Probing AGN variability with the Cherenkov Telescope Array

γ—2022 — 7th Heidelberg International Symposium on High-Energy Gamma-ray Astronomy

Tuesday 5th of July 2022

FLORIANE CANGEMI

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for the CTA CONSORTIUM

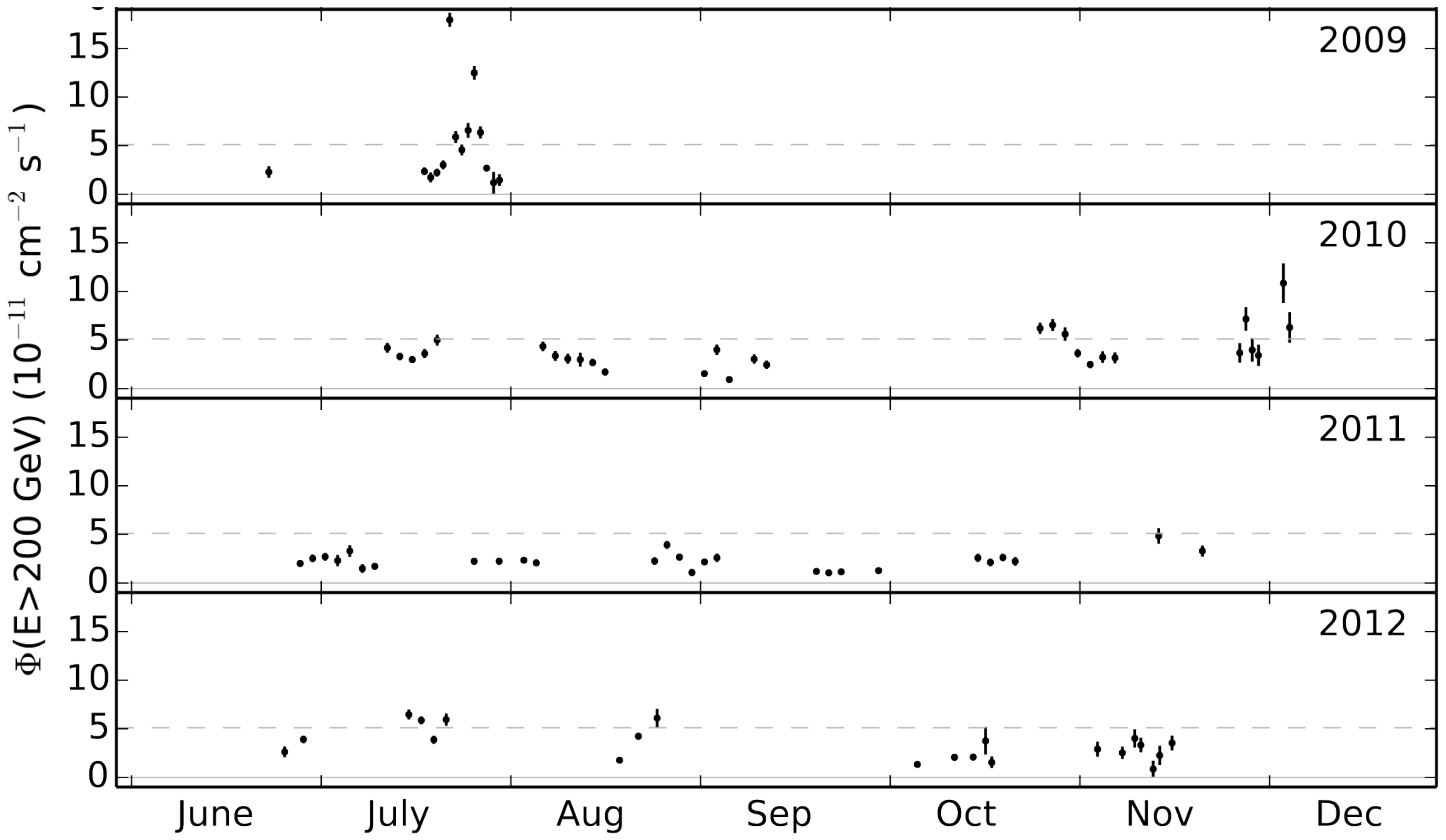
Variability in AGNs

AGNs can be **highly variable...**

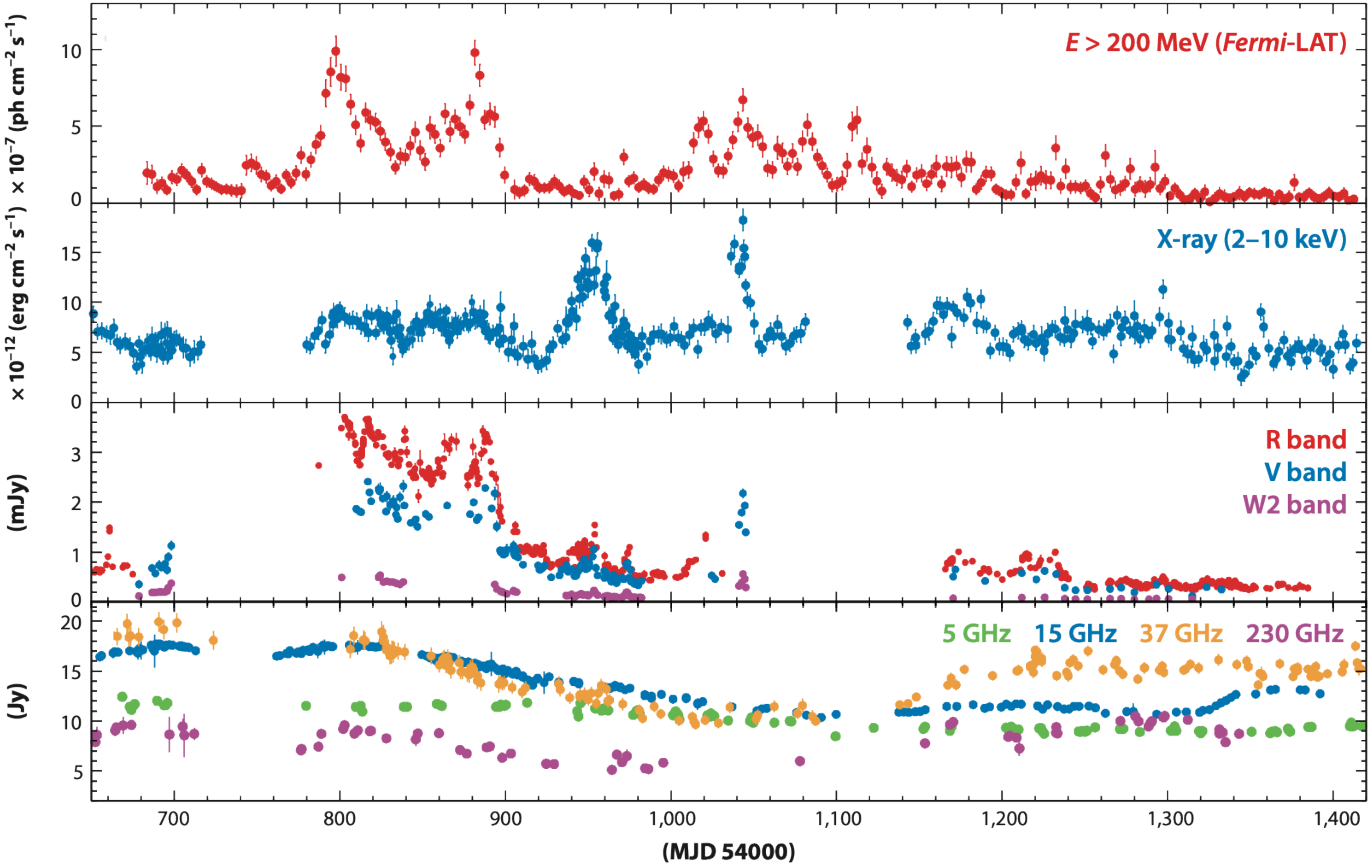
...in all wavelengths

From radio to γ-rays

PKS 2155—304 ***H.E.S.S. Collaboration+2016***



3C 279 ***Adapted from Hayashida+2012***



Variability in AGNs

AGNs can be **highly variable...**

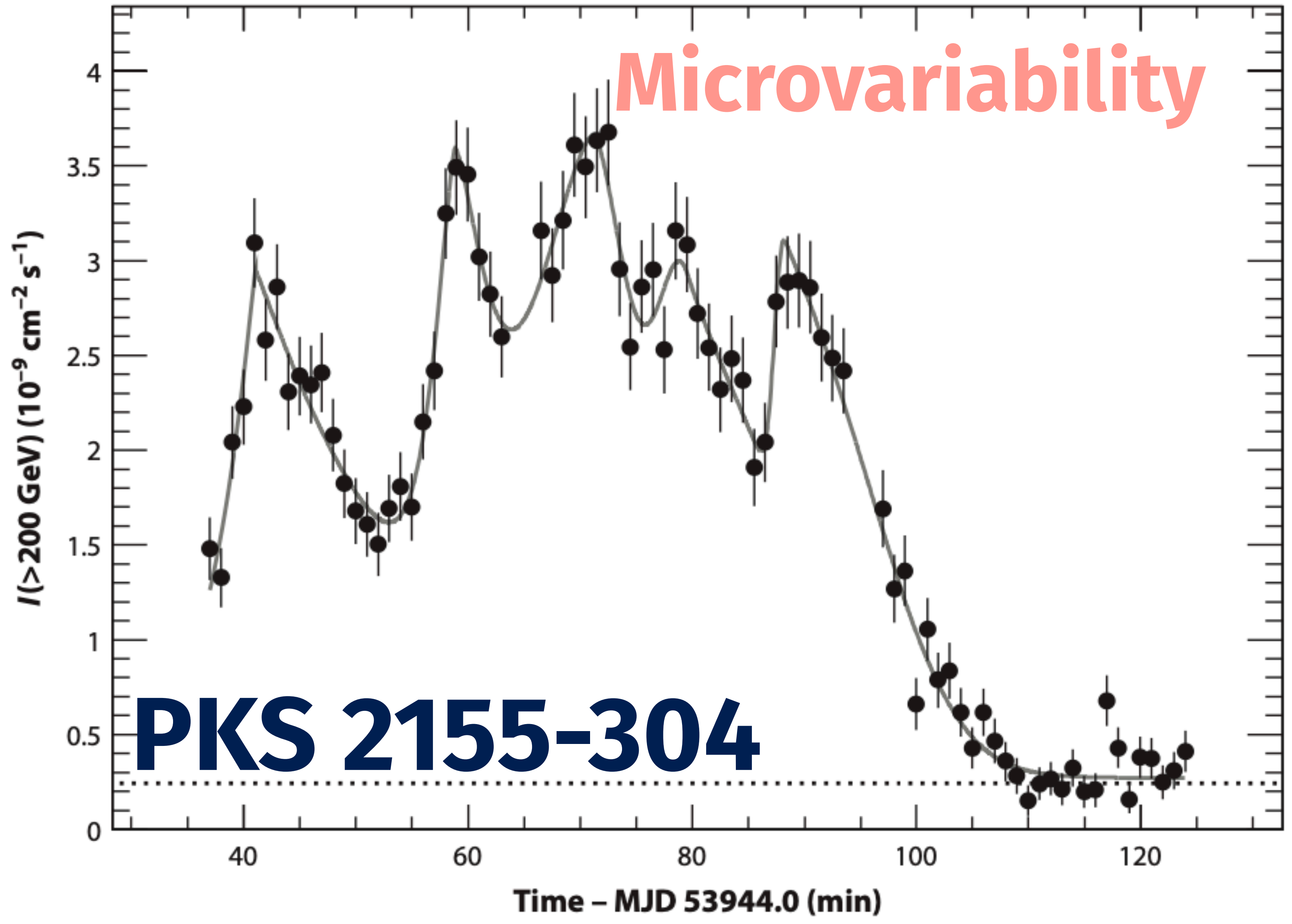
...at all timescales

Long-term variability (decades, years, months)

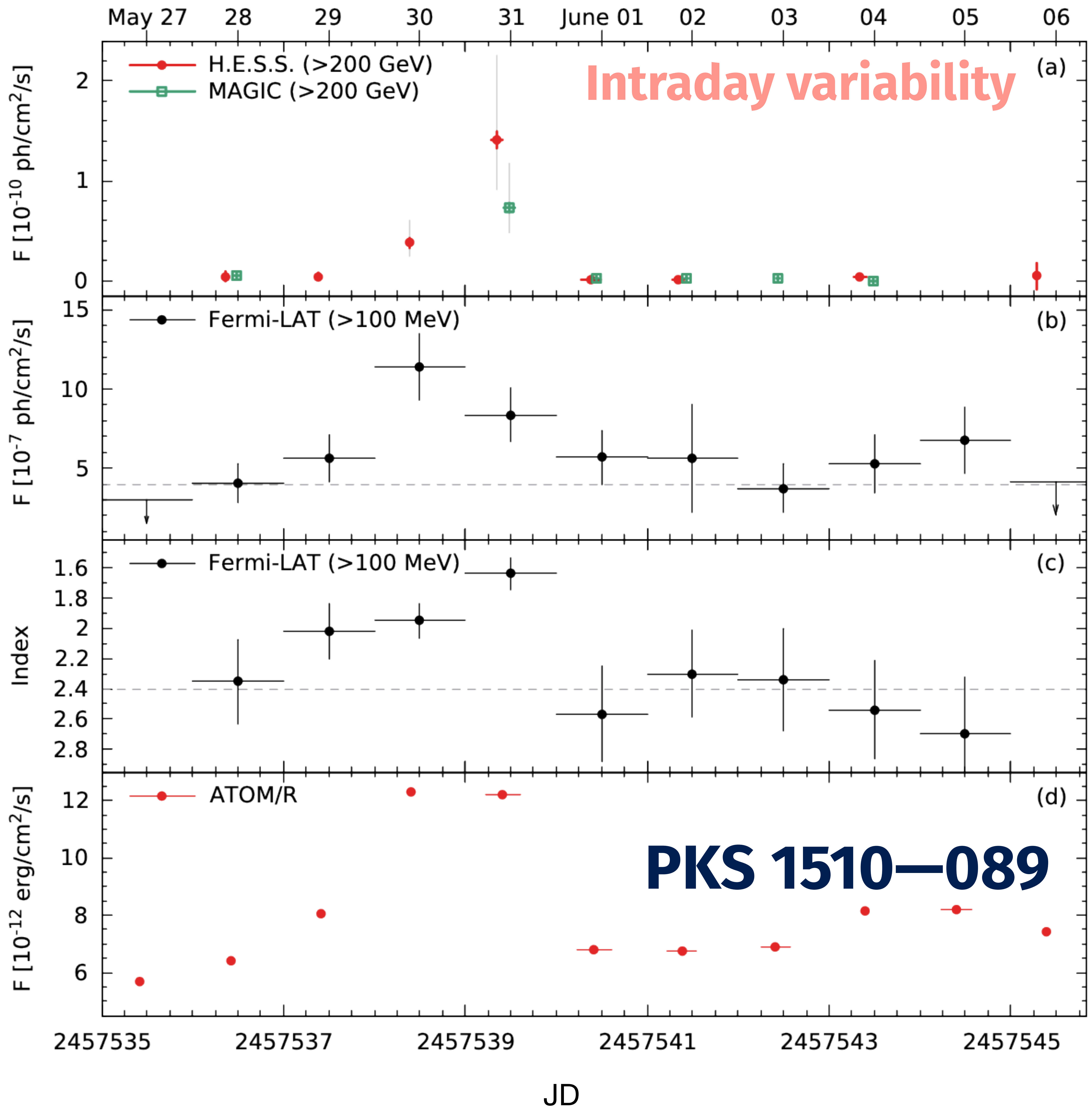
Intraday variability (within hours)

Microvariability (within a night, minutes)

H.E.S.S. Collaboration+2007



H.E.S.S.&MAGIC Collaborations+2021



Variability in AGNs

Where do these variabilities come from?

Long-term variability

- Jets **precession**?
- Tilted accretion disks?

Intraday variability and Microvariability

- Magneto-hydrodynamic **instabilities** in the jets/disk?
- **Shocks** in the jets?
- **Relativistic effects** due to jets orientation?

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What can we learn from studying variabilities in AGNs at VHE?

- Probe the **dynamics** and the **jet structure**;
- Infer **spatial scales** of the emission region;
- Provides unique insights into **accelerations processes** and **radiative mechanisms** occurring in relativistic jets?

Variability in AGNs

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CTA will be able to follow the emission from these objects with a very accurate time sampling and over a wide spectral coverage from 20 GeV to 300 TeV!

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CTA Observatory

CTA will be an array of more than 50 Cherenkov telescopes located in the northern and southern hemispheres.

South (Paranal desert, Chile)

North (Canary Islands Spain)

CTA Observatory

3 different sized telescopes

Medium Sized Telescope
100 GeV to 10 TeV

Small Sized Telescope
1 TeV to 300 TeV

One telescope already taking data on La Palma

Large Sized Telescope
20 GeV to 200 GeV

CtaAgnVar

In order to infer CTA capabilities to **characterize variability in AGNs** and **disentangle emission processes**, we have developed our simulation tool:

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CtaAgnVar — Python package based on **Gammapy** that **simulates realistic observations** of AGN flares and long-term light curves.

- Take into account **CTA observational constraints** and **source visibility** during the year;
- Use **latest instrumental responses** available for both sites;
- Track the source in the sky during the night and take into account the **evolution of the elevation angle**.

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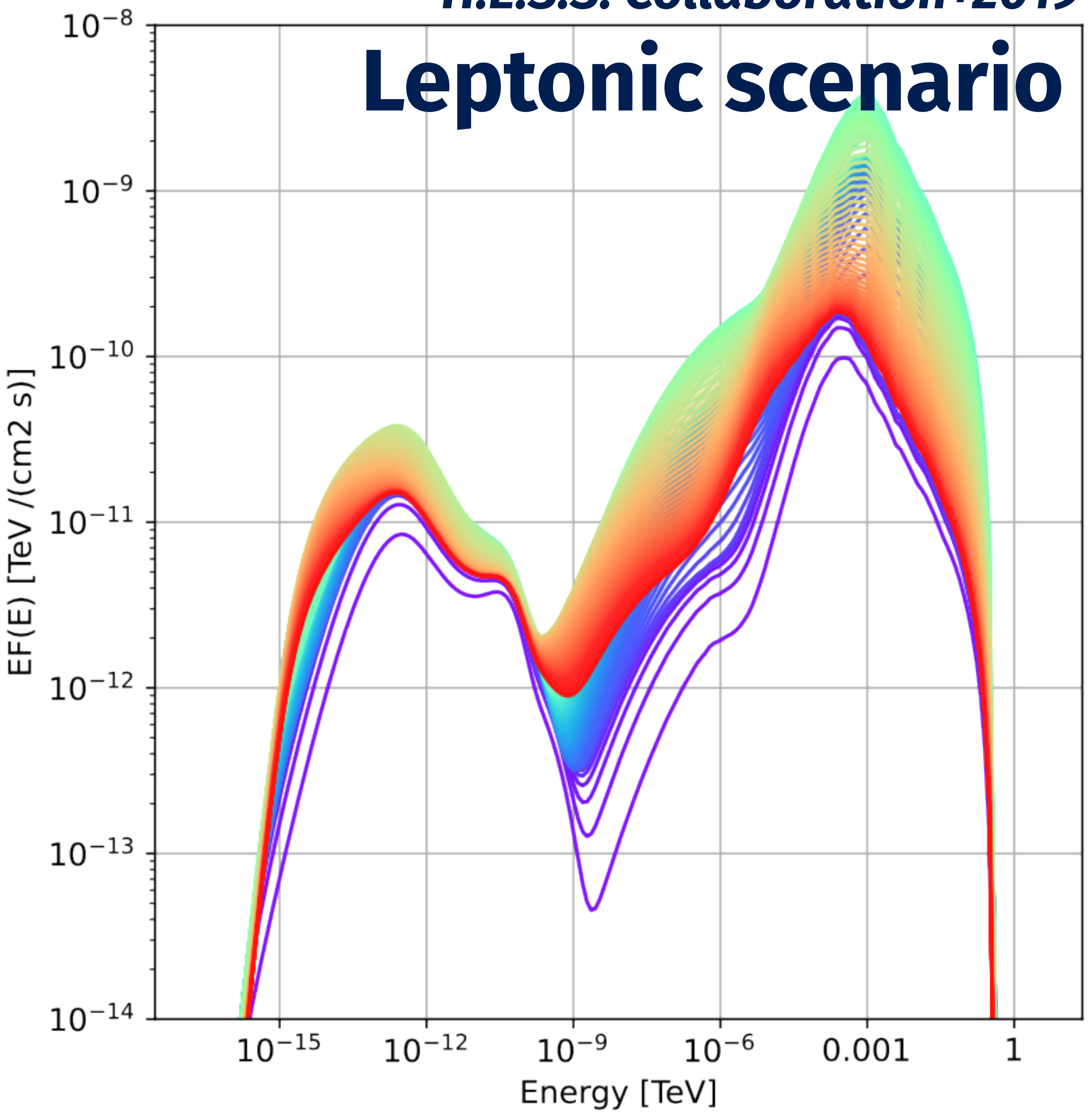
Flare simulations

3C 279 – June 2015 flare

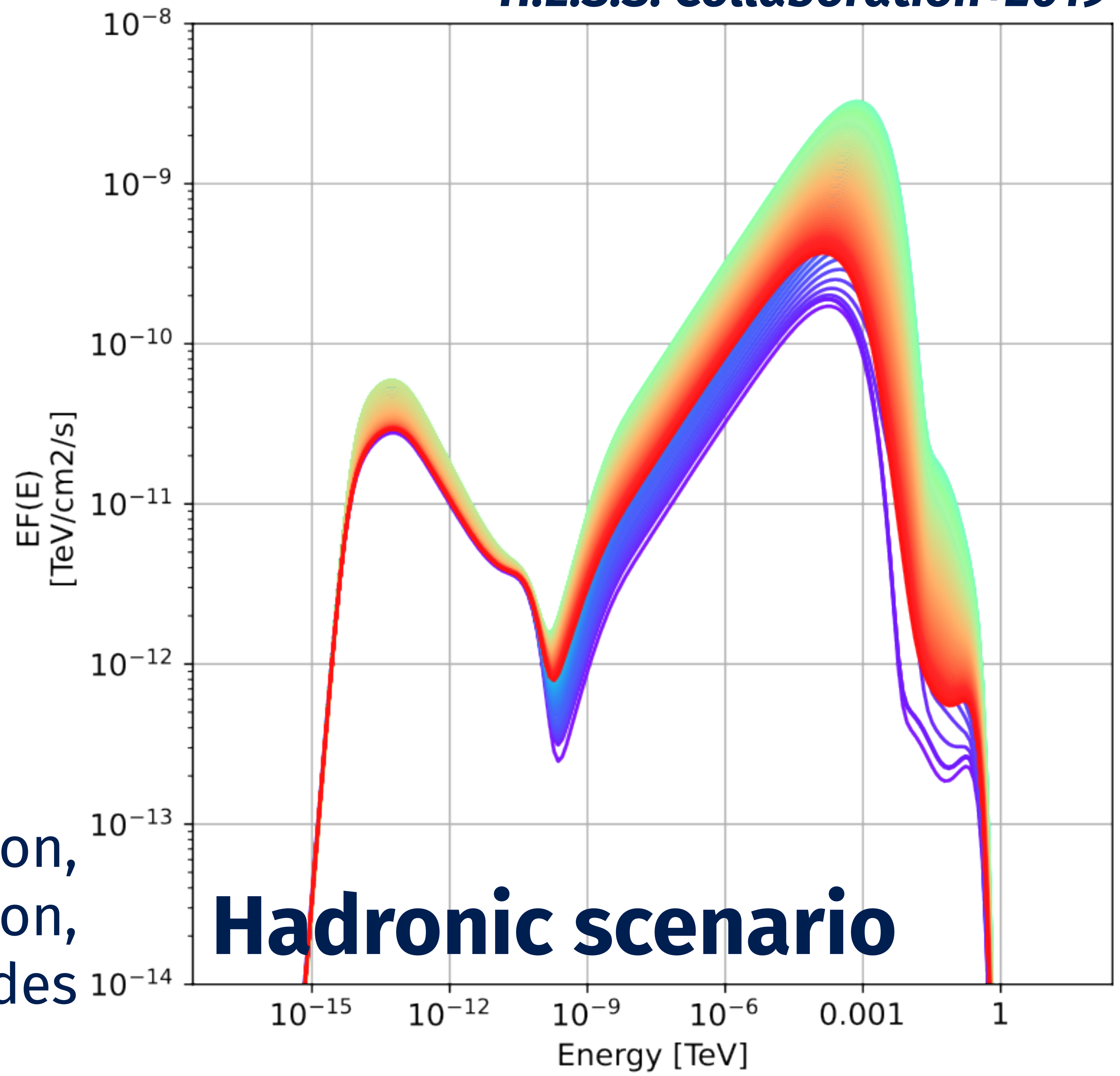
One zone time-dependent input models

H.E.S.S. Collaboration+2019



Standard SSC and IC processes with broad-line region, accretion disk and dusty torus

H.E.S.S. Collaboration+2019



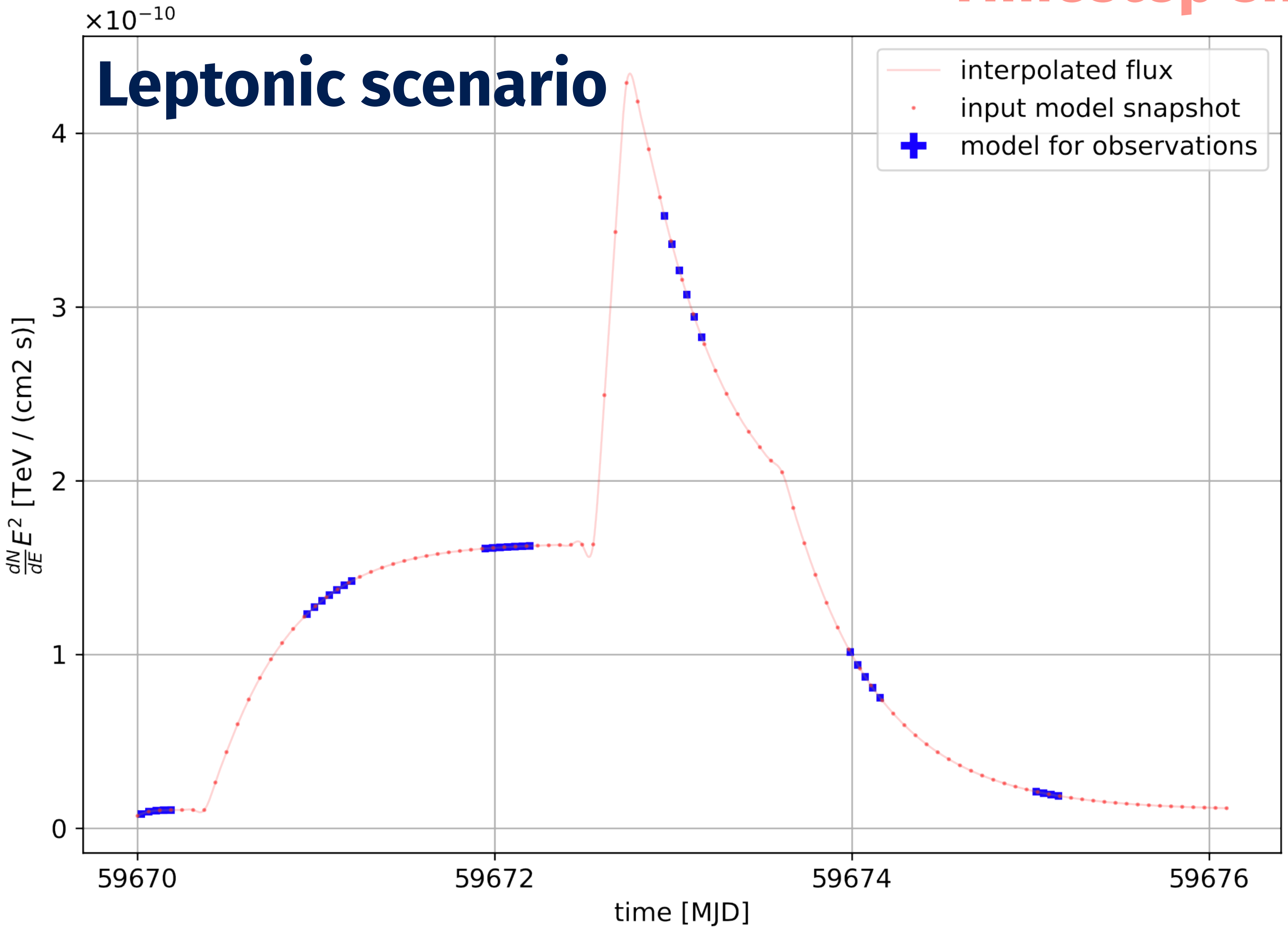
Electron synchrotron, proton synchrotron, Photo-meson cascades

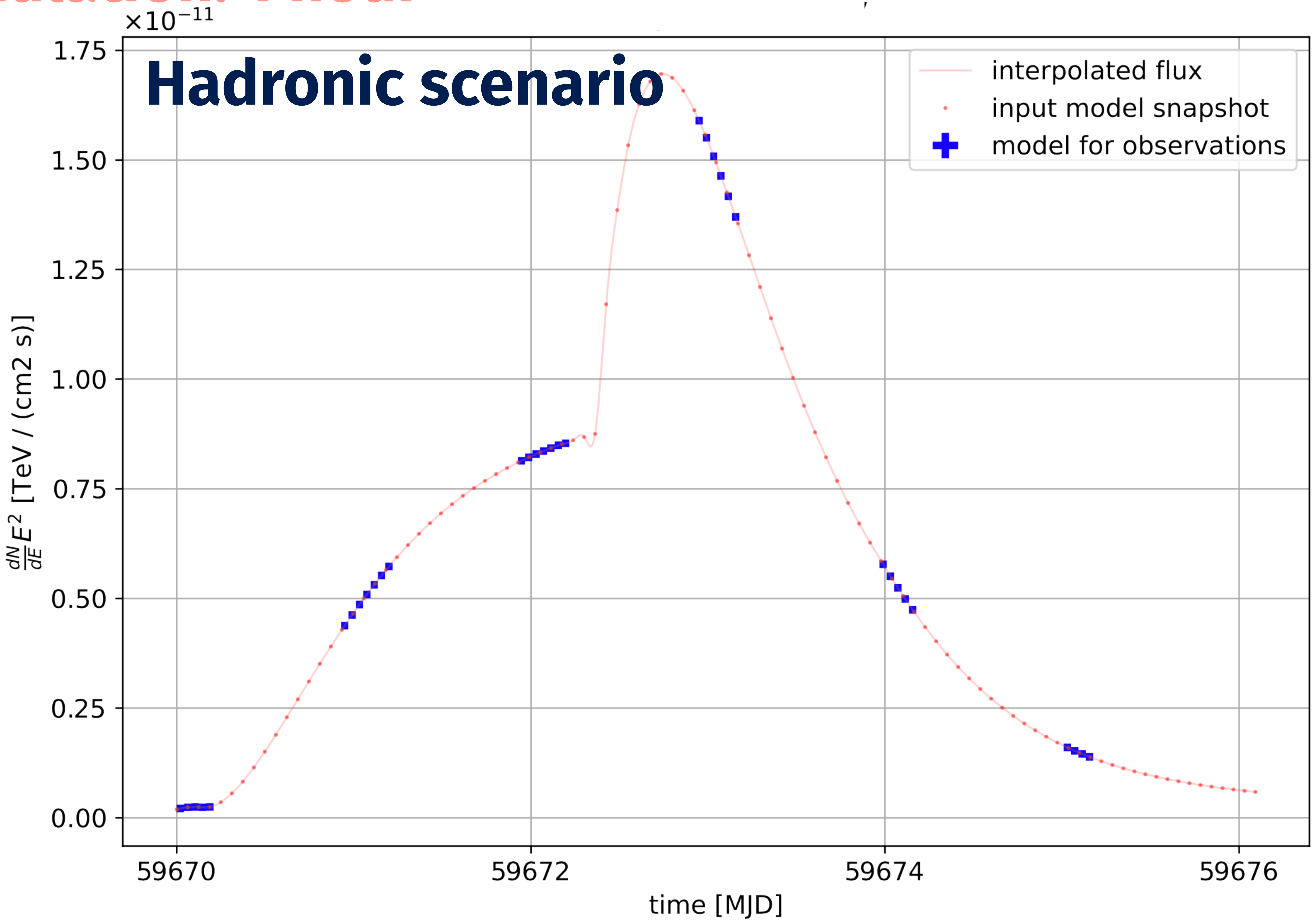
Flare simulations

3C 279 – June 2015 flare

From input model snapshots, **CtaAgnVar** calculates the interpolated flux and the temporal integrated model which will be used to **simulate realistic observations**.

Timestep simulation: 1 hour



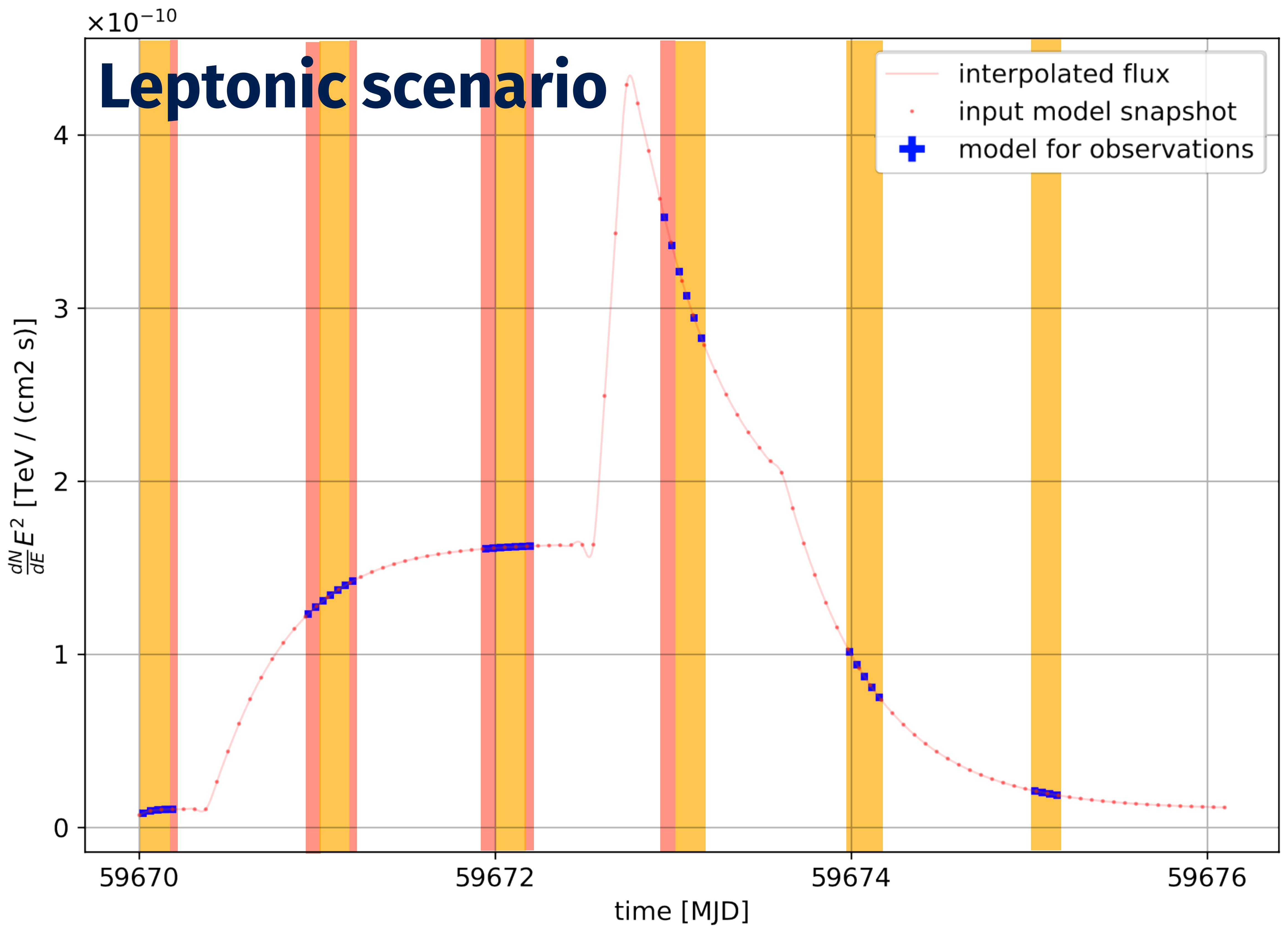


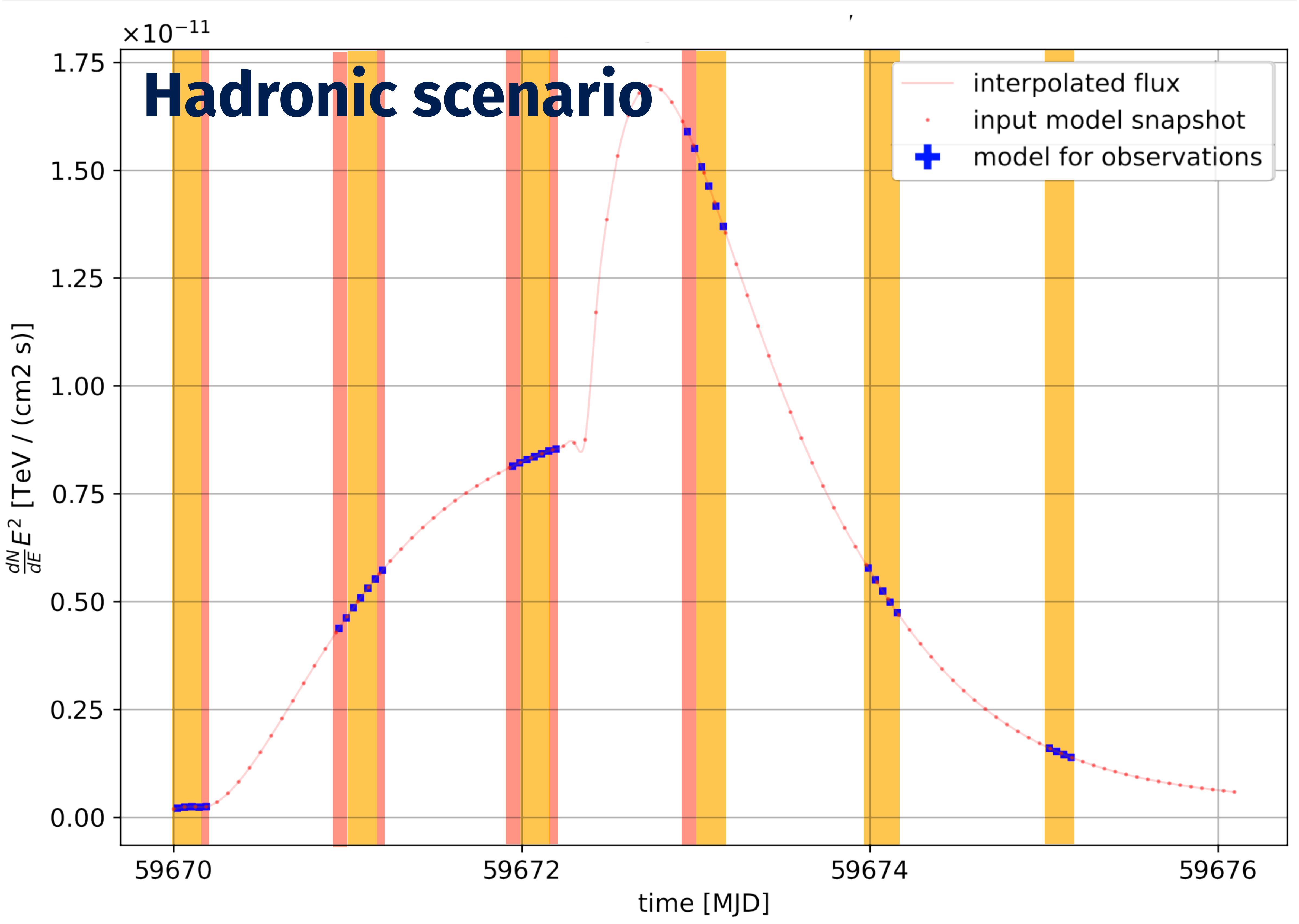
Flare simulations

3C 279 – June 2015 flare

Zenith angle 60°
Zenith angle 40°

CTA North





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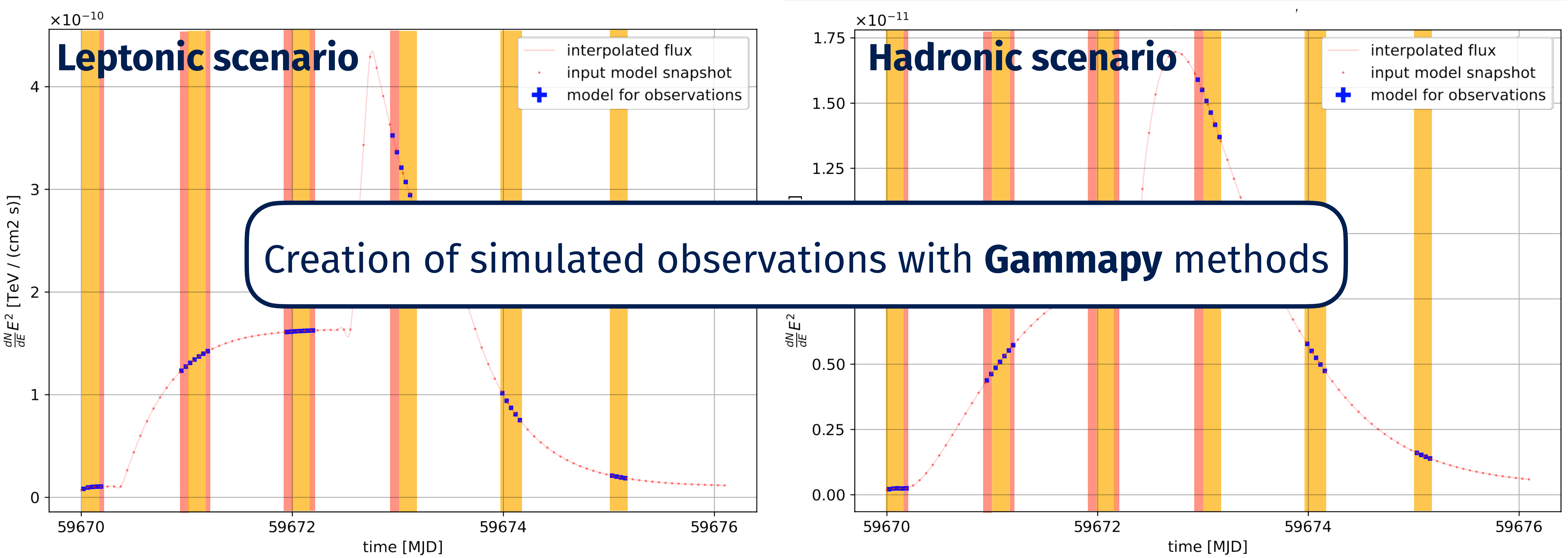

Creation of simulated observations with **Gammapy** methods

Flare simulations

3C 279 – June 2015 flare

For each timestep:

Fit the simulated observed spectra with phenomenological models

↓

Compute fluxes to obtain light curves

Flare simulations

3C 279 — June 2015 flare

For each timestep:

Compute fluxes to obtain light curves

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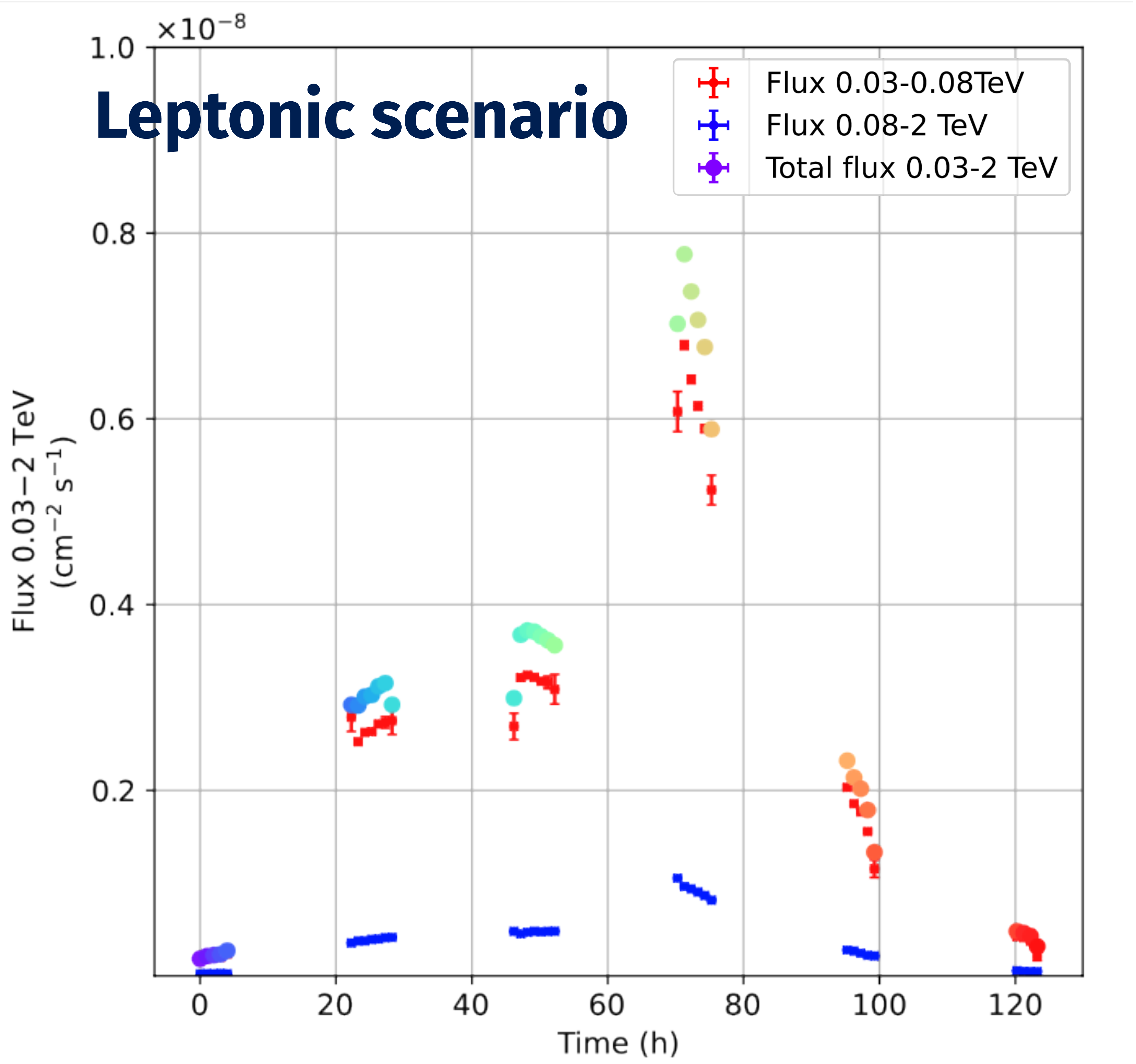
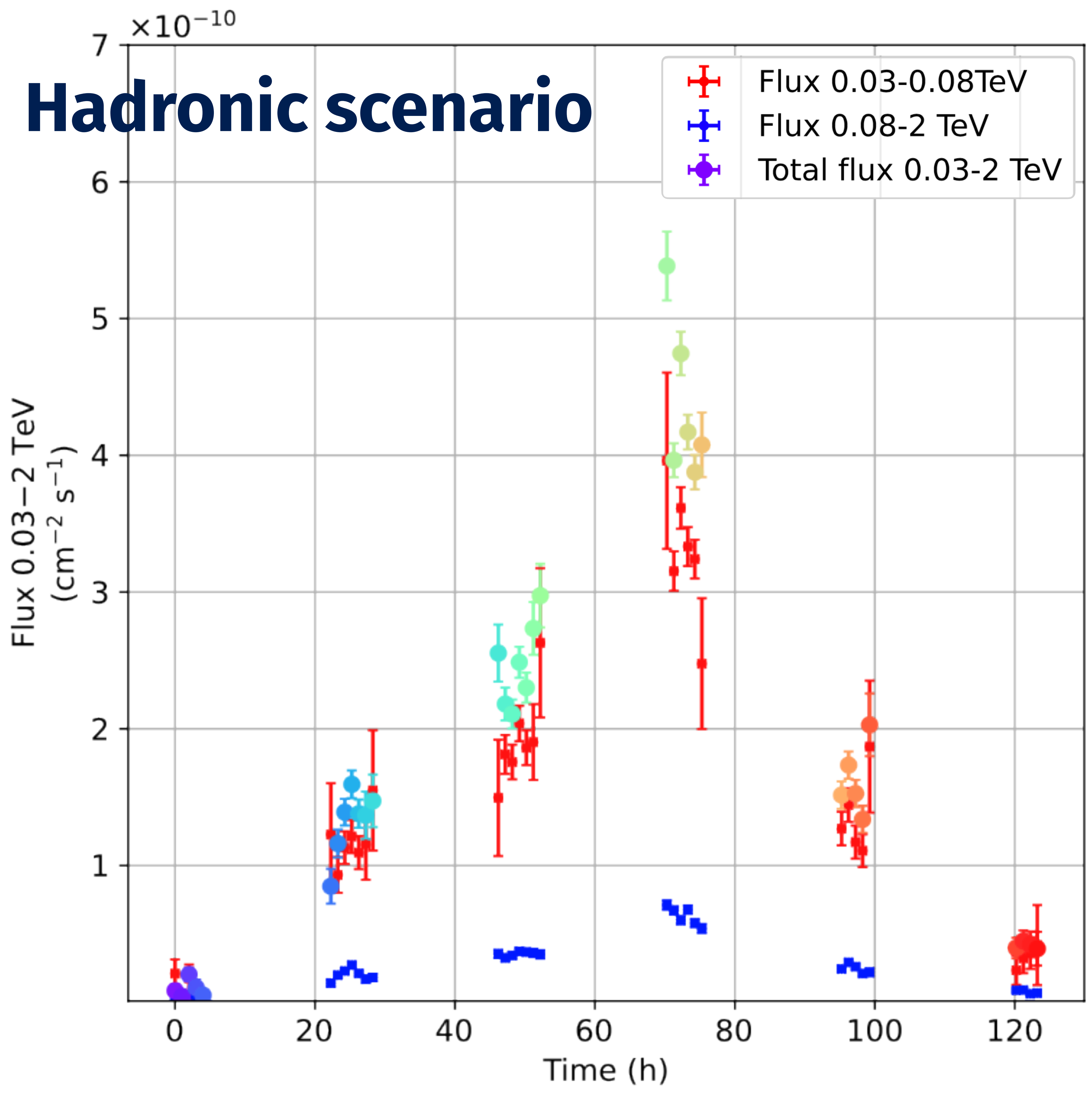


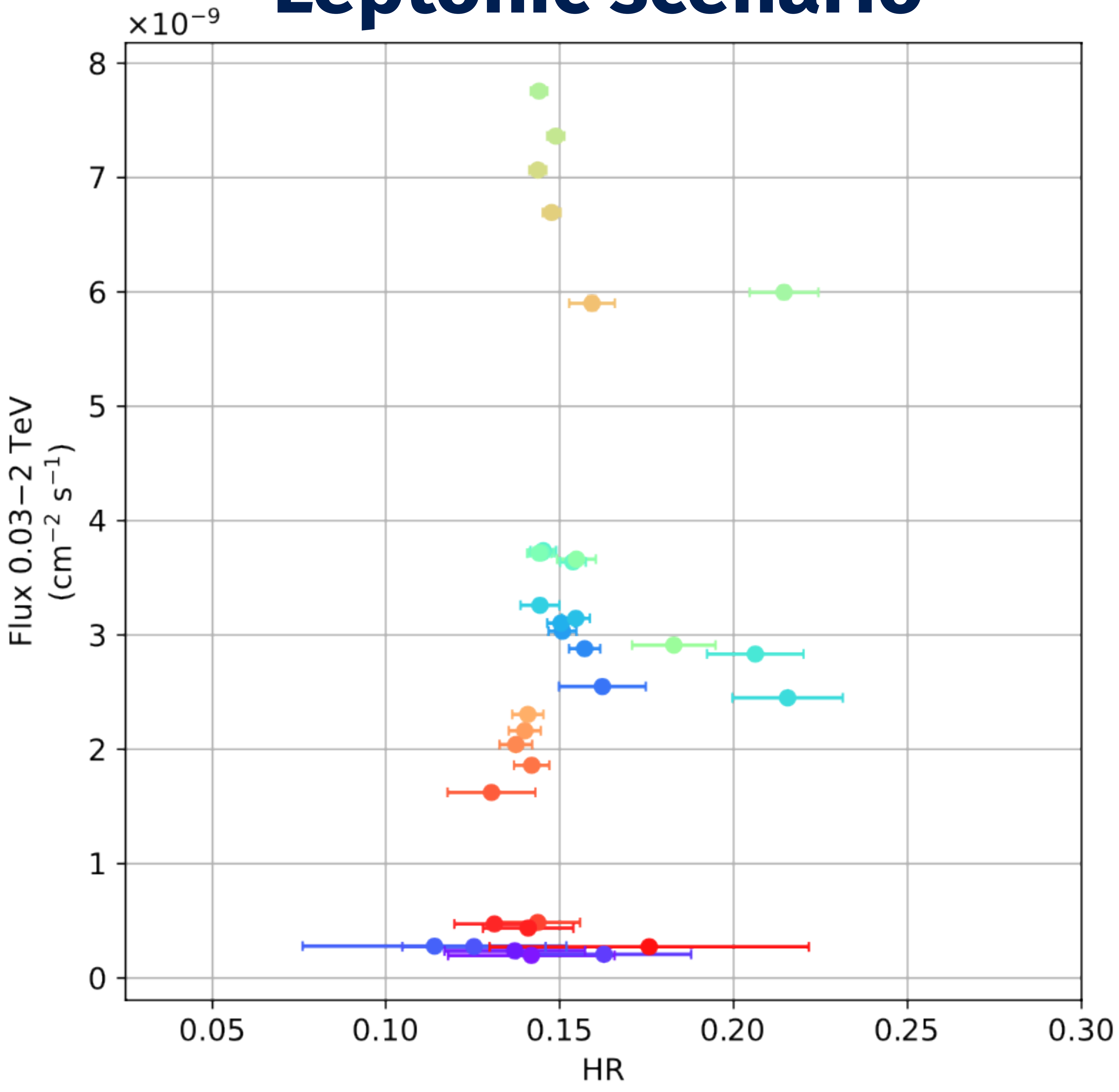


Flare simulations

3C 279 — June 2015 flare

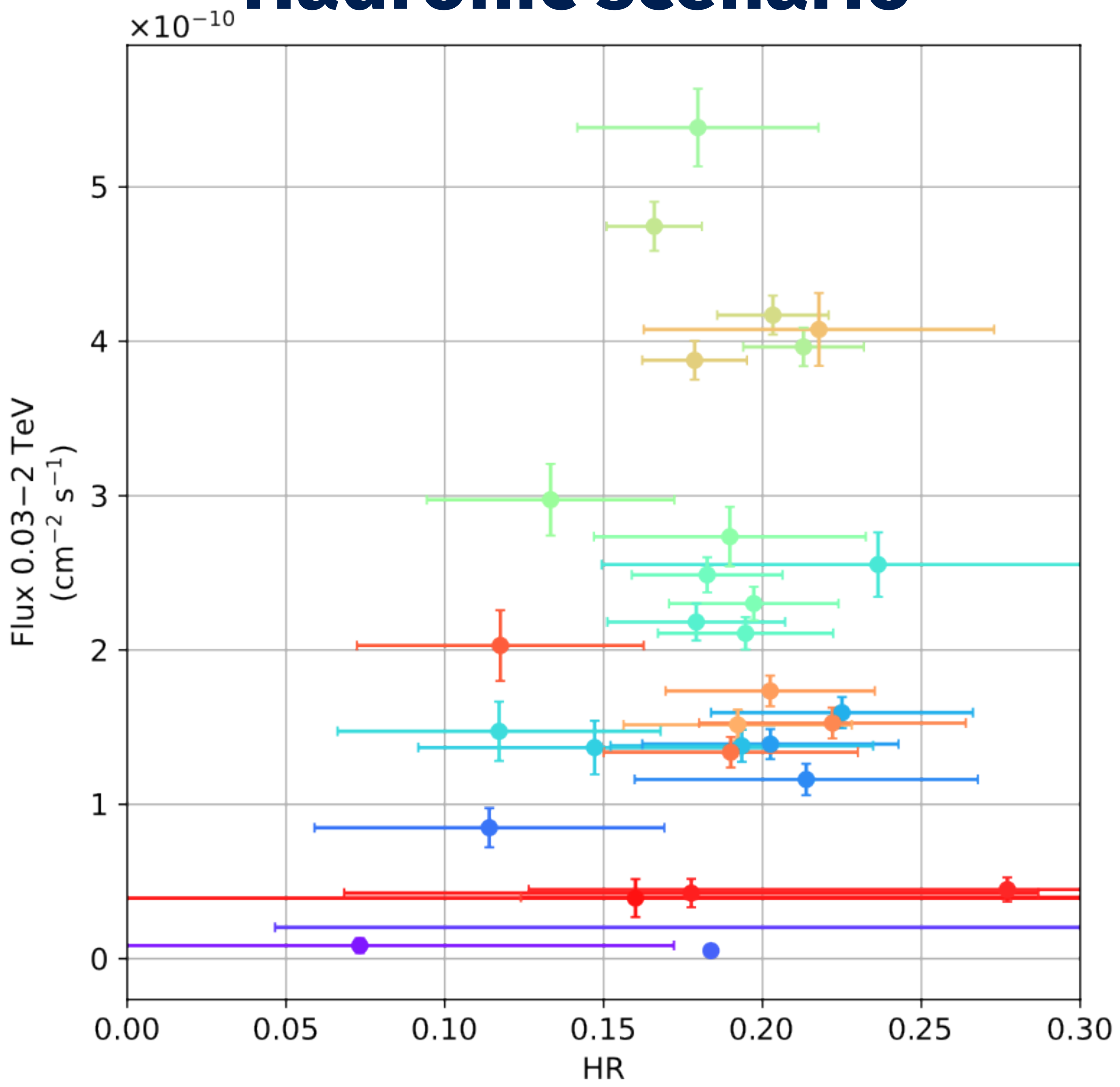
Hardness Intensity Diagram (HID)

Leptonic scenario



0.08–2 TeV / 0.03–0.08 TeV

Hadronic scenario



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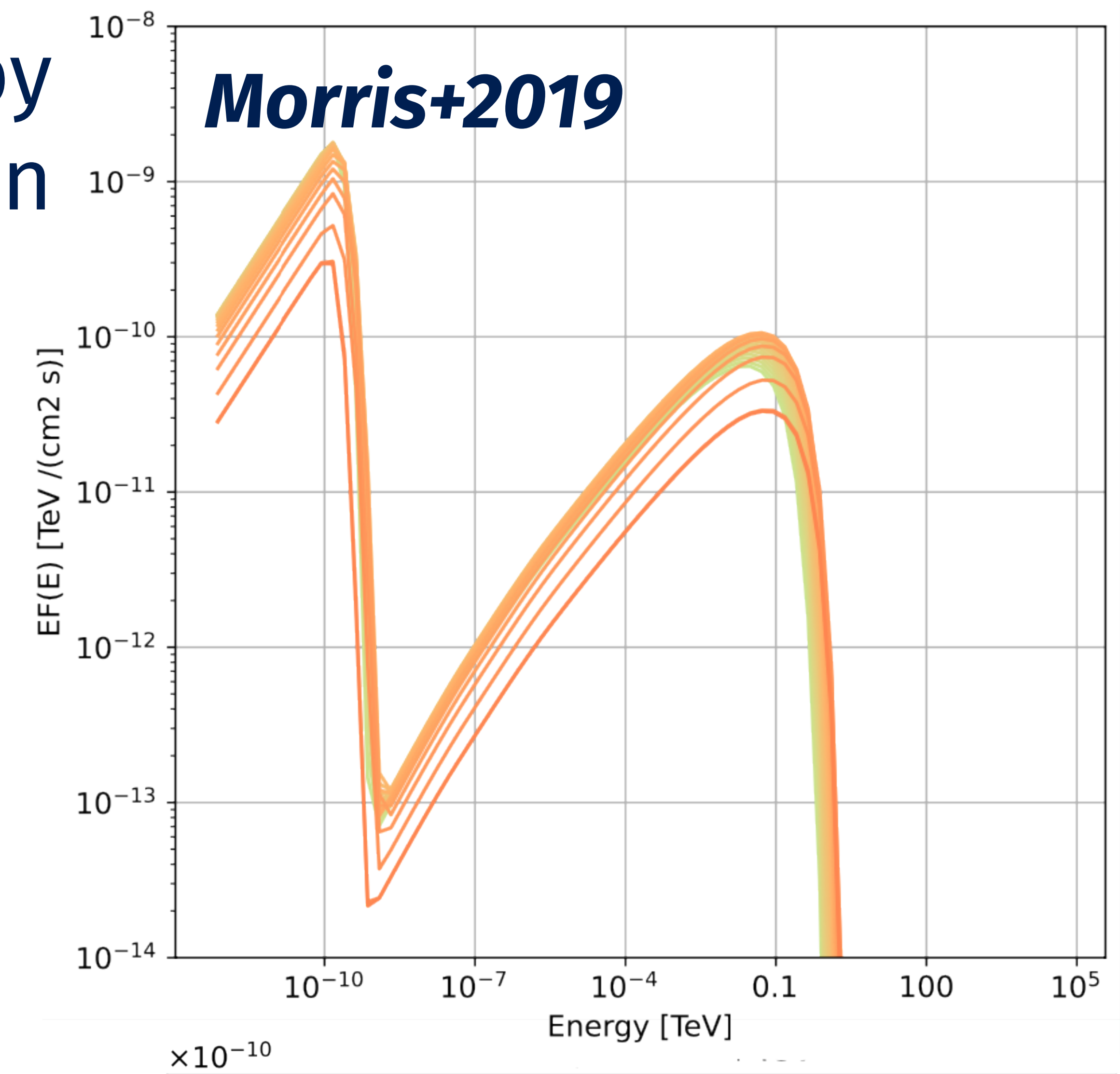
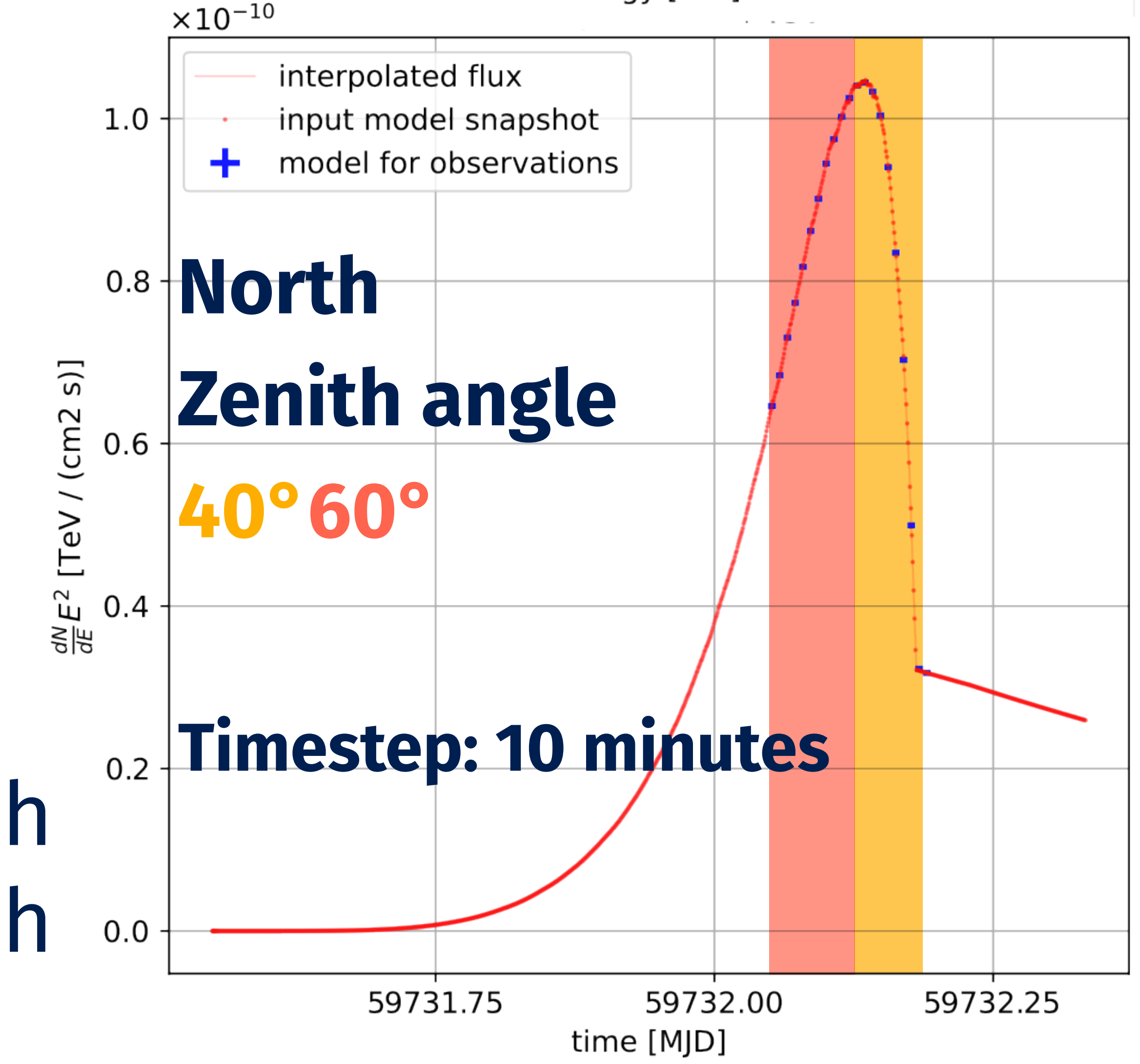
Flare simulations

BL Lacertae — October 2016 flare

SSC emission powered by magnetic reconnection





Total duration of the flare ~10h
Duration of observations ~ 3.5h

Flare simulations

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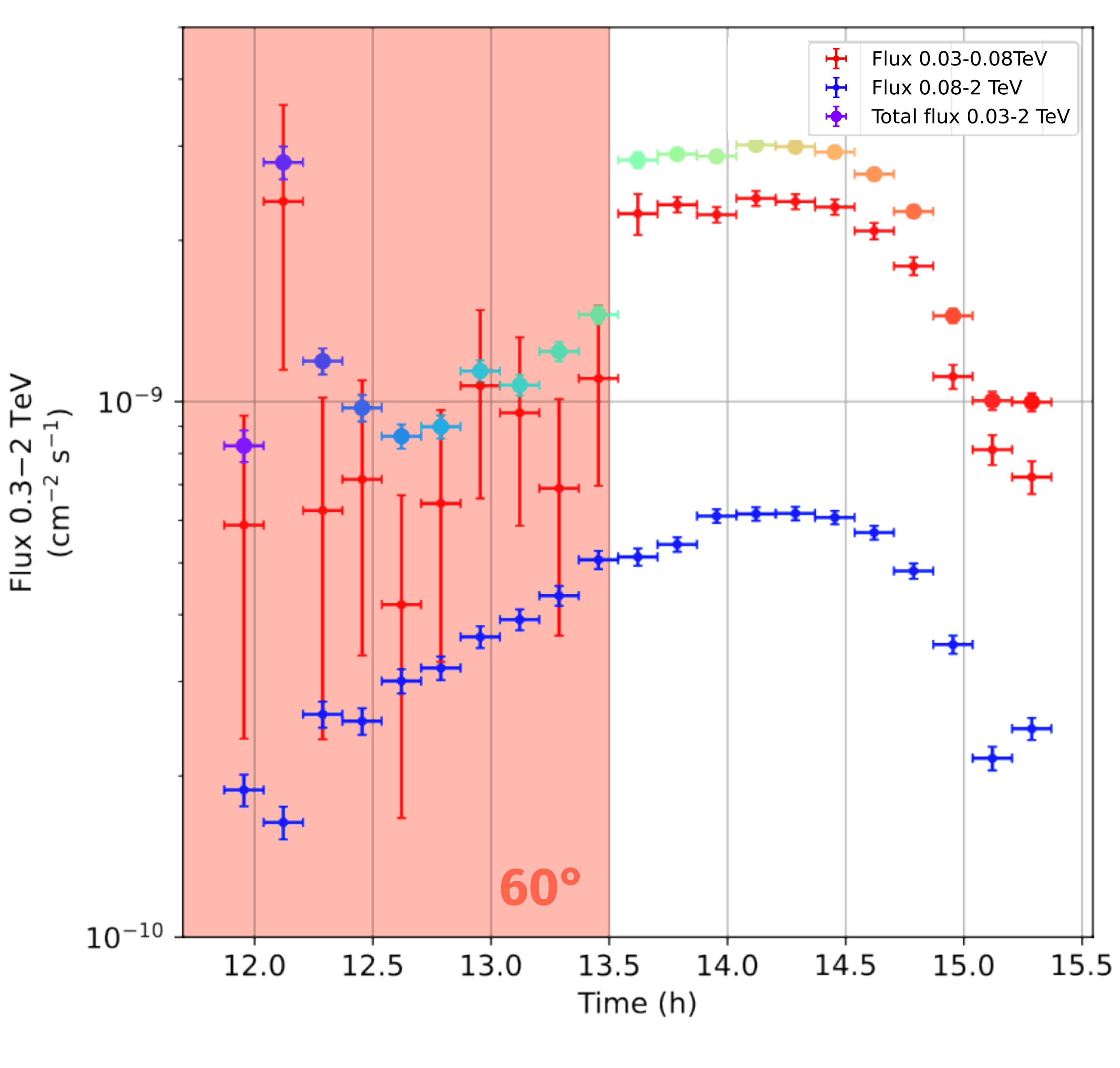

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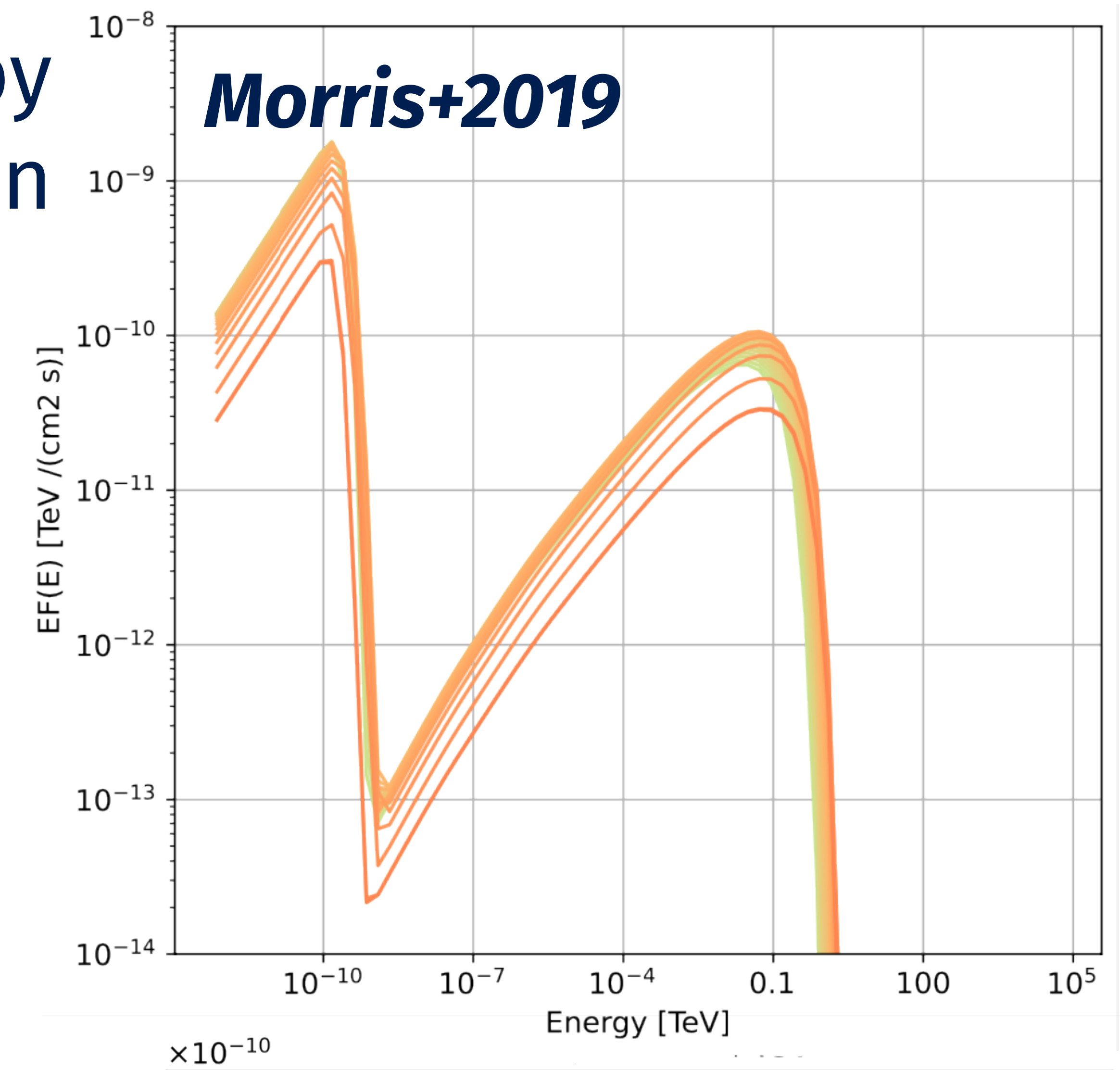

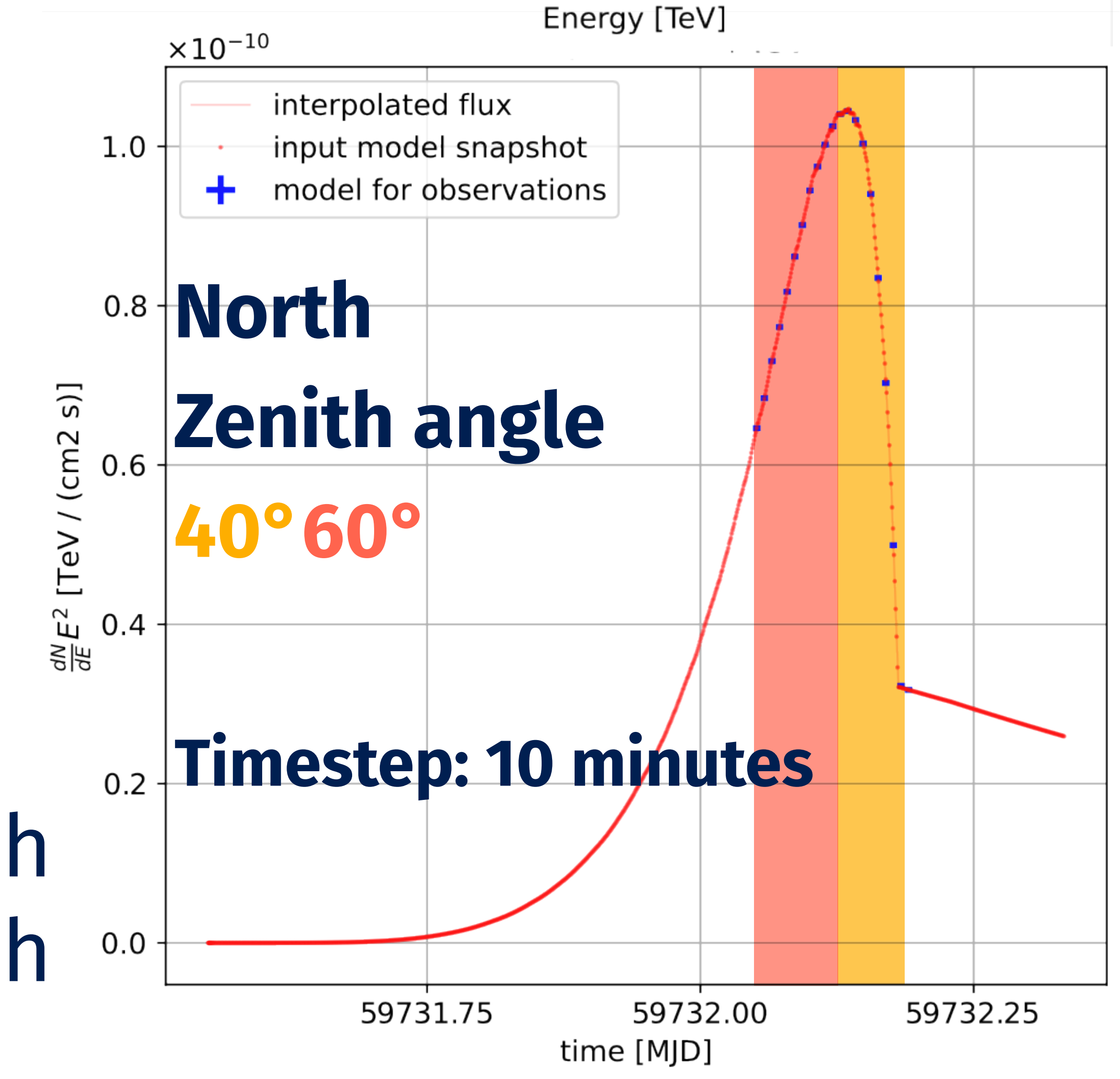

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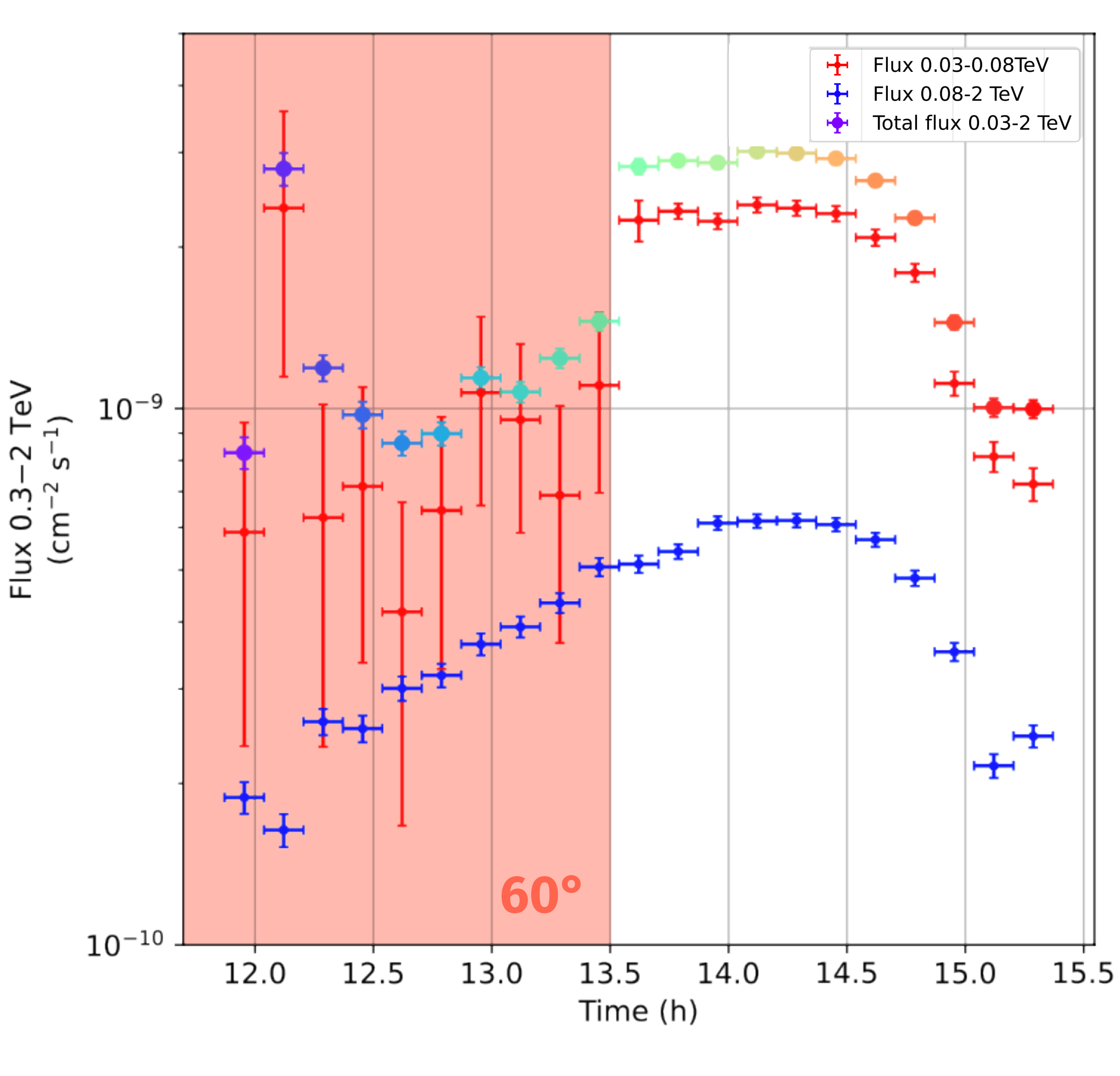
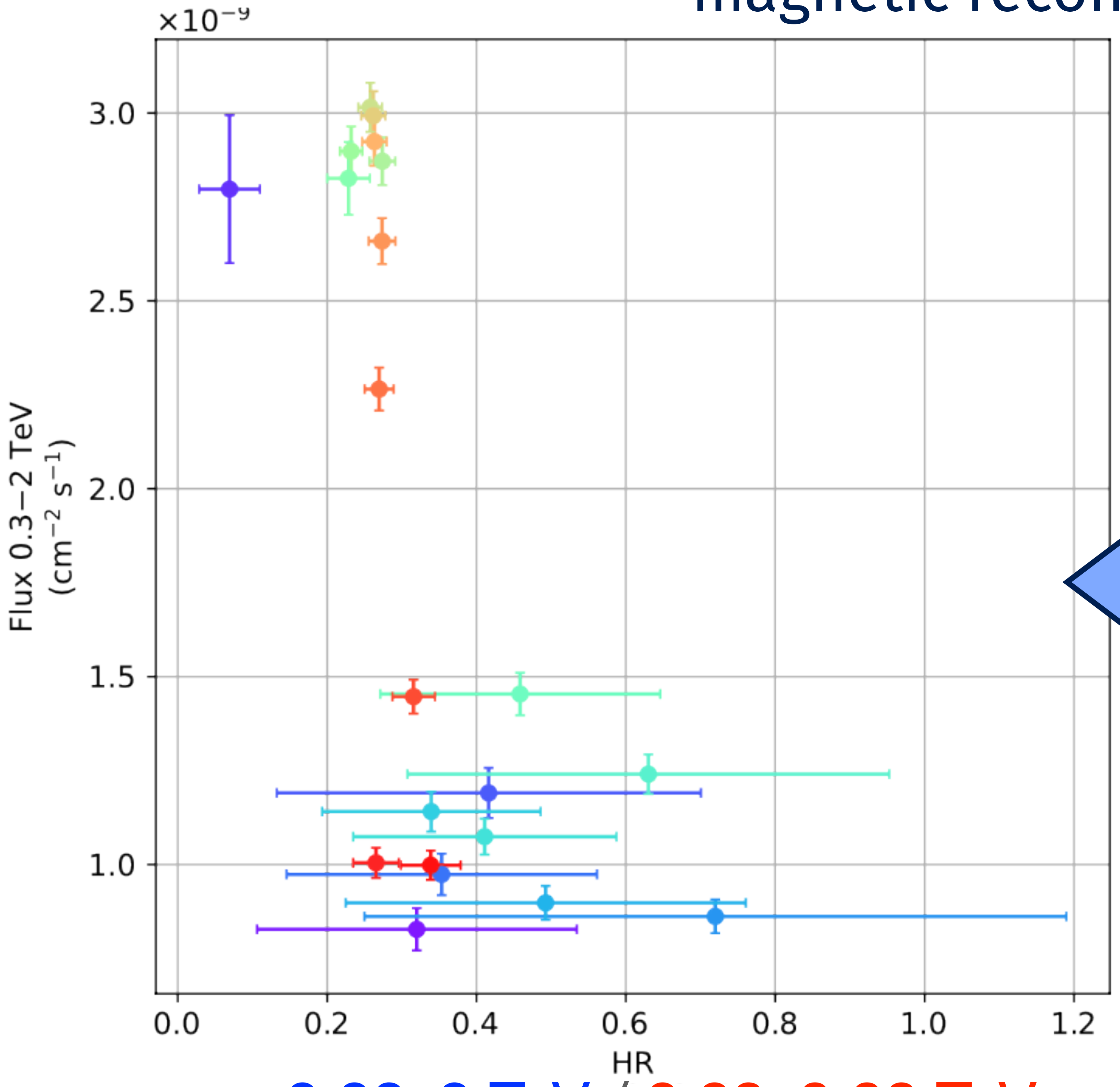
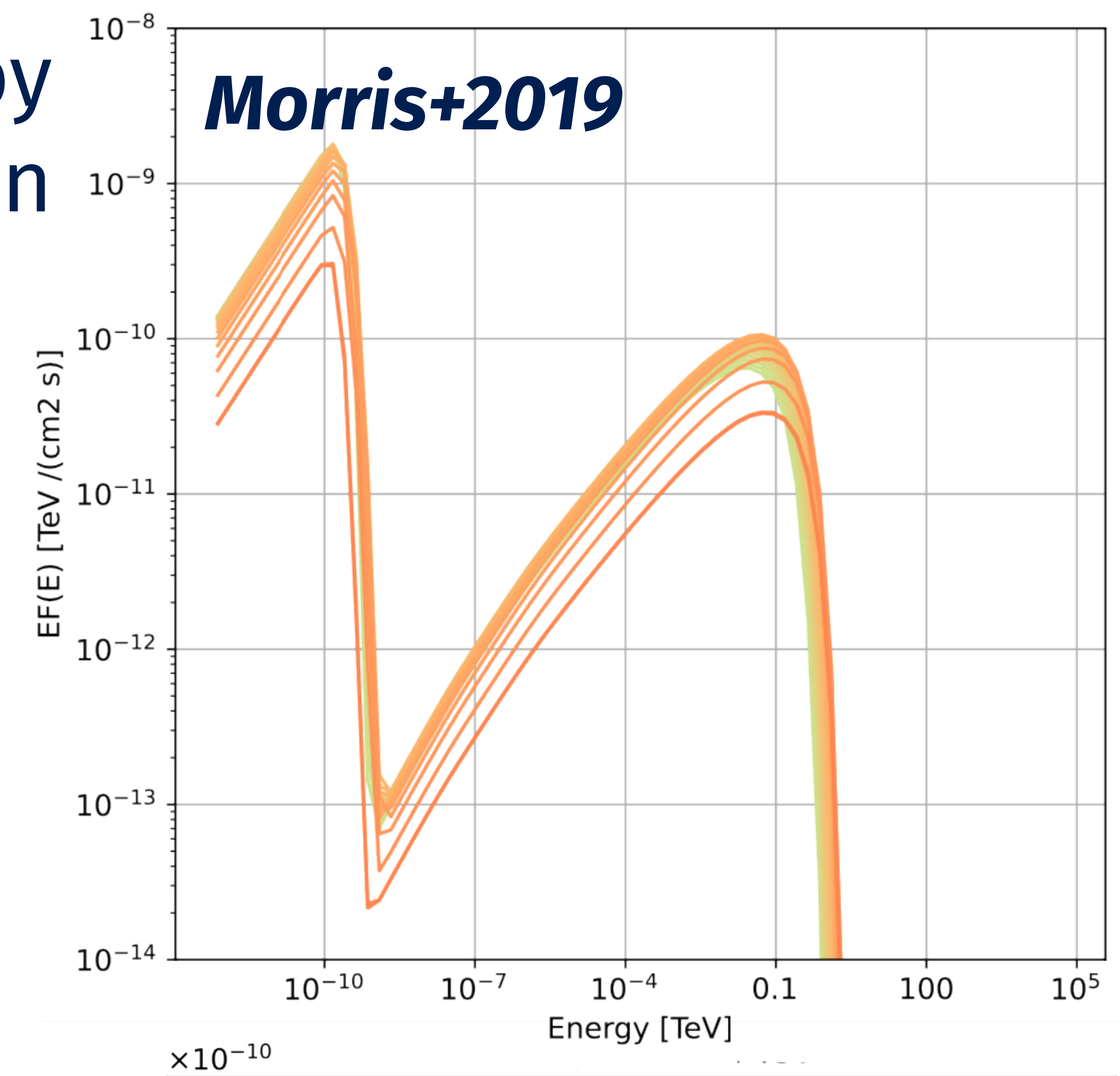
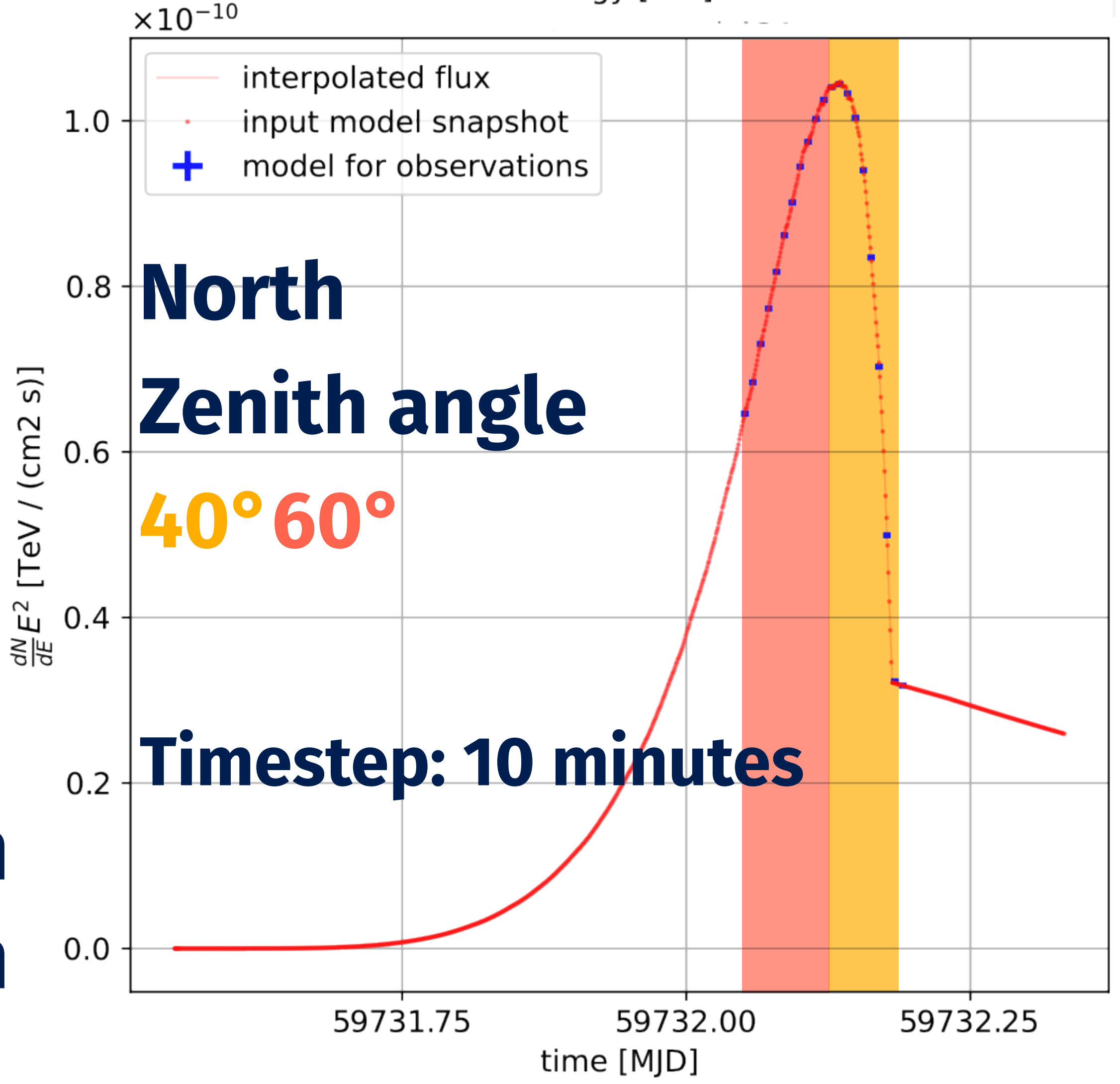




0.08–2 TeV / 0.03–0.08 TeV



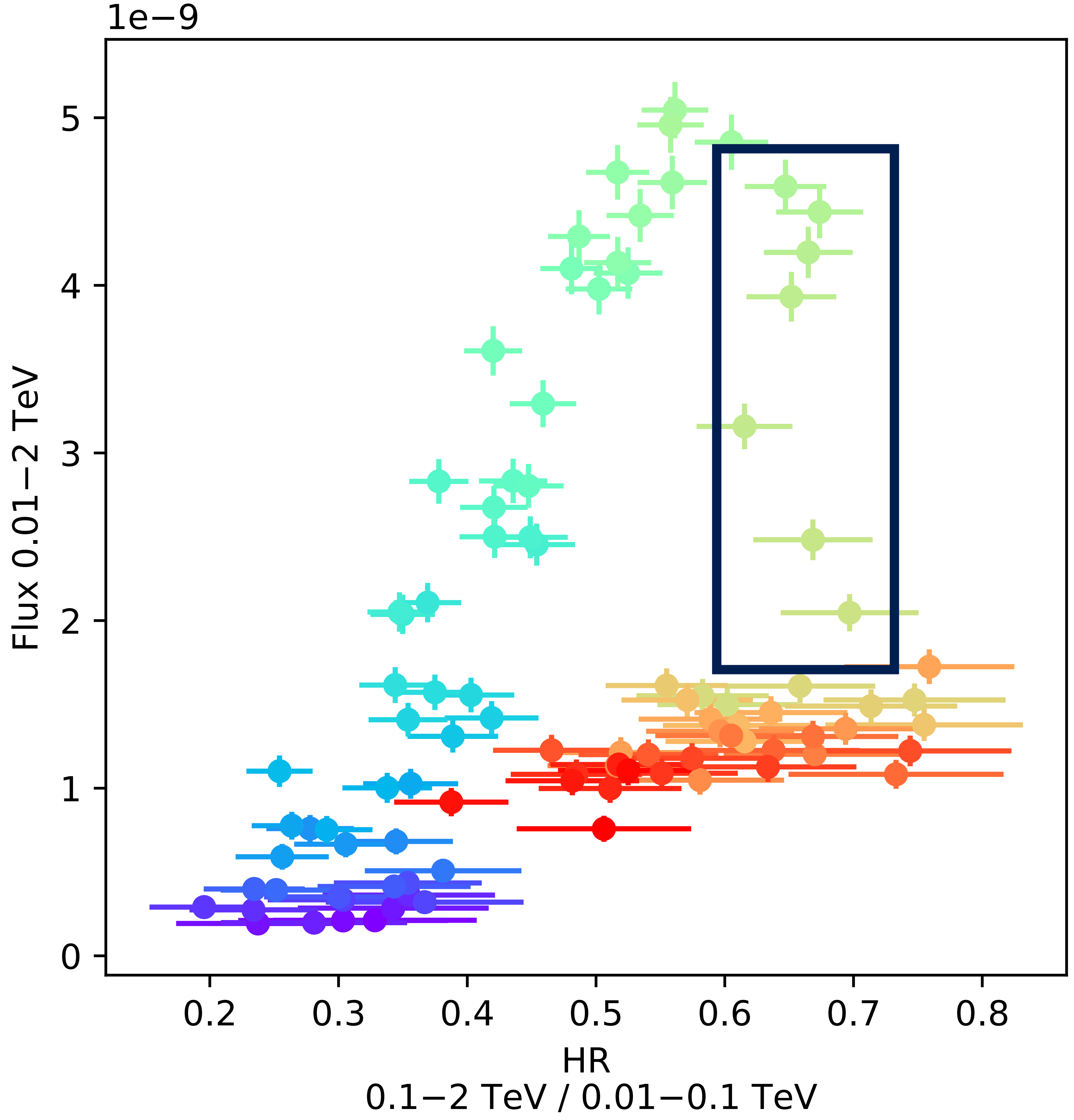


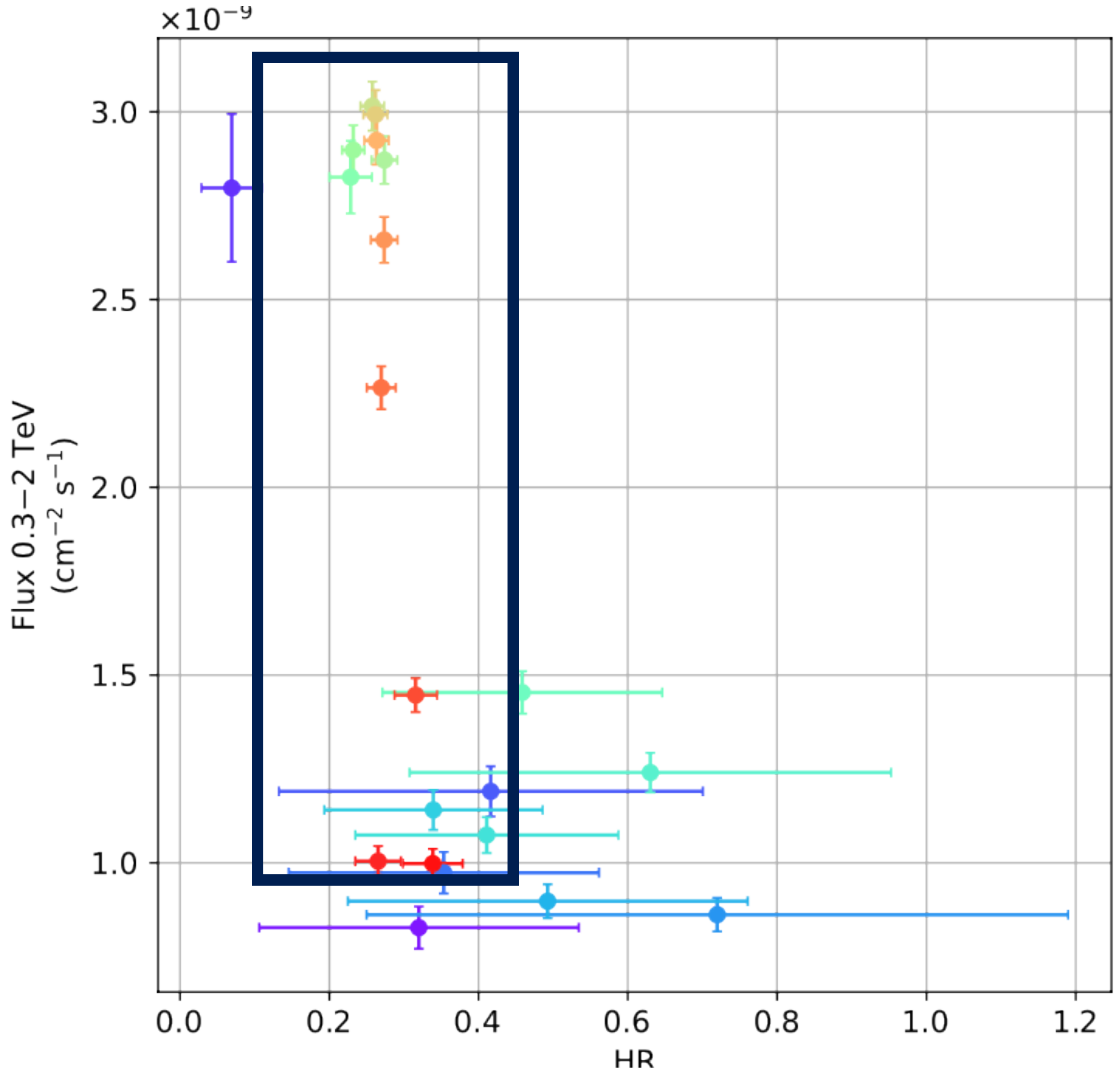
Total duration of the flare ~10h
Duration of observations ~ 3.5h

Flare simulations

BL Lacertae — October 2016 flare

If we were able to observe the totality of the flare with optimal observational conditions





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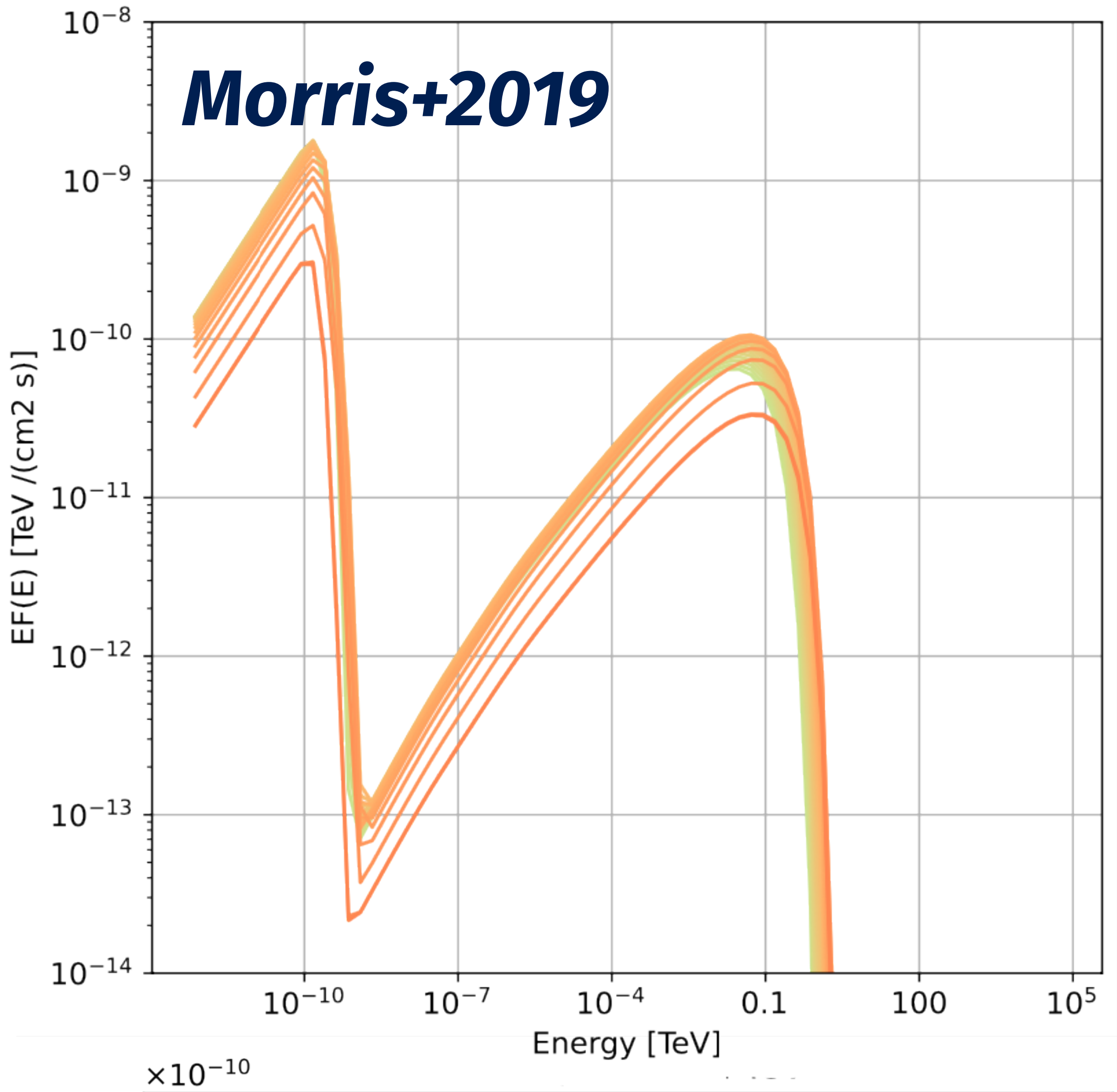
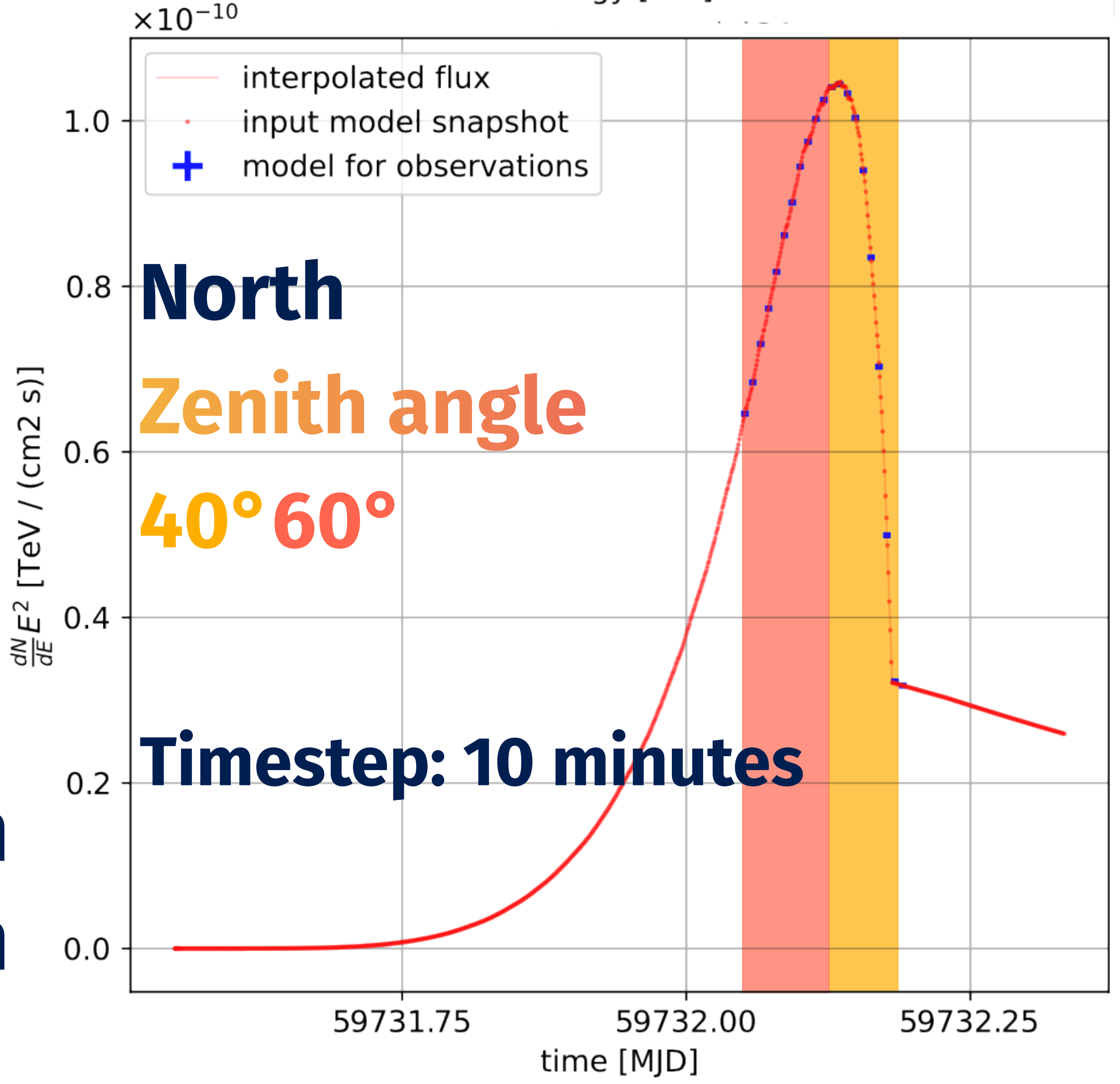


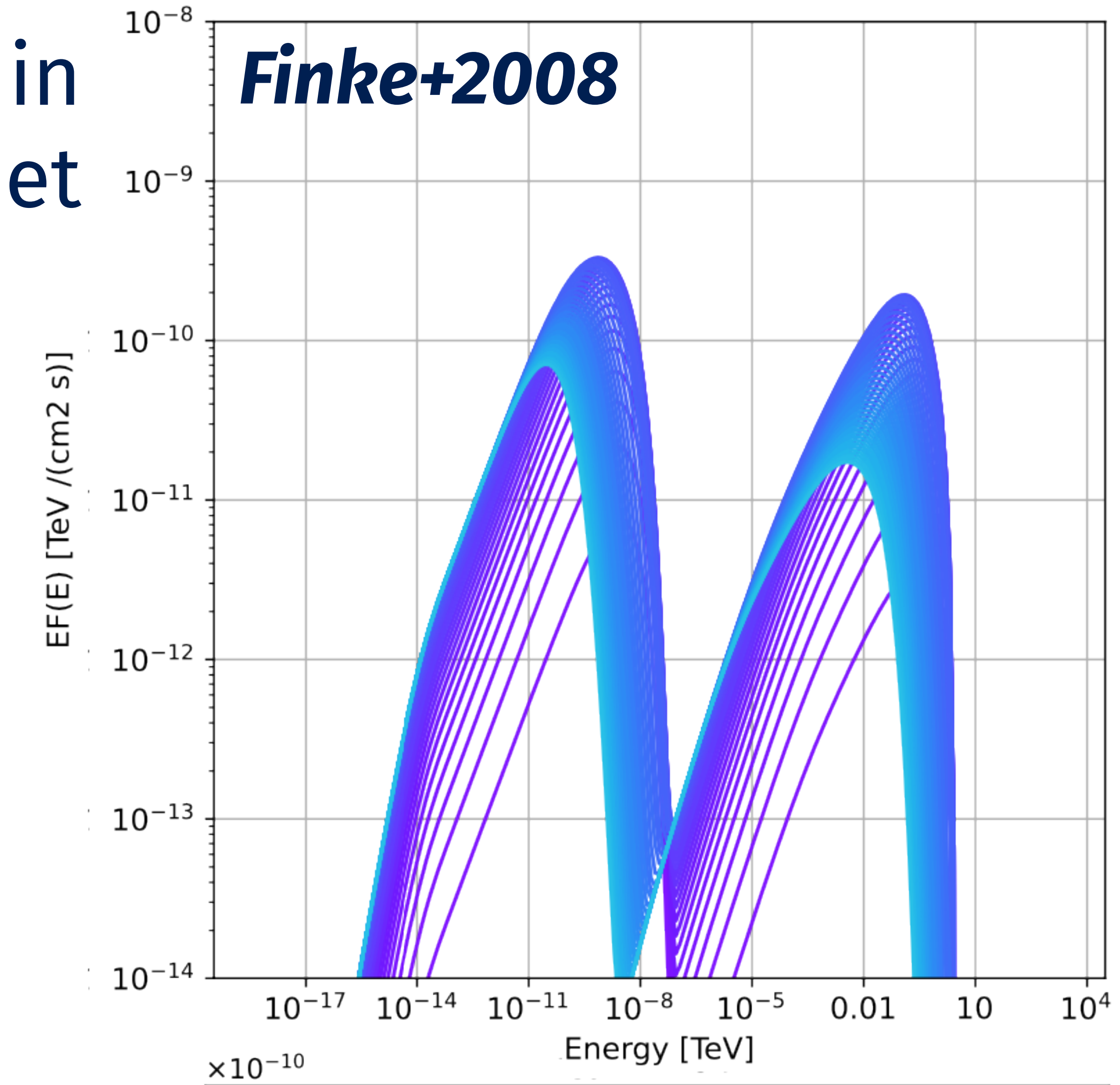


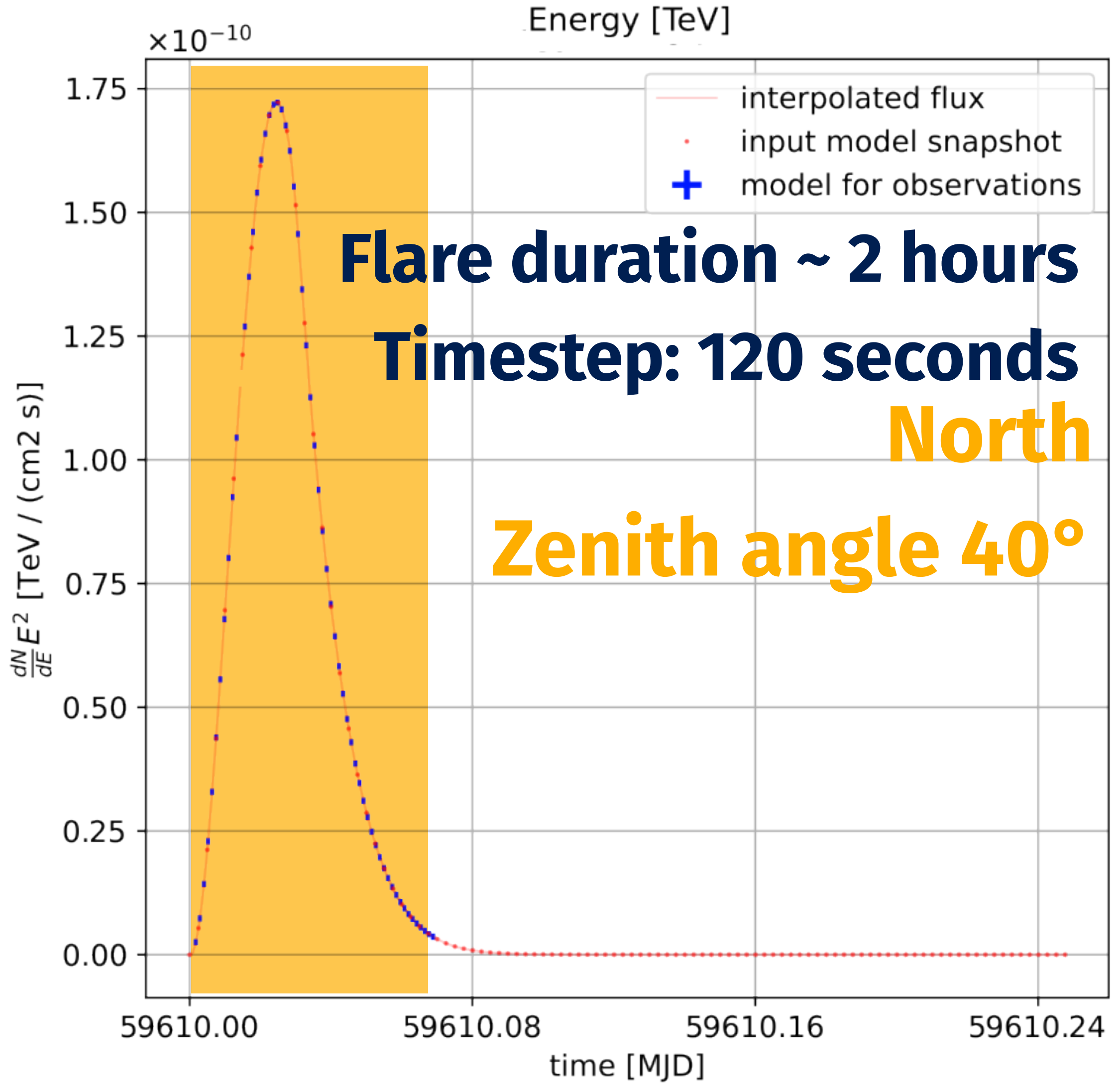
Total duration of the flare ~10h
Duration of observations ~ 3.5h

Flare simulations

Markarian 421 — March 2001 flare

SSC emission from electron in the jet





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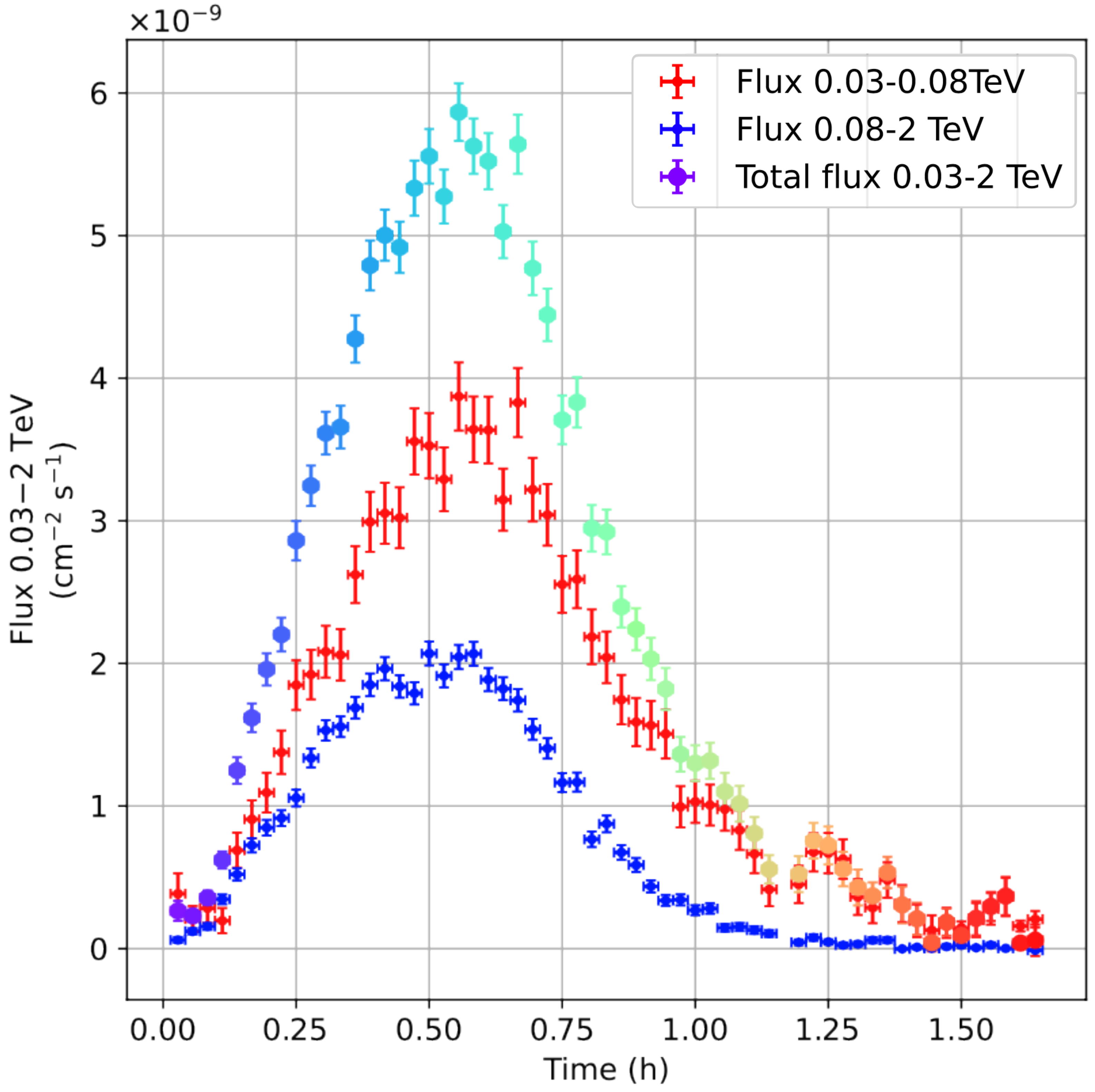

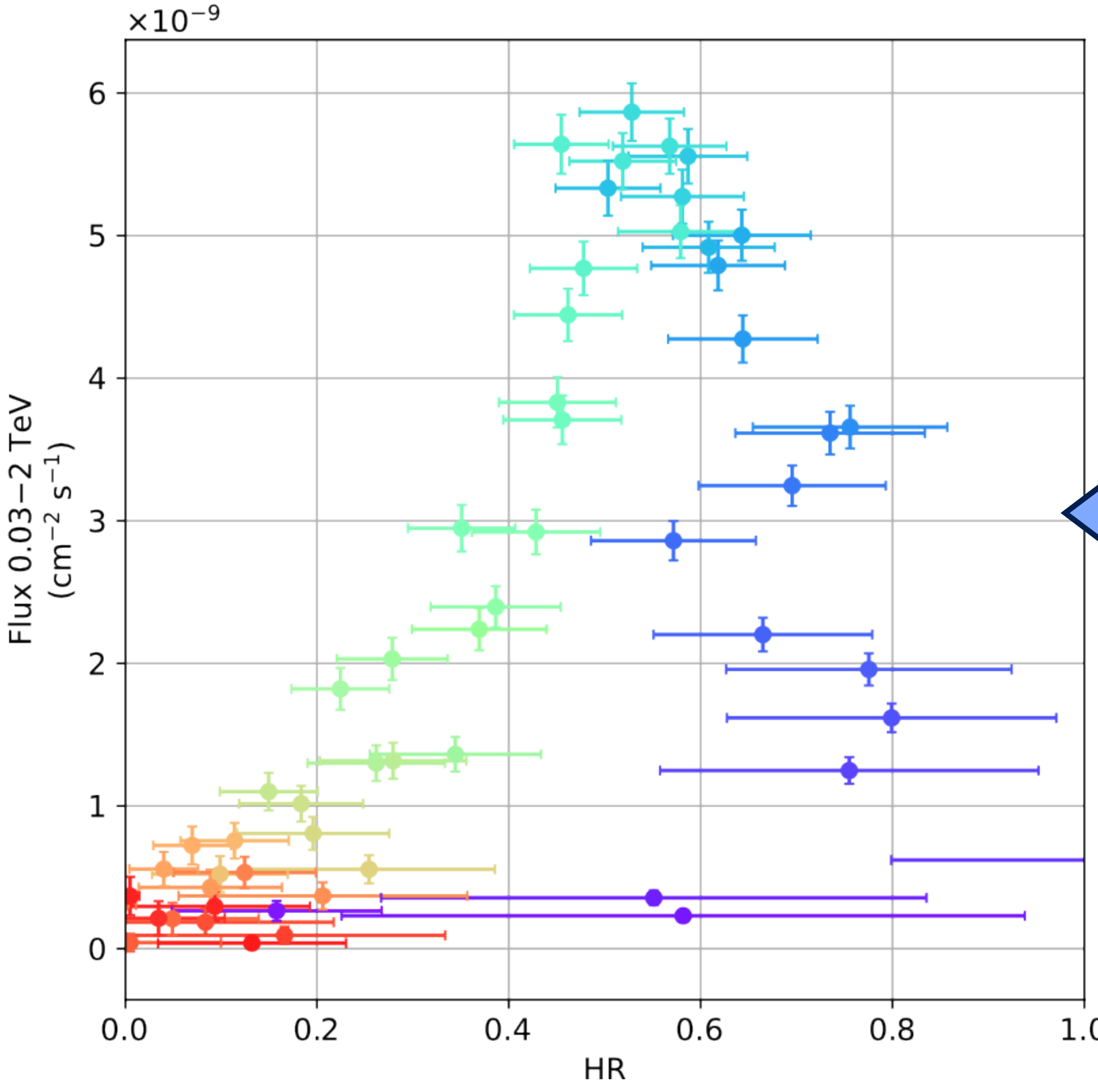

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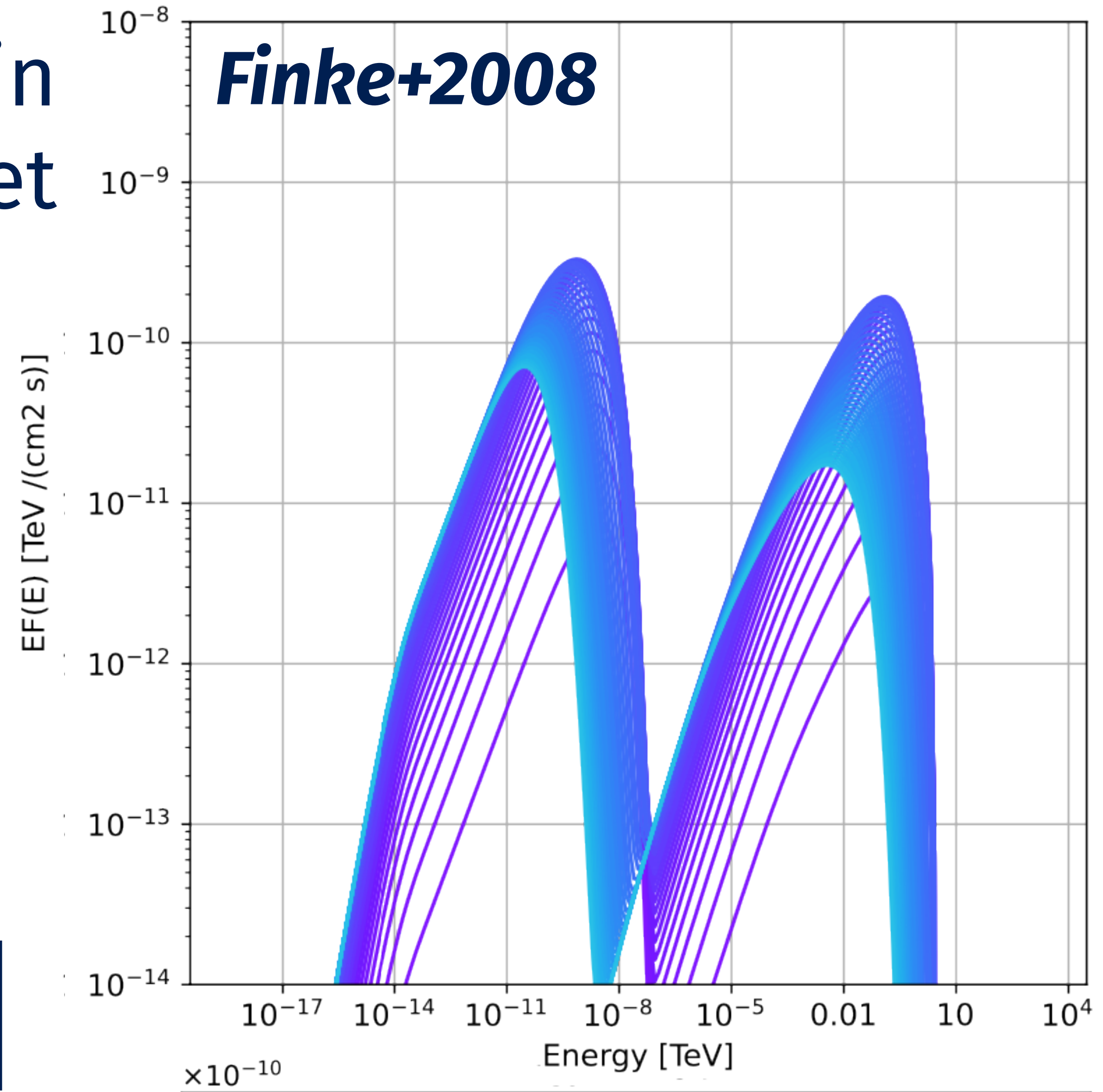

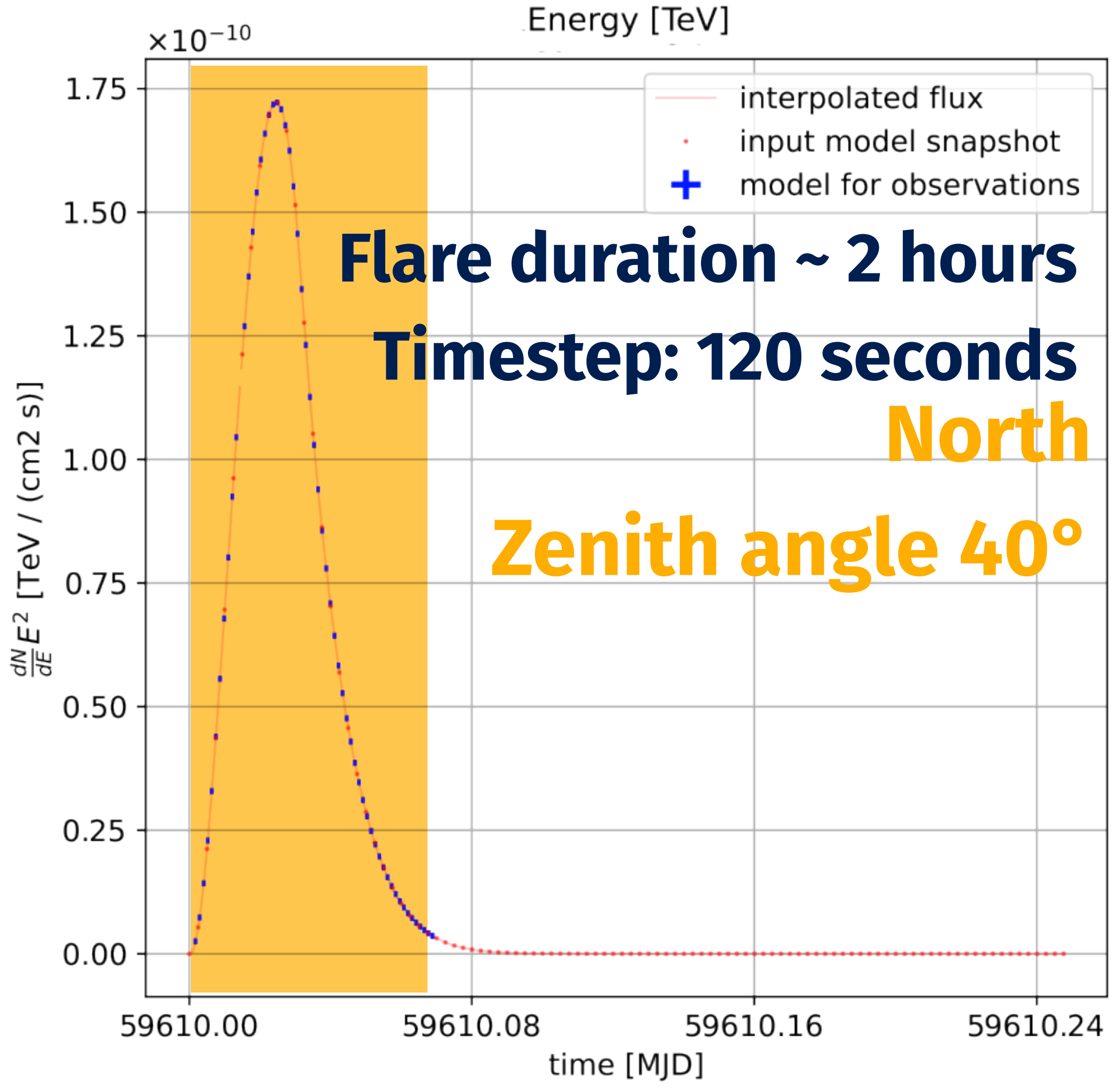

Long-term light curves

Input spectro-temporal model: $$\phi_z(E,t) = e^{-\tau_{\gamma\gamma}(E,z)}\phi_0(t)\left(\frac{E}{E_0}\right)^{-\Gamma(t)-\beta\ln\frac{E}{E_0}-\frac{E}{E_{\rm cut}}}$$

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Extragalactic Background Light absorption

Curvature

Cutoff

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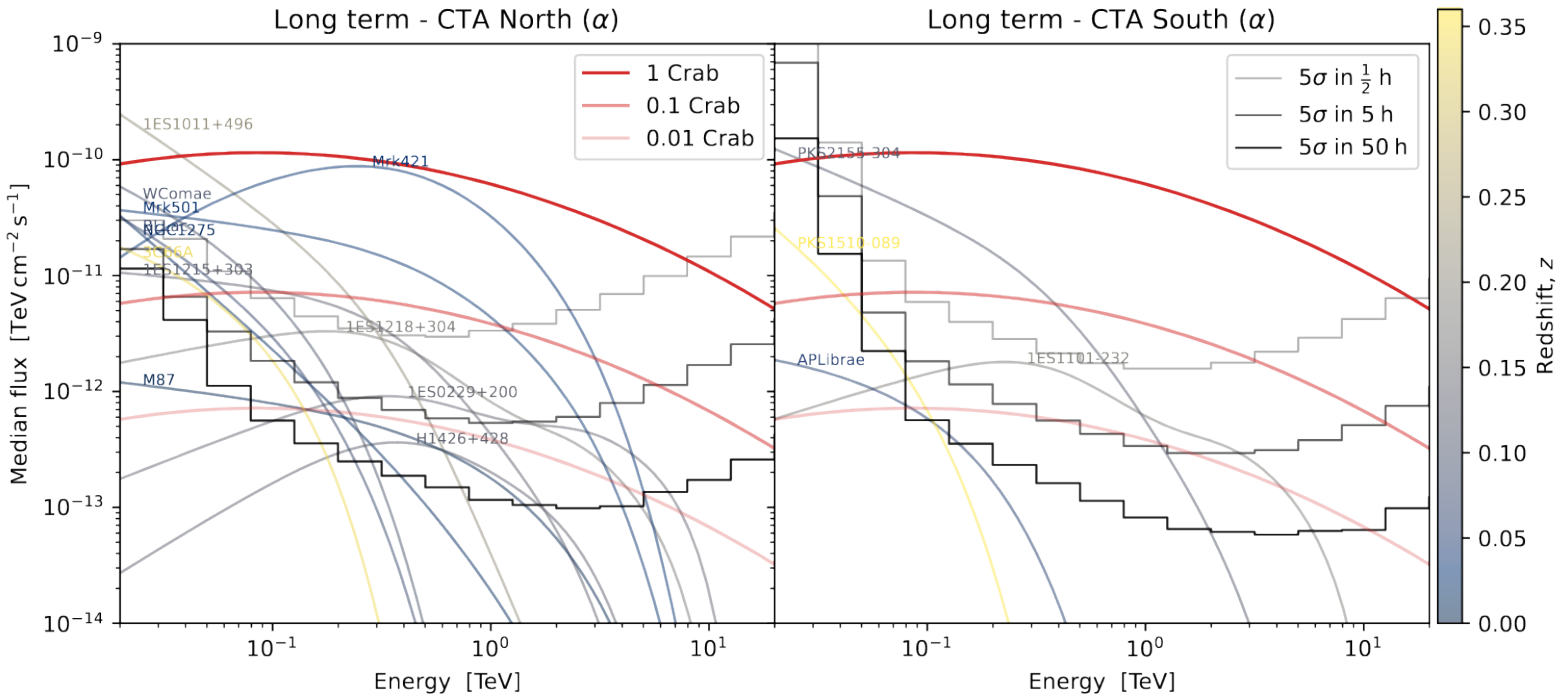
Static part ≡ median spectrum

E_{cut} β z

Static spectral parameters of **14 sources** from ***CTA Consortium+2020*** and literature



Long-term light curves

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Extragalactic Background Light absorption — Curvature — Cutoff

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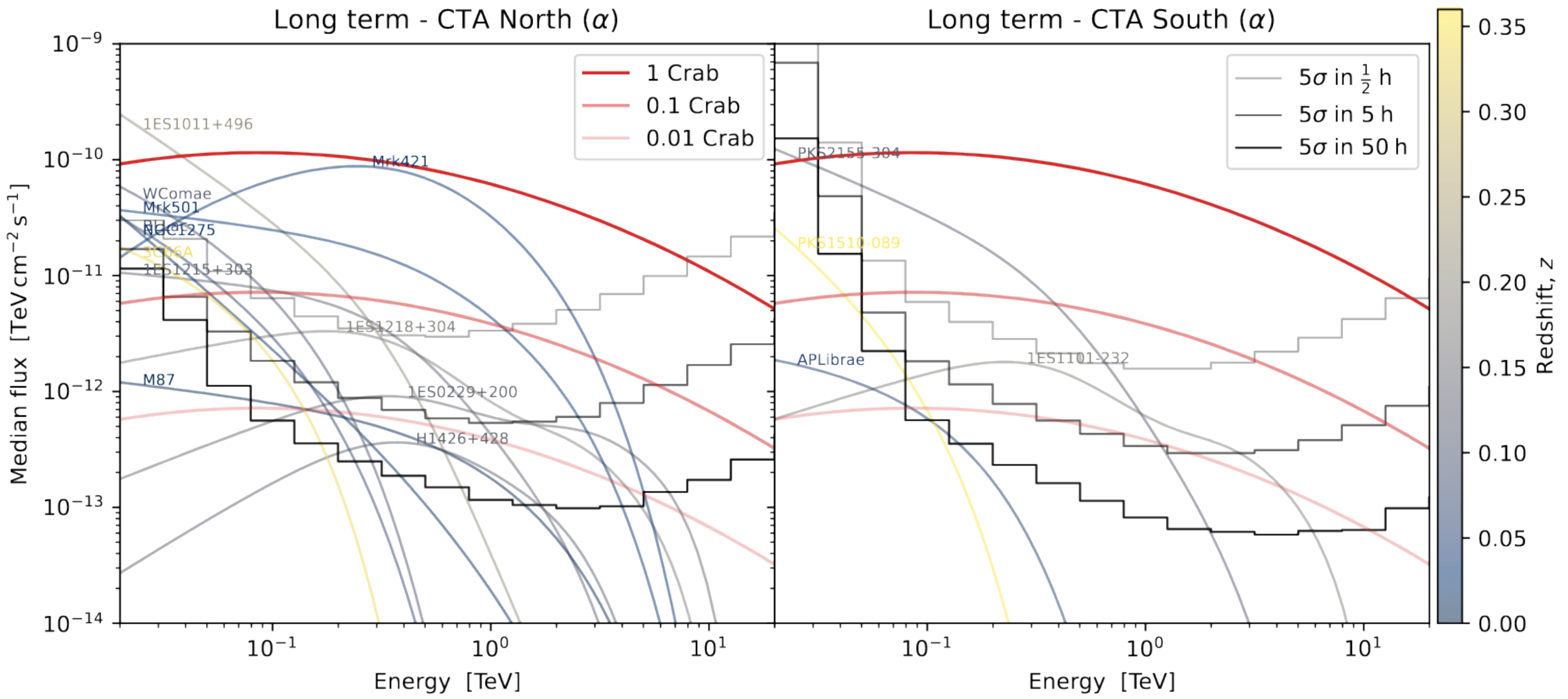
Static spectral parameters of **14 sources** from ***CTA Consortium+2020*** and literature

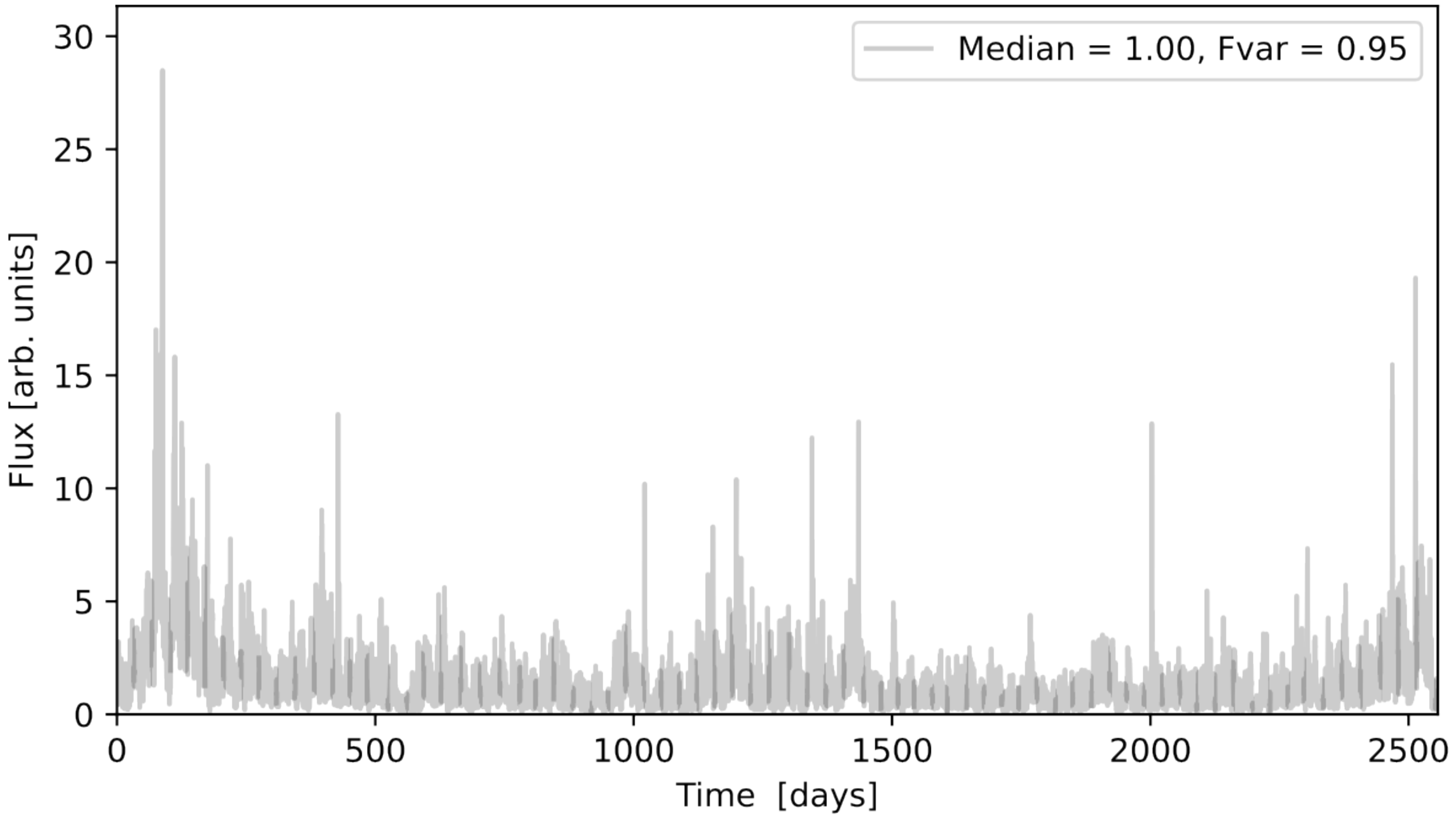
$\otimes$

Time-dependent part

$\phi_0(t)$ Log-normal process with a colored-noise time-dependence ***Emmanoulopoulos+2013***

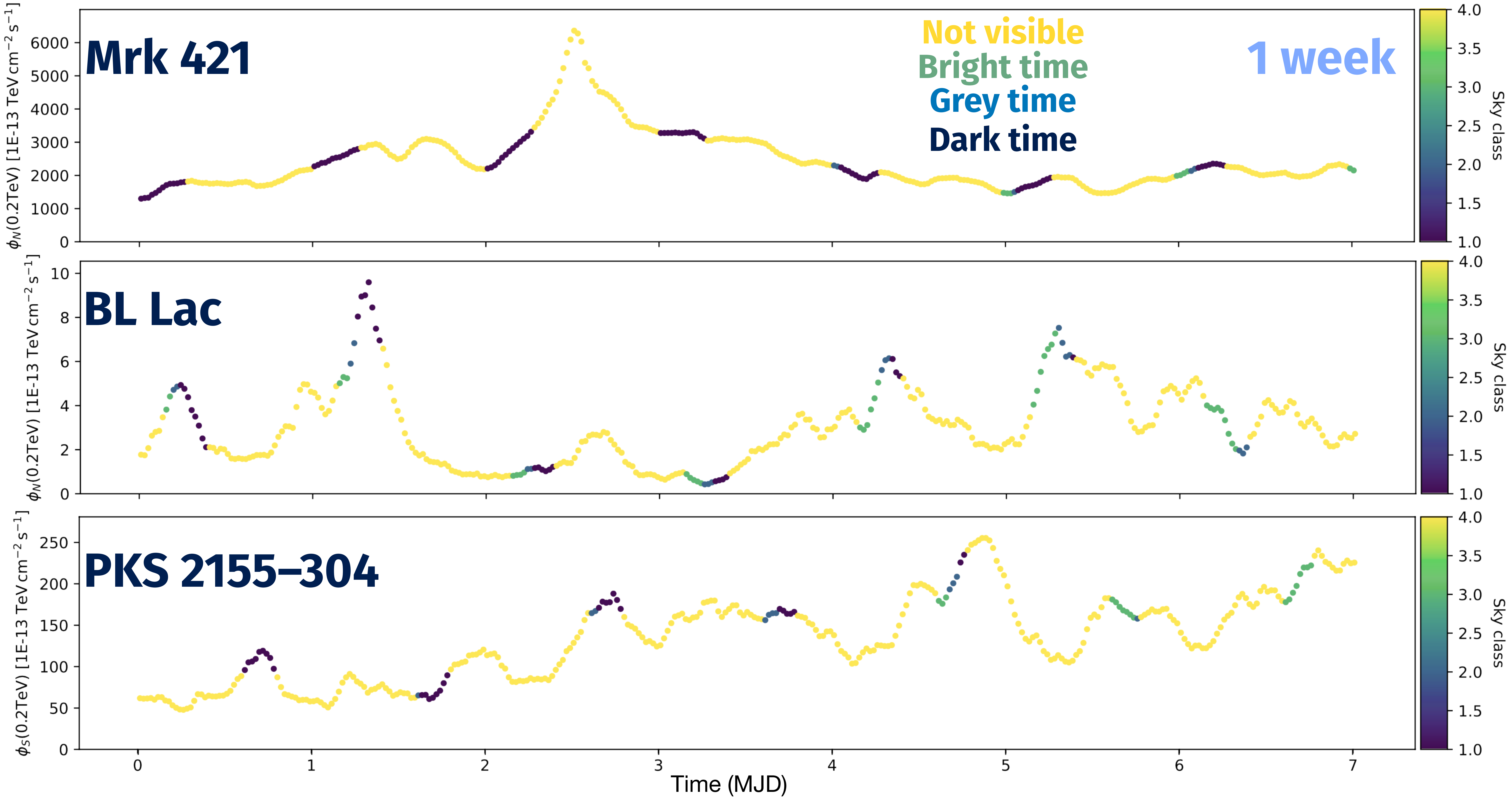
$\Gamma(t)$ Correlated with $\phi_0(t)$ (follow the harder when brighter relation)





Long-term light curves

Done for the 14 sources of dedicated CTA Key Science Project



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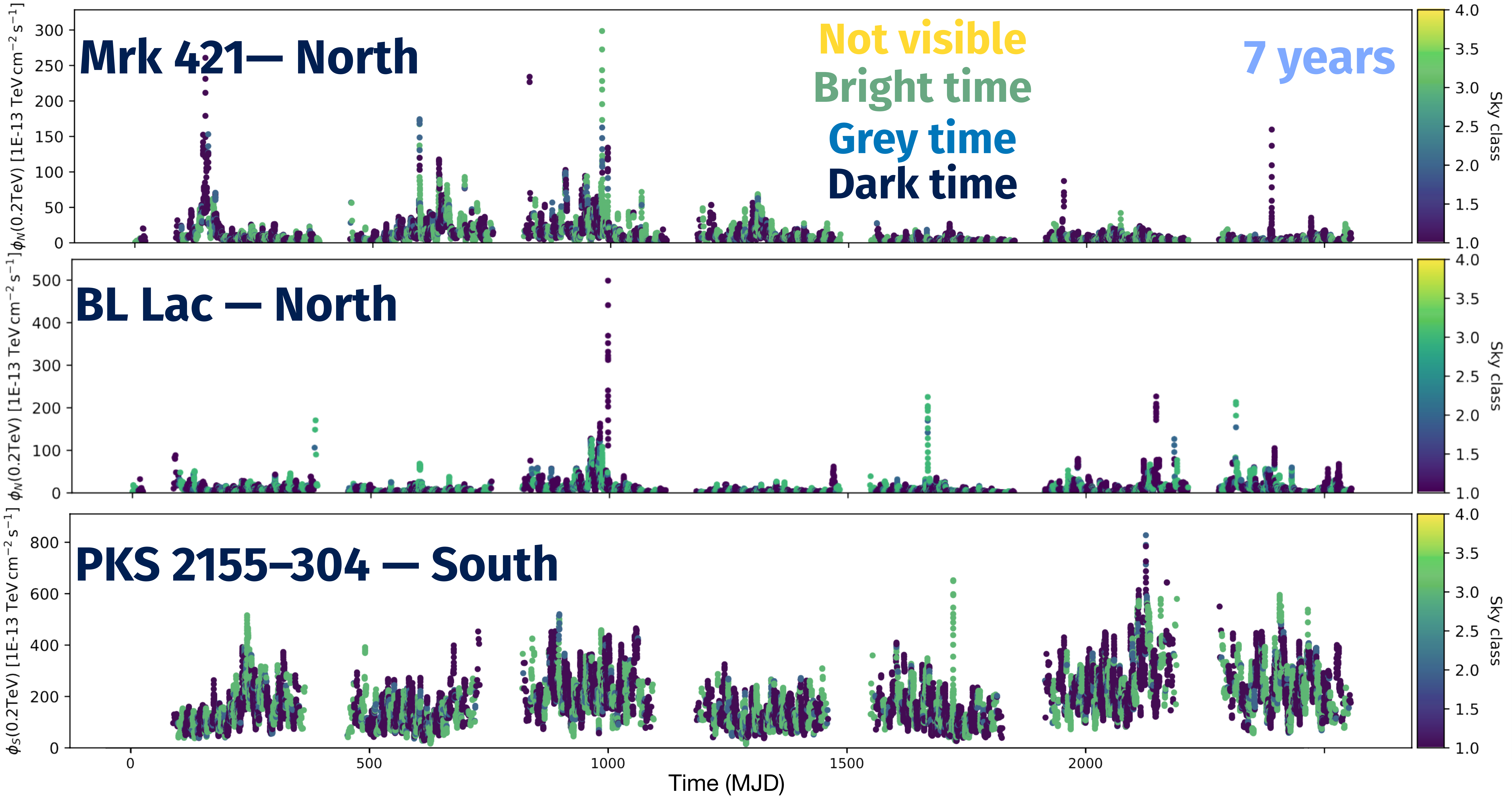

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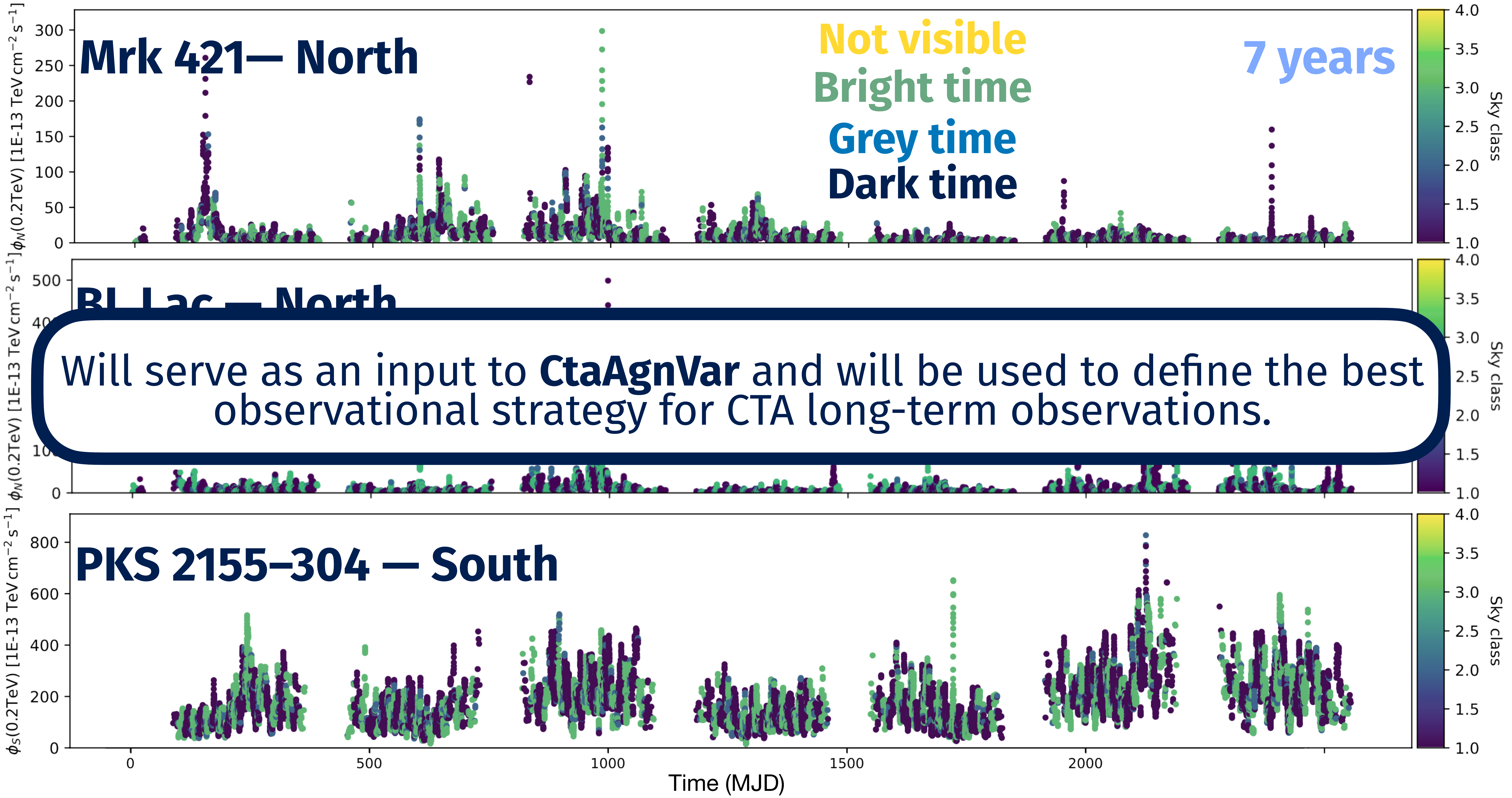

Will serve as an input to **CtaAgnVar** and will be used to define the best observational strategy for CTA long-term observations.

Summary and perspectives

Summary

- We have developed **new tools to simulate AGN flares and long-term light curves**;
- For very short flares (< ~3.5h), CTA will be able to **follow the whole flare with a fine time-binning** → possibility to observe hysteresis in an HID;
- For long flares, CTA will be able to catch part of the flare and eventually reconstruct an hysteresis in the HID;

→ Offer new possibilities to **exploit time-resolved analysis** and to **probe AGN short and long-term variability**!

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Perspectives

- **Flare simulations**: 3 typical flares with 4 theoretical models, more theoretical models will be investigated and compared;
- **Long term light curves**: reconstruct power spectrum and duty cycle of simulated AGNs with **CtaAgnVar**

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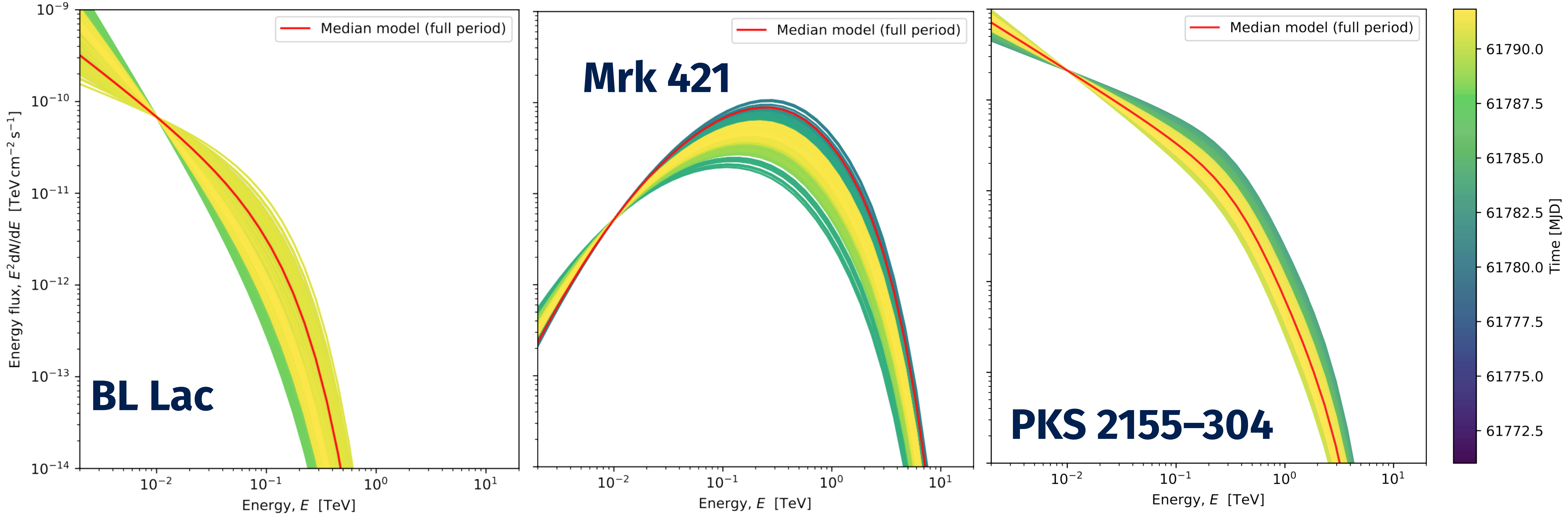
Thank you!

Additionnal slides

Long-term light curves

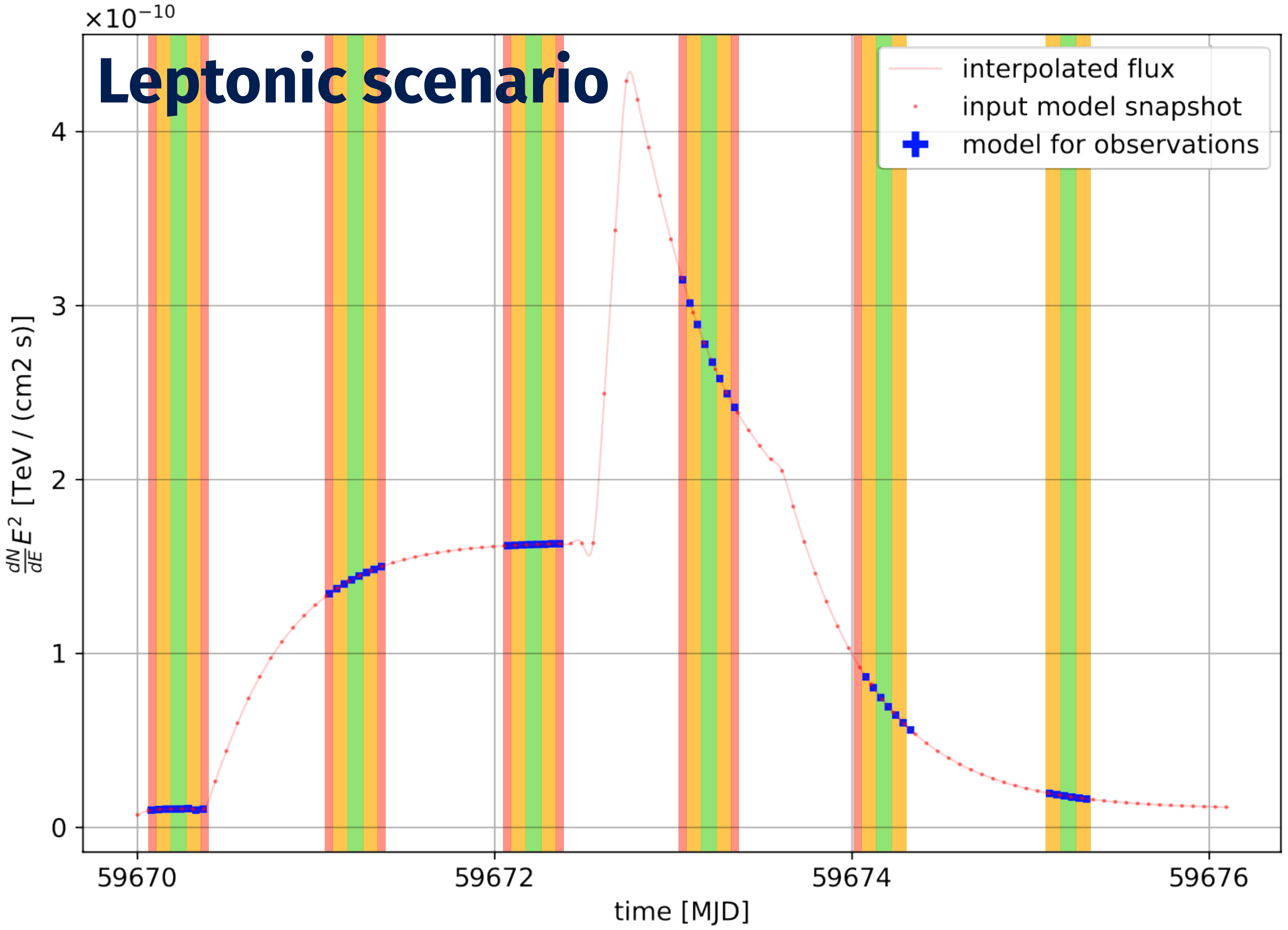


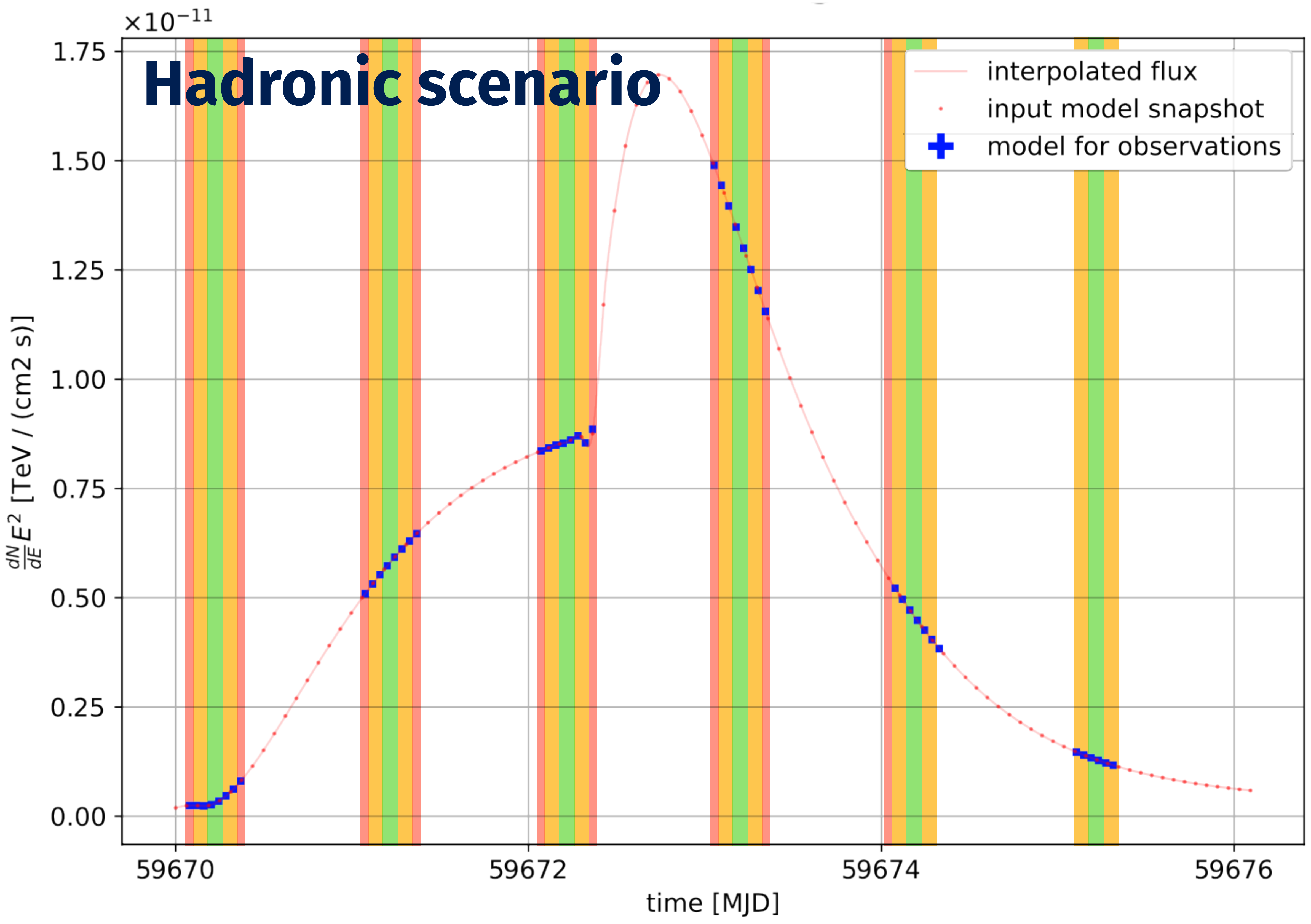
Flare simulations

3C 279 — June 2015 flare

Zenith angle 60°
Zenith angle 40°
Zenith angle 20°

CTA South





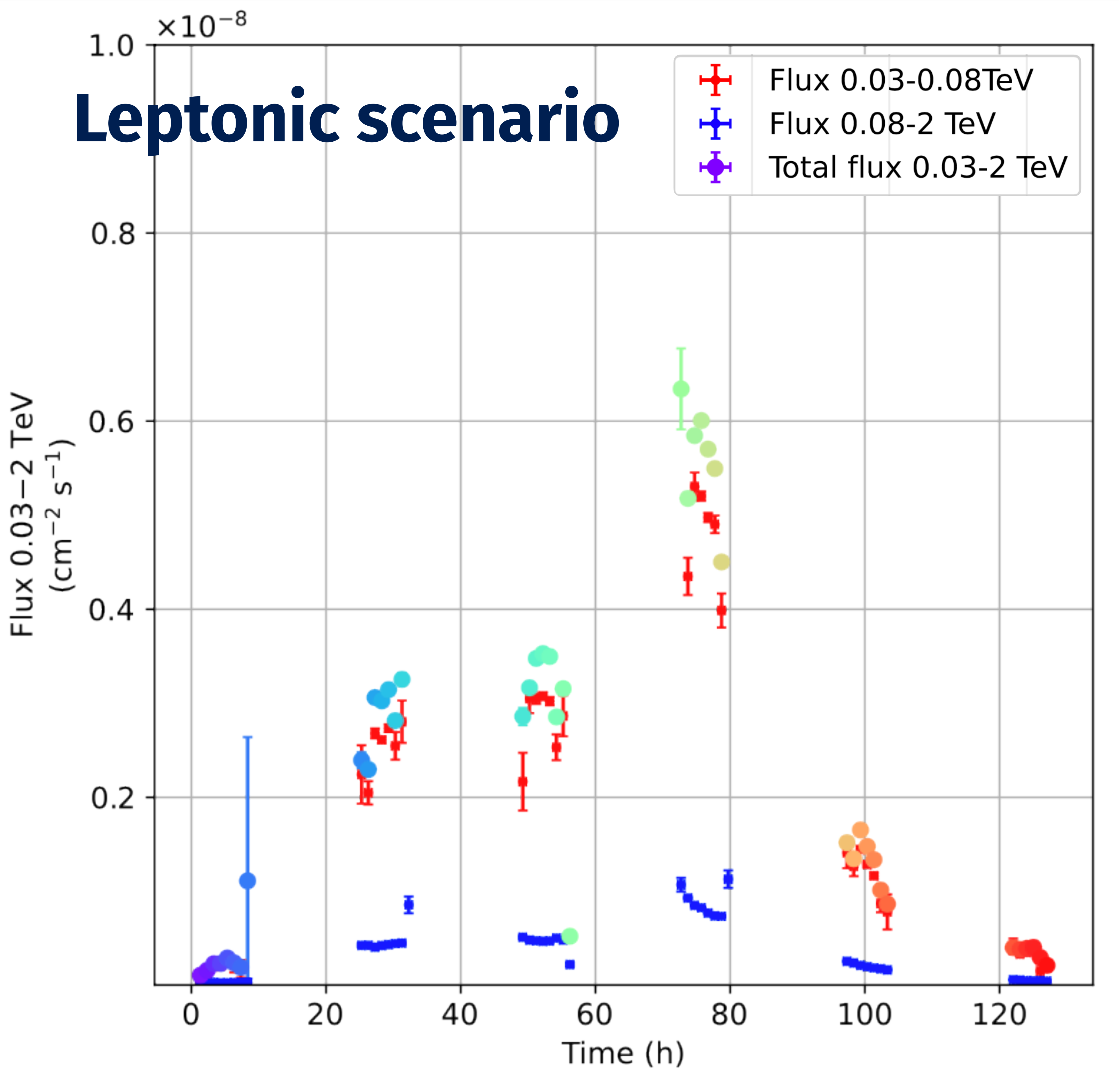
Flare simulations

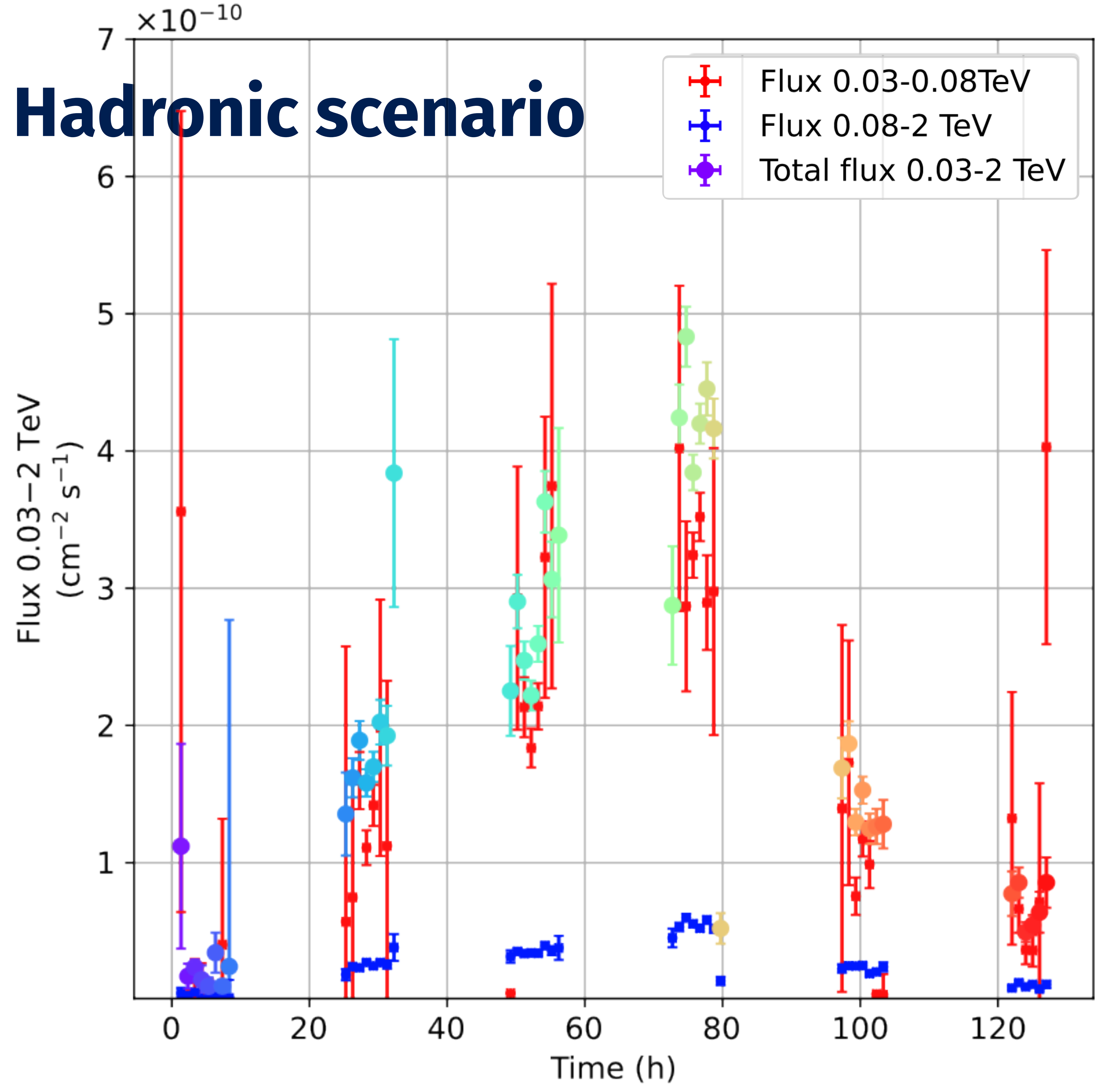
3C 279 — June 2015 flare

For each timestep:

Compute fluxes to obtain light curves

CTA South





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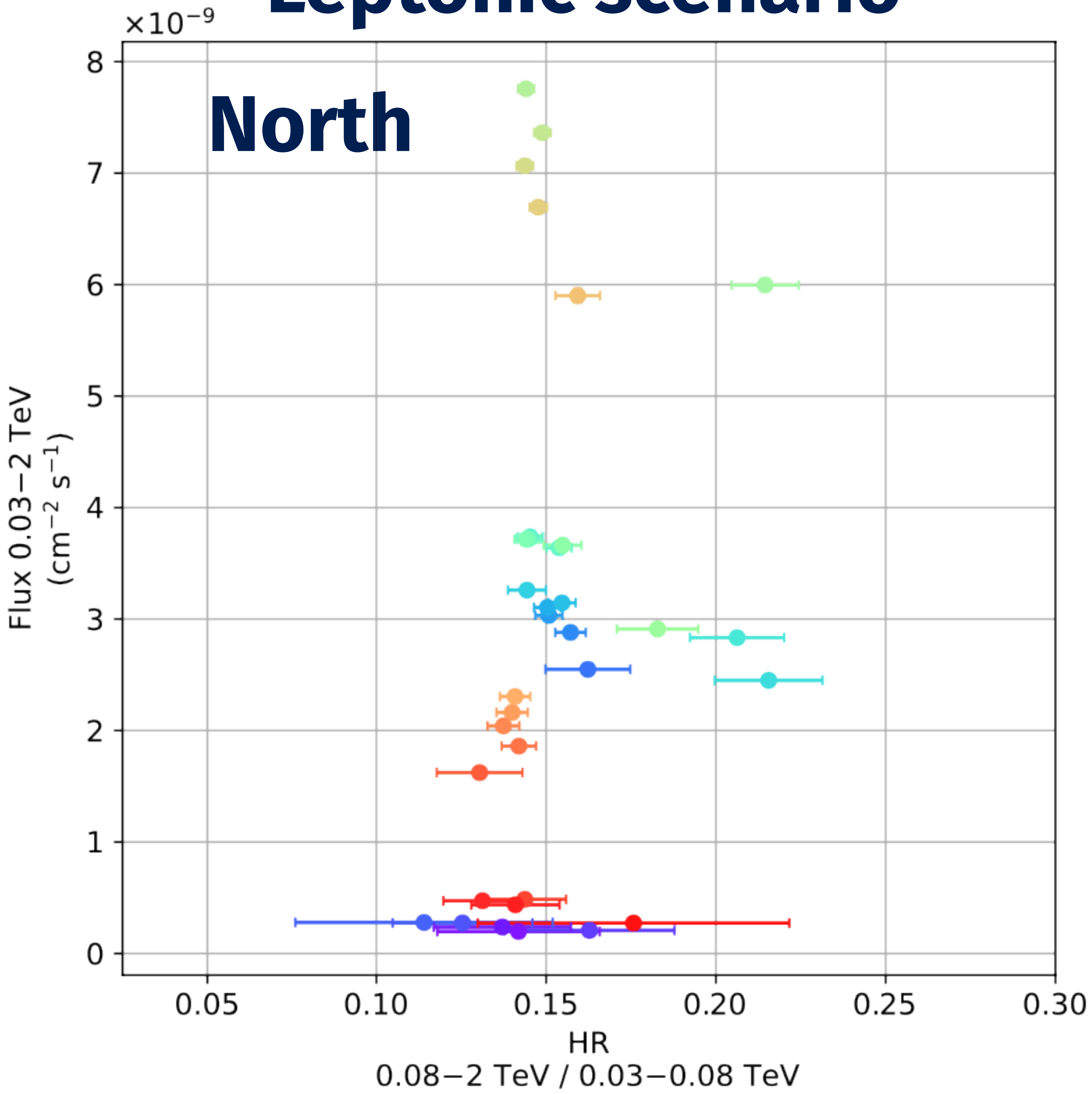
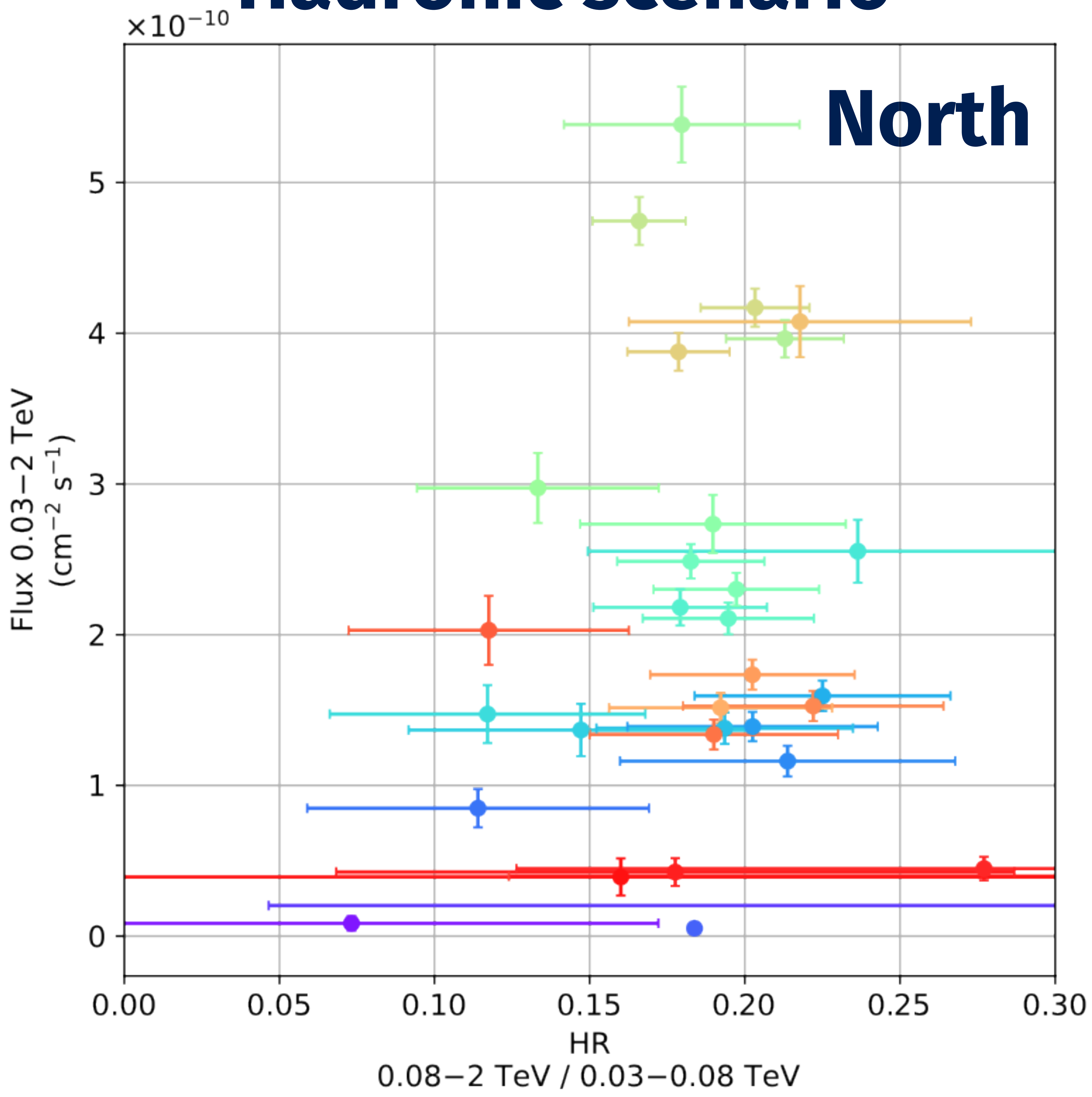


Hadronic scenario

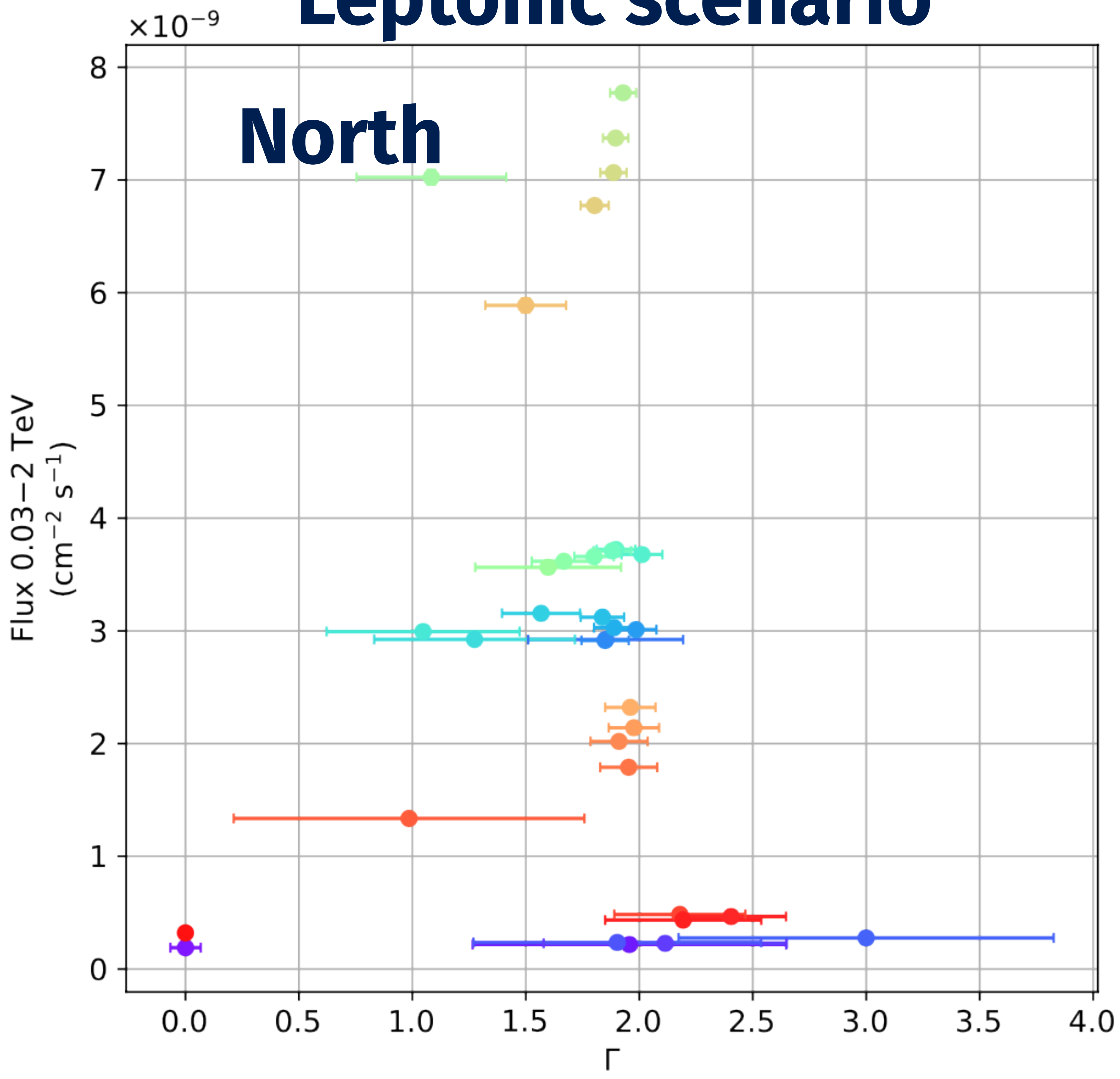


Flare simulations

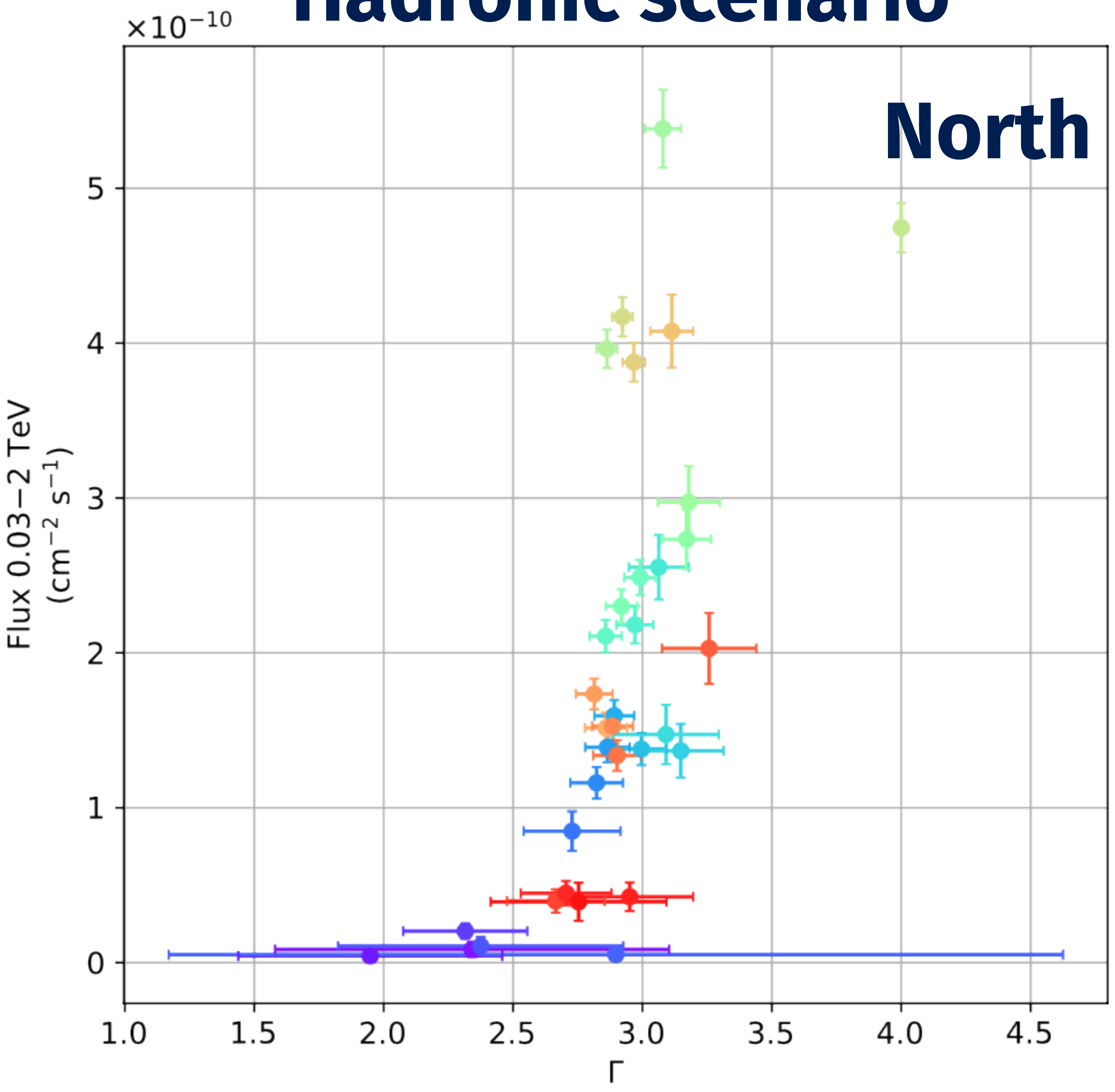
3C 279 — June 2015 flare

Hardness Intensity Diagram (HID)

Leptonic scenario



Hadronic scenario

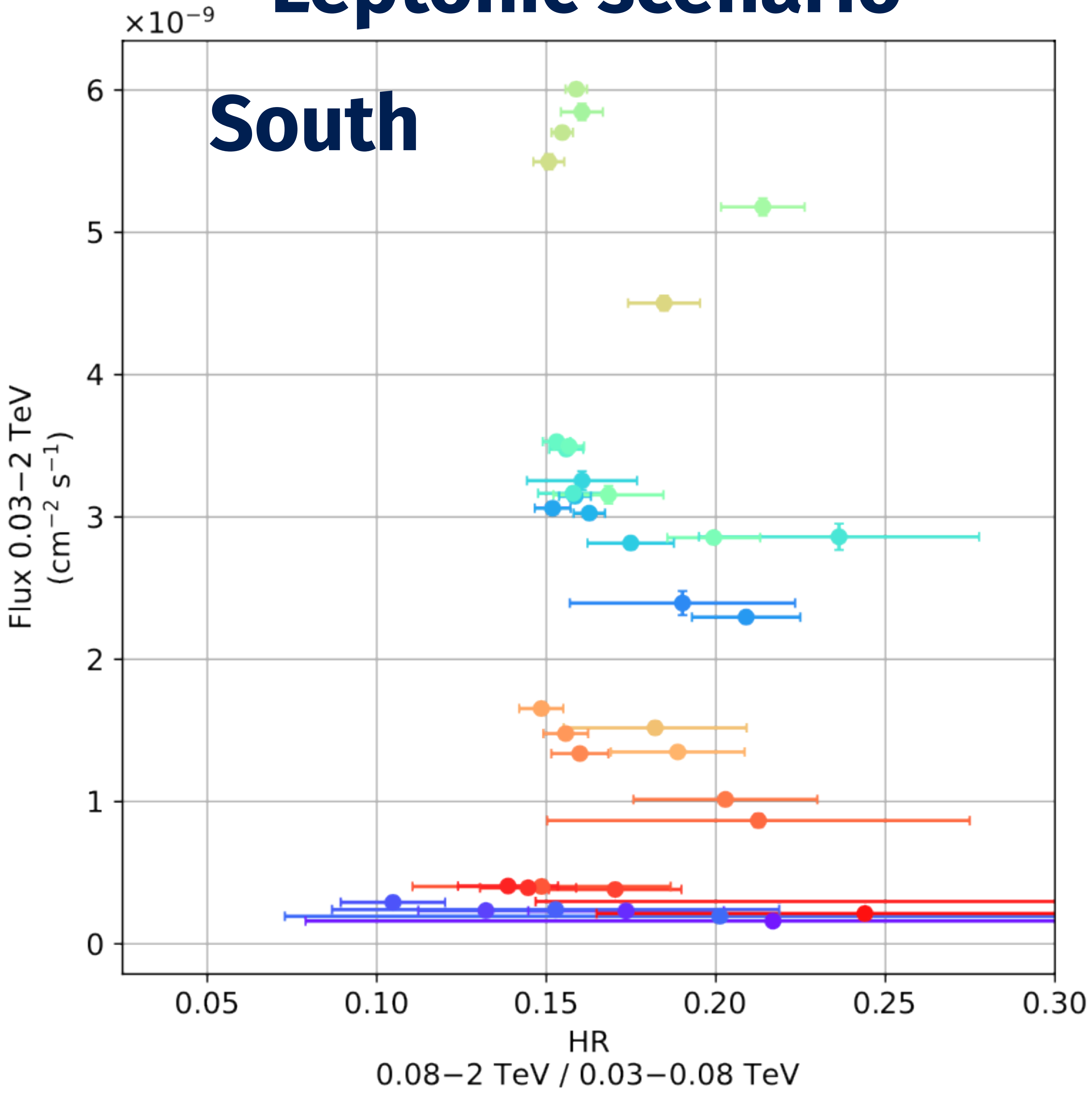


Flare simulations

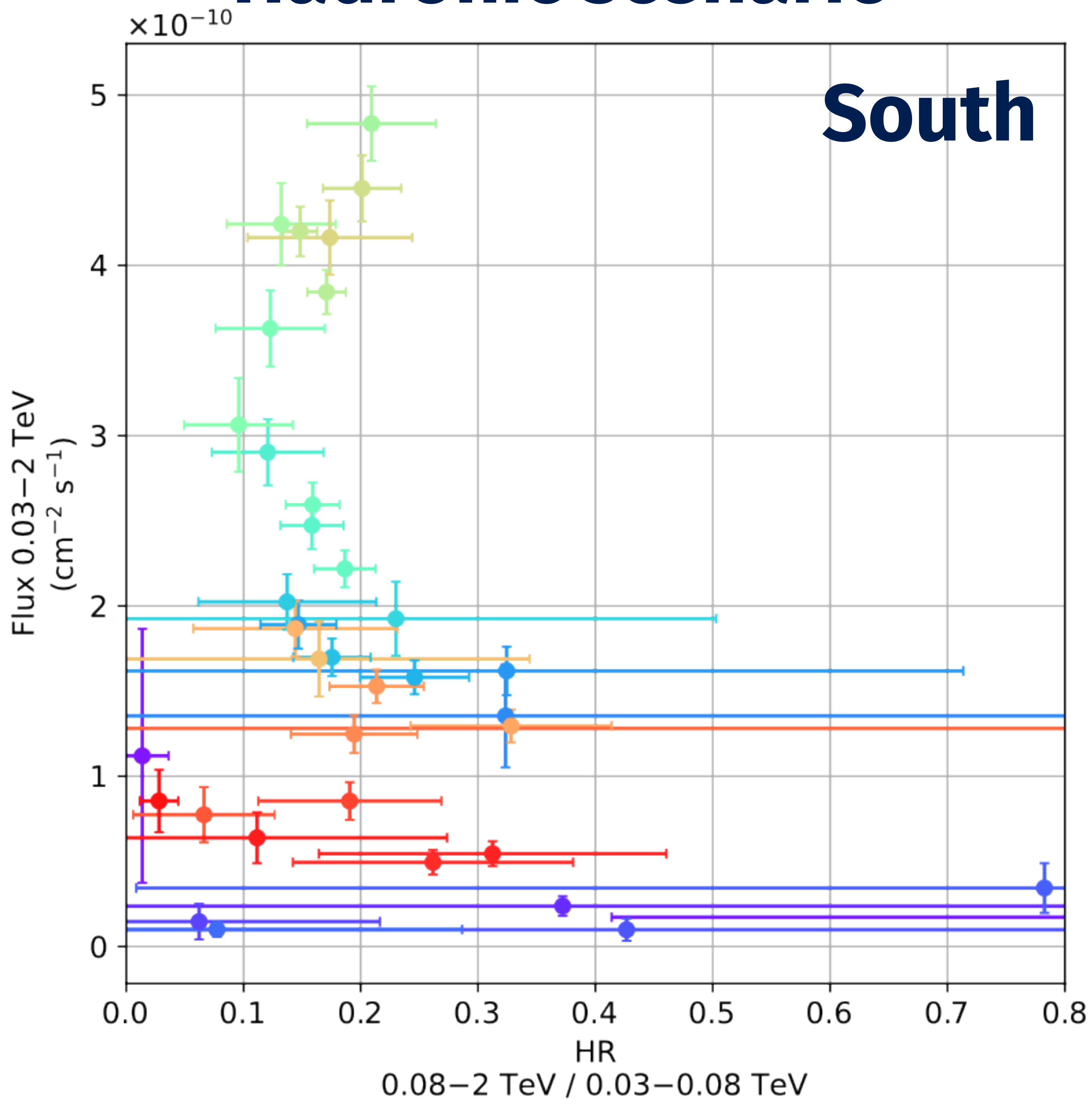
3C 279 – June 2015 flare

Hardness Intensity Diagram (HID)

Leptonic scenario



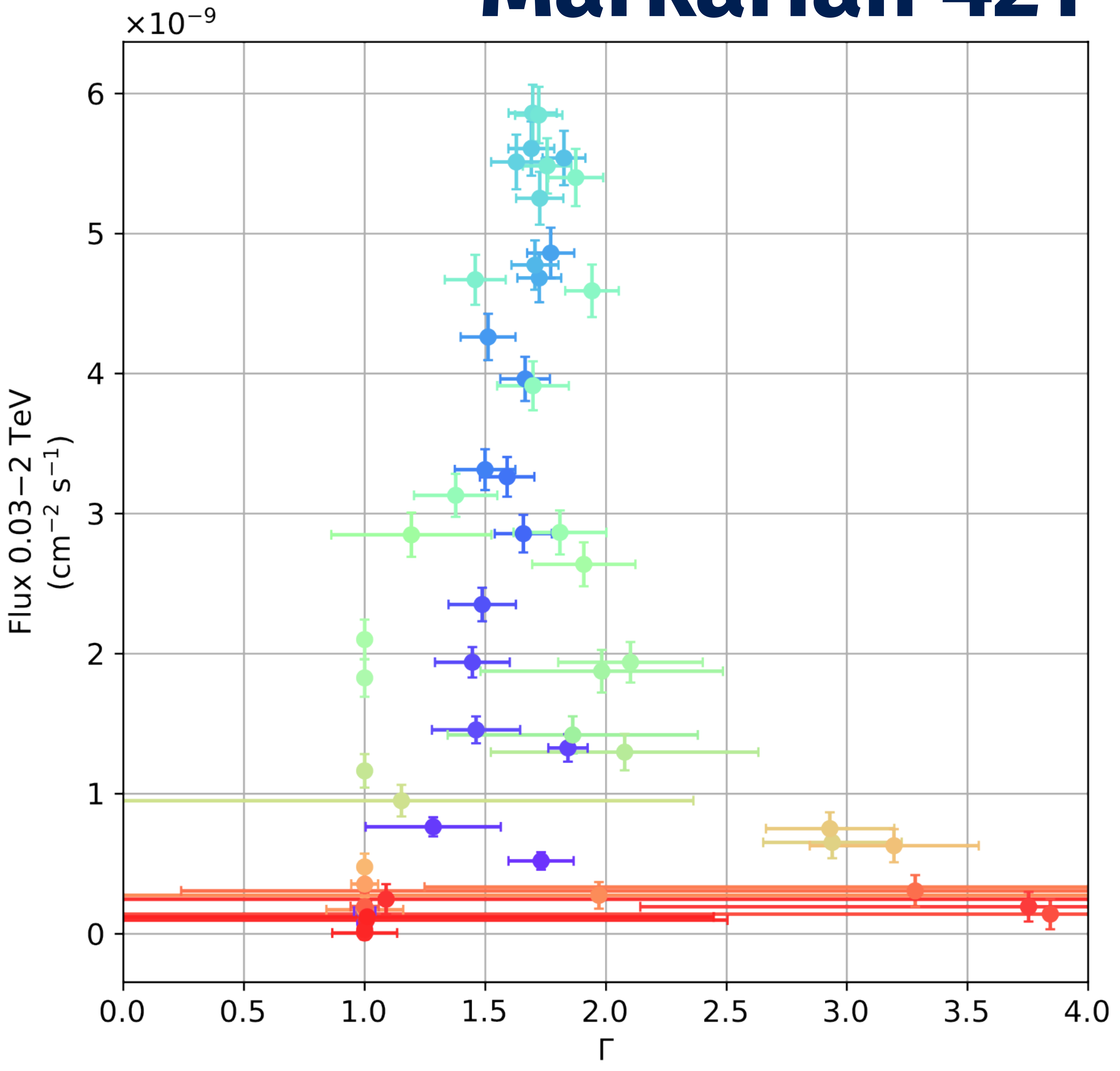
Hadronic scenario



Flare simulations

Hardness Intensity Diagram (HID)

Markarian 421



BL Lacertae