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On the physical meaning of the 2.1 keV absorption feature in 4U 1538−52

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The improvement of the capabilities of nowadays X-ray observatories, like *Chandra* or *XMM-Newton*, offers the possibility to detect both absorption and emission lines and to study the nature of the matter surrounding the neutron star in X-ray binaries and the phenomena that produce these lines. The aim of this work is to discuss the different physical scenarios in order to explain the meaning of the significant absorption feature present in the X-ray spectrum of 4U 1538−52. Using the last available calibrations, we discard the possibility that this feature is due to calibration, gain effects or be produced by the X-ray background or a dust region. Giving the energy resolution of the *XMM-Newton* telescope we could not establish if the line is formed in the atmosphere of the neutron star or by the dispersion of the stellar wind of the optical counterpart.

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1. Introduction

Thanks to the high-sensitivity and high-resolution instruments on board current X-ray observatories, like *XMM-Newton*, *Chandra* or *Suzaku*, it is possible to observe both emission and absorption lines in many X-ray sources: High Mass X-ray Binaries, Low Mass X-ray Binaries or Active Galactic Nuclei.

The detection and identification of spectral features are a tool to infer, for example, the chemical composition of the neutron star (NS) atmosphere, densities of the illuminated gas in the stellar wind or to estimate the magnetic field of the NS.

Absorption features at 0.7 keV, 1.4 keV and 2.1 keV have been detected in the isolated NS 1E 1207.4−5209 and several different interpretations were proposed ([11, 5, 1, 4, 7, 13]). In fact, depending on the spectral analysis of the *XMM-Newton* data, the feature at 2.1 keV is interpreted either as electron cyclotron absorption line ([1, 4, 12]) or as of instrumental origin ([6]).

In this work, we discuss the implications of the different interpretations of the 2.1 keV feature in 4U 1538−52.

2. Observation

The *XMM-Newton* observation of 4U 1538−52 started on August 14 and finished on August 15, 2003. The details of the data reduction can be found in [10]. We found strong residual structure around 2.1 keV and checked the instrumental origin with the *EPIC/pn* calibration team. Different possible formation mechanisms are discussed.

3. Spectral analysis

In order to identify new features, we have carried out a similar process to the one described in [10]. The first explanation for the presence of such absorption feature would be a bad correction of the well known decrease in the effective area near 2 keV due to the Au M edge. Therefore, we have conducted a systematic study to discard completely the instrumental origin.

First of all, to discard the possibility that this absorption feature could be related to a gain effect, the data were fitted using different gain and offset values (up to ±3% and ±0.05 keV, respectively). The line profile expressed as the ratio of spectral data to a best-fit model was always around 70%, suggesting that it is not a gain effect and that the absorption feature could be real. Figure 1 (right bottom) shows the residuals between the spectrum and the continuum model (three absorbed power laws) in the energy range 0.9–8.0 keV. Then, in order to rule out the possibility of a calibration issue related to the absorption feature, 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 *XCAL* team. The cross-calibration *XMM-Newton* database consists of ~150 observations of different sources, optimally reduced, fit with spectral models defined on a source-by-source basis[1]. The conclusion of this calibration study was that the equivalent width of this feature (39^{+11}_{-21} eV) is larger than the typical systematic uncertainties in this band (less than 5.3 eV) arguing against the instrumental origin.

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

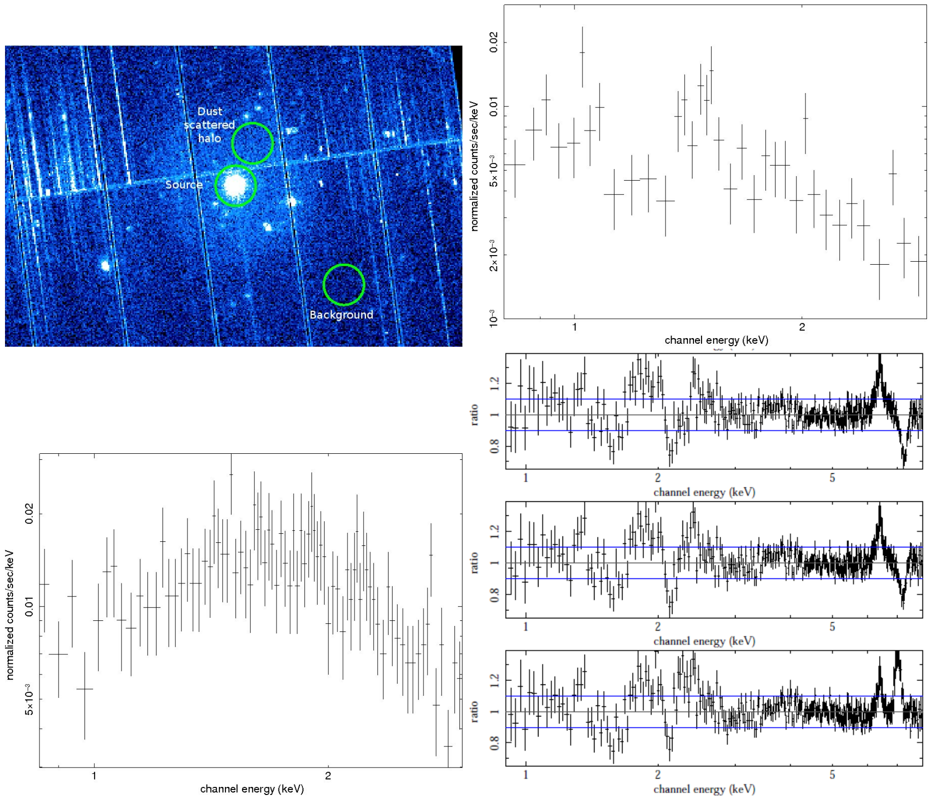

Figure 1: The circles show the extraction region (*left top*) from the background spectrum (*right top*) and the dust scattered halo spectrum (*left bottom*). Some residuals between the spectrum and the model changing the gain and offset values are also shown (*right bottom*).

Then we look for possible astrophysical origins. We have extracted spectra from two blank regions (see Figure 1 left top image) containing only the background and the background plus halo, using the same extraction radius. The spectrum of the dust scattered halo area has been corrected for the background. As can be seen, no absorption feature can be detected at 2.1 keV in any of them. The absorption feature appears only when the source is included in the extraction region suggesting a system origin. On the other hand, we tested the possibility that the soft component was due to the presence of an ionized absorber. Adopting the Absori model in xspec ([3]), we obtained an unsatisfactory fit to the data and there were still strong negative residuals around 2.1 keV.

In 4U 1538−52, assuming the observed feature is most likely intrinsic to the NS, there are two potential ways for the absorption feature to be generated in the NS atmosphere: cyclotron lines and atomic transition lines.

- **Cyclotron lines:** This hypothesis does not look plausible because this system presents two electron-cyclotron lines at ~21 keV and ~47 keV ([2, 9]). Alternatively, one can assume that this feature is associated with ion-cyclotron energies. However, the surface magnetic field needed for this interpretation is greater than the magnetic field inferred for the electron-cyclotron lines.

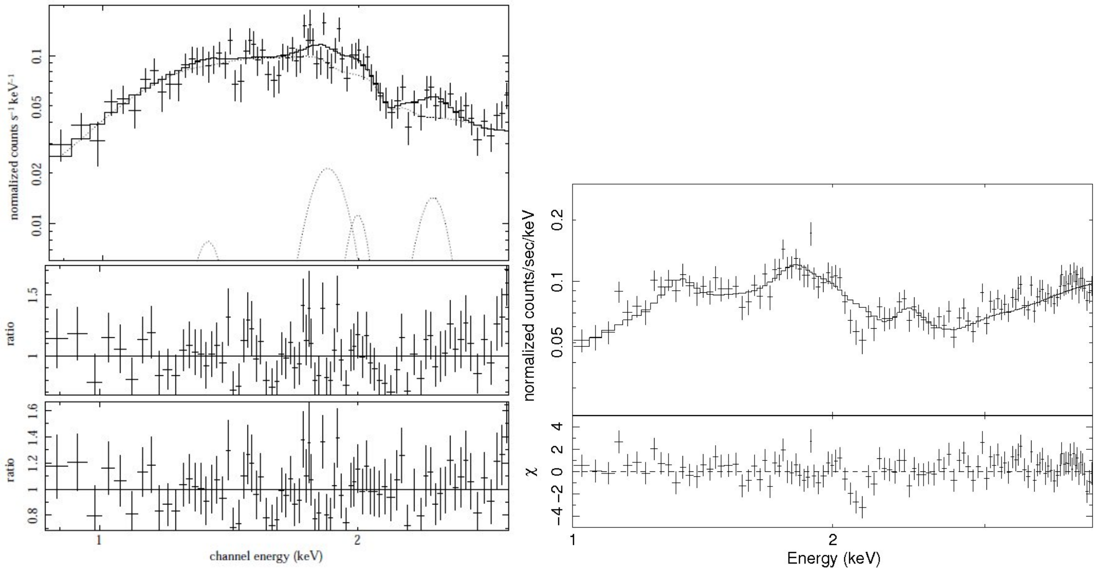

Figure 2: Recombination emission lines of He- and H-like species in the eclipse spectrum of 4U 1538−52. *Left top panel*: Spectrum and best fit model (an absorbed power-law modified by a Gaussian absorption line and four Gaussian emission lines) in the 0.8–3.0 keV energy range obtained with *PN* camera. *Left middle panel*: Residuals when comparing the data to a simple absorbed power-law plus four emission lines. *Left bottom panel*: Residuals when the absorption line has been included in the model. *Right panel:* Spectrum and best fit model (top) and residuals without the absorption line (bottom).

- **Atomic lines:** This possibility implies that the feature is formed in the NS atmosphere. We can exclude this feature as emerging from a hydrogen atmosphere because at any magnetic field and any reasonable redshift, there is no pair of strong hydrogen spectral lines whose energies would match the observed one. Therefore, one has to invoke heavier elements. Another possibility is an iron atmosphere at B around 10^{12} G ([5], [7]), but the iron atmosphere should show many more lines than the only one observed in the X-ray band ([8]) and an unreasonable value of gravitational redshift ([7]). An O/Ne atmosphere (He-like Oxigen, Li-like Oxygen) at B around 10^{12} G is plausible with the observed feature energy ([7]). However, the O/Ne atmosphere should show other absorption features at lower energies, but the soft excess of the system prevents us any confirmation about their presence.

4. Conclusions

We have presented the spectral analysis of the HMXB 4U 1538−52 using an *XMM-Newton* observation focusing our attention specifically within the energy range 0.8–3.0 keV. In this work, we show that the *XMM* spectrum of 4U 1538−52 shows a deep significant absorption feature at around 2.1 keV. 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.

Based on the spectral analysis we have derived the following conclusions:

- We conclude that the line is most likely of astrophysical origin and it is formed in the wind or the atmosphere of the NS.

- An O/Ne atmosphere is plausible, although other absorption lines should show at lower energies. The soft excess of the system and the *RGS* low level of counts prevents us any confirmation about their presence.

- Through a search in the main atomic lines databases we would have suggested it is due to atomic transitions of hydrogen and helium like Fe or Si ions but, existing models of ionized absorbers can not account for the line.

Acknowledgments

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