Absorption of GeV and TeV γ-rays in M87 and 3C 273

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Abstract

M87 and 3C273 are famous AGN with powerful jets. High energy gamma-ray emission from these jets has been calculated [10,11] with hadronic models in which accelerated protons interact with internal radiation (synchrotron) and/or external radiation fields. Leptonic models have also been used to model the gamma-ray emission of both objects[1]. GeV to TeV gamma-rays produced in the jets may or may not be absorbed by γ-γ pair production in the radiation fields of the accretion disk and torus. We investigate this problem for M87 and 3C 273. In the case of M87, a mis-aligned BL Lac object, there appears to be a deficiency in dust at parsec scales and we discuss the implications of the possible existence of a non-standard torus in M87 for the GeV to TeV gamma-ray emission from the jet. In the case of the quasar 3C 273, the disk emission is more important, we investigate to what extent the size and location of the gamma-ray emitting blob exposed to the anisotropic radiation field of the accretion disk affects the angular dependence of the gamma-ray absorption.

1. Introduction

The unification scheme for active galactic nuclei (AGN) assumes that the central nucleus of an active galaxy has a supermassive black hole, a relativistic jet anchored to an accretion disk, a dusty torus and clouds emitting broad emission lines. All these constituents but the jet, provide what is known as 'external' radiation fields which are photon targets for hadronic and leptonic jet models.

We shall compare the pair production opacity of GeV and TeV jet photons in the external radiation fields of different types of accretion disks and at different distances from the black hole. As standard models for the accretion disks we have chosen a geometrically thin accretion disk with jet (ADJ)[3] and an advection dominated accretion flow (ADAF)[7]. The ADJ model can explain the blue bump emission of the quasar 3C273, while the latter is suitable for low active AGN such as M87. Both sources, are AGN with relativistic jets pointing away from the observer [8,1]. Recently, the HEGRA team has published the first detection of >730 GeV photons for M87, at the 4σ level [6]. Collmar et al. [2] have reported

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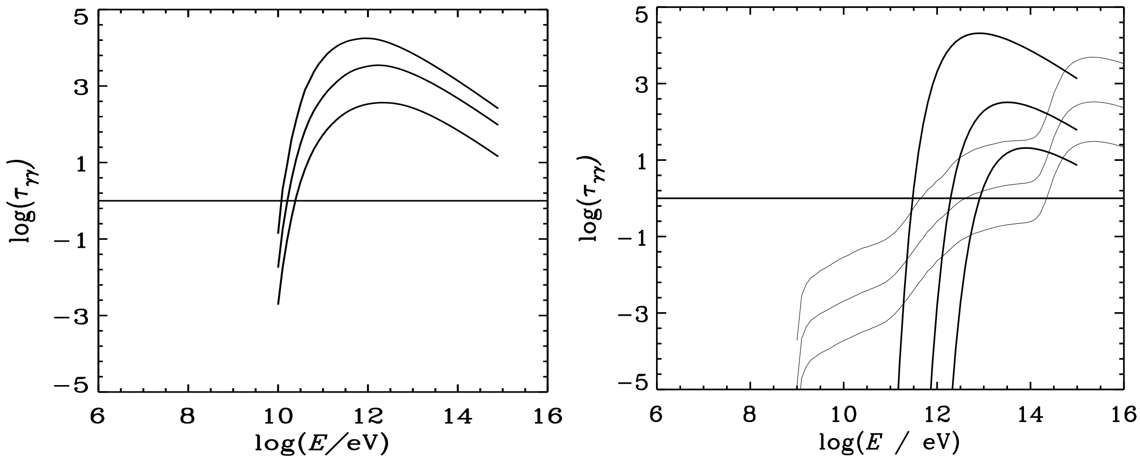

Fig. 1. **Left panel**: Optical depths for the absorption of GeV–TeV photons travelling along the jet from $z = (0.01, 0.1, 1)$ pc (top to bottom) to infinity interacting with ADJ disk photons that account for the 3C273 optical data. **Right panel**: Optical depth from a distance $z \ll 1$ pc from the black hole to infinity: in the infrared field of a compact torus with temperature $T = (100, 250, 1000)$ K (thick curves from bottom to top); in the radiation field of an ADAF(the M87 case) for $z = (0.001, 0.01, 0.1)$ pc (thin curves from top to bottom).

a significant γ-ray flux for 3C273 as detected by EGRET and COMPTEL up to energies of 10 GeV. None of these objects has been detected so far at TeV energies. Therefore, it is likely that photons with GeV and higher energies could have been annihilated by pair production against the disk photons. We analyse this aspect in this paper.

2. GeV-TeV γ-γ optical depths for 3C273

We used a relativistic accretion disk model (ADJ)[3] which is able to reproduce the UV bump in 3C273. The jet is assumed to extract mass and angular momentum from the in-falling gas, as well as energy at the boundary layer of the disk. The jet/disk symbiosis is reflected mainly in a modified photon disk spectrum, which is the target radiation used in the calculations the pair production opacity. In Fig.1 (left panel) we plot the optical depth $\tau_{\gamma\gamma}$ from the emitting region to ∞ of GeV and TeV photons produced in the jet and interacting with photons from an ADJ (parameters used for fitting the blue bump of 3C273: $M \sim 3 \times 10^9 M_\odot$, accretion mass rate $\dot{M} = 10 M_\odot/yr$, radius of the jet's base $R_{\rm jet} = 10 R_g$, where R_g is the gravitational radius, $a_* = 0.9981$, outflow mass rate $\dot{M}_{jet} = 0.1\dot{M}$). The anisotropy of the disk radiation is taken into account. From Fig 1. we can read that photons with energies > 10 GeV could be absorbed when emitted nearby the black hole. In blazars we may have ADJ disks with very low accretion mass rates or ADAFs (see [4] for a detailed analysis) which would provide a much weaker radiation field. Therefore, it is expected that the γ-γ absorption of GeV and TeV is strongly reduced for such objects. The fact that γ-rays at energies above 10 GeV have not been observed in 3C273 suggests that the emitting region could still be imbedded in the radiation field of the accretion disk or the internal radiation of the blob participates to the pair annihilation process.

Note about the very weak anisotropy of $\tau_{\gamma\gamma}$ on the surface of the blob: since the emission region in blazars and other types of AGN is seen as a "blob", we consider a sphere that emits GeV-TeV γ-rays and is exposed from behind to the anisotropic accretion disk radiation. The longitudinal size of the blob is neglected in this example. We calculated $\tau_{\gamma\gamma}^{blob\to\infty}$ of 100 GeV photons emitted all over the surface of the blob (Fig. 2). As expected 100 GeV photons directly exposed to the ADJ photons (same model as in Fig.1) would be easily absorbed. However, the anisotropy of $\tau_{\gamma\gamma}$ is per total very weak since the radius of the blob is smaller compared to its distance to the black hole. This analysis is a a tool for future studies of internal/external γ-γ absorption anisotropies when different radiation fields are considered.

3. γ-γ optical depths for M87: the torus and the ADAF radiation

M87 is usually classified as a Fanaroff-Riley Class I (FRI) radio galaxy having a relativistic jet. Despite of its proximity to us ($\sim$16 Mpc) it is not known with certainty whether or not M87 has a dusty torus. In the context of unification theories of AGN it is hard to accept that M87 completely lacks a dusty component. The lack of a prominent UV bump suggest that the inflowing gas settles into an ADAF[9]. As a consequence, the heating of any dusty torus would be currently inefficient. We have shown that M87 might still have sufficient dust around the nucleus such that its infrared emission may affect the escape of γ-rays[5]. We calculate the photon-photon pair-production optical depth $\tau_{\gamma\gamma}$ of GeV-TeV photons emitted by the jet of M87 interacting with IR photons from the torus as in [5]. The opacity is integrated from $z \ll 1$ pc to infinity (see Fig 1, right panel). The γ-γ opacity for the same γ-rays interacting with the anisotropic ADAF radiation field is also shown for three different positions of the emitting blob. The ADAF spectrum is taken from [9]. Our estimates show that the jet TeV emission (if produced in M87) could be attenuated only if the emission region is sufficiently close to the ADAF disk and the torus is cold enough.

Here we would like to comment on the relevance of the HEGRA measurements for the detection of the dusty torus in M87. The observed γ-ray HEGRA flux is in good agreement with our SED prediction[10]. Given the HEGRA data it is now possible to infer some of the hidden properties of the dusty torus. The fact that HEGRA has detected γ-ray emission at 730 GeV confirms that the torus (if it exists, see [5] and references therein for a complex discussion) should be

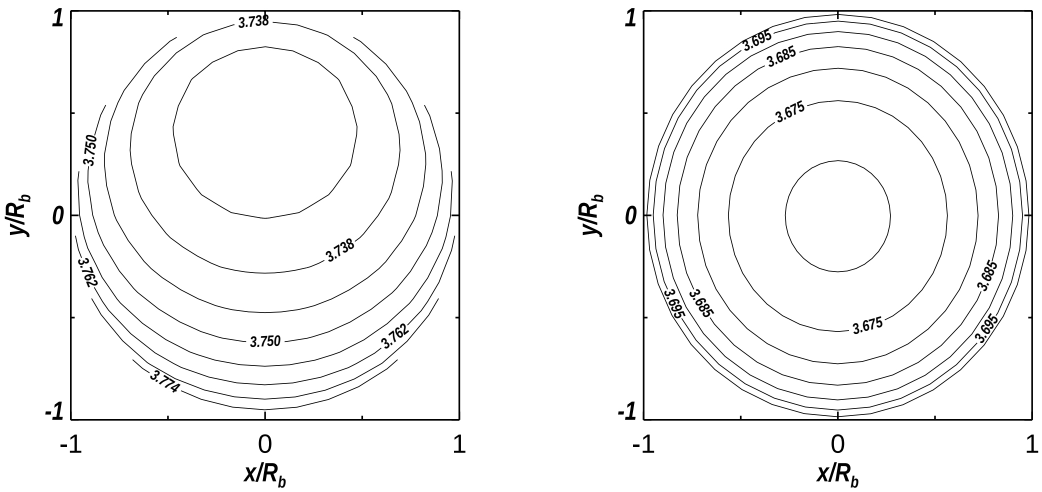

Fig. 2. The projected surface of the blob with radius $R_b = 3 \times 10^{15}$ cm on a plane perpendicular to the observer line of sight. Contour plot lines show the logarithms of $\tau_{\gamma\gamma}$ from the blob to ∞ of 100 GeV photons emitted at the blob surface. The observer line of sight makes an angle $\theta = 30^o$ (left panel) and $\theta = 0^o$ (right panel) with the jet axis. The blob is located at a distance $z = 0.01$ from the black hole. The anisotropy of $\tau_{\gamma\gamma}$(100GeV) on the surface of the blob is extremely weak for this case.

cold, with a temperature less than ~ 250 K, consistent with the interpretation of the directly observed infrared flux[12]. A cold torus prevents the annihilation of photons with energies < 1 TeV. The M87's proximity to us makes the absorption of γ-rays in the cosmic background radiation field insignificant.

4. References

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