DOUBLE STARS: THE CLOSEST AND THE MOST DISTANT SYSTEMS.

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Review and comments on two extremely different samples of binary and multiple stars: systems within 10 parsecs of the sun and systems discovered in galaxies of the Local Group.

1. BINARIES AMONG NEARBY STARS ($r \leq 10$ pc)

Binary and multiple stars within 10 pc - there are 49 binaries and 17 multiple systems known to this limit - furnish us with unique information about multiplicity among the low luminosity, least massive stars, mainly late main-sequence objects and degenerate dwarfs. Systems with $\pi \geq 0\overset{''}{.}100$ are listed in a review article by Worley (1968) and, with a few variants, in the forthcoming new edition of Vol. 6 of the Landolt-Börnstein Tables (H. H. Voigt, editor; see section 6.1.0.5). The latter list is based primarily on the Royal Greenwich Observatory Catalogue (1970) and Gliese's catalogue (1969) of nearby stars. Not always is the recognition of duplicity definitive: in one case, all the published information is a laconic note "SB" in Wilson's radial velocity catalogue, in another, an astrometric orbit was published in 1968 but the solution did not appear in a recent review of the topic by the same author. There can be, of course, no serious question about the duplicity of most stars in these lists; orbits have been calculated for just about half of the systems.

The sample is certainly not complete, as can be judged from the following tabulation - the three zones have equal volumes.

	0 - 6.6 pc	6.6 - 8.3 pc	8.3 - 9.5 pc
Singles (incl. sun)	47	27	32
Doubles	22(44)	11(22)	9(18)
Multiples	7(23)	6(19)	1(3)

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The multiplicity of the components indicated in the first two zones is 60 percent. The third zone is clearly affected by the additional incompleteness of the double star discoveries.

Among the nearby double stars, the great majority are the visual pairs: 41 systems, if we count the astrometric binaries, too. There are 7 spectroscopic binaries and one cpm pair (Gliese 49,51); in this system the projected distance between the components is 5900 AU. Due to the meagerness of the sample, obtaining a distribution function for the periods or major axes is not very promising. The relatively large number of separations between 100 AU and 1000 AU, nearly 25%, would make the semi-logarithmic distribution N - log a almost a constant with a flat maximum around the bin a = 4 to 8 AU. The resulting periods, about 10 to 25 years, correspond roughly to the "peak" in Abt and Levy's frequency curve for solar type stars, see Abt (1979), Fig. 6.

This sample is, however, entirely different, here the dM-stars dominate. The spectral types of the primaries are distributed as follows:

A-F : 2, G-K : 13, M0-M7 : 26.

A quirk of the spectral distribution makes the dM4 components particularly frequent, 14 out of the 26 M-type primaries - a fluctuation or perhaps a classification bias? Also, probably just a fluctuation in the very small sample but worth mentioning: the solar type stars (F6-G5) show the lowest binary frequency, 4 doubles against 11 singles.

We found 5 white dwarf components in the list of doubles, roughly 10 percent. A particularly important feature of the 10 pc survey is the comparatively high frequency of astrometric binaries and "unseen companions". A somewhat more extensive statistics by van de Kamp (1976) tentatively ascribes these objects the respectable number density of $0.21 \pm 0.06\ \mathrm{pc}^{-3}$. A detailed discussion of individual cases has also been given by him in 1975; in a few cases, however, there is no complete agreement, see for instance Heintz (1978). Several of these companions seem to have masses in the range 0.01-0.06 $M_\odot$ and at least some of them are well below Kumar's mass limit for main-sequence evolution. They are probably not "planets" and thus we recognize a new class of astronomical objects, nearly impossible to detect but being a component in binary systems. Their integral properties are easy to guess at: essentially cold hydrogen-helium configurations, 10 to 40 times more massive than Jupiter, sizes perhaps that of Uranus or Neptune, mean densities 500-600 gcm^{-3}. Structure and evolution of these bodies are, on the other hand, problems not yet considered.

Finally, how close to each other are the components of the closest binaries in this sample of nearby stars? Six pairs may have semi-major axes under 1 AU, five spectroscopic binaries and the astrometric pair

G24-16; in some cases the size of the orbit has to be estimated from the dispersion of the observed radial velocities. Even these pairs are not actually close binary systems, in terms of interaction between the components. An exception is perhaps Gliese 268, a dM5e star with a radial velocity range of 110 kms^{-1}! Checking this number and calculating an orbit would certainly be a rewarding task; the period can hardly be longer than 1-2 days, the mean distance between the components of the order of 1 to 2 x 10^6 km. Due to the smallness of the radii of late M-type or degenerate components, eclipses would still have a very low probability and no ellipticity effects are expected (although the star is suspected variable).

Given this distribution of the separations, it is not surprising that no eclipsing system has been discovered within 10 pc. (In the distance range 10 pc to 20 pc we do find a few very interesting objects: i Boo, CM Dra, YY Gem.) However small this sample of very late type dwarfs may be, it supports through the complete absence of contact type binaries the existence of a remarkably sharp cut-off for W UMa type systems at the spectral type K5.

The nearest multiple stars comprise 14 triplets, 2 quadruplets and 1 quintuple system. All combinations except eclipsing systems, are represented: visual, spectroscopic and astrometric binaries as well as cpm pairs. Some of these multiples are among the best known stellar objects, such as α Cen AB + Proxima, 40 Eri with its white dwarf component, the 61 Cyg system - although here the astrometric duplicity needs further confirmation. The highest multiplicity is that of the visual triple Gliese 644 having common proper motion with Gliese 643 which itself is a spectroscopic binary.

2. BINARY SYSTEMS IN NEARBY GALAXIES ($r < 10^6$ pc)

The sample of nearby binaries was dominated by visual pairs of low luminosity stars. In the galaxies of the Local Group we have, of course, no choice of discovering visual double stars and the objects we can reach the easiest way are all massive, high luminosity eclipsing systems; we can, in fact, select the very brightest systems in a galaxy. Spectroscopic studies may help, at the limits of our present observational techniques, in the case of LMC or SMC objects, but our best - and, for a long time, only - method of detection is the search for eclipses.

Nevertheless, there are improvements in our techniques of binary detection. The appearance of novae in a system indicates the presence of cataclysmic binaries, a well defined type of evolved, interacting system. And in recent years we were able to identify the majority of X-ray sources, well observable in nearby galaxies, with interacting binaries having as one component a compact object.

Five galaxies have been searched extensively for variable stars, among them eclipsing variables. Work on M31, M33 and the dwarf spheroidal system in Draco was done almost exclusively at the observatories on Mt. Wilson and Palomar Mountain; for the Magellanic Clouds, most of the early discoveries were made at the Southern station of the Harvard Observatory.

In the Clouds, almost 80 eclipsing systems have been recognized; recent lists of them were given by Payne-Gaposchkin and Gaposchkin (1966) and by Hodge and Wright (1967,1977). Although typical (evolved) Algol systems with B-type primaries are within easy reach of the surveys, they seem to represent only about 20% of the observed light curves; most systems have been classified as "β Lyrae type" - some of them may also represent semi-detached systems after the first phase of mass exchange. The brightest system has its M_{pg} close to -5, the light curve is shown in Fig. 1 (P = 4.34 days). Most systems have M_{pg} between -2 and -3.

The Clouds contain 7 or 8 X-ray sources, two of them identified with massive, early type spectroscopic systems (SMC X-1, LMC X-4). The absolute X-ray luminosities of the Magellanic Cloud sources are quite well determined; SMC X-1 and LMC X-4 are the two brightest sources known, close to $10^{39} ergs^{-1}$, Eddington's limit.

Another comparatively near system, the dwarf spheroidal in Draco, offers a striking contrast in its type and population as well, concerning binaries. No eclipsing systems have been found, in spite of a careful search of the central region (Baade, Swope 1961). The complete absence of giant binary systems corresponds exactly with what we find in globular clusters, representing a very similar stellar population.

In M33, there is only one known variable which "appears to be an eclipsing star", at about $m_{pg} \sim 19$ (Hubble 1926). This seems rather surprising since in this Sc spiral one would expect bright eclipsing

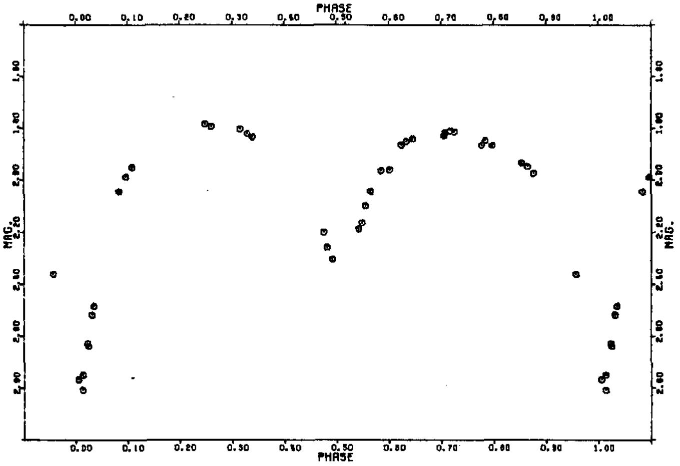

Fig. 1. Photoelectric U light curve of H.V. 2241 (in the LMC). Observations by Herczeg, ESO 1 m telescope.

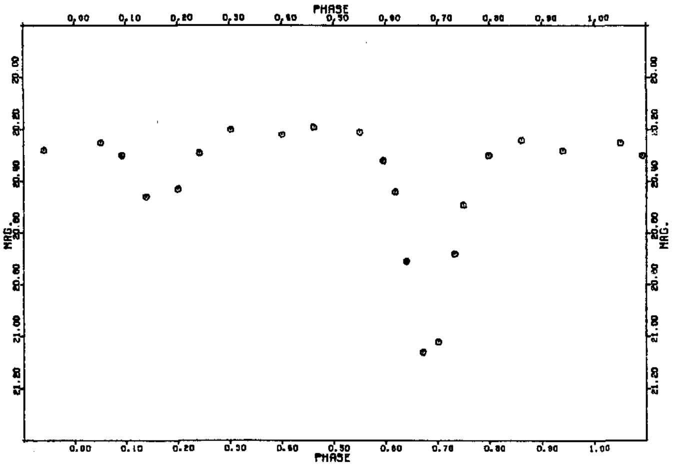

Fig. 2. Photographic light curve of "star G" (no. 75a in Field II). Gaposchkin, AJ 67, 358 (1962).

systems in numbers comparable to those in the Magellanic Clouds. A recent survey (van den Bergh et al. 1975) found no binaries among 38 new variables. However, this search was based on 67 Palomar Schmidt plates taken over an interval of nearly nine years, clearly not favorable to the discovery of variable objects with 5-15 days periods, as massive binary systems frequently have. Another problem is that the limiting magnitudes of the 48 in. Schmidt ($B \sim 20$, $V \sim 21$) exclude the bulk of bright eclipsing systems which would, at the distance modulus of 24.6, show up just beyond these limits. A "denser" and somewhat deeper survey is required to find these binaries.

The Andromeda galaxy offers the most interesting picture and the richest harvest as far as binaries go. Novae are observed by the hundreds in this galaxy, ever since Hubble's early investigations. A systematic search to detect variable stars was started by Baade using the 200-inch Hale telescope, and carried out by him, Miss Swope and Gaposchkin (see references 1963-1965). The search covered only a fraction of the area of M31, four circular fields of 15' diameter but even this limited program revealed almost as many eclipsing binaries as we know in the Magellanic Clouds.

Baade selected four fields south preceding the nucleus. Data of the fields and number of variables discovered is given below.

Field	Dist. from nucleus	Description	Variables	Eclipsing	Author
I	15'	Edge of main body	109	2	B,S
II	35'	"Mixed",between arms	223	9(+10ecl?)	G
III	50'	Rich spiral arm	334	36	B,S
IV	96'	Faint arm, 20 kpc	54	10	B,S

Most eclipsing systems are noted as "blue". Periods are given for 34 stars; β Lyrae type light curves dominate, except in Field III. The periods range from 2.3 days to about 960 days, but the range 4 to 10 days contains most of them. A well observed light curve is reproduced in Fig. 2 (P = $4\overset{d}{.}805$). The brightest system is V60 in Field III, in maximum m(pg) ∿ 18.9. The light curve resembles that of a massive contact system (P = 7.33 days), suggesting a young object.

The low frequency of massive binaries in Field I is puzzling. This field is in the main body of M31 but well outside the nuclear region. On Baade's identification figure much structure and dust lanes are clearly visible. This is the region, however, where in the spectrum of the galaxy, features of an earlier F-type spectrum fade out and features of the late giant spectrum become dominant: there is a change in the stellar population. This may have some importance for the binary counts. Numerous novae in this field (Baade found seven) suggest that evolved binary systems of lower mass and luminosity may be frequent.

A comparison of these systems with galactic objects is not quite trivial since we may not know the brightest eclipsing systems in our galaxy. We know however several massive systems of early spectral type and presumably very high luminosity; the light curves are mostly of "β Lyrae type". To mention a few: UW CMa, AO Cas, V380 Cyg, V382 Cyg, V Pup, V453 Sco, RY Scu, possibly β Lyrae itself. Transferred to M31, these systems would appear very much like one or other star in Baade's list.

Our knowledge of massive, luminous binary systems in M31 widened dramatically with the X-ray observations of HEAO 2 (Einstein Observatory), as reported in the memorable Nov. 15, 1979, issue of Astrophys. J. Letters (van Speybroeck et al.) While M31 was just a diffuse source for UHURU, now 69 sources have been found in it, one possibly coincident with the nucleus, 7 in globular clusters, 8 further cluster "candidates", 17 rather strongly concentrated in the inner bulge and 36 Population I sources distributed over the spiral arms. These latter sources almost certainly combine a massive early primary with a compact secondary, of the type of Cen X-3 in our galaxy or SMC X-1 in the Small Cloud. We may assume that the bulge-type sources are also binaries, as indirect evidence strongly suggests in the galaxy. Unlike the eclipsing systems in the M31 fields, representing but a small fraction of all objects of the kind, the census of the X-ray sources is nearly complete to the sensitivity limit.

The authors point out that M31 and the galaxy show some conspicuous systematic differences in their "X-ray population". This may be compared to systematic differences between the galactic X-ray sources and those in the Magellanic Clouds, recognized earlier (Clark et al. 1978).

Massive X-ray binaries do not show conspicuous light variations, and any correlation between Baade's lists and the HEAO 2 observations is unlikely. A comparison is further hindered by the circumstance that the X-ray observations neglected the outer regions of the south precedent half of M31 and only Field I was covered in both programs.

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