

## FIRST DETECTION OF WINDS IN RED GIANTS BY MICROWAVE CONTINUUM TECHNIQUES

S. A. DRAKE AND J. L. LINSKY<sup>1</sup>

Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards

Received 1983 April 11; accepted 1983 July 12

### ABSTRACT

We have observed eight red giants and supergiants at 4885 MHz (6 cm) with the Very Large Array in an attempt to detect continuum emission. The bright giant  $\alpha^1$  Her (M5 II) was detected at an average flux density of  $0.9 \pm 0.13$  mJy. Since the likely source of this emission is an ionized, optically thick component of a stellar wind, this detection implies a mass loss rate of  $2 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$  for the ionized gas. The fraction of the outflow in  $\alpha^1$  Her that is ionized (0.002–0.02) seems to be similar to that previously found for  $\alpha$  Ori and  $\alpha$  Sco A. Alpha Boo (K2 IIIp) and  $\beta$  Gem (K0 III) are probable and definite detections, respectively. The derived ionized mass loss rates for these two stars are about  $1 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$ , implying in the case of  $\alpha$  Boo that the wind is largely ionized.

*Subject headings:* stars: chromospheres — stars: late-type — stars: mass loss — stars: radio radiation — stars: winds

### I. INTRODUCTION

Single red giants and supergiants have been extremely difficult to detect as continuum radio sources. The best known and documented sources are  $\alpha$  Ori (M2 Iab) and  $\alpha^1$  Sco (M1 Ib) (Wischniewski and Wendker 1981; Newell and Hjellming 1982; Hjellming and Newell 1982, 1983). Heretofore, no single red giants (MK class III) have been detected. Observations of hot stars and pre-main-sequence stars at 6 cm have provided accurate mass loss rates for their ionized winds, and this technique should also be extremely useful for cool, luminous stars, although their winds may only be partially ionized. We have therefore begun a program of microwave observations using the NRAO<sup>2</sup> Very Large Array. (For a description of the VLA, see Thompson *et al.* 1980.)

The program stars are of G, K, and M spectral type and luminosity classes Ia through III, excluding close binaries and pre-main-sequence stars. Here we present results from our first two observing runs in which we have definitely detected at 6 cm the M5 II star  $\alpha^1$  Her and the K0 III star  $\beta$  Gem, probably detected  $\alpha$  Boo (K2 IIIp), and not detected five other stars. The detection of  $\beta$  Gem, and that of  $\alpha$  Boo, if confirmed, represent the first detections at radio wavelengths of winds from K giant stars.

<sup>1</sup>Staff Member, Quantum Physics Division, National Bureau of Standards.

<sup>2</sup>The National Radio Astronomy Observatory is operated by the Association for Research in Astronomy Inc., under contract with the National Science Foundation.

### II. OBSERVATIONS

Our observations were made at 4.885 GHz on 1983 January 21 when the VLA was in the C configuration and on 1983 May 20 when the array was in a hybrid C/D configuration. A maximum of 24 antennas provided usable data in the January observations and a maximum of 26 in the May observations. The final antenna solutions for both data sets contained only a handful of amplitude and phase closure errors greater than 8% and 8°, respectively, and none greater than 11% or 11°. Coordinates and fluxes for the eight stars for which good data are available are listed in Table 1. The fluxes quoted were determined from an observation of 3C 286, assuming a flux density of 7.41 mJy. Since we did not apply any limits on the ( $u$ ,  $v$ ) plane coverage for the latter, our fluxes should have uncertainties in the range  $\pm 5\%$ . Phase calibrators were observed at 30 minute intervals. Our criteria for a detection are:

1. The presence of peak radio flux coincident with the optical position to within the combined radio and optical uncertainties ( $\sim 2''$ ). Since our half-power beam width is  $\sim 4''$  in the C array observations and is  $\sim 5'' \times 10''$  in the C/D hybrid array, the 6 cm position can be a large source of uncertainty, particularly for weak sources. The major inaccuracy in the optical positions of the stars results from the large proper motion corrections.

2. The radio peak flux being at least 3 times the mean rms noise. According to Abbott *et al.* (1980), the probability of a random background source with a flux density greater than 0.5 mJy lying within  $0''.5$  of the optical

TABLE 1  
STELLAR COORDINATES AND 6 CENTIMETER FLUXES

STAR	OPTICAL COORDINATES <sup>a</sup>		VLA COORDINATES OF SOURCE		$S_\nu$ (mJy)	$\frac{S_\nu}{\sigma}$	ARRAY
	$\alpha$ (1950)	$\delta$ (1950)	$\alpha$ (1950)	$\delta$ (1950)			
$\alpha^1$ Her ...	17 <sup>h</sup> 12 <sup>m</sup> 21 <sup>s</sup> 93 <sup>b</sup>	+14°26'46".5 <sup>b</sup>	{ 17 <sup>h</sup> 12 <sup>m</sup> 21 <sup>s</sup> 90 17 12 21.97	{ +14°26'46".6 +14 26 46.5	1.15 0.80	6.6 8.0	C C/D
$\alpha^2$ Her ...	17 12 22.26 <sup>b</sup>	+14 26 45.1 <sup>b</sup>	{ ... ... }	{ ... ... }	$\leq 0.54^c$ $\leq 0.3^c$	... ...	C C/D
$\alpha$ Boo ....	{ 14 13 20.18 <sup>b</sup> 14 13 20.32 <sup>d</sup>	{ +19 25 24.9 <sup>b</sup> +19 25 24.8 <sup>d</sup>	14 13 20.30	+19 25 24.2	0.39	3.0	C
$\alpha$ Boo ....	{ 14 13 20.16 <sup>b</sup> 14 13 20.30 <sup>d</sup>	{ 19 25 24.2 <sup>b</sup> 19 25 24.2 <sup>d</sup>	14 13 20.04	+19 25 24.0	0.26	3.1	C/D
$\beta$ Gem ...	{ 7 42 13.95 <sup>b</sup> 7 42 14.08 <sup>c</sup>	{ +28 08 53.4 <sup>b</sup> +28 08 53.2 <sup>c</sup>	7 42 14.02	+28 08 51.5	0.55	3.9	C
$\beta$ Gem ...	{ 7 42 13.93 <sup>b</sup> 7 42 14.06 <sup>c</sup>	{ 28 08 53.4 <sup>b</sup> 28 08 53.2 <sup>c</sup>	7 42 14.01	+28 08 52.2	0.53	7.6	C/D
$\alpha$ Tau ....	4 33 3.05 <sup>b</sup>	+16 24 31.3 <sup>b</sup>	...	...	$\leq 0.37^c$	...	C
$\mu$ UMa ...	10 19 21.29 <sup>b</sup>	+41 45 07.3 <sup>b</sup>	...	...	$\leq 0.42^c$	...	
$\beta$ Crv ....	12 31 45.34 <sup>b</sup>	-23 07 11.7 <sup>b</sup>	...	...	$\leq 0.37^c$	...	C/D
$\mu$ Cep ....	21 41 58.50 <sup>b</sup>	58 33 00.7 <sup>b</sup>	...	...	$\leq 0.40^c$	...	C/D

<sup>a</sup>Includes proper motions to 1983.06 for C array observations and to 1983.38 for the hybrid array observations.

<sup>b</sup>Position and proper motion from the 1966 SAO Catalogue.

<sup>c</sup>Upper limits are  $3\sigma$ .

<sup>d</sup>Position and proper motion from Eggen 1979.

<sup>e</sup>Position and proper motion from AGK3 (Dieckvoss 1975).

position is only 1 in 40,000. For an error circle of  $2''$  radius, the probability is still only 1 in 2,500.

In order to avoid an intermittent problem (reported in recent VLA documents) of fictitious weak sources ( $S_\nu \sim 1$  mJy) appearing at the field center, we have offset the beam by  $15''$  either north or south of the expected target coordinates. Strong serendipitous sources of 25 and 75 mJy, respectively, are located near  $\alpha$  Boo and  $\mu$  UMa. Therefore, the intensity maps of these fields have been "CLEANed" of the sidelobes of these bright sources using the standard VLA utility programs (Clark 1980).

We present in Table 1 either the 6 cm flux density and the ratio of this quantity to the rms noise ( $1\sigma$ ) or the  $3\sigma$  upper limit. The detection is certain for  $\alpha^1$  Her (see Fig. 1), since we have two separate data sets with highly significant ( $\gg 3\sigma$ ) sources at the correct location. There is also clearly a radio source present very close ( $\sim 2''$ ) to the FK4 optical position of  $\beta$  Gem. This positional discrepancy is twice as large as the expected uncertainty in the position of a  $3\sigma$  radio source observed in the C configuration and thus may be significant. In this paper, we shall assume that the radio source is associated with  $\beta$  Gem. Even though we have two independent  $3\sigma$  detections of a radio source close to the optical position of  $\alpha$  Boo, we claim only a probable detection of this star and plan a reobservation of this field at higher signal-to-noise ratio and at a later date. If the source is real and associated with  $\alpha$  Boo, it should share the large stellar proper motion ( $> 2''$  per annum).

### III. DISCUSSION

We summarize relevant information about the stars in Table 2. The outflow velocity for  $\alpha^1$  Her is well known from many studies of its rich set of circumstellar absorption features. The velocity field for  $\mu$  Cep appears to be very complex as no fewer than five different circumstellar components have been observed (Bernat 1981) with radial velocities relative to the star ranging from  $-8$  to  $-47$  km s<sup>-1</sup>. We have therefore assumed a "mean" outflow velocity of 20 km s<sup>-1</sup>. The velocities of the winds from  $\alpha$  Boo and  $\alpha$  Tau were derived from the radial velocities of the violet-displaced absorption components in the Mg II resonance lines (e.g., Stencel *et al.* 1980), while for  $\mu$  UMa the velocity was taken from an optical study of its circumstellar features (Boesgaard and Hagen 1979). We adopt plausible velocities for  $\alpha^2$  Her,  $\beta$  Crv, and  $\beta$  Gem as there are no published measurements.

In the following discussion we have assumed the mechanism of radio emission is optically thick, free-free radiation from the ionized component of a constant velocity, cool ( $T \sim 10^4$  K) stellar wind. The microwave flux  $S_\nu$  is related to the ionized mass loss rate  $\dot{M}_{\text{ion}}$  by

$$S_\nu = 1.6 \times 10^{11} \left( \frac{\dot{M}_{\text{ion}}}{v_\infty} \right)^{4/3} \frac{1}{D^2} \left( \frac{\lambda}{6 \text{ cm}} \right)^{-0.6} \text{ mJy}, \quad (1)$$

where  $\dot{M}_{\text{ion}}$  is the mass loss rate of ionized gas in  $M_\odot$  yr<sup>-1</sup>,  $D$  is the distance in kpc, and  $v_\infty$  is the outflow

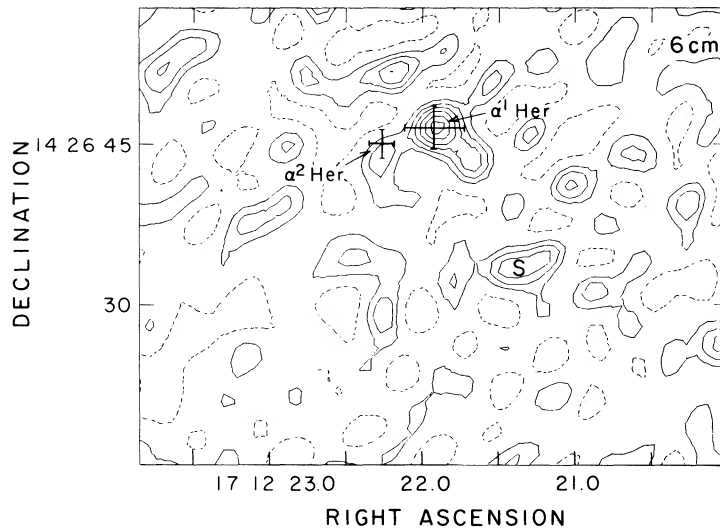


FIG. 1.—A contour map of the field containing  $\alpha^1$  Her and  $\alpha^2$  Her obtained from the January observations with a peak flux of 1.15 mJy. The base contour level (the first solid contour) corresponds to 0.2 mJy (the rms noise level), and the contour interval is also 0.2 mJy. The dashed contour represents the  $-0.2$  mJy level. The optical positions of  $\alpha^1$  Her and  $\alpha^2$  Her are indicated, but the optical position uncertainties are much smaller than the sizes of the crosses.

TABLE 2  
MASS LOSS RATES OF IONIZED GAS DERIVED  
FROM MICROWAVE OBSERVATIONS

Star	Spectral Type	Distance <sup>a</sup> (pc)	Wind Velocity (km s <sup>-1</sup> )	$\dot{M}_{\text{ion}}$ ( $M_{\odot}$ yr <sup>-1</sup> )
$\alpha^1$ Her ...	M5 II	125	10	$1.7 \times 10^{-9}$
	M5 III	60	10	$5.7 \times 10^{-10}$
$\alpha^2$ Her ...	G5 III	125	(50) <sup>b</sup>	$\leq 3.6 \times 10^{-9}$
	G5 III	60	(50) <sup>b</sup>	$\leq 1.2 \times 10^{-9}$
$\alpha$ Boo ....	K2 IIIp	11	40	$\sim 7.5 \times 10^{-11}$
$\beta$ Gem ...	K0 III	11	(40) <sup>b</sup>	$1.2 \times 10^{-10}$
$\alpha$ Tau ....	K5 III	18	30	$\leq 1.5 \times 10^{-10}$
$\mu$ UMa ...	M0 III <sup>c</sup>	29	15	$\leq 1.6 \times 10^{-10}$
$\beta$ Crv ....	G5 III	30	(50) <sup>b</sup>	$\leq 5.0 \times 10^{-10}$
$\mu$ Cep ....	M2 Ia	825	20	$\leq 3.0 \times 10^{-8}$

<sup>a</sup>Distances derived from trigonometric parallax, except for  $\alpha$  Her for which we have listed two differing spectroscopic parallaxes taken from Wilson 1976 and Reimers 1977a, and for  $\mu$  Cep, for which 825 pc was assumed on its presumed membership in the Cepheus OB2 association (Simonson and van Someren Greve 1976).

<sup>b</sup>Estimated velocities.

<sup>c</sup>Spectroscopic binary with a period of 230 days.

velocity in km s<sup>-1</sup>. We shall defer alternative interpretations of the radio emission until a subsequent paper. The mass loss rates quoted in Table 2 were obtained using equation (1) and refer only to the *ionized components* of the winds.

In a previous 6 cm survey of cool stars, Bowers and Kundu (1981) did not detect  $\alpha^1$  Her with a quoted upper limit of 0.5 mJy. Since we have detected  $\alpha^1$  Her as a 1.2 mJy source on 1983 January 21 and as a 0.8 mJy source on 1983 May 19, its radio flux is likely variable. The

*ionized* mass loss rate implied by our average measured flux and an assumed distance of 125 pc is  $2 \times 10^{-9} M_{\odot}$  yr<sup>-1</sup>; this can be compared with recent *total* mass loss estimates for this star (Bernat 1977; Gehrz and Woolf 1971; Hagen 1982; Hagen *et al.* 1981; Hagen, Stencel, and Dickinson 1983; Reimers 1977a, b; Sanner 1976) all based on optical and/or infrared studies. Since these total mass loss rates lie in the range  $8 \times 10^{-8}$  to  $1 \times 10^{-6} M_{\odot}$  yr<sup>-1</sup> (including only values not subsequently revised by the same author), we estimate that

the fraction of ionized material in the envelope of  $\alpha^1$  Her is 0.2%–2%. Model atmospheres (Auman and Woodrow 1975) of similar temperature and gravity to  $\alpha^1$  Her predict an ionization fraction of only  $10^{-6}$  to  $10^{-5}$  for the photospheric regions, and thus the wind is over-ionized with respect to the photosphere. The observed ionization fraction of the wind is equivalent to the ionization fraction of an LTE gas at a temperature of  $5\text{--}7 \times 10^3$  K. Calculations for the ionized fraction in  $\alpha$  Ori and  $\alpha$  Sco A based on the same type of analysis yield similar numbers.

The presence of a fairly substantial ionization in the wind of  $\alpha^1$  Her is not, in retrospect, too surprising. The detection of Fe I and Fe II emission lines (Herzberg 1948) and the strong chromospheric-type emission cores in Ca II (Wilson and Bappu 1957) and Mg II (Bernat and Lambert 1978; Stencel *et al.* 1980) resonance lines implies significant material at temperatures of  $5\text{--}10 \times 10^3$  K, while He I  $\lambda 10,830$  Å emission (O'Brien and Lambert 1979) is consistent with a warm extended wind. Our radio flux permits for the first time a quantitative estimate of the amount of this ionized material.

Two additional features should be commented about concerning the January 21 map containing the  $\alpha^1$  Her source. (1) There is a  $5''$  extension of the 1.2 mJy source in the southwest direction that corresponds to more than  $3 \sigma$ . This feature could not be resolved in the May observations. (2) There is a secondary source (labeled S) about  $15''$  south-southwest of  $\alpha^1$  Her in both observations that appears significantly nonpointlike in Figure 1. None of the other  $3 \sigma$  features in Figure 1 are present in the 1983 May map obtained with a higher signal-to-noise ratio, and thus they are presumably noise maxima.

A previous upper limit of 0.5 mJy at 6 cm for  $\alpha$  Boo (Bowers and Kundu 1981) is slightly above our probable detection level. The most sensitive previous upper limit for  $\beta$  Gem is 5 mJy at 3 cm (Wendker 1978). The flux densities of these K giants imply ionized mass loss rates of  $1.2 \times 10^{-10}$  and  $7.5 \times 10^{-11} M_{\odot} \text{ yr}^{-1}$ , respectively. There are few reliable estimates of mass loss rates for K giants and none to our knowledge for  $\beta$  Gem. Simply assuming the same mass loss rate per unit area as for the Sun, we estimate  $3 \times 10^{-12} M_{\odot} \text{ yr}^{-1}$  for  $\beta$  Gem. If instead we use the similar empirical scaling law, based mostly on M giants, suggested by Goldberg (1979) [ $\dot{M} = 3 \times 10^{-12} (R/R_{\odot})^2 M_{\odot} \text{ yr}^{-1}$ ], we derive  $3 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$ . These two values may bracket the actual value for this K giant.

Ayres, Simon, and Linsky (1982) have made two independent estimates for the mass loss rate of  $\alpha$  Boo of  $3 \times 10^{-10}$  and  $2 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$ , based on two different ultraviolet spectroscopic diagnostics. Line profile modeling of the asymmetric Mg II resonance lines in  $\alpha$  Boo by Chiu *et al.* (1977) implied  $\dot{M} = 8 \times 10^{-9} M_{\odot} \text{ yr}^{-1}$ , but their unrealistic assumptions of complete frequency redistribution of scattering photons and plane-parallel geometry make this estimate uncertain. In

a more recent calculation of the  $\alpha$  Boo Mg II line profiles that does not make these simplifications, Drake and Linsky (1982, 1984) derived a *total* mass loss rate of  $\sim 1 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$ . Since this value is similar to the *ionized* mass loss rate derived in the present study, we believe that the wind from  $\alpha$  Boo is largely ionized.

The upper limits on the ionized mass loss rates from  $\beta$  Crv,  $\alpha^2$  Her,  $\alpha$  Tau, and  $\mu$  UMa are consistent with the idea that, for most single G to early M type III stars,  $\dot{M}_{\text{ion}} \leq 1 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$ . The failure to detect  $\mu$  Cep implies that this M2 Ia star cannot have an ionized mass loss rate significantly greater than the M Iab stars  $\alpha$  Ori and  $\alpha$  Sco A for which  $\dot{M}_{\text{ion}} \sim 10^{-8} M_{\odot} \text{ yr}^{-1}$ . This is consistent with the radius of  $\mu$  Cep ( $1400 R_{\odot}$ ) being only 40% greater than that of  $\alpha$  Ori ( $1000 R_{\odot}$ ) and 75% greater than that of  $\alpha$  Sco A ( $800 R_{\odot}$ ).

#### IV. FUTURE PROSPECTS

The failure to detect  $\alpha$  Tau (18 pc),  $\mu$  UMa (29 pc), and  $\beta$  Crv (30 pc), with upper limits of 0.4 mJy implies that a practical upper limit for the distance,  $D_{\text{max}}$ , of detectable G–M giants at 6 cm may be about 20 pc. Thus, we would not expect to detect many more luminosity class III red giants, unless there are considerable variations in the mass loss rates for winds in such stars. The situation is more hopeful for the more luminous G–K stars if, as the present data suggest, the mass loss flux per unit surface area is similar for all luminous G–K stars, i.e., that  $\dot{M}_{\text{ion}} \propto R_{\star}^2$ . From equation (1), this means that  $S_{\nu} \propto R_{\star}^{8/3}$ , and thus for a fixed detection threshold, that  $D_{\text{max}} \sim R_{\star}^{4/3}$ . Given typical radii for G and K stars, this would imply  $D_{\text{max}} \approx 100\text{--}300$  pc for luminosity class II stars and  $D_{\text{max}} \approx 300\text{--}1000$  pc for Ib stars. We predict therefore that the VLA will likely detect a high percentage of the G and K supergiants and bright giants that lie within these distances.

Our detection of  $\alpha^1$  Her, and the previous detections of  $\alpha^1$  Sco and  $\alpha$  Ori, imply that the stellar winds from M I–II type stars may be easier to observe than previously assumed. Assuming that  $\alpha^1$  Her is at 125 pc and that its mass loss rate is typical for M II stars, we expect to detect M Iab stars out to 600 pc and M II stars out to 200 pc. This implies that a dozen or so luminous M stars should be detectable. We plan to test these predictions in future observations. We also plan to reobserve  $\alpha^1$  Her and  $\beta$  Gem at 2, 6, and 20 cm in order to derive a spectral index for the continuum emission, an important constraint on the microwave emission mechanism(s).

We acknowledge support of the National Aeronautics and Space Administration through grant NGL-06-003-057 to the University of Colorado. One of us (S. A. D.) would also like to thank the technical and scientific staff of the VLA for their most able advice and assistance, particularly D. Sramek, E. Fomalont, and P. Perley.

## REFERENCES

- Abbott, D. C., Biegging, J. H., Churchwell, E., and Cassinelli, J. P. 1980, *Ap. J.*, **238**, 196.
- Auman, J. R., and Woodrow, J. E. J. 1975, *Ap. J.*, **197**, 163.
- Ayres, T. R., Linsky, J. L., Vaiana, G. S., Golub, L., and Rosner, R. 1981, *Ap. J.*, **250**, 293.
- Ayres, T. R., Simon, T., and Linsky, J. L. 1982, *Ap. J.*, **263**, 791.
- Bernat, A. P. 1977, *Ap. J.*, **213**, 756.
- \_\_\_\_\_. 1981, *Ap. J.*, **264**, 184.
- Bernat, A. P., and Lambert, D. L. 1978, *M. N. R. A. S.*, **183**, 17P.
- Boesgaard, A. M., and Hagen W. 1979, *Ap. J.*, **231**, 128.
- Bowers, P. F., and Kundu, M. R. 1981, *A. J.*, **86**, 569.
- Clark, B. G. 1980, *Astr. Ap.*, **89**, 377.
- Chiu, H. Y., Adams, P. J., Linsky, J. L., Basri, G. S., Maran, S. P., and Hobbs, R. W. 1977, *Ap. J.*, **211**, 453.
- Dieckvoss, W., ed. 1975, *AGK3 Star Catalogue of Positions and Proper Motions*, 8 vols. (Hamburg-Bergedorf: Hamburger Sternwarte).
- Drake, S. A. and Linsky, J. L. 1982, *Bull. AAS*, **14**, 894.
- \_\_\_\_\_. 1984, in preparation.
- Eggen, O. J. 1979, *Ap. J. Suppl.*, **39**, 89.
- Gehrz, R. D., and Woolf, N. J. 1971, *Ap. J.*, **165**, 285.
- Goldberg, L. 1979, *Quart. J. R. A. S.*, **20**, 361.
- Hagen, W. 1982, *Publ. A.S.P.*, **94**, 835.
- Hagen, W., Dickinson, D. F., Humphreys, R. M., and Stencel, R. E. 1981, in *Second Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun*, ed. M. S. Giampapa and L. Golub (*Smithsonian Ap. Obs. Spec. Report No. 392*), p. 231.
- Hagen, W., Stencel, R. E., and Dickinson, D. F. 1983, *Ap. J.*, **274**, in press.
- Herzberg, G. 1948, *Ap. J.*, **107**, 94.
- Hjellming, R. M., and Newell, R. T. 1982, *Bull. AAS*, **14**, 918.
- \_\_\_\_\_. 1983, preprint.
- Newell, R. T., and Hjellming, R. M. 1982, *Ap. J. (Letters)*, **263**, L85.
- O'Brien, G., and Lambert, D. L. 1979, *Ap. J. (Letters)*, **229**, L33.
- Reimers, D. 1977a, *Astr. Ap.*, **61**, 217.
- \_\_\_\_\_. 1977b, *Astr. Ap.*, **67**, 161 (Erratum).
- Sanner, F. 1976, *Ap. J. Suppl.*, **32**, 115.
- Simonson, S. C., and van Someren Greve, H. W. 1976, *Astr. Ap.*, **49**, 343.
- Smithsonian Astrophysical Observatory Catalogue*. 1966, Publication No. 4562 (Washington, D. C.: Smithsonian Ap. Observatory).
- Stencel, R. E., Mullan, D. J., Linsky, J. L., Basri, G. S., and Worden, S. P. 1980, *Ap. J. Suppl.*, **44**, 383.
- Thompson, A. R., Clark, B. G., Wade, C. M., and Napier, P. J. 1980, *Ap. J. Suppl.*, **44**, 151.
- Wendker, H. J. 1978, *A Catalogue of Radio Stars, Abh. Hamburg Sternwarte*, **10**, Part 1.
- Wilson, O. C. 1976, *Ap. J.*, **205**, 823.
- Wilson, O. C., and Bappu, M. K. V. 1957, *Ap. J.*, **125**, 661.
- Wischnewski, E., and Wendker, H. J. 1981, *Astr. Ap.*, **96**, 102.

S. A. DRAKE and J. L. LINSKY: Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO 80309