Raniere de Menezes and collaborators, on behalf of the *Fermi*-LAT, H.E.S.S., MAGIC, VERITAS, ZTF and TELAMON Collaboration

Multi-Messenger observations of the γ-ray blazar 4FGL J0658.6+0636 consistent with an IceCube high-energy neutrino

Universidade de São Paulo

ICRC, July 2021

High-energy neutrinos can reveal sources of HE cosmic rays

There is incontrovertible evidence for the existence of high-energy astrophysical neutrinos. *

The spectrum clearly departs from that of the atmospheric neutrino background for energies > 100 TeV.

* See Aartsen+ 2013, 2018.

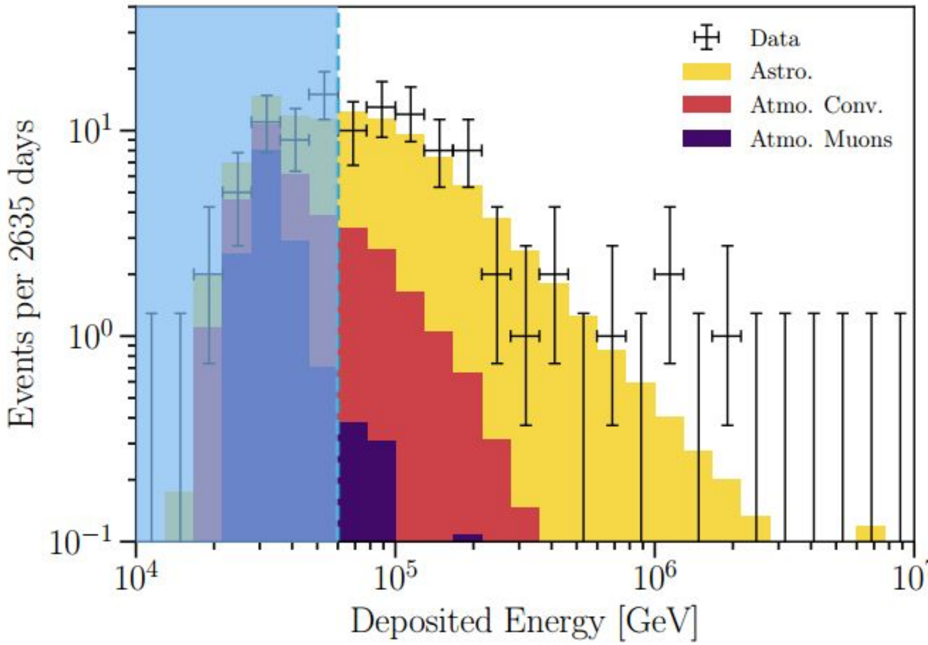
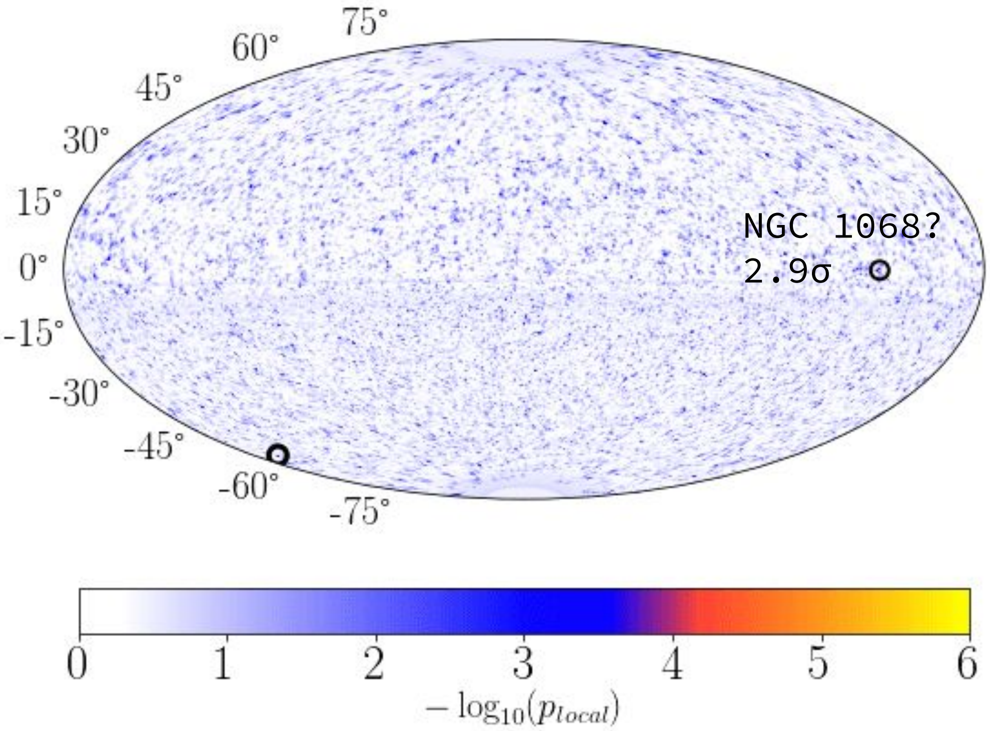


Figure: Abbasi et al. 2020.

The HE neutrino sky is basically isotropic



- Neither individual neutrino source detected at high confidence, nor any source class
- Events isotropically distributed (favoring extragalactic origin)

Figure: Aartsen et al. 2020.

A γ-ray blazar as the most-likely counterpart to a IceCube high-energy neutrino event

IC 170922A & TXS 0506+056

Neutrino emission in spatial and temporal coincidence with the flaring γ-ray blazar.

- BL Lac(*) object at z = 0.34.
- High-energy neutrino event with >183TeV
- Flaring γ-ray blazar (Tanaka+ Atel#10791)
- ~3σ post-trial chance coincidence correlation
- Lepto-hadronic models can adequately explain the observations (IC170922A) **
- ~3.5σ excess of archival lower-energy, time-clustered neutrinos
- No spectral evolution in the MWL SED at high energies (see also Padovani+ 2018).

* masquerading BL Lac, see Padovani+ 2019.
** see Cerruti+ 2019, and Keivani+ 2018.

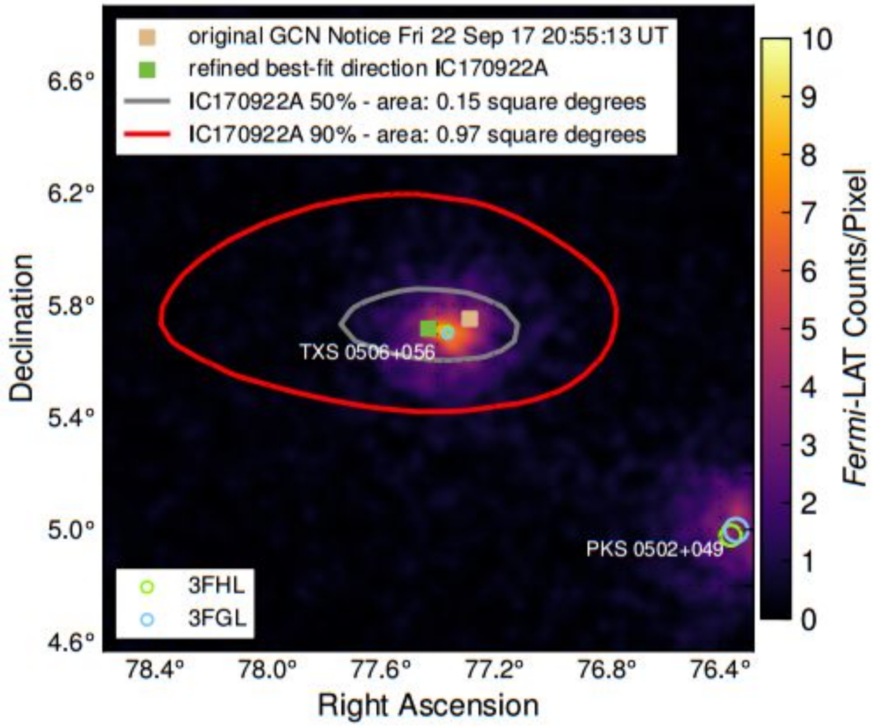


Figure: Aartsen et al. 2018.

There are several other γ-ray sources positionally consistent with neutrino events

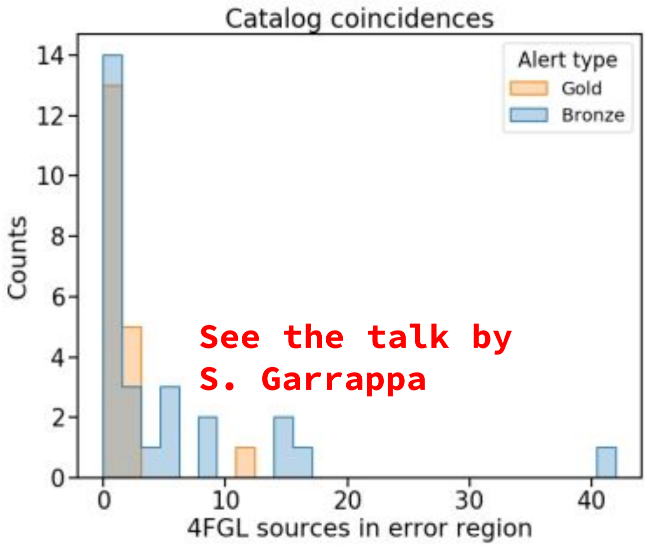
Among those, NVSS J065844+063711, a potential VHE blazar.

Fermi-LAT evidence for VHE emission from NVSS J065844+063711

ATel #14200; *S. Buson (Univ. Wuerzburg), S. Garrappa (DESY-Zeuthen) and C. C. Cheung (Naval Research Laboratory) on behalf of the Fermi Large Area Telescope Collaboration*
on 19 Nov 2020; 13:36 UT
Credential Certification: Sara Buson (sara.buson@gmail.com)

Subjects: Gamma Ray, >GeV, VHE, Neutrinos, Request for Observations, Blazar

- In 2018, a photon with 155 GeV was detected.
- On average, LAT detects 1 photon with > 10 GeV per year from this source.
- This source is listed in 3FHL (> 10 GeV catalog).



See the talk by S. Garrappa

In Nov. 2020, IceCube detected another neutrino coincident with a BL Lac object

The object is NVSS J065844 +063711/4FGL J0658.6+0636, a HSP blazar of unknown redshift.

This is the only Fermi-LAT source within the 90% containment region of IceCube-201114A.

- Neutrino energy proxy = 214 TeV
- Astrophysical Signalness = 0.56

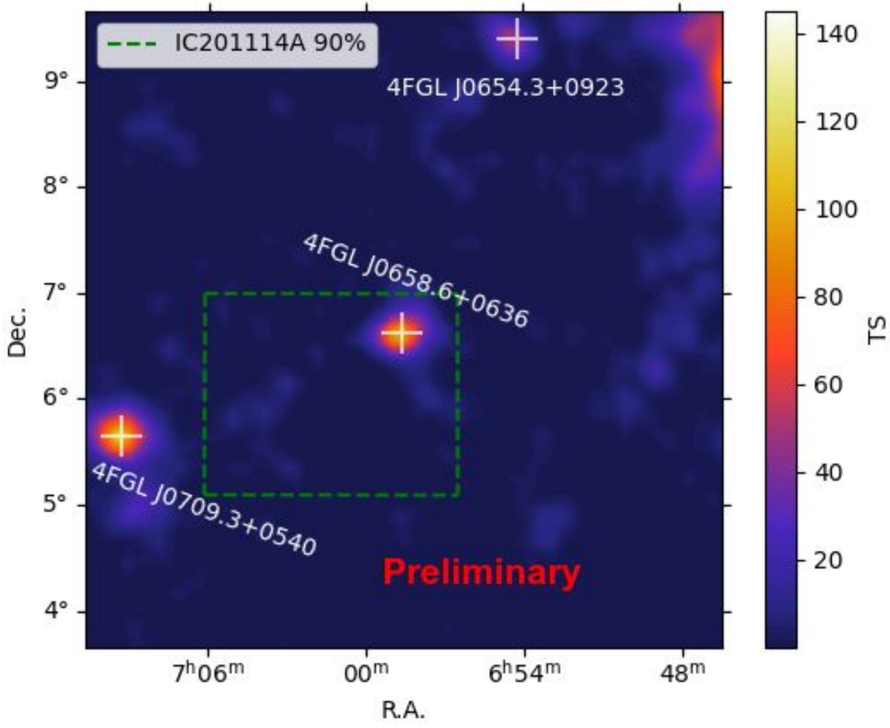


Figure: de Menezes et al. in prep.

No remarkable EM activity when the neutrino is detected

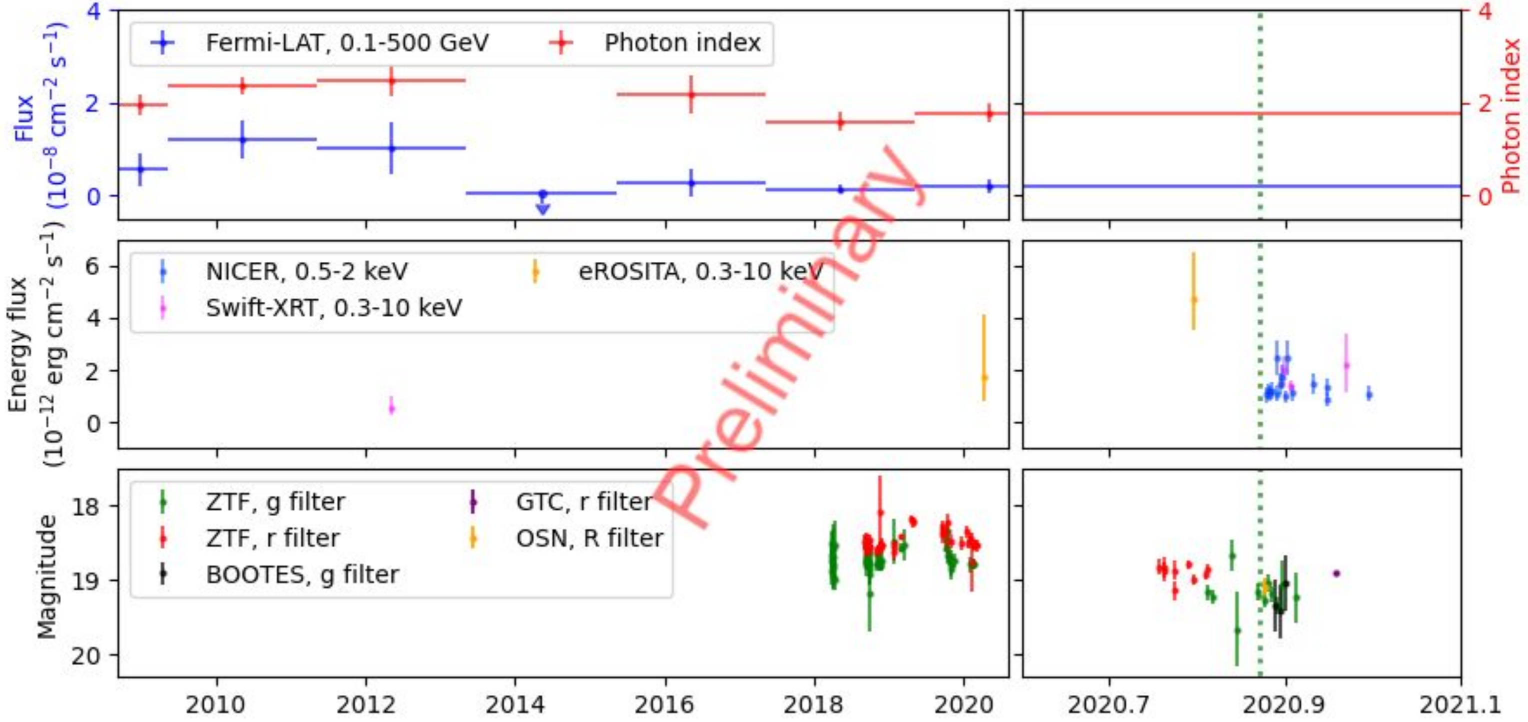
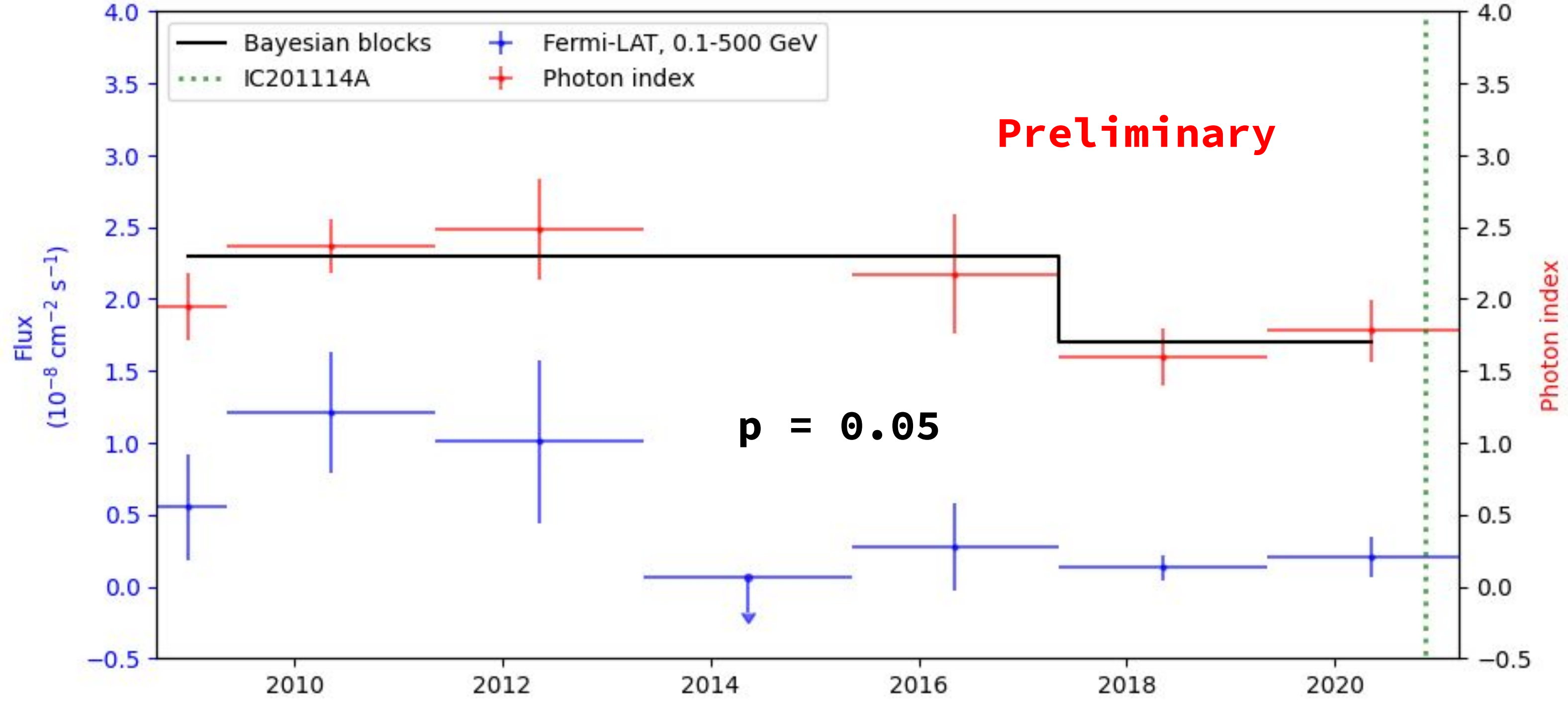


Figure: de Menezes et al. in prep.

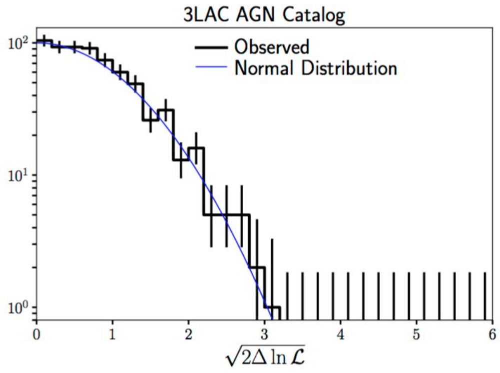
Gamma-ray photon index shows a hardening of the spectrum in the last 4 years



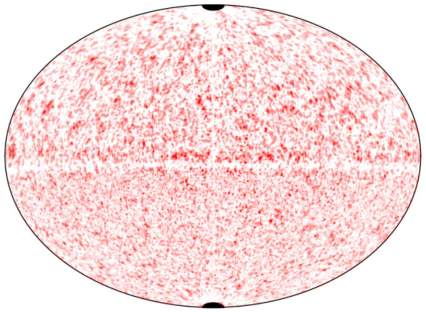
Interestingly, (non-significant) excess of archival low-energy neutrinos

From Hooper et al. 2019:

- First one-year IceCube operations (86-string configuration)
- Muon tracks observed by IceCube between May of 2011 and May of 2012
- Cross-correlation of 3LAC sources



[2Δln(L) > 6]:
J2235.3-4835,
J2152.9-0045,
J0358.7+0633,
J1016.0+0513,
J0658.6+0636,
J2039.0-1047,
J0353.0-3622,
J1018.5+0530,
J1251.3+1041,
J1146.8+3958,
J1516.9+1926



No evidence of neutrino emission from 3LAC sources, upon accounting for trials

Highest-significance hotspots:

Neutrino excess 2Δln(L) > 7.2 (pre-trial) at J0658.6+0636 location

Figure: Hopper et al. 2019.

Spectral evolution over time is highlighted by the MWL SED

Archival data collected between 2008~2017.

Quasi-simultaneous data collected within two months from the neutrino arrival.

Exception: LAT data collected in the last 4 years.

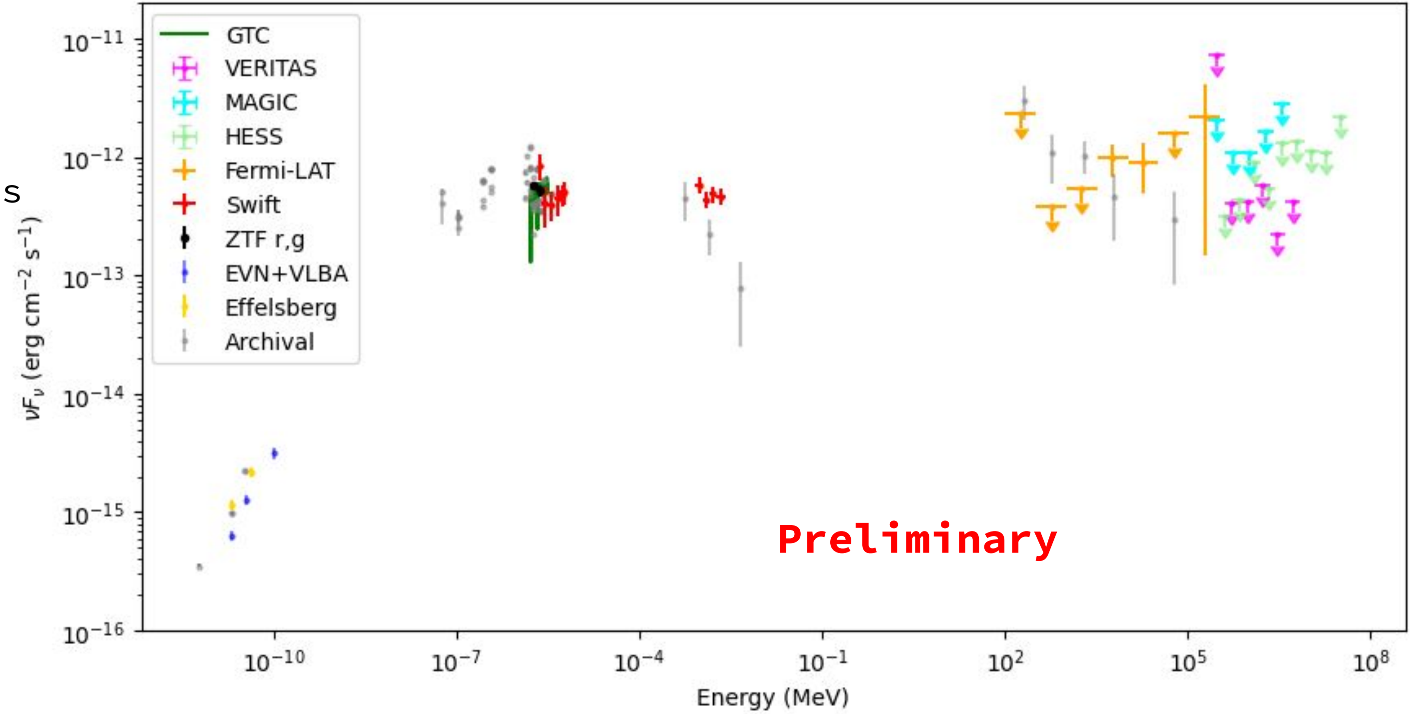
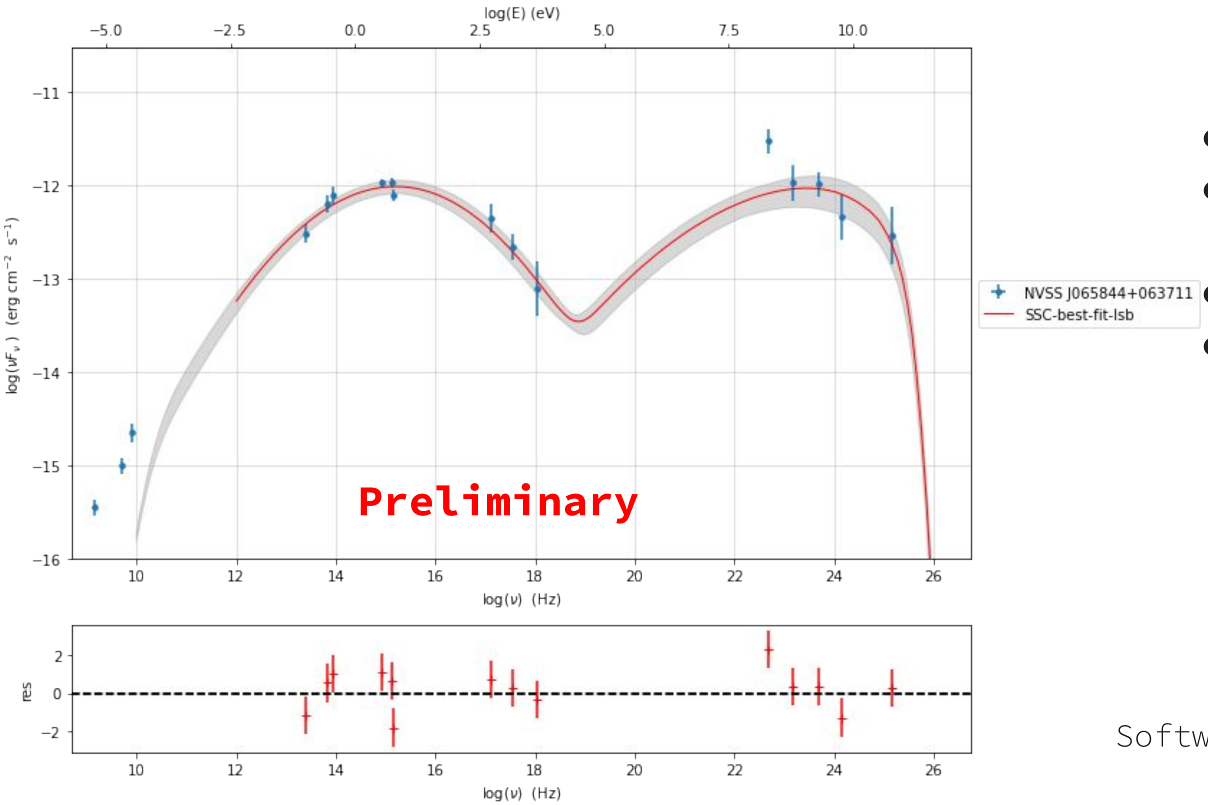


Figure: de Menezes et al. in prep.

Leptonic modeling of soft-spectrum γ-ray state



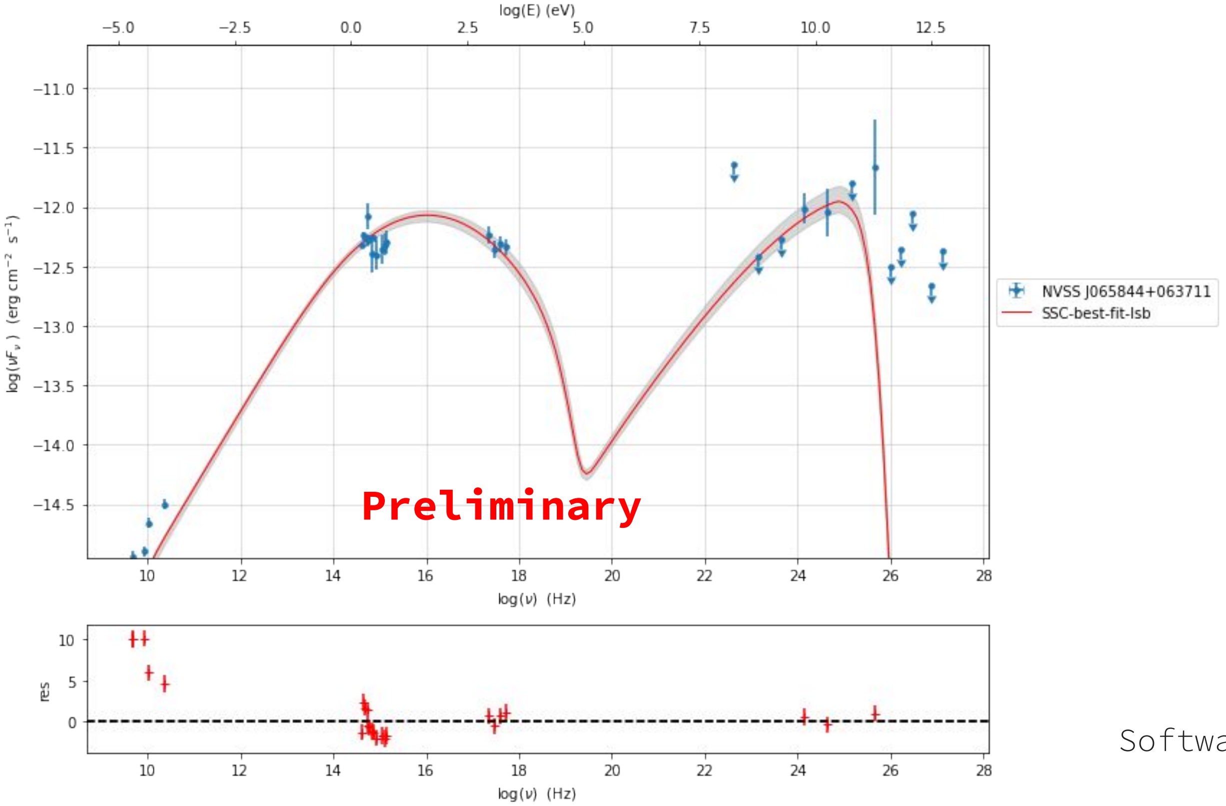
- Data from 2012~2013.
- EBL from Dominguez et al.2011.
- Assuming z = 1.
- Electron dist: broken PL

B = 0.2 G
ρ = 13.7 cm^{-3}
R = 3.7 x 10^{16} cm

Software: JetSet, Tramacere, 2020.

Figure: de Menezes et al. in prep.

Leptonic modeling of hard-spectrum γ-ray state



- Data quasi-simultaneous to the neutrino arrival.
- EBL from Dominguez et al.2010.
- Assuming z = 1.
- Electron dist: logPar + low-en. PL

B = 5 x 10^{-3} G
ρ = 1.6 cm^{-3}
R = 1.0 x 10^{17} cm

Software: JetSet, Tramacere, 2020.

Figure: de Menezes et al. in prep.

Summary

- Second candidate-VHE blazar positionally consistent with a well-reconstructed high-energy IceCube neutrino.
- No enhanced EM emission state is observed in coincident with the neutrino arrival.
  - SED displays a shift of the peaks, and a hardening at γ rays in the latest years.
  - Excess of archival IceCube neutrinos consistent with this blazar
- Leptonic models adequately describe the EM observations.
  - how / does the neutrino emission fit into this picture? -- Work in progress
- TBD: Is this neutrino-blazar association by chance? Complete statistical analysis in the upcoming paper.

Thank you!

Back up

No spectral evolution was observed in TXS 0506+056

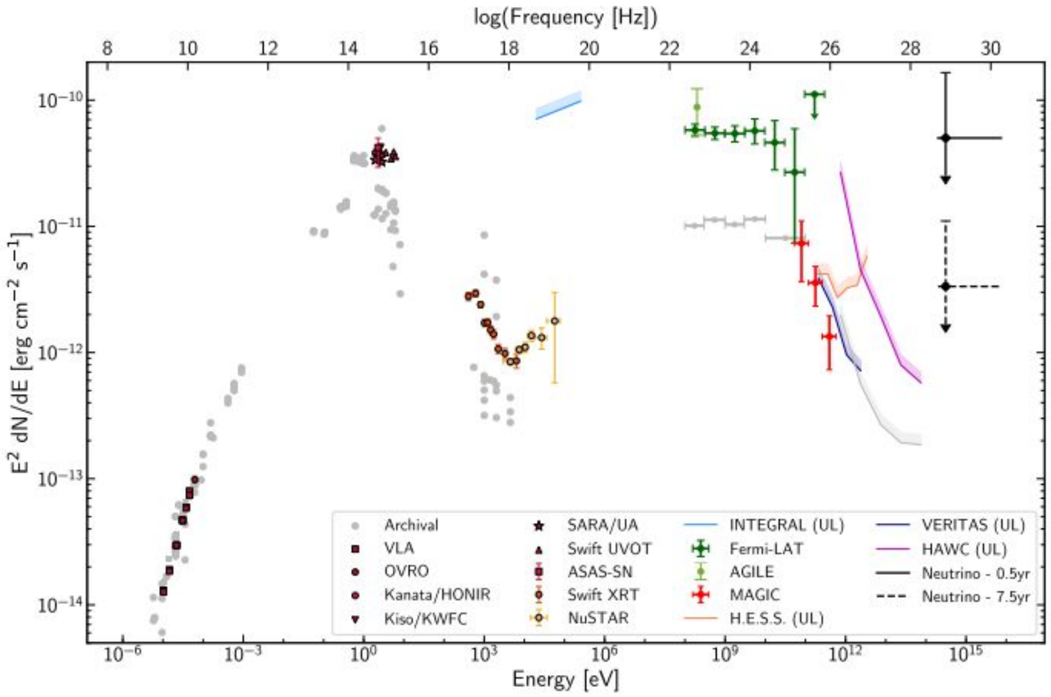


Figure: Aartsen et al. 2018.

Hardening in the g-ray spectrum of TXS 0506+056

- Padovani+ 2018 claim a hardening of the g-ray spectrum in TXS 0506+056, during the 2014-2015 neutrino excess
- But see also Garrappa+ 2019, Reimer+2019