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Cosmic Gamma-Ray Background Anisotropies and Dark Matter Annihilation

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The extragalactic cosmic gamma-ray background (CGB) is expected to provide indirect signatures of the presence of Dark Matter (DM) through gamma-rays produced in DM annihilations. In particular, DM can leave its imprint not only in the CGB energy spectrum but also in the peculiar pattern and intensity of the CGB anisotropies. These are expected to differ significantly with respect to the case of a pure astrophysical origin of the CGB due to the peculiar quadratic dependence $\propto \rho_\chi^2$ of the DM annihilation signal from the DM density. I will discuss the DM signatures expected in the power spectrum of the CGB anisotropies and the prospect for detection with the forthcoming Fermi/GLAST observatory.

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1. Introduction

Indirect astrophysical searches provide a promising complementary way to investigate the nature of Dark Matter (DM) with respect to direct detection or production in terrestrial accelerators. Theoretically motivated DM particles candidates are generally expected to self-annihilate in pair into standard model particles which can thus provide an indirect DM signature. Among the various produced secondaries, gamma-rays in particular are appealing because they can be detected efficiently and can travel in straight lines thus directly pointing back to the site of production. Given the quadratic dependence of the annihilation signal from the DM density, dense astrophysical environments are the most interesting sites to investigate. In particular, the galactic center, the galactic halo, dwarf galaxies and DM sub-galactic clumps have been considered [1, 2]. Finally, DM annihilation is also expected to leave a measurable imprint into the extragalactic diffuse cosmological gamma background (CGB)[3] as we will discuss more into details below.

2. CGB anisotropies

Gamma-rays from astrophysical sources have generally a power law spectrum with slope ~ 2.0 remnant of the Fermi shock acceleration processes taking place in the sources themselves. The spectrum of gammas from DM annihilation is instead generally harder with a slope ~ 1.5 with a sharp cutoff near the energy corresponding to the DM mass. DM is thus expected to leave its imprint in the CGB as “bump” in the energy spectrum [4 – 6]. However, astrophysical processes mimicking this feature are possible as for example in gamma rays from Pulsars where the acceleration phenomena are not of Fermi type [7]. In principle, a clear signature as a line in the spectrum from direct annihilation into photons is possible although this channel is generally loop suppressed producing only a tiny signal difficult to detect. A complementary signature would thus be extremely helpful in identifying a real DM contribution. To this aim, further information is available in the angular distribution of the CGB, which can have different properties for the background and for DM. Indeed, already in the pioneering work of ref.[8] (see also [9]) it was shown that DM is expected to give an higher anisotropy with respect to the astrophysical background especially at small angular scales. In general, besides the case of the CGB, the anisotropy analysis can be a powerful tool in looking for DM signatures [10].

To illustrate the anisotropy features we show in Fig.1 synthetic CGB maps obtained using an N-body simulation of cosmological structure formation (see [11, 12] for the details). The cosmological Large Scale Structure (LSS) given by the simulation is then folded with the expected window function $W(z)$ containing the history and rate of generation of the gamma signal with redshift z, and then integrated along the line of sight to produce the expected anisotropy maps. The maps refer to an energy cut $E_{\rm cut} > 1$ TeV where the gamma horizon is $\mathscr{O}(100)$ Mpc, comparable with the periodic box size of the simulation, although the results apply as well to the range 1-100 GeV, the energies of interest of Fermi (Glast). The figure illustrates the main difference induced by DM annihilation into the angular pattern of the CGB. In the upper panel the sources of gamma rays follow linearly the LSS distribution as approximately expected for the CGB astrophysical sources as blazars or galaxy clusters, while the lower panel assumes that the sources follow the LSS quadratically as in the case of DM annihilation. The difference between the two

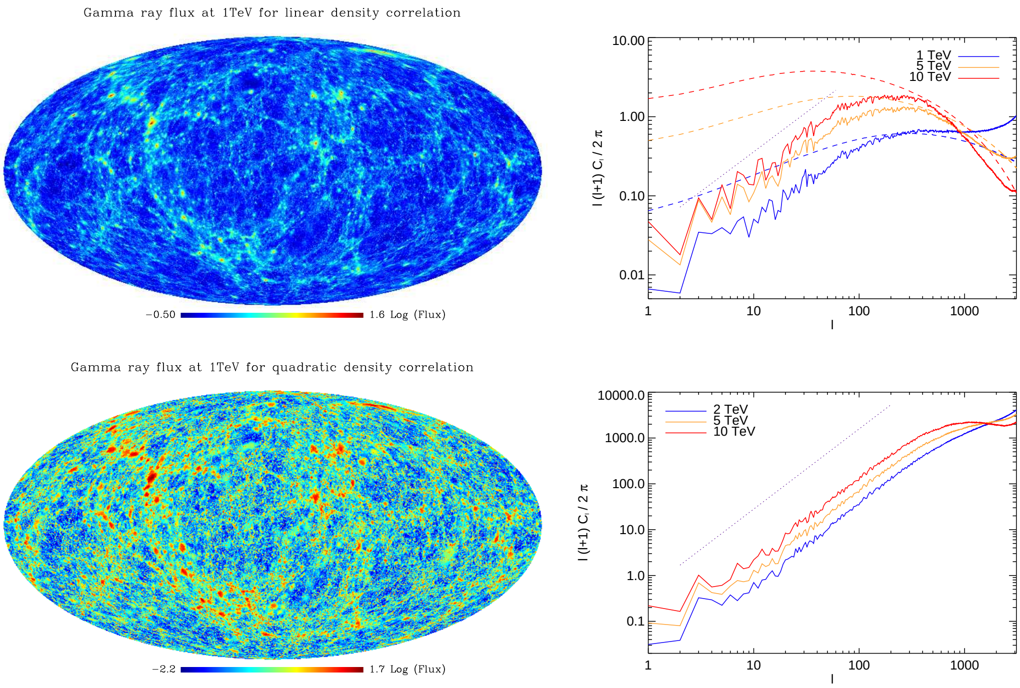

Figure 1: Left panels: anisotropy map of CGB for $E_{\rm cut} > 1$ TeV for sources following linearly (up) or quadratically (down) the cosmological LSS. Right panel: Angular power spectra of the CGB maps for various energy cuts [11].

maps, already recognizable by eye, can be expressed in quantitative way with the standard tool of the angular power spectrum C_l, i.e. the Fourier transform (Harmonic on the sphere) of the sky map of the signal, function of the multipole l. The power spectrum can be calculated for example with the HEALpix package [13]. The right panels of Fig.1 indeed show that the spectrum of the astrophysical signal has generally a flattening at intermediate multipoles $l \sim 100-200$. Further, at extremely high energies $E \gtrsim 3-4$ TeV interestingly the spectrum presents a turnover. These energies are not observable by Fermi although they can be relevant for ground based observatories like Milagro or Hawc [11]. The angular spectrum in the right lower panel shows instead that the anisotropies of gamma rays from DM are quite different with an overall higher intensity and much more power at small angular scales $l > 100-200$ with no indication of flattening.

3. Forecast

At the energies of interest of Fermi of ~ 10 GeV the statistical properties of the LSS inferred from the simulation can be used to predict the CGB anisotropy power spectrum. The intermediate step of synthetic CGB maps generation in this case is not necessary [12]. The predicted spectra for $E_{\rm cut} > 10$ GeV are shown in Fig.2 together with the error bars expected for 4 years of observation from Fermi. The error bars are basically settled by the Poisson noise limit (i.e. the number of gamma events collected) and by the angular resolution of Fermi which is expected to be $\sim 0.1°$ above 1 GeV providing sensitivity possibly until a multipole $l \sim 1000$. The expected number of events in turn is calculated assuming a CGB normalization as established by EGRET [3] and

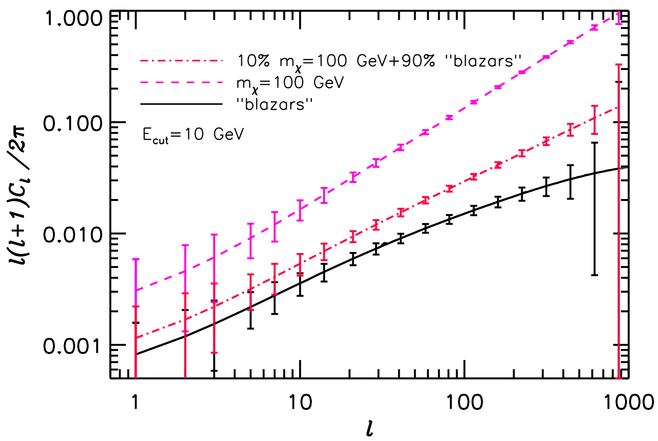

Figure 2: Angular spectra of the CGB for $E_{\rm cut} = 10$ GeV with 1 σ error bars for a 4-year GLAST survey. The EGRET normalization of the CGB is assumed. The various lines refers to the case in which DM annihilation from a $m_\chi = 100$ GeV WIMP contributes above 10 GeV for 100% of the CGB (pink dashed), the case in which the CGB is purely astrophysical in origin (black solid) and a mixed case with a 10% DM contribution and 90% astrophysical contribution (red dot-dashed). For brevity the astrophysical sources of the CGB are indicated generically as "blazars".

extrapolating to higher energies taking into account the expected spectral attenuation due to pair absorption [12].

The figure shows that in few years of operation Fermi should be able to detect at a significant level the CGB anisotropies in the case the CGB is purely astrophysical in origin. If on top of the pure astrophysical signal a DM contribution is present, the overall CGB anisotropies will be higher and correspondingly easier to detect. Clearly, however, what will be observed in reality is the sum of the astrophysical and DM signals. Thus, the DM signature in the anisotropy spectrum of the CGB will appear as an excess, in particular at high multipoles, with respect to the model power spectrum of the astrophysical signal alone. A more model independent signature is however possible if the statistic is enough to perform an analysis using different energy bins. Given that DM is expected to produce a signal only in a rather narrow energy band, the anisotropy excess will appear only in some energy bins giving a more robust signature.

Fig.2 also shows the anisotropy spectrum in the optimistic case of DM producing all the CGB above 10 GeV assuming the EGRET normalization and the case in which DM contributes by 10% of the EGRET normalization on the top of a dominant signal of astrophysical origin. While in the first case the DM signature is extremely pronounced, the 10% case still gives a significant excess to leave a detectable DM signature. A DM signal below the few % level, instead, starts to give an excess challenging for a clear discrimination with respect to the astrophysical background. Eventually, however, in the case in which the anisotropy spectrum of the CGB should not present any "anomaly", interesting and *complementary* limits on the DM properties should be achievable. Notice that we use the EGRET measurement as CGB normalization and we do not attempt to derive the DM signal from a specific DM particle model setup. This choice is motivated by the fact that the DM imprint in the CGB is basically sensitive to the DM signal normalization (which is basically proportional $\propto <\sigma v>_A / m_\chi^2$) rather than the specific particle physics details. For a given normalization, however, specific models producing it can be derived straightforwardly.

4. Summary and conclusion

In summary, the anisotropy analysis of the CGB seems promising as a possible signature for DM annihilation. Further work still needs to be done however to understand for example the role of galactic foregrounds and point sources in the extraction of the CGB anisotropy signal. A full simulation of the Fermi detector may be required as well. On the other hand, some further information can be exploited for example performing a cross-correlation of the CGB with galaxy surveys and/or dividing the CGB analysis in different energy bands. Progresses in these directions will be described in forthcoming works.

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