Dark Scattering

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Introduction

One of the most pressing issues in modern physics lies in the classification of dark energy. This is a phenomenon which not only appears to provide the bulk of the Universes energy content, but also gravitates in a repulsive manner, unlike any known substance. Prime candidates include the cosmological constant, scalar fields, and modifications to Einstein's theory of gravity. The first step in observationally distinguishing these models involves studying the cosmic geometry, since the cosmological constant makes a strong predictive statement on the trajectory of the cosmic expansion. Over the past decade, progress in this area has seen the redshift-distance relation tested by supernovae and Baryon Acoustic Oscillations (BAO) with a precision approaching 1%.

However, studying the expansion history alone is insufficient if we are to ever definitively exclude either scalar fields or modified theories of gravity. Therefore it is also of great importance to examine the growth of cosmic structure, an area which is attracting growing attention. This can be measured through various means such as redshift space distortions and weak gravitational lensing, though current constraints are relatively modest.

In performing this diagnosis of dark energy, we have implicitly been assuming that the physics within the dark sector of cosmology - dark matter and dark energy - is purely gravitational. Yet what limitations can we place on their physical behaviour? While the precise nature of any microphysics is highly uncertain, the broader picture is one in which energy may be transferred either from dark energy to dark matter, or vice versa. Cosmologies with energy exchange have been extensively studied in the literature, and have been shown to leave characteristic signatures within observables such as the Integrated Sachs Wolfe effect, the Hubble constant H_0, and the growth of cosmic structure.

Elastic Scattering

Here we present a new class of models where elastic scattering between the dark matter and dark energy fluids leads to a suppression in the growth of large scale structure. This may in turn provide a false signature of modified gravity. In a scenario with elastic scattering analogous to Thomson drag, the velocity perturbation equations for the dark matter fluid θ_c and dark energy fluid θ_Q are modified with the inclusion of a new drag term:

$$\theta'_c = -H\theta_c + \frac{\rho_Q}{\rho_c}(1+w)an_D\sigma_D\Delta\theta + k^2\phi$$

$$\theta'_Q = 2H\theta_Q - an_D\sigma_D\Delta\theta + k^2\phi + k^2\frac{\delta_Q}{1+w}$$

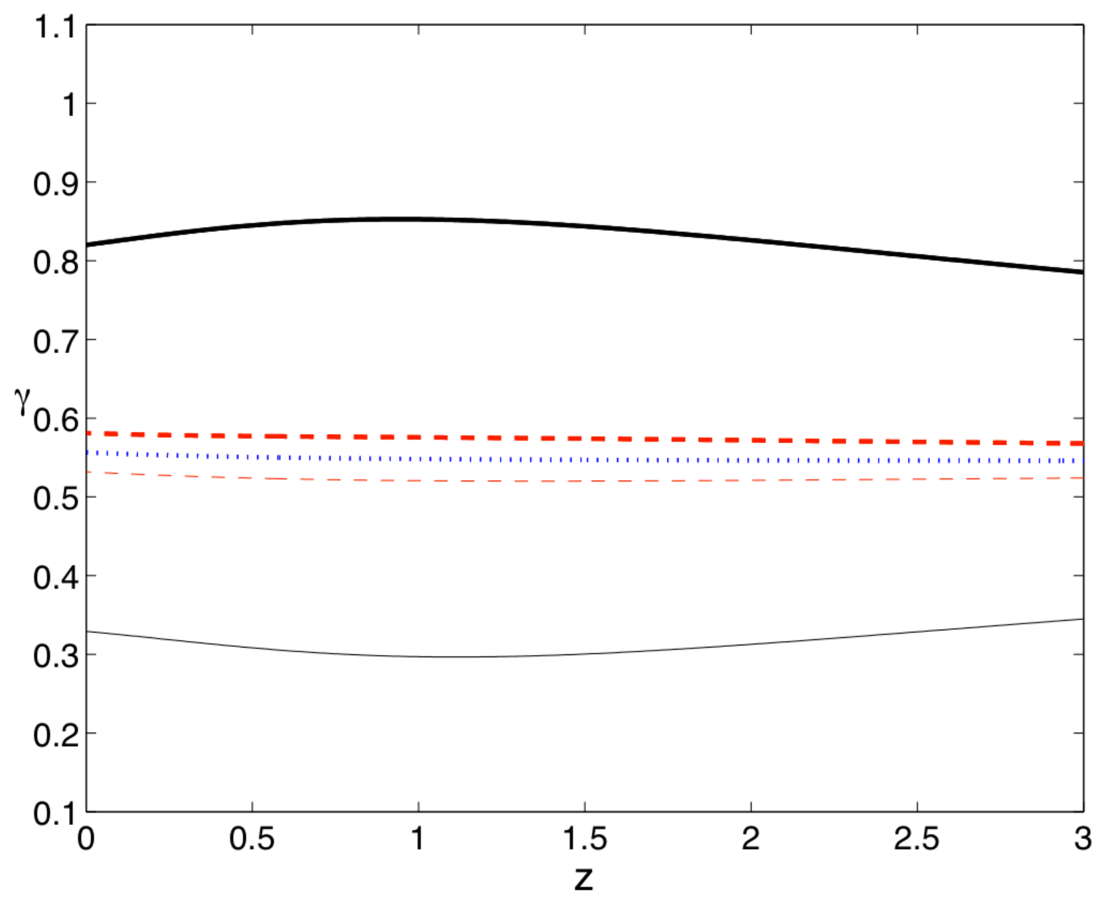

Figure 1: The evolution in the growth index as a function of the scale factor. Thick solid and dashed lines correspond to models of dark energy with w = −0.9 and w = −0.99 respectively. As with Figure 2, the dark matter - dark energy cross section is taken to be 500 b. The dotted line represents the standard case of zero scattering. Below the dotted line, the thin solid and dashed lines correspond to w = −1.1 and w = −1.01 models.

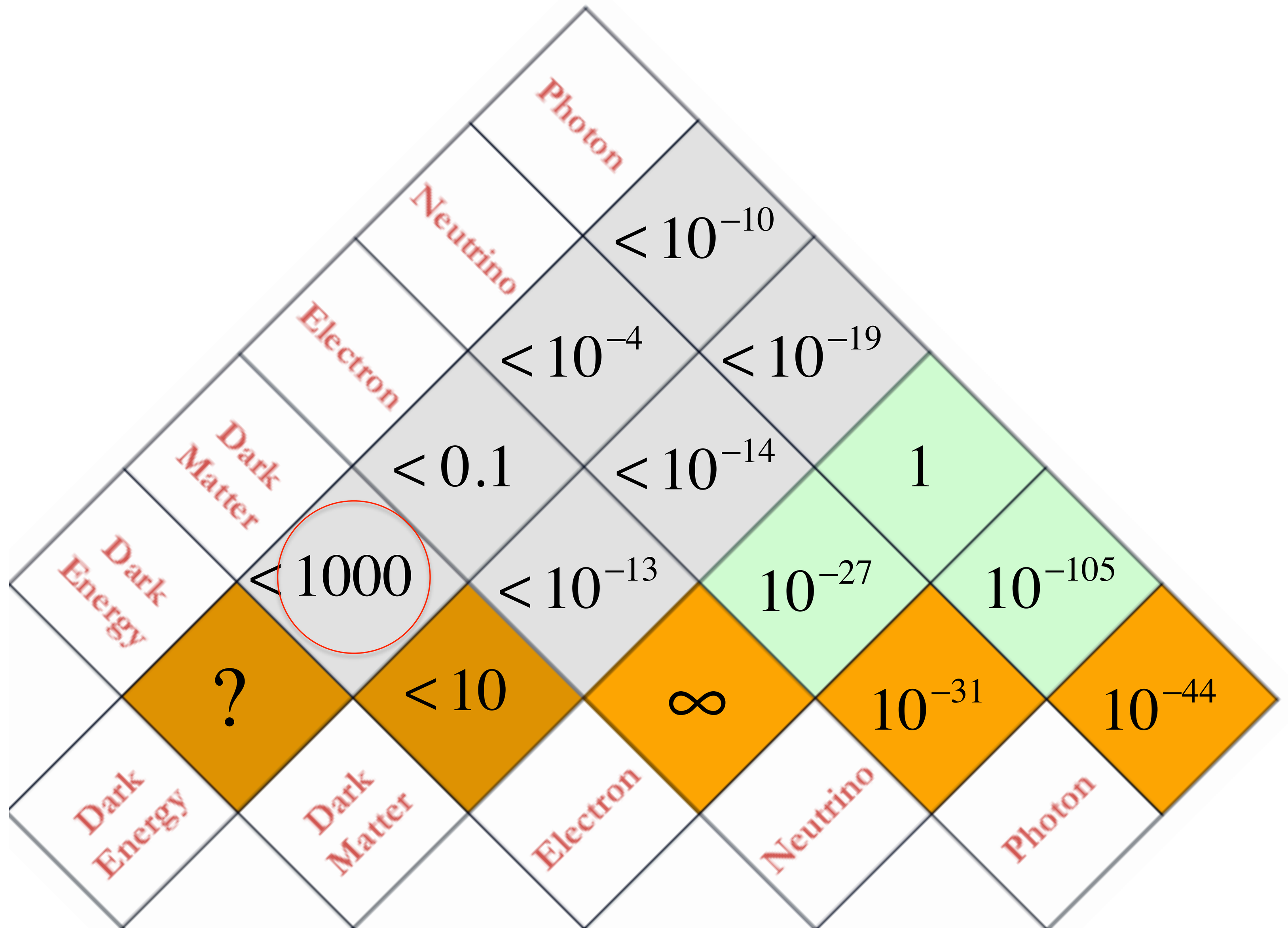

Figure 2: A collection of cross-sections between cosmologically significant particles, in units of barns ($10^{-24}cm^2$). We assume a collisional energy associated with the era of recombination, 3000K or equivalently ~ 0.3 eV. The dark matter particle is taken to have a mass of 10 GeV/c^2, and the dark energy equation of state w = −0.9.

Conclusions

In the event that dark energy takes some physical form (neither a cosmological constant, nor a manifestation of new gravitational physics), then we might expect it to interact in some additional non-gravitational manner. Figure 1 highlights the impact that elastic scattering may have on the linear growth of cosmological structure.

Owing to the persistently low energy density of dark energy, quite considerable cross sections are permitted, as illustrated in Figure 2. For an equation of state w = −0.9, this can exceed the Thomson cross section by two orders of magnitude before a significant impact is made on the growth of large scale structure.