Modes of Star Formation and the Origin of Field Populations
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Multiplicity of T Tauri Stars in Different Star Forming Regions

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Abstract. Multiplicity surveys of the Taurus-Auriga star-forming region and the Orion Trapezium Cluster show that their binary period distributions are significantly different from that of main-sequence field stars. Therefore, it is not possible that all field stars formed in regions like Taurus-Auriga or the Trapezium Cluster. However, a combination of both can explain the period distribution of main-sequence binaries, at least in the range covered by the surveys in Taurus-Auriga and Orion.

However, we know that a significant fraction of stars form in OB associations, which have not yet been included in this combination. Furthermore, it is not yet clear if the high multiplicity in Taurus-Auriga is typical for T associations. We will review the binary frequency and period distribution in several star forming regions and discuss the implications for the origin of the field star population.

1. Introduction

Kroupa (1995) proposed to use "Inverse dynamical population synthesis" to find out in which environment most field stars form. He used theroretical simulations of a population of binary stars that are initially grouped in an aggregate, and studied the evolution of the distribution functions of periods, eccentricities, and mass ratios. Comparison of the final binary distributions to those of main-sequence stars (Duquennoy & Mayor 1991) led to the conclusion that clustered star formation is the dominant mode of star formation, rather than formation in low-density regions like T associations.

We can apply the same technique, but use the *observed* period distributions of T Tauri stars (TTS) in different star-forming regions instead of theoretical models. This will allow us to find out what the typical star formation environment of field stars is without relying on assumptions about the initial conditions of the binary population.

2. Taurus-Auriga

All or nearly all T Tauri stars in the Taurus-Auriga T association form in binary systems (Leinert et al. 1993; Ghez et al. 1993; Köhler & Leinert 1998). This means that the binary frequency among TTS in Taurus-Auriga is enhanced by a factor of two compared to solar-type stars on the main sequence. This

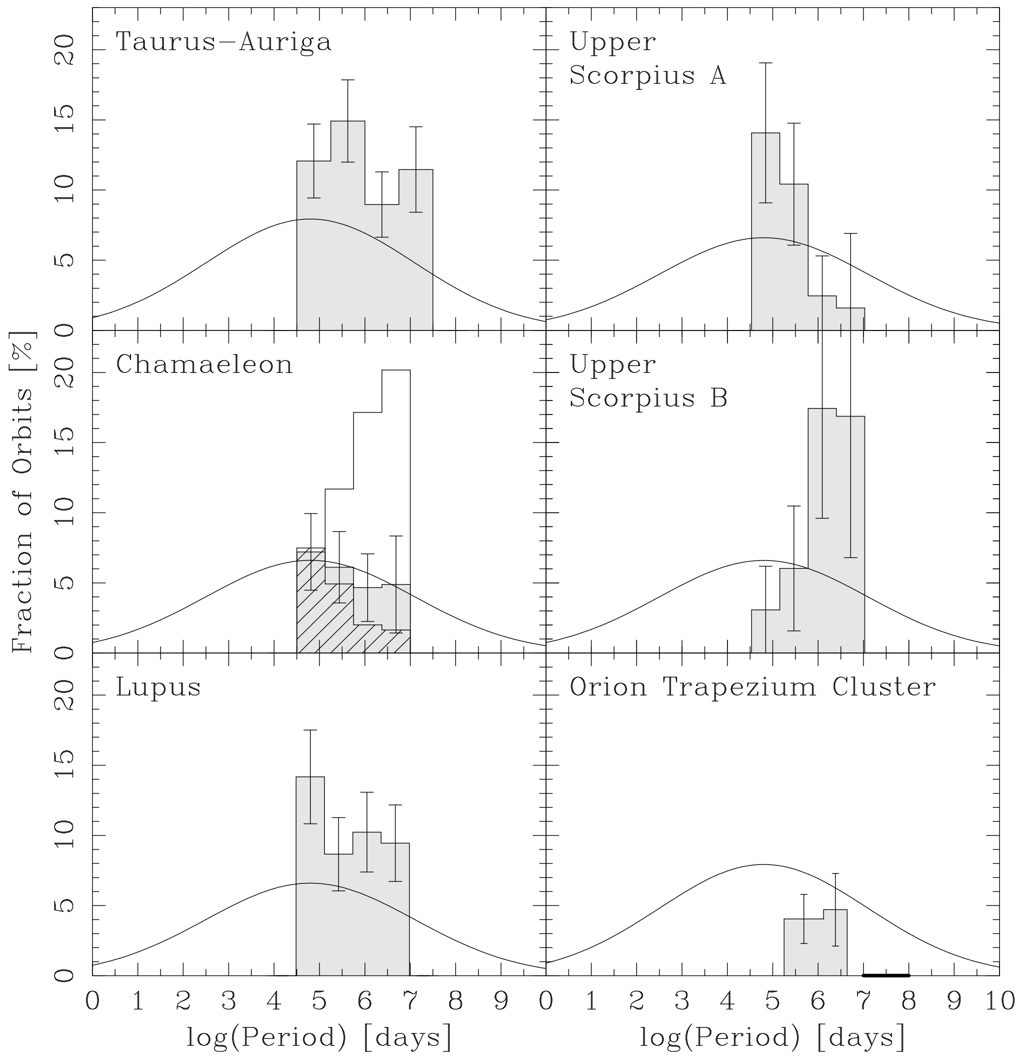

Figure 1. Binary frequency as a function of orbital period in the star-forming regions discussed here. By binary frequency we mean the number of companion stars with orbital period in a given interval divided by the total number of systems. The Gaussian-shaped curve is the distribution of binaries among solar-type main-sequence stars (Duquennoy & Mayor 1991), the histograms show the distribution among T Tauri stars in the star-forming region. In the panel for Chamaeleon, the distributions of TTS known before ROSAT (open histogram), TTS discovered by ROSAT (hatched), and of the combined sample (grey histogram) are plotted. The thick line in the panel for Orion indicates the result of Scally et al. (1999), who found no binaries in the separation range 1000 to 5000 AU.

enhancement is more or less constant within the errors over the whole period range studied (see Fig. 1). It is therefore not possible that a large fraction of main-sequence field stars formed in regions like Taurus-Auriga.

3. Chamaeleon

The Chamaeleon star-forming region is a T association similar to Taurus-Auriga. Some 17 stars were surveyed for binaries by Ghez et al. (1997). They found a binary frequency that was enhanced by a factor of more than three compared to the main sequence.

With the help of the ROSAT All-Sky Survey, 80 new T Tauri stars have been discovered by Alcalá et al. (1996). We conducted a binary survey of these stars (Köhler et al., in prep.) and find a significantly lower number of binaries among the stars discovered by ROSAT than among those known before ROSAT. The binary frequency of X-ray selected stars might even be lower than that of main-sequence stars.

If we combine both samples, the resulting binary period distribution is indistinguishable from that of the main sequence (see Fig. 1). This raises the question if the high binary fraction as found in Taurus-Auriga or the lower fraction as in Chamaeleon is typical for T associations.

4. Lupus

Lupus is yet another T association where ROSAT observations provided us with a sample of weak-line T Tauri stars, selected by their X-ray emission and confirmed to be young by follow-up spectroscopy (Krautter et al. 1997). We observed 127 of these stars to search for binaries. Preliminary results indicate that their binary frequency is about as high as in Taurus-Auriga, i.e. a factor 1.9 higher than among main-sequence stars (see Fig. 1). This suggests that a high binary frequency is indeed typical for T associations.

5. Scorpius-Centaurus

Scorpius-Centaurus is the most nearby OB association, which makes it well suited for a multiplicity survey. We searched for binaries in a sample of 104 young stars (Köhler et al. 2000), and found a binary frequency that is higher by a factor of 1.59 ± 0.34 compared to main-sequence stars. There are significant differences between the period distributions in the two subgroups Upper Scorpius A and B (see Fig. 1): The peak of the distribution of stars in US-A is at about 10^5 days, while that of stars in US-B is around $10^{6.5}$ days.

6. Orion Trapezium Cluster

Surveys in the Orion Trapezium Cluster found a frequency of binary systems similar to or even lower than that of main-sequence stars (e.g. Prosser et al. 1994; Petr et al. 1998). Theoretical studies show that only close binaries can survive in dense regions like the Trapezium cluster, since wide binaries are disrupted in stellar encounters. Indeed, Scally et al. (1999) used proper motion data to search for binaries with separations in the range 1000 to 5000 AU and arrived at the result that the Orion cluster contains no binaries at all in this separation range.

7. Taurus-Auriga plus Orion

We have seen that the binary period distributions in no star-forming region except Chamaeleon match that of main-sequence stars. Chamaelean seems not to be a typical T association, since both Taurus-Auriga and Lupus exhibit much higher binary frequencies. Furthermore, there exist observational and theoretical indications that most stars form in clusters (Lada et al. 1991; Kroupa 1995), so Chamaeleon is probably not a typical star-forming region.

To explain the period distribution of main-sequence binaries, it is therefore necessary to combine the distributions of at least two star-forming regions. We used the results of Taurus-Auriga and the Trapezium Cluster, since they are the best-studied T association and cluster. If we create a combined sample by drawing 1/3 of the stars from Taurus-Auriga and 2/3 from Orion, we obtain a surprisingly good fit to the distribution of main-sequence binaries (see Fig. 2), at least in the range where we have data from both star-forming regions.

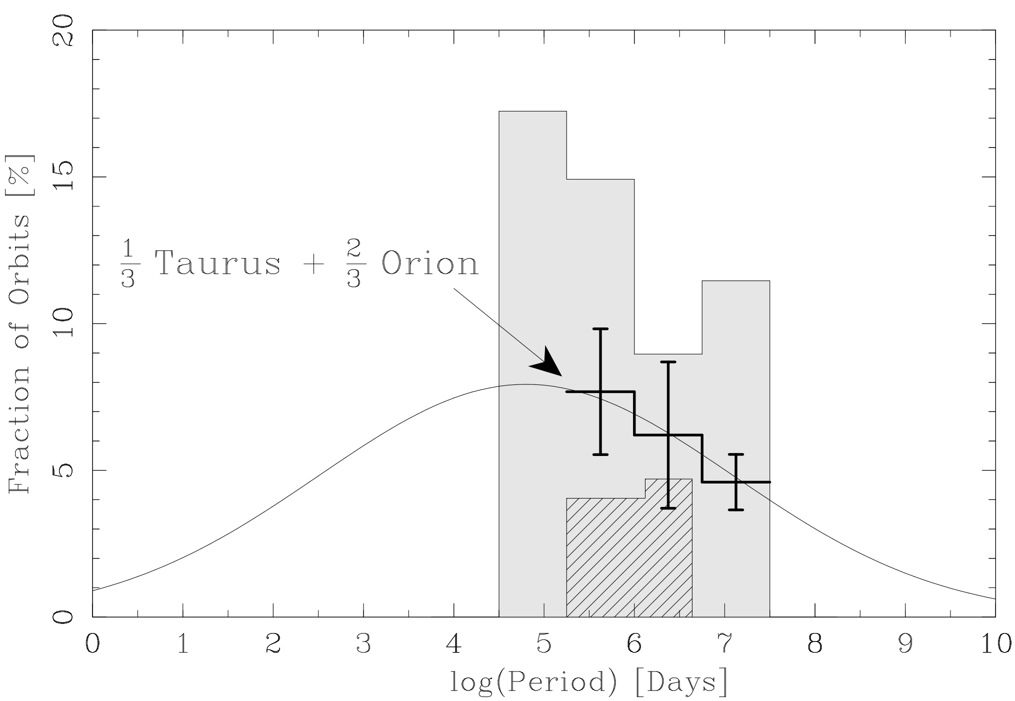

Figure 2. Binary period distributions of main-sequence stars (Gaussian-shaped curve), TTS in Taurus-Auriga (shaded histogram), and in the Orion Trapezium Cluster (hatched histogram). The thick line shows the period distribution of a combined sample, where 1/3 of the stars are taken from Taurus-Auriga, and the remaining 2/3 from Orion.

The statistical uncertainties of this result are large. If we assume that *no* binaries with periods longer than about 10^7 days form (and survive) in clusters, we can conclude that at least 1/4 of the field stars stem from regions like Taurus-Auriga.

Given the good agreement between the combined sample of TTS and the sample of main-sequence stars, we do not need to include OB associations in the mixture. However, it is clear that a significant fraction of field stars forms there. To address this issue with the help of binary statistics, we require much larger samples of binaries.

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