Momentum transfer in the dark sector

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ΛCDM: one model to rule them all...or maybe not?

Problems in the ΛCDM model

- At a fundamental level: cosmological constant problem and coincidence problem
- At the formation of structures: too-big-to-fail problem, the missing-satellite problem, the cusp-vs-core problem...
- Between data-sets: cosmological tensions in H_0, $_8$...

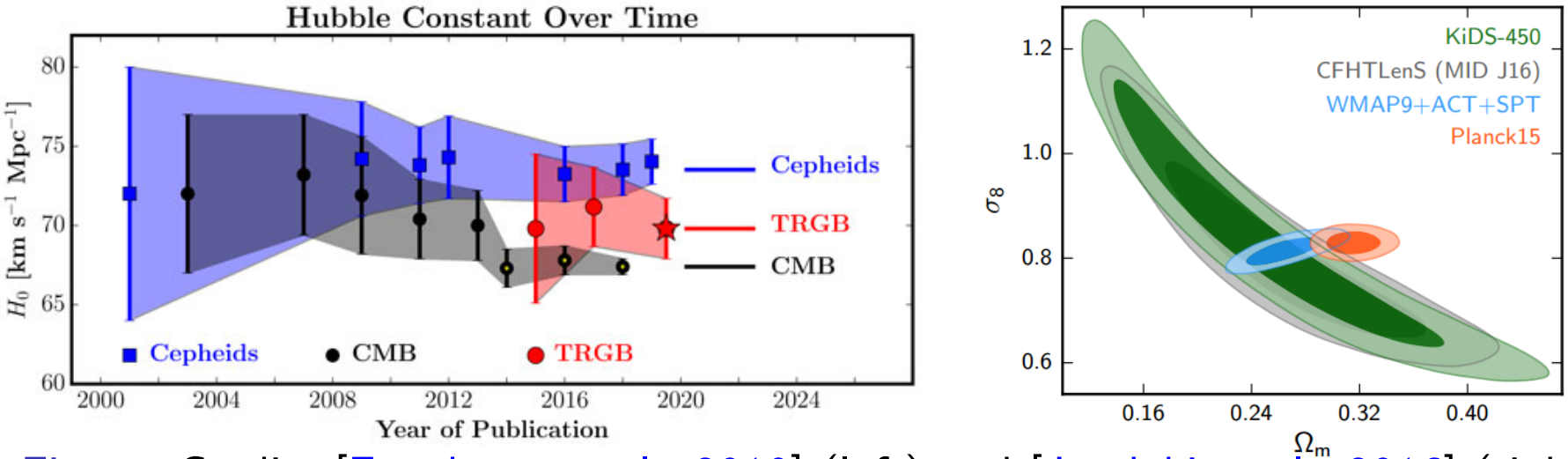

Figure: Credit: [Freedman et al., 2019] (left) and [Joudaki et al., 2016] (right)

Searching for alternatives

An appealing alternative model may include:

- Keep the background cosmology as closest to ΛCDM as possible
- Add minimal modification to the already known scenario
- The modification should have a motivation to be considered
- $_8$ tension: for example erase structure by a late-time mechanism
- H_0 tension: for example add somehow extra radiation

Here is where momentum transfer models can help

Covariantised dark Thomson-like scattering: foundations

Covariantised dark Thomson-like scattering

An interaction between dark energy and a matter fluid with no energy transfer but only momentum transfer

Bases on the non-conservation of the stress energy tensor as

$$r \quad T_{\mathrm{m_i}} \quad = \quad Q \quad ; \tag{1}$$

$$r \quad T_{\mathrm{DE}} \quad = \quad Q \quad ; \tag{2}$$

with $Q \quad = \bar{} (\quad ; k) \left(u_{\mathrm{DE}} \quad u_{\mathrm{m_i}} \right) .$

- No modification of background and density contrast equations but it does modify the Euler equations as

$$'_{\mathrm{m_i}} \quad = \quad H \quad _{\mathrm{m_i}} + k^2 \Phi + \Gamma (\quad _{\mathrm{DE}} \quad _{\mathrm{m_i}}) \tag{3}$$

$$'_{\mathrm{DE}} \quad = \quad (\quad 1 + 3 c_s^2) H \quad _{\mathrm{DE}} + k^2 \Phi + \frac{k^2 c_s^2}{1+w} \quad _{\mathrm{DE}} \quad \Gamma R (\quad _{\mathrm{DE}} \quad _{\mathrm{m_i}}) \tag{4}$$

Covariantised dark Thomson-like scattering: scales/times involved

- Regarding the scales:

  Large scale regime: comoving fluids ! $_{DE}$ ' m_i ! Q vanishes, no interaction

  Intermediate scale regime: competition between gravity and the interaction ! Dark Acoustic Oscillation (similar to BAO)

  Small scale regime: currently N-body simulation are studying this regime

- Regarding the timescales:

  Setting $\bar{}(\ ; k) = \frac{3H_0^3}{8\ G}$ (late time mechanism regarding $_8$ tension, zeroth order of a CPL-like or shift symmetry) only for very late Universe the coupling term will be efficient

Effects: power spectrum (JCAP08(2020)020 & JCAP07(2021)022)

Suppression on **small scales** with a characteristic k-dependence and **a shift of the turnover scale** without modifying the matter-radiation equality time *!* allowing to be distinguished from other effects.

`Dark energy - Dark matter` `Dark energy - Baryons`

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E ects: coupled system (JCAP08(2020)020 & JCAP07(2021)022)

The elastic model induces new peculiar velocities between matter components due to the coupling in velocities between dark energy and dark matter (left) or dark energy and baryons (left)
Also some DAO appear (similar to BAO as is a similar process)

Dark energy - Dark matter Dark energy - Baryons

Consequence: in the coupled system the pressure of dark energy preve the clustering of the matter coupled partner less clustering

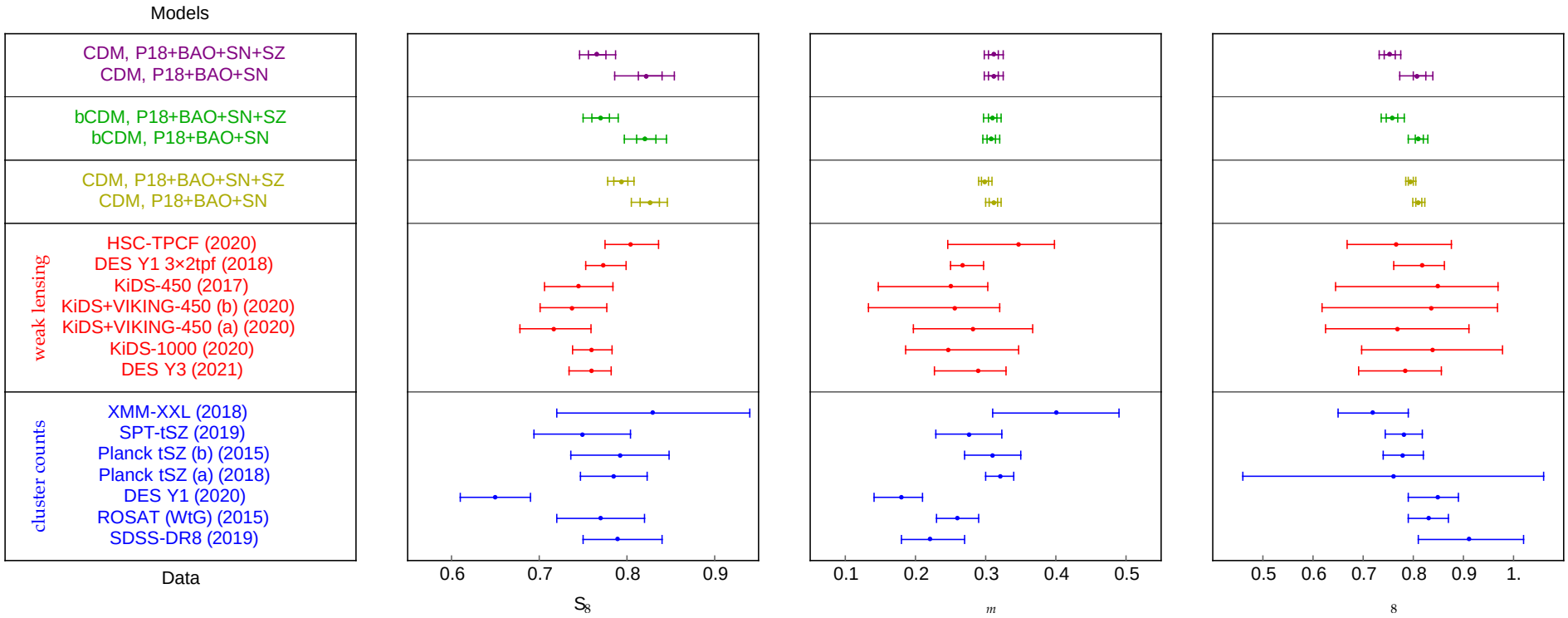
Case DE-DM: each data-set (Phys. Rev. D 104, 103503)

Case DE-DM: including all data-sets (SZ) (JCAP07(2021)022)

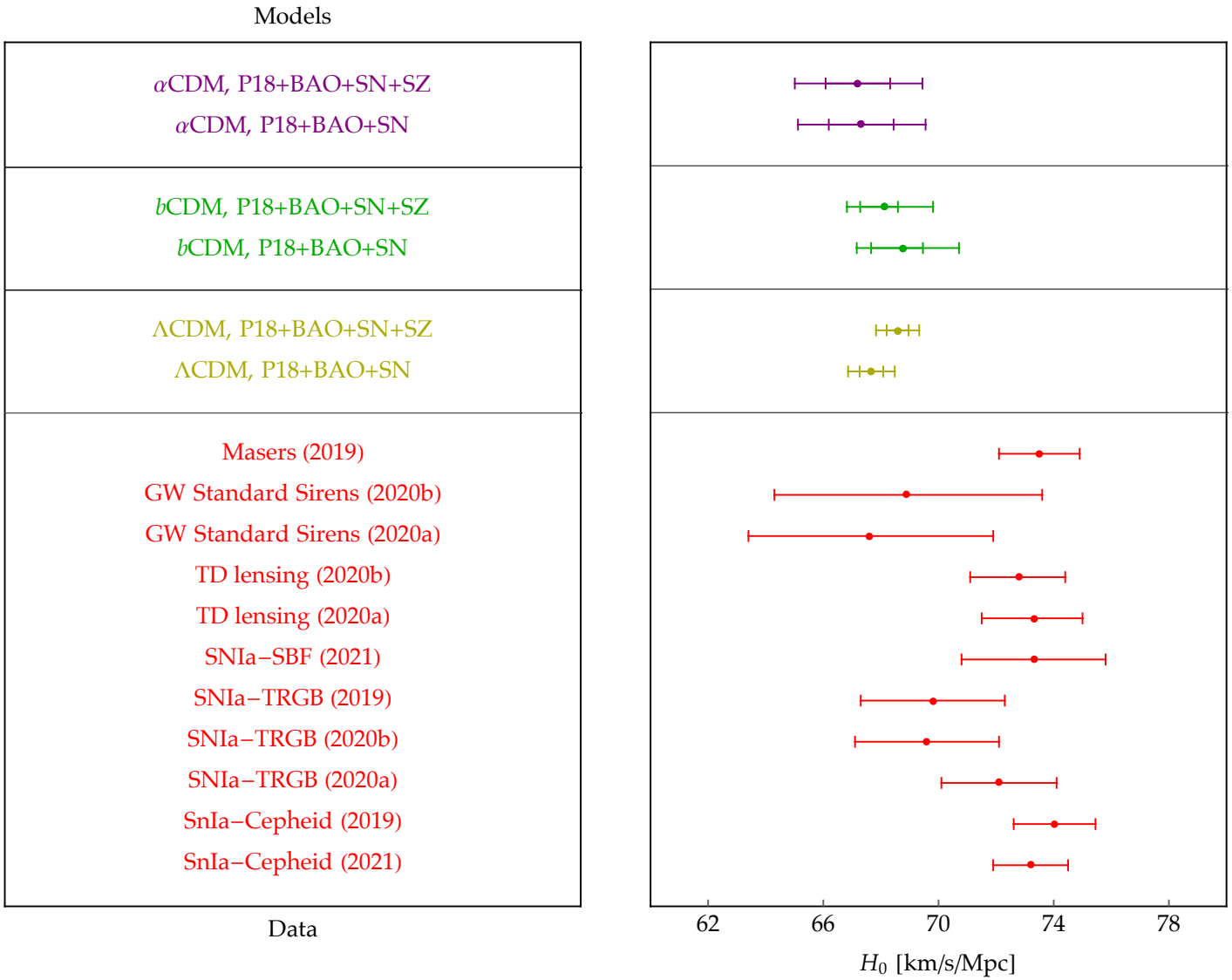
Case DE-B: including all data-sets (SZ) (JCAP08(2020)020)

σ_8 tension (Phys. Rev. D 104, 103503)

- CDM: Covariantised dark Thomson-like scattering for DE-DM with free N_e in the MCMC analysis
- *b*CDM: momentum transfer between DM and dark radiation instead of dark energy (see JCAP 03 (2021) 085 & Phys. Rev. D 104, 103503)



H_0 tension (Phys. Rev. D 104, 103503)



Thank you!!

W. L. Freedman et al. The Carnegie-Chicago Hubble Program. VIII. An Independent Determination of the Hubble Constant Based on the Tip of the Red Giant Branch. 7 2019. doi: 10.3847/1538-4357/ab2f73.

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