The IceCube event from Sept 22, 2017: observations and conclusions

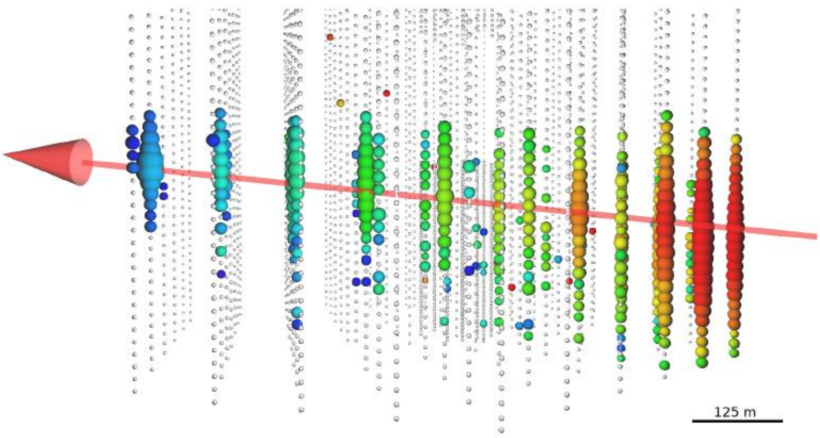
On July 12, 2018, SCIENCE has published two papers which herald a new phase of neutrino and multi-messenger astronomy.

- ***Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A*** (The collaborations IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA), *Science* **361**, eaat1378 (2018). DOI: 10.1126/science.aat1378

- ***Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert*** *Science* **361**, 147-151 (2018). DOI: 10.1126/science.aat2890

Titles of several follow-up papers to be published in other journals are listed below.

On Sept. 22, 2017, IceCube has observed a neutrino event with ~290 TeV energy (~45 times the energy of a proton of the Large Hadron Collider in CERN) and immediately alarmed the astronomers community. The neutrino turned out to be spatially coincident with the blazar TXS 0506+056. The Fermi-LAT satellite detector reported this source to emit gamma-rays with enhanced intensity since months, with energies in the GeV range. Shortly later, the MAGIC gamma-ray telescopes at La Palma observed the same object to be in a flaring state at energies of hundreds of GeV. Additional observations from radio wavelengths to very high-energy gamma rays provided a complete picture of the flaring source. The chance that the neutrino event and the gamma-ray observations are uncorrelated can be rejected at the 3σ level – which corresponds to a chance probability of about 1:1000.[1]



The high-energy IceCube neutrino event from Sept. 22, 2017. The time at which a Digital Optical Module (DOM) observed a signal is reflected in the color of the hit (red for earliest hits and blue for latest), and the size of a colored sphere is proportional to the amount of light observed at the DOM. The best-fit track direction is shown as an arrow.

[1] If they indeed *were* uncorrelated the neutrino was either one of the hundred thousand of neutrinos per year which are recorded with IceCube but emerge from the Earth's atmosphere, or indeed it was an astrophysical neutrino, but not from this source. Actually IceCube records about a dozen of astrophysical neutrinos per year, without being able to identify their origin so far.

Prompted by this observation, the IceCube collaboration has investigated data from the past 9.5 years of operation. At the location of TXS 0506+056, a time-variable excess of neutrinos was found between September 2014 and March 2015. This excess is inconsistent with the background-only hypothesis at the 3.5σ level – corresponding to a chance probability of about 1/5000. No bright flaring in gamma-rays are observed in the Fermi-LAT data archives from this time, but indications of a spectral hardening have been reported in the second of the follow-up papers listed below (Padovani et al.).

ANTARES, the much smaller neutrino telescope in the Mediterranean Sea, reports no significant excesses in neutrinos from the direction of TXS 0560+056: neither within $\pm$1 hours around the IceCube event from Sept. 22, 2017 nor in earlier time periods (fifth in the paper list below).

The implied neutrino luminosity of TXS 0506+056 is found to be at comparable levels to its observed gamma-ray luminosity. When both results are considered together, this provides compelling evidence (but not yet an undisputable discovery, i.e. an effect of 5 standard deviations), that blazars, especially TXS 0506+056, are a site of very-high-energy cosmic ray acceleration and that they contribute to the diffuse astrophysical neutrino flux which IceCube has detected in 2013 and is measuring with steadily increasing statistics since then.

Further detections and additional observations are needed to clearly resolve the source of all cosmic neutrinos observed by IceCube. However, neutrino astronomers of the Global Neutrino Network GNN can see light at the end of the tunnel. They have now an even stronger motivation than before to build the planned detectors with 2-5 times better point source sensitivity: KM3NeT in the Mediterranean Sea and the Gigaton Volume Detector GVD in Lake Baikal (both already under construction) and IceCube Gen2 at the South Pole (to be built in the 2020s). Last but not least, this a wonderful demonstration of the power of multi-messenger astronomy!

List of follow-up papers:

1. "The blazar TXS 0506+056 associated with a high-energy neutrino: insights into extragalactic jets and cosmic ray acceleration," The MAGIC Collaboration: M. L. Ahnen et al. Accepted for publication in *The Astrophysical Journal Letters*. DOI: 10.3847/2041-8213/aad083

2. "Dissecting the region around IceCube-170922A: the blazar TXS 0506+056 as the first cosmic neutrino source," P. Padovani, P. Giommi, E. Resconi, T. Glauch, B. Arsioli, N. Sahakyan, and M. Huber, Accepted for publication in *Monthly Notices of the Royal Astronomical Society*. DOI: 10.1093/mnras/sty1852

3. "VERITAS Observations of the BL Lac Object TXS 0506+056," VERITAS Collaboration: Abeysekara et al. *The Astrophysical Journal Letters* (2018). DOI:10.3847/2041-8213/aad053

4. "A Multimessenger Picture of the Flaring Blazar TXS 0506+056: Implications for High-Energy Neutrino Emission and Cosmic Ray Acceleration," A. Keivani, K. Murase, M. Petropoulou, D. B. Fox, S. B. Cenko, S. Chaty, A. Coleiro, J. J. DeLaunay, S. Dimitrakoudis, P. A. Evans, J. A. Kennea, F. E. Marshall, A. Mastichiadis, J. P. Osborne, M. Santander, A. Tohuvavohu, and C. F. Turley, Submitted to *The Astrophysical Journal*.

5. "Search for neutrinos from TXS 0506+056 with the ANTARES telescope," ANTARES Collaboration: A. Albert et al. Submitted to *The Astrophysical Journal Letters.*

6. "Interpretation of the coincident observation of a high energy neutrino and a bright flare" Shan Gao, Anatoli Fedynitch, Walter Winter, and Martin Pohl.
submitted to arXiv