Revisiting an Early Dark Energy Model and the Hubble Tension in a non-flat Universe

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The Cosmic Microwave Background (Sound Horizon of the Early Universe)

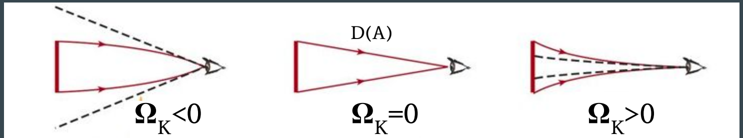
Standard Rulers allow us a look into the cosmic expansion history.

θ_{*}= 0.010419±.00030 (Planck Collaboration 2018)

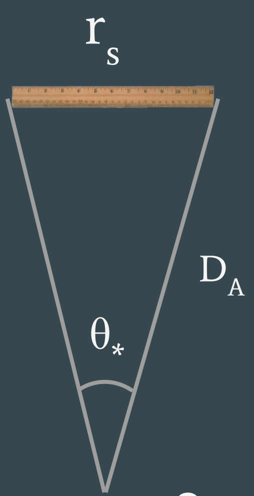
$r_s(z_*)$ = 144.46±0.48 Mpc

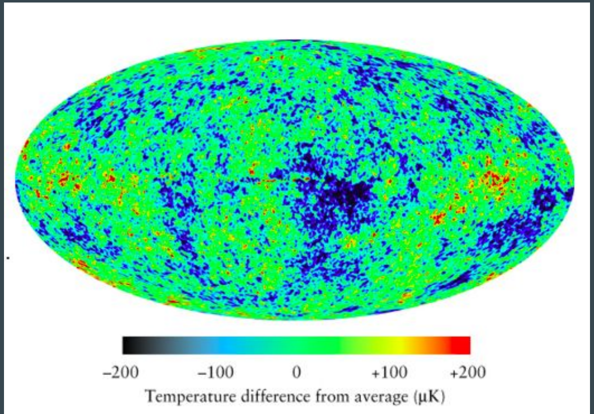
$$r_s(z_*) = \int_{z_*}^{\infty} \frac{dz}{H(z)} c_s(z),$$

D_A strongly relies on cosmic geometry



Closed Flat Open





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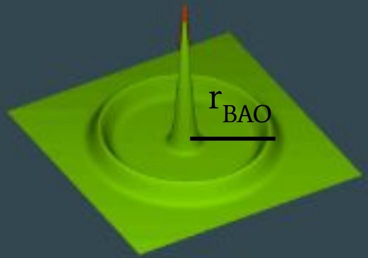
$$\theta_* = r_s / D_A$$

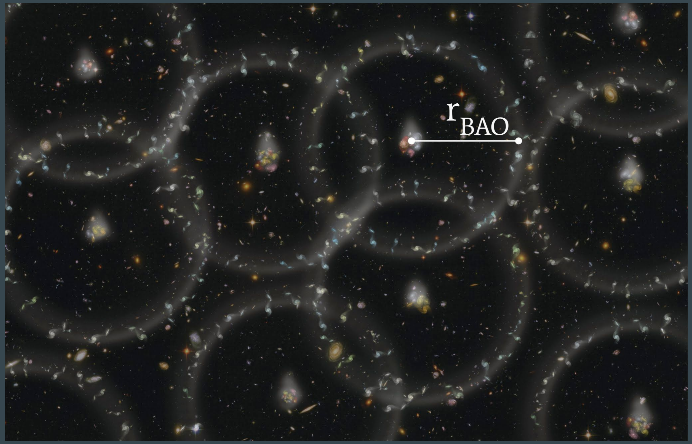
$$D_A \propto H_0^{-1}$$

Baryonic Acoustic Oscillations (Sound Horizon of the Late Universe)

r_{BAO} is measured by 3D galaxy maps such as BOSS/eBOSS (Alam et. al 2020)



Main implication of BAO is that it can be measured at late times (z_{BAO}<1).



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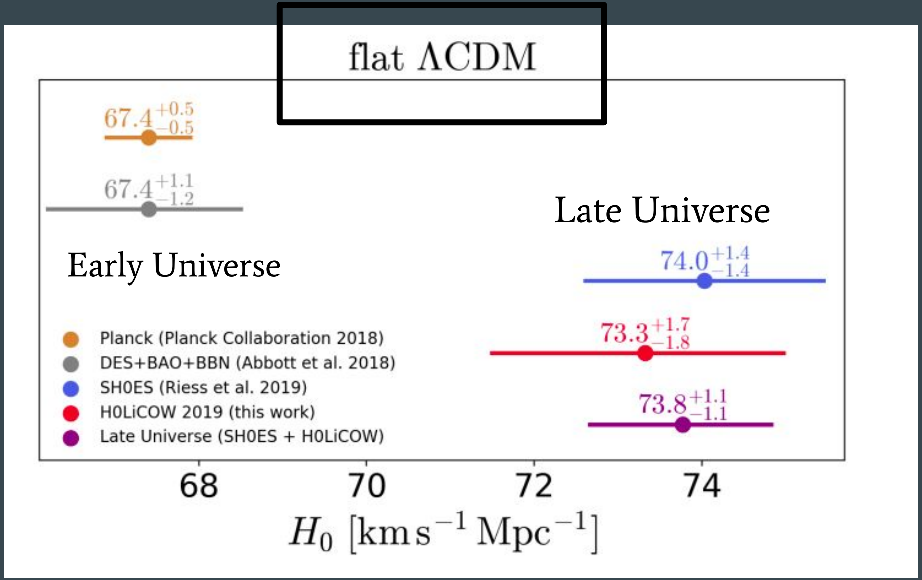
r_{BAO}= 147.21±0.48 Mpc (Planck Collaboration 2018)

The Hubble Tension

Faults in the ΛCDM have been brought to light.

The Hubble Constant, H_0, tells us how fast the current universe is expanding.



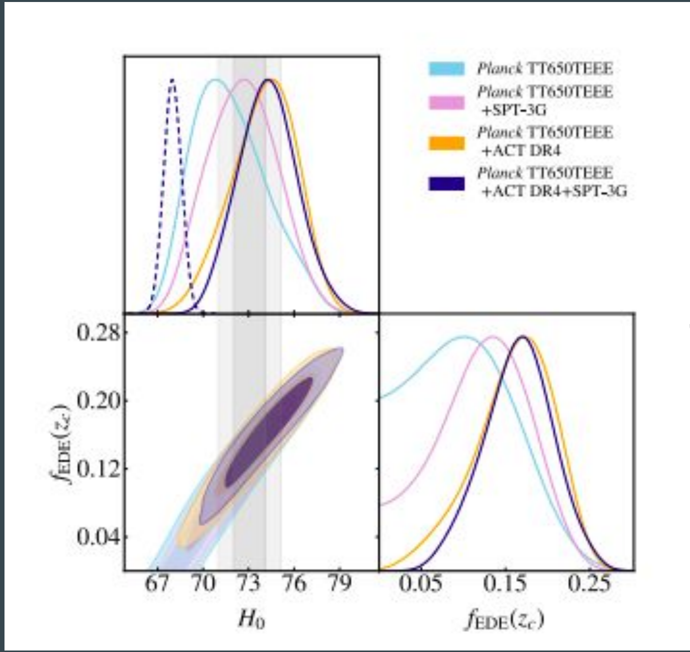
K.C. Wong et. al

Local Measurement (Late Universe):
Using SN-Ia as a "Standard Candle"
H_0=73 ± 1 km/s/Mpc (SH0ES)
(Riess et. al 2021)

CMB Measurement (Early Universe):
Using "Standard Rulers"
H_0=67.4 ± 0.5 km/s/Mpc
(Planck Collaboration 2018)

Early Dark Energy as a Solution of the Hubble Tension?

The Early Dark Energy model introduces an extremely light axion-like scalar field before recombination (z_*).
(Poulin et. al 2019, Hill et. al 2020, Smith et. al 2022)



(Smith et al. 2022)

We parametrize EDE using f_{EDE}, the maximal fractional contribution to the total energy density of the universe.

Previous works have found nonzero values for f_{EDE}

$$f_{\mathrm{EDE}}(z_c) = 0.163^{+0.047}_{-0.04}$$

$$H_0 = 74.2^{+1.9}_{-2.1}$$

Motivation and Goal of This Work

Motivation: An Early Dark Energy Model has been proposed to help solve the Hubble Tension in the current flat ΛCDM model. When proposing EDE we must revisit curvature due to making a change in the expansion history.

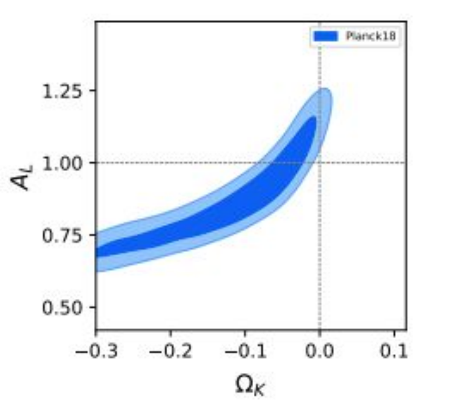
Goal: To answer the questions:

How is the Early Dark Energy claim affected by Ω_K (shape)?

Can it help to alleviate the Hubble Tension?

Method

Method: Running Monte Carlo Markov-Chain (MCMC) statistics using the publicly available codes `MontePython` and theory code `CLASS_EDE`.



Valentino et. al 2020

To isolate geometric degeneracy,

we varied A_L (Planck Collaboration 2018, Valentino et. al 2020)

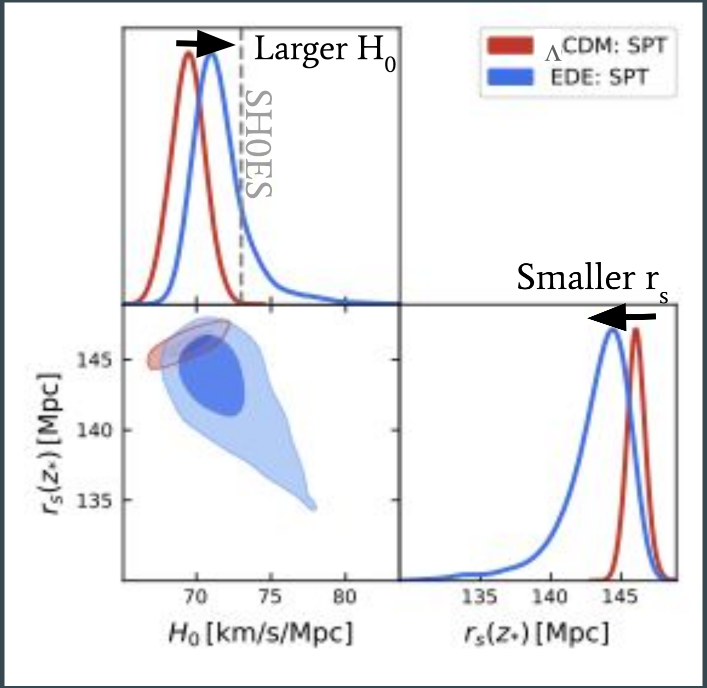
Data: CMB:Planck 2018: lmax=2500 (N. Aghanim et. al)

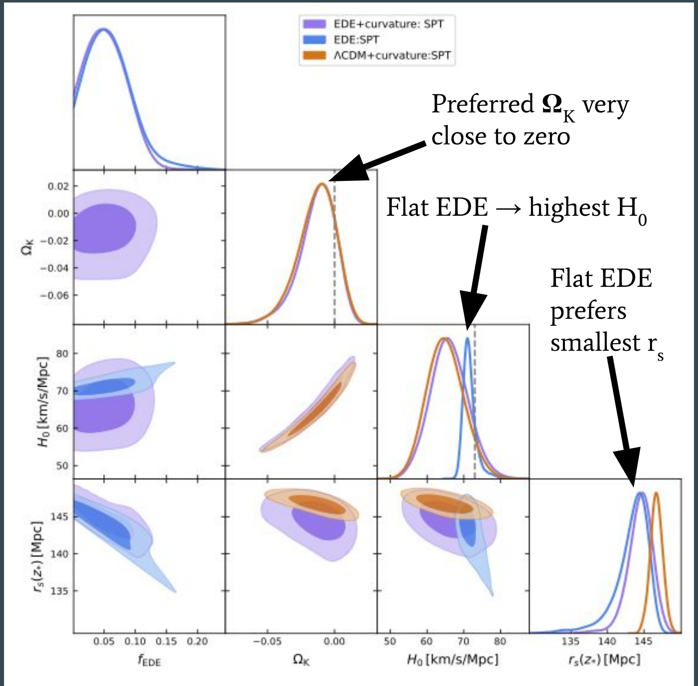
South Pole Telescope (SPT): lmax=3000 (Chudaykin et. al 2020)

BAO: Sloan Digital Sky Survey Data Release 12 (Alam et. al 2021)

Code Sources:
https://github.com/PoulinV/montepython_public_v3
https://github.com/mwt5345/class_ede
https://github.com/CobayaSampler/cobaya
https://getdist.readthedocs.io/
http://pla.esac.esa.int/pla/##cosmology

CMB Results: Impact of Ω_K using SPT Data





When using only SPT+Planck data, we find a preferred Ω_k to be very close to zero when it is allowed to vary. When the curvature is fixed to zero, the Hubble Constant, found here to be H_0=71.591±1.998, is closest to the measurement from SH0ES.

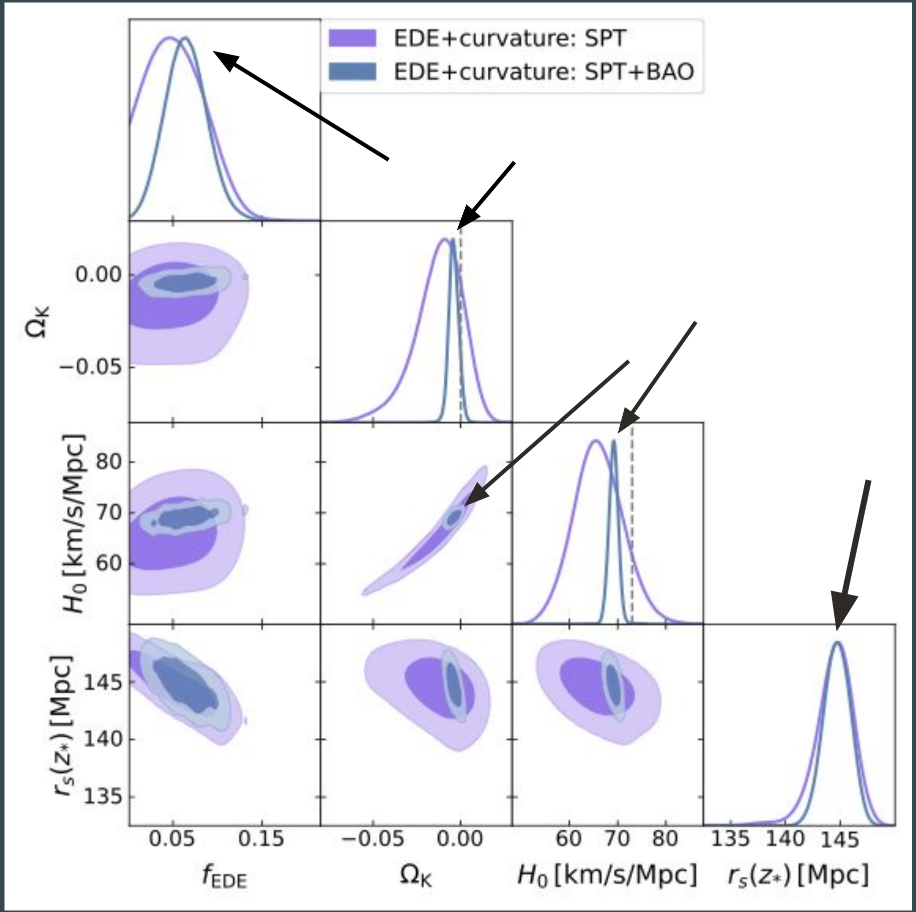
CMB and BAO Results

No impact on sound horizon

Degeneracy between $\boldsymbol{\Omega}_K$ and H_0 is broken resulting in higher H_0

A higher f_{EDE} value is preferred compared to SPT

$\boldsymbol{\Omega}_K = -0.004 \pm 0.003$ for BAO result



Summary and Ongoing Work

Early Dark Energy depends very slightly on shape when using CMB data but when BAO is added, $\Omega_K \rightarrow 0$ which raises H_0, but is still inconsistent with local data.

Even including Ω_K , EDE by itself cannot explain CMB, BAO, and SH0ES measurements at the same time.

Including data from ACT

New CMB and BAO datasets will be available in the near future and may help to refine parameters.

A Novel Early Dark Energy Model

Extremely light axion-like scalar field

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

Equation of state of the field is given by:

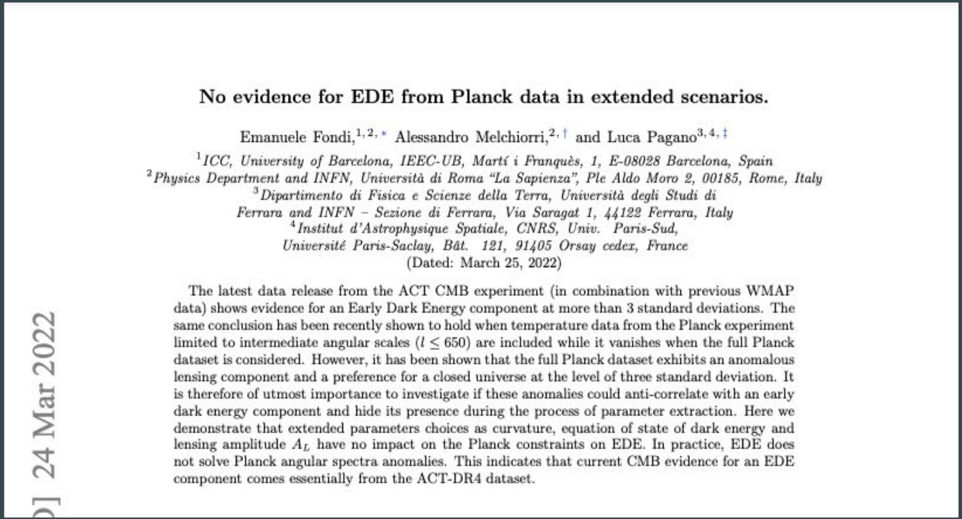
$$w_\phi = (n-1)/(n+1)$$ (Where we consider n=3)

Similar Work

The code CAMB uses an approximate effective axion fluid model

Other works directly solve the linearized field equations (Hill et. al)

Discrepancies are found when the two methods are compared



No evidence for EDE from Planck data in extended scenarios.

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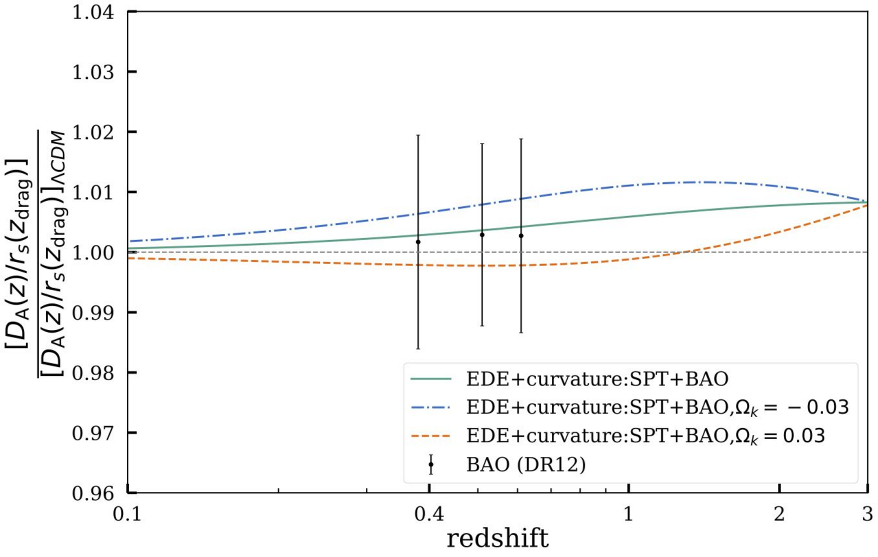
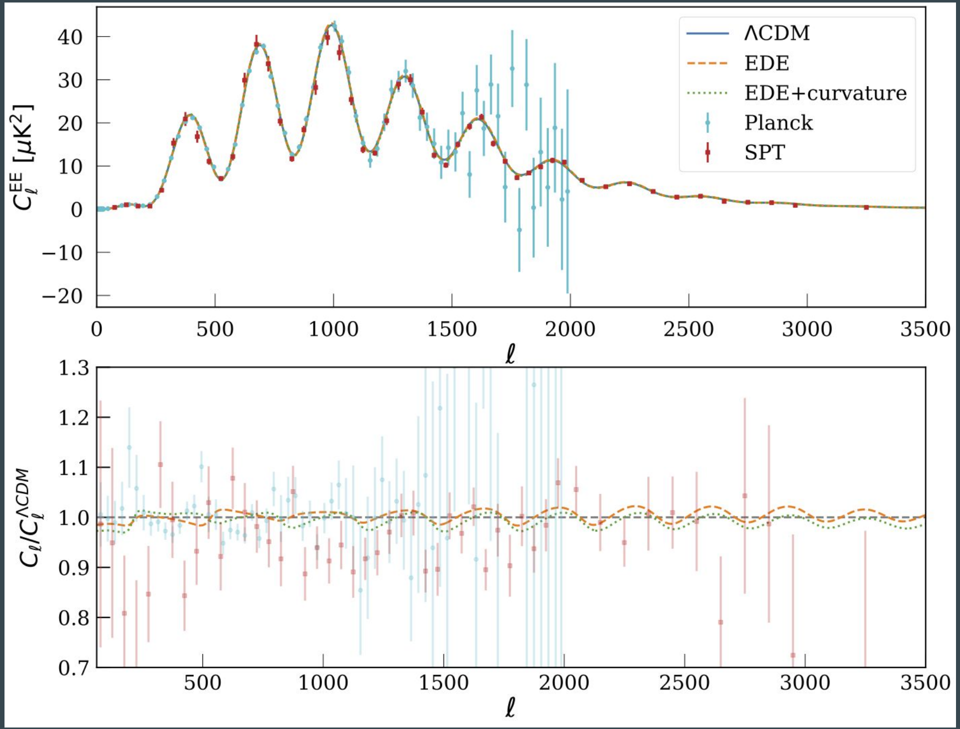
(Dated: March 25, 2022)

The latest data release from the ACT CMB experiment (in combination with previous WMAP data) shows evidence for an Early Dark Energy component at more than 3 standard deviations. The same conclusion has been recently shown to hold when temperature data from the Planck experiment limited to intermediate angular scales ($l \leq 650$) are included while it vanishes when the full Planck dataset is considered. However, it has been shown that the full Planck dataset exhibits an anomalous lensing component and a preference for a closed universe at the level of three standard deviation. It is therefore of utmost importance to investigate if these anomalies could anti-correlate with an early dark energy component and hide its presence during the process of parameter extraction. Here we demonstrate that extended parameters choices as curvature, equation of state of dark energy and lensing amplitude A_L have no impact on the Planck constraints on EDE. In practice, EDE does not solve Planck angular spectra anomalies. This indicates that current CMB evidence for an EDE component comes essentially from the ACT-DR4 dataset.

24 Mar 2022



1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
$\frac{[D_A(z)/r_s(z_{drag})]}{[D_A(z)/r_s(z_{drag})]_{\Lambda CDM}}$
0.1
0.4
1
2
3
redshift
EDE+curvature:SPT+BAO
EDE+curvature:SPT+BAO,$\Omega_k = -0.03$
EDE+curvature:SPT+BAO,$\Omega_k = 0.03$
BAO (DR12)



C_ℓ^{EE} [μK^2]
40
30
20
10
0
−10
−20
0
500
1000
1500
2000
2500
3000
3500
ℓ
ΛCDM
EDE
EDE+curvature
Planck
SPT
$C_\ell/C_\ell^{\Lambda CDM}$
1.3
1.2
1.1
1.0
0.9
0.8
0.7
500
1000
1500
2000
2500
3000
3500
ℓ