

Durham Research Online

Deposited in DRO:

10 April 2015

Version of attached file:

Published Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Brown, Anthony M. and Chadwick, Paula M. and Landt, Hermine (2014) 'Very high energy -ray emission from RBS 0679.', *Monthly notices of the Royal Astronomical Society.*, 445 (4). pp. 4345-4350.

Further information on publisher's website:

<http://dx.doi.org/10.1093/mnras/stu2321>

Publisher's copyright statement:

This article has been published in *Monthly Notices of the Royal Astronomical Society* © 2014 The Authors. Published by Oxford University Press on behalf of the Royal Astronomical Society. All rights reserved.

Additional information:

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in DRO
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full DRO policy](#) for further details.

Very high energy γ -ray emission from RBS 0679

Anthony M. Brown,^{*} Paula M. Chadwick and Hermine Landt

Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK

Accepted 2014 September 25. Received 2014 September 25; in original form 2014 June 24

ABSTRACT

In this paper, we report the *Fermi* Large Area Telescope (LAT) detection of Very High Energy (VHE; $E_\gamma > 100$ GeV) γ -ray emission from the BL Lac object RBS 0679. 5.3 years of LAT observations revealed the presence of three VHE photon events within $0^\circ.1$ of RBS 0679, with a subsequent unbinned likelihood analysis finding RBS 0679 to be a source of VHE photons at 6.9 standard deviations (σ). An unbinned likelihood analysis of the 0.1–100 GeV data, binned in 28-d periods, finds both the flux and spectral index to be variable, with a ‘softer-when-brighter’ trend in the global γ -ray characteristics. On the other hand, the 28-d periods in which the VHE photons were detected have spectral indices that are consistent with the 5.3 year average suggesting that the observed VHE emission is not associated with a spectral hardening event. The discovery of RBS 0679 in the 100–300 GeV energy range, combined with the non-detection above 390 GeV with the H.E.S.S. telescope array, suggest RBS 0679 to be an intriguing source that requires further follow-up observations with ground-based γ -ray observatories.

Key words: radiation mechanisms: non-thermal – galaxies: active – BL Lacertae objects: individual: RBS 0679 – galaxies: jets – gamma rays: galaxies.

1 INTRODUCTION

Launched in June 2008, the *Fermi* γ -ray Space Telescope affords an ideal opportunity to investigate the inner workings of active Galactic nuclei (AGN). To date, *Fermi* has spent over 95 per cent of its lifetime in *all-sky-survey* observing mode, whereby the Large Area Telescope (LAT) on board *Fermi* points away from the Earth and rocks north and south of its orbital plane on consecutive orbits. This rocking motion of the *Fermi*-LAT detector, coupled with its large effective area, allows *Fermi* to scan the entire γ -ray sky every two orbits, or approximately every three hours (Atwood et al. 2009). The scanning ability of the LAT has allowed us to catch AGN during brief flares of γ -ray activity (e.g. Dickinson & Farnier 2013), with these flares sometimes resulting in the discovery of Very High Energy (VHE; $E_\gamma > 100$ GeV) emission from the AGN (e.g. Ong & Fortin 2010; Aliu et al. 2012).

While its three-hour scan period is important for catching brief periods of flare activity from AGN, coupling *Fermi*-LAT’s continual scanning of the sky with a long mission lifetime allows us to construct a deep exposure of the extragalactic γ -ray sky. This deep exposure affords us the ability to perform searches for faint VHE sources which would otherwise go undetected by the pointed observations of ground-based Imaging Atmospheric Cherenkov Telescope (IACT) arrays. Utilizing such an approach, a recent study of

a deep ~ 5.3 year *Fermi*-LAT exposure uncovered VHE emission from the BL Lac object RBS 0970 (Brown 2014).

RBS 0679, also known as BZB J0543-5532, is a point-like radio source, at a redshift of $z = 0.273$ (Pita et al. 2014). Detected as a bright X-ray source with the *ROSAT* satellite (Voges et al. 1999), RBS 0679 has been optically identified as a BL Lac object (Anderson & Filipovic 2009). Discovered as a source of γ -rays in *Fermi*-LAT observations (Abdo et al. 2010a), RBS 0679 is included in both the 1 and 2 year LAT AGN catalogues (1LAC, Abdo et al. 2010b; 2LAC, Ackermann et al. 2011), as well as the recent $E_\gamma > 10$ GeV LAT catalogue (Ackermann et al. 2013). Recently the H.E.S.S. Collaboration has published an upper limit on RBS 0679 of $9 \times 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}$, from 8.1 h of observations (Abramowski et al. 2014). The energy threshold for this upper limit was 390 GeV. Interestingly, the H.E.S.S. observations found that, even after accounting for absorption of the γ -ray flux by the extragalactic background light (EBL), this upper limit is not compatible with a simple power-law extrapolation of RBS 0679’s 2LAC spectrum to above 390 GeV. This suggests the presence of an intrinsic break in the γ -ray spectrum, not associated with the process of EBL absorption.

This paper reports the discovery of VHE emission from RBS 0679. Using the same approach that discovered RBS 0970 as a VHE source, 5.3 years of *Fermi*-LAT data also revealed three ULTRACLEAN $E_\gamma > 100$ GeV events clustered within $0^\circ.1$ of RBS 0679. Unlike RBS 0970, the VHE emission detected from RBS 0679 does not coincide with severe spectral hardening, with the spectral index of the 0.1–100 GeV flux during the

^{*}E-mail: anthony.brown@durham.ac.uk

detection of the VHE photons being consistent with the 5.3 year average. However, the F_{γ} - Γ parameter space suggests a softer-when-brighter property for the global γ -ray characteristics throughout the 5.3 year data set. In Section 2, the *Fermi*-LAT observations and analysis routines used in this study are described, along with the results of the 0.1–300 GeV likelihood analysis. The results of the VHE study of RBS 0679 are shown in Section 3. A brief investigation into the global γ -ray characteristics of RBS 0679 when the VHE emission occurs is presented in Section 4, with the conclusions given in Section 5. It should be highlighted that this paper reports the discovery of VHE emission from RBS 0679. A follow-up publication with spectral energy distribution (SED) modelling and interpretation is currently in preparation and will follow shortly.

2 FERMI-LAT OBSERVATIONS AND DATA ANALYSIS

The data used in this study comprise all *Fermi*-LAT event and spacecraft data taken during the first 5.3 years of *Fermi*-LAT operation, from 2008 August 4 to 2013 December 12, which equates to a Mission Elapsed Time (MET) interval of 239 557 417 to 408 871 812. All SOURCE γ -ray events,¹ in the $0.1 < E_{\gamma} < 300$ GeV energy range, within a 13° radius of interest (RoI) centered on the 2LAC (Ackermann et al. 2011) position of RBS 0679, (α_{J2000} , $\delta_{J2000} = 85^{\circ}987$, $-55^{\circ}5344$), were considered. In accordance with the `PASS7_REP` criteria, a zenith cut of 100° was applied to the data to remove any cosmic ray induced γ -rays from the Earth's atmosphere. The good time intervals were generated by applying a filter expression of `'(DATA_QUAL==1) && (LAT_CONFIG==1) && ABS(ROCK_ANGLE)< 52'` to the data, where the `(DATA_QUAL)` and `(LAT_CONFIG)` flags remove sub-optimal data affected by spacecraft events and the `(ABS(ROCK_ANGLE))` flag removes data periods where the LAT detector rocking is greater than 52° .²

Throughout this analysis, version `v9R32P5` of the `FERMI SCIENCE TOOLS` was used in conjunction with the `P7REP_CLEAN_V15` and `P7REP_SOURCE_V15` instrument response functions (IRFs). The IRFs defines how the LAT detector performs for various parameters such as incident photon energy, incident angle and location of photon conversion within the detector. During the analysis, a model file consisting of both point and diffuse sources of γ -rays was employed. In particular, the model file consisted of the most recent Galactic and extragalactic³ diffuse models, and all γ -ray point sources within an 18° RoI centered on RBS 0679. The positions of these point sources, along with their spectral shapes, were taken from the 2FGL (Nolan et al. 2012). Located $13^{\circ}03'$ from RBS 0679, the extended γ -ray emission associated with the Large Magellanic Cloud was accounted for with the *Fermi*-LAT Collaboration's `LMC.FITS` spatial model, with the normalization and spectral parameters frozen to their 2FGL values. The normalization factor of the extragalac-

tic diffuse emission was left free to vary, while the Galactic diffuse template was multiplied by a power law in energy, the normalization of which was left free to vary.

Firstly, a binned maximum likelihood analysis was performed on the entire 5.3 year data set in the 0.1–300 GeV energy range. For RBS 0679 itself, a power-law spectral shape of the form $dN/dE = A \times (E/E_0)^{-\Gamma}$ was assumed, with the normalization, A , and the spectral index, Γ , left free to vary. The normalization and spectral parameters of all point sources within 13° of RBS 0679 were left free to vary, while the normalization and spectral parameters for all point sources within an annulus of 13° to 18° from RBS 0679 were fixed to those published in the 2FGL catalogue.

Utilizing the above described model, the binned likelihood analysis of the 5.3 year data set, utilizing the `P7REP_SOURCE_V15` IRF, resulted in the following best-fitting power-law function for RBS 0679:

$$\frac{dN}{dE} = (1.92 \pm 0.12) \times 10^{-13} \left(\frac{E}{3006.4 \text{ MeV}} \right)^{-1.82 \pm 0.05} \text{ photons cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1} \quad (1)$$

which equates to an integrated flux, in the 0.1–300 GeV energy range, of

$$F_{0.1 < E < 300 \text{ GeV}} = (1.14 \pm 0.14) \times 10^{-8} \text{ photons cm}^{-2} \text{ s}^{-1} \quad (2)$$

taking only statistical errors into account.⁴ For the best-fitting power-law description, a test statistic⁵ of $TS = 668$ was found, corresponding to an $\sim 26\sigma$ detection of RBS 0679 in the 0.1–300 GeV energy range over the 5.3 year period.

The long exposure of the analysed observations can result in additional faint sources being present in the data that are not present in the 2FGL. If these sources are present in the data, and not properly accounted for within the model file utilized during the likelihood analysis, they can artificially increase the significance of the γ -ray flux from RBS 0679 (e.g. Brown & Adams 2012; Macias et al. 2012; Brown 2014). To check if indeed any additional sources were present, a residual count map was constructed in the 0.1–300 GeV energy range. Shown in Fig. 1, the residuals map was obtained by subtracting a 'model' map⁶ from the observed counts map, and then dividing by the model map again. The residuals map shows fluctuations in the count residuals at the ± 1 per cent level. These fluctuations are consistent with random fluctuations and as such, the model used during the analysis is an accurate representation of the observed γ -rays, with no new γ -ray point sources being present.

3 VERY HIGH ENERGY γ -RAY PROPERTIES

A closer inspection of the individual photon events within 0:1 of RBS 0679 revealed the presence of three VHE γ -rays. All three γ -rays are classed as ULTRACLEAN events,⁷ a subclass of CLEAN

¹ SOURCE events have an event class of 2 in the `PASS7_REP` data, and have a high probability of being a γ -ray (see Ackermann et al. 2012b for details on event classification).

² See http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Data_Exploration/Data_preparation.html for details on LAT data selection.

³ For the Galactic diffuse model, we have used the LAT collaboration's 'gll_iem_v05.fit' model. For the extragalactic diffuse, we have used both the 'iso_clean_v05.txt' and 'iso_source_v05.txt' extragalactic diffuse models, depending upon whether source or clean photon events were considered. These models are available at <http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html>.

⁴ Primarily governed by the uncertainty in the effective area, the systematic uncertainty of the integrated flux is energy dependent and is currently estimated as 10 per cent at 100 MeV, down to 5 per cent at 560 MeV and back to 10 per cent for 10 GeV photons (Ackermann et al. 2012a).

⁵ The test statistic, TS , is defined as twice the difference between the log-likelihood of two different models, $TS = 2[\log L - \log L_0]$, where L and L_0 are defined as the likelihood when the source is included or not respectively (Mattox et al. 1996).

⁶ The model map was created with the `GTMODEL Fermi` tool in conjunction with the best-fitting model of the 0.1–300 GeV likelihood fit of equation (1).

⁷ See Ackermann et al. (2012b) for details on event classification.

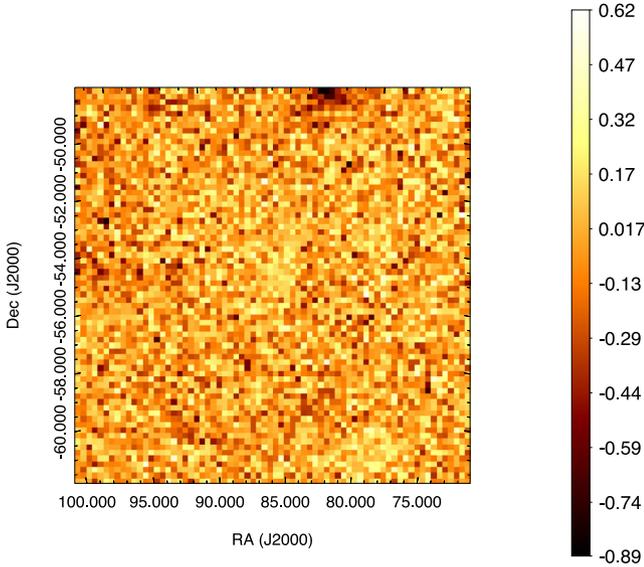


Figure 1. A residuals map, $((\text{counts} - \text{model})/\text{model})$, in the 0.1–300 GeV energy range, during the entire 5.3 year period, centered on the co-ordinates of RBS 0679. The colour scale is in units of percentage, with fluctuations in the residuals between the model and observed counts map being at the ± 1 per cent level. These fluctuations are consistent with random fluctuations and as such, show the model used during the analysis to be a good representation of the data. It is worth highlighting that the biggest percentage difference between the model and observed count maps, seen at the top of the residuals map, is positionally coincident with the 2LAC source PMN J0531-4827.

events that have the highest probability of being photons. Using the combined diffuse and point source model file from Section 2, with all normalization and spectral parameters frozen to the best-fitting values of the 5.3 year binned likelihood analysis, the GTSRCPROB *Fermi* tool was used to calculate the probability that each of the VHE γ -ray events originated from RBS 0679, as opposed to other sources such as the Galactic or extragalactic diffuse emission. The results of these probability calculations are shown in Table 1, along with the energy, time detected and $(\alpha_{J2000}, \delta_{J2000})$ of each photon event.

Considered in isolation, none of these $E_\gamma > 100$ GeV events are significant enough to consider RBS 0679 a source of VHE γ -rays, the most significant event being the 257 GeV photon detected on MJD = 56022.72787, with a $>4\sigma$ confidence of originating from RBS 0679, assuming Gaussian errors. The other two VHE events have a $>3\sigma$ confidence of originating from RBS 0679. However, the clustering of such energetic photons within a relatively small area can be significant given the small background rates detected by the *Fermi*-LAT above 100 GeV (e.g. Neronov, Semikoz & Vovk 2010; Tanaka et al. 2013). To determine if RBS 0679 is indeed a source of VHE γ -ray photons, an unbinned likelihood analysis, with the P7REP_CLEAN_V15 IRF, was applied to all $E_\gamma > 100$ GeV CLEAN⁸ events within 5° of RBS 0679 for the entire 5.3 year data set. To accommodate the smaller RoI, the model file used only considered point sources within 6° of RBS 0679. The normalization and spectral parameters of point sources within 5° were left free to vary, while point sources within the 5° to 6° annulus had their normalization and spectral parameters frozen to their 2FGL values.

⁸ CLEAN events have an event class of 3 in the PASS7_REP data, (see Ackermann et al. 2012b for details on event classification).

The diffuse components were treated the same as in Section 2, with the exception that the extragalactic diffuse was modelled with the iso_clean_v05.txt description. The resultant best-fitting power-law function for RBS 0679 in the 100–300 GeV energy range, was found to be

$$\frac{dN}{dE} = (0.06 \pm 0.3) \times 10^{-12} \left(\frac{E}{3006.4 \text{ MeV}} \right)^{-0.44 \pm 1.53} \text{ photons'; cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1} \quad (3)$$

which equates to an integrated flux of

$$F_{E > 100 \text{ GeV}} = (1.98 \pm 1.15) \times 10^{-11} \text{ photons cm}^{-2} \text{ s}^{-1} \quad (4)$$

again taking only statistical errors into account. It is worth highlighting that due to the limited number of photons with $E_\gamma > 100$ GeV, the statistical errors of the likelihood fit are large. The TS value of the best-fitting power law was TS = 47.5, equating to a significance of $\sim 6.9\sigma$. As such, this analysis represents the discovery of RBS 0679 as a source of VHE γ -rays.

To locate the origin of the VHE γ -ray emission, another *Fermi* tool, GTFINDSRC, was applied to all $E_\gamma > 100$ GeV events within 5° of RBS 0679. Using the same combined diffuse and point source model that was applied during the unbinned likelihood fit to the VHE data, the observed VHE γ -ray emission was found to originate from $(\alpha_{J2000}, \delta_{J2000}) = 85^\circ 9734, -55^\circ 535$, with a 95 per cent error radius of $0^\circ 025$. The VHE emission is therefore found to be spatially co-incident with the 2LAC position of RBS 0679.

4 DISCUSSION

With our discovery of VHE emission positionally coincident with RBS 0679, we firstly turn our attention to the apparent discrepancy between our result and the H.E.S.S. upper limit. Extrapolating our best-fitting power-law model from Section 3, and correcting for EBL extinction with the Franceschini, Rodighiero & Vaccari (2008) EBL model, we find that, within errors, there is no discrepancy between the two analyses. We do however note that there is a large uncertainty in the spectral index of our best-fitting power-law model. This large uncertainty, understandable given the small number of photons that the LAT has detected in the VHE regime, limits our ability to investigate the presence and nature of a cut-off in RBS 0679's VHE spectrum.

Investigating the presence and nature of a cut-off in the γ -ray spectrum of RBS 0679 requires detailed SED modelling studies, in conjunction with observations of RBS 0679 with the recently commissioned H.E.S.S.-II telescope. Detailed SED modelling studies of RBS 0679's broad-band emission are currently on-going, the results of which will be presented in a future publication. Along, with allowing us to better understand the inner workings of RBS 0679, these SED studies will allow us to better determine when to trigger H.E.S.S.-II observations. With an energy threshold of ~ 30 GeV, H.E.S.S.-II will allow us to observe both the high-energy component of the LAT spectrum and the low-energy component of the H.E.S.S. spectrum with greatly improved statistics. These improved photon statistics will allow us to determine conclusively if a cut-off in the spectrum is present. To investigate the global γ -ray properties of RBS 0679 during the emission of the VHE γ -rays, the temporal characteristics of the γ -ray flux and spectral index were investigated. The entire 5.3 year data set was binned into 28-d periods, with an unbinned likelihood analysis applied to each bin separately. The 28-d bin size was chosen simply as a compromise between having decent statistics in each bin, while being able to

Table 1. Summary of the three VHE events from RBS 0679 detected by *Fermi*-LAT. It should be noted that all three of these events are also ULTRACLEAN class events. The GTSRCPROB probabilities refer to the likelihood that the individual VHE photons originated from RBS 0679, as opposed to other sources such as the Galactic or extragalactic diffuse emission and have been calculated with the *Fermi* tool GTSRCPROB.

Energy (GeV)	MET (s)	MJD (d)	α_{J2000} (deg)	δ_{J2000} (deg)	GTSRCPROB probability
167	253 636 097.775	54845.60373	85.972	-55.502	0.999 865
136	293 442 157.552	55306.32201	85.994	-55.561	0.999 909
257	355 339 624.208	56022.72787	85.959	-55.528	0.999 98

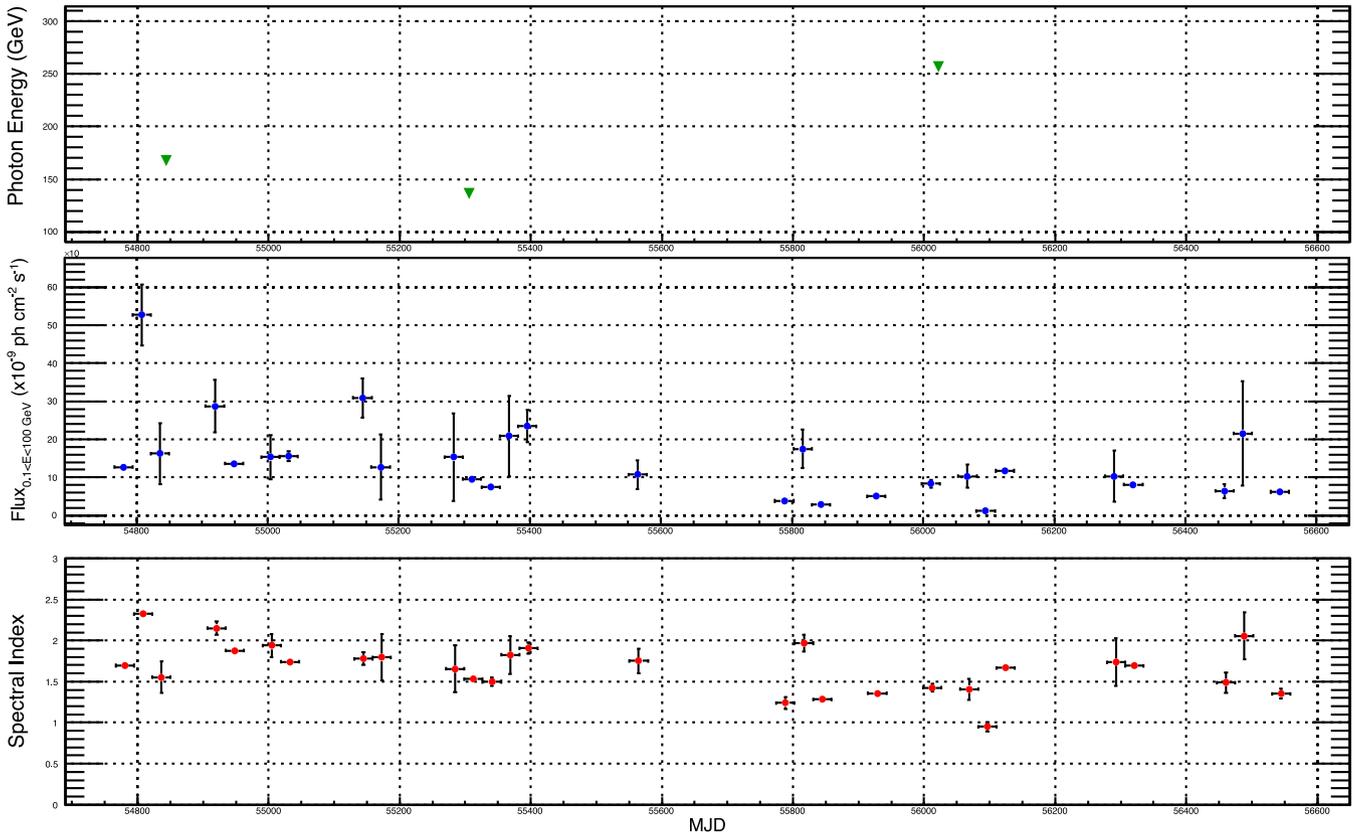


Figure 2. Top panel: arrival times in MJD of all $E_\gamma > 100$ GeV CLEAN events within 0.1° of RBS 0679. Middle panel: 0.1–100 GeV flux light curve, binned in 28-day periods. Only bins where the TS is greater than 10 are shown. Bottom panel: spectral index for each 28-day period where the TS ≥ 10 .

resolve structure within the light curve. All SOURCE events in the $0.1 < E_\gamma < 100$ GeV energy range were considered. The upper energy limit of 100 GeV was chosen so as to remove any possible bias to harder spectral indices caused by the presence of the VHE events. The good time intervals were selected as outlined in Section 2. The model file utilized in each *GTLIKE* fit was the same as that used in Section 2; that is, the normalization and spectral parameters of all point sources within 13° of RBS 0679 were left free to vary, while the normalization and spectral parameters for all point sources within an annulus of 13° – 18° from RBS 0679 were fixed to those published in the 2FGL. Only time intervals where the corresponding TS value was greater than 10 were considered, which equates to a significance of $\approx 3\sigma$. The resultant flux and spectral index ‘light curve’ can be seen in Fig. 2, along with the arrival times of all $E_\gamma > 100$ GeV photons within 0.1° of RBS 0679.

Kataoka et al. (2010) and Brown & Adams (2011) found that, for NGC 1275, it is the $E_\gamma \geq 1$ GeV γ -ray flux and spectral shape that

are important when triggering ground-based VHE γ -ray observations, with a higher $E_\gamma \geq 1$ GeV flux, or harder γ -ray spectrum, more likely to be associated with the emission of VHE γ -ray photons. Likewise, the majority of VHE photons detected from RBS 0970 coincided with severe spectral hardening (Brown 2014). However, this ‘harder-when-brighter’ phenomenon for the VHE emission is not universally applicable to all VHE emitting AGN, with Brown (2013) finding no such trend for the FSRQ PKS 1510-089. The variable nature of RBS 0679’s flux and spectral index, shown in Fig. 2, is clear to see. Indeed, a constant flux fit to the flux distribution of Fig. 2 has a χ^2_{red} of 289.9, while a constant index fit to the spectral indices distribution of Fig. 2 has a χ^2_{red} of 3337.7. Interestingly, in the F_γ – Γ parameter space, shown in Fig. 3, this flux and spectral variability shows a clear ‘softer-when-brighter’ trend. Such a trend has previously been seen in some AGN in *EGRET* data (e.g. Nandikotkur et al. 2007). More recently the H.E.S.S. Collaboration has seen both ‘softer-when-brighter’ and ‘harder-when-brighter’

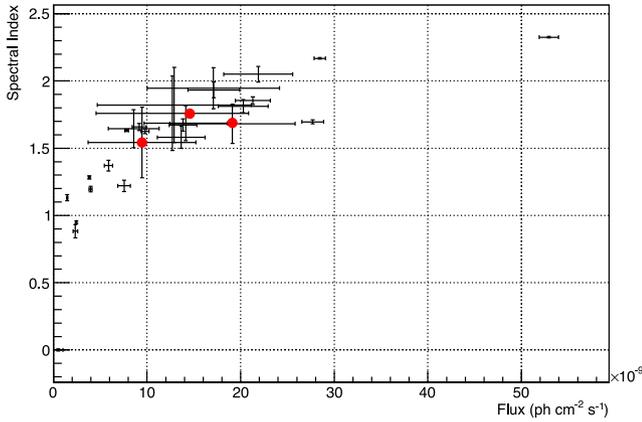


Figure 3. The F_γ – Γ parameter space of the individual 28-d intervals shown in Fig. 2. The F_γ – Γ parameter space shows a clear ‘softer-when-brighter’ tendency for the global γ -ray characteristics of RBS 0679. The red points represent the F_γ – Γ values for the 28-d period in which a VHE photon was detected.

Table 2. Summary of the global γ -ray properties of RBS 0679, in the 0.1–100 GeV energy range, during the 28-d period in which the VHE photons were detected, along with 5.3 year average values. The photon energy is in units of GeV, Flux and Δ Flux are in units of $\times 10^{-9}$ photons $\text{cm}^{-2} \text{s}^{-1}$ and are the 0.1–100 GeV flux and statistical error of the flux. Γ and $\Delta\Gamma$ are the spectral index and statistical error of the spectral index.

Photon energy	Flux	Δ Flux	Γ	$\Delta\Gamma$
167	19.13	6.69	1.68	0.15
136	14.56	0.39	1.75	0.01
257	9.47	5.76	1.54	0.26
5.3 year average	11.27	1.56	1.81	0.06

trends from the prominent BL Lac object PKS 2155-304 in the VHE regime, depending upon the flux level (Abramowski et al. 2010).

In the traditional synchrotron self-Compton⁹ model, a ‘softer-when-brighter’ trend can be reproduced by an increase in the magnetic field strength, a softening of the primary electron population or an increase in the size of the emission region and the associated adiabatic cooling. Outside of the SSC interpretation, a ‘softer-when-brighter’ characteristic suggests a rapid cooling of the highest energy particles as RBS 0679 brightens. To determine which of these effects, if any, are responsible for the observed ‘softer-when-brighter’ characteristic of RBS 0679 requires in-depth multiwavelength studies which we defer to a later paper.

At first glance, Fig. 3 suggests that RBS 0679 is not necessarily VHE bright during the harder spectral states. Considering the VHE photons on an individual basis, this does indeed appear to be true, with all three VHE photons being detected during months where the spectral index was consistent, within errors, with the 5.3 year average (see Table 2). None the less, it is worth noting that phe-

⁹ The γ -ray flux from BL Lac object subclass of AGN is often attributed to the synchrotron self-Compton (SSC) model, whereby the observed γ -ray flux is produced through the inverse Comptonization of synchrotron photons by a population of relativistic electrons (e.g. Krawczynski et al. 2004; Brown 2006; Abramowski et al. 2013).

nomenological studies by *Fermi* have found the majority of TeV bright AGN have a $\Gamma < 2$ in the 0.1–100 GeV energy range (Abdo et al. 2009). As such, while the emission of VHE photons from RBS 0679 does not appear to be associated with any spectral hardening phenomenon, the monthly spectral indices of RBS 0679 during the detection of the VHE γ -rays do follow the trend that VHE bright AGN have a $\Gamma < 2$ in the *Fermi*-LAT energy range.

With the detection of three ULTRACLEAN events within 0:1, the VHE detection of RBS 0679 is a robust result. As such, with a redshift of $z = 0.273$, RBS 0679 is a relatively distant, spectrally hard, VHE emitting BL Lac object. AGN with these characteristics are ideal for studying the intensity of the EBL (Aharonian et al. 2006) and the strength of the intergalactic magnetic field (IGMF; Neronov & Semikoz 2009). As such, besides better understanding the VHE properties of RBS 0679, ground-based observations with IACTs will also allow us to use RBS 0679’s γ -ray spectrum to study the EBL and determine the suitability of RBS 0679 for studying the IGMF.

5 CONCLUSIONS

With 5.3 years of *Fermi*-LAT data, RBS 0679 has been found to be a source of VHE γ -ray photons. With three ULTRACLEAN $E_\gamma > 100$ GeV photon events within 0:1 of RBS 0679, an unbinned likelihood analysis revealed the significance of this discovery to be at the 6.9σ confidence level. The 5.3 year integrated $E_\gamma > 100$ GeV flux was found to be $(1.98 \pm 1.15) \times 10^{-11}$ photons $\text{cm}^{-2} \text{s}^{-1}$.

An investigation of the global 0.1–100 GeV γ -ray characteristics during the 5.3 years revealed a ‘softer-when-brighter’ trend. Interestingly, the 28-d periods during which the VHE photons were detected had a spectral index that was consistent with the 5.3 year average, suggesting that the observed VHE emission is not associated with a spectral hardening event.

The detection of three ULTRACLEAN events within 0:1 of RBS 0679, coupled with the results of the 100–300 GeV unbinned likelihood analysis, suggest the VHE detection of RBS 0679 is a robust result. While the extrapolation of RBS 0679’s spectrum, as reported in previous *Fermi*-LAT catalogues, is inconsistent with the recently announced H.E.S.S. upper limit, the extrapolation of the best-fitting power law for the VHE discovered here is consistent with the H.E.S.S. upper limit. However, given the large uncertainty on the spectral index of this power-law fit does not significantly rule out the presence of a cut-off in the γ -ray spectrum. To investigate the presence of a cut-off in detail requires follow-up observations with IACT arrays such as H.E.S.S.-II or the future CTA (Acharya et al. 2013), in conjunction with in-depth SED modelling. This in-depth SED modelling is currently ongoing, the results of which we defer to a later publication.

ACKNOWLEDGEMENTS

We thank the referees for their comments and suggestions that has improved the quality of this paper. This work was undertaken with the financial support of Durham University and has made use of public *Fermi* data obtained from the High Energy Astrophysics Science Archive Research Center (HEASARC), provided by NASA’s Goddard Space Flight Center. This work has also made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. We thank the *Fermi*-LAT collaboration for the quality of the data and analysis tools that were used in this study.

REFERENCES

- Aharonian F. et al., 2006, *Nature*, 440, 1018
Abdo A. et al., 2009, *ApJ*, 707, 1310
Abdo A. A. et al., 2010a, *ApJS*, 188, 405
Abdo A. A. et al., 2010b, *ApJ*, 715, 429
Abramowski A. et al., 2010, *A&A*, 520, A83
Abramowski A. et al., 2013, *A&A*, 559, A136
Abramowski A. et al., 2014, *A&A*, 562, L4
Acharya B. S. et al., 2013, *Astropart. Phys.*, 43, 3
Ackermann M. et al., 2011, *ApJ*, 743, 171
Ackermann M. et al., 2012a, *ApJS*, 201, 4
Ackermann M. et al., 2012b, *ApJS*, 203, 4
Ackermann M. et al., 2013, *ApJS*, 209, 13
Aliu E. et al., 2012, *ApJ*, 750, 94
Anderson M. W. B., Filipovic M. D., 2009, *Serb. Astron. J.*, 179, 7
Atwood W. B. et al., 2009, *ApJ*, 697, 1071
Brown A. M., 2006, PhD thesis, Univ. Durham
Brown A. M., 2013, *MNRAS*, 431, 824
Brown A. M., 2014, *MNRAS*, 442, L56
Brown A. M., Adams J., 2011, *MNRAS*, 413, 2785
Brown A. M., Adams J., 2012, *MNRAS*, 421, 2303
Dickinson H., Farnier C., 2013, *A&A*, 552, 134
Franceschini A., Rodighiero G., Vaccari M., 2008, *A&A*, 487, 837
Kataoka J. et al., 2010, *ApJ*, 715, 554
Krawczynski H. et al., 2004, *ApJ*, 601, 151
Macias-Ramirez O., Gordon C., Brown A. M., Adams J., 2012, *Phys. Rev. D*, 86, 6004
Mattox J. R. et al., 1996, *ApJ*, 461, 396
Nandikortjur G., Jahoda K. M., Hartman R. C., Mukherjee R., Sreekumar R., Bottcher M., Sambruna R. M., Swank J. H., 2007, *ApJ*, 567, 706
Neronov A., Semikoz D., 2009, *Phys. Rev. D*, 80, 123012
Neronov A., Semikoz D., Vovk I. , 2010, *A&A*, 519, 6
Nolan P. L. et al., 2012, *ApJS*, 199, 31
Ong R., Fortin P., 2010, *Astron. Telegram*, 2272
Pita S. et al., 2014, *A&A*, 565, 12
Tanaka Y. T et al., 2013, *ApJ*, 777, 18
Voges W. et al., 1999, *A&A*, 349, 389

This paper has been typeset from a $\text{\TeX}/\text{\LaTeX}$ file prepared by the author.