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# Red giants in open clusters

## VIII. NGC 752*,**

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**Abstract.** The results of an 18-year radial-velocity survey of 30 red giants in the field of the open cluster NGC 752 are presented. The membership of 15 stars is confirmed. Four spectroscopic binaries have been discovered among the members and three orbits have been determined for H75, 110 and 208, with periods of 3321, 127 and 5276 days respectively. The binary frequency (27%) is normal. A search for additional members in a wide surrounding area (2°) yielded two possible new members: both are clump red giant candidates. The red giant distribution in the colour-magnitude diagram is somewhat unusual, with a clump containing 8 stars and a second, fainter feature extending to the blue, defined by 3 or 4 stars, which is not accounted for by theoretical isochrones.

**Key words:** techniques: radial velocities – binaries: spectroscopic – Hertzsprung-Russel (HR) diagram – open clusters and associations: individual: NGC 2354

### 1. Introduction

This paper, devoted to the intermediate-age open cluster NGC 752 = C0154+374 ($\alpha = 1^{\rm h}54.8$, $\delta = +37^\circ 26'$, B1950), continues our discussion of the membership and binarity of red giants in open clusters. The results of Paper IV (Mermilliod et al. 1995) are interesting in the present context because the two clusters studied, NGC 3680 and IC 4651, are very similar to NGC 752, as concerns their number of red giants, ages and colour-magnitude diagrams.

NGC 752 has been subjected to many studies because it is the closest intermediate-age cluster, located at 427 pc (Dzervitis & Paupers 1993). It is usually considered as metal-deficient with respect to the Sun, with [Fe/H] = $-0.15 \pm 0.05$ (p.e.) (Daniel et al. 1994) and to be slightly reddened, $E(B-V)$ = 0.035. Daniel et al. (1994) have discussed in their introduction the main reasons for which NGC 752 is a key cluster and the reader is referred to their paper for an extensive review of the recent literature. Our primary interest in NGC 752 is the binary frequency and the red giant branch morphology. Up to now, most of the red giants in NGC 752 were thought to be located in the clump, a long lived phase where helium burning takes place. The Geneva photometry presented here shows an unusual morphology of the red giant clump, with a fainter feature extending to the blue that is present neither in NGC 3680 nor in IC 4651. None of the red giants has been detected in X-ray (Belloni & Verbunt 1996).

NGC 752 has been compared with evolutionary models by Carraro et al. (1993), who suggest that models with convective overshoot should be preferred to the canonical ones. Daniel et al. (1994) identify a red hook at the top of the main sequence, which they also conclude can best be fit by convective overshoot models. The color and distribution of stars on the giant branch are also consistent with overshoot models, but the model luminosities are higher than the observed clump giants. In the comparison of canonical and overshoot models, a secure census of the red giant membership is crucial to define correctly the red giant locus in the colour-magnitude diagram (CMD), and the identification of binaries may also prove to be important if the photometry has been affected. The anomalous position in the CMD of the binary member H110 is an excellent example of this problem.

Although radial velocities have already been published for the red giants in NGC 752, only small numbers of observations were available for each star and these data do not allow clear detection of spectroscopic binaries. The orbital periods of red giant spectroscopic binaries are often quite long, and only a long-term observing program can detect long period, small amplitude binaries. The first extensive study was published by Rebeirot (1970), based on the Fehrenbach objective prism technique. Twenty four red giants in the field of NGC 752 have been observed by Pilachowski et al. (1988, hereafter referred to as PSH). Their sample included known members from Heinemann's (1926) list and 11 stars in the cluster corona. Most stars

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[*] Based on observations collected at the Haute-Provence Observatory (France)

[**] Tables 4a & 4b are available only in electronic form at CDS by ftp at 130.79.128.5 or on the Web at http://cdsweb.u-strasbg.fr/CDS.html

have two observations obtained over an interval of three months. Pilachowski et al. (1989) published an orbit for H110, one of our four binaries. Friel et al. (1989) have obtained moderate dispersion spectroscopy of 9 red giants in NGC 752.

This study also searches for new red giant members in the cluster corona. Ten red stars, selected from the study of Jungkvist (1931), as far as two degrees from the cluster centre have been observed.

## 2. Observations

Observations of red giants in NGC 752 were started independently with the radial-velocity scanner CORAVEL (Baranne et al. 1979) and with the CfA Digital Speedometers (Latham 1992). We describe separately the instruments and observations.

### 2.1. The sample definition

As part of the CORAVEL survey of radial velocities of red giants in open clusters we started observations of 13 NGC 752 red giants in September 1977. The sample initially included those red giants from the list of Heinemann (1926) which are generally accepted as cluster members on the basis of their UBV photometry and proper motions (Ebbighausen 1939) and Ebbighausen A3, a red giant not included in Heinemann's study. Later, star #69 from Lavdovski (1961) was added to the sample on the basis of its proper motion and Geneva photometry, as was star #81 from Rebeirot (1970), on the basis of its radial velocity (5 km s$^{-1}$), spectral type (K0 III), and $UBV$ colours from Rohlfs & Vanysek (1961). In fall 1981, four stars (H39, 103, 215 & 246) observed in the $UBViyz$ photometric system by Jennens & Helfer (1975) were added to the sample to check their membership.

Table 1 gives the cross-references between several numbering systems developed for NGC 752: Hein: Heinemann (1926), Reb: Rebeirot (1970), RV: Rohlfs & Vanysek (1961), Lavd: Lavdovski (1961), Vogt: Vogt (1923), Stock: Stock (1985), Fran: Francic (1989), Plat: Platais (1991). Ebbighausen (1939) used Heinemann's (1926) numbering system.

To this basic list we have added candidate red giants selected from Jungkvist's (1931) catalogue, part II. To search for candidate red giants we transformed Jungkvist's photographic magnitudes ($\mathrm{m}_v$) and colour indices (C.I.) into $V, B-V$ in the Johnson system with the aid of stars from his main catalogue (part I) and plotted a colour-magnitude diagram. Ten red giants falling more or less at the right place in the $(V, B-V)$ diagram were selected as candidate members. The identifications and basic data are summarized in Table 3. Stars J30 and J33 fall within the clump defined by the known members, J81 occupies a position very reminiscent of the binary H110 within the Hertzsprung gap and J29, 31, 39, 86, 88 and 108 could lie on the ascending giant branch. J99 (= Plat 1263 in Tables 1 and 2) also falls within the clump, but was afterwards found to be identical to star A3 from Ebbighausen (1939), which left 9 candidates. Anticipating our results, only the two clump stars (J30 and J33) turned out to have radial velocities consistent with cluster membership.

**Table 1.** Cross-references for Heinemann stars

| Hein | Reb | RV | Lavd | Vogt | Stock | Fran | Plat |
|---|---|---|---|---|---|---|---|
| | 54 | | 69 | | | | 172 |
| | 81 | 175 | 95 | | | 6 | 212 |
| 1 | 92 | 22 | 124 | 5 | 2 | 15 | 259 |
| 3 | 93 | 23 | 129 | 7 | 6 | 18 | 264 |
| 11 | 105 | | 151 | | 21 | 28 | 308 |
| 24 | 95 | 25 | 175 | | 41 | 48 | 350 |
| 27 | 86 | 20 | 179 | 12 | 47 | 55 | 356 |
| 39 | 97 | 26 | 206 | 17 | 64 | 67 | 394 |
| 75 | 163 | 29 | 273 | 28 | 119 | 105 | 506 |
| 77 | 135 | 45 | 277 | 31 | 123 | 116 | 512 |
| 103 | 165 | 31 | 322 | | 164 | 139 | 606 |
| 110 | 167 | 33 | 332 | 41 | 174 | 147 | 630 |
| 137 | 169 | | 368 | | 202 | 174 | 687 |
| 186 | 157 | 72 | 428 | 60 | 255 | 230 | 797 |
| 208 | 147 | | 461 | | 278 | 254 | 858 |
| 213 | 161 | 60 | 464 | 72 | 283 | 256 | 867 |
| 215 | 209 | 1 | 467 | 74 | 285 | 262 | 882 |
| 246 | 197 | 11 | 517 | 88 | 319 | 297 | 965 |
| 295 | 222 | 67 | 580 | 99 | 377 | 345 | 1089 |
| 311 | 226 | 65 | 615 | 107 | 397 | 371 | 1172 |
| | 268 | 367 | 655 | | 422 | 392 | 1263 |

### 2.2. Radial-velocity measurements

#### 2.2.1. CORAVEL observations

At least 15 radial-velocity measurements were obtained for each member star with the CORAVEL scanner (Baranne et al. 1979) installed on the 1-m Swiss telescope at the Haute Provence Observatory (OHP, France) from 1977 to 1993. Somewhat fewer measurements were obtained for non-members. As a rule integration times range from 5 to 10 minutes depending on the night quality and seeing. The precision of each measurement is better than 0.35 km s$^{-1}$ for most observations. The radial velocities were adjusted for zero-point differences to place them in the system defined by the southern CORAVEL. In total, 410 radial-velocity measurements of 30 stars were made.

#### 2.2.2. CfA observations

Observation of red giants in NGC 752 were undertaken independently with the Harvard-Smithsonian Center for Astrophysics (CfA) Digital Speedometers (Latham 1992) as part of a larger survey of NGC 752 members. These observations have been described in detail in Daniel et al. (1994). The precision of one observation is usually better than 0.50 km s$^{-1}$. Included in this sample were nine of the red giants listed in Table 2. The number of observations is given in the column ($\mathrm{n}_{CfA}$). In total, 84 radial-velocity measurements were made.

#### 2.2.3. Comparison of the radial velocity systems

Comparison of the mean radial velocities for 6 non-variable stars in common to both the CORAVEL and CfA studies showed that a zero point difference of -0.37 ± 0.14 km $s^{-1}$ (CORAVEL - CfA) exists between the two data sets. In order to keep the radial velocities in the same system as used in previous papers in this series, this small adjustment has been applied to the CfA measurements in order to compute the mean radial velocities given in Table 2 and the orbital solutions for the spectroscopic binaries. This small zero point uncertainty does not affect any of the conclusions of this paper.

### *2.3. Results*

The mean radial velocities obtained by combining the two sets of observations for the stars listed in Table 1 are presented in Table 2. The columns contain successively: Heinemann (1926) and Platais (1991) identifications, the BD numbers, $V$ and $[B-V]$ in the Geneva photometric system, $B-V$ in the Johnson system from Daniel et al. (1994), the membership probabilities from Platais (1991), the mean radial velocities or the centre-of-mass velocities for the three spectroscopic binaries and their errors in [km $s^{-1}$], the number of measurements from CORAVEL ($n_C$) and CfA ($n_{CfA}$), the probability P($\chi^2$) that the error of the mean merely reflects random observational errors for a constant-velocity star, radial velocities (mainly two observations per star) from Pilachowski et al. (1988), and remarks on binarity and membership (SB = single-lined spectroscopic binary, M = member, NM = non-member).

Results for Jungkvist's stars are presented in Table 3, which gives Jungkvist (1931) and Platais (1991) numbers, the HD and BD identification, the $V$ magnitudes and $(B-V)$ colour indices transformed from Jungkvist's photographic data, Jungkvist's spectral type, membership probability (Platais 1991), CORAVEL mean radial velocities and errors in [km $s^{-1}$], the number of measurements ($n_C$), the probability P($\chi^2$), the radial velocities from Pilachowski et al. (1988) for two stars in common, and a membership assessment. The errors given by Jungkvist in his tables are smaller than 0.02 mag on $m_{ph}$ and of the order of 0.03 mag on $m_v$.

Tables 4a and 4b give the individual observations made with CORAVEL and at CfA respectively. They are available in electronic form only at CDS from ftp at 130.79.128.5 or from the WWW server at http://cdsweb.u-strasbg.fr/cats/cats.html. Table 4b reproduces the original CfA observations without the small zero-point adjustment.

## 3. Discussion

### *3.1. Mean cluster velocity*

Based on 15 member red giants from Table 2 we find the mean radial velocity of NGC 752 to be 4.68 ± 0.11 (s.d. of the mean) km $s^{-1}$. The 0.82 km $s^{-1}$ difference with the value of 5.5 ± 0.6 (s.d.) km $s^{-1}$ derived by Daniel et al. (1994) from 33 (mainly main-sequence) stars results partly from the zero-point difference mentionned above (0.37 km $s^{-1}$) and partly from the gravitational redshift between red giants and solar-type dwarfs. In velocity units [km $s^{-1}$], the gravitational redshift is:

$$RV_g = 0.64(M/R)$$

with $M$ and $R$ in solar units. Following Nordström et al. (1997) we have $M/R \approx 0.9$ for the F dwarfs and $\approx 0.2$ for the red giants. Accordingly, the average dwarf velocities should be about 0.40 km $s^{-1}$ larger that those of the red giants. The addition of both effects precisely explains the observed difference. Nordström et al. (1997) observed a difference of 0.45 km $s^{-1}$ between the mean radial velocities of the dwarf- and red giant samples in NGC 3680. Our value (0.45 km $s^{-1}$) is, by chance, identical.

PSH determined a mean radial velocity of 5 km $s^{-1}$, while Friel et al. (1989) obtained 8.5 ± 3 km $s^{-1}$.

### *3.2. Membership*

#### 3.2.1. Central part

We formally exclude from membership stars with radial velocities differing from the cluster mean velocity by more than 3 times the dispersion calculated for the 15 members in Table 2, i.e. 1.22 km $s^{-1}$. This could be risky if undetected binaries belong to the sample. However, all stars excluded by this criterion are also non-members by other independent criteria. Our radial-velocity data confirm the membership of all previously known members, except one. The radial velocity for H186 is about 8 km $s^{-1}$ from the cluster mean velocity and indicates that it is not a member despite its high membership probability (P = 0.99) from proper motion. The velocity of H186 has remained stable for 5463 days, so that this difference of H186 is most probably not due to its being a spectroscopic binary.

We support Platais' conclusion that H27 is a cluster member; this star has been discarded in the past because of the discrepant proper-motion measure of Ebbighausen (1939). We take Lavdovski #69 (= Platais #172) as a probable cluster member in spite of its zero membership probability in Platais (1991), because it has a radial velocity very near the cluster mean and the Geneva photometry places it within the clump. It was selected from Lavdovski's (1961) proper motion, which indicated cluster membership, but it has unfortunately not been measured by Francic (1989). Finally, none of the four stars selected from Jennens & Helfer's (1975) observing list are members.

Except for these two cases (H186 and Plat 172) the radial-velocity criterion and the membership probabilities based on proper motions (Francic 1989; Platais 1991) are in very good agreement for the stars in the main field of the cluster.

#### 3.2.2. Cluster corona

Seven of the nine red giant candidates selected from Jungkvist's catalogue are non-members according to their radial velocities, while two, J30 and J33, have radial velocities in agreement with membership. Both stars are located at about 96′ from the cluster center, while the observed cluster diameter is somewhere between 50′ (Collinder 1931) and 75′ (Lyngå 1987). They could

**Table 2.** Summary data for the red giants in NGC 752

| Hein | Plat | BD | V | [B-V] | B-V | P | $V_r$ | $\epsilon$ | $n_C$ | $n_{CfA}$ | $\Delta$T | P($\chi^2$) | Vr$_{PSH}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 172 | 37° 404 | 8.890 | 0.314 | 1.018 | .00 | +4.75 | 0.11 | 15 | | 7039 | .068 | +4.5 | M, Lavd. 69 |
| | 212 | 36° 345 | 9.20 | | 1.080 | .00 | -2.10 | 0.33 | 19 | | 5561 | .000 | +0.4 | NM, SB, Reb. 81 |
| 1 | 259 | 37° 407 | 9.500 | 0.240 | 0.954 | .93 | +4.79 | 0.15 | 15 | | 6653 | .005 | +4.6 | M |
| 3 | 264 | 37° 408 | 9.558 | 0.269 | 0.996 | .25 | +4.11 | 0.10 | 15 | 8 | 6653 | .127 | | M |
| 11 | 308 | | 9.284 | 0.233 | 0.966 | .94 | +4.34 | 0.10 | 15 | 6 | 7040 | .100 | | M |
| 24 | 350 | 37° 412 | 8.922 | 0.306 | 1.011 | .99 | +4.92 | 0.11 | 15 | | 7040 | .131 | +4.9 | M |
| 27 | 356 | 36° 350 | 9.144 | 0.301 | 1.010 | .99 | +4.12 | 0.09 | 10 | | 5516 | .625 | +3.8 | M |
| 39 | 394 | 37° 415 | 8.09 | | 0.972 | .00 | -22.19 | 0.14 | 5 | | 4040 | .580 | -22.2 | NM, HD 11720 |
| 75 | 506 | 37° 418 | 8.972 | 0.305 | 1.003 | .98 | +4.46 | 0.06 | 42 | 6 | 7358 | .000 | +9.7 | M, SBO |
| 77 | 512 | 36° 358 | 9.392 | 0.331 | 1.029 | .98 | +4.55 | 0.09 | 15 | | 7039 | .562 | +4.3 | M |
| 103 | 606 | | 10.99 | | 1.173 | .00 | -26.76 | 0.17 | 5 | | 4338 | .543 | | NM |
| 110 | 630 | 37° 422 | 8.950 | 0.072 | 0.811 | .95 | +4.78 | 0.06 | 37 | 16 | 5975 | .000 | var | M, SBO, HD 11811 |
| 137 | 687 | 37° 424 | 8.926 | 0.313 | 1.026 | .99 | +4.81 | 0.09 | 15 | | 7040 | .347 | +5.5 | M |
| 186 | 797 | 37° 428 | 10.197 | 0.198 | 0.942 | .99 | -3.66 | 0.07 | 11 | 5 | 5463 | .925 | -3.7 | NM |
| 208 | 858 | 36° 368 | 8.95 | 0.394 | 1.085 | .99 | +4.86 | 0.06 | 44 | 15 | 7351 | .000 | +8.3 | M, SBO |
| 213 | 867 | 37° 432 | 9.029 | 0.294 | 1.004 | .99 | +5.50 | 0.10 | 21 | 8 | 7036 | .000 | +6.2 | M, SB |
| 215 | 882 | 36° 370 | 7.144 | 0.557 | 1.206 | .00 | +8.80 | 0.13 | 6 | | 4039 | .325 | | NM, HD 11885 |
| 246 | 965 | 36° 374 | 10.09 | | 1.001 | .00 | +10.83 | 0.15 | 6 | | 4338 | .450 | | NM |
| 295 | 1089 | 37° 441 | 9.288 | 0.227 | 0.963 | .99 | +4.74 | 0.07 | 16 | 10 | 7039 | .750 | +4.8 | M |
| 311 | 1172 | 37° 448 | 9.057 | 0.332 | 1.036 | .99 | +5.28 | 0.08 | 16 | 10 | 7039 | .636 | +4.1 | M |
| | 1263 | 37° 450 | 8.999 | 0.320 | 1.019 | .99 | +4.12 | 0.11 | 15 | | 7039 | .061 | | M, Ebb. A3 |

**Table 3.** Basic data and Coravel radial velocity observations for Jungkvist's stars

| Ju | Plat | HD | BD | V | B-V | SpT | P | $V_r$ | $\epsilon$ | $n_C$ | $\Delta$T | P($\chi^2$) | Vr$_{PSH}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | | 11216 | +36° 326 | 7.70 | 1.52 | K5 | | -6.42 | 0.20 | 6 | 4787 | .018 | | NM |
| 30 | | | +37° 386 | 9.23 | 0.99 | G5 | | +3.96 | 0.12 | 7 | 4786 | .535 | | M? |
| 31 | | 11224 | +37° 387 | 7.28 | 1.81 | M | | +54.40 | 0.59 | 5 | 4787 | .000 | | NM, SB |
| 33 | | | +36° 328 | 9.10 | 0.96 | K0 | | +4.51 | 0.12 | 7 | 4786 | .594 | | M? |
| 39 | | | +37° 392 | 9.63 | 1.05 | G5 | | -70.42 | 2.21 | 5 | 4787 | .000 | | NM, SB |
| 81 | | | +38° 379 | 9.16 | 0.82 | G0 | | -21.11 | 0.16 | 5 | 4787 | .350 | | NM |
| 86 | 670 | | +36° 362 | 8.29 | 1.40 | K2 | 0.00 | -41.55 | 0.19 | 5 | 4787 | .089 | -41.1 | NM |
| 88 | 898 | | +37° 436 | 8.88 | 1.19 | G5 | 0.00 | +11.54 | 0.17 | 6 | 4787 | .147 | +11.8 | NM |
| 108 | | 12231 | +37° 455 | 8.12 | 1.31 | K5 | | -62.02 | 0.21 | 6 | 4787 | .013 | | NM |

be halo or escaping members. If they are members, the available photometric data place them in the clump.

PSH have also tested the membership of 11 red stars from the Bonner Durchmusterung in the area surrounding NGC 752. Cross-references and relevant data are summarized in Table 5. The successive columns contain the BD number as used by PSH, cross-references with Jungkvist's (1931) and Platais' (1991) identifications, spectral types from Jungkvist, membership probabilities from Platais, and, for sake of completeness, the original radial velocities from PSH and the number of observations. The measurement uncertainties are typically 0.5 km s$^{-1}$. The membership estimates are based on radial velocities and proper motions. Two stars observed by PSH (BD +37° 415 and +37° 404) are identical to H39 and Platais #172 respectively and are not repeated in Table 5. BD +36° 362 (J86) and +37° 436 (J88) have also been observed with CORAVEL and our data are in good agreement with PSH observations (cf Table 3).

To summarize, the memberships of 18 stars (3 in the core and 15 in the halo) not included in Heinemann's study have been tested by us and PSH. Most stars are obviously non-members. However, we have confirmed the membership of Plat. 1263 (Ebb. A3), found one probable member (Plat. 172) and two possible halo members (J30 and J33).

### *3.3. Spectroscopic binaries*

Four red giant members have been discovered to be spectroscopic binaries (H75, 110, 208 & 213) and orbits for the first three have been determined from 46, 53 and 57 observations respectively. The orbital elements are given in Table 6 and the radial-velocity curves are displayed in Figs. 2 to 4. Four non-members are also binaries, but they have not been further observed.

**Table 5.** Cross-identification for the stars observed by Pilachowski et al. (1988)

| BD | Ju | Plat | SpT | P | V$_r$ | n | Remarks |
|---|---|---|---|---|---|---|---|
| +36° 343 | 65 | 136 | F8 | .00 | -13.2 | 1 | NM |
| +36° 345 | | 212 | | .00 | 0.4 | 2 | NM |
| +36° 346 | 74 | 213 | K0 | .00 | 0.3 | 2 | NM |
| +36° 354 | 82 | 393 | K2 | .00 | var | 2 | SB, NM |
| +36° 380 | 96 | 1205 | F5 | .00 | -1.0 | 2 | NM |
| +37° 437 | 89 | 904 | G5 | .00 | 12.0 | 2 | NM |
| +37° 447 | 95 | 1159 | F5 | .00 | 41.0 | 2 | NM |

The binary frequency is 27% (4/15). This value is close to the overall mean value for red giants in open clusters (23%) derived by Mermilliod & Mayor (1992).

### 3.3.1. H110

H110 was identified as a binary by Mayor & Mermilliod (1984), and orbital elements have been published by Pilachowski et al. (1989) based on the CfA radial-velocity measurements also included in the present discussion and additional KPNO CCD spectra. The solution given in Table 6 is based on 37 CORAVEL and 16 CfA observations. Our orbital elements are in very good agreement with those published by Pilachowski et al. (1989).

H110 ($V = 8.95$, $B-V = 0.81$) is located at an anomalous position in the CMD. One possible interpretation might be that the primary is a normal giant and the secondary is a hotter but fainter F dwarf. In this case the anomalous photometry would be attributed to the combined light of the two stars. However, there are some restrictions on the kind of giant that the primary can be. It cannot be a clump giant, because there is no way to get the total light observed for H110 by combining the light of a clump giant together with the light of a dwarf from the cluster main sequence or turnoff. The total light from H110 ($V$ = 8.95) is only 0.19 mag brighter than the faintest clump giant (H27 with $V = 9.14$), yet the $B-V$ colour is 0.51 mag bluer. The primary cannot be on the first ascending giant branch, because PSH observed no lithium in H110, yet they did detect strong lithium in the two bona fide first ascending branch giants H77 and 208. Presumably the lithium in the atmosphere of the primary of H110 was destroyed when it evolved past the first ascending giant branch.

If the primary of H110 is a “normal” giant, this leaves only the possibility that it is one of the stars slightly bluer and fainter than the clump. This possibility is illustrated in Fig. 1, where we have plotted the CMD from photoelectric $UBV$ data for stars with P $>$ 50%. An isochrone for log t = 9.20 (Schaller et al. 1992) has been plotted (solid curve) for a distance modulus of 8.10 and colour excess of 0.03 mag, as well as the upper limit for binaries composed of two equal stars (long-dashed curve). We illustrate one possible deconvolution of the total light for H110 into a “normal” giant primary and a dwarf secondary from the main-sequence single-star isochrone. For the primary we adopt the point indicated on the CMD by the open circle to the right and just below the clump ($V = 9.27$, $B-V = 0.98$). When combined with the light of an F dwarf from the isochrone ($V = 10.53$, $B-V = 0.40$), this gives the total combined light actually observed for H110. More generally, the dotted curve shows the locus on the CMD for the total light of a binary composed of our adopted giant primary combined with dwarf secondaries drawn from the isochrone.

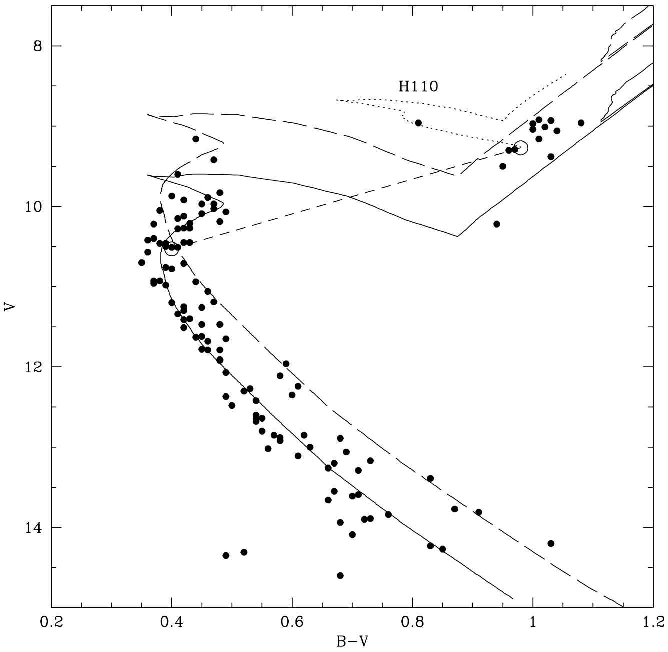

**Fig. 1.** Colour-magnitude diagram for NGC 752, with an isochrone for $\log t$ = 9.20, Z = 0.02 (Schaller et al. 1992) (solid curve) and the associated binary upper limit. 0.75 mag. brighter (long-dashed curve). The two open circles, linked by a short-dashed curve, represent the position of the red giant primary and main-sequence secondary of the red giant binary H110 resulting from the tentative photometric deconvolution. The dotted curve starting from the red giant position ($V$ = 9.27, $B-V$ = 0.98) describes the path followed by the composite colours of a binary with that red giant primary associated with main-sequence stars taken along the isochrone.

The photometric deconvolution illustrated in Fig. 1 implies that the secondary would contribute 31% of the total light at $V$. However, searches for secondary features in the correlation functions have been negative, both for the CORAVEL and the CfA observations. In particular, the two-dimensional correlation technique TODCOR (Zucker & Mazeh 1994) was used to analyze the CfA spectra and to set an upper limit of at most a few percent for the contribution of the light from the secondary at $V$.

The orbital period for H110 (127.34 days) is shorter than the critical period (350 or 400 days from the Padova or Geneva models, respectively) at the red giant tip corresponding to the primary filling its Roche lobe. Thus, the primary could not have evolved past the red giant tip without undergoing mass loss and/or mass transfer. We speculate that the anomalous position of H110 in the CMD may be the result of this Roche lobe overflow.

### 3.3.2. H75 and H208

The other two spectroscopic-binary members (H75 and 208) have quite long periods, which allow them to evolve well within their Roche lobes. The periods (3321 and 5276 days) are in fact so long that we have been able to cover barely more than one cycle, which explains the larger errors on the periods. H75 is definitively a clump star (see Fig. 5) and H208 appears to be located on the ascending giant branch, at the same magnitude as the clump, but at a redder colour.

Both stars seem to have companions fainter by at least 2 to 3 magnitudes because there is no sign of secondary features in the correlation functions for either the CORAVEL or the CfA observations. A small photometric effect seems to be visible on H208 which is slightly bluer than the isochrone.

A photometric difference of 3 magnitudes between the primary and the secondary gives a maximum mass of about 1.2 $M_\odot$ for H75 and H208. The spectroscopic orbital elements result in minimum masses of 0.84 and 0.81 $M_\odot$ respectively for the secondaries of H75 and H208, if a primary mass of 1.8 $M_\odot$ is assumed. The secondary masses are therefore constrained to the range 0.8 to 1.2 $M_\odot$. It is possible to put a tighter limit on the mass of the companion to H208 if we assume that the primary is on the theoretical isochrone for the first ascending branch plotted in Fig. 1 and the observed position for H208 to the blue of the isochrone is due to the light of a main-sequence secondary. In this case the photometric deconvolution would give a secondary with $V = 14.00$, $B - V = 0.82$, and mass = 0.88 $M_\odot$. If we assume, for H75, that the colour difference between H75 and H311, the reddest single clump star, is only due to binarity effects, then the maximum mass for the secondary is again close to 0.88 $M_\odot$. Therefore, by taking into account the photometry, one is able to reduce the uncertainties on the secondary masses and both secondaries seem to have masses around 0.85 $M_\odot$.

### 3.3.3. H213

H213 has a probability P($\chi^2$) $< 0.001$ that the observed scatter is due to random errors. The last observation made in 1996 shows a difference of more than 2.5 km s$^{-1}$ with respect to the measurements made around 1980 and this star is now considered as a *bona fide*, very long period spectroscopic binary.

### 3.3.4. Plat 212

The non-member star Platais 212 is also a spectroscopic binary, with a period of the order of 4500 days, a mean velocity of -2.2 km s$^{-1}$ and an amplitude slightly larger than 2 km s$^{-1}$. However, the phase coverage is not uniform and definitive elements cannot be computed yet.

Due to the limited number of observations for the other non-member binaries, it is not possible to estimate their periods and amplitudes.

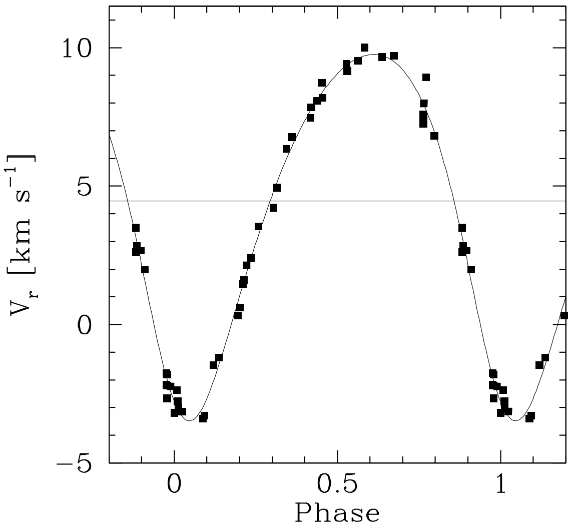

**Fig. 2.** Radial-velocity curve for H75.

**Table 6.** Orbital elements of three spectroscopic binaries

| Element | H75 | H110 | H208 |
|---|---|---|---|
| $P$ [d] | 3321.3 | 127.337 | 5276. |
| | 9.0 | .004 | 34. |
| $T$ [HJD-2440000] | 4176. | 9330.36 | 5567. |
| | 29. | .13 | 86. |
| $e$ | 0.224 | .00 | 0.139 |
| | .012 | .003 | .015 |
| $\gamma$ [km s$^{-1}$] | 4.46 | 4.78 | 4.86 |
| | .06 | .06 | .06 |
| $\omega$ [°] | 153.5 | | 357.4 |
| | 3.5 | | 5.9 |
| $K$ [km s$^{-1}$] | 6.62 | 25.48 | 5.40 |
| | .09 | .09 | .08 |
| f($m$) [$M_\odot$] | 0.0925 | 0.2189 | 0.0838 |
| | .0047 | .0023 | .0050 |
| $a$ sini [Gm] | 294.5 | 44.60 | 388.0 |
| | 5.5 | .17 | 9.4 |
| $\sigma(O-C)$ [km s$^{-1}$] | 0.40 | 0.42 | 0.39 |
| $n_{obs}$ | 48 | 53 | 59 |

## 4. The colour-magnitude diagram

The prominent feature in the CMD of the red giants (Fig. 5) is the clump represented by the eight stars H24, 27, 75 (SB), 137, 213 (SB), 311, and Plat 172 & 1263. Observations at 6707 Å for six of these clump giants have failed to detect lithium (H24, 137, 213, 311, Plat 172 PSH; H75, 213, 311, Gilroy 1989). In contrast, strong lithium has been detected for H77 and 208 (PSH, Gilroy 1989), which leads naturally to the interpretation that these two stars are the both on the first ascending giant branch, and therefore they have not yet destroyed the lithium in their atmospheres.

The four stars H1, 3, 11, and 295 describe a grouping to the blue and lower luminosity of the clump. No lithium has been detected for two of these stars (H1 and 295; PSH, Gilroy 1989),

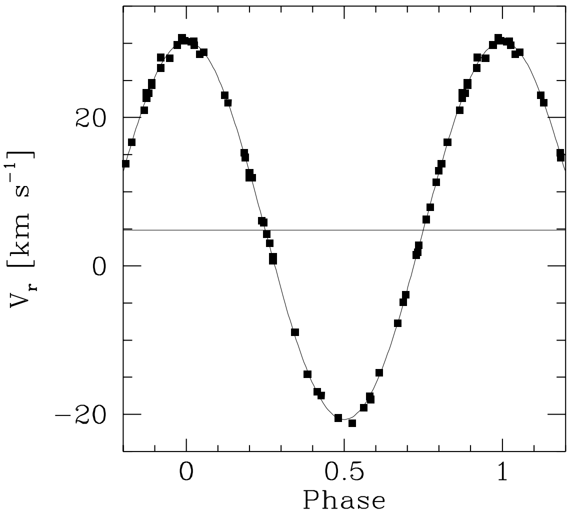

**Fig. 3.** Radial-velocity curve for H110.

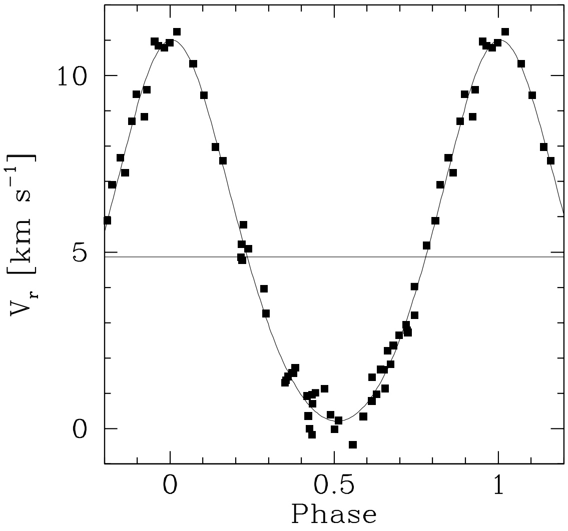

**Fig. 4.** Radial-velocity curve for H208.

which implies that they have evolved past the first ascending giant branch and have destroyed the lithium in their atmospheres. The other two stars, H3 and H11, have not been observed for lithium. H11 lies nearly half a magnitude above the theoretical isochrone for the first ascending giant branch, and presumably it has evolved past that stage. On the other hand, H3 lies only 0.07 mag above the isochrone, and its evolutionary stage is uncertain. Lithium observations for H3 could resolve this ambiguity, and would also be useful for H11 to confirm its evolutionary status.

Stars bluer and fainter than the clump have not been observed in the CMDs of NGC 3680 and IC 4651 (Mermilliod et al. 1995), although both clusters have ages similar to that of NGC 752. Evolutionary effects due to a close companion are ruled out by their constant radial velocities. The uncertainties on the photoelectric data ($\sigma(V) <$ 0.015 mag., $\sigma(colour) <$ 0.015 mag) are much too small to explain the spread of the red giants observed in the CMD. Secondary concentrations of red giants have been observed in several clusters (Mermilliod & Mayor 1989, 1989; Mermilliod et al. 1997) and NGC 752 offers one more example.

Each star could have a distant companion too separated to produce radial-velocity variation larger than 0.5 km s$^{-1}$ and too close to be seen optically, but which would shift the composite light to the observed positions in the HR diagram. This possibility should be checked for, but the probability that all four stars have such distant, undetected companions seems however to be low.

The positions of these five stars cannot be explained by standard theoretical isochrones. The simulations made by Carraro et al. (1993) produce a clump with some scatter, which depends on the simulated binary characteristics and rate. However, no effect can move the stars to a position below the clump. It should also be stressed that neither the Padova (Bertelli et al. 1994) isochrones, nor those from Geneva (Schaller et al. 1992) reproduce correctly the magnitude and colour of the clump for the best estimated reddening and distance-modulus. Both sets of models predict a clump magnitude too bright, although at quite different colours.

It is tempting to formulate the simple hypothesis that the stars found in the clump have undergone evolution through helium flash, while the other stars did not, because the red giant masses go from 1.79 at the bottom of the ascending giant branch to 1.88 at the red giant tip, according to the models of Schaller et al. (1992), and hence are very to close to the mass at which stars with core overshooting are supposed to undergo helium flash. Small differences in the exact mass of the core, due for example to different rotational history, could result in such a dichotomy. However, it does not explain why the luminosities of the stars in the helium burning stage that have undergone helium flash are brighter than those which have not undergone helium flash.

Another explanation may be provided by the study of NGC 6819 by Rosvick & VandenBerg (1998) who plotted the theoretical Zero Age Horizontal Branch (ZAHB) over the observed CMD to reproduce the clump position. Tripico et al. (1993) also referred to the ZAHB in their study of M67 clump stars. The shape of the ZAHB could help understanding the clump splitting observed in several clusters, but it would probably imply that the red-giant masses present differences larger than usually assumed.

## 5. Conclusion

A systematic radial-velocity survey has allowed us to strengthen the membership determination of 15 red giants in NGC 752, including two new candidate cluster red giant members in the central area (Platais 172 and 1263) and two possible members in the cluster halo. The census of red giants in the core is now probably complete and the number of halo members is certainly small: radial-velocity observation of 18 candidates in the cluster halo have yielded only two new probable red giants members. New spectroscopic orbits have been derived for three binaries. The binary frequency (27%: 4/15) is close to the mean value for red giants in open clusters (Mermilliod & Mayor 1992).

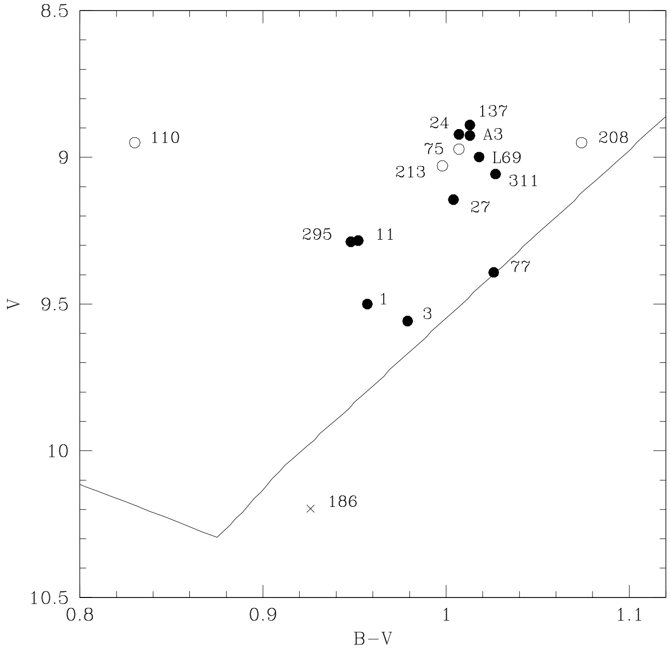

**Fig. 5.** Colour-magnitude diagram in the UBV system. The ascending giant branch of the isochrone for log t = 9.20 and Z = 0.02 (Schaller et al. 1992) has been set to pass through the position of H77. Star H1, 3, 11 and 295 are in a peculiar position. Open circles denote the binaries. H186 (cross) is a non-member. $(B - V)$ colours have been computed from Geneva photometry by the relation given by Meylan & Hauck (1981).

The distribution of the red giants in the colour-magnitude diagram is somewhat unusual. In addition to the prominent clump which contains eight stars, there are 3 or 4 red giants which lie both fainter and bluer than the clump. This observation is not accounted for by theoretical isochrones. More light could be shed on this question by observing clusters of similar age (log t $\sim$ 9.25) but containing more red giants. In addition, high-accuracy CCD photometry of clusters like NGC 2158, 6939 or 7789 should be analysed with emphasis on the red giants to investigate their distribution in the colour-magnitude diagram. However, reliable membership determination could be more difficult to assess due to the faintness of many of these stars. Therefore, radial-velocity determination of red giants in populous open clusters to assess membership and identify binaries is an important task for multi-fiber spectrographs on large telescopes.

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## References

Baranne A., Mayor M., Poncet J.-L. 1979, Vistas in Astron. 23, 279
Belloni T., Verbunt F. 1996, A&A 305, 806
Bertelli G., Bressan A., Chiosi C., Fagotto F., nasi E. 1994, A&AS 106, 275
Carraro G., Bertelli G., Bressan A., Chiosi C. 1993, A&AS 101, 381
Collinder P. 1931, Lund Obs. Ann no 2
Daniel S.A., Latham D.W., Mathieu R.D., Twarog B.A. 1994, PASP 106, 281
Dzervitis U., Paupers O. 1993, Ap&SS 199, 77
Ebbighausen E.G. 1939, Astrophys. J. 89, 431
Francic S. 1989, AJ 98, 888
Friel E., Liu T., Janes K.A. 1989, PASP 101, 1105
Heinemann K. 1926, Astr. Nach. 227, 193
Jennens P.A., Helfer H.L. 1975, MNRAS 172, 681
Jungkvist S. 1931, Medd. Astron. Obs. Upsala no 52
Latham D.W. 1992, in "Complemetary Approaches to Binary and Multiple Star Research", IAU Coll. No 135, Ed H. McAlister & W. Hartkopf, ASPC 32, 1000
Lavdovski V.V. 1961, Trudy Glavn. Astr. Obs. 73, 1
Lyngå G. 1987, Fifth Catalogue of cluster parameters (Strasbourg)
Mayor M., Mermilliod J.-C. 1984, in IAU Symp. no 105, Eds A. Maeder & A. Renzini (Dordrecht: Reidel), p. 411
Mermilliod J.-C., Mayor M. 1989, A&A 219, 125
Mermilliod J.-C., Mayor M. 1990, A&A 237, 61
Mermilliod J.-C., Mayor M. 1992, in "Binaries as Tracers of Stellar Formation", Eds. A. Duquennoy & M. Mayor (Cambridge: Cambridge University Press), p. 183
Mermilliod J.-C., Mayor M. 1996, A&A 307, 80
Mermilliod J.-C., Andersen J., Nordström B., Mayor M. 1995, A&A 299, 53
Mermilliod J.-C., Clariá J.J., Andersen J., Mayor M. 1997, A&A 324, 91
Meylan G., Hauck B. 1981, A&AS 46, 281
Nordström B., Andersen J., Andersen M.I. 1997, A&A 322, 460
Pilachowski C.A., Saha A., Hobbs L.M. 1988, PASP 100, 474
Pilachowski C.A., Willmarth D.W., Mathieu R.D., Latham D.W., Booth J., Armandroff T.E 1989, PASP 101, 991
Platais I. 1991, A&AS 87, 69
Rebeirot E. 1970, A&A 4, 404
Rohlfs K., Vanysek V. 1961, Astr. Abh. Hambourg V no 7
Rosvick J.M., VandenBerg D.A. 1998, AJ 115, 1516
Schaller G., Schaerer D., Meynet G., Maeder A. 1992, A&AS 96, 269
Stock J. 1985, RMAA 11, 103
Tripicco M.J., Dorman B., Bell R.A. 1993, AJ 106, 618
Vogt H. 1923, Astron. Nachr. 221, 43
Zucker S., Mazeh T. 1994, ApJ, 420, 806