Populations of High Energy Sources in Galaxies
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Gamma-Ray Emission from Microquasars

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Abstract. We present models for gamma-ray production in microquasars and we propose them as possible parent populations for different groups of EGRET unidentified sources. These models are developed for a variety of scenarios taking into account several possible combinations, i.e. black holes or neutron stars as the compact object, low mass or high mass stellar companions, as well as leptonic or hadronic gamma-ray production processes.

Keywords. X-rays: binaries, radiation mechanisms: nonthermal, gamma rays: theory.

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1. Introduction

It has been shown in Romero *et al.* (1999) that the distribution of the unidentified EGRET sources with galactic coordinates has a clear concentration of sources on the galactic plane plus a concentration in the general direction of the galactic center. This indicates a significant contribution from galactic sources. On the other hand, studying the galactic sources of the ASM catalog Grimm *et al.* (2002) found significant differences in the 3D spatial distribution of High-Mass X-Ray Binaries (HMXBs) and Low-Mass X-Ray Binaries (LMXBs) in our Galaxy. Whereas HXMBs are more concentrated towards the galactic plane with a vertical scale height of 150 pc, and clear indications of a distribution following the spiral structure, LMXBs have a strong tendency to concentrate towards the galactic bulge and their vertical distribution has a scale height of 410 pc.

2. High-Mass Microquasars – The Galactic Plane Population

2.1. *Leptonic Model: EC of the stellar photon field*

We propose that gamma-rays can be produced by external Compton (EC) scattering of UV stellar photons of the massive companions by relativistic leptons far from the base of the jet. We also take into account the interaction of these leptons with the photon fields of the disk and the corona. All the photon fields that interact with the jet are shown in Fig. 1. Let us consider a binary system where accretion onto the compact object results in the production of twin, relativistic e^+e^--pair jets propagating in opposite directions. The relativistic leptons are considered to have an isotropic power-law density distribution. In the lab frame: $n(\gamma) = \frac{k}{4\pi} D^{2+p} \gamma^{-p}$, with γ, the Lorentz factor of the leptons, k, a constant, and D, the Doppler factor, $D = [\Gamma\,(1 \mp \beta \cos\phi)]^{-1}$ with Γ and β the bulk Lorentz factor and velocity in units of c respectively, and ϕ the viewing angle. The specific luminosity is then obtained by integrating the scattering rate over the particle energy distribution, and multiplying by the observed photon energy and the photon number density (See Kaufman Bernadó *et al.* 2002 for details).

Fig. 2 shows the SED for simple models that we have calculated (see specific values in the caption of the figure). It can be seen that luminosities of $\sim 10^{36-37}$ erg s^{-1} can be obtained in the observer frame at EGRET's energy range, i.e. 100 MeV – 20 GeV

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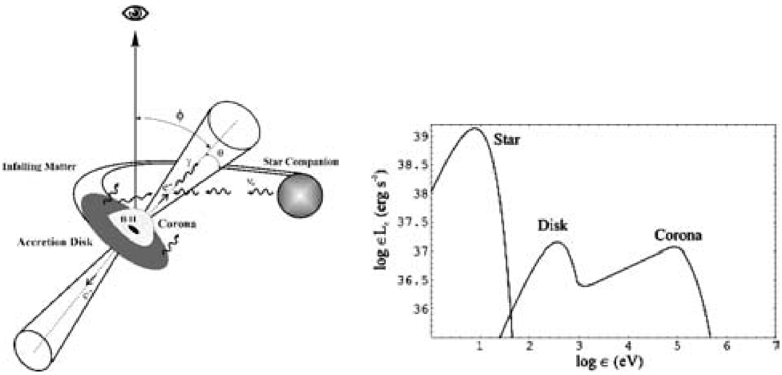

Figure 1. *Left*: The jet traverses photon fields created by the cold accretion disk, the hot corona, and the stellar companion. Inverse Compton up-scattering of some of these photons is unavoidable. Here θ is the half-opening angle of the cone defined by a possibly precessing jet. *Right*: Spectral enegy distribution of the external photon fields to which the jet is exposed.

(left panel of the figure) and therefore some variable unidentified EGRET sources in the galactic plane could be produced by microquasars with precessing jets. Another similar example can be seen in the right panel of Fig. 2 where the important difference with the former case is that the leptons of the jet are assumed to have a high energy cut-off in the TeV range. At TeV energies, where the spectral index is $\Gamma > 3$, the luminosity is $L(E > 1\ \text{TeV}) \sim 10^{32}$ erg s^{-1}. Hence, one of these microquasars located at a few kpc might be a detectable TeV gamma-ray source and thus they are potential targets for high-energy Cherenkov imaging telescopes like HESS or MAGIC.

We also studied the inverse Compton interactions with the other external photon fields due to the accretion disk and the corona (see Romero *et al.* 2002). We concluded that for high-mass microquasars (HMMQs) the predominant contribution comes in general from the scattering of the stellar photon field. This is explained by the higher luminosities obtained in this way for MeV gamma-ray energies. For higher energies, where the luminosities due to the upscattered disk and coronal photons might be important, the absorption by pair creation makes it difficult for these gamma-rays to escape in many cases.

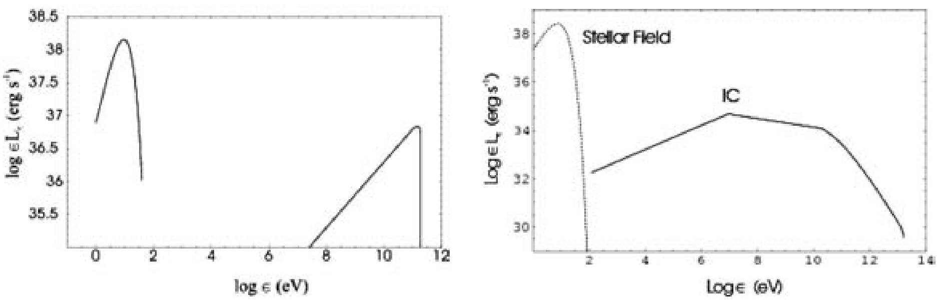

Figure 2. *Left*: spectral energy distribution (SED) of the scattered photons for a microquasar injecting a power-law spectrum of electrons in the photon field of the high-mass stellar companion. A cut-off at Lorentz factors $\gamma \sim 10^3$ has been assumed. The SED of the star is also shown (left top corner). *Right*: Inverse-Compton SED for a microquasar with a massive stellar companion. The jet electron index is $p = 2$ and electrons have a high-energy cut-off at multi-TeV energies. Notice the softening of the spectrum at high-energies due to the Klein-Nishina effect.

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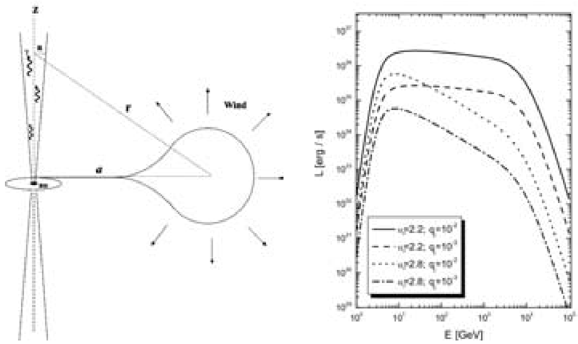

Figure 3. *Left*: In a HMMQ the stellar wind penetrates on a relativistic $e-p$ jet from the sides. The resulting interaction produces gamma-ray emission. *Right*: Spectral high-energy distribution for windy microquasars with proton index $\alpha_{\rm p} = 2.2$ and $\alpha_{\rm p} = 2.8$, for different jet/disk coupling constants (q_j). The jet inclination with respect to the line of sight is assumed to be 10 degrees. An angle of 30 degrees reduces the luminosity by about two orders of magnitude.

2.2. *Hadronic Model*

In this model the gamma-ray emission arises from the decay of neutral pions created in the inelastic collisions between relativistic protons in the jet and the ions of the stellar wind (see Fig. 3). The requisites for the model are a windy high-mass stellar companion and the presence of multi-TeV protons in the jet. The particle spectrum of the relativistic e-p flow is assumed to be a power law: $N'_{e,\,p}(E'_{e,\,p}) = K_{e,\,p}\; E'^{-\alpha_{\rm p}}_{e,\,p}$. Early-type stars, like OB stars, lose a significant fraction of their masses through very strong supersonic winds with typical mass loss rates $\sim 10^{-5} M_{\odot} {\rm yr}^{-1}$ and terminal wind velocities $\sim$2500 kms^{-1}. Some protons pertaining to the wind will diffuse into the jet (see Romero *et al.* 2003 and 2005 for details).

The right panel of Fig. 3 shows the spectral high-energy distribution for models with different values of the proton index and of the jet/disk coupling parameter $q_{\rm j}$, with the results obtained using a numerical integration routine. The luminosities obtained at TeV gamma-ray energies imply that hadronic microblazars which are optically thin to pair production can be detected as unidentified, point-like sources with relatively hard spectra. This kind of sources could display variability. Ground-based Cherenkov telescopes like HESS and MAGIC might detect the signatures of such sources on the galactic plane. Hadronic microblazars might be part of this population, as well as of the parent population of low latitude unidentified EGRET sources. The proposed mechanism predicts as well possible neutrino detections with km-size detectors since these particles are produced in the successive decays that follow the $p-p$ interaction.

3. Low-Mass Microquasars – The Galactic Center Halo Population

In the case of the subset of unidentified EGRET sources whose spatial distribution forms a halo around the galactic center, we suggest that their possible counterparts could be low-mass microquasars (LMMQs) that have migrated away from the galactic plane or escaped from globular clusters. Only leptonic models can be considered for the halo sources since the hadronic ones require the presence of an early type of companion star in order to ensure the existence of strong stellar winds. We performed detailed calculations of the jet inverse Compton emission in the seed photon fields from the star, the accretion disk, and the hot coronal region, in different configurations of parameters such as jet Lorentz factors, powers, and angles with the line of sight (see Fig. 4, left panel).

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These results show that even though the spectral index in the EGRET band matches that of the unidentified sources, the maximum predicted luminosity, $L_{max} \sim 4 \times 10^{29}$ $(E/100\ MeV)^{-0.5}$ erg s^{-1} sr^{-1}, is 5 orders of magnitude too faint to account for the typical halo source fluxes at distances of 5 to 10 kpc.

In contrast with high-mass systems where the external radiation energy density largely surpasses the magnetic one, Synchrotron-Self-Compton (SSC) emission in low-mass systems is likely to dominate even for a modest field strength of about 10G in the jet (see Fig. 4, right panel). The conclusion is that unlike the HMMQs case, the external Compton emission largely fails to produce the required luminosities observed from these unidentified EGRET sources and SSC emission appears as a promising alternative (see Grenier *et al.* 2005).

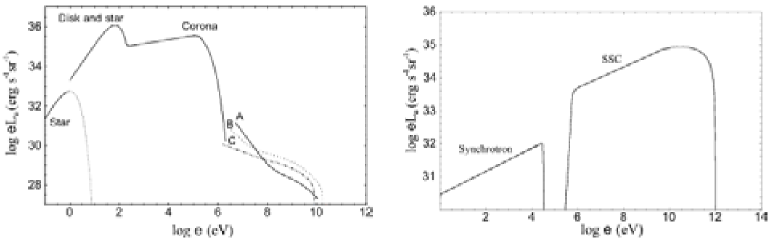

Figure 4. *Left*: SED of the EC emission from the jet of a microquasar with a K-M star companion, seen at angles of 5° (A), 15° (B), and 30° (C) from its axis, for $\Gamma = 3$, $q_{\rm jet} = 10^{-2}$, and a jet electron index p=2.3 with $\gamma_e^{\rm min} = 2$ and $\gamma_e^{\rm max} = 10^4$. *Right*: SED of the synchrotron and SSC emission from the jet of an extreme microblazar, with a 10 G magnetic field, seen at 1° from its axis, for $\Gamma = 10$, $q_{\rm jet} = 10^{-2}$, and a jet electron index p=2.3 with $\gamma_e^{\rm min} = 10$ and $\gamma_e^{\rm max} = 10^5$.

4. Prospects

In order to test these models in a statistically significant number of sources, a new generation of gamma-ray detectors is needed. These satellites are already planned for the quite near future, which is the case of the AGILE and GLAST missions. Their sensitivity is expected to be about 10 to 100 times better than the EGRET one. The existence of TeV emission in MQs might be soon confirmed by new and powerful instruments like MAGIC, HESS and VERITAS. In fact, the detection of microquasar LS 5039 at very high energy gamma rays has just been reported by the HESS collaboration (Aharonian *et al.* 2005). The microquasar LS5039 had already been associated with the EGRET source 3EG 1824-1514 by Paredes *et al.* (2000). On the other hand neutrino observations with IceCube and ANTARES will be crucial with respect to the hadronic model predictions.

References

Aharonian, F.A. *et al.* 2005, *Science* 309, 746
Grenier, I.A., Kaufman Bernadó, M.M., & Romero, G.E. 2005, *Ap&SS* 297, 109
Grimm, H.J., Gilfanov, M., & Sunyaev, R. 2002, *A&A* 391, 923
Kaufman Bernadó, M.M., Romero, G.E., & Mirabel, I.F. 2002, *A&A* 385, L10
Paredes, J.M., Martí, J., Ribó, M., & Massi, M. 2000, *Science* 288, 2340
Romero, G.E., Benaglia, P., & Torres, D.F. 1999, *A&A* 348, 868
Romero, G.E., Kaufman Bernadó, M.M., & Mirabel, I.F. 2002, *A&A* 393, L61
Romero, G.E., Torres, D.F., Kaufman Bernadó, M.M., & Mirabel, I.F. 2003, *A&A* 410, L1
Romero, G.E., Christiansen, H.R., & Orellana, M. 2005, *ApJ* 632, in press

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Discussion

Eracleous: In the cases of precessing jets, the disk has to be misaligned with the orbital plane of the binary. What could cause this?

Kaufman-Bernado: We do not consider why the disk is misaligned. We just assume that they are.

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