New analysis of Be, ^{6}Li and ^{7}Li in stars with orbiting exoplanets

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ABSTRACT

Light elements are important tracers of the internal stellar structure. Li and Be are both burned in the stellar interiors although Be requires much higher temperatures and thus we can expect to measure Be abundances in stars which have no detectable Li in their atmospheres. The study of these elements can give us information about processes related to the angular momentum history of these stars, since rotation and angular momentum loss are important mechanisms responsible for the depletion of light elements. Additionally, if pollution has played an important role in determining the high-metal content of planet host stars, we would expect to find a similar or even higher increase in the Li and Be contents of those stars. We present Be abundances in a new sample of 14 planet host stars and Li abundances for 451 stars from HARPS GTO survey.

BE: OBSERVATIONS AND ANALYSIS

We obtained near-UV high resolution spectra using the UVES spectrograph at the 8.2-m Kueyen VLT (UT2) telescope. These spectra have a spectral resolution R ~ 70000 and S/N ratios usually between 100 and 200. All the data were reduced using IRAF tools in the echelle package. These new targets were added to the previously analyzed in Santos et al. (2004) and Gálvez-Ortiz et al. (2009). The sample is formed by 14 planet host stars with spectral types from G2 to K3, luminosity classes V and IV and temperatures between 4804 and 6141 K.

Stellar parameters were taken from the detailed analysis of Sousa et al. (2008) and Santos et al. (2005). The abundance analysis was done in local thermodynamic equilibrium (LTE) using the 2002 version of MOOG code (Sneden, 1973) and a grid of Kurucz et al. (1993) ATLAS9 atmospheres. We derived the Be abundances fitting the spectrum region around Be II lines (λ 3130.420 Å and λ 3131.065 Å) although only the second one was used for the calculations.

BE: RESULTS

In Fig. 1 we present the derived Be abundances as a function of effective temperature where filled circles are stars with planetary companions and open circles denote comparison sample stars. Overall, no clear difference seems to exist between planet hosts and comparison stars. Be abundances decrease from a maximum near T_{eff} = 6100 K towards both higher and lower temperatures. Very little, if any, depletion has occurred for stars of this effective temperature. A similar maximum for the Li abundances is also found at about the same temperature. For higher temperatures the values of log *N*(Be) decrease forming the well-known Be gap for F stars, a feature that has a counterpart for Li. The maximum at 6100 K may be attributed to Galactic chemical evolution effects, since most of the stars in the temperature interval between 6000 and 6200 K are particularly metal-rich, and Galactic Be abundances are known to increase with the metallicity (Rebolo et al. 1988, Boesgaard et al. 1999).

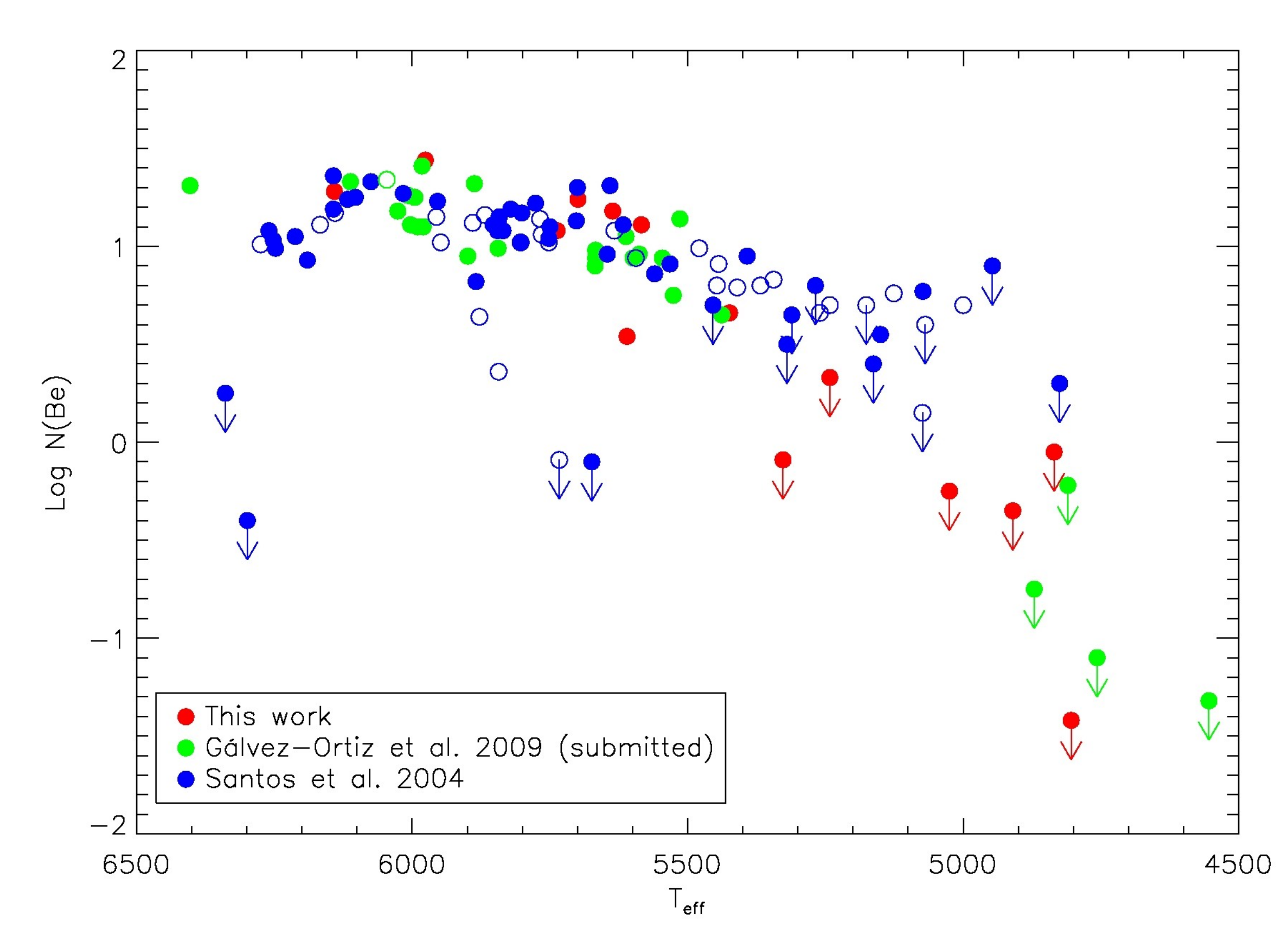

Fig 1. Be abundances as a function of effective temperature for stars with planets (filled circles) and stars without known planets (open circles).

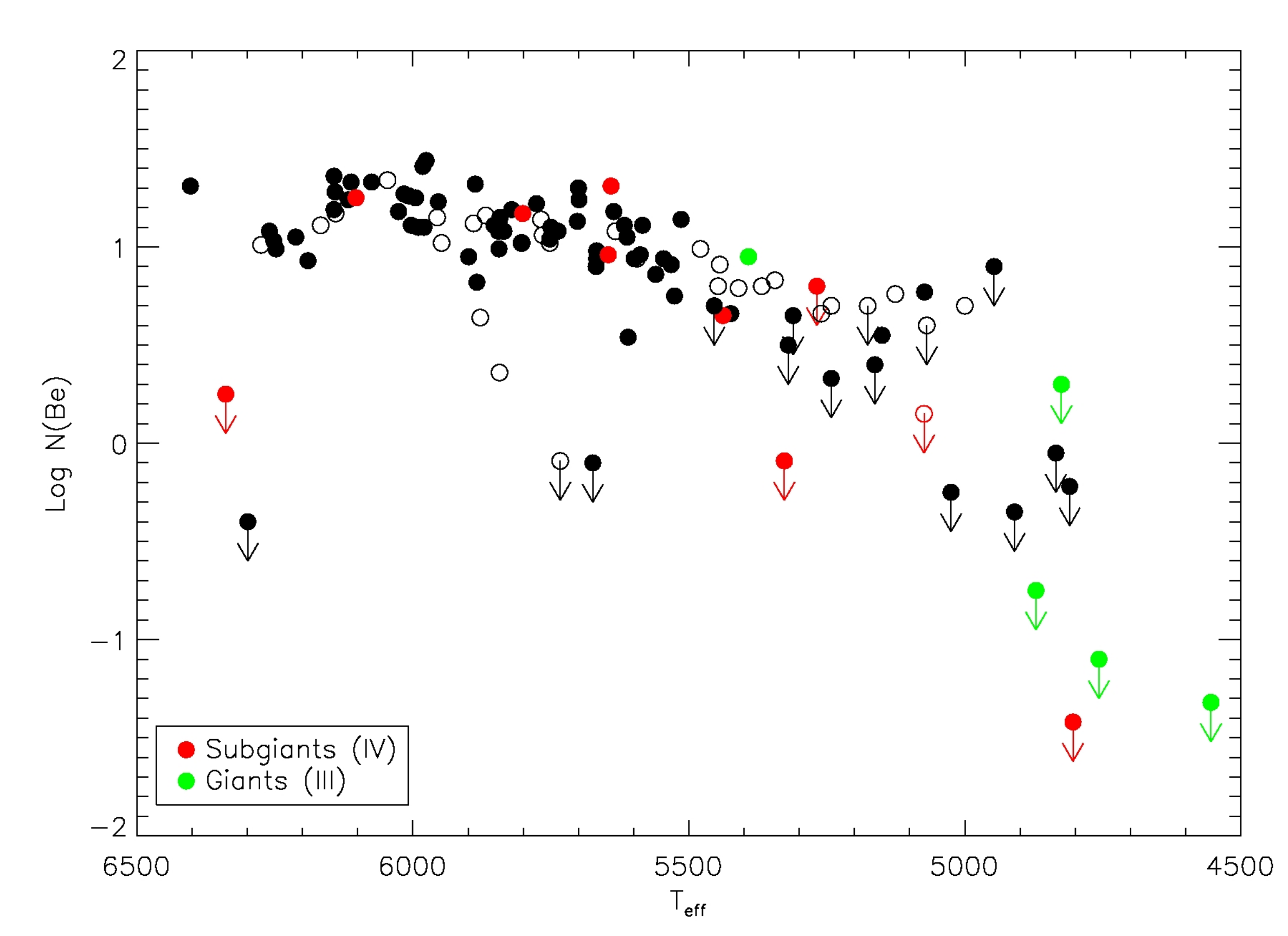

Fig 2. Be abundances as a function of effective temperature for stars with planets (filled circles) and stars without known planets (open circles). Black circles are dwarfs.

However, taking into account only dwarf stars with effective temperatures below 5500 K (see Fig. 2), we see clear depletion in both planet hosts and in the comparison sample. This trend is not expected from the mostly adopted models of Be depletion in solar-type stars (see Santos et al. 2004) which do not predict depletion rates below log N(Be)=0.8 at T_{eff} < 5500 K. Even more striking is the strong depletion in K-type stars. Secondly, we have found strong evidences for the existence of a group of solar-temperature dwarfs that have severely depleted their initial Be abundances. These stars should not exist based on the models of light-element depletion. In general, current observations cannot be fitted by the most popular models of light-element depletion (e.g. Pinsonneault et al. 1990), that may need the addition of other parameters. Although these conclusions do not seem to be related to the presence (or not) of planets, more data (mainly comparison cold stars) are needed to obtain a more clear answer to this point, that may have important consequences for the models of light-element depletion in solar-type stars.

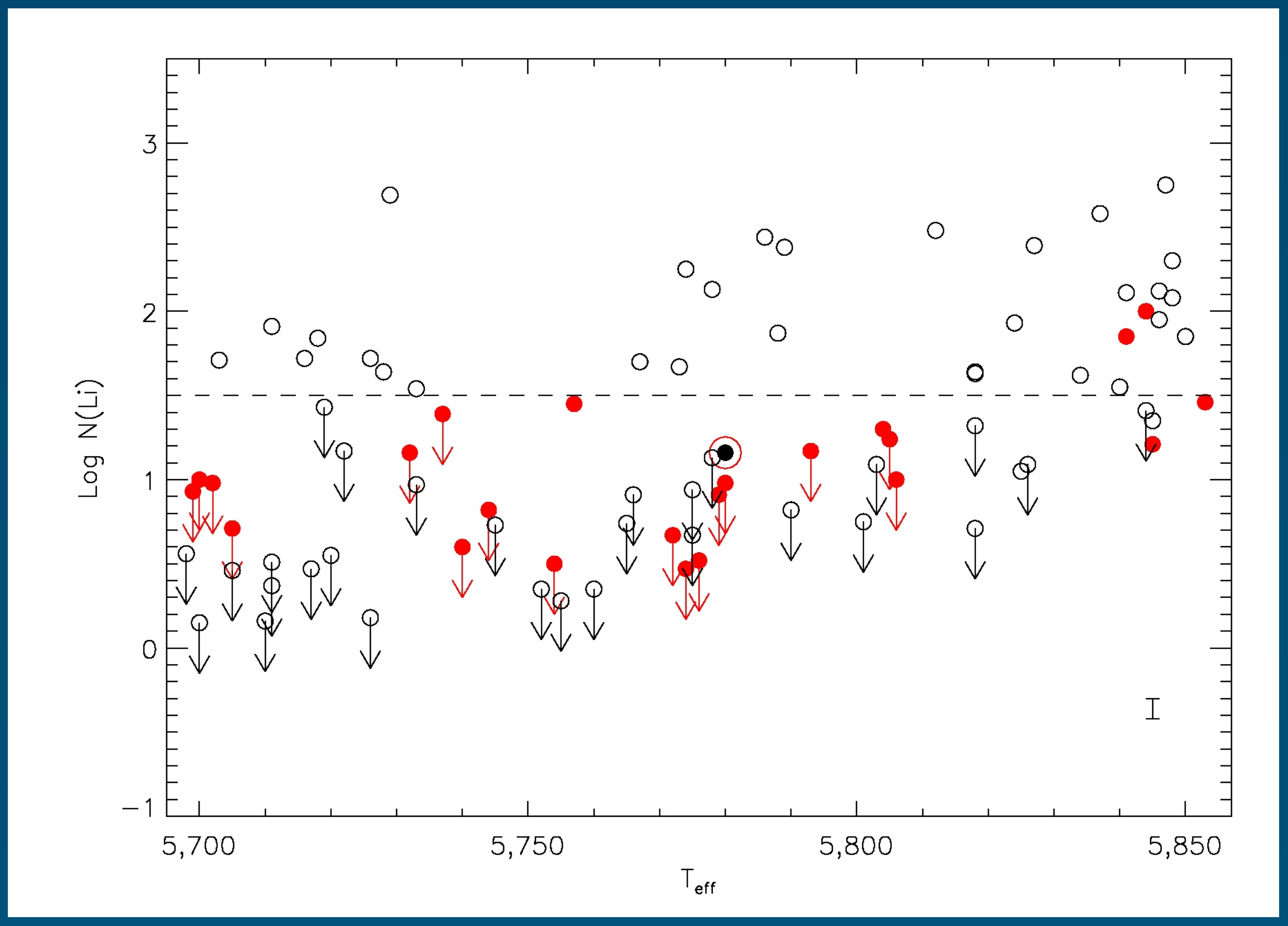

Fig 3. Li abundances as a function of effective temperature for stars with planets (red filled circles) and stars without known planets (open circles).

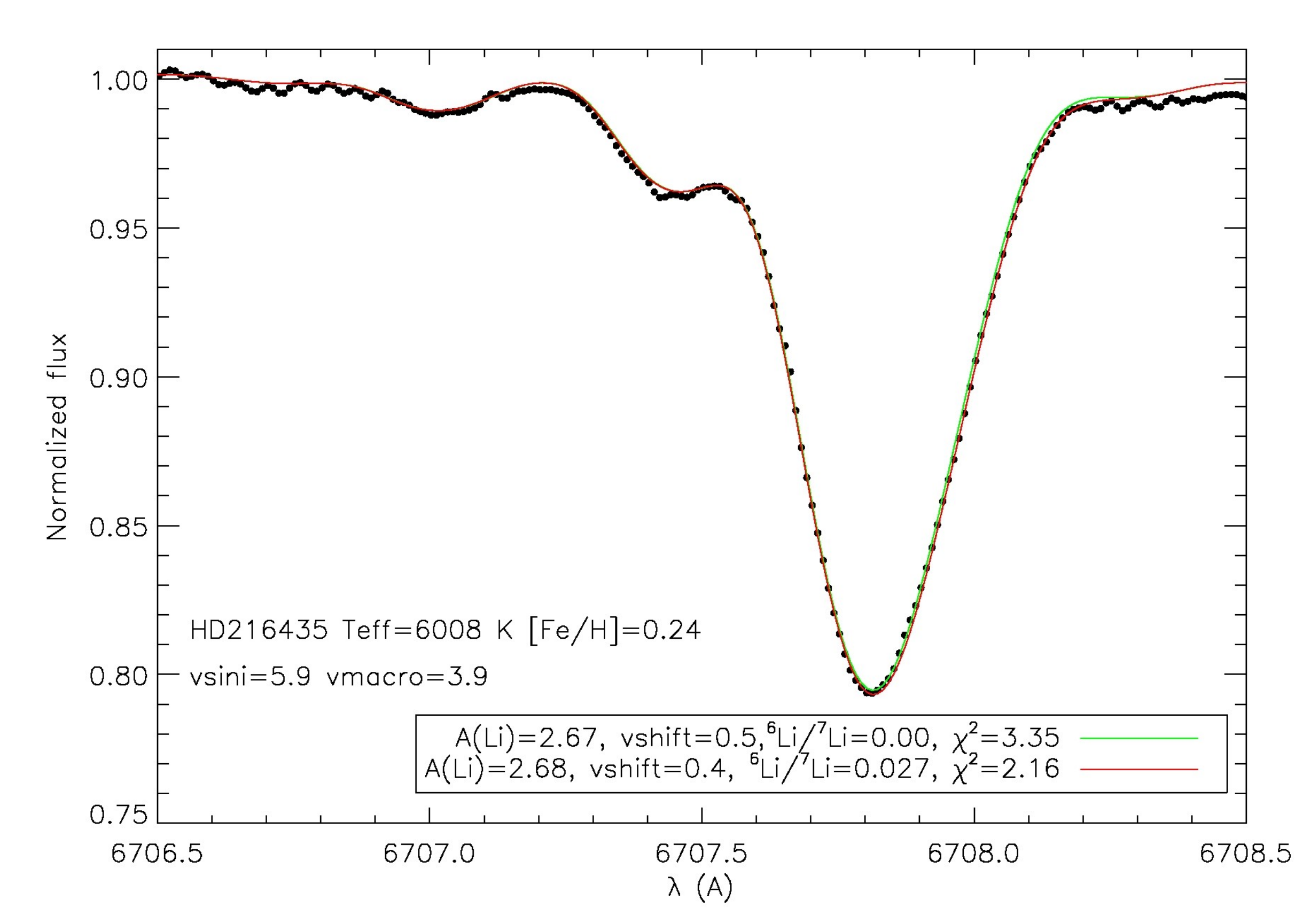

Fig 4. Spectral synthesis in Li λ 6707 Å region for the star HD216435. Velocities are in km/s.

^{6}Li/^{7}Li RATIO

Theoretical calculations predict that ^{6}Li is completely destroyed in the pre main sequence phase of stellar evolution for solar-mass stars while ^{7}Li requires higher temperatures. Therefore anomalously high ratios of ^{6}Li to ^{7}Li in normal pre-main sequence stars could be caused by the ingestion of planetesimals or even entire planets (Israelian et al. 2001). In Fig. 4 we show a preliminary spectral synthesis in the Li λ 6707 Å region for HD216435. For this analysis we used HARPS spectra and the line list from Ghezzi et al. (2009). Rotation velocities are derived from those spectra. In the figure we show the best fit (red line) that corresponds to ^{6}Li/^{7}Li=0.027. If we fix the ^{6}Li/^{7}Li ratio equal to zero the best fit (green line) is not as good as previous one in terms of χ^2 values. We have also analyzed HD82943 and preliminary results also provide the detection of ^{6}Li in this star (Israelian, 2001, 2003).

LI ABUNDANCES

We obtained Li abundances from high resolution spectra for a sample of 451 stars in the HARPS survey, spanning the effective temperature range between 4900 and 6500 K. These are unevolved, slowly rotating non-active stars from a CORALIE catalogue. Our abundance analysis, which followed standard prescriptions for stellar models, spectral synthesis code and stellar parameter determination (Sousa et al. 2008), confirm a peculiar behaviour of Li in the effective temperature range 5600-5900 K for the 30 planet bearing stars with respect 103 stars without planets in the comparison sample. To put this in a more solid statistical basis these two samples in the T_{eff} window 5600-5900 K and [Fe/H] between -0.5 and 0.5 dex, were extended by adding 16 and 13 planet host and comparison sample stars, respectively, for which we have obtained new Li abundances from high quality spectroscopic observations using the same spectral synthesis tools.

The Li abundance of some 20% of stars with exoplanets in the temperature range 5600–5900 K is log N(Li) ≥ 1.5 while for the 116 comparison stars the Li abundance shows a rather high dispersion with some 43% of the stars displaying Li abundances log N(Li) ≥ 1.5. This result becomes more obvious in solar analogue stars where some 50% of 60 “single” stars in the narrow window of T_{sun}± 80 K (T_{sun}=5777 K) appear with log N(Li) ≥ 1.5 while only two planet hosts out of 24 have log N(Li) ≥ 1.5 (Fig 3). We performed different two-sample statistical tests using ASURV13 (version 1.2). All tests consistently confirm (at the 3σ level) that the planet-host and single star populations are not drawn from the same parent population. We note that subgiants were not included in this study because they undergo dramatic changes in their internal structure that alters the surface abundance of Li. The Li over-depletion in planet bearing main sequence stars is a generic feature over the T_{eff}-restricted range T_{sun}±80 K and is independent of T_{eff} (or mass). We explore the possible explanations for this feature. First of all, lithium is expected to decrease with age. If planet host stars were on average older than comparison sample they would have depleted more lithium, but we don’t find any correlation between Li and age indicators like chromospheric activity or stellar rotation. Neither we found any correlation with metallicity. Our data show that the fraction of single stars with log Li > 1.5 is 50% at both [Fe/H] < 0 and [Fe/H] > 0.

We propose that the low Li abundance of planet-host solar-analogue stars is directly associated with the presence of planets due to the effect of these in the angular momentum evolution of the star and the surface convective mixing. Planet migration could possibly trigger angular momentum transfer in the convective zone but we don’t observe severely Li-depleted stars that host planets with shorter orbital parameters.

Alternatively, a long-lasting star–disc interaction during the pre-main sequence may cause planet-host stars to be slow rotators and develop a high degree of differential rotation between the radiative core and the convective envelope, also leading to enhanced lithium depletion (Bouvier 2008). To understand this Li extra depletion in stars with planets observations of younger stars and proper modelling are required.

REFERENCES

Boesgaard, A. M.; Deliyannis, C. P.; King, J. R. et al. 1999, AJ, 117, 1549

Bouvier, J. 2008 A&A, 489, L53

Fischer, D. A. and Valenti, J. 2005, ApJ, 622, 1102

Gálvez-Ortiz, M.C.; Delgado Mena, E.; González Hernández, J.I., Santos, N.C.; Israelian, G. and Rebolo R. 2009, submitted

Ghezzi, L.; Cunha, K.; Smith, V. V.; Margheim, S.; Schuler, S.; de Araújo, F. X.; de la Reza, R. 2009, ApJ, 698, 451

Israelian, G. Santos, N. C.; Mayor, M. and Rebolo, R. 2001, Nature, 411, 163

Israelian, G.; Santos, N. C.; Mayor, M. and Rebolo, R. 2003, A&A, 405, 753

Israelian, G.; Santos, N. C.; Mayor, M. and Rebolo, R. 2004, A&A, 414, 601

Israelian, G.; Delgado Mena, E.; Santos, N. C.; Sousa, S.; Mayor, M., Udry S.; Domínguez Cerdeña C., Rebolo, R. and Randich S. 2009, Nature, in press

Kurucz, R. L. 1993, CD-ROMs, ATLAS9 Stellar Atmospheres Programs (Cambridge: Smithsonian Astrophys. Obs.)

Rebolo, R.; Abia, C.; Beckman, J. E. and Molaro, P. 1988, A&A, 193, 193

Pinsonneault, M.H., Kawaler, S. D. and Demarque, P. 1990, ApJS, 74, 501

Santos, N. C.; García López, R. J.; Israelian, G.; Mayor, M.; Rebolo, R.; García-Gil, A.; Pérez de Taoro, M. R. and Randich, S. 2002, A&A, 386, 1028

Santos, N. C.; Israelian, G.; Randich, S.; García López, R. J. and Rebolo, R. 2004, A&A, 425, 1013

Santos, N. C.; Israelian, G.; García López, R. J.; Mayor, M.; Rebolo, R.; Randich, S.; Ecuvillon, A. and Domínguez Cerdeña, C. 2004, A&A, 427, 1085

Sousa, S. G.; Santos, N. C.; Mayor, M.; Udry, S.; Casagrande, L.; Israelian, G.; Pepe, F.; Queloz, D.; Monteiro, M. J. P. F. G. 2008, A&A, 487, 373