

Is neon a viable solution to the solar model problem? Insights from nearby B-type stars

Thierry Morel¹ and Keith Butler²

¹ Katholieke Universiteit Leuven, Departement Natuurkunde en Sterrenkunde, Instituut voor Sterrenkunde, Celestijnenlaan 200D, B-3001 Leuven, Belgium

² Universitäts-Sternwarte München, Scheinerstrasse 1, D-81679 München, Germany

E-mail: thierry@ster.kuleuven.be, butler@usm.uni-muenchen.de

Abstract. The recent downward revision of the solar CNO photospheric abundances now leads to severe inconsistencies between theoretical models for the Sun's internal structure and the results of helioseismology. There have been claims that the solar Ne abundance may be underestimated and that an increase in this ill-defined quantity could alleviate (or even completely solve) this problem. To address the validity of this hypothesis, we present a fully homogeneous non-LTE abundance analysis of the optical Ne I/II lines in a sample of 18 nearby B-type stars. Our *very preliminary* results point towards a mean neon abundance slightly higher than the new solar value, but apparently insufficient by itself to restore the agreement between the solar models and the helioseismological constraints.

1. Neon and the 'solar model crisis'

Recent state-of-the-art spectral analyses have led to a downward revision of the solar CNO abundances [1], which greatly affects the opacities in the solar interior and no longer leads to a satisfactory agreement between theoretical models for the Sun and the results of helioseismology (e.g. convection zone predicted too shallow). Neon contributes significantly to the metallicity, but has a very uncertain solar photospheric abundance because it can only be indirectly inferred from coronal lines or high-energy particles in cool stars. The solar Ne abundance is based on measurements of the [Ne/O] abundance ratio in the solar corona and has been scaled down following the decrease in the solar oxygen content. An upward revision of this ill-defined quantity has therefore been invoked as a possible way to compensate for the decrease in opacity arising from the lower metal abundances (e.g. [2]). Observations of a large sample of active stars with the *Chandra* X-ray observatory indeed seemed at first sight to indicate that the newly adopted solar Ne abundance was underestimated [3], but subsequent observations of solar-like stars (e.g. [4]) or quiescent solar regions (e.g. [5]) did not confirm this claim, thus leaving this question still open.

Several observational aspects related to the determination of abundances in stellar coronae are still not completely understood (see [6] for a review) and more trustworthy estimates are likely to be obtained from the direct analysis of Ne photospheric lines. Nearby OB stars may play a pivotal role in this respect, as they exhibit a substantial number of Ne I/II lines in their optical spectra. A study of a sample of B-type dwarfs in the Orion association recently suggested a relatively high Ne content [7], although this still falls short (by ~ 0.2 dex) of completely solving the controversy discussed above. To shed more light on this issue, here we present a fully

homogeneous non-LTE abundance analysis of a sample of 18 B0–B2 dwarfs/(sub)giants in the solar neighbourhood (within ~ 1 kpc, as estimated from *Hipparcos* parallaxes).

2. Methods of analysis

The atmospheric parameters are derived purely on spectroscopic grounds: T_{eff} is determined from the Si ionization balance, $\log g$ from fitting the collisionally-broadened wings of the Balmer lines and the microturbulent velocity from requiring the abundances yielded by the O II lines to be independent of the line strength (see [8] for full details). All stars are slow rotators and classical curve-of-growth techniques were used to derive the Ne abundances. The neon lines were modelled using fully line-blanketed Kurucz atmospheric models, the non-LTE line formation codes DETAIL/SURFACE and an extensive model atom consisting of 153, 78 and 5 levels for Ne I, II and III, respectively (along with the ground state of Ne IV). Our results are derived from the analysis of both the Ne I and Ne II features and are based on up to 16 lines for a given star.

3. First results

The Ne I lines are found to be formed under conditions largely departing from LTE, contrary to the Ne II lines which are also less sensitive to changes in the model atom (the non-LTE corrections typically amount to -0.50 and -0.05 dex, respectively).

We find a slight discrepancy (~ 0.2 dex) between the mean Ne I and Ne II abundances (Fig.1, left-hand panels). This problem can be solved by adopting a slightly cooler temperature scale and systematically shifting the T_{eff} values downward by 800 K ($\sim 4\%$), which is typical of the uncertainties. However, a better agreement between the two ions is also achieved when assuming LS coupling for Ne I (Fig.1, right-hand panels). This indicates that the collision rates may presently be underestimated and that more accurate atomic data could eventually lead to a satisfactory agreement between the Ne I and Ne II abundances. Work is underway to investigate this issue, but first indications suggest that our mean value will probably lie in between the new solar abundance (7.84 dex; [1]) and the value reported from the analysis of 8 Ne I transitions in 11 Orion B-type stars (8.11 dex; [7]).

4. Conclusions and perspectives

Our preliminary analysis of the photospheric Ne I/II lines in nearby B-type stars seems to indicate a mean neon abundance slightly higher than the most recent estimate for the Sun [1]. In contrast, an increase of the Ne abundance alone by a factor ~ 3 is required to restore the agreement between solar models and helioseismological data [9]. Although this appears unlikely based on our first results (see also [10] for theoretical arguments against such an explanation), definitive statements must await improvements in the model atom and a thorough search for any systematic trends in the data.

Acknowledgments

T. M. acknowledges financial support from the Research Council of Leuven University through grant GOA/2003/04. We are very grateful to C. Aerts, M. Desmet, P. Dufton and K. Uytterhoeven for kindly providing us with the high-resolution spectra of several of our targets.

References

- [1] Asplund M, Grevesse N and Sauval A J 2006 *Nucl. Phys. A* **777** 1
- [2] Antia H M and Basu S 2005 *ApJ* **620** L129
- [3] Drake J J and Testa P 2005 *Nature* **436** 525
- [4] Liefke C and Schmitt J H M M 2006 *A&A* **458** L1
- [5] Young P R 2005 *A&A* **444** L45

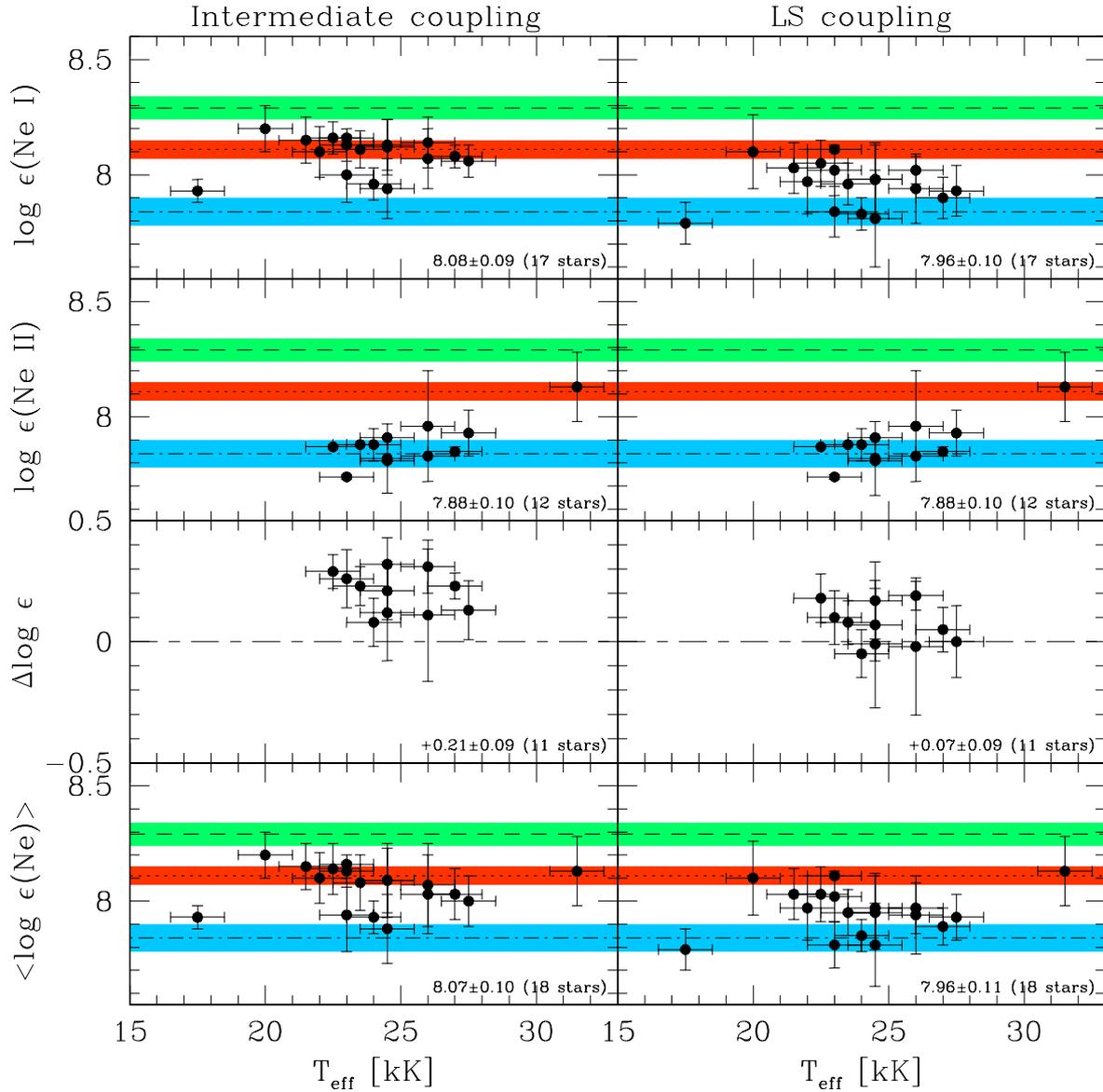


Figure 1. Abundance data as a function of T_{eff} assuming intermediate (left-hand panels) and LS (right-hand panels) coupling for Ne I. As can be seen, the slight discrepancy between the Ne I and Ne II values is lowered in the latter case. From top to bottom: variation of the Ne I abundances, the Ne II abundances, the difference between the abundances yielded by the Ne I and Ne II lines, and the mean abundances using lines of both ions. Note that the error bars only take into account the line-to-line scatter at this early stage of the analysis. The dashed, dotted and dashed-dotted lines indicate the neon abundance needed to reconcile solar interior models and the results of helioseismology (8.29 ± 0.05 dex; [9]), the mean Ne abundance determined for a sample of Orion B-type stars (8.11 ± 0.04 dex; [7]) and the new solar Ne abundance (7.84 ± 0.06 dex; [1]), respectively. The grey areas show the uncertainties. In the online version of this journal, these are indicated in green [9], red [7] and blue [1], respectively.

- [6] Güdel M 2004 *A&A Rev.* **12** 71
- [7] Cunha K, Hubeny I and Lanz T 2006 *ApJ* **647** L143
- [8] Morel T, Butler K, Aerts C, Neiner C and Briquet M 2006 *A&A* **457** 651
- [9] Bahcall J N, Basu S and Serenelli A M 2005 *ApJ* **631** 1281
- [10] Delahaye F and Pinsonneault M H 2006 *ApJ* **649** 529