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SEARCH FOR THE LEAST MASSIVE OBJECTS IN THE HYADES OPEN CLUSTER WITH THE HELP OF A WIDE STELLAR VIEW

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Abstract

We present a photometric survey and a survey of proper motions covering an area of 23.4 $\deg^2$ in the core of the open cluster Hyades. Searches have been made for new low-mass stars and brown dwarf candidates in the Hyades in order to improve the current mass function of the cluster down to sub-stellar masses. Using color-magnitude diagrams in the optical and infrared ranges, we have identified 66 photometric candidates for cluster members in the range $14.7^m < I < 20.5^m$. These results indicate that the mass function of the Hyades becomes poor for objects with masses below $\sim 0.15 M_\odot$ indicating that the Hyades probably lost the objects with the lowest mass as a result of dynamic evolution. We concluded that the Hyades core represents the so-called "desert" for the low-mass stars and brown dwarf and that most of the sub-stellar objects have already left this cluster.

Keywords: *the open cluster Hyades; a low-mass stars; a brown dwarf; mass function.*

PACS: *97.10.Nf; 98.20.Jp; 97.10.Xq; 97.20.Vs.*

Introduction

The exact initial mass function of galactic open star clusters allows us to reproduce the picture of the initial conditions for the formation of clusters and to study their further evolution. The mass function for the most massive members of the clusters has been analyzed in many detailed studies of bright of open star clusters. On the other hand, in recent decades, photometric studies of clusters have been focused on studying the mass function of the weakest members of the open star clusters. Surrounding open star clusters are very convenient targets for this purpose. There are several open clusters in the vicinity of the Sun, including the Pleiades, Hyades, the clusters at Praesepe (M44), and Coma Berenices (Melotte 111). Among these open star clusters, the Pleiades is the youngest cluster, which is ~ 120 million years, while the rest of the open star clusters are $\sim 500-600$ million years. The Hyades ($r = 46$pc) with an age of 625 million years[1], with a stellar population similar to the Pleiades, is one of the most studied open star clusters located in the solar vicinity. However, in contrast to young open star clusters (with an age of < 250 million years), Hyades has a clear deficit of low-mass stars and brown dwarfs. Our study focused on studying the statistics of low-mass members of this cluster, whose population composition is determined by a standard mass function increasing towards low masses ($\alpha = 2.35$

[2]). To this end, we searched for new low-mass stars and brown dwarf candidates in the Hyades to improve the localization of the modern mass function of this cluster based on a deep photometric survey covering the central core of the Hyades. Detailed results of this study are presented in the work of Melnikov et al. [3].

1 Observation and processing

We carried out a new in-depth survey of the Hyades wide-field RI range using a 2kx2k CCD camera at the Schmidt focus of the Alfred Jensch2-meter telescope at the Tautenburg Observatory (TLS, Germany). Photometric images of 65 sites were obtained in October-November 2006 and cover 23.4deg^2 in the area of the Hyades core. The nuclear part of the Hyades, which is 46 pc from the Earth, has a radius of R $\sim$ 2.8pc and occupies an area of $\sim$ 50 deg^2 in the sky. Thus, our photometric survey covers about 47% of the cluster core. Our calculations show that the completeness of our survey corresponds to 21.5$^\mathrm{m}$ in the R band and 20.5$^\mathrm{m}$ in I. The limiting magnitude in the R and I bands in this survey is about 1.5-2 mag. weaker than the completeness value, i.e., the limiting value is 23$^\mathrm{m}$ for the R-filter and 22.5$^\mathrm{m}$ for I.

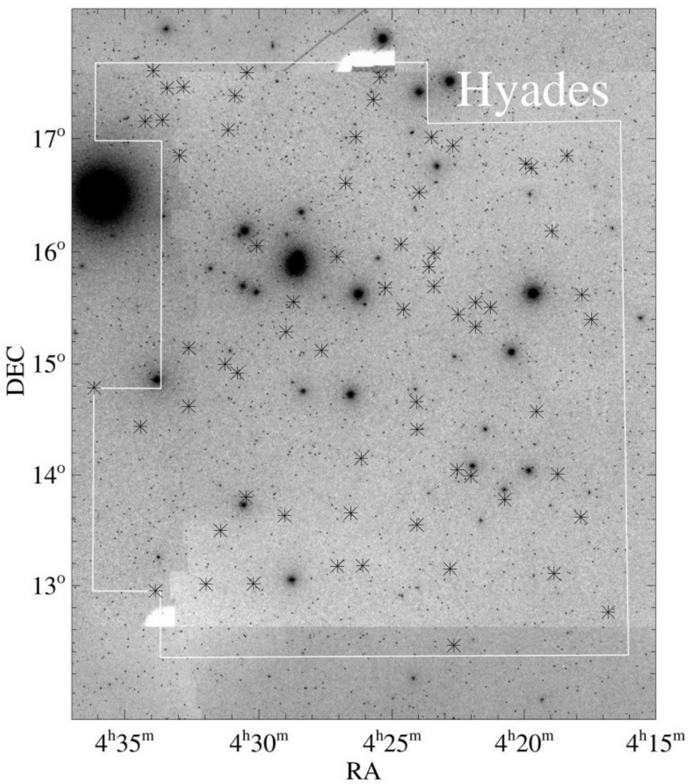

Figure 1: The area of Hyades is covered by a photometric view in TLS, the total area of which is 23.4 deg^2. Photometric candidates for the Hyades cluster are marked with asterisks.

Using the RI photometry of our survey together with the infrared JHK photometry available from the 2MASS and UKIDSS survey, we selected 66 photometric candidates using the modern theoretical BT-Settl model [4,5]. Photometric candidates cover

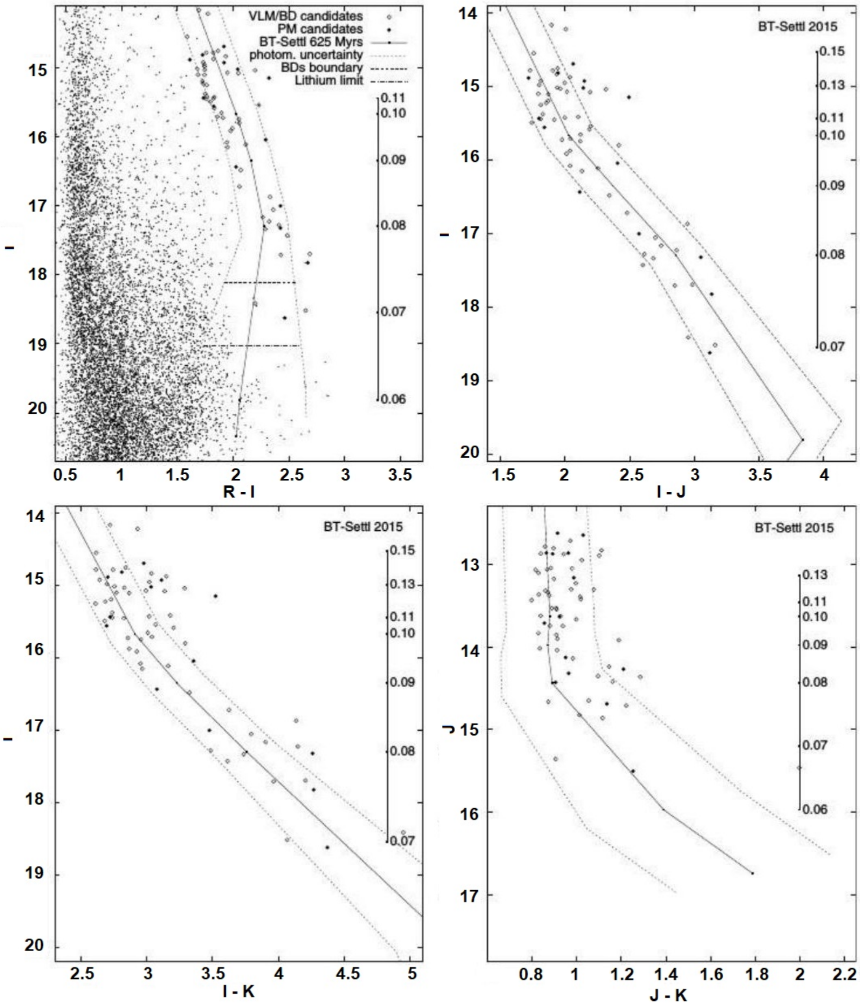

Figure 2: Color-magnitude diagrams I-(R-I), I-(I-J), I-(I-K) and J-(J-K) for Hyades optical candidates (circles) obtained from TLS and 2MASS /UKIDSS surveys; candidates selected based on the analysis of their own movements are marked with filled circles. The main sequence for the Hyades age (625 million years) and distance ($m - M = 3.33$) is shown as a solid line. The vertical line shows the mass scale. For example, the 1st diagram shows the field stars excluded from the subsequent analysis.

values from I $\sim 14.5^{\mathrm{m}}$ to 18.7^{m}, covering the mass range from $0.15\mathrm{M}_{\odot}$ to $0.07\mathrm{M}_{\odot}$ (67 Jupiter masses). Objects with I = $14^{\mathrm{m}}.5-17^{\mathrm{m}}.7$ correspond to spectral types from M_2 to $L_{\odot}$, based on the spectral-photometric classification of Kraus and Hillenbrand [6], while fainter objects (I>17 $^{\mathrm{m}}$.7) should have spectral types later than $L_{\odot}$. Assuming an age of 625 million years and assuming a distance to Hyades of 46 pc, the boundary in the color-magnitude diagrams between stellar and sub-stellar objects lies in the region I $\sim 18^{\mathrm{m}}.1$. The next step was to determine the proper motion of optical candidates to confirm their belonging to the population of the cluster. The proper motion of a member of the cluster should coincide within the error with the magnitude of the proper motion of the cluster. The proper motion measurements were based on several all-sky surveys such as POSS1 (R), POSS2 (R + I), 2MASS, UKIDSS, and WISE, which provided a 60-70-year epoch difference for bright objects. These measurements allowed us to separate the members of the cluster from the objects in the field, which have their motions lower or higher than those of the cluster. This selection led to the discovery of 14 likely members of the Hyades cluster (Fig. 3).

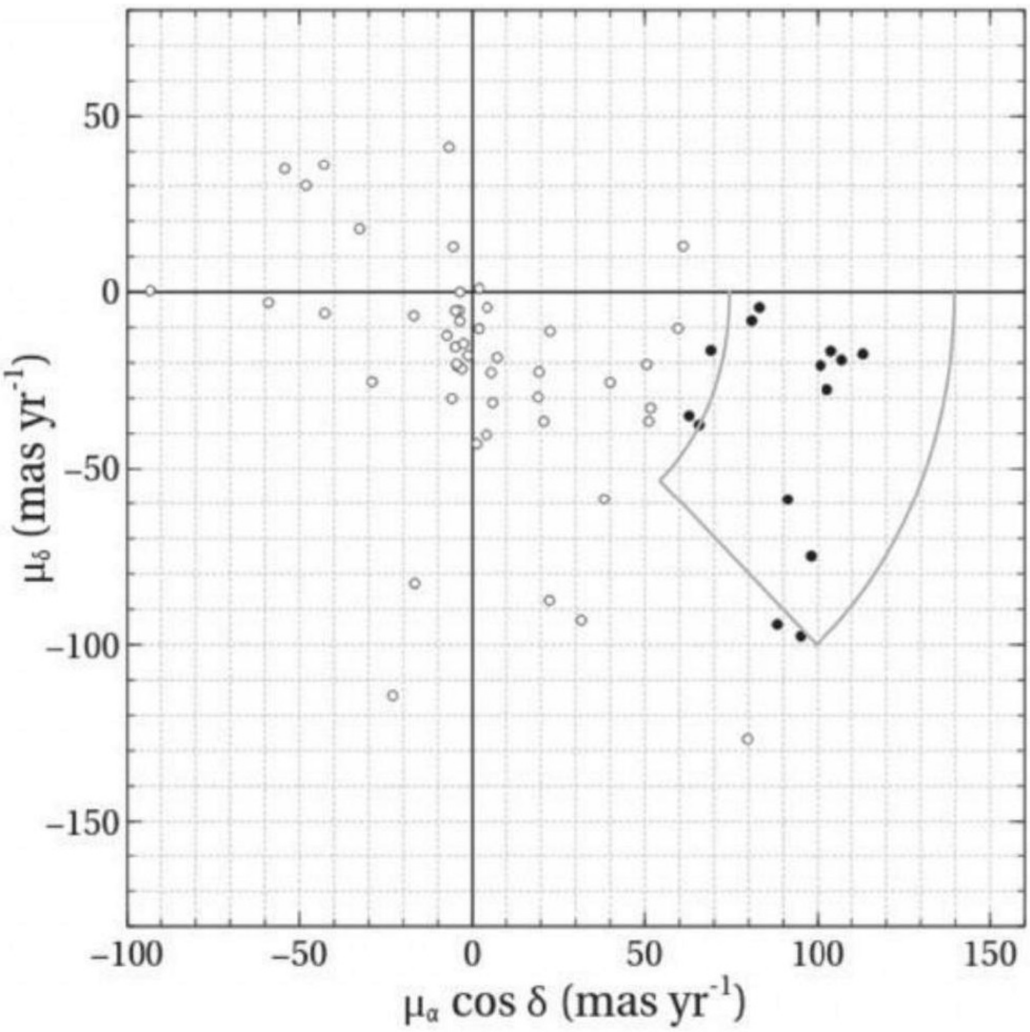

Fig.3. Diagram of proper motions for photometric candidates of Hyades. The gray sector defines the area of own movements expected for the Hyades. Taking into account the errors of determination, 14 objects (black circles) out of 66 optical candidates (empty circles) are classified as objects with proper motion corresponding to the Hyades cluster.

We have identified 4 new low-mass member candidates, while the remaining 10 stars on our list are identified with members of the cluster found in earlier studies. We also rediscovered the object Hy 6 [7] as a member of the Hyades. We classified it as a photometric candidate for sub-stellar objects based on a comparison of observed color-magnitude diagrams with a theoretical isochron model. This object (our classification is TLS-Hy-7) is located well below the boundary (I> $18^{m}.1$) separating low-mass stars and sub-stellar objects, and we classify it as a photometric "brown dwarf". No new photometric sub-stellar objects have been discovered in the region of the Hyades core.

We added our sample of objects to the list of Bovier et al.[8] to calculate the refined Hyades mass function (Fig. 4). Taking into account the detected objects, the mass spectrum of the cluster has become slightly flatter in the range of $(0.05-0.2)M_{\odot}$, but the difference between the mass functions of the Hyades and the Pleiades is still very clear. It should be borne in mind that this range includes not only the discovered brown dwarfs but also low-mass star members of the cluster. From the obtained mass function in this range of small masses, we found the slope of the dependence $\alpha = -1.1 \pm 0.2$, which is close to the value from Bovier et al. [8].

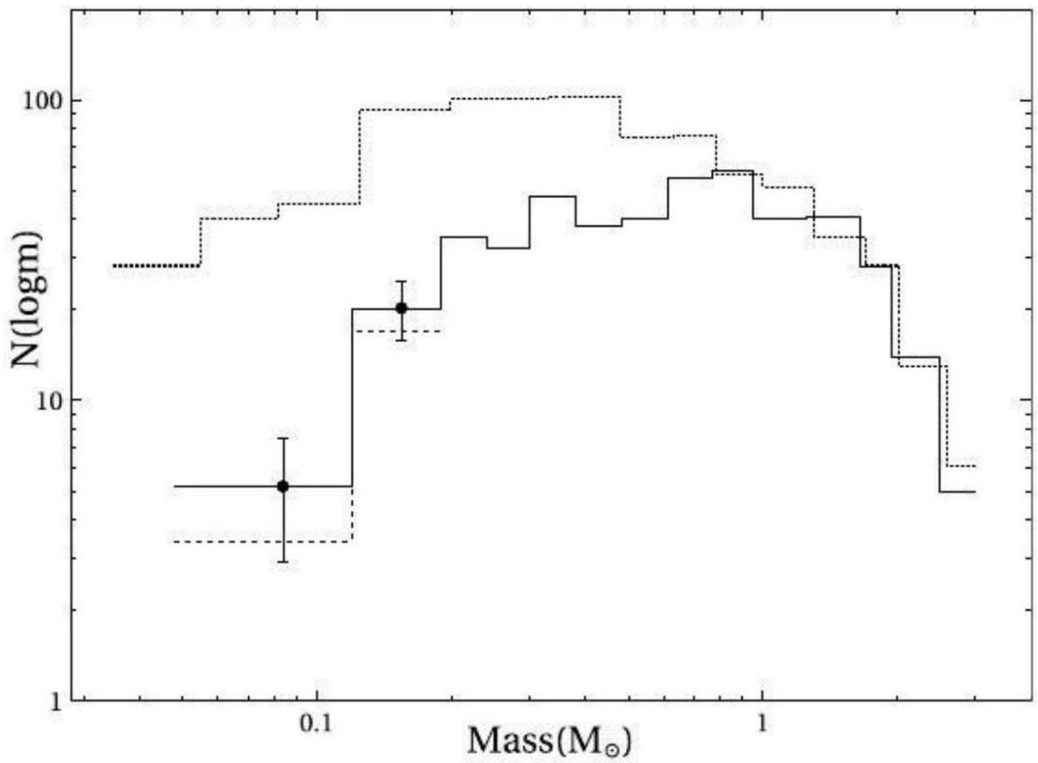

Fig.4. Comparison of the mass functions of the Pleiades (top) and Hyades (bottom). The solid line shows the mass function of the Hyades taking into account the TLS survey, and the dashed line (lower histogram) shows the survey results by Bovier et al.[8]. The Pleiades mass function is taken from the work of Bovier et al.[8].

2 Analysis of results

The updated Hyades mass function shows a strong deficit of the least-mass stars and substellar objects in the mass spectrum of this open cluster. This result can be explained as a consequence of the ongoing dynamic evolution of the Hyades (625 million years), which are older than the Pleiades (120 million years). Agekyan and Belozerova [9] showed that during the evolution of an open cluster, its members can leave the core and form an expanded halo around it. It is assumed that this effect may already be noticeable in open clusters with an age > 200 million years [10]. Comparing the shape of the mass function of the Hyades and the Pleiades, Bovier et al. [8] calculated that the Hyades lost > 90% of their original sub-stellar population ($M < 0.08M_{\odot}$). However, they concluded that at present $10-15$ "brown dwarf" can still be located in the Hyades core, whereas the original core contained up to 200 brown dwarf. However, although we used broad selection criteria that included photometric errors and physical cluster depth, as well as potential natural color variance [11], we did not find new in brown dwarf candidates, and only four in low-mass stars candidates were added to the previous list of members. We also note that the survey area in the TLS survey was 10deg^2 higher than that of Bovier et al. [8]. Modern numerical modeling of the Hyades cluster predicts that in the course of dynamic evolution, "evaporated" brown dwarf and other low-mass members form elongated tails extending from the main cluster core [12]. Modeling by Ernst et al. [13] shows that this tidal tail, consisting of lost objects, after 625 million years of evolution can reach 800 pc. Simple calculations show that if the escape velocity is several kilometers per second (for example, $\sim$ 3 km/s, [12]), then the former low-mass members can move away from the cluster core by several tens of parsecs after 625 million years of evolution and will be outsideour selection criteria. Therefore, we cannot exclude that the observed "desert" of the low-mass stars and brown dwarf in the Hyades may be a consequence of the situation when almost all members of the small mass left the cluster core and even its halo.

3 Conclusion

Thus, our results confirm the conclusion that the low-mass stars and/or brown dwarf deficit in the Hyades is a consequence of the gradual removal of low-mass cluster members as a result of weak gravitational collisions during the continuous dynamic evolution of the open cluster [8]. Moreover, our research, combined with the results of several previous studies, shows that the Hyades core has already lost most of its sub-stellar member population. As a result of this "evaporation", most of the low-mass members caught in the field of stars in the foreground probably mixed with the foreground dwarfs and migrated so that they are no longer projected onto the cluster core. "Evaporated" background objects that are projected onto the nucleus are probably much fainter than those still within the cluster volume, and it takes longer to capture images to detect such objects. Thus, we believe that the long-term evolution of the open cluster as a gravitational system leads to the loss of a large low-mass population and, as a consequence, to a weakening of the gravitational constraint of more massive members within the general gravitational field.

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