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X-ray/UV variability of narrow-line Seyfert 1 galaxies

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Abstract. Narrow-line Seyfert 1 galaxies (NLS1s) host low black hole masses ($M_{BH} \lesssim 10^7 M_\odot$) and are accreting at high accretion rates. These properties make NLS1s ideal AGN to study the coupling between the accretion disks and hot corona by studying UV and X-ray variability. Here we present UV and X-ray variability of the NLS1 1H 0707–495 which is well known for its relativistically broadened iron K and L lines. We found no obvious correlation between the UV and X-ray emission on light-crossing time, implying absence of significant reprocessed emission. The lack of reprocessing is most likely due to the strong bending of X-ray emission from a compact corona onto the innermost regions, giving rise to broadened iron lines but no illumination onto the intermediate/outer disk where reprocessed UV emission is expected. We also found X-ray spectral variability – spectral steepening with increasing X-ray flux, which cannot be due to the variations in the seed flux as the UV emission is not correlated with X-ray powerlaw shape. The observed spectral variability is most likely intrinsic to the hot Comptonizing corona.

Keywords : accretion, accretion disks – galaxies : active – galaxies : individual : 1H 0707–495 – galaxies : Seyfert

1. Introduction

Active galactic nuclei (AGNs) are the nuclei of galaxies that can continuously generate unusually large luminosity (up to 10^{47} ergs s^{-1}) in a compact region ($\lesssim 10^{14}$ cm) and over almost the entire electromagnetic waveband. AGNs are thought to be powered by accretion of material on to a central supermassive black hole ($M_{BH} \sim 10^5 - 10^{10}$ M$_\odot$). The continuum emission from AGNs in the X-ray, UV and optical is believed to arise from the accretion flow. The broadband continuum emission from radio-quiet AGN consists of three major components – the infrared bump arising from reprocessing of the UV emission by the dust in a range of temperatures, the big blue

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bump (BBB) which is thought to be directly related to the accretion process, and X-ray emission which is thought to consist of the high energy tail of the BBB, a powerlaw with high energy cut-off and reflection of this powerlaw (see e.g., Koratkar and Blaes 1999). The X-ray powerlaw component is almost certainly the Comptonization of the BBB in a hot corona. The continuum emission ionizes the circumnuclear gas giving rise to the observed broad emission lines from the broad-line region and narrow emission lines from the narrow-line region.

The nature of accretion disks in AGN is not well understood (Koratkar and Blaes 1999). At present, the observation of relativistic iron lines in the X-ray spectra of some AGNs is the only available proof of AGN disks (e.g., Tanaka et al. 1995; Miller 2007). Optical/UV emission from AGN are not well described by the standard disk model though there are uncertainties due to the intrinsic extinction and host galaxy contribution (Koratkar and Blaes 1999). If the X-ray emission from a compact corona is reprocessed into optical/UV in the disk, then the optical/UV emission is expected to lag behind the variations in the X-rays by light-crossing times. Thus, the relationship between the variability of reprocessed optical/UV and X-ray emission can be used to probe the accretion disks in AGN (see Connolly et al. 2015). However, the origin of the optical/UV variability in AGN is not clearly understood. It is also possible that the variations in the X-ray emission arising from a hot Comptonizing corona is caused by the variations in optical/UV seed photons from the disk. In this case, X-rays are expected to lag behind the optical/UV emission by the light-crossing times.

2. Timescales associated with the emission from an accretion disk

Light-crossing time: This is the time delay between the optical/UV emission from the disk and the X-ray emission from a central compact corona. Assuming only viscous heating of accretion disk, the emission from different radii of the disk can be described as blackbodies with different temperatures (e.g., Netzer 2013). Using Wien's law, the effective wavelength (λ_{eff}) of a filter bandpass can be converted to the temperature of a blackbody which peaks in the band. Comparing this temperature to that of standard accretion disk, one can calculate the disk radius with peak emission in the observed bandpass, and the light-crossing time between the central compact X-ray source and the region of the disk peaking in the observed filter bandpass (Smith and Vaughan 2007). The time delay arising from the light-crossing time can be derived to be

$$\tau_{lag} \approx 2.6 \times 10^5 \left(\frac{\lambda_{eff}}{3000\ \text{Å}}\right)^{4/3} \left(\frac{\dot{M}}{\dot{M}_{Edd}}\right)^{1/3} \left(\frac{M_{BH}}{10^8 M_\odot}\right)^{2/3} \text{ sec.} \quad (1)$$

The light-crossing time is important in case of disk irradiation. Other timescales associated with the accretion disk are (e.g. King 2008) as follows. The dynamical timescale is the shortest characteristic timescale corresponding to the Keplerian frequency.

$$t_{dyn} = \left(\frac{r^3}{GM_{BH}}\right)^{1/2} \approx 500 \left(\frac{M_{BH}}{10^8 M_\odot}\right) \left(\frac{r}{r_g}\right)^{3/2} \text{ sec.} \quad (2)$$

The readjustment to thermal equilibrium occurs on the thermal timescale, $t_{th} = \frac{1}{\alpha} t_{dyn}$, and the radial inflow of matter is governed by the viscous timescale, $t_{vis} \approx \frac{1}{\alpha} \left(\frac{r}{h}\right)^2 t_{dyn}$, where r and h are disk radius and height, $r_g = GM_{BH}/c^2$ and $\alpha \sim 0.1$ is the viscosity parameter.

3. The case of 1H 0707–495

1H 0707–495 is an extreme NLS1 with M_{BH} of $2.3 \times 10^6 M_\odot$ (Zhou and Wang 2005). It is well known for its broad relativistic iron K and L lines and the soft delay of ≈ 30 s which is interpreted as reverberation delay (Fabian et al. 2009). The detection of strong relativistic reflection features have already demonstrated the role of strong illumination in the inner accretion disk of this AGN. It is, therefore, interesting to study disk reprocessed emission from this AGN. We have studied four long *XMM-Newton* observations performed in 2008 (Pawar et al. 2015, in prep). We extracted time-resolved X-ray spectra in strict simultaneity with the OM UVW1 exposures, fitted absorbed blackbody for the soft excess (SE) plus powerlaw (PL) model, and calculated flux of the soft X-ray excess and the powerlaw components. We examined the variability of the UV emission in the UVW1 band, soft X-ray excess and the powerlaw flux. The intrinsic variability of a source can be quantified in terms of the fractional root mean square (rms) variability amplitude (Vaughan et al. 2003, and references therein) which is given by

$$F_{var} = \sqrt{\frac{S^2 - \overline{\sigma_{err}^2}}{\bar{x}^2}}, \tag{3}$$

where S^2 is the sample variance, $\overline{\sigma_{err}^2} = \frac{1}{N}\sum_1^N \sigma_{err,i}^2$ is the mean squared error, $\sigma_{err,i}$ is uncertainty in the measurements x_i. We found strongest variability in the PL component ($F_{var} \sim 70\%$), and the weakest variability in the UV ($F_{var} \sim 10\%$) for the four observations in 2008. The most rapid variability is observed in the PL component (a factor of 11 change in just 3 ks), the doubling timescale is comparable to the dynamical timescale $t_{dyn} \sim 170$ s at last stable orbit around a Schwarzschild black hole of mass $M_{BH} \sim 2.3 \times 10^6 M_\odot$. Weak UV variability at a level of 4% is observed on timescales as short as 3 ks, much shorter than the dynamical timescale, $t_{dyn} \sim 90$ ks, for the UV emitting region.

We also found that while the SE and PL components are positively correlated, the UV emission is not well correlated with the X-ray emission. Thus, the variability arising from the inner and outer regions are not correlated in 1H 0707–495. The absence of UV/X-ray correlation with a lag of light-crossing time ($\tau_{lag} \approx 9000$ s for $\dot{M}/\dot{M}_{Edd} \sim 0.1$, $M_{BH} \sim 2.3 \times 10^6 M_\odot$, UVW1 $\lambda_{eff} = 2910$ Å) implies that the UV emission is not dominated by the reprocessed emission. These results can be understood in terms of strong light bending model in which the primary X-ray emission from a compact corona is focused onto the inner accretion disk only causing strong blurred reflection as observed by (Fabian et al. 2009) but negligible illumination in the outer optical/UV emitting regions of the disk. The time-resolved X-ray spectral

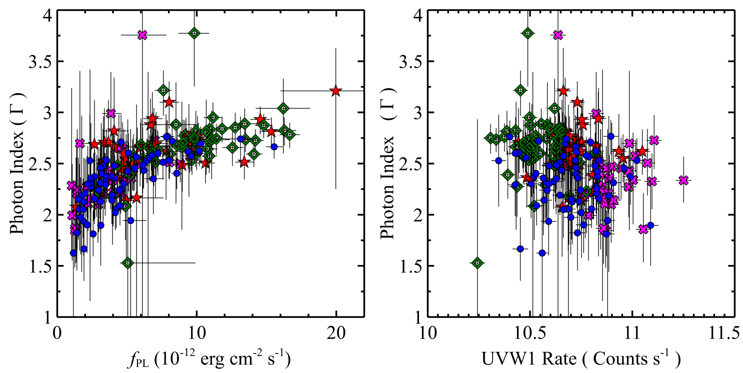

Figure 1. Spectral variability of 1H 0707–495. X-ray power law photon index as a function of power law flux (left) and UVW1 count rate (right).

analysis also revealed spectral variability with the powerlaw steepening with increasing X-ray flux (see Figure 1). Such trends have been observed previously (see e.g., Zdziarski and Grandi 2001) and have been interpreted in terms of thermal Comptonization models in which increased seed flux cools the corona causing in steeper powerlaw. The simultaneous UV and X-ray observations of 1H 0707–495 have provided an opportunity to test this model. We found no positive correlation between the powerlaw slope and the UV flux suggesting that the observed spectral variability is not caused by the variations in the seed flux. We attribute the X-ray spectral variability intrinsic to the corona.

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