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D. Koester, S. Moehler

Metal Abundances in Hot DA White Dwarfs

S. Schuh,[1] M. A. Barstow,[2] and S. Dreizler[1]

[1]*Institut für Astrophysik, Universität Göttingen, Friedrich-Hund-Platz 1, D–37077 Göttingen, Germany*
[2]*Department of Physics and Astronomy, University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom*

Abstract. We compare measured element abundances in hot DA white dwarfs from UV observations to predictions from our self-consistent non-LTE model atmosphere diffusion calculations.

1. Introduction

Due to their high surface gravity, the atmospheres of white dwarfs exhibit a quasi-monoelemental composition: a large fraction of all heavy elements has disappeared from the outer layers due to gravitational sedimentation. Traces of metals may however be sustained by radiative levitation. The radiative acceleration is exerted on trace elements by a non-LTE radiation field through the element's local opacity and therefore can vary strongly with depth, which results in a chemically stratified atmospheric stucture.

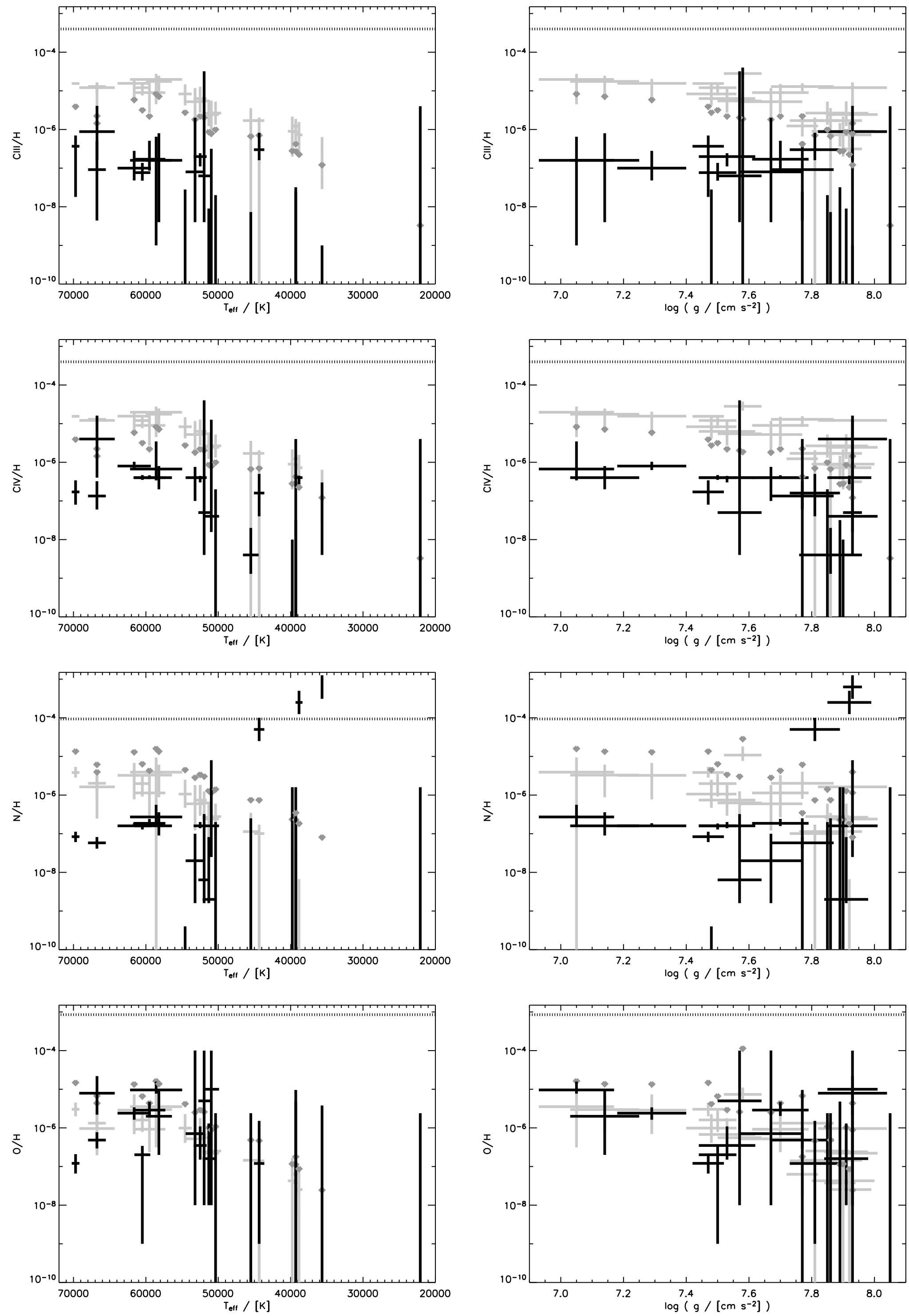
In an attempt to describe the chemically stratified atmospheres of hot white dwarfs, modifications to our model atmosphere program have been implemented to allow the self-consistent prediction of depth dependent abundance profiles.

Balancing the radiative acceleration and the effective gravitational acceleration (including the effects of the electrical field that builds up through diffusion of electrons) yields an equilibrium condition for each atomic species. Its solution yields equilibrium abundances. We present theoretical predictions from our model grid in comparison to previous calculations as well as to abundances measured from IUE and HST spectra.

2. Model Grid and Comparison to Models by Chayer et al. (1995a,b)

Self-consistent NLTE diffusion models are available in a T_{eff} range from 38 000 K to 71 000 K for $\log g$ between 7.2 and 8.4 (Schuh et al. 2002). From the full depth-dependent abundance stratification patterns, only the $\tau_{\text{ross}} = \frac{2}{3}$ values are used in Fig. 1. Full abundance tables, as well as high-resolution optical, UV, and far-UV spectra (not shown here) are also available.

Equilibrium abundances for $\tau_{\text{ross}} = \frac{2}{3}$ published by Chayer et al. (1995a,b, LTE, no iteration; no data for nickel) are shown for comparison using small dark grey symbols. In terms of "evolution" of diffusion codes, the systematic effects from one generation to the next are still considerable.



CIII/H
CIV/H
N/H
O/H
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
70000 60000 50000 40000 30000 20000
Teff / [K]
7.0 7.2 7.4 7.6 7.8 8.0
log (g / [cm s⁻²])

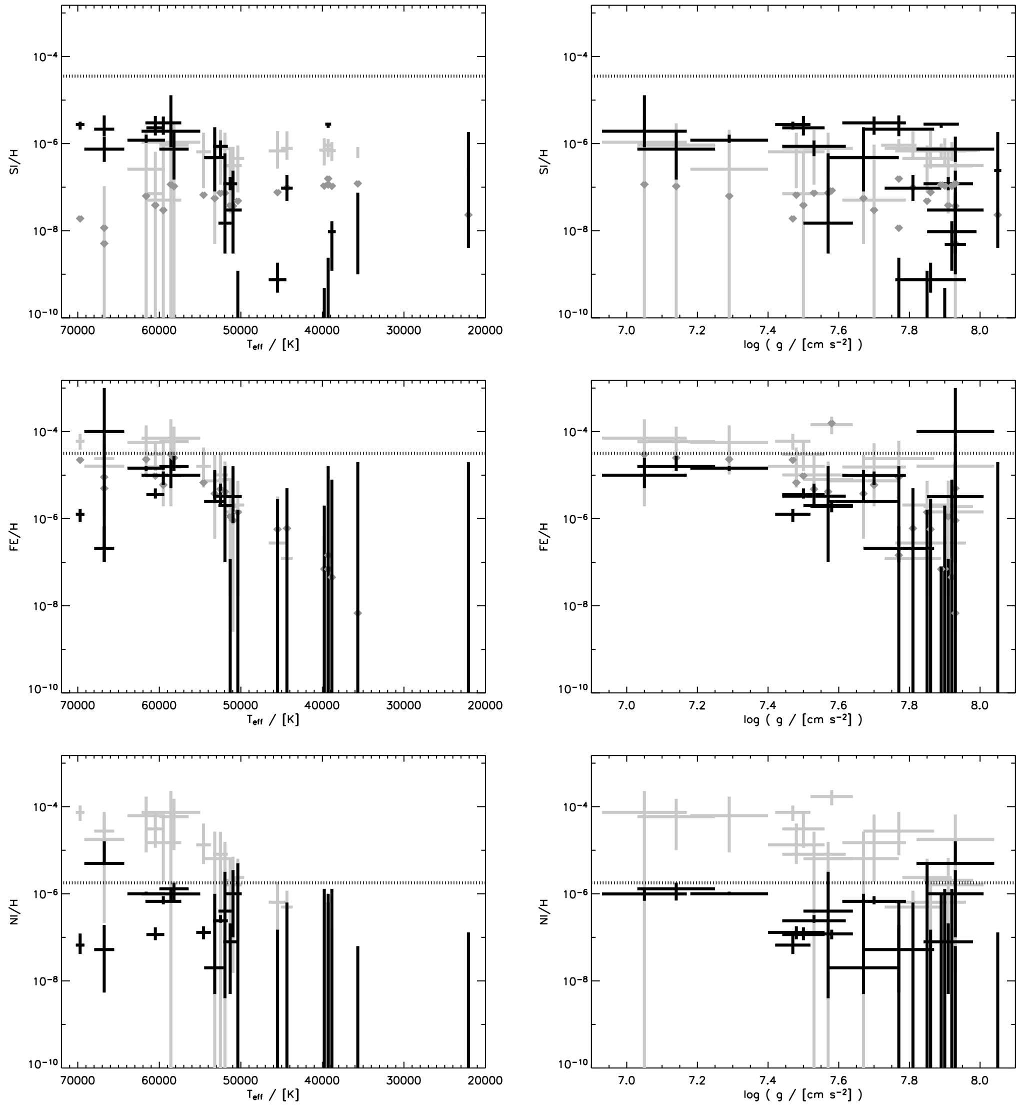


Figure 1. (continued from previous page) Black symbols: abundances measured by Barstow et al. (2003, B03) from observations using homogeneous models; errors in $T_{\rm eff}$ and abundances are the formal fitting errors taken from B03. Grey symbols: diffusion model predictions interpolated for $T_{\rm eff}$ and $\log g$ for each object as given in B03; $T_{\rm eff}$ errors as above. Error bars for abundances obtained by evaluating the abundance variation due to the given uncertainties in $T_{\rm eff}$ and $\log g$. Small dark grey symbols: the same for diffusion models by Chayer et al. (1995b) but without errors assigned. Dotted line: cosmic abundance of the element.

3. Comparison to Measurements by Barstow et al. (2003)

For carbon, both C III and C IV are consistently over-predicted. Theory and observations follow the same general temperature dependency but although theory runs in parallel to the observations its level is too high.

Nitrogen, although not as clearly as for carbon, is also over-predicted at higher temperatures; towards lower temperatures, the models follow the lower branch of the observed dichotomy. For an earlier discussion of one of the nitrogen-rich objects (RE J1032+535) see Holberg et al. 1999 (besides B03).

Oxygen generally follows the trend with temperature well, and the predictions are mostly consistent with the observational error bars. Compare also the successful application presented by Chayer et al. (2003).

Silicon, in contrast to C and N, shows opposite gradients with respect to temperature in theory and observation, effectively leading to a similarly good agreement as for O in the cross-over area but to under-predictions at higher temperatures and over-predictions below $\approx 50\,000$ K. The only exception is GD 394, considered to show an anomalously high silicon abundance, for which the absolute value is approximately reproduced by the models.

Iron is consistent with observations on a star by star basis over the full temperature range. This is in agreement with EUV observations (where Fe is the most important source of opacity) which can successfully be reproduced with the stratified diffusion models. On average across all stars however, the predicted iron abundance remains about a factor 2 higher than observed, a value of the order of the systematic error expected for the models.

Nickel should behave similarly to Fe within the framework of radiative levitation theory, which it effectively does, but this predicted behaviour is in disagreement with observations. The observed Ni is well below the prediction so that instead of $\frac{Fe}{Ni} \approx 1$, Fe and Ni are present in a roughly cosmic ratio (as already stated in B03).

With very few exceptions (objects belonging to the upper branch of nitrogen dichotomy, iron and nickel in PG 1342+444), all photospheric abundances seem to respect cosmic abundances as an upper limit. Given that equilibrium radiative levitation theory ignores any evolutionary constraints, this may be indicative of a "reservoir problem" (no unlimited supply of all elements available) in the real stars.

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