Multi-wavelength follow-up observations of ANTARES neutrino alerts

D. Dornic (CPPM)

D. Turpin (IRAP), M. Ageron, V. Bertin, J. Brunner, A. Mathieu (CPPM), F. Schüssler, B. Vallage (CEA/IRFU), S. Basa (LAM) on behalf the ANTARES, TAROT, MASTER, ZADKO, Swift, MWA, H.E.S.S. Collaborations
ANTARES in few numbers:

- 12-line data taking since 2008
- \( \sim 11000 \) detected neutrinos
- Angular resolution: 0.3-0.4° (median)
- Effective area: \( \approx 1 \text{m}^2 \) @ 30 TeV
- Visibility: \( \frac{3}{4} \) of the sky, most of the galactic plane
- Real-time data processing
External Inputs

- GCN notices: GRB, SGR, IC
- GW notices: LIGO/VIRGO
- FRB notices: SUPERB

* alerts also from SNEWS

ANTARES on-line data

- Run Control TATOo
  - 2 x On-line reconstructions
  - Alert trigger
  - On-line analysis

(Cf Poster #984)

External servers

- TAROT
- ZADKO
- MASTER
- GWAC
- SWIFT
- MWA
- HESS
- HAWC
- GCN
- Mail
- SMS

ANTARES neutrino alerts

**Triggers:**
- Doublet of neutrinos: \( \sim 0.04 \) events / yr.
- Single neutrino with direction close to local galaxies: \( \sim 1 \) TeV, \( \sim 10 \) events / yr.
- Single HE neutrinos: \( \sim 7 \) TeV, \( \sim 15 \) events / yr
  - Sub-sample HE neutrinos: \( \sim 5 \) TeV, 20 events / yr
  - Sub-sample VHE neutrinos: \( \sim 30 \) TeV, \( \sim 3-4 \) events / yr.

**Performances:**
- Time to send an alert: \( \sim 5 \) s
- First image of the follow-up: \(< 20 \) s (with TAROT/MASTER few alerts in 17 s)
- Median angular resolution: \( 0.3-0.4^\circ \)
- Dedicated optical image analysis pipeline

Multi-λ observatories

- TAROT
- HESS
- MASTER
- SVOM/GWAC
- MWA
- ZADKO
- HAWC
- SWIFT
- ROTSE
- ANTARES
Statistics of the sent neutrino alerts (07/2009-07/2017)
- 256 alerts sent to robotic telescopes
- 13 sent to Swift
- ~20 to MWA
- 2 to HESS
Visible:
161 alerts analyzed 01/2010-07/2017 from TAROT, ROTSE, MASTER (63% of all alerts)
=> 24 alerts with delay <1min (best: 17s)
=> no transient candidate associated to neutrinos

X-ray:
13 alerts analyzed 06/2013-07/2017
=> average delay ~5-6 hours
=> no transient candidate associated to neutrinos

=> Constrains on origin of individual neutrinos
=> Interpretation of the UL in the case of GRB afterglow
Alert VHE (Sept. 1, 2015)
(Nhit, Amp) = (127, 356), E ~ 50 TeV
RA=246.306°; dec=-27.468°

Sent after 10 s to MASTER, Swift-XRT
➡ Follow-up with Swift-XRT after 9h
➡ Follow-up with MASTER after 10h
Alert VHE (Sept. 1, 2015)
(Nhit, Amp) = (127, 356), E ~ 50 TeV
RA=246.306°; dec=-27.468°

Sent after 10 s to MASTER, Swift-XRT
➡ Follow-up with Swift-XRT after 9h
➡ Follow-up with MASTER after 10h

➡ Emission of a GCN notice (#18231) and an ATEL (#7987) after ~24h to require more follow-up to identify the X-ray flare
Great interest from the community: 15 ATels + 6 GCNs + few non-reported

- Neutrino
  IceCube: ATel 8097

- Optical
  Pan-STARRS: ATel 7992, 8027
  SALT: ATel 7993
  NOT: ATel 7994, GCN 18236
  WiFes: ATel 7996
  CAHA: Atel 7998, GCN 18241
  MASTER: ATel 8000, GCN18240
  LSGT: ATel 8002
  NIC: ATel 8006
  ANU: GCN 18242
  GCM: GCN 18239
  VLT/X-Shooter: private

- X-ray
  Integral: ATel 7995
  MAXI: ATel 8003
  Swift: ATel 8124, GCN 18231

- Radio
  Jansky VLA: ATel 7999, 8034

- Gamma-ray
  MAGIC: ATel 8203
  Fermi/GBM: GCN 18352
  HESS: private
  HAWC: private

=> USNO-B1.0 0626-0501169: young accreting G-K star, or a binary system of chromospheric active stars (RS CVn) undergoing a flaring episode that produced the X-ray emission.”
Long-term visible follow-up

**Long-term follow-up: TAROT/ROTSE**

- **Alert types:** 56 DIRECTIONAL + 121 HE trigger
- **Dedicated analysis pipeline** for TAROT/ROTSE images (stacking night-by-night + subtraction). MASTER used its standard online transient pipeline
- **No SN** (and no interesting transient) associated with the neutrinos
- **$N_{\text{exp}}(SN) = 0.3-0.4$** for the full follow-up [SN rate=$2.4 \times 10^{-4} \text{ yr}^{-1} \text{Mpc}^{-3}$]

**177 alerts with a “rather good” long-term follow-up** (> 3 nights for TAROT+ROTSE+ > 2 nights for MASTER)

- Alert types: 56 DIRECTIONAL + 121 HE trigger
- Dedicated analysis pipeline for TAROT/ROTSE images (stacking night-by-night + subtraction). MASTER used its standard online transient pipeline
- No SN (and no interesting transient) associated with the neutrinos
- $N_{\text{exp}}(SN) = 0.3-0.4$ for the full follow-up [SN rate=$2.4 \times 10^{-4} \text{ yr}^{-1} \text{Mpc}^{-3}$]
MWA radio follow-up

**Murchison Widefield Array**: Low-frequency (80-300 MHz) radio telescope in Western Australia with a ~1000 sq degrees field of view

Radio follow-up of 2 alerts

<table>
<thead>
<tr>
<th>Trigger ID</th>
<th>UT date</th>
<th>UT time</th>
<th>RA (deg)</th>
<th>Dec (deg)</th>
<th>Energy (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT 131121A</td>
<td>2013 Nov 21</td>
<td>14:58:28</td>
<td>53.5</td>
<td>-35.1</td>
<td>~ 1</td>
</tr>
<tr>
<td>ANT 140323A</td>
<td>2014 Mar 23</td>
<td>15:31:01</td>
<td>150.9</td>
<td>-27.4</td>
<td>~ 4</td>
</tr>
</tbody>
</table>

**Results**: no radio transient/variable sources

- Limits on progenitors if neutrinos are cosmic

If source at 20 Mpc, $\text{UL}(5\sigma) = 90-340 \text{ mJy} \rightarrow L_{150 \text{ MHz}} < 10^{29} \text{ erg/s/Hz} (<10^{37} \text{ erg/s})$

If NS-NS coalescence limit on the distance $z > 0.2$ (> 1 Gpc)
High-energy $\gamma$-ray follow-up

2016-17: Agreement ANTARES-H.E.S.S. to follow alerts

- H.E.S.S has followed 2 alerts shortly after the neutrino trigger.
  - ANT150901A: follow-up after ~2.5 days
    => No VHE transient source
    => $\Phi(E > 320GeV; 99\% C.L.) < 2.7 \times 10^{-8} m^{-2}s^{-1}$
  - ANT170130A: follow-up after 32s
    => No VHE transient source (Prelim)

Analysis of HAWC data at the time of the neutrino alert in progress
Conclusion

Very performant & efficient alert sending system:
  => Able sending in ~5s with a precision of 0.3-0.4° (3 muon-neutrino triggers)
  => Full multi-wavelength follow-up covering the whole EM spectrum
  => 256 alerts sent to robotic telescopes, 13 to Swift, a few to MWA & HESS
  => Up to now, no significant transient associated to the neutrinos

Start to implement the on-line framework within both KM3NeT ARCA & ORCA neutrino detectors (improved sensitivities)
In the KM3NeT Fr site, few months ago...