A CH star in the globular cluster NGC 6426

M. Sharina,1⋆ B. Aringer,2 E. Davoust,3 A. Y. Kniazev4,5,6 and C. J. Donzelli7,8

1Special Astrophysical Observatory, Russian Academy of Sciences, N. Arkhyy, KChR, 369167, Russia
2Department of Astronomy, University of Vienna, Türkenschanzstr. 17, A-1180 Wien, Austria
3IRAP, Université de Toulouse, CNRS, 14 Avenue Edouard Belin, 31400 Toulouse, France
4South African Astronomical Observatory, PO Box 9, 7935 Observatory, Cape Town, South Africa
5Southern African Large Telescope Foundation, PO Box 9, 7935 Observatory, Cape Town, South Africa
6Sternberg Astronomical Institute, Lomonosov Moscow State University, Moscow, Russia
7Instituto de Investigaciones en Astronomía Teórica y Experimental (IATE), Observatorio Astronómico OAC, Laprida 854, X5000BGR, Córdoba, Argentina
8Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Avenida Rivadavia 1917, C1033AAJ, Buenos Aires, Argentina

Accepted 2012 July 17. Received 2012 July 17; in original form 2012 July 3

ABSTRACT
We report on the serendipitous discovery of a carbon star near the centre of the low-metallicity globular cluster NGC 6426. We determined its membership and chemical properties using medium-resolution spectra. The radial velocity of $-159 \text{ km s}^{-1}$ makes it a member of the cluster. We used photometric data from the literature and the COMARCS stellar atmospheric models to derive its luminosity, effective temperature, surface gravity, metallicity, and approximate C, N and O abundance ratios. According to these properties, we suggest that this star is a genuine carbon-rich low-metallicity asymptotic giant branch star.

Key words: stars: carbon – globular clusters: individual: NGC 6426.

1 INTRODUCTION
The role of globular clusters (GCs) in the chemical evolution of galaxies can be better understood by studying carbon stars (CSs) in the former. Only two types of CSs have abundances and kinematics typical of the Galactic halo: giant and dwarf CH stars (McClure 1985; Green 1996). In the field most of these stars are binaries, where the primary owes its peculiar nature to mass transfer from its white dwarf companion rather than to dredge-up from the interior (McClure & Woodsworth 1990). There is no observational evidence for the exact nature of CH stars in GCs. The chemical differences between CH stars that are intrinsic asymptotic giant branch (AGB) stars and those in binary systems are detailed by Abia et al. (2003).

Only three CH stars were found in GCs so far: two in Ó Cen, RGO 55 and GRO 70 (Harding 1962; Dickens 1972), and a probable one in NGC 6402 (Côté et al. 1997). The two CH stars in Ó Cen cannot be in the horizontal branch phase (Abia et al. 2003). Both GCs are of low metallicity, and presumably belong to the Galactic halo. Searches for CH stars in other clusters have been unsuccessful (Palmer 1980; Palmer & Wing 1982).

We report on the serendipitous discovery of a CH star in a GC, and analyse its spectra to establish its properties and find clues as to its exact spectral type.

2 OBSERVATIONS AND DATA REDUCTION
The CH star is located about 24.5 arcsec or 1.6$r_c$ south-east of the centre of NGC 6426, a low-metallicity GC in the Galactic halo. Its coordinates, obtained with HST images and in the 2MASS All-Sky Point Source Catalog,1 are: RA(J2000) = 17$^h$44′55.50′′, Dec.(J2000) = +03′ 10.9′′.

The star was discovered during an observing run on 2010 June 10, at the 1.93-m telescope of the Observatoire de Haute-Provence (OHP), aimed at obtaining integrated spectra of Galactic GCs with the CARELEC spectograph (Lemaître et al. 1990) and grating 300 lines mm$^{-1}$. Two long-slit (5.5 arcmin × 2 arcsec) spectra were obtained at the same position and position angle (PA) = 145°7, both with 20-minute exposures and a seeing ~2.5 arcsec. The corresponding dispersion and spectral resolution were ~1.78 Å pixel$^{-1}$, and ~5 Å, respectively, and the spectral range was ~3700–6800 Å. Helium and neon lamps were exposed at the beginning and at the end of the night for wavelength calibration. For relative flux calibration and radial velocity calibration, one flux standard HR 8634 (Hamuy et al. 1992, 1994), two Lick standard stars (HR 5933 and HR 7030) from the list of Worthey et al. (1994), and an N-type CS (APM 2229+1902) from the list of Totten & Irwin (1998) were observed on the same night. The signal-to-noise ratio per resolution element at 5000 Å is S/N ~ 29.

In order to reach a better S/N in the blue and to benefit from a higher spectral resolution, additional long-slit spectra were obtained with the Southern African Large Telescope (SALT; Buckley, Swart & Meiring 2006; O’Donoghue et al. 2006) on 2012 April 12 and 20. We used the Robert Stobie Spectrograph (Burgh et al. 2003) to make two 600-s exposures with the grating GR900 and two 900-s exposures with GR2300. The slit width was 1.25 arcsec and PA = 146°. The final reciprocal dispersions are 1.78 and 0.34 Å

1 http://irsa.ipac.caltech.edu

© 2012 The Authors

Mon. Not. R. Astron. Soc. 426, L31–L35 (2012) doi:10.1111/j.1745-3933.2012.01317.x

Received 2012 July 17; in original form 2012 July 3
pixel$^{-1}$ and the corresponding spectral resolution full width at half-maximum (FWHM) = 3 and 1 Å, respectively, for the spectra taken with the two gratings. The reduction of the SALT long-slit data was done in the way described in Kniazev et al. (2008). Primary reduction of the data was done with the SALT science pipeline (Crawford et al. 2010).

The data reduction and analysis of the OHP observations were performed using MEAS and IRAF. The dispersion solution provides an accuracy of $\sim$0.08 Å for wavelength calibration. Possible systematics in the wavelength calibration due to instrumental flexure were studied using the [O I] $\lambda$5577 night sky line in the dispersion-corrected spectra, and by comparison of synthetic and observed spectra using the full spectrum fitting methods and constructing a detailed line spread function of the spectrograph (see e.g. Koleva et al. 2009).

Finally, the one-dimensional lower resolution SALT spectrum was flux calibrated using the corresponding OHP spectrum and summed with it. The S/N in the resulting spectrum reaches $\sim$15 at 4300 Å, $\sim$50 at 5000 Å and $\sim$160 at 6300 Å. The resolution of the spectrum obtained with the grating GR2300 is FWHM = 1 Å and the mean S/N at 4740 Å is $\sim$40. The final medium-resolution spectrum of the CS is shown in Fig. 1. The high-resolution spectrum was used separately to estimate C$^{12}$/C$^{13}$, as explained in Section 5.

3 RADIAL VELOCITY

The heliocentric radial velocity of our star was derived by cross-correlation with the spectrum of the star APM 2229+1902 using the IRAF FXCOR package. Before the cross-correlation we subtracted the continuum using the IRAF task continuum and high-order polynomials. The cross-correlation shift (object template) is 1.32 pixels. The radial velocity of our star is $V_h = -163 \pm 26$ km s$^{-1}$, taking into account a relative systematic shift (object template) derived from fitting of the night sky lines $[-1.2 - (-0.7) = -0.5$ pixel], and heliocentric corrections of $-26$ and $-10$ km s$^{-1}$ for our star and the template APM 2229+1902, respectively (which has a radial velocity $V_h = -348$ km s$^{-1}$). We also used the more robust pPXF method (Cappellari & Emsellem 2004) to measure the radial velocity on the same spectra. The result of the fitting is illustrated in Fig. 2. Maximum penalized likelihood suppresses the effect of noise in the solution, so the accuracy is higher. Applying the aforementioned corrections, the resulting heliocentric radial velocity $V_h = -159 \pm 5$ km s$^{-1}$. Both estimates are close to the radial velocity of NGC 6426, $V_h = -162 \pm 23$ (Harris 1996, 2010 edition). The probability that the CH star belongs to the field is very low, because using the Besançon model (Robin et al. 2003), we find that the distribution of radial velocities of the 428 stars in the V magnitude range 10–18 located within 10 arcmin from the centre of the cluster is centred around a mean velocity of $+13.22$ km s$^{-1}$, with a dispersion of 53.52 km s$^{-1}$.

4 PHOTOMETRIC INFORMATION

The photometric data for our CH star and the ones in NGC 6402 and Ω Cen, and two classical Galactic CH stars from the atlas of CSs by Barnbaum, Stone & Keenan (1996) are listed in Table 1. The successive rows are: (1) apparent visual distance modulus from Harris (1996, 2010 edition); (2) absolute magnitude in the V band corrected for Galactic extinction; (3) Galactic extinction from Schlegel, Finkbeiner & Davis (1998); (4)–(9) broad-band optical and infrared colours corrected for Galactic extinction; and (10) effective temperature.

To estimate the coordinates of the CH star in NGC 6402, we first obtained approximate coordinates on images from the CFHT archive, and then identified it more accurately on HST images. These coordinates are: RA(2000) = 17h 37m 36s.94, Dec.(J2000) = $-03^\circ 14' 55''$. The colours and magnitudes for stars in NGC 6426 in the optical bands were published by Hatzidimitriou et al. (1999) and Dotter, Sarajedini & Anderson (2011), using ground-based and HST images, respectively. Unfortunately, our star is saturated on the HST images. In the colour–magnitude diagram $2 \ http://www1.cadc-ccda.hia-iha.nrc-cnrc.gc.ca

Figure 1. Spectrum of the CH star. The main spectral features are indicated. The spectrum of a classic CH star HD5223 from Goswami (2005) is shown in grey for comparison.

Figure 2. Radial velocity determination for the CH star using the pPXF method.

Table 1. Optical and 2MASS photometric data for CH stars. See text for details. All the colours were corrected for Galactic extinction.
of Hatzidimitriou et al. (1999), it is the reddest star in the cluster, slightly brighter than the stars at the tip of the red giant branch. Photometric data in the $B$, $V$ and $I$ bands for the CH stars in NGC 6426 and $\Omega$ Cen were taken from Cannon & Stobie (1973), Côté et al. (1997) and Pancino (2007). Unfortunately, the CH star in NGC 6426 is too close to another star of the same magnitude to obtain reliable near-infrared magnitudes from either 2MASS or DENIS.\(^3\)

The data for HD5223 and V Ari were extracted from the SIMBAD astronomical data base.

We calculated the near-infrared colours of the stars in the SAO and TCS photometric systems using the 2MASS colours and the transformation equations from Carpenter (2001) and Ramírez & Meléndez (2004). With the colours thus derived, corrected for Galactic extinction, our star definitely falls in the box delimiting CH stars in the two-colour diagnostic diagram in the SAO photometric system by Totten, Irwin & Whitelock (2000). Its effective temperature calculated using relations from Alonso, Arribas & Martínez-Roger (1999) and the $(J-K_\text{b})$ colour in the TCS photometric system is $T_{\text{eff}}=4100\pm125\,\text{K}$. This corresponds to the class CH4 of Keenan (1993), which is equivalent to spectral type K4 III for oxygen stars. Similarly, the $T_{\text{eff}}$ of RGO 55 and RGO 70 are 4468 and 4287 K, respectively.

5 SPECTRAL ANALYSIS

5.1 Classification

The spectrum of the CH star was examined visually in terms of different spectral characteristics (Goswami 2005) to avoid possible misclassification with CN- and R-type CSs, which have spectra similar to those of CH stars. We compared the spectrum of the CH star with spectra at almost the same resolution for other such objects in the literature (e.g Barnbaum et al. 1996; Goswami 2005) and found an approximate similarity in the shape of the main spectral features with the spectra of two classical CH stars: HD5223 (type C-H3, $C_2$ index 4.5) and HD13826 (V Ari) (type C-H3.5, $C_2$ index 5.5). HD 5223 is a CH giant (see Fig. 1) with $[\text{Fe/H}]=-2.0\,$dex, $C/O=3.0$, and V Ari is a semi-regular pulsating star with $[\text{Fe/H}]=-2.4$, $\log (g)=-0.2$, $C/O=2$ and $^{12}\text{C}/^{13}\text{C}\sim6-10$ (Aoki & Tsuji 1997; Goswami 2005). The strength of the $G$ band of CH ($\sim4300\,\text{Å}$) in the spectrum of our star, a main characteristic feature of CH-type CSs, resembles that in the spectrum of HD 5223, and the same applies to the second branch near 4342 Å. The line at 4226 Å is very weak. It is blended by molecular bands. The lines of atomic hydrogen and Ba II are seen distinctly, which is not the case in CR stars. The intensity of the CN band in our star is larger than in the case of HD 5223 and V Ari. The $C_2$ molecular bands near 4737, 5165, 5635, 6052 Å are deeper than in HD 5223. This indicates a lower temperature for our star and/or a higher C/O ratio (Barnbaum et al. 1996; Goswami 2005).

CH stars are classified into two types which follow distinct evolutionary paths based on their $^{12}\text{C}/^{13}\text{C}$ ratios (e.g Goswami, Karinkuzhi & Shantikumar 2010). Late-type CH stars with $^{12}\text{C}/^{13}\text{C} \geq 100$ are intrinsic AGB stars that produce the s-process elements internally. Early-type CH stars with low values, $^{12}\text{C}/^{13}\text{C} \leq 10$ obtain the s-process elements via binary mass transfer. This is why the $^{12}\text{C}/^{13}\text{C}$ ratio is an important probe of stellar evolution. The band heads for $^{12}\text{C}^{12}\text{C}$, $^{12}\text{C}^{13}\text{C}$ and $^{13}\text{C}^{13}\text{C}$ (at 4737, 4744 and 4752 Å, respectively) are resolved even at medium resolution. In the following, we will estimate $^{12}\text{C}/^{13}\text{C}$ and other parameters as accurately as possible using model atmospheres.

5.2 Hydrostatic dust-free models

To estimate the effective temperature, surface gravity, C/O and $^{12}\text{C}/^{13}\text{C}$ for the CH star in NGC 6426, we used the hydrostatic dust-free models for carbon-rich giants of Aringer et al. (2009) extended towards higher $T_{\text{eff}}$, $\log (g)$ and C/O to fit the observational data. We chose the following model parameters: stellar mass $M_*=1\,M_\odot$, metallicity $[\text{Fe/H}]=-2.0\,$dex, and solar abundance for the other elements including the isotopic ratio $^{12}\text{C}/^{13}\text{C}=86.8$ (Scott et al. 2006). The metallicity was chosen equal to the metallicity of NGC 6426 (given by Harris 1996, 2010 edition). The model stellar mass roughly corresponds to the mass of stars at the main-sequence turnover point of NGC 6426 (Hatzidimitriou et al. 1999). Unfortunately, it is not possible to derive more accurate values of the mass and chemical abundance of the star, given the resolution of our spectra.

The synthetic spectra computed with the COMA code based on COMARCS model atmospheres (see Aringer et al. 2009) were degraded by convolution with a Gaussian function to fit the resolution of our data. The resulting synthetic colours were compared with the observed ones, providing additional arguments for a proper evaluation of the stellar parameters.

To obtain a good fit of the data with the stellar atmospheric models, which include colours and synthetic spectra, we had to change not only the abundance of carbon, but also those of N and O, because only increasing C at a given $T_{\text{eff}}$, $\log (g)$ did not allow us to fit the CN bands. A moderate increase of O with dredge-up or mass transfer is expected for CSs (e.g Lugaro et al. 2012, and references therein). Finally, we derived the following model parameters: $T_{\text{eff}}=4000\,\text{K}$, $\log (g)=0.5$, $C/O=10$, $[\text{N/Fe}]=+0.5\,$dex, $[\text{O/Fe}]=+0.5\,$dex which corresponds to an absolute magnitude $M_V=-2.57$ and the following synthetic colours: $B-V=1.71$, $V-K=3.44$, $V-I=1.57$, $J-H=0.67$, $H-K=0.24$, $J-K=0.91$. One can see from Table 1 that the agreement between the observed and model spectra and between the spectroscopic and photometric $T_{\text{eff}}$ has been reached in a wide spectral range.

Fig. 3 shows how this model fits our medium-resolution spectra. Although our aim was not to estimate the abundances of different

\(^3\) http://cdsweb.u-strasbg.fr/denis.html

© 2012 The Authors, MNRAS 426, L31–L35
Monthly Notices of the Royal Astronomical Society © 2012 RAS

Figure 3. Observed medium-resolution spectrum of the CH star in NGC 6426 (black) fitted with the model one (green): $T_{\text{eff}}=4000\,\text{K}$, $\log (g)=0.5$, $C/O=10$, $N/O=+0.5$. A model spectrum with lower $N$ abundance is shown in red.
is normal for C-rich 4000–4100 K, log (g) = 0.5, C/O = 0.5, [Fe/H] in intrinsic N or C bands in the model and 12C/13C, 13C/13C and 13C/13C are indicated by the arrows.

chemical elements on these spectra, the depth and shapes of the main molecular bands are fairly well adjusted. We did not vary the isotopic ratio 12C/13C, since there is no significant difference between the shape and depth of the C2 bands in the model and those in the spectrum in the range 4737–4752 Å. Fig. 4 shows a comparison between the higher resolution spectrum of the CH star and the best-fitting model. The increased N abundance allows the strong CN features to be better matched. The derived luminosity, Teff, log (g) and high isotopic ratio 13C/13C indicate that this is probably a genuine AGB star. The derived Teff is normal for C-rich thermally pulsating AGB stars at a very low metallicity (Marigo et al. 2008).

6 SURVIVAL OF BINARIES IN GLOBULAR CLUSTERS

We now examine the alternative possibility that the CH star is a binary star rather than a genuine AGB star.

The dense environment of GCs favours the formation of binary stars, which in turn play an important role in their dynamical evolution, by delaying the onset of core collapse (e.g. Heggie, Trenti & Hut 2006). This dense environment may also lead to the dissolution of wider binaries, so that the actual number of binaries depends on the central stellar density and core radius (Verbunt 2003), as well as on their separation.

In Fig. 5 we show the total encounter rate $\Gamma \propto \rho_\ell^{1.5}a_\ell^2$ versus the encounter rate $\gamma \propto \rho_\ell^{1.5}a_\ell$ for single binaries (Verbunt 2003) for GCs in the halo (defined as having [Fe/H] $<$ −0.80 dex). The parameters were calculated using the core radii $r_\ell$ and central luminosity densities $\rho_\ell$ from Harris (1996, 2010 edition) and the mass-to-light ratios from McLaughlin & van der Marel (2005). We assumed that the mass-to-light ratio of NGC 6426, not available in the catalogues, is $\sim 1.9$, which is the most probable value for Galactic GCs at low metallicities. The uncertainty on this M/L is small (of the order of 10 per cent). We also assumed that all binaries have the same semi-major axis $a$, which is a more drastic simplification.

The clusters are aligned along a relation of almost unit slope between the two encounter rates. The three GCs with known CH stars fall roughly in the middle of the relation. If all four CH stars are binaries, this suggests that no binaries can form when the total encounter rate is low, and that they are more rapidly disrupted than replenished if the encounter rate for single binaries is high. The number of known CH stars in clusters is admittedly too small to allow for any statistical inference on the probability of our CH star to be a binary. The three GCs have similar $\gamma$, but the parameter $\Gamma$ is lower in NGC 6426 than in the other two clusters, thus making our star perhaps less likely to be a binary star. However, as pointed out by Verbunt (2003), $\Gamma$ depends on the mass segregation, on the fraction of binaries and on their period distribution. Furthermore, both $\Gamma$ and $\gamma$ depend linearly on the semi-major axis, for which we assumed a universal value, but which can vary between a few and at least 200 $R_\odot$, so that presently a better way to determine the binary status of our star would be to monitor its radial velocity.

7 CONCLUSIONS

We have discovered a carbon star of CH type in NGC 6426 and derived its main physical and chemical parameters: $M_V = -2.58$ mag, $T_{\text{eff}} = 4000–4100$ K, log (g) $\sim 0.5$, [Fe/H] $\sim -2$ dex, C/O $\sim 10$, N/O $\sim +0.5$ dex and 13C/13C $\sim 87$. The data and the estimated encounter rates in the parent GC indicate that the object is likely an intrinsic low-metallicity carbon-rich AGB star, but additional extensive high-resolution observational and theoretical studies are needed to reveal the role of a possible presently invisible companion in its evolution.

ACKNOWLEDGMENTS

We thank Dr Goswami for providing spectra of CH stars, Prof. Sarajedini for sending us a table with the photometry of NGC 6426 and J.-P. Troncin who helped in the OHP observations. MS acknowledges partial support of grants GK. 14.740.11.0901 and RFBG 11-02-00639-a. BA acknowledges support from Austrian Science Fund (FWF) Projects AP2300621 & AP23586. AYK acknowledges support from the National Research Foundation of South Africa. This research is based on observations obtained with SALT, programme 2011-3-RSA-003, and it made use of the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. It used the facilities of the Canadian Astronomy Data Centre operated by the
National Research Council of Canada with the support of the Canadian Space Agency. It made use of the SIMBAD database, operated at CDS, Strasbourg, France. It also made use of the DENIS database. The DENIS project has been partly funded by the SCIENCE and the HCM plans of the European Commission under grants CT920791 and CT940627. It is supported by INSU, MEN and CNRS in France, by the State of Baden-Württemberg in Germany, by DGICYT in Spain, by FFWFBWF in Austria, by FAPESP in Brazil, by OTKA grants F-4239 and F-013990 in Hungary, and by the ESO C&EE grant A-04-046.

NOTE ADDED IN PRESS

After this Letter was accepted, we were informed that three more carbon stars are known in the globular cluster Ω Cen (Van Loon et al. 2007)

REFERENCES

Abia C. et al., 2003, PASA, 20, 314
Alonso A., Arribas S., Martínez-Roger C., 1999, A&AS, 140, 261
Aoki W., Tsuji T., 1997, A&A, 317, 845
Aringer B. et al., 2009, A&A, 503, 913
Barnbaum C., Stone R. P. S., Keenan P. C., 1996, ApJS, 105, 419
Buckley D. A. H., Swart R. P. S., Keenan P. C., 1996, ApJS, 105, 419
Cannon R. D., Stobie R. S., 1973, MNRAS, 162, 207
Cappellari M., Emsellem E., 2004, PASP, 116, 138
Carpenter J., 2001, AJ, 121, 2851
Côté P. et al., 1997, ApJ, 476, L15
Crawford S. M. et al., 2010, in Silva D. R., Peck A. B., Soifer B. T., eds, SPIE Proc. Vol. 7737, Observatory Operations: Strategies, Processes, and Systems III. Am. Inst. Phys., New York, p. 773725
Dickens R. J., 1972, MNRAS, 159, 7v

dotter A., Sarajedini A., Anderson J., 2011, ApJ, 738, 74
Goswami A., 2005, MNRAS, 359, 531
Goswami A., Karinkuzhi D., Shantikumar N. S., 2010, MNRAS, 402, 1111
Green P. J., 1996, in Wing R. F., ed., Proc. IAU Symp. 177, The Carbon Star Phenomenon. Kluwer, Dordrecht
Hamuy M. et al., 1992, PASP, 104, 533
Hamuy M. et al., 1994, PASP, 106, 566
Harding G. A., 1962, Observatory, 82, 205
Harris W. E., 1996, AJ, 112, 148
Hatzidimitriou D. et al., 1999, AJ, 117, 3059
Heggie D. C., Trenti M., Hut P., 2006, MNRAS, 368, 677
Keenan P. C., 1993, PASP, 105, 905
Kniazev A. Y. et al., 2008, MNRAS, 388, 1667
Koleva M., Prugnail Ph., Bouchard A., Wu Y., 2009, A&A, 501, 1269
Lemaître G. et al., 1990, A&A, 228, 540
Lugaro M., Karakas A., Stancliffe R. J., Rijs C., 2012, AJ, 747, 2
McClure R. D., 1985, J. R. Astron. Soc. Can., 79, 277
McClure R. D., Woodsworth A. W., 1990, ApJ, 352, 709
McLaughlin D. E., van der Marel R. P., 2005, ApJS, 161, 304
Marigo P. et al., 2008, A&A, 482, 883
O’Donoghue D. et al., 2006, MNRAS, 372, 151
Palmer L. G., 1980, PhD thesis, Ohio State Univ.
Palmer L. G., Wing R. F., 1982, AJ, 87, 1739
Pancino E., Galfo A., Ferraro F. R., Bellazzini M., 2007, ApJ, 661, L155
Ramírez I., Meléndez J., 2004, ApJ, 609, 417
Robin C., Reylé C., Derrière S., Picaud S., 2003, A&A, 409, 523
Schlegel D. J., Finkbeiner D. P., Davis M., 1998, ApJ, 500, 525
Scott P. C., Asplund M., Grevesse N., Sauval A. J., 2006, A&A, 456, 675
Totten E. J., Irwin M. J., 1998, MNRAS, 294, 1
Totten E. J., Irwin M. J., Whitelock P. A., 2000, MNRAS, 314, 630
Van Loon J. Th., Van Leeuwen F., Smalley B., Smith A., Lyons N. A., McDonald I., Boyer M. L., 2007, MNRAS, 382, 1353
Verbunt F., 2003, in Piotto G., Meylan G., Djorgovski S. G., Riezzo M., eds, ASP Conf. Ser. Vol. 296, New Horizons in Globular Cluster Astronomy. Astron. Soc. Pac., San Francisco, p. 245
Worthey G., Faber S. M., Gonzalez J. J., Burstein D., 1994, ApJS, 94, 687

This paper has been typeset from a TeX/LaTeX file prepared by the author.