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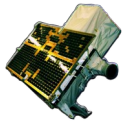

AGILE Satellite
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HIGH ENERGY ASTROPHYSICS
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Large-Scale Environments in BL Lac objects: Connecting Gamma-Ray Absorption Features to Neutrino Production

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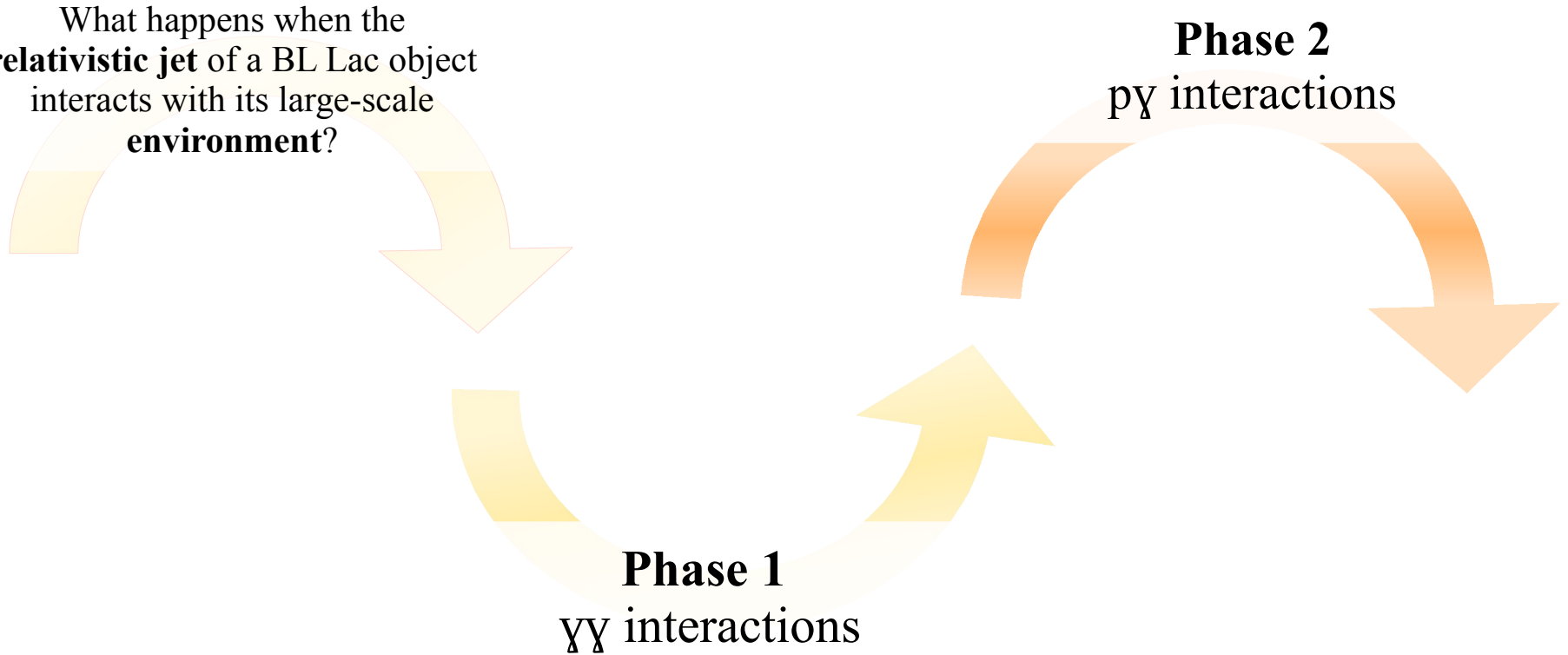
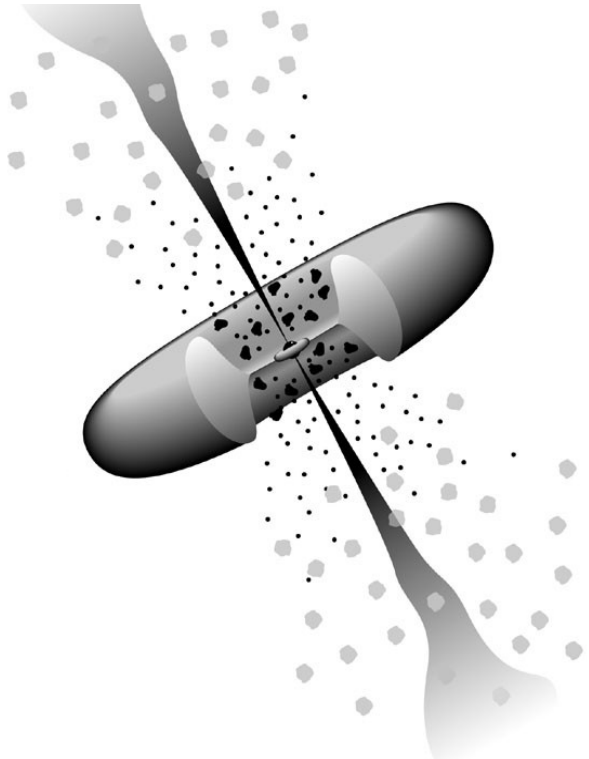
Overview

What happens when the **relativistic jet** of a BL Lac object interacts with its large-scale **environment**?



Environmental Structures in Active Galactic Nuclei

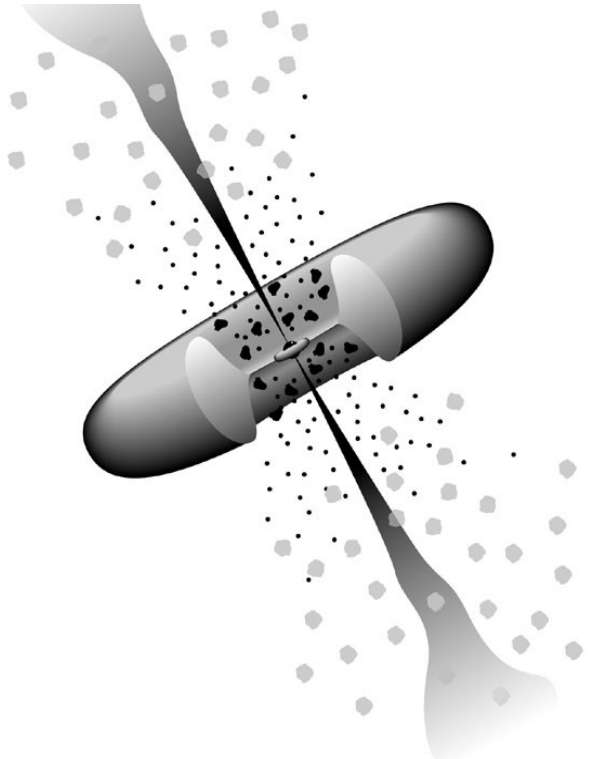


Adapted from Urry&Padovani+1995

Environment around jets of active galactic nuclei formed by medium- to large-scale structures, e.g.:

- Broad-line region (BLR)
- **Narrow-line region** (NLR)

Environmental Structures in Active Galactic Nuclei



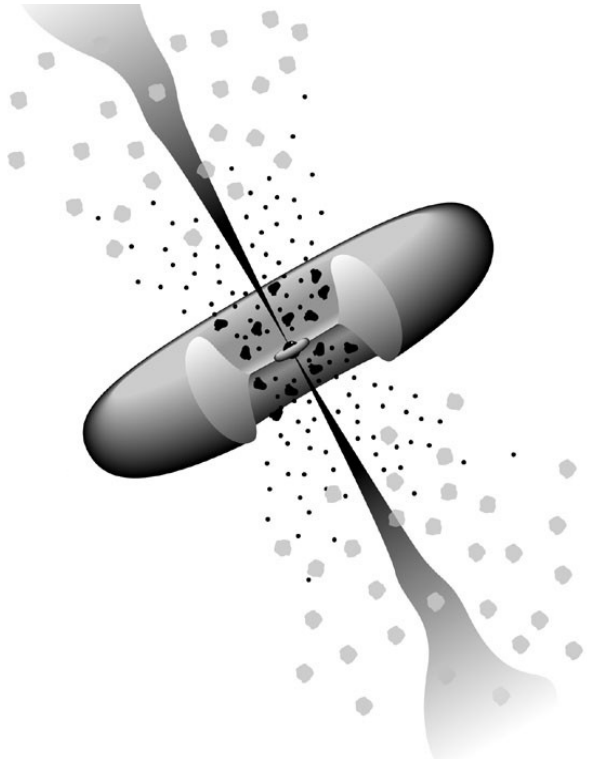
Adapted from Urry&Padovani+1995

Environment around jets of active galactic nuclei formed by medium- to large-scale structures, e.g.:

- Broad-line region (BLR)
- **Narrow-line region** (NLR)
- Further / intermediate regions in specific types of AGNs, depending on matter state and physical conditions: e.g. Intermediate (ILR) or extended narrow-line region, ENLR

Zoology of AGNs is very complex: correlated with their evolution history

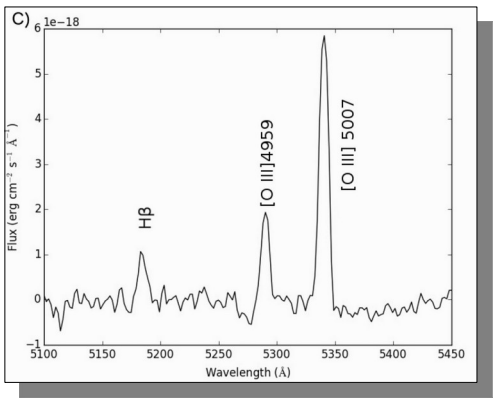
Environmental Structures in Active Galactic Nuclei



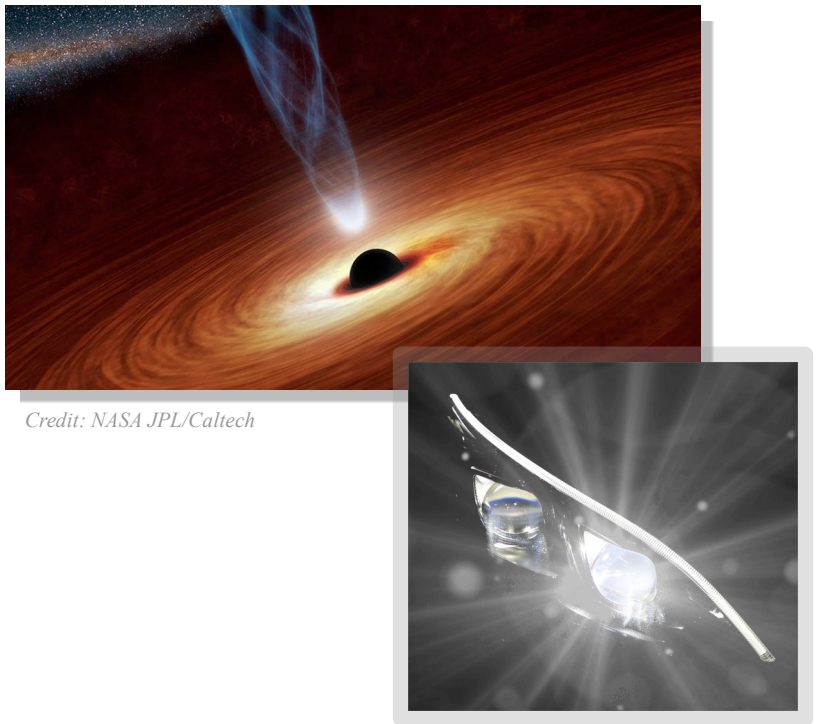
Adapted from Urry&Padovani+1995

How do we detect large-scale environments in AGNs?

Standard methods to detect large-scale environmental structures in AGNs are based on their **optical spectra**



Large-Scale Environmental Structures in BL Lac Objects



Credit: NASA JPL/Caltech

In **BL Lac objects**, the relativistic jet points directly to the observer.

The non-thermal continuum of the relativistic jet overwhelms any thermal emissions emitted from large-scale structures

✗ standard methods can not be applied

✓ **an indirect method may do the work!**

Which large-scale structures are present in BL Lac objects?

Do the large-scale structures survive to the evolution in BL Lac objects?

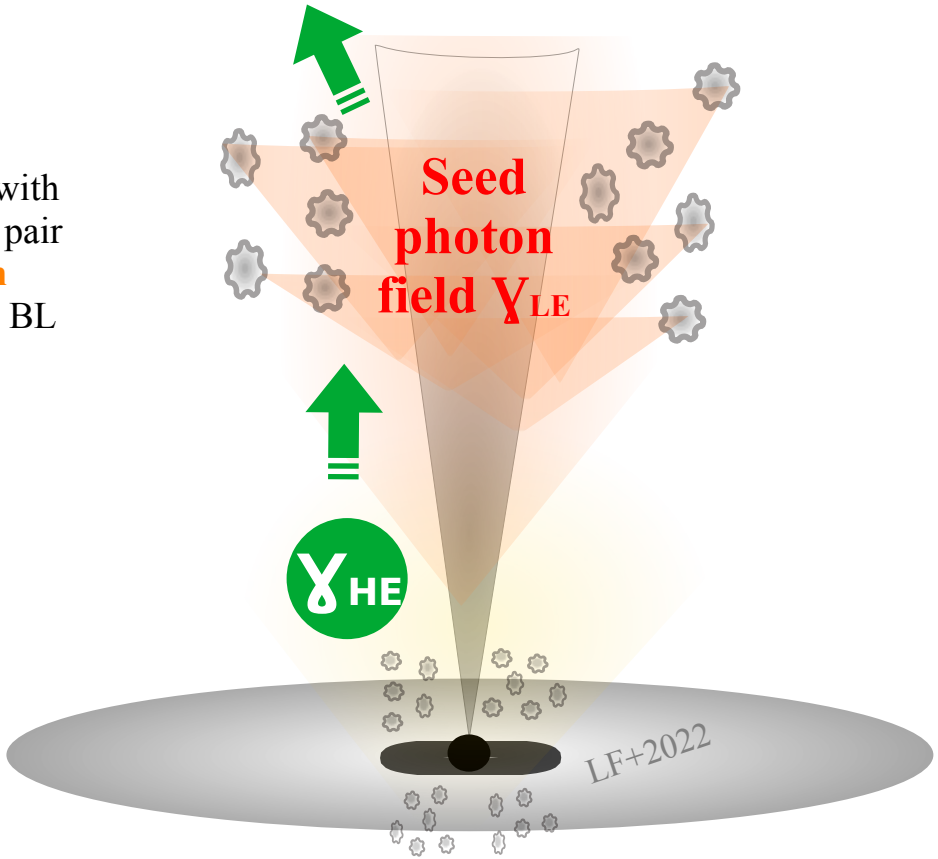
Phase 1

γ-γ interactions
→ absorption features
in the gamma-ray spectrum of BL Lac objects

LF, Vittorini, Tavani+2022, ApJ, 926, 95

Gamma rays of the jet may interact with optical-UV seed photon field via γ-γ pair production, producing **absorption features** in the γ-ray spectrum of the BL Lac object.

$$\gamma_{gamma} + \gamma_{seed} \rightarrow e^+ + e^-$$

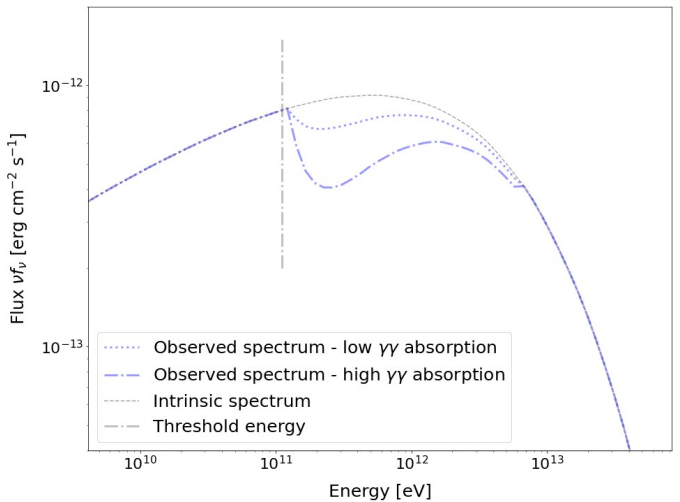


Theory vs real data

Phase 1

LF, Vittorini, Tavani+2022, ApJ, 926, 95

Theoretical absorption feature



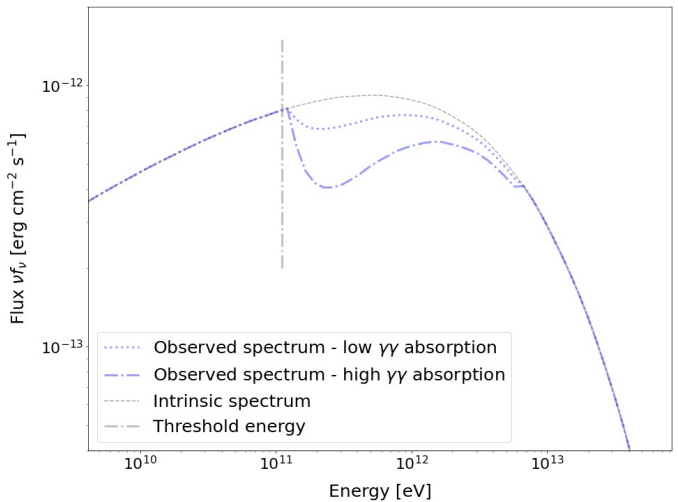
The properties of the absorption feature can be directly connected with the properties of the seed photon field
→ indirectly connected to the large-scale structure itself

Theory vs real data

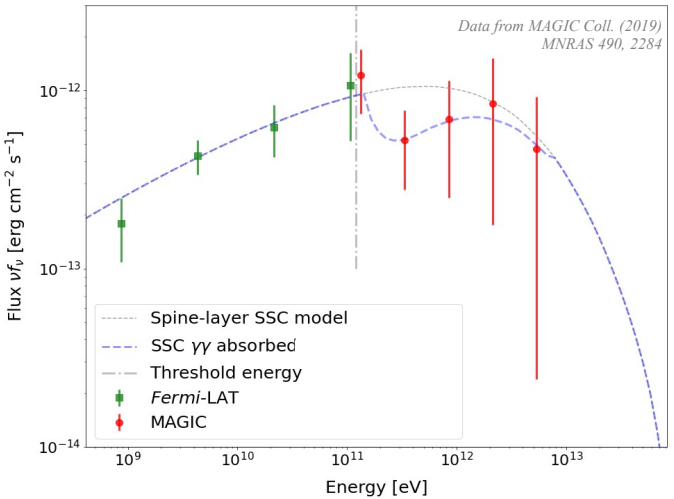
Phase 1

LF, Vittorini, Tavani+2022, ApJ, 926, 95

Theoretical absorption feature



Real data of a new extreme blazar PGC 2402248



Compatible with a narrow-line region!

How many?

A systematic analysis of gamma-ray spectra of BL Lac objects is being performed

Phase 1

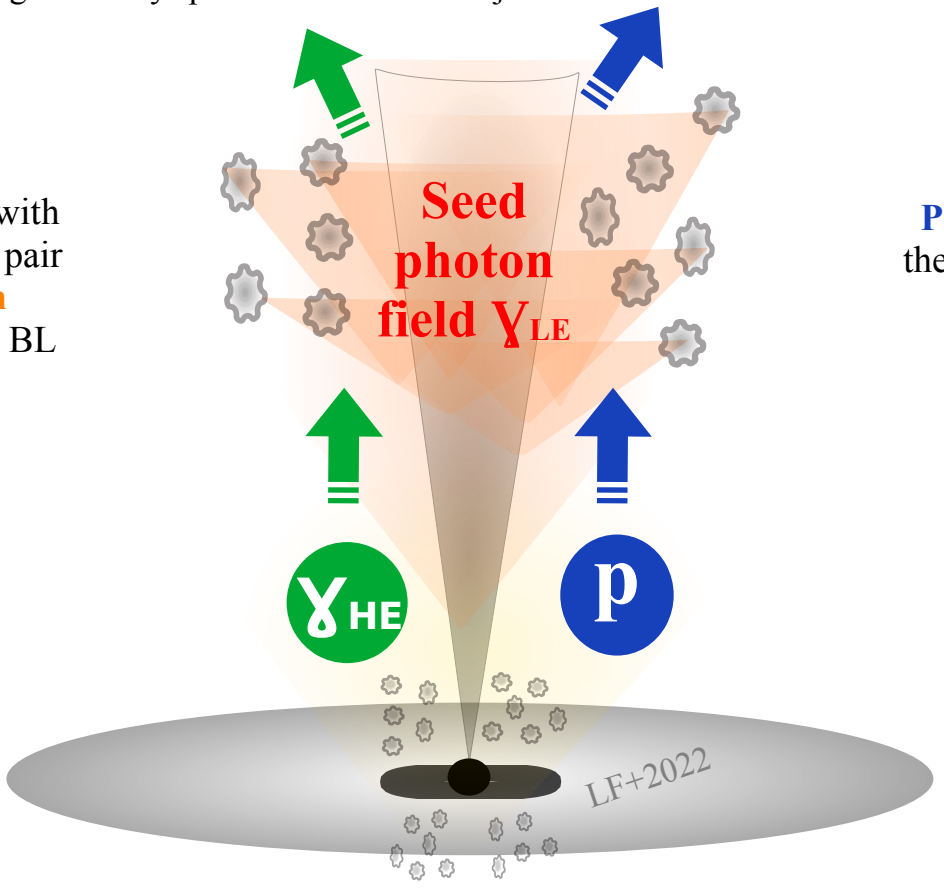
ɣ-ɣ interactions
→ absorption features
in the gamma-ray spectrum of BL Lac objects

Phase 2

p-ɣ interactions
→ neutrinos!

Gamma rays of the jet may interact with optical-UV seed photon field via ɣ-ɣ pair production, producing **absorption features** in the ɣ-ray spectrum of the BL Lac object.

$\gamma_{gamma} + \gamma_{seed} \rightarrow e^+ + e^-$

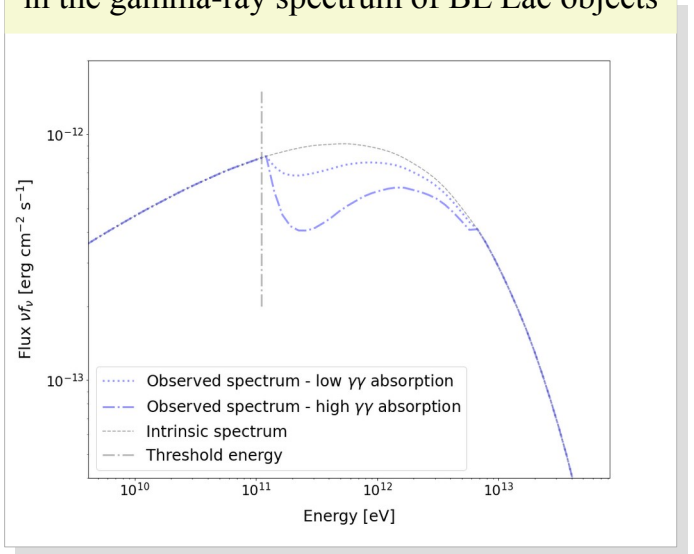


Protons in the jet may interact with these seed photon field via p-ɣ photo-meson production, eventually producing **neutrinos.**

Phase 1

Phase 2

γ-γ interactions
→ absorption features
in the gamma-ray spectrum of BL Lac objects



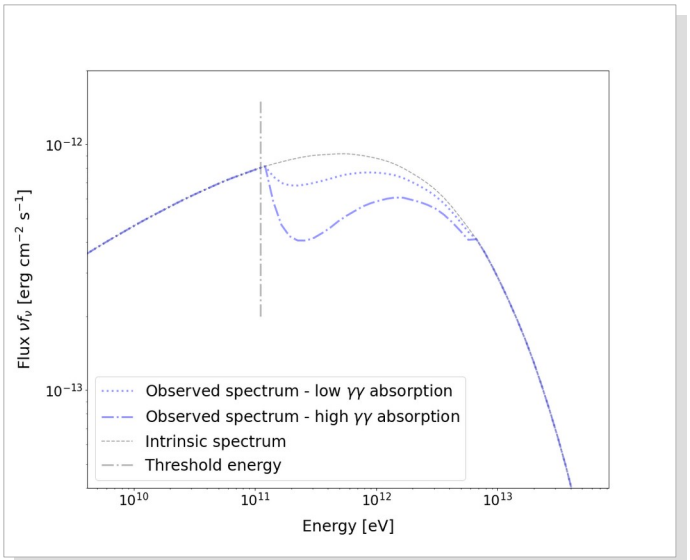
p-γ interactions

Neutrino spectrum and flux

Studying the correlation between the **gamma-ray absorption features** and the corresponding **neutrino flux**

Direct approach

LF+2024,
in preparation



1) Assume the **absorption feature** in the gamma-ray spectrum of the BL Lac object is due to the $\gamma\gamma$ interaction between the relativistic jet and the NLR
2) The **absorption factor** may correlate with the **efficiency** of neutrino production from pγ reactions following:

$$\tau_{\gamma\gamma}(\epsilon_\gamma^c) \simeq 10 \left(\frac{f_{p\gamma}(\epsilon_p)}{0.01} \right)$$

e.g. Murase+05, +16, +18

The stronger the absorption due to $\gamma\gamma$ interaction,
the higher the pγ efficiency

Key goals:

- Link the neutrino flux directly to the **absorption feature** in the gamma-ray spectrum of a BL Lac object
- Run **simulations** scanning over the interacting region, the relativistic jet, and the AGN properties
- Find the best conditions where neutrino production is significative

Conclusions

Context: Standard methods struggle to identify large-scale structures in BL Lac objects due to the dominant radiation from relativistic jets

This work:

- **Phase 1:** New method to provide indirect estimations on the large-scale environments studying **absorption features** in the **gamma-ray spectrum** of the BL Lac object, produced by the **$\gamma\gamma$ interaction** between the relativistic jet and the environmental photon fields.
- **Phase 2:** Explore how these interactions also trigger **$p\gamma$ processes,** potentially leading to production of **neutrinos from BL Lac objects**

Thank you!