Friedrich-Alexander-Universität Erlangen-Nürnberg

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Erlangen Centre for Astroparticle Physics

Towards a joint X-ray and gamma-ray analysis of Pulsar Wind Nebulae with Gammapy

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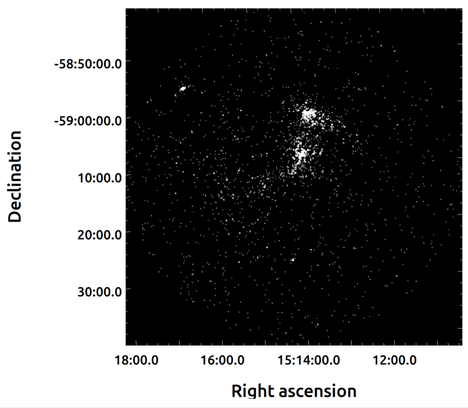
Motivation: For detailed studies of Pulsar Wind Nebulae (PWNe), objects that show photon emission across the entire electromagnetic spectrum, multiwavelength analyses are crucial. The comparison of especially X-ray and gamma-ray emission and their angular sizes can help us to constrain the properties of PWNe, such as their particle transport mechanism or their potential for the acceleration of hadronic particles.

In this vein we are working towards a joint analysis of eROSITA X-ray data [1] and H.E.S.S. gamma-ray data. To enable this process eROSITA data is adapted into the framework of Gammapy, a Python package for gamma-ray analysis [2] through a multi-step process of adapting the formats of not only the photon event list, but also all X-ray response functions, into open data formats compatible with Gammapy. This is accomplished using custom newly developed Python converter functions.
In this contribution we present the first eROSITA maps of the PWN MSH 15-52 in Gammapy, which we compare to the associated H.E.S.S. emission [3], whilst detailing the process of X-ray response format conversion and map creation in Gammapy.

eSASS/Xspec/DS9



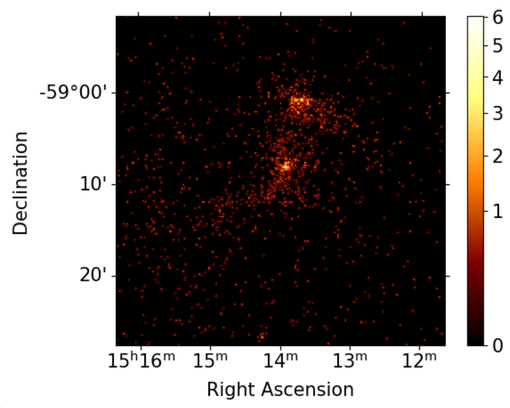
Eventfile

- FITS format produced by eSASS [4], shown in SAOImage DS9 [5]
- Containing image, event list, GTIs, pointing directions
- **`Eventfile_converter`** function to convert into format readable by Gammapy (e.g. keyword changes)

Gammapy

A **Python** package for **gamma-ray** astronomy

Events



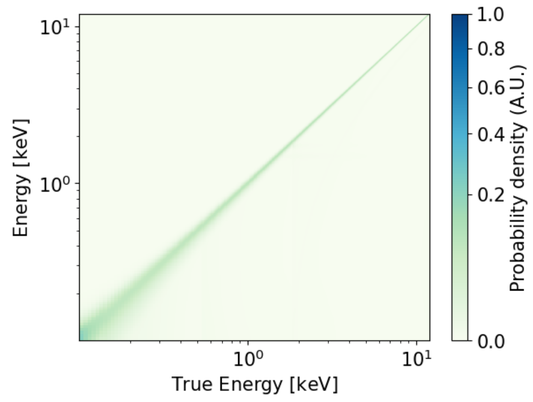
- Converted file: readable by Gammapy as **EventList**
- Creation of an **Observation** object containing the Eventlist and GTI

Energy Reconstruction

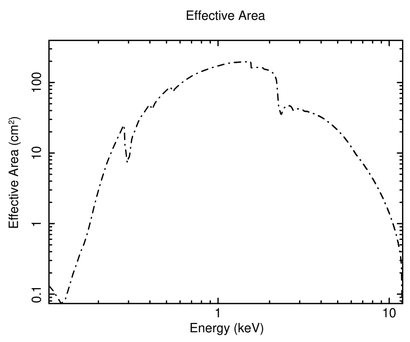
Response Matrix File (RMF)

- Containing conversion matrix between reconstructed and true energy
- Constant for all eROSITA data (with same filter patterns)
- **`Rmf_converter`** function to convert into a format readable by Gammapy

- Converted file readable by Gammapy as **EdispKernel**
- Creation of **EdispKernelMap** in later analysis

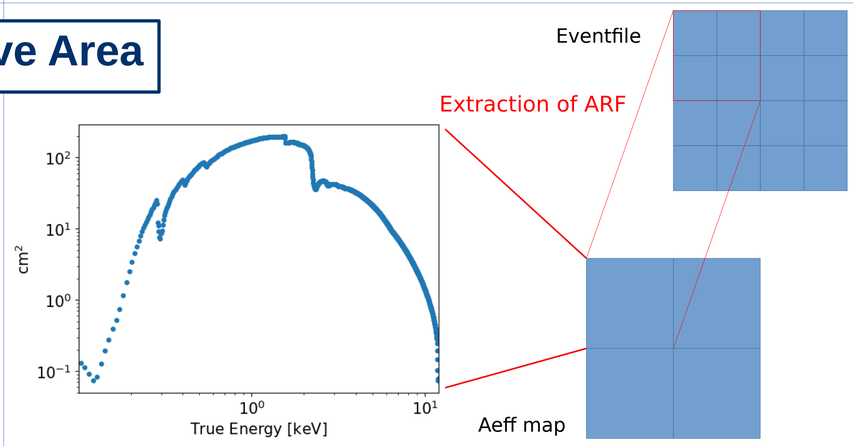


Effective Area



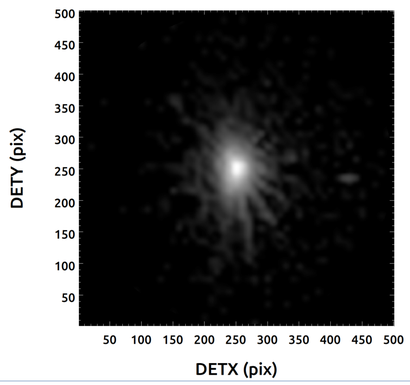
Ancillary Response Function (ARF)

- 1D effective area file for spectral analysis, shown in Xspec [6]
- Creation of 3D map through repeated ARF extraction
- Multiplied with exposure time map



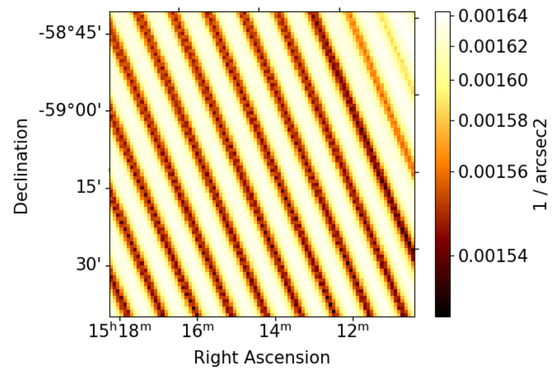
- **Exposure map**
- Readable by Gammapy as **WcsNDMap**
- Stripes due to scanning process of eROSITA

Point Spread Function (PSF)



- 2D images for different offsets and energies
- Calculation of radial PSF profiles
- Creation of map by temporal averaging over all pointing positions in present data

- Readable by Gammapy as **PSFMap**
- Stripes due to scanning process of eROSITA



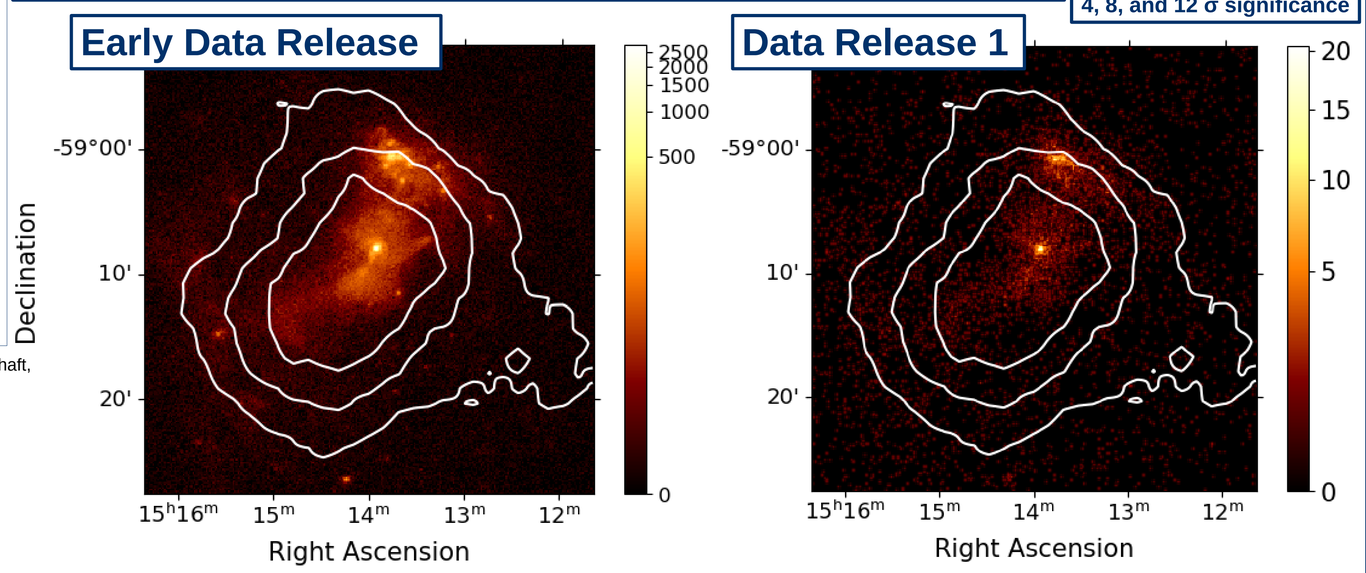
Background

- Subtract or fit spectrum of a background region

- Extraction of spectrum in background region
- Creation of “fake” OFF region in **MapDatasetOnOff** from background spectrum

MSH 15-52: eROSITA maps with H.E.S.S. contours

H.E.S.S. contours: 4, 8, and 12 σ significance



Summary: We present and showcase methods and scripts for converting eROSITA X-ray data into 3D formats that can be read and analysed by Gammapy.
We present the first eROSITA counts and IRF maps in Gammapy.

This will enable joint 3D analyses of X-ray and gamma-ray data on large scales and allow us to characterize the extent, spectra, and physical properties of Pulsar Wind Nebulae and Pulsar Halos.

References:
[1] Merloni et al. A&A 682 (2024) A34.
[2] Donath et al. A&A 678 (2023) A157.
[3] HESS DL3 DR1, H.E.S.S. collaboration
[4] Brunner et al. A&A 661 (2022) A1.
[5] Joye, W. A., & Mandel, E. 2003, in Astronomical Data Analysis Software and Systems XII, 295, 489.
[6] Arnaud, K. A. 1996, in Astronomical Data Analysis Software and Systems V, 101, 17.

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The eROSITA data shown here were processed using the eSASS software system developed by the German eROSITA consortium.