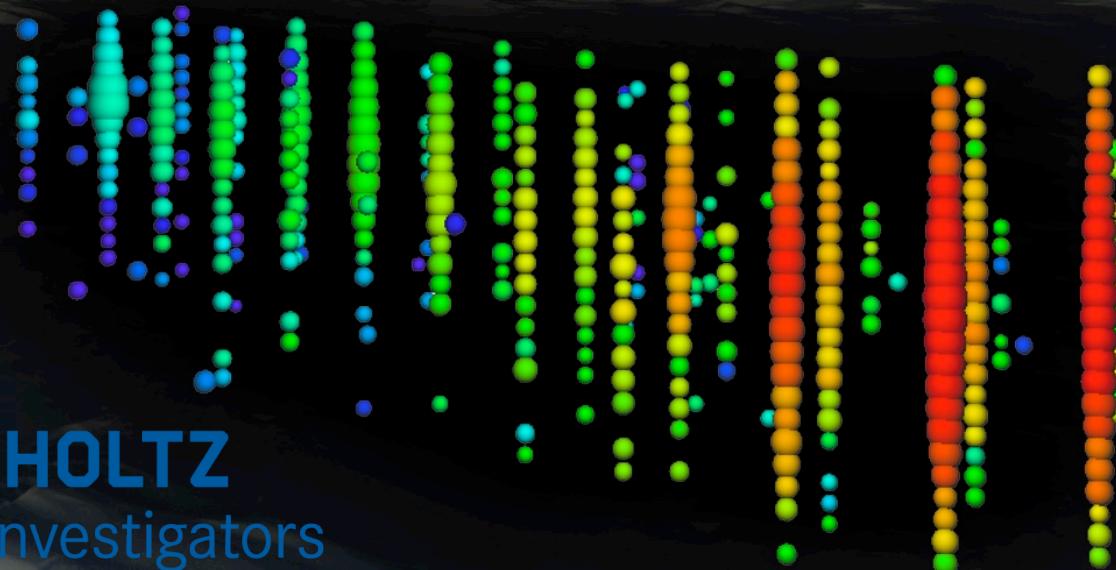


# Status of Blazar Observations from a Neutrino and gamma-ray point of view

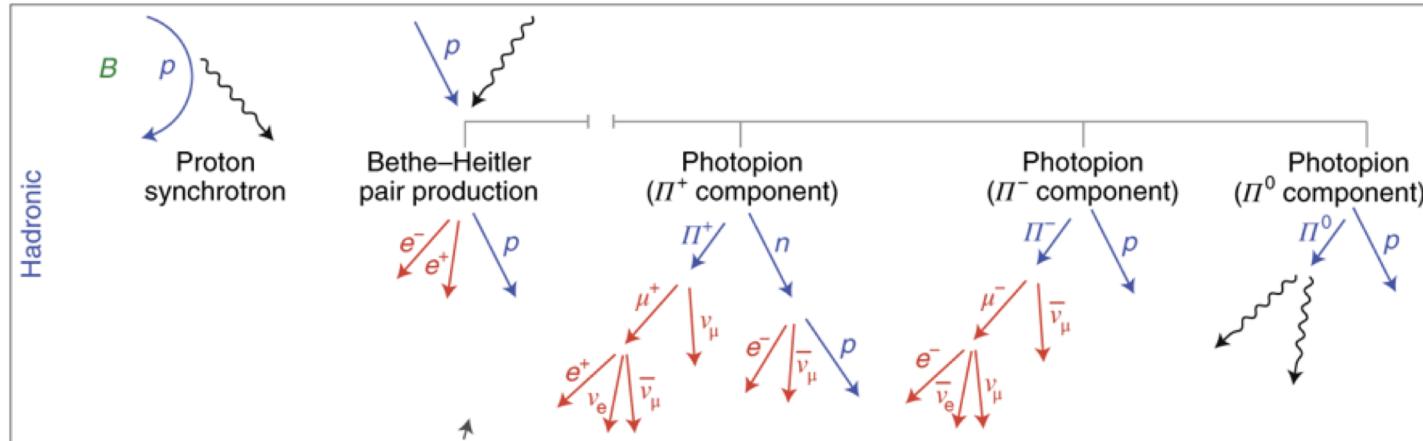
Anna Franckowiak



**HELMHOLTZ**  
Young Investigators

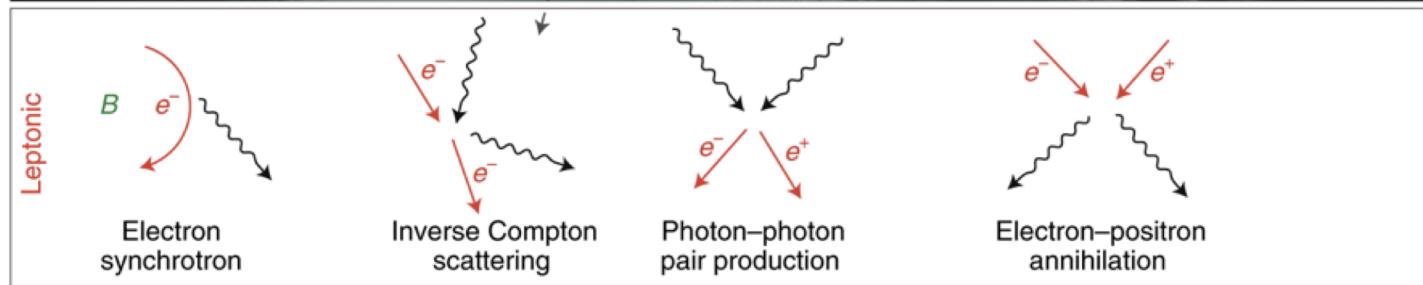
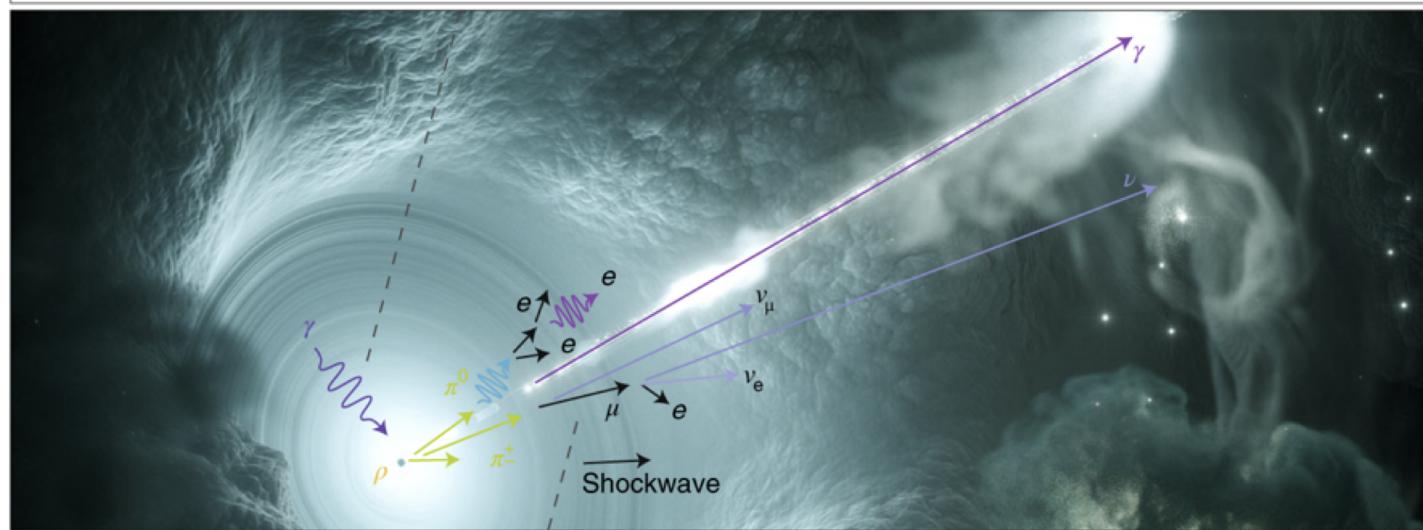
Cosmic Rays and Neutrinos in the Multi-Messenger Era, 11. December 2020





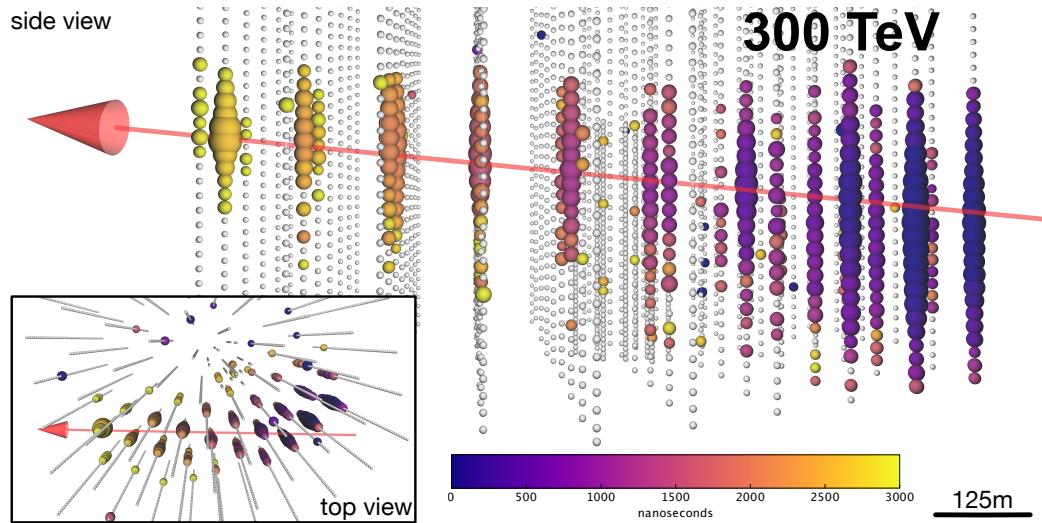
Production of  
~100 TeV neutrinos  
in  $\gamma\gamma$  scenarios  
need

- ~PeV protons
- photon target
  - a. observed in X-rays (~keV) if moving with the jet
  - b. observed in UV (~10eV) if stationary



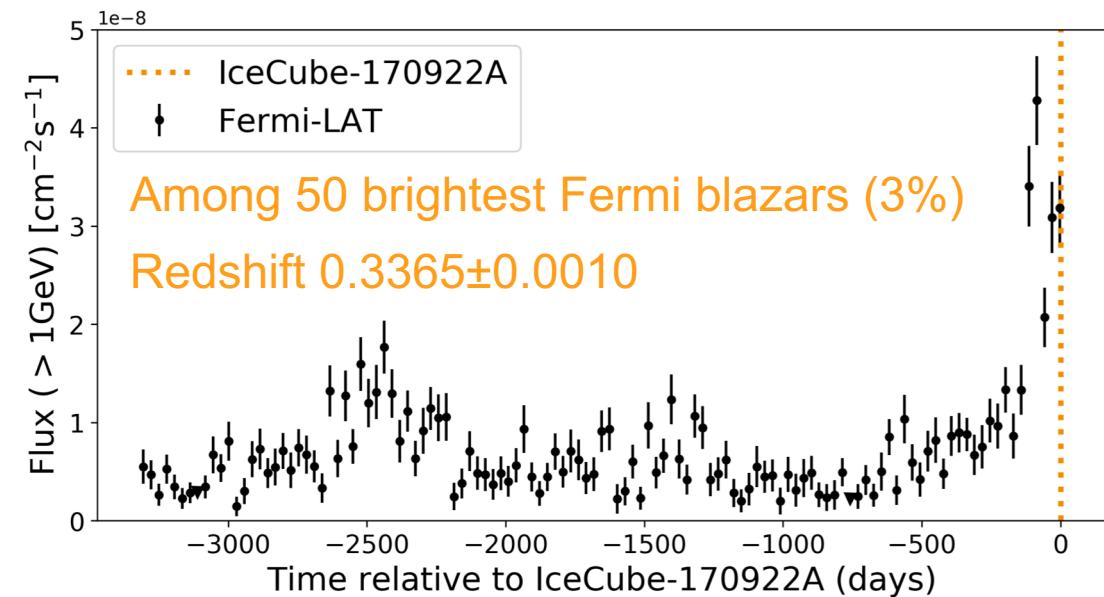
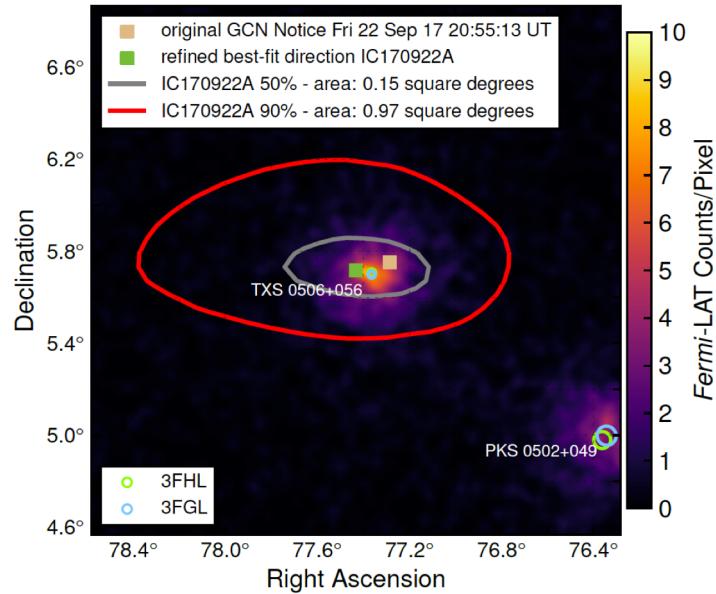
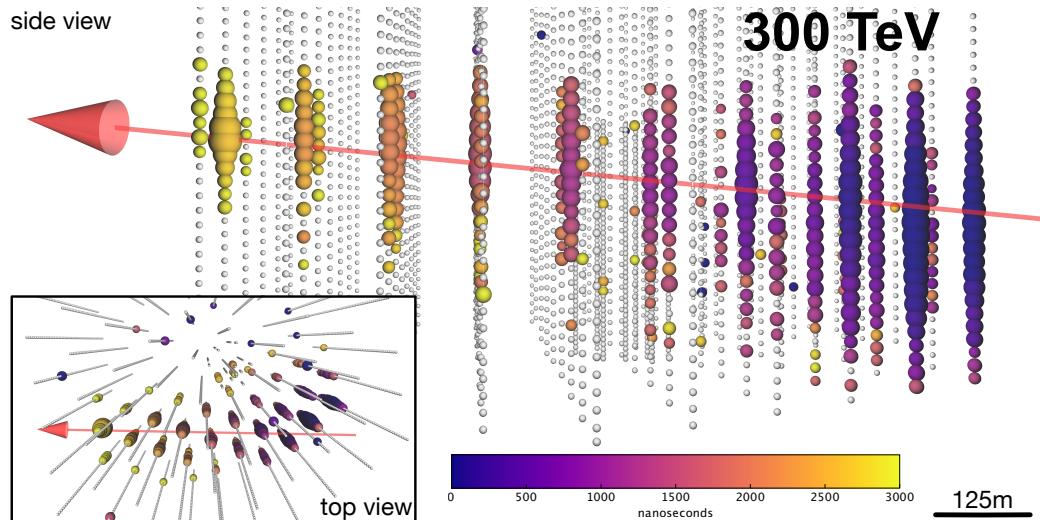
# First Promising Candidate: TXS 0506+056

Coincident with IC-170922A



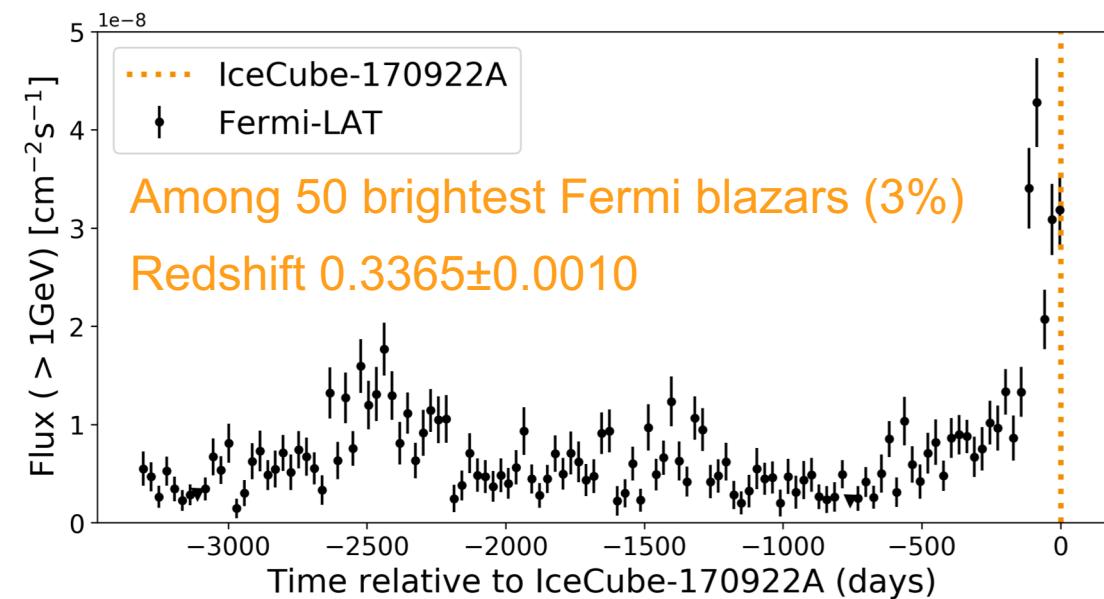
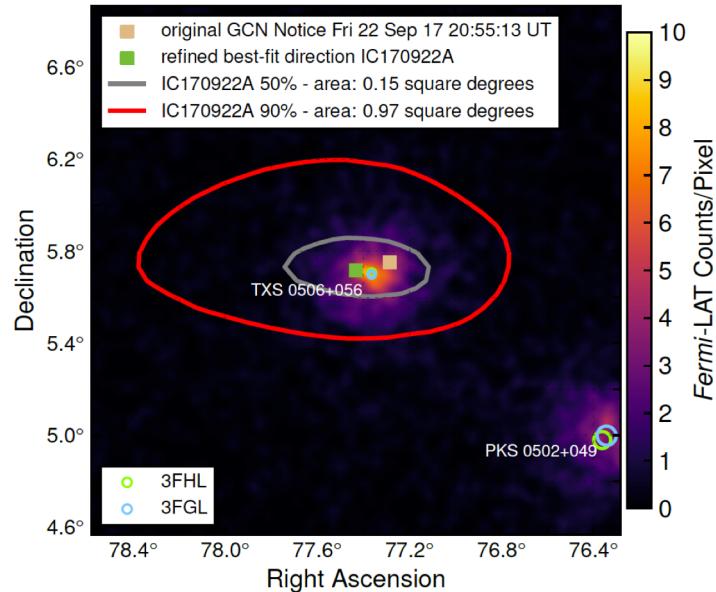
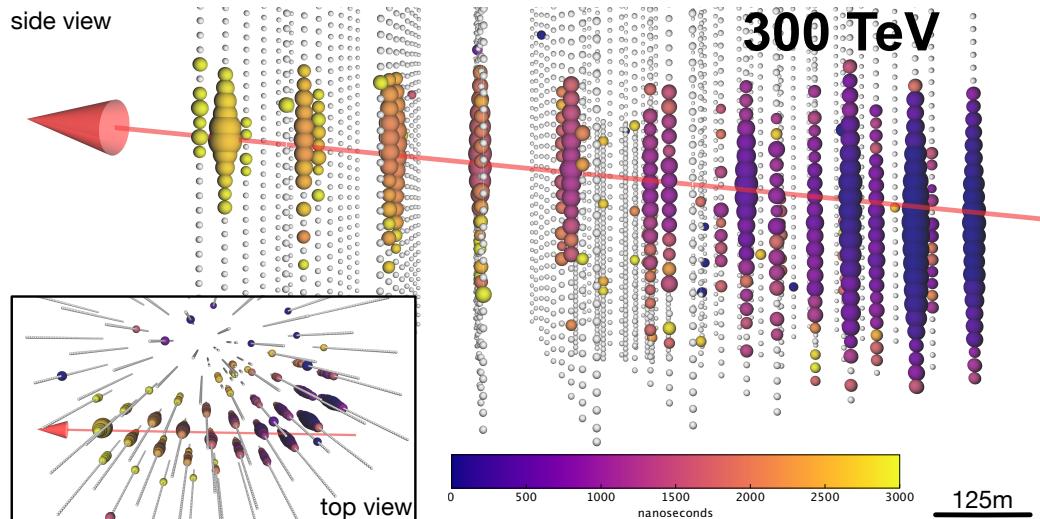
# First Promising Candidate: TXS 0506+056

Coincident with IC-170922A



# First Promising Candidate: TXS 0506+056

Coincident with IC-170922A



Post-trials significance:  
 $3.0\sigma$

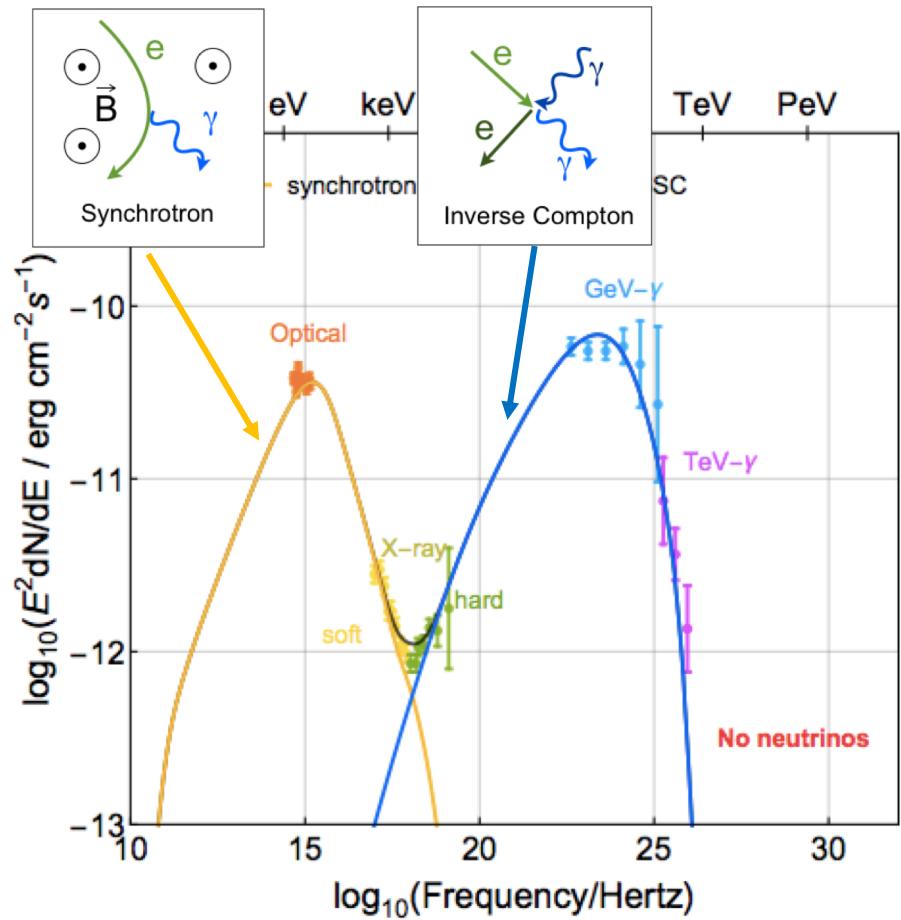
> 6PeV protons  
in the source

# Is TXS 0506+056 a BL Lac or FSRQ?

- BL Lac and FSRQ differ by the presence/size of emission/absorption lines in their optical spectrum
- TXS has weak emission lines with width < 5Å
- Standard empirical definition: line width < 5Å → BL Lac
- Intrinsically weak lines or diluted broad lines?

	BL Lacs	FSRQs	Masquerading BL Lacs
accretion	inefficient	efficient	efficient (but apparently not)
EW	< 5 Å	> 5 Å	< 5 Å
$L/L_{\text{Edd}}$	$\lesssim 0.01$	$\gtrsim 0.01$	$\gtrsim 0.01$
$\nu_{\text{peak}}^S$	any	$\lesssim 10^{14}$ Hz	$\gtrsim 10^{14}$ Hz

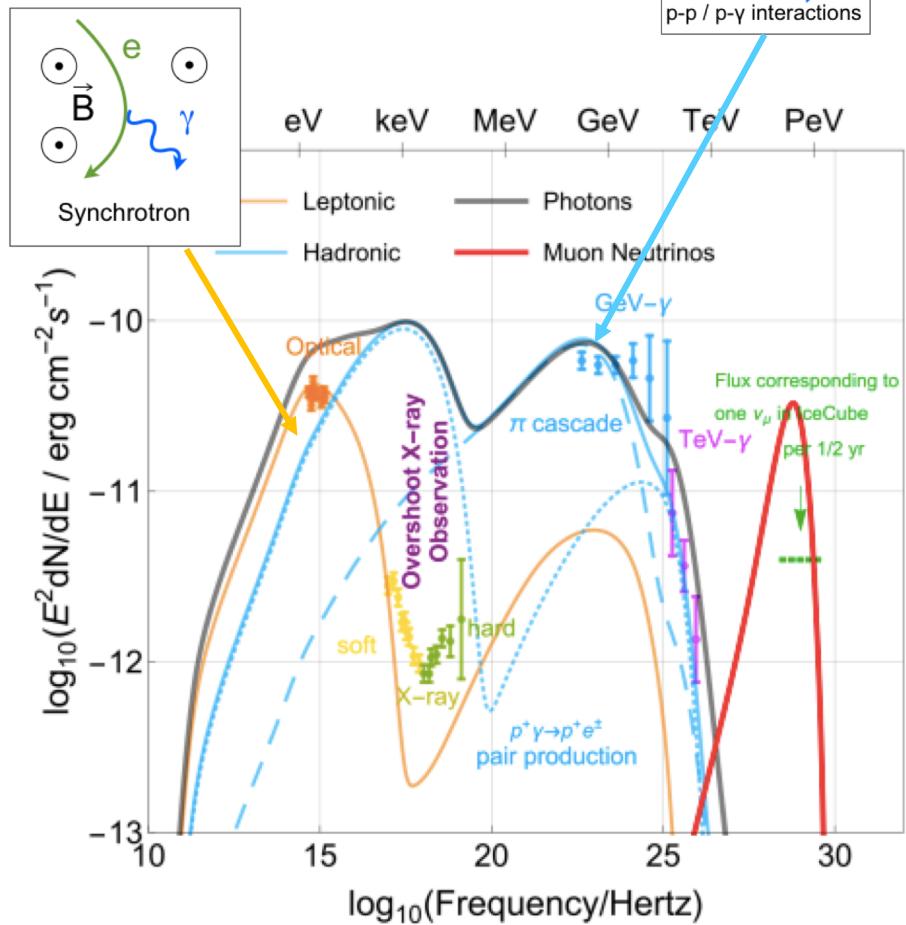
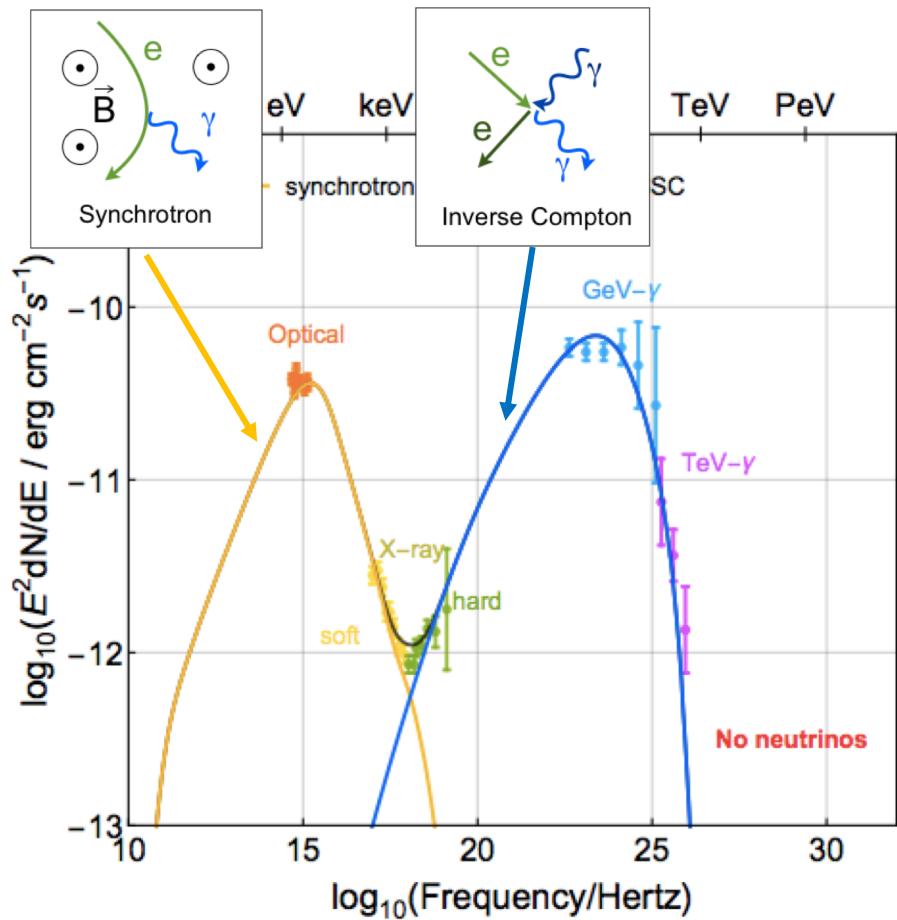
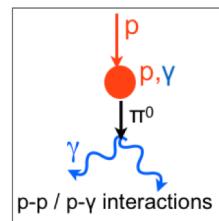
# Modeling – leptonic



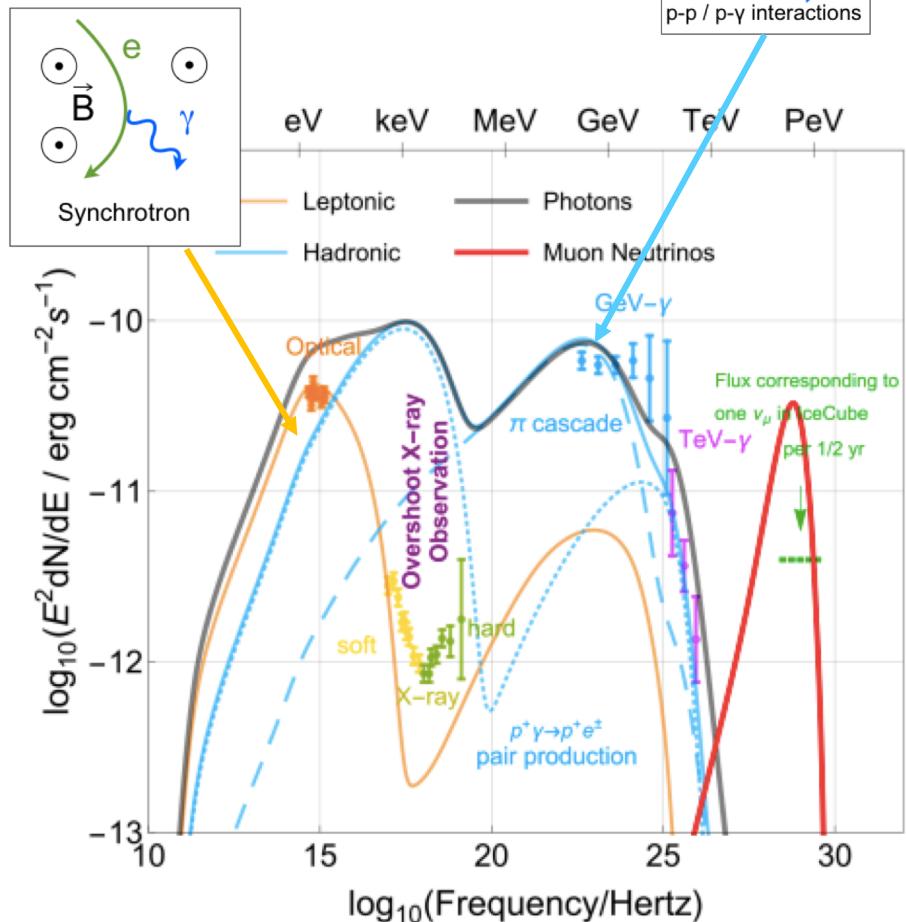
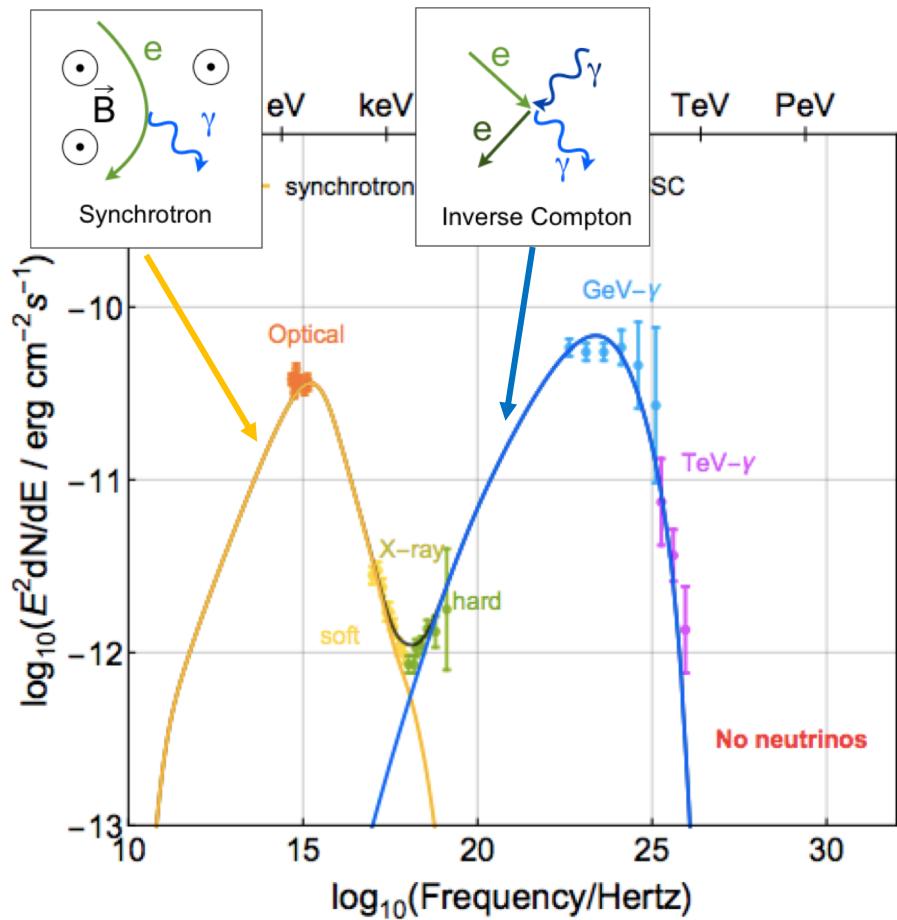
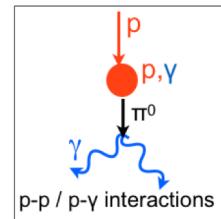
Gao et al., Nature Astronomy 2018,

Keivani et al., ApJ, 2018, MAGIC Coll., ApJ, 2018, Cerruti et al. MNRAS 2018, ...

# Modeling – leptonic, hadronic



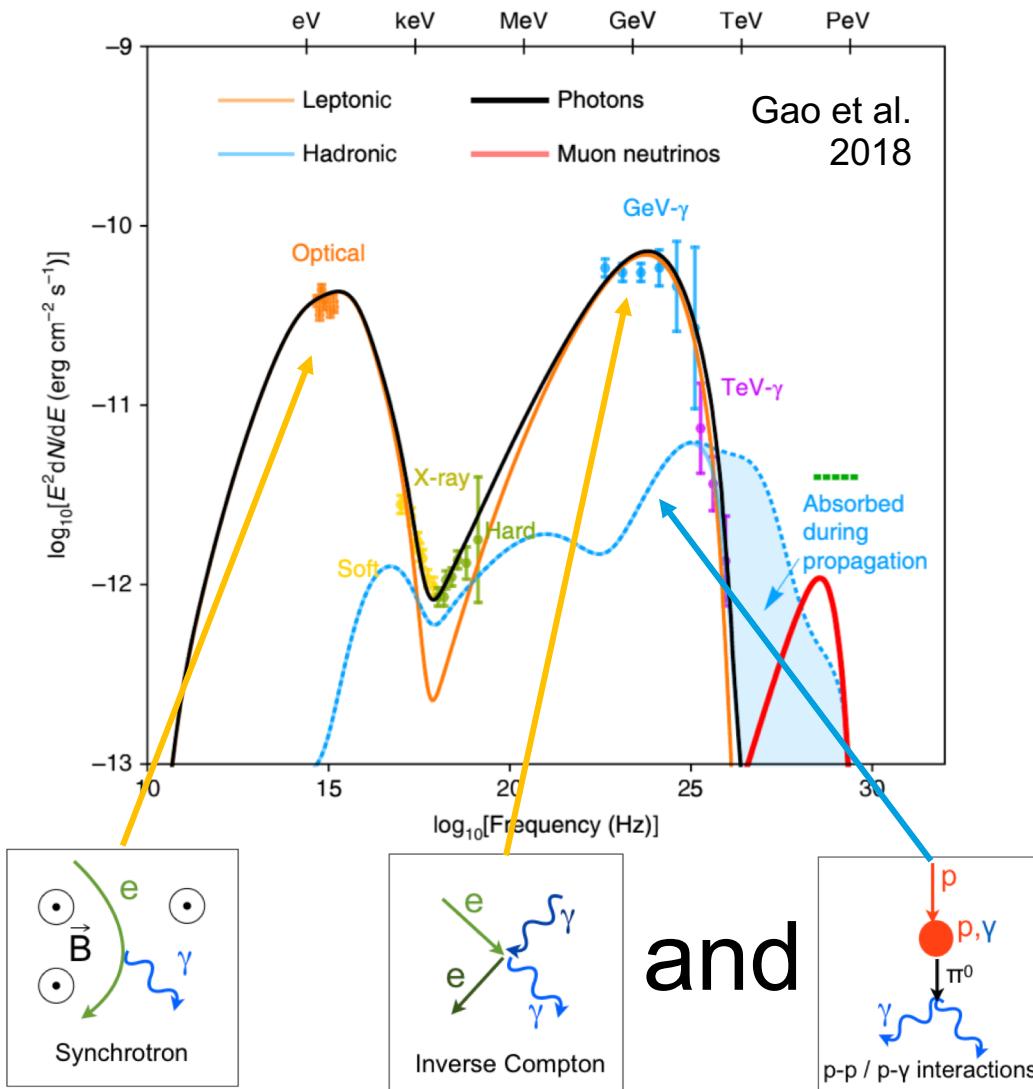
# Modeling – leptonic, hadronic



Simple one-zone hadronic models violate X-ray constraints  
 → More complex models needed

# Modeling – lepto-hadronic

See poster by M. Cerruti for blazar model comparison

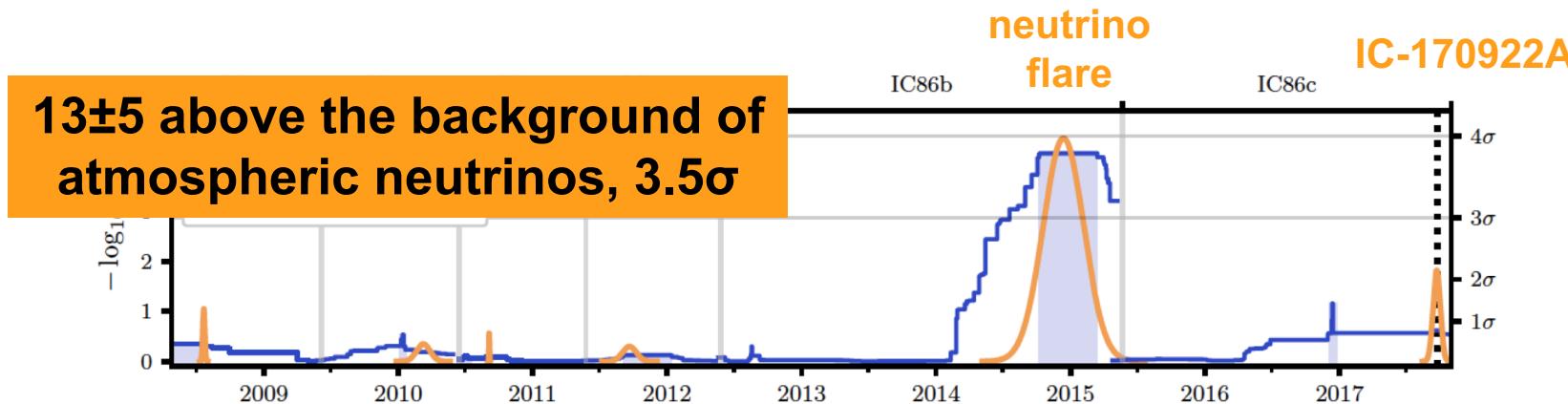


Gao et al., Nature Astronomy 2018,

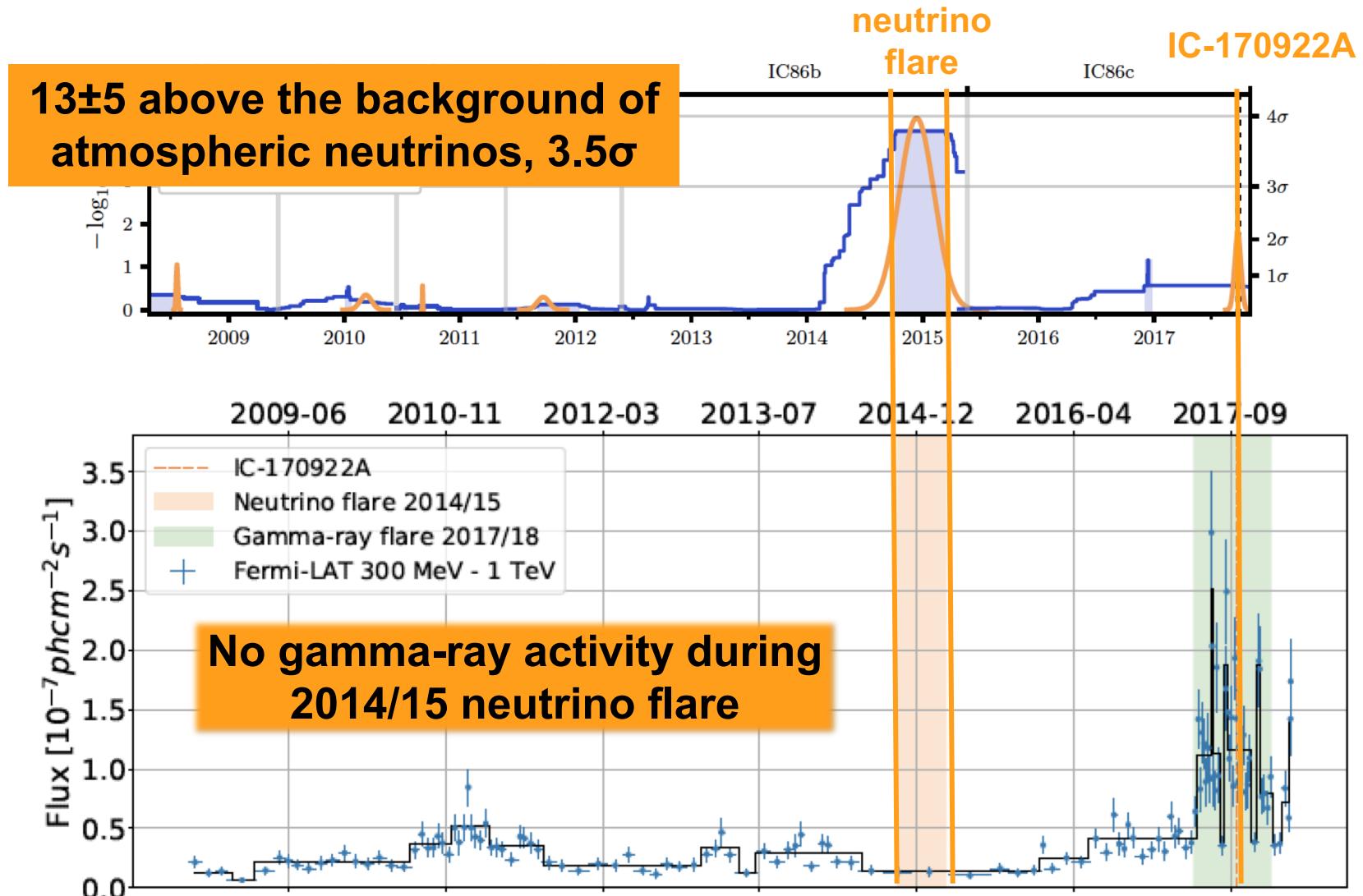
Keivani et al., ApJ, 2018, MAGIC Coll., ApJ, 2018, Cerruti et al. MNRAS 2018, ...

# Are there more Neutrinos from this Source?

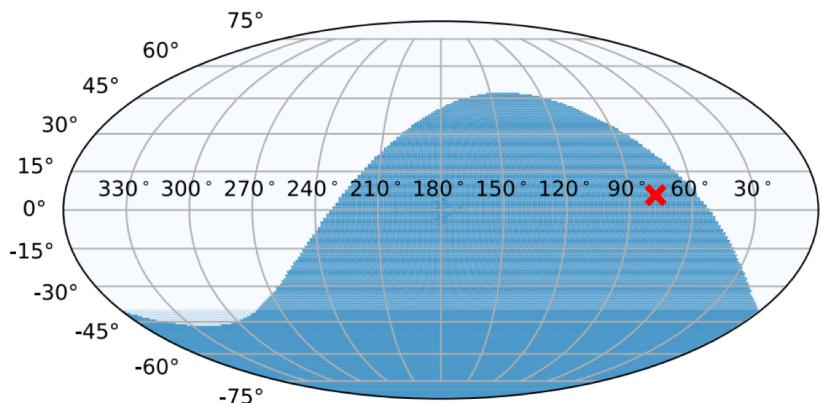
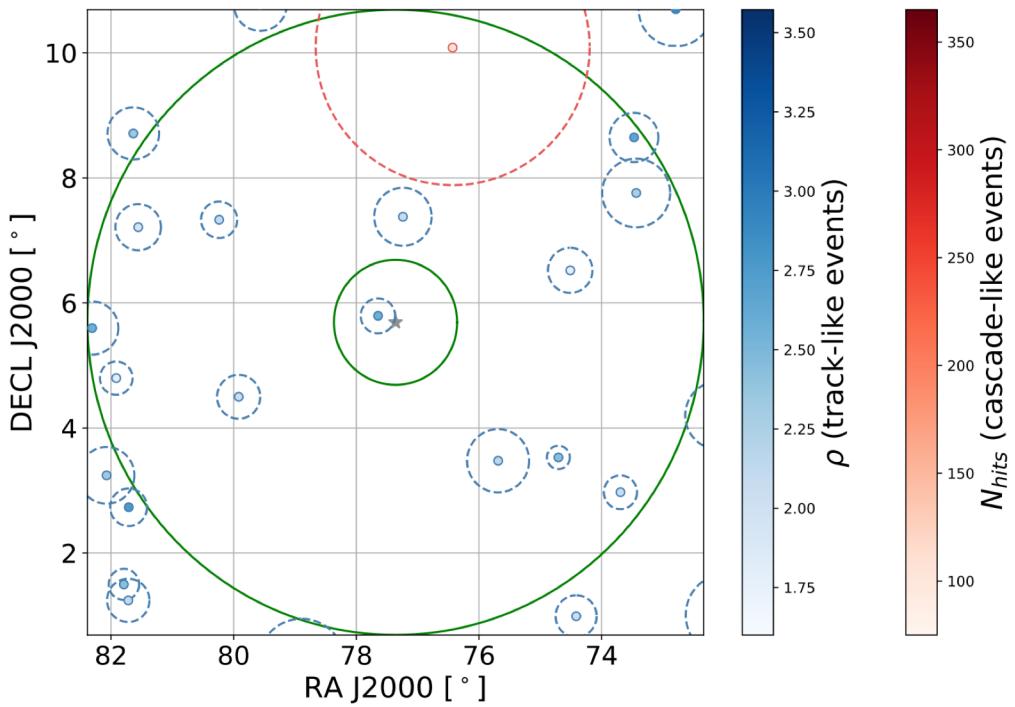
# Are there more Neutrinos from this Source?



# Is there also a Gamma-ray Flare?



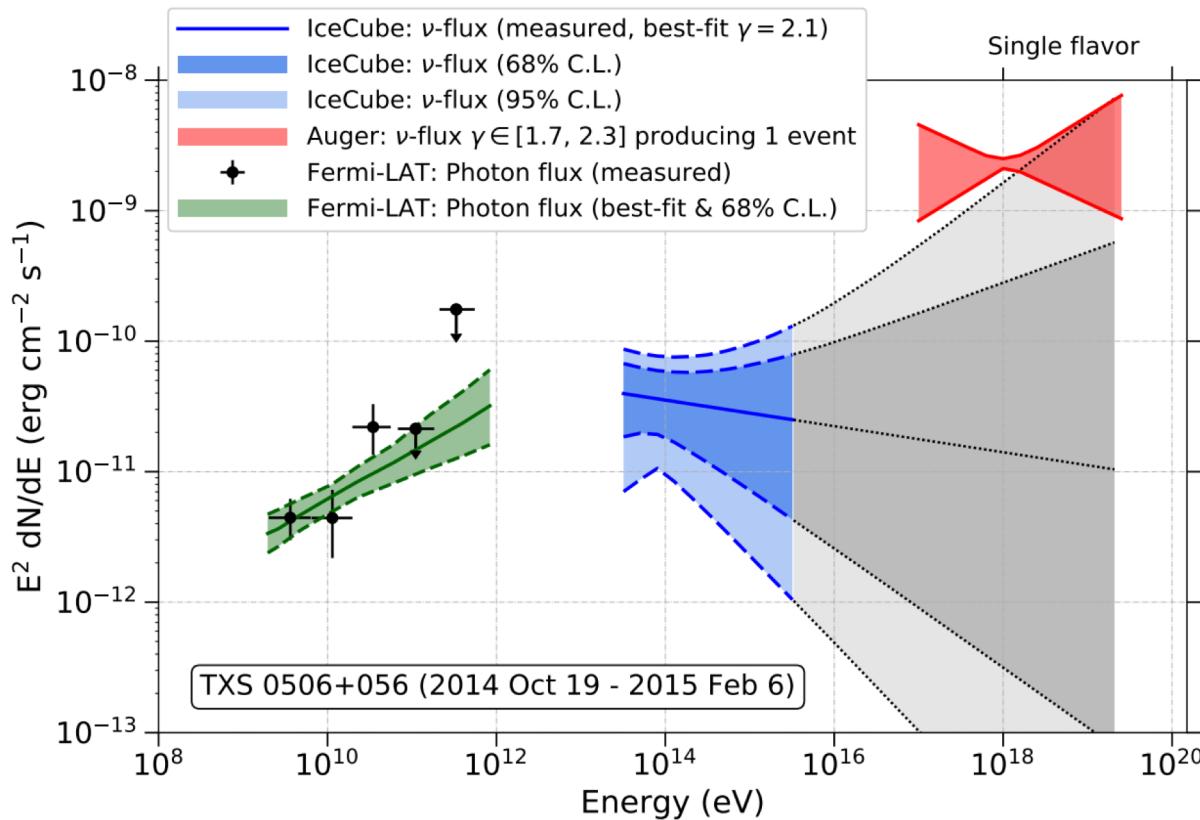
# Search for neutrinos from TXS with ANTARES



**Time-dependent analysis yield:** no events related to the source

**Time-integrated search**  
(2007-2017): 1.03 signal events fitted  $\rightarrow$  p-value of 3.4%

# Search for neutrinos from TXS with Auger



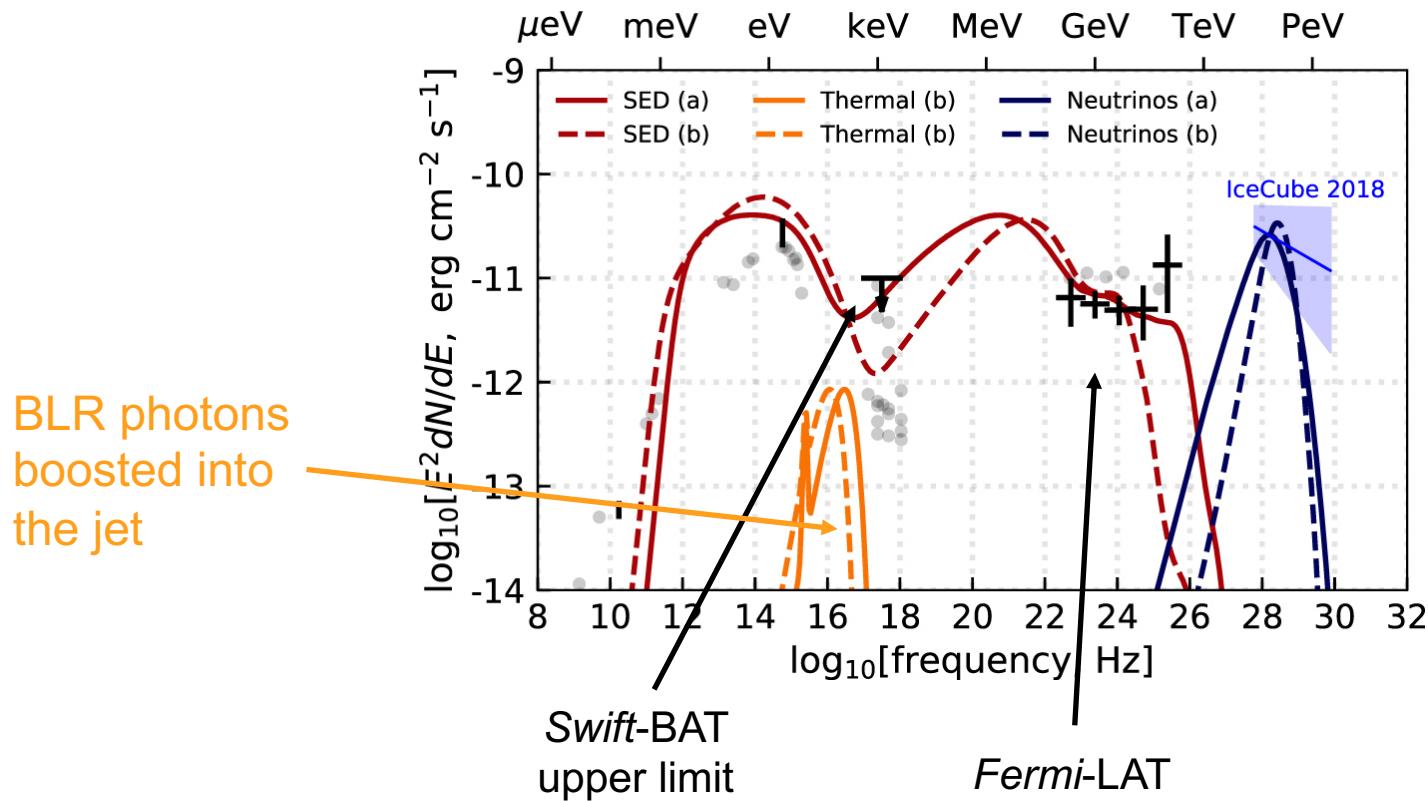
## Search in different time windows:

- 6 months around IceCube-170922A
- 110 days during „orphan“ neutrino flare
- Time-integrated (2004 – 2018)

No excess found

# Modeling of 2014/15 neutrino flare

neutrino luminosity is  $\sim 4$  times higher than gamma-ray luminosity  
→ challenge for models

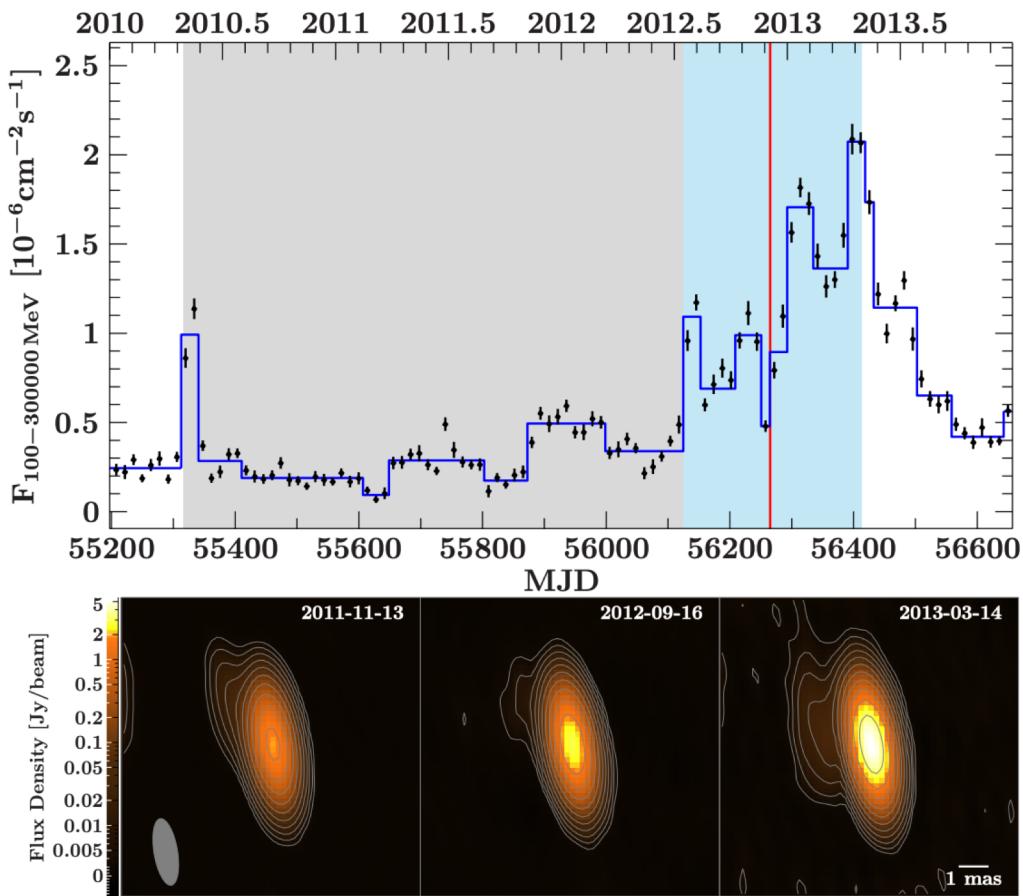


see e.g. Rodrigues et al. ApJL 874 2019, A. Reimer et al. ApJ 881 2019,  
F. Halzen et al. ApJL 874 2019

# Other candidates?

- Sources connected to single high-energy neutrinos?
- Neutrino flares from known sources?
- Contribution of blazars to the diffuse flux?

# Other Interesting Candidates – PKS B1424-418



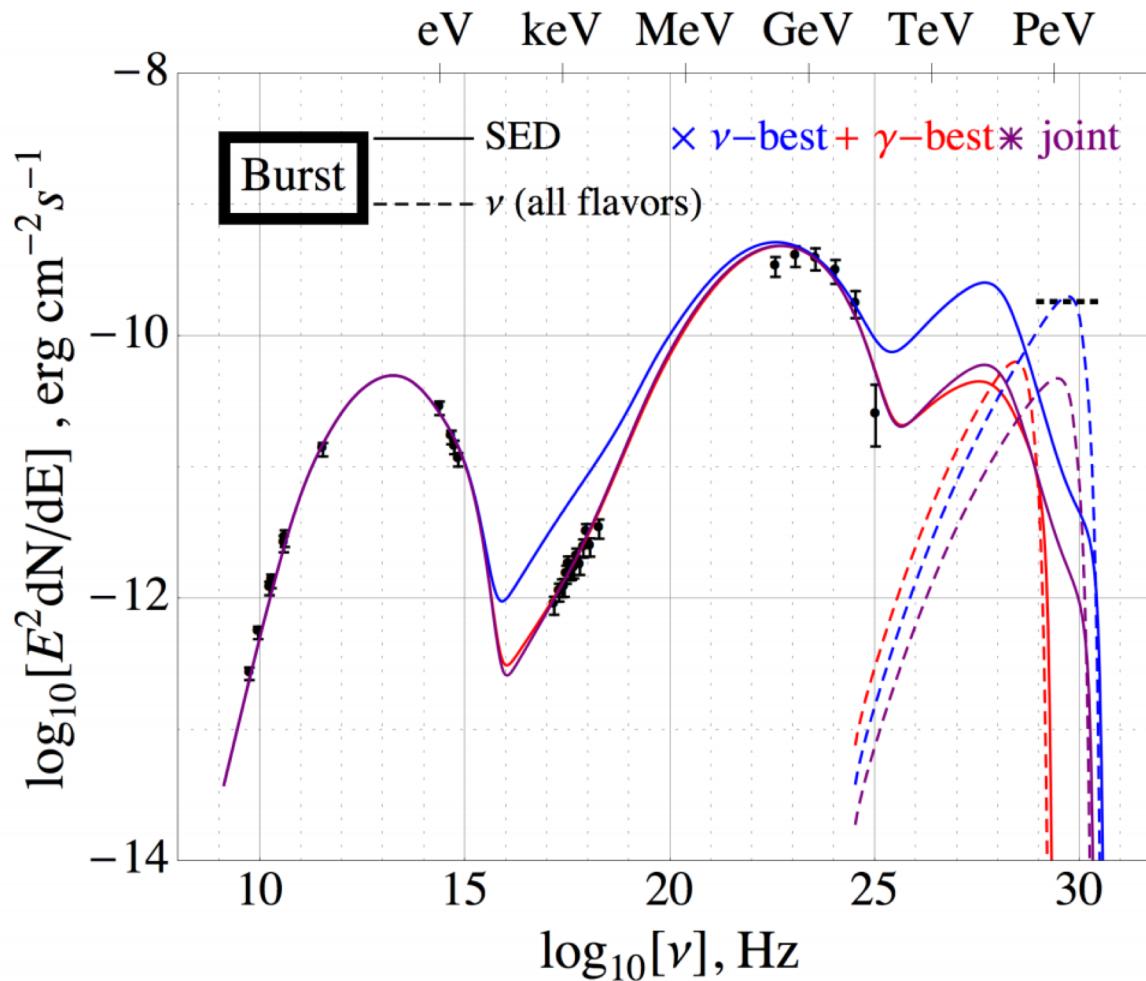
FSRQ

Giant gamma and radio flare

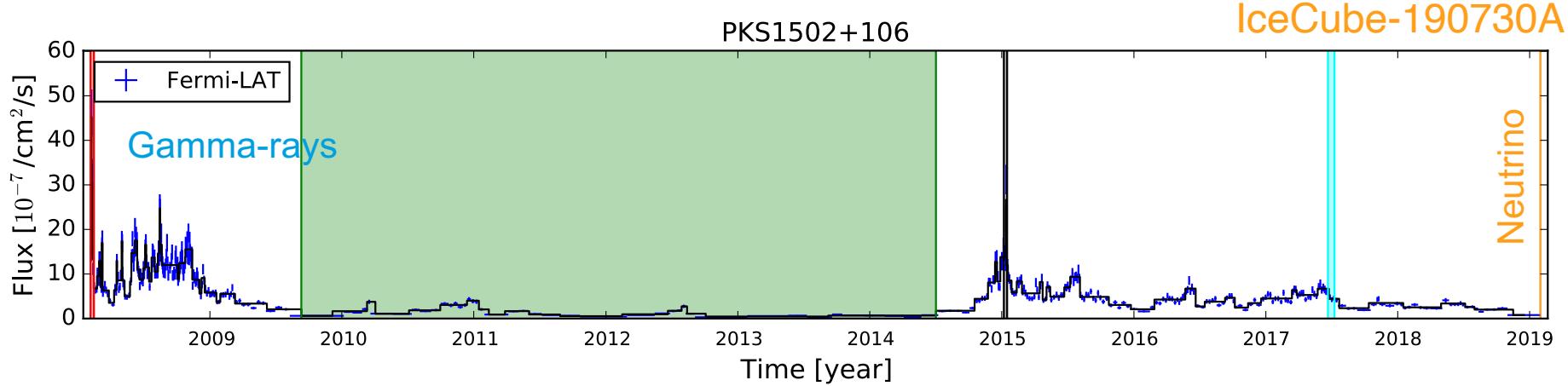
PeV neutrino “Big Bird”

Chance coincidence 5%

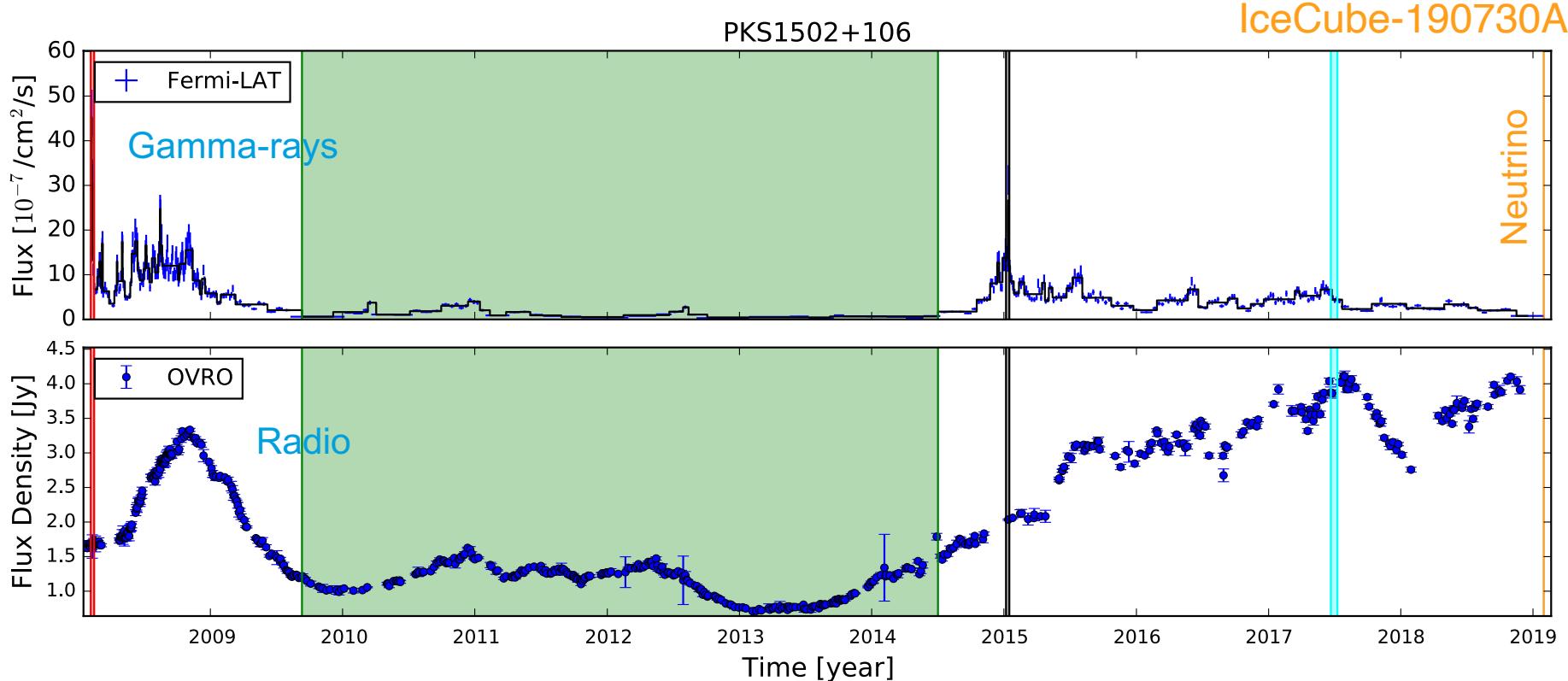
# Other Interesting Candidates – PKS B1424-418



# Other Interesting Candidates – PKS 1502+106



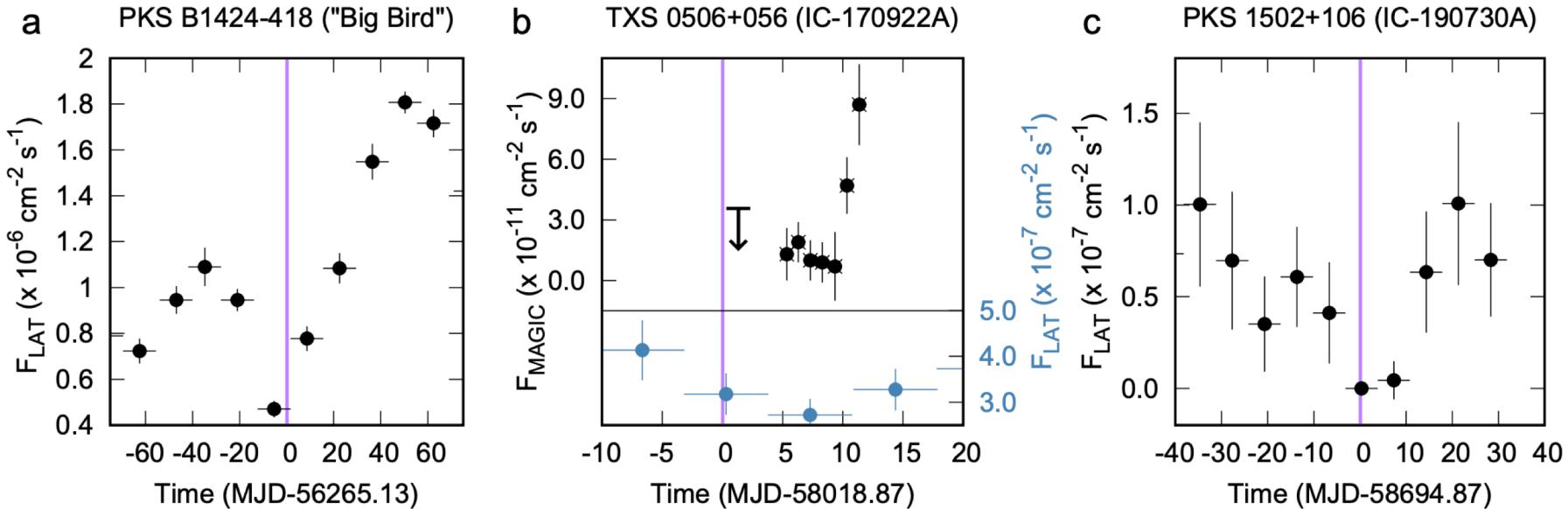
# Other Interesting Candidates – PKS 1502+106



FSRQ, 15 brightest among 2863 4LAC sources,  $z=1.84$

no gamma, but giant radio flare

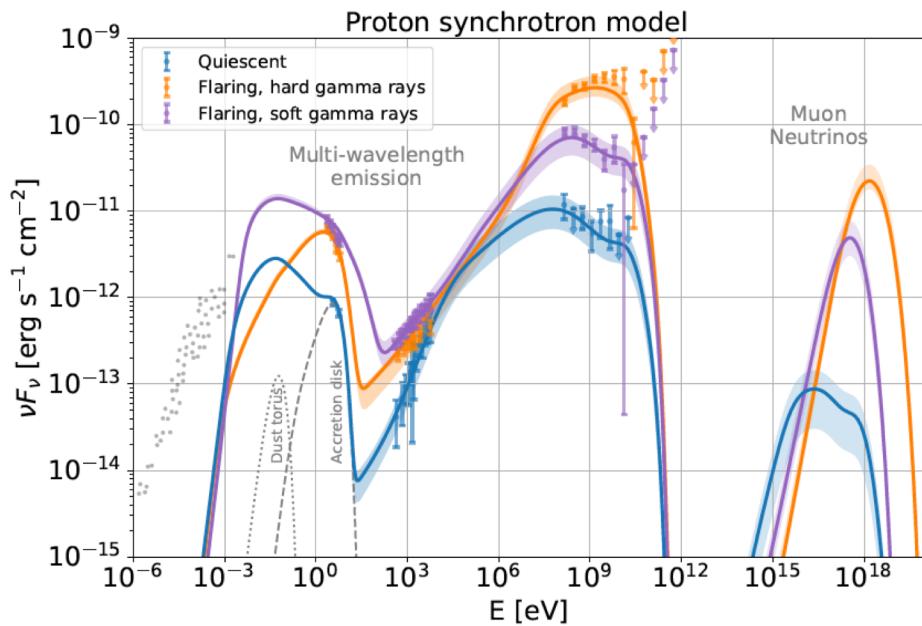
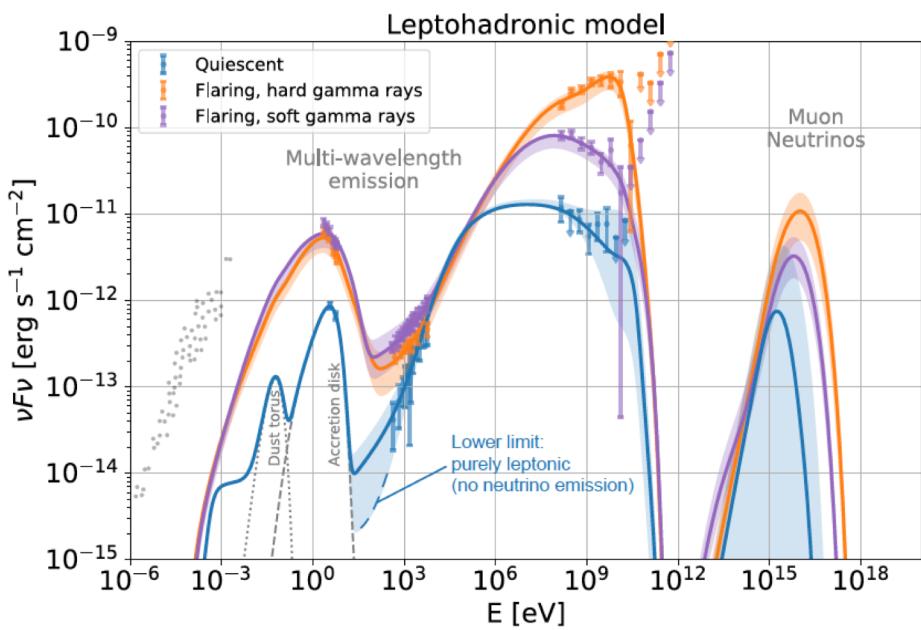
# Gamma-ray depletion?



Large target photon and proton density that helps produce neutrinos while temporarily suppressing observable gamma-ray emission

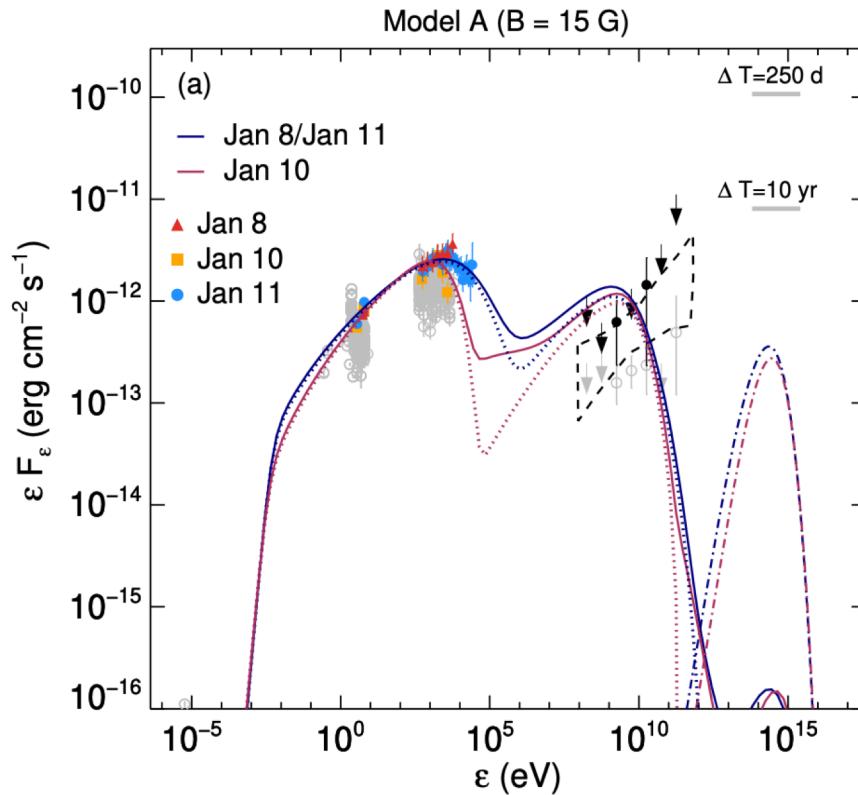
# Modeling of PKS 1502+106

See poster by S.  
Garrappa and talk  
by F. Oikonomou



Can be modeled by lepto hadronic and proton synchrotron  
→ Correlation between neutrino and gamma-ray flux

# Other Interesting Candidates - BZB J0955+3551 (3HSP J095507.9+355101)



Coincident with IceCube-200107A

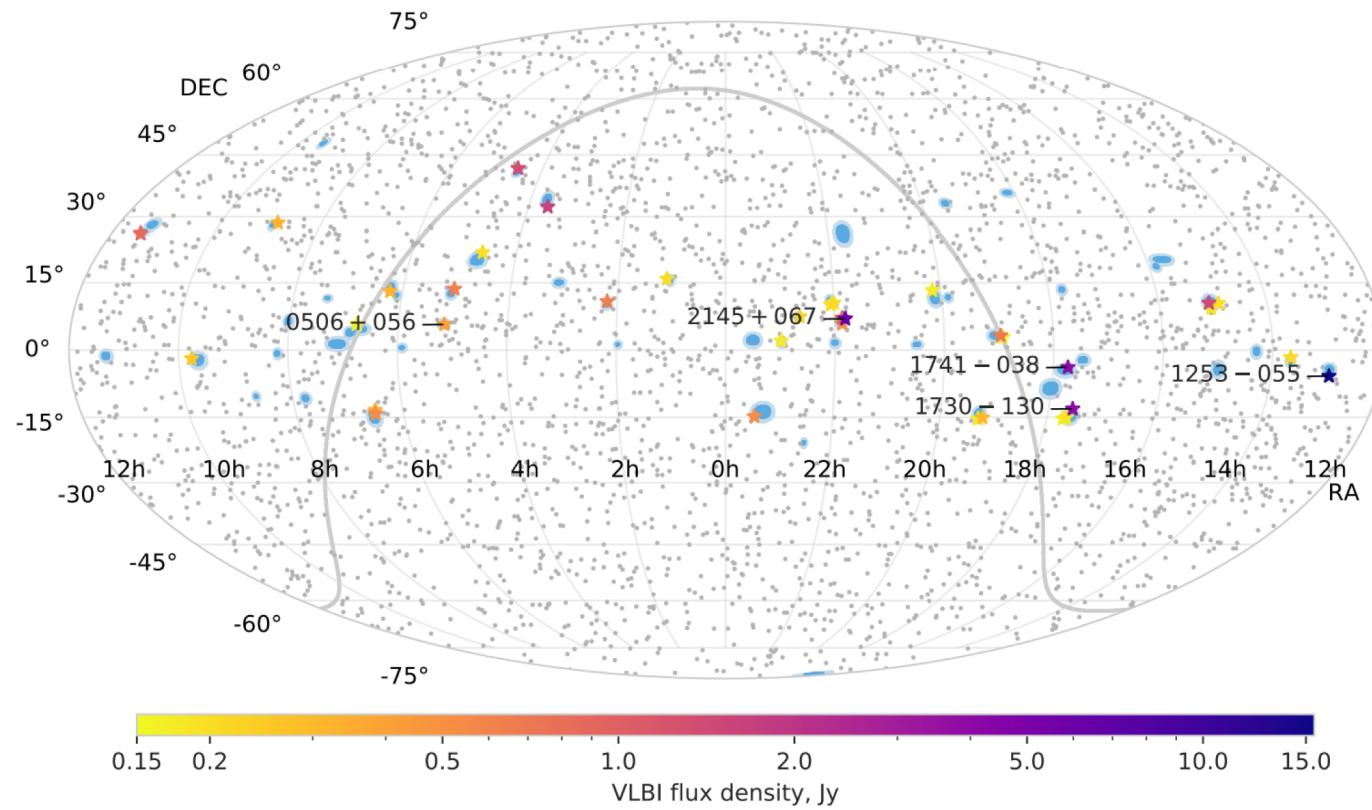
Hard X-ray flare during neutrino arrival, rapid flux variability

BL Lac, z=0.56

# Statistical analysis using a source catalog and all IceCube alerts

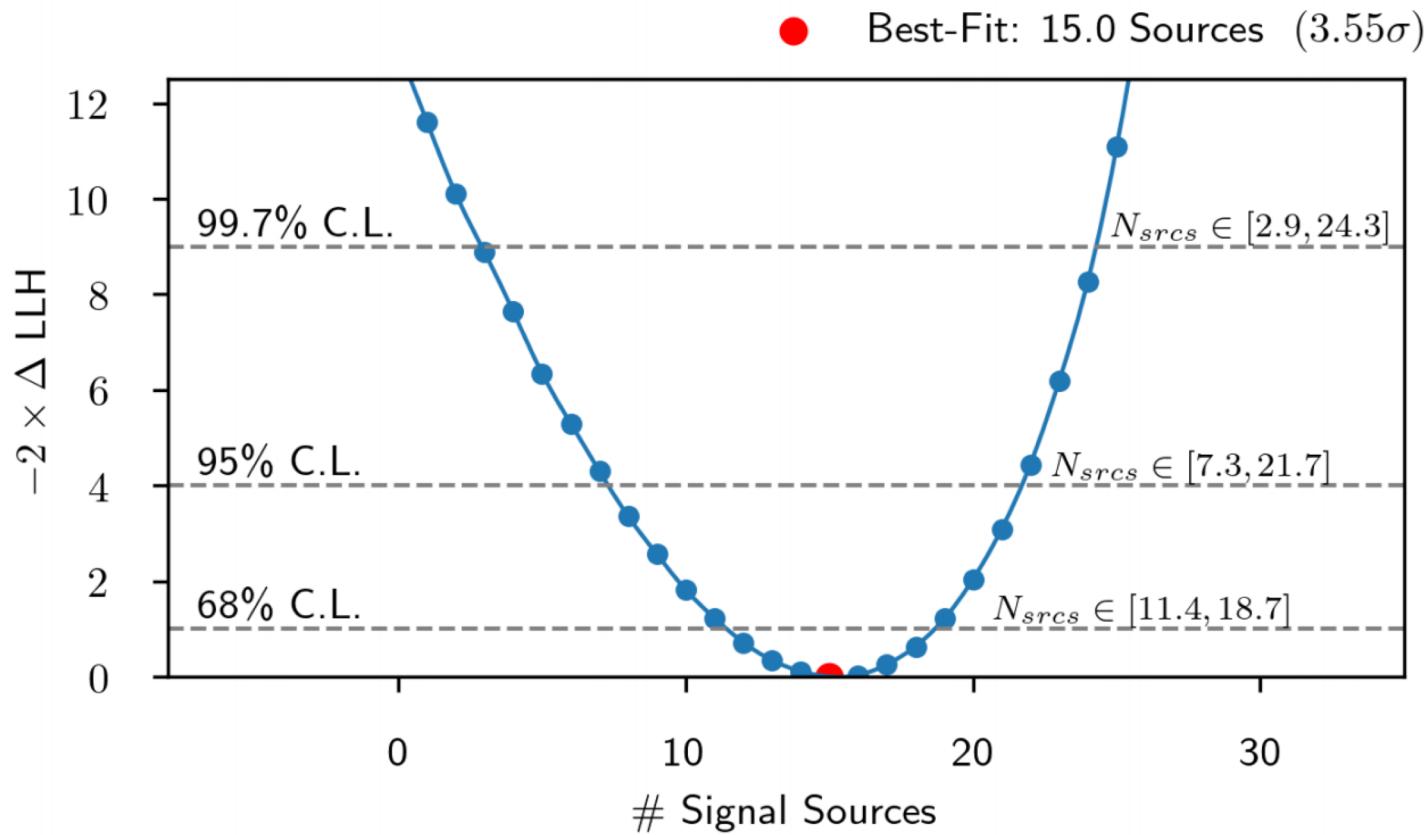
# Correlation with VLBI-flux-density limited sample of AGN

See talk by A. Plavin



Correlation of radio-bright AGN with IceCube neutrino alerts at chance coincidence of 0.2%

# Correlation with 3HSP catalog of high-energy peaked blazars



3.23 sigma (post-trial) excess of high and intermediate peaked synchrotron sources

# Other candidates?

- Sources connected to single high-energy neutrinos?
- Neutrino flares from known sources?
- Contribution of blazars to the diffuse flux?

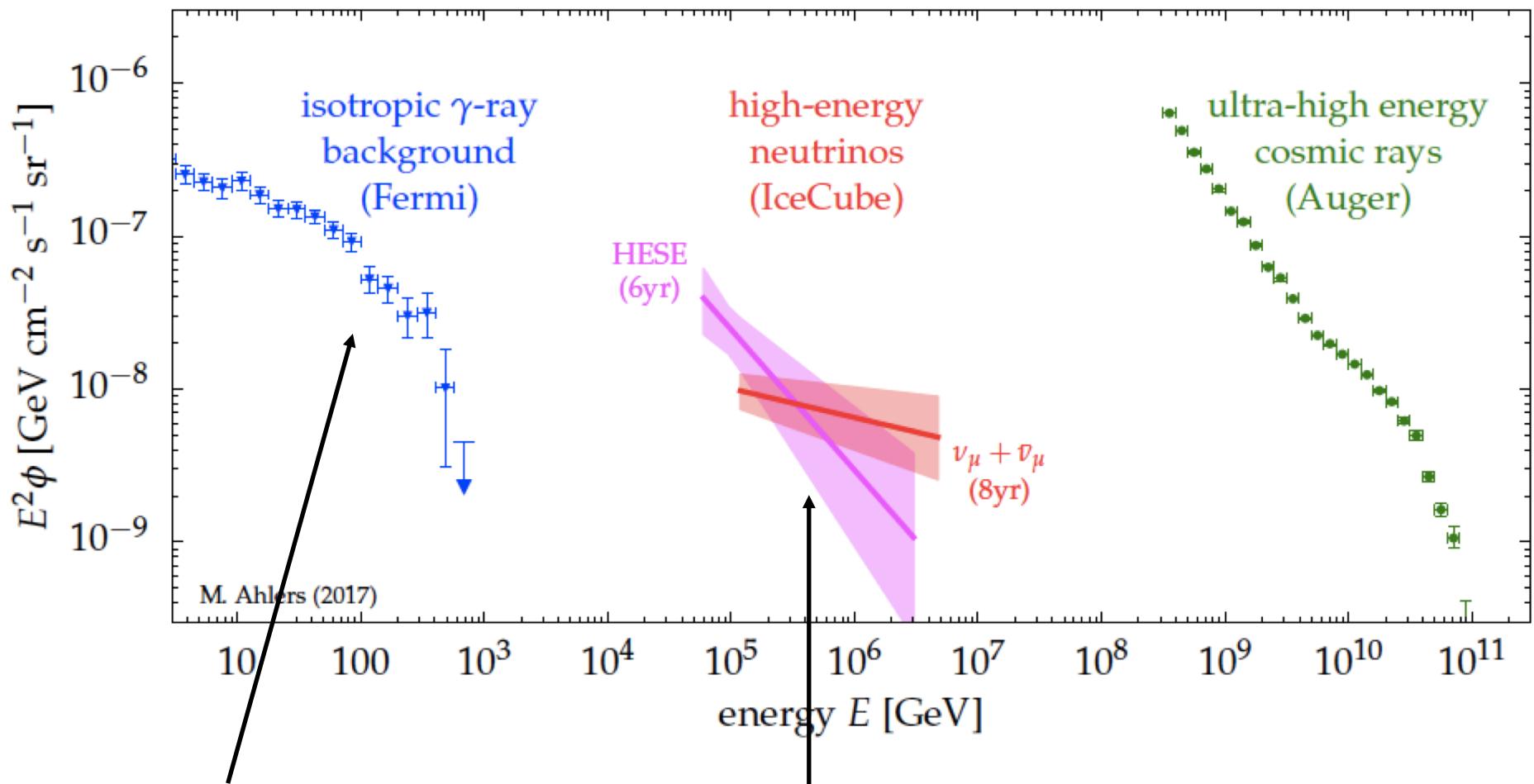




# Other candidates?

- Sources connected to high-energy neutrinos?
- Neutrino flares from known sources?
- Contribution of blazars to the diffuse flux?

# Diffuse Flux by blazars



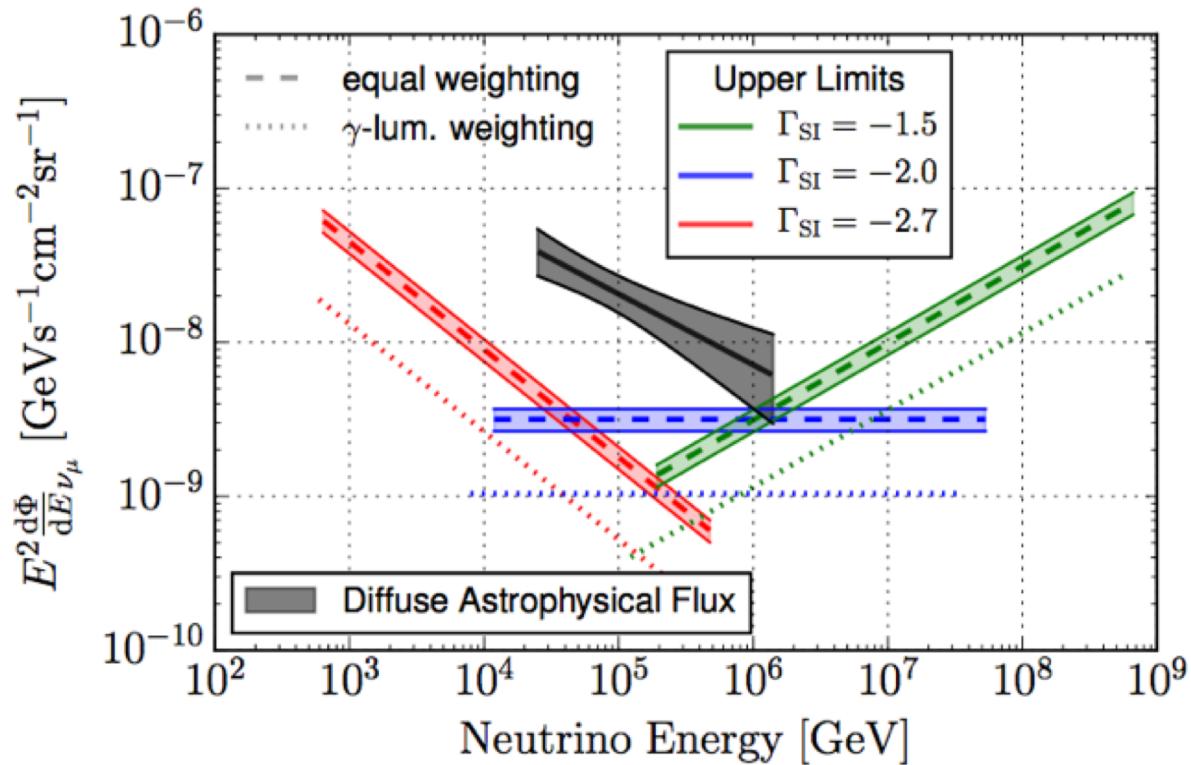
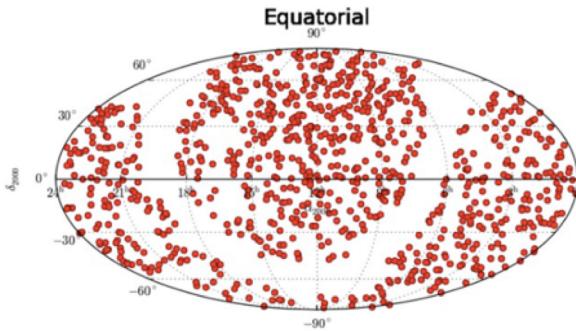
Dominated by blazars

Probe contribution of  
blazars through  
stacking analysis

# Do Fermi blazars produce all IceCube neutrinos?

Blazars dominate the diffuse gamma-ray background above 10 GeV

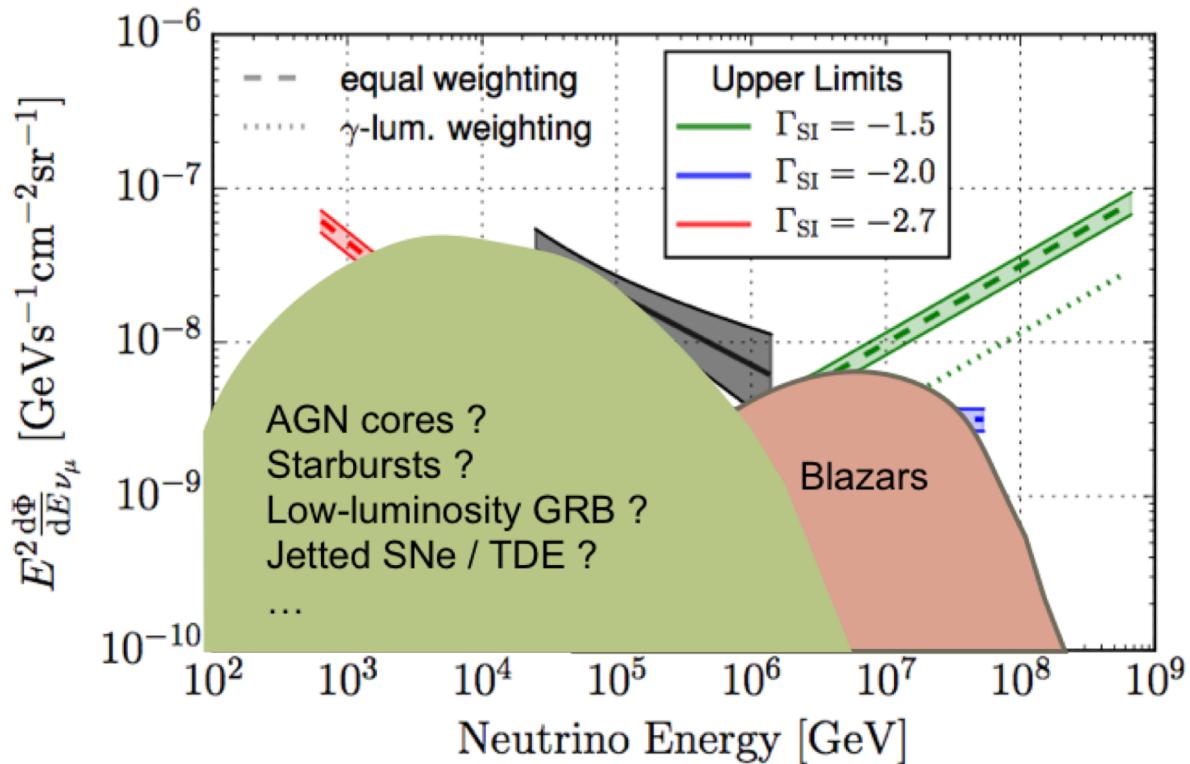
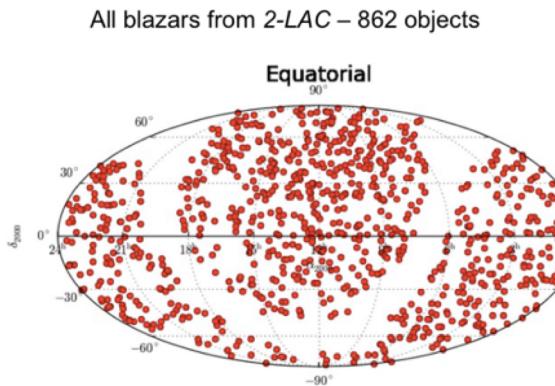
All blazars from 2-LAC – 862 objects



***Fermi-LAT blazars*** can only be responsible for a **small fraction** of the observed  $\nu$ 's.

# Multiple populations?

Blazars dominate the diffuse gamma-ray background above 10 GeV

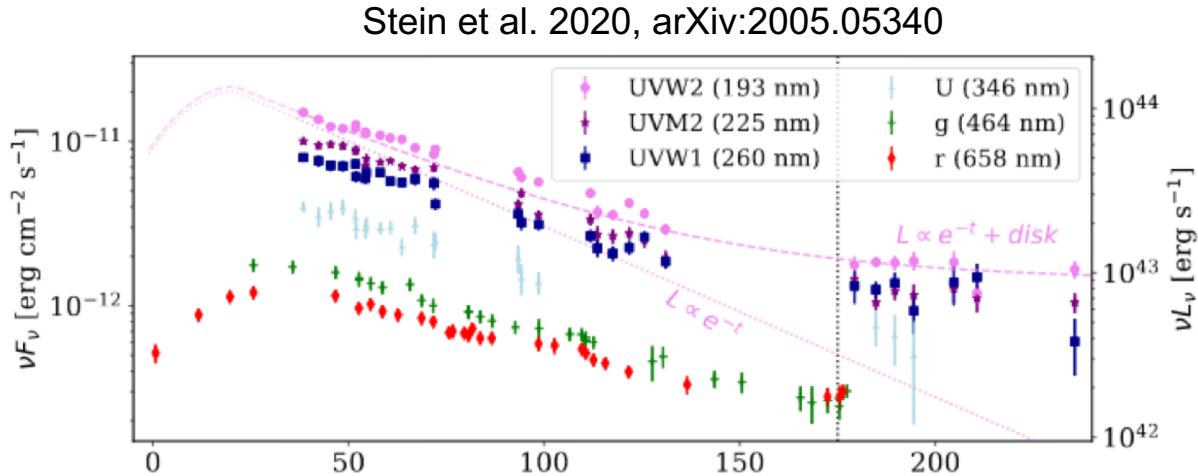


***Fermi-LAT blazars*** can only be responsible for a **small fraction** of the observed  $\nu$ 's.

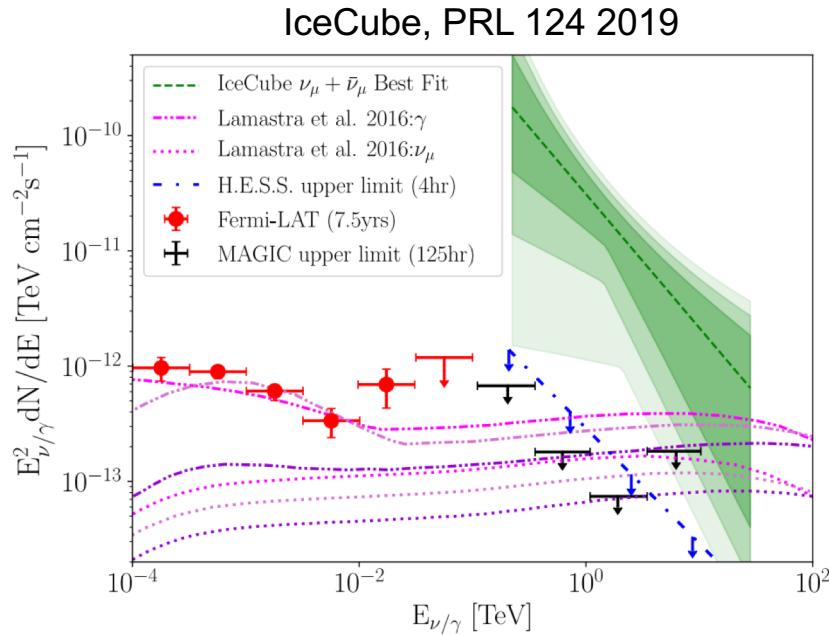
# Hints to other sources?

- TDE AT2019dsg,  
chance coincidence  
0.5%,  $z=0.051$
- Second event  
AT2019fdr

See poster by S. Reusch



- Starforming galaxy  
NGC 1068 (M77), 2.9  
sigma, 14Mpc



# Summary

- We have examples for single high energy neutrinos coincident with
  - High gamma-ray activity (TXS 0506+056, PKS B1424-418)
  - High radio flux (PKS 1502+106, PKS B1424-418)
  - High and hard X-ray activity (BZB J0955+3551 / 3HSP J095507.9+355101)
- Gamma-ray blazars are disfavored as the main source of the diffuse neutrino flux
- Hints for correlation of neutrinos with radio-bright AGN and high-energy peaked blazars

**Get input from theory what to look for and need to find more candidates based on that input**

# backup

# Do blazars produce all IceCube neutrinos?

