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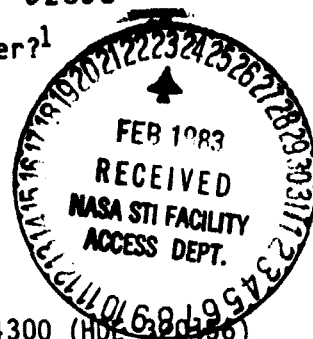
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LSS 4300, A Hot Counterpart of Upsilon Sgr and KS Per?¹

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ABSTRACT

A number of recent observations indicate that the star LSS 4300 (HDE 684956) is a high-temperature analog of the hydrogen-deficient binaries υ Sgr and KS Per. A preliminary model-atmosphere analysis based on high-dispersion spectra obtained at Kitt Peak and Cerro Tololo yields $T_{\text{eff}} = 14,400$ K, $\log(g) = 1.4$, $n(\text{H})/n(\text{He}) = 0.003$, and $n(\text{N})/n(\text{C}) = 20$ (the corresponding values for υ Sgr are $T_{\text{eff}} \approx 10,000$ K, $\log(g) \approx 1$, $n(\text{H})/n(\text{He}) \approx 0.0005$, and $n(\text{N})/n(\text{C}) \approx 20$). The optical emission-line spectrum of LSS 4300 is nearly identical to that of υ Sgr, including strong, broad H α , FeII and [Ca II] emission. The ultraviolet spectrum of LSS 4300 has been observed with IUE, and can be attributed almost entirely to the visible star. JHKL photometry of LSS 4300 obtained at Cerro Tololo reveals an infrared excess nearly identical to that of υ Sgr. We suggest that LSS 4300, like υ Sgr and KS Per, is a close binary system consisting of a helium supergiant of about one solar mass, and a secondary which is overluminous for its mass due to the accretion of matter from the primary, which is undergoing its second mass exchange.

Subject headings: stars: binaries -- stars: hydrogen-deficient --
stars: individual (LSS 4300)

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The stars υ Sgr and KS Per have long been considered to form a unique class of stars. Both are single-line spectroscopic binaries (Wilson 1914; Bidelman 1950; Heard 1962), and υ Sgr is probably an eclipsing binary as well (Eggen, Kron, and Greenstein 1950). In both cases, the visible component is an object of low surface gravity with an effective temperature of approximately 10,000 K which has lost its hydrogen-rich envelope, exposing to direct observation the material of the stellar core in which hydrogen has been depleted by nuclear reactions (Hack and Pasinetti 1963; Nariai 1967; Wallerstein, Greene, and Tomely 1967; Schönberner and Drilling 1983). These stars are nitrogen-rich, unlike the extreme helium stars and the hydrogen-deficient carbon stars, which are carbon-rich. In both cases, the secondaries have been observed in the UV (Duvignau, Friedjung, and Hack 1979; Hack, Flora, and Santin 1980; Drilling and Schönberner 1982b), and in both cases the secondary is underluminous for its spectral type (B2I-B3I). Infrared excesses and H α emission indicate mass loss and the presence of circumstellar material in both systems (Lee and Nariai 1967, 1969; Nariai 1967b). Schönberner and Drilling (1983) and Drilling and Schönberner (1982b) have presented a model similar to that of Plavec (1973) which is consistent with all presently existing observations of both systems, and in which the primary is a helium supergiant of about 1 solar mass and the secondary is an early-type star which is overluminous for its mass due to the accretion of matter from the primary. This model predicts that the primaries in both systems are undergoing their second mass loss. The purpose of the present paper is to describe in detail a number of recent observations which indicate that the star LSS 4300 (HDE 320156) is a high-temperature analog of υ Sgr and KS Per.

Drilling (1980) has shown that classification spectra of LSS 4300 are intermediate in all respects to those of υ Sgr, for which $T_{\text{eff}} \approx 10,000$ K, $\log(g) \approx 1$, and $n(\text{H})/n(\text{He}) \approx 0.0005$ according to Hack and Pasinetti (1963) and Schönberner and Drilling (1983), and the extreme helium star HD 168476, for which

$T_{\text{eff}} \approx 13,000 \text{ K}$, $\log(g) \approx 1.3$ and $n(\text{H})/n(\text{He}) < 0.0005$ according to Walker and Schönberner (1981) and Schönberner et al. (1982). This would suggest that the surface gravity and hydrogen abundance of LSS 4300 are similar to those of υ Sgr and KS Per, but that the effective temperature is somewhat higher. In order to obtain more information on the visible spectrum of LSS 4300, we have obtained high-dispersion image-tube spectra covering the wavelength range 3500–7000 Å with the Coudé feed at Kitt Peak (10 Å/mm dispersion) and the 4-meter echelle spectrograph at Cerro Tololo (4.6 Å/mm dispersion). The SiII/SiIII line-strength ratios on these plates indicate an even higher temperature than that derived for HD 168476. If we assume a microturbulent velocity of 10 km/sec, we obtain an effective temperature of 14,400 K using the model atmospheres of Schönberner et al. (1982). The profile of the He I 4471 line yields a surface gravity of 25 cm/sec/sec according to the same models, as illustrated in Fig. 1. The abundances obtained for some important elements are given in Table I, where they are compared to those obtained for KS Per (Wallerstein et al. 1967), the extreme helium star HD 124448 (Schönberner and Wolf 1974), and the sun (Allen 1973).^{*} The hydrogen/helium ratio is seen to be somewhat higher for LSS 4300 ($n(\text{H})/n(\text{He}) = 0.003$) than it is for υ Sgr or KS Per, but the nitrogen/carbon ratio ($n(\text{N})/n(\text{C}) = 20$) is very similar to that obtained for υ Sgr by Hack and Pasinetti (1963). We also find that LSS 4300 has an emission-line spectrum nearly identical to that of υ Sgr, including strong, broad H α , Fe II, and [Ca II]. In the case of υ Sgr, the emission lines are attributed to a gaseous shell enveloping the system, as they show no variations in radial velocity (Merrill 1944).

^{*}We have compared LSS 4300 to KS Per rather than υ Sgr in Table I because Schönberner and Drilling (1983) have shown that the hydrogen/helium ratio given by Hack and Pasinetti (1963) for υ Sgr is much too high. The abundances given by Wallerstein et al. (1967) for KS Per should therefore be more reliable than those given by Hack and Pasinetti (1963) for υ Sgr. Abundance ratios other than the hydrogen/helium ratio should, however, be of comparable accuracy for both stars.

we have also observed LSS 4300 with the International Ultraviolet Explorer satellite (Boggess et al. 1978a,b) over the wavelength range 1100-3200 Å at a resolution of 6 Å. This spectrum is compared in Fig. 2 with similar spectra of ν Sgr and the extreme helium star LSII+33⁰⁵, which has a slightly higher effective temperature than LSS 4300 (15,000 K), but a similar surface gravity and hydrogen abundance according to Schönberner et al. (1982). Also plotted in Fig. 2 are the results of UBVRIJHKL photometry of these three stars, as discussed below. The ultraviolet spectra of ν Sgr and LSII+33⁰⁵ were obtained from the National Space Science Data Center (Warren 1982), and in all three cases, the spectra were calibrated using the absolute calibration of Bohlin and Holm (1980), and de-reddened according to the reddening law of Seaton (1979) so as to cause a reversal of the interstellar feature at 2200 Å. This procedure yields the following values of E_{B-V} : 0.90 for LSS 4300, 0.12 for ν Sgr, and 0.22 for LSII+33⁰⁵. The continuous spectra of LSS 4300 and LSII+33⁰⁵ are seen to be quite similar in the ultraviolet, and the differences in the absorption line spectra can be attributed almost entirely to the differences in the carbon abundances of these two stars. This means that the ultraviolet spectrum of LSS 4300 is due primarily to the visible star.

That the ultraviolet absorption-line spectrum of LSS 4300 is due primarily to the visible star does not preclude the existence of a hot secondary similar to those of ν Sgr and KS Per. If we take $E_{B-V} = 0.5$ mag/kpc at $l = 354^{\circ}$ and $b = -2^{\circ}$ (Lucke 1978), $R = 3.2$, and $V = 9.77$ for LSS 4300 (Drilling 1983), then the value of E_{B-V} derived above yields a distance of 2 kpc and an absolute magnitude of $M_V = -4$ or -5 . The model atmosphere described above then yields a luminosity of 10,000 solar luminosities, which is comparable to those found for the visible components of ν Sgr and KS Per, and agrees well with theoretical models of 1 solar mass helium giants (Paczynski 1971; Schönberner 1977). Because the visible component of LSS 4300 is so much hotter than those of ν Sgr and KS Per, a star

similar to the secondaries in these systems would contribute less than 10% to the flux at wavelengths longer than 1400 \AA . There does, in fact, appear to be an ultraviolet excess for LSS 4300 shortward of 1400 \AA , as compared to LSII+33⁰⁵, even though the latter has a higher effective temperature. We are not, however, certain of the reality of this UV excess because our images are badly underexposed shortward of 1400 \AA and because of the uncertainties in the effects of interstellar reddening. The earlier conclusion by Drilling and Schönberner (1982a) that LSS 4300 must have a hot secondary on the basis of the IUE observations is, therefore, not justified, as it was based on the erroneous assumption that the effective temperature of the visible star was intermediate to those of ν Sgr and HD 168476.

JHKL photometry of LSS 4300, ν Sgr, and LSII+33⁰⁵ was obtained with the 1.5-meter telescope and InSb detector system at Cerro Tololo on the nights of 21 and 22 July 1980. Eighteen observations of stars included in the standard list of Elias, Frogel, Matthews, and Neugebauer (1982) were used to determine the zero-point corrections to the observed magnitudes and to correct them for atmospheric extinction. The results are given in Table II, and are plotted in Fig. 2 after having been calibrated according to Wamsteker (1981) and corrected for interstellar reddening using the values of E_{B-V} given above and van de Hulst's curve no. 15 (Johnson 1966). The results of UBVR photometry for the same three stars (Lee and Nariai 1967; Drilling 1983; Landolt 1983), calibrated according to Hayes (1979) and corrected for interstellar reddening according to the law of Nandy et al. (1975), are also plotted in Fig. 2, as are the results of the IUE observations described above. LSS 4300 shows an infrared excess very similar to that of ν Sgr, which has been attributed by Treffers et al. (1976) to circumstellar dust.

We suggest that LSS 4300 is the same type of system as ν Sgr (Schönberner and Drilling 1983) and KS Per (Drilling and Schönberner 1982b), i.e., one in

which the primary is a helium supergiant in or near its Roche-lobe overflow stage (Case BB mass exchange) with a mass of about 1 solar mass, and the secondary is overluminous for its mass (and underluminous for its spectral type) due to the accretion of matter from the primary. The system is now in its second phase of mass exchange, the primary having been stripped of nearly all of its hydrogen-rich envelope in an earlier, Case B, mass exchange. Because the primary is much hotter than those of ν Sgr and KS Per, we have not been able to use IUE observations to prove conclusively the existence of a hot secondary. If, however, the mass of this secondary is comparable to those of the secondaries of ν Sgr and KS Per (3-5 solar masses), its existence should be revealed by careful monitoring of the radial velocity of LSS 4300.

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TABLE I. Abundances of some important elements in the atmospheres of LSS 4300, KS Per, HD 124448, and the sun. The quantity tabulated is $\log(n_i)$, normalized such that $\log \sum \mu_i n_i = 12.15$ if the abundances of the missing elements are assumed to be solar with respect to the total mass.

| | LSS 4300 | KS Per | HD 124448 | Sun |
|----|----------|--------|-----------|-------|
| H | 9.0 | 7.5 | 7.5 | 12.00 |
| He | 11.5 | 11.5 | 11.5 | 10.93 |
| C | 8.0 | 6.1 | 9.5 | 8.52 |
| N | 9.3 | 9.1 | 8.8 | 7.96 |
| Mg | 7.9 | -- | 8.2 | 7.42 |
| Si | 7.8 | 7.6 | 7.5 | 7.52 |
| Fe | 7.5 | -- | 7.4 | 7.60 |

TABLE II. JHKL photometry of υ Sgr, LSS 4300, and LSII+33⁰5.

| Star | K | J-K | H-K | K-L |
|------------------------|-------|------|------|-------|
| Sgr | 2.53 | 1.40 | 0.84 | 1.32 |
| LSS 4300 | 5.88 | 1.61 | 0.91 | 1.38 |
| LSII+33 ⁰ 5 | 10.08 | 0.09 | 0.03 | -3.4: |

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FIGURE CAPTIONS

Fig. 1. The observed and theoretical profiles of the He I 4471 line for LSS 4300. The theoretical profile was computed using a model atmosphere with $T_{\text{eff}} = 14,400$ K, $\log(g) = 1.4$, and the abundances given in Table I. The filled circles represent mean values of two observations (m.e. = ± 0.02).

Fig. 2. Low-resolution IUE spectra and UBVRIJHKL photometry of ν Sgr, LSS 4300, and LSII+33⁰⁵. All fluxes have been corrected for interstellar reddening as described in the text.

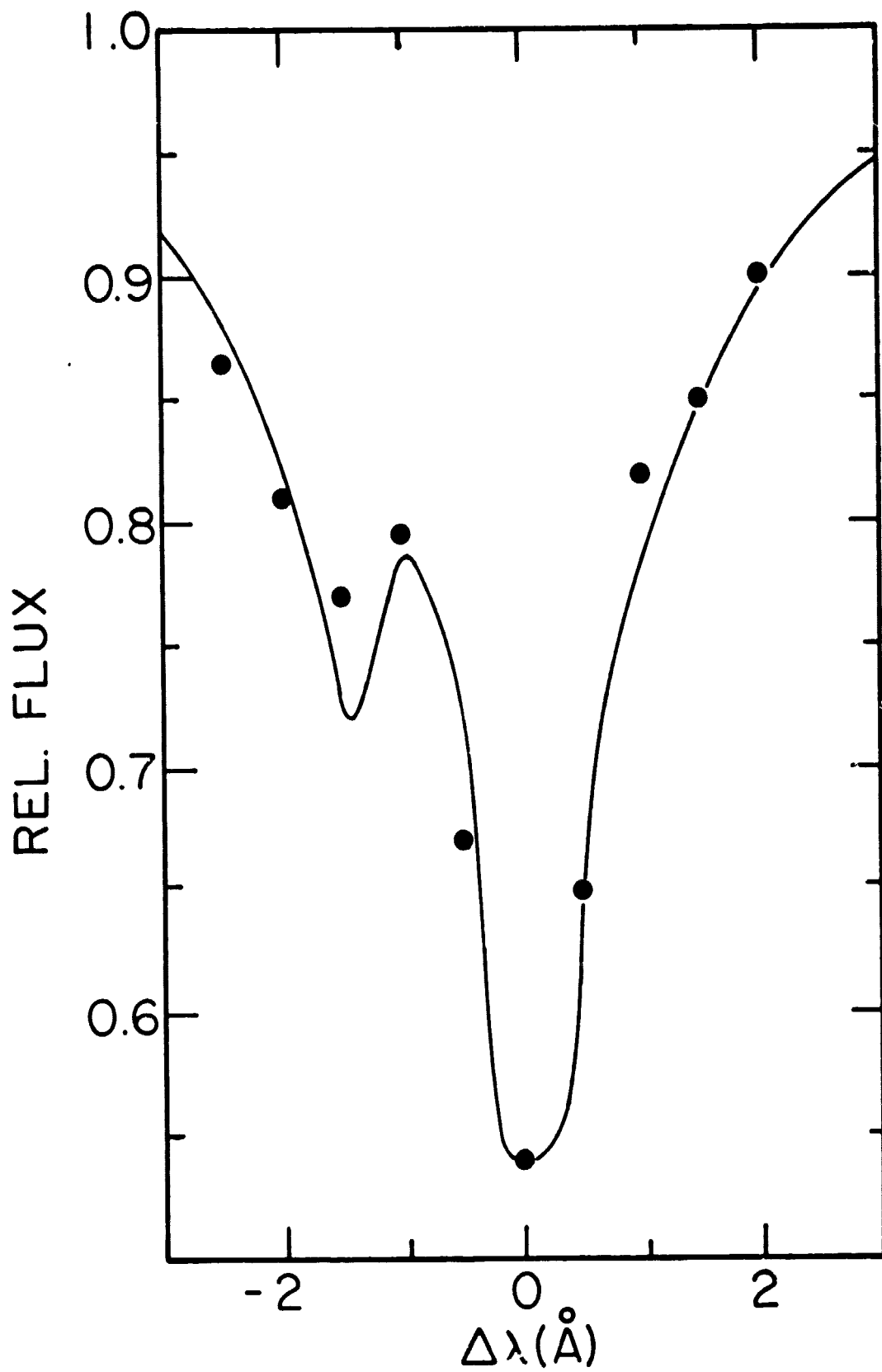


Fig. 1. Drilling and Schönberner

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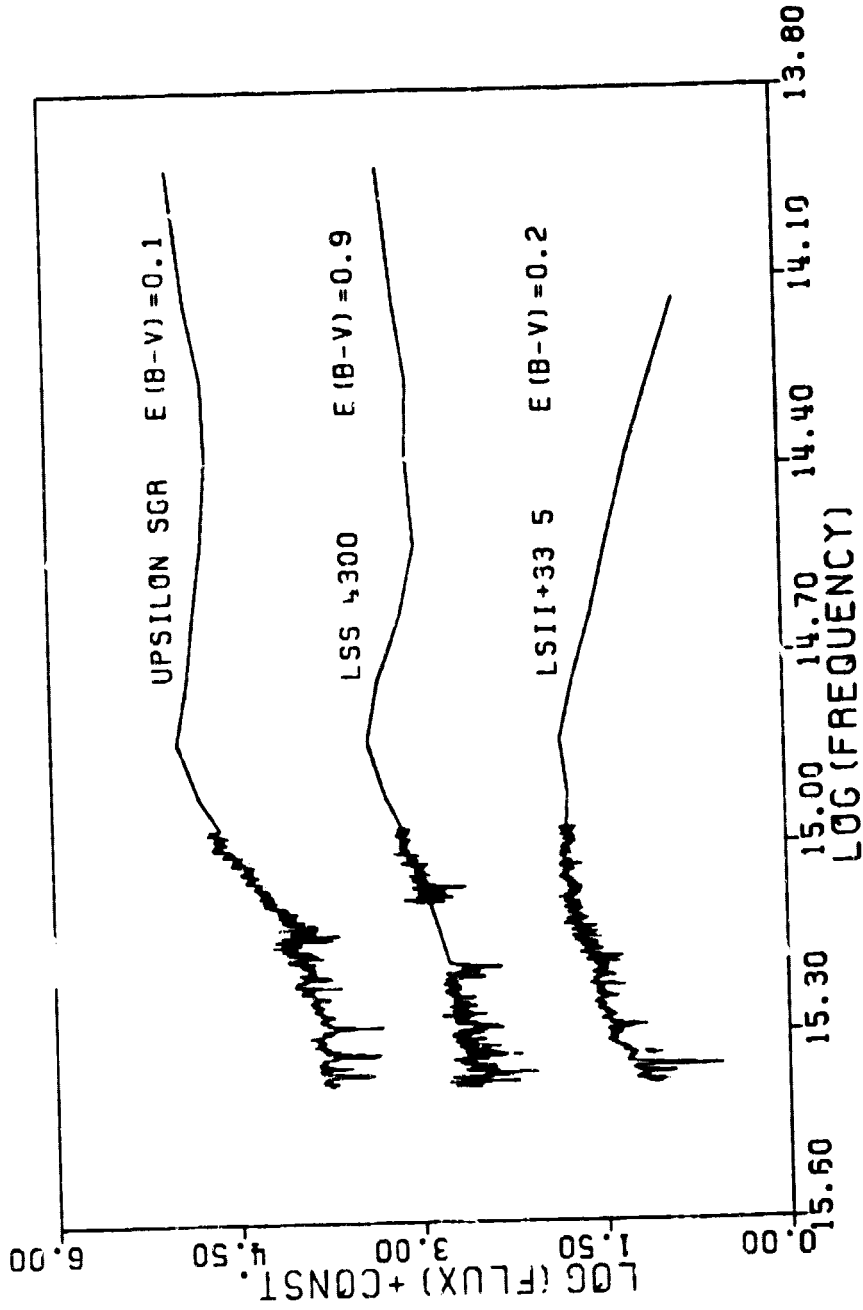


Fig. 2. Drilling and Schönberner