Université de Paris
Laboratoire Astroparticules et Cosmologie, Paris

Point source stacking with 11 years of ANTARES data

Julien Aublin for the ANTARES collaboration.

ICRC 2019, Madison. July 26, 2019

ANTARES talks @ ICRC 2019

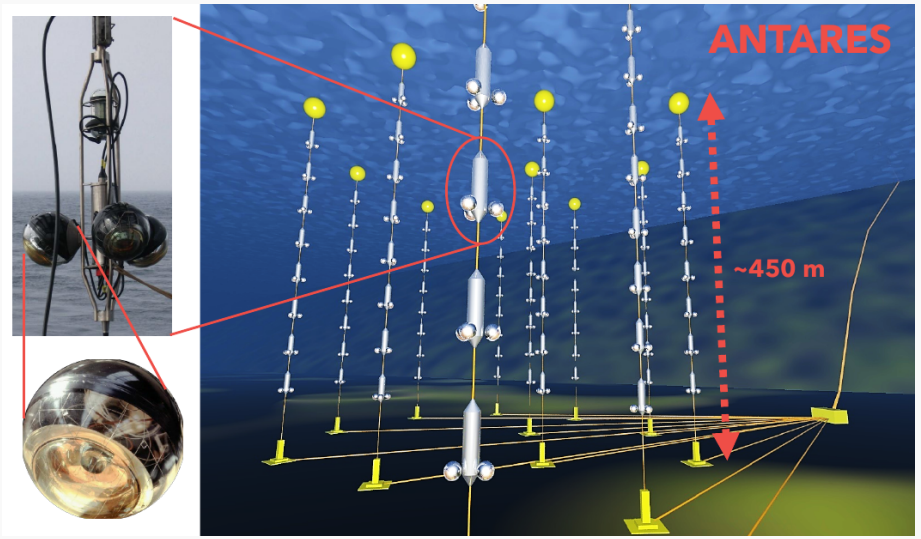
- High energy diffuse flux:
  Luigi Fusco, Friday, 18:00
- Combined ANTARES-IceCube point sources searches
  Giulia Illuminati, Saturday, 13:45
- Correlations of HE ν and Ultra-high Energy Cosmic Rays
  Anastasia Maria Barbano (IceCube), Saturday, 17:00
- Neutrinos in coincidence with HAWC γ-ray flares
  Mukharbek Organokov, Saturday, 18:15
- Multi-wavelength follow-up observations of ANTARES ν alerts
  Damien Dornic, Tuesday, 17:30
- Neutrino counterparts of GW events with ANTARES
  Marta Colomer, Tuesday, 18:15

The ANTARES detector

The ANTARES detector:

- Water Cherenkov detector operating since 2007
- Located 40 km offshore Toulon, France
- 2475 m depth in the Mediterranean sea

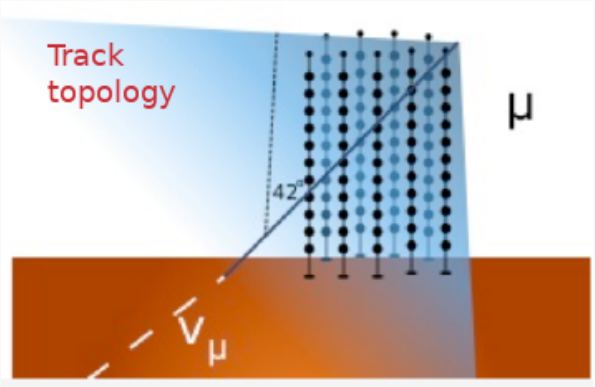
- Array of 885 PMT
- 12 detection lines, each with 25 storeys
- 3 PMT (10“) per storey, facing 45° downwards

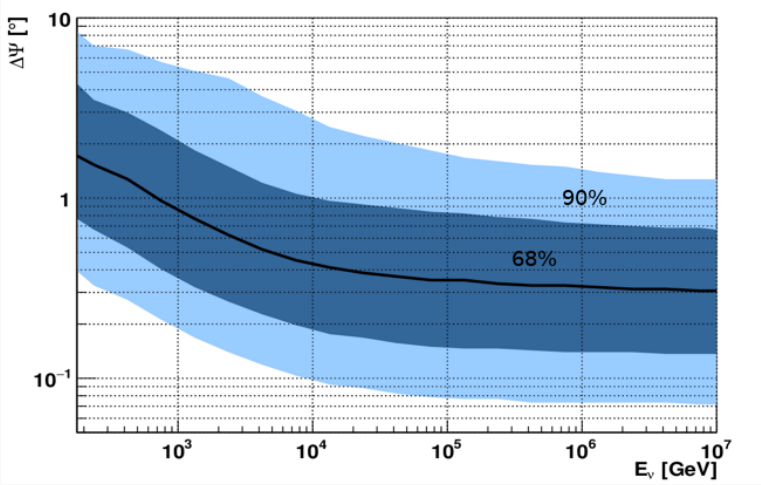


Data set

The ANTARES 11 yr Point Source Sample:

- Period: Jan 29, 2007 to Dec 31, 2017
- Total livetime: 3125 days
- 8754 events reconstructed and selected as tracks
- Visible sky: $\delta \in [-90°; +53°]$
- Median angular resolution: better than 0.4° above 10 TeV





Point source search: stacking analysis

Extended maximum likelihood method:

- H0: pure atmospheric neutrino background
- H1: signal+background

$$\mathrm{TS} = \ln\left(\frac{\max(\mathcal{L}(\mathrm{H}_1|\mathrm{x}))}{\max(\mathcal{L}(\mathrm{H}_0|\mathrm{x}))}\right)$$

with

$$\ln\mathcal{L}(\mathrm{H}_1|\mathrm{x}) = \sum_{\mathrm{i}}^{\mathrm{N}} \ln\left[\mu_{\mathrm{s}}\mathrm{S}(\mathrm{x}_{\mathrm{i}}) + \mu_{\mathrm{b}}\mathrm{B}(\mathrm{x}_{\mathrm{i}})\right] - \mu_{\mathrm{s}} - \mu_{\mathrm{b}}$$

$$\ln\mathcal{L}(\mathrm{H}_0|\mathrm{x}) = \sum_{\mathrm{i}}^{\mathrm{N}} \ln\left[\mu_{\mathrm{b}}\mathrm{B}(\mathrm{x}_{\mathrm{i}})\right] - \mu_{\mathrm{b}}$$

Two different implementations:

- 1) Global fitting (one TS), signal term written as:

$$S(x) = \frac{1}{\sum w} \sum_{j=1}^{N^{sources}} w_j \, s_j(x)$$

- 2) Perform individual fit for each source, sum the TS:

$$TS = \frac{1}{\sum w} \sum_{j=1}^{N^{sources}} w_j TS_j$$

Signal PDF

Point Spread Function:

$$S(x_i) = PSF(\alpha, E, \beta)$$

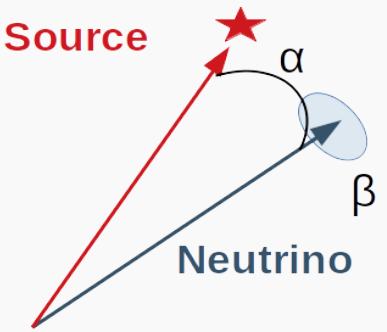
α: angle between ν direction and source position

E: neutrino estimated energy

β: angular uncertainty

Background PDF

$$B(x) = A(\sin\delta) \times f_b(E, \beta)$$



Weights of each source written as:

$$w_j = w_{model} \times \mathcal{A}(\delta_j) \qquad \text{with} \quad \mathcal{A} \rightarrow \text{acceptance}$$

Two different assumptions for w_{model}:

- Flux weight:

$$w_{model} \propto \Phi_{\gamma,X,IR,...}$$

- Equal weight:

$$w_{model} = 1$$

Target sources

Astrophysical catalogs

- Fermi 3LAC Blazars (1255 sources in FoV)

  [Ackermann et al. ApJ 2015]
- Star Forming Galaxy catalog observed in γ by Fermi (54 in FoV)

  [Ackermann et al. ApJ 2012]
- Giant radiogalaxies catalog selected in soft γ ray (53 in FoV)

  [Bassani et al. MNRAS 2016]
- Dust obscured AGN selected in X rays (10 in FoV)

  [Maggi et al. PhysRevD 2016]

HE Neutrino sample

- IceCube high energy tracks (55 sources in FoV)

  (35 tracks from 8 yr up-going muons + 21 HESE 6 yr)

  [IceCube collaboration, ICRC 2017]

Results

Results of the stacking analysis:

- No significant findings after trial factor correction
- Radiogalaxy catalog: p $= 2.8\sigma$ pre-trial
- Reduces to P $= 1.6\sigma$ post-trial

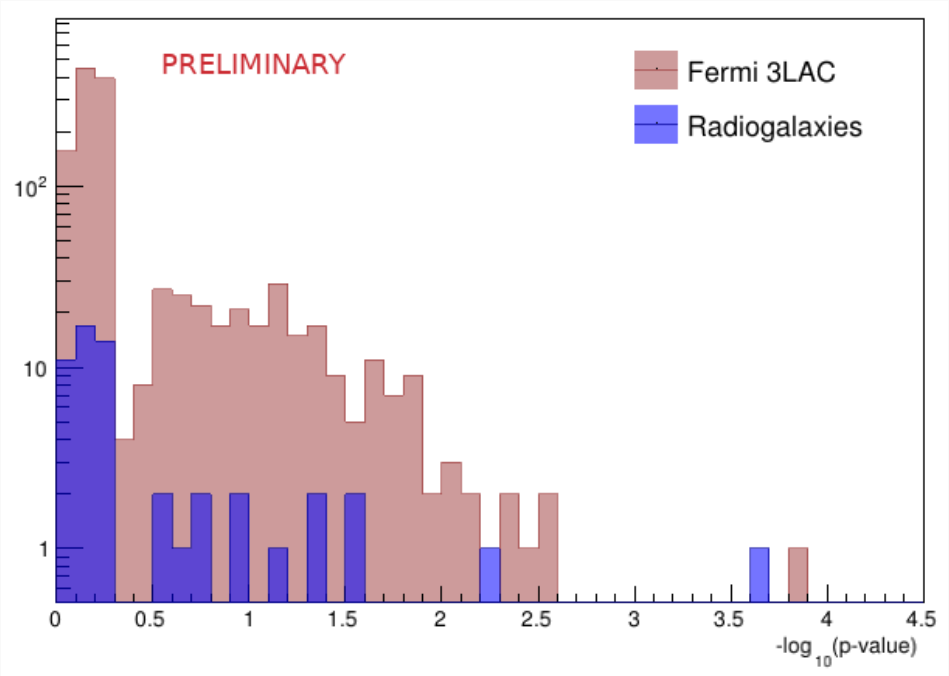
	Equal weighting				Flux weighting			
Catalog	TS	p	P	$\Phi^{UL}_{90\%}$	TS	p	P	$\Phi^{UL}_{90\%}$
Fermi 3LAC All Blazars	6.15	0.19	0.83	4.1	0.21	0.85	1.	2.0
Fermi 3LAC FSRQ	0.83	0.57	0.97	2.1	~ 0	~ 1	1.	1.7
Fermi 3LAC BL Lacs	8.3	0.088	0.64	4.6	0.84	0.56	0.96	1.9
Radio-galaxies	3.4	$4.8\ 10^{-3}$	0.10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

90% U.L given in equivalent E^{-2} diffuse flux, (10^{-9} GeV$^{-1}\cdot$cm$^{-2}\cdot$s$^{-1}\cdot$sr^{-1}).

Search for dominant sources

Individual point source search

- Compute p-values for each source of the
  - Fermi 3LAC catalog
  - Radiogalaxy catalog
- Search for outliers



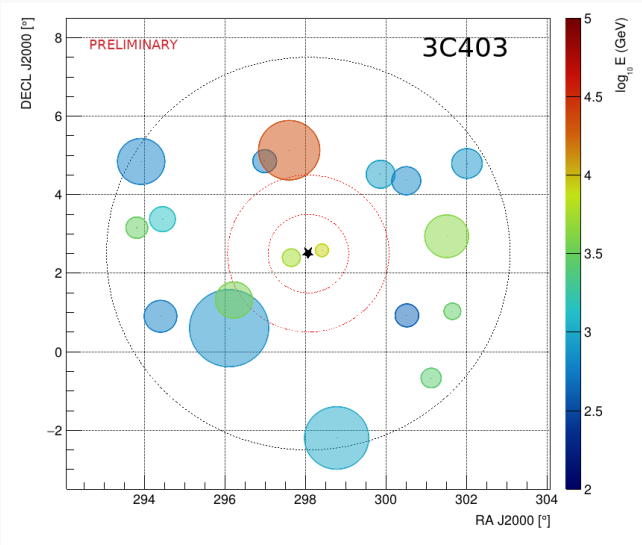
Sources with the lowest p-value

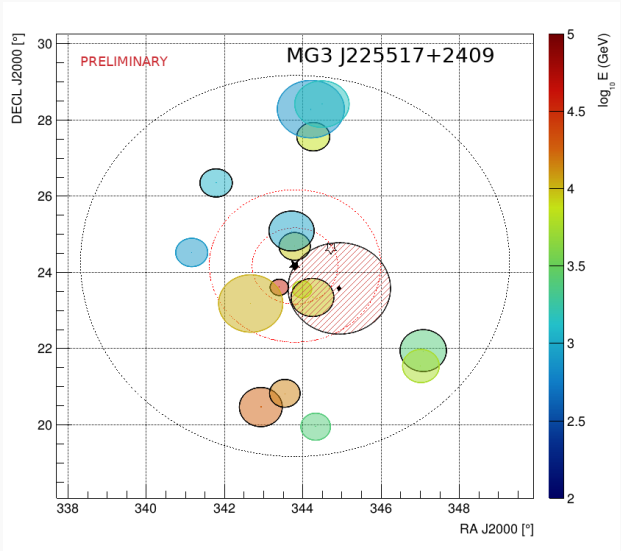
Radiogalaxy 3C403

- Seyfert II type, d=260 Mpc, RA=298.06°, $\delta = +2.5067°$
- p-value $p = 2.3 \times 10^{-4}$ (3.7σ)

Blazar MG3 J225517+2409

- LSP BLLac type, d=?, RA=343.81°, $\delta = +24.17°$
- p-value $p = 1.4 \times 10^{-4}$ (3.8σ)





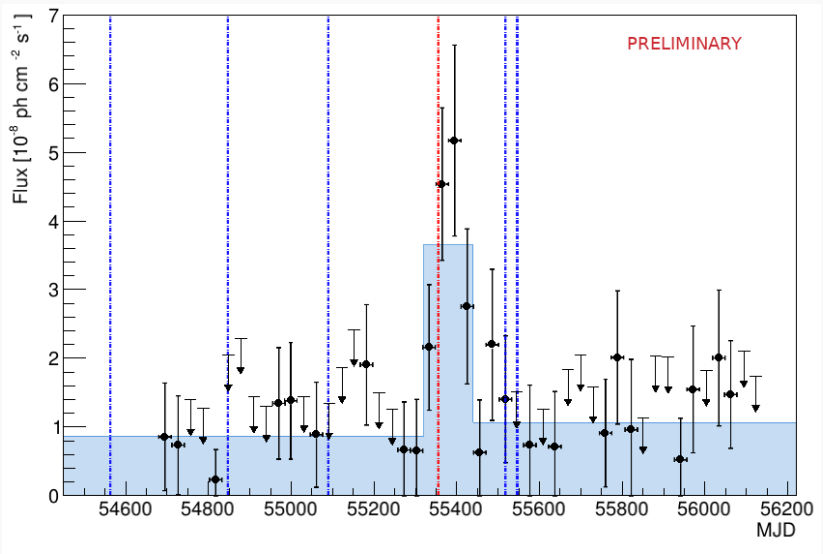
Dedicated time analysis for MG3 J225517+2409

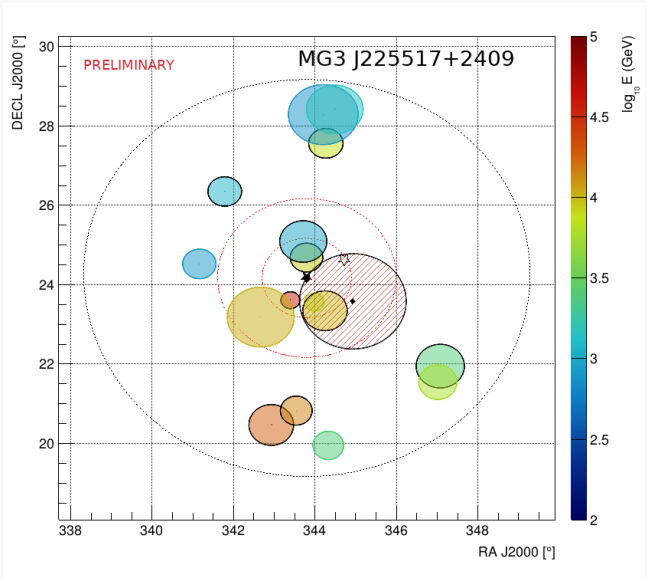
Time dependent likelihood analysis

- Fermi 3FGL γ-ray light curve presents a ~ 4 months flare
- Icecube up-going track # 3 occurs during the flare (July 2010)
- Time-dependent likelihood:

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

- Combine results of ANTARES & IC: $p_{\text{Combined}} = p_{\text{ANTARES}} \times p_{\text{IC}}$

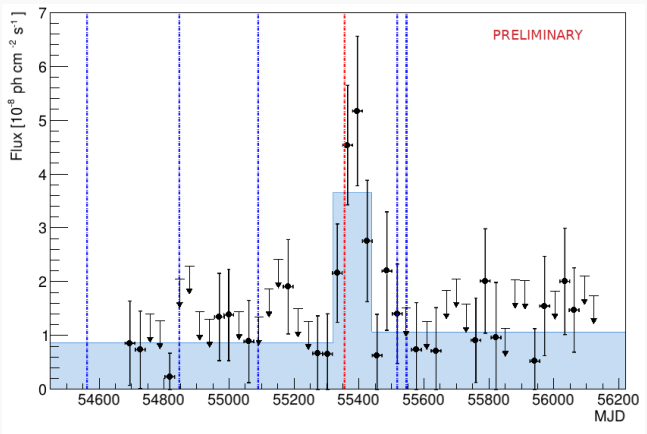


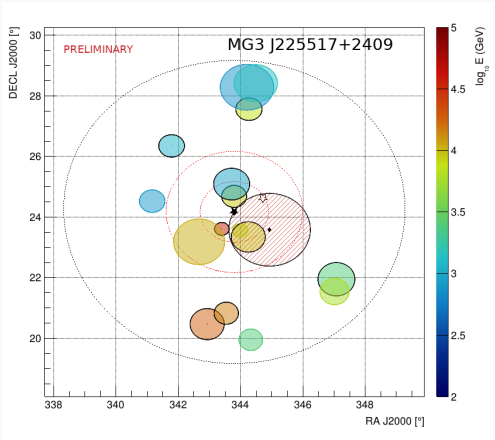


Dedicated time analysis for MG3 J225517+2409

Time dependent likelihood analysis

- Time-dependent PDF $f_S(t)$:
  - 1) use the 3FGL light curve (bayesian block)
  - 2) PDF = 0 except during the flare
- Results for hypothesis 1):
  - $p_{ANTARES} = 1.4 \times 10^{-4}$, $p_{IC} = 1.6 \times 10^{-3}$, $p_{Combined} \sim 2 \times 10^{-7}$
- Results for hypothesis 2):
  - $p_{ANTARES} \sim 1$, $p_{IC} = 5. \times 10^{-4}$, $p_{Combined} \sim 5. \times 10^{-4}$





Summary & Conclusion

- Stacking likelihood analysis using ANTARES 11 yr Point Source sample has been presented
- Search for global excess from sources in catalogs
- After trial factors correction, no significant results are found
- Interesting potential neutrino sources:
  - Radiogalaxy 3C403
  - Fermi Blazar MG3 J225517+2409
- Dedicated time analysis for Blazar MG3 J225517+2409
  - Continuous neutrino emission hypothesis: $p_{\text{Combined}} \sim 2 \times 10^{-7}$
  - Transient neutrino emission hypothesis: $p_{\text{Combined}} \sim 5 \times 10^{-4}$