2. FORMATION AND EVOLUTION OF STARS IN BINARY SYSTEMS

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NEW OBSERVATIONAL CLUES ON BINARY FORMATION IN THE GALAXY

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ABSTRACT. New observations of binaries are beginning to provide new clues on the formation and evolution of binary and multiple systems in a variety of stellar populations in the Galaxy. New orbital determinations are shedding light on the frequency and orbital characteristics of binaries in the disk and the halo of our Galaxy, both in clusters and the field. These results support the view that the formation of binaries involving solar-mass stars is relatively independent of the stellar environment. Evolutionary effects can have a major influence for close binaries with periods up to at least ten days, with a strong dependence on the age of the population. Progress towards determining the frequency of low-mass companions and planetary systems is promising but still very limited.

1. Introduction

Binaries are everywhere. They occur in every stellar environment in the Galaxy, whether in the field or in clusters, whether in the disk or in the halo. In the field, binaries are common in metal-rich and metal-poor populations alike, and are found among the oldest stars in the Galaxy and among the most recently formed.

To use the observed frequency and orbital characteristics of binaries to learn about their formation, one must take into account changes in these characteristics which may have resulted from evolutionary effects, such as the disruption of wide binaries by stellar encounters, circularization of the orbits and synchronization of the rotation for close binaries by tidal effects, and orbital changes due to mass transfer as one or both members of the binary undergoes stellar evolution. One might hope to avoid many of these evolutionary effects by studying binaries among stars that are just forming onto the main sequence. For the time being this approach is not feasible, because only nine spectroscopic orbits are available for pre-main-sequence stars (Mathieu 1988). Of course, to investigate the effects of metallicity and environment on binary formation, one may not be able to avoid working with samples where evolutionary effects are important.

In this brief introductory review I attempt to mention the areas of

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observational research where new results are having an impact on our views of binary formation in the Galaxy. Many of the new results for spectroscopic binaries have been made possible by the development of new instruments capable of mass-producing accurate radial velocities of faint stars (Philip and Latham 1985). On the astrometric side, the development of speckle interferometry techniques promises to close the classical period gap between spectroscopic and astrometric orbits (McAlister *et al.* 1987).

2. Binaries in the Galactic Disk

2.1. SOLAR-TYPE STARS IN THE FIELD

The frequency and characteristics of solar-type binaries in the disk have been reviewed nicely by Abt (1983). Recently Morbey and Griffin (1987) showed that many of the low-amplitude spectroscopic orbits derived by Abt and Levy (1976) were spurious. However, when 15 binaries were removed from the sample in the period range 0.1 to 10 yr, the incompleteness correction increased in rough compensation, so the overall frequency of binaries remains unchanged, albeit with larger uncertainties in the affected period range (Abt 1987).

2.2. STARS IN OPEN CLUSTERS

The frequency of binaries as a function of period for stars on the main sequence of the Hyades, the best studied open cluster, is indistinguishable from the Abt and Levy (1976) results for field dwarfs (Mathieu *et al.* 1985), supporting the view that the formation of binaries is the same in open clusters as in the field. In the Hyades, all the orbits with periods longer than 5.7 days are eccentric, while those with shorter periods are circular (Mayor and Mermilliod 1984), due to the effects of tidal circularization over the 0.8 Gyr lifetime of the cluster. Discounting this evolutionary effect, there is no evidence that the Hyades binaries were formed with a different distribution of eccentricities than the field binaries.

In the old open cluster M67, the binaries have a spatial distribution that is more concentrated to the center of the cluster than the single stars (Mathieu and Latham 1986). This is thought to be a result of dynamical relaxation of the more massive systems to the center of the cluster, and is not a reflection of the spatial distribution at the time of formation.

3. Binaries in the Galactic Halo

3.1. HALO DWARFS IN THE FIELD

Recent surveys of proper-motion stars have turned up hundreds of new high-velocity low-metallicity dwarfs which belong to a true Galactic halo population but happen to be passing through the local solar neighborhood (*c.f.* Fouts and Sandage 1986, Carney and Latham 1987). The radial velocities of these stars have been monitored for several years, and already dozens of new spectroscopic orbits have been solved (Latham *et al.*

1988). Although this survey for binaries is not yet complete, the preliminary indication is that binaries are just as frequent in the halo as in the disk. All the halo binaries with periods shorter than about 13 days have circular orbits, presumably due to tidal circularization over the lifetime of the Galaxy. For the halo binaries with periods longer than about 13 days, the distribution of orbital eccentricities is indistinguishable from that for the disk binaries. As far as we can tell from these limited results, the formation of binaries was the same in the halo as in the disk. In particular, we have not yet detected any effects of low metal abundances on the formation of binaries.

3.2 HALO GIANTS IN THE FIELD

There are several long-term efforts underway to monitor the radial velocities of halo giants, such as the stars on Bond's (1970, 1980) lists of metal-poor red giants, and the first few orbital solutions should be published soon. One should expect two main evolutionary effects: all binaries with periods less than roughly a year should have circular orbits because the expanded convection zone in the giants make the tidal mechanisms much more efficient; and the shortest period binaries should be removed from the sample as the result of stellar evolution and mass transfer. Otherwise one expects the binary population among the halo giants in the field to be consistent with the binaries among the halo dwarfs, from which the giants must have evolved.

3.3 GIANTS IN GLOBULAR CLUSTERS

Gunn and Griffin (1979) suggested that binaries are underabundant among globular cluster giants, and this impression has been supported by subsequent work. Although searches for spectroscopic binaries in globular clusters are finally uncovering a few candidates (Pryor *et al.* 1988; Pryor *et al.* 1989), so far only one cluster star, a giant in Omega Centauri, has an orbital solution (Mayor 1988). Did main-sequence binaries form much less frequently in globular clusters than in the field, perhaps because of the high-density environment, or have various evolutionary effects and stellar encounters removed the short- and long-period binaries from the observed sample of giants? The resolution of this question may require binary surveys of dwarfs in globular clusters, a rather daunting observational undertaking.

4. Low-Mass Companions

When binaries and multiple systems are formed, how is the available mass divided up among the components? Does the distribution of secondary masses continue right down into the range of planetary companions, or does the formation of a planetary system require a distinctly different process? Tantalizing progress has been made on three observational fronts - photometric, astrometric, and spectroscopic - but so far only the surface has been scratched in this field.

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4.1. PHOTOMETRIC SEARCHES

Searches for the infrared signature of cool low-mass companions are beginning to produce candidates for very low mass stars and even brown dwarfs below the hydrogen-burning limit of 0.08 solar masses (Forrest *et al.* 1988, Zuckerman 1988). These observations are difficult, and some of the announced candidates for brown dwarf companions have not been confirmed, for example VB8B (McCarthy, Probst, and Low 1985; Perrier and Mariotti 1987).

An important result from IRAS has been the detection of far-infrared excesses for dozens of stars (Backman 1988). In a few cases the infrared signal has been spatially resolved, indicating the sources are extended dust clouds, and in at least one case the cloud is flattened as would be expected for a disk geometry seen edge on. In a couple of cases it can be seen that there is an inner gap in the cloud inside a few tens of AU. Is this evidence for the formation of planets in the inner regions of giant dust clouds around these stars?

4.2. ASTROMETRIC ORBITS

Despite many years of hard work, most of the claims for astrometric orbits showing brown dwarf or even planetary companions are marginal at best. However, there are a few cases where the evidence seems reasonably compelling, such as the brown dwarf companion of LHS1047 (Ianna *et al.* 1988).

4.3. SPECTROSCOPIC ORBITS

Spectroscopic searches have the advantage that they are sensitive to close companions with short orbital periods, independent of the distance to the system. The disadvantage is that the viewing angle of a spectroscopic orbit cannot be determined from the radial-velocity data alone, thus introducing a fundamental ambiguity in the interpretation of any single orbital solution. A very low velocity amplitude may simply be the result of the orbit being viewed nearly face on.

Several instruments capable of measuring stellar radial velocities with a precision of about 10 m/s are now in operation. The results from a modest survey of 18 stars at the CFHT suggest that perhaps half of the stars have excess velocity variation that may be due to the presence of low-mass companions of roughly a few Jupiter masses (Campbell 1988). However, in only one case has even a tentative orbit been solved.

Two stars which have been observed intensively for many years because of their use as radial velocity standards have now been shown to have low-amplitude orbits. One of the Griffin standards, HR152, has a companion which would be 30 or 40 Jupiter masses if the orbit (McClure *et al.* 1985) is being viewed edge on, while an IAU standard, HD114762, has a companion that might be as small as 10 Jupiter masses (Latham *et al.* 1989). The orbital period for HD114762 is 84 days, and the primary star is similar to the sun, which would place the companion at the same distance as the orbit of Mercury.

Recently Marcy and Moore (1988) have reported a spectroscopic orbit for the M3 dwarf Gliese 623. They use various approaches to estimate that the companion has about 70 Jupiter masses.

There is some hope that large spectroscopic surveys for monitoring radial velocities will eventually provide some information on the frequency of low-mass companions. However, this approach can only reach the upper range of planetary-sized objects, and can not hope to detect earth-sized planets in reasonable orbits.

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