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Strong Soft X-Ray Excess in 2015 *XMM-Newton* Observations of BL Lac OJ 287

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Abstract

We report a strong soft X-ray excess in the BL Lacartae γ-ray blazar OJ 287 during long exposure in 2015 May, among two of the latest *XMM-Newton* observations performed in 2015 and 2018 May. In the case of the 2015 May observation, a log parabola model fits the EPIC-pn data well, while a log parabola plus a power law describes the overall simultaneous optical to X-ray spectra, suggesting the excess as the synchrotron tail. This interpretation, however, is inconsistent with the observed spectral break between near-infrared (NIR) and optical spectra, attributed to a standard disk around a supermassive black hole (SMBH). Based on this, we considered two commonly invoked accretion-disk-based models in active galactic nuclei (AGNs) to explain the soft excess: the cool Comptonization component in the accretion disk and the blurred reflection from the partially ionized accretion disk. We found that both cool Comptonization and blurred reflection models provide an equally good fit to the data, and favor a super-heavy SMBH of mass $\sim 10^{10}\,M_\odot$. Further investigation of about a month-long simultaneous X-ray and ultraviolet (UV) pointing observations revealed a delayed UV emission with respect to the 1.5–10 keV band, favoring X-ray reprocessing phenomenon as the dominant mechanism. The results suggest that the soft excess is probably caused by strong light bending close to the SMBH. The detected soft excess in the 2015 data and its disappearance in the 2018 data is also consistent with the presence of accretion-disk emission, inferred from the NIR–optical spectral break between 2013 May and 2016 March.

Unified Astronomy Thesaurus concepts: Galaxy nuclei (609); X-ray active galactic nuclei (2035); Active galaxies (17); High energy astrophysics (739); Galaxy jets (601); Relativistic disks (1388); Blazars (164); BL Lacertae objects (158); Supermassive black holes (1663)

1. Introduction

OJ 287 ($z = 0.306$) is one of the most luminous and rapidly variable BL Lacartae objects (BLLs) at radio to optical frequencies (Sitko & Junkkarinen 1985; Stickel et al. 1989). It is also one of the most extensively studied extragalactic active galactic nuclei (AGNs) over the entire electromagnetic spectrum from radio waves to γ-rays (Visvanathan & Elliot 1973; Hudec et al. 2013; Valtonen et al. 2016; Gupta et al. 2017; Britzen et al. 2018; Goyal et al. 2018; Kapanadze et al. 2018; Kushwaha et al. 2018a, 2018b and references therein). Apart from the typical stochastic variability of blazars and favorable observational properties like high radio and optical brightness, the most prominent features responsible for making the source famous are the presence of a recurrent regular optical outburst about every 12 years (Sillanpaa et al. 1988, 1996a) and its double-peaked structure (Sillanpaa et al. 1996b).

Two interpretations have been suggested in the literature for the regular optical outbursts. One class of models attributes the quasi-periodic outbursts to the interaction dynamics of accretion disk and supermassive black holes (SMBHs; Sillanpaa et al. 1988; Lehto & Valtonen 1996) in a binary SMBH system, while the other class of models attributes it to the Doppler-boosted jet emission as a consequence of geometrical alignment of precessing single (Britzen et al. 2018 and references therein) or double relativistic jets (Qian 2018 and references therein). The very first model by Sillanpaa et al. (1988) explained the periodicity to increased accretion flow due to tidal disturbances induced by the secondary SMBH in the accretion disk of primary SMBH. The model was modified after the observation of a sharp rise during the 1994 and 1996 outbursts by Lehto & Valtonen (1996), who attributed the periodicity and double-peaked structure as the impact of secondary SMBH on the primary accretion disk. The disk-impact binary SMBH model has been fairly successful in predicting the timing of the double-peaked $\sim$12 yr quasi-periodic outbursts (Hudec et al. 2013; Valtonen et al. 2016). It attributes the flare emission to thermal bremsstrahlung of the hot gas torn off during the impact, and constrains the SMBH masses to $\sim 1.8 \times 10^{10}\,M_\odot$ and $\sim 1.5 \times 10^{8}\,M_\odot$ for the primary and secondary SMBHs, respectively (Valtonen et al. 2012, 2016). The geometrical class of models, on the other hand, argues a total system mass in the range of a few times $\sim 10^{7}$–$10^{9}\,M_\odot$ (Shi et al. 2007; Britzen et al. 2018; Qian 2018 and references therein).

From the shape of the broadband energy spectra, it is known that that OJ 287 is a low-peaked BLL with the peak of the low-energy hump, attributed to synchrotron emission from the jet, at near-infrared (NIR) energies. The high-energy hump in the X-ray to γ-ray band normally peaks at $\sim$100 MeV (Abdo et al. 2010; Kushwaha et al. 2013). The synchrotron self-Compton (SSC) mechanism successfully describes it as typical X-ray emission, while γ-ray emission is shown to be due to the inverse Comptonization of a $\sim$250 K ($\sim$0.022 eV) torus photon field (EC-IR Kushwaha et al. 2013), contrary to the generally believed SSC origin of high-energy hump in BLLs. However, during its latest multiwavelength activity from 2015 December to 2017 July, OJ 287 exhibited a hardened MeV–GeV

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