The chemical composition of the peculiar companion to the millisecond pulsar in NGC 6397

E. Sabbi¹, R.G. Gratton², A. Bragaglia³, F. R. Ferraro¹, A. Possenti¹, F. Camilo⁵, and N. D’Amico⁴,⁶

¹ Dipartimento di Astronomia Università di Bologna, via Ranzani 1, I–40127 Bologna, Italy
e-mail: sabbi@bo.astro.it
² INAF–Osservatorio Astronomico di Padova, vicolo dell’Osservatorio 5, I–35122 Padova, Italy
³ INAF–Osservatorio Astronomico di Bologna, via Ranzani 1, I–40126 Bologna, Italy
⁴ INAF–Osservatorio Astronomico di Cagliari, Loc. Poggio dei Pini, Strada 54, I–09012 Capoterra, Italy
⁵ Columbia Astrophysics Laboratory, Columbia University, 550 West 120th Street, New York, NY 10027, USA
⁶ Dipartimento di Fisica Università di Cagliari, Cittadella Universitaria, I–09042 Monserrato, Italy

Abstract. We present the chemical composition of the bright companion to the millisecond pulsar J1740−5340 in NGC 6397, based on high resolution spectra. Though the large rotation velocity of the star broadens the lines and complicates the analysis, the derived abundances are found fully compatible with those of normal unperturbed stars in NGC 6397, with the exception of a few elements (Li, Ca, and C). The lack of C suggests that the star has been peeled down to regions where incomplete CNO burning occurs, favouring a scenario where the companion is a turn-off star which has lost most of its mass. In addition we found an unexpected large Li abundance, which suggests that fresh $^7$Li has been produced on the stellar surface.

Key words. Globular clusters: individual (NGC 6397) — stars: evolution — stars: abundances — pulsars: individual (PSR J1740−5340) — stars: millisecond pulsar — techniques: spectroscopic

1. Introduction

PSR J1740−5340 is a binary eclipsing millisecond pulsar (MSP) discovered by D’Amico et al. (2001a, 2001b) in the globular cluster NGC 6397. A bright and variable star, with anomalous red colours (hereafter COM J1740−5340), was identified by Ferraro et al. (2001) as the companion to the MSP. This is the first observed example of a MSP companion whose light curve is dominated by ellipsoidal variations, suggestive of a tidally distorted star, which almost completely fills (and is still overflowing) its Roche lobe.

Binary evolution calculations (e.g. Tauris & Savonije 1999; Podsiałowski, Rappaport & Pfahl 2002) and the optical detections of a few sources in the Galactic field (e.g. Hansen & Phinney 1998; Stappers et al. 2001) show that the most common companion to a binary MSP is either a white dwarf or a very light (0.01–0.03 $M_\odot$) almost exhausted not fully degenerate star. In the crowded stellar environment of a globular cluster, other kinds of companions are also possible, resulting from dynamical encounters in the cluster core. For example, the MSP 47 Tuc-W in 47 Tucanae is orbited by a companion whose position in the colour-magnitude diagram (CMD) suggests that it is a main sequence (MS) star heated by the pulsar radiation flux (Edmonds et al. 2002).

None of these hypotheses fit with the observed features of COM J1740−5340: it is too luminous to be a white dwarf (V≈16.6, comparable to the turn–off stars of NGC 6397, Taylor et al. 2001, Ferraro et al. 2001); its mass (∼0.3 $M_\odot$, Ferraro et al. 2003, hereafter Paper I, Kaluzny et al. 2003) is too high for a light stellar companion; finally, if originally it was a MS star, its anomalous red colour would imply a bloating of the atmospheric regions much larger than predicted by any available model (e.g. Podsiałowski 1991; D’Antona et al. 1996). As a consequence, many intriguing scenarios were proposed in order to explain the nature of this binary system (see Possenti 2002; Orosz & van Kerwijk 2002; Grindlay et al. 2002 for reviews).

The unusual brightness of COM J1740−5340 allows in principle a detailed study of its chemical composition and derivation of the structural parameters of this binary system, opening new possibilities in studying the origin of MSPs in clusters. In this framework we started a spectroscopic campaign with ESO telescopes; this paper is the third in a series which reports on these observations. In
Paper I we presented the first results based on the high resolution spectra: we provided the radial velocity curve, the mass ratio, the determination of the component masses, a preliminary evaluation of the metallicity and a discussion of the heating of the companion surface due to the impinging MSP flux. In Sabbi et al. (2003, Paper II) we showed the complex structure of the Hα line (deriving important information on the mass loss) and discussed the unexpected presence of He i lines, implying the existence of a very narrow heated region on the companion surface. This paper focuses on the chemical abundance analysis. The observational data are presented in §2, while in §3 we report on the rotational velocity, the atmospheric parameters and the equivalent widths of the observed spectral lines. §4 is devoted to the determination of the actual element abundances, which are discussed in §5.

2. Observations and data reduction

Eight high resolution spectra of COM J1740−5340, taken at different phases and covering the whole orbital period of the binary system (P ∼1.35 days) were acquired with the Ultraviolet-Visual Echelle Spectrograph (UVES) mounted at the Kueyen 8m-telescope (UT2) of the ESO Very Large Telescope on Cerro Paranal (Chile). More details on the observational strategy can be found in Paper I. COM J1740−5340 is located in a crowded region, hence seeing conditions are relevant to minimize contamination from nearby objects: all the spectra (but one) were taken with seeing between 0.9 and 1.2 ″. Our spectra cover, with some gaps, the wavelength range 3280–6725 Å, at a resolution R ∼ 40000; the S/N of the individual spectra varies, but it is typically 30–35 near Hα.

In the following analysis we started with the one-dimensional, wavelength calibrated spectra produced by the UVES pipeline (Ballester et al. 2000). All our abundance analysis is applied to the sum of two spectra acquired near the orbital quadratures (at orbital phases ∼ 0.02, and 0.56 respectively), when the radial velocities are required near the orbital quadratures (at orbital phases ∼ 0.02, and 0.56 respectively). After excision of cosmic rays and shift to zero radial velocities, we combined the spectra and re-binned them with 0.3 Å resolution in order to enhance the S/N (∼ 60 near Hα) up to the level required by the purposes of the present paper; there is no loss of information in doing so, given the width of the lines.

3. Analysis and error estimates

3.1. Rotation Velocity

The lines of COM J1740−5340 are greatly broadened by the rotation velocity of the star. In order to evaluate this quantity, we exploited the spectra of three subgiants (SGB) in NGC 6397 (i.e. stars with similar temperature and gravity). They were observed using a UVES configuration similar to ours within a project devoted to study the chemical composition of NGC 6397 (Gratton et al. 2001, hereafter G01). The positions of the three aforementioned subgiants and COM J1740−5340 are highlighted in the CMD shown in Fig. 1.

In order to derive the rotation velocity we selected the subgiant observed with the highest S/N ratio, namely # 793 in G01 ([Fe/H] = −2.04, T eff = 5478 K, log g = 3.4, S/N ∼ 100). It represents a very good template for a “not rotating” star: a firm upper limit to the projected rotation velocity has been recently set at V sin i ≤ 3.7 km s−1 (Lucatello & Gratton 2003).

A cross-correlation technique was applied to compare the spectrum of the selected subgiant with that of COM J1740−5340. This technique gives an upper limit to the real rotation velocity, because the cross correlation peak is widened by factors other than rotation (line width of the template star; micro- and macro-turbulence for the program star; instrumental profile). However, in our case these other widening factors are much smaller than those due to rotation of COM J1740−5340: the FWHM of the profiles of the template is 10.5 kms−1; typical macro-turbulent velocity for subgiants of NGC 6397 is 6.7 kms−1 (Lucatello & Gratton 2003); the microturbulent velocity for COM J1740−5340 is about 1.0 km s−1 (see below); and finally, the instrumental broadening is about 6 kms−1. When we sum in quadrature all these terms, the total contribution to line width is 13.9 km/s. We can then safely assume that the rotational velocity of COM J1740−5340 (expected to be about 50 kms−1) dominates the width of the cross-correlation peak.

As the blue part of the spectra is richer in lines and lacks telluric features, three different portions of this spectral region (namely λλ 4120−4180, 4120−4310, and 4361−4441 Å) were selected, avoiding strong lines like Ca II H and K, and Balmer. We have determined the FWHM (i.e. the rotational velocity) of the three cross-correlation peaks, fitting them with a Dirac δ function broadened by rotation effects, assuming a gray atmosphere, a normal limb-darkening law (coefficient equal to 0.6, appropriate for stars of this temperature), and several velocities. The V sin i, where i is the orbit inclination, in the three spectral regions are (see Fig. 2): 51.0 ± 1.5, 49.0 ± 1.5, and 48.0 ± 2.1 kms−1 respectively (1σ errors); the weighted average is V sin i = 49.6 ± 0.9 kms−1. A fully compatible value (V sin i = 48.6 ± 0.9 kms−1) has been obtained by subtracting quadratically the broadening terms due to the other factors mentioned above.

3.2. Atmospheric parameters: temperature and gravity

The COM J1740−5340 effective temperature (T eff) has been determined using two different approaches: examining the Hα lines in our spectra (a reddening free method, see e.g., G01) or adopting the broad band colours resulting from the photometric observations of Kaluzny, Rucinski &

\[ [A/B] = \log_{10}(N_A/N_B)_{\text{star}} - \log_{10}(N_A/N_B)_{\odot} \]

for element A and B.
Fig. 1. Position in the colour-magnitude diagram of the three subgiant stars examined in G01 (filled dots) and of COM J1740−5340 (star). COM J1740−5340 B and V magnitudes are taken from Kaluzny et al. (2003, Table 1, in quadrature).

Fig. 2. Peak of the cross correlation between COM J1740−5340 and star # 793 of G01 (solid line) in the spectral region included between λλ 4120–4180 Å, and examples of three possible choices of Vsin i (broken lines): the best fit in this case turns out to be 51 km s$^{-1}$.

Fig. 3. Determination of effective temperature from the H$\alpha$ wings. The upper panel shows the observed H$\alpha$ spectrum and a set of synthetic Kurucz models at different T$_{\text{eff}}$’s; the shaded region is excluded from the fit. The lower panel shows the corresponding ratios: the dashed horizontal lines represent ratio = 1 for each case; note that the best fit cases are for T$_{\text{eff}}$ = 5400 and 5600 K.

Thompson (2003). Unfortunately, too few lines were available to derive the T$_{\text{eff}}$ from line excitation.

- The shape of the H$\alpha$ absorption line wings is a good temperature indicator for T$_{\text{eff}}$ higher than about 5000 K (Fuhrmann et al. 1993); the core is best left out in all stars, and even more in our case, where an emission component is present (Paper II). Although this method assumes a “normal” atmosphere for COM J1740−5340, which is not strictly true (e.g., the star is not spherical), it is likely a good approximation for the deep regions where the H$\alpha$ wings forms. Even if there are other Balmer lines in our spectrum, we worked only on H$\alpha$ because it is less contaminated by metal lines, and less dependent on metallicity, gravity, and details in the convection treatment.

As a first evaluation, we tried to reproduce the H$\alpha$ wings with synthetic spectra based on the appropriate Kurucz (1995) model atmosphere, without overshooting: we assumed [Fe/H]=−2 (G01), and log $g$ = 3.5. Several different T$_{\text{eff}}$’s have been adopted (the cases at 5000, 5200, 5400, and 5600 K are shown in Fig. 3, top panel), and the best fit temperature appears to be T$_{\text{eff}}$ = 5500 ± 100 K. The best fit temperature has also been determined by the ratio of the observed and synthetic profiles (Fig. 3, lower panel, where identity between the two profiles is indicated by the horizontal lines) yielding the same T$_{\text{eff}}$. In these estimates, the adoption of a metallicity is the most important factor, while the surface gravity impact on T$_{\text{eff}}$ is small, (an error of 0.3 dex on log $g$ involves an error of 54 K on the evaluation of T$_{\text{eff}}$).
• The second method uses the photometric colours and implies independent knowledge of the reddening. Since the star is variable, we chose the average of the values published in the Table 1 of Kaluzny, Rucinski & Thompson (2003), obtaining (B-V)$_{\text{avg}}$ $\sim$0.74. We also assumed E(B − V) = 0.183, as recently derived from Strömgren and Johnson photometry (Gratton et al. 2003). From the appropriate Kurucz transformation, we derived T$_{\text{eff}}$ = 5560 ± 100 K. We did not use V − I for an independent determination, because we had only the Johnson-Cousins colour available, while Kurucz tables require both V and I in the Johnson system and this transformation is extremely uncertain in a Hα emitting star, like COM J1740−5340.

In summary, averaging the two temperatures, we obtain T$_{\text{eff}}$ = 5530 ± 70 K, in good agreement with previous estimations (Ferraro et al. 2001; Paper I; Orosz & van der Kerkwijk 2003).

The surface gravity g has been estimated from the position of COM J1740−5340 in the CMD and from its mass, as derived in Ferraro et al. 2001, 2003 respectively. Since the latter is constrained to be in the interval 0.22 − 0.32 M$_\odot$, we took a value of 0.3 M$_\odot$ and derived log g = 3.5 ± 0.2, which is confirmed both by the following abundance analysis and the ionization equilibrium.

3.3. Equivalent Widths

The equivalent widths (EWs) measured in our spectra have been used both for refining the set of atmospheric parameters (surface gravity from the equilibrium of ionization, and microturbulent velocity from elimination of trends with expected line strength) and for deriving the actual element abundances. For some elements (e.g., Li) and molecules (CH) we also used spectral synthesis. A general problem encountered in the analysis is that the rotation washed out the weak, high excitation lines, the ones most directly depending on the element abundance. We are thus left with strong and saturated lines, whose analysis is dependent on the microturbulent velocity $v_t$ and on the damping, respectively. For the latter we used the Barklem et al. (2000) treatment, the best available at the present time.

As a first step, EWs were measured on the unidimensional, extracted spectral orders using a gaussian function and an automatic routine working within the ISA package (Gratton 1988). A few lines, missed by the automated search, were added manually. Finally, the EWs actually used for the abundance analysis were derived from the relation between line depth and equivalent width (for a detailed description of the procedure see Bragaglia et al. 2001). The list of lines measured and used in the abundance analysis is given in Table 1, together with the adopted excitation potentials (E.P. in eV), the oscillator strengths (log gf’s), the observed EW in mÅ and the derived abundances. The typical error on the EWs is about 5 mÅ. Note that the measured EWs are influenced by rotation since the line broadening often produces blends. A discussion of the line broadening relevance for determination of the elemental abundance is given in next section.

We measured lines both of Fe I and Fe II; from the equilibrium of ionization we obtained a surface gravity value (log g = 3.46 ± 0.2) in perfect agreement with the one derived from photometry.

Optimization of the microturbulent velocity was done by comparing the abundances given by the intermediate strength lines with those derived from the strong ones, with well developed damping wings. In fact this would lead to a $v_t$ quite smaller than required to get a good ionization equilibrium, so we compromised on an average value, adopting $v_t$ = 1 (± 0.5) kms$^{-1}$.

In summary, the abundance analysis has been performed adopting the following atmospheric parameters: T$_{\text{eff}}$ = 5530 K, log g = 3.46, $v_t$ = 1.0 kms$^{-1}$; by the analysis of 12 Fe lines, we derive [Fe/H] = −1.85 ± 0.13 (see next Section for a better assessment of the errors). These values are to be compared with those used by G01 in the analysis of the NGC 6397 subgiants: T$_{\text{eff}}$ = 5478 K, log g = 3.42, $v_t$ = 1.32 kms$^{-1}$ and [Fe/H] = −2.05 ± 0.03.

4. The chemical abundance

How do the element abundances in COM J1740−5340 compare with those measured in other stars of NGC 6397? To address this question, we have considered three NGC 6397 SGB stars observed by G01 with a similar UVES configuration, and which display very similar atmospheric parameters (see §3.1). Combining the spectra of the three stars and convolving the summed spectrum with a rotational profile of 49.6 kms$^{-1}$ (see §3.1), we have built a high S/N template spectrum.

We can first exploit this template spectrum for assessing the typical uncertainty in our abundance analysis due to the effects of the rotation of COM J1740−5340. In fact, comparing the line EWs both in the original SGB summed spectrum and in the spectrum broadened by rotation, we have noticed a systematic increasing in the abundances measured from the latter (even of 0.5 dex). This confirms that no immediate comparison should be done with the chemical composition of non-rotating stars, since COM J1740−5340 lines are broadened: blends with nearby lines can increase the EWs, and the derived abundances may be in error. Another very important factor is that the atmospheric model for COM J1740−5340 is not adequate, given the non spherical — and possibly variable — geometry of COM J1740−5340: this mostly affects the ionized species, whose abundances are less reliable. From these considerations an error of 0.2 dex on the derived metallicity of [Fe/H] = −1.85 was considered, while the other abundances are determined with larger errors, about 0.3 dex.

Inspection of Fig. [I] (where they have been superimposed in four different regions comprising lines of Ca, Ti, Mg, Sr and Fe) demonstrates that the COM J1740−5340 and the SGB template spectra show an excellent agree-
Fig. 4. Comparison between the COM J1740−5340 spectrum (grey line) and the subgiants template (black line, obtained by averaging, and broadening to account for rotation, three normal NGC 6397 subgiant stars, G01). We show the spectral regions near lines of Ca\textsc{ii} (panel (a)), Ti\textsc{ii} (panel (b)), Ti\textsc{i} (panel (c)) and Sr\textsc{ii} (panel (d)). In all these regions many Fe\textsc{i} lines are also present.

This conclusion would nominally contrast with the values collected in Table 2, where the forth column lists the differences between the average values of the abundances for each species measured in COM J1740−5340 and those derived by G01 for normal subgiant not rapidly rotating stars in NGC 6397. Taking these estimates at face value, COM J1740−5340 would show an overabundance of various species, particularly iron. However, according to the aforementioned difficulties involved in the analysis, we conclude that, within the errors, the abundances of Fe, Na, Mg, and Ti in COM J1740−5340 are compatible with those measured in normal NGC 6397 stars.

4.1. Discrepant elements: Ca, C, Li

In the previous section we have shown that, once the broadening effects on EWs are taken into account, the chemical abundances of COM J1740−5340 are fairly similar to those of SGB stars. Nevertheless, even after adjustment for rotation, some elements still show disagreement in abundances with the other NGC 6397 stars. Since for the Sr\textsc{ii} and Ba\textsc{ii} only one line (coming from ionized species, whose abundance determination is less reliable) each is present in our spectra, we do not consider here these two elements, and focus only on the three others.

(i) Ca: We measured only four Ca\textsc{i} lines in our spectra, among which are the very strong ones at $\lambda\lambda$ 4226.74 Å and 6162 Å. Since the strength of these lines depends more on
Fig. 5. Evaluation of the carbon abundance from the CH band. Panel (a) shows a clear depletion in the region of the CH band in the COM J1740−5340 spectrum (grey line) with respect to the NGC 6397 subgiants template (black line). Panel (b) shows the result of spectral synthesis, demonstrating that C is strongly underabundant in the COM J1740−5340 atmosphere.

Fig. 6. In panel (a) we compare the COM J1740−5340 spectrum with the NGC 6397 subgiants template: the Li i line is clearly deeper than in the template. In panel (b) we show a comparison with four different synthetic spectra, demonstrating the high Li content.

$\nu_h$ than on abundance (hence they are rarely used), we retained only the two most reliable for abundance determination (namely at $\lambda\lambda$ 6122 Å and 6439 Å). We accurately checked our spectrum near the lines for cosmic rays and hidden blends, and directly compared it to the SGB template. COM J1740−5340 Ca i lines appear deeper than in the template, as a consequence there are differences in the EWs (e.g., about 20 mÅ for the 6122 Å line). Taking into account the slightly different atmospheric parameters for COM J1740−5340 and the SGB template, this implies a Ca i abundance about 0.4 dex higher for our star.

(ii) C: Comparing our spectrum to the template SGB one, it is clear that C is strongly underabundant in COM J1740−5340 (Fig. 5(a)). To get a quantitative esti-
Table 1. Equivalent widths (only for the most reliable lines) measured on the COM J1740–5340 spectrum and derived abundances. Li i, Ti ii, and Sr ii abundances come from synthetic spectra (SS flag in the last column), while Na i abundances have been corrected for departure from local thermodynamical equilibrium (NLTE).

| Elem. | λ (Å) | E.P. (eV) | log gf | EW (mA) | abund. | Notes |
|-------|-------|-----------|--------|---------|--------|-------|
| Li i  | 6707.80 | 0.00 | 0.19 | 2.2 | SS |
| Na i  | 5889.97 | 0.00 | 0.18 | 167.2 | 4.31 | NLTE |
| Na i  | 5895.94 | 0.00 | -0.12 | 167.2 | 4.61 | NLTE |
| Mg i  | 5172.70 | 2.72 | -0.32 | 247.1 | 5.66 |
| Mg i  | 5183.62 | 2.72 | -0.10 | 278.3 | 5.56 |
| Mg i  | 5528.42 | 4.34 | -0.52 | 64.0 | 5.64 |
| Ca i  | 6122.23 | 1.89 | -0.27 | 82.0 | 5.07 |
| Ca i  | 6439.08 | 2.52 | 0.39 | 71.5 | 4.81 |
| Ti ii | 4393.03 | 1.08 | -0.51 | 3.4 | SS |
| Fe i  | 4045.81 | 1.49 | 0.28 | 317.2 | 5.79 |
| Fe i  | 4063.59 | 1.56 | 0.06 | 267.1 | 5.91 |
| Fe i  | 4071.74 | 1.61 | -0.02 | 227.9 | 5.87 |
| Fe i  | 4202.04 | 1.49 | -0.71 | 124.7 | 5.74 |
| Fe i  | 4383.56 | 1.49 | 0.20 | 275.7 | 5.68 |
| Fe i  | 4404.76 | 1.56 | -0.14 | 192.9 | 5.73 |
| Fe i  | 5325.19 | 3.21 | -0.10 | 85.0 | 5.84 |
| Fe i  | 5405.78 | 0.99 | -1.84 | 82.5 | 5.48 |
| Fe i  | 5434.53 | 1.01 | -2.12 | 62.5 | 5.29 |
| Fe ii | 4923.93 | 2.89 | -1.35 | 91.8 | 5.89 |
| Fe ii | 5018.45 | 2.89 | -1.22 | 95.4 | 5.84 |
| Fe ii | 5316.62 | 3.15 | -2.02 | 52.7 | 5.81 |
| Sr ii | 4077.71 | 0.00 | 0.17 | 1.1 | SS |
| Ba ii | 6141.75 | 0.70 | 0.00 | 60.8 | 0.62 |

Table 2. Abundances of COM J1740–5340 (in column 2), compared to those of normal SGBs; see G01 for Fe, Na, and Mg, while the other values are still unpublished (see text).

| Element | abund. | abund. | Δ(abund.) |
|---------|--------|--------|-----------|
| COM     | SGB    |        |           |
| Fe i    | 5.70   | 5.42   | +0.28     |
| Fe ii   | 5.84   | 5.26   | +0.58     |
| Li i    | 4.46   | 1.2    | +1.00     |
| Na i    | 2.2    | 4.51   | -0.05     |
| Mg i    | 5.62   | 5.70   | -0.08     |
| Ca i    | 4.94   | 4.54   | +0.40     |
| Ti ii   | 3.4    | 3.39   | 0         |
| Sr ii   | 1.1    | 0.75   | +0.35     |
| Ba ii   | 0.62   | -0.06  | +0.68     |
If we removed it, it is possible that the line is still partially contaminated by this cosmic ray. Spectra at higher S/N are required to clearly assess the presence of the line at this phase.

5. Summary and Conclusions

We have presented the chemical composition of COM J1740−5340, the non-degenerate companion to the millisecond pulsar PSR J1740−5340 in NGC 6397. Abundance analysis of high resolution spectra has allowed us to determine the abundance of iron ([Fe/H] = −1.85 ± 0.2) and several other elements. The general conclusion is that the abundance is fully compatible with that of normal, single stars in NGC 6397, with a few notable exceptions (Ca, C, and Li) that may be attributable to the peculiar history of the star, subject to (extreme) mass loss and interactions with the millisecond pulsar. In particular, the strong C depletion seems to indicate that COM J1740−5340 is not a perturbed low mass main sequence star, but had instead a larger mass and has been peeled down to the present ∼ 0.3 M⊙. Future observations will allow the appropriate measure of N and O abundances, and would give further support to this hypothesis, if those elements are found overabundant and unchanged, respectively, with respect to other stars in NGC 6397.

From the derived chemical composition, we do not see any indication of accretion of elements from the type II supernova explosion that left behind the neutron star (e.g., Mg), since the composition of COM J1740−5340 is mostly similar to the other stars in the cluster. Several scenarios, among which we are not able to discriminate with the present data, are possible: i) the secondary has been acquired by the system only after the SN (star exchange in a collision); ii) the SN wind was too fast for the secondary star to accrete a significant amount of ejected material; iii) and/or the neutron star has had enough time to remove all the accreted material, together with a fair fraction of its own original mass, from the companion.

Acknowledgements. We thank E. Carretta and L. Cinque for useful comments and discussions. This work was supported by the Agenzia Spaziale Italiana (ASI).

References

Alexander, J.B. 1967, The Observatory, 87, 238
Ballester, P., Modigliani, A., Boitquin, O., Cristiani, S., Hanuschik, R., Kaufer A., & Wolf, Z. 2000, The Messenger, 101, 31
Barklem, P.S., Piskunov, N., & O’Mara, B.J. 2000, A&AS, 142, 467
Bonifacio, P., et al. 2002, A&A, 390, 91
Bragaglia, A., et al. 2001, AJ, 121, 327
Castilho, B.V., Pasquini, L., Allen, D.M., Barbuy, B., & Molaro, P. 2000, A&A, 361, 92
D’Amico, N., Lyne, A. G., Manchester, R. N., Possenti, A., & Camilo, F. 2001a, ApJ, 548, L171
D’Amico, N., Possenti, A., Manchester, R. N., Sarkissian, J., Lyne, A. G., & Camilo, F. 2001b, ApJ, 561, L89
