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THE GALACTIC SPACE FREQUENCY OF CLOSE BINARY SYSTEMS

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ABSTRACT

An investigation of the galactic space frequency of close binary systems and other stars with high angular momentum is made on the basis of several criteria for the binary nature of a star. Within an accessible range of 3 kpc around the Sun, which includes parts of three spiral arms, there occurs no significant variation (to within a factor of about 2) in the space frequencies of B-type radial-velocity variables, M-type supergiants with blue companions, and Be stars. Implications of this result for the problems of the origin of close binary systems, the distribution of angular momentum in the Galaxy, and the relative numbers of blue and red supergiants are discussed.

Subject headings: binaries — galactic structure — stellar statistics

I. INTRODUCTION

A knowledge of how the frequency of close binary systems varies with distance from the galactic center is of interest in problems concerned with the origin of binary systems, the distribution of angular momentum in the Galaxy, and the observed frequencies of various other classes of stars. The many published statistical studies of binary stars (see, e.g., Heintz 1969) have concentrated heavily on objects in the solar neighborhood. Since only luminous objects can be seen to a great distance within the Galaxy, the present attempt to derive the galactic space frequency is necessarily restricted to supergiants and early-type stars.

II. CRITERIA FOR BINARY NATURE

Various criteria for identifying the binary nature of early-type stars are discussed below. It will be convenient to discuss the binary frequency as a function of galactocentric distance R (where the Sun's position is taken to be $R = 10$ kpc). In the distance range accessible to study, $R = 7$–13 kpc, lie three spiral arms: the Sagittarius, Local, and Perseus arms (Kerr and Westerhout 1965). These arms describe, in the vicinity of the Sun, roughly circular arcs around the galactic center, and are located at galactocentric distances of $R = 8$, 10, and 12 kpc, respectively. For convenience, circular bands with a thickness of 2 kpc will be used to represent the arms. However, the most recent work indicates that our simple picture of the spiral arm pattern is fairly crude; the Carina-Centaurus feature is possibly an extension of the Sagittarius arm, rather than of the Local arm, which itself may be only a spur of the Sagittarius arm.

In order to find the dependence of binary frequency on location *along* the arms, three circular sectors will be defined in the galactic plane, as follows. Define the angle between the projected galactocentric radius vectors of the Sun and any star to be θ, increasing in the direction of galactic rotation. Then, over the distance range accessible to study, the three sectors are $\theta = -18°$ to $-6°$ (outer parts of the arms), $-6°$ to $+6°$ (middle parts), and $+6°$ to $+18°$ (inner parts).

a) Eclipsing and Spectroscopic Binaries

Periodic visual and spectroscopic variations, which can be clearly ascribed to the effects of orbital motion, provide the most solid information about the binary nature

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of a star. But binary systems for which good information (Batten 1967) or merely definite identification (Kukarkin *et al.* 1969) is available are relatively few in number, are usually close to the Sun, and are often discovered or investigated as a result of highly selective surveys. An attempt here to use systems with known orbits (those of § II*b*) in determining the galactic binary frequency was unsuccessful.

b) *Stars with Variable Radial Velocity*

Variability of radial velocity occurs frequently among early-type stars, and is usually interpreted as being due to orbital motion, although occasionally it may be due to atmospheric pulsation, turbulence, or mass loss, especially in supergiants (Abt 1957). Detailed examination of the statistics and character of the variability in early-type main-sequence stars has led to the discovery that about 50 percent of all early-type stars in the solar neighborhood are double (Petrie 1960; Jaschek and Gomez 1970).

The most extensive published catalog of early-type stars is that of Rubin *et al.* (1962), which includes spectroscopic and positional data for 1440 O–B5 stars within about 3 kpc of the Sun. Of the B0–B5 stars with luminosity classes III, IV, and V, only objects which are listed in the radial-velocity catalog of Abt and Biggs (1972) will be used here. A star will be considered to be double if an orbit is known, if the radial velocity is variable, or if double or triple lines appear. Seventy-nine percent of the stars thus classified as binaries have been classified on the basis of variable radial velocity.

Results for the binary frequency variation are shown in table 1. If the stars are grouped into smaller spectral intervals, essentially the same results emerge.

c) *Red Supergiants with Blue Companions*

Late-type supergiants that show anomalously blue colors or spectra with hot and cool components usually have early-type stellar companions. The frequency of binaries among late-type supergiants has been estimated by this method to be 10 to 25 percent (Stothers and Lloyd Evans 1970). The distribution of late-type supergiants over the nearest spiral arms has already been determined (Bidelman 1958; Lee 1970), and these supergiants are often members of clusters and associations (Stothers 1972*a*).

Sufficient data to study the galactic radial variation exist only for the M-type supergiants. Northern M supergiants are listed by Lee (1970), except for those in Perseus for which the list of Johnson and Mendoza (1966) may be used, while southern M supergiants in Carina are listed by Humphreys, Strecker, and Ney (1972). Results for the binary frequency variation are given in table 1.

TABLE 1

RATIO OF THE NUMBER OF BINARY-RELATED OBJECTS TO THE TOTAL NUMBER OF OBJECTS IN THE SAMPLE GROUP*

	Velocity Variable B0–B5 III, IV, V	Be B0–B5 III, IV, V	M + OB M0–M5 I
R = 7–9 kpc	0.12 ± 0.04 (59)	0.28 ± 0.07 (61)	0.25 ± 0.18 (8)
R = 9–11 kpc	0.38 ± 0.03 (358)	0.14 ± 0.02 (372)	0.22 ± 0.07 (49)
R = 11–13 kpc	0.35 ± 0.09 (40)	0.22 ± 0.07 (50)	0.14 ± 0.06 (44)
$\theta = -18°$ to $-6°$	0.08 ± 0.04 (48)	0.31 ± 0.08 (49)	0.23 ± 0.10 (22)
$\theta = -6°$ to $+6°$	0.39 ± 0.03 (359)	0.16 ± 0.02 (378)	0.28 ± 0.12 (18)
$\theta = +6°$ to $+18°$	0.25 ± 0.08 (40)	0.07 ± 0.04 (46)	0.15 ± 0.06 (46)

* The statistical error of the number n of binary-related objects is assumed to be $n^{1/2}$. The total number of objects in the sample group is listed in parentheses.

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d) *Wolf-Rayet Stars, Helium Stars, and X-ray Sources*

A number of unusual stellar objects have sometimes been suggested as being in binary systems. These comprise Wolf-Rayet stars (Smith 1968), helium stars (Hack 1967; Dinger 1970), and galactic X-ray point sources (Giacconi *et al.* 1972). However, they are relatively rare, their distances are uncertain, their population memberships are occasionally unclear, and not all of them are certain to be in binary systems.

e) *B-type Emission-Line Stars*

The observed rotational velocities of members of close binary systems are, on the average, lower than those of field stars of the same spectral type (Koch, Olson, and Yoss 1965); but the statistical spread of $v \sin i$ is large, the inclination effect is important, and few rotational velocities are available for distant stars (Boyarchuk and Kopylov 1964; Bernacca and Perinotto 1970, 1971; Uesugi and Fukuda 1970).

Be stars, on the other hand, are usually interpreted as being extremely fast rotators, spinning at or near breakup velocity at the equator, except in the case of supergiants, whose emission lines are associated with entirely different mass-loss processes. The high rotational velocities of classical Be stars seem to imply nonmembership in a close binary system, and in fact few are actually known to be binaries (Wackerling 1970). However, some peculiar Be stars are definite members of close binary systems, and are usually interpreted as swiftly rotating objects that have gained mass and angular momentum as a result of a mass transfer from their stellar companions (for example, in β Lyrae). The number of such objects seems to be relatively small, however. The Be phenomenon will therefore be used here, tentatively, as a statistical criterion for single stars. Whether or not the frequency of Be stars is actually a reliable complementary measure of the frequency of close binary systems, it is certainly indicative of high angular momentum, just as is the frequency of close binary systems. In the Galaxy, the spiral-arm patterns of Be stars are already known (Schmidt-Kaler 1964), and many of these stars belong to clusters and associations (Jaschek, Ferrer, and Jaschek 1971).

The OB star catalog of Rubin *et al.* (1962) can be used to select Be stars from the B0–B5 stars with luminosity classes III, IV, and V. More complete catalogs of Be stars have been published, but, because greater completeness in the needed survey of ordinary B stars does not exist, we have settled on the designations in the Rubin catalog. A check on our derived binary frequencies is provided by statistical data for 124 bright B2–B5 III, IV, and V stars used by Hardorp and Strittmatter (1970), who found that about 10 percent of the stars are emission-line and shell stars. (Shell characteristics may or may not be a rotational indicator and/or a binary indicator.) A similar percentage for emission-line stars has been derived by Merrill and Burwell (1933). The galactic space frequency of Be stars is shown in table 1; the trends are found to be the same if the stars are grouped into smaller spectral intervals. Since Be stars are brighter by several tenths of a magnitude than ordinary B stars of the same MK classification group and so are seen to a greater distance for a given limiting apparent magnitude, the galactic radial variation was redetermined by using a smaller cutoff distance of 2 kpc around the Sun; but the same trend emerged as that given in table 1.

III. CONCLUSION

According to table 1, the data for B velocity variables and Be stars suggest that, over the galactocentric distance range $R = 7$–13 kpc (which includes three spiral arms), the frequency of close binary systems decreases slightly with decreasing galactocentric distance and with increasing distance outward along the spiral arms. (Division of the data into individual spiral arms yields the same trends.)

However, these gradients need further confirmation, for the following reasons.

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First, in the case of the Be stars, the listed frequencies are all within 2 or 3 standard deviations of each other. Second, galactic regions *exterior* to the Sun's position do not show any significant gradient in the frequency of B velocity variables. This may imply that the number of radial-velocity measurements of B stars in *inner* galactic regions has been insufficient to establish variability in many cases; such a possibility is likely because most of the stars in question are southern stars. Third, no significant galactic variation appears in the frequency of spectroscopic binaries among the M supergiants. Of course, it is possible that these binaries, which are relatively wide systems (orbital periods of years) compared with the B-type spectroscopic binaries (orbital periods of days), have originated in a manner different from that for the very close binaries (see van Albada 1968). For the present, all we can conclude is that the smoothed space frequency of close binary systems probably varies by less than a factor of 2 within 3 kpc around the Sun.

It is well known that the angular velocity of galactic rotation drops off with increasing distance from the central galactic bulge (and the angular momentum per unit mass increases), but this is evidently not reflected in a strongly varying space frequency of close binary systems or of fast rotators. The reason may be that, per unit mass, the galactic angular momentum exceeds the stellar rotational and orbital angular momenta by several orders of magnitude. This suggests the importance of local turbulence of the interstellar medium in determining the angular momentum acquired by a protostar. At least in the solar neighborhood, turbulence appears to be more or less isotropic, as is evidenced by the randomness of orientation of the orbital planes of nearby binary systems (Heintz 1969). Another possible mechanism is stellar encounters (van Albada 1968; Havnes 1968).

The lack of a significant galactic radial variation in the frequency of close binary systems apparently rules out one possible explanation of the sharp variation observed in the ratio of the numbers of blue and red supergiants (Hartwick 1970; Stothers 1972*b*). For, if close binary systems were more frequent toward the galactic center, then fewer stars in that direction could evolve into the dimensions of a red supergiant, thus possibly explaining the relative deficiency of red supergiants as compared to blue supergiants at small galactocentric distances. An alternative explanation has been proposed, however, namely, that, on the average, more very young clusters and associations (as dated from the spectral type of the main-sequence turnup) occur toward the galactic center, and younger groups, in general, tend to have fewer red supergiants (Stothers 1972*b*). This increasing youthfulness toward the galactic center seems to be reflected also in the greater frequency of Wolf-Rayet stars, long-period Cepheids, Bok globules, dust, neutral hydrogen clouds, and metallic abundances in stars (Reddish 1967; Smith 1968; Searle 1971).

Of course, very young groups could also have more close binary systems among their most massive members without necessarily contradicting the results of table 1, because the B stars and M supergiants used there are, on the average, of somewhat lower mass than the most massive stars evolving in very young groups. On the other hand, a study of the luminosity function of all the M supergiants known in clusters and associations show that the brighter (more massive) ones are *less* frequently members of binary systems than are the fainter ones (Stothers 1972*a*). This observation probably carries more weight than the seemingly contradictory one of table 1, namely, that Be stars are relatively frequent toward the galactic center; the contradiction arises from the fact that very young clusters and associations have few or no Be stars (e.g., Mendoza 1958) (presumably because partial evolution away from the zero-age main sequence is required in order for a B star to become a Be star). Further work on this problem is clearly called for.

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