# RECENT SPECTROSCOPY OF X-RAY SOURCES AND SYSTEMS RELATED TO CATACLYSMIC VARIABLES: I.

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ABSTRACT: We present results of recent spectroscopic observations of A) some LMC X-ray sources, B) the X-ray burster 1735-44, and C) the peculiar emission-line binary BE UMa. From the short time scale variations and inferred low mass components each shows some similarities to more classical CV's.

A.) In the course of a large scale investigation of the stellar X-ray sources in the Magellanic Clouds being carried out by our group, Thorstensen and Charles, Helfand and others at Columbia, and Pakull some interesting stars have been identified. Of the approximately two dozen LMC sources for which Einstein HRI positions are available, nearly half have been found to be foreground sources, one is a background Seyfert, and several have yet to be identified. Of the half dozen known to be LMC stars, LMC X-4 is the only firmly identified supergiant binary of the type similar to Vela X-1 in the Galaxy. LMC X-1 may be identified with the supergiant R 148 but an equally probable candidate is a fainter star (No. 32 - Cowley et al. 1978) which shows only He II, λ 4686, in emission and lies some 6" away (Pakull, 1980) Single-trailed, 30 minute exposure spectra taken at CTIO show the He II emission to be highly variable in both intensity and velocity. On one plate the emission line was visible for about half the exposure and absent during the last half. On another plate the line was "curved" showing a velocity range of about 100 km $s^{-1}$. No other stellar features are apparent in the spectrum, although a bright nebula contributes strong H and [O III] emissions which would make it difficult to detect weak stellar hydrogen lines. Pakull has identified 0544-684 with a spectroscopically similar object. Our spectra show variable He II emission with no other obvious stellar features. Both stars are unlike anything we know in the Galaxy. With $M_B \sim -3$ these LMC objects are brighter than Sco X-1 or other bright-disk systems such as cataclysmic type variables even in outburst. The rapid variations suggest a low mass system, but the high disk luminosity is unusual.

Warren and Penfold (1975) identified a very blue star with LMC X-3.



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The HRI position now confirms this identification. The spectrum shows very broad hydrogen and He I absorptions with occasional Hβ P-Cygni emission. Our scattered observations over a few observing seasons and one by Johnston et al. (1978) show the velocity varies by ∿ 350 km $s^{-1}$ in < 2 days, although as yet we have not determined the period. The low mass implied by these variations suggests we may be seeing a very bright accretion disk, since the spectrum and luminosity do not fit any normal star at the distance of the LMC.

B.) From a photometric investigation of the X-ray burster 1735-44 McClintock and Petro (1981) suggested a possible 4.3 hour (orbital?) period. SIT Vidicon spectra were taken at CTIO with 30 minute time resolution to look for emission line changes. While only 2 hours of observations were obtained on each of two nights, we did find a curious pattern of line strength and velocity variations which repeated on the second night. The ratio of N III (4640 bl)/C III (4650 bl) changed systematically by a factor of 4 while the radial velocity of both blends varied together by ∿ 800 km $s^{-1}$. The cycle time of these changes was 2.85 hours, but we have insufficient data to know if these variations are periodic. The velocity probably refers to some gas streaming rather than to orbital motion since He II, λ 4686, shows a much smaller velocity range. The changing N III/C III intensity could possibly be due to varying resonance fluorescence of the N III.

C.) BE UMa is a unique emission line binary ($P = 2.29^d$) which has recently been discussed by Margon et al. (1981) and Ferguson et al. (1981). In spite of the strong emission lines causing it to look like a CV, they concluded that the system contains a low mass cool dwarf widely separated and not interacting with the very hot white dwarf. The heating by the white dwarf causes both an ∿ 1 magnitude sinusoidal light variation and the strong emission lines which are apparently produced on the inner heated hemisphere of the cool star. However, more recently Ando et al. (1982) have found deep eclipses at the bottom of the sinusoidal light curve and from the duration of the eclipses and the shape of the partial phases have inferred the primary must be a hot subdwarf.

We have obtained moderately high resolution spectra of the system throughout the orbit in order to determine the masses and to study the line profile and intensity variations. In addition we have modelled the continuous light curve to infer properties of the component stars.

From the phasing of our velocity curve it immediately became obvious that the published period needed some revision. Combining the Ando et al. time of eclipse and the time of minimum from the Harvard plate material, kindly supplied by Tokarz (1982), we derive a new ephemeris:

$$T_{min\ lt} = \text{HJD } 2444998.281 + 2.291171E \text{ days}$$

Further, from the emission line velocities, we find a mean amplitude and systemic velocity from all lines of:

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$K = 102$ km s$^{-1}$, $V = -60$ km s$^{-1}$ ($\omega = e = 0$)

implying $f(M) = 0.253\ M_\odot$

Additional constraints can be put on the geometry, masses and luminosities of the component stars by fitting the sinusoidal light curve using a radiative heating model and by considering the further limits the shape and duration of the eclipse impose. We find that no main-sequence secondary viewed at any angle can account for the observed light curve. Our best model gives:

Hot Star: $R = 0.028 \pm .008\ R_\odot$ $T = 130{,}000 \pm 10\%$ °K
Cool Star: $R = 1.6 - 2.4\ R_\odot$ $T = 3500 \pm 300$ °K
$i \sim 74° - 77°$ $q \sim M_{hot}/M_{cool} \sim 1 - 3$

For these ranges of i and q we find from the mass function that $M_{hot} \sim 0.6\ M_\odot$ while $M_{cool} \sim .2$ to $.6\ M_\odot$. Although the mass and temperature derived respectively from the velocities and the light curve of the cool star are in reasonable agreement, it is odd that the star is sufficiently evolved at this low mass to have a size of several solar radii. The system must have previously had a period of considerable mass exchange and loss. Furthermore our modelling shows, contrary to previous ideas, the secondary nearly fills its Roche lobe and some interaction between the components is probably occurring.

From the derived temperature and radius we can derive magnitudes of $M_{V(hot)} \sim +6.5$ and $M_{V(cool)} \sim +7.5$, in agreement with the depth of the visual light eclipse which appears to be total. Thus the hot star is considerably brighter and larger than a white dwarf (as Ando et al. found) and the cool star lies well above the main-sequence both in radius and luminosity. Perhaps this system will eventually become a CV like the old nova GK Per which combines a white dwarf/cool giant pair in a two day binary.

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DISCUSSION FOLLOWING A. COWLEY'S TALK

KITAMURA: The physical parameters depend upon how accurately the light curve is analyzed, did you analyze the light curve yourself?

COWLEY: Yes. Here is what the temperature distribution on the cool star must look like. You can see that it is enormously heated.

KITAMURA: How about the eclipse light curve?

COWLEY: We did not. Except to look at the duration of partial and total phases because that sets limits on the inclination and the radii, but we did not analyze them completely. The durations tell you that the inclination is not 90° it must be nearly grazing.

TAPIA: I have not seen the recent spectra that you have taken of BE UMa. Could you tell us, are they different from the first ones that you took, you told us that the object was very different now.

COWLEY: No, what I meant by different was that, before, I think that we all had the picture that it was a white dwarf and very far away, not in contact, was a low mass dwarf and the light curve analysis indicates that it must be a much larger star than the dwarf and the stars are nearly a semi-detached system, that is what I meant by different, not that the spectra are different. The spectra look just the same as they looked a year ago and two years ago.