

Open cluster remnants : an observational overview

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Abstract. The state of the art in the current research on the final stages of Open Star Clusters dynamical evolution is presented. The focus will be on observational studies and their achievements. By combining together photometric, spectroscopic and astrometric material, a new look at this exciting topic is now possible, thus providing a solid observational foundation for a new generation of theoretical studies on the subject.

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1. Introduction

Open Star Clusters are fragile ensembles of stars which hardly survive to the hostile Galactic disk environment. The Galaxy tidal field and close encounter with Giant Molecular clouds are the two most effective external processes driving dissolution of star clusters. Both numerical simulations (Terlevich 1987; Theuns 1992; de la Fuente Marcos 1997; Tanikawa and Fukushige 2005) and the observed age distribution of star clusters (Wielen 1971; Carraro et al. 2005a) suggest that the lifetime of most open clusters does not exceed 500 Myr.

Apart from external perturbations, a star cluster loses its stellar content during a three stages evolution (de la Fuente Marcos 2001). (1) Soon after its birth, a cluster quickly acquires a core-halo structure (Baume et al. 2004), being the halo formed by low mass stars moved outwards due to close encounters occurred in the inner regions. (2) The halo stars possess very eccentric orbits and, when passing close to the cluster centre,

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get kicked off violently, thus escaping the cluster. This is observationally seen in the low mass depleted main sequences of star clusters like NGC 3680 and NGC 7762 (Patat and Carraro 1995). (3) The combined effect of external perturbations and long distance encounters lead a cluster to slowly dissolve and merge with the general Galactic disk field.

The final residue of open star cluster evolution is often called an open cluster remnant (OCR). These ghostly objects are characterized by very low surface brightness and they are hardly distinguishable against the background field stars (de la Fuente Marcos 1997; 2001).

Recently, these objects have started to receive some attention mainly because they play a fundamental role in our understanding of the subject of open cluster evolution and dissolution, and, ultimately, on the origin of the field star population. Photometry, kinematics, binary percentage and membership are basic data to constrain N -body models of cluster dissolution, which aim to reconstruct –for instance– the Initial Mass Function (IMF) of Galactic clusters (e.g. de la Fuente Marcos 1997; Carraro et al. 2005b).

On the other hand, they may be what still remains of old clusters, and therefore once discovered they can allow us to improve on the statistics of old open clusters in the Galactic disk. These objects are widely recognised to be of paramount importance for our understanding of the formation and early evolution of the Galactic disk (Carraro et al. 1999).

2. A bit of history

The interest for dissolving star clusters dates back to the seventies (van Albada 1968; Loden and Rickman 1974; Wielen 1975), when the first small N -body simulations were carried out (Aarseth 1968), and the first candidates (Collinder 285, ADS 12696 and σ Ori, to give a few names) indicated. The common properties of these systems would be the presence of one or more tightly bound binaries.

Later on Loden (1993) using objective-prism plates investigated the frequency of clusters in the Milky Way under the hypothesis that the stars should have similar luminosities and spectral type. He found a significant amount of cluster remnants in the form of small groups of A-F stars. This criterion however fails firstly because it was not possible to detect later spectral type star condensations, and secondly because there are known regions in the sky with many stars sharing the same spectral type but in which it is difficult to find two stars with the same velocity.

Very recently, Bica et al. (2001) identified 34 neglected star clusters (see http://obswww.unige.ch/webda/dissolving_ocl.html) having relatively high galactic latitude ($|b| > 15^\circ$), being poorly populated and appearing to be candidate objects to be experiencing the late stages of star cluster dynamical evolution. For these objects the acronym POCR

–Possible Open Cluster Remnant– is used. In their study, Bica et al. (2001) basically select these candidates on the basis of star counts. All of them indeed clearly emerge from the background. However, the authors do not go beyond that, and do not provide any kinematical data to assess the real nature of the candidates.

3. One cautionary remark and three remarkable examples

In this section I shall provide 3 illustrative examples of the analysis of POCRs and the verdict on their nature.

Before entering into details of the analysis, a word of caution is in order. We are here dealing with the remain of a physical group, and therefore we expect that the remain itself exhibits all the features of a physical group. Following Platais et al. (1998), we define a physical group or a gravitationally bound system (at odd with a random sample of field stars), as an ensemble of stars which (1) occupy a limited volume of space, (2) individually share a common space velocity and (3) individually share the same age and chemical composition, producing distinctive sequence(s) in the H-R diagram.

As a consequence, a star by star analysis is mandatory before a verdict can be formulated on the nature of a stellar group, and it should possibly include photometry, spectroscopy and astrometry (Odenkirchen and Soubiran 2002; Villanova et al. 2004).

3.1 Upgren 1

The full saga of Upgren 1 ($\alpha_{2000} = 12^h35^m, \delta_{2000} = 35^{\circ}22'$) is reported in Baumgardt (1998).

It is a group of seven bright F stars close to the Sun which has been proposed as a remnant of a nearby very old open cluster (Upgren 1963, Upgren et al. 1982).

It must be noted that if this were the case, the cluster would be unique, since no old clusters are known to lie close to the Sun. Astrometry by Gatewood et al. (1988) revealed that all the stars lie at the same distance, but the system is composed by two substructures with different kinematics.

Stefanik et al. (1997) carried out a spectroscopic campaign showing that the group is composed by a long-period binary, a triple system and two stars with velocity clearly inconsistent with physical association with the other five stars. In addition, the velocity dispersion of the 5 “*member*” stars turned out to be too large to be bound under reliable assumption about the total mass. Finally, Baumgardt (1998) used Hipparcos proper motions and parallaxes to conclude that the star velocities are too different to be compatible with a bound group, and that only two (stars 3 and 5) out of the seven stars

share the same distance and projected velocity, making them a triple system, since star 3 was already known to be a long period binary. In conclusion, Uppgren 1 is not found to be a star cluster.

3.2 NGC 6994

The tale of NGC 6994 (Messier 73, $\alpha_{2000} = 20^h 59^m, \delta_{2000} = -12^\circ 38'$) is very interesting and to some extent represents a real lesson.

It was first described by Messier (1784) as “a cluster of three or four small stars which resemble a nebula at first sight”. Later observers specified that it consists of four stars of magnitude 10 - 13 in an oblique triangle and that the two brightest of these stars are BD-13° 5808 and BD-13° 5809. The object has since been listed in a number of catalogues of open clusters (e.g. Collinder 1931; Lyngå 1987). Collinder (1931) gave the diameter of the cluster as 2' to 3', but somehow presumed that it might contain about 200 members and perhaps be a globular cluster. Ruprecht (1966) on the other hand classified it as a barely conspicuous poor cluster with stars of almost equal brightness and marked it as a doubtful case. Bassino et al. (2000) and Carraro (2000) then undertook the first deep photometric studies of NGC 6994. These studies ended up with contradictory conclusions on the physical reality of the cluster.

This is simply telling us how photometry alone, namely H-R diagrams and star counts, cannot lead to a unique solution of the cluster nature problem.

Odenkirchen and Soubiran (2002) got two epoch Echelle spectra of the 6 brightest members, and collected from Tycho 2 their proper motion components. It turned out that the 6 stars which produce overdensity lie at different heliocentric distances, have different kinematics and have different metallicities (see Fig. 1).

Therefore they only fulfill the first of the three constraints for a cluster to be a physical system (see previous Sect.), and then we must conclude that Messier 73 has to be understood as a projective chance alignment of physically unrelated stars.

3.3 Collinder 21

The appearance of Collinder 21 (also designated as OCL 371 and C0147+270, $\alpha_{2000} = 01^h 50^m, \delta_{2000} = +27^\circ 05'$) on the sky is very impressive. It consists of about 10 stars (see Fig. 2 and Table 1) distributed in a ring-like structure in a very poorly populated field, which makes this structure to emerge very sharply. There are two well known binary stars in this circle: the visual binary system BD+26 305AB and the binary HD 11142, resolved by speckle interferometry, which presents a separation of 0''.56 between its components. All the other stars have much larger angular separation.

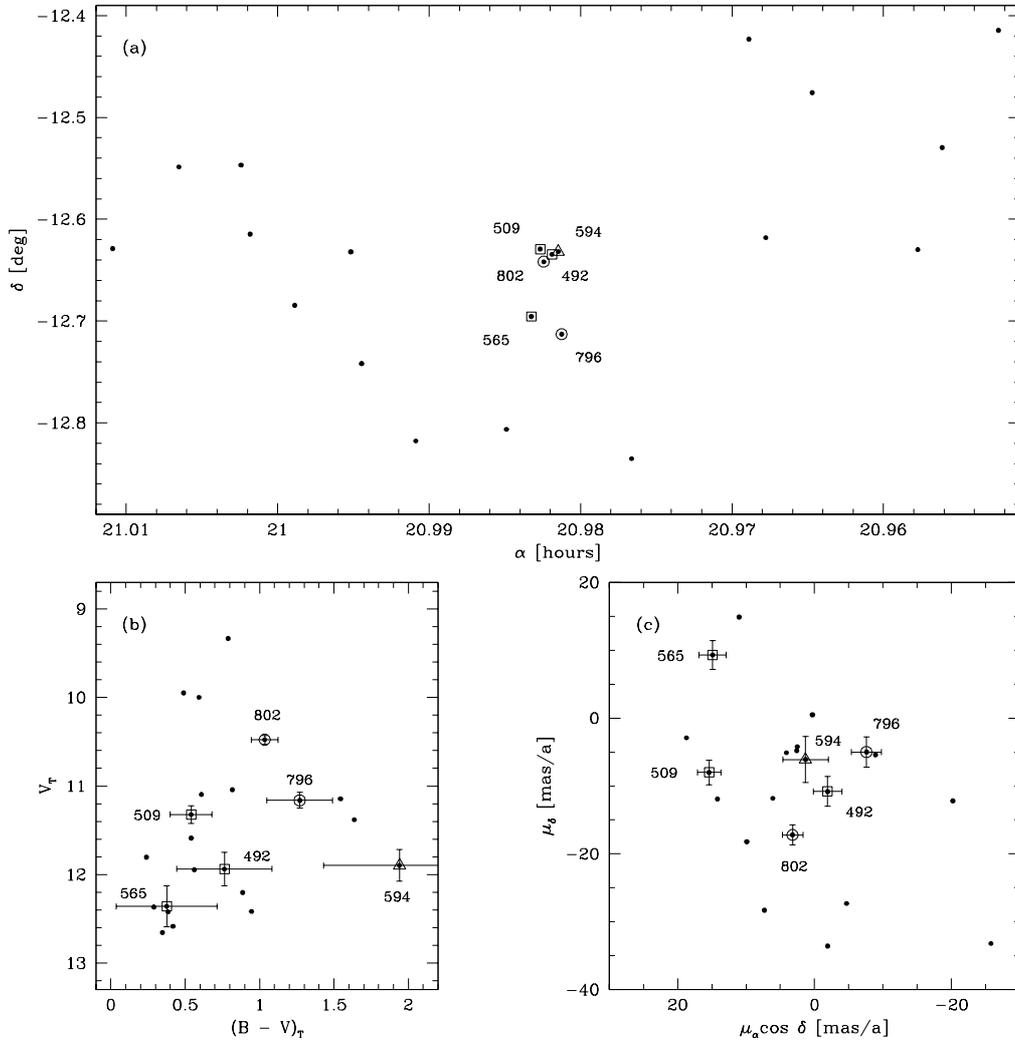


Figure 1. This figure has been taken from Odenkirchen and Soubiran (2002). Position, photometry and proper motions of all Tycho-2 stars in a $54' \times 30'$ field centered on NGC 6694. (a) Distribution on the sky. (b) Colour-magnitude diagram. (c) Vector point plot of Tycho-2 proper motions and proper motion errors. In each panel the spectroscopically observed stars are marked by open symbols and labelled with their Tycho number. The different symbol types distinguish dwarfs (open squares), giants (open circles), and one subgiant (triangle).

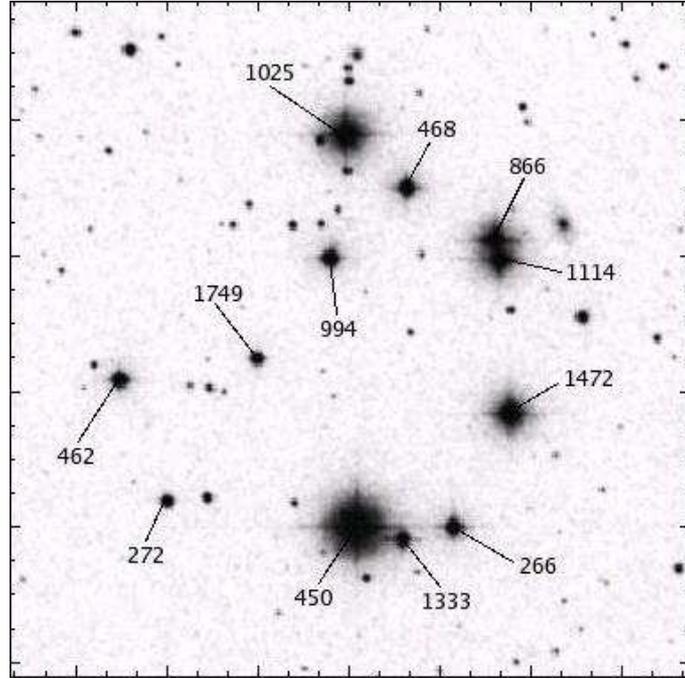


Figure 2. Identification map ($8'.14 \times 8'.14$, taken from DSS-2) for member candidates of Collinder 21 having proper motion measurements from Tycho 2. North is up, East on the left. The labels give the star numbers assigned in the Tycho-2 catalogue (in the sense TYC 1759- < ... >). Data for these stars are given in Tables 1 and 2. This figure has been taken from Villanova et al. (2004)

Table 1. Photometry and proper motion of the most obvious candidate members in the field of Collinder 21.

ID	TYC 1759-	Name	$\alpha(J2000.0)$	$\delta(J2000.0)$	V	$(B - V)$	$(U - B)$	$(V - I)$	$\mu_{\alpha} \cos \delta$ [mas/yr]	μ_{δ} [mas/yr]
1	450	BD+26 307	01:50:11.56	+27:01:59.0	8.20	0.45			56.5 ± 1.5	-33.5 ± 0.9
2	1472	BD+26 304	01:50:01.41	+27:03:40.0	9.80	0.61		0.82	5.1 ± 1.2	-11.0 ± 1.2
3	1025	BD+26 306	01:50:12.17	+27:07:47.1	9.69	1.75	1.65		-8.7 ± 1.4	-1.1 ± 1.4
4	468		01:50:08.22	+27:07:00.2	11.32	1.39	1.50	1.46	-0.7 ± 2.3	-3.3 ± 2.3
5	994		01:50:13.40	+27:05:57.5	11.17	0.74	0.44	0.95	48.7 ± 1.9	-11.5 ± 1.9
6	462		01:50:27.06	+27:04:09.7	11.32	0.59	0.26	0.83	-6.4 ± 1.9	-8.4 ± 1.9
7	1333		01:50:08.53	+27:01:49.4	11.61	0.89	0.69	1.07	-6.9 ± 1.2	+16.7 ± 0.9
8	266		01:50:05.23	+27:02:00.0	11.21	0.98	0.79	1.14	24.1 ± 1.9	4.3 ± 1.9
9	866	BD+26 305b	01:50:02.41	+27:06:13.8	10.09	0.85	0.58	1.04	-3.9 ± 1.3	-6.7 ± 1.2
10	1114	BD+26 305a	01:50:02.08	+27:05:56.6	10.36	1.08	1.08	1.18	-3.6 ± 1.8	-5.0 ± 1.8
11	1749		01:50:18.14	+27:04:28.9	12.34	0.56	0.27	0.78	11.9 ± 2.3	-5.5 ± 2.3
12	272		01:50:23.97	+27:02:23.1	12.81	0.65	0.27	0.86	1.9 ± 1.3	-8.4 ± 2.9

Note: star #1 was saturated in our photometry, and magnitude and colour have been taken from Tycho-2. Stars #7 and #12 have been taken from UCAC2 catalogue.

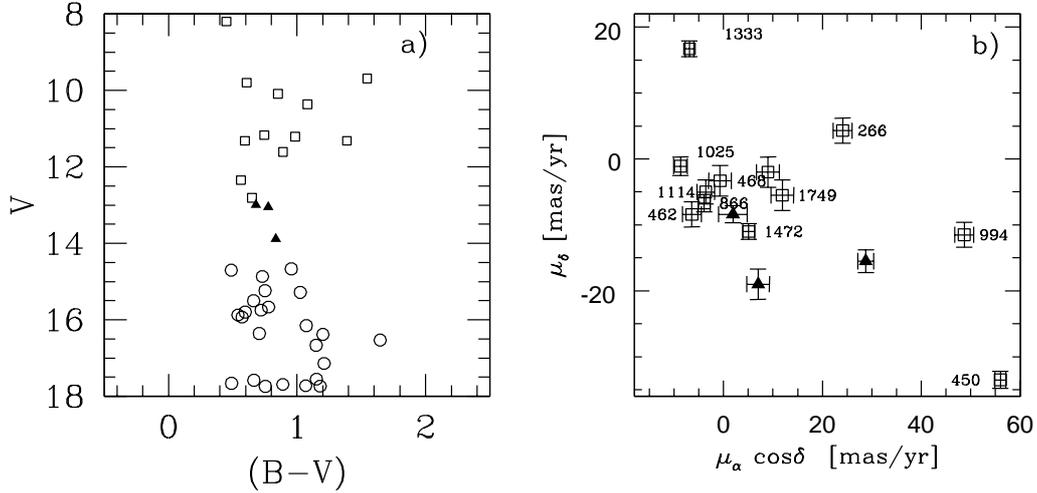


Figure 3. Photometry and proper motions in the region of Collinder 21. **a)** Colour-Magnitude diagram. Open squares are Tycho 2 stars having both proper motion and radial velocity measurements (see panel b) and Table 2), while filled triangles are stars having only proper motion measurements. **b)** Vector point plot of Tycho 2 proper motions and proper motion errors. Symbols are as in panel a). As for the identification, we are plotting here Tycho 2 numbering. See text for more details. This figure has been taken from Villanova et al. (2004)

This clustering was recently intensively studied by Villanova et al. (2004), who provided photometry and multi-epoch spectroscopy, and collected Tycho 2 proper motions for all the stars with available spectra.

The H-R diagram and the vector point diagram for all the candidate member stars having proper motion measurements in the field of Collinder 21 (see Fig. 2 for the identification) from the Tycho-2 catalogue are shown in Fig. 3 panels. 12 bright stars, in the magnitude range $8 \leq V \leq 13$, define the aggregate and are plotted in both panels as open squares. Proper motions are also available for 3 dimmer stars (solid triangles) which bridge (see the HRD in panel a) the brightest group to the bulk of the stars in the field. However these 3 stars have significantly diverse proper motion components (see Table 1). Coming back to the 12 brightest stars, their proper motion vectors range from about 3 to 68 mas yr^{-1} , while the typical uncertainties of the proper motions are about 2 mas yr^{-1} per component. It is evident that these stars do not share a common mean tangential motion. There are two clear pairs. One is the well known visual binary system BD+26 305ab (stars #866 and #1114), and the other is composed by the stars #1472 and # 272, which however deserve further investigation. Apart from these two pairs, the bulk of the stars exhibit a disordered motion.

Table 2. Spectroscopic results for Collinder 21.

ID	TYC 1759-	Date of Observation	S/N	Resolution	Julian Date	Rad. vel [km/s]	Sp. Type	(m-M) _V [mag]
1	450	04/07/2002	530	20000	2452468.5756	-3.2 ± 0.7	F9 V	3.90
		20/09/2003	300	3600	2452902.5724	7.4 ± 5.5		
		05/12/2003		3600	2452979.1951	42.4 ± 4.8		
2	1472	20/09/2003	360	3600	2452902.5906	5.3 ± 6.2	G0 V	5.35
		05/12/2003		3600	2452979.2083	11.7 ± 5.7		
3	1025	20/09/2003	330	3600	2452902.6222	55.2 ± 7.8	M8 III	10.84
		05/12/2003		3600	2452979.4393	68.3 ± 11.4		
4	468	09/10/2003	210	3600	2452922.4483	-25.5 ± 4.4	K2 III	10.52
		05/12/2003		3600	2452979.2983	-15.9 ± 10.3		
5	994	09/10/2003	230	3600	2452922.4725	46.9 ± 7.3	G8 V	5.67
		05/12/2003		3600	2452979.2378	37.5 ± 8.0		
6	462	09/10/2003	210	3600	2452922.5142	42.9 ± 7.4	G3 V	6.32
		05/12/2003		3600	2452979.3997	24.8 ± 6.4		
7	1333	05/12/2003	190	3600	2452979.5238	48.5 ± 4.6	K2 V	5.31
		04/01/2004		3600	2453009.3715	57.0 ± 5.2		
8	266	20/09/2003	230	3600	2452902.4968	50.7 ± 4.6	G8 III	9.86
		04/01/2004		3600	2453009.3979	40.4 ± 5.2		
9	866	20/09/2003	310	3600	2452902.4559	3.5 ± 5.7	G5 III	9.49
		04/01/2004		3600	2453009.4311	17.2 ± 7.9		
10	1114	20/09/2003	270	3600	2452902.5238	48.5 ± 4.6	K1 III	9.36
		04/01/2004		3600	2453010.3701	5.2 ± 5.7		
11	1749	20/09/2003	150	3600	2452980.2946	24.8 ± 7.2	F8 V	8.14
		04/01/2004		3600	2453010.3303	23.0 ± 7.1		
12	272	20/09/2003	120	3600	2452980.3317	33.9 ± 7.3	G0 V	8.36
		04/01/2004		3600	2453010.2885	41.2 ± 8.3		

For this object the authors provide 2 epochs medium resolution spectra for all stars but for #450, for which they add an Echelle spectrum. 5 stars turn out to be giants, and all the others are dwarfs. Though in this case the errors are large, from the analysis of Table 2 results we confirm that this star (#450) is a binary. Large velocity variations are also shown by the couple #866-#1114 (BD+26 305a,b), which however they are inclined to ascribe to their nature of visual binary. All the other stars show deviating radial velocity, roughly ranging from -20 km s^{-1} to $+60 \text{ km s}^{-1}$, thus suggesting that this circlet is not a physical aggregate. The possible proper motion pair (#1472-#272) is not confirmed by radial velocity measurements, and, on top of that, these two stars are located in quite different places (see Fig. 2).

Star's individual distances are derived based on spectral classification. The distance moduli ranges from 3.9 to 10.84 mag, which means a distance between 60 and 1470 pc. The reddening in this direction is 0.07 mag (Schlegel et al. 1998), and therefore these estimates do not change significantly due to it. The distance spread is too huge to be consistent with Collinder 21 being a physical aggregate.

4. Future directions

It is now quite clear how the nature of a stellar system must be searched for by using a variety of indicators, especially spatial velocities from proper motion and spectra. The cases I have discussed turned out to lead to negative solutions, but they were mainly meant to illustrate an effective method. With the advent of large proper motions and radial velocity surveys like GAIA, RAVE and SPM (Girard et al. 2004) the work will be much easier, and will certainly open a new epoch in the study of dynamical evolution of open star clusters.

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