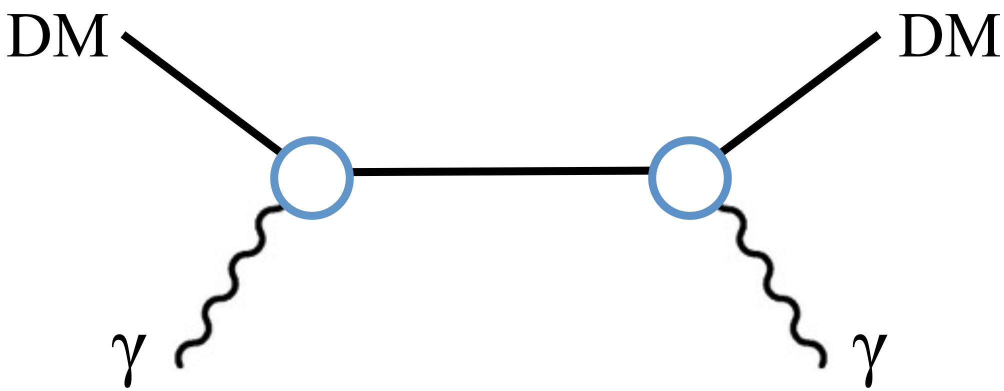
Using CMB data to study Dark Matter-Photon Interactions



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Motivation

- We don't yet know the nature of DM.
- Detection methods generally assume:
  - Late-time annihilations in our galaxy
  - Interactions with quarks

  } not always appropriate!
- DM-SM interactions dampen matter fluctuations, erasing all structure smaller than the *induced damping* scale:

$$l_{id} \sim \pi \left(\frac{H}{\Gamma_i} \right)^{1/2} \left. \frac{v_i t}{a} \right|_{dec(DM-i)}$$

Largest for relativistic particles

Bœhm et al. (2004)

- Can constrain the cross section using CMB data, independent of the vanilla DM assumptions.
- DM-γ interactions can occur through processes involving SM particles or magnetic and dipole moments.
- Preliminary result (pre-WMAP): $\sigma_{DM-\gamma} \leq 7 \times 10^{-30} (m_{DM} / \mathrm{GeV})\ \mathrm{cm}^2$ *Bœhm et al. (2002)*

Implementation

- Add DM-γ interaction to Euler equations:

DM-γ Interaction Rate

$$\dot{\theta}_b = k^2\psi - H\theta_b + c_s^2 k^2 \delta_b - R^{-1}\dot{\kappa}\left(\theta_b - \theta_\gamma\right)$$
$$\dot{\theta}_\gamma = k^2\psi + k^2\left(\delta_\gamma / 4 - \sigma_\gamma\right) - \dot{\kappa}\left(\theta_\gamma - \theta_b\right) \boxed{- \dot{\mu}\left(\theta_\gamma - \theta_{DM}\right)}$$
$$\dot{\theta}_{DM} = k^2\psi - H\theta_{DM} \boxed{- S^{-1}\dot{\mu}\left(\theta_{DM} - \theta_\gamma\right)}$$

$$\dot{\mu} \equiv a\sigma_{DM-\gamma} c n_{DM}$$

Ensures energy conservation

$$S \equiv (3/4)(\rho_{DM} / \rho_\gamma)$$

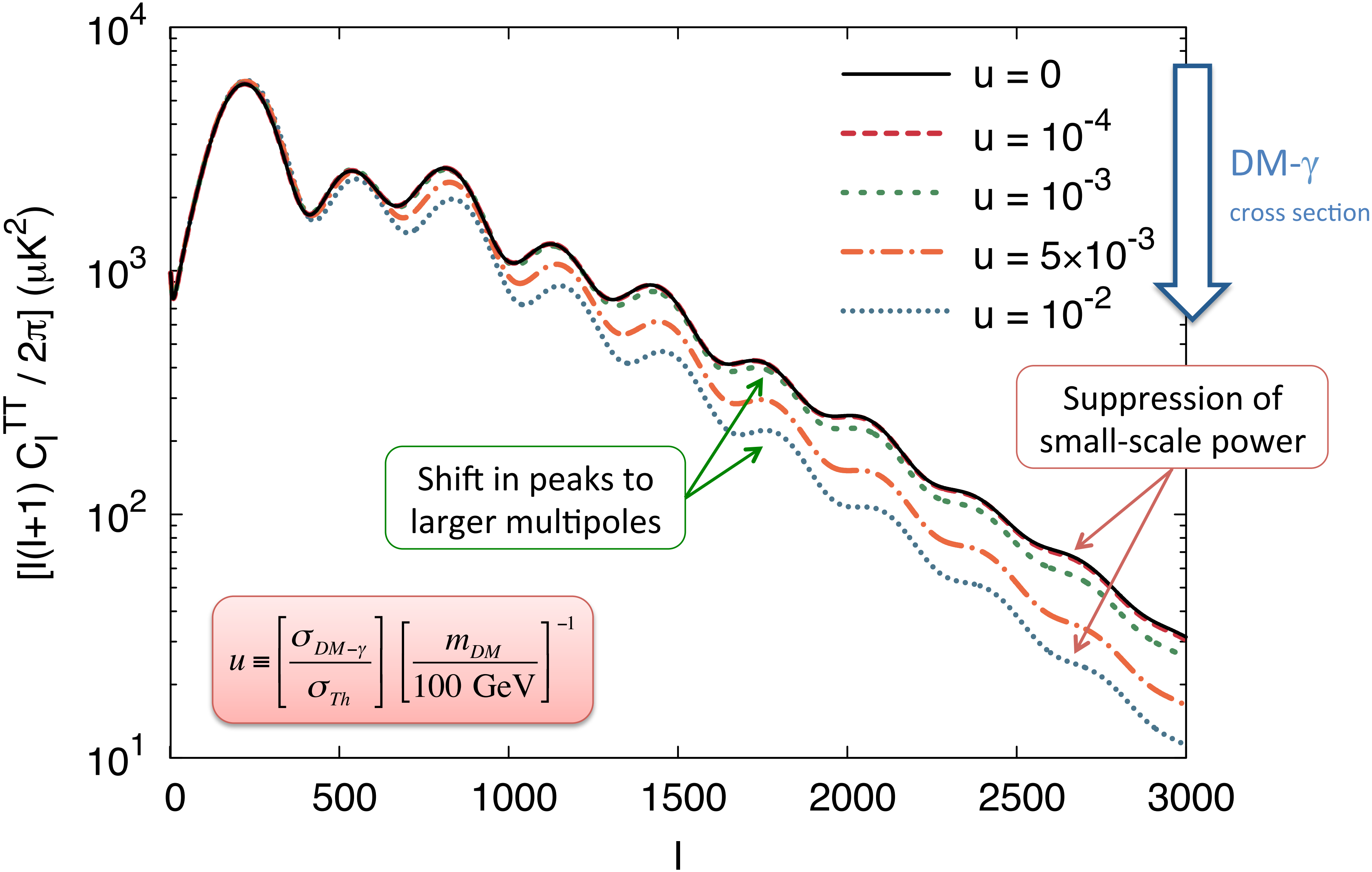
- Also need to modify photon temperature and polarisation equations.
- To quantify the effect on the CMB, we introduce:

$$u \equiv \left[\frac{\sigma_{DM-\gamma}}{\sigma_{Th}}\right]\left[\frac{m_{DM}}{100\ \mathrm{GeV}}\right]^{-1}$$

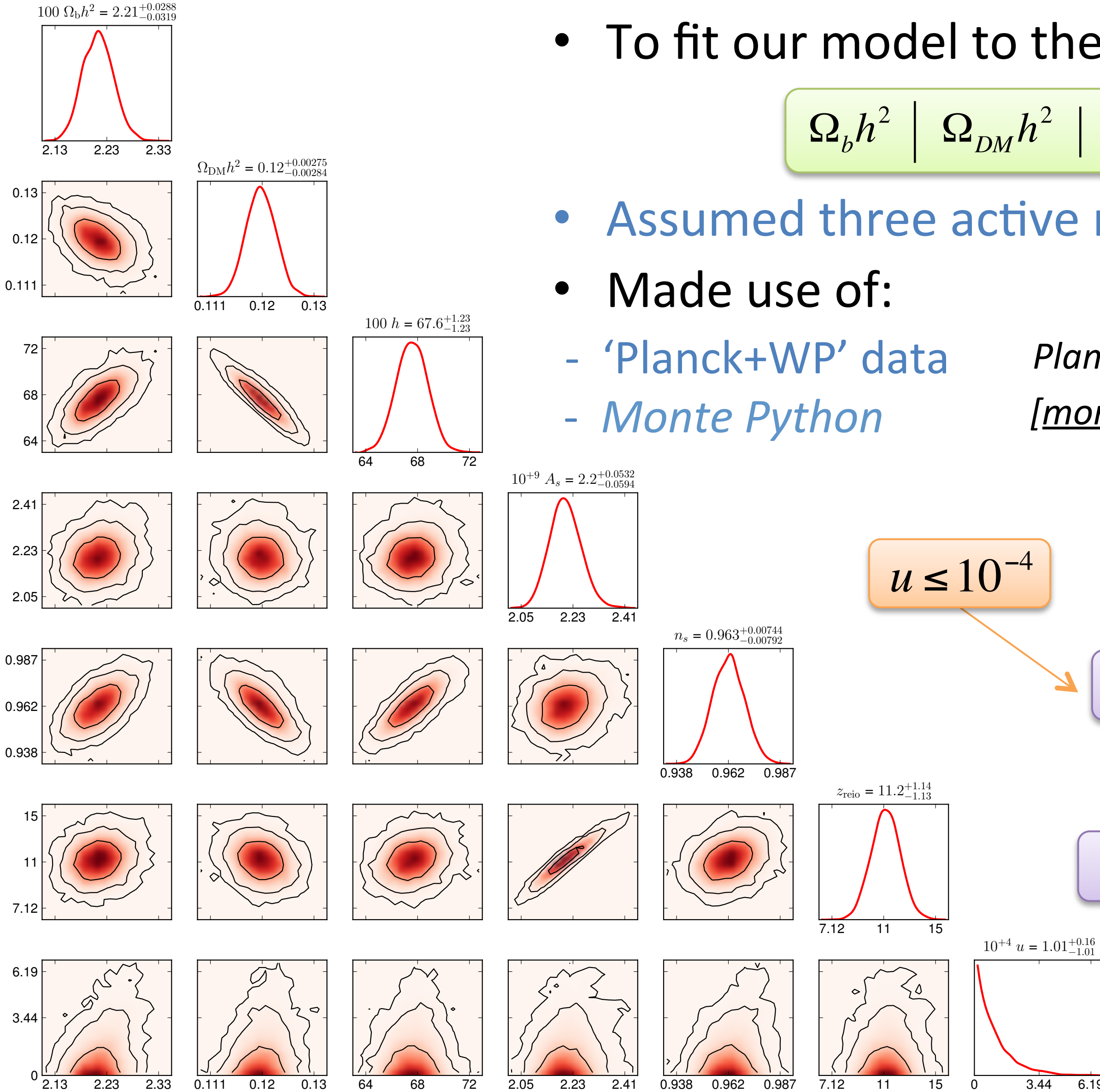
- We consider $\sigma_{DM\text{-}\gamma}$ const. and prop. T^2.
- Made use of:

  - Boltzmann code *CLASS* — *[class-code.net] Lesgourgues (2011)*
  - Line-of-sight integration approach — *Seljak & Zaldarriaga (1996)*

Effects on the CMB



Constraints from Planck



- To fit our model to the data, we varied:

$$\Omega_b h^2 \mid \Omega_{DM} h^2 \mid n_s \mid A_s \mid H_0 \mid z_{reio} \mid u$$

- Assumed three active neutrinos ($\Sigma m_\nu = 0.06$ eV).
- Made use of:
  - 'Planck+WP' data — *Planck Collaboration (2013)*
  - *Monte Python* — *[montepython.net] Audren et al. (2013)*

New constraints

$$u \leq 10^{-4}$$

Constant σ :

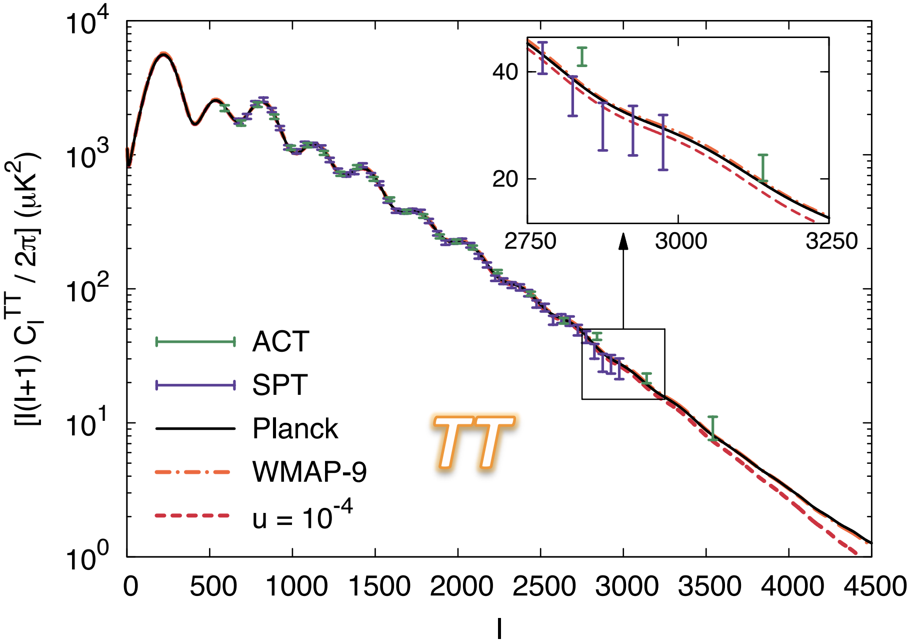
$$\sigma_{DM-\gamma} \leq 8 \times 10^{-31} (m_{DM} / \mathrm{GeV})\ \mathrm{cm}^2$$

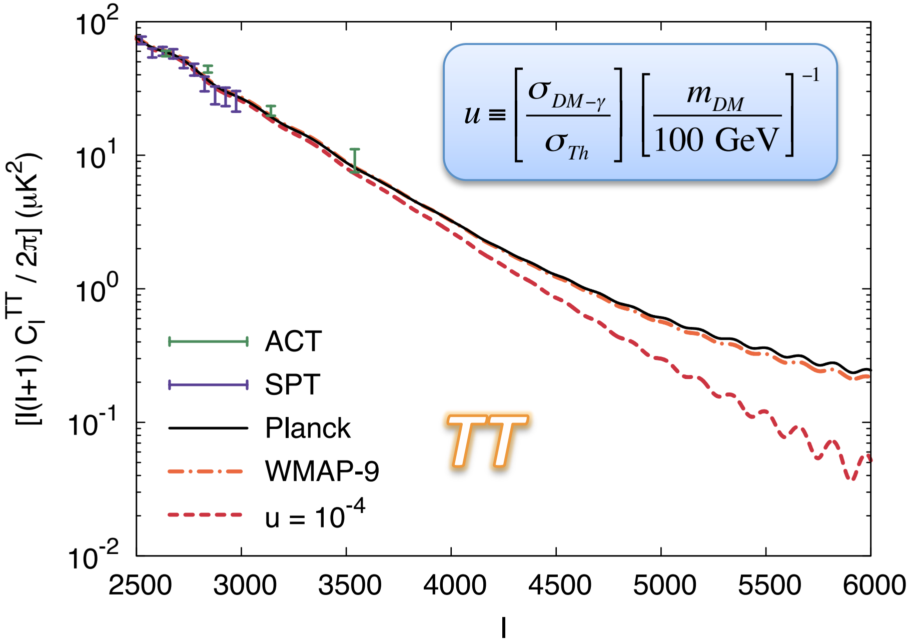
σ prop. T^2 :

$$\sigma_{DM-\gamma,0} \leq 6 \times 10^{-40} (m_{DM} / \mathrm{GeV})\ \mathrm{cm}^2$$

(at 68% CL)

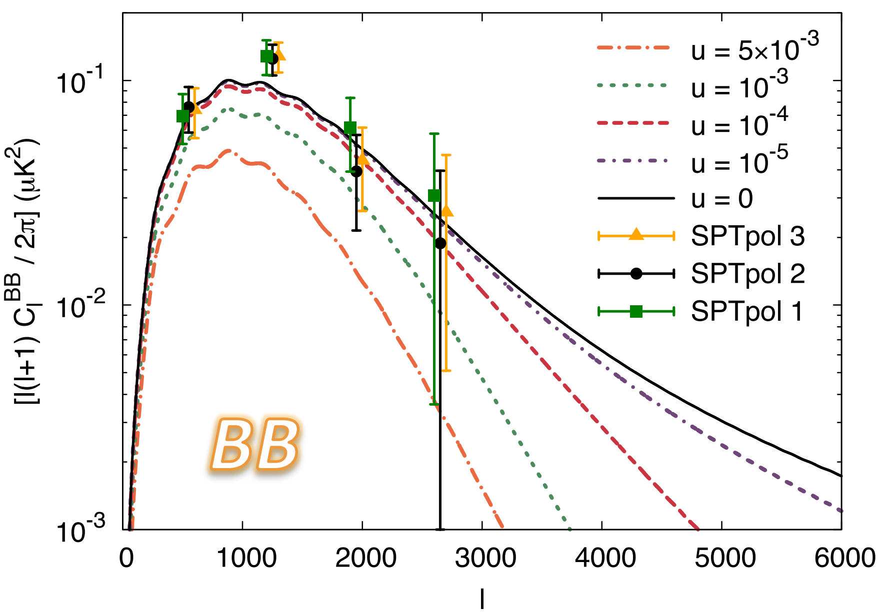
Prospects for future experiments



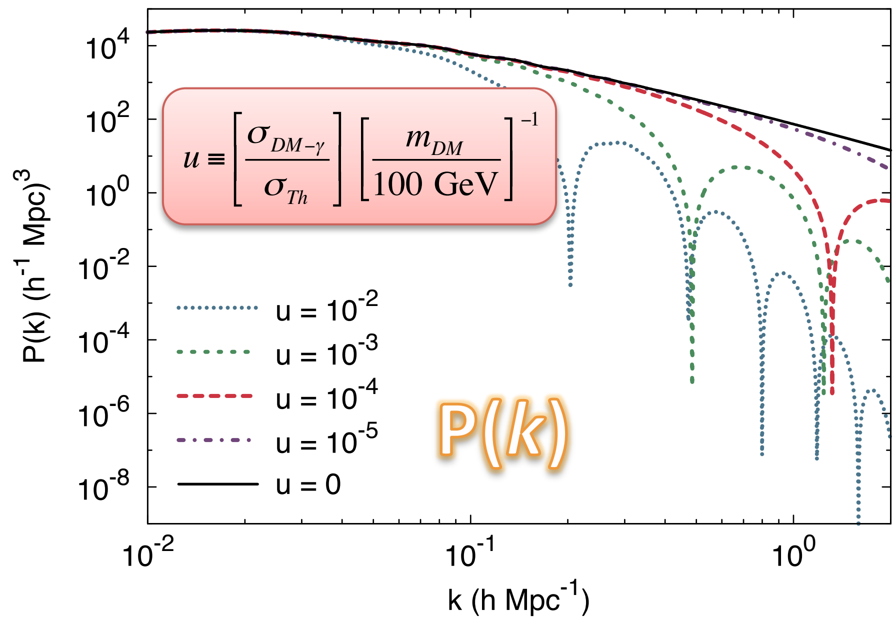


- Large deviation from ΛCDM for l > 3000.
- At l = 6000, power is suppressed by a factor 4 -> SPT, ACT.
- However, foregrounds are dominant in this region.
- Need to ensure accurate foreground modelling and removal.

Prospects for future experiments



- Large suppression of B-modes.
- First-season data from SPT can already rule out $u > 5 \times 10^{-3}$.
- Future data from SPT, POLARBEAR, SPIDER etc. could distinguish $u = 10^{-5}$ from ΛCDM.



- Damped oscillations in the P(*k*).
- Deviation from ΛCDM restricted to non-linear regime.
- Expect intermediate between CDM and WDM.
- LSS surveys: SDSS-III, Euclid etc.

Conclusions

- We have studied the effects of DM-photon interactions on the CMB.
- By comparing the spectra with Planck data, we have set stringent limits on the scattering cross section:

Constant σ : $\sigma_{DM-\gamma} \leq 8 \times 10^{-31} (m_{DM} / \mathrm{GeV})\ \mathrm{cm}^2$

σ prop. T^2 : $\sigma_{DM-\gamma,0} \leq 6 \times 10^{-40} (m_{DM} / \mathrm{GeV})\ \mathrm{cm}^2$

- For heavy DM (TeV), large constant cross sections with photons are allowed.
- For light DM (MeV), the cross section is of the order typically expected for (SM) weak interactions.
- A stronger result could be achieved using future C_l data from polarisation experiments and Planck, and information on the P(*k*).
- Importantly, one can use cosmological data to study DM interactions, independently of any theoretical prejudice.