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The Galactic Center as a Dark Matter γ-Ray Source

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Abstract The EGRET telescope has found evidence for a γ-ray source at the Galactic center (GC). We investigate whether the spectral features of this source are compatible with the γ-ray flux induced by pair annihilations of dark matter weakly interacting massive particles (WIMPs). We show that the discrimination between this interpretation and other viable explanations will be possible with GLAST, the next major γ-ray telescope in space. On the other hand, we also show that if the data will point to an alternative explanation, there will still be the possibility for GLAST to single out a weaker dark matter source at the GC. The talk is entirely based on Cesarini et al. 2003.

Key words: gamma-rays — dark matter — supersymmetry — Galactic center

1 INTRODUCTION

The evidence for cold dark matter (CDM) has been always confirmed over the latest years. Unveiling its nature is one of the major challenges in Science today. Weakly interacting massive particles (WIMPs) are among the leading dark matter candidates and are predicted in several extensions of the Standard Model of particle physics. The most popular case is that of the lightest neutralino in R-parity conserving supersymmetric models. Considerable effort has been put in the search for dark matter WIMPs in the last decade, with several complementary techniques applied (for a recent review, see, e.g., Bergström 2000). Among them, indirect detection through the identification of the yields of WIMP pair annihilations in dark matter structures seems to be a very promising method (Silk et al. 1984, Stecker et al.1985). Here we focus, as a signature to identify dark matter, on the possible distortion of the spectrum of the diffuse γ-ray flux in the Galaxy due to a WIMP-induced component, extending up to an energy equal to the WIMP mass (a list of other recent analysis on this topic includes Bergström et al. 2001a, 2001b, Bertone et al. 2002, Hooper et al. 2002, Merritt et al. 2002, Ullio et al. 02). Let us present in Fig. 1 the EGRET γ-ray data from a region of $\Delta\Omega \approx 10^{-3}$ sr around the GC, collected over a period of 5 years and reaching an energy of 10 GeV (Mayer-Hasselwander et al. 1998).

Our task in section 2 consists in investigating the conditions under which the GC EGRET data can be fitted by adding to the γ-ray background due to standard processes (π^0 decay, inverse Compton scattering, bremsstrahlung) a component due to WIMP annihilations in the

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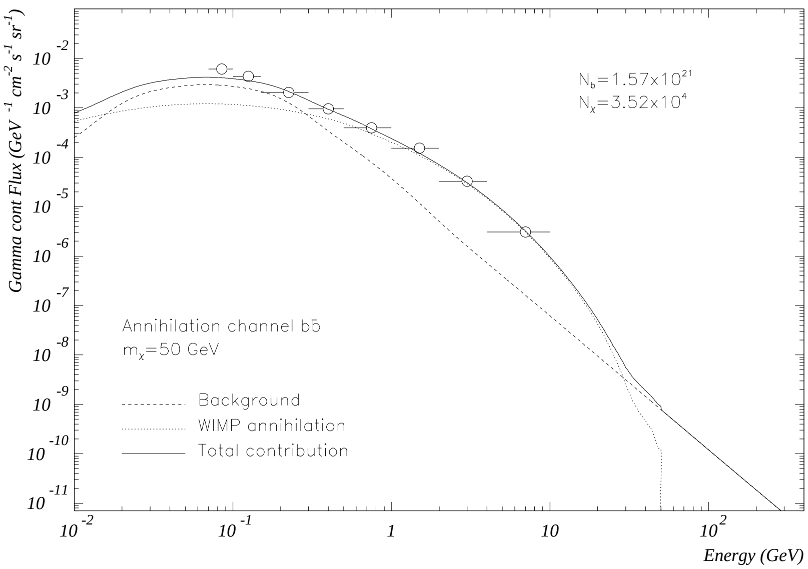

Fig. 1 The points are the EGRET γ-ray data from the GC ($\Delta\Omega \approx 10^{-r}$ sr). The lower line is the best fit using only the π^0-decay background component; the upper line is the corresponding fit when adding a γ-component due to neutralino annihilations.

dark matter halo. In section 3 we consider the possibility in which the GC excess identified by EGRET could not be entirely due to dark matter WIMP annihilations. Under such hypothesis of a weaker WIMP γ-ray signal from the GC, we study the corresponding WIMP signal detection capabilities of the next major γ-ray mission GLAST[1]. Section 4 contains our conclusions.

2 FITTING THE GC EGRET DATA

As already pointed out by other authors (Mayer-Hasselwander et al. 1998), there is a mismatch between the EGRET γ-ray flux coming from a close region ($\Delta\Omega = 10^{-3}$ sr) around the GC and the deficiting expectation due to the standard processes (π^0 decay, inverse Compton scattering, bremsstrahlung). The same situation also arises if one considers the EGRET data taken from a wider region (angular size $\sim 10 \div 20°$) around the GC (see Strong et al. 2000). It is then apparent the existence of an excess problem for the high energy cosmic γ-rays coming from the inner part of our galaxy, that offers the attractive possibility to be solved considering the γ-ray signal due to WIMP annihilations in the dark matter halo. Other possible solutions of such excess problem, that do not involve any WIMP dark matter signal, can be found, *e.g.*, in Strong et al. 2000. We have assumed that the total flux measured by EGRET can be described as the superposition of two contributions:

1. a component due the interaction of primary cosmic rays with the interstellar medium, with spectral shape defined by the function $S_b(E_\gamma)$ (background contribution),

[1] For a detailed description of the apparatus see Bellazzini 2002; a discussion of the main scientific goals can be found in Morselli 2002.

2. a component due to WIMP annihilations in the dark matter halo, whose energy spectrum is defined by $S_\chi(E_\gamma)$ (signal contribution).

We have written the total γ-ray flux as:

$$\phi_\gamma = \phi_b + \phi_\chi = N_b S_b + N_\chi S_\chi. \tag{1}$$

The factor N_b is dimensionless and depends on the density of the interstellar medium and on the primary cosmic ray flux. The factor N_χ is also dimensionless and is determined by the dark matter density profile $\rho(r)$ and by the solid angle under which one observes the GC region ($\Delta\Omega$). S_b depends on the physics governing the interaction of the primary cosmic rays (H or He) with the interstellar medium; while S_χ stems from the physics governing the WIMP annihilations and the consequent γ-ray production. The lack of experimental knowledge of the two normalization parameters N_b and N_χ has lead us to keep them free when fitting the GC EGRET data. Our candidate WIMP particle is the lightest neutralino in the minimal R-parity conserving extension of the standard model (MSSM). Two neutralinos can annihilate in the dark matter halo through an intermediate state given by a fermion-antifermion pair, by the gauge bosons W^+W^-, Z^0Z^0, or by some Higgs particle. Using the Galprop computer code (Strong et al. 2000), we have computed the continuum γ-ray yield due to the reaction chains through these intermediate channels; while using the DarkSusy code (Gondolo et al. 2002) we have obtained the corresponding γ-ray fluxes reaching the earth from the GC where the annihilations take place. The background component S_b has also been computed using the Galprop computer code (Strong et al. 2000). We have neglected the bremsstrahlung and inverse Compton scattering components, and considered only the π^0-decay component, which is supposed (see Strong et al. 2000 and Cesarini et al. 2003) to be the dominant one for the energies concerned in this work ($E > 100$ MeV, as can be seen from Fig. 1). In Fig. 1 we show the fit of the GC EGRET data that can be obtained using only the background component and the corresponding fit that one obtains adding the component due to neutralino annihilations in the $b\bar{b}$ channel and for a neutralino mass $M_\chi = 50$ GeV. For other channels the situation is similar. We see that the fit improves when adding the susy flux and we can give a quantitative measure of such improvement by giving in Fig. 2 the reduced χ^2 of the fit in the plane of the neutralino mass and of the dark matter density normalization factor N_χ. From Fig. 2 we can see that the reduced χ^2 of the fit passes from values higher than 100 to best fit values of the order of 10. An important prediction of this work that can be inferred from Fig. 2 is that the best fits of the EGRET GC data are obtained for low neutralino masses and for moderate neutralino densities (the best fit value of $N_\chi \sim 10^4$ corresponds to a moderate dark matter density profile).

3 GLAST AND THE GC REGION

We have seen that EGRET has identified a γ-ray excess in the GC region ($\Delta\Omega \approx 10^{-3}$ sr). We can now ask how this excess will be mapped by the upcoming detector GLAST, which with respect to EGRET will have a larger effective area, better energy and angular resolutions and will cover higher energy regions. In order to answer this question, we have fitted the GC EGRET data using the π^0-decay background component and the neutralino signal in the $b\bar{b}$ channel, as in Fig. 1. With this sort of parametrization of the GC EGRET data, we have simulated the corresponding data that would be taken by the GLAST detector in a two year observation with $\Delta\Omega$ equal to the EGRET angular resolution ($\Delta\Omega = 10^{-3}$ sr). The results are shown in Fig. 3. Comparing the EGRET data of Fig. 1 with the corresponding GLAST simulated data of Fig. 3, we can verify that GLAST will reach an higher spectral resolution and will have enough statistics to probe energies about 10 times higher than EGRET. GLAST will hence probably permit to say a final word about the necessity or not of an exotic component to explain the

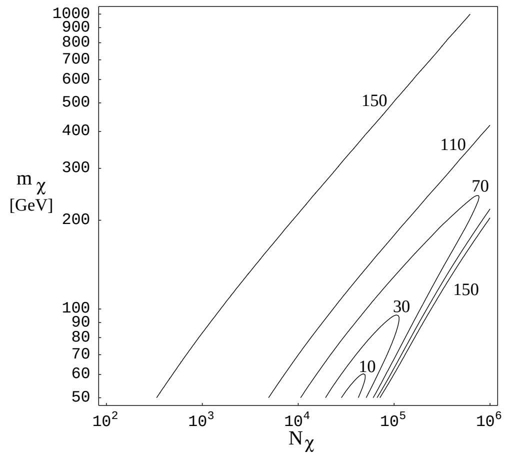

Fig. 2 Plot of the $\chi^2_{\rm red}$ for the fit of the GC EGRET data of Fig. 1 using the γ-ray flux of eq. (1), in the case of neutralinos annihilating in the $b\bar{b}$ intermediate channel.

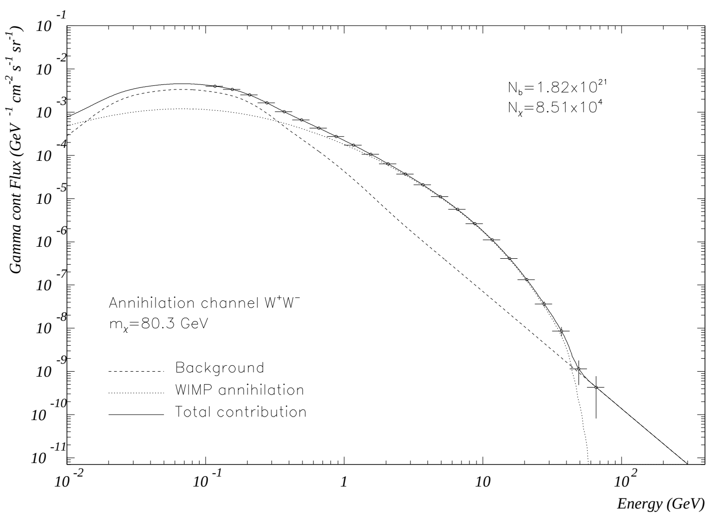

Fig. 3 Data points that GLAST would collect if the GC EGRET source was given by the fit given in Fig. 1. We have assumed two years of observation and $\Delta\Omega = 10^{-3}$ sr.

γ-ray emission from the GC. In Cesarini et al. 2003, it can be found an analogous analysis of the GC EGRET source which shows that, under certain assumptions, the GLAST detector will be capable to probe its angular structure and to detect it as an extended source.

Next we come to the last point of the talk. It could be the case that the GC γ-ray excess detected by EGRET could not be entirely due to WIMP annihilations in the dark matter halo. We have then tried to determine the conditions under which a a signal due to neutralino annihilations, as the one in Fig. 1 for example, could be discriminated from the π^0-decay background component by GLAST. In order to do this, we have fixed the background normalization N_b to the one that best fits the GC EGRET data and have left the N_χ factor appearing in eq. (1) free. Next, for a given supersymmetric model (*i.e.* a given set of weak scale parameters, masses, mixings, *etc.*), we have looked for the minimum value of N_χ that allows the discrimination at 5σ confidence level between the supersymmetric signal and the π^0-decay background flux. For the discrimination we have used a χ^2 criteria. In Fig. 4, we give an example of the typical results. There, we have worked with a particular supersymmetric model, called minimal supergravity scenario (mSUGRA) (see Cesarini et al. 2003), and we have given lines of constant minimum N_χ for the signal detection in the plane of two parameters of the model. For the analysis we have used a two year observation time and $\Delta\Omega = 10^{-5}$ sr, equal to the GLAST angular resolution. We see that GLAST will be able to detect the signal also for values of N_χ of the order of 10^4, that can be shown to correspond to moderate dark matter profiles. In Fig. 4, we have light-shaded the region where the neutralino has a cosmological relic abundance of the right order to constitute CDM ($0.1 < \Omega_\chi h^2 < 1$). The dark-shaded region is excluded by accelerator bounds or by some other physical reason.

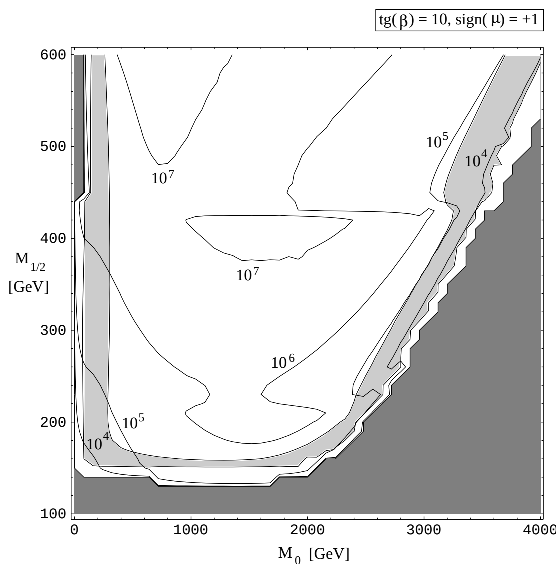

Fig. 4 Lines of constant minimum N_χ (see eq. 1) that allows GLAST to discriminate the γ-ray component from neutralino annihilations from the π^0-decay background component. The plane is a portion of the mSUGRA parameter space. We have assumed a two year observation time and $\Delta\Omega = 10^{-5}$ sr.

4 CONCLUSIONS

EGRET has found evidence for a γ-ray excess in the GC and we can account for this excess using a signal due to neutralino annihilations in the dark matter halo, especially in the case of low neutralino masses. GLAST will be able to measure much better this excess and to discriminate if to account for it an exotic component is really necessary or not. Gamma ray signals from neutralino annihilations in the GC will be detectable by GLAST also in the case in which they are weaker than the GC EGRET source.

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References

Bellazzini R., 2002, Frascati Physics Series Vol.XXIV, 353

Bergström L., 2000, Rept. Prog. Phys., 63, 793

Bergström L., Espö J., Gunnarsson C., 2001, Phys. Rev., D63, 083515

Bergström L., Edsjö J., Ullio P., 2001, Phys. Rev. Lett., 87, 251301

Bertone G., Sigl G., Silk J., 2002, Mon. Not. Roy. Astron. Soc., 337, 98

Cesarini A., Fucito F., Lionetto A., Morselli A., Ullio P., preprint astro-ph/0305075

Gondolo P., Edsjö J., Ullio P., Bergström L., Schelke M., Baltz E. A., 2002, proceedings of idm2002, York, England, September 2002, astro-ph/0211238; http://www.physto.se/~edsjo/darksusy/

Hooper D., Dingus B., preprint astro-ph/0210617

Mayer-Hasselwander H. et al., 1998, Astron. Astrophys., 335, 161

Merritt D., Milosavljevic M., Verde L., Jimenez R., 2002, Phys. Rev. Lett., 88, 191301

Morselli A., 2002, Frascati Physics Series Vol.XXIV, 363

Silk J., Srednicki M., 1984, Phys. Rev. Lett., 53, 624

Stecker F. W., Rudaz S., Walsh T. F., 1985, Phys. Rev. Lett., 55, 2622

Strong A. W., Moskalenko I. V., Reimer O., 2000, ApJ, 537, 763 [Erratum-ibid. **541** (2000) 1109]

Ullio P., Bergström L., Edsjö J., Lacey C., 2002, Phys. Rev., D66, 123502