長期多波長観測に基づくブレーザーBL Lacertaeの2024年ガンマ線増光期における放射メカニズムの研究

Study of the Emission Mechanism of BL Lacertae ~The Historical Gamma-ray Flaring Period in 2024~

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ABSTRACT

BL Lacertae (BL Lac) is known as a low-synchrotron peaked (LSP) BL Lac type object and it **showed historical outburst from 2020 to 2024.** We performed follow-up imaging polarimetric observations using Kanata telescope. Here we are showing the results of the multi-wavelength (MWL) observations using optical to GeV gamma-ray telescopes. As a main result, the **peculiar bright GeV gamma-ray flare was found in 2024.** We suggest the additional component (e.g., external Compton) to explain this GeV gamma-ray flare. Future advanced SED modeling and multi-messenger observations will be important to understand such a specific flare.

Introduction

Target: BL Lacertae (BL Lac)
- Redshift z ~ 0.069 [1]
- Low energy peaked BL Lac object [2]
- TeV flares detected also in the past [3], [4]
- **Huge flare was repeated from 2020**.
- UL of the neutrino flux in 2024 flare was reported (<6.6×10^{-2} GeV cm^{-2}, Atel#16890).

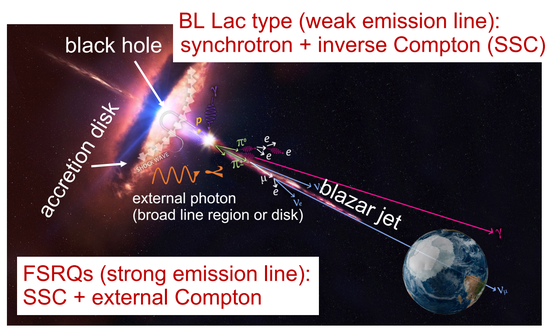

Fig.1: Illustration of the blazar for explain the emission mechanisms in the blazar jet. (credit: IceCube collaboration)

Observation

HONIR is an optical to near-infrared camera installed on the 1.5 m Kanata telescope. The imaging polarimetric observation have been performed from 2020. From the observation 2020-2021, we have also taken some long observations and the intraday variabilities were found. (Imazawa+23)

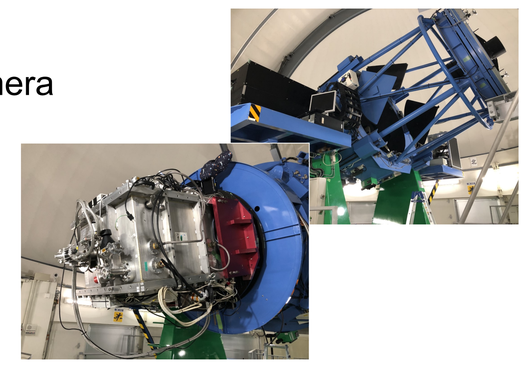

Fig.2: The pictures of Kanata telescope (upper right) and HONIR (lower left)

XRT is an X-ray telescopes installed on **Swift** satellite, and it was also monitoring BL Lac including the outburst period.

Analysis configuration:
model: Galactic absorption*power law; `wabs*pegpwrlw`
fixed parameters: nH=0.344×10^{22} cm^{-2}, minimum energy=0.2 keV, maximum energy=10.0 keV
free parameters: photon index, normalization

Softer-when-brighter trend was indicated from the X-ray spectrum. This trend may be related to the peak-shift of the synchrotron emission in the flaring period (see the right SED).

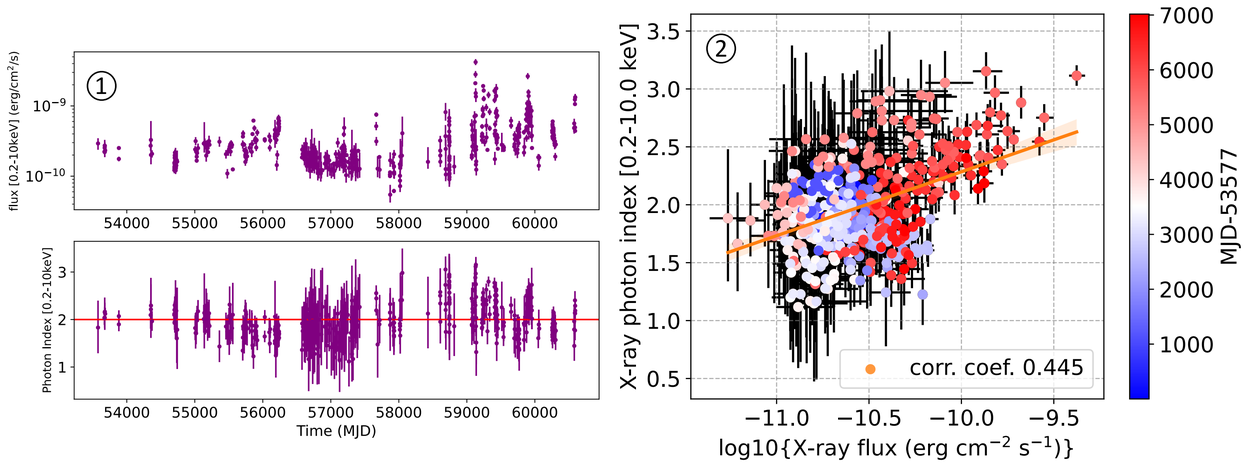

Fig.3: ① The obtained flux (upper) and photon index (lower) variations. ② The relation of the flux (horizontal axis) and the photon index (vertical axis).

NuSTAR have a hard X-ray telescopes and it observed BL Lac 1 week after the GeV gamma-ray flare in 2024. We analyzed it from 3−50 keV using the same model as XRT.

Fermi-LAT is a GeV gamma-ray detector which has an energy range 100 MeV~500 GeV. It has a wide field of view of ~3 degrees, and thus it can observe daily flux. We used only public data from Light Curve Repository[*1].

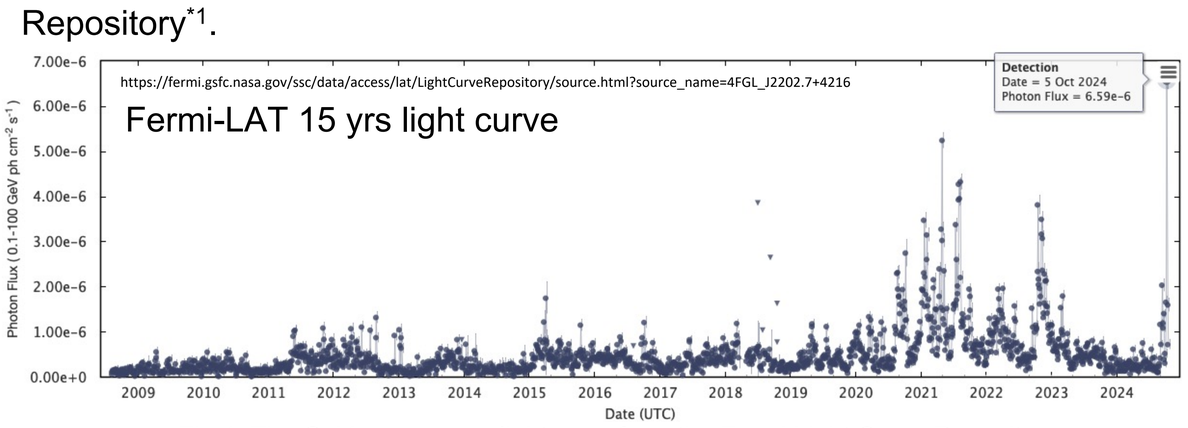

Fig.4: The GeV gamma-ray lightcurve from the Fermi Light Curve Repository.

*1 https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/source.html?source_name=4FGL_J2202.7+4216#

Result Ⅰ : MWL light curve (2020/8~2024/10)

The specific of the light curve each band:
1. **Peculiar high amplitude in Gamma-ray flare in 2024** October.
2. The gamma-ray/optical ratio was also high in the flare 2024.
3. **Optical PA ~90° in 2024** although other flare occurred around 0°.

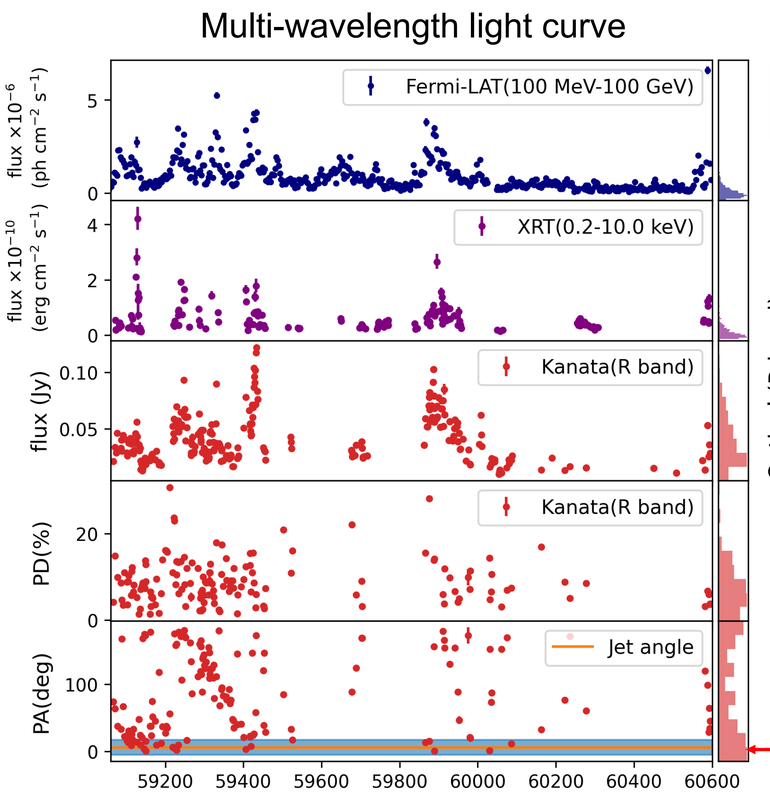

Fig.5: (left) MWL light curves of BL Lac from 2020 to 2024. From top to bottom panels: light curve taken by Fermi-LAT, Swift-XRT, Kanata, and results of the polarimetry observations. The orange line in the bottom panel shows jet position angle (2009-2017) and its standard deviation (from Casadio+21) . (right) The variations of the GeV gamma-ray and optical energy flux (unit in erg/cm^2/s).

Result Ⅱ : SED modeling for October 2024

We used mean flux: October 4-6th (for NuSTAR after a week), 2024.
The SSC+EC model may become a candidate for explain the high GeV-flux.

*free params: k, δ, B, p1, p2, (L_{disk})

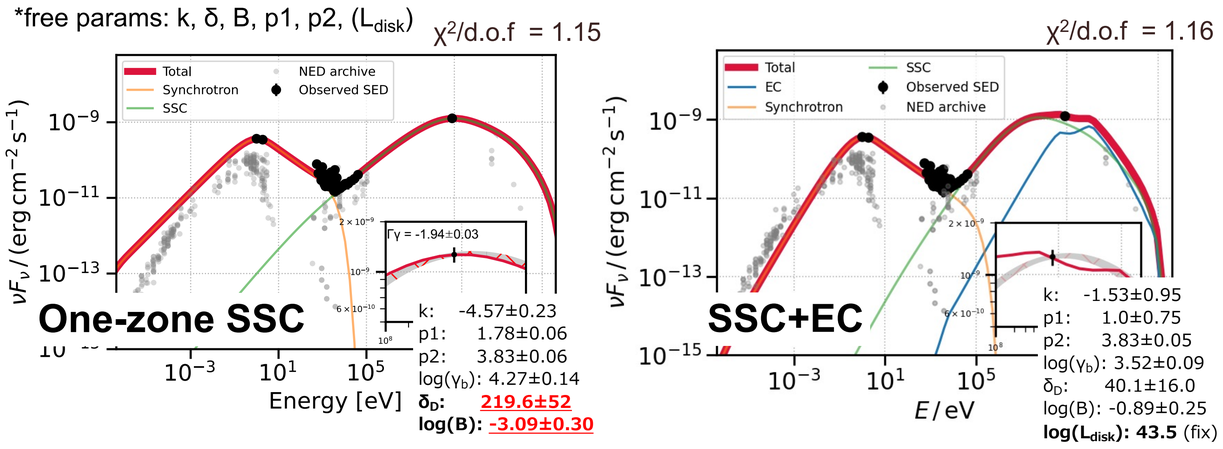

Fig.6: The SED fitting results with SSC (left) and SSC+EC (right) model made by `agnpy`, respectively.

One-zone SSC showed good fitting quality but too high δ_D and low B.
The SSC+EC model can be applied with conservative values including L_{disk} (Ghisellini+14 indicated $10^{43\text{-}46}$ erg/s for BL Lac type blazars.)

Discussion

☆ Particle acceleration mechanism based on the optical polarimetry
→ 2020-2022 flares (PA~0°, ⊥ jet direction) : explained by the shock-in-jet
→ 2024 flare (PA~90°, ∥ jet) : magnetic reconnection?

☆ Emission mechanism from the SED modeling
→ X-ray spectral index indicates the synchrotron dominance to X-ray band
→ 2024 GeV flare may contain the EC component. As a future works, the relation of the disk/jet and the energetics of the emission will be discussed.

References:
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