REVERSE ALGOLS

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ABSTRACT. An Algol is a binary system having a semidetached configuration where the less massive component is in contact with the critical equipotential surface. A reverse Algol is a binary system having a semidetached configuration where the more massive component is in contact with the critical equipotential surface. In 1985, Leung suggested 5 reverse Algol systems at the Beijing Colloquium. Two more such systems have been discovered recently. The spectral types of these systems range from early B to mid G. There is also a wide spread in mass ratio among these systems. There appear to be two types of reverse Algols, "hot" and "cool" systems. The hot systems have their more massive components as the hotter stars and the cool systems their more massive components as the cooler stars. The mass-radius relation of the reverse Algols is very similar to that of the contact and near-contact systems. It is believed that reverse Algols represent the pre-mass-reversal semidetached phase of close binary evolution. Since selection effects apply to both the regular Algols and reversed Algols in a similar manner, the evolutionary time scale between them would be simply the ratio of the number of confirmed systems of these two types of Algols.

1. INTRODUCTION

Since this is a colloquium on Algol systems, we should all be very familiar with the characteristics of these systems. In order to introduce the definition of a reverse Algol, we may state the main character of an Algol just for sake of completeness. Thus, the definition of an Algol is a close binary system having a semidetached configuration where the less-massive (usually cool) component is in contact with the critical equipotential surface (inner Jacobian/Roche surface). A typical Algol configuration can best be illustrated by Algol itself. Recently, Kim (1988) derived the best photometric solution from his new BV-light curves, by the Wilson-Devinney method. He successfully obtained the values of the third light and photometric mass-ratio (which confirmed the spectroscopic value) along with other photometric parameters. The configuration of a regular Algol is shown in Figure 1.

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The configuration of a reverse Algol is just the opposite. Thus, the definition of a reverse Algol is a close binary system having a semidetached configuration where the more-massive component is in contact with the critical equipotential surface. The first such system reported was BF Aur by Schneider, Darland and Leung (1979). In 1985, Leung (1988) reported five close binary systems having such a configuration, as shown by analysis of their light-curves by the Wilson-Devinney method. They are BF Aur, HD161756, RT Scl, ADS9019, HD199497. Recently, Lee (1988) reported another system, V1425 Cyg, from his photometric and spectroscopic studies. A typical reverse Algol is illustrated in Figure 2.

2. Observational Evidence

Generally, the dimensional physical parameters for a binary system are derived from its radial velocity curve(s) and photometric light-curve(s). However, the configuration (non-dimemsional) of the system comes from the light-curve solution. Accurate (or more realistic) photometrical parameters can only be obtained through careful analyses of the light curve(s) by methods employing "Roche" type geometry. Thus, in dealing with systems with semidetached, contact, and near contact configurations, we should not employ classical methods in deriving their photometric solutions.

Without a thorough analysis, we have no way of telling, by inspecting the light-curve or the radial velocity curve, whether a close binary system has a regular Algol or a reverse Algol configuration. Therefore, there is no bias, selection effect, or preferential treatment involved in the determination of the semidetached configuration of a reverse Algol. In practice, the same kind of analyses apply to both kinds of systems. At present, there is a general acceptance of the semidetached configuration of the regular Algol systems. In all fairness, one should not doubt the existence of Reverse Algols if we discover them in the same manner!

Aside from the five reverse Algol systems reported earlier (Leung 1988) we may add three more to this group; V1425 Cyg (Lee 1988), V790 Cen (Qiao and Leung 1988), and GO Cyg (Güdür, Gulmen and Sezer 1987), since all of these systems have their more massive components filling their respective critical equipotential surfaces. However, the data for some of these systems may require modification or updating.

Two solutions were reported for BF Aur (for mass-ratios of 0.83 and 1.20, see Leung 1988, Table IV or Schneider, Darland and Leung 1979, Table I). The UBV light-curves published by Mannino, Bartolini and Biolchini (1964) show the two minima to be essentially equal in depth and indistinguishable. The second entry for BF Aur in Table IV of Leung (1988) is erroneous, since it shows the "hot" component as 9K cooler than the cool one! (In the Wilson-Devinney notation $T_2 > T_1$.) The mass-ratio listed is in the conventional Wilson-Devinney notation of m_2/m_1 (= 1.2), not, as had been intended, m_C/m_H. The two solutions presented by Schneider et al. (1979) are in fact the same physical solution. Correct data for BF Aur are now given in Table I.

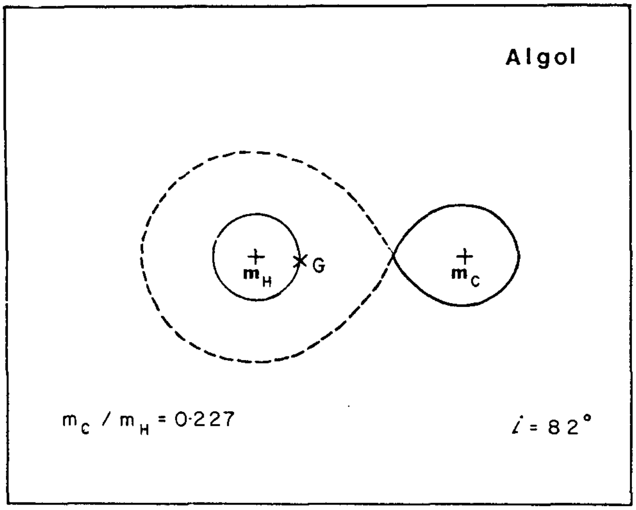

Figure 1. Typical configuration of an Algol (Algol itself, Kim 1988). Broken envelope represents critical potential surface. The centers of each component and center of mass are designated with plus signs and a cross, repectively.

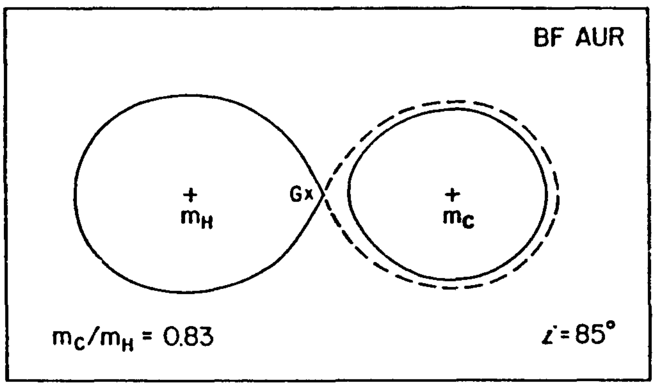

Figure 2. Typical configuration of a reverse Algol, (BF Aur) symbols are the same as in Figure 1.

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RT Scl was removed from the membership of Reverse Algols in Leung's list (1988) because of the extensive paper on this system by Hilditch and King (1986). They found that the mass-ratio of Rafert and Wilson was incorrect and the configuration of the system was not quite semi-detached (i.e. the more massive component fills only 93 per cent of the critical equipotential surface). However, at the Colloquium itself, Hilditch suggested RT Scl could be reverse Algol. Thus, it is retained in the present list.

Material communicated to the author by Güdür, Gulmen and Sezer (1987) indicates that GO Cyg may have the reverse Algol configuration. During the colloquium itself, however, Hill indicated that new spectroscopic data would soon be published by Holmgren, and the system has been deleted from the list.

The observed parameters of the seven systems are collected in Table I. The numerals listed below the data are the estimated probable errors associated with the derived parameters. Note that there are only three reverse Algols that have radial-velocity curves reported. Absolute dimensions of those three systems, BF Aur, V1425 Cyg, and RT Scl are also tabulated in Table I. Efforts should be made to obtain spectroscopic information on the other systems.

The inclinations of four systems are larger than 80°. Thus, the photometric parameters and configurations of these systems are very accurately determined. For V1425 Cyg (Lee 1988), even though the inclination is moderate, 71°, the photometric mass ratio (0.75 ± 0.01) and spectroscopic mass ratio from the cross-correlation method (0.75 ± 0.01, Lee and Leung 1988) matched perfectly. Therefore, the data derived for this system can be considered very reliable. In summary, four out of seven systems listed have accurate parameters.

The other systems; V790 Cen, V3894 Sgr, and HD199497 have small inclinations (less than 60°). The photometric parameters derived may be considered less reliable. However, based on our experience in obtaining photometric solutions for a very large number of systems in Lincoln we find that the configurations are generally very reliable even if the individual parameters may not be very accurately determined. Even in the case of multiple solutions, the computation stays in the same 'mode', i.e. the same configuration (see Leung and Wilson 1977 for description of the modes of operation).

Some astronomers argue that these systems may actually be detached systems with their massive components almost filling the critical potential surfaces. That is, they are only almost reverse Algols. We notice in the computing analysis (i.e. with the differential correction computing code of Wilson-Devinney) that all but two of the systems converged from their starting detached configurations, mode 2, into the semidetached configurations of modes 4 or 5 automatically. There were no indications of marginal semidetached solutions. The two exceptions were V1425 Cyg and RT Scl. For V1425 Cyg, there were two alternative solutions (Lee 1988), a semidetached and an almost semidetached. In the case of the almost semidetached solution, the massive component was only 1 per cent short of filling the critical potential surface! In RT Scl, the more massive component was 7 per cent short of filling the critical potential surface (Hilditch and King 1986). This is the only

TABLE I

REVERSE ALGOLS

Name	Sp	P Days	$\frac{M_C}{M_H}$	i	ΔT^a K	Ω_H	Ω_C	r_H	r_C	$L^{(v)}_H$	$M_\odot$ M_H	M_C	$R_\odot$ R_H	R_C	Ref	Slope
V790 Cen	B3 III	1.278	0.78	57.1	+5800	3.38	4.24	0.397	0.251	0.85					1	0.84[b]
HD116072			3	4		Ω in	4	7	4	5						
V3894 Sgr	B3 IV	2.619	2.46	57.9	- 982	6.77	5.89	0.234	0.459	0.24					1	0.75
HD161756			2	2		2	Ω in	1	2	3						
BF Aur	B5 V +	1.583	0.83	84.9	+ 9	4.07	4.20	0.391	0.341	0.56	4.3	3.6	4.4	3.9	2	0.75
	B5 V		1	1		Ω in	1	1	1	1	5	4	1	1		
V1425 Cyg	B5	1.252	0.75	70.6	+4970	3.34	3.57	0.400	0.313	0.73	4.4	3.3	3.6	2.8	3	0.88
			7	1		Ω in	1	1	1	1	8	8	1	1		
RT Scl	F2	0.512	0.44	80.7	+2180	c		0.444	0.282		1.6	0.7	1.6	1.0	4	0.57
				4		Ω in		1	2		2	1	1	1		
ADS 9019	G0 V	0.408	1.33	84.0	- 6	4.28	4.26	0.345	0.399	0.35					1	0.51
			2	4		3	Ω in	4	4	1						
HD199497	G5:	0.364	1.66	52.7	- 802	5.44	4.76	0.267	0.422	0.50					5	0.90
			3	5		8	Ω in	6	10	2						

a. ΔT = T(high mass) - T(low mass)
b. 0.84 is the compliment of 1.84
c. see text

1. Qiao & Leung 1988; 2. Schneider, Darland & Leung 1979; 3. Lee & Leung 1988; 4. Hilditch & King 1986; 5. Liu, Tan & Leung 1988.

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system among the seven to which the author has not contributed the actual computing analyses. As mentioned earlier, the membership of this system is based upon the presentation of Hilditch at this Colloquium. Therefore according to unbiased computations these systems (six if not seven) are semidetached systems.

3. Types of Reverse Algols

The spectral type of reverse Algols (Table I) ranges from early B to mid G. We should not be surprised if, as more systems are discovered the spectral range of reverse Algols may cover the entire spectral sequence. The mass-ratios also have a large spread among these systems. There is a very interesting characteristic that really stands out among them. For the systems with mass ratios (m_C/m_H) smaller than unity, it is the hot component that fills the critical potential surface. The opposite is true for the systems with mass ratios larger than unity. The schematic configurations of a hot and a cool system are shown in Figure 3. There are four hot (BF Aur, V1425 Cyg, RT Scl and V790 Cen) and three cool (ADS 9019, V3894 Sgr, and HD 199497) systems. In regular Algols, it is always the cool component that fills the critical potential surface!

4. Evolutionary stage of Reverse Algols

Absolute dimensions are known for only three of the systems (BF Aur, V1425 Cyg, and RT Scl - Table I). The locations of these systems in a log $R/R_\odot$ vs. log $M/M_\odot$ diagram are shown in Figure 4. If we define the line joining the components of a binary system as the mass-radius relation, the slopes of these lines are roughly parallel to the ZAMS and TAMS lines in Figure 4. Other groups of binary systems also show this characteristic. These are the contact and near contact systems (see Leung 1988). We would like to know if the other reverse Algols (with no absolute dimensions reported) share similar mass-radius relations.

The slopes of the ZAMS line estimated from theoretical models are about 0.46 and 0.70 for stars larger than $6M_\odot$, and less than $6M_\odot$, respectively. The slope for the TAMS line is about 0.74. The slope of the mass-radius relation for a binary system can be expressed as follows:

in absolute dimensions expression,

$$\text{slope} = \frac{\log (R_H/R_C)}{\log (M_H/M_C)}$$

or in dimensionless variables,

$$\text{slope} = \frac{\log (r_C/r_H)}{\log (m_C/m_H)}$$

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The slopes of the mass-radius relation for the reverse Algol systems have been calculated and are listed in the last column of Table I. The values computed from non-dimensional parameters are similar to those obtained from absolute dimensions. This suggests that the mass-radius relation for the reverse Algols is the same as for the contact and near contact systems, which leads us to conclude that the reverse Algol phase of evolution is very much related to the contact and near-contact phase of evolution in the close-binary stars evolutionary sequence.

The above results with a larger data base would enforce the interpretation that a reverse Algol may be at the pre-mass-reversal or pre-contact phase of close binary evolution (for a more detailed discussion see Leung 1988). In theory, the pre-mass-reversal semidetached phase (i.e. reverse Algol phase) immediately precedes the rapid mass-transfer phase in close binary eovlution. It is generally believed that this phase may be extremely short and we should not expect to observe systems with this type of configuration. For this paper we collected seven examples of the type. If they are confirmed, or more members are found, then our generally accepted time-scale for this phase must be wrong.

5. Interpretation of Hot and Cool Systems

In light of the last section, it is easy to see how the more massive component (which is also hotter) expands to fill the critical equipotential surface, as a consequence of a single star evolution. This evolutionary scheme will produce the configuration of a hot reverse Algol. How a close system can end up with the configuration of a cool reverse Algol is less obvious. If we inspect the temperature differences ΔT (defined as "massive component minus a less massive component") in Table I, by definition ΔT is negative for the cool systems. The values of ΔT are less than 1000 K, which corresponds to roughly a few spectral sub-types. In order to achieve the configuration of a cool reverse Algol, all we need is to have the massive component (originally the hotter component) evolved to the right side of its companion in the H-R diagram before it fills its critical potential surface. This scheme supposes that the original separation between the components was large enough (or the period was significantly longer than the zero-age contact period, the critical period for the system). The selection effect in observing more short-period than long-period systems will result in cool systems having temperature differences at about 1000 K. As more longer-period systems are discovered, we may find temperature differences for the cold systems as large as those listed for the hot systems. These systems will become the advanced-case-B-mass transfer systems.

6. Time-Scale of Reverse Algols

At the begining of our discussion, we mentioned that the same selection effects apply to both regular and reverse Algols. Thus, the very rough first-order (or zero-order) estimate of the time scale of the regular Algol phase to the reverse Algol phase will simply be the ratio of the

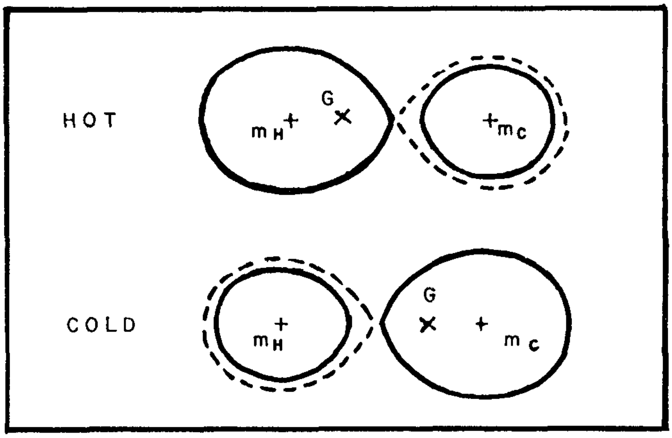

Figure 3. Typical configurations of hot and cool reverse Algols. Symbols are the same as in Figure 1.

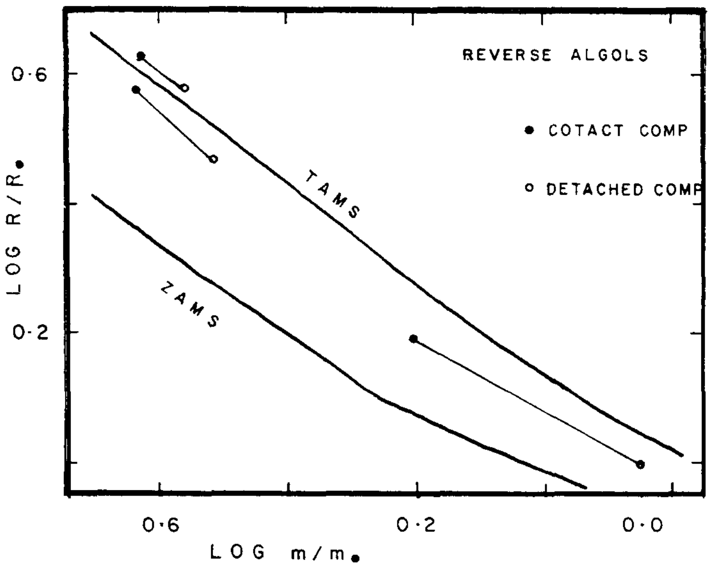

Figure 4. Log M vs log R diagram of reverse Algols. Filled circles represent contact components and open circles represent detached components.

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number of confirmed Algols to the number of confirmed reverse Algols. In the light of many discussions during this Colloquium about the uncertainty in cataloging Algol systems, the number of regular Algols is not readily known. No doubt some strict criteria on these systems will be set forth shortly and the number of confirmed members can be estimated accurately. If we assume the number of Algols with well-determined photometric solutions to be about 50, then the time-scale for the Algol phase to the reverse Algol phase may be 50 to 4 (not counting the systems with low inclinations in Table I). That is a ratio a little bit larger than 10 to 1.

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DISCUSSION

Walker commented that the light-curve of A.D.S. 9019 (HT Vir) was definitely that of a W UMa system - continuous variation of light and nearly equal minima. The period ($0^d.4$) and the spectral types (both G0 V) support this classification and even Leung's own values for the gravitational potentials were nearly equal. Walker did not see how Leung could maintain that this system was related to the Algols any more closely than W UMa itself. Leung emphasized, in reply, the distinction between a W UMa light-curve and a W UMa system. He maintained that not all systems with W UMa light-curves are found to be in contact, just as some systems with β Lyr light-curves are found to be so.

Hill pointed out that new data for GO Cyg would soon be published by Holmgren, and Leung's predictions for that system could be tested. Smak asked how Leung had determined the spectroscopic mass-ratios. Were there not dangers of error if radial velocities had been measured from asymmetric line profiles? Leung replied that he had taken the results from the literature; some systems had been measured by conventional techniques, others by cross-correlation. Hill commented that, in cross-correlation measurements, it is now possible - with the Wilson-Devinney or his own LIGHT2 code - to calculate theoretical line profiles to match the observed ones. This avoids the problem of deciding what the position of an asymmetric line-profile is, but the resulting radial velocities are model-dependent. In reply to a second question from Smak, Leung thought it possible that there is some spectroscopic evidence for mass-outflow from BF Aur and V1425 Cyg.

Richards emphasized the correlation between orbital inclination and third light, which makes it difficult to determine both quantities simultaneously by any least-squares method. Leung felt that this had not been a serious problem for the systems he had discussed. Kim's light-curves were good, and the correlation coefficients between the various parameters derived from them had not been large. Wilson confirmed that the correlation was often not important. He suggested that the distinction between Leung's "hot" and "cool" systems was one between systems in which one component was just underfilling its Roche lobe (maybe by so little that we could not say for sure) and systems in which mass transfer was actually in progress. Since there is very little room for circumstellar matter in these systems we should look for period changes. Leung replied that most of the systems had been discovered too recently for period studies to have been made.

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