Observation of the sub-TeV gamma-ray sky from the Southern Hemisphere

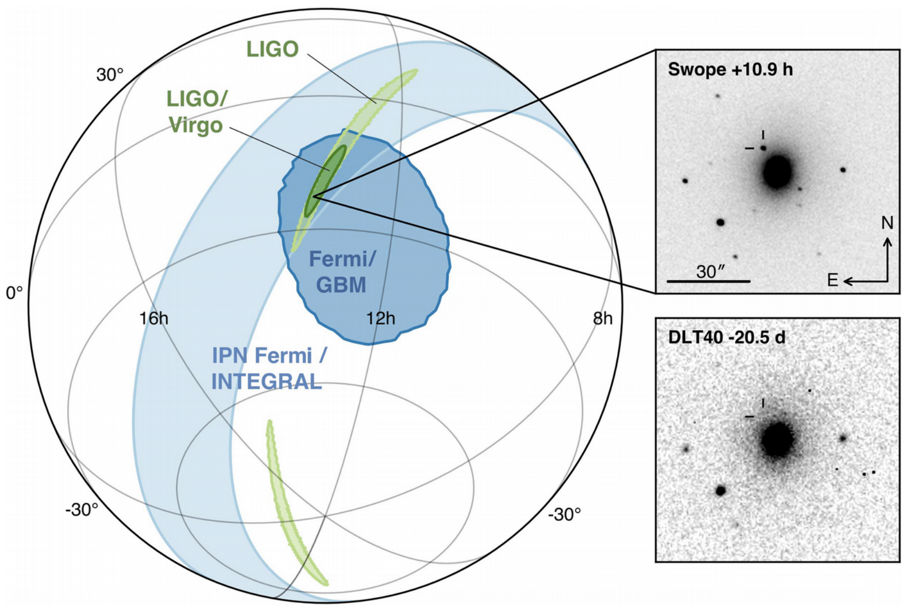
Giovanni La Mura, Ruben Conceição, Alessandro De Angelis,
Mário Pimenta, Bernardo Tomé

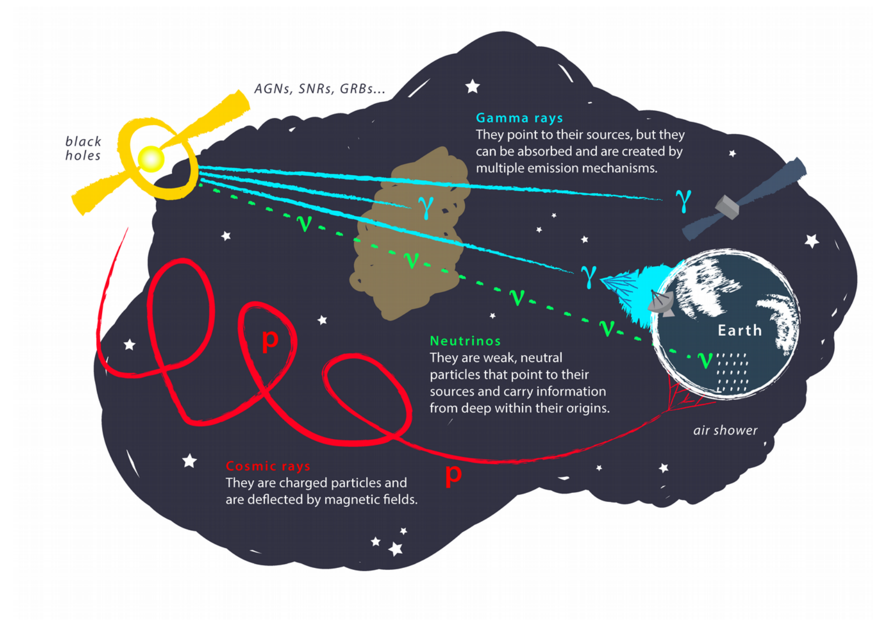
LIP

Wide FoV Southern Gamma-ray Observatory, 20-22 May 2019, Lisboa, Portugal

Gamma-ray monitoring in Multi-Messenger era

2017 has been a revolutionary year for Astrophysics: the first combined detection of elctro-magnetic + GW emission and the first identification of a UHE neutrino source have been finally carried out.



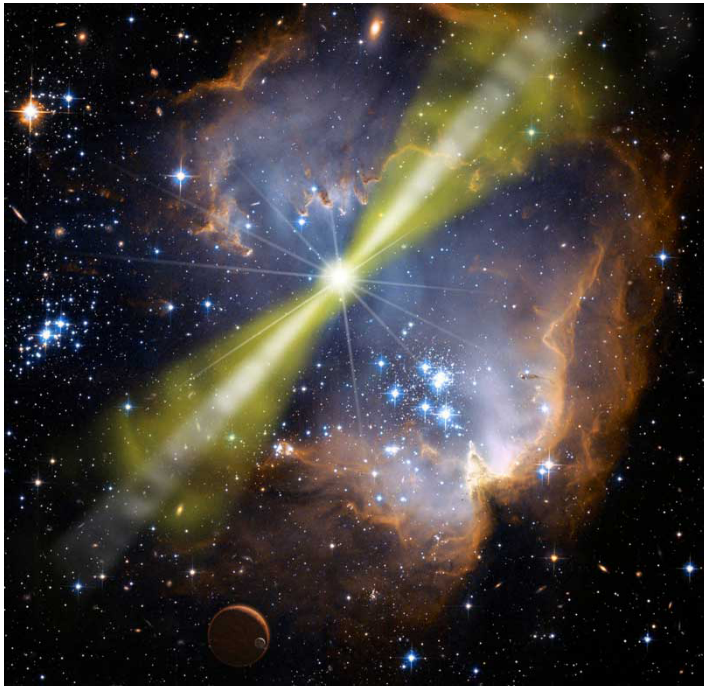


New runs from **LIGO / VIRGO** are now regularly issuing alerts, while the IceCube collaboration is collecting increasing evidence for **excess neutrino emission**, indicating the possibility to identify neutrino sources.

Gamma-ray monitoring played a **key role** to identify the electro-magnetic counterpart in both cases, addressing the Multi-Wavelength community in follow-up investigations.

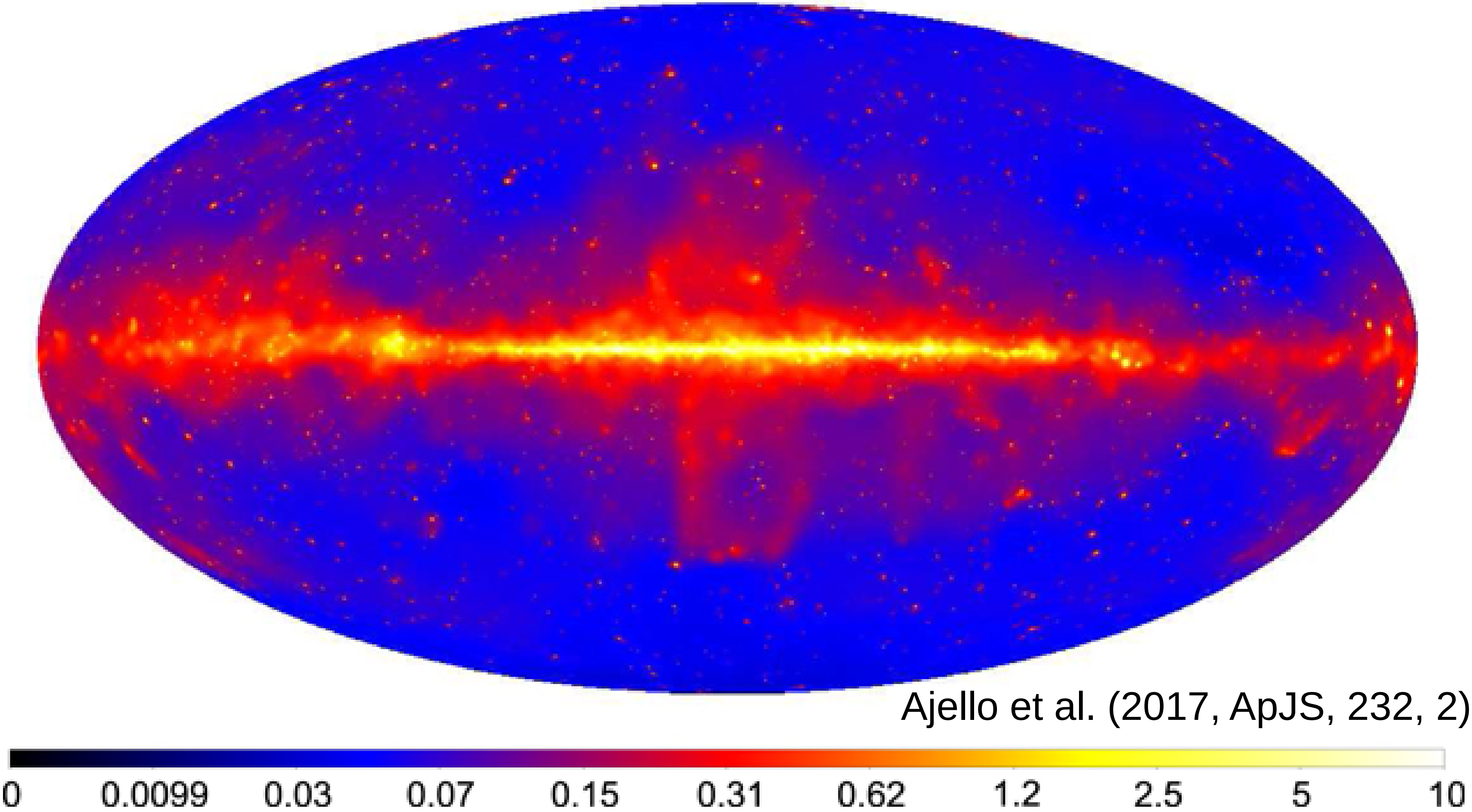
GRB 190114C: another long awaited detection

EVENT	E_{MAX}	*z*
GRB 080916C	25 GeV	4.350
GRB 090510	25 GeV	0.903
GRB 090902B	42 GeV	1.822
GRB 090926A	21 GeV	2.106
GRB 100414A	30 GeV	1.368
GRB 110213A	82 GeV	1.460
GRB 130427A	**94 GeV**	**0.340**
GRB 131231A	42 GeV	0.640
GRB 140928A	50 GeV	??
GRB 160509A	59 GeV	1.170
GRB 171010A	21 GeV	0.330
GRB 190114C	**> 300 GeV**	**0.420**



In January 2019 **MAGIC** announced detection of **GRB 190114C** at more than **300 GeV** (Atel #12390). It was expected that GRBs should be intrinsically capable of powering VHE emission, but direct observation was never obtained before. The emission mechanism is likely related with relativistic ejecta slamming in the progenitor's environment gas.

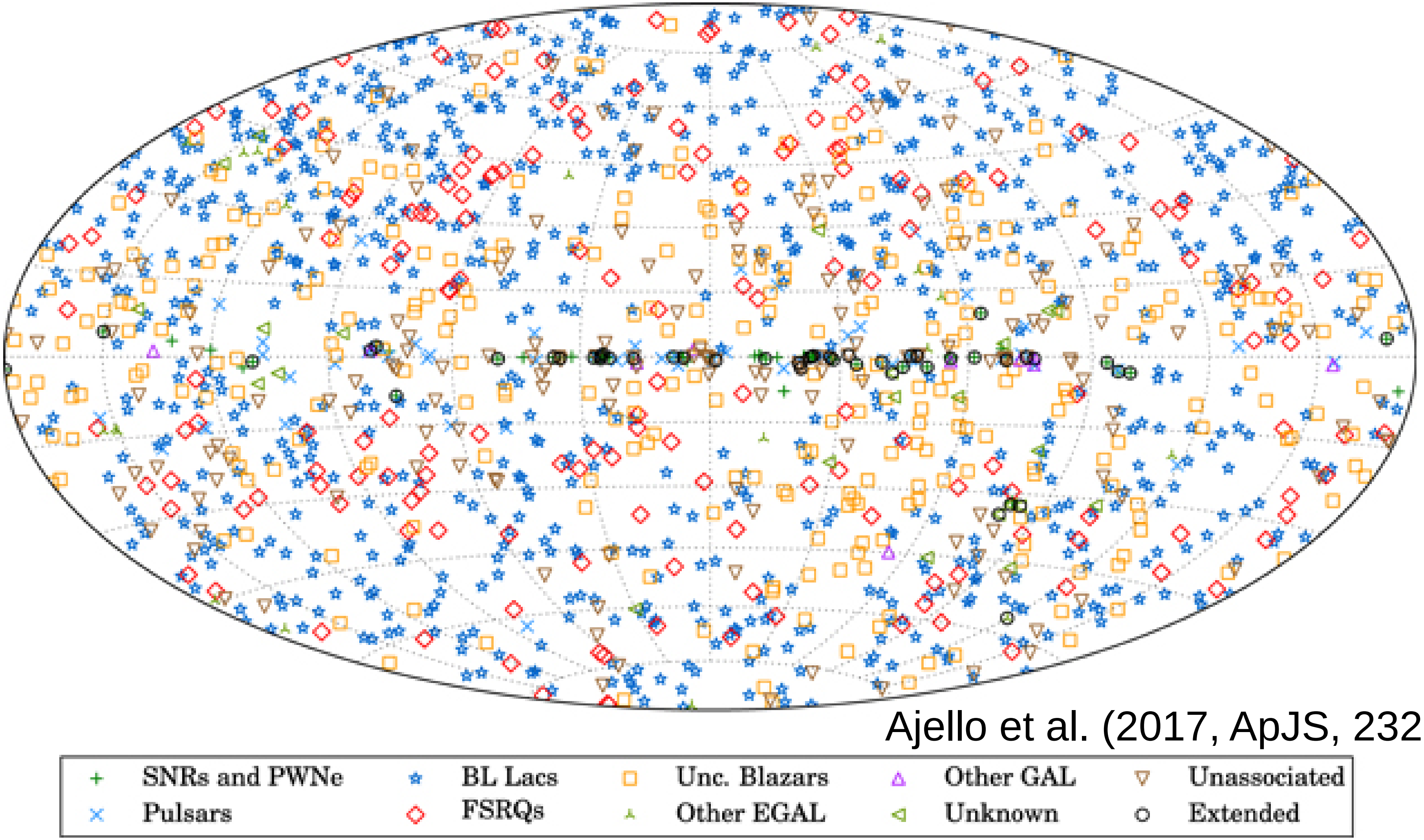
The VHE sky with Fermi (3FHL, E > 10 GeV)



Ajello et al. (2017, ApJS, 232, 2)

All sky map of VHE gamma-ray emission in 7 years of Fermi-LAT observations, presented in Galactic coordinates and Aitoff projection. Image units are counts and pixel size is (0.1 deg)^2.

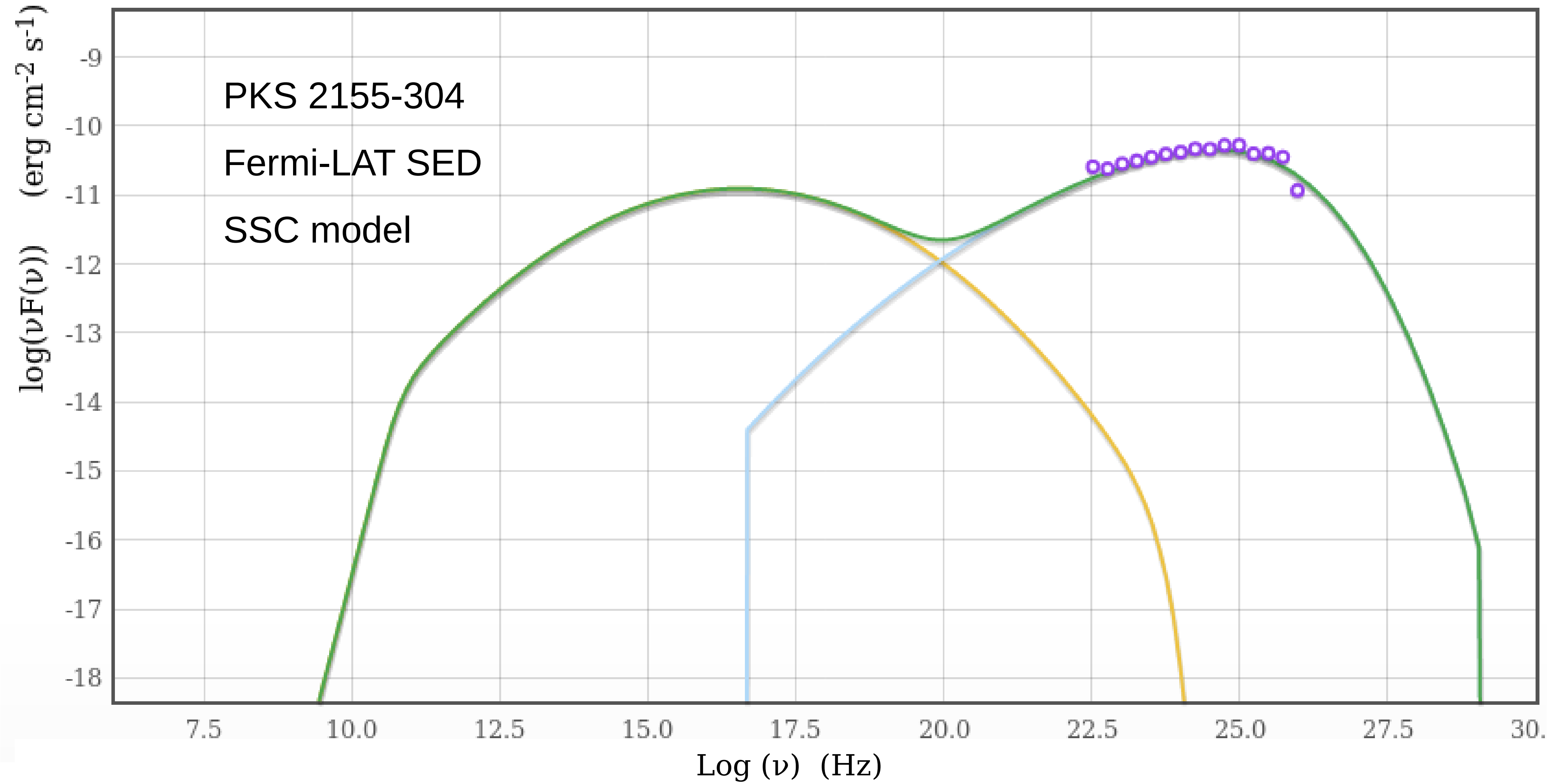
The VHE sky with Fermi (3FHL, E > 10 GeV)



Ajello et al. (2017, ApJS, 232, 2)

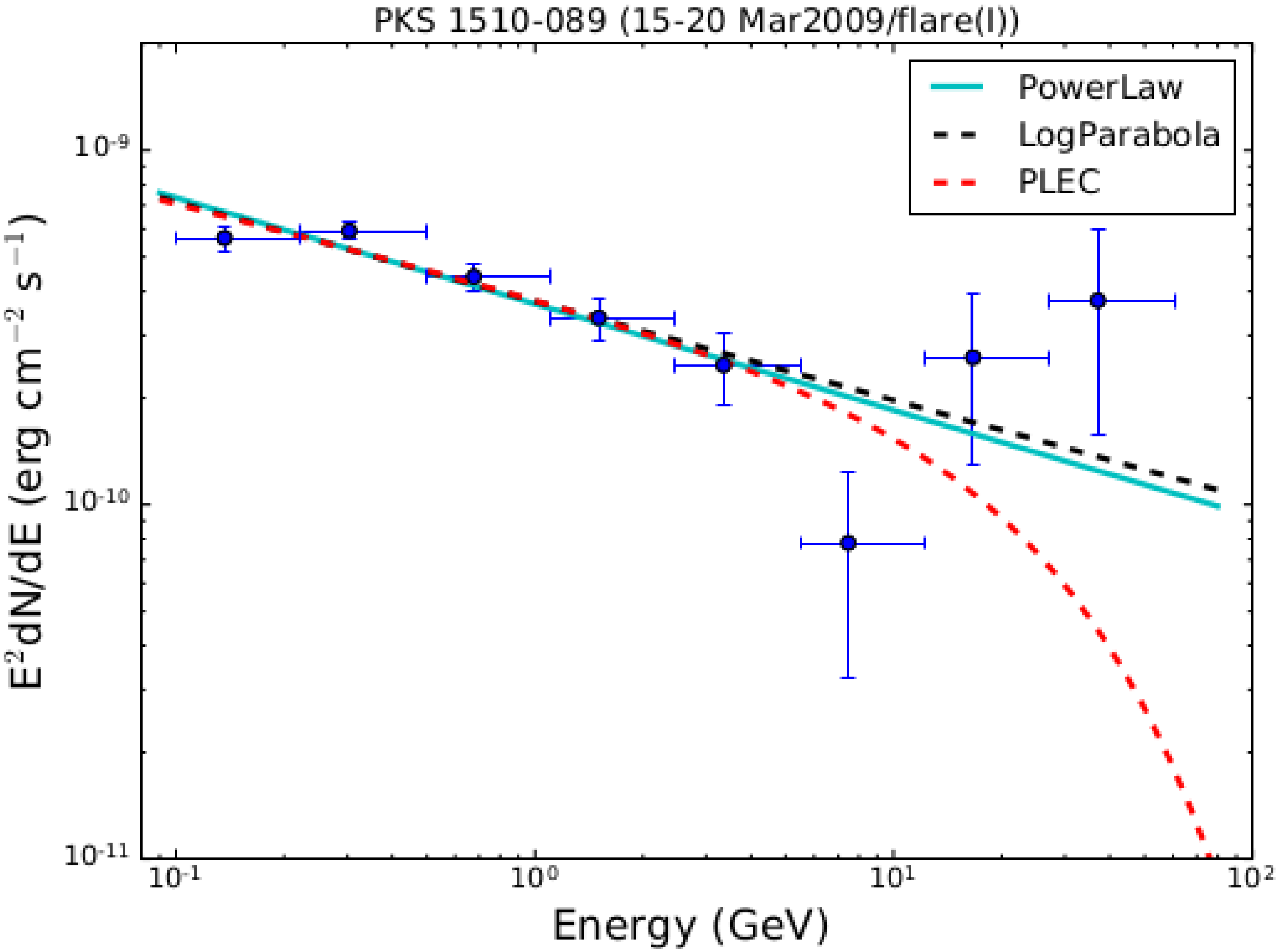
Distribution and classification of the 3FHL Catalogue sources, presented in Galactic coordinates and Aitoff projection. The Extra-Galactic sky is dominated by BLAZARs, while PULSARs and SuperNova Remnants are the main Galactic sources.

Gamma-ray sources: I - BLAZARs



Gamma-rays from BLAZARs and other AGN jets are well interpreted in the framework of inverse Compton scattering of various seed radiation fields (disk, Broad Line Region and dust in FSRQs, self synchrotron in BL Lacs). AGNs, however, are known for their unpredictable and remarkable variability, which represents a fundamental ingredient to understand jet physics.

Properties of AGN flares



PKS 1510-089

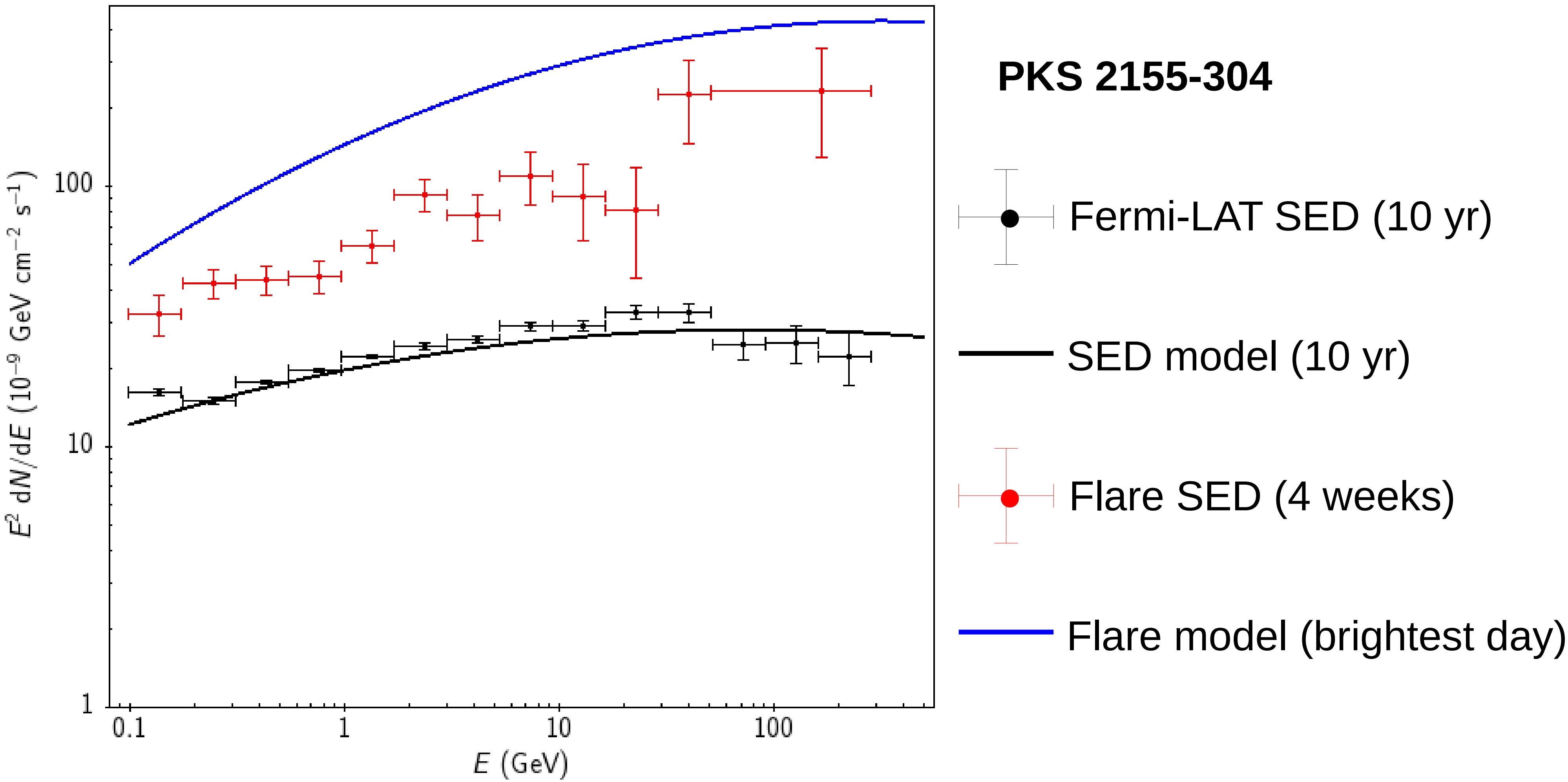
0.1 – 100 GeV SED

with Fermi-LAT

Prince et al. (2017, ApJ, 844, 62)

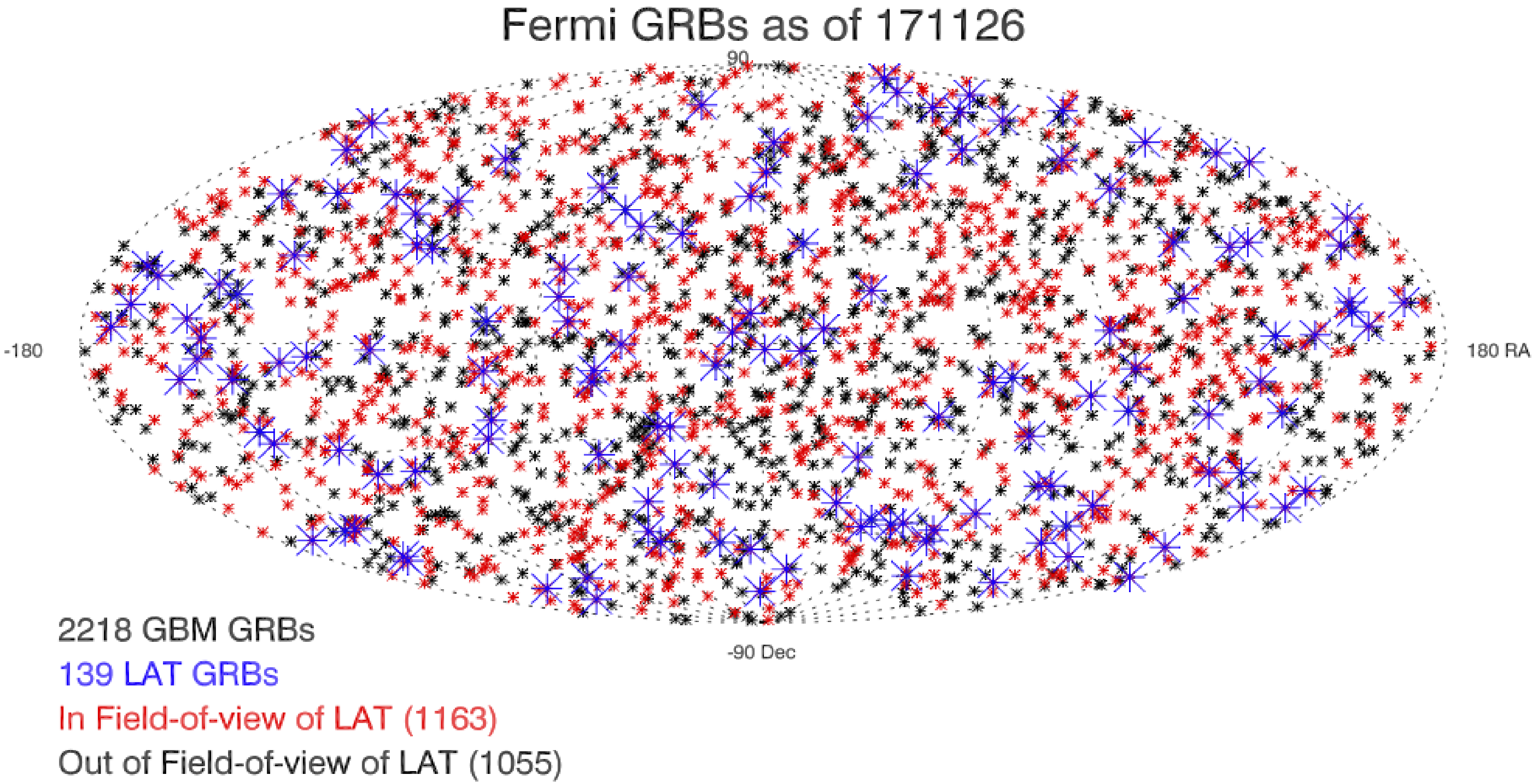
In VHE, AGN variability covers a wide range of time-scales: we observe weekly or even monthly flux modulations, as well as day- or few hours-long sudden flares. The flare spectrum usually comes in a form that adds up to the usual IC emission, with hints of hadronic contributions. Our current instrumentation is not sensitive enough to characterize these components.

Properties of AGN flares



During flares, BLAZARs undergo flux and spectral changes, typically exhibiting a “harder when brighter” configuration, although the statistics in the VHE domain remains extremely poor, due to the short duration of the highest states. Prompt response from facilities that are optimized to collect photons with $E > 100$, with a high duty cycle, is critically needed.

Gamma-ray sources: II - Gamma Ray Bursts



GRBs represent a second family of unpredictable sources that undoubtedly benefit from a wide FoV, continuous monitoring strategy. GRBs belong to two main families: long (core-collapse SNe) and short (NS-NS mergers). There are, on average, 1 or 2 triggers per day, mainly in the 100 keV – 100 MeV energy domain, but some with VHE afterglows.

GRB distribution properties

Number of GRBs detected in 10 yr by Fermi-GBM (0.15 – 30 MeV, 9.5 sr):

$$N_{GBM}(10\,\mathrm{yr}) = 2370 \quad \longrightarrow \quad N_{GBM}^{ALLSKY}(10\,\mathrm{yr}) \simeq 3135$$

Number of GRBs detected in 10 yr by Fermi-LAT (0.1 – 300 GeV, 2.4 sr):

$$N_{LAT}(10\,\mathrm{yr}) = 186 \quad \longrightarrow \quad N_{LAT}^{ALLSKY}(10\,\mathrm{yr}) \simeq 974$$

An instrument with a 2 sr FoV has an expected rate of GRBs in FoV of:

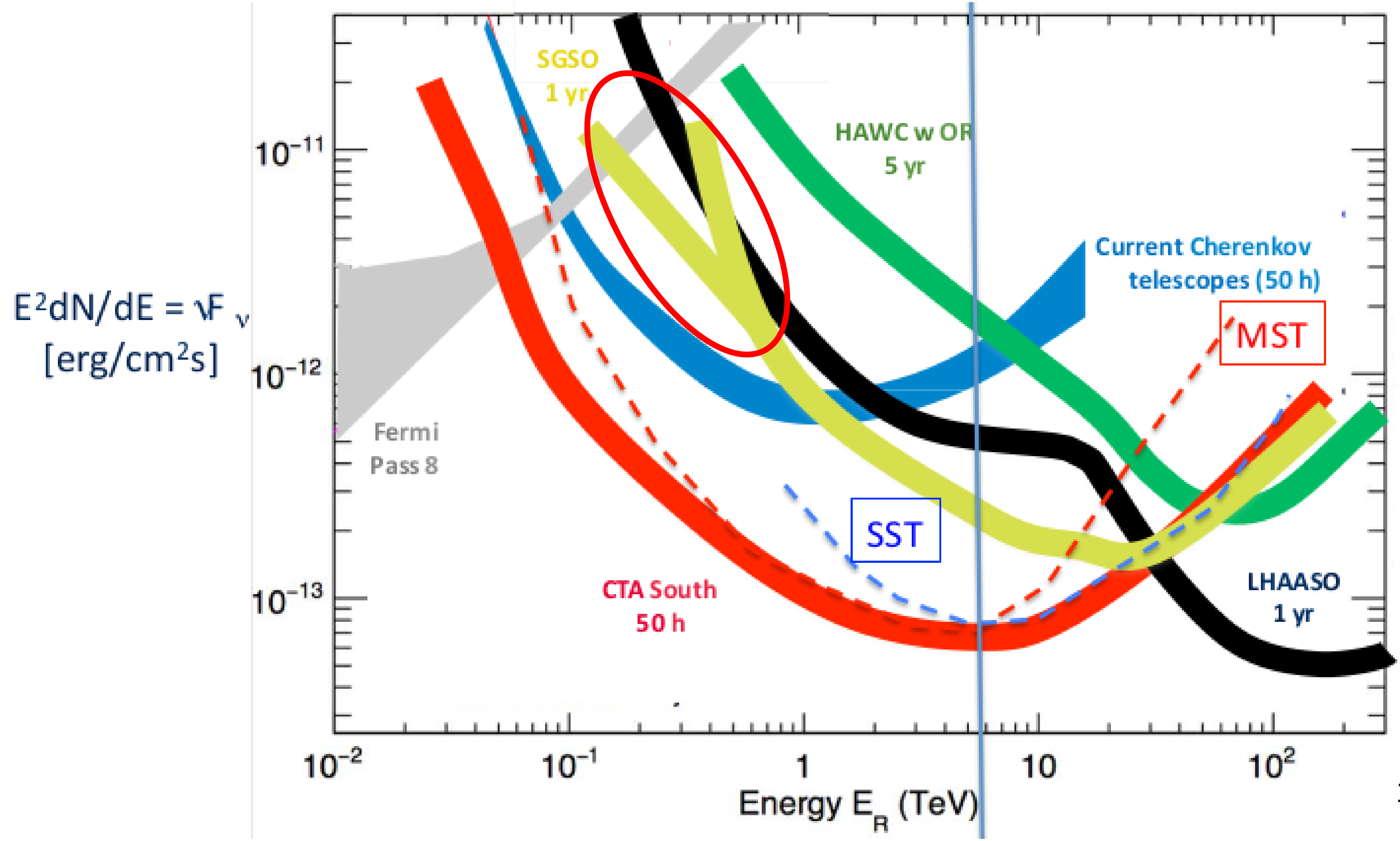
$$R_{FoV} = \frac{2\,R_{ALLSKY}}{4\pi}$$

The expected rate of observable GRBs can be obtained with assumptions on the total rate of events, which descend from the possibility that the events produce VHE emission. Using the energy windows of GBM and LAT, we know that 37% are detected with E > 100 MeV, but only 2.4% with E > 10 GeV. Assuming a power-law distribution, we can expect for E > 100 GeV:

$$0.1\,\mathrm{yr}^{-1} < R_{FoV}(\mathrm{VHE\text{-}GRB}) < 0.5\,\mathrm{yr}^{-1}$$

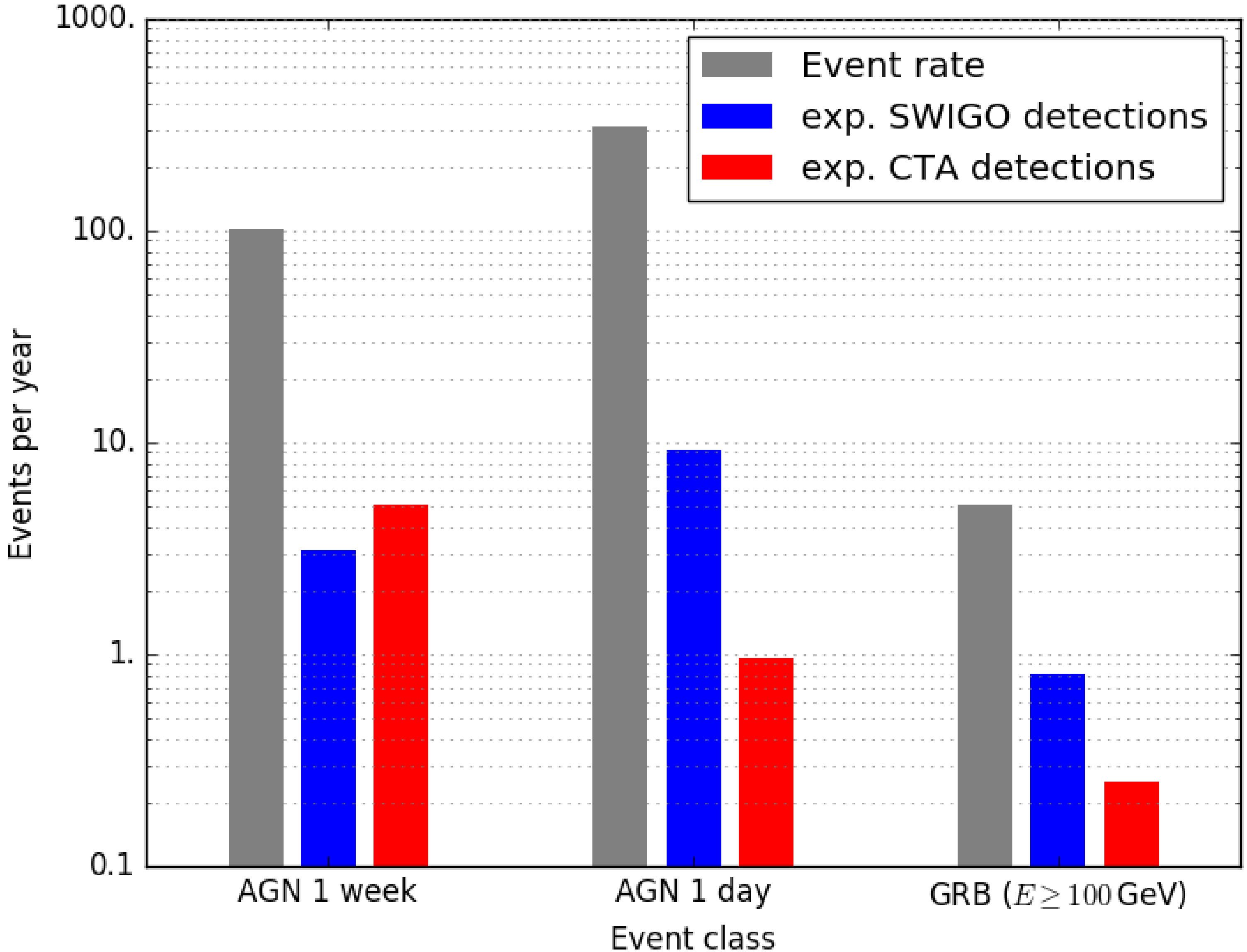
Complementarity with other facilities

All the source families listed so far have a critical focus on the properties of the sub-TeV spectrum, which is strongly connected with particle acceleration and high energy physical concepts. A strategy that considers this spectral domain will have a high impact.



The predicted detection rates

Based on Fermi All-sky Variability Analysis and GRB detection history (together with working assumptions on the instrument duty cycle), we can estimate how a wide FoV monitoring instrument would be able to operate in combination with CTA.



Cosmology with VHE gamma ray sources

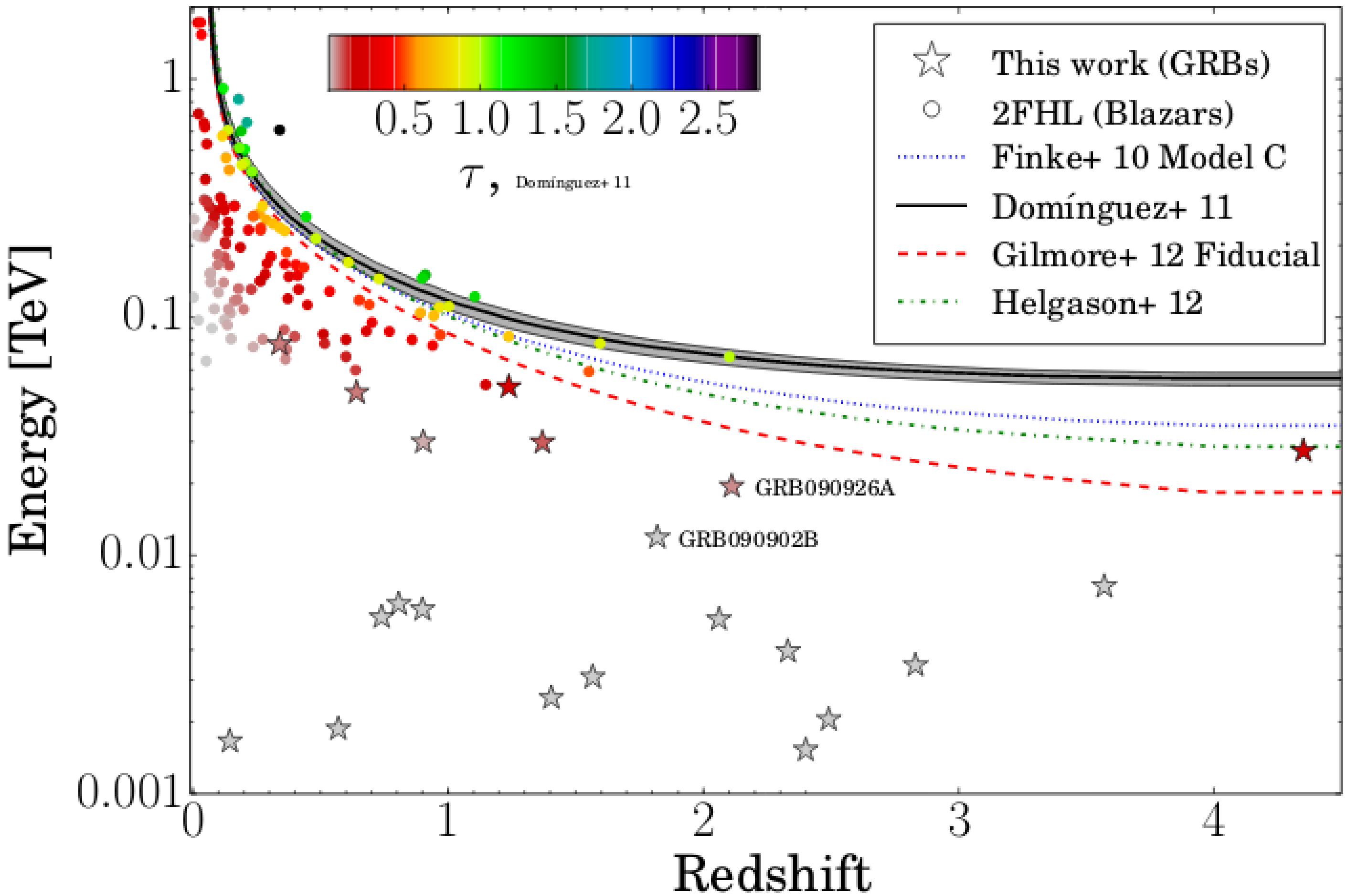
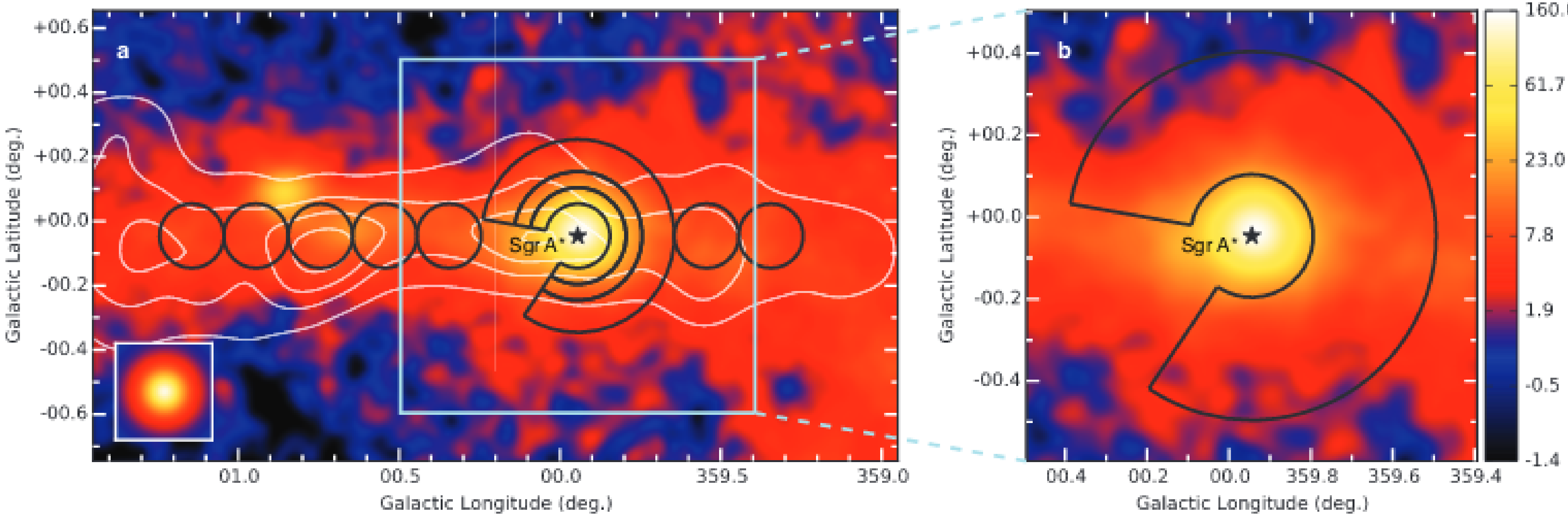


Figure from Desai et al. 2017, ApJ, 850, 73

Maximum Photon Energy vs. Redshift distribution for blazars and GRBs detected by Fermi-LAT. Optimizing the detection capabilities at energies $E > 100$ GeV will both address multi-wavelength / multi-messenger campaigns and constrain fundamental cosmological parameters.

Monitoring of Galactic Center



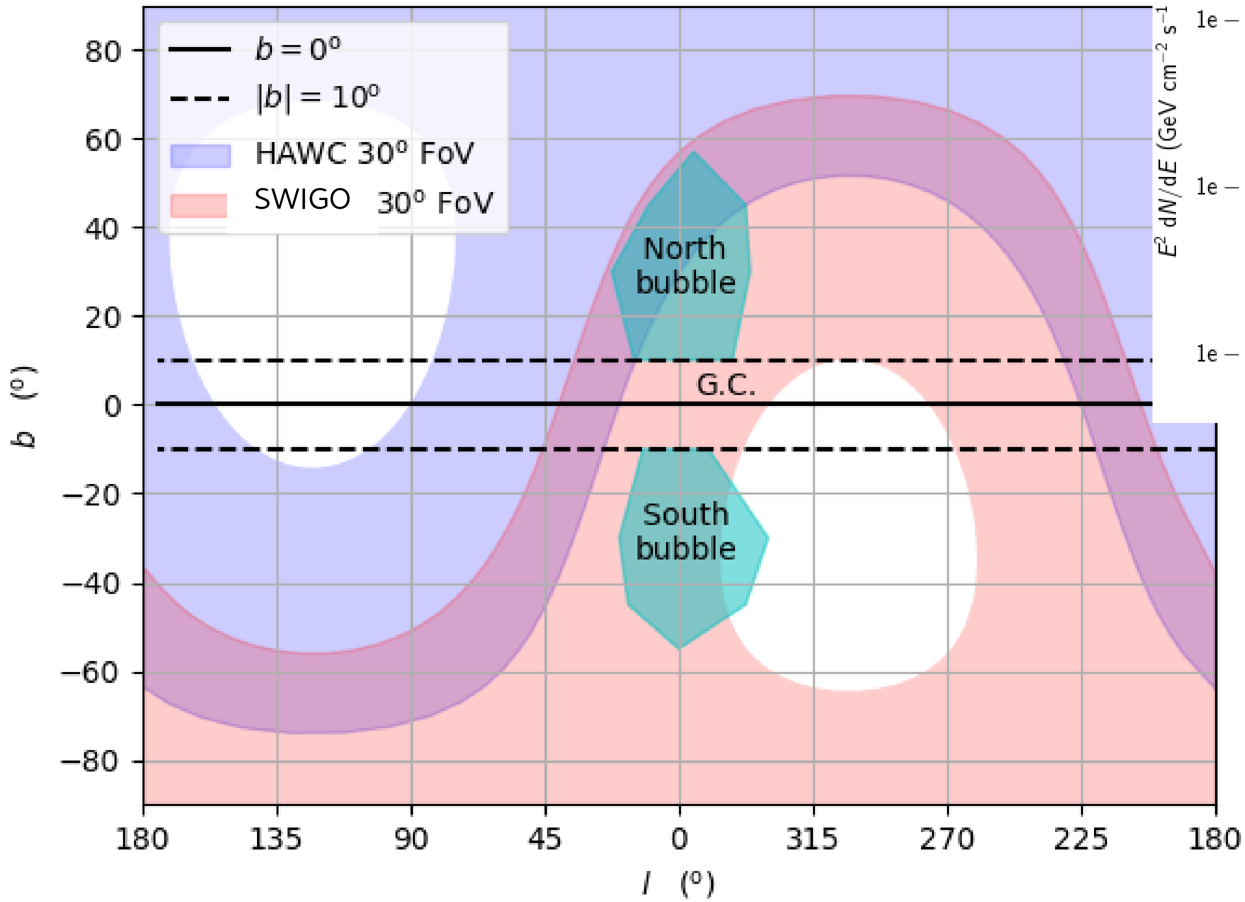
A view of the Galactic Centre in the TeV domain, produced by a scan performed with HESS (HESS Coll. 2016, Nature, 531, 476).

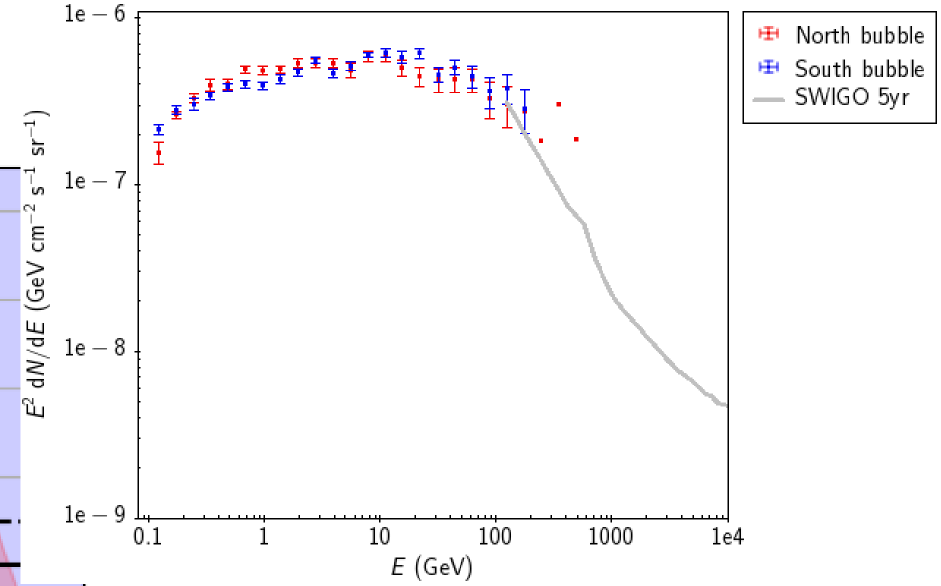
With a monitoring facility located in the Southern Hemisphere we shall moreover provide continuous coverage of the Galactic Center region, obtaining important indications on the nature of the diffuse gamma-ray emission, the existence of unresolved source populations and the activity of the central SMBH. These are high priority topics in the search of new physics and in the solution of long standing puzzles (such as the CR energy spectrum).

Monitoring of Galactic Center

HAWC sky coverage (within 30° from zenith)

compared to that of a facility located at 23° S





Spectra of the Northern and Southern Fermi Bubbles, compared with SWIGO estimated sensitivity to the visible area.

The field of view available to a EAS array located in the Southern Hemispere is obviously ideal to survey the Galactic plane and center.

Conclusions

- There is pressing need for multi-wavelength coverage of events currently at the frontier of Multi-Messenger Astrophysics
- Gamma-ray monitoring has already proved to be fundamental to address follow-up from other advanced facilities
- Covering the strategic gap in the spectral window between ground-based and satellite-driven observations will give the best prospects to work in combination with CTA
- The EAS approach is a suitable complementary way to answer the monitoring requirements of deep, high resolution observatories
- An extended spectral coverage is necessary to fully address the physics of particle acceleration and relativistic jets in AGN, some of the hottest topics of current Astrophysics

Acknowledgements

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

REPÚBLICA PORTUGUESA

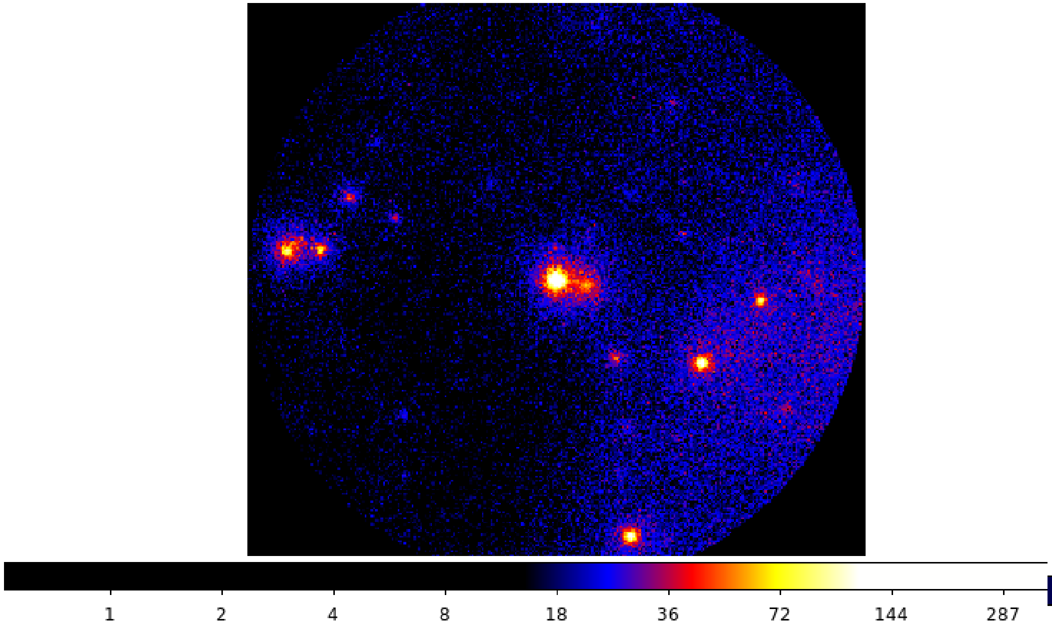
LIP

Gamma-ray Large Area Space Telescope
GLAST

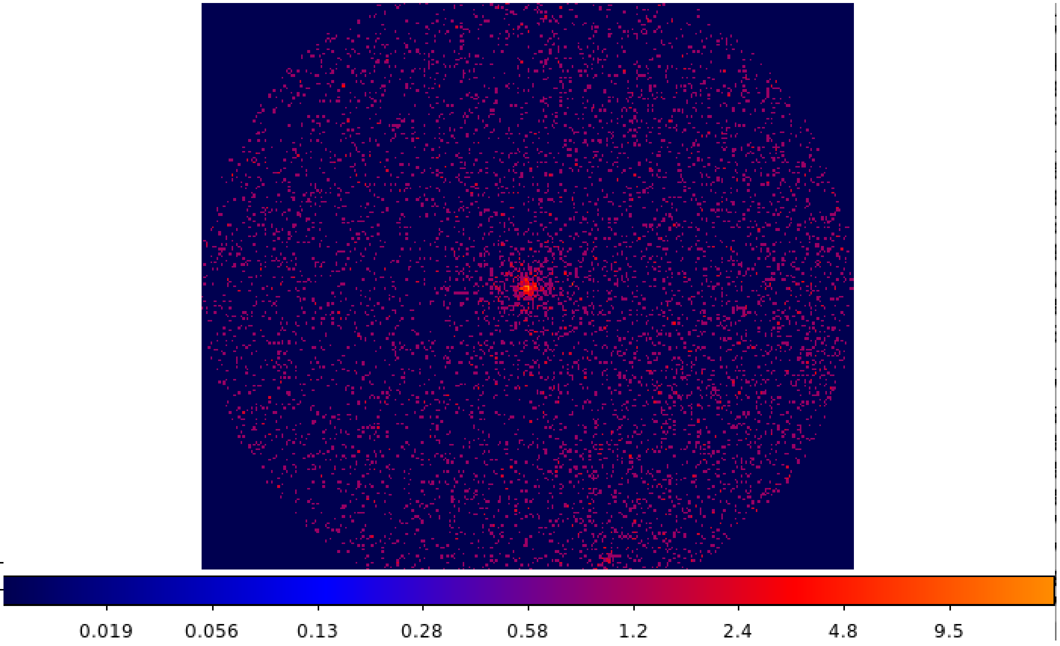
Backup slides

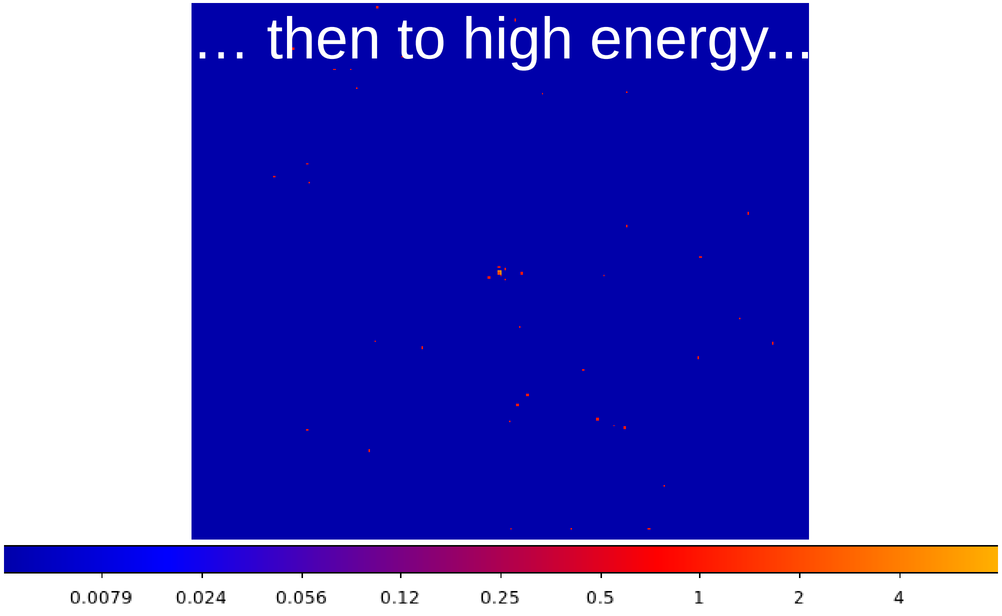
An example of what we currently have on flares

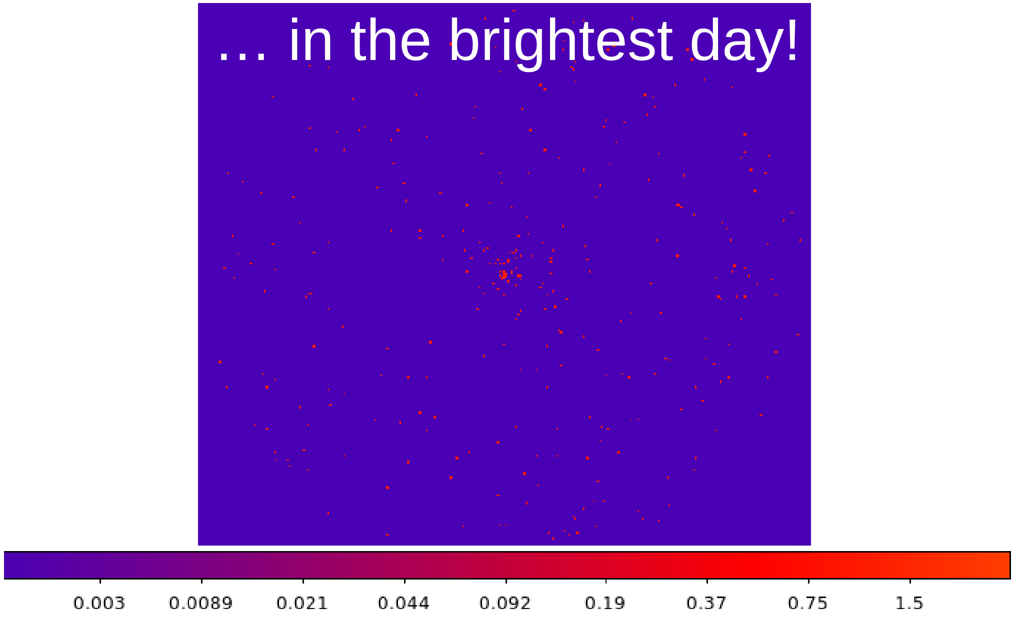
If we go from 10 years...



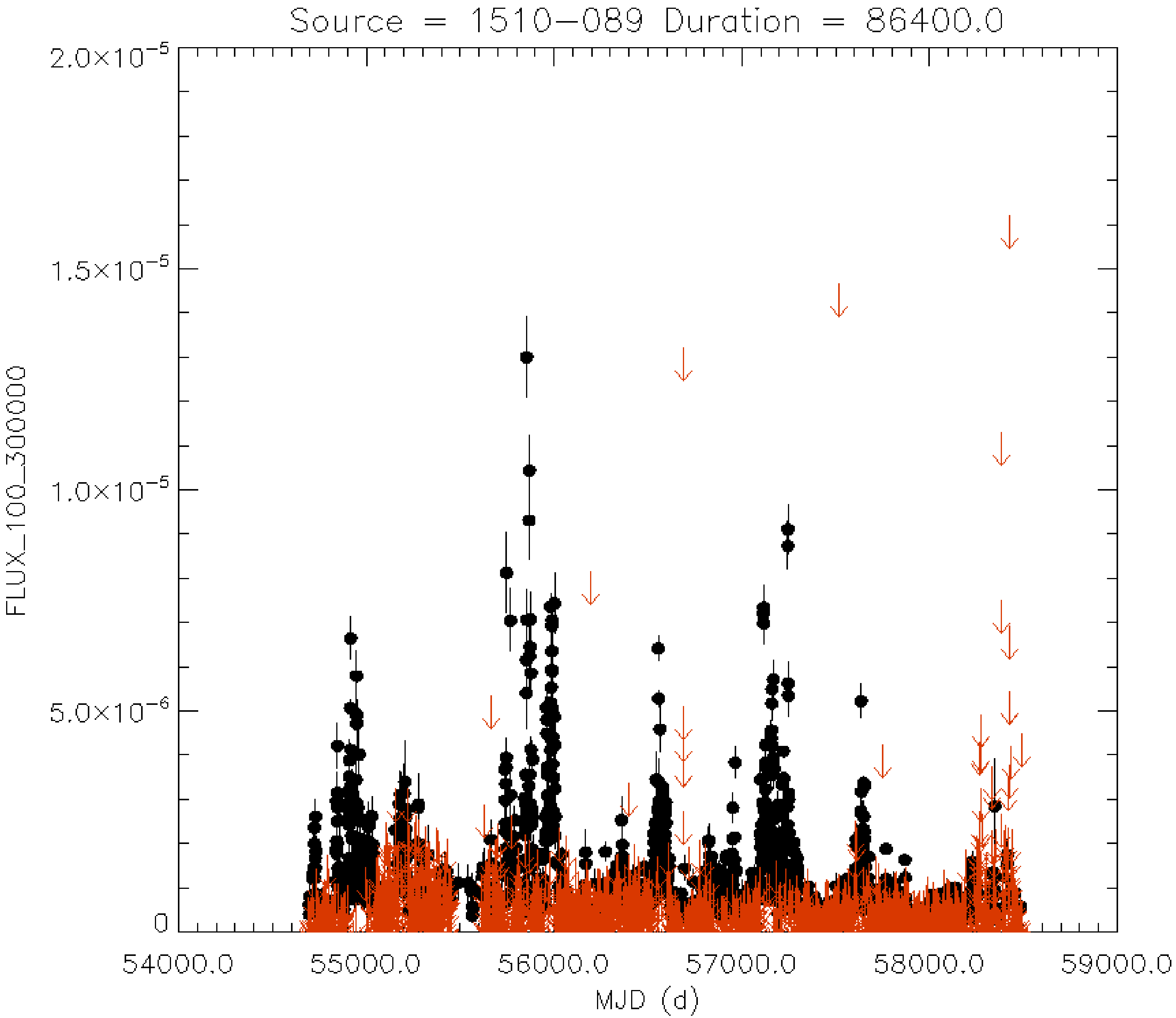
… to few weeks...



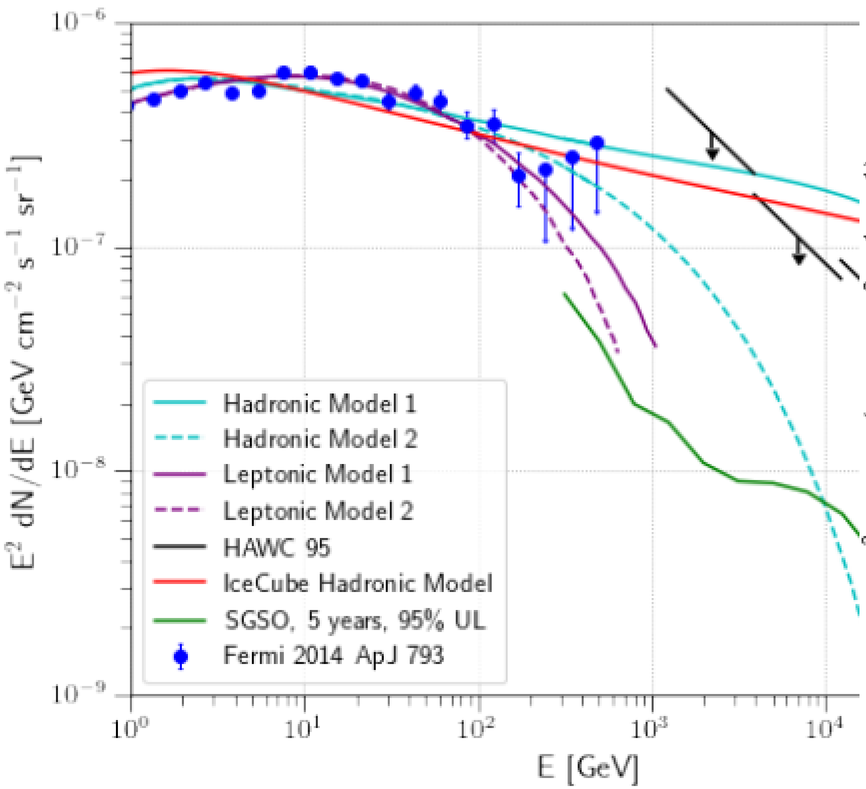




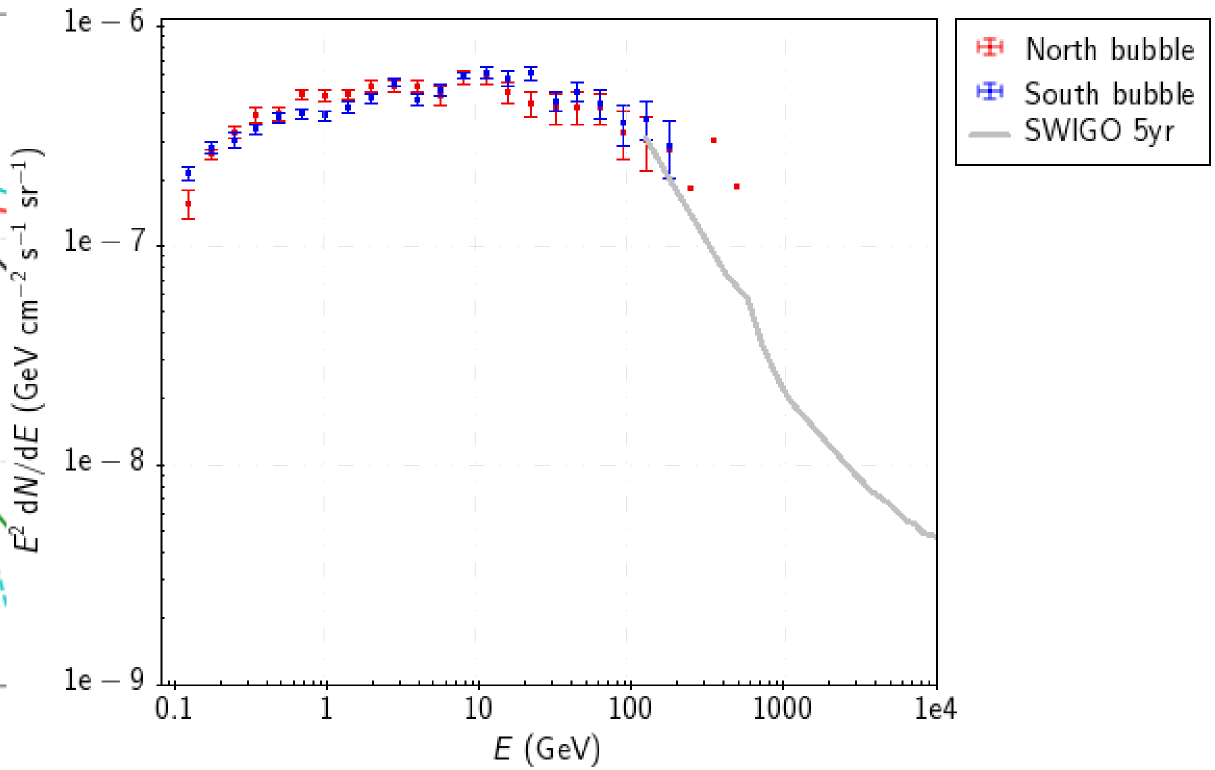
PKS 1510-089: a good example of blazar variability



SWIGO and the SGSO straw-man sensitivity

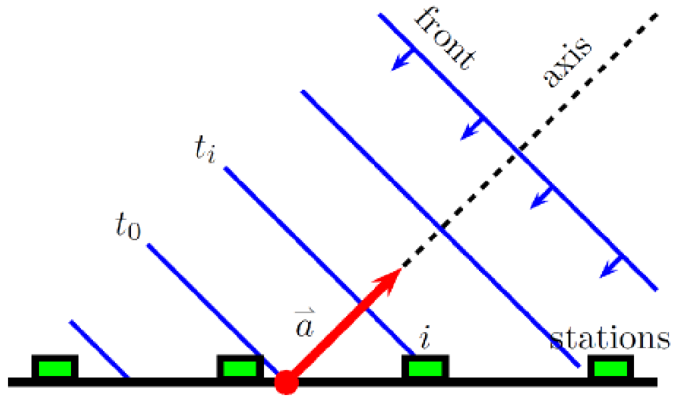


from Albert+ 19, arXiv:1902.08429v1

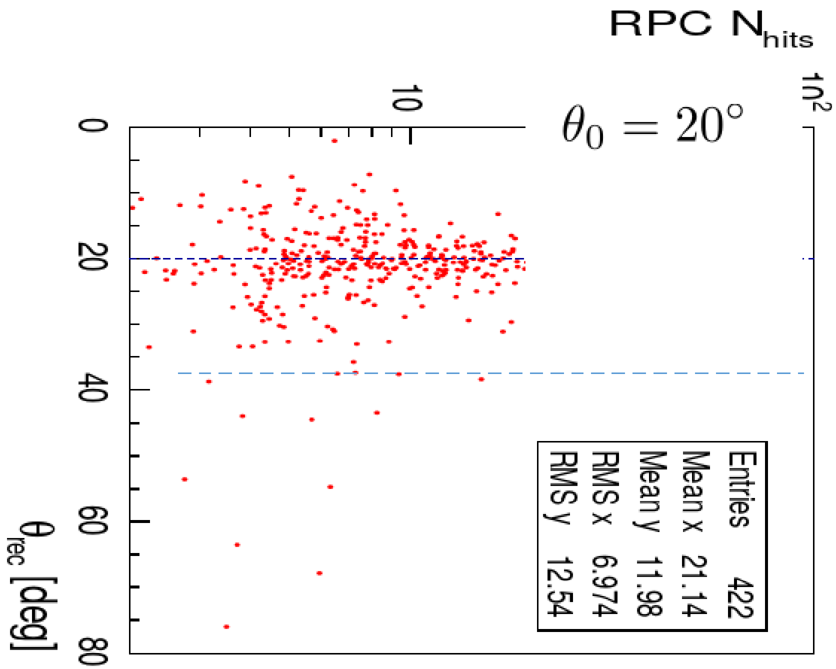


Reconstruction of shower geometry

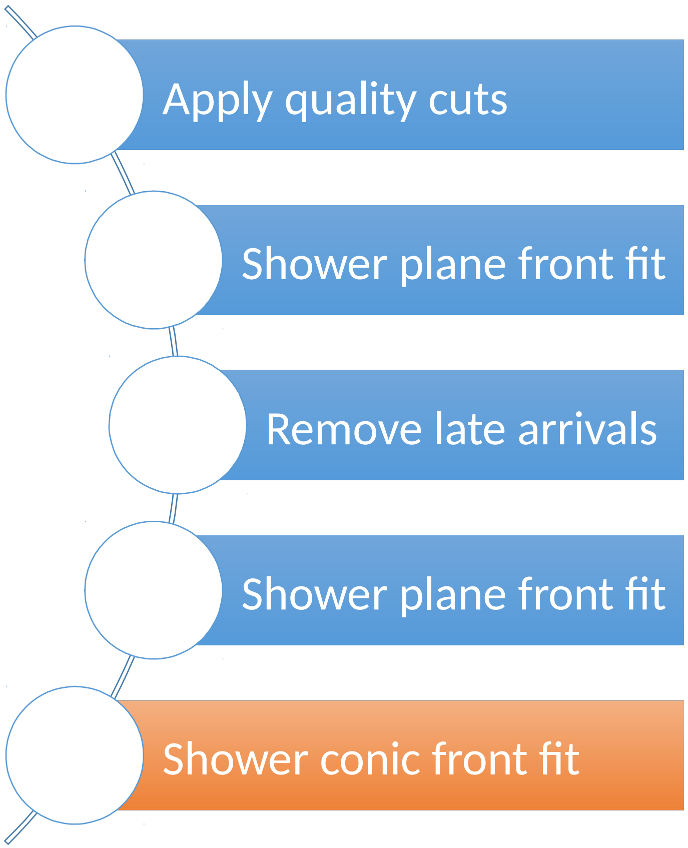
- ✧Use RPC hit time information to reconstruct the shower
  - ✧Take advantage of high spatial and time resolution



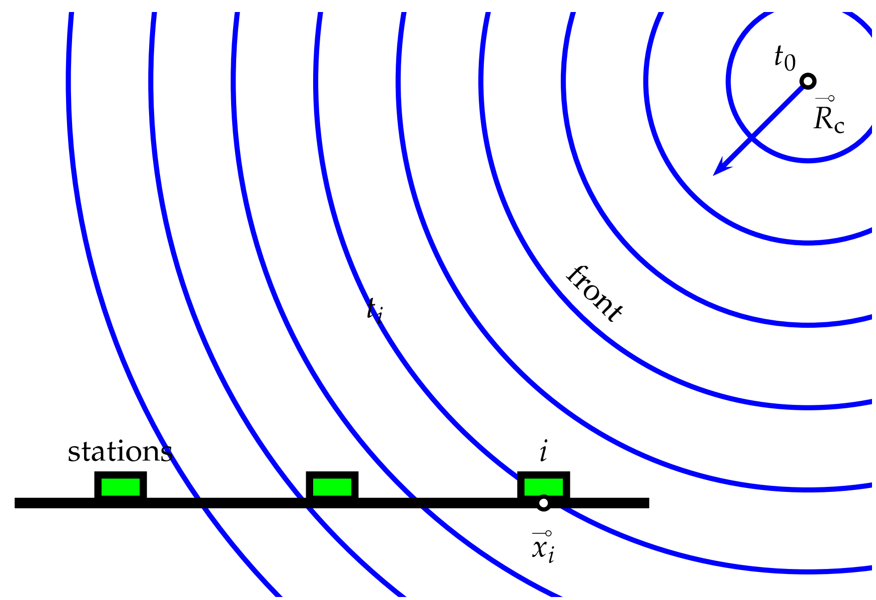
- ✧Shower geometry reconstruction:
  - ✧Use shower front plane approximation
  - ✧Analytical procedure
  - ✧Apply trigger conditions
  - ✧Apply cut on the number of registered hits by the RPCs



Reconstruction of shower geometry



- Use RPC hit time information
  - Fit the shower geometry using a shower conic front model
  - Depends on core position



Cosmic rays and station trigger rate