Measuring the VHE Cosmic Ray Electron Spectrum with VERITAS

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Introduction

Cosmic rays are relativistic charged particles that permeate our galaxy. There are two components of the cosmic rays: the nuclei of atoms (hadrons), or electrons. The hadronic component is dominated by protons, though nuclei of all chemical elements up to uranium have been detected. Hadronic cosmic rays have been extensively studied, and their energy spectrum has been measured well past 100 TeV. The electron spectrum, however, has only been measured at lower energies.

Until recently the cosmic ray electron spectrum was directly measured by balloon and satellite experiments. The small collection areas available for these experiments limits their measurements to ~< 500 GeV. In the past few years the ground based Imaging Atmospheric Cherenkov Telescopes (IACT) have been able to extend the electron spectrum into the tens of TeV range.

IACTs detect astrophysical VHE gamma rays indirectly. When a high energy gamma ray interacts with the Earth's atmosphere, it produces an electromagnetic cascade (also called an "air shower") consisting of high energy electrons, positrons, and photons. Most of the particles in the cascade are traveling faster than the speed of light in air, and, in a process similar to a sonic boom when a plane travels faster than the speed of sound, these particles emit what is known as Cherenkov radiation or Cherenkov light. A specially constructed optical reflector, called an "Imaging Atmospheric Cherenkov Telescope", can detect this flash of Cherenkov light. Analysis of the image of the air shower thus obtained provides information about the nature of the gamma ray that initiated the atmospheric cascade.

Cosmic rays also hit and interact in the Earth's atmosphere and produce atmospheric showers. These cosmic ray induced showers form an unwanted background from which the gamma ray signal must be extracted. Cosmic ray hadron produce air showers that have different characteristics than the gamma ray showers. Cosmic ray electron, however, produce showers almost identical to the gamma ray showers. Most of ground based VHE astronomy involves developing techniques to identify and eliminate as much as the cosmic ray background as possible. By doing this, the much weaker gamma ray signal is able to be detected.

VERITAS

VERITAS is the Very Energetic Imaging Telescope Array System located at the basecamp of the Fred Whipple Observatory in southern Arizona. The array contains four 12 meter Imaging Atmospheric Cherenkov Telescopes. Each telescope has a field of view of 3.5 degrees and is sensitive to gamma rays for energies ranging from 100 GeV to 30 TeV. [1]

In normal operation, VERITAS is used to detect sources of VHE gamma rays. In the final stages of analyzing the data, selection criteria are defined to keep the gamma like events and remove the cosmic ray events. These criteria can remove up to 99% of the background cosmic ray events. Those events that pass the cuts are binned into a 2D sky map representing the area in the sky observed by the IACTs. A typical gamma ray source spans only a small part of the sky map. The location of the source is called the "on source region". Events falling outside of the "on source" region are the "off source" events. This off source region is populated by cosmic ray events that passed the gamma like selection. The off source regions of the sky maps are used to estimate the number of cosmic ray events that remain in the on source region after removal of non-gamma like events and thus to determine the statistical significance of the gamma ray signal.

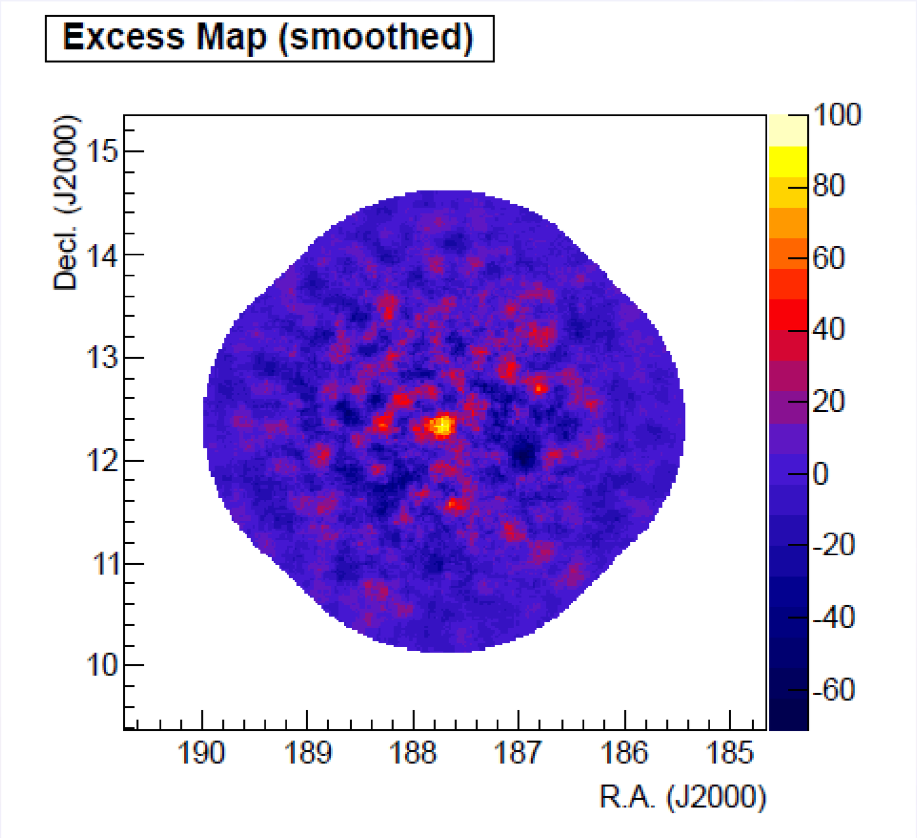

Figure 1: A gamma ray significance map of M87. M87 is the centered, yellow object.

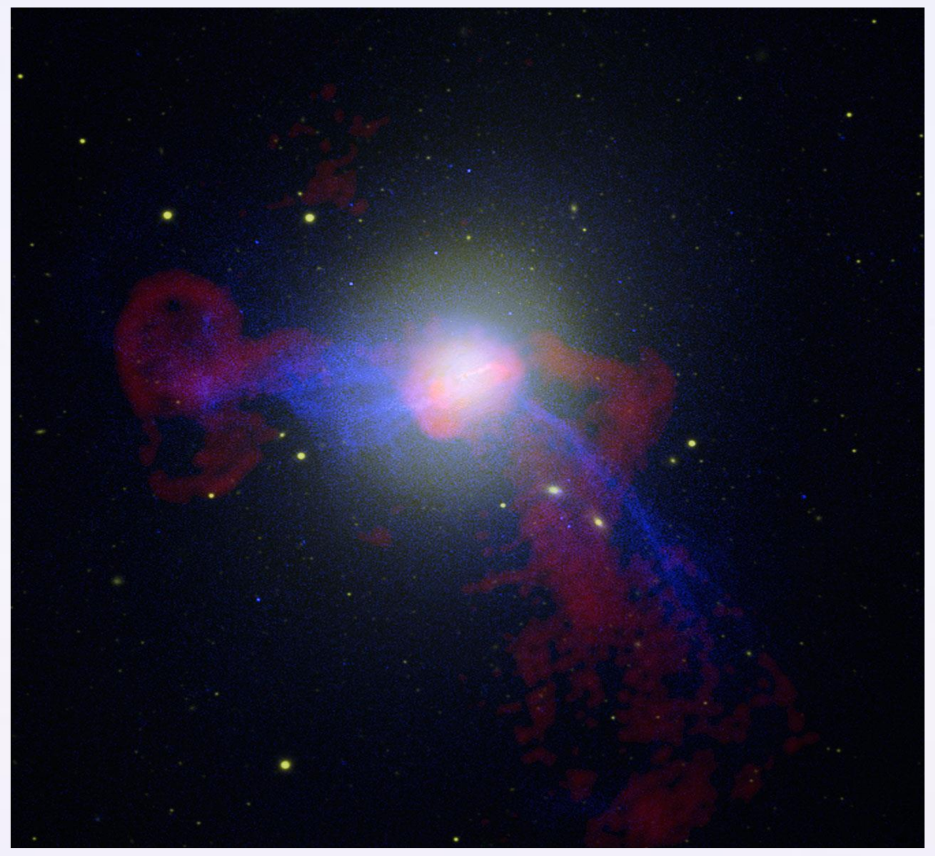

Figure 2: M87, a gamma ray source analyzed in this project, seen in a composite of x-ray, radio, and optical radiation.

Figure 3: One of four Imaging Atmospheric Cherenkov Radiation Telescopes used by VERITAS to detect gamma rays

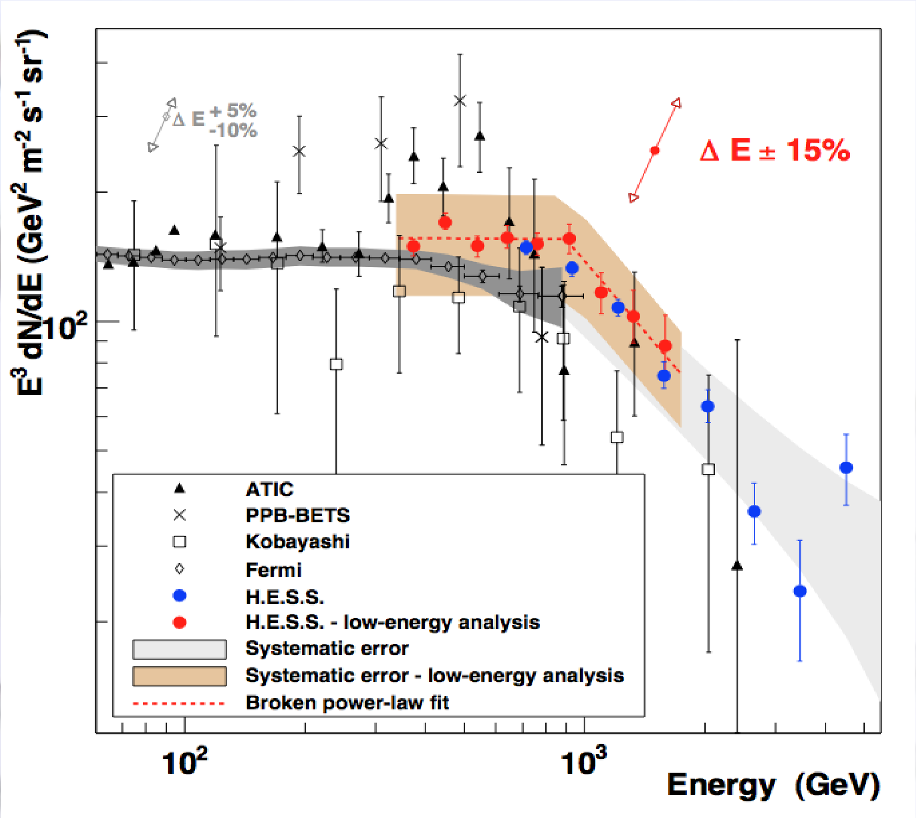

Figure 4: A graph of the number particles compared to their energies up to 5 TeV **[2]**

Source	Hours Processed	Source	Hours Processed	Sources to be processed
M87	22	W_Comae	12.5	Coma Berenices
Segue 1	25	BL_Lac	16	RGB J1243
Draco	27	1ES1218+304	19	PKS 1424
PG1553+113	11.5	Ursa Major2	46.5	RBS 1366
1ES0229+200	30.5	H1426+428	22.5	RGB J0152
Mrk421	32.5	W_Comae	12.5	1ES1118

Chart 1: A list of the sources processed, along with the number of hours processed for both. The end of the chart shows sources that will be analyzed when this experiment reaches its conclusion.

Electron Spectrum Method

The vast data sets accumulated by VERITAS on weak gamma ray sources provide a unique and novel opportunity to study the VHE electron spectrum. As mentioned before, electron events look almost exactly the same as gamma ray events in an IACT, thus the off source region of VERITAS sky maps contains electron events, as well as those cosmic ray events which pass the gamma like criteria.

The goal of this project is to extract the VHE electron spectrum from the background that exists in all VERITAS data. In this analysis we generate two sky maps for each data set. One map contains events which pass the gamma like criteria. We explicitly exclude the gamma ray source region so that the gamma like map will contain both electron and hadronic cosmic ray events but, to first order, no gamma ray events. Note, however, that if there is diffuse gamma ray emission in that sky direction, the off source regions of the sky map could contain gamma ray events. The second map contains events which pass the cosmic ray hadron criteria; these are the events that are rejected in a normal analysis looking for a gamma ray source. Monte Carlo simulations of cosmic ray hadrons will provide a means to use the number of events in the hadron map to estimate the number of hadron events passing the gamma like criteria, thus enabling us to extract, on a statistical basis, the number of cosmic ray electrons in the map.

Data Set

We have several criteria for choosing VERITAS archival data sets appropriate for this analysis. In order to avoid possible contamination of the off source sky map region from diffuse gamma rays, we are excluding data taken in or near the galactic plane. Furthermore, we restrict our analysis to high elevation data (elevation > 60˚) as this yield higher event rates. To also ensure the data was of high quality, only runs with optimum weather and hardware conditions were selected. WE also selected sources with a large amount of data, typically 10 or more hours. The VERITAS array underwent a major upgrade in the summer of 2012 and we restricted this analysis to data taken Sept 2012 to June 2015. Table 1 lists the names of the gamma ray source fields and the hours of data on each source matching our criteria.

Results

This project has not yet reached its conclusion. At this point, we have 12 sources fully analyzed, with more than 250 hours of data to use (see table 1). We have created both gamma ray maps (see Figure 2) and cosmic ray maps. Figure 1 shows the cumulative sky map for the extragalactic source M87 from 22 hours of data. Note the source the presence of the gamma ray signal in the center of the field. This is the region excluded from the electron analysis. The Monte Carlo simulation effort is lagging behind the data analysis effort, but should be completed this spring.

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References

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[2] Staszak, D. "Cosmic Ray Electron Analysis Update." Veritas Collaboration Meeting. Jan. 2015. Speech.