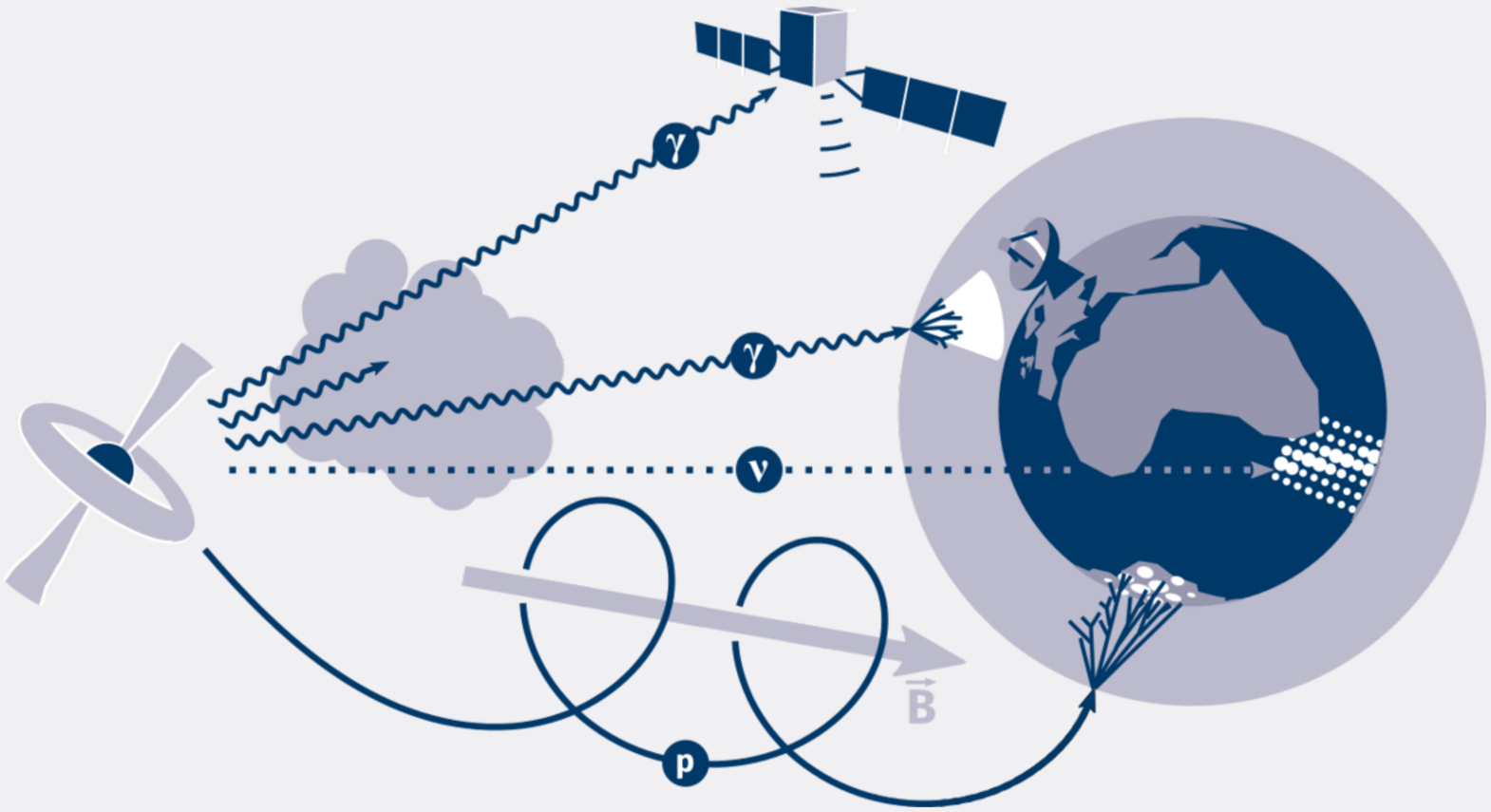
SEARCH FOR CANDIDATE NEUTRINO EMITTERS WITH SIMILAR FEATURES AS TXS 0506+056

I. Viale[1,2], E. Bernardini[1,2], G. Principe[3], C. Righi[4], F. Tavecchio[4]

[1] University of Padova,
[2] INFN Padova
[3] University of Trieste
[4] INAF O.A. Brera

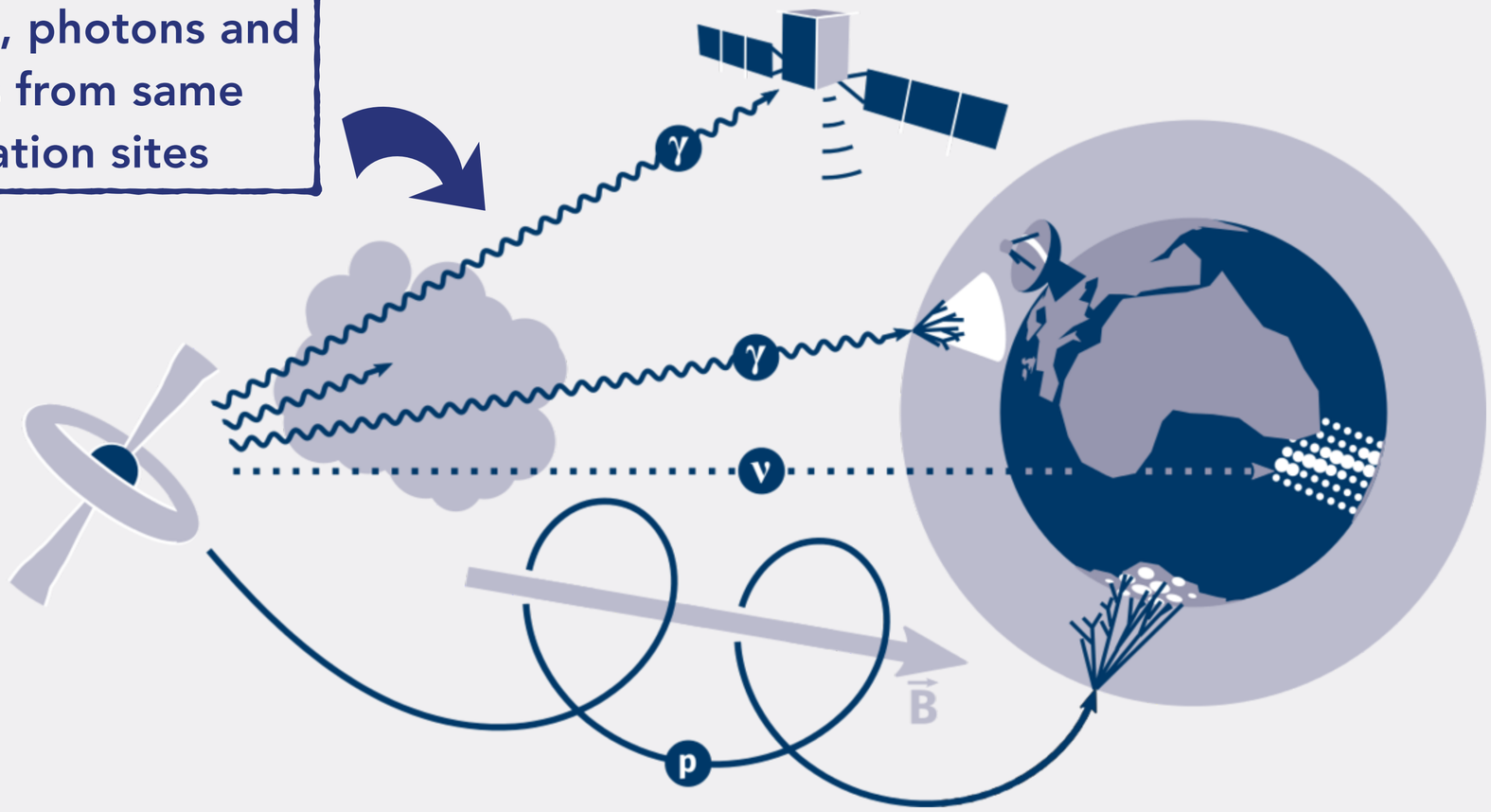
MULTIMESSENGER ASTROPHYSICS



Credits: iihe/IceCube

MULTIMESSENGER ASTROPHYSICS

Cosmic-rays, photons and neutrinos from same acceleration sites



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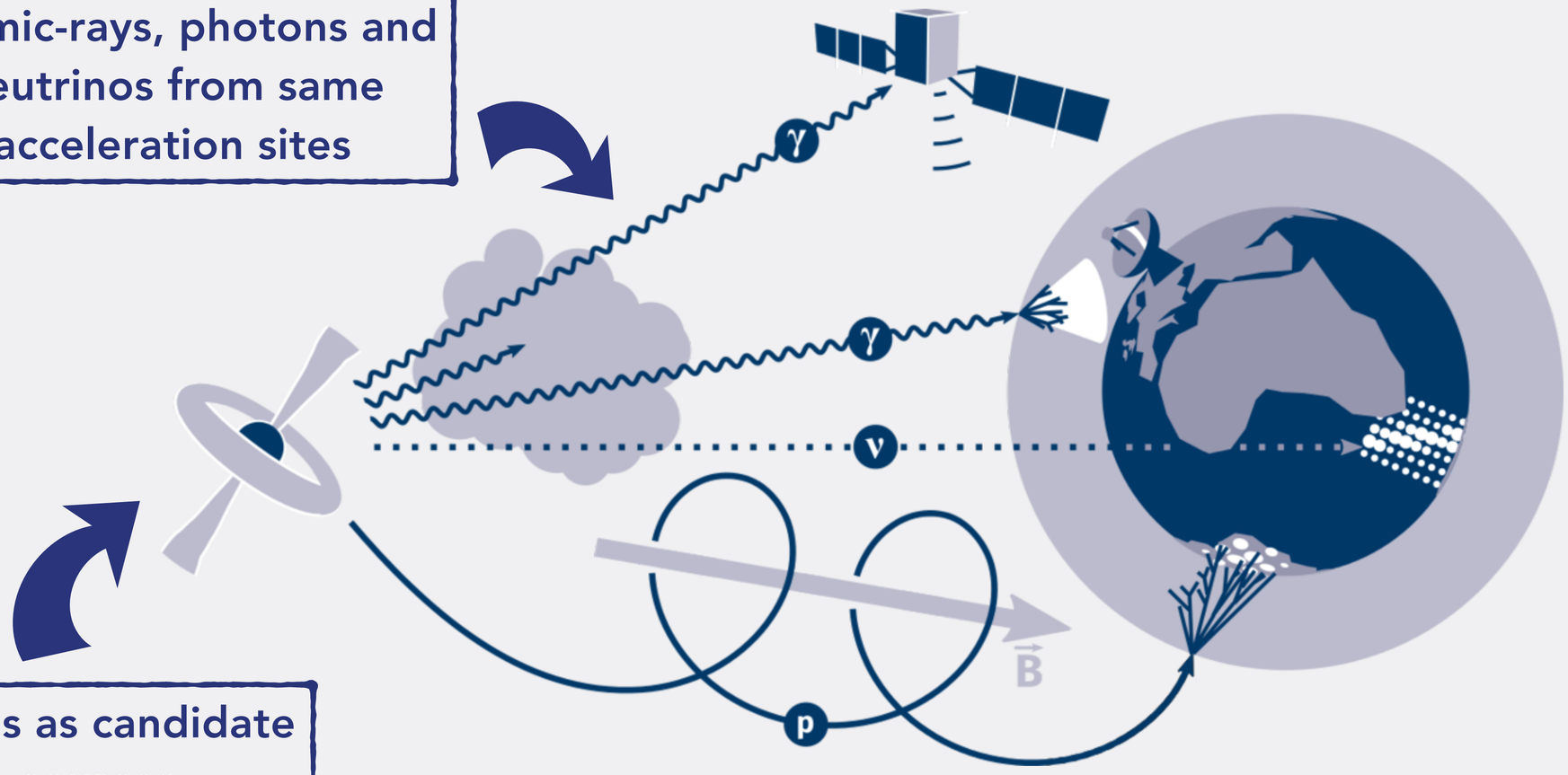

AGNs as candidate sources

Credits: iihe/IceCube

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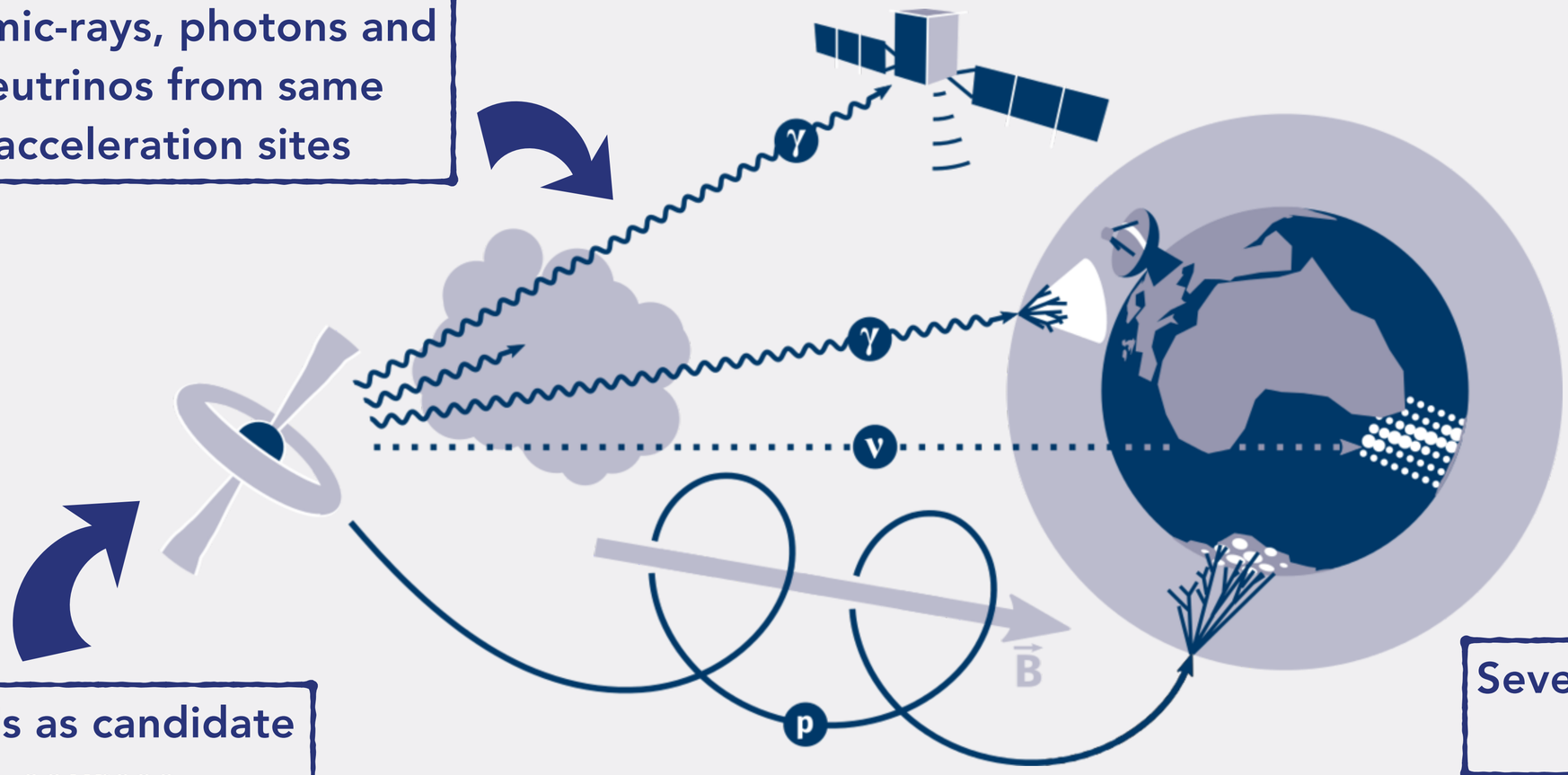


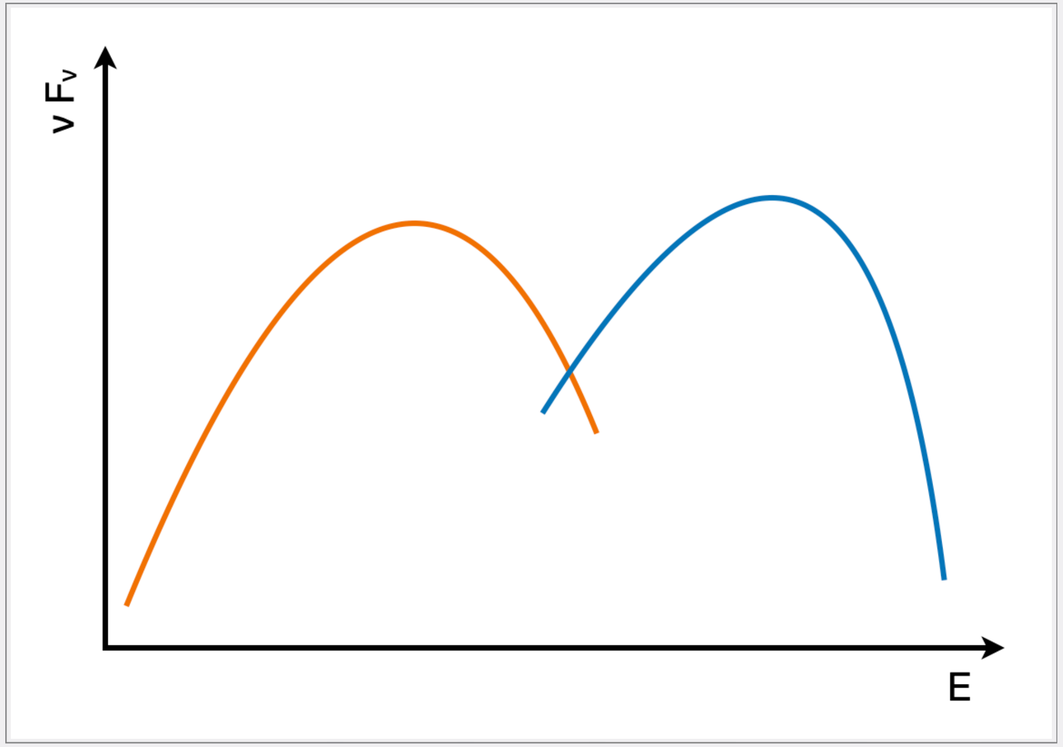
AGNs as candidate sources

Several instruments involved

Credits: iihe/IceCube

BLAZARS

- Subclass of AGNs with jet pointing to Earth



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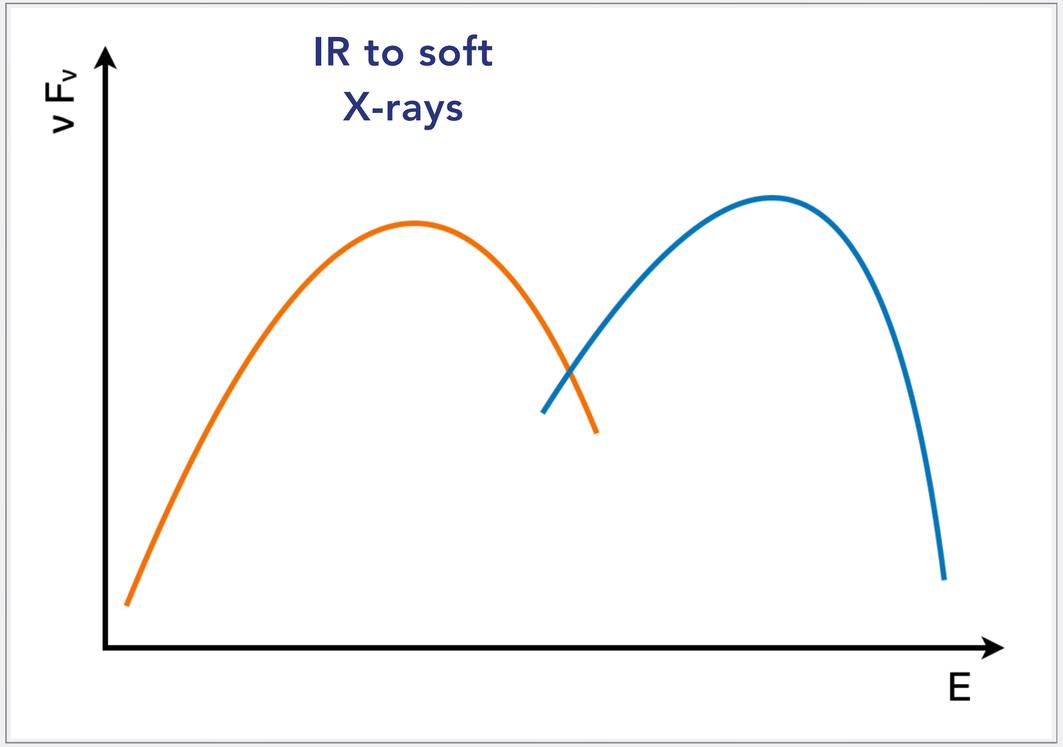

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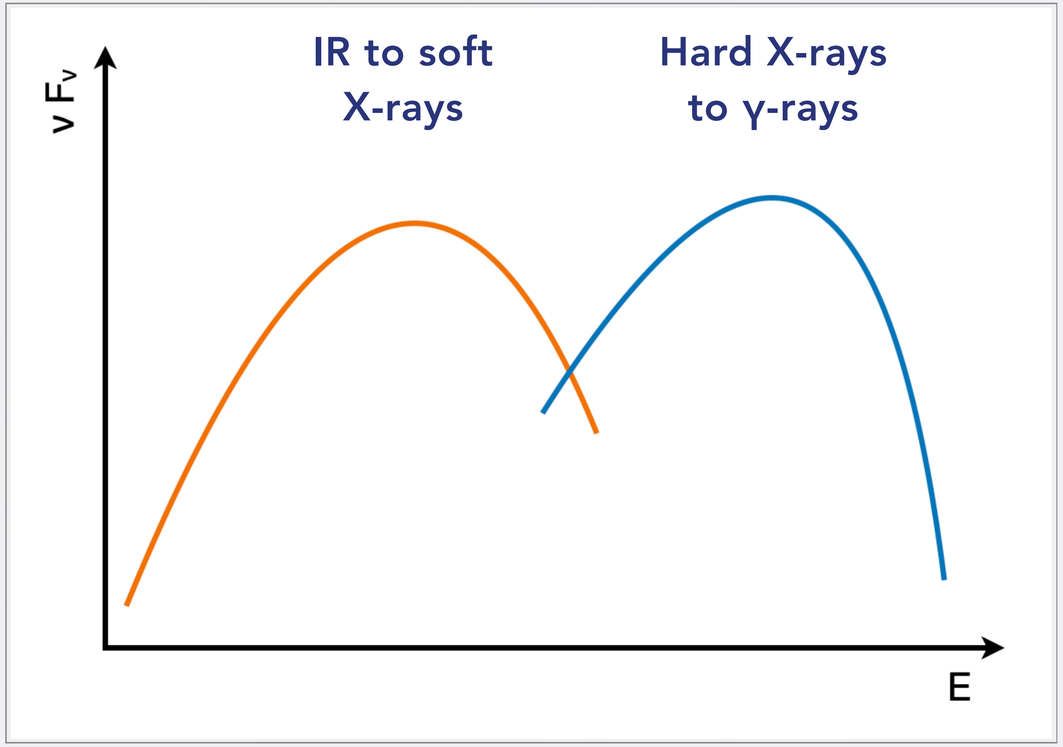

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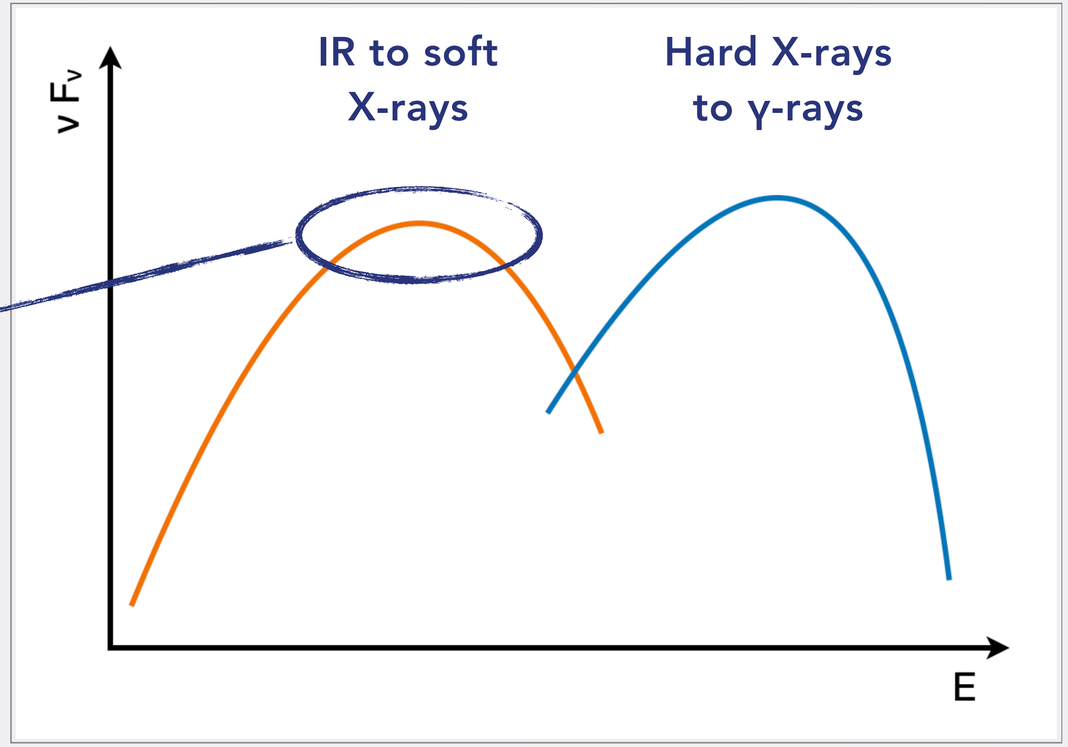
Synchrotron emission from relativistic electrons



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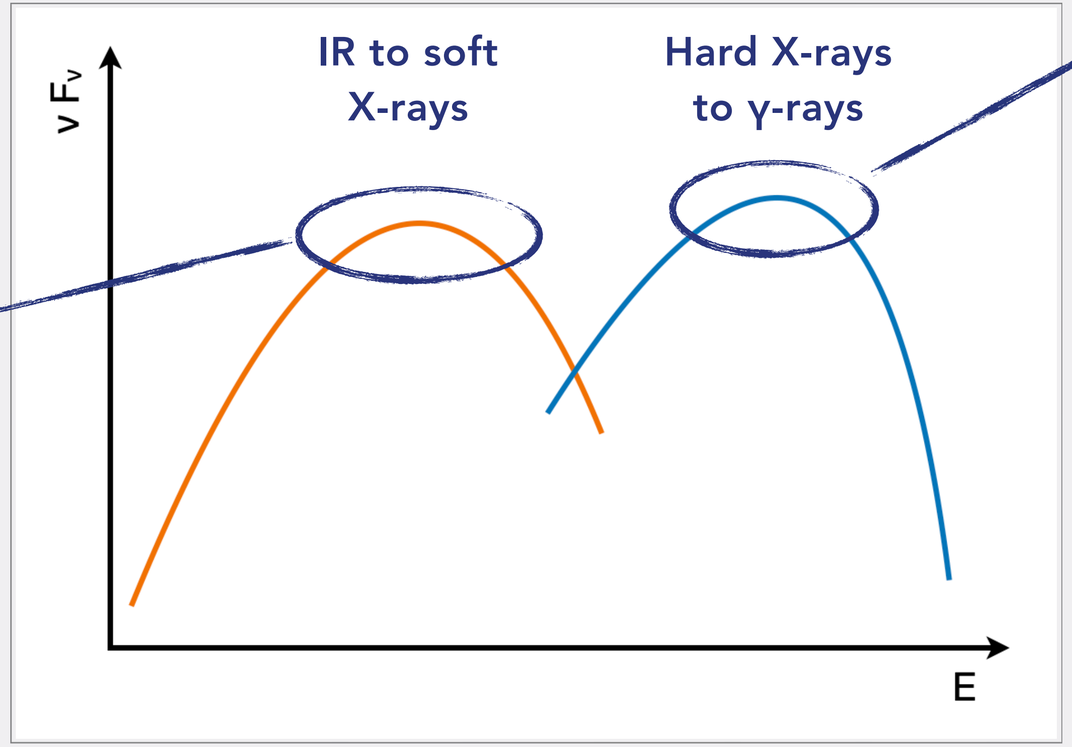

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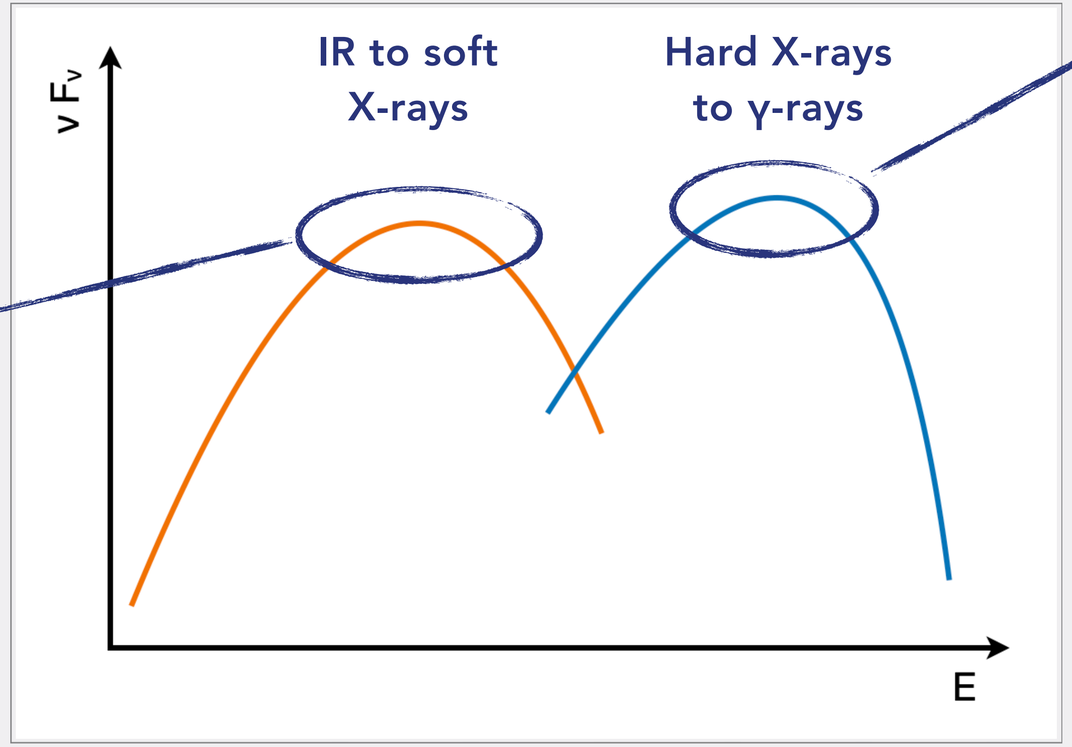

Inverse compton (SSC, EC)

Synchrotron emission from relativistic electrons

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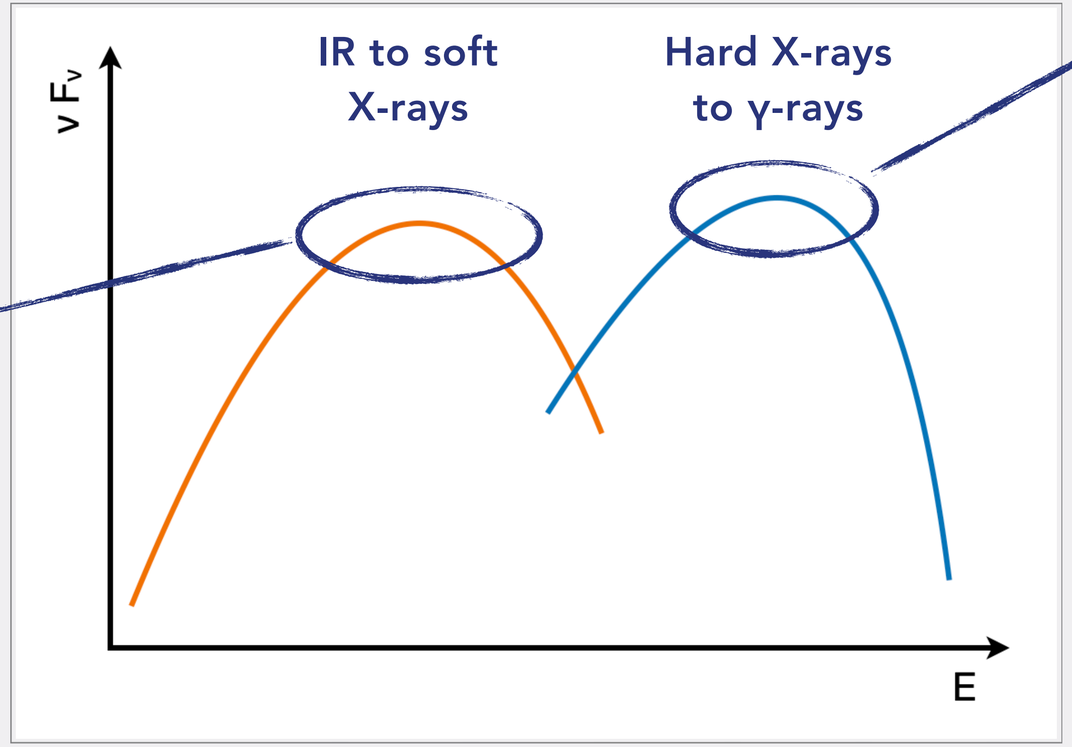

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Neutrino production!

BLAZAR SUBCLASSES AND BLAZAR SEQUENCE

FSRQs & BL Lacs

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Prominent
emission lines

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Weak or absent emission lines

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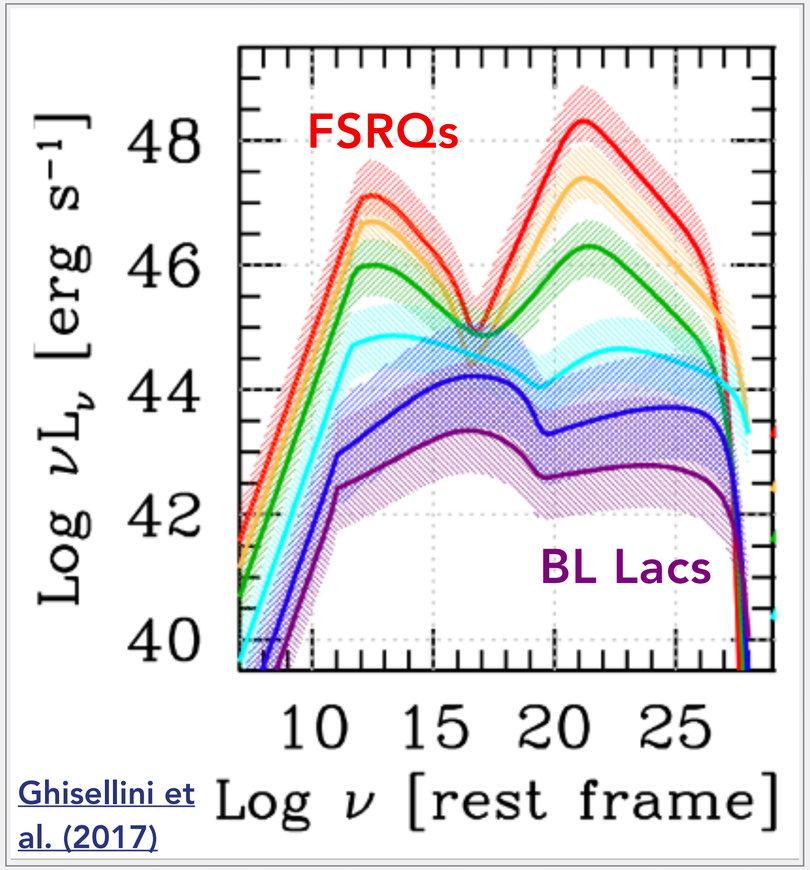
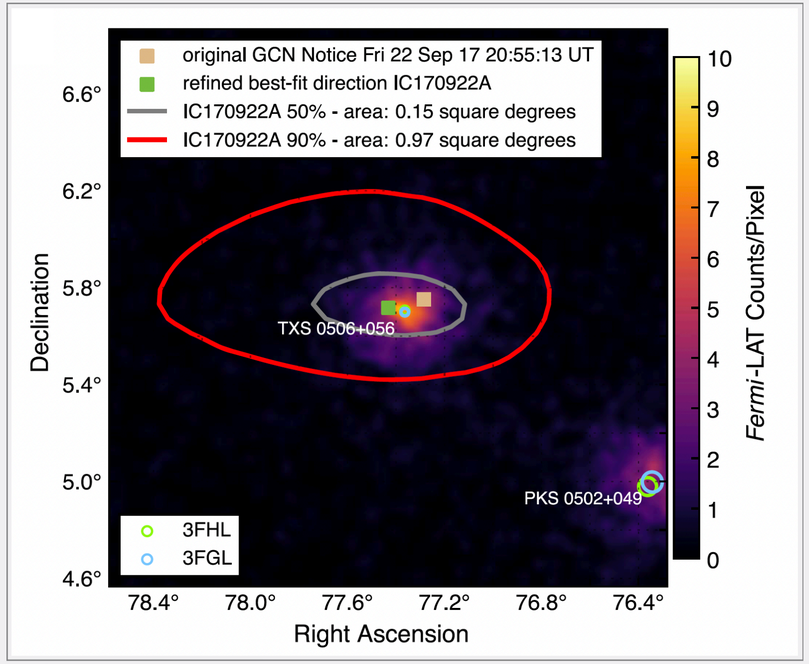
❖ Blazar sequence

- Correlation between peak frequencies of two bumps
- Correlation between total power and peak frequencies
- Increase of Compton dominance with total power

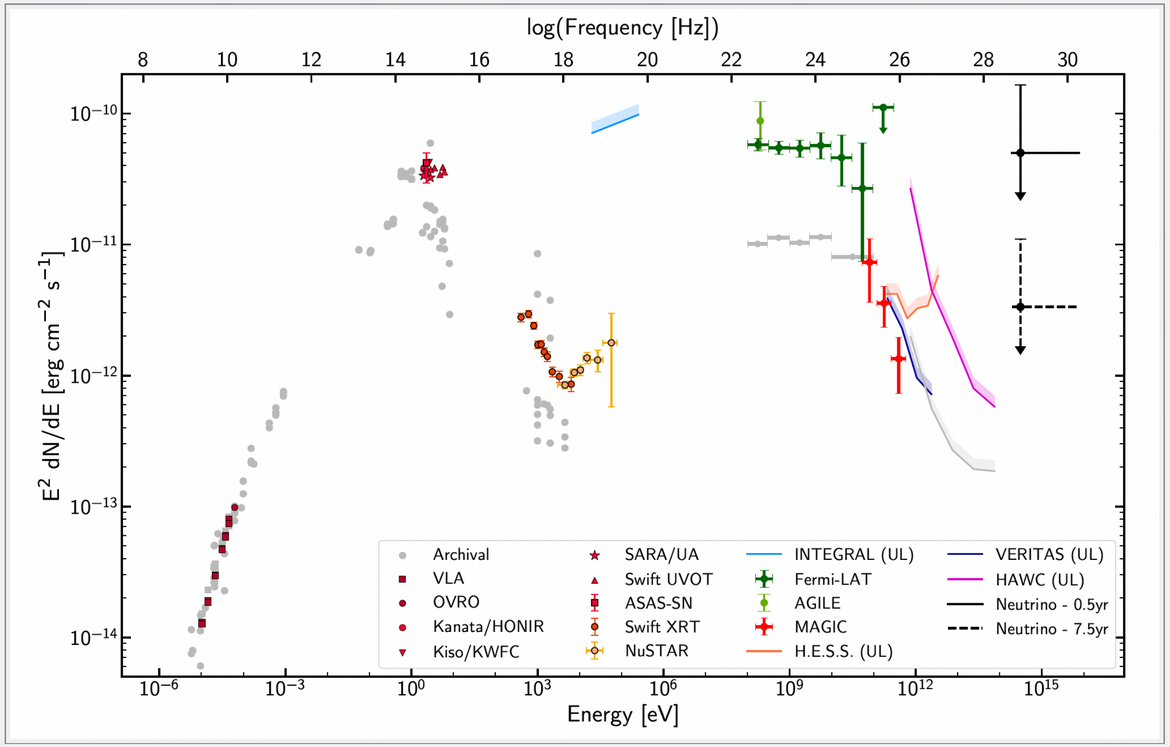


Ghisellini et al. (2017)

TXS 0506+056 & IC170922A



IceCube, Fermi, MAGIC et al. 2018, Science, 361, aat 1378



~3σ correlation of HE neutrino (~290 TeV) with blazar flare

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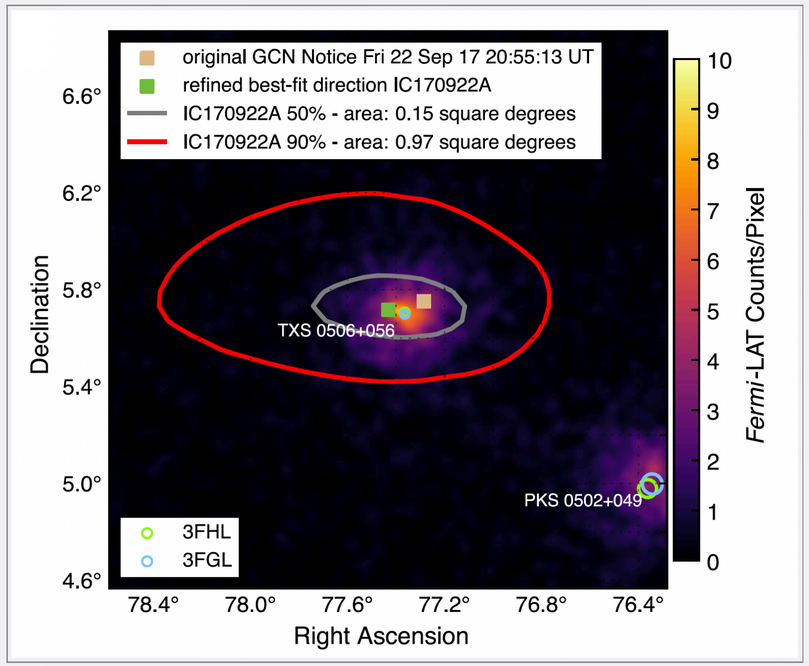

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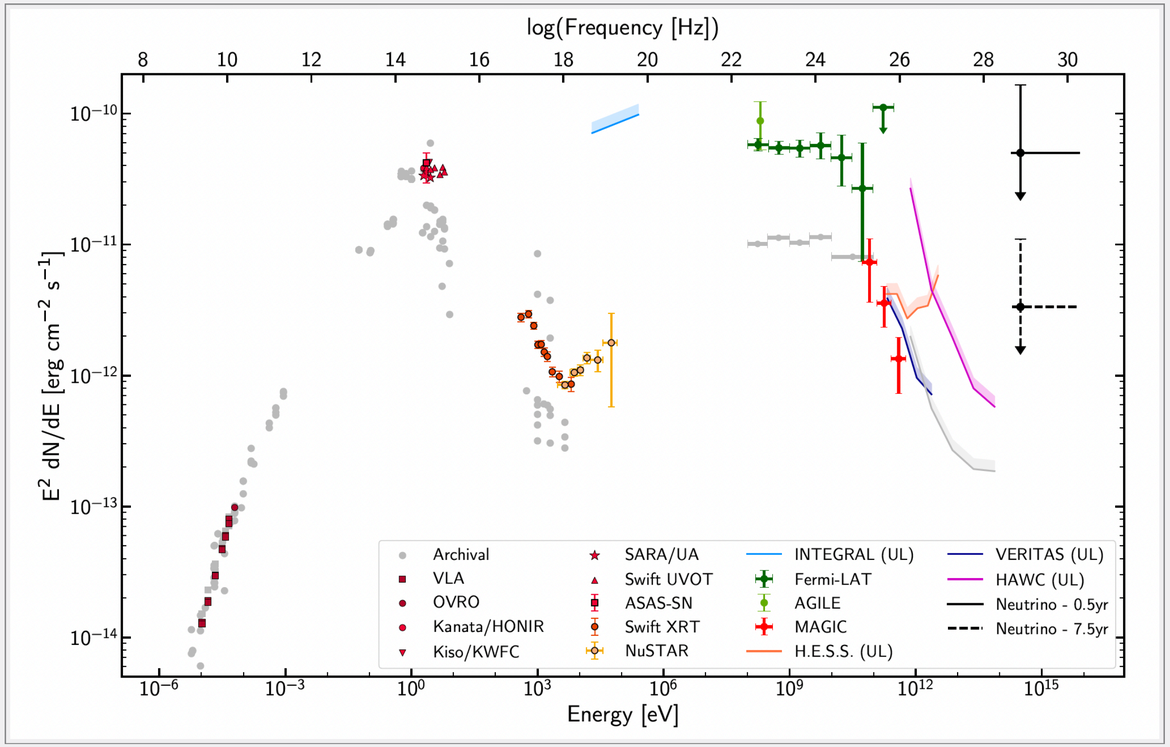

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First photon-neutrino multimessenger observation!

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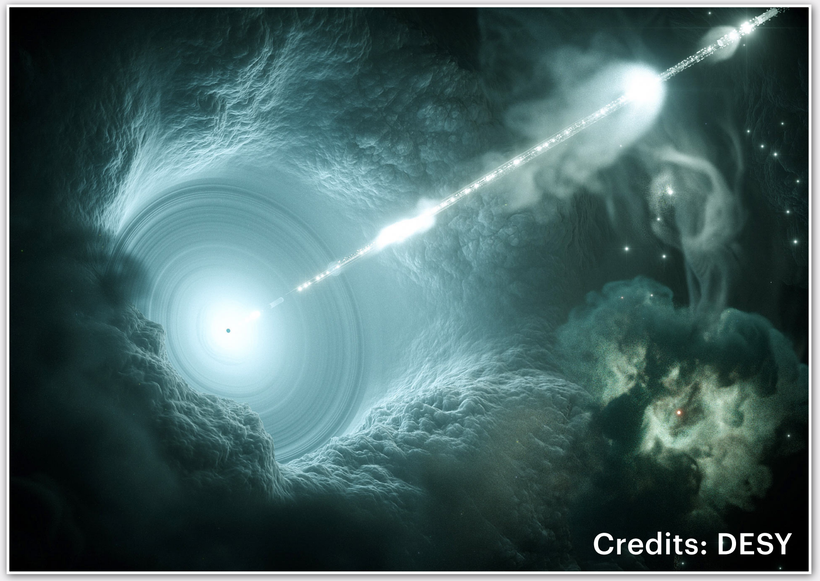

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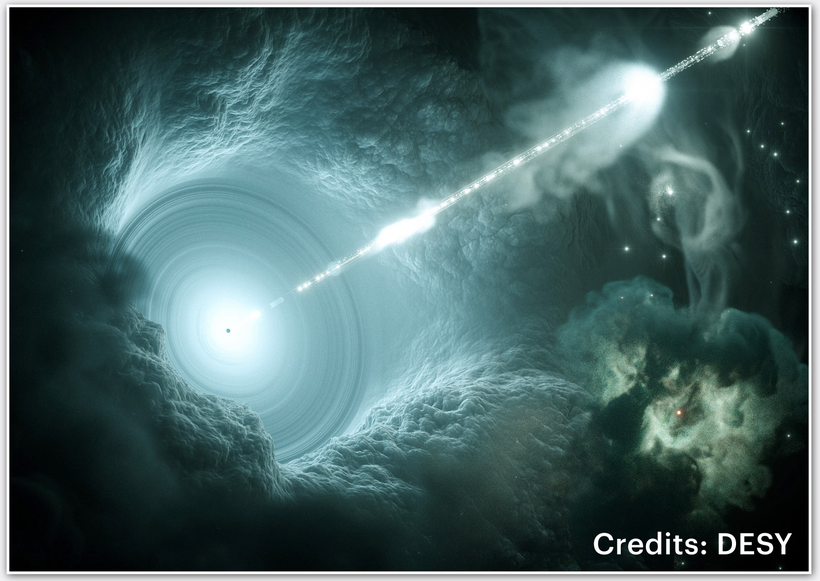
Blazar source discovered in 1987 but poorly studied until 2017



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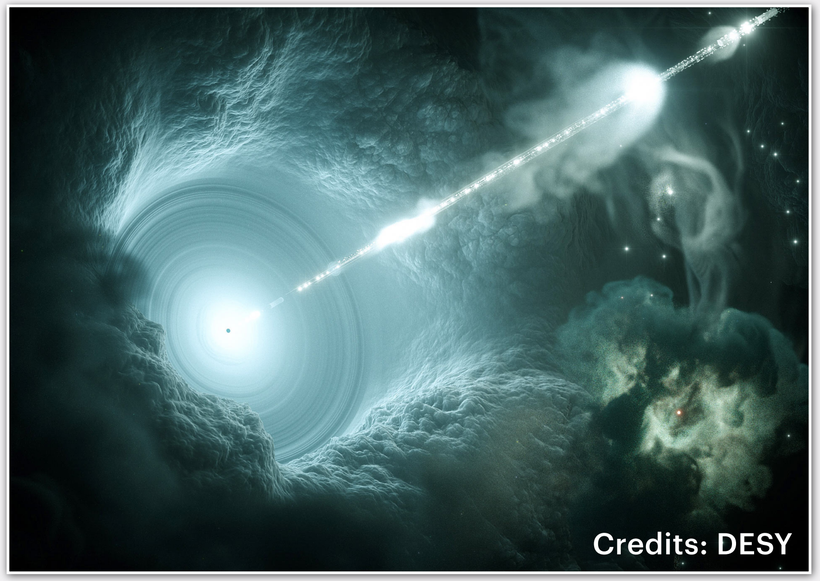

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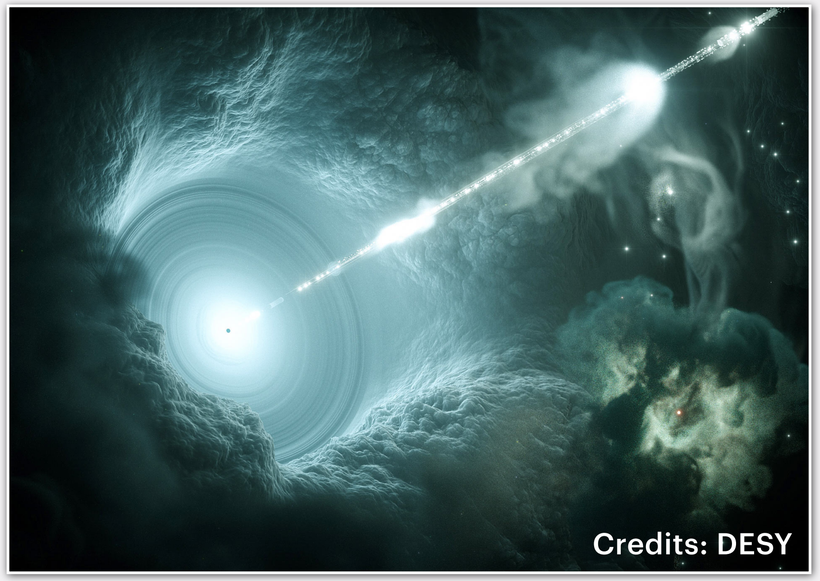

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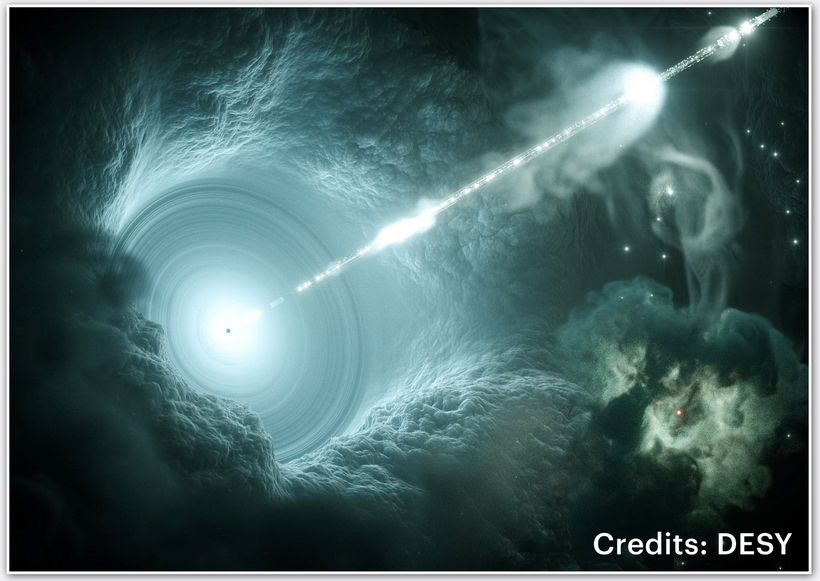

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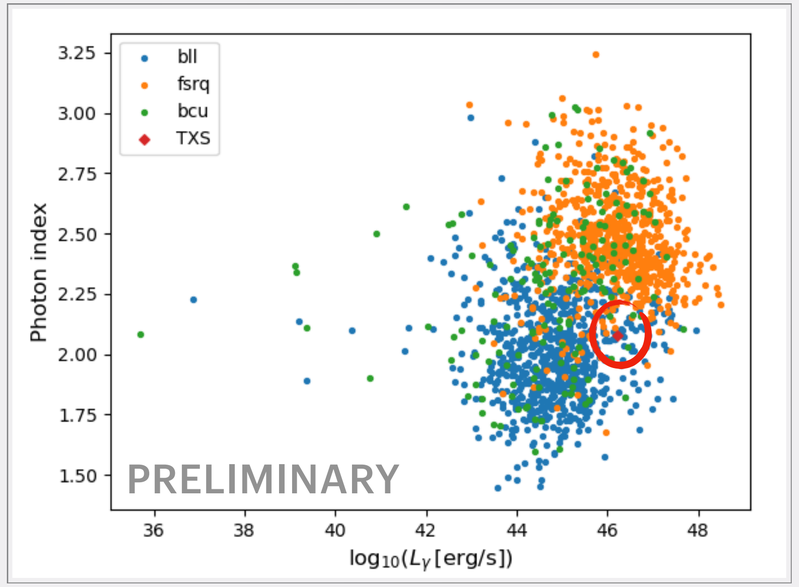
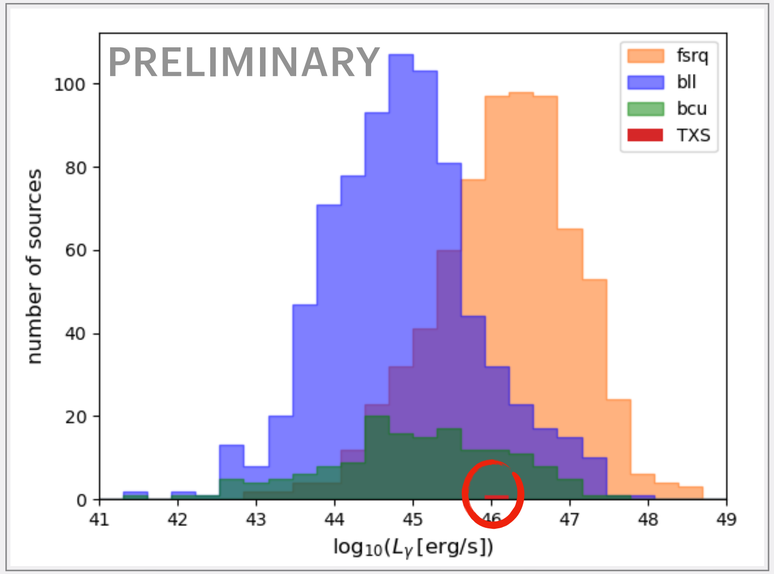
Initially classified as BL Lac type object, but FSRQ nature was suggested (Padovani et al. 2019)

WHY TXS 0506+056?

- Neutrino emission from TXS 0506+056 not fully understood
  - Source in the middle of the blazar sequence
    - Transitional properties between FSRQs and BL Lacs?





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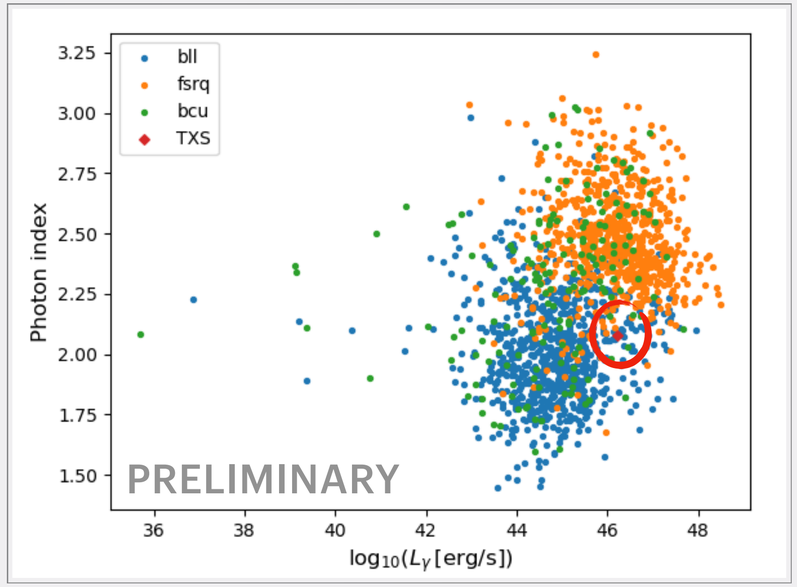
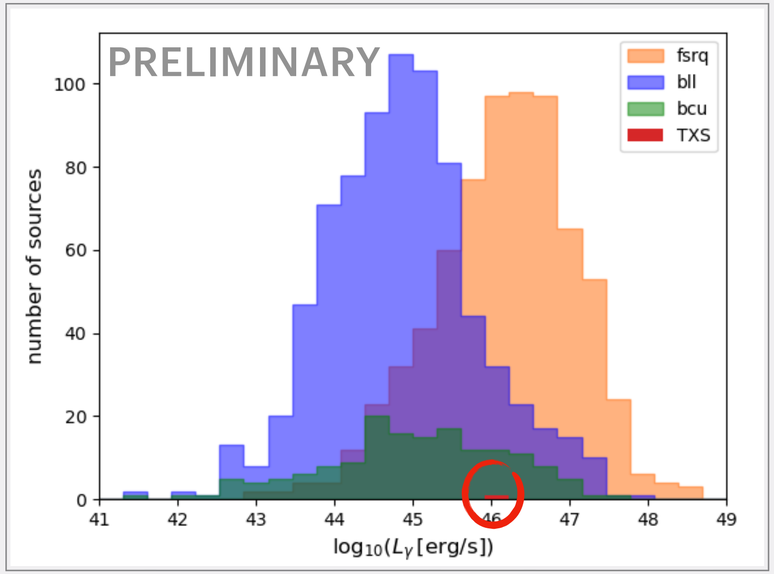
Select sample of candidate neutrino emitters chosen by constraining properties to be comparable to those of TXS 0506+056





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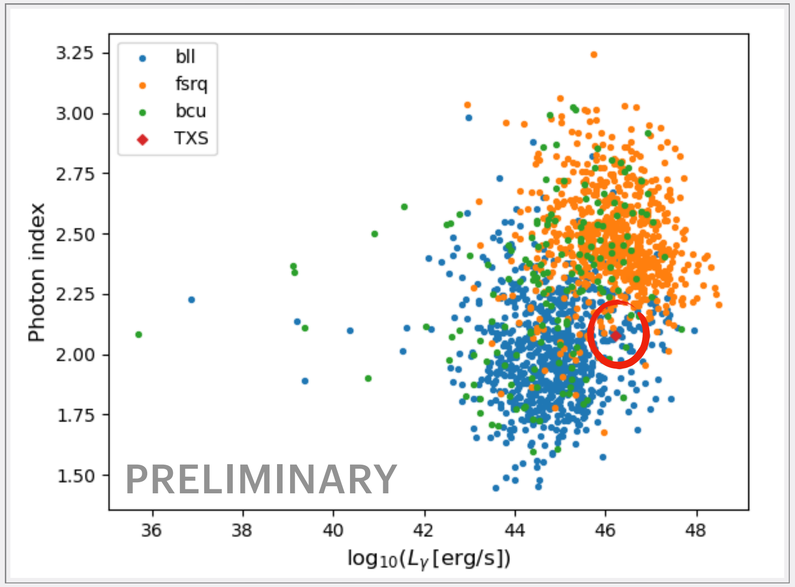
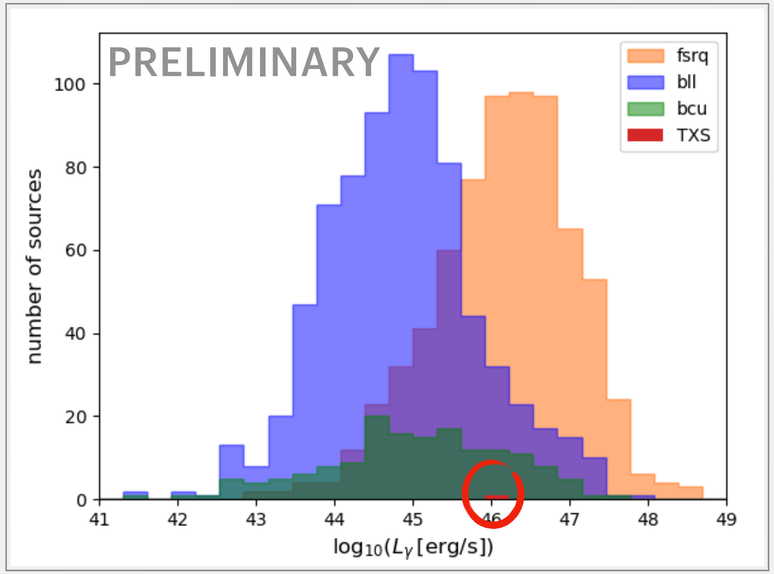
Aim of investigating accretion mechanism and SED in context of lepto-hadronic emission





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$$L_{TXS} = (1.62 \pm 0.04) \times 10^{46}\,\mathrm{erg/s}$$

$$\Gamma_{TXS} = 2.079 \pm 0.014$$

$$\nu_{syn} \simeq 3.55 \times 10^{14}\,\mathrm{Hz}$$

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RESULTING SAMPLE AND REDSHIFTS

- Resulting sample contains 27 sources including TXS 0506+056:
  - Mostly BL Lacs with high redshift
    - Inspection of redshift reliability
  - Sources with reliable redshift and info on spectral lines were kept

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- Only 3 sources fullfil the requirements:
  - 13 sources show no spectral analysis
  - 6 sources have reliable redshift but no info on spectral lines is found in refs
  - 3 sources only show a redshift lower limit given by absorption lines from host galaxy
  - 1 source went out of selection after redshift inspection ($z_{4LAC} = 1.18$, $z_{ref} = 0.43$)

REDSHIFTS

	z_{4LAC}	z_{ref}	lines	EW [Å]	FWHM [km/s]	L [erg/s]	Refs
TXS 0506+056	0.3365	0.3365	[O II] [O III] [N II]	0.07 0.05 0.05	500 600 300	1.0e41, 9.2e40, 6.7e40	Paiano2018, Landoni2020
PKS 0048-09	0.635	0.635	[O II] [O III] Hα	0.5 0.6 1.6	600 450 1300	1e41, 9.4e40, 1.6e41	Landoni2020
B3 1307+433	0.691	0.691	[O II] [O III]	1.2 0.5	800 600	2e42, 5.5e41	Landoni2020
GB6 J0114+1325	0.583	0.685	Hβ Mg II	/	3800 4300	1,24e43 2,45e43	Shaw2012

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All classified as BL Lacs

ACCRETION RATE

- Computation of L_{BLR} (Francis1991, Celotti1997):

$$L_{BLR} = \sum_i L_{i,obs} \frac{\langle L^*_{BLR} \rangle}{\sum_i L^*_{i,est}}$$

with $L_{i,obs}$ the observed line luminosity, $L^*_{i,est}$ the line ratio, $\langle L^*_{BLR} \rangle$ sum of line ratios

- Computation of L_{disk} from L_{BLR}: $L_{disk} \sim 10\, L_{BLR}$

- Computation of accretion rate $\dot{m} = \frac{L_{disk}}{L_{Edd}}$

where $L_{Edd} = 1.3 \times 10^{38} \frac{M_{BH}}{M_\odot} \frac{\mathrm{erg}}{\mathrm{s}}$ and assuming $M_{BH} = 10^8, 10^9\, M_\odot$

ACCRETION RATE

	L_{BLR} [erg/s]	L_{disk} [erg/s]	$\dot{m}_{high}$	$\dot{m}_{low}$
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GB6 J0114+1325	3.66×10^{44}	3.66×10^{45}	2.82×10^{-1}	2.82×10^{-2}

From Sbarrato et al. 2014:

$\dot{m} \gtrsim 0.01$ for FSRQs

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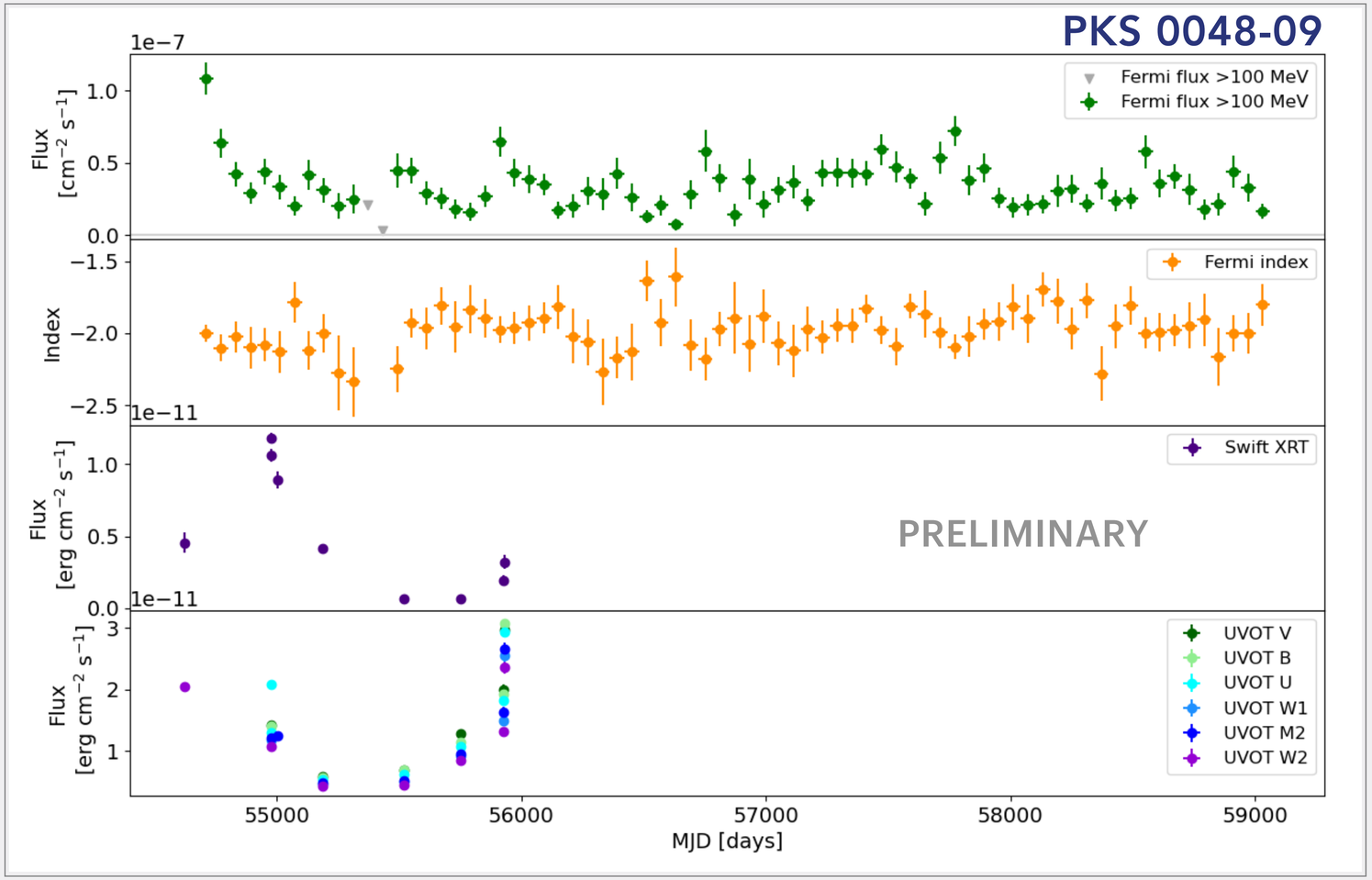
DATA ANALYSIS: LIGHTCURVE

Analyzed Fermi/LAT, Swift/XRT, Swift/UVOT data



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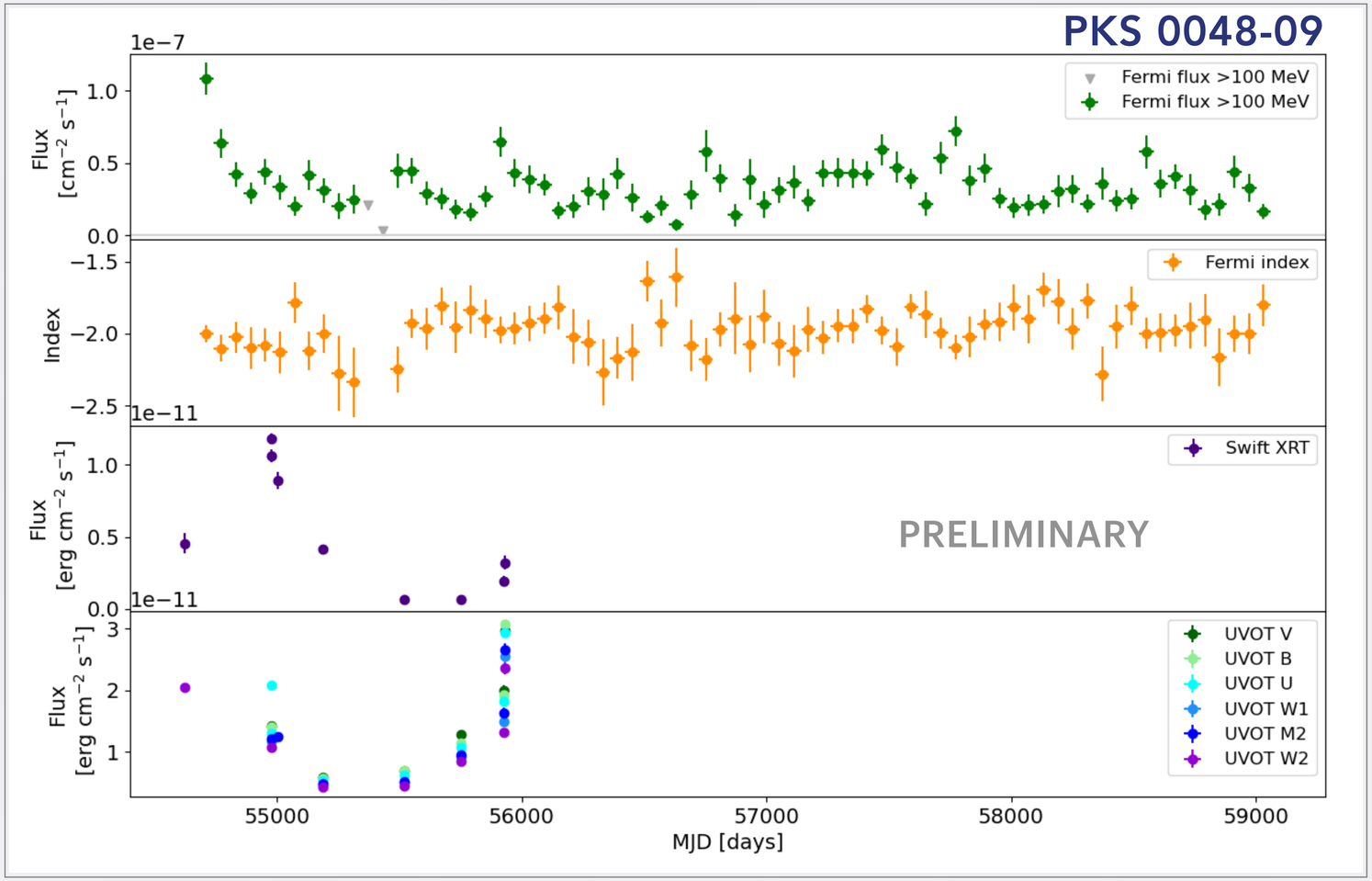
PKS 0048-09:

- Mostly low state
- 3 flares shifted in time
  - HE γ rays, X-rays, UV
- Simultaneous SEDs on low state and high state



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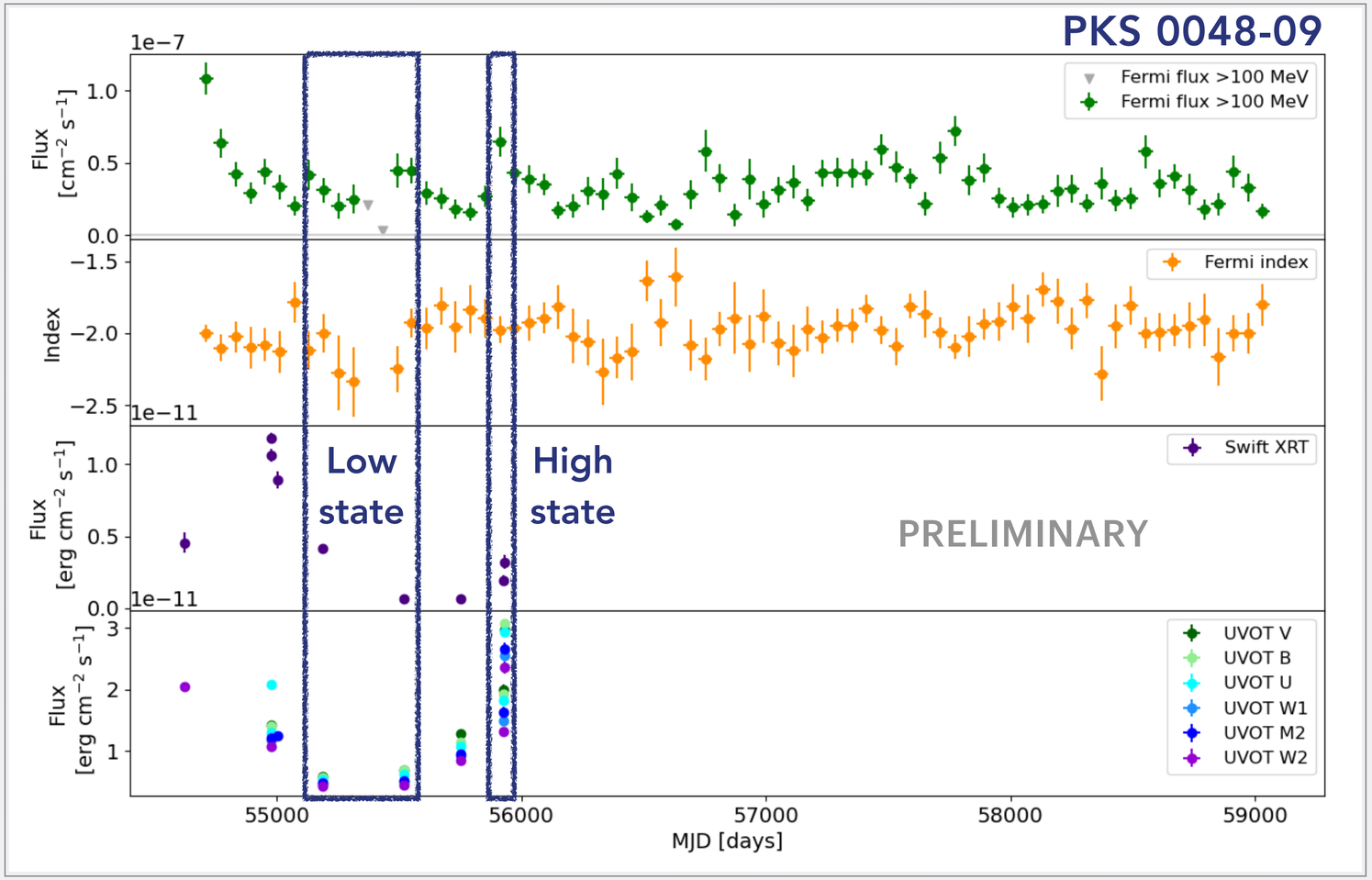

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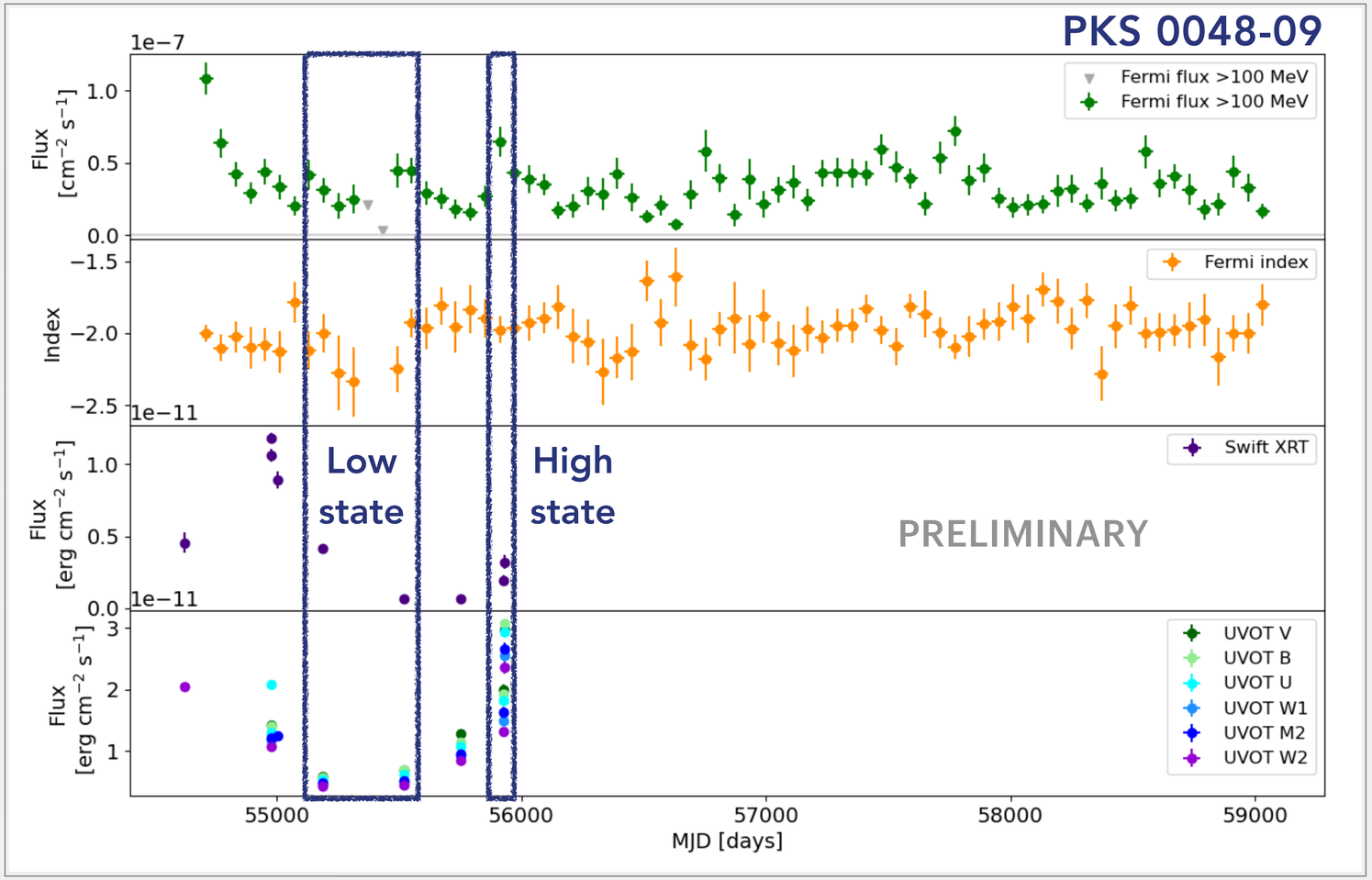
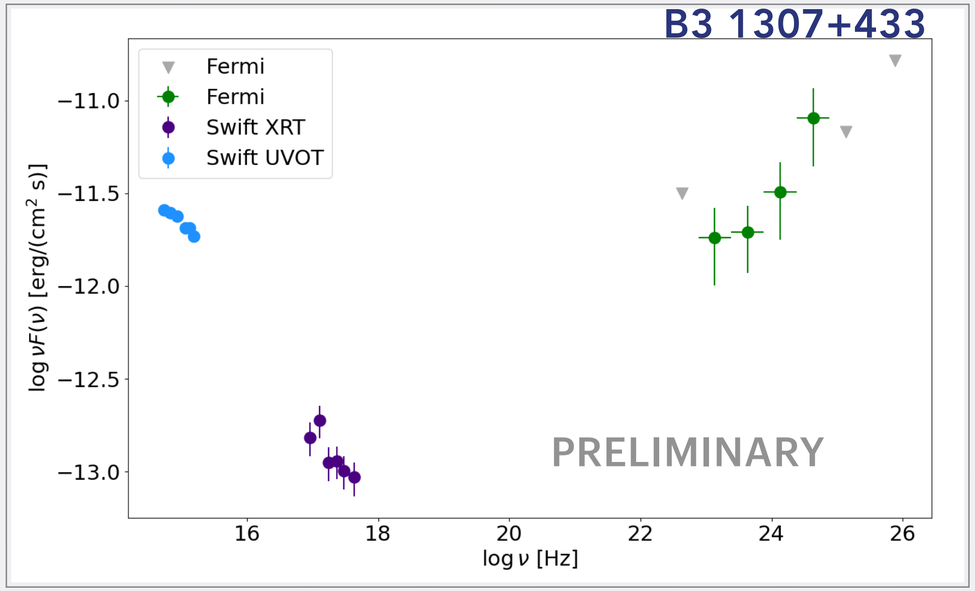
B3 1307+433 & GB6 J0114+1325:

- No flares observed in MWL LCs
- Simultaneous SED in low state



SUMMARY AND PERSPECTIVES

- TXS 0506+056 represents the most significant association between a HE neutrino and an astrophysical source
- Neutrino emission and nature of source are not fully understood
- Search for candidates with similar properties to investigate their nature
- From spectral lines to information on BLR and accretion
  - Different behaviours found
- Work in progress:
  - Modeling of SED in context of lepto-hadronic emission inside/outside BLR
  - Aim of getting info on neutrino flux and detectability prospects at TeV energies



Viale et al. in preparation

THANK YOU

BACKUP

SWIFT ANALYSIS

UVOT analysis:

❖ **Aperture photometry**

- Instrumental magnitude from photon counts

$$m_\lambda = Z_\lambda = 2.5 \log_{10}\left(\frac{\sum_{i=1}^{N} C_i - nC_{sky}}{t}\right)$$

❖ **Extinction**

- Real magnitude obtained by de-reddening

$$A_\lambda = E(B-V)[a_\lambda R_v + b_\lambda]$$

❖ **Energy range: 1700 - 6500 Å**

❖ We performed the analysis with the **uvotimsum** and **uvosource** tasks

XRT analysis:

❖ **Spectral fitting**

- Raw photon counts in instrument channels

$$C(I) = \int f(E)\, R(I,E)\, dE$$

❖ **Fitting of data** with **model spectrum**

$$M(E) = K\, E^{-\Gamma_X}\, E^{-n_H \sigma_{abs}}$$

❖ χ^2 or **Cash statistics** used

❖ **Energy range: 0.3 - 10 KeV**

❖ We performed the analysis using **xspec (v. 12.12.0)**

UVOT PARAMETERS

	V	B	U	W1	M2	W2
λ_c [Å]	5468	4392	3465	2600	2246	1928
FWHM [Å]	769	975	785	693	498	657
a_λ	1.0015	0.9994	0.9226	0.4346	0.0773	-0.0581
b_λ	0.0126	1.0171	2.1019	5.3286	9.1784	8.4402
Z_λ	17.89 ± 0.013	19.11 ± 0.016	18.34 ± 0.020	17.49 ± 0.03	16.82 ± 0.03	17.35 ± 0.03

FERMI ANALYSIS

Analysis:

- **Likelihood analysis on 13 years of LAT data**
  - Optimization, fit, localization, SED, lightcurve (2 months bin)
- **Likelihood analysis on selected periods**

We performed the analysis using Fermipy (v. 1.0.1)

Diffuse models:

- galdiff: gll_iem_v07.fits
- isodiff: iso_P8R3_SOURCE_V3_v1.txt

Model for the Fermi-LAT extend sources:

- LAT_extended_sources_10years.fits

Catalog:

We use one of the latest version of the **4FGL-DR2:**

- gll_psc_v27.fit

Data selection	Values
IRFs	P8R3_SOURCE_v3
PSF Classes	All [PSF0 and PSF1 excluded, E < 300 MeV [PSF0 excluded, 300 MeV < E < 1 GeV]
Time intervals	13 years
Energy range	100 MeV - 1 TeV
Zenith angle	< 105° [< 85°, E < 300 MeV] [< 95°, 300 MeV < E < 1 GeV]
Pixel size	0.1°