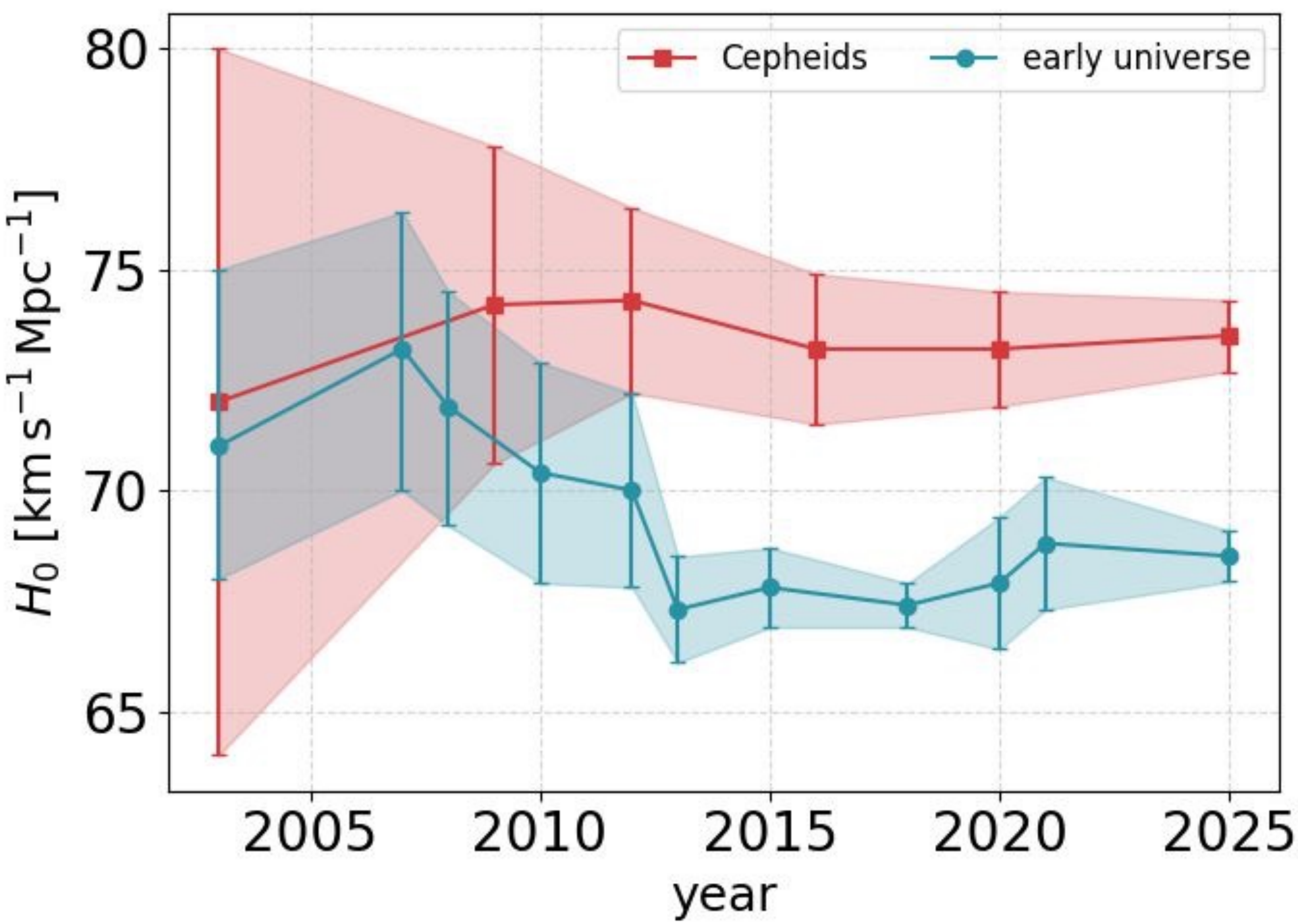
Multi-field EDE and the Hubble tension

marco bella

Univeristy of Trento -> UC Davis

hubble tension



EDE: a popular solution

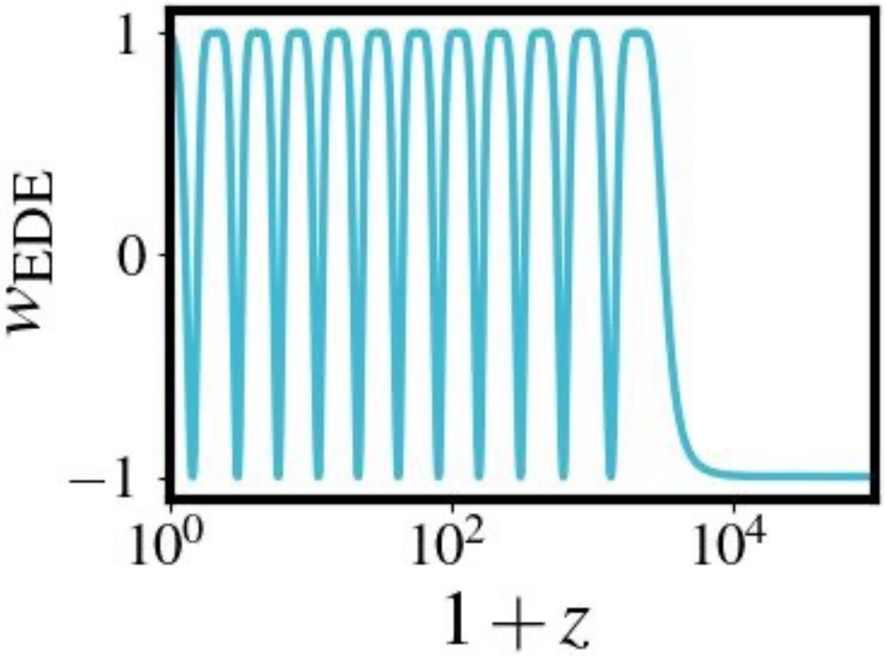
$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)^n .$$

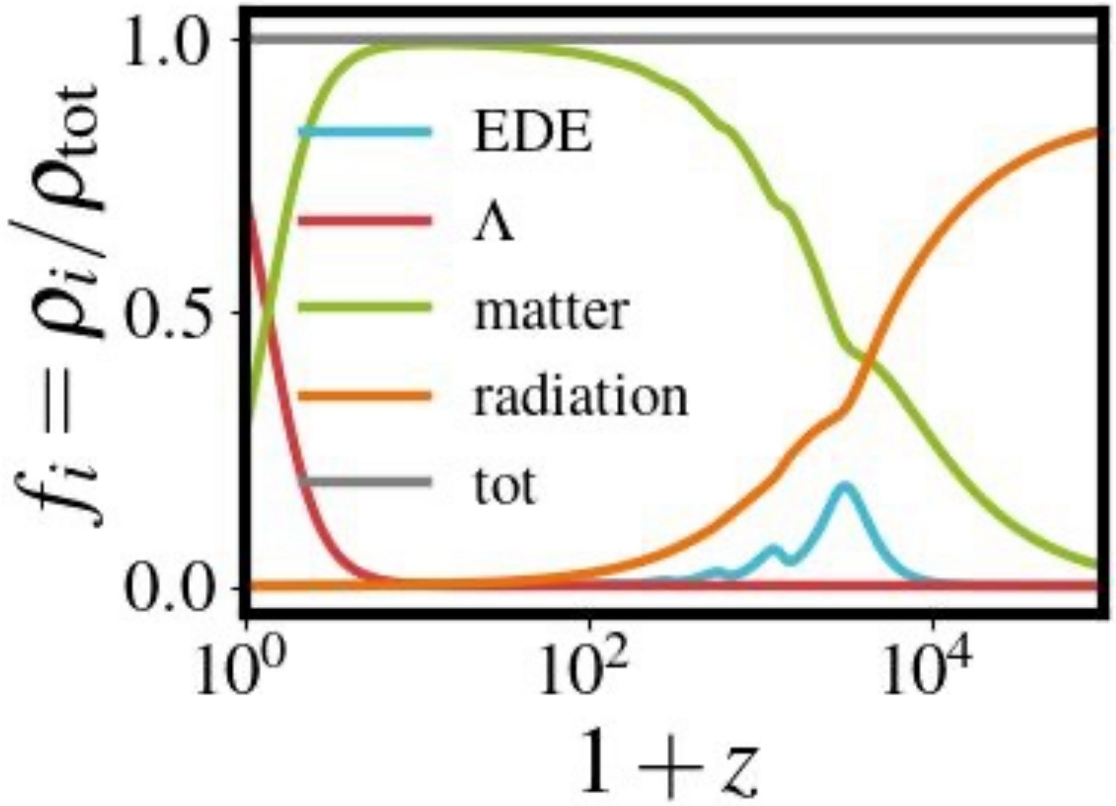
$$\phi(\tau, \mathbf{x}) \approx \phi^{(0)}(\tau) + \phi^{(1)}(\tau, \mathbf{x})$$

EDE: a popular solution

$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)^n .$$

$$\phi(\tau, \mathbf{x}) \approx \phi^{(0)}(\tau) + \phi^{(1)}(\tau, \mathbf{x})$$

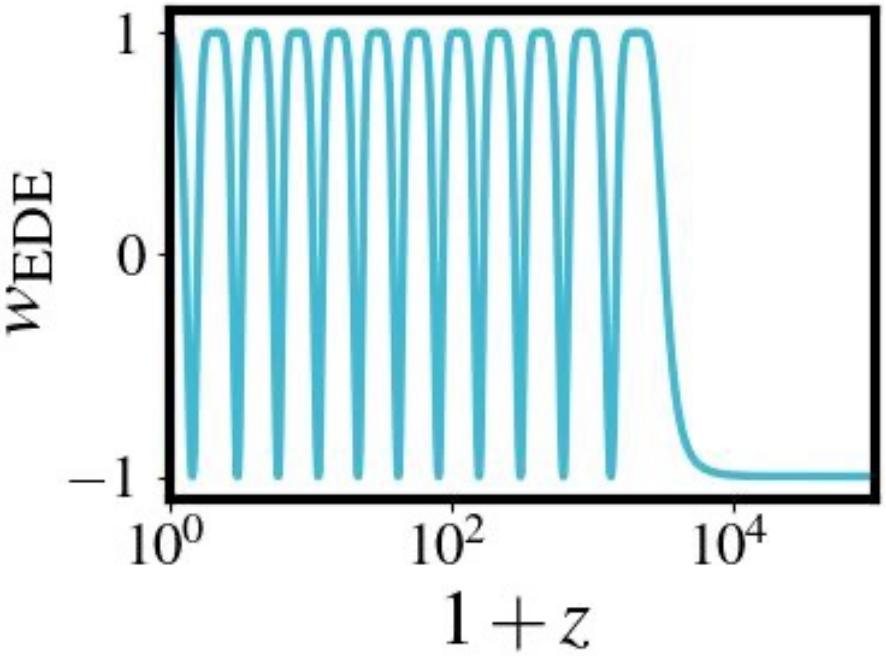


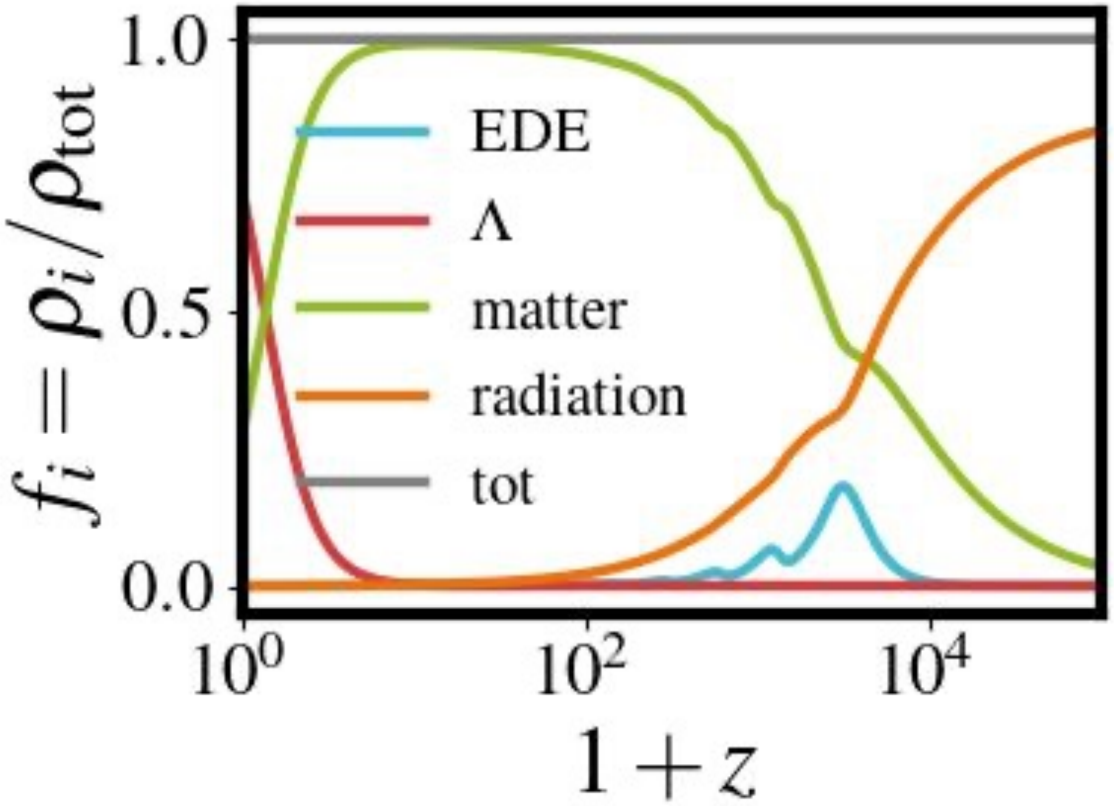


EDE: a popular solution

$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)^n .$$

$$\phi(\tau, \mathbf{x}) \approx \phi^{(0)}(\tau) + \phi^{(1)}(\tau, \mathbf{x})$$



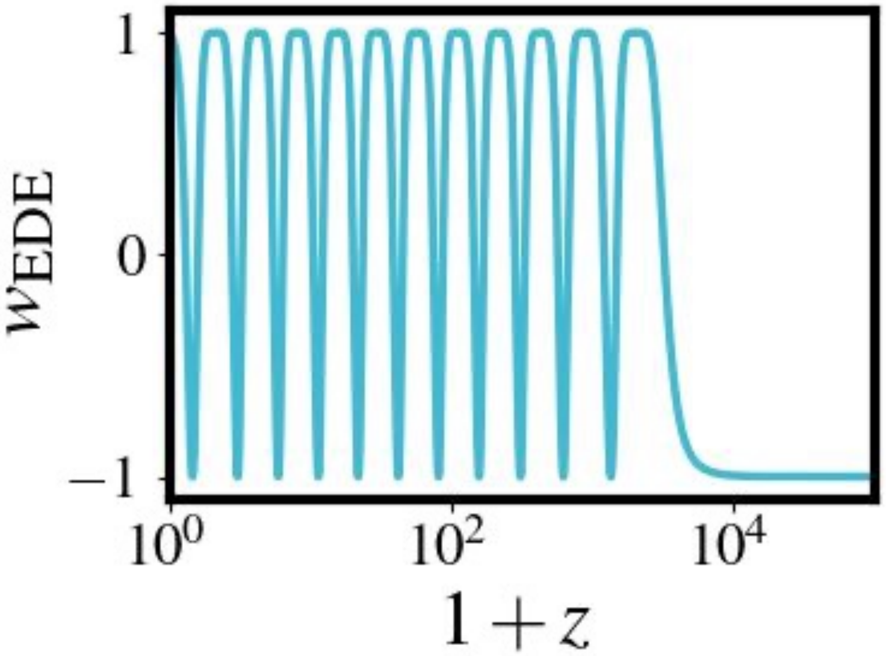


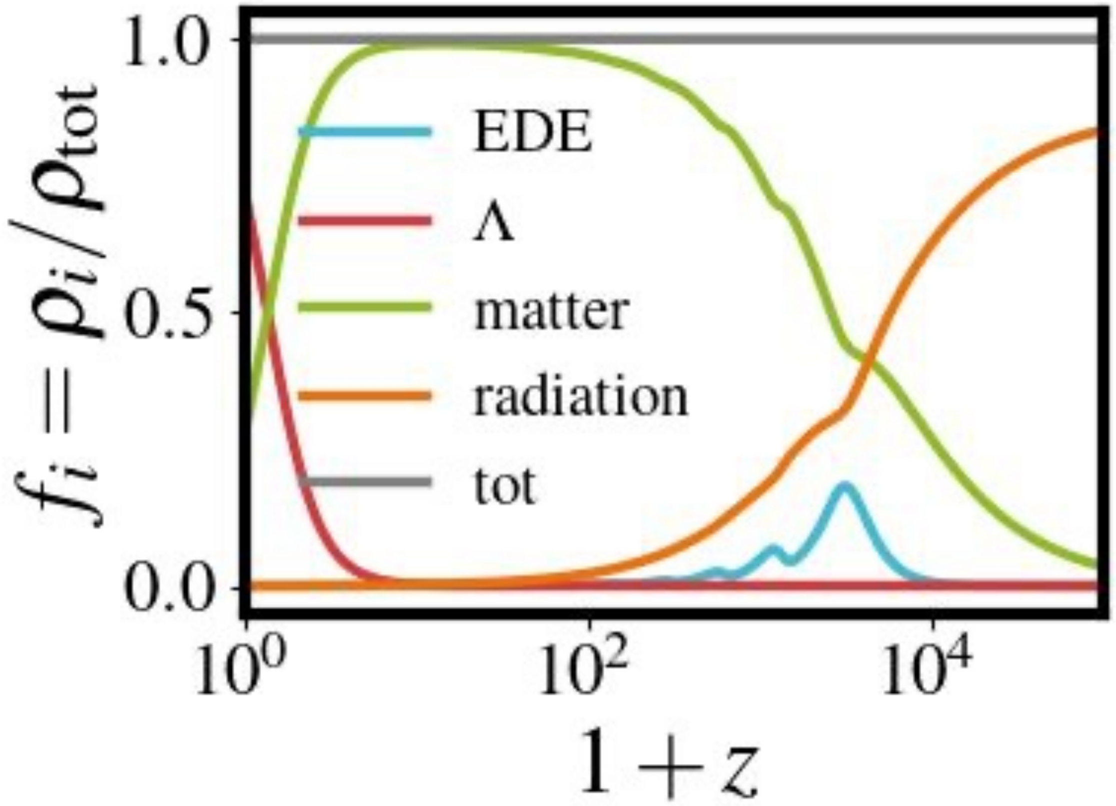
$$r_s^* \sim \int_{z^*}^{+\infty} \frac{dz}{H(z)}$$

EDE: a popular solution

$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)^n .$$

$$\phi(\tau, \mathbf{x}) \approx \phi^{(0)}(\tau) + \phi^{(1)}(\tau, \mathbf{x})$$



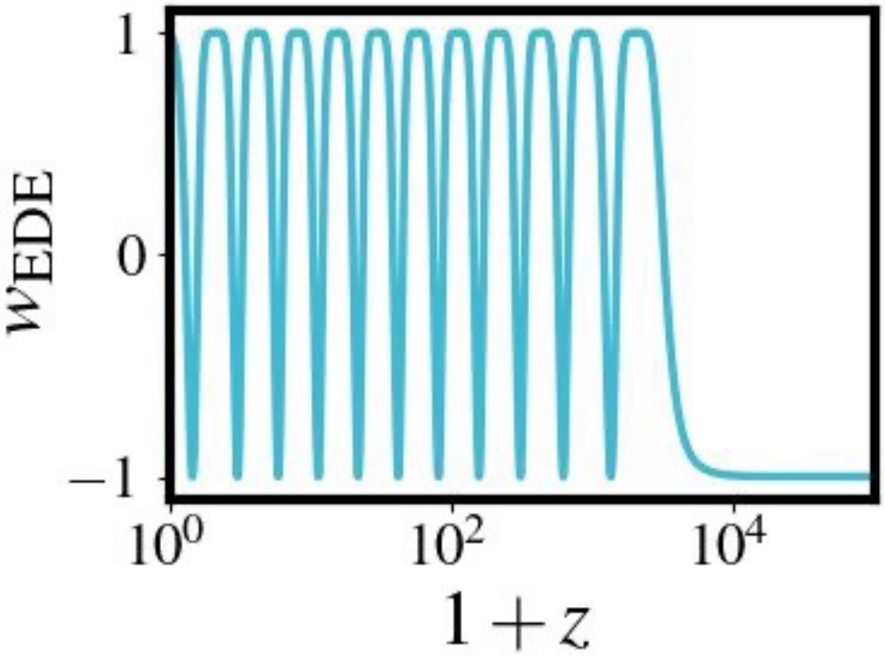


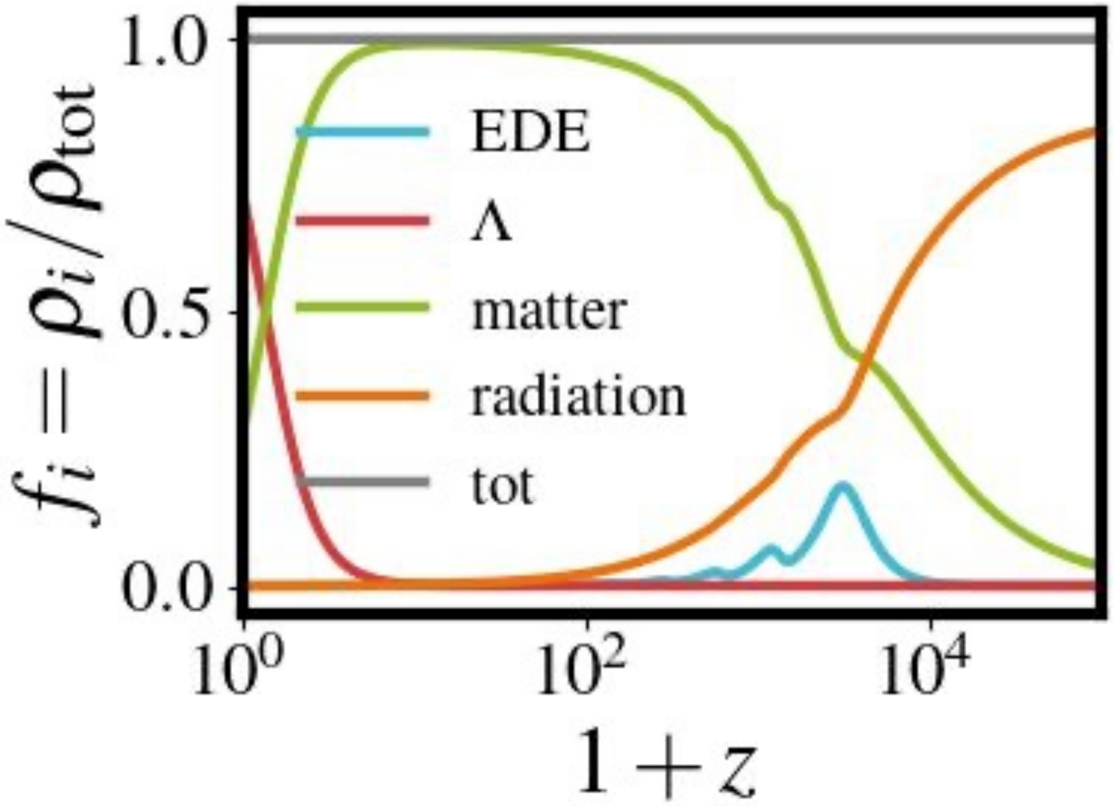
$$r_s^* \sim \int_{z^*}^{+\infty} \frac{dz}{H(z)} \qquad r_s^* \downarrow$$

EDE: a popular solution

$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)^n .$$

$$\phi(\tau, \mathbf{x}) \approx \phi^{(0)}(\tau) + \phi^{(1)}(\tau, \mathbf{x})$$





$$r_s^* \sim \int_{z^*}^{+\infty} \frac{dz}{H(z)} \qquad r_s^* \downarrow \qquad H_0 \uparrow$$

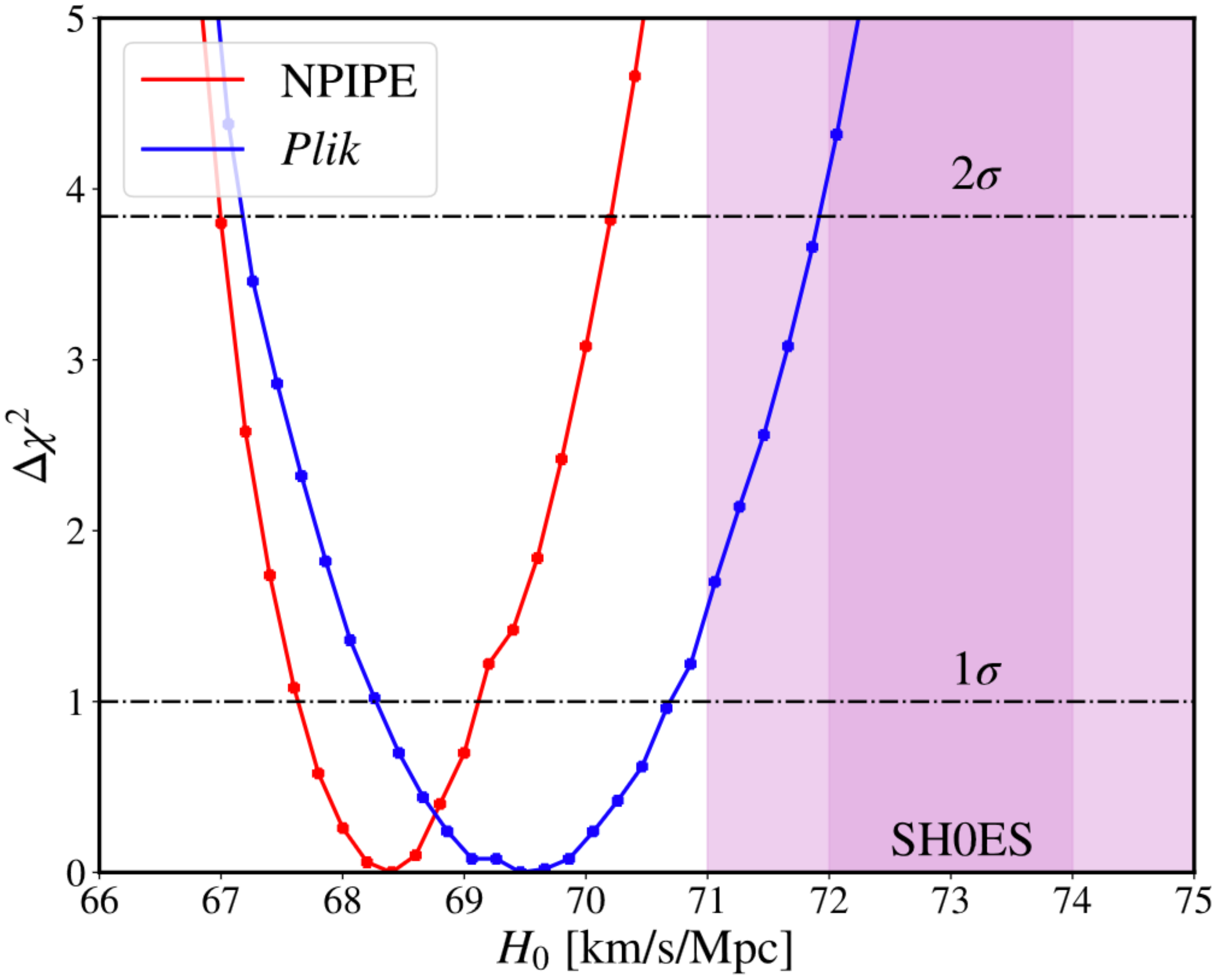
the NPIPE tragedy

the NPIPE tragedy

Planck PR4: high-l reanalysis

the NPIPE tragedy

Planck PR4: high-l reanalysis

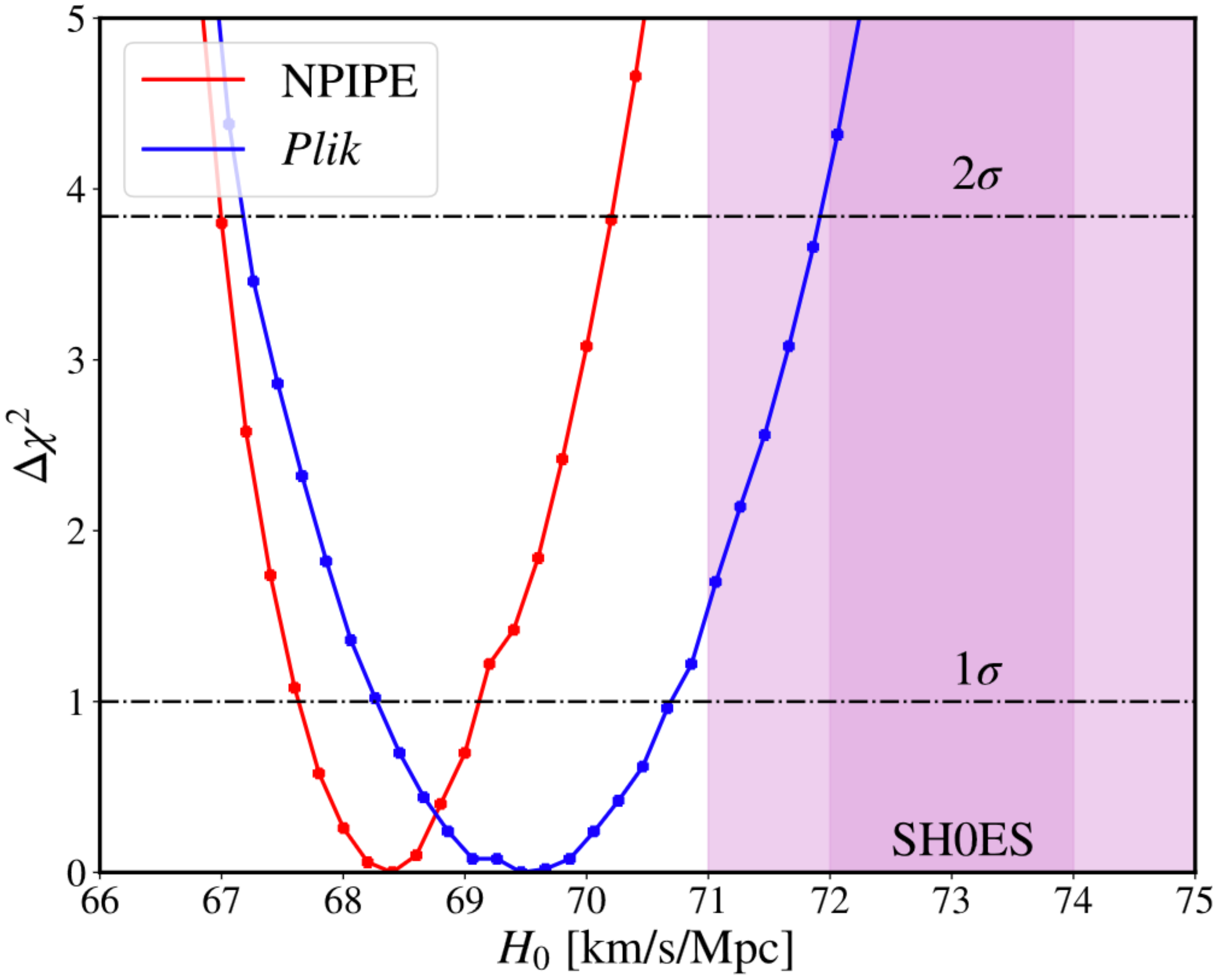


(Efstathiou, Rosenberg, Poulin 2311.00524)

the NPIPE tragedy

Planck PR4: high-l reanalysis

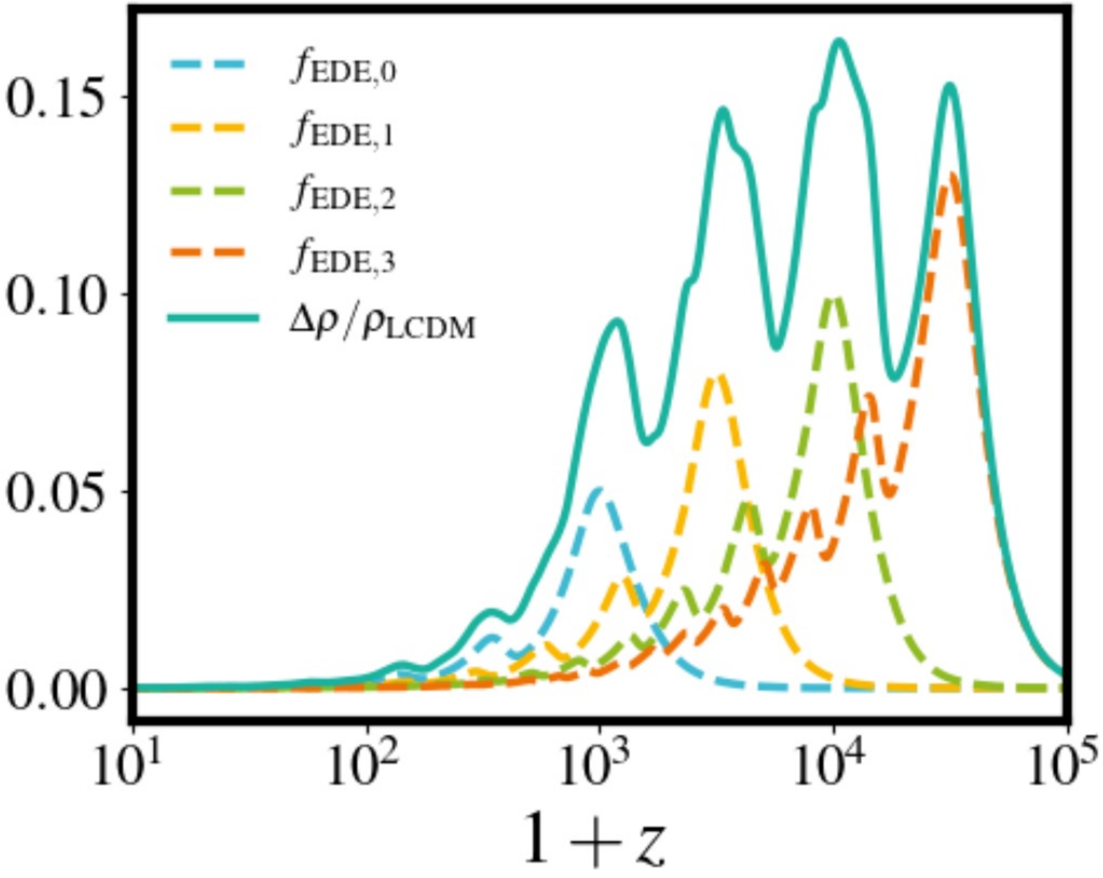
EDE: H_0 at 3.7σ from SHoES



(Efstathiou, Rosenberg, Poulin 2311.00524)

the model

the (physical) model

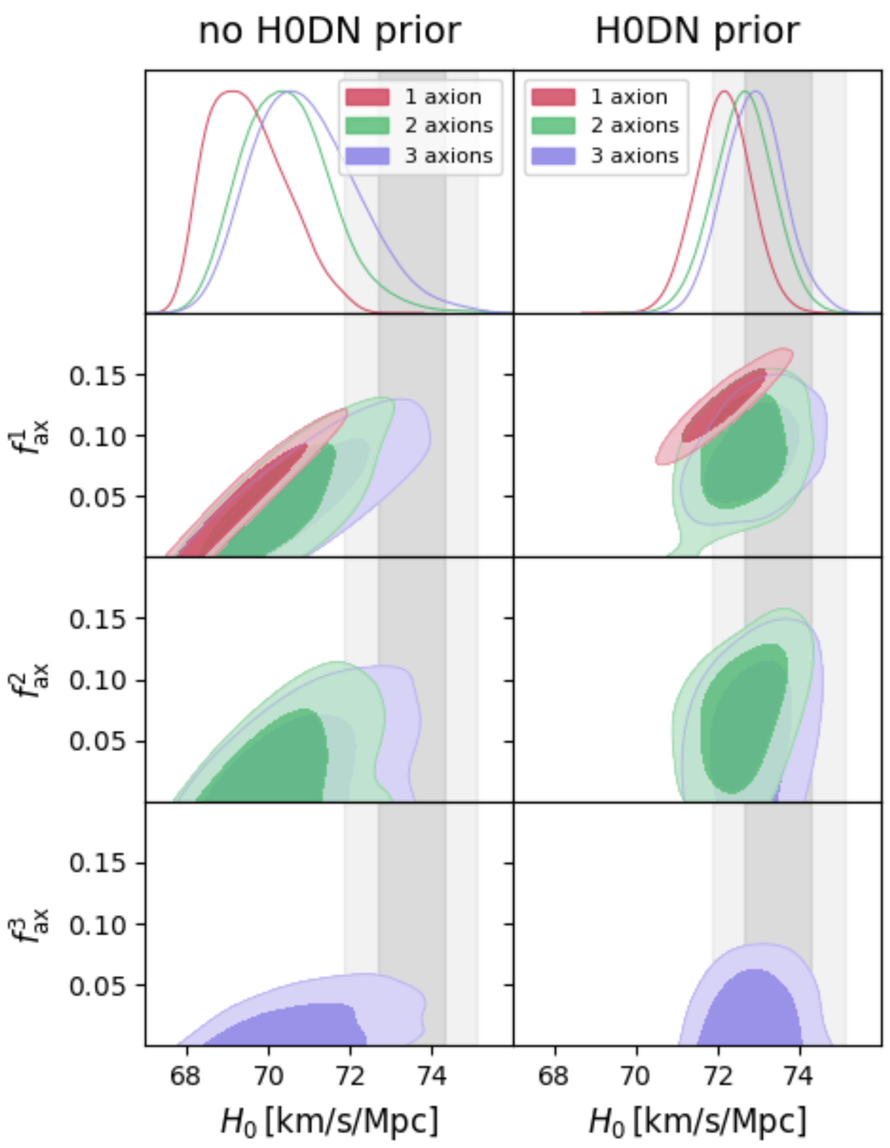


$$(f_{EDE,i} = \rho_{EDE,i}/\rho_{tot})$$

github.com/marcobeiia/mAxiCLASS

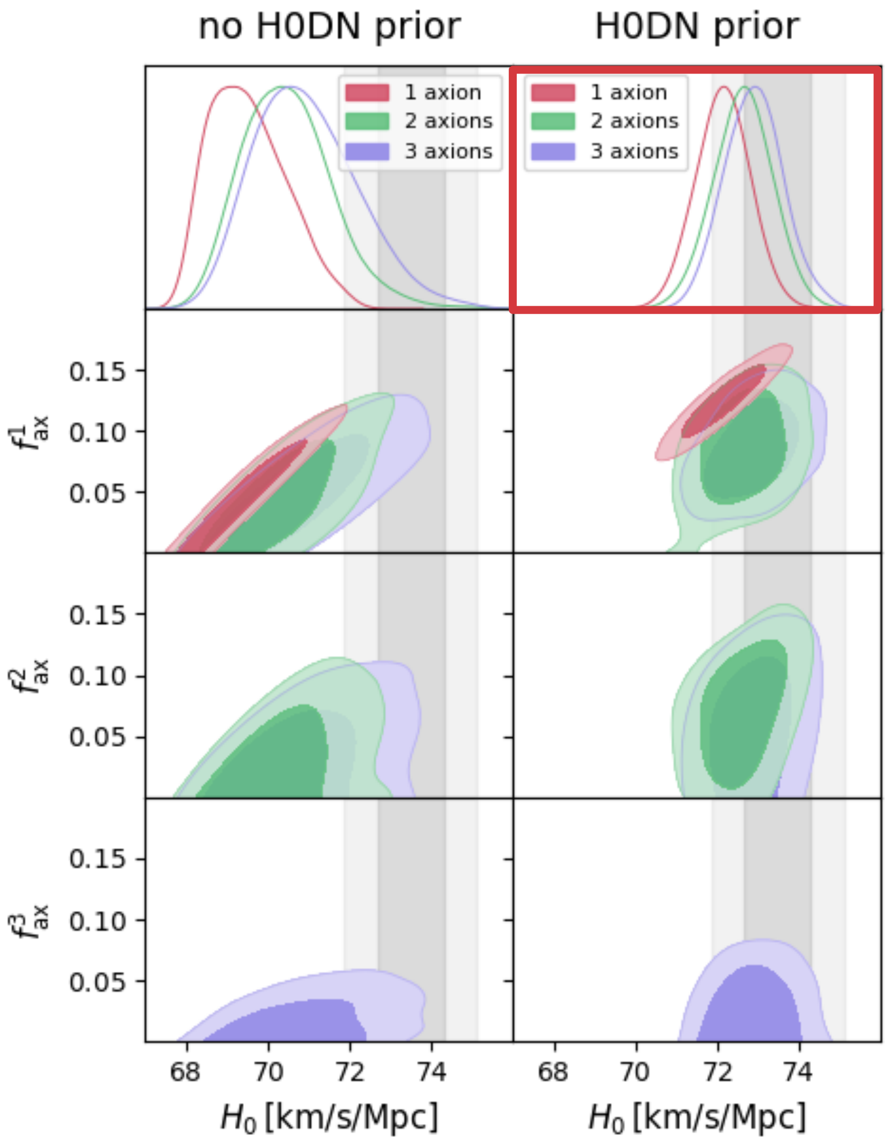
results

posteriors



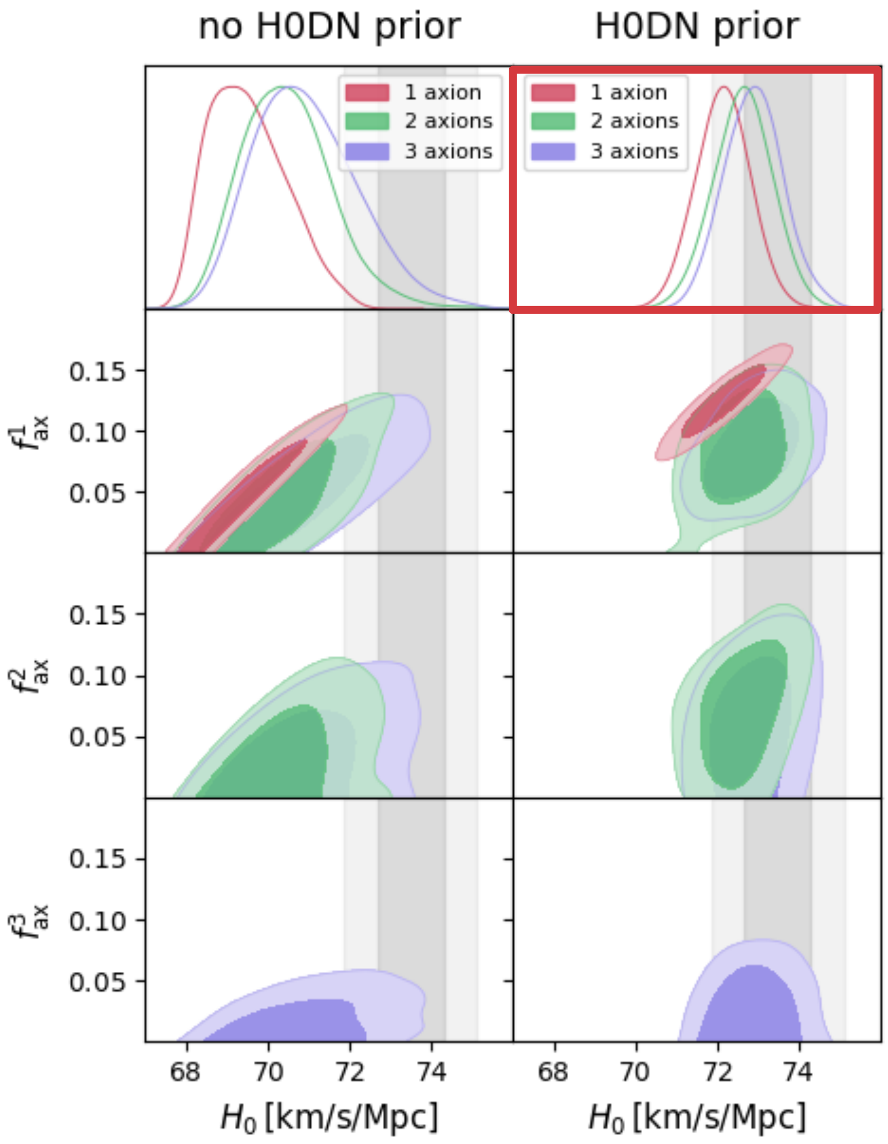
no H0DN prior
H0DN prior
1 axion
2 axions
3 axions
1 axion
2 axions
3 axions
f_{ax}^1
f_{ax}^2
f_{ax}^3
0.15
0.10
0.05
68
70
72
74
H_0 [km/s/Mpc]
H_0 [km/s/Mpc]

posteriors



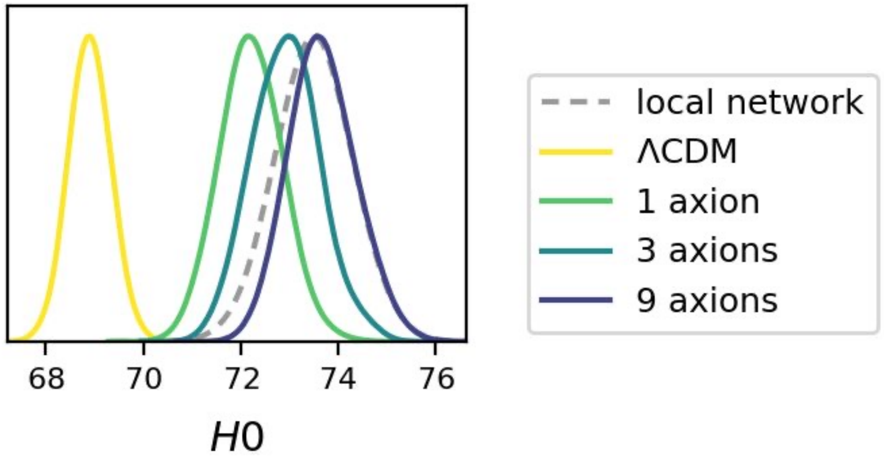
more fields -> higher Ho

posteriors

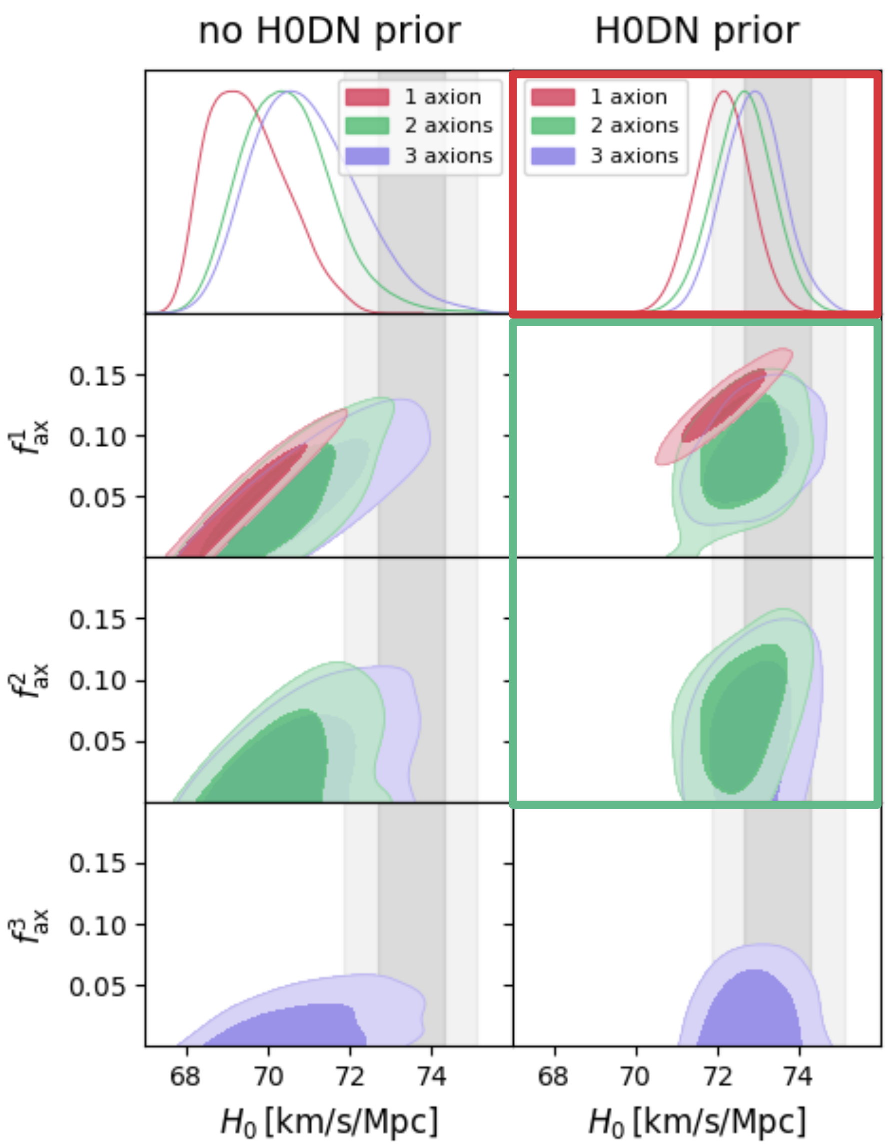


more fields -> higher Ho

MORE FIELDS -> HIGHER H_0!!!!



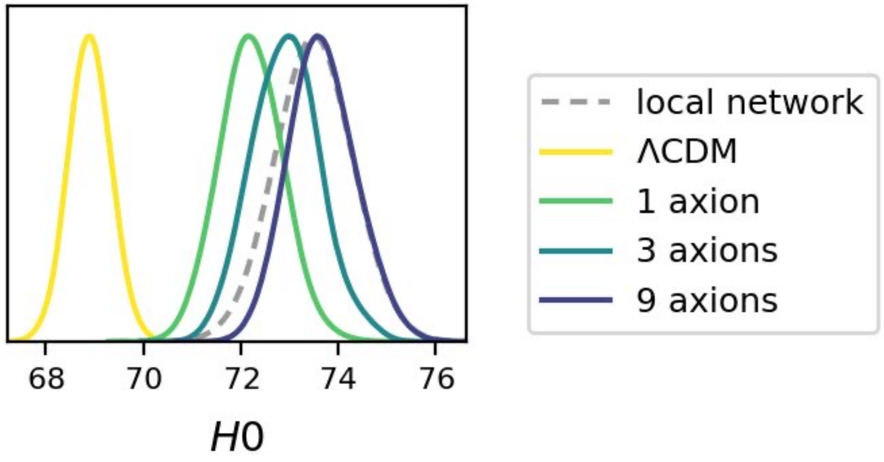
posteriors



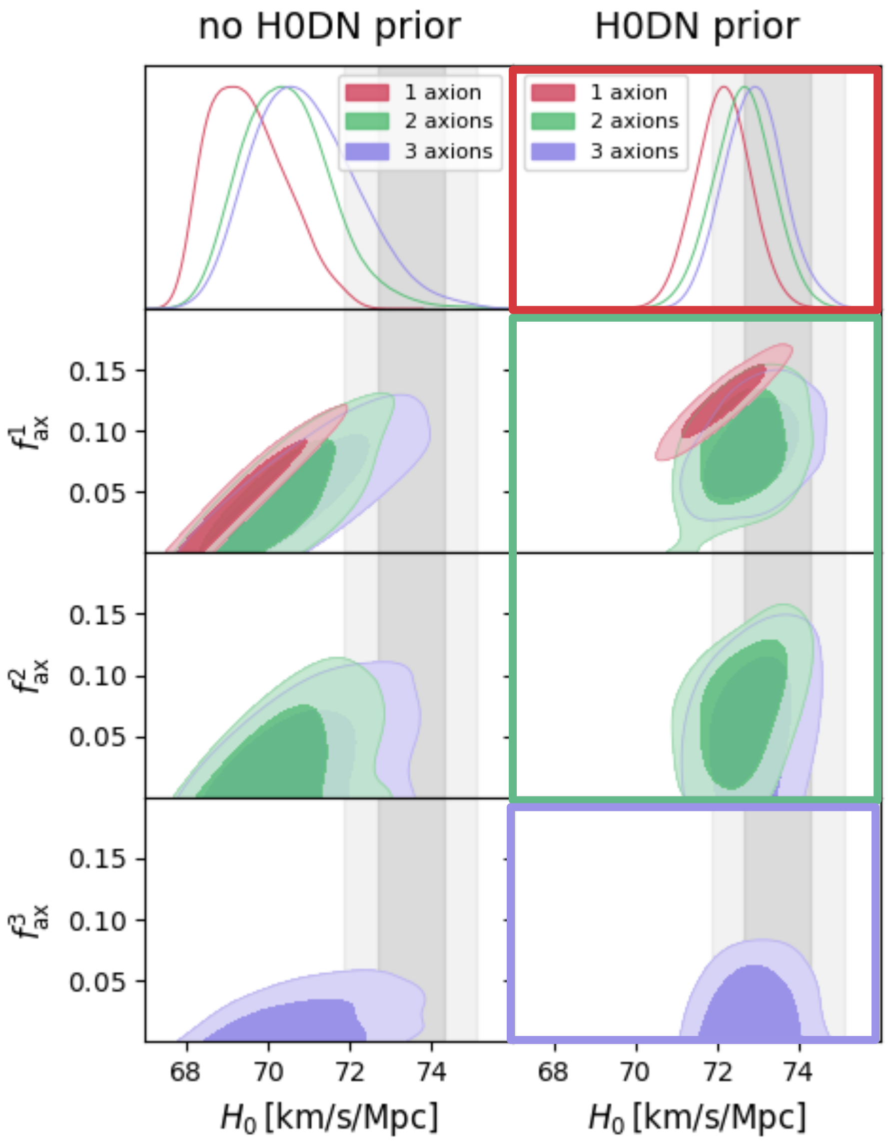
more fields -> higher Ho

$f_{ax}^{1,2} \neq 0$ at 1σ!

MORE FIELDS -> HIGHER H_0!!!!



posteriors

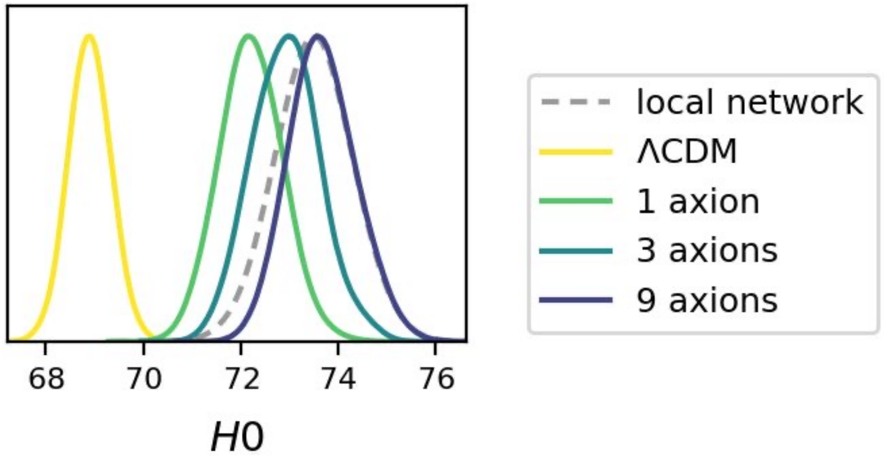


more fields -> higher Ho

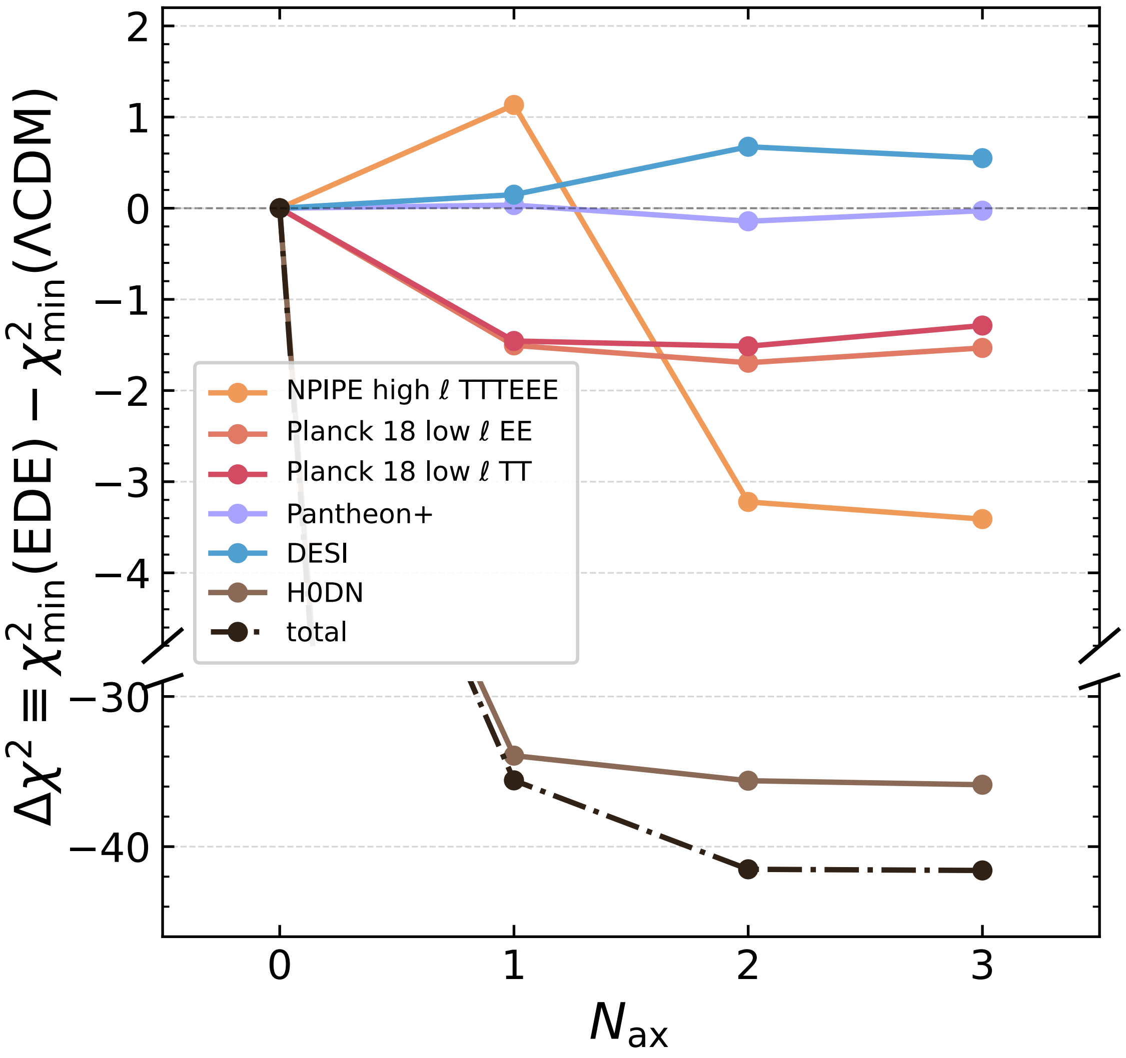
$f_{ax}^{1,2} \neq 0\ at\ 1\sigma!$

no need for the third field?

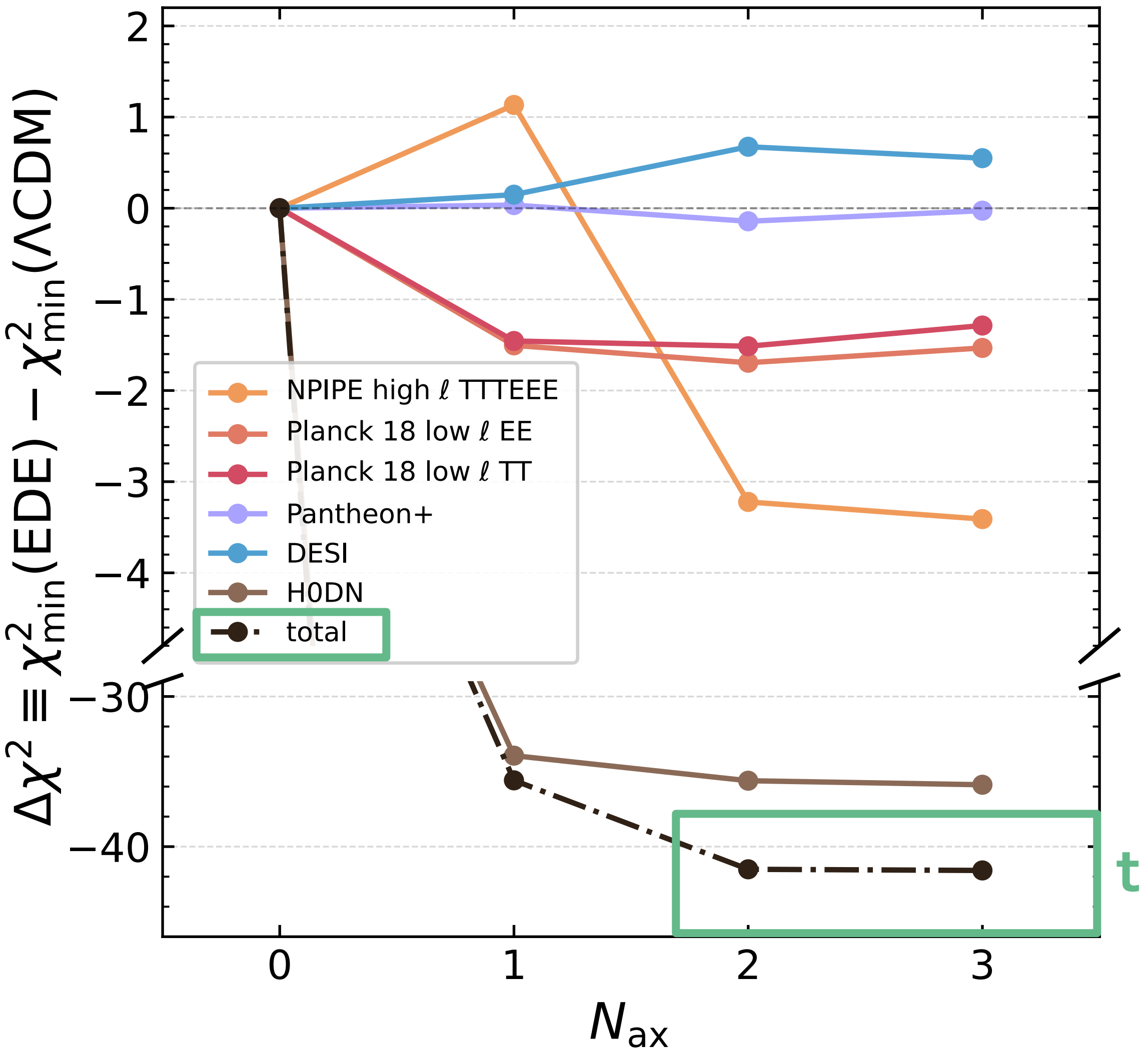
MORE FIELDS -> HIGHER H_0!!!!



chi2 per experiment

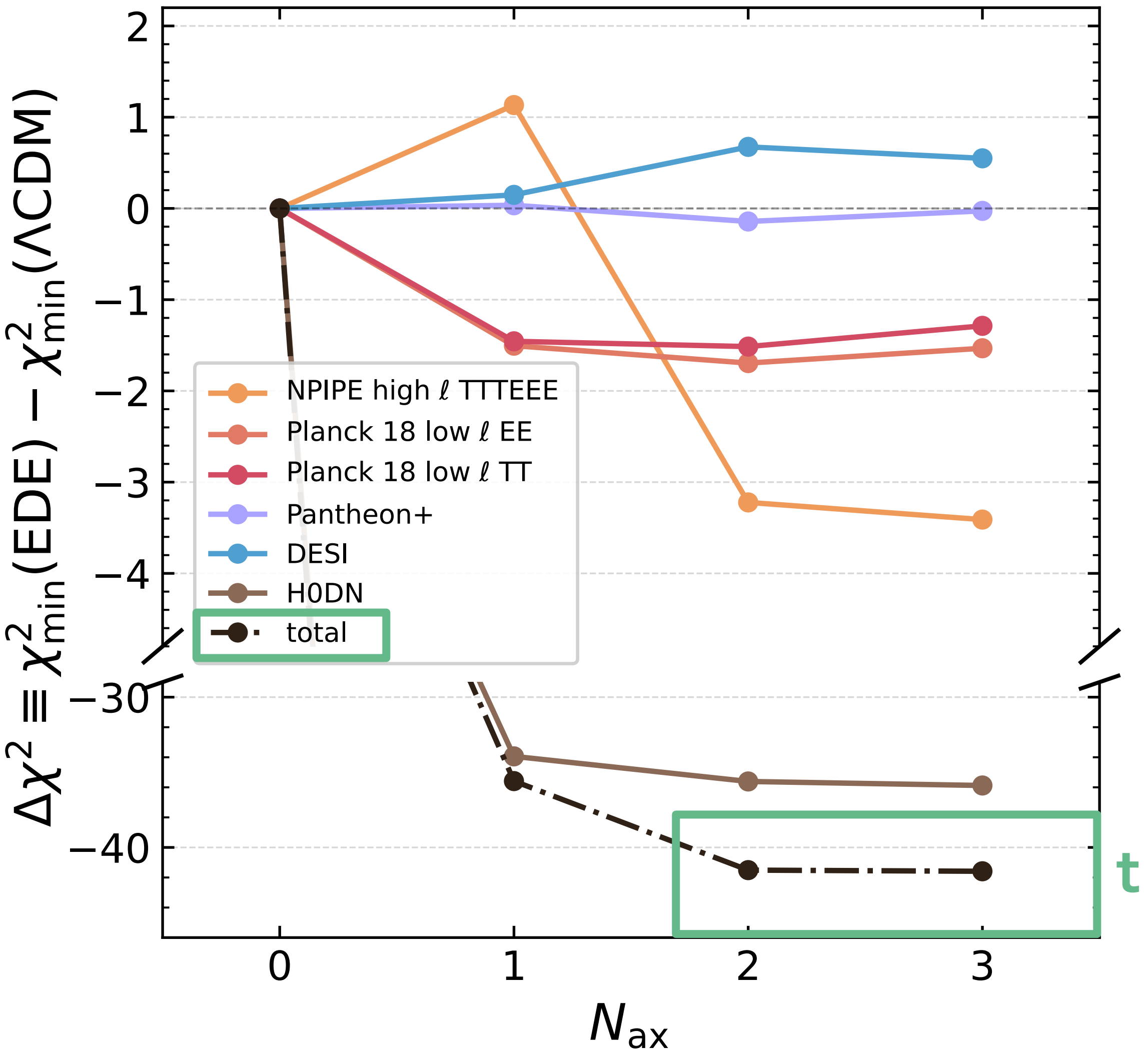


chi2 per experiment



third field doesn’t improve the fit!

chi2 per experiment

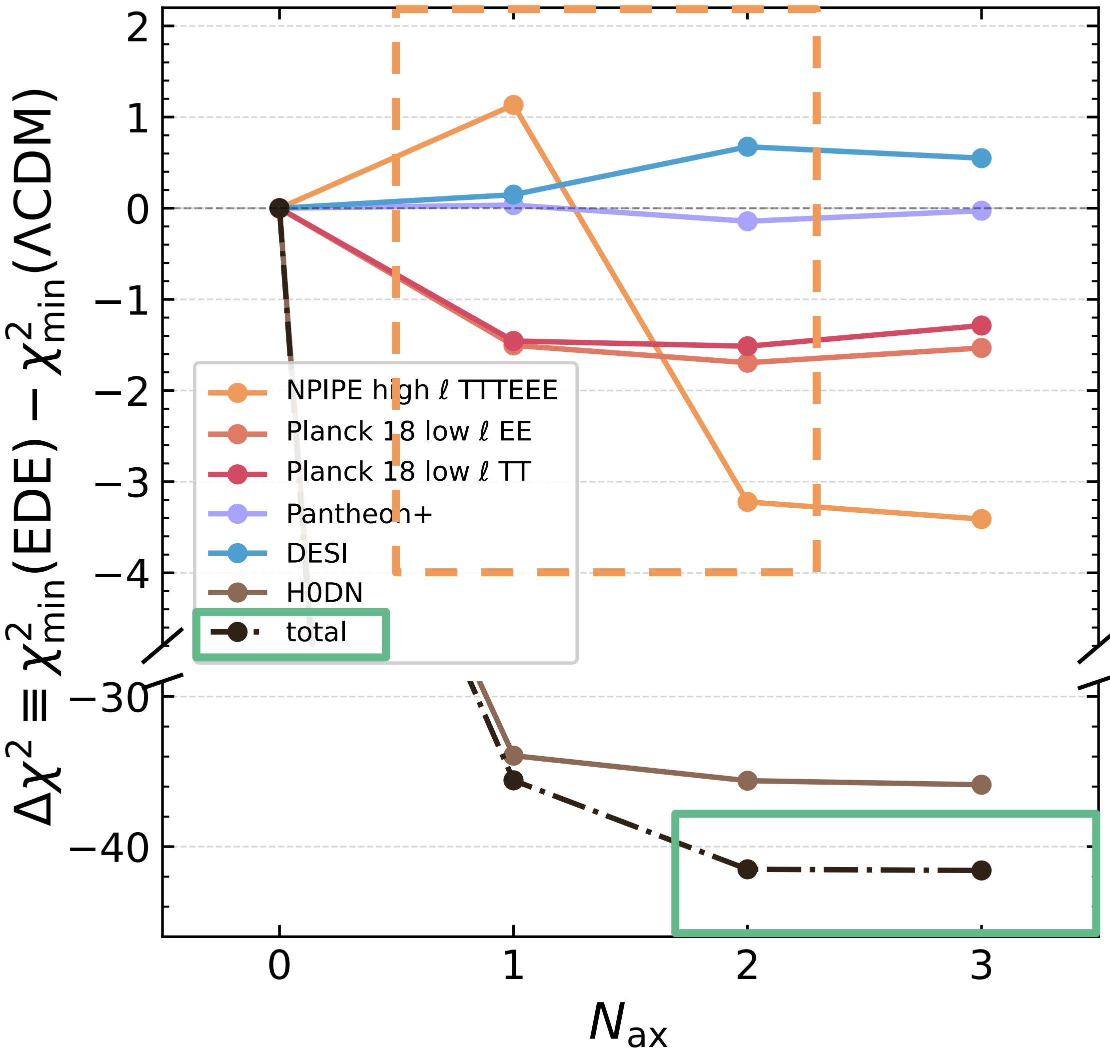


third field doesn't improve the fit!

$$\Delta\mathrm{AIC} = \chi^2_{\rm min}(\mathcal{M}) - \chi^2_{\rm min}(\Lambda\mathrm{CDM}) + 2k$$

chi2 per experiment

what's up with Planck?

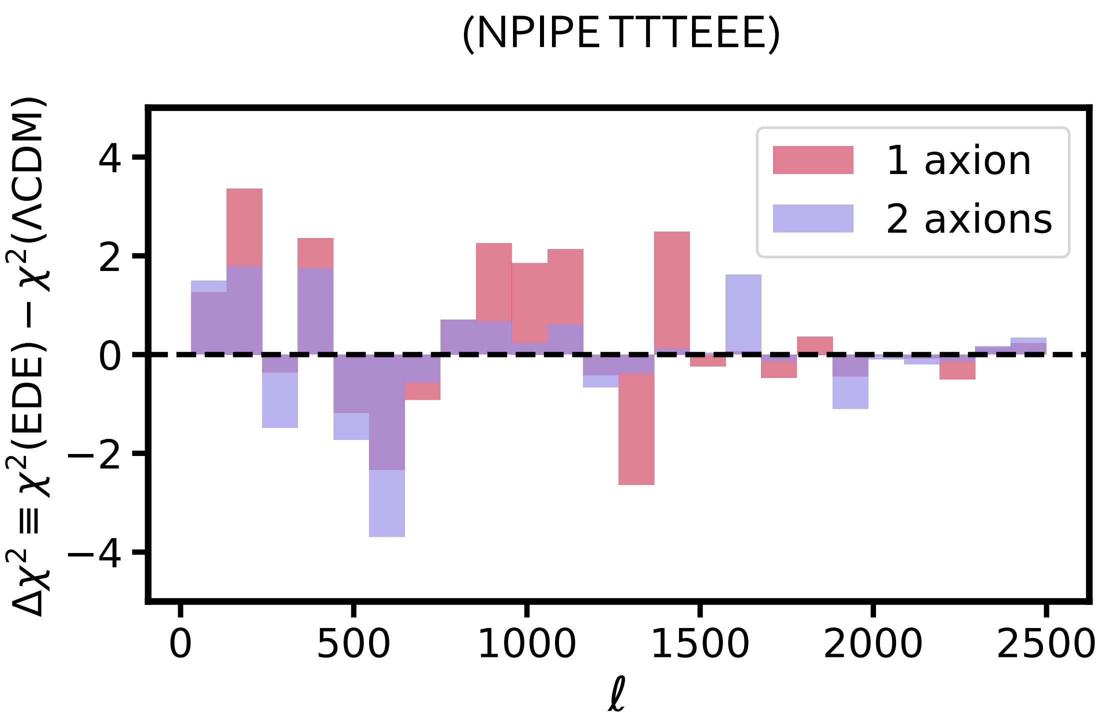


third field doesn't improve the fit!

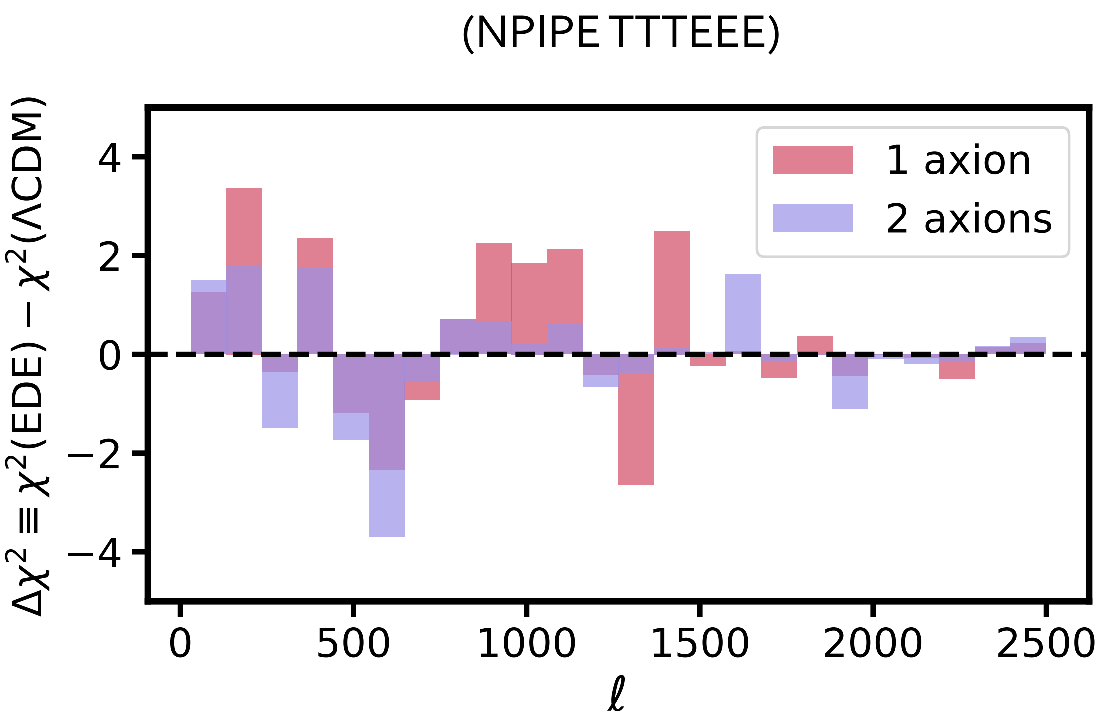
$$\Delta\mathrm{AIC} = \chi^2_{\rm min}(\mathcal{M}) - \chi^2_{\rm min}(\Lambda\mathrm{CDM}) + 2k$$

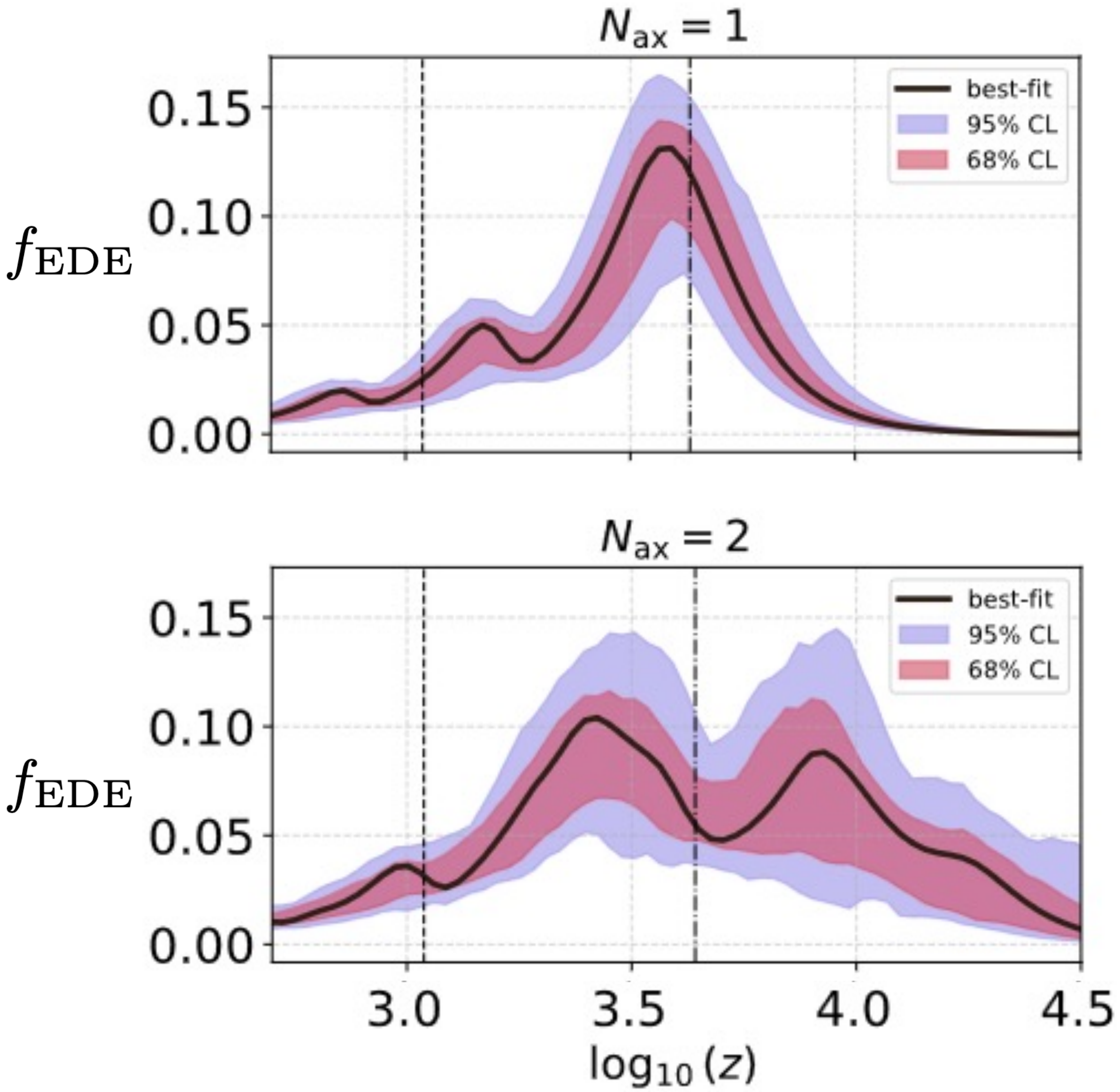
1 vs 2 axions

1 vs 2 axions


(NPIPE TTTEEE)
1 axion
2 axions
$\Delta\chi^2 \equiv \chi^2(\mathrm{EDE}) - \chi^2(\Lambda\mathrm{CDM})$
4
2
0
−2
−4
0
500
1000
1500
2000
2500
ℓ

1 vs 2 axions

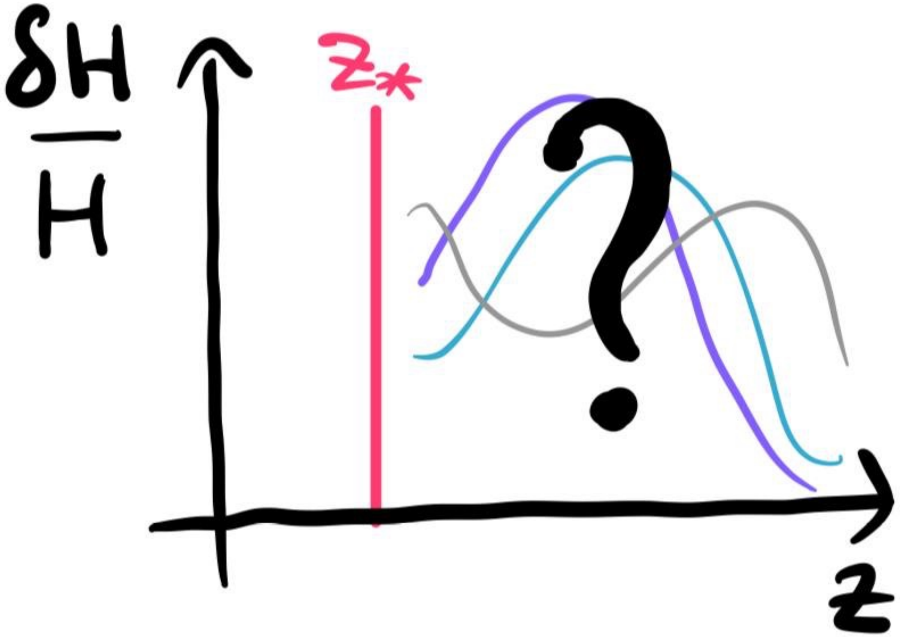




$$f_{\mathrm{EDE}}(z) \equiv \sum_i \rho^i_{\mathrm{ax}}(z)/\rho_{\mathrm{tot}}(z)$$

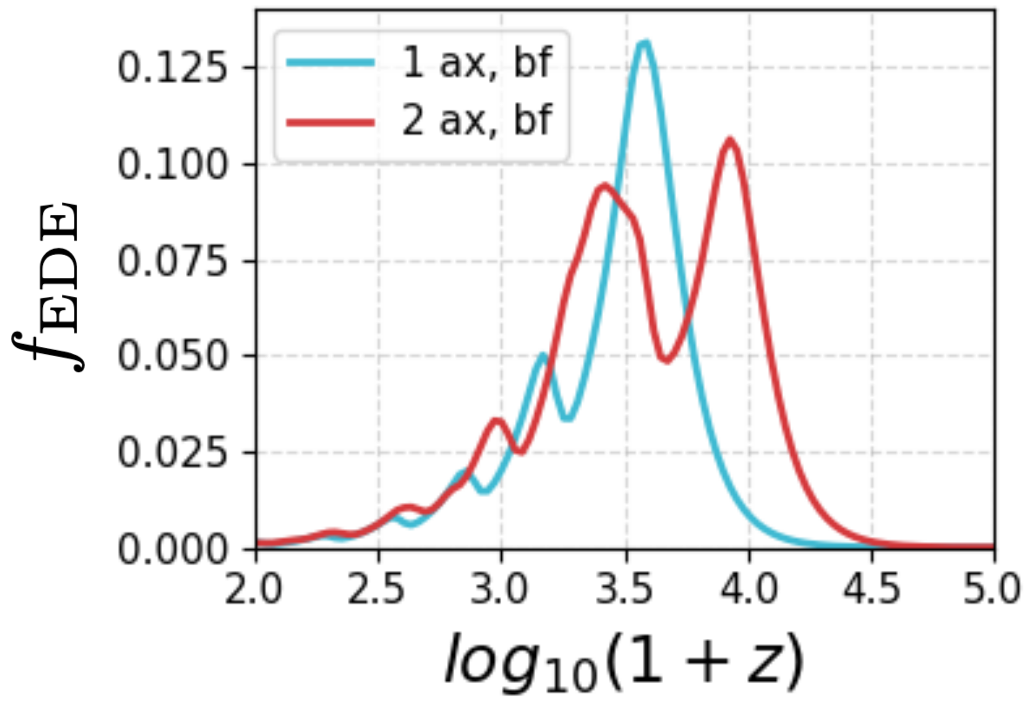
wrapping up

"what early expansion history solves the Hubble tension?"



wrapping up

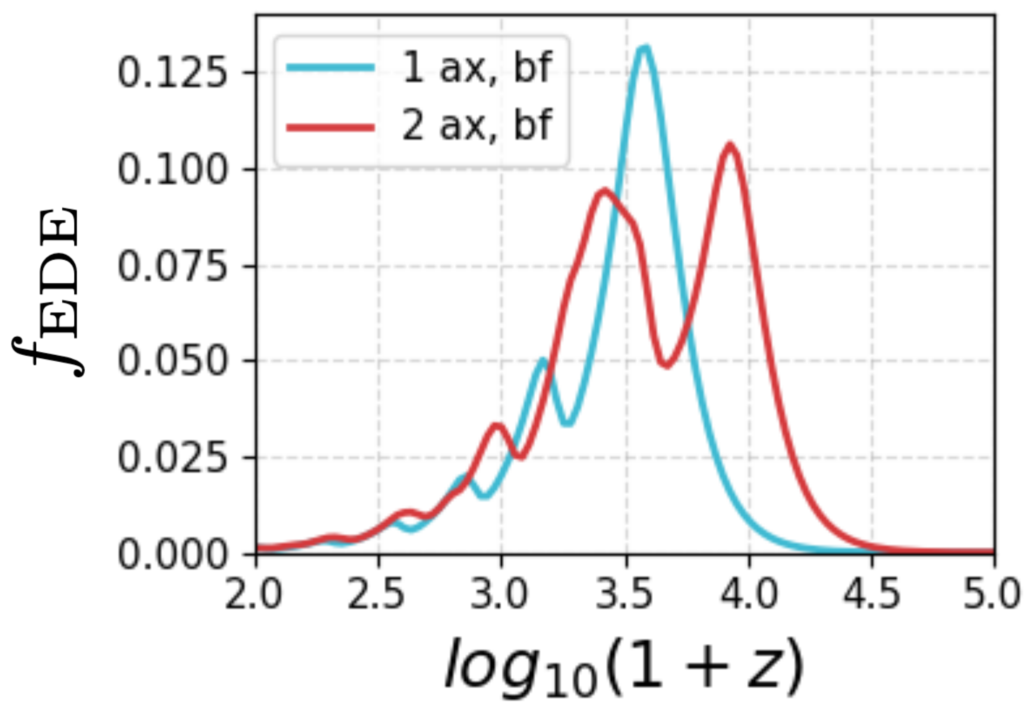
"what early expansion history solves the Hubble tension?"



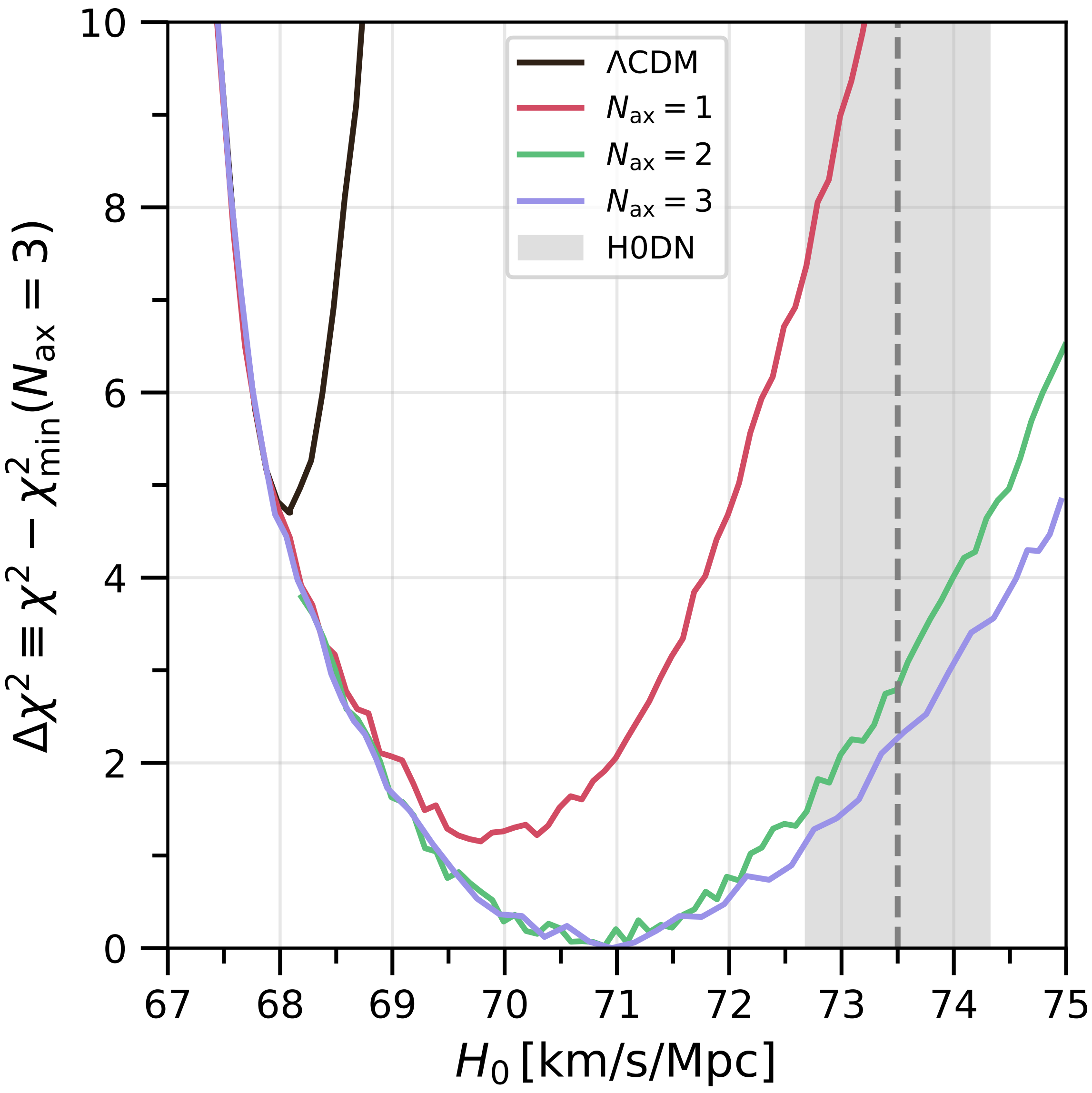
Planck likes it smooth :D

wrapping up

"what early expansion history solves the Hubble tension?"



Planck likes it smooth :D



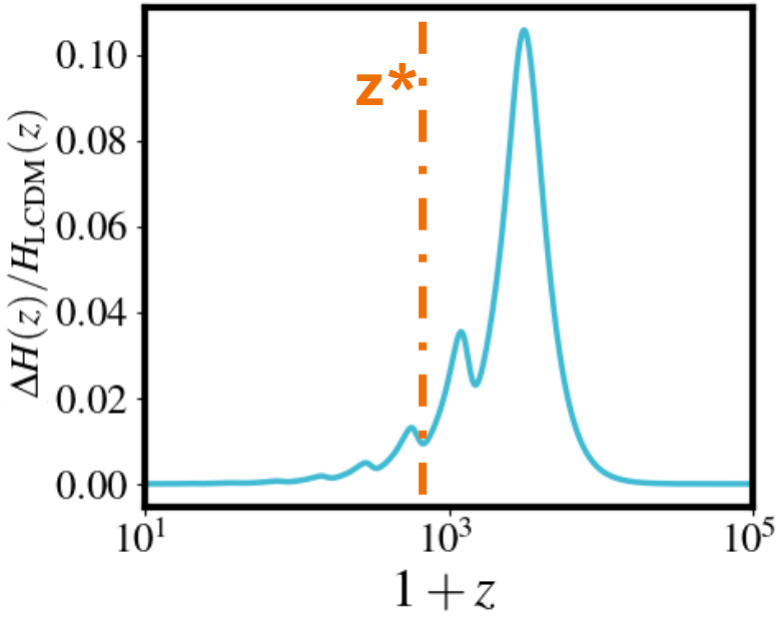
EDE not ded yet!

thank you!

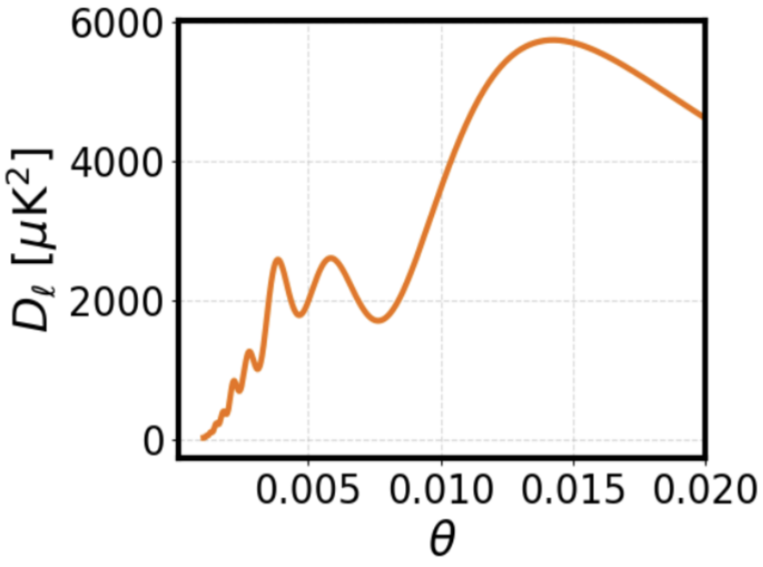
backup

EDE and Ho

boosts early hubble rate (H ~ ρ^2)



$$\boxed{\theta_s^* = \frac{r_s^*}{d_A^*}}$$



$$r_s^* \sim \int_{z^*}^{+\infty} \frac{dz}{H(z)}$$

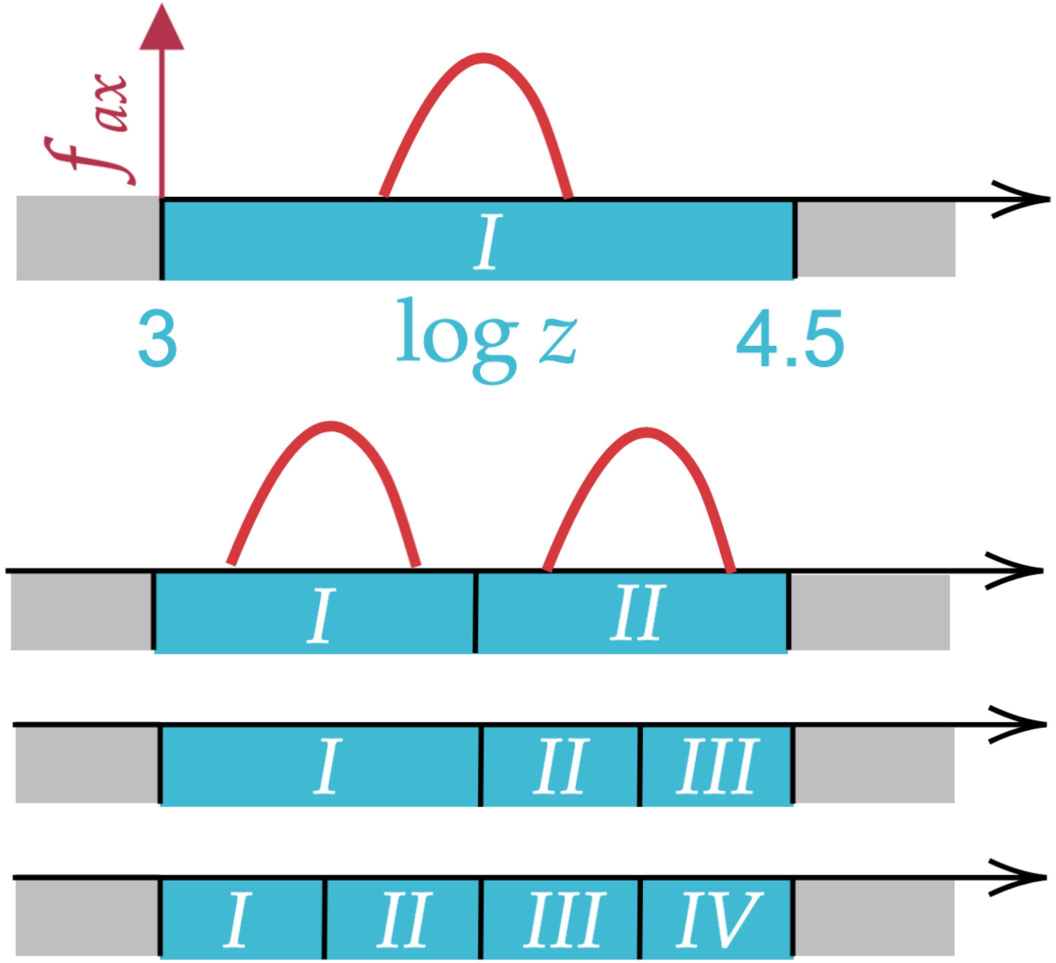
$$H(z > z^*) \uparrow$$

$$r_s^* \downarrow, \boxed{d_A^* \downarrow}$$

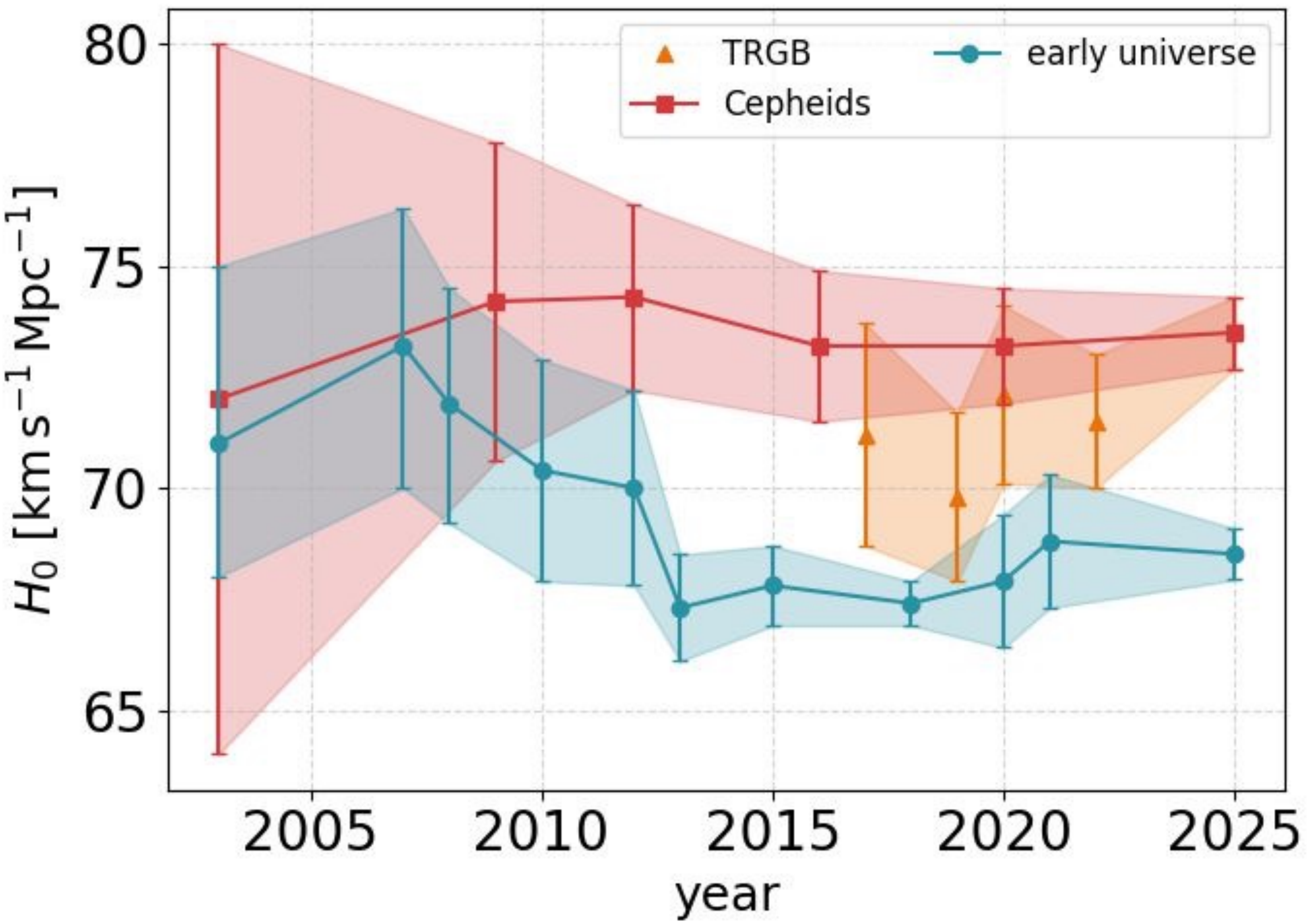
$$d_A^* \sim H_0^{-1}$$

$$H_0 \uparrow$$

multi-axion EDE: binning choice



more on Ho



TRGB
Cepheids
early universe
80
75
70
65
H_0 [km s^{-1} Mpc^{-1}]
2005
2010
2015
2020
2025
year

Ho-rd plane

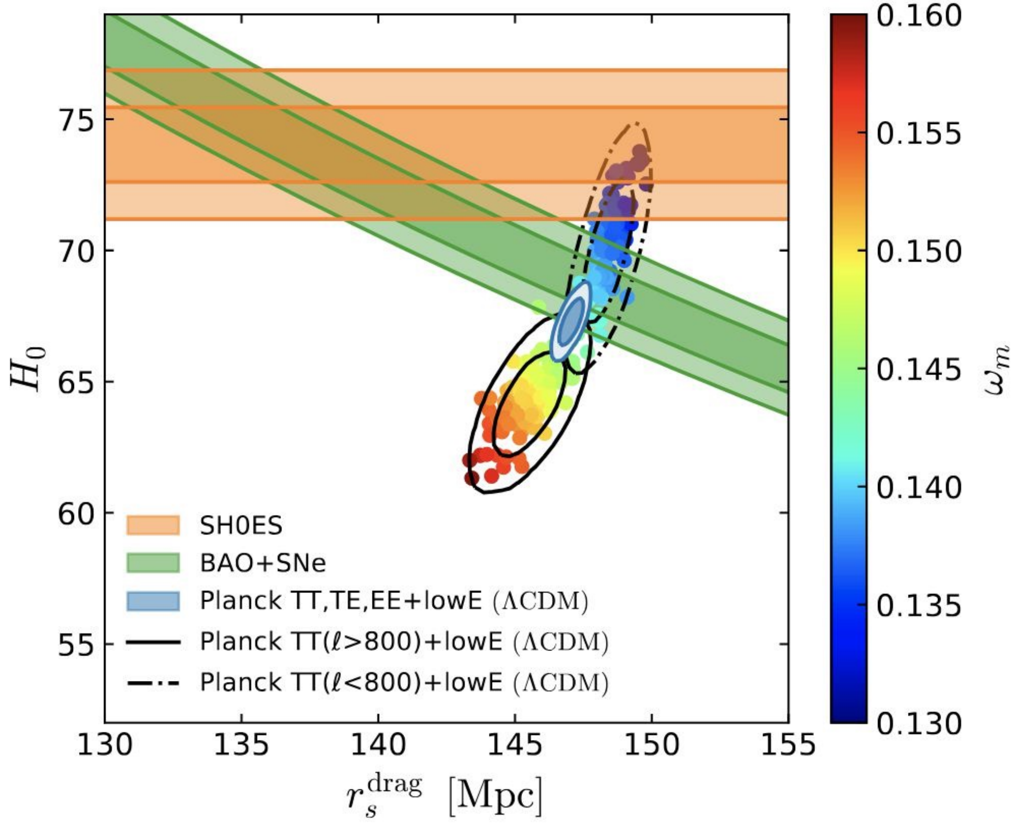
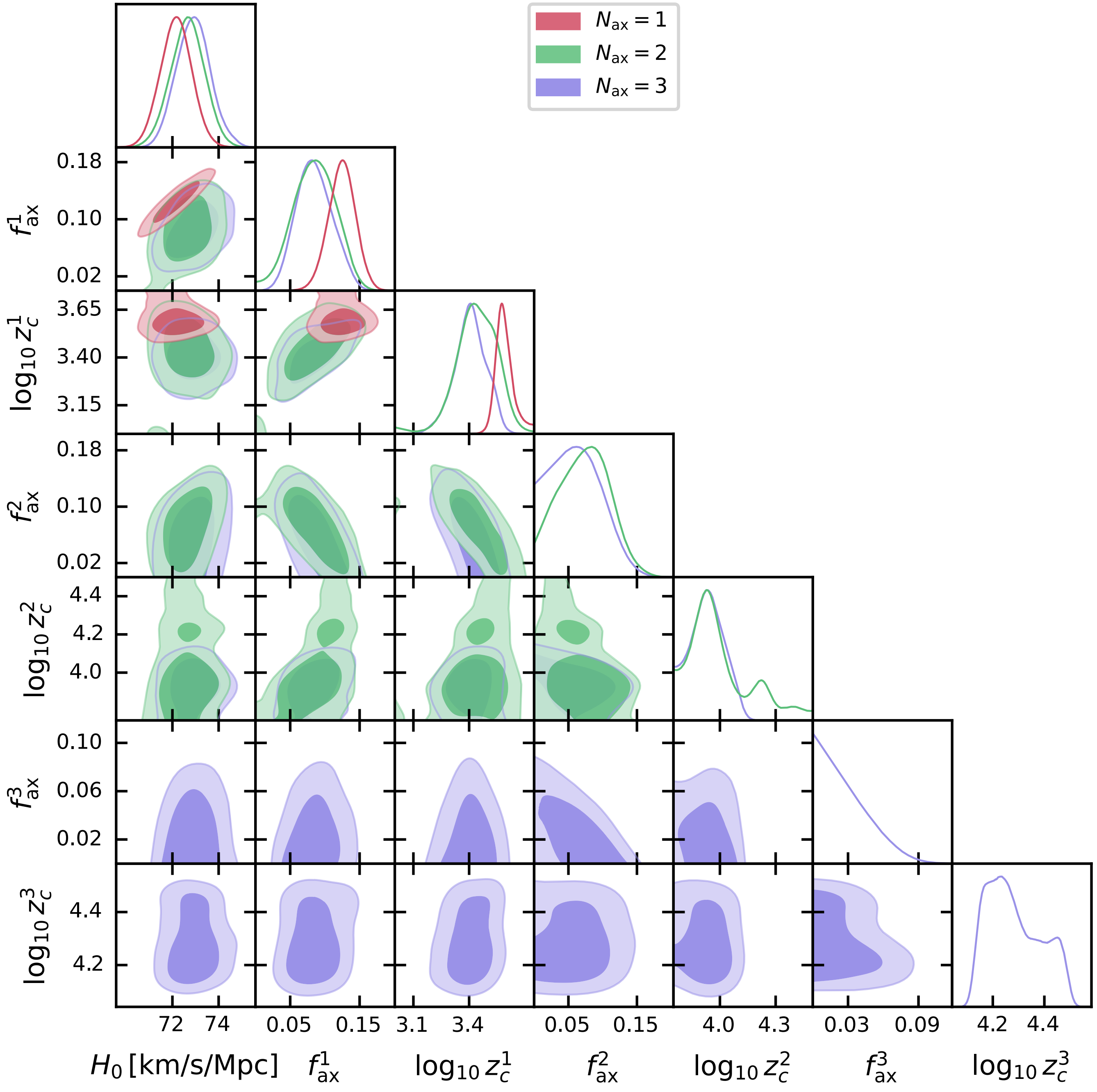


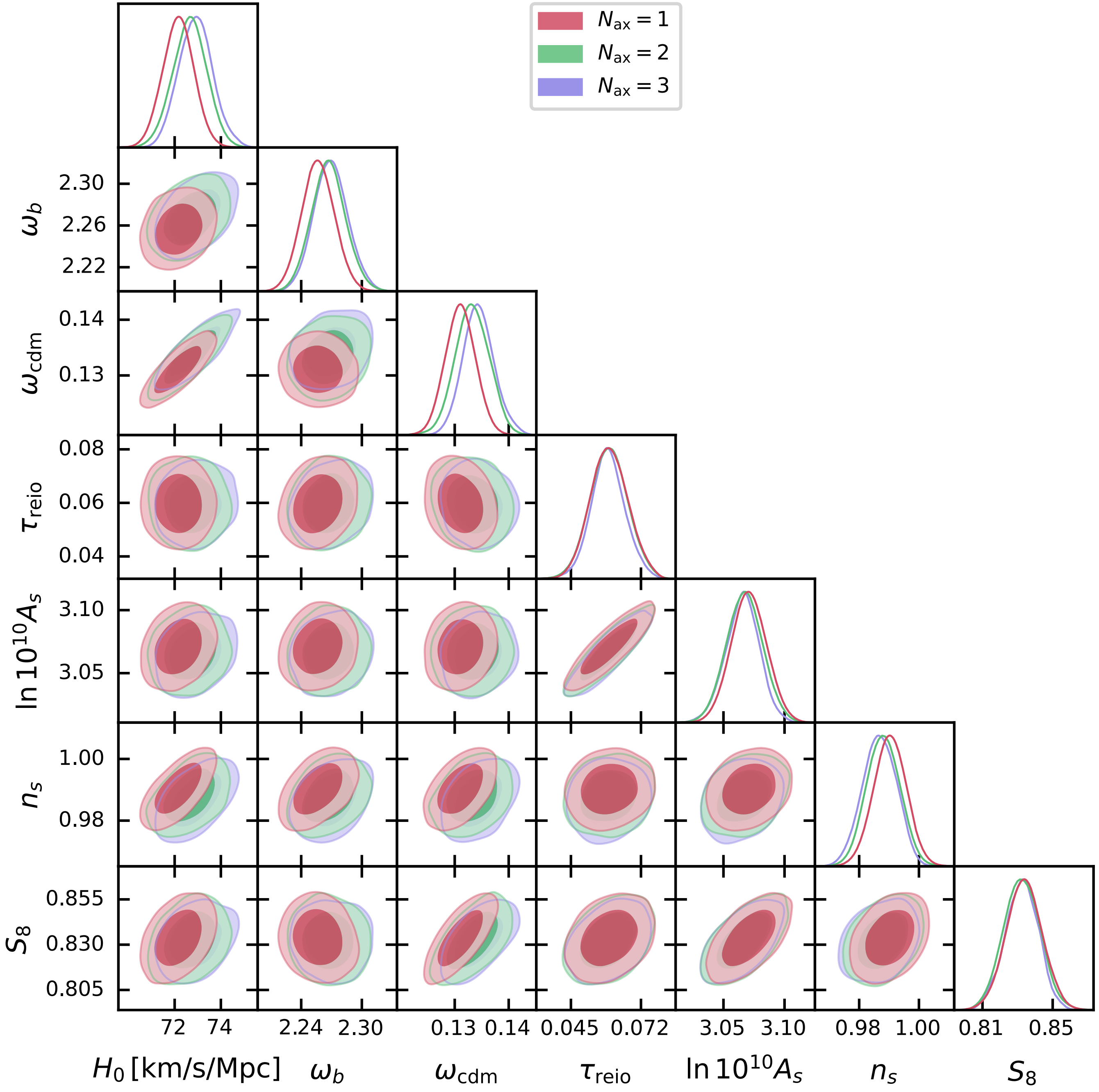
FIGURE 2.2: Degeneracy lines in the $H_0 - r_s$ plane. The shaded regions are 68% and 95% confidence regions. Different version of Planck data are used in this work, splitting the dataset at $\ell = 800$. The scatter is colour-coded with the value of $\omega_m = \Omega_m h^2$. The SHoES constraint is from [41], BAO data come from [31] and SNe from [35]. Reproduced from [51].

(Knox, Millea 1908.03663)

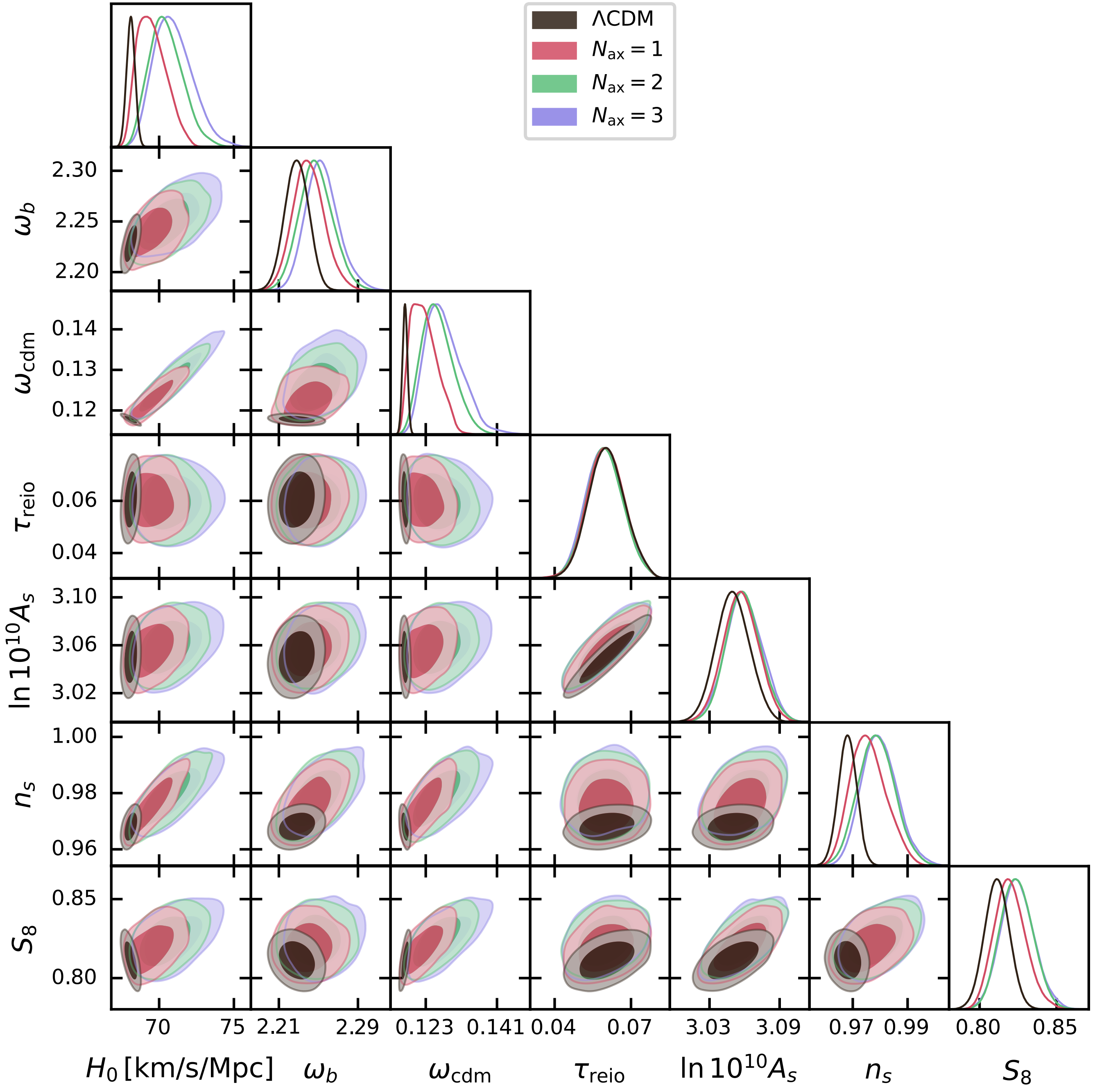
Pantheon+,
DESI,
HoDN
(axion sector)



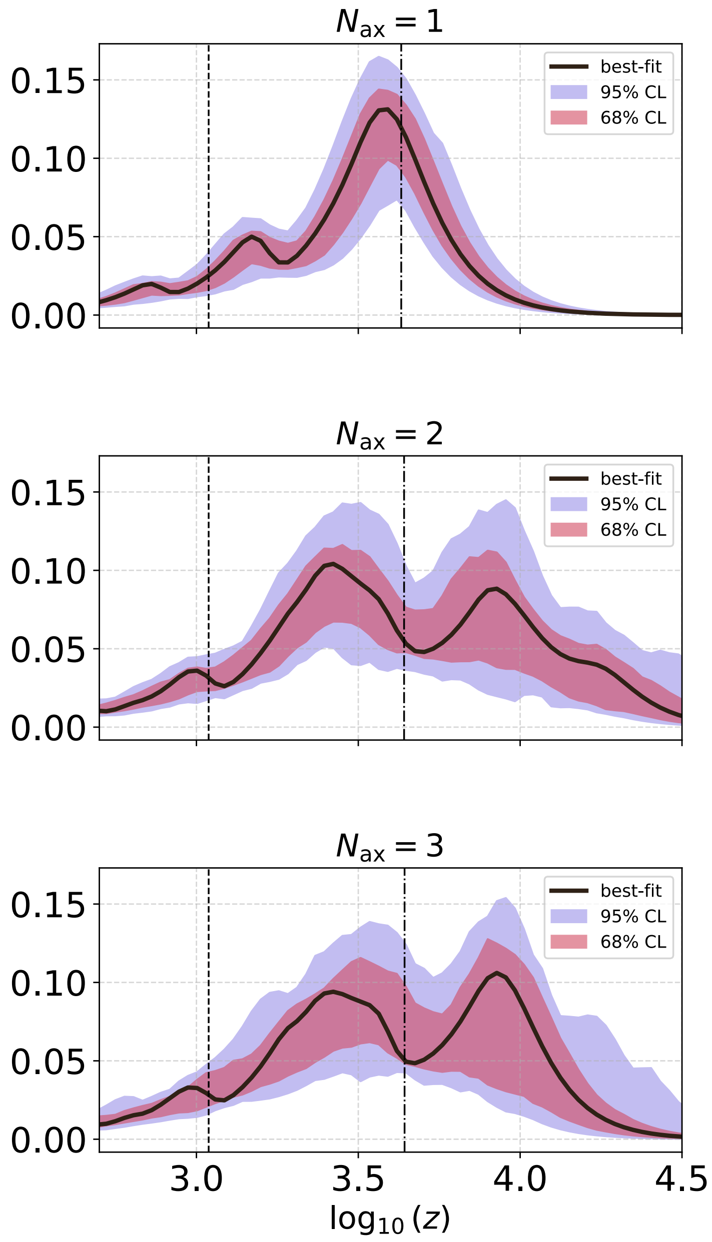
full posteriors (Pantheon+, DESI, HoDN)



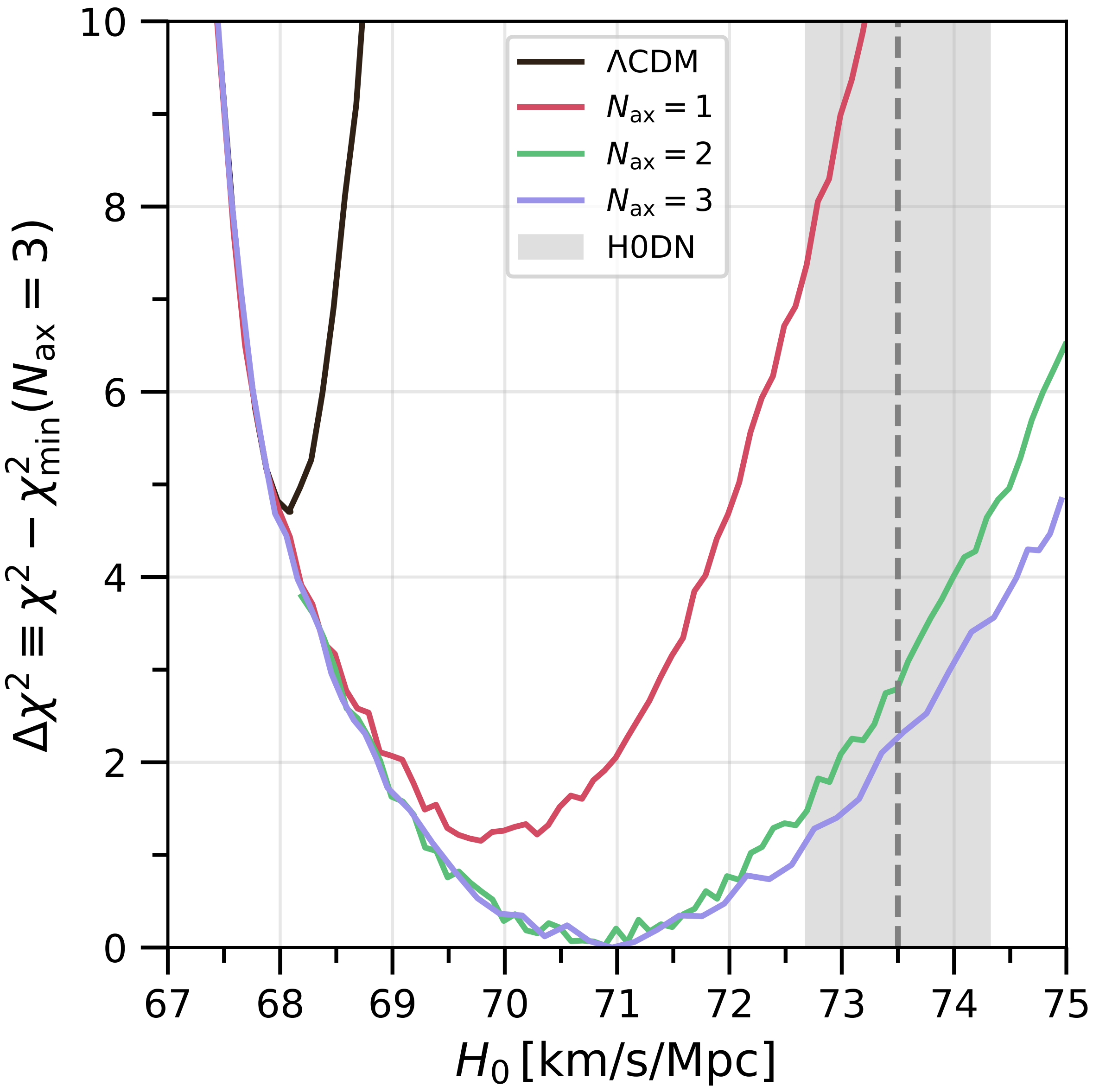
(Pantheon+, DESI)



1 vs 2 vs 3 axions



profile likelihoods!



tables

Model	Credible intervals		Confidence intervals
	with H0DN	no H0DN	Bestfit $^{+68\%}_{-}$ (95%)
ΛCDM	—	68.10 ± 0.28	$68.10^{+0.40}_{-0.40}$ $\left(^{+0.80}_{-0.80}\right)$
1 axion	$72.16^{+0.67}_{-0.68}$	$69.53^{+0.71}_{-1.20}$	$69.89^{+1.19}_{-1.03}$ $\left(^{+2.21}_{-1.99}\right)$
2 axions	$72.65^{+0.73}_{-0.75}$	$70.46^{+0.96}_{-1.27}$	$70.59^{+1.66}_{-1.24}$ $\left(^{+3.36}_{-2.42}\right)$
3 axions	$72.91^{+0.68}_{-0.73}$	$70.93^{+1.06}_{-1.47}$	$70.93^{+1.67}_{-1.49}$ $\left(^{+3.55}_{-2.73}\right)$

TABLE I. H_0 constraints (in km/s/Mpc) from the PD and PDH0 combinations. The first two columns show means and 68% Bayesian credible intervals with and without the H0DN prior. The third column shows frequentist confidence intervals from profile likelihoods on PD at 68% (95%).

Model	Q_{DMAP}	ΔAIC(PD)	ΔAIC(PDH0)
ΛCDM	6.3σ	-0.86	$+32.52$
1 axion	2.6σ	ref. model	ref. model
2 axions	1.5σ	$+2.96$	-1.70
3 axions	1.3σ	$+6.92$	$+1.76$

TABLE II. Tension and model comparison metrics. Q_{DMAP} measures the residual tension with the H0DN determination. The ΔAIC values are computed with respect to the 1-axion model, so $\Delta\mathrm{AIC} < 0$ indicates that the model in question is favored against the 1-axion model by the given combination.