

Discussing the physical meaning of the absorption feature at 2.1 keV in 4U 1538–52^{*}

J.J. Rodes-Roca^{1,2,**}, J.M. Torrejón^{1,2}, S. Martínez-Núñez², A. Giménez-García^{1,2}, and G. Bernabéu^{1,2}

¹ Department of Physics, Systems Engineering and Signal Theory University of Alicante, 03080 Alicante, Spain

² University Institute of Physics Applied to Sciences and Technologies, University of Alicante, 03080 Alicante, Spain

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High resolution X-ray spectroscopy is a powerful tool for studying the nature of the matter surrounding the neutron star in X-ray binaries and its interaction between the stellar wind and the compact object. In particular, absorption features in their spectra could reveal the presence of atmospheres of the neutron star or their magnetic field strength. Here we present an investigation of the absorption feature at 2.1 keV in the X-ray spectrum of the high mass X-ray binary 4U 1538–52 based on our previous analysis of the XMM-Newton data. We study various possible origins and discuss the different physical scenarios in order to explain this feature. A likely interpretation is that the feature is associated with atomic transitions in an O/Ne neutron star atmosphere or of hydrogen and helium like Fe or Si ions formed in the stellar wind of the donor.

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1 Introduction

The improvement of the capabilities of modern X-ray observatories, like *Chandra* or *XMM-Newton*, offers the possibility to detect and analyse both absorption and emission lines and to study the nature of the matter surrounding the compact object in many X-ray sources. The presence of emission lines in high mass X-ray binary systems (HMXBs) has been reported since the beginning of X-ray astronomy with different X-ray observatories, e. g., Centaurus X-3 with *ASCA* and *Chandra* (Ebisawa et al. 1996; Iaria et al. 2005), Vela X-1 with *ASCA* (Sako et al. 1999), 4U 1700–37 with *XMM-Newton* (van der Meer et al. 2005), Cygnus X-3 with *Chandra* (Paerels et al. 2000), and 4U 1538–52 with *XMM-Newton* (Rodes-Roca et al. 2011, hereafter referred to as Paper I).

The presence of absorption lines in HMXBs is scarcer and has been associated with cyclotron resonant scattering features (CRSFs) at energies greater than 10 keV, e.g., 4U 1907+09 with *BeppoSAX* (Cusumano et al. 1998), 4U 1538–52 with *Ginga*, *RXTE* and *INTEGRAL* (Clark et al. 1990; Rodes 2007; Rodes-Roca et al. 2009), Vela X-1 with *Mir-HEXE* and *RXTE* (Kendziorra et al. 1992; Kreykenbohm et al. 2002; Kreykenbohm 2004), Centaurus X-3 with *BeppoSAX* (Santangelo et al. 1998; Heindl & Chakrabarty 1999), OAO 1657–415 with *BeppoSAX* (Orlandini et al. 1999), GX 301–2 with *Ginga* (Mihara 1995), and LMC X-4 with *BeppoSAX* (La Barbera et al. 2001). Vela X-1 is the only HMXB where absorption K-edges, such as O, Si, S, and K-

and L-edges of Fe have been reported at energies below 10 keV (Goldstein et al. 2004).

In low mass X-ray binary systems (LMXBs) absorption lines have been detected with both *Chandra* and *XMM-Newton* below 10 keV, e.g., Circinus X-1 (Brandt & Schulz 2000; D’Aí et al. 2007), MXB 1659–298 (Sidoli et al. 2001), 4U 1820–30 (Boirin et al. 2004), and XB 1916–053 (Cackett et al. 2008). Other astrophysical X-ray sources, like active galactic nuclei (AGNs), have also shown X-ray absorption lines due to both transition H-like and He-like ions and inner-shell transitions in lower ionization species (Behar & Netzer 2002).

It is relevant for this work to mention the isolated neutron star (INS) 1E1207.4–5209, which is a unique system among the INSs because it shows more than one absorption spectral feature in the 0.5–3.0 keV energy range (Bignami et al. 2003). In fact, one, two or three of the absorption features appear above 1 keV, while the other INSs have absorption features at $E = 0.2 - 0.7$ keV (Ho et al. 2007). There are several studies suggesting that the absorption feature at 2.1 keV in this source corresponds to a cyclotron absorption line (the second harmonic). Discarding the instrumental origin, Bignami et al. (2003) explained the 2.1 keV feature as a cyclotron resonant absorption line because both the equivalent width and deviations from the continuum model were much stronger than instrumental or calibration effects. Later, Mori et al. (2005) concluded that the residuals around 2.1 keV were consistent in strength and position with the instrumental Au edge, doing a detailed analysis of the *XMM-Newton* data. However, Liu et al. (2006) also conclude the feature at 2.1 keV is more likely a cyclotron absorption line. The *Suzaku* obser-

* Data from XMM-Newton

** Corresponding author: e-mail: rodes@dfists.ua.es

vation of this source are likely in favour of the electronic cyclotron line (Takahashi et al. 2010). In conclusion, although the interpretation of the absorption feature at 2.1 keV in this isolated neutron star has been controversial, the cyclotron resonant scattering feature explanation is preferred.

The continuum models used in Paper I fit the spectrum of 4U 1538–52 satisfactorily. However, they failed to fit correctly the region around 2.1 keV which shows clearly an absorption feature near 2.1 keV (see Figure 1). In our analysis we discarded a gain instrumental effect. It is well known the existence of edges of instrumental origin due to the Au M edge near the energy of this feature. Therefore we have to analyse whether the residuals are consistent in strength and position with the Au M residuals observed in cross-calibration sources.

In this work, we discuss the different physical scenarios in which the detected absorption feature could be formed. In order to ensure that the absorption feature is not due to an instrumental effect, we have carried out a systematic study to rule this possibility out. First, we have discarded completely the instrumental origin in Section 2.1. Then, we have looked for a possible astrophysical origin (background, dust scattered halo and source) in Section 2.2. Finally, we have discussed where it could be formed either in the atmosphere of the neutron star (Section 2.3) or in the stellar wind (Section 2.4).

2 Observation and data analysis

The observation of 4U 1538–52 was carried out using the European Photon Imaging Camera (*EPIC*) aboard the *XMM-Newton* satellite. This source was observed for ~ 55 ks on 2003 August 14–15 (Obs. ID 0152780201). Both the *EPIC/metal-oxide semiconductor (MOS)* and *EPIC/PN* instruments (Strüder et al. 2001; Turner et al. 2001) were operated in *Full frame* mode, and the thin filter 1 (*MOS-1* and *PN*) and medium filter (*MOS-2*) were used. The observations details were summarised in Paper I.

The *EPIC/PN* observation data files (ODF) were processed using Science Analysis System (SAS) version 12.0.1 together with the latest calibration files, CCFs as of 2012 June starting from the ODF level running *eproc* and following the standard procedure for *XMM-Newton* spectra. Particular care was done to the selection of the background, halo, and source regions. In the *PN* field of view we selected the source and the background regions from the same chip with a circle of $35''$ and $60''$ radius, respectively, and rejecting the area possibly contaminated by out-of-time events or too near to the CCD edges. We defined the halo with an annulus region between $95''$ and $137.5''$ radius, excluding both all the point sources and the CCD edges. The spectra were rebinned in order to have at least 20 counts per channel.

The 80 ks long *XMM-Newton* observation has been divided into three time intervals. We have called the first ≈ 10 ks as out-of-eclipse observation, from ≈ 10 ks to ≈ 20 ks as eclipse ingress observation, and the last ≈ 60 ks as eclipse

observation. Following our spectral analysis in Paper I, we have modelled the X-ray continuum of the different time intervals of the observation by using either three absorbed power laws (out-of-eclipse and eclipse ingress observation) or two absorbed power laws (eclipse observation). Furthermore, the spectra of the source shows the presence of six emission lines corresponding to iron emission lines and He and H recombination lines (see Figure 1). These lines have been modelled by Gaussian functions. The absorption feature at 2.1 keV presents in our residuals has been modelled by an absorption Gaussian function.

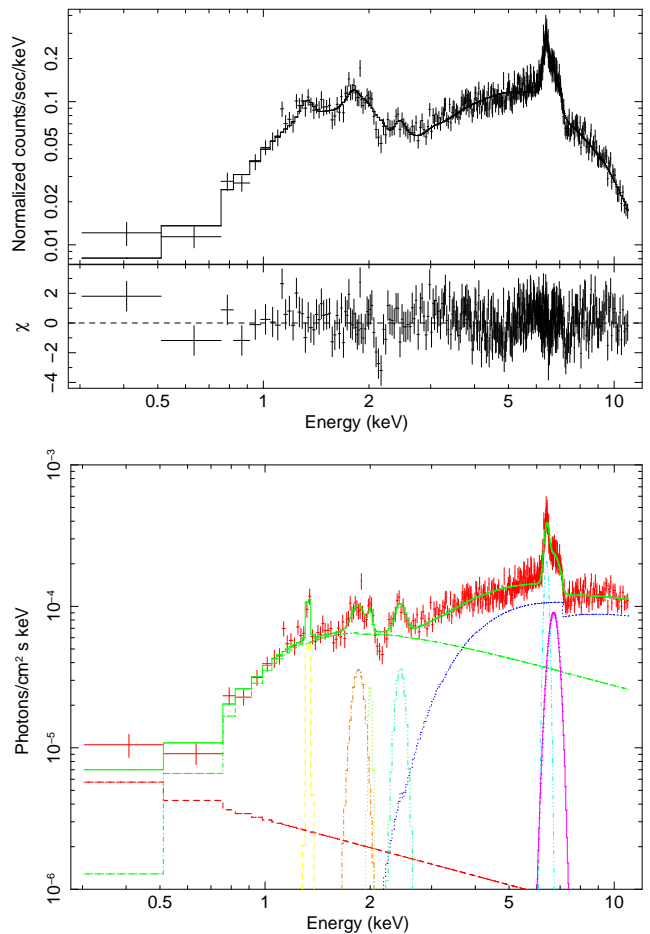


Fig. 1 Iron emission lines and recombination emission lines of He- and H-like species in the eclipse spectrum of 4U 1538–52. Spectrum and best fit model (two absorbed power laws modified by six Gaussian emission lines) in the 0.3–11.5 keV energy range obtained with *PN* camera and the residuals between the spectrum and the model (*top panel*). Unfolded spectrum with the individual model components (*bottom panel*). The absorption line which is not included in the model is clearly seen.

The spectral analysis was performed using XSPEC v12.8.0 in the energy range 0.3–10.0 keV. As a first step, as a result of the improvement of the instrumental response, we addressed the pulse-phase averaged spectrum

with respect to our previous analysis (Paper I) and confirmed that the spectral parameters were consistent taking their associated errors into account. Then we have changed this model slightly. The Tuebingen-Boulder ISM absorption model calculates the cross section for X-ray absorption by the ISM using the most up-to-dates ISM abundances (*tbabs* model in *XSPEC*). Therefore, we have used it instead of the *phabs* model in *XSPEC*, the absorption cross sections are adapted from Verner et al. (1996) (instead of Balucinska-Church & McCammon 1992), and the abundances are set to those of Wilms et al. (2000) (instead of Anders & Grevesse 1989). We also notice that the out-of-eclipse spectrum in Paper I has been divided into two spectra in this work (out-of-eclipse and eclipse ingress).

2.1 Discarding the instrumental effect

First of all, in order to rule out the possibility of a calibration issue, a careful study of this observation as well as a sample of observations used by the *XMM-Newton* cross calibration (*XCAL*) archive was performed by the *XMM-Newton* calibration team. The cross-calibration *XMM-Newton* database consists of ~ 150 observations of different sources, optimally reduced, fitted with spectral models defined on a source-by-source basis¹. Table 1 shows the EW of an unresolved Gaussian absorption feature with centroid energy fixed at 2.1 keV in a sample of *XCAL EPIC/PN* spectra of the sources listed below. The *XCAL* observations of 3C111, 1H1219+301, H1426+428 and PKS0548–322 showed no feature at 2.1 keV (equivalent width less than 5.3 eV), while in our observation there was clearly a feature with an EW = -39_{-21}^{+11} eV, using our best-fit model. We also notice that for on axis sources systematic calibration uncertainties are better than 5% in the determination of the total effective area over the spectral range from 0.4–12.0 keV for each *EPIC* instrument separately². The conclusion was that this absorption feature is larger than the typical systematic uncertainties in this energy range and, therefore, it is intrinsic to the system. Moreover, as the equivalent width of the 2.1 keV feature is ~ 8 times higher than the calibration uncertainties and the deviations from the continuum model are ~ 4 times higher than the calibration accuracy we can conclude that the line is resolved.

Finally, we also checked that no spectral feature at this energy is seen in another object presented in the same observation. We extracted the spectrum of the source 2XMM J154305.5–522709 (Watson et al. 2009) in the 0.3–10.0 keV band using the method described in Paper I. Then we fitted the spectrum with an absorbed power-law model adding two Gaussians for emission iron lines. The residuals between the data and the model showed no evidence of an absorption feature at 2.1 keV. These results give us confi-

Table 1 EWs in a sample of *XCAL EPIC/PN* spectra.

ObsID	EW (eV)
0065940101	-5_{-4}^{+3}
0552180101	$-1.0_{-2.1}^{+0.0}$
0111840101	-1_{-7}^{+0}
0111850201	$-0.0_{-2.4}^{+0.0}$
0165770101	$-0.0_{-1.4}^{+0.0}$
0165770201	-1_{-3}^{+0}
0212090201	$-0.0_{-1.5}^{+0.0}$
0310190101	$-0.0_{-1.1}^{+0.0}$
0310190201	-2_{-3}^{+0}
0310190501	-0_{-3}^{+0}
0142270101	-0_{-3}^{+0}

dence about the non-instrumental nature of the absorption feature.

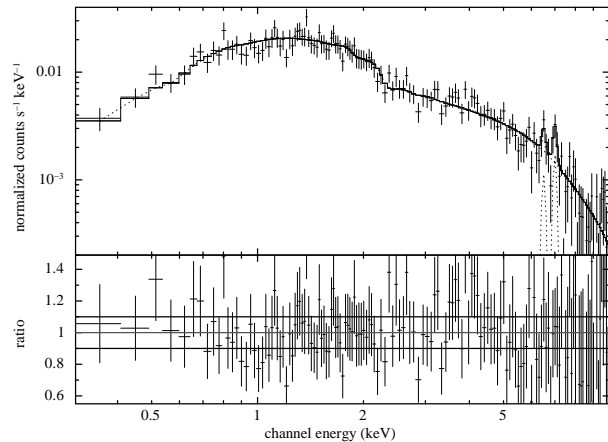


Fig. 2 2XMM J154305.5–522709 spectrum. The lower panel shows the residuals between the spectrum and the best fit model. Horizontal lines mark the 10% ratio differences.

2.2 Looking for the astrophysical origin

First, we have extracted spectra from two regions containing only the background and the background plus halo, using the extraction region described in the previous Section. These regions are depicted in Fig. 3, showing the corresponding spectra in Fig. 4. The spectrum of the dust scattered halo area has been corrected for the background. We have modelled this spectrum with two absorbed power-law components assuming a scattered and a soft components as the X-ray continuum from the halo. We have also included a Gaussian emission line to describe the fluorescent iron line at 6.4 keV. The residuals between the spectrum and the model around 2 keV are consistent with no absorption feature because the ratio differences are smaller than 10%. Therefore, no absorption feature has been detected in the 2.1 keV region either in the halo or in the background itself. The absorption feature appears only when the source is included in the extraction region suggesting a local origin. Therefore,

¹ http://www.iachec.org/meetings/2009/Guainazzi_2.pdf

² *EPIC* status calibration and data analysis, document XMM-SOCCAL-TN-0018 edited by M. Guainazzi, on behalf of the *EPIC* consortium

it must be formed either in the neutron star atmosphere or in the stellar wind of the donor.

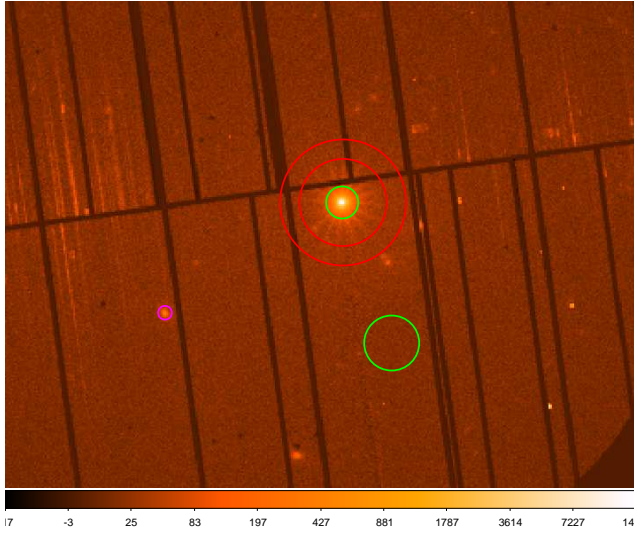


Fig. 3 PN image around 4U 1538–52. The open circles identify regions for source (middle green circle), background (bottom green circle), dust scattered halo (red annulus around central source), and 2XMM J154305.5–522709 (left magenta circle).

On the mechanism of formation of the absorption lines in the isolated neutron star 1E 1207.4–5209, the following suggestions have been proposed:

- they come from energy level transitions of once ionized helium ions in the strong magnetic field on the surface of the neutron star (Sanwal et al. 2002; Yuan et al. 2006);
- they are electron cyclotron absorption lines in an intense magnetic field (Sanwal et al. 2002; Yuan et al. 2006);
- they are formed by the proton cyclotron absorption in some strong magnetic field (Sanwal et al. 2002; Yuan et al. 2006);
- they are due to atomic transitions in some magnetized iron atmospheres (Rajagopal et al. 1997; Mereghetti et al. 2002); or
- they are due to transitions of hydrogen like O/Ne ions in the stellar atmosphere with a strong magnetic field (Mori & Hailey 2006).

More recently, Xu et al. (2012) have suggested that the absorption lines in 1E 1207.4–5209 could be explained in the framework of the hydro-cyclotron oscillation model.

On the mechanism of formation of the absorption lines in X-ray binaries, the following suggestions have been proposed:

- they come from absorption K-edges (i.e., Goldstein et al. 2004);
- they are electron cyclotron absorption lines in an intense magnetic field (see references in Sect. 1);

- they are due to atomic transitions of hydrogen and helium like Fe ions or other metals (i. e. Sidoli et al. 2003; Boirin et al. 2004; Sidoli et al. 2005; see also references in Sect. 1).

2.3 On the formation in the atmosphere of the neutron star

In 4U 1538–52, assuming the observed feature is intrinsic to the neutron star, there are two potential ways to produce it in the neutron star atmosphere: cyclotron lines and atomic transition lines.

2.3.1 Cyclotron lines

First we consider that the observed feature is a cyclotron line produced in a strongly ionised neutron star atmosphere. If we assume that this is electron cyclotron line, the feature could be interpreted as the fundamental of the electron-cyclotron energy $E_{ce} = 11.6 \times B_{12}/(1+z)$ keV in a magnetic field $B_{12} = B/(10^{12} \text{ G}) \sim 0.24$. However, 4U 1538–52 presents the fundamental electron-cyclotron line at around 21 keV (Clark et al. 1990; Robba et al. 2001; Rodes-Roca et al. 2009) and the first harmonic at around 47 keV (Rodes-Roca et al. 2009). Therefore, the hypothesis that this feature is an electron cyclotron line does not look plausible.

Alternatively, one can assume that the spectral feature is associated with ion-cyclotron energies, $E_{ci} = 0.63(Z/A)B_{14}$ keV, where Z and A are the atomic charge and atomic mass of the ion, respectively. The surface magnetic field needed for this interpretation is greater than the magnetic field inferred for the electron-cyclotron lines detected in this system. Then, this former scenario seems to be unlikely.

2.3.2 Atomic lines

The other possibility is that the observed feature is an atomic line formed in the neutron star atmosphere. Based on works about the structure and spectra of atoms in strong magnetic fields, mostly in fields below 10^{13} G (e. g. Ruder et al. 1994; Mori & Hailey 2002, 2006), we can exclude this feature as emerging from a hydrogen atmosphere because at any magnetic field and any reasonable redshift, there is no hydrogen spectral line whose energy would match the observed one. In fact, the 2.1 keV absorption feature cannot be produced by hydrogen atoms as the binding energy of a hydrogen atom never exceeds ≈ 1 keV at any magnetic field (Sanwal et al. 2002; Mori & Hailey 2006). As a consequence, spectral features greater than 1 keV suggest non-hydrogenic element atmosphere on the neutron star surface. Therefore, one has to invoke heavier elements. Another possibility is an iron atmosphere at B around 10^{12} G (Mereghetti et al. 2002; Mori & Hailey 2006), but the iron atmosphere should show many more than the only one observed feature in the X-ray

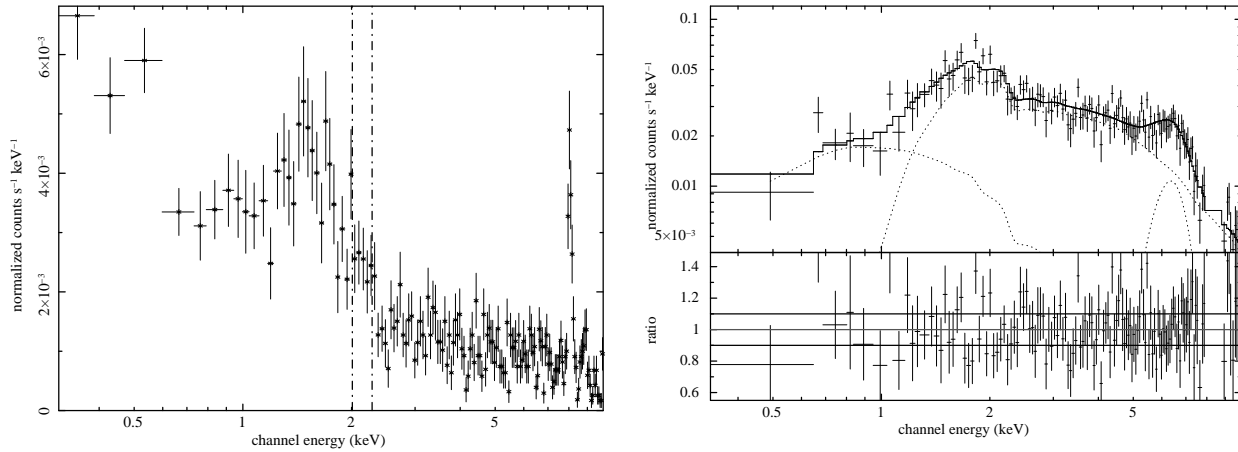


Fig. 4 *Left panel:* Background spectrum. Vertical lines show the 2.01–2.28 keV energy interval around the absorption feature. *Right panel:* Dust scattered halo spectrum.

band (Rajagopal et al. 1997) and an unreasonable value of gravitational redshift (Mori & Hailey 2006). The properties of the absorption line are consistent with an O/Ne atmosphere (He-like Oxygen, Li-like Oxygen) at B around 10^{12} G (Mori & Hailey 2006). The O/Ne atmosphere should show other absorption features at lower energies, but the soft excess of the system prevents their detection. We extracted the *RGS* spectrum to look for other absorption lines. However, the level of source counts at below 2 keV was too low (Rodes-Roca et al. 2011) and we could not detect other absorption lines to confirm this origin.

During the out-of-eclipse observation we can see the neutron star atmosphere directly. Mid-Z element atmosphere for strongly magnetized neutron star have been studied by Mori & Ho (2007). They constructed spectra with magnetic field of 10^{12} G and three different effective temperatures for carbon, oxygen and neon atmospheres. Their models showed numerous absorption lines, especially in low-temperature models, presenting heavier element atmospheres more absorption features (see Figures 11–16 in Mori & Ho 2007). Therefore we have interpreted the soft energy spectrum as generated in a partially ionized, strongly magnetized mid-Z element plasma (NSMAX model in *XSPEC*, Mori & Ho 2007, Ho, Potekhin & Chabrier 2008). We have changed the soft power-law component by a neutron star magnetic atmosphere model. The absorption feature at 2.1 keV could be produced by an oxygen/neon atmosphere with $B=10^{12}$ G and effective temperatures of $(3-5)\times 10^{12}$ K (see Figures 13 and 15 in Mori & Ho 2007). The magnetic field derived from the fundamental cyclotron line of this system $\approx 2.4 \times 10^{12}$ G is consistent with spectra from magnetized O/Ne atmosphere models. Figure 5 shows the spectra and residuals for this fit.

2.4 On the formation in the stellar wind

4U 1538–52 consists in an accreting neutron star deeply embedded in the wind of the B0 I star QV Nor. When the X-ray source is observed through the stellar wind

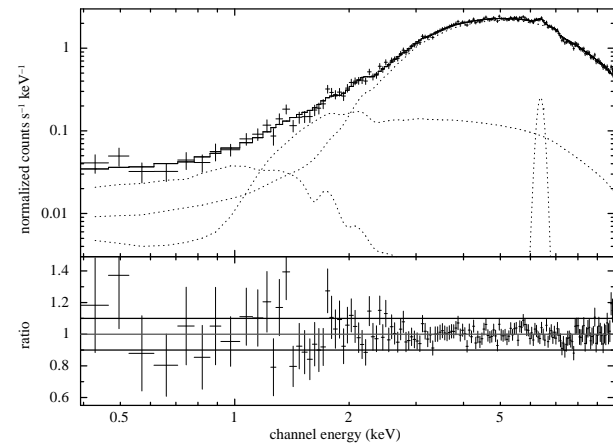


Fig. 5 Out-of-eclipse spectrum. The lower panel shows the residuals between the spectrum and the best fit model. Horizontal lines mark the 10% ratio differences. Soft power-law component is changed by a neutron star magnetic atmosphere model.

captured by the compact object, absorption K-edges, such as O, Si, S, and K- and L-edges of Fe are seen (Haberl, White & Kallman 1989). Many of them are not apparent in eclipse and the K-edge of Fe was the only one detected (Paper I). The soft excess at lower energies hides the possible absorption edges.

We also tested the possibility that the soft component was due to the presence of an ionized absorber. Adopting the *ABSORI* model in *XSPEC* (Done et al. 1992; Arnaud 1996), we obtained an unsatisfactory fit to the data and there were still strong negative residuals around 2.1 keV.

Figure 6 shows the eclipse ingress spectrum and best-fit model (three absorbed power-laws modified by two Gaussian emission lines) in the 0.3–10.0 keV energy range obtained with *PN* camera and residuals between the spectrum and the model (top left panel), the eclipse spectrum and best-fit model (two absorbed power-laws modified by six

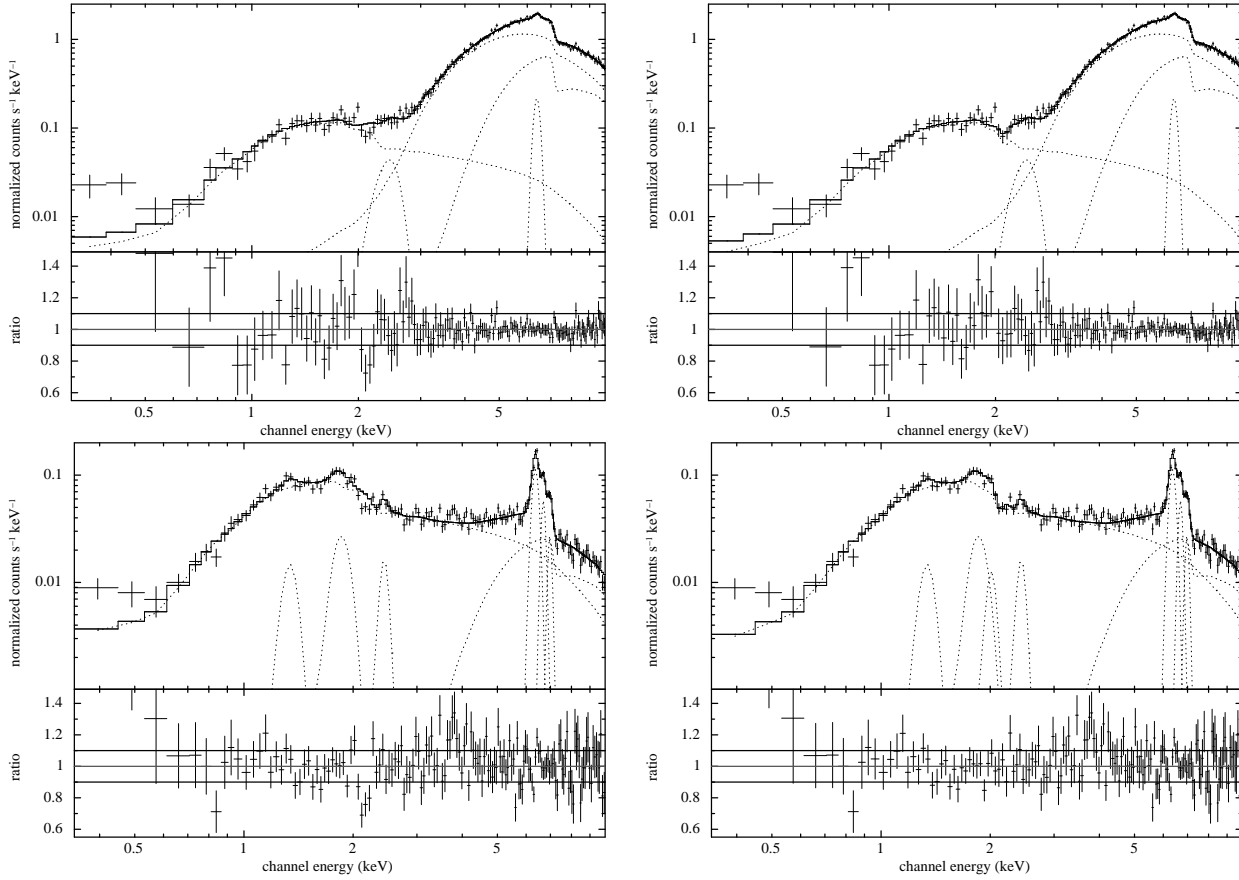


Fig. 6 *Top panel:* Eclipse ingress spectrum, best-fit model without (left) and with absorption feature (right), and the ratio of data to model. *Bottom panel:* Eclipse spectrum, best-fit model without (left) and with absorption feature (right), and the ratio of data to model. The absorption line is clearly seen.

Gaussian emission lines) and residuals between the spectrum and the model (bottom left panel). Assuming the absorption feature is formed in the stellar wind we have fitted the best-fit model derived in this work to the pre- and eclipse spectra without and with a Gaussian absorption line at 2.1 keV (see Figure 6 top right and bottom right panels, respectively). Adding a Gaussian absorption line both in the hard and in the scattered power-law component we obtained no improvement in the fit. But adding it in the soft power-law component we obtained a significant improvement in the fit of the eclipse spectrum (f-test probability 1.2×10^{-6}) and a slightly improvement in the fit of the eclipse ingress spectrum (f-test probability 0.020). The best-fit parameters of the line at 2.1 keV are given in Table 2. Uncertainties refer to a single parameter at 90% ($\Delta\chi^2 = 2.71$) confidence limit.

In order to identify the possible ions from which this feature could originate, we used atomic database available such as the van Hoof’s Atomic Line List³, the X-ray transition energies from the National Institute of Standards and Technology (NIST)⁴, the line finding list

Table 2 Fitted parameters for the absorption line detected in the eclipse ingress and the eclipse spectrum (Fig. 6).

Component	Parameter	Value
Eclipse ingress spectrum		
<i>Absorption line</i>	E (keV)	$2.13^{+0.05}_{-0.04}$
	σ (eV)	7 ± 6
	tau	1.0 (unconstrained)
	EW(eV)	30 ± 16
	χ^2_{ν} (dof)	1.0(157)
Eclipse spectrum		
<i>Absorption line</i>	E (keV)	2.12 ± 0.03
	σ (eV)	9^{+4}_{-5}
	tau	1.0 (unconstrained)
	EW(eV)	39^{+11}_{-21}
	χ^2_{ν} (dof)	1.3(154)

from XSTAR package⁵ and the CHIANTI atomic database for spectroscopic diagnostics of astrophysical plasmas⁶ (Dere et al. 1997; Dere et al. 2009). Therefore, we looked

³ <http://www.pa.uky.edu/~peter/atomic/index.html>

⁴ <http://www.nist.gov/pml/data/xraytrans/index.cfm>

⁵ <http://heasarc.gsfc.nasa.gov/docs/software/xstar/xstar.html>

⁶ <http://www.chianti.rl.ac.uk/line-list.html>

Table 3 X-ray transitions identified from the atomic databases used in this work.

Element/Ion	Transition	E (keV)	λ (Å)
van Hoof's atomic line list			
Fe XXVI	2-9	2.202	5.632
Si XIII	1s-1p ^o	2.183	5.681
Fe XXVI	2-8	2.171	5.711
Fe XXVI	2-7	2.127	5.829
NIST's database			
Si XIII	1s-1p ^o	2.183	5.681
CHIANTI's database			
Si XII d	1s ² 2p ² P _{1/2} -1s 2p (3P) 3p ² D _{3/2}	2.1322	5.8156
Si XII d	1s ² 2p ² P _{3/2} -1s 2p (3P) 3p ² D _{5/2}	2.1320	5.8162
Inner-shell absorption line (Behar & Netzer 2002)			
Si He I	1s-3P	2.182	5.682

for X-ray transitions in the energy range 2.03–2.21 keV or in the wavelength range 5.61–6.11 Å.

Nevertheless, we note that the cosmic abundance for silicon is 3.55×10^{-5} while for iron, aluminium, nickel, phosphorus, and zinc is 4.68×10^{-5} , 2.95×10^{-6} , 1.78×10^{-6} , 2.82×10^{-7} , and 3.98×10^{-8} , respectively. Taking this into account, we found the allowed transitions which are listed in Table 3 and suggest that the absorption feature is related to silicon (Si XII or Si He I) or iron (Fe XXVI) ions.

BeppoSAX spectrum of the LMXB EXO 0748–676 showed an absorption feature at 2.13 keV which was tentatively identified with absorption from highly ionized silicon (Si XIII, Sidoli et al. 2005). However, they did not performed any instrumental analysis in order to discard an inadequate modelling of the instrumental response.

3 Conclusion

We have presented the spectral analysis of the HMXB 4U 1538–52 using the *XMM-Newton* observation focusing our attention specifically in the absorption feature at 2.1 keV. In this work, we show that the *XMM* spectrum of 4U 1538–52 shows a deep significant absorption feature at $E = 2.12 \pm 0.03$ keV in the eclipse spectrum. Throughout a detailed analysis of the spectral region covering the absorption line, we have been able to discard an instrumental origin. Indeed, it is not present in any of the long term monitoring sources used for the *XMM* calibration. Likewise, it can not be accounted for by gain and/or offset corrections and the latest calibration files. We conclude that the line is of astrophysical origin.

In order to constrain its nature we have analysed the spectra from the dust scattered halo seen around the source and also the spectrum of the background itself. The absorption line is not present in either of the two. This strongly suggests that the line is formed locally, in the binary system

either in the stellar wind or in the atmosphere of the neutron star. We found two possible physical scenarios where the absorption line could be formed: an O/Ne atmosphere on the neutron star surface or atomic transitions of hydrogen and helium like Fe or Si ions in the stellar wind of the donor. We have not discarded its formation in the atmosphere of the neutron star, assuming it could be seen during the out-of-eclipse observation. Moreover, the 2.1 keV feature present in our eclipse spectrum has ≈ 8 times higher equivalent width and deviations from the continuum model at the level of $\approx 25\%$. We also notice that for on axis sources *EPIC* calibration accuracy is better than 5%. These results give us confidence that the feature is intrinsic to the system. Consequently, to confirm the nature of the absorption line one should investigate the presence of other features in the low energy band with a high-resolution and enough exposure time to achieve a good signal-to-noise at low energies.

Either scenario is of great astrophysical interest. We tried to look for more absorption lines analysing the *RGS* data of this source, but the level of counts was compatible with the background because this system is highly absorbed at low energies. Further studies at high resolution will be needed to use this absorption line as a potential diagnostic tool to study the properties of the neutron star atmosphere or the stellar wind of the donor.

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