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A Variability Study of Localized Sources Discovered by Milagro in the Galactic Plane

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Abstract: Milagro is a TeV gamma-ray observatory with a ~ 2 sr field of view and a $> 90\%$ duty factor. A recent survey of the Galactic Plane at 20 TeV by Milagro [3, 2] has discovered three new sources, along with four promising source candidates. Each of the new sources and most of the candidates have likely counterparts in the EGRET GeV catalog, some of which are possibly associated with pulsar wind nebulae (PWN) or supernova remnants (SNR). While such sources are not expected to be variable, the identification is not certain, and so an examination of the variability may help to differentiate between steady sources like PWN and SNR, and variable Galactic sources such as microquasars and x-ray binaries. A search for variability has been conducted on the Milagro sources and source candidates using time scales ranging from one week to a few years. The results of this search will be presented.

Introduction

The number of Galactic TeV gamma-ray sources has grown rapidly in recent years as next generation observatories, such as HESS and MAGIC, have come on line. The majority of these Galactic sources appear to be PWN or SNR [4], which are steady emitters. However, some are associated with X-ray binaries, and periodic emission has been seen [5]. In addition, evidence for variability is seen at GeV energies in many of the EGRET Galactic sources [7]. A Milagro survey of the Galactic Plane has found several new sources and source candidates. A firm identification of the candidates is not yet possible, but a search for variability may shed light on their nature.

The Milagro Detector

Milagro [6] 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 6m 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 $\sim 0.75°$ to $\sim 0.45°$ when outriggers are used in the reconstruction. Milagro's large field of view ($\sim$ 2sr) and high duty cycle ($> 90\%$) allow it to scan the entire overhead sky continuously, making it well-suited to searching for new sources of TeV gamma rays.

Survey of the Galactic Plane

A survey of the Northern Galactic Plane has been conducted at 20 TeV using Milagro data from July 2000 through January 2007 [3, 2]. In addition to the Crab Nebula, the survey found three new sources with high significance, along with four other likely source candidates, as listed in Table 1. The locations and extents shown in the table were found by fitting the event excess of each candidate with a 2-dimensional Gaussian. Most of the entries have likely EGRET counterparts, and several have possible associations with SNR and PWN, though the association is not certain. In addition, several of the candidates appear to be extended, and while extended sources are not expected to be variable, it is possible that the angular extent is due to the superposition of two or more unresolved sources. An examination of the variability (or lack there of) of these sources and source candidates may help in their identification.

Variability Study

For the variability study, weekly maps were generated using the A4 weighted analysis, which is described in [1]. The signal and background events in each map were smoothed according to the Milagro point spread function, which varies with event size and reconstruction method. The average sensitivity of this analysis may be estimated using the significance of the Crab Nebula over the full 6.5-year dataset: for a one-week time scale, a flare of 6 times the Crab flux at the declination of the Crab would result in a 5σ excess. For longer timescales, the sensitivity increases with the square root of time. Note, however, that the sensitivity is better for recent data than it is for the early data, due mainly to the addition of the outriggers.

Results

The results of this analysis will be presented at the conference.

References

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Table 1: Galactic Sources and Source Candidates

Object	Location (l,b)	Error Radius[a]	Pre-trials Significance	Extent Diameter	Counterparts
Crab	184.5, -5.7	$0.11°$	15.0	-	Crab Nebula
MGRO J2019+37	75.0, 0.2	$0.19°$	10.4σ	$1.1° \pm 0.5°$	GEV J2020+3658, PWN G75.2+0.1
MGRO J1908+06	40.4, -1.0	$0.24°$	8.3σ	$< 2.6° (90\% CL)$	GEV J1907+0557, SNR G40.5-0.5
MGRO J2031+41	80.3, 1.1	$0.47°$	6.6σ	$3.0° \pm 0.9°$	GEV J2035+4214, TEV J2032+413
C1	77.5, -3.9	$0.24°$	5.8σ	$< 2.0° (90\% CL)$	-
C2	76.1, -1.7	[b]	5.1σ	[b]	-
C3	195.7, 4.1	$0.40°$	5.1σ	$2.8° \pm 0.8°$	Geminga
C4	105.8, 2.0	$0.52°$	5.0σ	$3.4° \pm 1.7°$	GEV J2227+6106, SNR G106.6+2.9

[a]Statistical errors only. The systematic pointing error is $< 0.3°$

[b]Gaussian fit failed for this candidate.