Multi-Wavelength Observations of 1ES1959 in a Flaring State

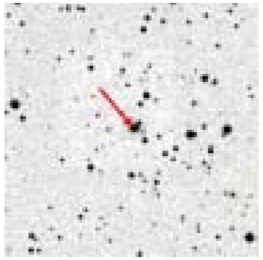
M. SCHROEDTER[1,2] FOR THE VERITAS COLLABORATION
E.FALCO[1], O. M. KURTANIDZE[3,4] AND M. NIKOLASHVILI[3]

[1]Smithsonian Astrophysical Observatory, [2]University of Arizona,
[3]Abastumani Observatory,
[4] Landessternwarte Heidelberg-Königstuhl and Astrophysikalisches Institut Potsdam

ABSTRACT

In May 2002, the BL Lacertae object 1ES1959+650 was detected in a high state at TeV energies by the VERITAS collaboration using the Whipple γ-ray observatory. 1ES1959, at a redshift of z=0.047, is the fifth BL Lac detected so far at the Whipple Observatory. Following the initial detection, the object was intensely monitored by the VERITAS collaboration during the next two months. TeV flaring was observed; at times the nightly average TeV signal was three times as bright as the Crab Nebula, the standard candle in TeV astronomy. 1ES1959 was also monitored in the optical and X-ray bands, overlapping with the TeV observations.

1 Introduction



The BL Lacertae object 1ES1959+650, redshift z = 0.047, is an active galaxy powered by a super massive black hole. It was discovered in 1993 by comparing the X-ray/radio/optical fluxes of objects in the *Einstein* IPC Slew Survey [1]. 1ES1959

was first detected at TeV energies by the Utah Seven Telescope Array collaboration [2] in mid-1998. It was seen in a flaring state in the TeV energy regime this Spring for the first time by the Whipple Observatory [3]. Following the initial detection, the object was intensely monitored by the VERITAS collaboration during the next two months [4],[5]. Overlapping with the TeV observations were R-band photometry, optical spectroscopy, and X-ray observations. The study of the cross-correlation of these energy bands is an important tool in restricting the possible emission and absorption processes of TeV photons.

2 Observations and Data Reduction

2.1 TeV observation

The Whipple Observatory 10 m reflector images Cerenkov light flashes from air showers initiated by TeV photons in the atmosphere. The telescope is located on Mt. Hopkins near Tucson, Arizona. It consists of 245 mirror facets arranged on a spherical support structure of Davis-Cotton design, with focal length 7.3 m. The camera consists of 490 ultraviolet-sensitive photomultiplier tubes, giving a 3.8 ° field of view. Currently, only the inner PMTs covering 2.6 ° are used in the analysis.

Telescope is shown in horizontal stow position.

Observations on 1ES1959 were taken from 16 May 2002 through 8 July 2002 (UT) for a total of 36 hrs. on source and 6.4 hrs. off source. The detection significance for ON/OFF paired observations is 8-σ with an average photon rate 1.5 ± 0.2 γ/min. Standard analysis of the data was done by moment fitting [6] of the events followed by cuts (Supercuts 2000) on *length*, *width*, *distance*, *length/size*, and *alpha* to reject the cosmic ray background. The lightcurve was calculated from on-source data, i.e. tracking analysis, with background estimated from off-source data.

The rate was then corrected empirically for elevation and throughput based on observations of the Crab Nebula, the standard candle at TeV energies, taken from

February to April 2002. Strictly, this is only valid if the sources have the same spectral index γ; $\gamma_{Crab} = 2.5$.

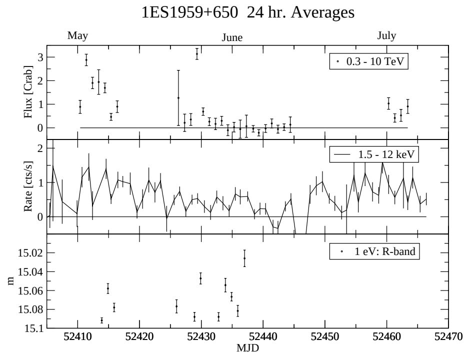
2.2 X-ray observation

The X-ray data was taken by the ASM detector on board the RXTE satellite. The ASM quick-look results were provided by the ASM/RXTE team. The average flux was calculated from five to ten 90-second dwells during each 24 hour interval. The ASM detects photons in the energy range from 1.5 keV to 12 keV, with peak sensitivity at 5 keV.

2.3 Optical observations

The R-band (650 nm) photometry was taken with the 70 cm telescope at the Abastumani Observatory in Georgia from 19 May to 11 June 2002. The frames were reduced using DAOPHOT II. The absolute magnitude of 1ES1959 was determined by comparison with 3 standard stars in the field of view [7].
Optical spectra were taken using the newly refurbished 6.5 m telescope at the MMT. The spectra were taken while 1ES1959 was active at TeV energies and one week later when the TeV flux was near zero. The first of the two spectra was measured on 5 June 2002 with a 300 lines/mm grating, the second spectrum was taken on 13 June 2002 with a 500 lines/mm grating. Total integration time for the first spectrum was 45 min and 10 min for the second. Not all cosmic ray contaminants were removed from the spectra. The relative change in spectral features was calculated by first normalizing to the smoothed continuum and then subtracting the two normalized spectra from one another. The smoothed continuum was calculated by first applying a 3 pixel wide box car average to the 300 lines/mm spectrum and a 5 pixel average to the 500 lines/mm spectrum. Then, both spectra were smoothed with a 100 pixel (200Å) box car average.

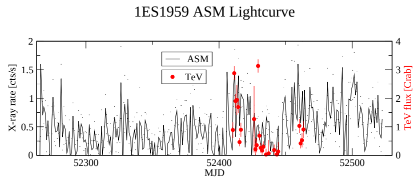
3 Lightcurve and Correlations



In the optical, 1ES1959 was very dim compared to the lightcurves from 1996-97 [8] and 1997-99 [9]. During those times the magnitude varied from 15.05 to 14.55. Thus, during our TeV detection the source was optically fainter and not as variable than usual.

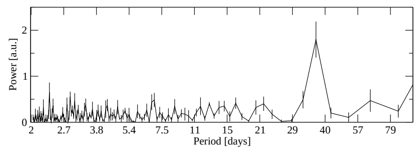
3.1 Quasi-periodic X-ray flaring

The figure below shows the X-ray flux and our measured TeV emission. It shows a series of X-ray flares spaced roughly 40 days apart. The X-ray error bars are indicated by dots.



The Fourier transform of the above ASM data is shown in the following figure. There is weak evidence for a 40 day period of X-ray flaring. A similar pattern of flaring activity was possibly found for Mkn 501[10].

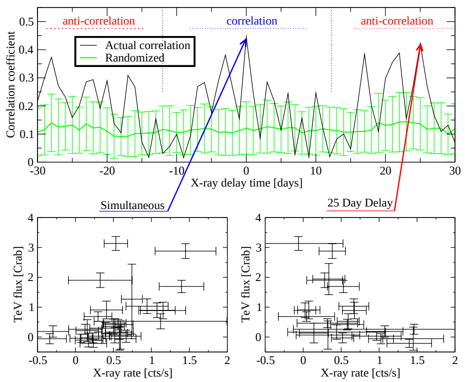
X-ray Fourier Transform



3.2 TeV and X-ray correlation

The X-ray - TeV linear correlation coefficient LCC is shown in the figure below with varying time delay between the two energy bands.

X-ray and TeV Linear Correlation



Simultaneous keV-TeV measurements are correlated with a LCC = 0.45. Here, simultaneous means ± 12 hours. To determine the significance of this, the keV and TeV flux measurements were randomized many times with respect to one another and the LCC was calculated for each random set. This resulted in a mean LCC = 0.1 ± 0.1, so we deduce that the correlation between X-ray and TeV flux is significant at the level of 3.5-σ. Assuming the LCC distribution to be gaussian, the probability of at least one 3.5-σ deviation in 61 independent measurements is 0.03.

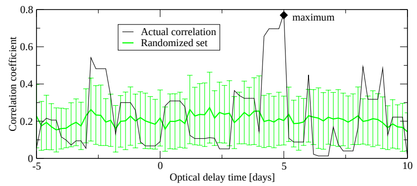
When the X-ray flux is time delayed by 25 days following the TeV flux, we find an anti-correlation of the X-ray and TeV flux. The LCC factor is 0.42, the probability for this to happen by chance is 0.15.

So, there is weak evidence for both a 40 day periodicity of the X-ray flux and correlation with TeV photon emission around the time of observation. A simultaneous correlation of X-ray and TeV flux has also been found during flares of Mrk 421 (1995) and Mrk 501 (1997) [11].

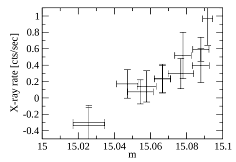
3.3 Optical and X-ray correlation

In 1ES1959, the X-ray and optical (R-band) emission appear to be correlated, though with the later delayed or lagging by 5 days. The LCC is 0.78, 5-σ away from a gaussian random distribution. The probability for this to occur in 16 independent samples is 9×10^{-6}. Delayed correlation between R-band and X-ray emission has also been seen in a flare of Mrk421 in 1996 [11].

Optical - X-ray Correlation

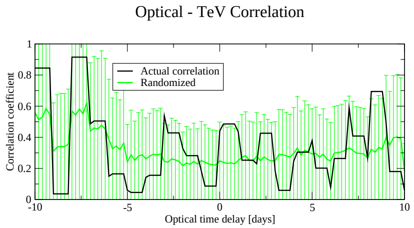


X-ray Flux vs. 5 Day Delayed R-band



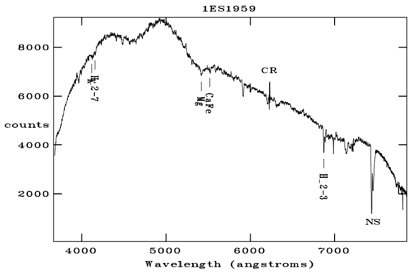
3.4 TeV and optical correlation

The TeV and R-band data sets are very unevenly spaced and we cannot see any correlation between the bands. The LCC, shown below, is compatible with a random distribution.

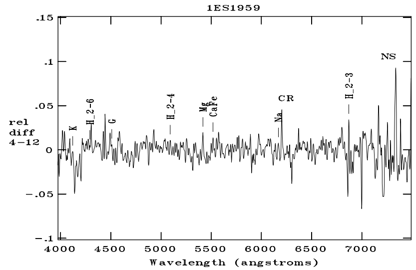


4 Optical spectra

The optical spectrum of 1ES1959 is featureless, typical of a BL Lac object, and does not show any significant emission lines. The spectrum shown below was taken while the TeV flux of 1ES1959 was two times that of the Crab. The spectrum is neither flux calibrated nor corrected for atmospheric extinction.



The relative change in the optical spectrum between states of high TeV emission and low TeV emission is shown in the figure below. For visual clarity a 3-pixel box smoothing was applied. The intensity of the following lines shows a decrease from 5 June to 13 June: H_α, labeled H_{2-3} (gfwhm = 9 Å), Mg (gfwhm = 9 Å), and $CaFe$ (gfwhm = 11 Å). Unfortunately, H_α is located in a region of strong night-sky absorption lines.



5 Summary

- Average TeV flux can rise and fall from near 0 to 3 times the Crab flux in one day.
- R-band brightness lags by 5 days behind X-ray flux.
- Weak evidence for a series of correlated TeV - X-ray flares.
- R-band was fainter than usual and showed small variability.
- Optical spectral line variability was small with no prominent spectral features.

Acknowledgments

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