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# Observations of M87 and Mkn40 at energies $E \geq 250\,\mathrm{GeV}$

**S. Lebohec**[1] **and the VERITAS collaboration**[2]

[1]Department of Physics and Astronomy, Iowa State University
[2]Whipple Observatory, Amado, AZ, 85645, USA

**Abstract.** Both M87 and Markarian 40 (Mkn40) have been mentioned as possible sources of Ultra High Energy Cosmic Rays. This motivated our observations of these two galaxies with the Whipple High Energy Gamma Ray Telescope. Our preliminary upper limit of $2.6 \times 10^{-11} cm^{-2} \cdot s^{-1}$ for the M87 flux above 250GeV nearly constrains models involving inverse Compton radiation.

## 1 Introduction

The galaxies M87 and Mkn40 were both recently mentioned as possible sources of Ultra High Energy Cosmic Rays. The AGASA experiment (Chiba et al. 1992) observed small scale clustering (Takeda et al.1999) at energies above $10^{19} eV$ and $4\times10^{19} eV$ in the direction of Mkn40 (VV144) an interacting galaxy at $z = 0.02$. The reported clustering occurs in a box where only 0.05 events are expected, a situation which could result from a chance coincidence smaller than $1\%$ according to the authors. The giant galaxy M87 at the center of the Virgo cluster has been thought as a possible source of the most energetic cosmic rays for a long time. This idea has been recently revived by the suggestion that UHECR would mostly be coming from M87 if their apparent isotropy is due to a deflection effect from the Milky Way galaxy wind (Ahn 1999). Both objects are at distances small enough for their possible UHECR output to remain only marginaly affected by the GZK cut-off at $5 \times 10^{19} eV$ (Greisen 1966). Both objects have size scales allowing the magnetic confinement of the most energetic cosmic rays (Hillas 1984).

This motivated the observation of Mkn40 and M87 with the Whipple $\gamma$-ray telescope at energies above $250 GeV$. The galaxy M87 also is a potential $\gamma$-ray emitter for reasons which a-priori are not connected with the question of the origin of UHE cosmic rays. For example, M87 being a dense system dominated by dark matter could be a $\gamma$-ray emitter due to neutralino annihilation (Baltz 1999). However it seems that the sensitivity of the current detector would only constrain marginal models of super-symmetric dark matter unless dark matter cusps extend to the galaxy center(Gondolo 2000). More interestingly, M87, a Fanaroff-Riley I (FRI) radio galaxy, presents all the characteristics of a misaligned high energy BL Lac (HBL) object with a jet $\sim 30^o$ from the line of sight (Tsvenatov 1998). Accordingly to this description of M87, the X-ray hump at $10^{15} - 10^{16} Hz$ could be of synchrotron nature. This picture leads Bai and Lee (2001) to expect a detectable inverse Compton component above $250 GeV$ reaching the level of $1.1 \times 10^{11} erg \cdot cm^{-2} \cdot s^{-1}$.

## 2 Observations and analysis

Mkn40 and M87 observations were made with the Whipple Observatory atmospheric Cherenkov imaging telescope (Cawley 1990). The telescope is located at an altitude of 2300m and consists of a 10 m diameter optical reflector with a 379 fast photomultiplier tube (PMT) camera (Finley 2001) in the focal plane with a spacing of $0.12^o$. For point sources, the image shapes and orientations can be used to distinguish $\gamma$-ray images from a much larger number of cosmic-ray hadron images (Hillas 1985).

Some observations were carried out in a standard ON-OFF mode in which the source (ON) is tracked for 28 minutes after which the telescope tracks a background region (OFF) covering the same path in elevation and azimuth for another 28 minutes. Some observations were carried out in a standard TRACK mode in which on source observation are not complemented by a background specific observation. Mkn40 was observed in 2000 and we obtained 2 ON-OFF pairs and 18 TRACKING runs. During the years 2000 and 2001, a total of 31 runs were taken in the direction of M87 with 12 of them in the ON-OFF mode. The telescope was triggered when any three neighbors (Bradbury 1999) out of the 379 PMTs exceeded a threshold corresponding to $\sim 15$ photoelectrons.

All observations presented in this paper were obtained at

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*Correspondence to:* S. LeBohec (lebohec@iastate.edu)

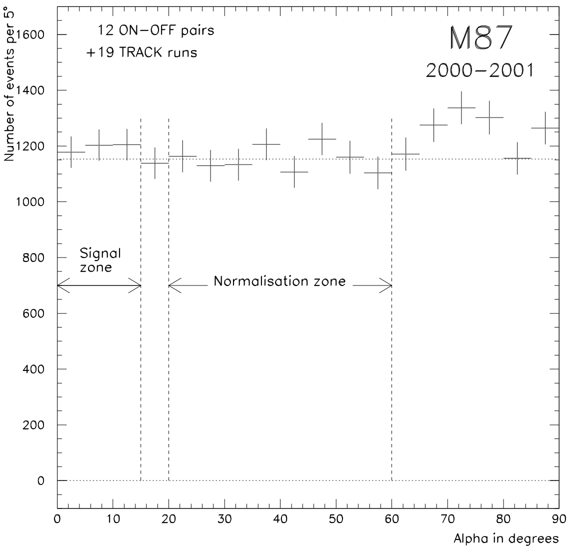

**Fig. 1.** Orientation angle distribution from which we derive an upper limit fo M87 $\gamma$-ray emission above 250GeV.

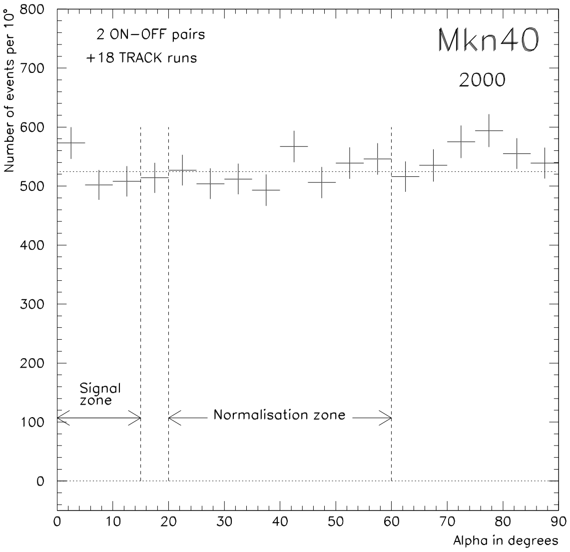

**Fig. 2.** Orientation angle distribution from which we derive an upper limit for Mkn40 $\gamma$-ray emission above 250GeV.

an elevation larger than $54^o$ and from Monte Carlo simulations we found that, if analyzed as described below, the 2000 data had a peak energy of $430GeV$ while in 2001 the peak energy was at $390GeV$.

Software "padding" (Cawley 1993) is used to compensate for differences in noise level in the ON and OFF runs. The image is also "cleaned" (Reynolds 1993) to alleviate the noise effects of pixels that are not part of the shower image. The image is then characterized by the image parameters calculated from the $1^{st}$ and $2^{nd}$ moments of the recorded light distribution. The image parameters are *Length*, *Width* and *Distance* from the center of the field of view (Fegan 1997). Boundary values applied on the image parameters and orientation for the events to be selected as $\gamma$-ray candidates were derived by maximizing the significance of the Crab Nebula observations obtained under similar conditions.

## 3 Results and conclusion

The signal should appear as an excess in the number of events with a small orientation angle as obtained after applying the selection criteria. The orientation angle distribution we obtained for our Mkn40 and M87 observations are shown in figure 1 and figure 2 respectively.

From Mkn40 we recorded an excess of +10 events with a significance of $+0.2\sigma$. By normalizing this result to our $\gamma$-ray detection rate toward the Crab in 2000 we derive the $3\sigma$ upper limit on the $\gamma$-ray flux from Mkn40 above $250GeV$ to be $1.9 \times 10^{-11} cm^{-2} \cdot s^{-1}$. This corresponds to an energy flux $3\sigma$ upper limit of $2.2 \times 10^{-11} erg \cdot cm^{-2} \cdot s^{-1}$. To our knowledge Mkn40 has never been observed before in this energy range.

From M87 we recorded an excess of +83 events in 2000 and +42 events in 2001 corresponding to significance of $+1.6\sigma$ and $+0.9\sigma$ respectively. By normalizing this result to our $\gamma$-ray detection rate toward the Crab in 2000 and 2001 we derive the $3\sigma$ upper limit on the $\gamma$-ray flux from M87 above $250GeV$ to be $2.2 \times 10^{-11} cm^{-2} \cdot s^{-1}$. This corresponds to an energy flux $3\sigma$ upper limit of $2.6 \times 10^{-11} erg \cdot cm^{-2} \cdot s^{-1}$. This is an improvement over previous results obtained with the same detector (Weekes 1972, Cawley 1985). It can be compared to the predictions from Bai and Lee (2001). Our $3\sigma$ upper limit is at a comparable level as the possible Compton component derived in their paper and does not support it. We searched for correlation between the excess we recorded toward M87 and the RXTE-ASM one-day averaged data with no success. The strongest flare observed with RXTE being contemporaneous with our data taking reached $2.5 cts/sec$ (ASM unit) without any significant $\gamma$-ray signal being detected on that day. The variability of M87 in the visible and X-ray domain on time scales of a few months could explain the non detection in the TeV regime and suggests that the object should be monitored.

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