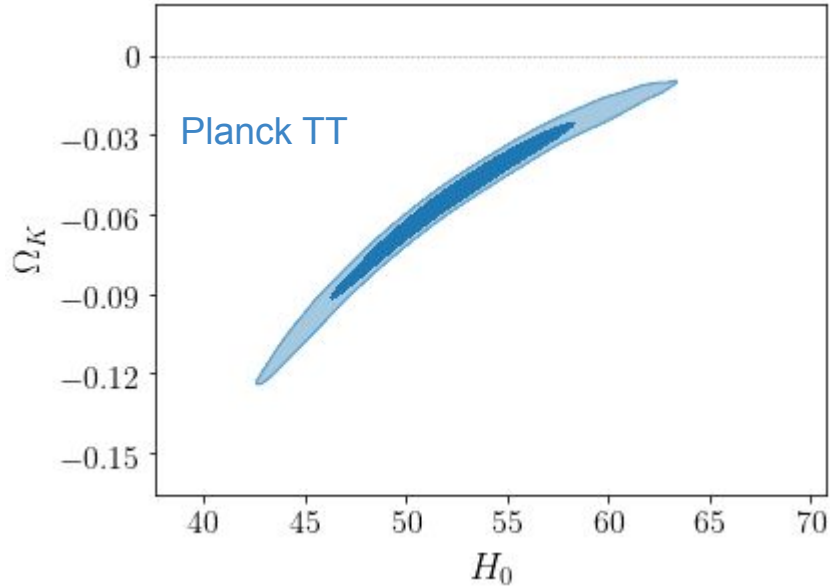


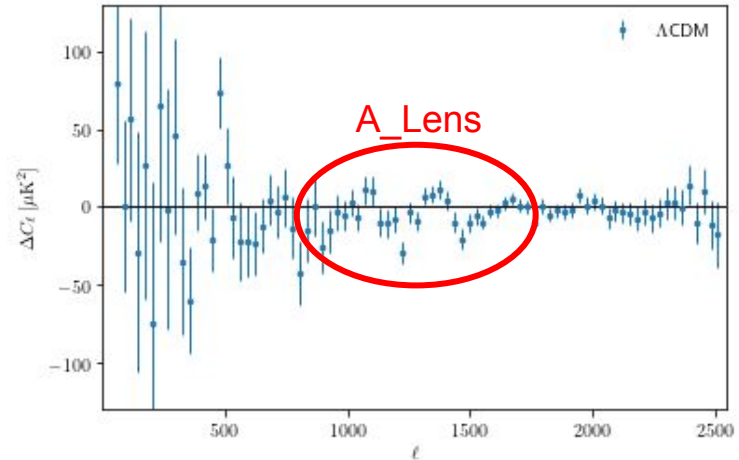
Is the Universe closed?

What is going on?

Primary CMB alone does **not** tell us much about curvature



- Geometric degeneracy between H_0/Ω_K
- Remaining preference for negative curvature driven by
 - Lack of power at low ℓ
 - ‘Oscillatory’ feature in TT shape:



So, curvature then?

$$\Omega_K = -0.056^{+0.028}_{-0.018} \quad (68\%, \text{Planck TT+lowE}),$$

~3 sigma

$$\Omega_K = -0.044^{+0.018}_{-0.015} \quad (68\%, \text{Planck TT,TE,EE+lowE})$$

Planck VI 2018

These cosmologies look very different at late times.

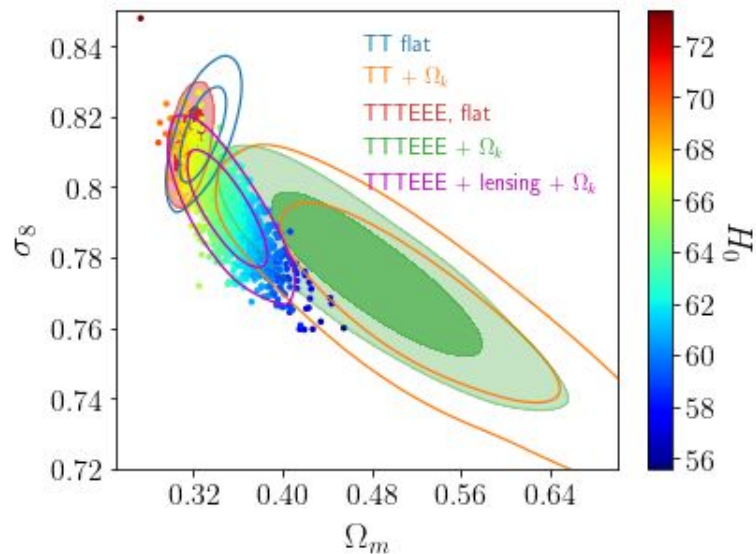
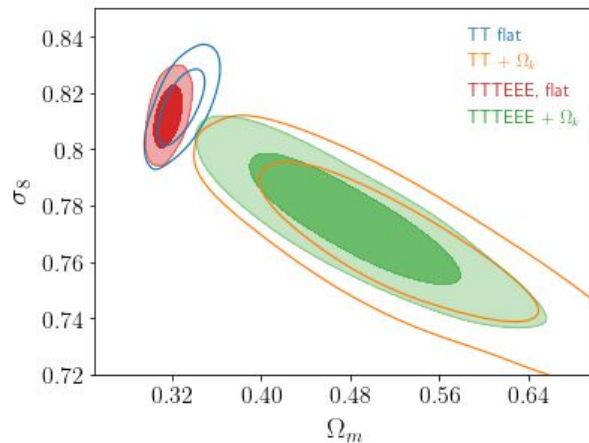
Negative curvature implies

- High Ω_m /small σ_8
- Small H_0

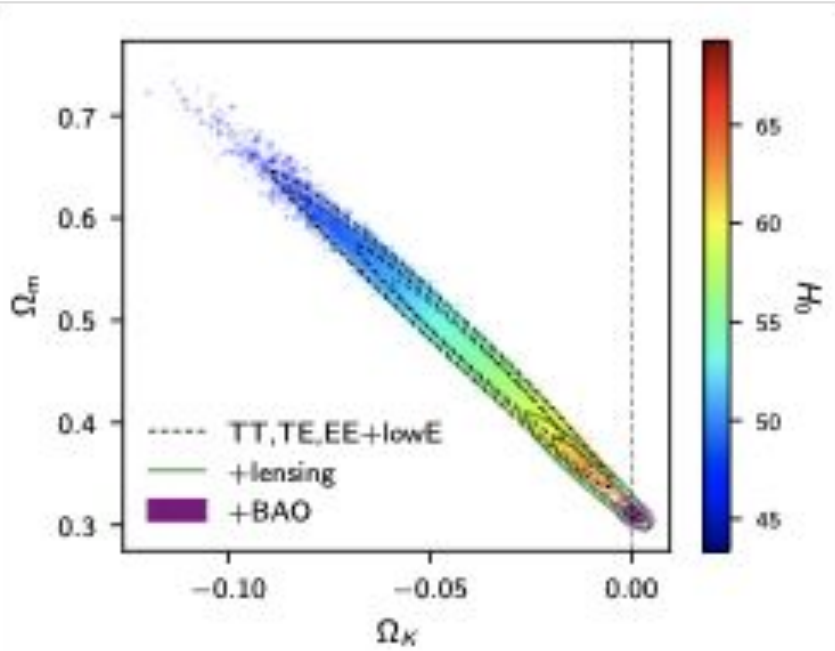
This is not seen by CMB lensing (or other LSS probes)

$$\Omega_K = -0.0106 \pm 0.0065 \quad (68\%, \text{TT,TE,EE+lowE} \\ \text{+lensing}).$$

~2 sigma



BAO completely breaks the geometric degeneracy

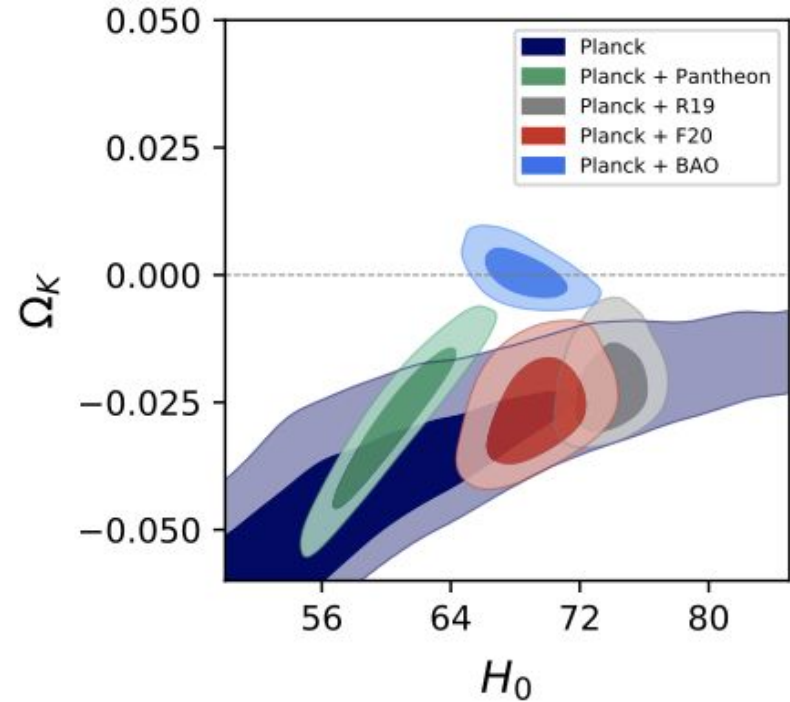
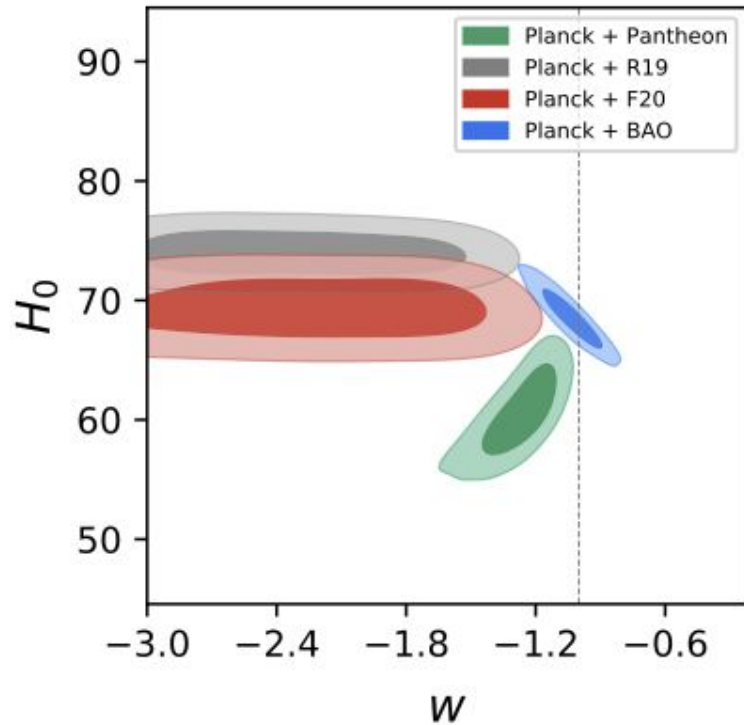


Planck VI 2018

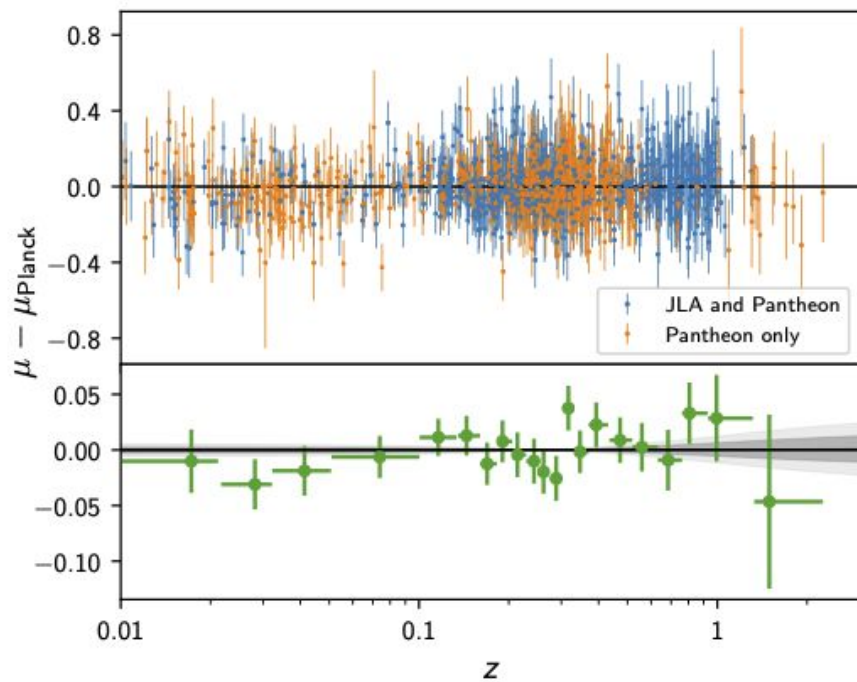
$$\Omega_k = 0.0007 \pm 0.0019 \quad (68\%, \text{TT, TE, EE+lowE} \\ \text{+lensing+BAO}).$$

Flatness to 0.2%

Di Valentino 2019 & Di Valentino 2020: what if we don't trust BAO?

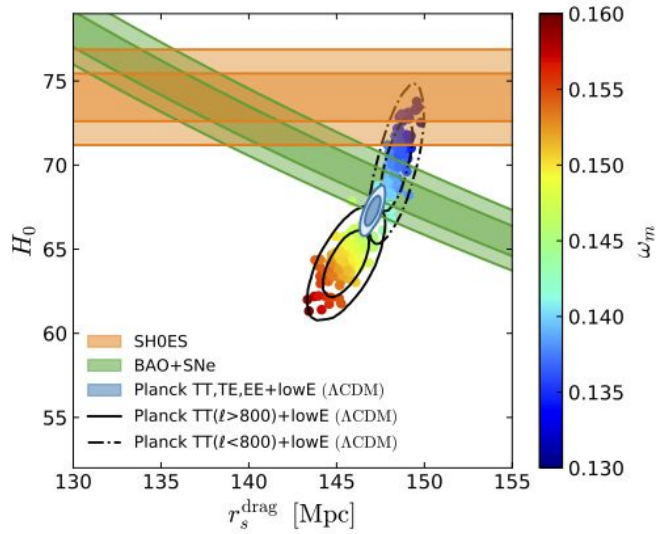


Data sets under the assumption of curvature are inconsistent.
Two tensions in play: A_{Lens} and H_0



Not sure what's going on with the Pantheon S_{nl}

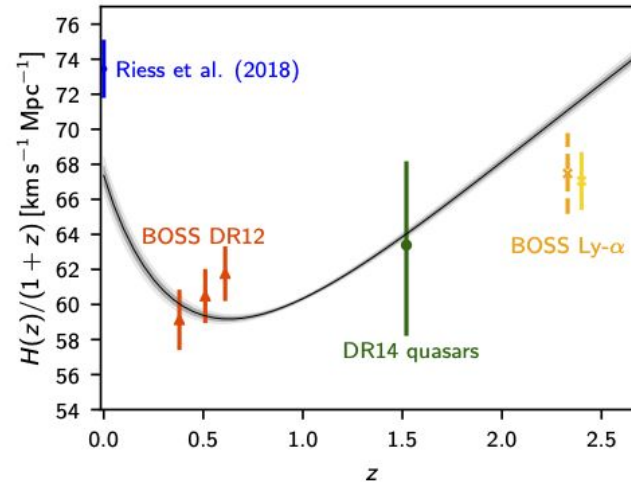
The real H_0 problem is the sound horizon:



<https://arxiv.org/abs/1908.03663>

Curvature does not fix that.

BAO peak is at ~ 150 Mpc
 Very difficult to have physics to change that
 at late times!



Planck VI 2018

A_Lens/Omega_k

A_Lens is driving curvature. What is going on?

- Depends strongly on details of nuisance modelling/likelihoods (i.e. plik vs camspec difference)
- Adding more data (Efstathiou & Gratton <https://arxiv.org/abs/1910.00483>) reduces A_Lens

Compatible with statistical fluctuation, but explanation unclear.

- Curvature as explanation **very** implausible: clashes with BAO, H0, CMB lensing, LSS...

H0

- No clear directions. A lot of things do not work. Maybe best understood as a mismatch in the LCDM sound horizon
- Very difficult to reduce sound horizon r_s without leaving other signatures

Good summary: Knox & Millea <https://arxiv.org/abs/1908.03663>

Summary

Two tensions:

- H_0 : this is most likely a problem of the sound horizon, very hard to change at late times
- A_{Lens} : significance/possible solutions unclear

Currently no model fits all pieces!