Open Archival Facilities for Very High Energy Astrophysics in a multipurpose context: from MAGIC to the Cherenkov Telescope Array

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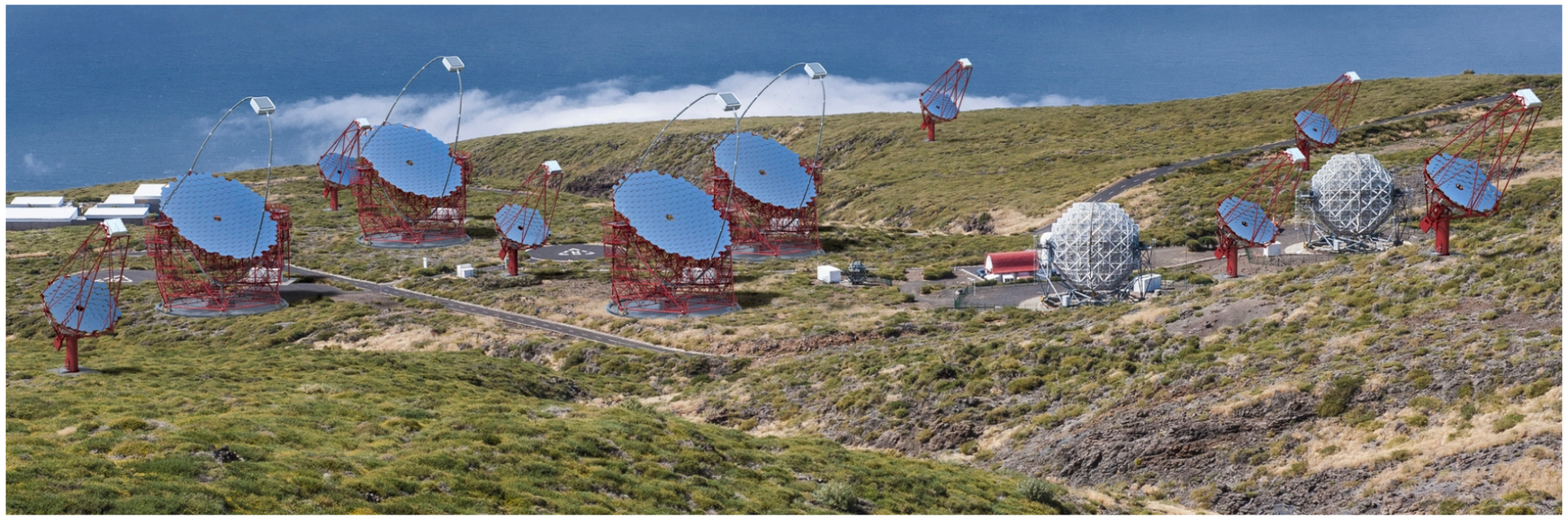
The Cherenkov Telescope Array Observatory

- Cherenkov Telescopes trace the most extreme events in the Universe, detecting photons in the TeV energy range.
- These photons interact with the Earth atmosphere and produce a flash of light, that is captured by the telescopes and then analyzed to understand the origin of the emission.
- Several Cherenkov telescopes already exist (MAGIC, HESS, VERITAS…), but CTA will be revolutionary both in terms of science and in terms of public access to the data.
- Array of telescopes of different sizes and two locations: La Palma (North) Chile (South). First Large-Size Telescope (LST-1) already observing; structures ready by ~2027.
- Many nations involved, important role of Italy (INAF, INFN, several universities).

Together, the northern and southern CTAO arrays will constitute the CTAO, which will be the first ground-based gamma-ray observatory open to the world-wide astronomical and particle physics communities as a resource for data from unique high-energy astronomical observations. The CTAO will be operated as an open, proposal-driven observatory for the first time in very high-energy astronomy. This is expected to significantly boost the scientific output of the CTAO by engaging a much wider research community.

Additionally, the CTAO will feed its data into a virtual observatory, which will allow scientists to probe multiple data centres seamlessly and transparently, provide analysis and visualization tools and give other observatories a standard framework for publishing and delivering services using their data.



PROCEEDINGS OF SCIENCE

Toward a Public MAGIC Gamma-Ray Telescope Legacy Data Portal

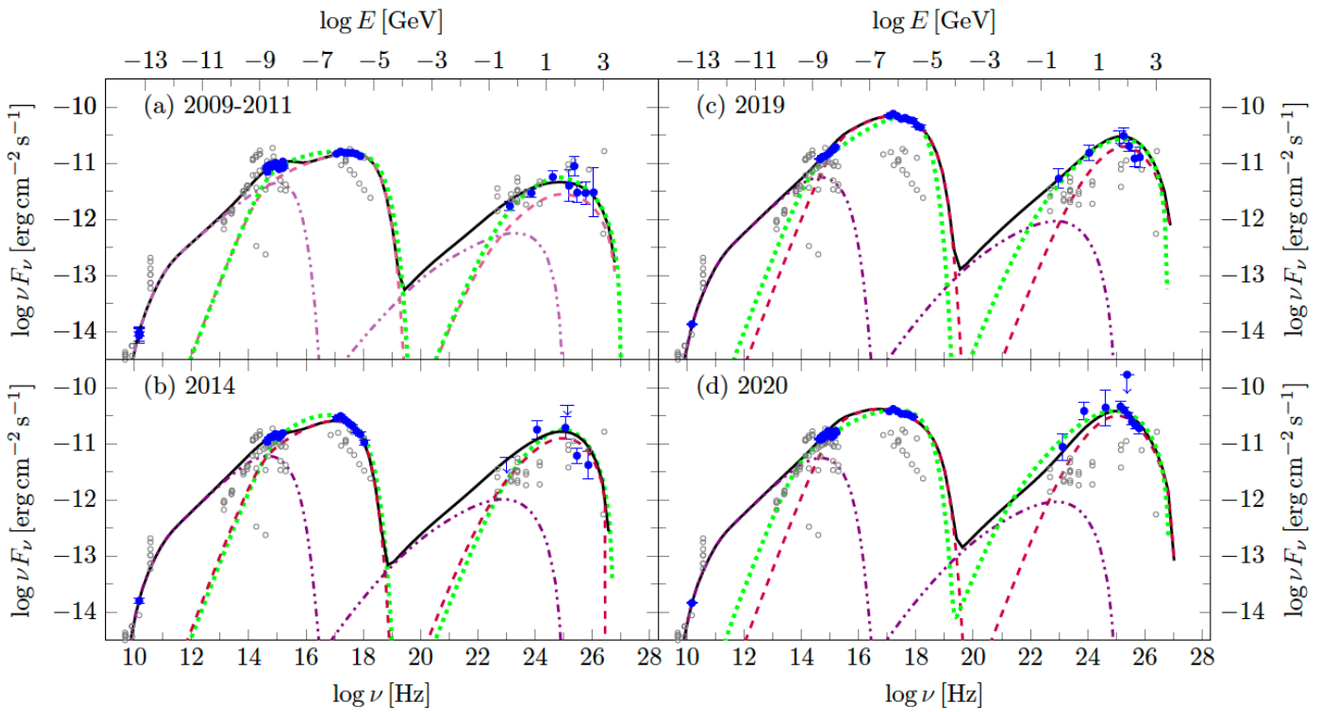
M. Doro[a], C. Nigro[e], E.Prandini[a], A. Tramacere[b], M. Delfino[c,d], J. Delgado[c,d], E. do Souto[c], L. Jouvin[c], J. Rico[c] for the MAGIC Collaboration*

The MAGIC telescopes are one of the three major IACTs (Imaging Atmospheric Cherenkov Telescopes) for observation of gamma rays in the TeV regime currently operative. MAGIC functions since 2003, and has published data from more than 60 sources, mostly blazars. MAGIC already provides astronomical `.fits` files with basic final scientific products such as spectral energy distributions, light curves and skymaps from published results. In future, the format of the files can be complemented with further relevant information to the community: a) by including the full multi-wavelength dataset enclosed in a publication, b) providing data in alternative easy-to-use formats such as ASCII or ECSV, which are accessible with other commonly used packages such as `astropy` or `gammapy`. Finally, besides high level products, activities have started to provide photon event lists and instrument response functions in a format such that scientists within and outside the community are allowed to perform higher level analysis. A second aim is to provide a full legacy of MAGIC data. This contribution will illustrate the achievements and plans of this activity.

Doro et al. (2019)

Towards a public archive of extragalactic sources studied by MAGIC

- During the years, MAGIC has studied a significant number of extragalactic sources in the most extreme energy range.
- However, as of today, no public archive for both TeV and multiwavelength products exists for MAGIC: currently, only a page with fits files is available (http://vobs.magic.pic.es/fits/)
- Other collaborations: VERITAS has archive publicly accessible on HEASARC.
- H.E.S.S.: built an online repository containing fits file and list of information in each paper.



MAGIC collaboration (2023)

A first effort: STeVECat

STeVECat, the Spectral TeV Extragalactic Catalog

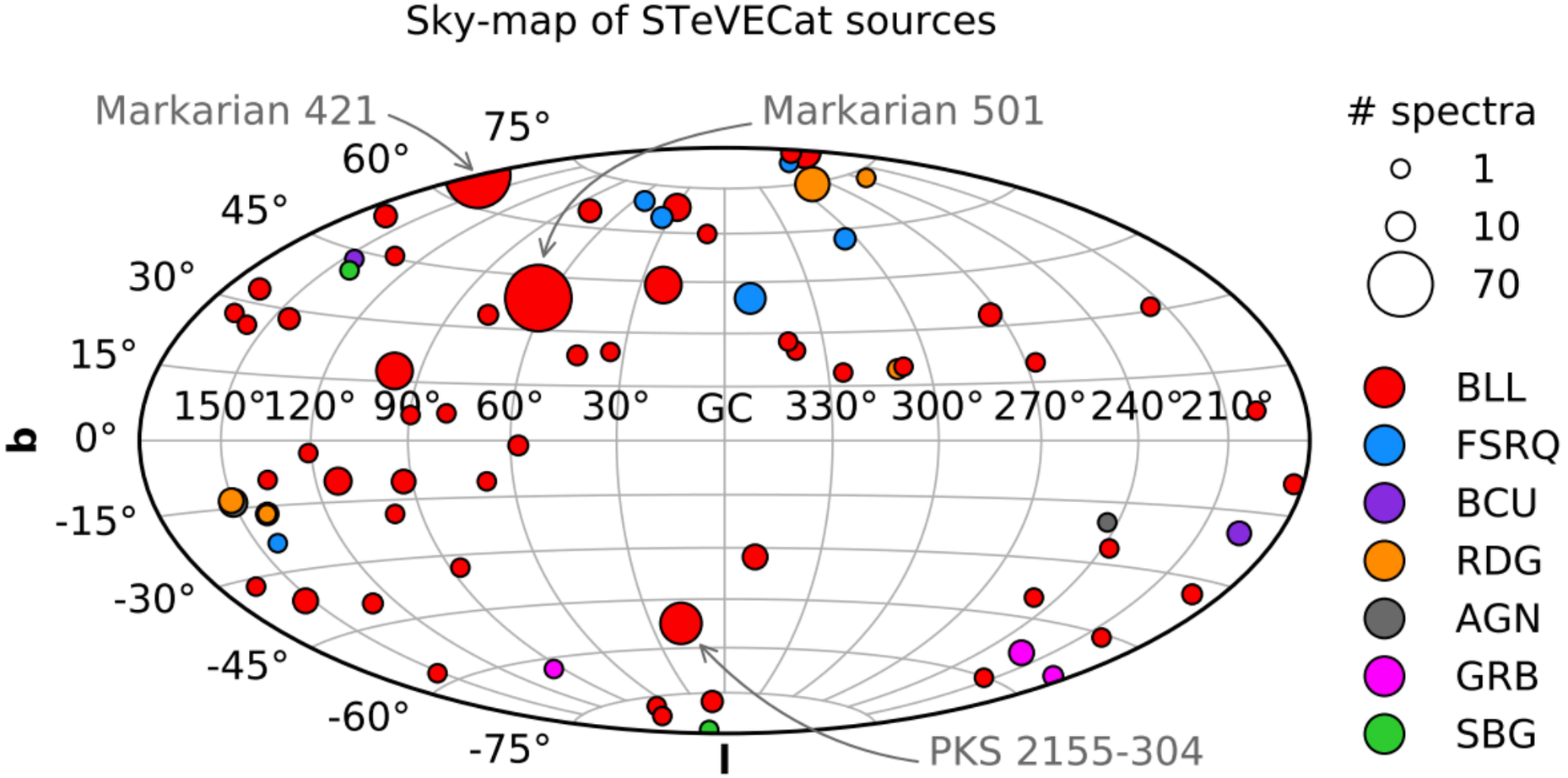
Lucas Gréaux,[a,*] Jonathan Biteau,[a] Tarek Hassan,[b] Olivier Hervet,[c] Mireia Nievas Rosillo[d,e] and David A. Williams[c]

The three main collaborations operating the current generation of imaging atmospheric Cherenkov telescopes (IACTs: H.E.S.S., MAGIC, VERITAS) publish their gamma-ray data in different formats and repositories. Extragalactic sources are highly variable at very-high energies (VHE, $E > 100\,\mathrm{GeV}$), and a unified repository would enable joint analyses of collections of extragalactic VHE spectra. To this aim, we have developed the Spectral TeV Extragalactic Catalog, STeVECat, which gathers high-level products of IACT observations from 1992 to 2021. We selected all publications in journals referenced in TeVCat that presented archival spectra with at least two points. We compiled the corresponding spectral data and formatted them following the convention adopted in available public repositories (GammaCat and VTSCat). In addition to spectral points with associated physical units, we provide meta-data featuring observation periods, livetime, excess counts over background and significance, as well as the coordinates, types and redshifts of the sources whenever available. STeVECat combines observations from 173 journal publications, compared to 72 in the previous reference compilation of extragalactic gamma-ray spectra (Biteau & Williams, 2015). STeVECat is the most extensive set of VHE extragalactic spectra collected so far, with 403 spectra from 73 sources. The full catalog can readily be loaded with GammaPy, the Science Analysis Tool selected by the Cherenkov Telescope Array Observatory. Our compilation efforts enable population studies of extragalactic gamma-ray sources, studies of the GeV-TeV connection, and studies of absorption on the extragalactic background light.

arXiV:2304.00835

A first effort: STeVECat

- Contains >100 GeV spectra from 173 publications
- Overall, 403 observations of 73 sources
- Data from MAGIC, H.E.S.S., Veritas
- Data formatted using the GammaCat and VTSCat standards
- Usable with GammaPy



Gréaux et al. (2023)

The next step: a more comprehensive effort

- While STeVECat represents an important step forward towards a public data library for TeV-detected extragalactic sources, there is further information that it is important to make accessible to the community.

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1. Multi-wavelength light curves

MAGIC collaboration (2023)

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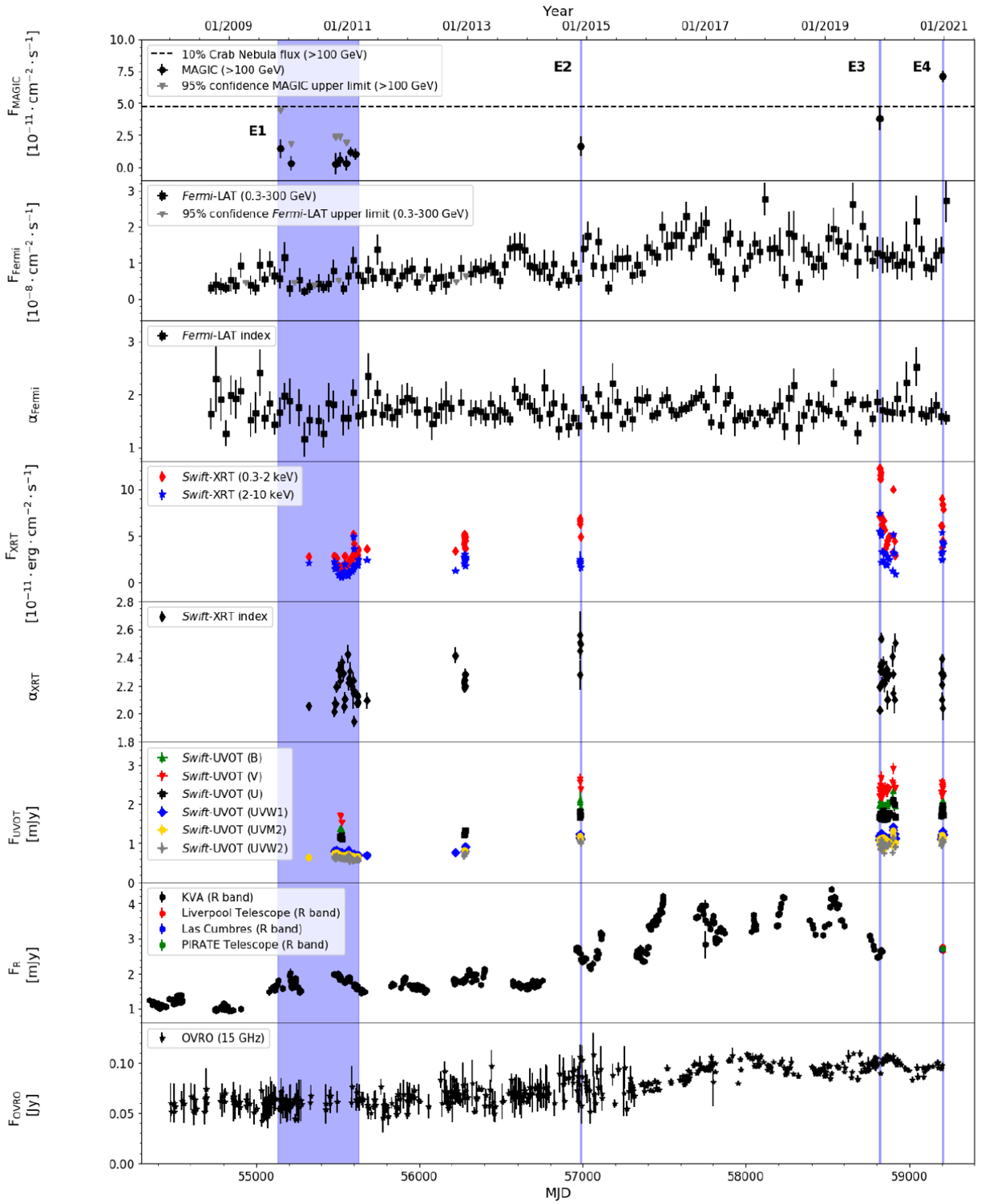

MAGIC collaboration (2023)

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1. Multi-wavelength light curves
2. Multi-wavelength SEDs

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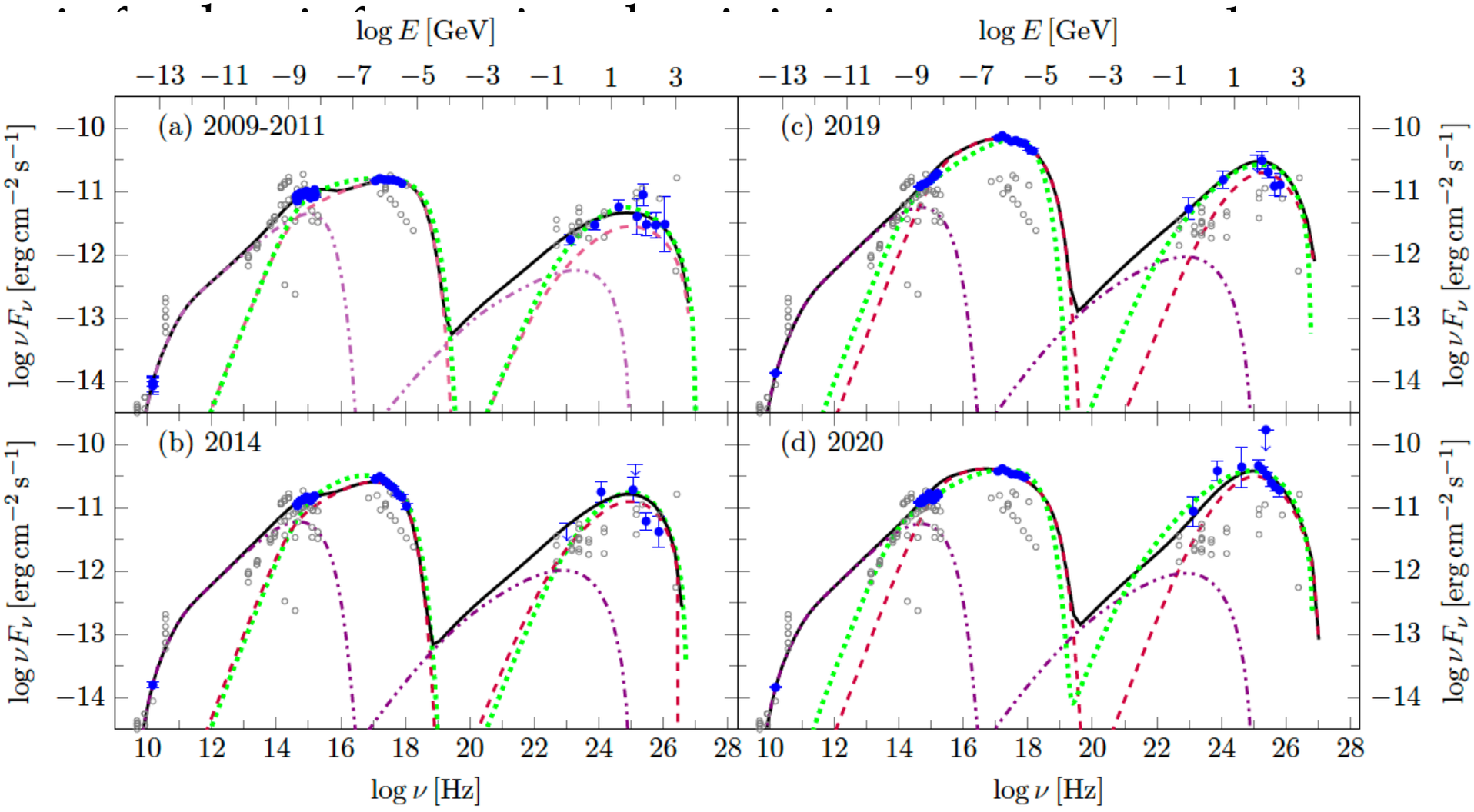

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1. Multi-wavelength light curves
2. Multi-wavelength SEDs

- Our project aims at including both these datasets in a public repository.

The project: all files in a common language

- Working on having all information from MAGIC papers in ecsv format

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The project: all files in a common language

- One yaml file for each paper
- All files will be uploaded on online repository (currently gitlab, but we will look for public repositories from our institutions), with additional material (Jupyter codes to plot and analyze the data, readme files summarizing the papers…)

```
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 Pcauthor:  Jorge Otero-Santos; Daniel Morcuende; Vandad Fallah Ramazani; Daniela Dorner; David Paneque
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```
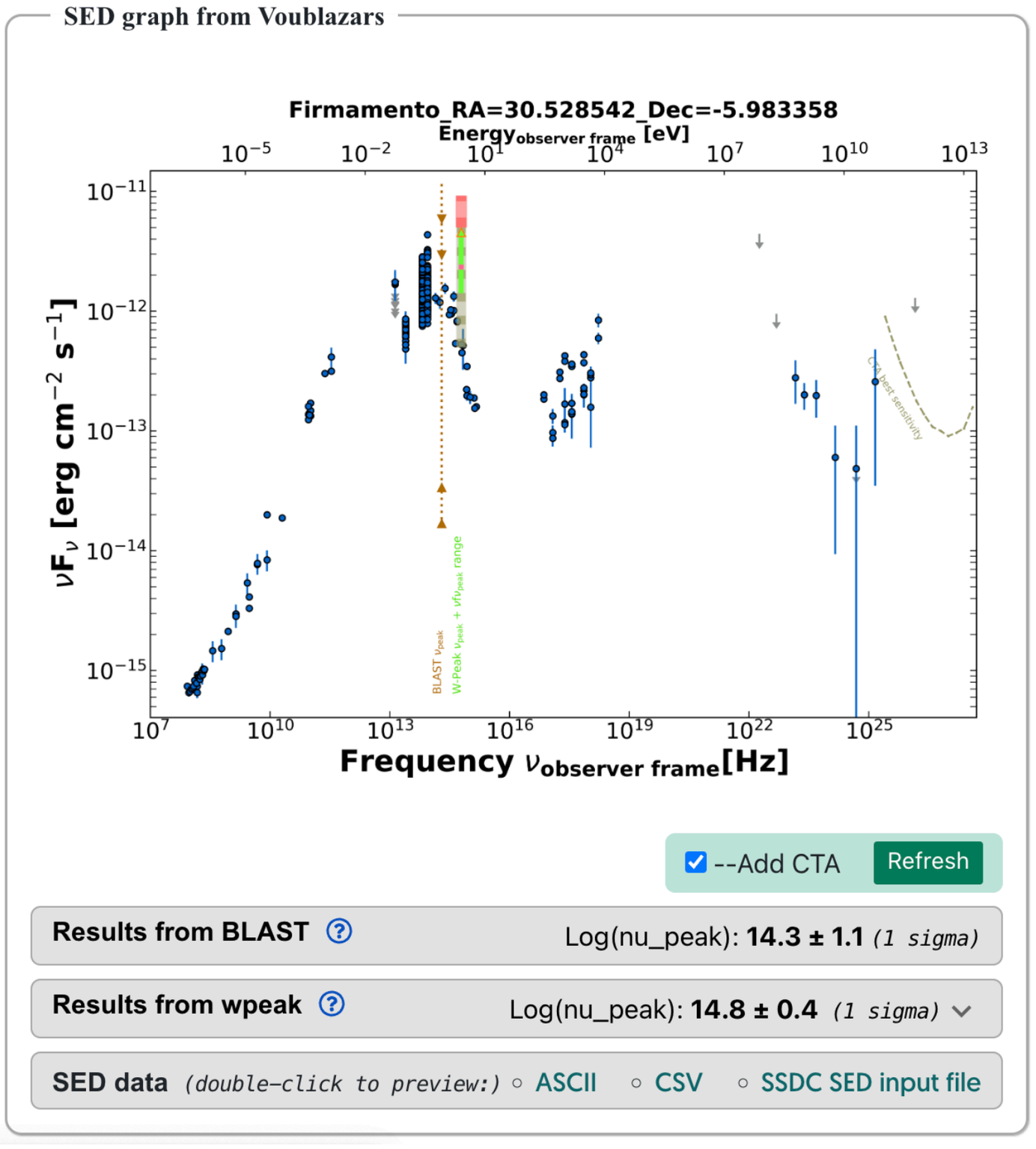

The project: making the dataset available to Open Public Tools

- The files will also be made accessible by public tools for the multi-wavelength analysis of blazars, such as the Open Universe VOU-Blazars one (https://sites.google.com/view/ou4blazars), the SSDC-ASI TeGeVCat (https://www.ssdc.asi.it/tgevcat/) and Firmamento (https://firmamento.hosting.nyu.edu/data_access)
- These tools allow one to produce spectral energy distributions of a source interest (which can be a known blazar as well as a new candidate target), and model them to get information on the SED properties (synchrotron peak location, variability…)
- Firmamento already includes information on CTA expected sensitivity as well: powerful tool to make predictions.



Conclusions

- MAGIC has now studied a significant number of extragalactic sources, and a public archive with all multiwavelength information reported in papers would significantly help the community.
- Multiple possibilities: reanalysis including new observations and/or new datasets, systematic studies of population of sources, reference for future observatories such as CTA (both for simulations and for candidates to prioritize in future observations).
- We are currently working on putting all the multiwavelength (SEDs, light curves) reported in MAGIC extragalactic papers in a universal format, to then report all the files in a public repository (gitlab). It would also be key to make these datasets open and available in the repositories of our institutions.
- Help of the community would be key for the success of this project: for example, providing access to datasets in ascii/fits format to ease the conversion process (in the future, we envision the release of the data to become a standard procedure when publishing a paper).
- Contacts: Michele Doro (michele.doro@unipd.it); Stefano Marchesi (stefano.marchesi@unibo.it); Elisa Prandini (elisa.prandini@unipd.it)