NuDM-2022, 25-28 September 2022 Sharm El-Sheikh, Egypt

IceCube Observation of Neutrinos from High-Energy Blazars and their production mechanism

Sarira Sahu
Instituto de Ciencias Nucleares
Universidad Nacional Autonoma de Mexico, Mexico City

- Introduction

On 22nd of September 2017, IceCube neutrino telescope in South Pole detected a track-like neutrino event (muon neutrino) with energy ~ 290 TeV (IceCube-170922A).

For the first time

- **Extensive follow-up observation from Radio to TeV ⇛ Enhanced emission in all these energy bands.**
- **Fermi-LAT (satellite) observed high state in GeV energy.**

HESS and VERITAS observations

- **On September 23, ~4 hr after the neutrino alert, HESS observed for 1.3 hr**
- **VERITAS observed for 1 hr in the direction of the source after ~12 hr of the IceCube alert**
- **Subsequent nights additional observations by both**
- **No Success**

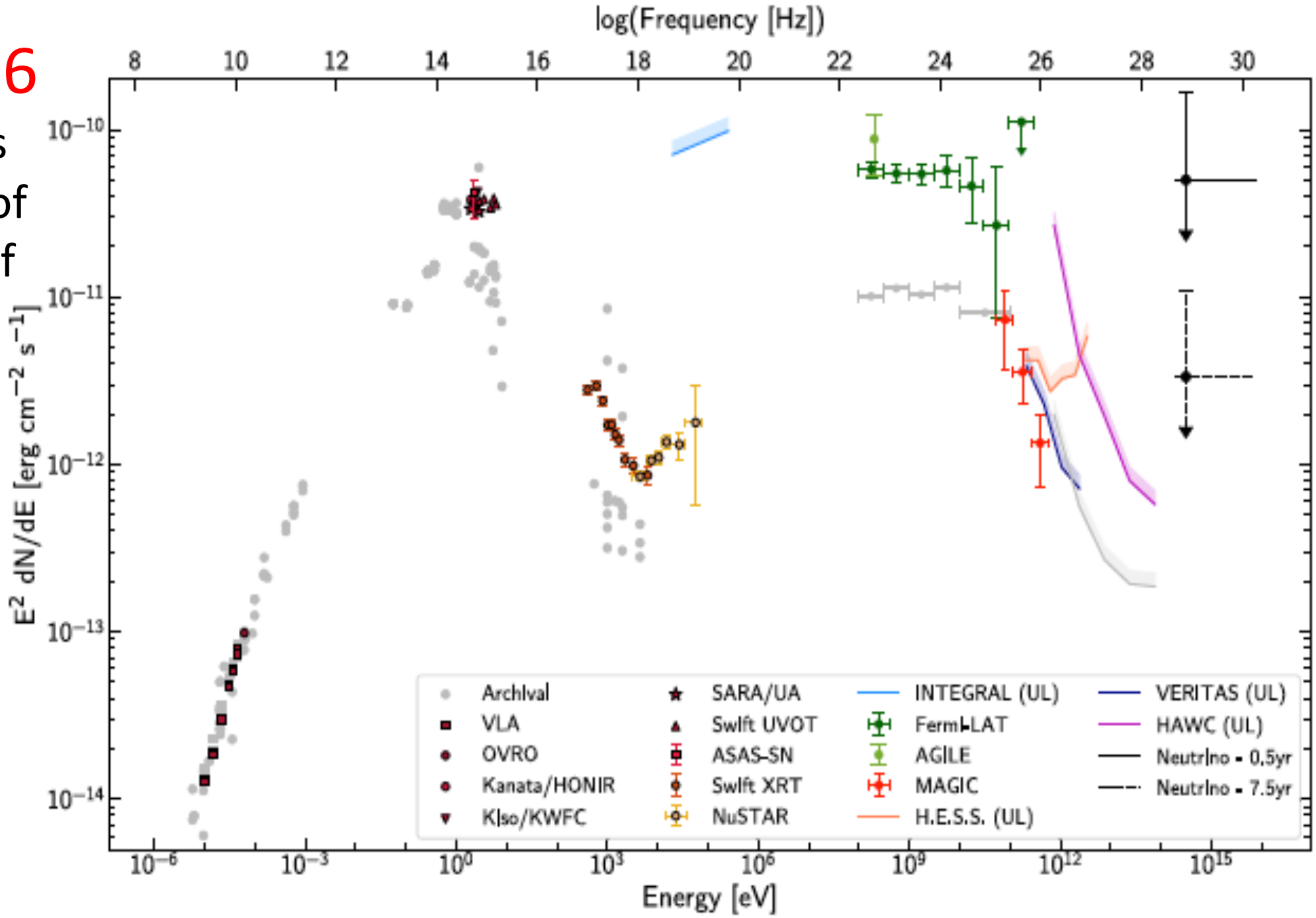
MAGIC Observation

- **On September 28, MAGIC observed VHE gamma-rays (> 100 GeV) from TXS 0506+056 for the first time**
- **This neutrino event is spatially and temporally associated with a Blazar TXS 056+056 (z=0.3365) which was in a flaring state in gamma-rays at that vary moment.**
- **Direct association between neutrino event IceCube-170922A and a point source TXS 0506+056**
- **Probably direct evidence → Blazars (AGN) can accelerate HECRs and produce neutrinos from $p\gamma$ and/or pp interactions !!!**

TXS056+056

Broad Band Obs within 14 days of The detection of IceCube -170922A

MAGIC
75 GeV < E_γ < 366 GeV



Previous Observations-I: Nature 12, 807 (2016)

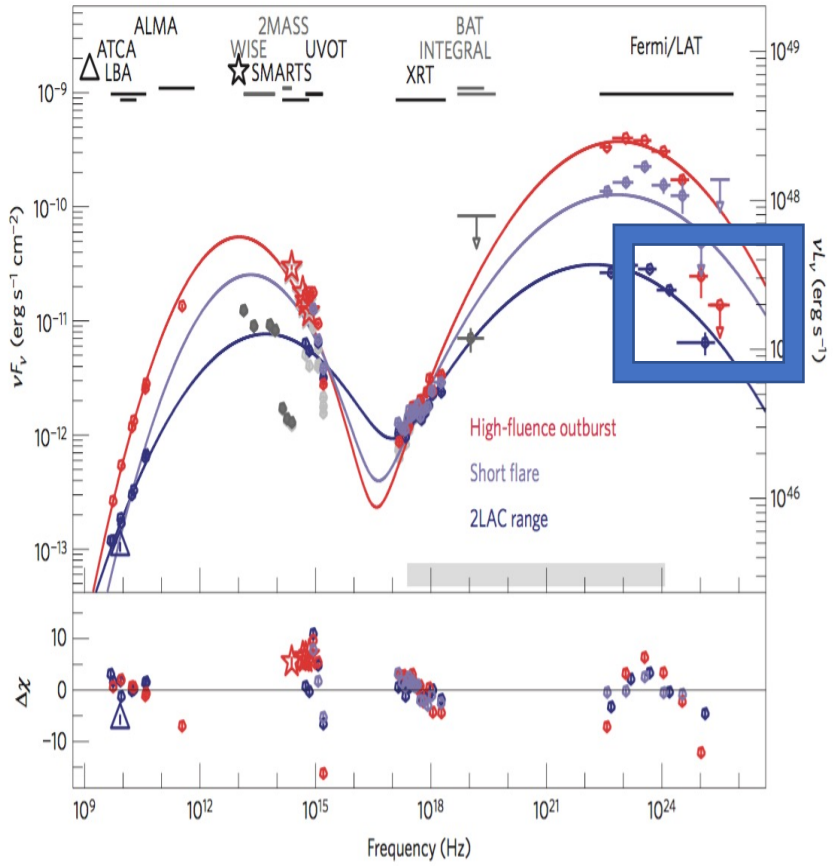
nature physics

ARTICLES

PUBLISHED ONLINE: 18 APRIL 2016 | DOI: 10.1038/NPHYS3715

Coincidence of a high-fluence blazar outburst with a PeV-energy neutrino event

M. Kadler[1]*, F. Krauß[1,2], K. Mannheim[1], R. Ojha[3,4,5], C. Müller[1,6], R. Schulz[1,2], G. Anton[7], W. Baumgartner[3], T. Beuchert[1,2], S. Buson[8,9], B. Carpenter[5], T. Eberl[7], P. G. Edwards[10], D. Eisenacher Glawion[1], D. Elsässer[1], N. Gehrels[3], C. Gräfe[1,2], S. Gulyaev[11], H. Hase[12], S. Horiuchi[13], C. W. James[7], A. Kappes[1], A. Kappes[7], U. Katz[7], A. Kreikenbohm[1,2], M. Kreter[1,7], I. Kreykenbohm[2], M. Langejahn[1,2], K. Leiter[1,2], E. Litzinger[1,2], F. Longo[14,15], J. E. J. Lovell[16], J. McEnery[3], T. Natusch[11], C. Phillips[10], C. Plötz[12], J. Quick[17], E. Ros[18,19,20], F. W. Stecker[3,21], T. Steinbring[1,2], J. Stevens[10], D. J. Thompson[3], J. Trüstedt[1,2], A. K. Tzioumis[10], S. Weston[11], J. Wilms[2] and J. A. Zensus[18]



e 2 | Dynamic SED of PKS B1424-418. The multi-epoch SEDs are fitted with two log parabolas for the 2LAC period (purple), the short 2010 flare

❑**In 2016 reported a PeV neutrino event from the Blazar PKS B1424-418 (!!), detected by IceCube. A shower event (angular error 16^0)**

Previous Observations-II:

- 2017 Lucareli et al. Reported a gamma-ray precursor flare with AGILE,
- coincidence with IceCube neutrino event but the significance was very marginal (**AGILE** (**A**stro-Rivelatore **G**amma a **I**mmagini **Le**ggero) is an X-ray and Gamma ray astronomical satellite of the Italian Space Agency (ASI) 30 MeV-50 GeV).

AGILE Detection of a Candidate Gamma-Ray Precursor to the ICECUBE-160731 Neutrino Event

F. Lucarelli[1,2], C. Pittori[1,2], F. Verrecchia[1,2], I. Donnarumma[3], M. Tavani[4,5,6], A. Bulgarelli[7], A. Giuliani[8], L. A. Antonelli[1,2], P. Caraveo[8], P. W. Cattaneo[9]Show full author list

Published 2017 September 8 •

The Astrophysical Journal, Volume 846, Number 2

Association of IceCube-170922A with blazar TXS 0506+056 provides direct evidence that AGN/Blazar can accelerate high energy CRs and produce neutrinos from pp and/or pγ interactions.

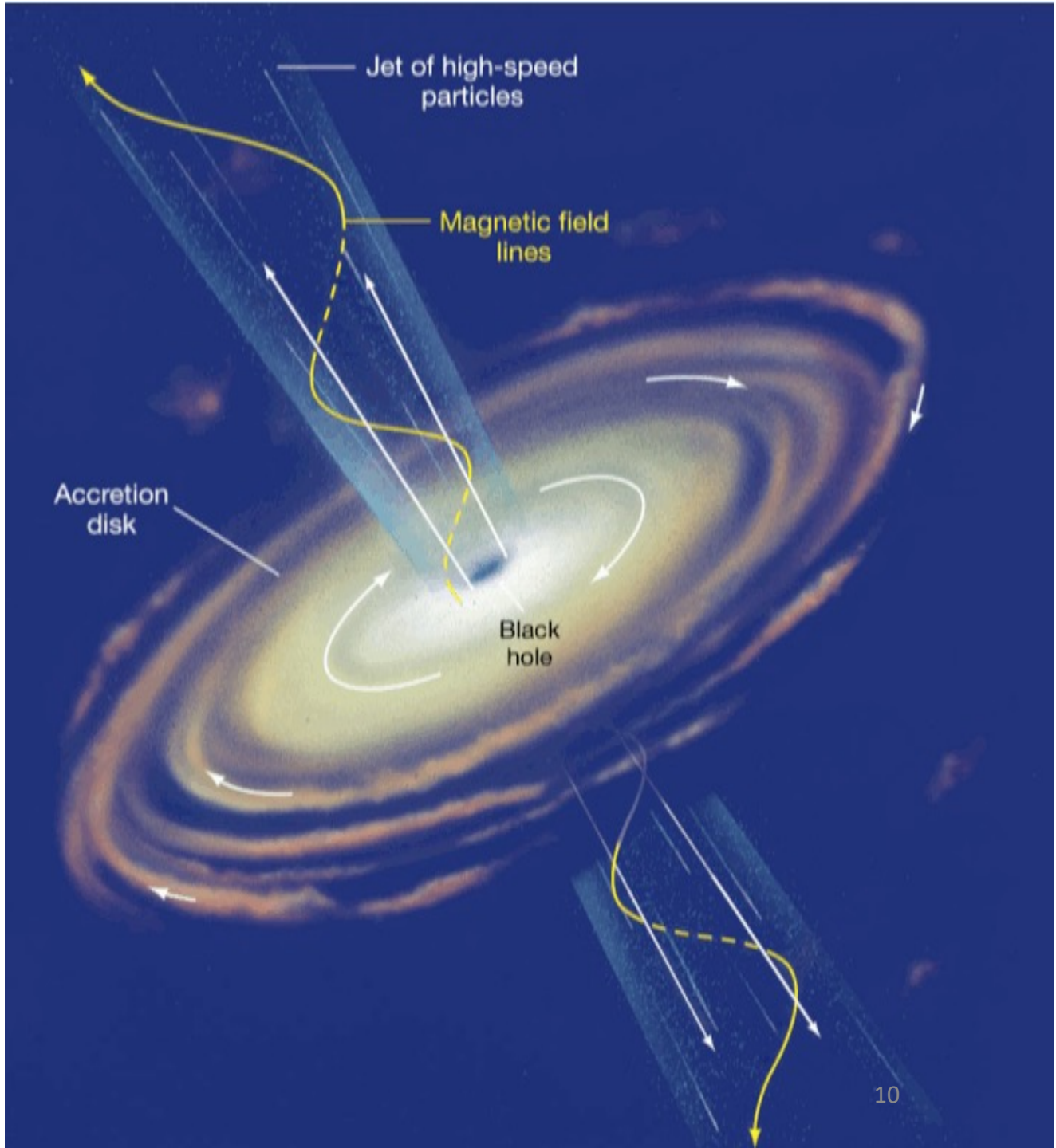
We have to understand What really Blazars are ?

What is a Blazar ?

What is a Blazar ?

Blazar is a subclass of Active Galactic Nuclei (AGNs)

- AGN emits EM radiation and its spectrum span from radio to gamma-rays
- A super massive BH is believed to sit at the center of the AGN surrounded by an accretion disk.
- Oppositely directed Jets $\perp$ to accretion disk .
- Unification scheme of AGN: Blazars and Radio galaxies are same objects viewed at different angles w.r.t. jet axis.

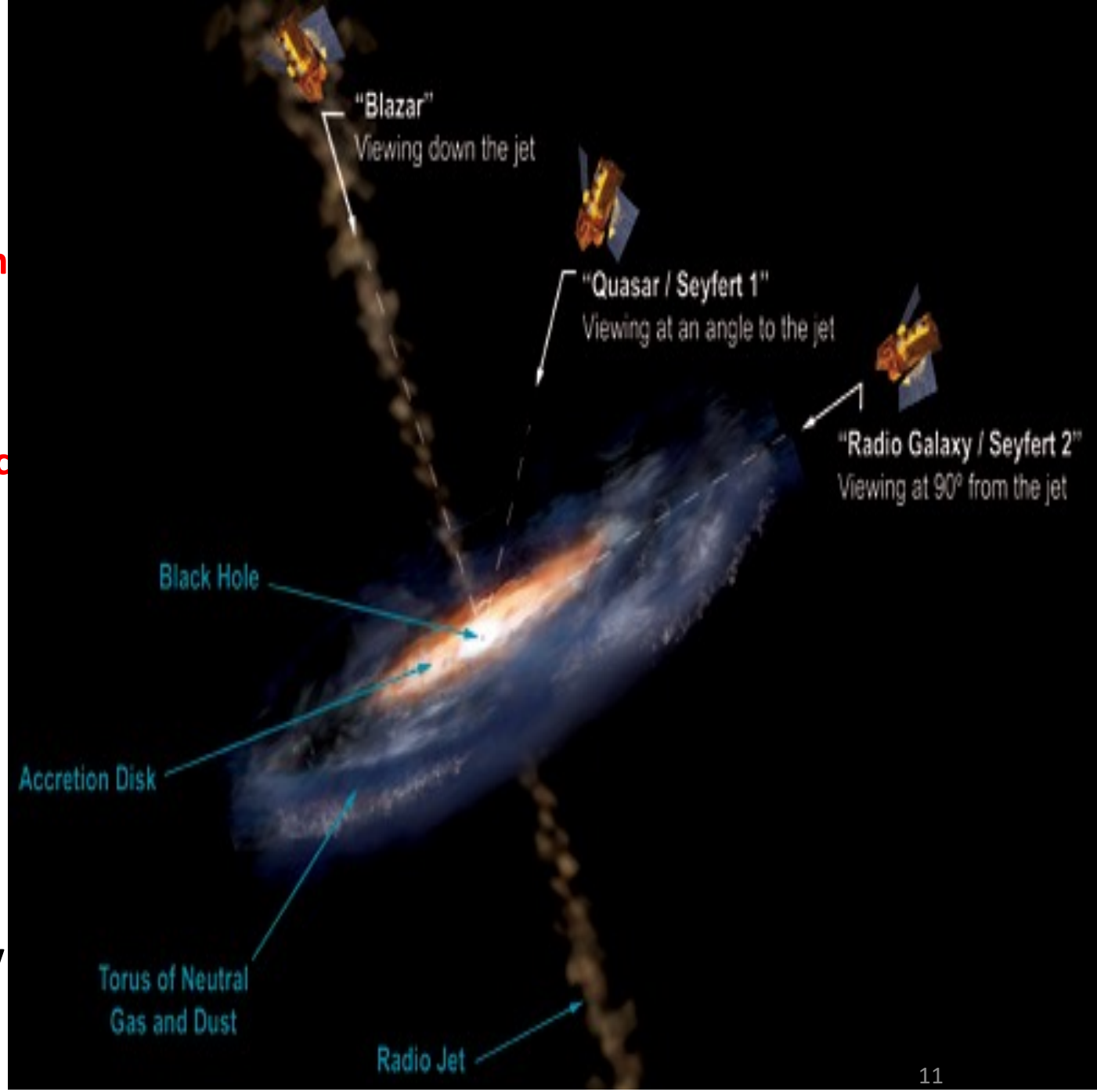


Blazars

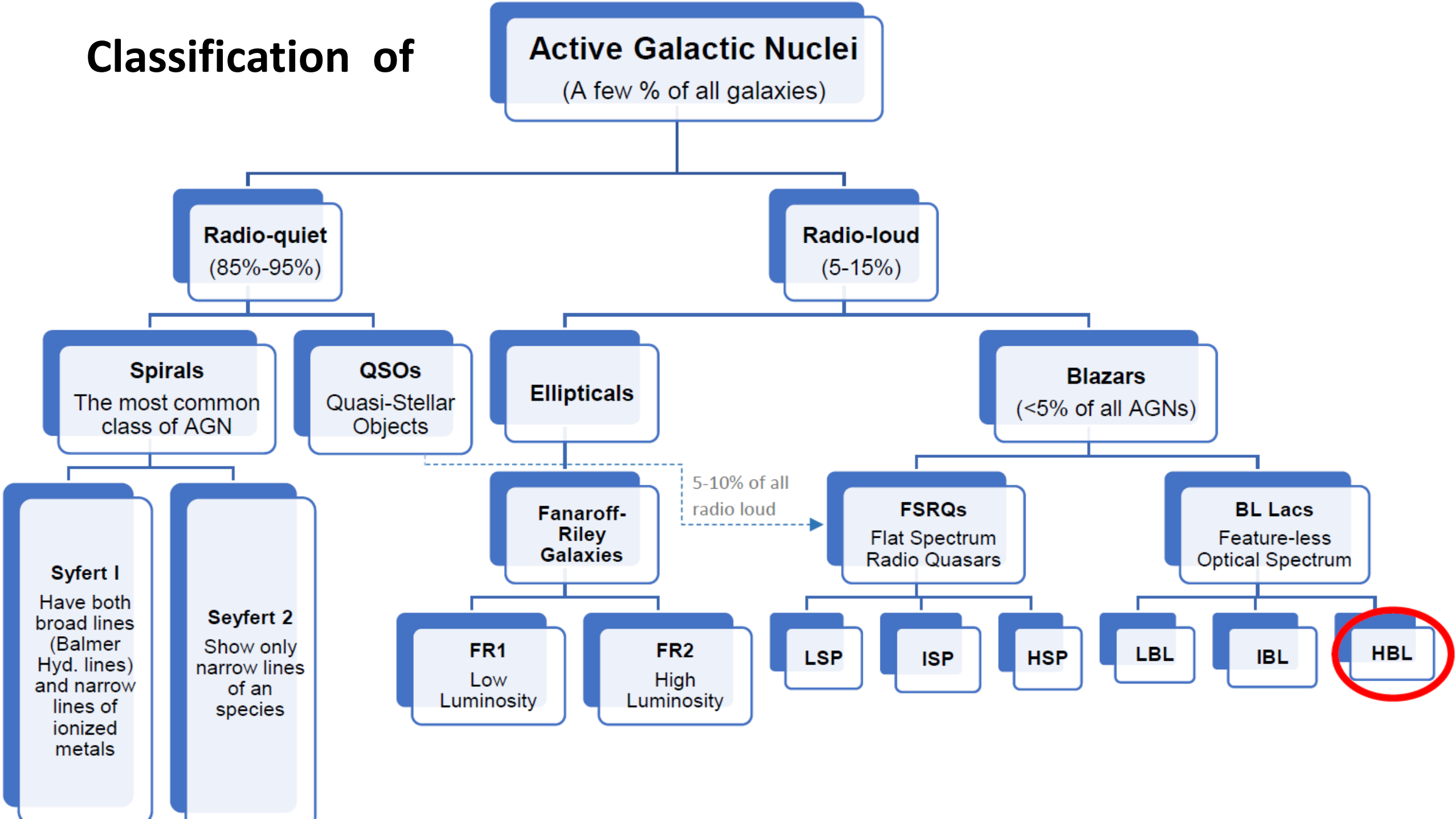
- Nonthermal spectra,
- Rapid variability across the entire em spectrum (Radio to ɣ-Ray)
- Highly relativistic plasma jet pointing along the
- line of sight to the observer.
- Small viewing angle of the jet, strong relativistic effects ➔
- Boosting of the emitted power
- Shortening of the time scale (minutes)

Reason to Study these Objects:

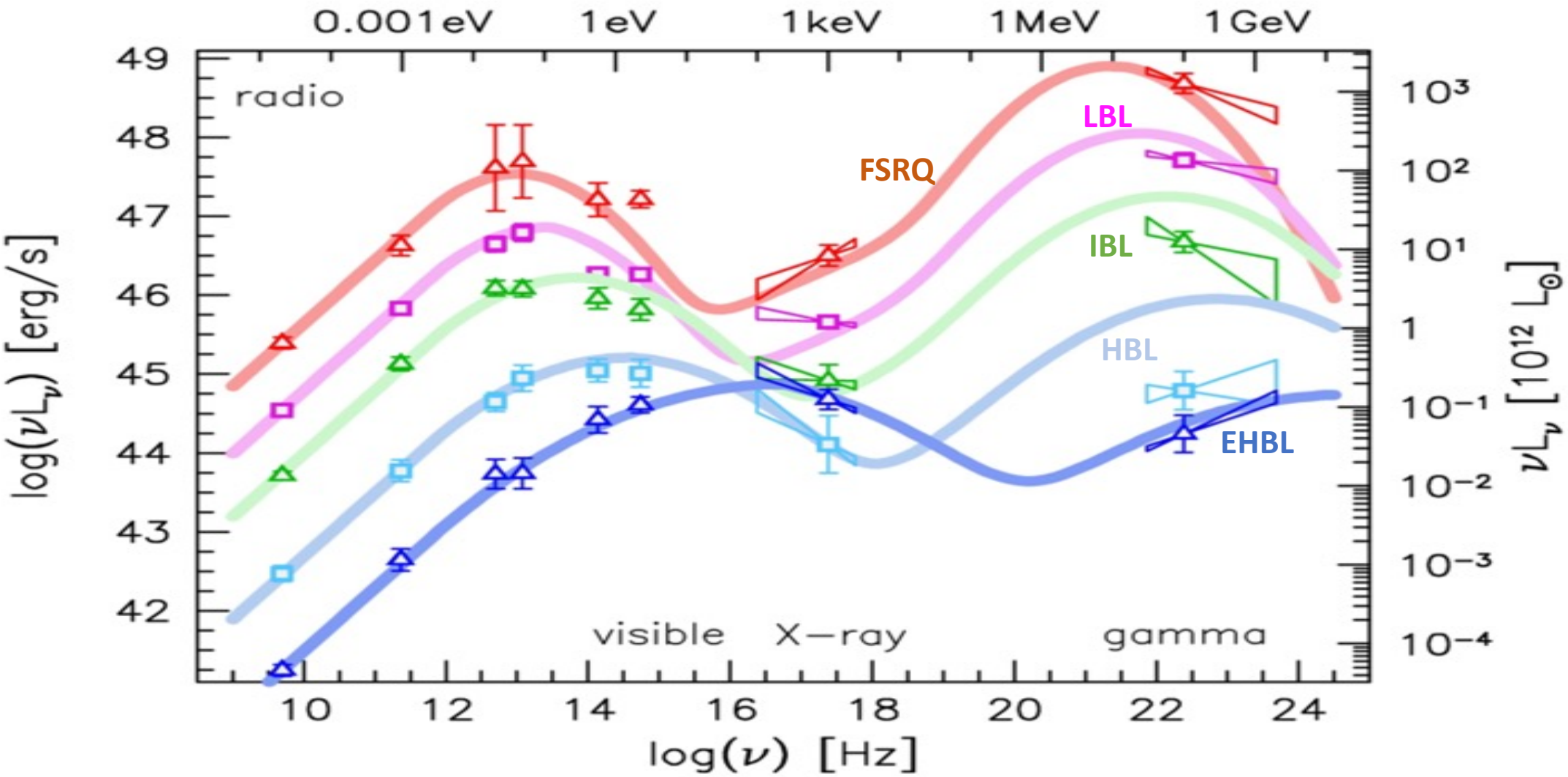
- ❑ Energy extraction mechanisms from the central supermassive Black Hole
- ❑ Physical properties of the Astrophysical Jets
- ❑ Accleration of the charged particles in the Jet
- ❑ Production of UHECRs, VHE Neutrinos, multi-TeV gamma-rays etc.
- ❑ Constraint the Extragalactic Background Light (EBL).



Classification of

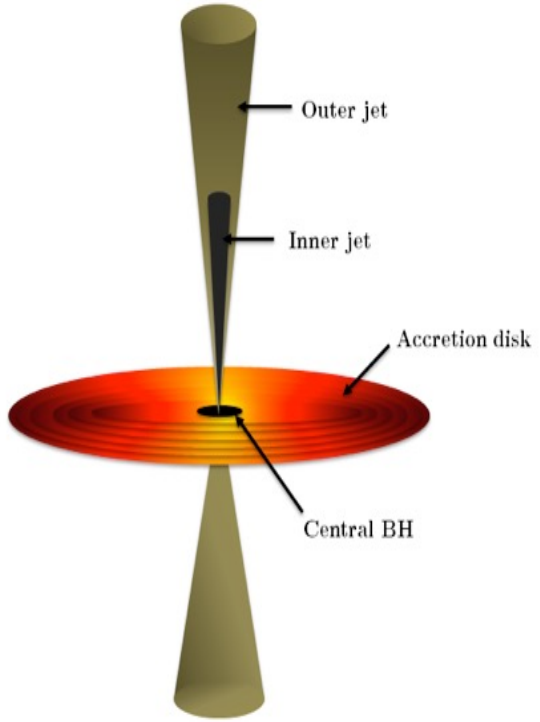


AGN spectrum ?



In the blazar jet environment to produce these very high energy neutrinos, we must satisfy the following time scales:

$$t'_{dyn} < t'_{acc} < t'_{p\gamma}$$



Photohadronic scenario

To produce pions through Δ-resonance

$$p + \gamma \rightarrow \Delta^{+} \rightarrow \begin{cases} p\pi^{0} \rightarrow p\gamma\gamma & \text{fraction 2/3} \\ n\pi^{+} \rightarrow ne^{+}\nu_{e}\nu_{\mu}\bar{\nu}_{\mu}\ , & \text{fraction 1/3.} \end{cases}$$

t'_{dyn}=$R'_f \approx 3.34\ 104\ R'_{f,15}$ sec

t'acc$\approx 3.9\ 104$ sec for E'_p = 352 TeV , B'=1 GeV

$T'_{p\gamma}$=6.65 10^6 sec

We assume that the VHE neutrinos are produced during the very high energy flaring state of TXS 0506+056 from the π+ decay and during this flaring epoch we have 2.5 ≤ δ ≤ 2.6. Solving for Aν gives

$$N_\nu = T \int_{E_1^*}^{E_2^*} \frac{dN}{dE_\nu} A_{eff}(E_\nu) dE_\nu,$$

38 TeV ≤ E_ν ≤ 7 PeV

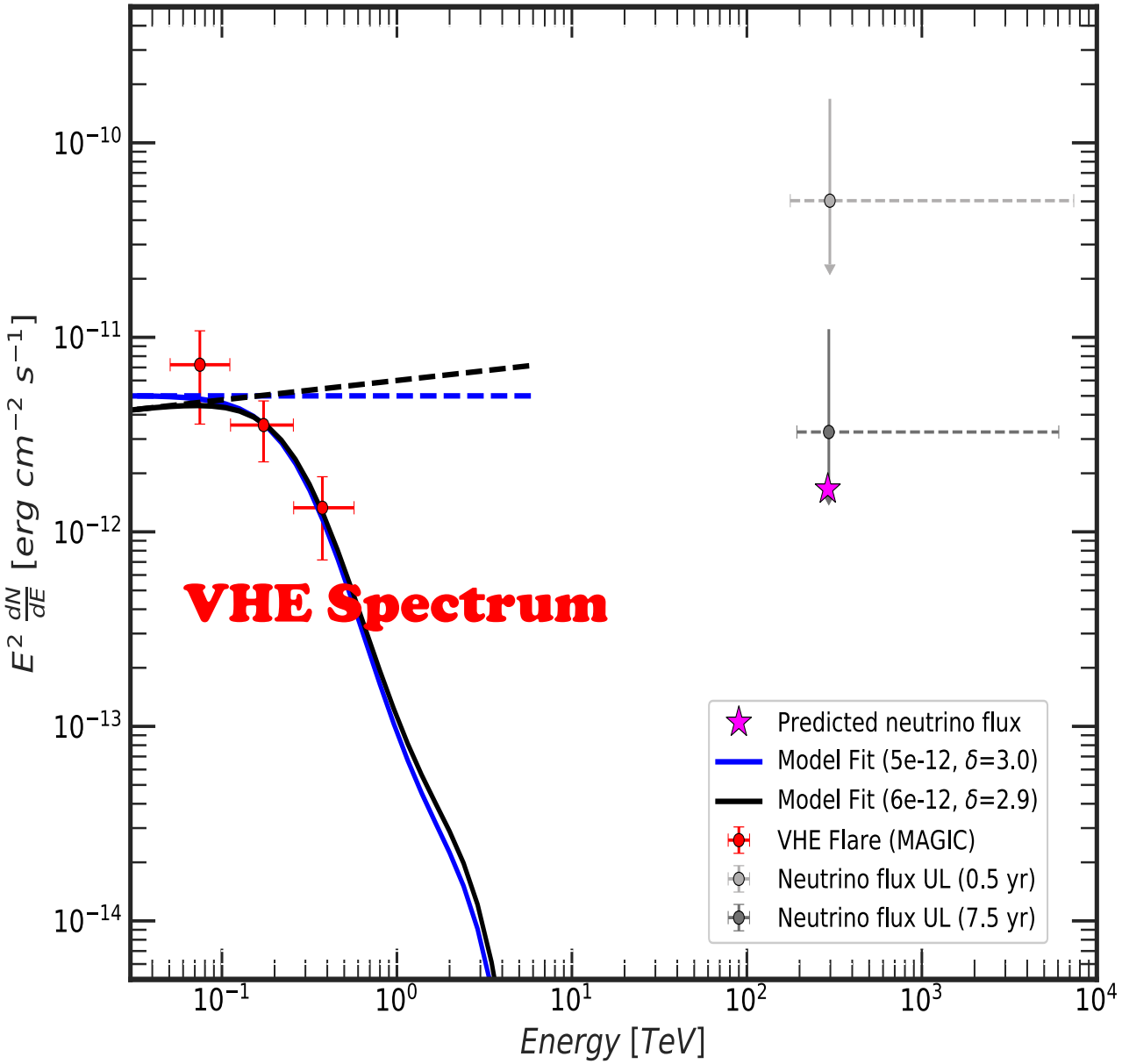
T is the observed time period, $E^*_{1,2} = E_{1,2}(1+z)$ and A_{eff} is the effective area of

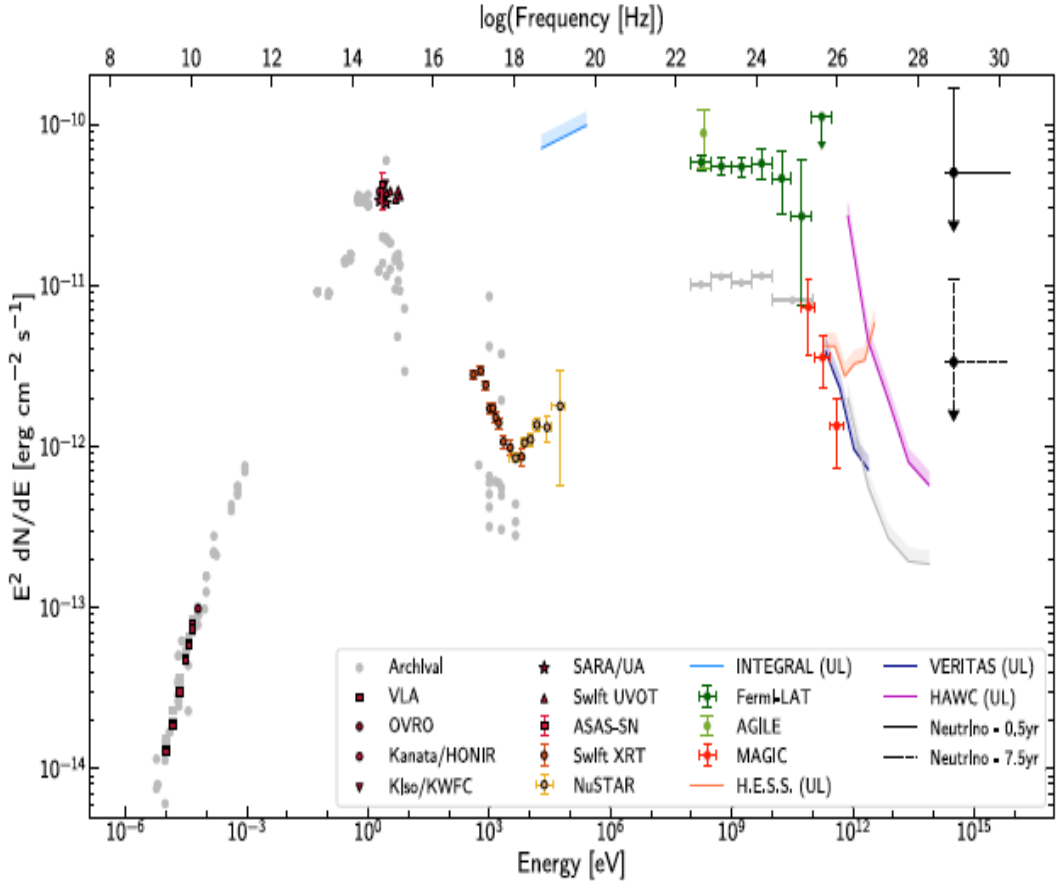
Neutrino interaction

$\delta = 2.5, 2.6$; $E_\nu = 290\ TeV$; $Aeff$ for muon neutrino

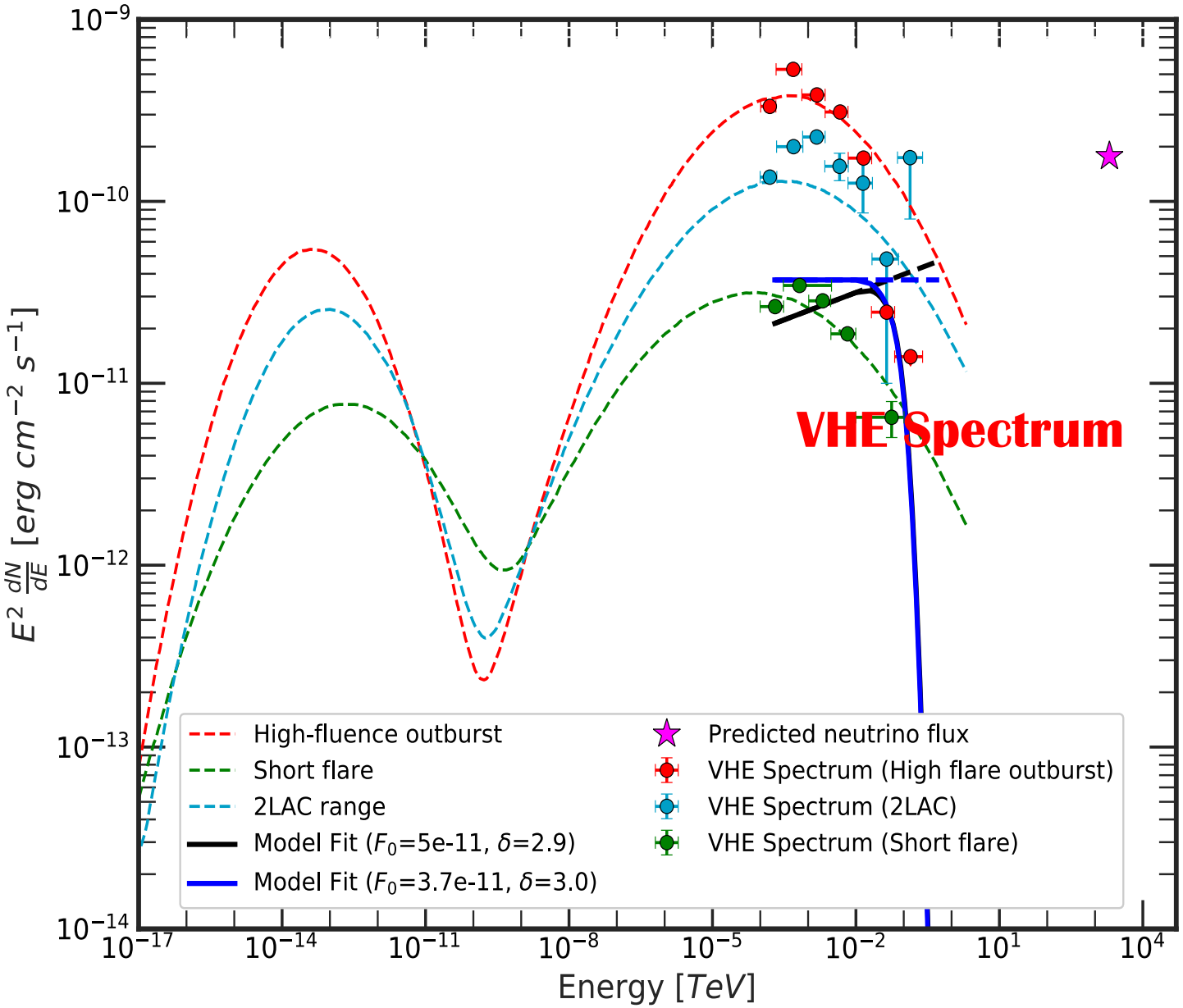
$$\frac{dN}{dE_\nu} = A_\nu \left(\frac{E_\nu}{E_0}\right)^{-\delta+1} \qquad A_\nu \simeq \frac{1}{T} \times \begin{cases} 5.0 \times 10^{-10}\,\mathrm{erg^{-1}cm^{-2}}, & \delta = 2.5 \\ 5.9 \times 10^{-10}\,\mathrm{erg^{-1}cm^{-2}}, & \delta = 2.6 \end{cases}.$$

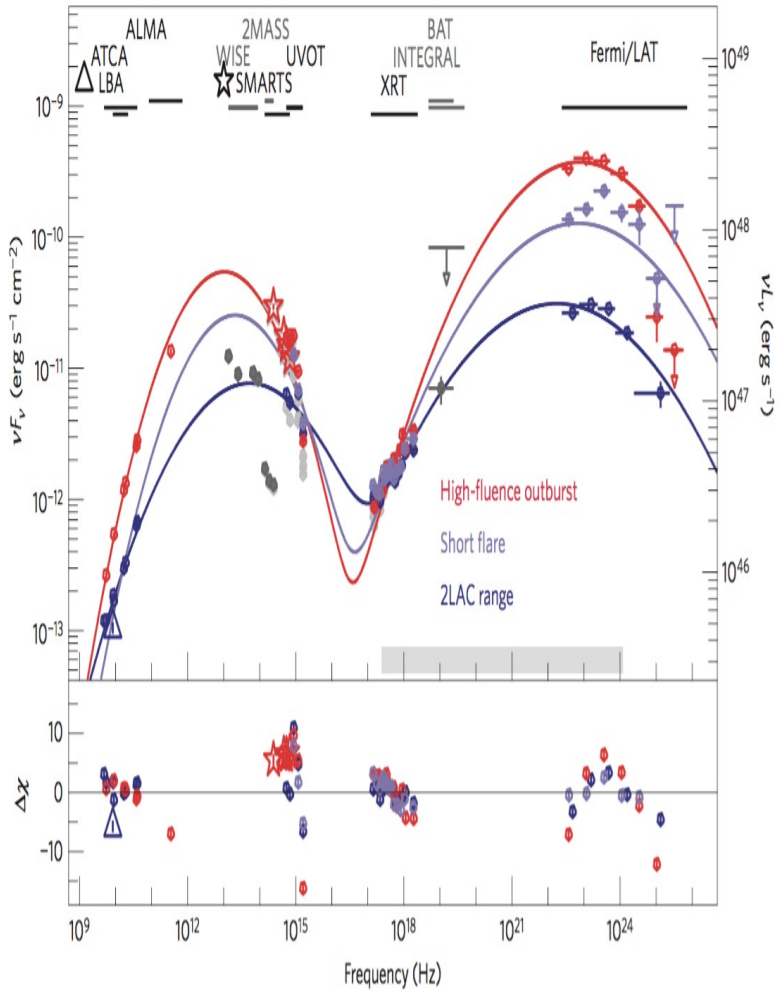
MAGIC OBSERVATION OF TXS 0506+056





Blazar PKS B1424-418





e 2 | Dynamic SED of PKS B1424-418. The multi-epoch SEDs are fitted with two log parabolas for the 2LAC period (purple), the short 2010 flare

TXS 0506+056

T (days)	δ	A_ν	$F_\nu(290\,TeV)$	F_ν^{int}
19	2.5	3.06×10^{-16}	1.34×10^{-11}	1.23×10^{-10}
	2.6	3.60×10^{-16}	1.41×10^{-11}	1.12×10^{-10}
60	2.5	1.14×10^{-16}	4.23×10^{-12}	3.90×10^{-11}
	2.6	1.32×10^{-16}	4.48×10^{-12}	3.55×10^{-11}
158	2.5	3.67×10^{-17}	1.61×10^{-12}	1.48×10^{-11}
	2.6	4.33×10^{-17}	1.70×10^{-12}	1.35×10^{-11}
360	2.5	1.61×10^{-18}	7.05×10^{-13}	6.49×10^{-12}
	2.6	1.90×10^{-17}	7.47×10^{-12}	5.91×10^{-12}

TABLE I. The neutrino normalization constant A_ν, neutrino flux at $E_\nu = 290$ TeV $F_\nu(290\,TeV)$ and the integrated neutrino flux F_ν^{int} are shown for $\delta = 2.5$ and 2.6 at different time windows. The A_ν is expressed in units of $\mathrm{erg}^{-1}\mathrm{cm}^{-2}$ and the fluxes are given in units of $\mathrm{erg}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Blazar PKS B1424-418

T (days)	δ	A_ν	$F_\nu(2\,PeV)$
288	2.5	1.68×10^{-15}	1.93×10^{-10}
	2.6	1.87×10^{-15}	1.60×10^{-10}
988	2.5	4.90×10^{-16}	5.62×10^{-11}
	2.6	5.47×10^{-16}	4.65×10^{-11}

TABLE II. The neutrino normalization constant A_ν, neutrino flux at $E_\nu = 2$ PeV the integrated neutrino flux F_ν^{int} are shown for $\delta = 2.5$ and 2.6 at different time units of A_ν and the fluxes are the same as given in Table 1.

Conclusions

- **VHE gamma-ray observed by MAGIC can be explained very well by Photohadronic model explains.**
- **As the 290 TeV neutrino event was observed 6 days prior to the neutrino event, we argue that the flaring must be in a very high state during the neutrino emission period $2.5 \leq \delta \leq 2.6$.**
- **Although, the IceCube-170922A neutrino event and the flaring of the blazar TXS 0506+056 are found to be correlated, further observation of neutrinos from blazars and the follow-up observations in VHE gamma-rays as well as in lower wavelenghts are necessary to establish a definite connection between them. This will also establish AGN as sources of high energy cosmic rays.**

Same conclusions for PKS B1424-418

Thank You