The X-ray spectrum of NGC 7213 and the Seyfert–LINER connection

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ABSTRACT

We present an XMM-Newton observation of the Seyfert-LINER galaxy NGC 7213. The RGS soft X-ray spectrum is well fitted with a power law plus soft X-ray collisionally ionised thermal plasma ($kT = 0.18^{+0.03}_{-0.01}$ keV). We confirm the presence of Fe I, XXV and XXVI K$\alpha$ emission in the EPIC spectrum and set tighter constraints on their equivalent widths of 82$^{+10}_{-13}$, 24$^{+9}_{-11}$ and 24$^{+10}_{-13}$ eV respectively. We compare the observed properties together with the inferred mass accretion rate of NGC 7213, to those of other Seyfert and LINER galaxies. We find that NGC 7213 has intermediate X-ray spectral properties lying between those of the weak AGN found in the LINER M81 and higher luminosity Seyfert galaxies. There appears to be a continuous sequence of X-ray properties from the Galactic Centre through LINER galaxies to Seyferts, likely determined by the amount of material available for accretion in the central regions.

Key words: X-rays: galaxies - galaxies: active - galaxies: Seyfert - galaxies: individual: NGC 7213

1 INTRODUCTION

Low ionisation nuclear emission line region (LINER) galaxies are characterised by optical emission line ratios which indicate a low level of ionisation [Heckman 1980]. The origin of these emission lines is still the subject of debate: the lines are attributed either to shock heating (Baldwin, Phillips & Terlevich 1981) or to photoionisation by a central AGN (Ferland & Netzer 1983; Halpern & Steiner 1983). For example, Dopita & Sutherland (1996) have shown that shock heating can produce the optical line ratios observed in LINER galaxies, with shock velocities of 150 - 500 km s$^{-1}$. Such shocks can originate from stellar processes (e.g. supernovae), and can also be produced as a result of a jet or a wind from an AGN. On the other hand, when the optical line ratios of LINERs were compared to those measured in Seyfert galaxies, Ferland & Netzer (1983) found that they could explain the lines in both types of object using the same photoionising AGN continuum shape, but with a systematic variation of ionisation parameter, from low values in LINERs to high values in Seyferts.

NGC 7213 is a nearby ($z = 0.005977$) S0 galaxy with AGN and LINER characteristics. It is clear that there is an AGN in this source, classified as a Seyfert 1 from its H$\alpha$ line width (full width at zero intensity $\sim 13000$ km s$^{-1}$, Phillips 1979). A variety of optical emission lines are observed in this galaxy with velocities ranging from 200 to 2000 km s$^{-1}$ FWHM (Filippenko & Halpern 1984, hereafter FH84). FH84 argue that photoionisation of clouds spanning a range of densities and velocities by a non-stellar continuum is likely to be the mechanism creating the optical line emission. By invoking high density rather than high temperature clouds, FH84 eliminate the need for shock heating.

Since its discovery as a low luminosity X-ray source (Marshall et al. 1978) NGC 7213 has been observed with several X-ray missions. The presence of a soft X-ray excess in NGC 7213 was implied by the results of an EXOSAT spectral survey of AGN [Turner & Pounds 1989] when the measured absorbing column for a single power law fit was found to be significantly lower than the Galactic value. In addition, the UV flux measured by Wu, Boggess & Gull (1983) was higher than would be expected from an extrapolation of the optical flux indicating that NGC 7213 may have a big blue bump (BBB), although weak compared to most Seyfert galaxies. The BBB is often interpreted as thermal emission from an accretion disc; if accretion discs are present in LINERs it is important to determine their properties if we are to understand the underlying emission mechanisms.

Turner & Pounds (1989) and Pounds et al. (1994) reported possible Fe K$\alpha$ emission in the X-ray spectrum ob-
served with EXOSAT and Ginga, but there was not sufficient resolution to unambiguously detect these features. Recently Bianchi et al. (2003) combined data from the pn camera on XMM-Newton with simultaneous data from the PDS instrument on BeppoSAX to investigate the iron line complex and reflection hump. They found that a neutral Fe Kα line is present, with excess emission at higher energies best explained as weak narrow emission lines from highly ionised iron. The data do not show the presence of a significant reflection hump, suggesting that the neutral Fe Kα line originates in Compton-thin material. They also suggest that the highly ionised Fe emission may arise in material photoionised by the AGN power law continuum.

Here we present an analysis of the high resolution RGS spectra, 0.3 - 2 keV EPIC spectra and OM photometry taken during the same XMM-Newton pointing. We revisited the iron line complex with an analysis of the combined pn and MOS1 spectrum in which it is possible to obtain better constraints on individual line features. Identifying the physical mechanisms producing the X-ray emission may provide some clues to the origin of the optical emission lines where at present neither shock heating nor photoionisation by the AGN can be ruled out. We also compare the X-ray spectral properties of NGC 7213 with those of the nearest LINER galaxy M 81, which has also been studied in detail using XMM-Newton (Page et al. 2003, 2004), and discuss the relationship between Seyfert galaxies and LINERs.

2 XMM-NEWTON OBSERVATION

NGC 7213 was observed on 2001 May 28/29 with XMM-Newton (Jansen et al. 2001) in the RGS Guaranteed Time Programme. The EPIC (Strüder et al. 2001; Turner et al. 2001) MOS1 and pn cameras were operated in small window mode with the medium filter. The EPIC MOS2 was in full frame mode (also medium filter) to image the entire galaxy. MOS2 will be omitted from the analysis due to pile-up, since the count rate was over three times higher than the recommended limit of 0.7 counts s⁻¹ for point sources (Ehle et al. 2003). The RGS instruments (den Herder et al. 2001) were in standard spectroscopy mode. The exposure times are 46448 s for MOS1, 42201 s for pn and 46716 s for each RGS instrument. No variability in flux was found during the observation so we produced a single spectrum from the entire observation for each X-ray instrument. The Optical Monitor was operated in imaging mode with optical and ultraviolet filters.

The RGS data were initially processed using the XMM-Newton SAS (Science Analysis Software) version 5.2. In each RGS, first and second orders were selected using pulse-height/dispersion regions containing 93 per cent of the pulse height distribution. Source+background spectra were taken from spatial regions containing 90 per cent of the point-spread function in the cross dispersion direction. Background spectra were obtained from regions excluding 95 per cent of the point-spread function. Response matrices were generated using the standard SAS rgsrmfgen task. The effective area of each response matrix was then divided by the ratio of a power law plus Galactic column fit to the XMM-Newton rev 0084 RGS spectra of the continuum source Mrk 421 to correct for the residual artifacts in the effective area calibration. After background subtraction, the individual first and second order spectra from RGS1 and RGS2 were resampled and coadded to produce a single spectrum, and the response matrices were combined accordingly.

The raw EPIC data were processed with the XMM-Newton SAS version 5.4. Spectra were constructed using single and double events in the pn and all valid event patterns (0-12) in MOS1. Source counts were taken from a circular region of radius 45″. In MOS1 a background spectrum was obtained from a nearby source-free region, 7 times larger in radius than the source extraction region. For the pn the background spectrum was taken from 3 separate circular regions totalling 5.76 times the area of the source circle. The MOS1 and pn spectra were then combined into a single spectrum with 45 eV bins using the method of Page, Davis & Salvi (2003) to improve the signal to noise. The March 2003 EPIC response files for small window were used with the resulting spectra.

The OM (Jansen et al. 2001) data were processed with XMM-Newton SAS version 5.4. For each of the three UV filters the sub-exposures were co-added and corrected for modulo-8 noise. The total exposure times amount to 4000 s, 7200 s and 8000 s for the UVW1, UVM2 and UVW2 filters respectively. Aperture photometry was performed using standard routines from IRAF. To minimise the contribution of the host galaxy a circular aperture of 4″ in diameter was used to measure the AGN flux, with a background determined from an annulus of inner diameter 5″ and outer diameter 7″. The resultant magnitudes were then corrected for the fraction of the point-spread function falling outside the aperture, deadtime, coincidence loss, and Galactic reddening (using the reddening law of Seaton 1979).

3 RESULTS

Spectral analyses of the data were performed using the XSPEC v11.2 X-ray spectral fitting package, using the χ² minimization technique. The Galactic column value used throughout is N_H = 2.04 × 10²⁰ cm⁻² (Dickey & Lockman 1990), and all line energies are quoted in the rest frame of the source.

3.1 RGS

The RGS spectrum of NGC 7213 is shown in Fig. 1. The spectrum is dominated by continuum emission, but shows emission lines, particularly from O VII and O VIII; the most important of these are detailed in Table 2. No significant absorption lines nor broad absorption features such as unresolved transition arrays (UTAs, Behar, Sako & Kahn 2001) in the RGS Guaran-
law and 3 emission lines, with energies fixed to the energies of the O VII triplet at the galaxies’ redshift. The best fit is shown in the top panel of Fig. 2 and the bottom panel of the O VII triplet at the galaxies’ redshift. The best fit

Table 1. Model fits to the RGS spectrum, with power law normalisations given in photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$ at 1 keV, $kT$ in keV, and MEKAL normalisations (= $\int n_e n_H dV$) given in units of $10^{22}$ cm$^{-3}$. The Galactic column is included in the fits and all errors are quoted at the 90 per cent confidence level for 1 interesting parameter.

| Model       | $\Gamma$ | PL norm/10$^{-3}$ | $kT$ | MEKAL norm/10$^{-3}$ | $\chi^2/\nu$ |
|-------------|----------|------------------|------|----------------------|---------------|
| PL          | 1.77$^{+0.02}_{-0.02}$ | 5.88$^{+0.06}_{-0.06}$ | -   | -                    | 586/498       |
| PL+MEKAL    | 1.76$^{+0.02}_{-0.02}$ | 5.85$^{+0.06}_{-0.06}$ | 0.18$^{+0.03}_{-0.01}$ | 6.7$^{+2.7}_{-2.4}$ | 554/496       |
| PL+2xMEKAL  | 1.76$^{+0.02}_{-0.02}$ | 5.80$^{+0.06}_{-0.06}$ | 0.18$^{+0.02}_{-0.03}$ | 0.56$^{+0.16}_{-0.22}$ | 6.7$^{+2.7}_{-2.4}$ | 3.1$^{+1.6}_{-1.9}$ | 546/494       |

To model the RGS spectrum we began with a power law modified by the Galactic absorption. The results for this and all the RGS spectral fits are given in Table 1. The best fitting photon index is $\Gamma = 1.77 \pm 0.02$. However $\chi^2/\nu$ is not good, and the model can be rejected at $> 99.5$ per cent confidence. To improve the fit we add a MEKAL thermal plasma component, and obtain an acceptable fit with a best fit thermal plasma temperature of $kT = 0.18^{+0.02}_{-0.01}$ keV. The model and data are shown in Fig. 1. Addition of a second thermal plasma component improves the fit only slightly ($\Delta \chi^2 = 8$ for 2 extra parameters) with a best fit temperatur of $kT = 0.56^{+0.16}_{-0.22}$ keV for the extra component. The O VII lines are reproduced well by the 0.18 keV thermal plasma component, but there appears to be some emission adjacent to O VIII Ly$\alpha$ in excess of the model (either 1- or 2-temperature plasma) prediction. This might indicate that the higher temperature component is physically extended, a component of the host galaxy bulge rather than of the active nucleus; alternatively, the emission could be broadened by doppler motions if it originates within the broad line region of nucleus. Unfortunately, further investigation of the O VIII emission line profile is precluded by the relatively low signal to noise ratio of the RGS spectrum. We have also tried adding a blackbody soft excess component to the model. This does not significantly improve the fit ($\Delta \chi^2$.

Figure 1. The RGS spectrum of NGC 7213 in the source rest frame with best fitting model (grey line). The positions of prominent emission lines are marked as well as the O I K edge from the Galactic interstellar medium.

Table 2. Important emission lines in the RGS spectrum. Flux is given in photon cm$^{-2}$ s$^{-1}$.

| $\lambda$ (Å) | ion    | Significance ($\sigma$) | EW (mÅ) | Flux /10$^{-6}$ |
|-------------|--------|------------------------|--------|-----------------|
| 16.77$^{+0.10}_{-0.11}$ | Fe XVII | 1.7 | 18$^{+16}_{-16}$ | 8$^{+7}_{-7}$ |
| 17.06$^{+0.12}_{-0.08}$ | Fe XVII | 1.5 | 20$^{+20}_{-20}$ | 9$^{+9}_{-9}$ |
| 19.03$^{+0.20}_{-0.27}$ | O VIII | 2.4 | 47$^{+47}_{-47}$ | 21$^{+8}_{-8}$ |
| 21.59$^{+0.05}_{-0.05}$ | O VII | 2.7 | 57$^{+57}_{-57}$ | 25$^{+14}_{-14}$ |
| 22.05$^{+0.06}_{-0.06}$ | O VII | 2.6 | 59$^{+59}_{-59}$ | 25$^{+15}_{-15}$ |
| 33.56$^{+0.39}_{-0.16}$ | C VI | 1.5 | 37$^{+37}_{-37}$ | 14$^{+14}_{-14}$ |
data, the fit is still not acceptable (90 per cent confidence limits given by the fit to the RGS the slope and normalisation of the power law to their upper
model, with a data:model ratio of up to 1.3. If we fix the continuum slope seen in EPIC is steeper than that of 
G\text{plasma}, while a photoionised plasma should lie to the left of the 
G line. Figure 2. Top panel: close up of the He-like O VII triplet in the 
RGS spectrum with best fitting power law plus 3-Gaussian model.
Bottom panel: confidence interval on the strength of the forbbidden 
and intercombination lines (x+y+z) against the resonance line (w). The solid, dashed and dotted contours correspond to 68, 90 
and 95 per cent respectively for two interesting parameters. The 
(w). The solid, dashed and dotted contours correspond to 68, 90 
and intercombination lines (x+y+z) against the resonance l ine

\begin{table}
\centering
\begin{tabular}{ll}
\hline
\textbf{\(\Gamma\)} & 1.73_{-0.01}^{+0.01} \\
\textbf{\text{norm}} & 5.65_{-0.10}^{+0.10} \times 10^{-3} \\
\textbf{\(E_1\)} & 6.41_{-0.02}^{+0.01} \\
\textbf{\(E_2\)} & 82_{-13}^{+10} \\
\textbf{\(E_3\)} & 6.66_{-0.05}^{+0.05} \\
\textbf{\(EW_1\)} & 24_{-9}^{+9} \\
\textbf{\(EW_2\)} & 6.98_{-0.07}^{+0.07} \\
\textbf{\(EW_3\)} & 24_{-13}^{+10} \\
\textbf{\(\chi^2/\nu\)} & 212/169 \\
\hline
\end{tabular}
\caption{Best fitting model to the 2 - 10 keV combined MOS1 and pn spectrum. The Galactic column is included in all fits. All energies are given in the source restframe (\(z = 0.005977\): E in keV and EW in eV. The power law normalisation is given in photons cm\(^{-2}\) s\(^{-1}\). Errors are quoted at the 90 per cent confidence level for 1 interesting parameter.}
\end{table}

the power law slope must still be increased to 1.950±0.006 and normalisation to 6.56±0.02 \times 10^{-3} photons cm\(^{-2}\) s\(^{-1}\) to obtain an acceptable fit to the 0.3 - 2 keV EPIC spectrum with \(\chi^2/\nu = 60/35\). Since the very low energies are less well calibrated for the EPIC cameras, we restrict the range to 0.5 - 2 keV. The continuum in this range can be adequately modelled by a single power law plus Galactic absorption (\(\chi^2/\nu = 345/208\)). It is also well fitted with a blackbody model (\(\chi^2/\nu = 305/208\)), but trying instead a multi-colour accretion disk (diskbb) model we find the parameters of this model cannot be constrained. However, we cannot draw strong conclusions from this result since cross calibration of the three instruments is not accurately known. The MOS/pn cross correlation agrees to within 10 per cent from energies of 0.4 keV upwards and EPIC and RGS appear to agree in normalisation to ±20 per cent, with the EPIC having a significantly steeper slope than the RGS in individual fits (Kirsch 2003). So the soft X-ray spectrum of this AGN shows some curvature, steepening towards lower energies. The soft-excess component noted by Bianchi et al. (2003) is a combination of this power-law-like excess and the MEKAL component. The existence of true soft-excess emission is, however, uncertain since the ~14 per cent soft flux increase could be accounted for by uncertainties in the cross calibration of the EPIC and RGS instruments.

3.3 The EPIC medium energy X-ray spectrum

A power law plus Galactic absorption is clearly a poor fit to the 2 - 10 keV EPIC data. The residuals in the pn data between 6 and 7 keV were corrected by Bianchi et al. (2003) with the inclusion of three emission lines, corresponding to Fe I, Fe XXV and Fe XXVI Ka. The availability of a simultaneous BeppoSAX PDS observation allowed these authors to rule out the presence of a significant Compton reflection component. Combination of the EPIC pn and MOS1 data provides better statistics than pn alone, allowing us to put tighter constraints on the parameters of spectral features. We fit a power law with Galactic absorption, plus 3 Gaussian lines of fixed narrow width (\(\sigma = 0.001\) eV) to the 2 - 10 keV combined pn-MOS1 spectrum. The best fit (\(\chi^2/\nu = 212/169\)) has a power law photon index of \(\Gamma = 1.73 \pm 0.01\), consistent with that found in the RGS soft X-ray data. The centroid energies of the emission lines in the fit to the com-

= 6 for 2 extra parameters), and the 3\(\sigma\) upper limit to the contribution of a blackbody component is 11 per cent of the 0.3-2 keV flux.

3.2 The EPIC soft X-ray spectrum

Having found that a power law plus MEKAL component is a good fit to the RGS data, we began by fitting the same model to the 0.3 - 2 keV combined EPIC pn-MOS1 spectrum. This gives \(\chi^2/\nu = 8865/33\). The fit is poor because the continuum slope seen in EPIC is steeper than that of the model, with a data:model ratio of up to 1.3. If we fix the slope and normalisation of the power law to their upper 90 per cent confidence limits given by the fit to the RGS data, the fit is still not acceptable (\(\chi^2/\nu = 7349/33\)). Keeping the single MEKAL component as fitted to the RGS data,
combined EPIC data are indeed consistent with iron fluorescence in low ionisation material, Fe XXV and Fe XXVI. These lines are well constrained and the results of the fit are given in Table 3.

4 DISCUSSION

4.1 Comparison with the Seyferts

The 2 - 10 keV spectrum of NGC 7213 resembles a typical Seyfert galaxy, which is dominated by a $\Gamma \sim 1.7$ power law and a 6.4 keV Fe Kα emission line. The 6.4 keV line in NGC 7213 is narrow (FWHM < 6820 km s$^{-1}$ at the 90 per cent confidence level), so it cannot originate in the inner parts of an accretion disc. Bianchi et al. (2003) concluded that, given the apparent absence of a reflection component in the BeppoSAX data, the neutral Fe Kα emission must arise from Compton-thin material out of our line-of-sight, either in the form of a torus with a column density of $N_H \sim 2 \times 10^{23}$ cm$^{-2}$ or the broad line region. The resolution of the EPIC cameras does not allow the two to be distinguished. The 2 - 10 keV spectrum of NGC 7213 differs from that typically observed in Seyfert 1s in that it contains significant emission lines from Fe XXV and Fe XXVI. These lines are not normally observed in the classical luminous Seyfert galaxies (e.g. NGC 3783, Kaspi et al. 2002; NGC 5548, Pounds et al. 2003; NGC 7469, Blustin et al. 2003), though they have been observed in some cases (e.g. NGC 5506, Bianchi et al. 2004). In contrast, these lines appear to dominate the Fe Kα emission in the nearby LINER M 81 (Page et al. 2004). The origin of the Fe XXV and Fe XXVI lines in M 81 is unclear (see Page et al. 2004 for a discussion), and this is also true for NGC 7213. They may be produced by photoionisation of Compton-thin material by the nuclear X-ray source (Bianchi et al. 2004), or may be collisionally ionised like the soft X-ray thermal plasma. Future observations of the Fe K region at higher spectral resolution, for example with the forthcoming Astro-E2 mission, might answer this question by allowing the application of line diagnostics to the Fe XXV triplet.

In the soft X-ray regime, NGC 7213 departs further from a Seyfert-like spectrum. The ionised gas which is seen in the soft X-ray spectra of Seyfert galaxies is usually found to be photoionised, whether it is seen in absorption or in emission (e.g. IRAS 13349+2438, Sako et al. 2001; NGC 3783, Kaspi et al. 2002; NGC 1068, Kinkhabwala et al. 2002). However, in the RGS spectrum of NGC 7213 we do not find any evidence for photoionised absorption, and the emission lines are collisionally ionised rather than photoionised (Fig. 2). Amongst AGN, collisionally ionised thermal plasma at soft X-ray temperatures, as observed in NGC 2371, may be a property specific to LINERs. In a study of 21 LINERs observed with ASCA, most were found to be well fitted with a hard X-ray power law ($\Gamma \sim 1.8$) plus a soft X-ray thermal plasma component with $kT < 1$ keV (Terashima et al. 2002). While this provides strong evidence for the presence of a soft X-ray emission line component in LINERs, the resolution of ASCA was not good enough to permit diagnostics which could distinguish between collisionally ionised and photoionised plasma. However, the very nearby LINER galaxy M 81, for which there is a long-duration RGS spectrum, does contain a significant component of soft X-ray collisionally-ionised thermal plasma (Page et al. 2003).

The XMM-Newton spectrum of NGC 7213 also deviates from that of a typical Seyfert in that it has little or no blackbody-like soft X-ray excess emission. This component is found in the X-ray spectra of most Seyferts (Pounds & Reeves 2002; Turner & Pounds 1989), the strongest being seen in the Narrow-line Seyfert 1 galaxies (NLS1s). The origin of the soft X-ray excess is unknown, but is often interpreted as the high energy tail of the thermal emission from an optically thick accretion disc (Turner & Pounds 1989), particularly in NLS1s (e.g. RE 1034+39, Pounds, Done & Osborne 1995).

4.2 Evidence for an accretion disc

Many Seyfert galaxies show strong evidence in X-rays for an accretion disc surrounding the black hole. The main indicators are a soft-excess, reflection, and broad Fe Kα line emission, all of which come from the inner parts of the accretion disc. None of these indicators are present in the XMM-Newton spectra of NGC 7213.

The UV bump in NGC 7213 is either absent or extremely weak compared to other Seyferts (Wu, Boggess & Gull 1983). The optical continuum emission of NGC 7213 comprises both non thermal emission from the AGN and stellar radiation (HF84). A decomposition of the spectrum, assuming a power law for the AGN contribution following $F_{\nu} \propto \nu^{-1.1}$, shows that more than 50 per cent of the total continuum emission at 3300 Å can be non-stellar. The actual flux level is uncertain by ±30 per cent and also depends on the visual extinction adopted. HF84 argue that the optical extinction is much higher than the Galactic value. However the XMM-Newton data show no evidence for any intrinsic absorption of the X-ray flux. Therefore we have adopted the AGN power law component...
of the optical spectrum, deconvolved from the stellar contribution by HF84, and assumed only Galactic absorption (A_V = 0.05). The nuclear spectral energy distribution of NGC 7213 is shown in Fig. 2. The ultraviolet data from the OM are in good agreement with an extrapolation of the optical power law to shorter wavelengths. There is no evidence for an optical/UV bump and consequently the AGN bolometric luminosity does not appear to be dominated by emission from an optically thick, geometrically thin accretion disc.

Assuming that NGC 7213 does contain an accretion disc, there are two possible explanations for the lack of UV emission. Either the disc does not extend close enough to the black hole to emit significantly in the optical/ultraviolet, or the disc extends close to the black hole but has such a low mass transfer rate that it contributes little to the overall emission.

Starting with the truncated inner-disc explanation, it is known that at low accretion rates, stable accretion flows can exist in which the inner part of the disc takes the form of an optically-thin, tenuous, hot corona. Because the inner, hot corona is a much less efficient radiator than a thin disc, much of the energy may be advected into the black hole rather than being radiated. This is known generally as an advection-dominated accretion flow (ADAF, Narayan & Yi 1995), and several derivatives of this model have since been developed to include, for example, more realistic geometries (e.g. CDAF model, Narayan, Igumenschev & Abramowicz 2000) and/or outflows (e.g. ADIOS model, Blandford & Begelman 1999), all of which require a truncated disc. A truncated inner disc plus ADAF is the configuration proposed to explain the spectra of black hole X-ray binaries (Esin et al. 1989; Esin, McClintock & Narayan 1997; Narayan, Garcia & McClintock 1997). The quiescent phase of the soft X-ray transients V404 Cyg and A0620-00 can be explained with the ADAF model, where the inner radius of the accretion disc lies at \( \sim 10^4 \) Schwarzschild radii (Narayan, Barret & McClintock 1997). To explain optical and UV observations of M81, Quataert et al. (1999) invoke an ADAF within the truncation radius of the disc. An ADAF model has also been successfully applied to describe the multiband emission from the Galactic Centre (Narayan et al. 1998). In ADAF-type models the soft X-ray and UV signatures of thermal disc emission are weak or absent because the geometrically thin, optically thick part of the disc does not extend close enough to the black hole. However, such accretion flows are also expected to produce outflows not yet observed in NGC 7213.

An alternative to a truncated disc is a disc which extends to the inner regions but which is in a ‘low state’; this can also account for the weak or absent disc emission from NGC 7213. Thermal-viscous ionisation instabilities, which can develop in a partial ionisation zone of an AGN accretion disc, can cause the disc to oscillate between high (bright) states and low (faint) states (Siemiginowska, Czerny & Kostyunin 1996). The disc spends most of the time in the low state with low luminosity, peaking in the IR and emitting negligible optical and UV radiation. This is analogous to the accretion disc instability which drives the dwarf nova outbursts in cataclysmic variables (Meyer & Meyer-Hofmeister 1984). However, although a low-state disc can account for the lack of primary disc emission, it ought to constitute an X-ray reflector subtending a substantial solid angle to the X-ray source.

4.3 Accretion rate

Both the ADAF and the ‘low-state’ disc models imply a significantly sub-Eddington accretion rate (e.g. a few percent of the Eddington rate or less for the ADAF model, Narayan & Yi 1995). To investigate the accretion rate in NGC 7213 we have estimated the bolometric luminosity of the active nucleus by integrating the radio to X-ray spectral energy distribution. For this we have used the radio measurements from Sadler (1984), the power law component in the optical, deconvolved from the stellar contribution by Halpern & Filippenko (1984), the UV flux measurements from the XMM-Newton OM and the XMM-Newton X-ray power law continuum. The bolometric luminosity thus obtained is \( 9 \times 10^{42} \) erg s\(^{-1}\). Previous estimates of the bolometric luminosity are significantly higher than our determination: \( L_{\text{bol}} = 10^{43.4} \) erg s\(^{-1}\) (Woo & Urry 2002) and \( L_{\text{bol}} = 10^{44.1} \) erg s\(^{-1}\) (Padovani & Rafanelli 1988). However, these values include the host galaxy as well as the AGN, so will overestimate the AGN luminosity by a considerable amount. The black hole mass has been estimated from the stellar velocity dispersion by Nelson & Whittle (1995), who obtained \( M_{\text{BH}} = 10^6 M_\odot \). Such a high black hole mass is consistent with the observed lack of significant X-ray variability during the 46 ks XMM-Newton observation. Combining the bolometric luminosity and mass estimates we find that the luminosity of NGC 7213 is approximately \( 7 \times 10^{-4} L_{\text{Edd}} \). Generally, Seyfert luminosities lie in the range 0.001-1 \( L_{\text{Edd}} \) (Wandel 1999). Padovani & Rafanelli (1988) found an average luminosity of \( \sim 0.2 L_{\text{Edd}} \) for the 34 local Seyfert 1 galaxies within their sample of AGN, although a much lower luminosity of \( \sim 0.005 L_{\text{Edd}} \) is inferred for local type 1 Seyfert galaxies from studies of their X-ray luminosity function (Page 2001). In any case, our luminosity estimate for NGC 7213 lies at or below the low end of the distribution of Seyfert luminosities. M81, the nearest known LINER, radiates at \( 4.2 \times 10^{-4} \) times its Eddington rate (Ho 1999), and a rate of \( 10^{-4} L_{\text{Edd}} \) was determined for the LINER NGC 4203 (Shields et al. 2001). The low luminosity AGN which are found in LINER galaxies may be typified by lower accretion rates than Seyferts, assuming approximately the same efficiency of mass accretion.

4.4 Comparison with M81: the Seyfert–LINER connection

An interesting comparison can be made between the X-ray spectra of NGC 7213 and M81; since M81 is the nearest LINER galaxy and has been studied in detail using XMM-Newton (Page et al. 2003; Page et al. 2004). The broad-band X-ray spectra of these two galaxies, at first glance, look remarkably similar, but whilst the continua are comparable we find substantial differences in the emission line parameters. The soft X-ray emission lines are less prominent in NGC 7213 than in M81, and the emission from collisionally ionised thermal plasma components in NGC 7213 comprises a much smaller fraction of the total 0.3-10 keV flux than in M81 (0.3 per cent, compared with 8.7 per cent in...
M81). Emission lines arising in collisionally ionised plasma are not normally observed in Seyfert galaxies. On the other hand the Fe I Kα line at 6.4 keV is commonly found in Seyferts (Nandra et al. 1997), and the equivalent width of this line is about twice as large in NGC 7213 as it is in M81. Therefore, although NGC 7213 contains the soft X-ray emission lines and Fe Kα lines of Fe XXV and Fe XXVI that are not normally observed in Seyfert galaxies but are seen in the LINER galaxy M81, the relative weakness of these lines and the strength of Fe I Kα in NGC 7213 make the X-ray spectrum of NGC 7213 much more Seyfert-like than that of M81. Therefore NGC 7213 appears to bridge the gap between ‘normal’ Seyfert galaxies and LINER galaxies such as M81.

It is likely then, that there is a continuous distribution of galaxy nuclei between the LINERs and ‘normal’ Seyfert nuclei, over which the X-ray spectral features characteristic of Seyferts such as the neutral Fe Kα line, become successively more prominent, while the features characteristic of LINERs such as soft X-ray emission lines diminish in significance. Accretion rate onto the black hole with respect to the Eddington rate is likely to be the overriding factor, with LINER galaxies accreting at much lower rates than Seyfert galaxies (Ho, Filippenko & Sargent 2003) and containing truncated discs. In fact, if we look at the observational properties of the Galactic Centre we find that it may also fit into this continuous distribution, at the opposite end of the scale to the Seyferts. The Galactic Centre contains a low-mass black hole with an extremely low accretion rate ($1.8 \times 10^{-6} \leq \dot{M}/\dot{M}_{\text{Edd}} \leq 1.5 \times 10^{-3}$, Falcke & Biermann 1999; Quataert, Narayan & Reid 1999) and with a luminosity of $L_{\text{Edd}}$. The emission from this region comes predominantly from thermal plasmas with strong soft X-ray emission (Baganoff et al. 2003). At higher energies Fe Kα emission is observed (Tanaka et al. 2000), the strongest line being at 6.7 keV. Therefore, the Galactic Centre begins the sequence: its characteristics being a very low $L/L_{\text{Edd}}$ ratio, dominance of thermal plasma emission and strong, highly ionised iron emission.

5 CONCLUSIONS

We present an XMM-Newton observation of the LINER galaxy NGC 7213 with the EPIC and RGS X-ray instruments and UV photometry with the OM. The X-ray spectrum is typical of a Seyfert galaxy, although with a much lower luminosity ($L_{\text{Edd}} = 1.7 \times 10^{42}$ erg s$^{-1}$). A collisionally ionised thermal plasma of temperature 0.18$^{+0.03}_{-0.01}$ keV is required in the RGS soft X-ray region where several low ionisation emission lines are detected, and we find no evidence for a significant blackbody-like soft-excess component. We suggest that this low ionisation thermal plasma may be a LINER characteristic. We constrain the equivalent widths of Fe I, XXV and XXVI Kα emission lines to $82^{+10}_{-13}$, $24^{+9}_{-11}$ and $24^{+10}_{-13}$ eV respectively.

The nuclear radiation at X-ray wavelengths in NGC 7213 is substantially more Seyfert-like than the AGN component in the nearby LINER galaxy M81, meaning NGC 7213 has the properties of a galaxy somewhere in between a typical Seyfert and a LINER galaxy. This supports the notion of continuity between the LINER and Seyfert classes, dictated by the luminosity of the central AGN and its accretion rate, both increasing from LINERs to Seyferts. In turn, the mass accretion rates depend critically on the amount of material present in the central regions surrounding the AGN. This continuous distribution can be extended to include the Galactic Centre, which shares some properties with LINER galaxies.

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