

The background of the slide features a large, blue, oval-shaped field of view, likely representing the AGILE satellite's field of view. A bright, horizontal band of red and orange light is visible across the center of this field, with several distinct red spots. In the bottom-left corner, there is a detailed image of the AGILE satellite, showing its solar panels and instruments.

AGILE & *neutrino* events

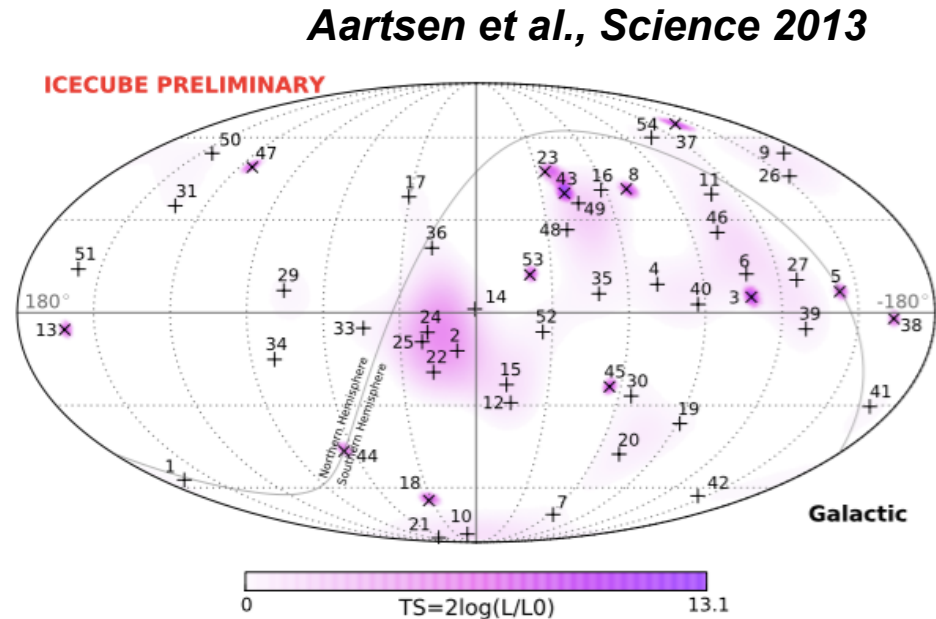
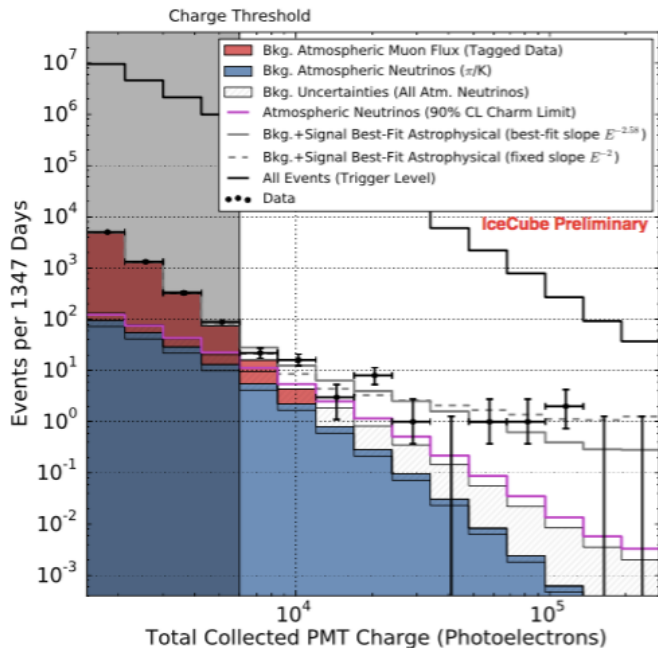
**Fabrizio Lucarelli
(SSDC/ASDC & INAF-OAR)**

Outlook

- **The ICECUBE diffuse neutrino signal and the GCN AMON alert sistem**
- **AGILE investigations of the ICECUBE-160731 event**
- **Search for E.M. counterpart of ICECUBE-160731 using ASDC MWL tools**
- **Search of gamma-ray counterparts in the AGILE data for all ICECUBE GCN AMON events**
- **Conclusions**

ICECUBE ν -signal (all-sky)

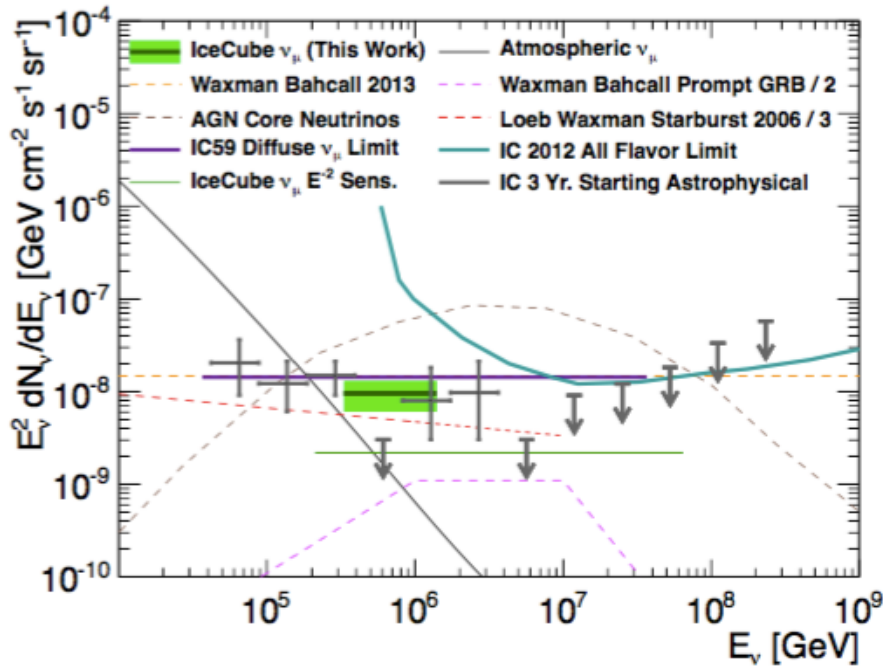
- First evidence of a diffuse flux of astrophysical neutrinos provided by ICECUBE using 3 and 4 years of data (2010-2014).
- In total, 54 “high-energy starting events” (HESE) with interaction inside the detector: mostly *shower-like* events from ν_e and ν_τ with ang. resolution of ~ 10 deg.



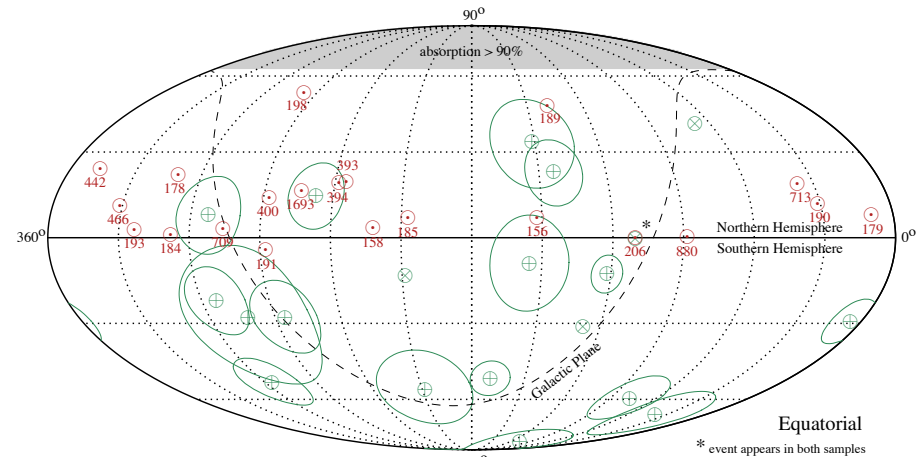
Diffuse flux spectral index: 2.58 ± 0.25 (4-years data)

ICECUBE ν_μ -signal (northern-sky)

- Evidence of a diffuse flux of astrophysical origin *also* in down-going muons produced by ν_μ (2010-2012 data).
- In total 21 ν_μ events with $E > 100$ TeV with higher angular resolution (< 1 deg).



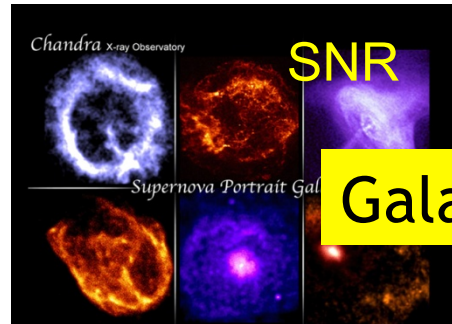
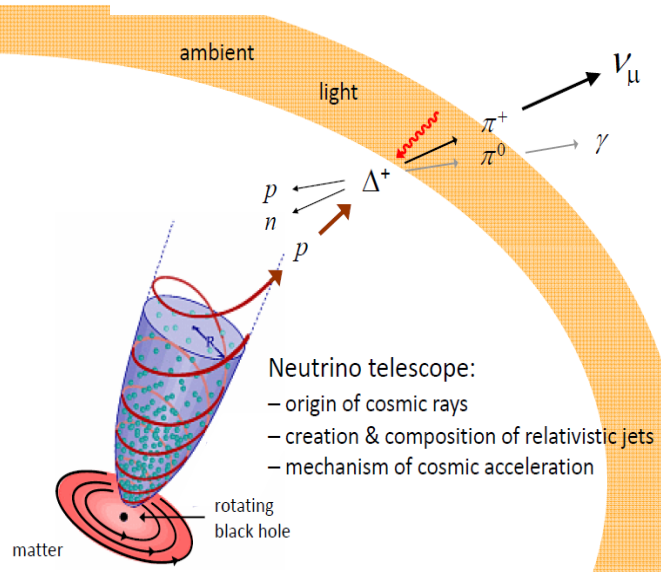
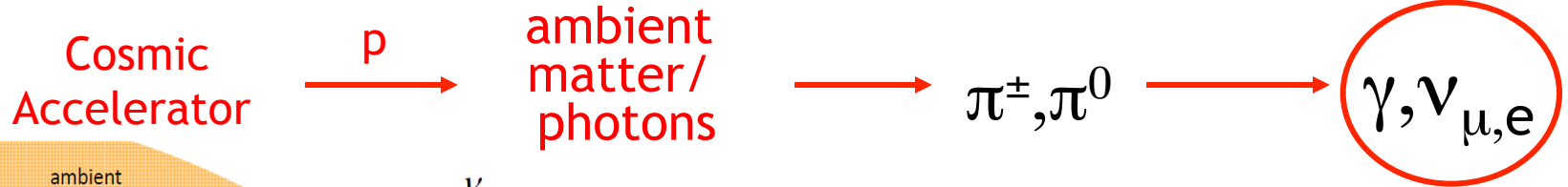
Aartsen et al., Phys. Rev. Lett. 115 2015



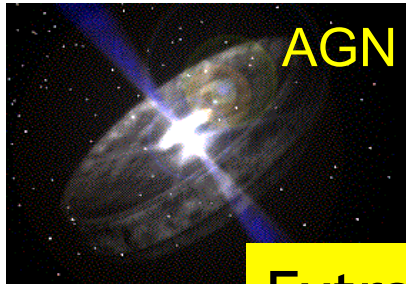
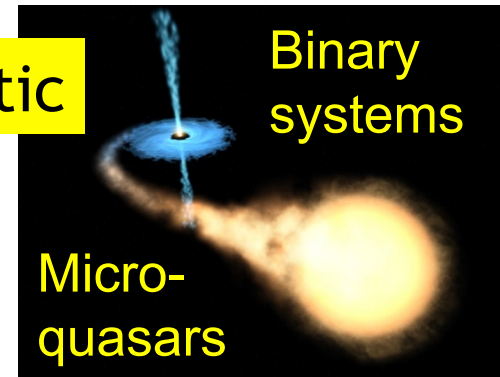
No clear known electro-magnetic (e.m.) counterparts identified yet

Neutrinos & gamma-rays from hadronic processes

Astrophysical beam dump



Galactic



Extra-galactic



Neutrino source candidates

- IceCube searches for point-like and extended sources of muon neutrinos found neither statistically-significant evidence for event clustering nor correlation of neutrinos with known astrophysical objects.
- Kadler et al. (2015) found one of the ICECUBE PeV-event was spatially and temporally coincident with a major gamma-ray outburst of the Flat Spectrum Radio Quasar (FSRQ) PKS B1424-418.
- Recently works (Resconi et al. 2017) provide hints that HBL sub-class of blazars may be the sources of some of the ICECUBE HESE neutrinos and UHECRs seen by Auger/Telescope Array.

ICECUBE ALERT SYSTEM

- Sources of cosmic neutrinos may be identified by rapid follow-up observations by electromagnetic ground and space-based observatories.
- Since April 2016, ICECUBE alerts the astronomical community through the GCN network whenever a clear detection of a cosmic neutrinos occurred.
- Only HESE *track-like* events with good angular resolution are published through the network.
- Expected ν -energies:
 - HESE events: sub-PeV/1 PeV;
 - EHE events: several hundred TeV

Expected occurrence rate: ~4/yr

Updated HESE/EHE event list

ICECUBE Event ID	T0 (yy/mm/dd hh:mm:ss)	Category
<u>67093193_127853</u>	16/04/27 05:52:32.00	HESE
<u>6888376_128290</u>	16/07/31 01:55:04.00	HESE/EHE
<u>26552458_128311</u>	16/08/06 12:21:33.00	EHE
<u>58537957_128340</u>	16/08/14 21:45:54.00	HESE
<u>38561326_128672</u>	16/11/03 09:07:31.12	HESE
<u>80127519_128906</u>	16/12/10 20:06:40.31	EHE
<u>65274589_129281</u>	17/03/12 13:49:39.83	HESE
<u>80305071_129307</u>	17/03/21 07:32:20.69	EHE

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AGILE INVESTIGATIONS OF THE ICECUBE-160731 EVENT

ICECUBE-160731 event

- **Extremely High Energy (EHE) neutrino detected by the ICECUBE experiment at**
T0=31/07/2016 01:55:04 UTC
- **Announced by GCN/AMON notice 128290_6888376 (http://gcn.gsfc.nasa.gov/notices_amon/6888376_128290.amon).**
- **Reconstructed arrival direction:**
RA,DEC (J2000)=(214.54, -0.33) +/- 0.75 [deg]
(90% stat+sys containment radius)
Gal Coords. l,b=(343.68, +55.52) deg

AGILE investigations of ICECUBE-160731

- **AGILE alert systems received automatically GCN/AMON notice emitted by the ICECUBE Coll.**
- **No significant detection in the AGILE-GRID data was found around T0 at the ICECUBE coords.**
- **BUT ... a gamma-ray excess above 100 MeV above 4 sigma was detected in the GRID data by the *AGILE* QL processing procedure a couple of days before, on a 48 hours integration between (T0 - 3; T0 - 1) days.**



The AGILE AGL J1418+0008 transient

- Very brief episode (1 – 1.5 days).
- 4.1σ pre-trial significance on (T0 – 2; T0 - 1) days interval.
- Peak significance of 4.9σ on the 24 hours integration (T0 - 1.8; T0 - 0.8) days (peak flux (E>100 MeV)~ $3.5E-06$ ph/cm²/s).
- Best-fit AGILE-GRID position:
l,b=(344.26, 55.86) [deg] +/- 0.8 [deg] (95% stat. c.l.)
→ new AGILE transients: AGL J1418+0008

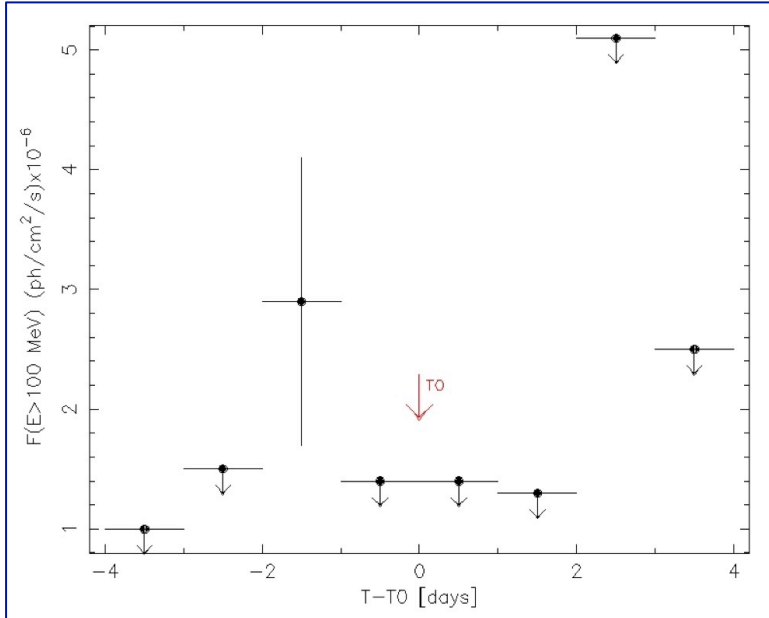
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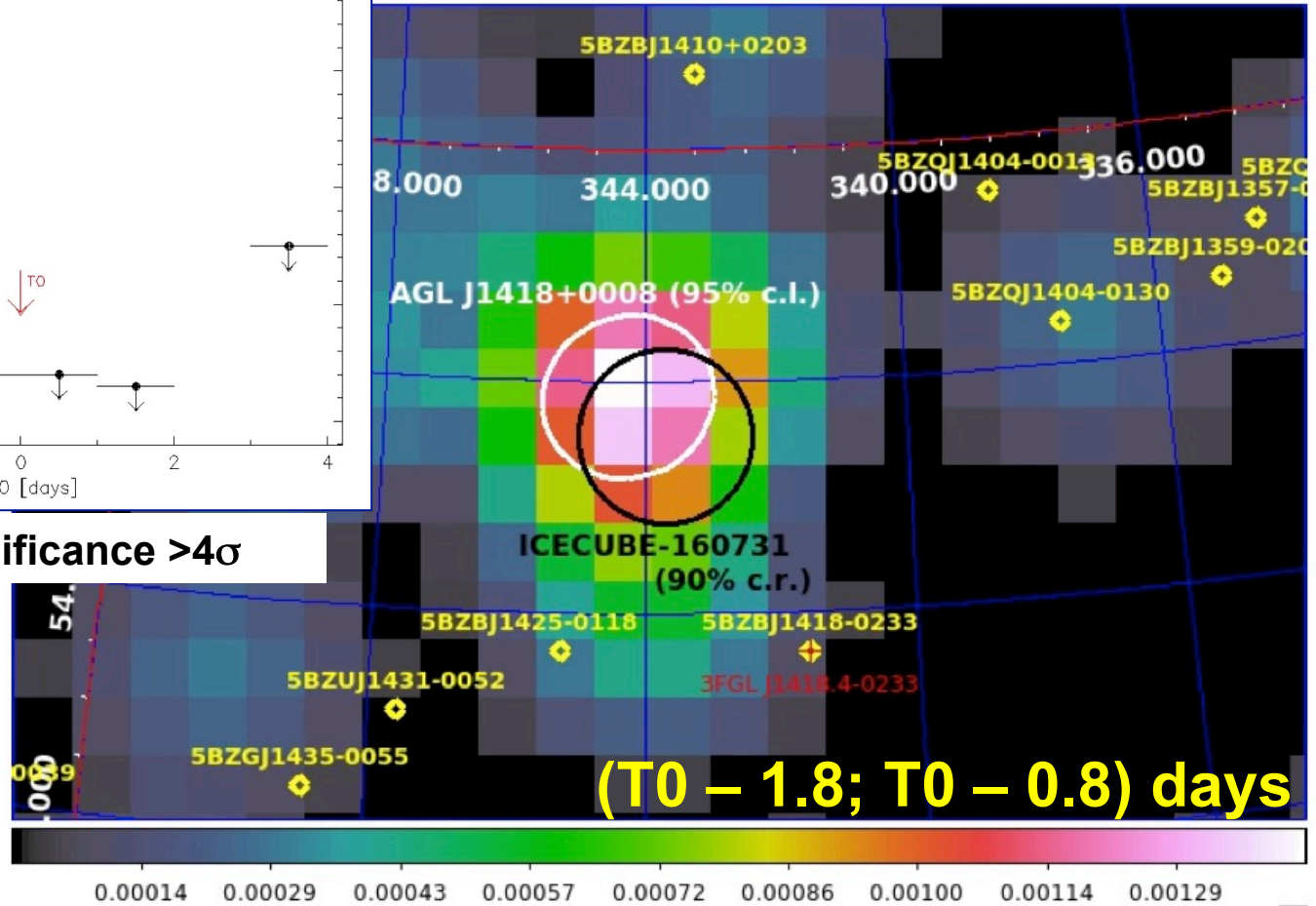
**AGL J1418+008 possible gamma-ray precursor
of the ICECUBE-160731 event (?)**

The AGILE AGL J1418+0008 transient

Lucarelli et al., submitted to ApJ

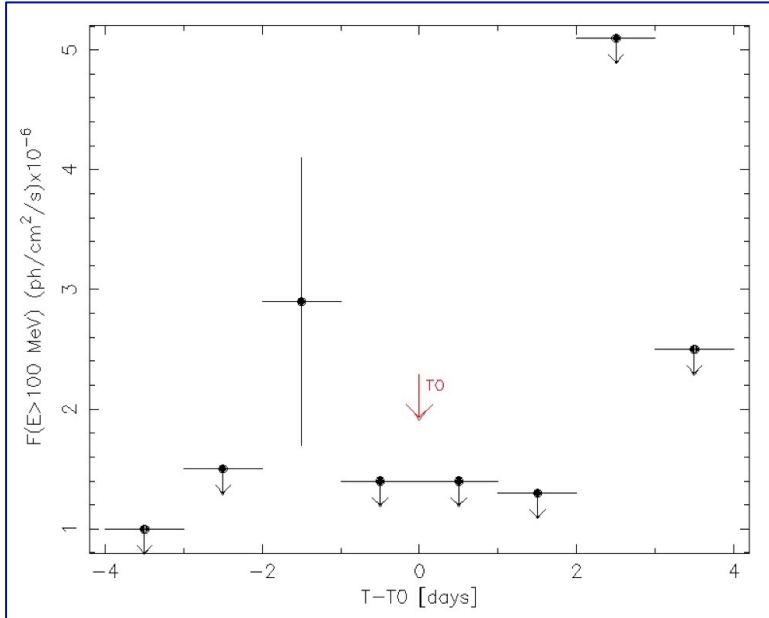


Post-trial significance $> 4\sigma$

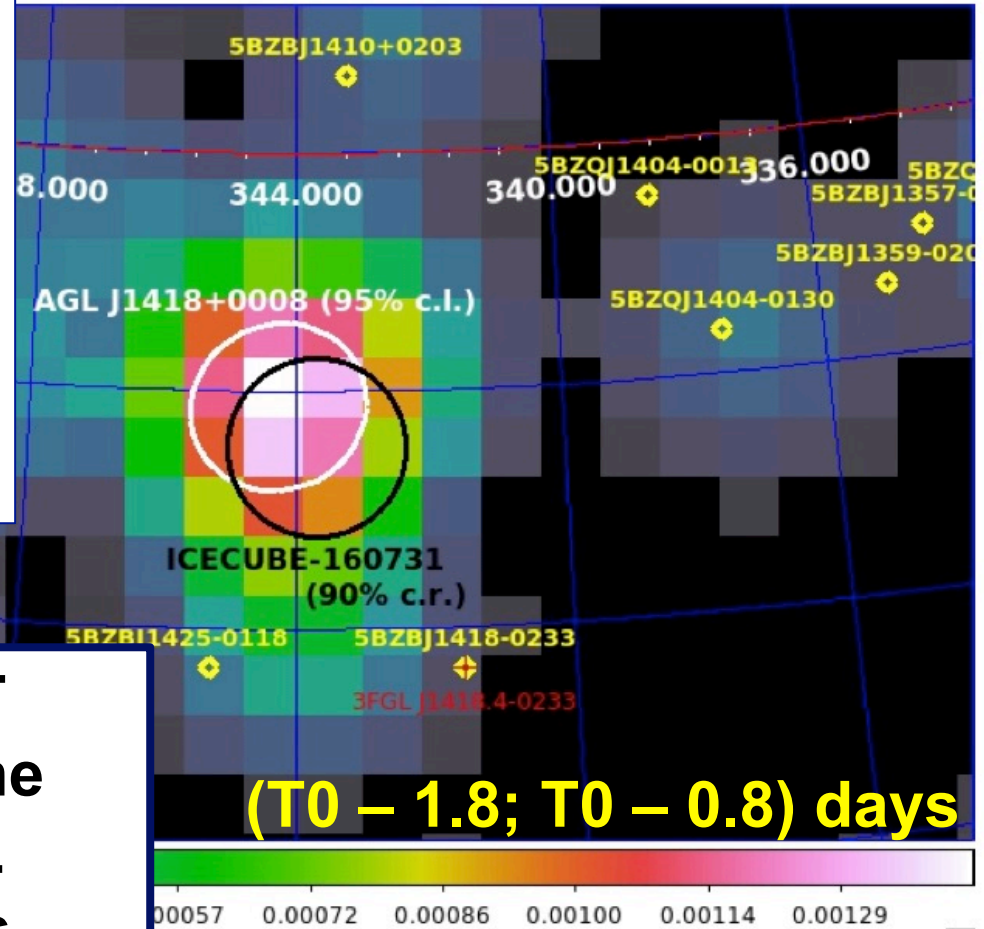


The AGILE AGL J1418+0008 transient

Lucarelli et al., submitted to ApJ



Post-trial significance $> 4\sigma$



No known blazars/LAT sources found inside the ICECUBE-160731/AGL J1418+008 error circles



MWL follow-up of the γ -event

- Follow-up observations from other observatories (FERMI-LAT, SWIFT, HAWK, MASTER, FACT, etc.) have been reported.
- No detections of transients/steady e.m. emission consistent with the ICECUBE-160731 position has been reported so far from other wavelengths.

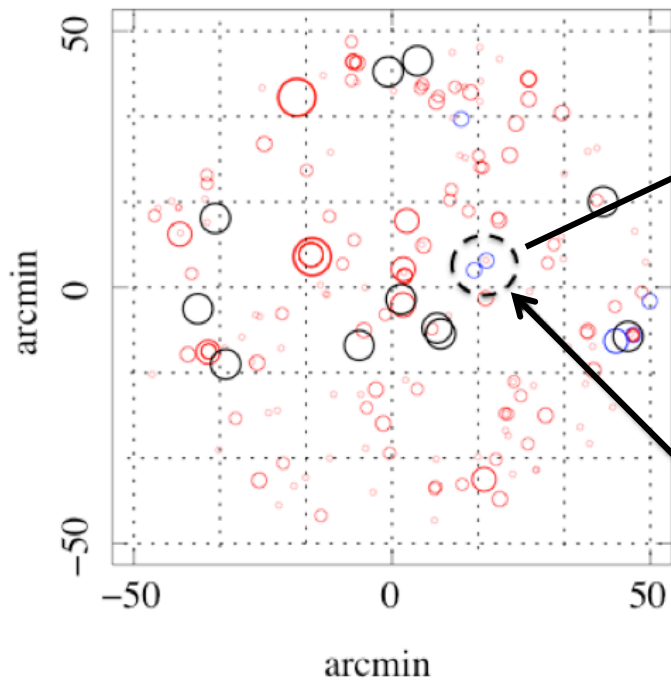
Mission/Observatory	ATel	GCN	Observation Time	Results
HAWK (TeV)	-	19743	30/07/16 21:28 – 31/07/16 02:59	No detection.
SWIFT (X-ray, Optical)	#9294	19747	31/07/16 03:00:46 - 14:51:52 UTC	Six known X-ray sources detected: no transients.
MASTER net (optical)	#9298	19748	2016-07-31 19:23:17 UT	No detection.
FERMI-GBM	-	19758	-	Position occulted by Earth at T0
FERMI-LAT	#9303	-	2.25 days from 2016 July 31.	No detection above 100 MeV
iPTF



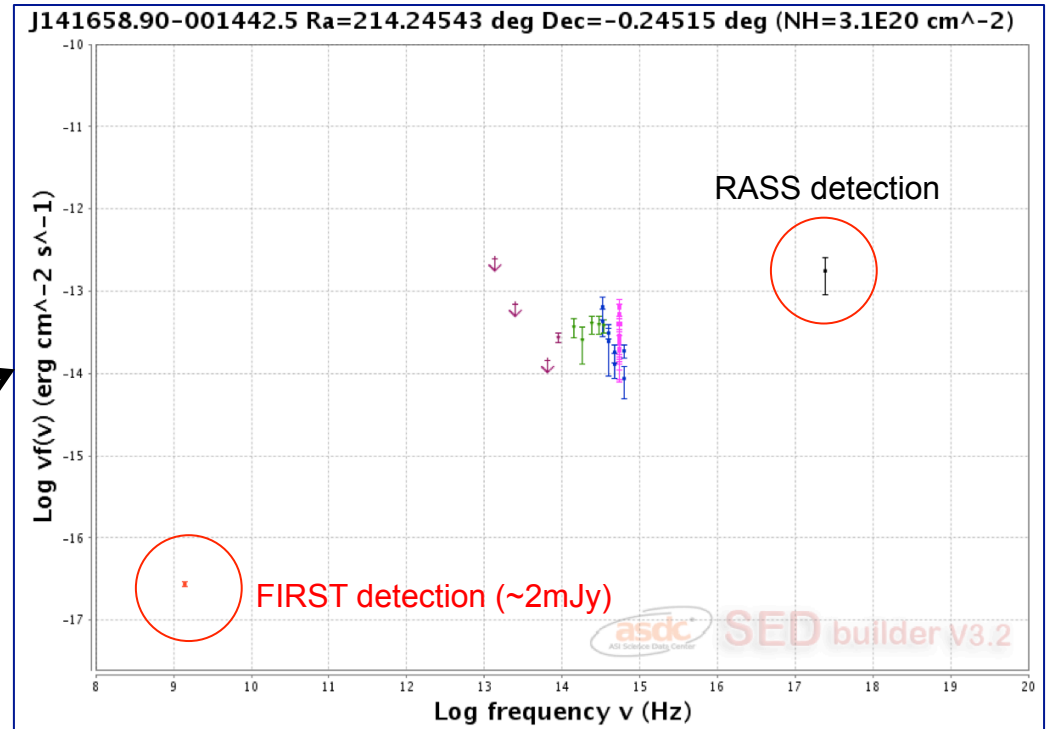
SEARCH FOR E.M. COUNTERPART OF ICECUBE-160731 USING ASDC MWL TOOLS

“Peek-a-boo! (I see you ...)”

Search around
ICECUBE-160731/AGL
J1418 using ASDC
SkyExplorer tool



ASDC SEDBuilder Tool

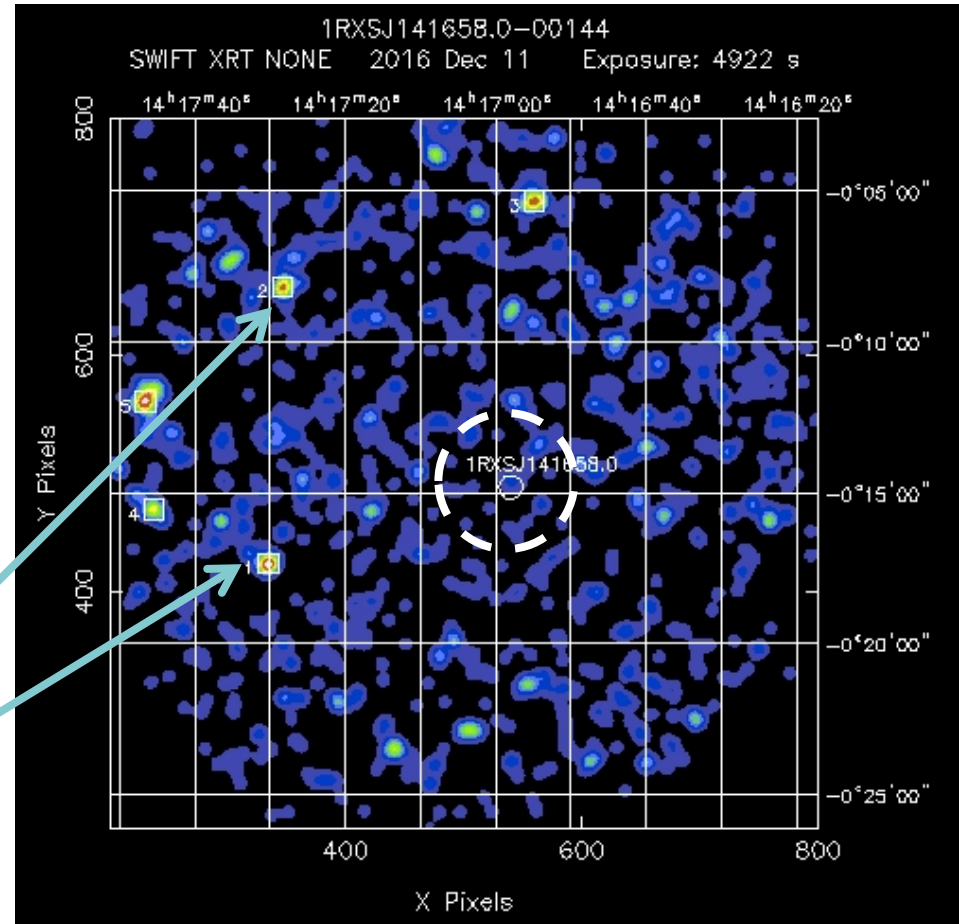


1RXS J141658-00144:
possible HBL blazar candidate →
ICECUBE-160731 emitter candidate?

Additional SWIFT ToO data on 1RXSJ141658

- 5 ks ToO observation performed ~6 months later than T0.
- No X-ray emission on the 1RXS J141658 position
→ HBL nature of this AGN candidate not confirmed.

5 un-catalogued X-rays sources detected during the ToO (study ongoing).



SEARCH OF GAMMA-RAY COUNTERPARTS IN THE AGILE DATA FOR ALL HESE/ EHE EVENTS



INVESTIGATING HESE/EHE events

- Two-fold goals: search for AGILE gamma-ray transients around ν -event T0/position (precursor/delayed emission) AND for other significant gamma-ray episodes from archival data.

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<u>67093193</u>	16/04/27 05:52 (57505.245)	HESE	Two $>4.5\sigma$ detections from archival data
<u>6888376</u>	16/07/31 01:55 (57600.079)	HESE/EHE	AGILE detection 1 day before T0
<u>26552458</u>	16/08/06 12:21 (57606.515)	EHE	4.7σ detection @ MJD=56449.113
<u>58537957</u>	16/08/14 21:45 (57614.907)	HESE	No detections $>4.5\sigma$
<u>38561326</u>	16/11/03 09:07 (57695.380)	HESE	No detections $>4.5\sigma$
<u>80127519</u>	16/12/10 20:06 (57732.838)	EHE	$\sim 4.4\sigma$ detection @ MJD=57066.1172
<u>65274589</u>	17/03/12 13:49 (57824.576)	HESE	No detections
<u>80305071</u>	17/03/21 07:32 (57833.314)	EHE	Low significance detection BEFORE T0



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PRELIMINARY



Summary

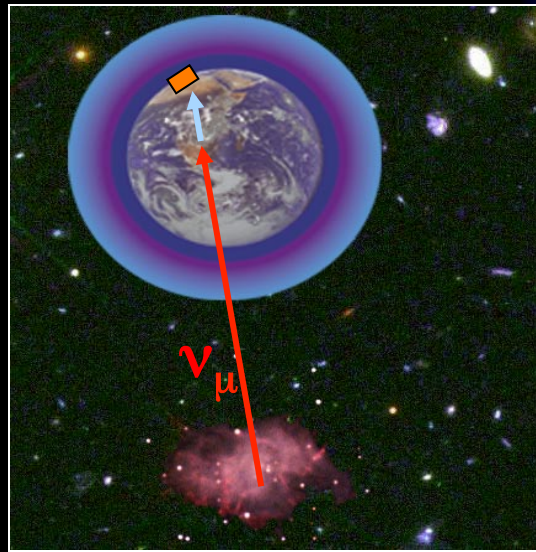
- **AGILE also fully involved in the MWL follow-up of ICECUBE events published through the GCN network.**
- **Like in the GW case, identification of gamma-ray signals spatially and (almost) temporally coincident with the neutrino positions is crucial to identify the neutrino emitter source and its e.m. counterpart.**
- **For the ICECUBE-160731 HESE event, AGILE detected a possible short gamma-ray precursor, peaked about 1.5 days before the neutrino event T0.**
- **No clear e.m. counterpart found yet (a possible HBL candidate has not been confirmed by SWIFT ToO data).**
- **Other ICECUBE HESE events are under investigations (both with AGILE data and using the MWL ASDC search tools to identify the possible e.m. counterpart).**

Stay tuned!

Backup Slides

ν -astronomy: main Detection Principle

Looking for upward-going muons as
signature of ν_μ interactions
($E_\nu = 1 \text{ TeV} \rightarrow \Theta_{\nu\mu} \approx 1^\circ$)



Sea bottom

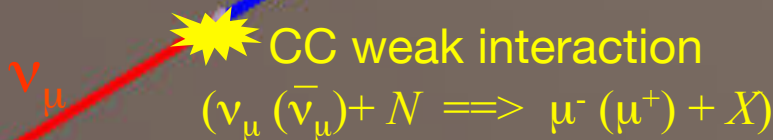
Detector: 3D PMT array placed at
depth (>2 km) in water or ice.
Natural shield against sunlight
and atmospheric CRs.

Cherenkov light
from μ

42°

The reconstruction is based on
local coincidences compatible
with the Cherenkov light front

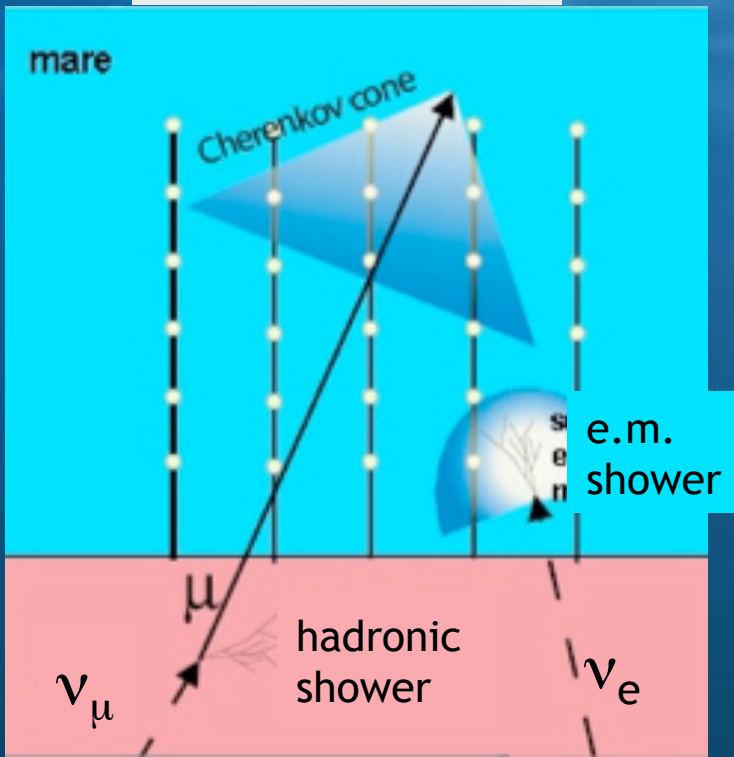
Energy threshold $\sim 10 \text{ GeV}$





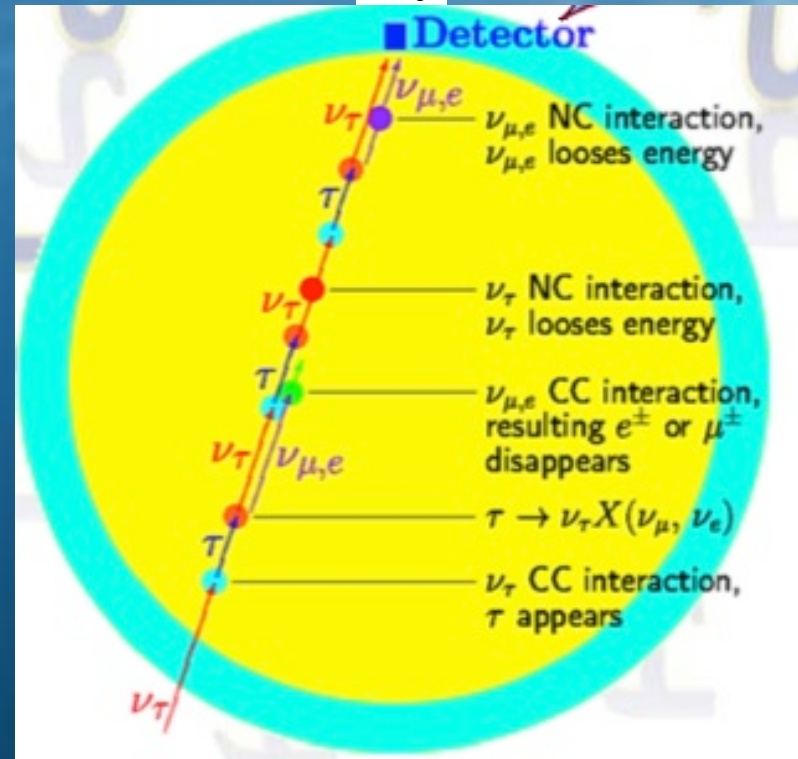
Other detection channels

CC $\nu_e N$ events



Contained events: better energy res. but worse ang. res.

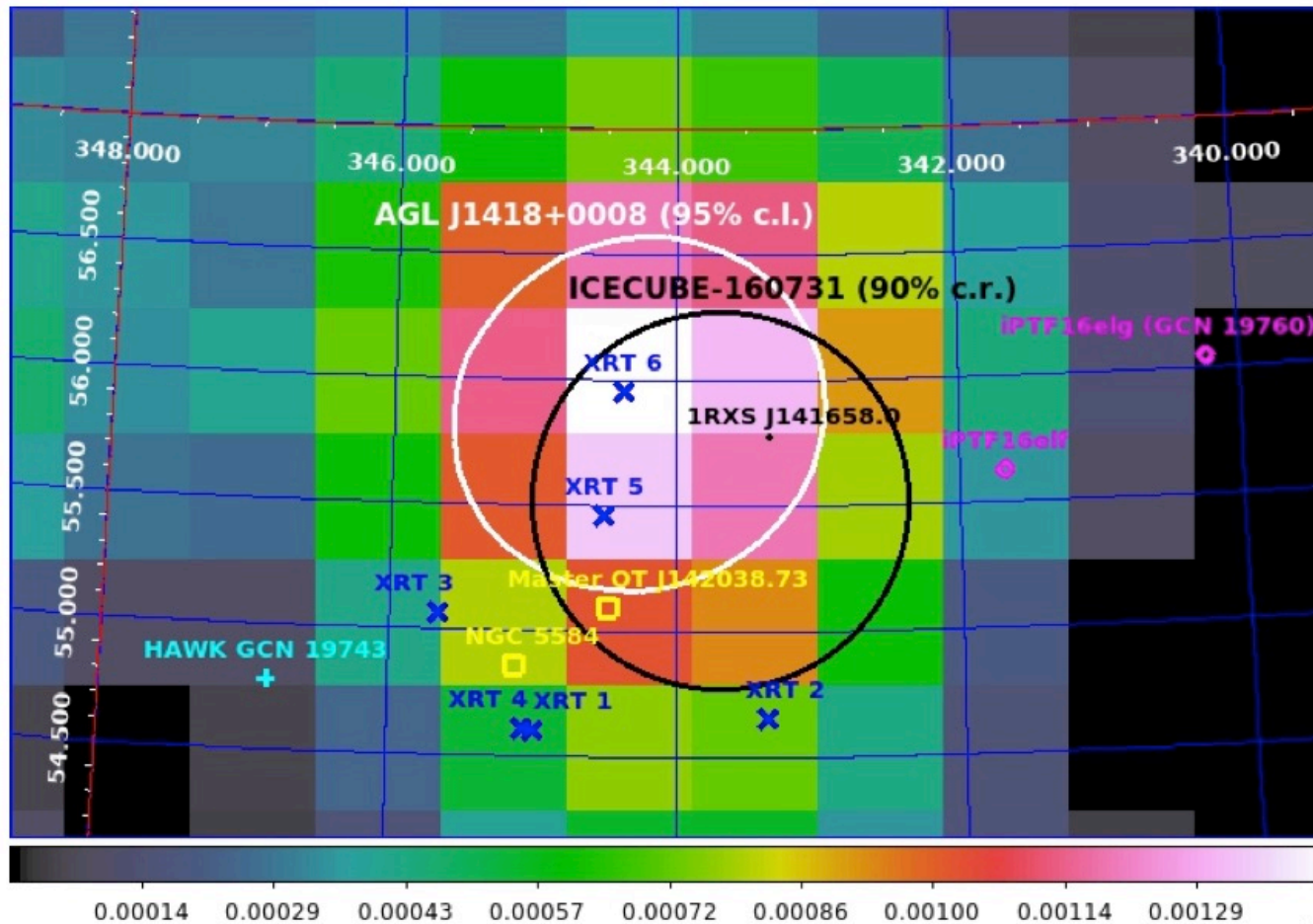
ν_τ



Visible by pile-up of events near 100 TeV

e.m. counterpart candidates found during the MWL follow-up

Lucarelli et al., submitted to ApJ



FERMI-LAT data on ICECUBE-160731/AGL J1418+0008

- FERMI-LAT ULs of $\sim 10E-07$ ph/cm²/s on 2.25 days and 8 days from T₀ backward.
- Poor LAT visibility during the AGILE best-interval detection: LAT exposure up to 10 GeV comparable to the AGILE one.

Lucarelli et al., submitted to ApJ

