XMM-Newton SPECTROSCOPY OF THE SEYFERT 1.9 / NEL GALAXY NGC 7314

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Preliminary analysis of an *XMM-Newton* observation of NGC 7314 shows that rapid variability in the 0.2−12 keV flux of this object is not associated with spectral changes. A significant amount of warm absorption is required to explain the complexity of the X-ray spectrum at low energies. The continuum and Fe Kα line emission are best explained by a power law spectrum with reflection and fluorescence in cold gas at some distance from the active nucleus, far out in the accretion disk or in a molecular torus.

1. Introduction

The Seyfert 1.9 / Narrow Emission Line galaxy NGC 7314 (z=0.00474), a member of the HEAO-1/A2 Piccinotti sample of AGN [1], was first seen to exhibit dramatic X-ray flux variability (on timescales as short as 2000 s) during EXOSAT ME observations [2]. Detailed analysis of its ASCA spectrum [3] [4] showed that the continuum could be best fitted by two power laws ($\Gamma \sim 2$ and 4), one absorbed by a neutral column $N_{\rm H} \sim 9 \times 10^{21}$ cm^{-2} and the other by the Galactic column (4.5×10^{20} cm^{-2} [5]) respectively. The inclusion of two neutral Fe Kα line emission components, one broad and one narrow, and of a Fe edge at 7.67 keV, was required to model the 5−8 keV data. While the gross spectral shape remained steady over the ASCA observation, rapid changes in the profile of the Fe line were observed, indicating that the line broadening was due to Doppler and gravitational effects in an accretion disk [6]: however, the variability below ∼6 keV was stronger than that in the narrow core of the line near 6.4 keV, suggesting that the latter may originate in distant, cold matter, such as a molecular torus, rather than in an accretion disk.

2. Observation and data analysis

NGC 7314 was observed by *XMM-Newton* in May 2001 for a total of about 45 ks. The EPIC-pn camera was operated in Small Window mode, the MOS cameras in Full Frame mode, the two RGS chains in Spectroscopy mode, and the OM in Imaging mode with the ultraviolet filter UVW2. In this paper we report only the analysis of the EPIC-pn and RGS data, which was carried out under SAS V5.3.3. A future publication [7] will report on the complete *XMM-Newton* dataset.

EPIC-pn lightcurves and spectra were extracted using the `xmmselect` task, with source regions of 41 arcsec radius in order to avoid the extraction regions extending off the edge of the data window. Background lightcurves and spectra were produced using the same size region as for the target, but positioned in an area empty of X-ray sources. The RGS spectra were extracted with `rgsproc` using standard settings for the size of the source and background regions. The latter were chosen to be adjacent to those containing the source in the spatial domain and coincident with those of the source in the spectral domain.

The lightcurves were analysed with IDL and the spectra with XSPEC v. 11.2.0.

3. Rapid variability of the X-ray flux

Figure 1 shows X-ray lightcurves of NGC 7314 in three different EPIC-pn energy bands (0.2−2, 2−6 and 6−12 keV, 200 s bins). The total 0.1−12 keV EPIC-pn flux is about 7 counts s^{-1} on average, and appears to be very variable, with several flares typically lasting from 2000 to 6000 s. The pattern of the variability is very similar in

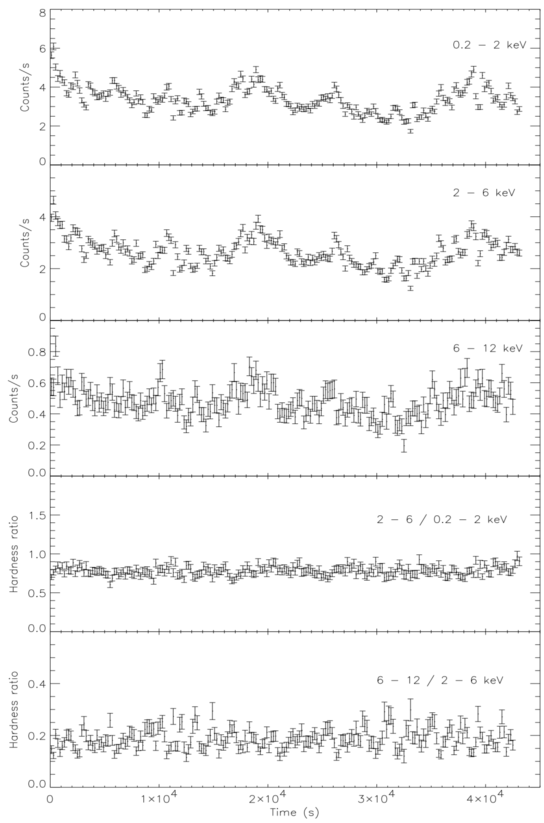

Figure 1. Top 3 panels: Background-subtracted EPIC-pn lightcurves in the bands 0.2−2, 2−6 and 6−12 keV, in 200 s time bins; bottom 2 panels, the hardness ratios (2−6 keV / 0.2−2 keV flux) and (6−12 keV / 2−6 keV flux) in 200 s time bins.

the three X-ray bands, with changes in flux by up to a factor of two in a few thousand seconds. At the bottom of Figure 1 are plots of the EPIC-pn 2−6 keV / 0.2−2 keV and 6−12 keV / 2−6 keV hardness ratios: they are consistent with being constant, implying that the variability observed is energy independent.

Episodes of very rapid variability are also seen in the EPIC-pn lightcurves of Figure 1: the most remarkable change occurs at ∼39,000 s into the observation, when the 0.2−2 keV flux drops from 5 to 3 counts s^{-1} (a 40% change) over 600 s, and then recovers to approximately the original level in the next 600 s. The observed flux doubling time of 4000 s (between 1.5 and 1.9 $\times 10^4$ s from the beginning of the observation) and the average 2−10 keV luminosity of 4 $\times 10^{42}$ erg s^{-1} (see section 5 below) are in good agreement with the correlation established for a sample of Seyfert galaxies and quasars and interpreted as evidence that the emitting plasma is close to being dominated by electron-positron pairs [8].

4. Fits to the continuum and Fe Kα line

We first fitted the integrated 0.3−12 keV EPIC-pn spectrum with a single power law and two neutral absorption components, one fixed at the Galactic value ($N_{\rm Gal} = 1.45 \times 10^{20}$ cm^{-2} [5]) and one, free to vary, local to NGC 7314; we also included a gaussian line to model the Fe emission around 6 keV. The fit is poor, with large positive residuals below 1 keV (χ^2_ν = 1.65 for 1137 d.o.f.). Replacing the cold with a warm absorber local to NGC 7314 (XSPEC model `absori`) produces a much better fit (χ^2_ν = 1.19 for 1134 d.o.f.): The power law has photon index Γ = 1.96 ± 0.01, the absorber is only mildly ionised (kT ∼ 1 eV) with an equivalent Hydrogen column of 6.1 $\times 10^{21}$ cm^{-2}; the centroid (6.49 ± 0.06 keV in the NGC 7314 rest frame) of the broad Fe line (FWHM = 805 $^{+181}_{-101}$ eV; EW = 168 $^{+17}_{-28}$ eV) corresponds to emission by Fe XX, indicating fluorescence in ionised gas, and would suggest an origin in the accretion disk. A fit of similar quality (χ^2_ν = 1.20 for 1131 d.o.f.) is obtained substituting the gaussian with a `laor` model component, which assumes the Fe line is originating in a disk where general relativity effects are important. However, in this case the broad Fe line is centred at ∼ 6.4 keV in the galaxy rest frame, i.e. consistent with neutral iron (as in the ASCA observations [6]).

The formal best fit (χ^2_ν = 1.17 for 1130 d.o.f.) is found introducing a cold reflection component (XSPEC model `pexrav`) in NGC 7314, in addition to the power law, Galactic absorption, warm absorber and gaussian line. In this case the power law slope is slightly steeper (Γ = 2.04), the warm absorber properties are essentially unchanged, the rest energy of the Fe line (6.39 ± 0.04 keV) is coincident with that expected from neutral gas, and the line is relatively narrow (FWHM = 203 eV) with a small equivalent width (45 $^{+12}_{-17}$ eV). The broad Fe line of the previous models is replaced by a narrow one and an Fe K-edge at 7.1 keV (see top panel of Figure 2). A small contri-

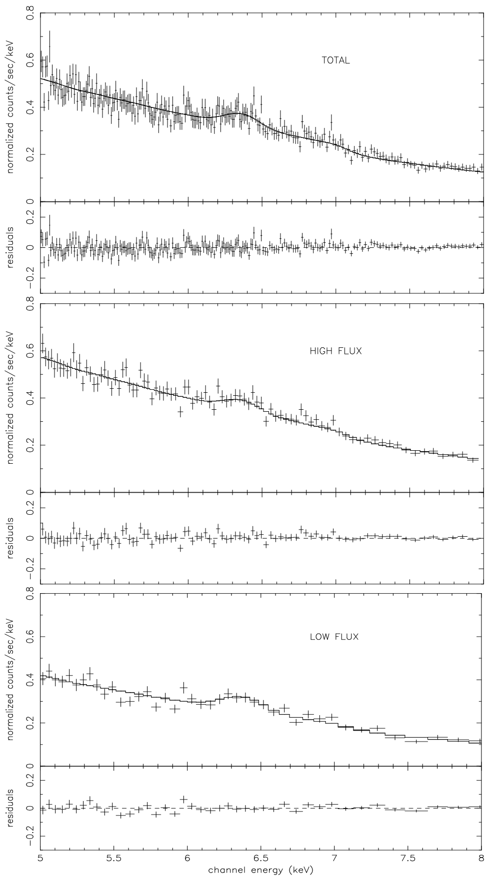

Figure 2. Top: EPIC-pn total spectrum of NGC 7314 in the region of the Fe Kα line, showing data and model, including a reflection component; Middle: Same as top, for high flux data; Bottom: Same as top, for low flux data.

bution from Fe Kβ line emission (at $\sim$ 14% of the flux in Fe Kα) can be expected at 7.06 keV. Including this makes no significant change to the overall fit, nor to the χ^2 value. Figure 3 shows the 0.3$-$12 keV EPIC-pn spectrum of NGC 7314, the best fit reflection model with no warm absorber nor Fe line components included, and the ratio of the data to this model (to emphasize the effects of the warm absorption and the Fe line emission).

Potentially the details of the soft X-ray spectrum of NGC 7314 could be better studied with the higher resolving power of the *XMM-Newton* RGS. Unfortunately, the large absorbing column in this object is most effective in the RGS band, and this results in a spectrum of low statistical

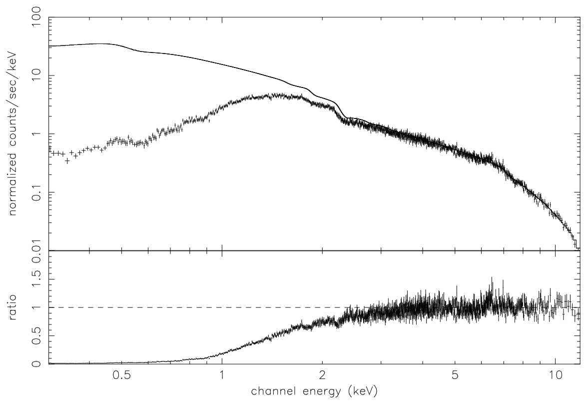

Figure 3. Top: EPIC-pn 0.3$-$12 keV spectrum of NGC 7314, with the best fit reflection model, but excluding the warm absorber and Fe line emission components; Bottom: Ratio of the data to the model

quality, where no features are distinguishable. A simultaneous fit of the EPIC-pn and RGS spectra is completely consistent with the best fit parameters of the EPIC-pn fit alone.

In order to compare the behaviour of the Fe line in the high and low states of the lightcurve separately, we accumulated spectra for the times when the 0.3$-$12 keV EPIC-pn flux was above and below 6 counts s^{-1} respectively; to improve the signal-to-noise ratio, the spectra were binned so that they contained at least 200 counts per spectral channel. We fitted these data with the same models as for the integrated spectrum. The best fit parameters of the continuum, the warm absorber and the Fe Kα line are very similar in all models for the total and the high and low flux spectra, and are consistent within the errors quoted. The only exception is the equivalent width of the Fe line, which shows some evidence of being larger in the low flux spectrum (87 $^{+32}_{-35}$ eV) than in the high flux one (36 $^{+26}_{-7}$ eV).

Figure 2 shows the EPIC-pn data in the region of the Fe line for the three spectra, and the best fit model, including the reflection and gaussian components. Clearly there is no significant change in the Fe line profile with flux level.

5. Discussion

Our *XMM-Newton* spectra of NGC 7314 are best reproduced by a model including a power law continuum, cold reflection, and absorption by mildly ionised gas at low energies. We also detect a narrow, gaussian shaped Fe Kα emission line originating in cold, neutral material. However, this fit ($\chi^2_\nu = 1.17$ for 1130 d.o.f.) is not formally much worse than one with a broad Fe line and no reflection ($\chi^2_\nu = 1.19$ for 1134 d.o.f.).

The average un-absorbed 2−10 keV luminosity of 4.1 $\times 10^{42}$ erg s^{-1} at source is consistent with previous measurements [3] [6] (we take $H_{\rm o} = 50$ km s^{-1} Mpc^{-1} and $q_{\rm o} = 0$). Unlike at the epoch of the ASCA observations (6.5 years previous to those with *XMM-Newton* [6]), we do not detect significant changes in the Fe line profile at high and low flux levels. Regarding the shape of the continuum, our single power law with cold reflection best fit formally is not dissimilar from the two power law parametrisation used for the ASCA data. We would argue, though, that the *XMM-Newton* data, covering a wider energy range with better sensitivity than ASCA, allow us to determine the spectral continuum shape more precisely: so we are able to disentangle the different spectral components in NGC 7314 (in particular around the energy of the Fe line) more clearly, defining a more physically consistent scenario, which provides more insights in the nuclear environment of this galaxy. It is because of its better physical self-consistency, on which we elaborate below, that we prefer a model with reflection and narrow Fe line emission.

The rapid variability observed by *XMM-Newton* is not associated with spectral changes. On the basis of the hardness ratio behaviour over time (Figure 1) and of the spectral fitting results we conclude that this variability must be due simply to changes in the level of the overall continuum. This suggests that we are seeing the nucleus, and changes in its X-ray emission, directly (as previously suggested by the ASCA observations [4]); however, we also find that the nuclear X-rays are seen in transmission through mildly ionised gas lying in our line of sight.

Reflection in cold material and fluorescence of neutral Fe producing relatively narrow line emission, which we also observe, are likely to take place at some distance from the nucleus, far out in an accretion disk, or, in the context of the unified model of AGN, in the vicinity of the putative molecular torus. The low equivalent width ($\sim$ 50 eV) of the Fe line, and the steep intrinsic power law continuum ($\Gamma \sim 2$) measured by *XMM-Newton* are in very good agreement with the distribution of these parameters reported for a sample of Seyfert galaxies studied with *Ginga* [9], where Fe line emission was first attributed to fluorescence in near-neutral material at some distance from the nucleus.

The possible evidence for the Fe line equivalent width to be anticorrelated with continuum level supports the scenario we propose: if the line were seen directly, rather than in reflection, it would vary with the continuum, instead of taking time to respond to changes in its level.

6. Conclusions

Preliminary analysis of the *XMM-Newton* observation of NGC 7314 shows that rapid variability in the 0.2−12 keV flux of this object is not associated with spectral changes. For the first time we recognise that warm absorption is required to explain the complexity of the X-ray spectrum at low energies. The continuum and Fe Kα line emission are best explained by reflection and fluorescence in cold gas at some distance from the active nucleus, far out in the accretion disk or in a molecular torus.

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