

# NGC 6994 – clearly not a physical stellar ensemble<sup>\*</sup>

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**Abstract.** The sparse stellar ensemble NGC 6994 = M73 has recently been discussed as a possible remnant of an old open cluster. In order to solve the controversy regarding the nature of this object we have taken high-resolution spectra of the six brightest stars within 6' angular distance of its nominal position. These stars are the only obvious candidate members of an eventual cluster or cluster remnant since fainter stars do not show any significant concentration in the plane of the sky. The radial velocities, atmospheric parameters, and absolute magnitudes derived from the spectra reveal that the six candidates do not share the same kinematics and lie at different distances from the Sun. The proper motions provided by the Tycho-2 catalogue show that there is also a large spread in the tangential motions of these stars, in agreement with the spectroscopic results. This leads to the conclusion that the few bright stars that constitute NGC 6994 are not a physical system (cluster, cluster remnant, or group). They must instead be understood as a projective chance alignment of physically unrelated field stars.

**Key words.** galaxy: open clusters and associations: individual: NGC 6994 – galaxy: open clusters and associations: general

## 1. Introduction

There is convincing evidence, from numerical simulations (e.g. Terlevich 1987; de la Fuente Marcos 1997) as well as from the observed distribution of cluster ages (Wielen 1971; Janes & Adler 1982; Lyngå 1981), that most of the open star clusters in the Milky Way undergo rapid dynamical evolution and decay on a time scale of 200–500 Myr. The dynamical evolution of an open cluster is driven (1) by mass-loss from stellar evolution of its most massive members, (2) by internal energy repartition in two-body interactions and encounters with binaries, and (3) by external perturbations due to the tidal forces exerted by the mean galactic field and by local inhomogeneities. In the final stage of its evolution an open cluster is expected to reduce to a small number of relatively massive stars, preferentially binaries, which have sunk to the cluster's core while the less massive members have progressively escaped into the galactic field (de la Fuente Marcos 1997). Since the Galactic disk contains several thousand open clusters and since the typical lifetimes of these clusters are short with respect to the age of the disk, it seems likely that

such cluster remnants exist in large numbers. It would be important to identify and investigate these remnants in order to check and constrain the numerical models of cluster evolution. However such small groups of stars are in general difficult to detect because they are seen in projection onto the field of foreground and background stars which dominate the stellar surface density, in particular in regions close to the galactic plane.

An interesting candidate for a very sparse cluster or cluster remnant is the object NGC 6994 = M73 ( $\alpha, \delta = 20^{\text{h}}58^{\text{m}}9, -12^{\circ}38'$  (J2000.0);  $l, b = 35^{\circ}7, -34^{\circ}0$ ) which is located at fairly high galactic latitude. 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 (Holetschek 1907; Reinmuth 1926). The object has since been listed in a number of catalogs of open clusters (e.g. Collinder 1931; Alter et al. 1958; 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

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<sup>\*</sup> Based on observations made with the spectrograph Elodie on the 1.93 m telescope at Observatoire de Haute Provence.

Carraro (2000) recently undertook the first deep photometric studies of NGC 6994. These studies ended up with contradictory conclusions on the physical reality of the cluster. Similar to Bassino et al. (2000), Bica et al. (2001) recently proposed NGC 6994 as a possible open cluster remnant.

In order to obtain a clear answer on the nature of NGC 6994, we decided to take high-resolution spectra of the few obvious bright member candidates and to derive their precise radial velocities and absolute magnitudes. In addition we also take into account the proper motions of the candidates as an important kinematic diagnostic. Clearly, small groups of physically related stars that do not stand out strongly against the underlying field can best be recognized by finding out whether the supposed members lie at a common distance and share a common space motion. In Sect. 2 of this paper we briefly review the different arguments regarding NGC 6994 that have been given in previous studies. In Sect. 3, we investigate the significance of NGC 6994 from the viewpoints of stellar surface density in different magnitude intervals and number statistics of bright stars. In Sect. 4 we consider the information available from proper motions. Section 5 then describes our spectroscopic observations and the results derived from them. In Sect. 6 we summarize our results and conclusions.

## 2. Previous studies on NGC 6994

Detailed investigations of the region of NGC 6994 exist only since recently. Bassino et al. (2000) have presented color-magnitude diagrams (CMDs) from CCD photometry in *BVRI* down to  $V = 21$  mag for a field of diameter  $9'.6$ . They argue that the distribution of stars in their CMDs provides evidence for the presence of an old open cluster. The cluster is supposed to have an angular diameter of at least  $9'$ , a distance of about 620 pc and an age of 2 to 3 Gyr. The members of the cluster are however not directly obvious from the structure of the CMD, and a CMD for a nearby comparison field, which would in this case be essential, is not provided. Twenty-four stars are proposed as member candidates, in particular all stars brighter than  $V = 14.5$  in the field. These candidates have been selected with an iterative process of isochrone fitting in the plane of  $(B - V, V)$ , but without the ability to take into account the color-magnitude distribution of field stars. In order to validate the result of this selection scheme the authors refer to predictions from a Galactic model by Reid & Majewski (1993), showing that their cluster member candidates are located on a sequence that lies away from the loci of simulated field stars. A critical point in this approach is that their comparison with the model relies on only one simulated sample. Since the field size is very small a single simulation may involve large fluctuations and so the CMD of only one simulated sample may not be representative. Our own experience from twenty simulations for the field of NGC 6994 obtained with the Besançon model of Galactic

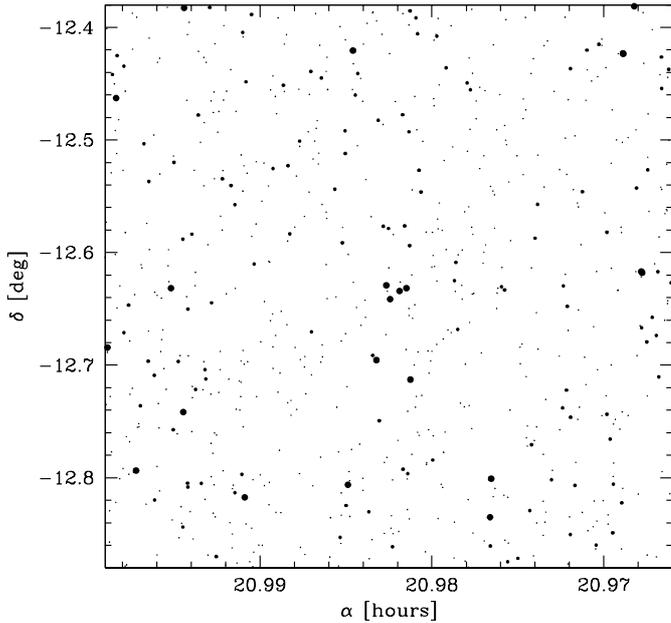
stellar population synthesis (Robin & Crézé 1986<sup>1</sup>) shows that there are indeed considerable variations from sample to sample and no evidence for a general disagreement between the simulated field CMDs and the observed CMD.

The second argument by which Bassino et al. support their assumption of the existence of a cluster is the shape of the radial stellar surface density profile, which they show in their Fig. 11. Including all stars from magnitude 10 to 21 within their field of radius  $4'.8$ , the profile shows a clear increase of the surface density within  $1'$  or  $1'.5$  of the center and a rather flat distribution outside this range. Bassino et al. interpret this as a proof for the existence of a cluster with radius  $\geq 4'.5$ . However, without evidence for a significantly lower surface density at radii beyond  $4'.5$  an alternative interpretation of this density profile is that it reveals merely the known concentration of four bright stars within about  $1'$  of the center plus a constant background density of field stars and no cluster of fainter stars. In order to verify the cluster hypothesis the stellar surface density profile needs to be investigated on a larger scale and in different magnitude ranges. (See Sect. 3 and Fig. 2.)

In a similar study, Carraro (2000) has obtained CCD photometry in *BVI* down to  $V = 22$  mag in a field of  $9' \times 9'$ . While the resulting color-magnitude diagrams look very much like those of Bassino et al., Carraro draws a completely different conclusion from his data. He claims to see a normal field star CMD without any distinct cluster feature. He thus declares NGC 6994 to be a random enhancement of four field stars rather than an open cluster or cluster remnant. On the other hand, he also states that 11 stars in his sample significantly emerge from the field. This is confusing since it appears to be an argument that is in favor of the existence of a cluster and thus in conflict with the former conclusion. Unfortunately, the essential comparison with the stellar content in at least one nearby control field is again missing. Hence there is no obvious way to recognize whether or not there is a significantly enhanced number of stars and whether the distribution of stars in the CMD is consistent or inconsistent with that of the field star population. Furthermore, Carraro's statement that the two brightest stars in the center of NGC 6994 belong to the solar neighborhood and have distances of 42 pc and 135 pc does not hold (see Sect. 5). The quoted distances are spurious because they have been derived from the very coarse (and in this case meaningless) trigonometric parallaxes given by the Tycho catalog (median standard error of 30–50 mas in the magnitude range in question; see ESA 1997, p. 142). In summary, neither of the two studies have provided clear indications of what NGC 6994 really is and which stars belong to it. Thus further investigations were required to find the answer.

Bica et al. (2001) have selected NGC 6994 and a number of other known stellar groups as possible open cluster

<sup>1</sup> The latest version of this model is available at [http://www.obs-besancon.fr/modele/modele\\_ang.html](http://www.obs-besancon.fr/modele/modele_ang.html)

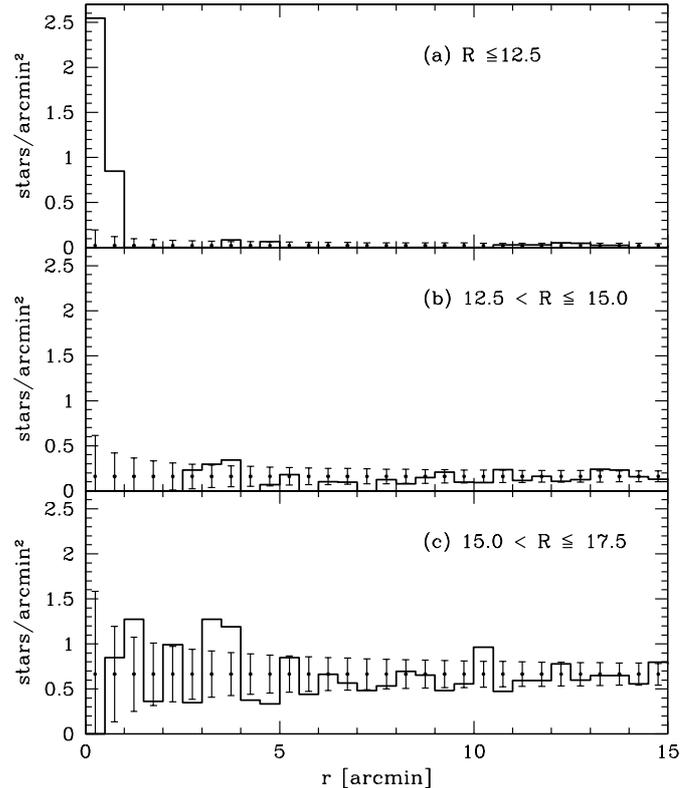


**Fig. 1.** Distribution of stars from the USNO-A2.0 catalogue (POSS-I) in a  $30' \times 30'$  around NGC 6994. The dot sizes indicate magnitudes in three ranges:  $R \leq 12.5$  (bold),  $12.5 < R \leq 15.0$  (medium),  $15.0 < R \leq 17.5$  (fine).

remnants on the basis of enhanced surface density with respect to the surrounding field. They point out that the number of stars counted down to  $B = 12.5$  mag in a field of  $9' \times 9'$  around NGC 6994 is five instead of only one that would be expected from the average counts in a larger surrounding area. This alone is however not an argument for the physical nature of this group since any distribution of stars goes along with local fluctuations so that enhancements of low numbers can turn up also randomly. It is therefore necessary to quantify the expected frequency of such fluctuations, as will be done in the next section.

### 3. Spatial configuration, surface density and number statistics

We begin our study with a reanalysis of the spatial distribution of stars in the field of NGC 6994 and around it using data from the USNO-A2.0 star catalogue (Monet et al. 1998; based on POSS-I) and the Tycho-2 star catalogue (Høg et al. 2000). Figure 1 shows the distribution of stars in a field of  $30' \times 30'$  around NGC 6994 down to  $R = 17.5$  mag according to USNO-A2.0. Figure 4a shows the stars from Tycho-2 in a somewhat larger field of  $54' \times 30'$ . Both reveal that the field of NGC 6994 is characterized by an unusual group of four bright stars, with magnitudes in the range  $10.4 \leq V_T \leq 11.9$  and mutual angular separations between  $0.4$  and  $1.0$ . The mean position of this group is regarded as the center of NGC 6994. The two brightest of its members are likely to correspond to the pair BD-13° 5808/5809 although we note that the BD positions are not entirely consistent with the real stellar configuration. Apart from this group, there are two more



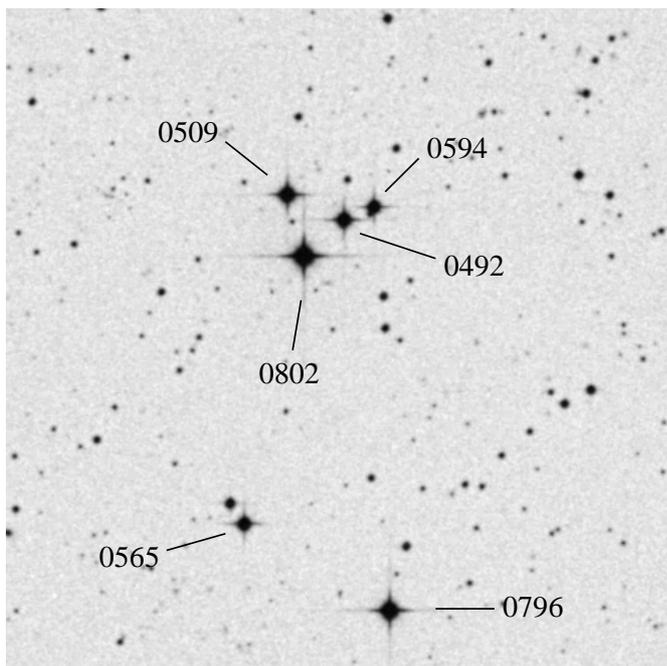
**Fig. 2.** Histogram of the surface density of the stars shown in Fig. 1, measured by counts in  $0.5$  wide annuli centered on  $\alpha = 20^{\text{h}}58^{\text{m}}55^{\text{s}}$ ,  $\delta = -12^{\circ}38'04''$ . Dots with error bars indicate the mean surface density of stars in the surrounding field and the expected  $1\sigma$  range of statistical fluctuations around this mean for each distance bin. Only stars with  $R \leq 12.5$  show an enhanced surface density near the position of NGC 6994. The histograms for the fainter stars are – within the statistical uncertainties – consistent with a constant surface density that is equal to the density of field stars.

stars of similar brightness ( $11.1 \leq V_T \leq 12.4$ ) about  $4'$  and  $5'$  to the south. These two may also be suspected to belong to the NGC 6994 complex. All other stars out to more than  $6'$  angular distance from the central group are at least 1 mag fainter than the aforementioned ones.

In Fig. 2 we show the surface densities of stars of different magnitudes as a function of angular distance from the center of NGC 6994 (based on USNO-A2.0). The central group of bright stars produces a strong local enhancement in the surface density of stars with magnitudes  $R \leq 12.5$  (see Fig. 2a). Fainter stars however, i.e., in the magnitude ranges from 12.5 to 15.0 and from 15.0 to 17.5 in  $R$  do not show signs of a spatial concentration towards NGC 6994 and therefore do not provide evidence for the presence of a cluster. Figures 2b and 2c show that the surface densities of stars in these magnitude intervals do not increase towards the center, but rather agree with the level of the surface density of surrounding field stars within the statistically expected uncertainty. In the faintest magnitude range there is a certain overdensity in the distance range from  $3'$  to  $4'$ , but too close to the limit of

**Table 1.** Cluster member candidates in NGC 6994: photometry, positions and proper motions from the Tycho-2 catalog.

TYC 5778-	$V_T$	$(B - V)_T$ [mag]	$\alpha_{ICRS}$ [ h m s ]	$\delta_{ICRS}$ [ ° ' " ]	$\mu_\alpha \cos \delta$ [mas yr <sup>-1</sup> ]	$\mu_\delta$
0802	10.48	1.04	20 58 56.77	-12 38 30.4	+3.2 ± 1.5	-17.2 ± 1.5
0509	11.32	0.54	20 58 57.59	-12 37 45.8	+15.4 ± 1.7	-8.0 ± 1.8
0594	11.90	1.94	20 58 53.32	-12 37 54.5	+1.3 ± 3.3	-6.1 ± 3.4
0492	11.94	0.76	20 58 54.79	-12 38 04.2	-1.9 ± 2.1	-10.8 ± 2.2
0565	12.36	0.38	20 58 59.68	-12 41 43.7	+14.9 ± 2.0	+9.3 ± 2.1
0796	11.16	1.27	20 58 52.50	-12 42 46.5	-7.6 ± 2.2	-5.0 ± 2.2

**Fig. 3.** Identification map ( $8' \times 8'$ , image from DSS-2) for the member candidates of NGC 6994 investigated in this paper. North is up and east to the left. The labels give the star numbers assigned in the Tycho-2 catalog (in the sense TYC 5778- $\langle \dots \rangle$ ). Data for these stars are given in Tables 1 and 2.

statistical noise to be considered as a proof of the existence of a cluster ( $< 2\sigma$ ). It therefore appears that the significance of NGC 6994 as a stellar ensemble is based solely on the clustering of the few stars brighter than 12.5 mag and that these are the only obvious member candidates for a cluster or cluster remnant in this place. Figure 3 and Table 1 provide an identification of these stars in terms of position and Tycho catalogue number (TYC). Table 1 also shows the Tycho-2 photometry and proper motions of these stars. We remark that although stars fainter than 12.5 mag do not indicate the existence of a cluster, it could nevertheless be that a few of the fainter stars are physically related to the brighter stars provided that the latter indeed form a physical group.

One may expect that the clustering of the bright stars in the plane of the sky is by itself a proof of the physical nature of NGC 6994. However, it turns out that this

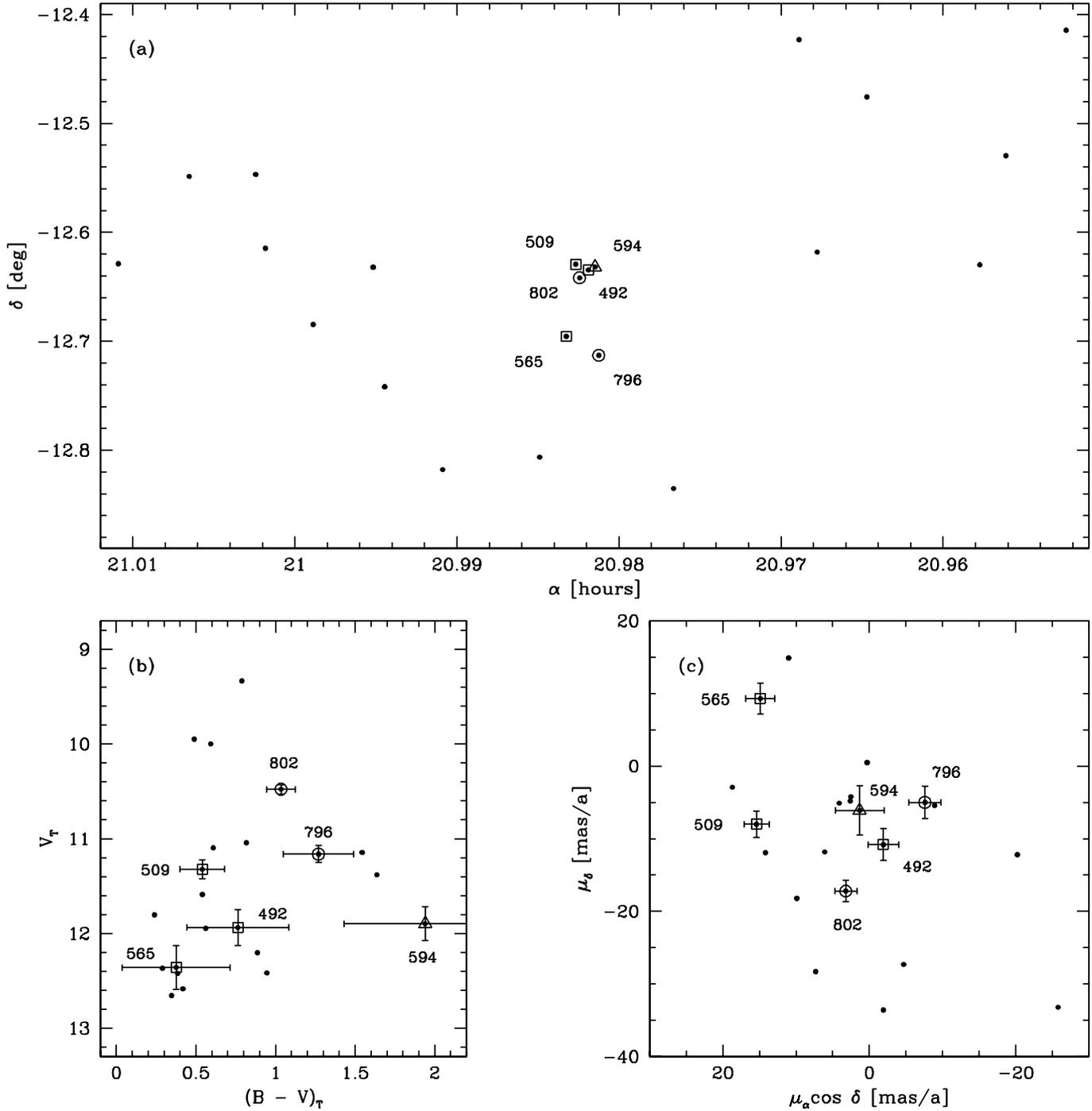
argument is not as strong as it appears. The statistics of objects in the Tycho-2 catalog shows that the mean surface density of stars with magnitude  $10.0 \leq V_T \leq 12.0$  in the region of NGC 6994 is  $\Sigma \simeq 38$  stars/deg<sup>2</sup>, including some allowance for the incompleteness of the Tycho-2 catalog towards the faint end of the above interval. For a random distribution of stars with mean surface density  $\Sigma$ , i.e., a distribution with number fluctuations that follows Poisson statistics, the probability of finding  $n$  neighbors in a circular field of radius  $\Theta$  around an arbitrarily selected star is given by:

$$p(n) = \frac{1}{n!} (\Sigma \pi \Theta^2)^n \exp(-\Sigma \pi \Theta^2). \quad (1)$$

Using  $\Sigma = 38$  stars/deg<sup>2</sup> and  $\Theta = 1'$ , the probabilities for  $n = 1, 2, 3$  are  $p(1) = 3.0 \times 10^{-2}$ ,  $p(2) = 4.5 \times 10^{-4}$ , and  $p(3) = 4.6 \times 10^{-6}$ . This means that the relative frequency for a random occurrence of a quadruple of stars like in NGC 6994 is about  $5 \times 10^{-6}$ . In other words, to find one such configuration randomly one needs a sample of about 170 000 stars or 4500 square degrees of sky with mean surface density of 38 stars/deg<sup>2</sup>. Therefore, from a statistical point of view the occurrence of NGC 6994 as a random grouping of physically unrelated stars is expected to be a rare case, but not so extremely rare that this possibility can be totally excluded. Turning it the other way round, the number statistics does not necessarily require that this particular group must be formed by physically related stars. Therefore, only proper motions and radial velocities can settle the question.

#### 4. Evidence from proper motions

Important information on the kinematics of the bright stars in and around NGC 6994 is provided by the proper motions available in the Tycho-2 catalogue. The Tycho-2 proper motions are based on the comparison between contemporary mean positions derived from the recent Tycho observations onboard Hipparcos and early-epoch positions observed many decades ago (see Høg et al. 2000 and references therein). Due to the long time-baseline they (1) have rather high precision (in contrast to the Tycho parallaxes mentioned in Sect. 2) and (2) are not subject to influences from short period orbital motion that – in the case of binaries – might otherwise substantially affect



**Fig. 4.** Position, photometry and proper motions of all Tycho-2 stars (Høg et al. 2000) in a  $54' \times 30'$  field centered on NGC 6994. **a)** Distribution on the sky. **b)** Color-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 TYC number (see Tables 1 and 2). The different symbol types distinguish dwarfs (open squares), giants (open circles), and one subgiant (triangle).

the observed photocentric motion (see e.g. Odenkirchen & Brosche 1999). In other words, the proper motion data from Tycho-2 directly indicate the long-term mean tangential motions of the stars.

In Fig. 4c the proper motions of all Tycho-2 stars in the  $30' \times 54'$  field around NGC 6994 are shown in a vector point diagram. The six cluster members candidates from

Table 1 are marked and identified by their TYC number. Figure 4c clearly demonstrates that these stars do not share a common mean tangential motion. The differences between the individual proper motion vectors are between 5 and 28  $\text{mas yr}^{-1}$  while the typical uncertainty of the proper motions is about 2  $\text{mas yr}^{-1}$  per component. Depending on the distances of the stars the

**Table 2.** Results from high-resolution spectroscopy.

TYC 5778-	Date of Observation	$S/N$	$V_r$ [ $\text{km s}^{-1}$ ]	$T_{\text{eff}}$ [K]	$\log g$	[Fe/H]	$M_V$ [mag]	$(m - M)_V$ [mag]
0802	04/07/2000	8.2	-26.6	$4720 \pm 60$	$2.64 \pm 0.05$	$-0.22 \pm 0.06$	$0.80 \pm 0.11$	9.58
0802	10/08/2001	10.4	-26.9	$4740 \pm 15$	$2.57 \pm 0.05$	$-0.24 \pm 0.07$	$0.91 \pm 0.06$	9.47
0509	04/07/2000	6.4	-53.8	$5887 \pm 50$	$4.07 \pm 0.02$	$+0.03 \pm 0.03$	$3.65 \pm 0.17$	7.62
0509	13/08/2001	16.4	-54.1	$5992 \pm 41$	$4.01 \pm 0.05$	$+0.01 \pm 0.02$	$3.58 \pm 0.14$	7.69
0594	05/07/2000	8.6	-21.5	$4882 \pm 64$	$3.19 \pm 0.11$	$-0.17 \pm 0.07$	$2.29 \pm 0.37$	9.42
0594	11/08/2001	7.0	-21.5	$5049 \pm 44$	$3.09 \pm 0.13$	$-0.08 \pm 0.04$	$2.31 \pm 0.45$	9.40
0492	04/07/2000	8.0	-8.9	$5707 \pm 68$	$4.21 \pm 0.12$	$+0.01 \pm 0.03$	$4.69 \pm 0.14$	7.17
0492	11/08/2001	11.0	-8.9	$5762 \pm 14$	$4.32 \pm 0.12$	$-0.05 \pm 0.05$	$4.70 \pm 0.14$	7.16
0565	05/07/2000	5.4	-30.6	$6234 \pm 25$	$4.00 \pm 0.02$	$-0.20 \pm 0.06$	$2.99 \pm 0.14$	9.33
0565	12/08/2001	13.5	-31.4	$6156 \pm 42$	$4.00 \pm 0.02$	$-0.36 \pm 0.05$	$3.06 \pm 0.15$	9.26
0796	05/07/2000	12.4	+34.7	$4748 \pm 42$	$2.60 \pm 0.04$	$-0.14 \pm 0.04$	$0.87 \pm 0.11$	10.17
0796	10/08/2001	7.5	+34.8	$4770 \pm 25$	$2.56 \pm 0.04$	$-0.17 \pm 0.05$	$0.82 \pm 0.14$	10.22

Note:  $S/N$  is the signal to noise ratio at 555 nm.

observed differences in proper motion correspond to differences in tangential space velocity of  $5 \text{ km s}^{-1}$  to  $28 \text{ km s}^{-1}$  ( $d = 200 \text{ pc}$ ) or  $20 \text{ km s}^{-1}$  to  $112 \text{ km s}^{-1}$  ( $d = 800 \text{ pc}$ ). Such velocity differences strongly exceed the velocity dispersion of an open cluster or a long-lived group and are more characteristic of the general velocity dispersion in the Galactic disk. Comparing the proper motions of the candidate stars to those of other Tycho stars in the surrounding field it is indeed seen that the spread of proper motions among the candidates is in agreement with the typical spread in the local distribution of field star proper motions. In summary, we find that the tangential motions of the candidate stars do not support the idea of a physical relationship between them but are rather favorable to the alternative assumption that these stars are part of the local field population.

## 5. Spectroscopic investigation

For further assessment of the kinematic coherence or incoherence of the six principal member candidates of NGC 6994 we recently obtained high-resolution spectra using the echelle spectrograph Elodie on the 1.93 m telescope of the Observatoire de Haute Provence (Baranne et al. 1996). All stars were observed at two epochs, in July 2000 and August 2001. The spectra cover the range from 390 nm to 680 nm at a resolving power of 42 000 and have signal-to-noise ratios of 5.4 to 16.4 at  $\lambda \simeq 555 \text{ nm}$ . The spectra were processed and calibrated with dedicated on-line data reduction software available at the telescope. Radial velocities were derived by cross-correlating the spectra with a digital template mask for spectral type F or K. There is abundant experience with the instrument showing that the accuracy of the radial velocities obtained in this way is better than  $1 \text{ km s}^{-1}$  for the considered stars of type F, G and K, even at relatively low

signal-to-noise ratios (Baranne et al. 1996; Delfosse et al. 1999). Estimates of the atmospheric parameters  $T_{\text{eff}}$ ,  $\log g$  and [Fe/H] and the absolute magnitude  $M_V$  of the stars were determined with the special TGMET software (Katz et al. 1998) in the same way as described in our previous open cluster study (Soubiran et al. 2000). Briefly, this software compares the observed spectrum to a library of empirical reference spectra and calculates the stellar parameters by weighted averaging over the parameter values of the five to ten best-matching reference stars.

The results of the reduction of the spectra are listed in Table 2. It turns out that there are no substantial variations in the radial velocities and the other stellar parameters between the two epochs for any of the six targets. The largest difference in radial velocity that occurs when comparing the results of the observations taken 13 months apart is about  $0.8 \text{ km s}^{-1}$  (in this case the spectral lines are broadened due to rotation), the other differences are  $\leq 0.3 \text{ km s}^{-1}$ . This assures that the velocity measurements are not significantly affected by orbital motion with a companion and hence directly represent the mean space velocities of the stars.

The radial velocities of the six targets cover the range from  $-54 \text{ km s}^{-1}$  to  $+35 \text{ km s}^{-1}$ . We find that there is no agreement between any of the velocities at the level of the uncertainty of the measurements which is  $\leq 1 \text{ km s}^{-1}$ . The two most closely coinciding radial velocities have a difference of  $4.1 \text{ km s}^{-1}$  (stars 0802 and 0565). There are three stars (0594, 0802, 0565) with radial velocities falling into the interval from  $-31 \text{ km s}^{-1}$  to  $-21 \text{ km s}^{-1}$ . The velocities of the other three stars are more widely dispersed. The three stars with somewhat similar velocities may at first sight appear as a kinematic subgroup. However, the differences in radial velocity are actually too large to interpret these stars as a wide triple system or a long-lived unbound group. Also, the proper motions and distances

of these stars (see below) are such that their tangential velocities must be even more deviant than their radial velocities. This is true in particular for stars 0565 and 0802 which have proper motions that differ by  $28 \text{ mas yr}^{-1}$  and hence can definitely not be part of the same kinematic group.

The values of the atmospheric parameters  $\log g$  and  $T_{\text{eff}}$  reveal that the sample of candidates contains three dwarfs, two red giants, and one subgiant. The absolute luminosities of the stars differ by up to 3.9 mag in  $V$ . This contrasts with a much smaller spread in the observed apparent  $V$  magnitude which is less than 2 mag. Comparing the spectroscopically determined absolute magnitude  $M_V$  and the photometrically measured  $V$  (standard  $V$  derived from Tycho-2 photometry via the transformation given in ESA 1997, p. 63) one obtains an estimate of the individual distance modulus of each star. The distance moduli are found to spread over 3 mag, ranging from 7.2 mag to 10.2 mag (see Table 2). This indicates that the distances of the stars differ by a factor of 4. According to the reddening maps of Schlegel et al. (1998) the reddening at the position of NGC 6994 is  $E(B - V) \simeq 0.045$  mag and varies between 0.038 mag and 0.065 mag in the  $20' \times 20'$  arcmin region around it. We thus assume that the extinction is near  $A_V = 0.15$  mag so that the unreddened distance moduli are only slightly smaller than the measured ones. The distances of the stars hence lie between 250 pc (0492) and 1 kpc (0796). Altogether we find that the distances and radial velocities of the six stars strongly contradict the hypothesis that they form a physical group and does not even provide support for the existence of a subgroup or a physical pair.

The metallicities of the six stars range from zero to about  $-0.3$  dex. The spread in metallicity suggests that the sample as a whole is not a chemically coherent group. It is possible to define subgroups of stars with similar metallicity, but these subgroups do not consistently match with the distributions of the other parameters, i.e. distance, radial velocity and tangential motion, and thus do not appear to be real.

## 6. Summary and conclusion

In Sect. 2 we pointed out that neither of the three recent studies involving NGC 6994 has provided truly convincing arguments for accepting or rejecting the hypothesis that it is a physical stellar system. In Sect. 3, we first showed that NGC 6994 is apparent as a stellar ensemble only by the concentration of a few stars brighter than 12.5 mag. A corresponding significant overdensity of fainter stars does not exist. We then deduced from the number density of bright stars around NGC 6994 that the relative frequency of close quadruples of stars like that of NGC 6994 in a random distribution of field stars is low, but not low enough to render the random occurrence of such a quadruple impossible. In Sect. 4 we demonstrated that the proper motion data from the Tycho-2 catalog provide a clear indication against the physical nature of the ensemble. The

proper motions do not show any characteristic concentration and instead point towards a large spread in the tangential space velocities of the stars that is consistent with the motions of the surrounding field stars. In Sect. 5 we presented and discussed radial velocities, atmospheric parameters and absolute magnitudes derived from high-resolution spectra of the six obvious bright member candidates of NGC 6994. We find that the sample contains three dwarfs, two giants and one subgiant. The radial velocities and absolute magnitudes yield further strong evidence against the hypothesis of a system of physically related stars. First, the radial velocities of the stars are substantially different from each other, which is unlikely to be due to binary orbital motion since reobservation at a second epoch assures that there are no significant variations with time. Second, the distance moduli of the stars which result from their spectroscopically determined absolute magnitudes and their apparent brightness do not agree with each other. The latter shows that the stars are not clustered at a certain location along the line of sight. Taking together the results from proper motions and spectroscopy we conclude that neither the sample as a whole nor a subgroup in it forms a physical stellar system. Instead the asterism called NGC 6994 appears to be a rare occurrence of a random grouping of a few physically unrelated stars in projection on the celestial sphere. This conclusion confirms the conjecture of Carraro (2000) who had doubted the existence of a cluster or cluster remnant because of the lack of a characteristic sequence in the color-magnitude diagram.

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