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Very high energy γ-radiation from the radio quasar 4C 21.35

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Abstract. A very high energy (VHE) γ-radiation was detected from a flat spectrum radio quasar (FSRQ) 4C 21.35 (PKS1222+21) by MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescopes on June 17^{th} 2010. 4C 21.35 is only the 3^{rd} FSRQ detected in VHE γ-rays. With its hard spectrum ($\Gamma = 2.72 \pm 0.34$) with no apparent cut-off at energies below 130 GeV and an extremely fast variation of flux (doubling in $8.6^{+1.1}_{-0.9}$ minutes), this detection poses a challenge to existing models of VHE γ-radiation from FSRQs. The most important results of observations performed by MAGIC telescopes are presented here, as well as some possible explanations of those results.

Keywords. 4C 21.35, PKS 1222+216, MAGIC, gamma-rays

1. MAGIC Telescopes

The Major Atmospheric Gamma Imaging Cherenkov (MAGIC) experiment is a system of two 17 m ground-based IACT (Imaging Atmospheric Cherenkov Telescopes). The telescopes record Cherenkov radiation from particle showers created when a γ-ray enters the atmosphere. These are currently the world's largest telescopes of their kind, and are sensitive to γ-rays of energies above 50–60 GeV. The experiment is situated in the Observatorio del Roque de los Muchachos on the Canary Island La Palma (28°N, 18°W), 2200 m a.s.l. The performance of the MAGIC telescope stereo system is discussed in Aleksić *et al.* (2011a).

2. MAGIC Observations, Data Analysis and Results

4C 21.35 is a Flat Spectrum Radio Quasar (FSRQ). An alternative designation (and the one usually used in VHE (very high energy) astronomy) is PKS 1222+216. It is only the 3^{rd} FSRQ detected in the VHE γ-ray band so far, and it is the 2^{nd} most distant VHE γ-ray source (z = 0.432 Osterbrock & Pogge (1987)) with a well-determined redshift.

MAGIC observed 4C 21.35 between May 1^{st} and June 19^{th} 2010. During that period a total of 16.5 hours of data was collected. A first hint of VHE γ-ray signal was spotted on May 3^{rd}. However, a positive detection (with significance above 5σ) came on June

17^{th}. The discovery was reported on in Aleksić *et al.* (2011b). The details of MAGIC data analysis can be found in Moralejo *et al.* (2009) and Aleksić *et al.* (2010).

4C 21.35 was observed on June 17^{th} for 30 minutes under moderate moonlight conditions. The energy threshold for this observation was 70 GeV. An excess of 190 γ-like events was collected (with a γ-ray rate of 6 min^{-1}) which translates to 10.2 σ. The light curve is shown in Fig.1. The constant flux hypothesis is rejected with high confidence (P $< 1.1 \times 10^{-5}$). The light curve was fitted by a linear and exponential fit. Both fits are acceptable, but the time scale can be determined from exponential fit only, which implies the flux doubling time of $8.6^{+1.1}_{-0.9}$ minutes. This is the fastest time variation ever observed in FSRQ, and among the shortest time scales measured on TeV emitters. The spectrum is shown in Fig.2. The observed spectrum has a slope of $\Gamma = 3.75 \pm 0.27$. VHE γ-rays interact with EBL (extragalactic background radiation) producing $e^- - e^+$ pairs. In order to obtain the intrinsic spectrum of the source, γ-rays that were absorbed have to be added to the measured spectrum. The expected absorption is calculated using EBL models. The intrinsic spectrum with the slope $\Gamma = 2.72 \pm 0.34$ is obtained using an EBL model from Dominguez *et al.* (2011). We see no evidence of a strong intrinsic cut-off below 130 GeV.

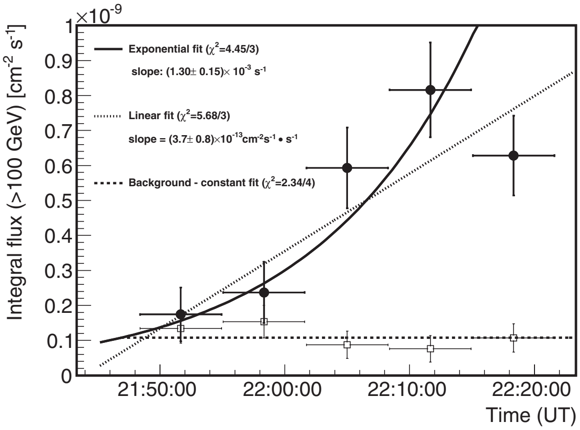

Figure 1. The light curve of 4C 21.35 on June 17^{th} 2010. Black full circles represent the signal, and grey empty squares the background. The full black line is an exponential fit of the signal, while the linear fit is represented by the black dotted line. The background was fitted by a constant shown by the grey dashed line.

3. Discussion

Since we see no evidence of a cut-off in the spectrum at energies below 130 GeV, we conclude that the site for production of VHE γ-rays must be somewhere outside the BLR (broad line region) (see for example Ghisellini & Tavecchio (2009), Reimer (2007), Tavecchio & Mazin (2009), Liu & Bai (2006)). The size of the BLR is estimated to be of the order of 10^{17} cm. At the same time the fast variability of the flux implies an extremely compact emission region with size of the order of 10^{14} cm. These two results taken together exclude the "canonical" emission scenario. One possible explanation of these features is a presence of a compact emission region within large scale jet as already suggested in Ghisellini & Tavecchio (2008), Giannios, Uzdensky & Begelman (2009) and Marscher & Jorstad (2010). Another possibility is a strong jet recollimation at certain point. See for example Nalewajko & Sikora (2009), Bromberg & Levinson (2009), or Stawarz *et al.* (2006). A two-zone scenario was proposed in Tavecchio *et al.* (2011).

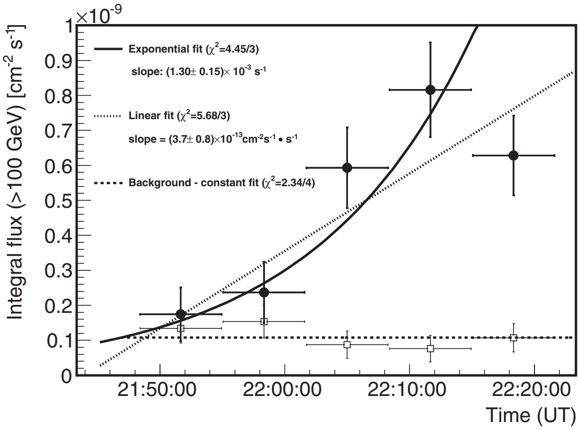

Figure 2. The Differential energy spectrum of 4C 21.35 above 70 GeV. The measured spectrum is represented by black circles, and the black line is the power law fit for observed spectrum. The blue squares represent the intrinsic spectrum, and the blue dashed line is the best fit to a power law of the intrinsic spectrum. The upper limits are given at 95% C.L. and indicated as arrows both for the measured and the intrinsic spectrum. The grey shaded area represents the systematic uncertainties of the analysis.

According to this model the rapidly varying VHE γ-ray emission originates in a small portion of the outflow blob outside BLR, while the emission at lower frequencies originates from the standard emission region. The standard jet can be either inside or outside of the BLR.

A report on a full multi wavelength campaign is in preparation, including a cross correlation study between radio, optical, x-ray and γ-ray data. We hope and expect that the results of that work will shed more light on this intriguing problem.

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