Detection of an Unidentified Extended Gamma-ray Source Close to the Galactic Supernova Remnant 3C 400.2

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Abstract

A new extended gamma-ray source (named as PS J1934.5+1845) was detected with a significance of ~13σ at a location of 1.83 degrees away from the radio location of the Galactic supernova remnant 3C 400.2 using about 9 years of Fermi-LAT data. The 68% containment radius of PS J1934.5+1845's extension was found to be 0.61 degrees and PS J1934.5+1845 is showing a power-law type spectrum with a spectral index of 2.38. In this presentation we will summarize the gamma-ray analysis methods and report on the analysis results related to the extension and spectrum of PS J1934.5+1845. We will also give preliminary results on the variability analysis and modeling of the spectrum of PS J1934.5+1845 in order to better understand its nature.

Introduction & Data Reduction

PS J1934.5+1845 was detected during the analysis of the mixed- morphology (MM; Rho & Petre 1998) supernova remnant (SNR) 3C 400.2 (also known as G53.6-2.2). We reported on this source in our recent published paper (Ergin et al. 2017).

To search for a gamma-ray emission in the GeV energy range, we analyzed the gamma-ray data of Fermi-LAT for the time period of 2008-08-04 to 2017-02-06. In this paper, we used the Fermi analysis toolkit *fermipy* version 0.8.0 (Fermipy). Using `gtselect` of *Fermi Science Tools* (FST), we selected the Fermi-LAT Pass 8 "Source" class and front+back type events coming from zenith angles smaller than 90° and from a circular region of interest (ROI) with a radius of 30° centered at the SNR's radio position.

The maximum likelihood fitting method (Mattox et al. 1996) was employed on the spatially and spectrally binned data using the P8R2_SOURCE_V6 version of the instrument response function. After the maximum likelihood fitting between 200 MeV and 300 GeV, the detection significance value is calculated, which is roughly the square root of the test statistics (TS) value, and larger TS values indicate that the null hypothesis (maximum likelihood value for a model without an additional source) is incorrect.

The model of the analysis region contains the diffuse background sources and all the point-like and extended sources from the Third Fermi-LAT Source Catalog (Acero et al. 2015) located within a square region with a side of 15° centered on the ROI center. The normalization parameters of sources that are within 3° are set free. All parameters of the diffuse Galactic emission (gll_iem_v6.fits) and the isotropic component (iso_ P8R2_SOURCE_V6_v06.txt) were freed. We also freed the normalization parameter of all sources with TS > 10 and fixed all the parameters for sources with TS < 10.

References

1) Acero, F., Ackermann, M., Ajello, M., et al. 2015, ApJS, 218, 41
2) T. Ergin, A. Sezer, H. Sano, R. Yamazaki, and Y. Fukui 2017, ApJ, 842, 22
3) Fermipy: http://fermipy.readthedocs.io/en/latest/index.html
4) Mattox, J. R., Bertsch, D. L., Chiang, J., et al. 1996, ApJ, 461, 396
5) Rho, J., & Petre, R. 1998, ApJL, 503, L167

Analysis & Results

The initial TS map was produced for a 10° × 10° analysis region using this model, showing gamma-ray excess close to the location of 3C 400.2 and at other locations within the analysis region. In order to obtain the exact TS value and location of the excess regions, we used an iterative source-finding algorithm in *fermipy*, called `find_sources`:

- Takes peak detection on a TS map to find new source candidates. The algorithm identified peaks with a significance threshold value higher than 3σ and taking an angular distance of at least 1°.5 from a higher amplitude peak in the map.
- It orders the peaks by their TS values and adds a source at each peak, starting from the highest TS peak.
- Then it sets the source position by fitting a 2D parabola to the log-likelihood surface around the peak maximum.
- After adding each source, having a significance value above 5σ, it re-fits the spectral parameters of that source.
- With this algorithm, we identified nine new sources within the analysis region.
- The algorithm also listed the sources with a significance between 3σ and 5σ. One of these sources, PS J1938.6+1722, was within the 95% confidence radius of the 3C 400.2 position. So, the name of PS J1938.6+1722 is used for 3C 400.2.

As a next step we analyzed the closer vicinity of 3C 400.2 by taking an analysis region of 5° × 5°. We followed the same analysis procedure as described for the 10° × 10° analysis region, except that we added two sources into the background model: PS J1934.5+1845, being the only bright gamma-ray source having a significance above 5σ within the analysis region, and PS J1938.6+1722, representing 3C 400.2 itself.

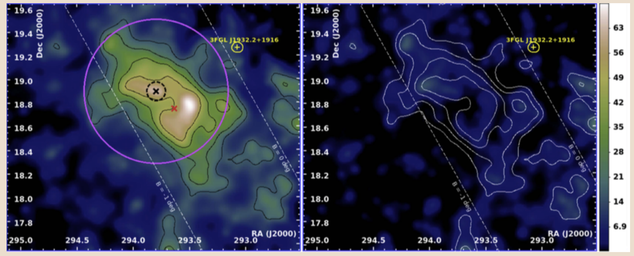
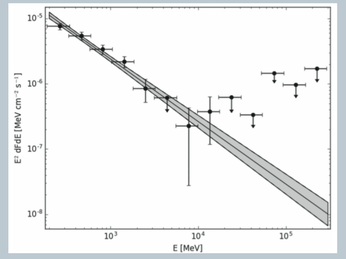


Figure 1: TS map of the gamma-ray emission, where PS J1934.5+1845 was not included in the background model (left panel). The initial spatial model of the source was taken as point-like, where its location was chosen as the red cross shown in the left panel. The best-fit position of the point-like source is shown with a black cross, and its positional error at a 95% confidence level is shown as a black dashed circle. The magenta solid circle represents the best-fit extension found using a radial Gaussian model centered around the best-fit position of PS J1934.5+1845. The right panel shows the gamma-ray TS map, where PS J1934.5+1845 was included as a point-like gamma-ray source in the background model. The black and white contours on both panels are the levels of the TS values, which are 16, 25, 36, 49, 69, and a gamma-ray source from the Third Fermi-LAT Source Catalog (Acero et al. 2015) is shown in yellow, together with its positional error circle. The white dashed lines correspond to the Galactic latitudes of −1° and 0°.

Results

Detection & Localization: PS J1934.5+1845, was detected at a location of 1°.83 away from the radio location of 3C 400.2. The detection significance was found to be ~13σ (i.e., TS = 161), assuming PS J1934.5+1845 as a point-like source during the source search procedure. Using the `localize` method of *fermipy*, the best-fit position for PS J1934.5+1845 was found to be R.A. (J2000) = 293°.79 ± 0°.08 and decl. (J2000) =18°.90 ± 0°.08 (R.A. (J2000) = 19^h 35^m $10^s.32$, decl. (J2000) = 18° 54' 07".20).

Extension Measurements: We used two models to parameterize the extended gamma- ray emission morphology of PS J1934.5+1845, disk and radial Gaussian models, where the width and location of the centers of the models were calculated by the `extension` method of *fermipy*. To detect the extension of a source, we used the TS of the extension (TS_{ext}) parameter, which is the likelihood ratio comparing the likelihood for being a point-like source (L_{pt}) to a likelihood for an existing extension (L_{ext}), TS_{ext} = 2log (L_{ext}/L_{pt}). The "Extension Width," which is the 68% containment radius of the extension model (R_{68}), was found to be 0°.6107 + 0°.0866 – 0°.1141, with a TS_{ext} value of ~40 for the radial Gaussian model. As an extended source, PS J1934.5+1845 was detected with a significance of ~13σ (i.e., TS = 168).



Spectral Measurements: The spectrum was fit to PL, where the spectral index is found to be Γ = 2.98 ± 0.09. The total photon flux and energy flux was found to be (2.99 ± 0.31) × 10^{-9} photons cm^{-2} s^{-1} and (1.20 ± 0.11) × 10^{-6} MeV cm^{-2} s^{-1}, respectively, for the point-like source model having a PL-type spectrum.

Assuming a PL-type spectrum for this extended source, we obtained Γ = 2.38 ± 0.07, and the total photon flux and energy flux of PS J1934.5+1845 was found to be (2.54 ± 0.23) × 10^{-8} photons cm^{-2} s^{-1} and (1.74 ± 0.16) × 10^{-5} MeV cm^{-2} s^{-1}, respectively.

Conclusion

We detected a new source, PS J1934.5+1845, at about 1°.8 away from 3C 400.2, having a significance of ~13σ. PS J1934.5+1845 was found to have a radial Gaussian type extension with a radius of ~0°.61. We investigated this source as a part of our analysis, due to the possibility that it might have been contributing to the gamma-ray emission of 3C 400.2. After fitting the extension and checking the TS value of 3C 400.2, we found out that the emission of PS J1934.5+1845 is not directly affecting the gamma-ray emission of 3C 400.2. The gamma-ray emission of PS J1934.5+1845 needs to be further investigated by modeling the SED in order to understand whether the dominating gamma-ray emission mechanism is leptonic or hadronic.