

HEASA 2026

Comparitive study of Orphan flare models

Insights from 3C 279 – model comparisons

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Aim - Questions to be answered

What physical process produces a strong gamma-ray flare without a simultaneous multiwavelength counterpart?

Are hadronic interactions expected to be associated with the production of very-high-energy neutrinos?

Are protons accelerated to ultra-relativistic energies in the jets of blazars?

Observational

ORPHAN FLARE ON 28 JAN 2018

3C 279 shows a strong VHE event — but no simultaneous Fermi-LAT flare.

SEDs in blazars

A spectral energy distribution (SED) shows how a source's emitted energy is distributed across frequency or photon energy.

1 Electron synchrotron component

The first broad component is produced by electrons spiraling in magnetic fields.

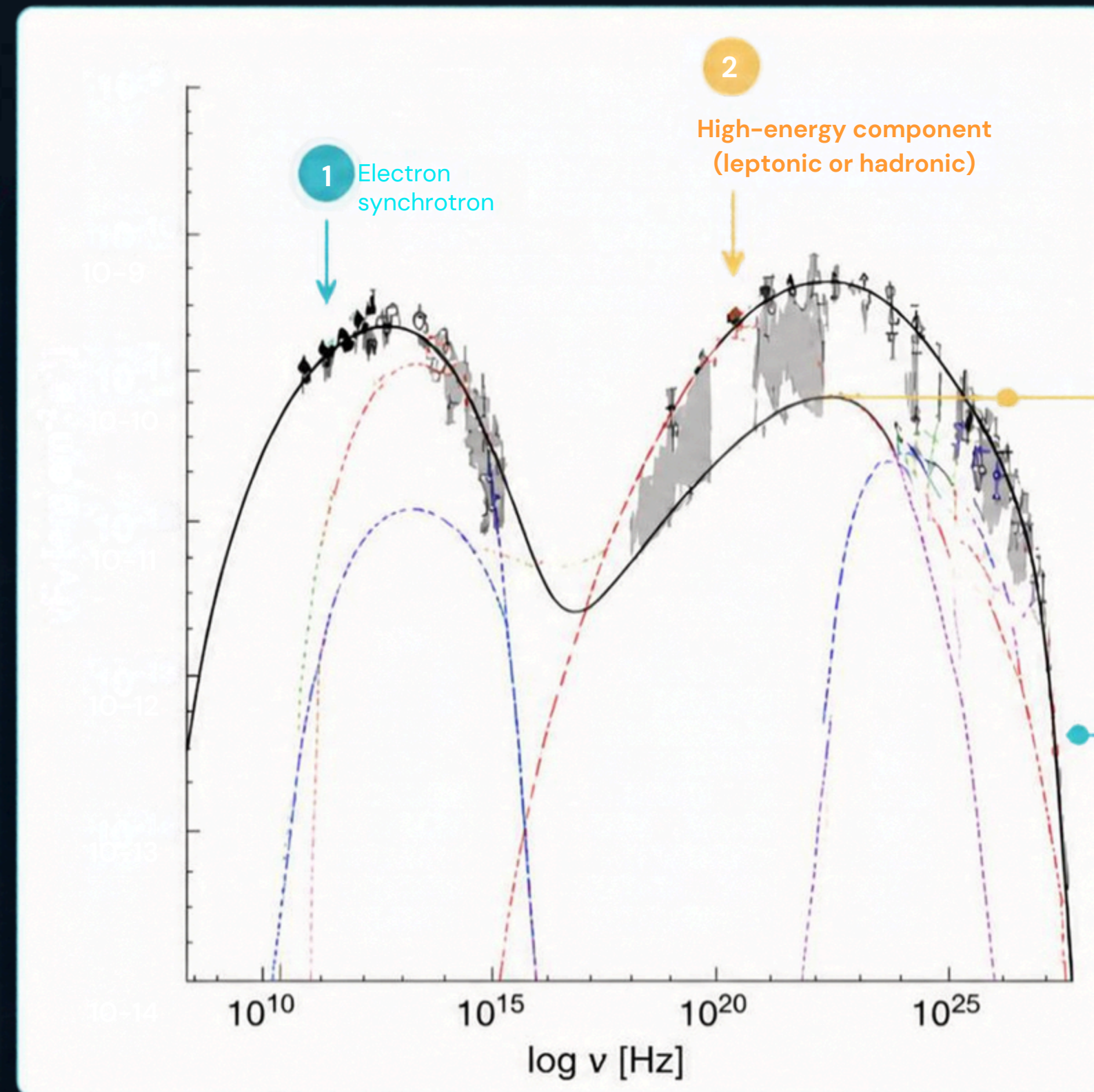
2 High-energy component (leptonic or hadronic)

The second component can arise from:

- **Leptonic:** inverse Compton scattering
- **Hadronic:** proton synchrotron radiation and photo-pion production



The shape and variability of the SED — comparing component peaks and high-energy behaviour — help distinguish competing models and address orphan-flare scenarios.



Compare peak frequencies

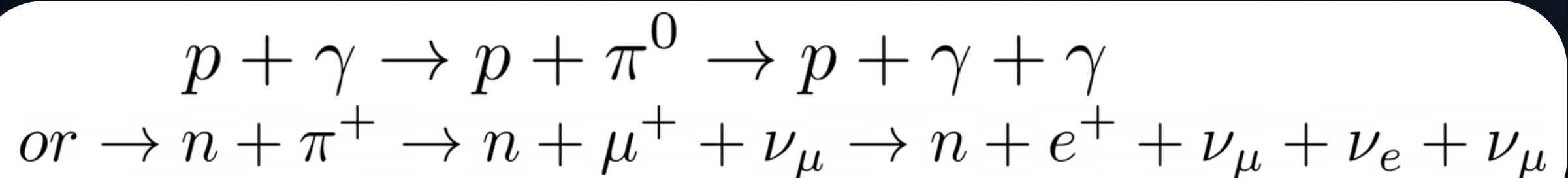
Peak positions restrain particle populations and magnetic fields.

Compare peak luminosities

Relative power of the components varies with jet power and model assumptions.

High-energy behaviour

The extension or cutoff at the highest energies helps discriminate between leptonic and hadronic scenarios.



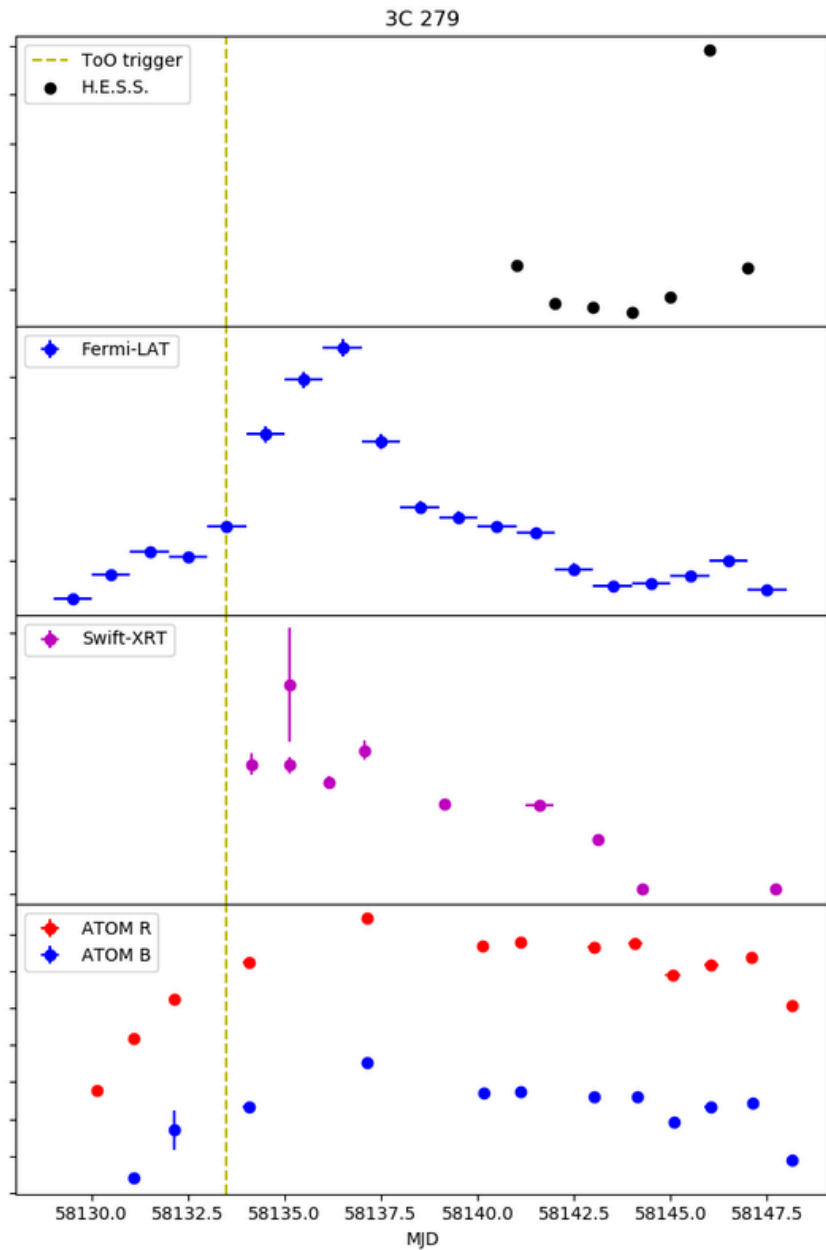
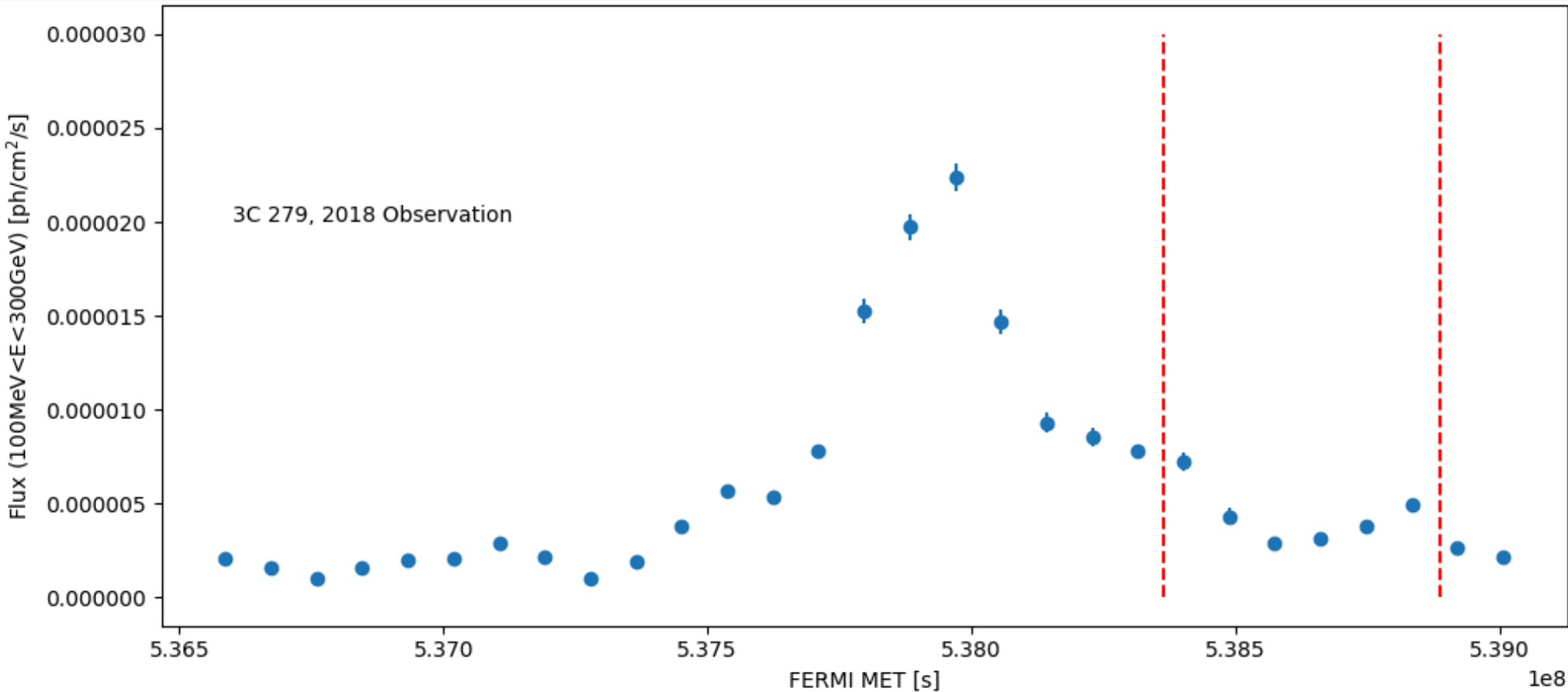
One band flares. The others stay relatively quiet.

ORPHAN FLARE

Strong variability in one energy band without simultaneous counterparts in others. Also often seen as a secondary flare following a multiwavelength primary flare

3C 279

Flat-spectrum radio quasar
redshift $z = 0.536$



Sequence: LAT + X-ray + optical flare → 11 days → orphan VHE flare on 28 Jan 2018

Three models to explain an orphan flare

01 Hadronic Synchrotron Mirror

Reflected synchrotron photons meet ultra-relativistic protons, producing delayed VHE emission.

02 Ring of Fire

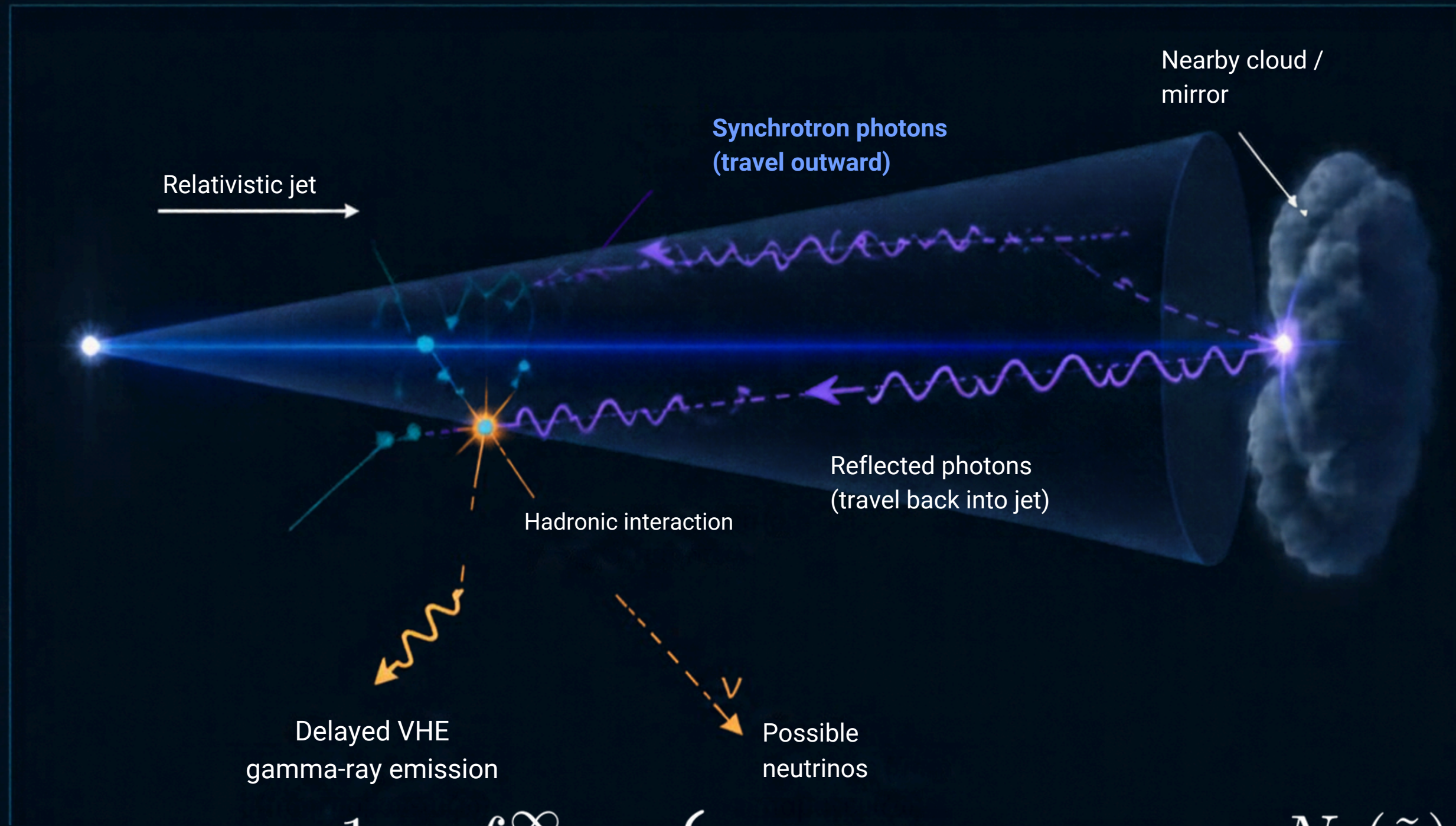
A relativistic blob crosses a shocked sheath or ring; inverse-Compton emission spikes in isolation.

03 Stochastic Dissipation

Flare behavior changes with dissipation location and conditions — a unified view of orphan and multiwavelength flares.

Hadronic Synchrotron Mirror Model

Laenita de Jonge and Prof Markus Böttcher



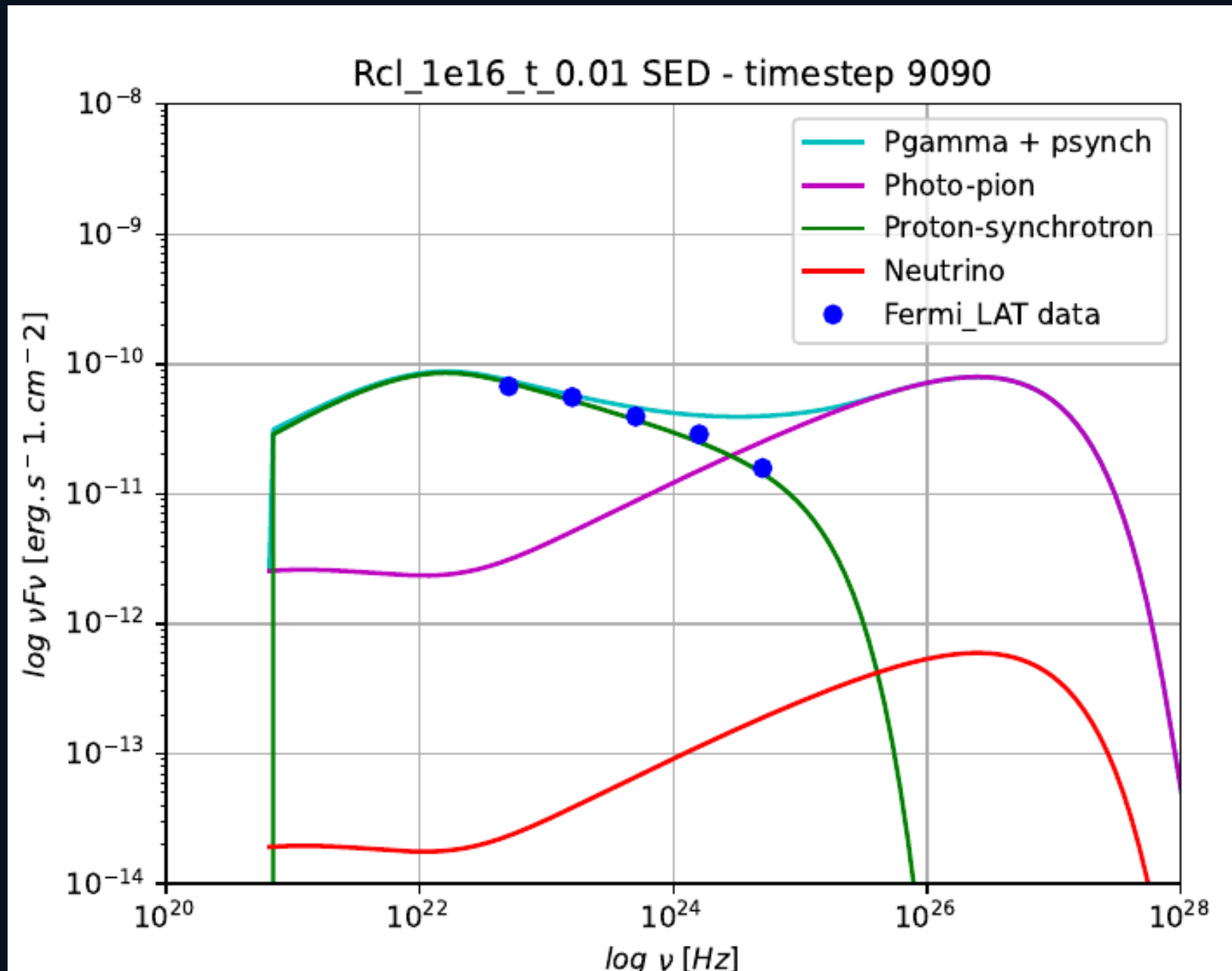
1. Relativistic electrons in the jet produce **synchrotron photons** that travel along the jet.
2. A nearby cloud or mirror **reflects a fraction** of these photons back into the jet.
3. The reflected photons interact with protons in the jet, creating a dense enough target photon field for photo-pion interactions.

This model **explains orphan VHE** flares and predicts possible **neutrino coincidences**. Example as done in [Böttcher, 2005]

$$N_e(\gamma) = \frac{1}{\nu_0 \gamma^2} \int_{\gamma}^{\infty} d\tilde{\gamma} \left\{ Q_e(\tilde{\gamma}) + \dot{N}_e^{\gamma\gamma}(\tilde{\gamma}) - \frac{N_e(\tilde{\gamma})}{t_{esc}} \right\}$$

- The photons from the photo-pion decay products are injected at high energies into the jet and form pair cascades.
- The cascades cause pair production and are responsible for the synchrotron radiation.

Hadronic synchrotron mirror model results



– KM3NeT: 7.39×10^{-2} events
 – IceCube: 2.69 events

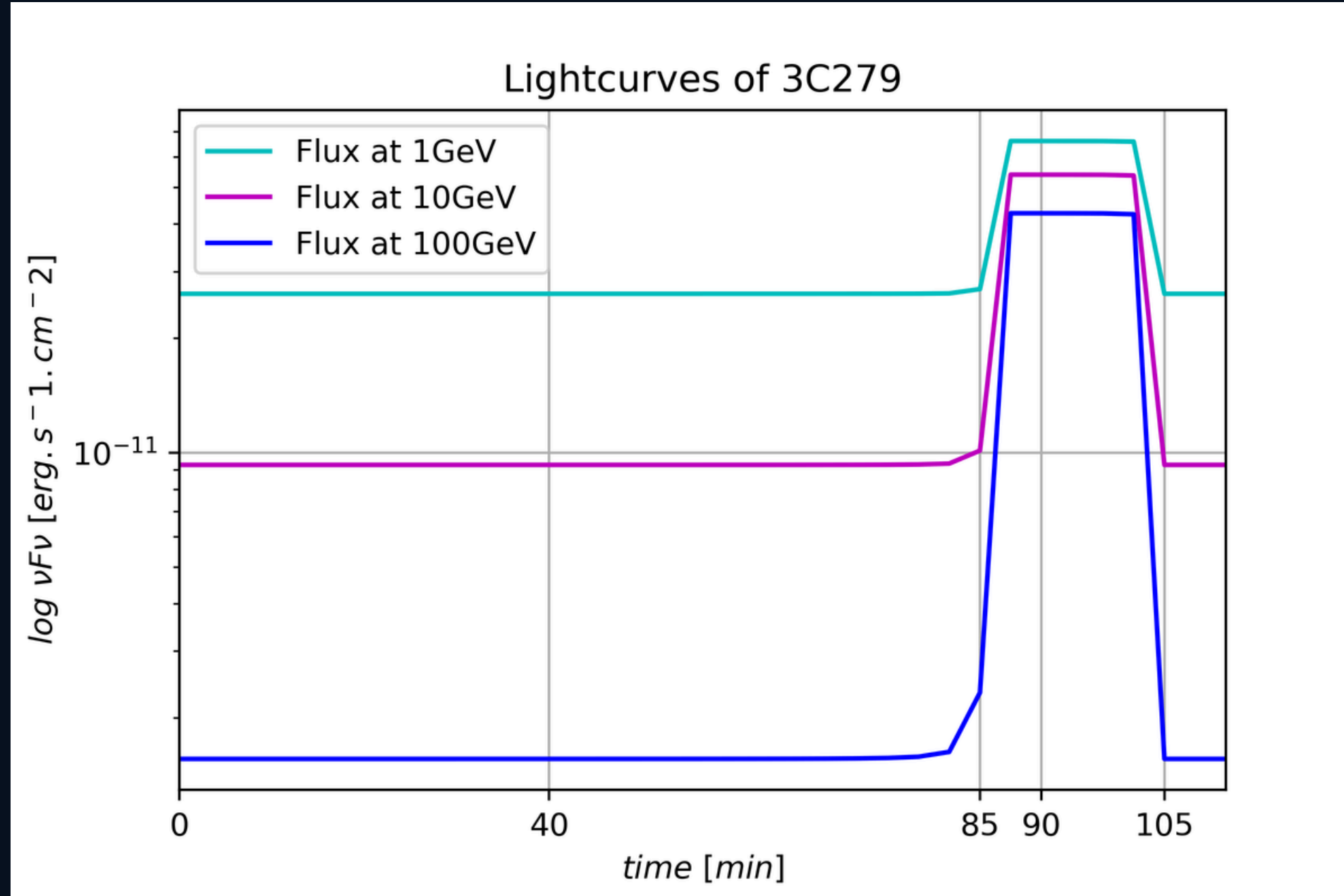
A neutrino coincidence would strongly favor hadronic activity and constrain the jet's energy budget.

Is the jet power proton or Poynting flux dominated?

- Close to equipartition
- Slightly proton dominated
- Jet power is a little bit larger than the Eddington luminosity.
- This can be explained by the fact that the jet is not in a steady state, so the jet power is only larger for the duration of the flare, and then reverts back to a lower value.

$$L_{Sum} \sim 2.8 \times 10^{47} \text{ erg.s}^{-1}$$

Hadronic synchrotron mirror model results



- The target photon field is dense enough for photo-pion interactions.
- This model does predict a moderate flare in Fermi-LAT, but with a much smaller amplitude than that of the VHE flare.
- This suggests that protons are accelerated to ultra-relativistic energies.
- The flare duration is predicted to be about half an hour long, the runtime of one H.E.S.S. observational run.
- Fermi-LAT typically needs longer integration times than half an hour to get a significant detection of 3C279, which could explain why no flare was seen in the Fermi-LAT light curve.

The Ring-of-Fire Model

By Dr. Nicholas R. MacDonald



1. The Encounter

A relativistic blob travels along the jet spine and crosses a localized ring of enhanced synchrotron photons produced by a shocked sheath.



2. Inverse-Compton Boost:

The blob inverse-Compton scatters these photons to gamma-ray energies, creating an intense, short-lived flare.



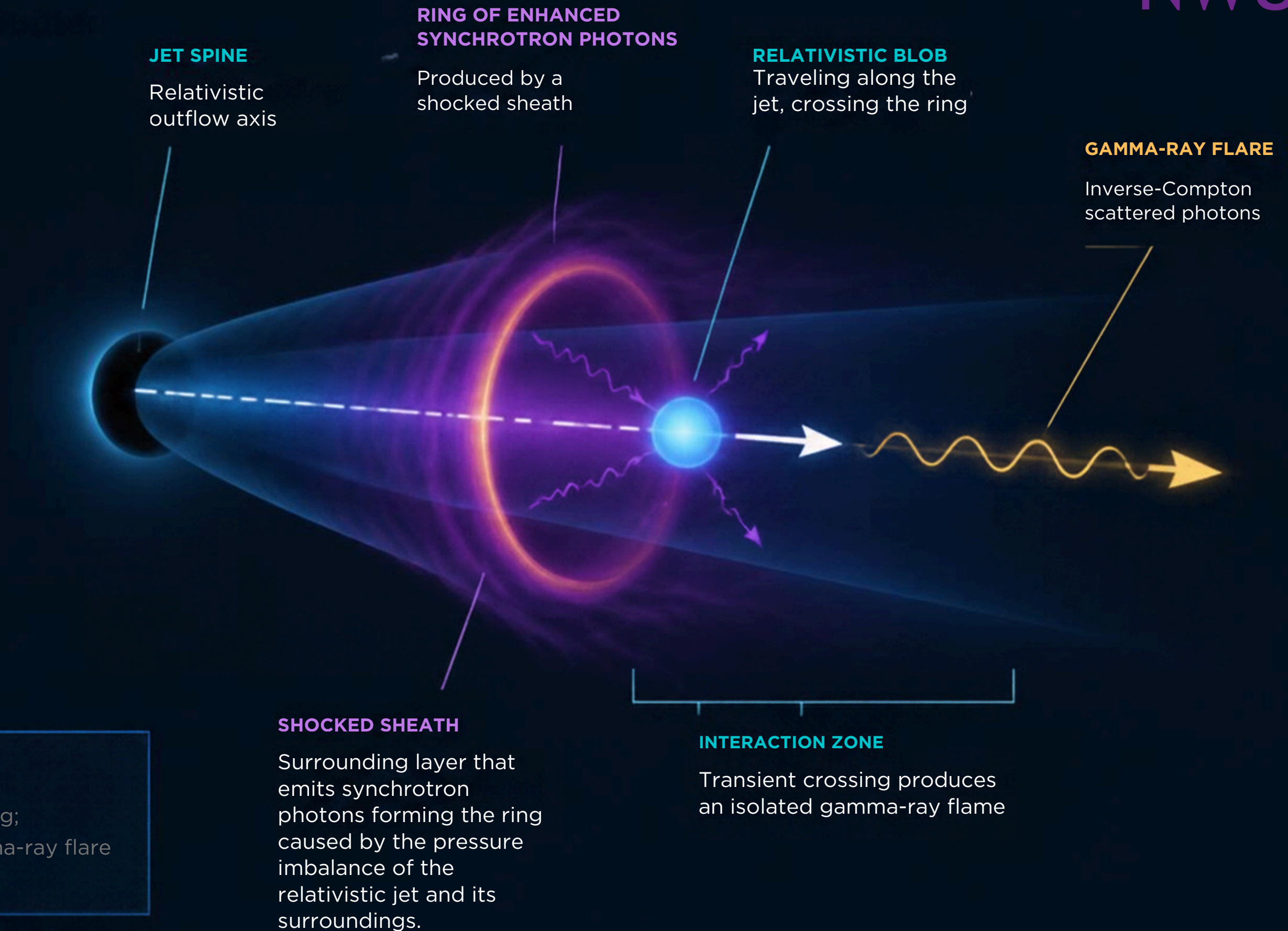
3. Orphan Signature

The gamma-ray flare is temporally isolated, with weak or absent optical and radio counterparts.

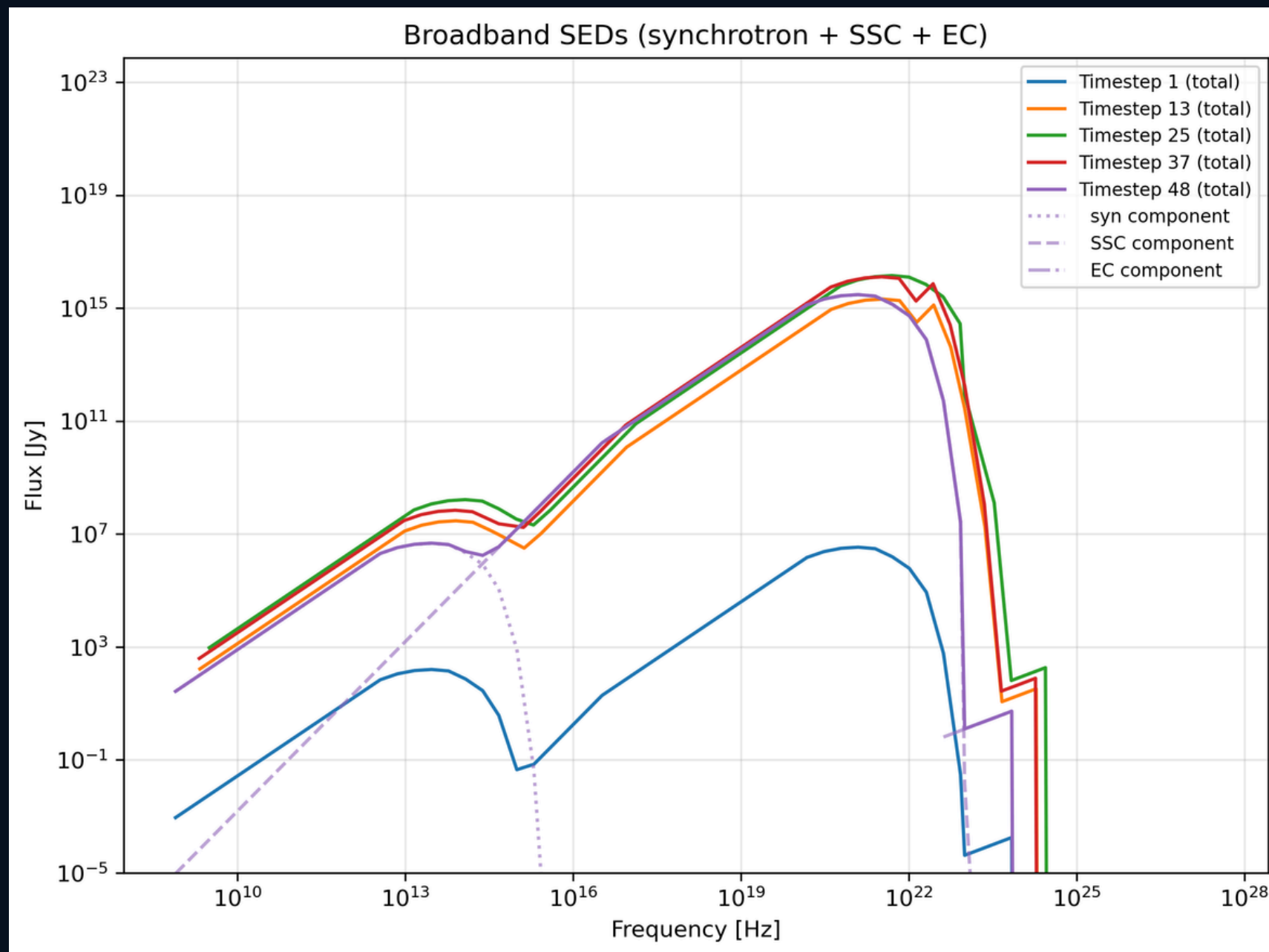


TAKEAWAY

The shocked sheath provides the photon ring; the crossing event creates a transient gamma-ray flare with no strong multiwavelength echo.



Ring-of-Fire Model results



Steady electron spectrum

Synchrotron + EC cooling balanced against injection, solved analytically rather than integrated numerically:

$$n(\gamma) = n_0 \gamma^{-s} (1 - q_1)^{s-2} + q \gamma^{-(s+1)} [1 - (1 - q_1)^{s-1}] / [m_e c^2 \beta (s-1)]$$

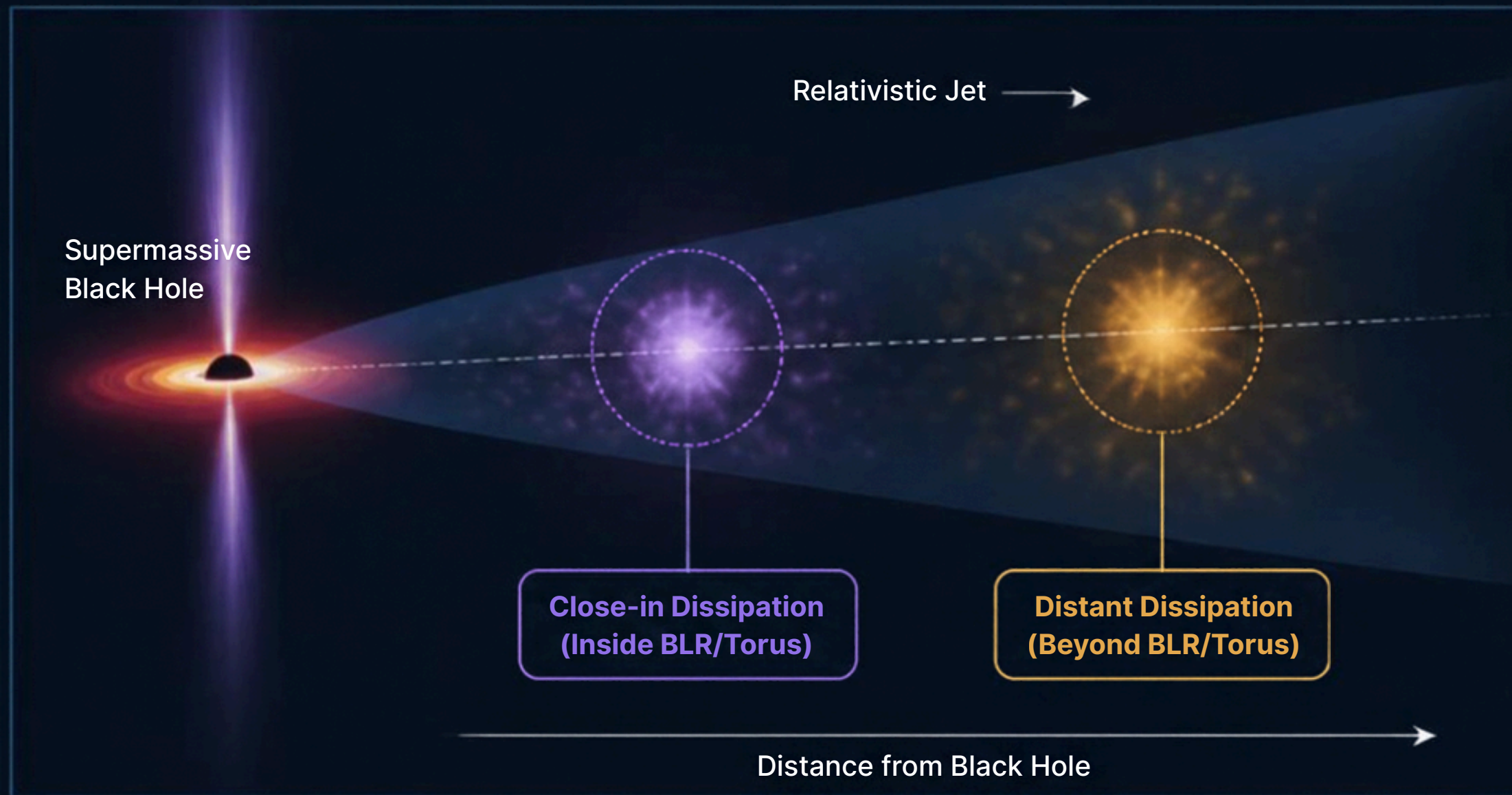
β is whichever cooling channel is switched on (synchrotron, or synchrotron+EC).

Explanation

- MacDonald et al. (2017) have had success using this model to model orphan flares in PKS 1510–089, 3C 273, 4C 71.01, 3C 279, 1055+018, CTA 102, and 3C 345 also using VLBI stacking techniques that reveal shocked sheaths.
- Electrons injected as a broken power law, cooled to steady state against synchrotron, SSC, and external Compton off BLR and dust-torus grey-bodies.
- Radiative transfer handed to naima — exact synchrotron kernel, full Klein-Nishina Compton cross-section — rather than a hand-rolled approximation.

Stochastic Dissipation: Unified Model for orphan and multiwavelength blazar flares

By Dr. Ruoyu Liu



Close-in Dissipation: Orphan Flares

Dissipation within the broad-line region (BLR) or dusty torus is dominated by external inverse-Compton scattering of external photons, producing a strong gamma-ray flare with little or no X-ray counterpart.



Distant Dissipation: Multiwavelength Flares

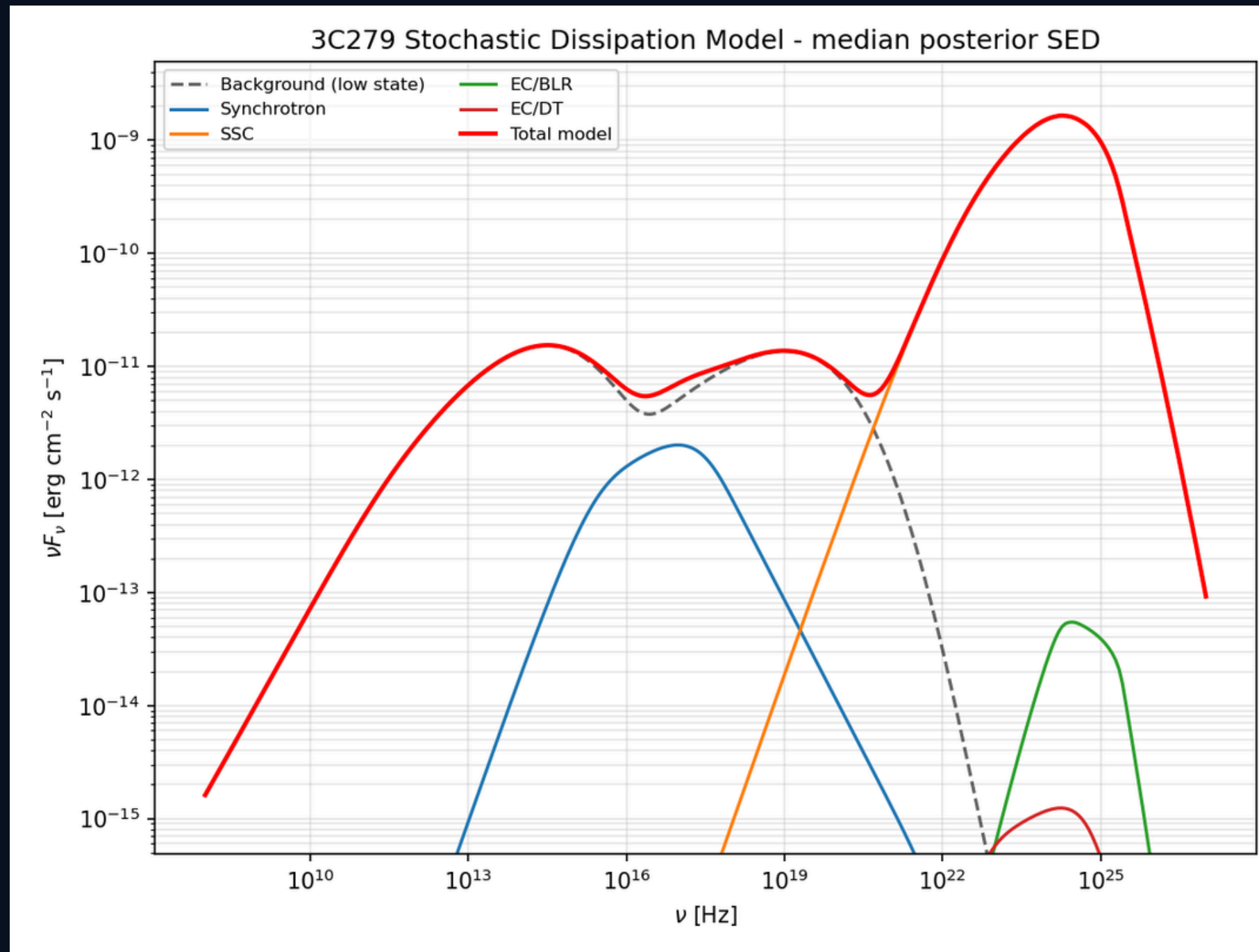
Dissipation farther down the jet has lower external photon density; synchrotron and SSC emission strengthen, producing correlated variability across gamma-ray, X-ray, and lower-energy bands.



KEY TAKEAWAY

The same jet physics — stochastic dissipation at different distances — naturally unifies orphan (gamma-ray—only) and multiwavelength blazar flares.

Stochastic dissipation reproduces the SED shape



Explanation

- Wang et al. (2022): a jet built from a sequence of blobs at different distances r from the black hole; blob size, field, and Doppler factor all scale with r .
- Electrons injected as a broken power law, cooled to steady state against synchrotron, SSC, and external Compton off BLR and dust-torus grey-bodies.
- Radiative transfer handed to naima — exact synchrotron kernel, full Klein–Nishina Compton cross-section — rather than a hand-rolled approximation.

Example parameters — not direct measurements

$$B \approx 18 \text{ G}$$

$$R = 10^{16} \text{ cm}$$

$$\Gamma = 20 \quad \cdot \quad s = 3.5$$

$$\nu_{\text{syn}} \approx 4.7 \times 10^{14} \text{ Hz}$$

$$\nu_{\gamma} \approx 1.59 \times 10^{23} \text{ Hz}$$

Differences between the hadronic and leptonic models

HADRONIC

- **Neutrino emission possible**
- **Delayed orphan VHE flare**
- **Harder highest-energy spectrum**

LEPTONIC

- **Correlated multiwavelength flare**
- **Short synchrotron–IC delays**
- **Syn + SSC + EC evolution**

Thank you for your time

Future plans

Investigating these three models across multiple objects and flaring events to gauge accuracy of each model.

Questions?

A photon checks into a hotel and is asked if he needs any help with his luggage.

The photon says “No thanks, I’m travelling light”.