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Search for TeV gamma ray emission from 4C 39.12 with the Whipple 10 metre Čerenkov Telescope

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Abstract. Amongst others, the Whipple Telescope has been used extensively over the past decade to search for VHE emission from active galaxies. Different criteria have been used in target selection. Here we report on a new candidate, 4C 39.12, a radio selected source in the 408 MHz B2 survey which includes the BL Lac objects Mkn 421 and Mkn 501. Given its low redshift (z=0.02) and the recent identification of a relativistic jet at a small angle with respect to the line of sight, 4C 39.12 is a fair candidate for VHE observations. This object has not been catalogued by EGRET but was detected by ROSAT at a level consistent with non-thermal emission from the core.

Over a period of 5 months 4C 39.12 was monitored for evidence of γ-ray emission with the Whipple Telescope, which has an effective energy threshold of 390 GeV. A 99.9% confidence upper limit to the flux of $21 \times 10^{-12}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is derived from these observations.

1 Introduction to 4C 39.12

4C 39.12 was targeted as a potential VHE γ-ray source for the first time in the 2000/01 Whipple 10 m Telescope observing season. It is a low power, compact radio source which, like the established γ-ray sources Mkn 501 and Mkn 421, has a flat radio spectrum and a higher than average core radio power with respect to its total radio output, making it a strong end-on jet candidate. 4C 39.12 was one of 12 radio galaxies for which VLBI images were obtained by Giovannini et al. (2001). Their 5 GHz VLBI observations of this object show a one-sided, relativistic ($\beta > 0.5$) jet visible to more than 50 pc from the core, which could be limb-brightened as in Mkn 501. They obtain a statistical constraint on the jet orientation with respect to the line of sight of $\theta < 45°$. The lack of obvious *large-scale* radio jets is consistent with an end-on projection scenario e.g. in which lobes are superimposed on the bright radio core. This, when considered together with the relatively high X-ray flux, is suggestive of an orientation angle $\theta < 20°$ (Laing , 2000).

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4C 39.12 was detected as a point-like source by the ROSAT HRI, at a level consistent with non-thermal emission from the core according to Canosa et al. (1999). No HST observations of 4C 39.12 are available and it is unclear as to whether it has a point-like nucleus in the optical.

Given the tendency of jet sources of intrinsically low radio power to show high synchrotron and inverse Compton peak frequencies, there appears to be a fair chance that this object may emit VHE γ-rays.

4C 39.12 lies quite close to the galactic plane (l = 154°.2, b = -13°.4) and is not an EGRET catalogued source. Since it is closer than Mkn 421, at a redshift of just 0.020, it is reasonable to assume that absorption by pair-production on infrared background fields should not significantly affect our ability to detect VHE γ-rays from this object.

2 Observations

Data were recorded between October 2000 and February 2001 with the 490 pixel camera of the Whipple 10 m Imaging Čerenkov Telescope. A selection of Hillas parameter cuts optimised using Crab Nebula data from this observing season, “Supercuts2001”, were applied to identifiy candidate γ-ray events (Finley et al., 2001).

The observation strategy was to monitor 4C 39.12 at a rate of one half hour on-source per night, in order to maximise the chance of obtaining data coincident with any episodic emission. A total of 12.7 hours of on-source data were recorded under good weather conditions. These include seven observations made in ON/OFF mode, recording for 28 minutes on-source followed by a similar off-source control observation.

One can apply a so-called TRACKING analysis to all on-source data, as in Quinn et al. (1999). Events with orientations such that they are not from the direction of the source are used, together with a “tracking ratio”, to determine the

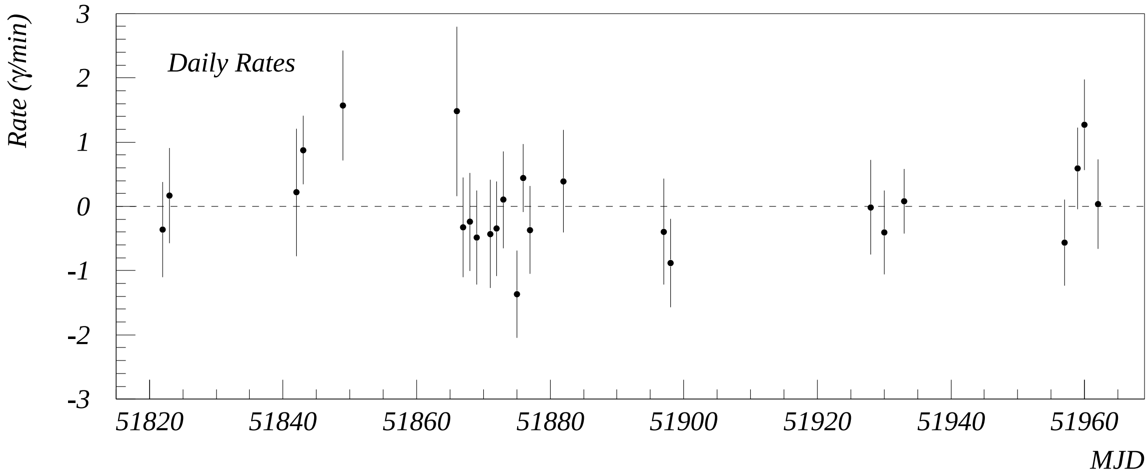

Fig. 1. Light curve for Whipple 10 m Telescope γ-ray observations of 4C 39.12 between October 2000 and February 2001

background level. The candidate γ-ray events are those with α-parameter values between 0° and 15° (Reynolds et al., 1993). For this analysis 73 hours of off-source data from the same season, taken under similar conditions, were used to obtain the tracking ratio appropriate to the 4C 39.12 dataset, which spans an elevation range of 55° - 80°.

3 Results

No statistically significant excess was obtained from the dataset as a whole either by applying a TRACKING analysis to all on-source data (giving 0.38 σ), or from an ON/OFF comparison of the seven paired observations (-0.54 σ). Nevertheless, the data were subsequently analysed on a night by night basis to search for any significant short-term excess, such as the 6σ level flare seen on one night which contributed to the Whipple Telescope detection of the BL Lac object 1ES 2344+514 (Catanese et al., 1998). The highest significance thus obtained was 1.9 σ, from a single 28 minute observation on MJD 51849. As can be seen from Figure 1, the γ-ray candidate rates obtained from our dataset are entirely consistent with a null result.

From the TRACKING analysis, a total of 9015 candidate γ-ray events was obtained for the dataset as a whole, whereas 8974 γ-ray like events were expected due to background. An upper limit was set on the mean number of γ-rays using the method of Helene (1983). This was then converted to a flux limit by comparison with contemporaneous Whipple 10 m Telescope results on the Crab Nebula, assuming a power law spectrum in the TeV range of index -2.49 (Hillas et al., 1998). We thus obtained an upper limit to the VHE flux from 4C 39.12 of I $_{(E>390\,GeV)} < 21 \times 10^{-12}$ cm^{-2}s^{-1} or about 0.17 times the Crab Nebula flux above this photon energy.

Our flux upper limit in terms of energy density νF_ν is presented in Figure 2. The archival data on this object are relatively scarce and have been gathered over several decades. Although the measurements are not contemporaneous they give a basis for rough comparison with the spectral energy distributions of known γ-ray AGN. The dashed line in Figure 2 represents the approximate position of the probable synchrotron peak in the spectral energy distribution of BL Lacertae, which was detected as a source of > 100 MeV γ-rays by Catanese et al. (1997). One may interpret the 4C 39.12 distribution as also exhibiting a turn-over in the optical regime but at a slightly higher frequency. It is clear from the ROSAT measurement (Canosa et al., 1999) that this peak does not extend far into the X-ray region as in the high-energy peaked blazars Mkn 421 and Mkn 501.

4 Discussion

The proximity of 4C 39.12 is such that our negative result can be considered to be due to intrinsic properties of this object, without reference to any absorption effect of the infrared background. Mkn 501 was originally discovered at an average flux level of 0.08 times that of the Crab Nebula after 66 hours of observation (Quinn et al., 1999). Our current flux upper limit for 4C 39.12 is approximately twice the Mkn 501 discovery level. Given the notorious multi-wavelength variability of AGN jet sources (Catanese et al., 1997) we do not rule out the possibility that 4C 39.12 may be detectable as a γ-ray emitter in future observations.

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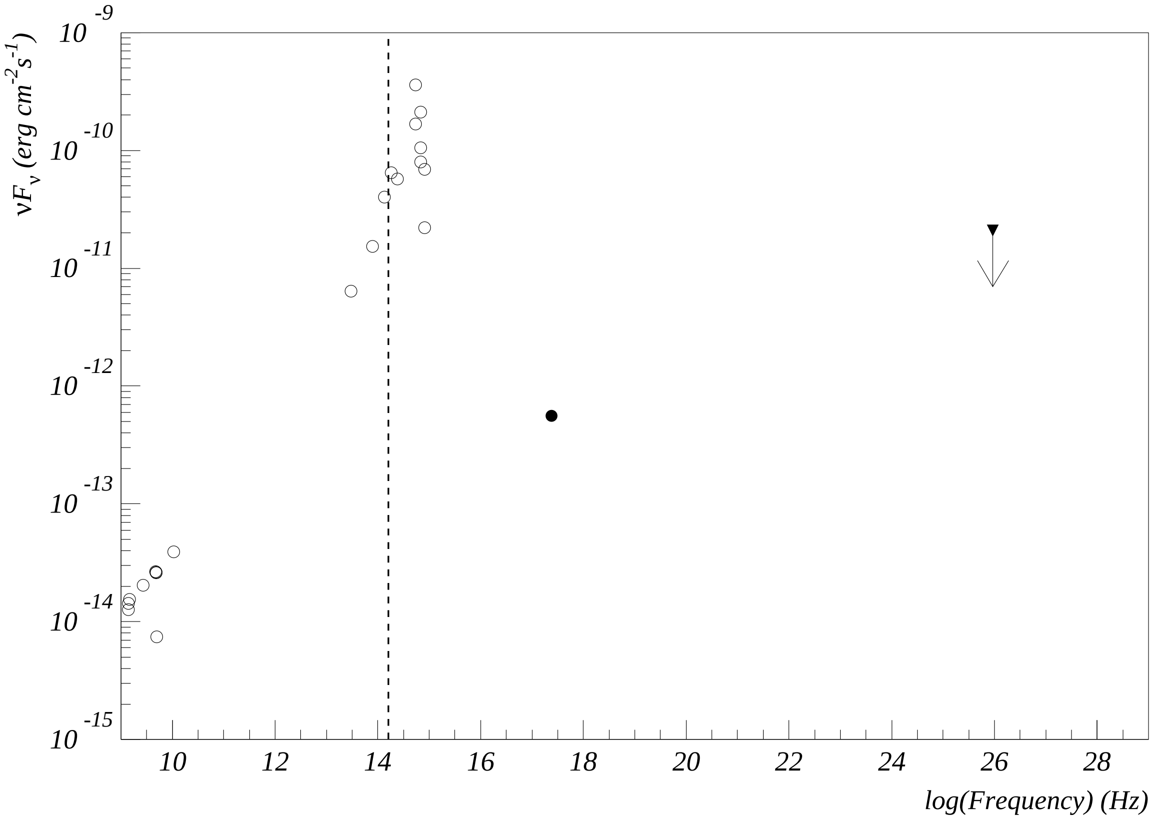

Fig. 2. Spectral energy distribution of 4C 39.12. The arrow indicates our upper limit. The filled circle is the ROSAT 1 keV measurement of Canosa et al. (1999). The open circles are archival data from the NED, Impey, Wynn-Williams & Becklin (1990), Giovannini et al. (2001) Neumann et al. (1994) and Fanti et al. (1986). Fanti et al. (1986) distinguish a core luminosity of one quarter of the total (plotted) at 1.4 GHz, whereas Canosa et al. (1999) report that the X-ray flux at 1 keV is entirely core dominated.

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