THE EFFECT OF CNO METAL ABUNDANCES ON THE SOFT X-RAY EMISSION FROM HE RICH WHITE DWARFS

M.A.Barstow

X-ray Astronomy Group, Physics Department, University of Leicester

University Road,Leicester, LE1 7RH, UK

ABSTRACT

Predicted soft X-ray fluxes for model atmospheres containing varying concentrations of CNO metals are compared with those observed by *EXOSAT* for the planetary nebula nucleus K1-16. An effective temperature in the range $\approx 125000 - 180000$K is determined for K1-16 and a limit on the concentration of CNO in the atmosphere (between 0.02 and 20×solar relative to He) obtained. Some comments on the application of the models to the apparently metal rich star H1504+65 are included.

1. INTRODUCTION

In recent years, soft X-ray emission has been detected from a number (≈ 30) of hot white dwarfs (WDs) by the *Einstein* and *EXOSAT* satellites. In general only photometric data from one or two bands are available. However, considerable success has been achieved in determining the interstellar HI columns and He abundances in DA WDs from such data with simple chemically homogeneous model atmospheres (eg. Petre et al, 1986; Paerels et al, 1987). Homogeneous atmospheres may not be physically realistic (see Vennes et al, 1988) but the indication of atmospheric composition obtained from the soft X-ray fluxes is not available from data in other wavebands. Modelling of hot He rich WDs has met with less success. Although the pure He models of Wesemael (1981) initially seemed to be able to explain observed *EXOSAT* count rates (Barstow, 1988), subsequent modelling (Holberg and Barstow, 1988) has revealed an unexpected enhancement in the flux distribution at wavelengths shortward of those covered by the Wesemael models and falling within the *EXOSAT* spectral range. Several He rich models with H:He abundances ranging from 0-1 were compared with the data but none were able to explain the relative intensities in thin lexan (3LX, $\approx 44 - 150$Å) and aluminium/parylene (Al/P, $\approx 44 - 240$Å) filters. For a given flux in the 3LX filter predicted Al/P fluxes were always higher than observed. Reduction of the Al/P flux relative to that in the 3LX band requires a steeper fall-off in the spectrum at energies above the HeII edge at 228Å. This can only be produced by the presence of additional opacity sources. Models containing CNO (Hummer & Mihalas, 1970) are available at appropriate temperatures and gravities (log g$>$ 6, T$>5\times10^4$K) but have only been computed for solar abundances and do not consider OVI transitions, which have been observed in the very hottest DO WDs. A self-consistent model atmosphere code (Williams et al, 1987) has been modified to consider **all** ionisation states of CNO and determine the effect of these metals on the predicted soft X-ray fluxes. The results of comparing model predictions with observed soft X-ray fluxes for the stars K1-16, allowing limits to its effective temperature (T) and CNO abundances to be estimated, and H1504+65 are presented in this paper.

https://doi.org/10.1017/S0252921100099589 Published online by Cambridge University Press

2. K1-16 SOFT X-RAY DATA AND MODELS

Eight hot DO WDs and related objects were observed by *EXOSAT* (Holberg and Barstow, 1988). The best photometric data were obtained for the planetary nebula nucleus K1-16 (in 4 filters). Observed count rates were 0.019 ± 0.0006, 0.0019 ± 0.0006, 0.0184 ± 0.0023 and 0.00084 ± 0.00050 count s^{-1} in 3LX, Al/P, 4LX (thick lexan, $\approx 44 - 140$Å) and B (boron, $\approx 67 - 120$Å) filters respectively. Furthermore, a firm upper limit on the line of sight interstellar absorbing column ($N_H = 2.36 \times 10^{20} cm^{-2}$) has been obtained from observations of a nearby QSO (Warwick et al, 1988) and its distance is known (1660pc; Kaler, 1983). K1-16 is chosen here to illustrate the results obtained with the model atmospheres. Temperatures for K1-16 are expected to be in excess of 80000K but it has not yet been possible to provide reliable estimates. The presence of CNO in He rich atmospheres is demonstrated by observations of CIV, CIII, NIII and OVI transitions in the optical and UV but their abundances remain undetermined.

The code used to compute the atmospheric models assumes LTE and a homgeneous composition. All ionisation species and excited states of CNO are included. Only continuum opacities are considered. Eddington fluxes have been calculated for models containing varying concentrations of H:He and He:CNO with the relative fractions of C:N:O held constant at solar values. The models cover frequencies from infra-red to soft X-ray, temperatures in the range 50000-200000K and log g values of 7 or 8 (Table I).

3. K1-16 RESULTS AND DISCUSSION

For a given T, N_H and model composition it is possible to calculate a predicted count rate for K1-16 in each *EXOSAT* filter by folding the model spectrum, normalised to the V magnitude (15.09), through the instrument response and an interstellar medium model. Count rates were predicted in each filter for each model temperature and a finely spaced grid of N_H values in the range $10^{18} - 10^{22} cm^{-2}$. The resulting tables were interpolated to determine the values of T and N_H corresponding to the observed K1-16 count rates. A family of constant count rate curves can then be displayed in the (T, N_H) plane as depicted in figure 1 for the model HHECNO111. The 3 curves shown for each filter correspond to the observed count rate and $\pm 1\sigma$ statistical errors. A model can be said to be consistent with the data if there is at least one region on the plot where all four sets of contours overlap. Table I summarises the results of these analyses on each model atmosphere, indicating the allowed ranges of temperature.

There is a band of models that are consistent with the observed K1-16 data. This implies that the concentration of CNO in the atmosphere of K1-16 lies between $0.02 \times$ solar and $20 \times$ solar (relative to He). However, constant relative proportions of C:N:O and a homogeneous distribution have been assumed. Adjusting the C:N:O ratios may alter this limit. If the atmosphere is non-homogeneous or layered the 'measured' CNO abundance reflects the opacity of the overlying material (probably nearly fully ionised H and He, cf. Vennes et al, 1988). The results are not very sensitive to either the concentration of H or the value of log g and altering these just modifies the allowed range of T. Imposing the known upper limit to N_H ($2.36 \times 10^{20} cm^{-2}$) allows the maximum values of T to be reduced but does not further constrain the acceptable range of models.

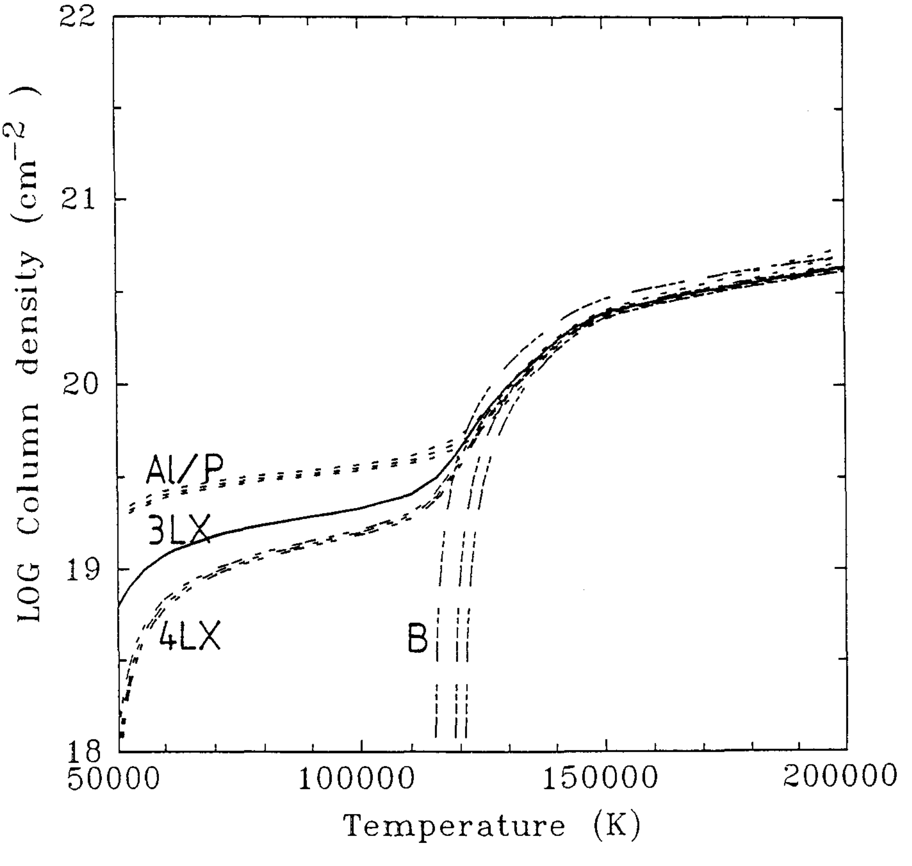
https://doi.org/10.1017/S0252921100099589 Published online by Cambridge University Press

TABLE I. Details of the atmospheric models studied and the temperature ranges allowed by each model for the observed K1-16 filter count rates.

Model	Abundances[1] H:He	CNO:He	log g	T range (K) of model	T limits for K1-16 (K)	T upper limit for $N_H = 2.36 \times 10^{20} cm^{-2}$
HHECNO100	S	S	7.0	50000-200000	145000-181000	155000
HECNO100	0	S	7.0	50000-200000	160000-181000	168000
HHECNO101	1	S	7.0 (8.0)	50000-200000	157000(150000)-185000(177000)	164000(167000)
HHECNO111	1	0.1S	7.0	50000-200000	138000-169000	147000
HHECNO121	1	0.01S	7.0	50000-200000	NONE	NONE
HHECNO131	1	0.02S	7.0	50000-200000	NONE	NONE
HHECNO141	1	0.05S	7.0	50000-200000	125000-164000	144000
HHECNO151	1	10.0S	7.0	50000-177000[2]	158000-177000	NONE[3]
HHECNO161	1	20.0S	7.0	50000-168000[2]	NONE	NONE
HHECNO161	1	20.0S	8.0	50000-200000	NONE	NONE

[1] S=Solar abundance; He:H=0.063, He:C=4.17×10^{-4}, He:N=8.71×10^{-5}, He:O=6.92×10^{-4}.
[2] Static model unstable above this temp. [3] No consistent model with this N_H

Figure 1. Curves of constant count rate, calculated for model HHECNO111, corresponding to the observed K1-16 fluxes and $\pm 1\sigma$ errors. The filter designations are as noted in the text.



https://doi.org/10.1017/S0252921100099589 Published online by Cambridge University Press

4. H1504+65

H1504+65 has been found to be an extraordinarily hot compact star that is apparently devoid of H and He (Nousek et al, 1986). Such estimates as can be made indicate that T is $\approx$ 160000K and $7 < \log g < 8$. Nousek et al were unable to match the observed *EXOSAT* count rates (6.97 ± 0.04-3LX, 0.47 ± 0.02-Al/P, 0.017 ± 0.002-B) to existing model atmospheres. The 3LX and Al/P count rates of H1504+65 can be predicted by the HHECNO101 (solar CNO) model, yielding $172000 < T < 200000$K and $4.4 \times 10^{19} < N_H < 10^{20}$. This is consistent with the estimates of Nousek et al, including their determination of N_H ($6.0 \pm 2.0 \times 10^{19}$cm^{-2}) from HI lyman alpha absorption. However, the corresponding B rate is a factor 2-3 lower than observed. Increasing the abundance of CNO appears to reduce this discrepancy but a high gravity (log g$\approx$ 8) is needed if a static atmosphere is to exist at the correspondingly higher temperatures required to generate the observed soft X-ray fluxes. Given the similarity between filter pass bands, it is difficult to see how any model might be modified to lower the B count rate sufficiently relative to the rates in the 3LX and Al/P filters.

Analysis of the structure of the HHECNO101 model indicates that for T$\approx$ 200000K He is almost completely ionised throughout the atmosphere. Consequently, the apparent lack of He may merely be due to the absence of observable transitions, as is the case for H in PG1159-035 and similar objects. Although further study of H1504+65 with these model atmospheres is necessary, these initial results suggest that it is not perhaps as anomalous as first supposed. It seems likely that it is closely related to the PG1159 group of objects (which includes K1-16) and that its observed peculiarities are a consequence of its high temperature.

6. ACKNOWLEDGEMENTS

I would like to thank Dr A.R.King for giving me access to the original model atmosphere programme and both Dr King & Dr J.B.Holberg for advice and encouragement during this work. I also acknowledge the support of the SERC through a Research Associateship.

7. REFERENCES

Barstow,M.A., 1988, Proceedings of the NATO ASI, Hot Thin Plasmas in Astrophysics, in press.

Holberg,J.B. and Barstow,M.A., 1988, in preparation.

Hummer,D.G. and Mihalas,D., 1970, *Mon.Not.R.astr.Soc.*, **147**, 339.

Kaler,J.B., 1983, *Astrophys.J.*, **271**, 188.

Nousek,J.A., Shipman,H.L., Holberg,J.B., Liebert,J., Pravdo,S.H., White,N.E. and Giommi,P., 1986, *Astrophys.J.*, **309**, 230.

Paerels,F.B.S., Heise,J., Kahn,S.M. and Rodgers,R.D., 1987, *Astrophys.J.*, **322**, 315.

Petre,R., Shipman,H.L. and Canizares,C.R., 1986, *Astrophys.J.*, **304**, 356.

Vennes,S., Pelletier,C., Fontaine,G. and Wesemael,F., 1988, preprint.

Warwick,R.S., Barstow,M.A. and Yaqoub,T.Y., 1988, in preparation.

Wesemael,F., 1981, *Astrophys,J.Suppl.*, **45**, 177.

Williams,G.A., King,A.R. and Brooker,J.R.E., 1987, *Mon.Not.R.astr.Soc.*, **266**, 725.

https://doi.org/10.1017/S0252921100099589 Published online by Cambridge University Press