A NEW TEMPERATURE DETERMINATION FOR SIRIUS B FROM IUE: IMPLICATIONS FOR THE OBSERVED SOFT X-RAY FLUXES

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ABSTRACT

We have used IUE archive observations to obtain a new and independent estimate of the effective temperature of Sirius B. In this effort we have modeled the observed Lyman alpha profile of Sirius B as a function of effective temperature and find; T_{eff} = 24,500 ± 500 K. This temperature is in good agreement with a recent result obtained from analysis of EXOSAT soft X-ray spectra of Sirius B. In addition to providing confirmation of the soft X-ray result, this temperature implies that Sirius B is significantly cooler and larger in radius than most previous estimates. The radius, $R = 0.090 \pm 0.005\ R_{\odot}$, implied by the lower temperature is well in excess of the radius of fully degenerate star having the mass of Sirius B. This investigation employed a unique set of SWP archive spectra, acquired with Sirius B in the small aperture, which have proved to be free of scattered light contamination from Sirius A.

INTRODUCTION

Sirius B has long been an object of particular interest and the subject of numerous detailed studies. Among the many reasons for the continued attention received by this star are its well determined astrometric mass and parallax, the nature of its soft X-ray emission, and its association with Sirius A. The latter circumstance has been the motivation for a wide range of suggestions regarding its evolutionary history. A major source continuing uncertainty regarding Sirius B has been its effective temperature. Achieving a reliable estimate for T_{eff} would help reduce uncertainties in the radius of Sirius B, allowing critical comparisions with mass-radius relationships, and also provide an important verification of the interpretations of various soft X-ray observations of this star.

Strong renewed interest in Sirius B developed in 1975 with the detection of soft X-ray emission (Mewe *et al.* 1975) from the Sirius system. Initially this was interpreted as coronal emission from either Sirius A or B; however, it was subsequently realized that the observations could be explained on the basis of photospheric emission from the pure hydrogen atmosphere of Sirius B (Shipman 1976), provided the temperature was high enough. Since 1975 Sirius B has been intensively observed by a large number of spacecraft including in the X-ray: ANS, HEAO 1, Einstein, and EXOSAT; and in the Ultraviolet: Copernicus, IUE, and Voyager. In spite of the well known problems posed by the proximity to Sirius A these efforts have succeeded in reducing many of the uncertainties associated with Sirius B, most notably its effective temperature. Current estimates have converged on temperatures in the range 26,000 K ± 2000 K. A recent thorough discussion of the observational constraints on the temperature and radius of this star is contained in Holberg, Wesemael, and Hubeny (1984) and Thejll and Shipman (1987). Interest now focuses on modeling the soft X-ray flux in terms of the effective temperature and photospheric helium content. Whether or not the temperature of Sirius B is closer to 25,000 K or 27,000 K has important implications for the interpretation of the soft X-ray emission, the helium content of its atmosphere, as well as models of its internal structure. Recently, Paerels *et al.* (1980) have determined that T_{eff} = 25,500 ± 500 Å, R = 0.0079 to 0.0085 $R_\odot$ and He/H = < 2×10^{-5}, best describe the overall energy distribution of Sirius B from the soft X-ray to the optical.

OBSERVATIONS AND ANALYSIS

In 1980 a series of five IUE SWP spectra (SWP 10073, 10074, 10076, 100122, and 10023) of Sirius B were acquired by M. Savedoff. Each consisted of a doubly exposed large and small aperture spectrum of Sirius. At the time Sirius B was located a distance of 10.14" and a position angle of 47.09° from Sirius A. A visual inspection of these spectra in the IUE archives revealed little apparent contamination from Sirius A, particularly in the important region of the broad Ly α profile. Subsequent analysis confirmed that three small aperture spectra (SWPs 10076, 10122 and 10123) were indeed free from any detectible contamination. This was verified in two ways. First, these spectra were found to be of identical shape, in spite of various exposure levels, and could be compared directly with similar IUE spectra of an analogous DA, CoD -38° 10980 (T_{eff} = 24,500 K and log g = 8.05). Except for the 1175-1250 Å region, where the Ly α profiles of the two stars are expected to differ due to different gravities, the spectral ratio was flat. Second, we successfully performed preliminary fits to the Ly α profile over the range 1150 to 1350 Å using a set of model atmospheres having gravities of log g = 8.5 to 8.65. A comparison of one such model, covering the entire SWP wavelength range, is shown in Fig. 1. In this comparison and that with CoD -38° 10980 *no* evidence of wavelength dependent contamination from Sirius A was found, in particular none which increased toward longer wavelengths. The expected wavelength dependence of any *spectrally neutral* scattered component from Sirius A is illustrated in Fig. 1 by a scaled template SWP observation of a typical A1 V star (δ UMi).

We analyzed the Ly α profile of Sirius B using techniques and model atmosphere grids similar to those used in the study of Ly α profiles in other DA white dwarfs (Holberg, Wesemael and Basile 1986). In this study it was demonstrated that the detailed analysis of DA Ly α profiles provide a reliable means of temperature estimation over the range 20,000 K to in excess of 60,000 K. Briefly, our procedure was to use the unnormalized small aperture fluxes for Sirius B and to fit for T_{eff} . This differs from previous Ly α profile analysis which was done on an absolute flux scale. Previous results have shown that the primary penalty paid for normalizing at 1300 Å is an approximate factor of two increase in uncertainty in the resulting T_{eff}.

We find that the Ly α profile of Sirius B indicates an effective temperature of T_{eff} = 24,500 ± 500 K. This result is significantly lower but still compatible with an earlier Sirius B Ly α result by Böhm-Vitense, Dettmann, and Karprandis (1979), who obtained 26,000 ± 1000 K. These authors employed an early epoch large aperture SWP observation of Sirius B in which an effort was made to exclude Sirius A from the large aperture. Their results were primarily based on comparisons of the data with theoretical Ly α profiles and depended on two alternate calibrations of the short wavelength end of the SWP camera.

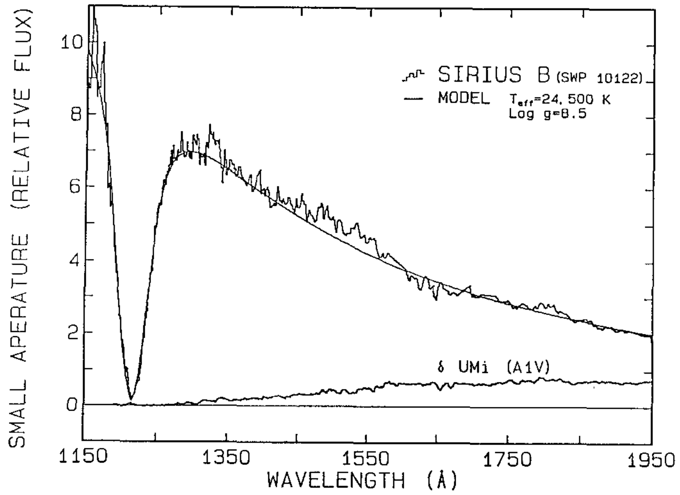

Figure 1 A comparison of the small aperture energy distribution of Sirius B from SWP 10122 with that of a model atmosphere specified by T_{eff} = 24,500 K and log g = 8.5. The ability of the model to generally match the observations throughout the SWP wavelength range is compelling evidence for the lack of any significant spectral contamination from Sirius A. An indication of the expected spectral shape of such contamination is illustrated by the arbitrarily scaled SWP energy distribution of the A1 star δ UMi.

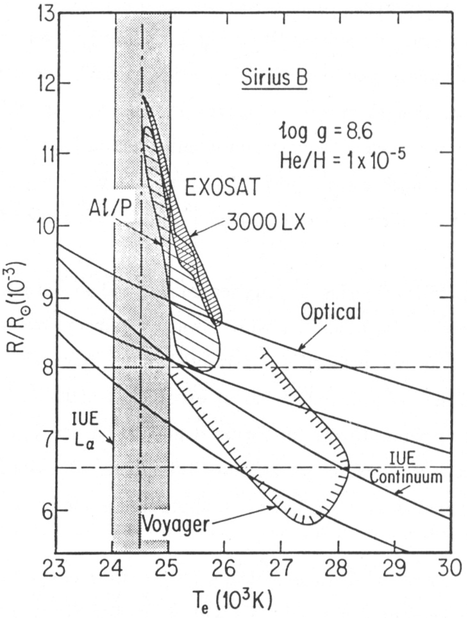

Figure 2 A comparison of existing constraints on the temperature and radius of Sirius B. The IUE Ly α results described here are shown as the vertical stippled region between 24,000 K and 25,000 K. The EXOSAT soft X-ray results of Paerels *et al.* (1988) are indicated by the two irregular hatched regions labeled "Al/P" and "3000 LX." The remaining regions correspond to ground-based photometry ("Optical"), the SWP spectrophotometry of Böhm-Vitense *et al.* ("IUE"), and Voyager far UV spectrophotometry ("Voyager"). These are all taken from Holberg *et al.* (1985). The horizontal dashed lines represent a 99% confidence range of radii corresponding to a 1.053 ± 0.005 $M_\odot$, ^{12}C white dwarf satisfying the Hamada-Salpeter mass-radius relationship.

DISCUSSION

In Fig. 2 we compare our new IUE results with previous constraints on the temperature and radius of Sirius B, including the recent EXOSAT results of Paerels et al. (1988). As can be seen, the Ly α and EXOSAT results are reasonably consistent for $T_{eff} \sim 25{,}000 \pm 500$ K and $R > 0.008\ R_\odot$. Additionally, if the analysis of the Voyager data were extended into this range of lower temperature and larger radii, it would also pass through this region. Considering all of the constraints the most consistent range of radii for Sirius B lies in the range $R = 0.0090 \pm 0.0005\ R_\odot$. Such radii are significantly larger than the range $R = 0.0072 \pm 0.0003\ R_\odot$ which are predicted for a fully degenerate star with a ^{12}C core using the Hamada and Salpeter (1961) relationship for an astrometric mass of $M = 1.053 \pm 0.0028\ M_\odot$ (Gatewood and Gatewood, 1978). Recently, Thejll and Shipman (1987) in reviewing the available observational constraints concluded that for T_{eff} between 26,000 to 28,000 K Sirius B lay 1 to 2 σ above the Hamada-Salpeter mass-radius relation. The larger radius implied by our cooler T_{eff} confirms this result and further increases the degree of the discrepancy.

The IUE Ly α results we present here are preliminary in that several of the SWP images have yet to be re-reduced to current IUE processing standards. Existing reprocessed images indicate that the additional data will serve to improve the S/N of the Ly α profiles and will not materially influence any of our results. A complete analysis and discussion of these data will be presented elsewhere.

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REFERENCES

Böhm-Vitense, E., Dettmann, T., and Kaprandis, S.: 1979, *Astrophys. J. (Letters)*, **232**, L189.
Gatewood, G. D., and Gatewood, C. V: 1978, *Astrophys. J.*, **225**, 191.
Hamada, T., and Saltpeter, E. E.: 1961, *Astrophys. J.*, **134**, 683.
Holberg, J. B., Wesemael, F., and Hubeny, I.: 1984, *Astrophys. J.*, **280**, 679.
Holberg, J. B., Wesemael, F., and Basile, J.: 1986, *Astrophys. J.*, **306**, 329.
Mewe, R., Heise, J., Groneschild, E. H. B. M., Brinkman, A. C., Schrijver, J. and Den Boggende, A. J. F.: 1975, *Nature Phys. Sci.*, **256**, 711.
Paerels, F. B. S, *et al.*: 1988, *Astrophys. J.*, **329**, 849.
Shipman, H. L.: 1976, *Astrophys. J. (Letters)*, **206**, L67.
Thejll, P., and Shipman, H. L.: 1987, *Pub. Astron. Soc. Pacific*, **98**, 922.