Using the virtual observatory to study the γ-ray sky

P. Kornecki (Paula.Kornecki@obspm.fr)[1], M. Servillat[1], C. Boisson[1], and M. Fuessling[2]

[1]LUTH - Observatoire de Paris   [2]CTAO gGmbH

Introduction

The growth of astrophysical data from science space missions, ground-based telescopes, and theoretical models, which have different services and data stores, has been exponential. The latter led to the necessity of unified ways of describing and accessing the data. The Virtual Observatory (VO) is a framework for astronomical datasets, tools, and services to work seamlessly, connecting the scientist with the data and service providers. Specific standards have to be defined and maintained to achieve this goal, and the International VO Alliance (IVOA) regulates these standards. Here we shed light on how the VO can facilitate scientific work by providing tools and utilities in the γ-ray astronomy domain.

Use of standards to make data FAIR

ESCAPE is a European H2020 project which focuses on the challenges of data-driven research in astronomy and particle physics. One of the objectives of ESCAPE is to make the data of the various multi-messenger facilities **openly accessible**. In particular, this includes developing and evaluating VO standards to make the very-high-energy scientific data follow the **"FAIR" (Findable, Accessible, Interoperable, Reusable) principles**.

We first need to properly describe the very-high-energy data products in the VO framework, to make it easily findable and accessible. This can be achieved by associating the proper metadata in the **standardised fields** of the VO ObsCore (observation core components) data model. We then need to provide the **detailed provenance** of the data products to foster their reusability.

How to quickly look at γ-ray data using VO tools

One can already use the VO to **find** and **access** γ-ray data. Here is an example:

1. we first **query the High Energy Spectroscopic System (H.E.S.S.) first data release (DL3 DR1)** [2]: one can use TOPCAT[1] to search high-energy catalogues. We here use the IVOA Table Access Protocol (TAP) in TOPCAT using the "TAP Query button", and run the query "SELECT * FROM hes_dr.vo_obscore_2" on the H.E.S.S. DL3 DR1 service.
2. we then **send the catalogue to ALADIN** [3] using an interoperable protocole (IVOA SAMP), in order to have a good visualisation of the source distribution in Galactic coordinates.
3. with ALADIN, we **load the Fermi all-sky maps** (Fermi colours HEALPix survey),
4. and **overlay the H.E.S.S Galactic plane survey** (HGPS).

We show the resulting image in Fig. 1.

Another helpful task is to search for spatial correlations between different catalogues of high energy sources. For example, the H.E.S.S sources can be correlated with the 4th Fermi catalogue (4FGL DR3). To do this, we load in TOPCAT the 4FGL catalogue through a TAP server and then choose the cross match tool option.
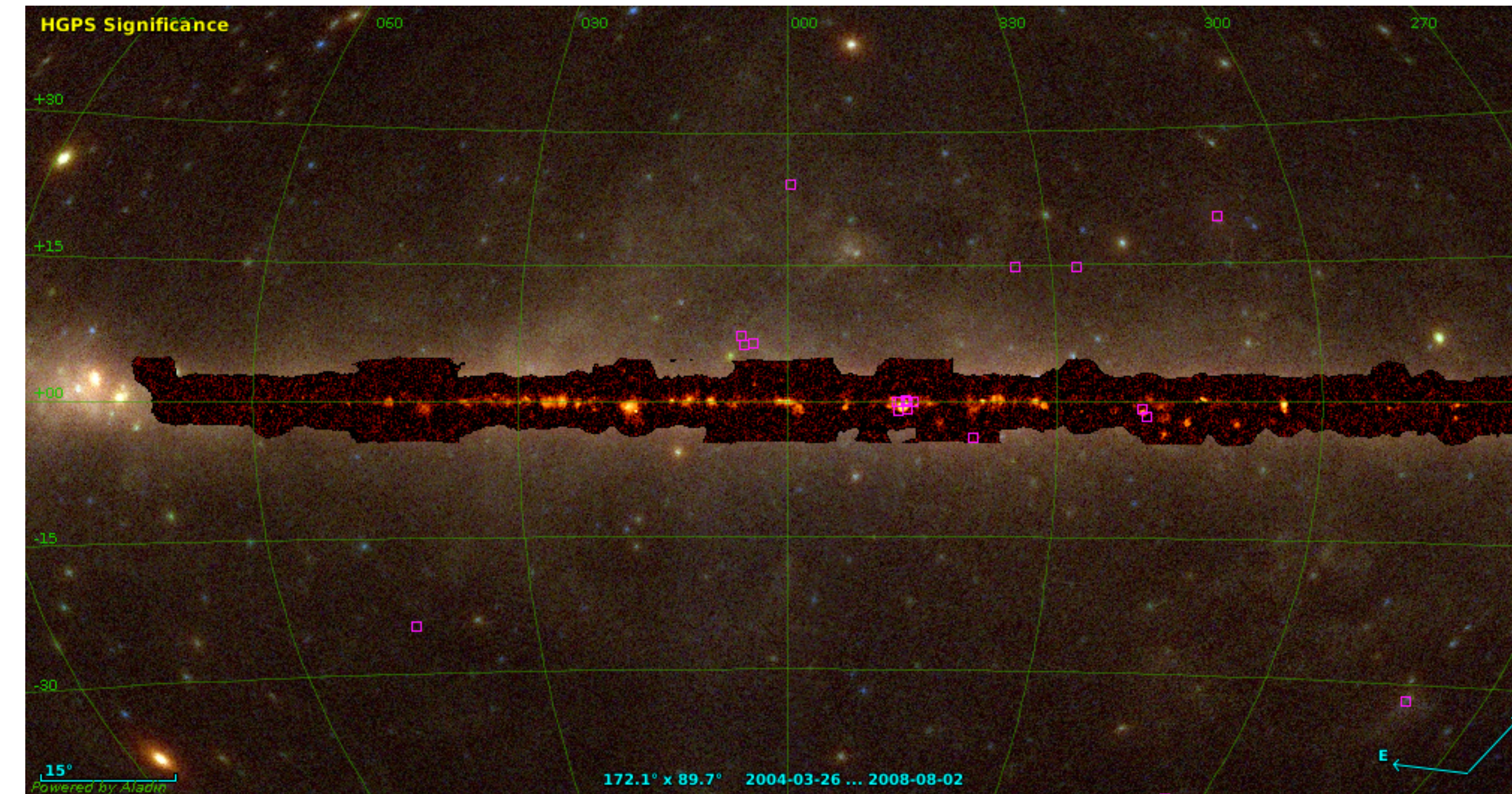

Figure 1: Aitoff projection including the *Fermi* 3 color HEALPix survey at the background, and the HGPS (H.E.S.S Galactic plane survey) γ-ray flux above 1 TeV for regions where the sensitivity is better than 10% Crab. The pink squares are the observations of the DL3 DR1.

Online analysis with Gammapy and OPUS based on standards

Though it is already possible to preview images and catalogues created from very-high-energy data, it is generally necessary to reprocess the data from the event lists in order to apply a specific analysis. Such an analysis can be performed using Gammapy [4], and run asynchronously on our work cluster with OPUS [5] (Observatoire de Paris UWS System).

→ **Gammapy** is a community-developped, open-source Python package now widely used by the community. It is also the official Science Tools library for the Cherenkov Telescope Array (CTA) Observatory.

→ **OPUS** is a job control system that facilitates access to analysis and simulation processes. It is based on two IVOA standards: the Universal Worker System pattern (UWS) to make the tool **interoperable**, and the Provenance Data Model to capture and expose the provenance information of jobs and results for **reusability**. As the tool is interoperable, jobs can be run either through a web interface or a script.

Data from the H.E.S.S. public data release may thus be analysed with Gammapy by connecting it with an OPUS platform [6]. We show in Fig. 2 the outputs of the gammapy_pks2155 job in OPUS which performs a complete spectral analysis of the point source PKS 2155-304.
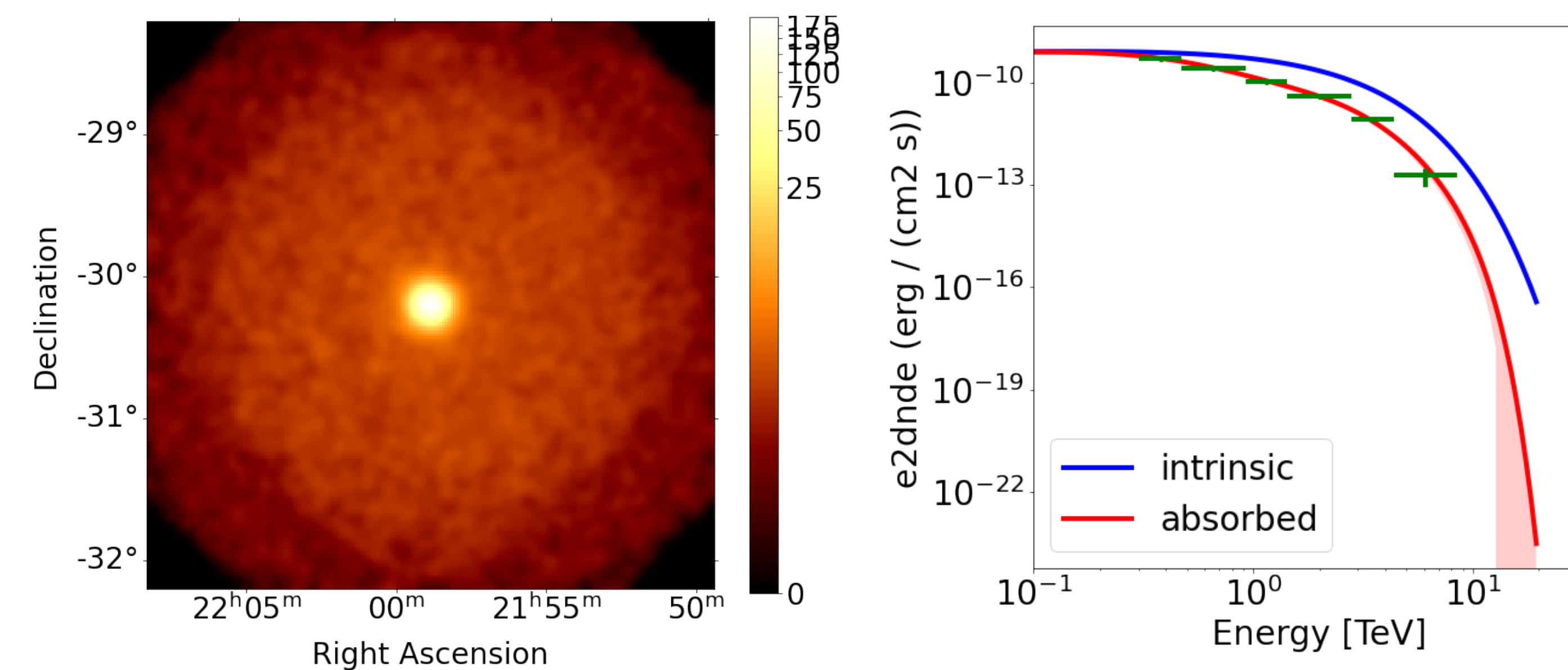

Figure 2: PKS 2155-304 data products. Left panel: Counts map with energies between 0.1 a 20 TeV. Right panel: Source spectrum. Blue line: intrinsec spectrum assuming a power-low with an exponential cutoff model; Red line: same model with the EBL absorption.

Discussions and conclusions

The standards provided by the VO allow the scientists to quickly discover and access the γ-ray data by VO servers and obtain it in a standardized way. In addition, with the knowledge of a single tool such as Gammapy, we have access to the analysis of data from several high-energy telescopes.

γ-ray data still needs to be adapted to VO standards. The upcoming Cherenkov Telescope Array is evolving towards the model of a public observatory. The corresponding data will be accessible by the VO as many others, which will ease the scientific work.

We conclude that the IVOA standards is a continuous evolution cycle that changes with the researcher's needs and is essential for improving the scientific community.

Acknowledgement

Links

1. http://www.star.bris.ac.uk/ mbt/topcat/
2. https://hess-dr.obspm.fr
3. https://aladin.cds.unistra.fr
4. https://gammapy.org/
5. https://opus-job-manager.readthedocs.io
6. https://voparis-uws-test.obspm.fr/client/jobs/gammapy_pks2155

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