Open clusters in our Galaxy: A joint Bulgarian-German project

Georgi Petrov
Institute of Astronomy and Rozhen NAO, Bulgarian Academy of Sciences
petrov@astro.bas.bg

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Abstract. The project started during 1996 and it have been initiated by prof. W. Seggewiss from Hoer List observatory, Bonn University. The project is conformable to the observational possibilities of the Rozhen NAO and tke Belogradchik AO. From the program list with ca. 70 objects for further investigation 30 open cluster from three different groups were selected: bright nearby clusters, open clusters in the direction of the galactic anticenter and probably binary open clusters. Ca. 900 CCD frames in the system UBVRI from the 2-m RCC telescope and in system BVRI from the 60-cm telescope have been taken for 30 open clusters, including 7 bright clusters, 16 (8 x 2) probably double open clusters and 7 clusters in the anticenter of the Galaxy. In addition data from 2-MASS have been used. A PSF photometry has been done. Here some results of the investigation of probably binary open clusters are presented. A good candidates for second binary clusters a Pismis 6 and Pismis 8.

Key words: Galaxy: open clusters, structure, binary open clusters, photometry, ages, metalicity

Разсеяни зевздни купове в Нашата галактика: съвместен българо-германски проект

Георги Петров

Проектът стартира през 1996 г по инициатива на проф. Сегевис – Бон, Обсерватория Хое Лист. Той е съобразен с наблюдателните възможности на НАО – Рожен и АО – Белоградчик. От програмния списък с около 70 купа за изследване бяха подбрани 30 разсеяни купа от различни групи: близки ярки купове, разсеяни купове в посока на антицентъра на Галактиката и вероятни двойни разсеяни купове. Получени са и са фотометрирани около 900 ССД-кадри в системата UBVRI на 2-м RCC телескоп и BVRI на 60-см теледссоп. В допълниние са използвани и данни от 2MASS обзора. Тук са представени главно резултатите по изследване на двойни разсеяни купове. Куповете Pismis 6 и Pismis 8 са вероятни членове на двойна система.

Introduction

Open clusters are physically related groups of stars held together by gravitational attraction. Originating from large cosmic gas and dust clouds, all member stars are of similar age and as all the stars in a cluster formed from the same diffuse nebula, they are all of similar initial chemical composition. Over 2100 open clusters are known in our Milky Way Galaxy (Dias 2002), and this is only a small percentage of the total population which is probably some factor higher. Nearly half of them have been observed so far in at least one photometric system and ca. 420 open clusters are comparatively well studied. The number of stars per cluster goes from several tens for the poorest objects, to several thousands for the most prominent clusters. According to WEBDA http://www.univie.ac.at/webda, open clusters are of great interest for astrophysicists because of these properties:

– The stars are at the same distance

This is true for most objects, because the effect of the cluster volume is smaller than the usual errors on magnitude determination and negligible in comparison with other effects like binarity and rotation. There is one cluster, namely the Hyades, for which a precise determination of the distances of the individual stars have been determined, thanks to the Hipparcos satellite.

– The stars have the same age

This assumption is true for intermediate-age and old clusters, but is questionable for very young and extremely young open clusters. The problem arises from our lack of knowledge on how a molecular cloud contracts and which is the sequence of stellar formation. Which one of the low mass stars or the massive stars do form first? Obviously, in young clusters, the massive stars are already on the main sequence or even started their evolution away from the main sequence, while the low mass stars are still in a phase of contraction. This is a domain in which the contribution of star clusters to the understanding of the laws of star formation has been and will be fundamental.

– The stars have the same chemical composition

So far, it has not been possible to prove the opposite and this is a good assumption. It implies that the material from which the stars formed was rather homogeneous. But the precise determination of the chemical composition is a difficult task and the uncertainties on the results are still rather large.

– The stars differ in their mass

Open clusters usually contain stars over a large range of mass – from more than 80 solar masses in the extremely young clusters, to stars less massive than 0.08 solar masses, i.e. the limit for brown dwarfs. Therefore, comparing the "standard" Hertzshprung-Russel Diagram (HRD), derived from nearby stars with sufficiently well-known distances, or the theory of stellar evolution, with the measured color-magnitude diagram (CMD) of star clusters, provides a considerably good method to determine the distance of the star clusters. Comparing their HRD with stellar theory provides a reasonable way to estimate the age of star clusters. The theoretical study of stellar evolution has provided convincing evidence that the stars of a cluster are all roughly of the same age, and thus have formed within a short period of time on the cosmic time scale, i.e. their HRDs represent isochrones, or pictures of stars of all the same age. The result that all the cluster HRDs can be explained by the theory of stellar evolution gives convincing evidence for this theory.

1 Description of the project

Several years ago a joint project "Structure of the GALAXY – open clusters in our Galaxy" have been started, included astronomers from University of Bonn and Hoer List Observatory (prof. W. Seggewis and PhD student A. Dieball) and Institute of Astronomy of the Bulgarian Academy of Sciences (prof. B. Kovachev, assoc.prof. G.Petrov and PhD student). The project itself includes three directions of investigations: selected open clusters in the direction of anticenter, bright open clusters and probably binary open clusters.

Studies of selected open clusters in the direction of anticenter was devoted to add the available data for the spiral structure of our Galaxy. Here we studied seven such cluster.

Some bright open clusters were chosen to complete CMDs and to determine their ages. The age is the most important parameter we are interested in (for example see Bica et al., 1993). For the larger clusters, i.e. such with large angular diameter, mosaic from several frames in each color was used to cover all the field of the cluster. For all of them the central part with the brightest stars was investigated.

A binary open star cluster could be defined as an object consisting of two open clusters. They can be basically described as:
(i) binary physical systems with common origin formed together from one and the same Giant Molecular Cloud (GMC), having comparable age and chemical composition – this is a true binary cluster;
(ii) binary physical systems arising from clusters formed in different part of the Galaxy and forming a pair with mutual gravitational capture – these clusters are expected to have different ages and chemical composition.

Table**??** represents the program list together with observed clusters marked.

2 Realization of the project

For a period of 4 years, end of 1996, 1997, 1998 and 1999, the next basic steps have been finished in the project:

1) Installed and tested CCD-camera ST-8 (Alexander fon Humboldt support) on the 2-m RCC telescope, latterly becomes as basic camera at 60-cm telescope at the Belogradchik observatory

2) Preliminary testing of the simple focal reducer on the 60-cm telescope

3) Ca. 900 CCD frames in U,B,V,R,I from the 2-m RCC telescope and in B,V,R,I from the 60-cm telescope have been taken for 30 open clusters, including 7 bright clusters, 16 (8 x 2) probably double open clusters and 7 clusters in the anticenter of the Galaxy (see Tabl.1).

4) All the frames were reduced in uniform manner and PSF photometry has been carried out. Details for all our observations and reductions could be found in Petrov & Kopchev (2008). For photometric reduction Stetson's DAOPHOT and ALLSTAR program packages, implemented in MIDAS, were used.

Standards in several star clusters were used – the clusters M 92 (mainly), NGC 7790, NGC 4147 and M 67. Improved standard sequences from the latest years have been taken from the works of Cristian et.al. (1985) – Standard sequences in M92, N4147, N7790, N7006, N2264, N2419 in B,V,R,I; Odewahn et.al. (1992) – Improved standard sequences in N7790, N4147 and N7006 in B,V,R, as well as Majewski et al. (1994) – Standard sequences in M92, SA 57 and Hercules in U,B,V,R,I. The Fig.**??** represents the color-magnitude diagrams for the clusters NGC 1907 and NGC 1912, build by Petrov & Kopchev (2008).

Following are some important data about telescopes and CCD cameras used: 1) 2-m RCC + CE200: Unbinned – scale 0.31 arcsec/px; Binned x2 – scale 0.31 arcsec/px
2) 2-m RCC + ST-8: Unbinned – scale 0.12 arcsec/px; Binned x2 – scale 0.24 arcsec/px; Binned x3 – scale 0.36 arcsec/px.
3) 2-m RCC + Vers Array 1300B: Unbinned – 0.26 arcsec/px.
4) 60-cm + ST-8: Unbinned – scale 0.21 arcsec/px; Binned x2 – scale 0.42 arcsec/px; Binned x3 – scale 0.63 arcsec/px.

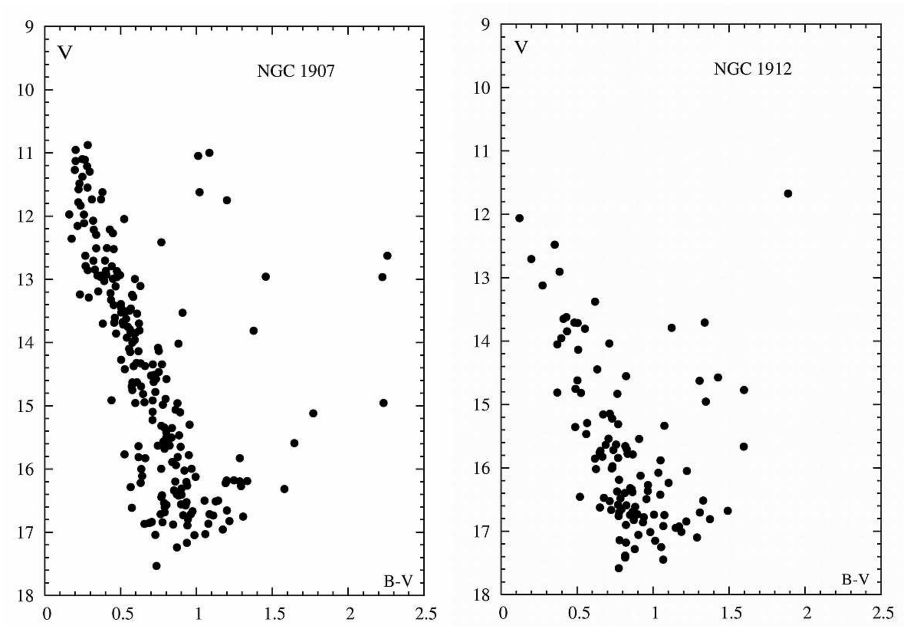

Fig. 1. Color-magnitude diagrams for open clusters NGC 1907 and NGC 1912

3 Probably binary clusters

During the last years testing the probably binary clusters become a leading direction of our investigation. PhD student V. Kopchev continues the investigations of open clusters, adding new observational data.

The existence of star cluster pairs in our neighboring galaxies – Magellanic Clouds, is established from several authors: Bhatia & Hatzidimitriou (1988), Vallenariet al. (1998), Dieball & Grebel (2000), de Oliveira et al. (2000). Dieball (2002) proposed a catalog of binary and multiple cluster candidates in the Large Magellanic Cloud with 473 members. Amongst more than 2100 open clusters in our Galaxy only one is well established double or binary cluster - 'h & χ Persei' (NGC 869 and NGC 884).

So, our Galaxy seems to show a lack of binary or multiple clusters when compared with the Magellanic Clouds. Whether this apparent lack of binary clusters in the Galaxy is real or not is a subject to discussion and several lists of binary open clusters candidates are proposed and studied by various authors: Lynga & Wramdemark (1984), Pavlovskaya & Filippova (1989), Tignanelli et al. (1990), Subramaniam et al. (1995), Loktin (1997), Muminov et al. (2000). Unfortunately, all lists of these authors do not overlapped themselves well. One of the most complete and well studied list is the one of Subramaniam et al. (1995) with 18 candidates pairs, including all program pairs.

Two principle questions arise:

- Is the difference between our Galaxy and Magellanic Clouds co. binary open clusters is real?
- Are there another typical binary open clusters as 'h and χ Persei' in our Galaxy?

Answering to these questions we can use the methods of extragalactic and stellar astronomy. One step is to define correctly "what binary open clusters are?". As working definition we accept: two clusters at distances ≈ 20 pc and with differences in the ages ≤ 10 Myrs. Next steps are analyzing of the CMDs and determining of the ages of the clusters. Below are some illustrations of age determination for several probably binary clusters to answer of the questions above.

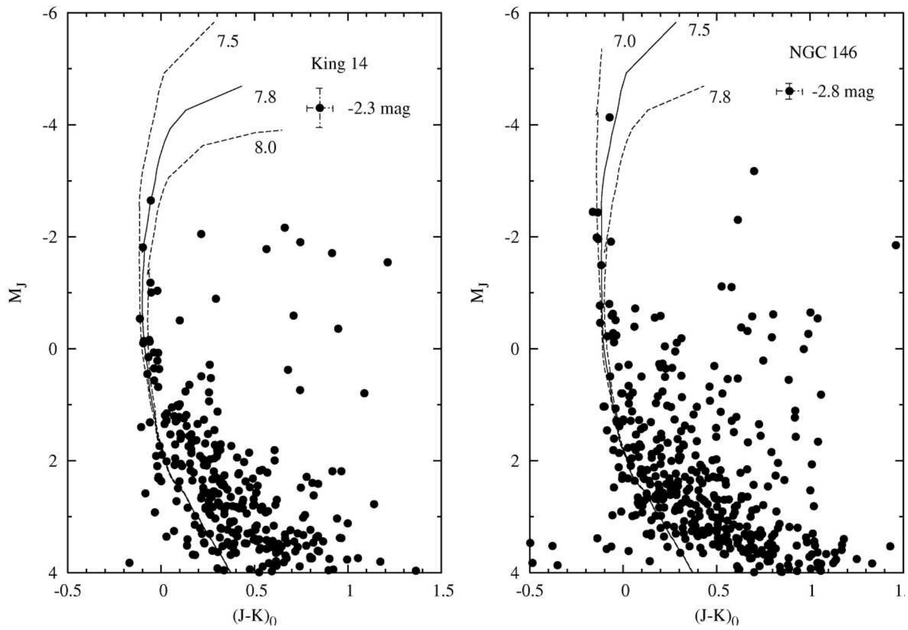

Fig. 2. Age determination for King14+NGC146 pair

Using 2MASS J and Ks photometry for the two open star clusters King 14 and NGC 146, and fitting CMDs with isochrones based on the Geneva models, the ages log(age) = 7.8 (63 ± 8 Myr) for King 14 and log(age) = 7.5 (32 ± 8 Myr) for NGC 146 have been determined (Kopchev et al, 2005). The CMDs are shown in Fig.**??**.

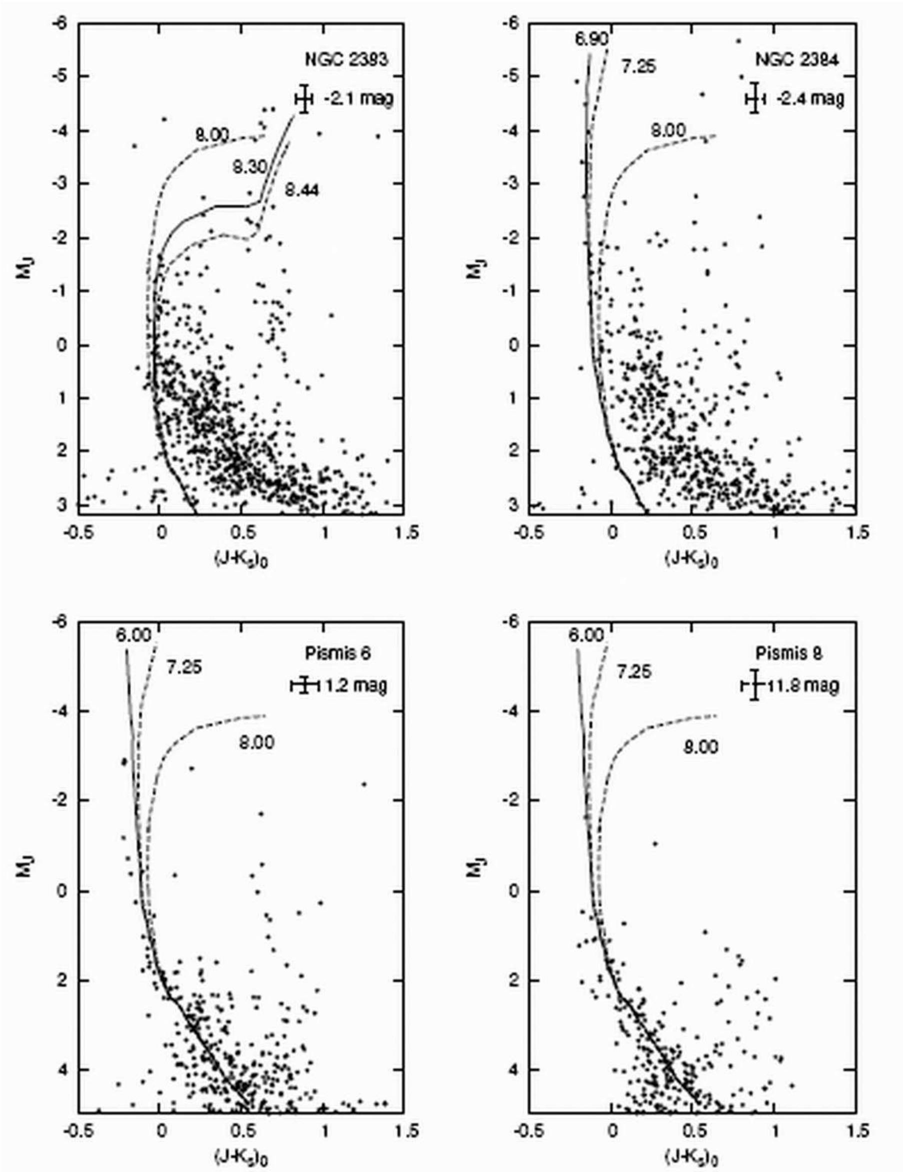

Fig. 3. Age determination for NGC2383+NGC2384 and Pismis6+Pismis8 pairs

Based on 2MASS J and Ks photometry for the open star clusters NGC 2383, NGC 2384, Pismis 6 and Pismis 8 and using CMDs with isochrones fit, the ages of log(age) = 8.3 (200 ± 6 Myr) for NGC 2383 and log(age) = 6.9 (8 ± 6 Myr) for NGC 2384 have been determined. For Pismis 6 and Pismis 8 we adopted a range of log(age) = 6–7 (1–10 Myr). Because their similar ages, Pismis 6 and Pismis 8 may been formed in single Giant Molecular Cloud, and they are a good candidates for a binary open cluster (Kopchev et al, 2006). The CMDs are shown in Fig.**??**.

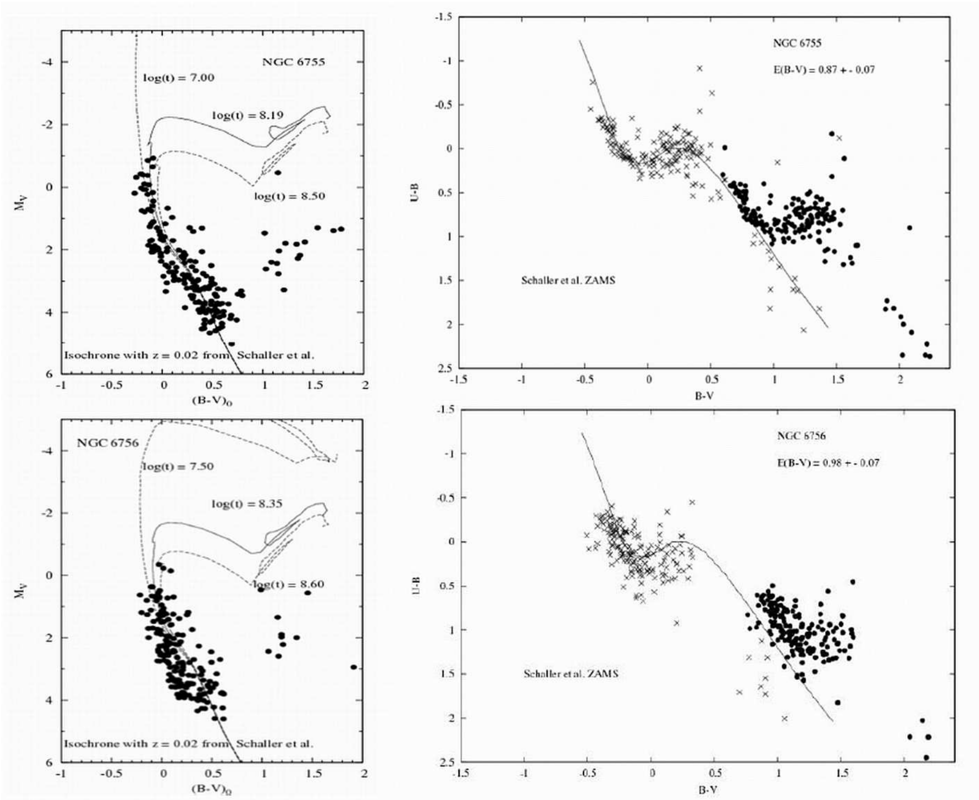

Fig. 4. Age determination for NGC6755+NGC6756 pair

A CCD UBVRI photometry of the possible binary open star cluster NGC 6755/NGC 6756 have been carried out. Our aim is to confirm or disapprove the binarity comparing their ages. For NGC 6755 log(age) = 8.19 (155 ± 8 Myr) and for NGC 6756 log(age) = 8.35 (224 ± 8 Myr) were found (Kopchev et al, 2007). This large age difference rejects the binarity based on age determination only. The CMDs are shown in Fig.**??**.

An age of 224 ± 25 Myr and distance 831 ± 72 pc was determined for NGC 7031 and 178 ± 25 Myr, 955 ± 84 pc for NGC 7086, respectively (Kopchev & Petrov, 2008). The respective CMDs are shown in Fig.**??**.

Conclusions

Based on our determinations of ages and metalicities of the open clusters investigated one could not consider surely these systems are binary open clusters. Because of they similar ages, Pismis 6 and Pismis 8 may be formed in a single Giant Molecular Cloud, and they are a good candidate for a binary system.

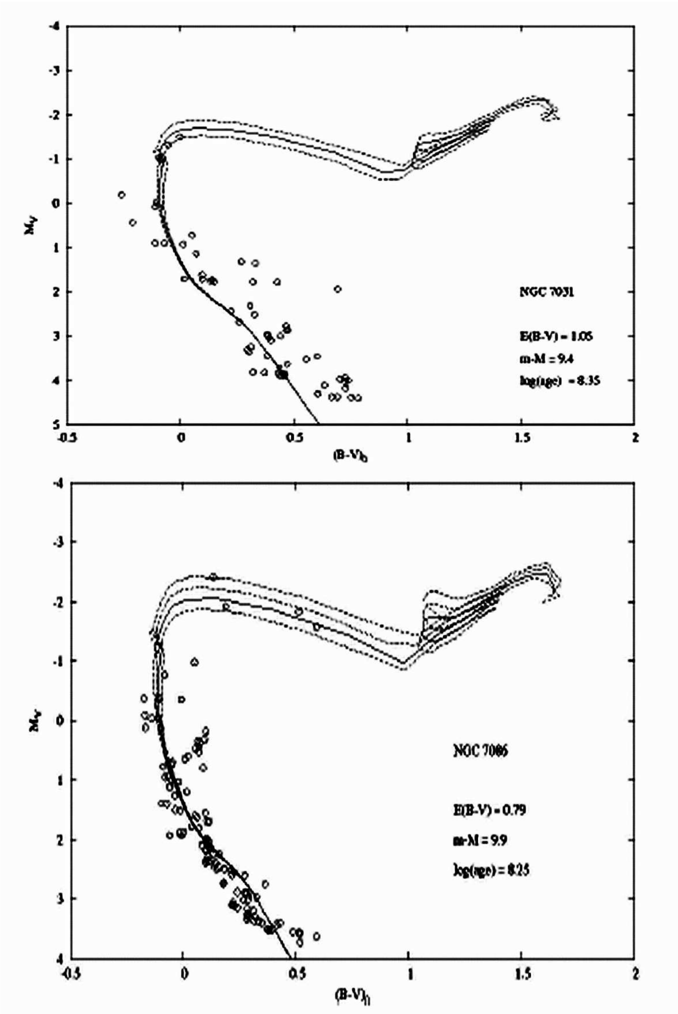

Fig. 5. Age determination for NGC7031+NGC7086 pair

The investigations continue involving the data from 2MASS mission (see e.g. Kopchev et al., 2006) and all the data from WEBDA and Open Clusters and Galactic Structure WEB-site http://www.astro.iag.usp.br/ wilton/.

References

Bhatia R., Hatzidimitriou D., 1988, *MNRAS*, 230, 215
Bica E., Ortolani S., Barbuy B., 1993, *A&A*, v.270, p.117
Cristian et.al., 1985, *PASP*, 97, 363
de Oliveira M. et al., 2000, *A&AS*, 146, 57
Dias S. et al., 2002, *A&A* 389,871
Dieball A., 2002, *Ph.D. Thesis*, University of Bonn
Dieball A., Grebel E., 2000, *A&A*, 358, 897
Kopchev V., Nedjalkov P., Petrov G., 2005, *C.r.Bulg.Acad.Sci.*, 58, 1363
Kopchev V., Petrov G., 2006, *Bulg. Astron. J.*, 8, 157
Kopchev V., Petrov G., Slavcheva L., 2007, *Bulg.J.Ph.*, 34, 236
Kopchev V., Petrov G., 2008, *Astronomische Nachrihten*, 329, 845
Kopchev V., Petrov G., Nedjalkov P., 2006, *Bulg.J.Ph.*, 32, 68
Loktin A., 1997, *A&A Transactions*, 14, 181
Lynga G., 1987, Catalogue of open star cluster data
Lynga G., Wramdemark S., 1984, *A&A* 132, 58
Majewski S. et al., 1994, *PASP*, 106, 1258
Muminov M. et al., 2000, *A&A Transactions*, v.18, p.645
Odewahn et.al., 1992, *PASP*, 104, 553
Odewahn S., Bryja C., Humphreys R., 1992, *PASP*, 104, 553
Pavlovskaya E., Filipova A., 1989, *Sov. Astron.* 33, 602
Petrov G. et al., 2001, *A&A*, 376, 745
Petrov G., Kopchev V., 2008, *Publ. Astron. Soc. Rudjer Bozhkovic*, 9, 405
Subramaniam A. et al., 1995, *A&A*, 302, 86
Tignanelli H. et al., 1990, *Rev. Mex. A&A*, 21, 305
Valenari C., Bettoni D., Chiosi C., 1998, *A&A*, 331, 506

Table 1. Open Clusters – program list

Name	RA	Decl.	Year	Remarks
Stock 19	00 01 48.0	55 45 00	1950	
Stock 20	00 22 06.0	62 22 00	1950	
NGC 136	00 28 42.0	61 15 00	1950	
King 14	00 29 00.0	62 53 00	1950	observed, D-1a
King 15	00 30 06.0	61 35 00	1950	
NGC 146	00 30 12.0	63 01 00	1950	observed, D-1b
King 16	00 40 42.0	63 55 00	1950	
Berke 61	00 45 24.0	66 58 00	1950	observed, anticenter
NGC 366	01 03 18.0	61 58 00	1950	
Stock 3	01 09 06.0	62 04 00	1950	
NGC 433	01 12 06.0	59 52 00	1950	observed, anticenter
Trumpl 1	01 32 18.0	61 02 00	1950	
NGC 609	01 33 42.0	64 18 00	1950	observed, anticenter
NGC 637	01 39 24.0	63 45 00	1950	
NGC 657	01 40 30.0	55 37 00	1950	
Czern 5	01 51 36.0	61 05 00	1950	
Czern 6	01 58 24.0	62 38 00	1950	
Basel 10	02 15 12.0	58 05 00	1950	observed, anticenter
Berke 63	02 15 48.0	63 31 00	1950	
Berke 64	02 17 06.0	65 40 00	1950	
Tomba 4	02 25 06.0	61 34 00	1950	
King 4	02 32 00.0	58 47 00	1950	
Czern 12	02 35 36.0	54 43 00	1950	
NGC 1193	03 02 30.0	44 11 00	1950	observed, anticenter
NGC 1220	03 08 00.0	53 09 00	1950	
Czern 15	03 19 30.0	52 04 00	1950	
NGC 1348	03 30 12.0	51 16 00	1950	observed, anticenter
NGC 1513	04 06 18.0	49 23 00	1950	observed, D-2a
Mayer 2	04 15 36.0	53 05 00	1950	
NGC 1545	04 17 06.0	50 08 00	1950	observed, D-2b
NGC 1624	04 36 36.0	50 21 00	1950	
Rupr 148	04 42 54.0	44 39 00	1950	
NGC 1663	04 45 48.0	13 04 00	1950	
NGC 1724	04 59 42.0	49 26 00	1950	
King 17	05 05 00.0	39 01 00	1950	
Berke 69	05 21 18.0	32 36 00	1950	
NGC 1883	05 22 12.0	46 30 00	1950	observed, anticenter
NGC 1907	05 24 42.0	35 17 00	1950	observed, D-3a
NGC 1912	05 25 18.0	35 48 00	1950	observed, D-3b
NGC 1931	05 28 06.0	34 13 00	1950	
Berke 20	05 30 24.0	00 11 00	1950	
NGC 1977	05 32 54.0	-04 52 00	1950	
Coll 74	05 45 48.0	07 23 00	1950	
Berke 72	05 47 18.0	22 11 00	1950	
Berke 22	05 55 42.0	07 50 00	1950	
Basel 8	06 31 30.0	08 07 00	1950	observed, D-4a
NGC 2251	06 32 00.0	08 24 00	1950	observed, D-4b
NGC 2383	07 24 40.0	-20 56 54	2000	D-5a
NGC 2384	07 25 10.0	-21 01 18	2000	D-5b
Pismis 6	08 39 04.0	-46 13 36	2000	D-6a
Pismis 8	08 41 36.0	-46 16 00	2000	D-6b
NGC 6755	19 05 18.0	04 09 00	1950	observed, D-7a
NGC 6756	19 06 12.0	04 36 00	1950	observed, D-7b
NGC 6811	19 38 12.0	46 33 59	2000	observed, bright
NGC 6819	19 41 18.0	40 11 00	2000	observed, bright
NGC 6939	20 31 24.0	60 38 00	2000	observed, bright
NGC 6996	20 54 42.0	44 26 00	1950	observed, D-8a
Coll 428	21 01 24.0	44 23 00	1950	observed, D-8b
NGC 7031	21 05 42.0	50 38 00	1950	observed, D-9a
NGC 7086	21 28 48.0	51 22 00	1950	observed, D-9b
NGC 7209	22 05 12.0	46 29 59	2000	observed, bright
NGC 7243	22 15 18.0	49 52 59	2000	observed, bright
NGC 7245	22 15 18.0	54 19 59	2000	observed, bright
NGC 7261	22 20 24.0	58 04 59	2000	observed, bright
NGC 7429	22 53 54.0	59 43 00	1950	observed, D-10a
Mark 50	23 13 06.0	60 12 00	1950	observed, D-10b

Rem.: Pismis 6 = NGC 2645; D-xx means 'DOUBLE'.