X-RAY SPECTROSCOPY OF RADIO GALAXY 3C120

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Abstract

3C120 is a bright, nearby FRI radio galaxy with a superluminal jet (e.g., Walker et al., 2001) and broad optical emission lines. We observed this source for 120 ks with *XMM-Newton* to search for relativistically broadened Fe Kα emission and to probe the structure of the inner accretion flow. This observation is supported by near-simultaneous multi-wavelength coverage in the radio (37 GHz), mm (250 GHz), optical, and UV bands. We caught 3C120 during a large radio flare, when the X-ray source was hard and in decline. The UV flux at 2900 Å is strongly correlated with the soft X-ray flux, consistent with Comptonization of UV photons or X-ray reprocessing. There does not appear to be a significant X-ray contribution from the relativistic jet. The Fe Kα line is narrow and there is no indication of relativistic line emission.

1 Introduction

One of the crucial questions in active galactic nucleus astrophysics is: what physical parameters control the strength of radio jets? The prime candidates include the spin of the central black hole and the accretion rate. The profile of the Fe Kα line can potentially be used to study the structure of the inner accretion flow and perhaps determine these parameters. This has been demonstrated with *ASCA* and *XMM-Newton* observations of the Seyfert galaxy MCG-6-30-15 (Tanaka et al., 1995; Wilms et al., 2001). *ASCA* observations of the radio galaxy 3C120 show the presence of a strong Fe Kα line (Grandi et al., 1997), but the profile shape depends on the assumed shape of the underlying continuum (Wozniak et al., 1998). *XMM-Newton* is well-suited to make accurate measurements of Fe Kα with high sensitivity and large wavelength coverage.

A second goal of our observation is to make simultaneous measurements of the X-ray and UV variability of 3C120, taking advantage of the *XMM-Newton* Optical Monitor. Previous observations hint that the X-ray spectrum steepens with increased UV flux, consistent with a Compton-scattering origin for the X-rays. In addition, Marscher et al. (2002) find a connection between X-ray dips and the ejection of new Very Long Baseline Interferometry (VLBI) radio components. This suggests a strong connection between the state of the X-ray emitting region and the production of a radio jet. Similar behavior is seen in the variability of microquasar GRS 1915+105 (Mirabel & Rodriguez , 1994, 1998)

2 X-ray spectrum

We use the EPIC pn and MOS2 cameras to study the X-ray Spectrum of 3C120 (Fig. 1, 2). The 3–10 keV hard X-ray spectrum is modeled by a power law with photon index $\Gamma = 1.8$ plus a neutral reflection component (Fig. 1). The neutral reflection fraction, $\Omega/2\pi = 0.4\pm0.4$, is not well constrained. Neutral Fe Kα emission is clearly seen in the residuals at 6.21 keV, consistent with the optical redshift of $z = 0.0330$. There is a weaker line at 6.74 keV, a blend of Fe XXVI Lyα and Fe I Kβ. The Fe Kα line width upper limit of FWHM $< 12\,000$ km s^{-1} is consistent with the instrumental profile. The line may originate in the broad line region (BLR) or a molecular torus. The equivalent width of 60 eV yields a covering fraction of $\Omega/2\pi = 0.4$, and constrains the fraction of beamed emission to be $< 40\%$.

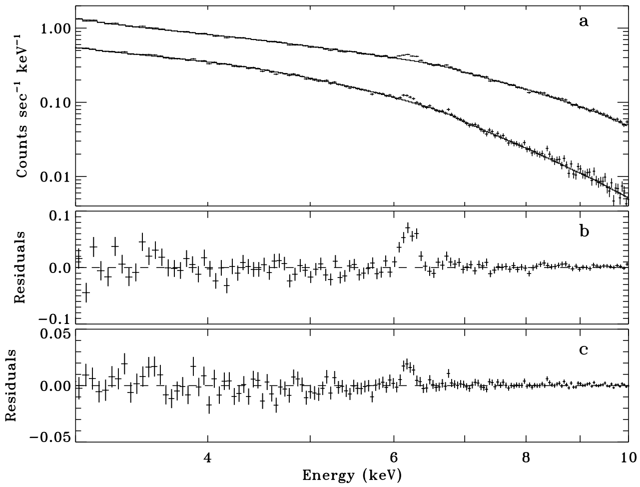

Figure 1: (a) Hard (3–10 keV) X-ray spectra, fit with power law plus Compton reflection. *XMM-Newton* pn (top) and MOS2 (bottom). (b, c) EPIC pn and MOS2 residuals, respectively. Narrow Fe I Kα and Kβ emission lines are from fluorescence in the BLR or a molecular torus. No relativistically broadened line is present, contrary to some past claims.

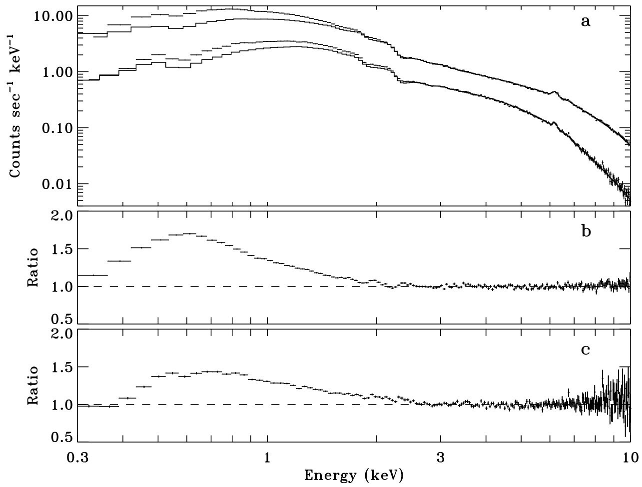

Figure 2: (a) Soft X-ray spectra. *XMM-Newton* pn (top) and MOS2 (bottom). (b, c) EPIC pn and MOS2 residuals, respectively, to the extrapolated hard X-ray model. A strong soft X-ray excess bump is evident.

There is no indication of any relativistic emission lines in our high S/N spectra.

When we extrapolate the hard X-ray spectral model down to the 0.3–2 keV band, there is a large soft X-ray excess bump (Fig. 2). This bump is fit best by an extra broken power-law component with indices $\Gamma_1 = -1.2$ and $\Gamma_2 = 2.7$, and a break energy of 0.56 keV. We try various physical models such as blackbody, multicolor disk blackbody, Wien, and Comptonized Wien. All of these models give very poor fits because they predict a much broader bump shape than is observed. An ionized disk model does not work either, because it predicts a number of discrete emission lines, including Fe XXV, which are not seen. We have accounted for the Galactic hydrogen column density of $N_{\rm H} = 1.7\times10^{21}$ cm^{-2}, which is estimated from the O I edge depth in the RGS spectrum (not shown). There is no indication of intrinsic neutral absorption, ionized absorption, or ionized emission in the RGS spectrum.

3 Spectral energy distribution

We took multi-wavelength data which are contemporaneous (within 10 days) of the *XMM-Newton* observations, in order to measure the spectral energy distribution (SED, Fig. 3). High frequency (37 GHz) observations were taken with the 14 m telescope at Metsähovi Radio Observatory, as part of an ongoing monitoring campaign. Even higher frequency observations in the mm-band (250 GHz) were gathered with the SEST telescope on La Silla. The optical spectrum was measured with LRIS on the Keck telescope, and the 2900 Å UV flux was measured with the *XMM-Newton* Optical Monitor. Our observations are in good agreement with archival photometry from the NASA Extragalactic Database (NED, Fig. 3b), except for the unusually strong flux at 250 GHz.

The optical-UV SED is not well matched by a simple multicolor disk blackbody model. This is not surprising, and more detailed modeling will be necessary to better parameterize the emission region. However, any strongly beamed component from the relativistic jet is ruled out by the strong optical and X-ray emission lines. The hard X-ray power-law may be attributed to Comptonized UV photons, but we have no ready explanation for the shape of the soft X-ray excess bump. The optical through X-ray luminosity is 1.3×10^{45} erg s^{-1}, 30% of the Eddington value for the 3×10^{7} $M_\odot$ black hole reverberation mass (Peterson et al., 1998). The 0.3–10 keV X-ray to optical luminosity ratio is 0.18, with 37% of that amount in the soft excess.

4 X-ray, UV, and radio variability

The *XMM-Newton* EPIC pn light curves are shown in Fig. 4a,b. The soft X-ray flux dropped by 18% over the course of the observation, while the spectrum hardened (Fig. 4c). This is consistent with previous ob-

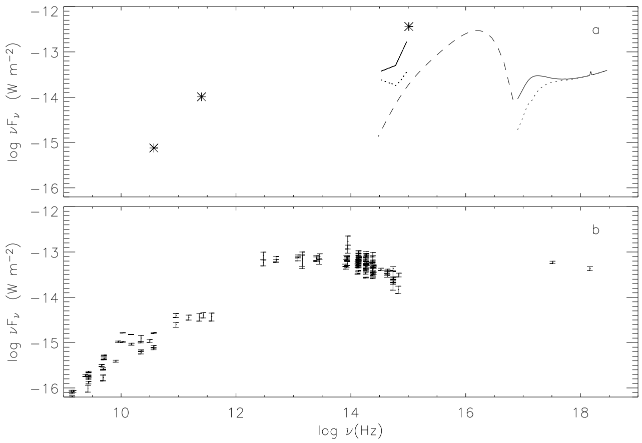

Figure 3: 3C120 Spectral energy distribution (SED). (a) August 2003 epoch. Optical and X-ray continuum models (solid lines) are corrected for Galactic reddening and absorption. The uncorrected continuum is given by the dotted lines. For comparison, a multicolor disk blackbody is shown (dashed line), for $M_{\rm BH} = 3\times10^7\ M_\odot$ and $L = 0.3\ L_{\rm E}$. Radio (37 and 250 GHz) and UV data are represented by asterisks. (b) Archival data from NED (1967-2003).

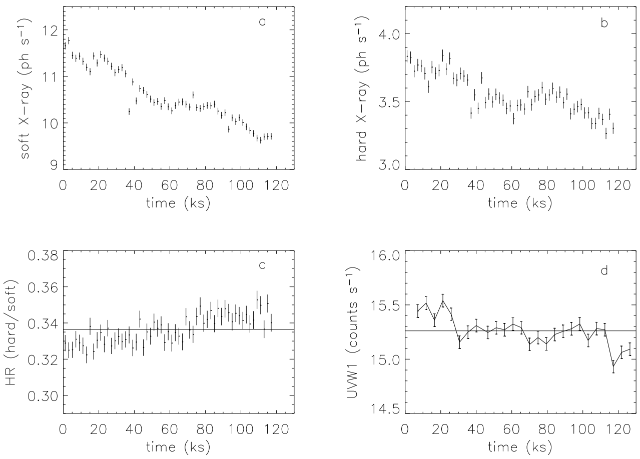

Figure 4: *XMM-Newton* EPIC pn and Optical Monitor, 2003 August 26–27 light curves. (a) Soft (0.3–2 keV) and (b) hard (2–10 keV) X-ray count rates decline. (c) The X-ray spectrum gradually hardens. (d) The UVW1 (2900 Å) flux falls by 2% over the same period. There is a strong correlation between UV and soft X-ray flux.

servations, which indicate a pivoting behavior for the hard X-ray spectrum (Halpern , 1985; Maraschi et al., 1991). The pivot energy is at $>$ 10 keV, outside the *XMM-Newton* bandpass. The drop in soft X-ray flux is accompanied by a strongly correlated drop in the Optical Monitor UVW1 (2900 Å) flux. This is the first time such a UV-X correlation has been demonstrated at the 10–100 ks timescale for this source. One explanation is that the X-rays are produced by Compton scattering of UV photons. Alternatively, the UV flux may be modulated by X-ray heating of an accretion disk. It will be necessary to take a longer observation to determine the sign of any lag between UV and X-rays and definitively distinguish between these models.

We monitored the radio variability from 2003–2004, to search for a X-ray/radio connection. 3C120 put on a spectacular show, with the 37 GHz radio flux doubling in a bright flare just 7 days after the *XMM-Newton* observation (Fig. 5). SEST observations show that the flare was already underway at 250 GHz at least 10 days before. The delay is likely caused by optically-thick synchrotron self-absorption at the lower frequency at early times. The short 17-day exponential rise time of the 37 GHz flare is unprecedented for this source, which typically takes 70 days (Teräsranta et al., 1998). The variability brightness temperature is T_b = 1.5×10^{12} K, indicating a Doppler factor of $D_{\rm var}$ = 3.1 (if the particles and magnetic field in the flaring region are in equipartition).

Monitoring with *RXTE* shows a strong X-ray dip 47 days prior to the *XMM-Newton* observation, which may herald the ejection of a new VLBI radio component (Marscher et al. 2004). However, this dip only lasted 2–4 days, after which 3C120 returned to a fairly typical X-ray spectral state. The flux level and hard X-ray spectral index of Γ = 1.8 are normal during the *XMM-Newton* observation. There is no indication that the ongoing radio flare has any effect on the optical or X-ray spectra. Apparently the X-ray emission region has already recovered from the event which precipitated the radio flare, and the radio flare only shows up after the radio emission region expands and becomes optically thin.

5 Conclusions

XMM-Newton observations of the radio galaxy 3C120 reveal narrow Fe Kα emission from the BLR or a molecular torus. There is no indication of any relativistic emission lines. The strong optical and X-ray emission lines exclude a large contribution to the continuum from the relativistic jet. There is a strong soft X-ray excess bump, which is described by a broken power-law model. This shape of this bump is not explained by thermal, Compton, or synchrotron emission models. However, the strength of the X-ray emission is

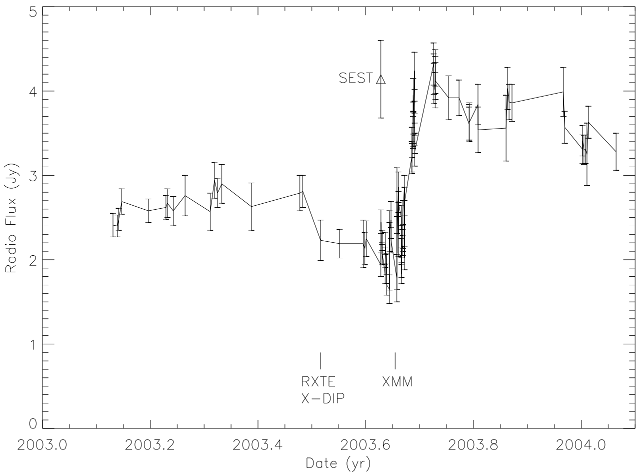

Figure 5: 37 GHz radio variability. The 120 ks *XMM-Newton* observation occurred 7 days before a bright radio flare, and after the onset of a flare at 250 GHz (1.8 mm). The radio flare was preceded by an X-ray dip observed with *RXTE* (Marscher 2004), which may have heralded the ejection of a new VLBI jet component.

strongly correlated with the UV. This is consistent with Comptonization of UV photons, but X-ray heating of an accretion disk can not be ruled out. It should be possible to determine a UV to X-ray lag with longer observations. A strong, fast radio flare occurred near the time of the *XMM-Newton* observation, but it doesn't appear to affect the optical to X-ray SED at that time. It will be important in the future to catch 3C120 during an X-ray dip, to more closely study the connection between the X-ray emission region and the ejection of VLBI radio components.

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