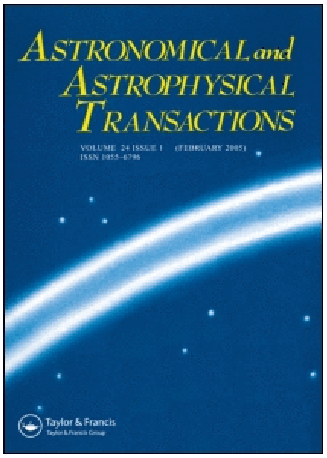

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Problems of the investigation of open star clusters

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Some problems of the investigation of open star clusters are discussed. The efforts of the staff of the Astronomical Observatory of Ural State University in this field are discussed too.

Keywords: Cluster; Stellar parameters; Galactic parameters

Open star clusters (OCLs) form a class of objects that play an extremely important role in stellar astronomy. For a long time OCLs served as the basis of the galactic and intergalactic distance scale. Now OCLs have to share this significant role with the trigonometric parallaxes of Hipparcos, but until the present day they have been the most important providers of information for stellar evolution theory, especially for massive stars and stars in stages before the main sequence, luminosity and mass functions. We must mention the role of OCLs in the investigation of the structure and evolution of the Galactic disc because they have been until now the only class of objects permitting the simultaneous estimation of distances from the Sun and astrophysical ages with adequate accuracy. Space observations, especially in the infrared (IR) spectral region, open up new opportunities in OCL investigations because they allow us to estimate the parameters of more distant and obscured clusters.

Investigations of OCLs at the Astronomical Observatory (AO) of the Ural State University (USU) was begun in the early 1950s by K.A. Barkhatova, who was a postgraduate student of P.P. Parenago. The foundation of the astronomical chair and the creation of the Astronomical Observatory of USU 40 years ago were due to Barkhatova. Initially under her direction the determination of the parameters of OCLs by photographic photometry and the investigation of the luminosity functions of numerous clusters were performed. Then the investigation field was widened by Barkhatova and her students to cluster dynamics, the properties of the subsystem of OCLs in the Galaxy, and cluster complexes. Until now the investigation of OCLs has been the main field of research of the AO USU. In this paper, we consider the state of OCL investigations in our observatory.

The main goals of stellar astronomy are the study of stellar distance and age scales. At present the distance scale is adjusted by the setting of the Hyades main sequence which is

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achieved using the moving-cluster method and is known with an accuracy to a magnitude of not less than ± 0.10 so that it is in accordance with the trigonometric parallaxes of Hipparcos (see [1] for a discussion of some problems connected with these parallaxes). Further study of the distance scale is not really possible until the new cosmic astrometric projects finished because the accuracy of the convergence point method has reached its limit and is confined by the inner velocity dispersion of cluster stars and the spread of cluster stars along the line of sight. As for the age scale, it can be said that, during the last two decades, no fundamental modifications to stellar evolution theory have been made. However, we are faced with the problem of the investigation of the ages of the youngest clusters, which is difficult because of some non-coordination between the evolutionary track sets for stars on and before the main sequence stages.

Let us consider the situation with the investigation of OCLs at present. The most complete list of OCLs currently is the catalogue of Dias *et al.* (www.astro.iag.usp.br/~wilton). The last version of this catalogue provided the data for 1753 clusters; 997 of these clusters have estimates of the distance from the Sun that are sometimes very unreliable. Three main parameters (reddening, distance and age) are given for 842 clusters, but only a quarter of this number have these values determined with appreciable accuracy. In the last 12 years, more than 500 new clusters have been added to the list of OCLs; the main role in this process has been played by the 2MASS point source catalogue. Substantially they are IR clusters, hardly visible in optics because of severe interstellar reddening, when interstellar extinction in the V band often exceeds a magnitude of 20^m. Figure 1 shows the curve of the surface density of OCLs versus the estimates of distances from the Sun in the projection on the Galactic plane. This density is expressed here as the number of clusters in a square with 100 pc side. We can see from the figure that up to a distance from the Sun of about 700 pc the sample of clusters may be regarded as complete and the surface density of clusters in this region is equal to 3.3 clusters per 10 000 pc^2. For larger distances the situation is evidently worse. For distances near 1 kpc the surface density falls to half the value, and for distances near 2 kpc it decreases to about a third. However, it is just distant clusters that plays the determining role in the investigations

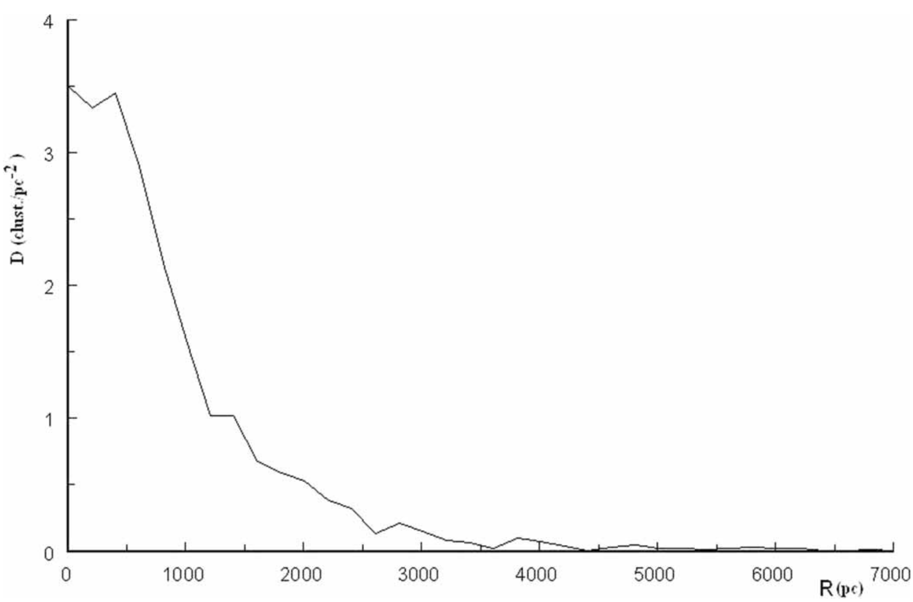

Figure 1. The surface density of OCLs versus the distance from the Sun in the projection on the Galactic plane.

of the kinematics and structure of the Galaxy, spiral structure and evolution of star-forming regions. It is easy to estimate that, in a circle of 6 kpc radius, up to 12 000 OCLs must exist. We can say that the problem of searching for new clusters is of current interest. We must mention in this connection that, in contrast with optical bands, in the IR it is difficult to search for new clusters with a low star density because the more populated stellar background is not suppressed by obscuration as it is in optics. At the same time in the IR bands the difficulties with the extraction of cluster members are increased, which causes errors in the estimation of cluster parameters to be insignificant.

The search for new OCLs will be continued with the use of data from global surveys such as 2MASS and GLIMPSE and we hope to obtain the parameters of many distant clusters in the near future. Especially interesting are the inner Galaxy region where, in the molecular ring, numerous newly born clusters must exist, and also the outer Galaxy region to clarify the situation with the spiral structure of the Galaxy. Photometric investigations of OCLs are taking place at many observatories, which promises an increase in the number of clusters with more accurately estimated parameters.

It should be mentioned that the capability for improvement in the accuracy of the distance scale has now been exhausted. At present the distance scale for OCLs is in accordance with both the trigonometric parallaxes of Hipparcos and the Hyades distance from the moving-cluster method. New space experiments will provide data of better quality to allow new attempts to be made in this direction. The same can be said about the scale of cluster astrophysical ages because during the last two decades there have been no considerable changes in stellar evolution theory.

The field of investigation of the researchers at our observatory is OCL. At present, we are starting to determine the parameters of OCLs from the data from the 2MASS point source catalogue. The main target is to create a computer program for estimation of these parameters to obtain a homogeneous set of values for the maximum number of clusters in addition to the earlier homogeneous catalogue of OCL parameters [2] on the basis of optical photometric systems. The 2MASS point source catalogue includes photometric data in three near-IR bands and has sufficient limiting stellar magnitudes. Most young distant OCLs are influenced by differential reddening, which leads to large errors in the estimated parameters from optical data. We hope that the IR data will help us to obtain more accurate estimates of the parameters of such clusters. Currently this work is in the stages of production of standard sequences on the Q_{JHK}–$(J-H)$ and $(J-H)$–$(H-K)$ planes and of checking the validity of the values of the important ratios $E(J-H)/E(H-K)$ and $A_J/E(J-H)$ for the 2MASS point source catalogue data. We perform this work by using the data for stars close to the Sun OCLs such as Pleiades, Praesepe and others. The members of these clusters are easily extracted with the help of proper motions from the UCAC-2 catalogue. Let us consider two figures for example. Figure 2 is a two-colour diagram for the *JHKs* bands for Pleiades stars and Praesepe cluster stars. We have obtained photometric data in the *JHKs* system from the UCAC-2 catalogue together with the proper motions for the extraction of cluster members. It is known that for Praesepe cluster stars the reddening is negligible; the magnitude of $E(B-V)$ is approximately 0.0. For the Pleiades stars we have an $E(B-V)$ magnitude of about 0.04, which corresponds to a low magnitude of $E(J-H)$ of approximately 0.01. In figure 2, the line of dereddened stars for a standard *JHK* system from the paper by Bessel and Brett [3] is shown by a solid curve. It can be seen from this figure that stars of two clusters are shifted from the curve to the right, mostly because of the deviation of the *Ks* band from the standard band, which can be easily corrected. The large scatter on the diagram indicates that the accuracy of the photometry is not very high and is very inhomogeneous. This leads to the conclusion that 2MASS data may be used for the estimation of parameters of clusters in stars that are sufficiently near, where low-accuracy data may have been rejected previously.

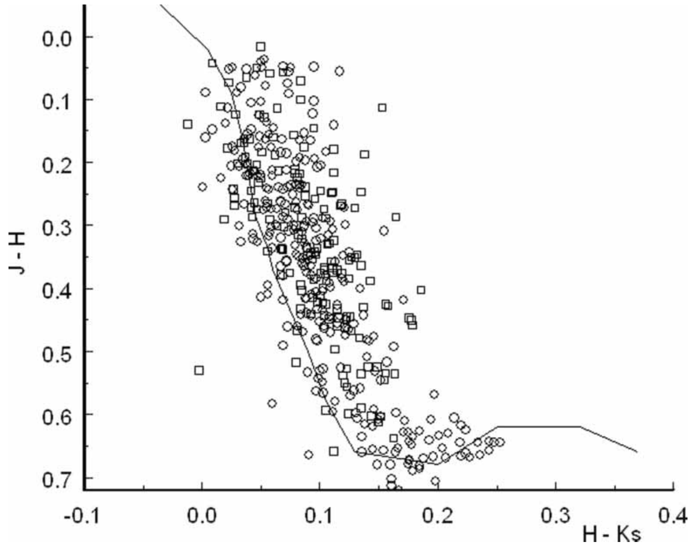

Figure 2. The $(J-H)$–$(H-Ks)$ diagram for Pleiades stars (open squares) and Praesepe cluster stars (open circles).

The $(J-H)$–$(H-K)$ diagram is not very convenient for the estimation of cluster reddening. The Q_{JHK}–$(J-H)$ diagram) is more promising. Such a diagram for Pleiades and Praesepe members is shown in figure 3, together with the line for non-reddened stars calculated from the data from [3]. The inclination of the line for non-reddened stars is consistent, which obviously allows us to estimate the reddening $E(J-H)$ with good accuracy.

The colour–stellar magnitude diagram for our samples of Pleiades and Praesepe stars is shown in figure 4 with the same designations as above. The isochrone for the age $\log t = 8.0$ from the data set of Bertelli *et al.* [4] is shown in figure 4 by a solid curve. It can be seen

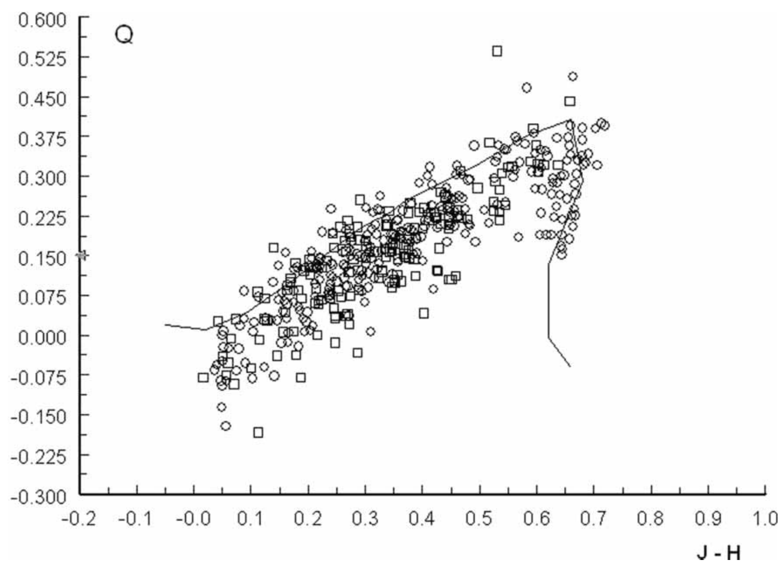

Figure 3. The Q_{JHK}–$(J-H)$ diagram for Pleiades and Praesepe stars, together with the line (solid curve) for non-reddened stars calculated from the data in [3].

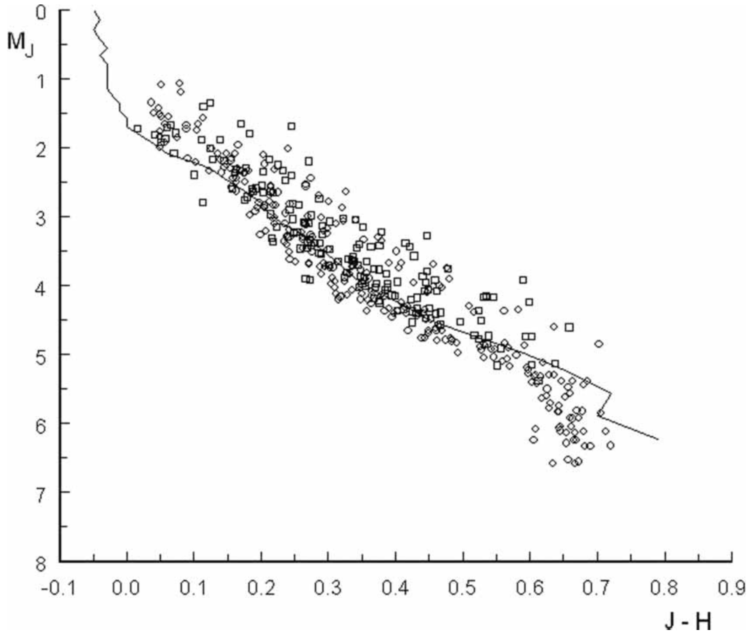

Figure 4. The $(J - H)$–M_J diagram for Pleiades and Praesepe stars.

from the figure that the magnitude of the width of the main sequence for single stars is not more that 0.05 for colour indices, which promises fine accuracy of the cluster distance moduli estimations for clusters containing sufficient bright stars. Above the main sequence of single stars, the sequence of double stars can be seen and this shows the good real accuracy of the photometry for the 2MASS point source catalogue data for an appreciable fraction of stars. The theoretical isochrone coincides with observed main sequence for all stars except the faintest, but there is some overall shift along the M_J axes. From the above discussion we can see that the 2MASS point source catalogue may be used for the determination of cluster parameters and in the near future we shall begin determination of parameters for all known clusters.

One more way to improve our knowledge on cluster parameters is the program of charge-couled device (CCD) photometry in the *UBV* system of poorly investigated clusters planned in our observatory. Our observatory is equipped with a 45 cm Schmidt telescope with a CCD device with a 2184 × 1472 pixel Alta U32 matrix of pixel size 6.8 μm × 6.8 μm. This system provides us with images with a field of $1^\circ \times 0^\circ.6$, which means that most clusters of interest are obtained in one image and there is no need to make mosaics. We carried out trial observations which informed us that we can perform photometric measurements of stars up to the limiting *V* magnitude of about 17 with an exposure time of approximately 2 min. The telescope now is undergoing modernization and we hope that we can start our own observational program during this autumn. The wide field of our images leads to a small number of pixels per star, which allows us to obtain a photometric accuracy of about 0.02 magnitude for stars in the measurable interval of stellar magnitudes; we can overcome this by obtaining an adequate number of images in every band of the *UBV* system.

The accuracy of cluster parameter determination may be improved by the use of proper motions for the extraction of cluster members. We hope to use our CCD images to obtain the equatorial coordinates of stars in clusters for the last epoch and, as data for the first epoch, we can use the images from the Digital Sky Survey readable in FITS format by our reduction program. Modern astrometric catalogues provide us with great numbers of faint reference stars in cluster fields. Our CCD images give a mean accuracy of star positions near 0".2 per image. In future, we hope that for the determination of proper motions the digitized old plate material will be accessible through the Virtual Observatory.

We should mention that our group uses data on open clusters to investigate the properties of the spiral structure of our Galaxy and the kinematics of stars in some nearby clusters.

It can be seen from the above that the investigation of open clusters has great prospects both in the world and at our observatory. New observations and the use of existing data from modern photometric and astrometric catalogues will provide us with new data for the investigation of the structure, kinematics and evolution of the Galaxy. In particular, the proper motions of clusters that we obtain from modern astrometric catalogues such as the Tycho-2 and UCAC-2 catalogues, which provide us with numerous cluster velocities of quality comparable with that of radial velocities, should be mentioned.

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