

Dark matter-dark energy interactions and their cosmological implications

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Based on
Lucca & Hooper 2020 [2002.06127]
and Lucca 2021a [2105.09249]

Presentation for the
EOS be.h Equinox meeting

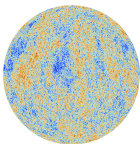


A way to short introduction to the H_0 tension

- ▶ Many independent and complementary probes of early/late universe
- ▶ Very good internal agreement → no reason to doubt the results

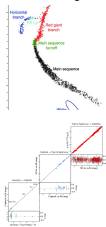
**Planck,
ACT, SPT,**

...



vs.

**Distance ladder,
gravitational lensing,
TRGB, ...**



...

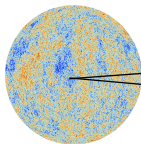
Redshift →

- ▶ Assume Λ CDM as cosmological model
- ▶ Use the CMB as anchor and project predictions until today

**Planck,
ACT, SPT,
...**

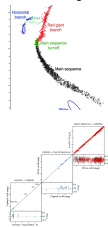
vs.

**Distance ladder,
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TRGB, ...**



Λ CDM

H_0



Redshift

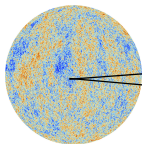
- ▶ Observe the local universe and infer the local expansion rate
- ▶ The two results should coincide but do not (by about 10%)!

**Planck,
ACT, SPT,**

...

vs.

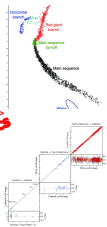
**Distance ladder,
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Λ CDM

H_0

Astrophysics



Redshift

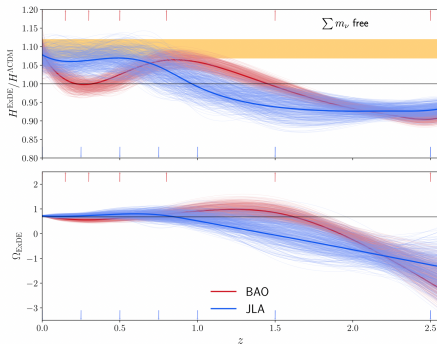
What could cause the discrepancy?

- ▶ Option 1: **wrong astrophysical assumptions** at play but by now too many independent observables would need to be very wrong at the same \rightarrow **very unlikely**
- ▶ Option 2: **systematics** in CMB or late-time probes \rightarrow **very unlikely** too for the same reason
- ▶ Option 3: **Λ CDM is wrong** and the universe is expanding faster than expected because of unknown physics \rightarrow **very much possible**

Out of the plethora of possible “solutions”, one very representative example is given by **dark matter - dark energy interactions**

Generalities of late-time “solutions”:

- ▶ **CMB anisotropy data alone unsuitable** to constrain late-time modifications of Λ CDM (only effect is to enlarge error bars)
- ▶ Fundamental to consider at least **BAO and SNIa data**, which have however been shown to **strongly prefer Λ CDM** over late-time variations of the expansion history (Poulin et al. '18 [1803.02474])
- ▶ Emergence of general **no-go theorem** for late-time solutions



Adapted from Poulin et al. '18 [1803.02474]

The model

Dark matter-dark energy interactions:

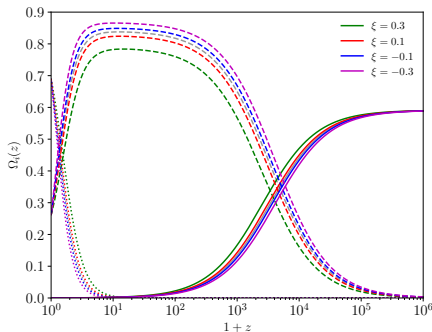
- ▶ **Main difference** with respect to Λ CDM: DM and DE **energy densities not conserved singularly** but coupled via an energy transfer function Q

$$\dot{\rho}_c + 3H\rho_c = Q \quad \text{and} \quad \dot{\rho}_x + 3H\rho_x(1 + w_x) = -Q$$

- ▶ **Many possible choices for coupling function** due to large freedom in the phenomenology of the interaction \rightarrow Intuitive approach: dependence on the fluids' energy densities and H
- ▶ One of the most **stable and successful options** is $Q = \xi H\rho_x$ (Gavela et al. '09, '10 [0901.1611, 1005.0295], Di Valentino et al. '17, '19 [1704.08342, 1908.04281]), with clear cosmological meaning: $\Lambda = \Lambda_0(1 + z)^\xi$
- ▶ As a consequence of this choice:
 1. If $\xi = 0$: one recovers Λ CDM
 2. If $\xi < 0$: energy flows from the DM to the DE (iDMDE model)
 3. If $\xi > 0$: energy flows from the DE to the DM (iDEDM model)

Key consequences:

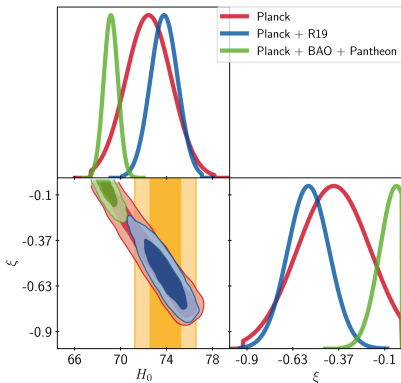
- ▶ If ξ is negative (positive) Ω_c increases (decreases) in the past with respect to Λ CDM, while Ω_x decreases (increases)



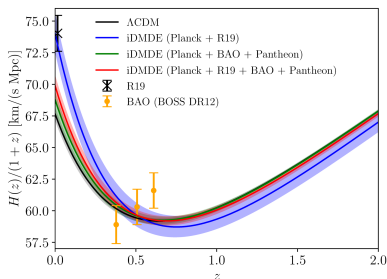
- ▶ The Hubble parameter increases (decreases) during the MD epoch
- ▶ The redshift of matter-radiation equality z_{eq} increases (decreases)

DM-DE interactions as a solution to the H_0 tension (the iDMDE model)

For the specific case of DM-DE interactions:



Adapted from Lucca & Hooper '20
(see e.g., also Di Valentino et al. '19a,b [1908.04281,1910.09853])



- ▶ *No-go theorem* still applies
- ▶ DM-DE interactions are therefore **not a successful solution**

Summary

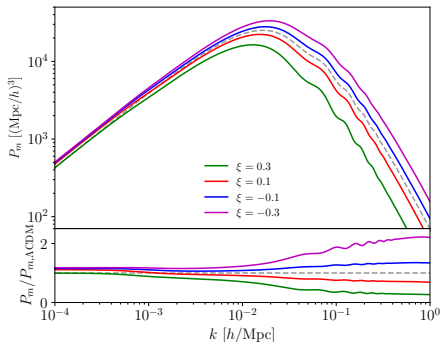
Summary:

- ▶ The H_0 tension is a discrepancy between the early-time inference and the local measurement of the Hubble parameter today
- ▶ Systematics and astrophysics aside, this tension (and others) might hint to a cosmological model beyond Λ CDM
- ▶ DM-DE interactions can be motivated at a very fundamental level and present large phenomenological freedom
- ▶ A very appealing choice assumes a coupling of the form $Q = \xi H \rho_x$
- ▶ The model fails to successfully solve the H_0 tension because of a broad *no-go theorem* against late-time models
- ▶ It can however significantly reduce the S_8 tension without worsening other tensions nor the fit to the data (please ask questions on this!)

DE-DM interactions as a solution to the S_8 tension (the iDEDM model)

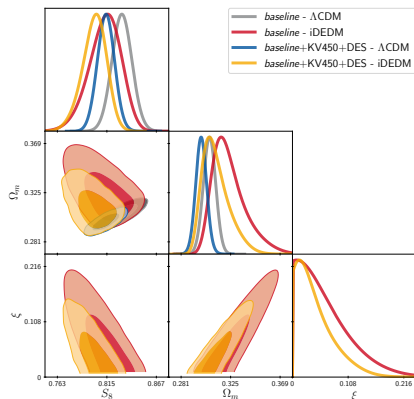
Recap:

- ▶ When ξ is positive $\Omega_c(z)$ is lower in the past compared to Λ CDM
- ▶ The redshift of matter-radiation equality decreases
- ▶ Shift of the peak of the matter power spectrum to lower values and overall suppression of the amplitude (in particular for $k > k_{eq}$)



Adapted from Lucca '21a

Considering data from Planck+BAO+Pantheon and from KV450+DES:



Adapted from Lucca '21a

- ▶ Successful solution (tension below 1.5σ once all data is included)
- ▶ Without worsening nor introducing any other tension and without worsening fit to data