Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 4 (HE part 1), pages 721–724

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Indirect Dark Matter Search at Intermediate Mass Black Holes with the MAGIC Telescope

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Abstract: Studies of the evolution of Super Massive Black Holes expected in the center of most galaxies predict the existence of some 100-1000 Intermediate Mass Black Holes (IMBH) also in our galaxy. Since IMBHs did not suffer major merging and baryonic accretion, they can have a very high density mini-spike DM distribution. The resulting high annihilation rate would make such objects very bright in gamma-rays. A strategy of searching for such objects as well as first results obtained with the MAGIC telescope are presented.

Intermediate Mass Black Holes

An open question of modern physics is how black holes at the center of many galaxies can reach masses up to 10^9 $M_\odot$, taking the name of supermassive black holes (SMBHs), within the life of the galaxy. In the studies of the evolution of such objects, intermediate mass black holes (IMBHs) play an important role as seeds for larger structure through major merging events. Nevertheless, a number of them are found to remain wandering objects inside the galactic halo [1].
The main characteristics of these putative objects depend on the evolution model, and two main scenarios can be drawn. In the first (Scenario I), around a hundred IMBH with masses around 10^5 $M_\odot$ are estimated to reside in the galactic halo. These IMBHs are formed as a result of the collapse of primordial gas in early forming halos. In the second scenario (Scenario II), a larger number, up to thousands lighter objects with masses around 20 $M_\odot$ are formed after the collapse of primordial low metallicity stars (Pop III stars). In both scenarios, the most characteristic feature is that IMBHs did suffer neither major baryonic accretion nor major merging, which instead characterize the evolution of SMBHs. They evolved almost undisturbed in the halo.
The DM — whichever form it presents — accretes around IMBHs undisturbed. The missing baryonic accretion allows the formation of pronounced enhancements (also called "mini-spikes") in correspondence with the center of the objects, because infalling baryons tend to slow down the dark matter accretion. The upcoming DM density profile of the mini-spike, as discussed below, has important consequences for their detection, and makes them possibly very brilliant objects in the gamma ray sky (the luminosity of an IMBH can be larger than the entire Milky Way DM induced luminosity!).

Gamma-rays emission from mini-spikes

Throughout the paper, we assume a ΛCDM cosmology, with $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$ and $H_0 = 71$ km s^{-1} Mpc^{-1}, and weakly interacting massive particle (WIMPs) as DM candidates. In particular two best candidates are studied: the supersymmetric *neutralino* (χ) in the SUSY framework, and the *Kaluza-Klein* state (LKP) within multidimensional theories. Both theories have a large literature (see for example [2, 3]).
In both scenarios, the annihilation of DM particles can produce gamma-rays in their final states. In the case of the neutralino, the annihilation can produce quark-antiquark couples that in turn hadronize, with the results of the production of a continuum gamma signals. Even if strongly suppressed, also a direct annihilation into two gammas is possible, resulting in a line emission at the DM energy.

$$\chi\chi \rightarrow \mathrm{h}\gamma \quad \chi\chi \rightarrow \mathrm{Z}\gamma \quad \chi\chi \rightarrow \gamma\gamma \qquad (1)$$

The differential spectrum of emission is typically a continuum up to the dark matter mass, with an exponential cut-off. It depends on the annihilation channel and the DM mass, but follows a general behavior [4] with the spectral index always equal -1.5:

$$\frac{dN^i_\gamma}{dx} = \eta \cdot x^{-1.5} \cdot e^{a-b\cdot x+c\,x^2-d\,x^3} \qquad (2)$$

where i identify the quarks, W, Z and gluons channel, $x = E/m_\chi$ is the ratio between the energy of the gamma and the DM mass, and the parameters on the exponential depends on the specific annihilation channel and the DM mass. Basically similar continuous spectra with an exponential cut-off are expected also from the leptonic channel. For the case of $b\bar{b}$ and M_χ 1 TeV, $a, b, c, d = 0.37, 16.05, 18.01, 19.50$ respectively (see [4] for a larger compilation). Figure 1 shows possible gamma-ray emission spectra for different annihilation channels.

The gamma ray flux from IMBHs is governed by the interplay between two factors: the topology of the emission region (the so-called astrophysical factor) and the cross sections of the DM (the particle physics factor). The former factor is connected with the dark matter profile around the object. One of the most widely studied profile, correct at least in the initial enhancements of the forming mini-halos, is the Navarro-Frenk-White profile (NFW) [5]:

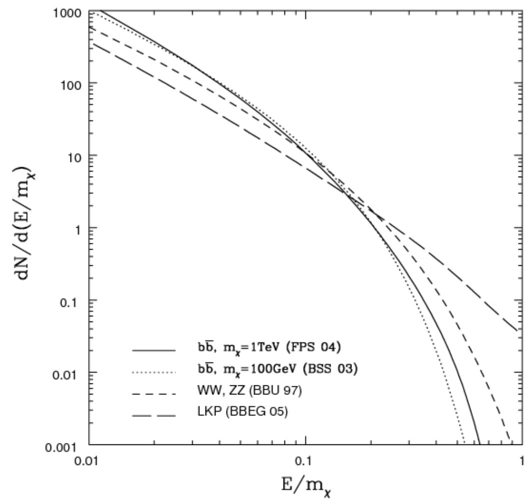

Figure 1: Gamma ray spectra for some neutralino and the LKP particle annihilation channels. Courtesy of [1]

$$\rho(r) = \rho_0 \left[\left(\frac{r}{r_s} \right) \left(1 + \frac{r}{r_s} \right)^2 \right]^{-1} \qquad (3)$$

where r_s is the distance from the center at which the radial profile slope changes. The profile after the adiabatic growth for the case of IMBH is:

$$\rho_{sp}(r) = \rho(r_{sp}) \left(\frac{r}{r_{sp}} \right)^{-7/3} \qquad (4)$$

where r_{sp} characterizes the region where Eq. 4 is valid. The profiles diverge at low radii until the DM annihilation rate defines an inner cut-off r_{cut}, which therefore depends on the DM particle properties and the density itself. The density between the black hole Schwarzchild radius and r_{cut} is then constant and equal to $\rho_{sp}(r_{cut})$).
The gamma-ray flux from DM annihilation from an astrophysical object has the general dependence [2]:

$$\frac{d\Phi(E)}{dE} = \frac{\sigma v}{2m_\chi^2}\frac{1}{d^2}\frac{dN_\gamma(E)}{dE}\int_{r_{cut}}\rho^2(r)\,r^2\,dr \tag{5}$$

where σv is the DM annihilation cross section times relative velocity, d is the object distance, dN/dE is the gamma spectrum and $\rho(r)$ the DM density profile.
In the case of IMBHs, the flux has a special dependence on the parameters [2]:

$$\frac{d\Phi(E)}{dE} \simeq (\sigma v)^{2/7}\,m_\chi^{-9/7} \tag{6}$$

The dependence on the DM mass passes from $\sim m_\chi^{-2}$ as in Eq. 5 to $\sim m_\chi^{-9/7}$ in Eq. 6, thus diminishing the decreasing of the flux as the DM mass increases.

Indirect dark matter observations with IACTs

IMBHs will have cut-off spectra at the DM mass, which is still an unknown parameter. An experimental lower mass limit exists at about 45 GeV from accelerator data and an upper limit at a few GeV is suggested by theoretical arguments [2]. This is an important parameter for a possible detection with the ground Imaging Cherenkov telescopes (IACT technique). Among the present IACTs, the MAGIC telescope [6, 7], located at the Canarian island of La Palma, has the lowest energy threshold at 60 GeV [8], reached thanks to the currently largest reflective surface of 17 m diameter. IACTs reveal the Cherenkov light cone produced by the charged particles of the electromagnetic shower induced by the gamma rays impinging the Earth in the high atmosphere. The light is collected in a multi-pixel camera which allows the *imaging* of the shower to reconstruct the characteristics (energy, direction, impact parameter, etc.) of the primary gamma.
The observability of an IMBH by IACTs therefore depends on the interplay between two factors: the value of the DM mass which determines the cut-off, and the value of the flux. As a consequence, for DM masses around the lower limit, a detection is possible only in case of very large fluxes. The galactic provenience of the gamma rays from IMBHs makes the attenuation from intergalactic radiation fields negligible.
The most important hindrance for DM observation from the ground, comes from the possible composition with other astrophysical gamma-emitters or diffuse gamma radiation. An example of this problem can be found in the observation performed one year ago of the Galactic Center, where there was strong expectations to observe a DM signal. In that case (see for example [9] for the observation and [10] for a discussion on the signal) the DM emission was clearly overshone by the stronger emission from the position coincident compact radio source SgrA*, believed to be a supermassive black hole, or the other coincident source SgrA East, a supernova remnant. For this reason, the search for IMBHs is best performed at high galactic latitudes, i.e. above 20 deg, far from the crowded galactic plane. The search for such objects had been performed for the MAGIC telescope, among the unidentified EGRET sources. Out of 270 sources observed by the satellite experiment, more than a hundred are still unconfirmed by other ground gamma experiments. Satellite gamma experiments like EGRET in the past, and AGILE or GLAST in the future, have in fact the best chance to observe such objects due to the sensitivity extended down to the MeV domain [11].
Among the unidentified EGRET sources, a first selection was performed for steady emitters, using the classification of Ref. [12]. After other quality filters, the spectrum, as observed by EGRET, was extrapolated to the VHE regime using Eq. (2) to estimate the observability for MAGIC, see Fig. 2.

A sample of candidates for observation was thus defined. One of the main problems with the EGRET references is the large uncertainty in the position of the source of on average 1° which collides with the reduced field of view of ground based telescope. A 10 times better positioning is expected from the GLAST sky surveys.

Observations

One candidate for being an IMBH was already observed during the second cycle of data taking with

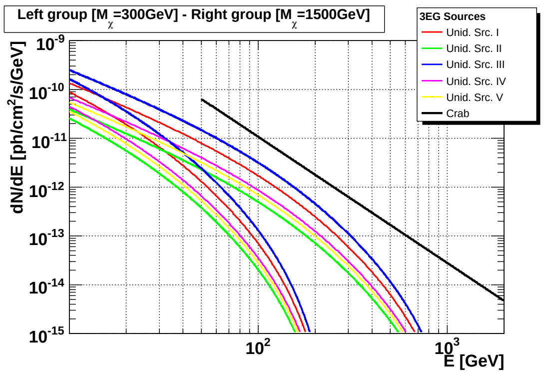

Figure 2: Spectra of a sample of unidentified EGRET sources extrapolated to the VHE regime with the spectrum in Eq. (2)

MAGIC (2005-2006), unfortunately without any clear indication of a signal. Upper limits on the flux could be determined for this source, giving only a very weak constraint on the DM emission from this object in the framework of the IMBH model.

With the new observation performed by the GLAST experiments, whose launch is foreseen within a few months, and also from the AGILE satellite which is already flying, important new pieces of information on the unidentified EGRET sources position, spectrum and flux will be available, allowing a better definition of the candidate observability.

Acknowledgments

We would like to thank the IAC for the excellent working conditions at the Observatory de Los Muchachos in La Palma. The support of the German BMBF and MPG, the Italian INFN and the Spanish CICYT is gratefully acknowldeged. This work was also supported by ETH Research Grant TH 34/04 3 and the Polish MNiI Grant 1P03D01028.

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