The Hubble tension, Early Dark Energy and the profile likelihood

based on ***LH, Ferreira (arXiv:2210.16296),***
***LH, Ferreira, Komatsu (ApJ.L.* 929 (2022) 1, L16)**

“New Physics from Galaxy Clustering”
Nov. 21, 2022, CERN

Laura Herold (MPA)

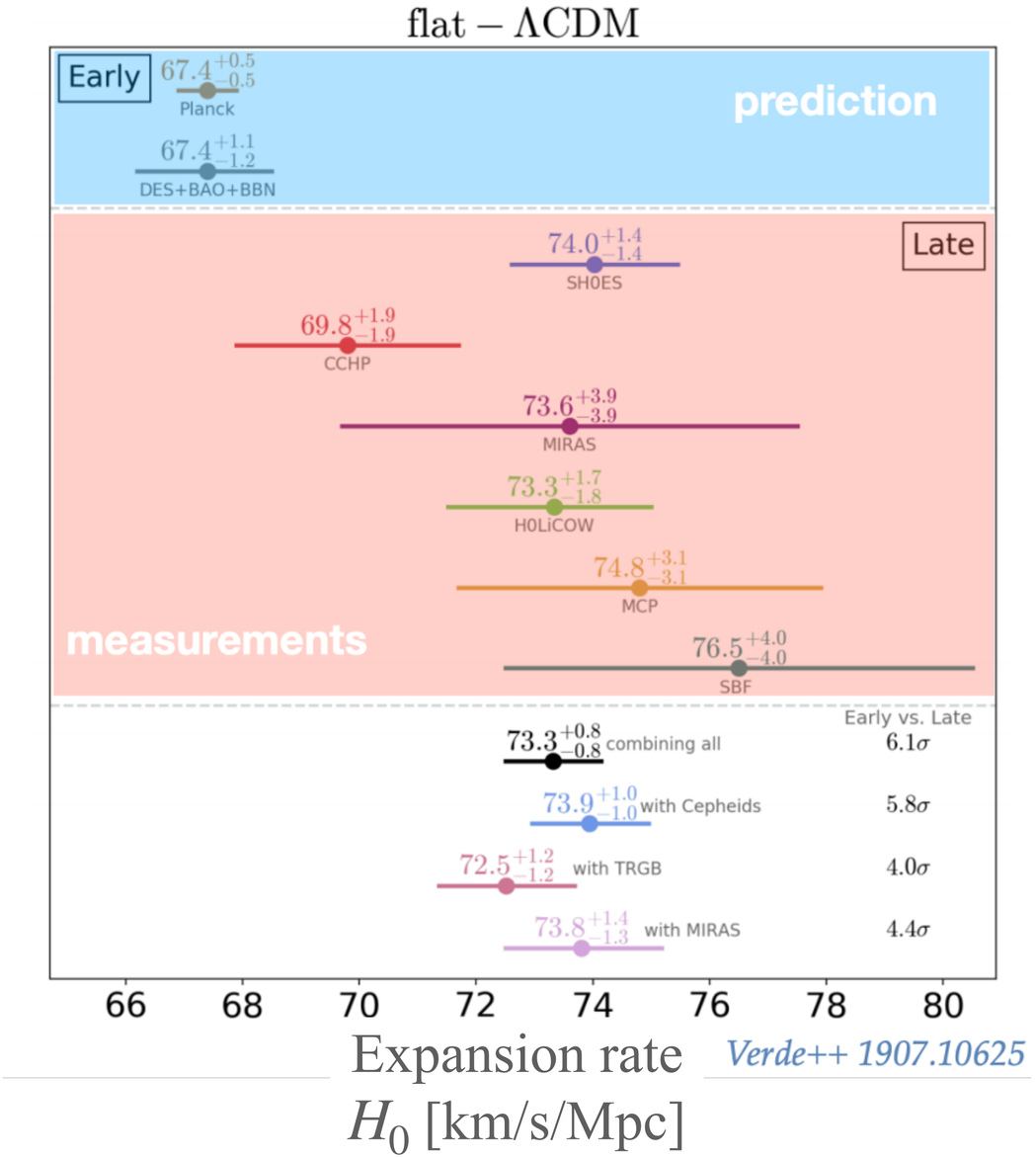
MAX PLANCK INSTITUTE
FOR ASTROPHYSICS

EDE and LSS

Prior volume effects in the EDE model?

New constraints using the profile likelihood

The Hubble tension



Most recent SH0ES results:

$H_0 = 73.04 \pm 1.04$ km/s/Mpc

$\rightarrow$ 5σ tension with *Planck*

Not only tension between two experiments but:

direct and indirect measurements

Systematics or new physics?

Early Dark Energy (EDE)

Kamionkowski et al. 2014, Karwal & Kamionkowski 2016, Caldwell & Devulder 2018, Poulin et al. 2019

Idea of EDE: Introducing a DE-like component before recombination reduces r_s.

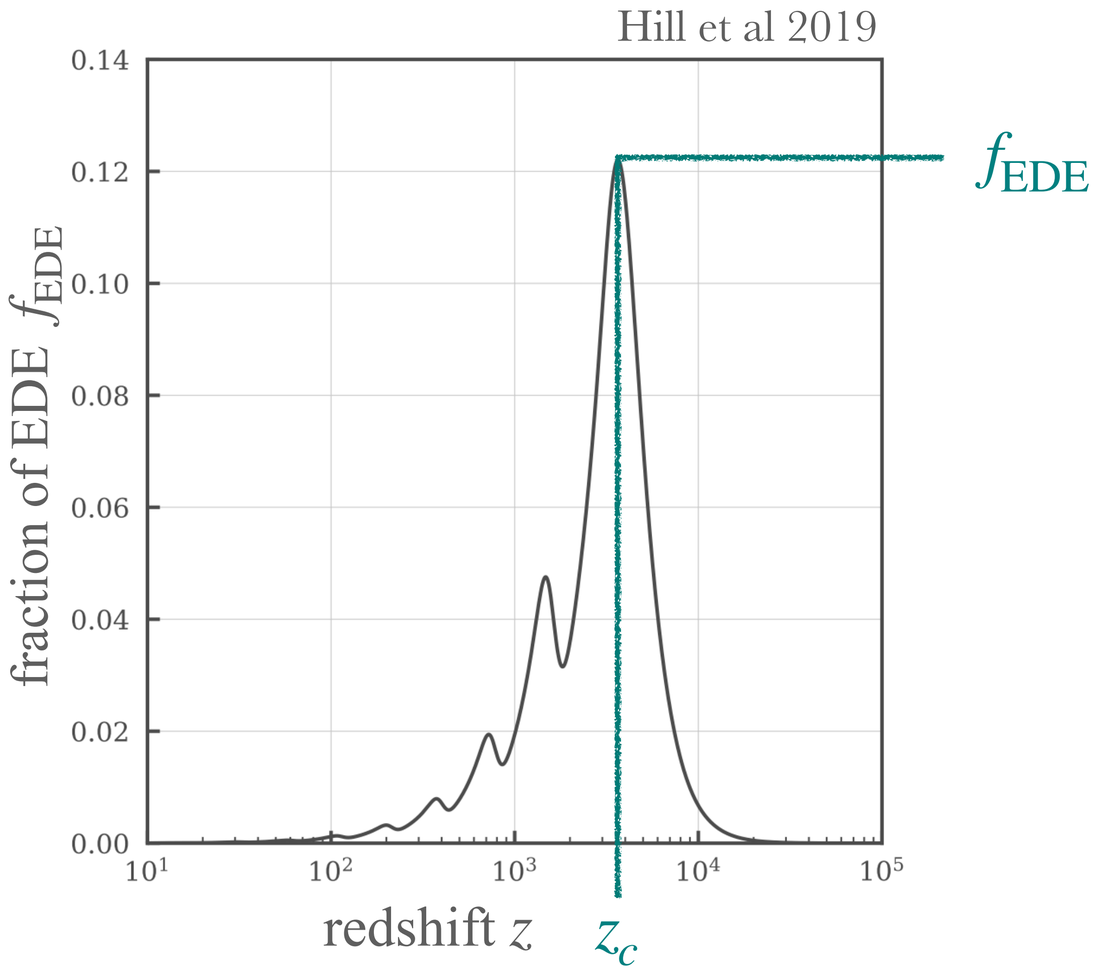
Canonical EDE model: scalar field ϕ with potential $V(\phi) = V_0 [1 - \cos(\phi/f)]^n,\ n = 3$ fixed.

Free parameters:

$f_{\rm EDE}$: max. fraction of EDE,

$\log(z_c)$: critical redshift at which EDE is max.,

$\theta_i \equiv \phi_i/f$: initial value of the field.



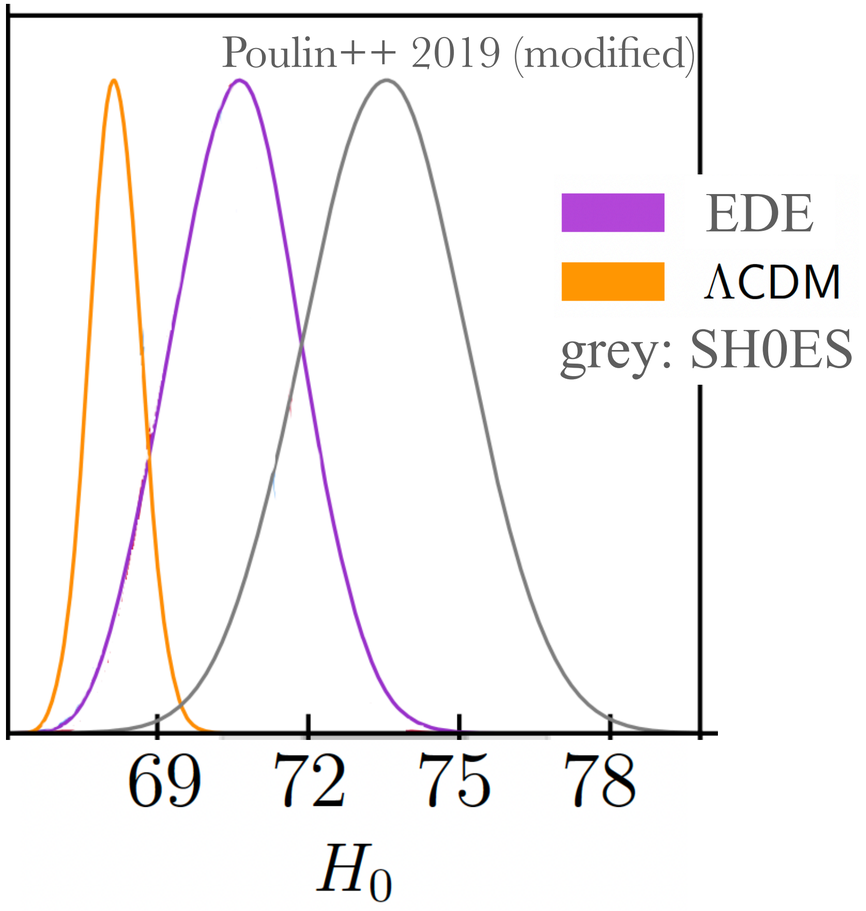
EDE can solve the H_0 tension

Poulin++ 2019

Data sets (MCMC): Planck + BOSS BAO + Pantheon + SH0ES

- $f_{\rm EDE} = 0.107^{+0.035}_{-0.030}$ (mean $\pm 1\sigma$)

- $H_0 = 71.49 \pm 1.20$ km/s/Mpc



Full-shape galaxy clustering: EDE is ruled out?

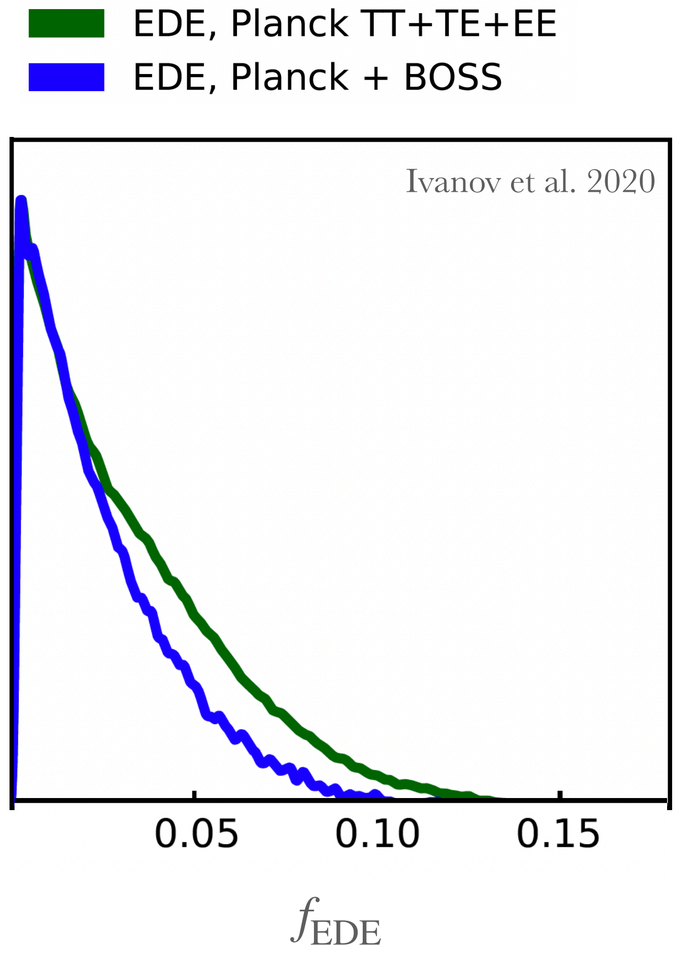
Ivanov++ 2020; D'Amico++ 2020

Data sets (MCMC): Planck + BOSS DR12 BAO + BOSS full-shape galaxy clustering analysis

- $f_{\rm EDE} < 0.072$ (95% CL)

- $H_0 = 68.54^{+0.52}_{-0.95}$ km/s/Mpc

→ EDE does not solve H_0 tension



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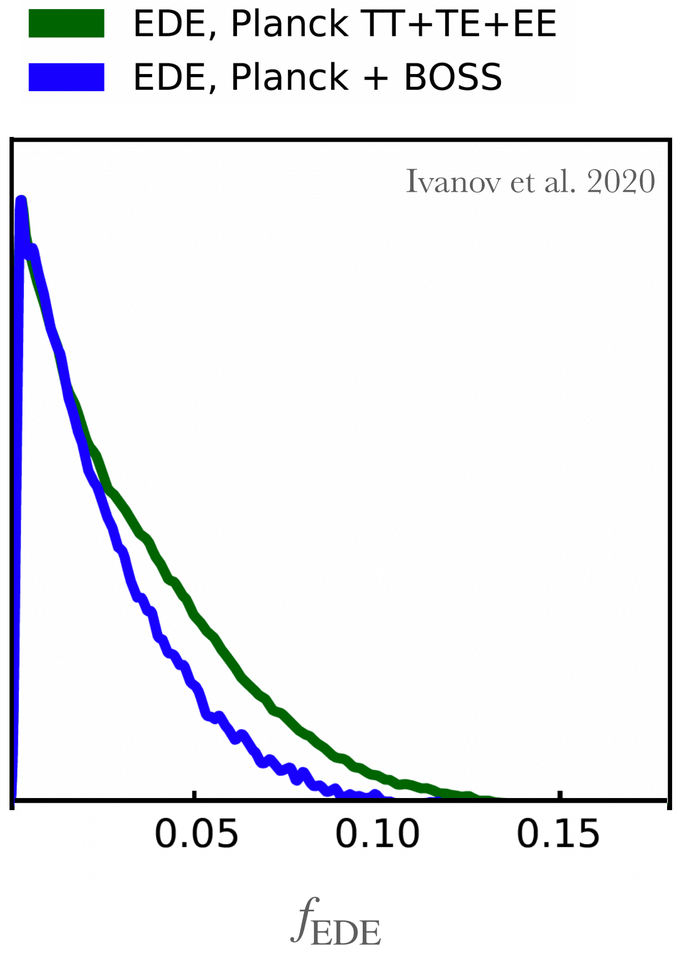


Could prior volume effects bias the MCMC results?

Smith++ 2020, Niedermann++ 2020, Smith++ 2021

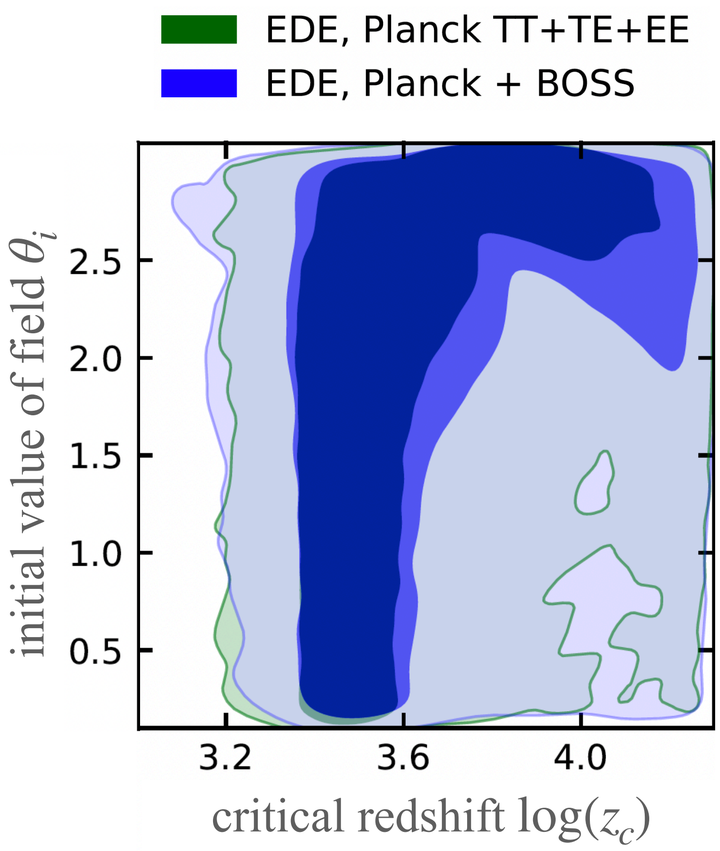
Table of content

Prior volume / projection / marginalization effects

…appear if the posterior is influenced by the prior volume.
Reasons:

- Model has too many parameters / data is not constraining.
- Posterior is very non-Gaussian.
- Parameter structure of the model generates large volume differences.

Ivanov et al. 2020



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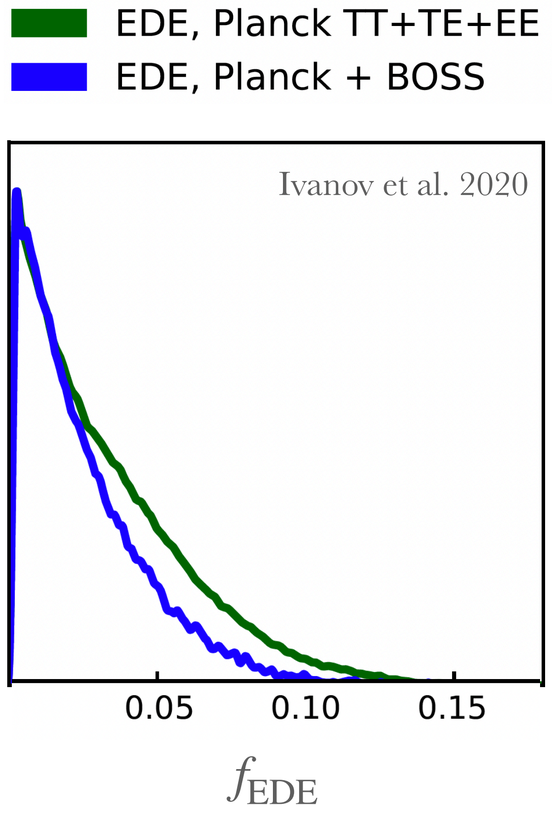

$f_{\rm EDE} \approx 0$: all values of z_c, θ_i degenerate with ΛCDM

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→ Bias in the marginalised posterior.

Idea: Profile likelihood is not subject to volume effects

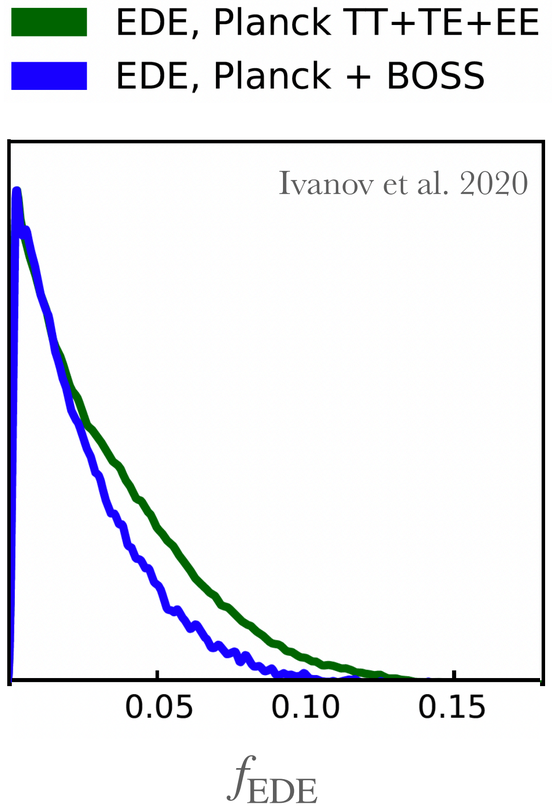

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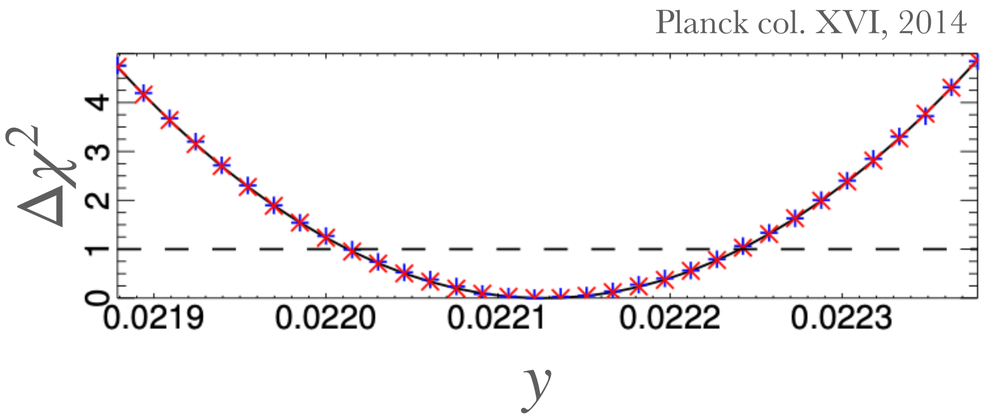
Table of content

Profile likelihood

Profile likelihood:

- Fix parameter y of interest to different values, minimize χ^2 w.r.t. all other parameters
- for Gaussian distribution this gives parabola in $\Delta\chi^2$



Confidence interval:

- Read off 1σ at the intersection with $\Delta\chi^2 = 1$ *(Neyman construction)*

Comparison to MCMC

MCMC (Bayesian statistics):

- Includes prior knowledge as priors: $P(M \mid D) \sim \mathscr{L}(D \mid M) \cdot P(M)$.
- Identifies bulk volumes that fit data well.

Profile Likelihood (Frequentist statistics):

- Only based on the likelihood $\mathscr{L}(D \mid M)$ or on $\chi^2 = -2\log(\mathscr{L})$.
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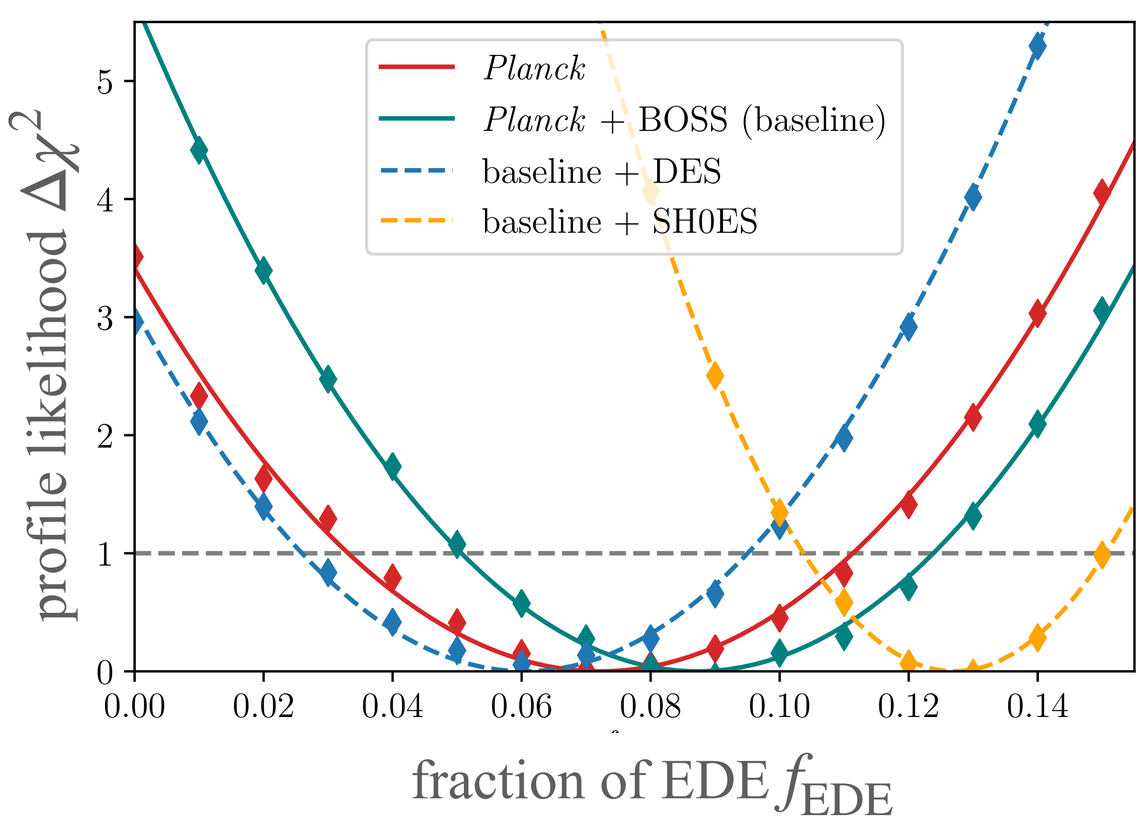
- Identifies bulk volumes that fit data well.
- Problem: If data is not constraining enough, can be subject to prior effects. Solution: Use more/better data, less free parameters.

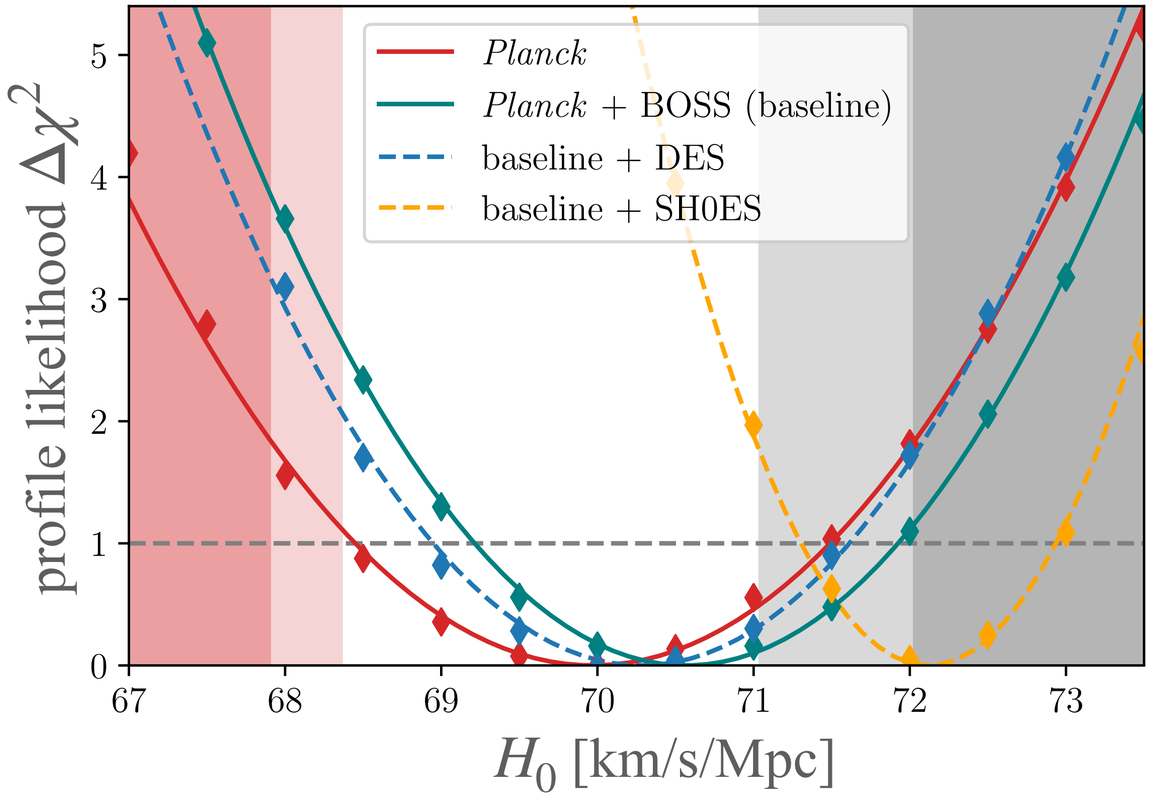
Profile Likelihood (Frequentist statistics):

- Only based on the likelihood $\mathscr{L}(D \mid M)$ or on $\chi^2 = -2\log(\mathscr{L})$.
- No posterior, no prior dependence.
- Problem: Can prefer cosmology with very small parameter volume — “fine tuning”. Solution: Construct physically motivated model.

Profile likelihood — EDE results

LH, Ferreira (arXiv:2210.16296)*





*Codes: MontePython (Brinckmann++), CLASS (Lesgourgues), CLASS-PT (Chudaykin++), CLASS_EDE (Hill++);
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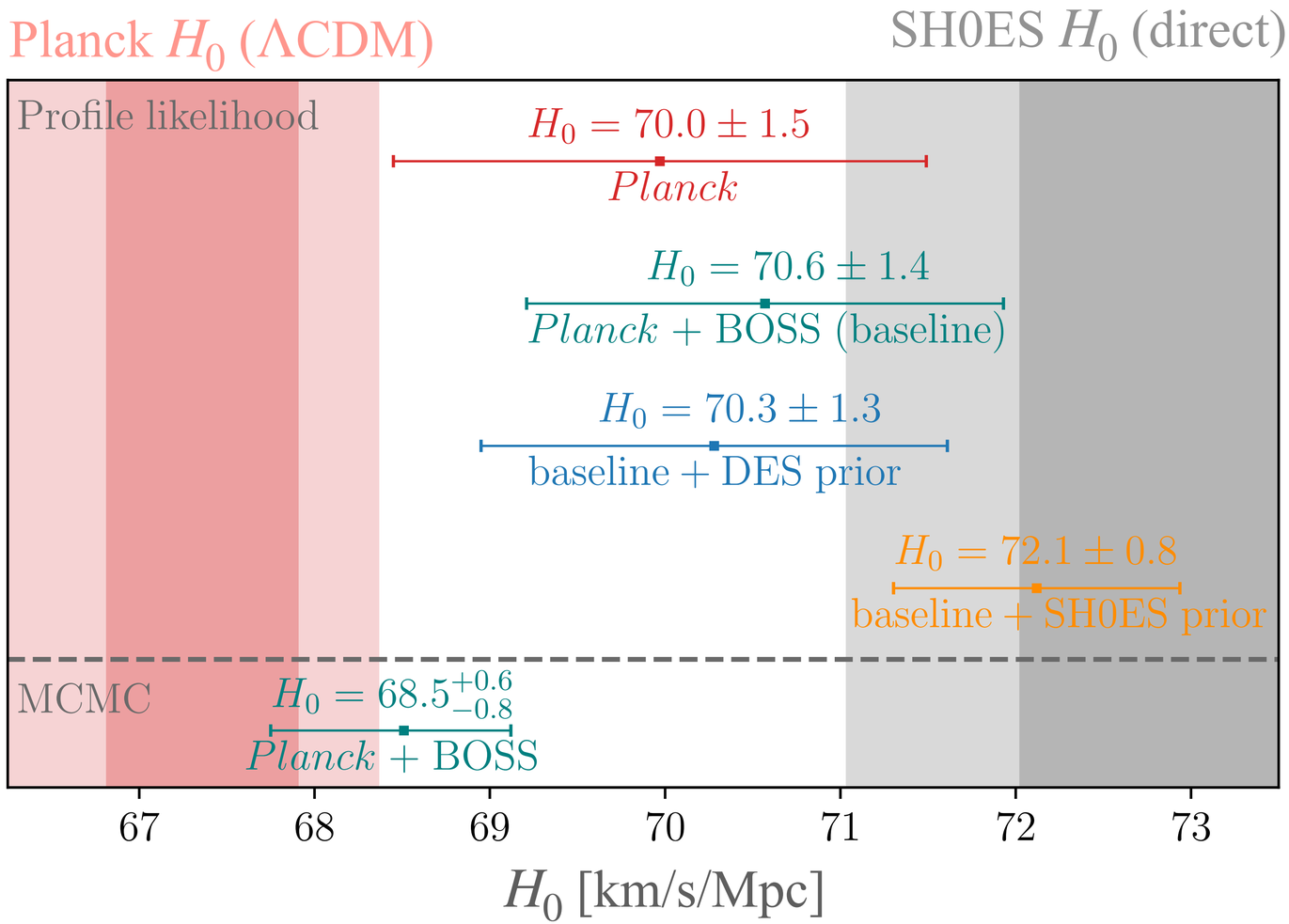

Results:

- Evidence for prior volume effects.
- H_0 in EDE model within $1.7\,\sigma$ of SH0ES measurement for all data sets (incl. galaxy clustering, weak lensing).
- EDE viable solution to Hubble tension.

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Prior volume effects

Important for beyond-ΛCDM models with many parameters
(e.g. EDE, decaying DM)

Profile likelihood

EDE is viable solution to the Hubble tension

Frequentist + Bayesian methods are complementary

Both have different shortcomings (fine tuning vs. prior volume effects)

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Thank you!