Observations of 1ES1959+650 with the HEGRA System of Imaging Air Cherenkov Telescopes

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Abstract

The nearby BL Lac object 1ES1959+650 ($z = 0.047$) has been observed with the HEGRA system of imaging air Cherenkov telescopes. Based upon a data-set of 94 hrs taken from July 2000 until October 2001, a weak detection ($\mathbf{5.4}\ \sigma$) has been obtained corresponding to a flux level of $\mathbf{8}\,\%$ of the Crab flux above an energy threshold of 2 TeV for the observations at zenith angles between 37° and 45°. During recent observations from May until July 2002, the source has been observed to undergo strong outbursts at TeV and X-ray energies. The energy spectrum during the flares is hard and exhibits curvature, whereas during the low-state a power-law with a photon-index of 3.3 ± 0.7 describes well the data.

1. Introduction

We report on observations carried out with the HEGRA stereoscopic system of imaging air Cherenkov telescopes (IACTs) on the nearby BL Lac object 1ES1959+650 ($z = 0.047$). The performance and status of the HEGRA system of IACTs is described in Horns et al. (2002).
The object 1ES1959+650 is not a member of the class of extreme BL Lac objects which are characterized by a flat X-ray energy spectrum with a peak in the spectral energy distribution (SED) at hard X-ray energies (Beckmann et al. 2002). However, 1ES1959+650 is an X-ray selected BL Lac object and based upon a simple scaling argument, it has been predicted to be a TeV source candidate (Stecker et al. 1996). A more refined approach shows consistently that in the framework of a self-synchrotron Compton model this object is indeed a viable candidate for TeV emission (Costamante and Ghisellini 2002).

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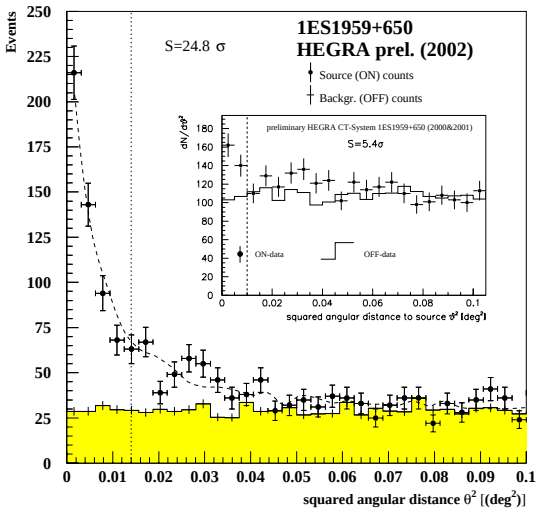

Fig. 1. The two histograms show the (preliminary) number of events detected from the source direction and the surrounding celestial region. The angle θ indicates the angular distance to the source direction. The data is binned in θ^2 to keep the solid angle for the bins constant. The inlaid histogram shows the result of observations carried out in the years 2000 and 2001 where the source remained at an overall low state. The long dashed histogram corresponds to the expected shape of the signal, the short dashed line indicates the angular cut.

2. Observations of 1ES1959+650

The HEGRA stereoscopic system of imaging air Cherenkov telescopes has been used to observe the nearby BL Lac object 1ES1959+650. The observations were carried out in the years 2000 (13 hrs), 2001 (81 hrs), and 2002 (63 hrs). The object culminates at La Palma latitude at a zenith angle distance of 37°, resulting in an energy threshold of $2-3$ TeV for the typical zenith angle range covered during the observations. A tentative detection at the level of 5 σ based upon the observations in 2000 and 2001 was first reported by Götting et al. (2002). Here we present the preliminary signal with a significance of $S = 5.4\ \sigma$ obtained during the 2000 and 2001 observational seasons (see inlaid histogram in Fig. 1.). The overall flux during the low flux detection amounts to ≈ 8 % of the Crab Nebula (0.08 Crab units) above 2 TeV.

During May 2002, the object increased in brightness (Dowdall et al. 2002, Horns& Konopelko 2002). The overall signal with a significance of $S = 24.8\ \sigma$ obtained during the observations carried out in 2002 is shown in Fig. 1.. The lightcurve (see Fig. 2.) shows the highest outbursts in May and July with an interleaved period of quietness in June. This behaviour matches quite well the variability observed by the RXTE all-sky monitor (ASM) covering the energy region between 2-10 keV. A separate target-of-opportunity programme with the pointed instruments on-board the RXTE satellite triggered by TeV observations lead to an extended (> 100 ksec) simultaneous observation of this source together with ground-based Cherenkov telescopes (Krawczynski et al. in preparation).

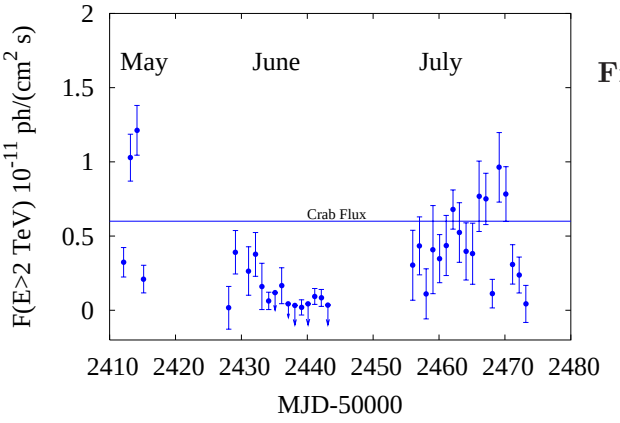

Fig. 2. For the three observational periods in May, June, and July 2002 we present the lightcurve of integral fluxes above 2 TeV. The gaps between data taking are a result of the presence of the moon. The solid line indicates the flux level of the Crab above 2 TeV.

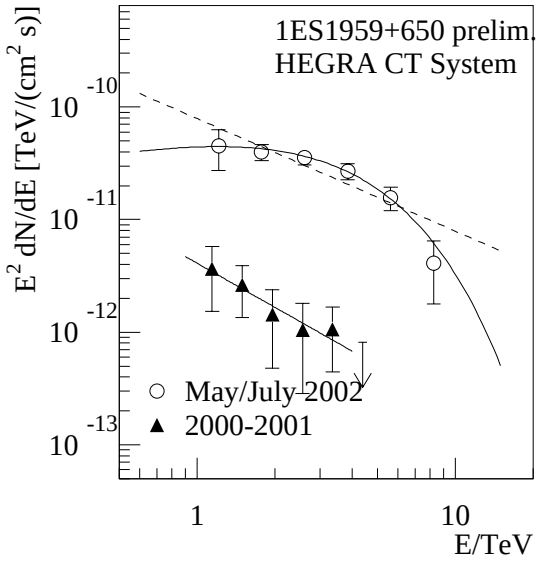

Fig. 3. Here we show the preliminary energy spectra in the flaring state by combining data from May 18/19, May 19/20 and July 13,14 where the integral flux exceeds one Crab unit and the observation time was longer than 1 hr. Also shown is the energy spectrum in the low state as we have observed it in the years 2000 and 2001. The high state spectrum is well described by a curved function of the form $dN/dE \propto E^{-1.5} \cdot \exp(-E/E_c)$ with $E_c = 2.4 \pm 0.4$ TeV. The photon index has been kept fixed because of the very limited range in energy.

3. Spectral variability

The TeV energy spectrum of 1ES1959+650 has been extracted from the 94 hrs of archival data gathered in the years 2000 and 2001. The reconstruction of energy spectra is based upon Monte Carlo generated collection areas (Aharonian et al. 1999). Since 1ES1959+650 remained in a weak flux state throughout the observations in the years 2000 and 2001, we apply tighter cuts to select γ-ray events and to improve the signal to noise ratio than described in Aharonian et al. (1999). Additionally, the energy reconstruction follows the approach described in Hofmann et al. (2000) reducing the relative energy resolution to typically $\Delta E/E = 10$ %. The same method has been applied to data collected during four nights (May 18/19, 19/20, July 13, and July 14 2002) with an average flux level exceeding one Crab unit above 2 TeV and sufficient observation time ($t > 1$ hr).

Both energy spectra are shown in Fig. 3.. The low flux state spectrum is well described by a pure power law with a photon index of 3.3 ± 0.7. For the high flux state, a power law fit results in a poor $\chi^2/d.o.f. = 10.7/4$ (see the dashed curve in Fig. 3.). A curved function $E^{-1.5} \cdot \exp(-E/E_c)$ describes the data very well ($\chi^2/d.o.f. = 0.78/4$). The cut-off energy is estimated by the fit to be $E_c = 2.4 \pm 0.4$ TeV. Note, we keep the power-law index fixed because of the proximity of the cut-off energy to the threshold energy of the observations.

4. Initial modeling of the source

We have attempted to model the broad-band SED of the source in the flaring state by using a "finite injection time" synchrotron self-Compton model (Ghisellini et al. 2002) where $t_{inj} = \Delta R'/c$ and $\Delta R'$ is the comoving thickness of the cylindrical emission region. This is the same model used in Beckmann et al. (2002) for the quiescent state.
The observational constraint of the X-ray emission during the flaring state is based upon the contemporaneous RXTE ASM data indicated in Fig. 4. as a series of flux measurements at 5 keV. The X-ray flux during these observations is considerably higher than during previous observations by BeppoSAX and ROSAT (Beckmann et al. 2002 and references therein). Unfortunately, the ASM data does not provide sufficiently good data to constrain the spectral shape of the X-ray emission. We also indicate the result of a contemporaneous optical observation by the MERCATOR telescope on La Palma (Uytterhoven priv. comm.) as an upper limit. The simultaneous low optical and high X-ray fluxes suggest a hard X-ray spectrum during the flare with a behaviour similar to what has been observed for Mkn 501. The two model fits (for the parameters see Table 1.), indicate a shift of the synchrotron peak position to a few keV, whereas the peak position during the quiescent state is estimated to be at a few eV (Beckmann et al. 2002).
The observation of TeV photons for this object at a redshift of $z = 0.047$ is very likely affected by absorption of high energy photons by pair-production on the low energy background radiation field. The intensity of the background radiation is unknown and currently only accessible by means of modeling based upon an assumed initial mass function and a measured star formation rate history of the universe. Here, we apply corrections for the absorption based upon a model of Primack et al. (2001). The optical depth is strongly energy dependent and therefore photons from a narrow wavelength band from 2-10 μm are targets for the high energy photons. We indicate the observed TeV energy spectrum together with the corrected source spectrum in Fig. 4..

Table 1. Input parameters of the homogeneous synchrotron self-Compton model. See Beckmann et al. (2002) for a detailed description of the parameters and the modeling of the quiescent state. Note, n indicates the power-law index for the electron spectrum beyond γ_{peak}.

Name	L' erg s^{-1}	R 10^{16} cm	B G	Γ	θ	n	γ_{min} 10^3	γ_{peak} 10^5	γ_{max} 10^6
1959+650 low	2.3×10^{42}	1.4	0.1	13	3.9	3.6	2	6.3	5
1959+650 high	6.3×10^{42}	2.5	0.09	14	3.8	3.3	1.4	8.7	2

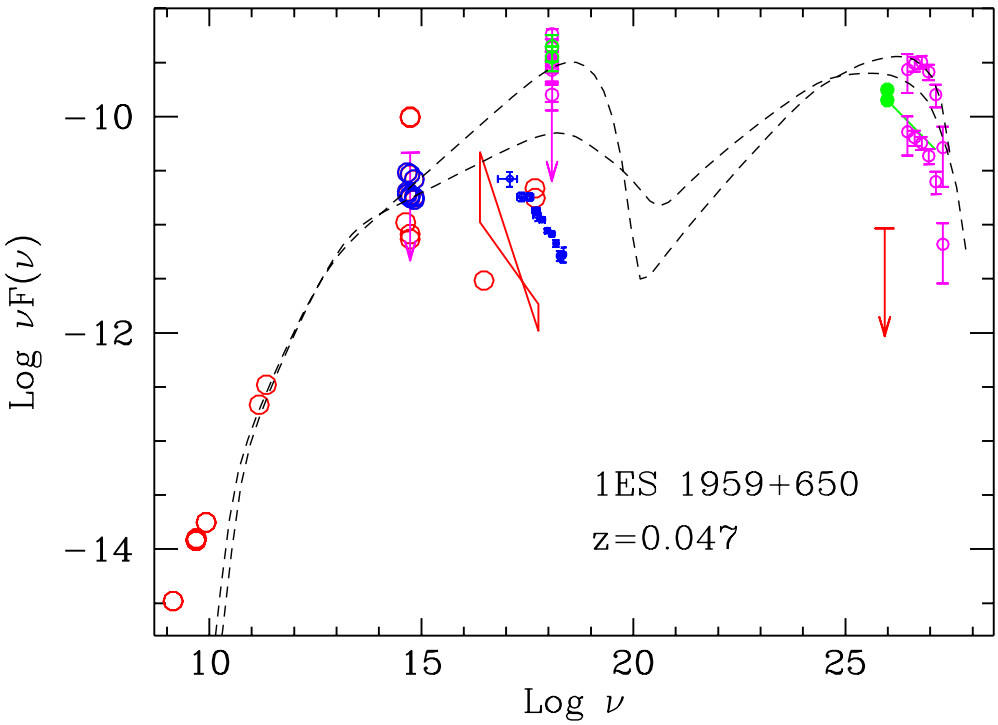

Fig. 4. Preliminary modeling of the spectral energy density (SED) using a finite injection time SSC model (Ghisellini et al. 2002). The parameters of the model are listed in Table 1. The archival data compilation is identical to Beckmann et al. (2002). The contemporaneous RXTE ASM flux and TeV spectrum as measured by HEGRA (open symbols at $\log(\nu/\mathrm{Hz}) > 26$ and an absorption corrected source spectrum using a model for the extragalactic background light based upon calculations from Primack et al. (2001) has been added. See the text for more details.

5. Discussion

We report the detection of 1ES1959+650 during observations carried out in the years 2000 and 2001. The object has been observed for a total of 94 hrs and report a detection at the level of $S = 5.4\ \sigma$. The integral flux above 2 TeV corresponds to 8 % of the Crab Flux. In May 2002 the source has been detected to be in a high state. Contemporaneous observations at X-ray energies indicate a strong increase of the flux with respect with the archival data taken during a quiescent state of the source. The TeV source is detected during the flaring state as a strong source reaching the level of 2 Crab units for several nights. The TeV energy spectrum has been derived for this object in the low and in the high state. The spectrum in the low state is soft and consistent with a power law with a photon index of 3.3 ± 0.7. During the high state, the energy spectrum becomes harder and exhibits curvature. A power-law fit with an exponential cut-off energy of $E_c = 2.4 \pm 0.4$ TeV describes well the data. However, since the cut-off energy is very close to the threshold energy for the given zenith angle range, we can not constrain the photon index for the lower energy part. The data appear to be compatible with a photon index of 1.5. An initial modeling of the contemporaneous optical, X-ray, and TeV data by a one-zone synchrotron self-Compton model indicates a shift of the peak position of the synchrotron peak towards an energy of a few keV or even higher. The modeled broad-band SED can also account for the observed TeV energy spectrum after applying a correction for absorption effects.

6. References

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