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Successful ToO triggers on the extragalactic sources with the MAGIC telescope

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Abstract: The MAGIC collaboration has been performing Target of Opportunity (ToO) observations whenever alerted that known or potential very high energy gamma-ray emitting extragalactic sources were in a high flux state in the optical, X-ray band or/and in the TeV energy range. Here we report on MAGIC observations performed after such triggers, results of the analysis, and a possible optical-TeV correlation seen in the data. Detections as well as spectral and temporal characterestics of Mkn 180, PKS 2155-304, and 1ES 1011+496 are reported.

Introduction

The search for very high energy (VHE, defined as $E > 100$ GeV) γ-ray emission from Active Galactic Nuclei (AGN) is one of the major goals for ground-based γ-ray astronomy. New detections open the possibility of a phenomenological study of the physics inside the relativistic jets in AGN, in particular to understand both the origin of the VHE γ-rays as well as the correlations between photons of different energy ranges (from radio to VHE). The number of reported VHE γ-ray emitting AGN has been slowly increasing and is currently 17 (May 2007). Eight of them have been seen by MAGIC, all of the them belonging to the BL Lac class of AGNs.

The spectral energy distribution (SED) of BL Lac objects normally shows a two bump structure. The first peak in high frequency peaked BL Lacs (HBLs) has a maximum in the X-ray band, whereas the second peak is located in the GeV-TeV band. It is believed that the radiation is produced in a highly beamed plasma jet, which is almost aligned with the observer's line of sight. A double peaked SED is normally attributed to a population of relativistic electrons, where one peak is due to synchrotron emission in the magnetic field of the jet, and the second peak is caused by inverse Compton (IC) scattering of low energy photons by the same parent relativistic electron population.

The known VHE γ-ray emitting BL Lacs are variable in flux in all wavebands. Correlations between X-ray-γ-ray emission have been found (e.g. [1]) although the relationship has proven to be rather complicated with γ-ray flares being also detected in the absence of X-ray flares [2] and vice versa [3]. The optical-TeV correlation has yet to be studied, but the optical-GeV correlations seen in 3C 279 [4] suggest that at least in some sources such correlations exist. Using this as a guideline, the MAGIC collaboration has been performing Target of Opportunity (ToO) observations whenever being alerted that sources were in high flux state in the optical and/or X-ray band.

In this paper we present the first detection of VHE γ-ray emission from Markarian 180 (Mkn 180), 1ES 1011+496, and results on PKS 2155-304.

Markarian 180

The AGN Mkn 180 (1ES 1133+704) is a well-known high frequency peaked BL Lac (HBL) at a redshift of $z = 0.045$ [5]. The observation of Mkn 180 was triggered by a brightening of the source in the optical on 2006 March 23. The alert was given as the core flux increased by 50% from

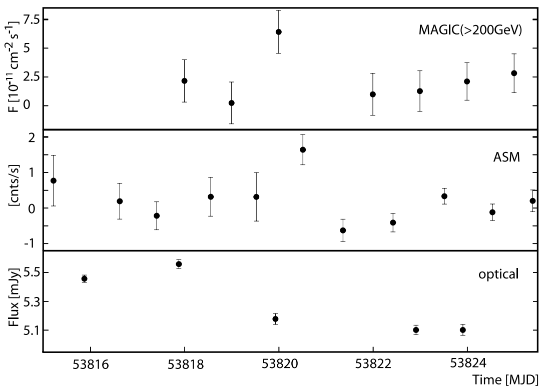

Figure 1: Lightcurve of Mkn 180 for MJD=53815-53825 (March 21 to March 31). Upper panel: VHE γ-rays measured by MAGIC above 200 GeV. Middle panel: ASM count rate. Lower panel: optical flux measured by KVA.

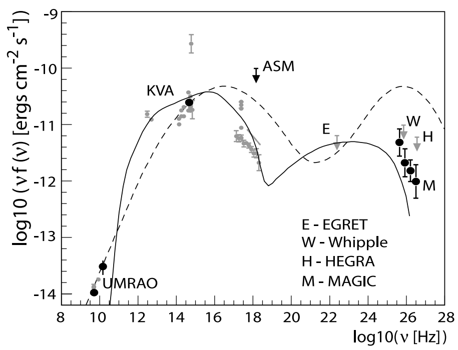

Figure 2: The Spectral Energy Distribution of Mkn 180. Simultaneous data (UMRAO, KVA, ASM, and MAGIC) are noted in black. Grey points represent historical data. The arrows denote the upper limits from ASM, EGRET, Whipple, and HEGRA. The solid line is from [7] and the dashed line is from [8].

its quiescent level value as determined from over three years of data recording. The simultaneous MAGIC, ASM[1] and KVA[2] lightcurve is shown in Fig. 1. Around this time Mkn 180 was also observed as part of the AGN monitoring program by the University of Michigan Radio Observatory (UMRAO). No evidence for flaring was found in the radio data between January and April 2006.

Mkn 180 was observed by MAGIC in 2006 during 8 nights (from March 23 to 31), for a total of 12.4 hours, at zenith angles ranging from 39° to 44°. After the standard analysis, a clear excess corresponding to a 5.5 σ excess was determined. No evidence for flux variability was found. The fit to the nightly integrated flux is consistent with a constant emission ($\chi^2 = 7.1$, 6 degrees of freedom). Fig. 1 shows the VHE lightcurve together with the ASM daily averages and the R-band by KVA flux data. The X-ray flux of the source is generally below the ASM sensitivity, but on March 25 a 3 σ excess was observed, which suggests that the source was also active in X-rays. The optical flux reached its maximum in the night MAGIC started the observations (March 23) and began to decrease afterwards. The measured energy spectrum of Mkn 180 can be well described by a power law:

$$\frac{\mathrm{d}N}{\mathrm{d}E} = (4.5 \pm 1.8) \times 10^{-11} \times \left(\frac{E}{0.3\,\mathrm{TeV}}\right)^{-3.3\pm0.7} \frac{1}{\mathrm{TeV\,cm^2\,s}}$$

The observed integral flux above 200 GeV is $F(E > 200\ \mathrm{GeV}) = (2.25 \pm 0.69) \times 10^{-11}\mathrm{cm^{-2}s^{-1}}$, which corresponds to $1.27 \times 10^{-11}\,\mathrm{ergs\,cm^{-2}s^{-1}}$ resp. 11% of the Crab Nebula flux measured by MAGIC. Details on the analysis and the results can be found in [6].

PKS 2155-304

PKS 2155-304 is a well-known HBL object, located in the Southern hemisphere at a redshift of $z = 0.117$ [9]. MAGIC observations were triggered by the Astronomer's Telegram 867 [10] reporting historically high fluxes of VHE γ-rays from PKS 2155-304. The VHE activity was supported by an optical brightening of the source and an increased X-ray activity.

MAGIC observed PKS 2155-304 for 6 nights in July – August 2006 at high zenith angles ranging from 58° to 68°. A clear signal corresponding to 11 σ excess was determined. Due to the high zenith

1. All-Sky-Monitor on-board the RXTE satellite, see http://heasarc.gsfc.nasa.gov/xte_weather/

2. See http://users.utu.fi/kani/1m/index.html

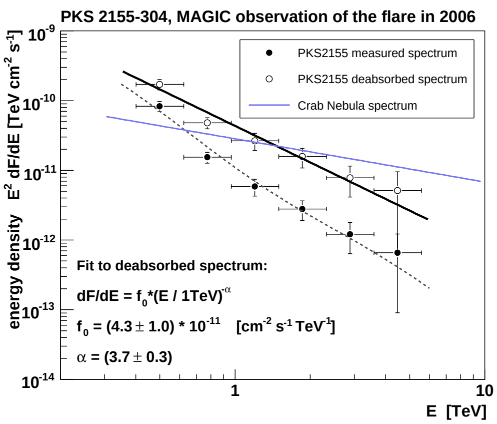

Figure 3: Averaged energy spectrum of PKS2155-304 for MJD=53944-53949 (2006 July 28 to August 2). The Crab Nebula spectrum is shown for comparison.

of observation, the energy threshold is higher. The analysis energy threshold for this data set is at about 600 GeV. An averaged energy spectrum of PKS 2155-304 is shown in Figure 3. The measured spectrum is consistent with a power law with a soft slope of $\alpha = 4.0$, whereas the deabsorbed energy spectrum [11] has a slope of $\alpha = 3.7 \pm 0.3$. The soft slope confirms findings by H.E.S.S. [12] and points to a IC peak position below 200 GeV. No significant flux variations were found in 30 min time bins along the 6 nights of observations.

1ES 1011+496

1ES 1011+496 is an HBL object for which we now determined a redshift of $z = 0.212 \pm 0.002$. Previously, this has been uncertain since it was based on an assumed association with the cluster Abell 950 [13]. The MAGIC observation was triggered by an observed high optical state of 1ES 1011+496 on 2007 March 12th.

After the alert, MAGIC observed 1ES 1011+496 in March–May 2007. The total observation time was 26.2 hours and the observation was performed at zenith angles ranging from $20°$ to $37°$. After removing runs with unusual trigger rates, mostly caused by bad weather conditions, the effective observational time amounts to 18.7 hours. Using the standard analysis chain for the MAGIC telescope data, a signal of 297 events over 1591 normalized background events was found, corresponding to an excess with significance of 6.2σ. The averaged energy spectrum of 1ES 1011+496 extends from $\sim 120\,\mathrm{GeV}$ to $\sim 750\,\mathrm{GeV}$ and can be well approximated by a power law:

$$\frac{\mathrm{d}N}{\mathrm{d}E} = (2.0 \pm 0.1) \cdot 10^{-10} \times \left(\frac{E}{0.2\,\mathrm{TeV}}\right)^{-4.0 \pm 0.5} \frac{1}{\mathrm{TeV\,cm^2\,s}}$$

After the correction for the EBL absorption [11], the slope of the spectrum is $\Gamma_{\mathrm{int}} = 3.3 \pm 0.7$ (χ^2 / NDF $= 2.55/2$), softer than observed for other HBLs in TeV energies and thus not providing new constraints on the EBL density. The energy spectrum can be nicely fitted by a simple leptonic model [14, 15]. However, we note that due to a lack of simultaneous X-ray and soft γ-ray data, the model is degenerated. To search for time variability the sample was divided into 14 subsamples, one for each observing night. Fig. 4 shows the integral flux for each night calculated for a photon flux above 200 GeV. The flux is statistically constant at an emission level of F($>$200 GeV)=(1.58 ± 0.32) $\cdot$ 10^{-11} photons $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In the inset of Fig. 4, we show integral fluxes above 200 GeV on a year-by-year basis. The first point in the inset corresponds to an earlier observation of 1ES1011+496 by MAGIC in 2006, which lead to a hint of a signal [16]. This hint can now be interpreted as being due to a lower flux state of the source than measured in 2007. Details on the analysis and the results can be found in [15].

Conclusions

The discovery of VHE γ-ray emission from Mkn 180 was triggered by an optical flare, but no significant variations in the VHE regime were found. The short observation period and the small signal do not allow to carry out detailed studies. It is therefore not possible to judge whether the detected VHE flux level represents a flaring or a quiescent state of the AGN. The rather steep slope of the VHE spectrum of Mkn 180 suggests an

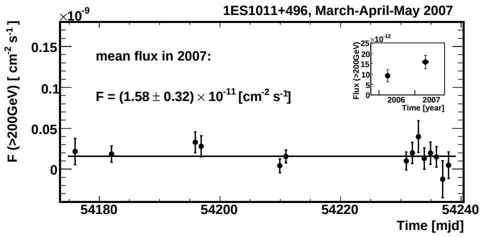

Figure 4: The night-by-night light curve of 1ES 1011+496 from 2007 March 17 (MJD 54176) to 2007 May 18 (MJD 54238). The year-by-year light curve is shown in the inset, the 2006 data point is from [16].

IC peak position well below 200 GeV, while the non-detection by EGRET gives a lower limit of $\sim$ 1 GeV for the peak position [17]. This is in agreement with the leptonic model of [7] suggesting the IC peak position at around 10 GeV.

The detection of PKS2155-304 with the MAGIC telescope proved the capability of the instrument to observe distant extragalactic γ-ray sources under large zenith angle if the sources are in a flaring flux state. Especially for multiwavelength campaigns, MAGIC observations are crucial in order to obtain independent energy spectra and light curves measurements at VHE.

We report the discovery of VHE γ-ray emission from the HBL object 1ES 1011+496 in the 2007 data set. With the redshift of $z = 0.212$, it is the most distant source detected to emit VHE γ-rays up to date. The discovery was as well triggered by an optical flare. The observed spectral properties (soft and no significant excess above ~ 800 GeV) are consistent with the state-of-the art EBL models and confirm recently derived EBL limits.

The discovery of VHE emission from Mkn 180 and 1ES 1011+496 during an optical outburst as well as an optical activity during the PKS2155-304 VHE outburst make it very tempting to speculate about the connection between the two energy bands. Further VHE observations with and without an optical trigger are needed to prove that there is indeed a correlation.

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