Association of IceCube neutrinos with radio sources observed at Owens Valley and Metsähovi radio observatories*

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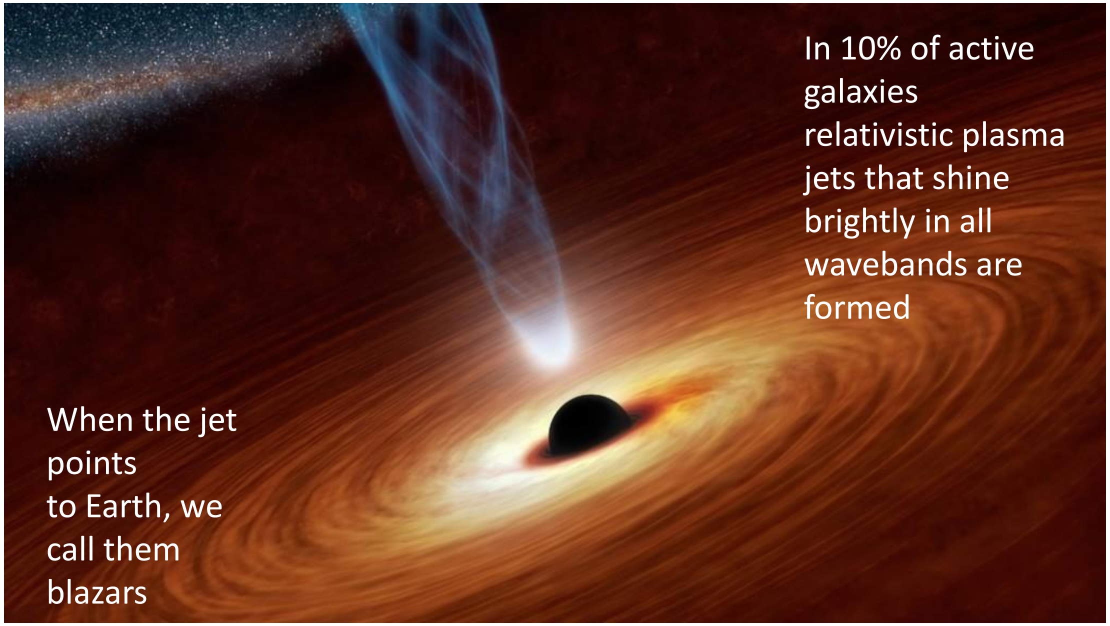
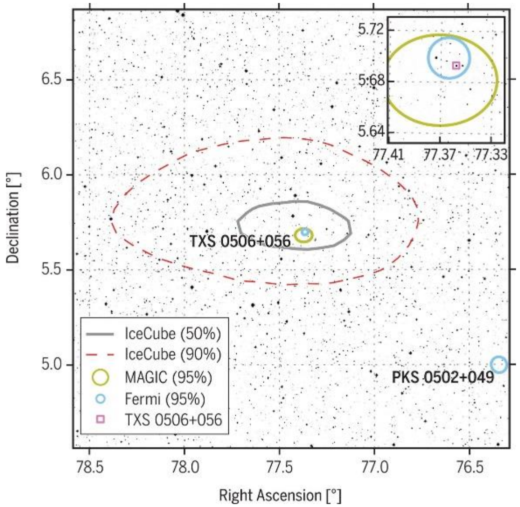
Blazars as candidate neutrino emitters

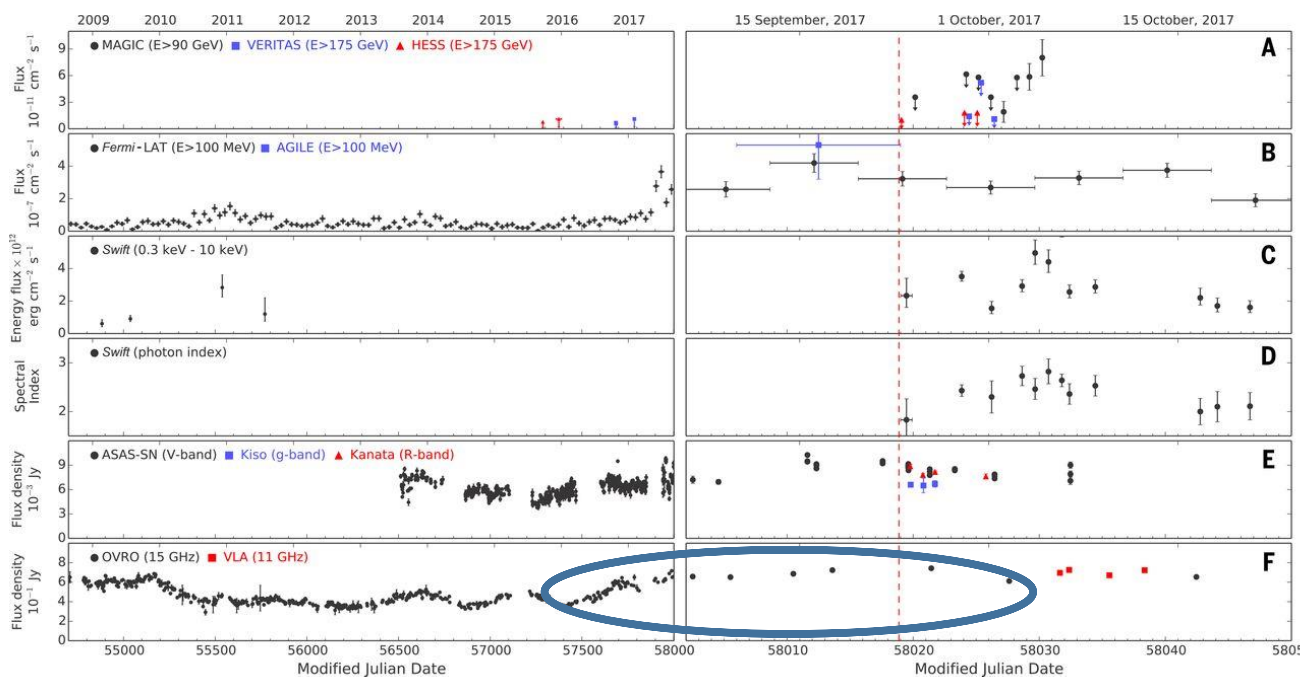
- In blazar jets electrons are accelerated to high energies, so also good candidates for proton acceleration
- Detection of neutrinos from blazars would confirm the existence of protons in the jets
- TXS0506+056: ”the smoking gun”



Credit: NASA JPL/Caltech

TXS 0506+056 radio association

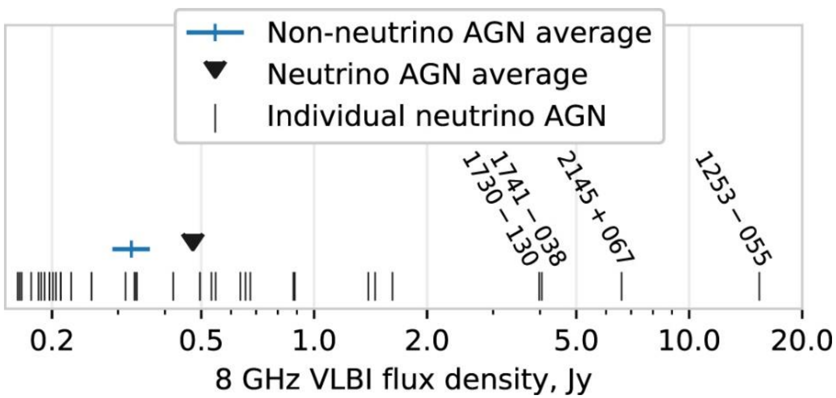




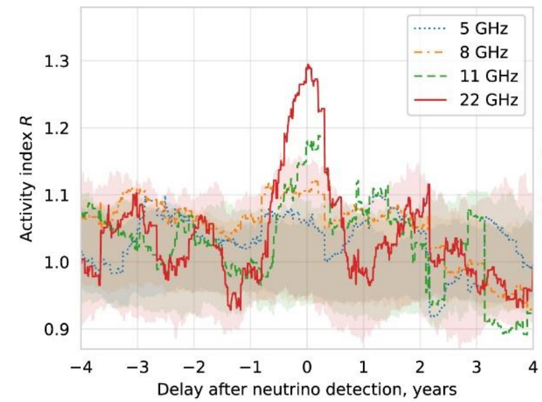
IceCube collaboration et al. 2018, Science

Association of neutrinos with compact radio sources and their variability?

Crossmatching radio fundamental catalogue (RFC) and neutrinos with >200TeV
Variability data from RATAN-600



- 36 AGN associated with 26 neutrino events
- Mean flux density of neutrino-associated sources is higher than in a random AGN population
- Chance-coincidence probability 0.2%



(a) All sources: 18 AGN close to neutrino events.

- 18 AGN associated with 14 neutrino events
- Mean activity index calculated from radio monitoring observations by the RATAN-600 telescope is higher in the neutrino associated sample
- Chance-coincidence probability 5%

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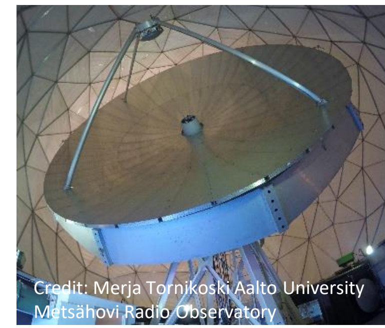
Plavin et al. 2020, ApJ, 894, 101

Systematic study using Owens Valley and Metsähovi blazar monitoring data

http://www.astro.caltech.edu/ovroblazars/

- OVRO 40-m monitoring program
  - 1795 AGN monitored twice / week
  - 1157 of them (CGRaBS sample) since 2008, others since 2009-2011
  - 15 GHz

- Metsähovi blazar monitoring program
  - 1000 AGN monitored
  - Some > 40 years
  - ~ 400 observed regularly
  - 183 had enough data between 2008-2020 to be included in this study
  - 37 GHz



- Same set of neutrinos as in Plavin et al. 2020, except using energy limit E >= 200 TeV
- In total 56 neutrino events

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Statistical analysis

- Associate neutrino events and radio source positions
  - 7-18 associated AGN with 6-15 neutrino events (depending on the radio sample used)
- Calculate the mean radio flux density of the associated sources
- Calculate the activity index around the neutrino event
  - See definition of activity index on the next slide
  - window size 2.3 yrs at 15 GHz, 1.4 yrs at 37 GHz (= typical flaring time scale)
- Compare these to random samples generated by shifting the IceCube neutrino positions randomly in right ascension

→ Obtain a random chance probability

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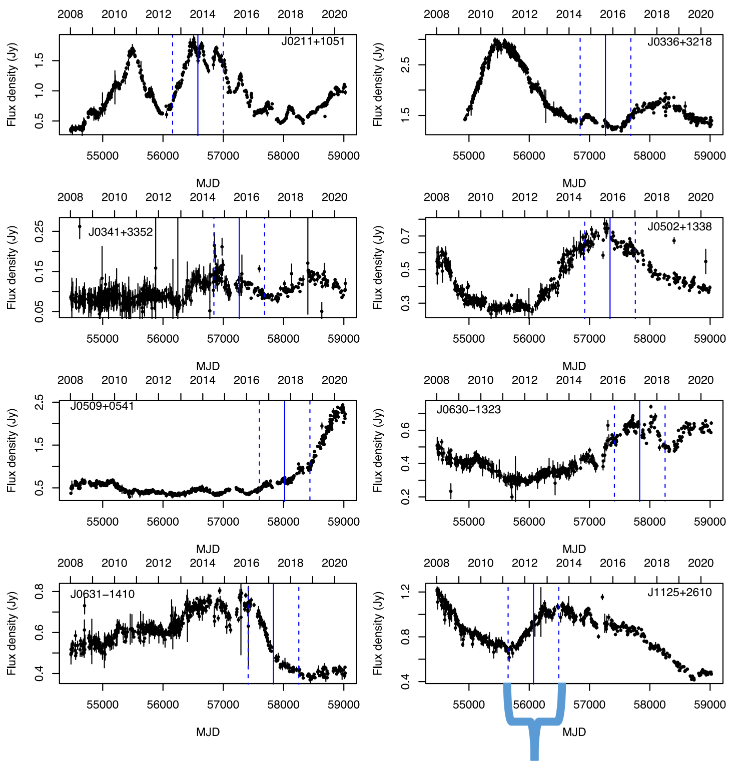
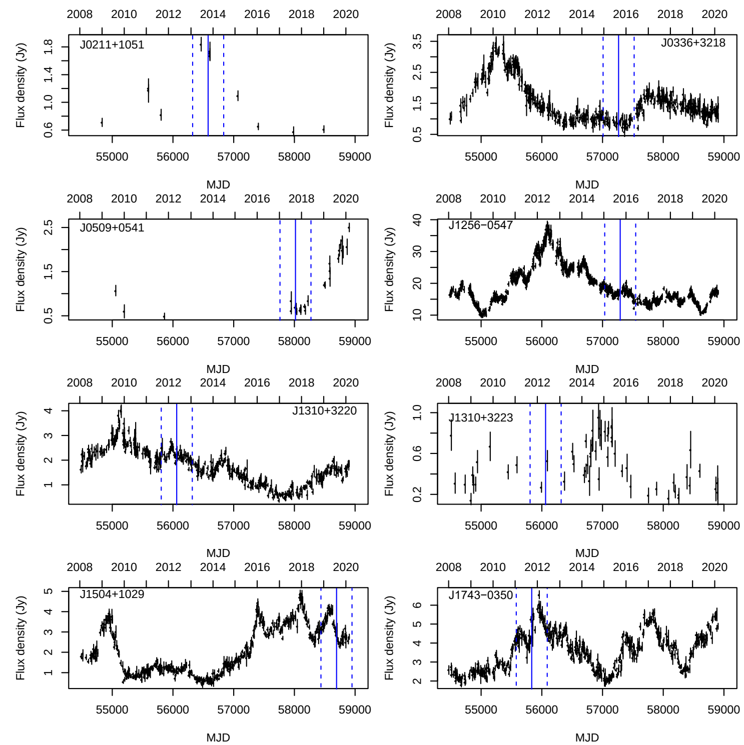
Radio light curves of some of the associations

OVRO 15 GHz



Metsähovi 37 GHz



Activity index = mean around the neutrino event / mean of the remaining LC

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Results

- Only 50% of the E > 200 TeV neutrinos are expected to be astrophysical
  - Our number of associations is much smaller than 56/2=28 (11-27%)

  →Our radio samples are not complete (Plavin found 26 associated events using the complete RFC sample)
- We don’t see a large difference in mean flux density of associated vs. random populations
- Not all the neutrino events coincide with a radio flare
- If there is a **large** radio flare at the same time as a neutrino event, it is unlikely to happen by random coincidence

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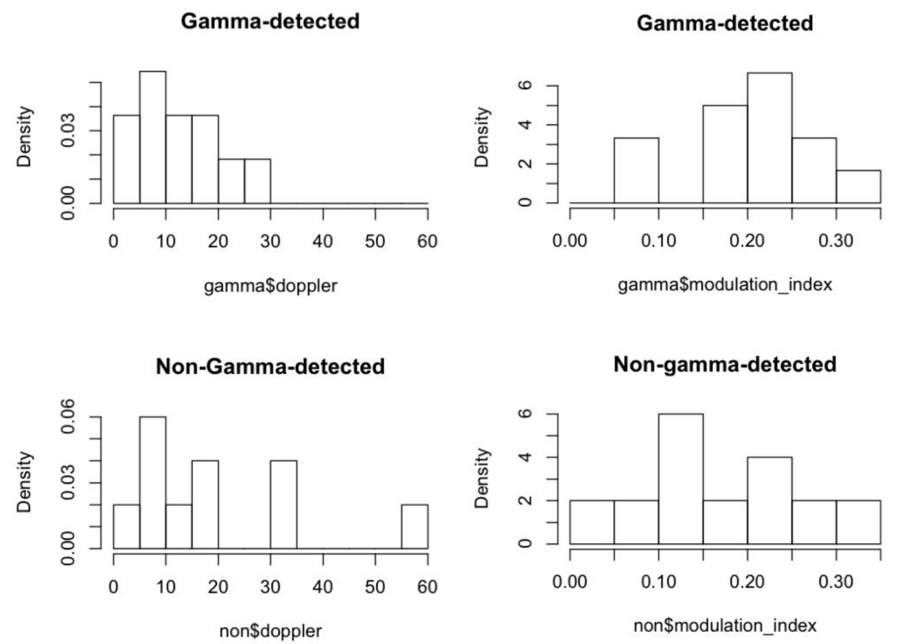
(Lack of) gamma-ray emission of the associated sources

- 9/ 20 of the OVRO associations are not detected by Fermi-LAT in GeV gamma-ray energies
- They have as high Doppler beaming factors and radio modulation indices as the gamma-ray detected sources
- Have fairly low synchrotron peak frequencies, which may explain their gamma-ray non-detection (see Lister et al. 2015, ApJ, 810, L9)
    - Dense photon fields required for neutrino emission may also absorb gamma-ray emission
- These sources are missing from most neutrino-blazar studies which concentrate on Fermi-detected sources only!



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Conclusions and outlook

- If there is a **large** radio flare in a blazar at the same time as a neutrino event, it is unlikely to happen by random coincidence
- Our current radio monitoring samples do not include all potential neutrino blazars
  - Need larger well-defined monitoring samples
  - Temporal association with more localized approach than activity index
- Non-gamma-ray sources need to be studied more carefully via detailed SED modeling to understand if they can be potential neutrino emitters

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