IV. MASSIVE BINARY SYSTEMS

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ANOMALOUS MASS RATIOS IN O-STAR BINARIES

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ABSTRACT

A study of the binary frequency among the O-stars finds that only 40% are binaries. They show a strong tendency to have mass ratios near unity and none with values less than 0.3. We discuss the evidence that mass loss is responsible for the observed mass ratios.

I. INTRODUCTION

Among the O-type stars stellar winds are widely-observed phenomena which are responsible for continuous mass loss at a rate that is significant on the star's evolutionary time scale (deLoore, DeGreve and Vanbeveren, 1978). In the case of close binaries, Hutchings (1976) has shown that the mass loss rate prior to Roche lobe overflow seems to be even higher than that found for similar single stars, but the binary nature of many O stars is not clear. In one of a series of papers on O stars, Conti has discussed the binary frequency of O stars by comparing new coude spectra radial velocities with previously published values (Conti, Leep and Lorre, 1977). Atmospheric motions in O stars can masquerade as orbital motion, so we have extended this survey by obtaining additional spectra of all O stars brighter than m_V = 7 and north of −50° (Garmany, Conti and Massey, 1980). There are 67 stars in this sample, and 40% of them are binaries with either orbits already computed or clear evidence for orbital motion. This figure of 40% is complete for any binary with a period less than about 10 days and a semi-amplitude greater than 15 km s^{-1}, so our results represent a complete sample of massive close binaries and can be compared with the predictions of Vanbeveren and deLoore (1979).

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II. MASS RATIOS OF THE O-TYPE BINARIES

Compared to later type stars, 40% is a rather low binary frequency, but it is not surprising when one considers the complete lack of binaries with mass ratios, Q, less than 0.3 in our sample. Previous evidence that low amplitude systems with Q < 0.3 may not exist has been given by Bohannan and Garmany (1978). The overabundance of double line systems (Garmany 1979) also suggests this, although it could be partly due to a flattening of the mass-luminosity relation for O stars. Figure 1 shows Q vs. binary period for all known O-type binaries. The binaries in our survey are underlined, showing that there is no major change in the distribution of Q with the addition of fainter systems. Obviously Q can only be directly determined for double line binaries, but we have estimated Q for single line systems from the spectroscopic mass of the primary and from an assumed $\sin^3 i$ = 0.67. There is a cutoff at Q = 0.3 and a strong peak around Q = 1.

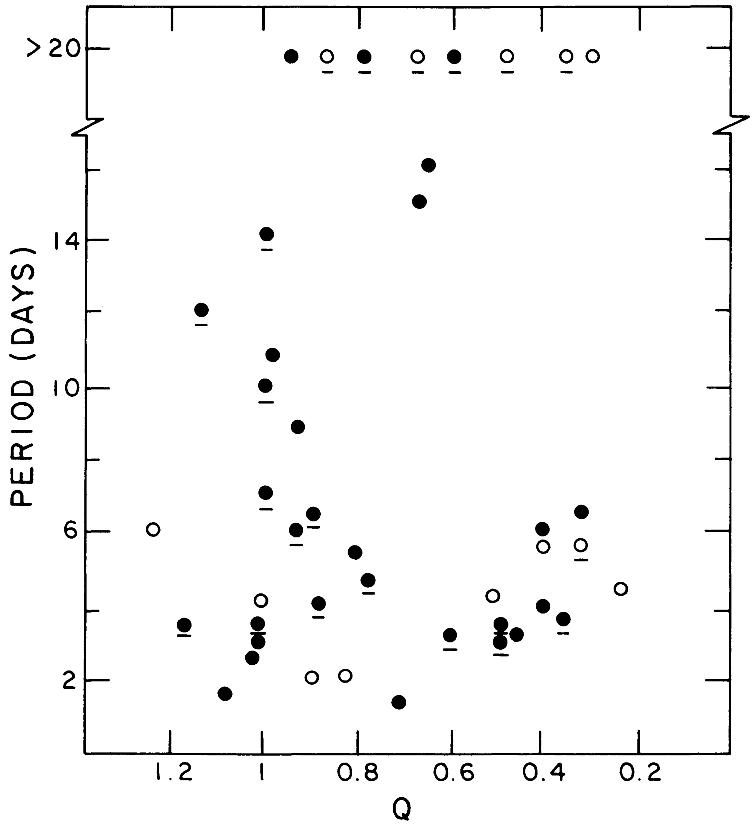

Fig. 1. The mass ratio, Q, vs. period for all presently known O-type binary systems. Underlined systems are included in our survey (• = double line, o = single line binaries).

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Let us first consider the reality of this cutoff: could it be a selection effect caused by our inability to detect low amplitude binaries? The answer is probably not, because unless the inclination of the system is very small, mass ratios between 0.1 and 0.3 are not too difficult to detect for short period binaries. For example, O-type binaries with periods less than 6 days and mass ratios of 0.15 will have velocity semiamplitudes of 50 km s^{-1}. At coude dispersions, typical internal mean errors are 3-5 km s^{-1} and plate-to-plate errors are 2-3 times the internal errors, so any real variation greater than about 20 km s^{-1} has been detected. This includes all systems with inclination greater than 30°. Furthermore, the cutoff in Q is not caused by the different evolutionary time scales of the stars in question. From the evolutionary models of deLoore, DeGreve and Lamers (1977) and Iben (1965) an O-type star will still be in core hydrogen burning when a companion as small as 4 $M_\odot$ arrives on the ZAMS. Therefore systems with mass ratios as small as 0.1 to 0.2 are to be expected unless they are somehow prevented from forming. Lucy and Ricco (1979) have discussed formation by fragmentation, which produces binaries with Q = 1, and by fission for which Q is typically 0.2. Perhaps fission is somehow prevented in massive stars, or perhaps after reaching the main sequence the primary inhibits further formation of the secondary.

In their evolutionary computations for massive close binaries including mass loss by a stellar wind, Vanbeveren and deLoore (1979) predict that the mass ratio of pre-Roche lobe overflow binaries will tend towards unity as the primary star loses mass faster than the secondary. The number of systems in Figure 1 with Q close to one supports Vanbeveren and deLoore's calculations, although mass loss is not the only mechanism which would produce this distribution. It should be noted that their calculations are based on the assumption that mass loss is proportional to luminosity but most of the available data concern only supergiant O stars.

Recently, Conti and Garmany (1979) have computed mass loss rates from observations taken with the IUE satellite of the ultraviolet P Cygni lines in six main sequence stars. We have fitted the observed profiles with a grid of theoretical profiles computed by Castor and Lamers (1979) and have derived mass loss rates which are much lower than predicted. Figure 2 shows $\dot{m}$ vs. M_{BOL} for all O stars whose status as either single or binary is known. Two things are apparent from this figure: First, the addition of main sequence stars with log $\dot{m} < -6$ destroys any linear relation between $\dot{m}$ and M_{BOL}, and second, the binaries do not show any clear pattern of greater mass loss. The missing factor in Figure 2 may be the age of the star, such that the star's mass loss rate increases as it evolves away from the main sequence.

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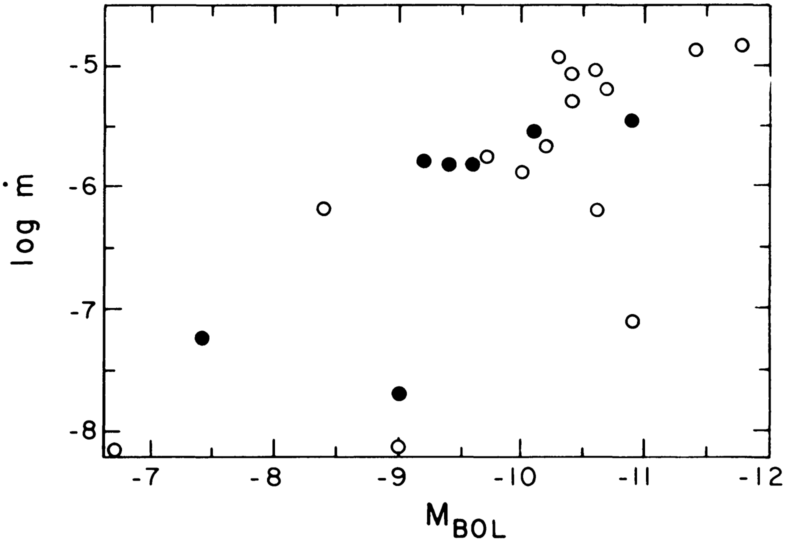

Fig. 2. Mass loss vs. M_{BOL}. Filled circles are binaries, open circles are single stars.

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DISCUSSION FOLLOWING GARMANY AND CONTI

Nariai: What is the time scale of your possible evolution on the Q-P diagram?

Garmany: It is comparable to the time the stars spend in core hydrogen burning, about 5×10^6 years. The rate of change of the period and Q are given, for example, by Vanbeveren (1979).

Vanbeveren: Stellar wind values are determined by using spherical symmetric models for the outflowing atmospheres. These models may not be applicable in binaries where deformations become important. On the other hand, it can be that the underlying hot coronal layers emit soft X-rays changing the ionization equilibrium in the stellar wind and thus changing the mass loss rate determinations.

Garmany: We don't yet know mass losses for enough binary systems to say if the mass loss rate is dependent on the inclination, but as an example HD 48099 probably has an i of about 30° and its rate is low. The evidence so far is more in favor of the mass loss rate being a function of evolutionary age. And yes, any change in our ionization model is directly related to a corresponding change in the derived mass loss rate.

Lucy: Since the Q = 1 peak also exists at later spectral types where it cannot be attributed to mass loss, it seems somewhat unreasonable to invoke mass loss to explain the peak for the O-type binaries.

Garmany: Yes, we could certainly explain the shape of the Q-period diagram by initial formation, although some binaries certainly have a high mass loss rate which would alter their Q.