Surveying The TeV Sky With Milagro

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Abstract. A wide field of view, high duty factor TeV gamma-ray observatory is essential for studying TeV astrophysical sources, because most of these sources are either highly variable or are extended. Milagro is such a TeV detector and has performed the deepest survey of the Northern hemisphere sky. In addition to detecting the Crab Nebula and Mrk 421, which are known TeV sources, Milagro has made the first detection of diffuse TeV emission from the Galactic plane. The Milagro data has been searched for unknown point sources and extended sources. A new extended TeV source is seen and is coincident with an EGRET unidentified source. Based on the success of Milagro, a second generation water Cherenkov gamma-ray observatory is planned which will give an increase in sensitivity of more than an order of magnitude.

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MILAGRO

Milagro [1] is a water-Cherenkov detector at an altitude of 2650m capable of continuously monitoring the overhead sky and is composed of a central 60m x 80m pond with a sparse 200m x 200m array of 175 “outrigger” tanks surrounding it. The pond is instrumented with two layers of photomultiplier tubes. The top “air-shower” layer consists of 450 PMTs under 1.4m of purified water while the bottom “muon” layer has 273 PMTs located 5m below the surface. The air-shower layer allows the accurate measurement of shower particle arrival times used for direction reconstruction and triggering. The greater depth of the muon layer is used to detect penetrating muons and hadrons to help distinguish between gamma-ray- and hadron-induced air showers. The outrigger array improves the core location and angular resolution of the detector by providing a longer lever arm with which to reconstruct events. The angular resolution improves from ~0.75° to ~0.45° when outriggers are used in the reconstruction.

Milagro’s large field of view (~2sr) and high duty cycle (>90%) allow it to monitor the entire overhead sky continuously, making it well-suited to searching for new TeV sources and scanning known sources at higher energies.

Improved Sensitivity

Two recent developments in the data analysis have improved Milagro’s sensitivity by a factor of ~2 over previously published techniques [2]. One improvement is a new parameter, known as A4, which more efficiently differentiates between gamma rays and the background [3]. The other development is the weighted analysis, in which events that are more likely to be gamma rays are given a higher weight. The weights are derived from Monte Carlo simulations. Use of the A4 parameter combined with the weighted analysis raises the median energy of detected events for a typical source to about 12 TeV.

OBSERVATIONS

An all-sky survey was conducted with data collected between July 2000 and March 2006, using the A4 analysis with event weighting. The brightest point in the survey (at 14σ) was the Crab Nebula, which is the standard candle of TeV gamma-ray astronomy. Markarian 421, an active galaxy known to emit TeV gamma rays, was seen at 4.5σ (the high median energy of this analysis is not good for Mrk 421, which has an exponential cutoff at 4 TeV [4]). In addition to these known sources, the survey detected emission along the inner Galactic plane, with a strong signal coming from the Cygnus region (the region around 75° in Galactic longitude).

Inner Galactic Plane

The detection of TeV gamma rays from the inner Galactic plane has already been reported by the Milagro collaboration [5]. In this analysis, the emission is resolved into regions along the plane, as seen in Figure 2, which shows the plane in Galactic coordinates. The brightest source, at long = 75.0°, lat = 0.6°, is spatially coincident with 2 EGRET unidentified sources (3EG J2021+3716 and 3EG J2016+3657). Analysis using events with the best angular resolution suggest that this source is either extended or that it is more than one source. The observed excess along the rest of the plane is presumably from a combination of point sources and diffuse emission, though the proportions are not yet clear.

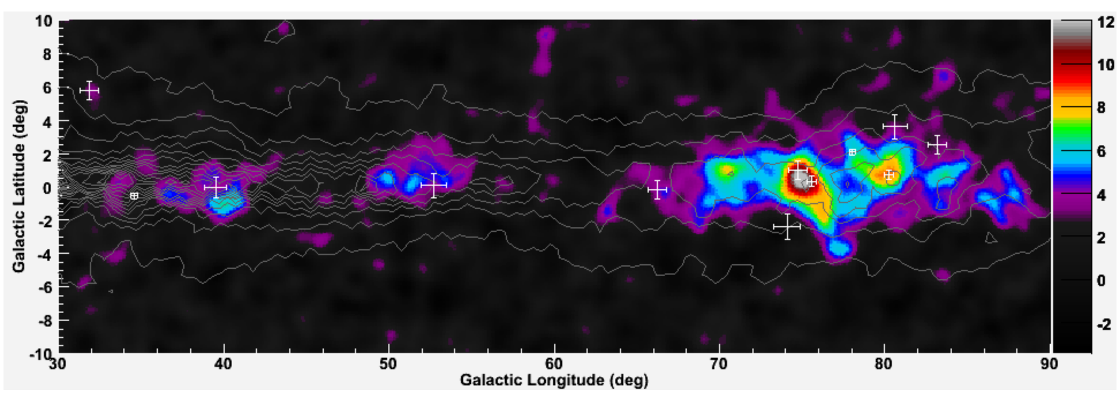

FIGURE 1. Significance map of the inner Galactic plane, in Galactic coordinates. The white crosses mark the positions of EGRET sources detected in the region, with the size of each cross corresponding to the positional uncertainty. The contours are from the EGRET model for diffuse gamma-ray emission [6].

FUTURE DETECTOR – HAWC

Based on the success of Milagro and the lessons learned with the water-Cherenkov technique to observe air showers, a proposal will be submitted to redeploy the Milagro PMTs and electronics in a new configuration called HAWC (High Altitude Water Cherenkov experiment). The HAWC detector will be a 150m x 150m pond at an elevation above 4000m. The PMTs will be placed in a single layer of intermediate depth, and curtains will be placed between the PMTs to provide optical isolation.

Monte Carlo simulations show that HAWC will have ~10 times the sensitivity of Milagro. The Crab Nebula will be detected in 1 day (4 hours), compared to ~4 months with Milagro. This improved sensitivity, combined with the ability to continuously monitor the overhead sky, will enable HAWC to work in symbiosis with other gamma-ray experiments.

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