Multiplicity of Population II stars

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Abstract

We report preliminary results of a multiplicity survey of about 200 known Population II stars that were identified in the HIPPARCOS catalog. This survey will enable us to test the hypothesis if the different initial star formation conditions in the galactic halo compared to the galactic disk might lead to differences in the binary frequency or in the distributions of periods and mass ratios.

1. Introduction

The frequency of binary stars and the distribution of their periods and mass ratios is – along with the Initial Mass Function – one of the key characteristics of the star formation process. Studies of binaries among nearby solar-type main-sequence stars show that about 53 % of the stars are binary or multiple systems (Duquennoy & Mayor 1991). Recent surveys of low-mass pre-main-sequence stars in the star-forming region Taurus-Auriga found a binary frequency of 80 – 100 %, depending on how the extrapolation to unresolved systems is carried out (Leinert et al. 1993; Ghez et al. 1993; Köhler & Leinert 1998). Studies of southern star-forming regions, e.g. Scorpius-Centaurus, give similar results (e.g. Simon et al. 1995; Brandner & Köhler 1998; Köhler et al. 2000).

All these studies dealt with Population I stars that formed within the galactic disk. Population II stars formed in the galactic halo, i.e. in a different environment, and differences in the initial star formation conditions might lead to differences in the binary frequency or the distributions of periods and mass ratios.

2. The Sample

We have identified a list of stars with precise metallicities and radial velocities (Carney et al. 1994; Norris 1986) in the HIPPARCOS catalogue. We then selected about 200 Halo stars, based on their low metallicities ($[m/H] < -1.4$) or kinematical properties (Jahreiss et al. 1997, Fuchs et al. 1999). Their typical distance from the Earth is about 100 pc (see figure 1).

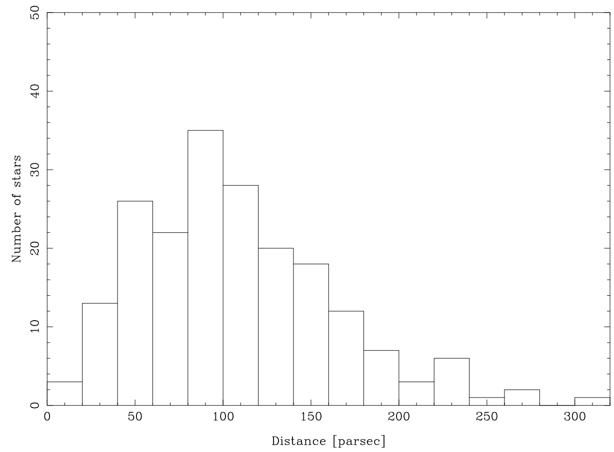

Fig. 1.— Distance distribution of the stars in our sample.

3. Observations and Data Reductions

Based on the results for Population I stars (both main-sequence and pre-main-sequence), we expect the peak of the distribution of binary separations around 30 AU, i.e. 0.3 arcsec. To resolve binary stars with separations of this order, it is necessary to use high-angular-resolution techniques such as speckle interferometry or adaptive optics.

We observed 56 of these stars in November 1997 with the NIR camera MAGIC at the 3.5 m telescope on Calar Alto, 11 additional stars with the SHARP camera at the NTT on La Silla in May 1998, and 7 more stars with OMEGA Cass at the 3.5 m telescope on Calar Alto in February 2000. In all three cases, speckle interferometry in the K band was used. These observations are sensitive to binaries with separations in the range 0.13″ (the diffraction limit of the telescope) and about 3″ (limited by the field of view of the camera). Data reduction was done with the `speckle` program written by one of us (R.K.), which was already used for our surveys of pre-main-sequence stars in Taurus-Auriga and Scorpius-Centaurus (Köhler & Leinert 1998; Köhler et al. 2000). In this program, the modulus of the complex visibility (i.e. the Fourier transform of the object brightness distribution) is determined from power spectrum analysis. The phase is computed using the Knox-Thompson algorithm (Knox & Thompson 1974) and from the bispectrum (Lohmann et al. 1983).

To search for binaries that are separated by more than 3″ we used MAGIC at the 1.23 m and 2.2 m telescopes on Calar Alto for direct imaging in the K band. Some 110 stars have been observed with the 1.23 m telescope in January 1999, and 58 stars with the 2.2 m telescope in June 1999. This data was reduced using the `daophot` package within IRAF.

4. Initial Results

Among the stars observed up to now, we find 23 binaries, 3 triples, and one quadruple, i.e. 32 companion stars. Five stars were discovered by speckle interferometry, 27 by direct imaging.

4.1. Period Distribution

To compare our results to the survey of Population I main-sequence stars by Duquennoy & Mayor (1991), we have to convert the angular separations of our binaries into orbital periods. Since the result of our observations is only the projected angular separation at the date of the observation, it is impossible to compute the orbital period of one given binary. Instead we follow the approach of Leinert et al. (1993) and Köhler & Leinert (1998), who rely on statistical arguments. To convert the angular separation into a linear separation, we make use of the distances measured by HIPPARCOS. The second step is to convert the projected separation into a semi-major axis, taking into account the probability for a binary to be observed in a particular position in its orbit and the inclination of the orbital plane. These two effects lead to a combined reduction factor of 0.95 (see Leinert et al. 1993 for details). Finally, we use Kepler's third law with a system mass of $1\,M_\odot$ to compute the orbital periods.

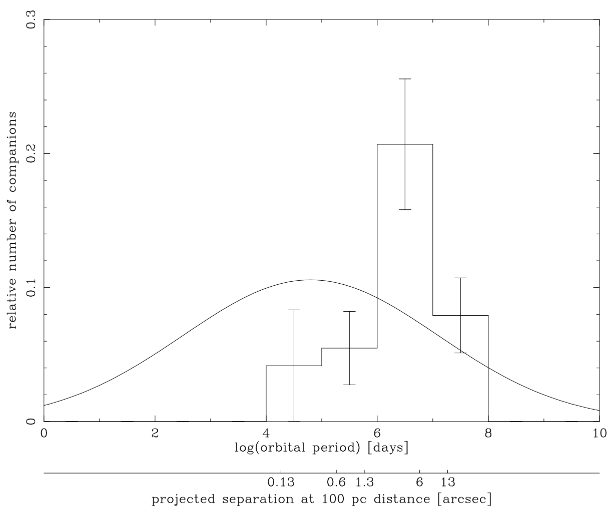

Fig. 2.— The binary period distribution of stars discovered in our survey (histogram) compared to that of Population I main-sequence stars (Gaussian curve, Duquennoy & Mayor 1991). The height of each bin shows the number of companion stars with orbital period in a given interval divided by the total number of systems observed. Therefore, triple systems are represented as two pairs.

Figure 2 shows the period distribution of the companion stars we discovered. According to this preliminary data, the peak of the period distribution of Population II stars is shifted to longer periods with respect to the distribution of Population I stars. This result has to be taken with caution, since only a limited number of stars has been observed with a resolution sufficient to discover binaries with periods shorter than $\approx 10^6$ days, therefore the statistical errors are large.

This shift in the peak of the period distribution is quite surprising, since one would expect that some binaries have been disrupted in stellar encounters when the Halo stars cross the galactic plane. This would preferentially destroy wide binaries and thus shift the peak to smaller separations and periods.

4.2. Mass Ratio Distribution

Another important characteristic of star formation is the distribution of mass ratios of the binary stars. To convert our measured flux ratios into mass ratios, we use the models of Baraffe et al. (1997). A linear fit to their models in the mass range $0.1\ldots0.8\,M_\odot$ gives the relation $M_K = 3.10 - 6.44 \cdot \log(M/M_\odot)$, where M_K is the absolute magnitude in the K band, and M the mass of the star. This can be transformed to $K_1/K_2 = (M_1/M_2)^{2.58}$, where K_1/K_2 is the flux ratio in the K band. We use this relation to convert the measured flux ratios of the binaries in our sample into mass ratios and plot the resulting distribution in figure 3. The mass ratio distribution of Population I stars (Duquennoy & Mayor 1991) is shown for comparison.

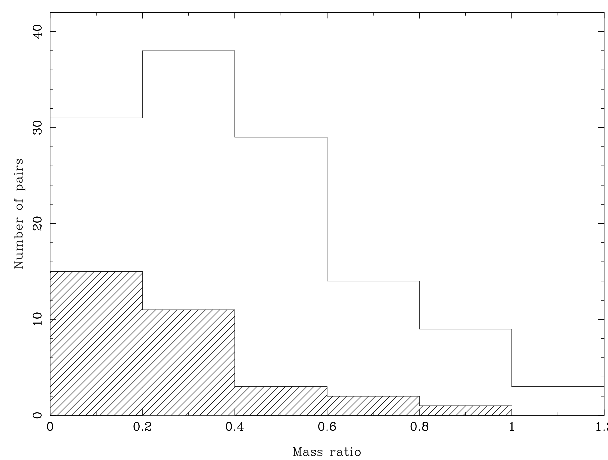

Fig. 3.— Mass ratio distributions of Population I main-sequence stars (open histogram, Duquennoy & Mayor 1991) and Population II stars (hatched histogram).

The distribution of Population I stars has a maximum at about 0.3, while the distribution of Population II stars is rising towards smaller mass ratios. One should be aware that the results of Duquennoy & Mayor contain corrections for undetected companions, without these corrections, the peak would be even more pronounced. On the other hand, the histogram for Population II stars contains only binaries that have actually been detected and no corrections.

If this difference in the distribution of mass ratios is true, it would indicate that the formation of Population I and Population II stars occured under different initial conditions. However, given the small number of Population II binaries, this result is still uncertain.

5. Summary

We are conducting a multiplicity survey of about 200 Population II stars. About one third of these stars has been observed with speckle-interferometric techniques, while 168 stars have been imaged with seeing-limited resolution. In total, we have found 32 companion stars up to now.

The peak of the period distribution of these binaries is shifted to longer periods compared to Population I stars. One would expect a shift in the opposite direction if it was caused by the disruption of binaries in stellar encounters occurring when the Halo stars cross the galactic plane.

We find a difference between the mass ratio distributions of Population I and II stars, too. While the distribution of Population I stars displays a broad peak at a mass ratio of about 0.3, the number of Population II stars shows a trend to increase towards even smaller mass ratios.

These results are still plagued by the small number of Population II stars that have been observed up to now. We plan to continue this survey to put our results on a firmer statistical basis.

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