Search for TeV Emission from Galaxy Clusters

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Galaxy clusters are predicted to be emitters of high energy gamma rays due to the relativistic particles accelerated by merger and accretion shocks. The gamma rays are produced either by inverse Compton scattering of relativistic electrons or by high energy proton cascades due to p-p collisions. Some predictions of TeV fluxes from clusters such as Coma are near the sensitivity of current detectors. In this paper we report upper limits for TeV gamma-ray emission from clusters using data from the Milagro gamma-ray observatory. Milagro is a unique TeV gamma-ray observatory, located in the mountains above Los Alamos, NM, that has a ~2 sr field of view and > 90% duty factor, making it ideal for surveying the sky for new classes of TeV astrophysical sources.

1. Introduction

Some fraction of the immense gravitational energy in a cluster of galaxies may result in the nonthermal production of accelerated particles. Observation of gamma-ray emission would be strong evidence for such acceleration. Gamma-rays will be produced by accelerated electrons through inverse Compton scattering on the cosmic microwave background as well as by accelerated protons interacting with matter to produce cascades containing π^o that decay to gamma rays and by the secondary electrons that inverse Compton scatter. These relativistic particles will synchrotron radiate as well and the entire multiwavelength spectrum from radio to gamma rays is needed to constrain the physical mechanisms responsible for the acceleration. Mechanisms such as accretion shocks [1,2] and merger shocks[3] have been considered with the former more capable of accelerating particles to the highest energies.

The nearby massive cluster Coma is a prime candidate for searching for TeV emission. However, there are many more clusters that can also be examined. These clusters can be subdivided by various characteristics, such as x-ray brightness, optical richness, and distance, all of which might be related to the gamma ray emission. For example, x-ray bright clusters have a large amount of hot gas which would serve as a target material for proton cascades. Or optically rich galaxies might represent more massive clusters that would have stronger accretion shocks. And obviously more distant clusters would expect to be dimmer on the average, especially at TeV energies where the gamma rays are absorbed by the extragalactic background of infrared to optical photons.

2. Milagro Analysis

Milagro is a detector for TeV gamma rays with a large field of view of ~2sr and a high duty factor of > 90%. The Milagro data has been used to survey the northern hemisphere sky for point sources of TeV gamma rays [4]. Thus Milagro is ideal to examine a large number of clusters to look for an average excess of TeV emission. The point spread function of Milagro can be approximated by a Gaussian of sigma equal to 0.7 degrees, which is also well suited for searching for emission from clusters. The model of Miniati [3] for accretion shocks in the Coma cluster gives the spatial shape of the predicted gamma-ray emission. Scaling this shape to different redshifts and convolving it with the Milagro point spread function, gives an optimal

bin size of radius 2 degrees for the Coma cluster and slightly smaller bins for larger redshifts where the sources become closer to a point source for which the optimum bin size has a radius of 1.2 degrees.

Clusters were selected primarily from the Abell catalog[5]. The source redshift was required to be less than 0.1 to avoid more distant sources that would have a larger absorption of TeV gamma-rays in transit. The source declination was constrained to be between 5 and 70 degrees where Milagro's exposure is relatively uniform. The analysis was performed for the two cases of considering the emission to be point like or to be extended as discussed previously.

3. Milagro Results

No significant emission was detected from the Coma cluster, the ensemble of 307 clusters, or from the three subdivisions of the clusters by their physical properties. The frequency distribution of the statistical significance of the 307 clusters is shown in Figure 1 as well as the expected distribution from background fluctuations. The different subcategories have similar distributions to Figure 1 in that no individual sources greatly exceed the expected distribution from background fluctuations. Table 1 gives the the upper limits on the average flux and the statistical significance of the combined excess from all the clusters in each of the categories. While all of the entries in the table have slightly positive excesses, this is not evidence of detection due to the low values as well as the different samples are not statistically independent because the same sources are in several categories.

Several authors have made specific predictions of the TeV flux from the Coma cluster [1,2,6] Figure 2 shows the Milagro upper limit placed on the multiwavelength spectral prediction of one of these models. This upper limit is in the range to begin constraining these models.
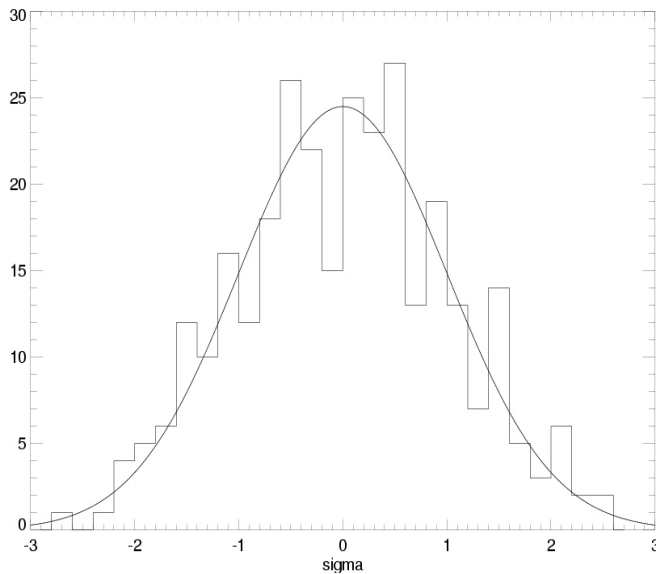

Figure1: The distribution of excess and deficits for 307 galaxy clusters within Milagro's field of view. The units of the x-axis is standard deviations (sigmas) of the Gaussian distributed background. The line shows a Gaussian of sigma equal one centered at zero as would be expected if no emission was detected from the clusters. This analysis was done with a bin size consistent with point source emission.

Table 1. Upper Limits on TeV Flux from Galaxy Clusters with redshift < 0.1 and Declination between 5° and 70°. The flux value given is that emitted by source and takes into account the absorption at different z. A differential photon source spectrum of E-2 is assumed and infrared absorption is given by the worst case absorption model of [7].

| Cluster Characteristic	# of Clusters	Point Source Bin Size of side 2.1°		Larger Bin Size which varies with redshift	
		Statistical Excess *(sigma)*	$E^2 dN/dE$ @ 1 TeV Upper Limit *(ergs/cm^{-2}s^{-1})*	Statistical Excess *(sigma)*	$E^2 dN/dE$ @ 1 TeV Upper Limit *(ergs/cm^{-2}s^{-1})*
Coma Cluster	1	1.8	1.6×10^{-11}	1.2	2.3×10^{-11}
All Clusters	307	0.2	2.0×10^{-12}	1.9	5.1×10^{-12}
All Clusters with x-ray flux>10	52	1.5	5.6×10^{-12}	1.6	9.3×10^{-12}
All Clusters with optical richness ≥ 2	28	1.7	1.0×10^{-11}	2.0	1.6×10^{-11}
All Clusters with redshift<0.04	56	0.9	2.6×10^{-12}	1.6	6.0×10^{-12}
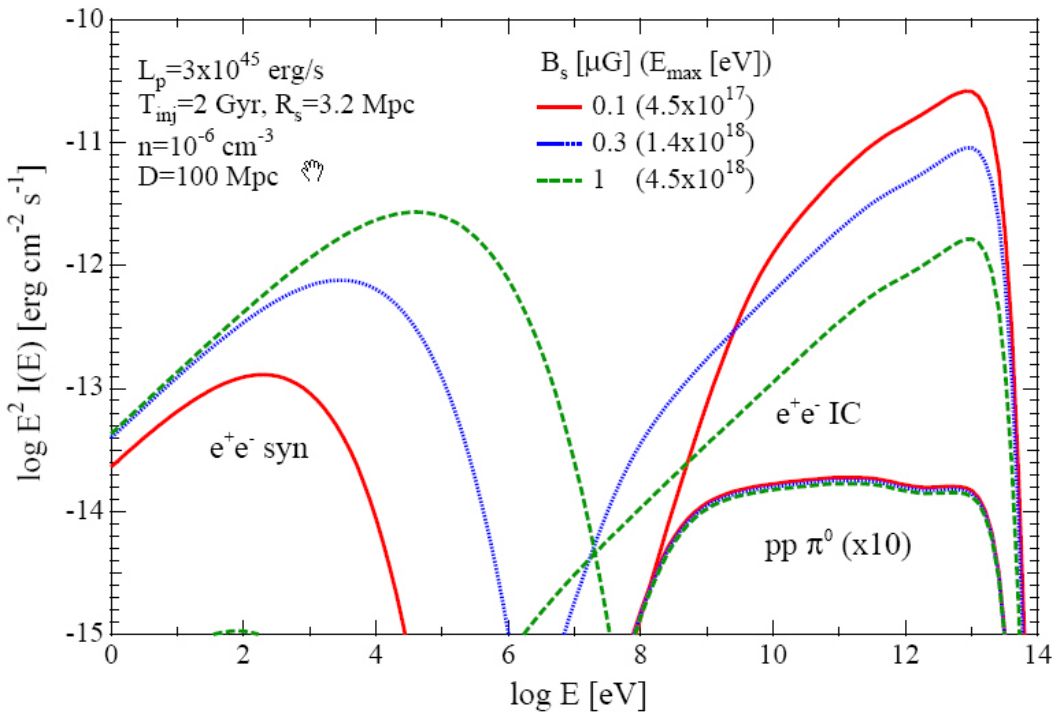
Figure 2: Model of the multiwavelength spectra of the Coma cluster due to protons accelerated in accretion shocks[2] and the Milagro flux upper limit.

4. Acknowledgements

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