Dark matter decaying in the late universe can relieve the H_0 tension

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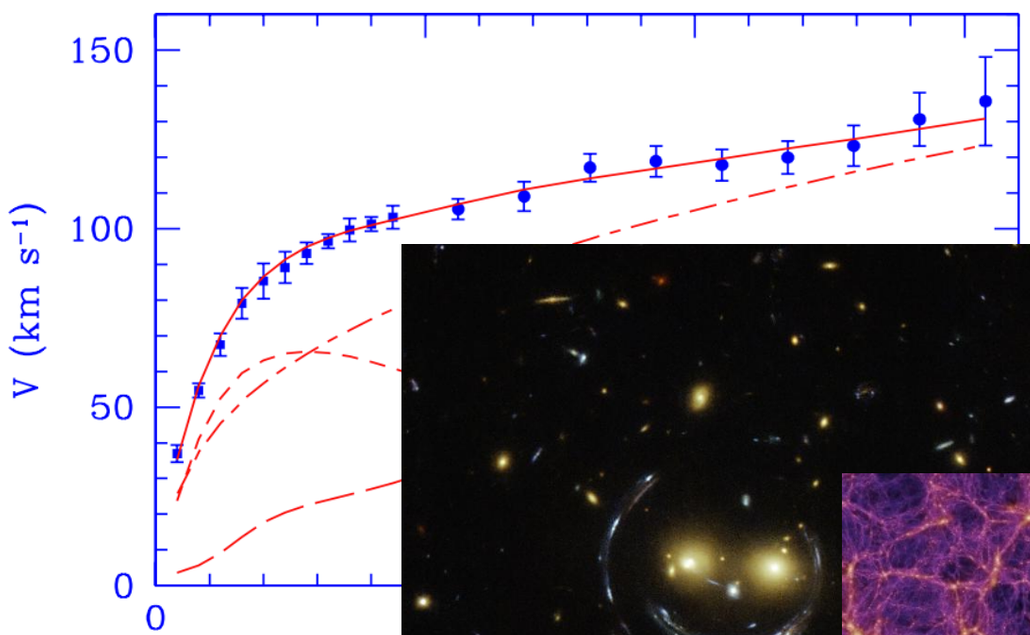
BROWN

Based on Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

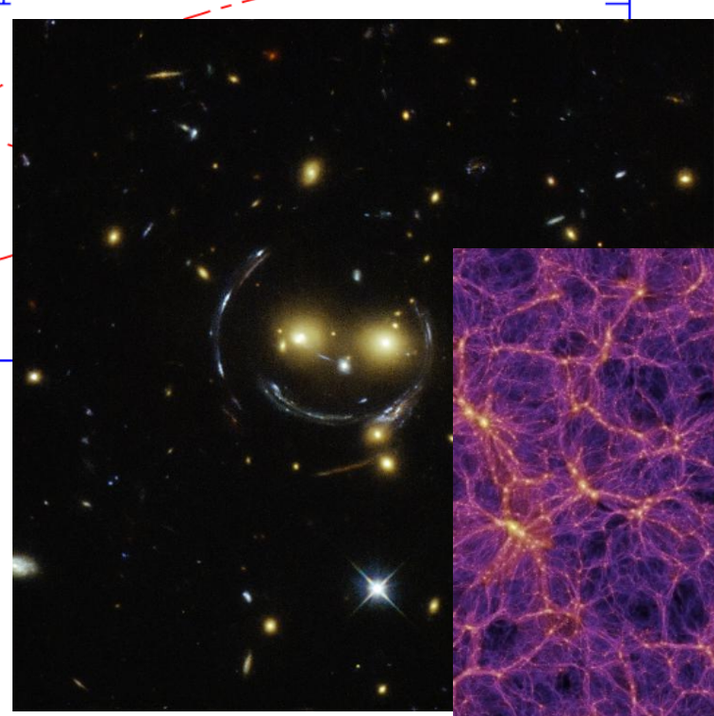
August 6 2019

The ΛCDM universe

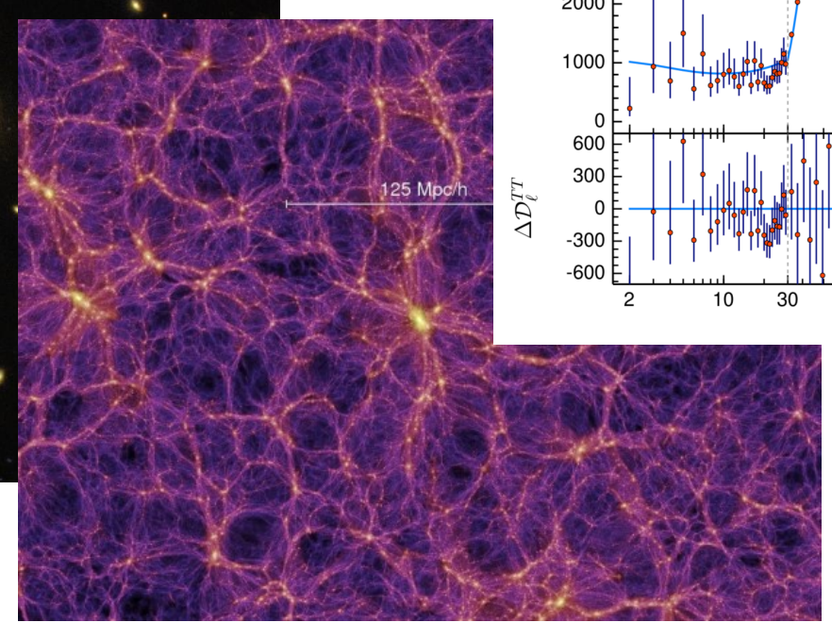
- Cold dark matter ~ 26%
- Dark energy in the form of a cosmological constant ~ 68%



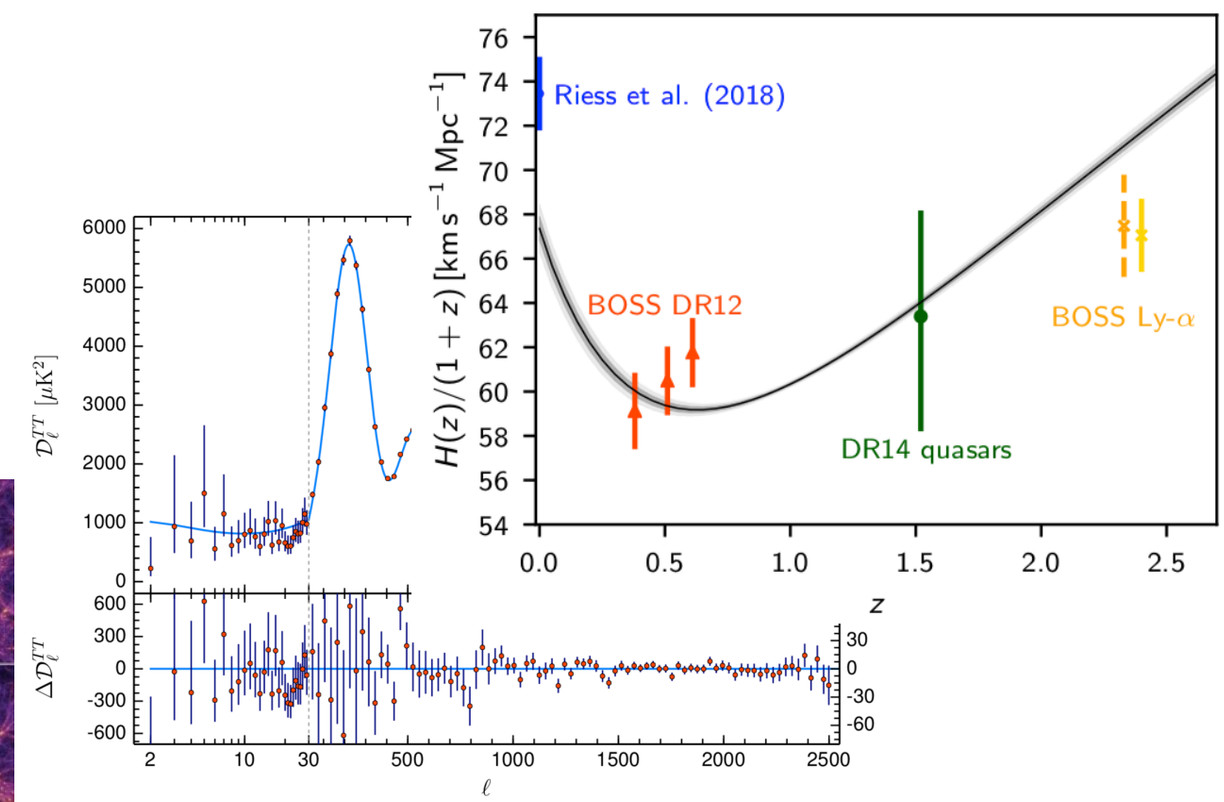
Corbelli & Salucci MNRAS 2000



NASA images

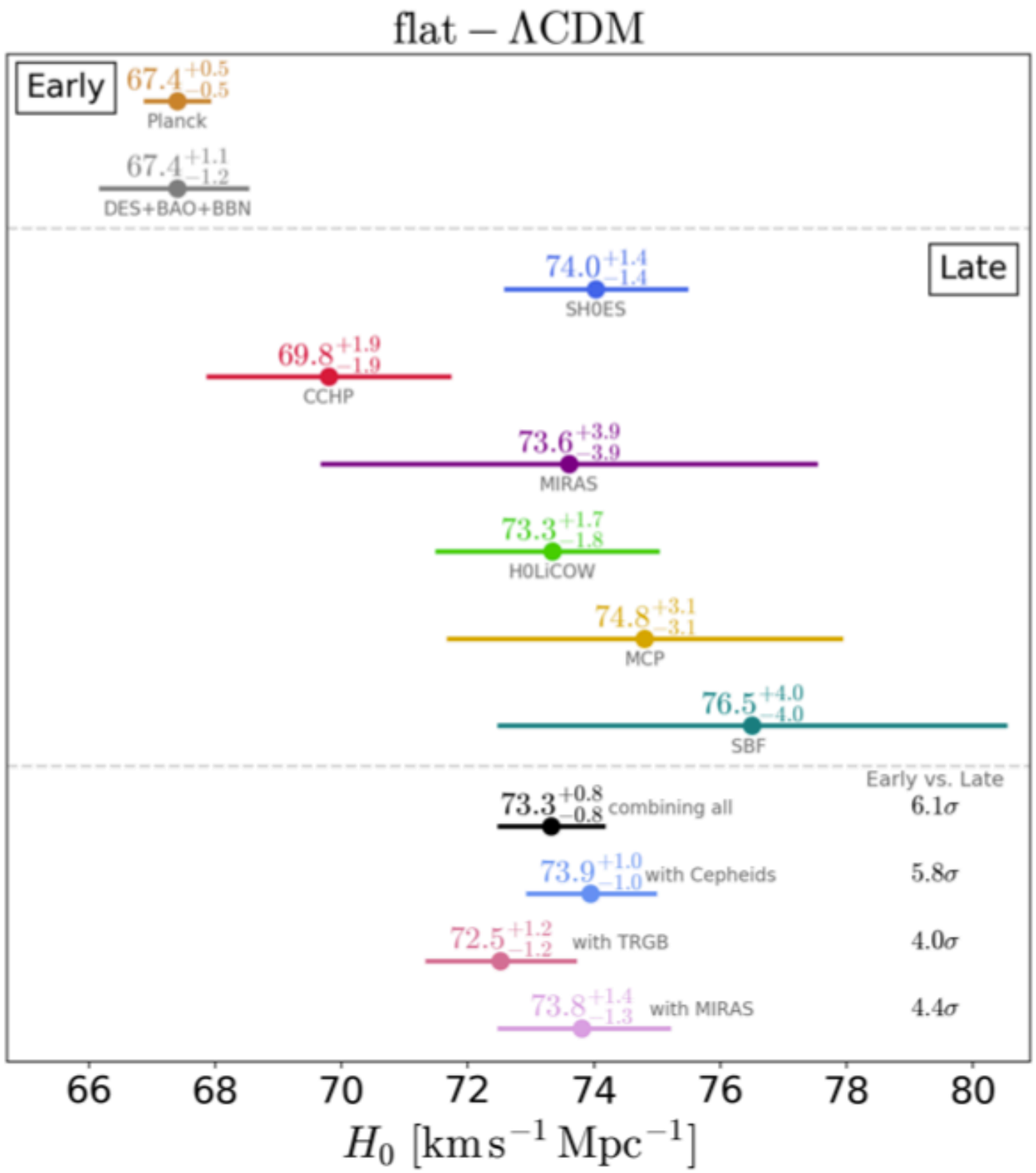


The Millennium Simulation Project



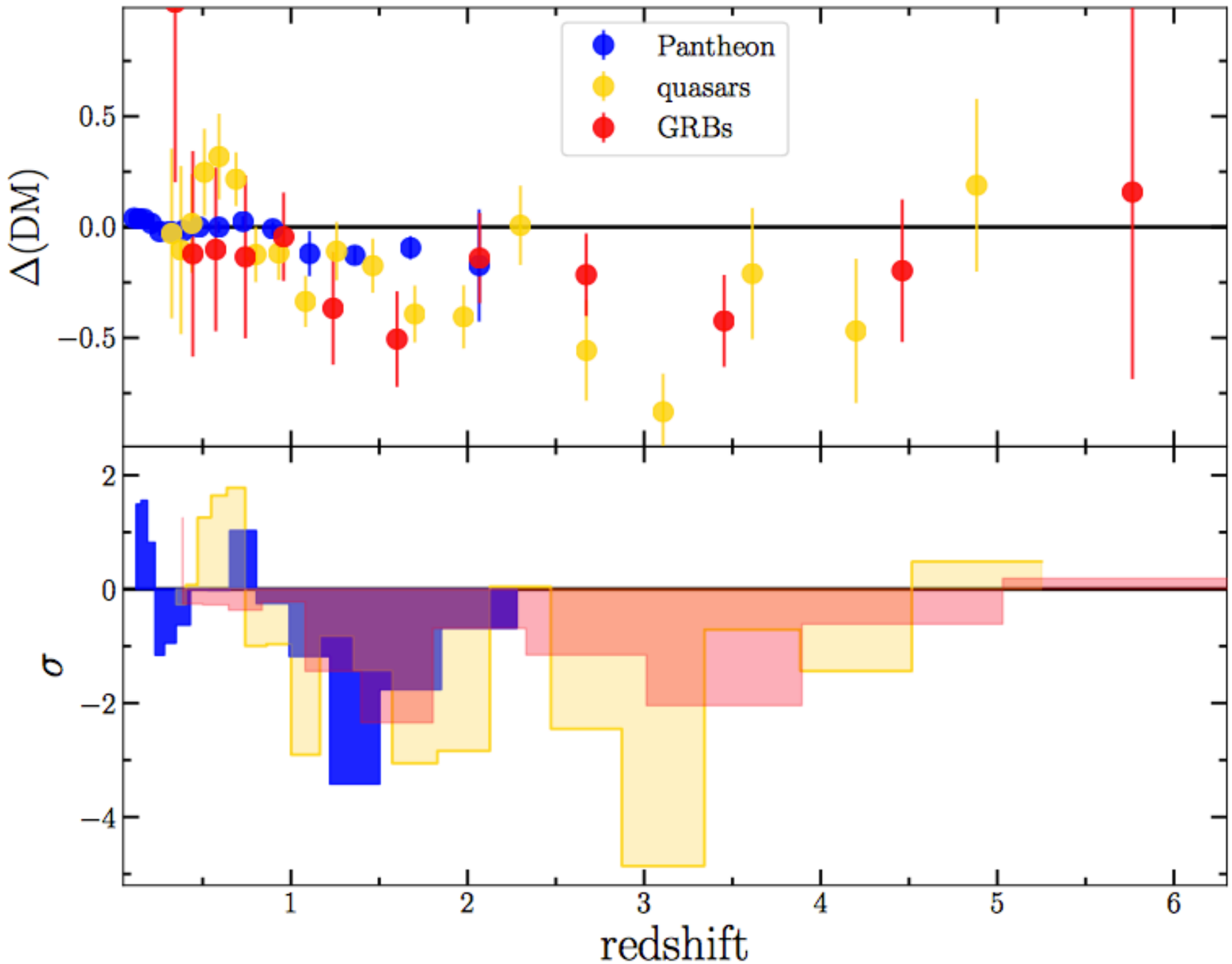
Aghanim, N., et al. *arXiv:1807.06209* (2018).

The Hubble tension



Verde, Treu, Riess arXiv:1907.10625

Tension with flat ΛCDM

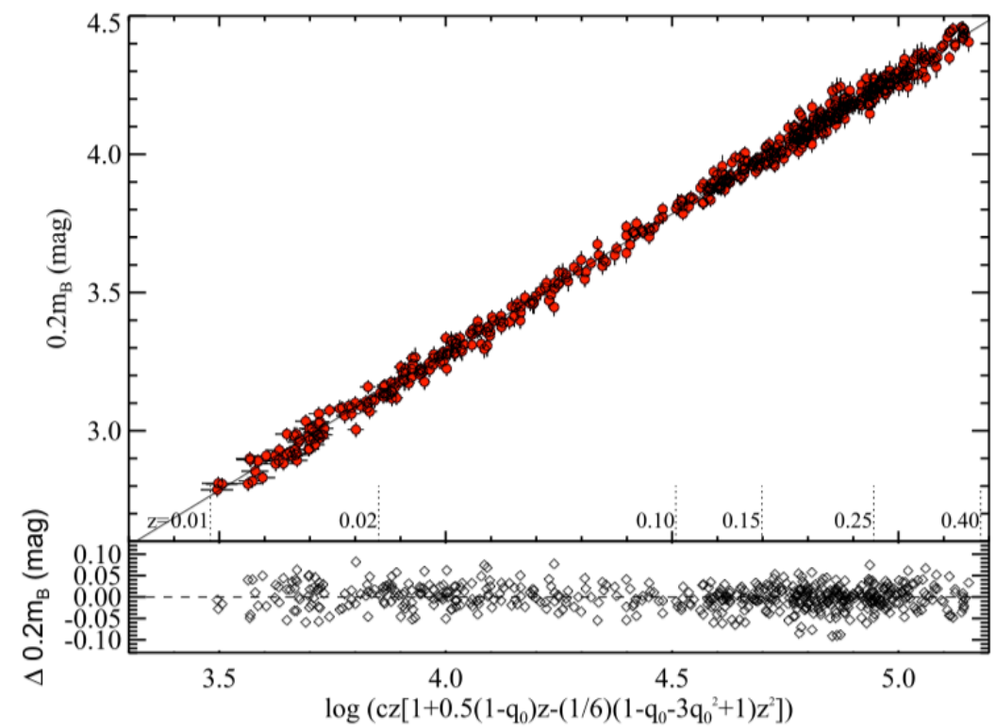


Lusso et al, arXiv:1907.07692

The distance ladder: SH0ES

$$\log H_0 = \frac{(m^0_{x,\mathrm{N4258}} - \mu_{0,\mathrm{N4258}}) + 5a_x + 25}{5}$$

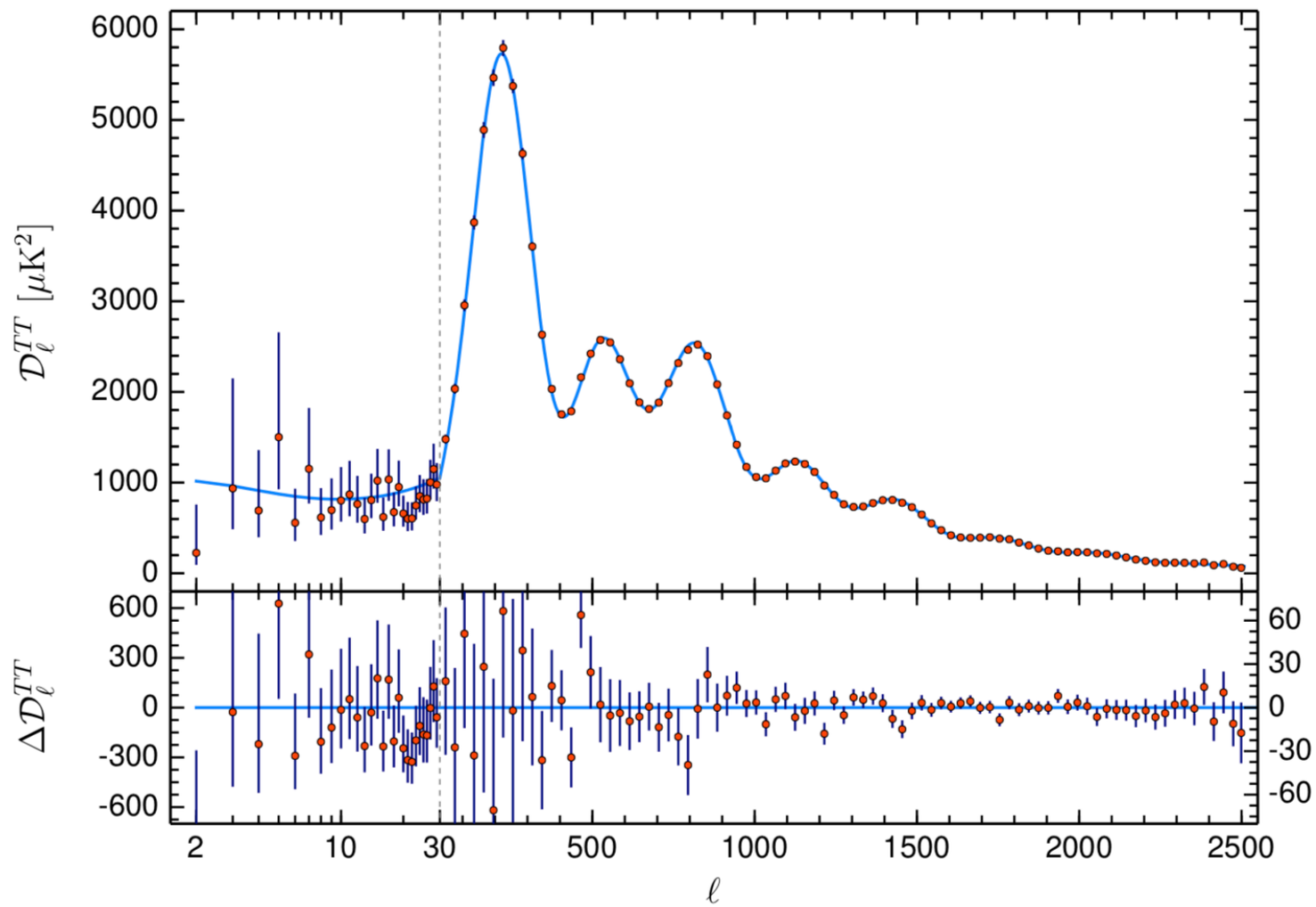
- Cepheid stars
- Supernovae of Type Ia
- 19 hosts of both
- 5 different methods of distance calibration



Riess, Adam G., et al. *The Astrophysical Journal* 826.1 (2016): 56.

The CMB Power spectrum

$$\Omega_b h^2$$
$$\Omega_m h^2$$
$$100\theta_{MC}$$
$$\tau$$
$$n_s$$
$$\ln(10^{10} A_s)$$



Aghanim, N., et al. *arXiv:1807.06209* (2018).

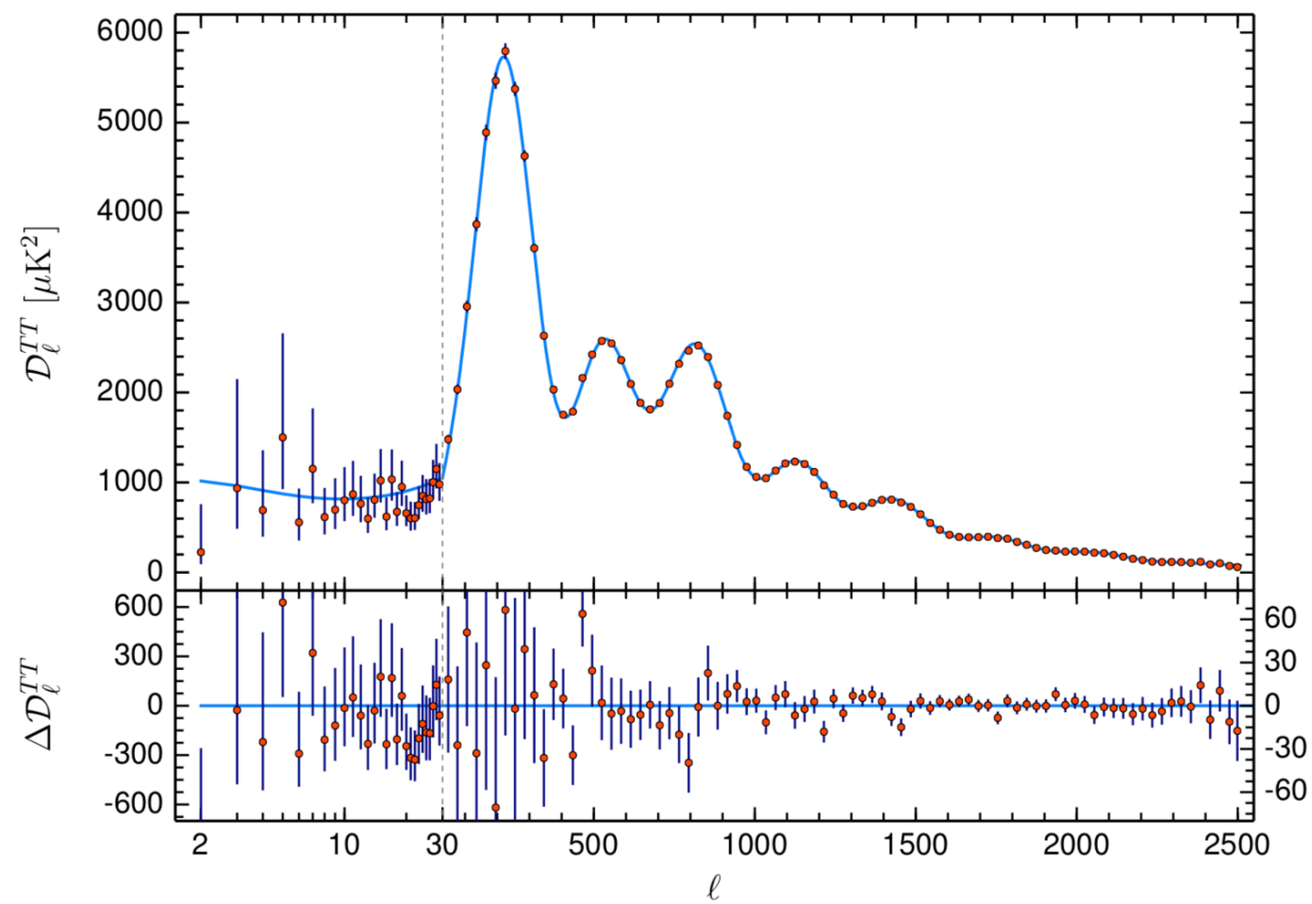
The sound horizon

$$l = 1/\theta_s \approx d_a/r_s$$

$$c_s \approx c[3(1 + 3\Omega_b/4\Omega_r)]^{-1/2}$$

$$r_s \approx \int_0^{t_*} c_s dt$$

$$d_a = d_L(z_*)/(1 + z_*)^2$$

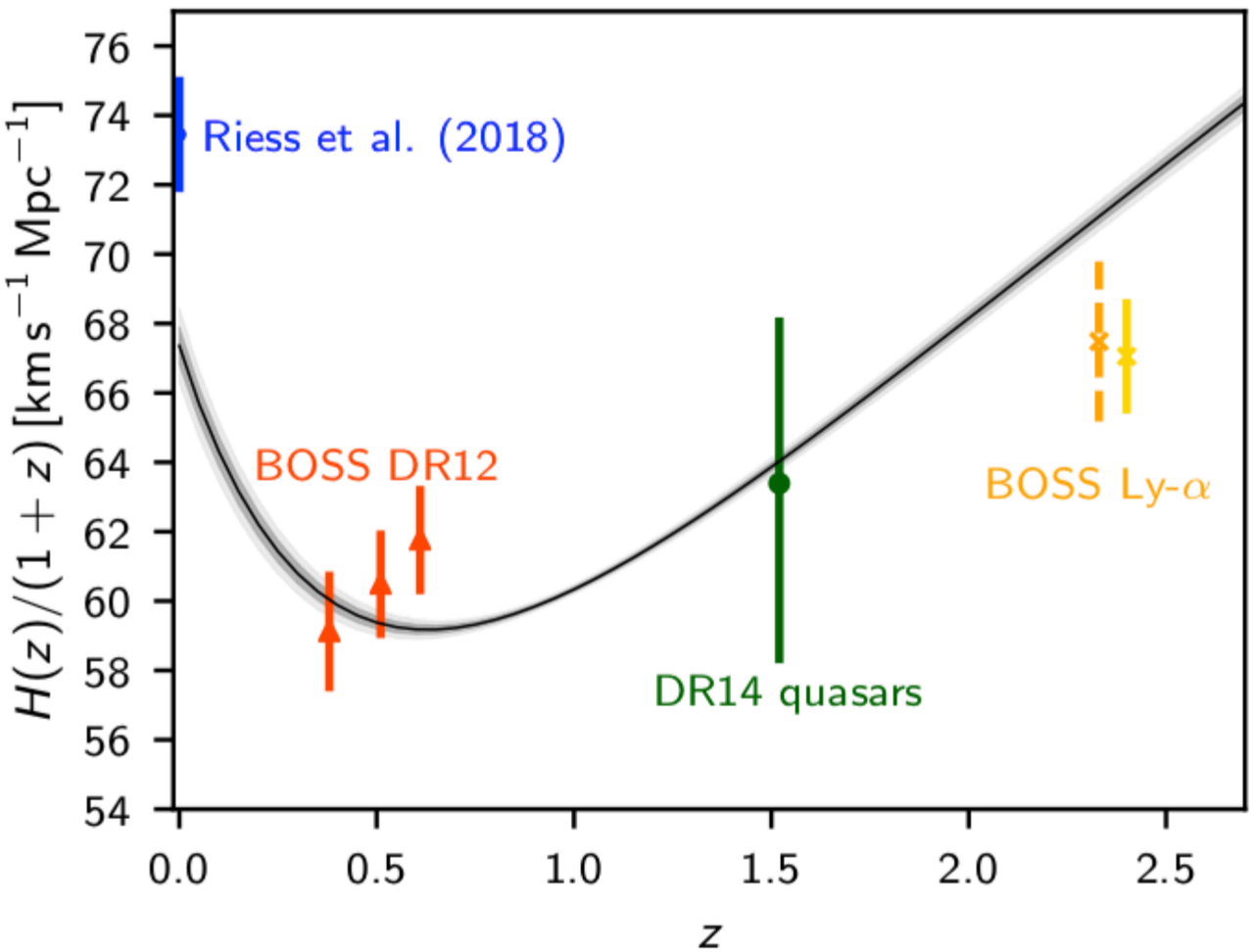


$$d_L(z_*) = \frac{c(1+z)}{H_0} \int_0^{z_*} \frac{dz}{\sqrt{\Omega_r(1+z)^4 + \Omega_m(1+z)^3 + \Omega_\Lambda}}$$

Aghanim, N., et al. *arXiv:1807.06209* (2018).

Planck 2018

- H_0^{R18} =73.24 km s^{-1} Mpc^{-1}
- H_0^{P18} =67.36 km s^{-1} Mpc^{-1} (TT,TE,EE+lowE+lensing)
- 3.6 σ disagreement (4.4 σ)



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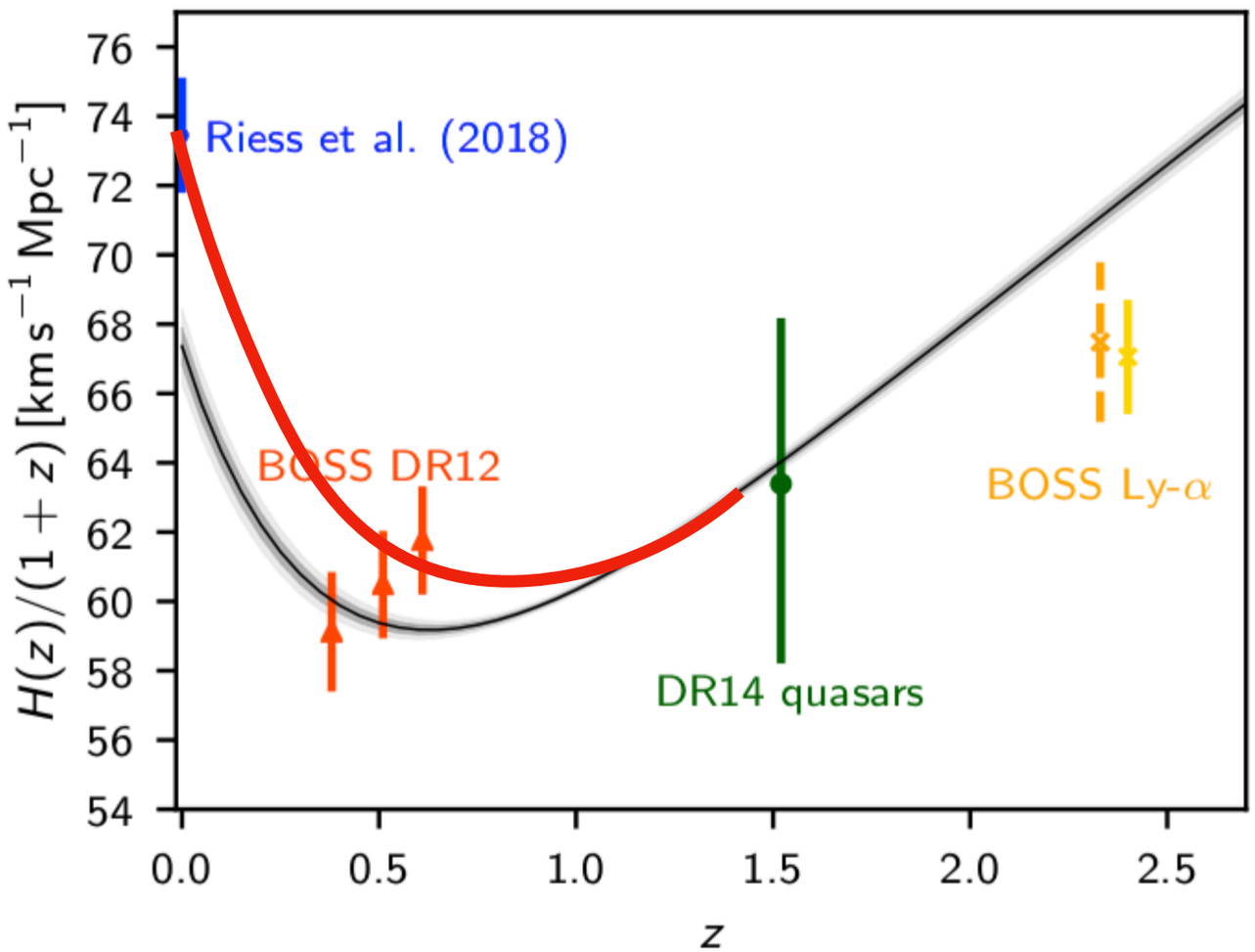
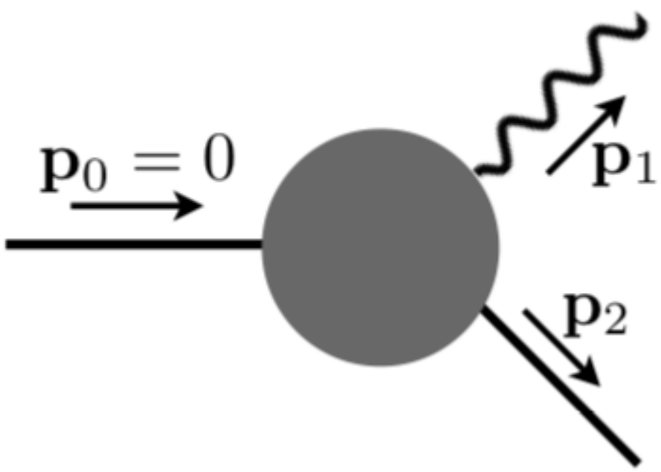


Riess, Adam G., et al. *The* Astrophysical *Journal* 861.2 (2018): 126.

Aghanim, N., et al.*arXiv:1807.06209* (2018).

Decaying Dark matter

$$\psi \rightarrow \chi\gamma$$



$$p_{\mu,0} = (m_0 c^2, \mathbf{0}),$$
$$p_{\mu,1} = (\epsilon m_0 c^2, \boldsymbol{p_1}),$$
$$p_{\mu,2} = ((1-\epsilon) m_0 c^2, \boldsymbol{p_2})$$

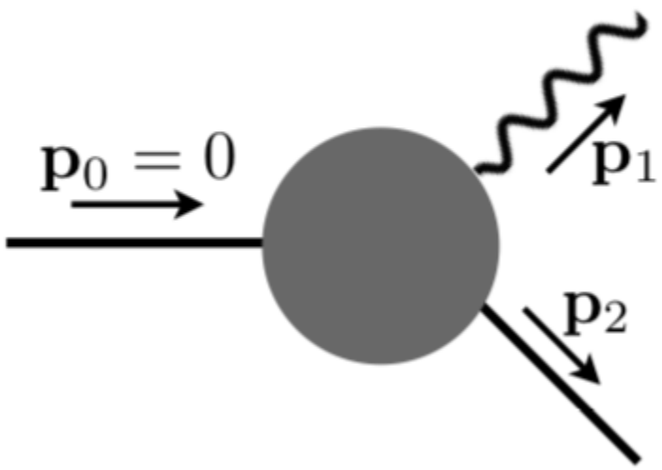
$$\epsilon = \frac{1}{2}(1 - \widetilde{m}^2)$$

$$\beta_2^2 = \frac{\epsilon^2}{(1-\epsilon)^2}$$

Blackadder and Koushiappas. PRD 90.10 (2014): 103527.

Blackadder and Koushiappas. PRD 93.2 (2016): 023510.

Decaying Dark matter



$$\frac{d\rho_0}{dt} + 3\frac{\dot{a}}{a}\rho_0 = -\Gamma\rho_0$$

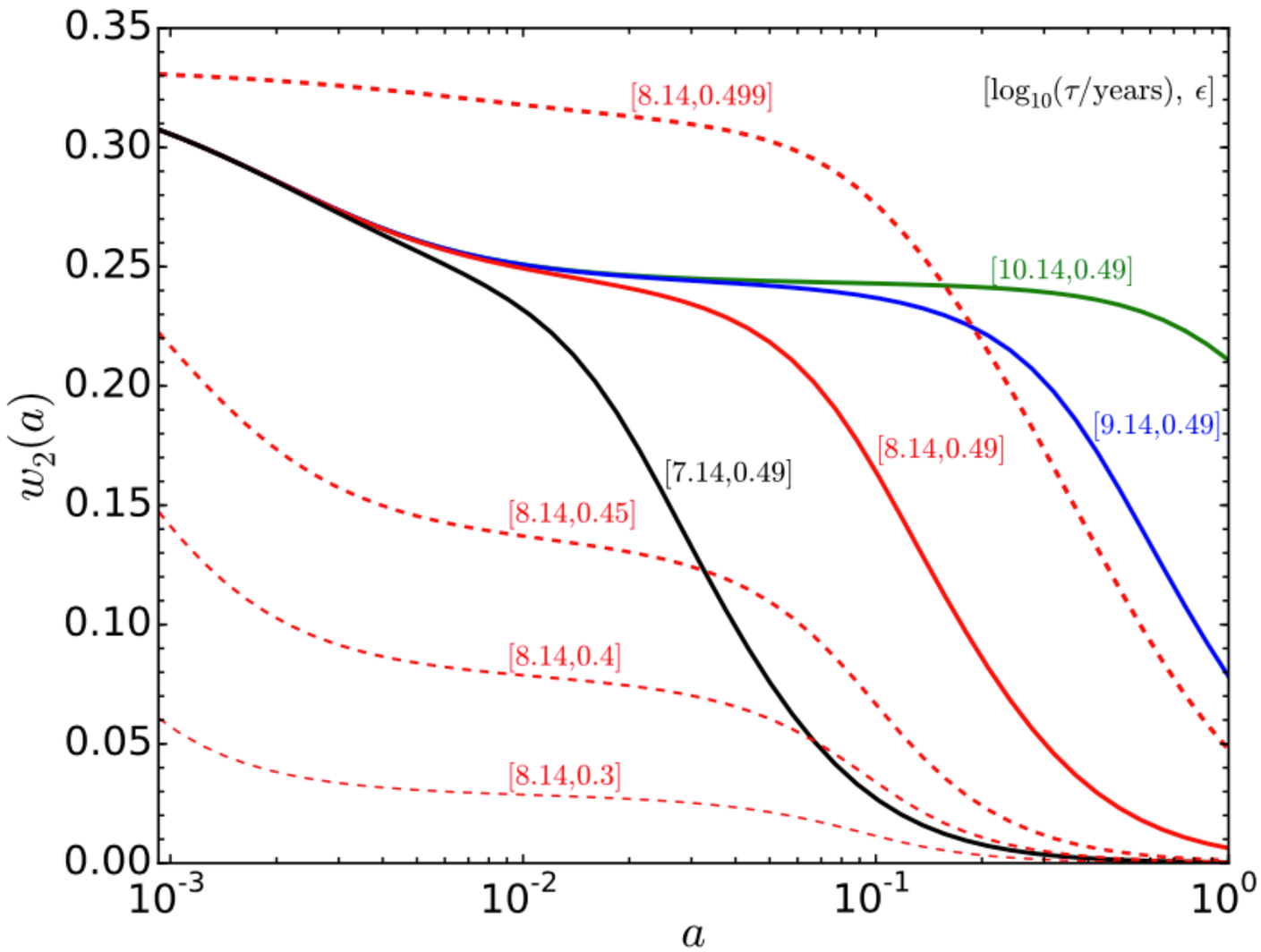
$$\frac{d\rho_1}{dt} + 4\frac{\dot{a}}{a}\rho_1 = \epsilon\Gamma\rho_0$$

$$\rho_2(a) = \frac{\mathcal{C}}{a^3}\int_{a_*}^{a} \frac{e^{-\Gamma t(a_D)}}{a_D H_D}\left[\frac{\beta_2^2}{1-\beta_2^2}\left(\frac{a_D}{a}\right)^2 + 1\right]^{1/2} da_D$$

Blackadder and Koushiappas. PRD 90.10 (2014): 103527. Blackadder and Koushiappas. PRD 93.2 (2016): 023510.

Evolution of the equation of state

$$w_2(a) = \frac{1}{3}\langle v_2(a)^2 \rangle$$



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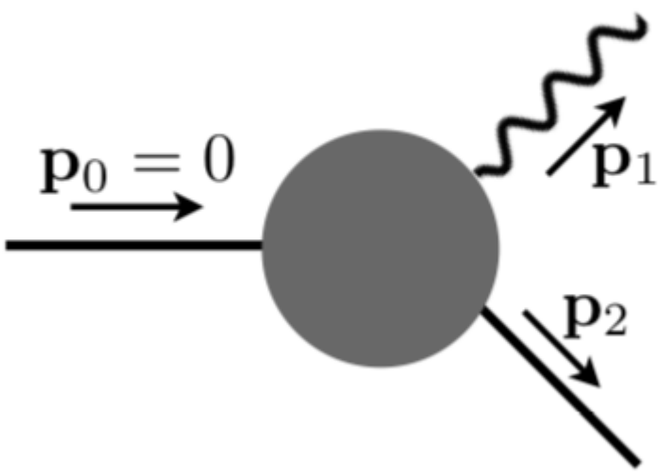


TABLE I: 95% Confidence Limits

model	ϵ	Γ (Gyr^{-1}) Upper Limit	Γ^{-1} (Gyr) Lower Limit	τ/t_0 Lower Limit
Two	0.499	0.040	25	1.8
Two	0.49	0.045	22	1.6
Two	0.45	0.054	19	1.4
Two	0.4	0.067	15	1.1
Two	0.3	0.074	13	0.98
Two	0.2	0.12	8.4	0.61
Two	0.1	0.12	8.4	0.61
Many	1	0.037	27	2.0
Many	0.5	0.069	14	1.1
Many	0.1	0.15	6.7	0.48

Blackadder and Koushiappas. PRD 93.2 (2016): 023510.

Decaying Dark matter

$$H^2(a) \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\sum_i \rho_i(a)$$

$$\sum_i \rho_i(a) = \rho_0(a) + \rho_1(a) + \rho_2(a) + \rho_r(a) + \rho_\nu(a) + \rho_b(a) + \rho_\Lambda$$

$$\{\tau, \epsilon, \Omega_{\rm DM}, h\}$$

$$-4 \leq \log_{10}\epsilon < \log_{10} 1/2$$

$$-3 \leq \log_{10}\tau \leq 4$$

$$0 \leq \Omega_{\rm DM} \leq 1$$

$$0.5 \leq h \leq 1$$

Run these against:

- Distance ladder measurements
- BOSS DR 12, DR 14 quasar BAO
- SDSS Ly-alpha auto- and cross-correlation function
- **Under the assumption that the universe is correctly described by Planck18 at recombination**

Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

Decaying Dark matter

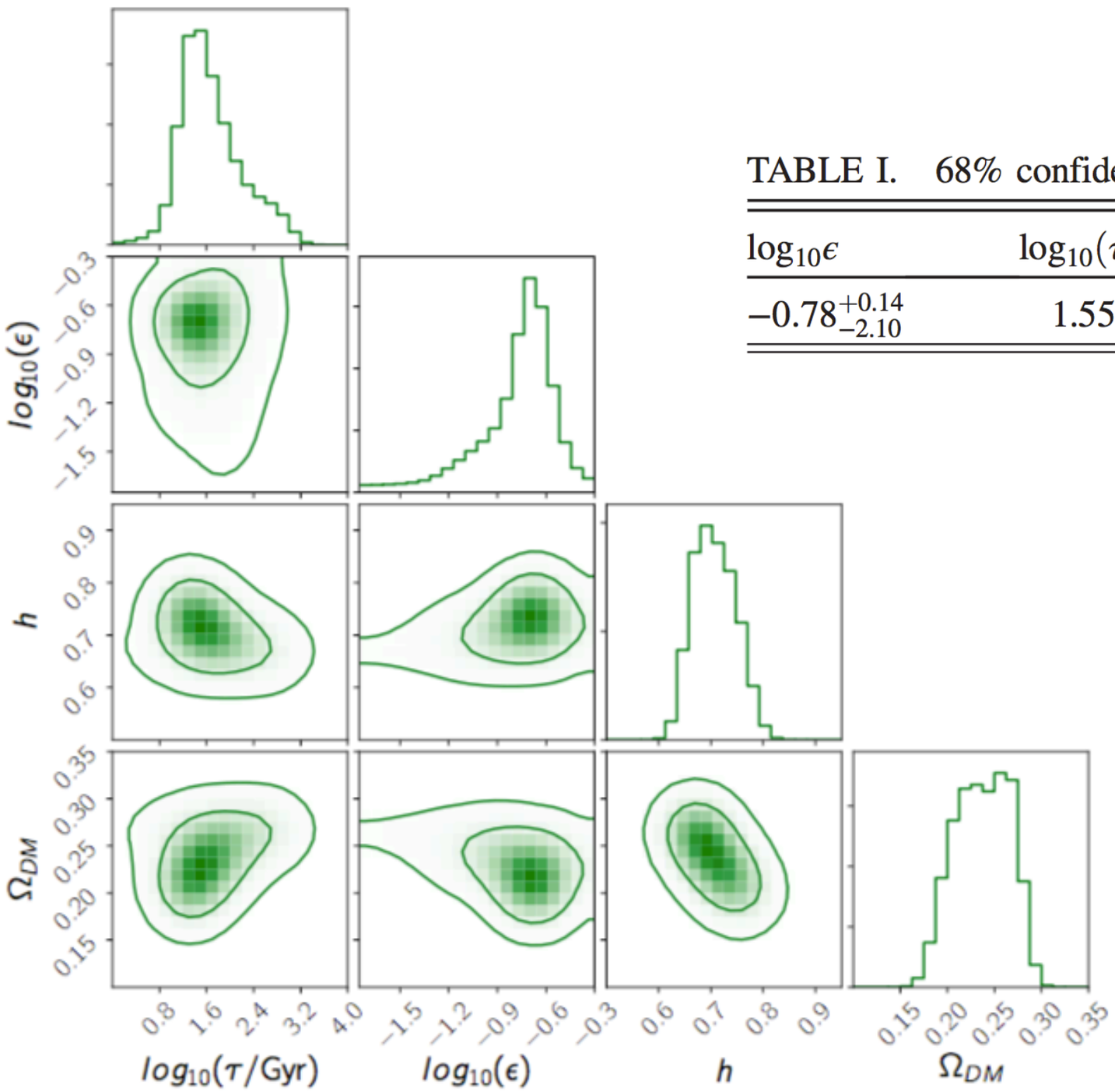
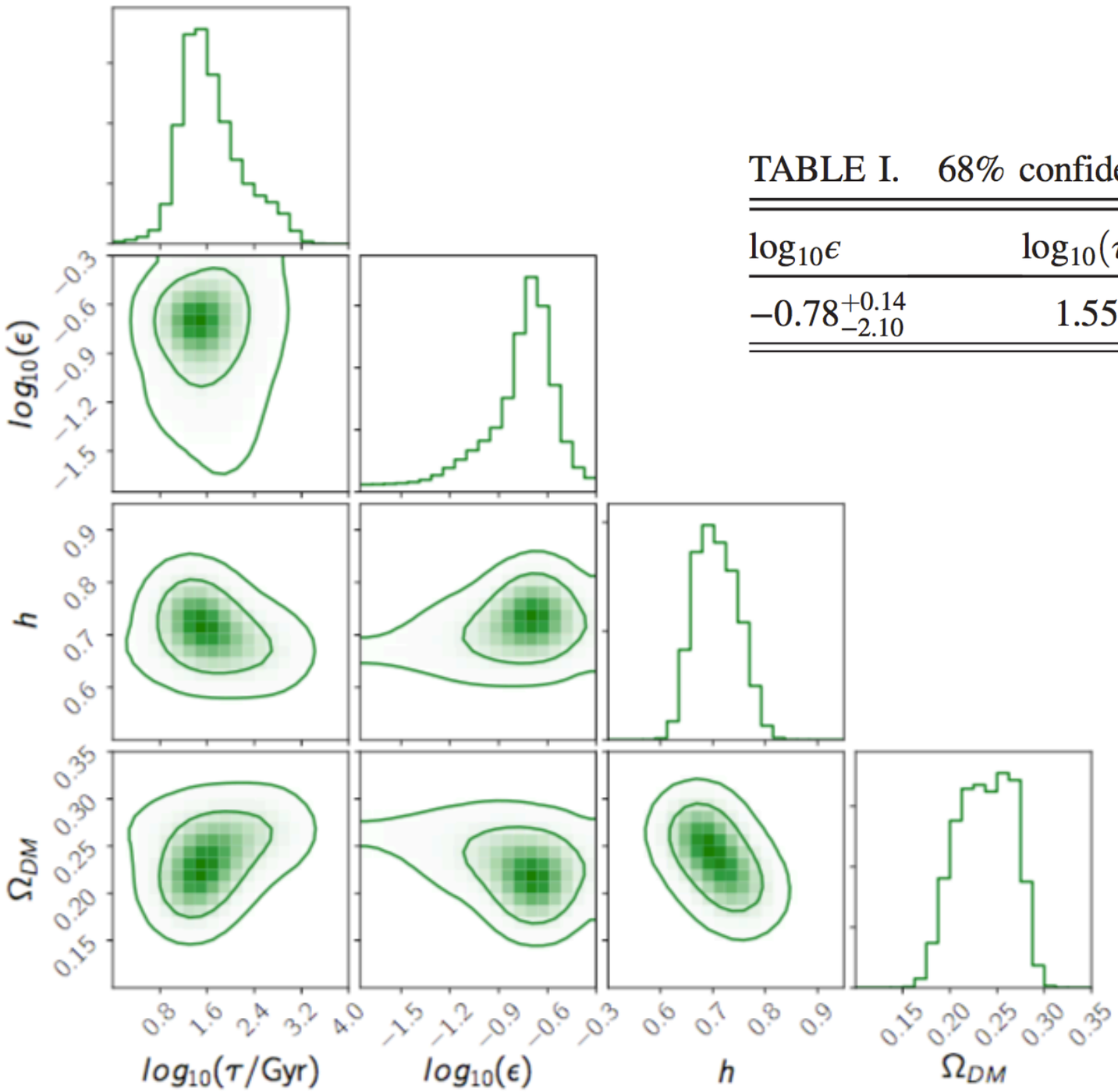


TABLE I. 68% confidence limits.

$\log_{10}\epsilon$	$\log_{10}(\tau/\mathrm{Gyr})$	Ω_{DM}	h
$-0.78^{+0.14}_{-2.10}$	$1.55^{+0.63}_{-0.25}$	$0.24^{+0.03}_{-0.03}$	$0.70^{+0.04}_{-0.03}$

Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

Decaying Dark matter



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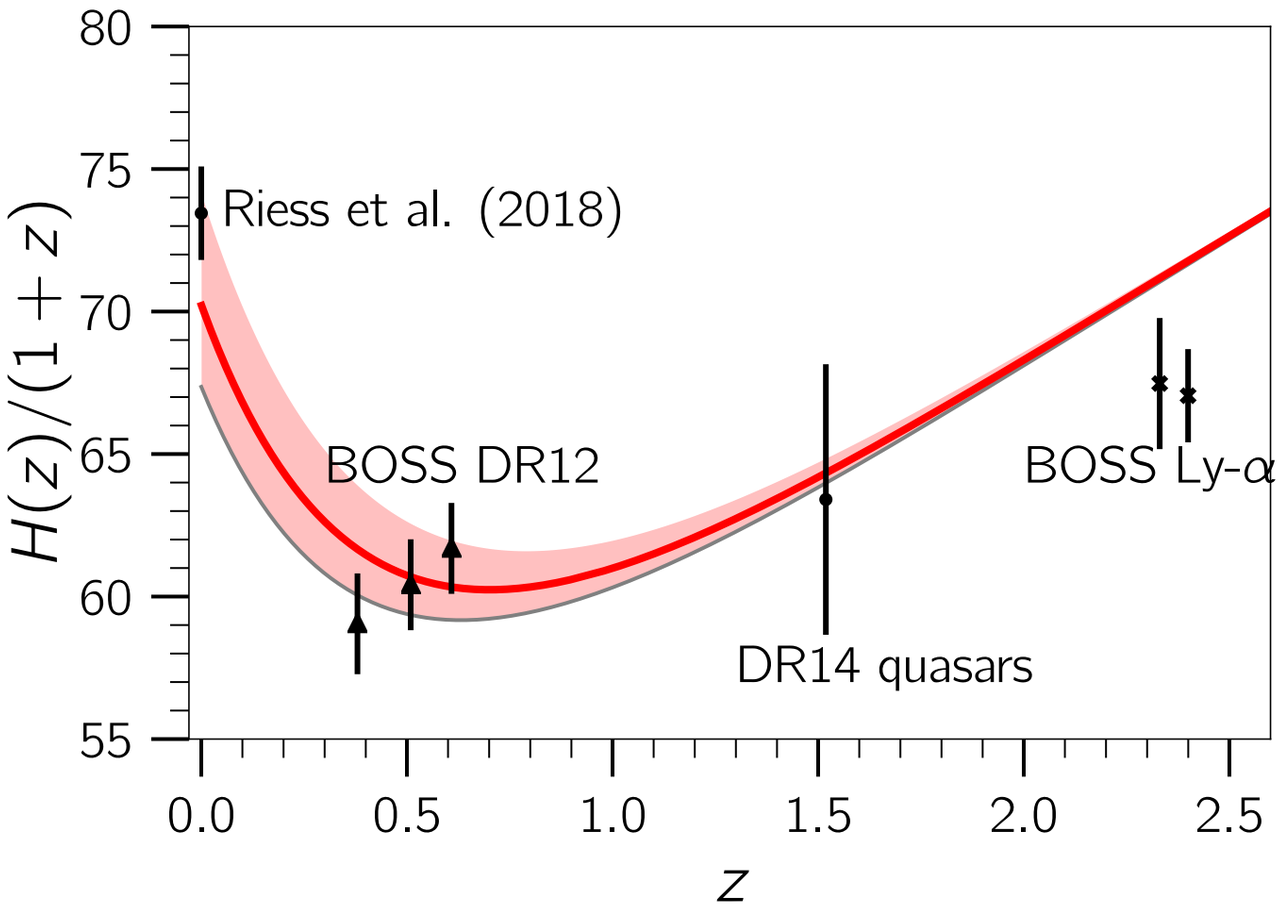
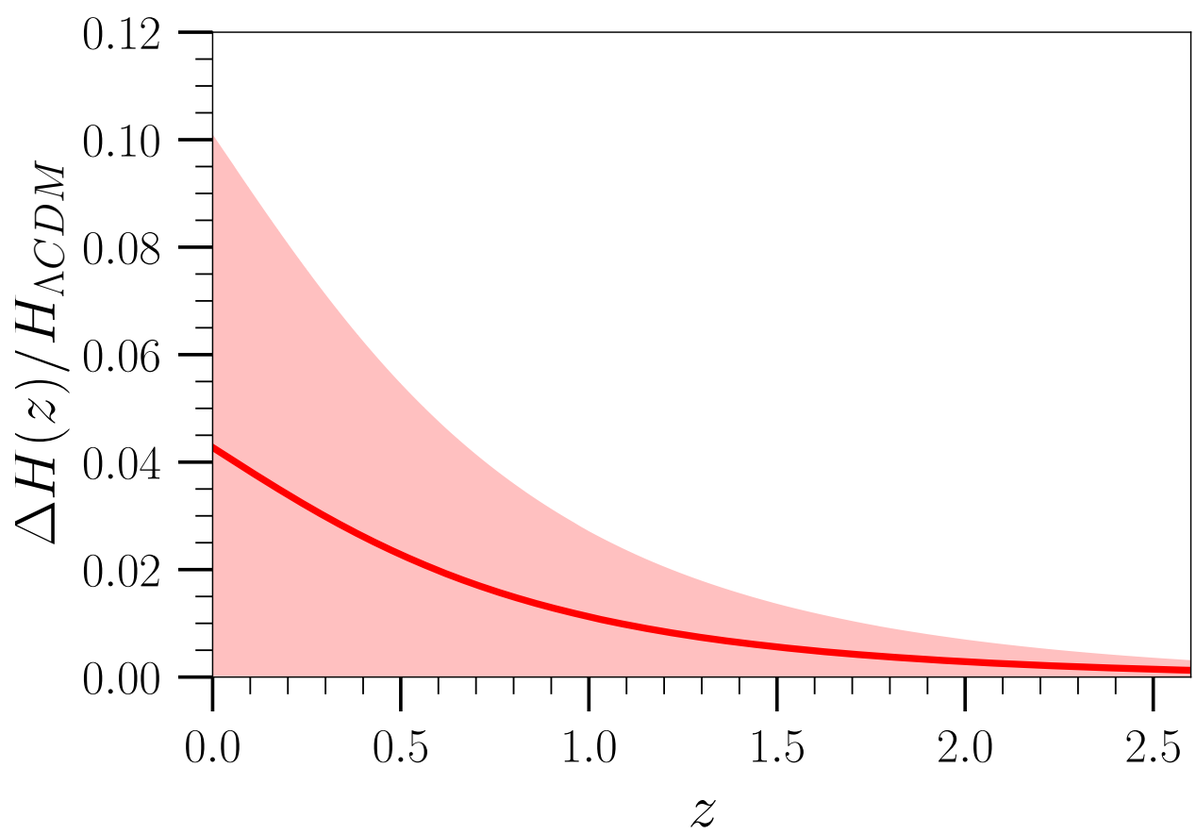
- Part of this allowed values of the lifetime parameter space is ruled out by the SDSS Ly-alpha power spectrum (see Wang et al., PRD 85, 043514 (2012) & PRD 88, 123515 (2013))
- BAO inverse distance ladder

Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

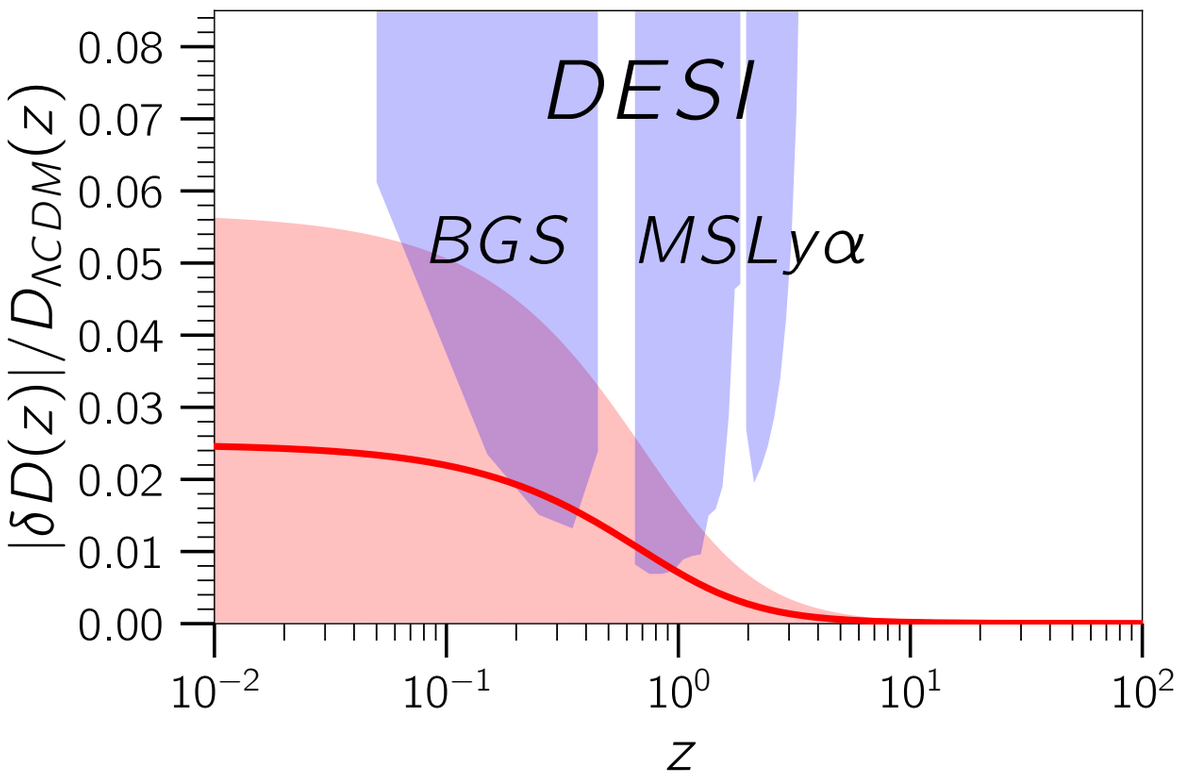
Relieving the tension



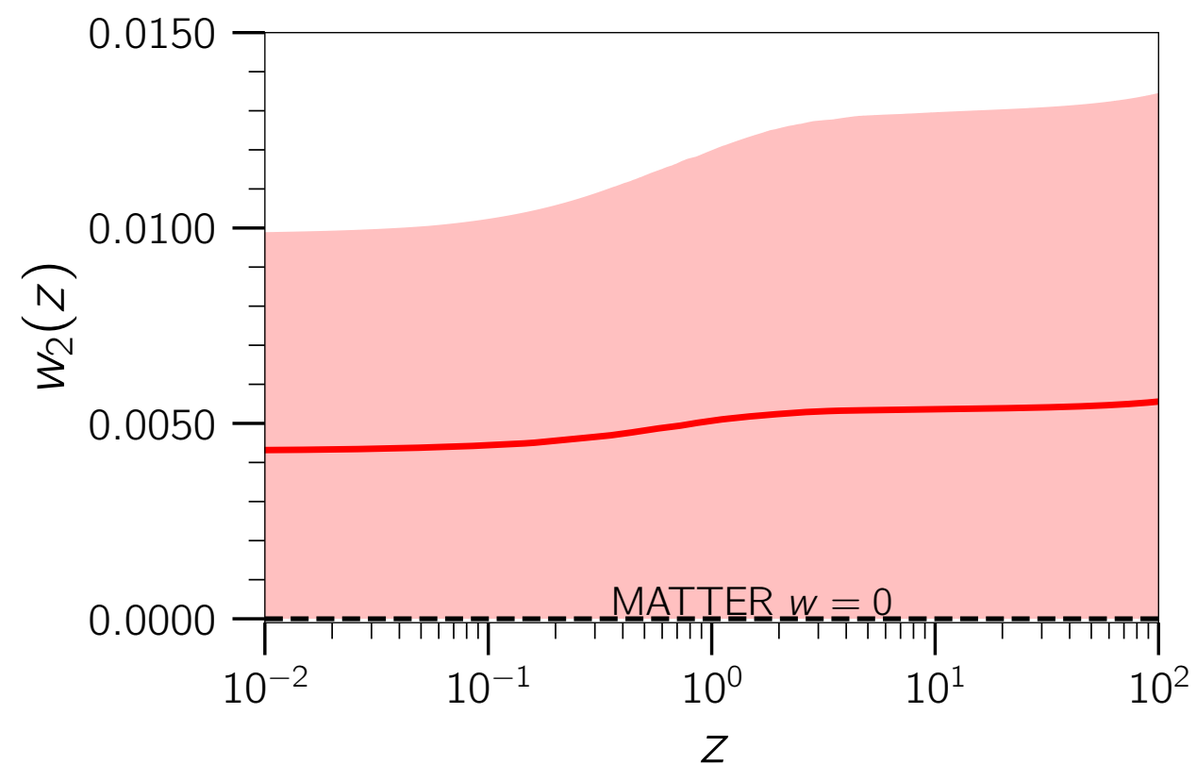


Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

Possible tests

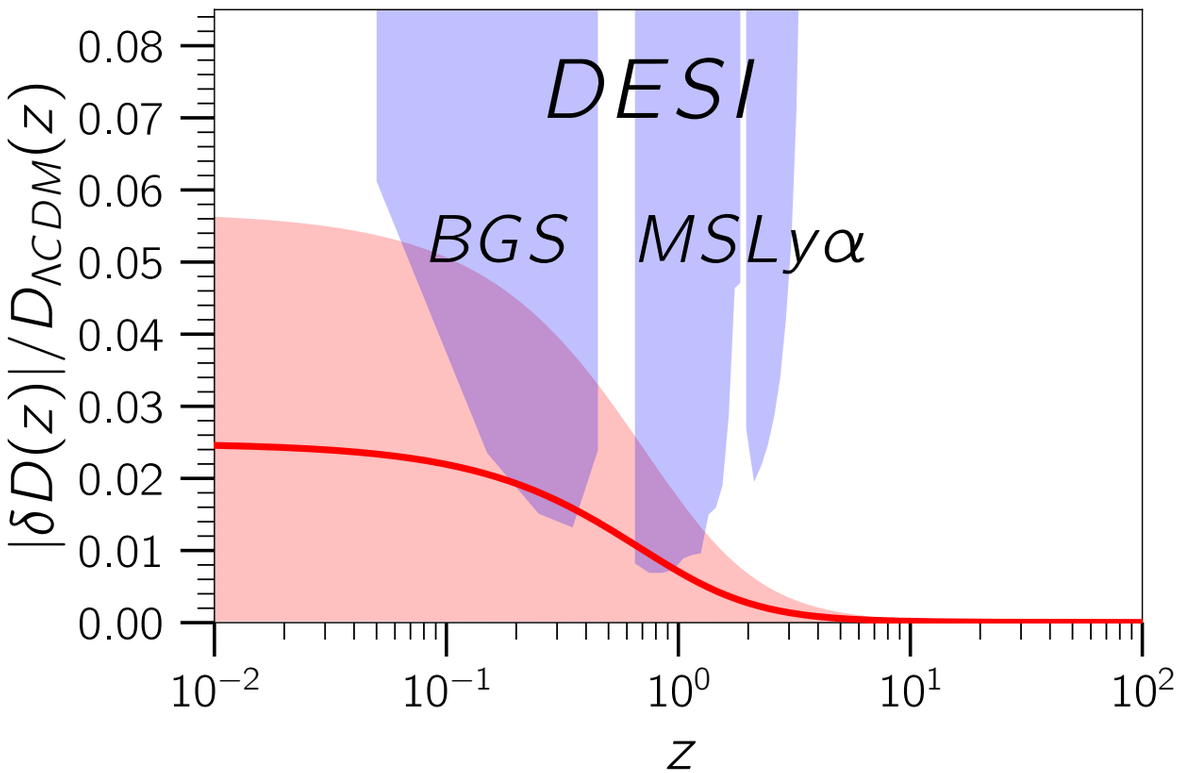


$$\frac{d^2D}{da^2} + \left(\frac{d\ln H}{da} + \frac{3}{a}\right)\frac{dD}{da} - \frac{4\pi G\rho_m}{a^2} = 0$$



Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

LSST



Vattis, Koushiappas & Loeb, Phys. Rev. D **99**, 121302(R) (2019)

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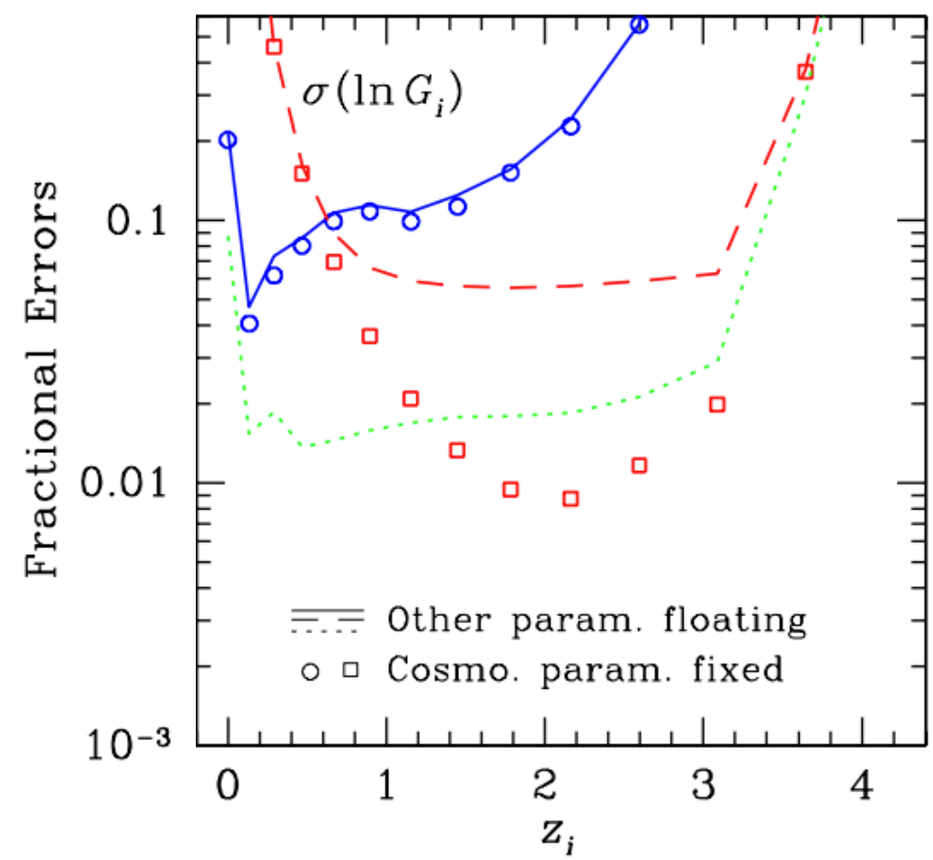

Zhan, Knox &Tyson The Astrophysical Journal, 690:923–936, 2009

Conclusions

- The Hubble tension could be a real problem that potentially requires some new physics.
- A Decaying Dark Matter model can help relieve the tension.
- Important caveat: The BAO inverse distance ladder.
- More investigation is required, especially on the effects in structure formation.
- LSST can help to probe such effects.

Thank you

Particle physics model

- Super Wimps or excited dark fermions decaying via a magnetic dipole transition

$$\Gamma \sim \delta m^3/\Lambda^2$$

$$\delta m = 1 - \sqrt{(1-2\epsilon)}$$

$$\epsilon \approx 0.17$$

$$\tau \approx 20\mathrm{Gyr}$$

$$\Lambda \approx 10^{16}\mathrm{GeV}$$

$$\delta m \approx 180\mathrm{MeV}$$