A Dark Sector to Restore Cosmological Concordance

Itamar J. Allali

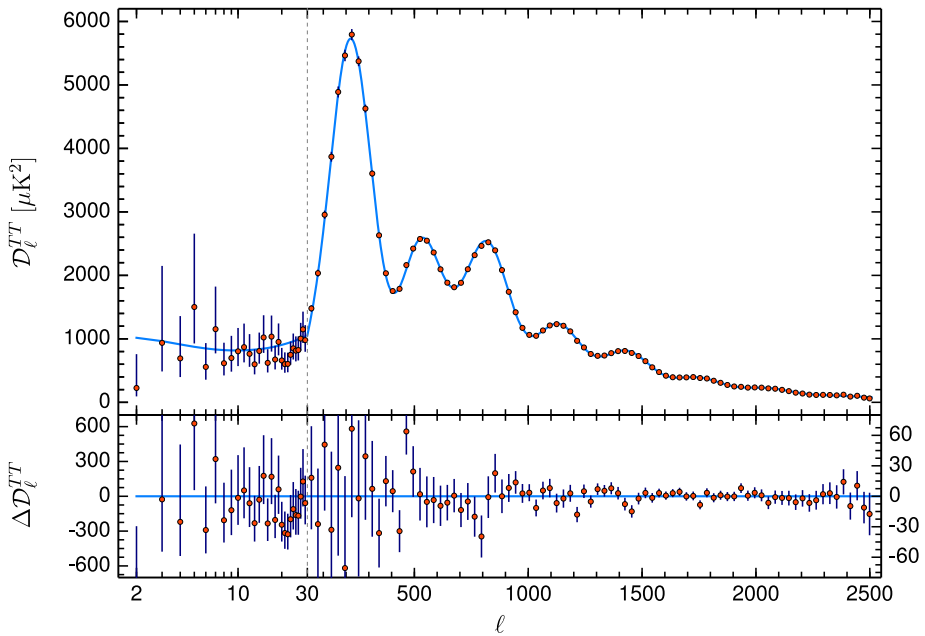
Phenomenology 2021 Symposium
University of Pittsburgh

May 24, 2021

Based on work with M.P. Hertzberg and F. Rompineve
2104.12798

CMB Observations

Leading description of expansion history is ΛCDM model



(from Planck 18 results, Aghanim et al 18)

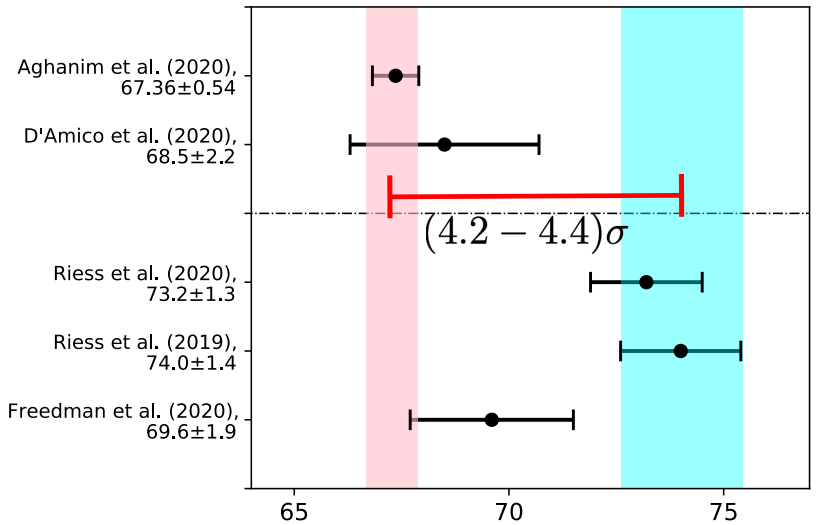
Fits CMB data very well

6 inferred parameters: ω_b, ω_{cdm}, A_s, n_s, τ_{reio}, H_0

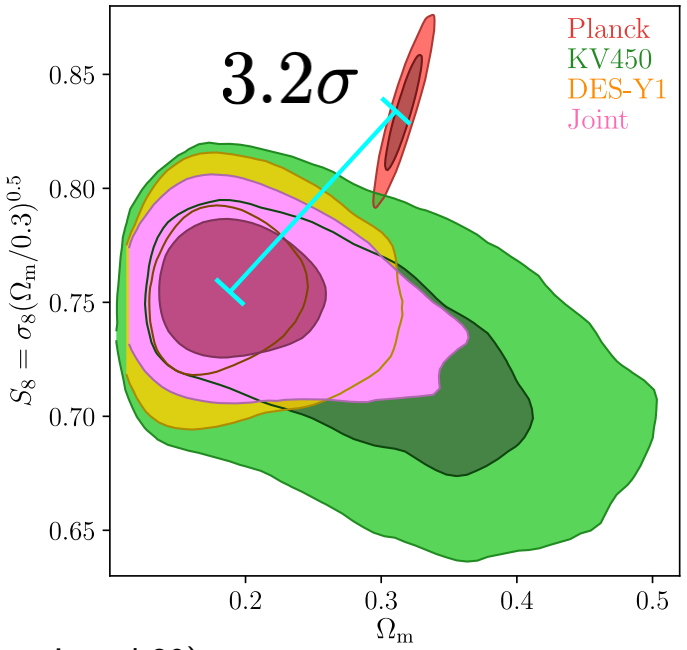
Agrees with other early probes (BAO, LSS)

Tensions with Late(r) Probes

- Hubble rate of expansion H_0
- Early and late-time probes disagree
- E.g. SH_0ES and TRGB



(adapted from Di Valentino et al 21)



(Asgari et al 20)

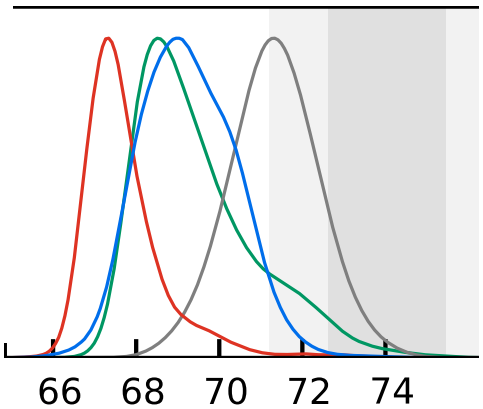
- Related to matter fluctuations in 8 Mpc/h sphere (today)
- $S_8 \equiv \sigma_8 \sqrt{\Omega_m/0.3}$

EDE Constrained by LSS

Early dark energy (EDE) followed by rapid decay increases H_0

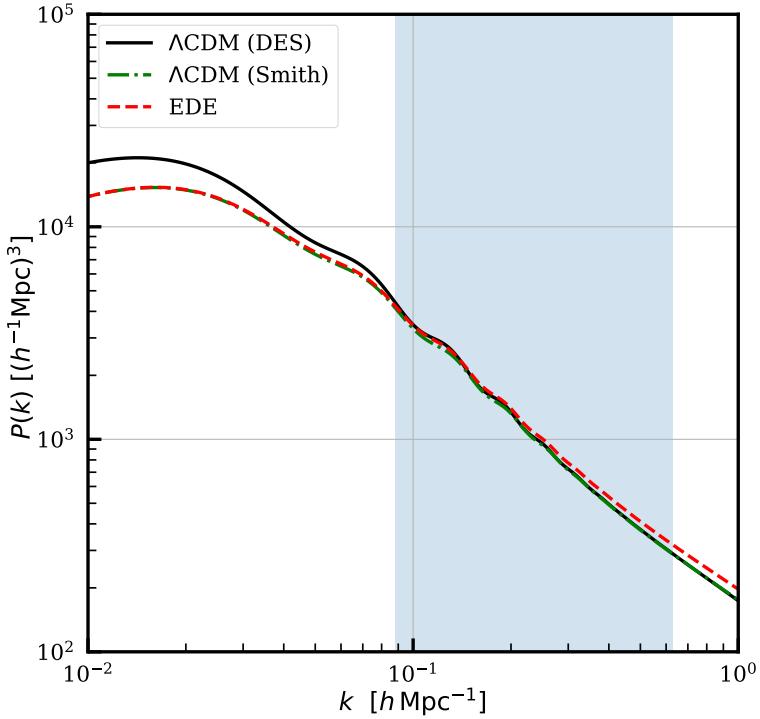
(Poulin + Smith + Karwal + Kamionkowski 18)

H_0 Tension remains



(D'Amico + Senatore + Zhang + Zheng 20)

S_8 Tension is worsened



(Hill + McDonough + Toomey + Alexander 20)

Late Time Matter Supression

Ultra light Axion (ULA) DM behaves like CDM except:

- Scale dependent sound speed

$$c_s^2 = \frac{k^2}{4a^2 m_a^2} \quad \text{for} \quad H \ll \frac{k}{a} \ll m_a \tag{1}$$

(Khlopov et al 85, Hu 98, Hwang + Noh 09 . . .)

- Suppresses scales smaller than axion Jeans scale at equality

$$k > k_{J,eq} \sim 0.1 \frac{h}{\text{Mpc}} \sqrt{\frac{m_a}{10^{-26}\,\text{eV}}} \tag{2}$$

(see Hlozek et al 14, Kobayashi et al 17. . .)

- Mixed ULA and CDM scenario could fit data better

A Dark Sector to Restore Concordance

A two component phenomenological model:

Decaying Dark Energy (DDE)

- Rapidly decays at z_{dde} with EOS $w = -1 \rightarrow > 1/3$
- Modeled as triggered decay of New EDE
  (Niedermann + Sloth 19, 20)
- Makes up $F_{dde} \equiv \rho_{dde}/\rho_{tot}$ at z_{dde}

Ultra-light Axion (ULA)

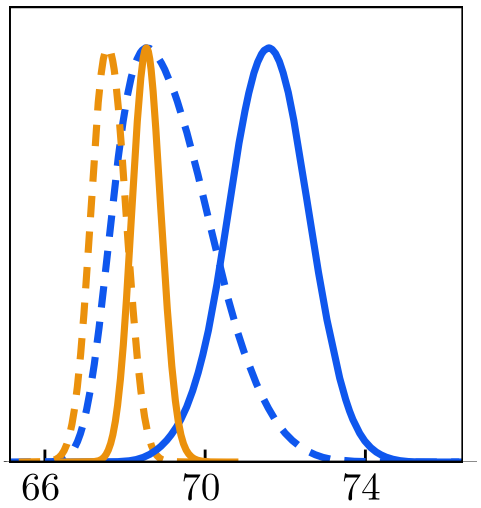
- Standard cosine potential, generic I.C.
- Begins oscillations at z_a, fixes the mass
- Makes up fraction of DM $r_a \equiv \Omega_a/(\Omega_a + \Omega_{cdm})$

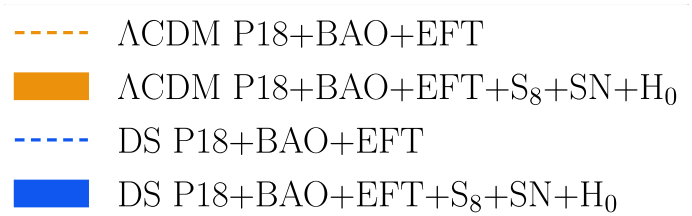
We fix $w = 2/3$, z_a ($m_a \sim 10^{-26}$ eV), leaving F_{dde}, z_{dde}, r_a free

MCMC using `MontePython` sampler
(Audren et al 12, Brinckmann + Lesgourgues 18)

Use modified `CLASS`, merge of `TriggerCLASS` and `AxiCLASS`
(Blas + Lesgourgues + Tram 11 | Niedermann + Sloth 19, 20 | Poulin et al 18, Smith et al 19)

Dark Sector (DS) Results



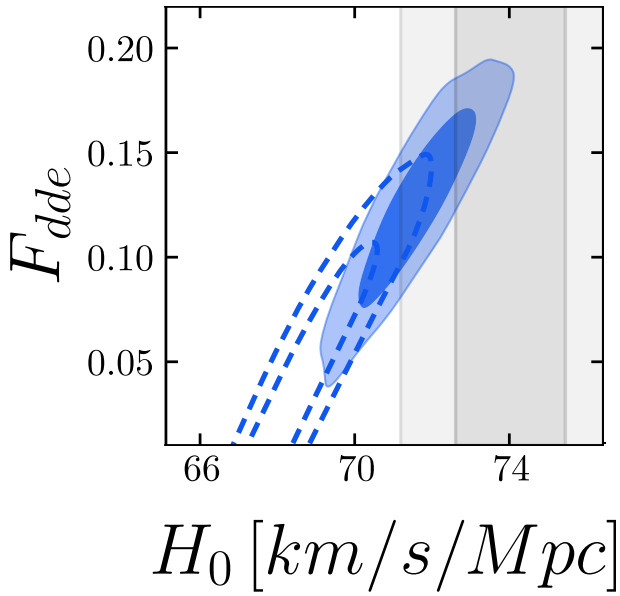


(EFT: `PyBird`, D'Amico + Senatore + Zhang 20)

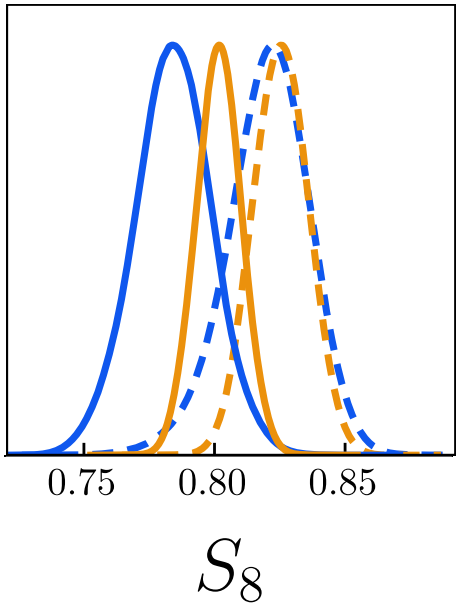
(H_0: SH_0ES, Riess et al 19)

Tension with SH_0ES:

	ΛCDM	DS
w/o SH_0ES	$4.3\,\sigma$	$3.0\,\sigma$
w/ SH_0ES	$3.7\,\sigma$	$1.4\,\sigma$



Dark Sector (DS) Results

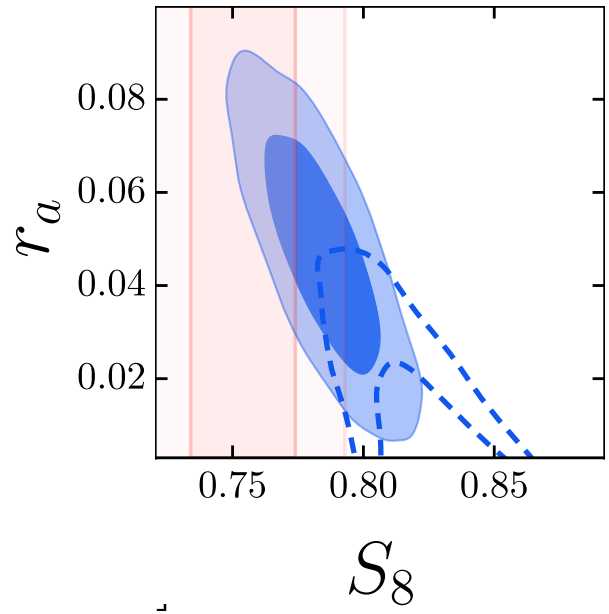


ΛCDM P18+BAO+EFT
ΛCDM P18+BAO+EFT+S_8+SN+H_0
DS P18+BAO+EFT
DS P18+BAO+EFT+S_8+SN+H_0

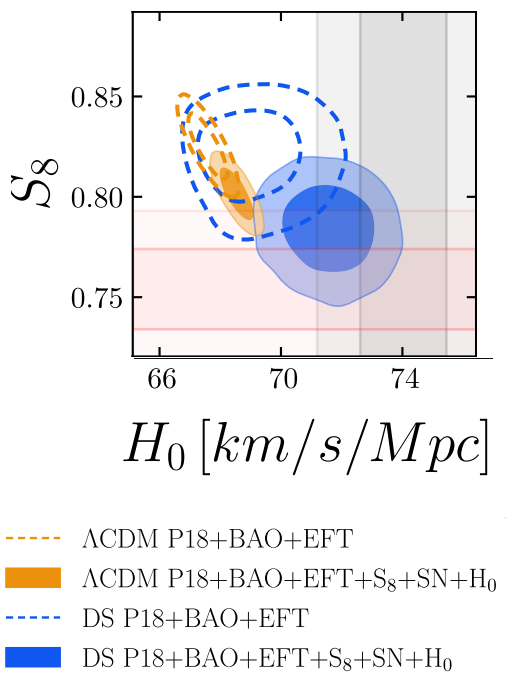
(S_8: KV/DES, Asgari et al 20)

Tension with KV/DES:

	ΛCDM	DS
w/o S_8 prior	$3.2\,\sigma$	$2.8\,\sigma$
w/ S_8 prior	$2.6\,\sigma$	$1.4\,\sigma$
w/ all priors	$2.2\,\sigma$	$1.2\,\sigma$



Summary



- Tensions between early and late universe probes hint at new ingredients
- Early-time modifications of ΛCDM constrained by LSS
- Dark sector with oscillating scalar DM and decaying dark energy components addressed H_0, S_8 tensions
- *Questions:* microphysical model, nonlinearities for mixed DM universe

	ΛCDM		DS	
	w/o priors	w/ priors	w/o priors	w/ priors
H_0 Tension	$4.3\,\sigma$	$3.7\,\sigma$	$3.0\,\sigma$	$1.4\,\sigma$
S_8 Tension	$3.2\,\sigma$	$2.2\,\sigma$	$2.8\,\sigma$	$1.2\,\sigma$