Searching for Sources of High-Energy Neutrinos with *Swift*

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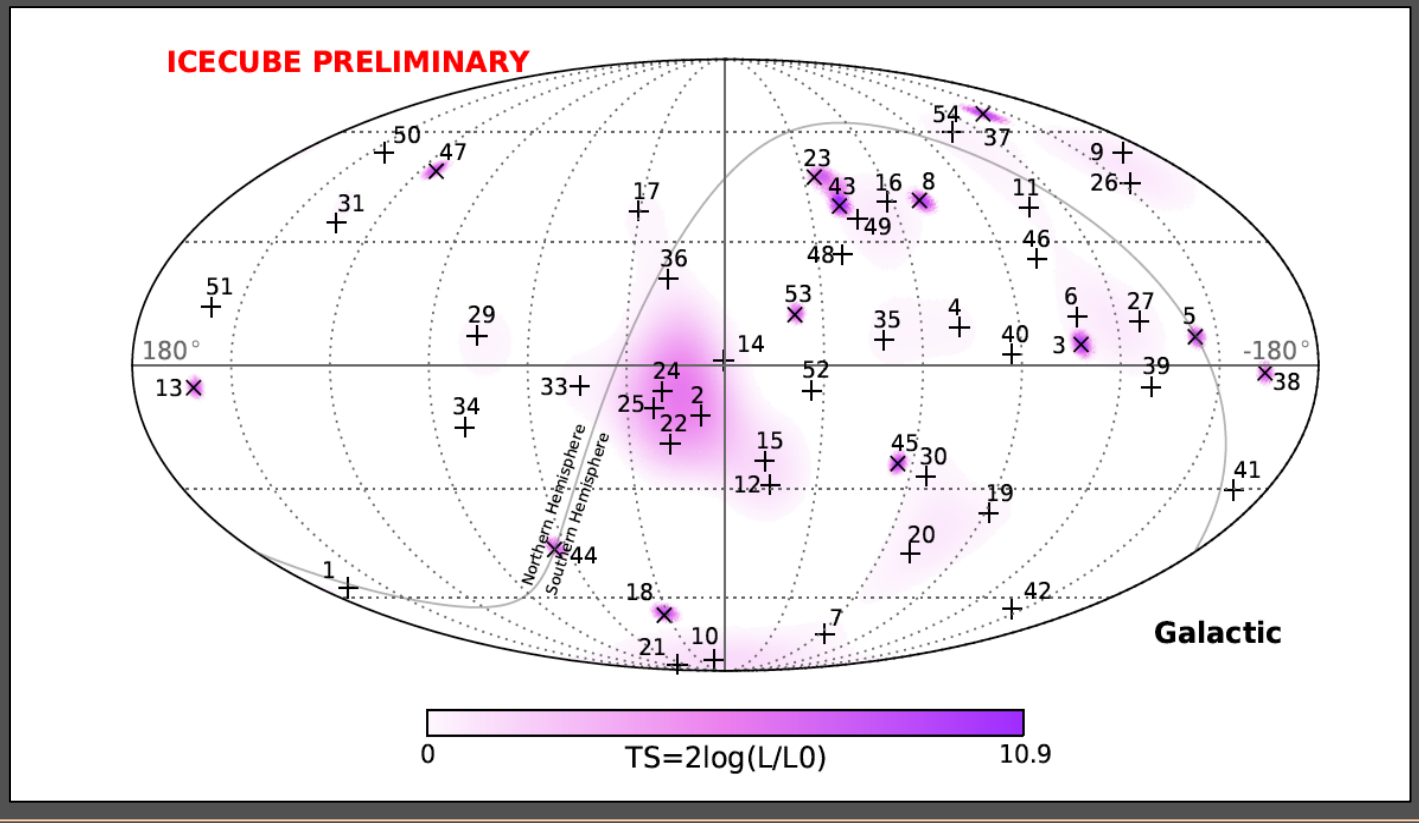
HAP Workshop | Monitoring the non-thermal Universe
Dec 7, 2016

IceCube Detection of High-Energy Neutrinos

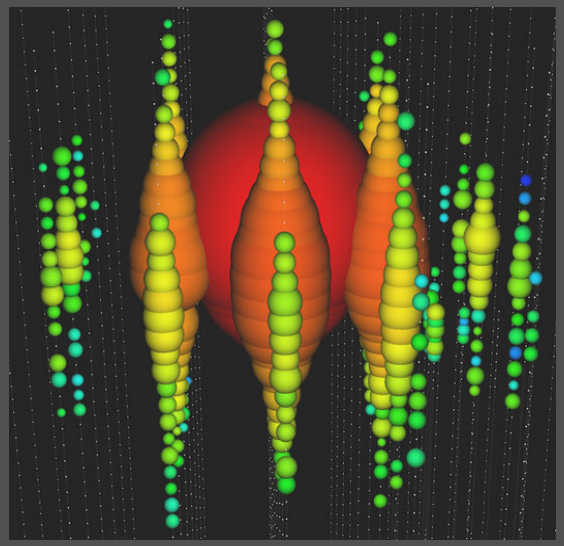


54 High-Energy Starting Events (HESE) in 4 years of data:

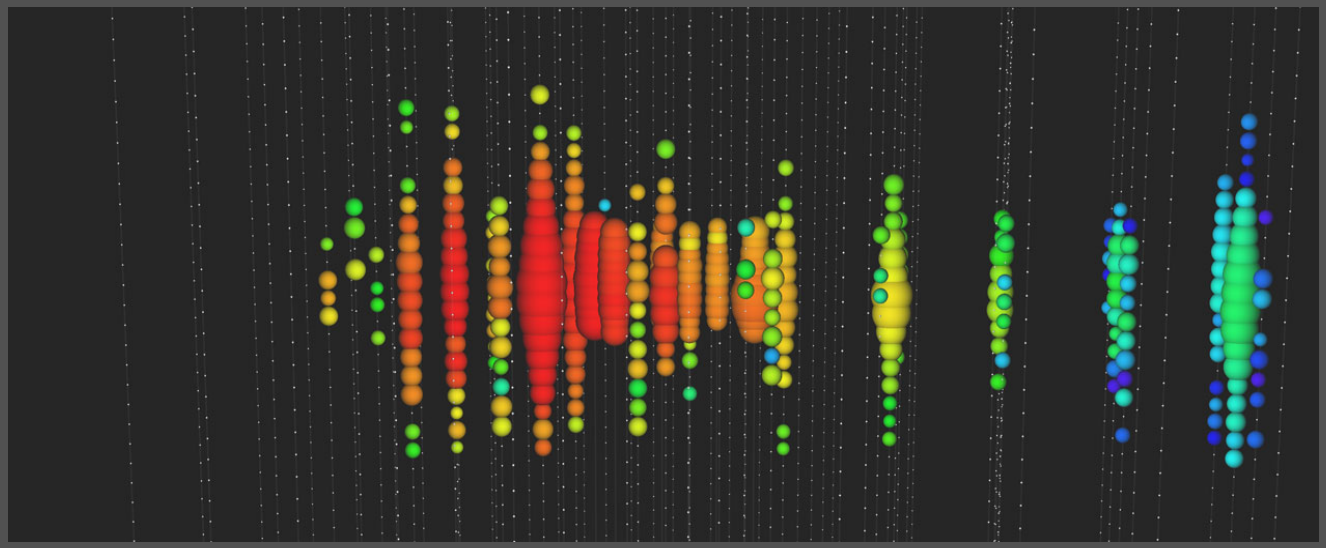
- Outer strings of the facility as a veto layer
- Large deposited energy in a restricted fiducial volume

→ Contamination by muons and atmospheric neutrinos reduced

HESE Topology



Cascade-like event
Average angular error 15°



Track-like event
Average angular error 1°

Track-like events resulting from charged-current interactions of muon neutrinos:

- better localization
- suitable for *Swift*

Neutrino Source Candidates

- The origin of HESE cosmic neutrinos is unknown.
- Candidate source populations include:
  - Gamma-ray busts
  - Blazars and other types of AGN
  - Ultra-luminous star-forming galaxies
  - Hupernovae
  - Other types of supernovae, including “quenched jet” GRBs.

A powerful approach to Source Identification

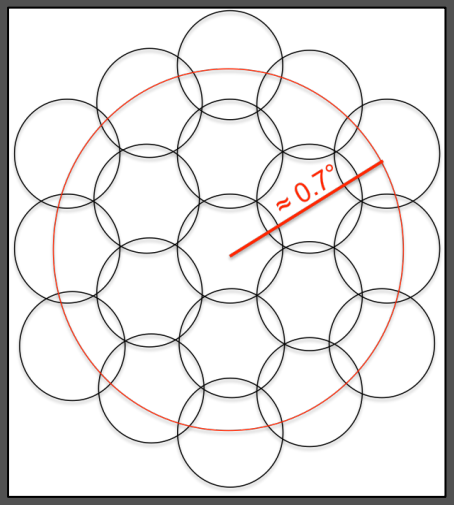
- Neutrino localizations are too uncertain
- Better approach to source identification:
  - Identify neutrino localization in realtime
  - Carry out a prompt search for its electromagnetic counterpart

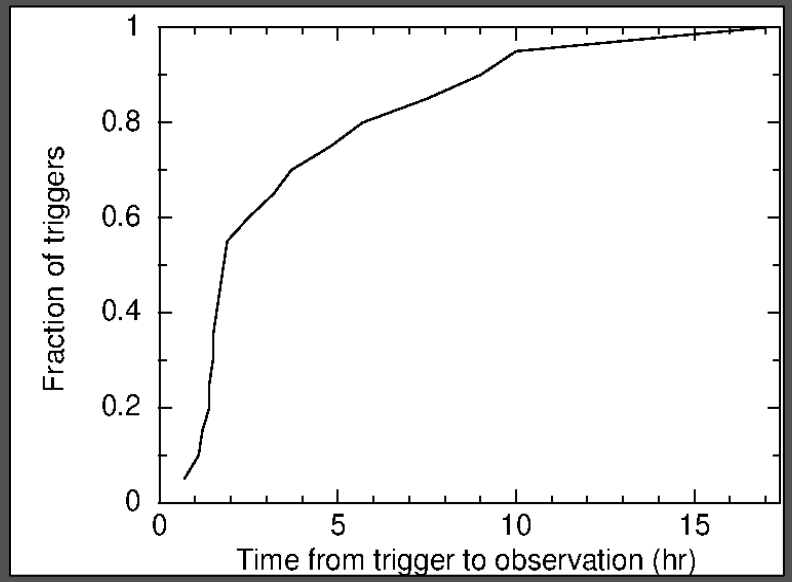
- HESE sample: high probability of being astrophysical
- Most proposed source populations: X-ray and optical emission

Swift: an ideal follow-up facility

Our proposal:

- 50% confidence error region of high-confidence (p_cosmic > 80%) HESE neutrinos
- Observe with Swift in 19-tile pattern



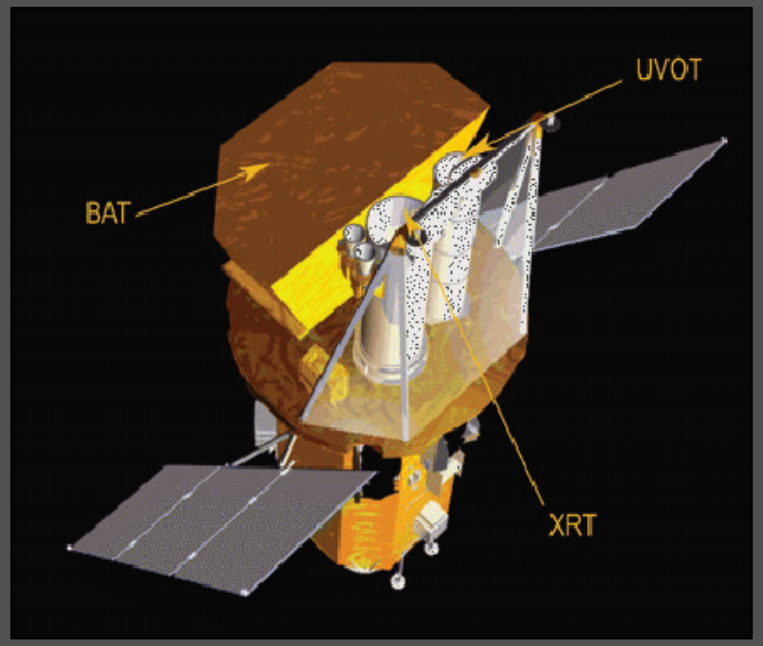


Evans, P. A. et al, 2015 MNRAS, 448, 3.

- Within 16 hours of the neutrino detection
- Automatic process
- XRT and UVOT

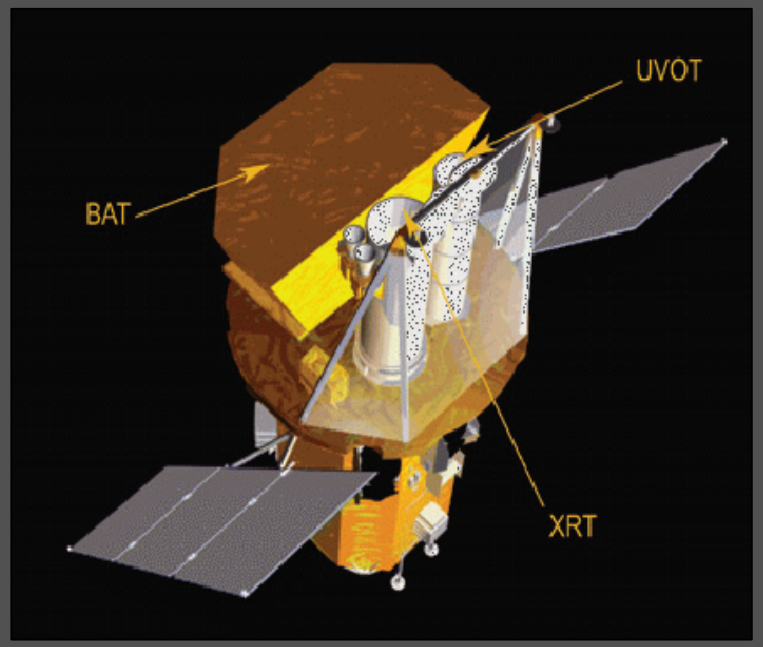
Follow-up Plan

- Cycle 12 approved and funded
- April 2016 – March 2017
- Three approved triggers: priority I TOO
- IceCube HESE realtime analysis:
  - Identified and localized at the South Pole
  - Telemetered via Wisconsin to AMON at Penn State (median latency ≈ 38 s)
  - Convert into GCN notices
  - Notices are publicly available (http://gcn.gsfc.nasa.gov/amon.html)
  - Swift follows up track-like HESE with flux of >7000 p.e.
- Recovers >50% of Swift GRB afterglows



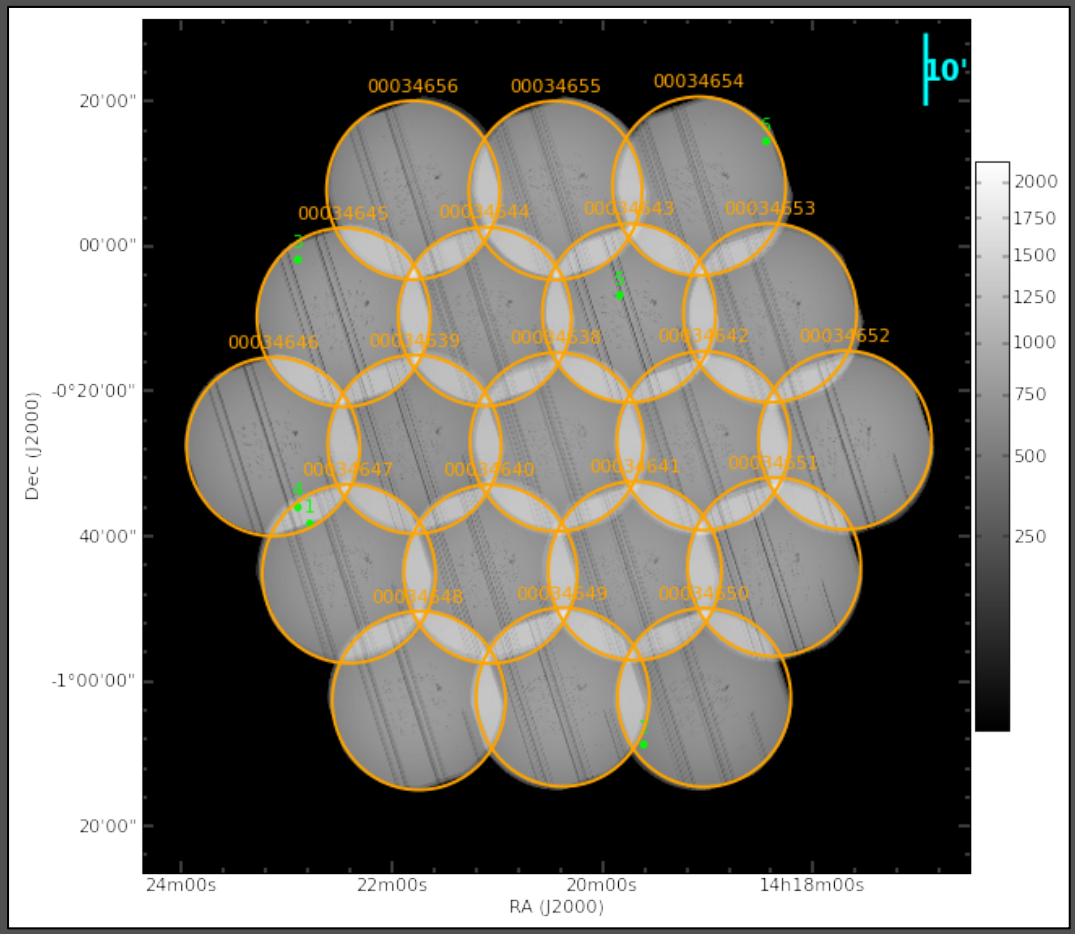
Follow-up Plan - Continued

- Automated analysis of the XRT data: University of Leicester (Phil Evans)
- Sources selected for subsequent monitoring:
  - Bright and previously uncatalogued X-ray source
  - Variability over the course of the tiling observations
- Search UVOT data for new and interesting/variable sources to submit for follow-up.
- New and variable sources (≈ 2) with subsequent follow-up observations:
  - Three daily epochs
  - Two Swift pointing
  - 1 ks per pointing
- Total observing request is
  - 31 ks (i.e. 19+2*3*2) per HESE or
  - 93 ks total.



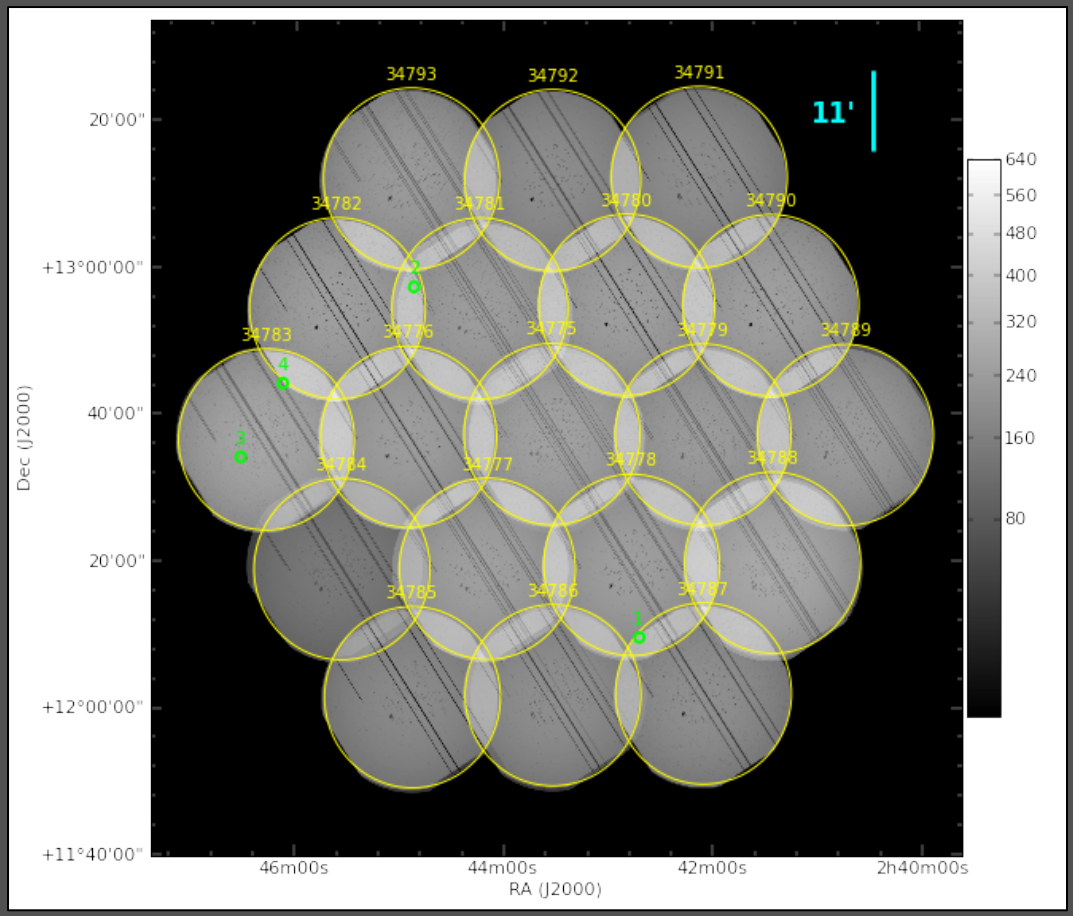
First Swift follow-up of a HESE alert

- IceCube-160731A:
  - 2016 July 31
  - (RA, Dec) = (215.109°, -0.458°)
  - Error 1.2°
- Swift followed up this event within about an hour
- Radius of 0.8°
- Observations: 03:00:46 – 14:51:52 UT
- Covered 2.1 deg^2
- XRT collected ≈ 800 s of PC mode data per tile
- Six X-ray sources → all known
- No transients in XRT or UVOT data



Second Swift follow-up of a HESE alert

- IceCube-161103A:
  - 2016 November 3
  - (RA, Dec) = (40.874°, +12.616°)
  - Error 1.2°
- Swift followed up this event within about five hours
- XRT radiator pointed towards Sun, made XRT very hot
- Radius of 0.8°
- Observations: 13:58:30 – 18:55:15 UT
- Covered 2.1 deg^2
- XRT collected between 150 and 250 s of PC mode data per tile
- Four X-ray sources → unknown but faint



Future Proposed Plan

- Add Extremely High-Energy (EHE) events in Cycle 13:
  - high-energy throughgoing tracks
  - energies exceeding several hundreds TeV
  - Better resolution (≈ 0.2°)
  - Expected rate 4 to 6 (2 background)
  - 7-pointing mosaic
  - Completion of tiling pattern within 10 hours
  - Recover >79% of Swift GRB afterglows
- Propose follow-up of 2 HESE and 4 EHE
  - 1 ks per pointing
  - new pointings for object of interest
  - two daily epochs at 2 ks per epoch
  - 27 ks per HESE, 11 ks per EHE (total of 98 ks)

Thanks