Results of a search for Gamma-Ray Counterparts of IceCube Neutrino Events in the AGILE Public Archive

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Abstract

The search for gamma-ray counterparts of IceCube neutrino candidates is relevant for understanding the role of blazars as possible sources of cosmic neutrinos. We searched for the counterparts of the IceCube neutrinos events observed in the period 2018-2020 in the AGILE gamma-ray satellite public archive. We present the AGILE candidate gamma-ray counterparts found within the IceCube 90% location regions centered on the best-fit neutrino candidate position. We show a selection of light curves and spectral energy distributions and we provide estimates of the gamma-ray flux above 100 MeV for the AGILE candidate detections. The possible associations with blazars are discussed.

Electromagnetic Counterparts of IceCube Neutrinos

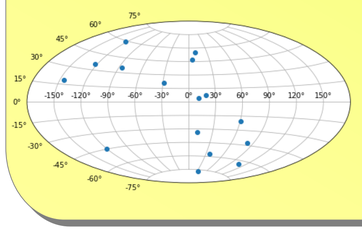
- In 2017 for the first time a gamma-ray flaring blazar, TXS 0506+056, was identified as the EM counterpart to the IceCube neutrino event IC-170922 (Aartsen+ 2018).
- Blazars are likely candidate high-energy neutrino sources, but not all blazar classes may contribute at the same level (Padovani+2016, Giommi & Padovani 2021, Hovatta+2021).
- Cosmic neutrino events are not necessarily associated to gamma-ray flares.

We performed a search for blazar candidates and AGILE gamma-ray counterparts within the 90% uncertainty location region of IceCube neutrino events using the public data archive of AGILE and SSDC multi-frequency data.

Previous studies: Lucarelli+ 2019, Giommi+ 2020, Franckowiak+ 2020, Kun+ 2021, Sahakyan+ 2022, Gasparri+ 2024

IceCube neutrino sample: 16 events, 2018-2020

IceCube Name	T_0 (MJD)	Event Type	RA (deg)	DEC (deg)	Energy ($\times 10^2$ TeV)	Signalness	l (deg)	b (deg)
IC-180908A	58369	EHE	$144.58^{+1.55}_{-1.45}$	$-2.13^{+0.9}_{-1.2}$	1.1998	0.34364	237.2	35.1
IC-181023A	58414	EHE	$270.18^{+2.00}_{-1.70}$	$-8.57^{+1.25}_{-1.30}$	1.1998	0.28016	19.4	7.2
IC-190503A	58606	EHE	$120.28^{+0.57}_{-0.77}$	$6.35^{+0.76}_{-0.70}$	1.0000	0.36266	215.2	18.4
IC-181014A	58405	HESE	$225.15^{+1.40}_{-2.85}$	$-34.80^{+1.15}_{-1.85}$	-	0.10	331.0	20.9
IC-190104A	58487	HESE	$357.98^{+2.3}_{-2.1}$	$-26.65^{+2.2}_{-2.5}$	-	0.35	31.6	-76.7
IC-190124A	58504	HESE	$307.40^{+0.8}_{-0.9}$	$-32.18^{+0.7}_{-0.7}$	-	0.91	10.8	-33.8
IC-190221A	58535	HESE	$268.81^{+1.2}_{-1.8}$	$-17.04^{+1.3}_{-0.5}$	-	0.37	11.4	4.2
IC-190331A	58573	HESE	$337.68^{+0.23}_{-0.34}$	$-20.70^{+0.30}_{-0.48}$	-	0.57	36.6	-57.3
IC-190504A	58607	HESE	65.79	-37.44	-	0.63	239.9	-44.7
IC-190619A	58653	GOLD	$343.26^{+4.08}_{-2.63}$	$10.73^{+1.51}_{-2.61}$	1.9870	0.54551	81.8	-42.5
IC-190730A	58694	GOLD	$225.79^{+1.28}_{-1.43}$	$10.47^{+1.14}_{-0.89}$	2.9881	0.67158	11.1	54.8
IC-190922A	58748	GOLD	$167.43^{+3.40}_{-2.63}$	$-22.39^{+2.88}_{-2.89}$	31.139	0.20165	274.1	34.7
IC-190922B	58748	GOLD	$5.76^{+1.19}_{-1.37}$	$-1.57^{+0.93}_{-0.82}$	1.8737	0.50501	106.8	-63.6
IC-191001A	58757	GOLD	$314.08^{+6.56}_{-2.26}$	$12.94^{+1.50}_{-1.47}$	2.1742	0.58898	60.2	20.3
IC-191119A	58806	GOLD	$230.10^{+4.76}_{-6.48}$	$3.17^{+3.36}_{-2.09}$	1.7648	0.44999	5.5	47.1
IC-200109A	58857	GOLD	$164.49^{+4.94}_{-4.19}$	$11.87^{+1.16}_{-1.36}$	3.7523	0.76931	237.2	59.3



$$Signalness(E,\delta) = \frac{N_{signal}(E,\delta)}{N_{signal}(E,\delta) + N_{background}(E,\delta)}$$

AGILE (Astro-rivelatore Gamma a Immagini LEggero)

AGILE was a gamma-ray astrophysics mission of the Italian Space Agency (ASI), with scientific and programmatic participation by INAF and INFN (Tavani+2009).

AGILE was launched in 2007, and after almost 17 years of successful scientific operations, the Italian satellite re-entered the atmosphere on 14 February 2024.

AGILE Payload: GRID (Gamma Ray Imaging Detector) (30 MeV-50 GeV), MCAL (Mini-Calorimeter) (300 keV-100 MeV), SuperAGILE (coded mask X-ray detector) (18-60 keV)

8 out of 16 AGILE light curves generated at the neutrino best positions available for the analyzed sample show a candidate detection (σ>3) within 1 yr from the event T_0

Light curves: dashed line at T_0, dotted lines at detection epochs

Four selected examples below

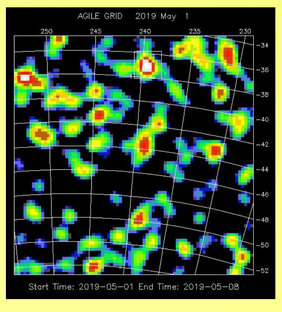
Previously unreported candidate counterparts in bold

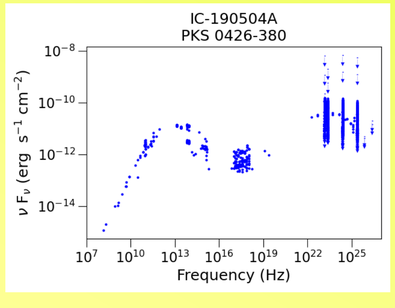
Analysis Tools

Light curves built using the public AGILE-LV3 web tool based on GRID data archive of pre-compiled exposure (EXP), count (COUNTS), diffuse background (GAS) maps provided by AGILE Data Center c/o the ASI Space Science Data Center (SSDC). (https://www.ssdc.asi.it/mmia/index.php?mission=agilelv3mmia)

SED Builder of the ASI Space Science Data Center SSDC for Spectral Energy Distributions.

VOU-Blazars (Chang+ 2019) for blazar candidate identifications and SEDs.



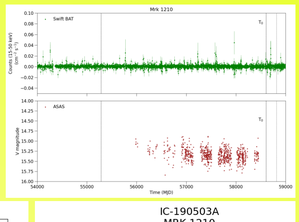


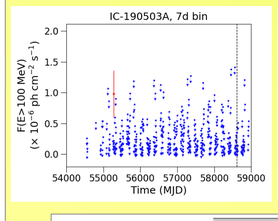
IC-190503A (EHE)

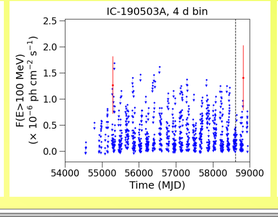
Candidate detections in 4d, 7d light curves.
Closest detection at ~ 7 months after T_0.

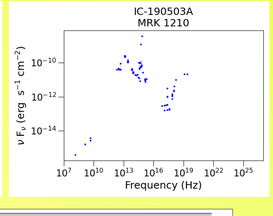
3 previously unreported candidate associated sources.

Bin (d)	MJD (d)	MJD error (d)	Flux ($\times 10^{-6}$ ph cm^{-2} s^{-1})	Flux error ($\times 10^{-6}$ ph cm^{-2} s^{-1})	$\sqrt{TS}$
4	55285.5	2.0	1.27	0.55	3.4
4	58817.5	2.0	1.41	0.62	3.4
7	55283.0	3.5	0.98	0.38	3.5









Candidate Associated sources	$N_{Candidate}$	Source name	Type	RA	DEC	Distance(arcmin)	γ-ray Counterpart
	1	3HSP J080056.5+073235	HBL	124.24	7.54	71.1	4FGL J0800.9+0733
	6	**MRK 1210**	Sy2	121.02	5.11	86.37	-
	7	**WISEA J080406.36+064843.3**	HBL	121.03	6.81	51.23	-
	4	**SDSS J080352.97+061704.3**	IBL	120.97	6.28	40.27	-

One previously reported candidate (*GCN 24378*): 3HSP J080056.5+073235 (HBL, 4FGL J0800.9+0733)

IC-190504A (HESE)

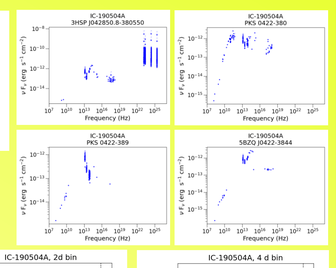
Light curves associated to 2AGL J0429-3755/PKS 0426-380, with candidate detections for all binning choices.

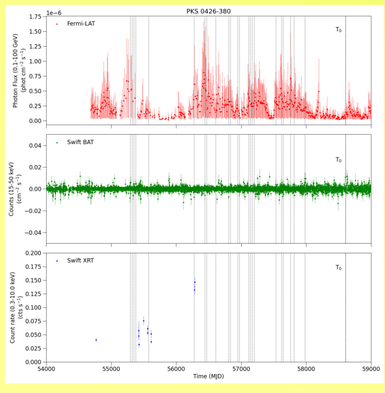
4 previously unreported candidate associated sources.

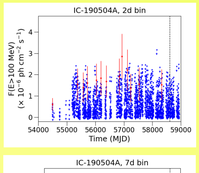
Closest candidate detection: ~ 9.4 months before T_0

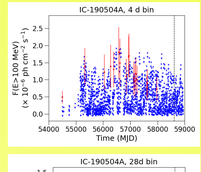
$N_{Candidate}$	Source name	Type	RA	DEC	Distance(arcmin)	γ-ray Counterpart
15	PKS 0426-380	LBL/IBL	67.17	-37.94	71.95	4FGL J0428.6-375
16	**3HSP J042850.8-380550**	IBL	67.21	-38.10	78.12	0
6	WISEA J042025.10-374445.0	IBL	65.11	-37.65	37.4	4LAC J0420.3-374
10	**PKS 0422-380**	LBL/IBL	66.17	-37.94	35.1	0
9	**PKS 0422-389**	LBL	66.14	-38.81	83.95	0
7	**5BZQ J0422-3844**	LBL/IBL	65.56	-38.75	79.2	0

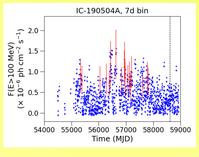
Previously reported candidates (*Giommi+ 2020, GCN 24401*): PKS 0426-380 (LBL) and 4LAC J0420.3-374 (IBL)

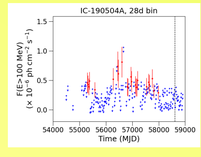










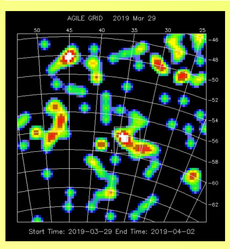


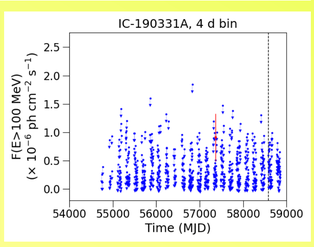
IC-190331A (HESE)

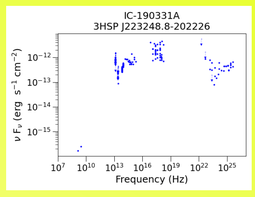
Candidate detection in 4d light curve (ΔT~ -3.3 yr).

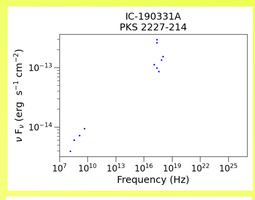
ATel #12623, Lucarelli+ (2019): new identified source AGL J2233-2212 spatially and temporally coincident with the neutrino event. AGILE detection with $\sqrt{TS}$~4 in T_0 ± 3 days obtained with targeted analysis.

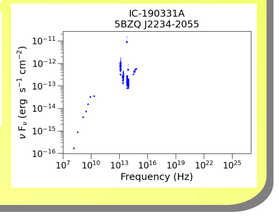
Bin (d)	MJD (d)	MJD error (d)	Flux ($\times 10^{-6}$ ph cm^{-2} s^{-1})	Flux error ($\times 10^{-6}$ ph cm^{-2} s^{-1})	$\sqrt{TS}$
4	57365.5	2.0	0.91	0.42	3.0











$N_{Candidate}$	Source name	Type	RA	DEC	Distance(arcmin)	γ-ray Counterpart
	AGL J2233-2212		338.3*	-22.2*		ATel #12623
16	**3HSP J223248.8-202226**	HBL	338.20	-20.37	35.3	4FGL J2232.6-2023
12	**PKS 2227-214**	LBL	337.65	-21.21	30.8	-
19	**5BZQ J2234-2055**	LBL	338.73	-20.92	60.83	-

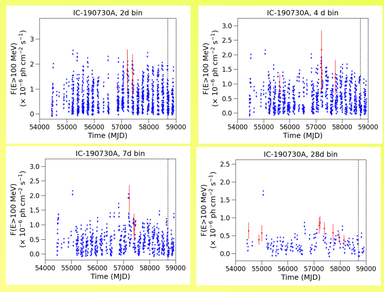
*±0.8 deg (95% stat. c.l.) ±0.1 deg (sys.)

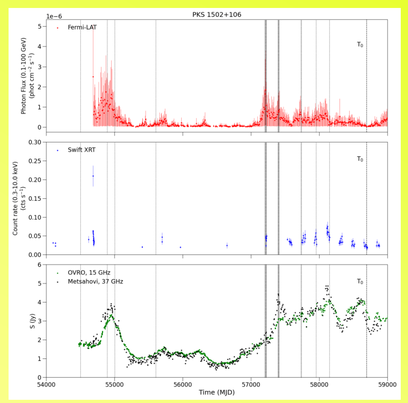
3 previously unreported candidate associated sources

IC-190730A (GOLD)

AGILE light curves associated to 2AGLJ 1507+1019/PKS 1502+106, with candidate detections for all binning choices.

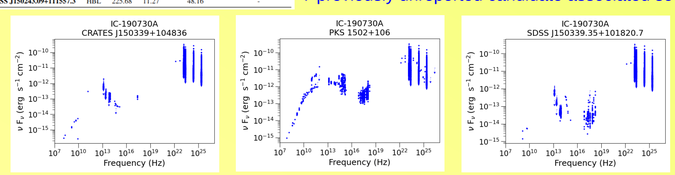
Closest candidate detection in 28 d light curve (ΔT~-1.5 yr), MJD = 58149.5±14.0 d, Flux = (0.38±0.14)e-6 ph/cm^2/s, $\sqrt{TS} = 3.4$





$N_{Candidate}$	Source name	Type	RA	DEC	Distance(arcmin)	γ-ray Counterpart
13	PKS 1502+106	LBL	226.10	10.49	18.59	2AGLJ1507+1019
17	3HSP J150604.4+102233	HBL	226.52	10.38	43.35	-
6	**SDSS J150340.61+101429.4**	LBL	225.91	10.25	15.12	-
8	**1WGA J1503.7+1018**	LBL	225.91	10.27	14.21	-
7	**CRATES J150339+104836**	IBL	225.91	10.81	21.69	-
9	**SDSS J150339.35+101820.7**	LBL	22.93	10.29	13.63	-
1	**SDSS J145920.92+103603.3**	HBL	224.84	10.60	56.87	-
3	**SDSS J150135.83+095818.6**	LBL	225.40	9.97	37.75	-
4	**SDSS J150243.09+111557.3**	HBL	225.68	11.27	48.16	-

7 previously unreported candidate associated sources



Preliminary Results and Conclusions

AGILE-GRID data do not show flaring sources or transients over time scales of the order of days around T_0 of the considered neutrino events in the sample.

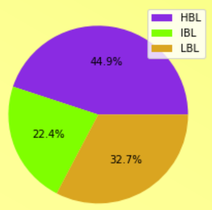
However, we note that 8 out of 16 light curves show a candidate detection ($\sqrt{TS} > 3$) within $T_0 \pm 1$ yr:

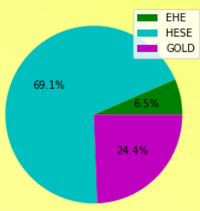
- 2/3 EHE neutrinos (IC-180908A, IC-190503A)
- 3/6 HESE neutrinos (IC-190104A, IC-190221A, IC-190504A)
- 3/7 GOLD neutrinos (IC-190619A, IC-190922A, IC-191001A)

IC-190221A: detection in time window $T_0 \pm 1$ month (7d bin).

HBL sub-class favoured compared to IBL, LBL subclasses.

HESE neutrinos more likely to be associated with possible AGILE gamma-ray counterparts.





Statistical analysis in progress
Paper in preparation