# Study of Structures and Emission Regions of Relativistic Jets with Optical Polarimetry and Multi-Wavelength Observation in Various Timescales

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Active galactic nuclei (AGNs) are bright cores of galaxies. It is widely known that about 1-10% of galaxies possess such as AGN. Among AGNs, radio-loud AGNs are thought to possess a relativistic jet which is an extremely powerful and fast outflow of plasma and emerges from the vicinity of the massive black hole. The AGN jets are characterized by high kinetic powers (the Lorentz factor of blob $\sim 10$) and large-scale structure ($\sim 10^6$ pc), but the mechanics behind the creation and the composition of the jets are still a matter of much debate. Blazars are thought to possess a relativistic jet that is pointing toward the direction of the Earth and the effect of relativistic beaming enhances its apparent brightness. They radiate in all wavebands from the radio to the gamma-ray bands via the synchrotron and the inverse Compton scattering process. Blazars are suitable objects to study the jets due to their relativistic effect which makes the jet radiation dominant on overall spectral energy distribution. Numerous observations are performed but the mechanism of variability, creation and composition of jets are still controversial. The aim of this study is to investigate the emission region which plays an essential role in the mechanism of variations in jets. Simultaneous multi-wavelength and optical polarimetric observations are powerful tools to probe the emission region in jets, thus, we set the goal as constructing the observation framework which have a capability of temporally high-dense multi-wavelength and optical polarimetric observation of AGNs within a few hours. We performed wide-band multi-wavelength (from radio to TeV gamma-ray) observations of relativistic jets in several types of AGNs with various timescales (from minute to year) to study of structures and emission regions of relativistic jets. Polarimetry and multi-wavelength observation. In this study, we focused on four AGNs; ISP blazar 3C 66A, HSP blazar Mrk 421, FSRQ CTA 102 and RL-NLSy1 PMN J0948+0022. First, we ensured the framework of multi-wavelength observations of AGNs. In order to study the emission mechanism, we performed multi-wavelength observations of 3C 66A and Mrk 421. Next, we establish the global observing network that has a capability of high-dense multi-color observation. We performed observations of CTA 102 and PMN J0948+0022 with timescales from a few minutes to a few months to confirm a presence of the smallest emission region.

In 3C 66A, we performed multi-wavelength long-term monitors. As a result, we find two distinct types of behaviors: one, in 2008, which shows a correlation between the optical properties and the gamma-ray flux, and the other, in 2009, which does not show a good correlation. This result indicates that the emission region is different between these periods. Those different behaviors between the gamma-ray and optical bands might be explained by postulating two different emission components. In Mrk 421, we performed long-term monitors in the optical, UV and X-ray band from 2010 to 2011. In 2010, the variability in the X-ray band is clearly large, while the optical and UV flux shows gradual decreasing. On the other hand, the variability in the X-ray band is small in 2011, although the variability in the optical and UV band is relatively large compared with that in 2010. We speculated that Mrk 421 has a different variability mechanism between 2010 and 2011: the variability of whole-band spectra in 2010 is explained by the scenario of injection of high energy electrons, such as "shock-in-jet" model which also can reproduce polarization properties. On the other hand, that in 2011 is described by the scenario of injection of high-energy electrons but no-longer accelerated to ultra-relativistic. In CTA 102, we performed optical/IR dense photometric and polarimetric monitors, following strong gamma-ray flares in 2012 September. The observed two flares can be explained by emergence of a new emission component which possesses highly-ordered magnetic field. Such a magnetic field configuration would be generated through compression by shocks propagating down the jet. The observed polarization angle perpendicular to the jet direction is not unreasonable under the effect of relativistically-moving radiation source. For a narrow-line Seyfert 1 galaxy PMN J0948+0022, we detected very rapid (minutes-scale) variability in the polarized-flux light curve. The polarization degree reached $36 \pm 3\%$ at the peak of the short-duration flare, while polarization angle remained almost constant. These results provide a new observational evidence that highly ordered magnetic field is present inside a very compact emission region of the order of $\sim 10^{14}$ cm and imposes severe constraints on theoretical studies unless central black hole mass is much smaller than currently considered.

We established the technique of separation of emission regions in the jets with optical polarimetry and multi-wavelength observation in several types of AGNs and various timescales. Our results prefer the multi-zone model which have a number of independent emission regions, rather than one-zone model which has been widely used in previous analysis of multi-wavelength observation. Consequently, we found common characteristics in tree of four objects whose polarization angle seems to align to the jet direction. The "shock-in-jet" scenario can explain high PD and direction of PA in each object. A compressed shock that is perpendicular to the jet flow makes the electric polarization vector to be perpendicular to the emission blob and aligned with the jet axis. On the other hand, CTA 102 shows another tendency of alignment between the jet and polarization angle. In general, FSRQs are thought to have weaker shocks and/or a stronger underlying magnetic fields such as large-scale helical magnetic fields. Given this complicated situation, the measured polarization angles significantly different from the jet direction can still be accounted for by the "shock-in-jet" scenario. The tendency of alignment between the polarization angle and the jet direction in flaring state might reflect the environmental differences such as magnetic fields between BL Lac objects and FSRQs.