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# EGRET EXCESS OF DIFFUSE GALACTIC GAMMA RAYS AS A TRACE OF THE DARK MATTER HALO*

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The diffuse Galactic gamma ray data, which were measured by the EGRET experiment, show a clear excess for energies above 1 GeV in comparison with the expectations from conventional Galactic models. The excess is seen with a similar energy spectrum in all sky directions, as expected for Dark Matter (DM) annihilation. The spectral shape of the excess is used to limit the WIMP mass to the 50–100 GeV range, while its directional dependence is used to determine a halo profile, which is consistent with a triaxial isothermal halo with additional substructure of Dark Matter in the disc. The latter is strongly correlated with the ring of stars around our galaxy at a distance of 14 kpc, thought to originate from the tidal disruption of a dwarf galaxy. It is shown that this ring of DM causes the mysterious change of slope in the rotation curve at $R = 1.1\,R_0$.

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## 1. Introduction

Cold Dark Matter (CDM) makes up 23% of the energy of the Universe, as deduced from the WMAP measurements of the temperature anisotropies in the Cosmic Microwave Background, in combination with data on the Hubble expansion and the density fluctuations in the universe [1]. The nature of the CDM is unknown, but one of the most promising candidates are weakly interacting massive particles (WIMPs). If the WIMPs are Majorana particles they can annihilate into pairs of Standard Model (SM) particles. The stable decay and fragmentation products are neutrinos, photons, protons, antiprotons, electrons and positrons. From these, the protons and electrons disappear in the sea of particles in the universe, but the photons and antimatter particles may be detectable above the background, generated by

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particle interactions. In this analysis we focus on gamma rays from *all* sky directions. Gamma rays have the advantage that they point back to the source and do not suffer energy losses, so they are the ideal candidates to trace the Dark Matter density, if one assumes the boost factor, representing local density fluctuations of the DM, to be similar in all directions.

## 2. Diffuse gamma rays

The EGRET experiment measured a sky map of the diffuse gamma rays [2]. With the propagation code `GalProp` [3] it is possible to calculate the flux for all directions and energies. If the propagation model parameters are tuned to reproduce the well measured fluxes of electrons and protons as well as the Boron to Carbon ratio (conventional model), it turns out that the propagation produces too less gamma flux at high energies beyond 1 GeV [4]. The main contribution of gamma rays are from the decay of pions produced in interactions of protons with the interstellar gas. The proton spectrum has to be harder to get $\pi^0$s with higher energy, which leads to a harder gamma spectrum (optimized model) [4]. But this model violates the locally measured spectrum of protons. This problem can be solved by the assumption that the proton flux at the earth is not representative for the whole Galaxy. In this case one looses the predictive power of the model. The excess in EGRET data for the conventional model is shown in figure 1.

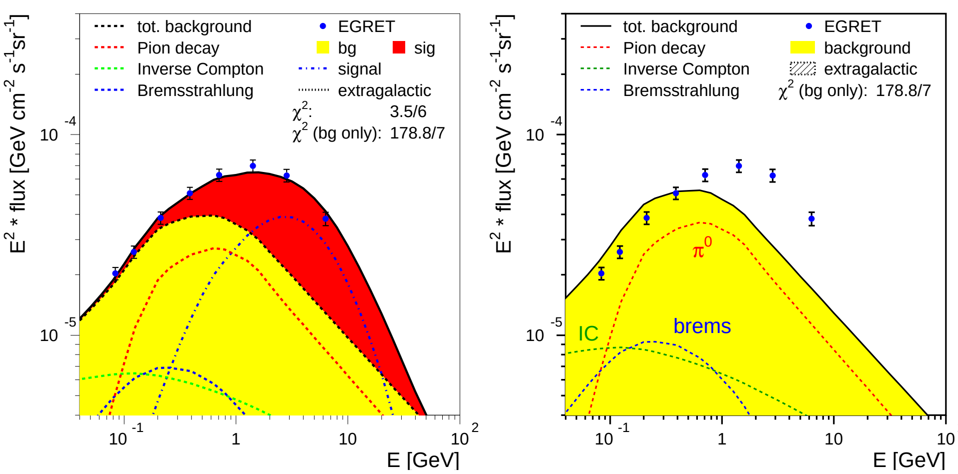


Fig. 1. Comparison of EGRET data and the Conventional Model. On the right hand side a DMA contribution is added to the Galactic background to explain the EGRET data better.

### 3. Dark Matter halo model

The energy dependence of the excess is similar for each region of the sky [5]. This leads to the assumption that the excesses in different directions have a source of the same origin, *e.g.* a DMA signal. If one adds such a signal to the GalProp prediction, the agreement of theory and data is improved significantly as can be seen in figure 1. The annihilation signal is calculated with the program package `DarkSusy` [6] for the case that DM has a supersymmetric nature. Since the annihilating WIMPs are almost at rest the spectral shape of the signal depends mainly of the WIMP mass. By scanning over the WIMP mass one gets an allowed range between 50 and 100 GeV [5]. The annihilation signal is proportional to the density squared, so it has to be multiplied by a boost factor, due to the clumpyness of the Dark Matter. Most of the DM is located in small clumps, which implicates the boost factors are similar for each region of the sky. However, since the absolute values of the excesses are different, the DM has to be distributed in such a way to fit the data over the whole sky. A possible parametrization of such a halo model looks like

$$\rho(r) = \rho_0 \left(\frac{r}{a}\right)^{-\gamma} \left[1 + \left(\frac{r}{a}\right)^{\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} ,$$

where $a$ is a scale radius and the slopes $\alpha$, $\beta$ and $\gamma$ can be thought of as the radial dependence at $r \approx a$, $r \ll a$ and $r \ll a$, respectively. The spherical profile can be somewhat flattened in two directions to form a triaxial halo.

To test a halo model, we divide the sky maps in 4 (latitude) times 45 (longitude) regions. Then we compare prediction and signal above 0.5 GeV with an uniform boost factor. The background was normalized to energies below 0.5 GeV, where the contribution of the DMA signal is expected to be small. If the halo model is chosen to be an isothermal profile ($\alpha = \beta = 2$, $\gamma = 0$) and the longitudinal profile in the Galactic plane is compared with the data, one can see that the fit is rather poor (see figure 2) while above the Galactic Plane the fit is acceptable. This implies that additional DM is needed in the Galactic Plane. It is usually assumed that DM does not interact with the visible matter. However, at the center of a spiral galaxy the gravitational potential is completely dominated by the visible matter and the DM halo will adjust to it. This adiabatic compression can lead to an enhancement of the DM density by factors of a few near the center of the Galaxy [7]. The DM usually forms sheets and filaments by gravitational collapse. Galaxies are formed along these topological structures, which leads to correlations in the orientation of galaxy clusters, but can lead to anisotropic infall at the galactic scale as well. Such an anisotropic infall along a filamentary structure can increase the density in the plane, preferentially at large radii, up to 100% [8]. In our Galaxy the observed ring of stars at a radius

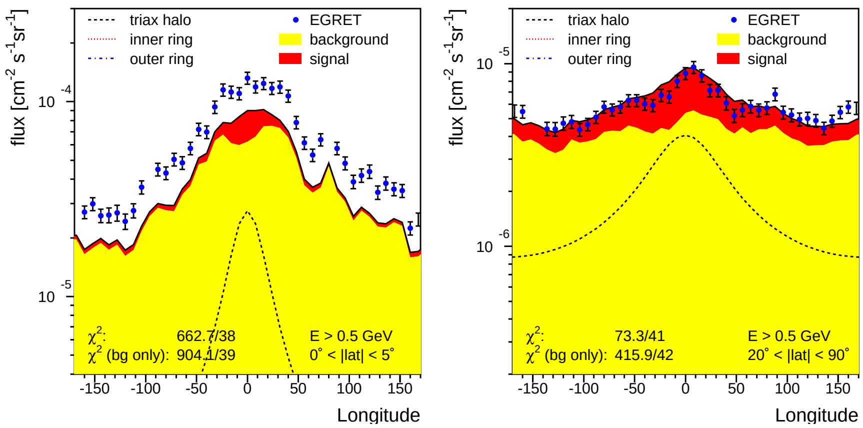


Fig. 2. Fit of an isothermal halo profile to the longitude profile. Since all 4 latitude ranges are fitted simultaneously with one boost factor, the flux is too low in the whole Galactic plane, while above the Galactic plane the fit is much better.

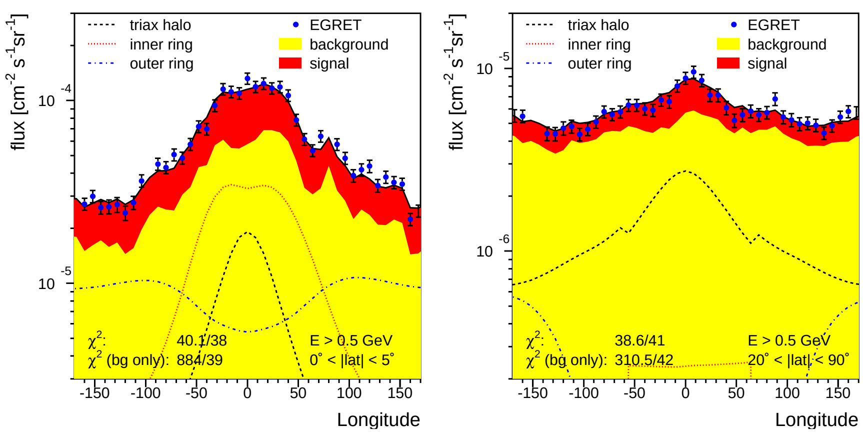


Fig. 3. Fit of the longitude profiles with an isothermal halo profile with additional rings of DM.

of about 15 kpc might be an example of such an anisotropic infall [9]. The radial width of the ring is of the order of 1 kpc. The ring should be disrupted by tidal forces, but the velocity dispersion of the population is small and the ring is stable. One explanation could be, that the stars are sitting in the gravitational minimum of a ring of DM formed by the anisotropic infall of a dwarf galaxy.

The enhancement of DM in the Galactic plane caused by these two effects is included in the halo model by adding an inner and an outer toroidal ringlike structure of DM in the Galactic plane. If the parameters of these two rings are adjusted the fit to the gamma ray data is improved significantly as can be seen in figure 3. It is interesting to note that the radius of the inner ring coincides with the ring of cold dense molecular hydrogen gas, which reaches a maximum density at 4.5 kpc and has a width around 2 kpc [2, 10]. The radius of the outer ring is 14 kpc, which coincides with the ring of stars, which was mentioned above. In our paper [5] the analysis is described in more detail.

## 4. Rotation curve

An additional constraint on the halo models is the rotation curve of our Galaxy. If all the available data [11] are averaged the rotation velocity shows a unexpected change of the slope at $\sim 12$ kpc. Only an increase of the density with increasing $r$, like a ring, is able to cause such an effect. The square of the rotation velocity $v^2$ is proportional to the derivative of the gravitational potential. An increasing density will result in a contribution with the opposite sign to $v^2$. The rotation curve for a halo model without and with rings is shown in figure 4.

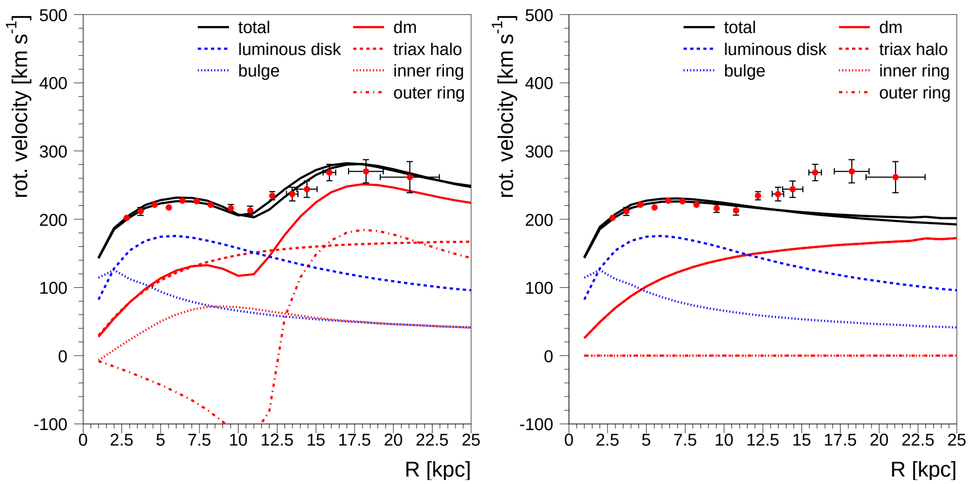


Fig. 4. Rotation curve for an isothermal halo with (left) and without (right) rings.

## 5. Supersymmetric interpretation

Supersymmetric extensions of the Standard Model provide a perfect candidate for Dark Matter: the lightest neutralino. It is a mixture of the SUSY partners of the neutral gauge and Higgs bosons. If $R$-parity is conserved the lightest supersymmetric particle is stable and if it was produced in the early hot Universe and froze out due to the hubble expansion it can explain the non-baryonic cold Dark Matter. The amount of supersymmetric particles which are left over is directly related to the annihilation cross section, which depends on the supersymmetric model parameters. In a recent paper [12] we have shown that it is not possible to constrain the supersymmetric parameter space by means of the relic density, due to a large uncertainty of the heavy pseudoscalar Higgs mass. But the WIMP mass range which is obtained from the spectral fit to the gamma ray data together with additional constraints (*e.g.* the light Higgs mass, the anomalous magnetic moment of the muon or $Br(b \to X_s\gamma)$) it excludes a wide region of the parameter space as can be seen in figure 5. The parameter region which is left over covers small values of $m_{1/2} \sim 100 \ldots 200$ GeV and comparable large values of $m_0$ of a few TeV. This leads to heavy squarks and light neutralinos both in the discovery range of a next generation collider machine like the LHC.

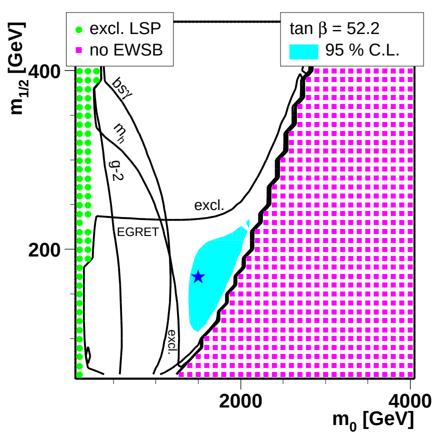


Fig. 5. The shaded area indicates the 95% CL parameter range in the $m_0$–$m_{1/2}$-plane allowed by the EGRET data, if the constraints from electroweak data, a neutral LSP and electroweak symmetry breaking (EWSB) are imposed as well. The individual constraints have been indicated by lines and dots.

## 6. Conclusion

We show the possibility of explaining the excess in diffuse gamma rays measured by EGRET with a DMA signal. The suggested DM distribution consists of a triaxial shaped isothermal profile with substructure in the galactic plane parametrized by one inner and one outer ring. This model explains the peculiar shape of the rotation curve of our galaxy. The WIMP mass needed to fit the spectral shape of the excess is in the range from 50 to 100 GeV, which is within the reach of next generation collider experiments.

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