Radio activity of BL Lacertae during gamma-ray outbursts

Daewon Kim (SNU)

S. Trippe, S. Lee, J. Park, J. Oh, T. Lee,
, G. Zhao, S. Kang, M. Kino, J. Kim,
K. Wajima, and J. Algaba

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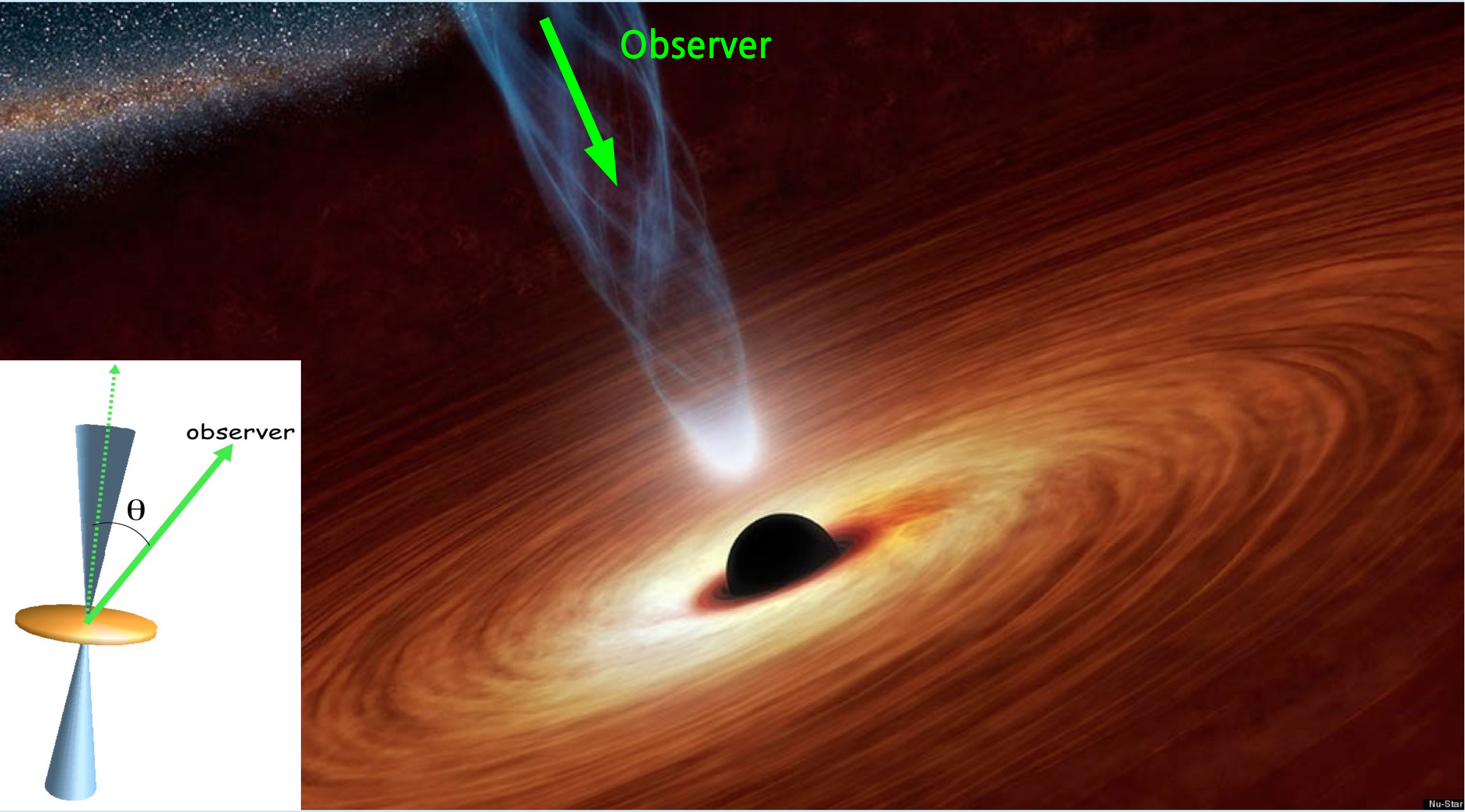
Outline

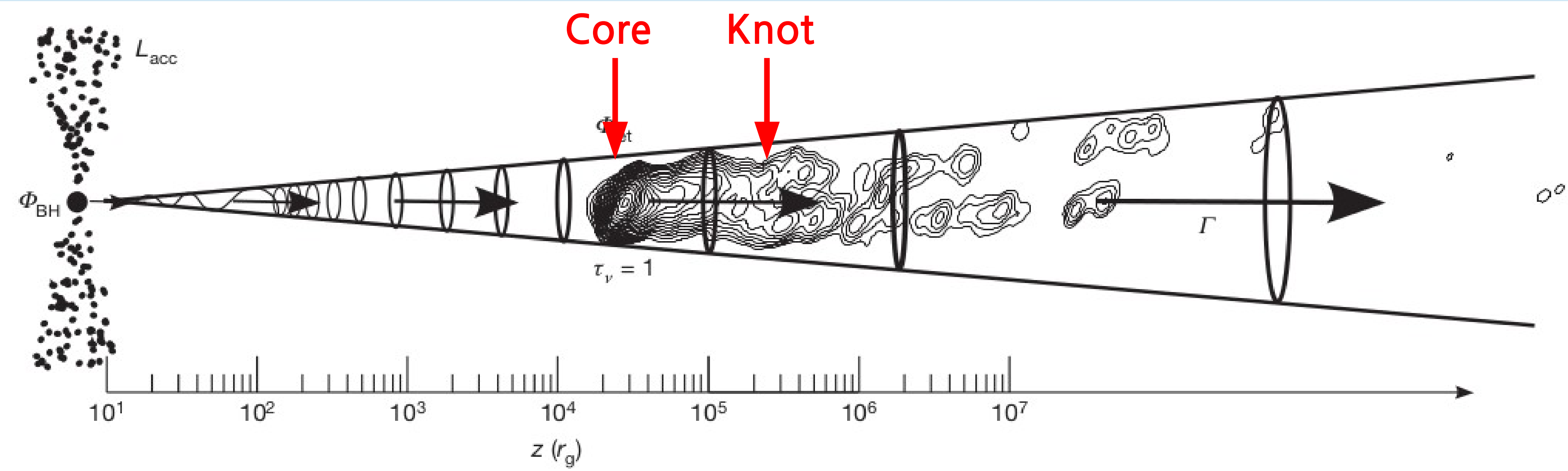
- Background
- Observation
- Results
- Summary

Blazar ?



- The most extreme class of AGN
  → nonthermal polarized emission, rapid variability, superluminal motion, etc.
- Very small viewing angle between the jet axis and the line of sight

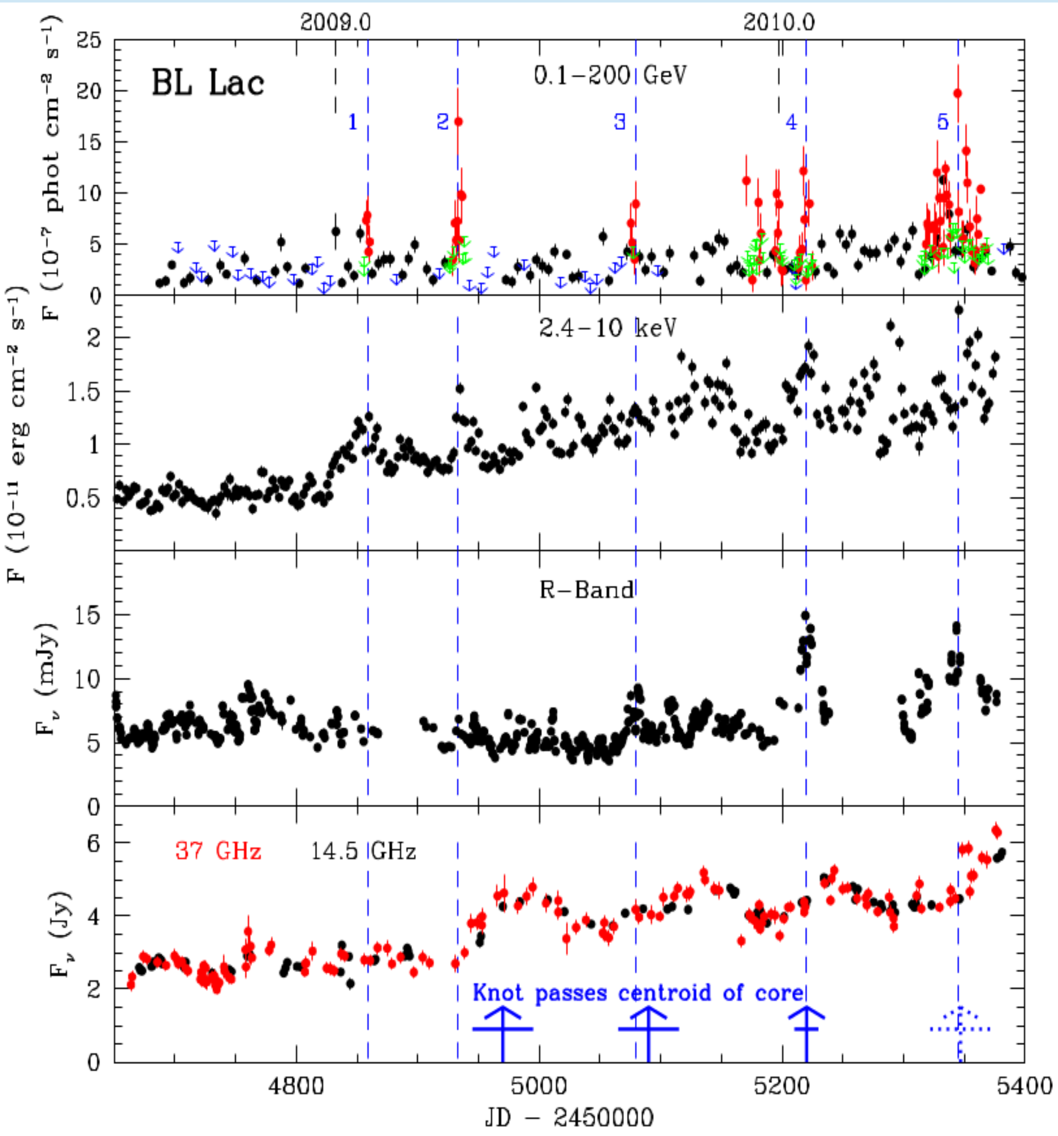
Morphology of Blazar Jet



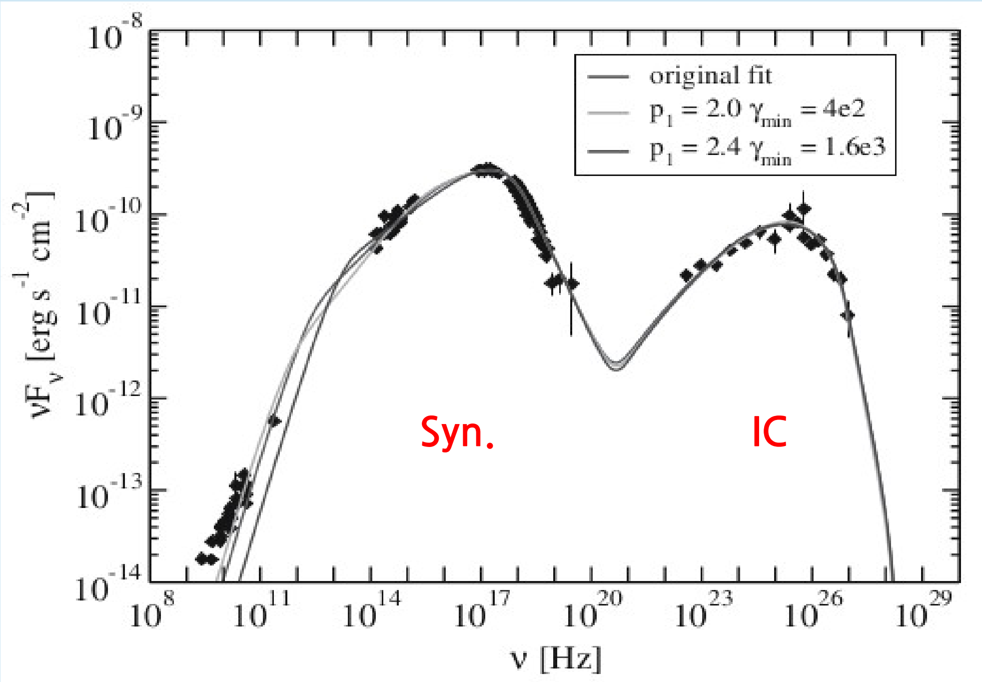
〈Zamaninasab et al. 2009〉

- VLBI revealed mm-wave structure of the jet
  (decomposition with high angular resolution, ~mas)
- Core at upstream of the jet
  (stationary feature in VLBI map, optical depth ~ 1)
- Knot at downstream of the jet
  (moving feature in VLBI map, mostly optically thin, arises in the core)
- Powerful tool for understanding how the jet works

Main Questions



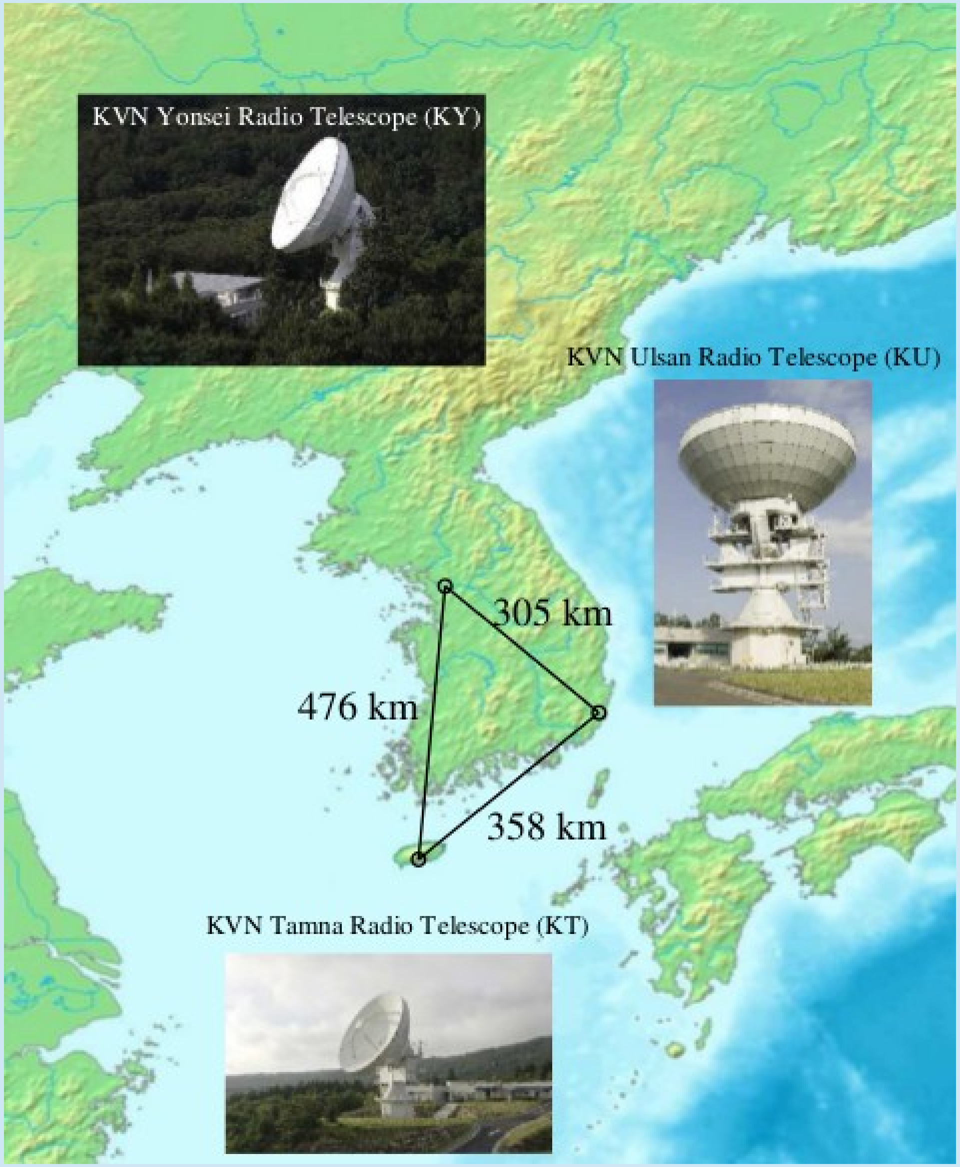
- Complex variability at multi-wavebands
  (rapid variations, correlated light curves, etc.)
- A lack of the physical processes in detail
- Observed properties should be studied
  (monitoring large samples & individual sources)
- Connection between radio and ɣ-ray
  (leading flare, new plasma ejection, etc.)



<Marscher et al. 2011>

<Beckmann 2012>

Data: IMOGABA & PAGaN



Korean VLBI Network (Lee et al. 2014)

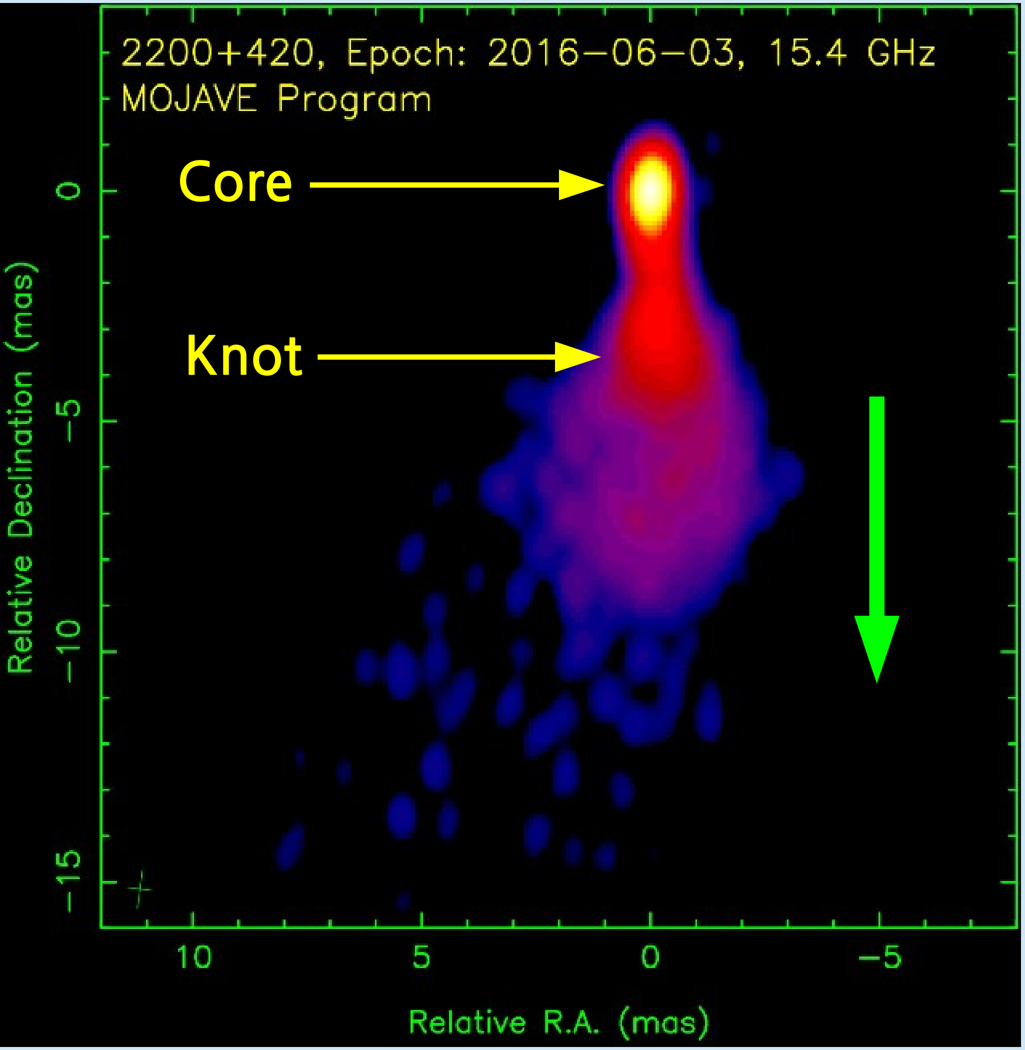
1. IMOGABA

- Interferometric Monitoring of Gamma-ray Bright AGNs
- Korean VLBI Network (KVN)
- Observing frequency: 22/43/86/129 GHz
- Multi frequency simultaneous observation
- Single polarization
- Snapshot mode with ~33 AGNs

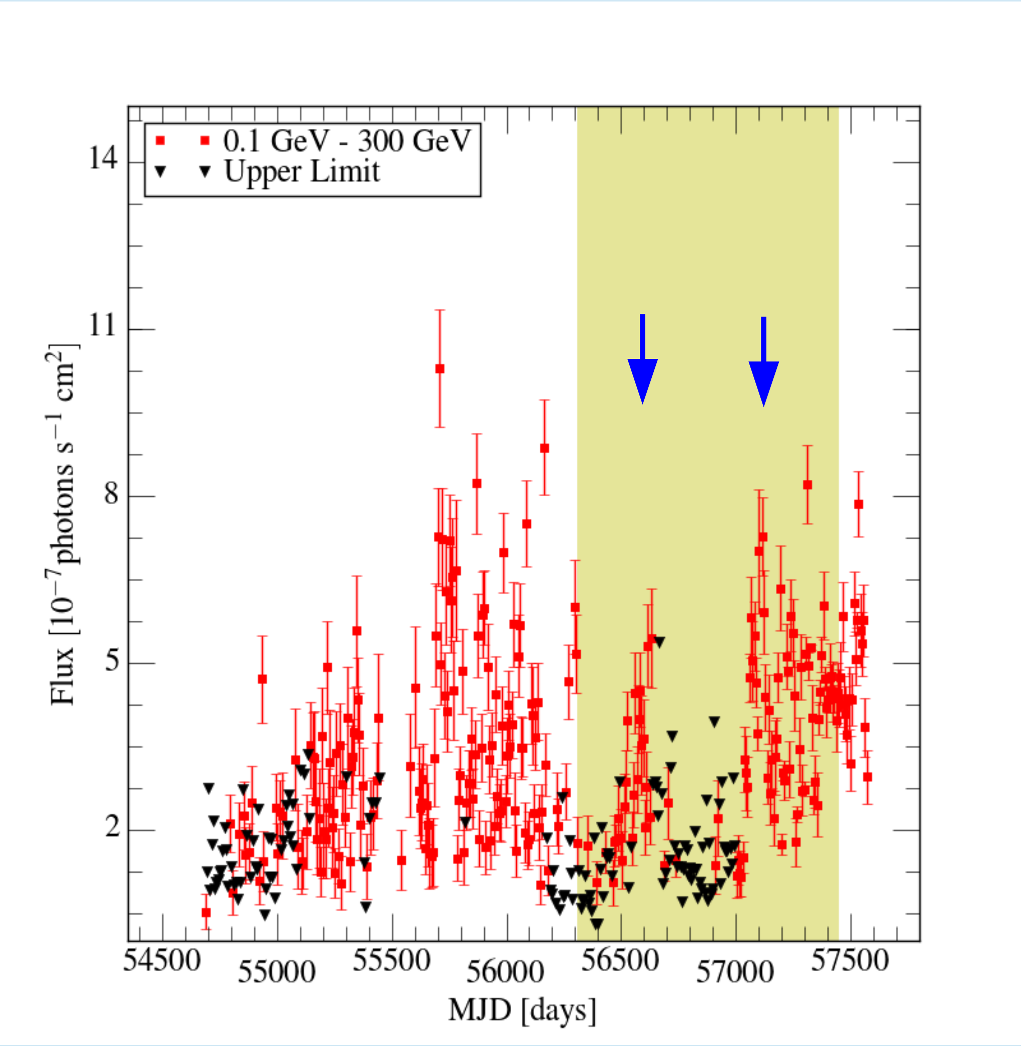
2. PAGaN

- Plasma-physics of Active Galactic Nuclei
- KVN & KAVA (KVN + VERA)
- Observing frequency: 22/43/86/129 GHz
- Dual polarization
- Full-track mode with a few AGNs

Target Source: BL Lacertae (BL Lac)



〈VLBA monitoring〉



〈Fermi-LAT monitoring〉

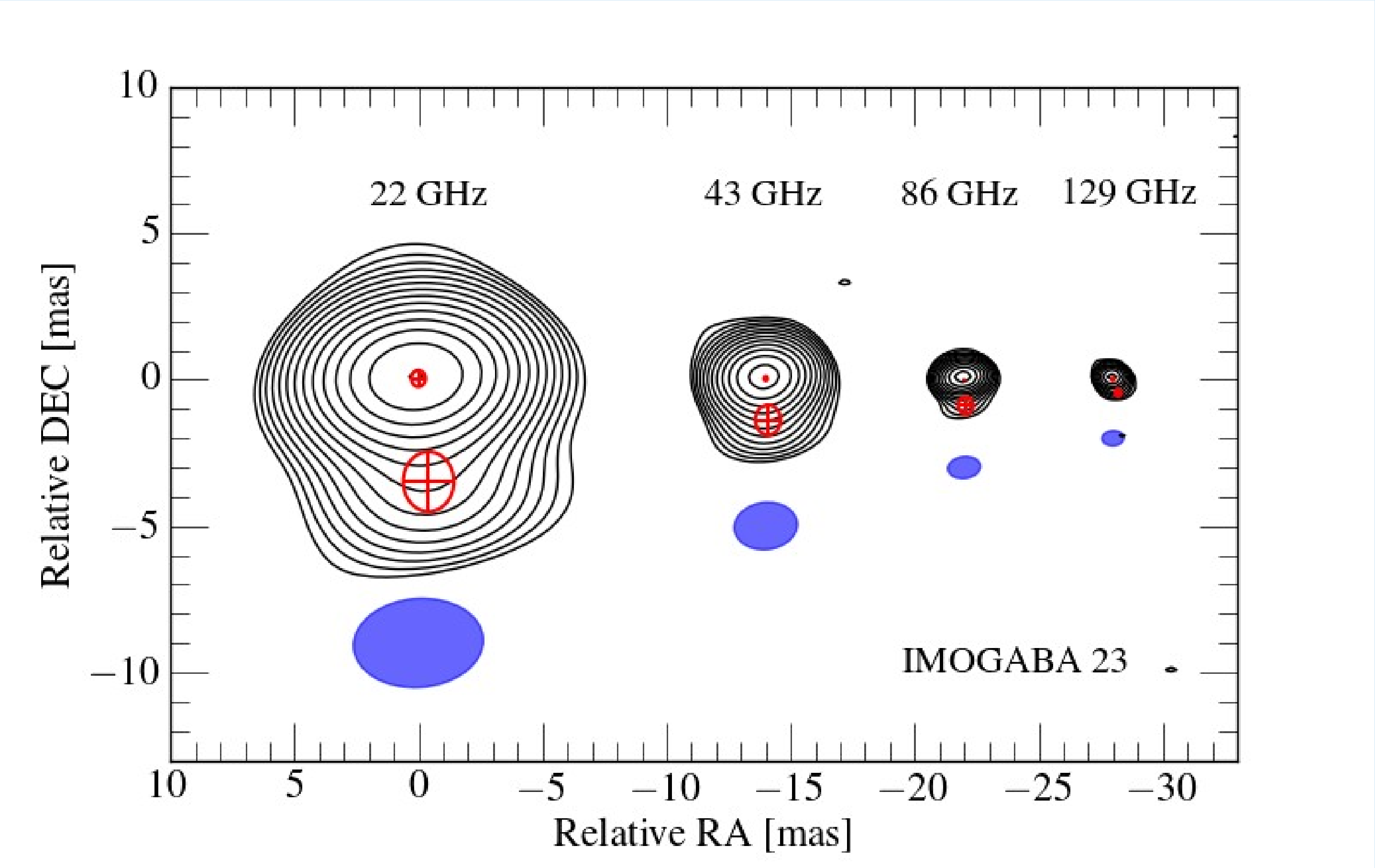
- Prototype of the BL Lac objects which is a subclass of blazar.
- Monitored by both IMOGABA and PAGaN.
- One of the bright (〉1Jy) AGNs showing the recent ɣ-ray outbursts

Observation Summary

Date	Project[a]	Frequency[b] (GHz)	t_{obs}[c] (min.)
2013 Jan 16	iMOGABA2	22/43/86	25
2013 Feb 27	iMOGABA3	22/43/86/129	25
2013 Mar 28	iMOGABA4	22/43/86/129	20
2013 Apr 11	iMOGABA5	22/43/86/129	30
2013 May 08	iMOGABA6	22/43/86	25
2013 Sep 24	iMOGABA7	22/43	25
2013 Oct 15	iMOGABA8	22/43/86	20
2013 Nov 20	iMOGABA9	22/43/86/129	30
2013 Dec 24	iMOGABA10	22/43/86/129	35
2014 Jan 02	PAGaN	22/43	240
2014 Jan 27	iMOGABA11	22/43	35
2014 Feb 28	iMOGABA12	22/43/86/129	55
2014 Mar 05	PAGaN	86	109
2014 Mar 22	iMOGABA13	22/43/86/129	35
2014 Apr 22	iMOGABA14	22/43/86/129	35
2014 Jun 13	iMOGABA15	22/43	45
2014 Sep 01	iMOGABA16	22/43/86	30
2014 Sep 27	iMOGABA17	22/86	30
2014 Oct 29	iMOGABA18	22/43/86	30
2014 Nov 28	iMOGABA19	22/43/86	25
2014 Dec 26	iMOGABA20	22/43/86	40
2015 Jan 15	iMOGABA21	22/43/86	35
2015 Feb 24	iMOGABA22	22/43/86	35
2015 Mar 26	iMOGABA23	22/43/86/129	35
2015 Apr 30	iMOGABA24	22/43/86/129	35
2015 May 27	PAGaN	43/129	251
2015 Aug 28	iMOGABA25[d]	”	”
2015 Sep 24	iMOGABA26	22/43/86/129	30
2015 Oct 23	iMOGABA27	22/43/86	35
2015 Nov 01	PAGaN	22/86	250
2015 Nov 04	PAGaN	43	250
2015 Nov 30	iMOGABA28	22/43/86/129	35
2015 Dec 28	iMOGABA29	22/43/86/129	35
2016 Jan 13	iMOGABA30	22/43/86/129	40
2016 Feb 11	iMOGABA31	22/43/86/129	30
2016 Mar 01	iMOGABA32	22/43/86/129	30

- Time range: Jan.2013 ~ Mar 2016
- Total 35 observations
- 30 from IMOGABA
- 5 from PAGaN
- 3 time gaps due to a system maintenance
- Some exception in observing frequency
  → failure at imaging
- Total on-source time
  ~0.5 h (IMOGABA) in average
  ~4.0 h (PAGaN) in average

Morphology of BL Lac in the KVN maps

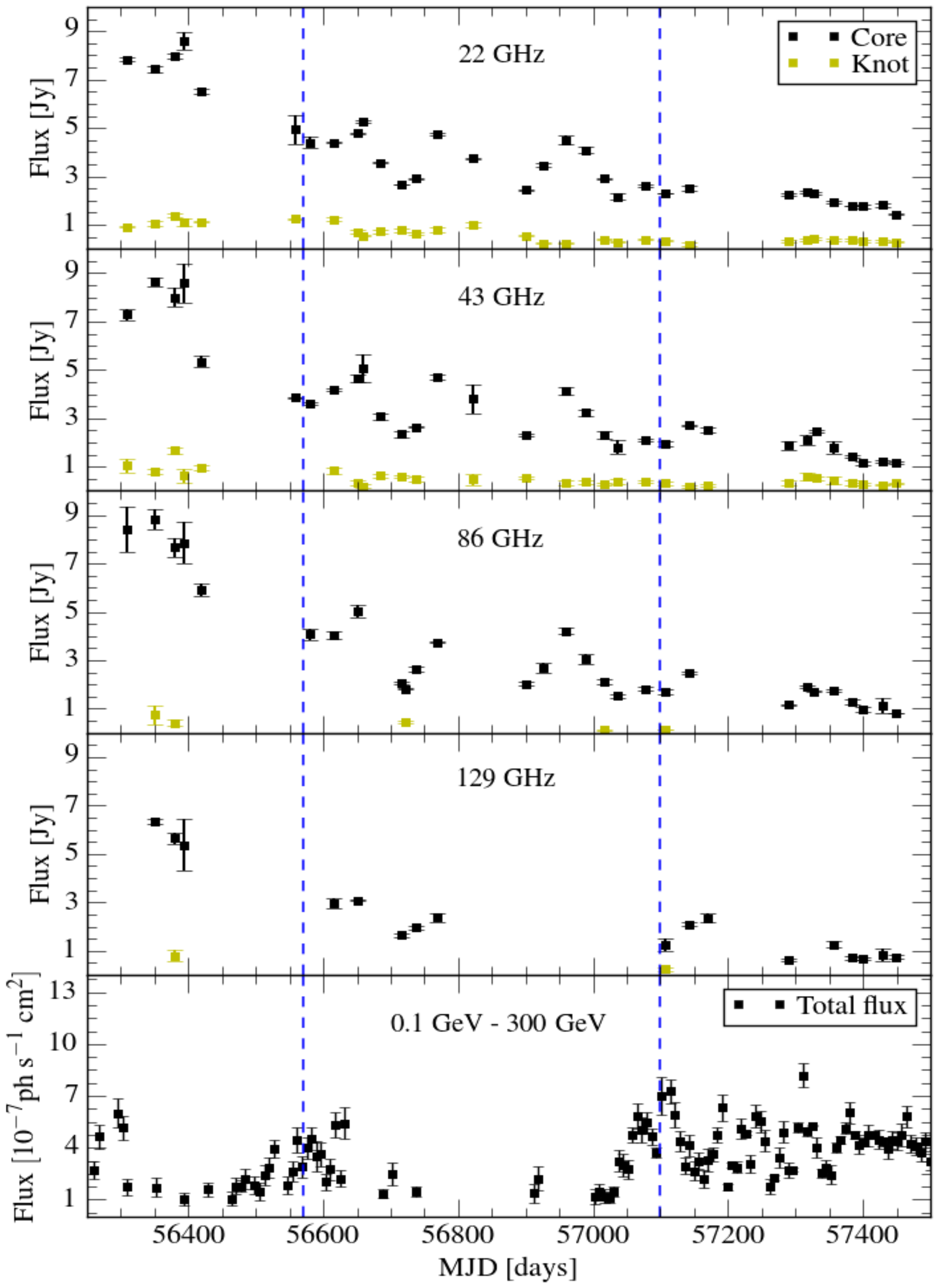


- Total intensity maps (22/43/86/129 GHz) of BL Lac obtained from the KVN.
- Core (center), one knot (downstream) from a circular Gaussian fit.
- No significant changes in radio structure with a quasi-stationary knot

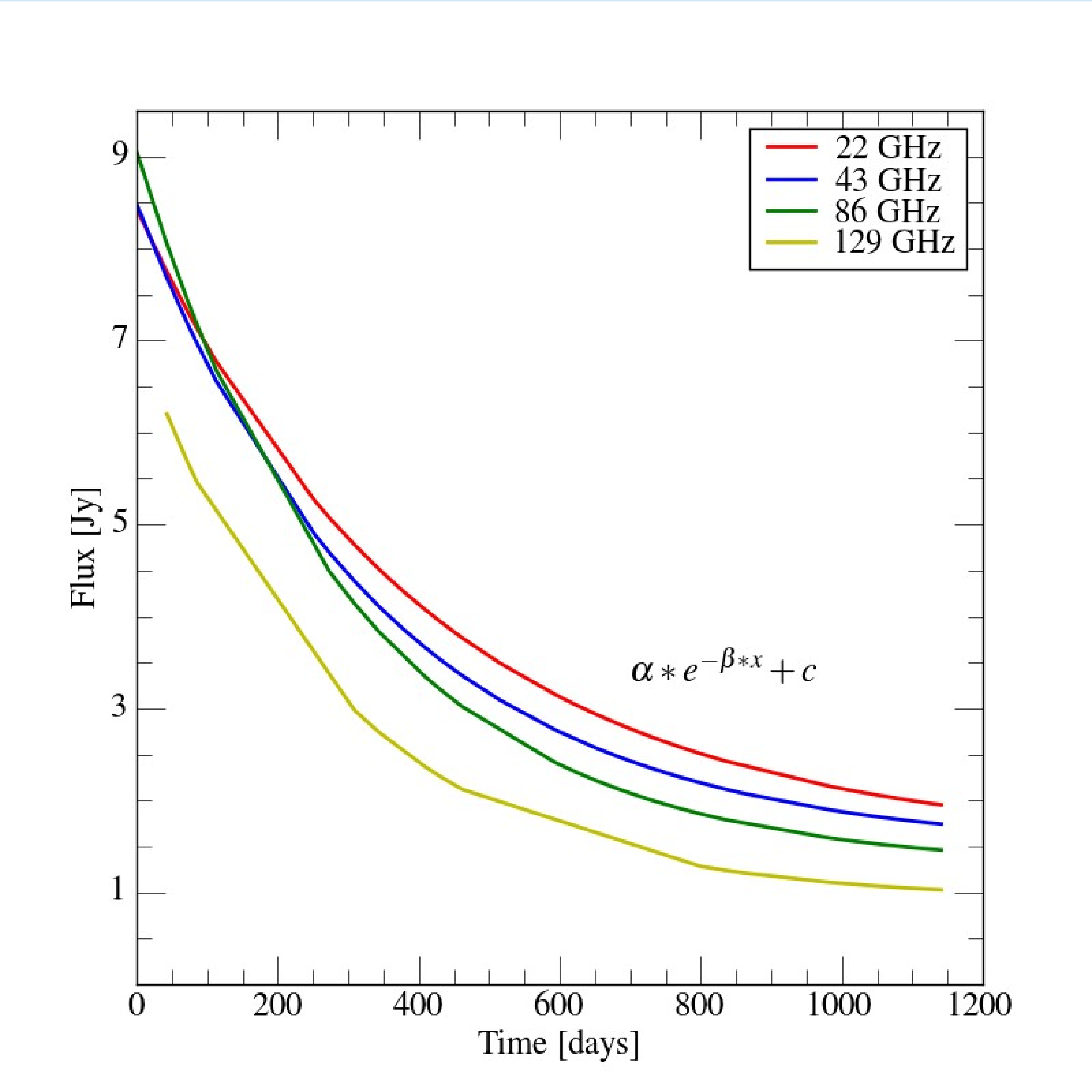
Variability

- Multi waveband light curves of BL Lac
- mm wavelengths from the KVN
- ɣ-ray from the Fermi-LAT
- Starting with the apex of a huge radio outb-urst (~9 Jy)
- Two ɣ-ray outbursts flared
- Remarkable counterparts are not found (leading feature)
- Possibly longer time lag in this source

2013.Jan 2016.Mar



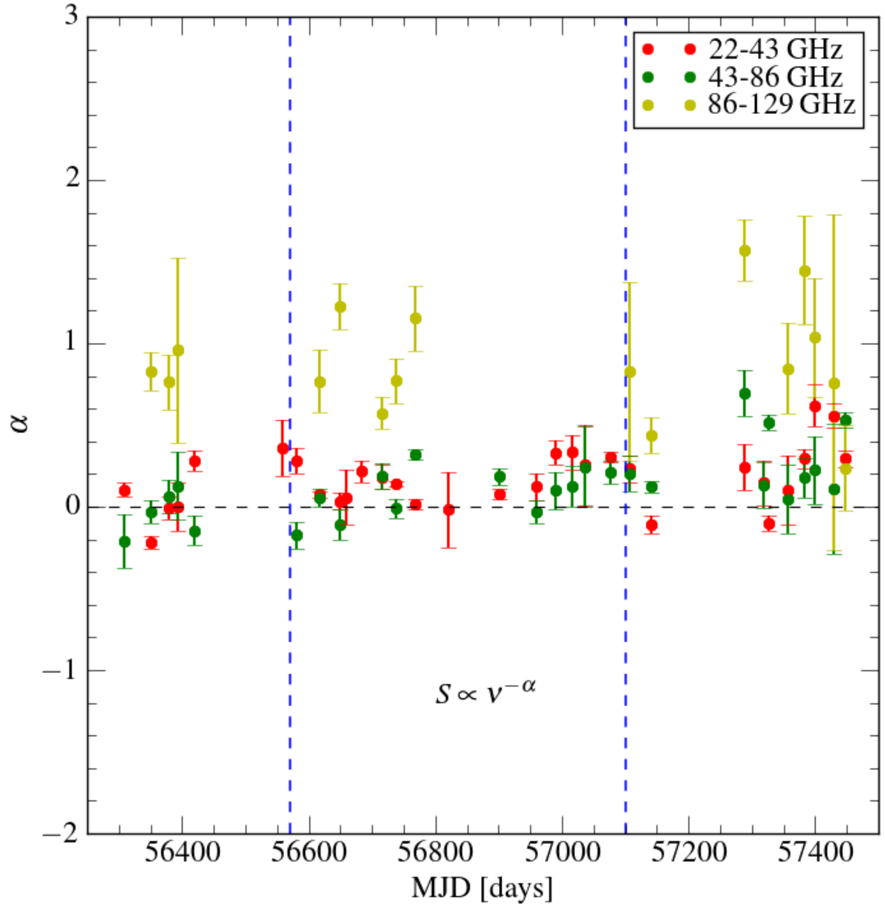
Flux Evolution



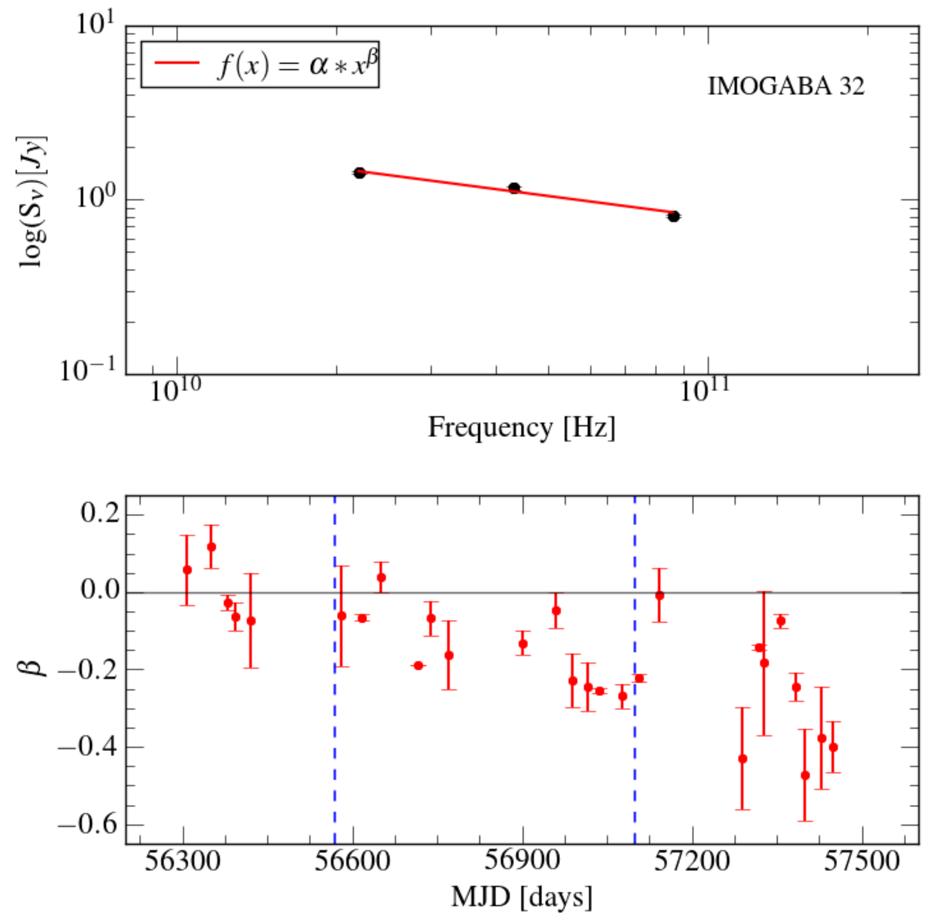
- An exponential fit to the core flux
- Common characteristic of flux outbursts in blazars.
- Decay time scales of ~
  13.69±2.83 (22 GHz) months
  11.72±2.64 (43 GHz) months
  10.33±1.89 (86 GHz) months
  9.42±1.83 (129 GHz) months
- Longer energetic lifetimes of lower energy electrons (Marscher et al. 2008)
- Stratification of flux level in later
- Large amplitude losses at 129 GHz

Spectral Evolution

Spectral index of the core

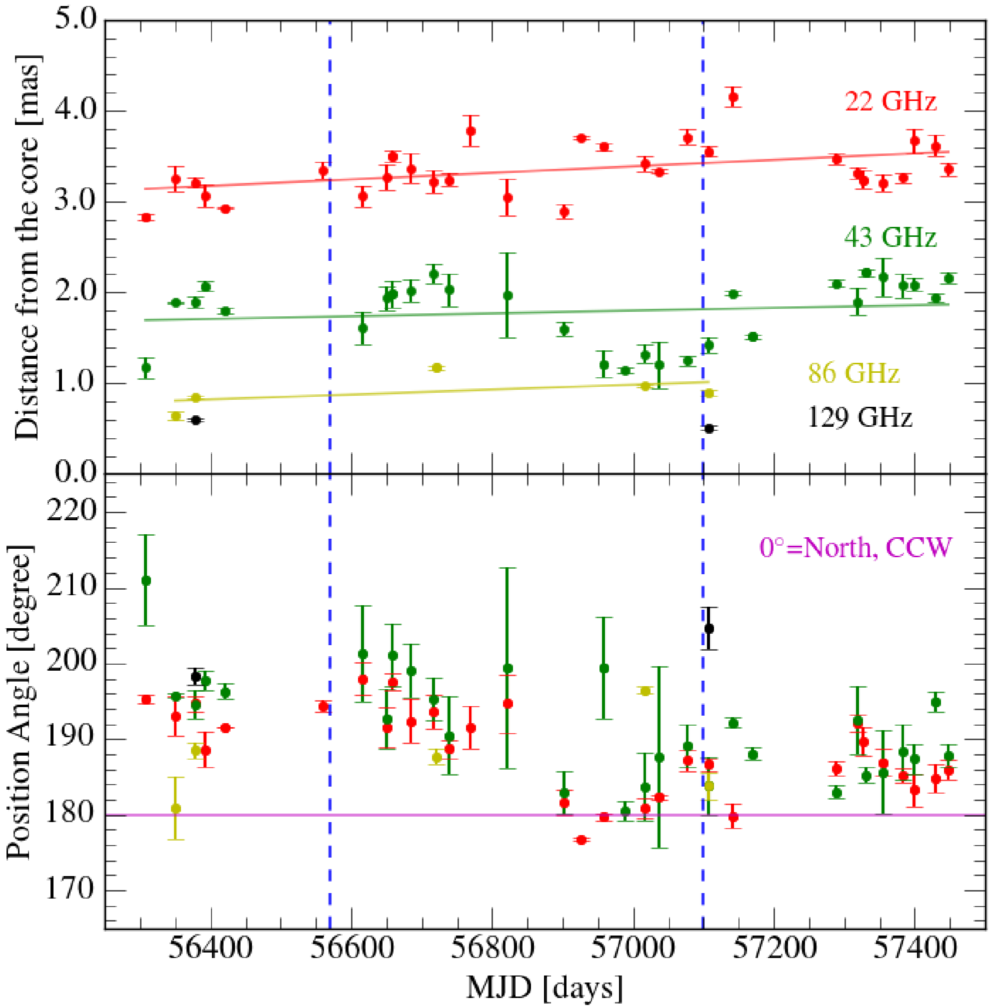


Spectra of the core (22/43/86 GHz)



- Mostly optically thick ($\alpha \approx 0$) emission
- An increase in opacity right before the second γ-ray outburst → possibly new ejection (Jorstad et al. 2013)
- Power-law distribution of particle energy
- Flat spectra corresponding major flares → Energetic shock acceleration

Extended Region



- Properties of the knot over time
- Quasi-stationary feature
- Blending effect of multi jet components
  → difficult at detailed kinematics
- Farther downstream in the jet at lower fre quencies (Marscher et al. 2014)
  3.2 mas (22 GHz)
  1.9 mas (43 GHz)
  0.9 mas (86 GHz)
  0.5 mas (129 GHz) roughly
- Bending trajectory in southwest
  → characteristic trajectory of BL Lac
- Both distance & angle before the second γ-ray event (MJD~57050) → New ejection?

Summary

- Complex behavior in multi-waveband light curves of blazars is known to be correlated with different wavelengths, should be studied by monitoring at various wavelengths.
- We present long-term radio activity of BL Lacertae at 22/43/86/129 GHz during ɣ-ray outbursts using a simultaneous multi-frequency observation of the KVN.
- In the mm wavelength light curves, we do not find any significant radio counterparts to the ɣ-ray outbursts.
- The huge radio outburst follows an exponential decay which is a common characteristic of blazar outbursts with the decay time scales of 9 ~ 13 months.
- Spectral evolution of the core of BL Lac shows the well-known properties of blazar jet Such as optically thick feature, power-law distribution of particle energy.
- Position angle of the knot indicates a bending the jet which is one of the known features of BL Lac. The results of distance, position angle and spectral index could be implying ejection of a new jet component from the core.