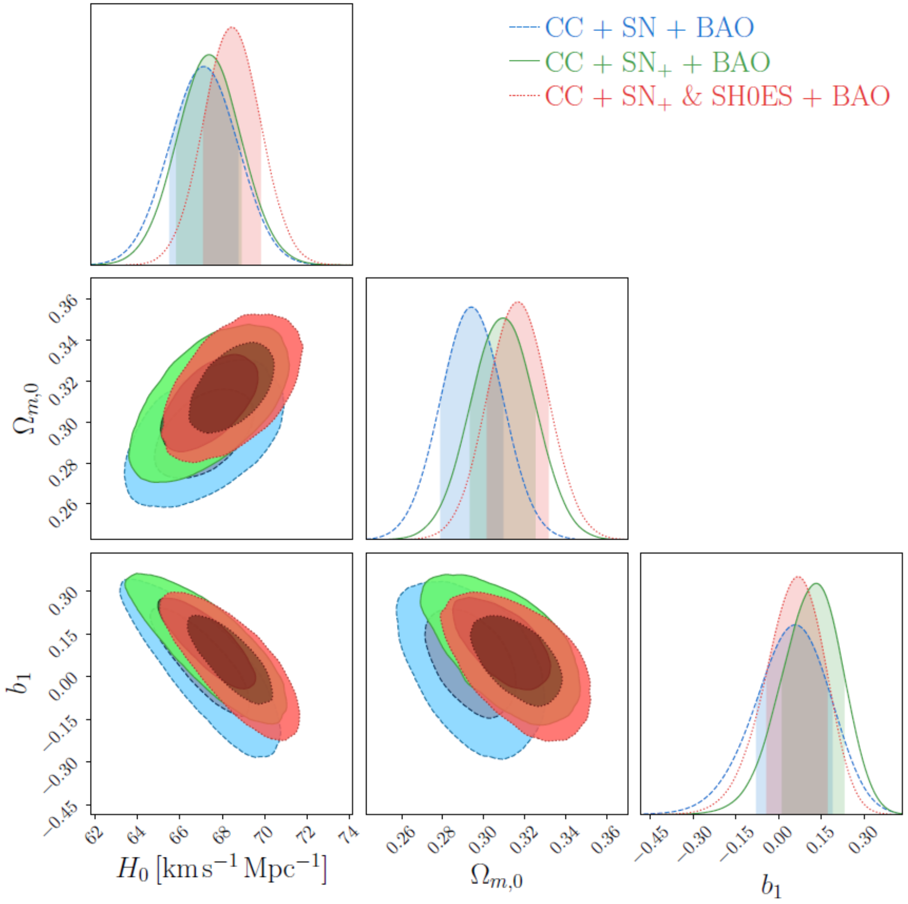
$$\boxed{E = \frac{H(z)}{H_0}}$$

$\Omega_r = 4.15 \times 10^{-5} / h_0$

$$F(T) = \alpha_1 T^{b_1}$$

f_1 – Power Law Model Results





f_1 – Power Law Model

$F(T) = \alpha_1 T^{b_1}$

Data Sets	H_0 [km s^{-1} Mpc^{-1}]	$\Omega_{m,0}$	b_1	AIC	BIC	ΔAIC	ΔBIC
CC + SN	68.6 ± 1.8	$0.350^{+0.045}_{-0.064}$	$-0.22^{+0.41}_{-0.48}$	1048.94	1068.88	1.45	6.43
CC + SN$_+$	67.7 ± 1.7	$0.324^{+0.061}_{-0.074}$	$0.16^{+0.36}_{-0.38}$	1426.81	1446.83	1.72	6.72
CC + SN$_+$ & SHOES	$\mathbf{68.9 \pm 1.4}$	$\mathbf{0.310^{+0.059}_{-0.078}}$	$\mathbf{0.24^{+0.33}_{-0.37}}$	**1420.02**	**1440.04**	**1.47**	**6.47**
CC + SN + BAO	$\mathbf{67.1 \pm 1.6}$	$\mathbf{0.294 \pm 0.015}$	$\mathbf{0.06 \pm 0.13}$	**1065.13**	**1085.13**	**1.68**	**6.68**
CC + SN$_+$+ BAO	67.4 ± 1.5	0.309 ± 0.016	$0.132^{+0.097}_{-0.120}$	1434.83	1454.91	0.54	5.66
CC + SN$_+$ & SHOES + BAO	68.4 ± 1.3	0.317 ± 0.015	$0.069^{+0.100}_{-0.111}$	1428.80	1448.88	1.55	6.57

Difference between ΛCDM and PLM in AIC & BIC

$$\text{AIC} = 2k - \ln(L)$$

No. of parameters in model

Maximum likelihood

$$\text{BIC} = k\ln(n) - 2\ln(L)$$

No. of data points

Linder Model

$$\overset{f(T)}{} \quad S = \frac{1}{16\pi G}\int d^4x\, e[-T + F(T)] + S_{\text{matter}}$$

f_2 – Linder Model

$$\boldsymbol{F(T) = \alpha_2 T_0\left(1 - \text{Exp}\left[-b_2\sqrt{T/T_0}\right]\right)}$$

- To obtain α_2 – evaluate the Friedmann equation at current times

$$\alpha_2 = \frac{1 - \Omega_{m_0} - \Omega_{r_0}}{1 - (1 + b_2)e^{-b_2}}$$

- Thus, the Friedmann equation for this model could be written as

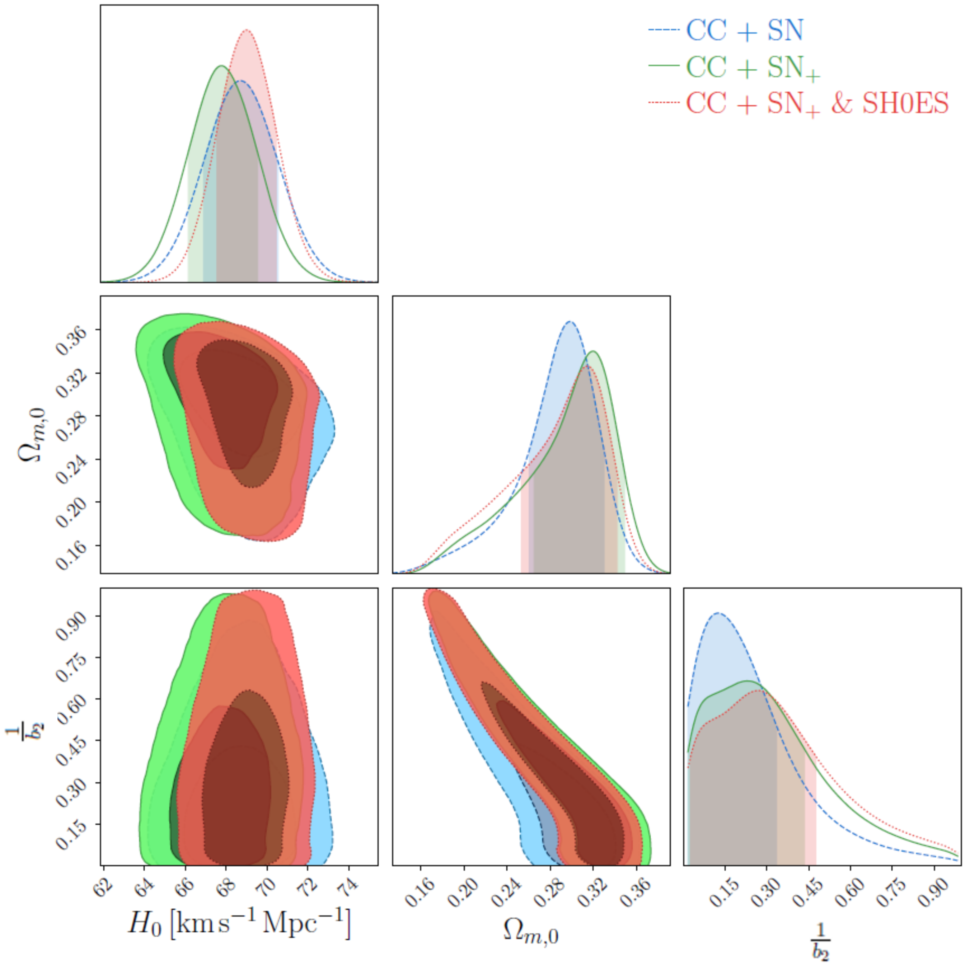
$$\boldsymbol{E^2(z) = \Omega_{m_0}(1+z)^3 + \Omega_r(1+z)^4 - \frac{1 - \Omega_{m_0} - \Omega_{r_0}}{1 - (1 + b_2)e^{-b_2}}\left[(1 + b_2E(z))\,\text{Exp}[-b_2E(z)] - 1\right]}$$

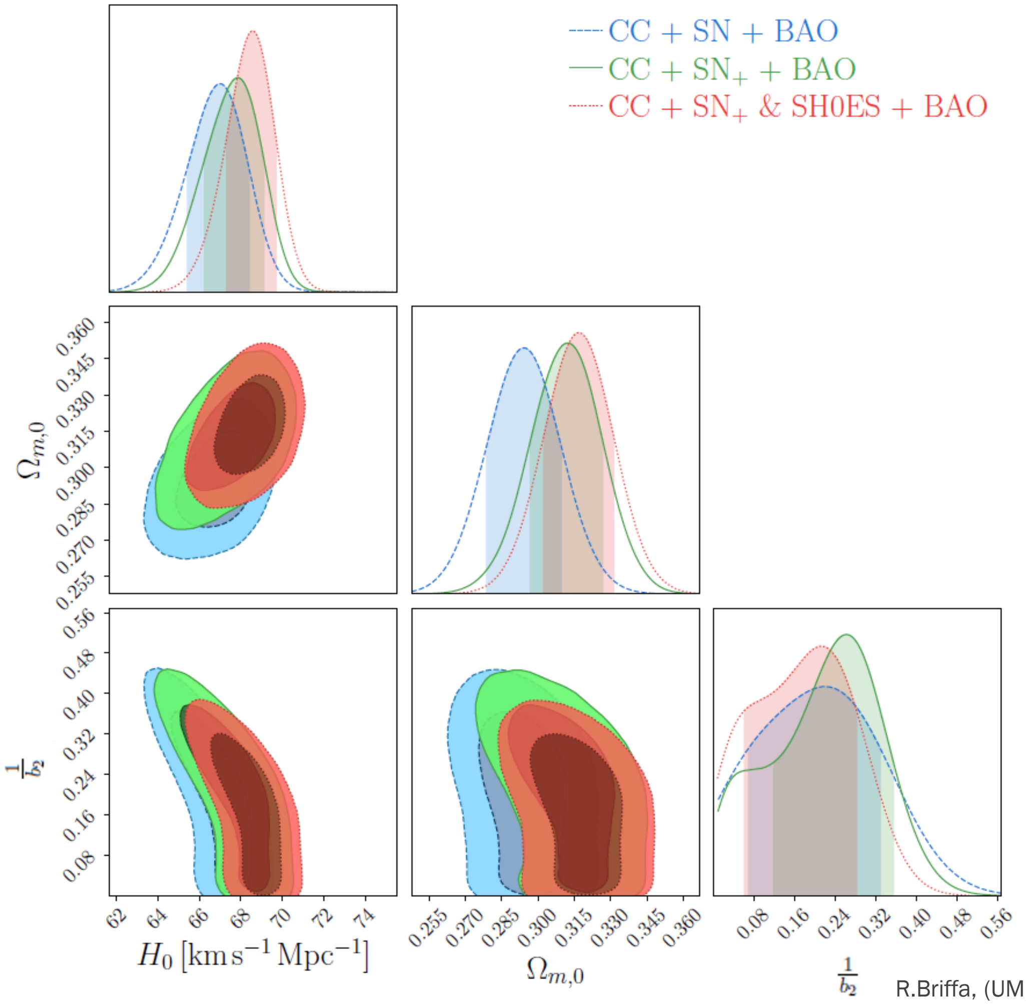
$\Omega_r = 4.15 \times 10^{-5} / h_0$

$$E = \frac{H(z)}{H_0}$$

f_2 – Linder Model Results

$$\boldsymbol{F(T) = \alpha_2 T_0\left(1 - \mathrm{Exp}\left[-b_2\sqrt{T/T_0}\right]\right)}$$





f_2 – Linder Model

$$\boldsymbol{F(T) = \alpha_2 T_0 \left(1 - \mathrm{Exp}\left[-b_2\sqrt{T/T_0}\right]\right)}$$

Data Sets	H_0 [km s^{-1} Mpc^{-1}]	$\Omega_{m,0}$	$\frac{1}{b_2}$	AIC	BIC	ΔAIC	ΔBIC
CC + SN	$68.7^{+1.8}_{-1.7}$	$0.298^{+0.031}_{-0.035}$	$0.12^{+0.21}_{-0.11}$	1049.49	1069.43	2.00	6.98
CC + SN_+	$67.7^{+1.8}_{-1.6}$	$0.319^{+0.030}_{-0.054}$	$0.23^{+0.20}_{-0.21}$	1426.83	1446.85	2.74	6.74
CC + SN_+ & SHOES	$\mathbf{69.8^{+1.4}_{-1.5}}$	$\mathbf{0.315^{+0.027}_{-0.061}}$	$\mathbf{0.27^{+0.21}_{-0.24}}$	**1420.05**	**1440.07**	**1.50**	**6.51**
CC + SN + BAO	$\mathbf{67.0^{+1.4}_{-1.6}}$	$\mathbf{0.294 \pm 0.016}$	$\mathbf{0.22^{+0.12}_{-0.15}}$	**1064.62**	**1084.52**	**1.06**	**6.06**
CC + SN_++ BAO	$67.9^{+1.3}_{-1.6}$	$0.312^{+0.014}_{-0.015}$	$0.262^{+0.094}_{-0.142}$	1434.52	1454.60	0.23	5.35
CC + SN_+ & SHOES + BAO	$68.6^{+1.1}_{-1.3}$	$0.317^{+0.014}_{-0.015}$	$0.212^{+0.070}_{-0.151}$	1428.50	1448.58	1.26	6.27

Difference between ΛCDM and PLM in AIC & BIC

$$\mathrm{AIC} = 2k - \ln(L)$$

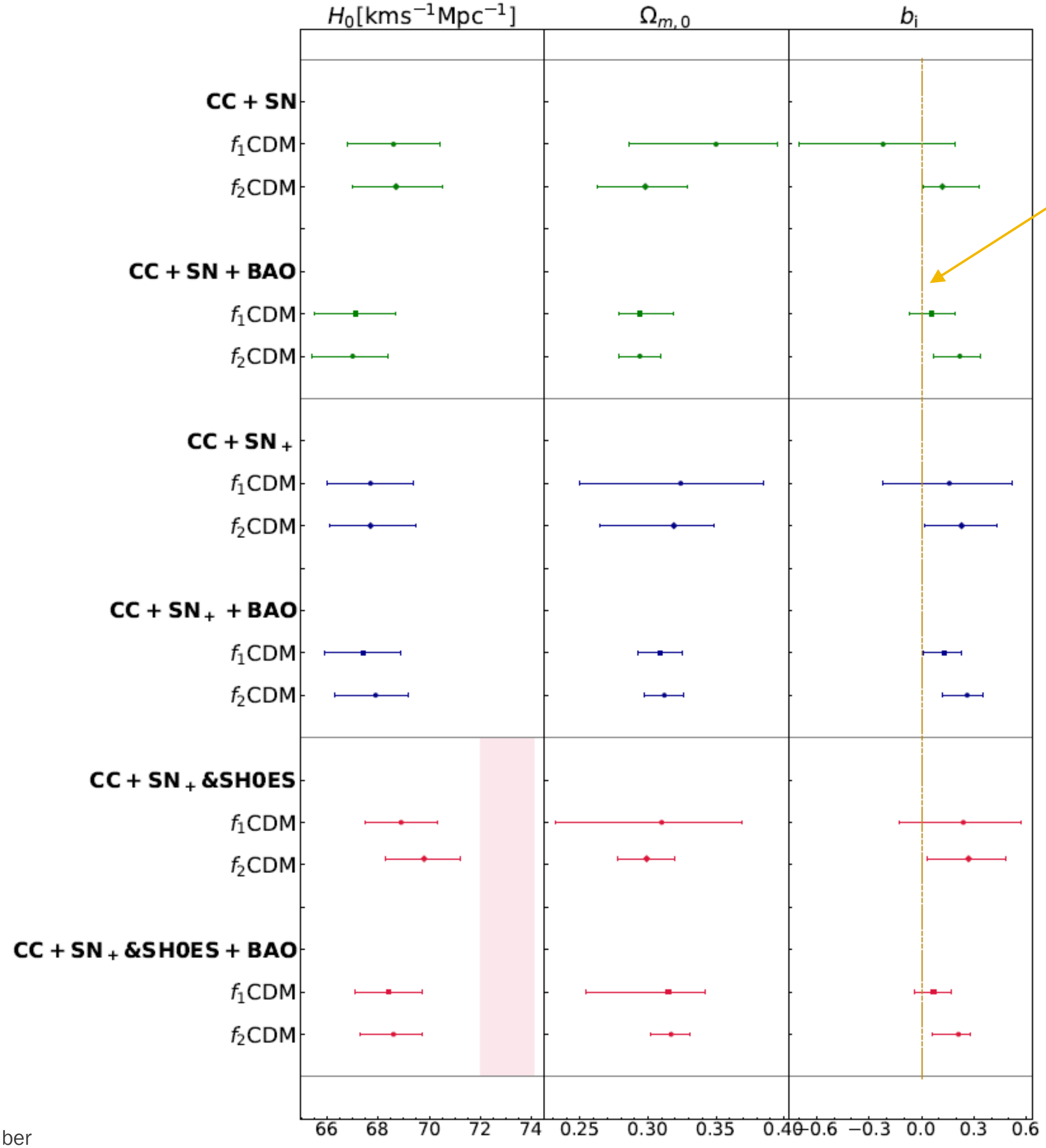
No. of parameters in model

Maximum likelihood

$$\mathrm{BIC} = k\ln(n) - 2\ln(L)$$

No. of data points

Conclusion



b = 0
ΛCDM model

🟥 R22 value ($H_0 = 73.04 \pm 104$ km s^{-1} Mpc^{-1})

Conclusion and prospects

- We have tested **2 *f*(*T*) models**
- **MCMC** allows us to **constrain the parameters** in these models
- Our interest: assess how the **cosmological parameters** are **altered**
- This analysis can be **extended** to other theories such as ***f*(*T, B*)**

Thank You