

Research Paper

Complex optical/UV and X-ray variability in Seyfert 1 galaxy Mrk 509

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Abstract

We performed a detailed spectral and timing analysis of a Seyfert 1 galaxy Mrk 509 using data from the *Neil Gehrels Swift* observatory that spanned over ~ 13 years between 2006 and 2019. To study the variability properties from the optical/UV to X-ray emission, we used a total of 275 pointed observations in this work. The average spectrum over the entire duration exhibits a strong soft X-ray excess above the power law continuum. The soft X-ray excess is well described by two thermal components with temperatures of $kT_{\text{BB1}} \sim 120$ eV and $kT_{\text{BB2}} \sim 460$ eV. The warm thermal component is likely due to the presence of an optically thick and warm Comptonizing plasma in the inner accretion disk. The fractional variability amplitude is found to be decreasing with increasing wavelength, i.e., from the soft X-ray to UV/optical emission. However, the hard X-ray (2–8 keV) emission shows very low variability. The strength of the correlation within the UV and the optical bands (0.95–0.99) is found to be stronger than the correlation between the UV/optical and X-ray bands (0.40–0.53). These results clearly suggest that the emitting regions of the X-ray and UV/optical emission are likely distinct or partly interacting. Having removed the slow variations in the light curves, we find that the lag spectrum is well described by the 4/3 rule for the standard Shakura–Sunyaev accretion disk when we omit X-ray lags. All these results suggest that the real disk is complex, and the UV emission is likely reprocessed in the accretion disk to give X-ray and optical emission.

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1. Introduction

Active galactic nuclei (AGNs) are strongly believed to be fuelled by accreting matter from the surrounding medium around the super-massive black hole (SMBH) at the centre. This has been recently confirmed through the observations of a nearby radio galaxy M87 with the Event Horizon Telescope (EHT; Akiyama et al. 2019). Imaging the central black hole and the accretion disk at the centre of other galaxies that are farther away is impossible even with EHT. There are, however, other indirect methods that are used to derive the physical structure and size of these objects. Continuum reverberation mapping (RM; Blandford & McKee 1982; Peterson 2014) technique is one such method in which the estimated time lag between the continuum emission in shorter and longer wavelength ranges has been used to derive the size of the broad-line region (BLR) and hence the black hole virial mass in several AGNs (Peterson et al. 2004; Bentz et al. 2009). Understanding of the emission mechanism in AGNs has been a topic of intense research for several decades. However, the origin of emission in different wavelength ranges of the electromagnetic spectrum and correlation between them remain ambiguous to date. The general picture is that the low energy photons (seed photons) in ultraviolet (UV) and optical bands are believed to be originated from the accretion disk and the broad-line region (BLR). These photons get inverse

Compton scattered in the hot electron plasma (corona), causing X-ray emission from the AGNs (Haardt & Maraschi 1991).

The origin of the UV/optical and X-ray variabilities and correlation between them have been one of the most intriguing questions in the studies of the physical size and structure of AGNs. In Seyfert galaxies, the energy spectrum is dominated by UV radiation which is believed to be originated from a multi-colour black-body disk (Koratkar & Blaes 1999). The X-ray/UV/optical emission from the accretion disk shows variabilities over timescales ranging from a few hours to years in the AGNs with black hole mass in 10^6 – $10^9 M_{\odot}$ range. Although the cause of the observed variabilities is not very well understood, several possible explanations are presented to interpret the results. The first and the obvious one is the fluctuations in the mass accretion rate (Arévalo et al. 2008). However, fluctuation in the mass accretion rate is insufficient to explain the variabilities on short timescales (i.e., hours to days) as these fluctuations drift on a viscous timescale, which is in years for AGNs. In many Seyfert galaxies, variations in X-rays have been found to lead UV/optical variations on short timescales (McHardy et al. 2014), which cannot be explained by density fluctuations. Fluctuations in X-ray leading over the UV/optical band is explained by the so-called ‘reprocessing model’. In this model, X-ray radiation from the central corona directly illuminates the accretion disk, thereby increasing its temperature. Heating of the accretion disk due to radiation from the corona makes the disk a source of enhanced radiation in UV/optical bands. In this process, the time delay between the driving radiation and reprocessed radiation is given by $\tau \propto \lambda^{\beta}$, where $\beta = 4/3$ for the standard Shakura–Sunyaev accretion disk (Cackett et al. 2007; McHardy

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