Computing Sky Maps using the Open-Source Package Gammapy and MAGIC Data in a Standardized Format

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MAGIC

Abstract

The open-source Python package Gammapy [1], developed for the high-level analysis of gamma-ray data, requires gamma-like event lists combined with corresponding instrument response functions. For morphological analysis, this data has to include a background acceptance model. Here we report an approach to generate such a model for the MAGIC telescope data, accounting for the azimuth and zenith dependencies of the MAGIC background acceptance. We validate this method using observations of the Crab Nebula with different offsets from the pointing position.

Characterisation of the MAGIC Background

To characterize the gamma-like background, a set of 745 MAGIC observations of non-significant sources is analyzed. This work builds on [2].

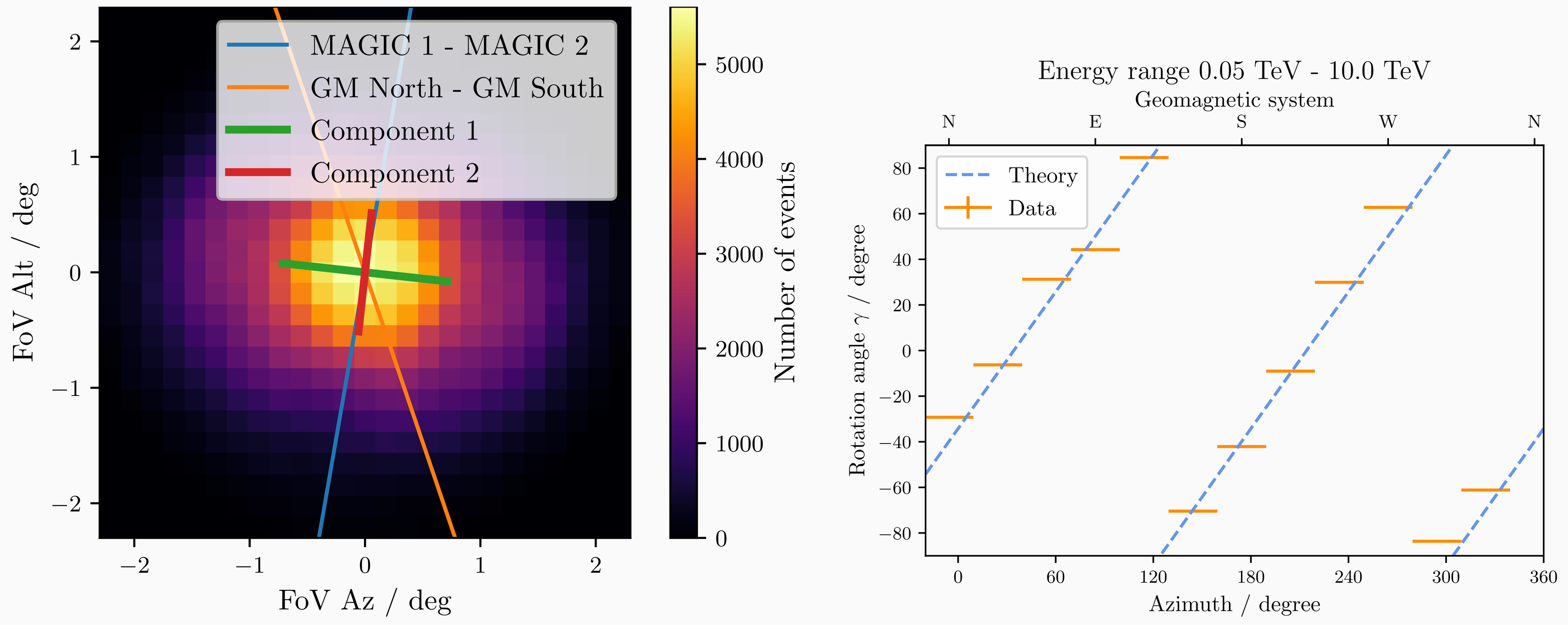

Figure 1: Left: A principle component analysis is applied to the counts in each azimuth bin. The plot show an exemplary azimuth bin from 9 ° to 39 °. The angle between the horizontal and the first principal component (green line) is called roation angle γ. Right: γ is rotating dependent on the azimuth angle. This can be explained by the non-symmetrical overlapping part of the viewing cones of MAGIC-I and MAGIC-II, which is also rotating in the FoV depending on the azimuth.

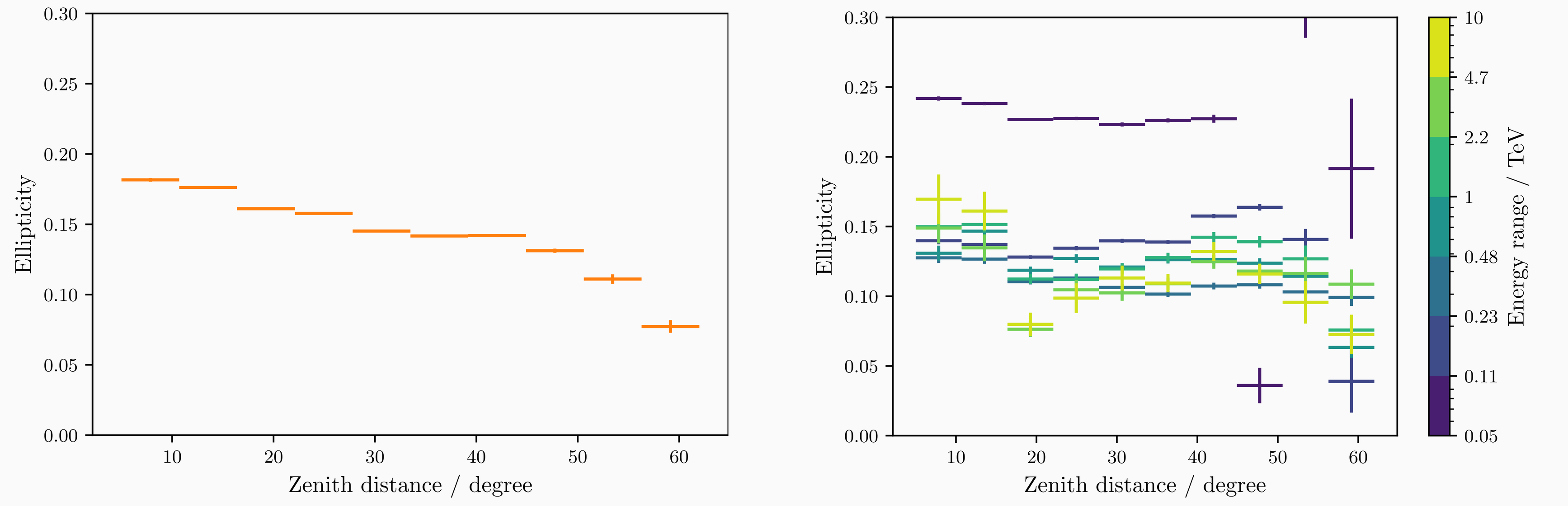

Figure 2: Left: Ellipticity of the background decreases with increasing zenith distance. Right: The ellipticity is higher at lower energies and quite constant over a large zenith range in a certain energy bin.

Creation of a Background Acceptance Model

For the creation of an acceptance model, this procedure is performed in several energy bins:

1. Derotate events from off observations around the theory rotation angle (of the corresponding pointing position from the corresponding off observation).
2. Rotate events around the theory rotation angle (of the pointing position from the observation for which the background should be calculated).
3. Histogram events and calculate background rate in $s^{-1}\,MeV^{-1}\,sr^{-1}$.

Save data according to the GADF as `3DBackground`.

Creation of Skymaps with Gammapy

Gammapy [1] offers the opportunity to normalize the background acceptance model to a single observation with different methods: `FoVBackgroundMaker` (fit method), `FoVBackgroundMaker` (scale method), `RingBackgroundMaker`. Multiple observations can be stacked to a single `MapDataset`, from which the `ExcessMapMaker` can produce skymaps. Here the results of the `FoVBackgroundMaker` (fit method) are shown:

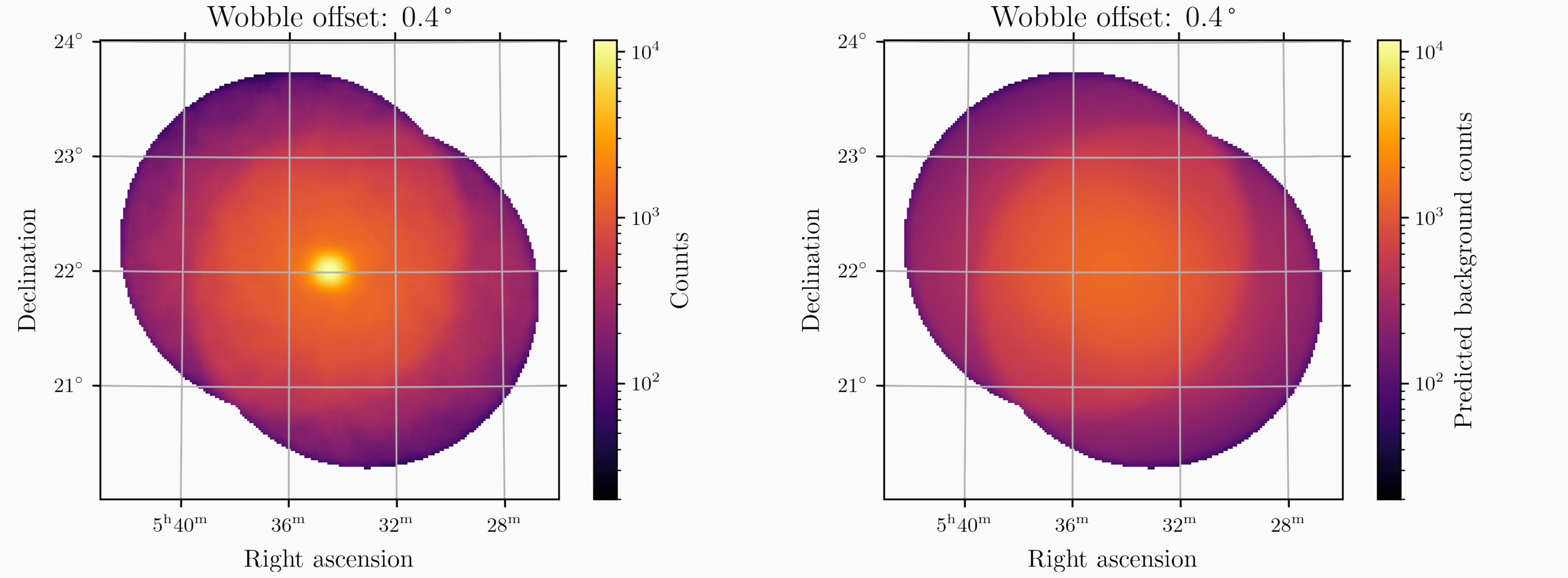

Figure 3: Counts map (left) and predicted background counts map (right) for a stacked Crab Nebula dataset.

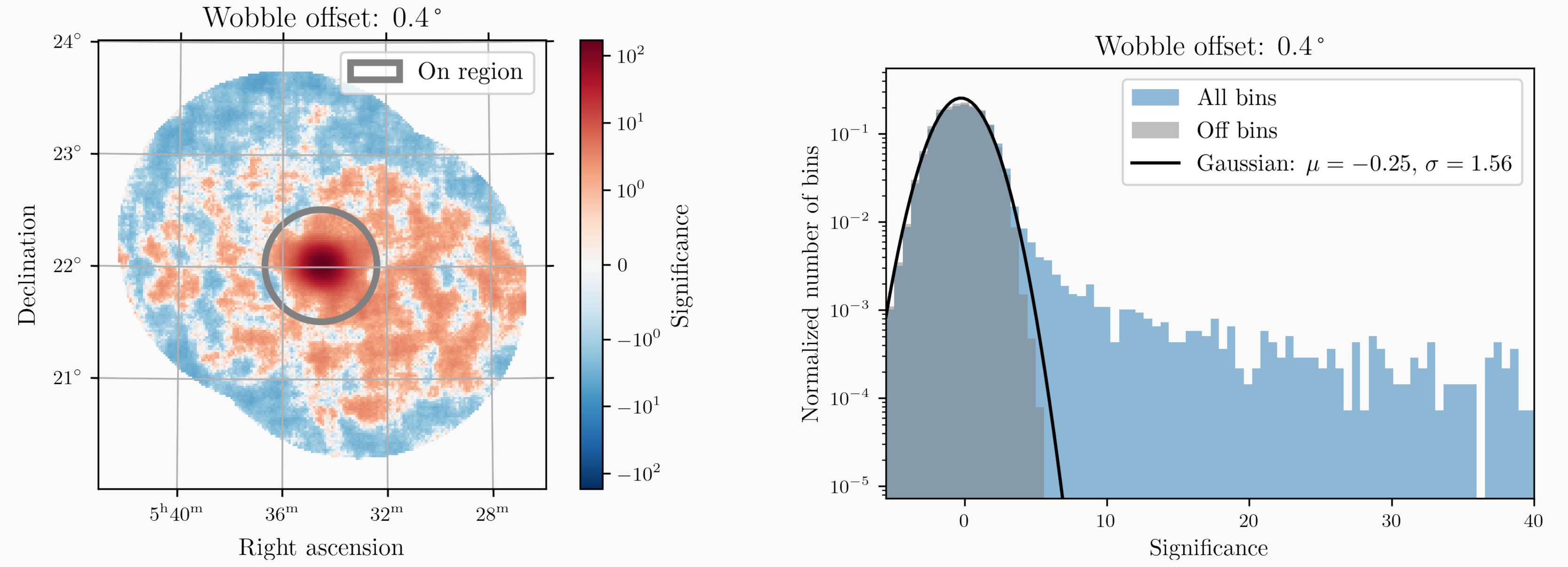

Figure 4: Significance map (left) for a stacked Crab Nebula dataset and corresponding significance value histogram (right).

Validation using multiple Crab Nebula Datasets

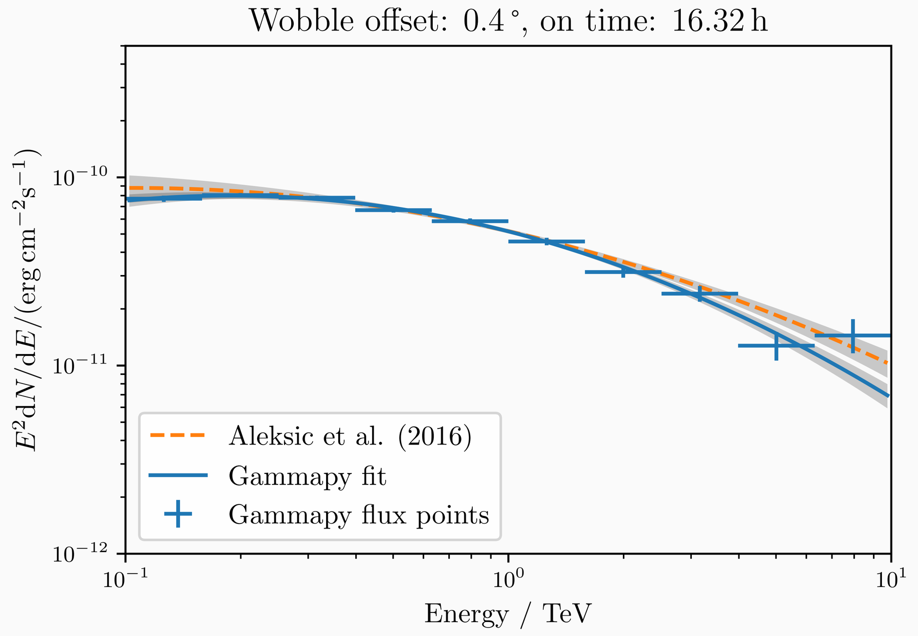

Figure 5: Resulting spectrum obtained with the Gammapy analysis in comparison with the MAGIC reference curve [3]. The data is fitted to a LogParabola Model. Here the result is shown for the standard wobble offset of 0.4 °.

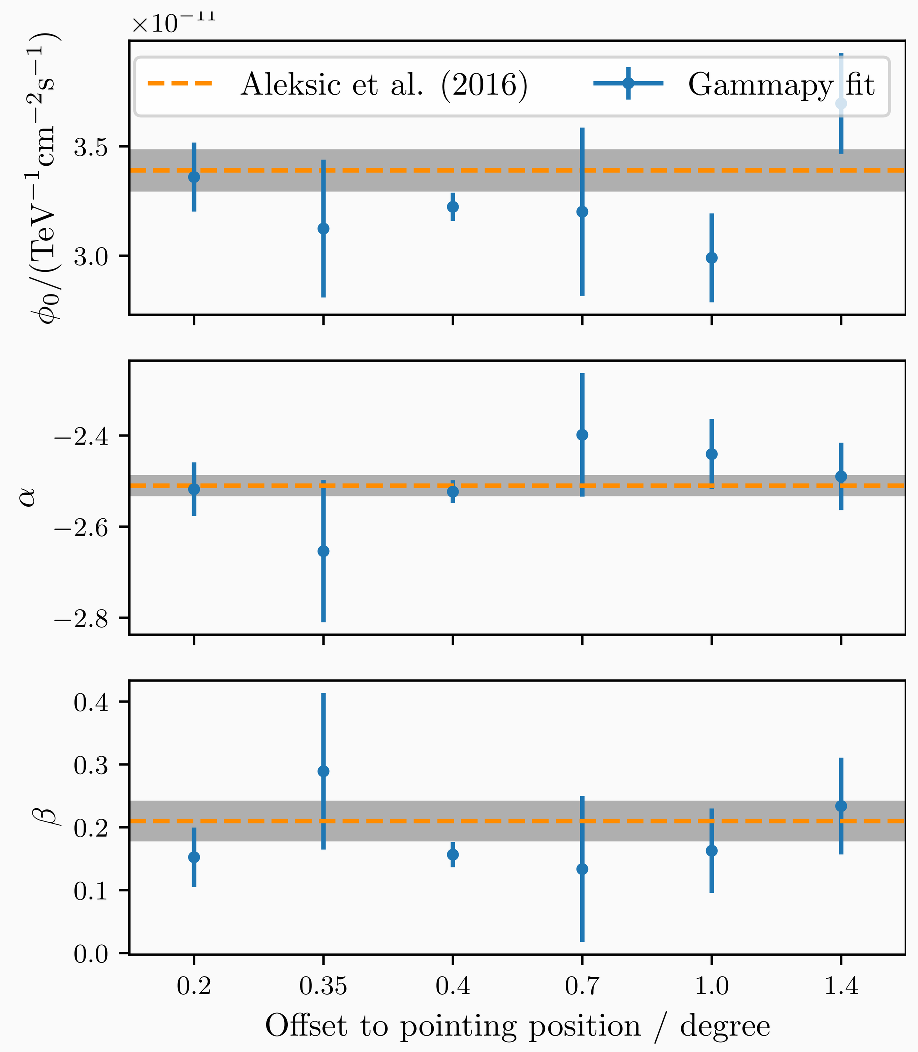

Figure 6: To validate the methods in the complete field of view, the methods are applied to Crab Nebula datasets [3] with different offsets to the pointing position. The data are taken under a zenith angle from 5 ° to 35 ° and the wobble offset of the observations vary from 0.2 ° to 1.4 °. The resulting spectral parameters of the fitted LogParabola model are shown on the left and are compared with the MAGIC reference values [3].

LogParabola Spectral Model

$$\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta \log\left(\frac{E}{E_0}\right)}$$

References

[1] C. Deil et al. Gammapy - A prototype for the CTA science tools. In: 35th International Cosmic Ray Conference (ICRC2017). Vol. 301. International Cosmic Ray Conference. Jan. 2017, 766, p. 766. arXiv: 1709.01751 [astro-ph.IM]. [2] E. Prandini et al. Study of hadron and gamma-ray acceptance of the MAGIC telescopes: towards an improved background estimation. In: Aug. 2016, p. 721. DOI: 10.22323/1.236.0721. [3] J. Aleksic et al. The major upgrade of the MAGIC telescopes, Part II: A performance study using observations of the Crab Nebula. In: Astroparticle Physics 72 (2016), pp. 76–94. DOI: https://doi.org/10.1016/j.astropartphys.2015.02.005.

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