with the InSb detector. For many programmes on extended sources the larger diaphragms (≤ 30″) and chopping amplitudes (≤ 4′) will compensate to some extent for the smaller telescope aperture compared with the 3.6-m and in some cases may even make this telescope more attractive.

IRSPEC (Infrared Spectrometer)

This is a cooled array spectrometer which is being developed for the 3.6-m telescope where it should provide for observations in the 1–5 μm region at a resolving power of ≃ 3000 through an input slot of up to 3 × 7″. The mechanical construction is now in progress and most of the critical assemblies should be delivered within the next 2–3 months. Final completion will depend largely on when we actually receive the 52-element InSb array being produced specially for this instrument and on the difficulties encountered in developing its associated electronics. A more detailed account of this instrument therefore will be reserved for a future *Messenger*.

Acknowledgements

Without wishing to offend the many other ESO staff involved with the projects described here, I feel that special mention should be made of P. Salinari who was responsible for most of the IR photometer design before escaping to Florence, A. van Dijsseldonk who alternately builds and repairs detector units with great enthusiasm in Garching and, on La Silla, D. Hofstadt, F. Gutierrez, J. Roucher plus J. Koornneef and C. Perrier who face the unenviable task of demonstrating to visiting astronomers what has been written here.

ANNOUNCEMENT OF AN ESO WORKSHOP ON

"GROUND-BASED OBSERVATIONS OF HALLEY'S COMET"

to be held in PARIS, 29–30 APRIL 1982

With the aim of stimulating and planning ground-based observations of Halley's comet during its next apparition in 1985–1986, ESO is organizing a workshop entitled "Ground-based Observations of Halley's Comet".

This workshop will take place at the Institut d'Astrophysique de Paris on 29–30 April 1982. It will include both review papers and short contributions with ample time for discussion.

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Mass Determination of Massive X-ray Binaries

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Introduction

Massive X-ray binaries consist of a normal component of spectral type O or B which is transferring matter to a compact companion, generally a neutron star, with possibly one exception, Cyg X-1, where the compact component could be a black hole. These compact stars have enormous magnetic fields (of the order of 10^{12} gauss), and extremely large gravities; accreted matter will be accelerated to velocities of half the light velocity, and guided by the field lines to restricted areas near the magnetic poles, the hot spots. These regions acquire in this way temperatures of the order of 10^7 K, and X-rays are generated. The X-rays are transported outwards as beams, and since the compact objects rotate rapidly, X-rays are observed as pulse-shaped beams.

In order to enable a good physical description of compact objects and to derive an equation of state, their masses have to be determined as accurately as possible.

Mass ratios for binary systems can be derived from the radial velocity curves of the two components. In the case of a double-lined spectroscopic binary this is possible from measurements of the amplitude of these variations. For X-ray binaries the optical spectrum of the non compact component leads to the radial velocity curve of this component; from the Doppler delay of the arrival time of the X-ray pulse the radial velocity curve of the compact companion can be derived. Hence when the compact star is a pulsar the system can be treated exactly as a double-lined spectroscopic binary.

Massive X-ray Binaries

A list of massive X-ray binaries with their characteristics is given in Table 1. The table shows the names, spectral types, magnitudes, orbital periods in days, eventual pulse periods in seconds, the optical luminosity and the distance in kpc. As can be seen from the table the best suited candidates for the determination of physical parameters are Vela X-1 (4U 0900-40), 4U 1700-37, SMC X-1, LMC X-4, Cen X-3, Wra 977, 1538-52 and Cyg X-1, since they have short periods and are not too faint. Vela X-1, SMC X-1, Cen X-3, Wra 977 and 1538-52 are pulsars so that in principle the two radial velocity curves can be derived.

The best suited one is Vela X-1, since its magnitude of $6\overset{m}{.}9$ offers the possibility to acquire high-resolution coudé spectrograms, and moreover it is a pulsar (already discussed by Mauder in *The Messenger* No. 24).

The Case of Vela X-1

Some hundred blue plates were taken by the Amsterdam-Brussels group (Astrophysical Institute, Brussels; Royal Belgian Observatory; Astronomical Institute, Amsterdam) with the 152-cm spectrographic telescope of ESO with reciprocal dispersions of 12 and 20 Å/mm in the wavelength range 3700-4900 Å. The plates were collected between April 1973 and May 1976. From the line positions, heliocentric radial velocities were derived (Van Paradijs et al. 1976, *Nature,* **259,** 547). In

Table 1. Hard spectra binary X-ray sources—Massive X-ray binaries.

Name	Source	Spectral type	m_v	P_{orb} (d)	P_{pulse} (s)	L_x	L_x/L_o	d (kpc)
γ Cas	0053+604					3E33	6E-6	0.3
	0114+650	B0.5IIIe	11.0				1.5E-4	
SMC X-1	0115−737	B0I	13.3	3.89		6E38	1.2	65
X Per	0352+309	09.5(III-V)e	6-6.7		835	1.2E34	1E-4	0.35
LMC X-4	0532−664	08III-V	14	1.4			1	55
HDE 245770	0535+262	09.7IIe	9.1			2E37	0.08	1.3
Vela X-1	0900−403	B0.5Ib	6.9	8.97	283	1.4E36	3E-3	1.4
Cen X-3	1119−603	06.5II-III	13.35	2.087	4.84	4E37	0.05	8
Hen 715	1145−619	B1Ve	9.0		292 297	6E36	0.2	1.5
Wra 977	1223−624	B1Ia	10.8	35	699	1E37	3E-3	2
GX 304-1	1258−613	B6-9e	14.7		272	2.1E36	0.3	2±1
	1538−522	B0I	14.5	3.7	529	4E36	0.01	7±2
HD 153919	1700−377	06.5f	6.6	3.4		3E36	5E-4	1.7
Cyg X-1	1956+350	09.7Iab	8.9	5.6		2E37	2E-2	2.5

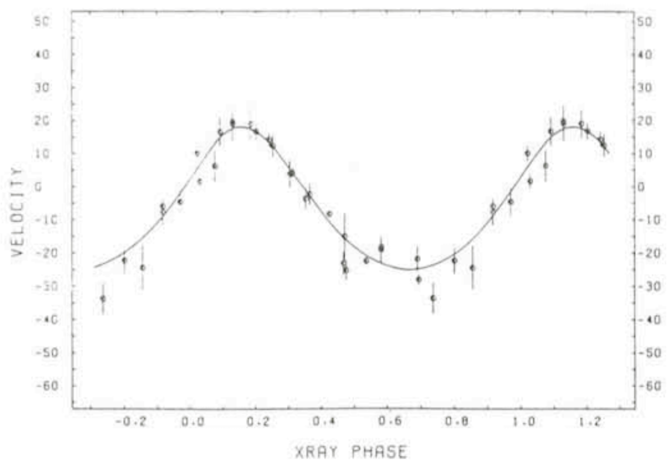

Fig. 1: *Variation of the radial velocity of HD 77581 with X-ray phase as obtained from all lines except the He I lines. Each point represents the average radial velocity for one plate. The error bars denote the mean error of the radial velocity variations. The curve drawn through the points depicts the best fit solution to the data points.*

Fig. 1 the variation of the radial velocity as a function of phase is shown.

The orbital elements we derived are: a period of 8.9681 ± 0.0016 days and an eccentricity of 0.136 ± 0.046. The observed pulse-arrival times given by Rappaport et al. (1976, *Astrophys. J. Letters,* **206,** L 105) were used for the determination of the orbital elements of the compact object: the pulse period is 283 s and the eccentricity 0.096 ± 0.019; a sin i = (32.83 ± 0.45) 10^6 km.

From the orbital elements, using all lines, the masses of the two components can be derived:

$$\frac{M_x}{M_\odot} \sin^3 i = 1.67 \pm 0.12$$

$$\frac{M_{opt}}{M_\odot} \sin^3 i = 20.5 \pm 0.9$$

Adopting a value for $\sin^3 i$ of 0.96, the masses can be estimated as 1.74 $M_\odot$ for the neutron star and 21.3 $M_\odot$ for the optical companion.

Other Massive X-ray Binaries Suited for Radial Velocity Studies

LMC X-4

Electronographic spectra (124 Å/mm) were obtained by Chevalier and Ilovaisky in 1977 (*Astron. Astrophys.* **59,** L 9)

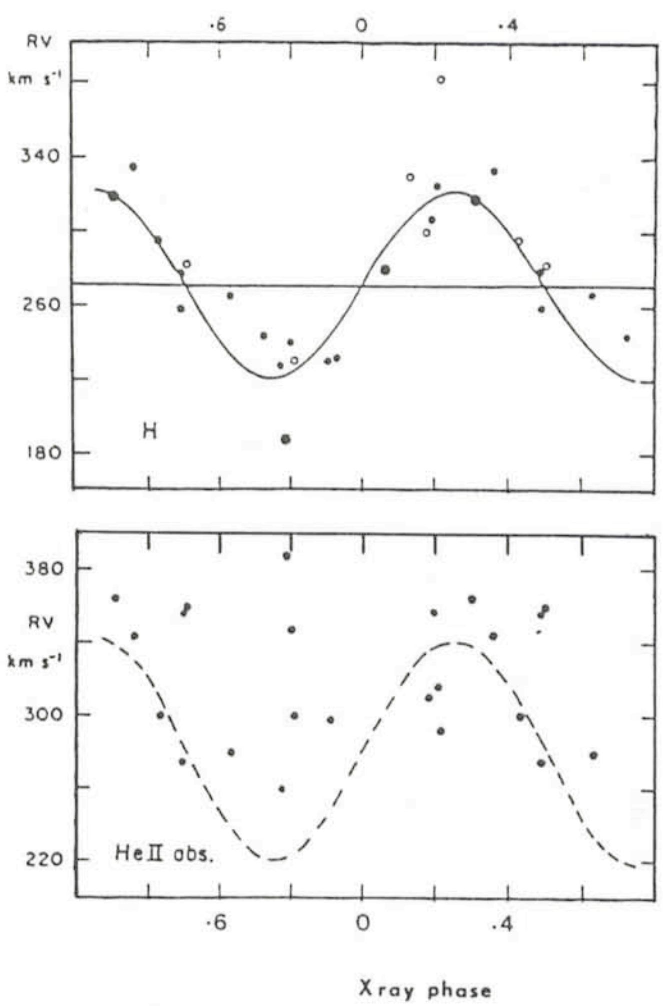

Fig. 2: *LMC X-4. Radial velocities measured from H absorption lines (top) and He II absorption lines (bottom).*

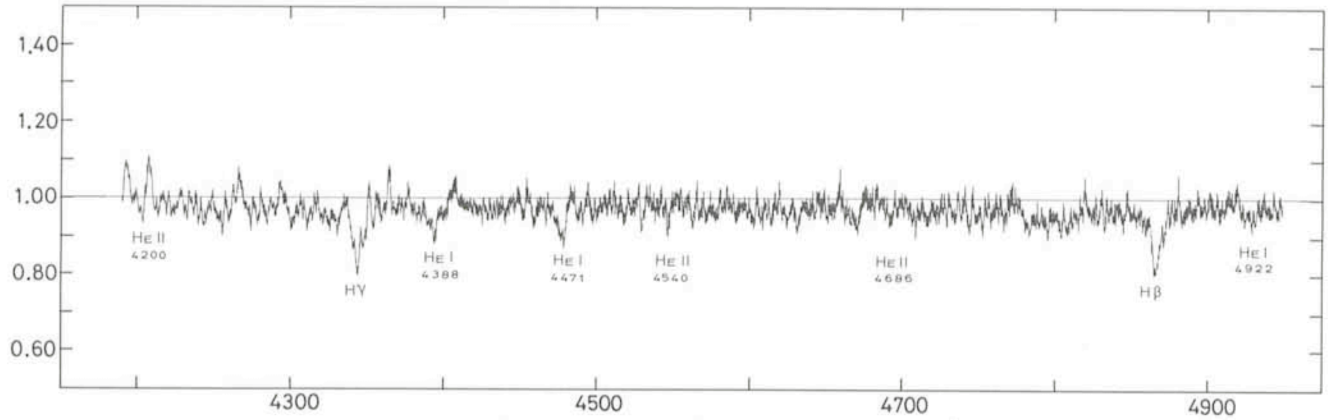

Fig. 3: *Spectrum of LMC X-4 in the blue region, between λλ 4200–5000.*

using the 152-cm ESO reflector. They derived an average radial velocity of the system from all their plates of ~300 km s^{-1} and, as upper limit for the semi-amplitude, they found ~35 km s^{-1} (± 15 km s^{-1}).

Hutchings, Crampton and Cowley (1978, *Astrophys, J.* **225,** 548) obtained a sequence of spectra of LMC X-4 during 1978, and they have succeeded to derive radial velocity curves, however with large spreads (Fig. 2). In February 1981 we took some spectra of this source with the image tube at the 3.6-m ESO telescope, at a reciprocal dispersion of 30 Å/mm in the wavelength range 4000-5000 Å, with the hope to improve the accuracy of the data. Also, at the end of October 1981, we took during two successive nights a sequence of LMC X-4 image-tube spectra at the same telescope. The number of lines suited for radial velocity determinations is satisfactory, and the lines are sufficiently sharp (Fig. 3). The analysis of our material is in progress, and we hope to be able to get improved radial velocity curves.

From the existing material we can already make an estimate of the parameters of the system. At the moment, no study of Doppler variations in the X-ray pulsation period is yet available, but the velocity of the compact star may be obtained from the He II λ 4686 emission line which is formed near this component. The deduced mass ratio is 10. From the X-ray eclipse duration we may determine the inclination angle and then using the third Kepler law and assuming that the luminous component fills its Roche lobe, we derive the distance between the two components (A = 16 $R_\odot$), the radius of the primary (R = 10 $R_\odot$) and the masses of both components: 24 $M_\odot$ and 2.4 $M_\odot$. From the spectral type O7 of the primary, its radius, the magnitude and the distance we derive a temperature (log T = 4.54) and a bolometric magnitude of $M_{bol} = -7.9$ which corresponds to log $L/L_\odot = 5.1$. Using our own evolutionary tracks this leads to a mass of 27 $M_\odot$ for the primary (and 2.7 $M_\odot$ for the neutron star). We note that this system does not require a strong mass loss, unlike other X-ray binaries.

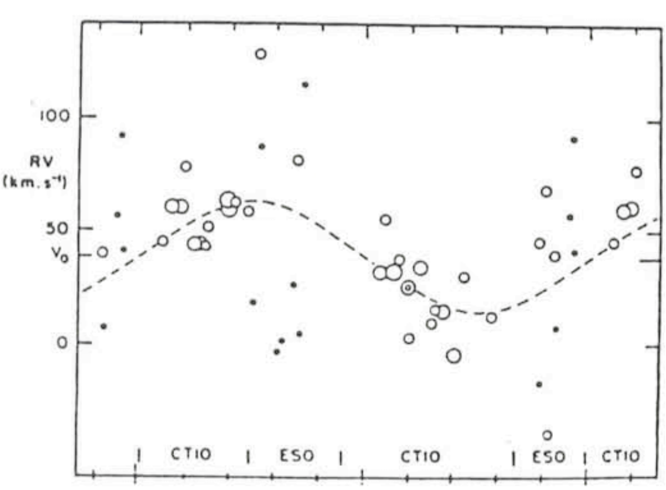

Fig. 4: *Cen X-3. Radial velocities and adopted circular orbit. Size of points indicates weight. Phase bins of CTIO and ESA data indicated (Hutchings et al., 1979, Astrophys. J.* **229,** 1079).

Wra 977 (4U 1223-62)

For this source more than 50 spectra have been collected so far by our group. The collection consists mainly of 62 Å/mm Echelec plates, obtained with the 1.52-m ESO telescope and the Lallemand camera between 1977 and 1981. Our experience with Vela X-1 already taught us that a large collection of plates is necessary to allow a satisfactory analysis. This is even more true in the case of Wra 977 where the orbital period is larger and where it is not possible to obtain plates of the quality of the 12 Å/mm coudé plates (as was our luck with Vela X-1).

The Echelec spectra can yield reliable radial velocities, provided that a careful and rather elaborate reduction procedure is followed. Even then the spectra have to be added by two at least in order to make the lines stand out from the noise. This clearly reduces the effective number of spectra available. Another problem is that we are not sure of the real period (in fact it is one of our main aims to determine it unequivocally), so that we are not sure to have a good phase coverage. Different periods have been proposed. The most likely, suggested from photometric data, is ~35 days. Such a period would be adequately covered by our plates.

4U 1538-52

This X-ray binary is very well suited for radial velocity studies, since it has a short period and is a pulsar. We have taken some spectra with the image tube, at the 3.6-m ESO telescope, with a reciprocal dispersion of 30 Å/mm; they are comparable with the LMC X-4 spectra with respect to the number of lines and their shape. The magnitude also is comparable. The orbital period of the system is short, 3.7 days. The pulse period is 529 s.

Combination of the radial velocity curves in the optical and in the X-ray range will allow to determine the masses of the components.

Cen X-3

This X-ray binary has an orbital period of 2.087 s, is eclipsing—the eclipse time is 0.5 d, the neutron star component is a

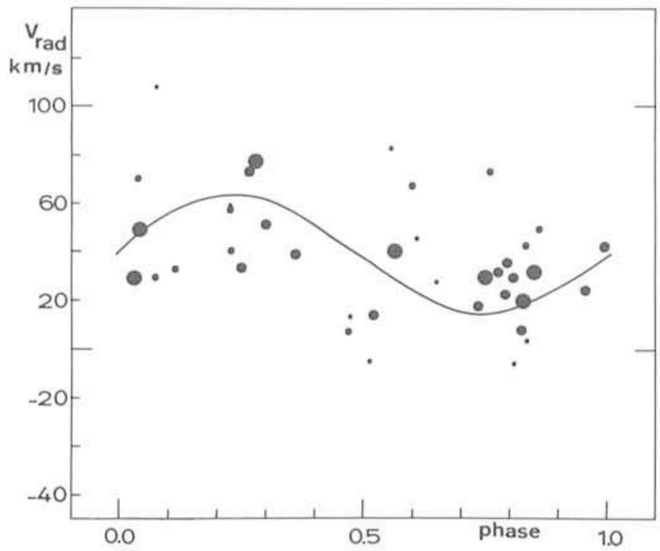

Fig. 5: *Cen X-3. Radial velocity curve derived from lines of Hγ, Hβ, He I 4471, He II 4541, obtained from Echelec and image-tube spectra. Size of points indicates weight.* $v_o = 39$ *km* s^{-1}*;* $K = 15$ *km* s^{-1}*.*

pulsar with a spin-period of 4.8 s. According to these characteristics Cen X-3 should be a marvellous candidate for a detailed analysis. However, the object is rather faint ($13^{m}.6$), so that high-resolution spectra cannot be obtained, and the spectrum is not rich in easily visible lines. An estimate of the radial velocities was performed by Hutchings, Cowley, Crampton, van Paradijs and White (1979, *Astrophys. J.* **229,** 1079) from image-tube spectra, 40 Å/mm, obtained at Cerro Tololo and at La Silla (Fig. 4). The amplitude is low, about 24 km s^{-1}.

Observations of this source with Uhuru, Ariel V and COS-B revealed that high and low states occur which can be explained in terms of an accretion disk.

In March 1976 Echelec spectra were obtained by the Observatoire de Meudon, using the 152-cm ESO telescope. The analysis of the ten 62 Å/mm spectra reveals periodic radial velocity variations in the HE II 4686 emission line, with a semi-amplitude of 400 km/s anticorrelated with the radial velocity variations of the Balmer He I and other He II lines.

In March 1981 fifteen image-tube spectra were obtained with the 3.6-m telescope at La Silla (reciprocal dispersion 30 Å/mm, widening 0.75 mm) by the Astrophysical Institute Brussels and the Astronomical Institute Amsterdam. This material was treated (partly at Meudon, partly at Brussels) together with some 20 Echelec plates, collected in 1977, 1978 and 1979, with a reciprocal dispersion of 62 Å/mm.

The radial velocity curve derived from the Hγ, Hβ, He I 4471 and He II 4541 lines is shown in Fig. 5. The analysis confirms the results of Hutchings et al.: $v_o = 40$ km/s, semi-amplitude $= 25$ km s^{-1}. The mass ratio is $q \sim 18$. From the eclipse duration we can derive that i is near 90°. The masses for the optical companion and the compact object are then 18 $M_\odot$ and 1 $M_\odot$ respectively.

Conclusions

The results obtained thus far show that the determination of radial velocity curves leads to reasonable values for the masses of the components of pulsating X-ray binaries. The masses derived in this way seem to agree with the general accepted picture of the evolution of massive close binaries, calculated with rather large mass loss rates, except for LMC X-4. Indeed, their position in the Hertzsprung-Russell diagram corresponds with the masses at our evolutionary tracks for decreasing mass, computed with mass loss rates about a factor 4 larger than the mass loss rates found in normal O-type stars. X-ray systems represent advanced stages of close binary evolution and offer us valuable information on the evolution of massive close binaries. Observations of X-ray sources therefore have to be continued. More specifically, elaborate radial velocity studies using a large amount of spectra for many sources will lead to accurate mass determinations as well for the optical component as for the compact companion; these latter masses are very important for the study of matter at extreme dense conditions.

Observations of the Small Amplitude β Cephei Stars

M. Kubiak, Warsaw University Observatory and Observatorium Hoher List

The reason why stars do sometimes pulsate seems to be satisfactorily explained by the present theory of stellar stability. The small but "irritating" exception is only the group of β Cephei stars: the physical mechanism of their variability remains till today essentially unknown. Observational characteristics of these stars can be summarized as follows: (i) they are located in a rather narrow instability strip on the H-R diagram in the vicinity of effective temperature of about 20,000° or spectral types B1–B2; (ii) periods are of the order of a few (3–6) hours; (iii) in some cases the shape of spectral lines varies with phase, the lines being broad on the descending and narrow on the ascending branch of the radial velocity curve; (iv) radial velocity curves are sometimes asymmetric or even discontinuous, particularly for the stars with large amplitudes; (v) maximum light occurs near the phase when the descending branch of the radial velocity curve crosses the mean velocity; (vi) in some of these stars two or more close frequencies are excited; in two cases triplets of equally spaced frequencies are observed.

All these features (except the first one) find more or less satisfactory explanations if we assume that β Cephei stars undergo non-radial oscillations. Fully admissible from the physical point of view, non-radial oscillations differ from the well-known radial pulsations in this respect that the elements of the star surface are subject to both radial and horizontal displacements. The surface of the star can be envisaged as being in a state of wavy motion, the waves being standing or propagating. The character of the motion (or the mode of oscillation) is fully described by two integer numbers l and m which, roughly speaking, give for a rotating star the number of nodes between the poles and the number of crests and valleys on the equator, respectively. Opposite signs of the same m denote similar waves propagating in opposite directions.

The complicated velocity field on the surface in interplay with general rotation of the star gives rise to characteristic profile variation during the cycle. For any (l, m) mode and phase, the shape of the profile can be computed numerically by summing