Cosmic gamma-ray background from dark matter annihilation

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Abstract. High-energy photons from pair annihilation of dark matter particles contribute to the cosmic gamma-ray background (CGB) observed in a wide energy range. The precise shape of the energy spectrum of CGB depends on the nature of dark matter particles. In order to discriminate between the signals from dark matter annihilation and other astrophysical sources, however, the information from the energy spectrum of CGB may not be sufficient. We show that dark matter annihilation not only contributes to the mean CGB intensity, but also produces a characteristic *anisotropy*, which provides a powerful tool for testing the origins of the observed CGB. We show that the expected sensitivity of future gamma-ray detectors such as GLAST should allow us to measure the angular power spectrum of CGB anisotropy, if dark matter particles are supersymmetric neutralinos and they account for most of the observed mean intensity. As the intensity of photons from annihilation is proportional to the density squared, we show that the predicted shape of the angular power spectrum of gamma rays from dark matter annihilation is different from that due to other astrophysical sources such as blazars, whose intensity is linearly proportional to density. Therefore, the angular power spectrum of the CGB provides a "smoking-gun" signature of gamma rays from dark matter annihilation.

1. Introduction

High-energy photons from annihilation of dark matter particles provide indirect means to probe the properties of dark matter. Annihilation signatures, especially gamma rays, have been searched for in regions where the dark matter density is expected to be high, as annihilation rate is proportional to the density squared, ρ_χ^2. Among some possibilities is the extragalactic background light, the cosmic gamma-ray background (CGB), which has been measured in a wide energy range [1]. It has been speculated that some fraction of the CGB may originate from annihilation of dark matter particles in halos distributed over cosmological distances [2, 3, 4, 5, 6].

Dark matter annihilation may be a viable explanation for the CGB, but do we know for sure that the CGB does come from annihilation? We argue that *anisotropy* of the CGB may provide a smoking-gun signature [7]. Although the CGB is isotropic at the leading order, anisotropy should also exist if the CGB originates from cosmological halos. The future gamma-ray detectors with an enhanced sensitivity and angular resolution, such as GLAST, should be able to see such anisotropy. We calculate the angular power spectrum in GeV region for supersymmetric neutralinos. We then discuss the detectability of CGB anisotropy by GLAST, showing that the predicted anisotropy can be easily measured by 1-year operation of this experiment.

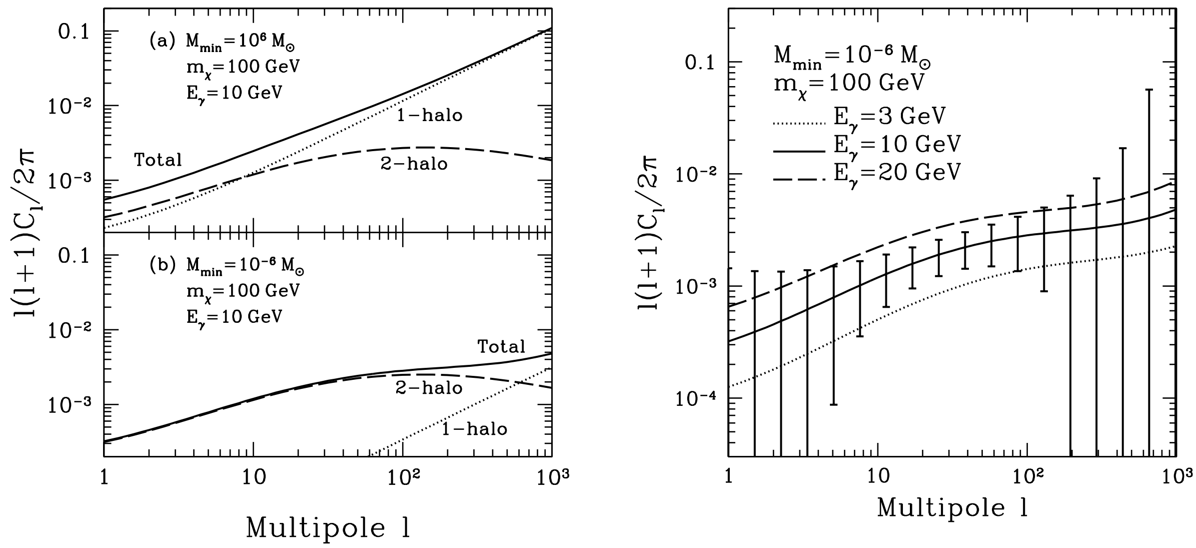

Figure 1. *Left.*—Angular power spectrum of the CGB, C_l, from annihilation of supersymmetric neutralinos, evaluated for (a) $M_{\rm min} = 10^6 M_\odot$ and (b) $M_{\rm min} = 10^{-6} M_\odot$. Note that C_l is dimensionless: the mean intensity squared should be multiplied in order to convert it to the units of intensity squared. The neutralino mass m_χ is assumed to be 100 GeV. The predicted angular spectrum is shown at the observed gamma-ray energy of $E_\gamma = 10$ GeV. Contributions to C_l from the 1-halo (dotted) and 2-halo (dashed) terms are shown as well as the total signal (solid). *Right.*—Angular power spectrum of the CGB, C_l, from annihilation of supersymmetric neutralinos, evaluated for $M_{\rm min} = 10^{-6} M_\odot$. The neutralino mass m_χ is assumed to be 100 GeV. The predicted angular spectrum is shown at the observed gamma-ray energy of $E_\gamma = 3$, 10, and 20 GeV. The 1σ error bars of C_l expected from GLAST for 1 year of operation are also shown at $E_\gamma = 10$ GeV.

2. Angular power spectrum

The full details for deriving the formulation of getting the angular power spectrum C_l are given in the other paper [7] on which this paper is based; we refer the interested reader to that paper. We here note that C_l roughly corresponds to the correlation between two points on the sky separated by an angle $\theta \approx \pi/l$.

We assume that the neutralino mass is 100 GeV. In Figs. 1(a) and 1(b) of the left panel, we show the predicted angular power spectrum evaluated at the observed gamma-ray energy of $E_\gamma = 10$ GeV for $M_{\rm min} = 10^6 M_\odot$ and $10^{-6} M_\odot$, respectively. Here $M_{\rm min}$ is the minimum halo mass, below which no halos are assumed to be formed with. The "1-halo term" represents correlations between particles within the same halo, whereas the "2-halo term" represents correlations between particles in two distinct halos.

We compare the predicted power spectrum with the expected sensitivity of the GLAST experiment. We take the following specifications for GLAST: the field of view is $\Omega_{\rm fov} = 4\pi f_{\rm fov} = 2.4$ sr, the angular resolution is $\sigma_b = 0.115°$, and the effective area is $A_{\rm eff} = 10^4$ cm^2 at 10 GeV. In addition, for the diffuse gamma-ray observation, the background contamination can be reduced to 5% of the CGB, which is a promising characteristic. Therefore, error of C_l is essentially determined by the Poisson noise of the cosmic signal. In Fig. 1 (*Right*), we show the predicted angular power spectrum at the observed gamma-ray energies of $E_\gamma = 3$, 10, and 20 GeV, assuming $M_{\rm min} = 10^{-6} M_\odot$, with the expected 1σ errors of C_l at $E_\gamma = 10$ GeV for

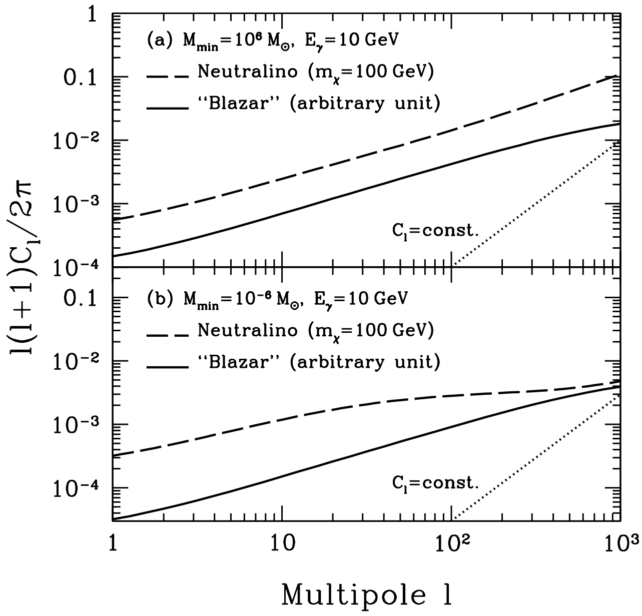

Figure 2. Shape of the angular power spectrum of the CGB expected from unresolved "blazars" with arbitrary normalizations. The power spectrum from annihilation of neutralinos with $m_\chi = 100$ GeV is also plotted as the dashed lines. The adopted gamma-ray energy is 10 GeV, and the minimum mass of dark matter halo is (a) $10^6 M_\odot$, and (b) $10^{-6} M_\odot$. The dotted lines show the shot noise (C_l = const.) with arbitrary normalizations, which represent the power spectrum of very rare sources.

$t = 1$ yr of observations. We find that the GLAST should be able to measure the angular power spectrum of the CGB fairly easily for 1 year of observations, if the dark matter particle is the neutralino with mass around 100 GeV and its annihilation dominates the observed CGB in GeV region. We obtained the similar figure in the case of $M_{\rm min} = 10^6 M_\odot$, which is shown in the other paper [7]. Therefore, we conclude that, if dark matter particles are supersymmetric neutralinos and the observed CGB in GeV region is dominated by their annihilation, the GLAST should be able to measure the angular power spectrum of CGB anisotropy, regardless of the minimum mass.

3. Discussion: Contributions from astrophysical sources

The angular power spectrum shown in Figs. 1 should be very characteristic of annihilating dark matter in extragalactic dark matter halos, as the gamma-ray intensity is proportional to the density squared. The intensity of gamma rays coming directly from other astrophysical sources should be linearly proportional to density. It is likely that blazars are the most dominant constituent of the GeV gamma rays over a wide energy range. Assuming that blazars are biased tracers of the underlying mass distribution, the two-point correlation function of blazars should be simply given by that of density fluctuations, $P(k)$. For more quantitative study, we perform the following simple analyses for the power spectrum of blazars.

First, if blazars are very rare objects, then their angular spectrum is entirely dominated by the shot noise. In this case the angular power spectrum does not depend on l, and thus $l(l+1)C_l$ is proportional to l^2 at $l \gg 1$. We show in Figs. 2(a) and 2(b) that the shot noise spectrum totally lacks the power on large angular scales (i.e., the spectrum is too steep), and can be easily distinguished from dark matter annihilation [7]. Second, we take the other extreme limit where blazars are quite common and trace the underlying matter density field, δ, fairly well. In this simplified prescription, the average number of blazars in a halo linearly increases with the host halo mass. In reality, however, this may not be true and we may also need to take into account the difference between a central galaxy and satellite galaxies within a dark matter halo.

We show the shape of the angular power spectrum expected from blazars in Figs. 2(a) and 2(b). (Normalizations are taken arbitrarily.) The small-scale power drops as we raise the minimum mass of host halos. In Fig. 2(a), we compare the blazar spectrum with the spectrum of CGB anisotropy from annihilation of neutralinos with $m_\chi = 100$ GeV for the large minimum mass, $10^6 M_\odot$. As we have noted before, the annihilation spectrum for $M_{\rm min} = 10^6 M_\odot$ is also dominated by the 1-halo term at all multipoles, which makes the annihilation and blazar spectrum actually look similar at $l < 200$. Above $l \sim 200$, however, the annihilation spectrum continues to grow whereas the blazar spectrum flattens out. In Fig. 2(b), we use the smaller minimum mass, $10^{-6} M_\odot$, which is probably more realistic for dark matter annihilation. In this case the dominant contribution comes from the 2-halo term, which makes the annihilation spectrum substantially flatter than the blazar spectrum. In other words, the annihilation spectrum has much more power at large angular scales, which should be easily distinguished from the blazar spectrum. The same argument should also apply to the CGB in the MeV region from Type Ia supernovae. (See Ref. [8] for another approach to calculating the angular correlation function of Type Ia supernovae.)

Although here we just showed results of very crude estimate with the normalization taken to be arbitrary, a more quantitative computation should be possible using the latest blazar luminosity function. A preliminary results show that dark matter signature should be detectable with GLAST, if the annihilation contribute more than 30% of the current CGB flux (and if remaining 70% is coming from blazars) [9]. This result is from the analysis including both the dark matter and blazar component, hence we have to somehow calibrate the blazar component and subtract it from the total. Since the angular power spectrum is independent of energy if the spectrum is power low [9], we can calibrate the blazar component at lower energies such as 100 MeV. In addition, one may also use the result of the clustering analysis of blazars detected as point sources by GLAST [10].

4. References

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