An Adaptive Optics Search for Binaries in the Orion Nebula Cluster

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Abstract. We report on the results of a binary survey in the outer parts of the Orion Nebula Cluster, 0.7 to 2 pc from the cluster center. The results should help to decide if the binary formation rate was lower in Orion than in Taurus-Auriga, or if many binaries formed initially, but were destroyed in close stellar encounters. We find that the binary frequency of low-mass stars does not depend on the distance to the cluster center. The companion star frequency of intermediate- to high-mass stars shows a trend to decrease with cluster radius, but the statistical significance of this trend is rather weak.

1 Introduction

Stellar multiplicity is very common among young solar-like stars, with companion star frequencies close to 100 % for young stars in well-known nearby star-forming T associations ([11,6], see [2] for a review). Therefore, our current understanding of star formation is that all or nearly all stars form in binary or multiple systems. However, the multiplicity of solar-type main-sequence stars is significantly lower, only about 55 % [4]. On the other hand, high binary frequencies are *not* observed among low-mass stars in stellar clusters. Binary surveys in the center of the young Trapezium Cluster (e.g. [16,15], see [12] for an overview), which is the core of the Orion Nebula Cluster (ONC), and in the young cluster IC 348 [3], as well as those in older ZAMS clusters [1,13] show binary fractions that are comparable to that of main-sequence stars, i.e. lower by factors of 2–3 than those found in loose T associations.

There are two prevailing theoretical explanations for this discrepancy: Either the initial binary fraction depends on the environmental conditions [5], i.e., only a relatively small fraction of the stars in Orion formed in binaries. The second theory is based on the disruption of binaries through close stellar encounters [9,10]. In this case the formation rate of binaries in Orion was as high as in

Taurus-Auriga, but many of the binaries were destroyed later in the dense core of the cluster.

In order to obtain observational support for one or the other proposed explanation, we carried out a multiplicity survey of stars in the outskirts of the ONC, about 0.7 to 2 parsec from the cluster center. With the current density of the cluster, the timescales for stellar interactions at these distances from the center are hundreds of times the age of the cluster. Therefore, the binary frequency in the outer part of the ONC will provide clues to the initial binary content and the dynamical evolution of the cluster.

The results presented here are still preliminary, a full analysis will be published elsewhere.

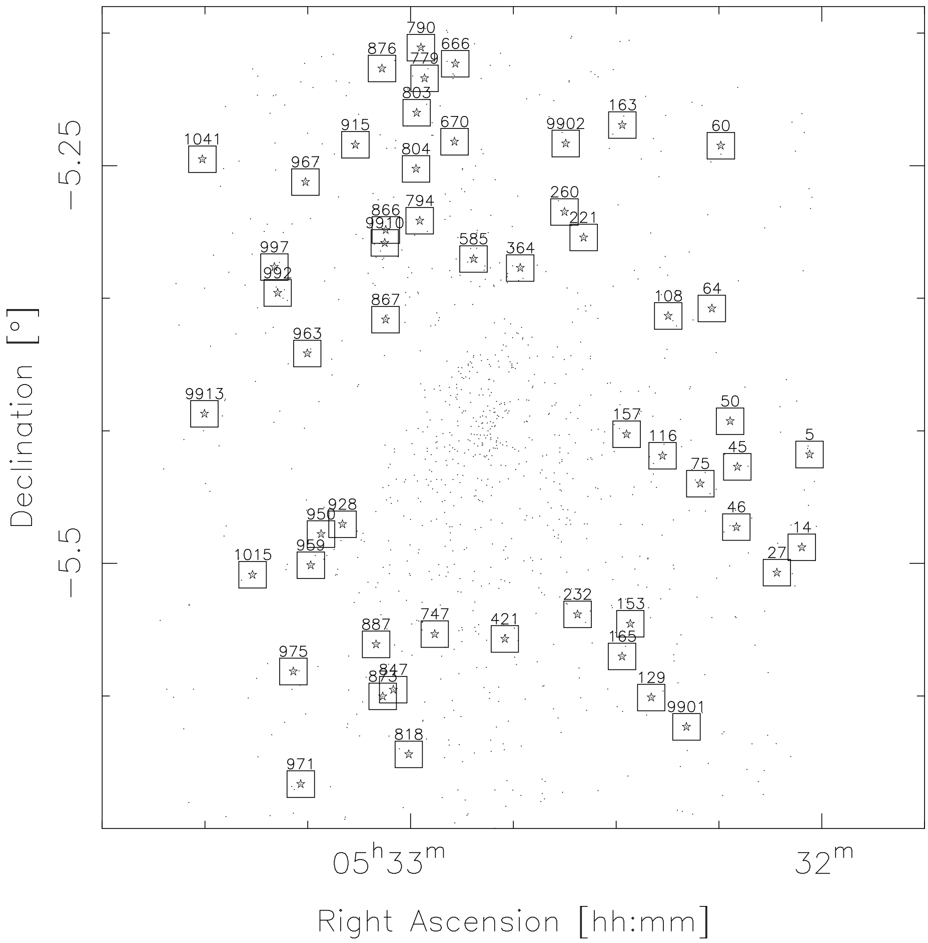

Fig. 1. Fields in the ONC observed for this work. The numbers are the designations in [8] for the stars used to guide the AO system, the dots mark all the stars in their catalog.

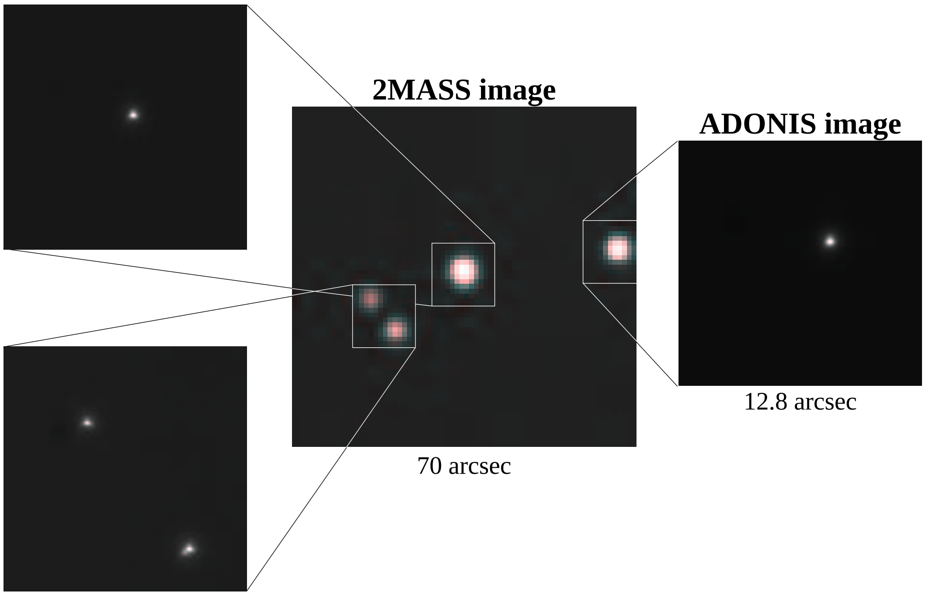

Fig. 2. Quicklook image from the 2MASS database of the region around JW0971, and the images obtained with Adaptive Optics in this field. The star to the southeast of JW0971 has a companion at 0.3″ separation. North is up and East to the left.

2 Observations and Data Reduction

Since the binaries we are interested in have sub-arcsecond separations, we decided to use Adaptive Optics (AO) to search for companion stars. AO systems need a relatively bright ($I < 12.5^{m}$) star within about 30″ from the target. We selected a list of stars from [8] at radii of 5–15 arcmin (0.7–2 pc) from the cluster center that fulfill this criterion (see Fig. 1). Then we used the Two-micron All-Sky Survey (2MASS) point source catalog (`http://www.ipac.caltech.edu/2mass/`) to find stars within 30″ from these guide stars. Figure 2 shows the field around the star JW0971 as an example, and our AO-corrected images of this field.

The larger part of the observations was carried out in three nights in December 2001 at the ESO 3.6 m telescope on La Silla. We used the AO system ADONIS with the SHARP II camera to obtain nearly-diffraction-limited images in the K_s-band. In February 2002, eleven fields were observed in one half night at the Keck II telescope. We used the Adaptive Optics system [18], and the NIRC 2 camera with the K_p filter.

The data were reduced following standard infrared-imaging techniques, i.e., sky-subtraction, flatfielding and badpixel-correction. We then used daophot within IRAF to find stars in the resulting images. Most companion stars are too close to their primary to be discovered by automatic procedures, they were found by visual inspection.

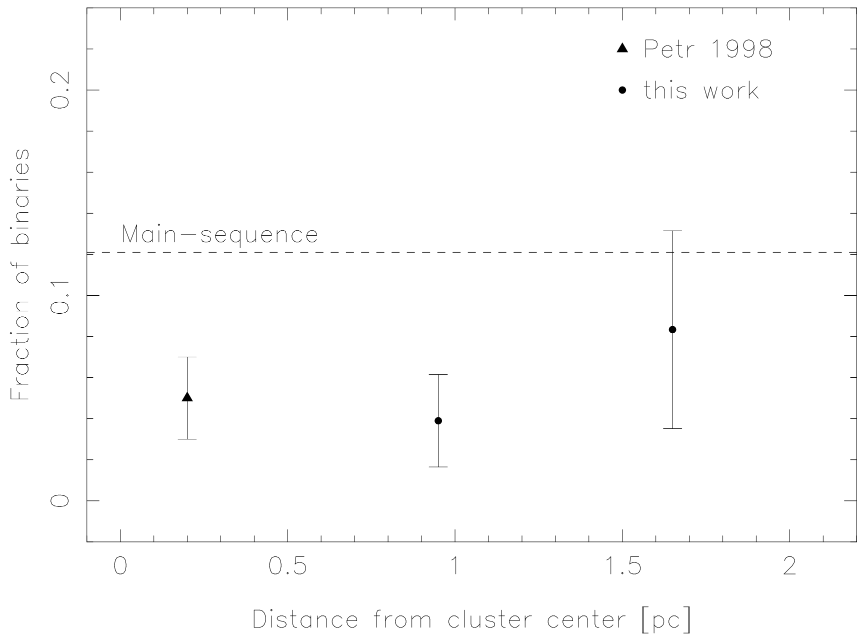

Fig. 3. Frequency of binaries among low-mass stars (mass range 0.1–1.4 $M_\odot$) as function of the distance to the cluster center. The dashed line shows the companion star frequency among solar-type main-sequence stars [4].

3 Results

In total, we observed 229 stars in 52 fields (see Fig. 1). We are sensitive to companions at separations in the range $0.13''$–$1.11''$ or 60–500 AU. The lower limit is the diffraction limit of the 3.6 m telescope in K, the outer limit was chosen to limit the number of chance alignments of unrelated stars. These limits are identical to those used by [15] for their binary survey in the center of the ONC.

We obtained masses for many of our targets from [7], and mass estimates based on infrared colors from 2MASS. According to these sources, we have 113 low-mass systems (in the mass range 0.1–1.4 $M_\odot$), with 88 masses from [7] and 25 from 2MASS. Six of these stars have companions, which is equal to $5.3 \pm 2.2\,\%$. This is not significantly higher than the result of [15], who found $5 \pm 2\,\%$ binaries among low-mass stars in the cluster core. Figure 3 shows the binary frequency at three distances from the cluster center. There is no significant tendency for a higher binary frequency in the outer parts of the cluster.

The multiplicity of high-mass stars in the core of the ONC is very high (e.g. [17] and references therein). We can use our data to check if the same is true in the periphery of the cluster. Our sample contains 40 systems with masses or mass estimates larger than 1.4 $M_\odot$ (35 from [7], 5 from 2MASS). However, there is only one star with a mass of over 10 $M_\odot$, the lower limit of the high-

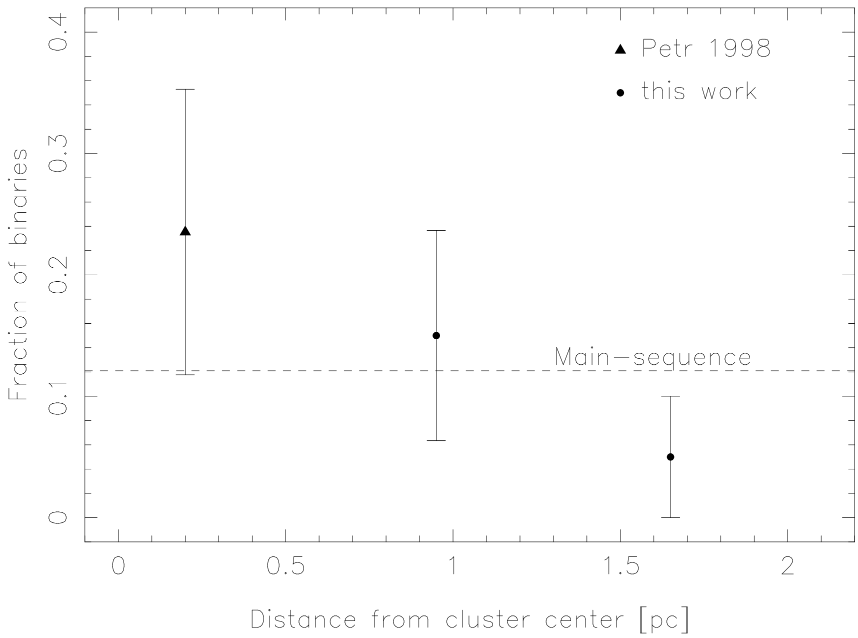

Fig. 4. Frequency of binaries among intermediate to high-mass stars (masses $> 1.4\,\mathrm{M}_\odot$) as function of the distance to the cluster center. The dashed line shows the companion star frequency among solar-type (i.e. low-mass) main-sequence stars [4]

mass subsample in [15], which makes a comparison with this high-mass sample meaningless. Instead, we went back to the original data in [14] and counted intermediate- to high-mass stars in their target list. There are 17 systems and four companions (two binaries, one triple) at separations in the range $0.13''$–$1.11''$, i.e. a companion star frequency of $24 \pm 12\,\%$. In the outer parts of the cluster, we find 4 companions, which yields a companion star frequency of only $10 \pm 5\,\%$. Figure 4 shows the results as function of the distance from the cluster center. Although the companion star frequencies in the cluster core and the outskirts differ by a factor of more than 2, the statistical uncertainties are large, so this is just barely a 1σ result.

4 Conclusions

We find no tendency for the binary frequency of low-mass stars to change with distance from the cluster center. This can be explained in two ways:

- Either the initial formation rate of binaries was much lower in Orion than in Taurus-Auriga, and dynamical disruption played only a minor role,
- or the Orion Nebula Cluster was much denser in the past, so that stars that are now at more than 1 pc distance from the center went through enough close encounters to reduce the companion star frequency to the level observed.

We find that binaries are more frequent among intermediate- to high-mass stars than among low-mass stars. We also find that the companion star frequency of intermediate- to high-mass stars tends to decrease with distance from the cluster center. However, this result is hardly statistically significant due to the small sample sizes.

This work is based on observations obtained at the European Southern Observatory, La Silla, proposal number 68.C-0539, and at the W.M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W.M. Keck Foundation. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain. This work has been supported in part by the National Science Foundation Science and Technology Center for Adaptive Optics, managed by the University of California at Santa Cruz under cooperative agreement No. AST-9876783, and by the European Commission Research Training Network "The Formation and Evolution of Young Stellar Clusters" (HPRN-CT-2000-00155).

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