Interferometric Monitoring of Gamma-ray Bright AGNs : J1159+2914

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Abstract

We present the results of multi-epoch monitoring of a blazar J1159+2914, one of the targets of a Very Long Baseline Interferometry (VLBI) monitoring program : Interferometric MOnitoring of GAmma-ray Bright AGNs (iMOGABA), as a Korean VLBI Network (KVN) Key Science Progrma (KSP). The observations were conducted simultaneously at 22, 43, 86, and 129 GHz, during 4 years from December 2012 to December 2016. Obtained total fluxes ranged from 0.26 and 2.88 Jy at all frequencies with a mean rms noise of 0.026 Jy. We also used the 15 and 230 GHz data observed by Owens Valley Radio Observatory and Sub-Millimeter Array, respectively. In order to analyze the characteristics of variabilites, we estimated variability time scale from 15 GHz, data, using three different functions, structure function, Gaussian function, and exponential function. Also, in order to study the multi-frequency correlations, we compared the light curve of 15 GHz with that of 22, 43, and 86 GHz, using cross-correlation analysis. Moreover, we estimated B-field strength using core sizes from VLBA 43 GHz data, turnover frequencies and maximum total fluxes from KVN data, and variability time scales from OVRO data, in order to study the variability of B-field nearby the radio emission region.

Introduction

Blazars are one of the sub-classes of AGNs with one of two jets being launched nearly toward us. Their emissions are highly Doppler boosted and they show dynamic variations. The origins of these drastic variations are usually presumed as source intrinsic or source extrinsic variations.

A blazar J1159+2914 (also known as 1156+295, 4C +29.45, and TON 599) has shown the wide time scale range of variations from hours to years. Many previous studies attempted to prove the mechanism of these variations (Liu et al. 2013, Wang et al. 2014).

The source is one of the targets of the monitoring program of the Korean Very Long Baseline Interferometry (VLBI) Network (KVN), named as Interferometric Monitoring of GAmma-ray Bright AGNs (iMOGABA). Since 2012 December, the iMOGABA observations have been conducted, nearly monthly, for 24 hours at each epoch, targeting on over 30 sources at 22, 43, 86, and 129 GHz, simultaneously (Lee et al. 2016). The purposes of the iMOGABA program as a KVN Key Science Program (KSP) are to study the correlation of behavior between radio and gamma-ray wavelengths in bright AGNs at gamma-ray wavelength and to constrain the characteristics of the gamma-ray flare from the AGNs.

Observations and Data Reduction

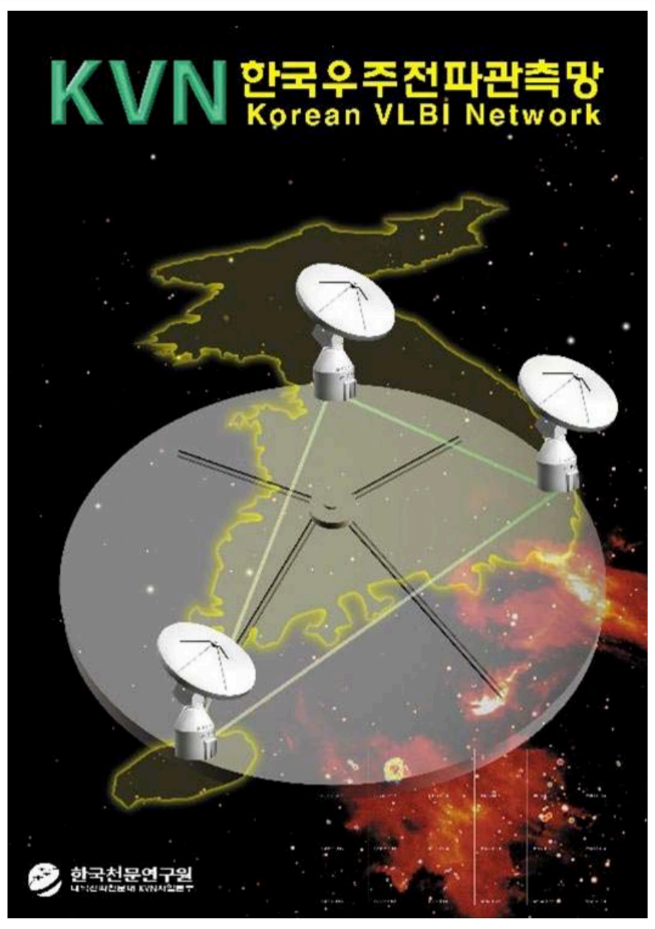


Figure 1. Korean VLBI Network

The multi-wavelength VLBI observations had been conducted from December 2012 to December 2016. A blazar J1159+2014 was observed for 33 epochs during that period. The target source was detected 33, 30, 31, and 22 of 33 epochs at 22, 43, 86 and 129 GHz, respectively.

Correlated data were reduced via the Astronomical Image Processing System (AIPS) with the *KVN pipeline* (Hodgson et al. 2016).

We imaged the reduced data from AIPS using DIFMAP program. Before imaging, we averaged the data every 30, 20, 10 and 10 seconds at 22, 43, 86, and 129 GHz, respectively. We assumed that the source is core dominated within KVN VLBI beam size for all epochs, so we CLEANed the images with CLEAN windows at image center, window sizes of 1.5 X 1.5, 0.76 X 0.76, 0.4 X 0.4, and 0.26 X 0.26 mas at 22, 43, 86, and 129 GHz, respectively. After the CLEANing, we obtained beam sizes, total CLEANed flux densities, peak flux densities, rms noises, dynamic ranges, and image qualities.

And we fitted the source with circular Gaussian models. After the model fitting, we obtained modeled total flux densities, peak flux densities, sizes and brightness temperatures of core for each epoch at each frequencies.

Multi-Wavelength Data

To confirm the correlations of flux variability in the wide range of wavelength, we compared our data with the both 15 GHz data obtained from Owens Valley Radio Observatory (OVRO), and 230 GHz data obtained from Sub-millimeter Array (SMA). Figure 2 shows the multi-wavelength light curves.

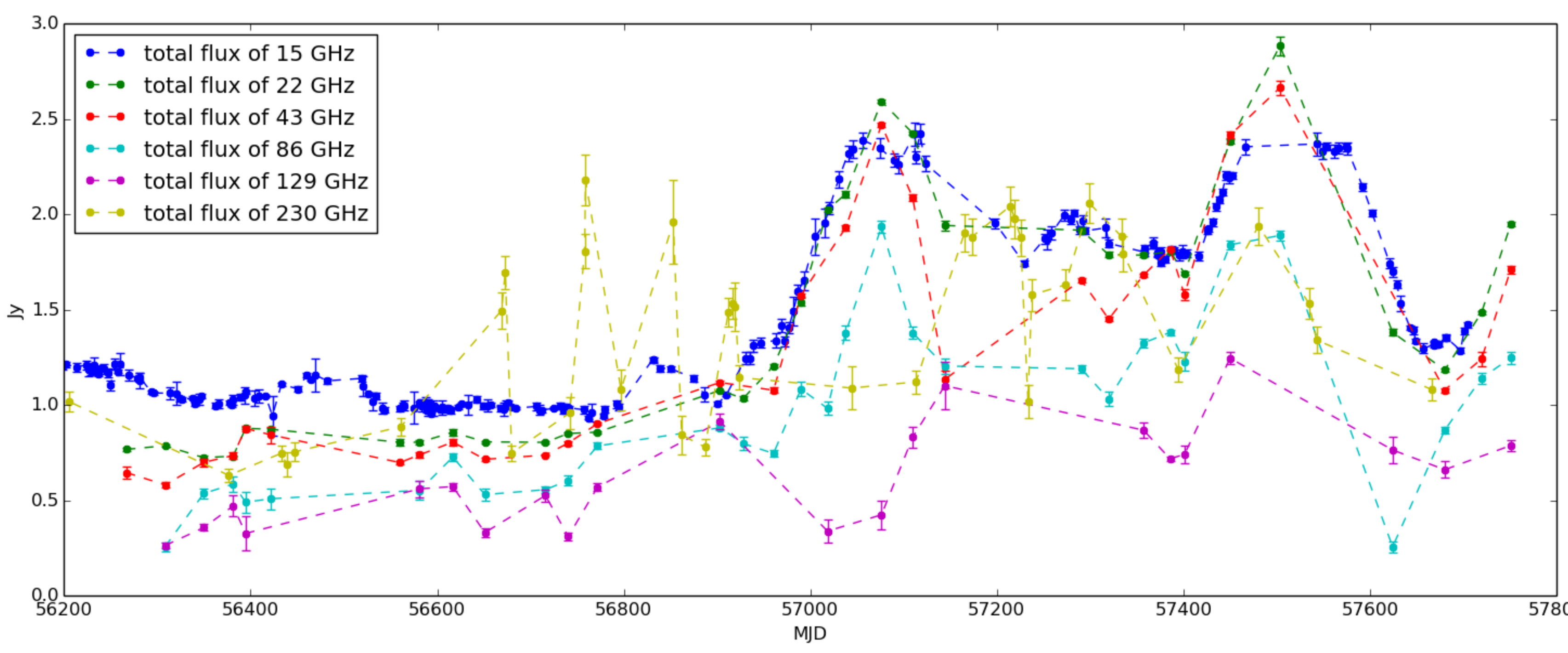


Figure 2. Light curves of J1159+2914

And to estimate the core sizes at 43 GHz, we re-modeled the published data from Boston University (BU) blazar group observed by Very Long Baseline Array (VLBA). Because, we presumed actual core sizes of J 1159+2914 are smaller than the beam size of KVN.

Then we estimated turnover frequencies and maximum flux for 17 epochs when the source detected at all four KVN frequencies. Here, we assumed flat spectrum, so α is 0. And we estimated c_1, c_2, and ν_r by curve fitting. Figure 3 is a curve fit image for epoch of iMOGABA 32 (MJD 57449). Obtained turnover frequencies ranged from 19 to 37 GHz and maximum fluxes ranged from 0.73 to 2.7 Jy. To estimate b-field strength at turnover frequencies, we re-estimated core sizes at turnover frequencies from core sizes at 43 GHz of BU data. And the obtained turnover frequencies were lower than 43 GHz, we assumed that data at 43, 86, and 129 GHz were originated from optically thin region, so we estimated spectral indices of optically thin region with 43, 86, and 129 GHz data. Obtained spectral indices of optically thin region ranged from -0.72 to -0.20.

$$S = c_1 \left(\frac{\nu}{\nu_r}\right)^{\alpha + c_2 \ln(\nu/\nu_r)}$$

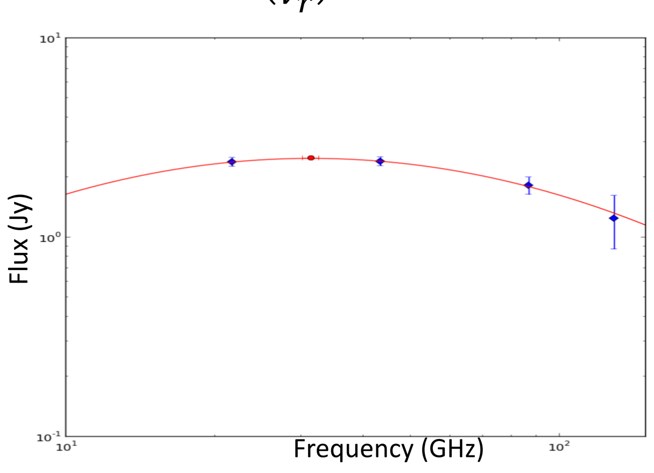


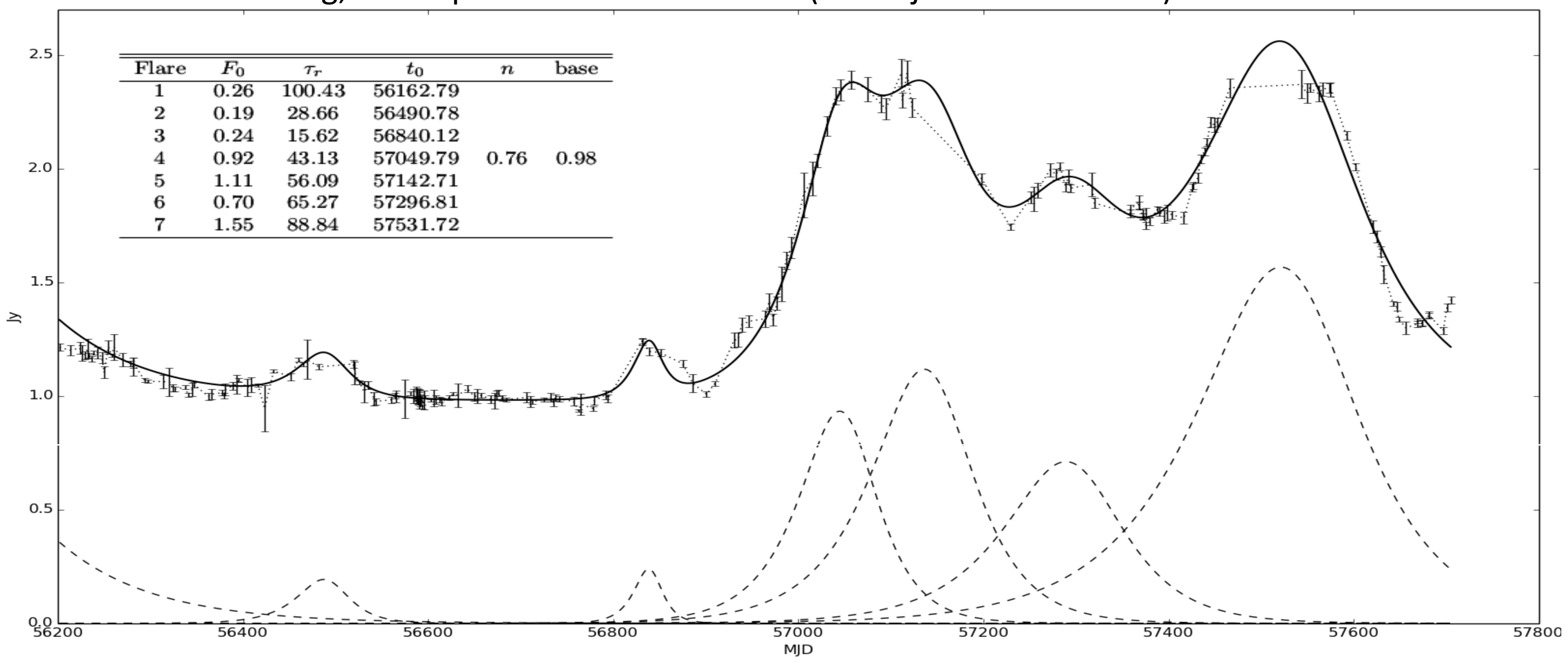
Figure 3. Turnover Frequency & maxmum flux

Variability time scale

In order to study the characteristics of time-dependent variations, we fitted the OVRO 15 GHz light curve using the following exponential function (Prince et al. 2017). Here, F_0 is local maximum flux, t_0 is time at a local maximum, τ_r is rising variability time scale and n is ratio rising and decaying variability time scales.

$$F(t) = 2F_0 \left[\exp\left(\frac{t_0 - t}{\tau_r}\right) + \exp\left(\frac{t - t_0}{n\tau_r}\right)\right]^{-1}$$

In this fitting procedure, we combined one half decaying flare and six rising and decaying flares with zero base line. Base line of light curve was estimated after summing all flares. Fitting parameters are listed in Fig. 3. We defined flares by visual inspection. We note that the rising time scales were longer than decaying time scales in this fitting, unlike previous several studies (Valtaoja & Lainela 1999).



Flare	F_0	τ_r	t_0	n	base
1	0.26	100.43	56162.79		
2	0.19	28.66	56490.78		
3	0.24	15.62	56840.12		
4	0.92	43.13	57049.79	0.76	0.98
5	1.11	56.09	57142.71		
6	0.70	65.27	57296.81		
7	1.55	88.84	57531.72		

Figure 4. Decomposition of Flares for OVRO Light Curve

Variability Brightness Temperature, Doppler Factor and B-Field Strength

We estimated variability brightness temperatures and Doppler factors using the following equations with above estimated variability time scales. But, we excluded the first flare because it showed only decaying phase. Here, ΔS is F_0, λ is observing wavelength, and D_L is luminosity distance. We used λ and D_L as 2 cm and 4477.8 Mpc, respectively. And α is the spectral index of the optically thin region. We assumed flat spectrum. Obtained T_B^{var} and δ_{var} are listed in the following table. Applying these δ_{var} to estimated core sizes, turnover frequencies, and maximum fluxes, we estimated b-field strengths using the following equation.

$$T_B^{var} = 3.47\times10^5 \Delta S \left\{\frac{\lambda D_L}{\tau_r (1+z)^2}\right\}^2$$

$$\delta_{var} = (1+z)\left(\frac{T_B^{var}}{10^{12}}\right)^{1/(3+\alpha)}$$

Flare	$T_B^{var}(10^{10}\mathrm{K})$	δ_{var}
2	97.41	7.96
3	406.40	12.81
4	208.01	10.24
5	147.33	9.13
6	69.25	7.10
7	82.34	7.52

$$B = 10^{-5} b(\alpha) S_m^{-2} \theta^4 \nu_c^5 \left(\frac{\delta}{1+z}\right)^{-1}$$

Here, $b(\alpha)$ is a factor depends on optically thin spectral index. Values of $b(\alpha)$ were referred from Marscher 1983. Obtained b-filed strengths are plotted in Figure 5. And we assumed the Doppler factor of 7.10 as the upper limit of other quiet phases. We found that b-field strengths between MJD 56600 and 56900 were significantly higher than other epochs. These high values are might affected by core sizes. Still, we have lots of debates for this result.

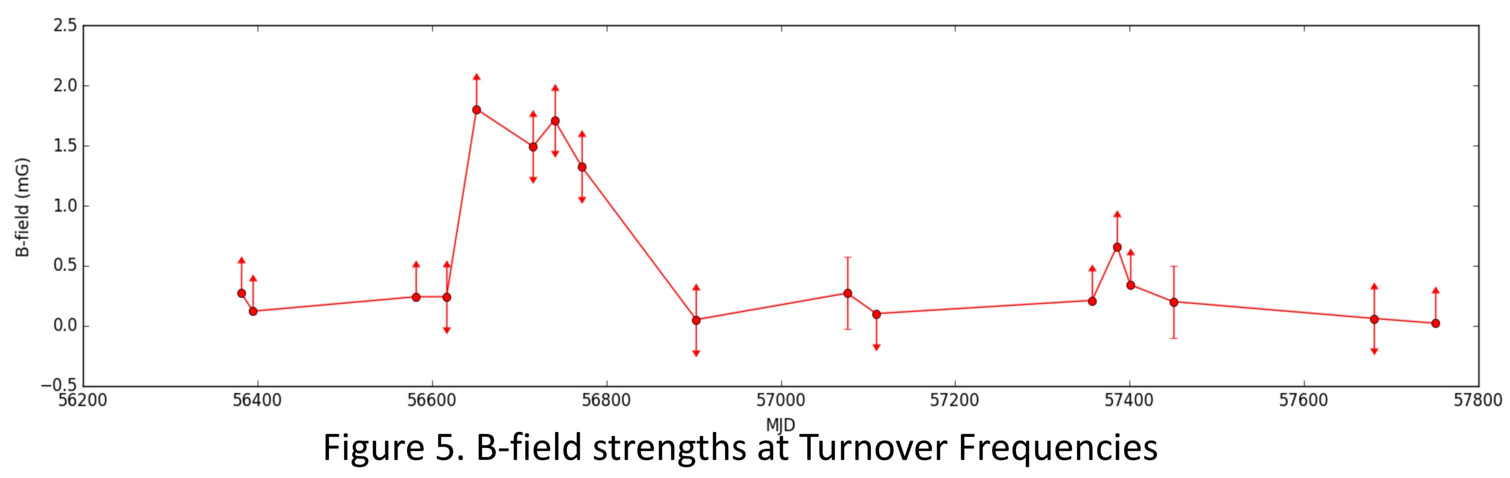


Figure 5. B-field strengths at Turnover Frequencies

Summary and Future Works

We observed a blazar J1159+2914, one of targets of iMOGABA, from 2012 December to 2016 December. We obtained CLEANed total fluxes, model-fit total fluxes, rms noises, dynamic ranges, and image qualities. Then we compared our light curves with that of OVRO and SMA data, in order to study multi-wavelength correlations. To estimate variability time scales, we fitted the light curve of OVRO 15 GHz data, using exponential function. And then, we estimated variability brightness temperatures and Doppler factors, in order to estimate b-field strengths. With estimated b-field strengths, we will discuss the conditions of relativistic jet. Also, we can compare the estimated b-field strengths with b-field strengths of equipartition condition. According to Algaba et al. 2017, b-field strengths of synchrotron self-absorption usually smaller than b-field strengths of equipartition condition.

References

Antonucci 1993
Favre et al. 2005
Gurwell et al. 2007
Hodgson et al. 2016
Jorstad & Marscher 2016
Lee et al. 2016
Lee et al. 2016
Lee et al. 2017
Liu et al. 2013
Marscher et al 2008
Prince et al. 2017
Richards et al. 2011
Valtaoja et al. 1999
Wang et al. 2014
Zhao et al. 2011