

On the Characteristics of Line Emissions from Binary X-ray Sources & Supernova Remnants

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X-ray spectroscopy of celestial X-ray sources can yield extremely interesting results on the physical conditions and processes that are responsible for the emission from these sources. Iron line emission at about 6.8 keV from many supernova remnants and X-ray binaries has already been observed by several workers. In this paper we present the available data on iron line emission from Tycho, Cas A and Her X-1 and discuss the implications.

1. Introduction

Iron line emission at energies around 6.8 keV has been observed in the X-ray spectra of several binary X-ray sources, supernova remnants and clusters of galaxies. Most of these results have been obtained from experiments employing proportional counters flown on rockets and on Ariel 5, OSO-8 and HEAO-1 satellites. Marar *et al.*¹ while reviewing the status of line emissions from supernova remnants had reported new evidence for the emission of sulphur lines at an energy of ~ 2.5 keV in the spectra of Cas A and Tycho supernova remnants. This evidence had been deduced from the X-ray spectra published by Gorenstein *et al.*² Sulphur line emission from Cas A has since been confirmed³ by means of more sensitive experiments flown on the HEAO-1 satellite.

In this paper the available data on iron line emission from two supernova remnants Cas A and Tycho are discussed and the relative abundances of iron and sulphur in them are derived. The iron line features in Her X-1 are also investigated.

2. Supernova Remnants

Table 1 lists the supernova remnants Cas A, Tycho and G287.8-0.5 from which iron line emis-

sion has been observed. An emission feature at 6.8 keV (1.85Å) has been observed in their spectra. Thermal spectra with temperatures in the range of $(40-60) \times 10^6$ K fit the X-ray observations of Cas A and Tycho. The flux in the emission feature arises from the resonance transition $1s^2-1s2p^1P$, the forbidden transition $1s^2-1s2s^3S$ and a number of satellite transitions of the Fe XXV ion. There may also be a small contribution from the Lyman- α line of Fe XXVI. A proportional counter does not have the necessary energy resolution to separate the individual line contributions and in fact gives only a measure of the total flux from all of them. We have listed in Table 1 the luminosity of the iron line feature and the luminosity of the continuum from 1-10 keV, both derived from the X-ray spectra of the remnants published in the references cited in the last column of Table 1. We note that the continuum luminosities (1-10 keV) reported by Culhane⁶ appear to be in error by at least an order of magnitude for the above three remnants. Our values of the ratio R of the luminosity of the line to that of the continuum differ significantly from those reported by Davison *et al.*,⁴ who used the continuum flux from 1 to 6 keV only. Had the continuum flux from 1 to 10 keV been used by

Table 1 — Iron Line Emission from Supernova Remnants

Source	Distance kpc	Temperature ($\times 10^6$ K)	Luminosity of iron line erg/sec	Continuum luminosity 1-10 keV erg/sec	Line feature to continuum ratio (R)	R From Davison <i>et al.</i> *	Reference
Cas A	3	59.7	6.14×10^{34}	3×10^{36}	0.02	0.14	4
Tycho	6	40.6	2.29×10^{34}	4×10^{36}	0.005	0.07	4
G 287.8-0.5	2.5	80	1.07×10^{34}	1×10^{35}	0.107	—	5

*Davison *et al.* use a distance of 3 kpc to Tycho as well as Cas A. They use continuum flux from 1 to 6 keV. If one uses continuum flux from 1 to 10 keV, R becomes 0.127 for Cas A and 0.069 for Tycho.
(see text)

Table 2 — Other Lines from SNRs

Source and distance kpc	Feature and its energy	Luminosity of feature erg/sec	Continuum luminosity erg/sec	Feature to continuum ratio	Reference number
Cas A (3)	Sulphur line 2.46 keV	1.62×10^{35}	3×10^{36} (1-10 keV)	0.54	2
Tycho (6)	do	2.4×10^{35}	4×10^{36} (1-10 keV)	0.60	2
Puppis A (2.2)	Oxygen 0.68 keV	3.57×10^{35}	2×10^{36} (0.5-2 keV)	0.18	9

Davison *et al.*⁴ the value of R would have changed from 0.14 to 0.127 for Cas A and from 0.07 to 0.069 for Tycho. These may be compared to our new values of 0.02 and 0.005, respectively. For a plasma with a temperature in the range $(40-60) \times 10^6$ K and a cosmic iron abundance ($N_{\text{Fe}}/N_{\text{H}}$) of 5×10^{-5} calculations by Mewe,⁷ and Tucker and Koren⁸ show that the expected value of the ratio of Fe XXV line and continuum fluxes is about 0.07. Hence our results indicate that the iron abundances in Cas A and Tycho are below the cosmic value; this contradicts the results obtained by Davison *et al.*⁴ who found that the iron abundance is equal to the cosmic value in Tycho and a factor two greater in Cas A. This may also mean that the assumption of dynamic equilibrium between ionization and recombination that one uses for coronal plasmas^{7,8} may not be applicable to the thermal X-ray emission from supernova remnants.

In Table 2 we give the results on the other X-ray lines observed from supernova remnants. Sulphur line emissions at ~ 2.5 keV from Cas A and Tycho observed in the spectra reported by Gorenstein *et al.*² and first pointed out by us are at the 4σ and 2.1σ significance level, respectively. HEAO-1 observations have confirmed the sulphur line emission from Cas A.

From calculations by Raymond and Smith,¹⁰ for an optically thin plasma with cosmic abundance and a temperature of $\sim 60 \times 10^6$ K, the ratio of the luminosities of the sulphur and iron lines ($L_{\text{S}} / L_{\text{Fe}}$) is expected to be ≈ 1.30 . We find that for Cas A this ratio is 2.64, indicating an overabundance of sulphur in comparison to the abundance of iron by a factor of 2. For Tycho at a temperature of 40×10^6 K deduced from the X-ray spectrum, the expected value of the ratio $L_{\text{S}} / L_{\text{Fe}} \approx 1$, while the observed ratio is ~ 10.5 . It appears therefore that sulphur is strikingly overabundant in Tycho when compared to the abundance of iron.

3. Her X-1

The iron line emission from the well studied binary X-ray source Her X-1 reveals many interesting

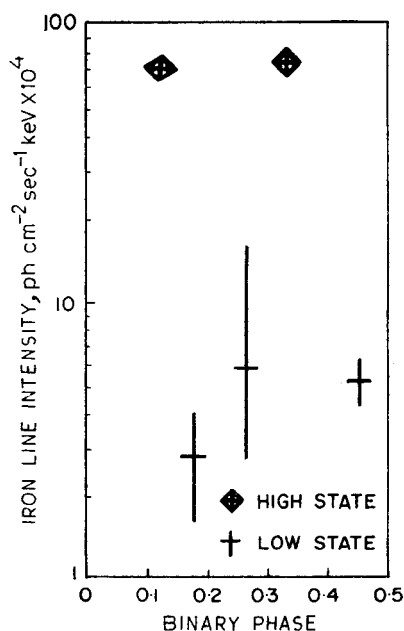


Fig. 1 — Iron line intensity versus orbital phase of Her X-1

features. Line emission occurs during the high as well as the low states. Fig. 1 shows a plot of the intensity of the iron line feature as a function of the orbital phase during the high and low states. While there is no evidence for variation of the intensity with phase during the high state, the available data during the low state indicate such a variation, with a maximum around phase 0.5. If the low state iron line emission is produced by fluorescence, say, from the surface of the primary star HZ Her or from a hot coronal gas around HZ Her, one does not expect iron line flux to be observed at phases ϕ such that $0.86 < \phi < 0.14$, since the reflected flux exhibits an eclipse twice as long as the normal eclipse which lasts during $0.93 < \phi < 0.07$. It would therefore be worthwhile to measure Her X-1 low state iron lines at phases between 0.07 and 0.14, and between 0.86 and 0.93 in order to verify this model. One or two measurements between phases 0.5 and 0.86 are also necessary to confirm unequivocally the variation with phase of the iron line emission.

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