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TeV γ-ray source MGRO J2019+37 : PWN or SNR?

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Abstract. Milagro has recently reported an extended TeV γ-ray source MGRO J2019+37 in the Cygnus region. It is the second brightest TeV source after Crab nebula in their source catalogue. No confirmed counterparts of this source are known although possible associations with several known sources have been suggested. We study leptonic as well as hadronic models of TeV emission within the context of Pulsar Wind Nebulae (PWN) and Supernova Remnant (SNR) type sources, using constraints from multi-wavelength data from observations made on sources around MGRO J2019+37. These include radio upper limit given by GMRT, GeV observations by Fermi-LAT, EGRET and AGILE and very high energy data taken from Milagro. We find that, within the PWN scenario, while both leptonic as well as hadronic models can explain the TeV flux from this source, the GMRT upper limit imposes a stringent upper limit on the size of the emission region in the case of leptonic model. In the SNR scenario, on the other hand, a purely leptonic origin of TeV flux is inconsistent with the GMRT upper limit. At the same time, a dominantly hadronic origin of the TeV flux is consistent with all observations, and the required hadronic energy budget is comparable to that of typical supernovae explosions.

Keywords. γ-rays, MGRO J2019+37, Observations.

1. Introduction

MGRO J2019+37 is one of the brightest sources in the Cygnus region and was first discovered by Milagro water Cherenkov telescope with very significant diffuse background. Milagro collaboration detected it with 10.9σ significance above isotropic background level (Abdo *et al.* 2007) and reported this to be a new source in this region . R.A. and decl. of the source are quoted to be $304.83 \pm 0.14_{stat} \pm 0.3_{sys}$ deg and $3.83 \pm 0.08_{stat} \pm 0.25_{sys}$ deg, respectively. Immediately after this discovery it drew attention of many people since it admits higher flux of γ-rays in TeV energies and then it has been associated with known sources in that region. For instance, MGRO J2019+37 has been associated with young Fermi pulsar PSR J2020.8+3649 and this pulsar is also considered to have possible association with one of the EGRET sources 3EG J2021+3716 (Roberts *et al.* 2002). GeV pulsation of this young pulsar was first detected by AGILE and was subsequently confirmed by Fermi observation. Radio observation by GMRT in this region shows no significant emission (Paredes *et al.* 2009) and they put some upper limit on the radio flux. Analysis of X-ray archival XRT data also shows no significant results. Lack of radio counterparts and presence of higher TeV γ-ray flux make it quite interesting source. In this article we built a model to explain the observed TeV flux considering multi-wavelength data which include the following viz., radio upper limit given by GMRT, X-ray upper limit from XRT data, GeV observation by Fermi-LAT (Abdo *et al.* 2009), EGRET (Hartman *et al.* 1999), AGILE (Halpern *et al.* 2008) and very high energy data taken from Milagro, in the framework of both pulsar wind nebula (PWN) and supernova remnant (SNR) scenario.

2. Models

We consider three photon emission processes :i) synchrotron radiation, ii) inverse Compton (IC) emission and iii) decay of neutral pions resulting from p-p collisions for both PWN and SNR scenarios. The spectra of electrons and protons in the emission volume are mentioned below.

2.1. *Pulsar Wind Nebula*

We assume that the nebula is filled with two types of relativistic electrons. First of this type is already cooled down by synchrotron radiation and is present in the nebula throughout the age of the pulsar. These low energetic electrons are called radio electron. The second population is freshly accelerated electrons in the wind and is called wind electrons. Total energy of all electrons are obtained from the rotational energy loss of the pulsar, resulting from its magnetic energy and the energy associated with relativistically charged particles. The spectral energy distribution of the two types of electrons are shown in Eqn. (2.1) and Eqn. (2.2), respectively. While the radio electrons follow single power law spectrum, the wind electrons have power law spectrum with an exponential cut-off at lower end as shown in Eqn. (2.2).

$$\begin{aligned} \frac{dN_r}{d\gamma} &= A_r \gamma^{-\alpha_r} \qquad (\gamma^r_{min} < \gamma < \gamma^r_{max}) \\ &= \quad 0 \qquad\qquad \text{(otherwise)} \end{aligned} \tag{2.1}$$

$$\begin{aligned} \frac{dN_w}{d\gamma} &= A_w \gamma^{-\alpha_w}\, exp\left[-\frac{\gamma^w_{min}}{\gamma}\right] \qquad (\gamma < \gamma^w_{max}) \\ &= 0 \qquad\qquad\qquad\qquad \text{(otherwise)} \end{aligned} \tag{2.2}$$

Energy spectrum of proton is obtained by considering the injected rate of stripped Fe nuclei from the surface of the neutron star and by measuring their acceleration and propagation through the outer gap (Bednarek & Protheroe (1997), Bednarek & Bartosik (2003)). This spectrum may easily be fitted with the power-law spectrum with an exponential cut-off at very high energy. We simply consider that protons inside the nebula follow a power law spectrum with spectral index 2.3 with an exponential cut-off at 1000 TeV.

2.2. *Supernova Remnant*

We consider that the supernova remnant is spherically symmetric and homogeneous and is filled with hydrogen gas with number density n_H. It is widely believed that cosmic particles are accelerated by Fermi shock acceleration in supernovae remnants. Therefore we consider power law spectra for both electrons and protons with same spectral index -2 and with spectral cut-offs for protons and electrons at 500 TeV and 80 TeV, respectively.

3. Results

3.1. *PWN as a candidate*

As mentioned in Sec. 2.1, we consider two different populations of electrons in the PWN scenario and both radio and wind electrons having energy between $\gamma = 1$ and $\gamma = 10^{10}$ with exponential cut-off being 100 GeV for wind electrons, are contributing to synchrotron photon spectra. Using these synchrotron photons as target for IC process we fit the data at GeV energies. In addition to this, CMB photons with mean temperature 2.7K and thermal dust photons having gray body spectrum are also considered as target

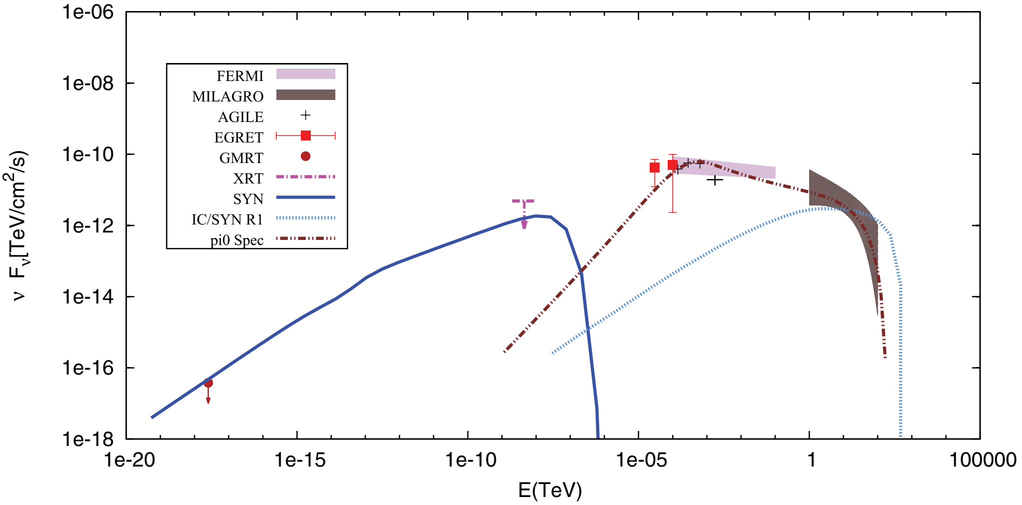

Figure 1. i) γ-ray energy spectrum from electrons for both Synchrotron and inverse Compton radiation processes (solid and dotted line, respectively). For inverse Compton radiation process, $r_{em} \sim 10^{-4}$ pc gives the best value for the fit. ii)(Double dot dashed line) γ-ray energy spectrum from decay of neutral pions ($\pi^0 \longrightarrow \gamma\gamma$) for the ambient proton density of 1 cm^{-3}.

photons. But, synchrotron photons contribute dominantly in this scenario. To calculate the flux from the IC emission we find out the density of target photons in the emission volume as follows: if L_ν is the differential luminosity and r_{em} is the radius of spherically symmetric emission volume, then the differential seed photon number density, n^ν_{seed}, is obtained as $L_\nu/4\pi ch\nu r^2_{em}$. In other words, L_ν is proportional to n^ν_{seed} r^2_{em}. But L_ν is bounded from above by F_{GMRT}/ν in the radio synchrotron range, where F_{GMRT} is the upper limit of radio emission from the position of MGRO J2019+37 in the Cygnus region. This implies an upper limit on n^ν_{seed} r^2_{em}. Since n^ν_{seed} is fixed by TeV flux, we get an upper limit on r_{em}. We estimate the radius of the emission volume to be about $10^{-4}pc$ which gives good fit to the observed TeV data as shown in Fig. 1.

For the case of pure hadronic contribution to γ-rays we consider ambient hydrogen density $< n_H >= 1/cm^3$, spectral index $\beta = 2.3$ and the distance to the source, $D =$ 3 kpc. Normalising proportionality constant of proton energy spectrum to the Milagro data point at TeV energy, we compute the necessary energy that must be supplied to the protons as $E_p \sim 4.5 \times 10^{49}$ ergs. Fig. 1 shows the γ-ray spectrum from decay of π^0's fits well with the TeV data.

3.2. *SNR as a candidate*

For SNR scenario, we also consider that high energy photons are produced by synchrotron radiation, IC process and decay of neutral pions. CMB photons with mean temperature 2.7 k are considered here as dominant targets for IC emission process. For p-p collision, we consider ambient proton density to be $1/cm^3$ as we considered in PWN scenario. Fig. 2 shows the spectral energy distribution of γ-rays for the processes mention above. We see that, leptonic model in this scenario is unable to explain the observed TeV flux due to stringent upper limit on the observed radio flux. But hadronic model can explain the observed TeV flux as shown in Fig. 2. We estimate the total energy of protons to be 3.15×10^{50} which is comparable to that of typical supernovae explosions.

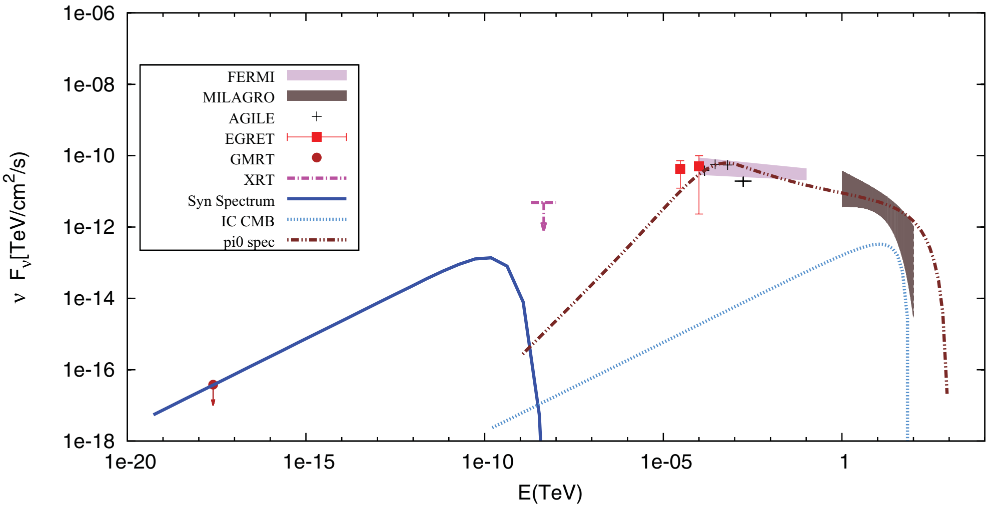

Figure 2. Spectral γ-ray energy distribution for three processes: i) Synchrotron emission spectrum (solid line), ii) IC with CMB photons (dotted line), iii) π^0 decay (double dot dashed line).

4. Conclusions

In this paper we carry out a study to find out the nature of the TeV γ-ray source MGRO J2019+37 as well as to explain the observed flux within the framework of PWN and SNR type sources. We find that for both PWN and SNR scenarios, hadronic contribution to γ-rays can explain the observed TeV flux. Purely leptonic origin of TeV flux can explain the observed flux for PWN and it also brings some constraint on the size of the emission volume. But, SNR scenario is inconsistent with the GMRT upper limit.

References

Abdo, A. A., *et al.* 2007, *ApJ*, 658, L33
Abdo, A. A., *et al.* 2009, *ApJS*, 183, 46
Roberts, M. S. E., *et al.* 2002, *ApJ*, 577, L19
Paredes, J. M., *et al.* 2009, *A&A*, 507, 241
Hartman, R. C., *et al.* 1999, *ApJS*, 123, 79
Halpern, J. P., *et al.* 2008, *ApJ*, 688, L33
Bednarek, W. & Protheroe, R. J. 1997, *PRL*, 79, 2616
Bednarek, W. & Bartosik, M. 2003, *A&A*, 405, 689

Discussion

Chakraborti: Shouldn't the source be self absorbed if it is so compact?

Saha L.: Yes, in general if the source is compact then there will be self absorption. We can consider the scenario in a little bit different way. We consider the density of synchrotron photon varies with distance from the center of the source. It follows gaussion function. Width of the gaussion function is being used to model the source. Using that we estimate the size of the remnant. So, there is still possibility that total size of the emitting volume is higher than estimated size. In that case there may not be that much absorption. We need obviously high resolution observation to unveil the nature of the source and also to get information about size of the emission volume.

SURNIS: What was the upper limit on the 610 MHz pulsar flux at GMRT? What was the resolution of the image?

SAHA L.: GMRT has put an upper limit of 1 mJy at 610 MHz. They have the survey of $3^o \times 3^o$ area as given by Milagro collaboration. In that area they didn't find any significant radio emission.

YADAV: Assuming that the MGRO source is a SNR, why is the the e/p ratio of 10^{-3} lower than that for Puppis SNR which was seen in previous talk? Is it age related?

SAHA L.: In case of Puppis SNR, the e/p ratio is consistent with observed galactic e/p ratio. There are no constraint on the model which explain Puppis multiwavelength data. In case of MGRO 2019+37, we have constraint on the modeling due to lack of radio and x-ray counterpart. Therefore, estimated e/p ratio is lower than observed value. It tells that it could not be source of galactic cosmic rays. It may not be related to age of SNR. Because, if we consider that the electrons are already cooled down as it is an old SNR then we may ask why protons are still getting accelerated. Therefore, that e/p ratio of 10^{-3} could not be related to age of the SNR.