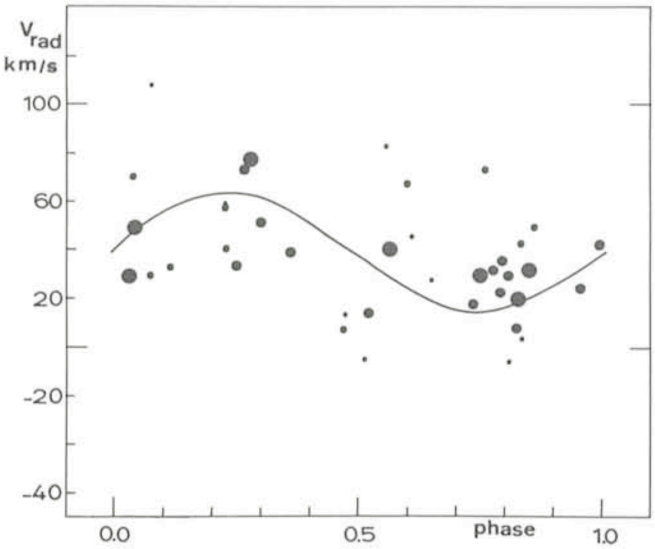

Fig. 5: *Cen X-3. Radial velocity curve derived from lines of Hγ, Hβ, He I 4471, He II 4541, obtained from Echelec and image-tube spectra. Size of points indicates weight.* $v_o = 39$ *km* s^{-1}; $K = 15$ *km* s^{-1}.

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

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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

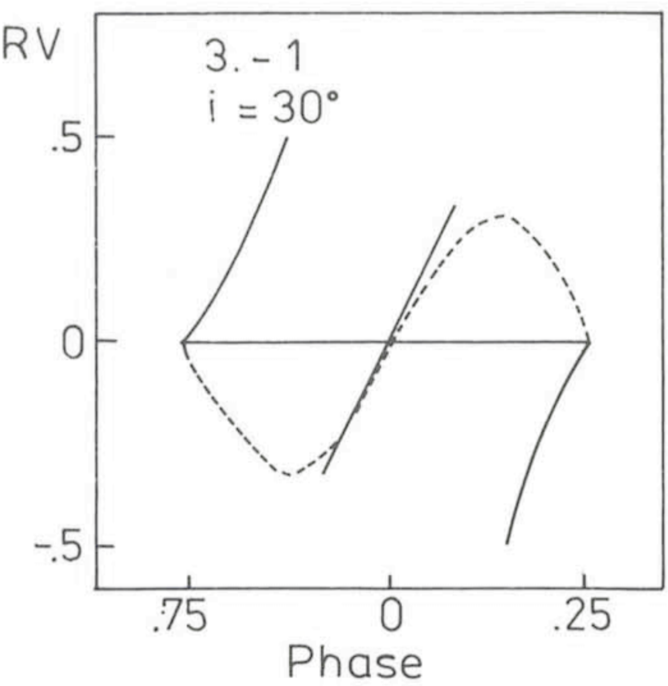

Fig. 1: *Radial velocity curve calculated for the mode (3, −1) and aspect angle 30°. The full line corresponds to the case where the line produced in the stellar atmosphere is infinitely narrow. The broken line represents the more realistic case of the line having intrinsic Gaussian shape. The vertical scale is arbitrary.*

up the contributions to the radial velocity coming from all points on the visible disk. Free parameters are: amplitude of velocity variations on the surface and aspect angle between the axis of rotation and the direction toward the observer. The immediate result of profile calculations is the observed radial velocity curve. The light variations can easily be found analytically; in the limits of linear approximations, they are sinusoidal for all modes, with the observed amplitude depending in a known way on the aspect angle.

Without going further into details, it is intuitively clear that the observed effects of non-radial oscillations must depend on the order l of the mode. For large l, when many waves are seen simultaneously, the changes of physical parameters across the disk will be "averaged" and the net effect will be small. In practice we do not expect to observe modes with l greater than, say, four. In other words, stars with strong light and radial velocity variations may rather—if at all—be identified with low l modes. In fact, essentially all results of mode identification based on observations of profile and radial velocity variations lead to the conclusion that in large amplitude stars, running waves corresponding to l equal 1 and 2 are most probably excited. The validity of this method of mode diagnostic is however restricted by two facts: firstly, β Cephei stars with large amplitude are scarce, and, secondly, the large amplitude of variations makes the presence of non-linear effects possible, which makes the unambiguous interpretation of the observed profiles more difficult.

Positive identification of modes in a large number of objects is of particular importance if we want to answer not only the question of how do these stars pulsate, but also why they are doing so? Among many ingenious mechanisms of β Cephei pulsation proposed till now, the most promising and simple seems to be the Stellingwerf's mechanism connected with some peculiarities in the opacity of stellar envelopes (see e.g. Dziembowski and Kubiak 1981, *Acta Astronomica,* **31,** 153). If this mechanism is indeed the right one, then no particular modes should be privileged, and modes with l from zero (pure radial pulsation) up to about 10 should be almost equally possible. The excitation of high l modes is hardly predicted by other mechanisms.

It follows from what was said above that the chance of finding high l modes is greater among the stars with small amplitudes. In such cases, however, we may not expect much information from profile or radial velocity variation. Fortunately, the high l modes are in a sense more "peculiar" than the low l ones. As an example, Fig. 1 shows the radial velocity curve for the 3, −1) mode observed at aspect angle 30°. Full lines represent the variations which would be observed if the intrinsic width of the lines produced in the atmosphere were infinitely small. The broken line is the same curve but obtained from lines having Gaussian shape. It can be seen that in both cases the phase relation between light (which has maximum at zero phase) and radial velocity variations should be opposite. This is only an example and more extensive calculations may reveal other interesting features of other modes.

Having in mind the possible importance of small amplitude β Cephei stars, Dr. W. Seggewiss and I included in our programme of simultaneous spectroscopic and photoelectric observations of β Cephei stars two small amplitude objects: ν and β Centauri. Thanks to the courtesy of the European Southern Observatory we had to our disposal the 1.52 m

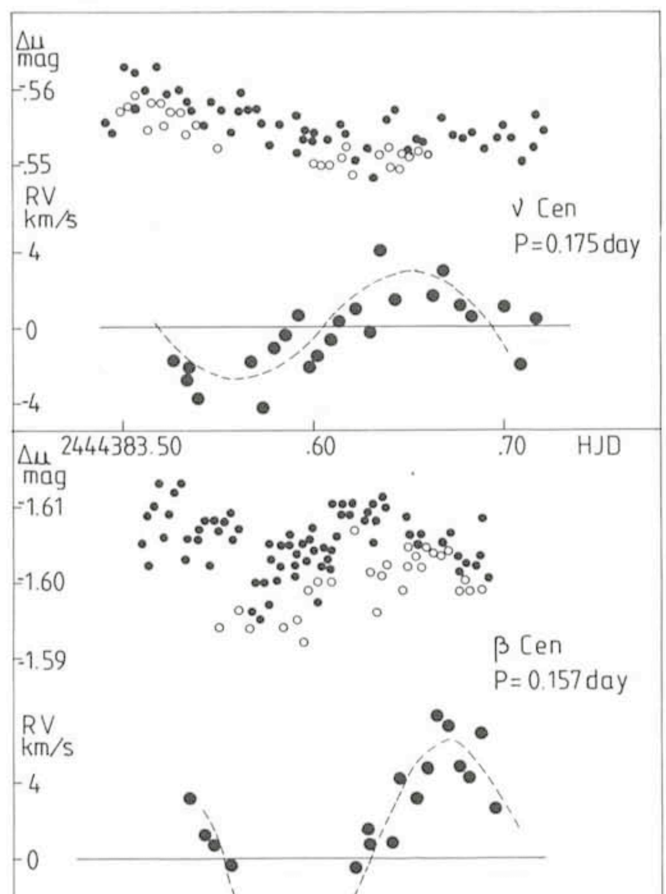

Fig. 2: *Light and radial velocity curves of ν and β Cen. Open circles denote photoelectric observations made on other nights and reduced to the night of simultaneous spectral and photoelectric observations. Only relative values are given.*

spectrographic and 0.5 m Danish telescopes at La Silla. The 12.3 Å/mm coudé plates of ν Cen were reduced at the ESO Data Reduction Centre in Garching, and the 3.3 Å/mm plates of β Cen were measured with the oscilloscope setting comparator at the Hoher List Observatory. Photoelectric observations were carried out with the aid of simultaneous four-channel uvby photometer. The results of these observations are shown in Fig. 2.

The radial velocity curves, in spite of their small amplitudes, are well defined and do not show any peculiarities. The accuracy of observations seems to be sufficient for determining both the moments of particular phases and the amplitudes (about 3 km/s for ν Cen and 6 km/s for β Cen). Points denote velocities actually observed, the broken line is a sinusoid fitted by eye to the observations. Both objects are bright, so the exposure times were typically 2–3 min.

The high brightness of the stars complicates somewhat the photoelectric observations. Fortunately for ν Cen a good comparison star exists, so the variability in the u-band with an amplitude of about 0.004 mag could be detected. The reality of the changes is confirmed by the observations made four nights later (open circles). Observations of β Cen were more difficult and are certainly less accurate. This star (one of the brightest in the sky) could be observed only with appropriate shielding of telescope aperture. The only reasonable comparison is α Cen differing largely in position and spectral type. Nonetheless, observations from two nights (dots and open circles), though not of excellent quality, strongly suggest the variability in the u-band with an amplitude of approximately 0.005 mag. (As was to be expected no trace of variability of these stars could be found in the B and V bands.)

Nevertheless, inspection of Fig. 2 immediately shows the different behaviour of the two stars. Phase relation between light and radial velocity in the case of ν Cen obeys the general rule that in β Cephei stars the maximum of brightness occurs at the descending branch of the radial velocity. In this respect the behaviour of β Cen seems to be opposite: maximum of brightness—if real—corresponds clearly to the middle of the ascending branch.

It would be premature at the moment to draw any firm conclusion about the mode excited in β Cen from the direct comparison with Fig. 1. It seems clear, however, that observations of small amplitude β Cephei stars, although troublesome, are worth being done and may really contribute to our understanding of these objects.

The Galactic Abundance Gradient

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Introduction

The study of chemical abundances and their variation from one galaxy to another or within individual galaxies is of fundamental importance for our understanding of the evolution of galaxies. The abundances of heavy elements in the interstellar medium provide a fossil record of the enrichment which has taken place due to nucleosynthesis in successive generations of stars. Gradients of heavy element abundances with distance from the galactic centre are predicted by models in which the rate of star formation varies across the galactic disk, and by dynamical collapse models of galactic evolution which involve fresh infall of primordial gas onto the disk over long periods of time. Different models predict different abundance gradients (in slope and shape), and abundance measurements give constraints on these models (see Pagel and Edmunds, 1981, *Ann. Rev. Astron. Astrophys.* **19,** 77, for a recent review).

H II regions provide the most accessible probe of current interstellar abundances. In computing abundances from line intensity ratios, an accurate knowledge of the electron temperature is essential: a 40 per cent change in the temperature can change the abundance by an order of magnitude. Optically, temperatures can only be measured for the brightest and hottest H II regions, and this severely limits the number of H II regions for which "absolute" abundances can be determined.

Radio recombination lines can be used to obtain accurate electron temperatures for a much larger number of galactic H II regions. They are strongest when the temperature-sensitive optical lines are weakest, i.e. at low temperatures. In addition they can readily be detected from relatively faint or heavily reddened H II regions. Thus the radio and optical methods are truly complementary. By carefully choosing the radio recombination lines to be observed in accordance with the emission measures of the H II regions, non-LTE corrections can be kept down to a few per cent, and uncertainties in the resulting temperatures are then limited only by observational factors, typically 5-10 per cent.

We have combined radio and optical spectroscopic observations of a large number of galactic H II regions in a novel approach to the determination of abundances and their distribution across the galactic disk. Accurate temperatures have been measured for 67 H II regions located between 3.5 and 13.7 kpc from the galactic centre; optical spectra have been obtained for 32 of these H II regions, bringing the total number of galactic H II regions with known (absolute) abundances from 18 to 43.

Some Preliminary Results

The radio observations were made using the 210-foot radio telescope at Parkes in Australia. Sample spectra, showing the 109α lines of hydrogen and helium, and the 137β line of hydrogen, are given in Fig. 1. These lines arise from transitions in the extreme outer parts of the atoms: the 109α line is due to a $n = 110 \rightarrow 109$ transition (n = principal quantum number), and the 137β line is due to a $n = 139 \rightarrow 137$ transition. Of special interest in Fig. 1 is the narrowness of some of these lines, proving that some H II regions have electron temperatures below 5,000 K ($\simeq$ 15 km s^{-1}).

Optical spectra were obtained using the Image Dissector Scanner (IDS) and the Image Photon Counting System (IPCS) on the ESO 3.6-m telescope, and with the IPCS at the Anglo-Australian Telescope. Fig. 2 shows a representative selection of these spectra. Variations in excitation conditions, temperature, and abundances are revealed by changes in the [O III]/Hβ