

5BZQ J0808+4950: A LEPTO-HADRONIC PERSPECTIVE ON THE CANDIDATE NEUTRINO EMITTER.

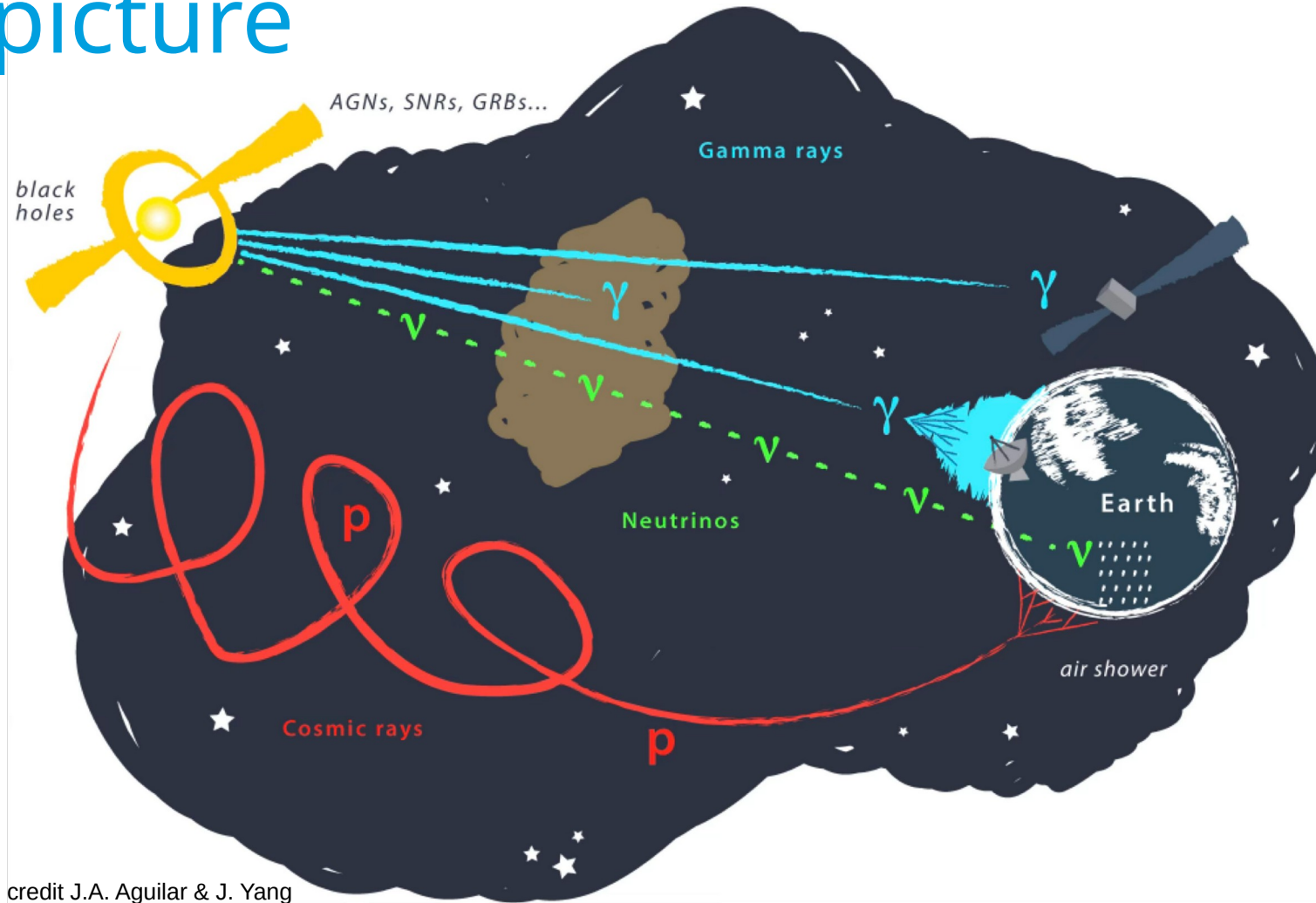
Margot Boughelilba – DESY

And collaborators: A. Azzollini, A. Bremer, S. Buson,
M. Lincetto, L. Pfeiffer, J.M. Sanchez Zaballa
– *on behalf of the Fermi-LAT collaboration*



Multi-Messenger and Numerical Techniques in Astrophysics Workshop –
Harokopio University – Greece – March 2, 2026

Motivation: multi-messenger picture

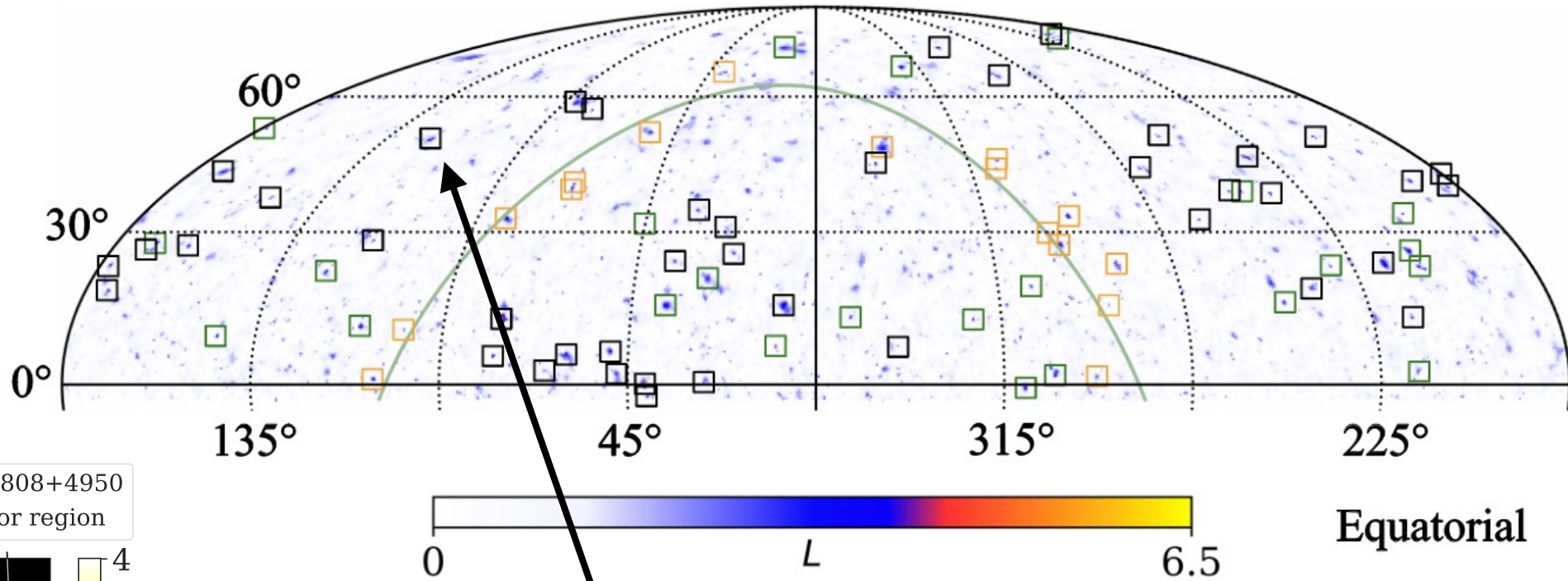


Active Galactic Nuclei: good candidates to accelerate (very) high energy cosmic rays.

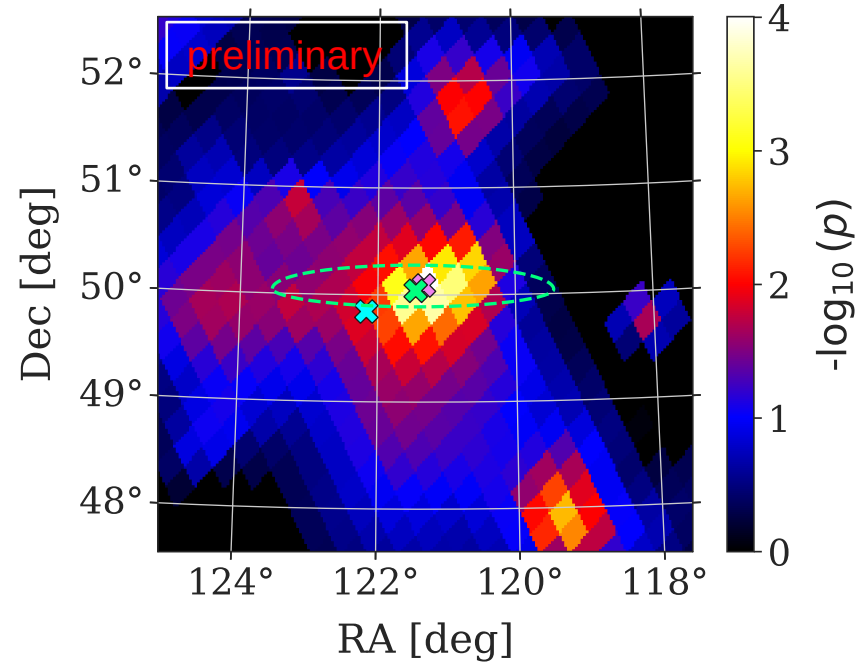
Where there are cosmic rays, there are in theory neutrinos (p γ , pp interactions). **But...** neutrino are elusive particles $\rightarrow$ IceCube observatory, KM3NeT.

A few high-energy neutrinos are spatially consistent with astrophysical sources possibly able to produce them: **TXS 0506+056, NGC 1068, PKS 1424-41, 3HSP J095507.9+355101, PKS 1502+106, PKS 0735+178...**

Motivation: ν event and hotspot



- ✕ IC J0805+5005
- ✕ 5BZQ J0808+4950
- ✕ IC110929A
- 90% error region



The blazar is spatially consistent with an IceCube neutrino hotspot (**IC J0805+5005**) (Buson et al 2023)

It is also close to the IceCube neutrino event **IC110929A** (IceCat-1, Abbasi et al. 2023)

MWL data

Fermi-LAT analysis:

5BZQ J0808+4950 associated with 4FGL
J0808.5+4950 in 4FGL-DR4

Reveals 5 gamma-ray blocks with Bayesian
block analysis. No significant variability in the
photon index.

X-rays: *Swift*-XRT and *NuSTAR*

New data from *Swift* Cycle 20 + *Swift* ToO
observation & archival data

UV: *Swift*-UVOT

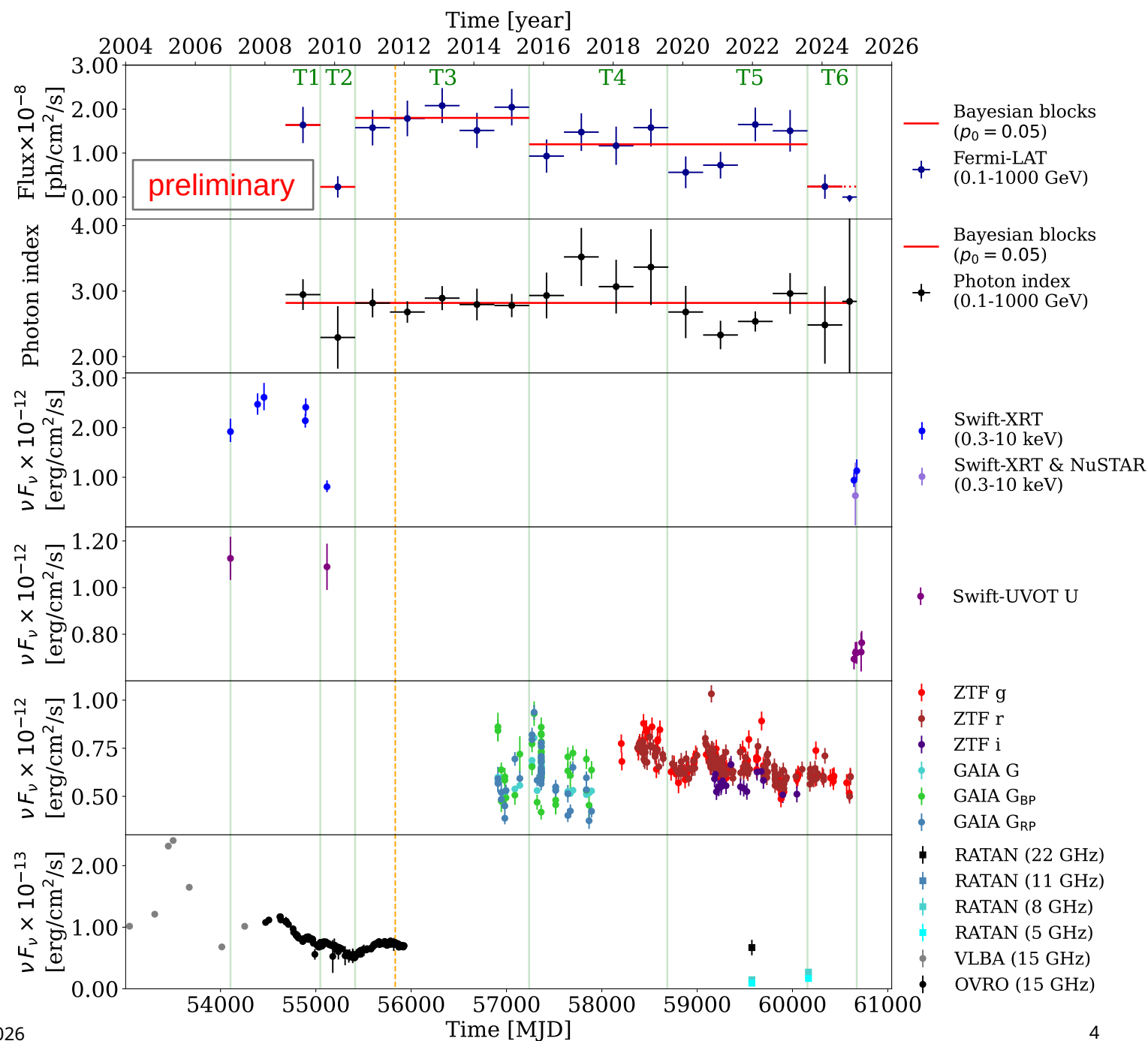
Simultaneously with *Swift*-XRT obs when
available.

Optical & IR: ZTF and GAIA

Photometric observation

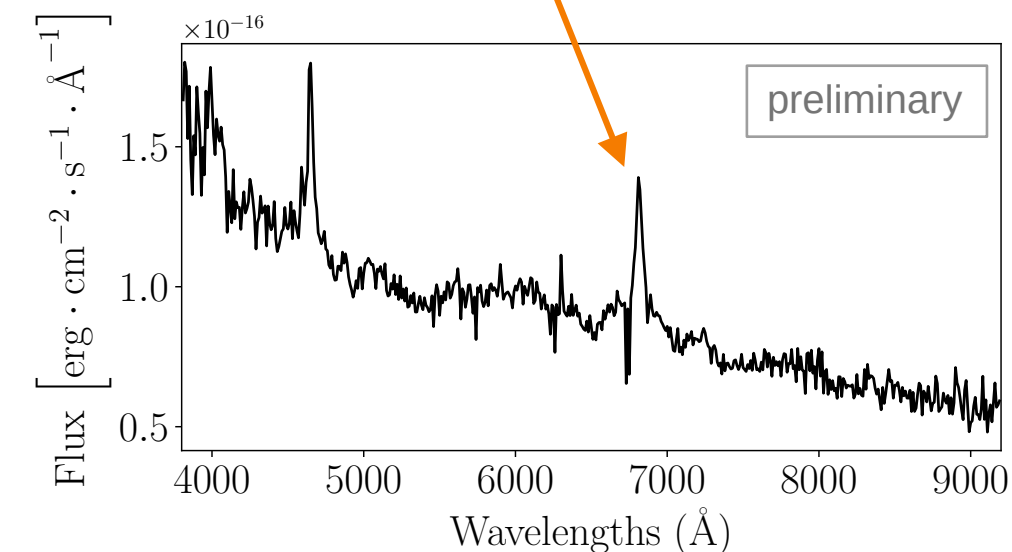
Radio: RATAN, OVRO and VLBA

< 100 GHz treated as upper limits in the SED

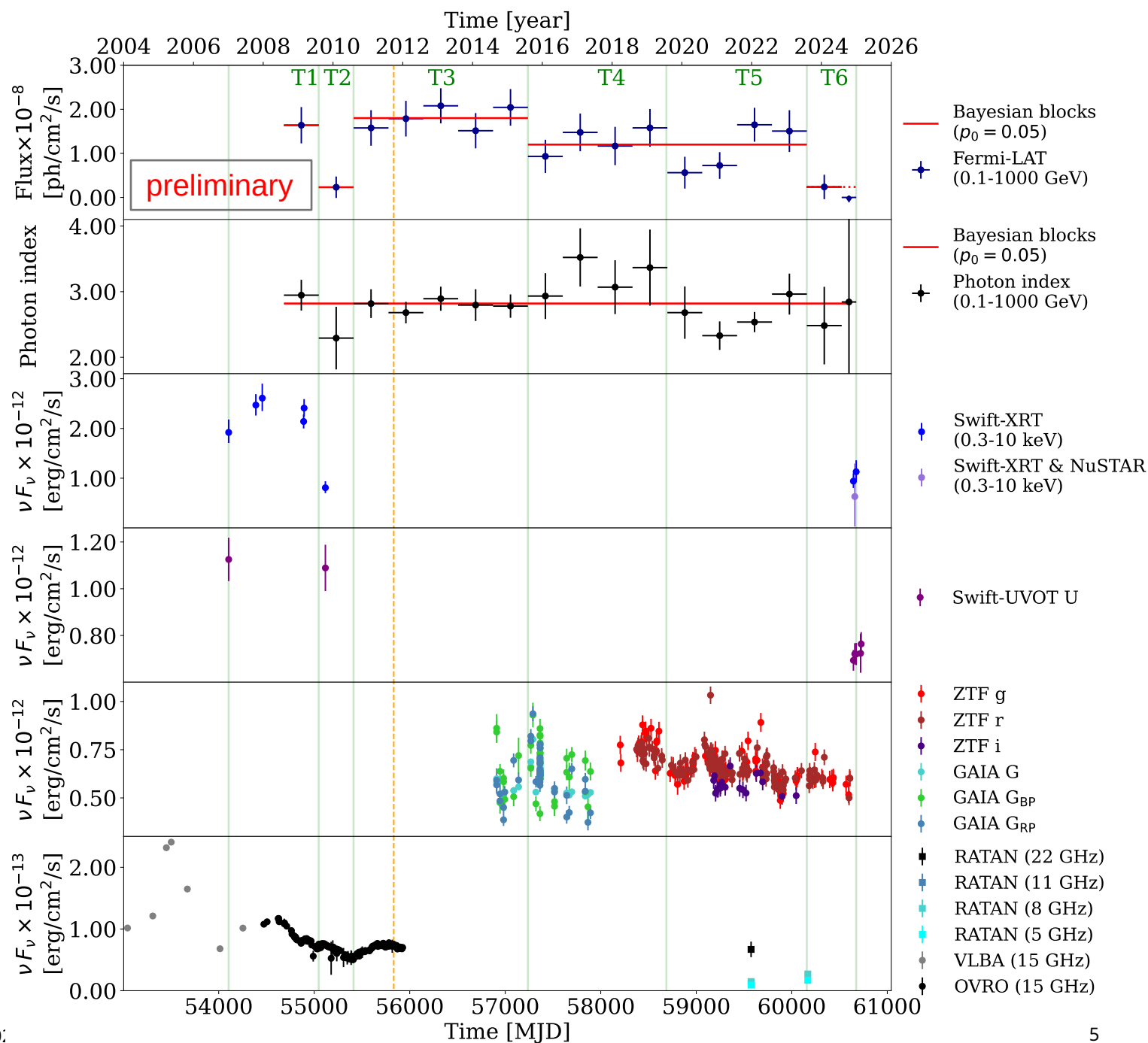


MWL data

Spectroscopy: MgII emission line →
redshift $z=1.4344$, $M_{\text{BH}} = 6.95 \times 10^8 \text{ solMass}$,
 $L_{\text{disk}} = 1.35 \times 10^{46} \text{ erg/s}$



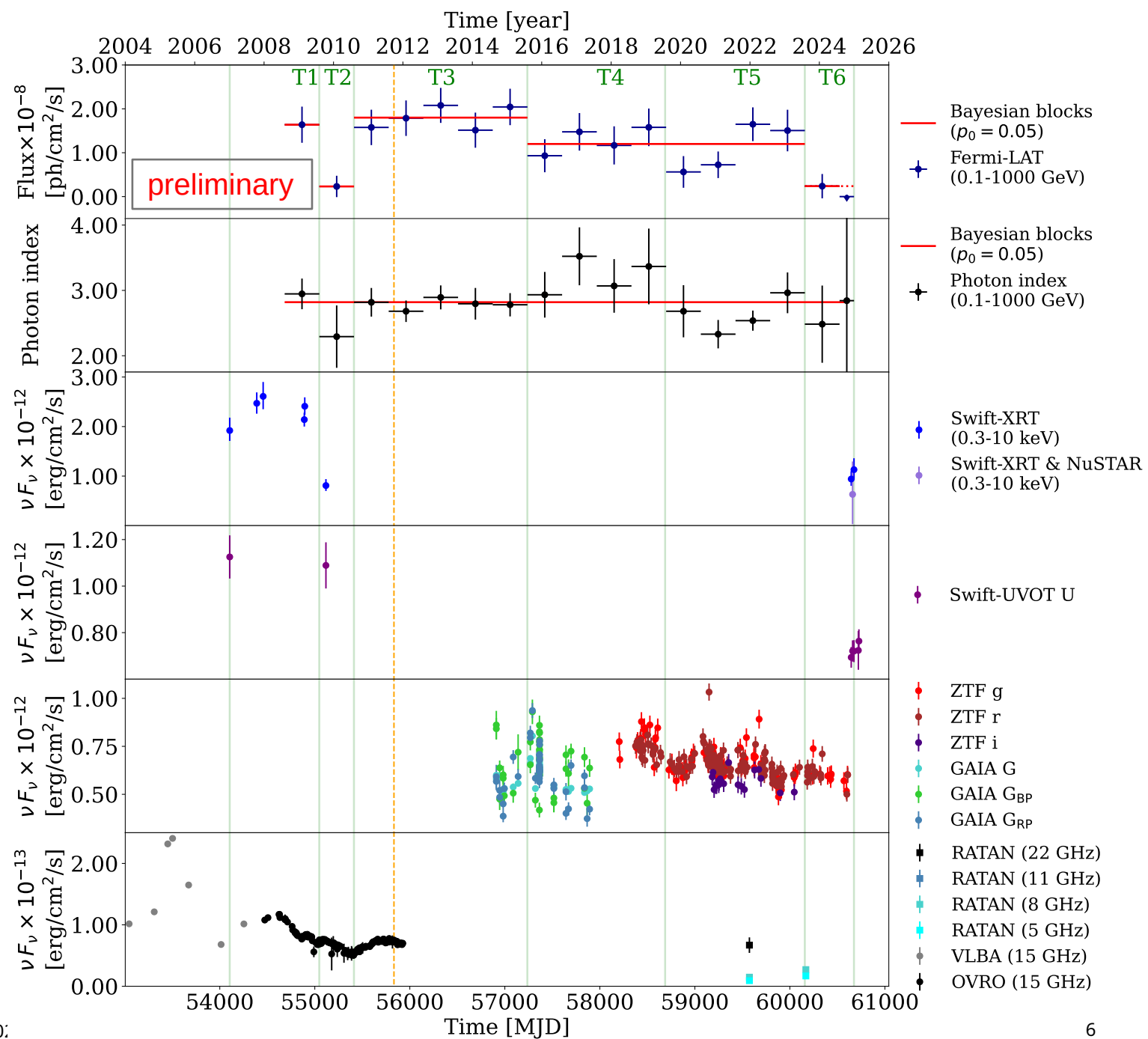
Azzollini et al. 2025, Spectrum from
SDSS-DR7 (Shen et al. 2011)



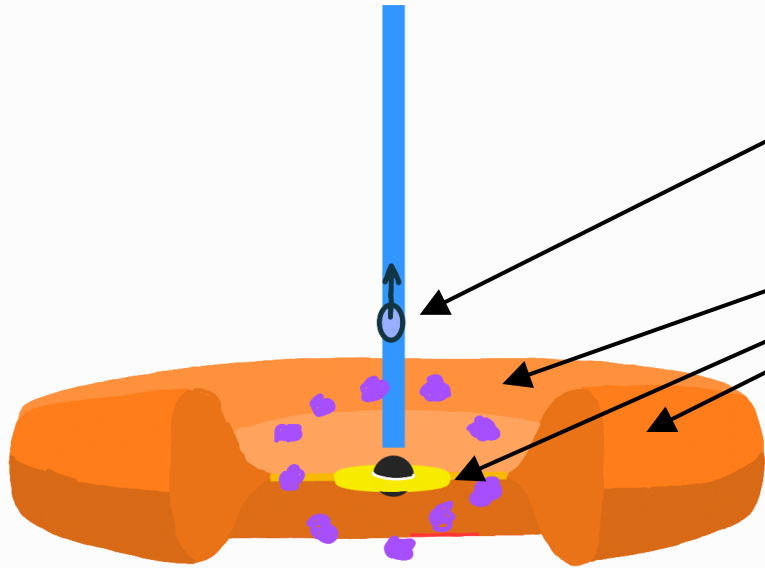
MWL data

Based on the different gamma-ray states, the (quasi) simultaneity of X-ray data & the low variability in the other bands → 6 epochs for which we aim to model the SED.

(Boughelilba et al., in prep)



Modeling approach



- **Jet model:** spherical blob, moving in a cylindrical jet with a Lorentz factor Γ_j . Injection of primary electrons and protons at a constant rate.
- **External photon fields:** accretion disk and BLR (properties estimated from spectroscopy) + dusty torus → important if the blob is injected close to the central object.
- **Interactions:** synchrotron radiation, inverse Compton scattering, photon-photon annihilation, Bethe-Heitler pair production, photo-pion production.
- **Framework:** AM³ software (solving the time-dependent partial differential equations of particles, Klinger et al. 2024)

Preliminary results

$$\begin{aligned} R' &\sim 3 \times 10^{16} \text{ cm} \\ B' &\sim 0.4 - 4 \text{ G} \\ \Gamma_j &\sim 25 \end{aligned}$$

“Blob” properties

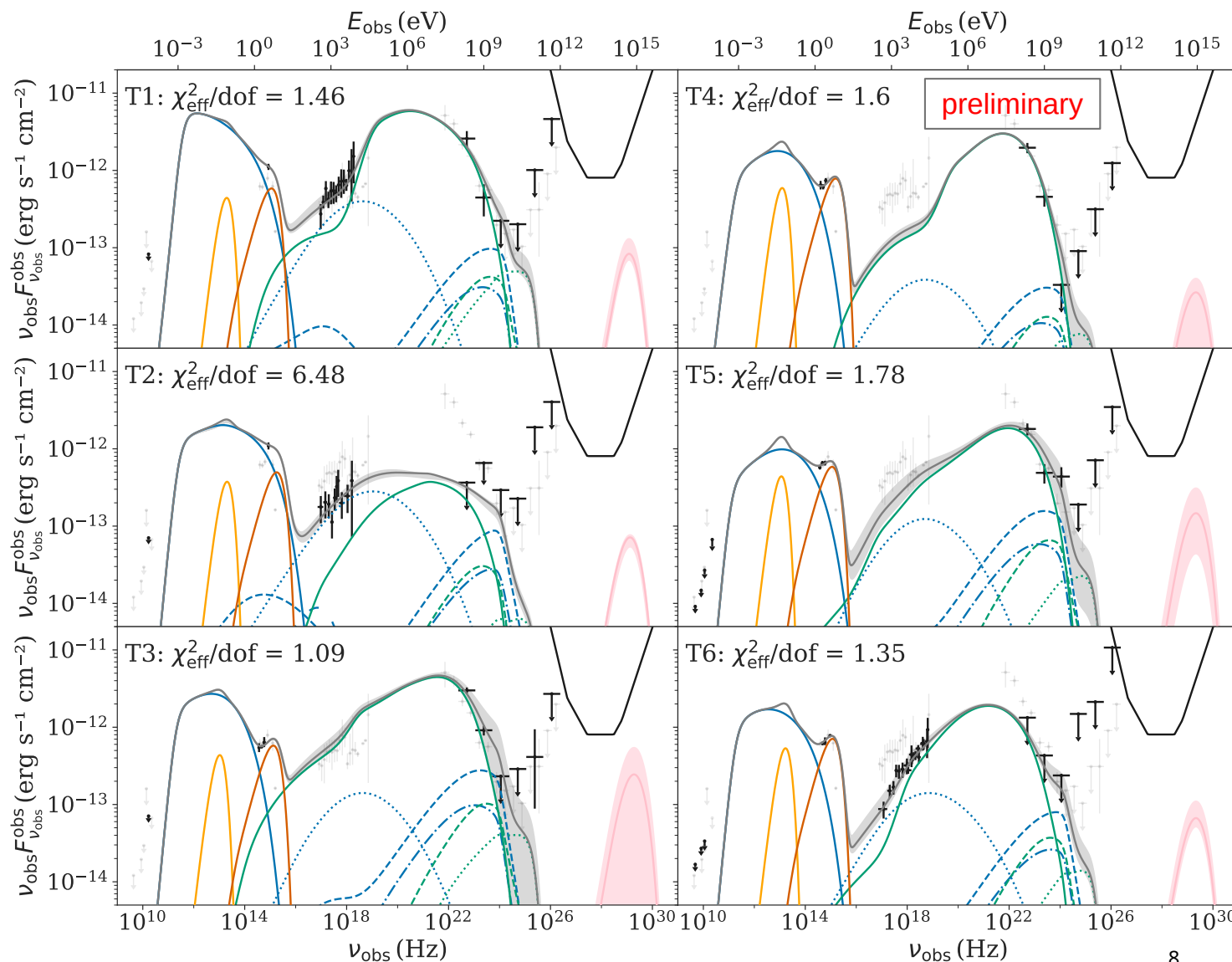
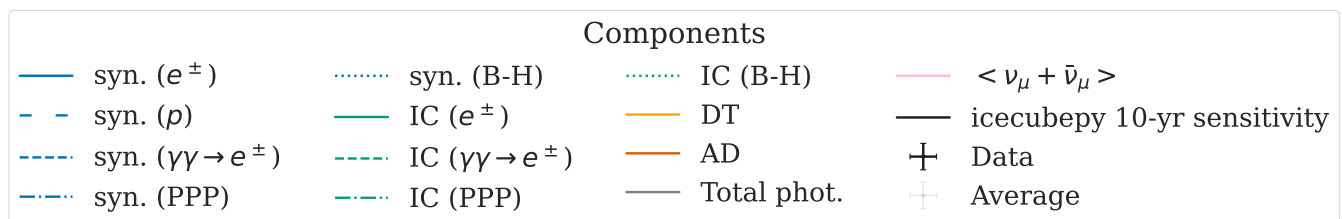
$$\begin{aligned} L_{\text{disk}} &\sim (1.4 - 2.4) \times 10^{46} \text{ erg/s} \\ T_{\text{torus}} &\sim (3-6) \times 10^2 \text{ K} \\ R_{\text{diss}} &\sim (0.9 - 1) R_{\text{BLR}} \end{aligned}$$

External fields

$$\begin{aligned} p_p &= 1.5 \text{ (fixed)} \\ L_p' &\sim 3 \times 10^{44} - 10^{45} \text{ erg/s} \end{aligned}$$

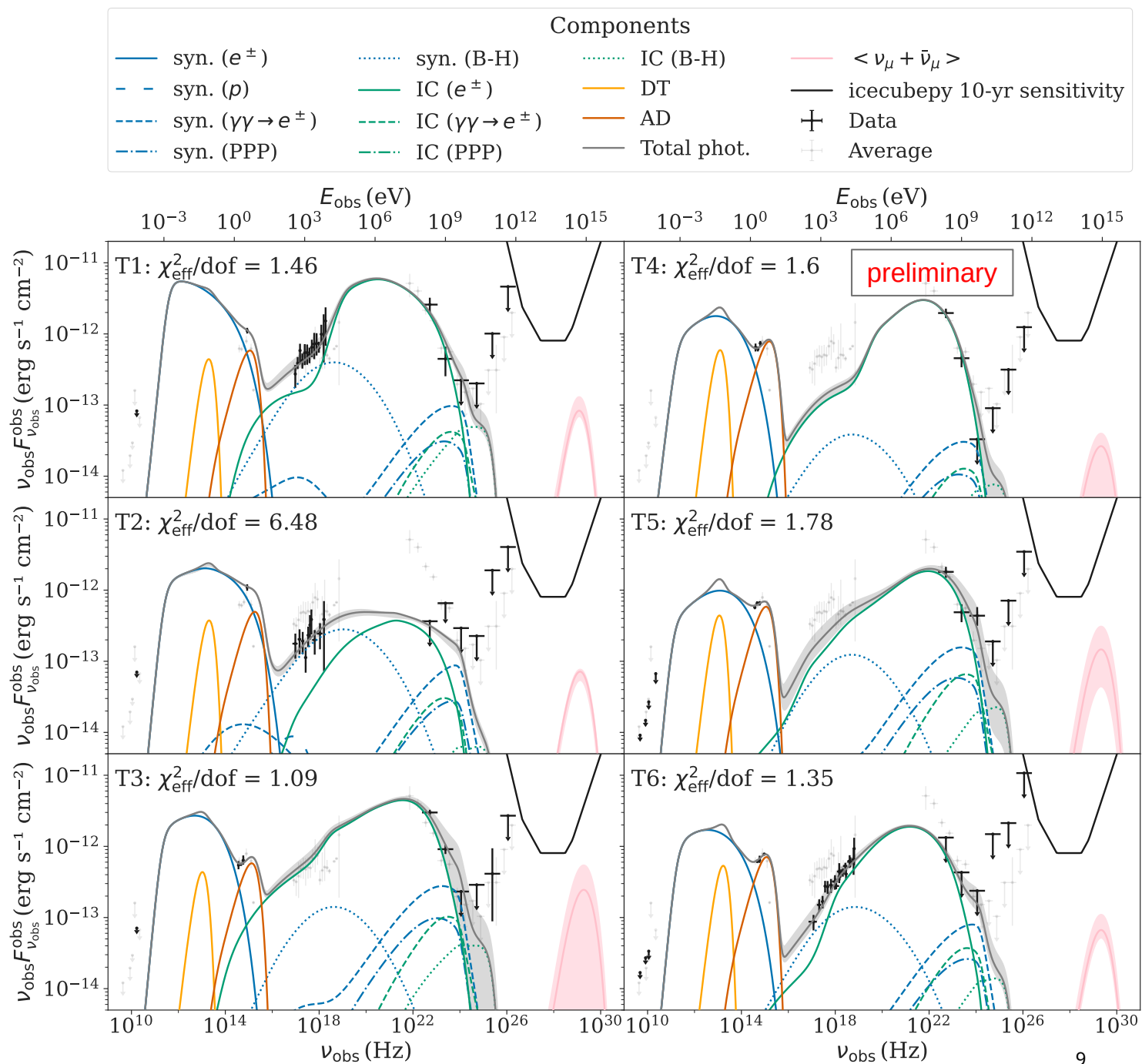
Injected particles

$$\begin{aligned} p_e &\sim 1.9 - 2.5 \\ L_e' &\sim 4 \times 10^{41} - 10^{43} \text{ erg/s} \end{aligned}$$



Preliminary results

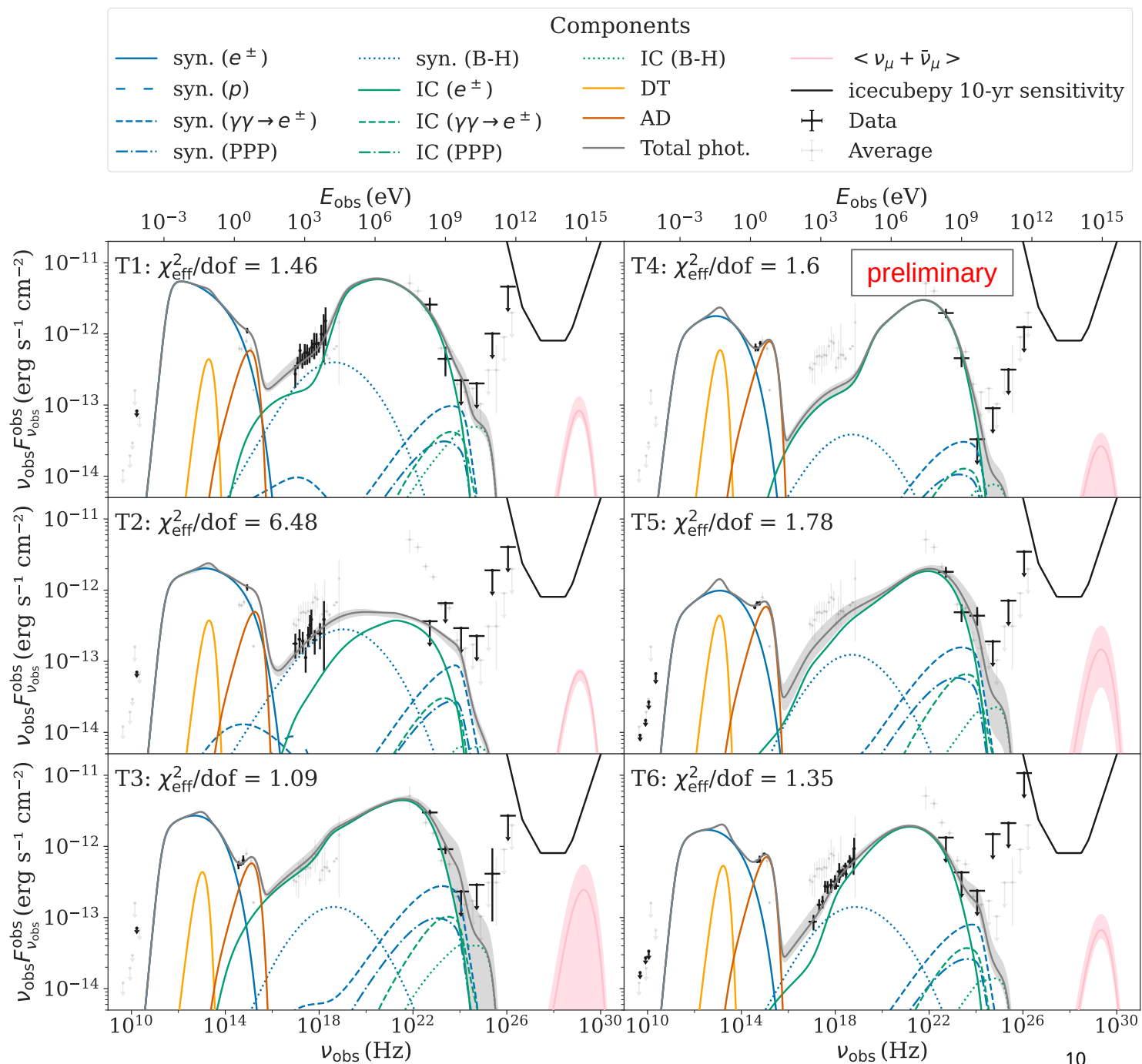
Predicted rate of IceCube neutrinos:
0.006 – 0.1 neutrino per epoch.
The highest rate during T3, which is the
epoch during which the IC event was
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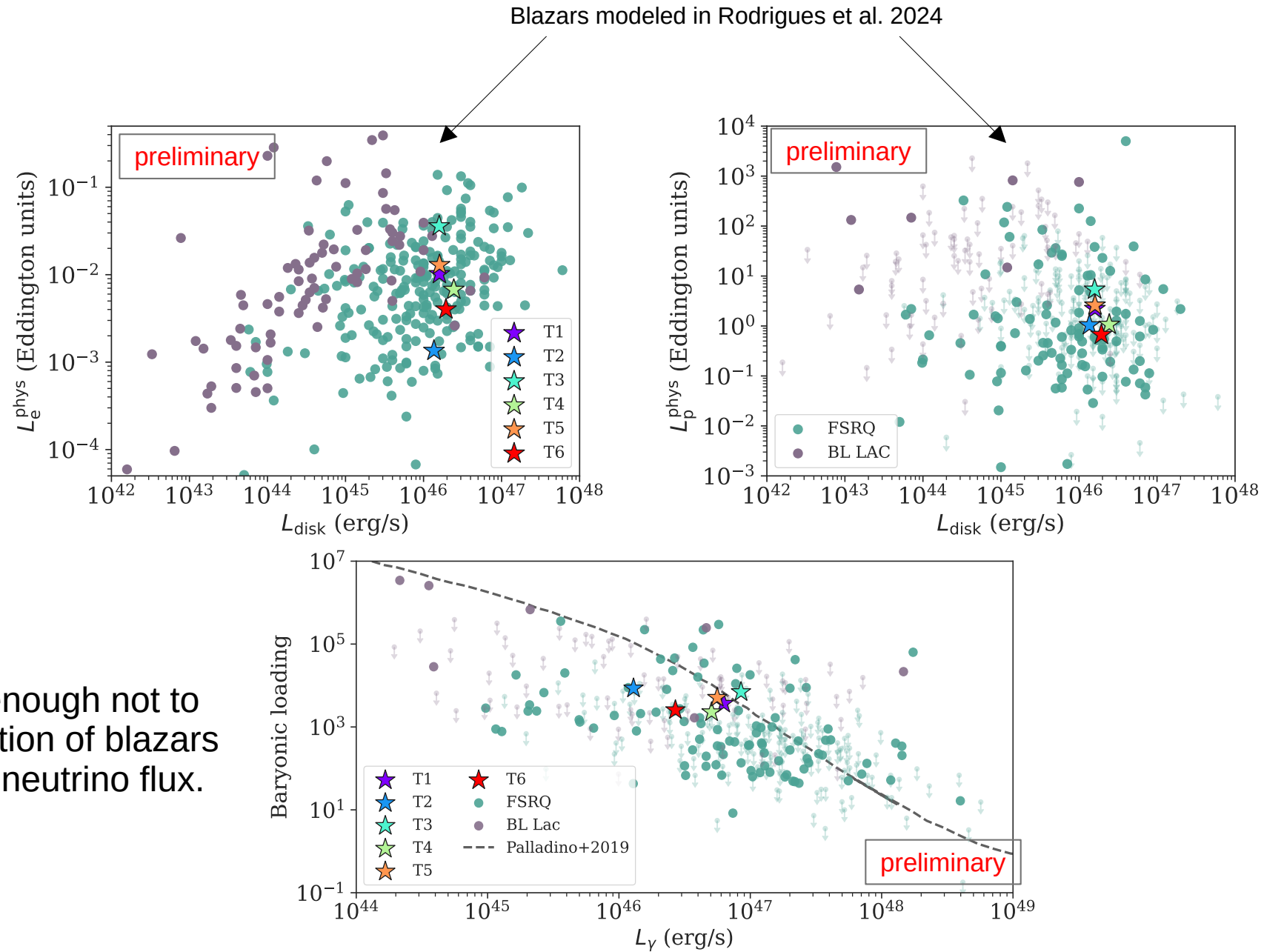
... BUT jet power above the Eddington
luminosity.



Preliminary results

Particle injection comparable to other modelled FSRQs with large L_{disk} .

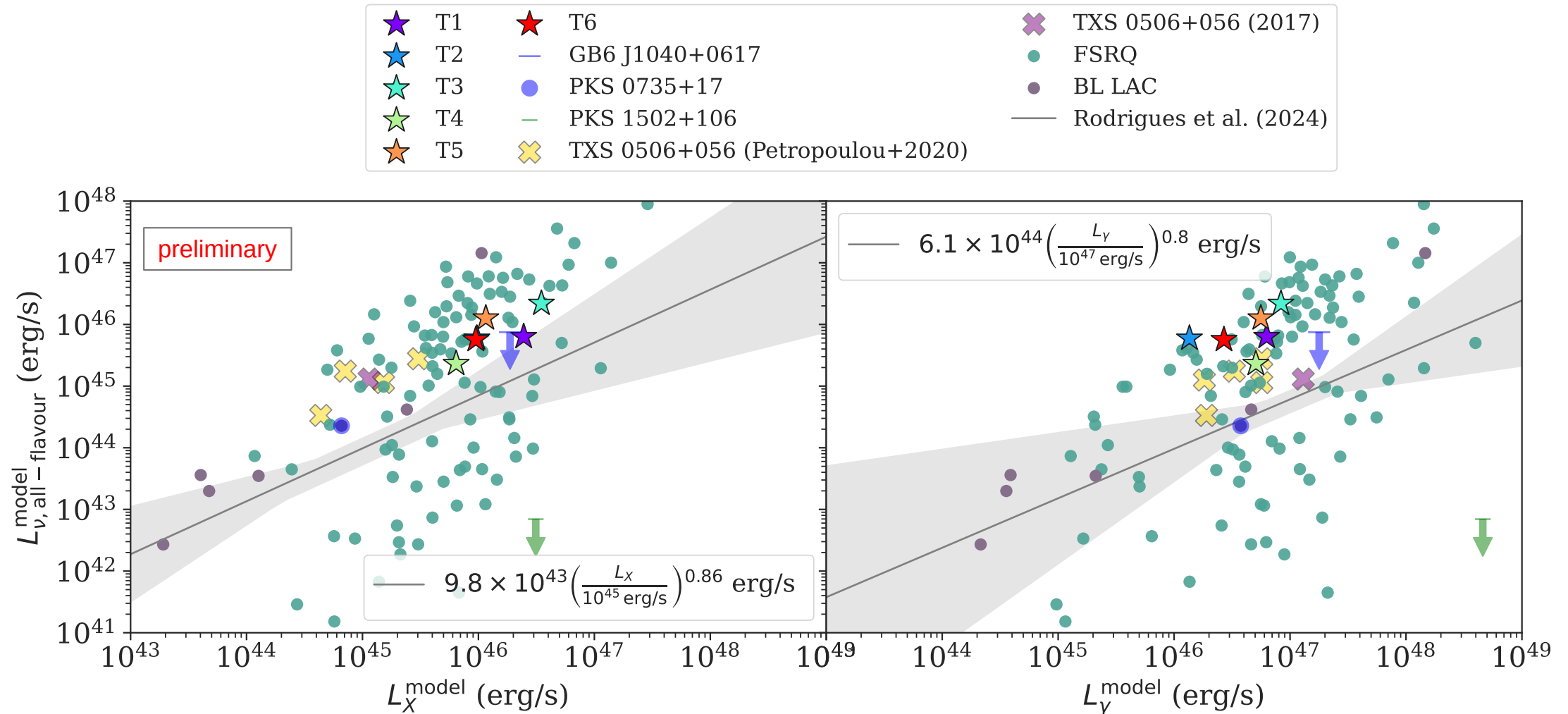
Baryonic loading low enough not to overshoot the contribution of blazars to the IceCube diffuse neutrino flux.



Preliminary results

Model predictions for J0808+4950 seem to align with models of other IC candidate sources:

- X-rays seem to follow the same trend as the global population of blazars but with larger neutrino luminosity
- Gamma-rays span over one order of magnitude.



Conclusion

- ★ We found lepto-hadronic solutions to model the 6 contemporaneous SEDs of 5BZQ J0808+4950.
- ★ The SED variations are mainly linked to the different injection of primary electrons and the magnetic field strength.
- ★ Sub-dominance of the hadronic processes even more when the gamma-ray flux is high.
- ★ Predicted neutrino flux peaks at $\sim 1\text{PeV}$. Predicted detectable neutrino by IceCube: 0.006 to 0.1 per epoch.
- ★ Largest predicted number (0.1 neutrino/epoch) contemporaneous with the IceCube high-energy event IC110929A: Poissonian confidence interval [0-2].
- ★ The physical quantities derived are comparable to the other IC blazar candidate models. Intrinsically, the X-rays seem to be a better proxy to the predicted neutrino luminosity than the gamma-rays.

(Boughelilba et al., in prep)

Back up

—	unit	T1	T2	T3*	T4	T5	T6	explored range
Start	—	2008-08-04	2009-08-04	2010-08-04	2015-08-03	2019-07-23	2023-08-01	—
End	—	2009-08-04	2010-08-04	2015-08-03	2019-07-23	2023-08-01	2024-12-31	—
R'_{blob}	cm	3.0×10^{16}	3.2×10^{16}	3.1×10^{16}	3.0×10^{16}	3.3×10^{16}	3.8×10^{16}	$[10^{15.7}, 10^{16.7}]$
B'	G	1.6	4.1	3.8×10^{-1}	5.0×10^{-1}	4.1×10^{-1}	1.1	$[10^{-1}, 10^{1.7}]$
δ	—	2.4×10^1	2.5×10^1	2.5×10^1	2.5×10^1	2.5×10^1	2.4×10^1	$[10^1, 10^{1.5}]$
$\gamma'_{\text{e,min}}$	—	2.1×10^1	1.7	1.3×10^1	5.0×10^1	1.8	7.0	$[1.0, 10^3]$
$\gamma'_{\text{e,max}}$	—	4.0×10^3	3.8×10^3	3.6×10^3	4.0×10^3	5.8×10^3	2.7×10^3	$[10^3, 10^{5.7}]$
p_{e}	—	2.4	1.9	2.5	2.3	2.3	2.1	$[1.5, 3.0]$
L'_{e}	$\text{erg} \cdot \text{s}^{-1}$	3.0×10^{42}	3.9×10^{41}	1.0×10^{43}	1.7×10^{42}	3.6×10^{42}	1.2×10^{42}	$[10^{40}, 10^{43}]$
$\gamma'_{\text{p,min}}$	—	1.0×10^2	1.0×10^2	1.0×10^2	1.0×10^2	1.0×10^2	1.0×10^2	fixed
$\gamma'_{\text{p,max}}$	—	1.0×10^6	1.2×10^6	1.8×10^6	2×10^6	2.0×10^6	2.0×10^6	$[10^5, 10^7]$
p_{p}	—	1.5	1.5	1.5	1.5	1.5	1.5	fixed
L'_{p}	$\text{erg} \cdot \text{s}^{-1}$	6.5×10^{44}	3.0×10^{44}	1.5×10^{45}	2.0×10^{44}	7.2×10^{44}	2.0×10^{44}	$[10^{43}, 10^{45.7}]$
M	$M_{\odot} \cdot \text{year}^{-1}$	2.8	2.4	2.8	3.8	2.8	3.4	$[1.94, 2.83]$
R_{in}	R_{g}	6.0	3.0	4.8	4.3	6.0	6.0	$[3.0, 10^1]$
$R_{\text{diss}}/R_{\text{BLR}}$	—	1.0	1.0	9.1×10^{-1}	1.0	9.3×10^{-1}	1.0	$[10^{-0.3}, 10^1]$
T_{torus}	K	5.9×10^2	6.1×10^2	3.1×10^2	3.7×10^2	3.4×10^2	5.0×10^2	$[10^2, 10^{3.1}]$
τ_{var}	days	1.2	1.2	1.2	1.1	1.2	1.5	—
$u'_{\text{e}}/u'_{\text{b}}$	—	8.5×10^{-2}	1.5×10^{-3}	4.8	5.5×10^{-1}	1.3	4.6×10^{-2}	—
$u'_{\text{p}}/u'_{\text{b}}$	—	1.8×10^1	1.2	7.2×10^2	8.7×10^1	2.7×10^2	7.6	—
L_{disk}	$\text{erg} \cdot \text{s}^{-1}$	1.6×10^{46}	1.4×10^{46}	1.6×10^{46}	2.4×10^{46}	1.6×10^{46}	1.9×10^{46}	—
η	—	1.8×10^{-2}	1.6×10^{-2}	1.8×10^{-2}	2.8×10^{-2}	1.8×10^{-2}	2.2×10^{-2}	—
$P_{\text{jet}}^{\text{inj}}$	$\text{erg} \cdot \text{s}^{-1}$	2.0×10^{47}	1.7×10^{47}	4.8×10^{47}	9.5×10^{46}	2.3×10^{47}	6.7×10^{46}	—
$P_{\text{jet}}^{\text{inj}}/L_{\text{Edd}}$	—	2.3	1.9	5.4	7.3×10^{-1}	2.6	7.6×10^{-1}	—
CD	—	1.1	1.8×10^{-1}	1.7	1.7	1.9	1.1	—
$N_{<\nu_{\mu}+\bar{\nu}_{\mu}>}$	—	$0.008^{+0.004}_{-0.001}$	$0.008^{+0.001}_{-0.001}$	$0.096^{+0.118}_{-0.096}$	$0.007^{+0.007}_{-0.007}$	$0.040^{+0.044}_{-0.028}$	$0.006^{+0.004}_{-0.001}$	—

Back up

