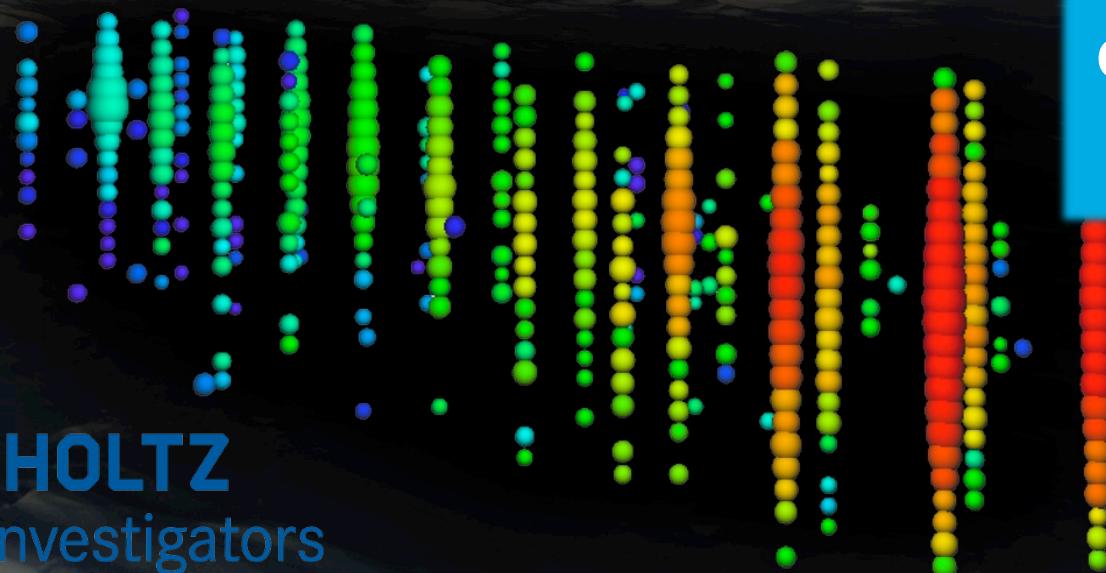


# Detection of a flaring blazar coincident with an IceCube high-energy neutrino

Anna Franckowiak for the  
IceCube and Fermi Collaboration



See also talks by  
C. Finley, T. Glauch,  
A. Fedynitch,  
G. Illuminati

**HELMHOLTZ**  
Young Investigators

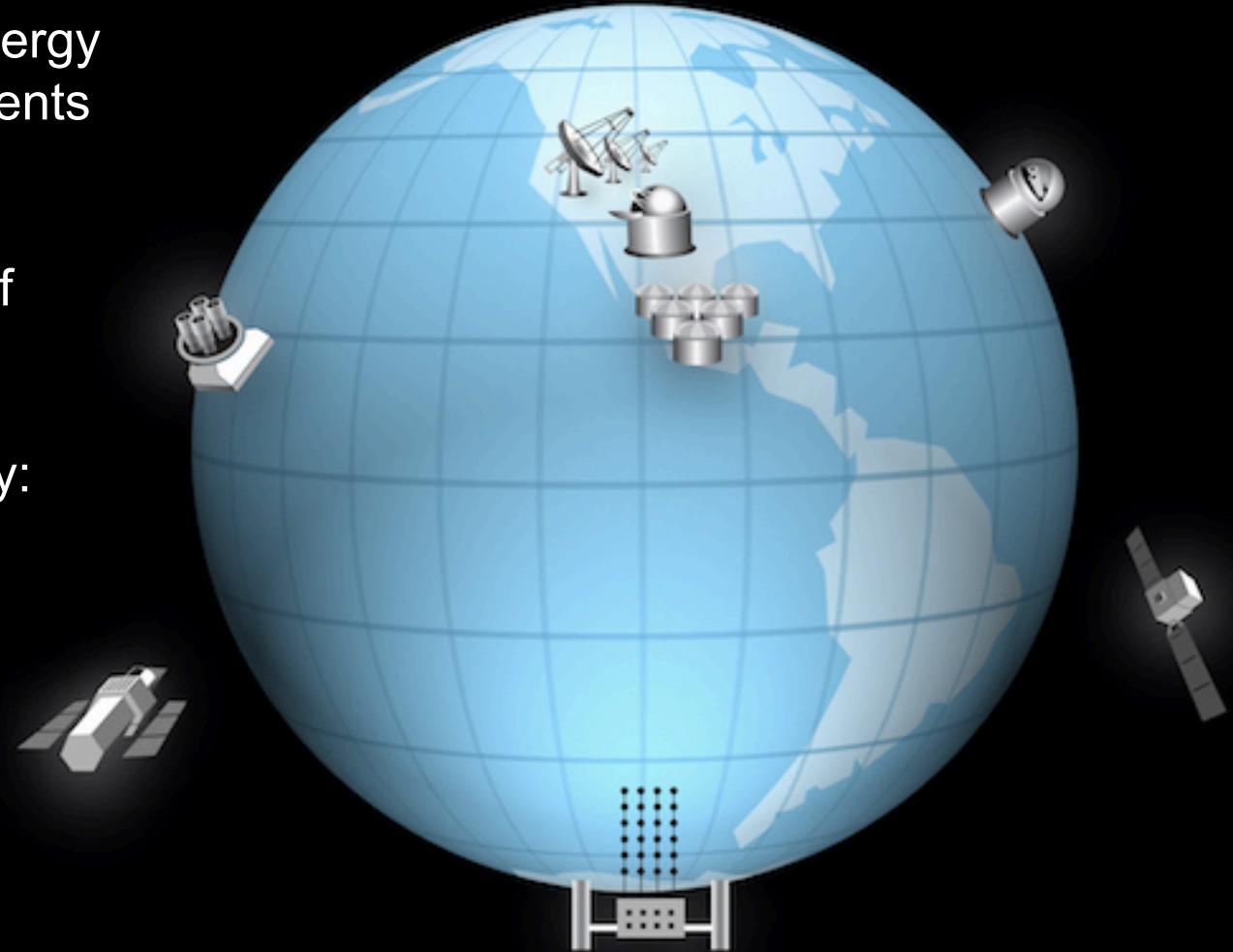
“VLVNT 2018” Dubna, October 2, 2018



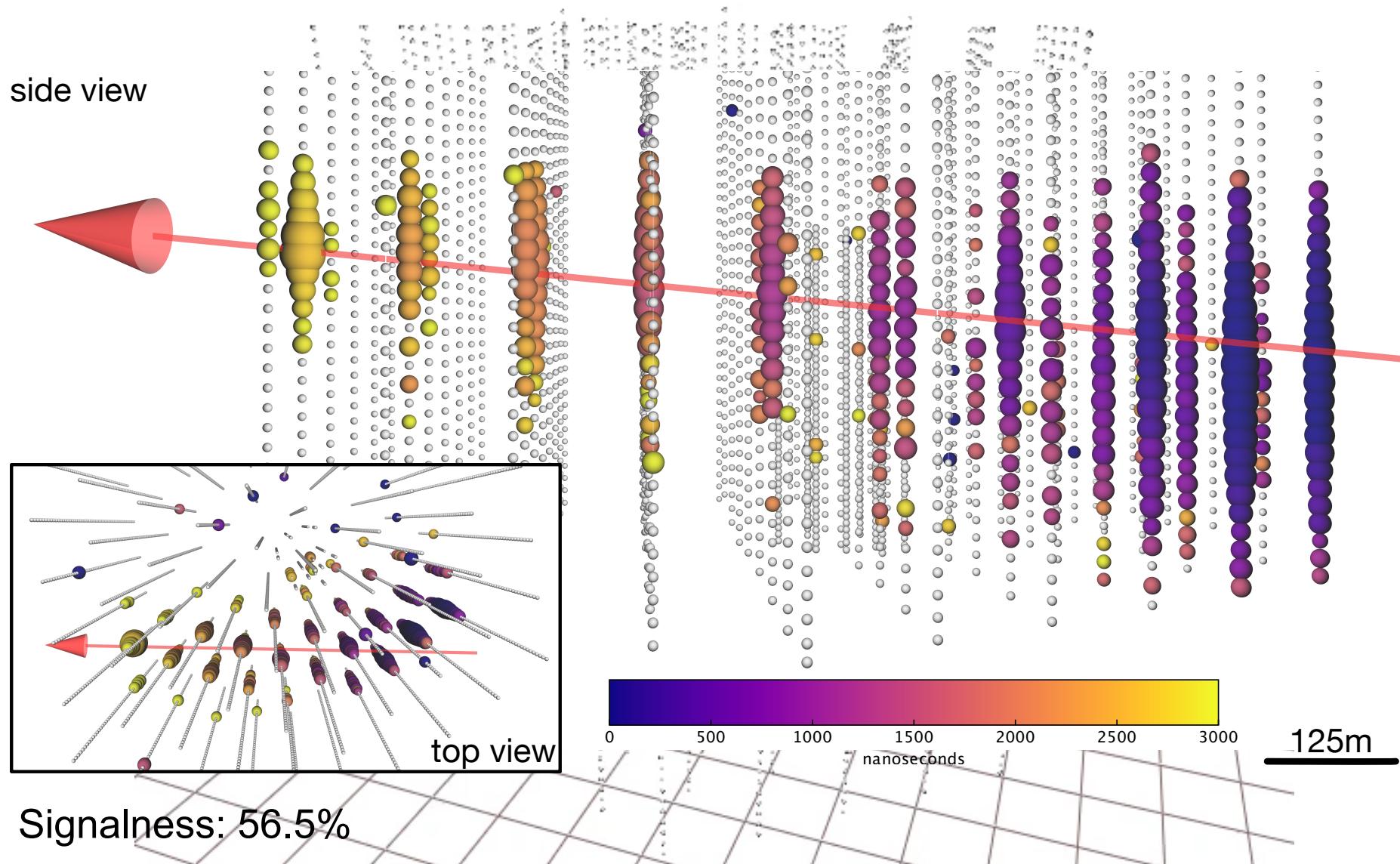
# IceCube Target of Opportunity Program

Public alerts since April 2016

- Single high-energy muon track events ( $> \sim 100\text{TeV}$ )
- 8 / yr,  $\sim 3$  / yr of cosmic origin
- Median latency: 30 sec



# IC-170922A – a 290 TeV Neutrino





# Fermi-LAT Finds Flaring Blazar

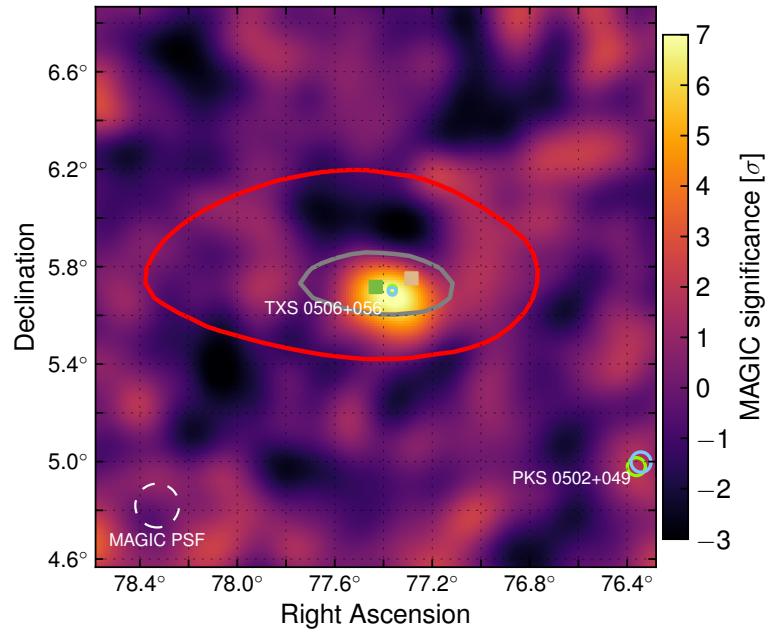
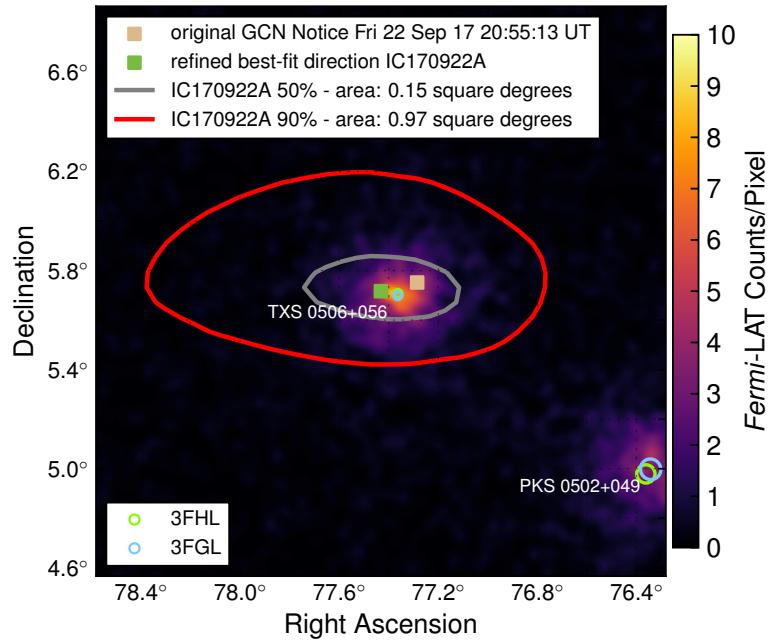


# Fermi-LAT finds Flaring Blazar



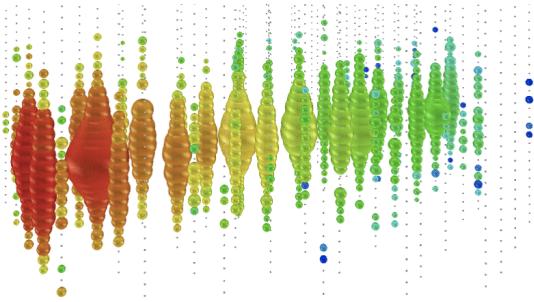
Among 50 brightest 3LAC sources

# MAGIC observes >100 GeV gamma rays



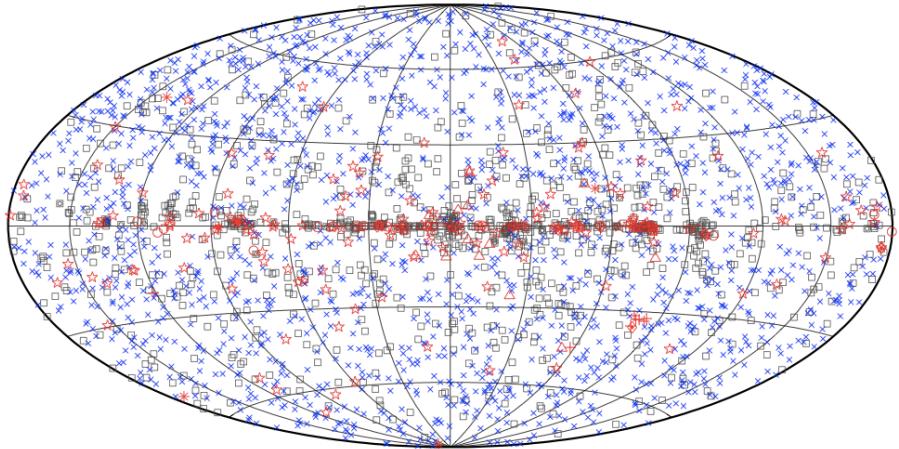
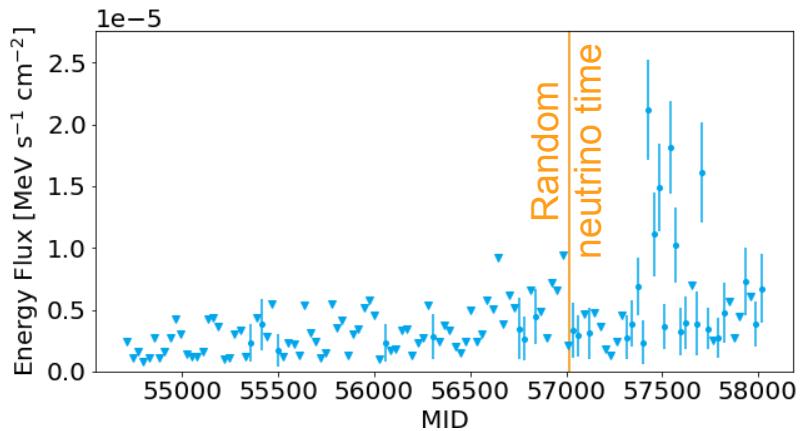
Sergi Luque  
© Espai Astronomic

# How Likely is it a Chance Probability?



**Step I:** Draw a random neutrino from a representative Monte-Carlo sample of high-energy muon-track events (EHE)

**Step II:** Are there any extra-galactic Fermi sources close in space to the neutrinos?



**Step III:** What is the gamma-ray energy flux in the time bin when the neutrino arrives?

# How Likely is it a Chance Probability?

$$TS = 2 \log \frac{\mathcal{L}(n_s = 1)}{\mathcal{L}(n_s = 0)} = 2 \log \frac{S}{B}$$

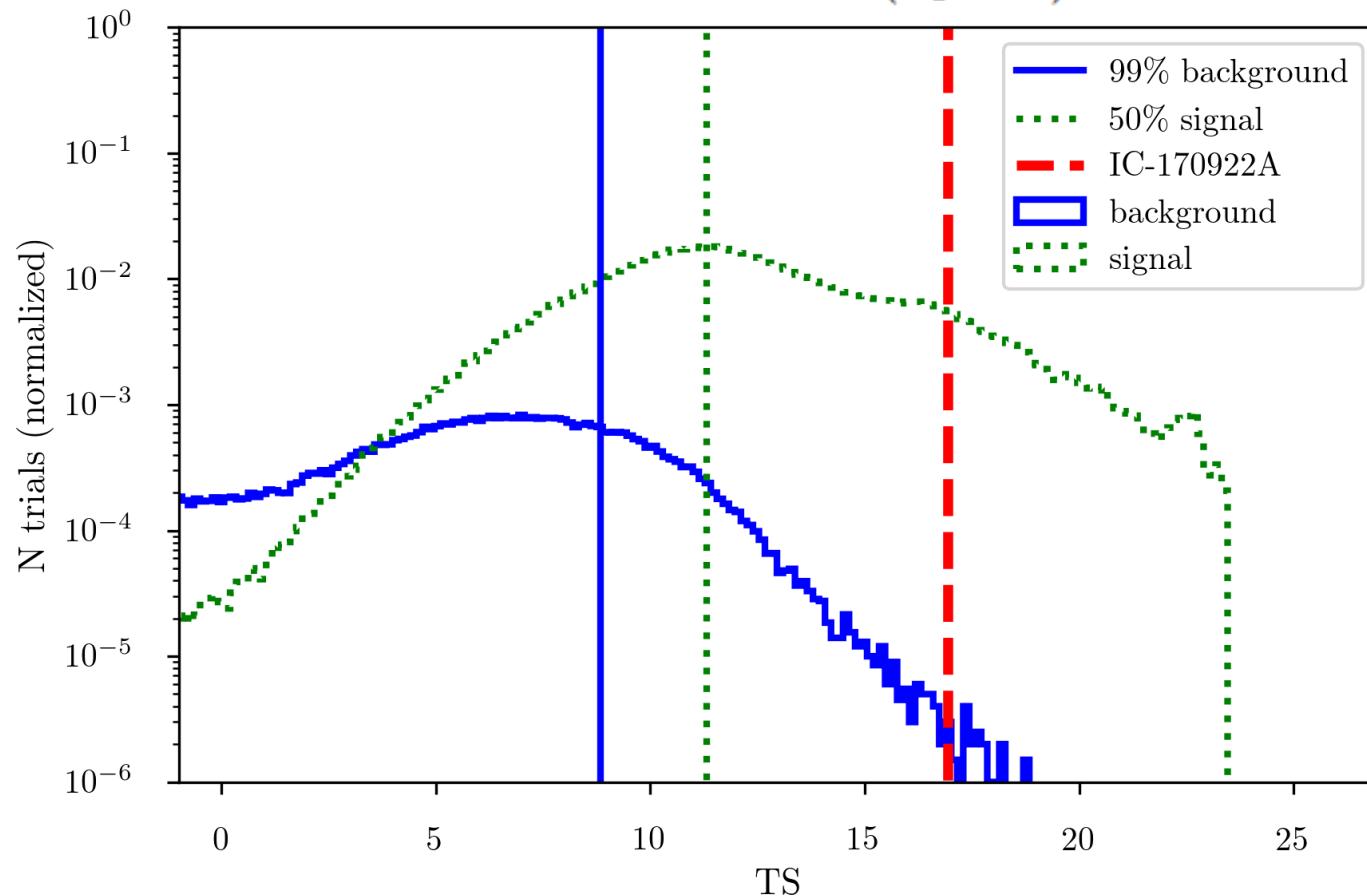
$$\mathcal{B}(\vec{x}) = \frac{\mathcal{P}_{BG}(\sin \theta)}{2\pi}$$

$$\mathcal{S}(\vec{x}, t) = \sum_s \frac{1}{2\pi\sigma^2} e^{-|\vec{x}_s - \vec{x}|^2/(2\sigma^2)} w_s(t) w_{\text{acc}}(\theta_s)$$

A diagram illustrating the components of the spatial term and acceptance. It features a large curly brace under the term  $\frac{1}{2\pi\sigma^2} e^{-|\vec{x}_s - \vec{x}|^2/(2\sigma^2)}$  labeled "Spatial term". To its right, two arrows point upwards from the labels "gamma-ray energy flux at time t" and "acceptance" to the terms  $w_s(t)$  and  $w_{\text{acc}}(\theta_s)$  respectively.

# How Likely is it a Chance Probability?

$$TS = 2 \log \frac{\mathcal{L}(n_s = 1)}{\mathcal{L}(n_s = 0)} = 2 \log \frac{\mathcal{S}}{\mathcal{B}}$$



Pre-trials p-value:  $4.1\sigma$

10 public alerts and 41 archival events →  
Post-trials p-value:  $3.0\sigma$

# Three models tested

Neutrino emission correlates with

1. gamma-ray energy flux in the range 1-100 GeV

$$w_s(t) = \phi_E(t) = \int_{1 \text{ GeV}}^{100 \text{ GeV}} E_\gamma \frac{d\phi_\gamma(t)}{dE_\gamma} dE_\gamma$$

2. relative gamma-ray flux variations in the range 1-100 GeV

$$w_s(t) = \phi_\gamma(t) / \langle \phi_\gamma \rangle$$

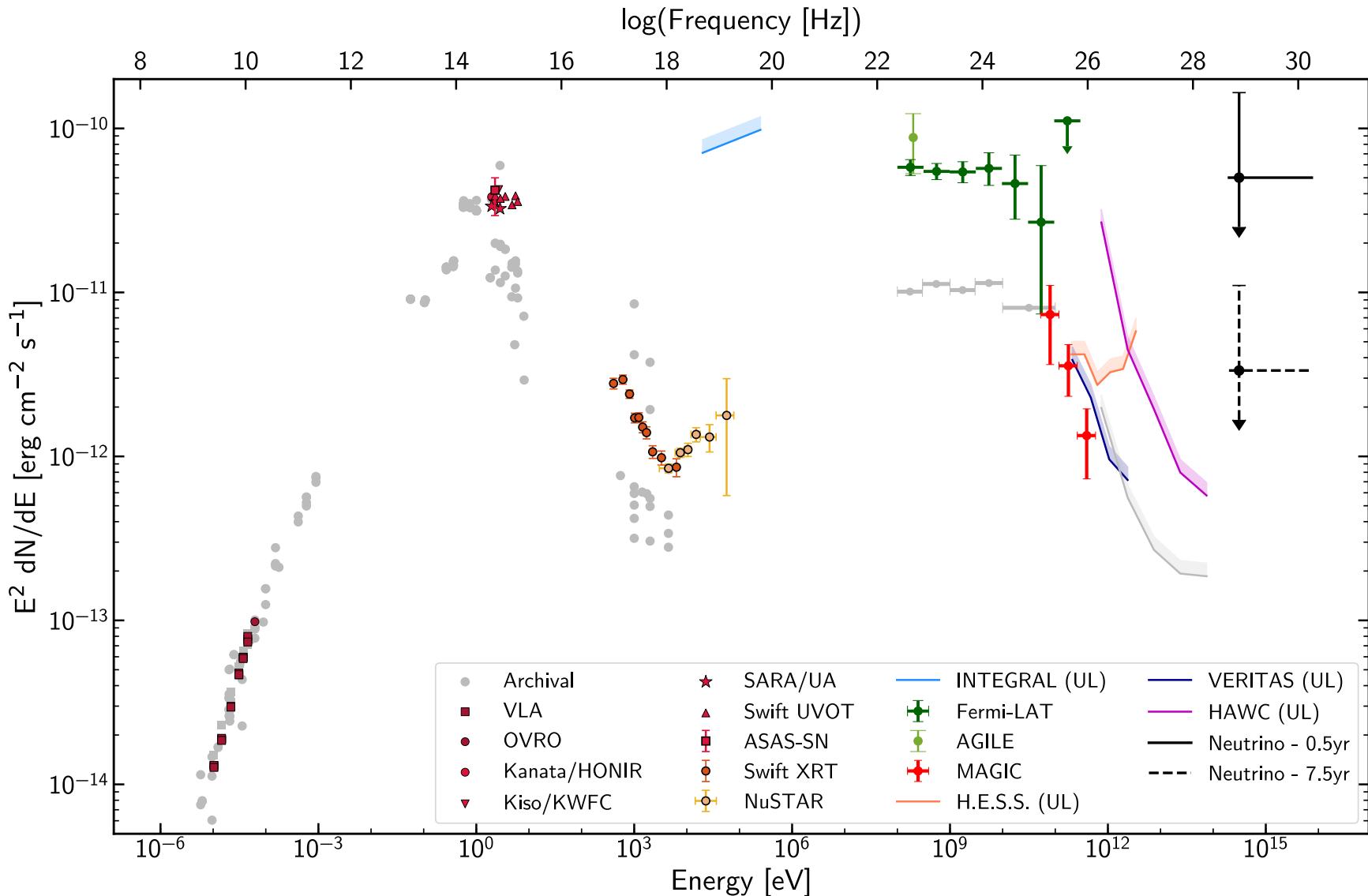
3. very high-energy gamma-ray energy flux in the range 100GeV-1TeV  
(extrapolated from Fermi energy range)

$$w_s(t) = \phi_E(t) = \int_{100 \text{ GeV}}^{1 \text{ TeV}} E_\gamma \frac{d\phi_\gamma(t)}{dE_\gamma} dE_\gamma$$

All tested models yield similar p-values

# The Multi-Messenger SED

Redshift  $0.3365 \pm 0.0010$   
 (S. Paiano et al. 2018)



# Are there more neutrinos associated to TXS?

See talk by Chad Finley

# Conclusion

- First high-energy neutrino with compelling electro-magnetic counterpart
- Luminous BL Lac object
- Activity seen in many wavelength

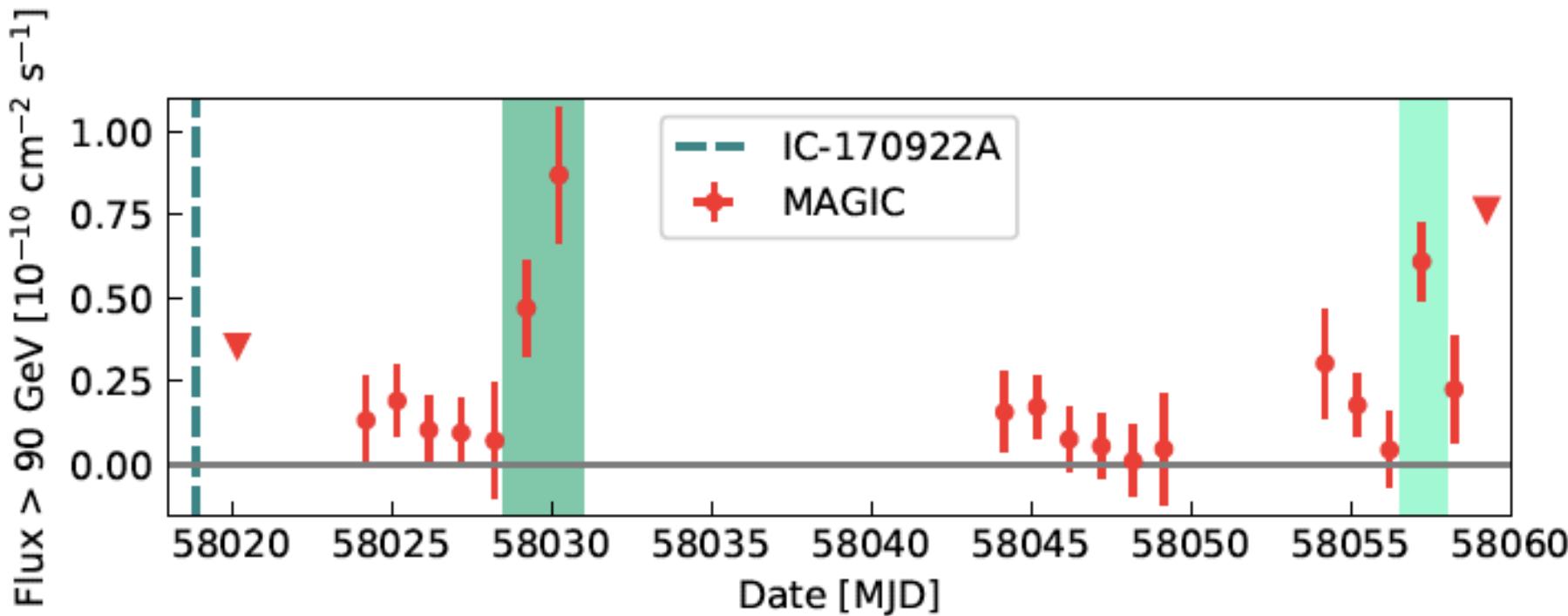
See talks by  
**C. Finley, T. Glauch,  
A. Fedynitch**

## Open Questions

- Which models can explain the MW data?
- How does this fit together with the 2014/15 neutrino flare without coincident EM activity?
- How can we find more such coincidences?

# Backup

# MAGIC finds variability on 1-day scale



Compact emission region

# The Multi-Messenger Light Curve

