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GINGA observations of an intense variable iron line in Mkn 841

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SUMMARY

We report on a *GINGA* observation of the luminous Seyfert 1 galaxy, Mkn 841, in which a strong iron line, of equivalent width ~ 400 eV, was seen. Comparison with a previous, fainter *GINGA* observation shows that this line is variable. The continuum power-law index of 1.5 is flatter than observed from typical AGN and suggests that there is an unusually strong reflected component in this source. In this it may be similar to the rapidly varying Seyfert 1 galaxy NGC 6814. The presence and strength of the reflected component in AGN is a useful ingredient in the construction of models of the innermost regions of such objects.

1 INTRODUCTION

The variable X-ray source in the Seyfert 1 nucleus of Mkn 841, which is at a redshift of 0.0366, was one of the first soft-excess sources to be discovered. *EXOSAT* observations, reported by Arnaud *et al.* (1985), showed a power-law spectrum of photon index 1.6 in the 2–10-keV band and a coincident bright, variable, soft X-ray source which greatly exceeded an extrapolation of that power law. The soft X-ray excess was interpreted as the high-energy tail of the quasi-thermal emission from an accretion disc surrounding a massive black hole in the centre of the nucleus. The relatively low temperature of the soft X-ray emitting material ($T \sim 200\,000$ K) means that the disc material is dense, optically thick and, from the point of view of X-rays of energy above ~ 1 keV, can be considered to have the same absorption and scattering properties as neutral material. Consequently, if from a similar region, the harder X-ray spectrum should show features produced by such processes. In particular, absorption by iron in the disc should lead to a fluorescent iron emission line in the spectrum of Mkn 841. We report here on the discovery of such an iron emission line, the strength of which is surprisingly large.

Absorption and scattering features in the X-ray spectra of Active Galactic Nuclei (AGN) were predicted by Guilbert & Rees (1988) (see also Lightman & White 1988) in their attempt to explain the soft excess as hard X-ray luminosity reprocessed by dense gas surrounding the nucleus. The expected iron emission line, measured to have an equivalent width of about 100 eV, has been found in the X-ray spectrum of the black hole candidate Cygnus X-1 (Fabian *et al.* 1989) and in the *GINGA* spectra of many AGN (Pounds *et al.* 1989; Matsuoka *et al.* 1990; Nandra, Pounds & Stewart 1990; Pounds *et al.* 1990). The strength and width of this line (George, Nandra & Fabian 1990) are consistent with a geometry in which the hard X-ray emission originates above and below the central parts of the accretion disc. Most recently, a further reprocessed component, an electron-scattered continuum, has been discovered (Matsuoka *et al.* 1990; Pounds *et al.* 1990) which is also in agreement with this geometry. In this observationally derived picture, most of the soft excess luminosity is generated within the accretion disc.

Although most of the objects observed so far agree with the above picture, a few Seyfert galaxies have stronger iron lines, indicating some complications in the model. The Seyfert 2 galaxy, NGC 1068, has a much stronger line (equivalent width ~ 1 keV, Koyama *et al.* 1989), which is plausibly produced in a large scattering region (size ~ 1 pc, Krolik & Kallman 1987) also responsible for the polarized optical emission lines (Antonucci & Miller 1985). In unified models for Seyfert AGN, such a scattering region should be present in all Seyferts. More relevant to Mkn 841 are the *GINGA* X-ray observations of the rapidly varying Seyfert 1 galaxy, NGC 6814, which has an iron line of equivalent width about 300 eV (Kunieda *et al.* 1990). This lines varies simultaneously with the continuum, on time-scales of hundreds of seconds or less, and must, therefore, originate very close to the centre of the nucleus. The strength of the line indicates a larger reprocessed fluorescent component than expected from a simple flat accretion disc irradiated by an outside isotropic X-ray source. This may be due to a different geometry allowing us to see a stronger reflected component, or to the X-ray source radiating anisotropically, as can occur if the inverse Compton process is involved and the 'seed' photon distribution is anisotropic (Ghisellini *et al.* 1990).

The iron line in Mkn 841, reported on here, is marginally

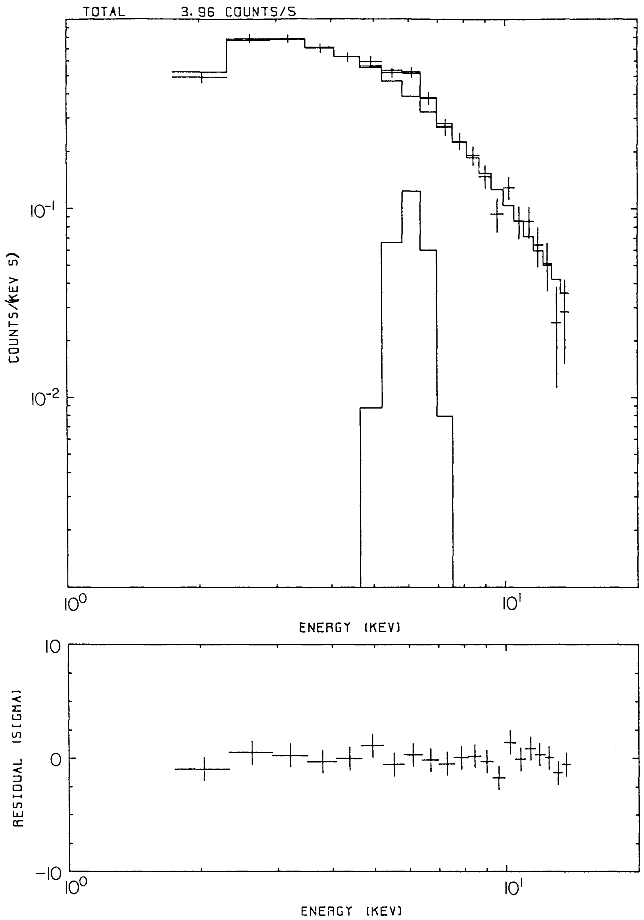

Figure 1. X-ray count spectrum from Mkn 841 as observed by *GINGA*. The best-fitting power-law model, including an iron emission line, is shown by the solid line.

stronger than that observed in NGC 6814. Such observations are important in modelling the innermost regions of massive accreting black holes.

2 THE *GINGA* OBSERVATIONS

Mkn 841 was observed by the X-ray satellite *GINGA* for 24 hr on 1990 July 23. The X-ray source was easily detected in the 2–10-keV band with a count rate of 3.7 count s^{-1}. The raw X-ray spectrum has a clear excess around 6 keV which we interpret as an iron emission line. After subtraction of the background spectrum, obtained from an observation the previous day of neighbouring blank sky, we fitted the X-ray spectrum with a model consisting of a power law plus an emission line. The intervening photoelectric absorption column density was fixed at the galactic H I value of $10^{20.4}$ cm^{-2} (Arnaud *et al.* 1985). We find that the photon index of the continuum is 1.51 ± 0.07 and that the iron line has an equivalent width of 380 ± 150 eV at 6.0 ± 0.2 keV. (Errors correspond to the 90 per cent confidence level for a single parameter.) This energy is consistent with the redshifted energy of fluorescent emission from 'neutral' iron (i.e. less ionized than Fe XVII) which has a rest energy of 6.4 keV. The best-fitting spectrum is shown in Fig. 1.

For comparison with model fits to other AGN, we have also fitted a simple 'reflection' model produced by Monte Carlo calculations of a power-law spectrum of X-rays scattered from a flat disc of neutral gas of cosmic abundances (see George *et al.* 1990). A good fit is also obtained in this case if the ratio of reflected component to the direct component is a factor of 2 higher than in the case of simple, isotroic illumination of a flat disc.

The X-ray luminosity of Mkn 841 derived from this observation is 5×10^{43} erg s^{-1} which is less than the 1984 *EXOSAT* observation (8×10^{43} erg s^{-1}), but more than a *GINGA* observation made on 1989 June 30 (3×10^{43} erg s^{-1}) when the count rate was 2.4 count s^{-1} in the 2–10-keV band. A strong iron line is consistent with the *EXOSAT* observation (and detected at a level corresponding to about 2σ). No iron emission was seen in the previous *GINGA* observation with an upper limit on the equivalent width of about 200 eV. Consequently, we can conclude that the iron line is variable, by at least a factor of 3, on a time-scale of a year or less. The previous *GINGA* observation and another *EXOSAT* observation will be reported elsewhere (George *et al.*, in preparation).

3 DISCUSSION

The strong, variable iron X-ray line in Mkn 841 cannot come from any large-scale scattering region, as is the case in NGC 1068, but probably originates from the inner regions of the accretion disc detected in soft X-rays. The large equivalent width of the line, as in NGC 6814, requires that simple 'reflection' models for the X-ray spectral features be modified. Although we cannot rule out an increased iron abundance for Mkn 841 in isolation, it is interesting that the indices obtained by fitting a simple power-law model to both that object and NGC 6814 are low (1.5 in Mkn 841 and 1.42 ± 0.07 in NGC 6814, Kunieda *et al.* 1990) when compared with the average AGN index of 1.7 (Mushotzky *et al.* 1980; Turner & Pounds 1989; Pounds *et al.* 1990). This suggests that the continuum is also involved, most probably through the contribution of the reflected continuum which must be large in both objects. We have found that in the case of Mkn 841, a direct power law of index about 1.7 together with a reflected component provide a satisfactory fit to the *GINGA* data.

With the present data, we cannot assess whether the increased reflection component is due to the geometry of the emission region or to the anisotropy of the hard X-ray emission process. A plausible geometrical configuration that can account for different fractions in different sources is for the disc to be clumpy with the soft X-rays originating in the clumps and the harder X-rays originating between the clumps. If the clumps have a scaleheight c and the harder X-ray emission has a scaleheight h, then when $h > c$ the direct component dominates, the clumps subtend about 2π sr to the hard emission and the equivalent width of the iron line is about 100 eV. On the other hand, if $h \sim c$ or $h < c$, less direct flux can emerge without scattering so that the reflected fraction is higher and the equivalent width larger.

The parsec-sized obscuring torus invoked in 'unified models' of AGN (Lawrence & Elvis 1982; Krolik & Kallman 1987) implies an iron line of equivalent width ~ 240 eV in the weaker spectrum of 1989, if the mean luminosity of Mkn 841 over the past 10 yr was $\sim 6 \times 10^{43}$ erg s^{-1}. This is marginally inconsistent with the measured upper limit.

4 CONCLUSIONS

The luminous X-ray source in Mkn 841 has an intense iron line that varies on a time-scale of a year at most. The equivalent width of this line is more than twice that of the line in a typical AGN. Both Mkn 841 and NGC 6814 (which has a similarly strong line) have a flat continuum spectrum compared with typical AGN. This result is simply explained by a model in which Mkn 841 and NGC 6814 have a larger reflected X-ray component than is expected from a simple flat disc with an exterior X-ray source.

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NOTE ADDED IN PROOF

Fluctuations in the X-ray background make estimates of the continuum strength more uncertain than assumed here, particularly in the 1989 observation to be discussed by George *et al.* (in preparation), which could be uncertain by ~ 30 per cent. This affects the equivalent width but not the intensity of the iron line. We thank K. Nandra for pointing this out to us.