Cosmological effects of DM-γ scattering

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ΛCDM is very successful, explaining observations over a wide range of scales. It assumes DM is completely **collisionless** and has **zero velocity**. However, one can ask...

C-**Dark**-M
But how dark?
- Self interacting DM
- DM-γ scattering (in the linear regime)
- DM-ν scattering
- DM-baryon scattering
- DM-DR scattering
- ...

Cold-DM
But how cold?
- Ultralight dark matter
- Warm dark matter
- ...

Interacting DM is automatically warmer.

[Bœhm et al. (2001, 2004)]

DM-γ scattering rate:

$$u_{\gamma\rm DM} = \frac{\sigma_{\gamma\rm DM}}{\sigma_{\rm Th}} \left(\frac{m_{\gamma\rm DM}}{100\,\rm GeV}\right)^{-1} \quad\Rightarrow\quad \dot\mu = a\, n_{\gamma\rm DM}\, \sigma_{\gamma\rm DM} \propto u_{\gamma\rm DM}\, \rho_{\gamma\rm DM}$$

Modified Boltzmann Equations:

$$\dot\theta_{\gamma\rm DM} = k^2\psi - \mathcal{H}\theta_{\gamma\rm DM} + c^2_{\gamma\rm DM}k^2\delta_{\gamma\rm DM} - \frac{4\rho_\gamma}{3\rho_{\gamma\rm DM}}\dot\mu\,(\theta_{\gamma\rm DM}-\theta_\gamma)$$

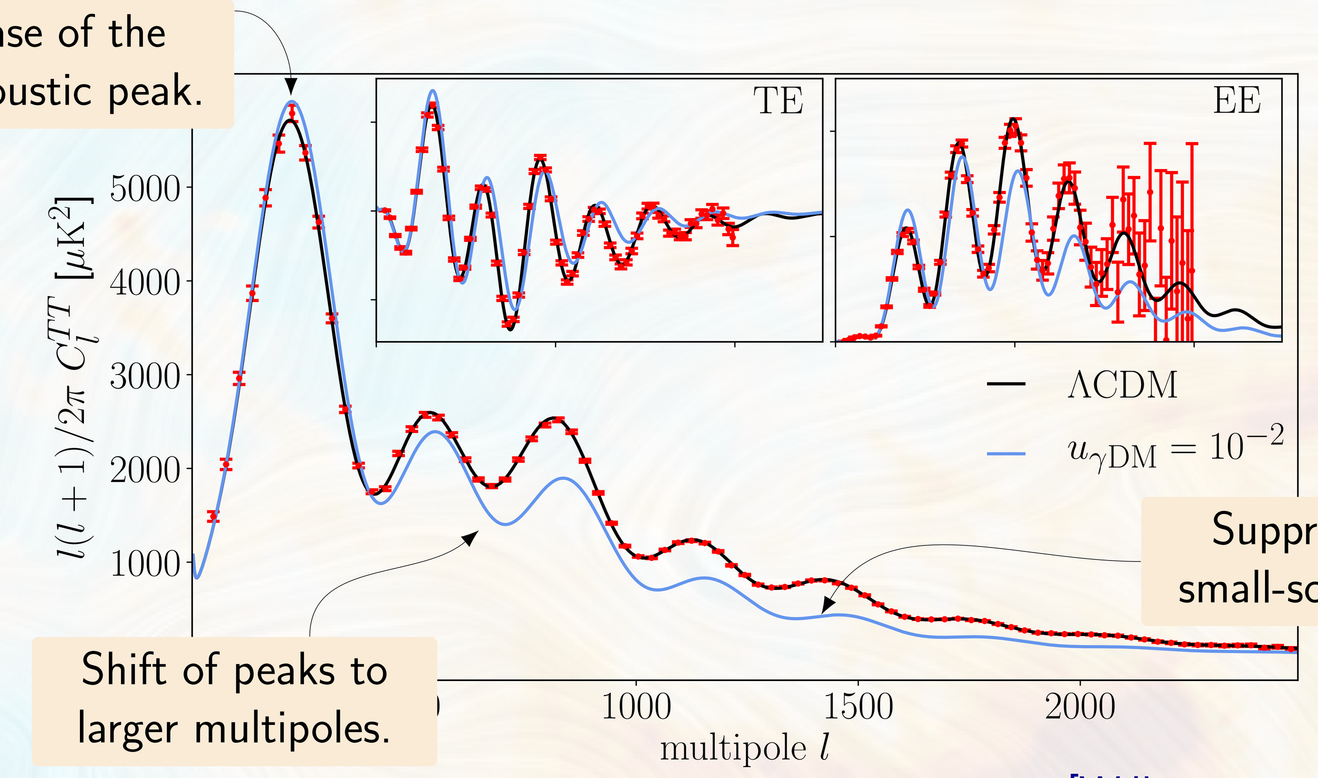
$$\dot\theta_\gamma = k^2\psi + k^2\left(\frac{1}{4}\delta_\gamma - \sigma_\gamma\right) + \dot\kappa\,(\theta_b - \theta_\gamma) + \dot\mu\,(\theta_{\gamma\rm DM} - \theta_\gamma)$$

$+$ for higher order photon multipoles : $\dot\kappa \to (\dot\kappa + \dot\mu)$

Improvements in this work

- Accurate treatment of the tight coupling regime.
- Parameter constraints including Planck polarization data.
- Inclusion of the dark matter sound speed.
- Extension to multicomponent DM ("mixed DM").

Effects of γ-DM scattering on the CMB spectrum



[Wilkinson et al. (2014)]

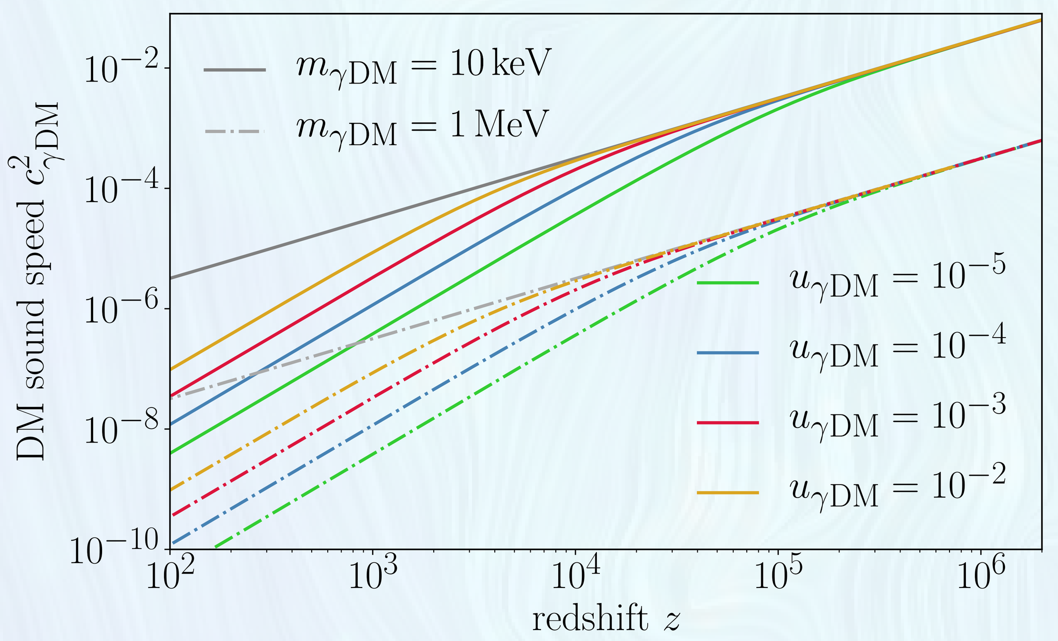
DM sound speed (arXiv[1802.0658])

At early times DM-γ scattering maintains kinetic equilibrium between the two species. Consequently, the DM temperature is larger, and the sound speed can become important.

$$c^2_{\gamma\rm DM} = \frac{k_{\rm B}T_{\gamma\rm DM}}{m_{\gamma\rm DM}}\left[1 - \frac{1}{3}\frac{\partial \ln T_{\gamma\rm DM}}{\partial \ln a}\right]$$

$$\dot T_{\gamma\rm DM} = -2\mathcal{H}T_{\gamma\rm DM} + \frac{8\rho_\gamma}{3\rho_{\gamma\rm DM}}\dot\mu\,(T_\gamma - T_{\gamma\rm DM})$$

$m_{\gamma\rm DM}$ mostly determines the size of the sound speed. $u_{\gamma\rm DM}$ sets the time of decoupling and has a subdominant impact.



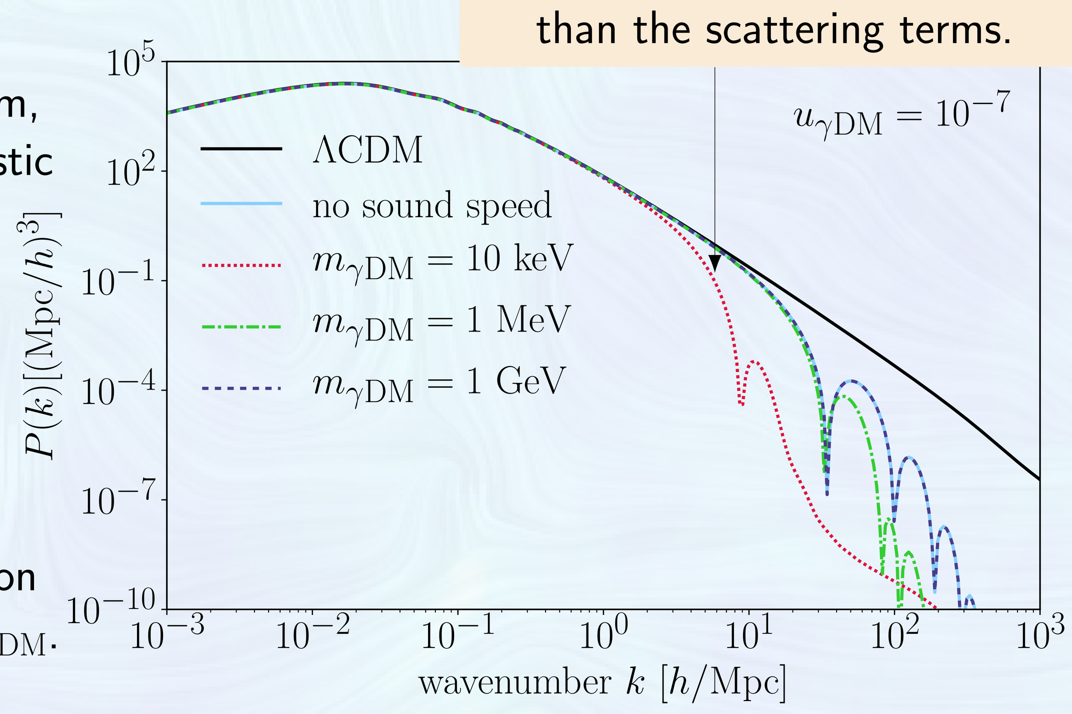
For $m_{\gamma\rm DM} \gtrsim 10\,\rm keV$ the DM sound speed has a negligible effect on the CMB spectra.

For small DM masses $c^2_{\gamma\rm DM}$ can have a more significant effect on the matter power spectrum than the scattering terms.

There are two damping mechanism, each associated with a characteristic scale of suppression:

- collision terms $\to$ suppression scale entirely set by $u_{\gamma\rm DM}$
- sound speed $\to$ suppression scale mostly set by $m_{\gamma\rm DM}$

Which effect dominates depends on the combination of $u_{\gamma\rm DM}$ and $m_{\gamma\rm DM}$.



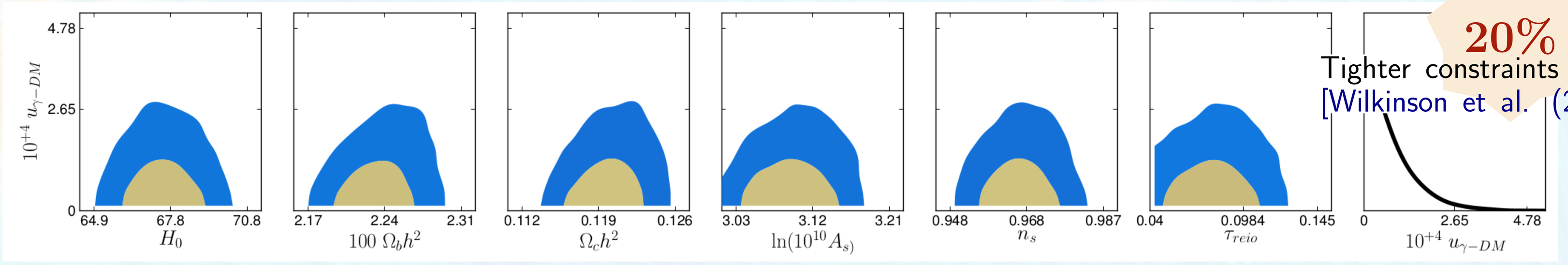
Constraints from Planck (arXiv[1802.0658])

We analyse the Planck 2015 temperature & polarization data to obtain limits on $u_{\gamma\rm DM}$:

- Computation of CMB spectra with CLASS [Blas, Lesgourgues, Tram (2011)]
- MCMC sampling with MontePython [Audren, Lesgourgues et al. (2012)]
- Parameter Space:

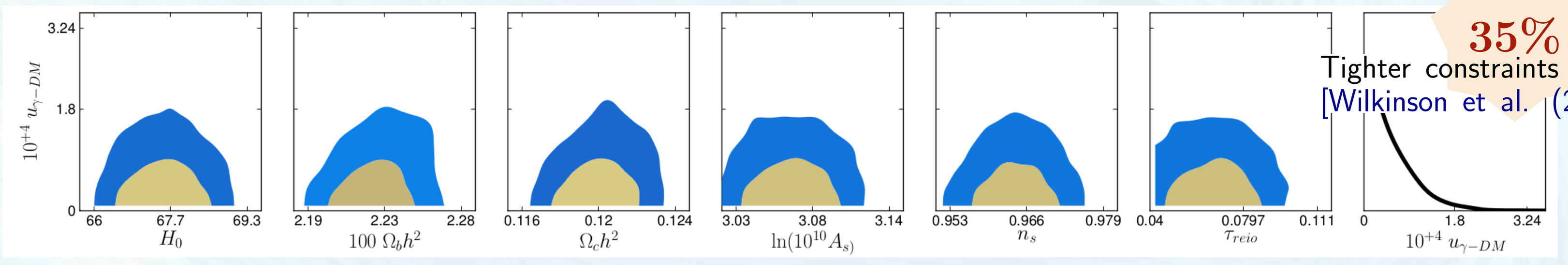
$$H_0 \,|\, \Omega_b h^2 \,|\, \Omega_{\rm DM}h^2 \,|\, \ln(10^{10}A_s) \,|\, n_s \,|\, \tau_{\rm reio} \,|\, u_{\gamma\rm DM}$$

"Planck TT + lowTEB": $\sigma_{\gamma\rm DM} < 1.5 \times (m_{\gamma\rm DM}/\rm GeV)\ \rm fm^2$



20% Tighter constraints than [Wilkinson et al. (2014)]

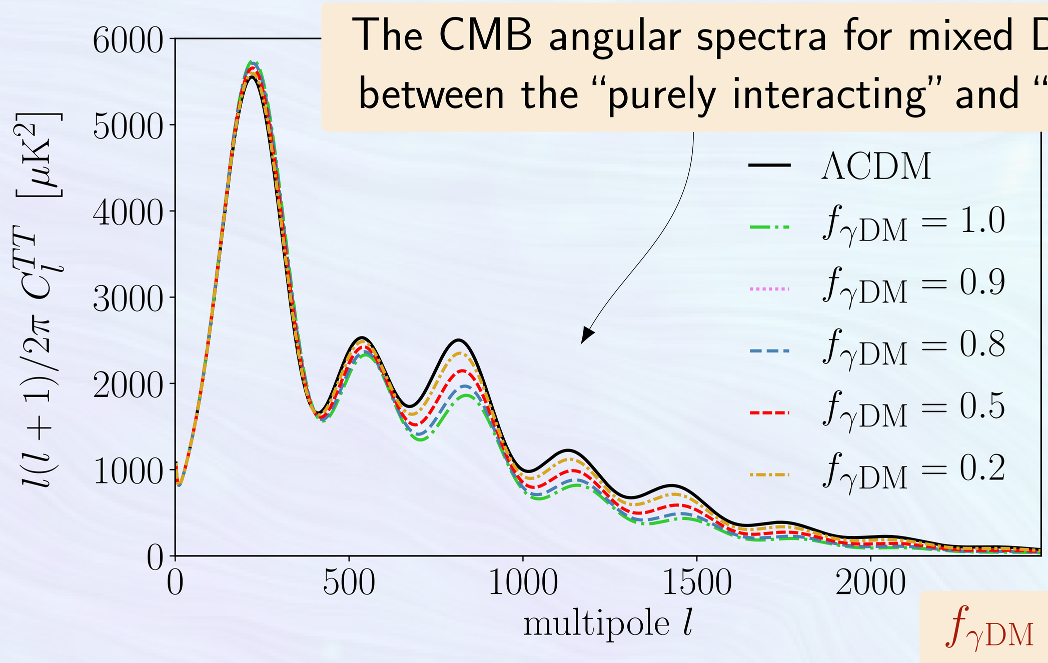
"Planck TTTEEE + lowTEB + lensing": $\sigma_{\gamma\rm DM} < 1.0 \times (m_{\gamma\rm DM}/\rm GeV)\ \rm fm^2$



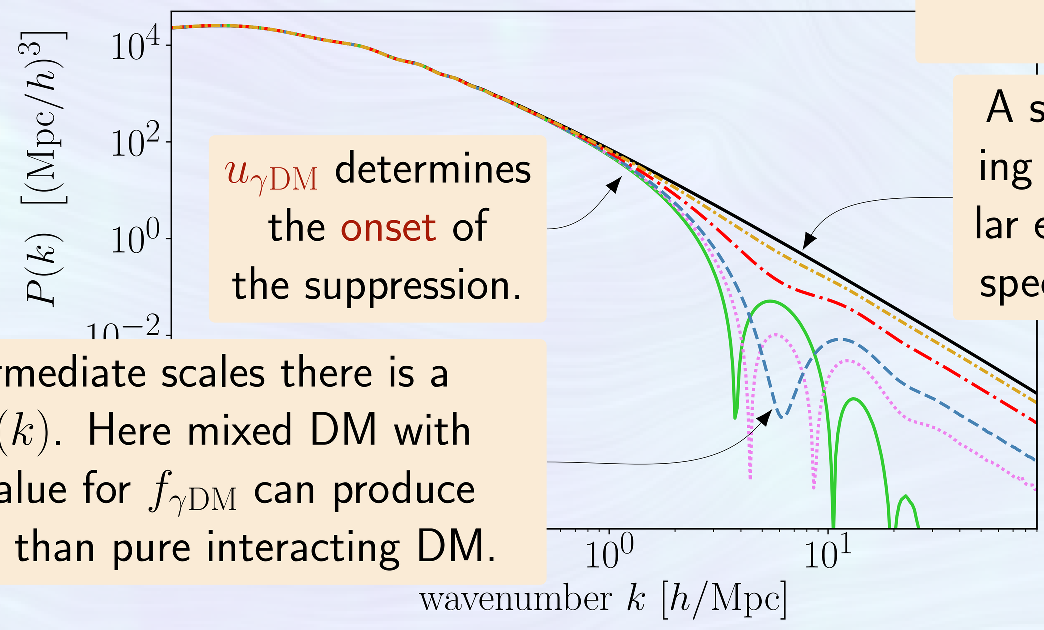
35% Tighter constraints than [Wilkinson et al. (2014)]

Mixed Dark Matter (arXiv[1807.10034])

There are two components of dark matter: on scatters elastically off photons (γDM), the other one is collisionles. The fraction of interacting DM is $f_{\gamma\rm DM} = \Omega_{\gamma\rm DM}/(\Omega_{\gamma\rm DM} + \Omega_{\rm CDM})$.



$f_{\gamma\rm DM}$ determines the magnitude of the suppression.



A small fractions of interacting DM can have a very similar effect on the matter power spectrum as neutrino masses.

At intermediate scales there is a dip in $P(k)$. Here mixed DM with a large value for $f_{\gamma\rm DM}$ can produce less power than pure interacting DM.

Neglecting $c^2_{\gamma\rm DM}$, i.e. assuming a heavy DM particle.