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H.E.S.S.

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Development of a background-estimation technique in regions of degree-scale gamma-ray emission for IACTs

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Motivation

The identification of extended degree-scale γ-ray structures is a challenging task for IACTs, due to their comparatively small field-of-view and a large background induced by cosmic-rays. To estimate this background, many approaches depend on the existence of a γ-ray-free region in each observation, from which the background rate, given the respective observation conditions, can be estimated.

This method presents a robust approach for the analysis of regions in which no such γ-ray free region is available. This is achieved by employing an energy-dependent background model created from archival observations [1] and estimating a normalization factor for each observation from independent observations of emission-free sky regions acquired under comparable conditions.

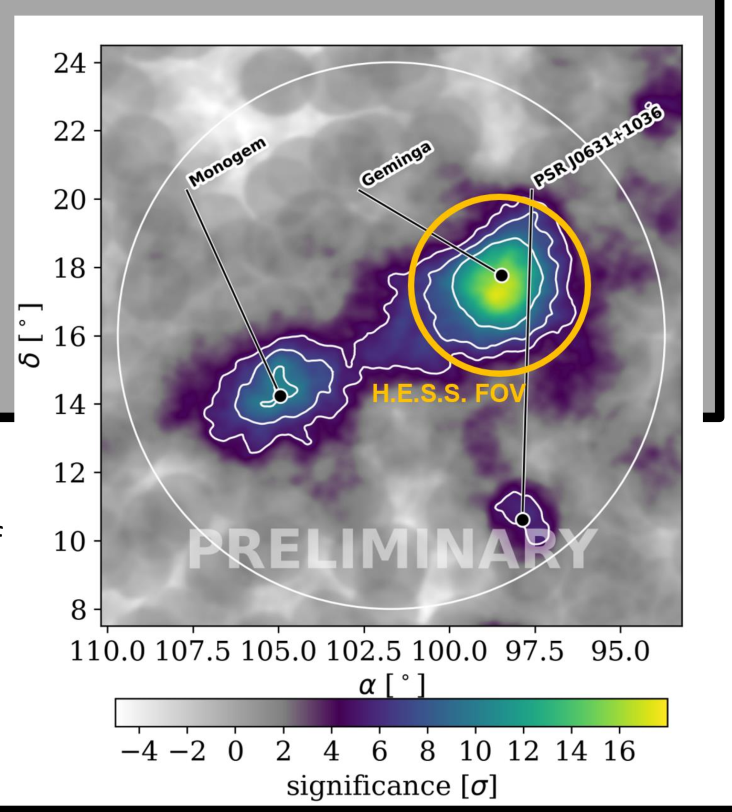

Figure 1: The Halo around Gemina as seen by HAWC, with the field of view of the small H.E.S.S. Telescopes overlayed. Adapted from [3]

OFF Run selection

OFF run criteria :

- Galactic latitude b > |10 °|
- ON and OFF run observed within a period of stable optical efficiency
- Same telescope combination as ON run

To find a suitable OFF run, the influence of various system parameters on the background rate was estimated by a Pearson correlation coefficient (r_j^2).

The best match over all parameters j is identified by minimizing

$$f = \sum_j r_j^2 \cdot \frac{x_{\rm on}^j - x_{\rm off}^j}{x_{\rm on}^j}$$

The validity range is the value below which a background rate deviation of less than 10% was observed

Matching Parameter	Validity range
Zenith angle	within Background model bins
Trigger Rate	Δr < 100 Hz
Observation duration	Δt < 120s
Transparancy coefficient [4]	Δτ < 0.05
Muon Efficiency [4]	Δε < 0.01
Night Sky Background	ΔNSB < 100 Hz

Validation

Data acquired by H.E.S.S. was analyzed using both the standard application of the background template, and the new run matching approach. The background spectra and resulting source properties were then compared.

This validation was performed for a variety of different sources:

- Empty sky regions
- Galactic extended sources (MSH 15-52, RX J1713.7-3946)
- Point-like sources (Crab Nebula, PKS 2155-304)

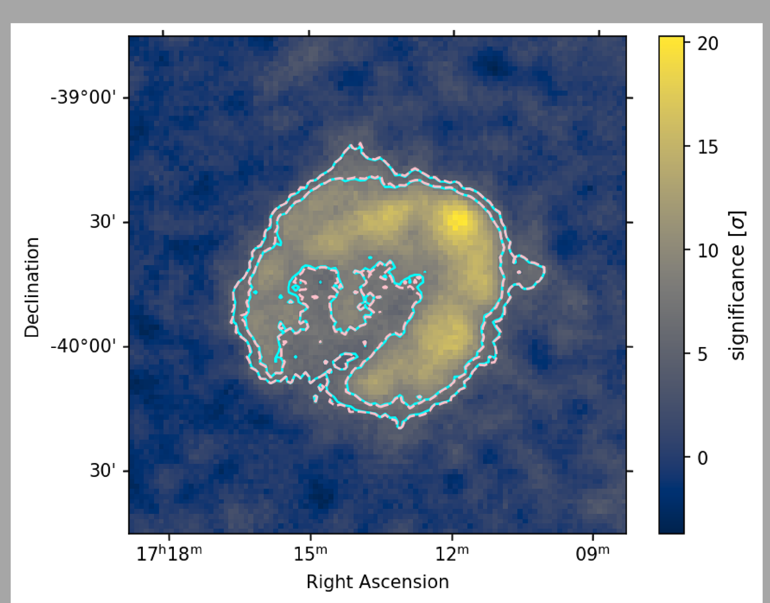

Figure 3: Li&Ma Significance Map of the region around RX J1713.7-3946. The 5σ and 8σ contours derived from the direct application of the background template are depicted in blue, while the contours derived from the run matching are shown in pink.

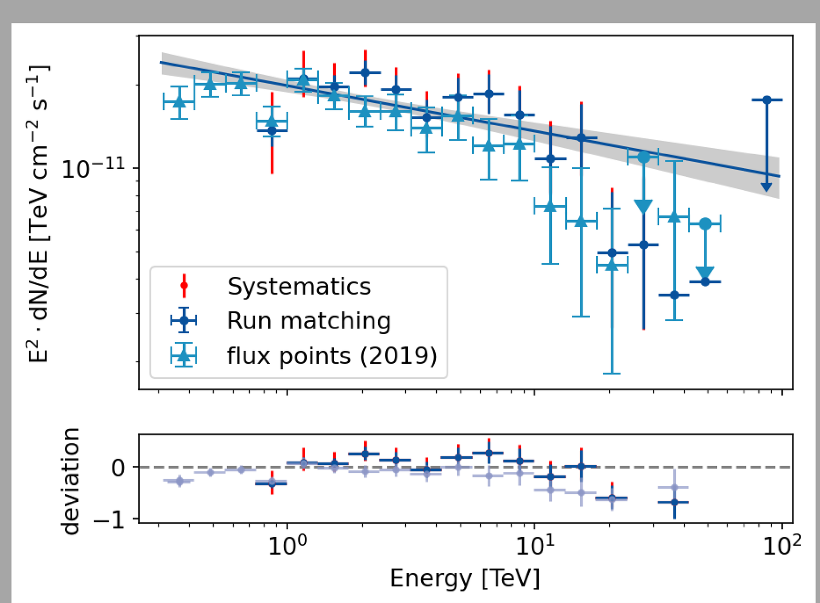

Figure 4: SED of RX J1713.7-3946 compared to an analysis of the same dataset performed in [1]

Background estimation

A Python package for gamma-ray astronomy

The Method is implemented in python and based on Gammapy [2],.

1. **Identification of a suitable OFF run** (see box on the left)
2. **Adjust the spectromorphological background template to the respective observation conditions:** Fit the spectral index δ and the flux normalization Φ of the background spectrum, such that: $R_{BG}^{*} = \Phi \cdot R_{BG} \cdot (E/E_0)^{-\delta}$
3. **Map the background rate to the ON run:** Use δ and Φ estimated from the OFF run to adjust the spectromorphological template of the ON run.
4. **Correct for differences in livetime and zenith angle**

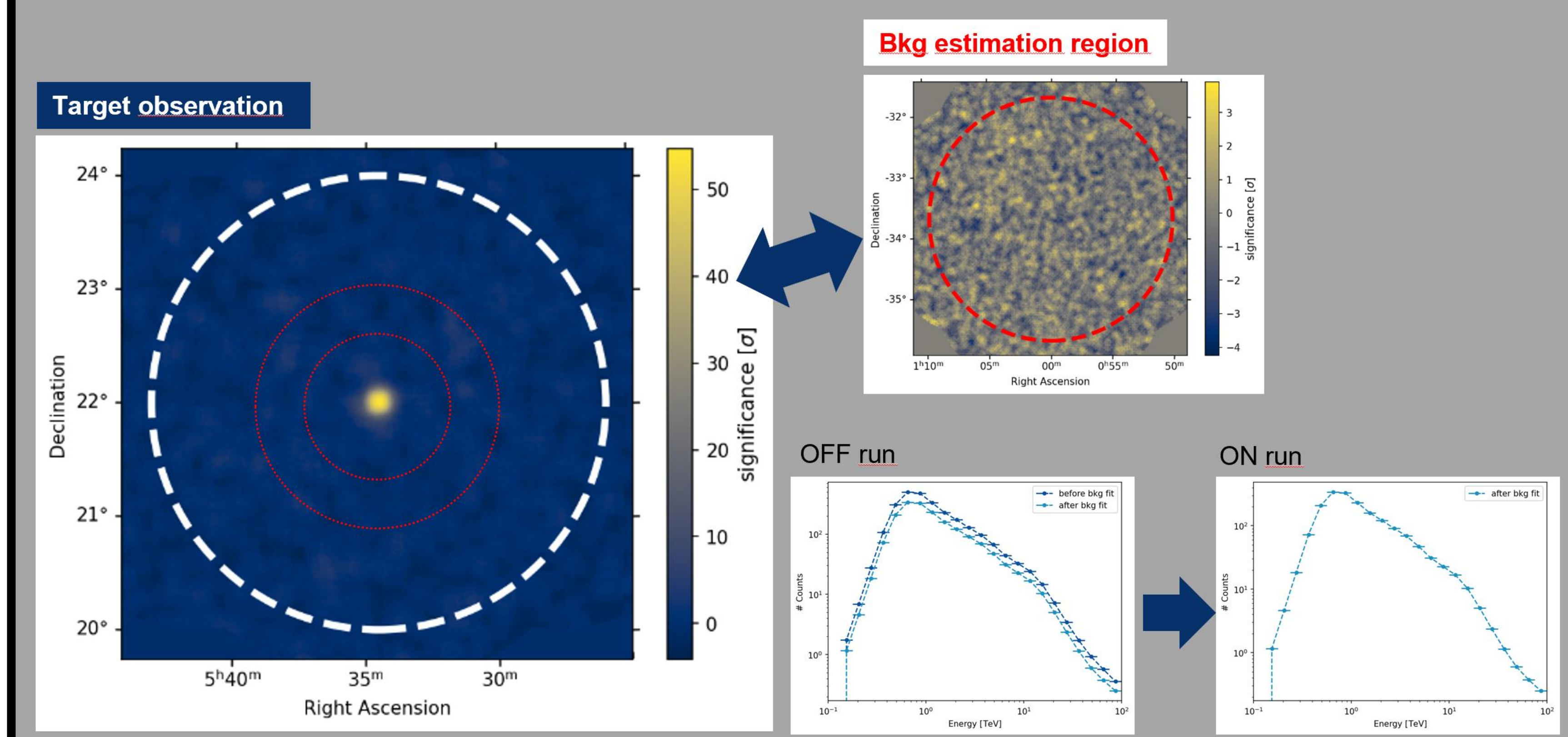

Figure 2:A significance map for an ON and OFF run respectively. The red dotted circles enclose the area which would be used typically for the background estimation. With this method, no other spatial connection except an equal size between ON and OFF region needs to be made. Additionally shown are the background spectra before and after the fit.

Conclusion

The background estimation method presented in this work performs comparably to the application of a spectromorphological background template while enabling us to analyze degree scaled structures using IACTs.

This is vital considering that there are currently no survey instruments observing the southern γ-ray sky.

Additionally, the population of sources observable with CTA will be increased, facilitating the use of the superior angular resolution to expand our knowledge of large extended structures previously uniquely detected by the Water Cherenkov Detectors.

References

[1] Mohrmann et. al. A&A 632 (2019) A72
[2] Donath et. al. A&A 678 (2023) A157
[3] Torres_Escobbedo et. al. PoS(ICRC2023)710
[4] Hahn et. al. AP 54 (2014)