The New Variability Phase of OJ 287 and Emergence of New Components in NIR to X-ray Region

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Abstract. We present a multi-wavelength (MW) spectral and temporal study of the recent activity of the claimed super-massive binary black hole system OJ 287 since December 2015. The overall MW activity can be divided into two durations: December 2015 – April 2016 (MJD: 57360 – 57500), showing strong activity from near-infrared (NIR) to gamma-rays and September 2016 – June 2017 (MJD: 57650 – 57930), showing intense NIR to X-ray variability concurrent with detection at very high energies (VHE) by VERITAS, but without any signatures of variability in the Fermi-LAT band. In the first duration, the variations are almost simultaneous and the SEDs show new components in NIR-optical and optical-UV region. The NIR-optical bump is consistent with standard accretion-disk (AD) description while the optical-UV appears consistent with contributions from the broad-line region. The extracted broadband SEDs also show a clear shift in gamma-ray SED peak and can be explained with inverse Compton scattering of photons from broad line region. In the second period, the variations are also simultaneous except for one duration during which X-ray leads the optical/UV by \(\sim 5-6\) day. The broadband SEDs, on the other hand, show a mixture of a typical OJ 287 SED and an HBL SED, consistent with an origin from two different zones, one located at sub-parsec scales and other at parsec scales.

Keywords. BL Lac objects: individual: OJ 287, radiation mechanisms: non-thermal

1. Introduction

Blazar are radio-loud active galactic nuclei (AGNs) with their jet align at a close angle to the observer’s line of sight. They are characterized by a rapid variability with emission spanning the entire accessible electromagnetic (EM) spectrum, high and variable polarization, and frequent detection of superluminal motion. Temporally, the variability is consistent with stochastic variation while in the spectral domain, they exhibit a characteristic broad double hump spectral energy distributions (SEDs). The lower energy hump is well understood be synchrotron emission from relativistic non-thermal electron population while high energy hump can arise from inverse Compton (IC) scattering of photons within the jet and/or surrounding photons depending on the location of emission region e.g. broad line region and torus IR photons at sub-parsec scales, torus IR photons at parsec scales etc (e.g. see Kushwaha et al.(2013)). In this scenario, the emission at different wavelengths is highly correlated, both in the spectral and temporal domain, due to being generated from the same underlying particle population. Thus, any change in lower energy hump of SED should be reflected at the higher energy hump as well.
2. OJ 287 & Recent MW Activity

OJ 287 is an optically bright BL Lac object with optical record available since 1890. It shows regular quasi-periodic outbursts of \(~12\) years in the optical band in addition to the typical stochastic variability of blazars. The regular feature has been suggested to be a result of precessing, binary supermassive black hole (SMBH) system (Valtonen et al.(2016) and references therein). The model, with many improvements since its inception, has been relatively successful in predicting the timing of these regular outbursts and predicted the latest of next outburst around December 2015 – January 2016.

As per prediction, an increase in NIR-optical emission was observed at November 2015 end. The predicted impact outburst was observed on December 5, 2016 (MJD 57361) with a relatively low optical polarization (< 10%, Valtonen et al.(2016)). However, a systematic rotation of \(\sim 200^\circ\) in optical polarization was observed (Gupta et al.(2017)), untypical for a dominant thermal emission as argued in the above model. Further, outburst at X-rays and \(\gamma\)-rays was also seen. Following this till mid-2017, the source has been very active across the entire EM spectrum which is the focus of our report here.

Temporally and spectrally, the overall MW activity can be clubbed into two durations: December 2015 – April 2016 (MJD \(~ 57300 – 57500\) ) and June 2016 – September 2017 (MJD \(~ 57650 – 57930\) ), as is originally presented in Kushwaha et al.(2018a) and Kushwaha et al.(2018b). The first duration showed activity from NIR to Fermi-LAT \(\gamma\)-ray energies while the second duration showed a historic NIR to X-ray activity but lacks variability at Fermi-LAT \(\gamma\)-ray energies. The historic phase coincided with the first ever detection of OJ 287 at VHE energies by VERITAS (O’Brien et al. (2017)).

Correlation study shows that the variations are simultaneous except for one period during the second duration which shows a systematic variation with optical/UV lagging X-ray by \(~5-6\) days. In the spectral domain, the first duration revealed two new features: a bump at NIR-optical interface and a hardened Fermi-LAT \(\gamma\)-ray spectrum with a shift in its peak location (e.g. Kushwaha et al.(2013) for comparison). The NIR-optical bump is consistent the standard Shakura-Sunyaev accretion disk description of the primary SMBH \((1.8 \times 10^{10} M_\odot)\) while the \(\gamma\)-ray spectral hardening and peak shift can be naturally produced if it originates as a result of IC scattering of BLR photons as reported in Nilsson et al.(2010) for previous impact periods. This explanation resonates with the fact that NIR-optical SED shows no sign of a shift in its peak location. The IC/BLR constraining the emission region location at sub-parsec scales. The SEDs during the second duration, on the other hand, show an additional non-thermal component peaking at X-ray energies during high activity states while the X-ray spectra show curved spectrum with departure consistent with the level of X-ray emission during the quiescent state of the first duration. The location of X-ray peak and coincident VHE detection is consistent with properties of HBL blazars and can be reproduced by an addition emission region at parsec scales if emission is related with peak escape events of the binary SMBH model.

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