Dark matter decays and the Hubble tension

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Based on Vattis, Koushiappas & Loeb, arXiv:1903.06220 (PRD accepted)
A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

BY EDWIN HUBBLE

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Communicated January 17, 1929
where $a$ is the scale factor and we assume no decays occurred prior to the redshift of recombination $z_{\text{rec}}$.

It is possible for it to be cold dark matter could be present in the late universe different from the models considered in [34, 53] where the assumption was that dark matter decays only to radiation; thus previously derived constraints and conclusions are obtained from the initial conditions [46] as:

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

Riess et al., 1903.07603

4.4σ
The Hubble parameter tension today

A.Riess et al., arXiv:1903.07603

The CMB Power spectrum

\{ \Omega_b h^2, \Omega_m h^2, 100\theta_M, \tau, n_s, \ln(10^{10} A_s) \}
The Hubble parameter tension today

Riess et al., 1903.07603

4.4σ

Early
Planck18+ΔCDM
BAO+BBN 4H
BAO+ACTPol,SPT,WMAP
r*+ inverse ladder

Here
Gaia DR2,HST π (R18a,b: SHOES)
SN Ia NIR (D17L,CSP B18)
HOLICOW-4 lenses (Birrer18)
R16 (SHOES)
Reanalysis of R16 (C16,FK17,FM18)

Late

\{Ω_b h^2, Ω_m h^2, 100θ_M C, τ, n_s, ln(10^{10} A_s)\} ±

Aghanim et al., 1807.06209

\log cz \left\{ 1 + \frac{1}{2} [1 - q_0] z - \frac{1}{6} [1 - q_0 - 3 q_0^2 + j_0] 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

Local universe measurements

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

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

---

Present value assuming universe is LCDM

Riess et al. (2018)

BOSS DR12

DR14 quasars

Planck18 LCDM

BOSS Ly-α

Riess et al., 861, 126 (2018)
The Hubble parameter tension today

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

\[ \frac{1}{a} \equiv 1 + z \]
Two-body decays

\[ \psi \rightarrow \chi \gamma \]

\[ \mathbf{p}_0 = 0 \quad \mathbf{p}_1 \quad \mathbf{p}_2 \]

\[ \beta_2 \equiv \frac{v_2}{c} = \frac{\epsilon}{1 - \epsilon} \]

\[ \frac{d\rho_0}{dt} + 3\frac{\dot{a}}{a}\rho_0 = -\Gamma \rho_0, \quad \frac{d\rho_1}{dt} + 4\frac{\dot{a}}{a}\rho_1 = \epsilon \Gamma \rho_0. \]

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

\[ p_{\mu,0} = (m_0 c^2, 0), \]

\[ p_{\mu,1} = (\epsilon m_0 c^2, \mathbf{p}_1), \]

\[ p_{\mu,2} = ((1 - \epsilon)m_0 c^2, \mathbf{p}_2) \]
Two-body decays

\[ \psi \rightarrow \chi \gamma \]

\[ p_0 = 0 \]

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

Dynamical equation of state

\[ \log_{10}(\tau/\text{years}), \epsilon \]

\[ w_2(a) \]

\[ a \]

Blackadder & Koushiappas PRD 90, 103527 (2014), PRD 023510 (2016)
Two-body decays

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

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

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

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

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)
Two-body decays

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

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_{DM}, h\}

\[-4 \leq \log_{10} \epsilon < \log_{10} \frac{1}{2}\]

\[-3 \leq \log_{10} \tau \leq 4\]

\[0 \leq \Omega_{DM} \leq 1\]

\[0.5 \leq h \leq 1\]

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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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.
Two-body decays

\[ \{ \tau, \epsilon, \Omega_{DM}, h \} \]

\[-4 \leq \log_{10} \epsilon < \log_{10} \frac{1}{2} \]

\[-3 \leq \log_{10} \tau \leq 4 \]

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\[0.5 \leq h \leq 1\]

Run these against:
- Distance ladder measurements
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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)
Two-body decays

\[
\{ \tau, \epsilon, \Omega_{DM}, h \} \\
-4 \leq \log_{10} \epsilon < \log_{10} 1/2 \\
-3 \leq \log_{10} \tau \leq 4 \\
0 \leq \Omega_{DM} \leq 1 \\
0.5 \leq h \leq 1
\]

Run these against:
- Distance ladder measurements
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Observation 3:
Not enough data — LCDM dominant as there is only one data point at late times.

Vattis, Koushiappas & Loeb 1903.06220 (PRD accepted)
We sample these:

\[ \{ \tau, \epsilon, \Omega_{DM}, h \} \]

We obtain these:

68% confidence intervals

\[
\log_{10} \epsilon = -0.78^{+0.14}_{-2.10} \\
\log_{10}(\tau/\text{Gyr}) = 1.55^{+0.63}_{-0.25} \\
\Omega_{DM} = 0.24^{+0.03}_{-0.03} \\
h = 0.70^{+0.04}_{-0.03}
\]

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

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Two-body decays

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

\[
\frac{|\delta D(z)|}{D_{\text{CDM}}(z)}
\]

\[
\begin{array}{c}
\text{DESI} \\
\text{BGS} \\
\text{MSL} \text{y} \alpha
\end{array}
\]

\[
\frac{w_2(z)}{\text{MATTER } w = 0}
\]
Dark matter decays

NEW PHYSICS

\[ \Delta w_0 = -0.08, \Delta w_a = -0.8 \]

\[ \Delta N_{\text{eff}} = +0.4 \]

\[ \Delta \Omega_k = -0.01 \]

\[ \text{DM} - \nu, \sigma = 10^{-33} \text{m}_{\text{DM}} \text{GeV}^{-1} \text{cm}^2 \]

Early DE, \( z = 10^4, \Omega_{\text{DE}} = 0.07 \)

4.4\( \sigma \)

Planck18 + \( \Lambda \text{CDM} \)

BAO + BBN, \( ^2 \text{H} \)

BAO + ACTPol, SPT, WMAP

r_s + inverse ladder

Gaia DR2, HST \( \pi \) (R18a,b: SHOES)

SN Ia NIR (DJL17, CSP B18)

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Riess et al., 1903.07603

64 66 68 70 72 74 76

\( H_0 \) (km s\(^{-1}\) Mpc\(^{-1}\))
The Hubble tension

A. Riess et al., arXiv:1903.07603

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New Physics

Planck18+ΛCDM

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Early DE, \( z = 10^4, \Omega_{\text{DE}} = 0.07 \)

4.4σ

Late

Early

64 66 68 70 72 74 76

\( H_0 \) (km s\(^{-1}\) Mpc\(^{-1}\))

Riess et al., 1903.07603
And that is the conclusion.

Vattis, Koushiappas & Loeb 1903.06220

Dark matter decays

Riess et al., 1903.07603