Hadronic signatures of Quasars captured by Fermi-LAT

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Instituto de Física - UNAM

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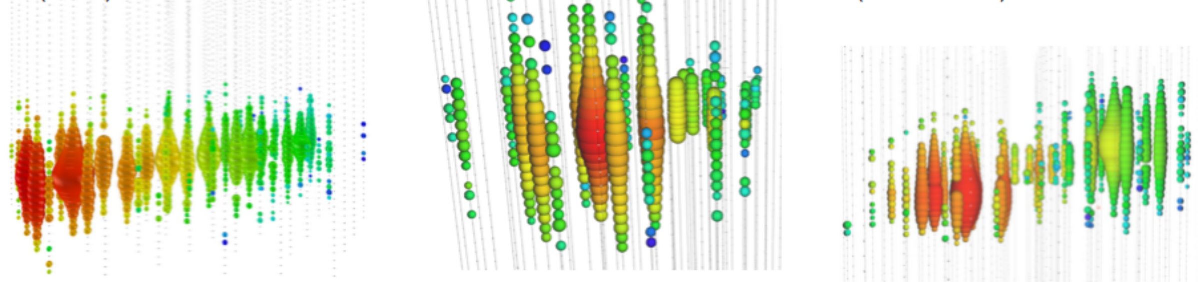
IceCube Observatory

Involve 7 stages of construction 2004-2011

https://icecube.wisc.edu/~kjero/Bootcamp/2015/Notebooks/Reconstruction_Introduction.html

(data) (data) (simulation)



Up-going track

Factor of ~2 energy resolution
< 1 degree angular resolution

Isolated energy deposition (cascade) with no track

15% deposited energy resolution
10 degree angular resolution (above 100 TeV)

"Double-bang"

(none observed yet: τ decay length is 50 m/PeV)

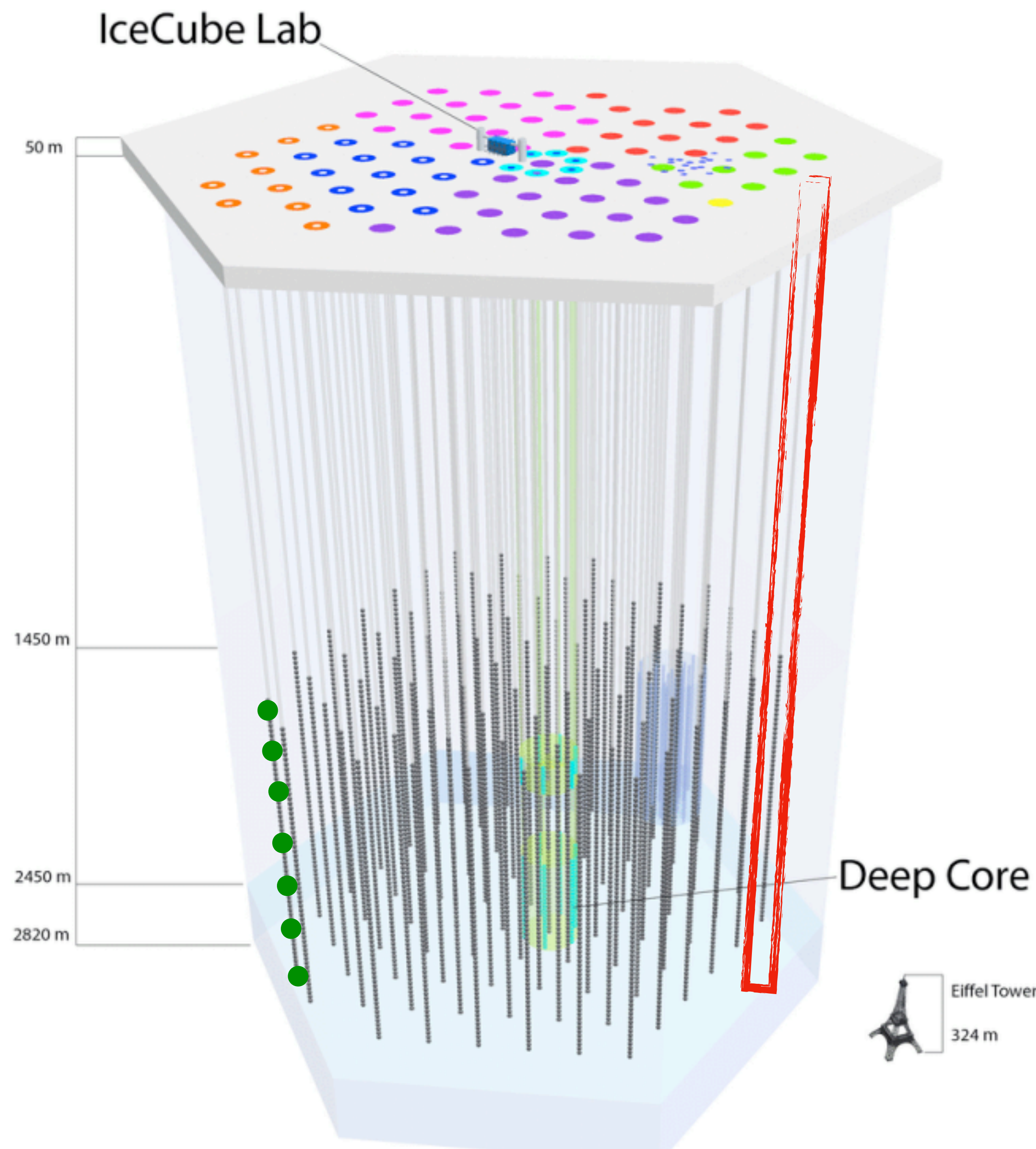
Early  Late

$E_\nu > 30$ TeV

In a volume of $1\mathrm{km}^3$ of ice,
IceCube consists of:

- 86 Digital Optical Module strings (DOM)

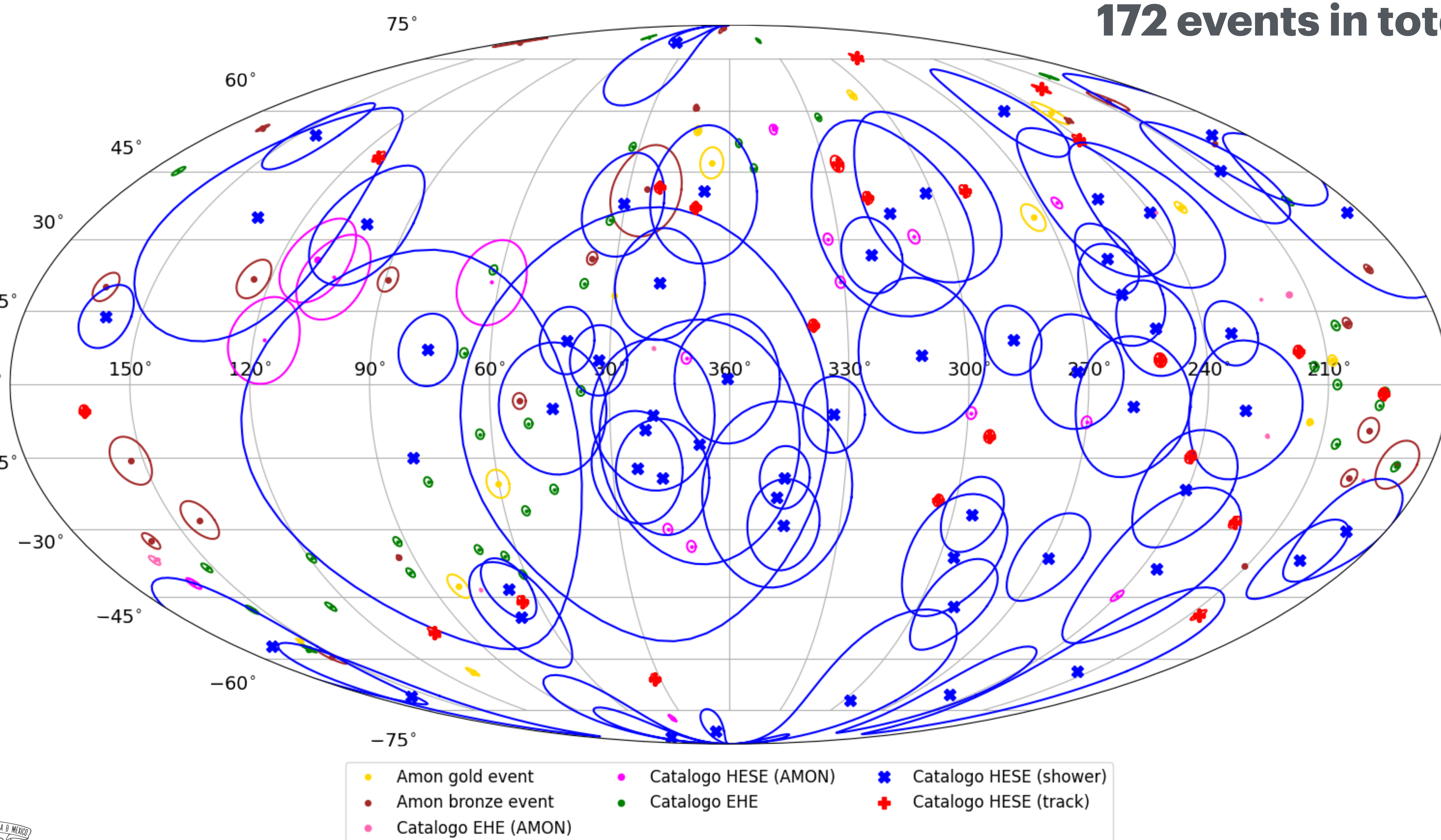
- 60 DOMs per string



https://myhubbleabode.com/2023/07/29/how-does-icecube-detect-neutrinos/

High Energy Neutrinos

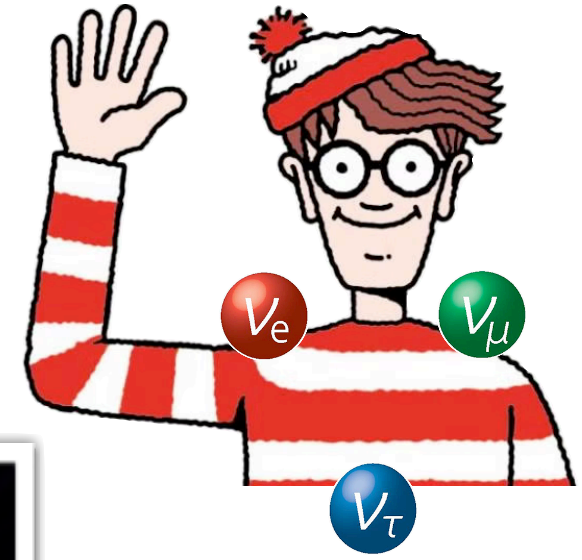
172 events in total



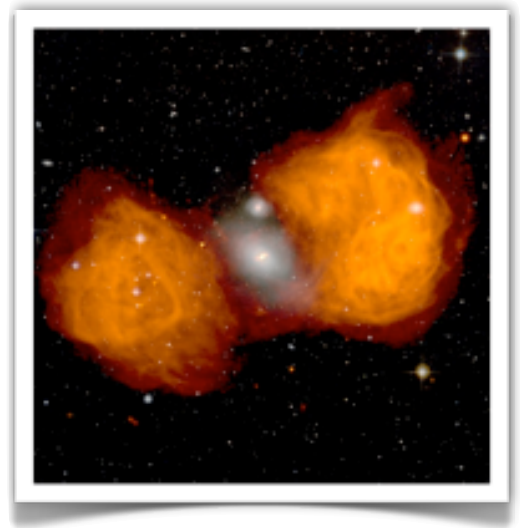
82 neutrinos from HESE catalog (**Aartsen et. al. 2013**)
32 neutrinos EHE catalog EHE(**Aartsen et. al. 2016**)

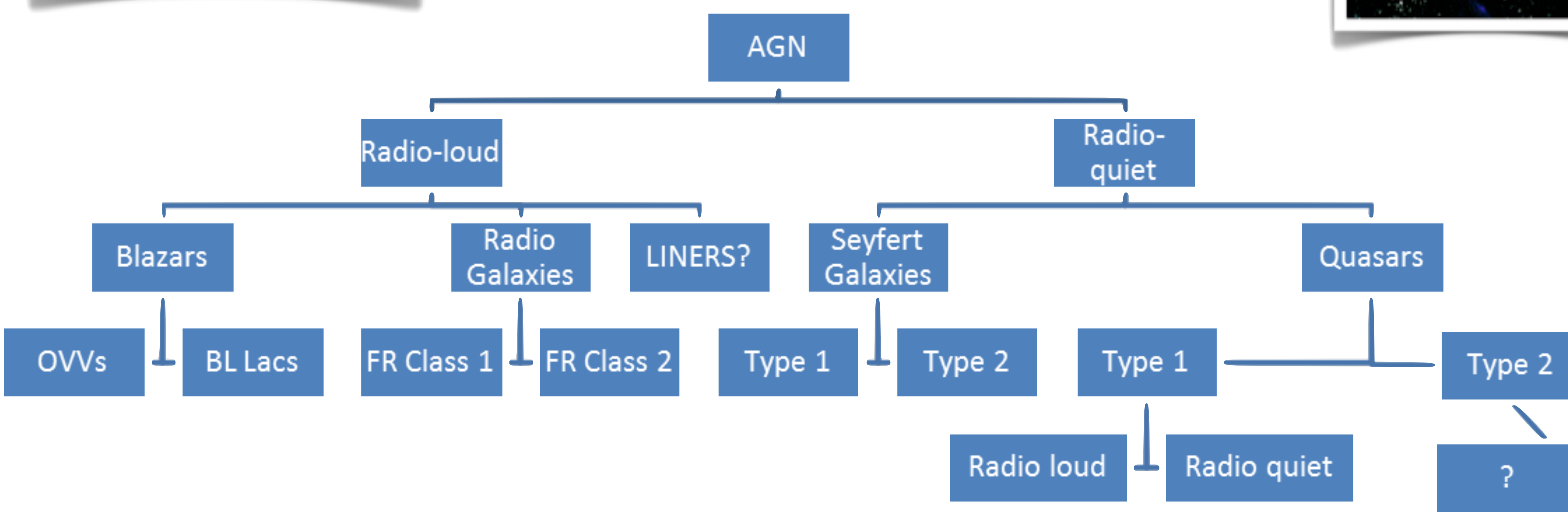
23 neutrinos HESE (AMON)
11 neutrinos EHE (AMON)
16 Bronze alert (AMON)
8 Gold alert (AMON)

High Energy Neutrinos



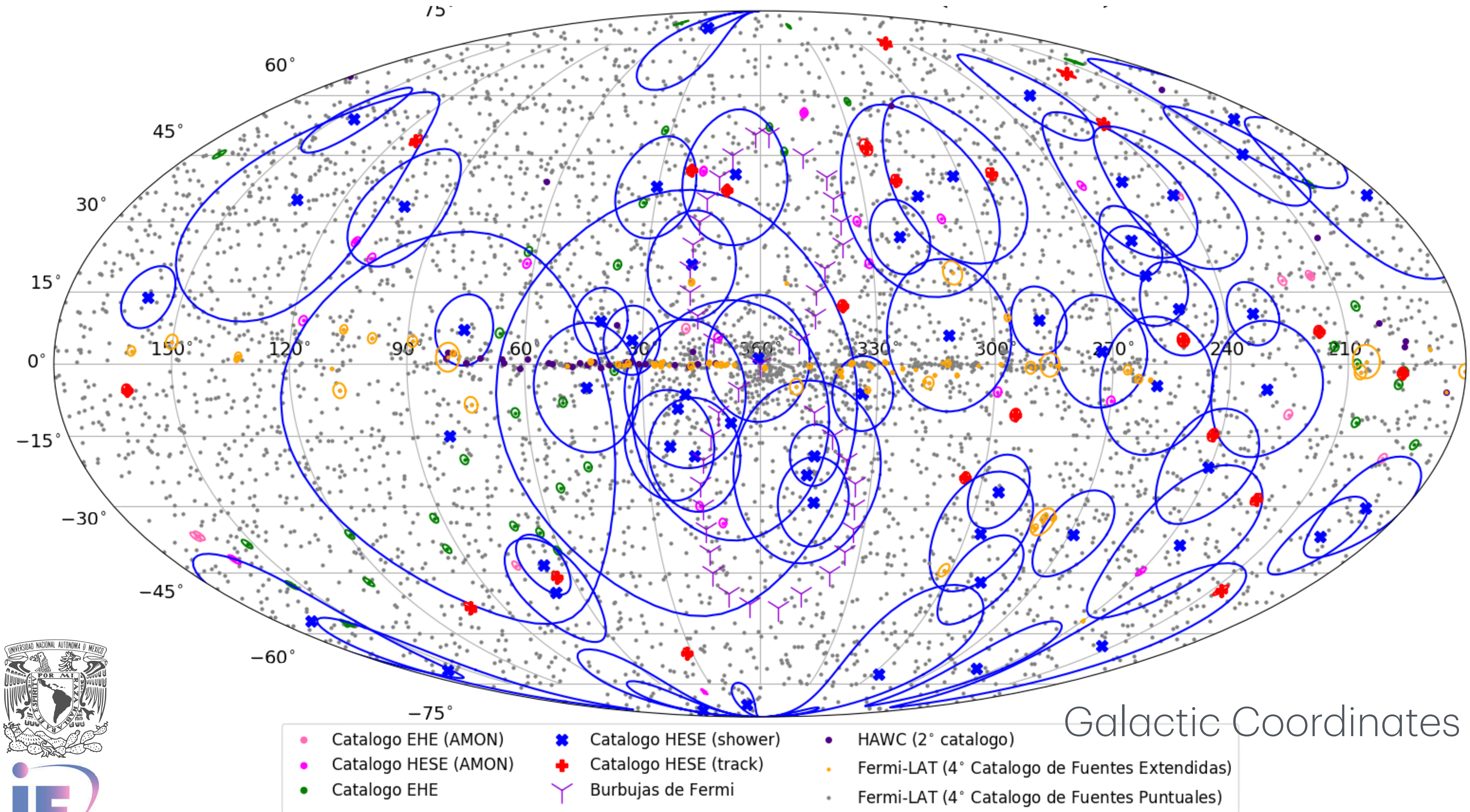
A quick look in the Active Nuclei Neighbourhoods





High Energy Neutrinos

High energy skymap (neutrinos + photons)

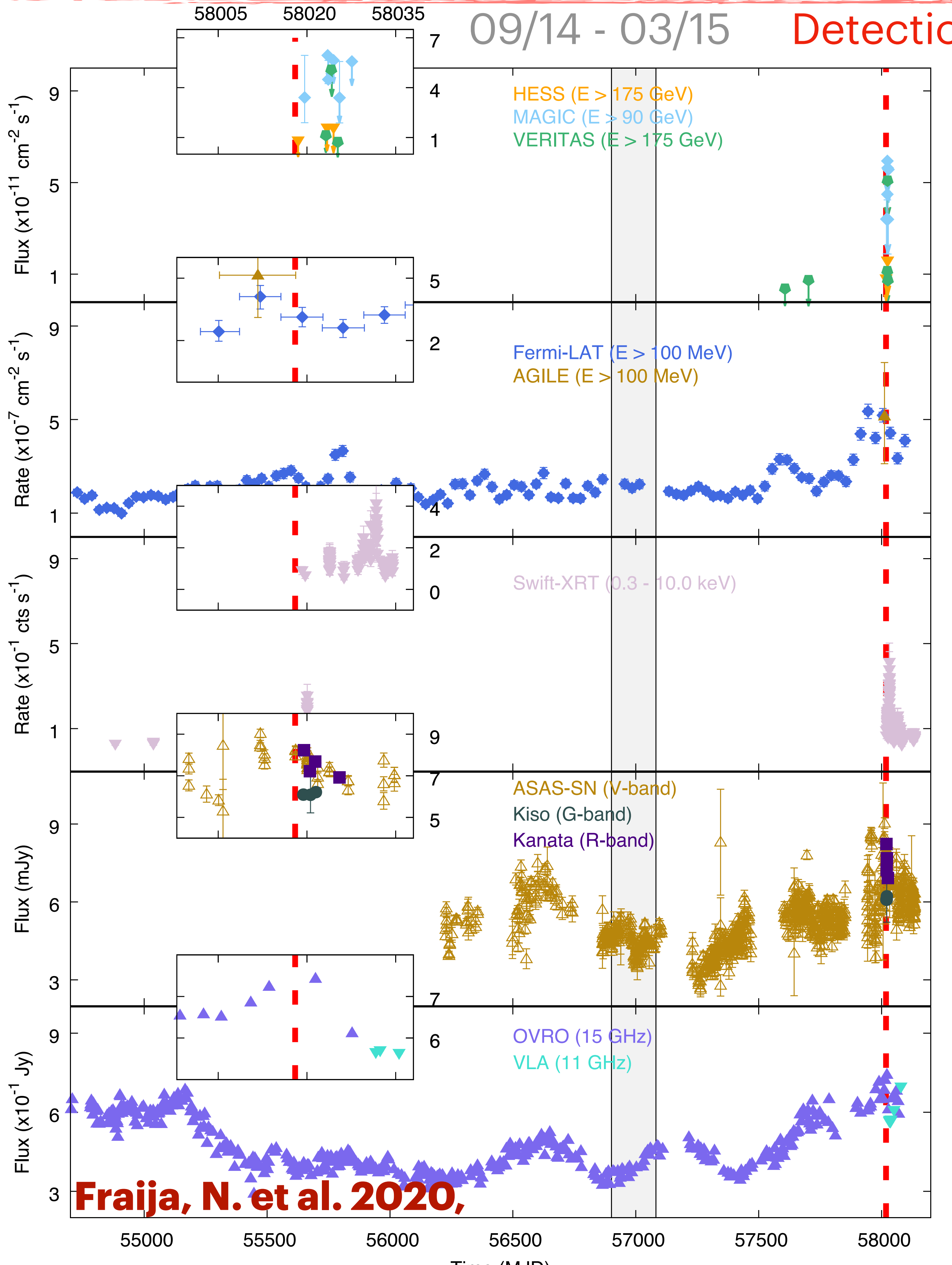


Galactic Coordinates

Neutrino Flare 09/14 - 03/15

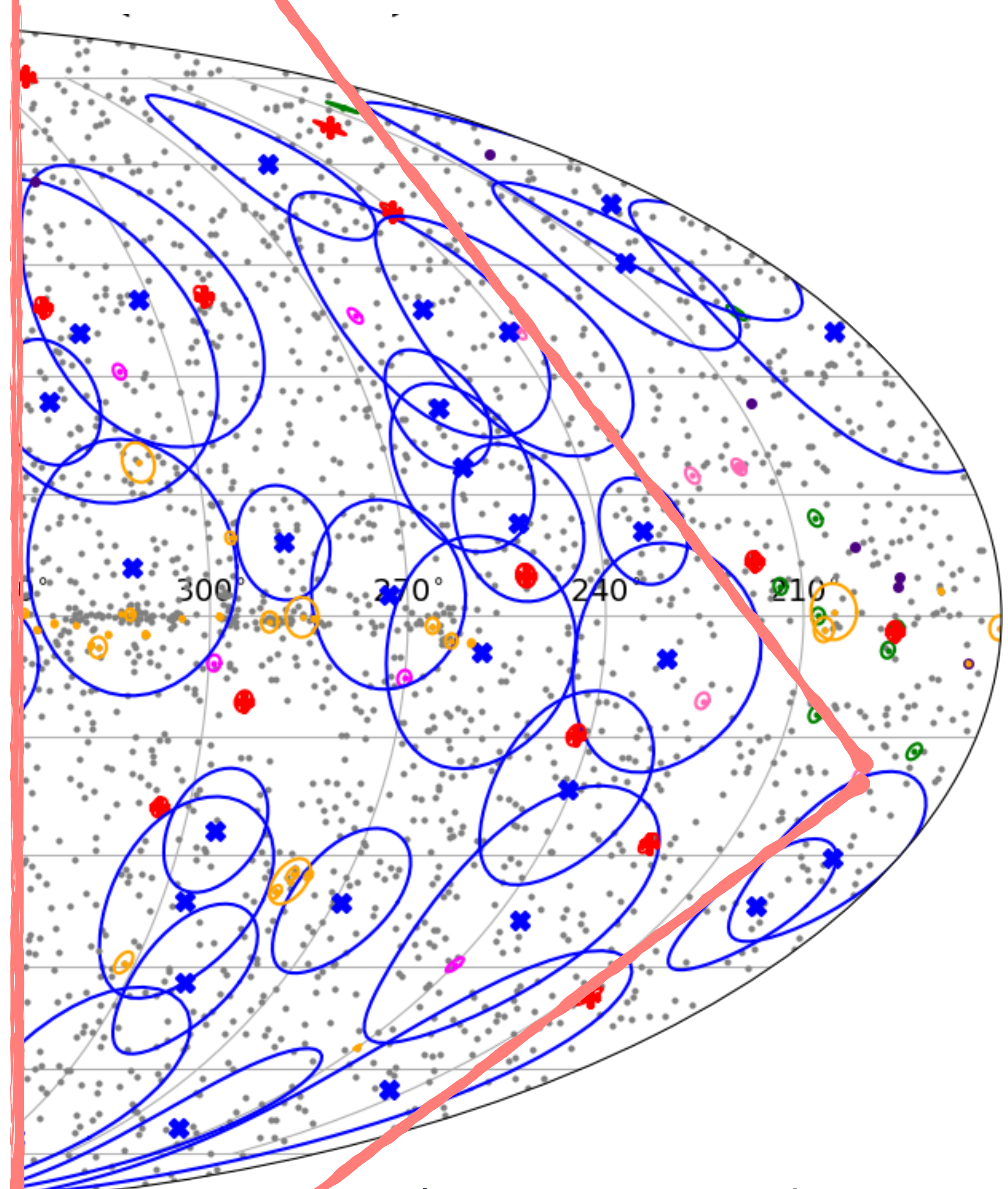
IC-170922A Detection

TXS 0506+056



Fraija, N. et al. 2020,

nos + photons)



Galactic Coordinates

WC (2° catalogo)

mi-LAT (4° Catalogo de Fuentes Extendidas)

mi-LAT (4° Catalogo de Fuentes Puntuales)

s captured by Fermi-LAT

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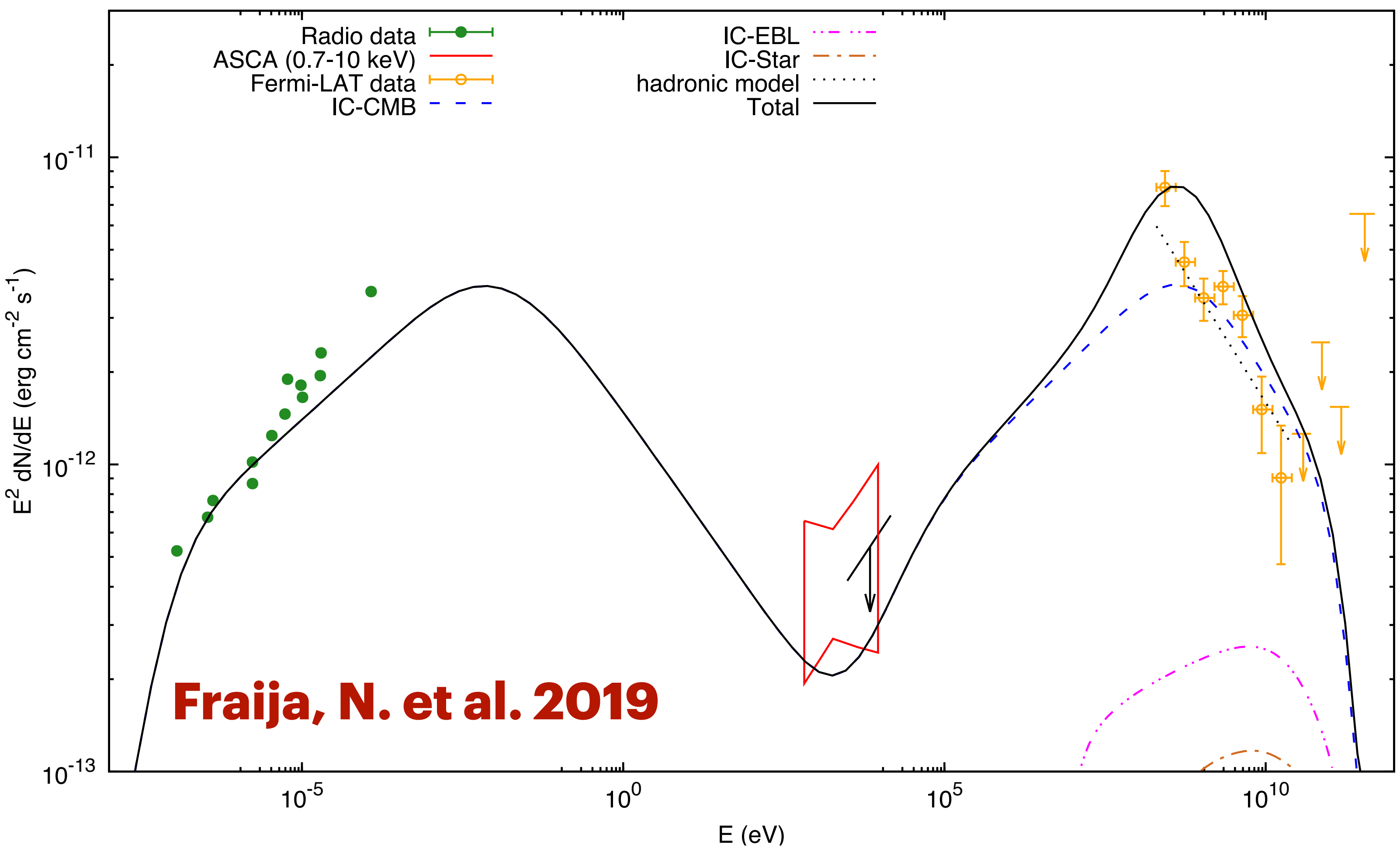
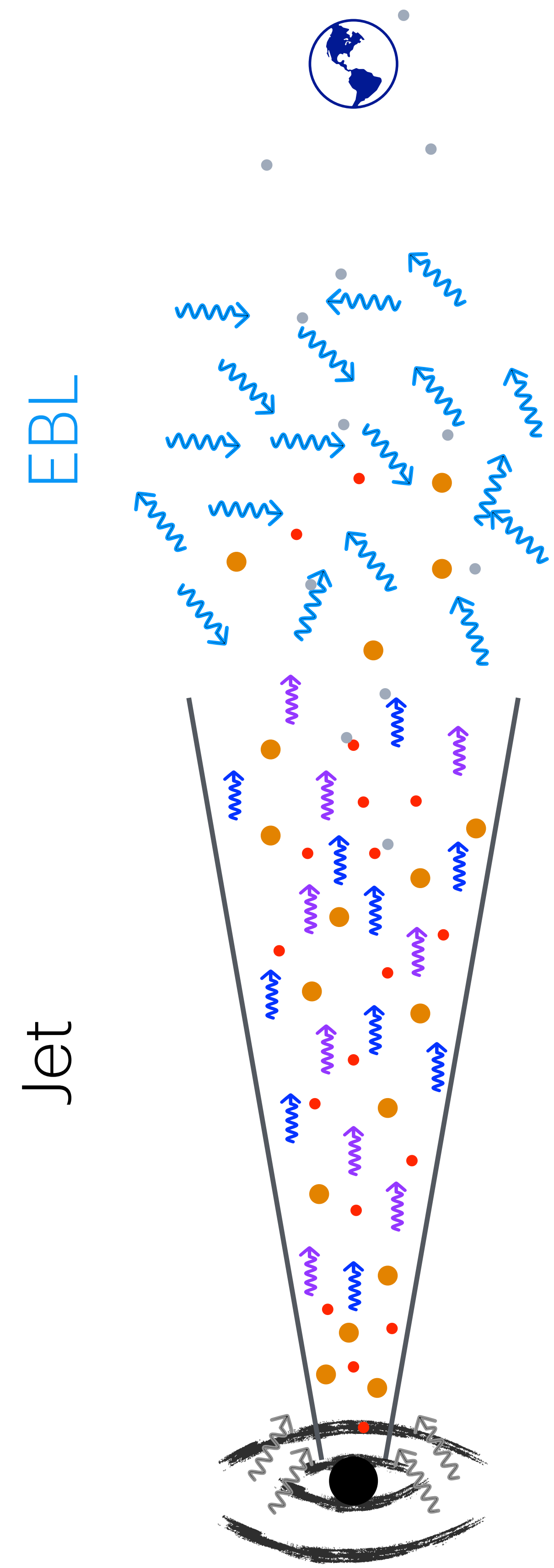
Hadronical Signatures on AGNs



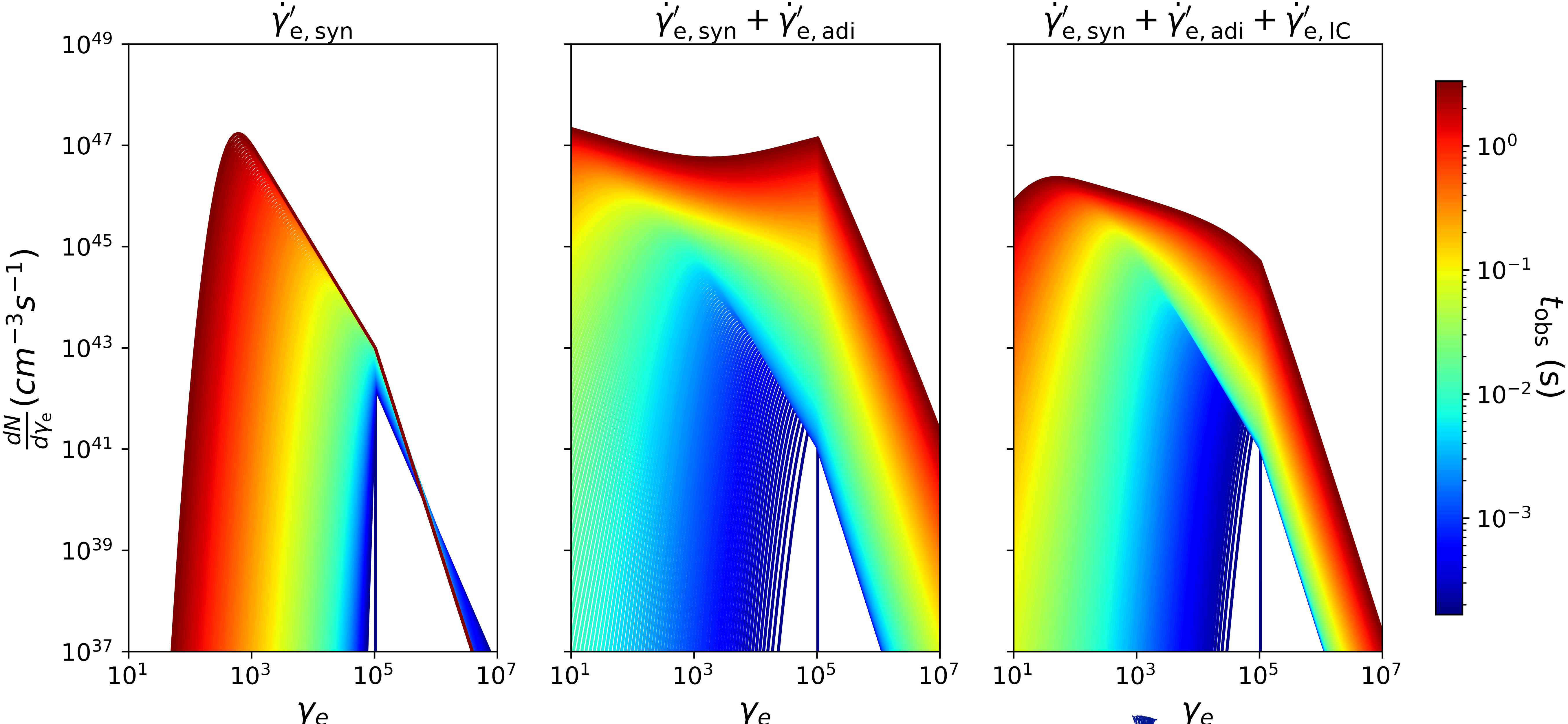
$$p+\gamma \rightarrow \begin{cases} p + a\pi^0 + b(\pi^+ + \pi^-) \\ \quad \hookrightarrow \boxed{\gamma+\gamma} \\ n + \pi^+ + a\pi^0 + b(\pi^+ + \pi^-) \end{cases}$$

$$\hookrightarrow \mu^+ + \boxed{\nu_\mu} \qquad \hookrightarrow \mu^- + \boxed{\bar{\nu}_\mu}$$

$$\hookrightarrow e^+ + \nu_e + \boxed{\bar{\nu}_\mu} \rightarrow e^- + \bar{\nu}_e + \boxed{\nu_\mu}$$



Time Dependent Electron Distribution



$$\frac{\partial}{\partial t}\frac{dN}{d\gamma}(\gamma'_e, t) = -\dot{\gamma}'_{e,\mathrm{tot}}\frac{\partial}{\partial \gamma}\frac{dN}{d\gamma}(\gamma'_e, t) + Q(\gamma'_e, t)$$

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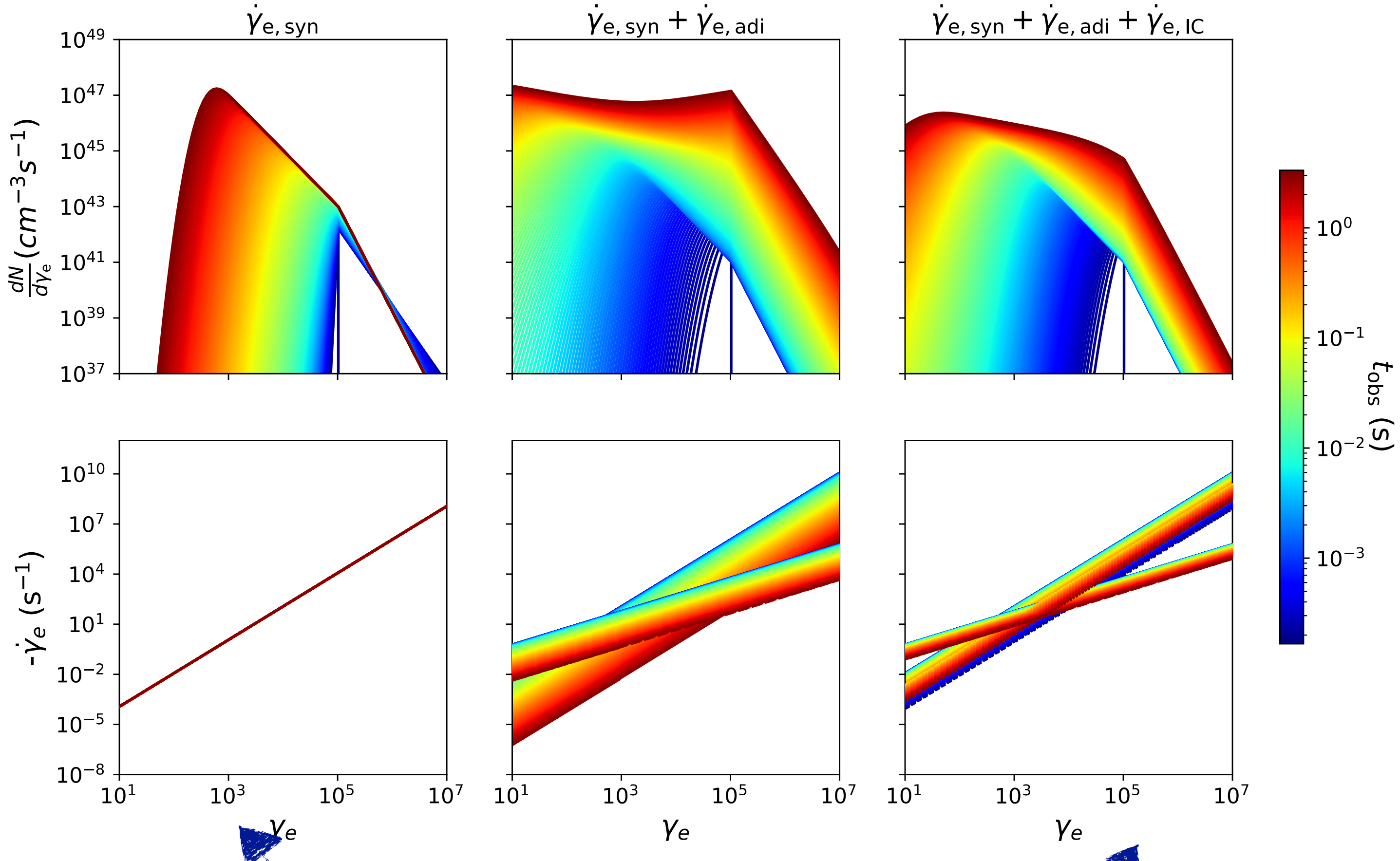
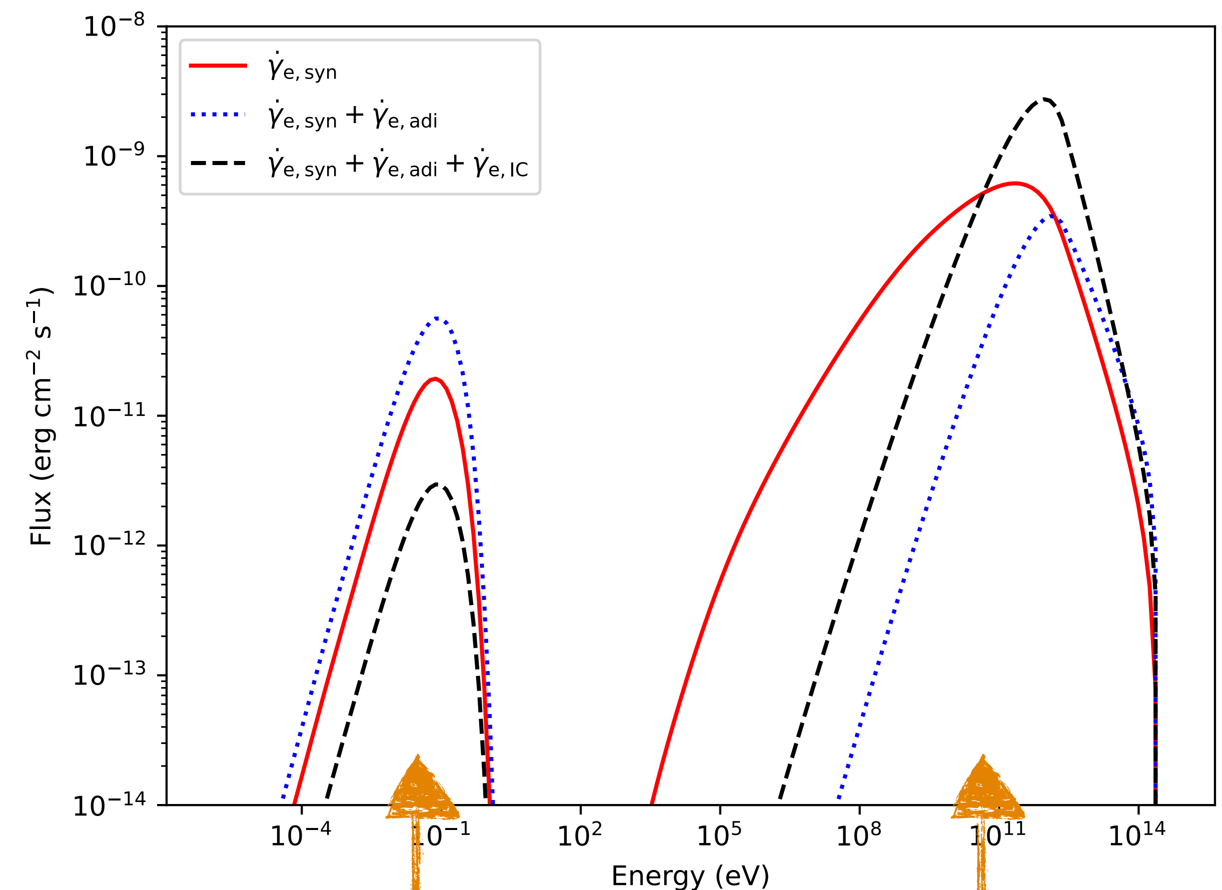
Time Dependent Electron Distribution



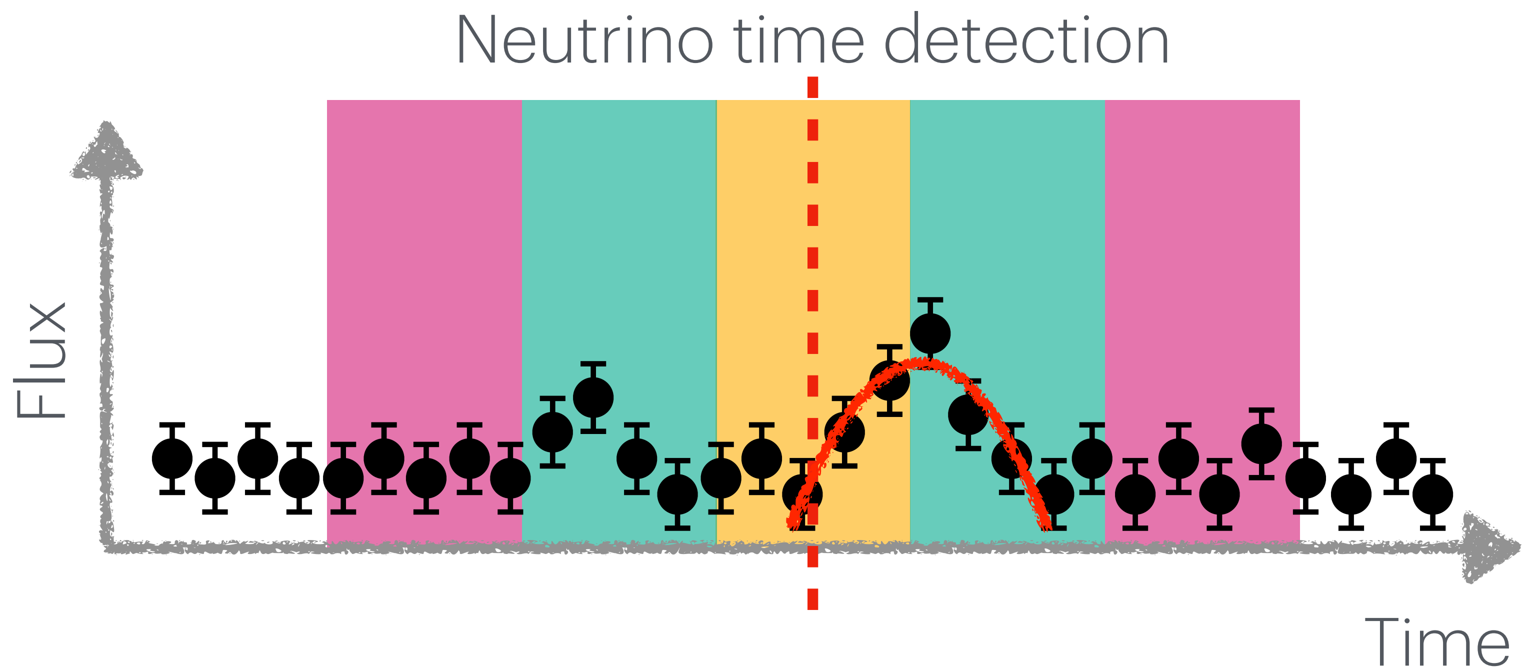


$$f^{syn}_{\epsilon} \propto \int \frac{dN}{d\gamma_e} R(x) d\gamma_e$$

$$\frac{\partial}{\partial t}\frac{dN}{d\gamma}(\gamma'_e, t) = -\dot{\gamma}'_{e,\mathrm{tot}}\frac{\partial}{\partial \gamma}\frac{dN}{d\gamma}(\gamma'_e, t) + Q(\gamma'_e, t)$$

$$f^{IC}_{\epsilon_s} \propto \iint \frac{f^{syn}_{\epsilon}\frac{dN}{d\gamma_e}K_{IC}(\Gamma, q)}{\gamma'^{2}\epsilon'^{3}} d\gamma_e d\epsilon$$

Search strategy



Three search windows have been defined centered on the time of neutrino detection, motivated by the activity of TXS 0506+056. (**IceCube Collaboration et. al. 2018, Acciari et al. 2022**).

- Weekly: Search for electromagnetic activity of the possible progenitor one week before and one week after the neutrino detection.
- Monthly: Search for electromagnetic activity of the possible progenitor one month before and one month after the neutrino detection.
- Annual: Search for electromagnetic activity of the possible progenitor one year before and one year after the neutrino detection.

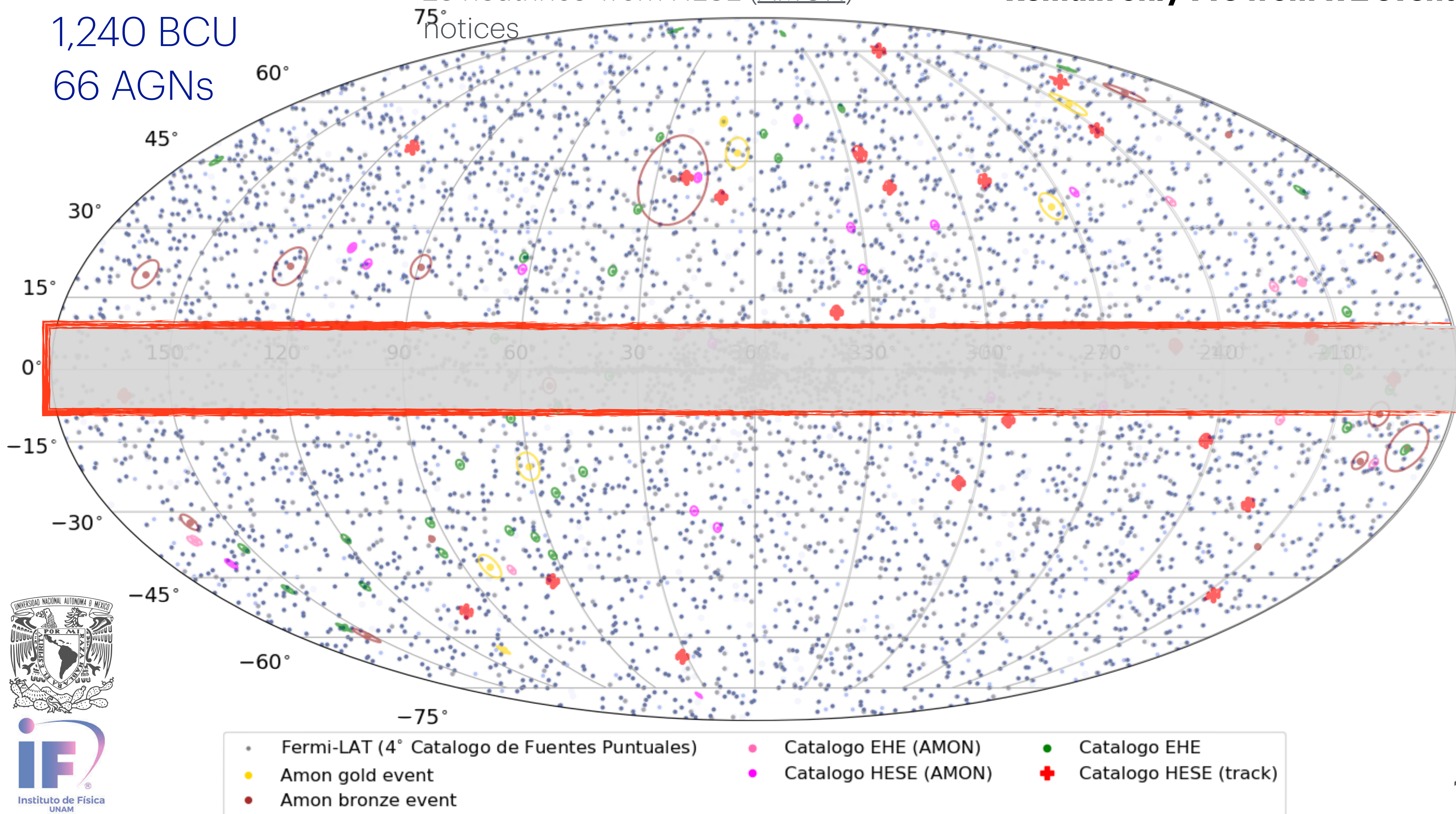
Spectral energy distribution quasi-contemporaneous to the neutrino detection as well as a historical one.

High Energy Messengers

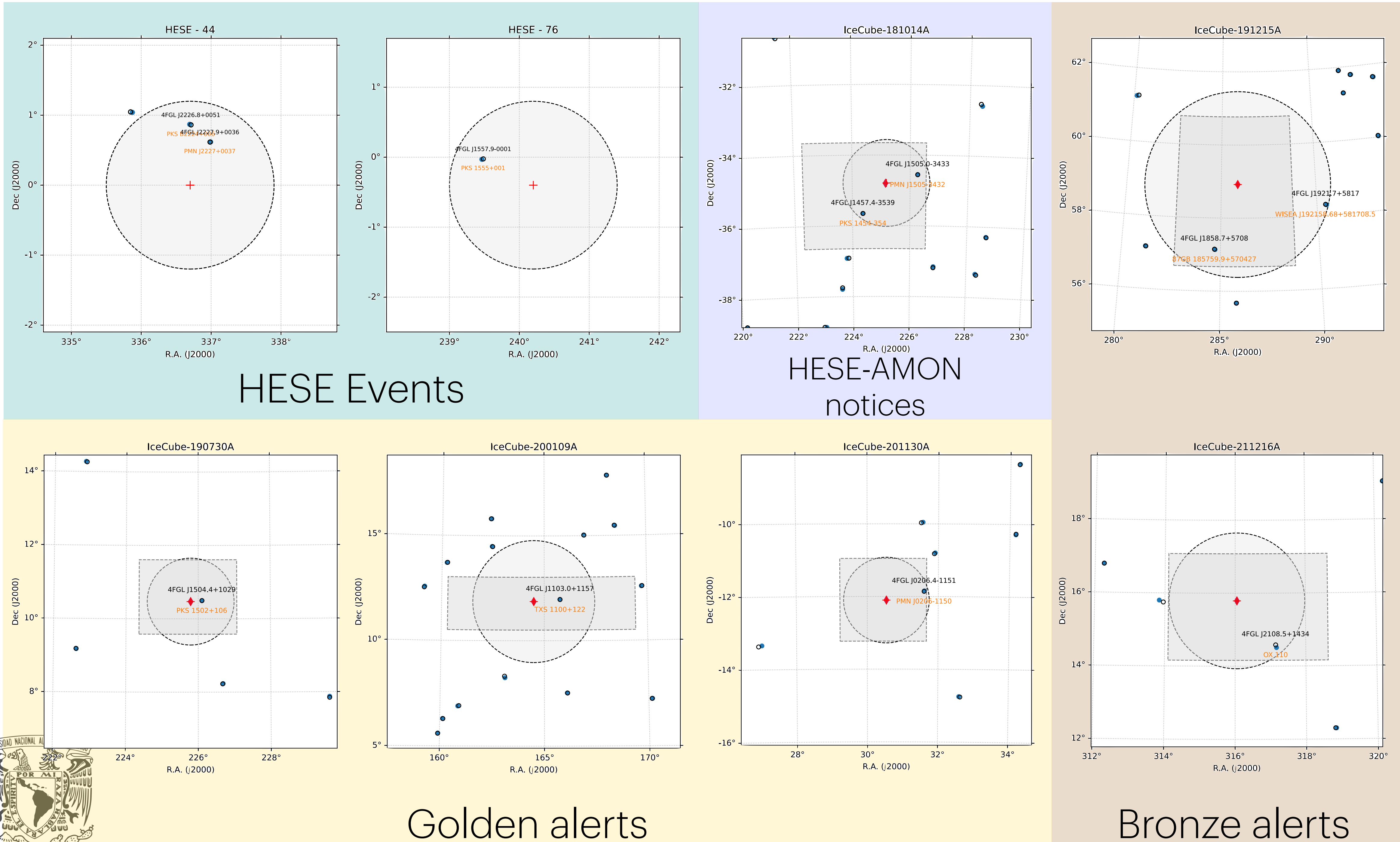
4LAC-DR2(3,125):
704 FSRQ
1,125 BL Lacs
1,240 BCU
66 AGNs

82 neutrinos from HESE catalog
(**Aartsen et. al. 2013**)
32 neutrinos from EHE catalog
(**Aartsen et. al. 2016**)
23 neutrinos from HESE (AMON) notices

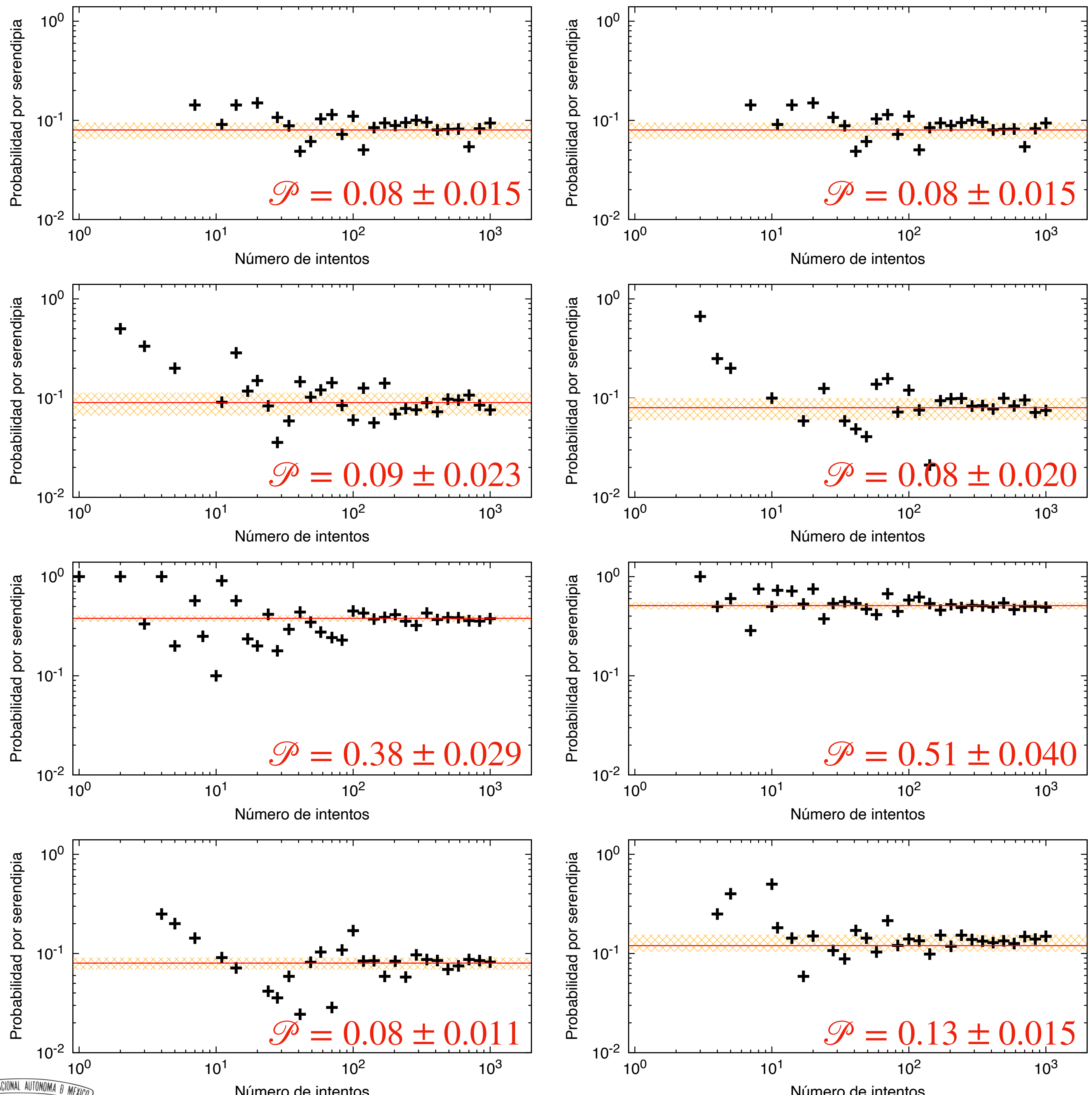
11 neutrinos EHE (AMON)
16 Bronze alert (AMON)
8 Gold alert (AMON)
Remain only 140 from 172 events.

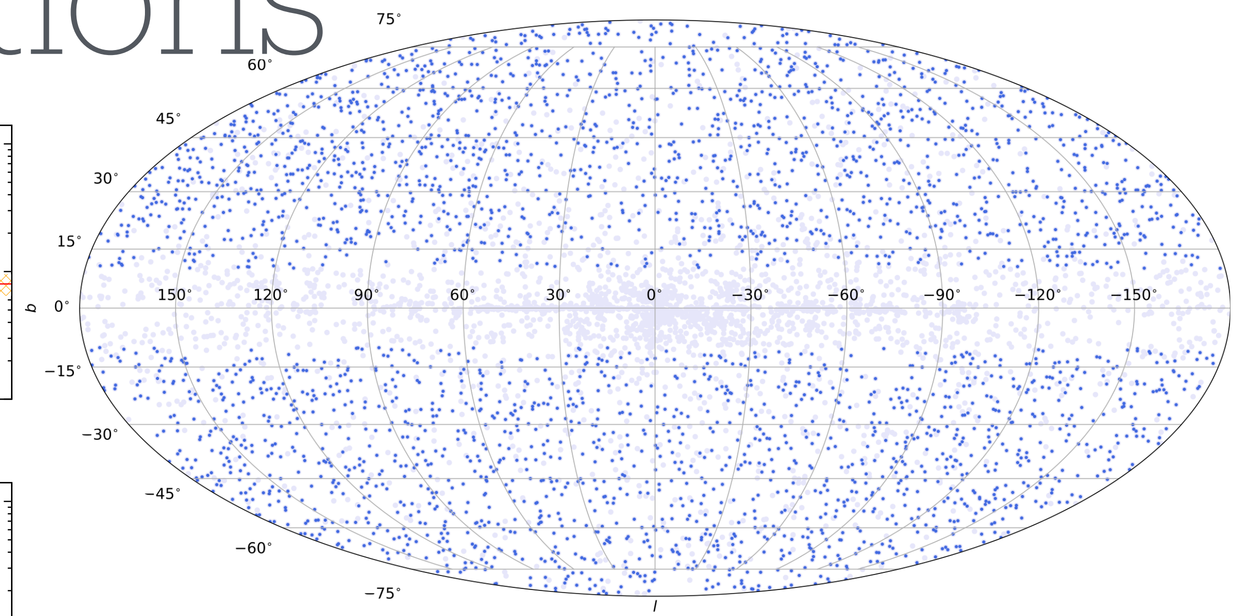


Serendipity correlations



Serendipity correlations





Neutrino detections were simulated with random positions in the sky in an equidistant manner:

$$l \in [0{,}360]^\circ,$$

$$|b| > \text{acrcsin}(\theta)\ ;\ \theta \in [10{,}90]^\circ$$

$$\mathscr{P} = \frac{N_{\text{acc}}}{N_{\text{CT}}};$$

N_{acc} is the simulated coincidences

N_{CT} is the number of attempts made

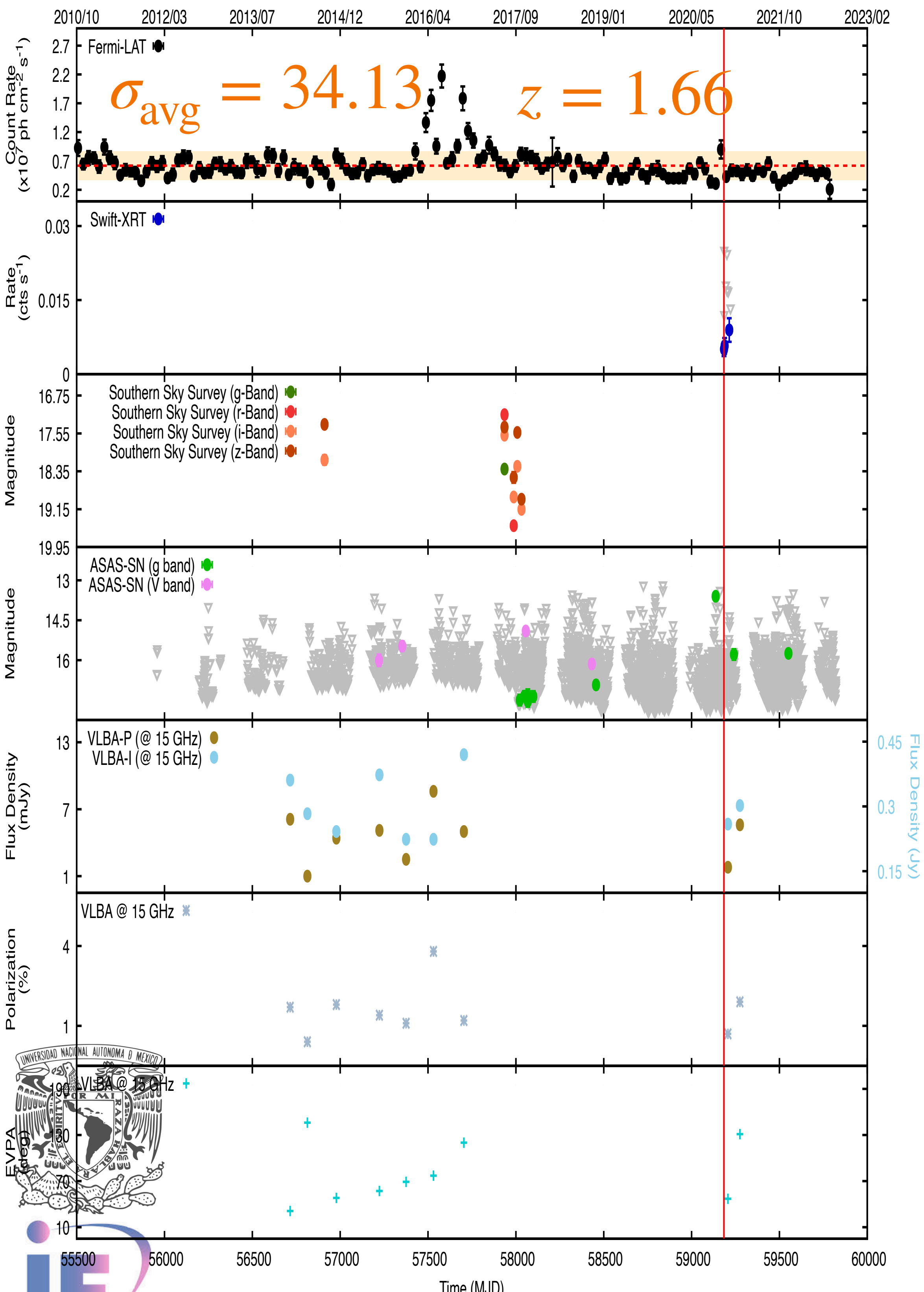
To claim statistical significance, it needs to satisfy:

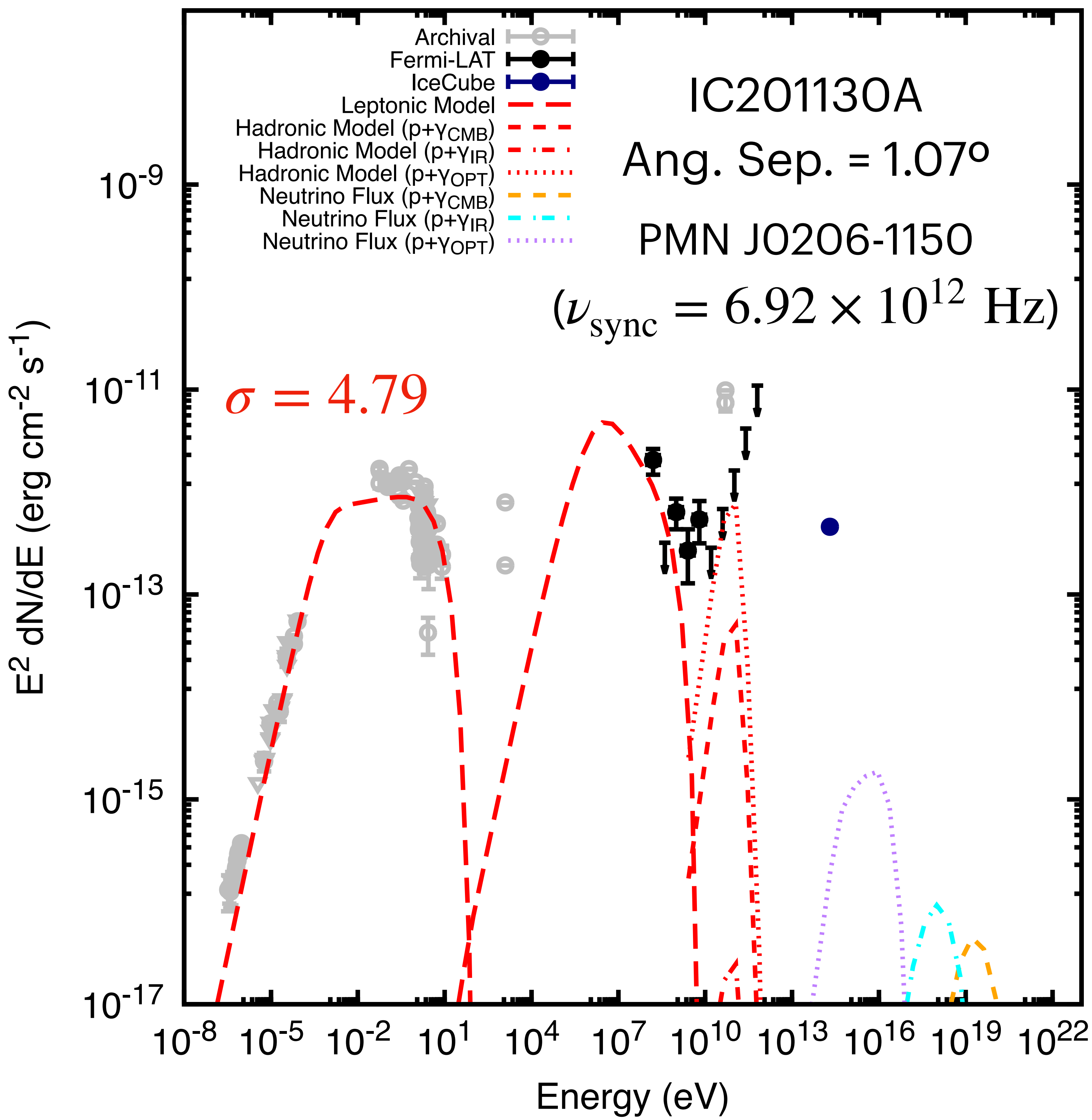
$$\mathscr{P} \ll 1$$

Results (4FGL J0206.4-1151)

Preliminary

Galván, A. et al. 2024. In prep





Summary

- The current model, calculating the luminosity values of proton $L_p \sim$ (0.03-4.27)x10^{45} erg/s, electron $L_e \sim$ (0.02-57.7)x10^{45} erg/s magnetic field $L_B \sim$ (0.09-64.7)x10^{45} erg/s with standard values in quasars, the model discrepancies one order of magnitude between the observed and predicted flux of high-energy neutrinos with this simple model.

- The hypothesis of considering a steady-state electron distribution is a rather strong consideration. Thus, solving the Fokker-Planck equation provides physical meaning to the model beyond considering a power law.

- More multifrequency observations are needed, as they provide information necessary to restrict parameters in the model.

Thanks for your attention