THE MASS OF MIRA

Recently one of us (Fernie 1959) has concluded that the mass of the typical long-period variable X Oph is close to 1 ☉, rather than the 15 ☉ frequently quoted in the literature for such a variable. Since Mira, as a long-period variable, is a close match to X Oph, it has seemed of interest to us to reinvestigate whether observations of Mira as a visual binary lend support to this contention that the masses of such stars are of the order of 1 ☉.

The data for this study have been taken from a compilation by Van Biesbroek (1959). Following this author, we have had no hesitation in rejecting the contentious observation by Aitken in 1926, which placed the companion at a very small distance and in another quadrant from all other measures. In rejecting this observation, we must also reject the orbit (period = 14 years) deduced by Parenago (1950), since it relies heavily on this particular observation.

While Van Biesbroek (1959) justifiably concludes that, because so small a portion of the apparent orbit has as yet been observed, the orbital elements are still indeterminate, we have proceeded to fit a variety of "possible" orbits and hence deduce a range of "possible" masses, because determination of the latter depends on a ratio of two elements which generally increase (or decrease) with each other among the "possible" orbits.

TABLE 1

POSSIBLE ORBITS FOR THE MIRA SYSTEM

Orbit	Period (years)	a	i	e
I. . . .	59	0″477	56°	0 97
II.	169	0″908	83°	.08
III.	261	1″288	85°	0.30

Thus the range of allowable masses is usually considerably more restricted than the range of allowable individual elements. That this is so was shown for X Oph (Fernie 1959).

The data were smoothed in the usual way by constructing individual plots of angle and distance against time and forcing curves through these, such that the condition

$$\rho^2 \frac{d\theta}{dt} = \text{constant}$$

was satisfied as nearly as possible. A plotting list was constructed from these curves and completion of the resulting arc attempted by the customary use of a thread and two pins. Some difficulty was experienced in this because of the high eccentricity of the apparent ellipse. However, three orbits covering a considerable range in elements were found to fit the observed arc reasonably well. While no claim is made that any of the elements given by these are necessarily true or even approximately so, some of their more important elements are shown in Table 1, since the order of magnitude of some of them may be of general interest. An attempt was made to find a "reasonable" orbit that would result in a total mass for the system of about 15 ☉ or more. The only one which could be found, however, departed so grossly from the observed arc as not to be worth further consideration.

The parallax of Mira is comparatively well determined. Burns (1941), allowing for the effect of the companion, found a trigonometric parallax of

$$p = +0\farcs020 \pm 0\farcs005 .$$

Scott (1942), by combining radial-velocity and radiometric data, found the parallax to be

$$p = 0\overset{''}{.}021 .$$

By employing the period-luminosity relation for the long-period variables as given by Wilson and Merrill (1942), we find

$$p = 0\overset{''}{.}019 \pm 0\overset{''}{.}003 .$$

We adopt

$$p = 0\overset{''}{.}020 .$$

With this parallax and an average apparent magnitude of about 10.9 (Van Biesbroek 1959), the companion has an average absolute visual magnitude of about +7.3, allowing a small correction for interstellar absorption. Joy (1926) places its spectral type at B8, meaning that its temperature is about that of a B8 star. The object therefore occupies a position on the H-R diagram very similar to that of the blue components of such stars as SS Cyg, AE Aqr, and T CrB. Moreover, its light-curve (Van Biesbroek 1959), so far as it is known, is quite similar to that of Z And when plotted on a suitable scale. It is further interesting to note that the long-period variable component of Mira is also not far from the position of the red component of T CrB in the H-R diagram.

TABLE 2

POSSIBLE MASSES FOR THE MIRA SYSTEM

	ORBIT		
	I	II	III
Total mass	3.9 ⊙	3.3 ⊙	3.9 ⊙
Max. mass of LPV if $m_B \geq 2.1$ ⊙	1.8 ⊙	1.2 ⊙	1.8 ⊙
Probable mass of LPV if $m_B = 2.6$ ⊙	1.3 ⊙	0.7 ⊙	1.3 ⊙

Using the above value for the parallax and the elements quoted in Table 1, we may calculate the total mass of the system. Since we are principally interested in the mass of the long-period variable, it is unfortunate that the mass of the B star is unknown. However, for the blue component of T CrB, Kraft (1958) found a minimum mass of 2.1 ⊙ and a more probable mass of 2.6 ⊙. For want of more specific data and in view of the physical similarity between the blue components of T CrB and Mira noted above, we adopt these figures for the present case. Results are shown in Table 2. We conclude from these figures that the earlier result from X Oph, viz., that the mass of typical long-period variables is close to 1 ⊙, is substantiated by the present investigation.

While this result is the principal conclusion of our note, it is of interest to speculate a little further on the nature of the system. Of the three orbits listed in Table 1, we reject I. Not only does it have an improbably high eccentricity and low period, but the periastron distance implied is less than the radius of the long-period variable. Of orbits II and III, II gives a slightly better fit to the observations but has an extremely low eccentricity for so wide a binary, although it should be borne in mind that motion through the circumstellar material undoubtedly present in this system would have reduced the original eccentricity considerably. Nevertheless, we prefer to accept orbit III as the more likely.

We note, first, that, despite the high inclination, eclipses are not to be expected. Basing our calculation on the probable luminosity and effective temperature (taken as 12800° K from Keenan and Morgan 1951) of the companion, we find its radius to be 0.089 $R_{\odot}$.

The system is therefore remarkable in having one star of radius over three thousand times that of the other, yet with the smaller star being perhaps twice as massive as the larger. Under these circumstances, even if the geometry of the orbit required eclipses and the most favorable conditions prevailed (long-period variable at minimum, blue region of spectrum, etc.), primary minimum would be only of the order of half a magnitude, which could easily be lost in the erratic behavior of the light-output of the individual stars.

These is considerable evidence (e.g., Crawford and Kraft 1956; Kraft 1958) to suggest that such systems as AE Aqr, SS Cyg, and T CrB are to be interpreted as ones in which the red component has, in the course of its evolution, expanded to fill its lobe of the inner Lagrangian surface and which, in attempting to expand further, is forced to lose mass through the inner Lagrangian point to the blue star. The luminosity of the blue star is then sustained primarily by the release of the accreted material's kinetic energy. In view of the similarity between these blue stars and Mira's companion, it is of interest to see whether the same mechanism could be operating in the latter case. We take the Lagrangian surfaces to be those computed by Kuiper (1941) for a mass ratio of 2. Then, for either orbit II or orbit III and the stars at closest approach, their separation is still about forty times the radius of the long-period variable, and the volume of the latter is less than 10^{-3} the volume of the Lagrangian lobe. Thus in this respect Mira is quite different from the above-mentioned systems. However, it is very probable that the long-period variable is losing mass secularly (Deutsch 1956), even though not forced to do so by constriction of the Lagrangian surfaces. In this case, the companion will still accrete some of the lost material. While we have no specific figure for the mass loss in Mira, we assume the figure of 2×10^{18} gm/sec, which has been found likely for a number of other systems, e.g., α Her (Deutsch 1956), AE Aqr (Crawford and Kraft 1956), T CrB (Kraft 1958), X Oph (Fernie 1958). Then, pursuing an analysis closely similar to that given for X Oph, we find that the companion has an average accretion rate of 10^{15} gm/sec, and, even if all the kinetic energy of the infalling material is converted to radiation, this will support no more than about 20 per cent of the observed luminosity. It may be possible that the reason why the blue component of Mira, unlike those of SS Cyg, T CrB, etc., does not show "strictly" periodic flares or nova outbursts is because its accretion rate is not quite high enough.

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