



ANTARES search for a stacking of point sources of neutrinos with 11 years of data



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ABSTRACT

A likelihood stacking method is used to assess the significance of a global excess of track-like neutrino events in correlation with the location of a list of astrophysical sources.

None of the tested catalog lead to a significant results, so upper limits on the flux per source are computed. However, a potential association between the blazar MG3 J225517+2409 detected in γ -ray by Fermi and 5 ANTARES events together with a high energy track detected by IceCube is reported. An a posteriori significance of $\leq 2.6\sigma$ is evaluated for the combination of ANTARES and IceCube data, when including time information.

METHOD

Extended maximum likelihood method:

$$\ln \mathcal{L}(H_1 || x) = \sum_i^N \ln [\mu_s S(x_i) + \mu_b B(x_i)] - \mu_s - \mu_b$$

with (μ_s, μ_b) fitted nb of signal/background events. Signal PDF for N_s sources is written as:

$$S(x_i) = \frac{1}{\sum_j w_j} \sum_{j=1}^{N_s} w_j s_j(x_i) \quad (1)$$

where $s_j(x_i)$ is the Point Spread Function, depending on energy E_i and angular accuracy β_i of each event. The weight of the j^{th} source is defined as

$$w_j = w_j^{\text{model}} \times \mathcal{A}(\delta_j)$$

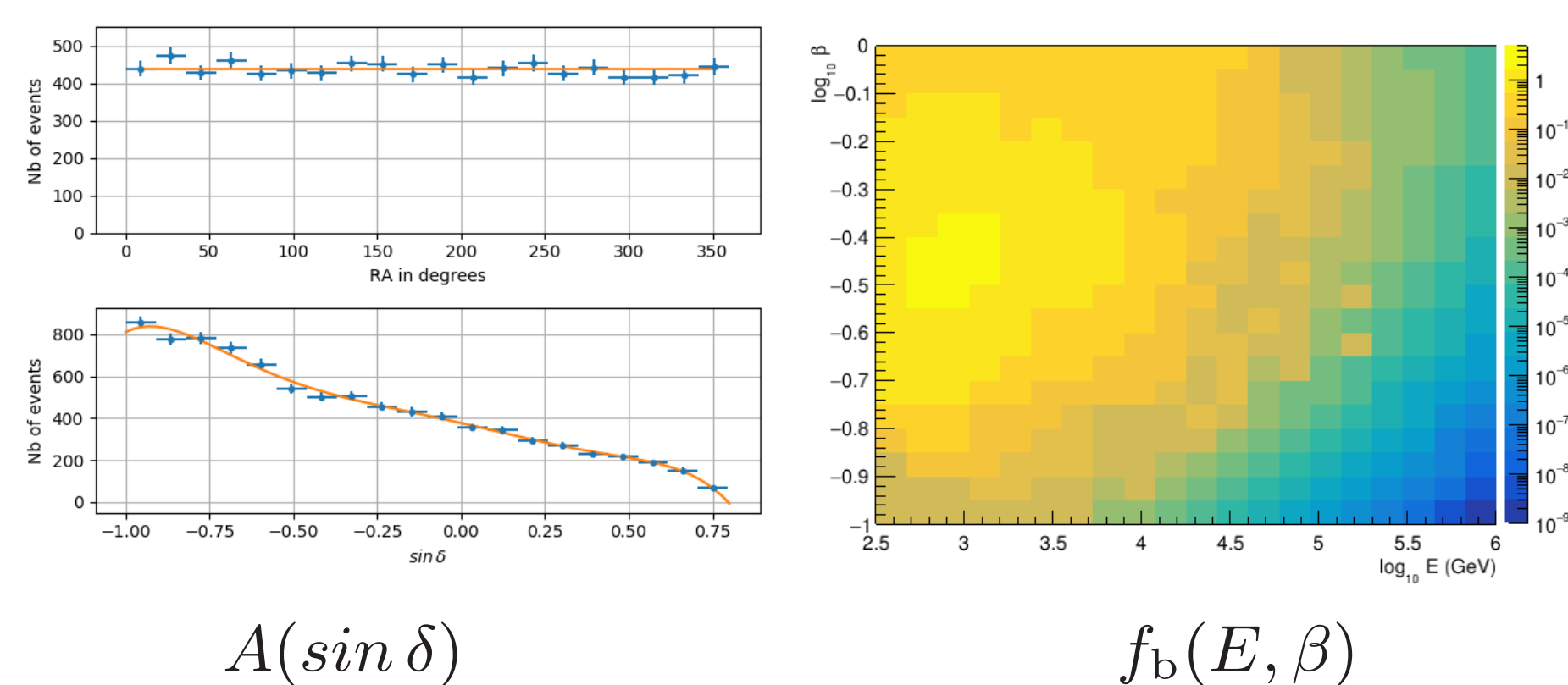
where \mathcal{A} is the acceptance, and with 2 assumptions:

- flux weighting: $w_j^{\text{model}} = \Phi_j^0(\gamma, X)$
- equal weight: $w_j^{\text{model}} = 1$

Background PDF independent of the RA, and writes:

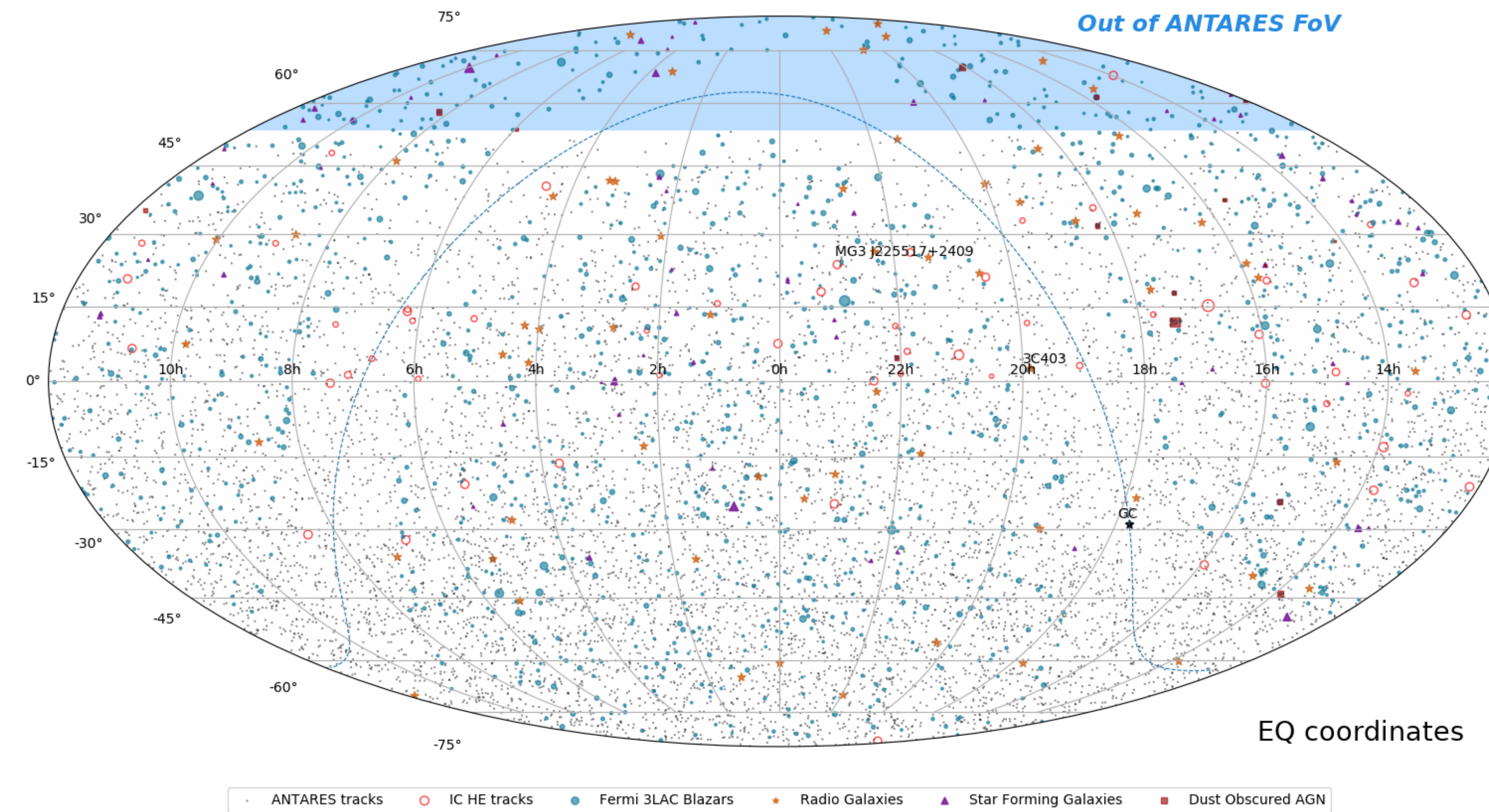
$$B(x_i) = A(\sin \delta_i) \times f_b(E_i, \beta_i) \quad (2)$$

where the distributions are built from real data:



TARGET SOURCES

- Fermi 3LAC blazar catalog (1420 objects) [1]
- Radio-galaxies catalog (65 objects) [3],
- IceCube HE tracks (56 events) [5], [6]
- Star Forming galaxies (64 objects) [2]
- Dust-obscured AGN (15 objects) [4]



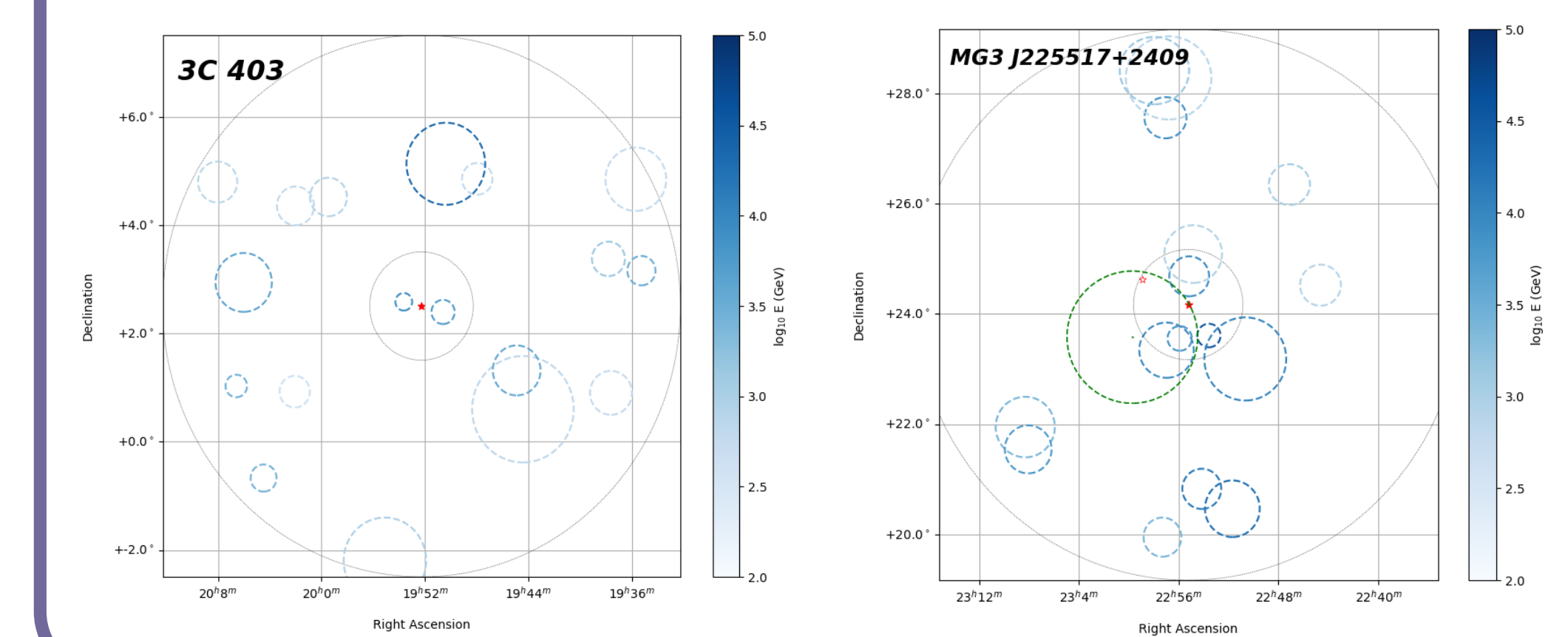
DATA SET

- Point Source (PS) sample 2007-2018
- Optimized for PS with E^{-2} spectrum
- 8754 track-like selected events
- Estimated ν energy $\in [\sim 100 \text{ GeV} - 1 \text{ PeV}]$
- Median angular resolution $< 0.4^\circ$ above 10 TeV.

SEARCH FOR DOMINANT SOURCES

Search for low individual p-values for Fermi 3LAC & Radio-galaxies catalogs:

- Radio-galaxy 3C403: $p = 2.8\sigma$ ($P = 1.6\sigma$)
- Blazar J225517+2409: $p = 3.8\sigma$ ($P = 1.4\sigma$)



RESULTS

The results of the likelihood stacking analysis are summarized in the following table.

Catalog	Equal weighting				Flux weighting			
	TS	p	P	$\Phi_{90\%}^{\text{UL}}$	TS	p	P	$\Phi_{90\%}^{\text{UL}}$
Fermi 3LAC All Blazars	6.15	0.19	0.83	4.1	0.21	0.85	1.	2.0
Fermi 3LAC FSRQ	0.83	0.57	0.97	2.1	~ 0	~ 1	1.	1.7
Fermi 3LAC BL Lacs	8.3	0.088	0.64	4.6	0.84	0.56	0.96	1.9
Radio-galaxies	3.4	$4.8 \cdot 10^{-3}$	0.10	3.3	5.1	$6.9 \cdot 10^{-3}$	0.13	3.7
Star Forming Galaxies	0.030	0.37	0.93	1.9	~ 0	~ 1	1.	1.6
Obscured AGN	$1.0 \cdot 10^{-3}$	0.73	0.98	1.4	~ 0	~ 1	1.	1.3
IC HE Tracks	0.77	0.05	0.49	0.96	-	-	-	-

90% C.L flux UL in diffuse E^{-2} flux for the (in units of $10^{-9} \text{ GeV}^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$).
For the IceCube HE tracks: UL in flux/source ($10^{-9} \text{ GeV}^{-1} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$).

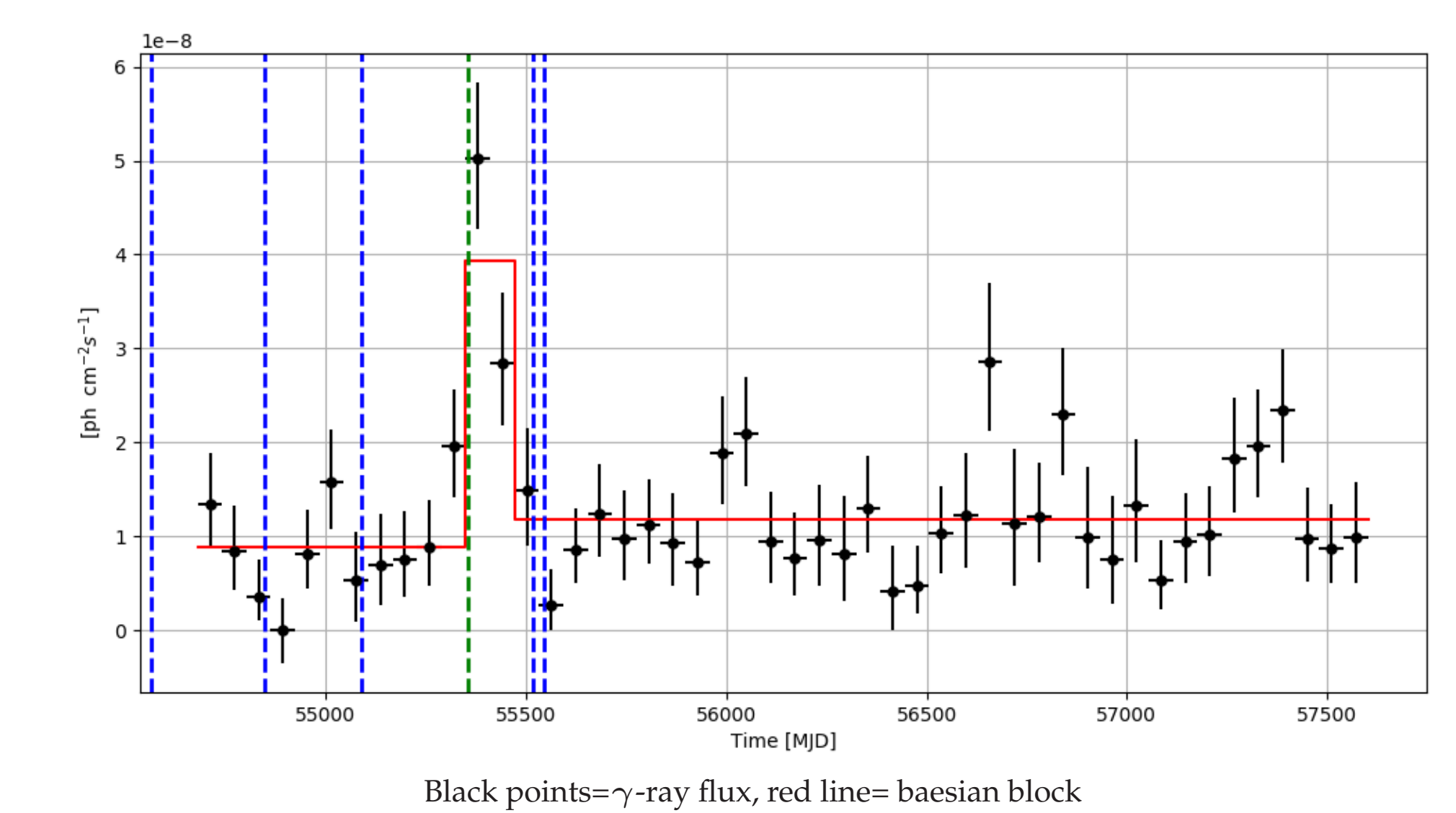
- Most significant association: Radio-galaxies with equal weight, post-trial $P = 0.1$.

REFERENCES

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BLAZAR MG3 J225517+2409

A posteriori time-dependent analysis using the γ -ray light curve from Fermi 4FGL [8]:



- Flaring activity (flux $\times 5$ during ~ 4 months)
- 5 ANTARES events (blue lines) at $< 1^\circ$ of the source ($P = 1.4\sigma$), but not during the flare.
Simple time clustering analysis around flare:
 $\tau = \frac{1}{N} \sum_{i=1}^{N=5} |t_i - t_F|$ gives $p = 2.3\sigma$
- Space & time p-value combination for ANTARES:
 $p_{\text{comb}} = p_{\text{space}} \times p_{\text{time}} \times (1 - \ln p_{\text{space}} \times p_{\text{time}}) = 2.3\sigma$
- 1 IceCube HE track at 1.1° , detected during flare (green line). Space-time likelihood: $p \sim 1.9\sigma$
- Combination ANTARES-IC gives a p-value:
 $p_{\text{Combined}} = p_{\text{ANT}} \times p_{\text{IC}} \times (1 - \ln p_{\text{ANT}} \times p_{\text{IC}}) = 2.6\sigma$.