Do NLS1s have a beamed outflow? An unusual X-ray perspective for Mrk 766

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Abstract. Recently, the detection of Gamma-ray emission from Narrow Line Seyfert 1s has suggested that these sources may emit beamed jets towards us. I report the results of a time-resolved spectral analysis of an XMM-Newton long observation of Mrk 766, showing that the X-ray source has been eclipsed several times by clouds with a cold, dense core, and a less dense, highly ionized tail. These clouds have blueshift velocities \( v > 10^4 \) km s\(^{-1}\) (as measured through He-like iron absorption lines), and are therefore part of a strong outflow. These results provide new important constraints on the geometry and structure of this source, and may be relevant to understand the peculiarity of NLS1s as a class of AGNs.

1. Introduction

X-ray absorption variability is a common feature in Active Galactic Nuclei (AGN). An analysis of a sample of nearby X-ray obscured AGN with multiple X-ray observations, performed a few years ago (Risaliti et al. 2002) revealed that column density (\( N_H \)) variations are almost ubiquitous in local Seyfert galaxies. More recent observations performed with XMM-Newton, Chandra and Suzaku further confirmed this finding. The physical implications of these measurements are that the circumnuclear X-ray absorber (or, at least, one component of it) must be clumpy, and located at sub-parsec distances from the central source. The comparison between different observations, typically performed at time distances of months-years, only provides upper limits to the intrinsic time scales of \( N_H \) variations. An improvement of these estimates can only be obtained through observational campaigns within a few weeks/days, and/or through the search for \( N_H \) variations within single long observations. Such short time-scale studies have been already performed for a handful sources: NGC 1365 (Risaliti et al. 2005, 2007, 2009), NGC 4388 (Elvis et al. 2004), NGC 4151 (Puccetti et al. 2007). In particular, in the case of the AGN in NGC 1365 we revealed extreme spectral changes, from Compton-thin (\( N_H \) in the range \( 10^{23} \) cm\(^{-2}\)) to reflection-dominated (\( N_H > 10^{24} \) cm\(^{-2}\)) in time scales from a couple of days to \( \sim 10 \) hours. Such rapid events imply that the absorption is due to clouds with velocity \( v > 10^3 \) km s\(^{-1}\), at distances of the order of \( 10^4 \) gravitational radii (assuming that they are moving with Keplerian velocity around the central black hole). The physical size and density of the clouds are of the order of \( 10^{13} \) cm and \( 10^{10} \) to \( 10^{11} \) cm\(^{-3}\), respectively.\(^1\) All these physical parameters are typical for Broad Line Region (BLR) clouds, strongly suggesting that the X-ray

\(^1\) For a detailed derivation and discussion of these parameters, we refer to Risaliti et al. 2009. A rough estimate is also mentioned here in Section 2.
Here I present a special case of X-ray absorption variability of the narrow line Seyfert 1 galaxy Mrk 766. The occultations found in this source are particularly interesting because of the (on average) unobscured state of this source, which implies that the absorption by an intervening cloud has a large impact on the observed spectrum, which allows a more detailed, otherwise impossible analysis of the cloud structure.

2. Time-resolved analysis of the X-ray emission of Mrk 766

Mrk 766 has been observed by XMM-Newton for six consecutive orbit, for a total time of about 700 ks. We analyzed this source through a two-step method based on (1) the study of the hardness ratio light curve, and (2) the spectral analysis of the time intervals defined in the first step. This approach is illustrated in Fig. 1.

The upper panel of Fig. 1 shows the standard 2-10 keV flux light curve for this observation, with the well known strong variability on time scales of thousands of seconds, or even shorter. The lower panel shows the light curve of the (6-10 keV)/(2-5 keV) flux ratio. In general, this light curve shows much smaller variations, indicating that the continuum shape remains the same during most of the luminosity variations. However, clear exceptions are observed in at least three intervals, highlighted in Fig. 1. During these intervals it is possible that a cloud with \( N_H \) of the order of \( 10^{23} \text{ cm}^{-2} \) has covered the central source, strongly decreasing the observed flux in the soft band, without affecting the hard band, and therefore increasing the observed hardness ratio.

Following this interpretation, in the first interval we should be observing a cloud uncovering the X-ray source (with the covering phase occurred before the beginning of the observation); in
the second interval another cloud should be covering the X-ray source, with the uncovering phase not observed due to the "dead time" between two consecutive *XMM-Newton* orbits. Finally, in the third interval we should be observing the whole eclipse.

In order to check this scenario, we performed a complete analysis of the spectra obtained from the three highlighted intervals, and of those obtained from the third and fourth orbit, representing the standard spectral state of the source. In this analysis we allowed all the main spectral parameters of the model to vary among the different intervals. The results of this study, illustrated in Fig. 2 are the following:

1) the 2-10 keV spectrum obtained from the third and fourth orbit (the "standard" state) is well reproduced by a typical model for type 1 AGNs, consisting of a power law, a reflection component and an iron emission line;

2) the variations observed in the first and second orbit can be completely reproduced through an obscuring cloud partially covering the X-ray source. Each of the three events (two in the first orbit, one in the second) are due to different clouds (with the first two possibly overlapping, see Figure 2. Results from the spectral analysis of the eclipses observed in Mrk 766. Top two panels: spectra, best fit model and residuals from the third and fourth orbit (Fig. 1), where no spectral changes are observed. Bottom panels: difference between the spectra in the three intervals with spectral variations (INT 1, 2 and 3, Fig. 1) and the best fit model for the third and fourth orbit (INT 4).
Figure 3. $\chi^2$ residuals for the six time intervals corresponding to: the three occultation events (1, 2 and 3AC), the first interval after the third occultation (3D), the remainder of the second orbit (3EF) and the whole third and fourth orbits (4). The presence of iron absorption lines when the cold absorption cloud is also present, suggest the presence of a ionized tail.

Risaliti et al. 2011 for details), with column densities in the range $1-3 \times 10^{23}$ cm$^{-2}$.

3) The residuals of the best fits for all the three intervals with occultations show the presence of absorption lines in the 6.7-8 keV energy interval (Fig. 3), compatible with highly ionized iron (Fe XXV and Fe XXVI). A subsequent fit showed that these features are statistically highly significant, and are blueshifted by several thousands km/s. No such line is detected in any of the other spectral intervals, i.e. the highly ionized absorber is associated to the neutral clouds responsible for the continuum spectral variations. A new fit which allow for a free ionization state for the obscuring cloud shows that the two components must have a difference in ionization parameter by a factor of at least 50.

3. Conclusions
The analysis presented above shows that three occultations by BLR clouds happened during the long XMM-Newton observation of Mrk 766. At the same time of the “eclipses” due to the nearly neutral clouds, iron absorption lines due to highly ionized iron were also present, with outflowing velocities of several $10^3$ km s$^{-1}$ (up to 15,000 km s$^{-1}$ for the third cloud). The different in ionization parameter between the two components is at least 50. This strongly suggests a cometary structure of the clouds (Fig. 4) with a high-density head, followed by a long, low density, highly ionized tail. In our model, the clouds have both an outflowing and a rotational ($\sim$Keplerian) component of the velocity. The rotational component is of the order of
Figure 4. Scheme of the proposed structure of the absorber responsible for the observed occultations. Left: structure of an eclipsing cloud, as viewed from a direction orthogonal to the line of sight. Right: a possible structure of the circumnuclear gas in Mrk 766, as viewed from the disc/torus plane. The cloud tail can be either in front or behind the cold core with respect to the source.

several thousands km/s, in order to cover the X-ray source (whose size is assumed to be a few gravitational radii) in the observed eclipsing time.

This analysis is the first direct X-ray evidence of the presence of ionized material rapidly outflowing from the central source in a Narrow-Line Seyfert 1, and may be related to the presence of beamed outflows, as recently suggested to explain the radio and gamma-ray emission of several NLS1.

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