# Hubble tension in k-essence dark energy

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## The Hubble Tension

Hubble tension is the discrepancy between two different methods of measuring the expansion rate of the Universe, the Hubble constant ($H_0$). That is:

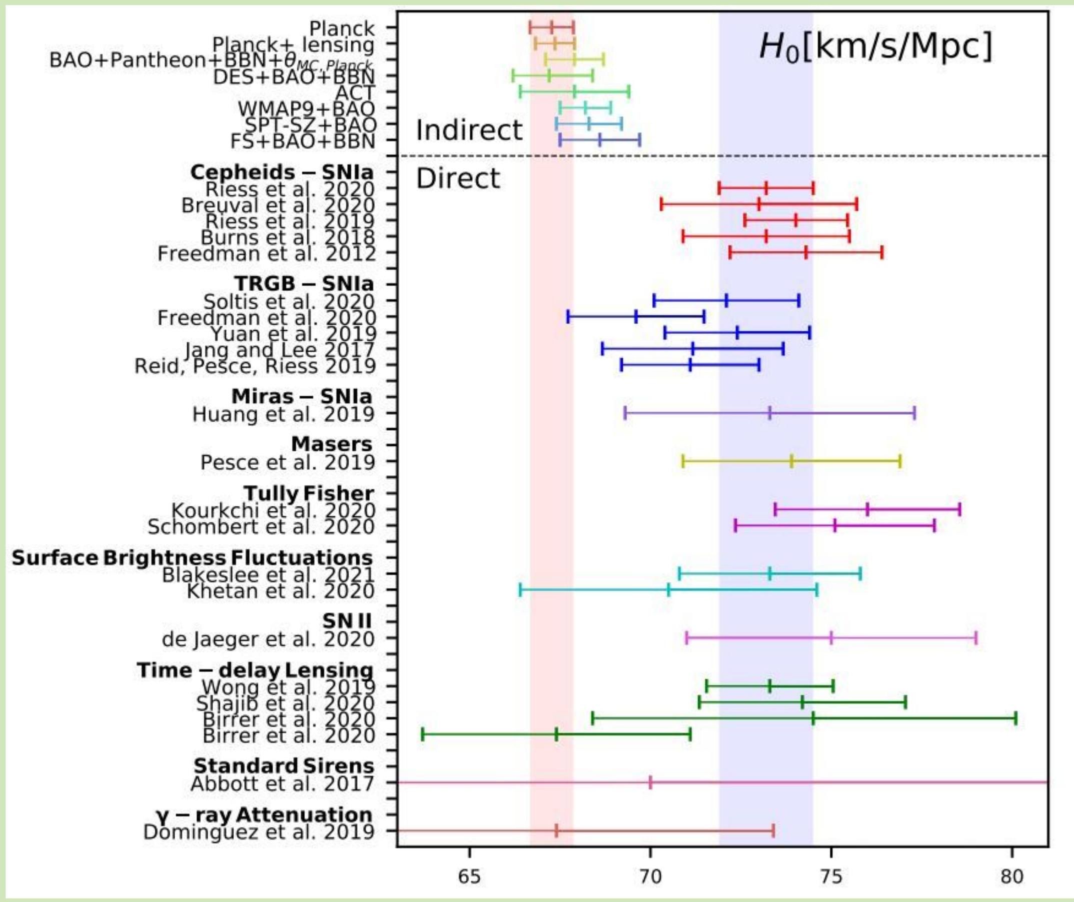


Figure 1. Discrepancies between different measurements of $H_0$. Image Credit: Eleonora Di Valentino et al., revised Jan 2021

- CMB method, where the standard ruler is the *sound horizon*, $r_s$, e.g. from Planck collaborations [1], where $H_0 \approx 67.27 \pm 0.6$ km/s/Mpc and Distance ladder method as done by SH0ES collaborations [3], where $H_0 \approx 73.04 \pm 1.04$ km/s/Mpc.
- A big statistical difference of $\sim 5.0\sigma$ discrepancy has been reported, hence the Hubble tension.

Resolving tension in $H_0$ might require:

1. Reducing the calculated distance sound travelled before recombination, $r_s$,
2. Modifying late time expansion to match the observed angular size of the CMB, or
3. Abandoning the standard cosmological framework in favour of new physics.

## Motivation

If Dark Energy (DE) is *not a simple cosmological constant*, but some field that evolves over time, it could naturally explain why: $H_0^{\text{early}}$(Planck)$\neq H_0^{\text{late}}$(SH0ES)

## The k-essence/Models

General Lagrangian of k-essence:

$$\mathcal{L} = P(\varphi, X), \quad X = -\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi, \quad (1)$$

where $P$ is an arbitrary function of the field $\varphi$ and its kinetic energy $X$.

Fluid density: $\rho_\varphi \equiv 2X\partial_X P_\varphi - P_\varphi$. (2)

Equation-of-state (EoS) parameter:

$$\omega_\varphi = \frac{P_\varphi}{2X\partial_X P_\varphi - P_\varphi}. \quad (3)$$

1. *Dilatonic ghost model*

$$P_\varphi = -X + c_1 X^2 e^{\lambda\kappa\varphi}. \quad (4)$$

2. *Tachyon field model [2]*:

$$P_\varphi = -U(\varphi)\sqrt{1 - 2c_1 X}, \quad (5)$$

$$U(\varphi) = \frac{M^{4+\alpha}}{\varphi^\alpha}, \quad (6)$$

where $c_1 = 1/M^4$ for a given mass scale $M$, $\alpha$ is any scalar

## Methodology

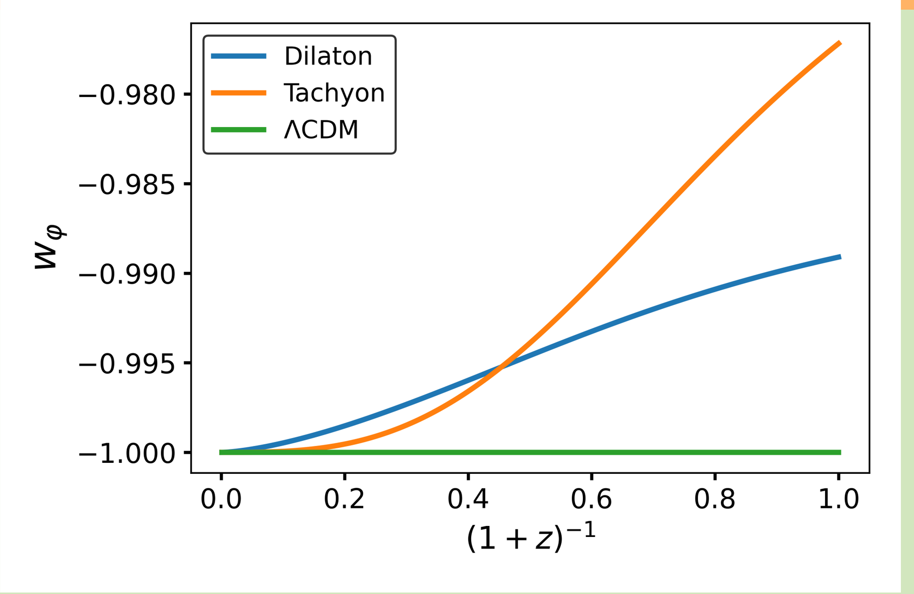


Figure 2. The plots of the EoS parameters (3) against scale factor, $a = 1/(1+z)$, compared to $\Lambda$CDM.

- We used Markov Chain Monte Carlo (MCMC) method to determined the best-fit values and posterior distributions of $\{H_0,\ \Omega_b h^2,\ \Omega_c h^2,\ \lambda,\ \alpha\}$, where $h = H_0/100$.
- Generated chains using `emcee` and extracted values using `GetDist` (gui).
- The priors: $\boldsymbol{H_0}$: $[60.0,\ 80.0]$; $\boldsymbol{\Omega_b h^2}$: $[0.02,\ 0.03]$; $\boldsymbol{\Omega_c h^2}$: $[0.1,\ 0.2]$; $\boldsymbol{\lambda}$: $[0.01,\ 0.01]$; $\boldsymbol{\alpha}$: $[0.5,\ 5.0]$

## Results

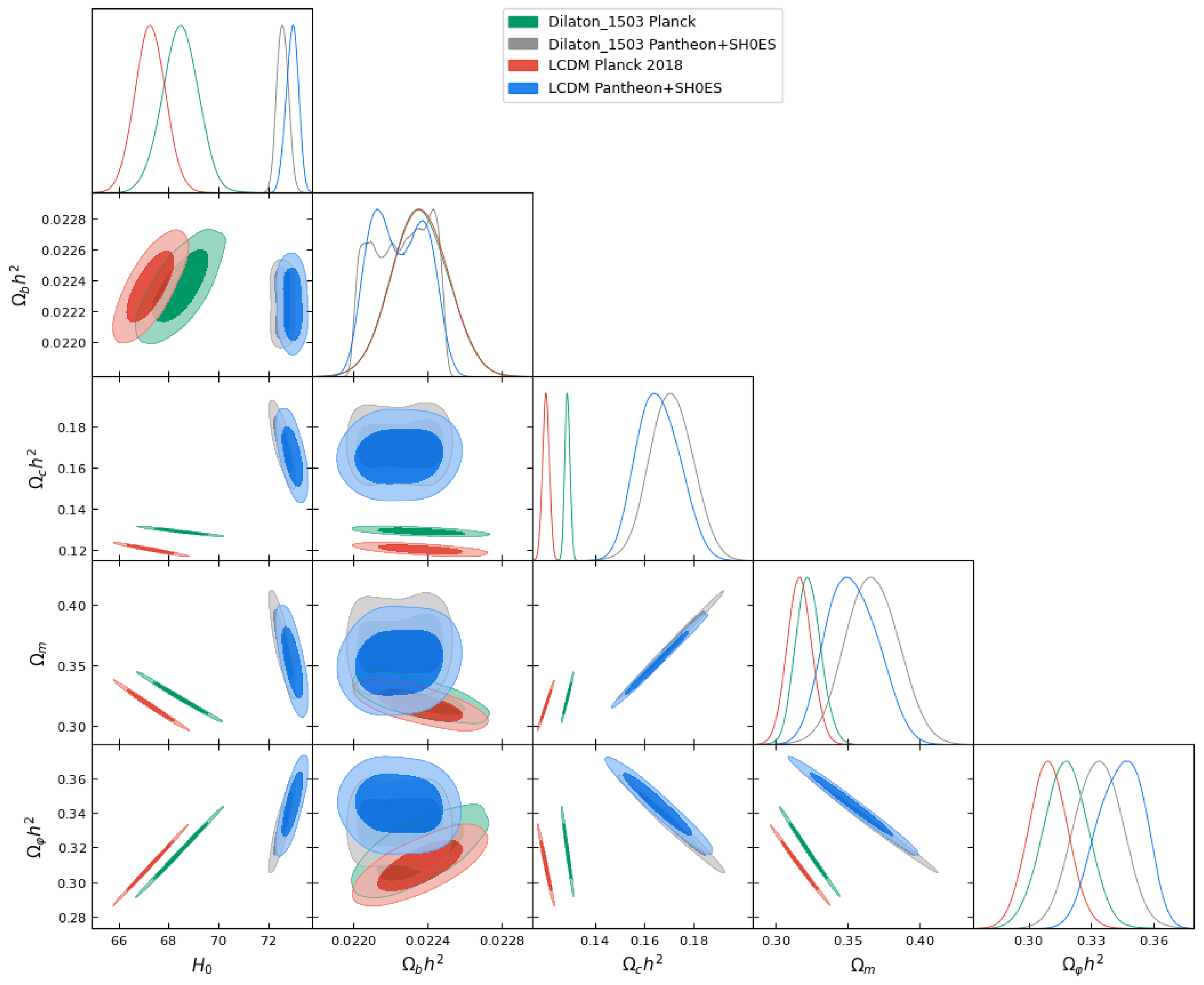


Figure 3. The marginalized posterior distribution of $H_0$, $\Omega_m$ and $\Omega_\varphi h^2$ for Planck 2018 (Plk), and Pantheon+SH0ES (PP) datasets with $\Lambda$CDM (red and blue curves) and dilaton (green and gray)

- Using PP datasets, tension with Planck results reduces from $8.80\sigma$ with $\Lambda$CDM to $5.41\sigma$ and $3.85\sigma$ using dilaton and tachyon models, respectively
- Performance exceeds $\Lambda$CDM, hence potential viability of dynamical dark energy.

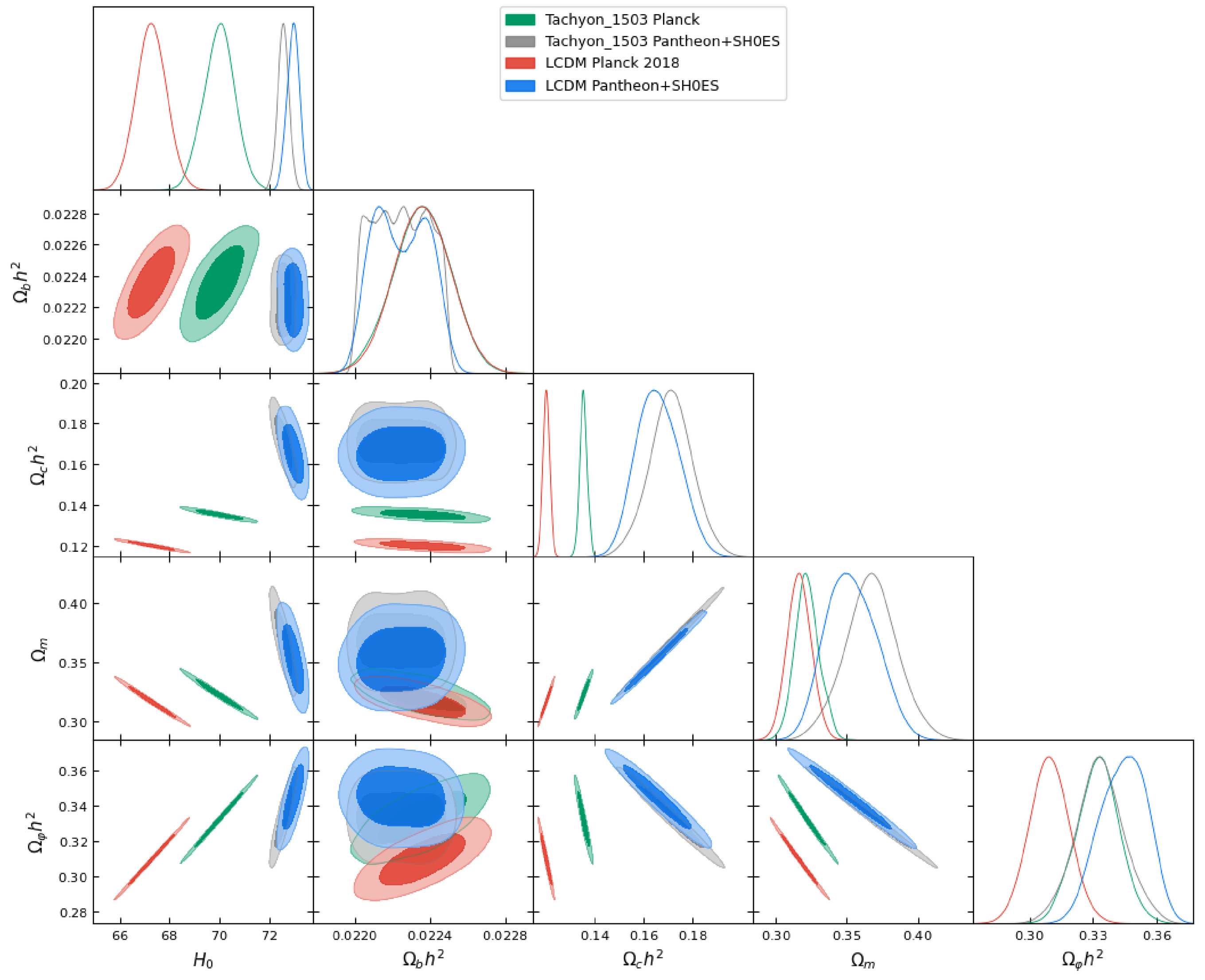


Figure 4. The marginalized posterior distribution of $H_0$, $\Omega_m$ and $\Omega_\varphi h^2$ for Plk, and PP datasets with $\Lambda$CDM (red and blue curves) and tachyon (green and gray)

## Table Summary

| Datasets/Model | $\Omega_m$ | $H_0$ | Tension with: Planck; | SH0ES |
|---|---|---|---|---|
| $\Lambda$CDM model | | | | |
| Planck 2018 | $0.3166 \pm 0.0084$ | $67.27 \pm 0.60$ | – | $4.81\sigma$ |
| PP | $0.3530 \pm 0.0170$ | $72.97^{+0.26}_{-0.23}$ | $8.80\sigma$ | $0.07\sigma$ |
| Dilaton model | | | | |
| Planck | $0.3226 \pm 0.0087$ | $68.49 \pm 0.72$ | – | $3.60\sigma$ |
| PP | $0.367 \pm 0.018$ | $72.58 \pm 0.23$ | $5.41\sigma$ | $0.43\sigma$ |
| Tachyon field model | | | | |
| Planck | $0.3220^{+0.0077}_{-0.0090}$ | $70.00 \pm 0.63$ | – | $2.50\sigma$ |
| PP | $0.367 \pm 0.019$ | $72.57 \pm 0.22$ | $3.85\sigma$ | $0.44\sigma$ |

Table 1. Statistical significance of the Hubble tension using Plk and PP datasets.

- Additional refinements: interactions in the dark sector, performing a full perturbation analysis, and incorporating the complete CMB likelihood are recommended.

## References

[1] N. Aghanim et al. In: (Sept. 2020). DOI: 10.1051/0004-6361/201833910.

[2] J. S. Bagla et al. In: (Mar. 2003). DOI: 10.1103/physrevd.67.063504.

[3] Adam G. Riess et al. In: (July 2022). DOI: 10.3847/2041-8213/ac5c5b.



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