

Astrophysical parameters of ten poorly studied open star clusters

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Abstract We present the fundamental parameters of ten open star clusters, nominated from Kronberger et al. who presented some newly discovered stellar groups on the basis of the Two Micron All Sky Survey photometry and Digitized Sky Survey visual images. Star counts and photometric parameters (radius, membership, distance, color excess, age, luminosity function, mass function, total mass, and dynamical relaxation time) have been determined for these ten clusters for the first time. In order to calibrate our procedures, the main parameters (distance, age, and color excess) have been re-estimated for another five clusters, which are also studied by Kronberger et al.

Key words: Galaxy: open clusters and associations: general — stars: luminosity function, mass function — catalogs, surveys — infrared: stars

1 INTRODUCTION

Open star clusters (OCs) are very important tools in studying the formation and evolution of the Galactic disk and the associated stellar evolution. The fundamental physical parameters of OCs, e.g. distance, reddening, age, and metallicity, are necessary for studying the Galactic disk. The Galactic, radial and vertical, abundance gradient can also be studied using OCs (Hou et al. 2000; Chen et al. 2003; Kim & Sung 2003; Tadross 2003; Kim et al. 2005). They are excellent probes of the Galactic disk structure (Janes & Phelps 1994; Bica et al. 2006). The strong interest in OCs comes from their fundamental properties. Among the 1784 currently known OCs, more than half of them have been poorly studied or even unstudied up to now (Piatti et al. 2011). The current paper is thus part of our continuing series whose goal is to obtain the main astrophysical properties of previously unstudied OCs using modern databases. Seventy-three percent of the clusters under investigation (11 of 15) are lying very near the Galactic plane ($-2.5^\circ \leq b \leq +4.2^\circ$). The most important advantage of using the NIR database (the Two Micron All Sky Survey, 2MASS) is the powerful detection of star clusters behind the thick hydrogen clouds, which are concentrated in the Galactic plane. Kronberger et al. (2006, hereafter K06) presented a list of stellar groups, the members of which are not confirmed to be open clusters or not.

Table 1 contains the equatorial and Galactic coordinates of all the fifteen clusters which are nominated for the present work. Five of them have their basic parameters, which were estimated by K06. These have been used as calibrated clusters in our procedures; they are designated by small

Table 1 Equatorial and Galactic Positions of the Clusters under Investigation

Cluster	α (h m s)	δ ($^{\circ}$ ' ")	G. Long. ($^{\circ}$)	G. Lat. ($^{\circ}$)
Riddle 4	02:07:22.7	+60:15:25	132.222	-1.238
Juchert 9 c	03:55:21.0	+58:23:30	58.838	58.392
Kronberger 1 c	05:28:21.0	+34:46:30	82.088	34.775
Teutsch 51 c	05:53:51.9	+26:49:47	88.466	26.829
Teutsch 11	06:25:24.4	+13:51:59	197.654	0.650
Alessi 53	06:29:24.5	+09:10:39	202.261	-0.664
Alessi 15	06:43:04.0	+01:40:19	210.489	-1.099
Juchert 12	07:20:56.7	-22:52:00	236.561	-4.123
Riddle 15	19:11:33.0	+14:50:04	48.357	2.455
Juchert 1	19:22:32.0	+12:40:00	47.728	-1.00
Patchick 89	19:59:33.0	+49:18:45	83.644	10.129
Toepler 1	20:01:17.6	+33:36:54	70.30	1.719
ADS 13292 c	20:02:23.3	+35:18:41	71.861	2.425
Teutsch 30 c	20:27:43.0	+36:04:32	75.354	-1.425
Teutsch 144	21:21:43.9	+50:36:36	92.735	0.459

c: Calibrated clusters which have the main parameters (ages, distances, and color excesses) estimated by K06.

letter (c) in Table 1. The photometric and structure properties for the remaining ten clusters have been studied here for the first time.

This paper is organized as follows. In Section 2, the data reductions have been presented; Star counts and field-star decontamination are presented in Sections 3 and 4 respectively. In Section 5, the photometric analysis yielding color magnitude diagrams (CMDs) is illustrated. The calibration of this work is obtained in Section 6. The luminosity and mass functions are presented in Section 7. The dynamical state is introduced in Section 8. Finally, the conclusion is devoted to Section 9.

2 DATA REDUCTION

The astrophysical parameters of the investigated clusters are observed J , H , and K_s photometry obtained from 2MASS of Skrutskie et al. (2006), available at (www.ipac.caltech.edu/2mass/releases/allsky).

2MASS is designed to close the gap between our current technical capability and our knowledge of the NIR Sky. It provides J , H , and K_s band photometry for millions of galaxies and nearly a half-billion stars (Carpenter 2001). While the 2MASS data alone can give important contributions to many fields of study, the scientific impact of many programs can be further enhanced by comparing 2MASS photometry with existing photometric measurements or by conducting follow-up observations. Two 1.3-m telescopes are used, one at Mount Hopkins in Arizona (Northern Survey) and the other at Cerro Tololo in Chile (Southern Survey). Each telescope was equipped with a three-channel camera, with each channel consisting of a 256×256 array of HgCdTe detectors. It is uniformly scanning the entire sky in the three NIR bands J (1.25 μm), H (1.65 μm) and K_s (2.17 μm). This survey has proven to be a powerful tool in the analysis of the structure and stellar contents of open clusters (Bica et al. 2003; Bonatto & Bica 2003). From Soares & Bica (2002), we can see that the errors are more significant for the K_s band at a given magnitude. So, J and H data have been used here to probe the faint stars of these clusters with more accuracy.

Data extraction has been performed using the known tool of VizieR for the 2MASS database. The investigated clusters' data have been downloaded under the following conditions:

- The clusters' data were extracted at a preliminary radius of about 20 arcmin from their obtained centers, and a nearby control field of the same area should also be downloaded;
- The clusters should have good images in the Digitized Sky Survey (DSS);
- They should clearly be rich clusters with prominent sequences in their CMDs;

- The photometric completeness limit at $J < 16.5$ mag is applied to the 2MASS data to avoid the over-sampling at the lower parts of their CMDs (cf. Bonatto et al. 2004);
- Stars with observational uncertainties in $J, H, K_s > 0.20$ mag have been eliminated;
- Membership criteria are adopted for the location of the stars in the CMD curves within $0.10 - 0.15$ mag around the zero age main sequence (ZAMS) (Claria & Lapasset 1986).

3 STAR COUNTS

3.1 Cluster Center's Determination

A cluster's center is defined as the center of the cluster's mass or the location of the maximum stellar density (the number of stars per unit area in the direction of the cluster). The cluster center (α, δ) has been estimated as explained in detail in Tadross (2005). All the clusters' centers in the present work are estimated and found to be in good agreement with K06 within errors of only a few arc seconds.

3.2 Clusters' Diameters Determination

A cluster's real diameter can be determined using the radial surface density of the stars of the cluster. The cluster border is defined as the surface which covers the entire cluster area and achieves enough stability in the background density, i.e. the difference between the observed density profile and the background one is almost equal to zero (for more details see Tadross 2005). It is noted that the determination of a cluster radius is made by the spatial coverage and uniformity of 2MASS photometry which allows one to obtain reliable data on the projected distribution of stars for large extensions around the clusters' centers (Bonatto et al. 2005). Although the spatial shape of the cluster may not be perfectly spherical, the fitting of the King (1962) model has also been applied to derive the cluster limited radius and the core radius. Figure 1 represents an example to derive the cluster's radius of Patchick 89. On the other hand, after finding the cluster's total mass (Sect. 7), the tidal radius can be given by applying the equation of Jeffries et al. (2001)

$$R_t = 1.46 (M_c)^{1/3}, \quad (1)$$

where R_t and M_c are the tidal radius and total mass of the cluster respectively.

4 FIELD-STAR DECONTAMINATION

Usually, field stars contaminate the CMDs of a cluster, particularly in faint magnitudes and red colors. Most clusters are located near the disk and/or the bulge of the Galaxy and show crowded contaminated main sequences. These contaminated stars are always seen as a vertical redder sequence parallel to the cluster's main sequence. CMDs of such clusters surely contain field stars that might lead to artificial isochrone solutions, i.e. one can always "fit" isochrones to such CMDs. Therefore, field-star decontamination must be used to define the clean CMDs and get better isochrone fitting. To achieve this, where at low latitudes the field stellar population is not homogeneous, a ring around the cluster with a radius four times the cluster limited radius is used as a nearby control field. From the comparison of the CMDs of such a cluster and its control field for a given magnitude and color range, we have counted the number of stars in the control field and subtracted this number from the cluster's CMDs. It can be noted that, for a well separated cluster, the mean density of the control field is always less than the central region of the cluster.

5 PHOTOMETRIC ANALYSIS (CMDs)

CMDs are established for the stars inside radii of $1', 2', 3'$, etc. from the optimized coordinates of the centers of the clusters under investigation. We have fitted the new theoretical isochrones computed

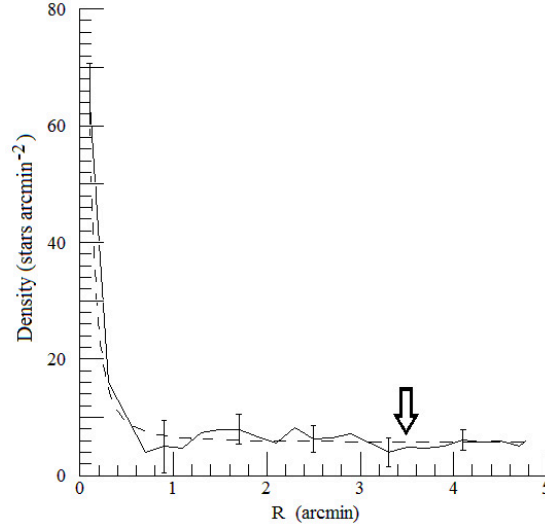


Fig. 1 An example for the radius determination of “Patchick 89,” the curved dashed line represents the fitting of the King (1962) model. The arrow refers to the point at which the radius is taken (at 3.5 arcmin). Also, the error bars represent 1σ Poisson scatter around the King fit. The background field density = 5.7 stars per arcmin², and the core radius = 0.07 arcmin.

with the 2MASS J , H and K_s filters (Bonatto et al. 2004; Bica et al. 2006) to derive the cluster parameters. The simultaneous fittings were attempted on the $J \sim (J - H)$ and $K_s \sim (J - K_s)$ diagrams for the inner stars, which should be less contaminated by the background field. If the number of stars is not enough for an accepted fitting, the next larger area is included, and so on. In this way, different isochrones of solar metallicity ($Z = 0.019$) of different ages have been applied on the CMDs of each cluster, fitting the lower envelope of the points matching the main sequence stars, turn-off point and red giant positions. Solar metallicity isochrones have been used with all our investigated clusters to unify the estimation of the main parameters, especially ages, distances and reddening. JHK color-color diagrams (CCDs) do not strongly depend on metallicity whereas reddening is represented as a straight vector on the CCDs. On the other hand, for relatively young clusters, the isochrone fitting could be somewhat tricky, since different pairs of distance moduli and color excesses could satisfactorily fit the cluster ZAMS. In order to avoid such degeneracy, a CCD has been plotted for each cluster and thus, guided by the Galactic reddening values of Schlegel et al. (1998), the realistic values of E_{J-H} and E_{J-K_s} can be estimated as shown in Figure 2. Although Schlegel’s reddening values are often overestimated at low Galactic latitudes, it is still a useful source of data. Comparing our estimated reddening values with the reliable ones of Schlegel’s, we found that our sample results are in agreement with Schlegel’s values within ranging errors of 0.08 mag. The distance modulus is taken at the proper values within a ranging fitting error of about ± 0.10 mag.

The observed data has been corrected for interstellar reddening using the coefficient ratios $A_J/A_V = 0.276$ and $A_H/A_V = 0.176$, which were derived from absorption ratios in Schlegel et al. (1998), while the ratio $A_{K_s}/A_V = 0.118$ was derived from Dutra et al. (2002). Therefore $E_{J-H}/E_{B-V} = 0.309$, $E_{J-K_s}/E_{B-V} = 0.488$, and then $E_{J-K_s}/E_{J-H} \approx 1.6$ can be derived easily from the above ratios, where $R_V = A_V/E_{B-V} = 3.1$.

Once the distance from the Sun ($R_\odot$) is estimated, the distance from the galactic center (R_G) and the projected distances on the galactic plane from the Sun ($X_\odot$ and $Y_\odot$) and the distance from galac-

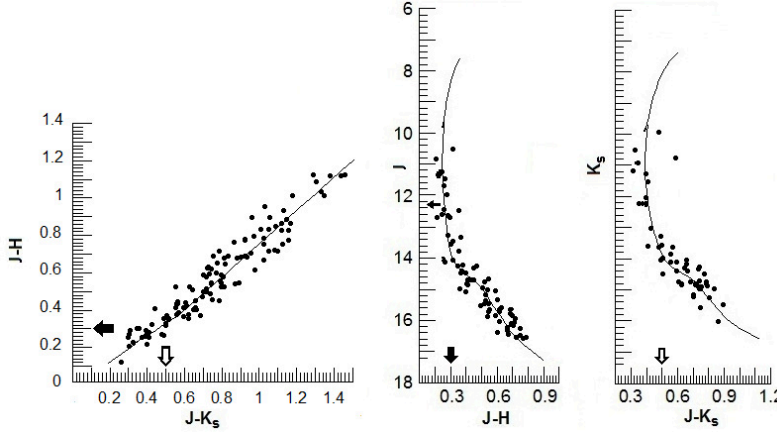


Fig. 2 JHK color-color and color-magnitude diagrams for the members of Riddle 4, as an example of the clusters under investigation.

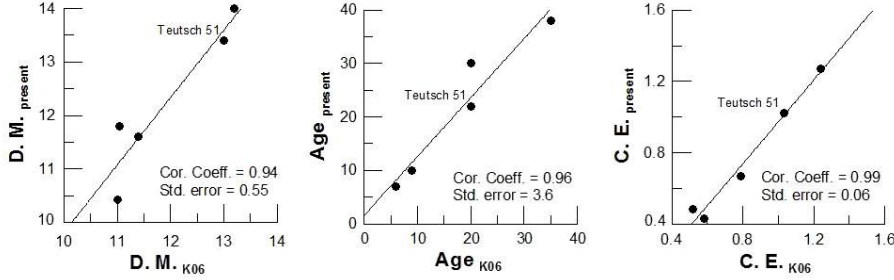


Fig. 3 Comparing our main results (distance moduli, ages, and color excesses) of the five clusters with those of K06 (the parameters of Teutsch 51 are taken from Koposov et al. 2008). The correlation coefficients and standard errors are shown for each relation respectively.

tic plane ($Z_{\odot}$) can be determined. For more details about the estimation of the Galactic geometric distances see Tadross (2011).

6 CALIBRATION OF THE PRESENT WORK

The main parameters of five previously studied clusters (Juchert 9, Kronberger 1, ADS 13292, Teutsch 30 and Teutsch 51) have been re-estimated in the present work and compared with those taken from K06. Note that Kronberger 1 and Teutsch 51 are taken from Koposov et al. (2008).

In this context, the main parameters of Kronberger 1 have been compared with Dias & Webda catalogs, K06 and Koposov et al. (2008). We found that our results agree with those of Dias & Webda and K06 more than those of Koposov et al. (2008). The main results of Teutsch 51 are found to agree somewhat with those of Koposov et al. (2008), more than those of K06. However, Figure 3 displays comparisons of the present main results (distance moduli, ages and color excesses) with the previous ones of K06. It is clear that the derived parameters are reasonable and very close to the published ones, which indicates that our reduction procedure using the 2MASS database is very reliable.

7 LUMINOSITY AND MASS FUNCTIONS

The luminosity function (LF) gives the number of stars per luminosity interval, or in other words, the number of stars in each magnitude bin of the cluster. It is used to study the properties of large groups or classes of objects, such as the stars in clusters or the galaxies in the Local Group.

In order to estimate the luminosity function, firstly we should count the observed stars in terms of absolute magnitude after applying the distance modulus. The magnitude bin intervals are selected to include a reasonable number of stars in each bin and derive the best possible statistics of the luminosity and mass functions. From LF, we can infer that massive bright stars seem to be centrally concentrated more than those with low mass and fainter ones (Montgomery et al. 1993).

As is currently understood, the LF and mass function (MF) are correlated with each other according to the mass-luminosity relation. The accurate determination of both of them (LF & MF) suffers from some problems, e.g. the field contamination of cluster members and the observed incompleteness at low-luminosity (or low-mass) stars, which may affect even poorly populated, relatively young clusters (Scalo 1998). On the other hand, the properties and evolution of a star are closely related to its mass, so the determination of the initial mass function (IMF) is needed, which is an important diagnostic tool for studying large quantities of star clusters. The IMF is an empirical relation that describes the mass distribution (a histogram of stellar masses) of a population of stars in terms of their theoretical initial mass (the mass they were formed with). Scalo (1998) defined the IMF in terms of a power law as

$$\frac{dN}{dM} \propto M^{-\alpha}, \quad (2)$$

where $\frac{dN}{dM}$ is the number of stars in mass interval ($M: M + dM$) within a specified volume of space, and α is a dimensionless exponent. The IMF for massive stars ($>1 M_{\odot}$) has been studied and well established by Salpeter (1955), where $\alpha = 2.35$. This form of the Salpeter IMF shows that the number of stars in each mass range decreases rapidly with increasing mass, see Figure 4.

The mass of each star in the investigated clusters has been estimated from a polynomial equation developed from the data of the solar metal abundance isochrones (absolute magnitudes vs. actual masses) at a specific age of each cluster individually. The summation of multiplying the number of stars in each bin by the mean mass of that bin yields the total mass of each cluster.

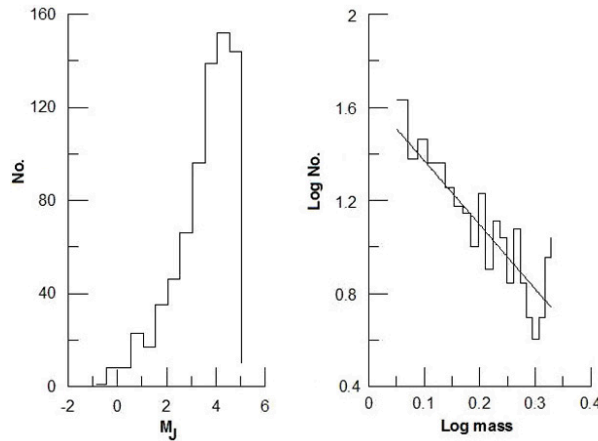


Fig. 4 An example of luminosity and mass functions for “Teutsch 144.”

8 DYNAMICAL STATE

The relaxation time (T_R) of a cluster is defined as the time in which the cluster needs, from the very beginning, to build itself and reach the stability state against the contraction and destruction forces, such as gas pressure, turbulence, rotation, and the magnetic field (cf. Tadross 2005). T_R depends mainly on the number of members, the cluster radius and the mean total mass. It can be written as

$$T_R = \frac{8.9 \times 10^5 \sqrt{N} \times R_h^{1.5}}{\sqrt{m} \times \log(0.4N)}, \quad (3)$$

where N is the number of the cluster members, R_h is the radius containing half of the cluster mass in parsecs, and m is the average mass of the cluster in solar units (Spitzer & Hart 1971). Using the above equation we can estimate the dynamical relaxation time of each cluster and compare it with its age. If the cluster's age is found to be greater than its relaxation time, then the cluster is dynamically relaxed, and vice versa.

9 CONCLUSIONS

Our analysis has been applied to estimating the astrophysical parameters of some newly discovered stellar groups according to K06. Hence, ten real open star clusters have been detected, which have calculated stellar density profiles with IMF slopes around the Salpeter's (1955) value. Also, the ages of these clusters are found to be greater than their relaxation times, which imply that these clusters are indeed dynamically relaxed.

All parameters of the investigated clusters are listed in Table 2, and the CMDs of each cluster are shown in Figure 5.

Table 2 Derived Astrophysical Parameters for the Investigated Clusters

Cluster	Age (Myr)	$m - M$ (mag)	$R_\odot$ (pc)	E_{B-V} (mag)	R (')	R_c (')	R_L (pc)	R_t (pc)	R_G (kpc)	$X_\odot$ (pc)	$Y_\odot$ (pc)	$Z_\odot$ (pc)	Mass $M_\odot$	Mem.	T_R (Myr)
Riddle 4	50	12.3	1993±92	0.91	2.2	0.13	1.3	9	9.95	1339	1475	-43	230	120	2.1
Juchert 9 c	35	14.0	4694±216	0.73	1.8	0.16	2.5	8	7.28	-1273	2105	3998	175	65	4.2
Kronberger 1 c	20	11.6	1715±79	0.48	2.2	0.30	1.1	8	8.44	-194	1396	978	195	140	2.1
Teutsch 51 c	800	13.0	2618±121	1.03	2.1	0.17	1.6	9	8.83	-63	2336	1182	210	136	3.4
Teutsch 11	500	13.3	3443±159	0.70	3.0	0.26	3.0	9	11.83	3280	-1044	39	220	155	9.6
Alessi 53	500	12.4	2360±109	0.61	6.4	0.29	4.4	10	10.72	2184	-894	-27	365	255	19.3
Alessi 15	450	12.8	2509±116	0.91	6.0	0.12	4.4	13	10.74	2161	-1273	-48	735	495	22.9
Juchert 12	300	13.2	3016±139	0.91	5.0	0.12	4.4	9	10.47	1658	-2510	-217	250	125	13.5
Riddle 15	500	12.6	1925±89	1.33	2.5	0.08	1.4	11	7.36	-1278	1437	82	385	275	3.6
Juchert 1	400	13.0	2286±105	1.36	1.6	0.05	1.1	9	7.16	-1538	1691	-40	200	157	2.1
Patchick 89	1600	12.3	2646±122	0.21	3.5	0.07	2.7	9	8.62	-288	2588	465	220	155	8.1
Toepler 1	400	13.0	2890±133	0.79	4.0	0.10	3.4	15	8.00	-974	2719	87	1120	668	16
ADS 13292 c	10	10.4	1021±47	0.42	1.5	0.16	0.4	15	8.24	-318	969	43	995	78	0.2
Teutsch 30 c	35	11.7	1387±64	1.12	1.8	0.19	0.7	11	8.26	-350	1341	-34	455	111	0.6
Teutsch 144	800	11.8	1704±79	0.73	5.0	0.30	2.5	14	8.75	81	1702	14	890	745	12.4

c: Calibrated clusters; see Table 1. Columns from left to right display, respectively, cluster name, age, distance modulus, distance from the sun, reddening values, angular radius, core radius, linear radius, tidal radius, distance from the Galactic center, the projected distances on the Galactic plane from the sun, X and Y , the distance from the Galactic plane, total mass, membership number, and time of relaxation.

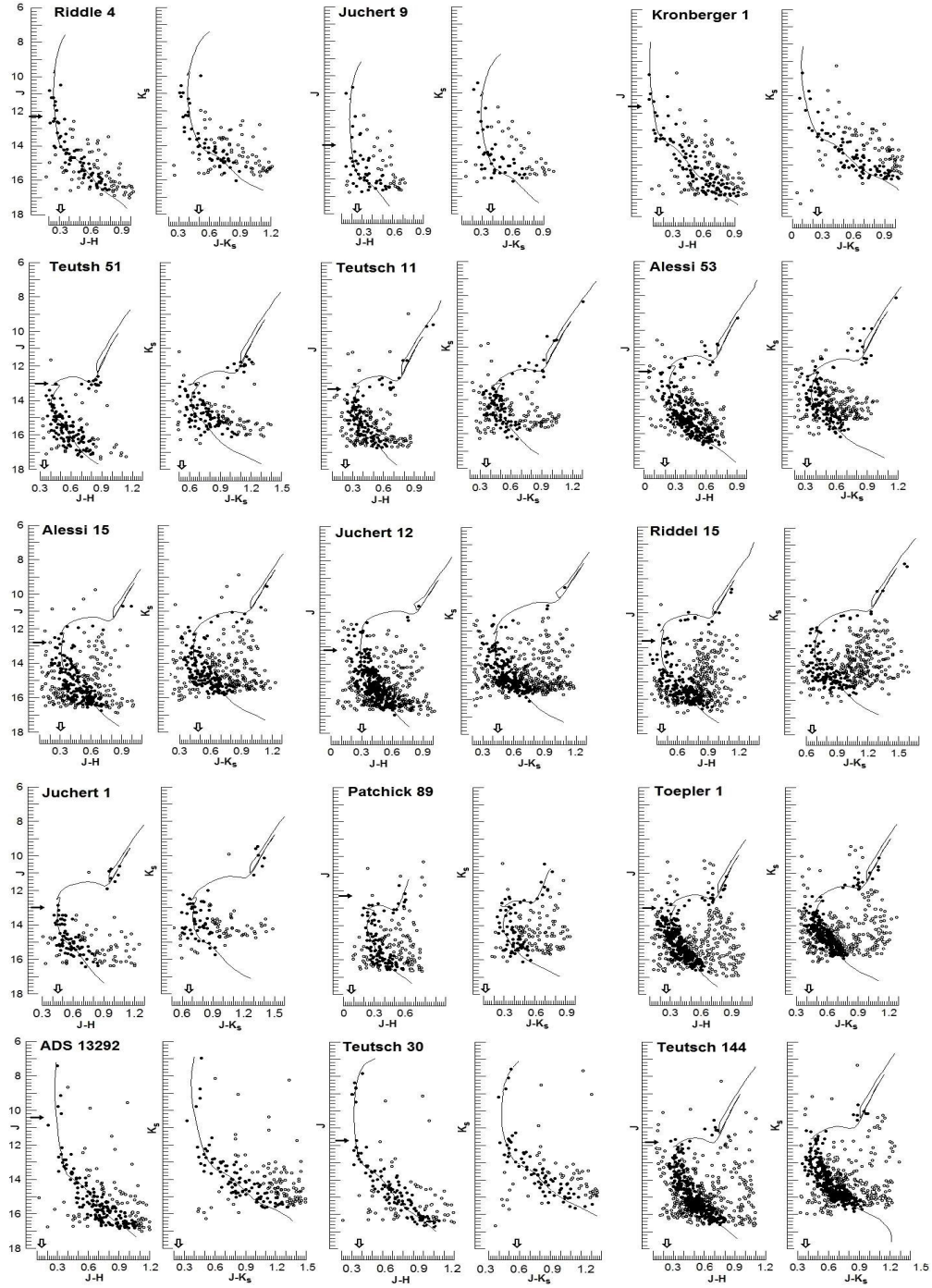


Fig. 5 Color-magnitude diagrams of the clusters under investigation. Filled and empty circles denote the stars lying close to and far from the fitted isochrones (photometric probable members and field stars) respectively. Horizontal and vertical arrows refer to the estimated distance moduli and the values of the color excesses in both diagrams for each cluster respectively.

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