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Partial-covering and reflection in the Narrow-line Seyfert 1 galaxy 1H 0707–495

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Abstract. Sharp spectral drops and/or spectral curvature have been discovered in the high-energy X-ray spectra of several Narrow-Line Seyfert 1 galaxies (NLS1). Two themes which appear relevant in discussing these features are partial-covering by a dense patchy absorber and reflection processes enhanced by light-bending close to the black hole. We present two *XMM-Newton* observations of the NLS1 1H 0707–495 separated by two years. We demonstrate that both models are rather successful at describing the spectral and timing properties at both epochs, as well as the long-term spectral variability.

Key words. galaxies: active – galaxies: individual: 1H 0707–495 X-rays: galaxies

1. High-energy spectral complexity and Narrow-line Seyfert 1s

Narrow-line Seyfert 1s (NLS1) have long been known for their extreme X-ray behaviour. With the superior sensitivity of *XMM-Newton* came the discovery of further complexity in the form of sharp spectral drops above 7 keV. The most extreme examples are 1H 0707–495 (Boller et al. 2002) and IRAS 13224–3809 (Boller et al. 2003). The edge features are sharp; not accompanied by fluorescence iron emission; and, at least in 1H 0707–495, time-variable (Gallo et al. 2004). The sharpness of the features and absence of Fe Kβ UTA absorption seem to dismiss a photoionisation origin for the edge-like structures. Lack of Fe Kα emission and Fe L edges dictate that if the drop is due to absorption then the absorber only partially covers the ionising source.

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Though 1H 0707–495 and IRAS 13224–3809 may be the most extreme examples of this behaviour, they are not exceptional. Such spectral complexity has been observed in several NLS1 (e.g. Longinotti et al. 2003; Pounds et al. 2004; Reeves et al. 2004). It is conceivable that such behaviour is ubiquitous in NLS1. Two equally attractive physical models have evolved as possible explanations for the described behaviour: partial-covering and reflection.

2. The history of 1H 0707–495

The first observation of 1H 0707–495 (z = 0.0411) with *XMM-Newton* in October 2000 (hereafter referred to as GT) revealed a sharp spectral feature at ∼ 7 keV in which the spectrum "jumped" by a factor of > 2 within a few hundred eV (Boller et al. 2002). The measured energy and sharpness of the feature implied K-absorption by neutral iron; however, the absence of a fluorescence line suggested a more complicated situation.

Two years after the first observation 1H 0707–495 was observed again (hereafter referred to as AO2; Gallo et al. 2004; Fabian et al. 2004). The main differences between the two observations are illustrated in Fig. 1.

3. The partial-covering interpretation

The basic picture of partial-covering is of a dense absorber which only partially covers the emitting region. In 1H 0707–495, the absence of a significant Fe L edge and narrow Fe K fluorescence line imply that the absorber is anisotropic and only partial covers the ionising source.

The two observations of 1H 0707–495 could be successfully modelled in context of partial-covering (Gallo et al. 2004). In both cases the intrinsic continuum was described by a power-law and a thermal disc component. The absorber was assumed to be neutral due to the sharpness of the feature and the absence of a Kβ UTA, both expected under low-ionisation conditions (Palmeri et al. 2002). The shift in the edge energy was interpreted as arising from an outflow of about $0.05c$. The diminished edge depth and increased flux in the AO2 observation was due to a decrease in the covering fraction of the absorber. The intrinsic luminosity of 1H 0707–495 was approximately equal at both epochs.

Partial-covering does not require intrinsic variability of the source (though it does not discriminate against it). It was shown that the flux and short-term spectral variability at both epochs could be understood as a change in only the covering fraction of the absorber (Tanaka et al. 2004; Gallo et al. 2004).

4. Reflection and light-bending considerations

If instead of an absorption edge we attribute the sharp spectral drop above 7 keV to the blue wing of a relativistically broadened iron line, we require a mechanism to produce the large equivalent widths and often reflection dominated spectra. Light-bending close to the black hole can achieve these results (e.g. Martocchia & Matt 1996; Miniutti & Fabian 2004).

Consider a compact primary continuum source at some height above the accretion disc. If the height above the accretion disc is small (a few gravitational radii), a large fraction of the emitted photons are bent toward the disc by the strong gravitational field of the central black hole, strongly reducing the direct power-law component which reaches the observer. In this case, most of the light is either lost in the black hole or will be reprocessed by the disc, yielding a reflection dominated spectrum. As the height of the source above the disc increases, the gravitational potential that the primary photons need to overcome is less. As a result the strength of the direct power-law component increases, while the reflection component diminishes. The flux and spectral changes can be explained as the primary continuum source moving up and down above the black hole.

Such a picture has been used to describe the behaviour of 1H 0707–495 at both epochs. During the low-flux GT observation the spectrum was in a reflection dominated state (primary source was very close to the black hole); whereas during the AO2 observation, 1H 0707–495 was in a higher flux state and two components were required: a power-law and reflection (Fabian et al. 2004). The flux and spectral variability could be understood in terms of light-bending as well.

5. The current state of affairs

Although the partial-covering and light-bending models involve fundamentally different physics, their appearance in the *XMM-Newton* energy range can be very similar (Fig. 2). Both models produce a spectral drop at high energies and a strong soft-excess below ~ 1.5 keV.

Both models face challenges. The sharpness of the drop is difficult to reproduce with the reflection model. The model can be improved by increasing the iron abundance, though in doing so the fit in the low-energy spectrum is degraded. A possible solution may be variable abundances (e.g. more Fe and less O). In the case of partial-covering the shift in

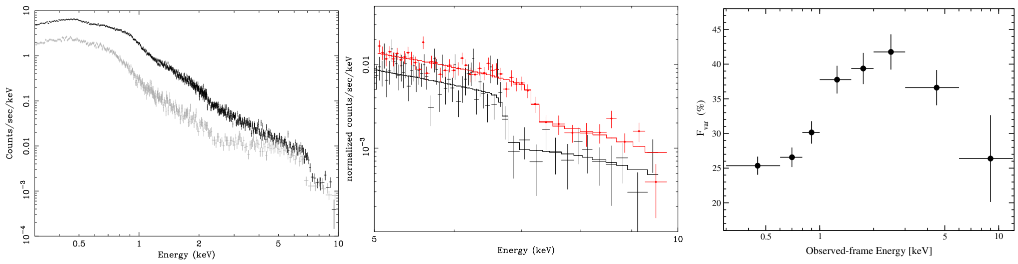

Fig. 1. Some results from the previous *XMM-Newton* observations of 1H 0707–495. Left panel: The 0.3–10 keV spectra during the GT (lower curve) and AO2 (upper curve) observations. A softer spectrum is notable during AO2. Most of the flux difference between the two observations is seen below ~ 5 keV. The soft-excess is also shifted to higher energies. Not clearly visible in this plot are the signatures of a warm medium which were present in AO2 (~ 1 keV), but absent during GT. Middle panel: The drop energy shifted from 7 keV to 7.5 keV, and the depth diminished by about 50% over the two years. Right panel: The rms spectrum during the AO2 observation. Significant spectral variability was present with the 1–5 keV band being the most variable. The rms spectrum during the GT observation showed no significant spectral variability.

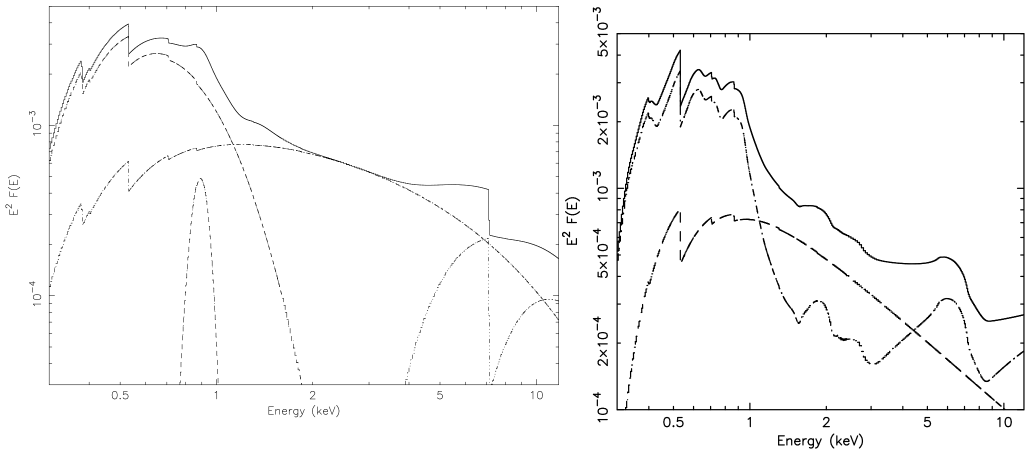

Fig. 2. The unfolded models (dashed lines) used to fit the AO2 data of 1H 0707–495. While the folded models (solid lines) appear very similar during this relatively low-flux state, there are significant differences in the two models that can be examined for in higher flux states. Left panel: The components of the partial-covering model during the AO2 observation. Right panel: The components of the reflection model during the AO2 observation.

drop energy requires a large mass and energy loss rate. Clumping the material can alleviate the problem, but it is not certain how significantly.

In principle the sharpness of the drop could reveal the correct model. The drop is intrinsically narrow in the case of a neutral absorber, but much wider for an emission line. However, we are limited by the lower resolution of *XMM-Newton* at higher energies. A realistic alternative is to monitor long-term flux-dependent spectral changes in 1H 0707–495. While there was a factor of five difference in the flux between the GT and AO2 observations, both data sets were obtained in relatively low-flux states. In fact, the GT observation of 1H 0707–495 was obtained in the lowest flux state ever recorded for this object. 1H 0707–495 has been observed to be ten times (Leighly et al. 2002) and possibly even 20–50 times brighter (Remillard et al. 1986). The potential in the flux-dependent spectral variability is that the partial-covering and reflection model will appear very different in higher flux states. In the light-bending scenario the flux changes are due to changes in the normalisation of the power-law component. It can be seen from Fig. 2 that as the power-law component increases, the depth of the edge *and* the strength of the soft-excess will diminish. Moreover, light-bending offers predictable timing behaviour (Miniutti & Fabian 2004) which can also be examined for. On the other hand, flux and spectral changes in the partial-covering model arise from changing the covering fraction of the absorber, while the intrinsic spectrum remains unchanged. This implies that in higher flux states the edge will diminish and the spectrum will become softer, but the soft-excess and warm absorber features will remain prominent.

6. Conclusions

XMM-Newton observations of NLS1 are revealing new complexities in the their X-ray spectra which were not recognised with previous missions. The concepts of light-bending and partial-covering appear relevant in describing these objects. Both models are potentially powerful in revealing information about the supermassive black hole environment.

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