H.E.S.S. observations of the flaring gravitationally lensed galaxy PKS 1830-211

H.E.S.S. Collaboration

DOI
10.1093/mnras/stz1031

Publication date
2019

Document Version
Final published version

Published in
Monthly Notices of the Royal Astronomical Society

Citation for published version (APA):
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Accepted 2019 April 7. Received 2019 March 27; in original form 2019 January 25

ABSTRACT

PKS 1830–211 is a known macrolensed quasar located at a redshift of $z = 2.5$. Its high-energy gamma-ray emission has been detected with the Fermi-Large Area Telescope (LAT) instrument and evidence for lensing was obtained by several authors from its high-energy data. Observations of PKS 1830–211 were taken with the High Energy Stereoscopic System (H.E.S.S.) array of Imaging Atmospheric Cherenkov Telescopes in 2014 August, following a flare alert by the Fermi-LAT Collaboration. The H.E.S.S observations were aimed at detecting a gamma-ray flare delayed by 20–27 d from the alert flare, as expected from observations at other wavelengths. More than 12 h of good-quality data were taken with an analysis threshold of $\sim 67$ GeV. The significance of a potential signal is computed as a function of the date and the average significance over the whole period. Data are compared to simultaneous observations by Fermi-LAT. No photon excess or significant signal is detected. An upper limit on PKS 1830–211 flux above 67 GeV is computed and compared to the extrapolation of the Fermi-LAT flare spectrum.

Key words: gravitational lensing: strong – diffuse radiation – gamma-rays: galaxies.

1 THE PKS 1830–211 GRAVITATIONALLY LENSED QUASAR

PKS 1830–211 is a high-redshift ($z = 2.5$; Lidman et al. 1999) flat-spectrum radio quasar (FSRQ) that has been detected in all wavelengths from radio to high-energy gamma-rays. It is a known gravitationally lensed object with two compact images of the quasar nucleus visible in the radio (Jauncey et al. 1991) and optical (Meylan et al. 2005) passbands. The Einstein ring, well visible at radio frequencies, comes from the imaging of the quasar jet (Kochanek & Narayan 1992). The quasar source is lensed by a foreground galaxy at $z = 0.89$ (Wiklind & Combes 1996). The angular size of the Einstein ring and separation of compact images is roughly 1 arcsec so that it cannot be resolved with high-energy instruments such as High Energy Stereoscopic System (H.E.S.S.; 50 GeV–50 TeV range) or Fermi-Large Area Telescope (LAT; 100 MeV–100 GeV range). PKS 1830–211 is seen as a bright, high-energy source by the Fermi-LAT instrument and had several flaring periods during the decade of Fermi-LAT observations. PKS 1830–211 is listed in the 1FHL (Ackermann et al. 2013) and the 3FHL (Ajello et al. 2017) catalogues with a photon index above 10 GeV of 3.55 ± 0.34 that corresponds to the average 'low-state' spectrum. No significant curvature in the spectrum was detected. Photons up to 35 GeV, potentially detectable by H.E.S.S., have been observed by Fermi-LAT (Ajello et al. 2017). Observations of these very high energy photons and the measurement of the very high energy tail of the spectrum would give useful constraints on extragalactic background light (EBL) at redshift $z = 2.5$.

Since the components of the lens cannot be resolved at high or very high energy, the evidence for lensing was searched indirectly on the observed light curve. Because of the different travel paths, the light curves of the two compact components of the lens have a relative time delay, measured in the radio (Lovell et al. 1998) and microwave (Wiklind & Combes 2001) passbands, of 26 ± 5 d. Barnacka, Glicenstein & Moudden (2011) have studied the first 3 yr of the Fermi-LAT light curve with cepstral and autocorrelation
methods. Evidence for a delay of 27.5 ± 1.3 d was found with a 3σ significance. The time delay between the compact images of PKS 1830–211 was also studied by the Fermi-LAT Collaboration (Abdo et al. 2015). They selected several flaring periods and calculated the autocorrelation function of the light curve. No significant peak was found. A possible peak of ~20 d was found with a 1-d binning of the data, which could be attributed to the ~20 d separation between two flaring events and perhaps to gravitational lensing. Barnacka et al. (2015) have argued that the time delay measured by high-energy instruments could be very different than the value measured by radio telescopes. The delay measured by Lovell et al. (1998) is obtained from the emission of the compact images. Since the jet of the PKS 1830–211 source is imaged close to the Einstein ring, the time difference between the initial burst and its lensed image can be much smaller if the source of high-energy emission is located inside the jet.

PKS 1830–211 is monitored by Fermi-LAT and its light curve is posted on the internet1 on a daily basis. H.E.S.S. observations of PKS 1830–211 were triggered by an alert posted by the Fermi-LAT team on 2014 August 2 (Krauss et al. 2014). The flare seen by the Fermi-LAT instrument started on July 27 and lasted ~4 d. The H.E.S.S. observations are described in Section 2 and data analysis in Section 3. The H.E.S.S. limits are compared to the Fermi-LAT signal in Section 4 and discussed in Section 5.

2 H.E.S.S. OBSERVATIONS

The very high energy (50 GeV–50 TeV range) gamma-ray observatory of the H.E.S.S. Collaboration consists of five Imaging Atmospheric Cherenkov Telescopes (IACTs) located in the Khomas Highland of Namibia (23°16′18″ S, 16°30′11″ E), 1800 m above sea level. From 2004 January to 2012 October, the array was a four-telescope instrument, with telescopes labelled CT1–4. Each of the telescopes, located at the corners of a square with a side length of 120 m, has an effective mirror surface area of 107 m², and is able to detect cosmic gamma-rays in the energy range 0.1–50 TeV. In 2012 October, a fifth telescope CT5, with an effective mirror surface area of 67 m² and an improved camera (Bolmont et al. 2014), was installed at the centre of the original square, giving access to energies below 100 GeV (H.E.S.S. Collaboration et al. 2017).

PKS 1830–211 was observed by the five telescopes of the H.E.S.S. IACT array between 2014 August 12 and August 26, to allow for the detection of delayed flares with time delays ranging from 20 to 27 d. The observations were taken at an average zenith angle of 12°.

3 DATA ANALYSES

This paper is based on a sample of 12.4 h of high-quality data. Data selection cuts have been described in H.E.S.S. Collaboration et al. (2017). Data were next analysed with the Model analysis (de Naurois & Rolland 2009) and cross-checked with the ImPACT analysis (Parsons & Hinton 2014), the two methods giving compatible results. The two analyses use different calibration chains. With both reconstruction chains, data of CT5 were analysed either alone (Mono reconstruction) or combined with the CT1–4 data (Combined reconstruction). The Mono reconstruction has an energy threshold of 67 GeV. The Combined reconstruction has a higher threshold of 144 GeV, but a larger effective area.

A point source is searched at the location of PKS 1830–211. Fig. 1 shows the distribution of the squared angular distance θ² of candidate photons from the target position. This distribution, obtained in the Mono analysis, is compared to the background from hadrons misidentified as photons. The background is calculated with the ring background method (Berge, Funk & Hinton 2007), other methods giving similar results.

Table 1 summarizes the number of candidate photons in the signal region, the expected background, and the significance of the excess, calculated with the Li and Ma formula (Li & Ma 1983). No significant excess of photons over background is seen by H.E.S.S. at the position of PKS 1830–211. A similar search using the Combined analysis also gives a negative result.

Because of the very soft spectrum measured by Fermi-LAT in the low state, PKS 1830–211 has a chance of being detectable by H.E.S.S. only during flares. The delayed flare lasts only less than about 4 d, however, due to the uncertainties on the date of the flare, it could have happened at any time between August 17 = MJD 56886 (time delay of 20 d) and August 24 = MJD 56893 (radio time delay of 27 d) as explained in Section 1. Fig. 2 shows the evolution over time of significance, binned by 28-min runs. No significant daily photon excess was detected during the H.E.S.S. observation period.

4 FLUX UPPER LIMITS AND COMPARISON TO THE FERMI-LAT SPECTRA

The non-detection by H.E.S.S. translates into 99 per cent confidence level (C.L.) upper limits on the average very high energy flux of PKS 1830–211 during H.E.S.S. observations. These upper limits are shown in Fig. 3. Red (respectively blue) arrows show the limits obtained from the Mono (respectively Combined) analysis and the corresponding solid lines show the effect of deabsorption using the EBL model of Gilmore et al. (2012).

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1https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/source/PKS_1830–211
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5 CONCLUSION

No significant delayed flare from PKS 1830–211 was detected by either H.E.S.S. or Fermi-LAT. The flare did not repeat or was too faint to be detected. Fig. 4 shows, however, that the detection of a strong flare would have been possible close to the Mono analysis energy threshold if the level of EBL absorption was at or below the absorption predicted by the model of Franceschini et al. (2008). Because of its lensed nature, observation of flaring event of PKS 1830–211 in the TeV passband could be useful to constrain EBL models at redshift as large as 2.5. The detection of the lensing time delay in future very high energy observations would help pinpoint the spatial origin of the high-energy emission (Barnacka et al. 2015). It would also permit more exotic applications such as constraining photon mass (Glicenstein 2017) or testing Lorentz invariance violation (Biesiada & Piorkowska 2009).
ACKNOWLEDGEMENTS

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the German Research Foundation (DFG), the Helmholtz Association, the Alexander von Humboldt Foundation, the French Ministry of Higher Education, Research and Innovation, the Centre National de la Recherche Scientifique (CNRS/IN2P3 and CNRS/INSU), the Commissariat à l’Énergie Atomique et aux Énergies Alternatives (CEA), the UK Science and Technology Facilities Council (STFC), the Knut and Alice Wallenberg Foundation, the National Science Centre, Poland grant no. 2016/22/M/ST9/00382, the South African Department of Science and Technology and National Research Foundation, the University of Namibia, the National Commission on Research, Science and Technology of Namibia (NCRST), the Austrian Federal Ministry of Education, Science and Research and the Austrian Science Fund (FWF), the Australian Research Council (ARC), the Japan Society for the Promotion of Science, and by the University of Amsterdam. We appreciate the excellent work of the technical support staff in Berlin, Zeuthen, Heidelberg, Palaiseau, Paris, Saclay, Tübingen, and in Namibia in the construction and operation of the equipment. This work benefited from services provided by the H.E.S.S. Virtual Organisation, supported by the national resource providers of the EGI Federation.

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MNRA

486, 3886–3891 (2019)