# THE ATMOSPHERIC COMPOSITION OF THE HOT PRE-DEGENERATE STAR H1504+65 REVISITED

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Nousek *et al.* (1986) have recently announced the discovery of a remarkable hot compact star, H1504+65, which *appears* to have an atmosphere devoid of hydrogen and helium. Although the object seems significantly hotter than the related PG1159 stars, its suggested atmospheric composition remains at variance with the He-rich composition inferred for the latter stars (Wesemael, Green, and Liebert 1985). Nousek *et al.* (1986) have brought forward convincing arguments against a H-dominated atmosphere in H1504+65; it seems that the object is definitely not an extremely hot DA star. On the other hand, the case against a He-rich atmosphere is much weaker and is based on the following circumstantial arguments: (1) no helium lines are detected in the spectrum of H1504+65 (the detection limit is ≈0.5 Å), (2) the ultraviolet continuum slope is steeper than that predicted from pure helium models *extrapolated* to effective temperatures larger than the upper limits of available grids ($T_e$ = 200 000 K for log g=7), and (3) the *EXOSAT* observations appear to conflict with the He interpretation, although suitable models (with high effective temperatures) are not readily available in this case also. Because of the lack of appropriate models, Nousek *et al.* (1986) have been careful not to rule out completely the possibility of a He-rich atmosphere for H1504+65. In particular, they admit that He II lines could probably be undetectable if H1504+65 had an effective temperature substantially larger than $T_e$ = 150 000 K. Nevertheless, they have found it tempting to hypothesize an atmosphere devoid of both hydrogen and helium. Coupled with the presence of weak C IV and O VI features in the spectrum of H1504+65, this has led to the suggestion that H1504+65 is actually a bare C/O nucleus (cf. Shipman 1987). Although this suggestion is interesting, it has undeservedly remained unchallenged and we have felt it appropriate to reexamine the case against a He-rich atmosphere with the help of further modelling efforts.

A detailed spectral synthesis study of a hot star such as H1504+65 presumably requires the inclusion of NLTE effects. Modelling of such objects is indeed proving to be quite a challenging task, as demonstrated by Werner, Heber, and Hunger (1988) for the case of PG1159-035. In addition, it is quite possible that the atmosphere of H1504+65 is expanding through the action of a residual wind and such an effect may have to be included as well (e.g., Kudritzki 1987). Short of these complications, one can nevertheless hope to constrain the atmospheric parameters of



https://doi.org/10.1017/S0252921100099887 Published online by Cambridge University Press

H1504+65 with the help of simpler, plane-parallel, static, LTE models covering the appropriate region of parameter space. To supplement the published models used by Nousek *et al.* (1986) –specifically the pure H models of Wesemael *et al.* (1980) extending to 200 000 K, the pure He models of Wesemael (1981) extending to 200 000 K, and the solar composition models of Hummer and Mihalas (1970) for nuclei of planetary nebulae–, we have computed a small grid of unblanketed uniform models with log g=7.0 and $T_e(10^3K)$= 120,140,160, and 180. The chemical compositions which have been considered are (1) pure He, (2) He-dominated with the addition of C, N, O, and Ne in solar proportions, (3) a similar mixture with the "metal" abundances reduced by a factor of 10, and (4) a half-and-half C/O composition by number. We report here on some partial results of an ongoing analysis of H1504+65 based on these models.

Our first clue is the energy distribution slope observed in H1504+65. Nousek *et al.* (1986) report a relationship $H_\lambda \propto \lambda^{-4.1 \pm 0.1}$ in the 1250–1800 Å range and extending into the optical region. We find that *none* of our models can account for such a steep spectral index. For example, the ultraviolet spectral index of our pure He models varies between 3.72 and 3.80 in the range 120 $\leq T_e(10^3K) \leq$ 180. It varies between 3.72 and 3.82 in the same temperature range for the two He-rich compositions with C, N, O, and Ne absorbers. The C/O models do not fare any better than the He-dominated atmospheres and, if anything, are slightly more discrepant with a predicted spectral index varying between 3.63 and 3.76 in the same temperature interval. It is thus clear that the chemical composition does not affect strongly the ultraviolet continuum slope in the range of temperature considered. In particular, invoking an atmosphere devoid of H and He does *not* help in explaining the observed ultraviolet spectral index. Inclusion of NLTE effects may well not affect significantly the present results, as the relevant opacities in the spectral range of interest are dominated by free-free transitions. It may be necessary to consider an expanding atmosphere around H1504+65 to account for the large spectral index observed.

Another result comes from an analysis of the *EXOSAT* data with our grid of model atmospheres. H1504+65 was observed with the LE1 detector through three different filters. The observed count rates were: 6.97 ± 0.04 counts $s^{-1}$ (thin Lexan; LX), 0.47 ± 0.02 counts $s^{-1}$ (Al/Parylene; Al/P), and 0.017 ± 0.002 counts $s^{-1}$ (Boron; B) (Nousek *et al.* 1986). Taking into account the known instrumental response, the predicted count rate in a given filter can be computed as a function of the interstellar neutral hydrogen column density ($n_H$) for a model which is normalized to the observed visual magnitude (V=16.24). For a known observed count rate, this procedure gives a unique value of $n_H$ for a given effective temperature and, thus, leads to a curve in the $\log(n_H)$–$T_e$ plane. More generally, the procedure gives rise to a family of curves (or band) by taking into account the measurement uncertainties. Acceptable models correspond to regions of the log $n_H$–$T_e$ plane where the bands for the three different filters overlap. An additional constraint comes from the independent estimate of $n_H$ (0.6 ± 0.2 × $10^{20}$ $cm^{-2}$) given in Nousek *et al.* (1986)



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and based on the detection of an interstellar Lyα feature in the small-aperture SWP *IUE* spectrum of H1504+65.

Figure 1 summarizes our results for the pure He models. It is seen that a consistent solution is not possible so that we can exclude these models. One of the reasons is that our high-temperature, pure He models are too bright in the EUV bandpass and, consequently, require an interstellar absorption which is too large as compared to the Lyα limit. Some atmospheric EUV absorbers are clearly needed. As shown by figure 2 (which illustrates the results for the models with the He-rich composition with C, N, O, Ne abundances at 1/10 of their solar values), the situation indeed improves significantly if such absorbers are included. We now find a marginal solution in the range 150 $\leq T_e$ ($10^3$K) $\leq$ 160 for the LX and Al/P filter data although the B band does not fit. A better solution is obtained if the abundances of the C, N, O, Ne absorbers are raised to their solar values. Figure 3 indeed shows that He-dominated models with 155 $\leq T_e(10^3$K) $\leq$ 180 can account for the *EXOSAT* LX and Al/P filter data as well as the Lyα constraint on $n_H$. A virtually identical solution, suggesting a temperature range 160 $\leq T_e(10^3$K) $\leq$ 180, is obtained for the C/O atmospheres. Thus, the *EXOSAT* data *cannot* discriminate between C/O atmospheres and He-rich atmospheres with solar traces of heavy elements. It should be noted that the lack of success experienced by Nousek *et al.* (1986) in their attempt at explaining the *EXOSAT* data in terms of the model atmospheres of Hummer and Mihalas (1970) is caused by the limitations of these exploratory models. Indeed, not all appropriate ionic species are included in these models (notably O VI), and expected photoionization edges are not included at wavelengths shorter than 100 Å.

We note that the B count rate appears too small for all of our model atmospheres. As an illustrative example, we find mutually consistent solutions for all data if we arbitrarily multiply the observed B count rate by a factor of 5 (see Fig. 3 and Fig. 4, in particular). It is not entirely clear at this stage why the B filter count rate remains inconsistent with the rest of the data but at least two possibilities exist. Because the B filter does not map out the same spectral range as the other filters, it is possible that other absorbers than He, C, N, O, and Ne affect significantly (and in a relative sense) the flux in this bandpass. This will have to be checked with models including a large number of absorbers. Moreover, it is possible that the B count rate has been underestimated because its point spread function has turned out to be much wider than initially estimated according to the discussion of Chiappetti and Davelaar (1984).

It is also of interest to point out that this analysis is entirely consistent (and this includes the problem with the B filter) with the independent study presented by Barstow (1988). Using his own grid of models with input physics quite similar to ours, Barstow finds that the LX and Al/P data of H1504+65 can be understood in terms of model atmospheres with log g = 7.0 and 172 $\leq T_e(10^3$K) $\leq$ 200. His preferred atmospheric composition is far from extreme with H and He in a one-to-one ratio (by number) and solar abundances of C, N, and O. This is quite similar to our own results for the He-rich models with solar abundances of C, N, O, and Ne, as H is not expected to play a major role at the temperatures of interest.

We can summarize the fundamental results of this paper in the following way: we find that we cannot discriminate between He-rich atmospheres with solar traces of heavy elements and exotic C/O atmospheres for H1504+65 on the basis of the observed ultraviolet slope and *EXOSAT* data. This weakens considerably the case against the He interpretation. Under those circumstances, we favor the simplest interpretation, i.e. that of a He-rich atmosphere for H1504+65. It remains to be shown that He II lines indeed fade below the detection level of ≈0.5 Å in the range $155 \leq T_e(10^3K) \leq 180$, our best estimate of the effective temperature of H1504+65. In addition, the observed line strengths of the few C IV and O VI features in the spectrum of H1504+65 must remain consistent with the predictions of He-rich model atmospheres with traces of C and O. We are currently considering these particular questions. Ultimately, a full NLTE calculation, possibly coupled to an expanding atmosphere, may be required to understand completely this extraordinary object.

This research has been supported in part by the NSERC Canada, by the fund FCAR (Québec), and by a E.W.R. Steacie Fellowship to one of us (GF).

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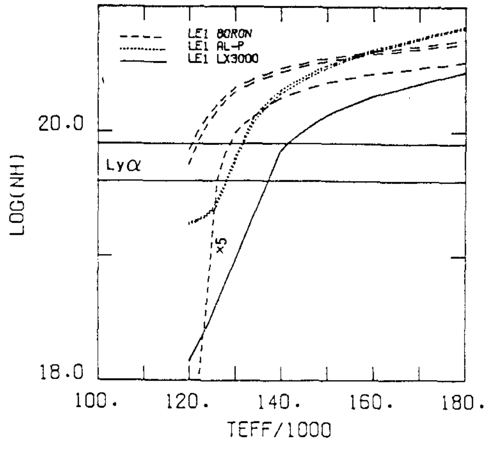


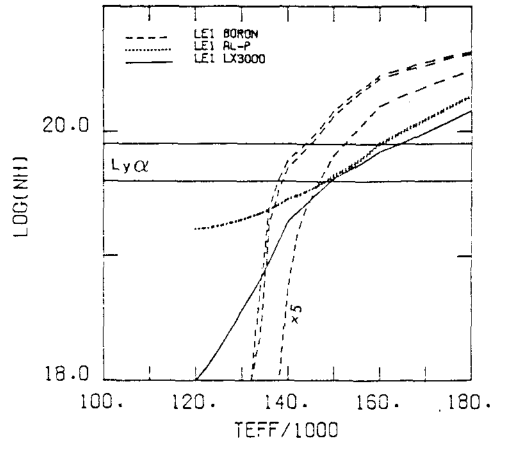
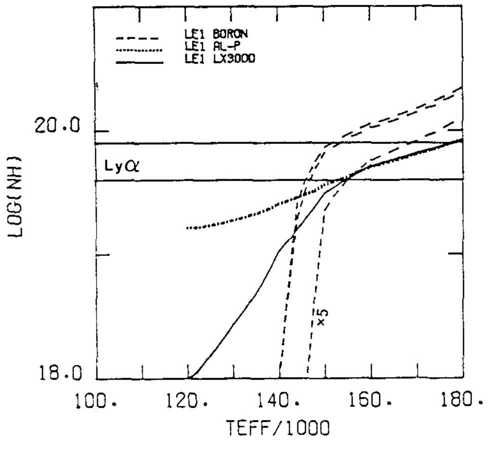




Figure 1. Relationship between the interstellar neutral hydrogen column density and effective temperature for pure He models of H1504+65 with log g=7.0. The continuous, dotted, and dashed lines correspond to family of curves consistent with the observed EXOSAT count rates in the LX, Al/P, and B filters, respectively. The lower dashed curve labeled "X 5" corresponds to a B count rate arbitrarily multiplied by a factor of 5. The two horizontal lines define the region where $n_H$ is constrained through Lya observations.

Figure 2. Same as Fig. 1, but for He-rich atmospheres with traces of C, N, O, and Ne at 1/10 solar values.



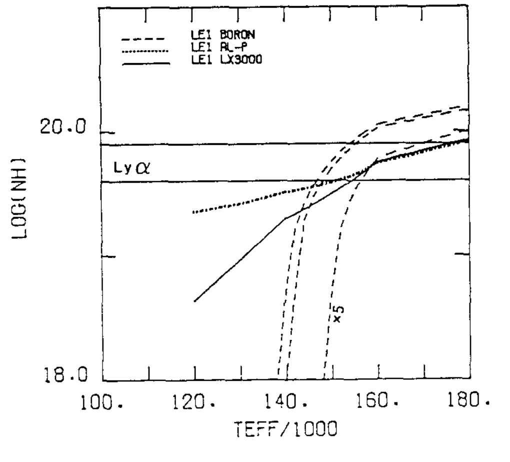




Figure 3. Same as Fig. 1, but for He-rich atmospheres with solar abundances of C, N, O, and Ne.

Figure 4. Same as Fig. 1, but for C/O atmospheres. C and O are in equal proportions by number.



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