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X-ray absorption variability in AGN

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Abstract. X-ray absorption variability is a common feature in Active Galactic Nuclei (AGN). Recent works of our group demonstrated that X-ray eclipses, on time scales of a few hours, occurred during several observations of local bright AGNs, without being spotted with traditional, time-averaged spectral analysis. These eclipses are remarkable events in themselves, but, more importantly, are a powerful way to investigate the inner structure of AGNs: they allow to measure the size of the X-ray source and the size, density and geometrical shape of the obscuring clouds. We show that WFXT would provide a real breakthrough in this field, allowing a systematic study of X-ray eclipses on hundreds of sources.

Key words. Galaxies: active

1. Introduction

X-ray absorption variability is common among Active Galactic Nuclei (AGN). Considering local bright obscured AGN with multiple hard X-ray observations, we found that N_H variations on time scales from months to a few years are almost ubiquitous (Risaliti et al. 2002).

More recently, such variability has been found at much shorter time scales, form a few hours to a few days, through campaigns of multiple observations within days/weeks, and detailed, time-resolved studies of long single observations.

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 ~10 hours (Risaliti et al. 2007, 2009). 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}-10^{11} cm^{-3}, respectively.

All these physical parameters are typical for Broad Line Region (BLR) clouds, strongly suggesting that the X-ray absorber and the clouds responsible for broad emission lines in the optical/UV are one and the same.

Although NGC 1365 remains the most extreme case of X-ray eclipses, similar occultation events have now been found in several more sources (about 10, including both type 1 and type 2 sources, see Risaliti (2009) for an updated list). These results prove that X-ray absorption variability within single observations is common in local AGNs. Therefore, it

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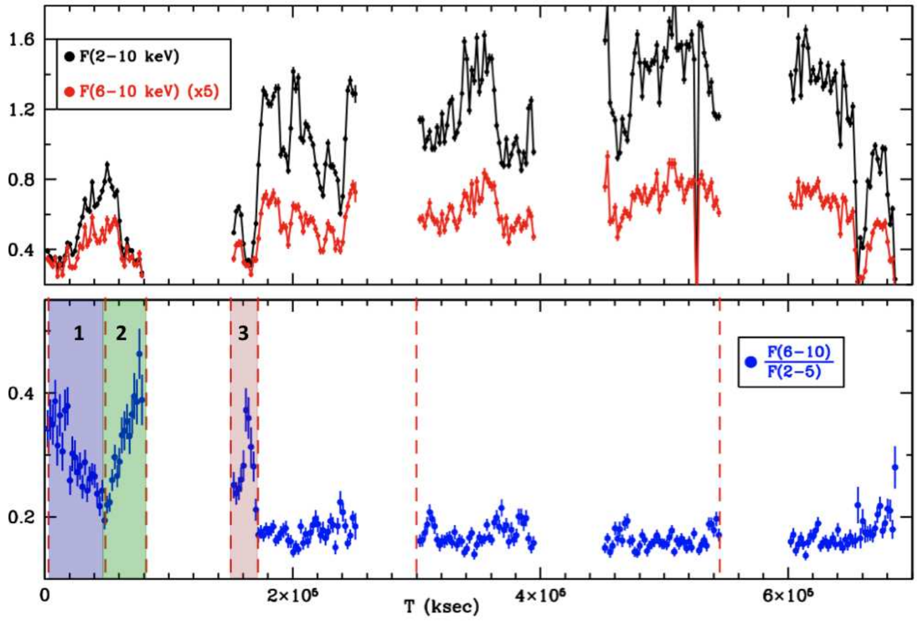

Fig. 1. Flux (top) and hardness ratio (bottom) light curves from the *XMM-Newton* long observation of Mrk 766. The observation is made in five consecutive *XMM-Newton* orbits.

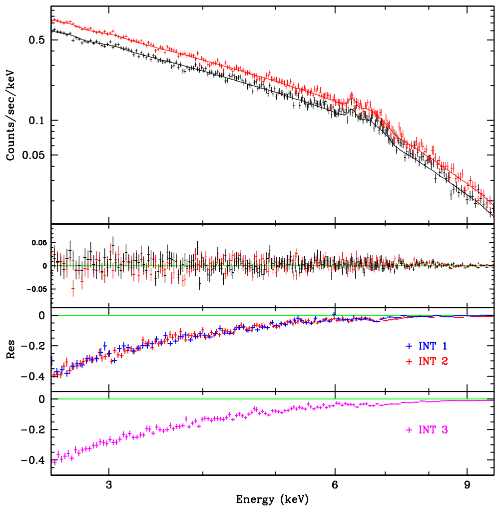

Fig. 2. Results from the spectral analysis of the eclipses observed in Mrk 766. Top two panels: spectra, best fit model and residuals from the third and fourh orbit (Fig. 1), where no spectral changes are observed. Bottom panels: difference between the spectra in the three intervals with spectral variations (Fig. 1) and the best fit model for the third and fouth orbit.

can be used as a tool to measure the properties of the X-ray absorbing clouds and, therefore, of the broad line region.

For this reason, a systematic study of X-ray eclipses in AGN would be invaluable to investigate the structure of the circumnuclear medium in AGN. Current observatories allow this kind of study only for a few bright sources with long *Suzaku* or *XMM-Newton* observations. In the future, new observatories with small fields of view, such as IXO, will be useful to better study single events, but only an observatory with both large efefctive area and large field of view, like WFXT, will be able to understand the relevance of this phenomenon in the general population of AGNs.

2. X-ray eclipses of AGNs

The method to search for X-ray eclipses in AGNs consists of a two-phase analysis: we first use the hardness-ratio light curve to select the time intervals where strong spectral variations occurred; we then perform a complete analysis of the spectra obtained from these intervals, in

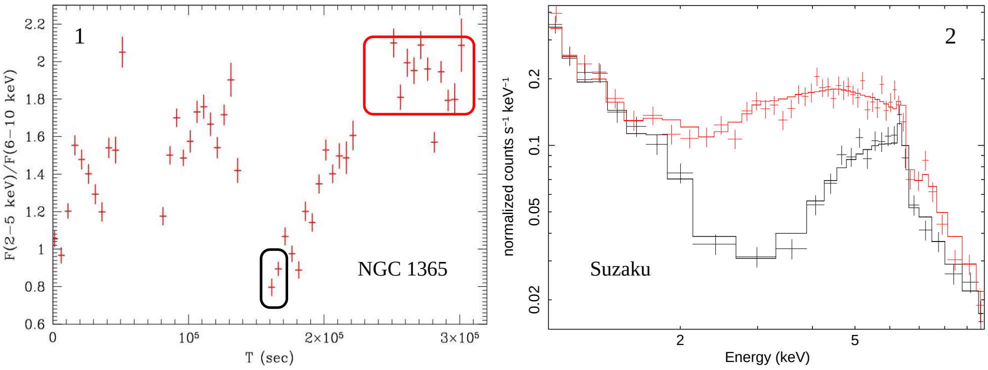

Fig. 3. Panel 1: Hardness ratio light curve form a *Suzaku* long observation of NGC 1365. Panel 2: Spectra obtained from the two intervals highlighted in the 1st panel.

order to measure possible N_H variations (and to check if the spectral changes are due to other effects, such as variations of the slope of the continuum emission).

As an example, this approach is illustrated in Fig. 1 for the long *XMM-Newton* observation of Mrk 766. We note that Mrk 766 is a Narrow Line Seyfert 1, so on average we do not expect to observe complete X-ray absorption of the X-ray source. However, as we show below, isolated clouds occasionally cross the line of sight, producing measurable absorption in the X-ray spectrum. 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} 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.

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 the 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 spectral variations observed in the three intervals discussed above are completely reproduced by three absorption components with column densities in the range 1-3 10^{23} cm^{-2}.

As mentioned above, this analysis is at present possible one for a handful, very bright sources. In the following Section we show how WFXT can expand this kind of analysis on fainter/more rapidly variable sources.

3. WFXT observations of AGN eclipses

In order to show the capabilities of WFXT in detecting X-ray eclipses, we start from an already observed event in the "best" source for this kind of studies, i.e. NGC 1365.

In Fig. 3 we show the results of a long *Suzaku* observation of NGC 1365 (Maiolino et al. 2010, subm.). The hardness ratio light curve shows strong variations (1st panel). A complete spectral analysis of several intervals, chosen following the hardness ratio variations,

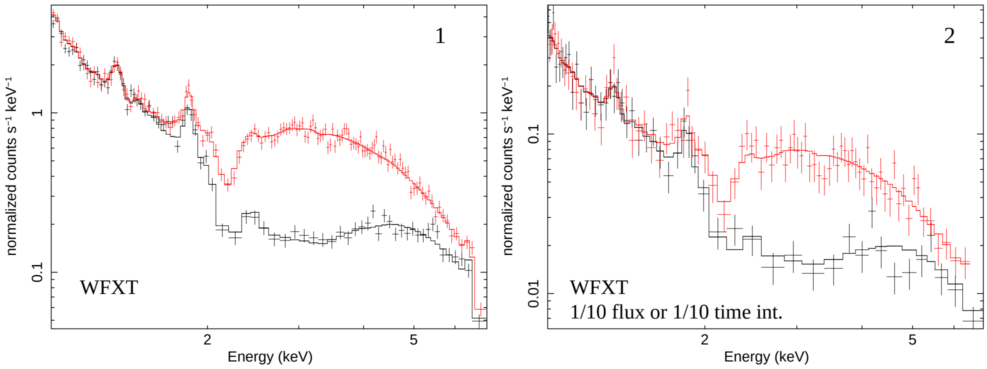

Fig. 4. WFXT simulations. Panel 1: simulation of the same events shown in Fig. 3, as observed with WFXT. Panel 1: same simulation, for a 10 times fainter source, or for the same source, but with spectra extracted from 10 times shorter intervals.

revealed that the whole observed variability can be reproduced with a constant continuum model, and a variable partial covering component. Two spectra obtained from two states with different hardness ratio are shown in the second panel.

Fig. 4 reveals the capabilities of WFXT to perform this kind of analysis: the same event observed with WFXT would produce the spectra in Panel 1, with a much higher S/N, and therefore with a more precise determination of the physical parameters of the obscuring cloud. The real possible breakthrough is however shown in Panel 2: this simulation show the same analysis performed with WFXT on a 10 times fainter source or, equivalently, on the same source, but selecting 10 times shorter time intervals. This imply that (1) the detection of X-ray eclipses will be possible for hundreds of sources, especially in the planned WFXT medium-depth survey; (2) in a few cases of very bright sources, it will be possible to investigate absorption variations on much shorter time scales than those accessible with currently available instruments.

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