VERITAS Blazar Observations - Recent Results

Peter Cogan (on behalf of the VERITAS Collaboration)

3600 University Ave, Physics Dept, Montreal, QC H3A 2T8, Canada

Abstract. We present the discovery of very high energy (VHE) gamma-ray emission from the high-frequency-peaked BL Lac object 1ES 0806+524 (z=0.138) and the intermediate-frequency-peaked BL Lac object W Comae (z=0.102) with VERITAS. VHE emission was discovered from these objects during the 2007/2008 observing campaign, with a strong outburst from W Comae detected in mid-March, lasting a few days. Quasi-simultaneous spectral energy distributions are presented, incorporating optical (AAVSO), and X-ray (Swift/RXTE) observations. We also present the energy spectrum of the distant BL Lac (z=0.182) 1ES 1218+304 which was detected by VERITAS during the 2006/2007 observing campaign. The energy spectrum is discussed in the context of different models of absorption from the diffuse extragalactic background radiation. We present multiwavelength observations of the blazar Markarian 421 (z=0.03), including a strong flare initially detected by the Whipple 10m gamma-ray telescope. Finally we present a broadband spectral energy distribution for 1ES 2344+514 (z=0.044) which is successfully fit using a one zone synchrotron self-Compton model.

Keywords: VERITAS, Gamma Ray, Blazar

PACS: 98.54.Cm

INTRODUCTION

VERITAS is a ground-based array of imaging Cherenkov telescopes with sensitivity in the 50 GeV to 50 TeV range. The array is located in southern Arizona at an altitude of 1280m. There are four 12m diameter telescopes in the array of the Davies Cotton design. Each telescope uses a 499 photomultiplier tube camera to image the brief shower of Cherenkov photons generated by the electromagnetic cascade which results when a high-energy gamma ray strikes the atmosphere.

Active galaxies are believed to harbour supermassive black holes at their center surrounded by a hot accretion disk. Highly dynamic collimated jets of relativistic particles stream away from the plane of the host galaxy. Particle interactions within the jet produce electromagnetic radiation across many wavebands, including TeV gamma rays. Blazars are that subset of active galaxies whose jet is orientated in the direction of earth. Such objects provide unique laboratories to study acceleration mechanisms at extreme energies.

With a wide energy range and excellent point-source sensitivity, VERITAS is the most sensitive instrument of its kind in the northern hemisphere and is well suited to observations of blazars. There are three main areas of interest that are studied using blazar observations with VERITAS. i) To determine the dominant gamma-ray production mechanisms in blazars ii) To understand blazar populations and expand the range of studied objects to low-frequency peaked BL Lac objects, intermediate-frequency peaked BL Lac objects and flat spectrum radio quasars iii) To understand the role of the infrared component of the extragalactic background light in the determination of intrinsic energy spectra.

In this paper we discuss the discovery of two new objects in the blazar class, and report on multiwavelength studies of several established sources.

DISCOVERY OF TEV GAMMA-RAY EMISSION FROM 1ES 0806+514

Deep VERITAS observations of the blazar 1ES 0806+514 (z=0.138) from 2006 to 2008 reveal a weak steady emission above 300 GeV (see Figure 1). Observations were carried out during the construction of VERITAS and incorporate data using two, three and four telescopes. The integral flux above 300 GeV is approximately 1% of the Crab Nebula flux. A detailed analysis of these data will be the subject of a forthcoming VERITAS publication.

DISCOVERY OF TEV GAMMA-RAY EMISSION FROM W COMAE

The intermediate-peaked BL Lac object W Comae (z=0.102) was initially discovered in the radio and later X-ray energy bands. At gamma-ray energies, it was detected by EGRET up to 25 GeV with no sign of a spectral cutoff.

VERITAS observed W Comae from January to April 2008 for a total of 39.5 hours. A total statistical excess of 4.9σ (see Figure 3) is recorded during the observing period, making W Comae the first intermediate-peaked BL Lac object to be detected in the TeV regime. The
FIGURE 1. Two dimensional map of statistical significance centered on 1ES 0806+524. This map indicates that the extent is consistent with a point source and there are no other significant TeV sources in the vicinity of 1ES 0806+524.

The majority of the signal is derived from a flare over four nights in March 2008 where the source is detected with a statistical significance of $6\sigma$. The differential energy spectrum is well described by a power law with spectral index $\Gamma = 3.81 \pm 0.35_{\text{stat}} \pm 0.34_{\text{sys}}$. The total flux above 200 GeV corresponds to roughly 9% of the Crab Nebula flux.

The light curve for the flare nights is fit by the function $\Phi(t) = \Phi_0 \times \exp \left( - \frac{(t-t_0)^2}{\sigma_t^2} \right)$ with the flare occurring at $t_0 = 54538 \pm 0.2$ MJD and with the characteristic time scale $\sigma_t = 1.29 \pm 0.28$ days. No significant flux variations were measured during the individual nights, and all other observations during the 39.5 hour exposure yield no signal. A second strong outburst from W Comae was detected by VERITAS in June 2008 with an integral flux which exceeded twice the level of the earlier flare.

Analysis of these data are ongoing.

Simultaneous SWIFT observations of W Comae were obtained in response to the detection of flaring behaviour with VERITAS. A total of 11.6 hours of SWIFT UVOT and XRT data are available. The SWIFT data were analysed using the HEAsoft and XRTPipeline tools.

The VERITAS and SWIFT data are combined with archival radio data, optical AAVSO data and archival EGRET data points to produce a broadband spectral energy distribution (SED) (see Figure 3). The AAVSO data were obtained in response to the Astronomer’s Alert telegram from VERITAS regarding the gamma-ray outburst from W Comae.

The SED can be modeled with either a single-zone synchrotron self-Compton, an external-Compton model or a hadronic synchrotron proton model. The single-zone synchrotron self-Compton model imposes the requirement of a relatively weak magnetic field of $\sim 0.007 G$ due to the large separation between the first and second peaks in the SED and the relatively low X-ray flux. The external-Compton model can also fit the data, but the required magnetic field has a more realistic value of 0.3 G.

See [6] in these proceedings for further details.

FIGURE 2. Two-dimensional map of statistical significance of the region centered on W Comae. The TeV blazar 1ES 1218+304 is visible to the North of W Comae.

VERITAS OBSERVATIONS OF 1ES 1218+304

The distant blazar 1ES 1218+304 ($z=0.182$) was observed by VERITAS between December 2006 and March 2007 with a three-telescope array. This blazar was first detected by MAGIC at TeV energies, albeit with a lower statistical significance. The more sensitive VERITAS observations allow a measurement of the spectrum beyond 1 TeV (see Figure 4) which opens up the possibility of studying effects of absorption due to the mid-infrared component of the extragalactic background light. This can be achieved by examining measured spectra for 1ES 1011-232 and 1ES 0229+200 in the TeV energy regime. Lower limits from galaxy counts derived from the Hubble Space Telescope deep sky survey are used in conjunction with various EBL scenarios to place a lower limit on the spectral hardness of the three blazars. In particular, the spectrum of 1ES 1218+304 is found to be harder than $-1.86 \pm 0.37$. A detailed analysis of the intrinsic spectrum of 1ES 1218+304 will be
FIGURE 3. Spectral energy distribution of W Comae comprising archival radio data, AAVSO data, SWIFT UVOT and XRT observations, archival EGRET data and VERITAS data. Fits to the data are shown for a synchrotron self-Compton (with and without an external-Compton component) and an archival hadronic synchrotron proton model.

FIGURE 4. TeV spectrum of 1ES 1218+304 measured with VERITAS - a comparison is shown with the spectrum measured by MAGIC, and to the spectrum of the Crab Nebula as measured by VERITAS.

the subject of a forthcoming publication. See [9] in these proceedings for further details.

TEV AND X-RAY STUDY OF MARKARIAN 421 IN 2008

The nearby blazar Markarian 421 (z=0.03) was observed by VERITAS in an active state in the first half of 2008. The gamma-ray flux was highly variable, ranging from 0.3 Crab units to 10 Crab units [10] above 0.5 TeV.

A total of 93 RXTE PCA pointings and 51 SWIFT XRT observations were analysed with standard HEAsoft tools. Combined, the SWIFT and XRT data allow a calculation of the X-ray flux from 0.2-10 keV. It was found that the data could be fit using both a simple power law and a log-parabola. The log-parabolic fit yielded a superior $\chi^2$ statistic and fit residuals with no systematic deviations. The spectral curvature is inconsistent with zero, which suggests the existence of an intrinsic curvature to the spectrum.

Consistent with previous observations, it is found that Markarian 421 is more variable in the harder X-ray band, and the source hardens during flaring. Using a discrete correlation function, it is found that the X-ray and TeV data are correlated with zero lag. This correlation favours inverse-Compton models for TeV gamma-ray emission. See [11] in these proceedings for further details.

BROADBAND SPECTRAL ENERGY DISTRIBUTION OF 1ES 2344+514

The nearby blazar 1ES 2344+514 (z=0.044) was observed by VERITAS from October 2007 to January 2008, resulting in a detection with a statistical significance of 20.5 sigma with 580 excess events. During the same period, 1ES 2344+514 was observed by SWIFT XRT for 9 observations and RXTE PCA for 52 observations. SWIFT recorded the highest known X-ray flux from 1ES 2344+514 on December 8th 2007, with an X-ray power law index ranging from $2.7 \pm 0.2$ to $1.87 \pm 0.04$. The TeV flux showed variability on a daily timescale, with a
FIGURE 5. Spectral energy distribution of 1ES 2344+514 comprising SWIFT UVOT and XRT observations, RXTE PCA observations, VERITAS and MAGIC observations. The data are fit for two periods using a synchrotron self-Compton model with reasonable parameters.

strong flare recorded on 6/7 December 2007 with an integral flux corresponding to \(1.41 \pm 0.05\) of the Crab Nebula flux above 300 GeV. A linear fit with slope \(0.7 \pm 0.1\) to the almost simultaneous X-ray and TeV fluxes suggests a correlation between X-ray and TeV emission on daily timescales. The broadband spectral energy distribution of 1ES 2344+514, comprising data from SWIFT UVOT and XRT, RXTE PCA and VERITAS is shown in Figure 5. The data can be modeled using a one zone synchrotron self-Compton model with reasonable parameters. See [12] in these proceedings for further details.

SUMMARY AND CONCLUSIONS

During the construction phase and first full year of operation, known and candidate TeV blazars have been the subject of observations by VERITAS. During this period, the blazars W Comae and 1ES 0806+524 have been uncovered as sources of TeV gamma-ray emission. W Comae is the first intermediate-peaked BL Lac object to be discovered. The true scientific potential of observations in the TeV regime are fully realised in the context of simultaneous multiwavelength observations. Data from AAVSO, the SWIFT UVOT and XRT, the RXTE PCA as well as archival EGRET and radio data have been combined with VERITAS observations in the TeV regime to produce broadband spectral energy distributions for W Comae and 1ES 2344+514. These SEDs can be successfully modeled using leptonic models. Contemporaneous observations of Markarian 421 with SWIFT, RXTE and VERITAS have allowed a detailed examination of X-ray/TeV correlations. Finally observations of 1ES 1218+304 have resulted in a measurement of the spectrum above 1 TeV. This measurement can be used in conjunction with various EBL scenarios to place a lower limit on the spectral hardness of three blazars. The first full year of operations of VERITAS has been an extremely fruitful period. Further results are anticipated from the exiting observing program.

ACKNOWLEDGMENTS

This research is supported by grants from the U.S. Department of Energy, the U.S. National Science Foundation, and the Smithsonian Institution, by NSERC in Canada, by PPARC in the UK and by Science Foundation Ireland.

REFERENCES

1. Swordy, S. 2008, The Astronomer’s Telegram, 1415, 1
2. Swordy, S. 2008, The Astronomer’s Telegram, 1422, 1
3. Acciari, V. A., et al. 2008, ApJ, 648, L73
4. Swordy, S. 2008, The Astronomer’s Telegram, 1565, 1
5. Verrecchia, F., et al. 2008, The Astronomer’s Telegram, 1582, 1
6. Beilicke, M. 2009, These proceedings
7. Albert, J., et al. 2006, ApJ, 642, L119
8. Madau, P., & Pozzetti, L. 2000, MNRAS, 312, L9
9. Fortin, P. 2009, These proceedings
10. Swordy, S. 2008, The Astronomer’s Telegram, 1506, 1
11. Reyes, L. 2009, These proceedings
12. Grube, J. 2009, These proceedings