Multi-frequency monitoring of S5 0716+714

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Introduction

BL Lac S5 0716+714 is known as an extremely variable and a bright BL Lacertae-type blazar which has a relativistic jet pointing to the line of sight. Due to the geometry of the jet, the radiation is Doppler boosted and amplified. S5 0716+714 has been observed complex variability in flux density on time scales of weeks to months across the entire electromagnetic spectrum from radio to gamma-ray bands (Rani et al. 2013; Bhatta et al. 2016; Chandra et al. 2015). In general, the variability of flux density is explained by the shock-in-jet model (Marscher & Gear 1985; Fromm et al. 2011) in radio frequencies. In our simultaneous multi-frequency observations over three years and seven months, six local peaks on time scales of weeks to months were detected at all observing frequencies. We investigate the individual local peaks of the flux density appearing different characteristics of S5 0716+714 to improve our understanding of the emission mechanism and location of emission region in the relativistic jet. For this purpose, we use various analytical methods at the frequency domain and compare theoretical models with the analytical results from our observations.

Observations and Data

We performed simultaneous multi-frequency single-dish observations of S5 0716+714 at 22 and 43 GHz using 21-m KVN radio telescopes over past 3 years and 7 months from 2010 November to 2014 June (MJD 55509 to 56814). The mean cadence of the flux density detection is ~5 days. We collected the UMRAO (8 GHz) from MJD 55504 to 56060, the OVRO (15 GHz), the CARMA (15 GHz) from MJD 56157 to 56821, and the SMA (230 GHz) data to analyze the multi-frequency flux density variability.

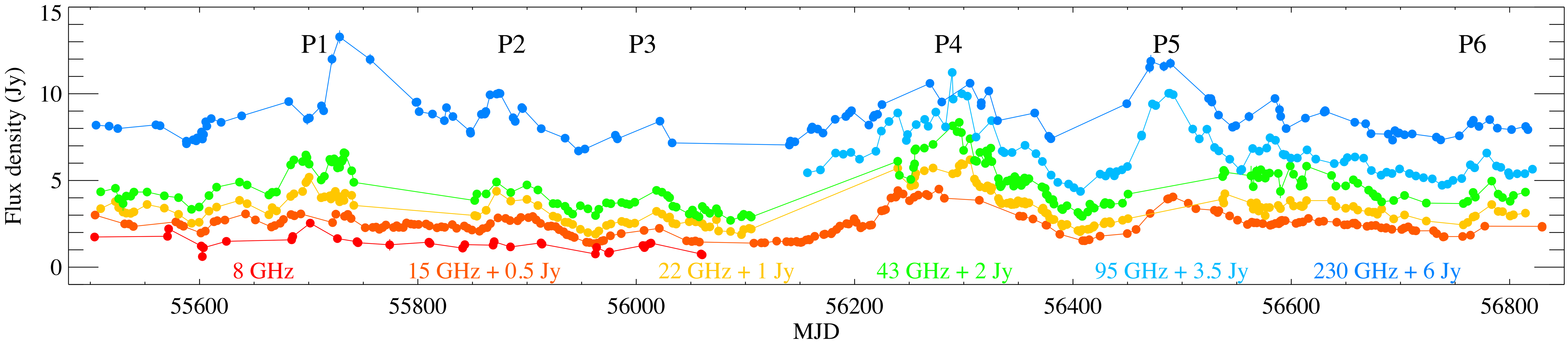

Fig. 1. Light curves of S5 0716+714 observed at 8 to 230 GHz over past 3 years and 7 months from November 2010 to June 2014.

Light curves

S5 0716+714 shows active flux density variability over 3 years and 7 months. Six local peaks which are showing different variability characteristics were detected at all frequencies (P1~P6).

Amplitude of variability

In order to estimate amplitude of the flux density variability in the different wavelengths, we computed modulation index ($m = \sigma_s/<S>$ [%], Fuhrmann et al. 2008). The plots of *m* are displayed in Fig. 2. The *m* increases with frequency in whole period of the light curves, the peak of *m* appears at 95 GHz. This seems to indicate that the source is optically thin at high frequency. From P1 to P3, the peaks of *m* are located at 230 GHz and from P4 to P6, the peaks are located 43 to 95 GHz.

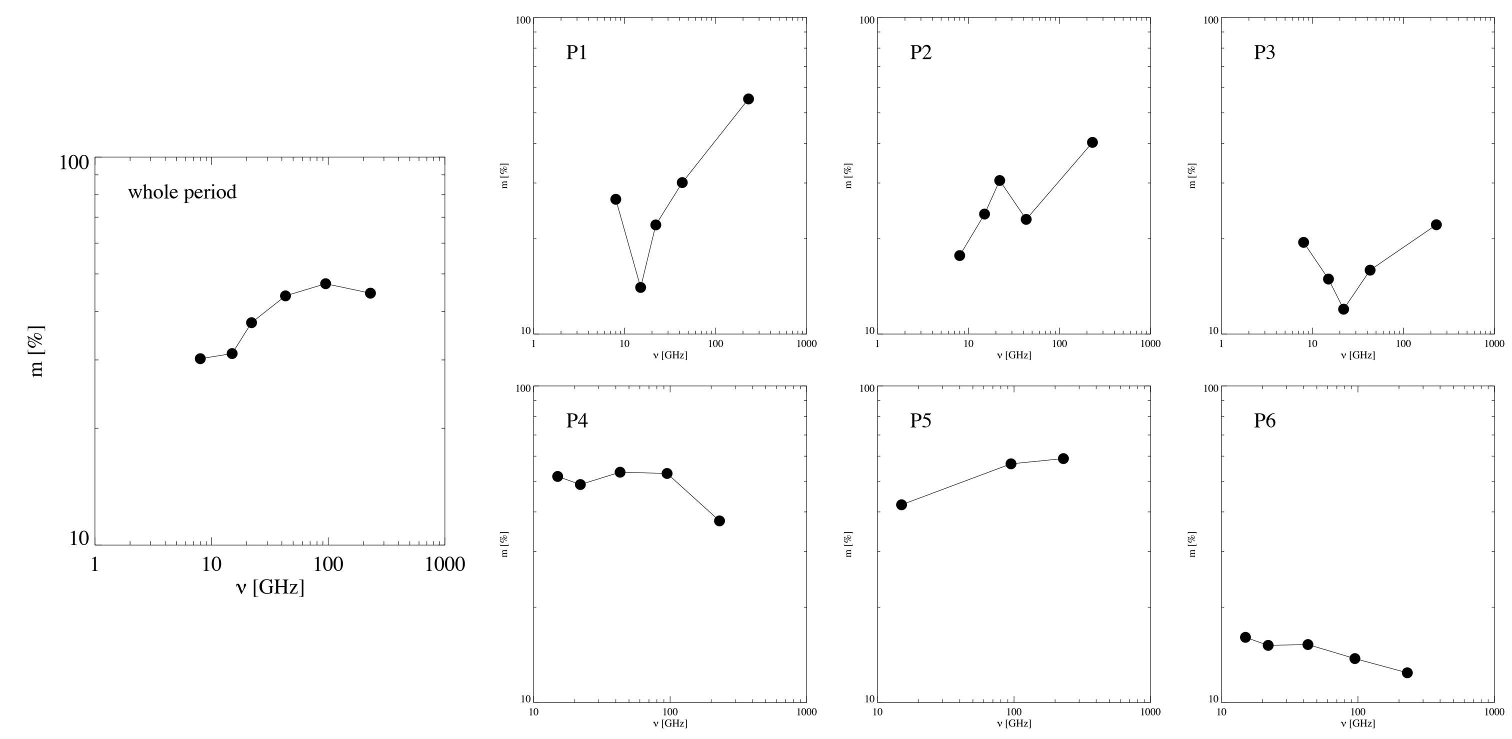

Fig. 2. Results of modulation index

Shock-in-jet model

We tested standard shock-in-jet model (Marscher & Gear 1987) for the four peaks (P2, P3, P4, and P6). In order to test, we first interpolated the data then fitted the spectra from 8 to 230 GHz using synchrotron self-absorption spectrum (Fromm et al. 2011). We obtained turnover-frequency (ν_c) and peak flux density (S_m) from the fit then plotted the time evolution of the ν_c and S_m for P2, P3, P4, and P6 (Fig. 3). In this case, S_m increases as $S_m \propto \nu_c^{\varepsilon_{adia}}$ with ε_{adia}=1.4 for P2, 0.9 for P3, 0.6 for P4 and P6 which is consistent with a adiabatic stage in the spectral evolution model of Marscher & Gear (1985), who discuss the evolution of propagating shock wave. This may indicate that the peaks are produced by a shock in the jet.

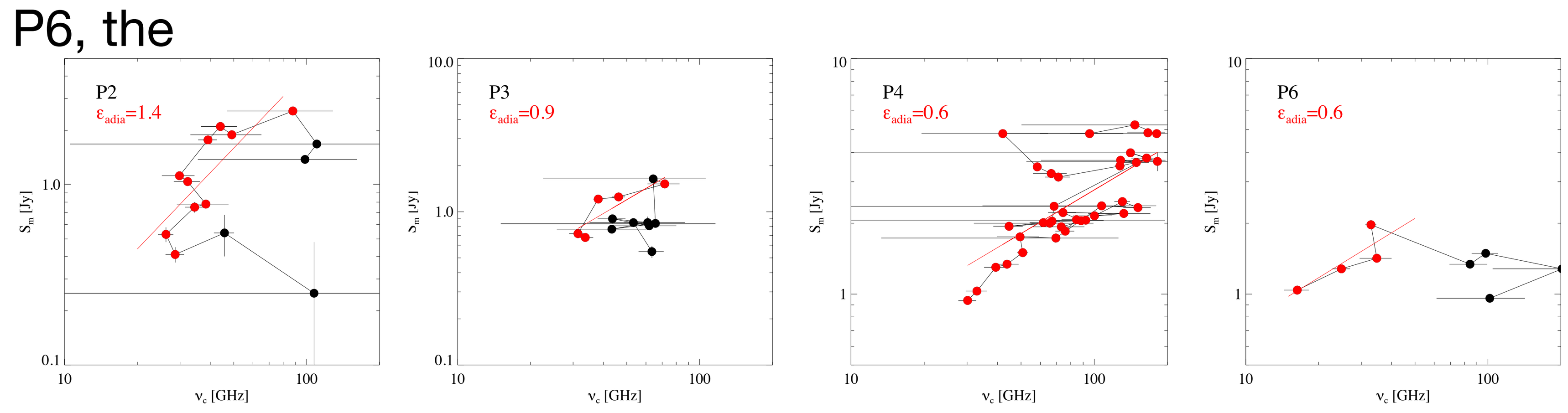

Fig. 3. Plots of turnover frequency vs. peak flux density for P2 to P6. Red symbols correspond to data points at decreasing flux density.

Magnetic field

We estimated magnetic field strength using the values of turnover frequency and peak flux density obtained from the synchrotron self-absorbed spectrum fitting (see, below equation). We adopted angular size θ of the source as 0.04 mas, Doppler factor δ as 7, redshift z as 0.127, and $b(\alpha)$ as 2.92. The estimated magnetic field strengths are 9mG-12G in P2, 25mG-2.6G in P3, 2.mG-40.9G in P4, and 0.5-7.9G in P6. The results are displayed in Fig. 4. From top to bottom, flux density light curves at 43 GHz for individual peaks, magnetic field strength, turnover frequency, and peak flux density in the time domain are displayed.

$$B = 10^{-5} b(\alpha)\theta^4 \nu_m^5 S_m^{-2}\left(\frac{\delta}{1+z}\right)$$ (Marscher 1983)

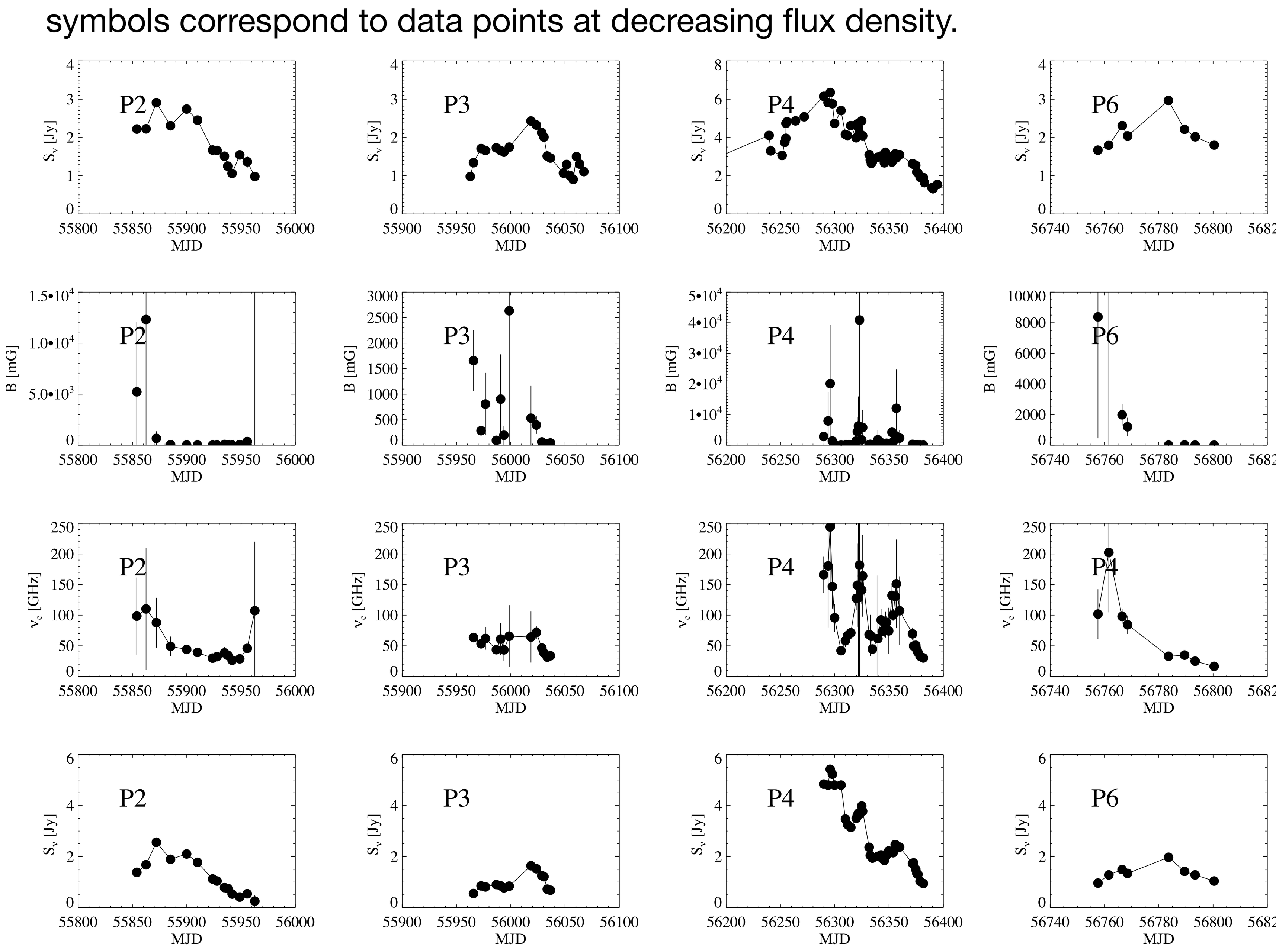

Fig. 4. Plots of flux density light curves at 43 GHz, B-field, turnover frequency ν_c, and peak flux density S_m in the time domain for P2 to P6.