

Eclipsing Binaries in Multiple-Star Systems

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ABSTRACT. About 80 eclipsing binaries are known to be components of multiple-star systems. This is less than 2% of all known eclipsing-binary systems, but the actual total is certainly much higher than this, as the majority of stars under review are in fairly bright, well-studied systems. Triple-star systems are by far the most common of these, but one system in five is a quadruple or higher-order system. Quadruple systems include both systems of hierarchy 2 (two widely spaced pairs, e.g., BV+BW Draconis) and hierarchy 3 (e.g., η Orionis). V772 Herculis and DN Ursae Majoris are in quintuple systems, and HR 3337 and the system that contains GZ Andromedae may also be quintuple. Castor, which contains the eclipsing binary YY Geminorum, is a very rare example of a sextuple-star system. Also considered are eclipsing binaries in compact star clusters such as SZ Camelopardalis and the two binaries in the Trapezium, BM Ori and V 1016 Ori. The most frequently encountered type of eclipsing binary to be found in multiple-star systems is that composed of two early-type (B5 or earlier) stars. Nearly all of the very close triple systems which have eclipsing-binary components are of this type. W Uma-type stars are also well represented among the multiple-star systems containing eclipsing binaries, but some other types are not. The RS Canum Venaticorum stars occur less frequently as components of multiple-star systems, and cataclysmic binaries appear to occur only very rarely as components of these systems. The physical and orbital properties of the multiple star systems are discussed in some detail in cases where the data are fairly complete, but it must be noted that many of the visual pairs have periods of revolution which are much too long to permit reliable determination of orbits. In triple-star systems with eclipsing binaries the ratio of P_2/P_1 ranges from less than 10 (for λ Tauri) to more than 10^7 in some cases. The questions of co-planarity of orbits and the membership of components in multiple-star systems are also considered.

1. INTRODUCTION

Although the majority of the eclipsing binaries are in systems that consist of only the two eclipsing components, a significant number of them do occur as components of triple-star systems or higher-order multiple-star systems. Although star clusters can be regarded as a type of multiple-star system, in the context of this paper this term is restricted to systems whose components are in closed orbits. A recent survey of visual binaries with variable components is that by Proust et al. (1981). About 300 systems are detailed in that work. Previous similar catalogs are those by Plaut (1934, 1940b), Baize (1962), and Petrova (1963). Walker (1979) has also prepared a list of variables in double stars, and this includes numerous systems not included in the other lists.

These catalogs surveyed all types of variable stars or stars suspected of variability that are observed in visual double-star systems. A different approach to this topic was taken by Fekel (1981), who examined the properties of close multiple stars. Both eclipsing and noneclipsing spectroscopic binaries were considered, but the upper limit of the period for the third component was restricted to about 200 years. Fekel's survey examined 43 systems, of which 6 have eclipsing binaries as components.

In this survey the properties of about 80 multiple-star

systems that contain eclipsing binaries are reviewed. Most of these are triple-star systems in which the third component is visually resolved from the eclipsing pair. But in several cases the third component is detectable only by spectroscopy or with such techniques as speckle interferometry. Several quadruple systems are recognized, and there are three or four probable quintuple systems as well as Castor, the well-known sextuple system, which contains the eclipsing binary YY Geminorum.

Trapezium-type systems are regarded as multiple-star systems, but they can also be considered as compact star clusters which contain numerous stars separated by comparable distances. The Trapezium itself is the center of an extensive cluster in Orion (see Walker, 1969) that contains two eclipsing binaries, BM Orionis (θ^1 Ori B) and V 1016 Orionis (θ^1 Ori A). Another example of an eclipsing binary in a star cluster is SZ Camelopardalis which together with its visual companion, ADS 2984 A, are the brightest stars in the compact cluster NGC 1502.

In addition to the various specific references cited in this paper, use has been made of the standard references on bright stars, double stars, eclipsing binaries, and spectroscopic binaries. Foremost among these are the works edited by Hoffleit and Jaschek (1982), Aitken (1932), Wood et al. (1980), and Batten et al. (1989).

2. GENERAL DISCUSSION

In Sec. 3 details are given for the systems covered in this survey. For the first group of these, details are given concerning the masses and spectra of the components, and the inclinations, eccentricities, and sizes of the orbits. For many of these systems the long periods are accurately known, but in numerous cases these can only be calculated from assumed masses, distances, and angular separations. All of these systems can be safely assumed to be physical systems (as opposed to optical pairs), but any periods of revolution that exceed 500 years must necessarily be taken as crude approximations.

What constitutes verification that a given eclipsing binary is indeed a member of a multiple-star system? If the eclipsing binary is a component of a fairly close visual binary system and if the components of that system display orbital motion or common proper motions, then one can be quite certain that this system is indeed multiple. But many of the systems listed in the catalog of Proust have widely spaced visual components. I have generally limited this survey of systems with visual components to those with $\rho=20''$ or less. If the third component is too close to be resolved visually, it may be resolved by speckle interferometry or by some other interferometric means.

Determinations of the orbits of wide visual binaries have always been fraught with uncertainties. Even for such a well-known system as Castor, the "definitive" value for the orbital period of the two bright visual components has undergone numerous revisions. Muller (1956) reported a period of 511 years, while Rabe (1958) working with a similar data base obtained $P=420$ years. The most current estimate (Heintz 1988) is $P=467$ years. Using only assumed masses and projected distances, one can calculate a period of 13,800 years for the orbit of YY Geminorum (Castor C) about Castor AB. Heintz, however, obtains a value of 37,000 years for this period after taking information concerning the proper motions of the components into account.

Most of the systems detailed in these listings are triple systems, consisting of an eclipsing binary coupled to a widely separated third component. The eclipsing binary periods are given in days and can be assumed to be accurate to at least the precision given. The periods for the third component are given in years, and they range from well determined to only crude guesses. Where possible orbital eccentricities and inclinations for these orbits are given. Although nearly all of the orbits for the eclipsing pairs are of low eccentricity, the orbits for the third components often have high eccentricities. The most extreme case is that of V772 Herculis, where an eccentricity of 0.96 is reported for the 20-yr orbit. If information is also known or can be safely assumed about the masses of the components, the sizes of the orbits can be computed. Where possible the value of a_2/a_1 is given. Fekel (1981) also considers the periastron distance of the larger orbit, $q=a(1-e)$,

and this ratio is given as well. Co-planarity of orbits is often considered in compact triple star systems, but it definitely breaks down for long-period orbits. [For further information on the co-planarity of orbits refer to the papers by Abt and Levy (1976, 1978) and by Fekel.] In this survey the quantity ϕ refers to the minimum angle of inclination between the two orbital planes.

In some cases the third component leaves a spectral signature in the spectrum of the eclipsing binary. The spectra of both Algol and V505 Sagittarii display sharp lines which arise from the third components of these systems, and both of these systems are now also resolved by speckle interferometry. It is also possible that the third component will cause a variable γ velocity in the system of the eclipsing pair. VV Orionis has long been known to have a third component, since its γ velocity is variable despite the fact that the third component itself is much too faint to display distinct lines in the spectrum of the eclipsing pair.

Although triple-star systems are by far the most common of the multiple-star systems that contain eclipsing binaries, higher-order systems do exist. Quadruple systems tend to be either of hierarchy 2 (two pairs of close double stars widely spaced) or of hierarchy 3 (four stars with three quite different spacings and orbital periods). An example of the former is the quadruple system that contains the eclipsing binaries BV and BW Draconis. Eta Orionis is an excellent example of the latter type of quadruple system.

Quintuple and sextuple systems are much rarer, but at least three or four systems in this survey appear to be quintuple. Castor is a well-known sextuple system, and it contains the eclipsing binary YY Geminorum. Sextuple stars are extremely rare, however, and the only other well-known case is β Tucanae, a system which contains no eclipsing binaries.

In the data that follow in Sec. 3 angular distances are given as a'' (if they are semimajor axes) or ρ'' (if they are measured separations only). All values based on assumed quantities are enclosed in parentheses. As can be seen from these data, there is a truly enormous range in the values of the ratios a_2/a_1 and P_2/P_1 . By far the smallest values of these ratios are for λ Tauri, where these quantities are 4.2 and 8.35, respectively. On the large side are the ratios for such systems as the quadruple W Ursae Majoris-type system BV and BW Dra where a_2/a_1 is about 100,000 and P_2/P_1 is about 3×10^7 . Angular separations are not given for IM Aurigae, IU Aur, FZ Canis Majoris, 4 Dra, VV Ori, DM Persei, or λ Tauri, since it is unlikely that these systems can be resolved with present-day techniques.

In very close triple-star systems the third component will have a pronounced effect on the orientation of the eclipsing pair. This is substantial in λ Tau and even more so in IU Aur, which has been undergoing a large-scale secular increase in the inclination of its orbit for several decades. In the latter system the third component is much more massive than is the case with λ Tau, and it is in an

orbit which is far from being co-planar with the eclipsing pair.

If the system is listed in the Aitken catalog, the ADS number is given. In most cases the eclipsing pair is the A component of the system. Although the Aitken catalog is remarkably complete, the author (Chambliss 1982) found the eclipsing binary AF Gem to also be a previously unreported visual binary. On the other hand, the evolved early-type eclipsing binary V367 Cygni has been reported by Heiser (1961) to have a bright companion only $0''.12$ from the eclipsing pair. Li and Leung (1987), however, found no trace of this component in their solutions, and thus it is believed that this object is spurious.

In the early days of the analyses of eclipsing binary light curves only the spherical model was generally available, and often this did not give a very good approximation to the geometry of many eclipsing binary systems. Investigators found that they could improve matters by adding a "third light" to the system in some cases. Such a procedure is valid only if there is clear evidence that a third component actually exists in a given system. In more recent years the use of more sophisticated models for dealing with the light variations of eclipsing binaries has made it unnecessary to add such a correction except in those cases where a third light is definitely present.

One of the indirect means by which a third component can be detected in an eclipsing binary system is from the light-time effect which will displace the times of minimum light in a sinusoidal fashion with a period equal to the period of revolution of the third component. A recent and thorough survey of this effect is that of Mayer (1990). For Algol this effect results is a well-known term with a semi-amplitude of about 5 min in the times of minimum light of the eclipsing pair (Friboes-Conde et al. 1970).

Other effects, however, can produce systematic variations in the times of minimum light of eclipsing binaries, and one should not be too hasty in concluding that an eclipsing system is triple on this type of evidence alone. Beavers et al. (1986) report a light-time effect with a period of 24.6 years for V471 Tau, and Srivastara (1988) reports a period of 22 years for a similar effect in ST Per. Both of these investigators conclude that these systems have third components whose orbital periods correspond to these intervals, but in the absence of any additional evidence supporting the presence of third components, the author feels that the conclusion that these systems are triple is at present premature. ST Persei does have a visual component, but this star is much too distant from the eclipsing pair to produce the observed effect. A similar 5.3-yr effect in the timings of minimum light for GZ And has been reported by Walker (1991), but additional evidence will be needed to confirm if this effect arises from the presence of an additional component in this multiple system.

Mayer reports eight additional eclipsing binary systems which have long-term systematic variations in their O-C

curves, and the periods of these variations range from 18 to 91 years. These systems are AR Aur, R CMa, TX Her, T LMi, RU Mon, U Oph, RT Per, and DR Vul. Additional evidence will be needed to confirm which, if any, of these systems are multiple.

For AH Cephei there is photometric evidence that a third light is present (see Drechsel et al. 1989), and this strongly supports the idea that a 63-yr term in the O-C curve of this system is due to the orbital motion of a third body. For IM Aur the sinusoidal variation has a very short period ($P=3.78$ yr), and it has been observed over several cycles. This lends support to the idea that this system has a third component with that orbital period, but the multiple nature of this system is not fully confirmed at present. AK Herculis is definitely a multiple-star system, but the question is whether it is a triple or a quadruple system. There is a visual component at $\rho=4''.7$, but the revolution period for this star about the eclipsing pair would be several millennia. AK Herculis is observed to show a sinusoidal variation with a period of about 75 years. This could be caused by a third component at a distance of about $0''.25$ from the eclipsing pair, but no such star has thus far been seen.

AK Herculis is a W UMa-type system, and these stars often prove to be components of multiple systems. Not all types of close binaries are common in multiple systems, however. Cataclysmic binaries appear to be especially uncommon as components of multiple-star systems. In Sec. 3 data are provided on 4 Draconis, which consists of a red giant and a cataclysmic pair. It does not display eclipses, but it is included in this survey because it is the only well-established case of a cataclysmic variable in a multiple-star system. The RS CVn-type stars also appear to be somewhat underrepresented as components of multiple-star systems, but WW Dra does appear to be an example of an RS CVn-type star which displays eclipses and also has a third component. There are a number of noneclipsing RS CVn-type stars, however, which are members of multiple-star systems.

In Sec. 3 details are given on about 35 multiple-star systems that contain eclipsing binaries as components. For each of these systems at least one recent reference is provided. All values in parentheses are estimates which have been made from the available data. The positions for the year 2000 are given. These are precise to 1^s in right ascension and to $1'$ in declination. The visual magnitudes given refer either to the entire system at maximum light, or to the components of the visual system if they are spaced by at least a few seconds of arc. The masses quoted are in solar mass units. Additional data can be obtained by referring to the sources noted and to the references which these sources provide.

In the second part of Sec. 3 less extensive data are given on other eclipsing binary systems which are known to have visual components.

3. DETAILS OF INDIVIDUAL SYSTEMS

AA Cet=HD 12180=ADS 1581 015805-2300

Eclipsing pair:	(ADS 1581 A)	$V=6.2$	$P=0^d5362$	$Sp=F2 V+F2 V$
Second pair:	(ADS 1581 B)	$V=7.5$	$P=?$	$Sp=F5 V+F5 V$
Both pairs:	$\rho=8''.4$	$r=800 \text{ AU}$	$d=95 \text{ pc}$	$P=(10,000 \text{ yr})$
	$a_{12}/a_1=(75,000)$		$P_{12}/P_1=(6.8 \times 10^6)$	$\log P_{12}/P_1=(6.83)$

References: Chambliss (1981); Rucinski and Kuluzny (1982).

GZ And=ADS 1693 A 021056+4434

Eclipsing pair:	$V=10.83$	$P=0^d3050$	$e=0.00$	$i=84^\circ$	$Sp=G5 V+G5 V$
ADS 1693 B:	$V=11.14$	$\rho=8''.2$	$r=1200 \text{ AU}$	$d=145 \text{ pc}$	
ADS 1693 C:	$V=11.91$	$\rho=13''.5$	$r=2000 \text{ AU}$		

Reference: Walker (1991).

Note: There is a sinusoidal 5.3-yr variation in the times of minimum light for GZ And. This may be due to the light-time effect of an unseen companion. ADS 1693 D is also in the group at $\rho=24''.4$, but judging from the color-magnitude data it appears that it is not a physical member of the system. ADS 1693 is at least a quadruple star, and it may be quintuple.

V559 Cas=HD 14817=ADS 1833 022540+6133

$V \text{ (of system)}=7.01$					
Eclipsing pair:	$P_1=1^d581$	$e=0.00$	$i=85.0^\circ$		
$Sp=B9 V+B9 V$	$\mathcal{M}=4.0+4.0$				
Third component:	$a''=0''.43$	$a=159 \text{ AU}$	$d=375 \text{ pc}$		
$P_2=581 \text{ yr}$	$e=0.68$	$i=47.2^\circ$			
$\phi=38^\circ$	$Sp=B9 V$	$\mathcal{M}=4.0$			
$a_2/a_1=3000$	$q_2/a_1=960$	$P_2/P_1=134,500$	$\log P_2/P_1=5.13$		

References: Fekel (1981); Worley and Heintz (1983).

Note: The visual binary orbit listed by Worley and Heintz and given here differs radically from that quoted by Fekel. A dynamical parallax can be calculated from these data. This implies a distance modulus of 6.9, which yields $M_V=+0.1$ for all three components together, a value which is much too faint for three B9 V stars. McAlister and Hartkopf (1988) give $\rho=0''.35$ for this system.

DM Per=HD 14871 022433+5601

$V \text{ (of system)}=7.86$					
Eclipsing pair:	$P_1=2^d728$	$e=0.00$	$i=77^\circ$		
$Sp=B5 V+A5 \text{ III}$	$\mathcal{M}=5.8+1.8$				
Third component:	$P_2=0.2683 \text{ yr}$	$e=0.00$	$i=(77^\circ)$	$Sp=(B6 V)$	$\mathcal{M}=(3.7)$
$a_2/a_1=8.5$	$P_2/P_1=35.93$		$\log P_2/P_1=1.555$		

Reference: Hilditch et al. (1986).

Note: The spectrum of the third component is not seen. This star is either underluminous or perhaps a binary itself.

Algol=Beta Per=HD 19356 030811+4057

$V \text{ (of system)}=2.12$					
Eclipsing pair:	$P_1=2^d867$	$e=0.02$	$i=82.4^\circ$		
$Sp=B8 V+G8 \text{ IV}$	$\mathcal{M}=3.7+0.8$				
Third component:	$a''=0''.086$	$a=2.66 \text{ AU}$	$d=31 \text{ pc}$		
$P_2=1.862 \text{ yr}$	$e=0.23$	$i=74^\circ$	$\phi=8^\circ$		
$Sp=Am$	$\mathcal{M}=1.7$				
$a_2/a_1=42.6$	$q_2/a_1=32.8$	$P_2/P_1=238.0$	$\log P_2/P_1=2.777$		

Reference: Fekel (1981).

Lambda Tau = HD 25204 040040 + 1229

V (of system) = 3.37				
Eclipsing pair:	$P_1 = 3^d 953$	$e = 0.00$	$i = 76^\circ$	
Sp = B3 V + A4 IV		$\mathcal{M} = 7.2 + 1.9$		
Third component:	$P_2 = 0.09$ yr	$e = 0.16$	$i = 69^\circ$	$\phi = 7^\circ$
Sp = (K0 V)	$\mathcal{M} = 0.7$			
$a_2/a_1 = 4.2$	$q_2/a_1 = 3.5$	$P_2/P_1 = 8.35$	$\log P_2/P_1 = 0.92$	

Reference: Fekel and Tomkin (1982).

Note: Lambda Tauri has by far the shortest period ratio of any triple-star system. A nodal precession rate of 7 or 8 yr is to be expected.

SZ Cam = HD 25638 = ADS 2984 040750 + 6220

Eclipsing pair:	(ADS 2984 B)	V = 7.04	$P_1 = 2^d 699$	$e = 0.00$	$i = 73^\circ$
Sp = 09.5 V + B0 V		$\mathcal{M} = 19 + 6.5$			
Third component:	(ADS 2984 A)	V = 7.07	$\rho = 18''$		
Sp = B0 III	$r = (11,000$ AU)		$d = 600$ pc		

Reference: Budding (1973, 1975).

Note: ADS 2984 A and SZ Cam are the brightest members of the compact cluster NGC 1502. Aitken lists more than ten members for this group. It is probably best to regard SZ Cam as an eclipsing binary in a star cluster rather than as a member of a multiple-star system with components that have closed orbits.

b Per = HD 26961 041814 + 5018

V (of system) = 4.54					
Ellipsoidal pair:	$P_1 = 1^d 527$	$e = 0.02$	$i = 55^\circ$	Sp = A2 V + F2 IV	$\mathcal{M} = 2.2 + 0.5$
Third component:	$a'' = 0''.032$	$a = 2.1$ AU	$d = 65$ pc	$P_2 = 1.921$ yr	$e = 0.24$
Sp = (F0 V)	$\mathcal{M} = (1.3)$				
$a_2/a_1 = (70)$	$q_2/q_1 = (53)$	$P_2/P_1 = 460$	$\log P_2/P_1 = 2.662$		

Reference: Hill et al. (1976).

Note: This is only one of two models assumed for this Algol-like ellipsoidal pair. The system is single-lined, so the masses of the other two components can only be guessed at.

IM Aur = HD 33853 051400 + 4621

V (of system) = 7.90					
Eclipsing pair:	$P_1 = 1^d 247$	$e = 0.00$	$i = 79^\circ$	Sp = B7 V + (A5 V)	$\mathcal{M} = 2.2 + 0.8$
Third motion:	$P_2 = 3.78$ yr	$L_3 = ?$	$d \sim 350$ pc		

References: Mammano et al. (1967); Gülmen et al. (1985); Mayer (1990).

Note: The O-C curve for this system displays a pronounced sinusoidal variation with a period of 3.78 yr. This is probably due to the influence of a third component, but the multiple nature of this system is not yet fully proven.

Eta Ori = HD 35411 = ADS 4002 05429 - 0223

V (of system) = 3.35					
Eclipsing pair:	(Aa + Ab)	$P_1 = 7^d 984$	$e = 0.00$	$i = (90^\circ)$	
Sp = B1 V + B3 V		$\mathcal{M} = 15.0 + 12.4$			
Third component:	(Ac)	$a'' = 0''.044$	$a = 18.2$ AU	$d = 410$ pc	
$P_2 = 9.22$ yr	$e = 0.43$	$i = (90^\circ)$	Sp = B1 V	$\mathcal{M} = 13.7$	
$a_2/a_1 = 64.4$	$q_2/q_1 = 36.7$	$P_2/P_1 = 422$	$\log P_2/P_1 = 2.625$		
Fourth component: (B)	$\rho = 1''.60$	$r = 660$ AU	$d = 410$ pc	$P_3 = (2300)$ yr	
Sp = B2 V	$\mathcal{M} = 13.0$				
$a_3/a_2 = (36.2)$	$P_3/P_2 = (250)$	$a_3/a_1 = (2,330)$	$P_3/P_1 = (105,000)$		
$\log P_3/P_2 = (2.40)$	$\log P_3/P_1 = (5.02)$				

References: McAlister (1976); Waelkens and Lampens (1988).

Note: Eta Orionis is an archetypal quadruple system of hierarchy 3. The inclination for the 9-yr period needs to be clarified. Aitken claims that there is a remote fifth component to this system, but it is probably optical. The new

investigation by Waelkens and Lampens (1988) indicates that $P_2=9.51$ yr. They also consider the possibility that the short-term intrinsic variation observed in this system arises in Eta Ori B rather than in the eclipsing pair.

IU Aur=HD 35652 052633+3447

V (of system)=8.19				
Eclipsing pair:	$P_1=1^d811$	$e=0.00$	$i(\sim 1990)=90^\circ$	
Sp=B0 V+B0.5 V		$\mathcal{M}=15.9+10.8$		
Third component:	$P_2=0.805$ yr	$e=0.4$	$i=50^\circ$	$\phi=40^\circ$
$L_3=0.20$	Sp=B3 II-III	$\mathcal{M}=(10)$		
$a_2/a_1=33$	$q_2/q_1=20$	$P_2/P_1=162$		$\log P_2/P_1=2.21$

Reference: Mayer and Drechsel (1987).

Note: The presence of a massive third component in an eccentric orbit with a small separation produces huge changes in the inclination of the eclipsing pair. The orbital inclination of IU Aur has been increasing at a rapid rate in recent years.

LY Aur=HD 35921=ADS 4072 052822+3522

V (of system)=6.66				
Eclipsing pair:	$P_1=4^d025$	$e=0.00$	$i=86.6^\circ$	
Sp=O9.5 III+B0.5 III	$\mathcal{M}=28+16$			
Third component:	$\rho=0''6$	$r=(900$ AU)	$d=(1500$ pc)	
Sp=(B2 V)	$L_3=0.07$	$P_2=(3600$ yr)		
$a_2/a_1=(3600)$	$P_2/P_1=(325,000)$	$\log P_2/P_1=(5.5)$		

References: Li and Leung (1985); Drechsel et al. (1989).

VV Ori=HD 36695 053332-0110

V (of system)=5.35				
Eclipsing pair:	$P_1=1^d485$	$e=0.00$	$i=85.6^\circ$	
Sp=B1 V+B4 V	$\mathcal{M}=10.2+4.5$			
Third component:	$P_2=0.33$ yr	$e=0.29$		
Sp=(A3 V)	$\mathcal{M}=2.3$			
$a_2/a_1=19.5$	$q_2/q_1=13.2$	$P_2/P_1=80.8$		$\log P_2/P_1=1.91$

Reference: Chambliss (1983).

Theta¹ Ori=HD 37020-3=ADS 4186 A-D 053517-0523

BM Ori (θ^1 Ori B):	V=7.90	$P=6^d470$	$e=0.00$	$i=84^\circ$	
Sp=B3 V+A7 IV	$\mathcal{M}=5.3+1.8$				
V 1016 Ori (θ^1 Ori A):	V=6.77	$P=65^d43$	$e=0.60$	$i=(90^\circ)$	Sp=O7 V+?
Also θ^1 Ori C:	Sp=O6 V	θ^1 Ori D:	Sp=B0 V		
Separations:	AB $\rho=8''7$	$r=3900$ AU	$d=450$ pc		
	AC $\rho=13''0$	$r=5850$ AU			
	AD $\rho=21''5$	$r=9700$ AU			

References: Hall and Garrison (1969); Sowell and Hall (1982).

Note: The Aitken and the Bright Star Catalogs list the components from E to W. The notation used by Walker (1969) lists them in order of decreasing brightness, whence A (Walker)=C(Aitken), B=D, C=A, and D=B. The visual magnitudes for the other two components are 5.16 and 6.72. There is no definitive light curve for V 1016 Ori, but the period now seems to have been established. There are many other stars in the immediate vicinity of the Trapezium, and this object should be looked upon as a star cluster rather than as a multiple star.

V 1031 Ori=HR 2001=HD 38735 054727-1032

V (of system)=6.02				
Eclipsing pair:	$P=3^d406$	$e=0.00$	$i=85.5^\circ$	
Sp=A8 III-IV+A5 IV-V	$\mathcal{M}=2.47+2.29$			
Third component:	$\rho=0''165$	$r=35$ AU	$d=215$ pc	
Sp=A6 IV-V	$\mathcal{M}=2.2$			

If $a_2=35$ AU, then $P_2=80$ yr, but Anderson et al. note that the relative velocities of the components are much less than one would expect if this were the case. They regard a ~ 400 AU and $P\sim 3500$ yr as being more realistic. References: Andersen et al. (1990); McAlister and Hartkopf (1988).

AF Gem = HDE 264750 064923 + 2124

V (of system) = 10.54
 Eclipsing pair: $P=1^d244$ $e=0.00$ $i=77^\circ$ Sp=B9 V + G0 IV
 Third component: $\rho=\sim 2''$ $d=(1000$ pc)

Reference: Chambliss (1982).

Note: This system was not recognized as a double star by Aitken. Although AF Gem appears to be a physical triple system, further observations are needed to confirm this.

FZ CMa = HD 52942 070146 - 1126

V (of system) = 8.05
 Eclipsing pair: $P_1=1^d273$ $e=0.00$ $i=87.5^\circ$
 Sp=B2 IV-V + B3 IV-V $\mathcal{M}=5.4+5.3$
 Third component(s): $P_2=1.469$ yr $e=0.56$ $i=(90^\circ)$
 $L_3=0.43$ Sp=(B4 III) $\mathcal{M}=(12\pm 4)$
 $a_2/a_1=72.5$ $q_2/a_1=31.9$ $P_2/P_1=421.5$ $\log P_2/P_1=2.625$

References: Moffat et al. (1983), Mayer (1990).

Note: The eclipsing pair is a double-lined spectroscopic binary, but lines of the third component are not seen in the spectrum despite the substantial contribution of this star to the light and mass of the system. Possibly the third light is really a pair of B4 V stars, in which case FZ CMa would be a quadruple system.

Castor = Alpha Gem = HD 60178 - 9 = ADS 6175 073436 + 3153

α^1 Gem = Castor B	α^2 Gem = Castor A			
Castor B:	Sp=A2m V	V=2.85	$P=2^d928$	$e=0.00$
Castor A:	Sp=A1 V	V=1.99	$P=9^d213$	$e=0.50$
Pair:	$a''=6''805$	$a=93$ AU	$d=13.7$ pc	
$P=467$ yr	$e=0.343$	$i=114.5^\circ$		
Castor A \mathcal{M} (both components) = 2.1		Castor B \mathcal{M} (both components) = 1.6		
YY Gem: V=8.91	$P=0^d8143$	$e=0.00$	$i=86.5^\circ$	
Sp=M1e V + M1e V	$\mathcal{M}=0.6+0.6$			
$\rho=71''$	$r=975$ AU	$P=(13,800$ yr)		

Reference: Heintz (1988).

Note: Both Castor A and Castor B are single-lined spectroscopic binaries. Heintz estimates a period of 37,000 yr for the revolution of Castor C about Castor AB. This takes into account the relative proper motions of the components.

NO Puppis = HR 3327 = HD 71487 082618 - 3904

V (of system) = 6.68
 Eclipsing pair: $P=1^d257$ $e=0.123$ $i=77.8^\circ$
 Sp=B8 V + A7 V
 Second pair: HR 3328 (HD 71488) $\rho=0''1$ $r=16$ AU $d=160$ pc
 $P=(32$ yr) Sp=A3 V + A3 V
 HR 3327 - 8: $\rho=8''1$ $r=1300$ AU $P=(15,000$ yr)

Reference: Grönbech (1976).

Note: HR 3327 - 8 is a quadruple system consisting of two pairs of rather similar stars. It should be possible to obtain a good orbit for HR 3328 with speckle interferometry.

HR 3337=HD 71663=ADS 6828 082829-0231

V (of system)=6.38			
Eclipsing pair:	$P_1=2^d500$	$e=0.01$	$i=86^\circ$
Sp=F0 V+(G0 V)	$\mathcal{M}=1.6+1.1$		
Second pair: $P_2=5^d977$	$e=0.01$	$i=45^\circ$	
Sp=A5 V+(F5 V)	$\mathcal{M}=2.0+1.3$		
Both pairs:	$a''=0^{\prime}32$	$a=26$ AU	$d=80$ pc
$P_{12}=53.0$ yr	$e=0.45$	$i=84^\circ$	
$a_{12}/a_1=542$	$q_{12}/a_1=298$	$P_{12}/P_1=7740$	$\log P_{12}/P_1=3.89$
$a_{12}/a_2=433$	$q_{12}/a_2=238$	$P_{12}/P_1=3240$	$\log P_{12}/P_1=3.51$

References: Bakos (1985); Fekel (1981).

Note: This system is actually probably quintuple. There is a 10^m5 star located $18''$ from these stars. At $d=80$ pc, the minimum distance of this star from the others is 1440 AU. According to Fekel (1991), the radial velocity of the faint component lies between the γ velocities of the two spectroscopic pairs, and this indicates that it is probably a member of this system.

XY Leo=BD+18°2307 100036+1730

V (of system)=9.45			
Eclipsing pair:	$P_1=0^d284$	$e=0.00$	$i=65.8^\circ$
Sp=K0 V+K0 V	$\mathcal{M}=0.81+0.50$		
Second pair:	$P_2=0^d805$	$e=0.0$	$i=(31^\circ)$
Sp=(M1 V)+(M3 V)	$\mathcal{M}=(0.50)+(0.35)$		
Both pairs:	$P_{12}=20.0$ yr	$d=52$ pc	$a''=0^{\prime}18$
$a_{12}=9.5$ AU	$a_{12}/a_1=870$	$P_{12}/P_1=25,700$	$\log P_{12}/P_1=4.41$
$a_{12}/a_2=435$	$P_{12}/P_2=9070$	$\log P_{12}/P_2=3.96$	

References: Hrivnak (1985); Barden (1987).

Note: XY Leonis is now established as being a member of a quadruple system similar to AA Ceti and its companion pair and to the BV and BW Dra system. In this case, however, the two pairs are very much closer to one another. The system should be resolvable with speckle interferometry.

QZ Car=HD 93206 104336-5954

V (of system)=6.16				
Eclipsing pair:	$P_1=5^d998$	$e=0.00$	$i=86^\circ$	
Sp=O9 V+B0 Ib	$\mathcal{M}=28+17$			
Second pair:	$P_2=20^d72$	$e=0.34$	$i=(60^\circ)$	
Sp=O9.7 Ib+(B2 V)	$\mathcal{M}=(40)+(9)$			
Both pairs:	$P_{12}=(\leq 25.4)$ yr	$d=2800$ pc	$\rho=(\leq 0^{\prime}012)$	$a \sin i=(\leq 34)$ AU

Reference: Leung et al. (1979).

Note: QZ Carinae is in an extremely massive quadruple-star system of hierarchy 2. This system has been under analysis for only a few years, but with time it should be possible to determine P_{12} with greater precision than is shown here.

DN UMa=HR 4560=HD 103483=ADS 8347 115506+4629

Eclipsing pair:	(ADS 8347 A)	V=7.2	$P=1^d730$	Sp=A3 V+A3 V
ADS 8347 B:	V=9.0	$\rho=0^{\prime}3$		
ADS 8347 C:	V=8.3	$\rho=3^{\prime}8$		
ADS 8347 D=HR 4561		V=7.0	$\rho=63^{\prime}0$	Sp=A1p

References: Gimenez et al. (1984); Garcia and Gimenez (1986); Popper (1986).

Note: This complex appears to be a quintuple system of hierarchy 3. Garcia and Gimenez attributed the shallow eclipses to component C, but Popper has proven that component A is the eclipsing pair. ADS 8347 ABC (HR 4560) is certainly a physical system, and ADS 8347 D (HR 4561) appears to be physically associated with the former. At a distance of 150 parsecs, the minimum separations for B, C, and D from A are 45, 570, and 9500 AU, respectively. Much more work is needed to clarify the complexities of this system.

4 Dra=CQ Dra=HD 108907 123007+6912

V (of system) = 5.07			
Cataclysmic pair:	$P_1 = 0^d1656$	$e = 0.00$	$i \leq 50^\circ$
Sp = (M4 V) + wd		\mathcal{M} of pair = (0.85)	
Third component:	$P_2 = 4.65$ yr	$e = 0.30$	$i \leq 50^\circ$
Sp = M3 III	$\mathcal{M} = (5.0)$		
$a_2/a_1 = (1000)$	$P_2/P_1 = 10,300$		$\log P_2/P_1 = 4.01$

Reference: Reimers et al. (1988).

Note: This system does not actually contain an eclipsing binary, since CQ Dra does not have eclipses. It is, however, the only well-known example of a cataclysmic binary known to be in a multiple-star system.

V701 Cen=HD 117470 133022-5141

V (of system) = 8.8			
Eclipsing pair:	$P = 0^d738$	$e = 0.00$	$i = 88^\circ$
Third component:	$\rho \leq 1''$	$P_2 = ?$	Sp = A0 V + A3 IV-V
			$L_3 \sim 0.30$ of system

Reference: Milano et al. (1988).

Note: The third component has been observed visually by Eggen. It should be easily resolved by speckle interferometry.

HT Vir=HD 119931=ADS 9019 134508+0514

V (of system) = 7.06			
Eclipsing pair: $P_1 = 0^d4077$	$e = 0.00$	$i = 90.0^\circ$	Sp = G0 V + G0 V
Third component:	$a'' = 1''09$	$a = 61$ AU	$d = 55$ pc
$P_2 = 312$ yr	$e = 0.63$	$i = 43.7^\circ$	$\phi = 45^\circ$
$a_2/a_1 = 6100$	$a_2/a_1 = 2250$	$P_2/P_1 = 280,000$	$\log P_2/P_1 = 5.44$

References: Heintz (1976); Walker and Chambliss (1985).

Note: The paper by Heintz was published prior to the discovery by Walker that ADS 9019 B is an eclipsing binary. The period of the visual binary is probably somewhat overestimated. McAlister and Hartkopf (1984) indicate $P_2 = 282$ yr.

DL Vir=HD 120901-2 135134-1837

V (of system) = 7.0			
Eclipsing pair:	$P_1 = 1^d315$	$e = 0.00$	$i = 84^\circ$
Sp = A3 V + (K0 IV)	$\mathcal{M} = 2.2 + 1.1$		
Third component:	$a'' = 0''029$	$a = 5.9$ AU	$d = 210$ pc
$P_2 = 6.25$ yr	$e = 0.49$	$i = 64^\circ$	$\phi = 20^\circ$
$a_2/a_1 = 167.7$	$q_2/a_1 = 90.6$	$P_2/P_1 = 1736$	$\log P_2/P_1 = 3.24$
			Sp = G8 III $\mathcal{M} = (1.9)$

Reference: Schöffel (1977).

Note: Attempts to resolve this system by speckle interferometry have thus far proven unsuccessful.

44i Boo=HD 133640=ADS 9494 150348+4740

V (of system) = 4.76			
Eclipsing pair:	$P_1 = 0^d2678$	$e = 0.00$	$i = 68.1^\circ$
Sp = G1 V + G1 V	$\mathcal{M} = 0.98 + 0.55$		
Third component:	$a'' = 3''6$	$a = 47$ AU	$d = 13$ pc
$P_2 = 225$ yr	$e = 0.43$	$i = 83.9^\circ$	$\phi = 16^\circ$
$a_2/a_1 = 5416$	$q_2/a_1 = 3466$	$P_2/P_1 = 307,000$	$\log P_2/P_1 = 5.487$
			Sp = F5 V $\mathcal{M} = 1.06$

References: Fekel (1981); Hill et al. (1989).

BV Dra and BW Dra=HD 135421=ADS 9537 A/B 151126+6156

BV Dra:	V=7.88	$P_1=0^d3501$	$e=0.00$	$i=76.3^\circ$
Sp=F9 V+F8 V	$\mathcal{M}=1.04+0.43$			
BW Dra:	V=8.61	$P_2=0^d2922$	$e=0.00$	$i=74.4^\circ$
Sp=G3 V+G0 V	$\mathcal{M}=0.92+0.26$			
Both systems:	$\rho=16''1$	$r=1150$ AU	$d=70$ pc	$P_{12}=(24,000$ yr)
$a_{12}/a_1=(105,000)$		$P_{12}/P_1=(2.5\times 10^7)$		$\log P_{12}/P_1=(7.40)$
$a_{12}/a_2=(128,000)$		$P_{12}/P_2=(3.0\times 10^7)$		$\log P_{12}/P_2=(7.48)$

References: Batten and Lu (1986); Kaluzny and Rucinski (1986); Hardie and Hall (1990).

WW Dra=HD 150708=ADS 10152 163846+6044

Eclipsing pair:	V=8.3	$P=4^d630$	$e=0.00$	$i=81.4^\circ$
Sp=G2 IV+K0 IV	$\mathcal{M}=1.3+1.3$			
Third component:	V=8.8	$\rho=8''2$	$r=820$ AU	$d=100$ pc
$M_V=+3.3$	Sp=(F2 V)	$P=(12,000$ yr)		

References: Plaut (1940a); Kriz (1965).

Note: This is a rather uncommon case of an eclipsing RS CVn-type system which has a third component. More work is needed to verify that the third component is indeed physically associated with the WW Dra system.

AK Her=HD 155937=ADS 10408 171304+1627

V (of system)=8.29				
Eclipsing pair:		$P=0^d4215$	$e=0.00$	$i=78^\circ$
Sp=F2 V+F6 V				
Fourth (or third?) component:	$\rho=4''7$	$r=450$ AU	$d=95$ pc	

References: Tunca et al. (1987); Woodward and Wilson (1977).

Note: This system has a well-known sinusoidal variation in its O-C curve which has been interpreted as the light-time effect arising from a third component. Various investigators have determined the period of this effect to lie in the range 58-78 yr. The visible companion would have a much longer period than this, so there is possibly an unresolved third component. For $P_2=75$ yr, the semimajor axis would be about 24 AU and a'' about $0''.25$.

HR 6469=HD 157482 172143+3958

V (of system)=5.5				
Eclipsing pair:	$P_1=2^d230$	Sp=F2 V+(G0 V)	$\mathcal{M}=1.65+1.15$	
Third component:	$P_2=5.53$ yr	$\rho=0''.063$	$r=3.15$ AU	$d=50$ pc
Sp=G5 IV	$\mathcal{M}=2.05$			
$a_2/a_1=(80)$	$P_2/P_1=905$	$\log P_2/P_1=2.96$		

References: McAlister et al. (1984); Hall et al. (1985).

Note: The third component of this close triple system is chromospherically active with a period of 83^d2 , which appears to be the rotation period of the G5 IV component. This system has been resolved by speckle interferometry.

V772 Her=HD 165590=ADS 11060 180550+2127

V (of ADS 11060 AB)=6.9				
Eclipsing pair=ADS 11060A:		$P_1=0^d8795$	$e=0.045$	$i=77^\circ$
Sp=G0 V+(M0 V)	$\mathcal{M}=1.0+0.6$			
Third component=ADS 11060 B:		$a''=0''.25$	$a=10.1$ AU	$d=42$ pc
$P_2=20.25$ yr	$e=0.958$	$i=83^\circ$	$\phi=6^\circ$	Sp=G0 V $\mathcal{M}=0.9$
$a_2/a_1=477$	$q_2/q_1=19$	$P_2/P_1=8407$	$\log P_2/P_1=3.92$	
Second pair=ADS 11060 C:		$V=9.0$	$P_3=25^d76$	$e=0.57$
Sp=K7 V+K7 V	$\mathcal{M}=0.7+0.7$			
ADS 11060 AB/C:	$\rho=28''2$	$r=1180$ AU		$P_4=(20,000$ yr)
$r_4/a_2=117$	$P_4/P_2=(1000)$	$\log P_4/P_2=(3.0)$		

References: Batten et al. (1979); Abt (1986); Bruton et al. (1989); Fekel (1991).

Note: This is a complex hierarchical quintuple system. The distant visual component is now proven to be a spectroscopic

binary, and it seems definitely to be physically associated with the triple system which includes the eclipsing pair. The eclipsing pair in this system is chromospherically active. This triple system shows the highest degree of orbital eccentricity found in any of the systems surveyed in this paper.

V505 Sgr=HD 187949 195306–1436

V (of system) = 6.46			
Eclipsing pair:	$P_1 = 1^d 183$	$e = 0.00$	$i = 80.5^\circ$
Sp = A2 V + G5 IV	$\mathcal{M} = 2.20 + 1.15$		
Third component:	$\rho = 0''.29$	$r = 37$ AU	$d = 128$ pc
$P_2 = (105$ yr)	Sp = F7 V	$\mathcal{M} = (1.2)$	
$r/a_1 = (1150)$	$P_2/P_1 = (32,400)$	$\log P_2/P_1 = (4.51)$	

References: McAlister et al. (1987); Khalessah and Hill (1991); Tomkin (1992).

Note: The paper by McAlister et al. overestimates the luminosity and hence the distance of V 505 Sgr. An estimated distance of 128 pc (instead of 200 pc as given by McAlister et al.) results in a period of about 105 yr instead of 310 yr as reported by the latter group.

VW Cep=HD 197433 203734+7532

V (of system) = 7.23			
Eclipsing pair:	$P_1 = 0^d 2783$	$e = 0.00$	$i = 60^\circ$
Sp = G8 V + K0 V	$\mathcal{M} = 0.90 + 0.25$		
Third component:	$a'' = 0''.51$	$a = 12.4$ AU	$d = 24$ pc
$P_2 = 30.4$ yr	$e = 0.60$	$i = 29^\circ$	$\phi = 31^\circ$
Sp = K0 V	$\mathcal{M} = 0.6$		
$a_2/a_1 = 1304$	$q_2/a_1 = 528$	$P_2/P_1 = 39,900$	$\log P_2/P_1 = 4.60$

References: Hershey (1975); Hill (1989).

EE Peg=HD 206155 213903+0905

V (of system) = 6.93					
Eclipsing pair:	$P_1 = 2^d 628$	$e = 0.00$	$i = 88.6^\circ$	Sp = A3m V + F5 V	$\mathcal{M} = 2.15 + 1.33$
Third component:	$a'' = 0''.029$	$a = 4.0$ AU	$d = 140$ pc	$P_2 = 4.008$ yr	
$e = 0.52$	$i \geq 28^\circ$	Sp = (K5 V)	$\mathcal{M} = (0.5)$		
$a_2/a_1 = (71)$		$q_2/a_1 = (34)$	$P_2/P_1 = 557$	$\log P_2/P_1 = 2.75$	

References: Lacy and Popper (1984); McAlister and Hartkopf (1988).

Note: The latter investigators found a component with a separation of $0''.258$ from this binary. It is likely that this is a fourth member of this system. With this separation, $r = 35$ AU and $P \sim 110$ yr.

AH Cep=HD 216014 224709+6458

V (of system) = 6.78					
Eclipsing pair:	$P_1 = 1^d 775$	$e = 0.00$	$i = 68^\circ$		
Sp = B0.5 V + B0.5 V	$\mathcal{M} = 17.7 + 15.6$				
Third component:	$a'' = 0''.08$	$a = 56$ AU	$d = 750$ pc		
$P_2 = 62.9$ yr	$e = 0.46$	$i = ?$	$L_3 = 0.043$	$\mathcal{M} = (9.4)$	
$a_2/a_1 = 609$	$q_2/a_1 = 329$	$P_2/P_1 = 12,940$		$\log P_2/P_1 = 4.112$	

Reference: Drechsel et al. (1989).

Note: The presence of a third body in this system is supported both by the need for a third light in the photometric solution and a sinusoidal variation in the O–C curve which is presumably due to the light-time effect of a third component.

In wide visual pairs there is the likelihood that the system in question may be only an optical pair. Photometric, spectroscopic, and astrometric data are necessary to confirm if such double star systems are indeed physical. Although U Cephei [V(max) = 6.8, B7 V] has an 11^m2 companion 14'' distant, the latter star has a spectral class of G8 III, and thus it cannot possibly be physically associated with U Cep. In general, systems in which the companion star has $\rho \geq 20''$ are not considered in this survey. This consideration may exclude a few physical systems, but without data other than ρ'' and Δm , it is probably justified in most cases.

Aitken (1932) used a series of limits for considering double stars, and it is worthwhile to review his criteria:

$m=4.0$	$\rho=100''$	$m=10.0$	$\rho=6''$
6.0	40''	12.0	2".5
8.0	16''	14.0	1''

In this case m refers to the visual magnitude of the brighter component. Such criteria are probably too liberal on the bright side, but too conservative on the faint side for determining whether or not a given pair of stars constitutes a physical binary system. Great attention, of course, should be paid to the spectral classes and absolute magnitudes of the stars if these are known.

In a few cases very wide pairs are known to have common proper motions and thus can be regarded as multiple systems. W Ursae Majoris, the prototype of that group of stars, has an optical "companion" at $\rho=7''$ but a common-proper-motion companion at $\rho=270''$ (Rucinski and Kaluzny 1982). At an assumed distance of 50 parsecs, this is equivalent to a minimum separation of 17,000 AU. Other probable wide pairs involving stars of the W UMa-type are CC Comae ($P=0^d2207$, $\rho=63''$) and AW UMa ($P=0^d4387$, $\rho=67''$). In both cases minimum separations of about 5000 AU are implied.

Although photometric data by themselves usually cannot prove conclusively that the components of a double star constitute a physical system, they may be able to differentiate between a system which is optical only and one which is most likely a physical system. Hall and Weedman (1971) presented photometric data on 19 eclipsing binary systems that have one or more visual companions. These authors examined only systems in which the angular separation is $5''$ or greater. In some cases, such as that of V342 Aquilae, the *UBV* data which they present clearly rule out the possibility of a physical system, but in several other instances the likelihood of a physical system is very much greater.

In Table 1 some additional eclipsing binary systems are listed which have a high likelihood of being physical systems. These data are taken from Proust et al. (1981), but in one case the angular distance is that given by McAlister et al. (1988). This is marked by an asterisk. None of these systems have orbits which are known at present, but speckle interferometry observations should reveal the nature of the orbit of QS Aquilae within a few years. It is already established that the eccentricity of the orbit of the third component of this system is quite high. QS Aquilae will doubtless prove to be a very interesting system, but much still remains to be known about it. Substantial orbital motion has also been observed in RW Tau.

4. SUMMARY AND CONCLUSIONS

In this paper about 80 eclipsing binaries that are components of multiple-star systems have been considered. Orbits for the third components of these systems have been determined for only a relatively small number of cases, and all of these that have been published to date are presented in Sec. 3 of this paper.

This sample of eclipsing binaries in multiple-star systems represents less than 2% of all known eclipsing binary systems. Undoubtedly the fraction of eclipsing binaries which are members of multiple-star systems is much higher than this, and such a conclusion is implied in the data given by Walker (1977). Most of the stars which have been discussed are fairly well observed systems, and nearly all are brighter than 10th magnitude. This cannot be said for the majority of the known eclipsing binary systems. Although numerous systems have been very thoroughly studied, often both by photometric and spectroscopic means, a survey of the finding list of Wood et al. (1980) reveals that for a great many systems a few photographic observations from survey plates together with a crude ephemeris are the only available data. Many of these systems may also have physical companions, but they are too poorly known at present for this to be established.

Although most types of eclipsing binaries are included in this survey, by no means are the ones in multiple-star systems evenly distributed among the various classes of eclipsing binaries. The two groups most conspicuous by their rarity are the cataclysmic binaries and the RS CVn stars. The latter group contains many bright and well observed systems, yet only one of these, WW Dra, is confirmed to be a triple star. V711 Tauri, a very well-known member of this group, has a visual companion at $\rho=8''$, which at its estimated distance of 31 parsec is equivalent to a projected distance of about 250 AU. But the interacting pair in this system has an orbital inclination of only about 33° , and thus it does not display eclipses (Fekel 1983). Two of the other systems reviewed in this survey, V772 Her and HR 6469, also have components with active chromospheres. For cataclysmic binaries the situation seems much more restrictive, although more selection factors may be at work here. At minimum light cataclysmic variables are always very faint, and they are generally of low luminosity. A companion to a cataclysmic variable would easily escape detection unless it were very close by. Any star more than a few arcseconds away from a cataclysmic binary would normally be assumed to be only a field star.

Strassmeier et al. (1988) have given a detailed survey of the binary stars known to have active chromospheres. These included not only the RS CVn binaries, but also the BY Dra variables and a number of other binaries known to have active chromospheres. Of the 168 stars which they survey about 10% appear to be in multiple-star systems. Two of these, WW Dra and V772 Her, are eclipsing binaries which have already been discussed in some detail in this paper. HR 6469 also contains a chromospherically active component, but it is the third companion rather than the eclipsing pair which shows this activity. The bright eclipsing binary ϵ UMi is also listed in their paper, but in this system the third component is at $\rho=78''$ with $\Delta m=6.8$. It is most unlikely that this is a physical companion. Since the RS CVn stars are detached systems with fairly widely spaced components, the majority of them do not display eclipses. Thus the apparent rarity of eclipsing RS CVn stars in multiple-star systems may not be real.

With the W UMa-type stars the situation is quite dif-

TABLE 1
Additional Eclipsing Binaries with Visual Companions

Name	Position	HD	ADS	P	$m(\max)$	$m(\text{comp})$	ρ''
UU Psc	001459+0849	1061	191	0.842	6.0	7.7	11.6
ζ Phe	010823-5515	6882		1.670	3.9	7.0	6.6
RS Tri	013341+2929		1326	1.909	11.2	11.2	5
X Tri	015924+2748	12211		0.972	8.9	13.7	6.7
BX And	020749+4043	13078	1671	0.610	8.6	10.7	19.6
EX Per	022251+5204			8.476	12.0	12.1	3
ST Per	025849+3908	18541		2.649	9.6	12.1	11.6
IX Per	033347+3157	22124	2622	1.326	6.6	10.6	5.4
RW Tau	040241+2804	25487	2944	2.769	8.0	12.5	1
AG Per	040538+3324	25833	2990	2.029	6.5	9.0	1.0
CD Tau	051619+2007	34335	3866	3.435	7.0	9.5	10.3
FI Ori	062219+1436	256320	5003	8.896	10.8	11.3	0.9
V Pup	075814-4914	65818		1.455	4.7	11.5	6.8
AW Pup	082356-2846			0.681	10.2	12.0	3.9
HP Car	101852-5718	89714		1.600	8.5	10.5	0.4
TX Leo	103400+0845	91636	7837	2.455	5.7	8.7	2.4
AM Leo	110108+1000		8024	0.366	8.2	10.2	11.3
MN Cen	112708-6118	99769		3.489	8.6	10.6	7.2
V 380 Cen	132603-6146	116795		1.087	9.6	14.0	8
EI Lib	153311-2256	138672		1.987	9.5	9.8	9.5
TW Dra	153333+6358	139319	9706	2.807	8.2	9.5	3.4
HH Nor	154201-5147	139966		8.583	10.3	11.4	12.6
SW Oph	161523-0656	146415		2.446	10.6	12.0	2.4
R Ara	163805-5658	149730		4.425	6.0	8.2	3.6
V1647 Sgr	175752-3656	163708		3.283	7.0	9.1	7.2
WX Sgr	175815-1724	163934		2.129	9.6	12.5	0.4
TZ Lyr	181511+4107		11219	0.529	9.4	11.4	2.9
AD Her	184910+2022	319425	11729	9.767	9.6	10.3	4.6
V526 Sgr	190658-3123	177994		1.919	9.7	11.3	9.9
V822 Aql	193014-0209	183794	12538	5.295	6.7	9.9	1.2
QS Aql	194010+1346	185936		2.513	5.9	6.6	*0.17
V346 Aql	200902+1017	191515	13438	1.106	9.0	11.4	2.5
V382 Cyg	201802+3617	228854		1.886	9.0	11.4	11.4
V478 Cyg	201854+3817	193611	13711	2.881	8.9	14.5	3.3
ZZ Cyg	202314+4652			0.629	10.6	11.6	8.5
KZ Pav	205646-7030	199005		0.950	7.8	8.7	7.3
RY Aqr	211910-1053	203069	14862	1.967	8.8	12.2	4.2
RU Ind	214701-5451			35.54	11.3	12.8	2.4
DX Aqr	220226-1658	209278	15562	0.945	6.2	7.4	3.7
ZZ Cep	224423+6802	215661	16252	2.142	9.3	8.8	3.5
SU Aqr	225102-1303	216309	16318	1.045	10.2	10.7	4.6

ferent. In this survey there are 13 members of this group (GZ And, 44i Boo, VW Cep, AA Cet, CC Com, BV Dra, BW Dra, AK Her, XY Leo, AM Leo, HT Vir, AW UMa, and W UMa) which all seem to be confirmed as members of multiple-star systems. Binnendijk (1970) noted that faint visual companions are also observed for ER Ori ($\rho = 13.6$) and for AH Vir ($\rho = 1.3$), but these stars like the close companion of W UMa itself appear to be optical only. Nonetheless, the overall percentage for W UMa stars in multiple systems is fairly high.

At one time it was considered that W UMa-type stars might be the progenitors of the cataclysmic binaries, but this theory now seems largely to have been discarded. Any such theory, however, would have to explain why the W UMa-type stars appear to be quite commonly encountered in multiple-star systems, while for the cataclysmic binaries the situation appears to be just the opposite.

Most common of all among the eclipsing binaries which are in multiple-star systems are those consisting of two

early-type (B5 or earlier) components. More than 25% of the systems mentioned in this survey fall into this class, and nearly all of the triple systems which involve third components in very small orbits (e.g., IU Aur, VV Ori, DM Per, and λ Tau) involve stars of this class.

As might be expected the number of confirmed quadruple systems involving eclipsing binaries is much smaller than is the number of triple-star systems. Eta Orionis, AA Ceti + ADS 1581 B, BV + BW Draconis, QZ Carinae, XY Leonis, and NO Puppis certainly fall into this class, and EE Pegasi also appears to be quadruple. HR 3337 is at least quadruple, and it may be quintuple. The same may be said for GZ And and for DN UMa. V772 Herculis now seems to be a confirmed quintuple. Castor is a very rare example of a sextuple star. Quadruple stars most often consist of two close pairs of stars separated by a large distance (hierarchy 2), and several of the examples mentioned above fall into this class. If HR 3337 is quadruple rather than quintuple, it would definitely also be of this

type. Less common are the quadruples of hierarchy 3, of which η Ori is a prime example. It is characterized by radically different periods of 8 days, 9 years, and about 2,300 yr. GZ Andromedae represents the rare appearance of a W UMa-type system in what can probably best be described as a very compact star cluster. The Trapezium in Orion is sometimes described as a quadruple (or sextuple) star, but as has already been noted, it is actually the center of a fairly sizeable star cluster. Nevertheless, it does contain two eclipsing binaries, BM Ori and V1016 Ori, the latter only recently discovered and still imperfectly known.

Batten (1973) has reviewed the frequencies of various types of multiple stars. Although different researchers have come to varying conclusions as to the frequencies of multiple star systems, it is felt that about 20%–30% of all binary stars should be at least triple, and of these about 20%–30% should be quadruple, etc. In this survey it has been found that about 15 out of the 80 systems reviewed probably have 4 or more components. Of these, five most likely have five or more components, and of these only one (Castor) has six components. Expressed as percentages, these rates are 19%, 33%, and 20%, respectively. Although the proportion of eclipsing binaries having third companions is almost certainly higher than 1 in 50, it seems that the numbers of quadruple and quintuple systems relative to those of lower order systems is about what one should expect given the small size of the sample. There seems little doubt, however, that cataclysmic variables are only infrequently associated with companion stars, and more work will be needed to determine why this is the case.

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