One of the more remarkable accomplishments of the recent generation of gamma-ray instruments, such as VERITAS, has been the detection of increasingly distant active galactic nuclei (AGN) at TeV energies. While the previous generation of imaging atmospheric Cherenkov telescopes (IACTs) were able to detect AGN at redshifts of ~z=0.1, modern day IACTs are now consistently detecting new AGN at redshifts of 0.3 with possible detections reaching out as far as z=0.5.

The AGN 1ES 0414+009 is such an object, lying at a redshift of z~0.29. This AGN has been detected as a very bright X-ray source with luminosities comparable to more well studied TeV AGN such as Mrk 421 and PKS 2155-304. From 2008-2011, VERITAS observed 1ES...
Multiwavelength Observations of the AGN 1ES 0414+009 with VERITAS, Fermi-LAT, Swift-XRT, and MDM

0414+009 for approximately 56 hours detecting the source at a statistical significance of 6.5 standard deviations above the background. Along with these observations, multiwavelength observations were carried out on 1ES 0414+009 in a broad range of radiative wavelengths including optical observations with the MDM observatory, hard X-ray coverage with Swift-XRT, and GeV gamma-ray observations with Fermi-LAT.

These multiwavelength observations were used to construct a spectral energy distribution (SED) of the source, which can be used to test models of emission in the AGN. While the more commonly used models to explain emission from TeV AGN utilize a purely leptonic population of accelerated particles, the SED constructed from VERITAS multiwavelength observations appear to indicate that a hadronic component to the class of jet-accelerated particles within 1ES 0414+009 may be necessary. Further observations with VERITAS are underway (as well as observations with multiwavelength partners) in order to increase the sensitivity of this measurement. These measurements will allow for more precise models of particle acceleration in AGN to be tested and further our understanding of the most distant TeV sources in the universe.

Figures from paper (click to get full size image):

Figure 1: The two-dimensional significance map of the 1ES 0414+009 region from VERITAS
Multiwavelength Observations of the AGN 1ES 0414+009 with VERITAS, Fermi-LAT, Swift-XRT, and MDM

observations made at VHE gamma-ray energies with the color scale representing units of standard deviation of the corresponding excess. The cross represents the optical position of the AGN from Hewitt & Burbidge (1993), the solid circle represents the best fit VERITAS position with associated statistical and systematic errors, and the dotted circle represents the position of the excess observed by Fermi-LAT (statistical error only). The white circle in the lower left corner represents the scale of the VERITAS point spread function of 0.12\degree.

Figure 2: The derived spectral points from both Fermi-LAT and VERITAS observations (nonsimultaneous) of 1ES 0414+009. The dotted line shows the power law fit to the Fermi-LAT spectrum extrapolated to TeV energies, while the solid line shows the power-law fit to the observed VERITAS TeV spectrum.

Figure 3: The VERITAS (top) and Fermi-LAT light curves for the observations detailed in this work. Errors shown on both light curves are statistical only.

Figure 4: The broadband SED constructed from the data sets described in the text. The top panel shows the SSC model results with contributions from primary synchrotron (dashed line), synchrotron self-Compton (dotted line), and EBL correct total (solid line). The middle panel shows the external Compton model results with contributions from primary synchrotron (dashed line), synchrotron self-Compton (dotted line), external Compton (dotted-dashed line), and EBL.
corrected total (solid line). The bottom panels shows the lepto-hadronic results with contributions from electron synchrotron (dotted line), proton synchrotron (dotted-dashed), proton synchrotron with electromagnetic cascades (dashed line), and EBL corrected total.