Dark-matter constraints from a cosmic index of refraction

David C. Latimer

Department of Physics and Astronomy
University of Kentucky
Lexington, KY 40506

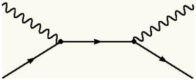
latimer@pa.uky.edu

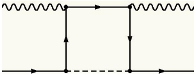
In collaboration with Susan Gardner from the University of Kentucky.

UNIVERSITY OF KENTUCKY

Motivation

Generically, dark matter interact with photons (if only through quantum fluctuations), resulting in a refractive index.





The real part of the refractive index will result in a time lag between simultaneously emitted pulses of light. The imaginary part of the index results in attenuation of a signal.

> An advantage to this approach is that effects are not sensitive to local fluctuations of DM density; instead, they rely upon the density averaged over a *very* long baseline.

Index of refraction

- The relationship between the refractive index and the forward Compton amplitude is

$$n = 1 + \frac{\rho}{4m_{dm}^2\omega^2}\mathcal{M}_{\text{fwd}}.$$

Here, ω is the measured photon frequency, and $\rho = 1.1 \times 10^{-6}$ GeV/cm^3 the present day DM density. [PDG]

- Model independent considerations inform us of the form of the amplitude at relatively low photon energies.

Forward Compton amplitude

- The low energy theorem of Compton scattering requires $\mathcal{M}_{\mathrm{fwd}} \sim -\varepsilon^2 e^2$ for particles of arbitrary spin as well as composite systems.

  [Low, PR **96**, 1428 (1954); Gell-Mann and Goldberger, PR **96**, 1433 (1954); Lapidus and Kuang-Chao, Sov. Phys. JETP **12**, 898 (1961); Brodsky and Primack, Ann. Phys. **52**, 315 (1969).]

- Neglecting spin, the amplitude will be a real and even function of ω (for photon energies below the inelastic threshold); additionally, the coefficients of the $\mathcal{O}(\omega^{2n})$ terms are positive.

  [Gell-Mann, Goldberger, and Thirring, PR **95** (1954); Goldberger, PR. **97** (1955) .]

- Spin dependent interactions can lead to odd powers in the expansion about ω. There presence could inform of the spin of DM.

Forward Compton amplitude (ii)

The full coherent amplitude has the form

$$\mathcal{M}_{\text{fwd}} = A + B\omega^2 + C\omega^4 + \mathcal{O}(\omega^6).$$

The low energy theorem sets $A = -\varepsilon^2 e^2$. The remaining coefficients B and C are required to be positive.

Returning to the refractive index, we have

$$n = 1 + \frac{\rho}{4m_{dm}^2}\left[\frac{A}{\omega^2} + B + C\omega^2 + \mathcal{O}(\omega^4)\right].$$

Time lag due to dispersion

A dispersive time lag for simultaneously emitted photons of energy ω_1 and ω_2 at redshift z is

$$\Delta t(\omega_1, \omega_2, z) \approx \frac{\rho}{4m_{dm}^2}\left[A'\left(\frac{1}{\omega_1^2}-\frac{1}{\omega_2^2}\right)K(z)+C'(\omega_1^2-\omega_2^2)J(z)\right].$$

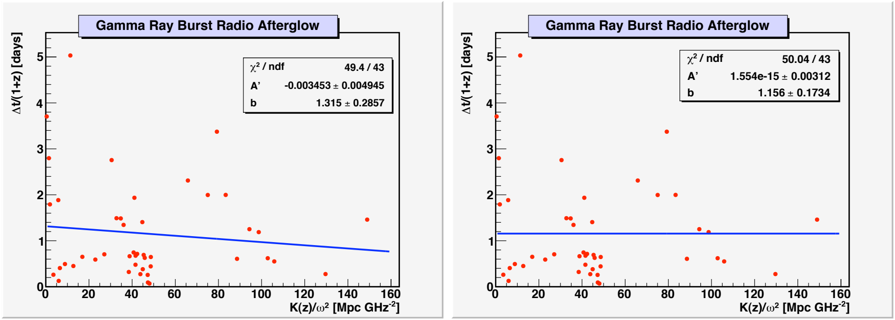
where $K(z)=\int_0^z(1+z')H(z')^{-1}\mathrm{d}z'$ and $J(z)=\int_0^z(1+z')^5H(z')^{-1}\mathrm{d}z'$. We solve for the Hubble constant at redshift z using the Friedman equation with

$$H(z)=H_0\sqrt{(1+z)^3\Omega_M+\Omega_\Lambda}$$

and the present day value for the Hubble constant $H_0 = 71 \pm 2$ km/s/Mpc.

To consider cosmological distance scales, we include a scale factor of $(1+z)^3$ for the DM density and a blueshift factor of $1+z$ for the photon energies.

Millicharged limits



Both fits yield a similar limit on millicharged DM at 95% CL:

$$\frac{|\varepsilon|}{m_{dm}} < 2 \times 10^{-6}\ \text{eV}^{-1}.$$

Summary

- Using general considerations, we have identified the form of the refractive index in a DM medium.
- Millicharged DM will have a ω^{-2} behavior at leading order. Dispersive effects for neutral DM will enter at order ω^2.

We advocate the observation of GRBs over a broad range of redshifts and frequencies, from radio to high energy gamma rays.
Additional data can further the effort in constraining DM properties.

Backups

Millicharged limits

[Davidson, Hannestad, and Raffelt, JHEP **05**, 003 (2000).]

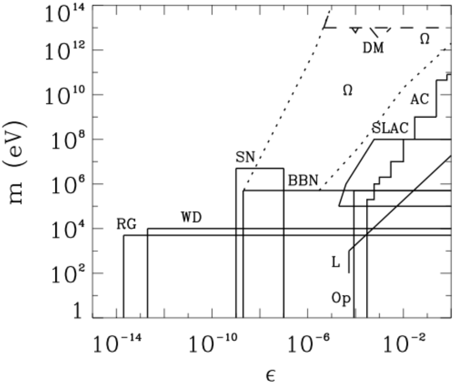


Figure 1: Regions of mass-charge space ruled out for milli-charged particles. The solid and dashed lines apply to the model with a paraphoton; solid and dotted lines apply in the absence of a paraphoton. The bounds arise from the following constraints: AC — accelerator experiments; Op — the Tokyo search for the invisible decay of ortho-positronium [27]; SLAC — the SLAC milli-charged particle search [28]; L — the Lamb shift; BBN — nucleosynthesis; Ω — $\Omega < 1$; RG — plasmon decay in red giants; WD — plasmon decay in white dwarfs; DM — dark matter searches; SN — Supernova 1987A.