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The Properties of the Absorbing and Line Emitting Material in IGR J16318–4848

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Abstract We analyzed the 2003 Target of Opportunity XMM–Newton observation of IGR J16318–4848, to derive the properties of the matter responsible for the obscuration and for the emission of Fe and Ni lines. The line of sight material has a column density of about $2{\times}10^{24}$ cm^{-2} but, from the Fe Kα line EW and Compton Shoulder, we argue that the average column density is a few $\times 10^{23}$ cm^{-2}, while the covering factor is about 0.1–0.2. The iron Kα line varies on time scales as short as 1000 s, implying a size of the emitting region less than $3{\times}10^{13}$ cm. An ongoing XMM–*Newton*/INTEGRAL monitoring campaign is confirming the non–transient nature of the source.

Key words: line: formation – X–rays: binaries – X–rays: individual: IGR J16318–4848

1 INTRODUCTION

IGR J16318−4848 was discovered by the ISGRI detector of the IBIS instrument onboard the INTEGRAL satellite (Corvoisier et al. 2003) on January 29, 2003, with a 15–40 keV flux of 50–100 mCrab. It was initially interpreted as a new "transient" X-ray source. However, a reanalysis of archival ASCA data revealed the presence of a source whose position was coincident with that of IGR J16318-4848 (Murakami et al. 2003), and with a 2–10 keV observed flux of about $4 \times 10^{-11}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$.

The INTEGRAL discovery prompted a Target of Opportunity observation with XMM-Newton (Jansen et al. 2001) on February 10, 2003. The EPIC spectra unveiled a variable and heavily absorbed source, with evidence for strong emission lines (Schartel et al. 2003). This is in agreement with the ASCA source, in which Revnivtsev et al. (2003) suggested a column density $> 4 \times 10^{23}\,\mathrm{cm^{-2}}$. Preliminary spectral fits (de Plaa et al. 2003) indeed indicated that during the XMM-Newton observation IGR J16318–4848 was obscured by a Compton-thick absorber $N_H = (1.66 \pm 0.16) \times 10^{24}\,\mathrm{cm^{-2}}$. The emission complex could be resolved in three lines, with centroid energy of 6.410 ± 0.003 keV, 7.09 ± 0.02 keV and 7.47 ± 0.02 keV.

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An optical counterpart has been found and studied in detail by Chaty & Filliatre (2004; see also Chaty's contribution to this volume). The companion is very likely a sgBe star; the distance is constrained to be in between 0.9 and 6.2 kpc.

In this paper we reanalyze the EPIC/pn spectrum with the aim to characterize the physical properties of the matter responsible for the obscuration of the X-ray source and the associated reprocessing features. This will be done by comparing the spectral fit results with Monte Carlo simulations (see Matt et al. 1999; Matt 2002). A more detailed analysis can be found in Matt & Guainazzi (2003). A combined XMM–*Newton* and INTEGRAL analysis is presented by Walter et al. (2003).

2 DATA ANALYSIS AND RESULTS: TIME AVERAGED SPECTRUM

Details on the data reduction can be found in Matt & Guainazzi (2003). Here, suffice it to say that, for simplicity, we analyzed pn data only, extracting the spectrum in a $52''$ region centred on the source and using single and double events. After screening for high background periods, the net exposure time is 22.3 ks.

The XMM-Newton spectrum is characterized by a heavily absorbed continuum and 3 emission lines (de Plaa et al. 2003). The lines are most naturally interpreted as the Fe Kα and Kβ and the Ni Kα. We therefore fitted the spectrum (in the 5–13 keV energy band) with the simplest possible model: an absorbed power law plus three (unabsorbed) narrow (*i.e.* intrinsic width, σ, fixed to 1 eV) Gaussian lines. In the absorption model we left the iron abundance free to vary independently of the other elements. As the absorbing matter results to be Compton–thick (see below), we included also Thompson absorption (model CABS). It is worth noting that this model, ignoring the scattering of photons, is, strictly speaking, valid only for absorbing matter along the line of sight with a negligible covering factor (see below for a discussion).

The fit is reasonably good (χ^2=99.1/64 d.o.f.), but residuals around the iron Kα line are visible, most likely due to the Compton Shoulder (CS), as already observed in the reflection spectrum of the AGN in the Circinus Galaxy (Bianchi et al. 2002; Molendi et al. 2003), and expected on theoretical ground (see Matt 2002 and references therein). Modeling for simplicity the Fe Kα Compton Shoulder with a Gaussian with centroid energy fixed to 6.3 keV, and σ fixed to 50 eV, a significant improvement is found (χ^2=80.9/63 d.o.f., corresponding to 99.96% confidence level). The best fit results for this baseline model are summarized in Table 1. The observed 2–10 keV flux is 6.7×10^{-12} erg cm^{-1} s^{-1}. The flux corrected for absorption is instead 1.1×10^{-9} erg cm^{-1} s^{-1}, corresponding to a luminosity of $1.3\times10^{35}d_1^2$ erg s^{-1}, where d_1 is the distance to the source in units of 1 kpc. The luminosity suggests a neutron star as the compact object, but of course further confirmations are needed.

Given the large column density of the line–of–sight absorber, if the covering factor of the absorbing matter is large, a significant contribution from photons scattered towards the line of sight is expected, as discussed in Matt et al. (1999). We therefore fitted the spectrum with the Monte-Carlo model described in that paper. The fit is completely unacceptable. It must be noted that the Matt et al. (1999) model assumed spherical geometry and homogeneous matter, while the covering factor may be significantly smaller than one and the average column density smaller than that on the line–of–sight (see below).

The energies of the Fe and Ni Kα lines correspond to neutral or low ionized atoms (House 1969). On the contrary, the Fe Kβ centroid energy is significantly larger than expected. This cannot be due to high ionization, not only because it does not agree with the Kα energy, but also because for significantly ionized matter the Kβ line becomes much fainter, to disappear completely for Fe XVII or more, when no M electrons remain. Instead the observed Kβ/Kα ratio ($0.20\pm^{0.02}_{0.03}$) is slightly larger than expected for neutral iron (see the discussion in Molendi et al. 2003). It should however be noted that, given the proximity to the iron edge, the parameters

Table 1 Best fit results for the baseline model. Equivalent widths are calculated against the unabsorbed continuum.

Γ	$1.60^{+0.07}_{-0.11}$
N_H (10^{24} cm^{-2})	$1.91^{+0.03}_{-0.04}$
A_{Fe}	$0.89^{+0.04}_{-0.03}$
E (Fe Kα) [keV]	$6.401^{+0.001}_{-0.001}$
F (Fe Kα) [10^{-5} ph cm^{-2} s^{-1}]	$14.8^{+0.4}_{-0.6}$
EW (Fe Kα) [eV]	13
E (Fe Kβ) [keV]	$7.099^{+0.001}_{-0.006}$
F (Fe Kβ) [10^{-5} ph cm^{-2} s^{-1}]	$3.05^{+0.33}_{-0.38}$
EW (FeK β) [eV]	3
E (Ni Kα) [keV]	$7.45^{+0.05}_{-0.02}$
F (Ni Kα) [10^{-5} ph cm^{-2} s^{-1}]	$0.85^{+0.19}_{-0.21}$
EW (Ni Kα) [eV]	1
F (Fe Kα CS) [10^{-5} ph cm^{-2} s^{-1}]	$1.88^{+0.59}_{-0.68}$

of the Kβ line are necessarily difficult to estimate, a task to be deferred to high resolution observations as those provided in the near future by ASTRO-E2.

The Ni to Fe Kα line ratio is about 6%, suggesting a possible Ni overabundance (see again the discussion in Molendi et al. 2003). In Table 2, the EW of the lines with respect to the unabsorbed continuum (to make easier the comparison with the expected value for the iron Kα presented in Matt 2002), are also given. The expected value of the ratio, f, between the Compton Shoulder and the line core is 0.44, to be compared with a measured value of $0.12\pm^{0.04}_{0.05}$. f does not depend much on the geometry, but rather on the column density (Matt 2002). The observed value would correspond to a column density of a few $\times10^{23}$ cm^{-2}, for which values around 100 eV of the EW of the line core are expected (a value of about 20 eV is instead expected for 1.9×10^{24} cm^{-2}). The observed EW is instead about 13 eV. It is then possible that the matter is very inhomogeneous, with a denser blob just on the line of sight (which is what the fit can measure) but an average optical depth an order of magnitude less, and a covering factor, taking into account the uncertainties on the power law index, of about 0.1–0.2. The lower (with respect to the line of sight) average column density, along with the relative small covering factor, would explain the failure of the Matt et al. (1999) model in fitting the data.

Because there is evidence that the absorbing material has a covering factor less than 1, part of the X–ray illuminated surface should be directly visible, producing a Compton reflection component (e.g. Matt, Perola & Piro 1991). As discussed above, the average column density is possibly as low as a few $\times10^{23}$ cm^{-2}; however, below the iron line energy the reflection component for this column density is very similar to that for Compton–thick matter (Matt et al. 2003). This component could therefore account for the excess emission below 5 keV (see Fig. 1, where the whole 0.3–13 keV spectrum is shown, after being fitted with the baseline model), and down to about 2 keV (the further excess at lower energies should have a different origin, maybe a confusing source or a dust scattering halo). Fitting the 2–13 keV spectrum with the baseline model gives χ^2=104.9/68 d.o.f., and a very flat (Γ=0.6) power law. The addition of a pure Compton reflection component (with the photon index linked to that of the absorbed power law, and fixed to 1.6) improves the fit significantly, giving χ^2=79.9/68 d.o.f.. The value of R, 0.003, implies that the visible part of the illuminated matter is very small (R is equal to 1 for 2π visible solid angle, i.e. a covering factor of 0.5). The other parameters are similar to those listed in Table 2. The iron line EW with respect to the reflection component is very large, $\sim$28 keV, implying that almost all of the line is related to the transmitted component.

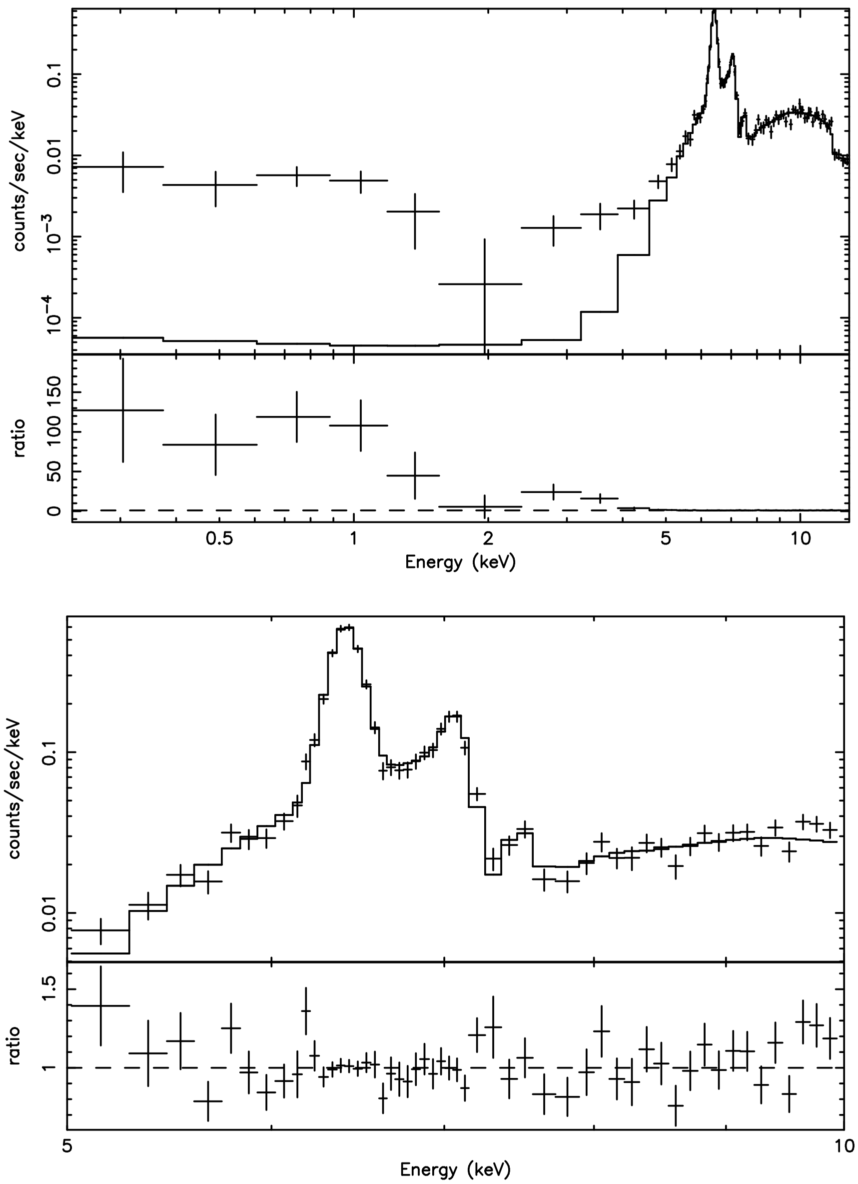

Fig. 1 Top panel: the overall 0.3–13 keV time integrated spectrum fitted with the baseline model. Bottom panel: the same, but restricted to the 5–10 keV range.

The small value of R may, at the first glance, appears rather surprising, given the value of the covering factor deduced from the iron line EW and the CS (about 0.1). It may be explained if, e.g., the absorber has a flat configuration and is seen at high inclination.

3 DATA ANALYSIS AND RESULTS: TEMPORAL BEHAVIOUR

Due to lack of space, we cannot discuss in detail the temporal behaviour of the source, for which we defer the reader to Matt & Guainazzi (2003). We just recall here that IGR J16318–4848 exhibits a complex variability pattern during the XMM-Newton observation, with large flux variations. The iron Kα line varies on time scales as short as 1000 s, implying a size of the emitting region not exceeding $\sim 3 \times 10^{13}$ cm. A time–resolved spectral analysis shows that the variations of the line–of–sight column density (if any) cannot explain the observed flux variability, which therefore must intrinsic.

4 WORK IN PROGRESS

A simultaneous XMM–*Newton* (PI: M. Guainazzi) and INTEGRAL (PI: E. Kuulkers) monitoring campaign is ongoing, with the aim of studying the source behaviour on different time scales. The campaign consists of three observations, the first two separated by one month, the third by about six months. The first two observations have already been performed in February and March, 2004. The XMM–*Newton* observations show that the source is still there, confirming that IGR J16318–4848 is not a transient source, even if a highly variable one. In fact, while the time–average flux of the first observation was about 20% higher than that of the 2003 TOO observation, during the second observation the flux dropped by about a factor 3. Despite the large flux variability, the spectrum in both observations is very similar to that of one year before. Even if a ~30% variation of the line-of-sight column density is apparent, this can explain only part of the observed variability, most of it being therefore intrinsic.

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