GLAST sensitivity to cosmological Dark Matter annihilations into γ-rays

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γ-rays from Cosmological WIMPs

Pair annihilation of weakly interacting massive particle (WIMP) dark matter into high energy photons taking place in dark matter halos at all redshifts might contribute to the extragalactic diffuse gamma-ray radiation. The 2γ-annihilation channel would give rise to a distinct feature in the spectrum, a line which is distorted by the integration over all cosmological redshifts [1].

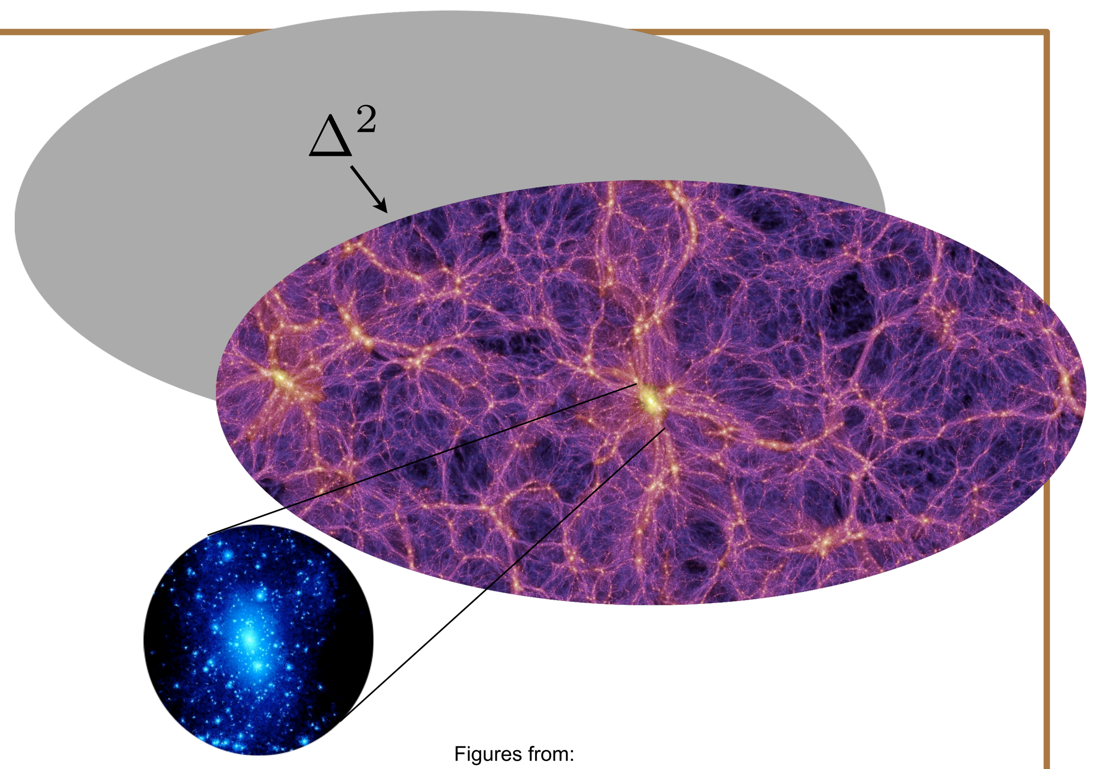
The differential flux of gamma-rays from cosmological WIMP annihilations can be calculated as in [2].

Halo Structures

The question of how dark matter is distributed on small, galactic and sub-galactic scale is still a matter of debate. However, N-body simulations show that large structures form by the successive merging of small substructures, with smaller objects usually being denser [3].

Since the annihilation rate is proportional to the dark matter density squared, "clumpiness" of dark matter can significantly boost the annihilation signal from cosmological WIMPs. The quantity $\Delta^2(z)$ describes the averaged squared over density in haloes, as a function of redshift.

Also within larger halos there might exist smaller, bound halos that have survived tidal stripping. These halos are indicated to have masses all the way down to $10^{-6}\ M_\odot$ [4]. Although not as numerous as the primary halos the substructure halos arise in higher density environments which makes them denser than their parent halo.



Figures from:
V. Springel http://www.mpa-garching.mpg.de/galform/press/

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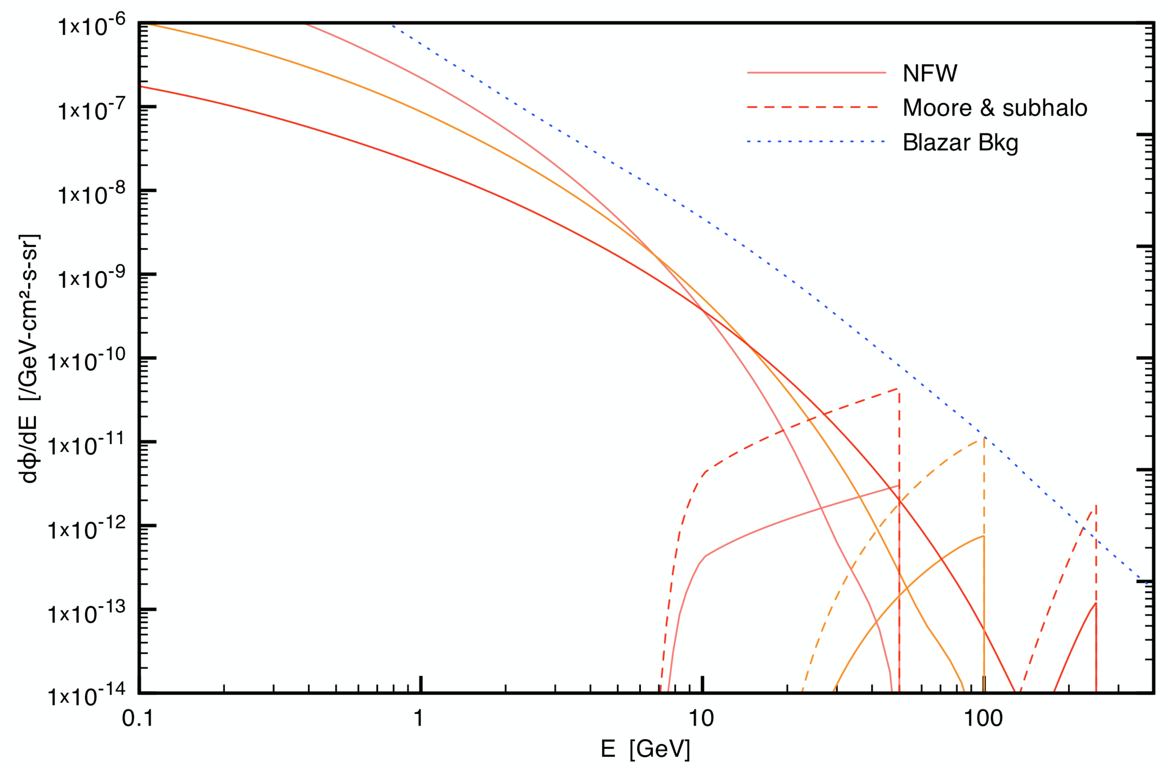
$$\frac{d\phi_\gamma}{dE_0} = \frac{\sigma v}{8\pi}\frac{c}{H_0}\frac{\bar{\rho}_0^2}{M_\chi^2}\int dz\,(1+z)^3\frac{\Delta^2(z)}{h(z)}\frac{dN_\gamma(E_0(1+z))}{dE}e^{-\tau(z,E_0)}$$



Calculated fluxes from cosmological WIMPs annihilating into 2γ final state and continuous spectra, from annihilations into bb-bar, with WIMP masses of 50,100, 250 GeV. The total cross section for annihilation is $<\sigma_{2b}v> = 3\cdot10^{-26}$ cm^3 s^{-1} and the branching into 2γ is 10^{-3} .

Astrophysics and cosmology

The extragalactic gamma-ray signal is strongly affected by absorption in the inter-galactic medium, especially at high engries. The absorption is parameterized by the parameter τ, the optical depth. The dominant contribution to the absorption in the GeV-TeV range is pair production on the extragalactic background light emitted in the optical and infrared range. For the optical depth as function of both redshift and observed energy we use the results of [5].

The dimensionless hubble parameter *h(z)* depends on the energy content of the universe which changes with redshift. For this we use the results from the WMAP three-year data [12].

Particle Physics

The preferred particle physics model enters the differential gamma-ray flux via the cross section σ, the WIMP mas $M\chi$ and the differential gamma-ray yield per annihilation *dN/dE.*

The annihilation yield is of the form:

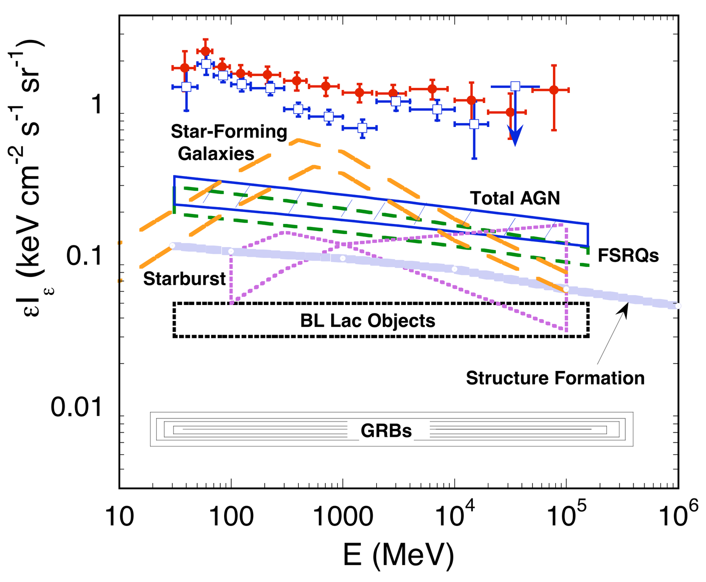
$$\frac{dN_\gamma(E)}{dE} = \frac{dN_{\rm cont}}{dE}(E) + b_{\gamma\gamma}\delta\left(m_\chi - E\right)$$

The first term is the contribution from WIMP annihilations into the full set of tree-level final states, containing fermions gauge or Higgs bosons, whose fragmentation/decay chain generates photons. These processes give rise to a continuous energy spectrum.

The second term is a line originating from annihilation into a two-photon final state. Although of second order, this term gives rise to monochromatic photons with energy $E = M\chi$.

Previous observations and backgrounds

The first indications of an isotropic, possibly extragalactic, flux came from the SAS-2 satellite [6] and where later confirmed by EGRET [7]. The determination of the extragalactic diffuse γ-ray background emission is, however, a very difficult task; in particular, it is dependent on the particular galactic foreground model. The first analysis that came out of EGRET has later been redone [8], with a different model of the galactic diffuse γ-ray continuum, using the GALPROP simulation code.



A comparison of the EGRB from Seekumar et al. [7] (red) and Strong et al. (blue) together with estimates of different diffuse, extragalactic backgrounds from unresolved point sources. Diagram taken from Dermer [8].

The "standard" model for explaining the EGRB is that it consists of diffuse emission from unresolved, γ-ray point sources such as blazars, quasars, starburst galaxies and starforming galaxies. Contributions from unresolved blazars, consistent with the EGRET blazar catalogue, could account for about 20% of the measured EGRB at 1 GeV. Taking into account predictions of starburst and starforming galaxies one gets about the measured values of the EGRB at 1 GeV [9]. However, these models under-predict the γ-ray flux at higher energies,arguing for new , hard γ-ray sources.

References:

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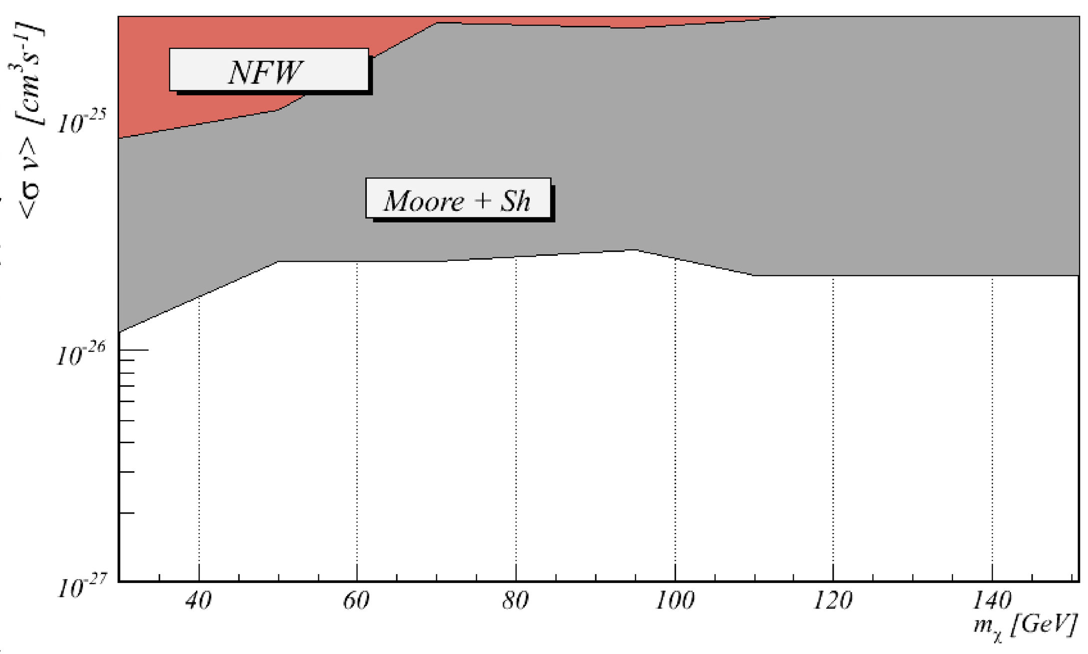
GLAST sensitivity

Fast detector simulations were done for a generic model of WIMPs annihilating into 2γ, giving a line, and into bb-bar, which gives a continuous spectrum, for different WIMP masses ranging from 50 GeV to 250 GeV. A $\chi 2$ analysis was performed, assuming that the background consists of unresolved blazars [2], to obtain a sensitivity plot in $<\sigma v>$ vs $M\chi$. The WIMP signal was computed using two different halo profiles for the normalization: the NFW profile [9] and one from Moore et al. [10] where we also have included the effect of substructures, assuming that they have three times the concentration parameter of the parent halo. The concentration parameters, as a function of halo mass, is distributed according to [13].

The result shows that GLAST is sensitive to total annihilation cross-sections of the order 10^{-26}-10^{-25} cm^3 s^{-1}, depending on the exact halo model, for a generic spectral shape consisting of a line and a continuum part.

It should be noted that, would the dominant fraction of dark matter indeed be thermal WIMPs annihilating according to our simplified model, cosmology would, to first order, constrain the cross-section to be $<\sigma v> \sim 3\cdot10^{-26}$ cm^3 s^{-1}. However, there are models and scenarios for dark matter that do allow for larger cross-sections, see eg. [11].

One should also note that the extragalactic background spectrum from astrophysical sources is very uncertain, especially at high energies.



3σ exclusion curves for one year of GLAST simulated data. Moore+Sh denotes the model according to Moore et al [10] with substructures, NFW denotes the Navarro Frank White profile [9].