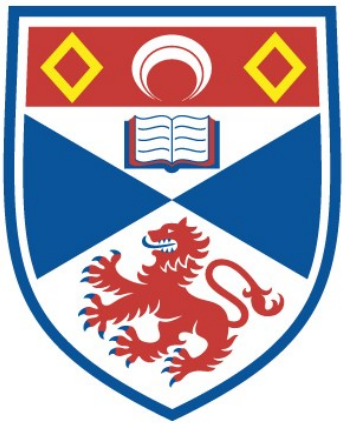
A SPECTROSCOPIC STUDY OF CONTACT BINARY SYSTEMS

Brian John McLean

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews



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A SPECTROSCOPIC STUDY

OF

CONTACT BINARY SYSTEMS

by

BRIAN JOHN McLEAN

A thesis submitted to the University of St.Andrews in application for the degree of Doctor of Philosophy.

St.Andrews August 1981

DECLARATION

Except where reference is made to the work of others, the research described in this thesis and the composition of the thesis are my own work. No part of this thesis has previously been submitted in application for a higher degree. I was admitted to the Faculty of Science of the University of St.Andrews as a research student under Ordinance General No.12 on the 1st October, 1978. I was accepted as a candidate for the degree of Ph.D. on the 1st October, 1979, under Resolution of the University Court, 1967, No.1.

Brian McLean

CERTIFICATE

I certify that B.J.McLean has spent nine terms in research at the University Observatory, St.Andrews, that he has fulfilled the conditions of Ordinance General No.12 and Senate Regulations under Resolution of the University Court, 1967, No.1, and that he is qualified to submit the accompanying thesis in application for the degree of Ph.D.

R.W.Hilditch

ABSTRACT

Spectroscopic observations of some of the brighter W Ursae Majoris type contact binaries in the northern hemisphere have been obtained at a medium dispersion of .20-30Å/mm. A computer program has been developed to process and analyse these spectra using modern digital reduction techniques in order to obtain more accurate spectroscopic data for such systems.

Radial velocity measurements have provided spectroscopic mass ratios which have been compared with the values derived from light curve synthesis. The improved mass ratios have removed the discrepancy which existed between the spectroscopic and photometric values in most of the systems observed.

The application of spectrum deconvolution techniques has revealed an asymmetry in the structure of two W subclass systems shown by the variation in the strength of the primary components' spectral lines. Measurement of the relative line strengths of the two components has provided further evidence for the presence of extensive magnetic starspots on the surface of the primary component of these systems.

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It is impossible not to acknowledge the research students, who have given many suggestions and inspired many ideas during the course of this research. In particular, P.S.Bunclark, G.C.Stewart and A.C.Davenhall for their aid in the development of some of the data processing techniques and associated computer programs, and also to A.Bridger, C.S.Jeffery, A.D.McFadzean, J.K.Worrell and P.G.Starkey for many extensive discussions of theoretical models of contact binaries.

Mr.J.R.Stapleton and many other people have helped me over the past three years and to all of them I extend my gratitude.

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CHAPTER 1

INTRODUCTION

1.1 OUTLINE

The W Ursae Majoris systems have long been of special interest, since they not only have the highest space density of any type of binary system (Shapley 1948), but they form a significant proportion of all late type stars in the solar neighbourhood (van't Veer 1975). An understanding of the structure and evolution of these systems is therefore of major importance in binary star theory.

These systems are eclipsing variables whose light curves have maxima which are strongly curved, and minima which are nearly equal in depth, while the spectrum usually contains lines from both components. Such systems are now recognised to be pairs of main-sequence or near main-sequence stars of late spectral type which have overflowed their respective Roche lobes so that they are in physical contact. The proximity of the stars causes many

complexities in both the light curve and the spectra, due to tidal distortion, reflection effect, gravitational darkening, line blending, rotational broadening and other interaction effects.

There has been much work carried out over the past twenty years on the rectification and analysis of light curves based on the ellipsoidal and Roche models, and more recently, on the synthesis of light curves. Together with the comparative ease of photometry, this has led to a preponderance of photoelectric data over spectroscopic observations which are more difficult to obtain and analyse. With modern equipment, however, more accurate spectroscopic work is possible so that further information on the physical properties of these systems can be determined. This work was begun, therefore, in an attempt to alleviate the shortage of spectroscopic data by embarking on a higher dispersion survey of as many systems as possible.

1.2 OBSERVED PROPERTIES

These systems lie near the main-sequence with spectral classes in the range F-K, with both components tending to be of similar type.

Periods of revolution of the W UMa binaries range from 0.2 to 1.0 days with the majority around 0.3 to 0.5 days (Kopal 1959, Eggen 1961, 1967). Many of the systems are subject to either sudden or continuous period changes which are usually attributable to mass exchange or loss (Rucinski 1973, 1974).

One of the main characteristics of W UMa systems is the shape of the light curves which are classified as EW. This means that the maxima are curved indicating extreme aspherical distortion of the components, and nearly equal depth minima so that the surface brightness of each star is similar. The amplitude of the light variations ranges from several tenths of a magnitude to just over one magnitude (Kopal 1959, Eggen 1961, 1967). The shape of the observed light curves contains a great deal of information on the geometry of the system, and an analysis by either conventional rectification methods or by light curve synthesis allows the shape of the stars to be determined. This suggests that both components fill or even overflow their Roche lobes (Binnendijk 1970, Moss and Whelan 1970, Rucinski 1973, 1974). A major problem with this type of analysis, however, is that the light curves are often asymmetric, and can vary significantly over short timescales (Binnendijk 1970), even from one cycle to the next as a result of activity within the system. This may be due to

gas streaming or possibly magnetic starspots (Mullan 1975, Binnendijk 1977, Hilditch 1981).

The colour index (B-V) is found to be almost constant with a slight reddening of less than 0.05 magnitudes at both minima indicating that the components have approximately the same mean effective temperature (Eggen 1967). The reddening is due to a combination of reflection and gravity effects which result in the averted hemispheres of the stars being slightly cooler and so redder.

Another important feature of the W UMa systems is that they appear to follow a fairly well defined period-colour relation (Eggen 1961, 1967) with the redder systems having shorter periods. This result is not unexpected, however, since the later spectral type stars will have smaller radii so that in the case of a contact system the separation will be less giving a correspondingly shorter period. The period-colour relation is one of the most important observational results that any theory must be able to reproduce.

Although the W UMa systems lie near the main-sequence on the HR diagram, they appear to follow a different mass-luminosity relation from that of the normal lower main-sequence stars. The components of the W UMa systems are observed to obey the relation (Kopal 1959, Kitamura

1959, Osaki 1965).

$$\log\left(\frac{L_1}{L_2}\right) = \alpha \cdot \log\left(\frac{M_1}{M_2}\right) \qquad 0.8 \lesssim \alpha \lesssim 1.0$$

whereas the empirical relation for m-s stars, derived from the latest compilation of stellar data (Popper 1980), requires the value of the slope α to vary between 3.2 and 3.9 along the main-sequence. This result implies that the primary appears underluminous for its mass, while the secondary is overluminous. The structure of the W UMa systems is, therefore, different from that of normal stars.

In general, it is quite difficult to obtain good spectra for these stars. The periods of revolution are short so the exposure times must also be short to obtain adequate time resolution. Consequently, a large telescope and fast spectrograph is required in order to study these stars. The absorption lines are wide and diffuse due to the high rotational velocities, so that accurate measurements are difficult, particularly when there is line blending (see fig.1). An investigation by Adams and Joy (1919) demonstrated that the periods of revolution and rotation for W Ursae Majoris were equal implying that the components are in synchronous rotation.

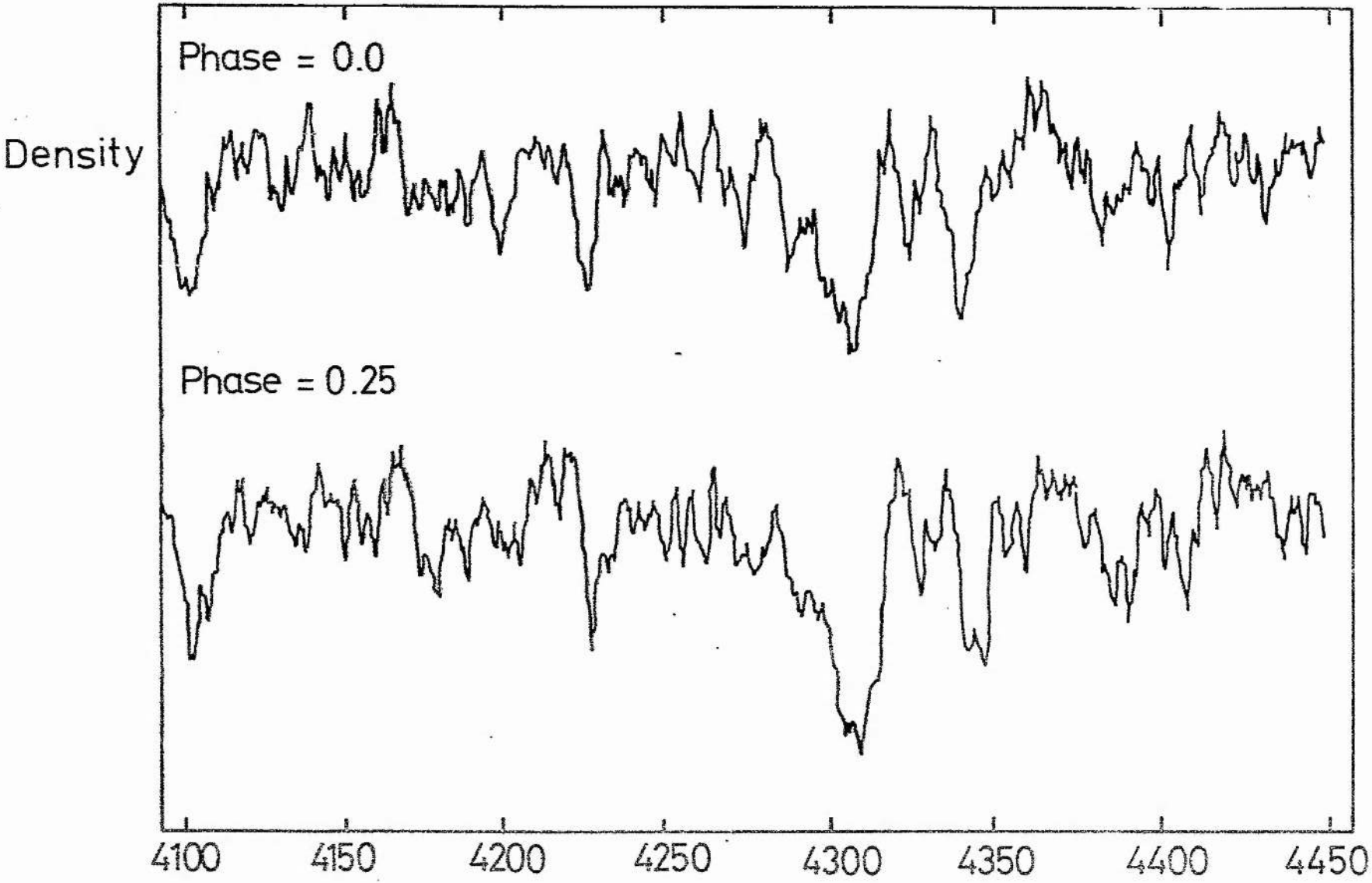


Fig 1 SPECTRUM OF W UMa

The semi-amplitudes of the components' radial velocity curves enable the minimum masses of the stars, and hence the mass ratio of the system to be determined, which, when combined with a photometric determination of the inclination, allows the masses and absolute dimensions to be derived. In many cases, however, the measured spectroscopic mass ratio differs significantly from that derived from the photometric analysis so that there is some uncertainty about the validity of the two methods. The values of the mass ratio lie in the range 0.08 to 0.90, and combined masses from 0.8 to 2.8 solar masses (Binnendijk 1970). It is important to note that equal mass components are not observed even though selection effects would make them the most likely to be discovered.

From an inspection of the radial velocity curves it can be determined whether the system is an A-type or W-type according to Binnendijk's (1970) classification. In a W-type system, the primary minimum is due to the more massive primary occulting the hotter secondary. Conversely, in an A-type system, the primary minimum is due to the transit of the cooler secondary across the primary. Since this original division, other differences have been noted (Rucinski 1974).

In general, class A systems tend to have somewhat earlier spectral types than the W group, and consequently have slightly higher masses and luminosities. The orbital periods of the W systems are continually changing, while in the A group the periods change sporadically. Variations in light curves are prominent in all W-type systems but are moderate, or even absent among the A-type systems. Although there is considerable overlap, the A group have smaller mass ratios. The envelopes seem to have a greater degree of contact in the A-type systems and their light curves conform much more satisfactorily to the contact model. These properties suggest that the W-type systems are the more unstable, showing a greater amount of activity which may be due to a state of marginal contact.

Several peculiarities have been noticed in the spectra of W UMa systems (Struve 1950). Firstly, when the absorption lines from both components are visible, a variation in the strengths of the lines is observed. The shorter wavelength lines tend to be stronger, irrespective of which star is approaching. In the spectrum of W Ursae Majoris itself, Struve remarked that, when the lines are double, the sum of their strengths does not add up to the strength of the single line at eclipse, as though there were some radiation filling in the lines at quadrature. These results should be treated with some caution, however, since

they were based on eye estimates of spectrograms and a limited spectrophotometric investigation by Binnendijk (1967) found this not to be generally true.

In several W-type systems, broad and diffuse emission lines of Ca II have been observed which may be associated with mass flow or circumstellar material. Recent observations using the International Ultraviolet Explorer (IUE) satellite of two W UMa systems (Dupree et al 1979) discovered that the UV spectrum contained strong emission lines of He II, N V, C IV, Si II and Si IV which do not appear to vary with phase suggesting that they are formed in an envelope. When combined with data from other binary systems, there appears to be a trend that the shorter period binaries have more intense UV emission. A possible explanation of this fact is that the emission is stimulated by the interaction of the hot plasma with the stellar magnetic field, which in a shorter period binary would be more tightly wound and concentrated.

The calculated temperature of the plasma ($T=2\times10^6$ K) would imply that emission would also occur in the soft X-ray region, and one W UMa system (VW Cep) has been tentatively identified as a weak X-ray source (Cruddace et al 1980). Results are not yet conclusive but a slight variation in this source was detected which could be caused by the

existence of a hot spot between the two stars. Satellite observations such as these using improved detectors will undoubtedly play a larger role in future work on these systems.

This has provided a brief summary of the observed properties of the W UMa systems, and for further information I would recommend the following review articles and the references quoted in them (Binnendijk 1970, Moss and Whelan 1970, Sahade and Wood 1978).

1.3 THEORETICAL MODELS

Kuiper (1941) showed that by a simple argument, based on the requirements of Roche geometry, that zero age contact binaries cannot exist unless the components are of equal mass. If both stars fill their critical lobes then

$$\log(R_1/R_2) = a \cdot \log(M_1/M_2) \qquad a = 0.46$$

However, the observed mass-radius relation for stars on the lower main sequence gives a = 1. The only way to satisfy both these requirements is for the masses to be equal but this is absolutely forbidden by observations. There are three ways to avoid this problem which has become known as Kuiper's paradox.

Firstly, it may be assumed that the stars are not in contact since there are systems for which the lines are not blended at quadrature. However, this is not true for all systems and the results of light curve analysis do show that the stars fill or even exceed their Roche lobes (Binnendijk 1970, Moss and Whelan 1970, Rucinski 1973, 1974).

Secondly, it could be assumed that the stars are evolved to some degree. The problem here is the large number of systems, and being similar to the lower main-sequence which evolve slowly, it would be surprising if so many systems were the product of evolution. It has been suggested that it only requires a little chemical evolution of at least one component to explain some of the systems (Hazlehurst 1970, Moss and Whelan 1970), but there are problems explaining the redder systems and the existence of two systems believed to be members of galactic clusters (TX Cnc and M67-33) which lie below the cluster turn-off and so are unevolved. At the present time the problem of the ages of such contact systems are still to be established. W UMa stars have been observed in both young and old open clusters, but not in any globular clusters. During a discussion at an IAU symposium (IAU symp. no.73 1977), the estimates of the lifetimes varied from 5×10^7 to 5×10^9 yrs.

Finally, it may be that the structure of the atmospheres of the components of W UMa stars are different from those of normal isolated stars. This is in fact the basis of the now generally accepted hypothesis which requires that the components are surrounded by a common convective envelope (CCE) as proposed by Lucy (1968a, 1968b). The W UMa systems have spectral types mainly in the range F-K where convection becomes important, so Lucy suggested a system containing two main-sequence stars in contact surrounded by a common, convective, optically thick envelope. The adiabatic constant of the envelope differs from that which either star would possess if it were single so that the stars have different equilibrium radii, thereby removing Kuiper's paradox.

Due to the high efficiency of convective mixing, such an envelope was assumed to have a single value for the entropy leading to similar atmospheres for the components, and in particular, to equal mean surface brightnesses as observed. This departure from the main-sequence mass-luminosity relation is merely due to the flow of convected energy between the components to equalise the entropy which leads to a cooling of the primary and a heating of the secondary.

Although this CCE model accounted for the anomalous mass-luminosity relation (Lucy 1968b, 1973), and yielded close fits to the light curves of the A-type systems (Mochnacki and Doughty 1972a, 1972b, Lucy 1973, Rucinski 1973), it failed to give even rough agreement with Eggen's (1961, 1967) period-colour relation, despite variations of the models parameters within reasonable limits (Lucy 1968a, Moss and Whelan 1970, Whelan 1972a, 1972b). Another major problem of the model was why the cooler W-type systems, which should have had stronger convection, did not fit the light curves, while the hotter A-type systems with little or no convection gave good agreement with the observations. Despite the problems, the existence of a common envelope does explain the structure and energy redistribution, and so forms the basis of the later modified models.

At the present time there are two main rival theories concerning the structure of contact binaries and there is some controversy as to which is the more realistic. These have become known as the Discontinuity (DSC) theory and Thermal Relaxation Oscillation (TRO) theory. Overall, they do resemble each other but for two differences in the assumed physics. What is the mode of energy transport, and what happens at the boundary between the stars and the common envelope ?

If we have two stars of different masses and temperatures in a contact configuration surrounded by a common envelope, then according to DSC theory (Shu, Lubow and Anderson 1976, 1979, Lubow and Shu 1977) fluid flow will take place in the envelope as a result of the uneven heating. This will occur along the closed equipotential surfaces where the gas can move easily because of slight horizontal differences in pressure. Below the Roche lobes, however, horizontal redistribution is much more difficult since access to the other star without doing work against gravity is available only at the inner Lagrangian point. Inside the lobes, therefore, the stars can be considered almost decoupled, so that temperature discontinuities may exist across the inner critical surface.

The envelope will be at a temperature somewhere between that of the two components, but cooler gas cannot sit stably on top of hotter gas so that a convection zone will be induced above the hotter primary, destroying the discontinuity on a dynamical timescale. In the case of the secondary with an overlying hotter envelope then the temperature difference would normally disappear on a thermal timescale as a result of diffusion, but DSC theory speculates that the contact discontinuity can be maintained by the matter flow within the envelope. If this is the case, then the system is in both mechanical and thermal

equilibrium and consequently stable. There has been a degree of controversy about the possible existence of a contact discontinuity, with detailed theoretical arguments both for (Shu et al 1979, Lubow and Shu 1979, Shu 1980) and against (Hazlehurst and Refsdal 1978, Papaloizou and Pringle 1979, Smith et al 1980).

On the other hand, as a result of Rucinski's (1973, 1974) investigations which suggested that the W-type systems are not in a state of thermal equilibrium, Lucy (1976) discarded this condition from his model to produce the TRO theory. This relaxation of the model specification made it possible to construct systems with a range of spectral types. Calculations showed that such systems would undergo thermal relaxation oscillations about a state of marginal contact (Lucy 1976, Flannery 1976, Robertson and Eggleton 1977) with a period of about 10^7 years (Hazlehurst 1976). The secondary component will be heated by thermal diffusion from the hotter envelope which results in an expansion of the star and subsequent mass transfer on to the primary. By conservation of angular momentum the separation will increase until contact is broken. When this occurs, the secondary will detach from its Roche lobe and shrink towards its naturally smaller ZAMS state for isolated stars. The primary, however, will try to expand to its larger ZAMS radius but since it already fills its Roche lobe this will

lead to mass transfer back on to the secondary, decreasing the separation until the stars come back into contact. These oscillations will continue until the stars evolve slightly, when it is found that the differential expansion between the components is sufficient to bring the stars into greater contact and allow thermal equilibrium to be achieved.

The W-type systems, which have been shown to be in a condition of marginal contact with shallow common envelopes (Lucy 1973, Rucinski 1973), can be identified with the unevolved model. On the other hand, the A-type systems are fully in contact with light curves closely fitted by the CCE model, and have more stable light curves and periods. The natural explanation of their stability on the TRO model is that they have achieved thermal equilibrium. For this to be true, Lucy concluded that they must be evolved and he showed that to achieve a solution in thermal equilibrium required a small mass ratio but large total mass. His hypothesis that they are evolved has been supported by Wilson (1978) when he demonstrated that the components of these systems may have larger than ZAMS radii, while the W systems do not. These ideas for the formation of the A-type systems implying that they have preferentially small mass ratios, larger total masses, bluer colours and earlier spectral type are consistent with the findings of Rucinski (1974).

A possible problem with this model is the apparent lack of EB, or semi-detached systems with periods less than 0.4 days. Due to the making and breaking of contact, the system should alternately exhibit EW and EB light curves. Calculations by Robertson and Eggleton (1977), however, indicate that the time spent out of contact may be small so that only a few percent may be expected to show departures from EW light curves. It has been suggested that even during the semi-detached phases light curve distortions would make the system appear to be still in contact (Rucinski 1978), possibly due to a temperature increase of the secondary as a result of the accretion of matter (Robertson and Eggleton 1977). Lucy and Wilson (1979) have proposed three possible candidates as being in this semi-detatched, mass transferring phase which they have designated as B-type systems.

At the present time, neither DSC nor TRO theory can be eliminated on purely theoretical grounds so it is necessary to decide on their merits by subjecting their predictions to observational tests. Qualitatively at least, TRO theory does appear to predict the properties of the A and W systems reasonably well, but since DSC theory has not been developed to the same degree giving specific predictions it cannot yet be disregarded. A discussion of observational tests of the two theories has been presented by Lucy and Wilson (1979).

One possible drawback with these models, however, is that they both assume conservation of mass and angular momentum and it has been suggested that this may be a serious omission (Webbink 1976, Nariai 1980, Vilhu and Rahunen 1980) when dealing with the evolution of W UMa binary systems. The results which suggest that there are periodic magnetic phenomena in the photospheres of contact binaries such as starspots (Mullan 1975, Binnendijk 1977), and sudden period changes (Bergéat et al 1972), led van't Veer (1976, 1979) to suggest that solar type prominences or magnetic flares could lead to the loss of large amounts of angular momentum in the form of a stellar wind, without significantly changing the total mass. This loss of momentum will result in an increase in the degree of contact, and a transfer of mass from the secondary to the primary so that the system evolves to smaller mass ratios on the thermal timescale of the secondary. We can only speculate what happens when a rather extreme mass ratio has been reached. It has been suggested that the components will break contact leading to the formation of a cataclysmic variable (Kraft 1962, Vilhu 1974), or alternatively, catastrophically coalesce into a single star (Struve 1950, Webbink 1976, van't Veer 1979) possibly forming a planetary system in the process. If this latter hypothesis is correct then the W UMa stars may form part of the normal evolution

of many solar type dwarfs.

This has been a broad and rather sketchy summary of the current theories concerning the structure and evolution of W UMa type contact binaries. It is clear, however, that the position of these stars is far from settled, and that a great deal of both theoretical and observational work remains to be done.

1.4 AIM OF PROJECT

In the past, it has been very difficult to obtain accurate spectroscopic data for the W UMa systems since it was necessary either to use relatively low dispersion in order to keep exposure times short, or degrade the spectrum by having insufficient time resolution. Another problem is that the line broadening and blending effects present in the spectra of such rapidly rotating contact binaries make accurate measurement difficult. Consequently, spectroscopic observations have been rather overshadowed by photometry of these systems, which, combined with the availability of models to synthesise light curves, has made this the main method of investigating the structure of W UMa stars.

With the introduction of faster spectrographs in recent years, it has become feasible to obtain reasonably high dispersion spectra whilst retaining sufficient time resolution. This data may be analysed using computer reduction techniques to provide more accurate spectroscopic data and so give another means by which we may study the properties of contact binaries. It was decided, therefore, to embark upon a spectroscopic survey of as many of the brighter W UMa systems as could be studied in the available time.

The aims of this work may be split into four sections.

1). The development of an easy to use computer package for the processing and reduction of the spectroscopic data. With the large amount of data expected and the problems associated with measurement, it was hoped that the use of digitised reduction methods would both speed up the procedure and make it more objective.

2). The determination of radial velocity curves for as many systems as possible to derive mass ratios, and to compare these results with those obtained from the photometric analyses. In some cases, significant discrepancies existed between the values determined from the two methods and it was hoped that the reason for this could be established. This could be due to either the inaccuracies in some of the

previous spectroscopic data, or possibly difficulties with the photometric models such as variable and asymmetric light curves affecting the results.

3). The determination of empirical velocity broadening functions (Anderson and Shu 1979), and to see if this method of investigating the structure of contact binary systems could be usefully employed.

4). A re-analysis of the light curves of some systems adopting the spectroscopic mass ratios obtained in this investigation.

CHAPTER 2

REDUCTION TECHNIQUES

2.1 OUTLINE

This chapter will be devoted to a description of the reduction procedures required in this work and the computer programs which were written to implement them. All of the spectroscopic reductions were carried out using the minicomputers in the Data Processing Laboratory of the University Observatory. One advantage of a completely in-house system relative to remote processing is that the user retains complete control over the data and the operation of the system. In addition, the design of the system may be altered to suit individual requirements. A description of the system and the facilities available has been presented at a recent conference on Astronomical Image Processing (Davenhall et al 1979).

The light curve synthesis was carried out using a Vax 11/780 computing system which was installed in the Computing Laboratory in June 1980 during the course of this work.

2.1.1 Hardware

The data reduction is based on two minicomputers, a Data General Nova 820 and a Honeywell H316, although during the course of this work the Nova was replaced by a PDP-11/23. The H316 supports a 7 Mbyte disc drive and a 9-track tape drive, while the Nova/PDP has three 2.5 Mbyte cartridge disc drives. A second tape unit was obtained along with the new minicomputer. Data may be transferred between the machines by a serial link through CAMAC. All the data obtained was held on disc while being processed and then transferred to magnetic tape for long term storage.

A Joyce Loebl Mark IIIc null-balancing microdensitometer was used to scan the spectrographic plates and record the results in a digital form. This is done under the control of one of the minicomputers, usually the H316, via a CAMAC interface with the data obtained being written directly on to disc.

The processing of data was carried out, at first, on the Nova 820 and later on the PDP-11/23 using Tektronix 4010 interactive graphics terminals. For hard copy graphical output, a Hewlett Packard Moseley 2D-4 chart recorder was available although an Anadex DP-9501 printer with graphics facility has recently been acquired.

2.1.2 Software

The minicomputers used run systems based on the FORTH programming language (Moore and Rather 1974). This was originally obtained under an SRC grant in order to evaluate its suitability for use in the minicomputers to be installed at the Northern Hemisphere Observatory (NHO). Although radically different to conventional languages, FORTH was found to be extremely flexible and well suited to a minicomputer environment and is now used exclusively.

FORTH is a highly modular language and is ideally suited to interactive processing, and since the machines are multi-programmed this allows several users to work simultaneously. The compiler is able to produce executable code after making only a single pass through the source code, which produces acceptable compilation times, even given the relatively slow speed of the minicomputers. Input and output to disc is controlled by a virtual memory system

which addresses the disc blocks as though they were in memory thus facilitating easy access to both programs and data stored on disc.

2.2 SPECTROSCOPIC IMAGE PROCESSING SYSTEM

As part of this project, a computer program was developed in order to reduce and analyse the spectra obtained. This was thought to be necessary not only to speed up the procedure, but to enable the use of image processing techniques to extract the maximum amount of information from the data. In addition, this type of analysis eliminates the human subjectivity inherent in visual measurements of plates, although care was taken not to automate the procedure entirely as interaction by the astronomer is both desirable, and in some cases essential.

Some software for image processing and spectroscopic reduction did exist when this work was started (Bunclark 1981, Stewart 1981), but not extensive enough nor directly applicable to my specific needs. It was felt that the best approach to the problem was to develop a program comprising many self-contained modules, each of which was a stage in the reduction procedure. These could be written separately and extended as required to provide a comprehensive reduction package. Wherever possible, existing software was

incorporated with some modifications in order to reduce the time spent in program development. This aim was achieved without much difficulty since FORTH is not only a flexible language allowing interaction, but it also lends itself to structured programming.

In practice, a basic program is loaded which contains all the elements which are common to all sections of the package. This includes the graphics routines, floating point arithmetic, wavelength calibration algorithm, definition of variable names and the assignment of data areas on the disc. The different modules, which are called by the user, are then overlayed above this enabling the use of common routines while keeping the size of the compiled program in core down to a minimum.

The routines now available are as follows :-

1). Joyce Loebl scanning

2). Wavelength calibration

3). Fourier noise filtering

4). Density to Intensity conversion

5). Normalisation to the continuum

6). Spectral line analysis

7). Feature removal

8). Radial velocity measurement

9). Velocity broadening determination

10). Data analysis

A detailed description of each procedure is given in the subsequent sections. Appendix B describes how to use the package while a complete program listing is included in Appendix C.

2.2.1 Joyce Loebl Scanning

A computer controlled Joyce Loebl Mark IIIc null-balancing microdensitometer was used to scan the spectrographic plates. This instrument measures the density on the plate by matching the intensity of a reference beam to that of a beam of light passing through the plate. The reference beam is passed through a glass wedge whose density varies continuously from one end to the other and this is moved until the intensity of the transmitted beam matches that of the measuring beam. As the wedge moves, an encoder records digitally the position (in the range 0-1023) which in turn gives the density of the photographic plate at that point under the measuring beam. The main problem of the Joyce Loebl compared to some more modern machines is that it requires a finite time for the wedge to travel and then come to an equilibrium position so that the measuring procedure is very slow. On the other hand, fluctuations in the intensity of the lamp or in the sensitivity of the photomultiplier do not affect the accuracy of the results

since both beams come from the same source and are measured by the same photomultiplier.

The plate carriage is moved in both the X and Y directions by means of stepping motors controlled by pulses from a CAMAC module which was designed by Mr D.M.Carr, Senior Scientific Officer in electronics at the University Observatory, and built in the Observatory Workshop. These motors cause leadscrews to rotate, which via a half-nut assembly, is converted to a translation of the plate carriage. A single step for either of the motors, with the standard gearing, corresponds to a displacement of the plate by 5 microns.

The computer program which controls the basic Joyce Loebl operations was written by Mr J.R.Stapleton, Scientific Officer at the University Observatory, in conjunction with Mr.P.S.Bunclark, a previous research student. It was only necessary, therefore, to implement additional routines to carry out multiple parallel scans, with a specified offset, in order to scan the comparison spectra along with the stellar spectrum.

Once the program has been loaded into the computer it is used by either a set of control buttons on the Joyce Loebl control panel or by typing instruction commands at a standard ASR 33 teletype.

An outline of the scanning procedure is as follows:- First of all, the plate is placed into the carriage holder which is then aligned so that the spectrum is parallel to the direction of travel. The height of the measuring slit is set to be slightly smaller than the width of the stellar spectrum in order that the maximum density is measured without including any clear plate. The slit width is then set to be equal to the sample interval so that no information is lost.

Once set up mechanically, control may be transferred from the terminal to the Joyce Loebl panel buttons. The carriage may be moved in four directions (up, down, left or right) at four different speeds. These may be used to centre the spectrum, or in conjunction with the 'CROSS' button, used to measure the current X,Y coordinates of the plate. The coordinate system used is simply the number of stepping motor steps from an arbitrary origin. After positioning the plate, control is returned to the terminal by pressing the 'BOX' button.

Scanning parameters such as the number of data points to be sampled and the distance between them, as well as the number of scans with a specified offset between each one are all set up in response to a series of questions from the computer. Once this is completed, scanning is commenced by typing in the appropriate command along with the disc area for storage. The measured density values are stored sequentially in a disc array where they are available for subsequent processing and analysis.

Three different modes of scanning were developed for this project. Firstly, a spectrum and both comparison arcs may be scanned in the order arc - spectrum - arc. Alternatively, multiple scans in either the X or Y directions may be performed in order to measure the calibration steps on photographic plates. The time taken for a typical arc - spectrum - arc scanning sequence of 2560 points per spectrum with a sampling step of 15 microns is about 15-20 minutes.

Once a scan has started it is possible to stop the procedure by means of the `HOLD` button on the Joyce Loebl control panel. This is sometimes necessary in order to re-adjust the focus, or if there is a system crash in one of the other minicomputers which is linked via CAMAC, to prevent failure of the scan. It is possible to restart and

continue the scan, once the 'crisis' has passed, by means of a 'CLEAR' button. In the event of a scan being started and it is found to be necessary to halt the entire process, then this may be done with an 'ABORT' button returning control back to the user at the terminal.

The accuracy of the measurements from the Joyce Loebl has been investigated by Blackman (1977) and Davenhall (1981) and will not be described here, other than to say that it was more than adequate for the purposes of this work.

2.2.2 Wavelength Calibration

It is necessary to determine the variation of wavelength with position along the length of the sampled spectrum, in order to convert to a wavelength scale. For this purpose, a least squares polynomial in terms of the wavelength was fitted to the measured positions of the comparison arc lines (Peterson 1979).This is of the form:-

$$X = n_5\lambda^5 + n_4\lambda^4 + n_3\lambda^3 + n_2\lambda^2 + n_1\lambda + n_0$$

where X = position and λ = wavelength.

The polynomial fit was implemented by modifying an existing program written by Mr.G.C.Stewart which carries out a least squares solution to find the coefficients of the polynomial, of up to a specified order, which gives the smallest rms residuals.

In practice, it order to ensure that the computations remained within the dynamic arithmetical range of the computer, it was found necessary to scale the position and wavelength such that

$Xs = X / 1000$ and $\lambda s = (\lambda - \lambda o) / 1000$

where λo is a predefined offset.

The determination of the wavelength calibration combines several different processes, the first of which is the selection of the comparison lines for measurement. It was considered that the best method of identifying arc lines reliably was for the astronomer to do this interactively, calling the line wavelengths from a catalogue held on disc and using the Tektronix 4010 cursor controls to mark the position of a line in the spectrum. Although, in principle, this could be achieved automatically, it was felt that the time necessary to develop and program a reliable algorithm could not be justified in view of the ultimate aim of the project - the analysis of astronomical data.

Secondly, the position of each line must be determined accurately. After some experimentation, the method finally employed was to fit a least squares parabola around the centre of the emission line profiles.

If a function of the form

$$y = ax^2 + bx + c$$

is fitted to the emission profile, then the position of the centre given by

$$x = -b/2a$$

In practice, the centre of the arc line profile is found by differentiating along the spectrum from the point marked by the cursor until a peak is detected. Once this point is found, the coefficients a,b and c are determined by the usual least squares technique enabling the central position of the arc line to be computed.

One assumption that this requires, is that the profile is symmetrical and may be fitted by such an analytic function. It was found though, that provided that the line was neither saturated, nor blended, that fitting to the central region of a line gave acceptable results.

If the plate holder has not been exactly aligned so that the motion of the carriage deviates slightly from parallel with respect to the spectrum, then the positions of the comparison arc lines on either side of the spectrum will not be the same. In order to take account of the effect of any such misalignment on the wavelength calibration, the position of a given line is taken to be the mean of the measured values taken from the lines on either side of the spectrum.

The procedure employed in the determination of the wavelength calibration is as follows. Plots of the two comparison arc spectra are displayed simultaneously on the graphics terminal, offset vertically from each other for clarity. The wavelength of a comparison line is called from a catalogue and the cursor used to mark its position in both arc spectra. Once the individual positions have been calculated, the mean value is entered automatically into the polynomial fit, and the user can proceed to the next line. Finally, after all the lines have been measured, the computer will determine the coefficients of the best-fitting polynomial of the form

$$X_S = a_5 \lambda_S^5 + a_4 \lambda_S^4 + a_3 \lambda_S^3 + a_2 \lambda_S^2 + a_1 \lambda_S + a_0$$

These six coefficients now describe completely the position-wavelength relation for the spectrum.

2.2.3 Fourier Noise Filtering

The techniques developed in information theory for the enhancement of digital images are now well known, with such methods able to restore much of the image quality lost due to the presence of noise. The routine application of Fourier transform techniques to astronomical data has only been practical since the development of the Fast Fourier Transform (FFT) algorithm. A discussion of this and its applications to data analysis may be found in a paper by Brault and White (1971). A program for computation of the FFT, based on the Cooley-Tukey version, had been written by Mr.P.S.Bunclark and was readily available for this application.

It has been shown that the highest frequency components in the power spectrum contain virtually no information since they are due to the noise in the data. Obviously, therefore, in order to restore the image, such high frequency components must be suppressed, while leaving the lower frequency components which contain the signal unaffected.

Let t(x) be the true spectrum, while n(x) is random noise. The observed degraded signal s(x) will be given by

$$s(x)=t(x)+n(x)$$

Since Fourier transforms are linear, the transform of the the above equation in terms of the frequency variable k is given by

$$S(k)=T(k)+N(k)$$

Correction for the presence of noise will take the form of a filter; that is, the various frequency components will be weighted in some way to diminish the effect of the noise.

$$S(k).F(k)=[T(k)+N(k)].F(k) = T'(k)$$

where F(k) is the optimum filter such that the error between the true signal T(k) and the restored signal T'(k) is minimised. The optimum filter has been shown to be (Gray 1976)

$$F(k) = 1 / [\ 1 + \{\ N(k)/T(k)\ \}^{2}\ ]$$

One problem with the realisation of the filter is that it involves the true signal T(k) rather than the noise contaminated signal S(k) which is observed. In practice, since it is an optimum filter, small deviations from the true filter shape should only result in second order errors. It is adequate, therefore, to use smooth, simple models for the power spectra of both the noise and the signal to replace the observed signal.

A convenient expression for T(k) is the Gaussian

$$T(k) = A \cdot 10^{-\alpha_o^2 k^2}$$

where A is the amplitude and α_o is a fitting parameter, chosen such that the filter has a value of 0.5 at the frequency cutoff in the transform domain where the noise begins to dominate the image signal.

Since the noise may be assumed to be random and uncorrelated with the signal it can be represented by a constant, the value of which is the average value of its power spectrum.

$$N(k) = B = \overline{P_n(k)}$$

The value of B may be determined from the high frequency components of the image transform where the noise dominates.

Combining these expressions for T(k) and N(k) the equation for the optimum filter becomes

$$F(k) = 1 \; / \; [\; 1 + (B/A)^2 \, 10^{2\alpha_o^2 k^2} \;]$$

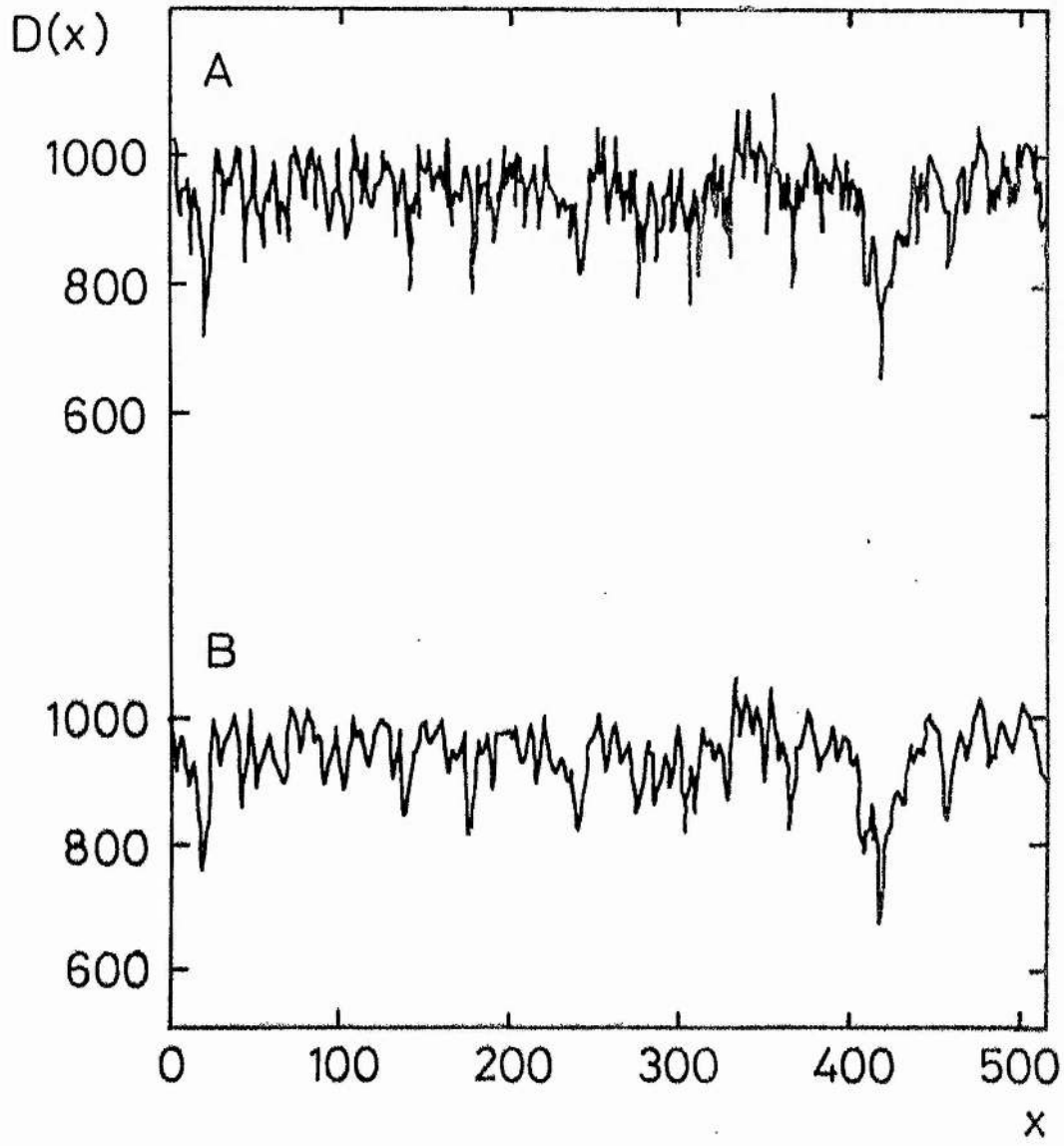
where A,B and α_o are the calculated fitting parameters. Gray (1976) has shown that this expression forms a reasonable filter (see fig.2).

An existing program, written jointly by Mr.P.S.Bunclark and Mr.G.C.Stewart, for carrying out noise filtering based on this method was available for use. This was modified to conform with the standard layout adopted for each routine in the reduction package, and to allow for ease of use. In addition, since processing of large numbers of similar spectra was to be carried out, a technique was developed to filter any given number of spectra which were held sequentially on the disc.

In order to process many spectra, it is necessary to determine the values of the fitting parameters A,B and α_o using some automatic method. The maximum amplitude A of the Fourier transform around the zero ordinate, and the noise level B at the highest frequencies are simple to find. Problems could arise, however, with the value of α_o , the cutoff frequency of the image. Since the spectra are similar, it was decided that a single value could be assumed for them all, provided that they were all taken using the same spectrograph, at the same dispersion and were of similar spectral type. This value was chosen by examining the power spectra of several images and a mean value taken. Any errors introduced by this assumption were found to be negligible.

Fig 2

APPLICATION OF FOURIER NOISE FILTER



A Raw Data
B Filtered Data

2.2.4 Density - Intensity Conversion

In order to convert the measured density values to the intensity of light incident upon the plate, it is first necessary to define the relationship between them. The relationship of Baker (1928) and de Vaucouleurs (1968) has been found not to be linear in some circumstances (Davenhall 1981). Following Smith and Bopp (1980), a polynomial fit was employed to define the relation as follows.

If I is the incident intensity, and d is the resultant density on the plate, the relation between them is assumed to be of the form

$$\log(I) = n_3 D^3 + n_2 D^2 + n_1 D + n_0$$

where D is the Baker density defined as

$$D = \log(10^d - 1)$$

The density d is derived from the machine reading, x, and the encoder conversion factor, f, using the equation

$$d = f.(x-x_0)$$

where x_0 is the mean plate background which is assumed to be constant over the plate.

A least squares procedure is used to determine the best fitting polynomial, of up to order 3, by relating the measured density values of the associated step wedge to the corresponding log(I) values.

Once the calibration has been established, it is a simple matter to use it to convert the measured density at each point in the spectrum to intensity.

2.2.5 Normalisation To Continuum

The continuum of the observed spectrum will generally vary with wavelength and so it is necessary to rectify the intensity of the spectrum to the corresponding continuum value at each point. This is done to enable measurements of line profiles and equivalent widths to be directly comparable with each other or with model predictions. In addition, this removes any low frequency components which might affect the measurement of radial velocities by crosscorrelation (see sect. 2.2.8.3)

It is first necessary to establish how the continuum varies with wavelength. Two different methods were investigated in this work, each of which has advantages and disadvantages in its use.

The first of the two techniques was to use a cubic polynomial to describe the continuum variations, and an algorithm for automatically fitting the polynomial was developed. An iterative routine was used where first a least squares cubic is fitted to the spectrum, followed by a removal of the data points which lie either more than 1σ below the cubic (i.e. absorption lines), or more than 2σ above the line (i.e. emission lines). With each iteration the level of the computed line approaches the true continuum. The main advantage of this method is that many spectra can be processed without interaction. On the other hand, the disadvantages are that this algorithm cannot be as accurate as human judgement, especially in very complicated spectra where there are features such as line blanketing etc.

The second method uses a spline function to describe the continuum variation, fitting to a series of points defined by the user as lying on the continuum. Polynomials are the most widely used functions for approximations because they have the simplest mathematical properties. However, it is now accepted that in many circumstances a spline function is a more adaptable fitting function than a polynomial with a comparable number of parameters (Greville 1969).

A spline function S(x), is defined as a function that results from piecing together polynomial arcs of degree k such that S(x) and its derivatives up to and including the (k-1)th derivative are continuous everywhere. An algorithm for computing a cubic spline and subsequent use in fitting a continuum had been programmed previously (Stewart 1981), and this was modified for use in the reduction package. This method for defining the continuum has the advantage that the astronomer can interactively constrain the function to follow the curvature of the continuum very accurately. Such a procedure is, however, very time consuming.

It can be seen that the two methods have very different characteristics and so the technique employed must be chosen to suit the requirements of the user. In cases where spectrophotometry is to be carried out, the interactive spline fit is better since an accurate continuum level is essential. On the other hand, if radial velocities are the only measurement, the automatic routine is quite adequate.

Once the continuum is defined, by either method, the rectified spectrum $R(\lambda)$ is given by,

$$R(\lambda) = S(\lambda) / C(\lambda)$$

where $S(\lambda)$ is the observed spectrum and $C(\lambda)$ is the

corresponding continuum level at that point in the spectrum.

2.2.6 Feature Removal

Occasionally, it is necessary to modify the observed spectrum in order to remove certain unwanted features. These may be plate scratches, corrupted data points, emission lines from street lights, etc. , or even stellar lines in some circumstances.

In order to do this, two simple routines are employed. The first of these simply replaces all the data values between two specified points in the spectrum by the continuum level. Alternatively, linear interpolation may be used to replace data values by a straight line between the given points.

2.2.7 Spectral Line Analysis

Once the measured spectrum has been converted to intensity and normalised, then quantitative measurements of the absorption lines may be obtained. A computer program for carrying out this had been developed (Stewart 1981), and this was subsequently modified in order to make it easier to use. These modifications incorporated the polynomial wavelength calbration and allowed lines to be selected automatically from a catalogue .

The scheme employed in this program is based upon an integration of the area contained in a given line, using a Simpson's rule quadrature formula. Several parameters are computed, namely, the central depth, equivalent width, the one quarter, one half and three quarter depth widths.

2.2.8 Radial Velocity Measurement

The measurement of radial velocities is very important in Astronomy, and indeed forms the bulk of the work in this investigation. Three different techniques were developed each of which shall now be described in detail.

2.2.8.1 Line Profile Fitting -

The most straightforward approach to the analysis of digital spectral data is to fit individual lines with a predetermined mathematical function, and then derive the line position from the empirically determined parameters of the fit. Since a least squares parabola routine was already in use (see sect. 2.2.2), it was decided to fit such a curve to the centre of each stellar line profile.

If one uses the function

$$y = a\lambda^2 + b\lambda + c$$

then the line centre is given by

$\lambda_c = -b/2a$

The observed radial velocity can then be computed using the Doppler formula

$v = c.(\lambda_c - \lambda_o)/\lambda_o$

where λ_o is the rest wavelength of the line, and c is the velocity of light.

In practice, a catalogue containing the wavelengths of the lines to be measured is held on disc and as each one is accessed, a plot of the spectrum around each region is displayed for the user to identify the line using the graphics terminal cursor. When all the lines have been measured, the mean velocity corrected for the solar motion, and its error is computed.

This approach has two disadvantages: the first is that the true line profile may not be truly represented by a simple mathematical function. In fact, in the case of a contact binary system, the spectra will contain asymmetric line profiles due to line blending. The second problem is that one is working with a limited subset of the data, in that only a small number of lines are measured, so that some information contained in the entire spectrum is lost.

2.2.8.2 Simulated Comparator Measurements -

The problem of fitting a mathematical function to a line profile may be avoided by determining the line centre by eye. In order to achieve this with accuracy, a routine was developed which, in effect, simulates the operation of an oscilloscope comparator measuring machine.

A display of the spectrum around each line is displayed on the graphics terminal on which is superimposed a reversed image of the same region. This reversed image may be shifted with respect to the original until the absorption (or emission) line in each plot is judged by the astronomer to be coincident. Once this position is found the computer then calculates the Doppler shift and hence the radial velocity.

An advantage of this technique is that greater accuracy can be achieved, especially where the line profiles are not symmetrical. The disadvantages though are that it is more time consuming and is still limited in the amount of available information used.

2.2.8.3 Cross-correlation -

A published investigation (Simkin 1974) indicated that the disadvantages inherent in the conventional methods of determining Doppler shifts could be avoided by the use of the cross-correlation technique. This has become widely used in recent years (e.g. Da Costa et al 1977, Tonry and Davis 1979), and in particular, the analog form of which has been very successfully applied in radial velocity spectrometers (Griffin 1967, Baranne et al 1979).

The usual form of the Doppler formula is

$$(\lambda_1 - \lambda_0)/\lambda_0 = v/c$$

i.e $$\Delta\lambda = \lambda_0 . v/c$$

which implies that the change in wavelength $\Delta\lambda$ is a function of both velocity and wavelength. However, if we take logarithms

$$\log\lambda_1 - \log\lambda_0 = \log[1+v/c]$$

i.e. $$\Delta \log\lambda = \log[1+v/c] = z$$

which means that the Doppler shift, z, is a function of radial velocity alone when represented in terms of $\log\lambda$.

To measure the radial velocity of a star, therefore, we can measure the amount by which its spectrum is shifted, plotted as a function of $\log\lambda$, with respect to that of a standard star of similar spectral type and known velocity. This can be done by computing the cross-correlation function between the observed spectrum, s(x), and the standard or template spectrum, t(x) (see fig.3).

Using the independent variable $x=\log\lambda$, then the cross-correlation function (c.c.f.) may be defined as

$$c(z) = a \int s(x).t(x-z).dx$$

where a is a scaling or normalisation factor.

This function will have a maximum value when the template spectrum t(x) has been shifted by the amount z to coincide with the observed spectrum s(x).

For observational data, these continuous functions become N discrete points which are sampled at equal intervals in Δx.

Let σ_s and σ_t be the rms errors of the spectra such that

$$\sigma_s^2 = \sum s(x)^2/N \text{ and } \sigma_t^2 = \sum t(x)^2/N$$

The normalised c.c.f. may then be expressed as

$$c(z) = \sum s(x).t(x-z)/[N.\sigma_s.\sigma_t]$$

It has been stated (Simkin 1974) that the most efficient method of calculating c(z) is in the frequency domain by using FFT techniques.

Let S(k) and T(k) be the discrete Fourier transforms of the spectra such that

$$S(k) = \sum s(x).\exp[-2\pi ikx/N]$$

$$T(k) = \sum t(x).\exp[-2\pi ikx/N]$$

Fourier transforming the formula for c(z) gives

$$C(k) = S(k).T^{*}(k)/[N.\sigma_s.\sigma_t]$$

where * indicates complex conjugation.
It may be shown, therefore, that the inverse transform may be written as

$$c(z) = \sum S(k).T(-k).\exp[2\pi ikx/N] \; / \; [N.\sigma_s.\sigma_t]$$

Although this may appear to be a very complicated technique, it is in practice very simple to employ. The procedure is to compute the Fourier transforms of both the observed and standard spectra, take the complex conjugate of the standard, and then form the inverse transform of their product.

The use of the FFT does introduce some complications however. Since the spectral segments become periodic functions when expressed in terms of a Fourier series, the computed c.c.f. will contain an overlap where terms from the end of one spectrum enter the start of the other. In reality, the spectra are not periodic, so that this overlap may distort the c.c.f. and can introduce significant error into measurement of velocity if the shift exceeds 10-20% of the array length (Simkin 1974). This effect is eliminated by extending the segments to twice their length with straight lines, and setting the mean of each data array to zero (Bendat and Piersol 1971).

It has been found to be convenient to keep a catalogue of Fourier transforms for a number of radial velocity standards of different spectral type, which have been previously processed in order to reduce the amount of computation. The standard can then be selected according to the requirements of spectral type, spectrograph, dispersion and wavelength range.

Once the c.c.f. has been computed, the position of the maximum can be found by either differentiating the function numerically, or by fitting a least squares parabola to the peak in the manner described previously (see fig.4).

Fig 3

CCF FOR SPECTRUM WITH RESPECT TO A STANDARD STAR

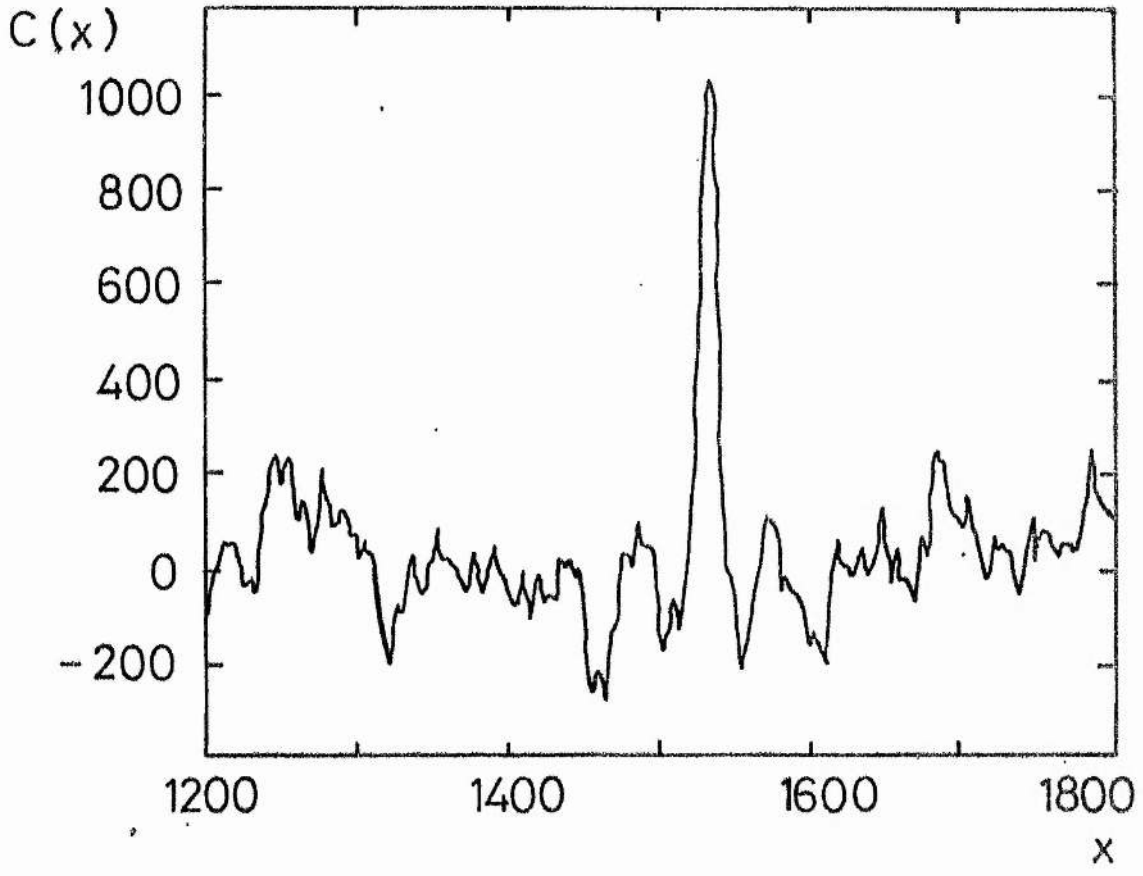
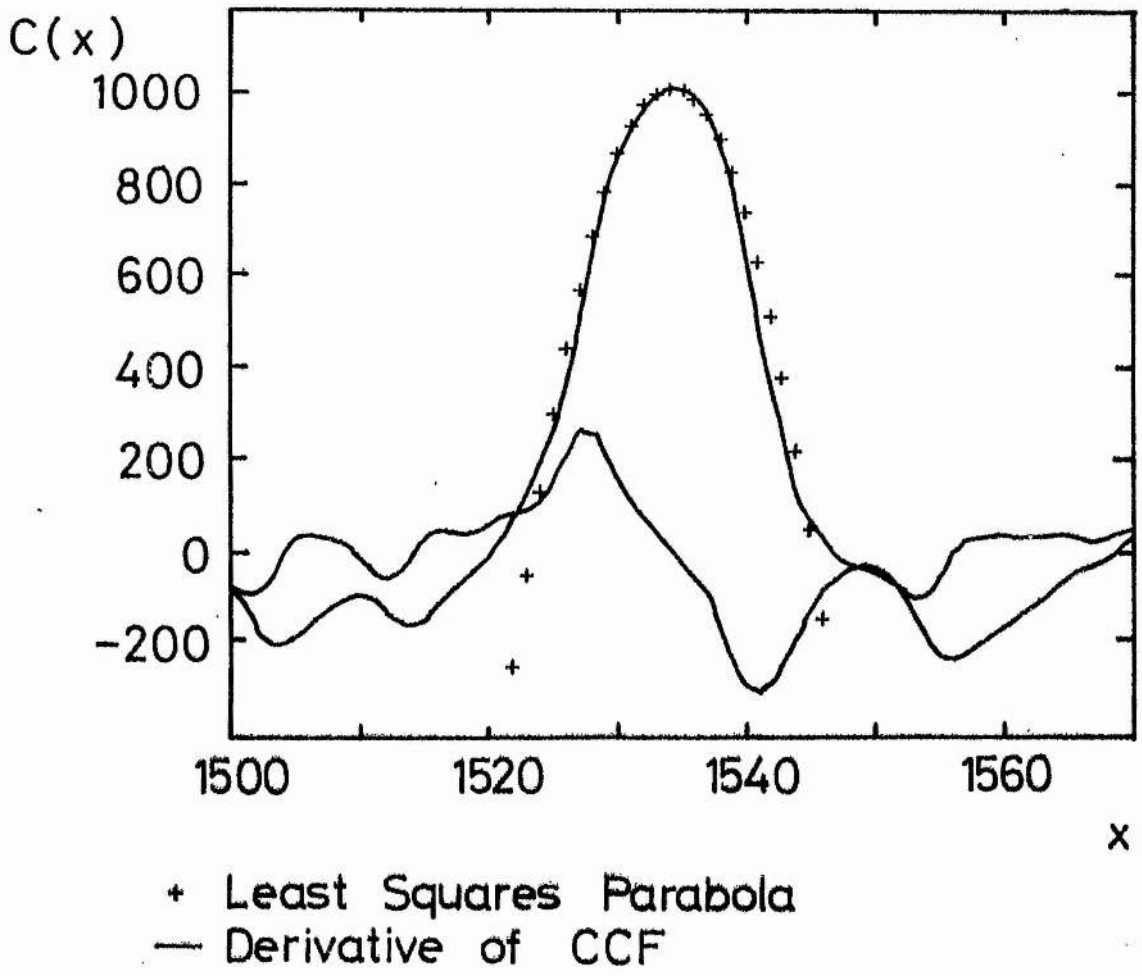


Fig 4

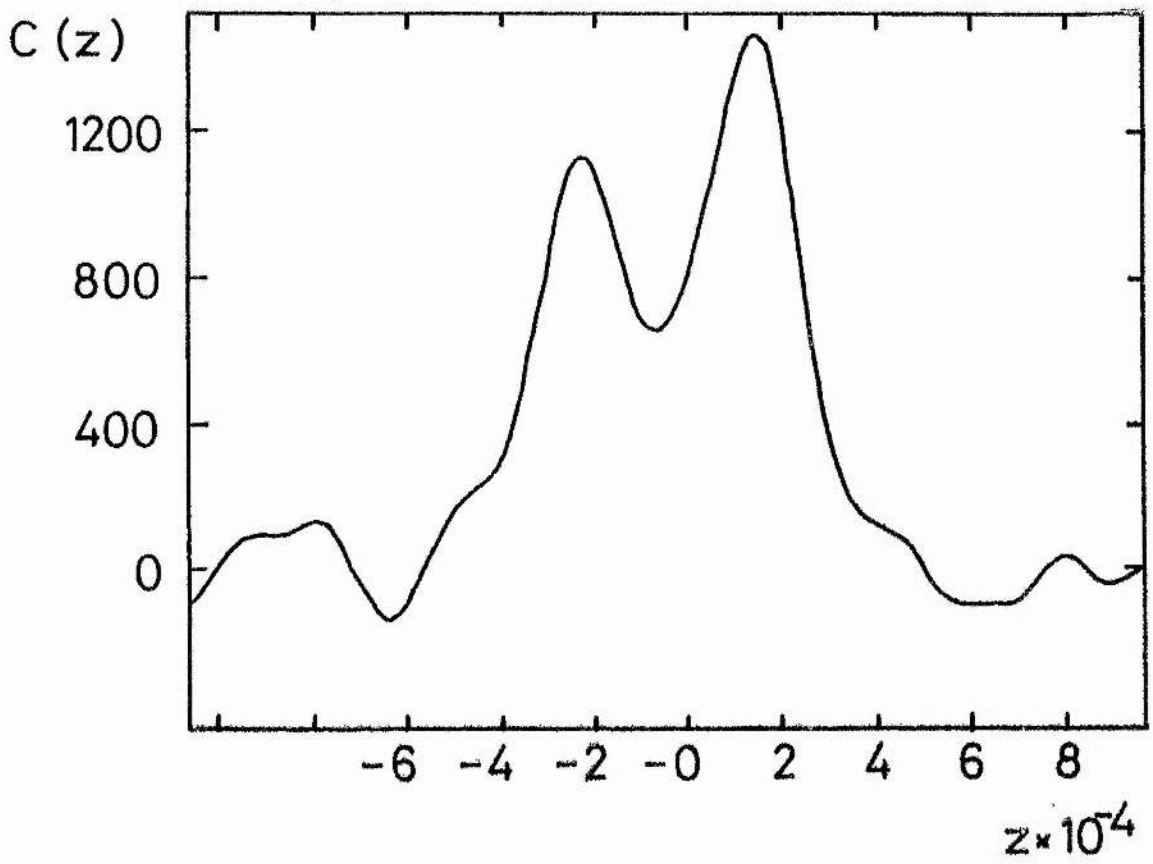
MEASUREMENT OF CCF PEAK



In the case of a binary system, where there are lines from both components in the spectrum, it is clear that as t(x) is shifted there will be two matches with respect to the spectrum s(x). Consequently, two peaks will be contained in the c.c.f., the positions giving the velocity of each component while the amplitude of each is proportional to the strength of the lines in the spectrum (see fig.5). Difficulties arise, however, if the lines from the two components are very heavily blended as this will result in the blending of the c.c.f. peaks. This is, of course, a similar problem to measuring individual blended lines by more conventional techniques. Consequently, accurate measurements are not obtained near eclipse phases when the lines are blended. In practice, it has been found that the cross-correlation method can be applied successfully for detached or semi-detached systems (Skillen, Hilditch 1980, private communication) later than spectral type A. Contact binaries, however, which are the subject of this investigation, pose more of a problem. The systems with spectral type K or later, have spectra which contain large numbers of heavily blended lines at all phases which result in distorted and asymmetrical cross-correlation functions that cannot be measured with any reasonable degree of accuracy. In this case, it was necessary to resort to the simulated comparator technique.

Fig 5

CCF FOR DOUBLE LINED SPECTRUM



On the other hand, the F and G type systems, which form the bulk of the data, can be measured successfully provided that the Balmer lines of Hydrogen and the G band are avoided since these are always blended and would otherwise affect the result.

2.2.9 Analysis Of Radial Velocity Curves

If one considers a binary star system, then the classical expression for the observed radial velocity is:-

$$V = V_o + K[\cos(w+v)+e.\cos(w)]$$

where the parameters are as follows:-

V_o - systemic velocity

K - semiamplitude

v -true anomaly

w - longitude of periastron passage

e - eccentricity

Many methods, both analytical and graphical, have been devised for calculating the elements from the velocity curve (Petrie 1962). The method of Wilson (1941), however, is very useful for deriving the mass ratio and the systemic velocity of a double lined spectroscopic binary independently of the other elements, particularly when data is sparse.

If we take the general equations

$$V_1 = V_o + K_1.[\cos(w+v)+e.\cos(w)]$$

$$V_2 = V_o + K_2.[\cos(w+v)+e.\cos(w)]$$

Putting $r = M_1/M_2 = K_2/K_1$, these reduce to

$$V_1 = V_o.(1+r)/r - V_2/r$$

$$V_2 = V_o.(1+r) - V_1.r$$

It can be seen that these define a straight line in the (V_1, V_2) plane which may be solved by least squares in order to determine V_o and r. A normal least squares solution assumes that all the error is in one or other of the observations. It is normal, therefore, in this case to solve both equations and take the mean value, even though this is not strictly correct.

Irwin (1973), however, has modified and extended the method to form a rigorous multi-error least squares differential correction technique.

It may be shown that

$$V_1 - V_2 = (K_1+K_2).[\cos(w+v)+e.\cos(w)]$$

so that in the case when the eccentricity is negligible, this becomes

$V_1 - V_2 = (K_1+K_2).(-\sin\theta)$

where $\theta = 360^{\circ}.(t-t_o).P$ are the phases of the observations.

A least squares value for (K_1+K_2) may be readily found from this equation, namely

$$(K_1+K_2)=\sum[-\sin\theta(V_1-V_2)]/\sum\sin^2\theta$$

The assumption of e=0 is a realistic one in many spectroscopic doubles, particulary contact binaries where the tidal interaction between the components is considerable. Support for this assumption is given by the fact that secondary eclipse occurs at phase 0.5 in these systems.

If one uses the relations

$K_1=(K_1+K_2)/(1+r)$

$K_2=(K_1+K_2).r/(1+r)$

and substitutes these into Wilson's equations for V_1 and V_2 we find that

$V_1 = V_o-(K_1+K_2).\sin\theta/(1+r)$

$V_2 = V_o+(K_1+K_2).\sin\theta.r/(1+r)$

Differentiating these equations and using finite differences we get the linear equations appropriate for a least squares differential correction,

spectrum is the integration of the 'local spectra' over the surface of the stars, each of which is characterised by the local values of the temperature, surface gravity, and the Doppler shift due to rotational broadening. This approach to the problem of contact binary structure was first proposed by Anderson and Shu (1979), when they presented an atlas of what they have termed rotation broadening functions.

Consider the appearance of an element dA on the photosphere of a system, at a position $\underline{r}$ as seen by a distant observer lying in the direction $\underline{o}$. If the photosphere is taken to be rotating rigidly with angular velocity $\underline{w}$, then the local velocity of the element is given by

$$\underline{v} = \underline{w} \times \underline{r}$$

If one considers a spectral line whose locally emitted width is zero i.e. a delta function, then the rotation broadening function is defined to be the normalised spectral line profile as seen by the observer.

Let the non-relativistic Doppler shift $\Delta\lambda/\lambda$ be denoted by z; then the rotation broadening function $b(z,\underline{o})$ is given by (Anderson and Shu 1979)

$$b(z,\underline{o}) = 1/H \cdot \int I(r,\mu) \cdot P(\underline{r},\underline{o}) \cdot \delta[z+\underline{o}\cdot(\underline{w}\times\underline{r})/c] \cdot \mu \cdot dA$$

where $I(\underline{r},\mu)$ is the intensity of the local flux emerging at the angle whose cosine is specified by μ, and H is the total intensity. $P(\underline{r},\varrho)$ is described as a 'penetration function' equalling zero if the element is not visible, and unity if seen by the observer, while the intrinsic line profile is represented by the delta function δ.

The broadening fuction can be given a simple geometrical interpretation if one assumes that the photosphere is rotating as a rigid body. In this case, the contours of constant radial velocity on the projected image are straight lines parallel to the projected axis of rotation. The value of the velocity is proportional to the distance from this axis. Furthermore, if one assumes that the surface is uniformly bright, the contribution to the rotation broadening function at a given velocity will be proportional to the length on the projected image of the corresponding velocity contour line. Consequently, the shape of the function will represent the projected shape of the system.

In reality, limb darkening, gravity darkening and the reflection effect will distort this strict proportionality although the rotation broadening function will still contain information on the shape of the stars. Determination of this function empirically may, therefore, provide a method

of investigating the properties of contact binary systems.

Anderson and Shu (1979) have computed an atlas of theoretical rotation broadening functions for a grid of mass ratio, filled fraction and orbital inclination assuming three different combinations of gravity and limb darkening. These functions were computed using the important assumption known as the uniform profile model i.e. the spectral profile remains constant over the projected surface except for the rotational Doppler shift. This assumption is a necessary one in order that the empirical broadening function can be compared with the theoretical one. It is known, however, that the spectral type of a W UMa star varies little with orbital phase (Binnendijk 1970), so that this assumption probably does not affect the results seriously.

A completely rigorous treatment, taking into account variations in the spectrum due to temperature and gravity variations accross the surface would involve computing synthetic line profiles (cf Hutchings 1973), rather than rotation broadening functions. This is a major computational problem, however, but a necessary step in future work on these systems when more accurate spectrophotometry is possible.

Fourier transform techniques may be used to determine empirical rotation broadening functions since under the uniform profile assumption the observed spectrum of a W UMa star is the convolution of its rotation function with the spectrum of a non-rotating star of the same spectral type (Simkin 1974, Gray 1976, Anderson et al 1980). There are several advantages in the use of FFT techniques. Firstly, the actual spectral lines have finite widths and are often blended which represents a serious obstacle to the direct comparison of individual spectral features with the theoretical function. In addition, FFT methods have a substantial gain in signal-to-noise ratio over analyses of individual spectral lines as a result of the statistical treatment of many lines which is implicit in the method.

If the intrinsic spectrum is denoted by k(y) and the instrumental profile by a(x), then the observed spectrum of a single non-rotating star is given by

$$t(x) = \int k(y).a(x-y).dy$$
$$= k(x)*a(x)$$

Similarly, the observed spectrum of a W UMa star will be given by

$$s(x) = \int k(y).a(x-y).b(x-y).dy$$
$$= k(x)*a(x)*b(x)$$

$= t(x)*b(x)$

In the transform domain, the convolution integral becomes a product

$S(k) = T(k).B(k)$

In principle, therefore, the broadening function can be obtained by a deconvolution of the observed spectrum with respect to the spectrum of a non-rotating standard star.

$B(k) = S(k)/T(k)$

In practice, however, there are difficulties with this approach since this procedure will produce a very noisy restored profile. This is due to the strong amplification of high frequency noise components during this inverse operation (Brault and White 1971, Simkin 1974). Even with careful noise filtering, the calculated rotation broadening functions are extremely noisy. The techniques described by Simkin (1974) to reduce this level of noise were not practical for use on the relatively slow minicomputers available due to the much greater computation required.

Despite these problems with noise, it was found possible to obtain empirical broadening functions, particulary for those systems with larger mass ratio so that the lines of both spectra were not obscured by the random

noise fluctuations in the derived function.

2.3 LIGHT CURVE SYNTHESIS

The light curve synthesis program of Rucinski (1976a,b,c) was employed for the re-analysis of published light curves using the spectroscopically derived parameters.

The input parameters required for the program are as follows :-

1). Mass ratio q

2). Orbital inclination i

3). Fill-out factor $f = (C - C_2) / (C_1 - C_2)$ (or $F = 1 - f$)

4). Reference temperature T

5). Temperature excess $x = (T_s - T_p) / T_p$

6). Gravity darkening exponent β

7). Bolometric albedo A

The model atmospheres of Kurucz (1979) were employed to specify the fluxes in either the UBV or uvby passbands while the limb darkening coefficients were taken from Al-Naimiy (1978).

A common problem with the analysis of W UMa type light curves is that they are frequently asymmetric. The approach adopted was to analyse each half of the light curve independently rather than assume that one or the other is

representative of the system. Cubic spline fits to the published observations, using a program developed by Hilditch, were used to generate normalised intensities at phase intervals of 0.01 for each half of the light curves. Partial derivatives expressing the dependence of the light curves on each of the parameters were computed using a Fortran program which called Ruscinski's synthesis code as a function. These derivatives, together with the observed light curve and the theoretical light curve are then entered into a differential least squares program. The parameters in the solution may be fixed, or allowed to vary as required. A number of iterations are usually required to approach the solution more closely.

CHAPTER 3

OBSERVATIONS

3.1 OUTLINE

The spectroscopic data in this investigation were obtained during three observing runs, two at L'Observatoire de Haute Provence and one at the Dominion Astrophysical Observatory. As a result of the nature of each visit and the equipment used, the procedure followed in making the observations varied in order to make best use of the time available.

The visits to O.H.P. were devoted entirely to obtaining spectra of W UMa systems. However, the speed of the spectrograph at the chosen dispersion was such that there were severe restrictions on the magnitude limit attainable. In order to retain sufficient time resolution (< 0.05 cycle), the exposure times had to be kept fairly short so that only systems brighter than 9th magnitude could be observed. Due to the scarcity of bright W UMa stars in

the Northern hemisphere the aim of the visit was to observe a few selected systems over their entire phase range in more detail. On the other hand, the spectra from D.A.O. were kindly obtained by Dr.R.W.Hilditch in addition to those he was obtaining for another project. Furthermore, an image tube spectrograph was employed so that stars as faint as 12th magnitude could be observed. For these reasons it was decided to observe a large number of systems with the observations timed to coincide with the quadratures wherever possible, so that the spectrosopic mass ratio of each could be determined using Irwin's method as previously described (sect.2.2.9)

3.2 OBSERVATIONS

3.2.1 O.H.P. 193 Cm Spectra

The coude spectrograph of the 193 cm reflector at the L'Observatoire de Haute Provence was used during the period 11th to 19th April 1979 with the assistance of Dr.R.W.Hilditch and two O.H.P. technicians. The configuration employed, camera 3 and grating B, provided spectra in the wavelength range $\lambda\lambda$ 3850 - 4950 angstroms at a dispersion of 20 A/mm. The standard slit width of 4mm was used, giving a projected width on the plate of 0.29mm, while the slit length of 0.35mm corresponded to 1.2 arcsec on the

sky. An iron arc was used to give the wavelength calibration with two exposures, each lasting 5 seconds, being made before and after each stellar exposure which had an average exposure time of 25-30 minutes. In order to achieve maximum speed, air baked IIaO plates were used which were then developed using MWP2. Initially, D19 was used in the developing process, but it was quickly found that the exposure times would be longer than that required to retain sufficient time resolution on account of the poor seeing conditions that prevailed at the time of observation. The developer employed, MWP2, gives a high contrast so that the exposure times could be reduced by about 30%, although this results in a much coarser, grainier finish.

Of the nine nights allocated, only one had excellent seeing, although a further three nights were sufficiently clear for spectroscopy. Approximately 50% of the time available was therefore useful. In this time, a total of 70 spectra were obtained of 3 W UMa systems (see Table 1), and 3 radial velocity standards (Sanford et al 1950, Sanford and Pearce 1952, Pearce 1955) (see Table 2).

3.2.2 D.A.O. Spectra

Dr.R.W.Hilditch kindly obtained spectra for this investigation using the Cassegrain spectrograph of the Dominion Astrophysical Observatory 72" telescope during the period 27th March to 2nd April 1980. An EMI three-stage electromagnetic image intensifier tube was employed in order to obtain spectra of some fainter systems. This does, however, result in the characteristic geometrical s-distortion of the spectra. The grating,which provided a dispersion of 30 A/mm, was adjusted so that the wavelength range 3900-4500A was contained within the linear portion of the recorded spectrum. Unbaked IIaO plates were used which were then developed in D19. Average exposure times using this equipment were around 5-10 minutes, much better than that obtained at O.H.P. .

A total of 102 spectra were recorded of 10 W UMa systems (see Table 1), and 3 radial velocity standards (see Table 2). Unfortunately, the spectra of 4 systems, AC Boo,RW Com, XY Leo and AH Vir were not taken around the times of quadrature. Consequently, radial velocity measurements could not be made of the individual components, so that more observations will be required at a later date.

3.2.3 O.H.P. 152cm Spectra

The O.H.P. 152cm reflector with coude spectrograph was used during the period 19th to 25th August 1980 with the assistance of Mr.D.M.Carr and the night technician. Camera A and grating A1 was employed giving spectra in the wavelength range 3850-4950A at a dispersion of 20A/mm. The slit width was set to 4mm giving a projected spectrum width of 0.27mm, while the slit length of 0.3mm corresponded to 1.3 arsec on the sky. As before,an iron arc was impressed on the plate using two 5 second exposures, one before and one after each stellar exposure. To minimise the exposure time, baked IIaO plates were used which were then developed using MWP2.

Of the 7 allocated nights, 5 were usable for spectroscopic work and in this time 75 plates of 3 W UMa systems (see Table 1), and 3 radial velocity standards (see Table 2) were obtained.

Table 1 :- W UMa systems observed

Star	Sp.	Per.	Mag. range	Class	n
	O.H.P. 193 cm Observations				
W Uma	F8	0.33	8.3 - 9.1	W	20
AW UMa	F2	0.44	8.2 - 8.7	A	20
V566 Oph	F4	0.41	7.6 - 8.1	A	13
	D.A.O. 72" Observations				
TZ Boo	G9	0.30	10.4 - 10.8	A/W	11
XY Boo	F8	0.37	10.0 - 10.3	A	12
AC Boo	F0	0.35	9.1 - 9.7	A/W	2
TX Cnc	G0	0.38	10.0 - 10.4	W	8
RW Com	G2	0.24	11.0 - 11.6	W	6
RZ Com	K0	0.34	11.0 - 11.7	W	10
CC Com	K5	0.25	11.4 - 12.3	W	11
XY Leo	K0	0.28	9.5 - 9.9	W	12
Y Sex	F8	0.42	10.2 - 10.7	A	9
AH Vir	K0	0.41	9.2 - 9.7	W	9
	O.H.P. 152 cm Observations				
VW Cep	G8	0.27	7.8 - 8.2	W	13
V566 Oph	F4	0.41	7.6 - 8.1	A	15
ER Vul	G2	0.70	7.3 - 7.5	A	20

Table 2 :- Radial velocity standards observed

Telescope	Star	Sp.	v	v sini	n
OHP 193	HD 89449	F5	+6.5	16.0	3
	HD 103095	G5	-99.0		7
	HD 144579	G8	-60.0		4
DAO 72"	HD 75935	G8	-18.9		4
	HD 112299	F8	+3.4		4
	HD 122693	F8	-6.3		2
OHP 152	HD 3712	G7	-3.8	21.0	7
	HD 204867	G1	+6.7	18.0	3
	HD 222368	F5	+5.2	6.0	7

3.3 MEASUREMENT OF RADIAL VELOCITY STANDARD STARS

A total of 41 spectra of 9 different standard stars were obtained during the course of the observations in order to check on both the accuracy of the equipment and the data reduction procedures.

Following the observations at OHP in April 1979, it was decided to compare the velocities determined by several different methods. In addition to using the cross-correlation technique, the plates were measured by line profile fitting, while 3 plates of one standard star, HD 89449, were measured in the more traditional manner using a long screw micrometer. This was done in order to check that the computer techniques gave results which lie on the standard radial velocity system. The results from this series of observations, along with the standard deviation of the mean due to the internal errors, are given in Table 3.

The spectra of the standard stars observed at DAO in March 1980 were reduced using the cross-correlation technique and the line profile fitting method since the micrometer measurements had shown that the computer techniques were working properly. The errors in these observations, as quoted in Table 3, are larger than those using OHP data. This is, of course, due to the poorer spectral resolution resulting from the slightly lower

dispersion combined with the image degradation caused by the image tube.

Finally, the observations at OHP in August 1980 were reduced only by the cross-correlation technique since the results obtained usng this method are considered to be of at least comparable, if not better, accuracy than the other methods.

These measurements have established, therefore, that there are no systematic errors in the measurement and reduction procedures used in this investigation. If one takes the differences between the radial velocities calculated by the cross-correlation method, and the published values, the rms error in the radial velocity of a spectrum due to internal and external errors, was found to be $\pm$ 2.7 km/s for the DAO spectra, and $\pm$ 0.8 km/s for the OHP spectra.

Table 3 :- Measurement of Radial velocity standard stars

Star	v (km/s)	c.c.f.	l.p.f.	l.s.m.
		O.H.P. 193 cm Observations		
HD 89449	+6.5	+6.1 +/- 1.4	+6.2 +/- 0.8	+6.3 +/- 2.4
HD 103095	-99.0	-99.1 +/- 4.7	-101.1 +/- 3.4	
HD 144579	-60.0	-60.6 +/- 4.9	-61.8 +/- 3.2	
		D.A.O. 72" Observations		
HD 75935	-18.9	-22.6 +/- 6.7	-25.4 +/- 3.9	
HD 112299	+3.4	+4.2 +/- 4.6	+3.2 +/- 2.3	
HD 122693	-6.3	-10.3 +/- 3.7	-10.3 +/- 7.8	
		O.H.P. 152 cm Observations		
HD 3712	-3.8	-2.5 +/- 4.4		
HD 204867	+6.7	+5.7 +/- 2.6		
HD 222368	+5.2	+5.7 +/- 1.9		

CHAPTER 4

ANALYSIS OF INDIVIDUAL SYSTEMS

4.1 W UMA

There have been several previous determinations of the radial velocity curves for this system (Adams and Joy 1919, Popper 1950, Struve and Horak 1950, Binnendijk 1967, Worden and Whelan 1973), the prototype of this class of object. The observations presented here were taken at O.H.P. at a dispersion of 20A/mm on the nights of 12th and 13th April 1979.

Phases were computed with the elements

$$MJD_{\odot} = 43929.9019 + 0.33363808.E$$

where the time of primary minimum and period was taken from that published by Tunca et al (1979).

Radial velocities were determined by cross-correlating the spectra with that of the radial velocity standard HD 89449 (F5) using the section of spectrum between 4125-4325A.

Table 4 :- Radial velocity measurements for W UMa from ccf.

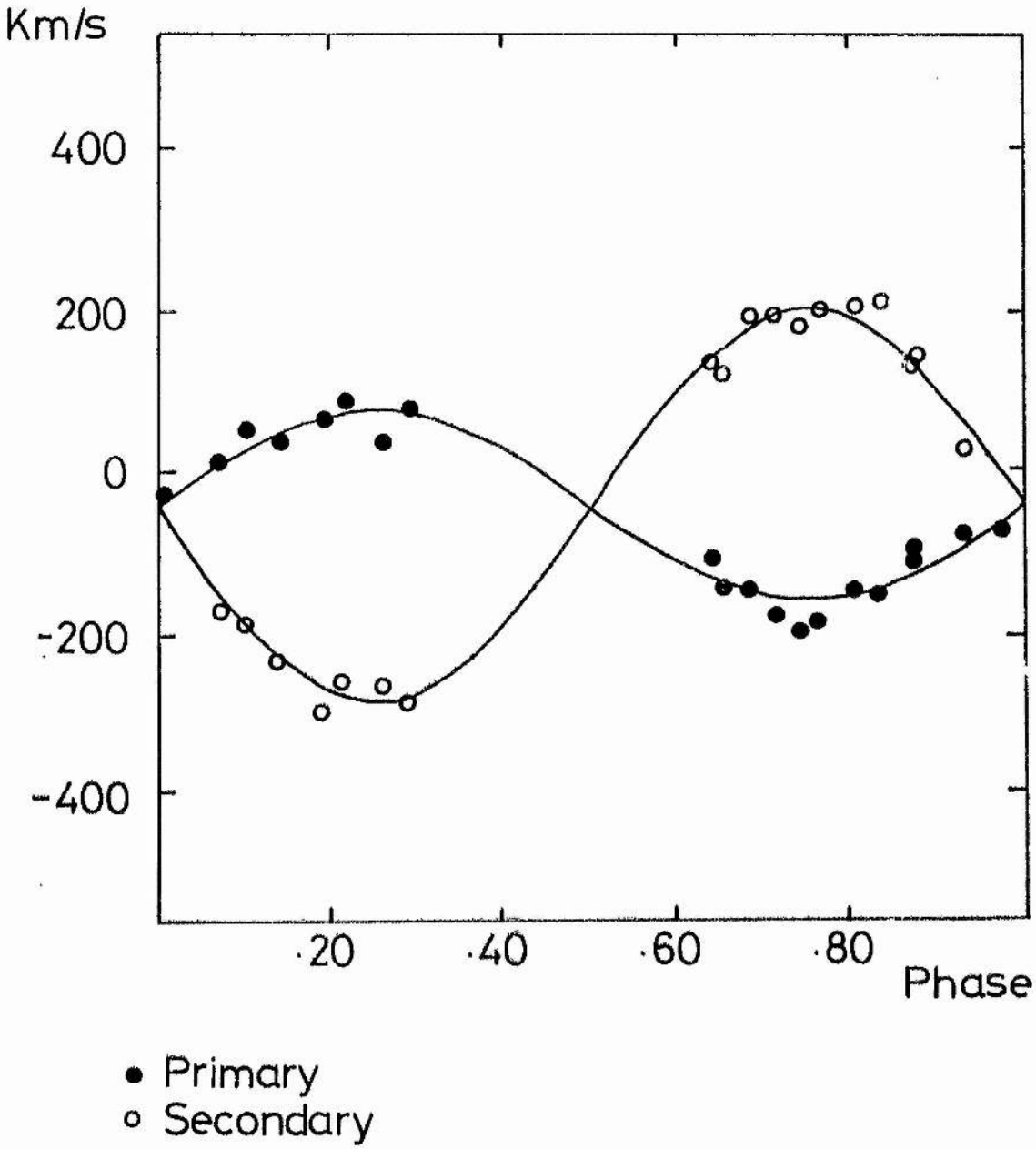
Plate no.	Hel.M.J.D. 43900.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
V4254	74.8186	0.65	-105	+138
V4255	74.8344	0.69	-142	+196
V4256	74.8532	0.75	-194	+186
V4257	74.8728	0.81	-140	+210
V4258	74.8969	0.88	- 95	+147
V4259	74.9169	0.94	- 70	+ 32
V4260	74.9457	0.02	- 24	-
V4261	74.9740	0.11	+ 58	-185
V4262	75.0044	0.20	+ 72	-294
V4263	75.0274	0.27	+ 42	-263
V4272	75.8240	0.66	-140	+126
V4273	75.8460	0.72	-175	+200
V4274	75.8622	0.77	-178	+207
V4275	75.8864	0.84	-146	+216
V4276	75.8989	0.88	-103	+139
V4278	75.9352	0.99	- 65	-
V4279	75.9664	0.08	+ 21	-166
V4280	75.9885	0.15	+ 44	-230
V4281	76.0114	0.22	+ 92	-257
V4282	76.5385	0.30	+ 84	-284

Table 5 :- Spectroscopic elements for W UMa.

Element	Unit	Worden & Whelan	Present work
V_o	km/s	-42.3 +/- 3	-37.8 +/- 4 (s.d.)
K_1	km/s	131.3 +/- 2	119.0 +/- 6
K_2	km/s	243.0 +/- 3	244.0 +/- 9
$a_1 \sin i$	10^6 km	0.60 +/- 0.01	0.55 +/- 0.03
$a_2 \sin i$	10^6 km	1.11 +/- 0.02	1.12 +/- 0.04
$a \sin i$	10^6 km	1.72 +/- 0.03	1.67 +/- 0.05
$M_1 \sin i$	$M_\odot$	1.18 +/- 0.05	1.11 +/- 0.11
$M_2 \sin i$	$M_\odot$	0.64 +/- 0.03	0.54 +/- 0.05
$(M_1 + M_2) \sin i$	$M_\odot$	1.82 +/- 0.06	1.65 +/- 0.12
$q = M_2 / M_1$	-	0.54 +/- 0.03	0.49 +/- 0.03

Fig 6

RADIAL VELOCITY CURVE FOR WUMa



The individual observations are presented in Table 4 and figure 6, while the resulting spectroscopic elements are given in Table 5 .

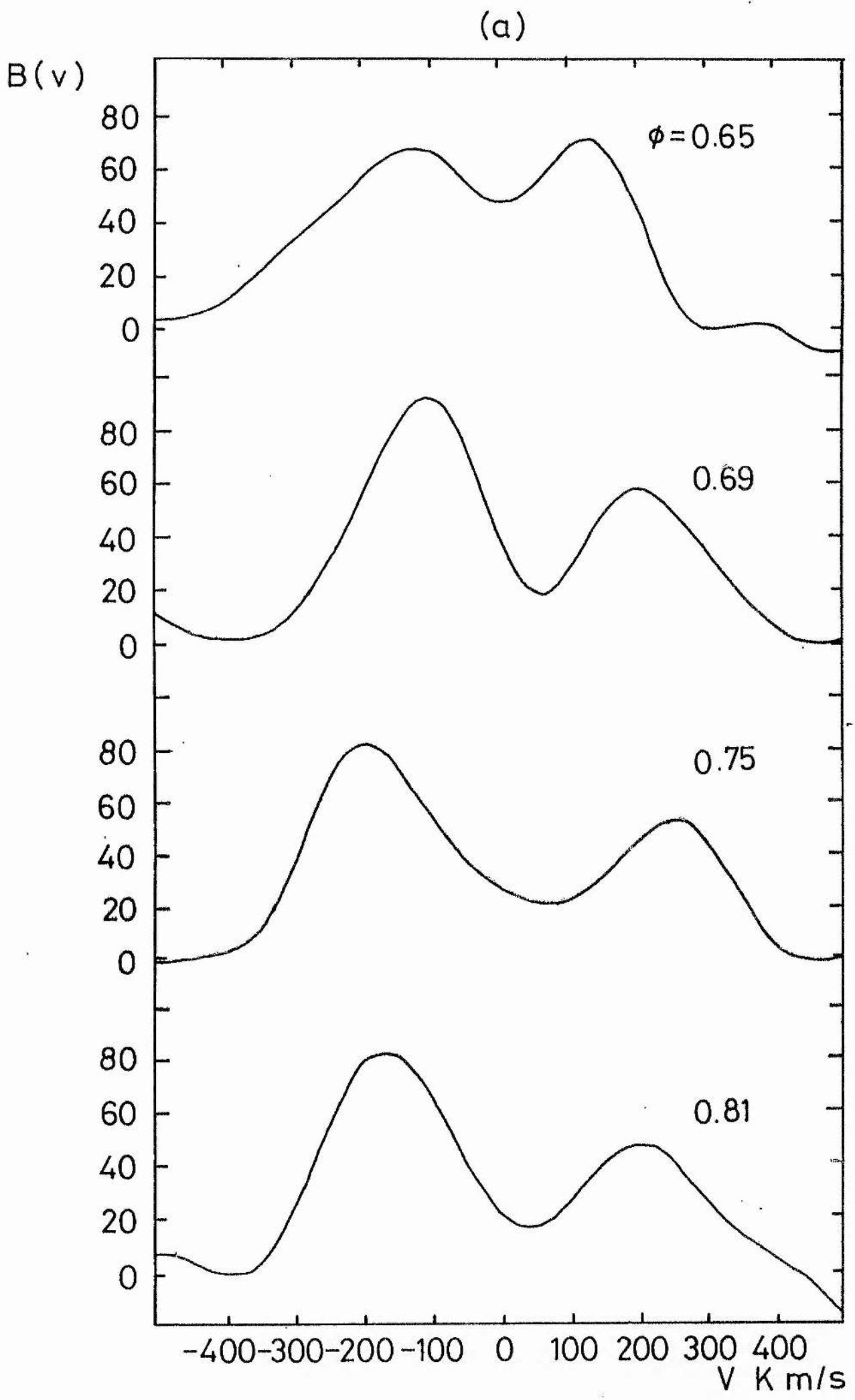
It can be seen that the mass ratio is slightly lower than that obtained by Worden and Whelan as is the systemic velocity. Their spectra were at a lower dispersion of 62A/mm and measured using an oscillosope comparator, whereas in this work a higher dispersion and a more objective numerical technique was used to determine the radial velocities. On the other hand, we have poorer time resolution and fewer data points. Consequently, it is felt that the differences in the elements are due to the errors of measurement rather than any variation in the system itself. In addition to determining the radial velocities by cross-correlation, the spectrum of the standard star was deconvolved from the observed spectra to produce empirical velocity broadening functions which are shown in fig 7 . The fact that the two components have been clearly resolved gives another means of determining the radial velocities and hence the mass ratio. Measurements of the velocities at the centre of each peak are given in Table 6 and fig 8, while the spectroscopic elements computed from these values are presented in Table 7.

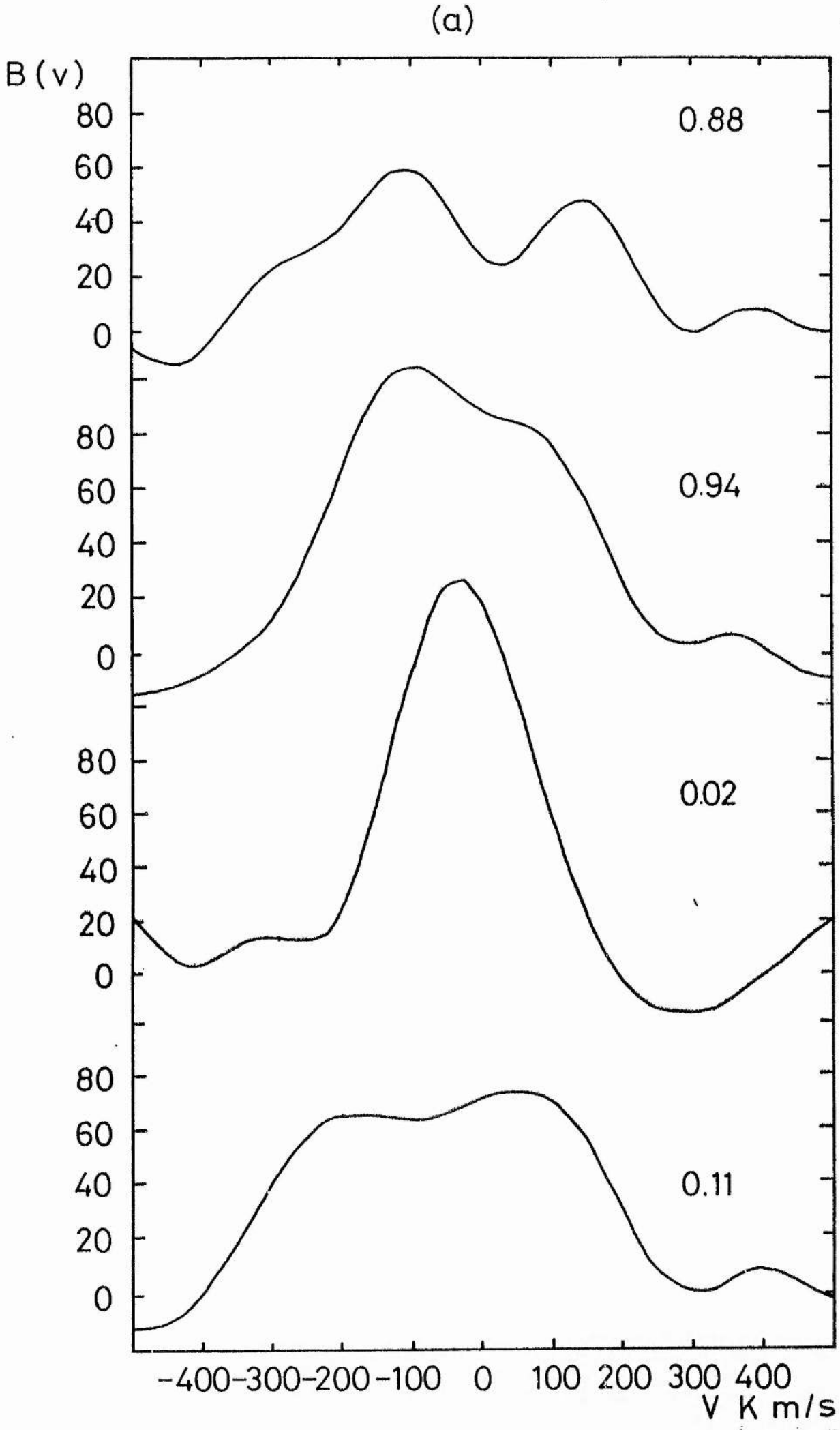
Figure 7

Velocity Broadening Functions for W UMa

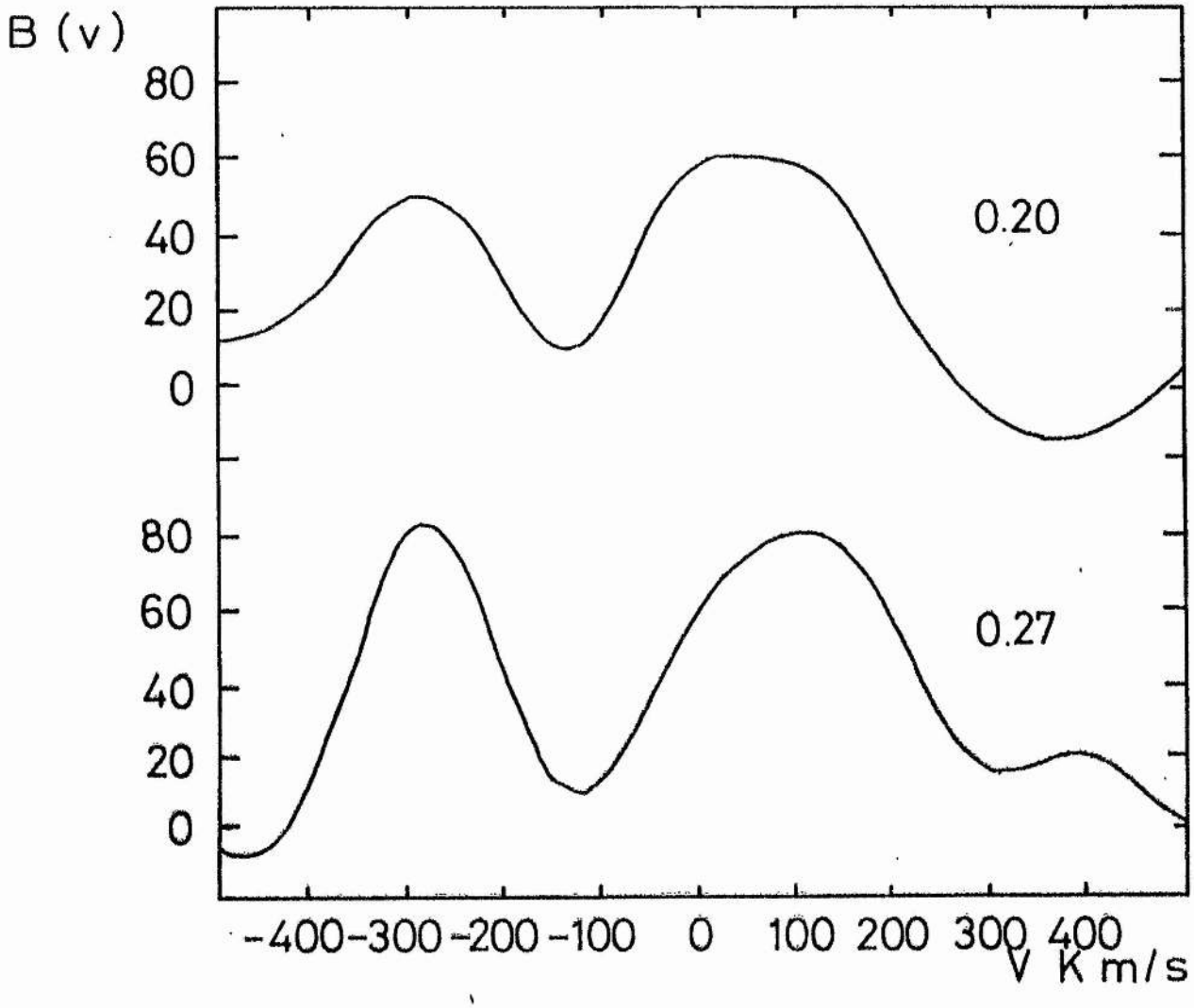
(a) Observations obtained on 12th April 1979

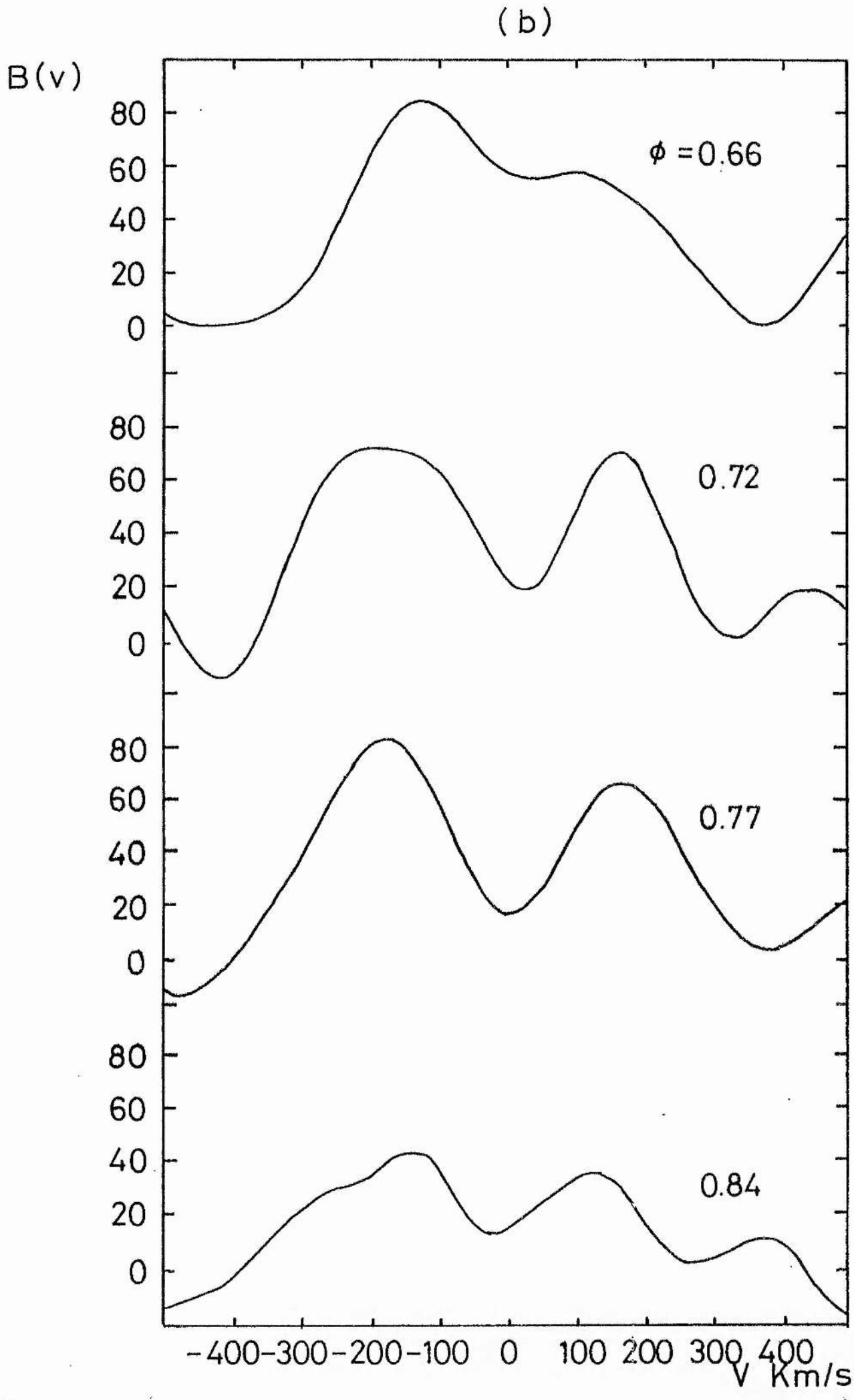
(b) Observations obtained on 13th April 1979

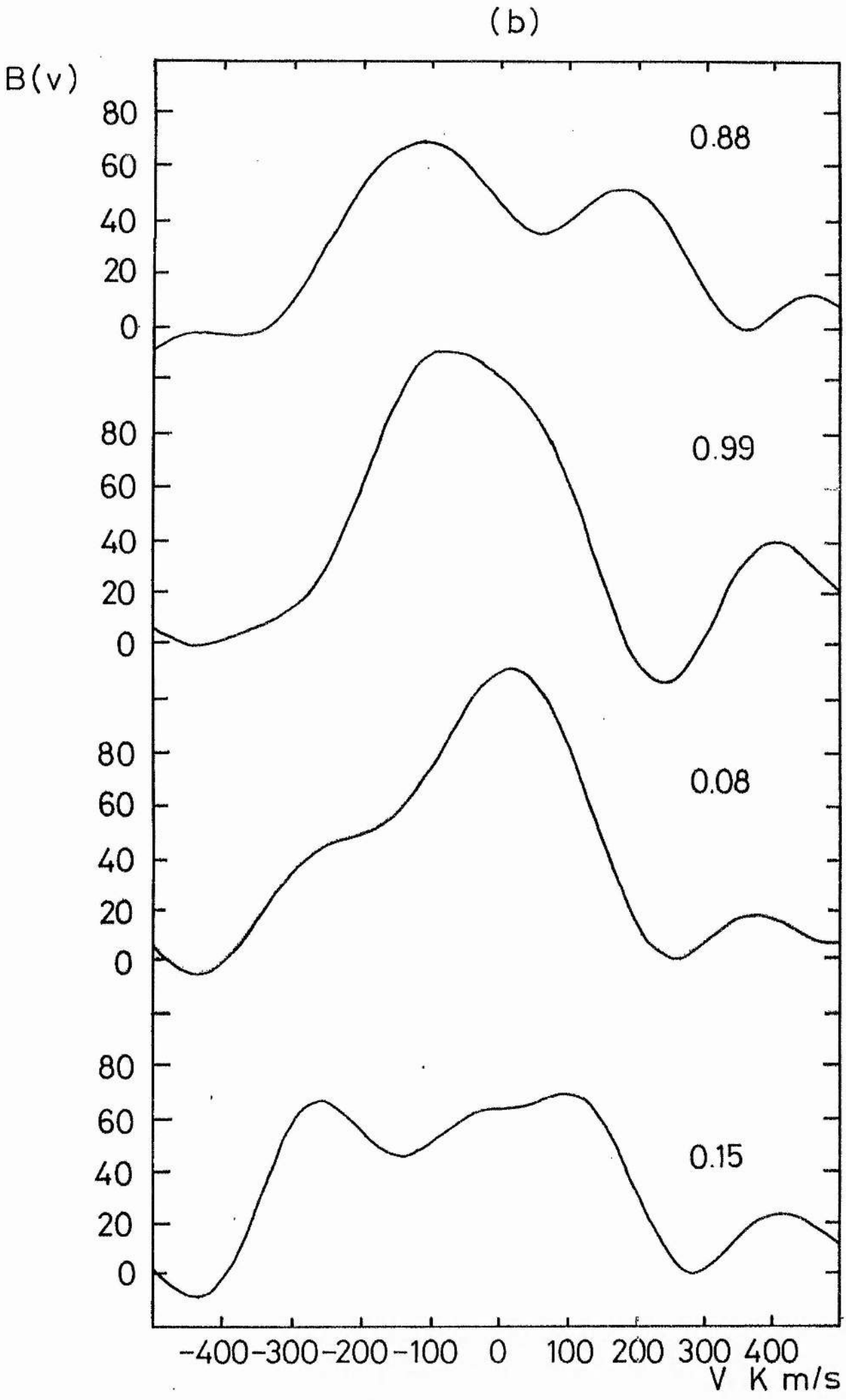

(a)
B(v)
80
60
40
20
0
φ=0.65
0.69
0.75
0.81
-400 -300 -200 -100 0 100 200 300 400
V K m/s


(a)
B (v)
80
60
40
20
0
0.88
0.94
0.02
0.11
-400 -300 -200 -100 0 100 200 300 400
V K m/s

(a)


B (v)
80
60
40
20
0
0.20
80
60
40
20
0
0.27
-400 -300 -200 -100 0 100 200 300 400
V K m/s


(b)
B(v)
80
60
40
20
0
φ =0.66
0.72
0.77
0.84
-400 -300 -200 -100 0 100 200 300 400
V Km/s


(b)
B(v)
80
60
40
20
0
0.88
0.99
0.08
0.15
-400 -300 -200 -100 0 100 200 300 400
V K m/s

(b)

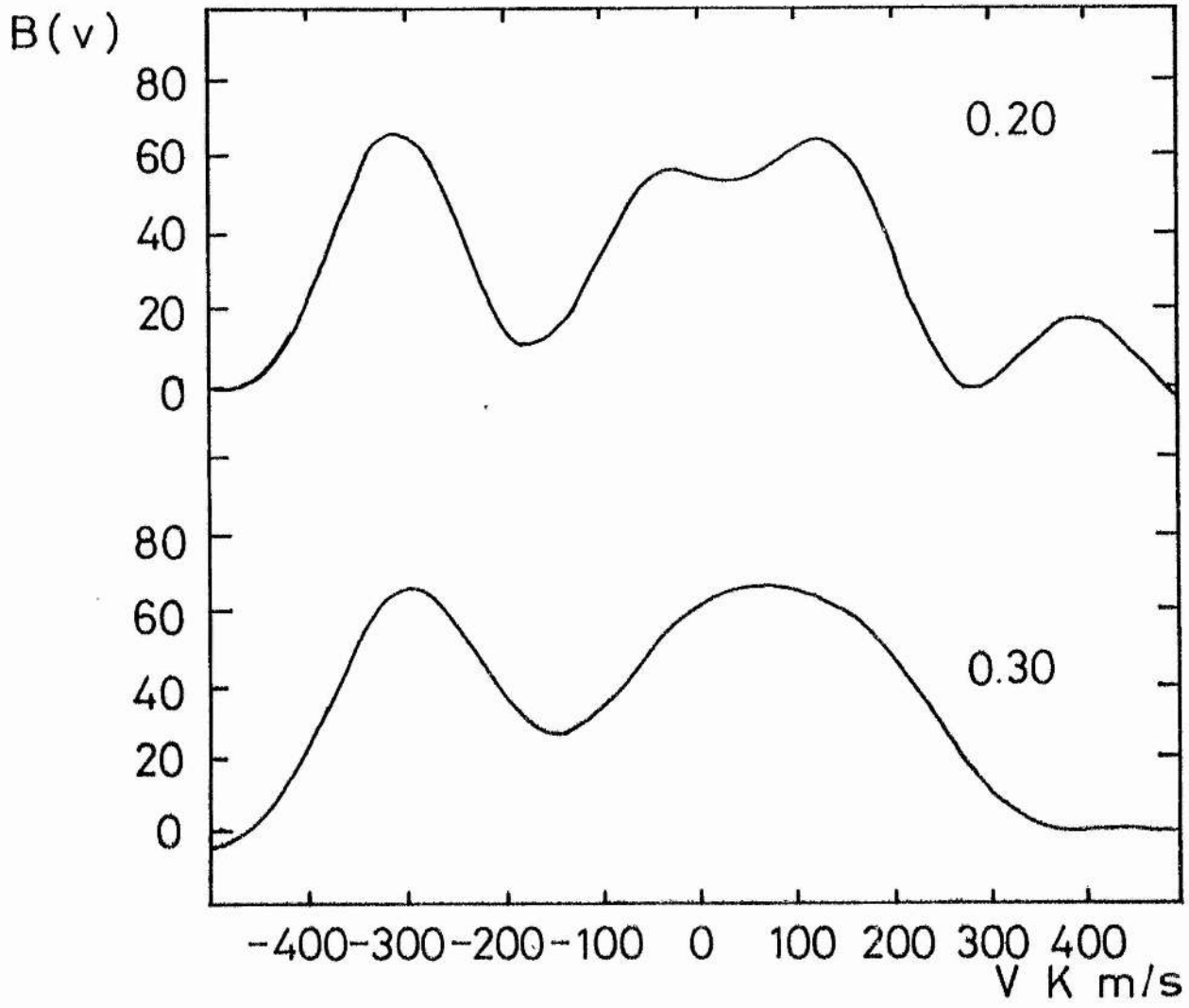

B(v)
80
60
40
20
0
0.20
80
60
40
20
0
0.30
-400 -300 -200 -100 0 100 200 300 400
V K m/s

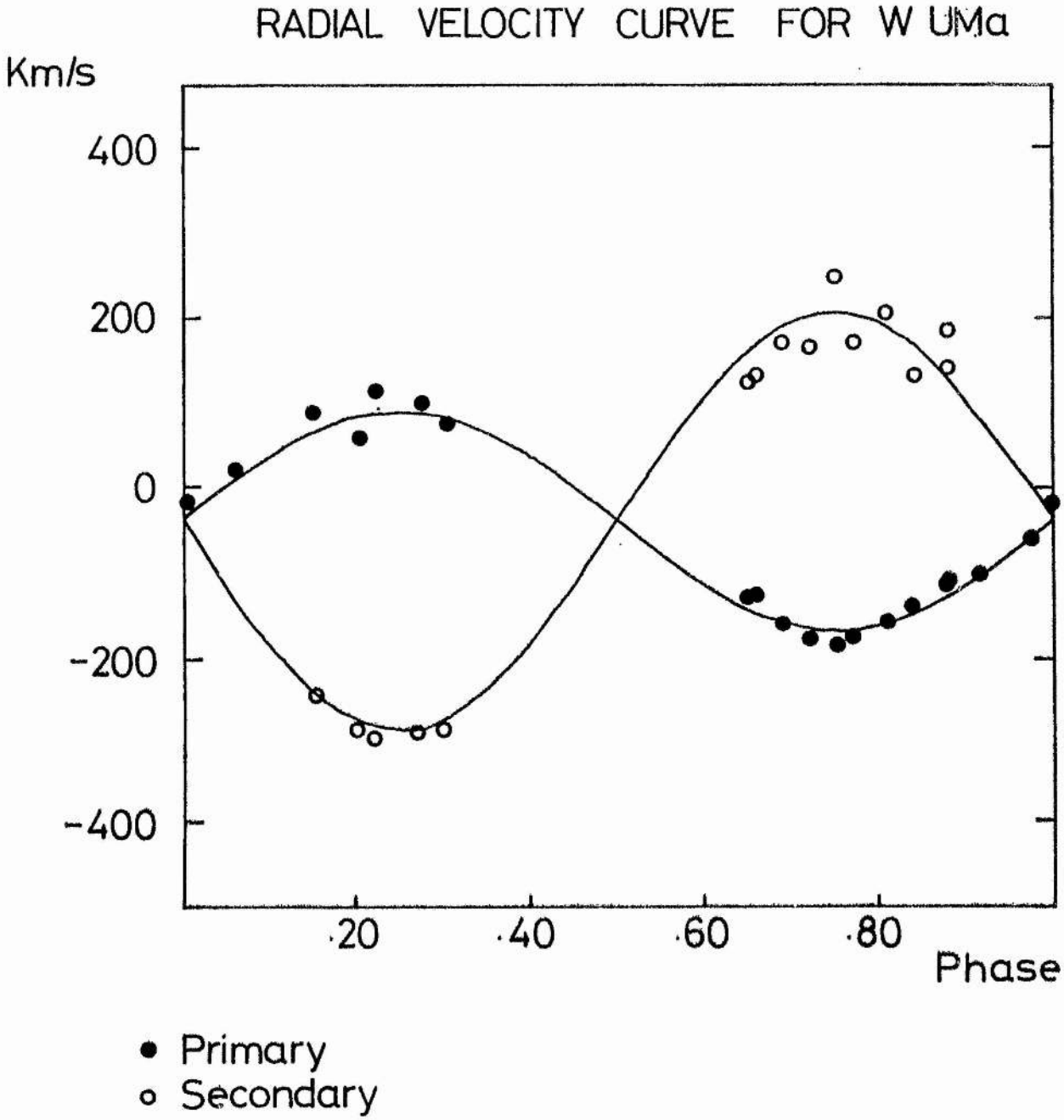
Table 6 :- Radial velocity measurements for W UMa from vbf

Plate no.	Hel.M.J.D. 43900.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
V4254	74.8186	0.65	-133	+123
V4255	74.8344	0.69	-163	+170
V4256	74.8532	0.75	-190	+250
V4257	74.8728	0.81	-165	+205
V4258	74.8969	0.88	-110	+183
V4259	74.9169	0.94	-100	-
V4260	74.9457	0.02	- 26	-
V4261	74.9740	0.11	+126	-110
V4262	75.0044	0.20	+ 53	-290
V9363	75.0274	0.27	+ 93	-294
V4272	75.8240	0.66	-127	+133
V4273	75.8460	0.72	-183	+163
V4274	75.8622	0.77	-180	+170
V4275	75.8864	0.84	-143	+130
V4276	75.8989	0.88	-115	+140
V4278	75.9352	0.99	- 53	-
V4279	75.9664	0.08	+ 23	-166
V4280	75.9885	0.15	+ 86	-247
V4281	76.0114	0.22	+113	-300
V4282	76.5385	0.30	+ 70	-290

Table 7 :- Spectroscopic elements for W UMa

Element	Unit	Present work
V_o	km/s	-43.7 +/- 6 (s.d.)
K_1	km/s	130.0 +/- 8
K_2	km/s	244.0 +/- 12
$a_1 \sin i$	10^6 km	0.60 +/- 0.03
$a_2 \sin i$	10^6 km	1.14 +/- 0.04
$a \sin i$	10^6 km	1.74 +/- 0.05
$M_1 \sin i$	$M_\odot$	1.23 +/- 0.11
$M_2 \sin i$	$M_\odot$	0.65 +/- 0.05
$(M_1 + M_2) \sin i$	$M_\odot$	1.88 +/- 0.12
$q = M_2 / M_1$	-	0.53 +/- 0.04

Fig. 8


RADIAL VELOCITY CURVE FOR W UMa
Km/s
400
200
0
-200
-400
·20
·40
·60
·80
Phase
• Primary
o Secondary

This set of elements is closer to those of Worden and Whelan, although the scatter around the fit is slightly greater. A mean value of the mass ratio of $q = 0.52 +/- 0.03$ taken from these three determinations shall be adopted for this system.

As well as measuring the positions of the peaks in the broadening functions, the height of each and the dip corresponding to the neck of the star can be recorded. These measurements are shown in Table 8 and figure 9. Under the uniform profile assumption, then the relative heights of these features enable a determination of the mass ratio and fill-out factor by interpolation into the atlas by Anderson and Shu (1979), on the basis of the DSC model. The ratio of the primary to the secondary, P/S, depends strongly on the mass ratio, while the fill-out factor is the dominant influence on the ratio of the neck to the primary, N/P, or the secondary N/S.

Obviously, the value of these ratios will vary with phase as the area of each component visible changes. Qualitatively, the expected changes are observed (see Table 9 and figure 10) in that the ratio P/S increases from secondary minimum until the secondary component is eclipsed, after which the ratio decreases again.

Table 8 :- Strength of features in vbf.

Pl.no.	Phase	Prim.	Sec.	Neck
V4254	0.65	66	70	46
V4255	0.69	93	58	18
V4256	0.75	83	73	20
V4257	0.81	84	48	16
V4258	0.88	70	53	36
V4259	0.94	105	-	-
V4260	0.02	146	-	-
V4261	0.11	94	66	-
V4262	0.20	61	50	8
V4263	0.27	78	81	7
V4272	0.66	84	57	-
V4273	0.72	74	72	20
V4274	0.77	85	67	20
V4275	0.84	67	58	35
V4276	0.88	60	50	24
V4278	0.99	111	-	-
V4279	0.08	111	-	-
V4280	0.13	68	67	44
V4281	0.22	65	68	10
V4282	0.30	65	65	26

Figure 9

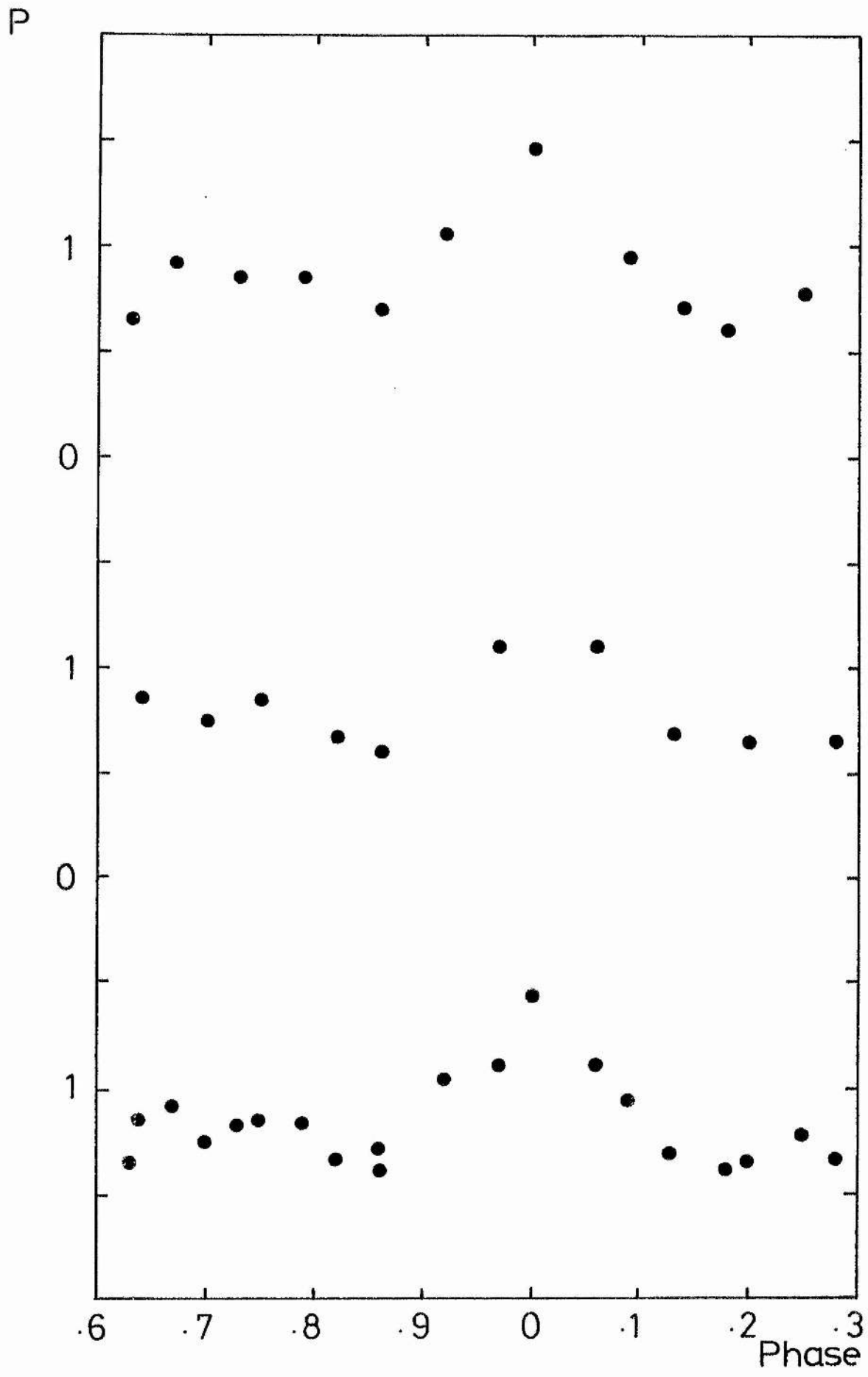
Measurements of the Broadening Functions

for W UMa

(a) Central height of primary component

(b) Central height of secondary component

The top diagrams contain the results for the night of the 12th April 1979, the centre gives the observations obtained on the night of the 13th April 1979, while the lower diagrams consist of the combined data.


(a)
P
1
0
1
0
1
.6
.7
.8
.9
0
.1
.2
.3
Phase

(b)

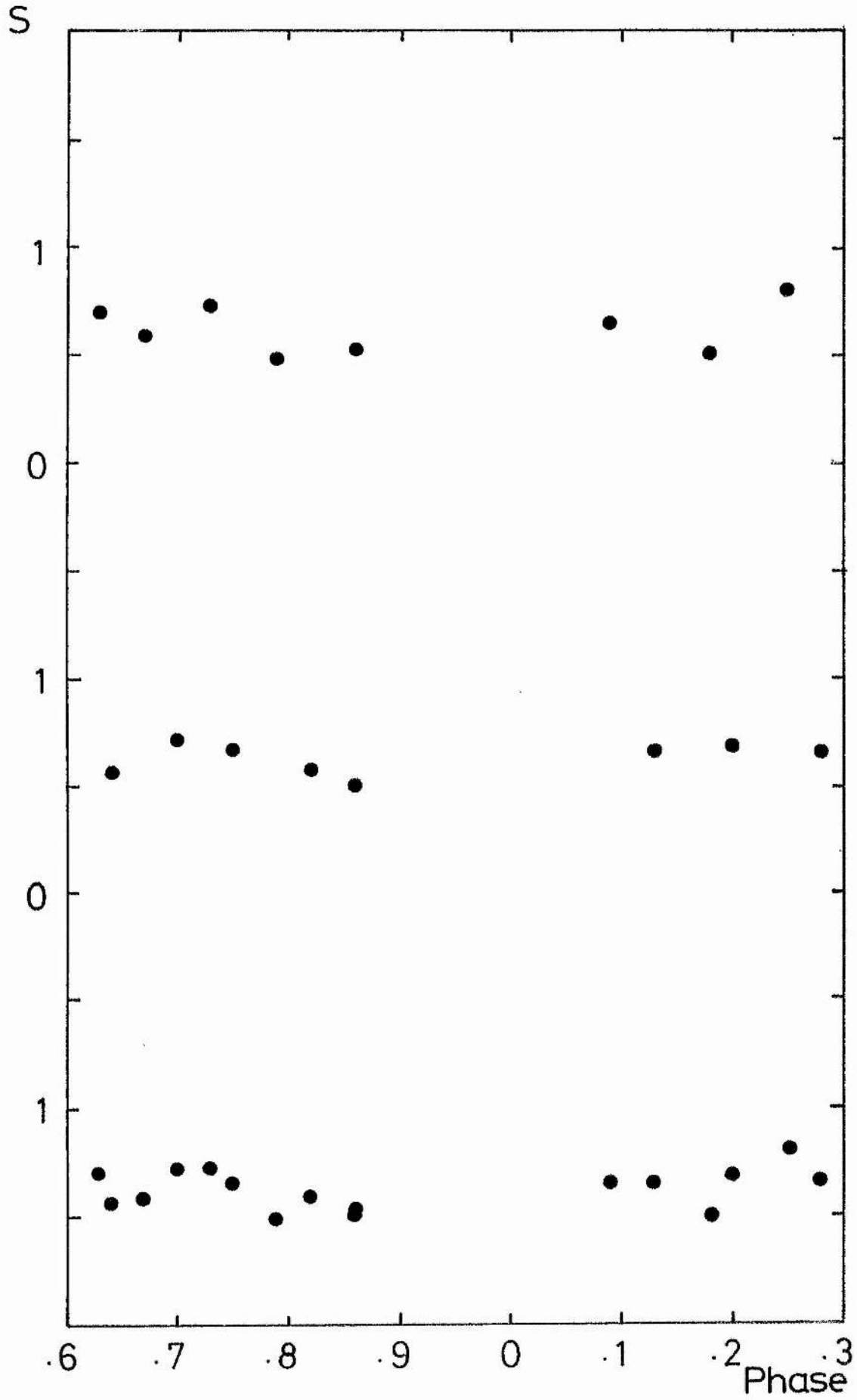


Table 9 :- Analysis of vbf

Pl.no.	Phase	P/S	N/S	P+S
V4254	0.65	0.94	0.66	136
V4255	0.69	1.60	0.31	151
V4256	0.75	1.14	0.27	156
V4257	0.81	1.75	0.33	132
V4258	0.88	1.32	0.68	123
V4259	0.94	-	-	105
V4260	0.02	-	-	146
V4261	0.11	1.42	-	160
V4262	0.20	1.22	0.16	111
V4263	0.27	0.96	0.09	159
V4272	0.66	1.47	-	141
V4273	0.72	1.03	0.28	146
V4274	0.77	1.27	0.30	152
V4275	0.84	1.16	0.60	125
V4276	0.88	1.20	0.48	110
V4278	0.99	-	-	111
V4279	0.08	-	-	111
V4280	0.15	1.02	0.66	135
V4281	0.22	0.96	0.15	133
V4282	0.30	1.00	0.40	130

Figure 10

Analysis of the Broadening Functions

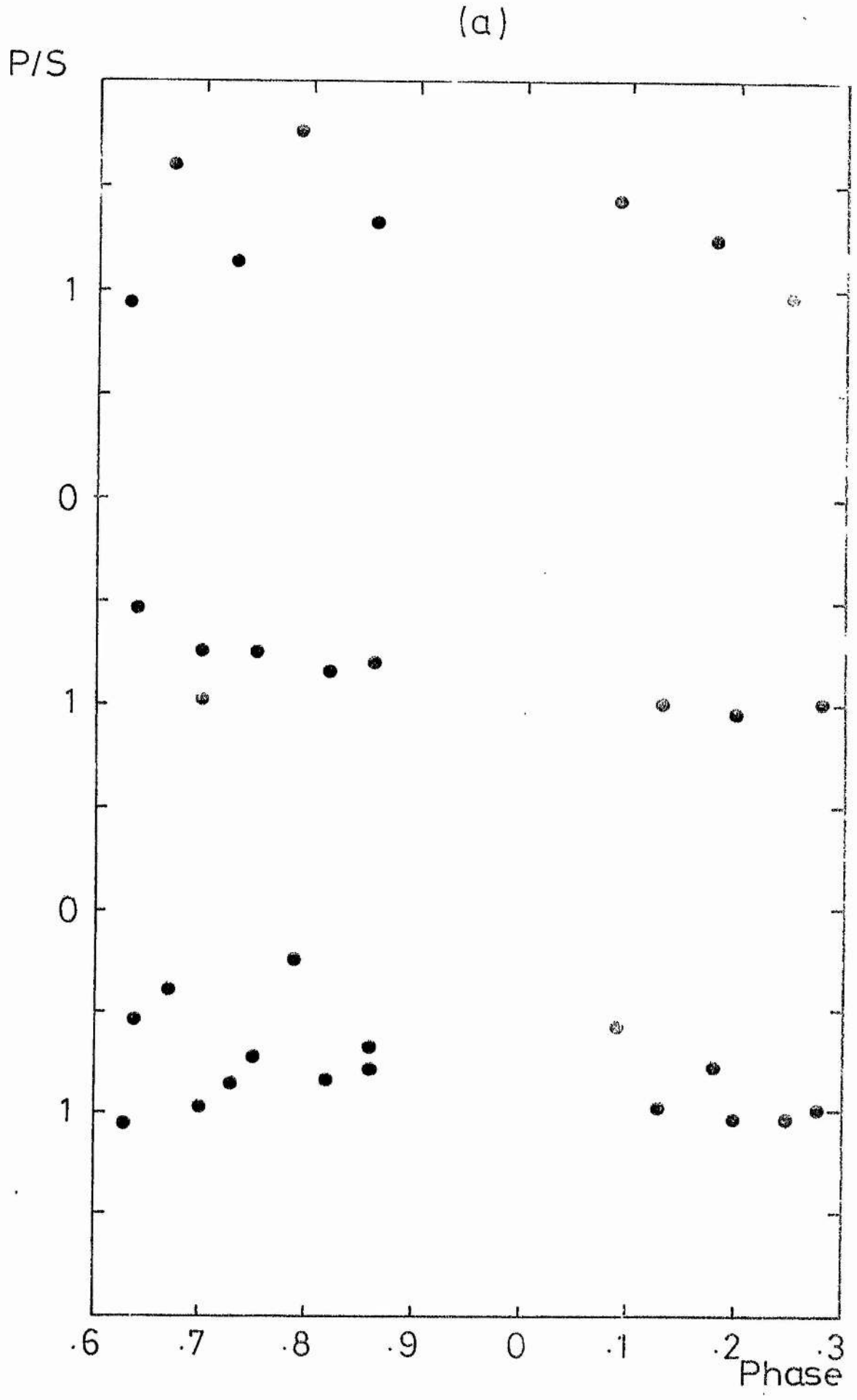
for W UMa

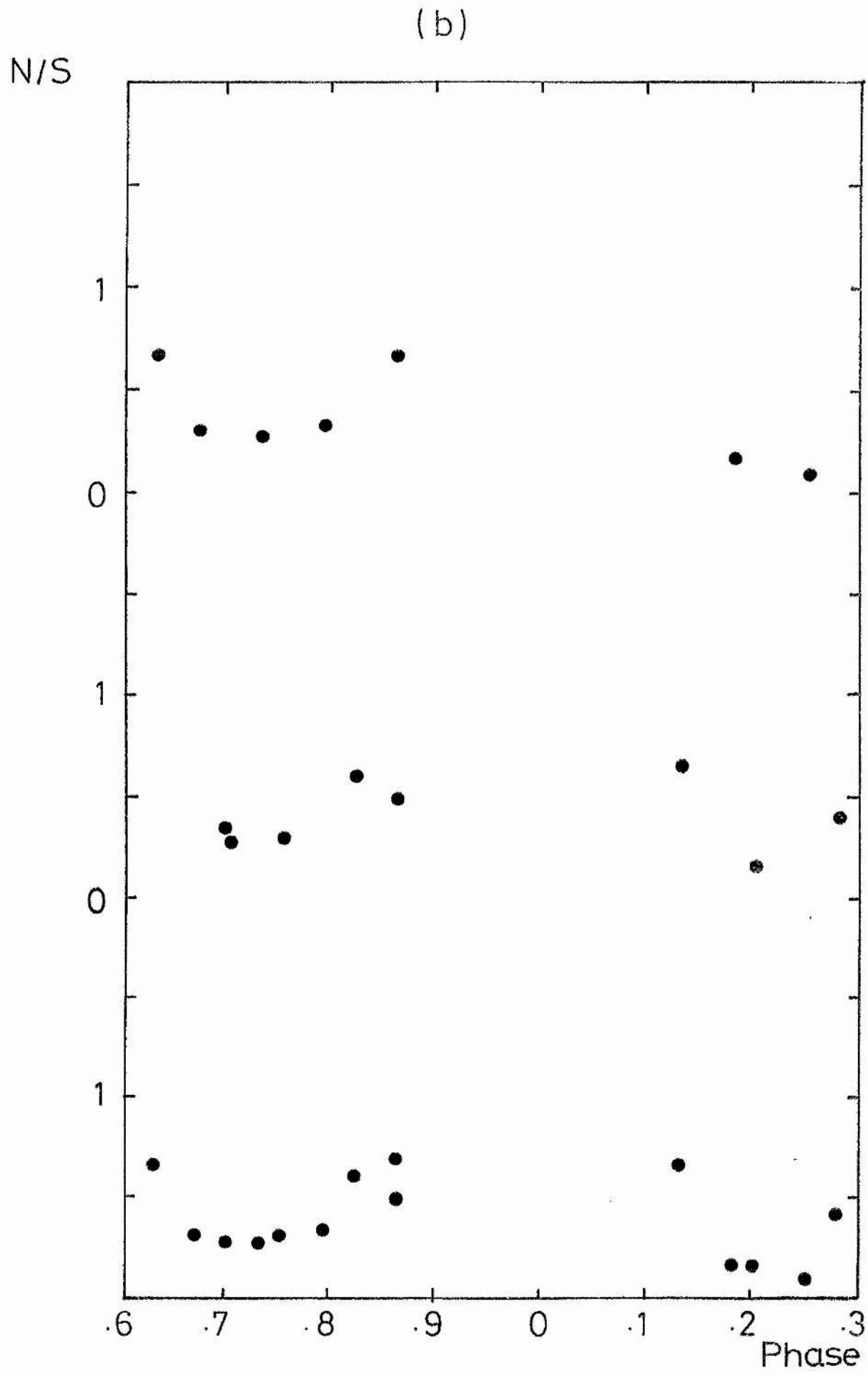
(a) Ratio of Primary to Secondary P/S

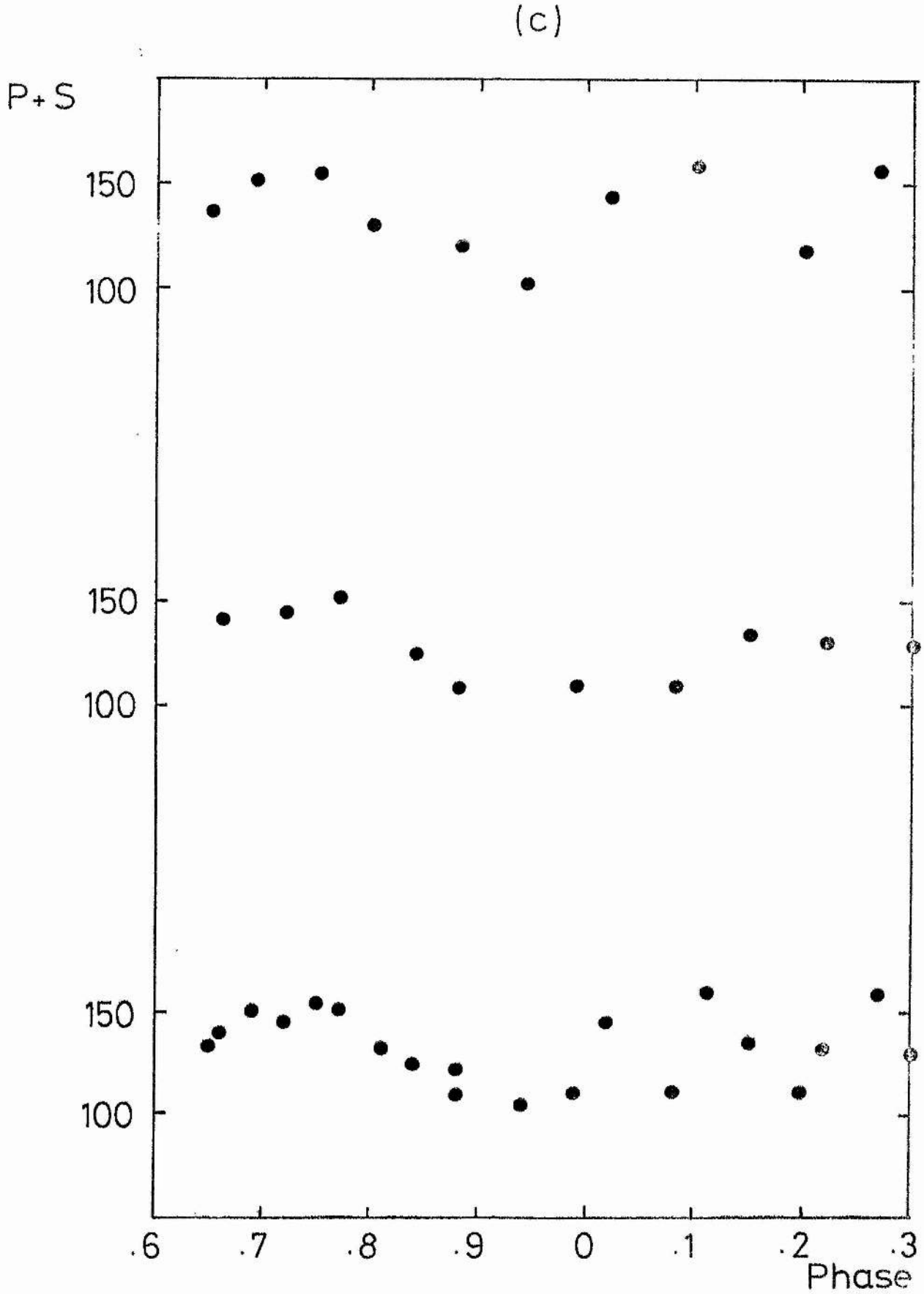
(b) Ratio of Neck to Secondary N/S

(c) Sum of observed strengths P+S

The top diagrams contain the observations made on the night of the 12th April 1979, the centre gives the results for the night of 13th April 1979, while the lower diagrams have the combined data.


(a)
P/S
1
0
1
0
1
.6
.7
.8
.9
0
.1
.2
.3
Phase


(b)
N/S
1
0
1
0
1
.6
.7
.8
.9
0
.1
.2
.3
Phase


(c)
P+S
150
100
150
100
150
100
.6
.7
.8
.9
0
.1
.2
.3
Phase

It would appear that in practice, the height of the primary at 1st quadrature is lower than that at 2nd quadrature, while the height of the secondary remains fairly constant. On the other hand, the value of N/S decreases to a minimum at the quadratures when the neck is clearly displayed, outside of which it is partially, or wholly obscured.

In order to estimate these system parameters, the mean of the ratios around each quadrature was computed. These are as follows :-

Ratio	1st Quad.	2nd Quad.
P/S	1.03 +/- 0.11	1.33 +/- 0.29
N/S	0.29 +/- 0.24	0.35 +/- 0.13

Assuming full limb darkening and a low value of the gravity darkening exponent as suggested by Eaton et al (1980) and Hilditch (1981), then interpolating into the atlas of velocity broadening functions gives the following results.

Parameter	1st Quad.	2nd Quad.
q	1.00 +/- 0.1	0.55 +/- 0.1
F	0.10 +/- 0.1	0.20 +/- 0.1

Although the values obtained for the fill-out factor are reasonably consistent with each other, and with results from previous photometric analyses, it is clear that the mass ratios derived from the two quadratures are in complete

disagreement. There are two possible intepretations of this phenomenon, namely that either the uniform profile assumption breaks down or the flux distribution over the surface changes significantly from one side of the system to the other.

The fact that the colours of the system remain fairly constant, and that the spectral type does not change significantly with phase supports the uniform profile assumption. It is possible though to alter the spectral profiles by having variable emission from a feature such as a circumstellar envelope or gas stream which raises the continuum or fills in the lines.

The alternative explanation of the flux distribution varying across the surface may be achieved by the occurrence of magnetic starspots and/or active regions (Mullan 1975), or by the presence of a mass transferring stream (Lucy and Wilson 1979).

Obviously, whatever the cause of the variation, these broadening function measurements show that there is a strong degree of asymmetry in this system which is probably related to both the asymmetric light curve and the short timescale variability.

An example of the variability of the system is shown by the variation in the sum P+S, which is related to the combined line depths. This was given in Table 9 and figure 10. It is clear that the lines are varying from night to night in the time interval from primary minimum to first quadrature. Unfortunately, we do not have observations after this point which may have provided further information on this variability which shows up as greatly increased scatter when the data is combined. The overall variation, however, of being strongest at quadrature and weakest at eclipse is simply due to the level of the continuum varying with the light output of the system.

If we assume that the uniform profile assumption does hold, then we can derive the following relations.

The flux level of the observed continuum C_o is the sum of the flux from the primary C_p and the secondary C_s.

i.e. $C_o = C_p + C_s$

If we let $C_s = X.C_p$, then it can be shown that the true heights of the broadening function peaks P_t and S_t, relative to their respective continua, are computed from their observed heights P_o and S_o using the relations

$$P_t = P_o .(1 + X)$$

$$S_t = S_o .(1 + X) / X$$

The problem with using these relations is that the value of X appears to be variable so that the true values cannot be

computed unless the light distribution is already known.

On the other hand, since the spectra of the stars are identical with the uniform profile assumption, we have $P = S$, which leads to the relation

$$P / S = 1 / X = F_p / F_s$$

The value of P/S then is directly equivalent to the ratio of the flux from the two components.

If we ignore any complications such as spots or streams, then the flux contributing to a given velocity contour is proportional to the size of the star D, perpendicular to the distance from the rotation axis corresponding to that velocity.

i.e. $F \propto D \cdot T^4$

so that

$$(P/S) = (D_p/D_s) \cdot (T_p/T_s)^4$$

If we adopt the equivalent radii of the stars from Worden and Whelan (1973) of $R_p = 1.07\ R_\odot$ and $R_s = 0.81\ R_\odot$, then

$$(P/S) = 1.32 \cdot (T_p/T_s)^4$$

It is interesting to note that if one adopts a temperature of 5800° K for the system (Hilditch 1981), and uses this relation to calculate the temperature ratio, then we can calculate the following :-

Parameter	1st quad.	2nd quad.
T_p/T_s	0.94 +/- 0.02	1.00 +/- 0.04
$T_s - T_p$	70 +/- 140	0 +/- 120
$X = \Delta T/T_p$	0.06 +/- 0.02	0.00 +/- 0.02

This temperature excess of the secondary at 1st quadrature corresponds closely to what is found from the photometric analyses (Hilditch 1981). Unfortunately, we do not have complete phase coverage as there is a gap from phase 0.3 through to 0.65 .

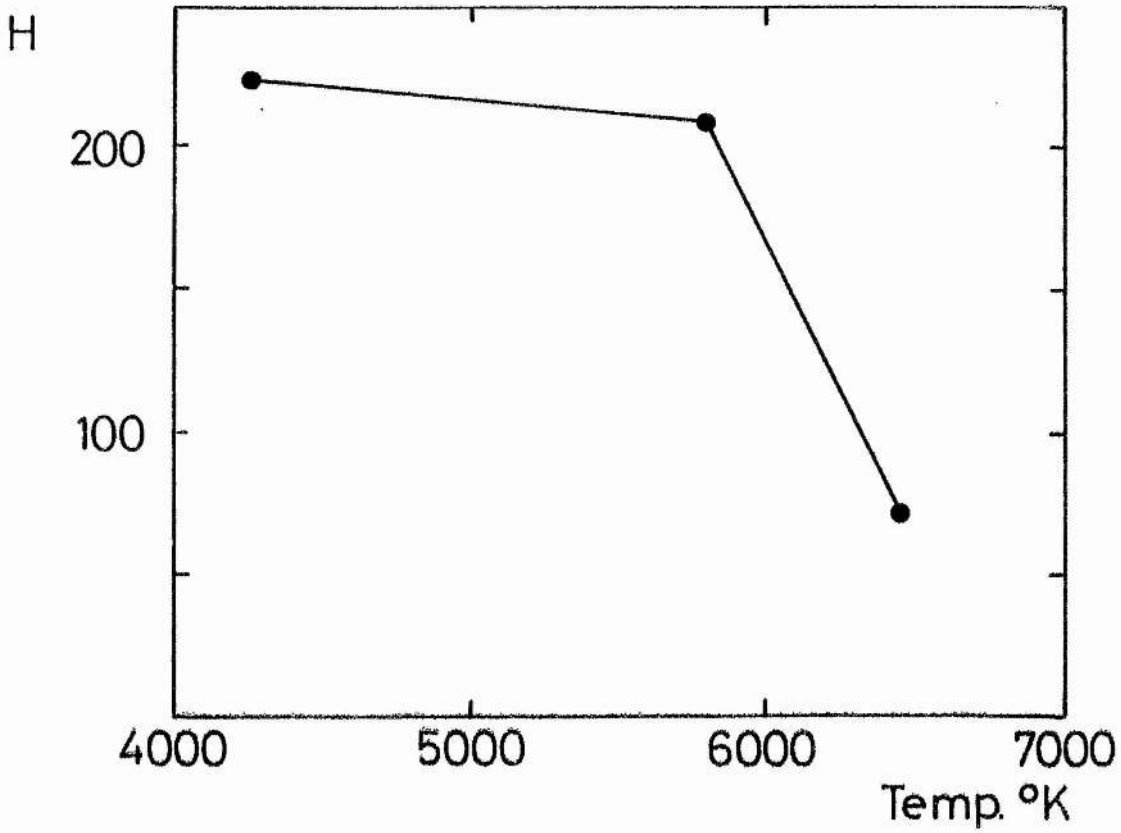
One problem with the existence of a temperature variation in the system is that the uniform profile assumption must break down. In order to investigate the effect of temperature on the strength of the broadening functions, the standard spectrum was deconvolved from the spectra of three standard stars of spectral types F5, G5 and K5. The strength, H, of the computed functions are shown in Table 10 and figure 11.

Table 10 :- Temperature dependance of vbf for standard

Sp	Temp. K	H
F5	6455	70
G5	5780	209
K5	4295	218

Fig 11

TEMPERATURE DEPENDENCE OF VBF
USING F5 STANDARD SPECTRUM



As expected, the strengths increase with decreasing temperature towards later spectral types. The change in the primary components lines could therefore be interpreted as an increase in temperature of about 200-300°K on its trailing hemisphere relative to its leading hemisphere. It is interesting to note that the strength of the function at mid primary eclipse would correspond to a temperature of about 6100°K, rather hotter than found from the colour of the system. Alternatively, this could be interpreted as the presence of some mechanism which reduces the strength of the lines.

There have been many photometric analyses of W UMa using the light curve synthesis technique (Mochnacki 1972, Hutchings and Hill 1973, Nagy 1974 and Hilditch 1981) which have derived mass ratios ranging from q = 0.40 to 0.47 when free to vary in the solution. One problem, however, is that previous photometric solutions have derived the mass ratio rather than fixing it at the spectroscopic value. For this reason, it was felt necessary to reanalyse published light curves for W UMa with the mass ratio fixed in order to determine the effect on the other system parameters.

Photoelectric observations of W UMa in the Stromgren uvby system have been published (Linnaluoto and Piirola 1979), the y band light curve being adopted as the

observations to which to fit the model. Due to the asymmetry of the light curve, observations from phases 0-0.5 and 0.5-0 were solved separately. The mass ratio was fixed at the spectroscopic value of 0.52, while the fill-out factor was taken to be 0.85 as derived from the broadening functions. A mean value for the orbital inclination of 83° was taken from the previous light curve synthesis results (Cester et al 1979). A reference temperature of 5800°K was adopted from the (b-y) colour (Rucinski and Kaluzny 1981) using the calibration with effective temperature given by Popper (1980) and no temperature excess of the secondary was assumed i.e. X = 0. The gravity darkening exponent β was taken to be 0.05 as derived observationally by Eaton et al (1980), and the bolometric albedo fixed at 0.5 following Rucinski (1969).

Due to the problems of analysing W UMa systems, it was decided to fix as many parameters as possible in order to get the best determination of those which were allowed to vary in the least squares solution. The mass ratio and reference temperature were fixed since these were determined from observations, while the albedo was fixed since it varied wildly when free to vary so that it appears to be indeterminate in the solution.

The remaining four parameters were solved in six different combinations : 1). f i β X 2). i β X 3). f i β 4). f i X 5). i β 6). i X. The initial parameters and the results of each solution after several iterations are presented in Table 11.

Table 11 :- Light curve synthesis results for W UMa (y band)

Initial Values :-

q	= 0.52	T	= 5800°K
f	= 0.85	X	= 0.00
i	= 83°.0	β	= 0.05
		A	= 0.5

Solution for phases 0.0 to 0.5 :-

Free parameters	f	i	β	X	$\Sigma (o-c)^2$
f i β X	0.78	80.9	-0.10	0.068	2.77 e-3
	0.02	0.3	0.02	0.003	
i β X	0.85	80.9	-0.04	0.066	3.39 e-3
		0.4	0.02	0.004	
f i β	0.78	80.9	-0.11	0.069	2.78 e-3
	0.02	0.3	0.02		
f i X	0.89	80.0	0.05	0.064	5.23 e-3
	0.02	0.4		0.005	
i β	0.85	80.8	-0.04	0.069	3.43 e-3
		0.4	0.02		
i X	0.85	79.3	0.05	0.064	6.06 e-3
		0.4		0.005	

Solution for phases 0.5 to 0.0 :-

Free parameters	f	i	β	X	$\Sigma (o-c)^2$
f i β X	0.76	81.1	-0.07	0.069	3.66 e-3
	0.02	0.4	0.03	0.009	
i β X	0.85	81.0	0.01	0.067	4.70 e-3
		0.4	0.02	0.004	
f i β	0.76	81.1	-0.07	0.069	3.66 e-3
	0.02	0.3	0.03		
f i X	0.86	80.4	0.05	0.066	5.21 e-3
	0.02	0.4		0.005	
i β	0.85	81.0	0.01	0.069	4.71 e-3
		0.4	0.02		
i X	0.85	80.4	0.05	0.066	5.21 e-3
		0.3		0.005	

Despite the asymmetry in the light curve of this system, the solutions for each half are very similar and follow the same trends. It would appear that the model requires a large temperature excess to fit the observations for all of the different solutions. The values of the gravity darkening exponent and the fill-out factor are strongly related in that β becomes negative while increasing the degree of contact to compensate. This is in agreement with Hilditch (1981) who analysed light curves obtained in the DDO photometric system. The main difference between this and previous analyses is that the larger mass ratio has resulted in a correspondingly lower value of the inclination by about 3 degrees.

In addition to synthesising an optical light curve, the ultra-violet observations obtained by Eaton et al (1980) using the ANS satellite were reanalysed with these geometrical parameters. The data was folded about phase 0.5 since there was no difference between the two halves of the light curve to within the errors of the photometry. Table 12 contains the results of fitting the model to the observations. The most striking difference between the optical and uv solutions is that the temperature difference between the components has dropped sharply, while the gravity darkening exponent remains close to the initial value. Once again, the solution tends to increase the

degree of contact when the value of β drops but this dependence is reduced compared to the optical solution. The value of the inclination is slightly lower than that obtained previously but not by any significant amount.

Table 12 :- Light curve synthesis results for W UMa (UV)

Initial Values :-

q	= 0.52	T	= 5800° K
f	= 0.85	X	= 0.00
i	= 83°.0	β	= 0.05
		A	= 0.5

Solution for folded light curve :-

Free parameters	f	i	β	X	$\sum(o-c)^2$
f i β X	0.74	80.1	0.03	0.020	1.16 e-2
	0.06	0.7	0.03	0.003	
i β X	0.85	79.5	0.08	0.017	1.27 e-2
		0.7	0.01	0.003	
f i β	0.72	80.2	0.02	0.022	1.17 e-2
	0.05	0.7	0.02		
f i X	0.78	79.8	0.05	0.019	1.18 e-2
	0.02	0.6		0.003	
i β	0.85	79.6	0.07	0.022	1.34 e-2
		0.7	0.01		
i X	0.85	79.8	0.05	0.022	1.49 e-2
		0.5		0.003	

In the analysis of the UV curve by Eaton et al, which assumed the geometry derived by Worden and Whelan (1973) from photometry, no temperature excess was found and the variation in the (2200-3300) colour limited the variation in the mean effective temperature of the disc to about 60°K. Their interpretation of the apparent temperature excess obtained from the optical light curves was that the radiation from the primary is diluted by spots which are evenly distributed over its surface. This would explain the W type light curve but not change the colour of the system if the spots are cool enough to appear black.

A slight temperature excess was found in the reanalysis of the UV data using the new geometry. However, the marked reduction in this parameter supports the view that the components are close to thermal equilibrium and that the apparent temperature difference is due to some effect that is not incorporated into the model. The existence of an asymmetry in W UMa shown by the broadening functions merely highlights the problems of understanding the structure of contact binaries.

In the absence of large temperature variations as indicated by the UV photometry, then we must explain the variation in the strength of the lines by some other mechanism. With constant temperature, the uniform profile

assumption would normally be expected to hold so that variations in the velocity broadening function will occur if the amount of contributing flux changes. On this basis, the simplest interpretation of the observations is that at 2nd quadrature we see the unperturbed system, while at both primary eclipse and 1st quadrature the amount of flux received has been reduced due to the presence of magnetic starspots as suggested by Mullan (1975). Unfortunately, the maximum following primary minimum is the brighter one so that this interpretation is precluded.

There are several methods of varying spectral line strengths without a temperature change, each of which must be considered as a possible explanation for the phenomena in this system.

First of all, there is the pressure dependence of line formation. At solar temperatures, the metal lines are mostly ionised so that they are very pressure sensitive. The ratio of the line absorption coefficient to the opacity is related to the electron pressure and hence to the surface gravity by the following equation (Gray 1976) :-

$l_\nu / k_\nu = \text{const.} / P_e = \text{const.} \; g^{-\frac{1}{3}}$

The surface gravity of W UMa is given by Rucinski and Kaluzny (1981) as $\log g = 4.40$, and in order to produce the observed change in the line strength the mean surface

gravity has only to be reduced to about log g = 4.07 on the advancing hemisphere of the primary component.

There is another possible mechanism for changing line strengths if starspots exist on the surface. In a convective zone, the modified mixing length theory (Deupree 1979) predicts a non-linearity of opacity with temperature. Consequently, if there is a region of high spot activity, the variation in temperature over the surface will result in a drop in effective opacity and so increase the line strengths. Unfortunately, for the X value derived for W UMa, this effect only amounts to a change of about 3-5% so that it is not large enough to be responsible.

Finally, the presence of a gas stream could alter the line strengths in the spectrum, either by weakening the lines due to emission, or strengthening by added absorption depending on the gas temperature, pressure and its location with respect to the system. The weakening of the absorption lines of the primary at the elongation when it is receding is a typical feature of a gas stream from secondary to primary (Sahade and Wood 1978).

Let us now consider possible models for the system to try and explain the observed light curve and spectroscopic variations.

If we once again assume that the portion of the system seen at 2nd quadrature is unperturbed, then the equality of temperatures derived from the broadening functions is in agreement with the photometry. In this case, then we must weaken ~~the~~ the spectrum of the primary component at 1st quadrature by the presence of gaseous material which is filling in the lines by emission. Mass flow has often been interpreted as the cause of the perturbations in the light curves of contact binaries and the reason for observed period changes (e.g. Cester 1969). This interpretation would be consistent with the Ca II H and K emission lines associated with the primary as stated by Struve (1950), although they were not visible in the spectra obtained for this investigation. Unfortunately, the matter contained in gas streams is almost completely ionised so that the dominant source of opacity is due to Thomson scattering by free electrons, so that the light from the system is partially obscured. In order to increase the flux from the system as observed, it would be necessary for a hot spot to form on the primary as the gas was accreted, and this of course, is in contradiction with both the UV colours and the apparent temperature excess of the secondary derived from the light curve synthesis. Another problem with this model is that mass transfer normally takes place through the inner Lagrangian point L_1. Since the components are in contact,

mass transfer should occur through the neck so that gas streams could only exist if the matter were funnelled along magnetic flux tubes connecting the two stars.

An alternative model would be to assume that most of the primary is covered in starspots as suggested by Mullan (1975) and Eaton et al (1980), while the spectrum lines of the primary are enhanced on its leading side by some mechanism. In this case, one would have to interpret the temperature equality of the components derived from the broadening functions at 2nd quadrature as a mere coincidence. The removal of flux by the presence of spots must be counteracted by the increase in line strength due to some mechanism. Such an increase in line strength could be achieved by a diffuse gas cloud or an extension of the envelope as suggested by Struve (1950). As has been calculated a relatively small decrease in the mean log g is required, much smaller than would be detectable as a change in the spectral classification.

The drop in the flux present in the lines at 1st quadrature gave an apparent temperature difference of 370° K while the light curve synthesis solutions gave a value of 375°K in very good agreement. Adopting this change in the effective temperature, it is possible to derive the effective area of the spots for a given spot temperature

using the formulae given by Mullan. If we have a spot of temperature T_u and relative area A on the surface of a star at temperature T_p, then, to a first approximation, the mean effective temperature will drop by ΔT given by

$$\Delta T / T_p = 0.25 \ (1 - T_u^4 / T_p^4) \ .A$$

The brightness of the primary will therefore be reduced by an amount

$$\Delta m_\lambda = -2.5 \log [1 - (1 - \beta).A]$$

with

$$\beta = [\exp(C_2/\lambda T_p)-1]/[\exp(C_2/\lambda T_u)-1]$$

where λ is the wavelength of observation and C_2=1.44 cgs. It is then possible to estimate the effect of this on the combined light of the system if the mass - luminosity relationship is assumed. Mullan adopted the m-l relation derived by Lucy (1968).

For the observed drop in effective temperature, the area of spots relative to the disc and the resulting magnitude changes are tabulated for a range of spot temperatures in Table 13. The most probable spot temperatures lie in the range 3000-4000°K so that about 30% of the surface of the primary must be covered by these magnetic spots. It can be calculated that to introduce the asymmetry in the height of the maxima, an increase in the spot density of only a few percent is required on the leading hemisphere of the primary (e.g. for spot

temperature of 3500 K, the observed change in Δ m of 0.03 mag. needs an increase in the area covered from 30 to 33%).

Table 13 :- Magnetic starspots on W UMa

T	A	Δ m(p)	Δm
2000	0.26	0.33	0.20
2500	0.27	0.34	0.21
3000	0.28	0.35	0.22
3500	0.30	0.36	0.23
4000	0.34	0.38	0.24
4500	0.41	0.39	0.25
5000	0.58	0.39	0.25

In the case of the sun, spots are often associated with active regions and flares, so that such phenomena are likely to be present on a larger scale on W UMa stars if there is such magnetic activity. These features could be used to explain the short timescale variability of the light curves and the occasional appearance of emission lines of ionised calcium associated with the primary. In addition, such activity would account for the chromospheric emission lines in the UV spectrum (Rucinski et al 1981).

It is possible that matter ejected by large prominences would be sufficient to form the gas cloud or extended envelope on the advancing side of the primary since material can take several days or even weeks to return to the surface, the envelope being replenished in the meantime by further activity. Struve (1950) has interpreted the spectrum variations of the s-d system UX Mon as being due to enhanced prominences on the leading hemispheres of the components, so that a similar effect may be responsible in W UMa systems.

To sum up then, the prototype system W UMa is a highly active W subclass system. The most plausible explanation of the observations, at the present time, is that there exists a strong degree of magnetic activity such as starspots, flares, chromospheric emission etc. with such phenomena able to account for many of the variations in the system. The changing depths of the spectral lines seems to indicate that the uniform profile assumption breaks down and that there is additional material on the leading side of the primary which enhances the line strengths. In order to investigate these effects more fully, much more extensive observations must be obtained, particularly high dispersion spectroscopy over an extended period of time.

4.2 AW UMA

This eclipsing variable is one of the most interesting contact binary systems. Analysis of the photometric observations show that AW UMa has the smallest known mass ratio of 0.08, and as Rucinski (1974) has pointed out, this star may be important for testing possible differences between the physical behaviour and the evolution of A and W type systems.

The only previous radial velocity study of this system was by Paczynski (1964) after the system was discovered to be a W UMa type variable. At that time, only the unresolved Hδ and Hγ lines could be measured so that the single velocity curve obtained was rather inconclusive. In this investigation, however, the much weaker secondary spectrum was detected in the cross-correlation function.

The observations were made at O.H.P. on the nights of the 11th, 15th, 17th and 18th April 1979 using a dispersion of 20A/mm.

Phases were initially computed from the ephemeris by Dworak and Kurpinska (1975)

$$MJD_{\odot} = 38044.2812 + 0.43873235.E$$

but is was found necessary to add a correction of 0.0175 days to the observed times in order to obtain the

solution to the radial velocity curves. This corresponds to a significant shortening of the period of this system, but the occurrence of a large change in the period has recently been reported (Woodward et al 1980, Istomin et al 1980).

Radial velocities were again determined by cross-correlation with the standard HD 89449, the individual observations being given in Table 14 and figure 12. The secondary velocities are, of course, less accurate due to the extreme weakness of the features since the light ratio, and hence the height of the correlation peaks, is of the order 10:1.

Several empirical velocity broadening functions were computed for AW UMa, but due to the fact that they are inherently noisier than cross-correlation functions, the secondary has been lost in the remaining noise. An example of the broadening functions obtained is presented in figure 13. Much better quality spectra would be required in order to enable this type of analysis to be carried out.

Table 14 :- Radial velocity measurements for AW UMa

Plate no.	Hel.M.J.D. 43900.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
V4247	73.9965	0.68	- 5	-349
V4248	74.0261	0.74	+16	-381
V4249	74.0478	0.79	-16	-435
V4292	77.9820	0.76	+12	-450
V4293	77.9912	0.78	0	-389
V4294	77.9995	0.80	+12	-433
V4295	78.0087	0.82	+27	-443
V4296	78.0191	0.85	0	-447
V4297	78.0287	0.87	-29	-295
V4298	78.0404	0.89	+ 5	-
V4305	79.8370	0.99	- 3	-
V4306	79.8607	0.04	-26	-
V4307	79.8819	0.09	-51	+263
V4308	79.9036	0.14	-32	+303
V4309	79.9357	0.21	-65	+374
V4310	79.9661	0.28	-62	+381
V4311	79.9961	0.35	-55	+303
V4312	80.0257	0.42	-40	+305
V4313	80.0578	0.49	+ 1	-
V4319	80.8473	0.29	-25	+373

Table 15 :- Spectroscopic elements for AW UMa

Element	Unit	Paczynski	Present work
V_o	km/s	-1 +/- 2	-17.0 +/- 7 (s.d.)
K_1	km/s	28 +/- 3	29.0 +/- 8
K_2	km/s	-	423.0 +/- 80
$a_1 \sin i$	10^6 km	-	0.18 +/- 0.05
$a_2 \sin i$	10^6 km	-	2.56 +/- 0.48
$a \sin i$	10^6 km	-	2.74 +/- 0.93
$M_1 \sin i$	$M_\odot$	-	3.94 +/- 1.22
$M_2 \sin i$	$M_\odot$	-	0.27 +/- 0.10
$(M_1 + M_2)\sin i$	$M_\odot$	-	4.21 +/- 1.29
$q = M_2 / M_1$	-	-	0.07 +/- 0.02

Fig 12

RADIAL VELOCITY CURVE FOR AW UMa

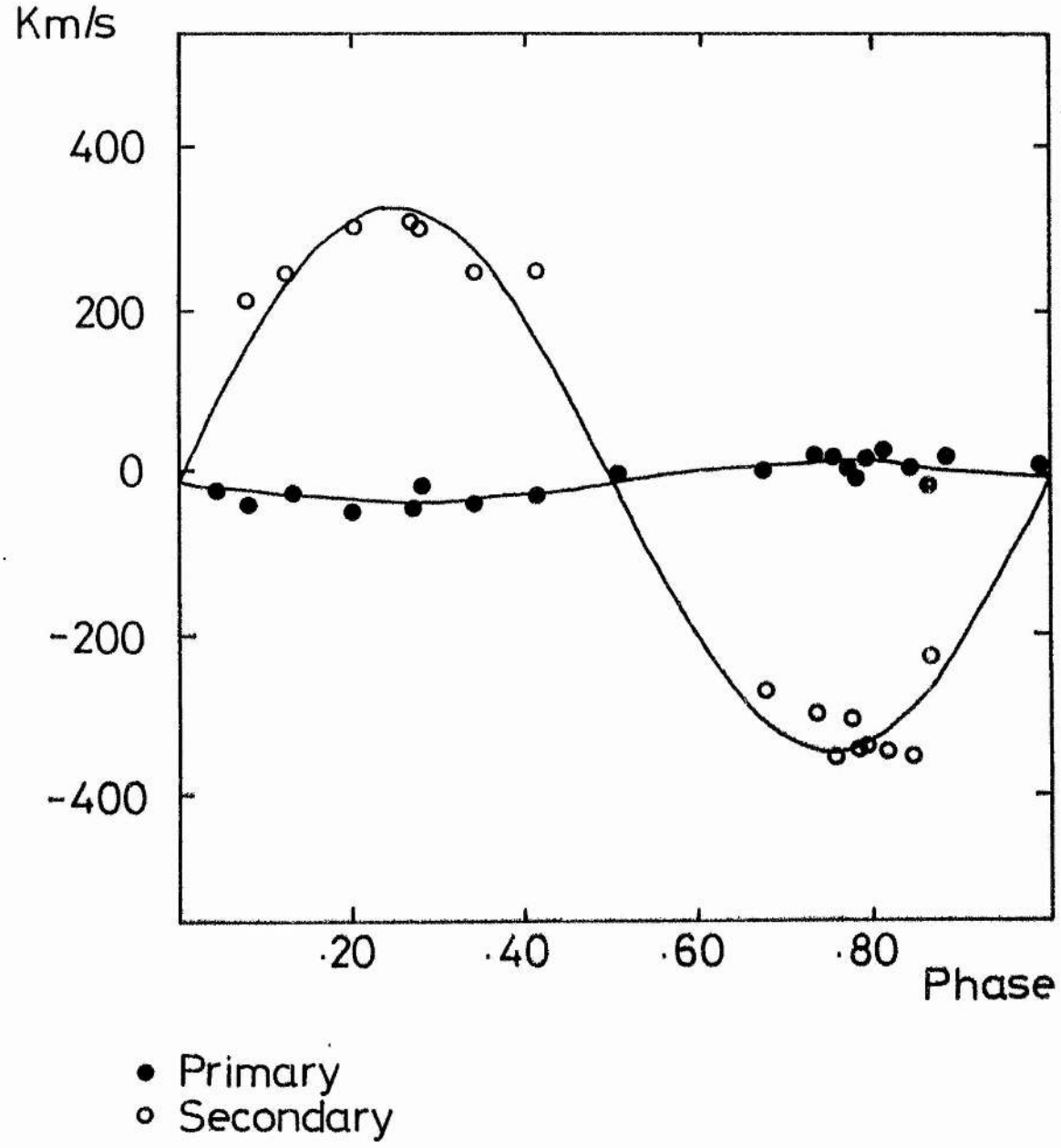
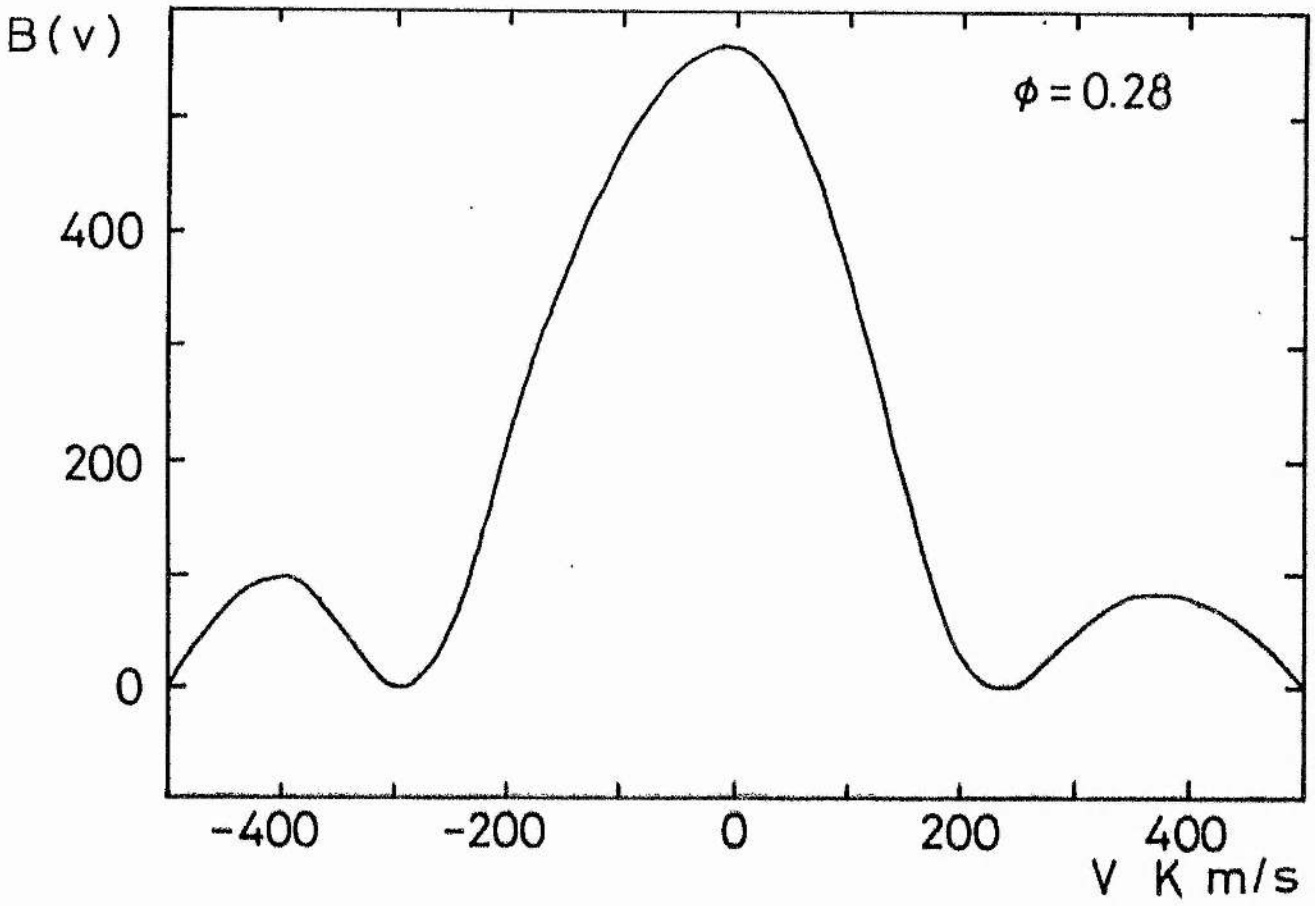
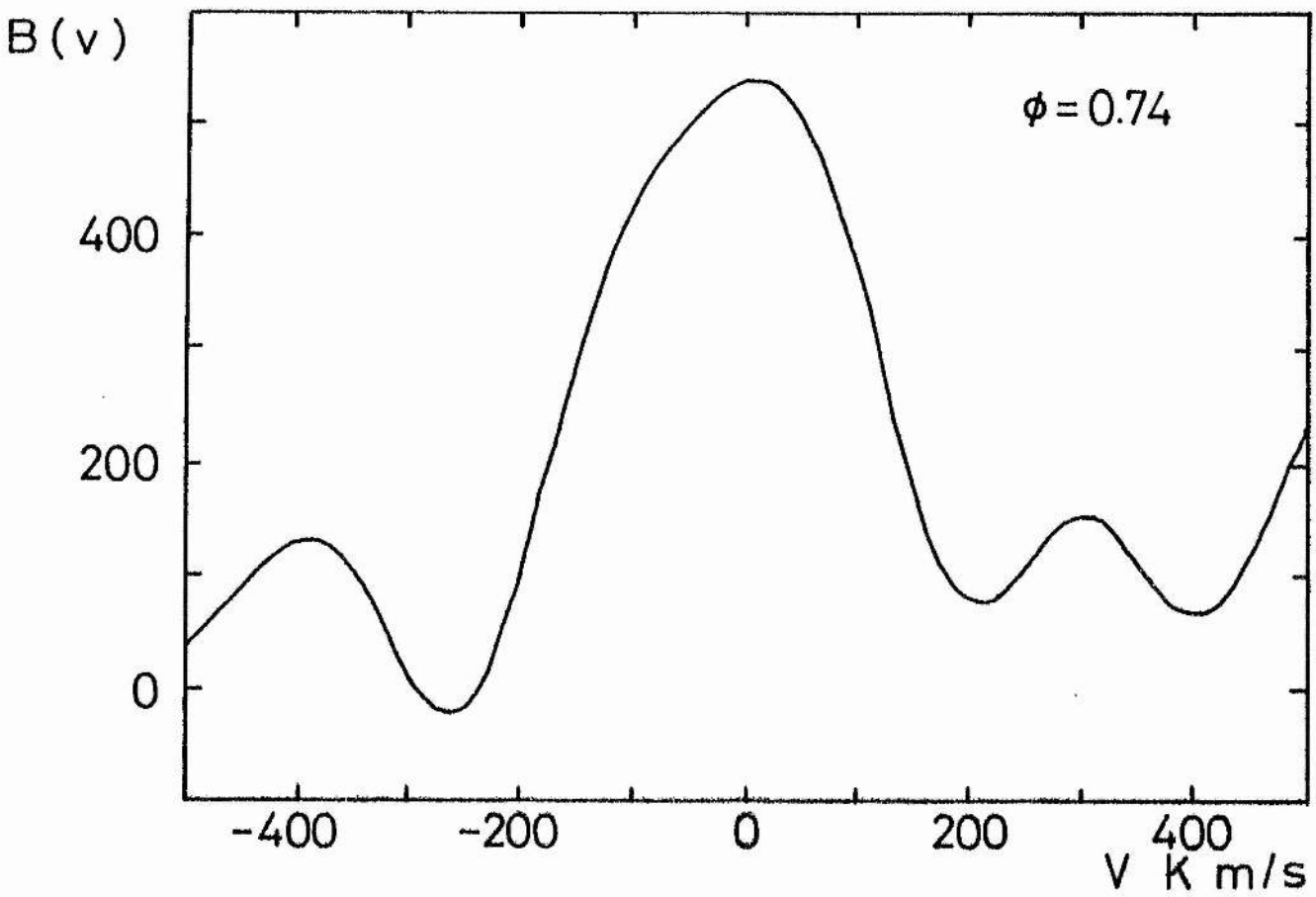


Figure 13

Velocity Broadening Functions for AW UMa

These diagrams show two broadening functions as examples which illustrate the fact that the secondary component lies below the noise level of the function.


B(v)
φ = 0.28
400
200
0
-400
-200
0
200
400
V K m/s


B (v)
400
200
0
-400
-200
0
200
400
V K m/s
$\phi = 0.74$

The light curve of this system shows a slight asymmetry (Woodward et al 1980), while the shallow eclipses are indicative of the low mass ratio. The eclipses are total so that the parameters of the system are able to be determined with greater accuracy as has been demonstrated by the consistency of the results obtained by different analyses (Maochnacki and Doughty 1972, Nagy 1974 and Woodward et al 1980). All of these solutions give a mass ratio of $q = 0.07$ to 0.08 in very good agreement with that determined spectroscopically.

4.3 V566 OPH

The spectroscopic elements of this system were first detemined by Heard (1965) from, as he states, rather poor quality spectrograms since the exposure times were of the order of 90 minutes.

The observations made in this investigation were first taken at O.H.P. on the nights of the 12th, 13th and 15th April 1979 using the 193 cm telescope. However, insufficient phase coverage was obtained during this series of observations. This necessitated the system being reobserved on the nights of the 19th, 21st and 24th August 1980 with the 152 cm telescope.

The phases were computed with the elements

$$MJD_{\odot} = 43675.9026 + 0.40964091.E$$

taken from Niarchos (1979).

The radial velocities were determined by cross-correlating the first and second sets of spectra with the radial velocity standards HD 89449 (F5) and HD 222368 (F5) respectively, these being the standard stars observed during each observing run with the same equipment.

Table 16 :- Radial velocity measurements for V566 Oph

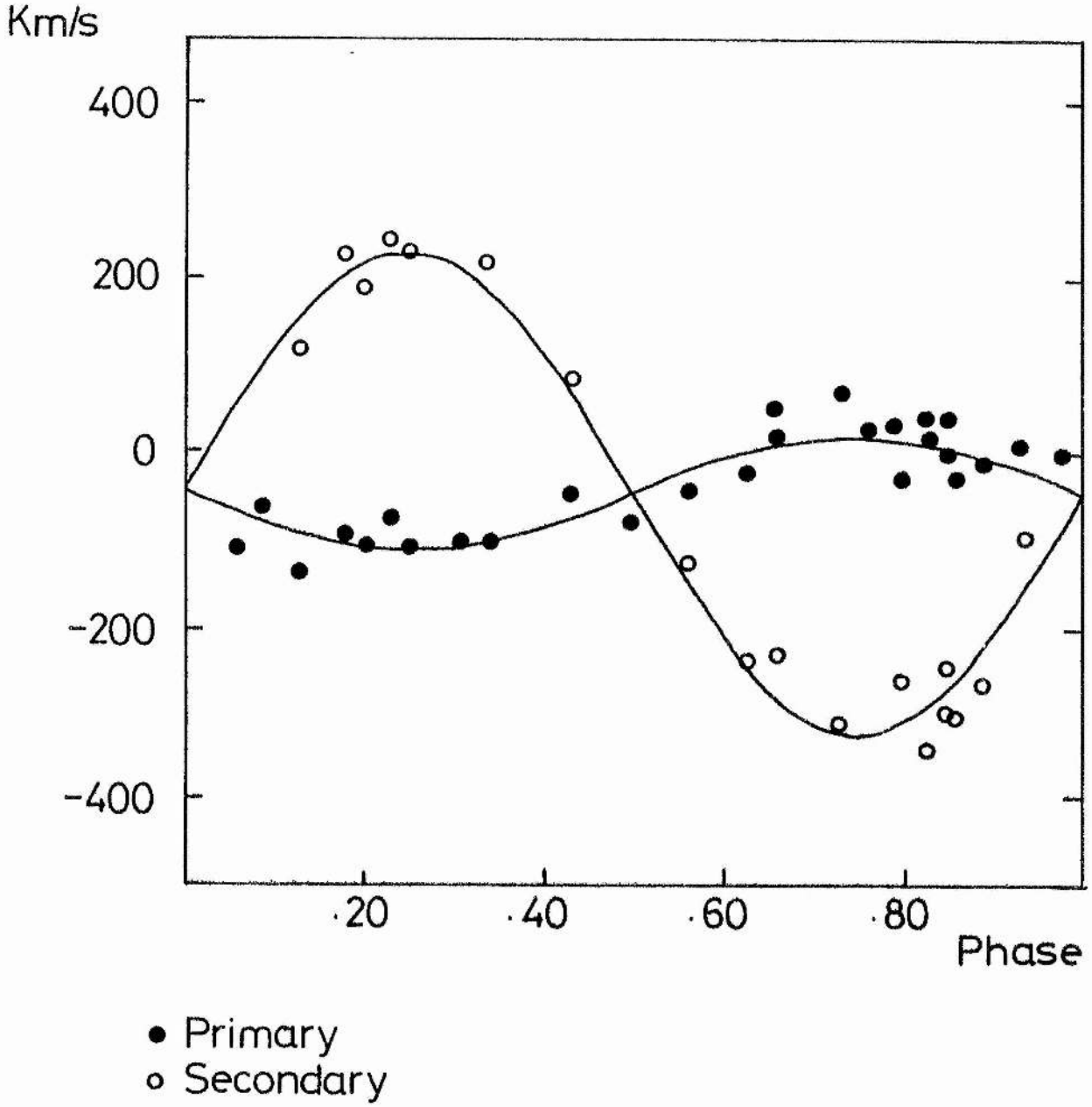
Plate no.	Hel.M.J.D. 43900.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
V4265	76.0853	0.80	+ 35	-
V4266	76.1020	0.84	+ 17	-342
V4267	76.1133	0.86	+ 1	-297
V4268	76.1278	0.90	- 10	-265
V4269	76.1445	0.94	+ 13	- 95
V4284	77.0738	0.21	-111	+188
V4285	77.0909	0.25	-109	+230
V4286	77.1096	0.29	- 92	-
V4287	77.1304	0.35	-102	+217
V4299	79.1615	0.06	-111	-
V4300	79.0948	0.14	-137	+120
V4301	79.1136	0.19	- 95	+230
V4302	79.1336	0.24	- 75	+246
	44400.0 +			
GA4618	70.8667	0.64	- 22	-236
GA4619	70.8896	0.69	+ 15	-
GA4620	70.9083	0.74	+ 70	-312
GA4621	70.9304	0.79	+ 60	-
GA4622	70.9583	0.86	+ 43	-244
GA4644	72.8346	0.44	- 47	+ 85
GA4645	72.8575	0.50	- 75	-
GA4646	72.8854	0.57	- 48	-125
GA4647	72.9271	0.67	+ 51	-231
GA4682	75.8229	0.74	+ 38	-
GA4683	75.8521	0.81	- 33	-264
GA4684	75.8779	0.87	- 29	-302
GA4685	75.9167	0.96	- 53	-
GA4686	75.9654	0.08	- 48	-
GA4687	76.0050	0.18	-	-

Table 17 :- Spectroscopic elements for V566 Oph

Element	Unit	Heard	Present work
V_o	km/s	-42.0 +/- 2	-47.4 +/- 6 (s.d.)
K_1	km/s	84.0 +/- 3	67.0 +/- 10
K_2	km/s	246.0 +/- 5	278.0 +/- 32
$a_1 \sin i$	10^6km		0.38 +/- 0.06
$a_2 \sin i$	10^6km		1.57 +/- 0.18
$a \sin i$	10^6km		1.95 +/- 0.19
$M_1 \sin i$	$M_\odot$		1.40 +/- 0.03
$M_2 \sin i$	$M_\odot$		0.34 +/- 0.01
$(M_1 + M_2)\sin i$	$M_\odot$		1.74 +/- 0.03
$q = M_2 / M_1$	-	0.34 +/- 0.02	0.24 +/- 0.03

Fig. 14

RADIAL VELOCITY CURVE FOR V566 Oph



These observations are shown in Table 16 and figure 14, while the computed elements are given in Table 17. The higher dispersion spectra, improved time resolution and more data points means that these results are of much improved accuracy when compared to those of Heard.

Once again, empirical velocity broadening functions were derived by deconvolving the standard spectrum from the spectra of V566 Oph, several examples of which are shown in fig.15 while the measurements of the heights of the features in the functions are given in Table 18. As can be seen from the graphs of these measurements (see figure 16), the noise level was such that there is a very large scatter. However, the mean values were computed to be :-

P = 30 +/- 5 S = 18 +/- 7 N = 7 +/- 5

so that the relative heights of the features are therefore given by :-

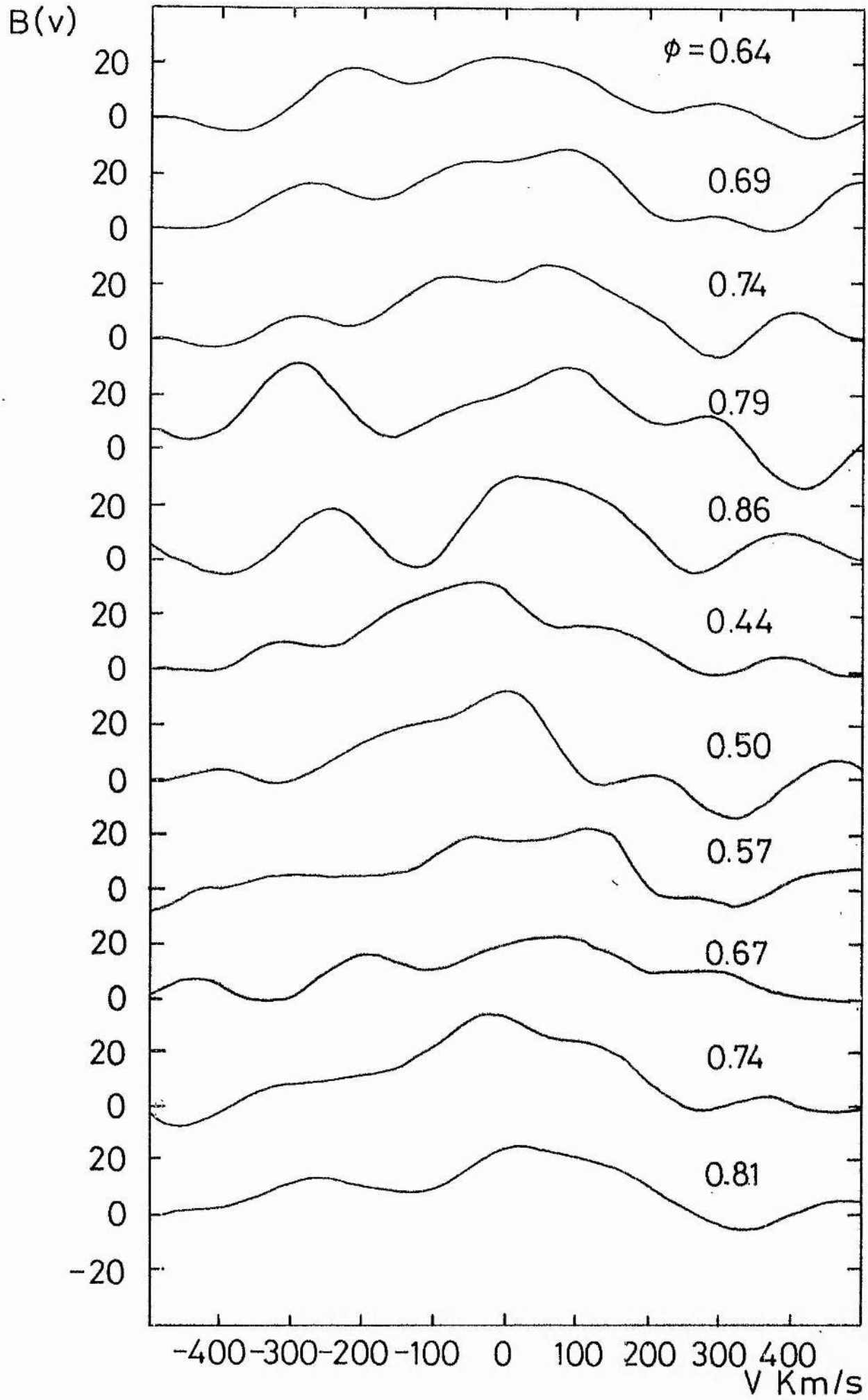
P/S = 1.7 +/- 0.7 N/S = 0.4 +/- 0.3

Since V566 Oph is an A-type system and the theoretical models represent them fairly well, it is to be expected that the value of the mass ratio and fill-out factor derived from Anderson and Shu's atlas would be reasonably well determined.

Figure 15

Empirical Velocity Broadening Functions

for V566 Oph


B(v)
φ = 0.64
0.69
0.74
0.79
0.86
0.44
0.50
0.57
0.67
0.74
0.81
20
0
-20
-400 -300 -200 -100 0 100 200 300 400
V Km/s

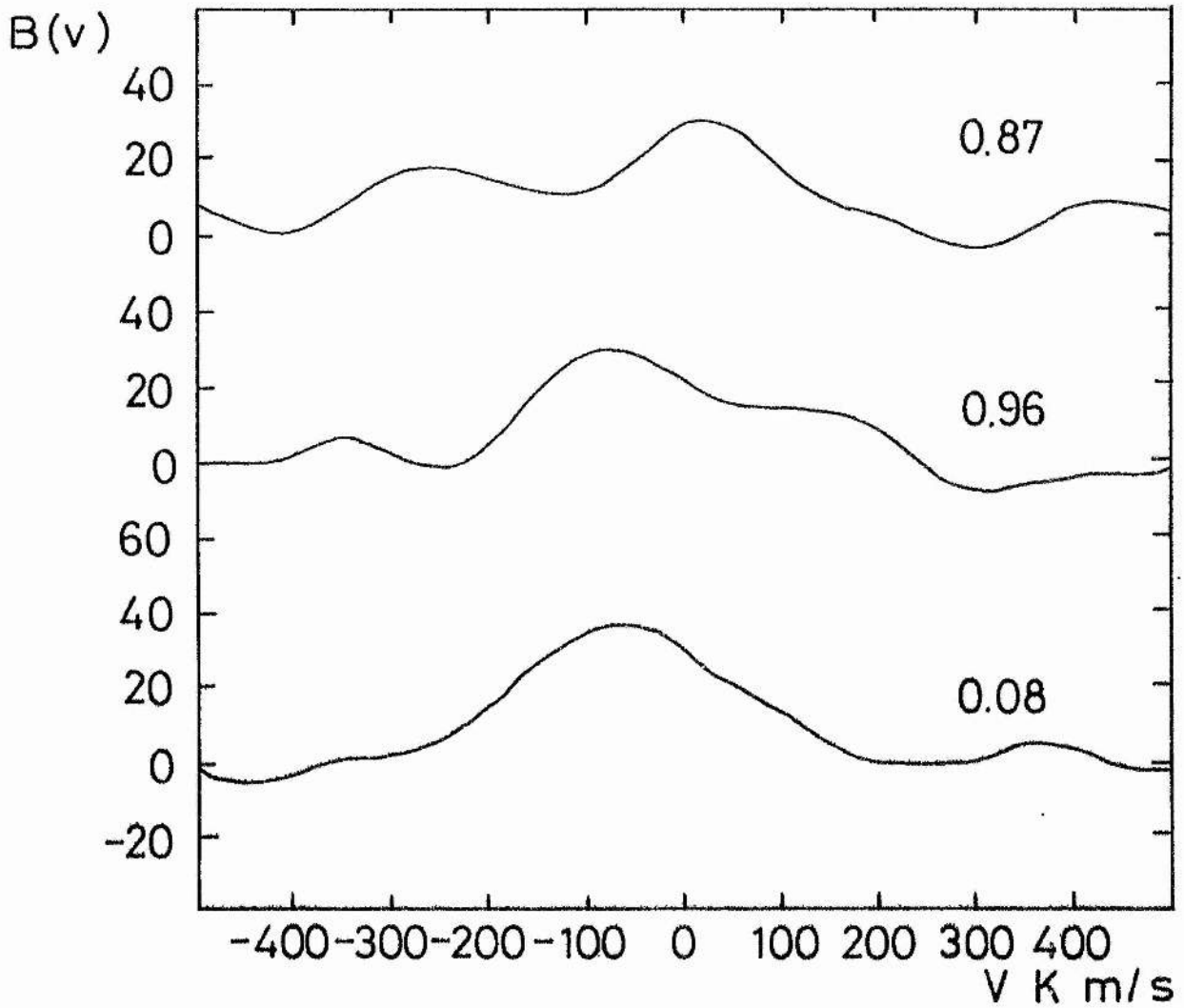

B(v)
40
20
0
40
20
0
60
40
20
0
-20
0.87
0.96
0.08
-400 -300 -200 -100 0 100 200 300 400
V K m/s

Table 18 :- Strength of features in vbf for V566 Oph

Pl.no.	Phase	Prim.	Sec.	Neck
V4265	0.80	33	19	10
V4266	0.84	36	27	8
V4267	0.86	24	26	6
V4268	0.90	36	23	16
V4269	0.94	33	-	-
V4284	0.21	25	10	0
V4285	0.25	-	-	-
V4286	0.29	25	13	0
V4287	0.35	35	12	0
V4299	0.06	-	-	-
V4300	0.14	-	-	-
V4301	0.19	22	10	0
V4302	0.24	30	30	2
GA4618	0.64	21	17	12
GA4619	0.69	28	17	10
GA4620	0.74	28	10	5
GA4621	0.86	30	32	7
GA4622	0.44	30	18	-
GA4644	0.50	32	-	-
GA4645	0.57	34	-	-
GA4646	0.67	23	-	-
GA4647	0.74	22	16	10
GA4682	0.81	35	10	-
GA4683	0.87	25	13	8
GA4684	0.96	30	18	11
GA4685	0.08	29	-	-
GA4686	0.18	38	-	-

Figure 16

Measurements of the Velocity Broadening Functions

for V566 Oph

(a) Central height of Primary component

(b) Central height of Secondary component

(c) Central height of Neck of system

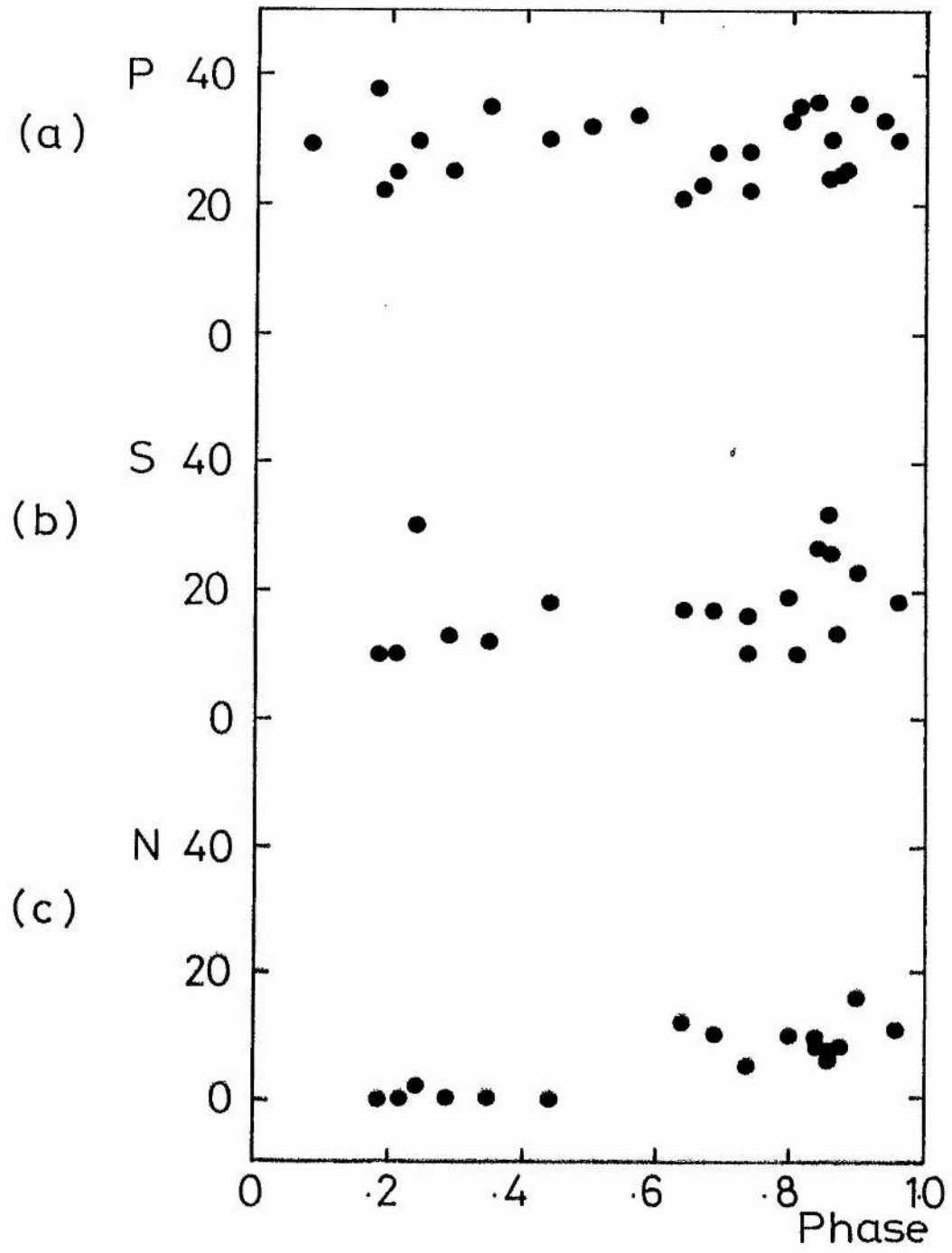

(a)
P
40
20
0
(b)
S
40
20
0
(c)
N
40
20
0
0
·2
·4
·6
·8
1·0
Phase

Table 19 :- Analysis of vbf parameters for V566 Oph

Pl.no.	Phase	P/S	N/S	P+S
V4265	0.80	1.74	0.53	52
V4266	0.84	1.33	0.30	63
V4267	0.86	0.92	0.23	50
V4268	0.90	1.57	0.70	59
V4269	0.94	-	-	33
V4284	0.21	2.50	0.00	35
V4285	0.25	-	-	-
V4286	0.29	1.92	0.00	38
V4287	0.35	2.92	0.00	47
V4299	0.06	-	-	-
V4300	0.14	-	-	-
V4301	0.19	2.20	0.00	32
V4302	0.24	1.00	0.07	60
GA4618	0.64	1.24	0.71	38
GA4619	0.69	1.65	0.59	45
GA4620	0.74	2.80	0.50	38
GA4621	0.86	0.94	0.22	62
GA4622	0.44	1.67	-	48
GA4644	0.50	-	-	-
GA4645	0.57	-	-	-
GA4646	0.67	-	-	-
GA4647	0.74	1.38	0.63	38
GA4682	0.81	3.50	-	45
GA4683	0.87	1.92	0.62	38
GA4684	0.96	1.67	0.61	48
GA4685	0.08	-	-	-
GA4686	0.18	-	-	-

Figure 17

Analysis of Broadening Functions for V566 Oph

(a) Sum of observed strengths P+S

(b) Ratio of Primary to Secondary P/S

(c) Ratio of Neck to Secondary N/S

The interpolated values assuming full limb darkening and low gravity darkening are as follows :-

$q = 0.3 +/- 0.2$

$F = 0.3 +/- 0.2$

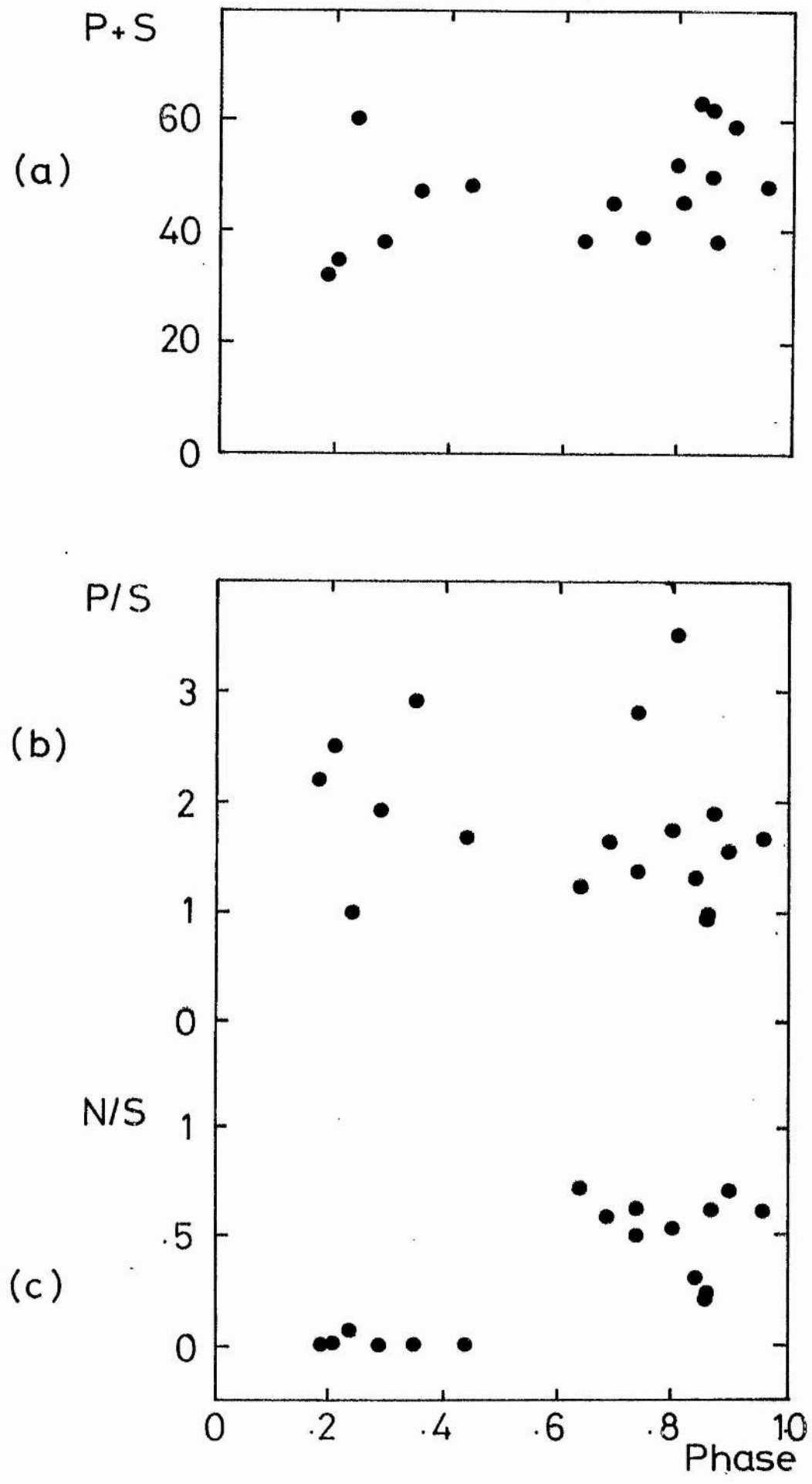
Unfortunately, the errors are very large due to the quality of the spectra and the noise present in the data processing. However, it would appear that the the mass ratio is in reasonable agreement with that already derived, while the degree of contact may be deeper than that for W UMa, a W-type system. Obviously, spectra with better signal to noise would be required to determine these quantities more accurately.

Assuming the relative radii of the components to be $(r_s/r_p) = 0.56$ (Nagy 1974), then we may use the relation previously derived to calculate the relative temperatures of the components, which gives us

$T_p / T_s = 0.99 +/- 0.10$

It would appear that the two components have nearly identical temperatures as is characteristic from photometric analyses of A-type systems (Rucinski 1974).

The light curve of this system has been well observed and appears to show very little asymmetry. No significant changes have occurred between observations several years apart. In addition, the eclipses are total so that the


P+S
60
40
20
0
(a)
P/S
3
2
1
0
(b)
N/S
1
.5
0
(c)
0
.2
.4
.6
.8
10
Phase

parameters are well determined. Several light curve solutions have been carried out (Mochnacki and Doughty 1972, Hutchings and Hill 1973 and Nagy 1974), all of which give a mass ratio of $q = 0.23$ to 0.24 which is in excellent agreement with that determined spectroscopically.

4.4 TZ BOO

This is one of the most peculiar of the W UMa systems (along with AC Boo and AM Leo) in that the depths of the primary and secondary eclipses interchange so rendering the criterion for a division into A-type and W-type systems meaningless.

A radial velocity investigation by Chang (1948) established velocity variations but he was unable to assemble a velocity curve. A more recent study of the system by Hoffmann (1978) was able to follow the velocity variations of the primary component but not the secondary.

The observations presented here were made at the D.A.O. at a dispersion of 30A/mm on the nights of 26th and 29th March 1980, timed to coincide approximately with the times of quadrature.

Phases were computed using the elements given by Hoffmann (1978)

$$MJD_{\odot} = 42153.369 + 0.2971637.E$$

Due to the very late spectral type (G6-K), the radial velocities were measured from individual lines using the comparator technique rather then cross-correlation which resulted in very blended peaks which could not be measured with any degree of accuracy. The individual observations

are shown in Table 20 and figure 18 while the calculated elements are in Table 21.

Table 20 :- Radial velocity measurements for TZ Boo

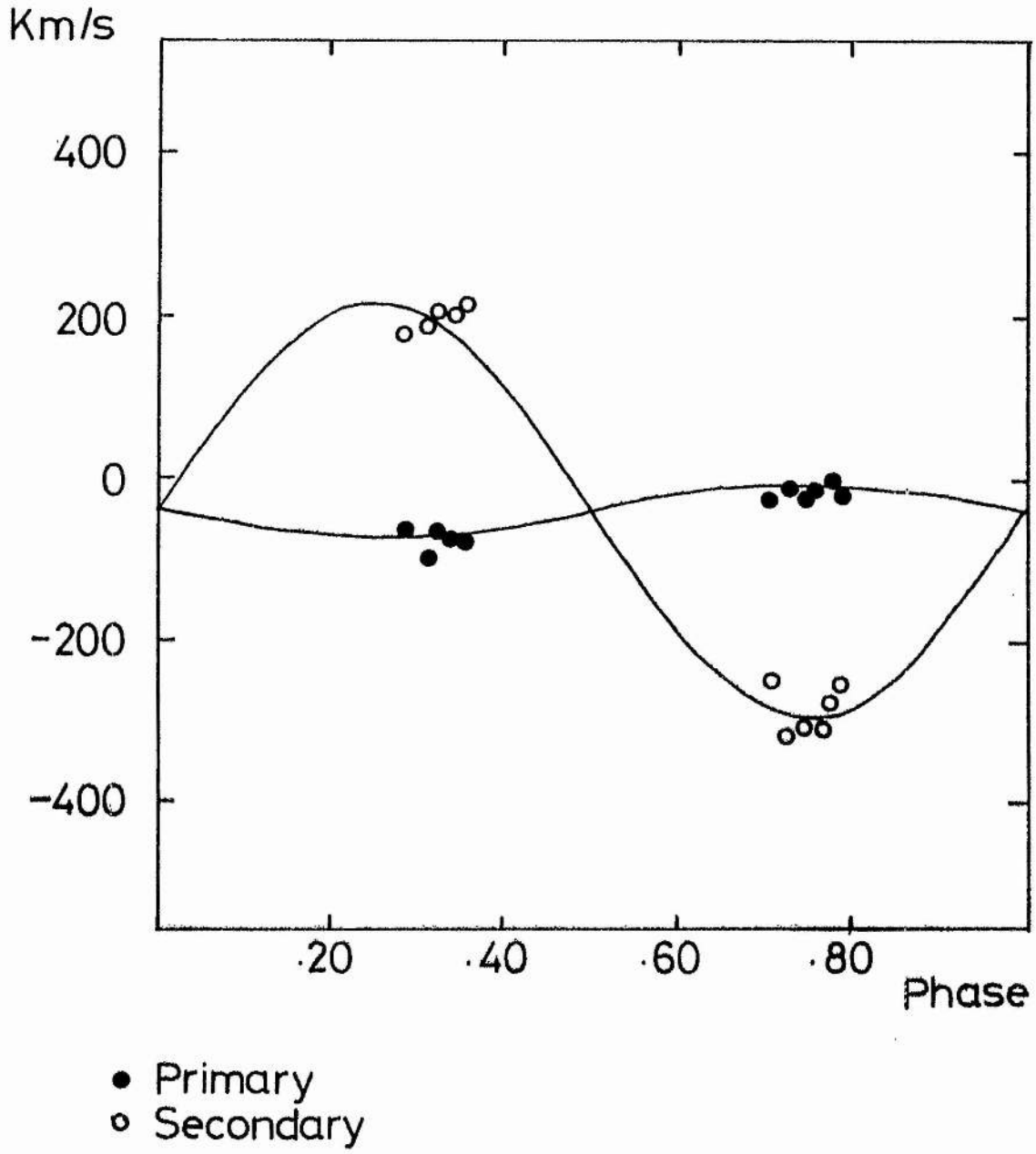
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86033	25.3493	0.72	- 17	-243
86034	25.3531	0.73	- 4	-313
86035	25.3587	0.75	- 15	-299
86036	25.3632	0.77	- 6	-301
86037	25.3680	0.78	+ 4	-267
86038	25.3722	0.80	- 15	-248
86092	28.4886	0.28	- 54	+185
86093	28.4973	0.31	- 90	+195
86094	28.5018	0.33	- 56	-
86095	28.5060	0.34	- 68	+208
86098	28.0105	0.36	- 49	-

Table 21 :- Spectroscopic elements for TZ Boo

Element	Unit	Hoffmann	Present work
$V_\odot$	km/s	+10	-36.7 +/- 5 (s.d.)
K_1	km/s	50	33.0 +/- 7
K_2	km/s		249.0 +/- 38
$a_1 \sin i$	10^6 km		0.13 +/- 0.03
$a_2 \sin i$	10^6 km		1.02 +/- 0.15
$a \sin i$	10^6 km		1.15 +/- 0.18
$M_1 \sin i$	$M_\odot$		0.61 +/- 0.18
$M_2 \sin i$	$M_\odot$		0.08 +/- 0.03
$(M_1 + M_2) \sin i$	$M_\odot$		0.69 +/- 0.20
$q = M_2 / M_1$	-		0.13 +/- 0.03

Fig. 18

RADIAL VELOCITY CURVE FOR TZ Boo



Despite the comparative lack of data, it is felt that these observations are of better quality than those of Hoffmann, and in particular, the detection of the secondary has provided a much more reliable determination of the mass ratio than the estimates made by other means.

The extreme variability of the light curve of TZ Boo (Hoffmann 1978) has prevented the use of the light curve synthesis technique to obtain a reliable determination of the system parameters. It would be logical to assume that TZ Boo is in fact an extremely low mass ratio W type system on account of this variability, rather than place it among the low mass ratio, but stable A type systems. On this basis, it is plausible to account for the large variations as being due to the appearance of magnetic starspots. Hoffmann (1980) has suggested that there is a solar-like activity cycle of period 3.5 years, and that the spots are formed preferentially on the surface of the primary star near the inner Lagrangian point.

From other properties of the system, an estimate of $q = 0.22 \pm 0.05$ was made for the mass ratio. This is higher than was derived spectroscopically.

4.5 XY BOO

It would appear that the observations presented here form the first radial velocity investigation of this system, and were made at the D.A.O. on the night of the 26th March 1980. The times of observation were again chosen to coincide with the times of quadrature.

Phases of the system were calculated using the elements

$$MJD_{\odot} = 42582.1769 + 0.3705466.E$$

obtained from the photometry of Winkler (1977).

The radial velocity standard HD 112299 (F8) was used as the template in order to determine the radial velocities by cross-correlation. These measurements are presented in Table 22 and figure 19, while the resulting elements are in Table 23 .

The light curve of XY Boo is typical of that for an A type system, showing little or no asymmetry and appear to be reasonably stable over long periods. An analysis of the light curve (Winkler 1977) using the Wilson and Devinney code derived a photometric mass ratio of $q = 0.18$ which is in good agreement with the spectroscopic value obtained in this investigation.

Table 22 :- Radial velocity measurements for XY Boo

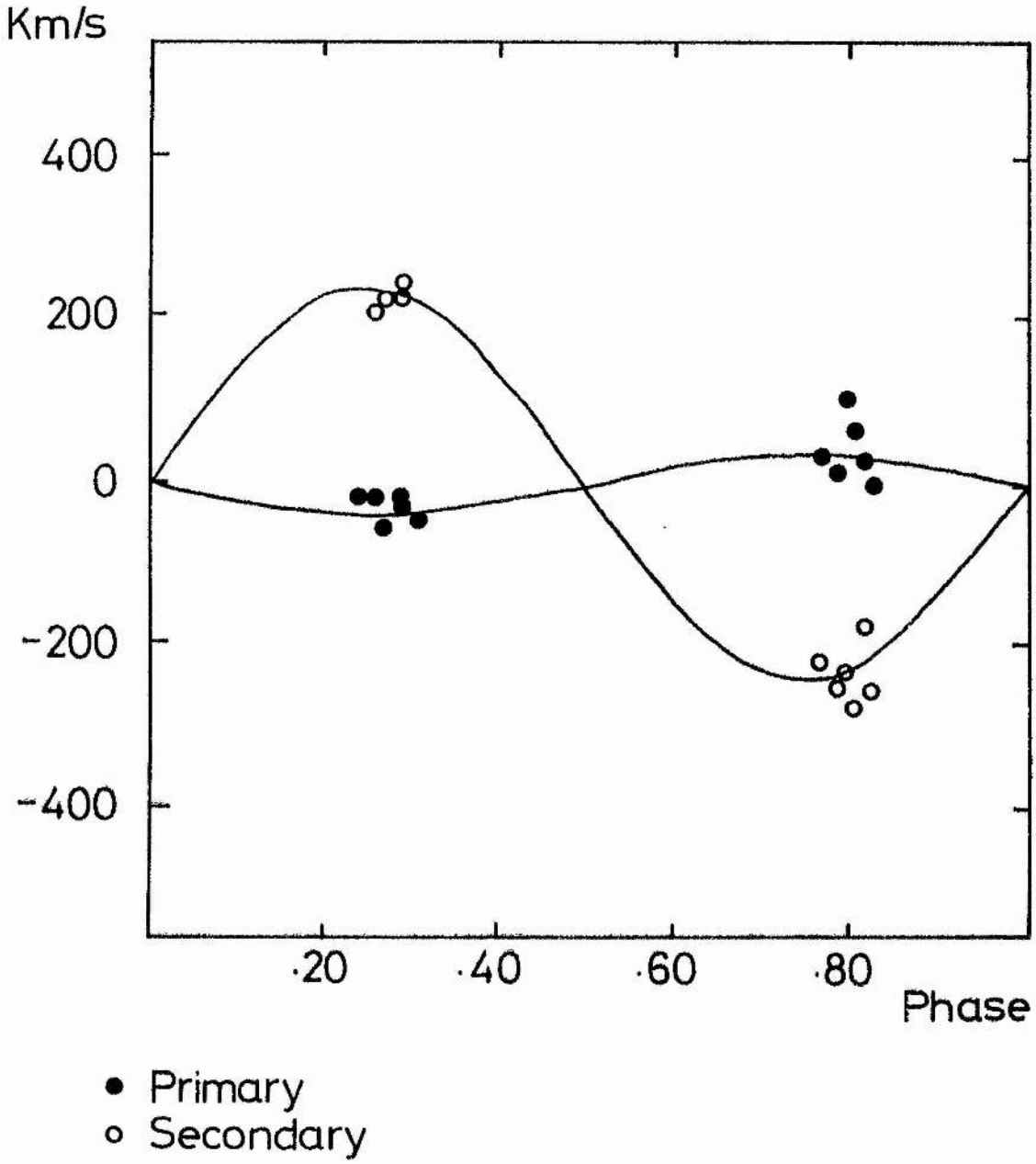
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86027	25.3216	0.25	- 13	-
86028	25.3254	0.26	- 12	+215
86029	25.3302	0.28	- 53	+230
86030	25.3361	0.29	- 20	+230
86031	25.3389	0.30	- 14	+250
86032	25.3421	0.31	- 28	-
86054	25.5167	0.78	+ 39	-220
86055	25.5219	0.79	+ 20	-250
86056	25.5275	0.81	+111	-230
86057	25.5313	0.82	+ 74	-275
86058	25.5355	0.83	+ 38	-175
86059	25.5386	0.84	+ 6	-255

Table 23 :- Spectroscopic elements for XY Boo

Element	Unit	Present work
$V_\odot$	km/s	+2.1 +/- 7 (s.d.)
K_1	km/s	39.0 +/- 11
K_2	km/s	245.0 +/- 58
$a_1 \sin i$	10^6 km	0.20 +/- 0.04
$a_2 \sin i$	10^6 km	1.25 +/- 0.03
$a \sin i$	10^6 km	1.45 +/- 0.05
$M_1 \sin i$	$M_\odot$	0.76 +/- 0.27
$M_2 \sin i$	$M_\odot$	0.12 +/- 0.04
$(M_1 + M_2) \sin i$	$M_\odot$	0.88 +/- 0.27
$q = M_2 / M_1$	-	0.16 +/- 0.04

Fig 19

RADIAL VELOCITY CURVE FOR XY Boo



4.6 TX CNC

This W-type system is important in our understanding of the structure and evolution of W UMa systems, in that it lies below the turnoff of the Praesepe cluster of which it is a member, implying that is unevolved. A previous spectroscopic study has been carried out by Whelan and Worden (1973).

The observations in this survey were obtained at the D.A.O. on the nights of the 29th March and 1st April 1980, again being timed to coincide with quadrature.

The elements given by Hilditch (1981) were used to calculate the phases of observation.

$$MJD_{\odot} = 43191.2828 + 0.38288157.E$$

Radial velocities were measured by cross-correlating the spectra against the standard star HD 112299 (F8), and these are shown in Table 24 and figure 20. The elements of the system are given in Table 25 . When comparing the results with those of Whelan and Worden, we are once again in the unfortunate position of using a higher dispersion and numerical measurement technique, while only having a limited amount of data. Consequently, the differences in the computed elements are due to the errors in the measurements and so one is unable to determine which set of elements more

nearly represents the system.

Light curve synthesis solutions for TX Cnc give mass ratios ranging from $q = 0.50$ to 0.62 depending upon the adopted parameters. This is consistent with the fact that it has a low inclination and so the mass ratio is poorly determined photometrically. This system, unlike most other W types, displays little asymmetry in its light curve so that either there is little activity or it is uniformly distributed over the surface.

Table 24 :- Radial velocity measurements for TX Cnc

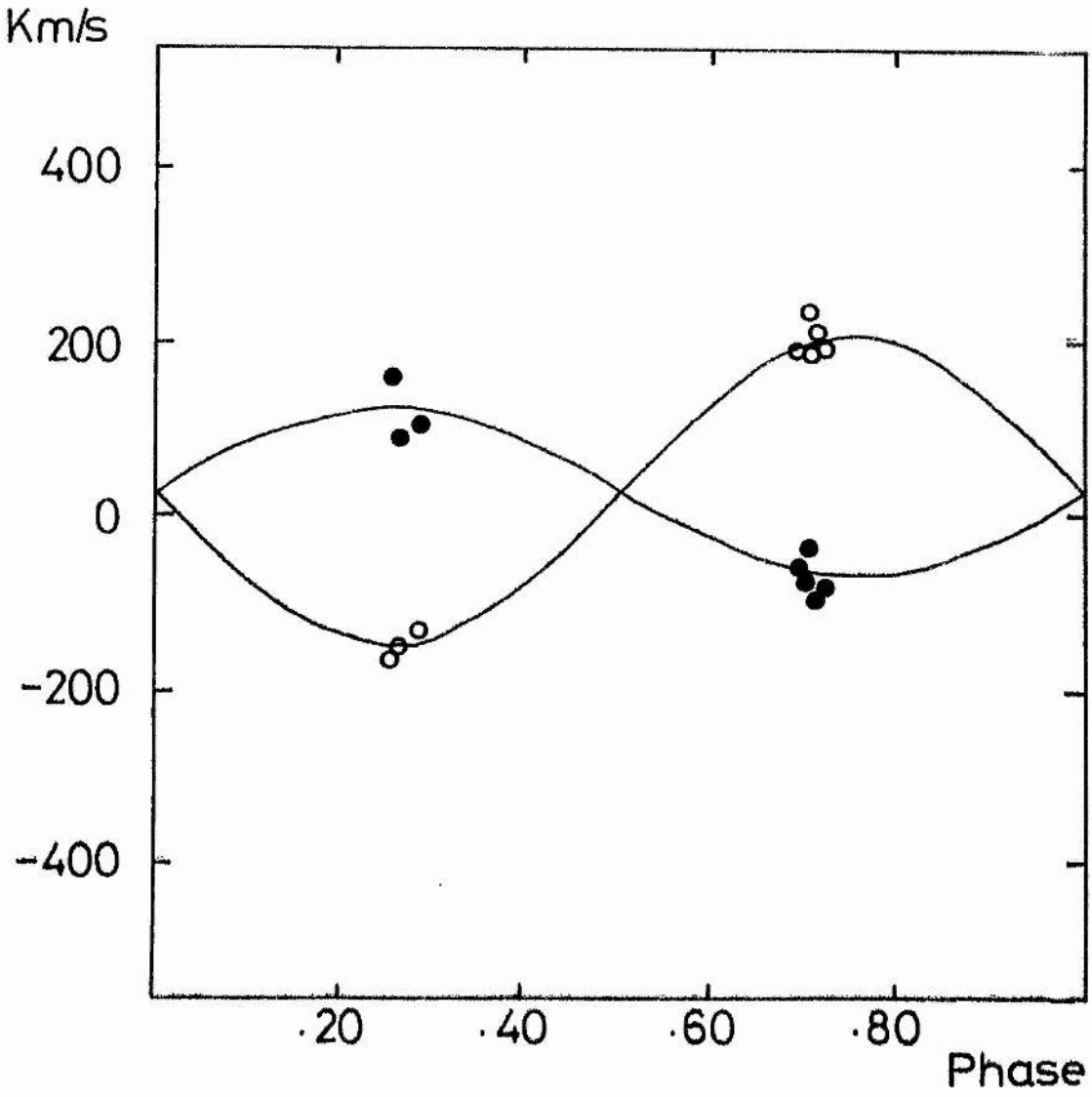
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86069	28.3189	0.69	- 55	+194
86070	28.3224	0.70	- 34	+240
86071	28.3255	0.71	- 74	+190
86072	28.3283	0.72	- 93	+197
86073	28.3311	0.73	- 78	+195
86121	31.2138	0.25	+130	-172
86122	31.2197	0.27	+ 65	-135
86123	31.2252	0.28	+ 90	-100

Table 25 :- Spectroscopic elements for TX Cnc

Element	Unit	Whelan & Worden	Present work
V_o	km/s	+26.6 +/- 3	29.0 +/- 6 (s.d.)
K_1	km/s	117.3 +/- 3	96.0 +/- 8
K_2	km/s	189.8 +/-4	181.0 +/- 11
$a_1 \sin i$	10^6 km	0.62 +/- 0.02	0.51 +/- 0.04
$a_2 \sin i$	10^6 km	1.00 +/- 0.02	0.96 +/- 0.06
$a \sin i$	10^6 km	1.62 +/- 0.04	1.47 +/- 0.07
$M_1 \sin i$	$M_\odot$	0.71 +/- 0.04	0.56 +/- 0.07
$M_2 \sin i$	$M_\odot$	0.44 +/- 0.03	0.30 +/- 0.06
$(M_1 + M_2)\sin i$	$M_\odot$	1.15 +/- 0.05	0.86 +/- 0.09
$q = M_2 / M_1$	-	0.62 +/- 0.04	0.53 +/- 0.06

Fig 20

RADIAL VELOCITY CURVE FOR TX Cnc



● Primary
○ Secondary

4.7 RZ COM

The last spectroscopic investigation of this system was by Struve and Gratton (1948) who obtained the radial velocity curves for both components, although the quality of the orbit obtained was rather poor due to the long exposure times and relatively low dispersion spectra (76A/mm).

Several observations of this star were made on the nights of 26th and 29th March 1980 at the D.A.O. around the times of quadrature which were calculated using the ephemeris given in the Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems (Batten et al, 1978).

$$MJD_{\odot} = 25005.109 + 0.3385.E \quad (\text{epoch } T_{\odot})$$

Due to the late spectral type, the radial velocities were determined by measurements of individual lines using the simulated comparator technique. The results are presented in Table 26 and figure 21, while the calculated elements are in Table 27. Once again, it is felt that the better quality spectra and improved time resolution means that the elements of the system are more accurate than those of Struve and Gratton.

Table 26 :- Radial velocity measurements for RZ Com

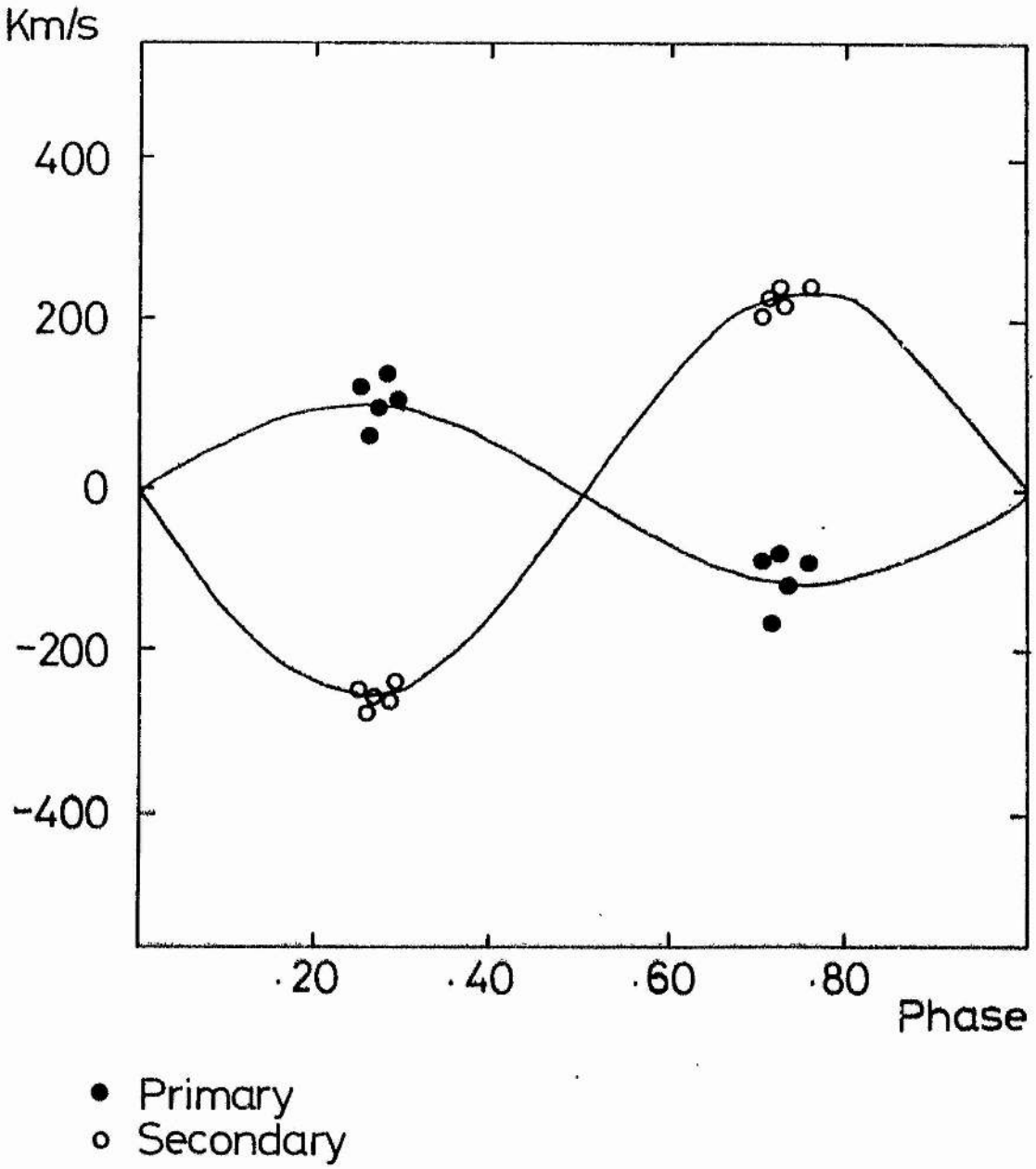
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86049	25.4877	0.70	- 38	+220
86050	25.4919	0.71	- 42	+225
86051	25.4954	0.72	- 85	+218
86052	25.5058	0.74	-112	+243
86078	28.3836	0.25	+125	-245
86079	28.3867	0.26	+ 67	-267
86080	28.3895	0.27	+ 99	-251
86081	28.3929	0.28	+141	-250
86082	28.3964	0.29	+110	-237

Table 27 :- Spectroscopic elements for RZ Com

Element	Unit	Struve & Gratton	Present work
$V_\odot$	km/s	12	- 1.8 +/- 5 (s.d.)
K_1	km/s	130	107.0 +/- 6
K_2	km/s	270	248.0 +/- 9
$a_1 \sin i$	10^6 km		0.50 +/- 0.03
$a_2 \sin i$	10^6 km		1.16 +/- 0.05
$a \sin i$	10^6 km		1.66 +/- 0.06
$M_1 \sin i$	$M_\odot$		1.10 +/- 0.09
$M_2 \sin i$	$M_\odot$		0.48 +/- 0.05
$(M_1 + M_2)\sin i$	$M_\odot$		1.58 +/- 0.10
$q = M_2 / M_1$	-	0.48	0.43 +/- 0.03

Fig 21

RADIAL VELOCITY CURVE FOR RZ Com



Light curves obtained by Broglia (1960) shows that this system varies in a similar to many other W type systems, showing marked asymmetry and short timescale variability. Binnendijk (1964) has interpreted the changes to be due to the appearance of dark spots on the inner hemisphere of the primary. This would conform to the spot model for W type systems described earlier, and provides further support for its validity.

Light curve synthesis solutions obtain a mass ratio of $q = 0.42-0.43$ (Wilson and Devinney 1973, Binnendijk 1977) which is in very good agreement with the spectroscopic value. This was an unexpected result since the two determinations nearly always differ for W type systems.

4.8 CC COM

This system has the shortest known period of this class of object, and as such lies at the low-mass and low-temperature end of the contact binary sequence. A photometric and spectroscopic investigation of CC Com by Rucinski (1976) and Rucinski et al (1977), has shown that this is a typical W-type system so establishing the continuity of properties along the sequence down to a spectral type of mid-K.

The ephemeris given by Rucinski (1976)

$$MJD_{\odot} = 42467.33070 + 0.2206842.E$$

was used to compute the phases of the observations made during this study on the nights of 26th, 27th March and 1st April 1980.

Crosscorrelation of the spectra was once again unable to provide velocity measurements due to the severe line blending of many lines in this K type spectum. Consequently, the comparator technique was used to measure the velocities of individual metallic lines in the spectra. The observations, which were made around quadrature, are presented in Table 28 and figure 22, while the computed elements are in Table 29. Comparing the results obtained with those of Rucinski et al, it is again clear that there are still significant errors in measurement. The main

problem in this work was the relatively low number of data points so that the higher dispersion has not improved the elements of the system.

Table 28 :- Radial velocity measurements for CC Com

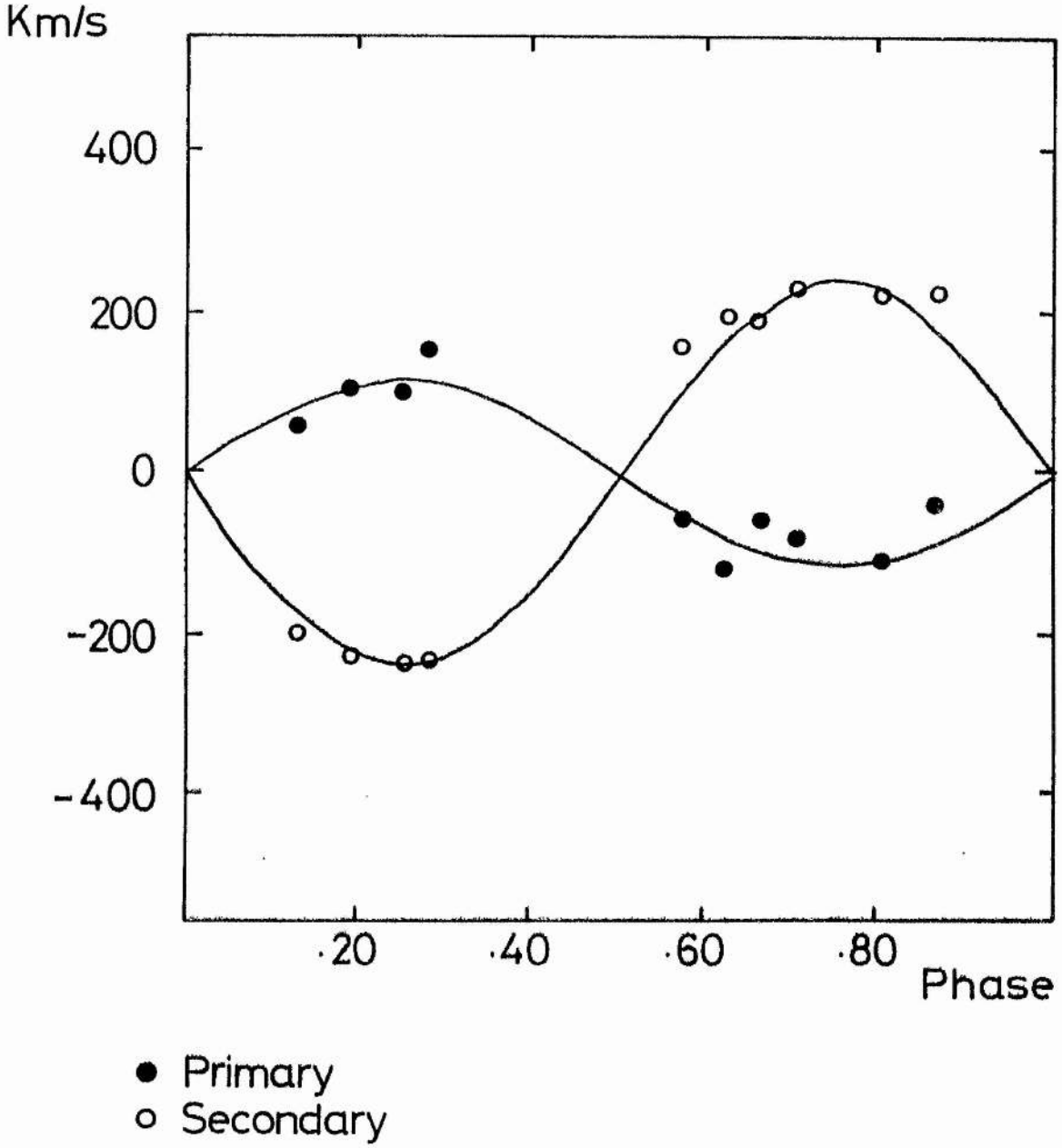
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86046	25.4493	0.81	-114	+217
86047	25.4632	0.87	- 40	+226
86048	25.4760	0.93	- 47	+149
86064	28.2659	0.57	- 59	+154
86065	28.2777	0.63	-123	+193
86066	28.2874	0.67	- 63	+191
86067	28.2961	0.71	- 84	+224
86126	31.2599	0.14	+ 55	-205
86127	31.2737	0.20	+101	-233
86128	31.2849	0.25	+ 96	-244
86129	31.2935	0.29	+147	-241

Table 29 :- Spectroscopic elements for CC Com

Element	Unit	Rucinski et al	Present work
$V_\odot$	km/s	-10.4 +/- 5.4	- 0.3 +/- 6 (s.d.)
K_1	km/s	122.0 +/- 5.5	113.0 +/- 9
K_2	km/s	235.9 +/- 4.8	241.0 +/- 16
$a_1 \sin i$	10^6 km	0.52 +/- 0.01	0.34 +/- 0.03
$a_2 \sin i$	10^6 km	0.57 +/- 0.01	0.73 +/- 0.05
$a \sin i$	10^6 km	1.09 +/- 0.02	1.07 +/- 0.06
$M_1 \sin i$	$M_\odot$	0.69 +/- 0.06	0.69 +/- 0.09
$M_2 \sin i$	$M_\odot$	0.36 +/- 0.03	0.32 +/- 0.04
$(M_1 + M_2) \sin i$	$M_\odot$	1.05 +/- 0.07	1.01 +/- 0.10
$q = M_2 / M_1$	-	0.52 +/- 0.03	0.47 +/- 0.04

Fig 22

RADIAL VELOCITY CURVE FOR CC Com



In conjunction with the spectroscopic observations described by Rucinski et al (1977), a photometric light curve was obtained and analysed by Rucinski (1976). The inclination of the system is almost exactly 90 so that the solution should be well determined. This resulted in a mass ratio of $q = 0.52$, slightly higher than obtained in this work but in good agreement with the previous spectroscopic investigation. Rucinski also derived a relative temperature difference of $X = 0.05$ which is typical for many W type systems. If one explains this as starspots on the primary, then a slight excess is required on the trailing side in order to account for the fainter maxima following primary minimum. This is in contrast to that found for W UMa where the second maxima was the fainter one. Further evidence for magnetic activity on CC Com was the occurrence of an increase in the UV excess by 0.25 magnitudes for a short period, which was interpreted as being due to some sort of atmospheric emission phenomenon.

4.9 Y SEX

The observations of this system during this work represent the first spectroscopic study of this A-type contact binary. Spectra were obtained on the night of the 1st April 1980, again being timed to coincide with the quadratures of the system.

The phases were computed using the ephemeris

$$MJD_{\odot} = 39521.964 + 0.41981543.E$$

given by Hill (1979).

Radial velocities were determined by cross-correlating the binary star spectra with the radial velocity standard HD 112299 (F8). The resulting measurements ae shown in Table 30 and figure 23, the calculated elements being in Table 31.

The light curve for Y Sex has been obtained and analysed by Hill (1979) who derived a photometric mass ratio of $q = 0.18$ in excellent agreement with the spectroscopic value. It should be noted that there are small asymmetries in the light curve and there is evidence that a change has taken place over the past 20 years, indicating that activity is still present in this A type system.

Table 30 :- Radial velocity measurements for Y Sex

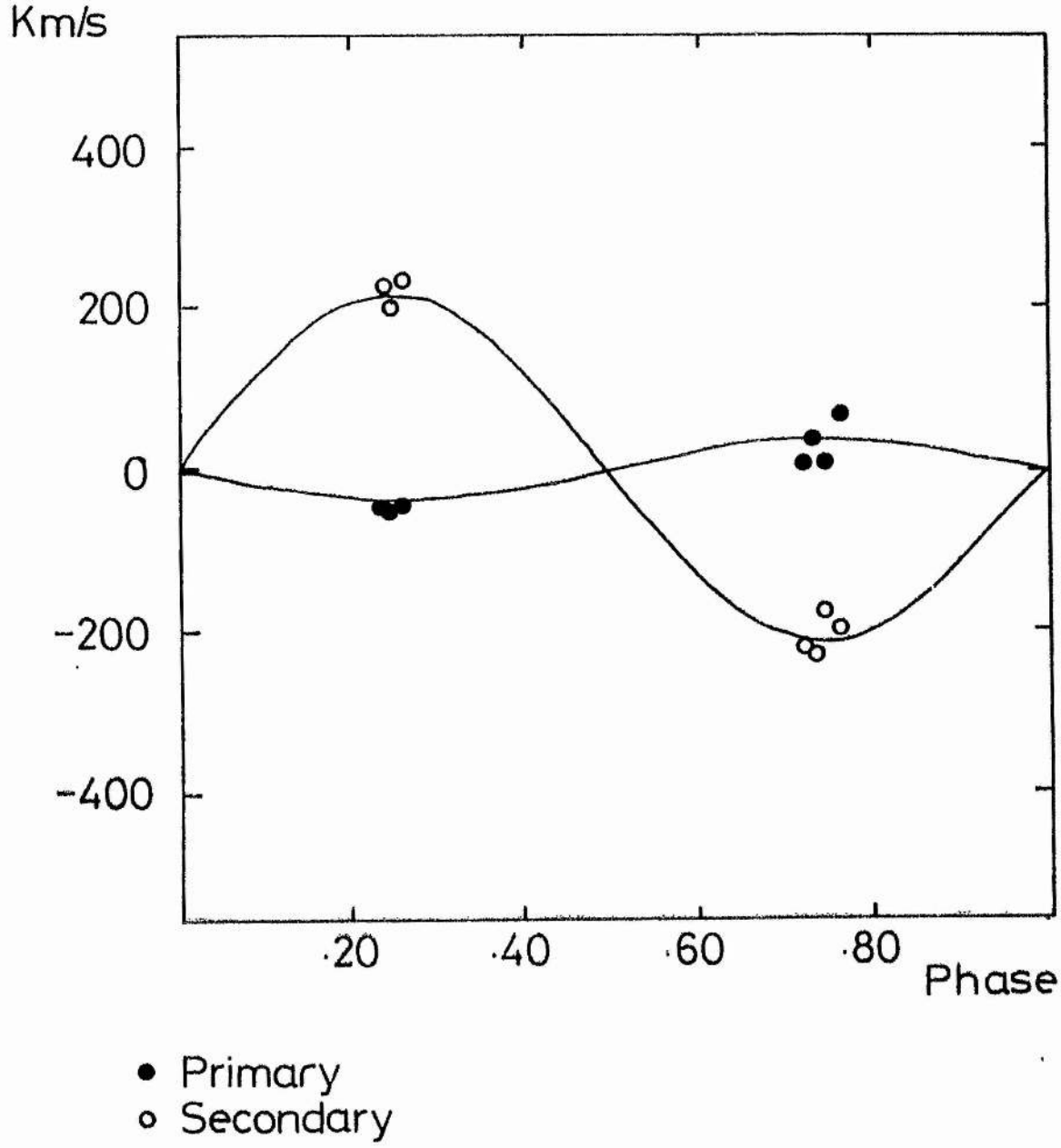
Plate no.	Hel.M.J.D. 44300.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
86115	31.1737	0.73	+ 20	-215
86116	31.1790	0.75	+ 45	-225
86117	31.1838	0.76	+ 22	-170
86118	31.1904	0.77	+ 80	-190
86119	31.1960	0.79	+ 40	-
86120	31.2022	0.80	+ 5	-
86142	31.3873	0.24	- 37	+240
86143	31.3921	0.25	- 40	+215
86144	31.3977	0.27	- 35	+250

Table 31 :- Spectroscopic elements for Y Sex

Element	Unit	Present work
V_o	km/s	+ 9.8 +/- 6 (s.d.)
K_1	km/s	40.0 +/- 8
K_2	km/s	218.0 +/- 31
$a_1 \sin i$	10^6 km	0.23 +/- 0.05
$a_2 \sin i$	10^6 km	1.26 +/- 0.18
$a \sin i$	10^6 km	1.49 +/- 0.19
$M_1 \sin i$	$M_\odot$	0.63 +/- 0.16
$M_2 \sin i$	$M_\odot$	0.11 +/- 0.02
$(M_1 + M_2) \sin i$	$M_\odot$	0.74 +/- 0.16
$q = M_2 / M_1$	-	0.18 +/- 0.03

Fig 23

RADIAL VELOCITY CURVE FOR Y Sex



4.10 VW CEP

This system has been the subject of extensive photometric investigations since the light curve is highly variable. The results of a two-year international campaign has been summarised by Kwee (1966). More recently however, special interest has been attached to VW Cep when Dupree (1978) found high excitation far ultra-violet lines in IUE spectra, while Cruddace (1978) has reported a low level soft X-ray source for which this system is the only 'peculiar' object contained within the position error box. Hershey (1975) has shown that VW Cep is a triple system, with the third component moving in a highly eccentric orbit of period 30 years, so that it is far enough away to have a negligible tidal or thermal influence on the contact components.

Spectra were obtained of VW Cep on the nights of the 19th, 20th and 24th August 1980, and by coincidence, was observed photometrically on the nights of the 19th, 21st, 25th and 26th by Linnell (1981) using the Automated Filter Photometer at Kitt Peak. Interestingly, he noted that the times of the minima varied with the passband of observation and I shall return to this fact later.

The phases were calculated using Linnell's time of primary minimum as observed in the B band (corresponding approximately to the wavelength region observed spectroscopically) and the period given by Hopp et al (1979).

$$MJD_{\odot} = 44470.2785 + 0.27831481.E$$

The motion of the triple system around the common centre of gravity does affect the observed times of minimum of the eclipsing system. The light time correction for the orbital motion has been computed for the time of observation by Linnell using the orbital elements of Hershey. This correction, added to the heliocentric time of observation was -0.01453 days.

Unfortunately, the light of the third component contaminates both the observed light curve and the spectrum of the system making analysis complicated. Crosscorrelation functions of the spectra with a standard star contained a triple peak which were strongly blended together so that radial velocity measurements obtained this way were of uncertain accuracy. In order to try and obtain the radial velocities, simulated comparator measurements were made of the spectra with care being taken to avoid the lines due to the third component.

Table 32 :- Radial velocity measurements for VW Cep

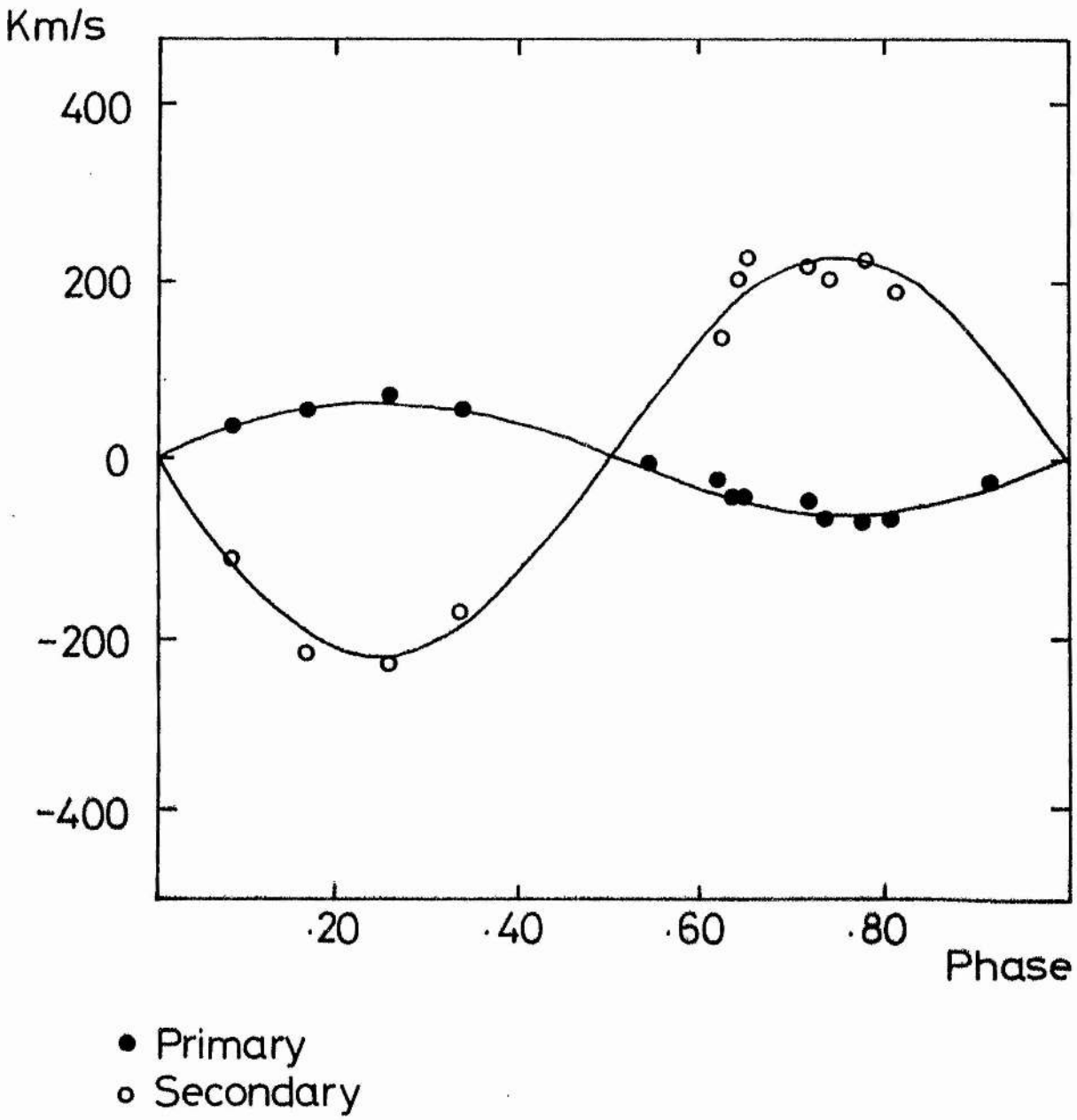
Plate no.	Hel.M.J.D. 44400.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
GA4624	71.0396	0.68	- 26	-
GA4625	71.0654	0.78	- 53	+209
GA4630	71.8521	0.60	- 3	-
GA4631	71.8821	0.70	- 74	+222
GA4632	71.9054	0.79	- 71	+197
GA4633	71.9258	0.81	- 55	+182
GA4634	71.9583	0.98	- 15	-
GA4635	72.0033	0.15	+ 33	-
GA4636	72.0258	0.23	+ 62	-232
GA4637	72.0513	0.32	+ 47	-243
GA4638	72.0742	0.40	+ 53	-181
GA4689	76.0542	0.70	- 62	+198
GA4690	76.0917	0.84	- 54	+219

Table 33 :- Spectroscopic elements for VW Cep

Element	Unit	Binnendijk	Present work
V_o	km/s	+10	-10.3 +/- 6 (s.d.)
K_1	km/s	90 +/- 2	64.0 +/- 8
K_2	km/s	220 +/- 3	238.0 +/- 20
$a_1 \sin i$	10^6 km	0.34	0.25 +/- 0.03
$a_2 \sin i$	10^6 km	0.84	0.92 +/- 0.07
$a \sin i$	10^6 km	1.18	1.17 +/- 0.08
$M_1 \sin i$	$M_\odot$	0.61	0.63 +/- 0.04
$M_2 \sin i$	$M_\odot$	0.25	0.17 +/- 0.07
$(M_1 + M_2)\sin i$	$M_\odot$	0.86	0.80 +/- 0.08
$q = M_2 / M_1$	-	0.41	0.27 +/- 0.03

Fig. 24

RADIAL VELOCITY CURVE FOR VW Cep



The velocities measured are given in Table 32 and figure 24, although it must be stated that the effect of the third component will have distorted the results. The resulting elements are presented in Table 33.

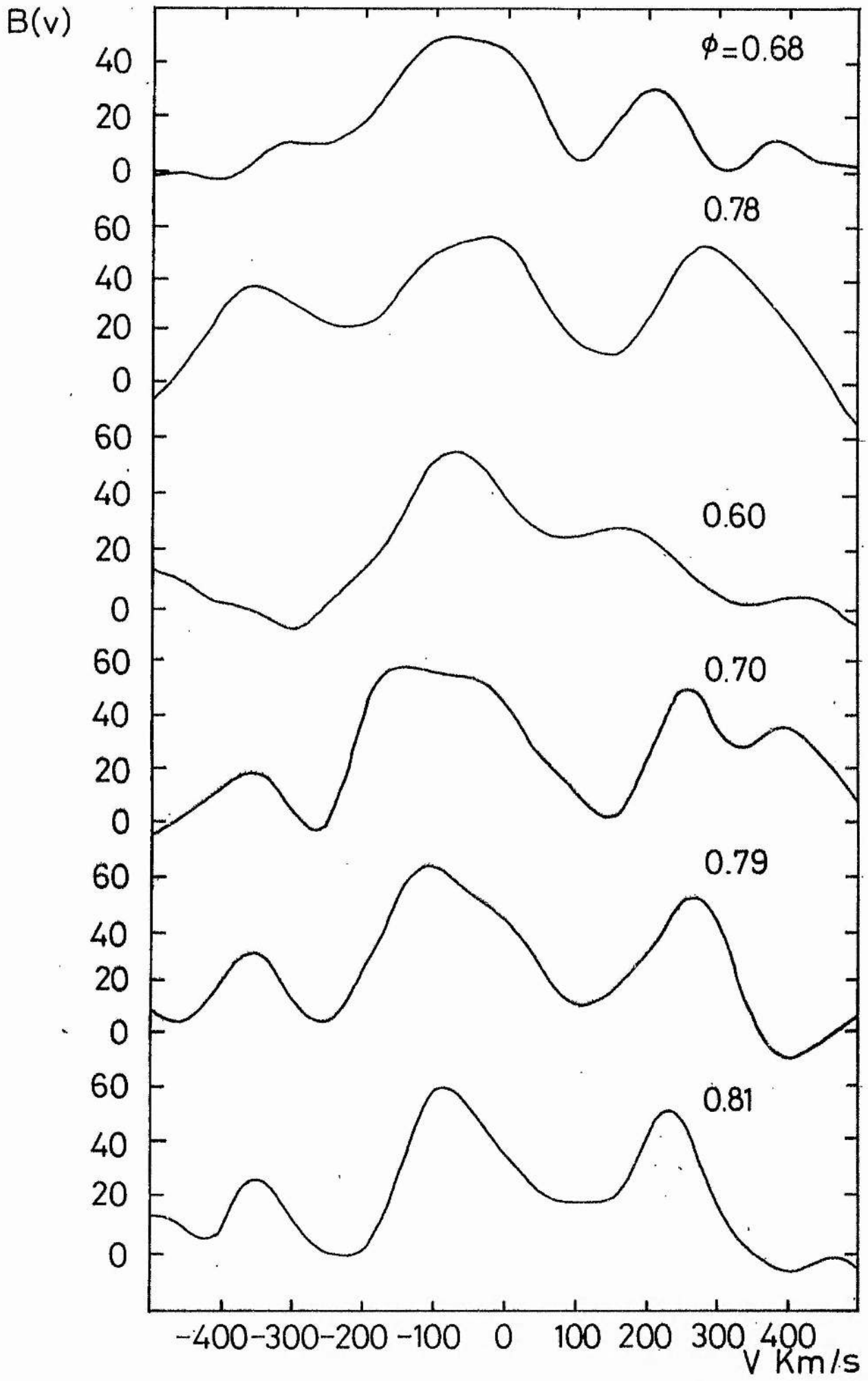
There have been two previous spectroscopic investigations of VW Cep, by Popper in 1948 and Binnendijk in 1967. The usual difficulties in measurement and line blending, possibly aggravated by the presence of the previously unknown third component, resulted in large differences in the elements.

Once again empirical velocity broadening functions were computed from the spectra by deconvolving the standard spectrum (see figure 25). The third component is clearly detected, often distorting the spectrum lines . However, it proved to be easier to measure the velocities of the two main components from these broadening functions so that a more reliable determination of the elements could be made. These velocities are given in Table 34 and fig. 26, while the new set of spectroscopic elements are presented in Table 35. If one compares these to those derived previously, the effect of the third component has obviously been severe.

Figure 25

Empirical Velocity Broadening Functions

for VW Cep


B(v)
φ=0.68
0.78
0.60
0.70
0.79
0.81
40
20
0
60
40
20
0
60
40
20
0
60
40
20
0
60
40
20
0
60
40
20
0
-400 -300 -200 -100 0 100 200 300 400
V Km/s

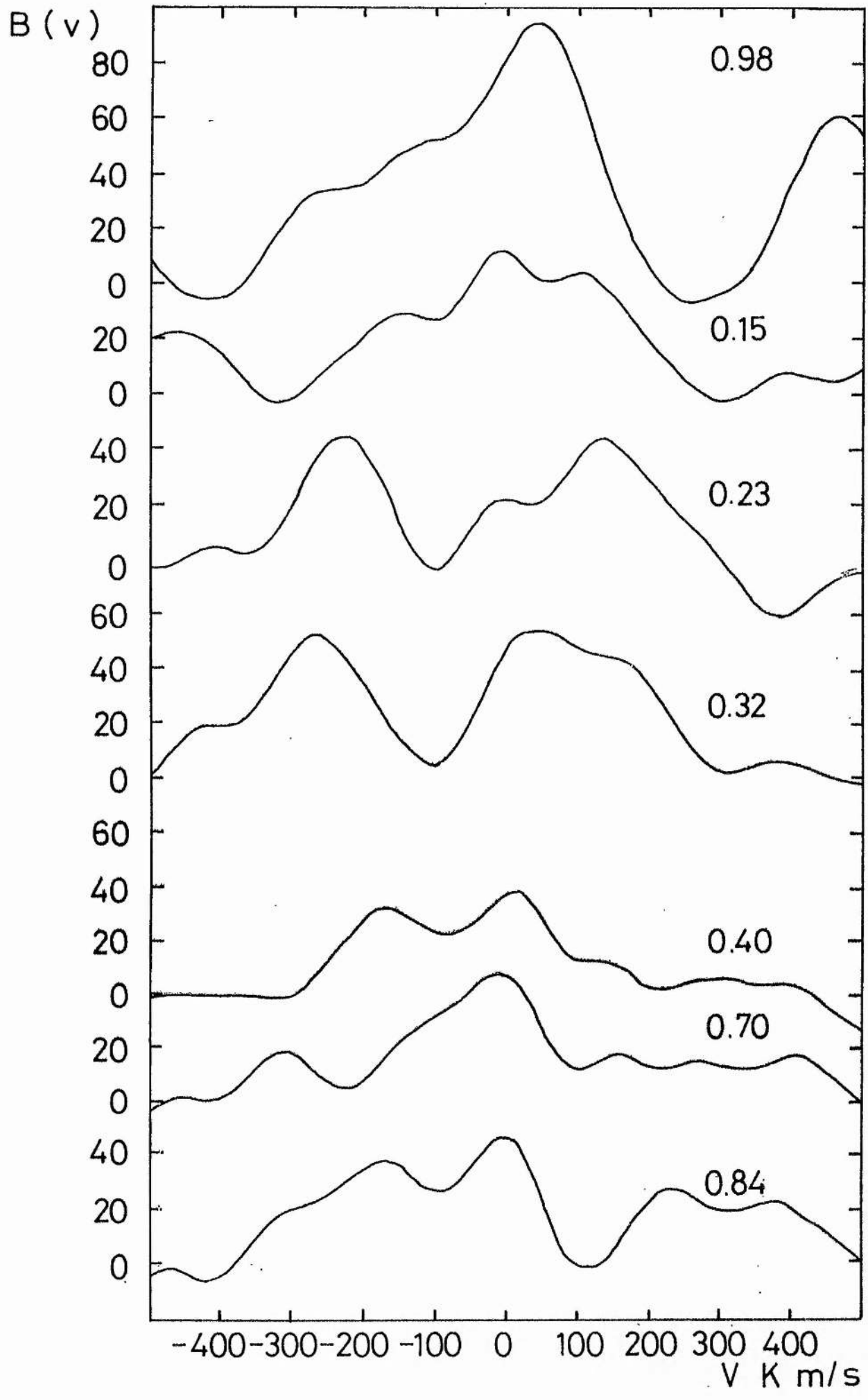

B (v)
80
60
40
20
0
20
0
40
20
0
60
40
20
0
60
40
20
0
40
20
0
20
0
40
20
0
0.98
0.15
0.23
0.32
0.40
0.70
0.84
-400 -300 -200 -100 0 100 200 300 400
V K m/s

Table 34 :- Radial velocity measurements for VW Cep from vbf

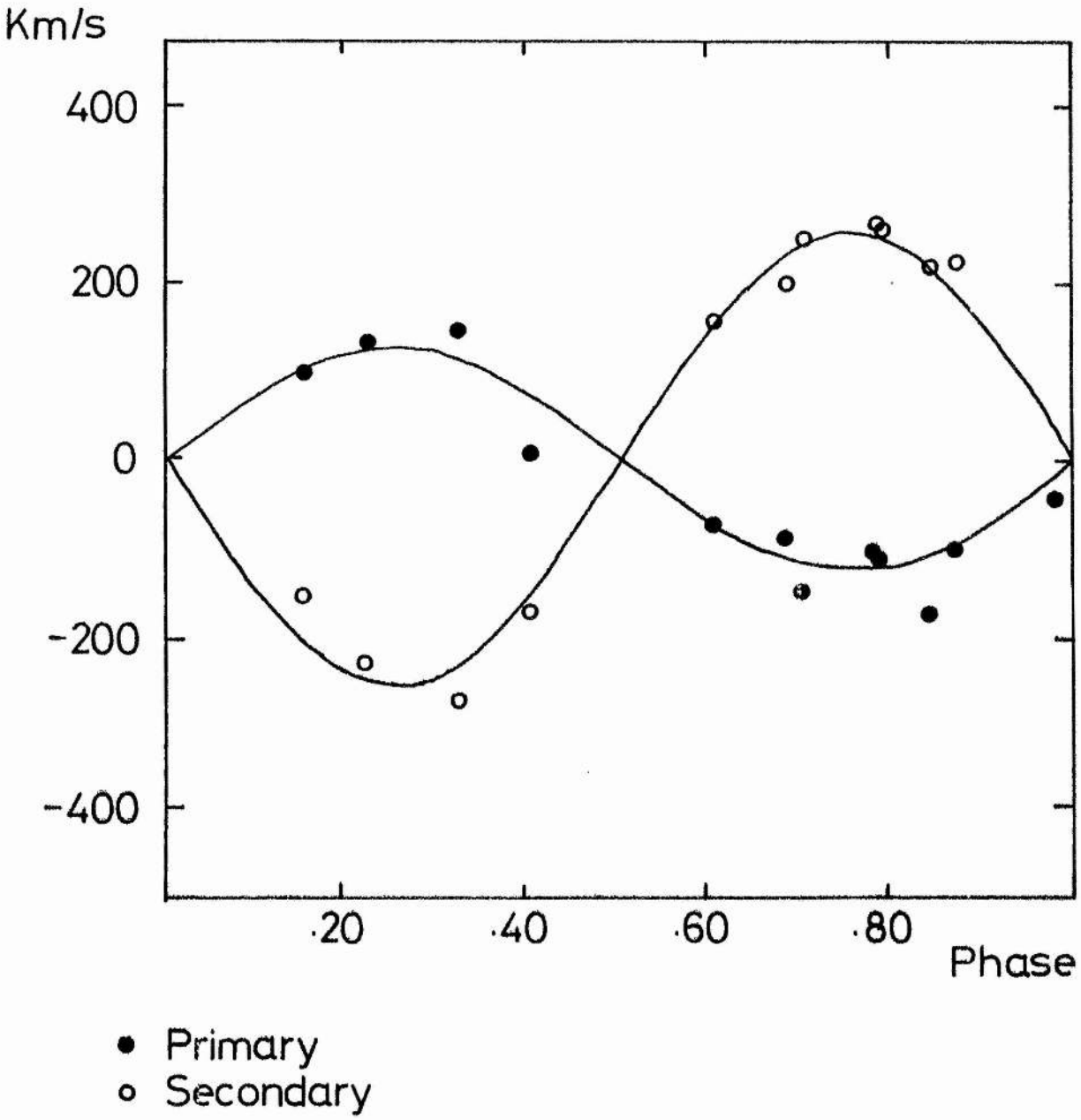
Plate no.	Hel.M.J.D. 44400.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
GA4624	71.0396	0.68	- 82	+207
GA4625	71.0654	0.78	-100	+278
GA4630	71.8521	0.60	- 68	+161
GA4631	71.8821	0.70	-146	+257
GA4632	71.9054	0.79	-107	+268
GA4633	71.9258	0.81	- 93	+232
GA4634	71.9583	0.98	+ 43	-
GA4635	72.0033	0.15	+100	-150
GA4636	72.0258	0.23	+136	-229
GA4637	72.0513	0.32	+150	-271
GA4638	72.0742	0.40	+ 11	-168
GA4689	76.0542	0.70	- 15	-
GA4690	76.0917	0.84	-171	+225

Table 35 :- Spectroscopic elements for VW Cep

Element	Unit	Present work
V_o	km/s	+ 2.7 +/- 9 (s.d.)
K_1	km/s	126.0 +/- 13
K_2	km/s	261.0 +/- 21
$a_1 \sin i$	10^6 km	0.69 +/- 0.04
$a_2 \sin i$	10^6 km	1.44 +/- 0.06
$a \sin i$	10^6 km	2.13 +/- 0.08
$M_1 \sin i$	$M_\odot$	1.62 +/- 0.14
$M_2 \sin i$	$M_\odot$	0.78 +/- 0.07
$(M_1 + M_2) \sin i$	$M_\odot$	2.40 +/- 0.15
$q = M_2 / M_1$	-	0.48 +/- 0.06

Fig 26

RADIAL VELOCITY CURVE FOR VW Cep



The heights of the broadening functions were found to vary in a similar manner to those of W UMa in that the primary lines were weaker at 1st quadrature than at 2nd quadrature, while the secondary lines remained fairly constant although there is a large scatter in the measurements (see Table 36 and figure 27). These measurements were used to derive estimates of the mass ratio and degree of contact.

	1st quad.	2nd quad.
P/S	1.15 +/- 0.32	1.37 +/- 0.38
N/S	0.01 +/- 0.06	0.17 +/- 0.06
q	0.80 +/- 0.30	0.50 +/- 0.10
F	-0.10 +/- 0.30	0.30 +/- 0.20

It is important to note here that these values of q and f were derived using full limb darkening and radiative gravity darkening law (i.e. β =0.25) as this was the only way of obtaining a fit to the very low value of N/S.

As in the case of W UMa, the system parameters derived from the observations at second quadrature seem to agree with those obtained by other methods, while those from 1st quadrature appear to be anomalous.

Table 36 :- Strength of vbf features for VW Cep

Pl.no.	Phase	Prim.	Sec.	Neck
GA4624	0.68	50	30	5
GA4625	0.78	53	50	10
GA4630	0.60	56	28	24
GA4631	0.70	58	50	4
GA4632	0.79	63	53	12
GA4633	0.87	60	52	18
GA4634	0.98	93	-	-
GA4635	0.15	44	28	-
GA4636	0.23	44	45	-3
GA4637	0.32	45	53	5
GA4638	0.40	40	33	23
GA4689	0.70	48	-	-
GA4690	0.84	38	28	-

Table 37 :- Variation of vbf parameters for VW Cep

Pl.no.	Phase	P/S	N/S	P+S
GA4624	0.68	1.67	0.17	80
GA4625	0.78	1.06	0.20	103
GA4630	0.60	2.00	0.86	84
GA4631	0.70	1.16	0.08	108
GA4632	0.79	1.19	0.23	116
GA4633	0.87	1.15	0.35	112
GA4634	0.98	-	-	93
GA4635	0.15	1.57	-	72
GA4636	0.23	0.98	-0.07	91
GA4637	0.32	0.85	0.09	98
GA4638	0.40	1.21	0.70	73
GA4689	0.70	-	-	-
GA4690	0.84	1.36	-	66

Figure 27

Measurements of the Broadening Functions

for VW Cep

(a) Central height of Primary component

(b) Central height of Secondary component

(c) Central height of Neck of system

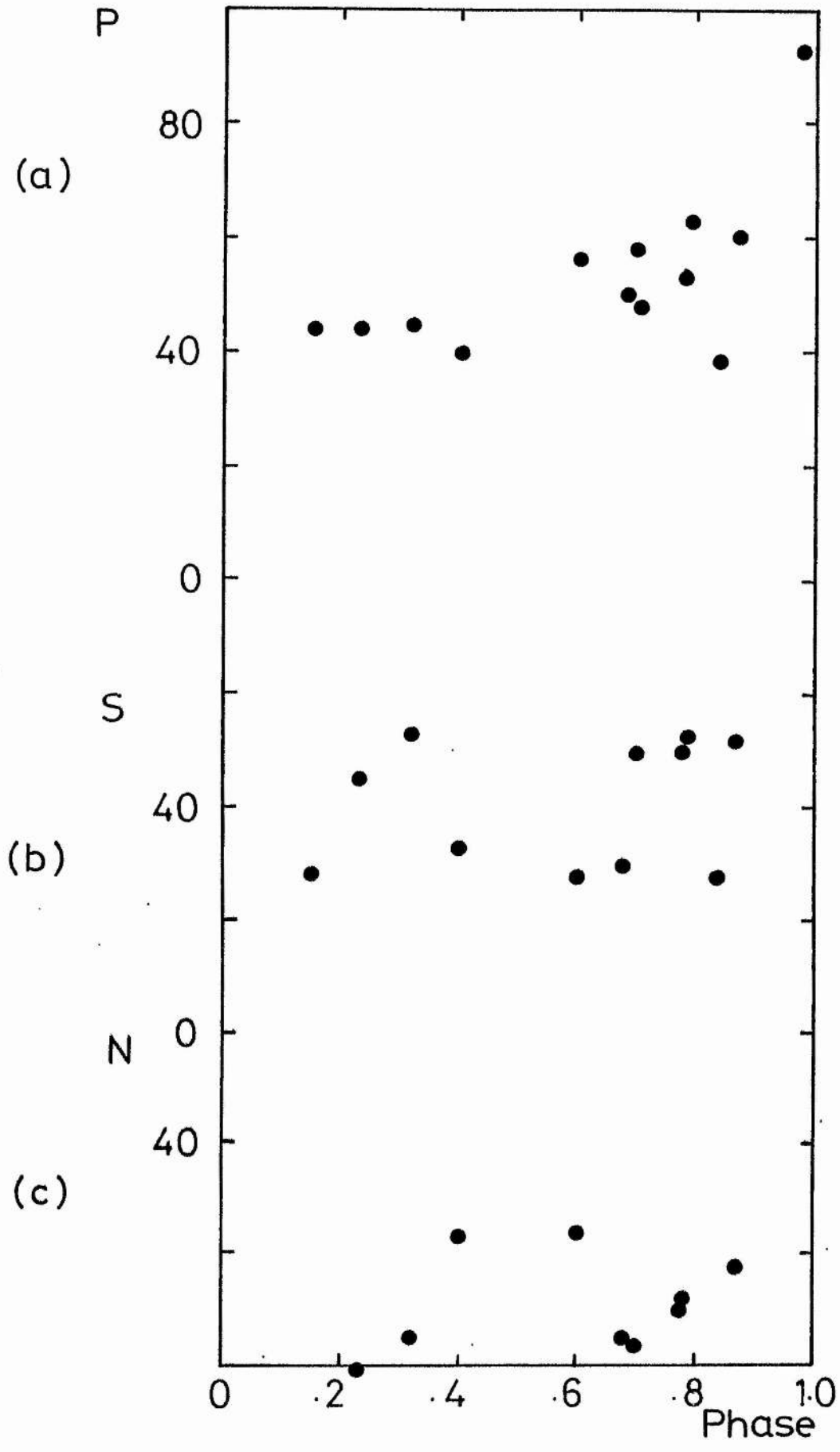

P
80
(a)
40
0
S
40
(b)
N
0
40
(c)
0
.2
.4
.6
.8
1.0
Phase

Figure 28

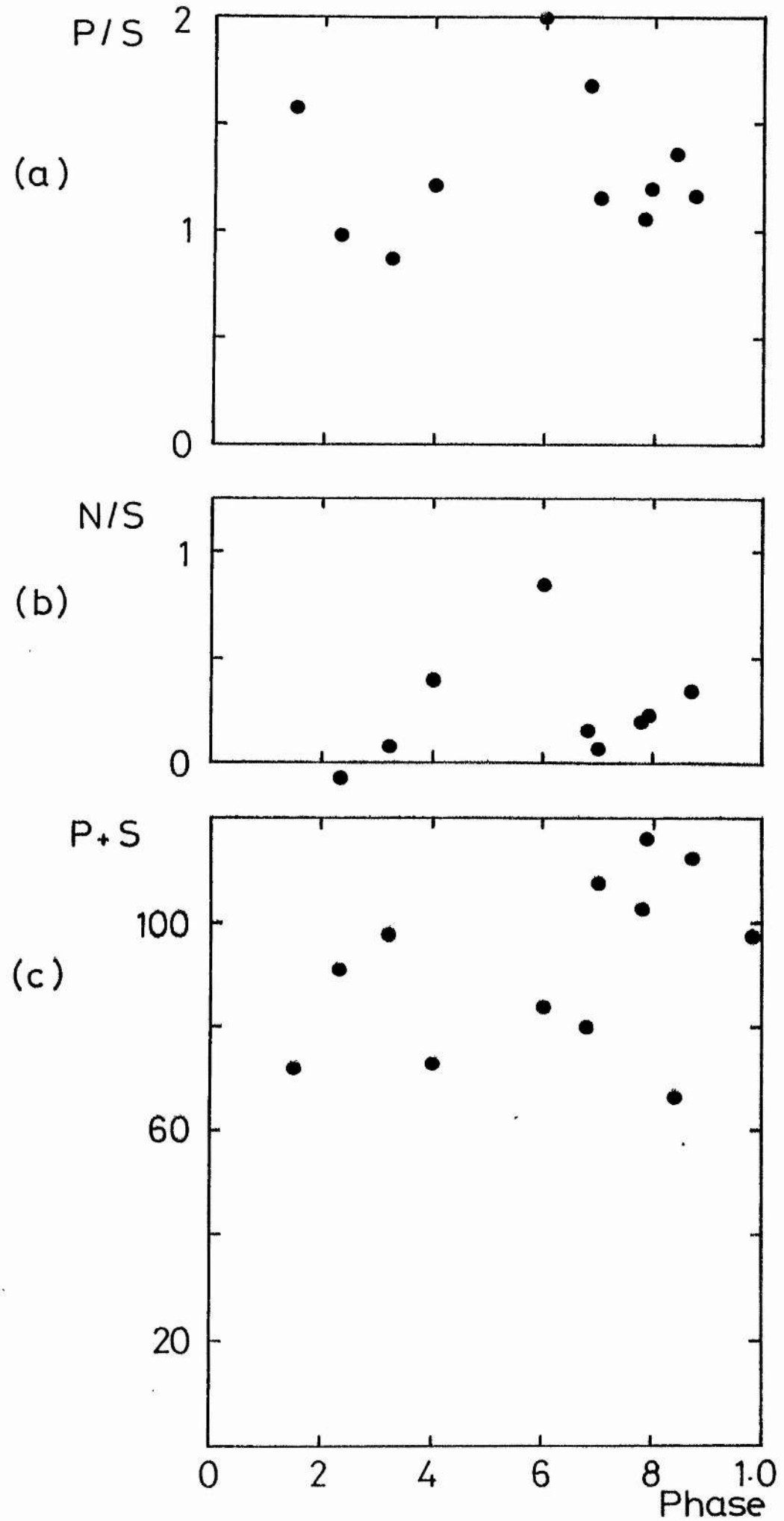
Analysis of Broadening Functions

for VW Cep

(a) Ratio of Primary to Secondary P/S

(b) Ratio of Neck to Secondary N/S

(c) Sum of observed strengths P+S


P/S
2
(a)
1
0
N/S
1
(b)
0
P+S
100
(c)
60
20
0
2
4
6
8
1·0
Phase

A temperature of 5500°K was adopted for the system from the observed spectral type. A mass ratio of 0.5 would give the relative radii of the components to be $r_p/r_s = 1.32$ so that under the uniform profile assumption the relative temperature of the components could be derived.

	1st quad.	2nd quad.
T_p / T_s	0.96 +/- 0.06	1.01 +/- 0..06
$T_s - T_p$	200 +/- 300	-50 +/- 300
$\Delta T / T_p$	0.04 +/- 0.06	-0.01 +/- 0.06

The temperature excess found at 1st quadrature is again typical of that derived from photometric analyses of W-type systems, while the apparent equality of the temperatures at 2nd quadratures is also striking, despite the large errors involved.

A direct comparison of the temperatures, fill-out factor and gravity darkening values obtained with previous photometric results is not possible since the mass ratio was not accurately known. For this reason, a published light curve was reanalysed using Rucinski's synthesis code with the mass ratio fixed at the new spectroscopic value.

It should be noted that this system has a highly variable light curve so that in the absence of a 'true' light curve it was felt that any set of observations was adequate for this purpose. Ideally, the light curve

obtained by Linnell (1981) should be employed, this being the most likely to relate to the observed spectral changes, however, it was not available at the time of writing. The observations adopted were those for the V band presented by Kwee (1966), and once again the two halves of the light curve were solved separately. Prior to the analysis, the light from the 3rd component ($\Delta m = 2.9$: Heintz 1975) was removed from the observations.

The mass ratio was fixed at the spectroscopic value of 0.48, while the fill-out factor was taken to be 0.80, the mean value derived from the velocity broadening functions. Orbital inclination was taken to be 65° from the analysis by Cristescu et al (1979). A reference temperature of 5500°K was adopted from the (b-y) colour (Rucinski and Kaluzny 1981) using the calibration with effective temperature given by Popper (1980), and no temperature excess of the secondary was assumed. Initially, the gravity darkening was set to $\beta=0$, and the albedo was again fixed at A=0.5 following Rucinski (1969). The final results after several iterations are given in Table 38.

Table 38 :- Light curve synthesis results for VW Cep

Initial Values :-

q	= 0.48	T	= 5500°K
f	= 0.80	X	= 0.00
i	= 65°.0	β	= 0.00
		A	= 0.5

Solution for phases 0.0 to 0.5 :-

Free parameters	f	i	β	X	$\Sigma(o-c)^2$
f i β X	0.92	71.9	0.43	0.045	2.95 e-3
	0.04	0.4	0.05	0.007	
i β X	0.80	72.1	0.28	0.040	3.71 e-3
		0.4	0.02	0.008	
f i β	0.92	72.0	0.42	0.040	2.99 e-3
	0.03	0.3	0.05		
f i X	0.80	72.5	0.05	0.036	3.83 e-3
	0.02	0.3		0.007	
i β	0.80	72.1	0.28	0.040	3.72 e-3
		0.3	0.02		
i X	0.80	72.5	0.05	0.036	3.83 e-3
		0.2		0.007	

Solution for phases 0.5 to 0.0 :-

Free parameters	f	i	β	X	$\Sigma(o-c)^2$
f i β X	0.83	72.4	0.32	0.138	4.76 e-3
	0.04	0.4	0.07	0.013	
i β X	0.80	72.4	0.28	0.135	4.80 e-3
		0.4	0.03	0.012	
f i β	0.80	72.7	0.27	0.120	4.97 e-3
	0.04	0.3	0.06		
f i X	0.79	72.6	0.05	0.131	4.87 e-3
	0.02	0.4		0.011	
i β	0.80	72.7	0.26	0.120	4.97 e-3
		0.3	0.02		
i X	0.80	72.8	0.05	0.129	4.91 e-3
		0.2		0.010	

It appears that the asymmetry in the light curves has resulted in a large difference in the derived temperature excess which varied from 135°K to 500°K ! The inclination was once again well defined in all solutions but at a higher value than the previous analyses which assumed a lower mass ratio. It is important to note that the value of the gravity darkening is large, about the radiative value of 0.25 in agreement with that required by the broadening functions. This is surprising since the temperature of the system is fairly low so that convection would be expected to be more important. As in the case of W UMa there is a correlation between the value of the gravity darkening and the fill-out factor. However, the usual trend in these solutions was to increase β and so decrease the degree of contact.

A recent study of the colour changes displayed by VW Cep (Linnell 1980) has established that the two components are in very good thermal equilibrium so that the temperatures of the stars are nearly equal. In many ways the system displays similar properties to W UMa. A weakening of the primary component's lines at the brighter maximum by the amount predicted from photometric temperature excess, while the relative line strengths at 2nd quadrature give nearly equal temperatures under the uniform profile assumption. On the other hand, there are marked differences

such as the larger gravity darkening and the large change in the apparent temperature excess between the two halves of the light curve.

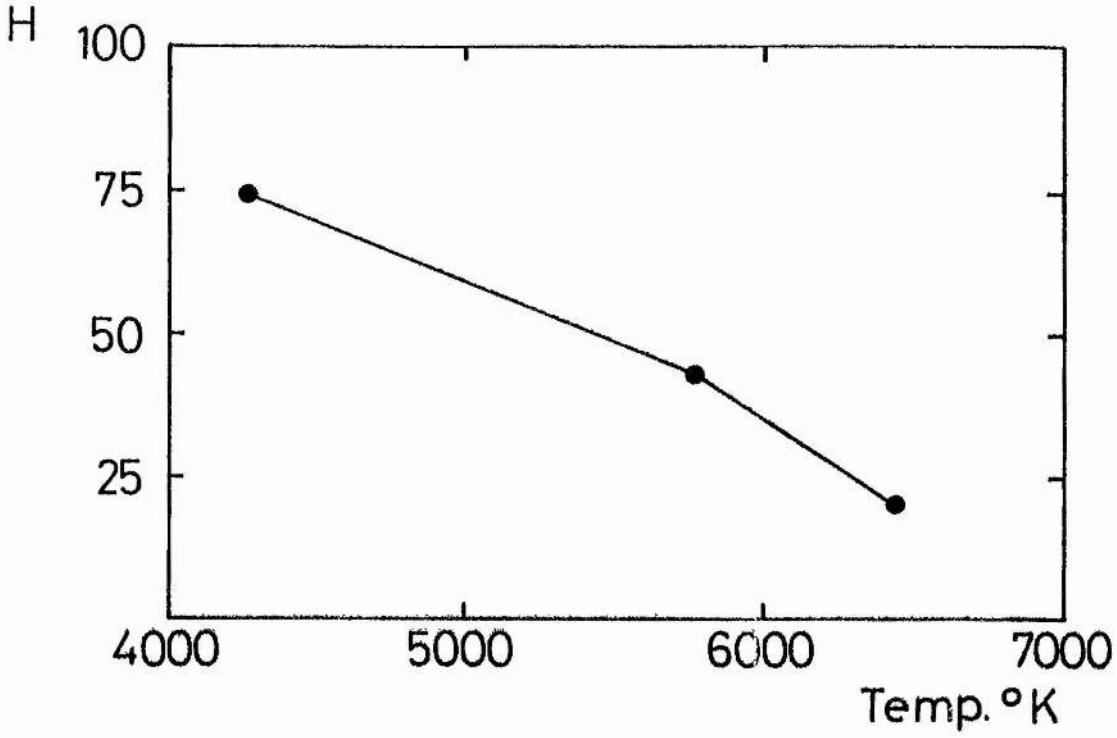
As is typical of many W type systems VW Cep shows a highly variable light curve with the height of both maxima and minima varying. In addition, the minima often appear asymmetric. These effects have been interpreted by van't Veer (1973) as due to hot gas flowing from large optical depths to the envelope in the region of the inner Lagrangian point, with the differing heights of the maxima being due to unequal emission on the two sides of the system. If this view is adopted then the spectroscopic variations could once again be interpreted as a region of higher temperature on the trailing side of the primary (see Table 39 and figure 29). This would however, be in contradiction with the light curve synthesis which established a temperature excess of the secondary.

Table 39 :- Temperature dependence of vbf for standard star

Sp	Temp. °K	H
F5	6455	19
G5	5780	42
K5	4295	71

Fig 29

TEMPERATURE DEPENDENCE OF VBF
USING GI STANDARD SPECTRUM



Let us now consider the starspot model as a possible explanation of the observations. The drop in the primary components flux resulted in a temperature excess of X = 0.04 obtained from both the velocity broadening functions at 1st quadrature and the light curve synthesis of the first half of the light curve. This is similar to what was found for W UMa. A larger drop in the flux was found from the second half of the light curve, while the uniform profile assumption has to break down and the primary components lines must be enhanced by some means.

The required spot sizes and resulting magnitude changes are given in Table 40 for a range of spot temperatures. Obviously, there is a large non-uniformity in the distribution of the spots over the primary components surface. These results imply that the inner hemisphere of the primary is approximately 50% covered in spots, while the other side is only about 20% obscured. It is interesting to note that the effect of such a spot distribution would give the appearance of large gravity darkening as was found. The underlying physical cause of such a distribution can only be speculated at since there is no theory to describe magnetic fields in contact binaries.

Table 40 :- Magnetic Starspots for VW Cep

T = 5500°K X = 0.04

T°K	A	Δm(p)	Δm
2000	0.16	0.19	0.12
2500	0.17	0.20	0.13
3000	0.18	0.21	0.13
3500	0.19	0.21	0.14
4000	0.22	0.22	0.14
4500	0.29	0.23	0.15
5000	0.51	0.23	0.15

T = 5500°K X = 0.12

T°K	A	Δm(p)	Δm
2000	0.49	0.73	0.43
2500	0.50	0.75	0.45
3000	0.53	0.80	0.46
3500	0.57	0.83	0.47
4000	0.67	0.89	0.48
4500	0.87	0.92	0.50

The stronger lines in the primary component's spectrum at 2nd quadrature must occur in a similar manner to that of W UMa but the effect is not quite so large implying a smaller extension of the envelope. Using the relationship between the ratio of line absorption coefficient to opacity and surface gravity, one can calculate that the mean surface gravity must drop from log g = 4.43 (Rucinski and Kaluzny 1981) to log g= 4.20 .

Once again though, the strengthening of the lines has almost exactly offset the drop in the flux due to the spots. Is this another coincidence or is there some relation between the depth of the envelope and the spot activity, or even that the starspot model is incorrect ?

It is, of course, difficult to interpret the light curve and spectrum changes when the observations were not made simultaneously since the possibility exists that one or either of the series of observations has been modified by some activity on the system. For example, Linnell's (1981) photometry indicated a slight colour change which implied a higher source temperature on the side following primary minimum in disagreement with the norm for the system (Linnell 1980). In addition, he noted that the time of minimum depended on the passband of observation. Primary minimum comes first in U followed by B, V, R and I with an

interval of about 60 seconds between U and I. This sequence is reversed for secondary minimum while the time range increases to 150 seconds. Such a phenomenom can be interpreted as being due to an asymmetry in the system which distorts the shape of the minima. This may be either increased emission at 1st quadrature due to higher temperature/mass flow, or in contrast, an excess of starspots on the other side of the primary. Much more combined observations are needed to try and resolve this situation.

4.11 ER VUL

This system was observed on the basis of its classification given in the General Catalogue of Variable Stars which was used to compile a list of systems which could be observed. It is now clear however, that it is a detached system with the characteristic EW light curve being due to the fact that the two components are of nearly equal mass (Al-Naimiy 1981).

Spectroscopic observations of ER Vul were made on the nights of the 21st, 22nd, 23rd and 24th August 1980 with the OHP 152cm coude spectrograph at a dispersion of 20A/mm. Phases were calculated with the elements

$$MJD_{\odot} = 43730.8679 + 0.698082.E$$

taken from the photometry by Al-Naimiy (1978).

The radial velocities were determined by cross-correlating with the spectrum of the standard star HD 204867 (G1). It was immediately obvious that the peaks in the function, and hence the spectral lines, were much narrower than those previously obtained for contact systems, implying a lower rotational velocity. Consequently, the velocities could be measured with a greater degree of accuracy. These measurements and the derived spectroscopic elements are presented in Tables 41 and 42 and fig. 30.

Table 41 :- Radial velocity measurements for ER Vul

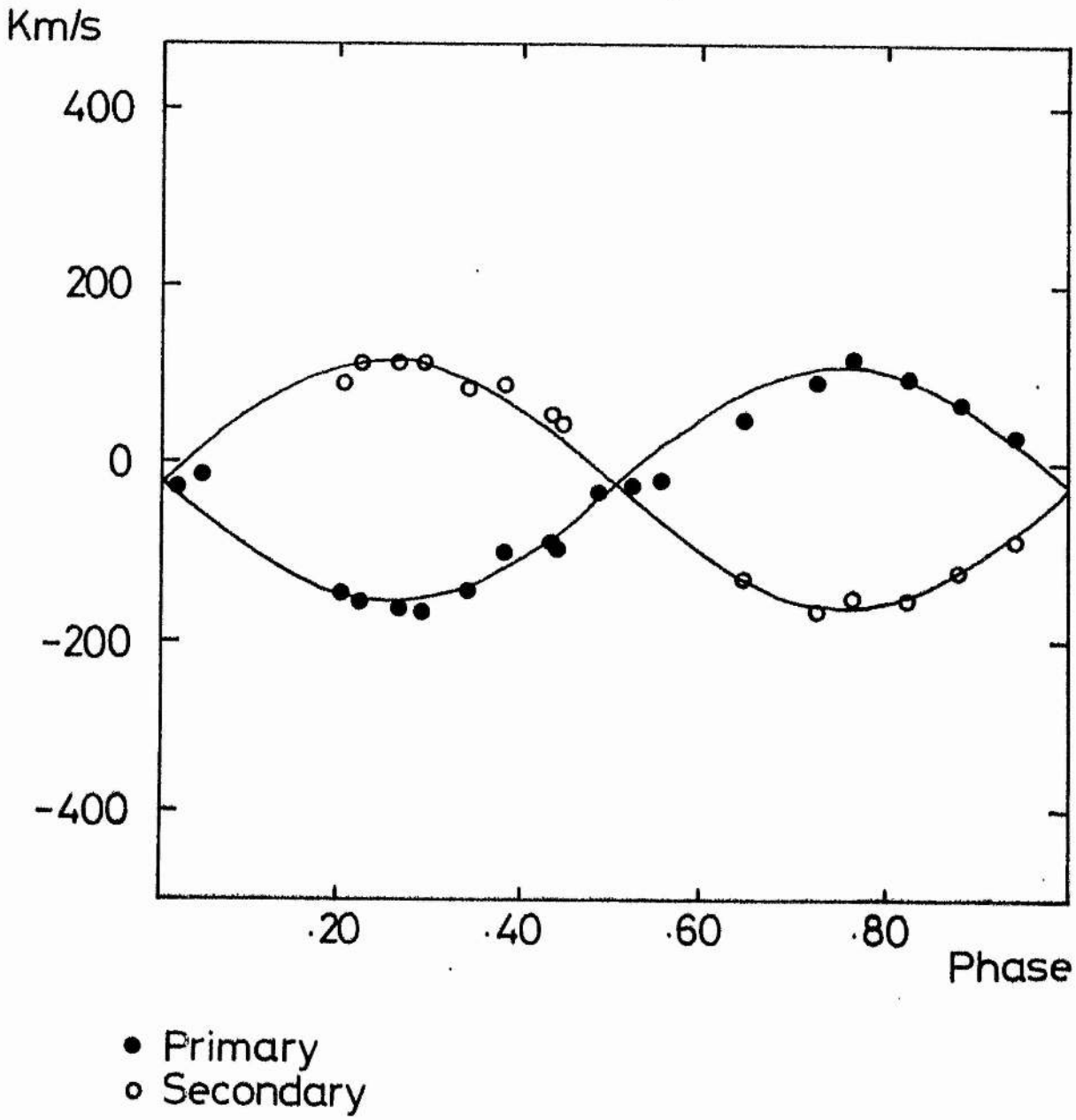
Plate no.	Hel.M.J.D. 44400.0 +	Phase	Primary v (km/s)	Secondary v (km/s)
GA4654	73.0654	0.20	-146	+ 92
GA4655	73.0904	0.23	-156	+115
GA4656	73.1125	0.26	-163	+113
GA4659	73.8304	0.29	-169	+117
GA4660	73.8613	0.34	-147	+ 87
GA4661	73.8929	0.38	-100	+ 92
GA4662	73.9271	0.43	- 86	+ 59
GA4663	73.9592	0.48	- 16	-
GA4664	73.9917	0.52	- 20	-
GA4665	74.0229	0.57	- 22	-
GA4666	74.0500	0.61	+ 72	- 81
GA4667	74.0750	0.64	+ 56	-126
GA4672	74.8300	0.72	+ 99	-164
GA4673	74.8583	0.76	+125	-148
GA4674	74.8992	0.82	+103	-152
GA4675	74.9408	0.88	+ 75	-117
GA4676	74.9813	0.94	+ 38	- 81
GA4677	75.0250	0.00	- 26	-
GA4678	75.0613	0.05	- 14	-
GA4688	76.0292	0.44	- 96	+ 49

Table 42 :- Spectroscopic elements for ER Vul

Element	Unit	Northcott & Bakos	Present work
V_o	km/s	-25.2 +/- 0.8	-22.9 +/- 3 (s.d.)
K_1	km/s	138.5 +/- 1.4	136.0 +/- 4
K_2	km/s	149.3 +/- 1.4	139.0 +/- 2
$a_1 \sin i$	10^6 km	1.33	1.31 +/- 0.04
$a_2 \sin i$	10^6 km	1.43	1.34 +/- 0.03
$a \sin i$	10^6 km	2.76	2.65 +/- 0.05
$M_1 \sin i$	$M_\odot$	0.89	0.76 +/- 0.03
$M_2 \sin i$	$M_\odot$	0.83	0.75 +/- 0.04
$(M_1 + M_2)\sin i$	$M_\odot$	1.08	1.51 +/- 0.05
$q = M_2 / M_1$	-	0.93 +/- 0.02	0.98 +/- 0.05

Fig. 30

RADIAL VELOCITY CURVE FOR ER Vul



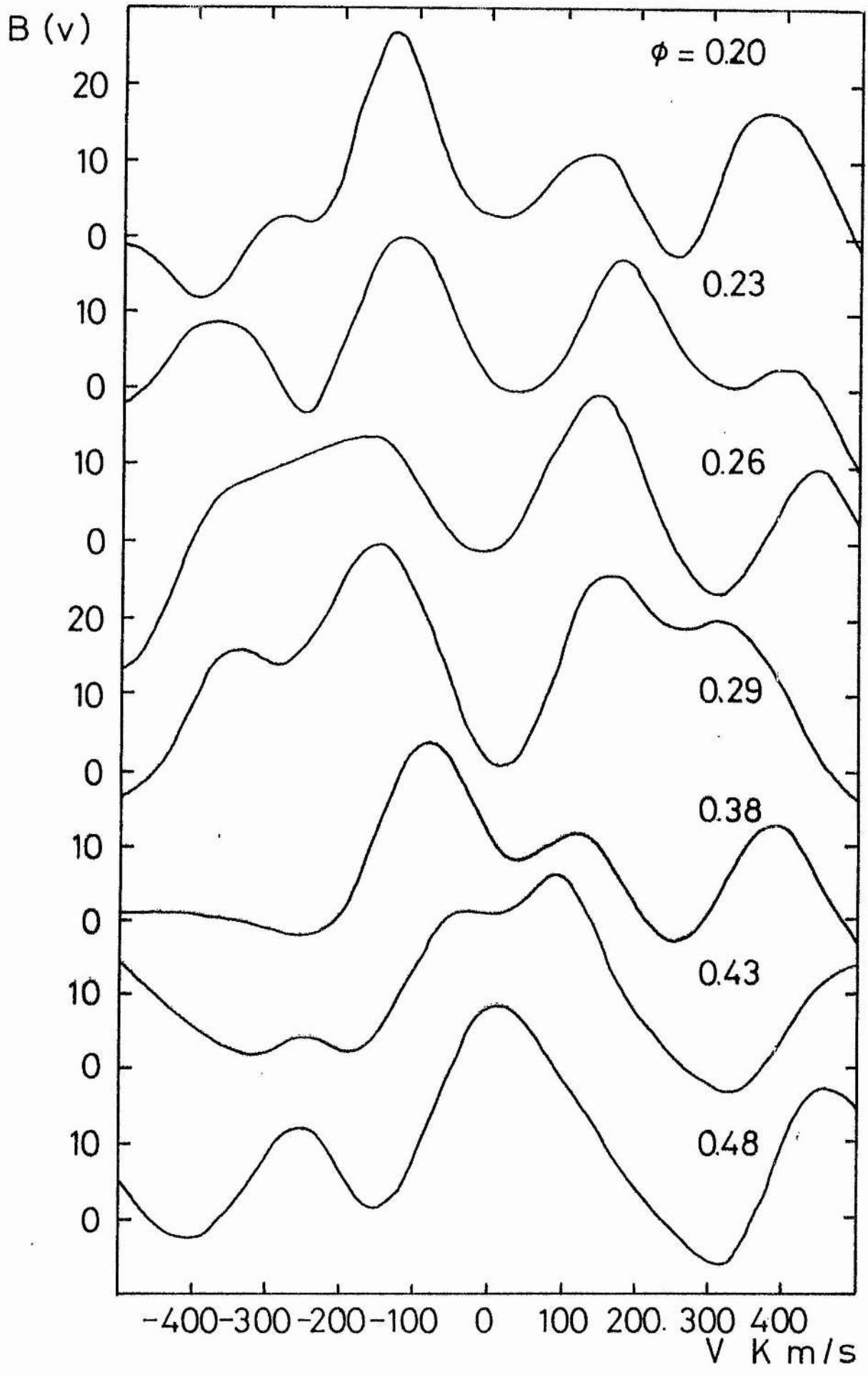
Empirical velocity broadening functions were also computed (see figure 31), initially to compare a contact with a detached system. However, it soon became clear that there were variations in this system also. This is perhaps not so surprising when one considers the fact that there is intrinsic variability which distorts the light curve, and variations in the sharpness of the spectral lines has been reported (Northcott and Bakos 1956,1957).

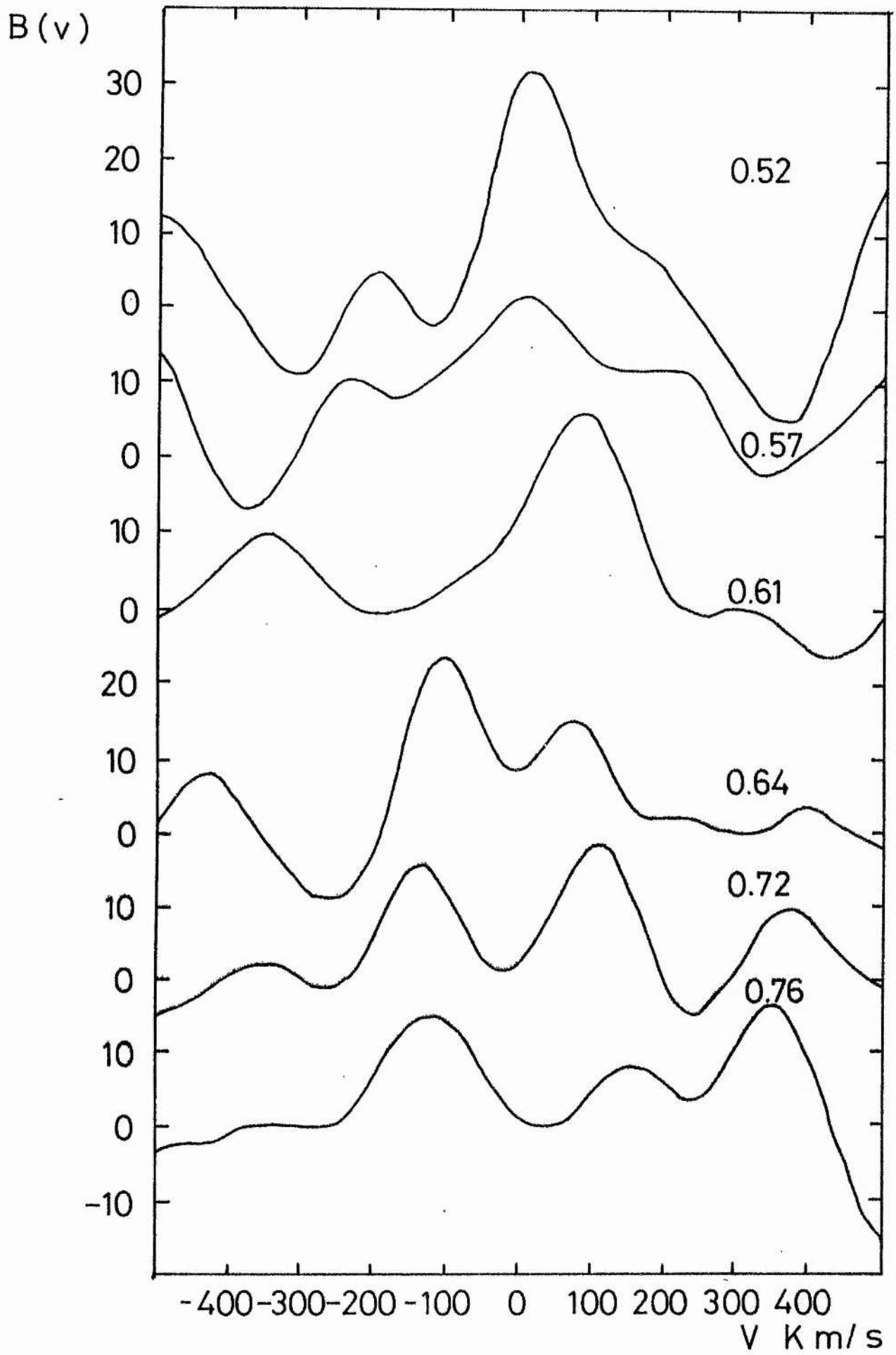
Measurements of the functions (Table 43) show that while the strength of the secondary lines remains fairly constant, the primary was weaker at 2nd quadrature relative to 1st quadrature. The light curves of the system (Northcott and Bakos 1956,1967) show that the maximum following secondary minimum is lower corresponding with the decrease in the strength of the primary components lines. This is in contrast to the contact systems where the increased maximum occurs when the primary components lines are weaker.

Figure 31

Empirical Velocity Broadening Functions

for ER Vul


B (v)
φ = 0.20
0.23
0.26
0.29
0.38
0.43
0.48
20
10
0
-400 -300 -200 -100 0 100 200 300 400
V K m/s


B (v)
30
20
10
0
10
0
10
0
20
10
0
10
0
10
0
-10
0.52
0.57
0.61
0.64
0.72
0.76
-400 -300 -200 -100 0 100 200 300 400
V K m/s

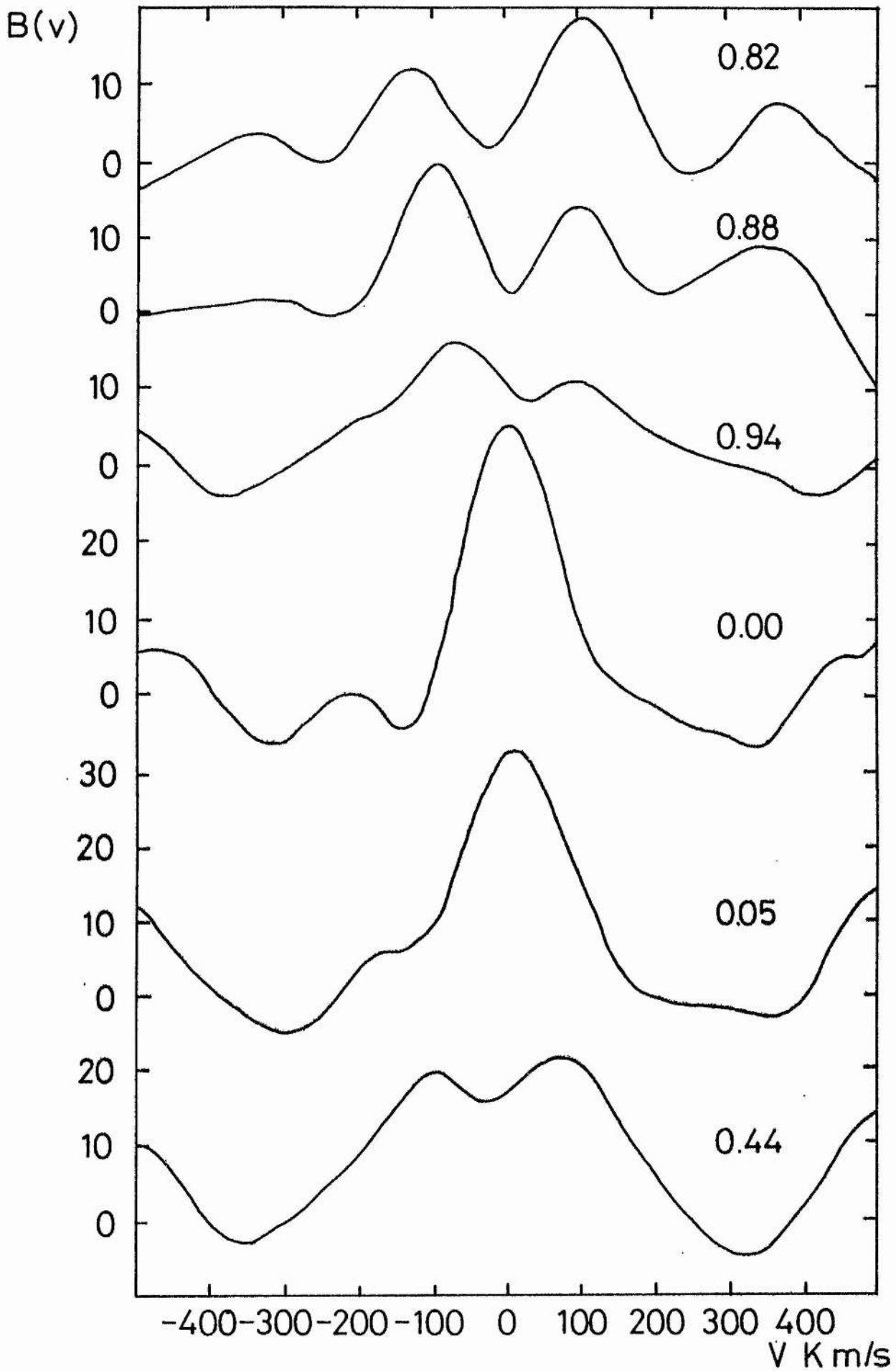

B(v)
0.82
0.88
0.94
0.00
0.05
0.44
10
0
10
0
10
0
20
10
0
30
20
10
0
20
10
0
-400 -300 -200 -100 0 100 200 300 400
V K m/s

Table 43 :- Strength of vbf features for ER Vul

Pl.no.	Phase	Prim.	Sec.	Neck
GA4654	0.20	27	12	3
GA4655	0.23	20	17	-1
GA4656	0.26	15	20	1
GA4659	0.81	30	26	1
GA4660	0.34	29	17	-1
GA4661	0.38	24	12	8
GA4662	0.43	21	26	-
GA4663	0.48	29	-	-
GA4664	0.52	32	-	-
GA4665	0.57	22	-	-
GA4666	0.61	26	-	-
GA4667	0.64	15	24	8
GA4672	0.72	18	15	1
GA4673	0.76	8	15	0
GA4674	0.82	19	12	2
GA4675	0.88	14	20	3
GA4676	0.94	11	17	9
GA4677	0.00	36	-	-
GA4678	0.05	33	-	-
GA4688	0.44	20	22	17

Figure 32

Measurements of Broadening Functions

for ER Vul

(a) Central height of Primary component

(b) Central height of Secondary component

(c) Central height of Neck of system

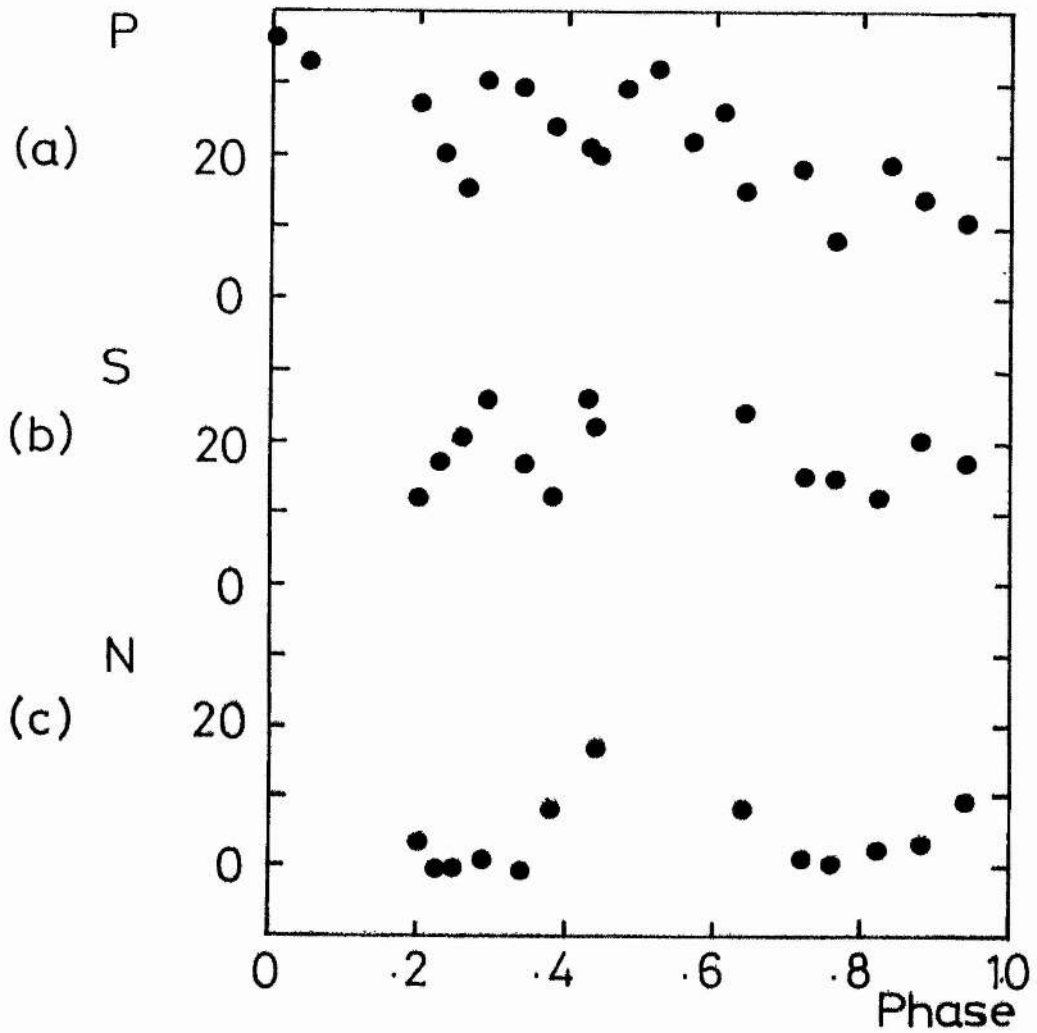

P
(a)
20
0
S
(b)
20
0
N
(c)
20
0
0
·2
·4
·6
·8
1·0
Phase

Table 44 :- vbf parameters for ER Vul

Pl.no.	Phase	P/S	N/S	P+S
GA4654	0.20	2.25	0.25	39
GA4655	0.23	1.18	-0.06	37
GA4656	0.26	0.75	-0.05	35
GA4659	0.29	1.15	0.04	56
GA4660	0.34	1.71	-0.06	46
GA4661	0.38	2.00	0.67	36
GA4662	0.43	0.81	-	47
GA4663	0.48	-	-	29
GA4664	0.52	-	-	32
GA4665	0.57	-	-	22
GA4666	0.61	-	-	26
GA4667	0.64	0.63	0.33	39
GA4672	0.72	1.20	0.07	33
GA4673	0.76	0.53	0.00	23
GA4674	0.82	1.58	0.17	31
GA4675	0.88	0.70	0.15	34
GA4676	0.94	0.65	0.53	28
GA4677	0.00	-	-	36
GA4678	0.05	-	-	33
GA4688	0.44	0.91	0.77	42

Figure 33

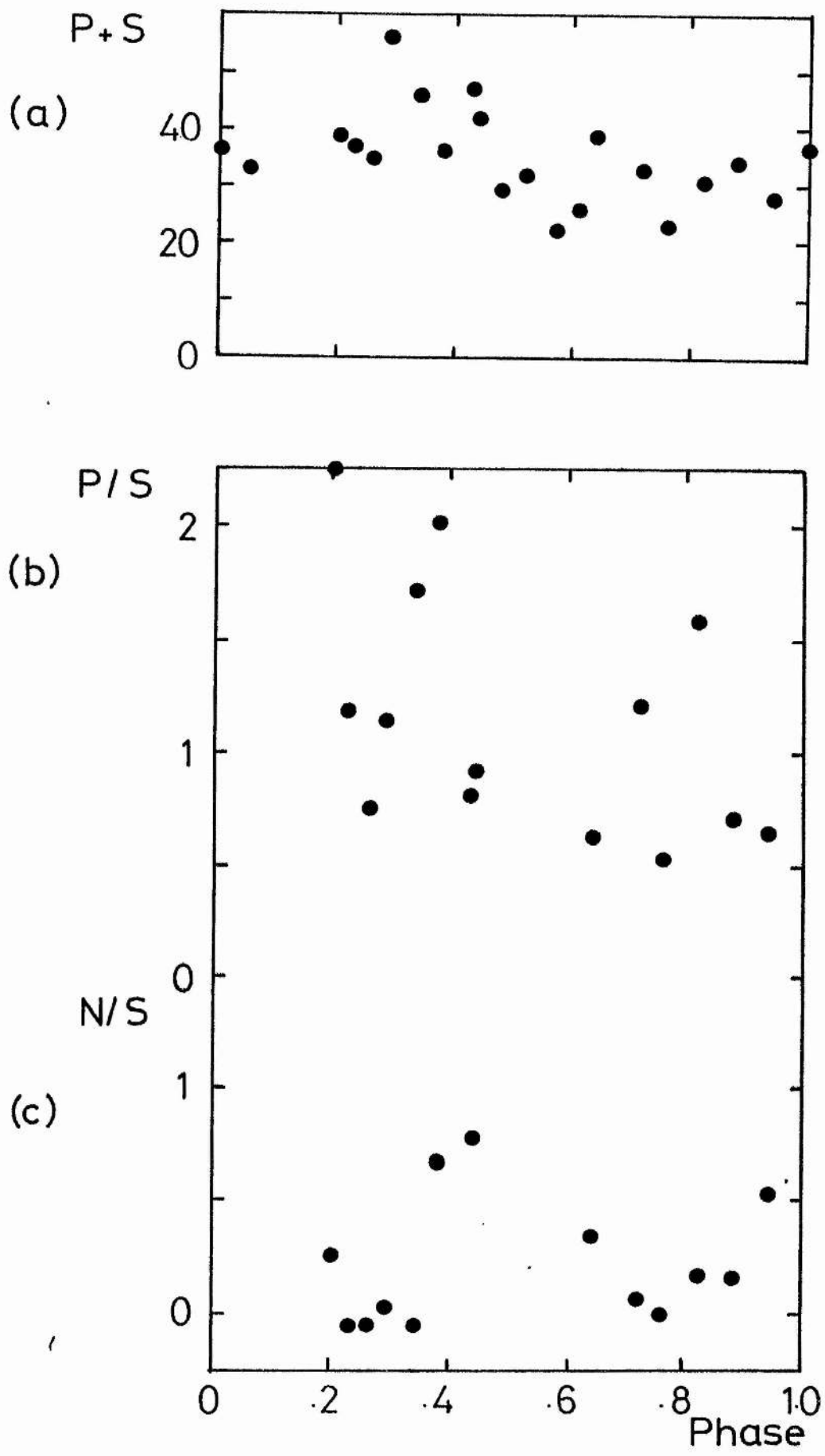
Analysis of Broadening Function

for ER Vul

(a) Sum of observed strengths P+S

(b) Ratio of Primary to Secondary P/S

(c) Ratio of Neck to Secondary N/S


P+S
(a)
40
20
0
P/S
(b)
2
1
0
N/S
(c)
1
0
0
.2
.4
.6
.8
1.0
Phase

Measurements of the broadening functions around the two quadratures gives the following results :-

	1st quad.	2nd quad.
P	24 +/- 6	14 +/- 4
S	17 +/- 5	16 +/- 3
N	0 +/- 2	1 +/- 2
P/S	1.4 +/- 0.5	0.9 +/- 0.3
N/S	0.0 +/- 0.2	0.1 +/- 0.2

Obviously, the atlas of Anderson and Shu cannot be used to estimate the mass ratio and fill-out factor since the system is detached and the components are not in thermal equilibrium. Clearly, the very low value of the ratio N/S supports the view that the components are not in contact.

The temperature of the components derived from their spectral types and photometry are 6000°K for the primary and 5570°K for the secondary. This is a sufficiently large difference for the change in the appearance of the spectrum to change i.e. the uniform profile assumption in invalid.

This star has been listed by Hall (1976) in the table of short period group of RS CVn binaries, and the Ca II H and K lines have been observed in emission by Bond (1970). In addition, this system shows variability in the levels of light outside eclipse and in the depth of secondary minimum. Magnetic starspots which are believed to be characteristic

of RS CVn systems would appear to be the most probable explanation of these features.

Since the height of the velocity broadening function is proportional to the flux which is equivalent to the fourth power of the effective temperature, it can be shown that

$$X = \Delta T / T = (P_1^{-4} - P_2^{-4}) / P_1^{-4}$$

Taking $P_1 = 24$ and $P_2 = 14$, the relative temperature change of the primary if spots are present is $X = 0.126$. If we adopt a temperature of 5900°K derived from the (b-y) colour (Hilditch and Hill 1975), this gives a drop in effective temperature of 740°K due to the presence of spots on the trailing side of the primary. Table 45 shows the relative area of spots and the corresponding magnitude variations for various spot temperatures. The magnitude variation on the combined light was computed using the mass - luminosity relation given by Popper (1980). It is clear that about 50% of this side of this system would have to be spotted and that the expected magnitude variation between the maxima would be about 0.4 magnitudes. Since the observed difference is only about 0.01-0.02 magnitudes this explanation is obviously in error.

Table 45 :- Magnetic starspots for ER Vul

T	A	Δ m(p)	Δ m
2000	0.42	0.61	0.44
2500	0.43	0.61	0.46
3000	0.45	0.63	0.48
3500	0.45	0.63	0.48
4000	0.53	0.63	0.48
4500	0.63	0.58	0.43
5000	0.86	0.43	0.30

Alternatively, there may be a gas stream from secondary to primary so that there is additional material obscuring the trailing side of the primary. This would result in the veiling of this components spectral lines as is typical of such streams (Sahade and Wood 1978). It has been established that the gas in such streams are nearly completely ionised so that Thomson scattering by free electrons will lower the height of the maxima as is observed. A typical gas stream has a density of about 10^{13} particles/cm (Batten 1973) which can produce a drop of 0.1 magnitudes, so that the observed drop can easily be produced with a less dense stream or only part of the disc obscured. It is apparent, therefore, that a gas stream is a more plausible explanation of the variations in this system.

CHAPTER 5

CONCLUSION

5.1 MASS RATIO DISCREPANCY

In this investigation, radial velocity curves for 10 contact systems have been determined which has enabled a measurement of the spectroscopic mass ratio. A comparison of these results with the photometric mass ratios is given in table 46.

Table 46 :- Comparison of q(ph) and q(sp)

Star	Type	q(ph)	q(sp)
XY Boo	A	0.18	0.16 +/- 0.04
V566 Oph	A	0.23	0.24 +/- 0.03
Y Sex	A	0.19	0.18 +/- 0.03
AW UMa	A	0.08	0.07 +/- 0.02
TZ Boo	W	-	0.13 +/- 0.03
CC Com	W	0.52	0.47 +/- 0.04
VW Cep	W	0.53	0.48 +/- 0.06
W UMa	W	0.42	0.52 +/- 0.03
RZ Com	W	0.43	0.43 +/- 0.03
TX Cnc	W	0.57	0.53 +/- 0.06

There is good agreement between the values for all of the A type systems implying that the models of such systems are fairly representative. On the other hand, the results for the W type systems are not in quite such good agreement, probably due to the inadequacy of the models used to interpret the light curves as seen by the analysis of W UMa and VW Cep earlier in this work. It seems most likely that the higher degree of activity in the W type systems, indicated by the asymmetries and variability of the light curves influences the photometric solution to some extent. The lower level of activity for the A type systems does not cause such problems in the analysis.

It is not possible to explain the differences as an effect of eclipse and tidal distortion on the line profiles (Hutchings 1973) since the effect is not significant for the metallic lines which were used in the measurements. Another suggestion is that an absorbing gas stream between the binary star and the observer (van't Veer 1977) would systematically displace the centre of gravity of the line profiles produced by the approaching component to shorter wavelengths. This view is not supported by the velocity broadening functions as they did not show a feature producing any asymmetry in the line profiles.

It is felt, therefore, that the results from this higher dispersion data indicates that it is problems with the photometric model which produces a larger mass ratio error for some of the W type systems. This does not mean that one accepts all previous spectroscopic mass ratios as correct since much of the earlier work still suffers from low dispersion, poor time resolution and the problems of measurement as described previously.

5.2 CONTACT BINARY MODELS

The A type W UMa systems can be successfully explained by the standard model of a contact binary (Rucinski 1978) in that the light curves can be accurately reproduced and the mass ratios obtained from spectroscopic and photometric methods agree reasonably well. On the other hand, the light curves of the W type systems with deeper occultation eclipses cannot be explained without altering the stellar atmosphere parameters such as the temperature difference, gravity darkening, limb darkening or albedo. In addition, it is necessary to explain the intrinsic variability of the light curves and the asymmetries in the systems revealed by the variations in the strength of the primary component's spectral lines.

Recent work tends to support the fact that the two components are, in fact, in thermal equilibrium but that the flux from the primary is reduced by the existence of starspots. Further evidence for such magnetic activity is provided by the UV and X-ray observations which indicate strong chromospheric and coronal activity.

It is clear that in such systems, the stellar atmosphere parameters X, β and A will be affected by the distribution of spots so that in the solution, the geometrical parameters will be distorted to stay within the framework of the model. An example of this was found in VW Cep where there is a non-uniform distribution of spots which mimicked a large gravity darkening leading to a decrease in the degree of contact. In addition, it was found that fixing the mass ratio at the spectroscopic value only affected the inclination significantly and did little to the other parameters. This provides further evidence that one should prefer spectroscopic mass ratios when reasonably accurate data is available.

The variation in the spectrum of the primary component can be most easily explained in terms of a slight extended envelope on the leading side. Is this related to the magnetic activity or mass transfer between components through the envelope ?

The low value of gravity darkening obtained for W UMa is similar to that required by the DSC model. However, there are still severe theoretical criticisms of some of their other assumptions which are required to reproduce the light curves. A recent summary of observational material by Mochnacki (1981) concluded that the B type systems, proposed by Lucy and Wilson (1979) as evidence for the semi-detached phase of the TRO model, were in fact, peculiar evolved systems. It seems more likely that in systems with extensive magnetic activity, that there will be a rapid evolution of the system as angular momentum is lost through a magnetic stellar wind. This would mean that there would be insufficient time for a nuclear evolution from W to A type systems as described by TRO theory.

This scenario of contact binary evolution has been advocated by Vilhu and Rahunen (1980) and van't Veer (1976, 1979, 1981) who has established that almost all contact binaries have nearly equal components at the moment of formation, and that as angular momentum is lost from the system it will transfer mass from the secondary to the primary so evolving towards lower mass ratios. Calculations indicate that the rate of transfer will increase rapidly as the system evolves and that the degree of contact between the components increases. This model not only explains the division between the properties of the W and A type systems,

but also the observed mass ratio function which increases towards lower mass ratios. It is reasonable to suppose that as the degree of contact increases, the difference in the probability of spot formation between the two components will decrease (Mullan 1975) so that spots are less likely to alter the light curve significantly. This would account for the ability for the standard contact binary model to reproduce the A type light curves.

This theory of evolution for W UMa systems implies that they are short lived phenomena probably forming when the two components of a detached system come into contact as a result of angular momentum loss. The final result of their evolution has still to be resolved, the most probable being either coalescence to form a single star or a cataclysmic variable.

5.3 SUGGESTIONS FOR FUTURE WORK

It has become clear during the course of this investigation that it is now possible to obtain more accurate measurements of the spectra of contact binary systems by employing modern equipment and digital reduction techniques. When one considers the lack of accurate spectroscopic data for such systems it is felt that one of the most immediate tasks is to extend this type of

investigation to many more stars. It is a sobering thought when one realises that the 10 systems observed in this study comprise 40% of the W UMa systems with spectroscopic data. The continuation of this survey is therefore desirable in order to determine the properties of these systems more accurately.

In this work, empirical velocity broadening functions have played a major role in the analysis of some systems. Although the use of this technique in the determination of the parameters of these systems as envisaged by Anderson and Shu (1979) is not possible, at least for the W type systems, they do show how the spectral lines vary with phase giving additional information about the stars. The main problem with this type of analysis is that the procedure is inherently noisy.

The cross-correlation technique for measuring radial velocities can be used on nearly all spectra, even if there is poor signal to noise because of its matched filter characteristics so that it is useful in determining the velocity curves of the low mass ratio systems.

In principle, however, the broadening function technique is the superior one since it gives more information and enables a determination of the radial velocity without blending effects present. If one could

obtain spectra with good signal to noise, for example using a large telescope with some digital detector such as a reticon or IPCS, this technique would be extremely valuable.

It is clear from the analysis of W UMa and VW Cep that much theoretical work still remains to be carried out concerning the structure of contact systems. In particular, the effect of magnetic activity should be investigated as this may provide a much better understanding of the W UMa stars.

In conclusion, contact binary stars have the distinction of being members of a very common, yet poorly understood class of object. As such, they are bound to provide many fascinating challenges for Astronomers, both observationally and theoretically for many years to come.

" There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable."

Douglas Adams.

APPENDIX A

REFERENCES

Abrami,A. and Cester,B.
1963 Oss.Astron.Trieste 320

Adams,W.S. and Joy,A.H.
1919 Astrophys.J.49,189

Al-Naimiy,H.M.K.
1978 Astrophys.Sp.Sc.53,181

Al-Naimiy,H.M.K.
1978 Inf.bull.var.stars no.1479

Al-Naimiy,H.M.K.
1981 Astron.Astrophys.supp.43,85

Anderson,L. and Shu,F.
1979 Astrophys.J.supp.40,667

Anderson,L., Raff,M. and Shu,F.
1980 IAU symp.no.88,485

Baranne,A., Mayor,M. and Poncet,J.L.
1979 Vistas in astron.23,279

Batten,A.H.
1973 Binary and Multiple Systems of Stars
(Pergammon Press)

Batten,A.H., Fletcher,J.M. and Mann,P.J.
1978 Pub.dom.astrophys.obs.15,121

Bendat,J.S. and Piersol,A.G.
1971 Random Data : Analysis and measurement
procedures (Wiley)

Bergeat,J., Lunel,M., Sibille,F. and van't Veer
1972 Astron.Astrophys.17,215

Binnendijk,L.
1964 Astron.J.68,22

Binnendijk,L.
1967 Pub.dom.astrophys.obs.13,27

Binnendijk,L.
1969 Astron.J.74,211

Binnendijk,L.
1970 Vistas in astron.12,217

Binnendijk,L.
1977 Vistas in astron.21,359

Blackman,C.P.
1977 Thesis (St.Andrews)

Bond,H.E.
1970 Publ.ast.soc.Pacific 82,321

Bookmyer,B.B.
1976 Publ.ast.soc.Pacific 88,473

Brault,J.W. and White,O.R.
1971 Astron.Astrophys.13,169

Broglia,P.
1960 Cont.Milano-Merate no.165

Bunclark,P.S.
1981 Thesis (in prep.)

Cester,B.
1969 Mem.soc.ast.It.40,489

Cester,B., Fedel,B., Giuricin,G., Mardirossian,F.
Mezzetti,M. and Predolin,F.
1979 Mem.soc.ast.It.50,553

Chang,Y.C.
1948 Astrophys.J.107,101

Cristescu,C., Oprescu,G. and Suran,M.D.
1979 Inf.bull.var.stars 1686

Cruddace,R.G., Freidmann,H., Byram,E.T., Wood,K., (pto)

Meakins,J., Yentis,P., Shore,G.H. and Chubb,T.A.
1980 Astrophys.J.235,L77

Da Costa,G.S., Freemann,K.C., Kalnajs,A.J.,
Rodgers,A.W. and Stapinski,T.E.
1977 Astrophys.J.82,810

Davenhall,A.C.
1981 Thesis (in prep.)

Davenhall,A.C., Bunclark,P.S., Fraser,C.F.,
McLean,B.J., Stapleton,J.R. and Stewart,G.C.
1981 J.Brit.int.soc.34,145

Deupree,R.G.
1979 Astrophys.J.234,228

Dupree,A.K., Black,J.H., Davis,R., Hartmann,L.
and Raymond.J.C.
1979 The First Year of IUE,p217 (Univ.coll.London)

Dworak,T.Z. and Kurpinska,M.
1975 Acta astr.25,417

Eaton,J.A., Chi-Chao,W. and Rucinski,S.M.
1980 Astrophys.J.239,919

Eggen,O.J.
1961 Roy.obs.bull.no.31,101

Eggen,O.J.
1967 Mem.R.ast.soc.70,part 4

Flannery,B.P.
1976 Astrophys.J.205,217

Gray,D.F.
1976 The Observation and Analysis of Stellar
Photospheres (Wiley)

Greville,T.N.E.
1969 Theory and Application of Spline Functions
(Academic press)

Griffin,R.F.
1967 Astrophys.J.148.465

Hall,D.S.
1976 IAU coll.no.29,287

Hazlehurst,J.
1970 Mon.Not.R.ast.soc.149,129

Hazlehurst,J.
1976 IAU symp.no.73,323

Hazlehurst,J. and Refsdal,S.
1978 Astron.Astrophys.62,L9

Heard,J.F.
1965 J.R.ast.soc.Canada 59,258

Heintz,W.D.
1975 IAU inf.circ.vis.doub.stars no.64

Hershey,J.L.
1975 Astron.J.80,662

Hilditch,R.W. and Hill,G.
1975 Mem.R.ast.soc.79,101

Hilditch,R.W.
1980 private comm.

Hilditch,R.W.
1981 Mon.Not.R.ast.soc.196,305

Hill,G. 1979 Publ.Dom.astrophys.obs.15,297

Hoffmann,M.
1978 Astron.Astrophys.supp.33,63

Hoffmann,M.
1980 Astron.Astrophys.supp.40,263

Hopp,U., Witzigmann,S. and Kiehl,M.
1979 Inf.bull.var.stars no.1599

Hutchings,J.B.
1973 Astrophys.J.180,501

Hutchings.J.B. and Hill,G.
1973 Astrophys.J.179,539

Hutchings,J.B. and Hill,G.
1973 Astrophys.J.180,501

Irwin,J.B.
1973 Astrophys.J.179,241

Istomin,L.F., Orlov,L.M. and Kulagin,V.V.
1980 Inf.bull.var.stars no.1802

Kopal,Z.
1959 Close Binary Systems (Wiley)

Kraft,R.P.
1962 Astrophys.J.135,408

Kuiper,G.P.
1941 Astrophys.J.93,133

Kurucz,R.L.
1979 Astrophys.J.supp.40,1

Kwee,K.K.
1966 Bull.ast.Inst.Netherlands supp.1,245

Linnaluoto,S. and Piirola,V.
1979 Astron.Astrophys.supp.36,33

Linnell,A.P.
1980 Publ.ast.soc.Pacific 92,202

Linnell,A.P.
1981 Inf.bull.var.stars no.1967

Lubow,S.H.
1977 Astrophys.J.216,517

Lubow,S.H.
1979 Astrophys.J.229,657

Lucy.L.B.
1968a Astrophys.J.151,1123

Lucy,L.B.
1968b Astrophys.J.153,877

Lucy,L.B.
1973 Astrophys.Sp.Sc.22,381

Lucy,L.B.
1976 Astrophys.J.205,208

Lucy,L.B. and Wilson,R.E.
1979 Astrophys.J.231,502

Mochnacki,S.W.
1972 Bull.Am.asr.soc.4,394

Mochnacki,S.W. and Doughty,N.A.
1972 Mon.Not.R.ast.soc.156,51

Mochnacki,S
1981 Astrophys.J.245,650

Moore,C.H. and Rather,E.D.
1974 Astron.Astrophys.15,529

Moss,D.L. and Whelan,J.A.J.
1970 Mon.Not.R.ast.soc.149,147

Mullan,D.J.
1975 Astrophys.J.198,563

Nagy,T.A.
1974 Thesis (Univ.Pennsylvania)

Nariai,K.
1980 IAU symp.no.88,511

Northcott,R.J. and Bakos,G.A.
1956 Astron.J.61,188

Northcott,R.J. and Bakos,G.A.
1967 Astron.J.72,89

Papaloizou,J. and Pringle,J.E.
1979 Mon.Not.R.ast.soc.189,50

Pearce,J.A.
1955 Trans.IAU no.9,441

Peterson,D.M.
1979 Publ.ast.soc.Pacific 91,546

Petrie,R.M.
1962 Astronomical Techniques ch.23 (Chicago)

Popper,D.M.
1948 Astrophys.J.108,490

Popper,D.M.
1950 Publ.ast.soc.Pacific 62,115

Popper,D.M.
1980 An.rev.astron.astrophys.18,115

Robertson,J.A. and Eggleton,P.P.
1977 Mon.Not.R.ast.soc.179,359

Rucinski.S.M.
1969 Acta astr.19,245

Rucinski,S.M.
1973 Acta astr.23,no.2

Rucinski,S.M.
1974 Acta astr.24,no.2

Rucinski,S.M.
1976a Publ.ast.soc.Pacific 88,244

Rucinski,S.M.
1976b Acta astr.26,227

Rucinski,S.M.
1976c Publ.ast.soc.Pacific 88,777

Rucinski,S.M., Whelan,J.A.J. and Worden,S.P.
1977 Publ.ast.soc.Pacific 89,684

Rucinski,S.M.
1978 Nonstationary Evolution of Close Binaries
p117 (Polish Scientific Publishers)

Rucinski,S.M. and Kaluzny,J.
1981 (preprint)

Rucinski,S.M. et al
1981 (in prep.)

Sahade,J. and Wood,F.B.
1978 Interacting Binary Stars (Pergammon Press)

Sanford,R.F., Moore,J.H. and Pearce,J.A.
1950 Trans.IAU no.7,312

Sanford,R.F. and Pearce,J.A.
1952 Trans.IAU no.8,452

Shapley,H.
1948 Harvard obs.mon.no.7

Shu,F., Lubow,S.H. and Anderson,L.
1976 Astrophys.J.209,536

Shu,F., Lubow,S.H. and Anderson,L.
1979 Astrophys.J.229,223

Shu,F., Lubow,S.H. and Anderson,L. (pto)

1980 submitted to Astrophys.J.

Shu,F. 1980 IAU symp.no.88,477

Simkin,S.M.
1974 Astron.Astrophys.31,129

Skillen,I.
1981 Private comm.

Smith,D.H., Robertson,J.A. and Smith,R.C.
1980 Mon.Not.R.ast.soc.190,177

Smith,S.E. and Bopp,B.W.
1980 Publ.ast.soc.Pacific 91,225

Stewart,G.C.
1981 Thesis (in prep.)

Struve,O. and Gratton,L.
1948 Astrophys.J.108,497

Struve,O.
1950 Stellar Evolution (Princeton Univ.Press)

Struve,O. and Horak,H.G.
1950 Astrophys.J.112,178

Tunca,Z., Tumer,O. and Evren,S.
1979 Inf.bull.var.stars no.1607

Vilhu,O. and Rahunen,T.
1980 IAU symp.no.88,491

Webbink,R.F.
1976 Astrophys.J.209,829

Whelan,J.A.J. and Worden,S.P.
1973 Mon.Not.R.ast.soc.183,133

Wilson,O.C.
1941 Astrophys.J.93,29

Wilson,R.E. and Devinney
1973 Astrphys.J.182,539

Wilson,R.E. and Biermann,P.
1976 Astron.Astrophys.48,349

Wilson,R.E. (pto)

1978 Astrophys.J.224,885

Winkler,L.
1977 Astron.J.82,648

Woodward,E.J., Koch,R.H. and Eisenhardt,P.R.
1980 Astron.J.85,50

Worden,S.P. and Whelan,J.A.J.
1973 Mon.Not.R.asr.soc.163,391

van't Veer,F.
1975 Astron.Astrophys.40,167

van't Veer,F.
1976 IAU symp.no.73,343

van't Veer,F.
1977 IAU coll.no.42,388

van't Veer,F.
1979 Astron.Astrophys.80,287

van't Veer,F.
1981 Astron.Astrophys.98,213

APPENDIX B

S.I.P.S. USER GUIDE

INTRODUCTION

This has been developed to provide a comprehensive, self contained system of processing and analysing digitised spectral data, such as is obtained from modern electronic imaging devices or from scans of spectrographic plates using a microdensitometer e.g Joyce Loebl at St Andrews University Observatory.

The package was developed to run on the Nova 820 using FORTH but has since been implemented on the PDP-11/23, and it is this version that is described in detail.

The package is divided into self-contained units, each of which is used to carry out a particular step in the reduction procedure. These are as follows :-

1) Basic package
2) Plate scanning
3) Wavelength calibration
4) Noise filtering
5) Density-Intensity conversion
6) Normalisation to continuum
7) Spectral line analysis
8) Feature removal
9) Radial velocity measurement
10) Velocity broadening functions
11) Data analysis

Once the basic package has been loaded, each of the reduction stages are accessed by using a single loader word. A more detailed description is given of how to use each section later in this appendix.

BASIC PACKAGE

This is the heart of the system, containing many of the basic definitions that are used in all the sub-sections such as the graphics capabilities, variable names, floating point arithmetic, data areas and the wavelength calibration.

Load command is 2000 LOAD

When one loads the package the computer will respond by asking if the default disc areas are to be used to hold data during the processing procedure. At the present time these are 4900-99 on disc DC10 which is suitable for processing spectra up to 2560 data points long. It is important to note that only one user can use any given work area so it may be neccessary for you to set up another area if someone else is using the package . In response to this question, enter Y or N. In the case where alternative data areas are to be defined, enter the following :-

LENGTH OF SPECTRA IN BLOCKS = enter maximum length of spectra
WORK AREA = disc area where data is to be operated upon

(NOTE: Please ensure that entire work area is contained within your allocated disc blocks, since one requires 20 x N disc blocks where N is the length in blocks of the spectra to be processed).

At this point, the graphics may be used with the normal commands which are documented elsewhere, however a brief summary is given below.

n SPECTRUM :- where n is the disc area of spectrum
lx ux X SIZE :- where lx and ux are the lower and upper limits in the X-direction to be plotted
ly uy Y SIZE :- where ly and uy are the lower and upper limits in the Y-direction to be plotted
SPLOT :- command to plot spectrum

The other main part of the program that is common to the entire package is the wavelength calibration which is required for the radial velocity determination and the spectral line analysis. This is in the form of a polynomial of up to fifth order represented by the following :-

XS=N5(LS)**5+N4(LS)**4+N3(LS)**3+N2(LS)**2+N1(LS)+N0

where N0,N1,N2,N3,N4 and N5 are the polynomial coefficients, and XS and LS are scaled variables of the form

XS= X/1000 and LS=(L-LZERO)*1000

X=position , L=wavelength , LZERO=wavelength offset

The reason for the scaling and wavelength offset is the arithmetic range of the computer, and it is important to ensure that you always use the same value for the offset. By default this is 3700 angstroms, so unless you are working on wavelengths less than this it is not neccessary to alter the value.

The commands which may be used at any time to examine or alter the calibration are listed below :-

CALIBRATE :- enter new coefficients
COEFFICIENTS :- examine current coefficients
SETZERO :- alter value of wavelength offset

At any time when a spectrum has been plotted, the wavelength at any position can be found assuming a calibration has been entered. This is done by entering the command WAVE then positioning the cursor and hitting the space bar. The wavelength will then be computed and displayed.

PLATE SCANNING

This section is an adaptation of the standard Joyce Loebl control package, in order to enable one to scan the spectrum and both of the comparison arcs to obtain a more accurate wavelength calibration. In addition, multiple scans in either X or Y can be performed to scan calibration wedges. This part of the program can only be used by the computer controlling the Joyce loebl CAMAC modules, which at the time of writing is the Honeywell H316. In pratice, this simply means that the package is loaded via the computer link that is documented elsewhere.

Loader command is SCANNING

(N.B. If the package is larger than the amount of dictionary space available in any partition then a reduced version may be loaded by the command 2008 LOAD).

On loading, the computer will ask questions about the parameters of the scan to be performed :-

NO.OF POINTS = no.of data points to be sampled
SAMPLE STEP = distance between data points in microns
(machine steps in multiples of 5 microns)
NO.OF SCANS = no.of parallel scans to be performed
SEPARATION = distance between scans in machine steps
(one step = 5 microns)

If at any time you wish to alter these parameters, this may be done by typing the command PARAMETERS and entering them as before.

The digital data produced is stored by the computer on disc, being held in blocks of 512 points, so it is necessary that the length of each scan is a multiple of 512 to enable ease of reduction in later stages.

Control may be transferred to the Joyce Loebl panel by the command PANEL and the buttons can be used to centre and align the spectrum. If necessary, the `CROSS` button may be used to measure positions on the plate in machine step coordinates. When this is presed, the current position is printed on the terminal. After setting up the microdensitometer mechanically, control is returned to the computer by means of the `BOX` button.

In order to start a scan then enter one of the following commands :-

```
To scan spectrum    :- n PSCAN
To scan wedge in X :- n WXSCAN
To scan wedge in Y :- n WYSCAN
```

where n is the disc area in which scan is to be stored.

The Joyce Loebl will then begin scanning under the control of the computer unless aborted from the control panel or prompted by another terminal.

In the case where a spectrum is scanned, the computer will automatically carry out three scans in the sequence arc/spectrum/arc.

WAVELENGTH CALIBRATION

It is neccessary to obtain a calibration curve for the spectrum in order to calculate wavelengths for each data point. This is achieved by obtaining the position of selected arc lines in both comparison spectra by fitting a least squares parabola to the line profile, taking the mean position for each line and calculating a least squares polynomial in terms of wavelength as described in the section on the Basic Package.

Loader command WAVELENGTH

On loading this section of the package, the computer will present you with a list of options for the comparison spectra, and it is neccessary to enter the code no. required from the list displayed.
These are :-

-N) : < delete catalogue no. N >
0) : < enter new set of lines >
N) : list of comparison lines available

It is possible to display and reselect from this list at any time by the command CATALOGUE

The master catalogue of lines is held in block 2200 on the system disc and although the individual catalogues may be stored anywhere on disc, it is recommended that they are placed between blocks 2201 and 2224 which has been allocated for this purpose.

When one wishes to enter some new lines by typing the code 0 the computer will ask which block they are to go into and whether it is a new catalogue or simply adding lines to a previous catalogue. After replying to this, in the case of a new file a title can be entered. This is done by simply entering up to 15 characters of text at this point. The wavelengths of the comparison lines may then entered in response to the computer.

Once a catalogue has been selected or created it is possible to list, change or delete the individual wavelengths using the following commands:-

LIST-LINES :- prints current list of wavelengths used
DELETE :- asks which line no. is to be deleted
ands moves remaining lines to fill gap
CHANGE :- asks which line no. is to be altered
and asks for new value

Once the comparison lines are selected or entered, it is possible to start measuring their positions for the calibration. Type the command SETARC and enter the following data:-
ARC 1 = disc area of first comparison arc
ARC 2 = disc area of second comparison arc

To display part or all of the arc spectra, use the command lx ux DISPLAY where lx and ux are the lower and upper limits of the plot.

Each arc line is successively accessed by the command NEXTARC (or ALT MODE key) where the wavelength is displayed and then the cursor used to pick off the corresponding line in first the upper and then the lower comparison arc spectrum. This procedure is carried out until all the lines have been measured.

This measurement is done by the computer searching to the right of the cursor position (note:- this means that you place the cursor slightly to the left of each line) until a peak is found in the data. After plotting a cross at this point, a least squares parabola is fitted to the line profile to determine the centre of the line. It is the mean of the positions for each arc line that is taken in the solution.

If any line has been incorrectly measured then it may be removed at the time by the command REJECT and then remeasured with NEXTARC. This can also be used if the line to be measured lies outside the range of the display limits, when one can reject the first measurement, plot the appropriate section and remeasure.

Sometimes a line may be found to be unsuitable for measurement for various reasons e.g. blended or underexposed, in which case the command SKIP will ignore the measurement and move onto the next line in the catalogue.

Once all the lines have been selected type CALIBRATION when the computer will fit a least squares polynomial of up to fifth order with the smallest residuals.

It is possible to remove lines from the fit by typing n EXCLUDE where n is the line no. in the table.

Similarly, lines may be re-entered into the fit by typing n INCLUDE where n is the line no. in the table.

This sequence of including/excluding lines and calibration fits can be continued as many times as neccessary to obtain a satisfactory fit.

At this stage, the calibration coefficients are now set up so that one could continue the analysis on the spectrum without entering the values. However, it is recommended that a note of the coefficients is taken so that it is not neccessary to repeat this procedure if at a later stage the spectrum is to be re-analysed. There is a facility to direct the results to the printer if it is not in use. This is done with the command PRINTOUT . A title of up to 20 characters can be given at this stage, and then the results will be printed for later reference.

NOISE FILTERING

This section is used to filter the high frequency component due to noise from the data using Fourier techniques, and is not always necessary in the case of good quality spectra. The method used is that of an optimum filter , obtained from fitting a Gaussian to the spectrum in the Fourier frequency domain.

Loader command is NOISEFILTER

Once loaded, there is the option of noise filtering an indivual spectrum, or indeed many such spectra provided that they are together on disc, of the same length and are to be filtered to the same degree.

a) Single spectrum

Loader command SINGLE

The computer will then ask for the following data :-

SPECTRUM = disc area where spectrum is stored
NO.POINTS = length of spectrum
THRESHOLD = limiting size of frequency components to be removed
(e.g. Threshold of 5 will smooth features less than 5 data points wide)

If a mistake is made entering this data, or if a value is to be altered then this may be input again by typing the loader command SINGLE again.

The filtering process is started using the command AUTOFILTER

b) Multiple spectra

Loader command MULTIPLE

The computer will then ask for the following data :-

NO.POINTS = length of spectrum
THRESHOLD = limiting size of frequency points to be removed

It is then necessary to specify whether the spectra are stored with their comparison arcs or not. This is done by entering one of the following codes :-

1) Spectra stored successively on disc without arcs
2) Spectra stored successively on disc with intervening arcs.

One then continues to entering the following parameters :-

BLOCK LENGTH = size of spectra in blocks
FIRST SPECTRUM = disc area where first spectrum is stored
LAST SPECTRUM = disc area where last spectrum is stored

If a mistake is made, or a value to be altered, then this may be done by typing the loader command MULTIPLE again and re-entering the parameters.

The filtering process is then started using the command AUTOFILTERING

DENSITY-INTENSITY CONVERSION

This part of the image processing has been split into two sections, each of which corresponds to a distinct part of the procedure. These are as follows :-

a) Measurement of step wedge
b) Conversion to intensity

Loader command is INTENSITY

The relation between density and intensity is taken to be a least squares polynomial of up to order 3 of the form :-

$$\log(I)=W3(BD^{**}3)+W2(BD^{**}2)+W1(BD)+W0$$

where W0,W1,W2 and W3 are the polynomial coefficients and BD is the Baker density defined as

$$BD = \log((10^{**}d) - 1)$$

d is the measured density above the plate fog.

a) Wedge calibration

Loader command is WEDGESET

The first step in this procedure is to enter the log I values corresponding to each step on the wedge, unless this has been set up previously. Type the command ENTER and enter the following data:-
DATA AREA = disc area where log I values are to be stored
NO.STEPS = no.of intensity levels on wedge

It is then necessary to enter each of the log I values as prompted by the computer.

The next stage is to measure the wedge which is done using the command CALIBRATION and entering the following data
SPECTRUM AREA FOR WEDGE = disc area where scan is held
NO.POINTS IN SCAN = length of scan
DATA AREA FOR LOG I = disc area where log I values held

The scan of the wedge will then be plotted, and the cursor will appear. The next operation is to average the plate background by moving the cursor to the left, hitting the space bar, moving to the right and again hitting the space bar.

The density levels must each be measured in a similar manner, in the same order that the log I values were stored. If a level cannot be measured then hitting the space bar for the second time WITHOUT MOVING the cursor will ignore the corresponding measurement.

Once all the levels have been measured the computer will then ask for the order of polynomial to be fitted (up to order 3), and will then proceed to calculate this.

It is possible to remove measurements from the fit by typing n EXCLUDE where n is the level no. in the table.

Similarly, a measurement may be re-entered into the fit by typing n INCLUDE where n is the level no. in the table.

This sequence of including/excluding measurements and SOLVE may be used as many times as necessary to obtain the best fit.

At this stage, the calibration coefficients are now set up so that one could continue with the conversion to intensity of the corresponding spectra without entering the values. However, it is recommended that a note of the coefficients is taken for future reference so that it is not necessary to repeat this procedure if the spectrum has to be re-processed at a later stage. There is a facility to direct the results to the printer if it is not in use. This is done with the command PRINTOUT . A title of up to 20 characters can be given at this stage,

b) Density-Intensity Conversion

Once the coefficients of the Baker density relationship are known, then it is possible to convert measured density to relative intensity by means of this relation for each of the spectra to be processed.

Loader command PLATESET

Once this section is loaded the parameters for each spectrum may be entered using the command SETSPEC and input the following data :-
SPECTRUM = disc area where spectrum is stored
NO.OF POINTS = length of spectrum

The computer will then ask if the calibration coefficients are set up. If not, then typing N will allow you to input

the coefficients at this point.

The spectrum will then be plotted for examination so that the remaining parameters may be set up :-

PLATE FOG = measured density of plate fog
LOWER LIMIT = lower x limit of conversion
UPPER LIMIT = upper x limit of conversion

(NOTE :- the reason for the limits on the conversion is that each point must be above the plate fog, so that any noise present near the fog level must be avoided.)

It is possible to examine the calibration coefficients at any time with the command PRINT-COEFFICIENTS and if necessary input the coefficients using SET-CALIBRATION

Once this has all been set up then the conversion may be started by typing D-I and when finished, the spectrum in relative intensity units will be plotted for examination.

NORMALISATION TO CONTINUUM

In order to obtain a rectified spectrum, a continuum must be defined and then each data point normalised to this level. There are two methods available for this procedure as follows :-

a) Spline fit
b) Cubic fit

The spline function is defined by using the cursor to set the continuum level at a number of points along each individual spectrum. Consequently, this procedure requires interaction with the astronomer to a larger extent than the cubic fit, however, it must be stressed that in many cases where judgement of the level is required, this is the better method. The computer fit of a cubic is only suitable for those cases where an accurate continuum is not essential such as measurement of radial velocities, but has the advantage of being able to process many spectra without any interaction.

Loader command CONTINUUM

On loading this section of the package you are given the option of the cubic or spline function as the method of fitting the continuum.

a) Spline Fit

Loader command MANUAL

The parameters of the spectrum to be processed are defined using the command SETSPEC and entering the following data
SPECTRUM = disc area of spectrum
NO.OF POINTS = length of spectrum

The unrectified spectrum will then be plotted for examination.

To define the continuum one uses the command CSET and entering the following
NO.POINTS = no.of continuum points to be defined

and then positioning the cursor at each point and hitting the space bar. This is repeated until all the points are set. If necessary, additional points may be entered by repeating the command CSET and giving the extra number of points. It is very important that successive data points

are in order of increasing X value so care must be taken positioning the cursor. In addition it should be noted that the spline function can only fit between point numbers 2 and N-2, so that the ends of the spectrum are not rectified.

Once all of the points have been defined, the normalisation is carried out by typing the command RECTIFY. After the computation has finished, the spectrum will be plotted out for examination.

b) Cubic Fit

Loader command AUTO

Once loaded, there is the option of rectifying an individual spectrum, or indeed many such spectra provided that they are together on disc and contain the same number of data points.

i) Single spectrum

Loader command SINGLE

The computer will ask for the following data :-
SPECTRUM = disc area of spectrum
NO.POINTS= length of spectrum

The process is then started using the command NORMALISE. It should be noted that this is a relatively slow procedure so that this is a good time to do something else (or have a coffee break!).

ii) Multiple spectra

Loader command MULTIPLE

The computer will then ask for the following data :-
NO.POINTS= length of spectrum
It is then necessary to specify whether the spectra are stored with their comparison arcs or not. This is done by entering one of the following codes:-
1 - Spectra stored sucessively on disc without arcs.
2 - Spectra stored with intervening arcs.
One then continues to enter the parameters
BLOCK LENGTH = size of spectra in blocks
FIRST SPECTRUM= disc area where first spectrum is stored
LAST SPECTRUM= disc area where last spectrum is stored.

The normalisation is then started using the command AUTONORMALISE.

SPECTRAL LINE ANALYSIS

This section is an adaptation of the routine developed by G.C.Stewart for the measurement of spectral lines.

Loader command PHOTOMETRY

On loading this section of the package, the computer will present you with a list of options for the lines to be measured, and it is necessary for you to enter a code no. from the list displayed.
These are :-
-N) : delete catalogue no. N
0) : enter new lines
N) : select catalogue no.N

It is possible to display and reselect from this list at any time using the command CATALOGUE.

The master catalogue is held in block 2260 on the system disc, and although the individual catalogue may be stored anywhere on disc, it is recommended that they are placed between blocks 2261 and 2279 which have been allocated for this purpose.

When one wishes to enter a new set of lines by typing the code 0, the computer will ask which block they are to be stored in and whether this is a new catalogue or simply adding lines to an existing one. In the case of a new file, it is necessary to enter a title for future reference by entering up to 15 characters of text. The elements and corresponding wavelengths are then entered in response to the computer.

Once a catalogue has been selected or created, it is possible to list, change or delete the individual lines using the following commands :-
LIST-LINES : prints current catalogue of lines
DELETE : asks for and deletes specified line no.
CHANGE : asks for and changes values for given line.

Once the lines to be measured are set up, it is time to start measuring. Type the command SETSPEC and enter the following :-

SPECTRUM = disc area of spectrum
IS WAVELENGTH CALIBRATION SET UP ? :reply Y or N
(if N , enter coefficients for calibration)

Each line to be measured is sucessively acessed by the command NEXT when the section of spectrum around the line is displayed, and then the rest wavelength is marked on the screen.

It should be noted that the plot is of the +/- DXL points on either side of the centre value. By default, this is +/- 20. If one wishes to plot more or less than this, it is done by typing n = DXL where n is half of the number of points to be plotted.

The spectral line is measured by using the cursor three times to define the limits of the line.
1) Mark centre of line
2) Mark left hand limit of line
3) Mark right hand limit of line

The computer will then integrate the area contained within the line and store the parameters in a catalogue. The equivalent width and central depth are printed on screen as a check.

If the measurement is wrong one can either repeat it or ignore it using the commands REPEAT or REJECT.

The command NEXT is used repeatedly to measure all of the lines in the catalogue. Once completed, the results are printed out with the command FINISH.

FEATURE REMOVAL

This section of the package is used to remove unwanted features from the spectrum such as plate flaws, emission lines from streetlights etc.

Loader command REMOVAL

To enter the parameters of the spectrum to be processed type SETSPEC and enter the block no. and no.of data points contained in the spectrum.

If necessary, one can replot the spectrum at any time using any of the standard graphics commands.

There are two commands available :-
REMOVE :- replaces section between cursor marks by continuum level
REPLACE :- replaces section between cursor marks by straight line using linear interpolation.

RADIAL VELOCITY MEASUREMENT

This part of the package was developed to measure the Doppler shift of the spectral lines to determine the radial velocity of the spectrum.

Loader command VELOCITY

On loading, you are required to select a method of measurement by entering one of the following code nos.
1 - Line profile fitting
2 - Simulated comparator
3 - Crosscorrelation

a) Line Profile Fitting

Once you have selected this method, the computer will present you with a list of the catalogues of lines available. To select an option, enter the appropriate code no.
-N) : delete catalogue no.N
0) : enter new lines
N) : select catalogue no.N

It is possible to display and reselect from this list at any time using the command CATALOGUE.

The master catalogue is held is blk. 2220 on the system disc, and although individual catalogues may be held anywhere on disc it is recommended that they are placed between blks. 2221 and 2239 which have been allocated for this purpose.
The manipulation of these catalogues is exactly the same as that described previously in the section on spectral line analysis.

In order to set up the parameters of the spectrum one types the command SETSPEC and enters the following:-
SPECTRUM = disc area of spectrum
RSUN ? : enter Y/N
(if N input R.A. Dec. L.S.T. for the star, and the components of the solar motion DX, DY and DZ in km/s).
WAVELENGTH CALIBRATION SET UP ? : enter Y/N
(if N , enter coefficients of calibration)

By default the computer will measure absorption lines, but it is possible to measure emission lines also. The two modes are set up using the commands PEAKS and TROUGHS, and can be used at any time.

The lines are measured sucessively using the command NEXT when the section of spectrum around the rest position of the line is plotted. As described under the spectral line analysis, the amount plotted can be varied by changing the value of DXL.

The velocity of the line is measured by placing the cursor to the left of the line centre and pressing the space bar. This initiates a search to the right of the cursor until a minimum (or max.) is found with its position being more accurately determined by fitting a least squares parabola about that point.

If the measurement is bad, one can either repeat or ignore it with the commands REPEAT and REJECT. All of the lines are measured using NEXT whereupon the results are printed with the command FINISH.

It is possible to exclude or include individual measurements in the calculation of the mean velocity using the commands n EXCLUDE or n INCLUDE where n is the line no. The results are displayed using OBSERVATIONS.

Once completed, the results can be directed to the printer using the command PRINTOUT along with a title of up to 20 characters.

b) Simulated Comparator

Once selected, the procedure is very similar to that described for the line profile fitting routine, with the same set of catalogues being used. The only difference is the method of measurement.

In additionto the plot of the section of spectrum, a reversed image is also displayed, and it is necessary to move this image until they are coincident around the centre of the line being measured. This movement is done by the commands >> or << which asks for the distance, in data points, by which the reversed image is to be moved in that direction.

Once satisfied with the measurement, it can be entered into the output catalogue using the command SAVE. After all the lines have been measured, the same routines as described in the previous section are also available.

Cross-correlation

This section of the package is used to calculate the cross-correlation function by shifting the spectrum with respect to that of a standard star in order to calculate the velocity of the star. A catalogue of fourier transforms of standard stars is held on disc in order to minimise the amount of computation involved during processing.

a) Standard Spectrum

If a standard spectrum is not already set up in the system, (type CATALOGUE for those available) then it is necessary to set one up.

Type STANDARD and enter the following data:-

```
SPECTRUM              = disc area of spectrum
RSUN ?                : enter Y/N
LSTART                = start wavelength to be used in ccf
LSTOP                 = end wavelength
NO.POINTS             = no.data values to be interpolated
VELOCITY              = radial velocity of standard spectrum
WAVELENGTH CALIBRATION ? : enter Y/N
DISC AREA FOR TRANSFORM  = data area for storage
(nb 8 x no.points required e.g. 512pts->4096pts=8blks.)
```

The current catalogue is then listed and one enters the code 0 to store the data. One also enters the following information at this point:-

```
STAR NAME     : up to 10 char.
SPEC.TYPE     : up to 4 char.
PLATE SCALE   : up to 4 char.
TELESCOPE     : up to 16 char.
```

Once completed you are asked if your input is correct, and if not, this last section will repeat until corrected.

After all the relavent data is stored, the transform is computed using the command *STND.

b) Program Spectra

To compute the ccf of a spectrum, type the command STAR and enter the following:-

```
SPECTRUM = disc area of spectrum
RSUN ?  :  enter Y/N
WAVELENGTH CALIBRATION ?  :  enter Y/N
```

One then selects the standard spectrum required from the displayed list by entering the appropriate code no.

The calculation is started using the command *SPRM and entering the filter threshold required for the removal of noise from the ccf. (typical value 2-3). Once completed, the ccf is plotted on the Tektronix screen.

The velocity of a feature in the ccf may be computed using one of the following commands.

[FRV] :- brings up the cursor and prints velocity corresponding to X-position.
FRV :- brings up cursor, searches to right and fits parabola around max.

The function can be redisplayed using FNDISPLAY.

Often it is more convenient to expand the scale and plot out the function between specified velocity limits. This is done using the following sequence of commands :-
VELAXES :- enter lower and upper velocity limits.
DISPLAY :- plots function between limits.

The velocity may be measured using the commands:-
[RV] :- brings up cursor and gives velocity corresponding to X-position.
RV :- brings up cursor , searches to right and fits parabola of specified no.points to max.
A plot of the fit to the peak may be displayed using the command FIT.

VELOCITY BROADENING FUNCTIONS

This section is used to deconvolve a section of standard spectrum from the corresponding section of the program spectrum.

Loader command BROADENING

The routines used are identical with those described under the cross-correlation section and the same catalogue of standard fourier transforms is employed. Interaction with the computer is carried out using exactly the same commands.

Due to the noise inherent in this technique, the filter threshold specified will be much larger (typically 10-20), a little experimentation is advised to find the best value for the particular series of spectra.

DATA REDUCTION ROUTINES

This is a collection of miscellaneous routines that were found to be useful for my particular work, and as such are by no means comprehensive.

Loader command REDUCTIONS

There are four main sections included in this package.
1) Statistics
2) Solution of RV curve by Irwin's method
3) Period finding
4) Graph plotting

a) Statistics

There are routines for both one and two parameter computations.

Loader command STAT-PAK

On loading the computer wil ask if you wish to use one or two parameters (enter 1 or 2).

1) One parameter

ENTER :- asks if creating new catalogue or adding points to an existing one. Input no.of points and enter the values.

VALUES :- prints current catalogue

DELETE :- deletes specified entry no.

CHANGE :- changes specified entry no. to new values

SOLVE :- computes mean, st.dev. and st.err. of values.

2) Two parameters

The catalogue manipulation commands ENTER, VALUES, DELETE and CHANGE are used in the same way as described in the previous section but operate on both X and Y values. There are 4 subsections which may be acessed:-

i) Statistics

Loader command STATISTICS

Command SOLVE gives mean, st.dev., st.err. and coefficient

of correlation.

ii) Linear least squares
Loader command LINE

Command SOLVE fits straight line to X and Y values.

iii) Power least squares
Loader command POWER

Command SOLVE fits power curve to X and Y values.

iv) Exponential least squares
Loader command EXPONFIT

Command SOLVE fits exponential curve to X and Y values.

b) Radial Velocity Curve Solution

This is a routine which uses Irwin's method to derive the spectroscopic elements from the radial velocity curve of a double-lined binary assuming that the eccentricity is zero.

Loader command ORBIT

The data values i.e. Phase, Primary velocity and Secondary velocity are held in a disc catalogue as before. Once again, the data is entered, displayed and altered using the commands ENTER, VALUES, DELETE and CHANGE as described previously.

It is sometimes necessary to move the observations in phase using the command PHASES which asks for the amount which is to be added to all the existing phase values.

This technique is a differential least squares method so it requires initial values which are close to the final result. The solution is initiated by the command SOLVE and entering the following data :-
PERIOD = period of binary in days.
Q = initial mass ratio
V0 = initial systemic velocity

The program then iterates to a solution with the results being printed out. Occasionally, the iteration will fail if the system of equations becomes indeterminate. This will

happen if, for a particular set of data values, the initial values are not close enough, or sometimes the solution is divergent.

The results can be output using the command RESULTS while the fit to the data can be plotted using the command DISPLAY.

c) Period Finding

This is a rather crude routine which implements the period finding scheme outlined in IBVS 1347 for finding periodicities in variable stars.

Loader command PERIOD

The data, Time, Measurement and Weight, are held in a disc array using the standard ENTER, VALUES, DELETE and CHANGE commands.

The period search is initiated using the command SOLVE and entering the following :-
MIN.PERIOD - shortest period
MAX.PERIOD - longest period
INCREMENT - period increment between searches

Once completed, the resulting periodogram is displayed and the period(s) determined from the peak(s) in the function. It is suggested the the procedure is used iteratively, each search confining the period more closely.

d) Graph Plotting

This part of the package implements useful routines in addition to those available with the standard graphics package in the system.

Loader command GRAPH

On loading the computer will ask for a disc block which to use as workarea. After entering this, you get the option to work on an existing catalogue entering the appropriate block no. if this is required.

The data values i.e. X and Y are again held in disc arrays and are manipulated using the standard commands ENTER, VALUES, DELETE and CHANGE.

It is possible to change between many catalogue held on disc using the command CATALOGUE so change the disc area.

In addition to the commands for creating the catalogue there are some for altering the data values:-

INTERCHANGE - swaps X and Y values
OPERATE - carries out arithmatical operation on either X or Y values.
Select operation from following codes.
(1) + (2) - (3) x
(4) / (5) log (6) alog
and enter numeric value to be used.

The scale of the picture can be altered with the command SETAXES which asks for lower and upper limits in both X and Y. If required the plot can be scaled so that equal X and Y increments correspond to equal X and Y distances when plotted. This is done using WINDOW.

The data values can be plotted in several ways :-

DISPLAY - plots values as crosses
DDISP - plots values as dots
n CPLOT - plots values as graphics character n
SNAKE - joins the values by series of striaght lines

Finally, it is possible to fit a least squares polynomial to th data values of up to order 7. This is done using the command FIT which brings up the cursor and uses all the data points between the lower and upper cursor positions X1 and X2 in th polynomial fit. The computer will fit the polynomial with the smallest rms error.

There are several additional commands using the polynomial:-

PLOT - plots poly. between cursor positions X1 and X2
CONNECT - select X1 and X2 with cursor, and a straight line will be drawn between Y(X1) and Y(X2).
POSITION- returns Y(X) for cursor position X.

FACILITIES

If in doubt about what is available in the package, the command FACILITIES will provide a brief outline and the main Loader words.

APPENDIX C

S.I.P.S. PROGRAM LISTING

```
2000
 0 ( BJM - CONTROL BLOCK )
 1 EMPTY       0 WARNING !
 2 27 C. 12 C. 1000 MS       CR
 3 .# SPECTROSCOPIC IMAGE PROCESSING SYSTEM " CR
 4 .# ========================================== " CR CR
 5    8 +BLOCK LOADER SCANNING     48 +BLOCK LOADER WAVELENGTH
 6   59 +BLOCK LOADER NOISEFILTER  64 +BLOCK LOADER INTENSITY
 7   77 +BLOCK LOADER CONTINUUM    88 +BLOCK LOADER PHOTOMETRY
 8  102 +BLOCK LOADER REMOVAL     103 +BLOCK LOADER VELOCITY
 9  119 +BLOCK LOADER BROADENING  138 +BLOCK LOADER REDUCTIONS
10  182 +BLOCK LOADER FACILITIES
11  1 +BLOCK LOAD ( BASIC PACKAGE )
12
13
14
15
```

```
2001
 0 ( BJM - REDUCED GRAPHICS )
 1 : PAGE 27 C. 12 C. 1000 MS ;
 2
 3 457 LOAD ( GRAPHICS )
 4 459 LOAD ( SPECTRUM BASICS )
 5 460 LOAD ( SPECTRUM DISPLAY )
 6 461 LOAD ( AVPT. ETC. )
 7 453 LOAD ( ARBITRARY PLOTTING )
 8 639 LOAD ( CROSSPLOT )
 9 USERSFLPT ( FLOATING POINT )
10 .
11 : HEADING OFF DRAW ALPHA ;
12
13 2 +BLOCK LOAD
14
15
```

```
2002
 0 ( BJM - SPLITSCREEN GRAPHICS )
 1 : VR VARIABLE ; : BOTC 40 Y CORNER ! ; : TOPC 440 Y CORNER ! ;
 2  VR HALF-FLAG  VR SPLIT-FLAG  VR SSAVE  VR AXS 0 , 0 , 0 ,
 3 : PACKSAVE SAREA SSAVE ! ;
 4 : PACKSWITCH SSAVE @ PACKSAVE SPECTRUM ;
 5 : GAXPAR  X ORG 2@  X RNG 2@  2OVER V+ ROT SWAP 2SWAP ;
 6 : SAXPAR  Y SIZE  X SIZE ;
 7 : FULLSCREEN  1 SPLIT-FLAG ! 630 Y FRAME ! 40 94 X CORNER 2! ;
 8 : SPLITSCREEN  PACKSAVE  GAXPAR  AXS 4!  BOTC  0 HALF-FLAG !
 9     0 SPLIT-FLAG !   275 Y FRAME !  150 X CORNER ! ;
10 : ?SC  SPLIT-FLAG @  ABORT" SCREEN NOT SPLIT "
11     ;   ( TASK IS TO TIDY UP THE MESSAGE )
12 : SWITCH  PACKSWITCH  GAXPAR  AXS 4@  SAXPAR  AXS 4! ;
13 : BOT  ?SC  HALF-FLAG @  IF  SWITCH  BOTC  0 HALF-FLAG ! THEN ;
14 : TOP  ?SC  HALF-FLAG @ NOT IF SWITCH TOPC 1 HALF-FLAG ! THEN ;
15 : AXBAR  COORDS DROP DUP  Y ORG @  VBAR  CR ;
```

```
2003
 0 ( BJM - BASIC VALUES,CONSTANTS,DATA AREAS )
 1 : INT INTEGER ;  : 2INT 2INTEGER ;
 2 FL 3. 2INT F3 FL 15. 2INT F15 FL 1000. 2INT F1000
 3 FL 5. 2INT F5 FL 100. 2INT F100
 4
 5 0 INT NO 0 INT SHIFT 5 INT NOP 0 INT CH
 6 0 INT DATAPOINT 0 INT CCF/VBF 0 INT M
 7 10000 INT STND
 8 4900 INT SPRM 4940 INT AREA
 9 4980 INT WAREA  4998 INT OAREA
10 10000 INT SPEC  10000 INT SOURCE  10000 INT DEST
11 FL 300000. 2INT C-VEL
12 F0. 2INT RVSTND F0. 2INT RSUN
13 F0. 2INT LSTART F0. 2INT LSTOP F0. 2INT LSCALE
14 10 2 FMT
15 -->

2004
 0 ( BJM - USEFUL WORDS )
 1 : SASET ['] SAREA ! ;
 2 : F@ @ FLOAT ;
 3 : SPECTRUMDATA  PT F@ ;
 4 : SPECTRUMDATA  ['] SPECTRUMDATA  := DATAPOINT ;
 5
 6 : [BAR] CURSOR 2DROP CR X CORNER @ - FLOAT RNG @ FLOAT F*
 7 FRAME @ FLOAT F/ ORG @ FLOAT F+ CR ;
 8
 9 : SIGNAL 10 0 DO 50 0 DO 7 C. LOOP 100 MS LOOP ;
10
11 : Y/N BEGIN CR ." Y OR N ? " KEY ['] CH !
12 CH 89 = IF 1 1 ELSE CH 78 = IF 0 1 ELSE
13 CR ." INVALID CHARACTER ! " 0 THEN THEN END CR ;
14 -->
15 ;S

2005
 0 ( BJM - WAVELENGTH CALIBRATION )
 1 F0. 2INT LAMDA FL 100. 2INT DL F0. 2INT XM FL 0.01 2INT DIFF
 2 F0. 2INT N0 F0. 2INT N1 F0. 2INT N2 F0. 2INT N3 F0. 2INT N4
 3 F0. 2INT N5           FL 3.7 2INT LZERO
 4
 5 : ZEROSET CR ." REFERENCE WAVELENGTH = " FASK
 6 F1000 F/ := LZERO ;
 7
 8 : CALIBRATE ZEROSET CR ." ORDER  COEFFICIENT" 6 0 DO CR I .
 9 3 SPACES FASK LOOP := N5 := N4 := N3 := N2 := N1 := N0 CR ;
10
11 : COEFFICIENTS CR ." ORDER  COEFFICIENT"  10 6 FMT
12 CR 0 . N0 F. CR 1 . N1 F. CR 2 . N2 F.
13 CR 3 . N3 F. CR 4 . N4 F. CR 5 . N5 F. CR 10 2 FMT ;
14
15 -->
```

2006

```
( BJM - WAVELENGTH CALIBRATION )
: X-XS F1000 F/ ;                : XS-X F1000 F* ;
: L-LS F1000 F/ LZERO F- ;   : LS-L LZERO F+ F1000 F* ;

: XCALC L-LS 2DUP 2DUP 2DUP 2DUP F5 FPWR N5 F* 2SWAP F4 FPWR
N4 F* F+ 2SWAP F3 FPWR N3 F* F+ 2SWAP F**2 N2 F* F+ 2SWAP N1 F*
F+ N0 F+ XS-X ;

: LCALC := XM FL 100. := DL F0. LS-L := LAMDA BEGIN LAMDA XCALC
XM F- F0< IF LAMDA DL F+ := LAMDA ELSE DL F2 F/ := DL LAMDA DL
F- := LAMDA THEN LAMDA XCALC XM F- FABS DIFF F< END LAMDA ;

: WAVE [BAR] LCALC F. ;
-->
```

2007

```
( BJM - SETTING WORKAREA )
0 INT BL   0 +BLOCK
: DISCAREA-SET CR CR  CR
." DO YOU WISH TO SPECIFY ALTERNATIVE WORK AREA ON DISC ?"
CR ." DEFAULT : 4900-4999 SUITABLE FOR 5 BLOCK SPECTRUM "
CR CR Y/N IF CR CR
." SPECTRUM OF LENGTH N BLOCKS ( 1 BLK = 512 PTS )" CR
." YOU REQUIRE 20*N BLOCKS OF WORK AREA" CR CR
." LENGTH OF SPECTRA IN BLOCKS = " ASK := BL CR
." WORK AREA = " ASK := SPRM CR
SPRM BL 8 * + := AREA  SPRM BL 16 * + := WAREA
SPRM BL 20 * + 2 - := OAREA THEN 13 IN-LINE L#LOAD ;
DISCAREA-SET  EXIT
FORGET BL
: SUBTASK ;     1 WARNING !
FACILITIES
```

2008

```
( BJM - PLATE SCANNING )
JOYCE LOAD
0 INTEGER JUMP 0 INTEGER M

: INCBLKS N 2 1024 */MOD SWAP 0= NOT IF 1+ THEN
   SAREA + SPECTRUM FLUSH ;

: NXSCAN ZEROSET BACKLASH 0 DO 0 JUMP I * GOTO
   BACKLASH XSCAN INCBLKS FLUSH LOOP ;
: NYSCAN ZEROSET BACKLASH 0 DO JUMP I * 0 GOTO
   BACKLASH YSCAN INCBLKS FLUSH LOOP ;

: PSCAN SPECTRUM ZEROSET 0 JUMP MINUS GOTO 3 NXSCAN FLUSH ;
: WXSCAN SPECTRUM ZEROSET M NXSCAN FLUSH ;
: WYSCAN SPECTRUM ZEROSET M NYSCAN FLUSH ;
-->
```

```
2009
 0 ( BJM - PLATE SCANNING )
 1 : PARAMETERS
 2 CR ." NO.OF POINTS                          = " ASK PTS
 3 CR ." SAMPLE STEP IN MICRONS                = " ASK 5 / STEPSIZE !
 4 CR ." NO.OF SCANS                           = " ASK := M
 5 CR ." SCAN SEPARATION IN MACHINE STEPS= " ASK := JUMP CR ;
 6
 7 CR .# PLATE SCANNING PACKAGE FOR RADIAL VELOCITIES" CR CR
 8 CR .# SPECTRUM SCAN :- (DISC AREA) PSCAN "
 9 CR .# WEDGE SCAN(X) :- (DISC AREA) WXSCAN "
10 CR ." WEDGE SCAN(Y) :- (DISC AREA) WYSCAN" CR CR
11
12 PARAMETERS
13 ;S
14 ;S
15 ;S
```

```
2010
 0 ( BJM - DISC ARRAYS )
 1 10000 INTEGER WORKAREA
 2  VARIABLE AP                    0 AP !
 3
 4 :ORPHAN + 1024 /MOD WORKAREA + BLOCK + ; DUP
 5 : IARRAY AP @ SWAP 1+ 2*  AP +! CONSTANT
 6         DOES>  @ SWAP 2* ADOPT ;
 7 : FARRAY AP @ SWAP  1+  4 * AP +! CONSTANT
 8         DOES>  @ SWAP 4 *  ADOPT ;
 9
10 : !D ! UPDATE ;
11 : +!D +! UPDATE ;
12 : 2!D 2! UPDATE ;
13 : F+!D F+! UPDATE ;
14
15
```

```
2011
 0 ( BJM - FOURIER TRANSFORMS )
 1 COMPLEX-ARITH ( LOAD COMPLEX ARITHMETIC )
 2
 3 4 CONSTANT N     4 CONSTANT NV    4 CONSTANT KS
 4 10000 CONSTANT CAREA
 5
 6 : FDATA ['] CAREA ! CAREA . ;
 7 : ABCOMPLEX 8 1024 */MOD     CAREA + BLOCK  + ;
 8 : AB! ABCOMPLEX 4! UPDATE ;
 9 : AB@ ABCOMPLEX 4@ ;
10 : .DATA 0 DO CR I 5 .R I AB@ F. F. LOOP ;
11 1 +BLOCK 18 +BLOCK : FFT IN-LINE IN-LINE DO
12 0 WARNING ! I LOAD 1 WARNING ! LOOP ;
13  18 +BLOCK LOADER -FFT
14 19 +BLOCK LOAD
15
```

```
2012
 0 ( BJM - FOURIER TRANSFORMS )
 1 ?SPACE 3500 < IFTRUE CR .* NO ENOUGH FFT SPACE * QUIT    IFEND
 2 0 AP !  FLUSH
 3 20 IARRAY FACTOR    0 CONSTANT ZERO
 4 : INIT F0. FCONSTANT ; INIT A0 INIT A1 INIT A2 INIT A3
 5 INIT B0 INIT B1 INIT B2 INIT B3 INIT CM INIT SM INIT C1 INIT C2
 6 INIT C3 INIT S1 INIT S2 INIT S3
 7 FL 6.283185 FCONSTANT RAD   FL 0.8660254 FCONSTANT C30
 8 0 CONSTANT K0 0 CONSTANT K1 0 CONSTANT K2 0 CONSTANT K3
 9 0 CONSTANT JK 0 CONSTANT KF 0 CONSTANT KH 0 CONSTANT JF
10 0 CONSTANT MM 0 CONSTANT JJJ 0 CONSTANT JJ 0 CONSTANT KK
11 0 CONSTANT KB 0 CONSTANT M 0 CONSTANT SPAN 0 CONSTANT KT
12 0 CONSTANT KN 0 CONSTANT II
13 EXIT
14 : <N DUP <R N < N 0= R> N > AND OR ;
15   UNFORTUNATELY, THERE ARN'T THE REQUIRED 1721 WORDS LEFT.


2013
 0 ( BJM - FOURIER TRANSFORMS )
 1 : SQFACTS NV ['] KK ! 0 ['] M ! 2 ['] JJJ ! 4 ['] JJ !
 2            0 ['] JF !   1   0 FACTOR !D
 3  BEGIN BEGIN  KK JJ / DUP ['] II !   JJ * KK = IF
 4           1 ['] M +! JJJ M FACTOR !D  II ['] KK ! AGAIN
 5           JJJ 2 = IF 3 ['] JJJ ! ELSE 2 ['] JJJ +! THEN
 6           JJJ DUP * ['] JJ !    JJ KK > END   M ['] KT ! ;
 7 : 2,3,K ['] JJJ ! BEGIN KK JJJ / DUP ['] II !  JJJ *  KK  =  IF
 8          1 ['] M +!   JJJ  M FACTOR !D  II ['] KK  ! AGAIN ;
 9 : REMFACTS 2            2,3,K    KK 1+ 3 DO
10 .           I            2,3,K  2 +LOOP
11             KT FACTOR @  M FACTOR @  > IF  KT
12             ELSE M THEN FACTOR @ ['] KK !
13             KT 0 > IF   1 KT DO  1 ['] M +!
14             I FACTOR @  M FACTOR !D     -1 +LOOP  THEN ;
15   SQFACTS REMFACTS     FORGET SQFACTS


2014
 0 ( BJM - FOURIER TRANSFORMS )
 1 M IARRAY C    M IARRAY D    M 1+ IARRAY BB
 2 KK 1- DUP 2DUP  FARRAY CK  FARRAY SK  FARRAY CF  FARRAY SF
 3 KK 1- 2/ DUP 2DUP  FARRAY AP FARRAY BP FARRAY AM FARRAY BM
 4 M DUP DUP FARRAY RD  FARRAY CC  FARRAY SS
 5
 6
 7
 8
 9
10
11
12
13
14
15
```

```
2015
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 1STAT JJJ 1- FACTOR @  JJJ  FACTOR @  +  4  =  DUP JJJ BB !D
 2         IF -1 ['] JJJ +!  0 JJJ BB !D  THEN ;
 3 : 2STAT M ['] JJJ ! BEGIN JJJ 1 > IF 1STAT -1 ['] JJJ +! AGAIN
 4         DZERO 1 BB !D  M 1+ BB !D  KS NV /  0 C !D
 5         0. ['] KN !    KS  0 D !D ;
 6 : 3STAT JJJ FACTOR @ ['] KK !    JJJ 1- C @  KK  *  JJJ C !D
 7         JJJ 1- D @  KK  /  JJJ D !D     RAD  JJJ C @ FLOAT F/
 8         JJJ RD 2!D       RAD KK FLOAT F/ ['] C1 2!D
 9         KK 2 > IF C1 FCOS JJJ CC 2!D  C1 FSIN JJJ SS 2!D THEN ;
10 : 4STAT M 1+ 1 DO I ['] JJJ ! 3STAT LOOP
11         M BB @ IF  M 1-  ELSE  M  THEN  ['] MM !
12         MM 1 > IF  MM 2 - C @ FLOAT M RD 2@ F* ['] SM 2!
13         SM FCOS ['] CM 2!   SM FSIN ['] SM 2!    THEN ;
14  2STAT 4STAT  FORGET 1STAT
15
```

```
2016
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 5STAT KN ['] KB ! KS ['] KN +! 0 ['] JJ ! 1 ['] II !
 2         F1 ['] C1 2! F0. ['] S1 2!  1 ['] ZERO ! ;
 3 : 6STAT II 1+ BB @ IF  1 ['] II +!  4  ELSE II FACTOR @ THEN
 4         ['] KF !   II D @ ['] SPAN !   ZERO NOT IF
 5         JJ FLOAT II RD 2@ F* ['] S1 2!
 6         S1 FCOS ['] C1 2!  S1 FSIN ['] S1 2!  THEN ;
 7 : 7STAT ZERO NOT IF   C1 F**2  S1 F**2  F-  ['] C2 2!
 8         F2 C1 F* S1 F* ['] S2 2!  C2 C1 F* S2 S1 F* F- ['] C3 2!
 9         C2 S1 F*  S2 C1 F*  F+  ['] S3 2!      THEN ;
10
11
12
13
14
15
```

```
2017
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 8STAT K0 SPAN + ['] K1 ! K1 SPAN + ['] K2 ! K2 SPAN + ['] K3 !
 2         K0 AB@ ['] A0 2!  ['] B0 2! ;
 3 : 9STAT K1 AB@ ['] A1 2! ['] B1 2!  K2 AB@ ['] A2 2! ['] B2 2!
 4         K3 AB@ ['] A3 2! ['] B3 2!  ;
 5 : -10STAT K1 AB@ 4DUP  C1 F* 2SWAP S1 F* F-  ['] A1 2!
 6                        S1 F* 2SWAP C1 F* F+  ['] B1 2!
 7           K2 AB@ 4DUP  C2 F* 2SWAP S2 F* F-  ['] A2 2!
 8                        S2 F* 2SWAP C2 F* F+  ['] B2 2!  ;
 9 :ORPHAN   K3 AB@ 4DUP  C3 F* 2SWAP S3 F* F-  ['] A3 2!
10                        S3 F* 2SWAP C3 F* F+  ['] B3 2!  ;
11 : 10STAT  -10STAT ADOPT ;
12 :ORPHAN  B0 B2 F+ B1 F+ B3 F+   A0 A2 F+ A1 F+ A3 F+   K0 AB!
13          B0 B2 F+ B1 F- B3 F-   A0 A2 F+ A1 F- A3 F-   K1 AB!
14          B0 B2 F- A1 F+ A3 F-   A0 A2 F- B1 F- B3 F+   K2 AB!
15   B0 B2 F- A1 F- A3 F+   A0 A2 F- B1 F+ B3 F-   K3 AB! ;
```

```
2018
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 12STAT 8STAT  ZERO IF  9STAT  ELSE  10STAT  THEN  ADOPT ;
 2 : 13STAT ZERO NOT IF 7STAT THEN   KB  KB 1- SPAN + DO
 3          I ['] K0 !     12STAT    -1 +LOOP ;
 4 : 14STAT ZERO NOT IF C1 F**2  S1 F**2  F-  ['] C2 2!
 5          F2 C1 F* S1 F*  ['] S2 2!   THEN ;
 6 :ORPHAN  K0 SPAN + ['] K1 !  K1 SPAN + ['] K2 !
 7          K0 AB@ ['] A0 2!  ['] B0 2!          ZERO IF
 8          K1 AB@ ['] A1 2!  ['] B1 2!   K2 AB@ ['] A2 2!
 9          ['] B2 2!          ELSE  -10STAT   THEN ;
10 :ORPHAN  B0 B1 F+ B2 F+   A0 A1 F+ A2 F+   K0 AB!
11          A0  A1 A2 F+  F.5 F* F-  ['] A0 2!
12          A1 A2 F-  C30 F*  ['] A1 2!
13   B0  B1 B2 F+ F.5 F*  F-  ['] B0 2!  B1 B2 F- C30 F* ['] B1 2!
14          B0 A1 F+  A0 B1 F-   K1 AB!
15          B0 A1 F-  A0 B1 F+   K2 AB!   ;
```

```
2019
 0 ( BJM - FOURIER TRANSFORMS )
 1 SWAP ( : K0-1 K0 DUP 0= IF 1 1 0 D- DROP ELSE 1- THEN ;)
 2 : 17STAT  14STAT  KB  DUP 1- SPAN +    DO  I ['] K0 !
 3           [SWAP] ADOPT [SWAP] ADOPT    -1 +LOOP ;
 4 : +18STAT K0 AB@ 2SWAP 4DUP B0 F-  2SWAP  A0 F-  K2 AB!
 5                                B0 F+  2SWAP  A0 F+  K0 AB!  ;
 6 : 18STAT K2 1- DUP     ['] K2 !   AB@  ['] A0 2!  ['] B0 2!
 7          +18STAT ;
 8 : 19STAT BEGIN K0 1- DUP ['] K0 !  KB < NOT IF 18STAT AGAIN ;
 9 : 20STAT -1 ['] K2 +!
10          K2 AB@ 4DUP  C1 F*  2SWAP  S1 F*  F-  ['] A0 2!
11          S1 F*  2SWAP  C1 F*  F+  ['] B0 2!      +18STAT ;
12 : 21STAT BEGIN K0 1- DUP ['] K0 !  KB < NOT IF 20STAT AGAIN ;
13 : 22STAT KB SPAN + DUP ['] K0 !  SPAN + ['] K2 !
14          ZERO IF 19STAT ELSE 21STAT THEN ;
15
```

```
2020
 0 ( BJM - FOURIER TRANSFORMS )
 1 :ORPHAN  KF 1- DUP ['] JK !  2/ ['] KH !  II 1- D @ ['] K3 !
 2          KB SPAN + ['] K0 ! ;
 3 :ORPHAN   KK 1+  1  DO  I CF 2@ 2DUP C1 F*  I SF 2@ S1 F*   F-
 4          I 1+ CF 2!D  S1 F* I SF 2@ C1 F* F+ I 1+ SF 2!D LOOP ;
 5 : 25STAT [SWAP] ADOPT  ZERO NOT IF   JK 1- ['] KK !
 6          C1 1 CF 2!D  S1 1 SF 2!D   [SWAP] ADOPT  THEN ;
 7 :ORPHAN  KH 1+ 1 DO    JK I - ['] KK !
 8          I CK 2@ C2 F* I SK 2@ S2 F*  F-  2DUP
 9          KK CK 2!D  I 1+ CK 2!D
10          I CK 2@ S2 F*  I SK 2@ C2 F*  F+  I 1+  SK 2!D
11          I 1+ SK 2@ FMINUS KK SK 2!D     LOOP ;
12 : 27STAT KF JF = NOT IF II CC 2@ 2DUP 2DUP ['] C2 2!  1 CK 2!D
13          JK CK 2!D   II SS 2@ 2DUP ['] S2 2!  1 SK 2!D
14          S2 FMINUS  JK SK 2!D   [SWAP] ADOPT   THEN ;
15
```

```
2021
 0 ( BJM - FOURIER TRANSFORMS )
 1 :ORPHAN   K0 1- DUP ['] K0 ! ['] K1 !  K0 K3 + ['] K2 !
 2           K0 AB@ 4DUP ['] A0 2! ['] B0 2! ['] A3 2! ['] B3 2! ;
 3 : 28STAT K1 AB@ ['] A1 2! ['] B1 2!
 4          K2 AB@ ['] A2 2! ['] B2 2!  ;
 5 : 29STAT KF JJJ - ['] KK !
 6      K1 AB@ 4DUP JJJ CF 2@ F* 2SWAP JJJ SF 2@ F* F- ['] A1 2!
 7                  JJJ SF 2@ F* 2SWAP JJJ CF 2@ F* F+ ['] B1 2!
 8      K2 AB@ 4DUP KK CF 2@ F* 2SWAP KK SF 2@ F* F- ['] A2 2!
 9                  KK SF 2@ F* 2SWAP KK CF 2@ F* F+ ['] B2 2! ;
10 :ORPHAN  A1 A2 4DUP  F+ JJJ AP 2!D  F- JJJ AM 2!D
11          B1 B2 4DUP  F+ JJJ BP 2!D  F- JJJ BM 2!D
12          JJJ AP 2@ ['] A3 F+!   JJJ BP 2@ ['] B3 F+! ;
13
14
15
```

```
2022
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 31STAT [SWAP] ADOPT  KH 1+ 1 DO  I ['] JJJ !
 2          SPAN DUP ['] K1 +!  MINUS ['] K2 +!
 3          ZERO IF  28STAT  ELSE 29STAT THEN [SWAP] ADOPT LOOP ;
 4 :ORPHAN  SPAN DUP ['] K1 +!  MINUS ['] K2 +!   JJJ ['] JK !
 5         A0 ['] A1 2! B0 ['] B1 2! F0. 2DUP ['] A2 2! ['] B2 2! ;
 6  :ORPHAN [SWAP] ADOPT  KH 1+ 1 DO
 7    I AP 2@ JK CK 2@ F* ['] A1 F+! I AM 2@ JK SK 2@ F* ['] A2 F+!
 8    I BP 2@ JK CK 2@ F* ['] B1 F+! I BM 2@ JK SK 2@ F* ['] B2 F+!
 9    JJJ ['] JK +!  JK KF < NOT IF KF MINUS ['] JK +! THEN LOOP ;
10 :ORPHAN [SWAP] ADOPT B1 A2 F+ A1 B2 F-  K1 AB!
11          B1 A2 F-  A1 B2 F+  K2 AB! ;
12 : 35STAT B3 A3 K0 AB!       K0 DUP ['] K1 !  K3 + ['] K2 !
13          KH 1+ 1 DO I ['] JJJ !  [SWAP] ADOPT   LOOP ;
14 : 36STAT BEGIN   31STAT   35STAT K0 KB > NOT  END KF ['] JF ! ;
15
```

```
2023
 0 ( BJM - FOURIER TRANSFORMS )
 1 CREATE L2  0 , 0 ,
 2 : L3STAT
 3          4 KF = IF 13STAT ELSE 3 KF = IF 17STAT
 4     ELSE 2 KF = IF 22STAT ELSE
 5     25STAT 27STAT 36STAT  THEN THEN THEN ;
 6 : 37STAT BEGIN I1 2 - C @ JJ + ['] JJ ! JJ I1 1- C @ < NOT IF
 7          -1 ['] I1 +!  I1 C @ MINUS ['] JJ +!   AGAIN ;
 8 : 38STAT MM ['] I1 !  0 ['] ZERO !  I1 1- D @ ['] KB +! ;
 9 : 39STAT C1 ['] C2 2! CM C1 F* SM S1 F* F- ['] C1 2!
10                       SM C2 F* CM S1 F* F+ ['] S1 2! ;
11
12
13
14
15
```

```
2024
 0 ( BJM - FOURIER TRANSFORMS )
 1 : L1L2L3  BEGIN ( L1: )      5STAT
 2           BEGIN [ L2 ! ]  6STAT
 3           BEGIN [ L2 2+ ! ]  L3STAT
 4           II MM < DUP IF 1 ['] II +! THEN NOT [ L2 @ ] END
 5           38STAT  KB KN < DUP IF 37STAT
 6           II MM = DUP IF DROP 39STAT THEN NOT [ L2 2+ @ ] END
 7           II BB @ IF 1 ['] II +! THEN THEN NOT [ L2 @ ] END
 8           KN N < NOT      ( GOTO L1 )  END ;
 9 : MIXED L1L2L3     1 ['] II !
10         KT 1 > IF  1 KT 1- DO  -1 I FACTOR +! UPDATE
11                    I FACTOR @ ['] II +!  -1 +LOOP  THEN ;
12  MIXED 7 C. ?SPACE .   FORGET 5STAT
13
14
15
```

```
2025
 0 ( BJM - FOURIER TRANSFORMS )
 1 II IARRAY S
 2 : L5STAT JJJ D @ KB + DUP ['] K2 ! ['] K3 !
 3           JJJ 1- C @ DUP   ['] JJ ! ['] JK !
 4           KB JJ + ['] KO ! JJJ C @ JJ - ['] SPAN ! ;
 5 : L7STAT BEGIN KO AB@ K2 AB@ KO AB! K2 AB!
 6           1 ['] KO +!  1 ['] K2 +!  KO KK < NOT END ;
 7 : 1L6STAT BEGIN KO JJ + ['] KK !   L7STAT  SPAN ['] KO +!
 8           SPAN ['] K2 +!   KO K3 < NOT END ;
 9 : 2L6STAT BEGIN 1L6STAT KO K3 SPAN + < DUP IF
10           JJ JJJ D @ - ['] KO +!   THEN   NOT END ;
11 : 3L6STAT BEGIN 2L6STAT JJJ D @ ['] K3 +! K3 KB - JJJ 1- D @ <
12           DUP IF K3 JK + ['] K2 ! JJ ['] JK +! K3 JJJ D @ - JK +
13           ['] KO !    THEN  NOT END ;
14
15
```

```
2026
 0 ( BJM - FOURIER TRANSFORMS )
 1 : L8STAT BEGIN 1 ['] II +!  JJJ II S !D  II KK < NOT END ;
 2 : 1L5STAT BEGIN L5STAT 3L6STAT JJJ KT < DUP IF
 3           JJJ FACTOR @ II + ['] KK !    1 ['] JJJ +!
 4           L8STAT THEN NOT END ;
 5 : 2L5STAT BEGIN BEGIN 1L5STAT    K3 ['] KB !   II 0 > DUP IF
 6           II S @ ['] JJJ !    -1 ['] II +!    THEN NOT END
 7           KB N < DUP IF 1 ['] JJJ ! THEN NOT END ;
 8 : 1PERMUTE KT 0 > IF 1 ['] JJJ ! F0. ['] KB ! ['] II ! 2L5STAT
 9              THEN KT C @ ['] JK ! KT D @ ['] SPAN !
10              KT MINUS ['] M +! SPAN JK / 2 - ['] KB ! ;
11 1PERMUTE KB IARRAY R  JK 1- DUP FARRAY TA  FARRAY TB
12 : 40STAT KB 1+ 1 DO KT ['] KK !
13           BEGIN KK 1+ D @ ['] JJ +!  JJ  KK D @  < NOT IF
14           KK D @ MINUS ['] JJ +!  1 ['] KK +!  AGAIN
15           JJ I = IF I MINUS  ELSE JJ THEN I R !D LOOP ;
```

```
2027
 0 ( BJM - FOURIER TRANSFORMS )
 1 : 41STAT KB 1+ 1 DO I R @ 0 > IF I ['] K2 !
 2          BEGIN K2 R @ ABS ['] K2 !
 3          K2 I = NOT IF K2 R @ MINUS  K2 R !D AGAIN THEN LOOP ;
 4 : 1LBSTAT BEGIN 1 ['] JJJ +! JJJ R @ 0< NOT END
 5           JJJ R @  ['] KK !  JK KK * KB + ['] KO ! ;
 6 : LCSTAT BEGIN KO II + AB@ II TA 2!D  II TB 2!D
 7          1 ['] II +! II JK < NOT END   0 ['] II ! ;
 8 : LDLESTAT BEGIN KK R @ MINUS ['] KK ! KO ['] JJ !
 9            JK KK * KB + ['] KO !  BEGIN   KO II + AB@
10            JJ II + AB!                    1 ['] II +!
11            II JK < NOT END   0 ['] II !   KK JJJ = END ;
12
13
14
15


2028
 0 ( BJM - FOURIER TRANSFORMS )
 1 : LFSTAT BEGIN II TB 2@ II TA 2@  KO II + AB!
 2          1 ['] II +!  II JK < NOT END  0 ['] II ! ;
 3 : 2LBSTAT BEGIN BEGIN  1LBSTAT  LCSTAT  LDLESTAT  LFSTAT
 4           JJJ K2 < NOT END 0 ['] JJJ !
 5           SPAN ['] KB +!  KB KN < NOT END ;
 6 : LASTAT 0 DUP DUP ['] KN ! ['] II ! ['] JJJ !
 7          BEGIN KN ['] KB ! KS ['] KN +!
 8          2LBSTAT  KN N < NOT END ;
 9 : 2PERMUTE KT M 1- < IF  M 1+ KT DO
10            I D @ JK / I D !D     LOOP
11            0 ['] JJ !  40STAT 41STAT LASTAT  THEN ;
12 2PERMUTE
13 FORGET FACTOR
14
15


2029
 0 ( BJM - FOURIER TRANSFORMS )
 1 ?SPACE 3750 < IFTRUE CR .# NO SPACE FOR -FFT" QUIT  IFEND
 2 F0. FCONSTANT NFLOAT
 3 : -B'S F1 NV FLOAT F/ ['] NFLOAT 2!
 4        N 0 DO I AB@ NFLOAT F* 2SWAP NFLOAT FMINUS F*
 5        2SWAP I AB! LOOP ;
 6 : B'S N 0 DO I AB@ 2SWAP FMINUS 2SWAP I AB! LOOP ;
 7 -B'S FFT B'S FORGET NFLOAT
 8 EXIT
 9
10
11
12
13
14
15
```

```
2030
 0 ( BJM - FOURIER TRANSFORMS )
 1 : CASET ['] CAREA ! ;
 2 : VALUES DUP := NO 2* DUP DUP ['] N ! ['] NV ! ['] KS ! ;
 3 : FOURIERDATA   ABCOMPLEX 2@ MULT F* ;
 4 : FOURIERDATA    ['] FOURIERDATA := DATAPOINT ;
 5
 6 10 :P CORRPLOT N MOD ABCOMPLEX 2@ PFIX ;
 7 11 :P DIFFERENTIAL DUP 1+ CORRPLOT SWAP 1- CORRPLOT - ;
 8 12 :P PLOT AB@ AMPLITUDE PFIX ;
 9
10
11
12
13
14
15
```

```
2031
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 120 FARRAY PX 120 FARRAY PY  120 FARRAY PW
 2  8 FARRAY AK   104 FARRAY   PA
 3
 4 F0. 2INT PB F0. 2INT PC F0. 2INT S1 F0. 2INT S2 F0. 2INT SMIN
 5 0 INT LA    0 INT LS    0 INT NI    0 INT NORD
 6 0 INT 1LAST 0 INT IK    0 INT IJ    0 INT LT    0 INT KK
 7 0 INT IKK   0 INT KKI   0 INT KKJ
 8 0 INT II    0 INT III   0 INT IIJ   0 INT IIIJ
 9 0 INT PL    0 INT PK    0 INT PJ    0 INT IMIN
10 0 INT IMIN  0 INT NKK   0 INT KKK
11 0 INT NN    0 INT NNN   0 INT LAST
12 -->
13 ;S
14 ;S
15 ;S
```

```
2032
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 : IFIJ 1- LS * + LA + ;
 2
 3 : 1POLY  NNN NN - 1+ ['] NI !
 4 NNN 1+ NN DO I PW 2@ F0. F= IF 0 1- ['] NI +! THEN LOOP
 5 NI 3 < IF 0 ['] NORD ! 1 ABORT" NI < 3 " THEN
 6 LAST DUP DUP ['] 1LAST ! ['] IK ! NI - 2 + 0 > IF
 7 NI 2 - ['] LAST ! THEN LAST DUP 2 + ['] LS ! 3 * 2 + ['] LA !
 8 LAST 2* 1+ ['] LT !
 9 4 1 DO F0. I PA 2!D F0. LT I + PA 2!D LOOP
10 NNN 1+ NN DO I PW 2@ 1 PA F+!D I PW 2@ I PX 2@ F* ['] PB 2!
11 PB 2 PA F+!D I PX 2@ PB F* 3 PA F+!D I PW 2@ I PY 2@ F*
12 LT 1+ PA F+!D I PY 2@ PB F* LT 2 + PA F+!D LOOP 1 ['] NORD ! ;
13 -->
14 ;S
15 ;S
```

```
2033
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 : 4POLY KK 1+ 2 DO I J IFIJ ['] III !
 2 KK 1+ KKK DO J I IFIJ ['] IIJ ! 1 I IFIJ ['] KKI !
 3 KKI PA 2@ III PA 2@ PC F* F* FMINUS IIJ PA F+!D LOOP LOOP ;
 4
 5 : 7POLY NNN 1+ NN DO I PW 2@ 2DUP I PX 2@ 2DUP 2DUP
 6 PJ 1- FLOAT FPWR 6 2UP F* PJ PA F+!D
 7 PJ FLOAT FPWR 4 2UP F* PJ 1+ PA F+!D
 8 NORD FLOAT FPWR F* I PY 2@ F* IKK PA F+!D 2DROP LOOP ;
 9
10 : 8POLY NORD LAST < IF 1 ['] NORD +! NORD 2* ['] PJ !
11 F0. PJ PA 2!D F0. PJ 1+ PA 2!D NORD 1+ LT + ['] IKK !
12 F0. IKK PA 2! 7POLY 0 ELSE IMIN ['] NORD !
13 1LAST ['] LAST ! 1 THEN ;
14 -->
15 ;S


2034
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 : 2POLY KK 1 DO I KK IFIJ ['] IKK ! I LT + ['] PK !
 2 KK 1 DO I 1- J + ['] IK ! J I IFIJ ['] IJ !
 3 IK PA 2@ IJ PA 2!D LOOP PK PA 2@ IKK PA 2!D LOOP ;
 4
 5 : 3POLY KK 1 DO KK I IFIJ DUP >R F1 FMINUS R> PA 2!D ['] KKI !
 6 I 1+ ['] KKK ! KK 1+ KKK DO F0. KK I IFIJ PA 2!D LOOP
 7 1 I IFIJ ['] KKI ! F1 KKI PA 2@ F/ ['] PC 2!
 8 KK 1+ 2 DO I J IFIJ ['] III ! KK 1+ KKK DO J I IFIJ ['] IIJ !
 9 1 I IFIJ ['] KKI ! KKI PA 2@ III PA 2@ PC F* F* FMINUS IIJ PA
10 F+!D LOOP LOOP PL 1+ 1 DO KK 1+ KKK DO J I IFIJ ['] IIJ ! J 1+
11 I IFIJ ['] IIIJ ! IIIJ PA 2@ IIJ PA 2!D LOOP LOOP LOOP ;
12 -->
13 ;S
14 ;S
15 ;S


2035
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 : 6POLY F0. ['] S2 2! NORD 1+ KK IFIJ ['] NKK !
 2 NNN 1+ NN DO NKK PA 2@ ['] S1 2! NORD 1+ 1 DO NORD 1+ I - KK
 3 IFIJ ['] IKK ! J PX 2@ S1 F* IKK PA 2@ F+ ['] S1 2!D LOOP
 4 S1 I PY 2@ F- F**2 I PW 2@ F* ['] S2 F+! LOOP
 5 NI PL - FLOAT ['] PB 2! S2 PB F/ FSQRT ['] S2 2!
 6 NORD 1 > NOT S2 SMIN F< OR IF S2 ['] SMIN 2!
 7 NORD ['] IMIN ! PL 1+ 1 DO I KK IFIJ PA 2@ I AK 2!D LOOP THEN ;
 8
 9 : 5POLY NORD 1+ DUP ['] PL ! 1+ ['] KK ! ;
10 -->
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2036
 0 ( BJM - LEAST SQUARES POLYNOMIAL )
 1 : CLEAR F0. ['] PB 2! F0. ['] PC 2!
 2 F0. ['] S1 2! F0. ['] S2 2! F0. ['] SMIN 2! ;
 3 : SCLEAR 22 0 DO ['] LA I 12 * + 0 SWAP ! LOOP ;
 4  ( THIS CLEARS 22 INTEGERS BY A NASTY METHOD ********** )
 5 : ACLEAR 8 0 DO F0. I AK 2!D LOOP 104 0 DO F0. I PA 2!D LOOP ;
 6 : CLEARALL CLEAR SCLEAR ACLEAR ;
 7
 8 : POLYFIT CLEARALL 1POLY BEGIN 5POLY
 9 2POLY 3POLY 6POLY 8POLY END ;
10 : CALCPOLY F0. NORD 2+ 1 DO 2OVER I 1- FLOAT FPWR I AK 2@ F* F+
11 LOOP 2SWAP 2DROP ;
12
13 : DATA-PRINT NNN 1+ 1 DO CR I PW F? I PX F? I PY F? LOOP ;
14 : ERRS NNN 1+ 1 DO CR I 4 .R I PX F? I PY F? I PX 2@ CALCPOLY
15          I PY 2@ F- F. LOOP ;
```

```
2037
 0 ( BJM - SPLINE FUNCTION )
 1 10000 CONSTANT POINTS
 2
 3 : PTNUMBER POINTS BLOCK 1020  +  ;
 4 : XI 6 * POINTS BLOCK + ; : YI XI 2+ ;
 5  : XI! XI ! UPDATE ;
 6 : YI! YI 2! UPDATE ; : XI XI @ ; : YI YI 2@ ;
 7 : ACCEPT PTNUMBER @ DUP 150 > ABORT" PTNUMBER TOO BIG" 1+ DUP
 8   >R  YI! R> XI! 1 PTNUMBER +! UPDATE ;
 9
10 : PRINTPOINTS CR PTNUMBER @ 1+ 0 DO I XI 6 .R I YI F. CR LOOP ;
11 : CLEARPOINTS 0 PTNUMBER ! UPDATE  ;
12 : FLO FLOAT ;
13 : FVR FVARIABLE ;
14 -->
15 ;S
```

```
2038
 0 ( BJM - SPLINE FUNCTION )
 1 12 CONSTANT NP   VARIABLE RP   1 RP !
 2 FVR LP1    FVR L1    FVR L2    FVR FP1    FVR FP2
 3
 4 : RANGES DUP 2 XI - SWAP NP 1- XI - * ;
 5 : RPSET BEGIN DUP DUP RP @ 1+ XI - 0< NOT IF 1 RP +!
 6         THEN RP @ 1+ XI - 0< END ;
 7
 8 : LP1C F1 RP @ XI RP @ 1+ XI - FLO F/ LP1 2! ;
 9 : L1C RP @ 1+ XI - FLO LP1 2@ F* L1 2! ;
10 : L2C RP @ XI - FLO F0. LP1 2@ F- F* L2 2! ;
11 : FP1C RP @ DUP 2DUP 2>R >R 1+ YI R> 1- YI F- R> 1+ XI R> 1-
12        XI - FLOAT F/ FP1 2! ;
13 :  FP2C RP @ DUP 2DUP >R 2>R 2+ YI R> YI F- R> 2+ XI R> XI
14         - FLOAT F/ FP2 2! ;
15 -->
```

```
2039
 0 ( BJM - SPLINE FUNCTION )
 1 : PA RP @ YI L2 2@ F2 F* F1 F+ F* L1 2@ F**2 F* ;
 2 : PB RP @ 1+ YI L1 2@ F2 F* F1 F+ F* L2 2@ F**2 F* ;
 3 : PC RP @ 1+ XI - FLOAT FP2 2@ F* L2 2@ F**2 F* ;
 4 : PD RP @ XI - FLOAT FP1 2@ F* L1 2@  F**2  F* ;
 5
 6 : P DUP DUP L1C L2C DUP PD ROT PC PB PA F+ F+ F+ ;
 7
 8 : PARCHANGE RP @ SWAP RPSET SWAP RP @ - IF LP1C FP1C
 9              FP2C THEN ;
10
11
12
13
14
15
```

```
2040
 0 ( BJM - HELIOCENTRIC CORRECTION )
 1 F0. 2INT RSUN F0. 2INT RA F0. 2INT HA F0. 2INT DEC
 2 F0. 2INT DX F0. 2INT DY F0. 2INT DZ F0. 2INT VA F0. 2INT VD
 3 FL 360. 2INT F360 FL 86164. 2INT SEC FL 6378.2 2INT RADIUS
 4
 5 : D-R F2 F* PI F* F360 F/ ;  : H-R F15 F* D-R ;
 6
 7 ( CORRECTIONS FOR RADIAL VELOCITY )
 8 : CORRECTION
 9 RA FCOS DEC FCOS F* DX F* RA FSIN DEC FCOS F* DY
10 F* F+ DEC FSIN DZ F* F+ FMINUS := VA
11 F2 PI F* RADIUS F* DEC
12 FCOS F* HA FSIN F* SEC F/ FMINUS := VD
13 VA VD F+ 2DUP := RSUN
14 CR ." RSUN = " F. ." KM/S" CR ;
15 -->
```

```
2041
 0 ( BJM - HELIOCENTRIC CORRECTION )
 1 : RSUN-CALC
 2 CR ." RA= " FASK H-R := RA ." DEC= " FASK D-R := DEC
 3 ." LST= " FASK H-R RA F- := HA CR ." DX= " FASK := DX
 4 ." DY= " FASK := DY ." DZ= " FASK := DZ CORRECTION ;
 5
 6 : SETUP CR
 7 ." SPECTRUM = " ASK := SPEC  CR
 8 CR ." DO YOU KNOW THE SOLAR VELOCITY " Y/N
 9 IF CR ." RSUN= " FASK := RSUN CR ELSE RSUN-CALC THEN ;
10 EXIT
11 : CALC CR ." RA=" FASK H-R := RA ." DEC=" FASK D-R := DEC
12 CR ." DX=" FASK := DX ." DY=" FASK := DY ." DZ=" FASK := DZ
13 CR ." NO.VALUES=" ASK 0 DO CR ." LST=" FASK H-R RA F- := HA
14 CORRECTION LOOP ;
15
```

```
2042
 0 ( BJM - DATA HANDLING )
 1 F0. 2INT SUM  F0. 2INT AVPTS  256 INT N/4 767 INT 3N/4
 2 : REORD N 2/ 0 DO I AB@ N 2/ I + AB@ I AB! N 2/ I + AB! LOOP ;
 3 : TRANSFER F0. := SUM  NO 0 DO I PT @ FLOAT SUM F+ := SUM LOOP
 4 SUM NO FLOAT F/ := AVPTS NO 2/ := N/4 NO 3 * 2/ 1- := 3N/4
 5 N 0 DO I N/4 < I 3N/4 > OR IF F0. F0. I AB! ELSE F0. I N/4 -
 6 PT @ FLOAT AVPTS F- F1000 F/ I AB! THEN LOOP ;
 7 : BACKTRANSFER NO 0 DO I N/4 + N MOD ABCOMPLEX 2@ F1000 F*
 8 AVPTS F+ FIX I PT ! UPDATE LOOP ;
 9 ( CROSS-CORRELATION ROUTINE )
10 : XSPEC N 0 DO STND CASET I 0= IF 0 ELSE N I - THEN AB@
11 SPRM CASET I AB@ C* I AB! LOOP ; : CCF ['] XSPEC := CCF/VBF ;
12 ( DECONVOLUTION ROUTINE )
13 : DECONVOLVE N 0 DO SPRM CASET I AB@ STND CASET I AB@ C/
14 SPRM CASET I AB! LOOP ; : VBF ['] DECONVOLVE := CCF/VBF ;
15
```

```
2043
 0 ( BJM - LOG LAMDA CONVERSION )
 1 F0. 2INT XC  F0. 2INT Y1  F0. 2INT Y2  0 INT XI
 2
 3 : LOGSCALE
 4 CR ." ENTER WAVELENGTH REGION TO BE USED"
 5 CR ." START= " FASK := LSTART CR ." STOP = " FASK := LSTOP
 6 LSTOP FLOG10 LSTART FLOG10 F- NO FLOAT F/ := LSCALE ;
 7
 8 : LOGCONV
 9 LSTART XCALC FIX := SHIFT
10 NO 0 DO I FLOAT LSCALE F* LSTART FLOG10 F+ FALOG XCALC
11 F1 FMAX  NO SHIFT + 1- FLOAT FMIN 2DUP := XC FIX := XI
12 SOURCE SASET  XI PT @ FLOAT := Y1  XI 1+ PT @ FLOAT := Y2
13 Y2 Y1 F- XC XI FLOAT F- F* Y1 F+
14 DEST SASET FIX I PT ! UPDATE LOOP ;
15
```

```
2044
 0 ( BJM - MAX/MIN FINDING ROUTINE )
 1 0 INT +PLACE 0 INT WAY  F0. 2INT PEAK
 2
 3 : CGRAD DUP 1+ DATAPOINT EXECUTE ROT 1- DATAPOINT EXECUTE F- ;
 4 : -PLACE -3 ['] +PLACE +! BEGIN 1 ['] +PLACE +! +PLACE CGRAD
 5 F0. WAY EXECUTE END +PLACE 1- CGRAD 2DUP +PLACE CGRAD F- F/
 6 +PLACE 1- FLOAT F+ ;
 7 : F'SCALE ORG F@ F- FRAME F@ F* RNG F@ F/ FIX ;
 8 : FSCALE 2SWAP Y F'SCALE -ROT X F'SCALE CORNER 2@ V+ ;
 9 : PLACEMARK -PLACE 2DUP 2DUP FIX DATAPOINT EXECUTE
10 2SWAP FSCALE OFF -8 -5 V+ DRAW ALPHA .+ CR ;
11
12 : 2PK BAR 3 + := +PLACE PLACEMARK 2DUP := PEAK ;
13
14 : PEAKS ['] F<  := WAY  ;  : TROUGHS ['] F>  := WAY  ;
15
```

```
2045
 0 ( BJM - LST.SQ.PARABOLA )
 1 9 FARRAY MATRX 3 FARRAY CONST 3 FARRAY SOL  : ZERO 9 0 DO F0. I
 2 MATRX 2!D LOOP 3 0 DO F0. I CONST 2!D F0. I SOL 2!D LOOP ;
 3 : =MN 1- 3 * + 1- ;  : GAUSS/SOLVE  4 2 DO  4 2 DO
 4 J I =MN MATRX 2@  J 1 =MN MATRX 2@  1 1 =MN MATRX 2@  F/
 5 1 I =MN MATRX 2@ F* F-  J I =MN MATRX 2!D LOOP
 6 I 1- CONST 2@  I 1 =MN MATRX 2@  1 1 =MN MATRX 2@  F/
 7 0 CONST 2@ F* F- I 1- CONST 2!D LOOP
 8 3 3 =MN MATRX 2@  3 2 =MN MATRX 2@  2 2 =MN MATRX 2@  F/
 9 2 3 =MN MATRX 2@  F* F-  3 3 =MN MATRX 2!D
10 2 CONST 2@  3 2 =MN MATRX 2@  2 2 =MN MATRX 2@  F/
11 1 CONST 2@ F* F- 2 CONST 2!D
12 2 CONST 2@ 3 3 =MN MATRX 2@ F/ 2 SOL 2!D
13 1 CONST 2@ 2 3 =MN MATRX 2@ 2 SOL 2@ F* F- 2 2 =MN MATRX 2@ F/
14 1 SOL 2!D  0 CONST 2@ 1 2 =MN MATRX 2@ 1 SOL 2@ F* F- 2 SOL 2@
15 1 3 =MN MATRX 2@ F* F- 1 1 =MN MATRX 2@ F/ 0 SOL 2!D ; -->


2046
 0 ( BJM - LST.SQ.PARABOLA )
 1 ( N.B. ---- MAX/MIN ROUTINE NEEDED )
 2 0 INT PTS  F0. 2INT X'  F0. 2INT X0  F0. 2INT Y' FL 3. 2INT F3
 3 : F+!D F+! UPDATE ;  0 INT LLIM 0 INT ULIM
 4 : POINTS ['] PTS ! ZERO 2PK FIX PTS 1- 2/ + 1+ DUP := ULIM
 5 PTS - := LLIM  ULIM LLIM DO I PTS + FLOAT PEAK F- := X'
 6 I DATAPOINT EXECUTE := Y' X' F4 FPWR 1 1 =MN
 7 MATRX F+!D X' F3 FPWR 2DUP 1 2 =MN MATRX F+!D 2 1 =MN MATRX F+!D
 8  X' F**2 2DUP 2DUP 2DUP 1 3 =MN MATRX F+!D 2 2 =MN MATRX F+!D
 9 3 1 =MN MATRX F+!D Y' F* 0 CONST F+!D X' 2DUP 2DUP 2 3 =MN MATRX
10  F+!D 3 2 =MN MATRX F+!D Y' F* 1 CONST F+!D Y' 2 CONST F+!D LOOP
11  PTS FLOAT 3 3 =MN MATRX 2!D  GAUSS/SOLVE
12 1 SOL 2@ F2 0 SOL 2@ F* F/ FMINUS PEAK F+ PTS FLOAT F- := X0 ;
13 : QUAD 2DUP F**2 0 SOL 2@ F* 2SWAP 1 SOL 2@ F* F+ 2 SOL 2@ F+ ;
14 13 :P QUADPLOT PTS + FLOAT PEAK F- QUAD FIX ; : FIT 13 APLOT ;
15 -->


2047
 0 ( BJM - LST.SQ.PARABOLA )
 1 F0. 2INT SX  F0. 2INT SX2  F0. 2INT SY  F0. 2INT SDRES
 2 F0. 2INT DIS  F0. 2INT X+  F0. 2INT X-
 3
 4  : XCAL 2 SOL 2@ 2SWAP F- 0 SOL 2@ F* F4 F* 1 SOL 2@ F**2 2SWAP
 5 F- 2DUP := DIS F0. F> IF 1 SOL 2@ FMINUS 2DUP DIS FSQRT 2DUP
 6 2ROT 2SWAP F+ -2ROT F- 0 SOL 2@ F2 F* 2DUP 2ROT 2SWAP F/ := X-
 7 F/ := X+ THEN ;
 8
 9 : ERROR F0. := SX F0. := SX2 F0. := SY
10 ULIM LLIM DO I DATAPOINT EXECUTE
11 XCAL DIS F0. F> IF F1 SY F+ := SY I FLOAT X0 F< IF X+ ELSE
12 X- THEN I PTS + FLOAT PEAK F- F- 2DUP SX F+ := SX F**2 SX2 F+
13 := SX2 THEN LOOP SY SX2 F* SX F**2 F- FSQRT SY F/ := SDRES ;
14
15
```

```
2048
 0 ( BJM - WAVELENGTH CALIBRATION / BASICS )
 1 FORGET SUBTASK  : SUBTASK ;
 2 10 2 FMT     0 WARNING !
 3 -46 +BLOCK LOAD ( SPLITSCREEN GRAPHICS )
 4 -38 +BLOCK LOAD ( DISC ARRAYS )
 5 -17 +BLOCK LOAD ( LST.SQ.POLYNOMIAL )
 6
 7 -4 +BLOCK LOAD SPECTRUMDATA PEAKS ( MAX/MIN ROUTINE )
 8 -3 +BLOCK LOAD ( LST.SQ.PARABOLA )
 9
10 WAREA ' WORKAREA !
11 0 INT ARCNO 0 VARIABLE OP
12
13 : SETARC SPLITSCREEN 0 C'] ARCNO ! CR
14 TOP ." ARC 1= " ASK SASET BOT ." ARC 2= " ASK SASET ;
15 -->
```

```
2049
 0 ( BJM - WAVELENGTH CALIBRATION / MEASUREMENT CATALOGUE )
 1 OAREA INT OBSAREA
 2
 3 : OBS 14 16 1024 */MOD OBSAREA + BLOCK + ;
 4 : NPTS -1 OBS ;
 5 : LPOS OBS ;
 6 : XPOS OBS 4 + ;
 7 : FLAG OBS 8 + ;
 8
 9 : INCLUDE 1 SWAP FLAG !D ;
10 : EXCLUDE 0 SWAP FLAG !D ;
11 : ZERO NPTS @ 0 DO F0. I XPOS 2!D 0 I FLAG !D LOOP ;
12 -->
13 ;S
14 ;S
15 ;S
```

```
2050
 0 ( BJM - WAVELENGTH CALIBRATION / ARC LINE CATALOGUE )
 1 10000 INT ARC-CAT
 2
 3 : VAL 14 4 1024 */MOD ARC-CAT + BLOCK + ;
 4 : NLINES -1 VAL ;
 5 : LLAB VAL ;
 6
 7 : CLEAR-CATALOGUE 0 NLINES !D ;
 8 -->
 9 ;S
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2051
 0 ( BJM - WAVELENGTH CALIBRATION / ARC LINE CATALOGUE )
 1 : LIST-LINES CR ." NO.  WAVELENGTH"
 2 NLINES @ 0 DO CR I DUP . LLAB F? LOOP ;
 3
 4 : CREATE-CATALOGUE CR ." NO.LINES= " ASK CR CR
 5 ." WAVELENGTH" CR
 6 NLINES @ + NLINES @ DO CR FASK I LLAB 2!D 7 C.
 7 NLINES @ 1+ NLINES !D LOOP ;
 8
 9 : CHANGE CR ." NO.=" ASK ." WAVELENGTH=" FASK ROT LLAB 2!D ;
10
11 : DELETE CR ." NO.=" ASK NLINES @ SWAP DO
12 I 1+ LLAB 2@ I LLAB 2!D LOOP NLINES @ 1 - NLINES !D ;
13 -->
14 ;S
15 ;S
```

```
2052
 0 ( BJM - WAVELENGTH CALIBRATION / PROCEDURE )
 1 : NEXTARC ARCNO NLINES @ = IF ." END OF CATALOGUE" CR ELSE
 2 ARCNO LLAB 2@ 2DUP F. ARCNO LPOS 2!D
 3 TOP NOP POINTS XO 2DUP F. BOT NOP POINTS XO 2DUP F.
 4 F+ F2 F/ ARCNO XPOS 2!D
 5 1 ARCNO FLAG !D 1 ['] ARCNO +!  7 C. THEN ;
 6 : ) NEXTARC ;
 7
 8 : DISPLAY ERASE 2DUP TOP X SIZE X-GRID X-AXIS SPLOT
 9 BOT X SIZE SPLOT ;
10 0 1000 Y SIZE
11
12 : REJECT -1 ['] ARCNO +! ;
13 : SKIP -1 ['] ARCNO +! 0 ARCNO FLAG !D 1 ['] ARCNO +! ;
14 -->
15 ;S
```

```
2053
 0 ( BJM - WAVELENGTH CALIBRATION / OUTPUT )
 1 : PRINT-CALIBRATION
 2 ERASE ." LINE   WAVELENGTH      XPOS    (O-C)IN    (O-C)EX"
 3 NPTS @ 0 DO CR I 3 .R 2 SPACES I LPOS F? I XPOS F?
 4 I LPOS 2@ L-LS CALCPOLY XS-X I XPOS 2@ 2SWAP F-
 5 I FLAG @ 0 = IF 10 SPACES THEN F. LOOP
 6 1 AK 2@ := NO 2 AK 2@ := N1 3 AK 2@ := N2 4 AK 2@ := N3
 7 5 AK 2@ := N4 6 AK 2@ := N5 CR CR ." ORDER   COEFFICIENT"
 8 10 6 FMT 6 0 DO CR I DUP . 1+ 3 SPACES AK F? LOOP
 9 10 2 FMT CR CR ." LZERO= " LZERO F1000 F* F. ;
10 -->
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2054
 0 ( BJM - WAVELENGTH CALIBRATION / OUTPUT )
 1 CREATE NAME  20 ALLOT
 2
 3 0 +BLOCK
 4 : PRINTOUT NAME 20 BLANK CR ." ENTER TITLE : "  NAME 20 EXPECT
 5 13 IN-LINE L#LOAD ;
 6 -->
 7 ;S
 8 ;S
 9 ;S
10
11
12
13 PRINT  10 2 FMT  CR .# Wavelength calibration :  "
14 NAME  20 TYPE CR CR PRINT-CALIBRATION CR CR
15


2055
 0 ( BJM - WAVELENGTH CALIBRATION / CALCULATION )
 1 : CALIBRATION
 2 FULLSCREEN
 3 ERASE ." MAX.ORDER POLYNOMIAL REQUIRED = " ASK ['] LAST !
 4 ARCNO NPTS !D  0 OP !
 5 NPTS @ 0 DO I FLAG @ 1 = IF 1 OP +!
 6 I LPOS 2@ L-LS OP @ PX 2!D
 7 I XPOS 2@ X-XS OP @ PY 2!D
 8 F1 OP @ PW 2!D THEN LOOP
 9 1 ['] NN ! OP @ ['] NNN !
10 LAST 5 > NOT IF POLYFIT PRINT-CALIBRATION ELSE
11 CR ." POLYNOMIAL CAN ONLY FIT UP TO ORDER 5" CR THEN ;
12 ERASE
13 CR CR .# WAVELENGTH CALIBRATION MODE" CR
14 -->
15 ;S


2056
 0 ( BJM - WAVELENGTH CALIBRATION / ARC LINE MASTER CATALOGUE )
 1 2200 INT MASTER-CATALOGUE
 2
 3 : M-VAL 1+ 64 1024 */MOD MASTER-CATALOGUE + BLOCK + ;
 4 : NSETS -1 M-VAL ;
 5 : TITLE-IN  PAD 30 BLANK  PAD 30 EXPECT  PAD SWAP
 6             M-VAL 30 MOVE ;
 7 : TITLE-OUT M-VAL  30 TYPE ;
 8 : CATALOGUE-BLOCK M-VAL 60 + ;
 9
10 : DELETE-CATALOGUE
11 NSETS @ SWAP DO I 1+ M-VAL 60 + @ I M-VAL 60 + !D
12 I 1+ M-VAL I M-VAL 30 MOVE UPDATE
13 LOOP NSETS @ -1 + NSETS !D ;
14 -->
15 ;S
```

```
2057
 0 ( BJM - WAVELENGTH CALIBRATION / ARC LINE MASTER CATALOGUE )
 1 : ENTER
 2 CR ." BLK.NO.=     " ASK := ARC-CAT
 3 CR ." DO YOU WISH TO CREATE NEW CATALOGUE ?" Y/N 1 = IF
 4 CR ." ENTER TITLE "
 5 1 NSETS +!D NSETS @ TITLE-IN 7 C.
 6 ARC-CAT NSETS @ CATALOGUE-BLOCK !D CLEAR-CATALOGUE
 7 CREATE-CATALOGUE ELSE
 8 CREATE-CATALOGUE THEN ;
 9
10 -->
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S



2058
 0 ( BJM - WAVELENGTH CALIBRATION / ARC LINE MASTER CATALOGUE )
 1 : CATALOGUE CR ." CATALOGUE OF ARC LINES AVAILABLE" CR
 2 CR ." NO.  TITLE" 23 SPACES ." BLK"
 3 CR ." ==========================================="
 4 CR ." -N) < DELETE CATALOGUE NO. N >"
 5 CR ."  0) < ENTER NEW LINES >"
 6 NSETS @ MINUS 0< IF NSETS @ 1+ 1 DO CR I 2 .R 41 C. 1 SPACES
 7 I TITLE-OUT 2 SPACES I CATALOGUE-BLOCK ? LOOP THEN
 8 CR CR ." ENTER NO.REQUIRED " ASK := M
 9 M 0= IF ENTER THEN
10 M 0 < NSETS @ 0 > AND IF M MINUS DELETE-CATALOGUE THEN
11 M 0 > NSETS @ M < NOT AND IF
12 M CATALOGUE-BLOCK @ := ARC-CAT THEN ;
13
14 1 WARNING ! CATALOGUE
15



2059
 0 ( BJM - NOISEFILTER / BASICS )
 1 FORGET SUBTASK : SUBTASK ;
 2 0 WARNING !
 3
 4 -48 +BLOCK LOAD ( FFT )
 5 -49 +BLOCK LOAD ( DISC ARRAYS )
 6 -17 +BLOCK LOAD ( DATA HANDLING )
 7
 8 WAREA ' WORKAREA !
 9 F0. 2INT (B/A)2   F0. 2INT ALPHA0   F1 2INT A   F0. 2INT B
10 -->
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2060
 0 ( BJM - NOISEFILTER / PARAMETERS )
 1 : BASET F/ F**2 ['] (B/A)2 2! ; : GFIX 1000 FLOAT F* FIX ;
 2
 3 : F(S) F**2 ALPHA0 F**2 F* F2 F* 2DUP F10 F< IF
 4         FALOG (B/A)2 F* F1 F+  F1 2SWAP F/ ELSE 2DROP F0. THEN ;
 5
 6 : GAUS F**2 ALPHA0 F**2 F* 2DUP F10 F> IF
 7         2DROP F0. ELSE FMINUS FALOG A F* THEN ;
 8
 9 : CUTOFF (B/A)2 FLOG10 F2 F/ FMINUS FSQRT ROT
10         FLOAT F/ := ALPHA0 ;
11
12 : NOISE F0. ROT DUP 2* >R N 2/ DUP ROT + SWAP DO I AB@
13 AMPLITUDE F+ LOOP F2 F* R> FLOAT F/ 2DUP F. A BASET ;
14 -->
15 ;S
```

```
2061
 0 ( BJM - NOISEFILTER / PROCEDURE )
 1 500 INT PTNOISE  1000 INT PTCUTOFF
 2
 3 : FILTER N 2/ 1 DO I FLOAT F(S) 2DUP 2DUP 2DUP I AB@ 2>R F*
 4 2SWAP 2R> F* I AB! N I - AB@ 2>R F* 2SWAP 2R> F* N I - AB! LOOP
 5 F0. F0. N 2/ AB!  ;
 6
 7 : PARAMETERS ." NO.POINTS = " ASK VALUES ." THRESHOLD= " ASK
 8 N SWAP /  := PTCUTOFF  N 10 / := PTNOISE ;
 9
10 : AUTO  F0. 20 1 DO I AB@ AMPLITUDE FMAX LOOP := A
11 A F. PTNOISE NOISE PTCUTOFF CUTOFF ;
12 : AUTOFILTER AREA CASET TRANSFER FFT
13                AUTO FILTER -FFT BACKTRANSFER SIGNAL ;
14 -->
15 ;S
```

```
2062
 0 ( BJM - NOISEFILTER / PROCEDURE )
 1 4 :P GAUSPLOT FLOAT GAUS B F+ GFIX ; : GAUSPLOT 4 APLOT ;
 2 5 :P FILPLOT  FLOAT F(S) GFIX ;      : FILPLOT  5 APLOT ;
 3 : DISPLAY X SIZE ERASE AXES SPLOT ;
 4
 5 : SETSPEC CR ." SPECTRUM= " ASK SPECTRUM CR PARAMETERS CR
 6 ." TYPE AUTOFILTER TO CONTINUE" CR ;
 7
 8 : SINGLE SETSPEC ;
 9 1 +BLOCK LOADER MULTIPLE
10 1 WARNING !
11
12 PAGE .# NOISE FILTERING MODE " CR
13 CR .# A) SINGLE SPECTRUM  - TYPE SINGLE"
14 CR .# B) MULTIPLE SPECTRA - TYPE MULTIPLE" CR
15 : MINITASK ;
```

```
2063
 0 ( BJM - NOISEFILTER / MULTIPLE SPECTRA )
 1 FORGET MINITASK : MINITASK ;
 2 0 INT LLIM 0 INT ULIM 0 INT CDM 0 INT BLKLENGTH
 3 : LENGTH CDM 1 = IF BLKLENGTH THEN
 4 CDM 2 = IF BLKLENGTH 3 * THEN ;
 5 : FILTERING CR CR PARAMETERS CR CR CR
 6 ." 1) : SPECTRA STORED SUCCESSIVELY ON DISC" CR
 7 ." 2) : SPECTRA STORED WITH THEIR ARCS ON DISC"
 8 CR CR ." ENTER CODE REQUIRED " ASK := CDM
 9 CR CR ." BLOCK LENGTH = " ASK := BLKLENGTH
10 CR ." FIRST SPECTRUM= " ASK := LLIM
11 CR ." LAST SPECTRUM= " ASK LENGTH + := ULIM
12 CR ." TYPE AUTOFILTERING TO CONTINUE " CR CR ;
13 : AUTOFILTERING ULIM LLIM DO CR I DUP . SPECTRUM AUTOFILTER
14 TIME LENGTH +LOOP ;
15 PAGE .# MULTIPLE NOISE FILTERING MODE " CR FILTERING


2064
 0 ( BJM - DENSITY/INTENSITY CALIBRATION )
 1 FORGET SUBTASK : SUBTASK ;
 2 0 WARNING !
 3 -54 +BLOCK LOAD ( DISC ARRAYS )
 4 FL 0.002578 2INT FACT
 5 F0. 2INT W0 F0. 2INT W1 F0. 2INT W2 F0. 2INT W3
 6 0 INT FOG F0. 2INT RMS F0. FVARIABLE SUM
 7 CREATE NAME  20 ALLOT
 8
 9  1 +BLOCK LOADER WEDGESET
10 10 +BLOCK LOADER PLATESET
11 : MINITASK ;
12 PAGE .# DENSITY-INTENSITY CALIBRATION AND CONVERSION MODE " CR
13 CR .# TYPE WEDGESET :- STEP WEDGE CALIBRATION"
14 CR .#       PLATESET :- D-I CONVERSION" CR
15


2065
 0 ( BJM - WEDGE CALIBRATION )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 0AREA INT OBSAREA
 4 0 INT OP
 5
 6 : OBS 1+ 16 1024 */MOD OBSAREA + BLOCK + ;
 7 : NPTS -1 OBS ;
 8 : LOGI OBS ;
 9 : DENS OBS 4 + ;
10 : FLAG OBS 8 + ;
11
12 : INCLUDE 1 SWAP FLAG !D ;
13 : EXCLUDE 0 SWAP FLAG !D ;
14 : ZERO NPTS @ 0 DO F0. I DENS 2!D 0 I FLAG !D LOOP ;
15 -->
```

```
2066
 0 ( BJM - WEDGE CALIBRATION )
 1 : ENTER
 2 CR ." DATA AREA = " ASK := OBSAREA
 3 CR ." NO.STEPS  = " ASK := OP
 4 CR OP NPTS !D  ZERO
 5 CR ." ENTER LOG I VALUES FOR EACH STEP " CR
 6 CR ." STEP NO.     LOG I"
 7 OP 0 DO CR I 5 .R 5 SPACES FASK I OBS 2!D LOOP ;
 8
 9 : CHECK
10 CR ." STEP NO.  LOG I     DENSITY  FLAG"
11 NPTS @ 0 DO CR I 5 .R I LOGI 2@ F. I DENS 2@ F.
12 I FLAG @ 5 .R LOOP CR ;
13 -->
14 ;S
15 ;S
```

```
2067
 0 ( BJM - WEDGE CALIBRATION )
 1 : FOG-LEVEL AVPT DROP DUP := FOG . ;
 2
 3 : STEP-LEVEL AVPT DROP ;
 4
 5 : LEVELS
 6 FOG-LEVEL
 7 NPTS @ 0 DO STEP-LEVEL
 8 XFROM @ XTO @ = NOT IF DUP .  1 I FLAG !D
 9 FOG - FLOAT FACT F* FALOG F1 F- FLOG10 I DENS 2!D
10 ELSE DROP F0. I DENS 2!D 0 I FLAG !D
11 THEN LOOP ;
12 -->
13 ;S
14 ;S
15 ;S
```

```
2068
 0 ( BJM - WEDGE CALIBRATION )
 1 WAREA ' WORKAREA !
 2 4 INT ORDER 16 FARRAY [A] 4 FARRAY [B] 4 FARRAY [C]
 3 0 INT NN F0. 2INT T F0. 2INT XVAL F0. 2INT YVAL FL 6. 2INT F6
 4 : F@ @ FLOAT ;  : MN SWAP 4 * + ;
 5
 6 : [A@] MN [A] 2@ ;  : [A!] MN [A] 2!D ;  : [A+!] MN [A] F+!D ;
 7 : [B@] [B] 2@ ;     : [B!] [B] 2!D ;     : [B+!] [B] F+!D ;
 8 : [C@] [C] 2@ ;     : [C!] [C] 2!D ;     : [C+!] [C] F+!D ;
 9 : CLEAR 4 0 DO 4 0 DO F0. I J [A!] LOOP F0. I [C!] LOOP ;
10 : CLEARALL CLEAR 4 0 DO F0. I [B!] LOOP ;   CLEARALL
11
12 : YCALC 2DUP 2DUP 2DUP F**2 2SWAP F* 3 [B@] F* 2SWAP F**2
13 2 [B@] F* F+ 2SWAP 1 [B@] F* F+ 0 [B@] F+ ;
14 -->
15 ;S
```

```
2069
 0 ( BJM - WEDGE CALIBRATION )
 1 : ACCUMULATE CLEAR
 2 NPTS @ 0 DO I FLAG @ 1 = IF I LOGI 2@ := YVAL I DENS 2@ := XVAL
 3 F1 0 0 [A+!]  YVAL 0 [C+!]  XVAL 2DUP 0 1 [A+!] 1 0 [A+!]
 4 XVAL F**2 2DUP 2DUP 0 2 [A+!] 1 1 [A+!] 2 0 [A+!]
 5 XVAL 2DUP F**2 F* 2DUP 2DUP 2DUP
 6 0 3 [A+!] 2 1 [A+!] 1 2 [A+!] 3 0 [A+!]
 7 XVAL 2DUP F**2 2SWAP F**2 F* 2DUP 2DUP 1 3 [A+!] 2 2 [A+!]
 8 3 1 [A+!]
 9 XVAL 2DUP 2DUP F**2 2SWAP F**2 F* F* 2DUP
10 2 3 [A+!] 3 2 [A+!]
11 XVAL 2DUP 2DUP F**2 2SWAP F**2 F* 2SWAP F**2 F*
12 3 3 [A+!]    YVAL XVAL F* 1 [C+!]
13 YVAL XVAL F**2 F* 2 [C+!]
14 YVAL XVAL 2DUP F**2 2SWAP F* F* 3 [C+!] THEN LOOP ;
15 -->
```

```
2070
 0 ( BJM - WEDGE CALIBRATION )
 1 : SOLVE-MATRIX
 2 ORDER 1- := NN
 3 ORDER 0 DO 0 I [A@] := T
 4 NN 0 DO I 1+ J [A@] T F/ I J [A!] LOOP
 5 F1 T F/ NN I [A!]
 6 ORDER 0 DO I J = NOT IF 0 I [A@] := T
 7 NN 0 DO I 1+ J [A@] I K [A@] T F* F- I J [A!] LOOP
 8 NN J [A@] T F* FMINUS NN I [A!] THEN LOOP LOOP
 9 ORDER 0 DO F0. := T
10 ORDER 0 DO J I [A@] I [C@] F* T F+ := T LOOP
11 T I [B!] LOOP ;
12 -->
13 ;S
14 ;S
15 ;S
```

```
2071
 0 ( BJM - WEDGE CALIBRATION )
 1 0 INT XMIN 0 INT XMAX 0 INT YMIN 0 INT YMAX
 2 14 :P PLOTCURVE FLOAT FL 100. F/ YCALC FL 100. F* FIX ;
 3 : CURVEPLOT 14 APLOT ;
 4 0 +BLOCK : CAPTIONS 14 IN-LINE L*LOAD ;
 5 : PLOTVALUES 0 := XMIN 0 := XMAX 0 := YMIN 0 := YMAX
 6 2 X DECIMALS ! 2 Y DECIMALS ! NPTS @ 0 DO I FLAG @ 1 = IF
 7 I DENS 2@ FL 100. F* FIX DUP XMIN MIN := XMIN XMAX MAX := XMAX
 8 I LOGI 2@ FL 100. F* FIX DUP YMIN MIN := YMIN YMAX MAX := YMAX
 9 THEN LOOP XMIN XMAX X SIZE YMIN YMAX Y SIZE
10 OFF CROSSPLOT NPTS @ 0 DO I FLAG @ 1 = IF
11 I LOGI 2@ FL 100. F* FIX I DENS 2@ FL 100. F* FIX
12  LIGHT THEN LOOP LINEPLOT AXES CAPTIONS ;
13 -->
14 300 175 HEADING HP" LOG I"
15 50 800 HEADING HP" BAKER DENSITY" ALPHA
```

```
2072
 0 ( BJM - WEDGE CALIBRATION )
 1 : STEPS
 2 CR ." SPECTRUM AREA FOR WEDGE    " ASK SPECTRUM
 3 CR ." NO.POINTS IN SCAN          = " ASK 0 SWAP X SIZE
 4 CR ." DATA AREA FOR LOG I        = " ASK := OBSAREA
 5 0 X DECIMALS ! 0 Y DECIMALS !
 6 0 1000 Y SIZE ERASE AXES SPLOT LEVELS ;
 7 : PRINT-CALIBRATION F0. SUM 2! 0 := OF
 8 CR ." STEP NO.  LOG I     DENSITY        O-C      FLAG"
 9 NPTS @ 0 DO CR I 5 .R I LOGI 2@ 2DUP F. I DENS 2@ 2DUP F.
10 YCALC F- 2DUP F. I FLAG @ DUP 5 .R 1 = IF F**2 SUM F+!
11 1 ['] OF +! ELSE 2DROP THEN LOOP SUM 2@ OF FLOAT F/ := RMS
12 CR CR ." ORDER     COEFFICIENT    ERROR"
13 4 0 DO CR I DUP 5 .R [B@] F. I 1 [A@] RMS F* FSQRT F. LOOP ;
14 -->
15 ;S


2073
 0 ( BJM - WEDGE CALIBRATION )
 1 -71 +BLOCK LOAD ( SPLITSCREEN )
 2 : SOLVE PAGE PLOTVALUES 757 200 HEADING
 3 CR ." ORDER OF POLYNOMIAL TO BE FITTED = " ASK 1+ := ORDER
 4 CLEARALL ACCUMULATE SOLVE-MATRIX
 5 0 [B@] := W0 1 [B@] := W1 2 [B@] := W2 3 [B@] := W3
 6 PAGE PRINT-CALIBRATION
 7 SPLITSCREEN PLOTVALUES CURVEPLOT FULLSCREEN ;
 8 : CALIBRATION  STEPS SOLVE ;
 9  0 +BLOCK
10 : PRINTOUT NAME 20 BLANK CR ." ENTER TITLE : " NAME 20 EXPECT
11    14  IN-LINE  L#LOAD ;
12 PAGE .# STEP WEDGE CALIBRATION MODE " CR 1 WARNING !
13 EXIT
14 PRINT   10 2 FMT  CR .# WEDGE CALIBRATION : "
15 NAME  20 TYPE CR CR PRINT-CALIBRATION CR CR  ;


2074
 0 ( BJM - DENSITY:INTENSITY CONVERSION )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 10000 INT RECT 10000 INT RECTPOINTS
 4   VARIABLE PLATE FL 0.002578 FVARIABLE FACTOR    FACTOR 2!
 5   VARIABLE LLIMIT   VARIABLE ULIMIT
 6 F0. 2INT BD 0 INT SFMAX
 7
 8 : GFIX F1000 F* FIX ;
 9 : QT 2 1024 */MOD RECT + BLOCK + ;
10 : QT! >R GFIX R> QT ! UPDATE ;
11 : QT@ QT @ ;
12 : LOM FACTOR 2@ F* FALOG F1 F- FLOG10 ;
13 -->
14 ;S
15 ;S
```

```
2075
 0 ( BJM - DENSITY:INTENSITY CONVERSION )
 1 : SET-CALIBRATION CR ." ORDER   COEFFICIENT"
 2 4 0 DO CR I . 3 SPACES FASK LOOP
 3 := W3 := W2 := W1 := W0 CR ;
 4
 5 : PRINT-COEFFICIENTS CR ." ORDER   COEFFICIENT" 10 6 FMT
 6 CR 0 . W0 F. CR 1 . W1 F. CR 2 . W2 F. CR 3 . W3 F.
 7 10 2 FMT ;
 8
 9 : D-I ULIMIT @ 1+ LLIMIT @ DO I PT @ PLATE @ -
10 FLOAT LOM := BD W3 F1 3 0 DO BD F* LOOP F*
11 W2 BD F**2 F* F+ W1 BD F* F+ W0 F+ FALOG I QT! LOOP
12 LIMITS  DO I PT @ SPMAX MAX := SPMAX LOOP 0 SPMAX 200 + Y SIZE
13 PAGE AXES SPLOT SIGNAL ;
14 -->
15 ;S
```

```
2076
 0 ( BJM - DENSITY:INTENSITY CONVERSION )
 1 : SETSPEC CR ." SPECTRUM = " ASK SPECTRUM SAREA ['] RECT !
 2 CR ." NO.OF POINTS = " ASK 1- 0 SWAP X SIZE
 3 0 1000 Y SIZE
 4 CR ." IS THE BAKER DENSITY CALIBRATION SET UP ? "
 5 Y/N NOT IF SET-CALIBRATION THEN
 6 PAGE AXES SPLOT
 7 767 0 HEADING ." PLATE FOG = " ASK PLATE !
 8 CR ." LOWER LIMIT = " ASK LLIMIT !
 9 CR ." UPPER LIMIT = " ASK ULIMIT !
10 CR ." TYPE D-I TO CONVERT DENSITY TO INTENSITY " ;
11
12 PAGE .# DENSITY-INTENSITY CONVERSION MODE " CR
13 1 WARNING !
14
15
```

```
2077
 0 FORGET SUBTASK  : SUBTASK ;
 1
 2 1 +BLOCK : MANUAL IN-LINE LOAD ;
 3 4 +BLOCK : AUTO IN-LINE LOAD ;
 4
 5 : MINITASK ;
 6
 7 PAGE .# SELECT METHOD OF FITTING TO CONTINUUM" CR
 8 CR .# COMPUTER FIT USING CUBIC :- TYPE AUTO"
 9 CR .# MANUAL FIT USING SPLINE  :- TYPE MANUAL" CR
10
11
12
13
14
15
```

```
2078
 0 ( BJM - NORMALISATION TO CONTINUUM )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 -41 +BLOCK LOAD ( SPLINES )
 4 -68 +BLOCK LOAD ( DISC ARRAYS )
 5 10000 CONSTANT RECT 10000 CONSTANT RECTPOINTS
 6 FL 1000. 2DUP FVARIABLE F1000 FCONSTANT THOU
 7 0 VARIABLE LLIMIT 1 VARIABLE ULIMIT 1000 INT CONT
 8
 9 : GFIX FL 1000. F* FIX ;
10 : RPTSET RECTPOINTS ['] POINTS ! ;
11 : QT 2 1024 */MOD RECT + BLOCK + ;
12 : QT@ QT @ ;
13 : QT! >R GFIX R> QT ! UPDATE ;
14 -->
15 ;S



2079
 0 ( BJM - NORMALISATION TO CONTINUUM )
 1 : CONTSET RPTSET ." HOW MANY PTS ? " ASK
 2 0 DO AVPT SWAP FLOAT ACCEPT LOOP ;
 3
 4 : CSET RPTSET ." NO.OF PTS ? " ASK
 5 0 DO COORDS FLOAT ACCEPT LOOP ;
 6
 7 : RECTIFY RPTSET 1 RP ! PTNUMBER @ 1- XI 2 XI DO I PT @ FLOAT I
 8 PARCHANGE P F/ I QT! LOOP  2 XI 0 DO 1000 I PT !D LOOP
 9 LIMITS DROP PTNUMBER @ 1- XI DO 1000 I PT !D LOOP FLUSH
10 PAGE AXES SPLOT SIGNAL ;
11
12 -->
13 : RPLOT 2 APLOT 3 Y DECIMALS ! AXES 0 Y DECIMALS ! ;
14 -->
15 ;S



2080
 0 ( BJM - NORMALISATION TO CONTINUUM )
 1 : SETSPEC CR ." SPECTRUM = " ASK SPECTRUM SAREA ['] RECT !
 2 CR ." NO.OF POINTS= " ASK 1- 0 SWAP X SIZE PAGE AXES SPLOT
 3 0AREA ['] RECTPOINTS ! RPTSET 0 PTNUMBER ! UPDATE
 4 767 0 OFF DRAW ALPHA
 5 CR ." TYPE CSET OR CONTSET TO DEFINE CONTINUUM"
 6 CR ."       RECTIFY TO NORMALISE THE SPECTRUM" CR ;
 7 1 WARNING !
 8
 9 PAGE .# SPLINE FIT TO CONTINUUM " CR
10
11
12
13
14
15
```

```
2081
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 -71 +BLOCK LOAD ( DISC ARRAYS )
 4 WAREA ' WORKAREA !
 5 : EAS ERASE AXES SPLOT ;  : DISPLAY X SIZE EAS ;
 6
 7 4 INT ORDER
 8 16 FARRAY [A] 4 FARRAY [B] 4 FARRAY [C]
 9
10 0 INT NN 0 INT NPTS 0 INT ITERATION
11 F0. 2INT T FL 6.0 2INT F6
12 F0. 2INT XVAL F0. 2INT YVAL
13 F0. 2INT RMS
14 F0. 2INT SIGMA  F10 2INT CSIGMA
15 -->


2082
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 : F@ @ FLOAT ;  : MN ORDER * + ;
 2
 3 : [A@] MN [A] 2@ ;  : [A!] MN [A] 2!D ;  : [A+!] MN [A] F+!D ;
 4 : [B@] [B] 2@ ;     : [B!] [B] 2!D ;     : [B+!] [B] F+!D ;
 5 : [C@] [C] 2@ ;     : [C!] [C] 2!D ;     : [C+!] [C] F+!D ;
 6
 7 : CLEAR 4 0 DO 4 0 DO F0. I J [A!] LOOP F0. I [C!] LOOP ;
 8 : CLEARALL CLEAR 4 0 DO F0. I [B!] LOOP ;   CLEARALL
 9
10 : YCALC FLOAT X-XS 2DUP 2DUP F3 FPWR 3 [B@] F* 2SWAP F**2
11 2 [B@] F* F+ 2SWAP 1 [B@] F* F+ 0 [B@] F+ ;
12 -->
13 ;S
14 ;S
15 ;S


2083
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 : ACCUMULATE CLEAR
 2 LIMITS DO I PT F@ := YVAL I FLOAT X-XS := XVAL
 3 I YCALC YVAL F- 2DUP SIGMA F< -ROT FMINUS SIGMA F2 F* F< AND IF
 4 F1 0 0 [A+!]  YVAL 0 [C+!]
 5 XVAL 2DUP 0 1 [A+!] 1 0 [A+!]
 6 XVAL F**2 2DUP 2DUP 0 2 [A+!] 1 1 [A+!] 2 0 [A+!]
 7 XVAL F3 FPWR 2DUP 2DUP 2DUP
 8 0 3 [A+!] 2 1 [A+!] 1 2 [A+!] 3 0 [A+!]
 9 XVAL F4 FPWR 2DUP 2DUP 1 3 [A+!] 2 2 [A+!] 3 1 [A+!]
10 XVAL F5 FPWR 2DUP 2 3 [A+!] 3 2 [A+!]
11 XVAL F6 FPWR 3 3 [A+!]
12 YVAL XVAL F* 1 [C+!]
13 YVAL XVAL F**2 F* 2 [C+!]
14 YVAL XVAL F3 FPWR F* 3 [C+!] THEN LOOP ;
15 -->
```

```
2084
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 : PARAMETERS CR ." NO.POINTS=" ASK 1- 1 SWAP X SIZE ;
 2
 3 : SOLVE
 4 ORDER 1- := NN
 5 ORDER 0 DO 0 I [A@] := T
 6 NN 0 DO I 1+ J [A@] T F/ I J [A!] LOOP
 7 F1 T F/ NN I [A!]
 8 ORDER 0 DO I J = NOT IF 0 I [A@] := T
 9 NN 0 DO I 1+ J [A@] I K [A@] T F* F- I J [A!] LOOP
10 NN J [A@] T F* FMINUS NN I [A!] THEN LOOP LOOP
11 ORDER 0 DO F0. := T
12 ORDER 0 DO J I [A@] I [C@] F* T F+ := T LOOP
13 T I [B!] LOOP ;
14 -->
15 ;S


2085
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 : RMSCALC 0 := NPTS F0. := RMS
 2 LIMITS DO I PT F@ := YVAL
 3 I YCALC YVAL F- 2DUP SIGMA F< -ROT FMINUS SIGMA F2 F* F< AND IF
 4 I YCALC YVAL F- F**2 ['] RMS F+! 1 ['] NPTS +! THEN
 5 LOOP RMS NPTS FLOAT F/ FSQRT := SIGMA ;
 6
 7 : FIT CLEARALL F1000 := SIGMA 0 := ITERATION
 8 BEGIN ACCUMULATE SOLVE RMSCALC 1 ['] ITERATION +!
 9 SIGMA CSIGMA F< ITERATION 10 > OR END ;
10 .
11 : RECTIFY LIMITS DO I PT F@ F1000 F* I YCALC F/
12 FIX I PT ! UPDATE LOOP ;
13 : NORMALISE FIT RECTIFY ;
14 -->
15 ;S


2086
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM )
 1 4 :P CONTPLOT YCALC FIX ;  : CONTPLOT 4 APLOT ;
 2
 3 : SETSPEC CR ." SPECTRUM= " ASK SPECTRUM CR PARAMETERS CR
 4 ." TYPE NORMALISE TO CONTINUE " CR ;
 5
 6 : SINGLE SETSPEC ;
 7 1 +BLOCK : MULTIPLE IN-LINE LOAD ;
 8 1 WARNING !
 9
10 PAGE .# AUTOMATIC CONTINUUM FIT AND NORMALISATION" CR
11 CR .# A) SINGLE SPECTRUM  - TYPE SINGLE"
12 CR .# B) MULTIPLE SPECTRA - TYPE MULTIPLE "
13
14
15
```

```
2087
 0 ( BJM - AUTOMATIC NORMALISATION TO CONTINUUM / MULTIPLE )
 1 0 INT LLIM 0 INT ULIM 0 INT CDM 0 INT BLKLENGTH
 2 : LENGTH CDM 1 = IF BLKLENGTH THEN
 3 CDM 2 = IF BLKLENGTH 3 * THEN ;
 4 : NORMALISING CR CR PARAMETERS CR CR CR
 5 ." 1) : SPECTRA STORED SUCCESSIVELY ON DISC" CR
 6 ." 2) : SPECTRA STORED WITH THEIR ARCS ON DISC"
 7 CR CR ." ENTER CODE REQUIRED " ASK := CDM
 8 CR CR ." BLOCK LENGTH = " ASK := BLKLENGTH
 9 CR ." FIRST SPECTRUM= " ASK := LLIM
10 CR ." LAST SPECTRUM= " ASK LENGTH + := ULIM
11 CR ." TYPE AUTONORMALISE TO CONTINUE " CR CR ;
12 : AUTONORMALISE ULIM LLIM DO CR I DUP . SPECTRUM NORMALISE
13 TIME LENGTH +LOOP ;
14 PAGE .# MULTIPLE NORMALISATION MODE " CR NORMALISING
15
```

```
2088
 0 ( BJM - SPECTROPHOTOMETRY )
 1 FORGET SUBTASK  : SUBTASK ;
 2 0 WARNING !
 3 -78 +BLOCK LOAD ( DISC ARRAYS )
 4 -86 +BLOCK LOAD ( SPLITSCREEN )
 5 0 INT LINENO 20 INT DXL 10000 INT RECT 10000 INT RECTPOINTS
 6 0 CONSTANT AAT 10000 CONSTANT CAT
 7 FL 1000. FCONSTANT THOU
 8 VARIABLE LLIMIT 0 ,  VARIABLE ULIMIT 1 ,  1000  INT CONT
 9 FL 0.002578 FVARIABLE FACTOR SWAP , ,
10 .   FVARIABLE E-W      0 CONSTANT LMDA 0 CONSTANT SLOG
11     FVARIABLE RMIN     FVARIABLE LMIN     FVARIABLE R0/2
12     FVARIABLE R1/4     FVARIABLE R3/4     FVARIABLE R90%
13 F1 FCONSTANT RESIDINTENT 0 CONSTANT CURRENT 0 CONSTANT LONG
14 0 INT XOFF 0 INT YOFF 0 INT LX 0 INT UX
15 -->
```

```
2089
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : DR 2DROP DROP 2DROP DROP ;
 2 : GARBAGE CONT FLOAT F1000  F/ 2DUP RMIN 2@ F- F2 ;
 3 : QT 2 1024 */MOD RECT + BLOCK + ;
 4 : FQT@ QT @ FLOAT F1000 F/ ;
 5 : GFIX THOU F* FIX ;
 6 : QT@ QT @ ;
 7 : QT! >R GFIX R> QT ! UPDATE ;
 8 : 2@! 2@ ROT 2! UPDATE  ;
 9 : 2+DUP 4 + DUP ;
10 : LOM FACTOR 2@ F* FALOG F1 F- FLOG10 ;
11 : F2/ F.5 F* ;
12 : FLO FLOAT ;
13 -->
14 ;S
15 ;S
```

```
2090
 0 ( BJM - SPECTROPHOTOMETRY )
 1 F1 FCONSTANT DIS
 2 : NX-ORD FLOAT LCALC ;
 3 : NWAVE BAR NX-ORD F. ;
 4 : NDISP FLOAT 2DUP F1 F+ LCALC 2SWAP F1 F- LCALC
 5 F- F2 F/ ['] DIS 2! ;
 6 : NL-ORD XCALC FIX ;
 7
 8 2 :P RPLOT QT@ ;
 9 : RPLOT 2 APLOT ;
10 -->
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2091
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : WIDTH BAR LLIMIT ! BAR ULIMIT ! ;
 2 : CH ULIMIT @ LLIMIT @ - 2 MOD IF -1 ULIMIT +! THEN ;
 3
 4 : SIMPSON CH ULIMIT @ QT@ LLIMIT @ QT@ + DOUBLE ULIMIT @
 5           LLIMIT @ - 1 DO I LLIMIT @ + QT@ I 2 MOD IF 2* 2*
 6             ELSE 2* THEN
 7         M+   LOOP DFLOAT 3000 FLOAT F/ ;
 8 : ACONT ULIMIT @ LLIMIT @ - FLO CONT FLO F1000  F/ F* ;
 9
10 .: EQW WIDTH SIMPSON ACONT 2SWAP F- F. ;
11
12 : BOX COORDS COORDS SWAP >R Y SIZE R> X SIZE ;
13 -->
14 ;S
15 ;S
```

```
2092
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : 1G CAT BLOCK ;
 2 : CLEAR 0 1G !D ;
 3 : 1GROW 40 1000 */MOD CAT + BLOCK + ;
 4 : IGNORE -1  1G +! UPDATE ;
 5
 6 : KEEP 1 1G +! UPDATE 1G @ 1GROW
 7        DUP LMIN 2@! 2+DUP E-W 2@! 2+DUP RMIN 2@! 2+DUP R1/4 2@!
 8        2+DUP R0/2 2@! 4 +  R3/4 2@!  ;
 9
10 : GPRINT 8 3 FMT CR CR ." LAMDA         E.W.       R.C.    "
11 ." W(1/4)     W(1/2)  W(3/4)" CR CR 1G @ 1+ 1 DO CR I 1GROW
12 24 0 DO DUP I + F? 4 +LOOP DROP LOOP 10 2 FMT ;
13 -->
14 ;S
15 ;S
```

```
2093
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : WPLOT LMDA IF 1GROW 2@ F/ ELSE DROP
 2 THEN SLOG IF FLOG10 THEN ;
 3 : INTERP LONG IF LLIMIT @ ['] CURRENT ! ELSE ULIMIT @ ['] 
 4 CURRENT ! THEN BEGIN LONG IF 1 ELSE -1 THEN ['] CURRENT +!
 5 CURRENT FQT@ RESIDINTENT F< END CURRENT NX-ORD CURRENT LONG IF
 6           1- ELSE 1+ THEN NX-ORD F- CURRENT FQT@ 2DUP CURRENT
 7           LONG IF 1- ELSE 1+ THEN FQT@ F- 2SWAP RESIDINTENT F-
 8    2SWAP F/ F* FMINUS CURRENT NX-ORD F+ LMIN 2@ F- FABS F2 F* ;
 9 : INTERP ['] RESIDINTENT 2! INTERP ;
10 : IR0 F1 RMIN 2! ULIMIT @ LLIMIT @ DO I FQT@ 2DUP RMIN 2@ F< IF
11       RMIN 2! I NX-ORD LMIN 2! ELSE 2DROP THEN LOOP
12       RMIN 2@ CONT 1000 - FLOAT F1000  F/ F- RMIN 2! ;
13 : IR1/4 GARBAGE F2 F* F/ F- INTERP R1/4 2! ;
14 : IR2/4 GARBAGE F/ F- INTERP R0/2 2! ;
15 : IR3/4 GARBAGE F1 F+ F* F2/ F2/ F- INTERP R3/4 2! ; >B
```

```
2094
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : IEQWA WIDTH LLIMIT @ ULIMIT @ + 2/ NDISP SIMPSON ACONT 2SWAP
 2    F- CONT FLOAT F1000  F/ F/ DIS F* E-W 2! ;
 3 : SHORT 0 ['] LONG ! ; : LONG 1 ['] LONG ! ;
 4 : CSET COORDS := CONT DROP ;
 5 : IPARAS CSET  IEQWA IR0 IR1/4 IR2/4 IR3/4 KEEP ;
 6 : HWIDE WIDTH LLIMIT @ NX-ORD ULIMIT @ NX-ORD F- ;
 7 : BOTH LONG IPARAS R1/4 2@ R0/2 2@ R3/4 2@
 8        SHORT IPARAS R3/4 2@ F+ F2/ R3/4 2! R0/2 2@ F+ F2/ R0/2
 9             2!  R1/4 2@ F+ F2/ R1/4 2! IGNORE IGNORE KEEP ;
10 .
11 : PLOT DUP 1- 2* ['] YOFF ! - 2* ['] XOFF !   1G @ 1+ 1 DO
12    I 1GROW YOFF + DUP 2@ I WPLOT GFIX SWAP XOFF + 2@ I WPLOT
13 GFIX CHARPOS .* LOOP CR ;
14 -->
15 ;S
```

```
2095
 0 ( BJM - SPECTROPHOTOMETRY / SPECTRAL LINE CATALOGUE )
 1 10000 INT SPL-CAT
 2
 3 : VAL 1+ 32 1024 */MOD SPL-CAT + BLOCK + ;
 4 : NLINES -1 VAL ;
 5 : ELEMENT-IN PAD 10 BLANK   PAD 10 EXPECT
 6 PAD SWAP VAL 10 MOVE UPDATE ;
 7 : ELEMENT-OUT VAL  10 TYPE ;
 8 : LLAB VAL 20 + ;
 9
10 : CLEAR-CATALOGUE 0 NLINES !D ;
11 -->
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2096
 0 ( BJM - SPECTROPHOTOMETRY / SPECTRAL LINE CATALOGUE )
 1 : LIST-LINES CR ." NO.  WAVELENGTH  ELEMENT"
 2 NLINES @ 0 DO CR I . I LLAB F? 5 SPACES I ELEMENT-OUT LOOP ;
 3
 4 : CREATE-CATALOGUE CR ." NO.LINES= " ASK CR CR
 5 ." ELEMENT      WAVELENGTH" CR ." ========================="
 6 NLINES @ + NLINES @ DO CR I ELEMENT-IN 7 C. 3 SPACES
 7 FASK I LLAB 2!D NLINES @ 1+ NLINES !D LOOP ;
 8
 9 : CHANGE CR ." NO.=" ASK := M ." ELEMENT " M ELEMENT-IN 7 C.
10 3 SPACES ." WAVELENGTH=" FASK M LLAB 2!D ;
11
12 : DELETE CR ." NO.=" ASK NLINES @ SWAP DO
13 I 1+ LLAB 2@ I LLAB 2!D I 1+ VAL I VAL 10 MOVE LOOP
14 NLINES @ 1 - NLINES !D ;
15 -->
```

```
2097
 0 ( BJM - SPECTROPHOTOMETRY / PROCEDURE )
 1 : DISPLAY X SIZE PAGE SPLOT LIMITS := LX := UX
 2 LINENO LLAB 2@ XCALC FIX DUP 1000 SWAP 500 JOIN
 3 LX FLOAT LCALC FIX UX FLOAT LCALC FIX X SIZE -200 -5 X INC 2!
 4 AXES FULL GRID LX UX X SIZE ;
 5 : NEXT LINENO NLINES @ = IF ." END OF CATALOGUE" CR ELSE
 6 LINENO LLAB 2@ XCALC FIX DUP DXL - SWAP DXL +
 7 DISPLAY 300 0 HEADING ." LINE        REST WAVELENGTH"
 8 275 0 HEADING LINENO ELEMENT-OUT LINENO LLAB F? IPARAS
 9 300 500 HEADING ." EQUIVALENT WIDTH" 275 500 HEADING E-W F?
10 300 800 HEADING ." CENTRAL DEPTH" 275 800 HEADING RMIN F?
11 200 0 HEADING ." OPTIONS AVAILABLE :-" CR
12 ." NEXT    : PROCEED WITH NEXT LINE" CR
13 ." REPEAT  : REMEASURE LINE" CR
14 ." REJECT  : REJECT LINE FROM MEASUREMENTS" CR
15 ." FINISH  : END MEASURING" CR 1 ['] LINENO +! THEN ; -->
```

```
2098
 0 ( BJM - SPECTROPHOTOMETRY )
 1 : REJECT -1 1G +! UPDATE ;
 2 : REPEAT -1 ['] LINENO +! REJECT NEXT ;
 3 : FINISH FULLSCREEN PAGE GPRINT ;
 4
 5 : SETSPEC CR ." SPECTRUM = " ASK SPECTRUM SAREA ['] RECT !
 6 CR ." IS THE WAVELENGTH CALIBRATION SET UP ? "
 7 Y/N NOT IF CALIBRATE THEN
 8 0 := LINENO SPLITSCREEN TOP
 9 DAREA ['] CAT ! 0 1G !D ;
10
11 1 WARNING !
12 PAGE .# SPECTROPHOTOMETRY MODE " CR CR
13 -->
14 ;S
15 ;S
```

```
2099
 0 ( BJM - SPECTROPHOTOMETRY / MASTER CATALOGUE OF LINES )
 1 2260 INT MASTER-CATALOGUE
 2
 3 : M-VAL 1+ 64 1024 */MOD MASTER-CATALOGUE + BLOCK + ;
 4 : NSETS -1 M-VAL ;
 5 : TITLE-IN  PAD 30 BLANK  PAD 30 EXPECT
 6       PAD SWAP M-VAL 30 MOVE UPDATE ;
 7 : TITLE-OUT M-VAL 30 TYPE ;
 8 : CATALOGUE-BLOCK M-VAL 60 + ;
 9
10 : DELETE-CATALOGUE NSETS @ SWAP DO I 1+ M-VAL 60 + @
11 I M-VAL 60 + !D I 1+ M-VAL I M-VAL 30 MOVE UPDATE
12 LOOP NSETS @ -1 + NSETS !D ;
13 -->
14 ;S
15 ;S
```

```
2100
 0 ( BJM - SPECTROPHOTOMETRY / MASTER CATALOGUE OF LINES )
 1 : ENTER
 2 CR ." BLK.NO.=     " ASK := SPL-CAT
 3 CR ." DO YOU WISH TO CREATE NEW CATALOGUE ?" Y/N 1 = IF
 4 CR ." ENTER TITLE "
 5 1 NSETS +!D NSETS @ TITLE-IN 7 C.
 6 SPL-CAT NSETS @ CATALOGUE-BLOCK !D CLEAR-CATALOGUE
 7 CREATE-CATALOGUE ELSE
 8 CREATE-CATALOGUE THEN ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2101
 0 ( BJM - SPECTROPHOTOMETRY / MASTER CATALOGUE OF LINES )
 1 : CATALOGUE CR ." CATALOGUE OF LINES AVAILABLE" CR
 2 CR ." NO.  TITLE" 23 SPACES ." BLK"
 3 CR ." ==========================================="
 4 CR ." -N) < DELETE CATALOGUE NO. N >"
 5 CR ."  0) < ENTER NEW LINES >"
 6 NSETS @ MINUS 0< IF NSETS @ 1+ 1 DO CR I 2 .R 41 C. 1 SPACES
 7 I TITLE-OUT 2 SPACES I CATALOGUE-BLOCK ? LOOP THEN
 8 CR CR ." ENTER NO.REQUIRED " ASK := M
 9 M 0= IF ENTER THEN
10 M 0 < NSETS @ 0 > AND IF M MINUS DELETE-CATALOGUE THEN
11 M 0 > NSETS @ M < NOT AND IF
12 M CATALOGUE-BLOCK @ := SPL-CAT THEN ;
13
14 1 WARNING ! CATALOGUE
15
```

```
2102
 0 ( BJM - FEATURE REMOVAL )
 1 FORGET SUBTASK  : SUBTASK ;
 2 0 WARNING !
 3 -92 +BLOCK LOAD ( DISC ARRAYS )
 4 0 INT LX 0 INT UX
 5 : DISPLAY X SIZE PAGE AXES SPLOT ;
 6 : REMOVE BAR BAR SWAP DO 1000 I PT !D LOOP FLUSH ;
 7 : REPLACE BAR := LX BAR := UX UX LX DO I LX - UX PT @ LX PT @ -
 8 * UX LX - / LX PT @ + I PT !D LOOP FLUSH ;
 9
10 : SETSPEC CR ." SPECTRUM = " ASK SPECTRUM
11 CR ." NO.POINTS = " ASK 0 SWAP DISPLAY ;
12
13 PAGE .# FEATURE REMOVAL MODE" CR CR
14 1 WARNING !
15


2103
 0 ( BJM - VELOCITY MEASUREMENT / METHOD SELECTION )
 1 FORGET SUBTASK : SUBTASK ;
 2 0 +BLOCK 0 +BLOCK : SELECT-METHOD 4 IN-LINE L#LOAD ASK := M
 3 11 IN-LINE L#LOAD ;  SELECT-METHOD  EXIT
 4 ERASE
 5 CR CR .# METHODS OF MEASUREMENT AVAILABLE ARE :-"
 6 CR .# (1) : LINE PROFILE FITTING "
 7 CR .# (2) : SIMULATED COMPARATOR "
 8 CR .# (3) : CROSSCORRELATION "
 9 CR CR .# ENTER METHOD REQUIRED "
10 EXIT
11 M 1 = IFTRUE 1 +BLOCK LOAD  7 +BLOCK LOAD  IFEND
12 M 2 = IFTRUE 1 +BLOCK LOAD 10 +BLOCK LOAD  IFEND
13 M 3 = IFTRUE 2 16 +BLOCK L#LOAD CCF IFEND
14 M 1 = M 2 = OR IFTRUE 13 +BLOCK LOAD IFEND
15


2104
 0 ( BJM - SPECTRAL LINE VELOCITY / BASICS )
 1 0 WARNING !
 2 -102 +BLOCK LOAD ( SPLITSCREEN GRAPHICS )
 3  -94 +BLOCK LOAD ( DISC ARRAYS )
 4  -64 +BLOCK LOAD ( RV CORRECTIONS )
 5 WAREA ' WORKAREA !
 6
 7 0 INT NOBS
 8 20 INT DXL
 9 0 INT LINENO F0. 2INT LLINE F0. 2INT VLINE
10 F0. 2INT SX F0. 2INT SX2 F0. 2INT MEAN F0. 2INT SD F0. 2INT SE
11 -->
12 -->
13 -->
14 -->
15 -->
```

```
2105
 0 ( BJM - SPECTRAL LINE VELOCITY / MEASUREMENT CATALOGUE )
 1 OAREA INT OBSAREA
 2 : OBS 1+ 16 1024 */MOD OBSAREA + BLOCK + ;
 3 : NPTS -1 OBS ;
 4 : LOBS OBS ;
 5 : VOBS OBS 4 + ;
 6 : FLAG OBS 8 + ;
 7 : INCLUDE 1 SWAP FLAG !D ;
 8 : EXCLUDE 0 SWAP FLAG !D ;
 9
10 : CLEAR 0 NPTS !D 0 ['] LINENO ! ;
11 : SETSPEC SETUP SPEC SASET CLEAR
12 CR ." IS WAVELENGTH CALIBRATION SET UP ? "
13 Y/N NOT IF CALIBRATE THEN SPLITSCREEN TOP
14 CR ." TYPE NEXT TO BEGIN .." ;
15 -->
```

```
2106
 0 ( BJM - SPECTRAL LINE VELOCITY / SPECTRAL LINE CATALOGUE )
 1 10000 INT SPL-CAT
 2
 3 : VAL 1+ 32 1024 */MOD SPL-CAT  + BLOCK + ;
 4 : NLINES -1 VAL ;
 5 : ELEMENT-IN PAD 10 BLANK   PAD 10 EXPECT
 6         PAD SWAP VAL 10 MOVE UPDATE ;
 7 : ELEMENT-OUT VAL 10 TYPE ;
 8 : LLAB VAL 20 + ;
 9
10 : CLEAR-CATALOGUE 0 NLINES !D ;
11 -->
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2107
 0 ( BJM - SPECTRAL LINE VELOCITY / SPECTRAL LINE CATALOGUE )
 1 : LIST-LINES CR ." NO.  WAVELENGTH  ELEMENT"
 2 NLINES @ 0 DO CR I . I LLAB F? 5 SPACES I ELEMENT-OUT LOOP ;
 3
 4 : CREATE-CATALOGUE CR ." NO.LINES= " ASK CR CR
 5 ." ELEMENT      WAVELENGTH" CR ." ==========================="
 6 NLINES @ + NLINES @ DO CR I ELEMENT-IN 7 C. 3 SPACES
 7 FASK I LLAB 2!D NLINES @ 1+ NLINES !D LOOP ;
 8
 9 : CHANGE CR ." NO.=" ASK :=: M ." ELEMENT " M ELEMENT-IN 7 C.
10 3 SPACES ." WAVELENGTH=" FASK M LLAB 2!D ;
11
12 : DELETE CR ." NO.=" ASK NLINES @ SWAP DO
13 I 1+ LLAB 2@ I LLAB 2!D I 1+ VAL I VAL 10 MOVE LOOP
14 NLINES @ 1 - NLINES !D ;
15 -->
```

```
2108
 0 ( BJM - SPECTRAL LINE VELOCITY / CALCULATION )
 1 : OBSERVATIONS ERASE
 2 F0. := SX F0. := SX2 0 := NOBS
 3 NPTS @ 0 DO I FLAG @ 1 = IF
 4 I VOBS 2@ SX F+ := SX 1 NOBS + := NOBS THEN LOOP
 5 SX NOBS FLOAT F/ := MEAN
 6 NPTS @ 0 DO I FLAG @ 1 = IF I VOBS 2@ MEAN F- F**2
 7 SX2 F+ := SX2 THEN LOOP
 8 SX2 NOBS FLOAT F/ FSQRT 2DUP := SD NOBS FLOAT FSQRT F/ := SE
 9 ." NO.    WAVELENGTH      V(IN)       O-C(IN)      V(EX)    O-C(EX)"
10 NPTS @ 0 DO CR I 5 .R I LOBS F@ I VOBS 2@ 2DUP MEAN F- 2SWAP
11 I FLAG @ 1 = IF F. F. ELSE 23 SPACES F. F. THEN LOOP
12 CR CR ." HELIOCENTRIC VELOCITY =" MEAN F.
13 ." +/- " SD F. ." (SD)" SE F. ." (SE)    KM/S" CR ;
14 -->
15 ;S


2109
 0 ( BJM - SPECTRAL LINE VELOCITY / CALCULATION )
 1 CREATE NAME  20 ALLOT
 2
 3 0 +BLOCK
 4 : PRINTOUT
 5 NAME 20 BLANK  CR ." ENTER TITLE : " NAME 20 EXPECT 7 C.
 6 13 IN-LINE L#LOAD ;
 7 EXIT
 8
 9
10
11
12
13 PRINT   CR .# RADIAL VELOCITY MEASUREMENTS : "
14 NAME  20 TYPE CR CR OBSERVATIONS CR CR
15


2110
 0 ( BJM - SPECTRAL LINE VELOCITY / PROFILE FITTING )
 1 -66 +BLOCK LOAD SPECTRUMDATA TROUGHS  ( MAX/MIN ROUTINE )
 2 -65 +BLOCK LOAD ( LST.SQ.PARABOLA )
 3
 4 0 INT LX 0 INT UX
 5
 6 : DISPLAY X SIZE ERASE POINTPLOT SPLOT LIMITS := LX := UX
 7 LINEPLOT LINENO LLAB 2@ XCALC FIX DUP 1000 SWAP 500 JOIN
 8 LX FLOAT LCALC FIX UX FLOAT LCALC FIX X SIZR  -200 -5 X INC 2!
 9 AXES FULL GRID LX UX X SIZE ;
10
11 : MEASURE
12 NOP POINTS FIT X0 LCALC := LLINE
13 LLINE LINENO LLAB 2@ F- LINENO LLAB 2@ F/ C-VEL F*
14 RSUN F+ := VLINE ;
15 -->
```

```
2111
 0 ( BJM - SPECTRAL LINE VELOCITY / PROFILE FITTING )
 1 : NEXT LINENO NLINES @ = IF ." END OF CATALOGUE" CR ELSE
 2 LINENO LLAB 2@ XCALC FIX DUP DXL - SWAP DXL +
 3 DISPLAY 300 0 HEADING ." LINE         REST WAVELENGTH"
 4 275 0 HEADING LINENO ELEMENT-OUT LINENO LLAB F?
 5 MEASURE LINENO LLAB 2@ NPTS @ LOBS 2!D 1 NPTS @ FLAG !D
 6 VLINE NPTS @ VOBS 2!D 1 NPTS @ + NPTS !D 1 ['] LINENO +!
 7 300 500 HEADING ." WAVELENGTH" 275 500 HEADING LLINE F.
 8 300 800 HEADING ." VELOCITY KM/S" 275 775 HEADING VLINE F.
 9 200 0 HEADING ." OPTIONS AVAILABLE :-" CR
10 ." NEXT    : PROCEED WITH NEXT LINE" CR
11 ." REPEAT  : REMEASURE LINE" CR
12 ." REJECT  : REJECT LINE FROM MEASUREMENTS" CR
13 ." FINISH  : END MEASURING" CR THEN ;
14 -->
15


2112
 0 ( BJM - SPECTRAL LINE VELOCITY / PROFILE FITTING )
 1 : REJECT -1 NPTS @ + NPTS !D ;
 2
 3 : REPEAT -1 ['] LINENO +! REJECT NEXT ;
 4
 5 : FINISH FULLSCREEN OBSERVATIONS ;
 6
 7 PAGE .# LINE PROFILE FITTING MODE " CR CR
 8
 9
10
11
12
13
14
15


2113
 0 ( BJM - SPECTRAL LINE VELOCITY / SIMULATED COMPARATOR )
 1 F0. 2INT XC F0. 2INT Y1 F0. 2INT Y2 0 INT XI
 2 0 INT CEN F0. 2INT DXS 0 INT LX 0 INT UX
 3
 4 : DISPLAY ERASE CEN DXL - CEN DXL + X SIZE SPLOT POINTPLOT OFF
 5 LIMITS DO CEN FLOAT DXS F+ 2DUP I FLOAT F- F+ 2DUP := XC FIX :=
 6 XI XI PT @ FLOAT := Y1 XI 1+ PT @ FLOAT := Y2 Y2 Y1 F- XC XI
 7 FLOAT F- F* Y1 F+ FIX I LIGHT LOOP ALPHA LINEPLOT LINENO
 8 LLAB 2@ XCALC FIX DUP 1000 SWAP 500 JOIN LIMITS := LX := UX
 9 LX FLOAT LCALC FIX UX FLOAT LCALC FIX X SIZE -200 -5 X INC 2!
10 AXES FULL GRID LX UX X SIZE ;
11 -->
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2114
 0 ( BJM - SPECTRAL LINE VELOCITY / SIMULATED COMPARATOR )
 1 : X-V CEN FLOAT DXS F+ LCALC 2DUP := LLINE LINENO LLAB 2@
 2 F- LINENO LLAB 2@ F/ C-VEL F* RSUN F+ := VLINE ;
 3
 4 : SAVE LINENO LLAB 2@ NPTS @ LOBS 2!D VLINE NPTS @ VOBS 2!D
 5 1 NPTS @ FLAG !D 1 NPTS @ + NPTS !D 1 ['] LINENO +! FO. := DXS ;
 6
 7  : REJECT 1 ['] LINENO +! FO. := DXS ;
 8
 9 : FINISH FULLSCREEN OBSERVATIONS ;
10
11 PAGE .# SIMULATED COMPARATOR MODE" CR CR
12 -->
13 ;S
14 ;S
15 ;S
```

```
2115
 0 ( BJM - SPECTRAL LINE VELOCITY / SIMULATED COMPARATOR )
 1 : NEXT LINENO NLINES @ = IF ." END OF CATALOGUE" CR ELSE
 2 LINENO LLAB 2@ 2DUP XCALC FIX := CEN DISPLAY X-V
 3 300 0 HEADING ." LINE          REST WAVELENGTH"
 4 275 0 HEADING LINENO ELEMENT-OUT F.
 5 300 500 HEADING ." WAVELENGTH" 275 500 HEADING LLINE F.
 6 300 800 HEADING ." VELOCITY KM/S" 275 800 HEADING VLINE F.
 7 200 0 HEADING ." OPTIONS AVAILABLE :-" CR
 8 ." >>      : MOVE REVERSED IMAGE RIGHT" CR
 9 ." <<      : MOVE REVERSED IMAGE LEFT" CR
10 ." SAVE    : ACCEPT RESULT" CR ." REJECT : REJECT RESULT" CR
11 ." NEXT    : PROCEED TO NEXT LINE" CR
12 ." FINISH : END MEASURING" CR THEN ;
13 : >> CR ." SHIFT=" FASK ['] DXS F+! NEXT ;
14 : << CR ." SHIFT=" FASK FMINUS ['] DXS F+! NEXT ;
15
```

```
2116
 0 ( BJM - SPECTRAL LINE VELOCITY / MASTER CATALOGUE OF LINES )
 1 2220 INT MASTER-CATALOGUE
 2
 3 : M-VAL 1+ 64 1024 */MOD MASTER-CATALOGUE + BLOCK + ;
 4 : NSETS -1 M-VAL ;
 5 : TITLE-IN  PAD 30 BLANK   PAD 30 EXPECT
 6         PAD SWAP M-VAL 30 MOVE UPDATE ;
 7 : TITLE-OUT M-VAL 30 TYPE ;
 8 : CATALOGUE-BLOCK M-VAL 60 + ;
 9
10 : DELETE-CATALOGUE NSETS @ SWAP DO I 1+ M-VAL 60 + @
11 I M-VAL 60 + !D I 1+ M-VAL I M-VAL 30 MOVE UPDATE
12 LOOP NSETS @ -1 + NSETS !D ;
13 -->
14 ;S
15 ;S
```

```
2117
 0 ( BJM - SPECTRAL LINE VELOCITY / MASTER CATALOGUE OF LINES )
 1 : ENTER
 2 CR ." BLK.NO.=     " ASK := SPL-CAT
 3 CR ." DO YOU WISH TO CREATE NEW CATALOGUE ?" Y/N 1 = IF
 4 CR ." ENTER TITLE "
 5 1 NSETS +!D NSETS @ TITLE-IN 7 C.
 6 SPL-CAT  NSETS @ CATALOGUE-BLOCK !D CLEAR-CATALOGUE
 7 CREATE-CATALOGUE ELSE
 8 CREATE-CATALOGUE THEN ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S



2118
 0 ( BJM - SPECTRAL LINE VELOCITY / MASTER CATALOGUE OF LINES )
 1 : CATALOGUE CR ." CATALOGUE OF LINES AVAILABLE" CR
 2 CR ." NO.  TITLE" 23 SPACES ." BLK"
 3 CR ." ==========================================="
 4 CR ." -N) < DELETE CATALOGUE NO. N >"
 5 CR ."  0) < ENTER NEW LINES >"
 6 NSETS @ MINUS 0< IF NSETS @ 1+ 1 DO CR I 2 .R 41 C. 1 SPACES
 7 I TITLE-OUT 2 SPACES I CATALOGUE-BLOCK ? LOOP THEN
 8 CR CR ." ENTER NO.REQUIRED " ASK := M
 9 M 0= IF ENTER THEN
10 M 0 < NSETS @ 0 > AND IF M MINUS DELETE-CATALOGUE THEN
11 M 0 > NSETS @ M < NOT AND IF
12 M CATALOGUE-BLOCK @ := SPL-CAT  THEN ;
13
14 1 WARNING ! CATALOGUE
15



2119
 0 ( BJM - CROSSCORRELATION AND VELOCITY BROADENING )
 1 FORGET SUBTASK : SUBTASK ;
 2 0 WARNING !
 3 15 +BLOCK LOADER CATALOGUE
 4 -108 +BLOCK LOAD ( FFT )
 5 -109 +BLOCK LOAD ( DISC ARRAYS )  WAREA ' WORKAREA !
 6  -77 +BLOCK LOAD ( DATA HANDLING ) VBF
 7  -76 +BLOCK LOAD ( LOG LAMDA )
 8  -79 +BLOCK LOAD ( RV CORRECTIONS )
 9
10 1 +BLOCK LOAD ( FILTER )
11 5 +BLOCK LOAD ( PLOTTING )
12 9 +BLOCK LOAD ( NORMALISING )
13 3 +BLOCK LOAD ( STND/STAR )
14
15
```

```
2120
 0 ( BJM - C.C.F. AND V.B.F. / NOISEFILTER )
 1 F0. 2INT (B/A)2   F0. 2INT ALPHA0   F1 2INT A   F0. 2INT B
 2 : BASET F/ F**2 [']  (B/A)2 2! ; : GFIX 1000 FLOAT F* FIX ;
 3
 4 : F(S) F**2 ALPHA0 F**2 F* F2 F* 2DUP F10 F< IF
 5        FALOG (B/A)2 F* F1 F+  F1 2SWAP F/ ELSE 2DROP F0. THEN ;
 6
 7 : GAUS F**2 ALPHA0 F**2 F* 2DUP F10 F> IF
 8        2DROP F0. ELSE FMINUS FALOG A F* THEN ;
 9
10 : CUTOFF (B/A)2 FLOG10 F2 F/ FMINUS FSQRT ROT
11        FLOAT F/ := ALPHA0 ;
12
13 : NOISE F0. ROT DUP 2* >R N 2/ DUP ROT + SWAP DO I AB@
14 AMPLITUDE F+ LOOP F2 F* R> FLOAT F/ 2DUP F. A BASET ;
15 -->
```

```
2121
 0 ( BJM - BROADENING FUNCTION / NOISEFILTER )
 1 500 INT PTNOISE  1000 INT PTCUTOFF
 2
 3 : FILTER N 2/ 1 DO I FLOAT F(S) 2DUP 2DUP 2DUP I AB@ 2>R F*
 4 2SWAP 2R> F* I AB! N I - AB@ 2>R F* 2SWAP 2R> F* N I - AB! LOOP
 5 F0. F0. N 2/ AB!  ;
 6
 7 : PARAMETERS ." FILTER THRESHOLD= " ASK
 8 N SWAP /  := PTCUTOFF  N 10 / := PTNOISE ;
 9
10 : AUTO  F0. 20 1 DO I AB@ AMPLITUDE FMAX LOOP := A
11 A F. PTNOISE NOISE PTCUTOFF CUTOFF ;
12
13 4 :P GAUSPLOT FLOAT GAUS B F+ GFIX ; : GAUSPLOT 4 APLOT ;
14 5 :P FILPLOT  FLOAT F(S) GFIX ;       : FILPLOT  5 APLOT ;
15
```

```
2122
 0 ( BJM - C.C.F. AND V.B.F.  / STANDARD )
 1 : STANDARD SETUP CR ." NO.POINTS= " ASK VALUES LOGSCALE
 2 CR ." VELOCITY = " FASK RSUN F- := RVSTND
 3 CR ." IS THE WAVELENGTH CALIBRATION SET UP ? "
 4 Y/N NOT IF CALIBRATE THEN
 5 CR ." DISC AREA TO STORE STANDARD TRANSFORM = " ASK := STND
 6 PAGE CATALOGUE
 7 CR ." TYPE *STND TO CONTINUE " ;
 8
 9 : *STND SPEC := SOURCE AREA := DEST LOGCONV
10 AREA SASET STND CASET TRANSFER  FFT SIGNAL ;
11 -->
12
13
14
15
```

```
2123
 0 ( BJM - C.C.F. AND V.B.F.  / STAR )
 1 : STAR  SETUP
 2 CR ." IS THE WAVLLENGTH CALIBRATION SET UP ? "
 3 Y/N NOT IF CALIBRATE THEN ERASE
 4 ." TYPE *SPRM AFTER SELECTION OF STANDARD" CR CATALOGUE ;
 5
 6 : *SPRM
 7 CR PARAMETERS SPEC := SOURCE AREA := DEST LOGCONV AREA SASET
 8 SPRM CASET TRANSFER FFT
 9 CCF/VBF EXECUTE AUTO FILTER
10 -FFT REORD  SIGNAL FNDISPLAY ;
11
12 1 WARNING !
13 PAGE
14 CR ." TYPE STANDARD OR STAR " CR CR
15
```

```
2124
 0 ( BJM - C.C.F. AND V.B.F.  / VELOCITY SCALE )
 1 0 WARNING !
 2 -80 +BLOCK LOAD FOURIERDATA PEAKS  ( MAX/MIN ROUTINE )
 3 -79 +BLOCK LOAD ( LST.SQ.PARABOLA )
 4
 5 F0. 2INT VEL  F0. 2INT I/ERR
 6 F0. 2INT BMIN F0. 2INT BMAX
 7 0 INT VMIN 0 INT VMAX
 8 0 INT FI F0. 2INT FC F0. 2INT RY1 F0. 2INT RY2
 9
10 : VCONV N 2/ FLOAT F- LSCALE F* FALOG F1 F- C-VEL F* ;
11 : VCALC VCONV RVSTND F+ RSUN F+ ;
12 : ZCALC C-VEL F/ F1 F+ FLOG10 LSCALE F/ NO FLOAT F+ ;
13
14 -->
15
```

```
2125
 0 ( BJM - C.C.F. AND V.B.F. / PLOTTING )
 1 : SCALING F0. := BMIN F0. := BMAX
 2 VMAX FLOAT ZCALC FIX VMIN FLOAT ZCALC FIX DO
 3 I ABCOMPLEX 2@ 2DUP BMAX FMAX := BMAX BMIN FMIN := BMIN LOOP
 4 BMIN FFIX BMAX FFIX Y SIZE ;
 5
 6 : VTRANS VMAX VMIN - 0 DO
 7 I VMIN + FLOAT ZCALC 2DUP := FC FIX := FI
 8 SPRM CASET FI ABCOMPLEX 2@ := RY1 FI 1+ ABCOMPLEX 2@ := RY2
 9 RY2 RY1 F- FC FI FLOAT  F- F* RY1 F+
10 AREA CASET I ABCOMPLEX 2!D LOOP ;
11
12 : VELAXES CR ." SPECIFY VELOCITY RANGE IN KM/S" CR
13 CR ." PLOT FROM " ASK := VMIN ."  TO " ASK := VMAX  VTRANS ;
14 -->
15
```

```
2126
 0 ( BJM - C.C.F. AND V.B.F. / PLOTTING )
 1 : [FRV] SPRM CASET [BAR] VCALC F. ." KM/S" CR ;
 2
 3 : FRV CR ." NO.POINTS IN FIT=" ASK := NOP
 4 SPRM CASET NOP POINTS XO VCALC := VEL
 5 ERROR XO SDRES F- VCALC VEL F- FABS := I/ERR
 6 CR VEL F. ." +/- " I/ERR F. ." KM/S " CR ;
 7
 8 : [RV] AREA CASET [BAR] VMIN FLOAT F+  F. ." KM/S" CR ;
 9
10 : RV CR ." NO.POINTS IN FIT=" ASK := NOP
11 AREA CASET NOP POINTS XO 2DUP VMIN FLOAT F+ := VEL
12 ERROR SDRES  FABS := I/ERR
13 CR VEL F. ." +/- " I/ERR F. ." KM/S " CR ;
14 -->
15
```

```
2127
 0 ( BJM - C.C.F. AND V.B.F. / PLOTTING )
 1 0 +BLOCK : CAPTIONS 9 IN-LINE L#LOAD ;
 2 : DISPLAY
 3 PAGE VMIN VMAX X SIZE AXES CAPTIONS AREA CASET
 4 0 VMAX VMIN - X SIZE 10 APLOT ;
 5 : FNDISPLAY 0 N X SIZE SPRM CASET AXES 10 APLOT ;
 6 ( : VPLOT VELAXES DISPLAY ; )
 7 1 WARNING !
 8 EXIT
 9 50 800 HEADING HP" V  KM/S"
10 ' DECONVOLVE ' CCF/VBF @ = IFTRUE
11 600 100 HEADING HP" B(V)" CR  CR  IFEND
12 ' XSPEC ' CCF/VBF @ = IFTRUE
13 700 100 HEADING HP" CROSSCORRELATION FUNCTION"
14 600 100 HEADING HP" C(Z)" CR  CR  IFEND
15
```

```
2128
 0 ( BJM - C.C.F. AND V.B.F. / NORMALISATION )
 1 0 WARNING !
 2 F0. 2INT ASUM F0. 2INT NSLEV 0 INT NPOINTS
 3 0 INT SV  0 INT ODSINI 0 INT LLIM 0 INT ULIM
 4
 5 : FIND-NOISE 0 := NPOINTS F0. := ASUM BAR BAR SWAP DO
 6 I ABCOMPLEX 2@ ASUM F+ := ASUM 1 NPOINTS + := NPOINTS LOOP
 7 ASUM NPOINTS FLOAT F/ := NSLEV ;
 8 : NSET COORDS FLOAT F1000 F/ := NSLEV DROP ;
 9
10 : FIND-AREA F0. := ASUM ULIM LLIM DO I ABCOMPLEX 2@
11 NSLEV F- ASUM F+ := ASUM LOOP ;
12
13 : NORM VMAX VMIN - 1+ 0 DO I DUP ABCOMPLEX 2@ NSLEV F-
14 ASUM F/ ODSINI FLOAT F**2 F1000 F/ F* ROT ABCOMPLEX 21D LOOP ;
15 -->
```

```
2129
 0 ( BJM - GRAPH PLOTTING )
 1    0 INT SX1    0 INT SX2
 2    0 INT SY1    0 INT SY2
 3
 4 : WINDOW SX1 SX2 ABSCISSA  SY1 SY2 ORDINATE  40 Y CORNER !
 5     X RNG 2@ 11 14 */ > IF 700 Y FRAME ! 700 X RNG @
 6     Y RNG @ */ DUP X FRAME ! MINUS 1000 + X CORNER ! ELSE
 7     94 X CORNER ! 906 X FRAME ! 906 Y RNG @ X RNG @ */
 8     Y FRAME ! THEN ;
 9
10 : SETAXES CR ." X COORD. FROM " ASK  := SX1
11 ." TO " ASK  := SX2  CR ." Y COORD. FROM " ASK  :=
12 SY1  ." TO " ASK  := SY2   SX1 SX2 X SIZE
13 SY1 SY2 Y SIZE WINDOW ;
14 -->
15
```

```
2130
 0 ( BJM - C.C.F. AND V.B.F. / NORMALISATION )
 1 : PARAM CR ." SYSTEMIC VELOCITY=" ASK := SV
 2 CR ." NORMALISING FACTOR IN KM/S=" ASK := ODSINI
 3 SV ODSINI - VMIN - := LLIM
 4 ODSINI SV + VMIN - := ULIM
 5 CR ." SET NOISE LEVEL " CR ." TYPE NORMALISE TO CONVERT " CR ;
 6 : NORMALISE FIND-AREA NORM
 7 VMIN := SX1 VMAX := SX2 VMIN := SY1 VMAX := SY2 WINDOW
 8 DISPLAY ;
 9
10 : LEVEL VMAX VMIN - 14 0 DO I DUP ABCOMPLEX 2@ NSLEV F-
11 ROT ABCOMPLEX 21D LOOP ;
12
13 1 WARNING !
14
15
```

```
2134
 0 ( BJM - MASTER CATALOGUE OF STANDARDS )
 1 2240 INT MASTER-CATALOGUE
 2
 3 : PZ PAD 20 BLANK ;
 4 : M-VAL 14 64 1024 */MOD MASTER-CATALOGUE + BLOCK + ;
 5 : NSETS -1 M-VAL ;
 6 : NAME-IN PZ PAD 10 EXPECT  PAD SWAP  M-VAL 10 MOVE UPDATE ;
 7 : NAME-OUT M-VAL 10 TYPE ;
 8 : SP-IN PZ PAD 4 EXPECT  PAD SWAP M-VAL 10 + 4 MOVE UPDATE ;
 9 : SP-OUT M-VAL 10 + 4 TYPE ;
10 : A/MM-IN PZ  PAD 4 EXPECT  PAD SWAP M-VAL 14 + 4 MOVE UPDATE ;
11 : A/MM-OUT M-VAL 14 + 4 TYPE ;
12 : TEL-IN PZ PAD 16 EXPECT  PAD SWAP M-VAL 18 + 16 MOVE UPDATE ;
13 : TEL-OUT M-VAL 18 + 16 TYPE ;
14 -->
15 ;S
```

```
2135
 0 ( BJM - MASTER CATALOGUE OF STANDARDS )
 1 : STND-ST M-VAL 34 + ;
 2 : NO-ST M-VAL 36 + ;
 3 : LSTART-ST M-VAL 38 + ;
 4 : LSTOP-ST M-VAL 42 + ;
 5 : LSCALE-ST M-VAL 46 + ;
 6 : RVSTND-ST M-VAL 50 + ;
 7
 8 : STDEL NSETS @ SWAP DO
 9 64 0 DO J 1+ M-VAL I + @ J M-VAL I + !D LOOP
10 LOOP NSETS @ 1- NSETS !D ;
11
12 : CHECK-N NSETS @ 0< IF 0 NSETS !D THEN ;
13 CHECK-N
14 -->
15 ;S


2136
 0 ( BJM - MASTER CATALOGUE OF STANDARDS )
 1 : ENTER
 2 NSETS @ 1 + NSETS !D BEGIN
 3 CR ." STAR NAME          :" NSETS @ NAME-IN 7 C.
 4 CR ." SPECTRAL TYPE      :" NSETS @ SP-IN 7 C.
 5 CR ." PLATE SCALE A/MM   :" NSETS @ A/MM-IN 7 C.
 6 CR ." TELESCOPE          :" NSETS @ TEL-IN 7 C.
 7 CR ." IS ABOVE DATA ENTERED CORRECTLY ? " Y/N 1 = END
 8 STND NSETS @ STND-ST !D
 9 NO NSETS @ NO-ST !D
10 LSTART NSETS @ LSTART-ST 2!D
11 LSTOP NSETS @ LSTOP-ST 2!D
12 LSCALE NSETS @ LSCALE-ST 2!D
13 RVSTND NSETS @ RVSTND-ST 2!D ;
14 -->
15


2137
 0 ( BJM - MASTER CATALOGUE OF STANDARDS )
 1 0 +BLOCK : SELECT-CATALOGUE CR ." CATALOGUE OF STANDARDS " CR
 2 CR ." NO.  STAR      SP   A/MM    WAVELENGTH    BLK    TELESCOPE"
 3 CR ." ================================================================"
 4 CR ." -N) < DELETE STANDARD NO. N >"
 5 CR ."  0) < ENTER NEW STANDARD >"
 6 NSETS @ MINUS 0< IF NSETS @ 1+ 1 DO CR I 2 .R 41 C. 1 SPACES
 7 I NAME-OUT 2 SPACES I SP-OUT I A/MM-OUT 2 SPACES
 8 4 0 FMT I LSTART-ST F? ." - " I LSTOP-ST F? I STND-ST @ 5 .R
 9 3 SPACES I TEL-OUT LOOP THEN 10 2 FMT
10 CR CR ." ENTER NO.REQUIRED " ASK := M M 0= IF ENTER ELSE
11 M 0< IF M MINUS STDEL ELSE M STND-ST @ := STND M NO-ST @ VALUES
12 M LSTART-ST 2@ := LSTART M LSTOP-ST 2@ := LSTOP
13 M LSCALE-ST 2@ := LSCALE M RVSTND-ST 2@ := RVSTND
14 THEN THEN 15 IN-LINE L#LOAD ;  SELECT-CATALOGUE     EXIT
15 FORGET MASTER-CATALOGUE
```

```
2138
 0 ( BJM - REDUCTIONS CONTROL BLOCK )
 1 FORGET SUBTASK : SUBTASK ;
 2
 3  1 +BLOCK LOADER STAT-PAK
 4 12 +BLOCK LOADER ORBIT
 5 23 +BLOCK LOADER SEARCH
 6 36 +BLOCK LOADER GRAPH
 7
 8 PAGE .# REDUCTION ROUTINES AVAILABLE"
 9 CR    .# ================================" CR CR
10 CR .# STAT-PAK :- STATISTICS"
11 CR .# ORBIT    :- RADIAL VELOCITY CURVE SOLUTION"
12 CR .# SEARCH   :- PERIOD FINDING"
13 CR .# GRAPH    :- GRAPH PLOTTING ROUTINES" CR
14 : SUB-SUBTASK ;
15
```

```
2139
 0 ( BJM - STATISTICAL PACKAGE - CONTROL BLOCK )
 1 FORGET SUB-SUBTASK : SUB-SUBTASK ;
 2 -129 +BLOCK LOAD ( DISC ARRAYS )
 3 6 +BLOCK LOADER STATISTICS
 4 7 +BLOCK LOADER LINEFIT
 5 8 +BLOCK LOADER EXPONFIT
 6 9 +BLOCK LOADER POWERFIT
 7 10 +BLOCK LOAD ( FACILITIES )
 8
 9 3 +BLOCK 1 +BLOCK : SELECT
10 CR CR ." ENTER NO.OF PARAMETERS " ASK := M
11 M 1 = IF [SWAP] IN-LINE LOAD THEN
12 M 2 = IF [SWAP] IN-LINE LOAD THEN ;
13 : MINITASK ;
14 SELECT
15
```

```
2140
 0 ( BJM - STATISTICAL PACKAGE - 1 PARAMETER STATISTICS )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 0AREA INT OBSAREA
 4 : OBS 1+ 2 512 */MOD OBSAREA + BLOCK + ;
 5 : OP -1 OBS ;
 6
 7 : ENTER CR ." IS THIS A NEW CATALOGUE ? " Y/N IF 0 OP !D THEN
 8 CR ." NO.VALUES= " ASK := M
 9 OP @ M + OP @ DO CR I 3 .R 3 SPACES
10 ?ASK I OBS 2!D 1 OP +!D LOOP ;
11
12 : DELETE CR ." NO.= " ASK OP @ SWAP DO I 1+ OBS 2@ I OBS 2!D
13 LOOP -1 OP +!D ;
14 : CHANGE CR ." NO.= " ASK ." VALUE= " ?ASK ROT OBS 2!D ;
15 -->
```

```
2141
 0 ( BJM - STATISTICAL PACKAGE - 1 PARAMETER STATISTICS )
 1 : VALUES CR ." NO.     VALUE"
 2 OP @ 0 DO CR I 3 .R I OBS F? LOOP ;
 3
 4 : FC FO. FCONSTANT ;  FC SX  FC SX2  FC XM  FC XSD  FC XSE
 5
 6 : SOLVE CR CR   FO. ['] SX 2!  FO. ['] SX2 2!
 7 OP @ 0 DO I OBS 2@ ['] SX F+! LOOP SX OP @ FLOAT F/ ['] XM 2!
 8 OP @ 0 DO I OBS 2@ XM F- F**2 ['] SX2 F+! LOOP
 9 SX2 OP @ FLOAT F/ FSQRT ['] XSD 2! XSD OP @ FLOAT FSQRT F/ ['] 
10 XSE 2! ." MEAN=" XM F. CR ." SD   =" XSD F. CR ." SE   =" XSE F. ;
11
12 PAGE  .# ONE PARAMETER STATISTICS " CR CR
13 1 WARNING !
14
15
```

```
2142
 0 ( BJM - STATISTICAL PACKAGE - 2 PARAMETER STATISTICS )
 1 FORGET MINITASK : MINITASK ;
 2 0 WARNING !
 3 0AREA INT OBSAREA
 4 : OBS 1+ 8 1024 */MOD OBSAREA + BLOCK + ;
 5 : OP -1 OBS ;
 6
 7 : ENTER CR ." IS THIS A NEW CATALOGUE ? " Y/N IF 0 OP !D THEN
 8 CR ." NO.VALUES= " ASK := M
 9 OP @ M + OP @ DO CR I 3 .R 3 SPACES FASK FASK 2SWAP I OBS 4!
10 UPDATE 1 OP +!D LOOP ;
11 : DELETE CR ." NO.= " ASK OP @ SWAP DO I 1+ OBS 4@ I OBS 4!
12 UPDATE LOOP -1 OP +!D ;
13 : CHANGE CR ." NO.= " ASK := M ." VALUES= " FASK FASK
14 2SWAP M OBS 4! UPDATE ;
15 -->
```

```
2143
 0 ( BJM - STATISTICAL PACKAGE - 2 PARAMETER STATISTICS )
 1 : VALUES CR ." NO.        X           Y"
 2 OP @ 0 DO CR I 3 .R I OBS 4@ F. F. LOOP ;
 3
 4 : FC FO. FCONSTANT ;
 5 FC SX FC SY FC SXY FC SX2 FC SY2
 6 FC XM FC XSD FC XSE FC YM FC YSD FC YSE FC CORR
 7 FC M FC MERR FC C FC CERR FC SRES FC RMS
 8 FC A11 FC A12 FC A21 FC A22 FC B1 FC B2 FC DET
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2144
 0 ( BJM - STATISTICAL PACKAGE - 2 PARAMETER STATISTICS )
 1 : LSTSQ
 2 A11 A22 F* A12 A21 F* F- ['] DET 2!
 3 A22 DET F/ A12 DET F/ FMINUS A21 DET F/ FMINUS A11 DET F/
 4 ['] A22 2! ['] A21 2! ['] A12 2! ['] A11 2!
 5 A11 B1 F* A12 B2 F* F+ ['] C 2!
 6 A21 B1 F* A22 B2 F* F+ ['] M 2! ;
 7 : ERROR
 8 RMS F**2 A11 F* FSQRT ['] CERR 2!
 9 RMS F**2 A22 F* FSQRT ['] MERR 2! ;
10 PAGE  .# TWO PARAMETER STATISTICS" CR CR
11 1 WARNING !
12 : TINYTASK ;
13
14
15
```

```
2145
 0 ( BJM - STATISTICAL PACKAGE - 2 PARAMETER STATISTICS )
 1 FORGET TINYTASK : TINYTASK ;  0 WARNING !
 2 : SOLVE  F0. ['] SX 2!  F0. ['] SY 2!
 3 F0. ['] SX2 2!  F0. ['] SY2 2!  F0. ['] SXY 2!
 4 OP @ 0 DO I OBS 4@ ['] SX F+! ['] SY F+! LOOP
 5 SY SX OP @ FLOAT 2DUP -2ROT F/ ['] XM 2! F/ ['] YM 2!
 6 OP @ 0 DO I OBS 4@ XM F- 2DUP F**2 ['] SX2 F+! 2SWAP YM F- 2DUP
 7 F**2 ['] SY2 F+! F* ['] SXY F+! LOOP
 8 SX2 OP @ FLOAT F/ FSQRT ['] XSD 2! XSD OP @ FLOAT FSQRT F/ ['] 
 9 XSE 2! SY2 OP @ FLOAT F/ FSQRT ['] YSD 2! YSD OP @ FLOAT FSQRT
10 F/ ['] YSE 2! SXY OP @ FLOAT F/ XSD YSD F* F/ ['] CORR 2!
11 CR ." XMEAN=" XM  F. ."       YMEAN=" YM  F.
12 CR ." XSD  =" XSD F. ."       YSD  =" YSD F.
13 CR ." XSE  =" XSE F. ."       YSE  =" YSE F.
14 CR CR ." COEFFICIENT OF CORRELATION =" CORR F. ;   EXIT
15 1 WARNING !
```

```
2146
 0 ( BJM - STATISTICAL PACKAGE - LST.SQ.LINE )
 1 FORGET TINYTASK : TINYTASK ;  0 WARNING !
 2 : SOLVE  ." Y = MX + C " CR
 3 F0. ['] SX 2! F0. ['] SY 2! F0. ['] SX2 2! F0. ['] SXY 2!
 4 F0. ['] SRES 2!
 5 OP @ 0 DO I OBS 4@ 2DUP ['] SX F+! 2DUP F**2 ['] SX2 F+!
 6 2SWAP 2DUP ['] SY F+! F* ['] SXY F+! LOOP
 7 OP @ FLOAT ['] A11 2! SX 2DUP ['] A12 2! ['] A21 2!
 8 SX2 ['] A22 2! SY ['] B1 2! SXY ['] B2 2! LSTSQ
 9 CR ."            X            Y          ∠Y " CR
10 OP @ 0 DO CR I 5 .R I OBS 4@ 2DUP F. M F* C F+
11 2OVER F. F- 2DUP F. F**2 ['] SRES F+! LOOP
12 SRES OP @ 2 - FLOAT F/ FSQRT ['] RMS 2! ERROR
13 CR CR ." M=" M F. ." ±" MERR F.
14 CR ." C=" C F. ." ±" CERR F. ;
15 1 WARNING !
```

```
2147
 0 ( BJM - STATISTICAL PACKAGE - LST.SQ.EXPONENTIAL CURVE )
 1 FORGET TINYTASK : TINYTASK ;  0 WARNING !
 2 FC M1 FC C1  FL 0.43429 FCONSTANT E
 3 : SOLVE  ." Y = C1 * EXP ( M1 * X )" CR
 4 F0. ['] SX 2! F0. ['] SY 2! F0. ['] SX2 2! F0. ['] SXY 2!
 5 F0. ['] SRES 2!
 6 OP @ 0 DO I OBS 4@ 2DUP ['] SX F+! 2DUP F**2 ['] SX2 F+!
 7 2SWAP FLOG10 2DUP ['] SY F+! F* ['] SXY F+! LOOP  LSTSQ
 8 M E F/ ['] M1 2!  C FALOG ['] C1 2!
 9 CR ."            X            Y          ∠ΔY " CR
10 OP @ 0 DO CR I 5 .R I OBS 4@ 2DUP F. M1 F* EXP C1 F*
11 2OVER F. F- 2DUP F. ['] SRES F+! LOOP
12 ERROR CR CR ." RMS ERROR =" SRES OP @ 1- FLOAT F/ FSQRT F.
13 CR CR ." M1=" M1 F. CR ." C1=" C1 F. ;
14 EXIT
15 1 WARNING !


2148
 0 ( BJM - STATISTICAL PACKAGE - LST.SQ.POWER CURVE )
 1 FORGET TINYTASK : TINYTASK ;  0 WARNING !
 2 FC M2 FC C2
 3 : SOLVE  ." Y = C2 * X PWR M2 " CR
 4 F0. ['] SX 2! F0. ['] SY 2! F0. ['] SX2 2! F0. ['] SXY 2!
 5 F0. ['] SRES 2!
 6 OP @ 0 DO I OBS 4@ FLOG10 2DUP ['] SX F+! 2DUP F**2 ['] SX2 F+!
 7 2SWAP FLOG10 2DUP ['] SY F+! F* ['] SXY F+! LOOP  LSTSQ
 8 M ['] M2 2!  C FALOG ['] C2 2!
 9 CR ."            X            Y          ∠ΔY " CR
10 OP @ 0 DO CR I 5 .R I OBS 4@ 2DUP F. M2 FPWR C2 F*
11 2OVER F. F- 2DUP F. ['] SRES F+! LOOP
12 ERROR CR CR ." RMS ERROR =" SRES OP @ 1- FLOAT F/ FSQRT F.
13 CR CR ." M2=" M2 F. CR ." C2=" C2 F. ;
14 EXIT
15 1 WARNING !


2149
 0 ( BJM - STATISTICAL PACKAGE - FACILITIES )
 1 PAGE .# STATISTICAL PACKAGE                    BJM MARCH 1979" CR
 2 CR .# SECTION              FUNCTIONS"
 3 CR .# =======              ==========" CR
 4 CR .# 1PARAMETER" CR .# ==========="
 5 CR .#                      MEAN, ST.DEVIATION, ST.ERROR" CR
 6 CR .# 2PARAMETERS" CR .# ==========="
 7 CR .# 1) STATISTICS        MEAN, ST.DEVIATION, ST.ERROR"
 8 CR .#    ----------        COEFFICIENT OF CORRELATION" CR
 9 CR .# 2) LINEFIT           LST.SQ.STRAIGHT LINE FIT"
10 CR .#    --------" CR
11 CR .# 3) POWERFIT          LST.SQ.POWER CURVE FIT"
12 CR .#    ---------" CR
13 CR .# 4) EXPONFIT          LST.SQ.EXPONENTIAL CURVE FIT"
14 CR .#    ----------" CR
15
```

```
2150
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 FORGET SUB-SUBTASK : SUB-SUBTASK ;  0 WARNING !
 2 -140 +BLOCK LOAD ( DISC ARRAYS )
 3 : 6@ 6 N@ ;  : 6! 6 N! ;
 4 : FC F0. FCONSTANT ;
 5 FC K1 FC K2 FC K1+K2 FC Q FC 1/Q FC V0 FC V1 FC V2 FC THETA
 6 FC DR FC DV0 FC DK1+K2 FC DK1 FC DK2 FC VERR FC RERR FC ECC
 7 FC PERIOD  FL 100. FCONSTANT F100 F2 PI F* FCONSTANT 2PI
 8 FC RMS FC 1RMS FC 2RMS FC DELTA FC SUM FC 1SUM FC 2SUM FC 3SUM
 9 FC SA FC SAA FC SV1 FC SV2 FC SV1A FC SV2A
10 FC A11 FC A12 FC A21 FC A22 FC B1 FC B2 FC DET
11 FC M FC C FC MERR FC CERR
12 10 CONSTANT LIMIT FL 0.01 FCONSTANT QDIFF F1 FCONSTANT VDIFF
13 0 CONSTANT ITERATIONS   FC QN FC VN
14 -->
15 -->
```

```
2151
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 OAREA INT OBSAREA           0 INT NVM
 2 : OBS 1+ 16 1024 */MOD OBSAREA + BLOCK + ;
 3 : NOP -1 OBS ;
 4 : SAVE >R 2SWAP 2ROT 2PI F* R> OBS 6! UPDATE ;
 5 : ENTER CR ." IS THIS A NEW CATALOGUE ? " Y/N IF 0 NOP !D THEN
 6 CR ." NO.VALUES=" ASK := NVM CR CR ." PHASE    V(P)    V(S)"
 7 NOP @ NVM + NOP @ DO CR FASK 3 SPACES FASK 3 SPACES FASK I SAVE
 8 1 NOP +!D LOOP ;
 9 : VALUES CR ."           PHASE     PRIMARY   SECONDARY"
10 NOP @ 0 DO CR I 5 .R I OBS 6@ 2PI F/ F. F. F. LOOP ;
11 : DELETE CR ." NO.=" ASK NOP @ SWAP DO I 1+ OBS 6@ I OBS 6!
12 UPDATE LOOP -1 NOP +!D ;
13 : CHANGE CR ." NO.=" ASK := NVM ." VALUES=" FASK 3 SPACES
14 FASK 3 SPACES FASK NVM SAVE ;
15 -->
```

```
2152
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : PHASES CR ." PHASE CHANGE=" FASK ['] DELTA 2!
 2 NOP @ 0 DO I OBS 6@ DELTA 2PI F* F+ 2DUP 2PI F> IF 2PI F- THEN
 3 2DUP F0. F< IF 2PI F+ THEN I OBS 6! UPDATE LOOP ;
 4
 5 : LSTSQ
 6 A11 A22 F* A12 A21 F* F- ['] DET 2!
 7 A22 DET F/ A12 DET F/ FMINUS A21 DET F/ FMINUS A11 DET F/
 8 ['] A22 2! ['] A21 2! ['] A12 2! ['] A11 2!
 9 A11 B1 F* A12 B2 F* F+ ['] C 2!
10 A21 B1 F* A22 B2 F* F+ ['] M 2! ;
11
12 : LSTSQ-ERROR
13 RMS F**2 A11 F* FSQRT ['] CERR 2!
14 RMS F**2 A22 F* FSQRT ['] MERR 2! ;
15 -->
```

```
2153
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : K1+K2CALC
 2 F0. ['] SUM 2! F0. ['] 1SUM 2! F0. ['] 2SUM 2! F0. ['] 3SUM 2!
 3 NOP @ 0 DO I OBS 6@ ['] THETA 2! ['] V1 2! ['] V2 2!
 4 V1 V2 F- ['] SUM F+!
 5 THETA FSIN FMINUS ['] 1SUM F+!
 6 THETA FSIN FMINUS F**2 ['] 2SUM F+!
 7 THETA FSIN FMINUS V1 V2 F- F* ['] 3SUM F+! LOOP
 8 NOP @ FLOAT ['] A11 2! 1SUM 2DUP ['] A12 2! ['] A21 2!
 9 2SUM ['] A22 2! SUM ['] B1 2! 3SUM ['] B2 2!
10 LSTSQ M ['] K1+K2 2!
11 F0. ['] 1SUM 2!
12 NOP @ 0 DO I OBS 6@ ['] THETA 2! ['] V1 2! ['] V2 2!
13 K1+K2 THETA FSIN FMINUS F* V1 V2 F- F- F**2 ['] 1SUM F+! LOOP
14 1SUM NOP @ 1- FLOAT F/ MERR F* FSQRT ['] DK1+K2 2! ;
15 --->


2154
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : V1CALC F1 Q F/ ['] 1/Q 2!
 2 V0 K1+K2 THETA FSIN F* F1 1/Q F+ F/ F- ;
 3
 4 : V2CALC F1 Q F/ ['] 1/Q 2!
 5 V0 K1+K2 THETA FSIN F* 1/Q F* F1 1/Q F+ F/ F+ ;
 6
 7 : K1CALC F1 Q F/ ['] 1/Q 2!
 8 K1+K2 F1 1/Q F+ F/ ['] K1 2! ;
 9
10 : K2CALC F1 Q F/ ['] 1/Q 2!
11 K1+K2 1/Q F* F1 1/Q F+ F/ ['] K2 2! ;
12 --->
13 ;S
14 ;S
15 ;S


2155
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : LSTSQ-SOLUTION
 2 NOP @ 2* FLOAT ['] A11 2!
 3 K1+K2 F1 1/Q F* F**2 F/ SA F* F2 F* 2DUP ['] A12 2! ['] A21 2!
 4 K1+K2 F1 1/Q F+ F**2 F/ F**2 SAA F* F2 F* ['] A22 2!
 5 SV1 SV2 F+ ['] B1 2!
 6 SV1A SV2A F+ K1+K2 F1 1/Q F+ F**2 F/ F* ['] B2 2!
 7 LSTSQ
 8 C ['] DV0 2! M ['] DR 2!
 9 DV0 V0 F+ ['] V0 2!
10 F1 Q F/ DR F+ F1 2SWAP F/ ['] Q 2! ;
11 --->
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2156
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : ERRORS
 2 F0. ['] SUM 2! F0. ['] 1SUM 2! F0. ['] 2SUM 2!
 3 NOP @ 0 DO I OBS 6@ ['] THETA 2! ['] V1 2! ['] V2 2!
 4 V1 V1CALC F- F**2 ['] 1SUM F+!
 5 V2 V2CALC F- F**2 ['] 2SUM F+! LOOP
 6 1SUM NOP @ 1- FLOAT F/ FSQRT ['] 1RMS 2!
 7 2SUM NOP @ 1- FLOAT F/ FSQRT ['] 2RMS 2!
 8 1SUM 2SUM F+ NOP @ 2* 1- FLOAT F/ FSQRT ['] RMS 2!
 9 LSTSQ-ERROR
10 CERR ['] VERR 2! MERR ['] RERR 2!
11 DK1+K2 F**2 K1 F**2 RERR F**2 F* F+ FSQRT
12 F1 1/Q F+ F/ ['] DK1 2!
13 DK1+K2 F**2 DK1 F**2 F- FSQRT ['] DK2 2! ;
14 -->
15 ;S


2157
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : DIFFERENTIAL-CORRECTION
 2 F0. ['] SA 2! F0. ['] SAA 2! F0. ['] SV1 2! F0. ['] SV2 2!
 3 F0. ['] SV1A 2! F0. ['] SV2A 2! F0. ['] 1SUM 2! F0. ['] 2SUM 2!
 4 K1+K2CALC
 5 NOP @ 0 DO I OBS 6@ ['] THETA 2! ['] V1 2! ['] V2 2!
 6 THETA FSIN 2DUP ['] SA F+! F**2 ['] SAA F+!
 7 V1 V1CALC F- THETA FSIN F* ['] SV1A F+!
 8 V2 V2CALC F- THETA FSIN F* ['] SV2A F+!
 9 V1 V1CALC F- ['] SV1 F+! V2 V2CALC F- ['] SV2 F+! LOOP
10 LSTSQ-SOLUTION
11 K1CALC K2CALC
12 ERRORS ;
13 -->
14 ;S
15 ;S


2158
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 10 :P PRIMARY FLOAT F100 F/ 2PI F* FSIN K1+K2 F*
 2 F1 1/Q F+ F/ V0 2SWAP F- FIX ;
 3 11 :P SECONDARY FLOAT F100 F/ 2PI F* FSIN K1+K2 F*
 4 1/Q F* F1 1/Q F+ F/ V0 F+ FIX ;
 5 0 100 X SIZE -400 400 Y SIZE 2 X DECIMALS !
 6 0 +BLOCK : AMESSAGE 750 0 OFF DRAW ALPHA 14 IN-LINE L@LOAD ;
 7 0 +BLOCK : BMESSAGE 50 850 OFF DRAW ALPHA 15 IN-LINE L@LOAD ;
 8 : DISPLAY ERASE AMESSAGE AXES BMESSAGE CROSSPLOT
 9 NOP @ 0 DO I OBS 6@ ['] THETA 2! ['] V1 2! ['] V2 2!
10 V1 FIX THETA 2PI F/ F100 F* FIX LIGHT
11 V2 FIX THETA 2PI F/ F100 F* FIX LIGHT
12 LOOP LINEPLOT  10 APLOT 11 APLOT ;
13 -->
14 HP" Radial" HPCR HP" Velocity" HPCR HP" Km/s"   EXIT
15 HP" Phase"
```

```
2159
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : RESULTS 8 2 FMT
 2 CR ." MEAN ERRORS :-"
 3 CR ." PRIMARY  =" 1RMS F. ." KM/S"
 4 CR ." SECONDARY=" 2RMS F. ." KM/S" CR
 5 CR ." K1=" K1 F. ." ±" DK1 F. ." KM/S"
 6 CR ." K2=" K2 F. ." ±" DK2 F. ." KM/S"
 7 CR ." VO=" VO F. ." ±" VERR F. ." KM/S" CR
 8 CR ." Q =" Q F. ." ±" RERR 1/Q F/ Q F* F. CR
 9 FL 13751. PERIOD F* 2DUP K2 F* 2SWAP K1 F*
10 CR ." A1SINI=" E. ." KM" CR ." A2SINI=" E. ." KM" CR
11 FL 1.036 F10 FL -7. FPWR F* K1+K2 F**2 F* PERIOD F*
12 2DUP K1 F* 2SWAP K2 F*
13 CR ." M1SIN3I=" F. ." MSUN" CR ." M2SIN3I=" F. ." MSUN" CR
14 CR 10 4 FMT ;  -->
15 ;S


2160
 0 ( BJM - SPECTROSCOPIC ORBIT )
 1 : SOLVE
 2 CR CR ." ENTER INITIAL VALUES" CR  0 ['] ITERATIONS !
 3 CR ." PERIOD=" FASK ['] PERIOD 2! CR
 4 ." Q =" FASK ['] Q 2! CR ." VO=" FASK ['] VO 2! CR CR
 5 BEGIN Q ['] QN 2! VO ['] VN 2!  1 ['] ITERATIONS +!
 6 DIFFERENTIAL-CORRECTION
 7 Q QN F- FABS QDIFF F< VO VN F- FABS VDIFF F< AND
 8 ITERATIONS LIMIT > OR 7 C. END
 9 CR ." NO.ITERATIONS=" ITERATIONS . CR
10 RESULTS ;
11 1 WARNING !
12 ERASE
13 .# SPECTROSCOPIC BINARY PROGRAM" CR CR
14 .# RADIAL VELOCITY CURVE SOLUTION USING IRWIN'S METHOD" CR
15


2161
 0 ( BJM - PERIOD FINDING )
 1 FORGET SUB-SUBTASK : SUB-SUBTASK ;
 2 0 WARNING !
 3 -151 +BLOCK LOAD ( DISC ARRAYS )
 4
 5 F0. 2INT A0 F0. 2INT A1 F0. 2INT A2 F0. 2INT C1 F0. 2INT C2
 6 F0. 2INT XI F0. 2INT SHIFT F0. 2INT SUM
 7 F0. 2INT DP F0. 2INT NP
 8 F0. 2INT OMEGA F0. 2INT SMAX
 9 F0. 2INT PERIOD F0. 2INT PMIN F0. 2INT PMAX
10
11 : RESET-SUM F0. := SUM ;
12 -->
13 ;S
14 ;S
15 ;S
```

```
2162
 0 ( BJM - PERIOD FINDING )
 1 10000 CONSTANT OBSAREA
 2
 3 : OBS 1+ 32 1024 */MOD OBSAREA + BLOCK + ;
 4 : NPTS -1 OBS ;
 5 : TOBS OBS ;
 6 : MOBS OBS 4 + ;
 7 : WOBS OBS 8 + ;
 8 : XOBS OBS 12 + ;
 9 : FOBS OBS 16 + ;
10
11 OAREA ' OBSAREA !
12 -->
13 ;S
14 ;S
15 ;S
```

```
2163
 0 ( BJM - PERIOD FINDING )
 1 10000 CONSTANT TRANS-AREA
 2
 3 : VAL 1+ 8 1024 */MOD TRANS-AREA + BLOCK + ;
 4 : NVAL -1 VAL ;
 5 : PER VAL ;
 6 : I(P) VAL 4 + ;
 7
 8 WAREA ' TRANS-AREA !
 9
10 : CLEAR 0 NPTS !D 0 NVAL !D ;
11
12 -->
13 ;S
14 ;S
15 ;S
```

```
2164
 0 ( BJM - PERIOD FINDING )
 1 : X-CALC
 2 NPTS @ 0 DO I TOBS 2@ OMEGA F* PI F* F2 F* I XOBS 2!D LOOP ;
 3
 4 : F-CALC
 5 RESET-SUM
 6 NPTS @ 0 DO I WOBS 2@ I MOBS 2@ F* [']  SUM F+! LOOP
 7 SUM NPTS @ FLOAT F/ := SHIFT
 8 NPTS @ 0 DO I MOBS 2@ SHIFT F- I FOBS 2!D LOOP ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2165
 0 ( BJM - PERIOD FINDING )
 1 : A0-CALC
 2 RESET-SUM
 3 NPTS @ 0 DO I WOBS 2@ ['] SUM F+! LOOP
 4 SUM FSQRT F1 2SWAP F/ := A0 ;
 5
 6 : A1-CALC
 7 RESET-SUM
 8 NPTS @ 0 DO I XOBS 2@ FCOS F**2 I WOBS 2@ F* ['] SUM F+! LOOP
 9 SUM RESET-SUM
10 NPTS @ 0 DO I XOBS 2@ FCOS I WOBS 2@ F* ['] SUM F+! LOOP
11 SUM F**2 A0 F**2 F* F- FSQRT F1 2SWAP F/ := A1 ;
12 -->
13 ;S
14 ;S
15 ;S
```

```
2166
 0 ( BJM - PERIOD FINDING )
 1 : A2-CALC RESET-SUM
 2 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FSIN F**2 F* ['] SUM F+! LOOP
 3 SUM SUM F**2 A0 F**2 F* F- RESET-SUM
 4 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ 2DUP FCOS 2SWAP FSIN F* F*
 5 ['] SUM F+! LOOP SUM F**2 A1 F**2 F* F- RESET-SUM
 6 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FCOS F* ['] SUM F+! LOOP
 7 SUM F**2 A1 F**2 F* A0 F4 FPWR F* RESET-SUM
 8 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FSIN F* ['] SUM F+! LOOP
 9 SUM F**2 F* F- RESET-SUM
10 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FCOS F* ['] SUM F+! LOOP
11 SUM A1 F**2 F* A0 F**2 F* F2 F* RESET-SUM
12 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FSIN F* ['] SUM F+! LOOP
13 SUM F* RESET-SUM
14 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ 2DUP FCOS 2SWAP FSIN F* F*
15 ['] SUM F+! LOOP SUM F* F+ FSQRT F1 2SWAP F/ := A2 ;   -->
```

```
2167
 0 ( BJM - PERIOD FINDING )
 1 : C1-CALC
 2 RESET-SUM
 3 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FCOS F* 1 FOBS 2@ F*
 4 ['] SUM F+! LOOP SUM A2 F* := C1 ;
 5 : C2-CALC
 6 RESET-SUM
 7 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FSIN F* I FOBS 2@ F*
 8 ['] SUM F+! LOOP SUM A2 F* RESET-SUM
 9 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ 2DUP FCOS 2SWAP FSIN F* F*
10 ['] SUM F+! LOOP SUM RESET-SUM
11 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FCOS F* ['] SUM F+! LOOP
12 SUM RESET-SUM
13 NPTS @ 0 DO I WOBS 2@ I XOBS 2@ FSIN F* ['] SUM F+! LOOP
14 SUM F* A0 F**2 F* F- A1 F* A2 F* C1 F* F- := C2 ;
15 -->
```

```
2168
 0 ( BJM - PERIOD FINDING )
 1 : TRANSFORM
 2 F0. ;= NP 0 NVAL !D
 3 BEGIN
 4 PMIN DP NP F* F+ ;= PERIOD
 5 F1 PERIOD F/ ;= OMEGA X-CALC
 6 A0-CALC A1-CALC A2-CALC
 7 C1-CALC C2-CALC
 8 C1 F**2 C2 F**2 F+ NP FIX I(P) 2!D
 9 PERIOD NP FIX PER 2!D
10 F1 ['] NP F+!
11 1 NVAL +!D
12 PERIOD PMAX F< NOT END ;
13 -->
14 ;S
15 ;S
```

```
2169
 0 ( BJM - PERIOD FINDING )
 1 : ENTER
 2 CR ." IS THIS A NEW CATALOGUE ? "
 3 Y/N IF CLEAR THEN
 4 CR ." NO.OBSERVATIONS= " ASK CR CR
 5 CR ." NO.     TIME      MEASURE     WEIGHT"
 6 NPTS @ + NPTS @ DO CR
 7 I 3 .R 4 SPACES FASK I TOBS 2!D 4 SPACES FASK I MOBS 2!D
 8 4 SPACES FASK I WOBS 2!D 1 NPTS +!D LOOP F-CALC ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2170
 0 ( BJM - PERIOD FINDING )
 1 : RESULTS
 2 CR ."      PERIOD         I(P)"
 3 NVAL @ 0 DO CR I PER F? I I(P) F? LOOP ;
 4
 5 : VALUES
 6 CR ."  NO.      TIME       VALUE  REL.VALUE      WEIGHT"
 7 NPTS @ 0 DO CR I 3 .R I TOBS F? I MOBS F? I FOBS F?
 8 I WOBS F? LOOP ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S
```

```
2171
 0 ( BJM - PERIOD FINDING )
 1 : DELETE CR ." NO.= " ASK NPTS @ SWAP DO
 2 I 1+ TOBS 2@ I TOBS 2!D I 1+ MOBS 2@ I MOBS 2!D
 3 I 1+ WOBS 2@ I WOBS 2!D I 1+ XOBS 2@ I XOBS 2!D
 4 I 1+ FOBS 2@ I FOBS 2!D LOOP -1 NPTS +!D ;
 5
 6 : CHANGE CR ." NO.=" ASK := M
 7 ." TIME=" FASK M TOBS 2!D ." VALUE=" FASK M MOBS 2!D
 8 ." WEIGHT=" FASK M WOBS 2!D F-CALC ;
 9 -->
10 ;S
11 ;S
12 ;S
13 ;S
14 ;S
15 ;S


2172
 0 ( BJM - PERIOD FINDING )
 1 : DISPLAY
 2 F0. := SMAX
 3 PMIN FL 100. F* FIX PMAX FL 100. F* FIX X SIZE  0 1000 Y SIZE
 4 2 X DECIMALS ! 3 Y DECIMALS ! -200 Y INC !
 5 NVAL @ 0 DO I I(P) 2@ SMAX FMAX := SMAX LOOP
 6 NVAL @ 0 DO I I(P) 2@ SMAX F/ F1000 F* I I(P) 2!D LOOP
 7 ERASE AXES OFF NVAL @ 0 DO I I(P) 2@ FIX
 8 I PER 2@ FL 100. F* FIX LIGHT LOOP ALPHA
 9 13 4251 L#LOAD 14 4251 L#LOAD 15 4251 L#LOAD CR ;
10 HISTOGRAM
11 -->
12
13 767 0 OFF DRAW ALPHA HP" PERIODOGRAM"  EXIT
14 720 20 OFF DRAW ALPHA HP" I(P)"  EXIT
15 40 800 OFF DRAW ALPHA HP" PERIOD"  EXIT


2173
 0 ( BJM - PERIOD FINDING )
 1 : SOLVE
 2 CR ." ENTER SEARCH PARAMETERS...."
 3 CR ." MIN.PERIOD  = " FASK := PMIN
 4 CR ." MAX.PERIOD  = " FASK := PMAX
 5 CR ." INCREMENT   = " FASK := DP
 6 F-CALC
 7 TRANSFORM SIGNAL DISPLAY ;
 8 1 WARNING !
 9
10
11
12
13
14
15
```

```
2174
 0 ( BJM - GRAPH PLOTTING )
 1 FORGET SUB-SUBTASK : SUB-SUBTASK ;
 2
 3 0 WARNING !
 4
 5 -164 +BLOCK LOAD ( DISC ARRAYS )
 6 -143 +BLOCK LOAD ( LST.SQ.POLY.)
 7
 8 : HEADING OFF DRAW ALPHA ;
 9
10 FL 1000. ' MULT 2!  3 3 X DECIMALS 2!
11 -->
12
13
14
15
```

```
2175
 0 ( BJM - GRAPH PLOTTING )
 1 10000 INT OBSAREA
 2 : OBS 1+ 8 1024 */MOD OBSAREA + BLOCK + ;
 3 : OP -1 OBS ; : SCRUB 0 OP !D ;
 4 : ENTER CR ." CATALOGUE AREA = " ASK := OBSAREA
 5 CR ." IS THIS A NEW CATALOGUE ? " Y/N IF 0 OP !D THEN
 6 CR ." NO.VALUES= " ASK := M OP @ M + OP @ DO CR I 3 .R 3 SPACES
 7 FASK FASK 2SWAP I OBS 4! UPDATE 1 OP +!D LOOP ;
 8 : INTERCHANGE OP @ 0 DO I OBS 4@ 2SWAP I OBS 4! UPDATE LOOP ;
 9 : DELETE CR ." NO.= " ASK OP @ SWAP DO I 1+ OBS 4@ I OBS 4!
10 UPDATE LOOP -1 OP +!D ;
11 : CHANGE CR ." NO.= " ASK := M ." VALUES= " FASK FASK
12 2SWAP M OBS 4! UPDATE ;
13 : VALUES CR ." NO.      X        Y"
14 OP @ 0 DO CR I 3 .R I OBS 4@ F. F. LOOP ;
15 -->
```

```
2176
 0 ( BJM - GRAPH PLOTTING )
 1 : DDD OP @ 0 DO I OBS 4@ PFIX -ROT PFIX SWAP
 2 MARK PLEXEC LOOP ;
 3
 4 : VPLOT CROSSPLOT DDD LINEPLOT ; : DPLOT DOTTY DDD LINEPLOT ;
 5 : DISPLAY PAGE AXES VPLOT ;  : DDISP PAGE AXES DPLOT ;
 6
 7 : CPLOT := CH OP @ 0 DO I OBS 4@ PFIX -ROT PFIX
 8 SWAP SCALE  -2 -2 CHSIZE V*/ V+  OFF DRAW
 9 CH HP. LOOP ALPHA ;
10
11 -->
12
13
14
15
```

```
2177
 0 ( BJM - GRAPH PLOTTING )
 1    0 CONSTANT X1    0 CONSTANT X2
 2    0 CONSTANT Y1    0 CONSTANT Y2
 3
 4 : WINDOW X1 X2 ABSCISSA  Y1 Y2 ORDINATE  40 Y CORNER !
 5     X RNG 2@ 11 14 */ > IF 700 Y FRAME ! 700 X RNG @
 6     Y RNG @ */ DUP X FRAME ! MINUS 1000 + X CORNER ! ELSE
 7     94 X CORNER ! 906 X FRAME ! 906 Y RNG @ X RNG @ */
 8     Y FRAME ! THEN ;
 9
10 : SETAXES CR ." X COORD. FROM " FASK PFIX ['] X1 !
11 ." TO " FASK PFIX ['] X2 ! CR ." Y COORD. FROM " FASK PFIX ['] 
12 Y1 ! ." TO " FASK PFIX ['] Y2 !  X1 X2 X SIZE Y1 Y2 Y SIZE ;
13 -->
14
15
```

```
2178
 0 ( BJM - GRAPH PLOTTING )
 1 0 INT LX 0 INT UX 0 INT NPOS
 2 F0. 2INT XPOS F0. 2INT YPOS
 3
 4 : SET-POLY OP @ 0 DO I OBS 4@ I 1+ PX 2!D
 5 I 1+ PY 2!D F1 I 1+ PW 2!D LOOP ;
 6
 7 : PLOTPOLY OFF UX LX DO I FLOAT MULT F/ CALCPOLY PFIX
 8 I LIGHT LOOP ALPHA ;
 9 : PLOT BAR := LX BAR := UX PLOTPOLY ;
10 : POSITION BAR FLOAT MULT F/ 2DUP := XPOS CALCPOLY := YPOS
11 767 500 HEADING ." X = " XPOS F. ." Y = " YPOS F. CR ;
12 : CONNECT BAR DUP FLOAT MULT F/ CALCPOLY PFIX
13 BAR DUP FLOAT MULT F/ CALCPOLY PFIX JOIN ;
14 -->
15
```

```
2179
 0 ( BJM - GRAPH PLOTTING )
 1 : FIT SET-POLY
 2 COORDS DROP := LX 0 := NPOS
 3 BEGIN 1 ['] NPOS +! LX NPOS PX 2@ PFIX < END
 4 NPOS ['] NN !
 5 COORDS DROP := UX OP @ 1+ := NPOS
 6 BEGIN -1 ['] NPOS +! UX NPOS PX 2@ PFIX > END
 7 NPOS ['] NNN !
 8 767 0 HEADING ." MAX.ORDER = " ASK ['] LAST !
 9 POLYFIT PLOTPOLY 730 0 HEADING ." ORDER FIT = " NORD . ;
10
11 : COEFF CR ." ORDER  COEFFICIENT" NORD 1+ 0 DO CR I .
12 I 1+ AK F? LOOP ;
13 : SNAKE OP @ 1- 0 DO I OBS 4@ PFIX -ROT PFIX
14 I 1+ OBS 4@ PFIX -ROT PFIX  JOIN LOOP ;
15 -->
```

```
2180
 0 ( BJM - GRAPH PLOTTING )
 1 0 INT XYSEL 0 INT AOP F0. 2INT NUM
 2 : OPERATE
 3 CR ." DO YOU WISH TO OPERATE ON X OR Y VALUES " KEY := XYSEL
 4 CR ." SELECT ARITHMETIC OPERATION"
 5 CR ." 1 : +" CR ." 2 : -" CR ." 3 : *" CR ." 4 : /"
 6 CR ." 5 : LOG" CR ." 6 : ALOG" CR ." ENTER CODE NO." ASK := AOP
 7 AOP 5 < IF CR ." ENTER NUMERIC VALUE " FASK := NUM THEN
 8 OP @ 0 DO I OBS 4@ XYSEL 89 = IF 2SWAP THEN
 9 AOP 1 = IF NUM F+ THEN AOP 2 = IF NUM F- THEN
10 AOP 3 = IF NUM F* THEN AOP 4 = IF NUM F/ THEN
11 AOP 5 = IF FLOG10 THEN AOP 6 = IF FALOG  THEN
12 XYSEL 89 = IF 2SWAP THEN I OBS 4! UPDATE LOOP ;
13 -->
14
15
```

```
2181
 0 ( BJM - GRAPH PLOTTING )
 1 : SETUP PAGE CR ." WORKAREA=" ASK ['] WORKAREA !
 2 CR ." DO YOU WISH TO PLOT AN EXISTING CATALOGUE ? "
 3 Y/N IF CR ." CATALOGUE BLK.= " ASK ['] OBSAREA ! THEN ;
 4 SETUP
 5 ! CATALOGUE CR ." BLK.NO.=" ASK := OBSAREA ;
 6 1 WARNING !
 7
 8
 9
10
11
12
13
14
15
```

```
2182
 0 ( BJM - FACILITIES AVAILABLE )  PAGE
 1 .# Spectroscopic Image Processing System :-" CR
 2 .# ==========================================" CR
 3 CR .#  1) WAVELENGTH     :- WAVELENGTH CALIBRATION"
 4 CR .#     ~~~~~~~~~~~~~~~~   FITTING TO ARC SPECTRA"
 5 CR .#  2) NOISEFILTER    :- SMOOTHING OF SPECTRA USING"
 6 CR .#     ~~~~~~~~~~~~~~~~~  FOURIER TECHNIQUES"
 7 CR .#  3) INTENSITY      :- WEDGE CALIBRATION"
 8 CR .#     ~~~~~~~~~~~~~~~~   DENSITY-INTENSITY CONVERSION"
 9 CR .#  4) CONTINUUM      :- NORMALISATION OF SPECTRA"
10 CR .#     ~~~~~~~~~~~~~~~~   TO CONTINUUM"
11 CR .#  5) PHOTOMETRY     :- ANALYSIS OF SPECTRAL LINES"
12 CR .#     ~~~~~~~~~~~~~~~~   LINE WIDTHS AND DEPTHS"
13 -->
14
15
```

```
2183
 0 ( BJM - FACILITIES AVAILABLE )
 1 CR .#  6) REMOVAL          :- REMOVAL OF SPURIOUS POINTS"
 2 CR .#     ~~~~~~~             OR UNWANTED FEATURES"
 3 CR .#  7) VELOCITY         :- RADIAL VELOCITY MEASUREMENT"
 4 CR .#     ~~~~~~~~            A) LINE PROFILE FITTING"
 5 CR .#                         B) SIMULATED COMPARATOR"
 6 CR .#                         C) CROSS-CORRELATION"
 7 CR .#  8) BROADENING       :- DECONVOLUTION OF SPECTRA"
 8 CR .#     ~~~~~~~~~~          BROADENING FUNCTIONS"
 9 CR .#  9) REDUCTIONS       :- DATA ANALYSIS"
10 CR .#     ~~~~~~~~~           A) STATISTICS"
11 CR .#                         B) RADIAL VELOCITY CURVES"
12 CR .#                         C) PERIOD FINDING       "
13 CR .#                         D) GRAPH PLOTTING       "
14 CR CR .# SELECT PROCESS REQUIRED BY ENTERING LOADER WORD
15
ok
```