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# Spectroscopic studies of 4U1735 – 44; Evidence for binary motion

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**Summary**. We have obtained optical spectroscopy of the X-ray burst source 4U1735 – 44 with spectral resolution of ~ 1.6 Å and a time resolution of ~ 30 min. There is strong evidence for cyclic He II velocity variations, but we are unable to confirm or deny either of the previously reported possible binary periodicities in the source. However, kinematic arguments suggest that the companion can be classified as being of spectral type F0–K5 V and the presence of the Ca II K interstellar absorption line at λ3933 leads to a lower limit on the distance of the source of ~ 2.0 kpc.

## 1 Introduction

The galactic bulge objects 4U1636 – 53 and 4U1735 – 44 are two of the more interesting burst sources in that simultaneous observations of X-ray and optical bursts have now been well documented (Pedersen *et al.* 1982; Grindlay *et al.* 1978). X-ray bursts from 4U1735 – 44 were originally detected by *SAS-3* (Lewin *et al.* 1977), and an optical identification with a faint emission-line star was made soon afterwards (McClintock *et al.* 1977). Timing studies of these objects and allied spectroscopic work indicate that the optical bursts originate from reprocessing in an accretion disc (McClintock *et al.* 1979; Pedersen *et al.* 1982, Canizares, McClintock & Grindlay 1979). Reports of periodicity in 4U1735 – 44 have so far been contradictory, with photometric evidence in favour of a ~ 4.3 hr period with an amplitude of 0.2 mag (McClintock & Petro 1981) and spectroscopy suggesting velocity variations on a 2.86 hr cycle (Hutchings, Cowley & Crampton 1983).

It has proved to be particularly difficult to classify the primaries in low-mass X-ray binaries, due to the small fraction of the optical light that they provide. Firm observational evidence that X-ray bursters are binary systems has also proved difficult to obtain (van

**Table 1.** Line positions and equivalent widths for the observed spectral features.

| Date, MJD | Blend wavelengths* (Angstroms) |  | Equiv. Widths (Angstroms) |  |
|---|---|---|---|---|
| 81 Jul 25 | NIII | CIII | NIII | CIII |
| 44809.482 | 4638.0 ± 1.3 | 4653.6 ± 3.3 | 1.4 ± 1.1 | 0.6 ± 0.5 |
| 44809.507 | 4638.9 ± 3.5 | 4654.1 ± 1.2 | 1.5 ± 1.5 | 0.6 ± 0.5 |
| 44809.531 | 4643.9 ± 0.7 |  | 4.5 ± 2.3 |  |
| 44809.556 | 4639.9 ± 4.0 |  | 6.9 ± 3.2 |  |
| 83 Jul 4 |  |  |  |  |
| 45519.567 | 4642.4 ± 1.5 |  | 2.1 ± 1.0 |  |
| 45519.590 | 4639.6 ± 0.5 | 4649.7 ± 0.8 | 1.6 ± 0.6 | 0.7 ± 0.5 |
| 45519.613 | 4638.6 ± 2.4 |  | 3.7 + 1.4 |  |
| 45519.636 | 4634.0 ± 0.6 | 4646.4 ± 1.8 | 1.4 ± 0.7 | 3.3 ± 1.4 |
| 45519.659 | 4633.9 ± 0.5 | 4648.9 ± 0.3 | 7.2 ± 1.3 | 1.7 ± 0.6 |
| 45519.682 | 4639.1 ± 0.2 |  | 0.8 + 0.3 |  |
| 45519.705 | 4637.1 ± 0.8 | 4648.7 ± 0.2 | 2.8 ± 1.1 | 2.1 ± 0.7 |
| 45519.728 | (4628.0 ± 1.7) | (4665.6 ± 0.6) | (12 ± 4) | (9 ± 2) |

|  | He II 4686* (Angstroms) |  | Equiv. Widths (Angstroms) |  |
|---|---|---|---|---|
| 81 Jul 25 |  |  |  |  |
| 44809.482 | 4684.0 ± 0.8 |  | 1.4 ± 1.0 |  |
| 44809.507 | 4683.0 ± 0.8 | 4690.7 ± 0.9 | 1.9 ± 1.1 | 0.3 ± 0.3 |
| 44809.531 | 4681.7 ± 0.9 | 4688.9 ± 1.9 | 1.3 ± 1.0 | 1.5 ± 1.4 |
| 44809.556 | 4684.4 ± 0.8 | 4679.4 ± 2.1 | 1.2 ± 0.6 | 0.3 ± 0.3 |
| 83 Jul 4 |  |  |  |  |
| 45519.567 | 4680.3 ± 0.2 |  | 3.0 ± 0.7 |  |
| 45519.590 | 4681.3 ± 0.5 | 4686.4 ± 0.4 | 2.7 ± 1.0 | 0.5 ± 0.4 |
| 45519.613 | 4684.6 ± 0.5 |  | 2.7 ± 0.6 |  |
| 45519.636 | 4685.1 ± 0.2 | 4690.1 ± 0.3 | 1.5 ± 0.5 | 1.4 ± 0.6 |
| 45519.659 | 4686.1 ± 0.4 |  | 5.0 ± 1.0 |  |
| 45519.682 | 4687.9 ± 0.8 |  | 6.2 ± 1.3 |  |
| 45519.705 | 4685.6 ± 0.2 |  | 1.7 ± 0.6 |  |
| 45519.728 | (4683.4 ± 0.4) |  | (9.0 ± 1.9) |  |

* Two wavelengths are given for the He II line when it is split, one wavelength is given for both Bowen blends when separation is impossible.

Paradijs 1983). We present here the results of an attempt to reach a more detailed understanding of the basic parameters of 4U1735 – 44, using time resolved, high resolution spectroscopy to search for radial velocity variations.

## 2 Observations

The first set of four consecutive spectra (integration time 2000 s) were obtained at the Anglo-Australian telescope (AAT) on 1981 July 25, using the RGO spectrograph and IPCS, working at 66 Å mm$^{-1}$. A further series of seven consecutive 1800 s integrations was made at the AAT on 1983 July 4 at 33 Å mm$^{-1}$, and in this sequence the object and a comparison star (star 3 in the notation of Jernigan *et al.* 1977) were observed simultaneously along the slit. An eighth integration had to be curtailed after ~ 900 s due to cloud. By careful use of Cu-Ar arc spectra between integrations we obtained a wavelength calibration of better than ~ 0.05 Å. The projected slit width was 1.6 Å, and the instrumental resolution was 1.61 ± 0.01 Å (FWHM).

The data were all analysed with the same computer program, which fitted Gaussian line profiles plus a parabolic continuum to the emission lines. This procedure is based on the Marquardt algorithm (Bevington 1969) and utilizes a non-linear least-squares fitting technique. Arc lines close to the spectral lines of interest were similarly fitted so as to minimize any systematic errors, improving the relative accuracy between the two data sets to ~ 0.01 Å. The observations, and the values obtained for the fits, are summarized in Table 1.

## 3 Results

The spectrum of 4U1735 – 44 is characterized by a blue continuum with weak highly variable emission lines (McClintock, Canizares & Backman 1978). Both sets of our spectra are similar (Fig. 1), with the most dominant features in the summed spectra being He II

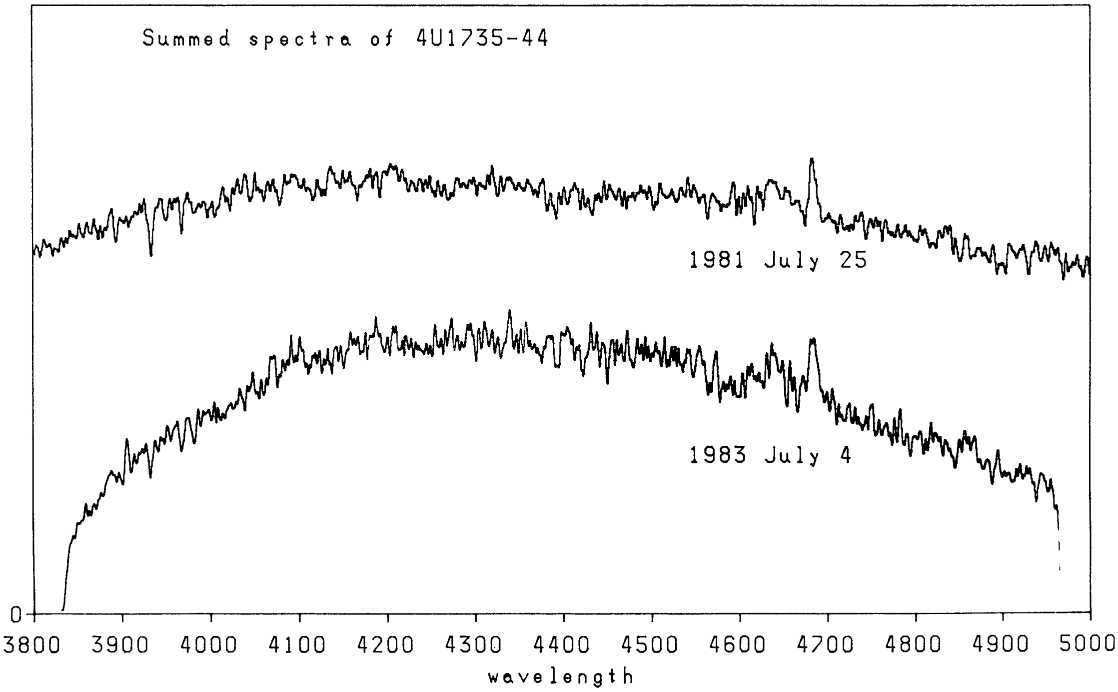

**Figure 1.** The summed spectra from the two series of integrations.

λ4686, and the N III/C III blend at λλ4630–50. There are hints of N III emission at λ4100, and He II λ4541, but the possible O II at λ4300 previously observed (Canizares *et al.* 1979) is ambiguous in our observations. A persistent narrow Ca II *K* absorption feature at λ3933 is present in both data sets (eq. widths = 0.7 ± 0.3 Å and 0.6 ± 0.3 Å).

A detailed discussion of the λ4640 emission in X-ray stars (McClintock, Canizares & Tarter 1975) established that the Bowen fluorescence process is responsible for the broad, structureless feature in this region, with the C III blend centred at ~ λ4650, and the N III at ~ λ4639, and at λλ4097 + 4103. Unfortunately, the related O III λ3774, λ3791 emission lines are beyond our wavelength range in one case, and not clearly visible in the other.

The individual spectra show considerable variation in the shape of the He II line, as can be seen in Fig. 2. The line is clearly identifiable in the 1981 observations, but in the 1983 set is so weak as to be barely separable from the continuum in integrations 3 and 4. It frequently shows signs of double peaks (integrations 2, 4, 6, 8 of 1983), perhaps caused by motions in the disc. At any given time the line is spread over 500–1000 km $s^{-1}$. Assuming

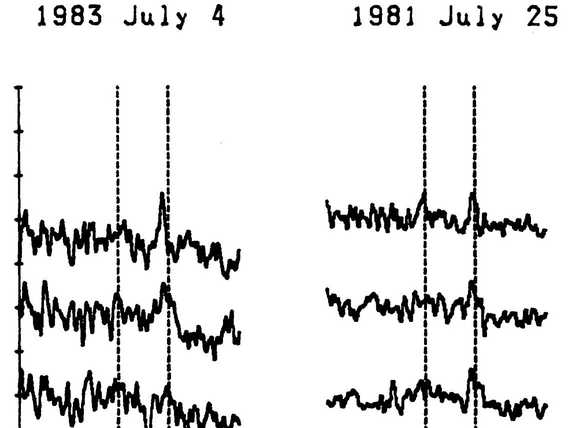

**Figure 2.** Spectra from individual integrations, highlighting radial velocity variations in the He II λ4686 line. The dotted lines indicate the rest positions of the λ4686 line and the λ4640 Bowen blend as a guide to the eye.

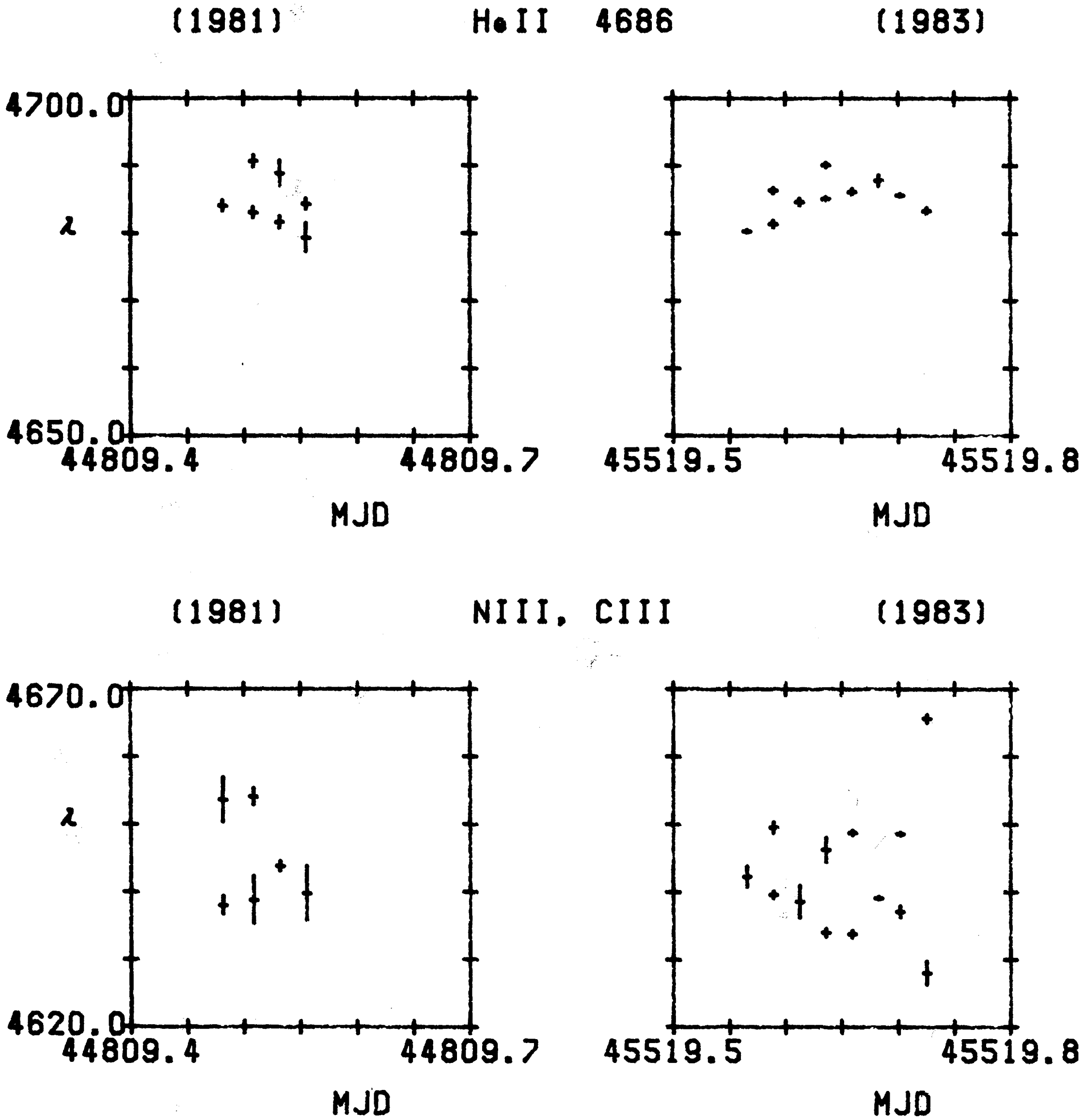

**Figure 3.** Plots of He II λ 4686 line and the C III and N III Bowen blends against Modified Julian Date. The vertical extent of the cross gives the degree of uncertainty of the measurement.

a neutron star mass of $1.4\,M_\odot$ this linewidth corresponds to an orbital radius of $\sim 0.5\,R_\odot$ for the emitting material.

A summary of line positions and equivalent widths of the important features of the spectra appears in Table 1, and a graphial representation of this appears as Fig. 3. Estimates of the errors in the fitting of each line are included.

A guide to the relative intensity of 4U1735 – 44 during the 1983 observations can be obtained by taking the ratio of the target object and the comparison star, for the waveband examined (λλ 3800 – 5000). These data are plotted in Fig. 4, and show that there were significant variations in luminosity during the observations.

## 4 Discussion

When bursts occur, the observed delay of optical bursts with respect to X-ray bursts of 1–3 s (McClintock *et al.* 1979) implies that reprocessing of X-rays takes place in matter

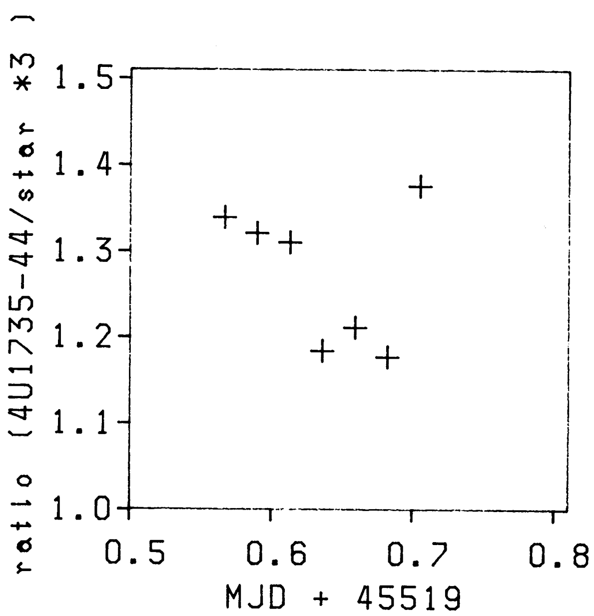

**Figure 4.** Plot of the ratio of the total counts in the waveband from the comparison star and the object star, against time (MJD + 45519). The size of the cross indicates the uncertainty in the measurement.

in the vicinity of the compact object. Pedersen *et al.* (1982) construct a detailed model of the optical bursts in the similar system 4U1636 – 53 and conclude that the site for reprocessing is an accretion disc with radius close to that of the Roche lobe around the neutron star. The observed lack of eclipses among this class suggests that this disc is thick (Milgrom 1978; Hammerschlag-Hensberge, McClintock & van Paradijs 1982). We will thus assume as a starting point that the He II λ4686 line is formed by reprocessing in the inner part of the accretion disc, rather than in streaming material beyond, and falling into, the disc.

It can be seen from Fig. 3 that there is evidence of cyclic behaviour in the He II λ4686 line, which implies a cycle length of ~ 4 hr. However, this is not sufficient to confirm or deny either the 4.3 hr photometric period or the possible 2.86 hr spectroscopic period for 4U1735 – 44. Hutchings *et al.* (1983) derive velocity variations in the C III and N III Bowen blends which are very large, but it is important to emphasize that variable X-ray illumination of the emitting region will lead to just such a shift in the ionization balance of these blends, thus rendering them of dubious value in determining the dynamics of the system. An examination of Fig. 3 shows that while the He II variations are reasonably well-behaved, the blend positions we derive appear to be subject to considerable scatter.

The difference between the maximum and minimum observed wavelength of the He II λ4686 line (in the 1983 observations alone) of 5.8 ± 0.6 Å (ignoring integration 6, in which the line structure is confused) implies that $K_X$, the velocity semi-amplitude of the X-ray object, is 186 ± 19 km s$^{-1}$. From the photometric period and the supposition that the secondary is a Roche-lobe filling main-sequence star, McClintock & Petro (1981) find a spectral type for the primary of M0. However, this would imply a maximum velocity semi-amplitude of 137 km s$^{-1}$, which is much smaller than observed.

This datum allows us to set a lower limit on the mass of the companion, given some further assumptions. We choose 1.0 and 1.5 $M_\odot$ to cover the range of expected neutron star masses. The absence of X-ray eclipses constrains the system inclination to be less than 70° (Chanan, Middleditch & Nelson 1976). Application of Kepler's law for periods of 2.86 and 4.3 hr then leads to the minimum companion masses given in Table 2. The latest possible spectral type for the companion under these assumptions is about K5 V (Allen

**Table 2.** Table of allowed masses for the companion star.

| Period (hrs) | $M_x$ | $M_s$ | q | spectral type |
|---|---|---|---|---|
| 4.3 | 1.0 | $> 0.77$ | $< 1.30$ | earlier than K0 |
| 4.3 | 1.5 | $> 0.95$ | $< 1.58$ | " G5 |
| 2.86 | 1.0 | $> 0.63$ | $< 1.59$ | " K5 |
| 2.86 | 1.5 | $> 0.78$ | $< 1.92$ | " K0 |

$q = M_x/M_s$. $M_x$ and $M_s$ in solar masses.

1973). The derived masses are strongly dependent upon the K-velocity and thus the results in Table 2 are subject to an uncertainty of ± half a spectral class.

Canizares *et al.* (1979) have shown that the distribution of burst sources and the distance thus derived conspires with the optical faintness of the source and the lack of stellar features to limit the spectral type of the companion to later than ~ F0. Thus the range of spectral types permitted becomes F0–K5 V.

The centroid of the Ca II K line shows no radial velocity variation and is identified with interstellar absorption, although other expected interstellar bands at λ4428 and λ4882 (Herbig 1975) are not present, the former at a level substantially below that expected. The equivalent width of the Ca line argues for a distance of ~ 2.0 kpc (Allen 1973). However, given the galactic coordinates of the souce ($l = 346.1$, $b = -7.0$) (Jernigan *et al.* 1977) and an assumed galactic scale height of ~ 100 pc, it is likely that most of the interstellar absorption takes place within the first kiloparsec, so we take this figure as a lower limit. Assuming a distance comparable with the other intense galactic bulge sources places it amongst the galactic halo sources, at a height of ~ 1.2 kpc above the galactic plane.

## 5 Conclusions

The analysis of high-resolution spectra, and system constraints imposed by previous observations, suggest that the minimum mass of the secondary is ~ $0.63\,M_\odot$. Thus a tentative estimate of the spectral type is F0–K5 V. Interstellar absorption provides a lower limit to the distance of the source of 2 kpc, although it is more likely to be a galactic halo source at 5–10 kpc. However, the period of 4U1735 – 44 is still unconfirmed and more high-resolution spectroscopic work will be required before a sufficiently accurate set of radial velocities can be obtained.

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