CONTACT BINARIES OF SPECTRAL TYPE O

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The eclipsing binaries UW CMa, AO Cas, and V729 Cyg have been systems of great interest for over fifty years. The light curves are complex and suffer significant changes on a time scale of months, but the primary attraction of these systems is that both components have O-type spectra; thus they present us with some of the few possibilities for direct measurement of absolute dimensions of very massive stars. Much effort has been expended on these systems, but no really consistent model has emerged.

Most of the difficulties are due to the closeness of the components; tidal distortions and reflections complicate the picture greatly. To handle this problem we adopted the Wilson and Devinney (1971) approach to photometric solution. Published photoelectric observations of high quality (± 0.01 mag) were employed in our analysis. Despite attempts to make detached and semi-detached models fit, all three systems were best represented by contact configurations. The computed light curves fit the observations considerably better than any previous models, but there still are minor discrepancies due primarily to asymmetries in the light curves (the models are symmetric).

Absolute dimensions were calculated by combining the newly determined photometric parameters with the published spectroscopic orbits; the results are summarized in Table 1. [A description of our procedure is given in our papers on these systems, Leung and Schnieder (1978a,b) and Schneider and Leung (1978)]. The primaries of UW CMa and V729 Cyg are among the most massive stars ever directly measured.

The evolutionary state of these systems can be seen from the mass-radius diagram (Fig. 1, which includes the known contact systems of spectral type B). Both UW CMa and AO Cas are still in the hydrogen burning phase of evolution but have evolved off the ZAMS, they are probably examples of case A mass exchange. The status of V729 Cyg is

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TABLE 1

CONTACT O SYSTEMS

Star	Period (days)		R_1	$(R_\odot)$ R_2	M_1	$(M_\odot)$ M_2	% Overcontact
UW CMa	4.39	07+07f	20	18	46	34	23
AO Cas	3.52	08.5III+08.5III	13	14	25	29	3.4
V729 Cyg	6.60	07fIa+OfIa	33	17	59	14	31

not as clear, except it appears to be considerably more evolved and may represent a system having undergone (undergoing?) case B exchange.

For components in a contact system:

$$\frac{R_1}{R_2} \sim \left(\frac{M_1}{M_2} \right)^{0.46} .$$

Thus a line connecting them (as in Fig. 1) will be nearly parallel to the ZAMS and TAMS lines for stars of high mass. Therefore both components will appear equally evolved. This problem of evolution into contact is indeed an exciting albeit an extremely difficult one.

As one might expect, each system exhibits unusual and confusing features. UW CMa has a very complex light curve with a displaced secondary maximum, and spectroscopic studies have found mass ratios ranging from 0.75 to 1.3! AO Cas has an inclination of 51°, the light variation is due almost entirely to its ellipsoidal shape. V729 Cyg has a very small mass ratio (0.237) and a 10,000° K temperature difference between the components. The largest discrepancy, which all three systems have to some degree, lies with the relative luminosity of the components. The contact model can differ wildly from the observed spectroscopic luminosity ratio, for example, the spectroscopic luminosities of the components of V729 Cyg are roughly equal, while the contact model predicts a ratio of eight! If our models are correct the clearly line formation in massive contact systems is due to a new, poorly understood mechanism.

Future work planned by the authors includes a search for further examples of massive contact systems (DH Cep appears to be the best candidate) by K.C.L. and improved spectroscopic observations using the photon counting device built by Steve Shectman (D.P.S. with P. J. Young). Other areas of needed investigation are monitoring of period changes in these systems for evidence of mass transfer along with the aforementioned evolution and line formation problems.

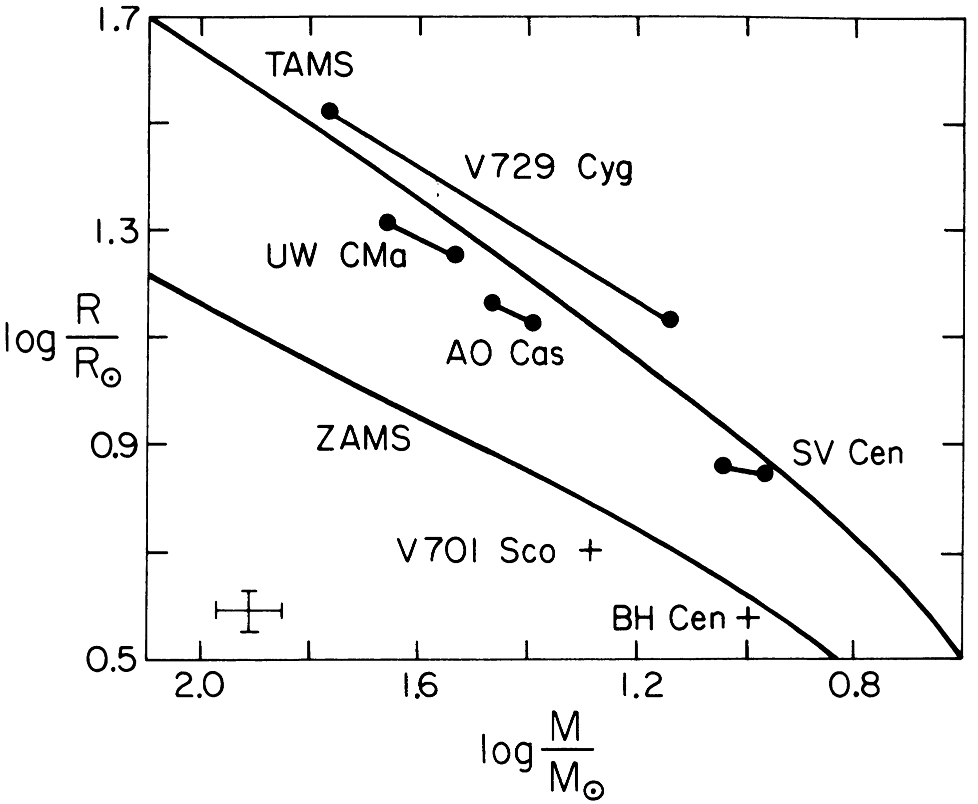

Figure 1. Mass-radius diagram for early-type contact systems. The zero-age main sequence (ZAMS) and terminal-age main sequence (TAMS) of Stothers (1972) are shown as smooth curves. The estimated errors for the mass and radius (assuming the mass ratio is reliable) are shown in the lower left-hand corner.

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DISCUSSION FOLLOWING LEUNG AND SCHNEIDER

Hutchings: In the case of 29 CMa (= UW Cma) the spectroscopic data give a consistent picture of a e>0 orbit. Since both spectroscopic and photometric analyses may give spurious results we must understand why, before we say which is correct (if either). Similar problems occur with AO Cas. Your analyses do not allow consideration of 1) e≠0, 2) deviations from Roche geometry by rotation, mass flow or radiation pressure.

Schneider: A contact system cannot have an orbital eccentricity: if an eccentricity is certain it would be fatal to our model. Several of our contact systems (UW CMa, AO Cas, V1073 Cyg) do have measured eccentricities ranging up to 0.12. In an extremely close or contact system a "pseudo-eccentricity" can arise due to tidal distortions, eclipses, and reflections. In all three systems we find that when these effects are allowed for the contact models fit the observations very well. One troublesome point with UW CMa is your measurement of enhanced mass transfer when the stars are closest (in the eccentric orbit model). The contact model says any enhanced rate would be due to the geometry of the system, your results are an uncomfortable coincidence. As to the effects of radiation pressure I think Bob Wilson has some enlightening thoughts.

Wilson: The radiation pressure question can be put in some perspective by noting the following points. Because of the von Zeipel gravity darkening law, we expect the local gradient of radiation pressure to be co-linear with the vector of gravitational acceleration. Thus in regard to a component's own self-radiation, radiation pressure force acts only to reduce gravity, and thus has no effect on the figures of stars of a fixed size. The problem comes in with the irradiation from the other star. Even here one can find a case in which the effects should be fairly small. This case is that in which the system is known to be overcontact. Then only a part of the inner-facing surface is irradiated and, more important, it is then reduced by a considerable projection effect. However I do not want to underplay the effect of radiation pressure on the figures of detached components, since it is probably quite important for such cases of spectral type O.

Abbott: How certain is your mass of 46 $M_{\odot}$ for the primary of UW CMa?

Schneider: The main problem in determining the masses for UW CMa lies in the extreme difficulty of detecting the secondary. Spectroscopic studies have reported values for the mass ratio (secondary/primary) ranging from 0.75 to 1.3. We believe the mass ratio is less than one because of the faintness of the secondary; if the mass ratio was greater than one our models have the secondary more luminous. As to the specific value of q we are not certain, but we think that the primary's mass probably lies between 35 and 50 $M_\odot$. A more reliable estimate will require better spectroscopic observations.