Multimessenger Data Analysis in the era of CTA

AGN and neutrino emission

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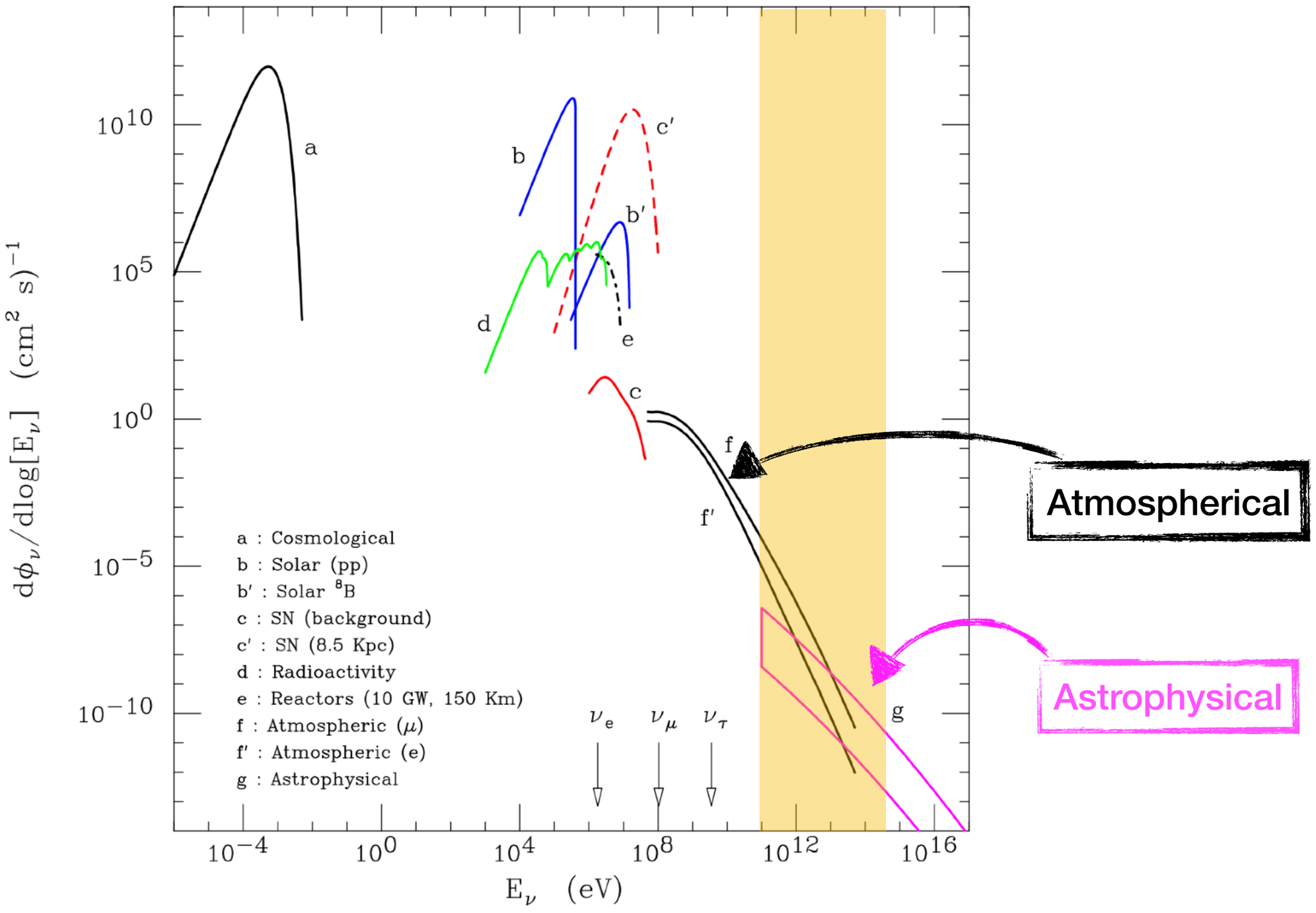
NATIONAL INSTITUTE FOR ASTROPHYSICS

Outline

- Introduction
- NGC 1068
- Low luminosity radiogalaxies
- Blazar
  - FSRQ as neutrino sources
  - BL Lacs as neutrino sources
    - The case of TXS 0506+056
    - Some models
- Conclusions

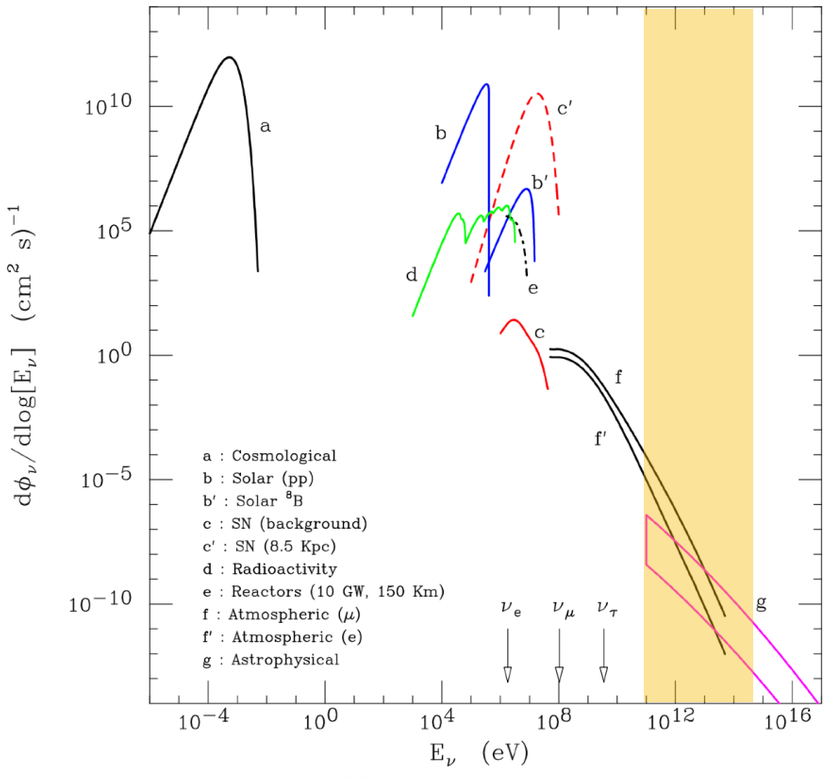
Neutrino flux



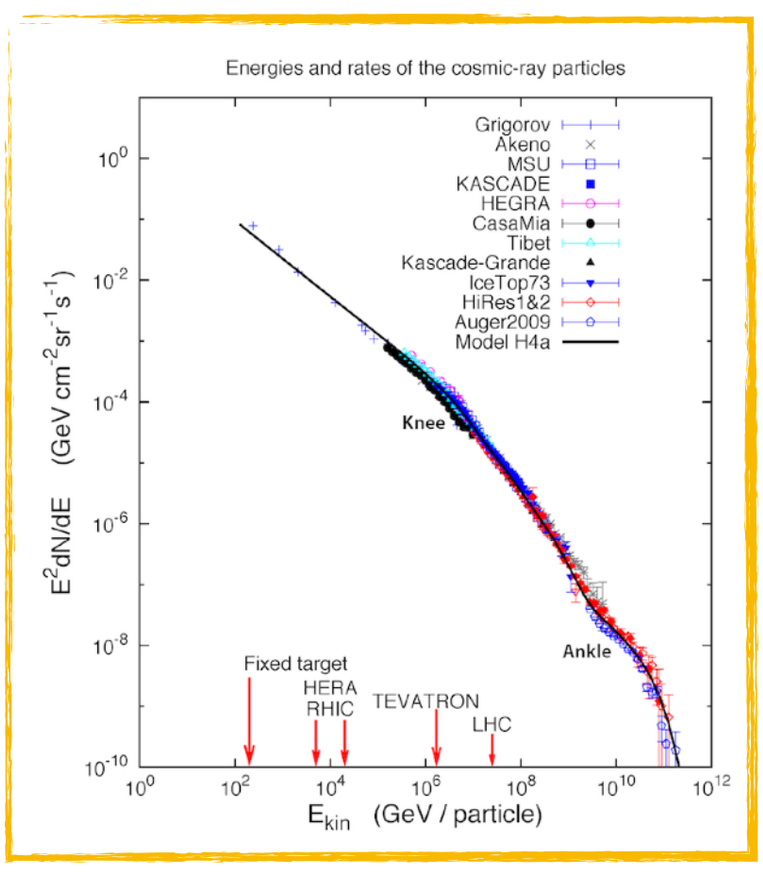
Lipari, 2003

Neutrino flux

- Tracers of cosmic rays
- Information on the galactic and extragalactic accelerators

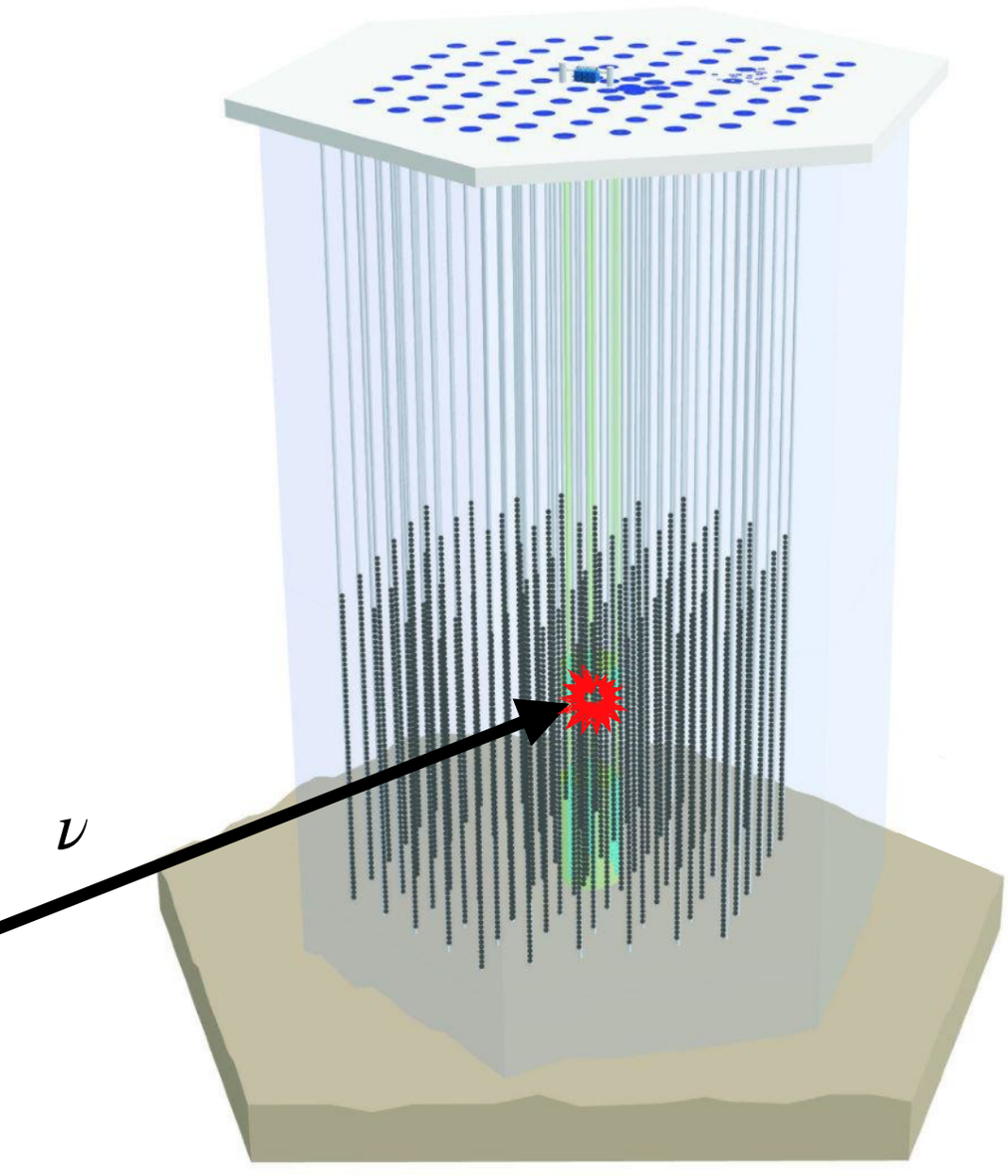


Lipari, 2003

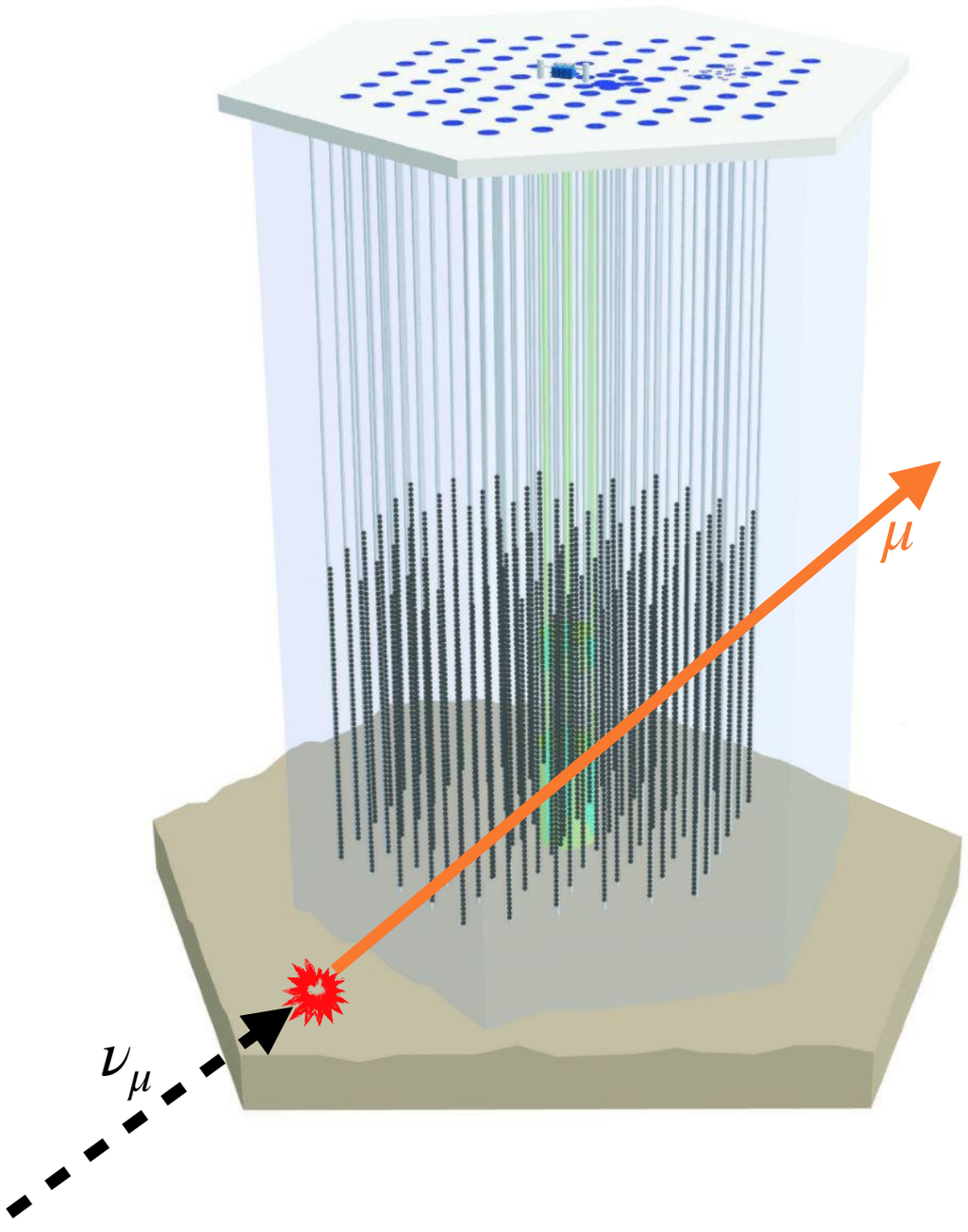


Neutrino signature on ice

Cascade



Track



Neutrino signature on ice

Cascade

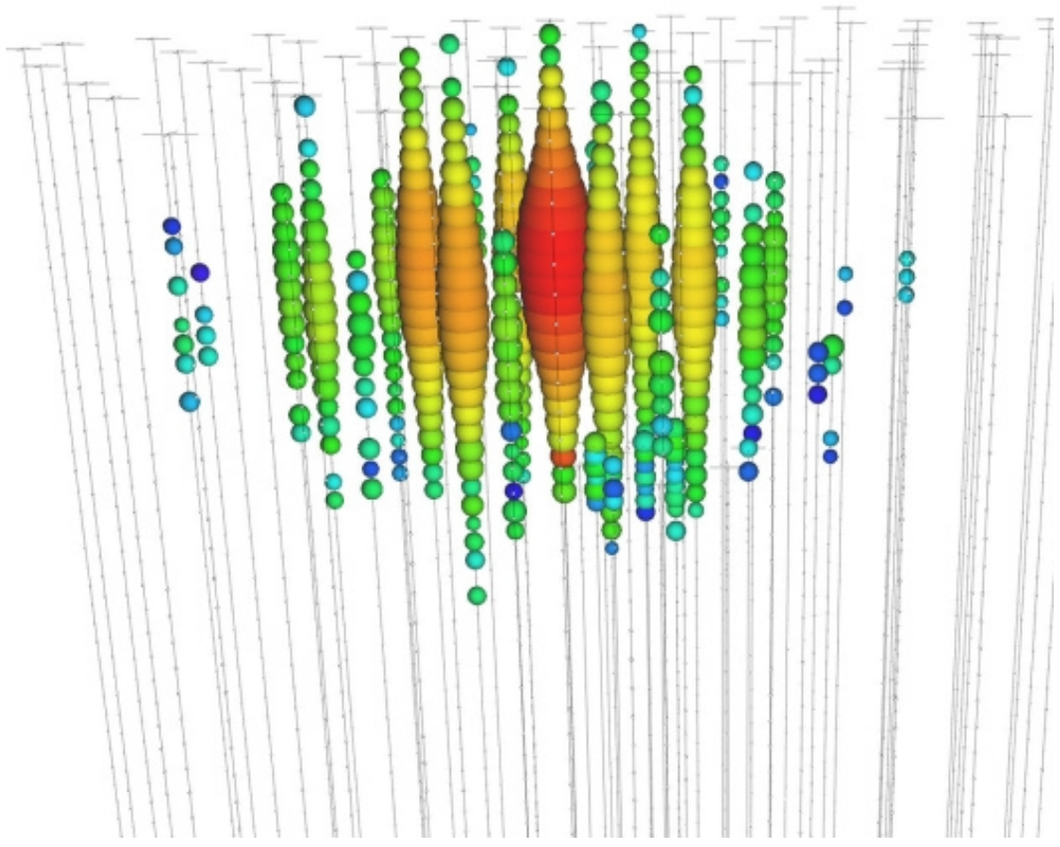
Track

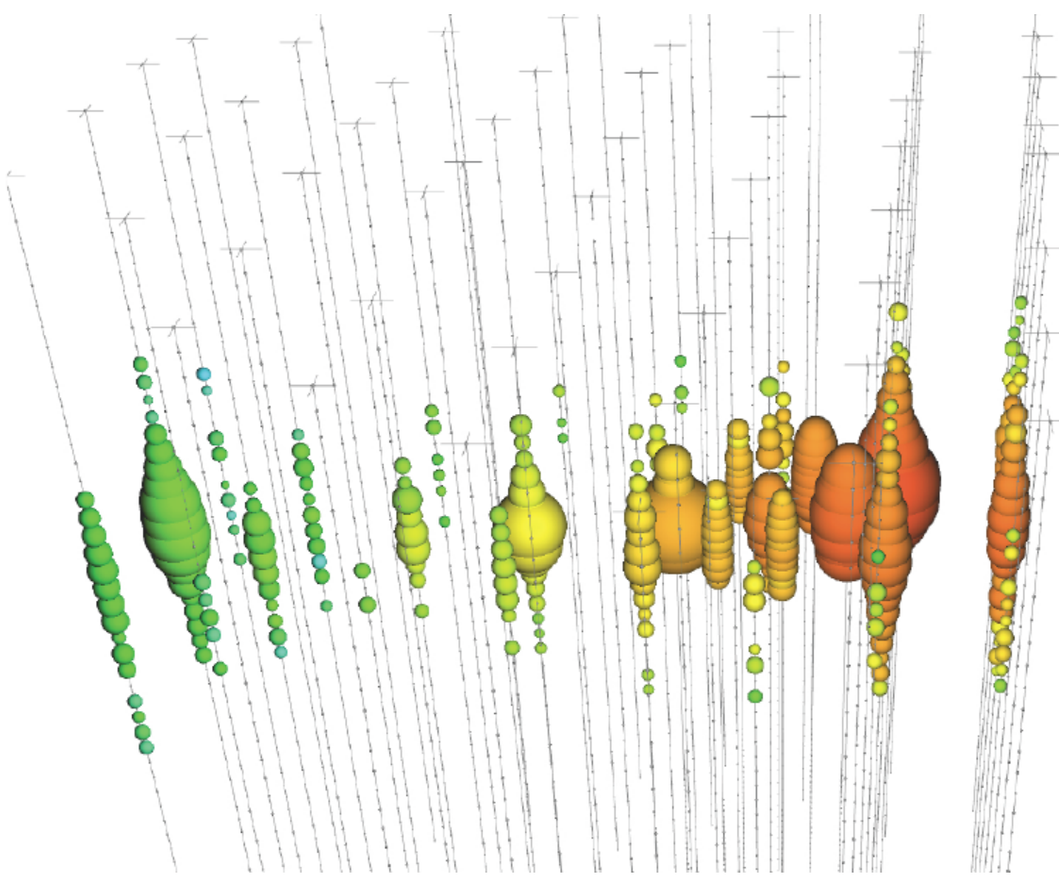
High Energy Starting point Events (HESE)

$$\nu_x + N \rightarrow \nu_x + X$$

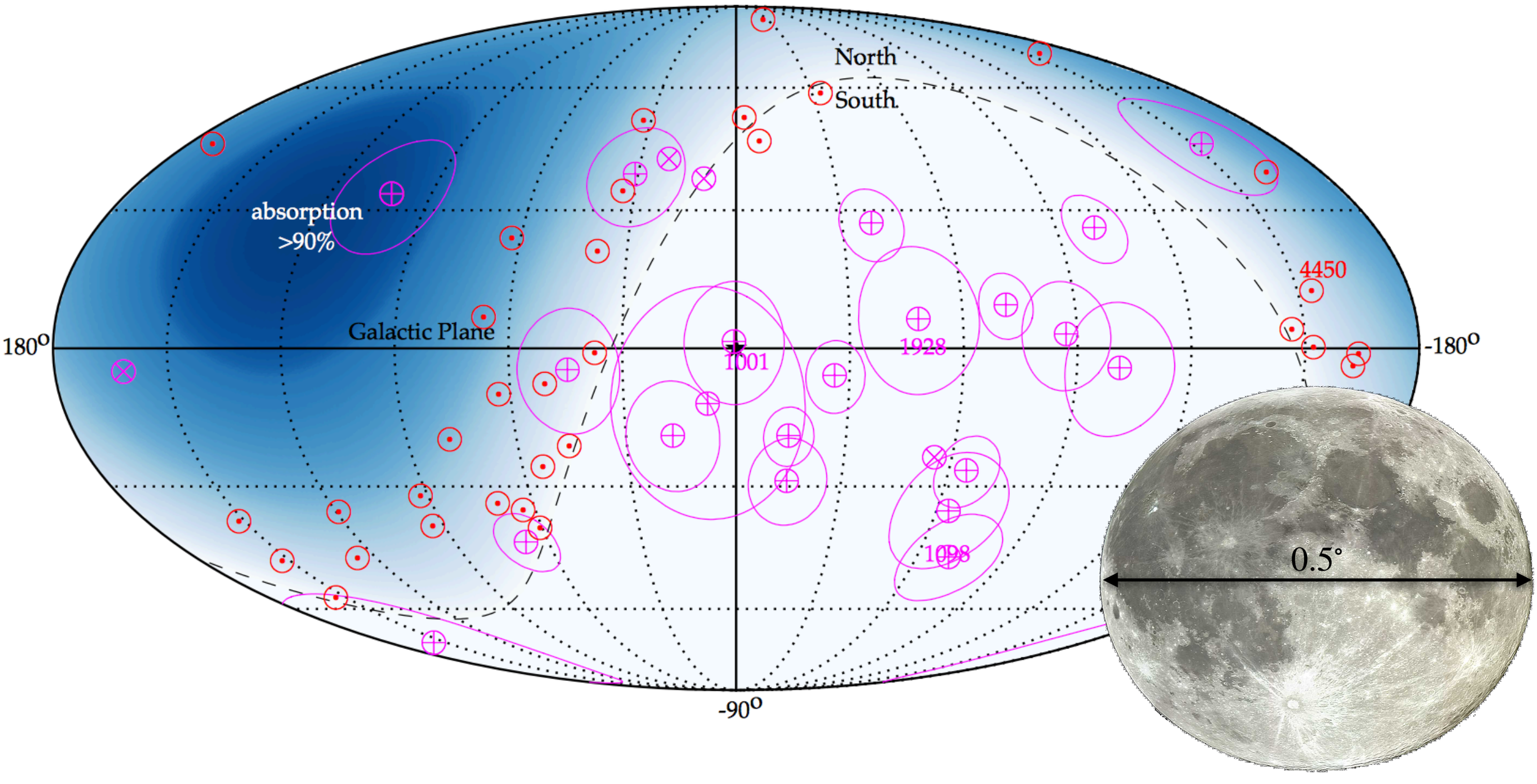
$$\nu_x + N \rightarrow x + N$$

$$\nu_\mu + N \rightarrow \mu + N$$



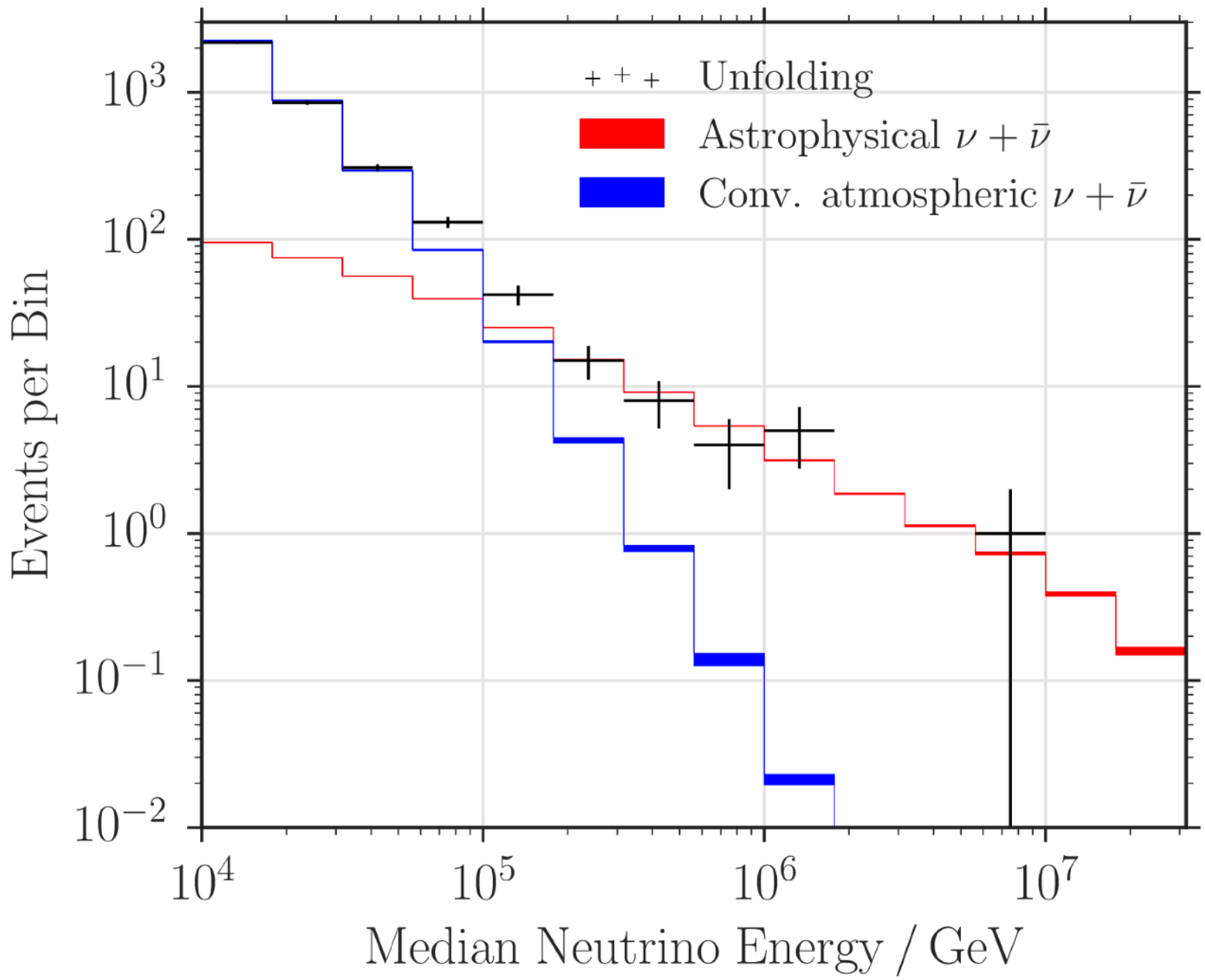


Discovery by Ice Cube



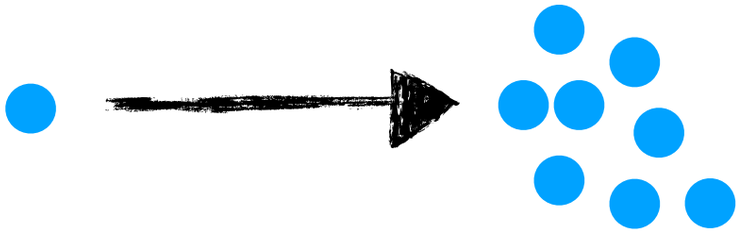
IceCube Collaboration et al., 2017a

Discovery by Ice Cube

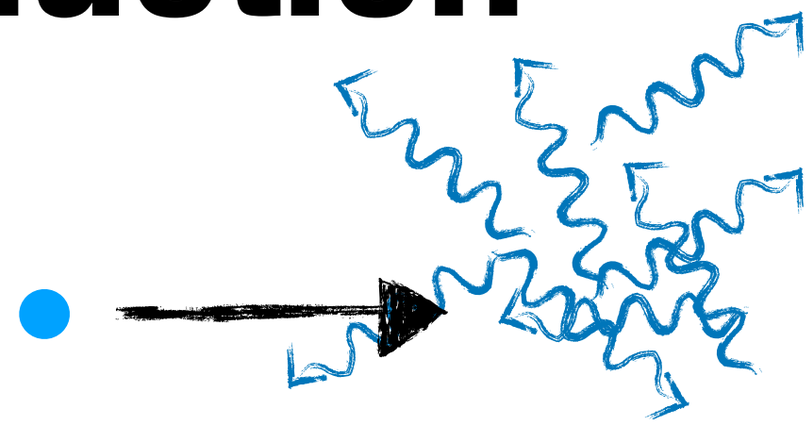


IceCube Collaboration et al., 2017a

HE neutrino production



$$p + p \rightarrow \pi + X$$



$$p + \gamma \rightarrow \pi + X$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \rightarrow e^{\pm} + \nu_{e} + 2\nu_{\mu}$$

$$\pi^{0} \rightarrow \gamma + \gamma$$

$$E_{\nu} \sim \frac{E_{p}}{20}$$

HE neutrino production

$p + p \rightarrow \pi + X$

- Galactic sources
- Star forming Galaxies
- AGN Winds
- Radiogalaxies

Palladino & Vissani 16
Palladino & Winter 18
Neronov et al. 16a,b,c
Tamborra et al. 14
Loeb & Waxman 06
Lamastra et al. 14,16
...

$p + \gamma \rightarrow \pi + X$

- Radiogalaxies
- Jets (GRB or Blazar)

Waxmann & Bahcall 97
Mannheim 95
Atoyan & Dermer 03
Bottcher et al. 13
Petropoulou et al. 15,16
Tavecchio et al. 14,15
Righi et al. 17,18
...

HE neutrino production

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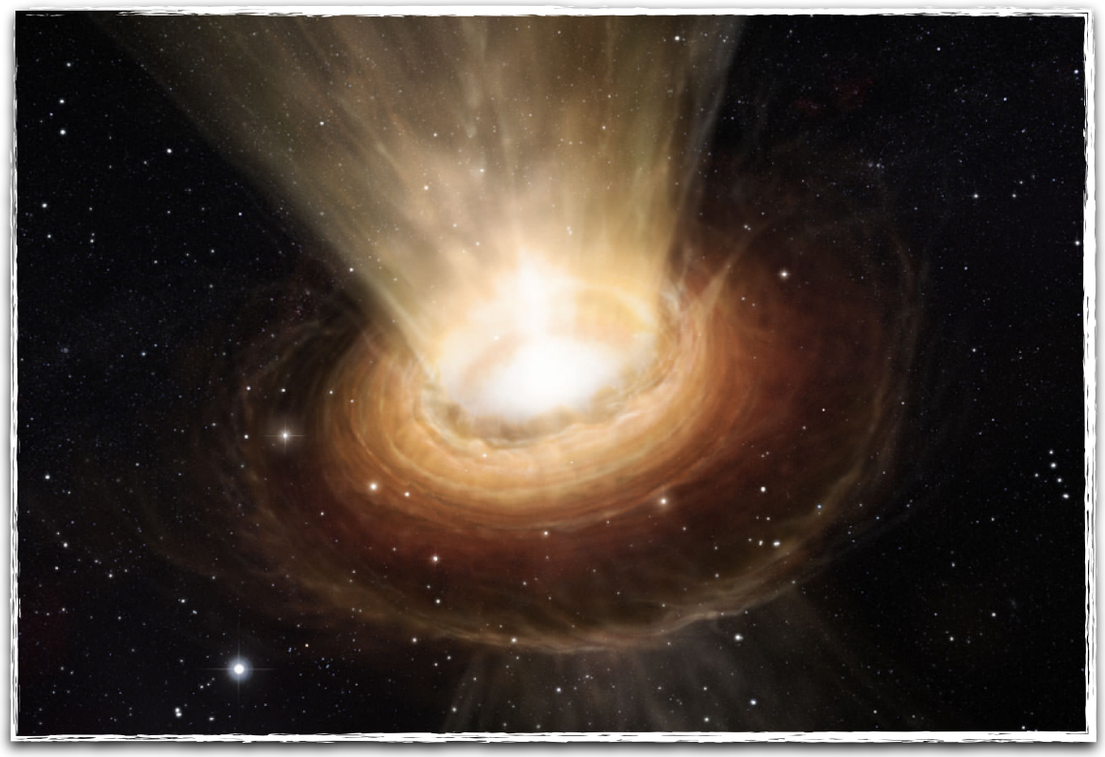

Palladino & Vissani 16
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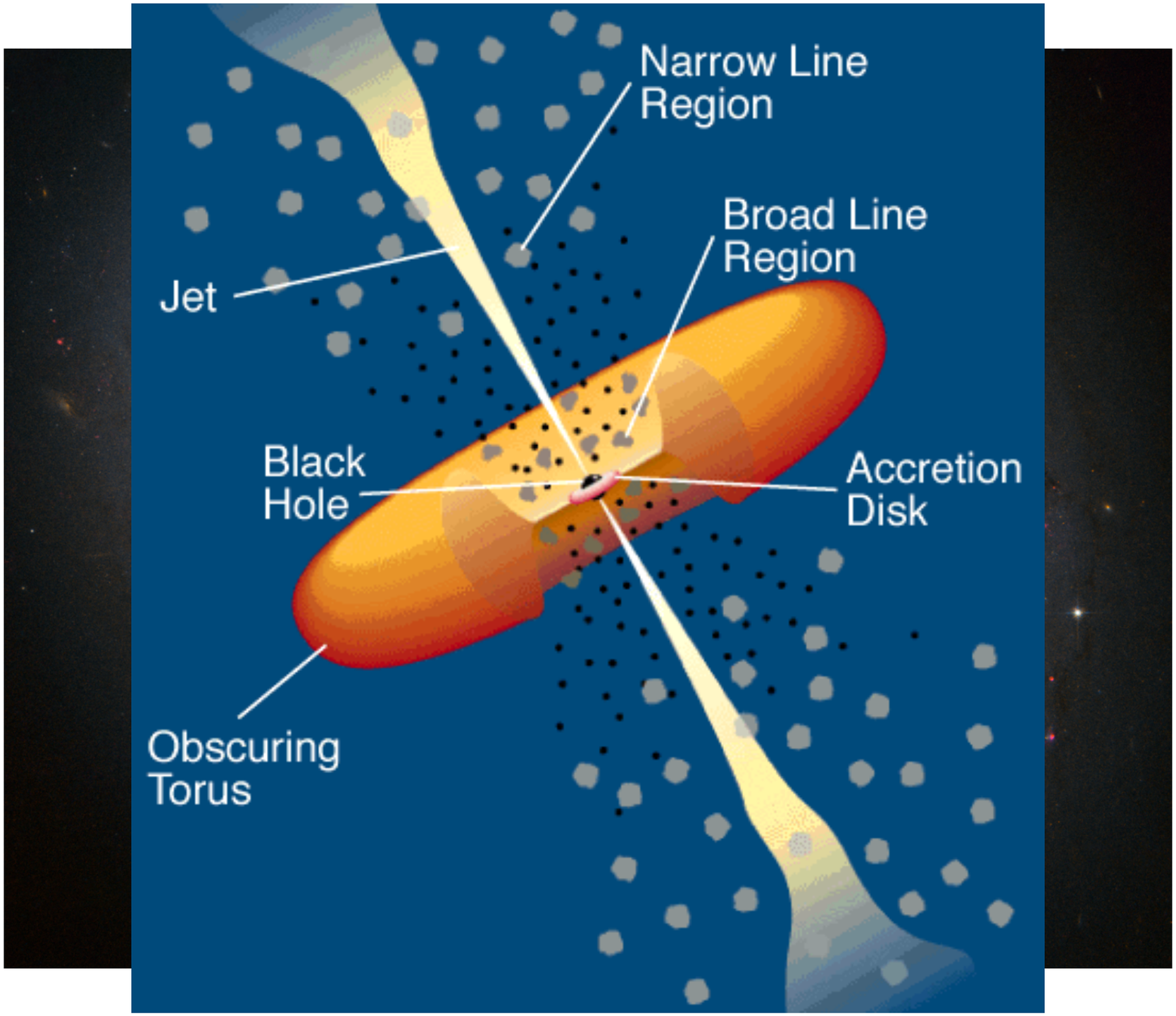
...

Active Galactic Nuclei

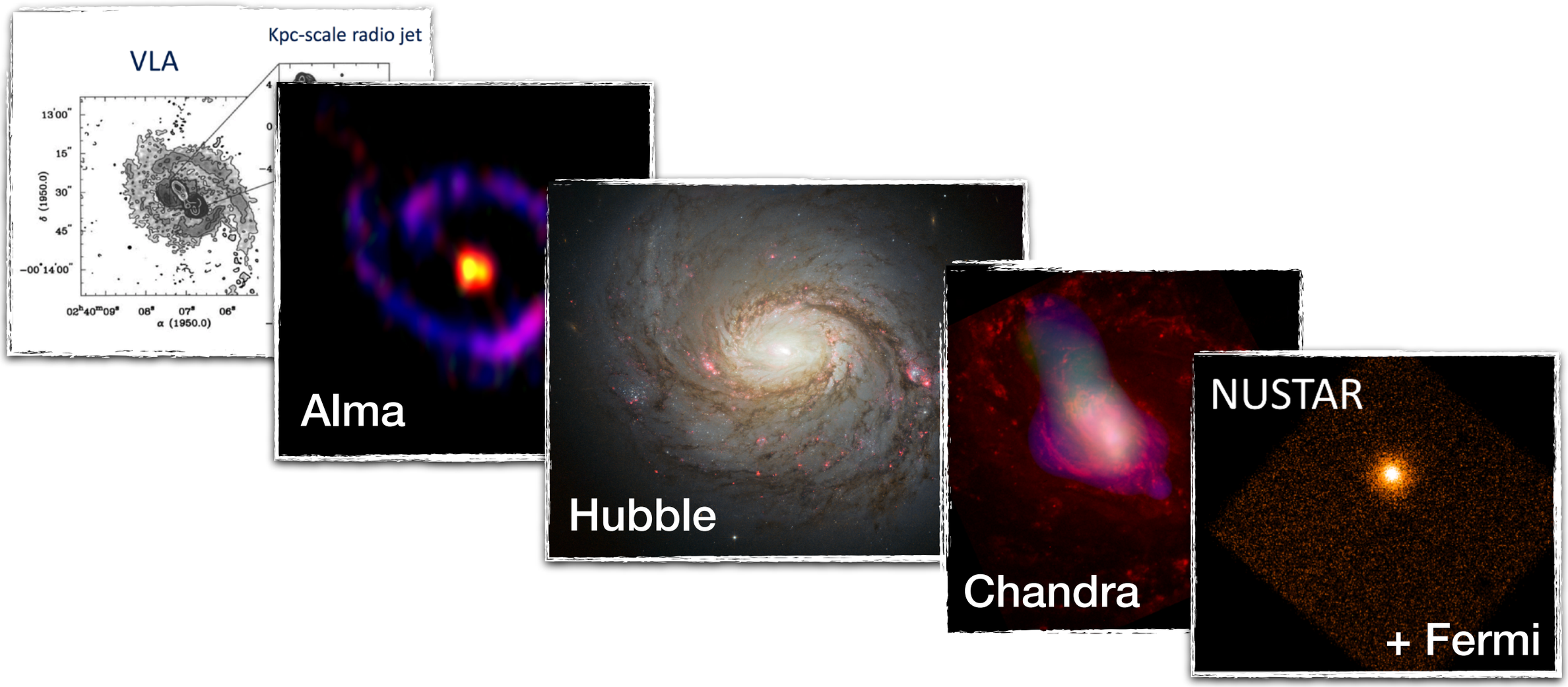


$$p + p \rightarrow \pi + X$$

AGN Winds

the case of NGC 1068

Radio mm optical X-ray Gamma-ray



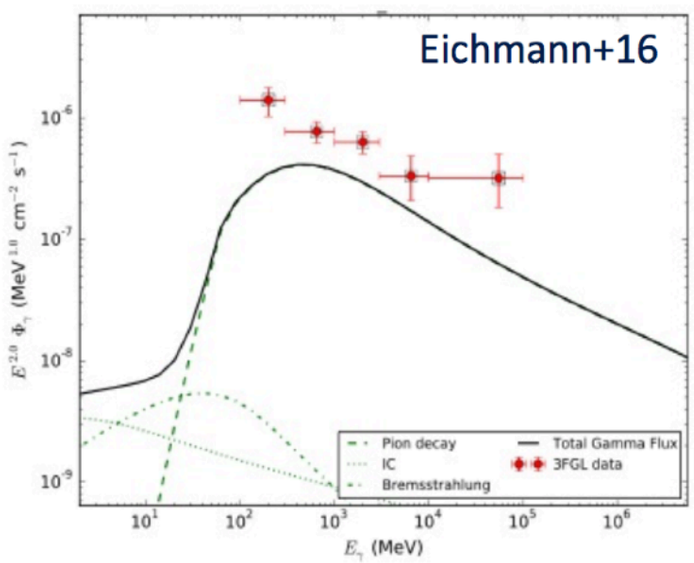
$p + p \rightarrow \pi + X$

AGN Winds

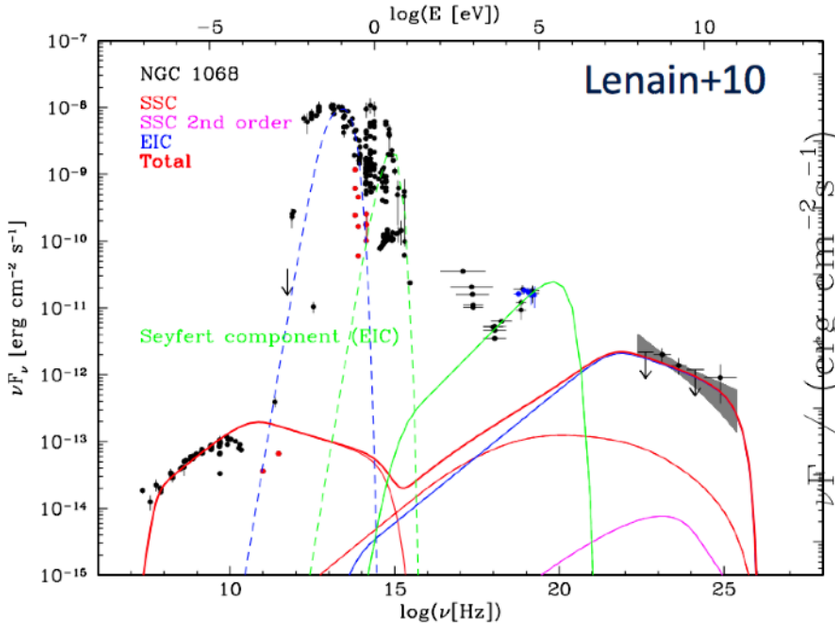
the case of NGC 1068

Where gamma emission comes from?

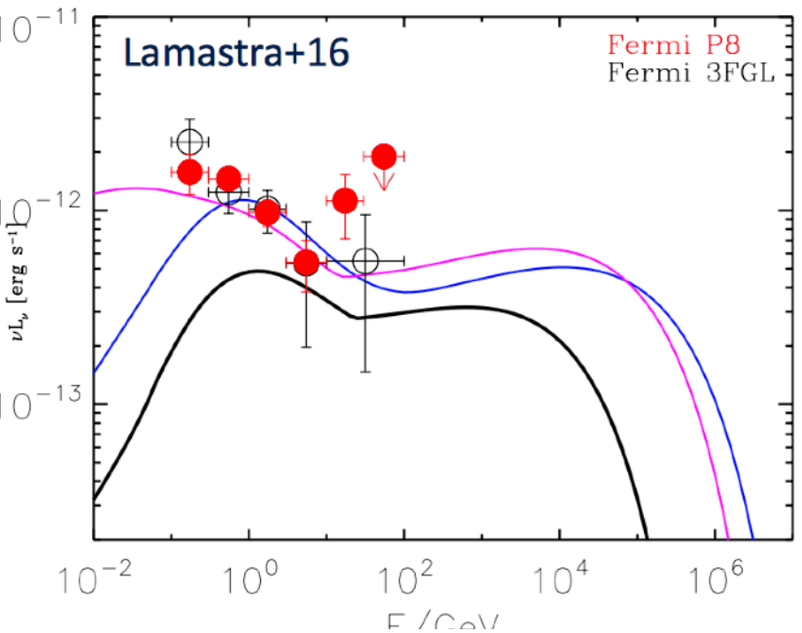
Starburst model



AGN jet model



AGN wind model



Lamastra et al. 2016

$p + p \rightarrow \pi + X$

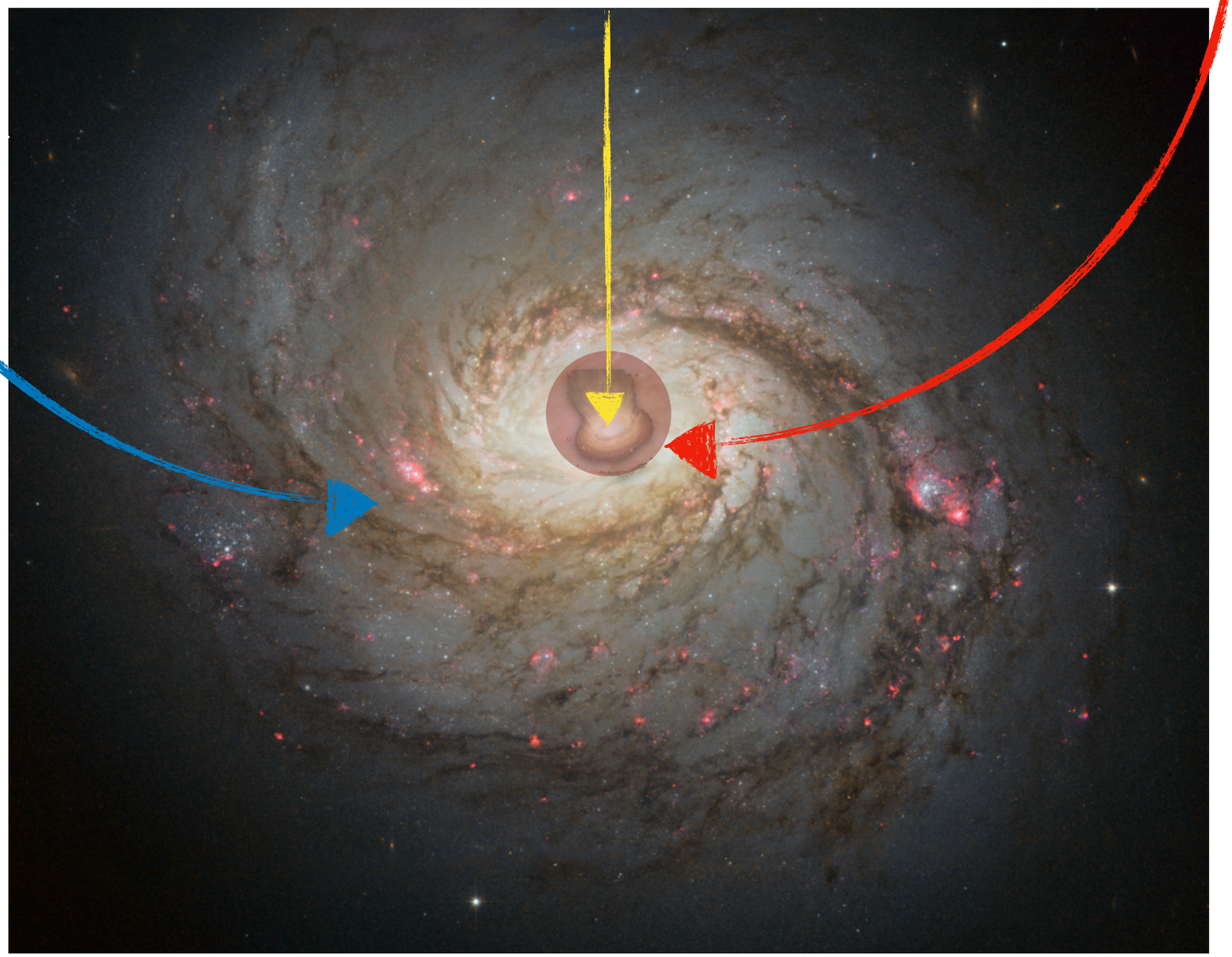
AGN Winds

the case of NGC 1068

NGC 1068 Galaxy

AGN Wind

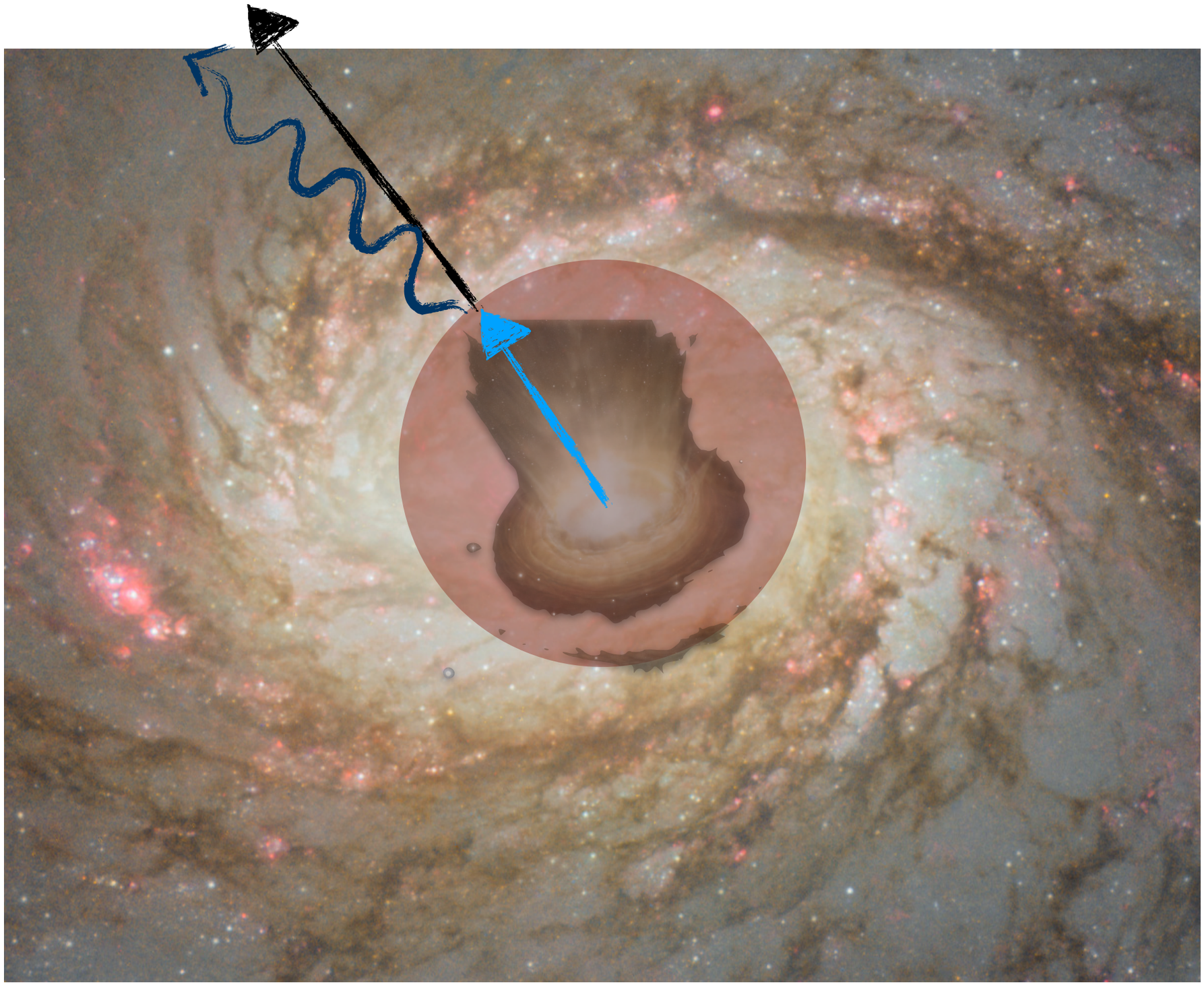
Shock with the ISM



$$p + p \rightarrow \pi + X$$

AGN Winds

the case of NGC 1068



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AGN Winds

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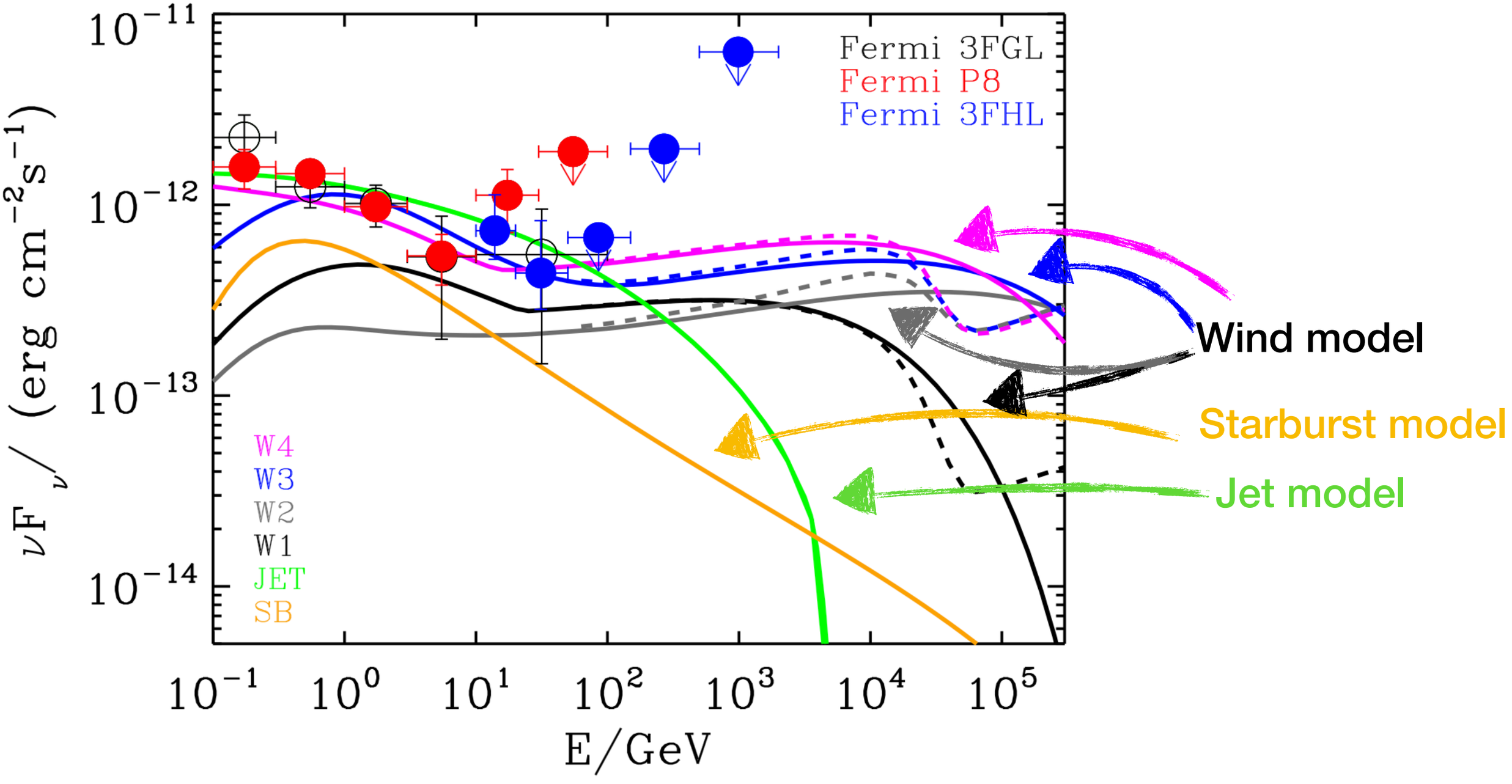

Lamastra et al. 2019

$p + p \rightarrow \pi + X$

AGN Winds

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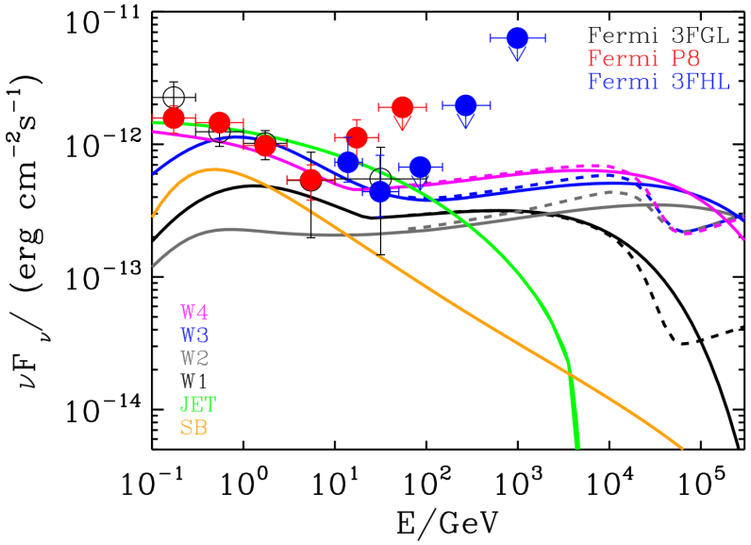
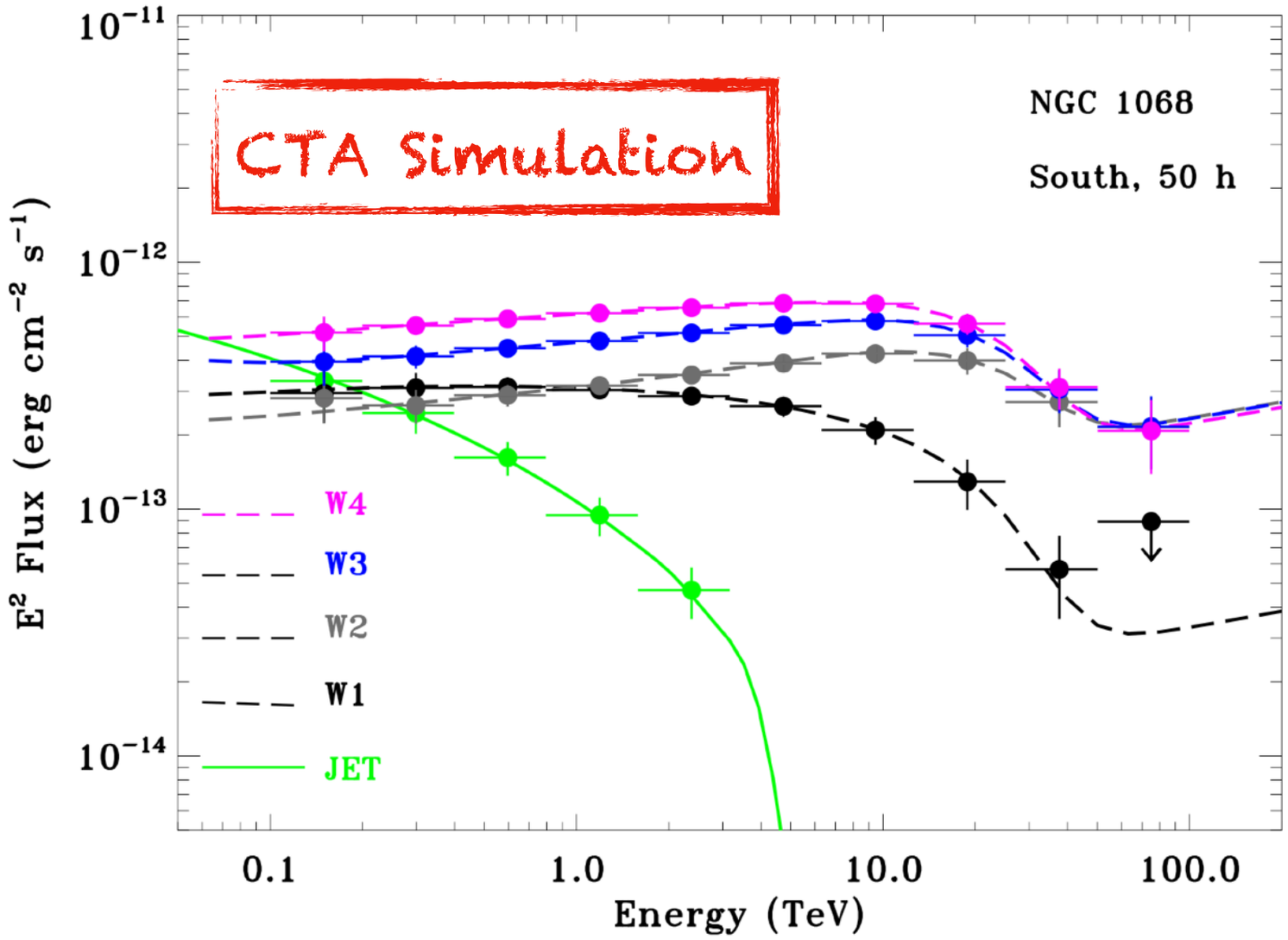


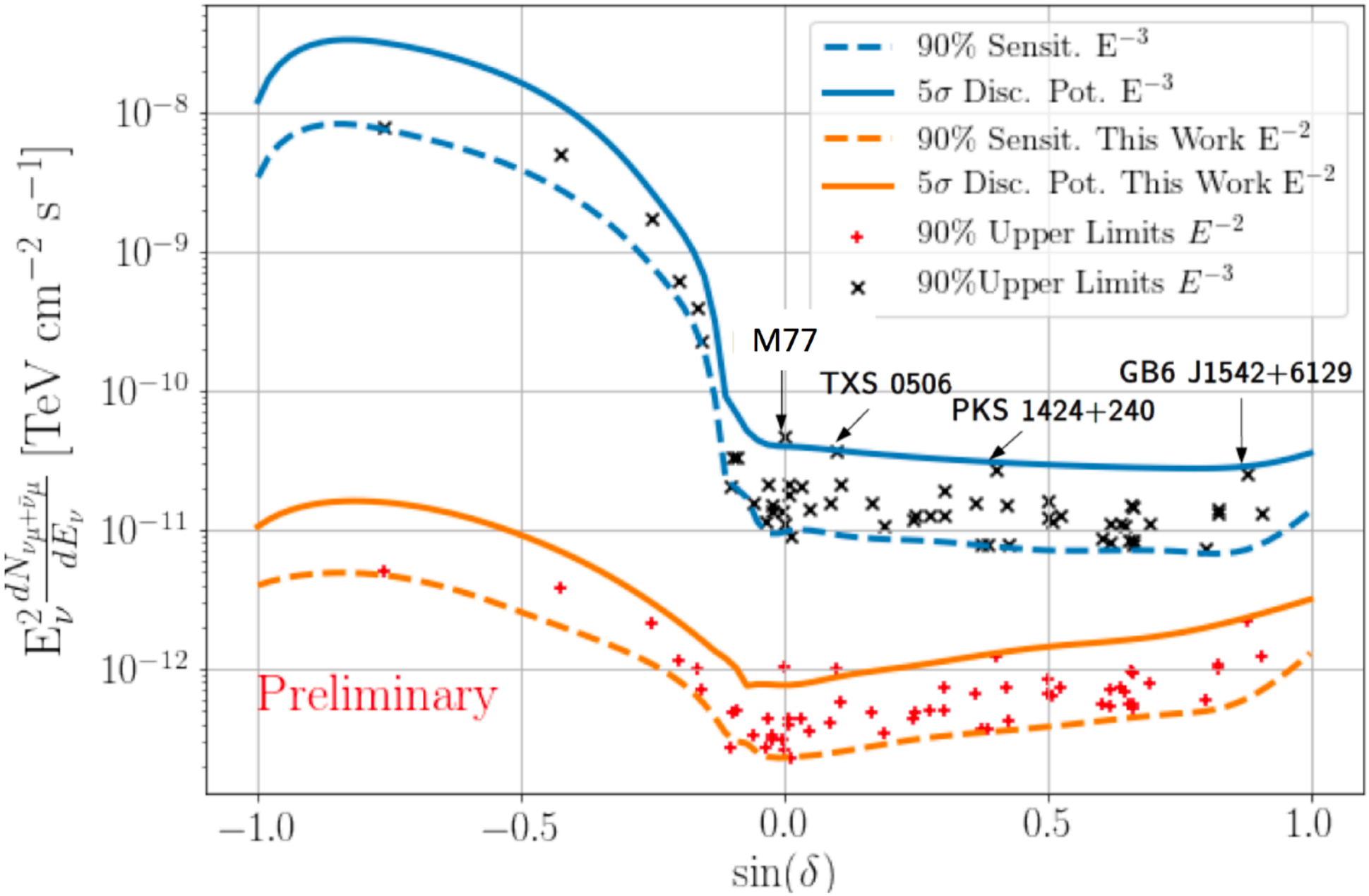


Lamastra et al. 2019

$p + p \rightarrow \pi + X$

AGN Winds

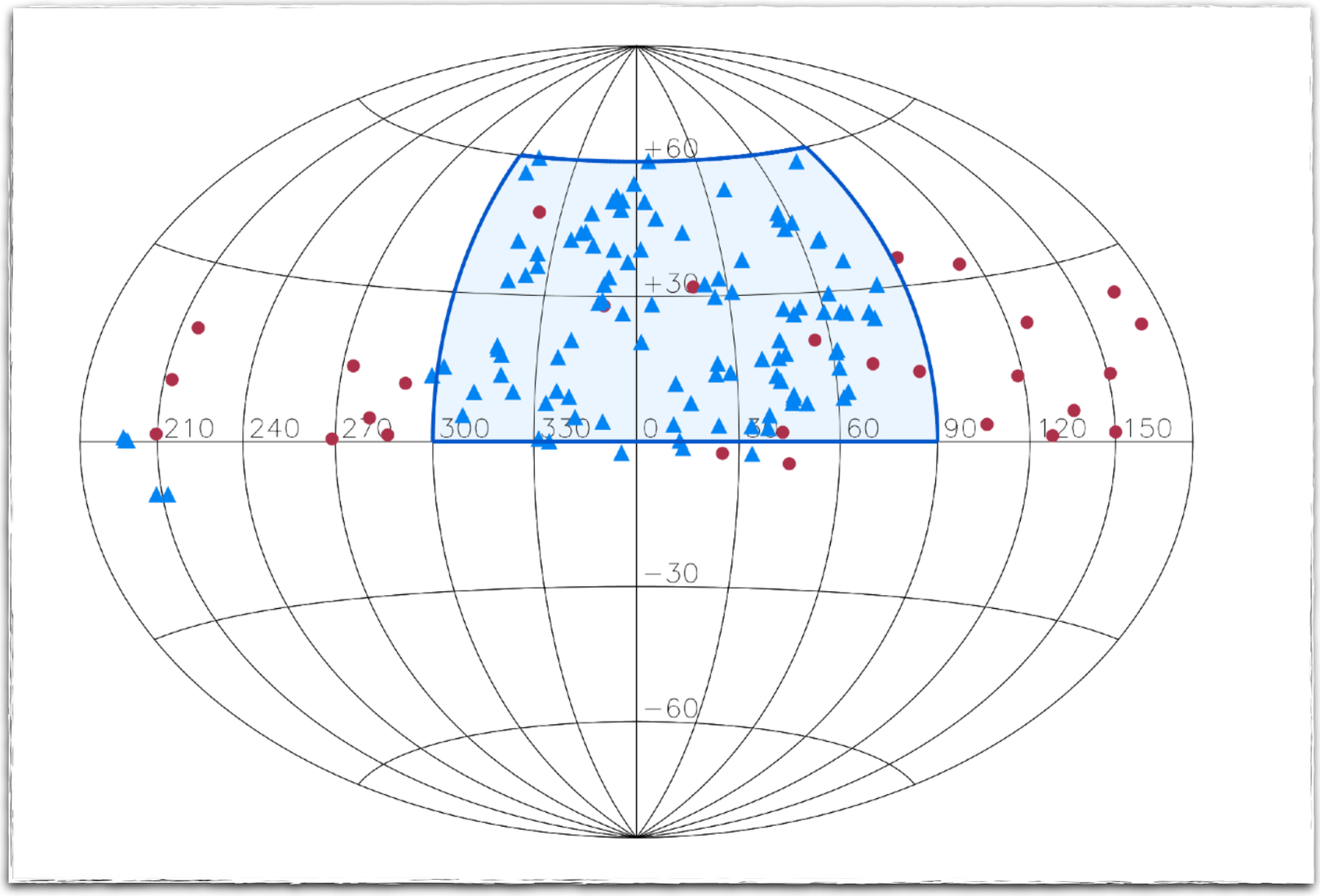
the case of NGC 1068 … or M 77



$p + p \rightarrow \pi + X$

Radiogalaxies

the case of FR0



- Weak source
- Extremely numerous
- Jet not able to reach large scale
- FR0 observed with Fermi

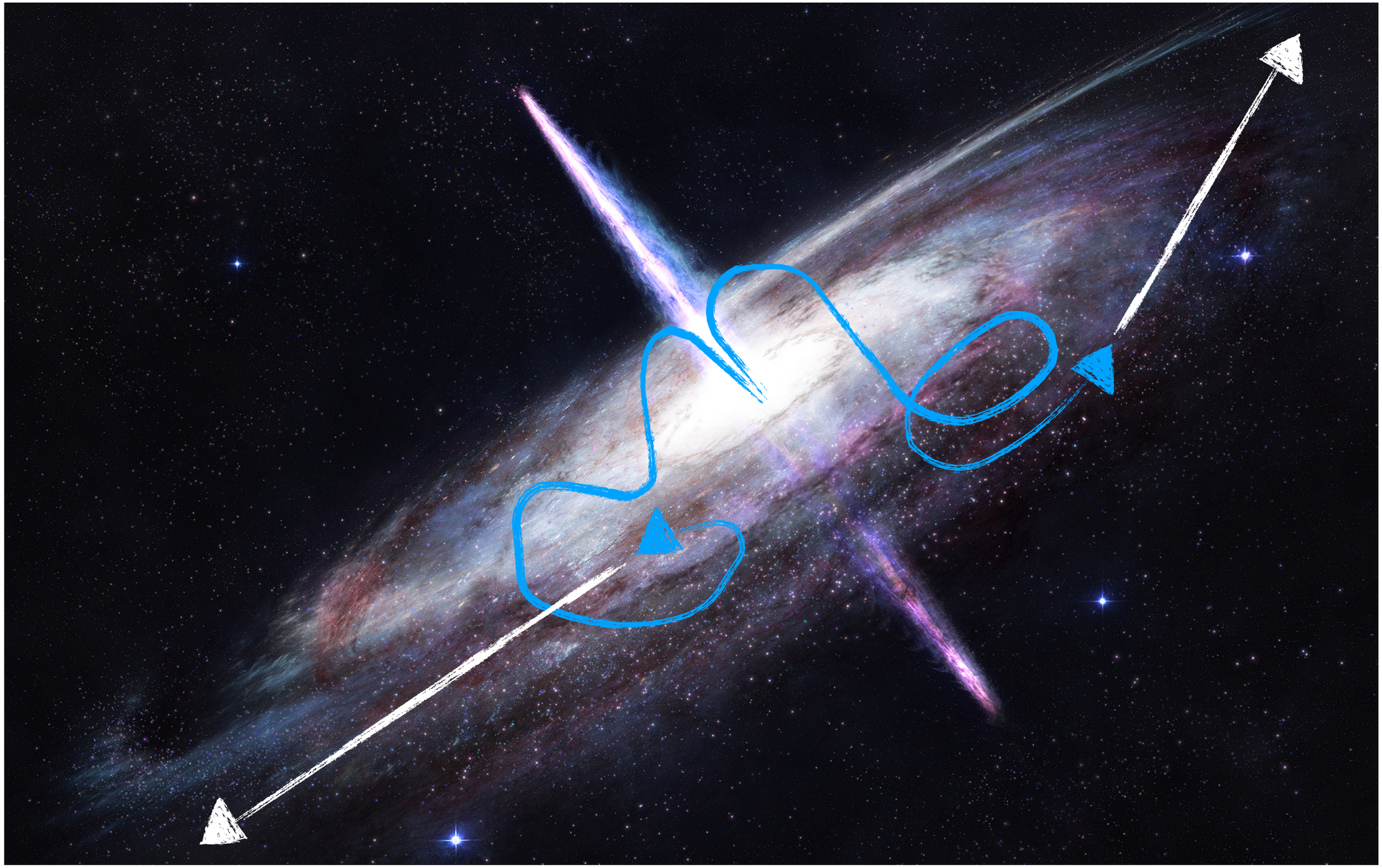
Baldi et al. 2015, 2017

Tavecchio et al. 2018

$p + p \rightarrow \pi + X$

Radiogalaxies

the case of FR0



Tavecchio et al. 2018

HE neutrino production

$p + p \rightarrow \pi + X$

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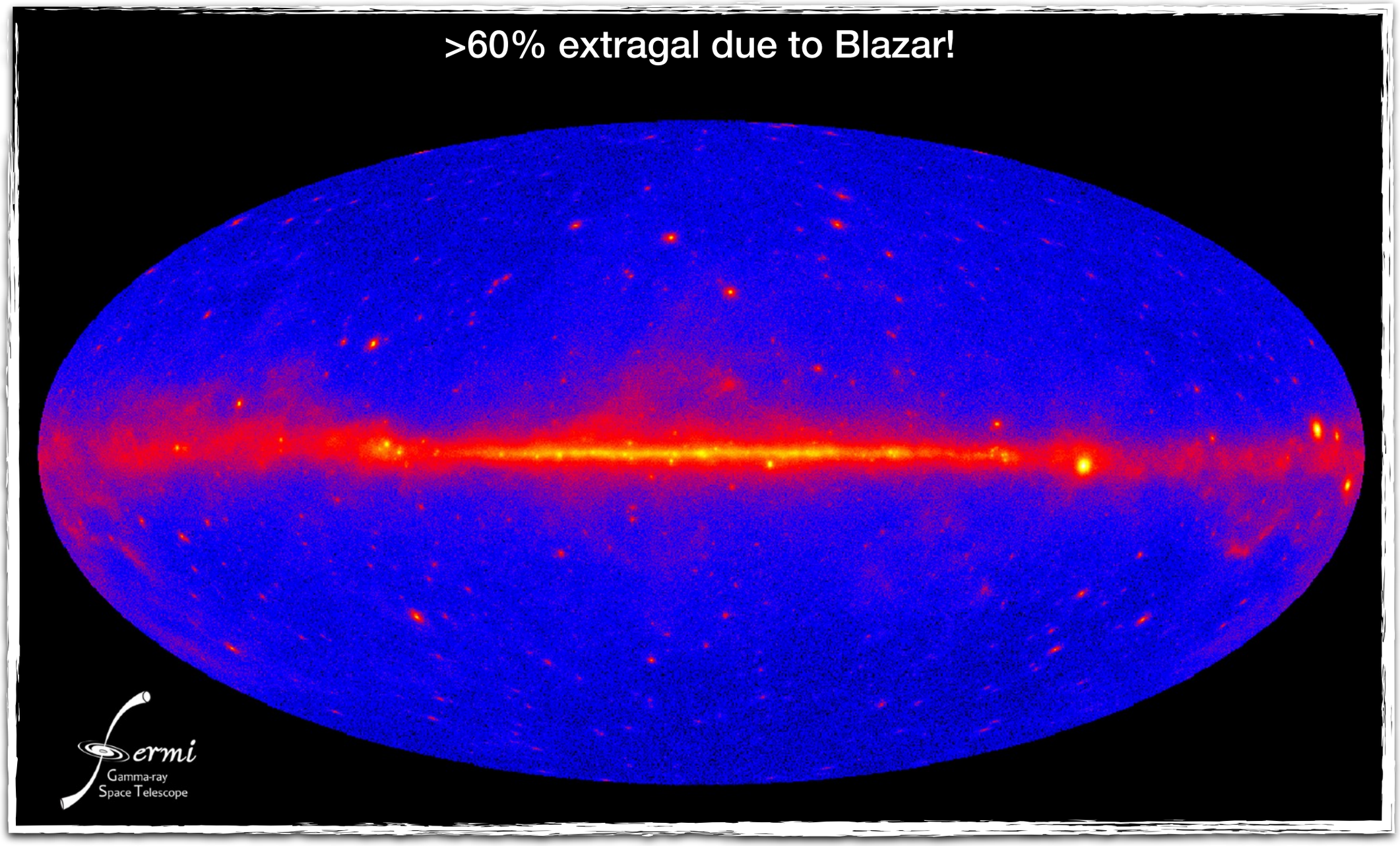
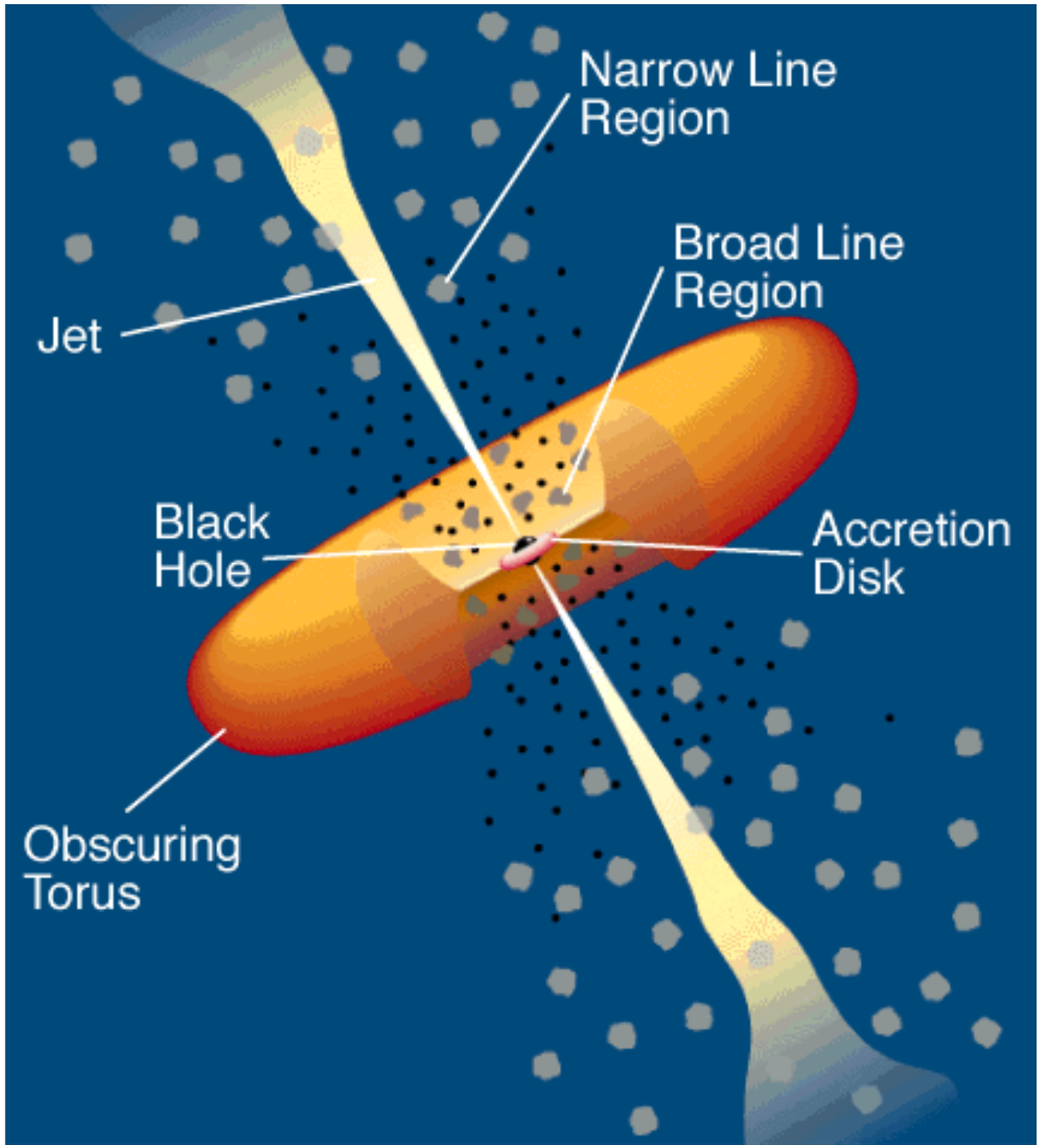
Righi et al. 17,18
...

Neutrinos from Blazars

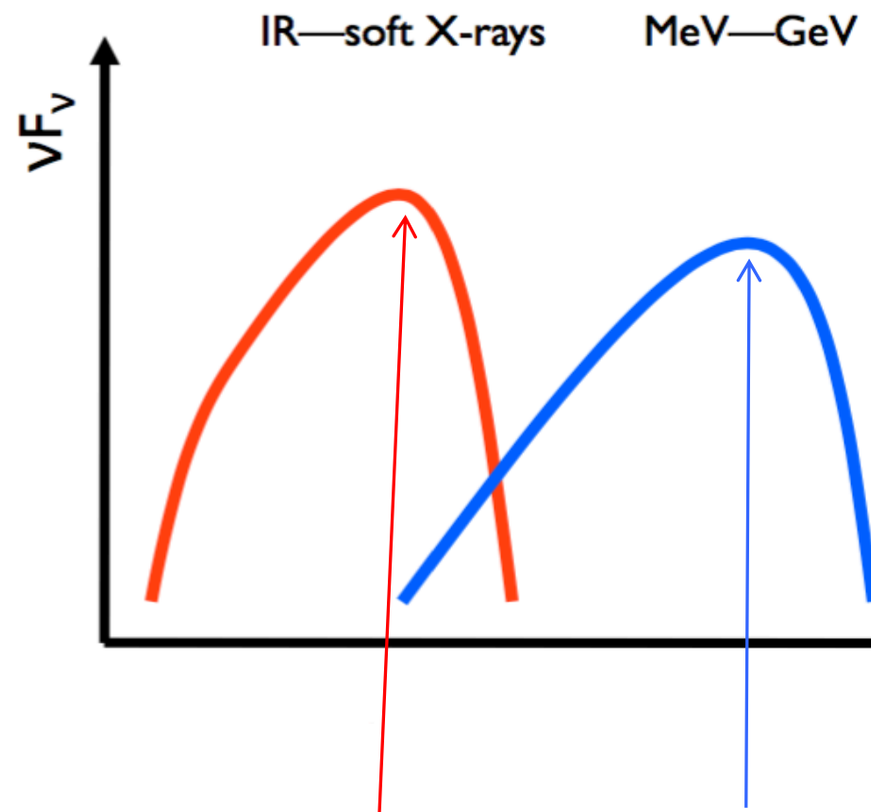


What are Blazars?



Blazars

Spectral Energy Distribution (SED)
Dominated by the relativistically boosted non-thermal continuum emission of the jet



MODELS

Leptonic

Hadronic

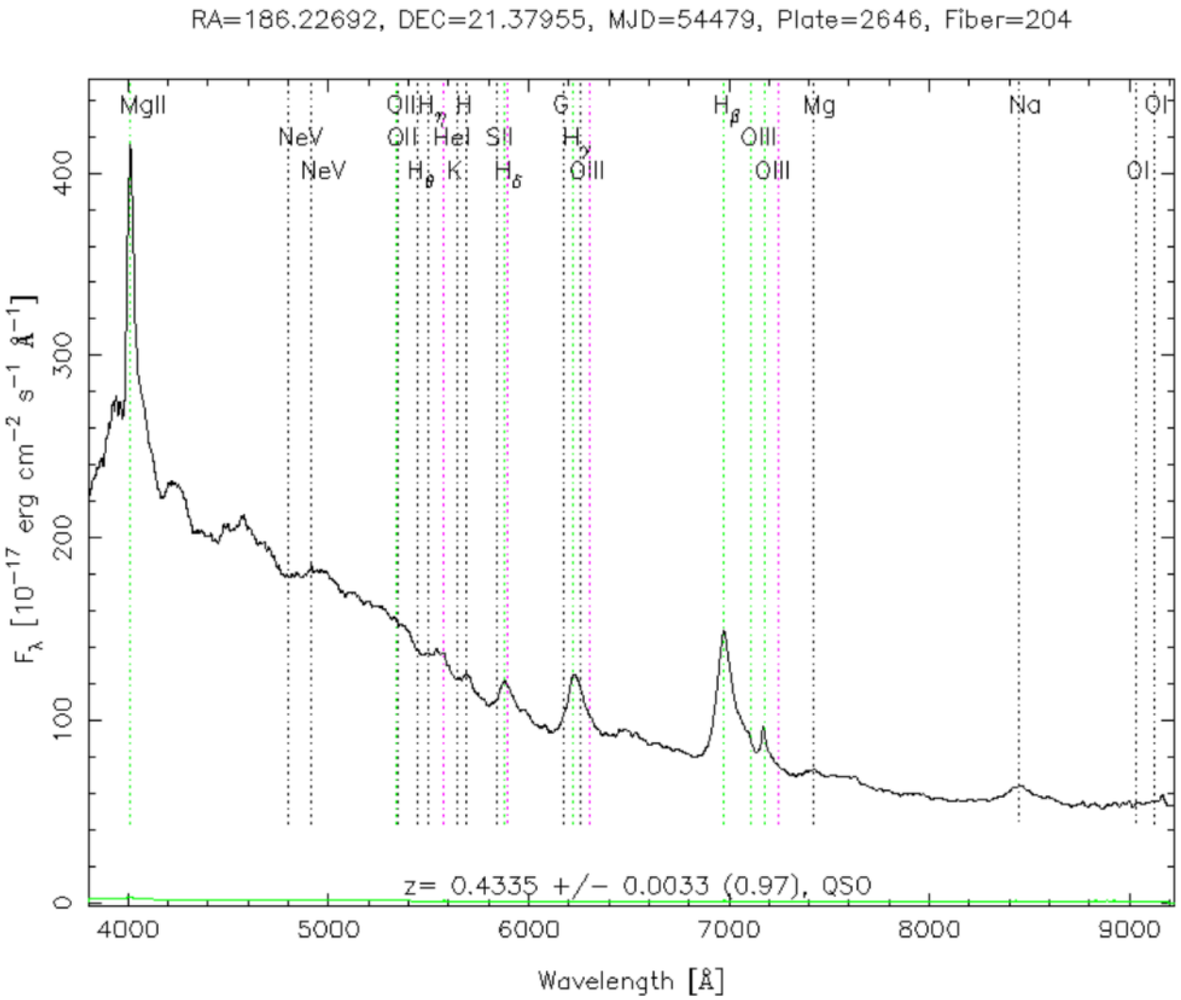
Synchrotron

Inverse Compton

Reprocessed photo-meson products or synchrotron (protons)

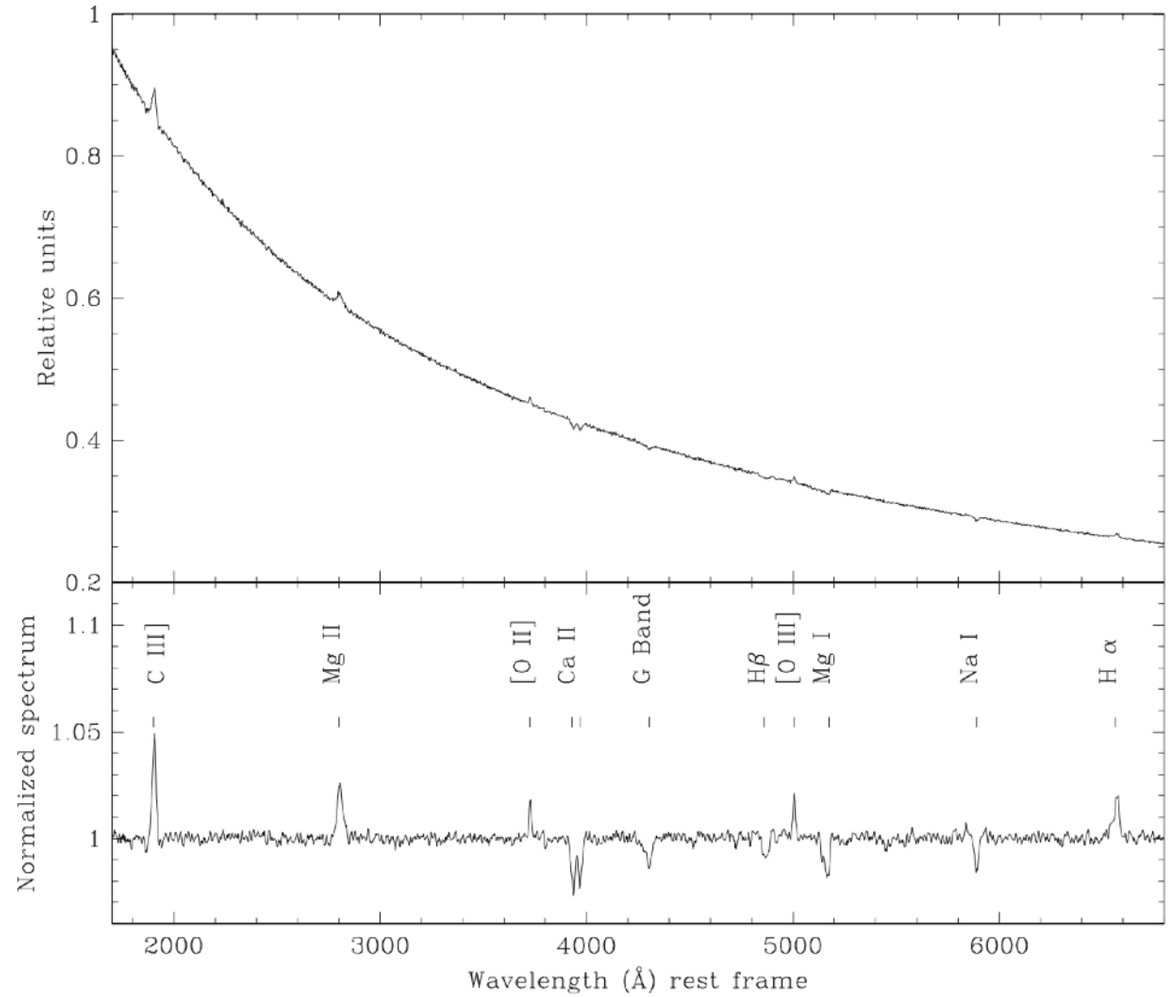
Blazars

FSRQs



Farina et al. 12

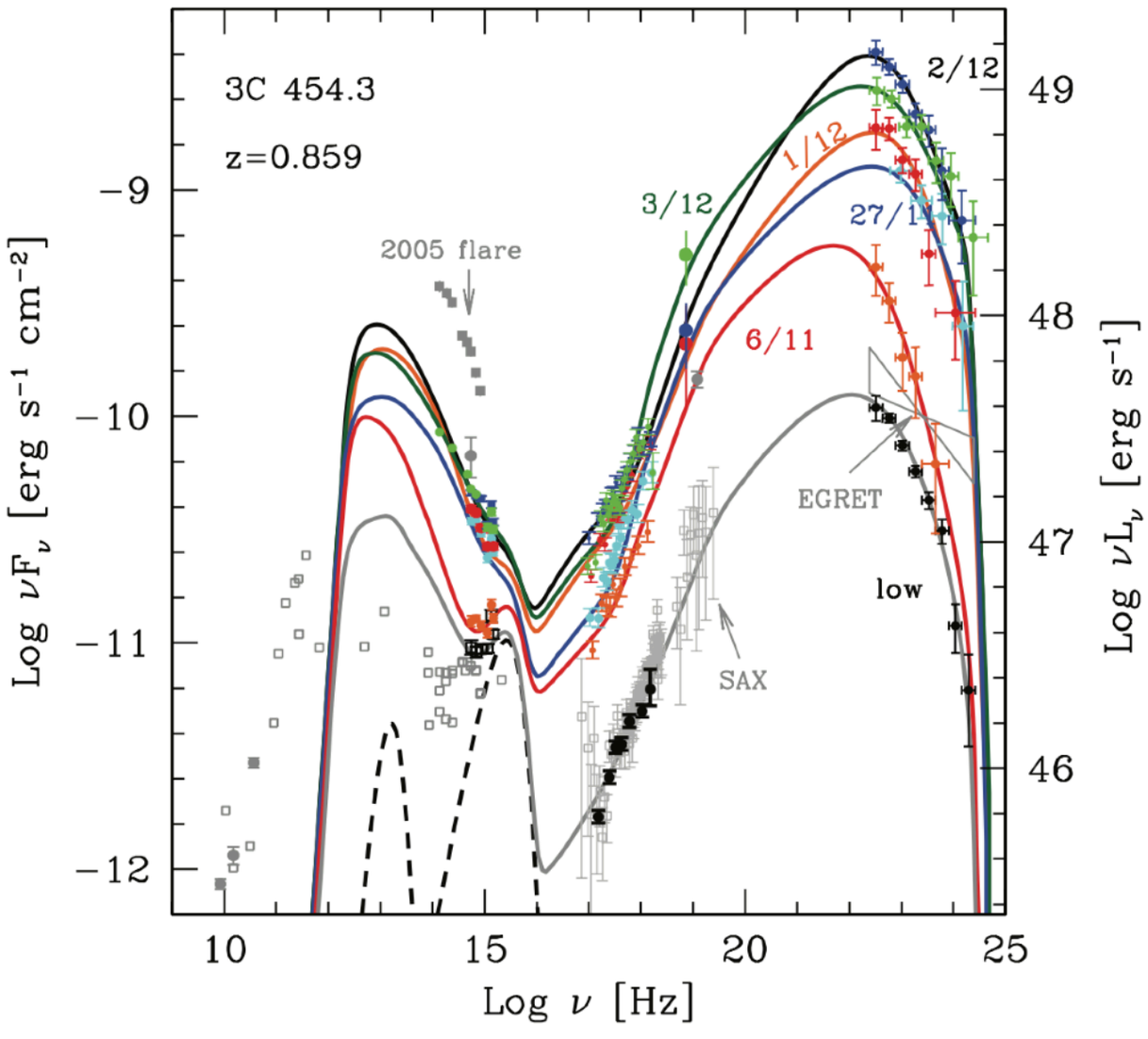
BL Lacs



Landoni et al. 13

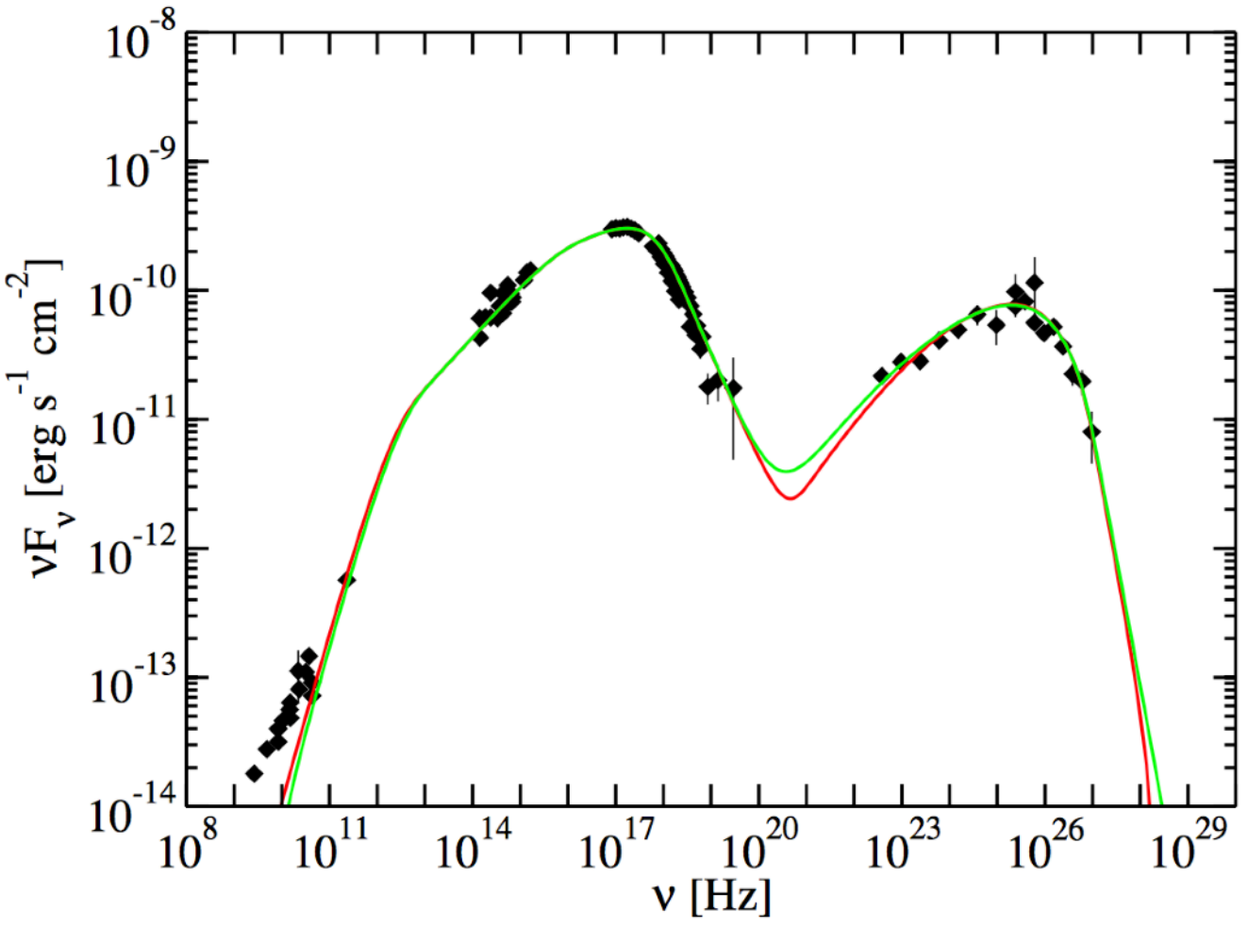
Blazars

FSRQs



Bonnoli et al. 11

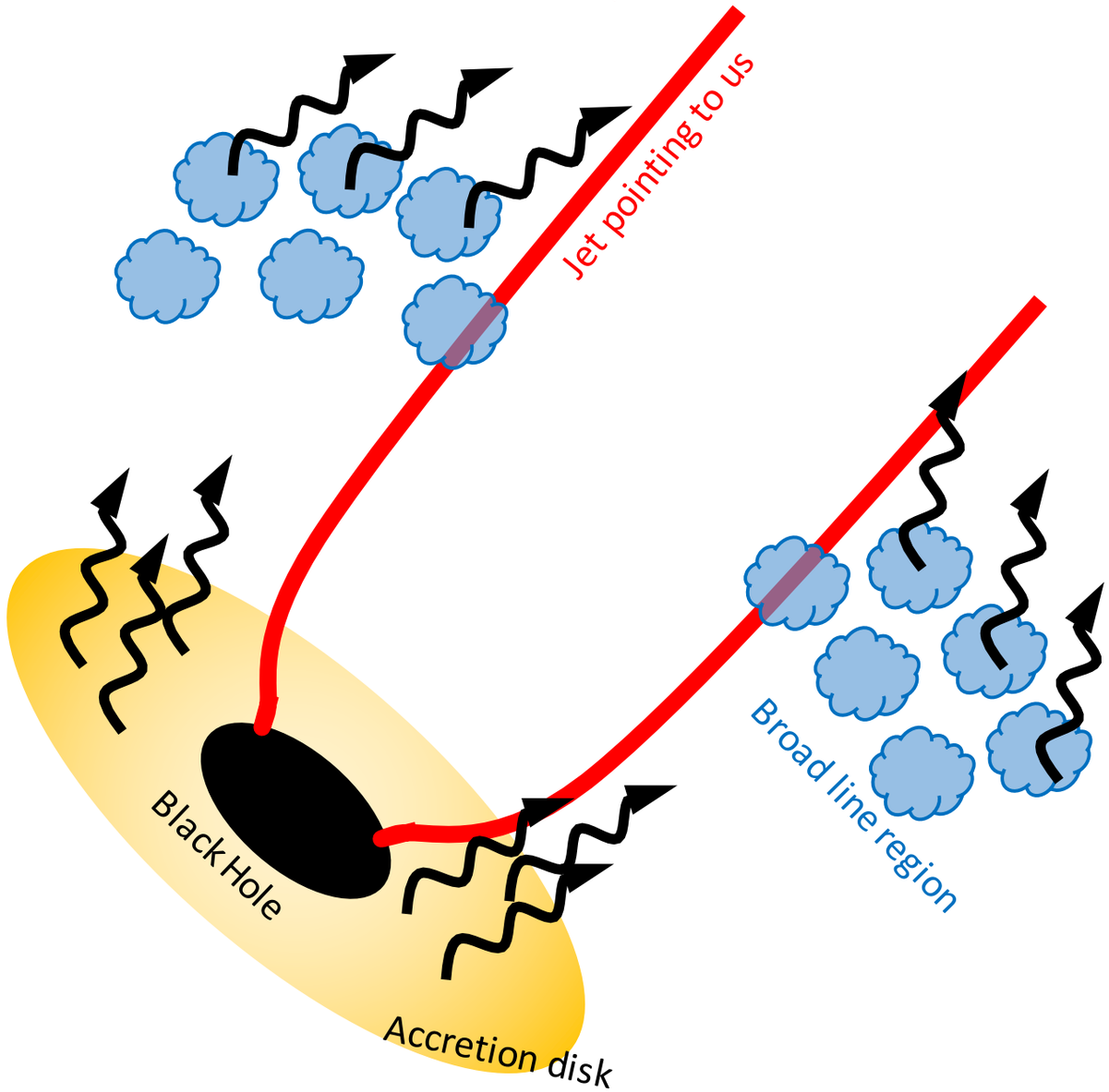
BL Lacs



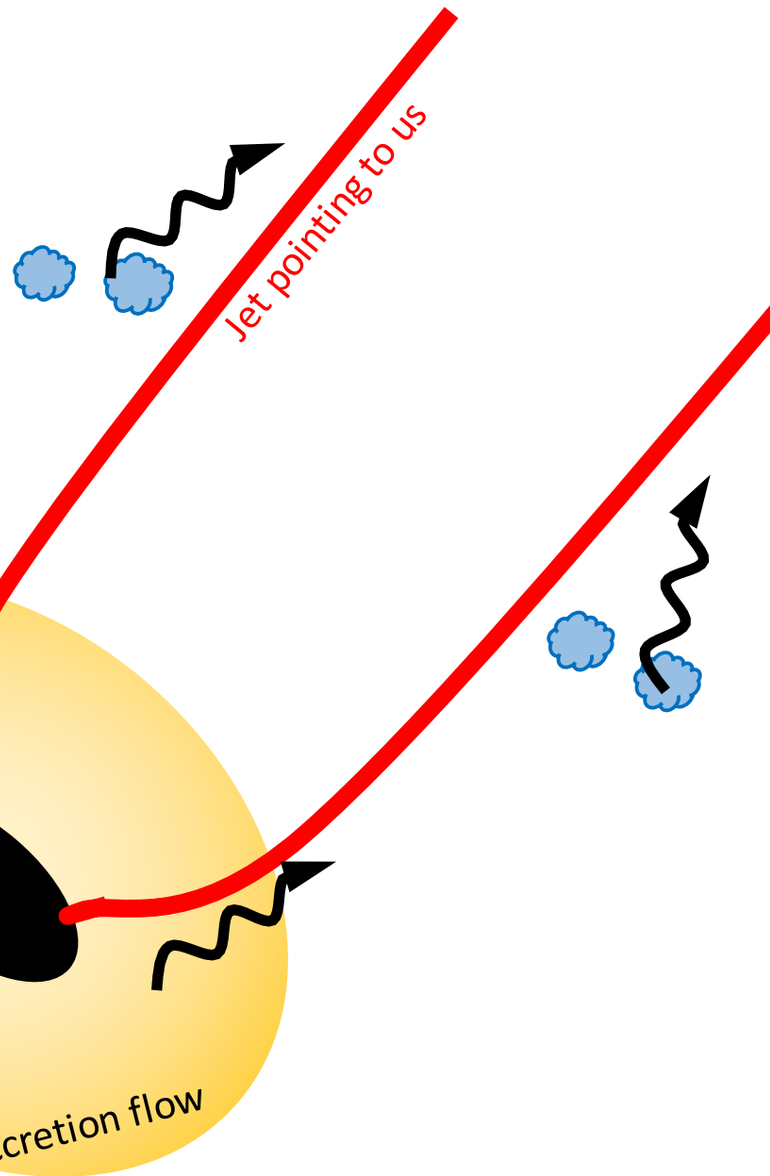
Abdo et al. 11

Blazars

FSRQs

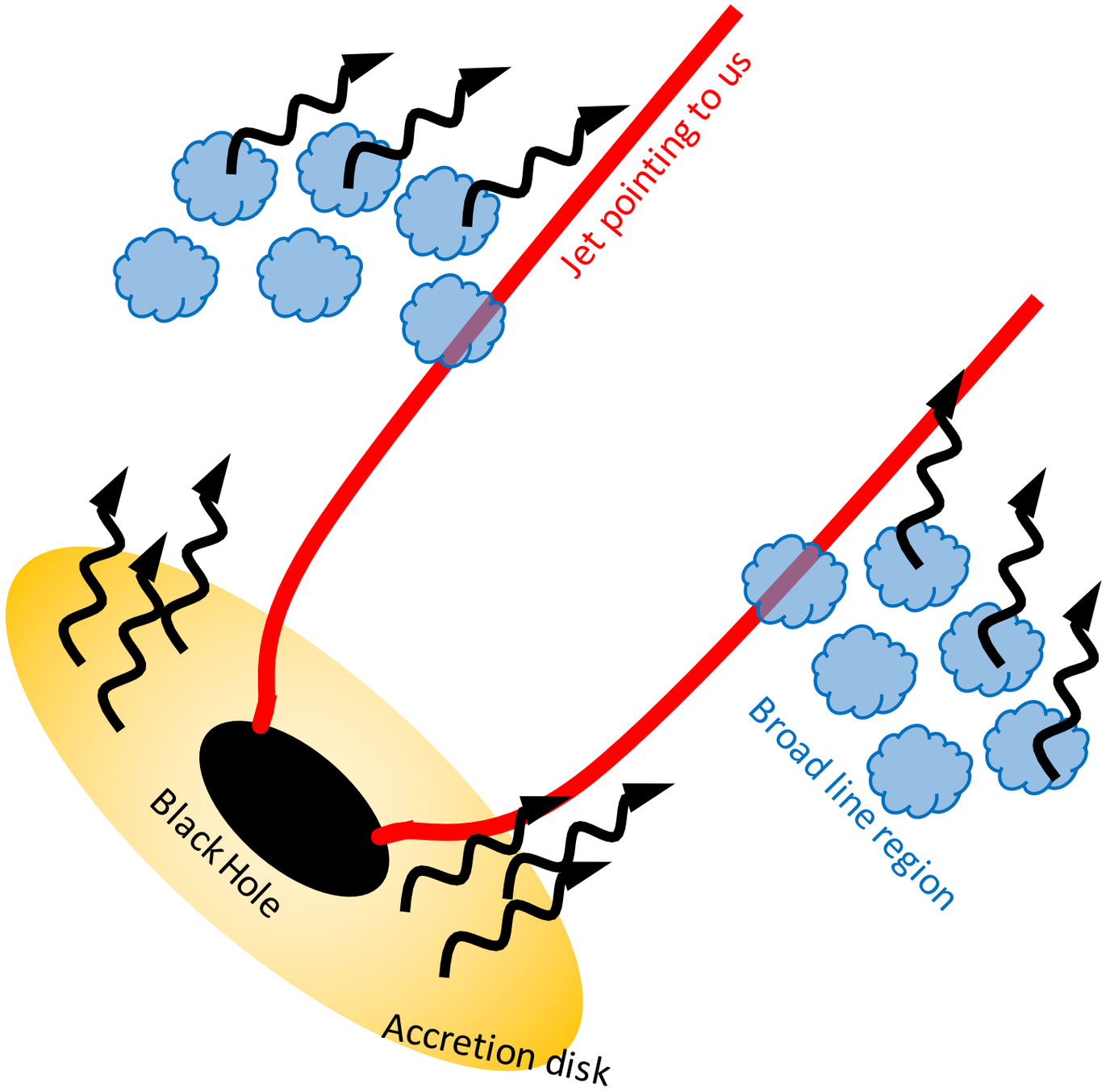


BL Lacs



$$p + \gamma \rightarrow \pi + X$$

FSRQs as neutrino sources



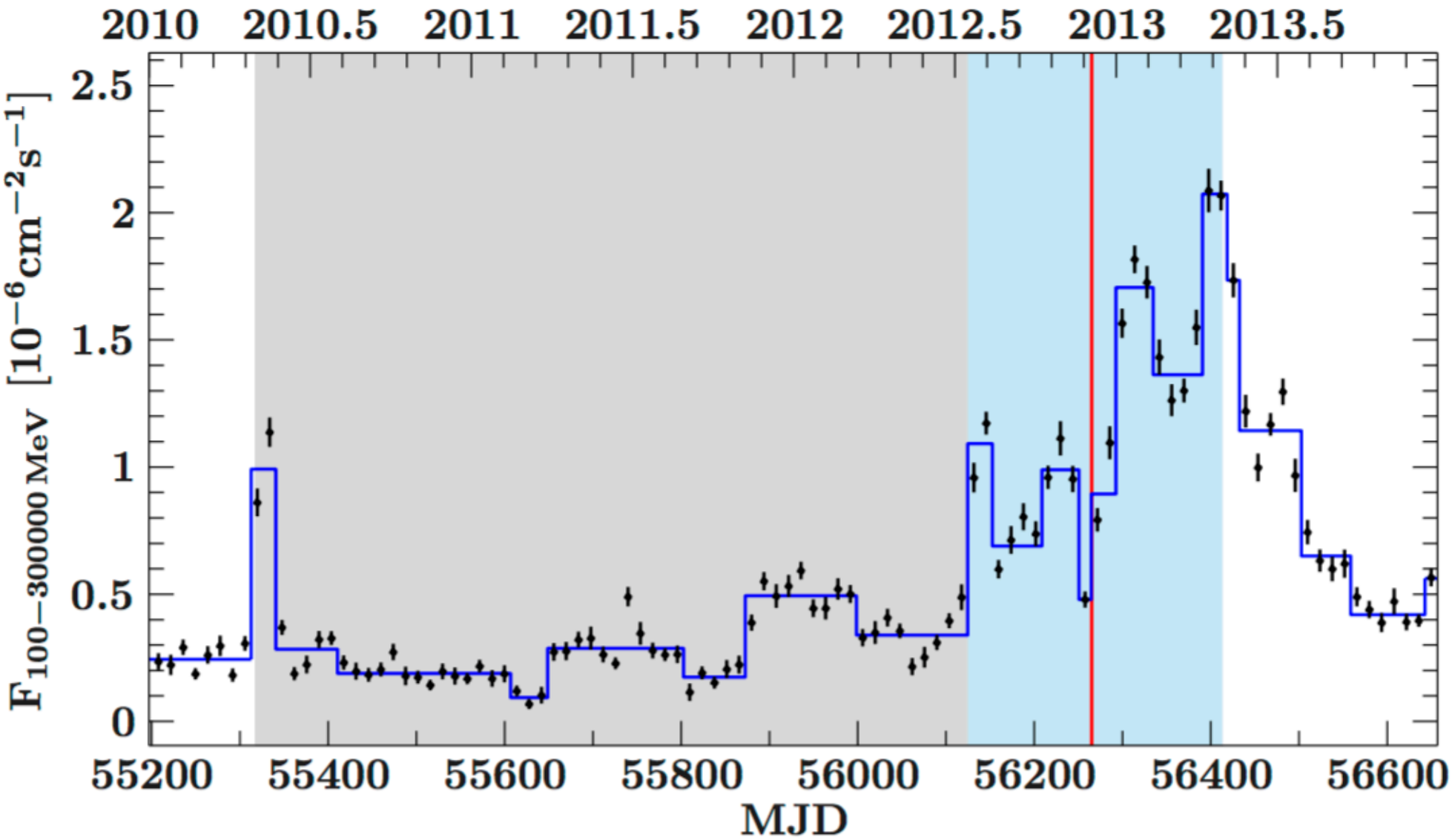
Environment rich of photons:

- Synchrotron radiation
- BLR radiation
- Torus radiation

$$p + \gamma \rightarrow \pi + X$$

FSRQs as neutrino sources

☑ Possible correlation between a HESE and a flaring FSRQ

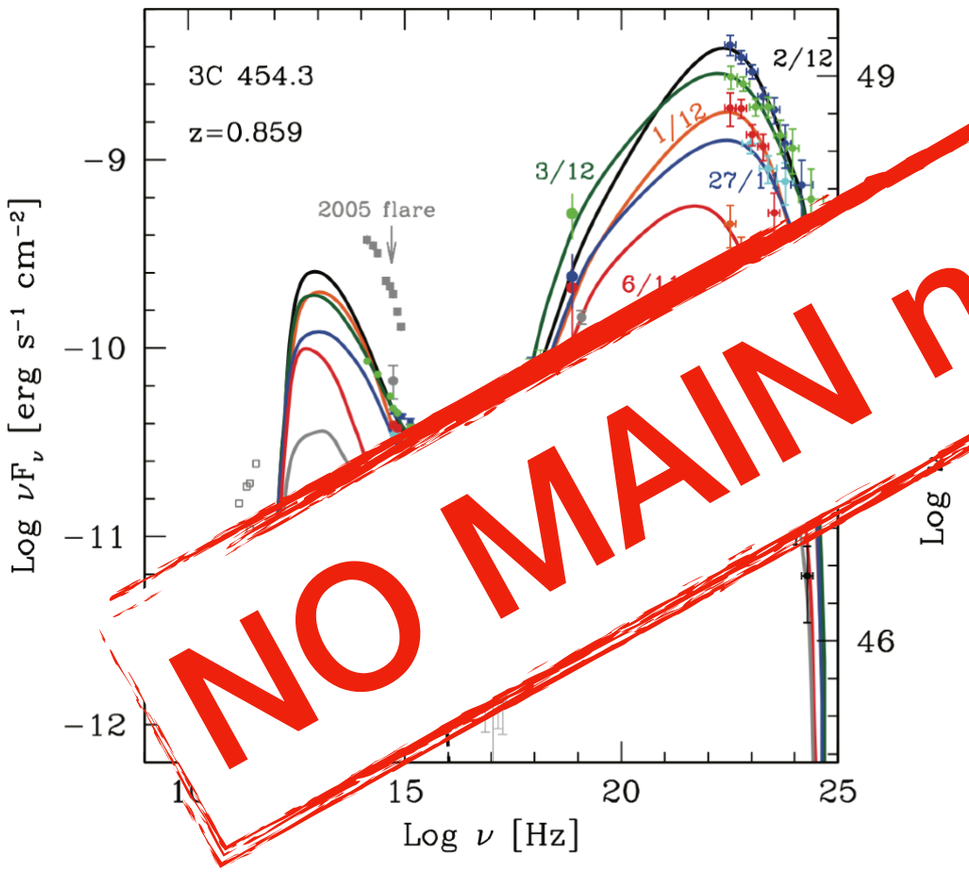


Kadler et al. 17

$$p + \gamma \rightarrow \pi + X$$

FSRQs as neutrino sources

Powerful but RARE → High [illegible] ected



Bonnoli et al. 15

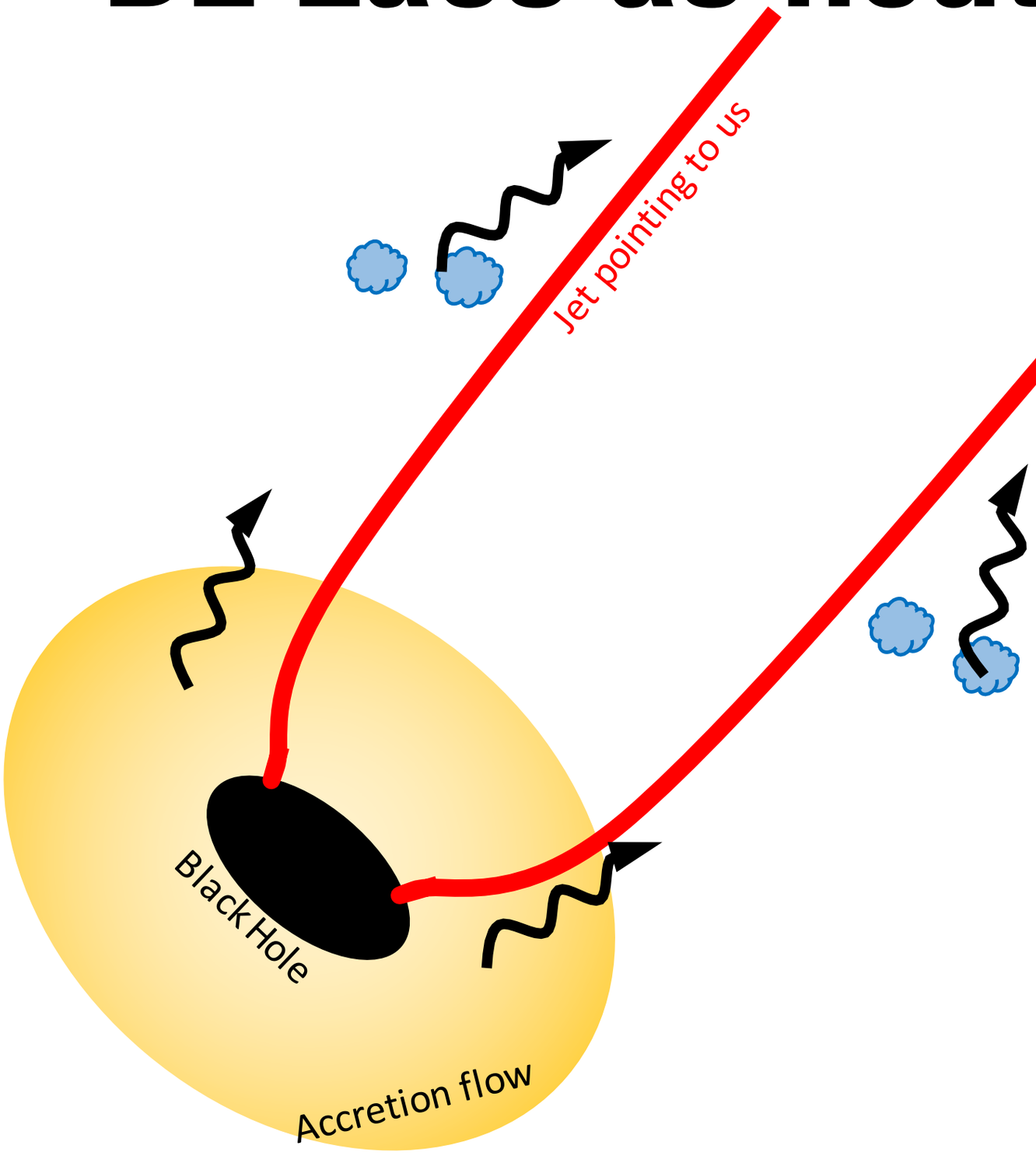
Detection expected!

Murase & Waxman 17

NO MAIN neutrino emitters!

$$p + \gamma \rightarrow \pi + X$$

BL Lacs as neutrino sources

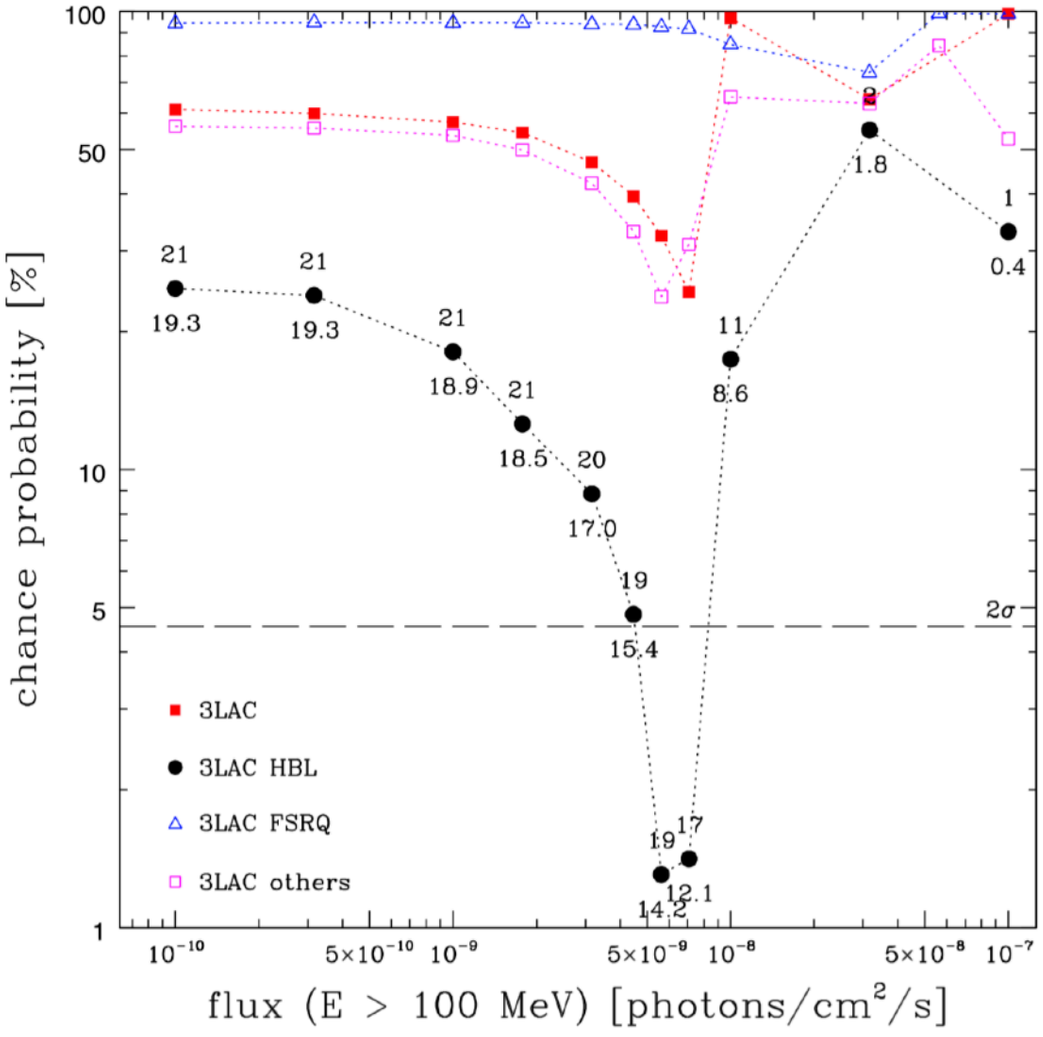


Environment poor of photons:

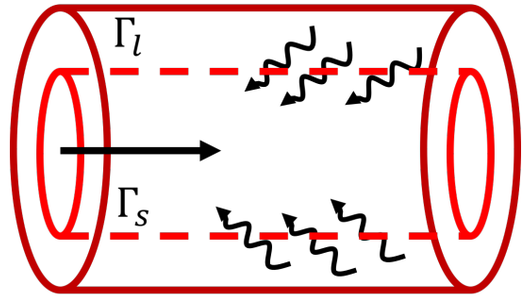
- Synchrotron radiation
- Inefficient accretion

$$p + \gamma \rightarrow \pi + X$$

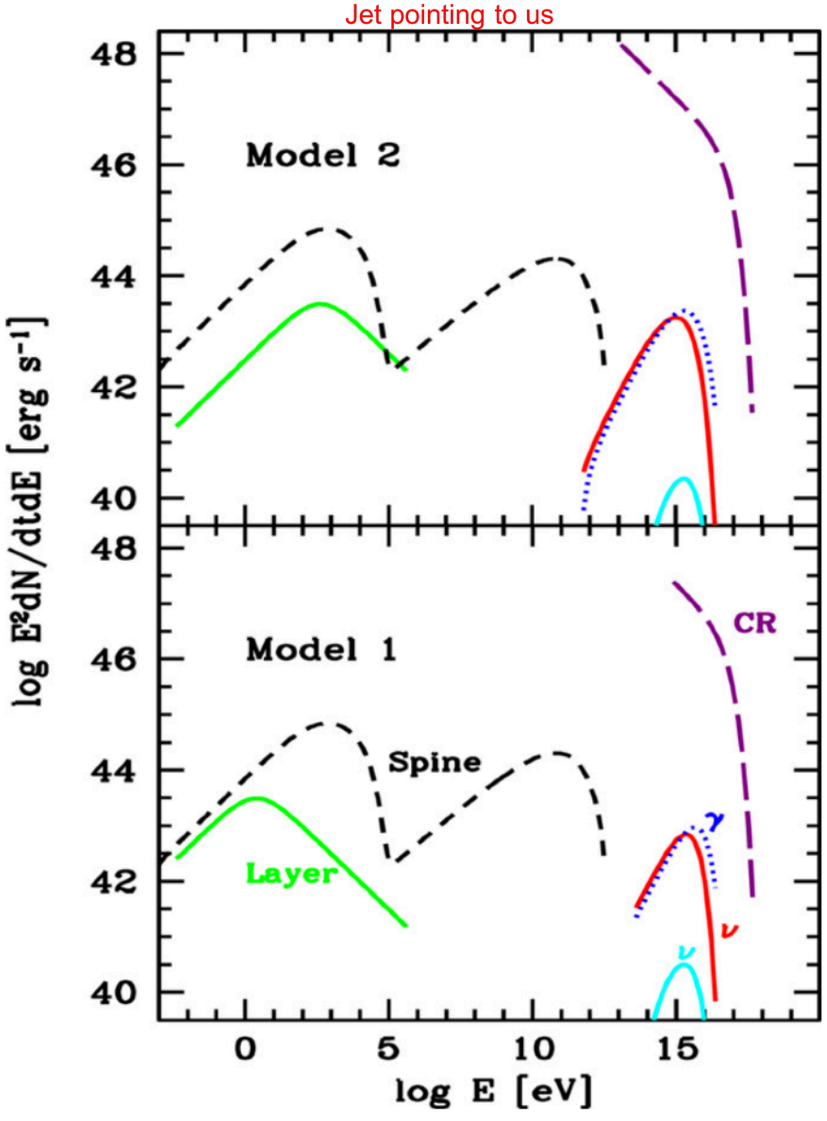
State of the art until 2016



Padovani et al.16



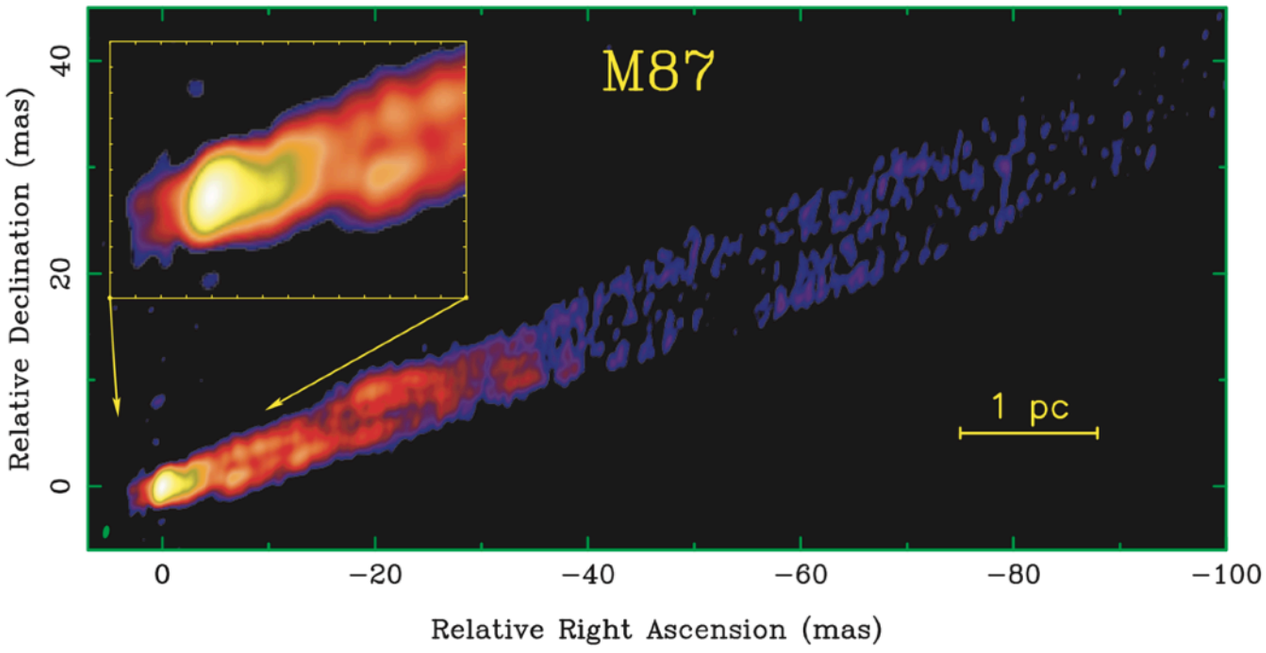
Jet pointing to us



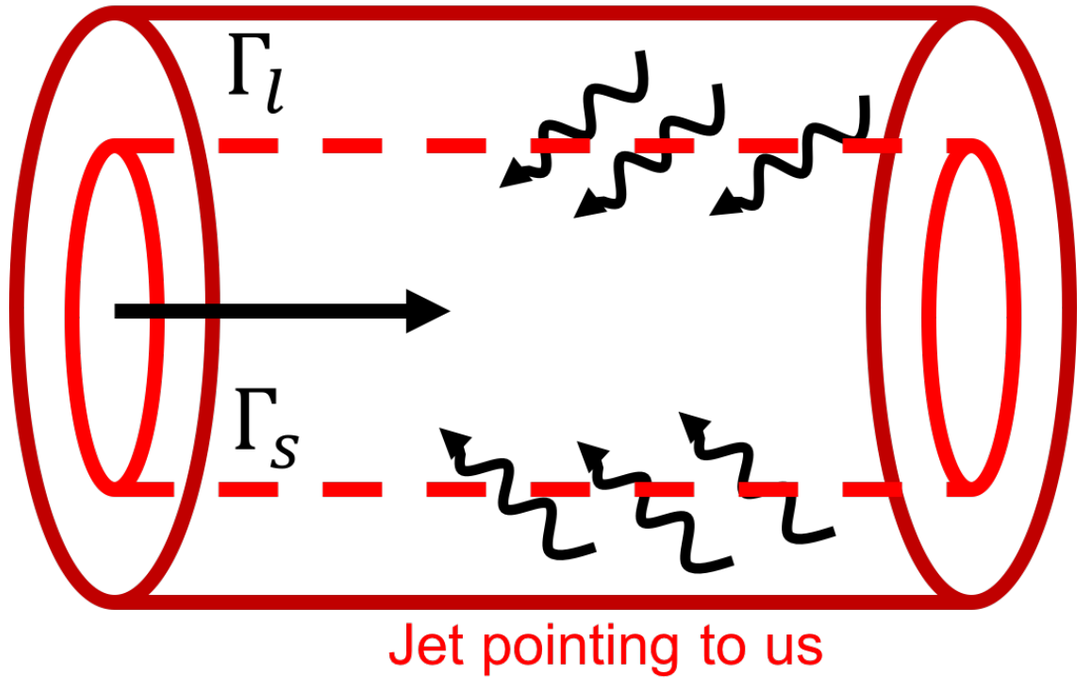
Tavecchio et al. 14,15

$$p + \gamma \rightarrow \pi + X$$

BL Lacs as neutrino sources



Kovalev et al. 07



Ghisellini et al. 05

IC 170922A & TXS 0506+056

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TITLE:   GCN CIRCULAR
NUMBER:  21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:    17/09/23 01:09:26 GMT
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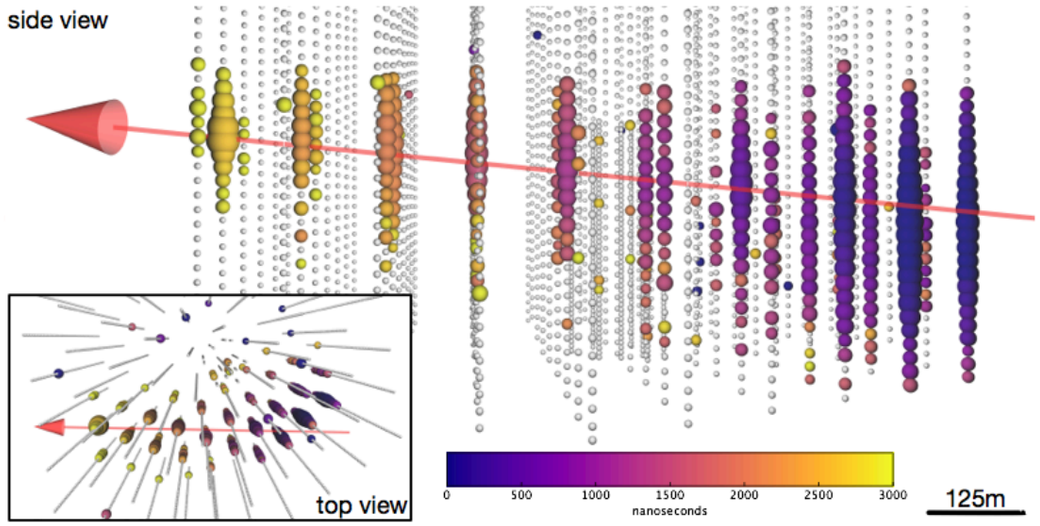
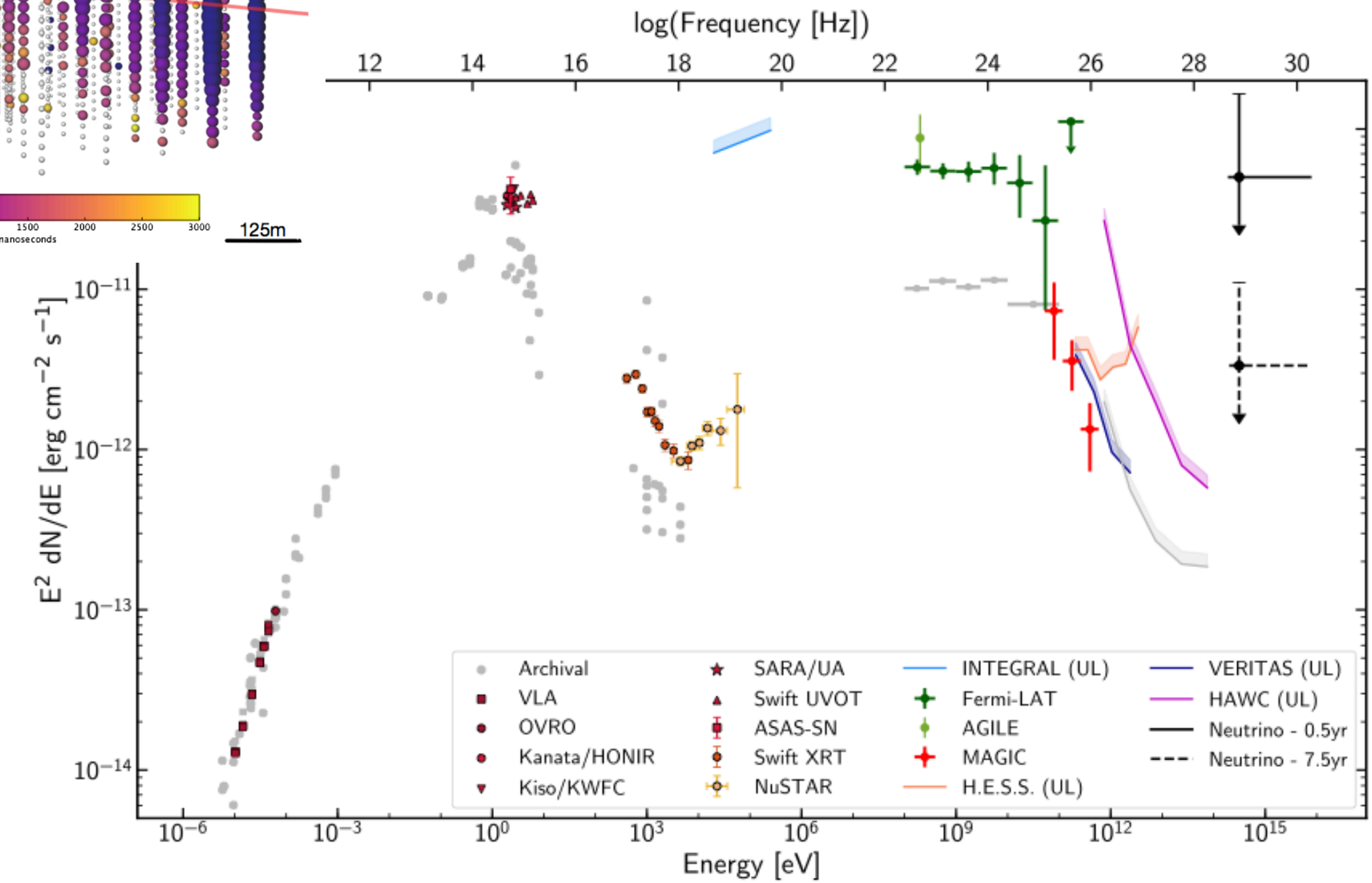
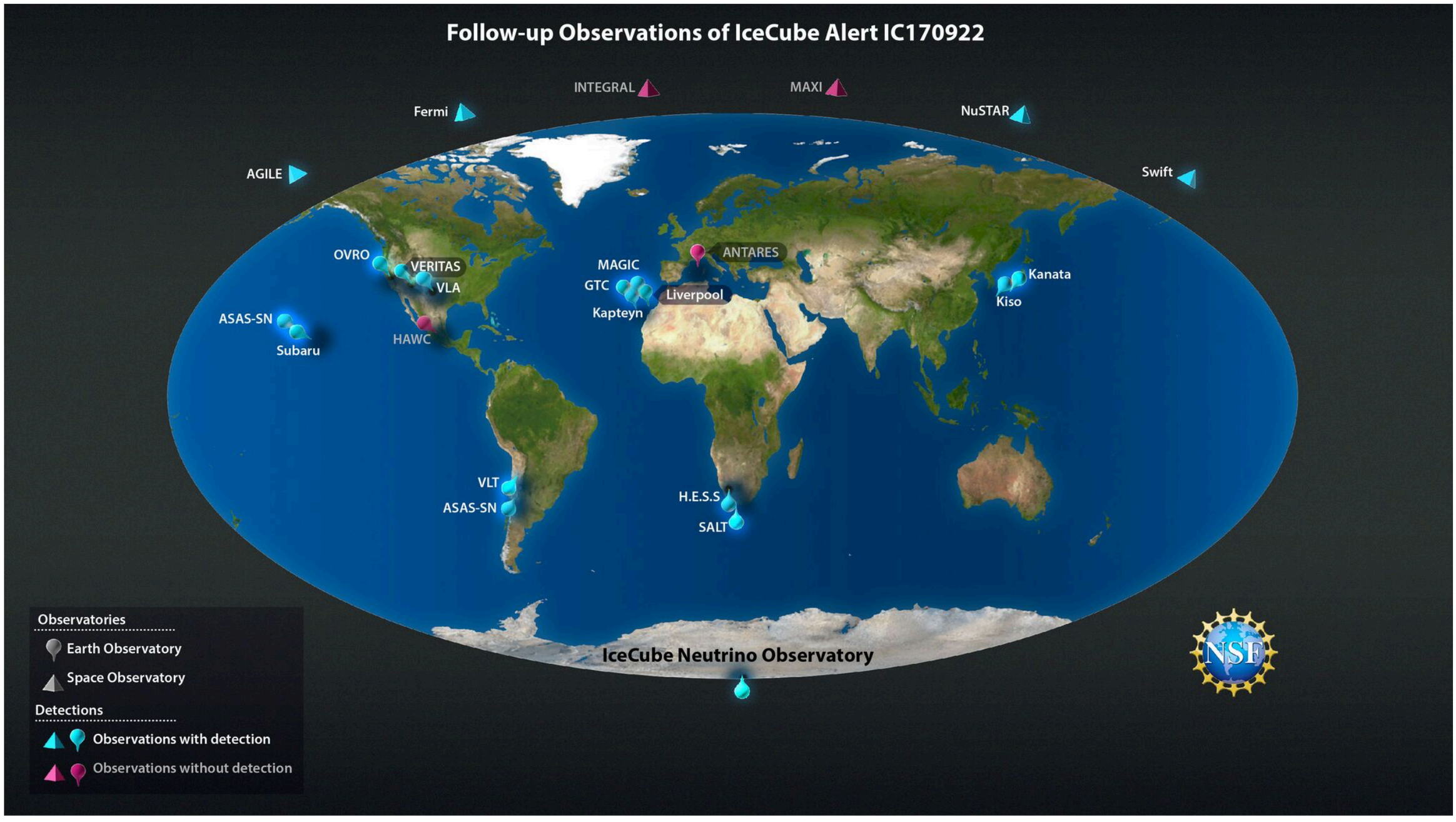


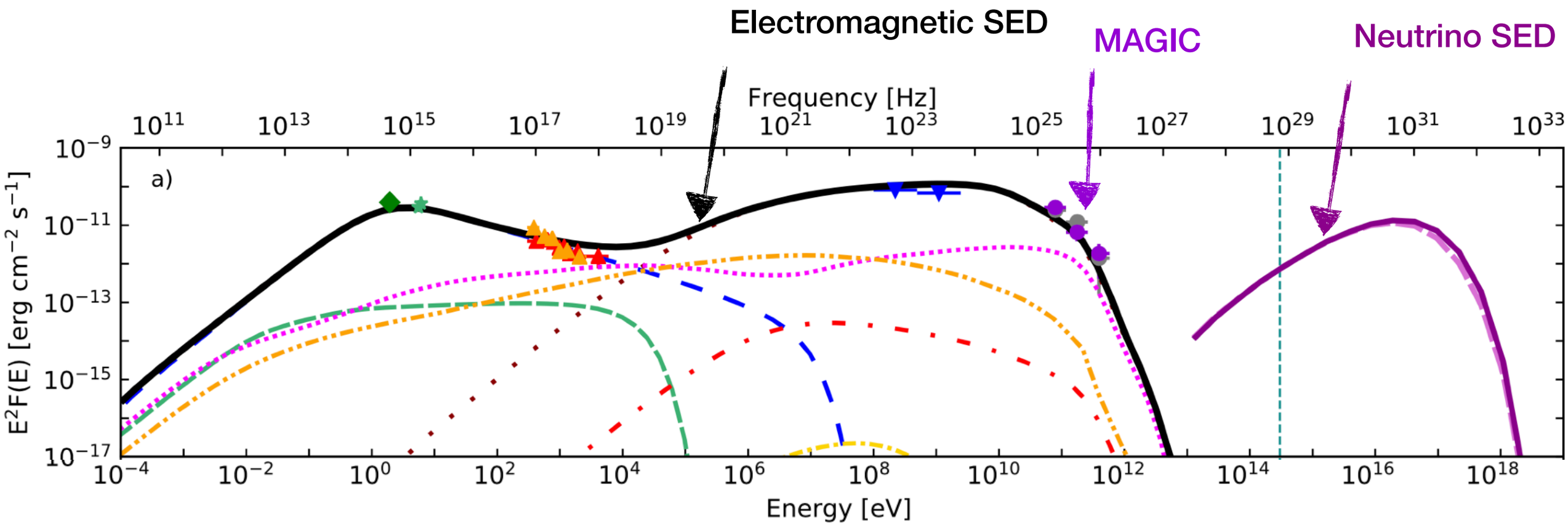


IceCube et al. 18

IC 170922A & TXS 0506+056

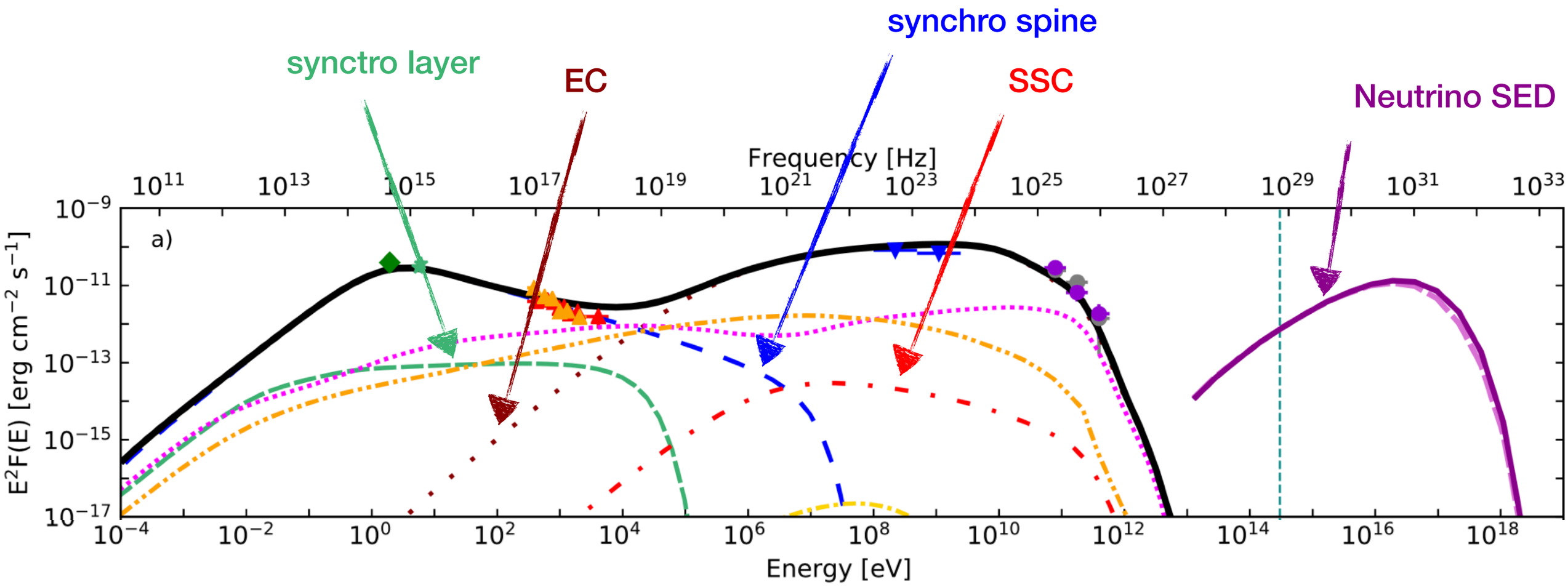


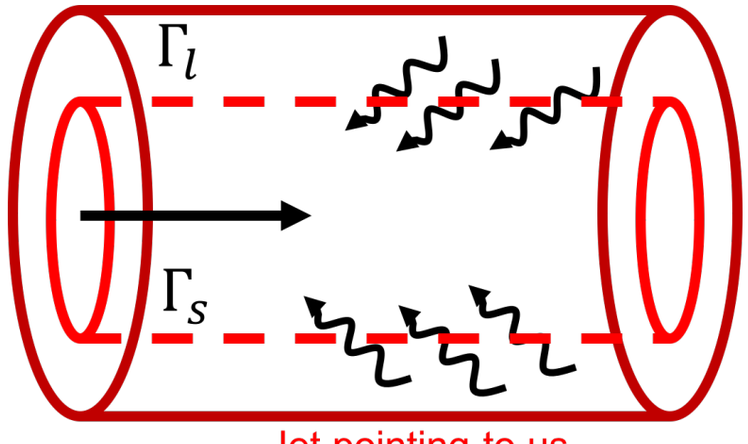
TXS 0506+056 with MAGIC



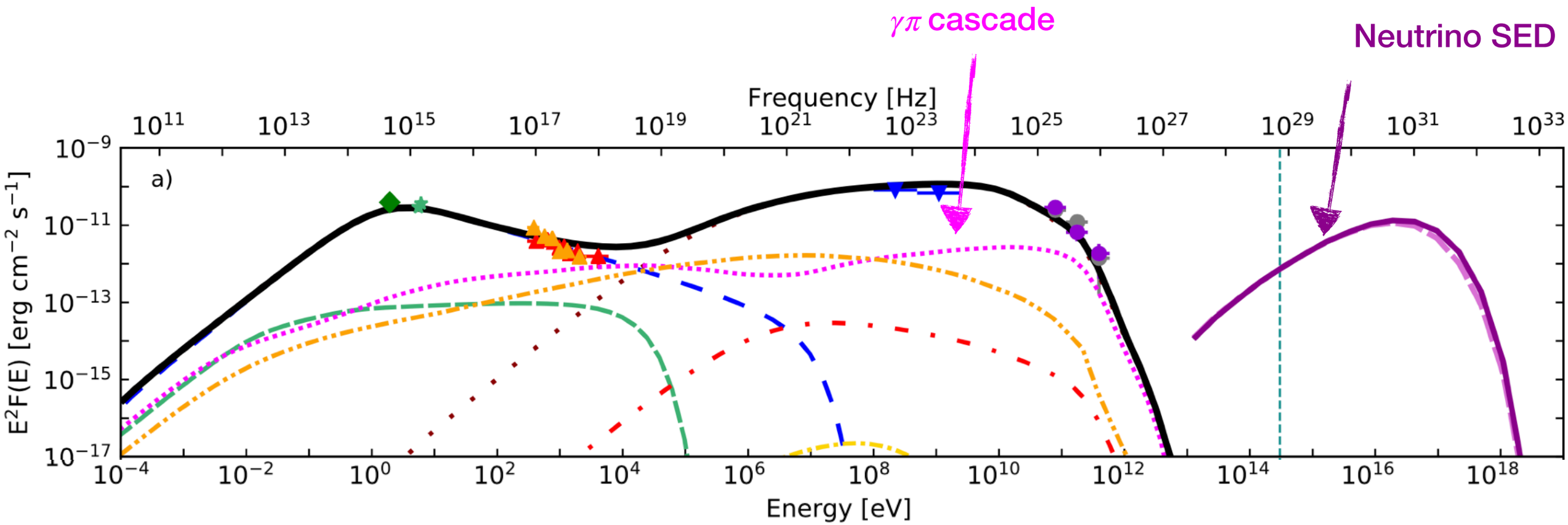
MAGIC 18

TXS 0506+056 with MAGIC





TXS 0506+056 with MAGIC



MAGIC 18

$$\pi^0 \rightarrow \gamma\gamma$$

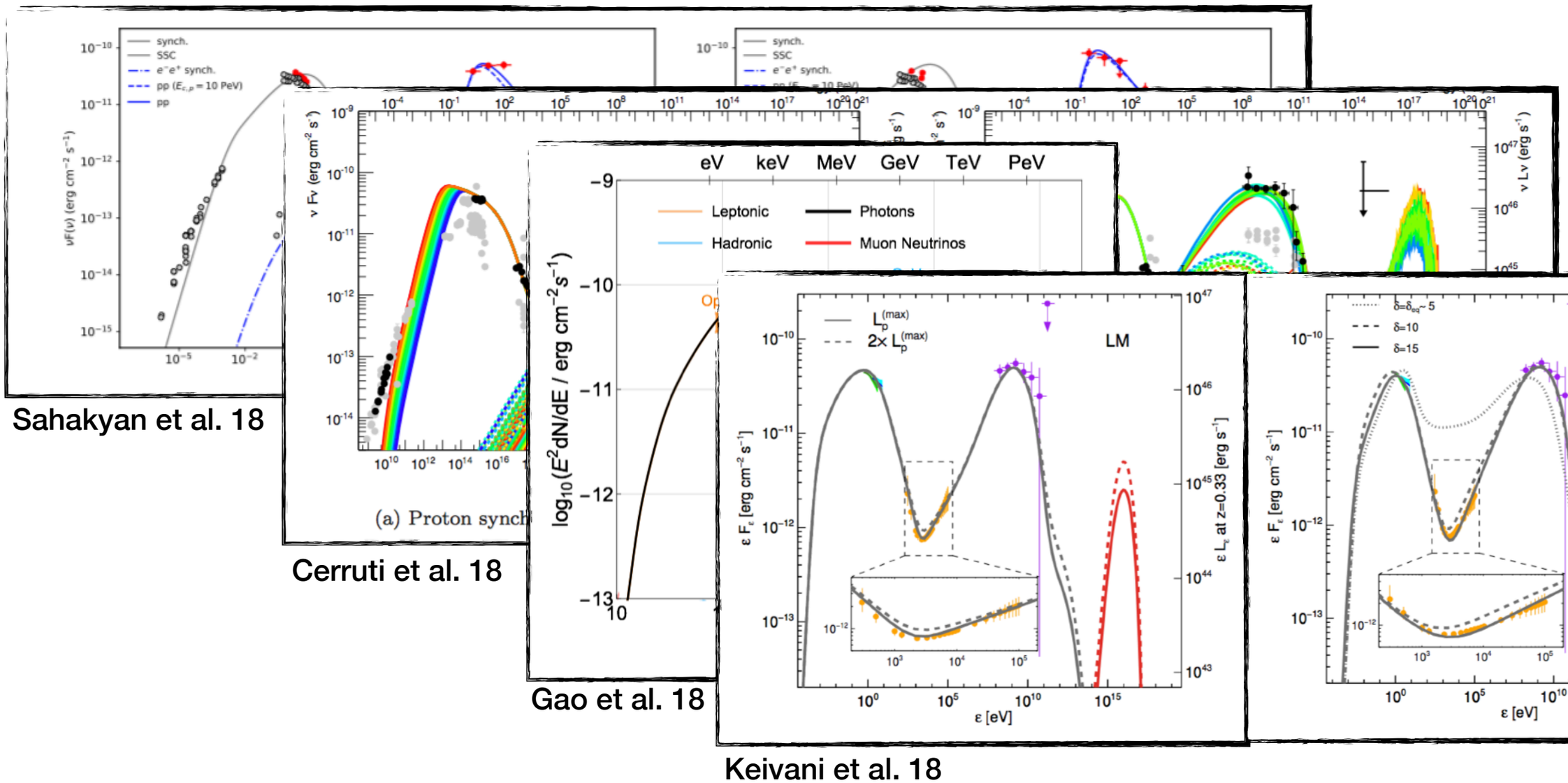
$$\gamma + \gamma \rightarrow e^+e^-$$

$$e^+ + \gamma \rightarrow e^+ + \gamma$$

$$\gamma + \gamma \rightarrow e^+e^-$$

What we learnt from TXS

- Neutrino emission constrained by cascade flux in X-ray band
- Pure hadronic model does not work
- One zone models implausible



Sahakyan et al. 18

Cerruti et al. 18

Gao et al. 18

Keivani et al. 18

Take home messages

- Multimessenger astronomy with neutrinos has started…more or less
- Blazars seems to be the best bet as counterpart of E>100TeV neutrinos
- Transient objects seems the easiest object to observe with IceCube
- Now we have strong constraints on Blazar theory
- Waiting for new events…

Thanks!