Study on the Emission Mechanism of a TeV Blazar “OP 313” with Multi-Wavelength Observation

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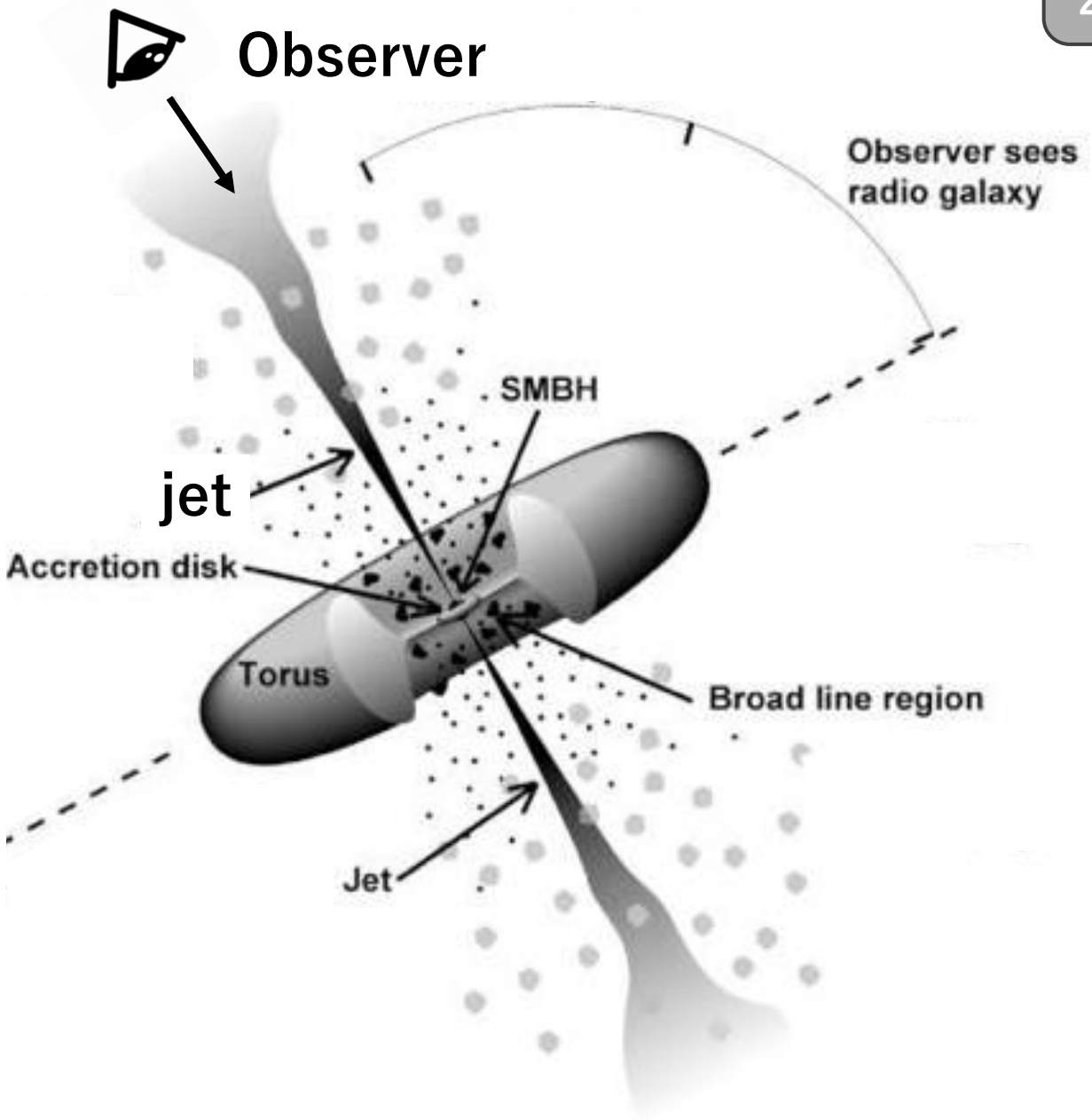
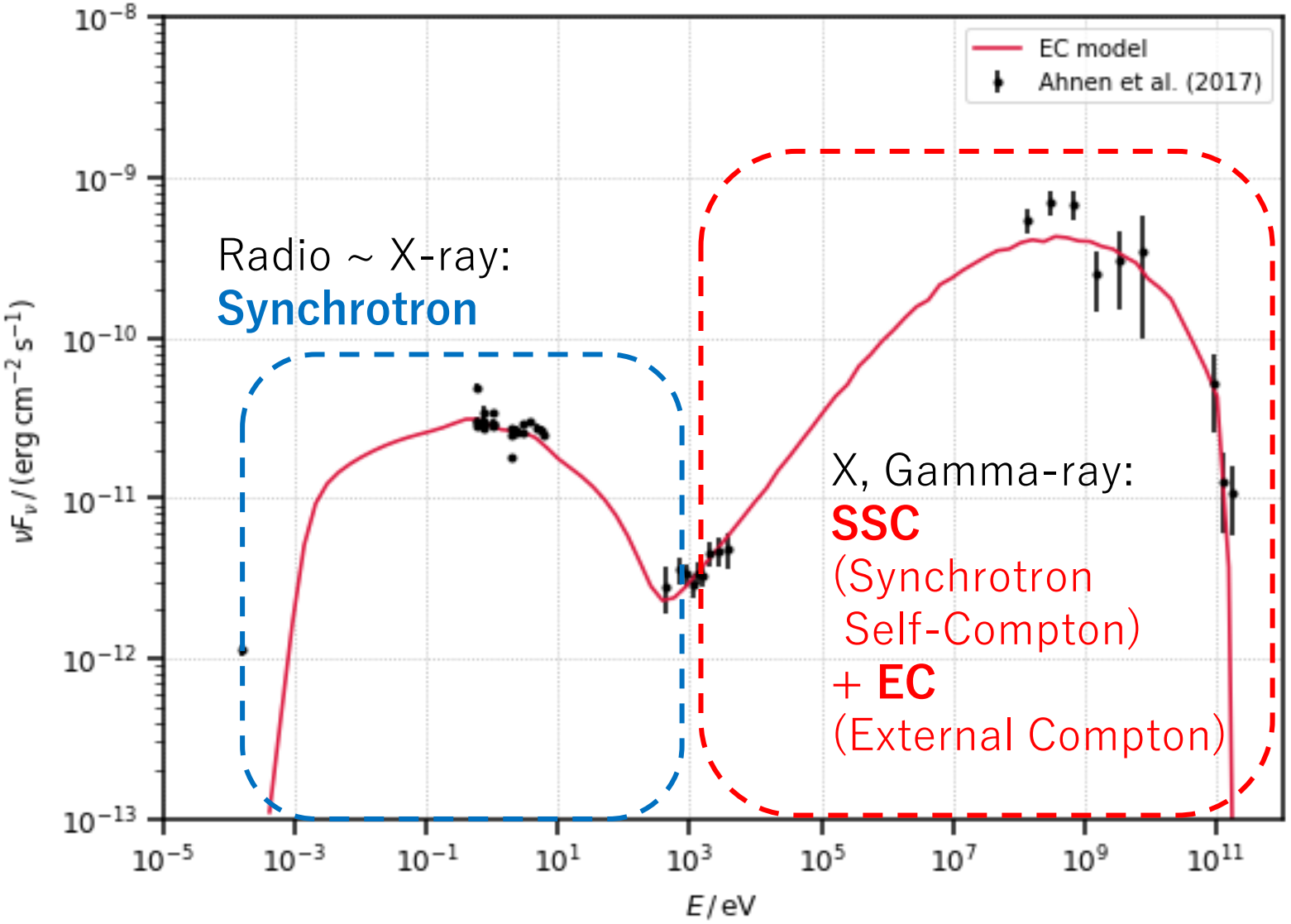
Blazars

- **Blazars:** radio-loud AGNs with relativistic jets aligned close to our line of sight.
- This alignment leads to **Doppler-boosted emission** and rapid flux variability and high polarization.
- **BL Lacs:** weak or no optical broad lines, its HE emission is predominantly from the SSC.
- **FSRQs:** strong disk, BLR and dusty torus; EC emission is important.
- FSRQs are rare at VHE bands due to **large distances and gamma-ray absorption** by the BLR and EBL.



Credit: fermi.gsfc.nasa.gov/science/eteu/agn/

The SED of Blazars



Unresolved Issues with Blazar

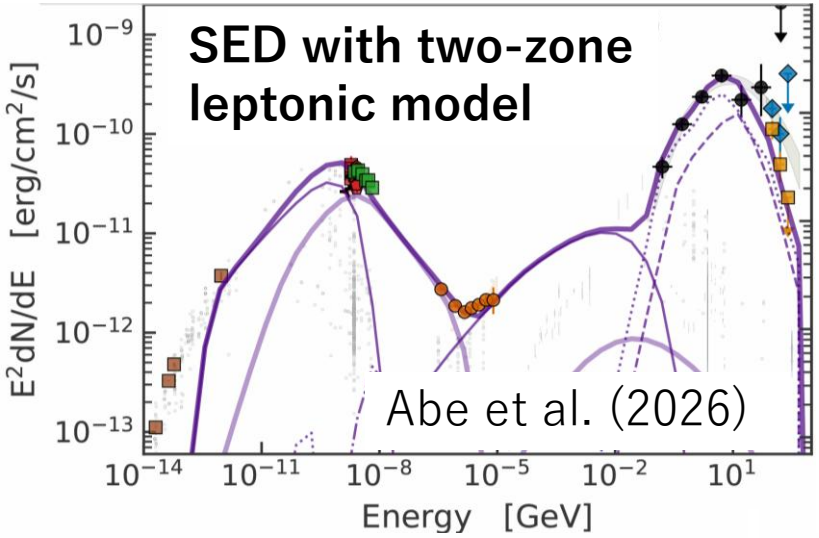
- Jet Drive Mechanism
- Particle acceleration mechanism, Radiation mechanism

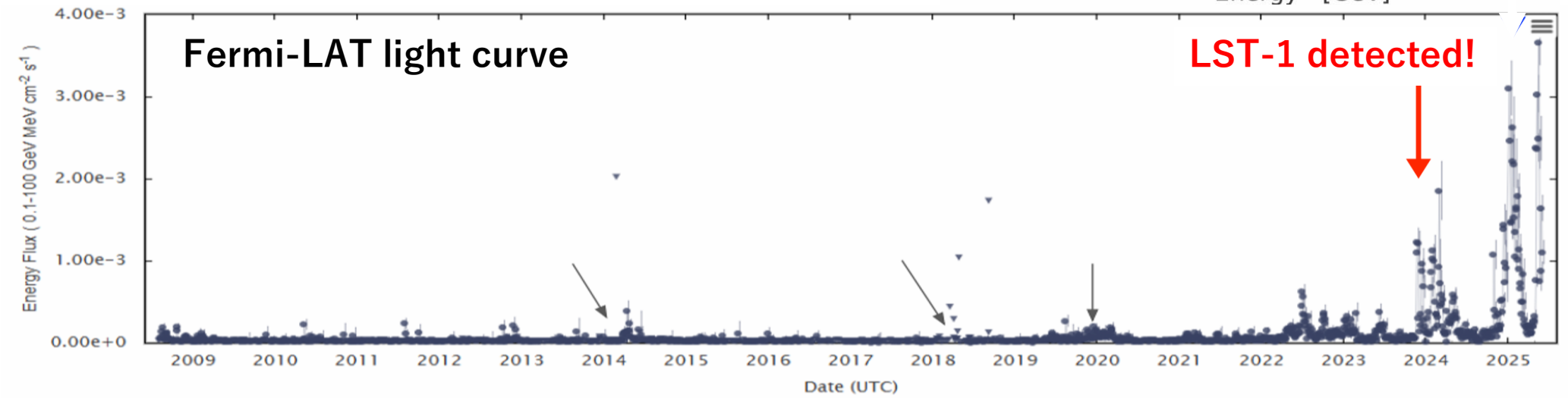
High-energy emission mechanism is still debated.

- Single-zone leptonic model?
- Multi-zone leptonic model?
- Hadronic model?

OP 313

- It exhibited a **historic brightening** in gamma rays.
- **Observed by LST-1.**
  The observation period: December 10 ~ 19, 2023.
- **Most distant VHE FSRQ: z=0.997**
- Abe et al. (2026) conducted a multi-wavelength observation campaign aligned with the LST-1 observation period and modeled the SED using a **two-zone leptonic model**.

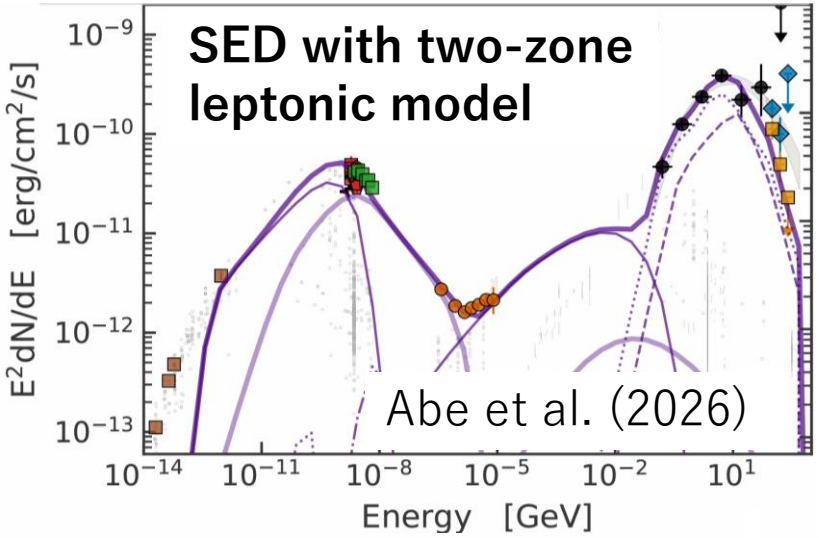


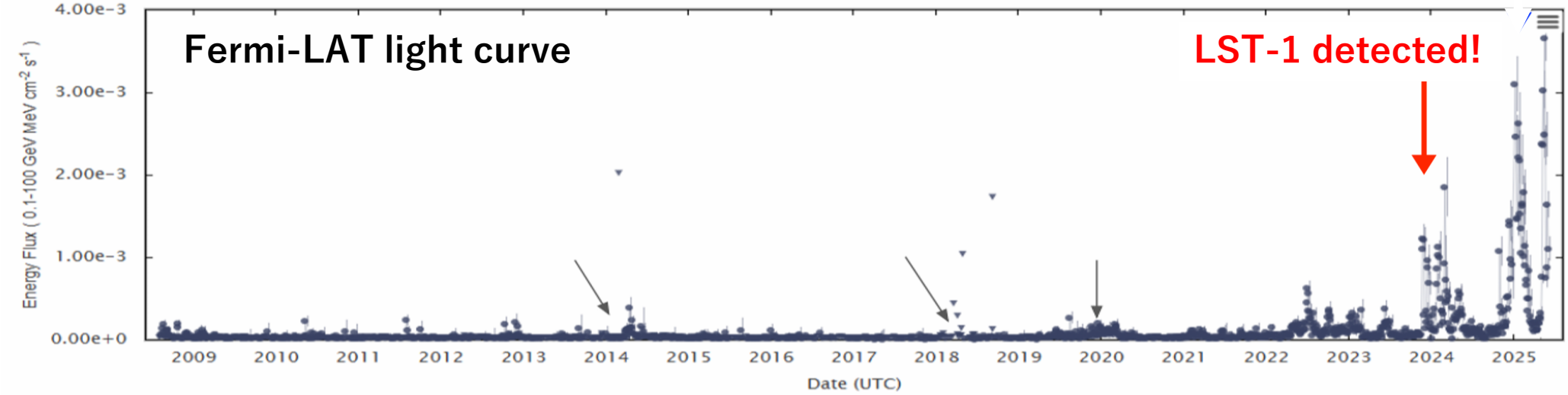


OP 313

In this work,

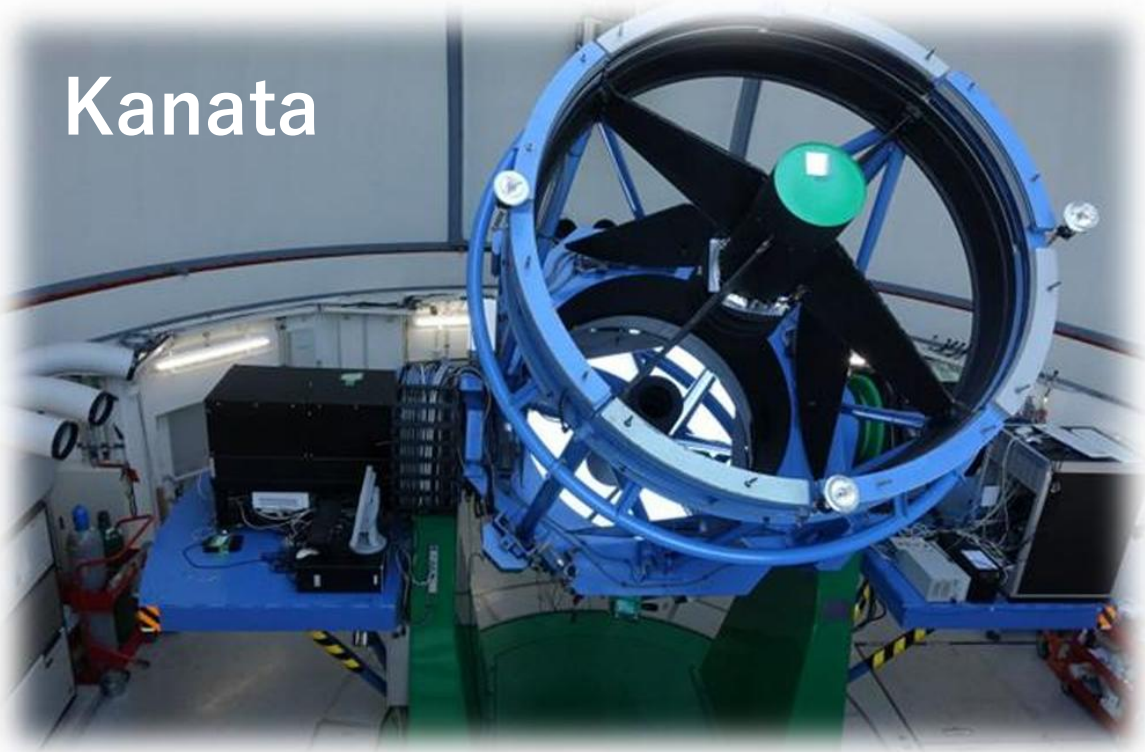
- We conducted a long-term monitoring observation from **December 2023 to July 2025** using the **Kanata telescope** at Higashi-Hiroshima Observatory.
- We also carried out SED modeling with multi-wavelength data.
- **Can two years of spectral data be explained using the same two-zone model?**





Observations

Optical, Near-IR:
- Swift/UVOT (Bands: U, B, V)
- **Kanata/HONIR** (Bands: R, J)
  - Primary mirror with a diameter of **1.5 meters**, fourth largest in Japan.
  - Capable of Photometric or polarimetric observations in two bands **simultaneously**.



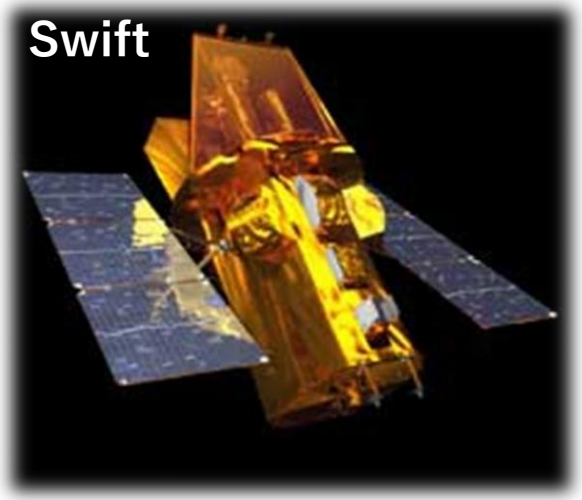
VHE Gamma-ray:
- CTAO/LST1

(digitized from Abe et al. (2026))

Gamma-ray:
- Fermi/LAT

X-ray, UV:
- Swift/XRT, UVOT (Bands: W2, M2, W1)

Credit: NASA



Credit: NASA

Light Curves

Flare 1: optical/UV flare,
VHE gamma-ray was detected.

Flare 2: optical/gamma-ray flare

Flare 3: sharp gamma-ray flare

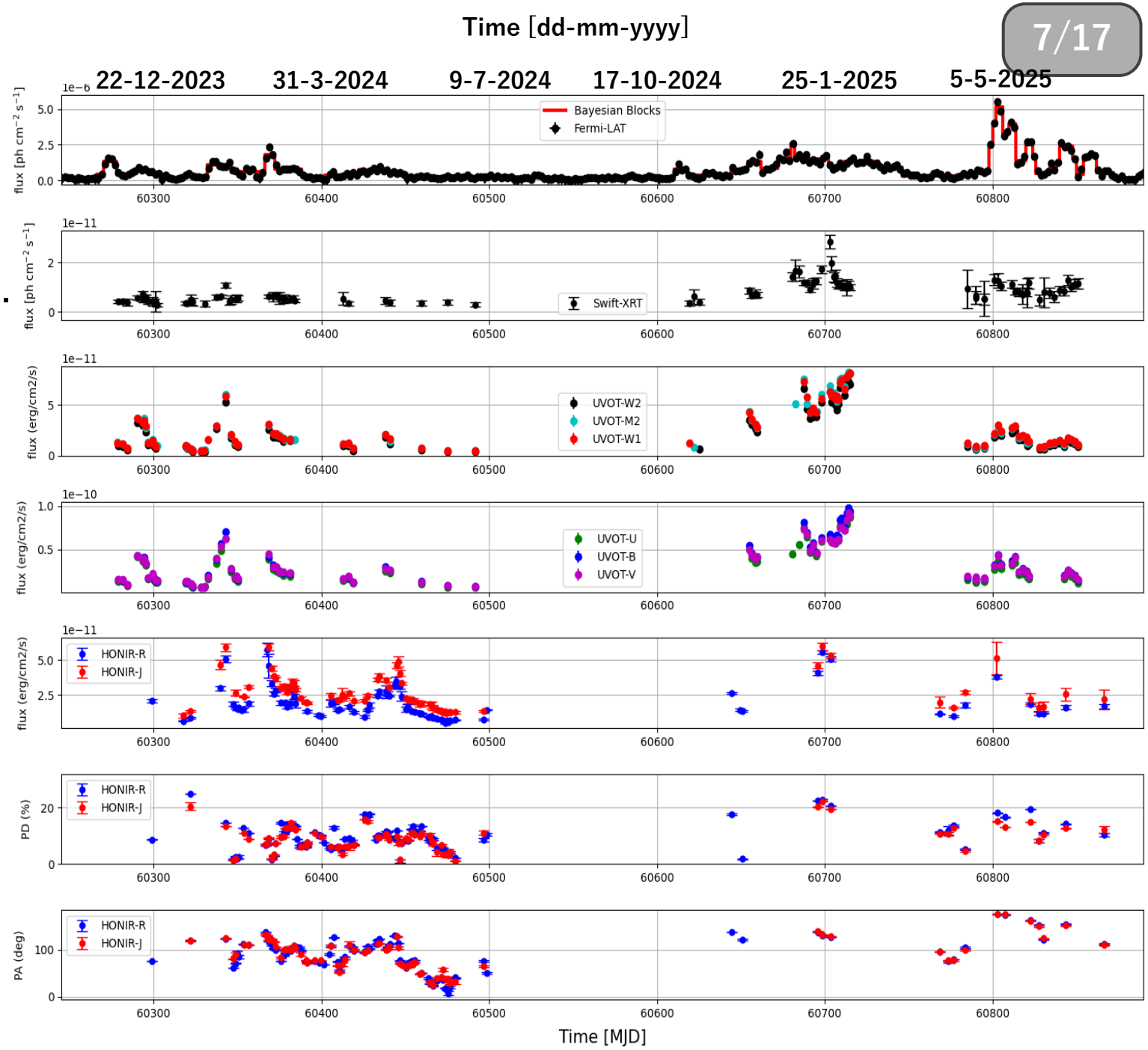
Flare 4: wide optical flare

Flare 5: several gamma-ray flares,
X-ray is the brightest.

Flare 6: maximum gamma-ray flare

Flare 7,8: gamma-ray flare

Flare 9: gamma-ray flare



Light Curves

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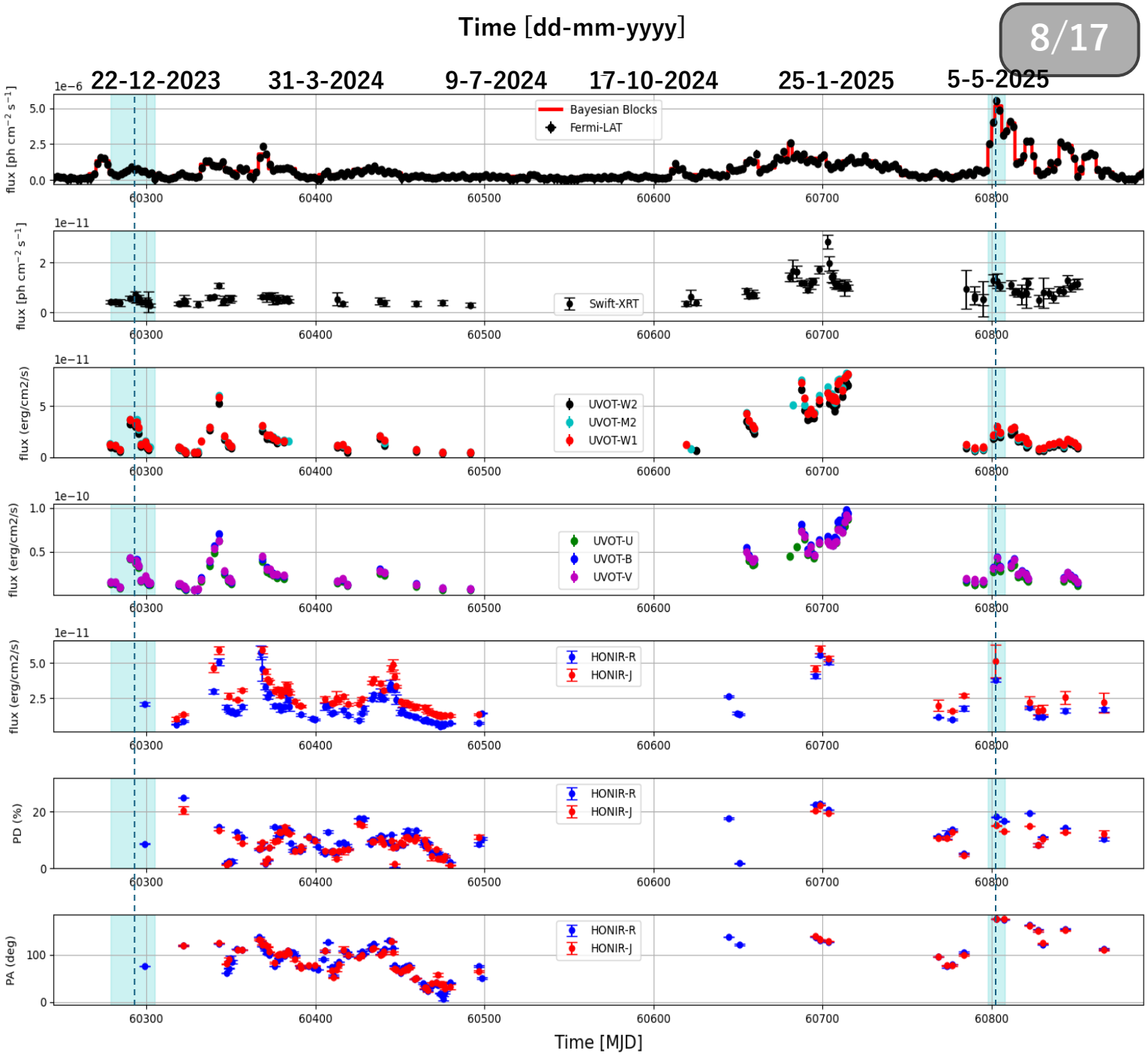
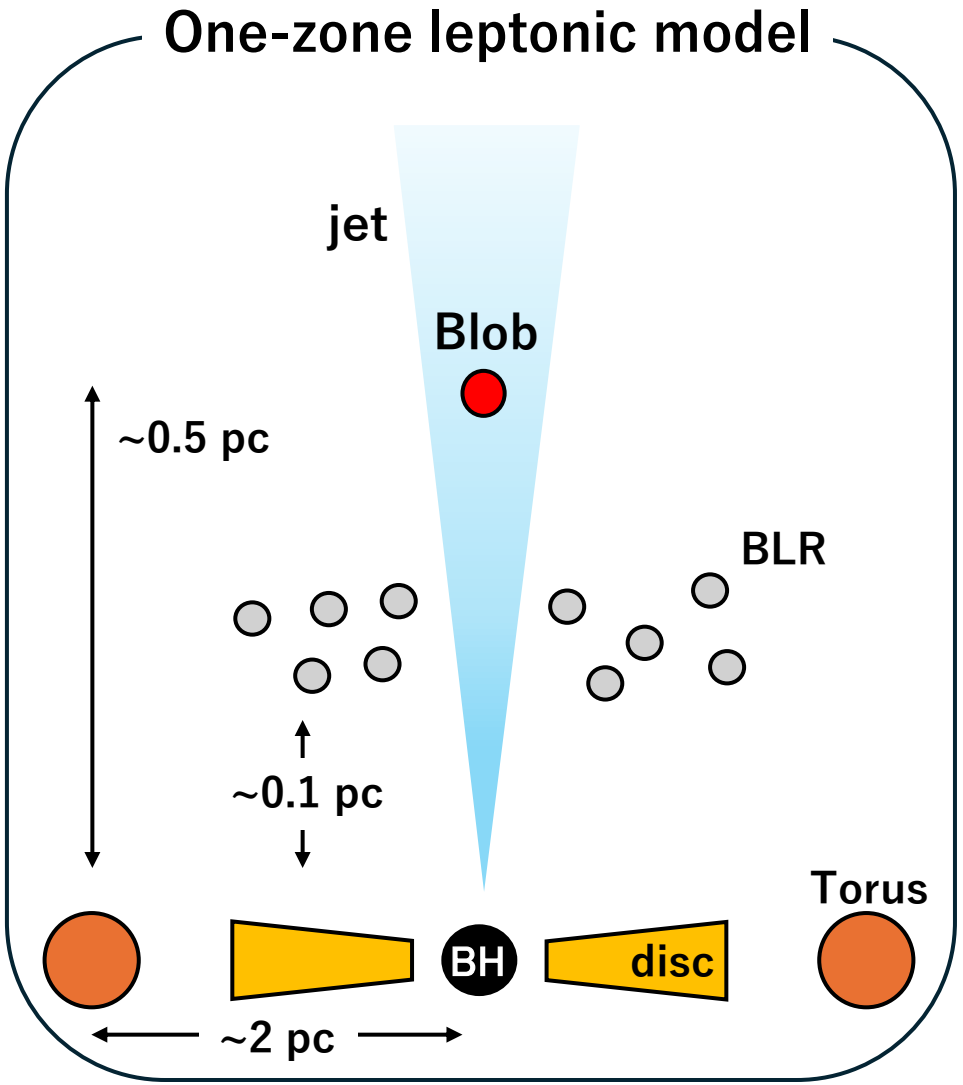
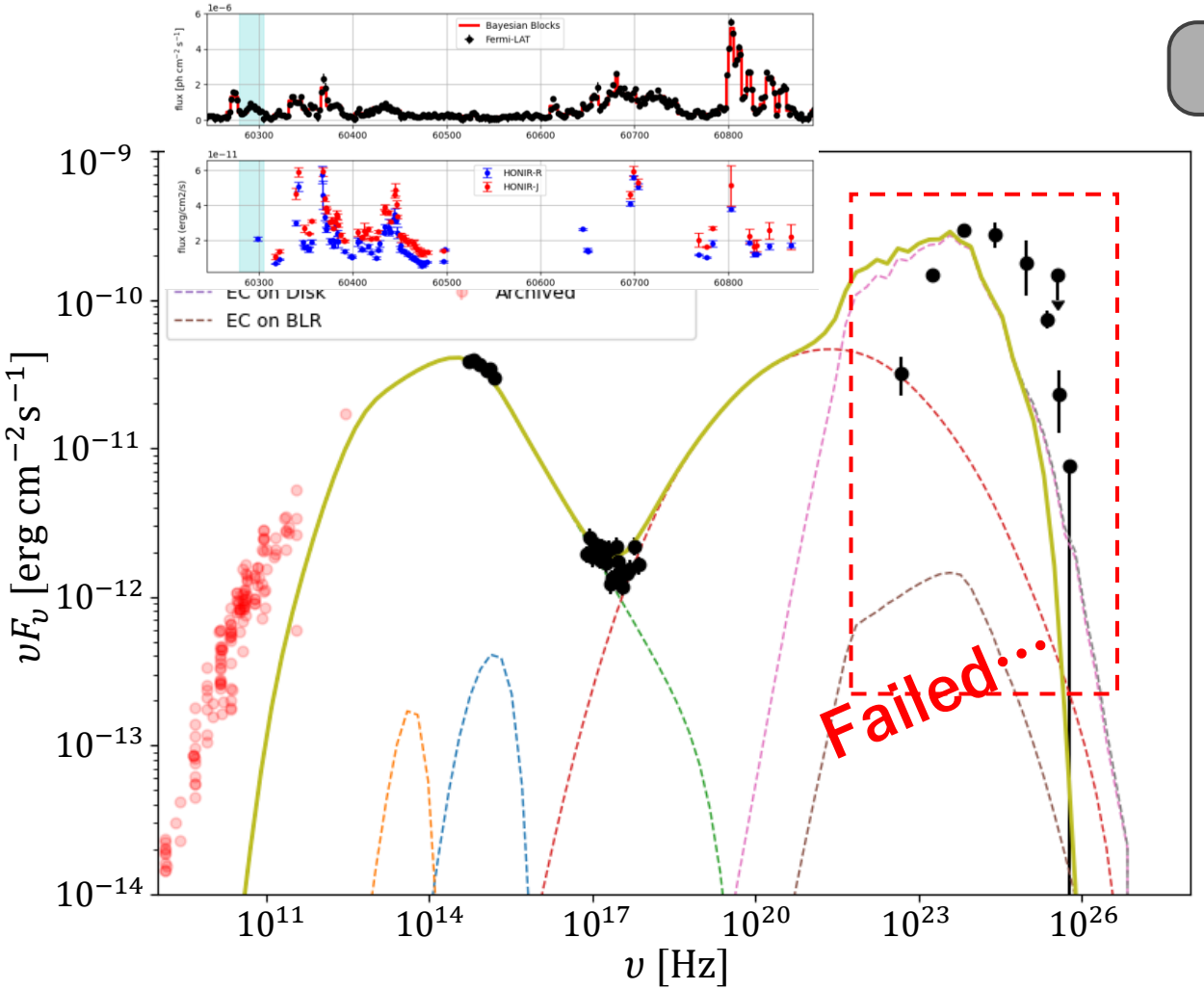


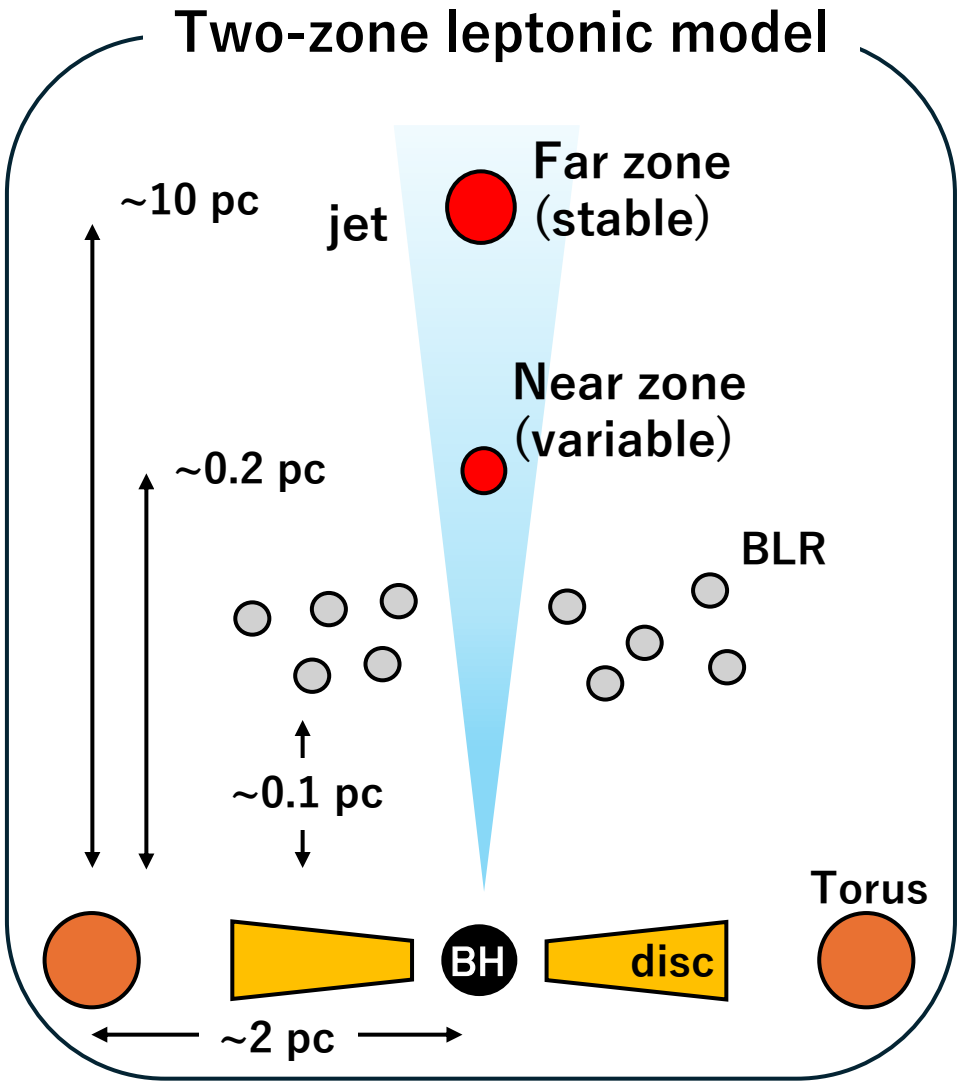
SED modeling

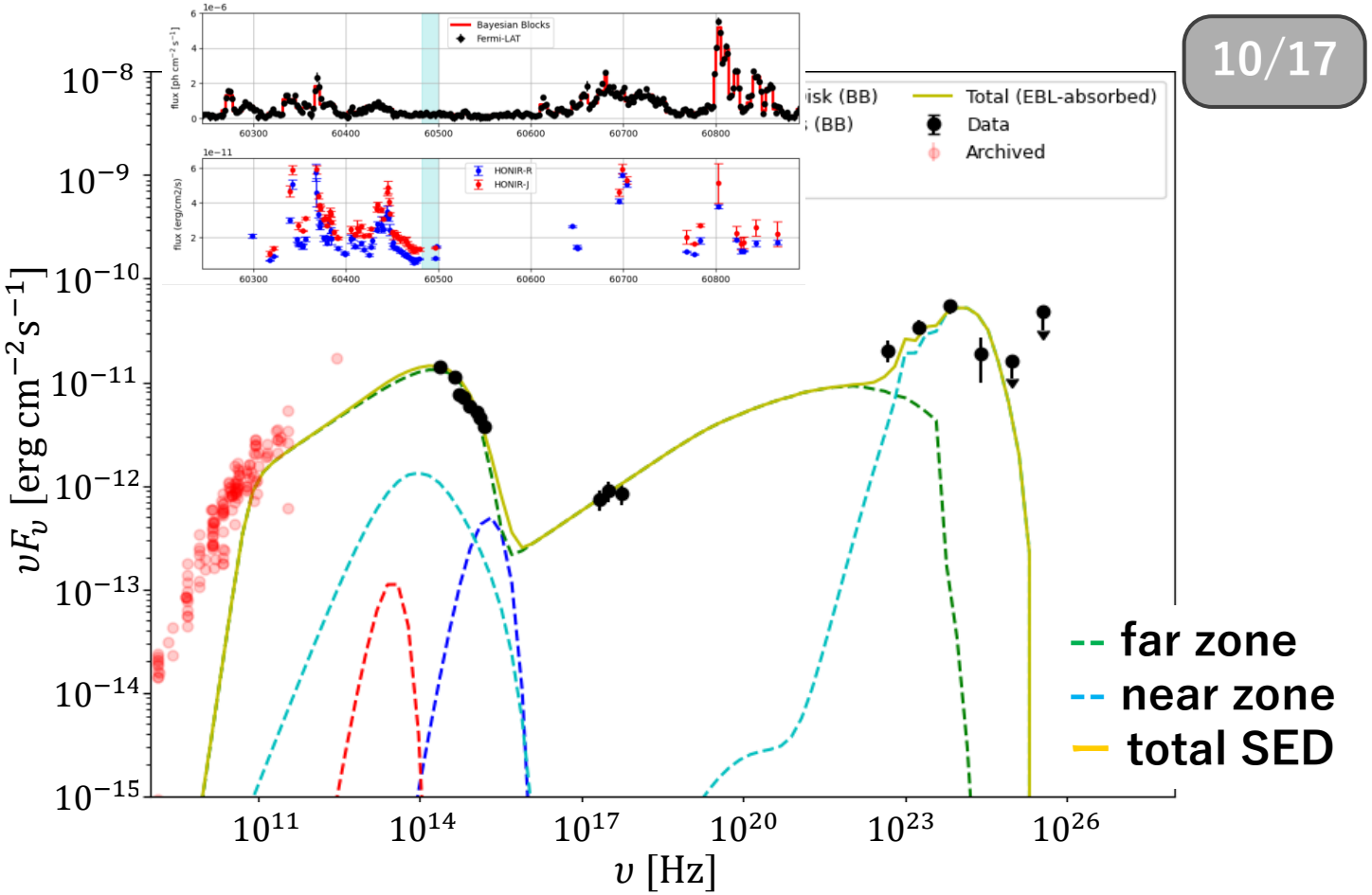




- Model: **one-zone leptonic model**
- Electron distribution: Broken Power Law
- No matter how we adjusted the SED parameters, the model didn't match the gamma-ray band data.
- Radiation across the entire band **cannot** be attributed to radiation **from a single blob**.

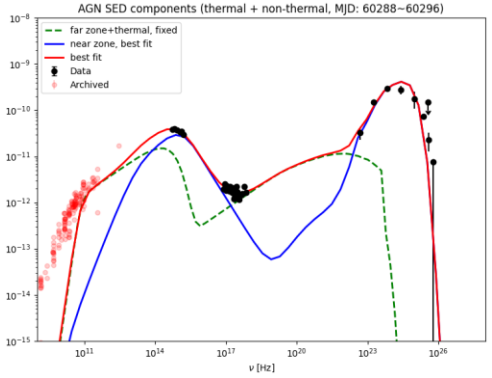
SED modeling



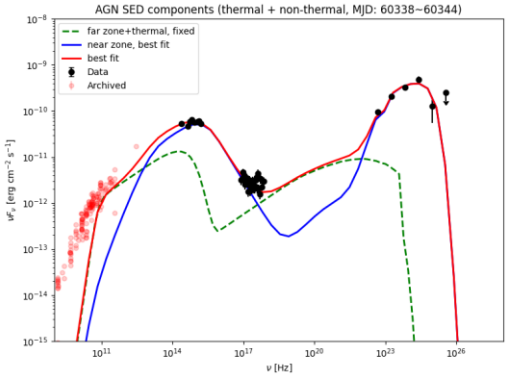


- Model: **two-zone leptonic model**
- The **far-zone parameters are fixed** based on the optical and X-ray data from the **quiet period**.
- Among the parameters of the **near zone**, only the **parameters related to the electron distribution are free**, while the **parameters of the blob structure are fixed**.
- $\boldsymbol{\Gamma_{near} = 50, \delta_{near} = 99}, Size_{near} = 1.0 \times 10^{16}\ cm$

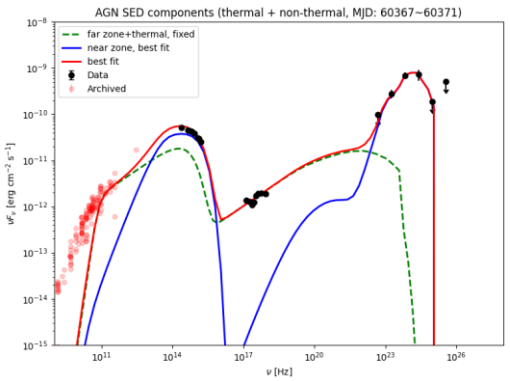
SED modeling



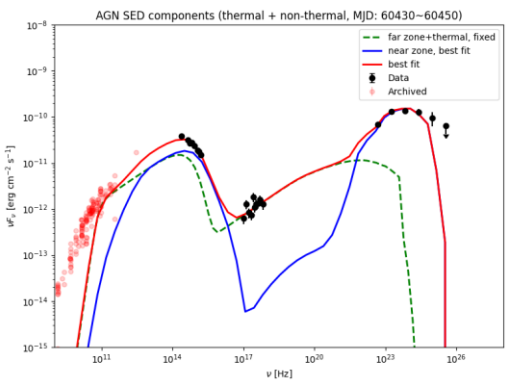
Flare 1



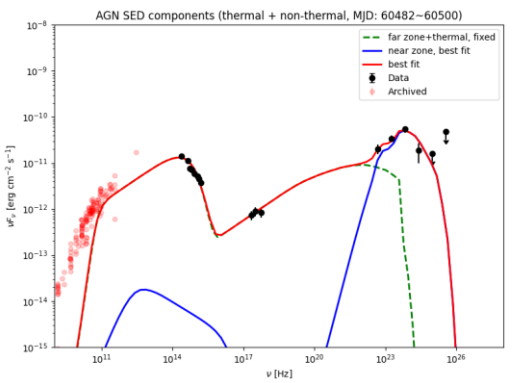
Flare 2



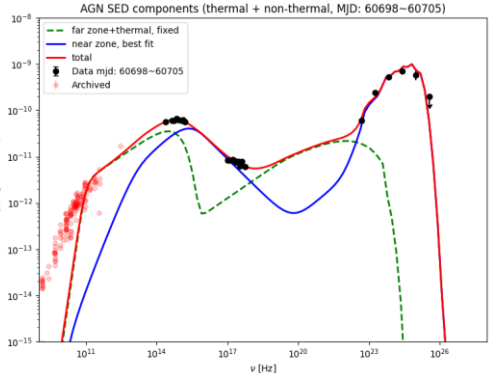
Flare 3



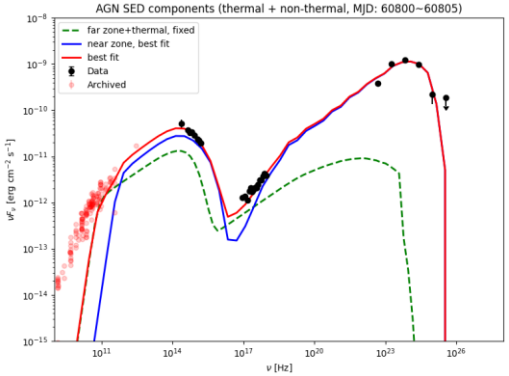
Flare 4



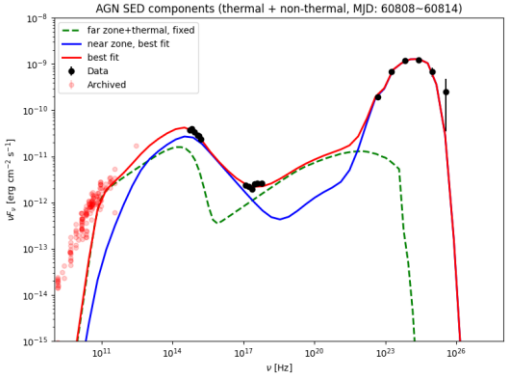
Quiescent period



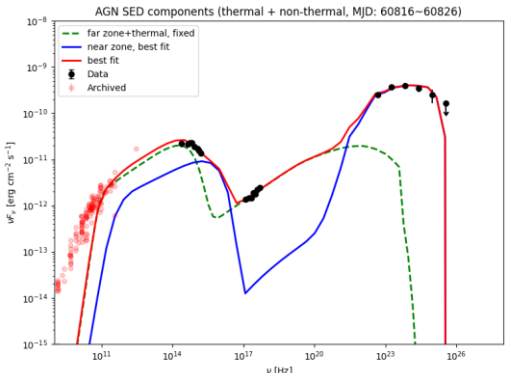
Flare 5



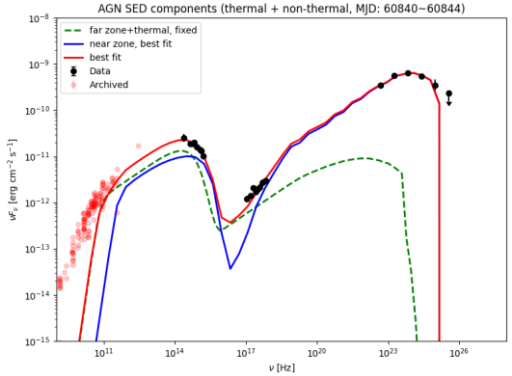
Flare 6



Flare 7

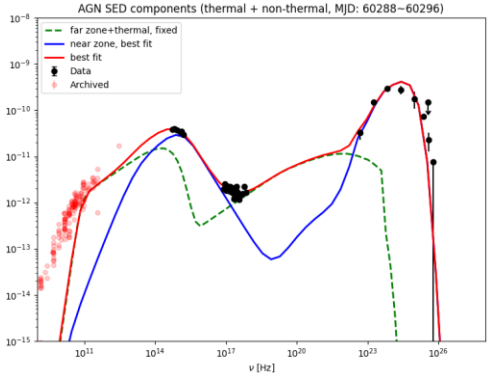


Flare 8

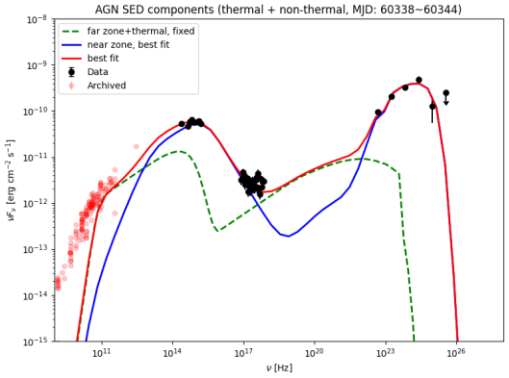


Flare 9

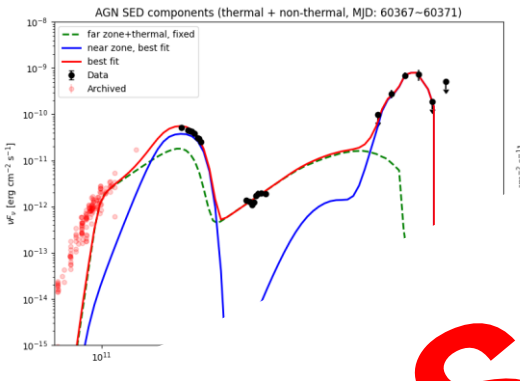
SED modeling

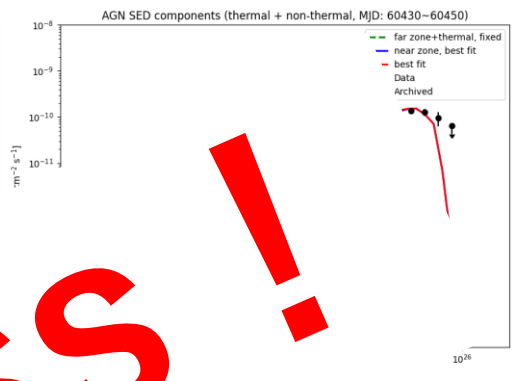


Flare 1

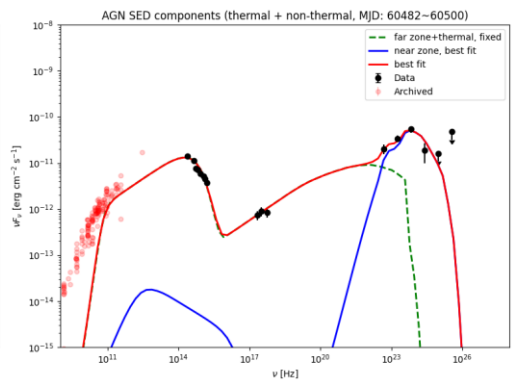


Flare 2



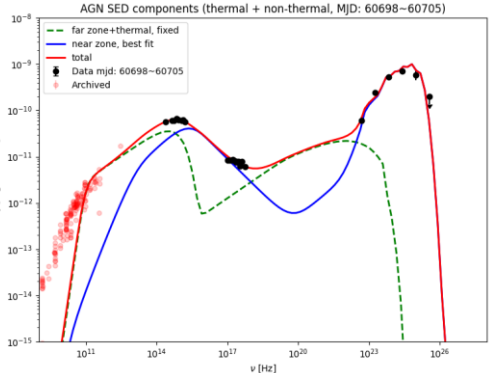


Flare 4

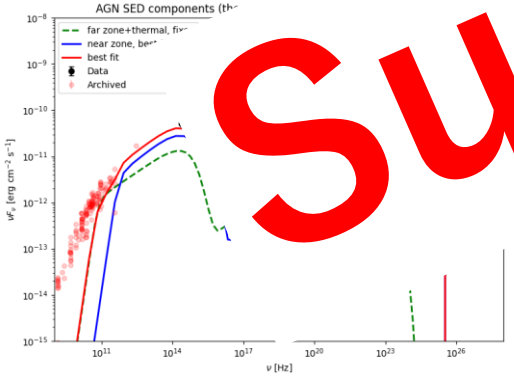


Quiescent period

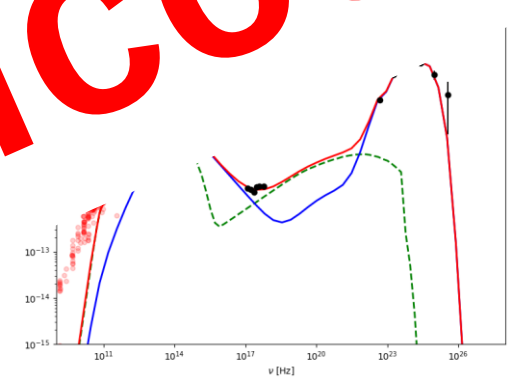
Success !



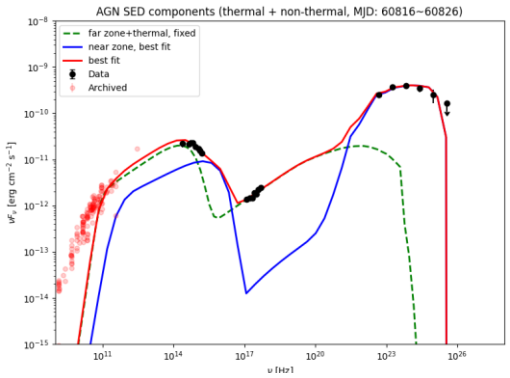
Flare 5



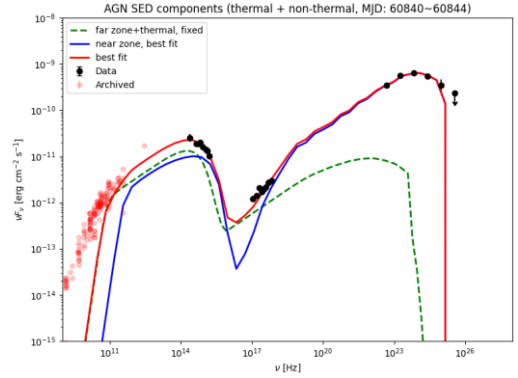
Flare 6



Flare 7



Flare 8

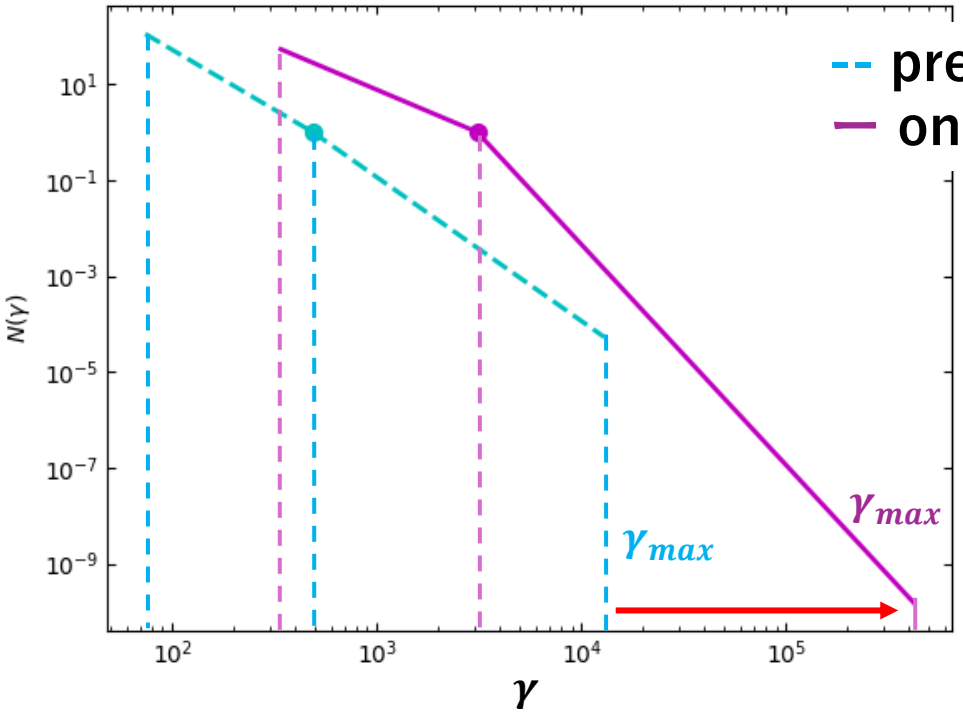


Flare 9

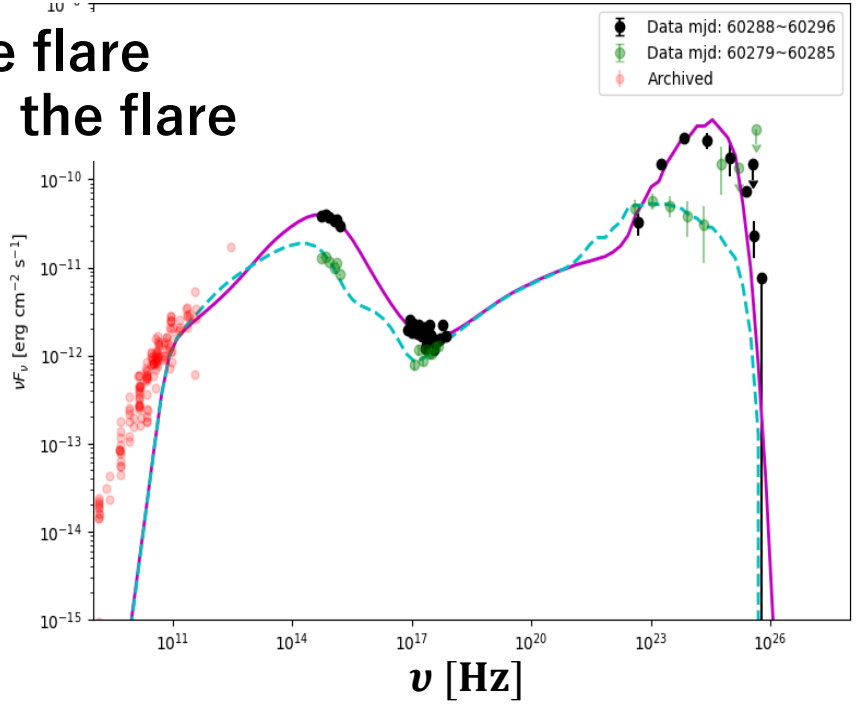
Discussion

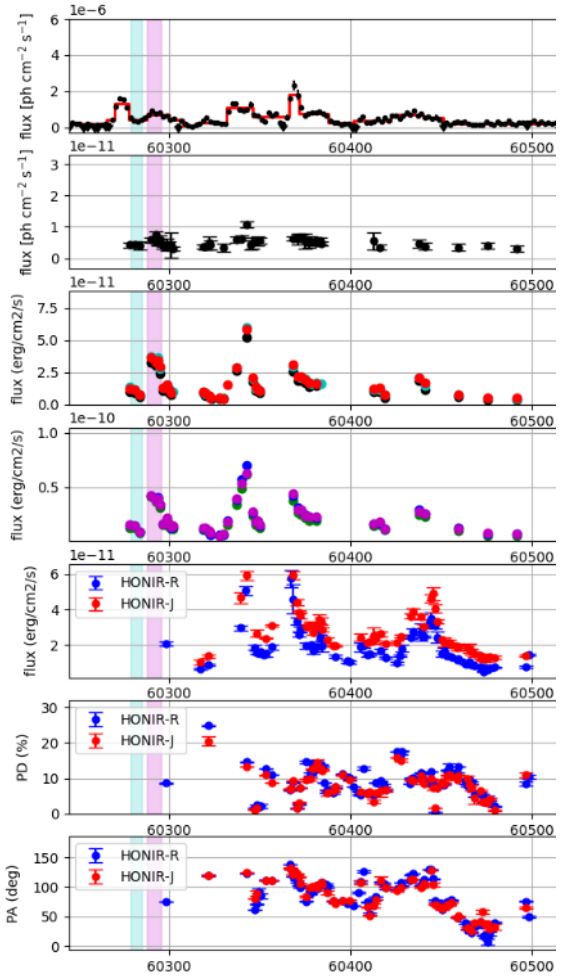
Flare 1: optical/UV flare, small gamma-ray flare,
VHE gamma-ray was detected.

Electron Distribution



SED

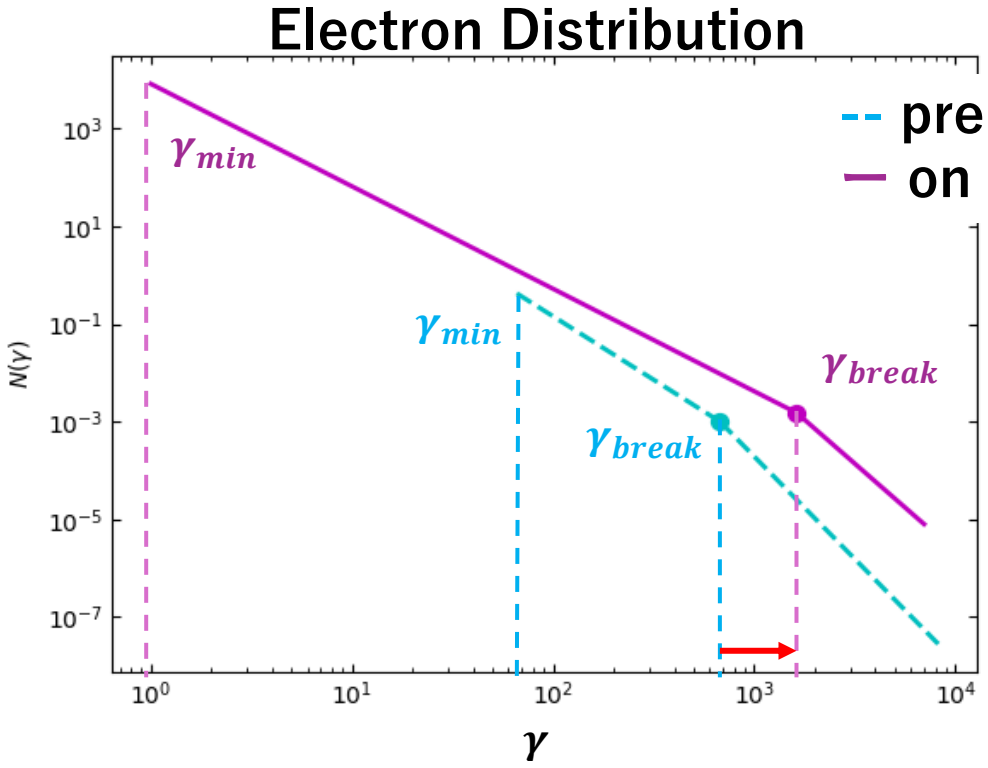


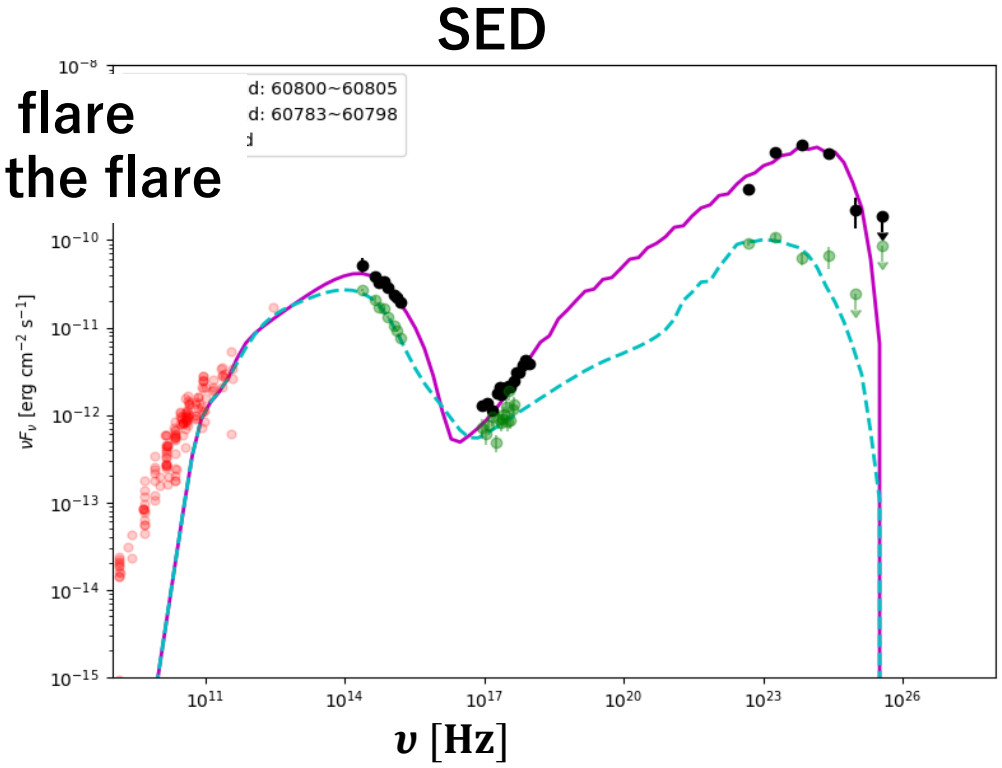


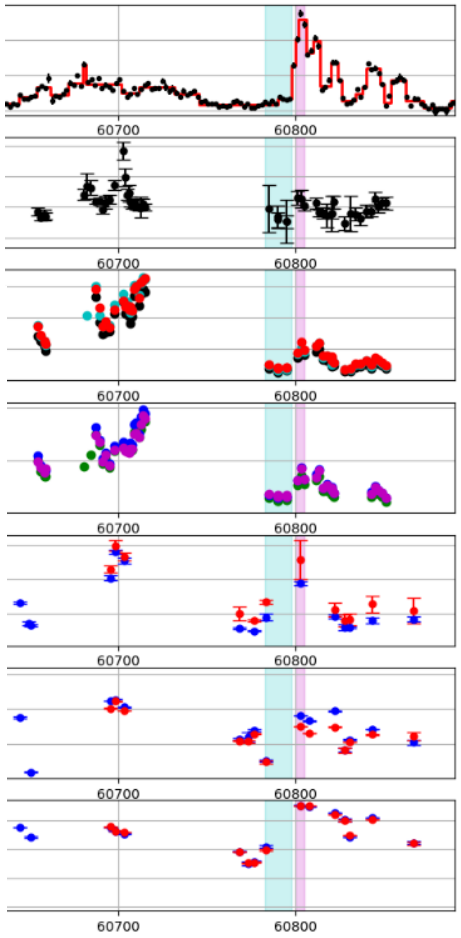
- The flare 1 occurred because the low-energy side of the electron distribution became harder, resulting in more high energy electrons being injected into the blob.
- Because γ_{max} increased and higher-energy electrons were injected into the blob, VHE gamma rays were detected.

Discussion

Flare 6: maximum gamma-ray flare, optical flare







- γ_{min} is ~ 1. γ_{break} increased and the electron distribution became harder.
- The flare 6 was caused by an increase in the number of high energy electrons injected into the blob.

Discussion

Is a large Doppler factor $\delta_{near} = 99$ reasonable for OP 313 ?

Previous studies:
OP 313 shows a **BL Lac-like state** during flares
(e.g. Zhang+25, Santos+26)

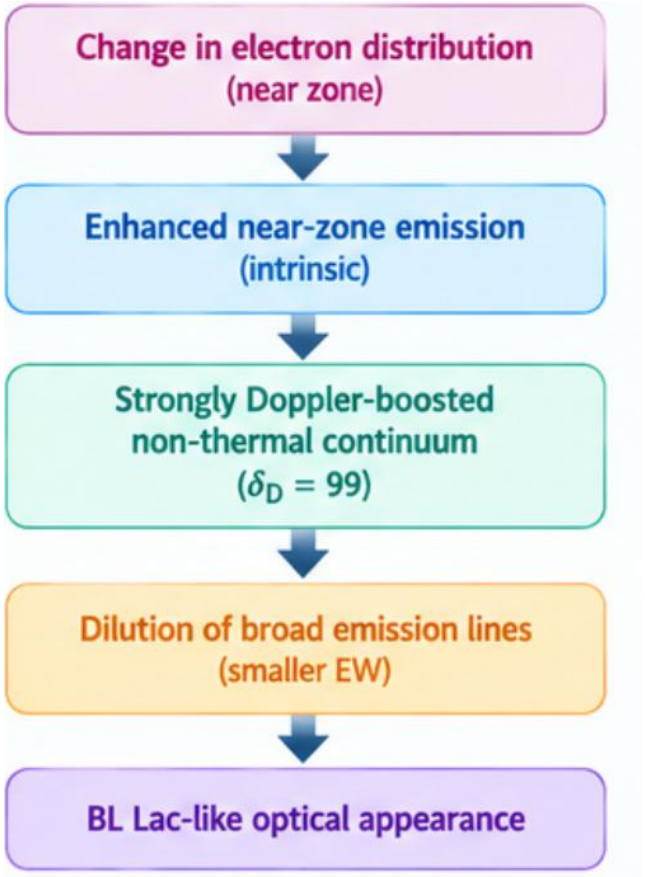
- Mg II emission-line EW decreases during the flare
- The enhanced continuum makes the broad emission lines appear weaker
- OP 313 can therefore temporarily appear BL Lac-like

Previous interpretation:
Enhanced continuum associated with a change in the accretion rate.

Discussion

Is a large Doppler factor $\delta_{near} = 99$ reasonable for OP 313 ?

Our interpretation:



- Comparable extreme Doppler factors have been invoked to explain extreme **BL Lac flares** with simple one-zone leptonic/SSC models.
  (e.g. Ghisellini+08, Abramowski+12, Ouyang+24)

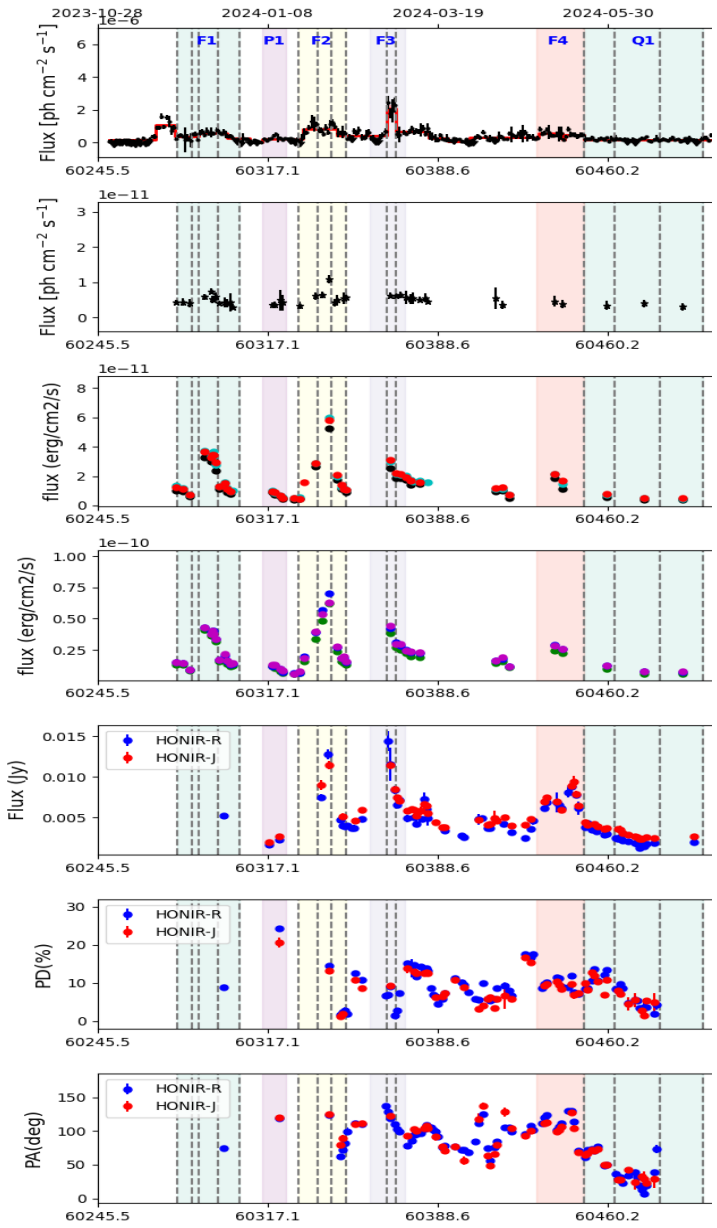
- Although $\delta_D \sim 100$ is unusual for an FSRQ,
  it is physically plausible, and provides an independent, **jet-based interpretation** of the BL Lac-like state of OP 313.

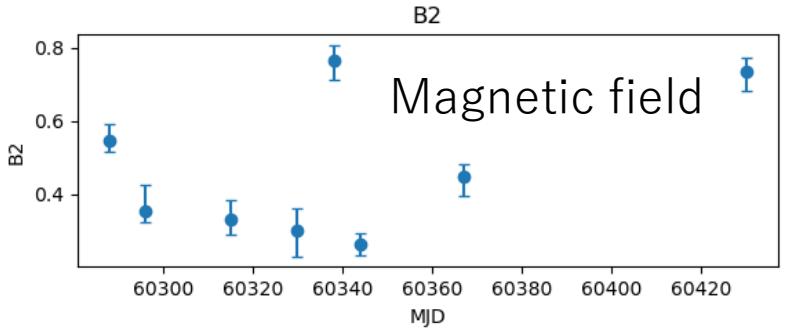
Summary

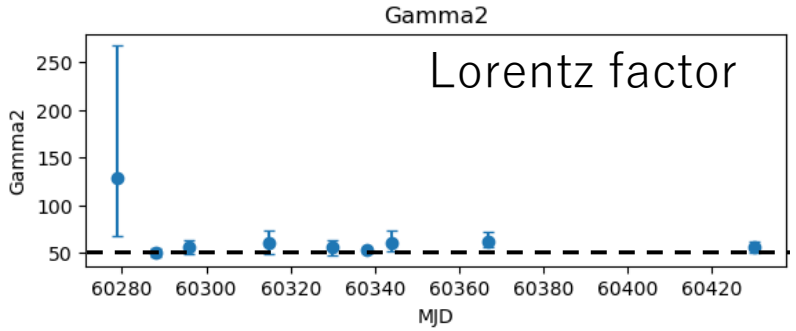
- OP 313 is the most distant AGN in which VHE gamma rays have been detected.
- Nine gamma-ray flares were identified during two years of monitoring observations.
- The observational data can be explained with a two-zone leptonic model for all observation periods.
- The flares are caused by changes in the electron distribution.
- OP 313 is an FSRQ that appears similar to a BL Lac object during flares.

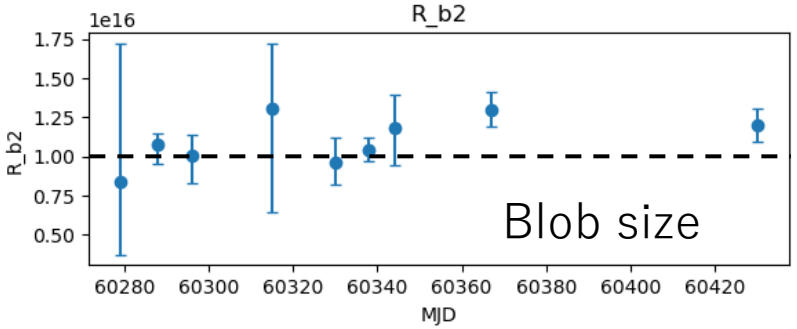
Thank you !

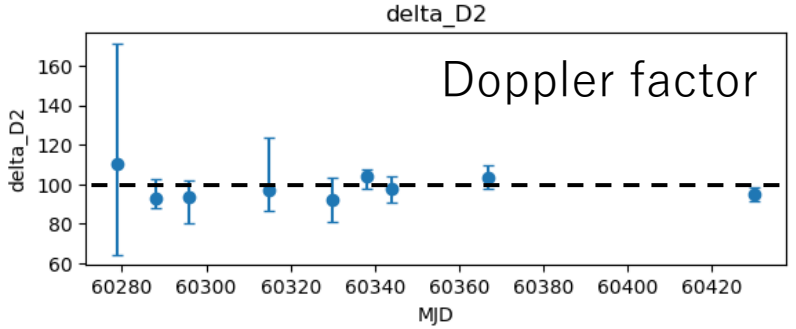
Time Variation of parameters







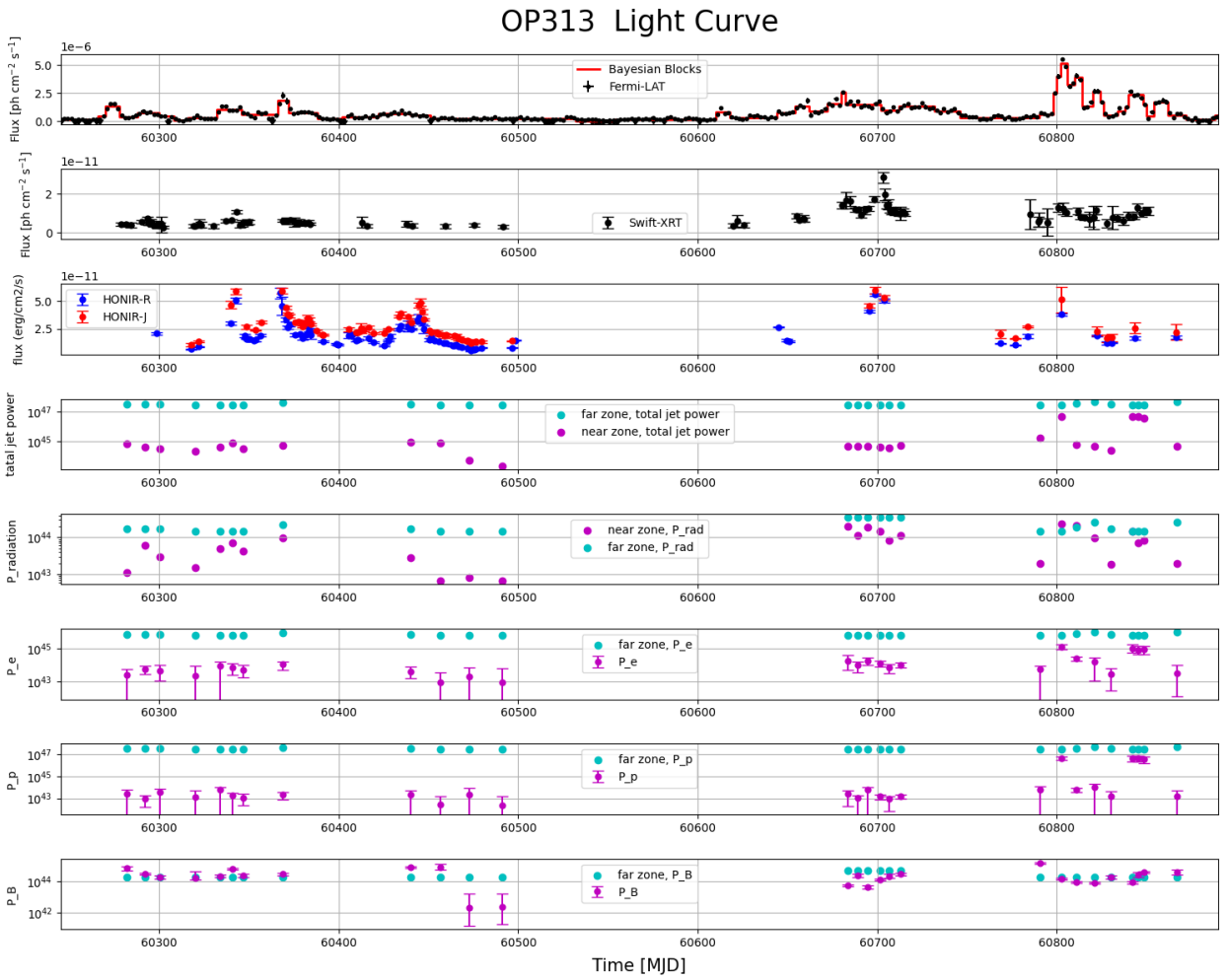




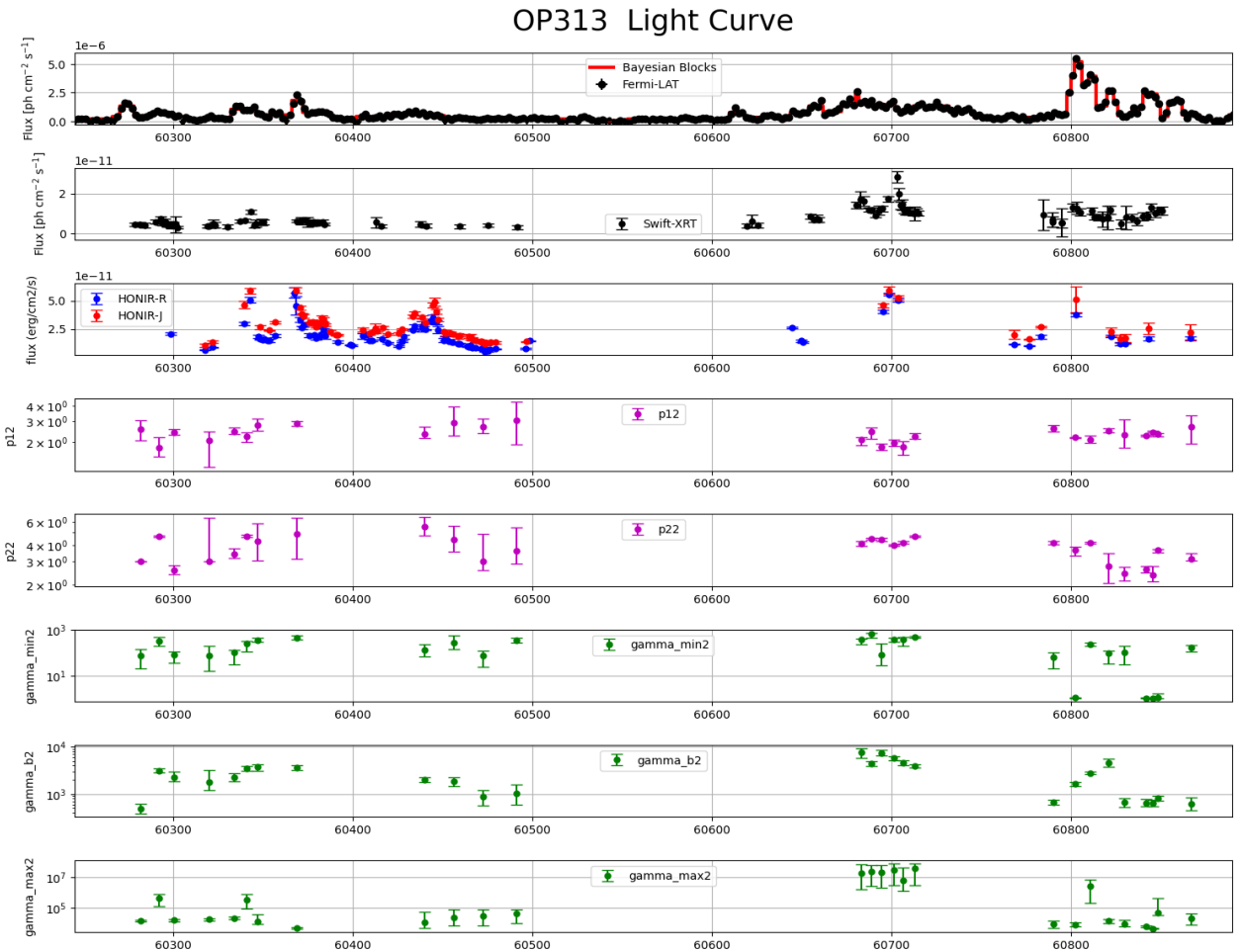
・**In case of the parameters of the blob structure are free.**

--- $\boldsymbol{\Gamma_{near} = 50, \delta_{near} = 99}, Size_{near} = 1.0 \times 10^{16}\ cm$

Time Variation of parameters



Jet Power



Electron Distribution Parameters