A TiO study of the black-hole binary GRO J0422+32 in a very low state

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ABSTRACT

We present 53 simultaneous photometric (I band) and spectroscopic (6900-9500 Å) observations of J0422+32, taken during December 1997. From these we determine that J0422+32 was in its lowest state yet observed, at $I=20.44 \pm 0.08$. Using relative spectrophotometry, we show that it is possible to correct very accurately for telluric absorption. Following this, we use the TiO bands at 7055 Å and 7589 Å for a radial velocity study and thereby obtain a semi-amplitude of $378 \pm 16$ km s$^{-1}$, which yields $f(M)=1.191 \pm 0.021 M_\odot$ and $q=9.0^{+2.7}_{-1.2}$, consistent with previous observations. We further demonstrate that this little explored method is very powerful for such systems. We also determine a new orbital ephemeris of $HJD=2450274.4156 \pm 0.0009 + 0.2121600 \pm 0.0000002 \times E$.

We see some evidence for an ellipsoidal modulation, from which we determine the orbital inclination of J0422+32 to be less than $45^\circ$. We therefore calculate a minimum mass for the primary of $2.22 M_\odot$, consistent with a black hole, but not necessarily the super-massive one proposed by Beekman et al (1997). We obtain a M4-5 spectral type for the secondary star and determine that the secondary contributes $38 \pm 2\%$ of the flux that we observe from J0422+32 over the range 6950-8400 Å. From this we calculate the distance to the system to be $1.39 \pm 0.15$ kpc.

Key words: black hole physics - binaries: close - stars: fundamental parameters - stars: individual (GRO J0422+32) - stars: late-type - accretion, accretion discs.

1 INTRODUCTION

From the study of X-ray transient systems, it is possible to determine the masses of stellar-mass black-holes, by observing the cool secondary star during quiescence (see e.g. Charles, 1999). In this paper we present new observations of the late-type secondary star in the soft X-ray transient GRO J0422+32 (Nova Per 1992/ V518 Per). Since the discovery of J0422+32 on August 5th 1992, whilst in outburst, by the ‘Compton Gamma Ray Observatory’ (Paciesas et al, 1992), there have been three subsequent ‘mini’ outbursts: December 1992 (Harmon, Fishman & Paciesas, 1992), August 1993 (Filipenko & Matheson, 1993) and December-January 1993/4 (Zhao et al, 1993). The system has been observed at $I=20.03$ (Orosz & Bailyn 1995) and $I=20.22$ (Casares et al 1995), but never, as we show in this paper, in absolute quiescence. Therefore, observations in the optical have been dominated by the flux emitted from the accretion disc around the compact object, making observations of the M-star difficult. Here we present results showing that J0422+32 was fainter still in December 1997, thus observations of the secondary were more accessible, due to less contamination from the disc.

Previously, Beekman et al (1997) have determined a minimum mass of the compact object (black hole) of $15 M_\odot$, from an I band light-curve. From calculations by King, Kolb & Burderi (1996) based on the ‘disc instability model’, where the mass transfer rate must be below a critical level in order for low mass X-ray binary systems to become transient, a minimum mass of the compact object can be calculated. If their assumptions are correct, Beekman et al (1997) calculated a minimum mass of the compact object of $28 M_\odot$. This mass is impossibly large for stellar evolution models. From studying the ellipsoidal modulation alone, we constrain the black-hole to have a much lower minimum mass, which is consistent with the evolution of massive stars that form black holes.

We present a new method for conducting a radial velocity study in such systems with a late-type secondary star. Previously, the strong TiO features seen in M-stars have not been used, as it is very difficult to correct accurately for the telluric absorption that lies on top of them. Instead, the Na I
doublet at 8183, 8195Å is commonly used. However, by placing two stars along the slit, J0422+32 and a local early-type star, we can correct for the telluric absorption very accurately. It was also thought that the TiO bands were far too broad to allow accurate cross correlation. The bands themselves are broad, but have within them, very sharp features. In this work we show, using the two TiO bands at 7055Å and 7589Å, how effective cross-correlating these regions can be. We also exploit the good telluric absorption correction to determine the spectral type of the M-star accurately, through measuring the depths of these two TiO bands.

A 5.1 hour period, assumed to be the orbital period, has been observed in earlier data sets (e.g. Chevalier & Ilovaisky, 1994; Casares et al, 1995; García et al, 1996). Earlier still, values close to 5.1 hours were observed as the system declined from the initial outburst (e.g. Chevalier & Ilovaisky, 1992; Kato, Mineshige & Hirata, 1992). This period has not been observed in other datasets, e.g. Shirader et al (1994) and Martin et al (1995). We have used our data to refine the orbital period and to determine a new ephemeris.

2 OBSERVATIONS

Three nights of simultaneous spectroscopy and photometry were taken on 1997 December 1-3. However, most of the third night was lost to bad weather and time was also lost in the preceding two nights due to technical problems. The photometry was taken with the 2.5m Isaac Newton Telescope (INT), using a Johnson I band filter. Exposures of 600 seconds were recorded on the ‘Wide Field Camera’. The observations were taken with J0422+32 at 6 different positions on the chip, so that fringing effects could be corrected later.

The spectroscopy was taken using the 4.2m William Herschel Telescope (WHT) and the ISIS double beam spectrograph at Cassegrain focus. We used a slit width of 1 arc-second. Again integration times of 600 seconds were used, so that the orbital smearing was less than the resolution of the data. On the red arm, the 1124x1124 pixel TEK2 CCD camera gave a dispersion of 2.7Å/pixel and a resolution of about 5.4Å. Copper-neon arc spectra were taken for wavelength calibration. On the blue arm the EEV10 2148x4200 CCD camera was employed, giving a dispersion of 0.96Å/pixel and a resolution of about 3.4Å, with a useful wavelength range of ≃3000–6000Å. Flat-fields were taken after every image to correct the corresponding spectrum of J0422+32. To create the flat-field, a polynomial was fitted to each flat-field, by which it was then divided.

To extract the spectra, an optimal extraction algorithm (Horne 1986) was used. The spectra were wavelength calibrated using the arc spectra taken at the same position as the object frame. The J0422+32 spectrum was then divided by the other star on the slit to remove atmospheric bands. The second star on the slit was determined to be a late F-star from the blue spectrum, primarily from the 4000Å break and the calcium H and K lines. No further analysis was made of the blue spectra, as the data were far too noisy. The red arm spectrum in the region of interest was intrinsically featureless. In total there were 53 good red arm spectra, each with a signal-to-noise of about 3 per pixel. The second star on the slit was approximately 6 times brighter than J0422+32, hence there was no degradation in signal-to-noise due to dividing by the F-star.

3 DATA REDUCTION

3.1 Spectroscopy

A bias frame was subtracted from each flat-field and target frame. Each flat-field frame taken closest in time and at roughly the same hour angle and declination was used to correct the corresponding spectrum of J0422+32. To create the flat-field, a polynomial was fitted to each flat-field, by which it was then divided. To extract the spectra, an optimal extraction algorithm (Horne 1986) was used.

The spectra were wavelength calibrated using the arc spectra taken at the same position as the object frame. The J0422+32 spectrum was then divided by the other star on the slit to remove atmospheric bands. The second star on the slit was determined to be a late F-star from the blue spectrum, primarily from the 4000Å break and the calcium H and K lines. No further analysis was made of the blue spectra, as the data were far too noisy. The red arm spectrum in the region of interest was intrinsically featureless. In total there were 53 good red arm spectra, each with a signal-to-noise of about 3 per pixel. The second star on the slit was approximately 6 times brighter than J0422+32, hence there was no degradation in signal-to-noise due to dividing by the F-star.

3.2 Photometry

A median stacked bias frame was subtracted from each frame. However, the frames had to be flat-fielded in a similar manner to infrared data, due to a severe fringing pattern on the CCD. This was done by using sets of six image frames, taken offset from each other, removing one (hereafter the ‘single’ frame) and leaving five from which a median stack was made. The modal value of the median stack was scaled to be the same as that of the single frame and then the scaled median stack was subtracted from the single frame of the set. In this way, the fringing pattern on the single frame was removed (e.g. Beekman et al, 1997). The frames were not flat-fielded, as the flat-fielded frames were ~30% noisier, pixel-to-pixel, than the unflat-fielded frames.

The raw, sky-subtracted counts were obtained for each star using an optimal extraction technique (Naylor 1998). A nearby star was used to define a point spread function and this PSF was then used to calculate a weight map for each pixel of J0422+32 and other stars in the frame. A weight map clipping radius of almost double the FWHM seeing was used to recover between 95 and 99 percent of the available signal to noise. The other star that was taken on the slit during the spectroscopy was identified from the position angle of the slit on the sky and then J0422+32 was divided by this to remove sky transparency variations.

The standard stars PG1047 and its associated companions (Landolt 1992) were also observed during the run. These were reduced in the same manner as the target and the zero-point from each star was calculated. A mean was made of the four zero-points, to find the approximate zero-point for the CCD. Using this value, the approximate I-band magnitude for J0422+32 of I≃20.4 was calculated, using a frame with a similar airmass to that of the standard star frame. This was further refined, as described in Section 4.2.1.

4 DATA ANALYSIS
4.1 Spectroscopy

To derive a radial velocity curve, various sections of the spectra were cross correlated against each other. To do this we used the cross-correlation technique outlined in Tonry and Davis (1979), to produce a cross-correlation function (CCF). A quadratic was fitted through the CCF peak so as to determine the maximum point, corresponding to the radial velocity shift for that spectrum. Initially we cross-correlated individual spectra against each other to determine the radial velocity variation and to check the period. We cross-correlated the region across the TiO band at 7055 Å and the Ca II region between 8450 and 8750 Å, the latter of which has been used previously e.g. Casares et al (1995). A period search was performed using a Fourier transform routine. From this and the 'cleaned spectrum', we found no significant periods, including the orbital period.

The 53 spectra were then binned into 8 phase bins, using the same ephemeris as Beekman et al (1997), derived from the extensive photometry of Chevalier & Ilovaisky (1996) and spectroscopy of Filipenko, Matheson & Ho (1995).

4.1.1 Radial velocities from TiO

Each spectrum then had a signal-to-noise of about 7/pixel and was cross-correlated with the weighted mean of the other spectra (that had been shifted to rest using a semi-amplitude of 375 km s$^{-1}$ (mid-point of generally accepted semi-amplitudes) and the $T_o$ of Beekman et al, 1997, where $T_o$ is the first inferior conjunction of the late-type star for the dataset). The regions 7000-7500 Å and 7500-8000 Å were used to cross-correlate the two strongest TiO bands. Using the new $T_o$ and semi-amplitude obtained from the radial velocity curve (e.g. Fig. 2), we repeated the above method until the change in $T_o$ between successive calculations was negligible. This gave us a $T_o=2450783.6463\pm0.0004$ (from the beginning of our dataset), a change of 0.013 in orbital phase (0.003 days) and a new radial velocity of 378±16 km s$^{-1}$.

From shifting on this new $T_o$, the steps in the TiO bands and the potassium lines are sharper, indicating that this $T_o$ is more accurate. The $1\sigma$ error in the semi-amplitude was calculated by creating radial velocity errors (weighted according to the number of spectra in each phase bin) to produce a $\chi^2$ of 1 (Fig. 4) shows the 8 phase-binned spectra and the CCF resulting from cross-correlating the region 7000-7500 Å with the weighted mean spectrum of the remaining spectra. The peak of the CCF can clearly be picked out from all but one phase and the orbital motion of the system can be seen.

To compare our accuracy with previous results, we rescaled the error bars of Harlaftis et al (1999), so that a fit to their radial velocity curve also gave a $\chi^2=1$. We obtained a radial velocity of 378±15 km s$^{-1}$, from their data. The 4% error on our radial velocity is comparable to that obtained with 20% more observing time and using a 10m telescope (Harlaftis et al, 1999). Thus we have shown that using TiO bands for radial velocity studies can be a very powerful tool.

† We also tried cross-correlating each phase bin against other M star spectra (see Sec. 5.4), but the results were not as accurate.
4.1.2 The new ephemeris

From the new T_o, we re-determined the orbital period, using our data and that of Chevalier & Ilovaisky (1996), Filipenko, Matheson & Ho (1995), Harlaftis et al (1999) and Casares et al (1995), so as to extend the base line. Each T_o was adjusted to the phase convention used here in equation 1. A period of 0.2121600±0.0000002d was found to fit all the data, with a T_o of 2450274.4156±0.0009. This gives a new ephemeris of,

$$HJD = 2450274.4156(9) + 0.2121600(2) \times E$$

where HJD is the Heliocentric Julian Date and E the cycle number. Phase zero for this ephemeris is taken to be the inferior conjunction of the late-type star.

4.2 Photometry

4.2.1 How bright is J0422+32?

From our initial estimate of the magnitude of J0422+32, it appeared that J0422+32 had become considerably fainter over the 3 years since it was last observed. Previously, J0422+32 was found to be ~0.14 magnitudes brighter when observed by Casares et al (1995) in December 1994 and I~0.33 magnitudes brighter when observed by Oroz & Ballyn (1995) in October 1994. To verify this, we used the following method.

The Casares et al (1995) observation is the lowest published value to date. We reanalysed the Casares et al (1995) data by obtaining the frames taken at the JKT in December 1994 from the RGO Astronomy Data Centre. These we reduced in the same manner as the J0422+32 photometry that we obtained in December 1997 from the INT, although a simple flat-fielding technique was used, as there was no fringing effect on these CCD frames. Photometry was carried out on the 1994 data of J0422+32 and 7 stars in the neighbourhood and on the same stars in the 1997 data. Both the frames used were from a similar phase (φ≈0.67). In each case, J0422+32 was divided by each of the other 7 stars in the frame and the relative counts compared from the two years. The 1997 data was found to be 22±3% fainter than the 1994 data of I=20.22±0.07 (where the 3% error is the standard deviation calculated from the ratio between the 1997 and 1994 data for each of the 7 stars). This indicates that we observed J0422+32 at an I magnitude of 20.44±0.08. This is the lowest state that J0422+32 has been observed to date, which indicates that in 1994, it had not yet reached its quiescent value, following the outburst and subsequent mini-outbursts.

4.2.2 Orbital modulation

To search for periodicities in the photometry, a Fourier transform routine was used. From the power spectrum, we found no significant evidence for the orbital period reported by others (e.g. Filipenko, Matheson & Ho, 1995), nor any other period.

However, as binning the spectroscopic data on the 5.1 hour period had been so successful, the data were then binned into the same 8 phase bins, of 0.125 of the orbital period. Each bin had a minimum of 5 points in it. The weighted mean relative flux was calculated and an average phase, for each bin. Plotting relative flux against phase, an ellipsoidal modulation, as seen by Beekman et al (1997), Chevalier & Ilovaisky (1996), Martin et al (1995) etc is therefore evident. However, we observe excess flux between phases ~0.4-0.6, which may be due to the irradiation of the M star by the inner edge of the accretion disc (e.g. Shahbaz, 1994), although why the X-ray heating should increase during this low state, is unclear. From examining the database from the All-Sky Monitor on the X-ray Timing Explorer (XTE) for J0422+32 around this observation period, the X-ray activity was minimal. It is however possible, that since J0422+32 had declined from outburst in December 1997, the disc opening angle should also have decreased (see e.g. Webb et al, 1999). Therefore more X-rays from the inner parts of the disc would be able to impinge on the secondary star, and thus heat the surface between phases 0.4-0.6.

Our interest is to measure the maximum allowed amplitude in this light-curve, to constrain the inclination of this system (see Sec. 5.3). Clearly, a larger amplitude is possible if we ignore the ‘X-ray heated’ points. We therefore fitted the flux variation between phases ~0.6-1.4. The maximum flux variation is 0.014. Taking into account that only 38% of the flux observed emanates from the M star (see Section 5.3), the maximum percentage flux variation is 16% from the secondary star alone.

5 RESULTS AND DISCUSSION

5.1 Flux Calibration

We plotted the relative flux from each spectroscopic observation against each simultaneous photometric observation, to compare the fluxes. This was done by summing the J0422+32 spectra over the range of the photometric pass-band (7250-9500Å) and dividing this by the sum of the comparison star over this same range and then plotting this against the photometric observations (Fig. 1). There is a large scatter about the best fit line to the spectroscopy
versus photometry, showing that there are considerable differences in the light losses at the slit between the two stars. We therefore decided to correct for these slit losses, by multiplying each J0422+32 spectrum by the ratio between the photometry and the spectroscopy.

The second (local) star observed on the slit to be used as a comparison star, was flux calibrated using the flux standard SP 2209+178 (BD +17 4708), in the following way. The instrument response function derived from the flux standard was used to flux the weighted mean of the 53 spectra of the comparison star. The flux level was virtually insensitive to changes in the airmass. A smooth curve was fitted to the fluxed mean comparison star spectrum. The J0422+32 spectrum (divided by the comparison star) could then be fluxed by multiplying by this curve and remain corrected for telluric absorption. The J0422+32 fluxed spectrum was dereddened using an E(B-V)=0.3 (Harlaftis et al, 1999 and Beekman et al, 1997) and barycentric radial velocity corrected (Fig. 3).

5.2 Search for the ellipsoidal modulation

We searched for the ellipsoidal modulation of the secondary star in two ways. We measured flux deficits for each of the 8 phase bins, as described in Wade & Horne (1988), but the errors were large (25-100%). To get a higher signal-to-noise, varying proportions of the summed spectrum (Fig. 2) were subtracted from each of the 8 phase binned spectra. The region 7000-8100 Å was used, as it contains two strong TiO bands, but no Ca lines. A line was fitted to the residuals and we used $\chi^2$ to determine the best fitting proportion of the summed spectrum at each phase. This measure could also reveal ellipsoidal variation. Although the errors were smaller (10-20 percent), only a singly-humped lightcurve was seen rather than a double-humped curve. This is probably due to irradiation of the front face of the M star, where the hotter temperatures diminish the quantity of TiO.

5.3 Orbital parameters of J0422+32

Using the relationship between the amplitude of the ellipsoidal variation and the inclination of the system (Shalbazz 1994), we determined the maximum orbital inclination of J0422+32 to be 45°, for the maximum amplitude obtained with the photometry (in which we can see evidence of ellipsoidal variation, see Sec. 4.2.1). Using the semi-amplitude obtained from our radial velocity study of 378±16 km s$^{-1}$, we obtained a mass function of 1.191±0.021M$_{\odot}$. We used this new mass function, the esini of 90$^{+27}_{-25}$ km s$^{-1}$ (Harlaftis et al 1999) and the inclination, to obtain a new q value of 9.0$^{+2.7}_{-2.2}$, where q is the mass of the primary (compact object) divided by the secondary. From this we can constrain the mass of the primary to be greater than 2.2M$_{\odot}$. Although this is below 2.9M$_{\odot}$ (the upper bound on the mass of a neutron star, Kalogera & Baym (1996)), it is well above the canonical value for a neutron star (1.4M$_{\odot}$) and would imply a super-massive neutron star if the compact object were as little as 2.2M$_{\odot}$. Further to that, from evidence in previous work, e.g. Sunyaev et al (1993), who show that J0422+32 has many of the same characteristics as seen in the other black hole candidate X-ray transients, J0422+32 must indeed contain a black hole.

5.4 The spectral type of the secondary star in J0422+32

The dereddened summed spectrum was normalised to unity at 7500Å. We measured the flux deficits across the two strongest TiO bands, namely those at 7055Å and 7589Å, as described in Wade & Horne (1988) and Section 5.2. Having continuum prior to the band at 7055Å, unlike Wade & Horne, we could fit the continuum across this first band between 6900-7000Å and 7450-7550Å. We also measured the drop between 7140 and 7190Å. Over the second band, we again used the same regions as Wade & Horne (1988); the continuum was fitted between 7450-7550Å and 8130-8170Å and the drop measured between 7640-7690Å. From this we obtain the ratio of $d_{\nu}(7264)/d_{\nu}(7165)$ to be 0.91$^{+0.45}_{-0.25}$. This implies that the secondary star in J0422+32 is an M4-5 star, using Wade & Horne’s table 3.

As this result gives a slightly later spectral type for the secondary star than Harlaftis et al (1999), M2$^{+2}_{-1}$ or Casares et al (1995), M2±2 we employed a second method in order to confirm the spectral type. Spectra of G14 stars GI 335A (M0 star), GI 361 (M2), GI 436 (M3) and GI 402 (M5), were observed and reduced in the same manner as J0422+32. Although simultaneous spectrophotometry was not possible, a bright, rapidly rotating B star was observed at a similar airmass. By dividing the G14 star spectrum by the B star, we corrected for telluric absorption. The G14 stars were fluxed in the same manner as the J0422+32 spectrum (Section 5.2). These too were normalised to unity at 7500Å.

Varying proportions of the normalised G14 stars were then subtracted from the normalised, dereddened spectrum of J0422+32. A quadratic was fitted to the residuals and

† NB: Martin et al (1995) propose that the secondary star is anything between an M0-5
the $\chi^2$ of the fit to this quadratic was calculated as a measure of the goodness of fit. This also gives an indication of the proportion of the flux observed that emanates from the secondary star. From this, the best fitting spectrum to J0422+32 was spectral type M5. However, as we had failed to observe an M4 star, due to the onset of bad weather, we constructed a mean of the M3 and the M5 star to simulate a star that was approximately an M4. This gave as good a fit as the M5 star. Also, as the error on the reddening is possibly large, we carried out both experiments on the non-reddened spectrum to check that the uncertainty in the reddening correction had not affected our spectral typing. However, both the reddened and non-reddened spectra gave the same results. We therefore conclude that the secondary star in J0422+32 is M4-5. The reason for the discrepancy between our measurements and those of previous workers is probably their shortage of later type spectral standards. Both Harlaftis et al (1999) and Casares et al (1995) observed no stars later than M2, with the same apparatus used to observe J0422+32.

5.5 Comparison with previous mass determination

Previously Beekman et al (1997) used a method based on the disc instability model, following work done by King, Kolb & Burderi (1996), to determine the minimum mass of the compact object (revised version, Beekman 1999 and King & Kolb, 1999). The mass transfer rate must be below a critical level for a low mass X-ray binary system to become transient and therefore a minimum mass can be calculated. From this Beekman et al (1997) determined that the minimum mass of the compact object in J0422+32 was at least 32$M_\odot$. This was calculated using the mass and radius of a main-sequence M2 star, as in Gray (1992). However, the values for M stars are uncertain (Jones et al, 1994). Using values from Leggett et al (1996) and Jones et al (1994) for the M2 standard star Gl 411 and the revised calculations as given in Beekman (1999) and King & Kolb (1999), we obtain a much more reasonable minimum mass of the black-hole of 11.9$M_\odot$. However, we have shown that the spectral type of the secondary star is somewhat later than M2. For an M4.5 star (Gl 268), a star that is consistent with our spectral classification of M4-5, we calculate that the black hole mass must be greater than 0.75$M_\odot$. Although this seems considerably smaller than our minimum mass derived from the radial velocity curve, it should be noted that the revised minimum compact object masses in Beekman (1999) and King & Kolb (1999) are all considerably lower than the minimum masses calculated from the respective radial velocity curves. King & Kolb (1999) also describe a second method by which they determine the minimum mass of the compact object, from the spectral type and therefore the mass of the secondary star, for stars of spectral type K and earlier. However, as we have shown that the secondary star in J0422+32 is of spectral type M4-5, this method is not applicable to this system. We have therefore solved the problem of the black hole in J0422+32 having an impossibly large mass and also demonstrated that these equations support our radial velocity calculations.
5.6 Distance
We calculated that 38±2% (2σ error) of the light emanates from the secondary star in the spectral range 6950-8400 Å, by subtracting varying proportions of the normalised Gliese stars from the normalised spectrum of J0422+32 (Sec. 5.3). This implies that 62±2% of the observed flux originates from the accretion disc in this region. This is considerably more, although still consistent with Casares et al (1995), who estimated that the secondary is emitting 48% of the light in the spectral range 6700-7500 Å.

From an E(B-V)=0.3 and A_v/E(B-V) = 3.1 (Seaton, 1979 and Howarth, 1983), we obtain an A_v of 0.93. The I band absolute magnitude of an M4 star, Gl 213 (Kirkpatrick et al 1993) is M_I =9.86, and with only 38% of the flux coming from the secondary, it would have an I band magnitude of ±21.50. Hence, we calculate that the distance to J0422+32 is 1.39±0.15 kpc. This is not only consistent with, but also far more accurate than other previous measurements of distance, e.g. Callanan et al (1995), who give a lower limit of 1kpc and a probable upper limit of 2kpc.

Using this value for the distance and the X-ray flux of 3.5×10^{-8} ergs cm^{-2} s^{-1} (Harmon et al, 1992) in the 40-230 keV range during the main outburst, we calculate that the luminosity is somewhat lower than the Eddington luminosity (2.8×10^{38} ergs s^{-1}) at only 8×10^{36} ergs s^{-1}. There may, however, be considerable flux in other wavebands, for which there are no data available (Shahbaz, Charles & King, 1998).

6 CONCLUSION
From our data, we determine that J0422+32 was in its lowest state yet observed during December 1997, at I=20.44±0.08. Following a comprehensive search we measure a period of 0.2121600±0.000002 days, consistent with previous analysis. From the same radial velocity study, we determine a tightly constrained semi-amplitude of 378±16 km s^{-1}. Thus we have shown that using TiO bands for radial velocity studies is a very powerful tool. We also determine a new T_o of 2450274.4156±0.0009.

Further to this we see some evidence for ellipsoidal modulation, implying a maximum inclination for J0422+32 of 45°. We obtain a new mass function of 1.19±0.021 M⊙ and q=9.0^{+2.7}_{-1.2}, from which we have calculated a minimum mass for the primary of 2.22 M⊙, consistent with a black-hole, but not necessarily as a super massive one. However, this is only a minimum mass and the maximum is not constrained. We also revise the calculations of Beekman et al (1997) to demonstrate that the minimum possible mass of the black hole is similar to other black hole systems.

We have shown that it is important to perform a slit correction to the spectra, to calculate the correct flux for such a faint system. We obtain a spectral type of the secondary of M4-5 and determine that the secondary star contributes 38±2% of the flux that we observe from J0422. From this we calculate the distance to the system to be 1.39±0.15 kpc.

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