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Evolution and period changes in binary stars*

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1. Introduction

As has been the practice in the past I shall address myself to the research activity of the Centre of Advanced Study in Astronomy (CASA) during the preceding several years. One of the important areas of research at Hyderabad has been the dynamics of interacting galaxies under the guidance of Prof. S. M. Alladin. I shall refer to this internationally recognised piece of work only in passing, partly because I am not involved in that work and partly because Prof. Alladin has been its best exponent.

We are also engaged in another theoretical exercise of computing profiles of spectral lines produced in the atmospheres of planets by the process of Rayleigh scattering. This work is still in progress and I shall have an opportunity to return to it next year when we hope to be able to present some new results.

Today, I am going to restrict myself to giving you a consolidated account of the binary star research that is being carried out by Prof. M. B. K. Sarma, Prof. N. B. Sanwal, myself and our students : M. Parthasarathy, A. G. Kulkarni, P. Vivekananda Rao, B D. Ausekar and T. Panchatsaram. I shall try to indicate how we have been utilizing the 48-inch and 15-inch telescopes of Japal-Rangapur and Nizamiah Observatories for such studies for the last one decade.

First, a word about the choice of the field. In my case, it goes back to my student days at Berkeley. Like most Indians I used to feel then, rather erroneously, that the best brains engage themselves in theoretical research. So, inspite of my limitations, I had also toyed with the idea of doing theoretical work in stellar evolution under Prof. L. G. Henyey. But my earlier exposure to solar astronomy at Kodaikanal had made me aware of the importance of observations, specially because of the historical lacuna of records of such tradition in India. Consequently my ideal was to follow the footsteps of Prof. J. L. Greenstein of Caltech who was equally at ease in theory and observations. Then, I argued to myself that since theoretical research does not require any costly and sophisticated equipment it can be pursued in India on one's own. It would, therefore, be better to get acquainted with the techniques of observation, particularly those which could be used later in India without much difficulty. Inspiration from Prof. Otto Struve and excellent courses in fundamental research techniques of photometry and spectroscopy given by Prof. H. F. Weaver made me choose the field of binary stars. Finally, before returning to India in 1959 I decided to concentrate on photometric observations with the 20-inch telescope of Leuchner

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observatory, for two reasons : (i) It was clear that in the immediate future we would have only small and medium sized telescopes which will not be much useful in spectroscopic research except for the brightest stars; (ii) *UBV* photometry of eclipsing binaries should be a natural and essential extension of the *UBV* photometry of single stars. I have not regretted that choice although I do feel the handicap of not being familiar with the electronic gadgetry so essential in all modern astronomical research. Further, it took one complete decade for possessing a telescopic system to put the above plan into operation because of the various delays in the 48-inch telescope project of CASA.

2. UBV photometry of eclipsing binaries

Our knowledge about the evolution of single stars owes much to the *UBV* and other multicolour photometry of single stars in clusters and in the general background. The colour magnitude diagram has become a standard tool in the interpretation of the evolutionary history of star clusters and galaxies. A commensurate effort in the case of close binary stars is needed to unravel the mystery of their formation and subsequent evolution. Various scenarios based on the idea of mass transfer through the first Lagrangian point have been proposed for systems with selected combinations of the primary and secondary masses. Such theoretical computations have indicated that a wide variety of objects ranging from W Ursa Majoris and Algol systems to Wolfe-Rayet stars, cataclysmic variables, novae and X-ray binaries can be produced in this manner. However, one needs a strong observational base covering the whole gamut of binary stars. Photometric observations in the standard *UBV* or narrow band Stromgren filters have to be obtained for as many systems as possible, and they should be supplemented with spectroscopic data of high accuracy.

Now, the photometric determination of magnitudes and colours of the individual components of a close binary system is quite difficult and time consuming, because we have to remove the effects of eclipses by observing the complete light curve and deriving the photometric elements. Personally I believe that it would be justified if a few telescopes are completely tied down with such observational programs for a couple of decades, particularly if the persons using that facility are so inclined by virtue of their research interests and training. It would, of course, be desirable that the telescopes be equipped with the latest observational devices which make use of as large a fraction of the incoming photons as possible. But the most important thing is to obtain fundamental astronomical data of permanent value.

In our humble effort since 1970 we have been able to gather photometric data for 15 binary systems, 12 of which were observed with the 48-inch reflector of Japal-Rangapur Observatory and three with the 15-inch refractor of Nizamiah Observatory. They include two contact systems, RV Crv and SX Crv, three Algol type semi-detached systems, HU Tau, RU Eri and TT Hya, two detached systems, WX Eri and EU Hya, four RS CVn binaries, WY Cnc, HR 1099, TY Pyx and UV Pis, and four other binaries, V Crt, RZ Eri, TT Aur and CW CMa whose light curves are yet to be analysed. Photometric elements have been obtained for seven systems. Table 1 gives the colours and spectral types of their components. Absolute dimensions have been determined for two systems, TT Hya and TY Pyx, by combining our photometric elements with the spectroscopic data published in literature.

Table 1. Colours and spectral types of binary components observed at Centre for Advanced Study in Astronomy, Hyderabad

Binary	Primary				Secondary			
	V	*B−V*	*U−B*	Sp	*V*	*B−V*	*U−B*	Sp
RV Crv	8.67	+0.33	+0.10	F0				
RU Eri	9.42	+0.40	—	F0–4V	12.28	+0.63	—	G3–K5V
TT Hya	7.53	+0.03	−0.02	A1V	8.90	+0.97	+0.28	K1 III
HU Tau	—	−0.035	—	B9V	—	+0.142	—	F5IV
WX Eri	8.57	+0.36	—	F3V	11.20	+0.56	—	G8V
EU Hya	10.45	+0.34	—	F2V	12.80	+0.85	—	G6V
TY Pyx	7.55	+0.72	—	G5V	7.70	+0.76	—	G6V

I shall now describe the important characteristics of each of the 11 systems for which the light curves have been analysed.

(1) RV Corvi : This star belongs to a group of contact binaries which fall between the early type massive systems of β Lyrae class and the later type W Ursa Majoris contact systems. They have not been studied in much detail so far. RV Crv itself was observed photoelectrically for the first time by our group with the 48-inch telescope (Abhyankar *et al.* 1974).

(2) SX Corvi : The star BD −18° 3437, which was chosen as a comparison star for RV Crv, turned out to be a contact binary of W UMa-type, showing variations of light curve from night to night (Sanwal *et al.* 1974). It is the first discovery of a variable star with the 48-inch telescope, the star is now designated as SX Corvi.

(3) HU Tauri : This is a fairly bright Algol system which was observed in *B* and *V* colours with the 15-inch refractor of Nizamiah Observatoıy by Parthasarathy & Sarma (1980). The star was later studied spectroscopically by Parthasarathy, who was able to obtain the absolute dimensions of the components (Parthasarathy 1980). As is usual with the Algol systems the secondary is found to fill its Roche lobe making it a semi-detached system.

(4) RU Eridani : From a study in *B* and *V* colours with the 48-inch telescope Sarma & Sanwal (1981) have found this star to be a semi-detached system in which the primary, an F0–4 star, fills its Roche lobe and not the secondary.

(5) TT Hydrae : This is an important Algol system for which photoelectric light curves in *UBV* have been obtained for the first time with the 48-inch telescope (Kulkarni & Abhyankar 1978). They not only gave good eclipse elements (Kulkarni & Abhyankar 1980) but also provided definitive values for the masses and radii of the two components, thanks to the excellent radial velocity curves obtained by Popper (1979). The model that emerges from this study (Kulkarni 1980) consists of an A1V main sequence primary with mass of 2.61 $M_\odot$ and radius of 2.01 $R_\odot$ accompanied by a giant secondary of spectral type K1 III having a mass of 0.70 $M_\odot$ and radius of 5.53 $R_\odot$. The secondary does not completely fill its Roche lobe and appears to be still in the pre-main-sequence contraction phase. The primary has an asymmetric circumstellar envelope which may be responsible for the UV excess during the primary eclipse.

(6) WX Eridani : This star has been observed photoelectrically for the first time by us with the 48-inch telescope (Abhyankar *et al.* 1978). The photometric solution (Sarma & Abhyankar 1979) shows that the system is a detached one. But the primary appears to be a δ Scuti type variable of spectral type F3.

(7) EU Hydrae : This detached system was also observed photoelectrically for the first time with the 48-inch telescope (Kulkarni *et al.* 1978, Kulkarni 1978) yielding good light curves and photometric solution for the system (Kulkarni 1980). Spectroscopic observations of this system are badly needed.

I now turn to the RS CVn stars observed by M. B. K. Sarma and his colleagues.

(8) WY Cancri : Observations of this star in 1973–74 and again in 1976–77 show that the light curve varies from year to year. It is a typical characteristic of RS CVn systems, which is attributed to varying spot activity on the surface of one or both components. The variation in WY Cnc can also be interpreted as the effect of an envelope of changing thickness surrounding the cool star (Sarma 1976).

(9) TY Pyxidis : This system is usually included in the lists of RS CVn stars. However, detailed photometric study with the 15-inch refractor by Vivekananda Rao & Sarma (1981) shows that it does not have the common characteristics of such systems. There is no variation in the depths of minima and no indication of a migrating wave outside eclipses. They find that the system consists of two detached identical stars of spectral type G5V and G6V. But they appear to be in the pre-main-sequence contraction phase and resemble T Tauri stars.

(10) UV Piscium : In addition to showing the RS CVn characteristics of a migrating wave outside eclipses, this system appears to have one component which is variable in light. *UBV* light curves obtained with the 48-inch telescope during three observing seasons are being analysed by Vivekananda Rao for delineating the various effects of migrating wave, eclipses and variability.

(11) HR 1099 : This is a spectroscopic binary which does not show eclipses, although there is light variation roughly in phase with the orbital period. But the minimum is found to shift along the spectroscopic phase from year to year. This wave motion is attributed to the spot activity on one of the components. Recent observations made by Sarma & Ausekar (1980) with the 15-inch refractor of Nizamiah Observatory give a period of about 5 yr for the forward migration of the wave. This can be explained by differential rotation in the atmosphere of the spotted star. The equator is assumed to rotate in synchronism with the orbital period and the rotation is considered to be slower at higher latitudes like the sun. Thus, since the spots occupy zones of latitudes between 5° and 35° they rotate slower and lag behind causing a delay in the observed times of minimum.

3. Period changes in binary stars

I shall now turn to period changes in binary stars as they have a bearing on the evolution of the components. Attention to the importance of studying period changes in binaries was first drawn by Kuiper (1941) and Wood (1950). The idea of Crawford (1955) that mass exchange plays an important role in the evolution of close binaries added further impetus to such studies. Since then, many theoretical investigations have been made to see how the loss of mass by the system or the exchange of mass between components could affect the period of a binary. The results have been applied to describe qualitatively the observed changes in the periods of several systems. However, there is no clear cut evidence for any system regarding the direct correlation of the period changes to its evolution as inferred from other photometric and spectroscopic studies. It is, therefore, necessary to re-examine these hypothesis and place them in juxtaposition to simple geometrical effects like the light time effect due to the presence of a third body or apsidal motion. T. Panchatsaram, a UGC Teacher Fellow at CASA has selected about two dozen systems for detailed study of period changes as a part of his Ph.D. thesis. It is his experience that only photo-electric times of minima are likely to give reliable results because the visual and photographic determination of minima are not sufficiently accurate. I shall next present the results for two systems for which some definitive results have been obtained.

(i) SW Lacertae is a W UMa-type binary whose $O - C$ diagram is interpreted as evidence of period changes caused by redistribution within or loss of matter out of the system. In this case we (Panchatsaram & Abhyankar 1981b) have been able to show that the observed times of photoelectric minima can be well represented by the orbital motion of a triple system around a hypothetical fourth body. First we note that the $O - C$ curve obtained on the basis of the light elements of Kreiner & Zofiafrasinka (1977) indicates that the basic period itself is larger than their value. After lengthening their period by 0.0000572 day we obtain an $O - C$ diagram which can be very well represented by a sum of two sine terms of periods 19.67 and 70.25 yr. Their amplitudes then give the masses of the third and fourth bodies which come out to be 0.97 $M_\odot$ and 1.05 $M_\odot$ respectively, if we take $i = 90°$. A smaller inclination of 60° would increase these masses by about 20 per cent, but they would still be below the Chandrasekhar limit. Hence, they are likely to be white dwarfs of low luminosity which make them undetectable by other means.

(ii) RT Persei is another system in which the variable period has been attributed to the presence of a third body. However, later observations deviated markedly from the prediction based on this hypothesis giving rise to the suspicion that irregular changes in period are superposed over the light time effect of the third body. Mancuso & Milano (1975) have even questioned the presence of the third body. Panchatsaram (1981) has now been able to show that all the observed minima can be well represented if we postulate the presence of a fourth body. The derived orbits of the third and fourth bodies have periods of 41.86 and 100 yr, eccentricities of 0.3 and 0.6, masses of 0.49 to 1.14 $M_\odot$ and 0.40 to 0.88 $M_\odot$ respectively, for $i \geqslant 30°$. These values are reasonably small for the stars to remain undected by spectroscopic means.

The above discussion brings out clearly that astrometric studies of all eclipsing binaries, which show long term period changes, are vital for deciding the presence of additional bodies in the system.

4. Secular variation of period

In many systems the times of minima can be represented by a quadratic ephemeris

$$t_{\min} = t_0 + P_0 E + \alpha E^2. \qquad \ldots(1)$$

This is interpreted as a secular change of period given by

$$P = P_0 + 2\alpha E, \qquad ...(2)$$

which is positive or negative depending upon the sign of α. Such period changes are attributed to mass loss or mass exchange phenomena. However, mass loss or mass transfer from less massive to more massive star always causes an increase in the period while α is found to have both positive and negative signs in different systems. Hence it is necessary to look for another cause for secular change of period.

I shall illustrate by considering the two systems K0 Aql and TV Cas which are quite similar. Both of them have main sequence primaries of mass about 3 $M_\odot$ and oversize secondaries of masses $0.6 M_\odot$ and $1.4\ M_\odot$, respectively. If the evolved secondaries are loosing mass to the primaries, then both systems should show a secular increase of period. Actually K0 Aql does show a secular increase of period, but TV Cas shows a secular decrease. Since we expect the same mechanism to operate in both systems the cause of their secular period change should be other than mass exchange.

Now, both K0 Aql and TV Cas are presumed to have undersize secondaries in the pre-main-sequence contraction phase of evolution (Roxburgh 1966a, 1966b, Field 1969). It is therefore natural to ask whether such contraction can affect the period of the binary. Change in the size of a star will change its moment of inertia and hence the rotational angular velocity. If the star happens to be a member of a close binary system then we expect synchronism between the period of rotation and orbital motion, which can be achieved by an exchange of angular momentum between the rotational and orbital motions. In this way contraction or expansion of the components of the binary can affect its period. We (Panchatsaram & Abhyankar 1981a) have obtained the following simple expression for the fractional period change:

$$\frac{\dot{P}}{P} = \frac{4\{I_1(\dot{R}_1/R_1) + I_2(\dot{R}_2/R_2)\}}{3I_1 + 3I_2 - \mu a^2}, \qquad ...(3)$$

where R_1, R_2 = radii of the two components,
I_1, I_2 = moments of inertia of the two components,
μ = reduced mass,
a = separation of the components.

On applying equation (2) to K0 Aql and TV Cas we expect a secular increase in period in both systems. In the case TV Cas, the period change is obviously of the wrong sign and in the case of K0 Aql it is found to be too small by an order of magnitude, when compared with the observed $\dot{P}/P$. We are, therefore, inclined to believe that the secular variation of period in these and other stars are most probably due to the light time effect caused by the presence of a third body.

It may be noted that the dominant term μa^2 in the denominator of equation (3) is negative, which makes the sign of the period change opposite to that of the change in size. This has some interesting consequences for the theory of binary evolution by the process of mass transfer through the first Lagrangian point L_1. In this theory it is believed that the more massive primary expands during evolution away from the main sequence, fills its Roche lobe and transfers mass to the secondary. During the process of mass transfer the period decreases reducing the size of the orbit as well as the Roche lobes, and thus helps accelerate the mass transfer process. We can now infer that the beginning of the mass transfer can be further advanced as a consequence of equation (3), because even while the star expands the period decreases causing a contraction of the Roche lobe. Thus as the star expands to fill the Roche lobe, the Roche lobe itself contracts to meet the stellar surface somewhat earlier.

5. Gravitational detection of third body

Presence of a third body accompanying an eclipsing binary can be inferred either by the difficulty experienced in deriving the photometric elements from the eclipse light curve, or by the deviations in the observed times of minima from those computed with the help of a given ephemeris. In the latter case if P_t is the true period of the binary and $P_0 = P_t(1 + (\gamma/c))$ the apparent mean period which includes the Doppler effect caused by the space motion, γ, of the triple system we have for the observed times of minima

$$(O - C) = t - (t_0 + P_0 E) = z_{12}/c \qquad \text{...(4a)}$$

where

$$z_{12} = r_{12} \sin i \sin (v + \omega) \qquad \text{...(4b)}$$

is the distance of the binary from the sky plane passing through the centre of mass. If the $O - C$ curve shows a significant portion of the cyclic variation of z_{12} it is possible to determine P_0 as well as the orbital parameters of the third body by using equations (4) and (5) as we saw for SW Lac earlier. But the solution becomes difficult if only a small part of the cyclic variation has been observed. One may ask the question : Is it possible to get any information about the third body in the latter case? The answer turns out to be : yes to some extent provided we have a secular variation of period as represented by equations (1) and (2).

First of all we note that from equation (2) we can find

$$\frac{\dot{P}}{P_0} = \frac{1}{P}\frac{dP}{dE}\frac{dE}{dt} = \frac{2\alpha}{P_0^2} \qquad \text{...(5)}$$

which has the dimension of reciprocal time. On multiplying it by c, the velocity of light, we get a quantity which has the dimensions of acceleration. It can be easily seen that by differentiating the Dopper formula

$$\frac{P-P_0}{P_0} = \frac{\dot{z}_{12}}{c}$$

we get,

$$\frac{\dot{P}}{P_0} = \frac{\ddot{z}_{12}}{c}$$

or

$$\ddot{z}_{12} = c\,\frac{\dot{P}}{P_0}. \qquad \text{...(6)}$$

Therefore, the times of minima represented by equation (1) indicate that the system is experiencing a constant acceleration in z-direction for a considerable length of time. The source of this acceleration would obviously be a third body in the system.

Now in order to derive information about the third body we start from the equation of motion for a two body system with reference to the centre of mass

$$\ddot{\vec{r}}_{12} = -G(m_{12} + m_3)\,\frac{\vec{r}_{12}}{r^3}, \qquad \ldots(7)$$

where m_{12} is the combined mass of the eclipsing binary, m_3 is the mass of the third body and $\vec{r} = \vec{r}_{12} - \vec{r}_3$. Equation (7) immediately gives

$$\ddot{z}_{12} = -\frac{G(m_{12} + m_3)\, r_{12} \sin i \sin (v + \omega)}{r^3}$$

or

$$\ddot{z}_{12} = -\frac{G m_3 \sin i \sin (v + \omega)}{r^2}. \qquad \ldots(8)$$

Then substituting $r = \dfrac{a(1 - e^2)}{1 + e \cos v}$ ...(9)

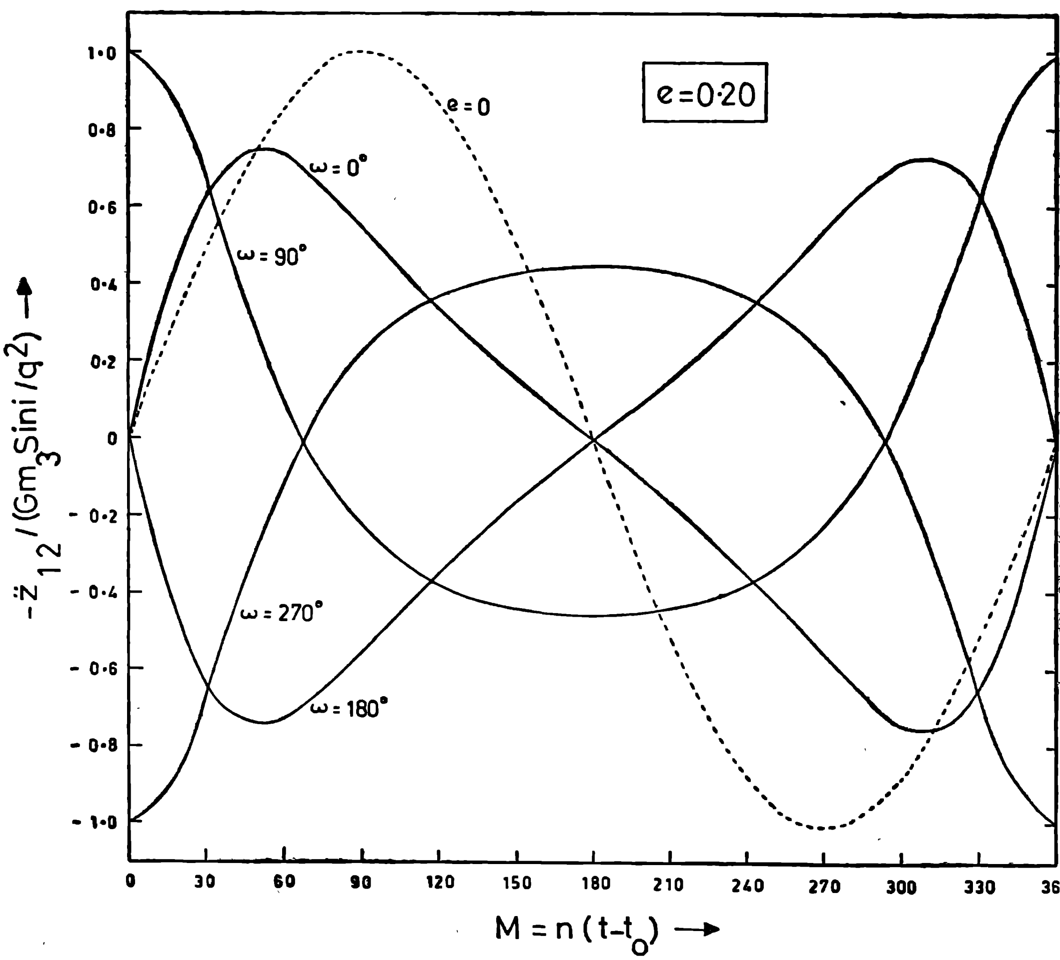

Figure 1

we get

$$\ddot{z}_{12} = -\frac{Gm_3 \sin i}{q^2} \frac{\sin (v + \omega)\ (1 + e \cos v)^2}{(1 + e)^2} \qquad \ldots(10)$$

where $q = a(1 - e)$ is the periastron distance.

Figures 1 to 4 show plots of $-\ddot{z}_{12}/(Gm_3 \sin i/q^2)$ as a function of the mean anomaly M for $e = 0$, 0.2, 0.4, 0.7 and 0.77 and $\omega = 0$, 90°, 180° and 270°. It is observed that the acceleration $\ddot{z}_{12}$ remains constant for a considerable fraction of the period near $M = v = 180°$ when $\omega = \pm 90°$. The fractional duration of constant acceleration increases and the value of constant acceleration decreases as we go from a circular to a parabolic orbit. Therefore, the likelihood of observing a detectable constant acceleration for a good length of time is maximum for intermediate values of e between 0.4 and 0.7 which also happens to be the modal range of eccentricities of the visual binaries.

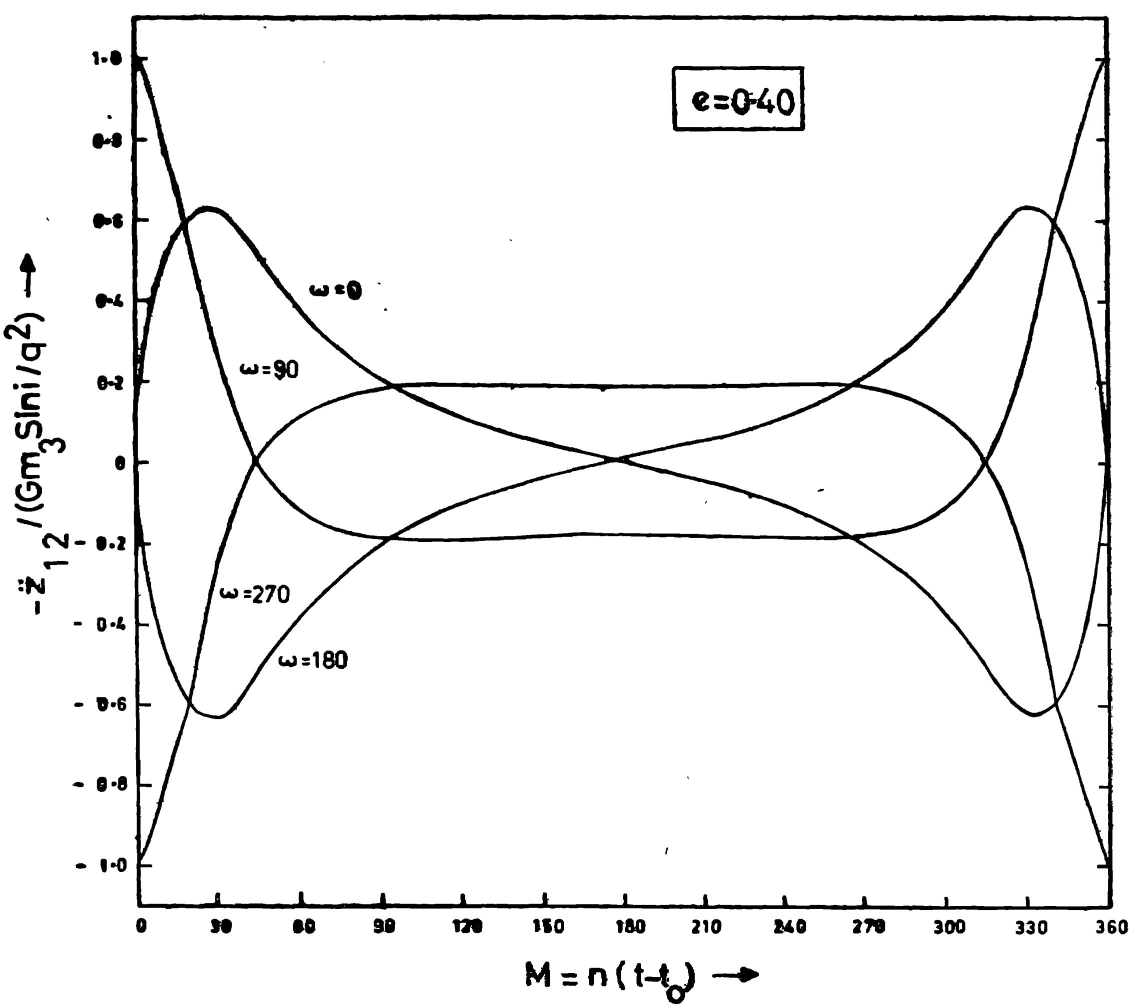

Figure 2

The absolute value of the above constant acceleration is given by

$$\left| \ddot{z}_{12} \right| = \frac{Gm_3 \sin i}{a^2(1+e)^2} \qquad \ldots(12)$$

from which we get the mass function

$$f(m) = \frac{m_3^3 \sin^3 i}{(m_{12} + m_3)^2} = \frac{|\ddot{z}_{12}|^3 \; P_3^4 \; (1+e)^6}{64\pi^6} \qquad \ldots(13)$$

where P_3 is the third body period in years, masses are in solar units and $\ddot{z}_{12}$ in a.u/yr^2.

If we, therefore, identify the acceleration given by equations (5) and (6) with that given by equation (12) we can find the mass function for the triple system from equation (13). Here expressing the distance, time and mass in astronomical units, years and solar masses, respectively, we can write.

$$\left| \ddot{z}_{12} \right| = c \left| \frac{\dot{P}}{P_0} \right| = \left| \frac{\dot{P}}{P_0} \right|_{\mathrm{sec}^{-1}} \times 1.996 \times 10^{12} \, \frac{\mathrm{a.u}}{\mathrm{yr}^2}. \qquad \ldots(14)$$

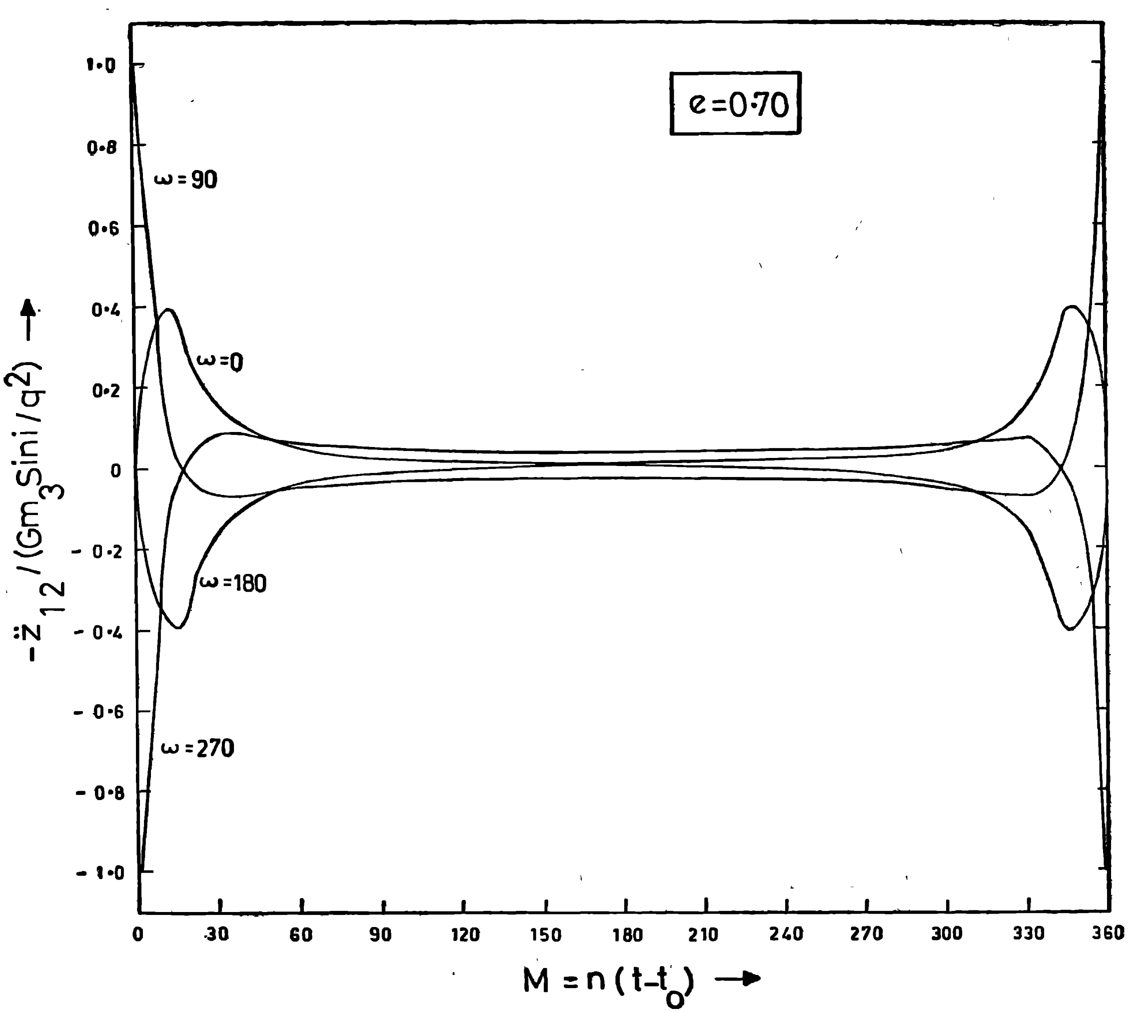

Figure 3

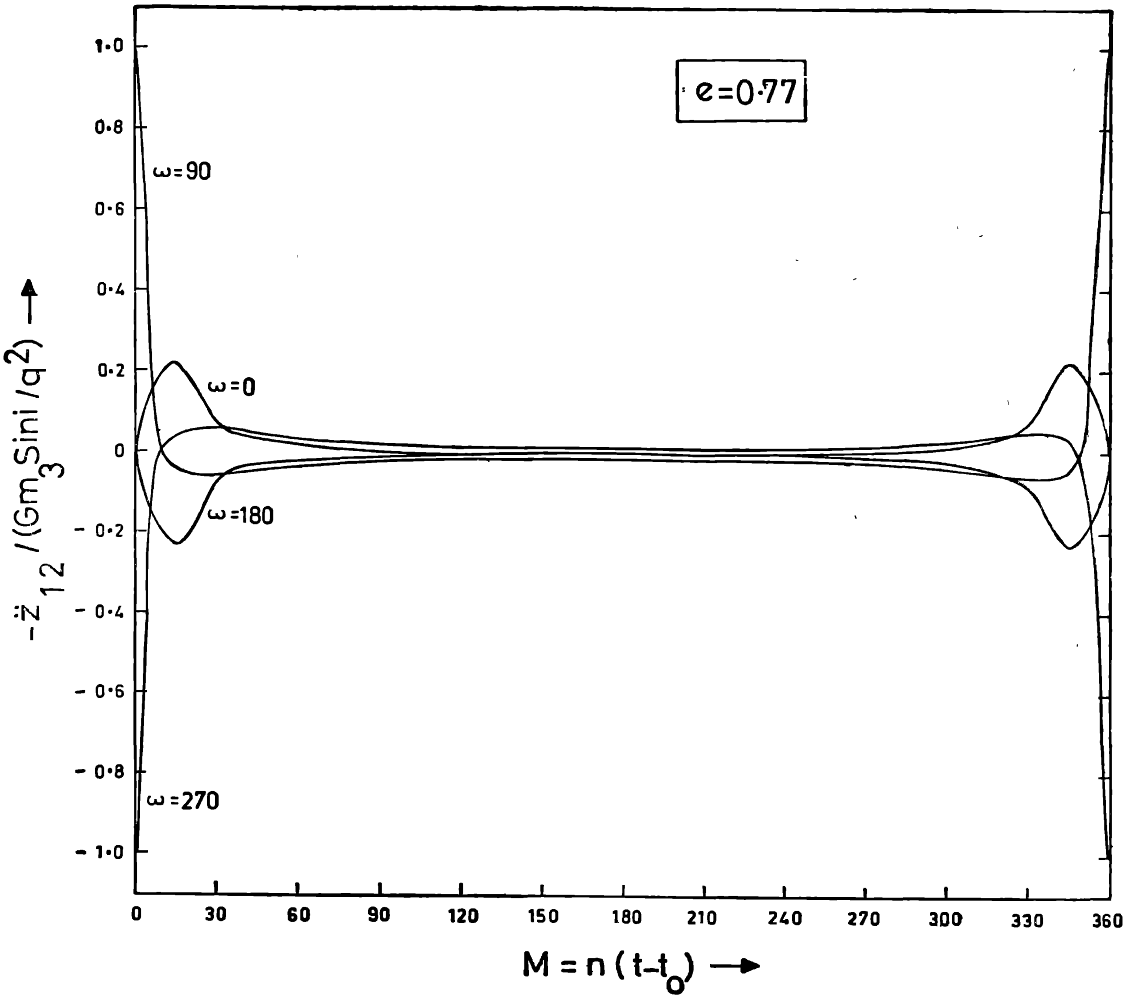

Figure 4

6. Trial applications of theory

Obtaining the mass function from equation (13) requires a knowledge of P and e. In the absence of such data we can approach the problem from a statistical view point. For example, the most probable value of e for visual binaries is 0.6. Further, for this value of e the constant acceleration given by equation (12) lasts for about half the period. Therefore, we may put $e = 0.6$ and $P =$ twice the duration of constant acceleration in equation (13). Let us see whether this statistical method works in the case of systems for which a better knowledge of the orbit is already available.

We have seen in section 3 that in the case SW Lac, the third body orbit is fairly well determined, but the orbit of the fourth body is only partially evident. Representing the $O - C$ curve, obtained after removal of the third body motion, by a parabola we get $(\dot{P}/P_0) = -2.39 \times 10^{-14}\ \mathrm{s}^{-1}$ over a period of 28 yr. So, putting $P_3 = 55$ yr and $e = 0.6$ in equation (13) we obtain $f(m) = 0.272$. For $m_{123} = 2.94\, M_\odot$ and $i = 90°$, it gives $m_4 = 1.47\, M_\odot$ which is about one and half times the value of $m_4 = 1.05\, M_\odot$ derived from a circular orbit of period 70 yr.

A similar analysis for RT Persei gives $(\dot{P}/P_0) = -3.34 \times 10^{-15}\ \mathrm{s}^{-1}$ over a period of 90 yr for the fourth body motion. So, again putting $P_3 = 180$ yr and $e = 0.6$

Table 2. Third body representation of K0 Aql and TV Cas

Star	K0 Aql	TV Cas
$\dot{P}/P_0$	56.44×10^{-15} sec^{-1}	-14.36×10^{-15} sec^{-1}
Duration	15 yr	30 yr
Assumed P_3	30 yr	60 yr
Assumed e	0.6	0.6
$f(m)$	0.316 $M_\odot$	0.0824 $M_\odot$
m_{12}	3.49 $M_\odot$	4.49 $M_\odot$
m_3	2.16 $M_\odot$	1.43 $M_\odot$
Range of m_3	1.5 to 3.2 $M_\odot$	1 to 2 $M_\odot$

in equation (13) we obtain $f(m) = 0.0847$, and for $m_{123} = 2.74\ M_\odot$ we find $m_4 = 0.98\ M_\odot$. This is also about 50 per cent higher than the value of 0.62 $M_\odot$ derived from a similar orbit of 100 yr period.

We are therefore inclined to draw the conclusion that the above statistical method gives us the mass of the unseen third companion of a binary within a factor of 3/2. If we now apply this method to the systems of K0 Aql and TV Cas which show secular variation of period we obtain the results given in Table 2.

The derived masses are large enough to be detected by other means, although the lower limits might make them undetectable white dwarfs. Alternatively, the third body itself may be a close pair of smaller masses which would make it quite faint for detection. Anyway, the hypothesis of a third body in the case of these systems appears to be tenable and should be explored by further spectroscopic, astrometric and photometric observations.

I hope this review of the binary star research at CASA would convince you that there is still much thrill left in this old branch of astrophysics.

Finally, I shall briefly describe with the help of slides the activity at Japal-Rangapur Observatory during the total solar eclipse of 1980 February 16. As you know, it was perhaps for the first time that the path of totality passed over a major astronomical observatory. Consequently a large number of Indian and foreign astronomers took advantage of the observatory facility for carrying out their eclipse experiments. At the peak of activity about 40 U.S. astronomers, 25 scientists from other Indian institutes such as Physical Research Laboratory and Satellite Application Centre of Ahmedabad, Udaipur Solar Observatory, National Physical Laboratory etc.; 20 members of staff and students from our Centre and about 15 persons from the Zoology Department of Osmania University were present on the small hillock, where the observatory is located. There were about four to five thousand other visitors including technicians from Hyderabad Doordarshan (TV) and Andhra Pradesh Films Development Corporation. The sky was somewhat cloudy before and during the first phases of the eclipse. But the sun came out of the clouds a few minutes before totality and the observers were happy to find that most of their experiments were successful.

Two of our own three experiments were successful. One pertained to the photography of the corona with a double polarigraph by Sri Anthony Raju, a Teacher Fellow at CASA. The other was the radio observations of the sun at 3-cm wavelength by Dr Lokanadham who had put up a new 10-ft dish for this purpose in collaboration with Prof. R.V. Bhonsle of Physical Research Laboratory, Ahmedabad. Our students had also rigged up several cameras with which they were able to obtain excellent photographs of the diamond ring, Bailly's beeds, prominences as well as of inner and outer coronas on colour and black and white films.

References

Abhyankar, K. D., Parthasarathy, M., Sanwal, N. B. & Sarma, M. B. K. (1974) *Astr. Ap. Suppl.* **13**, 101.

Abhyankar, K. D., Sarma, M. B. K. & Kulkarni, A. G. (1978) *Contributions from Nizamiah and Japal-Rangapur Observatories, No.* 5.

Crawford, J. A. (1955) *Ap. J.* **121**, 71.

Field, F. V. (1969) *M. N. R. A. S.* **144**, 419.

Kreiner, J. M. & Frasinka, Z. (1977) *Inf. Bull. Var. Stars No.* 1285.

Kuiper, G. P. (1941) *Ap. J.* **93**, 133.

Kulkarni, A. G. (1978) *Contributions from Nizamiah and Japal-Rangapur Observatories, No.* 7.

Kulkarni, A. G. (1980) Thesis, Osmania University, Hyderabad.

Kulkarni, A. G. & Abhyankar, K. D. (1978) *Contributions from Nizamiah and Japal-Rangapur Observatories, No.* 9.

Kulkarni, A. G. & Abhyankar, K. D. (1980) *Ap. Sp. Sci.* **67**, 205.

Kulkarni, A. G., Rao, C. R. & Swaminathan, R. (1978) *Contributions from Nizamiah and Japal-Rangapur Observatories, No.* 6.

Mancuso, S. & Milano, L. (1975) *Ap. Sp. Sci.* **32**, 385.

Panchatsaram, T. (1981) *Ap. Sp. Sci.* **77**, 179.

Panchatsaram, T. & Abhyankar, K. D. (1981a) *J. Ap. Astr.* **2**, 29.

Panchatsaram, T. & Abhyankar, K. D. (1981b) *Bull. astr. Soc. India*, **9**, 31.

Parthasarathy, M. (1980) Thesis, Madurai-Kamraj University, Madurai.

Parthasarathy, M. & Sarma, M. B. K. (1980) *Ap. Sp. Sci.* **72**, 477.

Popper, D. M. (1979) (Personal).

Roxburgh, I. W. (1966a) *Ap. J.* **143**, 111.

Roxburgh, I. W. (1966b) *Astr. J.* **71**, 133.

Sanwal, N. B., Sarma, M. B. K., Parthasarathy, M. & Abhyankar, K. D. (1974) *Astr. Ap. Suppl.* **13**, 81.

Sarma, M. B. K. (1976) *Bull. Astr. Inst. Czech.* **27**, 335.

Sarma, M. B. K. & Abhyankar, K. D. (1979) *Ap. Sp. Sci.* **65**, 443.

Sarma, M. B. K. & Ausekar, B. D. (1980) *Acta Astr.* **30**, 101.

Sarma, M. B. K. & Sanwal, N. B. (1981) *Ap. Sp. Sci.* **74**, 41.

Vivekananda Rao, P. & Sarma, M. B. K. (1981) *Acta* **31**, 107.

Wood, F. B. (1950) *Ap. J.* **112**, 196.