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IRC +10 420: A HOT SUPERGIANT MASER

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ABSTRACT

IRC +10 420, of spectral type F8 Ia, is a maser in the OH molecule's ground-state lines at 1612, 1665, and 1667 MHz. Two 1612 MHz components are separated by 58 km s^{-1}, with peak fluxes of 47 and 7 Jy. Upper limits are given for the 1720 MHz OH line and the 22,235 MHz H_2O line. New infrared data are also presented.

Subject headings: masers — stars: supergiants

I. INTRODUCTION

The optical and infrared spectra of the bizarre star IRC +10 420 have been described by Humphreys *et al.* (1973). Photographic optical spectra showed a normal-appearing absorption-line spectrum, and Humphreys *et al.* obtained an approximate classification of F8–G0 I. However, a huge infrared excess was observed. Broad-band photometry showed an infrared spectrum that steadily increased toward long wavelengths, a spectrum remarkably similar to the infrared spectrum of η Carinae. IRC 10 420 is stellar-appearing, with no surrounding nebulosity. Our subsequent analysis of a spectrum (3900–5000 Å) obtained by R. M. Humphreys with the Steward Observatory 90 inch (229 cm) telescope indicates a spectral type of F8 Ia, or perhaps Iab, for IRC 10 420. No emission lines are apparent at 67 Å mm^{-1}, nor is there any obvious anomaly in the 5000–7000 Å region visible in an echellette spectrum.

We have searched for 18 cm maser emission of the OH molecule from a restricted sample of relatively warm stars (early F to early M) that have extensive dust shells. IRC 10 420 was included in our survey. Our intention was to provide new data for OH formation and pumping theories, as most observational work to date has concerned M stars. Of the 12 stars we observed, IRC 10 420 has by far the largest and most unusual infrared excess; and it alone showed OH maser emission. It has strong emission at 1612 MHz that is not distinguishable from that associated with known OH supergiants. However, while the spectral type of the central star is F8 Ia, the earliest-type 1612 MHz and main-line masers seen until now are of spectral type M3 or later (VY CMa, VX Sgr, PZ Cas, and S Per). Also, IRC 10 420 is itself of great interest, and OH data will be useful in determining the nature of its circumstellar shell. This paper describes our OH observations, a negative H_2O result, and new high-resolution 10 μ spectral data for IRC 10 420. Also, negative results at 1612 MHz for 11 reddened intermediate-type supergiants are briefly described.

II. OH OBSERVATIONS

The OH 18 cm survey was conducted during the period 1975 February 7–10 with the 140 foot (43 m) radio telescope at the National Radio Astronomy Observatory.[1] Additional OH observations of IRC 10 420 were obtained with the 120 foot (37 m) telescope at the Vermilion River Observatory of the University of Illinois on 1975 November 7–11 and December 16. On the 140 foot telescope the NRAO 1610–1720 MHz prime focus front-end was used with the 384-channel autocorrelator. Typical system temperature was 70 K. At the 120 foot telescope a single-stage uncooled parametric amplifier was used with a 64-channel autocorrelator. The system temperature was 210 K at 1720 MHz and 155 K at 1612 MHz. The ratio of total flux to antenna temperature was measured to be 3.8 Jy K^{-1} for the 140 foot, and 5.2 Jy K^{-1} for the 120 foot.

IRC +10 420 is a maser in the OH lines at 1612, 1665, and 1667 MHz. Figure 1 shows 140 foot spectra in these lines obtained on the morning of February 10. A slight change in telescope focus renders the flux calibration for Figure 1 more uncertain than that for the negative results. The flux uncertainty for the Figure 1 spectra may be as large as ± 30 percent. However, this is a very conservative estimate of the error; low-resolution (0.73 km s^{-1}) 1612 MHz spectra of IRC 10 420 obtained on the afternoon of February 9 (before the focus change) agreed in temperature with similar test

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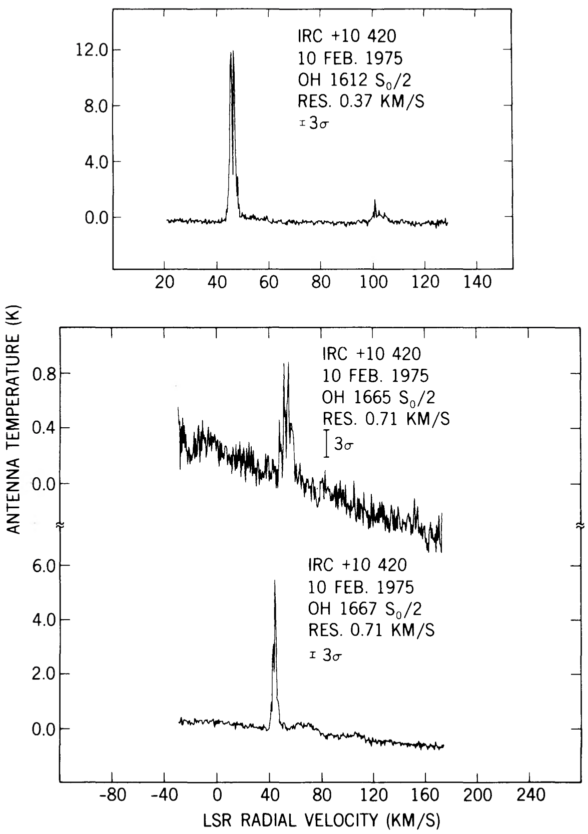

FIG. 1.—OH ground-state spectra of IRC +10 420. *Top*, the 1612 MHz line with velocity resolution 0.37 km s^{-1}. *Middle*, the 1665 MHz line with resolution 0.71 km s^{-1}. *Bottom*, the 1667 MHz line with resolution 0.71 km s^{-1}. Radial velocities for the three spectra are with respect to the LSR. The 3 σ bars are derived from the receiver parameters. Antenna temperatures (*ordinates*) are expressed as $\frac{1}{2}[T_a(\text{p.a. }0°) + T_a(\text{p.a. }90°)]$. Antenna temperatures here are related to total flux by the factor 3.8 Jy K^{-1}.

spectra obtained on February 10 to within 6 percent. Time was not sufficient at the 140 foot for 1720 MHz spectra. The available 140 foot polarization data (linear at 0° and 90°) show no significant indication of polarization in the three lines observed.

The November and December observations of IRC 10 420 made with the VRO 120 foot telescope, using linear polarization at 0° P.A., showed no changes in the 1612 and 1667 MHz profiles at a resolution of 0.29 km s^{-1}. A sensitive search for 1720 MHz emission was made. Nothing was observed at the 1720 line over the velocity range of the 1612 line, with resolution 1.24 km s^{-1}, to a limit of 0.25 K, or 1.3 Jy (5 σ limit). An analysis of the 120 foot 1612 MHz data yielded the position

$$\alpha(1950) = 19^{h}24^{m}24^{s} \pm 4^{s} ,$$
$$\delta(1950) = +11°15\overset{'}{.}6 \pm 1' .$$

This position agrees within the errors with the location of the F8 star, as given by Humphreys *et al.* (1973), and with the IRC position.

The negative results that were obtained with the 140 foot at 1612 MHz are summarized in Table 1. The stars were selected on the basis of their photospheric temperatures and their infrared color excesses. They were observed in linear polarization, for equal periods of time at position angles 0° and 90°. Spectral resolution was equivalent to 0.73 km s^{-1}. Six of the stars in Table 1 were also observed in 18 cm OH by Bowers and Cornett (1973). They reported negative results for these and similar variable stars to a limit of 1 Jy. Our 5 σ temperature limits correspond to 0.5–1 Jy. Also, Turner (1969) has given a negative result for RS Pup in the 1720, 1612, and 1665 lines.

III. OTHER OBSERVATIONS OF IRC +10 420

Silicate emission at 10 μ from IRC 10 420 is apparent in the broad-band photometry of Humphreys *et al.*

TABLE 1

1612 MHz NEGATIVE RESULTS

Object	Spectral Type*	$[3.6]\mu - [11.3]\mu$ Color Index†	$5\Delta T_{\rm rms}$ (K)	LSR Velocity Range Searched (km s^{-1})
RV Tauri Stars:				
AC Her.........	F2p Ib–K4e (Rp)	4.9	0.19	−115 to 95
U Mon..........	F8e Ib–K0p Ib	4.2	0.12	−88 to 122
R Sge...........	G0 Ib–G8 Ib	3.0	0.26	−78 to 132
R Sct...........	G0e Ia–K0p Ib (M3)	1.2	0.20	−49 to 161
RV Tau.........	G2e Ia–M2 Ia	3.2	0.13	−81 to 119
SR and I variables:				
W Cep..........	K0ep Ia (M2) + O?	3.52	0.12	−99 to 101
RW Cep........	G8 Ia (M0: Ia0)	2.88	0.13	−105 to 95
89 Her..........	F2 Ia (F1e Ia)	2.90	0.12	−110 to 90
AX Sgr.........	G8 Ia (M2)	3.09	0.30 (P.A. 0°)	
			0.42 (P.A. 90°)	−78 to 132
Long-period Cepheids:				
RS Pup.........	F8–K5	0.7	0.14	−105 to 95
SV Vul..........	F7 Iab–K0 Iab	1.5	0.19	−89 to 121

* Kukarkin *et al.* 1969; Morgan and Roman 1950; Cowley 1969.

† Gehrz 1972; Hackwell and Gehrz 1974; Gehrz and Woolf 1971. The effective wavelengths vary slightly.

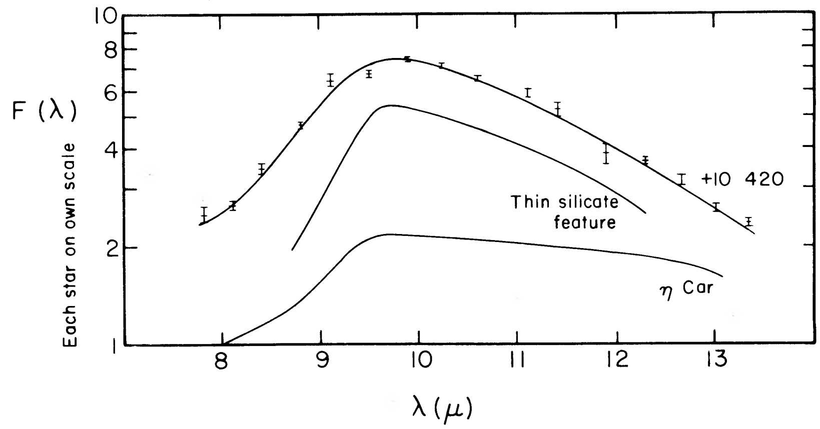

FIG. 2.—The infrared spectra of IRC +10 420 and η Car, in the region of the 10 μ silicate feature. The η Car spectrum is adapted from Robinson *et al.* (1973).

Figure 2 compares a higher resolution 10 μ spectrum of IRC 10 420 with that of η Car (Robinson, Hyland, and Thomas 1973). We obtained the IRC 10 420 spectrum with the Mount Lemmon 60 inch (152 cm) telescope of the Universities of Minnesota and California–San Diego, in the same manner as described in Woolf (1973). Both IRC 10 420 and η Car show 10 μ silicate emission. However, the silicate emission of η Car is optically thicker than that of IRC 10 420. The 10 μ spectrum of IRC 10 420 is similar to those of VX Sgr and VY CMa.

We have searched for 1.35 cm H_2O maser emission from IRC 10 420, with the NEROC Haystack[2] 120 foot (37 m) telescope, on 1975 July 22 and 24. No emission was detected in right or left circular polarization over the 1612 MHz velocity range, with a resolution of 2.25 km s^{-1}. The weather on July 24 was generally poor. The July 22 data indicate an upper limit equal to 0.23 K for peak $S_0/2$ (approximately 4 Jy).

IV. DISCUSSION

The OH spectrum of IRC 10 420 is similar to the OH spectra of the five cool supergiant masers in all known respects. The characteristic two-component pattern is seen at 1612 MHz with a 58 km s^{-1} separation. This separation is large by Mira variable standards but not unusual for a cool supergiant. Our negative result at 1720 MHz is also typical of the cool OH/IR stars. However, at least four of the five cool supergiant masers show H_2O emission; in 1975 July, 10 420 did not. Also, the optical spectrum of IRC 10 420 is peculiar (for a maser star) in that it is so normal-appearing.

We can determine a kinematic distance to IRC 10 420 from the 1612 MHz spectrum. For the direction to IRC 10 420 ($l = 47°$, $b = -2°.5$) an intrinsic center-of-mass radial velocity $v_* = 104$ km s^{-1} (the velocity of the redshifted 1612 component) is extremely unlikely for a Population I object. Even at the midpoint of the 1612 spectrum, ~ 75 km s^{-1}, a small residual velocity remains with respect to neutral hydrogen 21 cm observations toward nearby points. A value of v_* much closer to the blueshifted 1612 MHz component, while consistent with galactic rotation models, is not compatible with current stellar-maser models. For $l = 47°$ the distance to the galactic subcentral point is 6.8 kpc, and the corresponding radial velocity with respect to the local standard of rest (LSR) is 66 km s^{-1}, according to the circular rotation law ($b = 0°$) given by Burton (1971). If $v_* = 75$ km s^{-1}, this distance gives the smallest discrepancy with circular galactic rotation.

The color excess $E(B - V) = 2.15$ mag for IRC 10 420. The reddening law of the circumstellar shell is not known, and assuming $A_v/E(B - V) = 3$ probably only gives a lower limit = 6.45 mag to the total V-mag absorption.

Adopting a distance = 6.8 kpc, $m_v = 11.2$, and $A_v \geq 6.45$, we have $M_{\rm bol} \approx M_v$ brighter than -9.4. The star is overluminous for its spectral type and extremely luminous for any spectral type. The 6.8 kpc distance renders the OH emission of IRC 10 420 by far the strongest known for a star. Also, while presumably a young star, IRC 10 420 would be 297 pc below the galactic plane.

The distance can be forced down somewhat by invoking (1) noncircular galactic rotation, (2) an increase in the residual velocity with respect to hydrogen, (3) a v_* smaller than 75 km s^{-1}, or (4) some combination of these factors. However, eventually a trade-off would have to be made among competing anomalous situations.

We note again the ordinary-looking optical spectrum of IRC 10 420 and its broad-band infrared resemblance to η Car. OH interferometric observation of IRC 10 420 should prove to be extremely interesting.

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