Cyclotron Resonance Scattering Feature in 4U 1538-522

Abstract

We have analysed the NuSTAR spectra for 4U 1538-522 using a phenomenological model to study the Cyclotron Resonance Scattering Feature (CRSF) and compare our results with those obtained from AstroSat-LAXPC data. We obtain a well constrained CRSF around 22 keV which is consistent with LAXPC results. We also detect a narrow Fe Kα emission line around 6.4 keV and report a 90% confidence range for both.

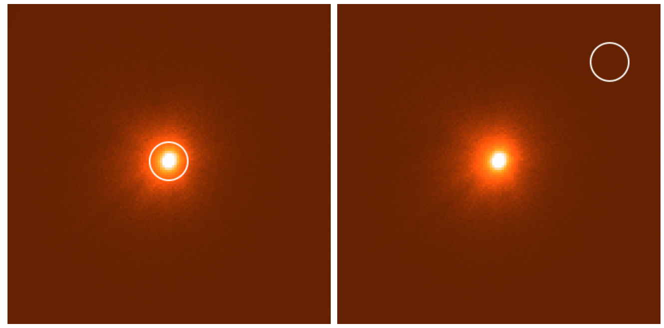
1 Introduction

X-ray binaries are an interesting class of binary stars which are luminous in the X-ray energy band. They usually comprise of a normal main sequence star and a compact object (neutron star or black hole). The pair has to be close enough for the compact object to accrete matter from its companion and hence emit X-rays. The spectra of these objects are thoroughly studied to determine and constrain their physical properties.

Varun et al. (2019) have studied one such X-ray binary - 4U 1538-522 using AstroSat-LAXPC data to determine its cyclotron line characteristics, popularly known as the Cyclotron Resonance Scattering Feature (CRSF; Schönherr et al., 2007). This feature arises from the strong magnetic fields of neutron stars, and often appears as a broad absorption in the spectrum. The centroid energy of CRSF can be used to determine the magnetic field. In this study, we analyse the NuSTAR (Harrison et al., 2013) data for the same X-ray binary and compare our results with Varun et al. (2019).

2 Observation and Data Reduction

NuSTAR is a hard X-ray imaging telescope operating in the 3-79 keV energy band. 4U 1538-522 has been observed by NuSTAR a total of four times. We have used the latest observation publicly available on HEASARC, dated 2019 May 02. We retrieved the clean event files for both FPMA and FPMB detectors created by the NuSTAR Science Operations Center. The spectra were obtained using the NUPRODUCTS command, part of the HEASOFT V6.28.2. Circular extraction regions of 20" radius were used for the source and background spectra calculation, as shown in Figure 1.



(a) (b)

Figure 1
FPMA image of 4U 1538-522, along with source (a) and background (b) regions

The spectra obtained were rebinned to have 70 minimum counts per energy bin, using the *grppha* grouping tool (Blackburn, 1995) in HEASOFT.

3 Spectral Analysis

Both the FPMA and FPMB spectra were loaded together in XSPEC (Arnaud, 1996) for simultaneous analysis. Keeping in mind the objective to compare results with Varun et al, the 4-40 keV energy range was chosen. For X-ray binaries such as 4U 1538-522, the continuum spectra at high energies are usually modelled phenomenologically by various models comprising of a powerlaw with quasi exponential high energy cutoffs. Of the various models mentioned in Varun *et al*, we have used the `highecut` model.

In order to fit simultaneously, a constant multiplier was used to account for the minor differences in gains of FPMA and FPMB. A galactic absorption factor was also used with a fixed value of nH = 0.74E+22 cm^{-2}(HI4PI Collaboration et al., 2016). The model in XSPEC notation can be written as `constant*tbabs*highecut*powerlaw`. Figure 2 shows the plot of a simultaneous fit performed using the `fit` command.

As evident in the figure, the continuum model fails to describe the data adequately, and gives a relatively poor fit with a Chi-Squared value of 1832 for 882 dof. The model particularly fails to account for the emission feature around 6.4 keV (expected to be Fe Kα line) and the absorption feature around 22 keV (CRSF).

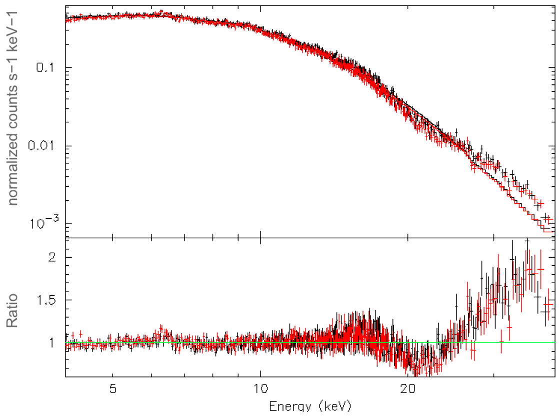


Figure 2

Top panel: FPMA (red) and FPMB (black) spectra shown with the initial simultaneous model fit; Bottom panel: Ratio of data to model. Notice features around 6.4 keV and 22 keV

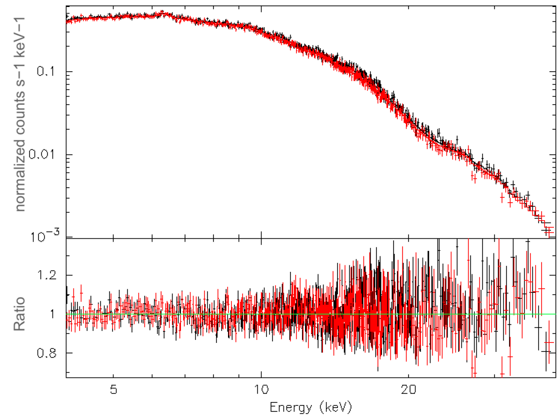


Figure 3

Top panel: FPMA (red) and FPMB (black) spectra shown with the modified simultaneous model fit; Bottom panel: Ratio of data to model. The features have been accounted for.

The feature around 6.4 keV was modelled by a Gaussian using the model component `gauss` in XSPEC. The feature around 22 keV was modelled with an absorbed Gaussian component `gabs`. After these modifications, the new model can be written as `const*tbabs*highecut*gabs*(powerlaw+gauss)`. Figure 3 shows the plot obtained after simultaneous fitting of the new model.

4 Discussion and Conclusion

The modifications made to the model significantly improved the statistics of the fit, giving a Chi-Squared value of 901 for 876 dof. Table 1 shows the best fit values obtained for the new model. The Fe Kα emission line is constrained within 6.30-6.39 keV, and the CRSF is constrained within 21.7-22.1 keV with 90% confidence. The results obtained are consistent with Varun et al. (2019) and comparable to Hemphill et al. (2016). Our results therefore prove as an additional confirmation of the Cyclotron Resonance Scattering Feature observed in 4U 1538-522 by AstroSat-LAXPC in July 2017.

5 Acknowledgements

This study has used the archival NuSTAR data available at the High Energy Astrophysics Science Archive Research Center Online Service, provided by the NASA Goddard Space Flight Center.

References

Arnaud, K. A. 1996, in Astronomical Society of the Pacific Conference Series, Vol. 101, Astronomical Data Analysis Software and Systems V, ed. G. H. Jacoby & J. Barnes, 17

Blackburn, J. K. 1995, in Astronomical Society of the Pacific Conference Series, Vol. 77, Astronomical Data Analysis Software and Systems IV, ed. R. A. Shaw, H. E. Payne, & J. J. E. Hayes, 367

Harrison, F. A., Craig, W. W., Christensen, F. E., et al. 2013, ApJ, 770, 103, doi: 10.1088/0004-637X/770/2/103

Hemphill, P. B., Rothschild, R. E., Fürst, F., et al. 2016, MNRAS, 458, 2745, doi: 10.1093/mnras/stw470

HI4PI Collaboration, Ben Bekhti, N., Flöer, L., et al. 2016, A&A, 594, A116, doi: 10.1051/0004-6361/201629178

Schönherr, G., Wilms, J., Kretschmar, P., et al. 2007, A&A, 472, 353, doi: 10.1051/0004-6361:20077218

Varun, Maitra, C., Pragati, P., Harsha, R., & Biswajit, P. 2019, MNRAS, 484, L1, doi: 10.1093/mnrasl/sly234

Component	Parameter	Unit	Value
TBabs	nH	10^{22}	0.740000 frozen.
highecut	cutoffE	keV	13.9759 +/- 0.151015
highecut	foldE	keV	11.8326 +/- 0.170793
gabs	LineE	keV	21.9033 +/- 0.115229
gabs	Sigma	keV	2.67280 +/- 0.133965
gabs	Strength		3.23997 +/- 0.197889
powerlaw	PhoIndex		1.14213 +/- 6.71966E-03
powerlaw	norm		3.76742E-02 +/- 5.36715E-04
gaussian	LineE	keV	6.34690 +/- 2.90692E-02
gaussian	Sigma	keV	8.47063E-02 +/- 5.20071E-02
gaussian	norm		2.55663E-04 +/- 3.08724E-05

Table 1

Best fitting spectral parameters for 4U 1538-522 using the modified continuum model