

# Tentative observation of a gamma-ray line at the Fermi-LAT

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**Abstract.** Using 43 months of public gamma-ray data from the Fermi Large Area Telescope, we find in regions close to the Galactic center at energies of 130 GeV a  $4.6\sigma$  excess that is not inconsistent with a gamma-ray line from dark matter annihilation. When taking into account the look-elsewhere effect, the significance of the observed signature is  $3.2\sigma$ . If interpreted in terms of dark matter particles annihilating into a photon pair, the observations imply a partial annihilation cross-section of about  $10^{-27} \text{ cm}^3 \text{ s}^{-1}$  and a dark matter mass around 130 GeV. We will review aspects of the statistical analysis and comment on possible instrumental indications.

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## INTRODUCTION

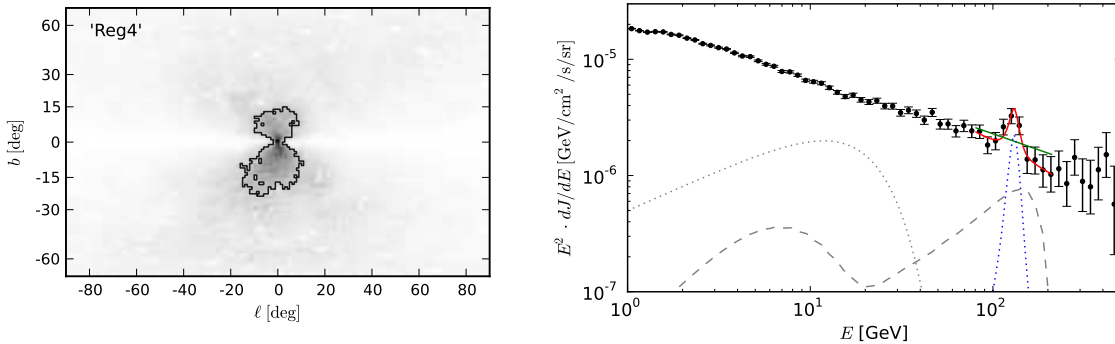
Searches for signatures from dark matter (DM) annihilation in the gamma-ray data are plagued by the question of how to disentangle astrophysical foregrounds from an actual DM signal. Gamma-ray lines, as well as the sharp pronounced features coming from final-state radiation and virtual internal Bremsstrahlung, are long known to provide smoking gun signatures for DM annihilation, as they would clearly stand out of the continuous astrophysical background flux.

The recent discovery of line-like features around 130 GeV in the Fermi Large Area Telescope (LAT) data by Bringmann et al. [1] and Weniger [2], and its subsequent confirmation by Tempel et al. [3] and Su & Finkbeiner [4], has initiated a torrent of activities trying to explain this signature alternatively as a signal for DM annihilation, exotic pulsar winds [5], or studying the possibility that it could be due to an instrumental effect [6, 7] (for a recent review on indirect DM searches via gamma rays, with emphasize the 130 GeV feature and a complete list of relevant references, see Ref. [8]).

In this proceedings contribution, we shortly review the methods that were adopted in Refs. [1, 2] to reveal the line structure, comment on possible instrumental indications (for a detailed discussion see Ref. [6]), and we close with a brief outlook.

## GAMMA-RAY LINES AND FERMI-LAT

Almost all existing searches for gamma-ray lines from WIMP annihilation are based on a dedicated analysis of the gamma-ray energy spectra measured in regions-of-interest (ROIs) with large S/N for DM signals. The basic philosophy is to look for line-like features on top of a smooth background spectrum. In order to trade the uncertainties in the background flux for statistical errors, the spectral analysis is typically confined to a



**FIGURE 1.** *Left panel:* Target region Reg4 from [2], optimized for large S/N in case of slightly contracted profile. *Right panel:* Gamma-ray flux measured within that region by Fermi-LAT. An excess of events around 130 GeV is clearly visible in the data. We show the fits to the data in the energy range 80–210 GeV (see Ref. [2] for details). For direct comparison we show a very hard spectrum with super-exponential cut-off (left dotted line;  $\sim E^{-1.3} \exp[-(E/20 \text{ GeV})^2]$ ) and the ICS emission from monoenergetic 230 GeV electrons at the GC (dashed), both with arbitrary normalization.

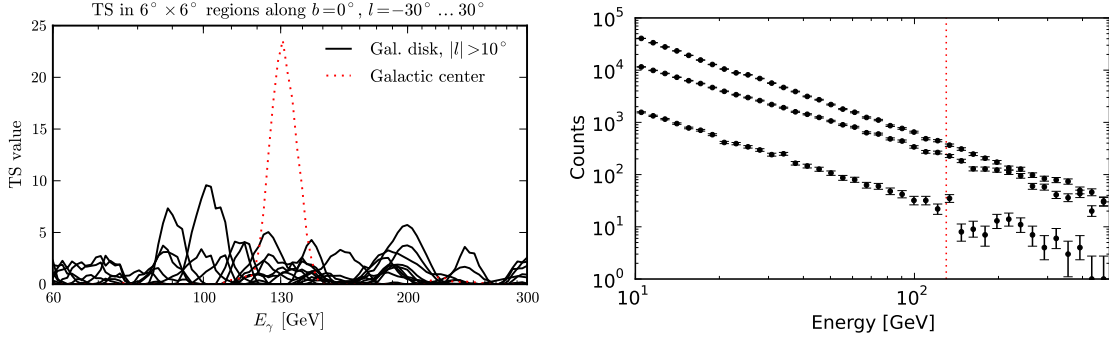
small energy range around the line energy of interest. The smooth background spectra can then be approximated – at first order – by a single power-law.

The main novelty of Refs. [1, 2] (besides including all available Fermi-LAT data) is the use of an adaptive method to find ROIs optimized for different profiles of the Galactic DM halo. One of these regions (for a slightly contracted profile) is shown in the left panel of Fig. 1 by the black line [2]. The differential flux measured from this ROI is plotted in the right panel; it exhibits a surprisingly clear and sharp excess of events around 130 GeV. The solid lines to the right represent a power-law only (power-law + line signal) fit to the data, restricted to the range 80–210 GeV. The local significance for the presence of a line signal is  $4.6\sigma$  [2] (even higher significances were found in the template analysis of Ref. [4]). The gray dotted line at the left shows for comparison a hard spectrum with super-exponential cutoff; the gray dashed line shows the inverse Compton scattering (ICS) radiation from a mono-energetic electron population at the Galactic center (GC). None of the spectra is sharp enough to fit the 130 GeV excess.

In order to check whether the observed excess is due to a mis-calibrated effective area or energy reconstruction we analysed test samples with a very low S/N for a DM line signal, like regions along the Galactic disk or the Earth limb.

In the left panel of Fig. 2, we show the TS values found when searching for lines at different energies in different regions along the Galactic plane. The black lines correspond to partially overlapping  $6^\circ \times 6^\circ$  regions away from the GC; the red line corresponds to a region of same size but centered on the GC. The only significant line signature is the one at the GC around 130 GeV. Fits are performed as in Ref. [2] for SOURCE class events.

Earth limb photons, which stem from cosmic rays interacting with the Earth atmosphere, provide a smooth reference spectrum for systematic checks. In the right panel of Fig. 2, the bottom data points shows Earth limb photons (with zenith angles  $Z > 110^\circ$ ) that hit the LAT at incidence angles in the range  $30^\circ \lesssim \theta \lesssim 45^\circ$ . A significant line-



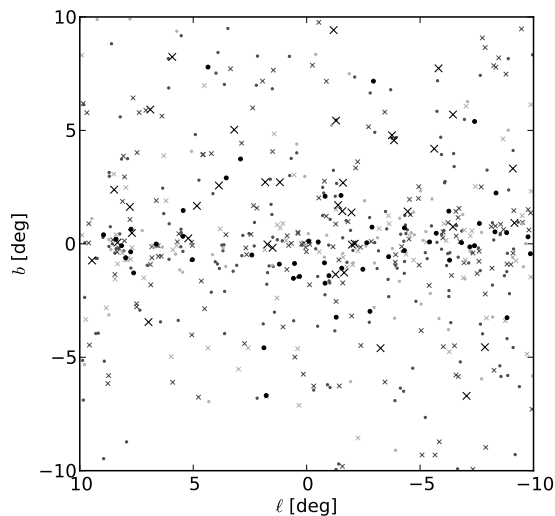
**FIGURE 2.** *Left panel:* TS value in different  $6^\circ \times 6^\circ$  regions along the Galactic plane, centered on  $|\ell| = 0^\circ$  (dotted line) and  $|\ell| = 12^\circ, 15^\circ, \dots, 30^\circ$  (solid lines). *Right panel:* from top to bottom this plot shows the Earth limb events ( $Z > 110^\circ$ ), all events with incidence angles in the range  $\theta = 30^\circ \dots 45^\circ$ , and Earth limb events with the same incidence angle range ( $Z > 110^\circ$  &  $\theta = 30^\circ \dots 45^\circ$ , see also ‘suspicious Earth limb line’ events in Ref. [6].)

like feature or spectral distortion around 130 GeV appears, with a formal local significance well above  $3\sigma$  [6]. However, when considering *all* events with incidence angles  $30^\circ \lesssim \theta \lesssim 45^\circ$  but any zenith angle  $Z$  (central data points), or *all* Earth limb events ( $Z > 110^\circ$ ) with any incidence angle  $\theta$  (top data points), the structure disappears. Note that although an instrumental effect can depend on  $\theta$ , it would be surprising if it depends on  $Z$ ; a feature in the physical flux can depend on  $Z$  but not on  $\theta$ . Clearly, more data from the Earth limb is needed to check whether the feature in the low incidence angle Earth limb data is a statistical fluke or points to a serious problems with the processing of  $> 100$  GeV PASS 7 events (for more details see Ref. [6]).

In Ref. [4], it was found that the 130 GeV feature shown in Fig. 1 is not exactly centered on the GC; instead, a  $\sim 1.5^\circ$  shift to the west of the GC is observed. The events contributing to the 130 GeV excess are shown in black in Fig. 3 as function of Galactic longitude  $\ell$  and latitude  $b$ ; the adopted energy range is 120–140 GeV. Already this plot suggests that the 130 GeV excess is not centered on the GC, although considerably more data is required to make robust statements about its distribution. For comparison, we also show the 70–110 GeV and 150–300 GeV sidebands in dark and light gray, respectively.

## CONCLUSIONS

The observation of a gamma-ray line close to the GC would be an impressive smoking gun signature for annihilation of DM in the Universe. In the Fermi-LAT data, we find strong indications for such an excess at around 130 GeV. The formal significance is high, making it unlikely to be a statistical fluke, although a final confirmation requires more data to reproduce the signal without trials. Right now, the main concern is whether the PASS 7 processing of LAT events is reliable at high energies, where the low statistics still limits a sufficient in-flight study of instrumental effects. A first indication for such an instrumental effect might be the observation of a line-feature at 130 GeV in a subset of the Earth limb data, although this feature is not present in other more orthodox test



**FIGURE 3.** Spatial distribution of line events close to 130 GeV (CLEAN events from 4 Aug 2008 to 5 Sep 2012). Black dots (crosses) correspond to front (back) converting events in the range 120–140 GeV. The dark (light) gray dots/crosses show the sidebands 70–110 GeV (150–300 GeV) for comparison. The events around 130 GeV are clustered slightly west from the GC.

samples. In any case, it would be difficult to understand how such feature could map onto the GC. However, even after trials, the probability for the Earth limb line to be produced by chance is already uncomfortably low and about  $\sim 1\%$ . Clearly, more data is urgently required, to clarify whether this is a statistical fluke or a real effect.

## ACKNOWLEDGMENTS

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