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The very high energy gamma ray spectra of 1ES 1959+650 and Mrk 421 as measured with the Whipple 10 m telescope.

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Abstract. In observations made with the Whipple 10 m telescope, 1ES 1959+650 ($z = 0.048$) was caught in a high flaring state in May 2002, concurrent with a high X-ray state, and in June 2002, for which there was no corresponding X-ray flare. The spectra for both of those occasions are well fitted by a power law of differential spectral index ~ -2.8. The relative stability of the spectral index for those flares argues strongly in favour of a two-component model as to the emission zones for the two radiation regimes.

Markarian 421 ($z = 0.031$) was observed to be in a high flaring state, at levels of ≥ 3 Crab, during March and April 2004. The average spectrum over this time period shows evidence for a cut-off in the spectrum at ~ 5 TeV, similar to a cut-off seen during an equivalently strong episode of flaring activity in 2001. The continued appearance of this feature indicates a long term stability, either in the physical conditions at the source, or in the intervening medium (such as attenuation on the extra-galactic infra-red background radiation).

INTRODUCTION

In the unified scheme blazars are the classification of active galactic nuclei with a highly relativistic plasma jet that is closely aligned to the observer's line of sight; however not much else is definitively known beyond that. In a νF_ν representation the spectral energy distribution displays two broad peaks. Currently the most popular theories attribute the

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lower energy peak to synchrotron radiation from a population of relativistic electrons and the higher energy peak comes from the inverse Compton scattering of a photon field off the relativistic electrons. The seed photon field for the scattering has a number of possibilities for its origin: it could be the synchrotron photons from the electron population itself in synchrotron self-Compton (SSC) models [11]; whereas external Compton models can have the photons coming the accretion disc [3], or reflected from emission line clouds [16] for example. Alternative models have an hadronic precursor to the high energy emission, such as the decay of pions formed in cascades generated by an energetic proton beam crossing a target in the jet [1], or from proton synchrotron radiation [12]. Knowing the intrinsic spectrum of a blazar would aid immeasurably in resolving which of the various models accurately reflects the processes at work in these extreme environments. Unfortunately the measurement of the intrinsic spectra of blazars at the very highest energies is complicated by the fact that the TeV photons are attenuated on the diffuse extra-galactic background radiation (DEBRA) over the large distances between the blazars and ourselves. Before the intrinsic spectra, and consequently the physical models, can be resolved this attenuation needs to be taken into account. Happenstance, however, means that the DEBRA in the relevant region ($\sim 5-60\,\mu$m) is difficult to measure [4]. By cultivating a large catalogue of gamma-ray emitting blazars at various redshifts and with well measured spectra it should be possible to solve these two, seemingly unrelated, problems of the intrinsic spectra of blazars and the form of the DEBRA in the infra-red region.

The Whipple 10 m imaging atmospheric Cherenkov telescope was the first to discover TeV radiation coming from blazars [15] and has a long tradition of monitoring candidate blazar objects, which often can only be successfully detected during transient episodes of flaring activity. A description of the telescope can be found in [5]. Presented here are the preliminary results of very high energy (VHE, $E \geq 300\,$GeV) spectral analyses of Whipple 10 m observations taken during major flaring episodes from the blazar 1ES 1959+650 in the summer of 2002 and the blazar Mrk 421 in early 2004. The spectral analysis method follows that outlined in [13].

THE 1ES 1959+650 FLARES OF 2002

A total dataset of 39.3 hours of on-source and 7.6 hours off-source data for background comparison were taken between May 16th and July 8th 2002. Due to the time of year the flares were observed the data were obtained at large zenith angles and the analysis had to account for this and the temporal variation of the telescope efficiency by the method of LeBohec & Holder [10]. Strong night to night variability was evident with a mean flux of 0.64 ± 0.03 that of the Crab Nebula and a maximum of 5 Crab. The largest change in rate corresponded to a doubling time of 7 hours. Whipple data taken on the 4th of June (MJD542429) showed a strong ‘orphan’ gamma-ray flare, reaching a high flux of 4 Crab, whilst simultaneous X-ray observations showed no increase in activity and HEGRA observations taken 5 hours earlier saw 1ES1959 in a low flux state [7].

There are 2.8 hours of paired observations taken in May on the nights of MJD52411, MJD52412, MJD52414 and MJD52416 that were suitable for a spectral analysis to be

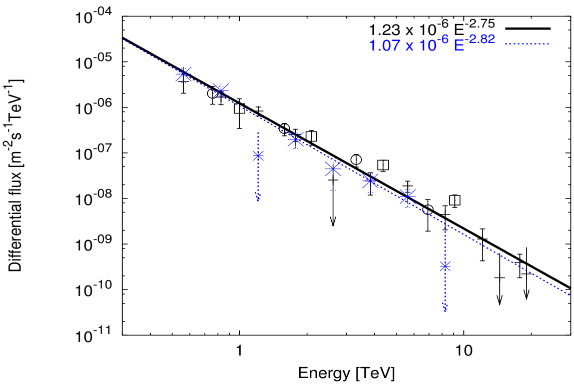

FIGURE 1. The VHE spectrum for 1ES1959+650 during flaring activity in 2002. The dashed line and starred points correspond to the 'orphan' flare seen on the 4th June. All other shapes represent May data sub-sets.

carried out. For these observation there is an average rate of 3.44 ± 0.4 gammas per minute and the time and flux averaged differential spectrum is

$$\frac{dN}{dE} = (1.23 \pm 0.3_{\text{stat.}} \pm 0.33_{\text{sys.}}) \times 10^{-6} E^{-2.75 \pm 0.16_{\text{stat.}} \pm 0.21_{\text{sys.}}} \text{m}^{-2}\,\text{s}^{-1}\,\text{TeV}^{-1}$$

where the first error is statistical and the second is the systematic uncertainty. The orphan flare data from the 4th June has an average rate of 4.9 ± 0.2 gammas per minute and yields a spectrum of

$$\frac{dN}{dE} = (1.07 \pm 0.16_{\text{stat.}} \pm 0.57_{\text{sys.}}) \times 10^{-6} E^{-2.82 \pm 0.15_{\text{stat.}} \pm 0.3_{\text{sys}}} \text{m}^{-2}\,\text{s}^{-1}\,\text{TeV}^{-1}$$

The increase in the systematic error for this second data-set arises from the fact that the observations were taken in tracking mode [6, 14] and so matching off-source runs had to be selected from the general observational database. The spectra for both flares are displayed in figure 1.

Both of the data-sets could be adequately fit by a pure power-law form and so show no clear evidence of a cut-off in the spectrum. This does not preclude the existence of a cut-off, because the statistics are insufficient to rule the possibility (it should be noted that the early spectra derived for Mrk 421 [17] showed no cut-off feature either, for similar reasons). Moreover, a cut-off could exist below the threshold energy of the spectral fit, which is relatively high because of the large zenith angle of the observations together with technical difficulties in the analysis associated with changes in detector gain.

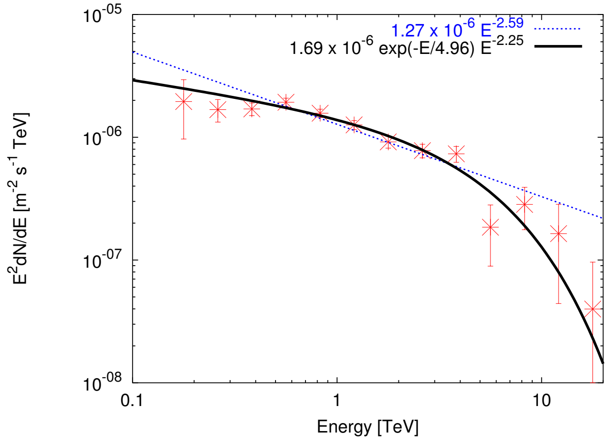

FIGURE 2 ... h Whipple 10 m
IACT durin ... s an exponential
cut-off term

THE MRK 421 FLARES OF 2004

This analysis is for a total of 5.6 hours on source data taken during high flaring activity during March and April 2004, with an average rate of 7.7 ± 1.7 gammas per minute (~ 3 Crab). These observations could be fit by a power law differential spectrum of the form

$$\frac{\mathrm{d}N}{\mathrm{d}E} = (1.27 \pm 0.07_{\text{stat.}} \pm 0.16_{\text{sys.}}) \times 10^{-6} E^{-2.59 \pm 0.07_{\text{stat.}} \pm 0.2_{sys.}} \,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$$

but, as seen in figure 2, the data are significantly better fit after an exponential cut-off term was added to the spectral form thus

$$\frac{\mathrm{d}N}{\mathrm{d}E} = (1.69 \pm 0.07_{\text{stat.}} \pm 0.16_{\text{sys.}}) \times 10^{-6} \exp\left(-\frac{E\,[\mathrm{TeV}]}{5 \pm 2}\right) E^{-2.25 \pm 0.07_{\text{stat.}} \pm 0.2_{\text{sys.}}} \,\mathrm{m}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$$

with the reduced χ^2 of the fit going from 2.29 to 1.18. respectively. The value of the cut off term is in good agreement with the value of $4.3 \pm 0.3_{\text{stat.}}$ seen in strong flaring activity in Mrk421 in 2001 [8].

Spectra were also calculated for some multiwavelength observations carried out in conjunction with RXTE, with the data runs split according to the X-ray flux level. In figure 3 it can be seen that whilst the average flux levels between the two energy regimes seem to correlate well, there is no evidence for spectral hardening with increasing X-ray flux within the uncertainties. Ongoing studies will look at whether there is any change in the spectral index associated with increasing VHE flux only, as seen in the 2001 flares for Mrk 421 [9]. Further details on this multi-wavelength campaign are given elsewhere at this conference [2].

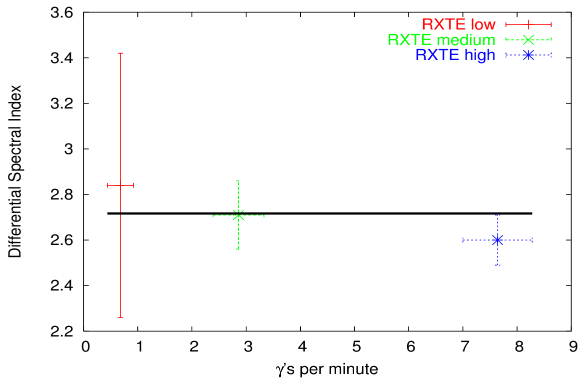

FIGURE 3. The spectral index for Mrk 421 characterised at three averaged RXTE flux levels.

CONCLUSIONS

The preliminary results of spectral analyses of observations taken with the Whipple 10 m IACT of the blazars 1ES 1959+650 and Mrk 421 during episodes of flaring activity have been presented here. The observation of an 'orphan' flare from 1ES 1959 is evidence that a one-zone SSC model is insufficient to explain the high energy emission from this object. The spectral index of the VHE observations seems to be consistent between episodes of correlated and uncorrelated X-ray emission. This could be important information in refining models of the physical processes at work in this kind of object and aid in our understanding of the intrinsic spectrum. Mrk 421 was observed in a very high state which gave evidence of a cut-off to the spectrum at $E \simeq 5$ TeV; this is very similar to a cut-off noted in the spectrum of equivalently large flares observed in 2001 that had a cut-off at $E \simeq 4.2$ TeV. The stability of the feature over such a period of time could also yield important information on the intrinsic processes at work and on the composition of the intervening extra-galactic radiation field.

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