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VLA* Observations of Extreme Hydrogen Deficient Stars

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Abstract. VLA observations at 2 and 6 cm have been obtained for six hydrogen-deficient stars R CrB, HD 160641, BD – 9°4395, V348 Sgr, MV Sgr and Sgr *v* Upper limits to the massloss rates have been estimated for some of these using the upper limits to the radio flux density.

Key words: Stars, hydrogen-deficient—stars, radio observations—stars, massloss— stars, individual— VLA observations

1. Introduction

Massloss in extreme hydrogen-deficient stars is an important phenomenon in understanding their evolution (Renzini 1983; Iben 1984) as well as in understanding the physical mechanism responsible for massloss (Hamann, Schönberner & Heber 1982). Extreme hydrogen-deficient stars comprise both hot and cool stars as well as variable and nonvariables. Hamann, Schönberner & Heber have obtained the rates of massloss for three nonvariable hot hydrogen-deficient stars from the profiles of ultraviolet resonance lines. They find that the massloss rates are similar to those of normal stars of the same luminosity and seem to decrease with increasing radius. However, these analyses arc strongly model dependent. The radio detection of free-free emission from ionized mass outflows probably provides the most accurate method for the determination of massloss rates. Therefore, we have observed a sample of hydrogen deficient stars with VLA at 2 and 6 cm. Although we could not detect any radio emission, we could set upper limits to the flux density which enabled setting upper limits to the massloss rates for some of these objects.

2. Observation

The observations of six of the hydrogen deficient stars were obtained with the VLA (Napier, Thompson & Ekers 1983) in the A configuration on 12 December 1983. Each

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source was observed in snapshot mode at 6 cm (C-band) and 2 cm (U-band) with a bandwidth of 50 MHz in each band. The data were acquired in both AC and BD IFs (4835 MHz and 4885 MHz in C-band; 14915 and 14965 MHz in U-band). The data from two IFs were combined to make maps. A region of about 1 arcmin × 1 arcmin was mapped at 6 cm and 20 arcsec × 20 arcsec at 2 cm. As the positions of the stars were known quite accurately the regions searched for detection of radio emission were considered adequate. The maps were cleaned and restored using the standard software package AIPS. The results are tabulated in Table 1 along with other stellar data.

3. Massloss rates

Write & Barlow (1975) and Panagia & Felli (1975) have derived simple relations between the rate of massloss $\dot{M}$ and radio flux density S_ν at frequency ν when the flow is uniform and spherically symmetric with a velocity V_∞ independent of radius and time. The majority of the radio emission should originate far from the star so that the velocity can be approximated by the terminal value and the density is assumed to vary as r^{-2}. The Wright & Barlow formulation gives

$$\dot{M} = \frac{0{\cdot}095\, \mu\, V_\infty\, S_\nu^{3/4}\, D^{3/2}}{z\, \gamma^{1/2}\, g^{1/2}\, \nu^{1/2}} \qquad M_\odot\ \mathrm{yr}^{-1}$$

where V_∞ the terminal velocity in km s^{-1}, S_ν in Jy, ν in Hz, D the distance in kpc. The remaining parameters depend on composition, kinetic temperature T and ionization equilibrium in the radiating gas; μ is the mean atomic weight per nucleon, γ is the number of electrons per ion, z is the rms average charge of the ion, and $g(\nu, T)$ is the Gaunt factor (Spitzer 1962). Since spectral analyses of many of these objects indicate that their atmospheres are rich in helium (Cottrell & Lambert 1982; Dahari & Osterbrock 1984; Drilling *et al.* 1984), we adopt helium as the major constituent of the wind.

3.1. *Programme Stars*

RCrB: Altenhoff *et al.* (1976) give an upper limit of 5 mJy at 10·6 GHz from the observations obtained in 1973. The present estimate is more sensitive (< 0.3 mJy at 5 GHz). We adopt $\mu = 4$, $y = 1$ and $z = 1$. The estimation of terminal velocity of the gas is uncertain. The massloss is indicated by the absorption components of Mg II lines of – 55 and – 28 km s^{-1} relative to the stellar absorption spectrum (Rao, Nandy & Bappu 1981). However, at the time of light minimum emission linewidths indicate expansion velocity of 250 km s^{-1}. If we adopt the terminal velocity as 100 km s^{-1}, then the upper limit to the massloss rate of ionized gas is < $7{\cdot}9 \times 10^{-7}$ $M_\odot$ yr $^{-1}$. However, the presence of low-density circumstellar material is indicated by the presence of emission lines of λ3727 of [OII] when the star is faint (> 13 mag). From the infrared flux, the massloss rate has been estimated as ~ 10^{-5} $M_\odot$ yr^{-1} (Forrest 1974) which is far in excess of our upper limit.

HD 160641: We adopt $\mu = 4$, $z = 2$ and $y = 2$ as well as the distance and terminal velocity from the analysis of Hamann, Schonberner & Heber (1982). The present estimate of the massloss rate < $8{\cdot}9 \times 10^{7} M_\odot$ yr^{-1} (Table 1) is consistent with their estimate.

Table 1. Upper limits to flux density and massloss.

Star	Spectral type	T_{eff} K	Distance pc	2 cm: Beam size arcsec	2 cm: Upper limit (3σ) flux density mJy	6 cm: Beam size arcsec	6 cm: Upper limit (3σ) flux density mJy	V km s^{-1}	(Upper limit) M $M_\odot$ yr^{-1}
R CrB	F8Ib	7000 (6)	1380 (1)	0.45 × 0.14	0.66	1.08 × 0.39	0.28	(100)	7.9×10^{-7}
BD − 9°4395	B0	24000 (4)	1860 (2)	0.44 × 0.20	0.81	1.48 × 0.55	0.28	600	2.4×10^{-6}
HD160641	O	32500 (4)	1000 (2)	0.43 × 0.23	1.14	1.38 × 0.64	0.34	550	8.9×10^{-7}
V348 Sgr	B0–B1	23000 (3)	2200 (3)	0.44 × 0.26	0.84	1.37 × 0.74	0.34	(100)	1.8×10^{-6}
MV Sgr	B2	18000 (4)	2690 (4)	0.44 × 0.24	0.93	1.46 × 1.20	0.34	(500)	1.2×10^{-5}
υ Sgr	Ap + B3	10500 (4)	600 (5)	0.44 × 0.21	0.88	1.16 × 1.13	0.30	700	5.4×10^{-7}

References to columns 3 and 4:
(1) Assuming $M_v = -5$ (Rao, Nandy & Bappu 1981)
(2) Hamann, Schönberner & Heber (1982)
(3) Rao & Nandy (1985)
(4) Drilling *et al.* (1984); Rao & Nandy (1982)
(5) Rao & Venugopal (1985)
(6) Cottrell & Lambert (1983)

BD – 9°4395: The terminal velocity again is taken from Hamann, Schönberner & Heber, μ = 4, z = 2 and y = 2 have been adopted. The distance is estimated by adopting $\log L_*/L_\odot = 4.0 \pm 0.5$ and $E(B-V) = 0.31$.

MV Sgr: We adopt μ = 4, z = 1, y = 1. The distance is estimated by adopting M_v = – 1 and $E(B-V) = 0.5$. The terminal velocity is very uncertain, lack of line-shifts in the low-resolution IUE spectra gives a velocity < 500 km s^{-1}. The upper limit to the massloss rate is quoted in Table 1. The ultraviolet spectra show changes in line strengths of Fe II, Al II *etc* (Rao & Nandy 1982) indicating massloss.

V 348 Sgr: We adopt μ = 4, y = 1 and z = 1. The emission linewidths indicate an expansion velocity of ~ 50 km s^{-1} (Houziaux 1968; Dahari & Osterbrock 1984). If we adopt the terminal velocity of ~ 100 km s^{-1} then $\dot{M} \lesssim 1.8 \times 10^{-6} M_\odot$ yr^{-1} for the ionized gas (Table 1). The star is known to be surrounded by an optical nebulosity extending to 8–10 arcsec. The distance has been estimated as 2.2 kpc by Rao & Nandy (1985) which leads to a $N_e \sim 2 \times 10^3$ cm^{-3} estimated from nebular Hβ emission and which agrees well with the value of N_e independently estimated from forbidden lines. The analysis of Dahari & Osterbrock (1984) show that the star's CII emission-line region is characterised by $T \sim 2 \times 10^4$ K.

υ Sgr: This is one of the three known hydrogen-deficient binary stars. It has a period of 138 days. The IUE spectrum shows resonance lines due to NV, CIV, SiIV *etc.* strongly in absorption, indicating massloss with a terminal velocity of 700 km s^{-1}. The observational aspects have been discussed by Rao & Venugopal (1985). We adopt μ = 4, z = 2, γ = 2, $T_e \sim 10^5$ K. The present upper limit to the radio flux density indicates a massloss rate $\leqslant 5.4 \times 10^{-7} M_\odot$ yr^{-1} (Table 1). In the evolution scheme proposed by Plavec (1973) and Schönberner & Drilling (1983), the system is supposed to have lost or to be losing 4 to 12 $M_\odot$ from the primary star. The present rate of massloss is not sufficient to have reduced the primary to a hydrogen-deficient star of 1 $M_\odot$. Most of the matter must have been lost, to the system already in an earlier phase of evolution.

4. Discussion

The upper limits to the rate of massloss obtained for HD 160641 and BD – 9° 4395 are in agreement with the upper limits $10^{-7.2}$ and $10^{-7.7}$ $M_\odot$ yr^{-1}, respectively, determined earlier by Hamann, Schönberner & Heber (1982) from ultraviolet spectral lines.

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