From

Hubble tension

to

Harrison-Zeldovich spectrum

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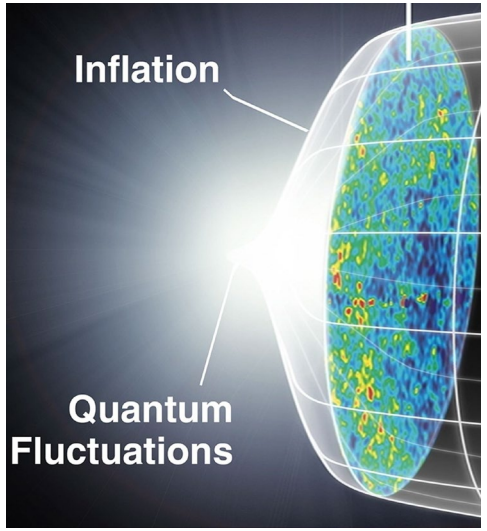
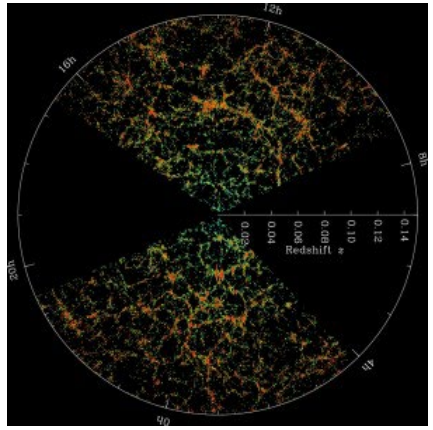
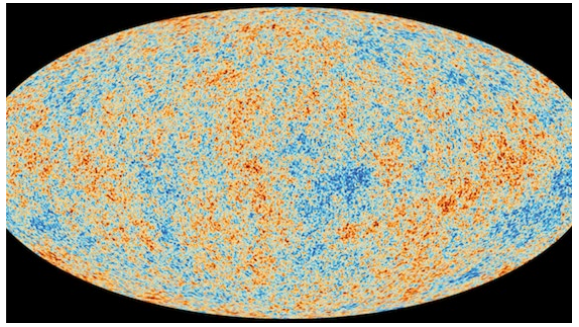


Models of very early Universe:
Inflation, bounce ...

Primordial perturbation





Fluctuations today:
CMB, LSS ...

Late Universe:
galaxies, halos …

Primordial perturbation

- Scalar:

$$\mathcal{P}_s(k) \propto k^{n_s}$$

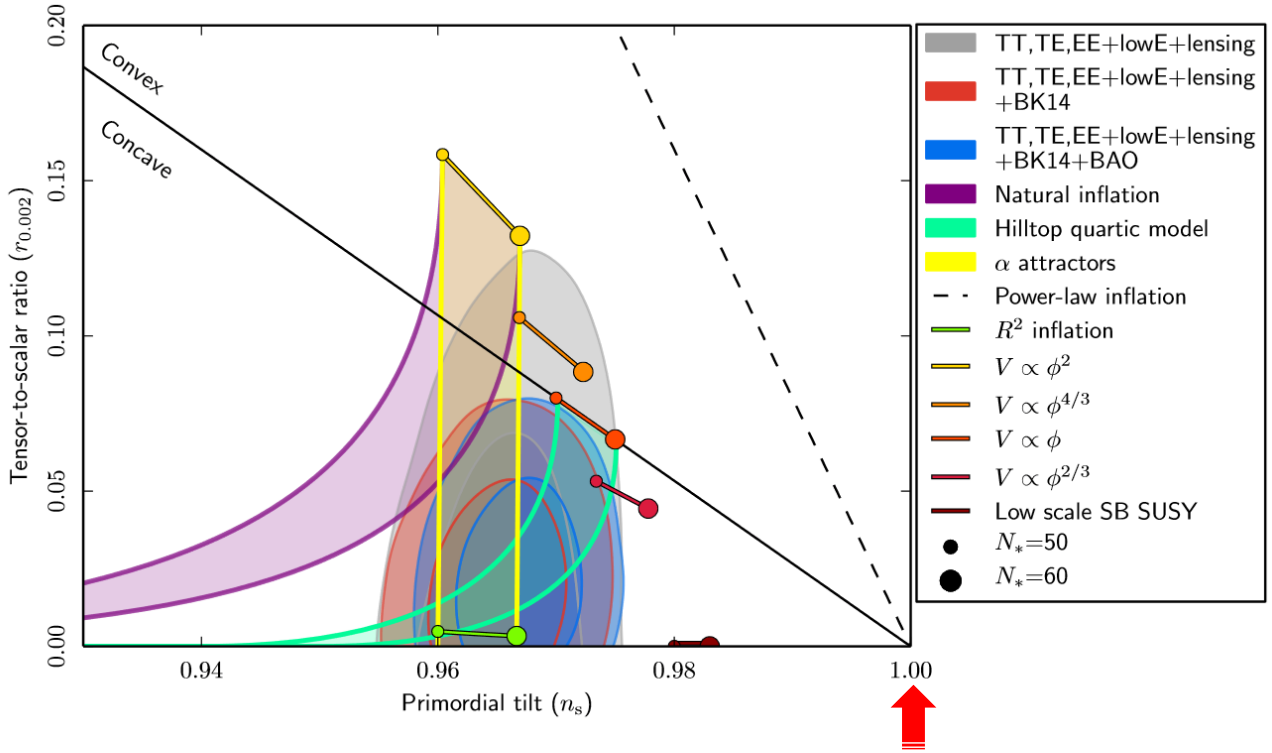
In 1970s, Harrison, Zeldovich, Peebles:

$$n_s = 1$$

(Harrison-Zeldovich spectrum)

- Tensor:

$$r = \frac{\mathcal{P}_t}{\mathcal{P}_s}$$



Planck Collaboration. *Astron.Astrophys.* 594 (2016) A20

Primordial perturbation

ΛCDM ?

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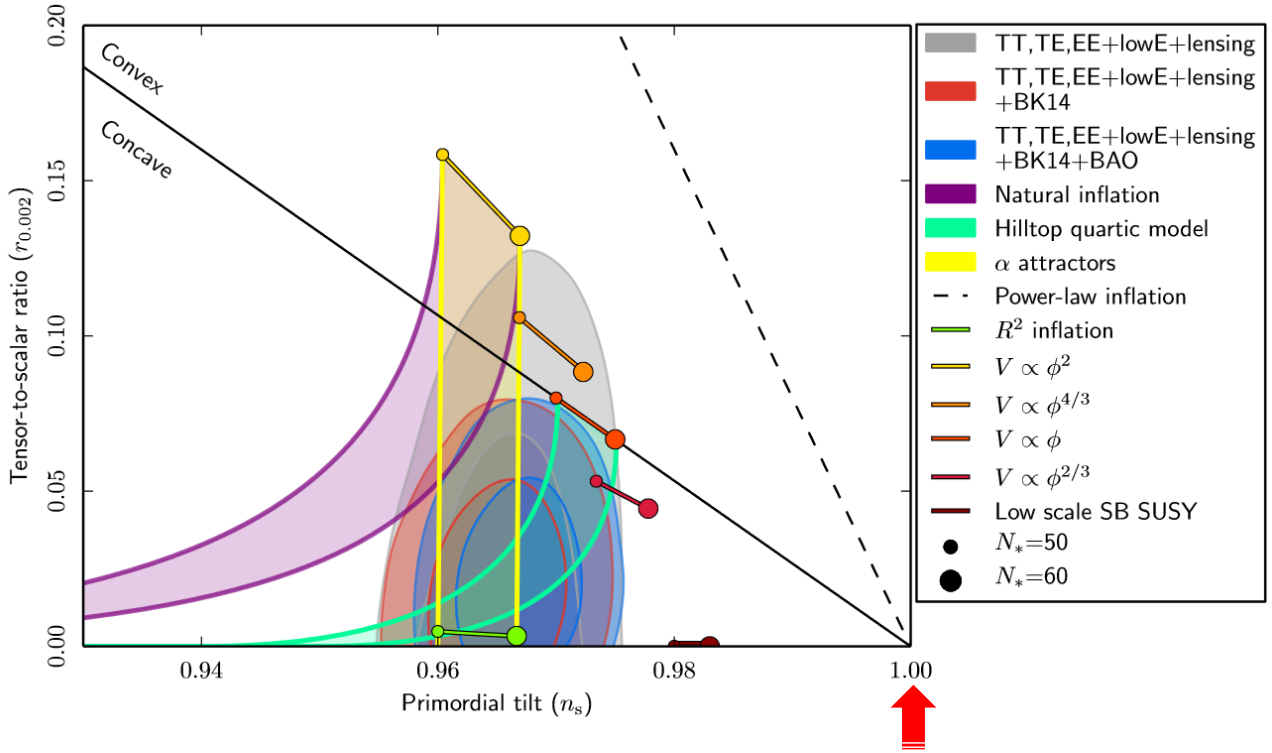

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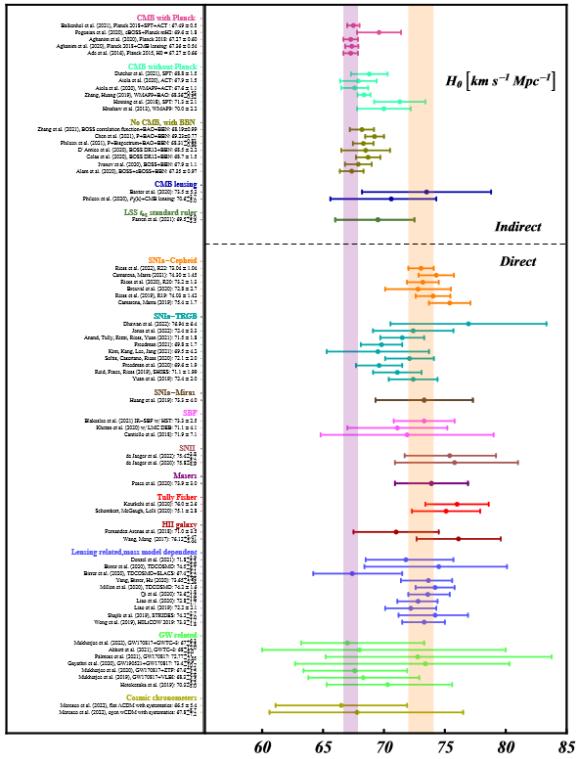
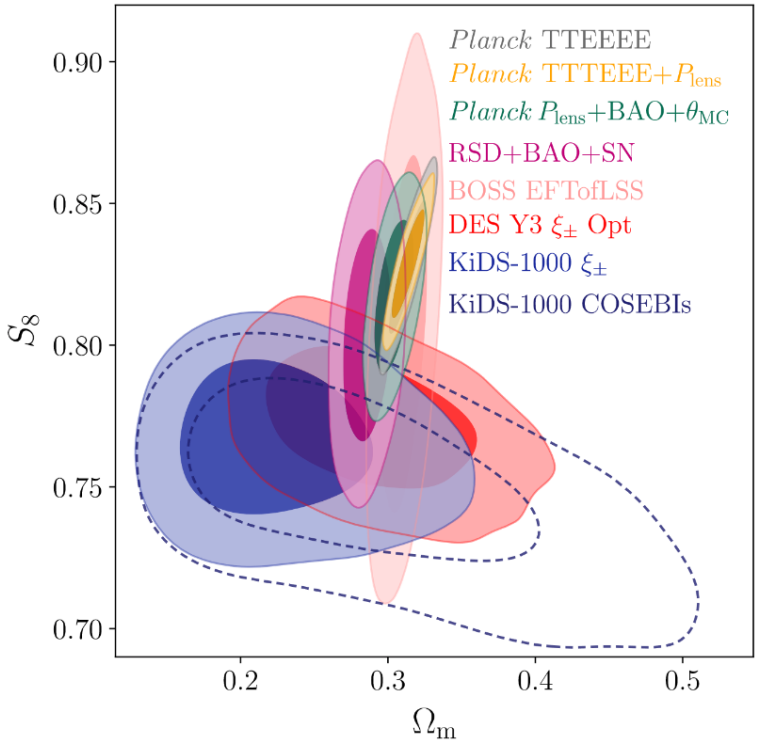
Tensions in Cosmology

Hubble tension



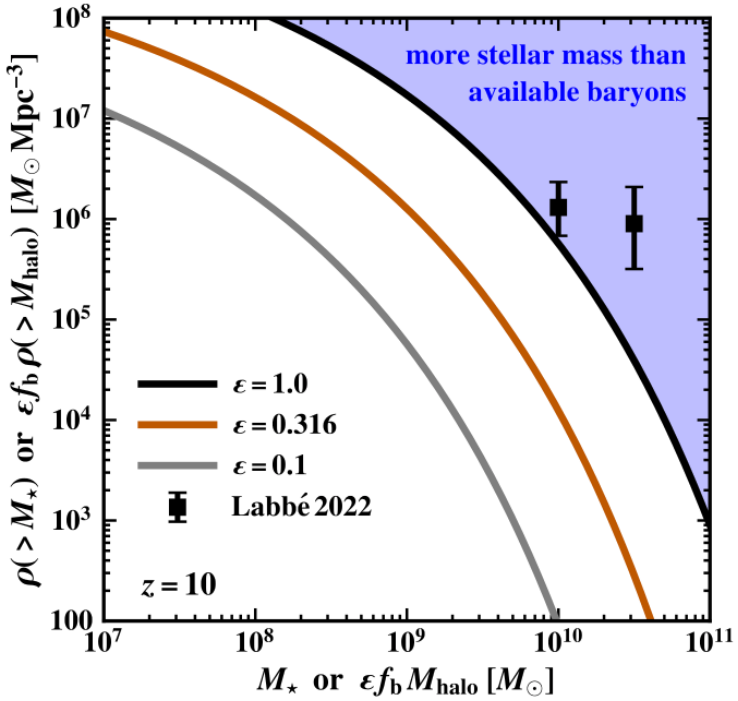
Abdalla E et al. *JHEAp* 34 (2022) 49-211

S_8 tension



Amon A, Efstathiou G. A. arXiv: 2206.11794

JWST

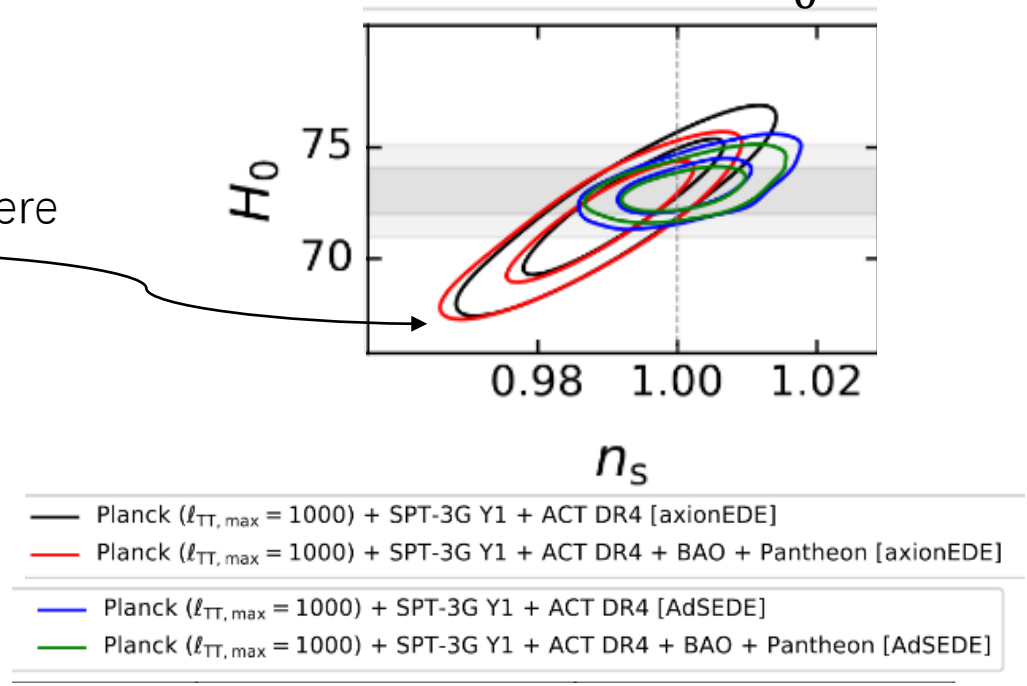


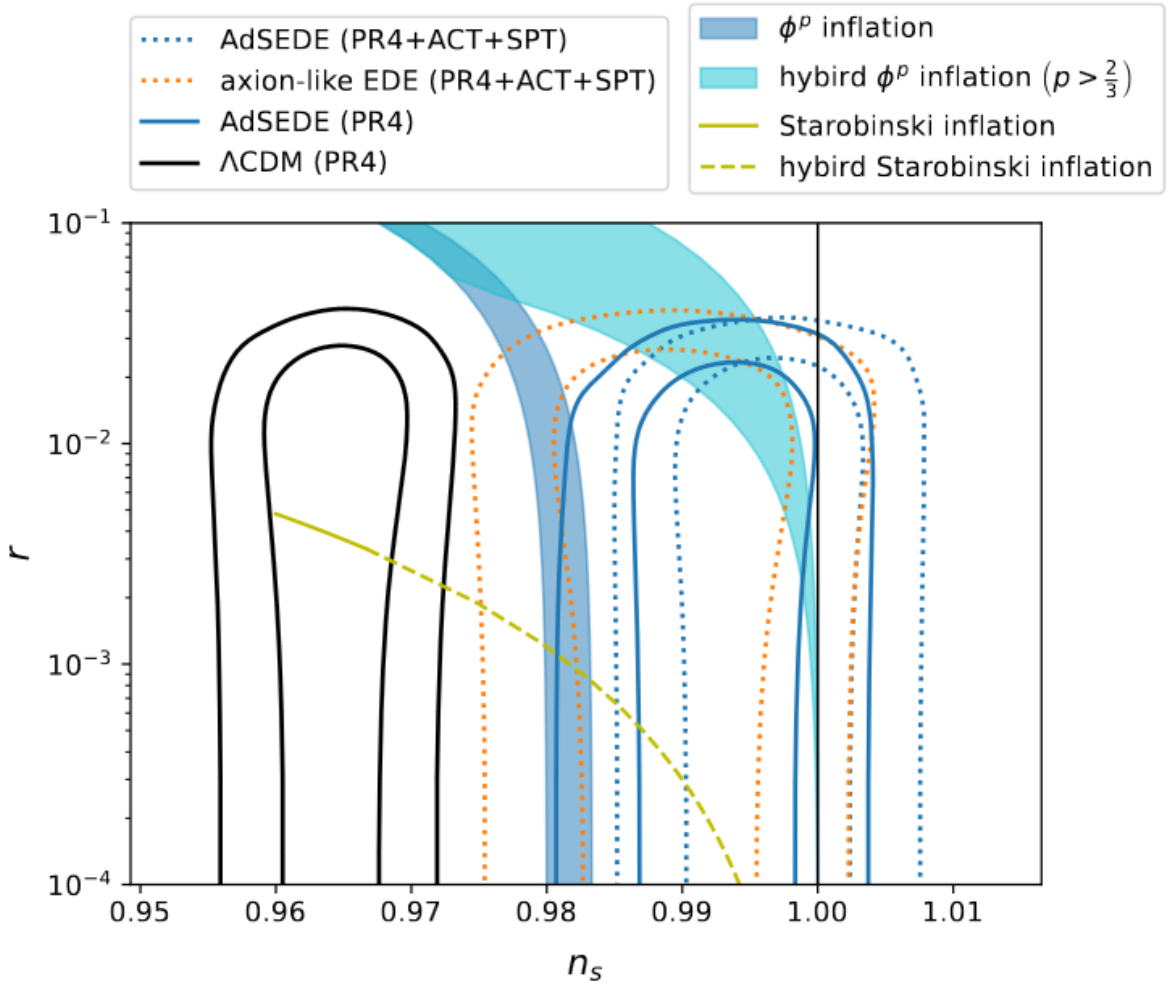
Boylan-Kolchin M. arXiv: 2208.01611

The impact of EDE

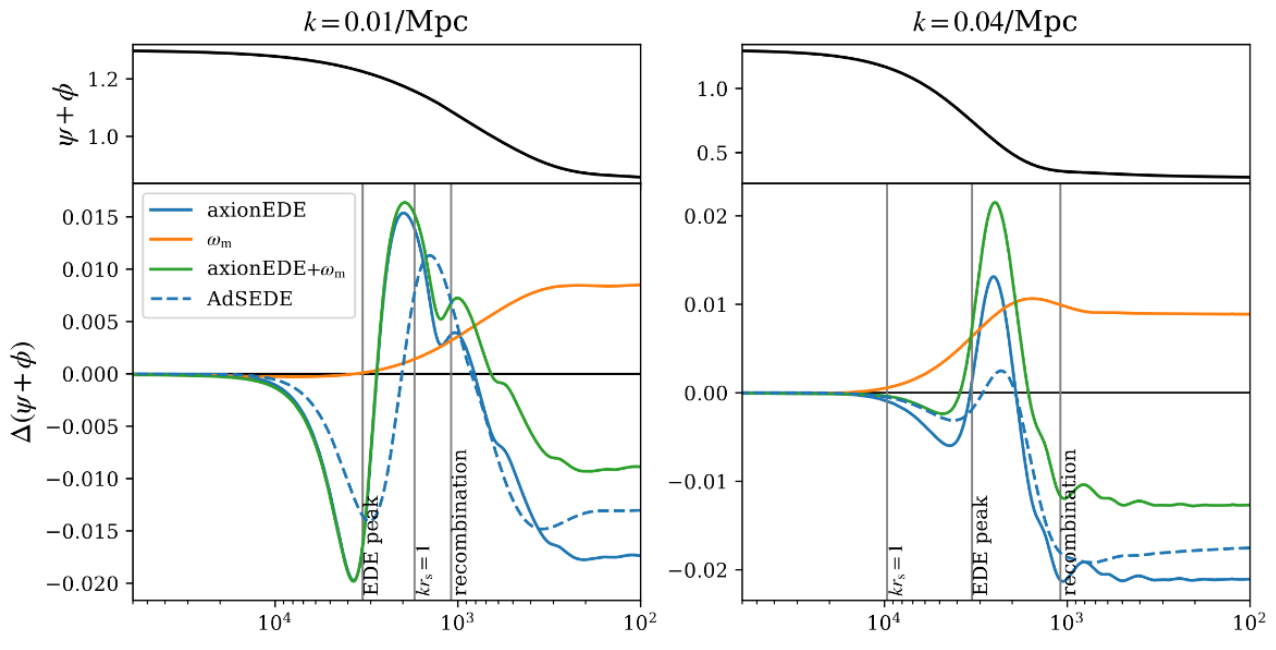
$$\delta n_s \approx (0.3\sim0.4)\frac{\delta H_0}{H_0}$$

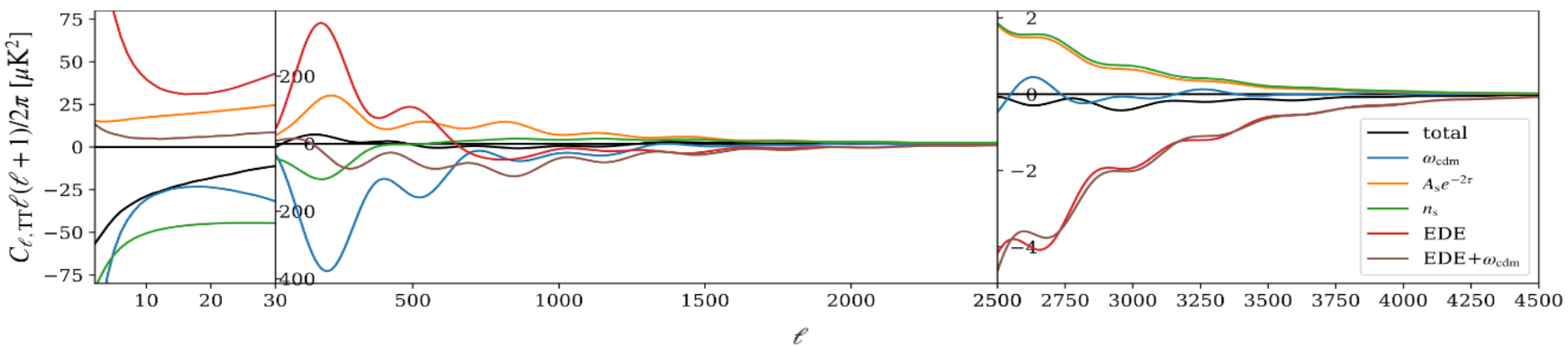
ΛCDM here





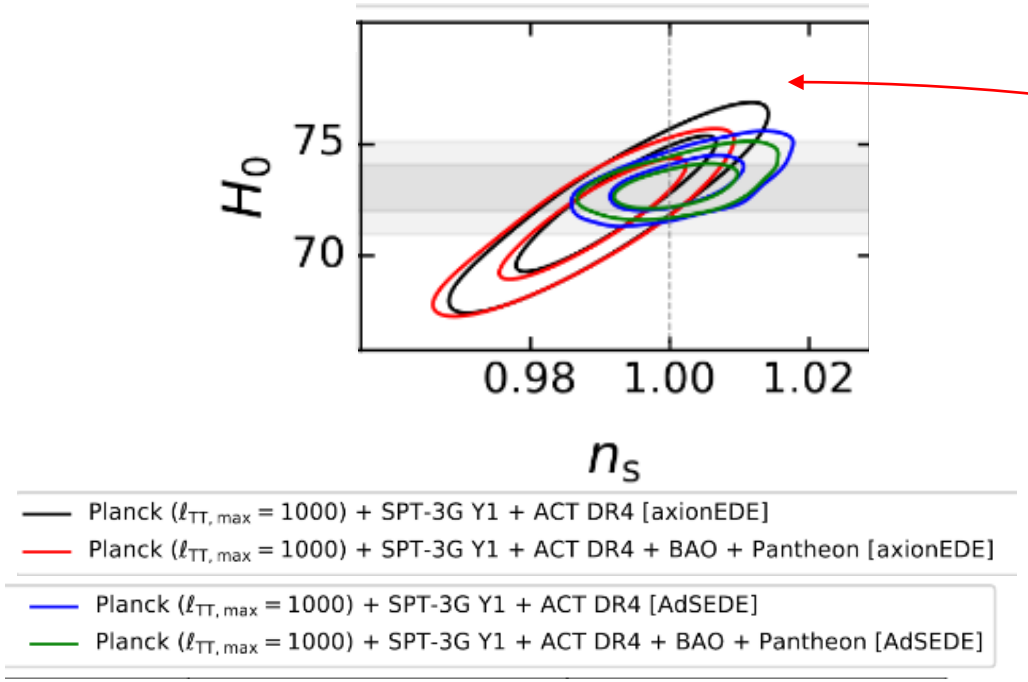
Is this a general phenomenon?
Let's see the origin of this phenomenon!





faster decay of
the Weyl potential
↓
enhancement of
early ISW effect
↓
enhancement of
CMB power spectrum of $\ell \lesssim 700$
↓
larger ω_{cdm} & overall amplitude
↓
rise n_s

The impact of EDE on n_s



$n_s = 1?$

Harrison-Zeldovich spectrum?

Comparison bewteen two models

The old model

- ΛCDM
- We have free n_s to choose (prior)

The new model

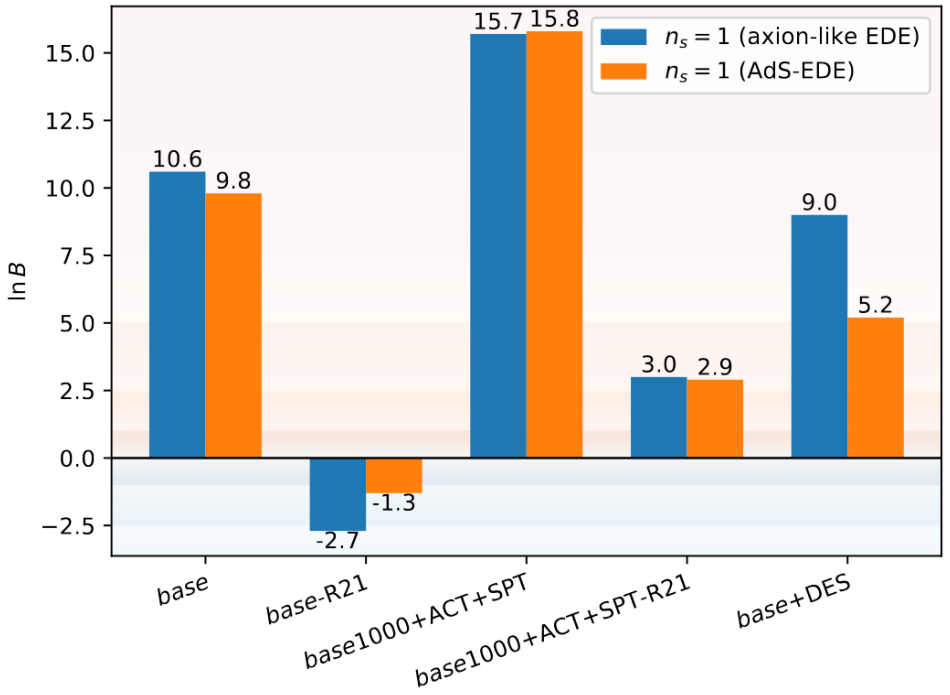
- EDE (so there are additional parameters)
- We choose a Harrison-Zeldovich spectrum

Statistic I: Bayes ratio

$$P = \frac{\mathcal{L}(D|\Theta, \mathcal{M})\,\pi(\Theta|\mathcal{M})}{\mathcal{Z}(\mathcal{M})}$$

$$B = \frac{\mathcal{Z}_{new}}{\mathcal{Z}_{old}}$$

- Benefit: penalizes large parameter space
- Drawback: What kind of priors should we use?



Base: Planck + BAO + Pantheon
Base1000: Base(Planck $\ell_{TT,max} = 1000$) + ACT + SPT-3G

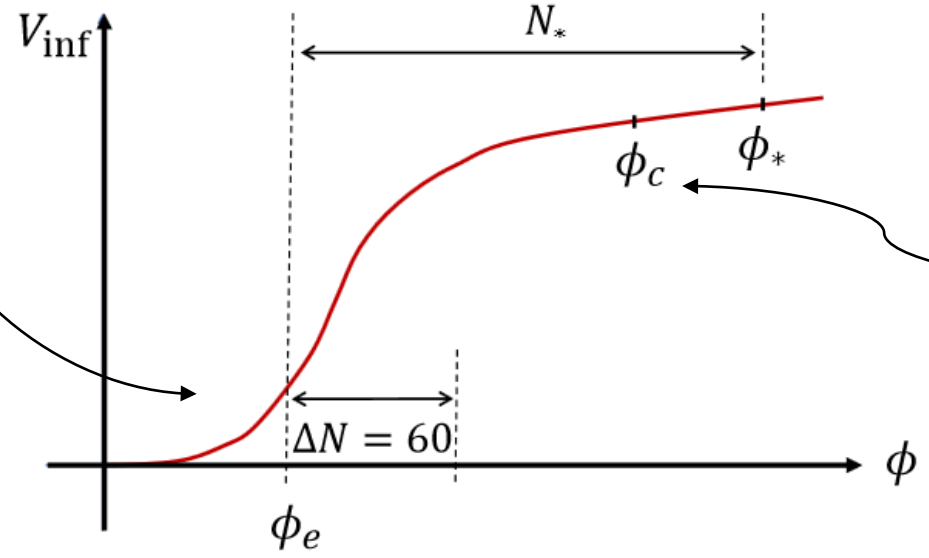
Statistic II: Suspiciousness

$$\ln S = \left\langle \chi^2_{n_s=1\ (\mathrm{EDE})} \right\rangle_{\mathcal{P}} /2 - \left\langle \chi^2_{\text{standard }\Lambda\mathrm{CDM}} \right\rangle_{\mathcal{P}} /2$$

- Benefit: We don't need to worry about the choice of priors.

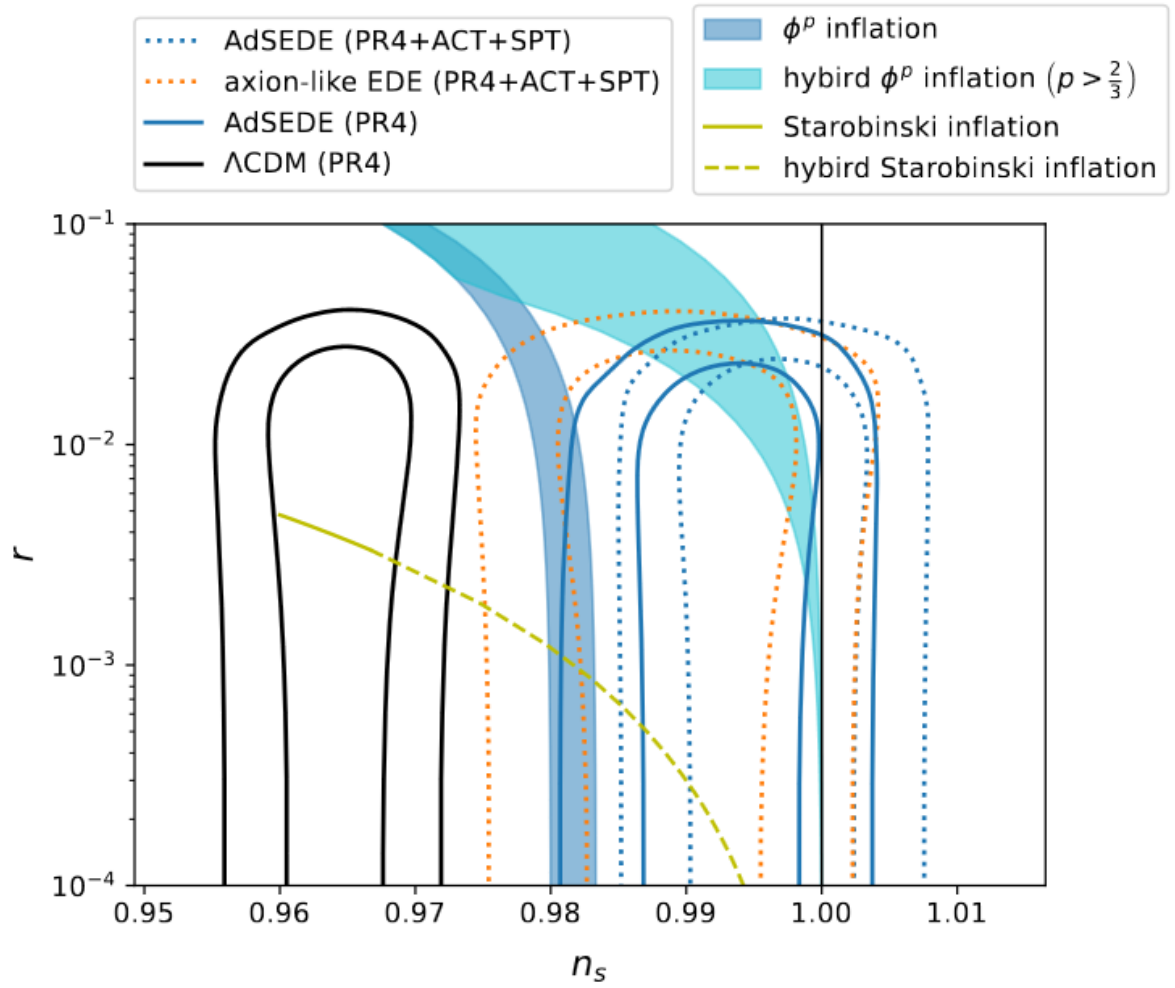
Dataset	$n_s = 1$ (axion-like EDE)		$n_s = 1$ (AdS-EDE)	
	Suspiciousness	p-value	Suspiciousness	p-value
base	-13.5	2×10^{-7}	-8.5	2×10^{-5}
base-R21	0.0022	0.37	6.44	1
*base*1000+ACT+SPT	-17.9	1×10^{-9}	-13.0	5×10^{-7}
*base*1000+ACT+SPT-R21	-5.18	0.00082	-0.67	0.14
base+DES	-11.54	7×10^{-6}	-4.33	6×10^{-3}

single field slow-roll inflation models: $n_s - 1 = -\frac{\mathcal{O}(1)}{N_*}$



Hybrid inflation:
end by a waterfall instability

New constraint on the $r - n_s$ plane



Conclusions

✓Positive relation between n_s and H_0

✓Evidence for $n_s = 1$

✓Explanation for $n_s = 1$ with inflation

? Impact of $n_s = 1$ in late Universe

? Other tensions