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AGILE Detection of a Candidate Gamma-Ray Precursor to the ICECUBE-160731 Neutrino Event

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Abstract

On 2016 July 31 the ICECUBE collaboration reported the detection of a high-energy starting event induced by an astrophysical neutrino. Here, we report on a search for a gamma-ray counterpart to the ICECUBE-160731 event, made with the *AGILE* satellite. No detection was found spanning the time interval of ± 1 ks around the neutrino event time T_0 using the *AGILE* "burst search" system. Looking for a possible gamma-ray precursor in the results of the *AGILE*-GRID automatic Quick Look procedure over predefined 48-hr time bins, we found an excess above 100 MeV between 1 and 2 days before T_0, which is positionally consistent with the ICECUBE error circle, that has a post-trial significance of about 4σ. A refined data analysis of this excess confirms, a posteriori, the automatic detection. The new *AGILE* transient source, named AGL J1418+0008, thus stands as a possible ICECUBE-160731 gamma-ray precursor. No other space missions nor ground observatories have reported any detection of transient emission consistent with the ICECUBE event. We show that *Fermi*-LAT had a low exposure for the ICECUBE region during the *AGILE* gamma-ray transient. Based on an extensive search for cataloged sources within the error regions of ICECUBE-160731 and AGL J1418+0008, we find a possible common counterpart showing some of the key features associated with the high-energy peaked BL Lac (HBL) class of blazars. Further investigations on the nature of this source using dedicated *SWIFT* ToO data are presented.

Key words: astronomical databases: miscellaneous – BL Lacertae objects: general – gamma rays: galaxies – neutrinos

1. Introduction

Neutrino astronomy using underwater and under-ice Cherenkov detectors has entered a new era with the completion of the ICECUBE and ANTARES telescopes (Halzen & Klein 2010; Ageron et al. 2011) and the subsequent first clear detection of a diffuse background of very high-energy (VHE) extra-terrestrial neutrinos (IceCube Collaboration 2013; Aartsen et al. 2015). No significant clustering of neutrinos above background expectation has been observed so far (Aartsen et al. 2017a), but the ICECUBE apparatus might reach the necessary sensitivity or accumulate enough statistics to unambiguously detect anisotropy or clustering of events within a few more years of observations.

Emission of TeV–PeV neutrinos might be due to exceptionally energetic transient phenomena like flaring activities from active galactic nuclei (AGNs), gamma-ray bursts (GRBs), or supernovae explosions (Anchordoqui et al. 2014). A direct correlation between gamma-rays and neutrinos from astrophysical sources is expected whenever hadronic emission mechanisms are at work. In particular, several theoretical works assume that neutrino production occurs in astrophysical beam dumps, where cosmic rays accelerated in regions of high magnetic fields near black holes or neutron stars interact via proton–proton (pp) or proton–photon (pγ) collisions with the matter or the radiation field surrounding the central engine, or in a jet of plasma ejected from it, also giving rise to gamma-ray emission (see Halzen 2017 for a review).

Supernovae remnants (SNRs) expanding in dense molecular clouds and microquasars in our Galaxy, as well as the AGNs of the blazar class, are the main neutrino-source candidates up to PeV energies (Mannheim & Biermann 1989; Mannheim 1995; Halzen & Zas 1997; Protheroe et al. 1998; Bednarek 2005; Vissani 2006; Sahakyan et al. 2014). In addition to the identification of the pion excess in gamma-ray observations of SNRs interacting with molecular clouds (Giuliani et al. 2011; Ackermann et al. 2013), the detection and identification of a clear neutrino point-like source would provide evidence of proton and hadron acceleration processes, resolving the long-lasting problem of the origin of cosmic rays (at least up to multi-PeV energies).

Since 2016 April, the ICECUBE experiment has alerted the astronomical community, almost in real time, whenever an extremely high-energy, single-track neutrino event (with energy in the sub-PeV to PeV range) was recorded. The communication is sent through the ICECUBE_HESE (a single high-energy starting ICECUBE neutrino) and the ICECUBE_EHE (extremely high-energy ICECUBE neutrino) GCN/AMON notice systems (Aartsen et al. 2017b) a few seconds after the event triggers. The instant notice provides a first determination of the statistical relevance of the event and the reconstructed neutrino arrival direction, projected onto the sky, with its 90% and 50% containment radius (c.r).[15]

On 2016 July 31, the ICECUBE Collaboration reported a HESE GCN/AMON notice[16] announcing the detection of a high-energy, neutrino-induced, track-like event at time $T_0 = 01{:}55{:}04.00$ UT (MJD = 57600.07990741). The event was also classified as an EHE event, possibly having an energy higher than several hundred TeV[17] and a signalness[18] of ~ 0.85. This neutrino detection triggered a broadband follow-up by several space and ground-based instruments, searching for an electromagnetic (e.m.) counterpart to associate with the neutrino emission.

In what follows, we report on a search for a gamma-ray counterpart of the ICECUBE-160731 neutrino event, made using the data of the *AGILE* satellite. The paper is organized as follows. In Section 2, we describe the main *AGILE* instrumental characteristics and its unique capabilities for searching for gamma-ray counterparts to triggered events of very short duration. In Section 3, we present the results of the *AGILE* observations, both near the prompt neutrino event time T_0 and in archival data. In Section 4, we report on the multi-wavelength (MWL) follow-up, and in Section 5 we search for a possible e.m. counterpart candidate using the cross-catalog search tools available from the ASI Science Data Center (ASDC).[19]

2. *AGILE* as a Detector of Transient Gamma-Ray Sources

The gamma-ray satellite *AGILE* (Tavani et al. 2009), launched on 2007, has just completed its 10th year of operations in orbit. The main onboard instrument is the gamma-ray imaging detector (GRID), which is sensitive to gamma-rays in the energy range 30 MeV–50 GeV, and is composed of the gamma-ray Silicon Tracker, the Mini-calorimeter (MCAL), and the anti-coincidence (AC) system forparticle background rejection. The coaxial X-ray (20–60 KeV) detector Super-*AGILE* completes the satellite scientific payload.

Since 2009 November, *AGILE* has operated in the so-called spinning observation mode, in which the satellite rotates around the Sun-satellite versor. In this operation mode, the *AGILE* gamma-ray imager approximately observes the whole sky every day, with a sensitivity (at the 5σ detection level) to gamma-ray fluxes above 100 MeV of the order of $(3 \div 4) \times 10^{-6}$ ph cm^{-2} s^{-1}.

[15] For ICECUBE_EHE notices, only source errors at 50% c.r. are given.

[16] http://gcn.gsfc.nasa.gov/notices_amon/6888376_128290.amon

[17] Quote from the ICECUBE_EHE event information web page https://gcn.gsfc.nasa.gov/amon_ehe_events.html.

[18] Probability that the neutrino event is of astrophysical origin.

[19] http://www.asdc.asi.it

As already demonstrated in the recent follow-up of the gravitational-wave event GW150914 (Tavani et al. 2016) and in dozens of Astronomer's Telegrams (ATel) and GCN circulars, *AGILE* is a very suitable instrument for performing searches for short transient gamma-ray sources and gamma-ray counterparts to multi-messenger transient events like the neutrino event observed on 2016 July 31.

The main characteristics that make *AGILE* in spinning mode an important instrument for follow-up observations of multi-messenger counterparts are:

1. a very large field of view (FoV) of 2.5 sr for the *AGILE*-GRID;
2. a best sensitivity to gamma-ray fluxes above 30 MeV of the order of $(2 \div 3) \times 10^{-4}$ ph cm^{-2} s^{-1} for typical single-pass integrations of 100 s;
3. a coverage of 80% of the whole sky every 7 minutes;
4. a gamma-ray exposure of ~ 2 minutes for any field in the accessible sky, every 7 minutes;
5. between 150 and 200 passes every day for any region in the accessible sky;
6. sub-millisecond triggers for very fast events.

Despite its small size (approximately a cube with sides ~ 60 cm), the *AGILE*-GRID achieves an effective area of the order of 500 cm^2 between 200 MeV and 10 GeV for on-axis gamma-rays, and an angular resolution (FWHM) of the order of 4° at 100 MeV, decreasing below 1° above 1 GeV (Cattaneo et al. 2011; Chen et al. 2013; Sabatini et al. 2015).

A very fast ground segment alert system allows the AGILE Team to perform the full *AGILE*-GRID data reduction and the preliminary Quick Look (QL) scientific analysis only 25–30 minutes after the telemetry downloads from the spacecraft (Pittori 2013; Bulgarelli et al. 2014).

The *AGILE* QL on-ground system implements two different kinds of automatic analyses:

1. A "burst search" system, involving both GRID and MCAL instruments, is used to look for transients and GRB-like phenomena on timescales ranging from a few seconds to tens of seconds.[20] The burst search system runs on predefined time windows of 100 s, and it may be also triggered by external GCN notices (Zoli et al. 2016).
2. A "standard" *AGILE*-GRID *QL* analysis, based on a maximum likelihood (ML) algorithm (Mattox et al. 1996; Bulgarelli et al. 2012), is used to detect gamma-ray transients above 100 MeV on timescales of 1–2 days (Bulgarelli et al. 2014). This automatic procedure routinely runs over predefined 48-hr time bins.

Given the *AGILE* effective area and sensitivity, these collecting time intervals are the most appropriate to accumulate enough statistics and to maximize the signal-to-noise ratios in both cases.

3. *AGILE* Investigations of ICECUBE-160731

The ICECUBE-160731 best-fit reconstructed neutrino arrival direction in equatorial coordinates is (from Rev. #1 of the GCN notice):

$$\text{R.A., Decl.(J2000)} = (214.5440, -0.3347) \pm 0.75(\text{deg})$$

[20] A special sub-millisecond search for transient events detected by MCAL is operational on board (Tavani et al. 2009).

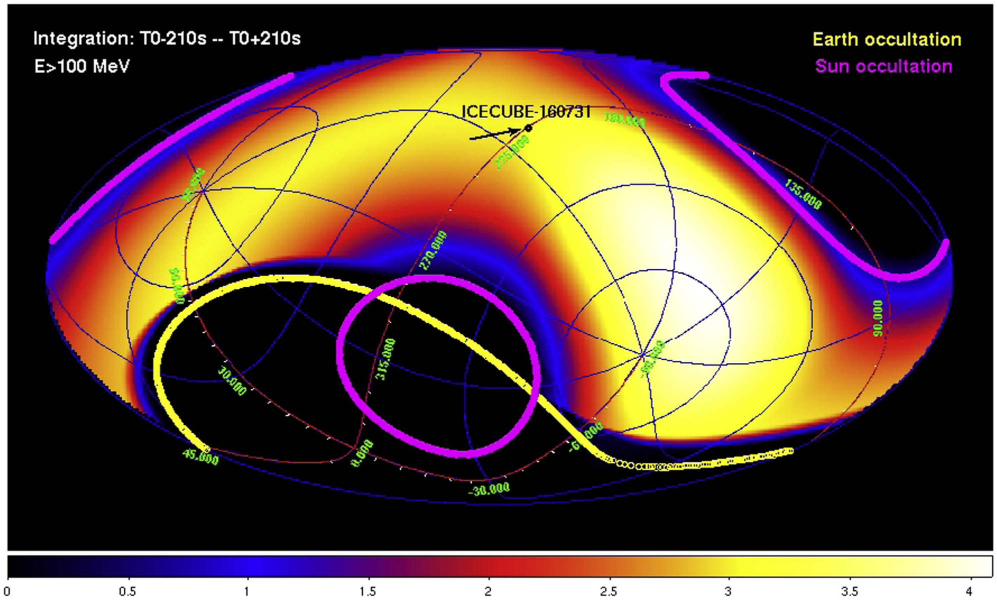

Figure 1. Hammer–Aitoff projection, in Galactic coordinates, of the *AGILE* gamma-ray exposure in (cm^2 s sr) (bin size of 0°.5) after one complete rotation in spinning mode, time-centered at the ICECUBE-160731 event time T_0. The neutrino event error circle is shown in black. The magenta and yellow contours show, respectively, the Sun/anti-Sun exclusion regions and the average Earth occultation during the considered integration time: (T_0 − 210; T_0 + 210) s.

(90% statistical plus systematic c.r.), corresponding to Galactic coordinates: l, b = (343.68, 55.52) (deg). In the next sections, the details of the automatic and refined *AGILE* data analysis of the ICECUBE-160731 event are reported.

3.1. Prompt Event

The search for a GRB-like prompt event on short timescales ranging from a few to tens of seconds, and connected to the ICECUBE neutrino emission, was performed with the *AGILE* burst search system. The system was triggered by the first ICECUBE GCN/AMON notice reported a few tens of seconds after T_0. The automatic procedure searches for prompt gamma-ray emission on predefined 100 s time-interval bins ranging from $T_0 - 1000$ to $T_0 + 1000$ s. On these short timescales, the method of the ML is not applicable, and an aperture photometry is applied. The significance of the signal with respect to the background is calculated using the Li & Ma formula (Li & Ma 1983).

Near T_0, the reconstructed neutrino-source position had good visibility for the *AGILE*-GRID FoV, neither occulted by the Earth nor by the exclusion regions around the Sun and anti-Sun positions (see Figure 1). No significant detection was found in the GRID data from the event position in any of the 100 s time bins that were scanned. The 3σ upper limit (UL) for the emission in the range 30 MeV–50 GeV, estimated in the 100 s time bin with the highest exposure on the event position, is 5.7×10^{-4} ph cm^{-2} s^{-1}.

Moreover, using the data of the *AGILE*-MCAL and the AC scientific ratemeters, we have searched for burst-like events in the energy range of 0.4–100 MeV and 70 keV–tens of MeV, respectively. No significant event has been detected in either of the two detectors.

3.2. The Search for Gamma-Ray Precursor and Delayed Emission

Since the astrophysics and the timescales of the phenomena related to the emission of these extremely high-energy neutrinos are still uncertain, in addition to our investigations near T_0, we also explored the *AGILE*-GRID data taken a few days before and after T_0, searching for a possible gamma-ray precursor or delayed emission on longer (daily) timescales possibly connected to the neutrino event.

Interestingly, a gamma-ray excess above 100 MeV with a pre-trial ML significance of 4.1σ, compatible with the ICECUBE error circle, appeared in the results of the *AGILE*-GRID automatic QL procedure between one and two days before T_0. This detection was reported in ATel #9295 (Lucarelli et al. 2016).

The automatic *AGILE* QL procedure has run on predefined 2-day integration time since 2009 November, which was when the spinning observation mode began. The *AGILE* source ML detection method derives, for each candidate source, the best parameter estimates of source significance, gamma-ray flux, and source location. The ML statistical technique, in use since the analysis of EGRET gamma-ray data (Mattox et al. 1996), and adapted to the *AGILE* data analysis (Chen et al. 2011; Bulgarelli et al. 2012), compares measured counts in each pixel with the predicted counts derived from the diffuse gamma-ray model to find statistically significant excesses consistent with the instrument point-spread function.

An *AGILE* QL detection is in general defined by the condition $\sqrt{\mathrm{TS}} \geqslant 4$, where TS is the test statistic of the ML method defined as $-2\log(\mathcal{L}_0/\mathcal{L}_1)$, where $\mathcal{L}_0/\mathcal{L}_1$ is the ratio between the ML of the null hypothesis over the point-like source hypothesis, given the diffuse *AGILE* gamma-ray background model (Giuliani et al. 2004). This threshold has been calibrated over various timescales and different background conditions (e.g., on or outside the Galactic plane; Bulgarelli et al. 2012).

To evaluate the post-trial significance of the automatic QL detection mentioned above, we used the probability distribution of the ML TS computed in Bulgarelli et al. (2012). The probability of having at least one detection due to a background fluctuation, for any position within the predefined region of interest (ROI) of 10° radius used in the ML fitting procedure with a significance $\sqrt{\mathrm{TS}} \geqslant \sqrt{h}$, in N independent trials, is given by $P_1(N) = 1 - (1 - p)^N$, where p is the p-value (that is, the probability of finding a false positive detection in a single observation) corresponding to h. The p-value for a detection with $\sqrt{\mathrm{TS}} \geqslant 4.1$ outside the Galactic plane[21] is 3.8×10^{-5}. By considering all the generated maps with enough exposure in spatial coincidence with the neutrino error circle (amounting to 226 since the beginning of the spinning observation mode), the probability of having one detection by chance in $N = 226$ trials is $P_1(226) = 8.5 \times 10^{-3}$. The chance probability of the *AGILE* detection becomes at least two orders of magnitudes lower if we consider the probability P_2 of spatial coincidence of the *AGILE*-GRID excess with the ICECUBE error region within the 10° radius ROI. The combined post-trial probability then becomes $P_1 \times P_2 \sim 8.5 \times 10^{-5}$, which corresponds to a 3.9σ post-trial significance.

A refined analysis has been performed both to confirm the automatic QL result (applying more stringent cuts to further reduce the background contamination from albedo events) and to find a better temporal characterization of the gamma-ray transient positionally consistent with the ICECUBE-160731 position.

In the refined GRID data analysis, we created a light-curve symmetric with respect to T0, using a time bin of 24 hr, which is the minimum integration time needed by the GRID to detect a medium or high flaring gamma-ray source above 100 MeV with enough statistics.[22]

A search for gamma-ray emission above 100 MeV using the *AGILE* ML around the ICECUBE position has thus been performed over the time interval $(T_0 - 4;\ T_0 + 4)$ days. Exposure, counts, and diffuse emission maps of each time bin were generated using the official *AGILE* scientific analysis software (release: BUILD 21; response matrices: I0023)[23] (Chen et al. 2011), applying a cut of 90° on the albedo events rejection parameter and taking an *AGILE*-GRID FoV radius of 50°. In comparison, the predefined *QL* maps are generated with a looser albedo cut of 80° and a larger acceptance FoV radius of 60°. GRID data acquisition during the passage over the South Atlantic Anomaly (SAA) is suspended. Each time bin of the light curve has been analyzed by means of the ML algorithm, assuming a gamma-ray source at the ICECUBE position. Figure 2 shows the resulting gamma-ray light curve, where, for each bin, the ML gamma-ray flux estimate above 100 MeV or the 95% C.L. UL at the input ICECUBE-160731 position is shown.

A gamma-ray excess above 100 MeV, with a ML significance of 4.1σ, is detected in the bin centered 1.5 days before the T_0 (from MJD = 57598.07991 to MJD = 57599.07991), confirming the automatic QL detection (Lucarelli et al. 2016). The candidate gamma-ray precursor has an estimated flux of

$$F(E > 100\ \mathrm{MeV}) = (3.0 \pm 1.2) \times 10^{-6}\ \mathrm{ph\ cm^{-2}\ s^{-1}},$$

with centroid Galactic coordinates

$$l, b = (344.01, 56.03) \pm 1.0\ (\mathrm{deg}) \times (95\%\ \mathrm{stat.\ c.l.}) \pm 0.1\ (\mathrm{deg})(\mathrm{syst.}),$$

compatible with the ICECUBE-160731 position.

[21] As expected by Wilks' theorem (Wilks 1938), the TS values in this case follow the $\frac{1}{2}\chi^2$ distribution with one degree of freedom.

[22] Only in some exceptional bright flares may the integration time bin be reduced below 24 hr (see, e.g., Striani et al. 2011; Vercellone et al. 2011).

[23] http://agile.asdc.asi.it/public/AGILE_SW_5.0_SourceCode/

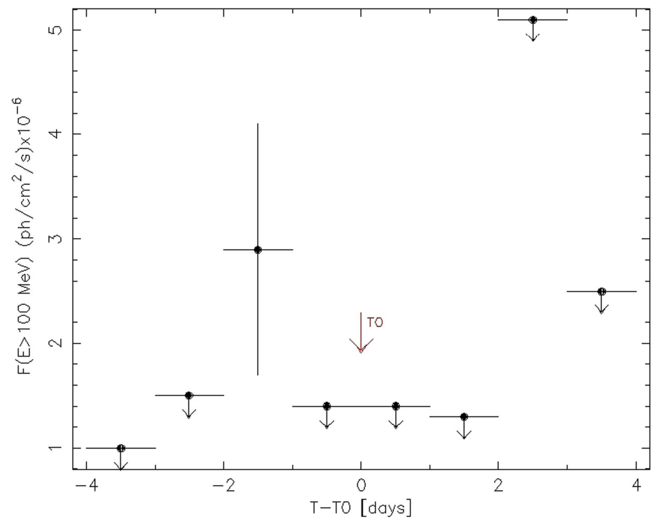

Figure 2. An a posteriori refined analysis showing the *AGILE*-GRID 1-day time bin light curve starting at $T_0 - 4$ days (MJD = 57596.07991), obtained from the *AGILE* ML analysis performed at the ICECUBE-160731 position over each integration bin.

The *AGILE* a posteriori refined analysis on a 24-hr basis shows that the excess is particularly short in time, mostly concentrated between 2016 July 29 and 30. By examining the arrival times of the gamma event file, we found a clustering of 5 counts in less than 7 hr around $(T_0 - 1)$ day within 1°.5 from the ICECUBE centroid. In particular, on the 24-hr integration from MJD 57598.25 to 57599.25 $((T_0 - 1.8;\ T_0 - 0.8)$ days), which fully contains the event clustering, we obtained a ML significance of the peak gamma-ray emission of 4.9σ at the Galactic centroid coordinates $l, b = (344.26, 55.86) \pm 0.8$ (deg) (95% stat. c.l.) $\pm$ 0.1 (deg) (syst.), with a flux $F(E > 100\ \mathrm{MeV}) = (3.5 \pm 1.3) \times 10^{-6}\ \mathrm{ph\ cm^{-2}\ s^{-1}}$.

The new *AGILE* transient, named AGL J1418+0008, positionally consistent with the ICECUBE-160731 error circle, might then be a possible precursor to the neutrino event.

Figure 3 shows the *AGILE*-GRID intensity map centered at the ICECUBE-160731 position, in the 24-hr time interval correspondent to the peak significance. The white region defines the 95% C.L. ellipse contour of the *AGILE*-GRID detection AGL J1418+0008, which is compatible with the ICECUBE-160731 90% c.r. error circle (black circle). Figure 3 also shows the position of the known sources from the 5th edition of the BZCAT and *FERMI*-LAT 3FGL catalogs (Acero et al. 2015; Massaro et al. 2015). None of these known sources lie within the *AGILE* or ICECUBE error circles. A further search of the Second and Third *FERMI*-LAT high-energy source catalogs (2FHL and 3FHL; Ackermann et al. 2016; The Fermi-LAT Collaboration 2017) does not show any possible association with known gamma-ray counterparts. The closest 3FHL source is 3FHL J1418.4-0233 (associated to the BL Lac blazar 5BZB J1418−0233 Massaro et al. 2015), which is more than 2° away from the neutrino position.

3.3. The Search for Gamma-ray Emission in AGILE Archival Data

All public *AGILE*-GRID archival data from 2007 December up to 2016 November have been investigated in order to search for other possible previous and later gamma-ray transient

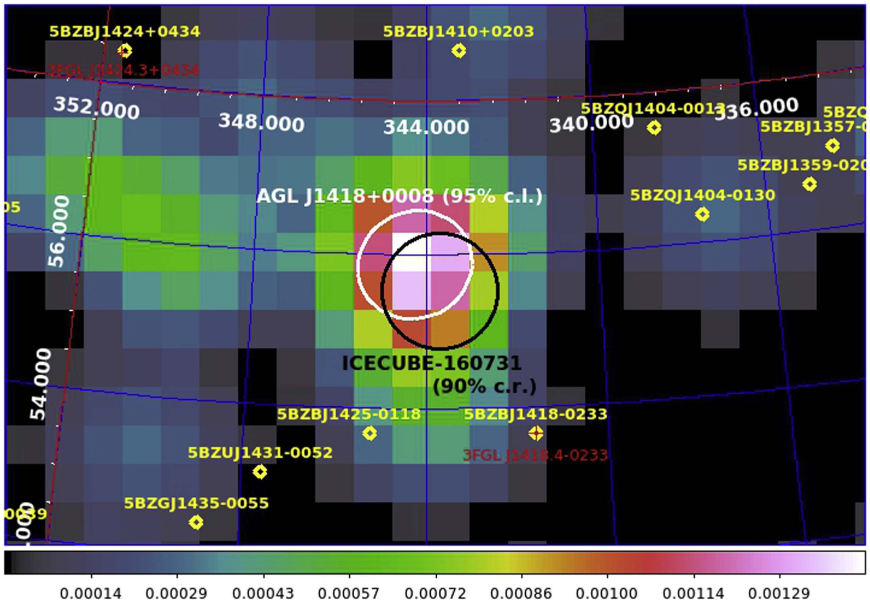

Figure 3. *AGILE*-GRID intensity map in (ph cm^{-2} s^{-1} sr^{-1}) and Galactic coordinates, centered at the ICECUBE-160731 position, from $T_0 - 1.8$ to $T_0 - 0.8$ days. The black circle shows the 90% c.r. of the neutrino event, while the white circle shows the 95% C.L. ellipse contour corresponding to the *AGILE*-GRID ML detection, AGL J1418+0008, which is described in the text. The classified AGNs from the BZCAT Catalog (Massaro et al. 2015) and the *FERMI*-LAT sources from the 3FGL Catalog (Acero et al. 2015) are shown in yellow and in red, respectively. None of these known sources appear within the ICECUBE and *AGILE* error circles.

episodes around the ICECUBE-160731 position. This long-timescale search was performed using the *AGILE*-LV3 online tool (Pittori et al. 2014), accessible from the ASDC Multi-mission Archive webpages.[24] This tool allows fast online interactive analysis based on the Level-3 (LV3) *AGILE*-GRID archive of pre-computed counts, exposure, and diffuse background emission maps.

The search for transient emission above 100 MeV on 2-day integration times did not show any other significant detection other than the one detection compatible with the *AGILE* QL result between one and two days before T_0 (over a total of 271 analyzed maps).

We finally performed a ML analysis centered on the ICECUBE position using the LV3 pre-computed maps for the entire *AGILE* observing time (9 years). We obtained a UL of 3.5×10^{-8} ph cm^{-2} s^{-1} ($E > 100$ MeV, for a 95% C.L.).

4. MWL Follow-up of ICECUBE-160731

The ICECUBE-160731 detection triggered a thorough campaign of MWL follow-up observations. These observations covered a large part of the entire e.m. spectrum, from the optical band (Global MASTER net, iPTF P48, LCOGT) to the VHE gamma-rays (HAWC, MAGIC, HESS, ...).

Very few observatories and space missions were observing the neutrino event position to T_0. Apart from *AGILE* and facilities like HAWC, ANTARES, and *FERMI*-LAT, which have access to a large part of the sky for almost the whole day, all the others had to repoint to the ICECUBE position a few minutes or even hours after T_0. In this section, we will summarize the most interesting results of the MWL follow-up, referring the reader to Table 4 for a summary of all other observations published in ATel and GCNs in the hours and days after the event.

[24] URL: http://www.asdc.asi.it/mmia/index.php?mission=agilelv3mmia.

In the X-ray band, *SWIFT* observed the ICECUBE-160731 error circle region starting approximately from ($T_0 + 1$) hr to ($T_0 + 12$) hr (Evans et al. 2016a, 2016b). The XRT instrument on board the *SWIFT* satellite detected six sources in the 0.3–10 keV band. Figure 4 features a zoom-in of the *AGILE*-GRID intensity map over the integration of the *AGILE* peak detection, with the location of the six *SWIFT*-XRT sources numbered 1 to 6 (blue crosses in Figure 4). After the revision of the best-fit neutrino arrival direction and its error radius, three of the detected XRT sources eventually lay outside the revised ICECUBE-160731 error circle. Only sources #5 and #6 are still compatible with the neutrino position (and within the *AGILE* ellipse contour), while source #2 remains just on the border.

In the optical region, the Global MASTER Optical Network performed a search for optical transients in the time interval ($T_0 + 17$; $T_0 + 21$) hr (Lipunov et al. 2016a, 2016b). They only detected a point-like event, classified as MASTER OT J142038.73−002500.1, that might have been induced by particles crossing the CCD, and the bright NGC 5584 galaxy (which, anyhow, is already outside the revised error circle) (yellow boxes in Figure 4). Rapid follow-up observations in the optical/IR band, started only 3.5 hr after T_0, were performed by the Palomar 48-inch telescope (iPTF P48) (Singer et al. 2016). They detected two optical transient candidates at $1\overset{\circ}{.}1$ and $2\overset{\circ}{.}0$ from the initial neutrino candidate position (magenta diamonds in Figure 4).

In the gamma-ray band, *FERMI*-GBM could not observe the region at T_0 because the position was occulted by the Earth (-Burns & Jenke 2016), while *FERMI*-LAT reported only flux ULs (95% C.L.) above 100 MeV of 10^{-7} ph cm^{-2} s^{-1} in 2.25 days of exposure starting from 2016 July 31 00:00 UTC, and of 0.6×10^{-7} ph cm^{-2} s^{-1} in 8.25 days of exposure starting from 2016 July 25 at 00:00 UTC (Cheung et al. 2016). As shown in the Appendix the non-detection of any gamma-ray precursor to

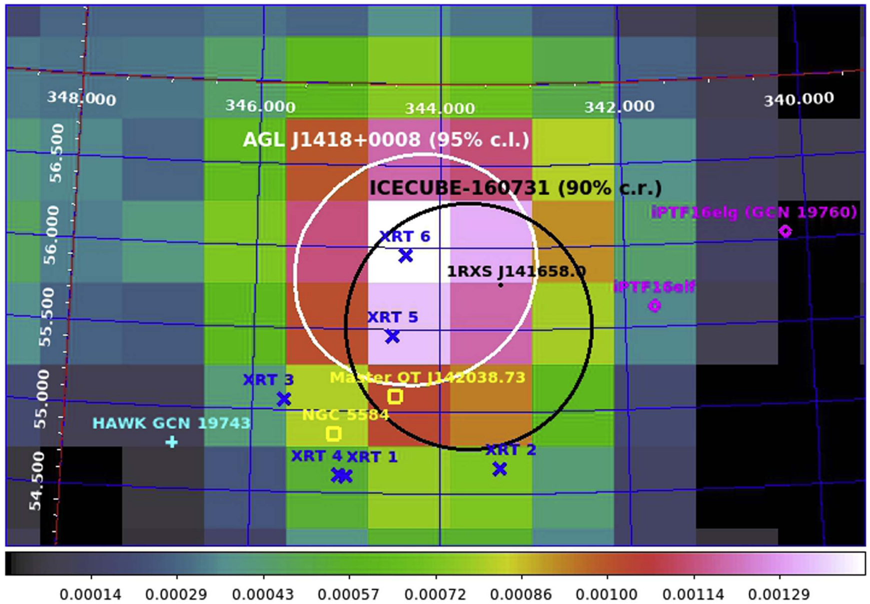

Figure 4. *AGILE*-GRID intensity map in (ph $\mathrm{cm^{-2}\,s^{-1}\,sr^{-1}}$) zoomed-in around the ICECUBE-160731 position, in the time interval ($T_0 - 1.8$; $T_0 - 0.8$) days. The black and white circles again show, respectively, the 90% c.r. of the ICECUBE event and the 95% C.L. contour of the *AGILE*-GRID detection AGL J1418+0008. The figure also shows the positions of several e.m. candidates found during the MWL follow-up. Cyan cross: HAWC best archival search result (Taboada 2016); blue crosses: the six *SWIFT*-XRT sources reported in Evans et al. (2016a, 2016b); yellow boxes: two optical sources (one steady, one transient) detected by the Global MASTER net (Lipunov et al. 2016a, 2016b); magenta diamonds: two optical transients detected by iPTF P48 (Singer et al. 2016); black point: the X-ray source 1RXS J141658.0−001449, which appears within both error circles, and is one of the best neutrino-emitter candidates found in the additional search made with the ASDC tools described in the text.

Table 1
Optical and X-Ray Sources Detected within the Revised ICECUBE-160731 Error Circle during the MWL Follow-up

Mission/Observatory	Source ID/name[a]	R.A. (J2000) (deg)	Decl. (J2000) (deg)	Association	Class
SWIFT-XRT (ATel #9294)	XRT #2	214.90209	−1.145917	2QZ J141936.0−010841	quasar
SWIFT-XRT (ATel #9294)	XRT #5	214.95898	−0.11266	2QZ J141949.8-000644	quasar
SWIFT-XRT (ATel #9294)	XRT #6	214.61169	0.24144	2MASS J14182661+0014283	star
Global MASTER net (ATel #9298)	OT J142038.73−002500.1[b]	215.161375	−0.416694	SDSS J142041.62−002413.1	galaxy
iPTF P48 (GCN 19760)	iPTF16elf	213.555124	−0.894361	Z 18–88	galaxy

Notes.
[a] See Figure 4.
[b] The astrophysical origin of this transient is not confirmed.

Fermi-LAT might be due to a low exposure of the ICECUBE region during the *AGILE* gamma-ray transient.

At the time of the neutrino event T_0, the *INTEGRAL* satellite, which also has the capability to cover almost the whole sky (Savchenko et al. 2016), was not observing because it was close to perigee inside the Earth radiation belts.

The ICECUBE region was also observed in the VHE band by several experiments (see Table 4). Apart from HAWC, which has a 24-hr duty cycle, all the others could repoint to the ICECUBE position hours after T_0, reporting only flux ULs above different energy thresholds. During a search for a steady source using archival data, the HAWC Collaboration reported a location with a pre-trial significance of 3.57σ at R.A., decl. (J2000) = (216.43, 0.15) (deg) (Taboada 2016); shown as a cyan cross in Figure 4), although it was more than 2° away from the neutrino error circle. Considering the number of trials quoted in the HAWC GCN, this is not a significant detection.

5. Possible Neutrino-emitter e.m. Sources in the ICECUBE-160731 and *AGILE* AGL J1418+0008 Error Regions

In what follows, we will further investigate whether some of the steady/transient sources found during the MWL follow-up are good candidates as the ICECUBE-160731 emitter. In particular, we decided to review only the e.m. sources still within the revised ICECUBE error region, plus the closest optical transient detected by iPTF48 (named iPTF16elf, Singer et al. 2016; see Figure 4). Table 1 shows the main characteristics of the five e.m. sources satisfying the chosen selection criteria. The table also shows the most likely known association as reported from each of the ATel announcing the detection obtained during the follow-up.

To find some of the key features of one of the most promising neutrino-emitter candidates, high-energy peaked BL Lac (HBL) AGNs (Padovani et al. 2016; Resconi et al. 2017), we reviewed the initial counterpart association and investigated the broadband spectral properties of each object.

The first two *SWIFT*-XRT sources detected during the follow-up, #2 and #5 (Evans et al. 2016a), are consistent with the position of two known quasars: source #2 is 9.″12 from 2QZ J141936.0−010841[25] (2QZ Cat, Croom et al. 2001), while source #5 is 4.″5 from 2QZ J141949.8−000644.[26] By looking to their spectral energy distributions (SEDs), built using both the XRT detections and MWL archival data, neither of the two quasars shows hints of high-peaked synchrotron emission, which is one of the key features used to identify a HBL type of AGN. Moreover, they completely lack radio emission, which leads us to conclude that they might be radio-quiet quasars and we can discard them as possible emitters of the ICECUBE-160731 neutrino.

XRT source #6 is ∼2.″5 from 2MASS J14182661+0014283, a known G-type star, and it thus can also be excluded as a possible source candidate of the neutrino emission.

Concerning the two optical transient candidates OT J142038.73 −002500.1 and iPTF16elf, they are both positionally consistent with two galaxies (respectively, SDSS J142041.62−002413.1 ($z = 0.054$) and Z 18–88 ($z = 0.038$)), which form part of a cluster. For both, there are no evident indications of blazar features in their respective SEDs.

In addition to reviewing the five e.m. candidates found during the ICECUBE-160731 MWL follow-up, we searched for other possible counterparts within the ICECUBE 90% error circle by exploring the ASDC resident and external catalogs using the online ASDC SkyExplorer tool.[27] In particular, we focused our search on known radio and X-ray sources that might show the typical characteristics of HBL/HSP AGN blazars (Chang et al. 2017): low radio fluxes and low IR-radio spectrum slopes; high X-ray-to-radio flux ratios; ν and synchrotron peaks above 10^{15} Hz.

A query of 50 arcmin around the ICECUBE-160731 centroid Galactic coordinates l, b = (343.68, 55.52 deg) selecting, among others, radio and X-ray sources from the FIRST (White et al. 1997) and RASS Catalogs (Voges et al. 1999, 2000), returned several objects (see Figure 5). Following the search criteria defined above, one of the most interesting objects resulting from the query was a RASS source appearing at ∼19 arcmin from the center, 1RXS J141658.0−001449, with a position and related uncertainty R.A., decl. (J2000) = ($14^{h}16^{m}58^{s}.0$, $-00°14'49''$) ± 25″, (indicated by the dashed circle in Figure 5). This cataloged X-ray source is the only one in the field showing a FIRST weak radio source ($F = 1.99$ mJy; R.A., decl. (J2000) = ($14^{h}16^{m}58^{s}.27$, $-00°14'44''.87$)) within its error circle. A further search in the ASDC optical catalogs found a faint galaxy, SDSS J141658.90 −001442.5 (mv ∼ 23), at 9.6 arcsec from the FIRST source (14.8 arcsec from the RASS source).

Assuming the radio/optical/X-ray emission comes from the same galaxy, we have produced the SED shown in Figure 6. The high value of the ratio between the 1RXS J141658.0 −001449 flux density in the 0.1–2.4 keV band and the FIRST radio source νF_{ν} value at 1.4 GHz (respectively the black and red points in Figure 6) might hint at non-thermal synchrotron emission peaking above 10^{15} Hz, which is typical for a HBL

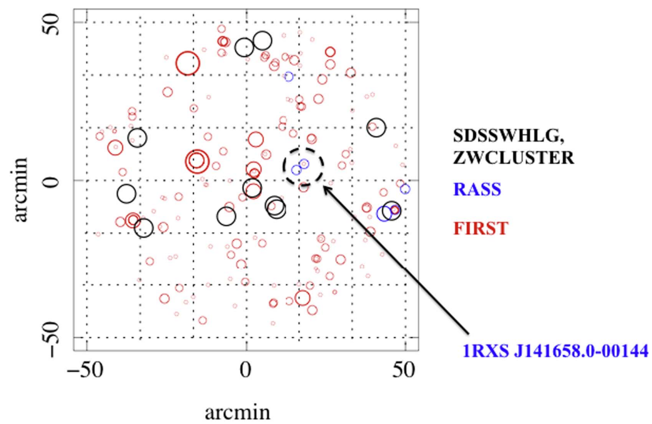

Figure 5. R.A.-decl. sky map (J2000), obtained with the ASDC SkyExplorer tool, showing known radio, optical, and X-ray sources within 50 arcmin from the ICECUBE-160731 position. The map also covers most of the 95% C.L. error circle of the *AGILE* detection described in Section 3.2. Black circles show sources from the SDSSWHLGC and the ZWCLUSTER catalogs (Zwicky et al. 1961; Wen et al. 2009); blue circle sources from the *ROSAT* All Sky Survey (RASS) catalogs (Voges et al. 1999, 2000); red circles are radio sources from the FIRST survey at 1.4 GHz (White et al. 1997). The dashed circle indicates the position of the RASS 1RXS J141658.0−001449 source and the nearby FIRST 1.4 GHz radio source (the blue circle with the smaller red circle inside), a possible HBL AGN candidate (see the text for details).

AGN blazar. Considering these types of e.m. sources as the most likely neutrino emitters, the X-ray source 1RXS J141658.0−001449 (and the plausible host galaxy SDSS J141658.90−001442.5) appears as one of the candidates for inciting the ICECUBE-160731 event.

This source was not in the field covered by the 2016 July 31, *SWIFT* series of ToO observations (Evans et al. 2016a). Interestingly, the source also lies within the 95% error ellipse contour of the *AGILE* detection that occurred before the neutrino event time T_0 (see Figure 4).

5.1. SWIFT ToO Data on the 1RXS J141658.0−001449 Field

To better estimate the position and the spectrum of the RASS 1RXS J141658.0−001449 source (which was not in the field covered by the first *SWIFT* series of ToO observations (Evans et al. 2016a)) and determine a stronger spatial correlation with the radio and optical sources described above, a new *SWIFT* ToO has been submitted and executed in 2016 December, almost six months later than the ICECUBE-160731 neutrino detection.

The data were collected in five distinct ∼1 ks exposures centered on the 1RXS J141658.0 source position between 2016 December 11 00:32:59 UT and 2016 December 15 07:07:53 UT and are entirely in Photon Counting (PC) mode.[28]

Figure 7 shows the (smoothed) cumulative XRT count map in the 0.3–10 keV energy range, with an overall exposure of 4.9 ks. The position of the 1RXS J141658.0 source (with its quoted error circle) is superimposed onto the map (white circle near the map center). No apparent X-ray excess is visible at the 1RXS J141658.0 position.

Using the XIMAGE *sosta* algorithm, we derive a 3σ UL of 3.1×10^{-3} cts s^{-1} in the XRT energy band on the 1RXS J141658.0 position. Assuming a source with a power-law

[25] Also known as [VV2010] J141936.0−010840 (VV2010 Cat., Véron-Cetty & Véron 2010) and SDSS J141935.99-010840.2 (SDSS Cat.—Release #7, Abazajian et al. 2009).
[26] Also known as [VV2010] J141949.9−000644 (Véron-Cetty & Véron 2010), 2MASS J14194982−0006432 (2MASS Cat., Cutri et al. 2003), and SDSS J141949.83−000643.7 (Abazajian et al. 2009).
[27] https://tools.asdc.asi.it

[28] Corresponding *SWIFT* OBSERVATION IDs: from 00034815001 to 00034815005.

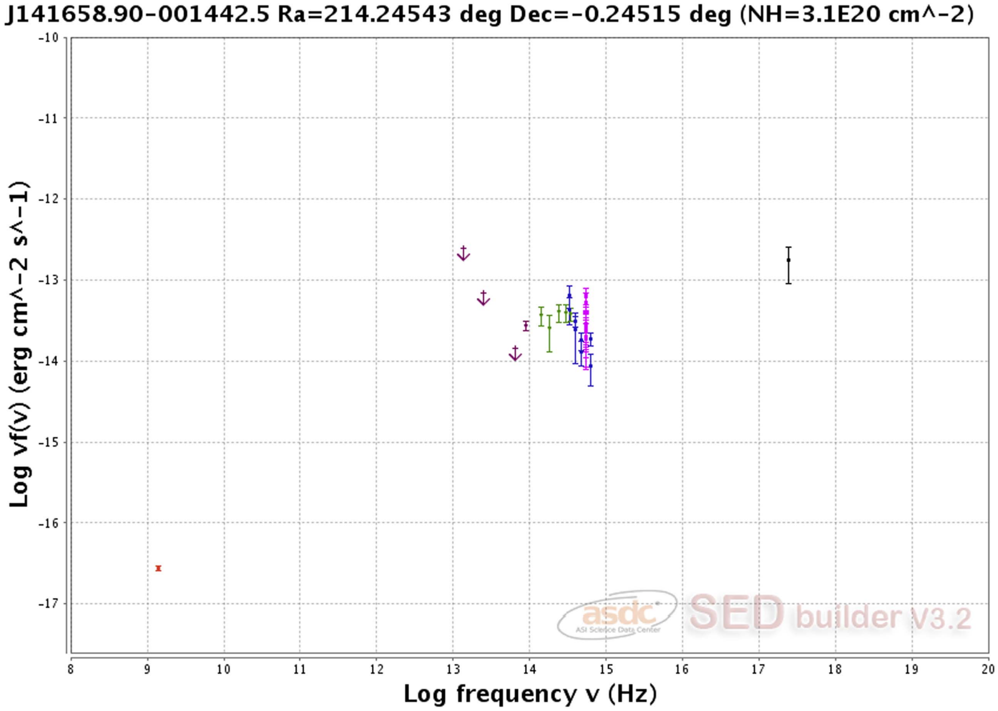

Figure 6. Spectral energy distribution (SED) of the possible HBL candidate, the faint galaxy SDSS J141658.90−001442.5, found within the ICECUBE-160731 error circle. The galaxy appears within the 25″ error circle of the RASS source 1RXS J141658.0−001449 (νF_{ν} value shown as black point in the SED), along with a FIRST 2 mJy radio source (red point). Optical and IR data of the galaxy SDSS J141658.90 come from: the Sloan Digital Sky Survey (SDSS)—Releases #7 and #13 (blue points, Abazajian et al. 2009; SDSS Collaboration et al. 2016); the Catalina Real-time Transient Survey (CRTS; magenta points, Drake et al. 2009); the VIKING survey (green points, Edge et al. 2013); and the AllWISE Data Release (purple points, Cutri et al. 2014).

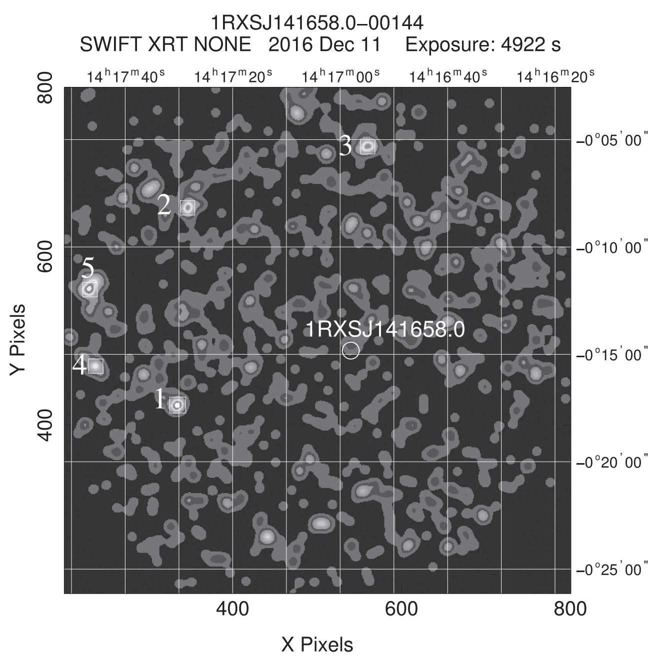

Figure 7. Smoothed *SWIFT*-XRT count map (0.3–10 keV) centered on the *ROSAT*/RASS-FSC 1RXS J141658.0−001449 source, obtained from the *SWIFT* ToO executed on December 2016, almost six months later than the ICECUBE-160731 neutrino detection. Total exposure: ∼4.9 ks. The white boxes show the 5 field sources detected using the XIMAGE detect algorithm. No significant X-ray excess is found at the 1RXS J141658.0 position.

photon index of 1.7, we evaluated a UL of 4.6×10^{-3} cts s^{-1} in the *ROSAT* PSPC band. This value is well below the count rate of $(2.19 \pm 1.04) \times 10^{-2}$ quoted for 1RXS J141658.0 −001449 in the RASS-FSC Catalog. This might indicate an intrinsic variability of the source, which was significant only during the RASS observation. It should be noted that this source does not appear anymore in the second *ROSAT* all-sky survey (2RXS) Catalog (Boller et al. 2016), an extended and revised version of the 1RXS Catalog that contains a significantly reduced number of low reliability sources.

Applying the XIMAGE detect algorithm to the overall 5 ks XRT count map, weighted by the corresponding sum of each single XRT exposure, five (uncataloged) X-ray field sources are detected within the FoV (see Figure 7). Table 2 reports count rates, source coordinates, SNR ratios, and probability of being a background fluctuation for all five detections. Studies of the characteristics of the five field sources are ongoing.

6. Discussion and Conclusions

We reported the results of *AGILE* gamma-ray observations of the ICECUBE-160731 neutrino event error region. These observations covered the event sky location at the event time T_0 and also allowed us to search for e.m. gamma-ray counterparts before and after the event.

Our analysis of the *AGILE*-GRID data in the time window $T_0 \pm 1$ ks with the *AGILE* burst search system has not shown any significant gamma-ray excess above 30 MeV from the neutrino position. Moreover, no burst-like events were detected using the *AGILE*-MCAL and the AC ratemeters around T_0. Instead, an automatic detection above 100 MeV, compatible with the ICECUBE position, appeared from the *AGILE* QL procedure on a predefined 48-hr interval centered around 1.5 days before T_0. Considering the number of trials performed by the *AGILE* QL system and the probability of having a gamma-ray excess in coincidence with the neutrino position, the automatic detection reaches a combined post-trial significance

Table 2
SWIFT-XRT Detections in the 0.3–10 keV Band from the ToO Centered on the 1RXS J141658.0−001449 Source

ID	Count Rate (cts s^{-1})	R.A. (J2000) (hh mm ss)	Decl. (J2000) (dd mm ss)	Prob.	SNR
1	3.16E-03 ± 1.1E-03	14 17 30.209	−00 17 21.842	6.541E-08	2.9
2	2.33E-03 ± 8.8E-04	14 17 28.391	−00 08 10.772	1.884E-06	2.7
3	3.06E-03 ± 1.1E-03	14 16 54.849	−00 05 20.036	2.425E-07	2.8
4	2.75E-03 ± 1.1E-03	14 17 45.479	−00 15 32.932	5.285E-06	2.5
5	4.39E-03 ± 1.4E-03	14 17 46.553	−00 11 59.302	2.972E-10	3.2

of about 4σ. A refined data analysis confirms the QL detection already reported in ATel #9295 (Lucarelli et al. 2016). This new *AGILE*-GRID gamma-ray transient, named AGL J1418+0008, is rather concentrated in time, showing a clustering of events around $(T_0 - 1)$ days, and reaching a peak ML significance of 4.9σ on the 24-hr integration covering the interval $(T_0 - 1.8;\ T_0 - 0.8)$ days. AGL J1418+0008 thus stands as possible ICECUBE-160731 gamma-ray precursor.

No other space missions or observatories have reported any clear indication of a transient e.m. emission consistent with the neutrino position and time T_0. This non-detection of an e.m. counterpart at any of the wavelengths covered by the ICECUBE-160731 follow-up does not exclude the possibility of a bright rapid gamma-ray flare precursor occurring just before the neutrino detection. Most of the instruments involved in the e.m. follow-up, in fact, could repoint their instruments only hours or even a day after T_0, and might have missed the flaring episode seen by *AGILE* at $E > 100$ MeV.

As said in the MLW follow-up summary, *FERMI*-LAT did not report any evidence of a precursor above 100 MeV. As we show in the Appendix, this might be due to a very high *FERMI*-LAT observing angle and a very low exposure of the ICECUBE region with respect to the *AGILE* observations.

Given the high Galactic latitude of the ICECUBE neutrino arrival direction ($b = 55.52$ (deg)), we do expect an extragalactic origin for this event. Indeed, several authors (i.e., Ahlers & Halzen 2014; Padovani et al. 2016) assume that blazar AGNs are the main VHE neutrino-emitter candidates and the only sources capable of explaining the common origin of the diffuse neutrino background seen by ICECUBE, the extragalactic cosmic-ray component, and the isotropic diffuse gamma-ray background observed by *FERMI* (Ackermann et al. 2015). Kadler et al. (2016) found, for the first time, a significant probability that one of the ICECUBE PeV events was spatially and temporally coincident with a major gamma-ray outburst of the Flat Spectrum Radio Quasar PKS B1424−418. Considering that there is a substantial fraction of blazar populations that are not yet resolved, Kadler et al. estimated that around 30% of the detected multi-TeV/PeV neutrinos will not be associated with any known gamma-ray blazar, which appears to be the case for the ICECUBE-160731 event.

Recently, Resconi et al. (2017) found that a significant correlation between known HBL blazars, ICECUBE neutrinos, and ultra-high energy cosmic rays (UHECRs) detected by the Auger and the Telescope Array (TA) exists. We thus searched for a HBL candidate counterpart inside the common ICECUBE and *AGILE* AGL J1418+0008 error circles and found a possible HBL source, the Sloan faint galaxy SDSS J141658.90−001442.5, which appears within the positional error of the RASS source 1RXS J141658.0−001449 and close to a FIRST 2 mJy radio source. The ICECUBE-160731 *SWIFT* follow-up, although rapid, did not cover the field around this possible e.m. candidate. A new *SWIFT* ToO then has to be submitted in order to better characterize this RASS-FSC source. Unfortunately, the ToO was performed about six months after the neutrino event, and the analysis of the XRT data from the almost 5 ks exposure did not reveal any significant X-ray emission at the 1RXS J141658.0 position, providing a 3σ UL of 3.1×10^{-3} cts s^{-1} in the 0.3–10 keV band. We thus cannot currently confirm our hypothesis about the HBL nature of this source, which, anyhow, might have been detected during the *ROSAT* survey because it was in an intrinsic X-ray high-state.

Other possible PeV neutrino emitters have been proposed, like Starburst galaxies, giant radio galaxies with misaligned jets, and GRBs (see Ahlers & Halzen 2014 for a review). Lipunov et al. (2016c), for example, correlated another recent ICECUBE HESE neutrino event (ICECUBE-160814) with an optical transient that occurred almost 10 days after the event time. They postulated that the neutrino emitter might be an ejecting white dwarf in a binary system. This is an intriguing possibility, although the power budget available in these systems (optical companion plus compact object) could not be sufficient to accelerate protons up to multi-PeV energies in order to produce sub-PeV/PeV neutrinos from pp collisions.

None of the other e.m. sources proposed up to now as neutrino-emitter candidates are able to explain the bulk of MWL/multi-messenger (neutrinos plus cosmic rays) observational data like the HBL/HSP class of blazars (Resconi et al. 2017). Indeed, the probability of finding a blazar of this class in a 1° radius sky-area like the ICECUBE-160731 error circle is quite low. Assuming, in fact, an HSP density of the order of 5×10^{-2} deg^{-2} from the 2WHSP catalog (Chang et al. 2017), there are approximately 5 HSP/HBL AGNs for every 100 squared degrees of sky. Thus, the probability of finding one of these objects within the roughly 3 squared degrees covered by the ICECUBE error circle is about 0.15%. In the specific case of the ICECUBE-160731 neutrino, for example, we have not yet found any other potential HBL candidate other than the one not confirmed with the dedicated *SWIFT* ToO observations. Moreover, the *AGILE* transient, which was not confirmed by *FERMI* (although this was caused by a poor *FERMI*-LAT visibility just before T_0), might indicate a possible soft gamma-ray source, in disagreement with the hard-spectrum gamma-ray features expected for the HBLs.

Nevertheless, the HBL scenario can still hold if we assume a lepto-hadronic process occurring within the blazar jet (Righi et al. 2017), where the bulk of broadband e.m. emission is due to synchrotron and inverse Compton leptonic processes, while protons would be mainly responsible for the neutrino flux (from the decay of charged pions produced by photo-meson production on the soft photons field within the jet). In that case, Righi et al. (2017) foresee that a soft gamma-ray component, peaking at MeV/GeV energies, would be expected from reprocessing of VHE photons from the decay of π^0's that originated in the $p\gamma$ collisions within the jet. The *AGILE* observation of the gamma-ray transient AGL J1418+0008, compatible with the neutrino position and very close in time to the event T_0, *if* associated with the ICECUBE event, could then be explained by such a hadronic mechanism.

To conclude, there is also the possibility that the source of the ICECUBE-160731 neutrino event might be either a different AGN type or a different class of source, even though we cannot currently exclude a moderately bright HBL that has not yet been identified.

We would like to thank Paolo Giommi and Matteo Perri for the many fruitful discussions and the valuable help with the analysis of the *SWIFT* ToO data, and Paolo Lipari for the very useful comments about the paper. We also thank the *SWIFT* Team for making the *SWIFT* ToO observations possible, in particular M. H. Siegel, the *SWIFT* Observatory Duty Scientist. *AGILE* is an ASI space mission with programmatic support from INAF and INFN. We acknowledge partial support through the ASI grant no. I/028/12/0. Part of this work is based on archival data, software, or online services provided by the ASI SCIENCE DATA CENTER (ASDC). It is also based on data and/or software provided by the High Energy Astrophysics Science Archive Research Center (HEASARC), which is a service of the Astrophysics Science Division at NASA/GSFC and the High Energy Astrophysics Division of the Smithsonian Astrophysical Observatory. This research has also made use of the SIMBAD database and the VizieR catalog access tool, operated at CDS, Strasbourg, France.

Software: AGILE scientific analysis software (BUILD 21; Chen et al. 2011), XIMAGE.

Appendix
A Comparison between *AGILE* and *FERMI*-LAT Data during the ICECUBE-160731 Event

In this appendix, we verify that the *FERMI*-LAT non-detection of the *AGILE* possible gamma-ray precursor of the neutrino 160731 event might be due to poor exposure and a non-optimal viewing angle of the ICECUBE error circle.

We have compared the *FERMI*-LAT attitude data with the *AGILE* data during the time interval ($T_0 - 2$; T_0) days (MJD 57598.07991÷57600.07991) and found that *FERMI*-LAT observed the ICECUBE error circle at an off-axis angle lower than 50° only for 3.9% of its total exposure time, while for *AGILE* the exposure time below the same off-axis angle amounted to 27.4% of the total (see Figure 8).[29]

Further investigations of the *FERMI* spacecraft data also show several periods of untaken data during the same time interval (amounting to ~15% of the total observation time), particularly near ($T_0 - 1$) days (as can be seen from Figure 8), where *AGILE* found a clustering of gamma-like events compatible with the ICECUBE error circle.

To prove that during this period the *AGILE* and *FERMI*-LAT exposures on the ICECUBE region were *at least* comparable, we have evaluated the exposures for both instruments on time intervals of 24, 12, and 6 hr centered at ($T_0 - 1$) days (MJD = 57599.07991), where the *AGILE* detection reached its peak significance.

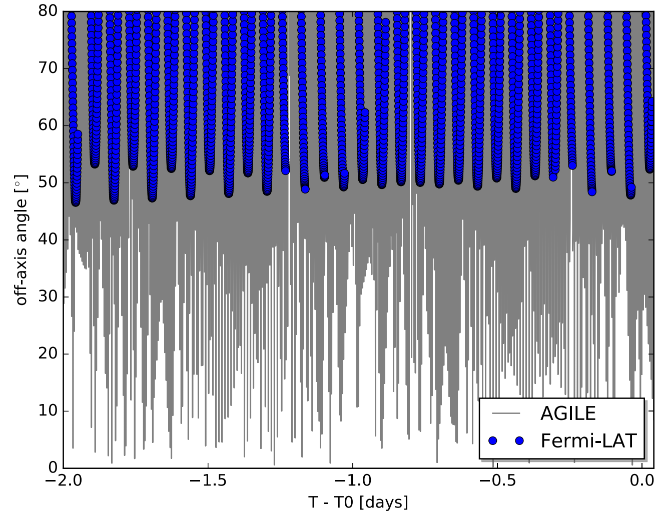

Figure 8. Time evolution of the ICECUBE-160731 region off-axis angles as observed by *AGILE* and *Fermi*-LAT during the 48-hr time interval of ($T_0 - 2$; T_0) days (MJD 57598.07991÷57600.07991).

Table 3
AGILE and *FERMI*-LAT Exposures on the ICECUBE-160731 Error Circle during the Period of Detection of the Possible Gamma-Ray Precursor AGL J1418+0008

Interval (MJD)	Duration (hr)	*AGILE* Mean Exp (cm^2 s)	*FERMI*-LAT Mean Exp (cm^2 s)
57598.25÷57599.25	24	3.7E+06	3.8E+06
57598.75÷57599.25	12	1.7E+06	1.2E+06
57598.875÷57599.125	6	8.2E+05	4.7E+05

Note. For both instruments, a maximum off-axis angle of 50° between the source and FoV center has been assumed.

We downloaded Pass8 data[30] around the position of ICECUBE-160731, and using version v10r0p5 of the Fermi Science Tools provided by the Fermi satellite team[31] and the instrument response function P8R2_SOURCE_V6, we calculated the mean exposure values on the neutrino error circle on those different integration times. We selected Pass8 FRONT and BACK source class events, and in order to be comparable with the *AGILE* spectral sensitivity (optimized for the observation of soft gamma-ray sources with typical spectral indexes of 2÷2.1), we limited the event energies to between 0.1 and 10 GeV.

Table 3 shows the values of the *FERMI*-LAT and *AGILE* exposures on the different time intervals chosen and for a maximum off-axis angle between the source and FoV center of 50°.

The LAT exposure on the 24-hr interval MJD 57598.25 ÷57599.25 becomes comparable with the *AGILE* exposure of 3.7×10^6 cm^2 s obtained under the same maximum viewing angle and the same integration time. On the shorter intervals of 12 and 6 hr around ($T_0 - 1$) days, the *AGILE* exposure becomes even larger than the *FERMI* one. Assuming, thus, a

[29] At high values of the off-axis angle (>50°), the Fermi/LAT sensitivity is up to 50% lower than the nominal on-axis value.

[30] From the *FERMI* data ASDC mirror (https://tools.asdc.asi.it).

[31] http://fermi.gsfc.nasa.gov

Table 4
Summary of the MWL Follow-up of the ICECUBE-160731 Event

Mission/Observatory (Energy band)	ATel #	GCN Circular #	Observation/Integration Time (UTC)	Comments
HAWC (TeV gamma-rays)	⋯	19743	2016 Jul 30 21:28:57–2016 Jul 31 02:59:15	No detection around neutrino event time T_0 (most significant location (1.12σ) at R.A., decl. (J2000) = 214.67, 1.04 deg). From archival data, a pre-trial 3.57σ detection from R.A., decl. (J2000) = 216.43, 0.15 deg is reported.
SWIFT (X-ray, Optical/UV)	9294	19747	2016 Jul 31 03:00:46–2016 Jul 31 14:51:52	Six known or cataloged X-ray sources detected (0.3–10 keV) but no transient events. No transient sources detected in the simultaneous UVOT data.
AGILE (Gamma-rays)	9295	⋯	2016 Jul 29 02:00–2016 Jul 31 02:00 2016 Jul 28 08:00–2016 Jul 30 08:00	$>4\sigma$ pre-trials detection on the interval 2016 Jul 28/2016 Jul 30 (08:00) UT.
Global MASTER net (Optical)	9298	19748	From 2016 Jul 31 19:23:17 on	No optical transients detected inside 2 square degrees around the center of ICECUBE-160731 Rev. #0 error circle. Detected one likely particle CCD event (OT J142038.73−002500.1) and the NGC 5584 galaxy.
FACT (TeV gamma-rays)	⋯	19752	2016 Jul 31 21:42–2016 Jul 31 22:25	No detection.
HESS (TeV gamma-rays)	9301	⋯	2016 Jul 31/ Aug 01 (1 hr) 2016 Aug 01/02 (1 hr)	No detection.
FERMI-LAT (Gamma-rays)	9303	⋯	2.25 days from 2016 Jul 31 00:00 8.25 days from 2016 Jul 25 00:00	No detection above 100 MeV.
FERMI-GBM (X-ray/ Gamma-rays)	⋯	19758	Neutrino event trigger time (T_0).	Position occulted by Earth at T_0. Flux UL at 3σ level (12–100 keV) on the interval Jul 30–Aug 1.
iPTF P48 (Optical/IR)	⋯	19760	From 2016 Jul 31 05:22 on.	No optical transients detected close to the ICECUBE updated error circle. Two optical transient candidates (iPTF16elf and iPTF16elg) detected at 1.1 and 2.0 deg from the neutrino candidate position, both consistent with known galaxies.
MAXI/GSC (X-ray)	9313	⋯	At 2016 Jul 31 02:32. From 2016 Jul 20 to 2016 Aug 03.	No detection on the 2–20 keV band within the ICECUBE error circle, neither near T_0 nor in the period Jul 20–Aug 3. 3σ U.L., are provided.
MAGIC (TeV gamma-rays)	9315	⋯	2016 Jul 31 21:25–2016 Jul 31 22:47	No detection above 600 GeV.
ANTARES (TeV/PeV neutrinos)	9324	19772	$T_0 \pm 1$ hr $T_0 \pm 1$ day	No up-going muon neutrino candidate events recorded within three degrees of the ICECUBE event coordinates. 90% ULs on the fluence from a point-like source are reported.
Konus–Wind (X-ray/ Gamma-rays)	⋯	19777	$T_0 \pm 1000$ s From 5 days before to 1 day after T_0.	No triggered events detected. 90% C.L. upper limits are reported on the 20–1200 keV fluence for typical short and long GRB spectra.
LCOGT (Optical)	9327	⋯	From 2016 Jul 31 23:04:41 till 2016 Aug 03 18:29:11.	No detection of new optical sources down to 3σ limiting magnitudes >19.

very short gamma-ray flare, as the *AGILE* detection indicates, this might imply the possibility that *FERMI*, given the very low exposure and the large viewing angle of the ICECUBE-160731 position during this period, lost most of the gamma-ray transient episode. Differences in the event classification algorithms between the two instruments can also result in a detection/non-detection in cases with short gamma-ray transients at a level of 4σ above the background.

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