Variable gamma-ray emission from microblazars

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Abstract. We propose a model for gamma-ray emitting microblazars based on the Compton interaction of a relativistic electron-positron plasma, ejected in a jet feature, with the UV-photon field provided by a high-mass stellar companion. Taking into account the gravitational effects of the star upon the accretion disk, we predict a jet precession which results in a variable, periodic, high-energy gamma-ray source. The specific case of Cygnus X-1 is briefly discussed.

1. Introduction

The third EGRET catalog contains approximately 170 unidentified gamma-ray sources. A significant number of them seem to be Population I objects. Two main groups of sources are distinguished at mid and low galactic latitudes, one related to the Gould belt region and the other formed by brighter sources at lower latitudes. These sources are suspected to be galactic and their possible counterparts include early-type stars (both isolated and in binary systems), accreting neutron stars, radio-quiet pulsars, interacting SNRs, and microquasars.

We will concentrate on the last possibility, proposing a model for high-energy emission in microquasars with jets forming a small angle with the line of sight. These microblazars are expected to have highly variable and enhanced non-thermal flux due to Doppler boosting.

2. Model

Let us consider high-mass binaries with disk accretion onto the compact object (black hole). Twin relativistic $e^+e^-$-pair jets are ejected in opposite directions. The relativistic plasma is injected into the external photon fields generated by the accretion disk, the corona, and the companion star (typically UV photons), producing inverse Compton (IC) high-energy emission. The resulting IC specific luminosity in the case of external monoenergetic and isotropic photon fields is given by:

$$\frac{dL}{d\epsilon d\Omega} \approx D^{2+p} \frac{kV\sigma_T cU^{2p-1}}{\pi \epsilon_0 (1 + p)(3 + p)} \left( \frac{\epsilon}{\epsilon_0} \right)^{-(p-1)/2}$$

(1)
where $D = [\Gamma (1 - \beta \cos \phi)]^{-1}$ is the Doppler factor, $\phi$ the viewing angle, $\epsilon$ the final photon energy, $\sigma_T$ the Thomson cross section, $U$ the energy density of the photon field, $k$ is a constant, and $p$ is the spectral index of the particle energy distribution given by $N(E) \propto E^{-p}$.

*Figure 1* left panel shows the results obtained from the calculation of the spectral energy distribution for a specific object with $p = 2.3$. Notice that eq. (1) has to be modified by a factor $\left(1 - \cos \phi_0\right)^{(p+1)/2}$ in the case of interactions with disk photons, which arrive from behind the jet. In the coronal case, the resulting spectrum is not a power-law because of the Klein-Nishina effects [8]. Details of the calculations can be found in [9].

![Figure 1. Left: Results of the model for an injection electron spectrum with index $p = 2.3$ in a cylindrical jet forming a viewing angle of 30 degrees. The bulk Lorentz factor is $\Gamma = 5$. Three different component are shown, resulting from the up-scattering of star (A), disk (B), and corona (C) photons. Radiation absorbed in the local photon fields is shown in dashed lines. Parameters for the thermal photon fields correspond to the case of Cygnus X-1. Right: Precessing jet model.](image-url)

The companion star in a high-mass microblazar system not only provides a photon field for IC interactions, but also a gravitational field that can exert a torque onto the accretion disk around the compact object. The effect of this torque, in a non-coplanar system, is to induce a Newtonian precession of the disk. If the jets are coupled to the disk, as it is usually thought [10], then the precession will be transmitted to them (a sketch of this situation is presented in *Figure 1* right panel).

We can then introduce a time-parametrization of the jet viewing angle $\phi(t)$ [11]. In this way, the boosting amplification factor given in eq. (1) will periodically oscillate as a function of time. A very weak, otherwise undetected gamma-ray microblazar can increase its flux due to the precession and then enter within the sensitivity of an instrument like EGRET, producing a variable unidentified gamma-ray source (see [12] for details).
3. Cygnus X-1

This object is a potential candidate for the proposed model. Cyg X-1 is a black hole candidate with $M \sim 10 M_\odot$ and a luminous high mass companion (an O9.7 Iab star with $L \sim 10^{39}$ erg/sec). It presents a continuous non-thermal radio jet with an apparent bending that could be attributed to precession. The source has been repeatedly detected at MeV gamma-ray energies by the interplanetary network and by BATSE.

Calculations of the high-energy (keV-MeV) non-thermal spectrum, taking into account jet interactions with photons from the stellar companion, the accretion disk and the corona have been done (see Figure). It can be observed that the major contribution to the total luminosity is from the IC scattering of stellar photons. For a viewing angle of $\sim 30$ degrees and a half-opening angle of the precession cone of $\sim 16.5$ degrees, there is a variation of about 1 order of magnitude in the emission measured in the observer’s frame because of the precession. This means that when the jet is closer to the line of sight, the maximum non-thermal luminosity can reach values of $\sim 10^{38}$ erg/sec, as observed.

4. Future prospects

Most of the gamma-rays produced within the coronal region will be absorbed by pair creation. The annihilation of these pairs would produce a broad, blue-shifted feature in the MeV spectrum. Soon operating INTEGRAL satellite will be able to probe Cygnus X-1 spectrum and its temporal evolution at this range of energies, providing new tools to evaluate and constrain models like the one presented here. AGILE and GLAST GeV observations will also help to establish the high-energy cut-off of the injected particle spectrum, shedding light on the energetics of the jet.

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