A Step in Understanding the Hubble Tension

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arXiv: 2111.00014

H_0 Tension

- Local measurement: 73.2 ± 1.3 km/s/Mpc (Riess et al 2021)
  - Distance ladder w/ Type 1a SN & Cepheids

- Value from ΛCDM (fit to CMB): 67.4 ± 0.5 km/s/Mpc (Planck 2018)

~ 4σ tension

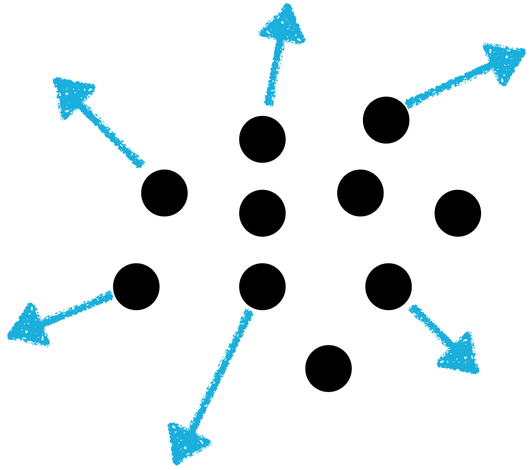
Simplest extension of ΛCDM - add extra radiation

$$\Delta N_{\rm eff} = \frac{\rho_{DR}}{\rho_{1\nu}}$$

ΛCDM : $N_{\rm eff} = 3.044$

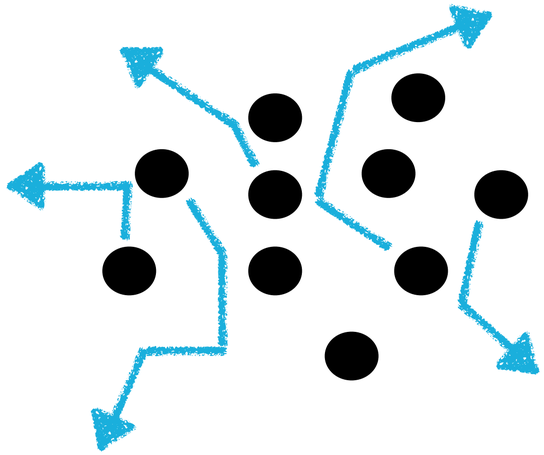
Radiation is dark

Free-streaming (no interactions) radiation

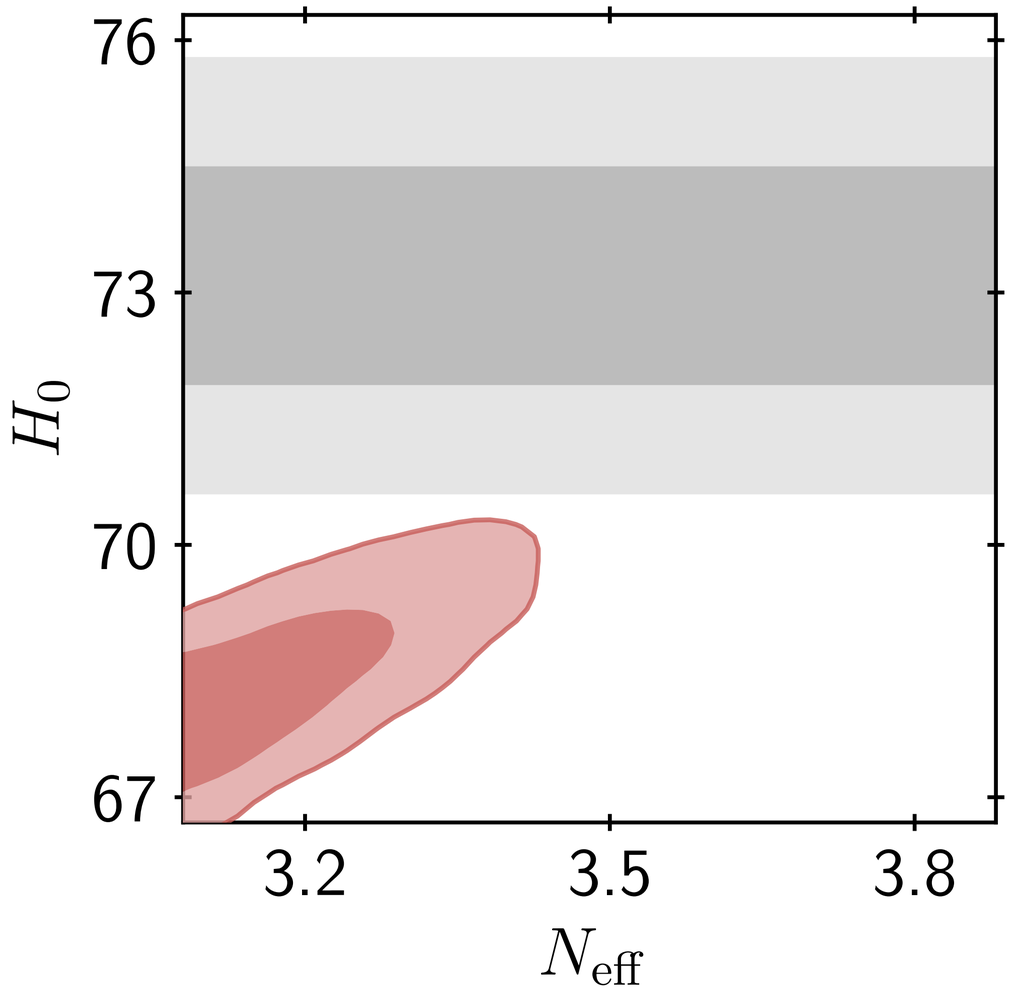


$$'c_s^2 = 1'$$

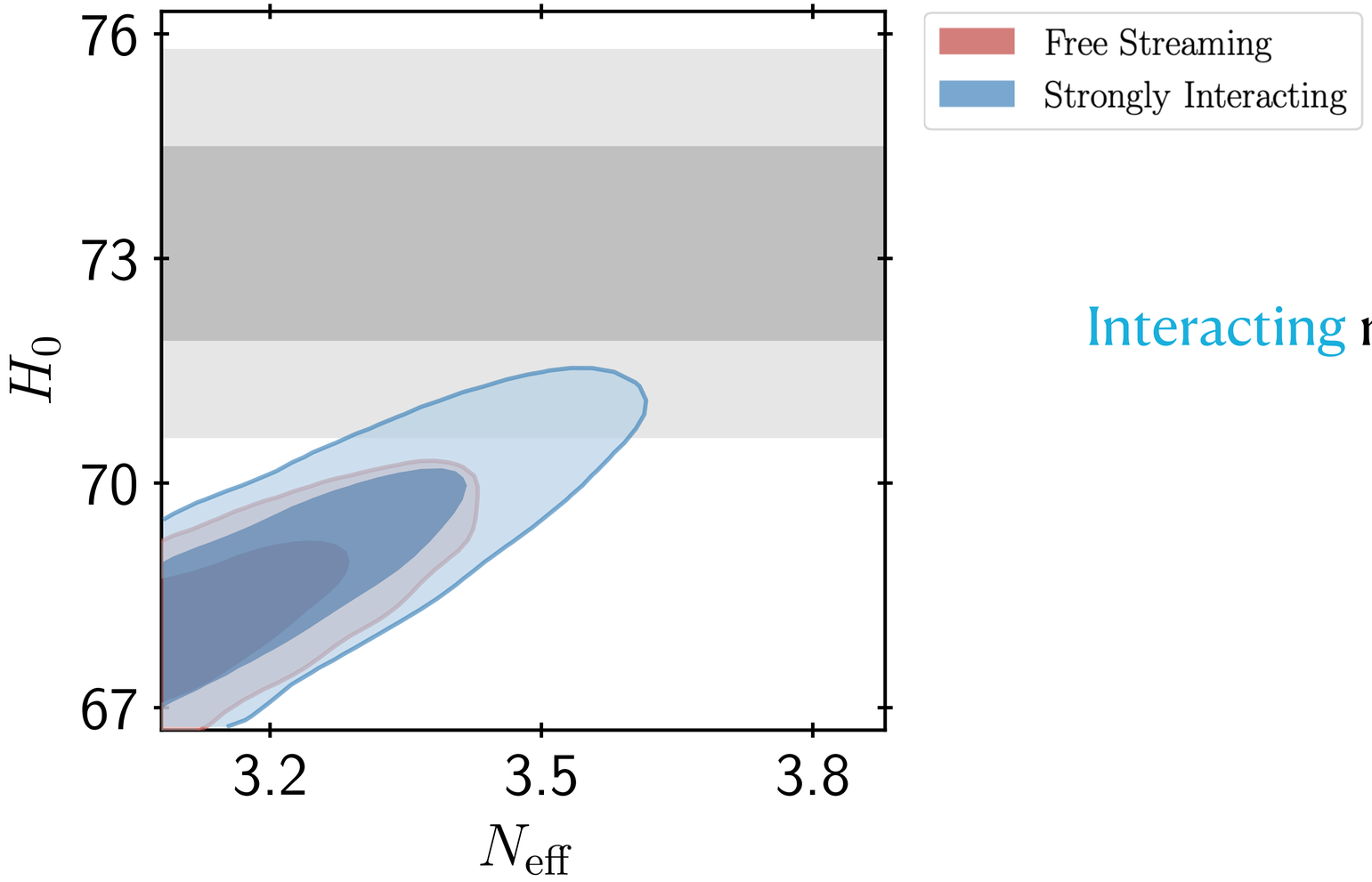
Strongly interacting radiation



$$c_s^2 = 1/3$$



Free-streaming radiation model is too constrained



Interacting radiation (SIDR) is better

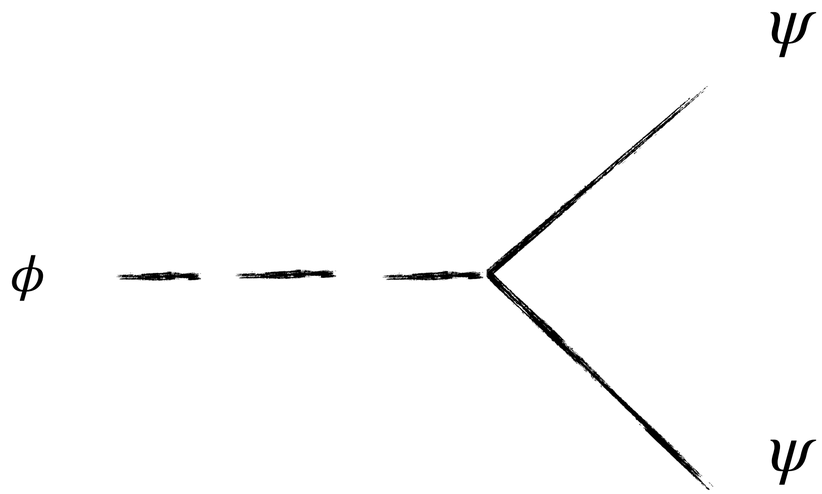
but still $> 3\sigma$

Consider a simple model with two particle species

Wess-Zumino Dark Radiation (WZDR)

Massive scalar - ϕ (~eV)

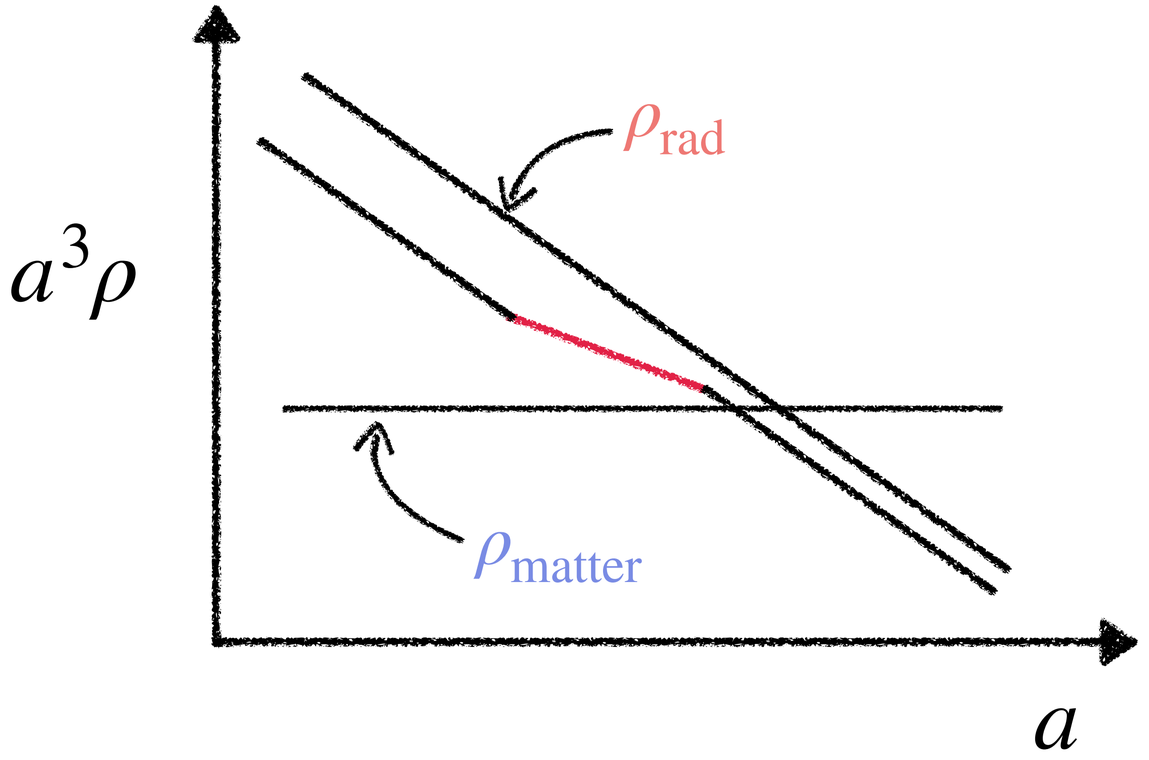
Massless fermion - ψ



What happens at the mass threshold?

Massive particles become non-relativistic and decay

A mix of relativistic ~ a^{-4} and non-relativistic ~ a^{-3} particles



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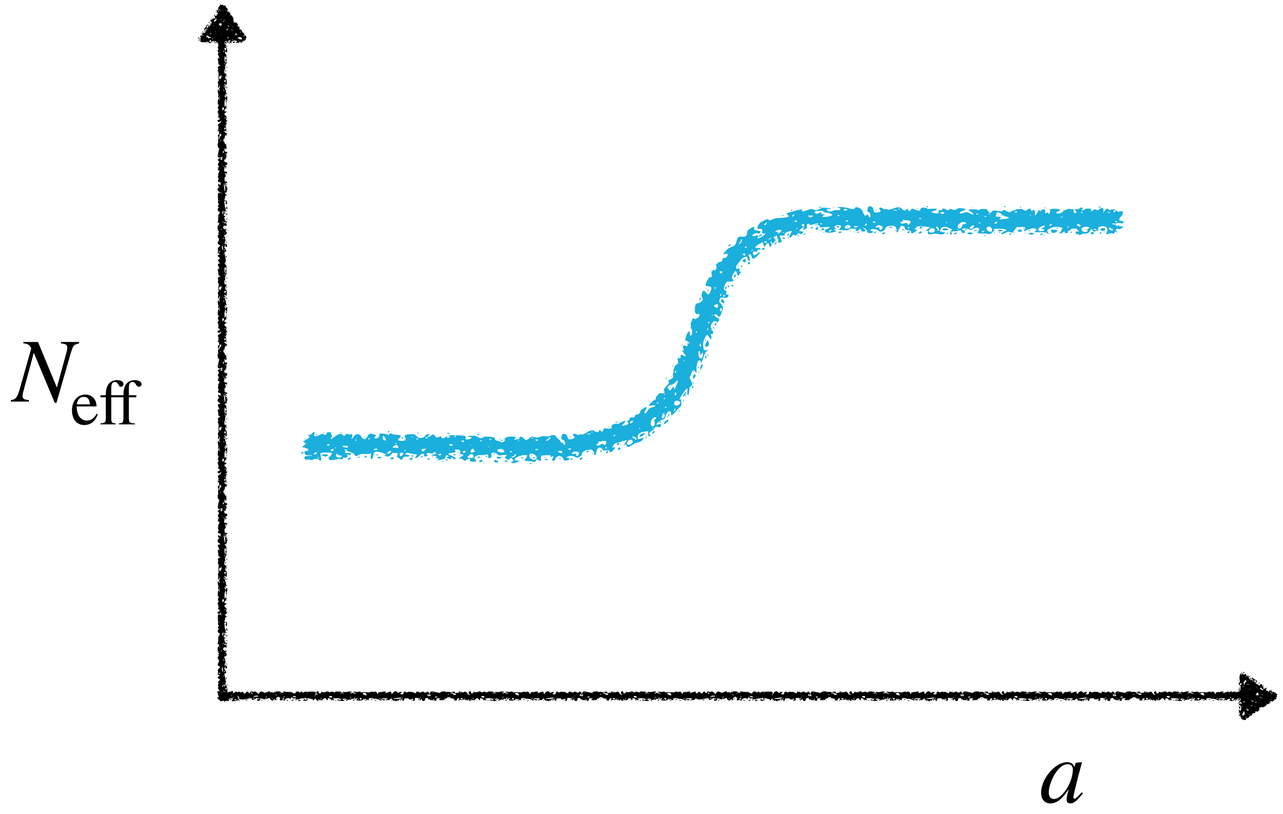

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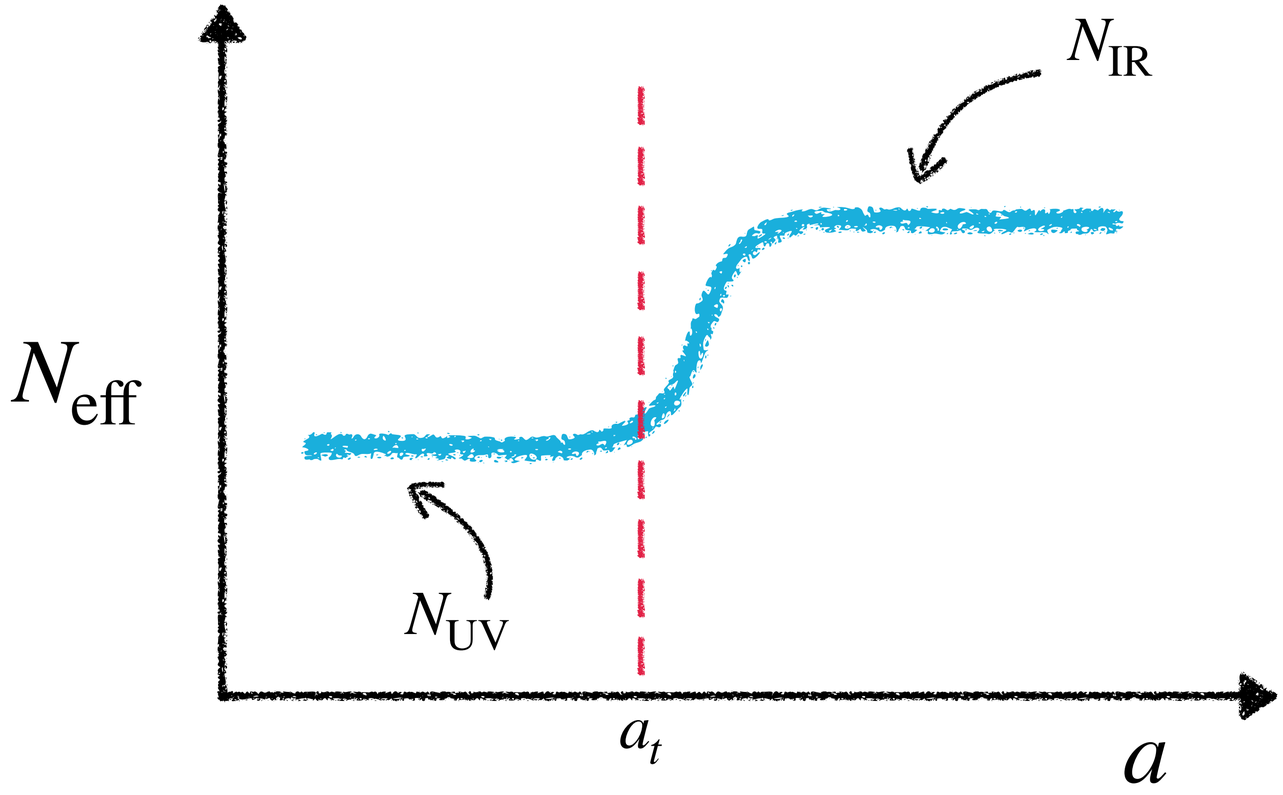

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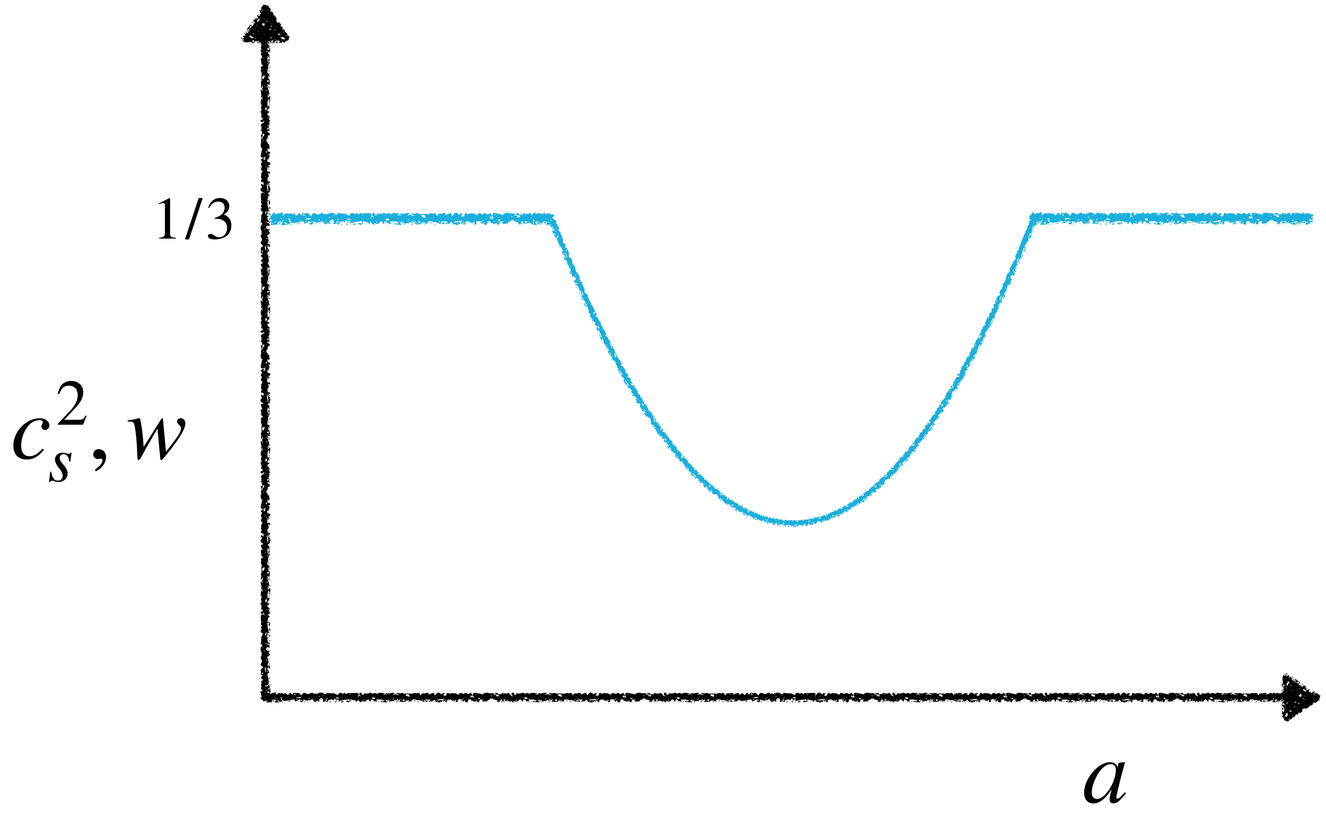
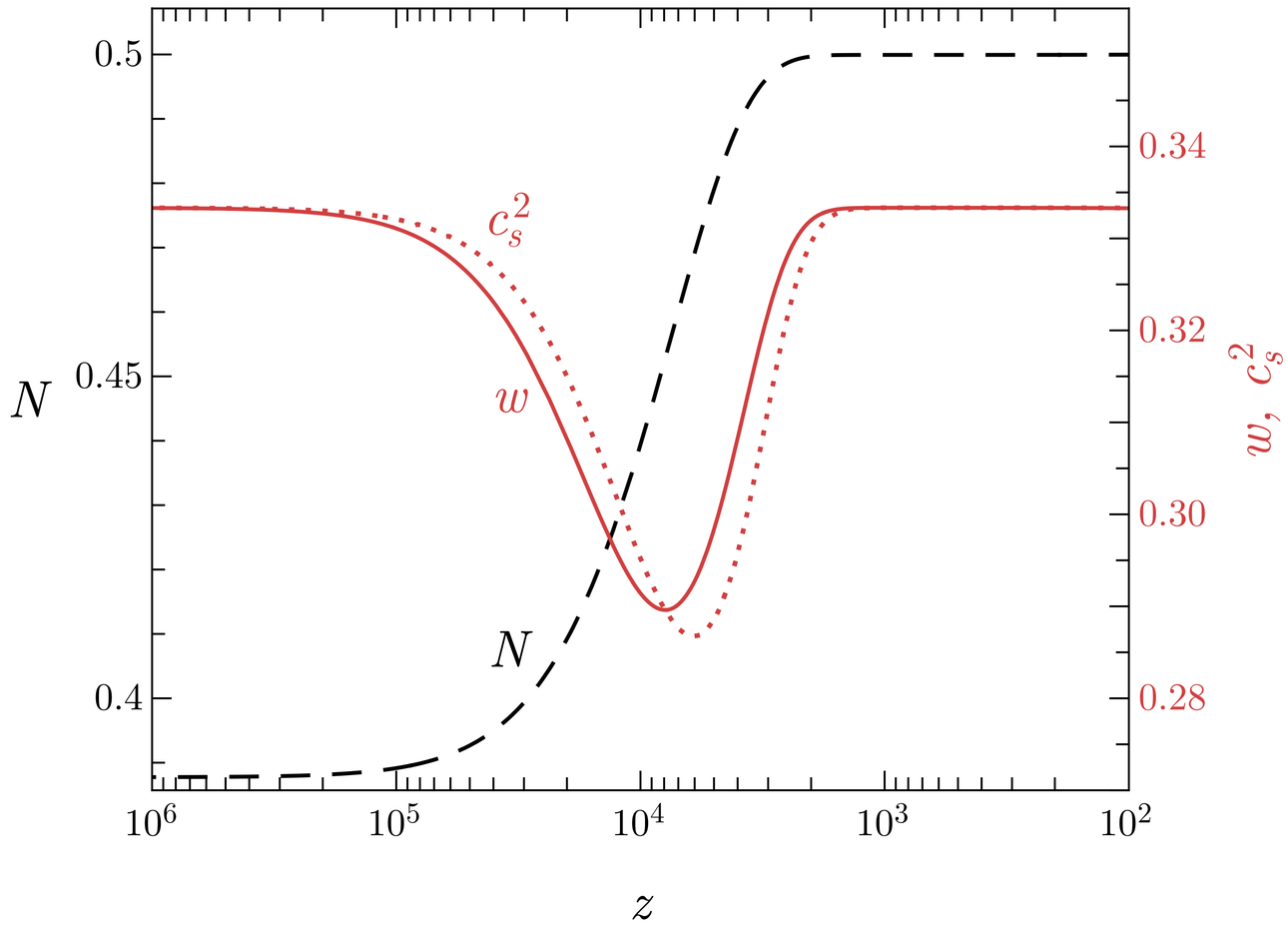


Entropy Conservation:

$$S = a^3 \frac{\rho(T) + P(T)}{T} = \text{constant}$$

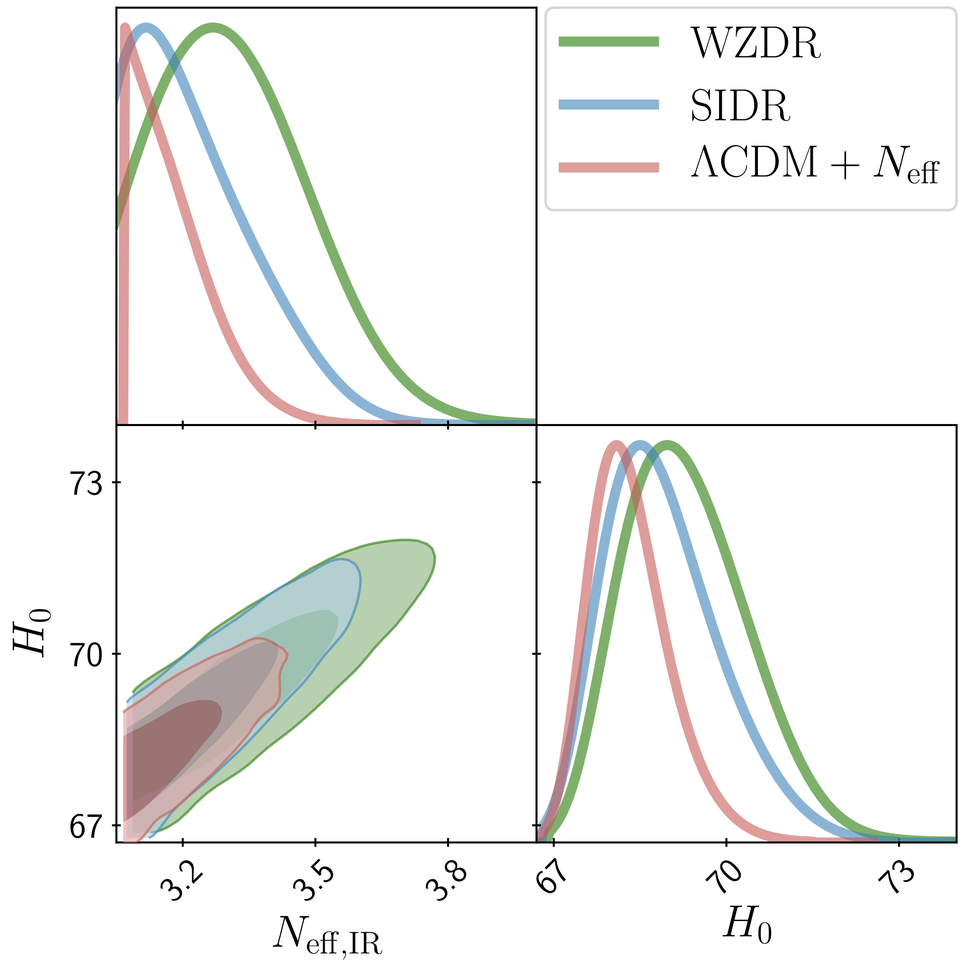


Data

$\mathscr{D}$ - Planck 2018 TT, EE, TE and Lensing, BAO(6dF, MGS, BOSS DR12), Pantheon

$\mathscr{D}+$ - Planck 2018 TT, EE, TE and Lensing, BAO(6dF, MGS, BOSS DR12), Pantheon, SHOES

Results



Model	Tension	$\Delta\chi^2$
ΛCDM + $N_{\rm eff}$	$3.7\,\sigma$	-5.7
SIDR	$3.1\,\sigma$	-10.6
WZDR	$2.7\,\sigma$	-15.1

The H_0 Olympics: A fair ranking of proposed models [Schöneberg *et.al.* 2107.10291]

Summary

- Simplest extensions of ΛCDM include adding extra radiation
- If the radiation is interacting: a simple model includes a massive particle (WZDR)
- WZDR does well in external metrics comparing solutions to the Hubble tension
- Next: Natural extensions include interactions with the dark matter