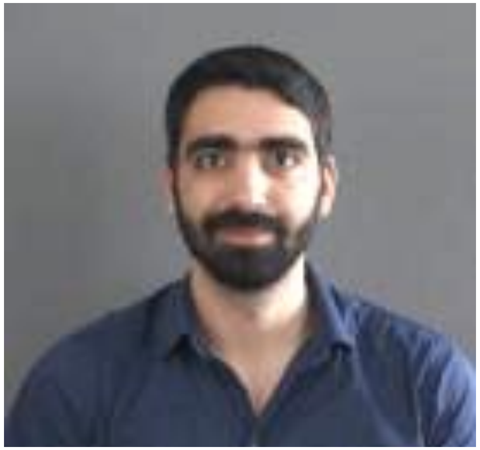
Dark matter decays and the Hubble tension

Savvas M. Koushiappas

BROWN

Kyriakos Vattis



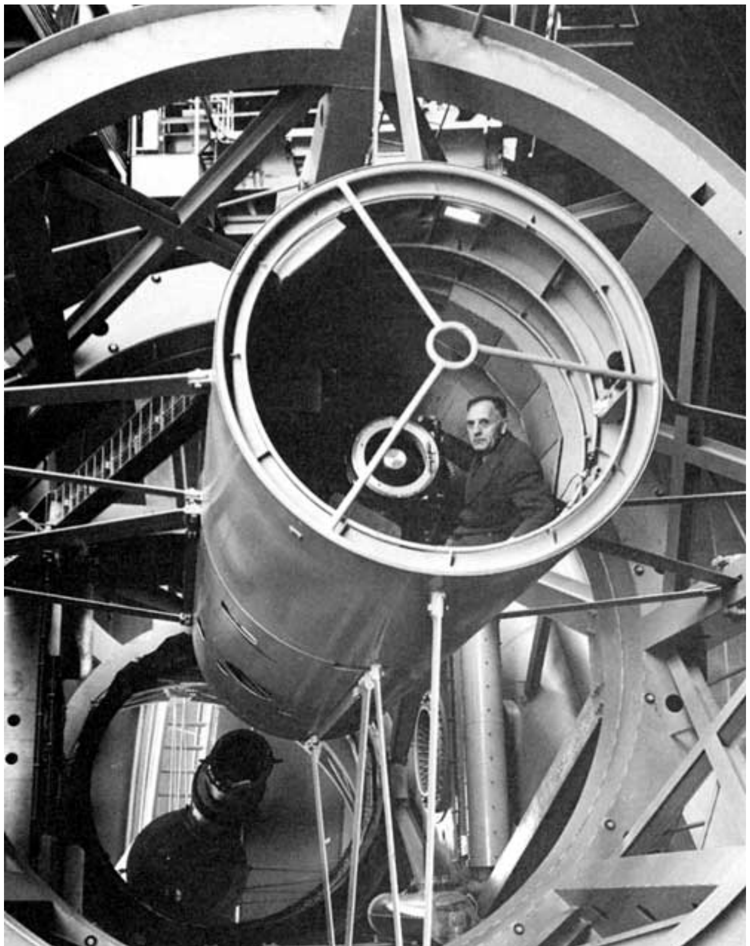
Based on Vattis, Koushiappas & Loeb, arXiv:1903.06220 (PRD accepted)

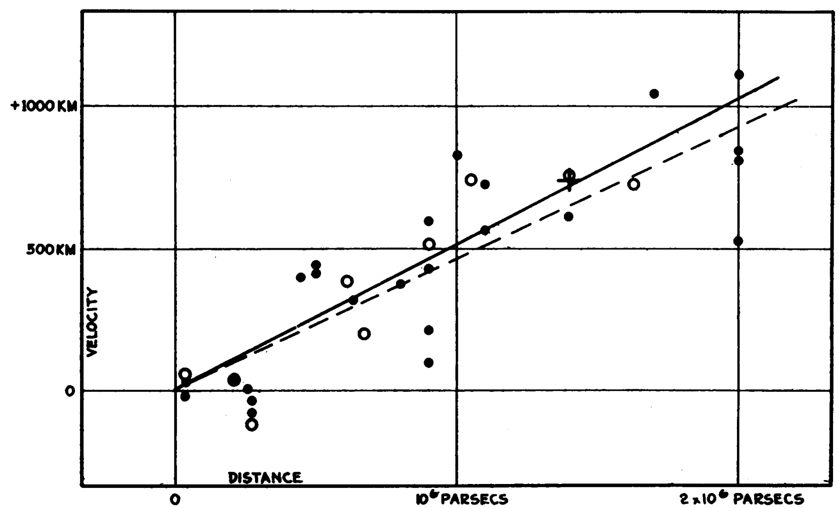
A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

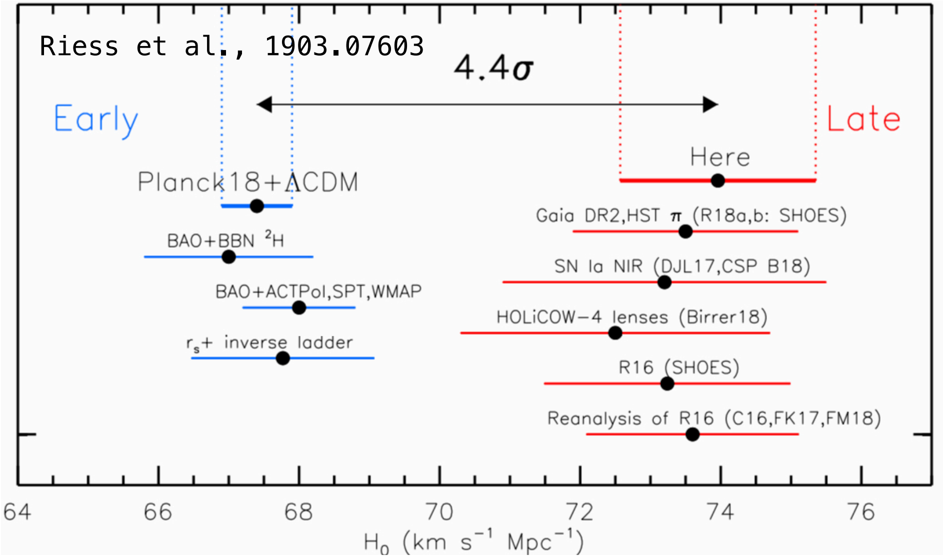
Communicated January 17, 1929





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

The Hubble parameter tension today



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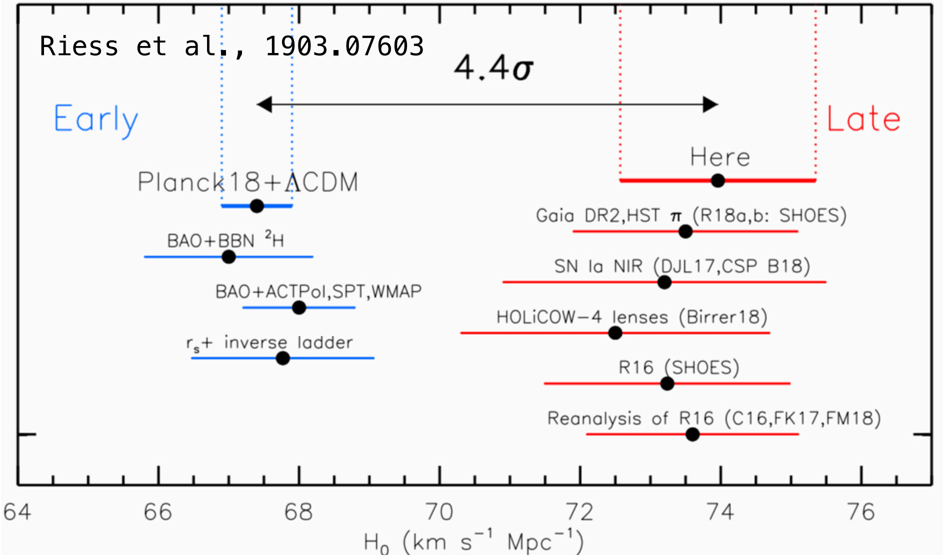
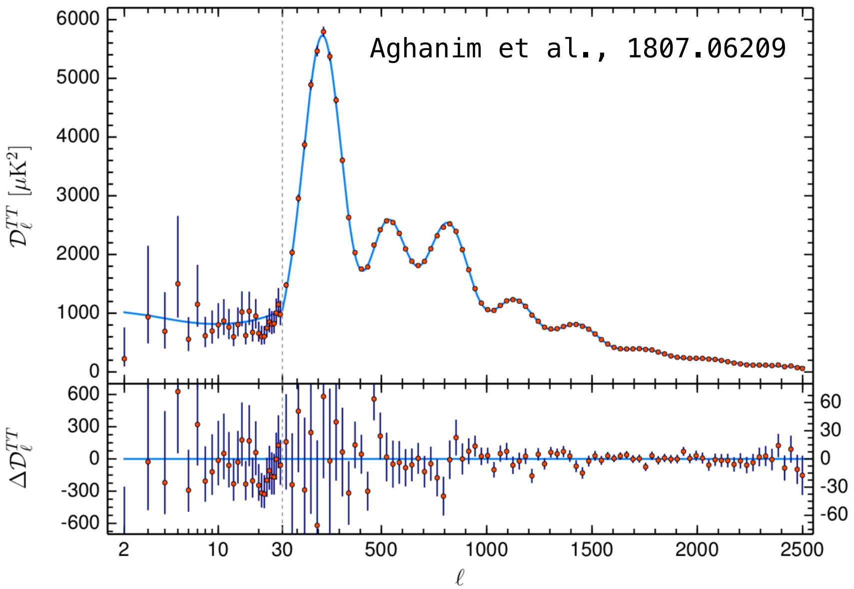


$$\{\Omega_b h^2, \Omega_m h^2, 100\theta_{MC}, \tau, n_s, \ln(10^{10} A_s)\}$$



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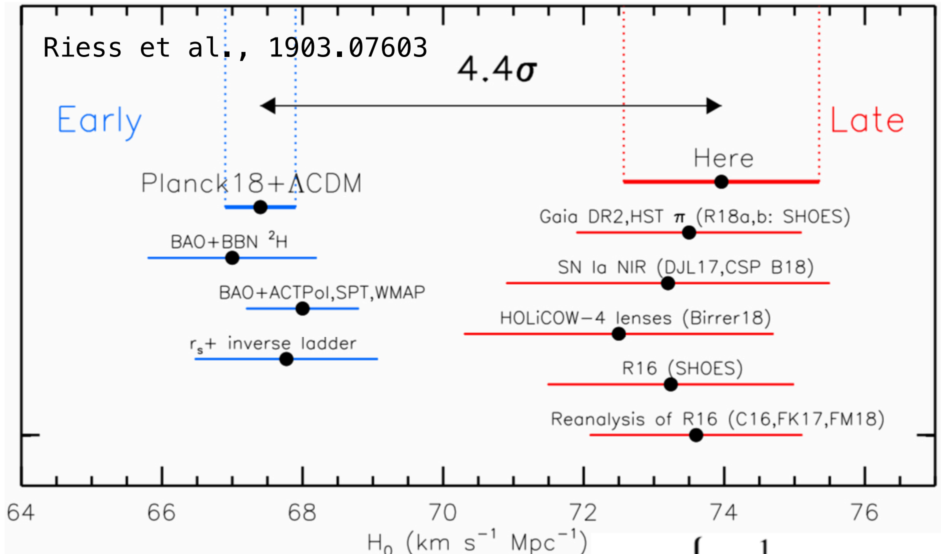
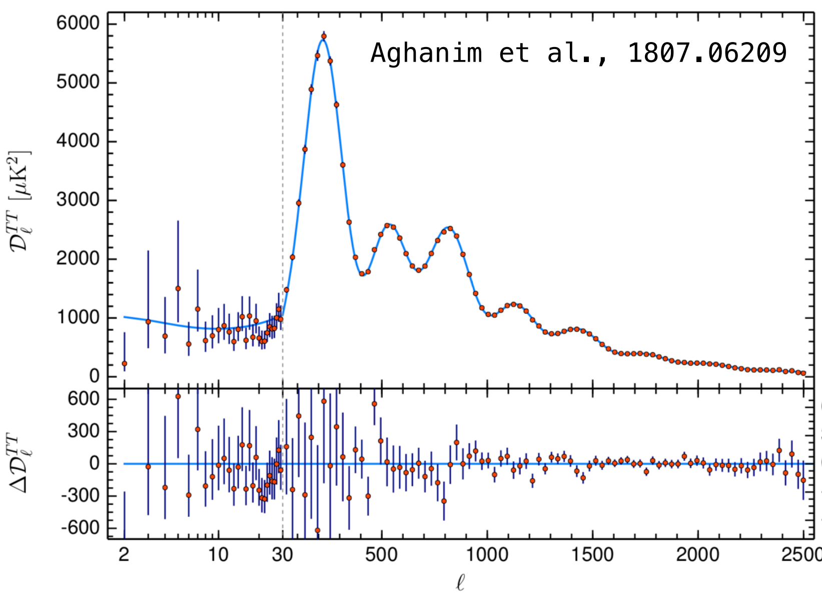
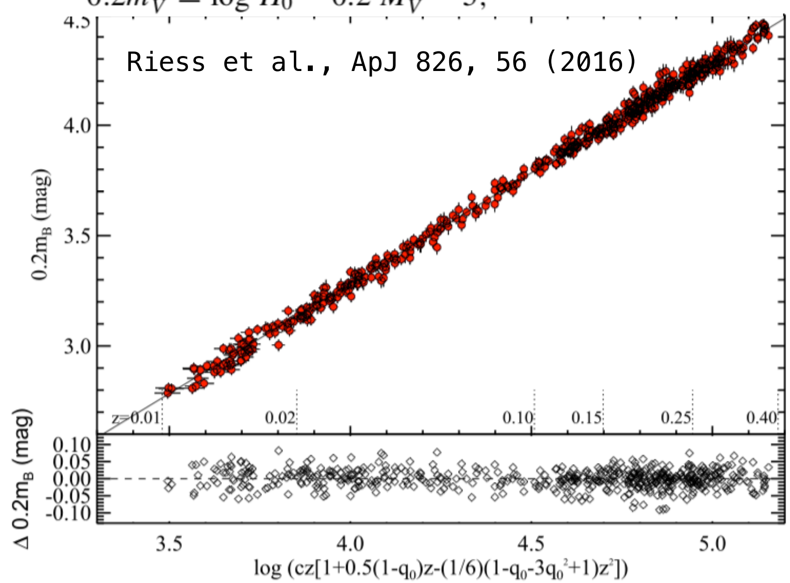


$$\{\Omega_b h^2, \Omega_m h^2, 100\theta_{MC}, \tau, n_s, \ln(10^{10} A_s)\}$$

$$\log cz \left\{1 + \frac{1}{2}\left[1 - q_0\right] z - \frac{1}{6}\left[1 - q_0 - 3q_0^2 + j_0\right] z^2 + O(z^3)\right\}$$

$$-0.2 m_V^0 = \log H_0 - 0.2\, M_V^0 - 5,$$

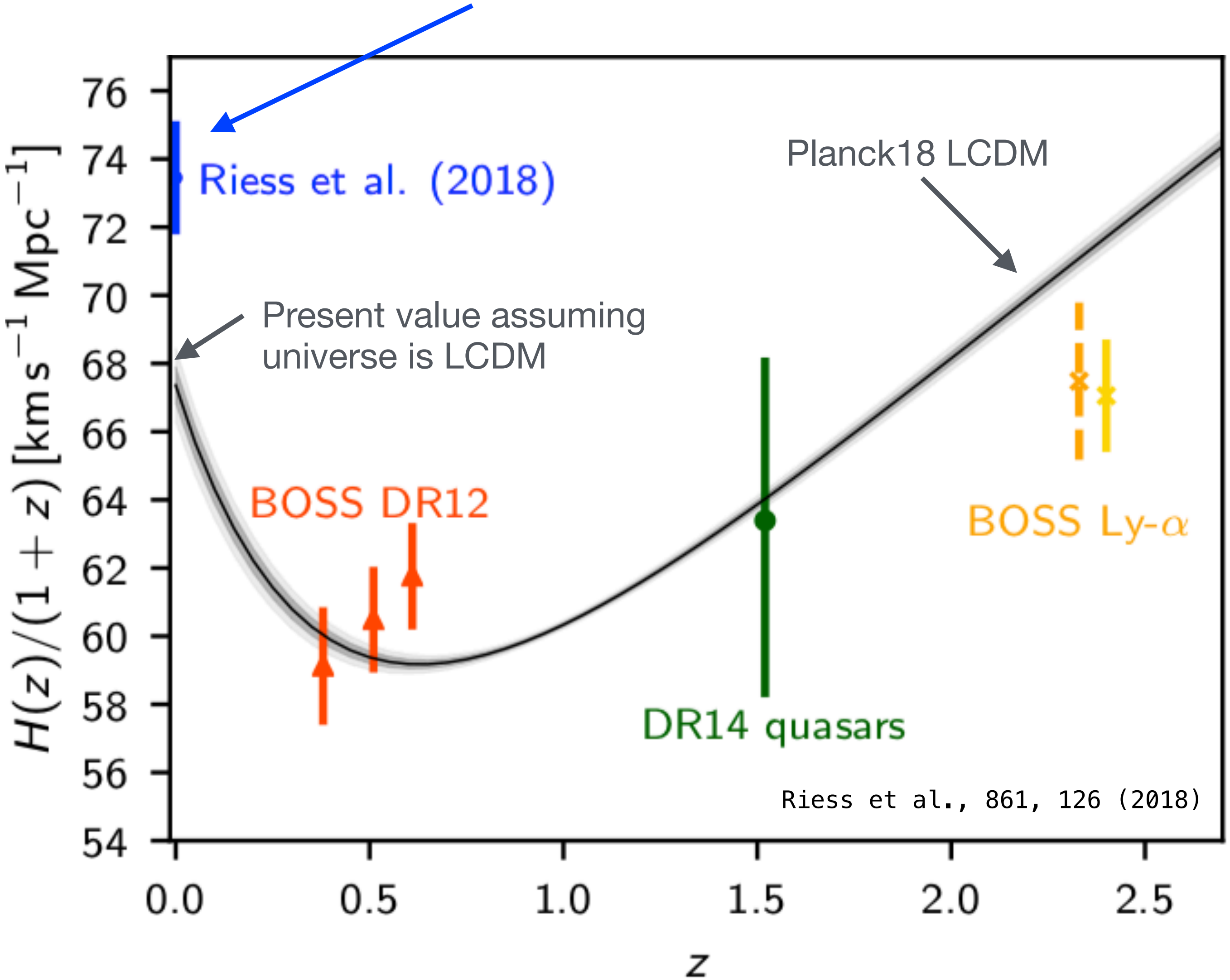




The Hubble parameter tension today

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

$$\frac{1}{a} \equiv 1 + z$$



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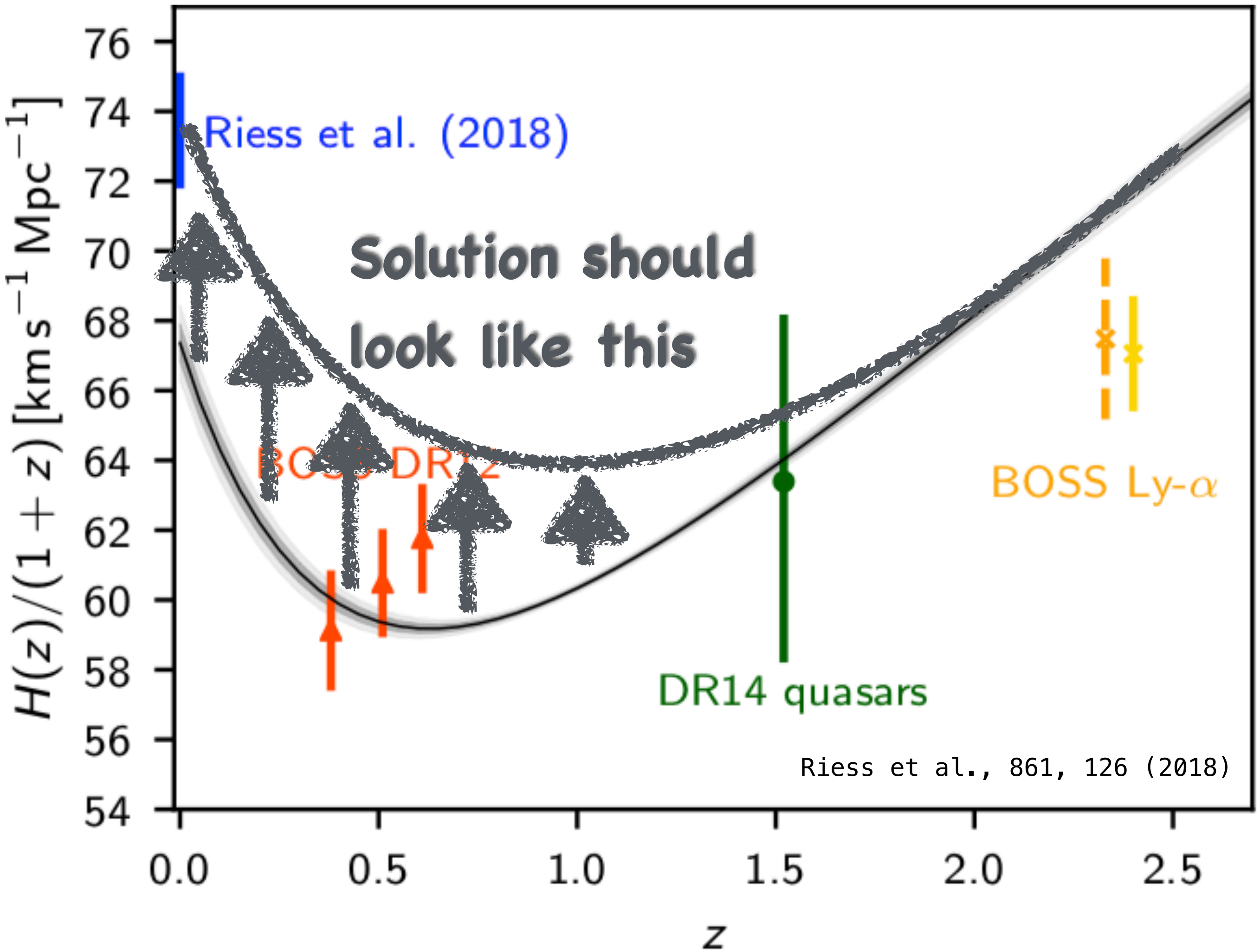
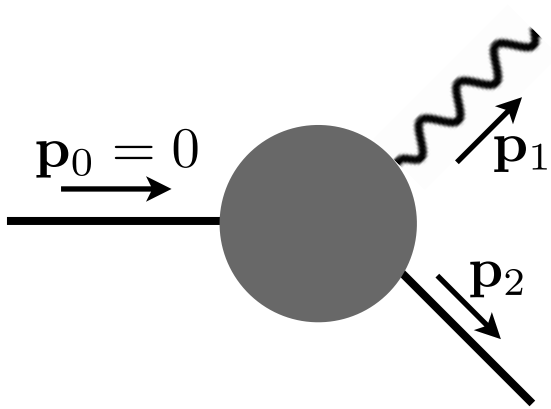


Two-body decays

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



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

$$\beta_2 \equiv v_2/c = \epsilon/(1-\epsilon)$$

$$\frac{d\rho_0}{dt} + 3\frac{\dot{a}}{a}\rho_0 = -\Gamma\rho_0, \qquad \frac{d\rho_1}{dt} + 4\frac{\dot{a}}{a}\rho_1 = \epsilon\Gamma\rho_0$$

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

Blackadder & Koushiappas PRD 90, 103527 (2014), PRD 023510 (2016)

Two-body decays

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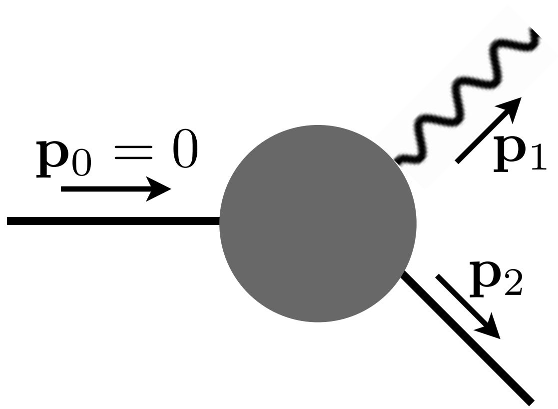
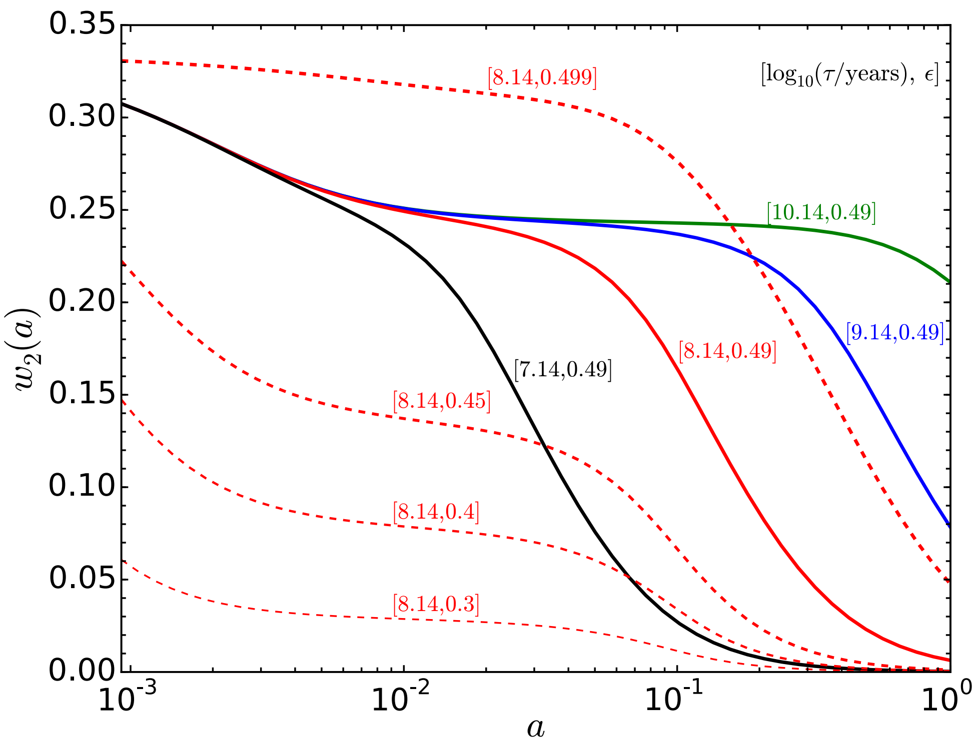


$$w_2(a) = \frac{1}{3}\langle v_2(a)^2 \rangle$$

Dynamical equation of state



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Two-body decays

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

$$\begin{aligned} \sum_i \rho_i(a) \;&=\; \rho_0(a) + \rho_1(a) + \rho_2(a) \\ &+\; \rho_r(a) + \rho_\nu(a) + \rho_b(a) + \rho_\Lambda \end{aligned}$$

$\{\Omega_m, \tau\}_{\rm fixed}$ $\quad \epsilon \uparrow \quad H(a=1) \downarrow$

$\{\Omega_m, \epsilon\}_{\rm fixed}$ $\quad \tau \downarrow \quad H(a=1) \downarrow$

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

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Major assumption:

The universe is correctly described by Planck18

at the epoch of recombination.

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

Two-body decays

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

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

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

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

$$0.5 \leq h \leq 1$$

Run these against:

- Distance ladder measurements
- BOSS DR 12, DR 14 quasar BAO
- SDSS Ly-alpha auto- and cross-correlation function

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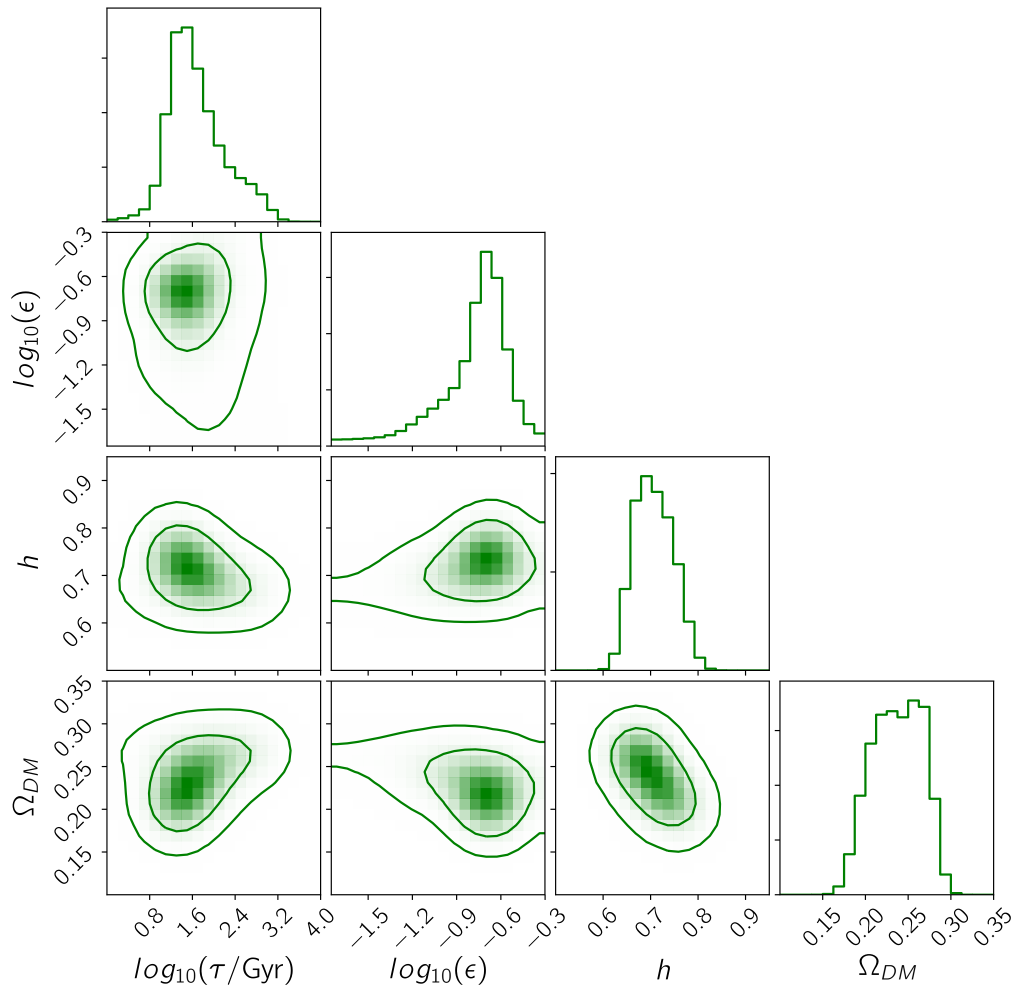

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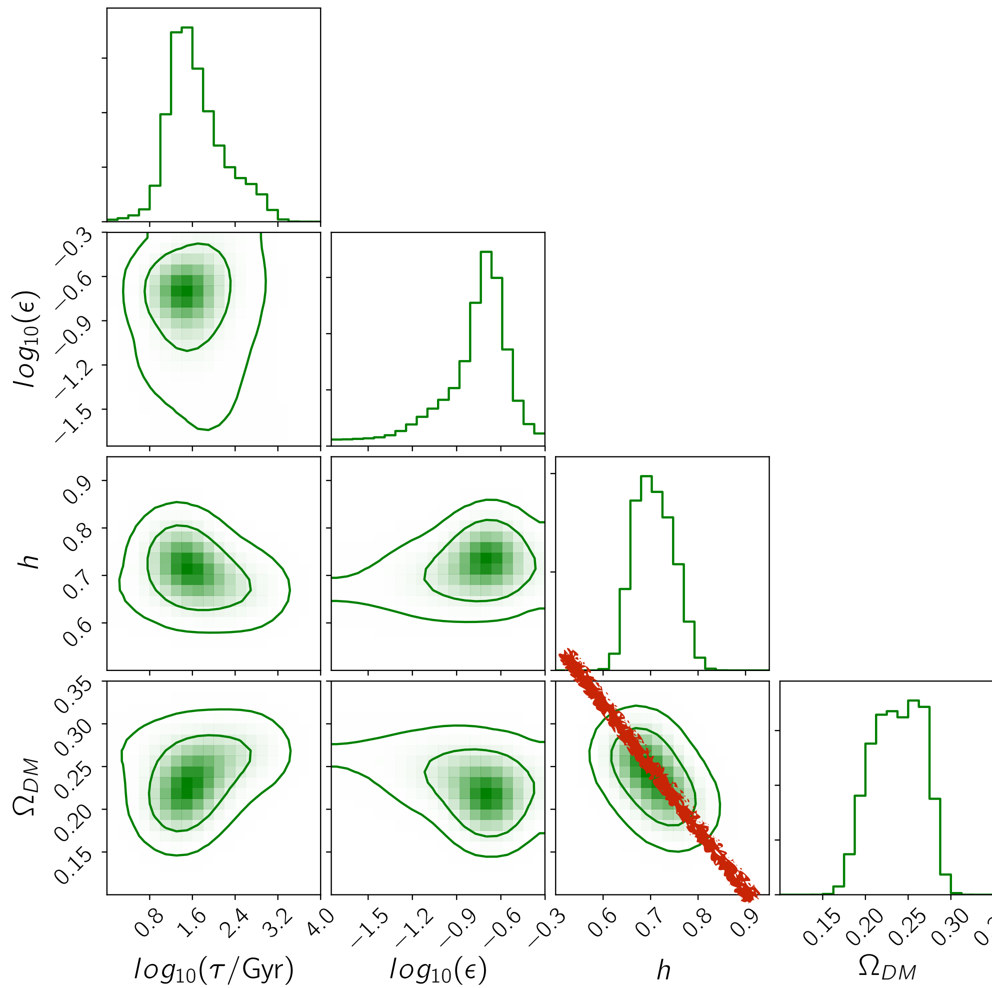

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Observation 1:

Increasing h requires the universe to expand faster at late times which means matter-dark energy equality must occur earlier — thus lowered value of matter density.

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

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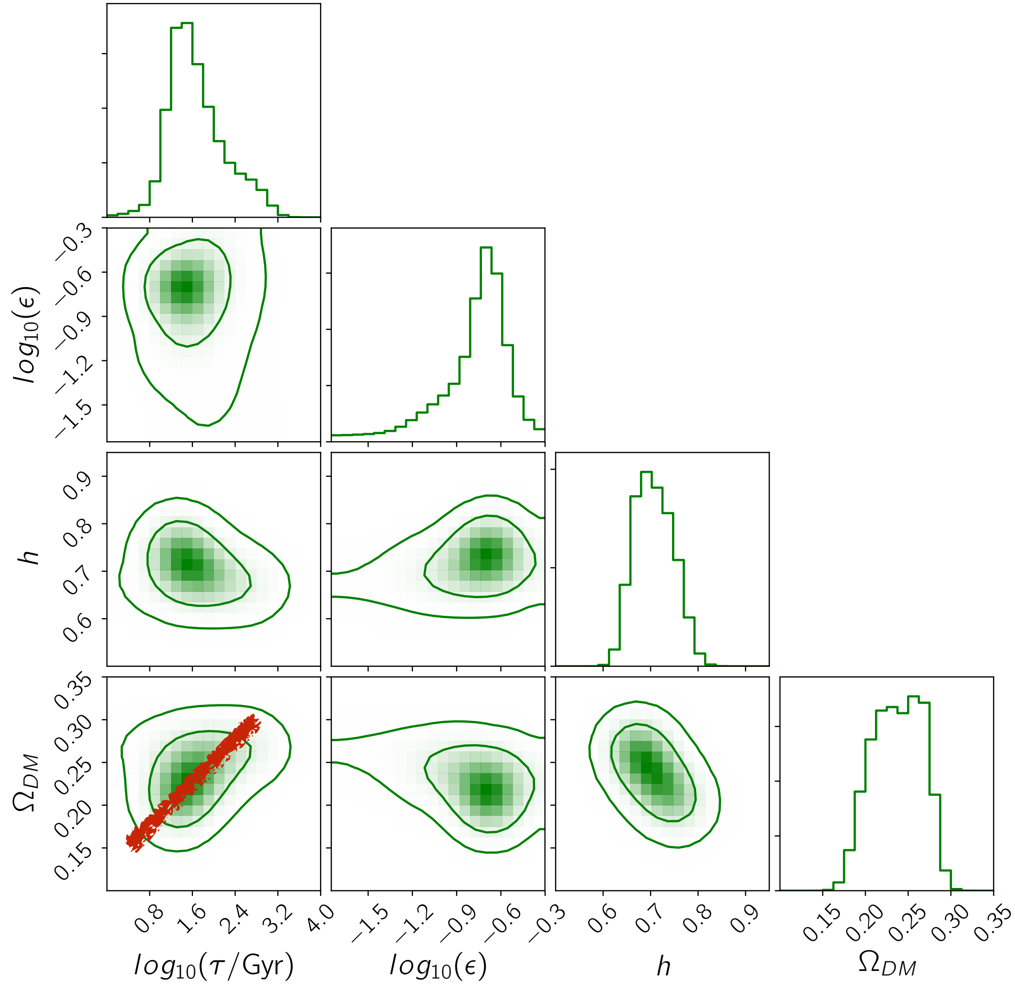

Observation 2:

Lowering lifetime requires less matter density for same reason (need to move matter-dark energy equality earlier).

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

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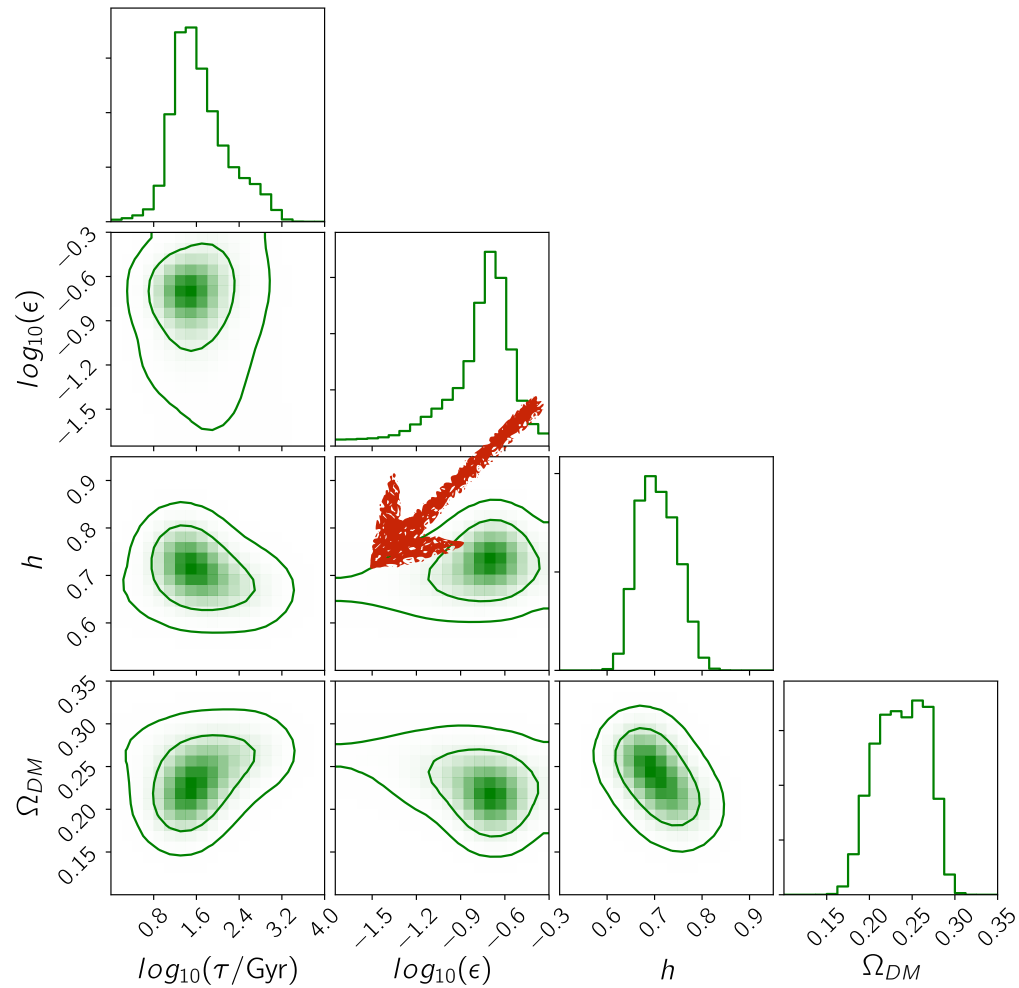

Run these against:

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- SDSS Ly-alpha auto- and cross-correlation function

Observation 3:

Not enough data — LCDM dominant as there is only one data point at late times.

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

Two-body decays

We *sample* these:

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

We *obtain* these:

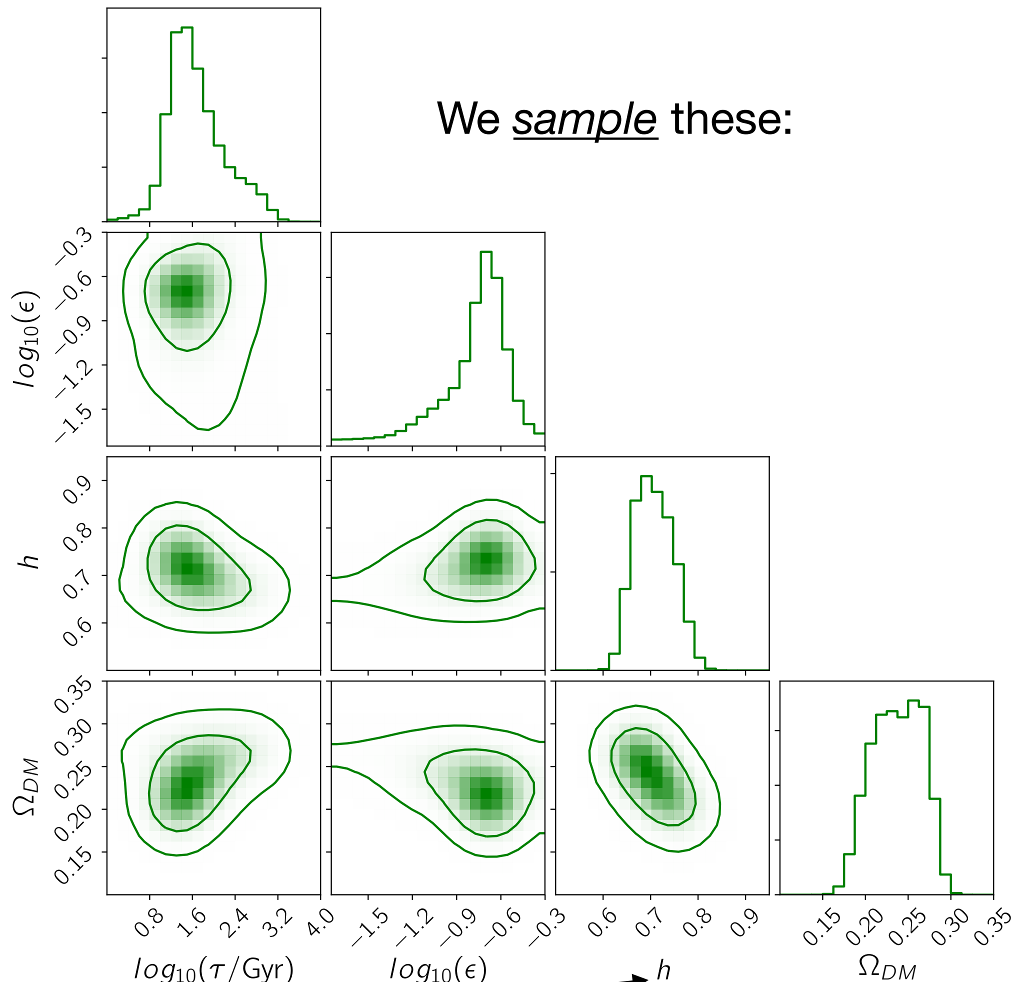
68% confidence intervals

$$\log_{10}\epsilon = -0.78^{+0.14}_{-2.10}$$

$$\log_{10}(\tau/{\rm Gyr}) = 1.55^{+0.63}_{-0.25}$$

$$\Omega_{\rm DM} = 0.24^{+0.03}_{-0.03}$$

$$h = 0.70^{+0.04}_{-0.03}$$



However this is the derived value while this is the sampled value

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)

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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))

However the preferred value of the lifetime may not correspond to the largest change in the value of H

`Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)`

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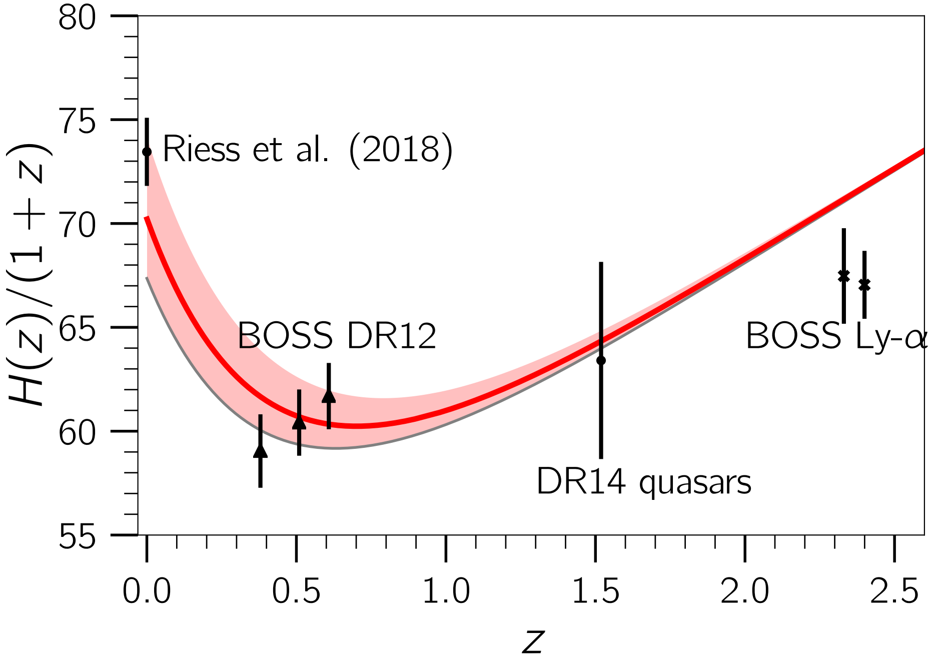

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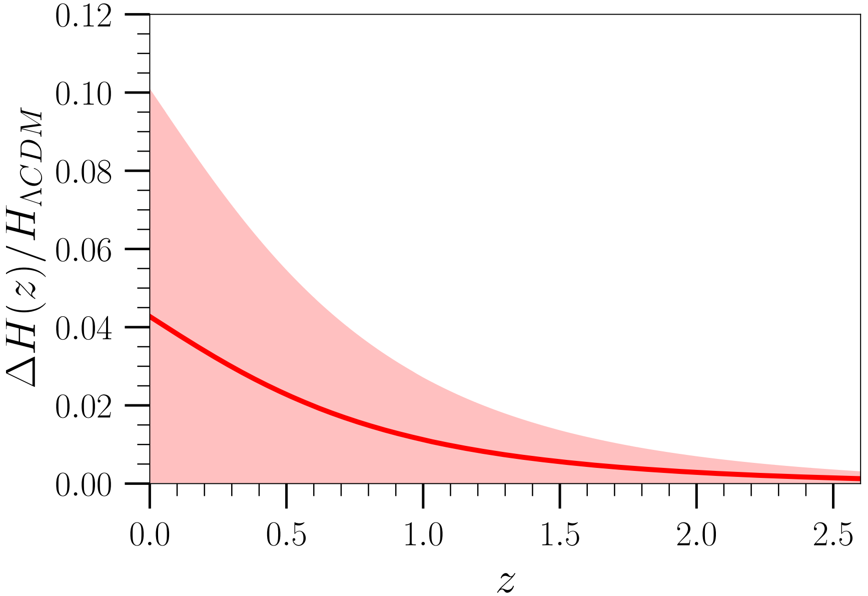

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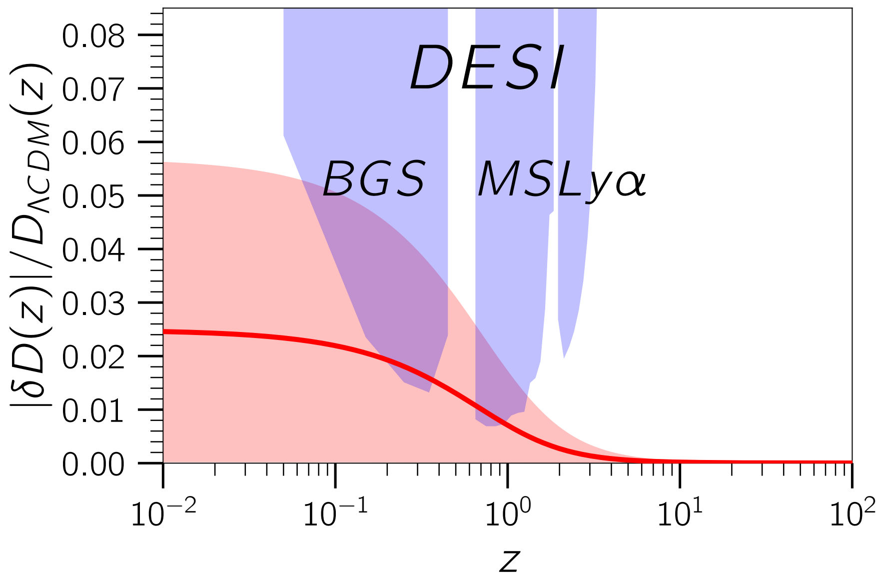
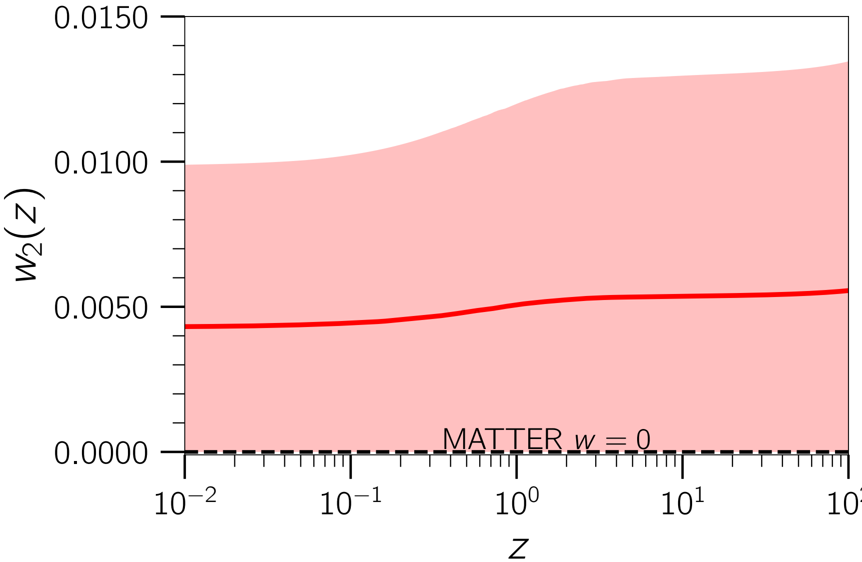


$$\frac{d^2 D}{da^2} + \left(\frac{d\ln H}{da} + \frac{3}{a}\right)\frac{dD}{da} - \frac{4\pi G\rho_m}{a^2} = 0$$



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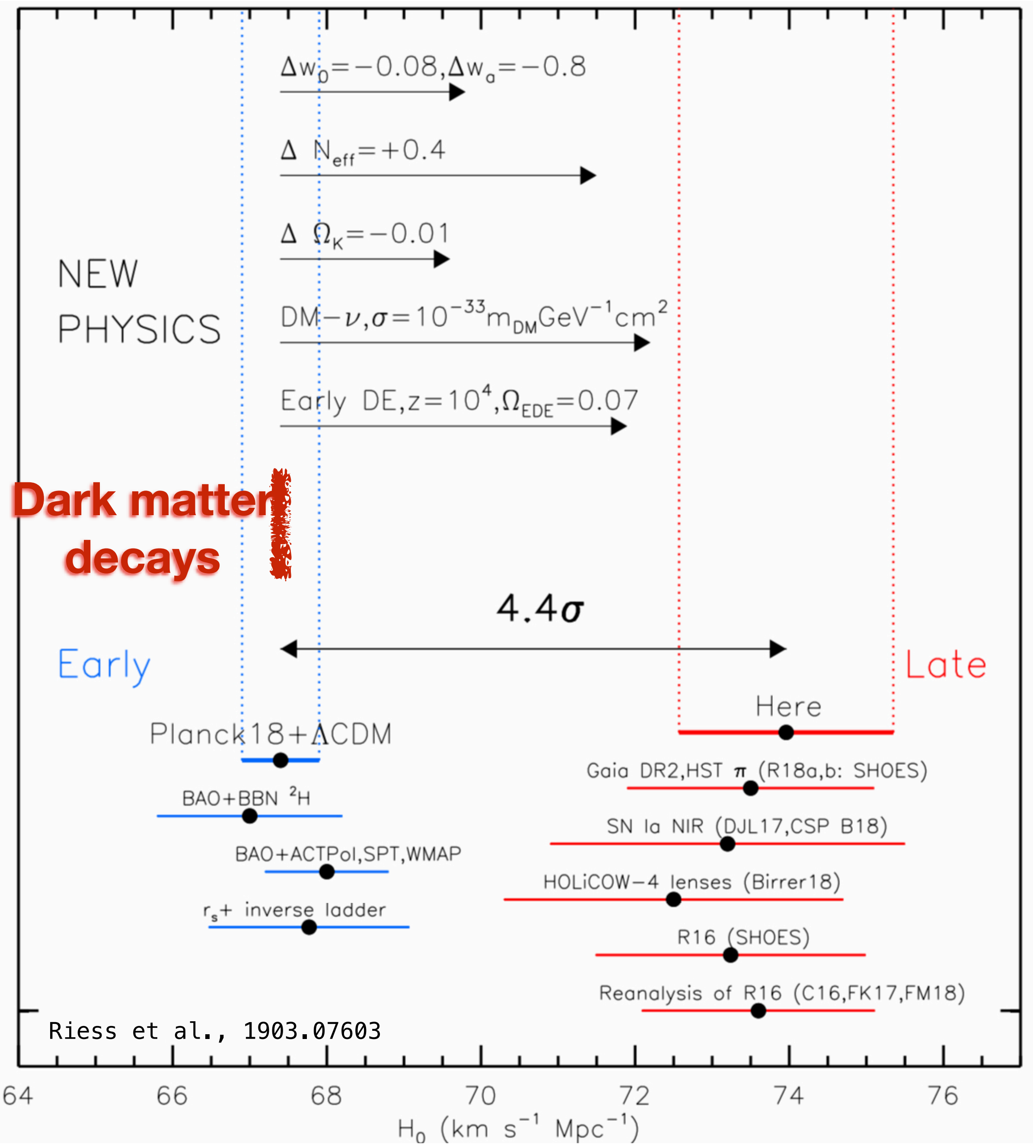

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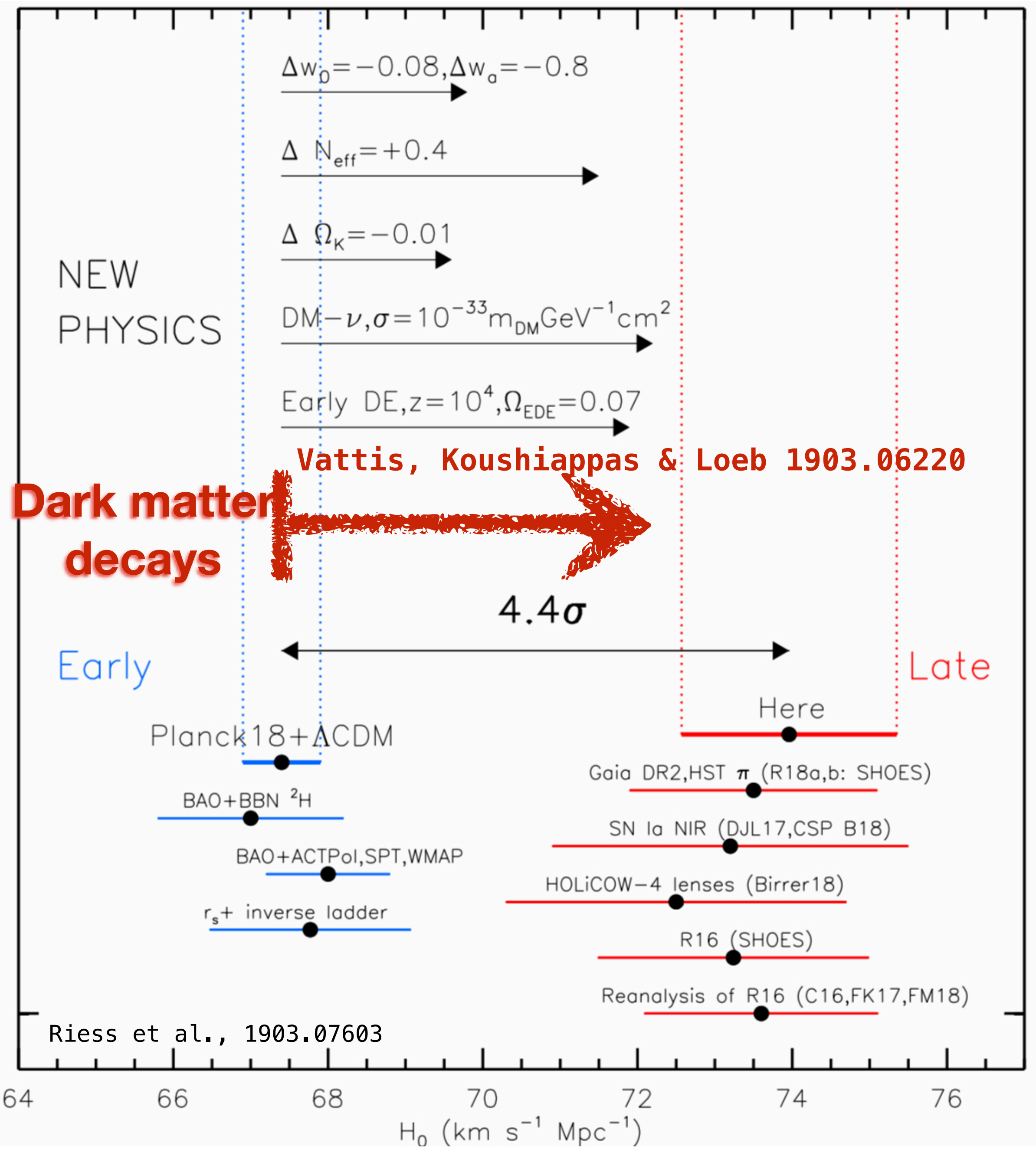
$\Delta\ N_{eff}=+0.4$
$\Delta\ \Omega_K=-0.01$
NEW PHYSICS
$DM-\nu, \sigma=10^{-33} m_{DM} GeV^{-1} cm^2$
Early $DE, z=10^4, \Omega_{EDE}=0.07$
Dark matter decays
4.4σ
Early
Late
Here
Planck18+ΛCDM
BAO+BBN ^2H
BAO+ACTPol,SPT,WMAP
r_s+ inverse ladder
Gaia DR2,HST π (R18a,b: SHOES)
SN Ia NIR (DJL17,CSP B18)
HOLiCOW−4 lenses (Birrer18)
R16 (SHOES)
Reanalysis of R16 (C16,FK17,FM18)
Riess et al., 1903.07603
64
66
68
70
72
74
76
$H_0\ (km\ s^{-1}\ Mpc^{-1})$



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Vattis, Koushiappas & Loeb 1903.06220
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H_0 (km s^{-1} Mpc^{-1})

And that is the conclusion