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SYMMETRIC VELOCITY STRUCTURE IN THE SiO MASER SPECTRUM OF R CASSIOPEIAE

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The SiO $J = 1\text{–}0$, $v = 2$ lines are exterior to the $v = 1$ in velocity, strongly suggesting shell-like structure in the emission region.

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Consistencies and correlations in the velocity patterns of microwave masers associated with long-period variables have fostered several interpretations of the maser process and its relationship to stellar mass loss. Recent high-resolution, nearly simultaneous observations of the SiO $J = 1\text{–}0$, $v = 1$ and 2 masers have shown an interesting new velocity correlation that may bear upon the interpretation of all masers. The SiO lines in at least one star, R Cassiopeiae, have a symmetric velocity distribution with the $v = 2$ lines exterior to the $v = 1$ in velocity.

The $v = 1$ and 2 spectra of R Cas taken on 1977 February 11 about 30 minutes apart are superimposed in Figure 1 (see Spencer et al. 1977 for a description of the observing system and technique). The polarization was linear with the electric vector in the north-south direction. The radial velocity scale is based on $\nu(v = 1) = 43122.027$ MHz and $\nu(v = 2) = 42820.539$ MHz, and the spectral resolution is 15 kHz (0.1 km s^{-1}) which is equal to the uncertainty in the predicted rest frequencies (Manson et al. 1977). The velocities of the important microwave and optical spectral features are also noted in Figure 1 and listed in Table I. The interesting feature of the SiO spectra is that the $v = 1$ and 2 spectra have two main velocity components symmetric about the same radial velocity (approximately 26 km s^{-1}) but the $v = 2$ components are shifted from the central velocity by about 1 km s^{-1} more than the $v = 1$ features. This pattern is suggestive of shell-like structure in the SiO emission region and is similar to the H_2O and OH velocity patterns observed in some stars (Dickinson and Kleinmann 1977). Although R Cas is the best case, several SiO sources including o Ceti, NML Cygni, R Leonis, W Hydrae, and Orion also show this symmetry with the $v = 2$ components exterior to the $v = 1$ in velocity. The fact that the $v = 1$ and 2 velocities show a high degree of symmetry about the H_2O maser and SiO $J = 2\text{–}1$, $v = 0$ velocity is also significant, but the apparent "doubling" (i.e., the presence of two distinct velocities) should not be taken as a general feature of SiO source spectra: at least as many "triples" as "doubles" are seen at $J = 1\text{–}0$ (Schwartz et al. 1977).

The interpretation of the shell-like SiO velocity structure in R Cas depends on which of the two popular models for the optical and maser velocities in the long-period variables is assumed.* Both models, briefly described below, assume a circumstellar mass-loss flow with typical velocities $\sim$ 10–100 km s^{-1}.

A. The *linear* model proposed by Wilson and Barrett (1972) follows the conventional interpretation of the optical absorption lines as indicating the photospheric and mean stellar velocity (i.e., $V_{abs} = V_*$). Circumstellar features, and OH, H_2O, and SiO maser emission are seen at lower velocities between the absorption velocity and the emission line velocity, V_{em}, which presumably represents the maximum velocity of escaping material near the stellar surface. The emitting regions lie along a line of sight to the star, the masers are assumed to be radially beamed so that regions too far off the line of sight do not contribute and emission from the backside of the flow is either nonexistent or is obscured by the star. Symmetry in the velocity patterns is perhaps caused by the presence in the flow of a propagating shock wave at some radius which excites the maser emission.

B. The symmetric model advocated by Reid (1976) rejects the conventional interpretation of the optical spectrum and assumes that the stellar velocity is approximately the centroid of the maser velocities. The maser emission is beamed as in the linear model but originates from a spherical region so that emission from the front and backside of the flow is observed. This geometry implies maser velocity patterns symmetric about the stellar velocity as is characteristic of the 1612 MHz OH emission in many stars and the main-line OH and H_2O patterns in some stars.

*Note that there is a distinction between the long-period variable sources such as R Cas, R Aquilae, etc., "supergiant" sources such as VY Canis Majoris, VX Sagittarii, etc. The optical velocities in supergiant sources are consistent with the *symmetric* model (Wallerstein 1977).

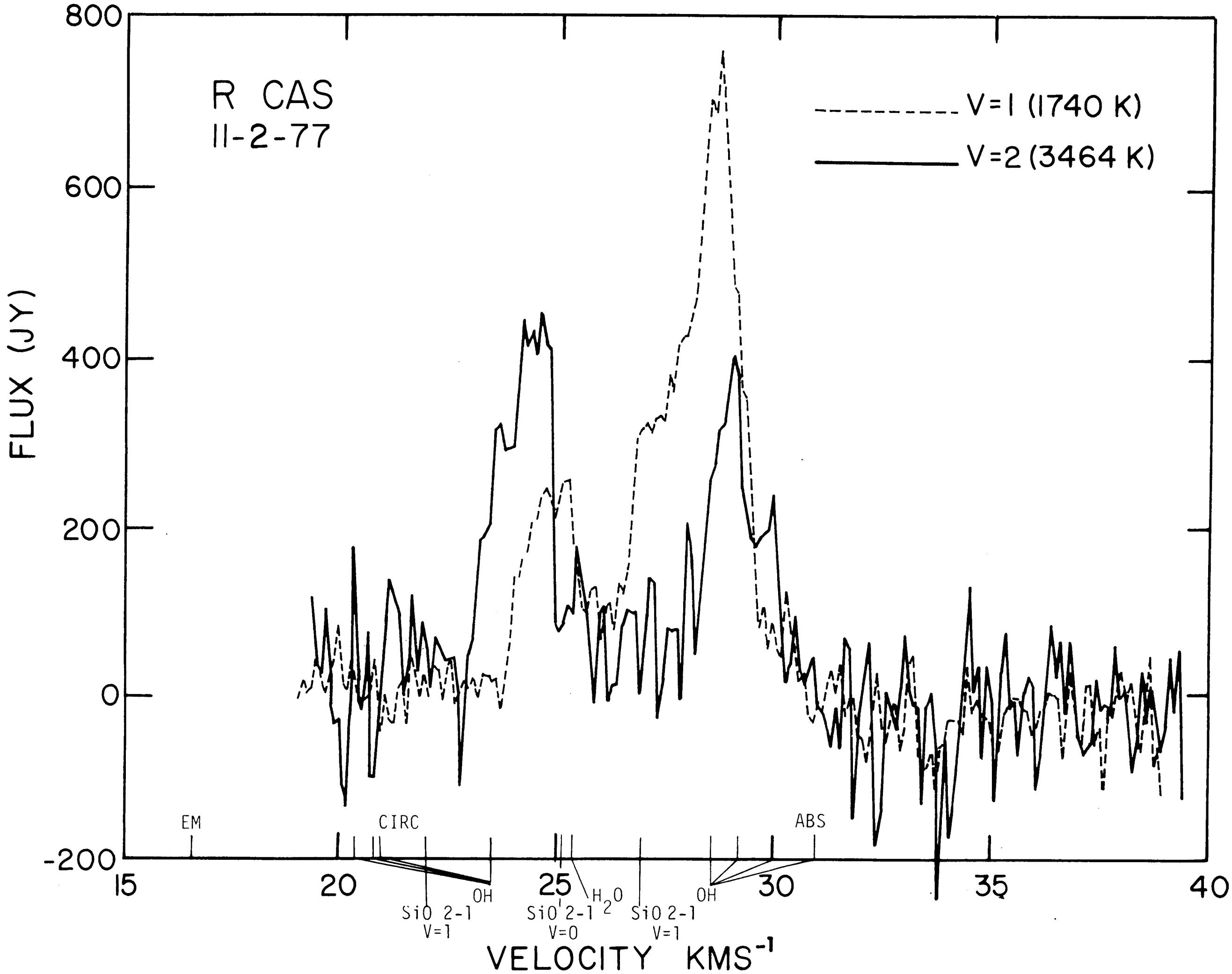

FIG. 1—SiO $v = 1$ and $v = 2$ spectra of R Cas superimposed showing shell-like structure. The velocities of various optical and radio features are noted on the velocity axis.

TABLE I

Radial Velocities in R Cas

	V_R (km s^{-1} LSR)	
Optical:		Wallerstein (1975)
V_{abs}	31.0	
V_{em}	16.5	
V_{circ}	21.0	
Radio:		
OH (1665)	20.3, 23.5, 28.6, 30.0	Wilson et al. (1972)
(1667)	20.7, 29.3, 31.0	
H_2O	25.3 (10-27-76)	Dickinson (1977, private communication)
SiO J=2-1		Buhl et al. (1975)
v=0	25.1	
v=1	22.0, 27.0	

The problem is that although the *symmetric* model better explains the observed maser velocity patterns and has some statistical support (and is more esthetic), detailed analysis of individual stellar spectra as has been done by Wallerstein (1975) very strongly supports the *linear* model. The high degree of symmetry of the SiO $v = 1$ and 2 velocity pattern must be regarded as support for the spherical model particularly if another simple assumption is made. If the system is transformed to a velocity system at rest with respect to the star, $u = V_* - V$, the simplest mass-loss flow would obey a relation

$$u(r) = [u_\infty^2 - (u_\infty^2 - u_0^2)\, R/r]^{1/2} \quad .$$

If R is the stellar radius and the flow is driven by pulsation or photospheric shockwaves expelling material which just escapes from the stellar gravitational field, then $U_\infty \sim 0$, $u_0 = u_{em}$ and thus $u(r) = u_{em}\,(R_*/r)^{1/2}$. In the symmetric model for R Cas, $V_* \sim 26$ km s^{-1}

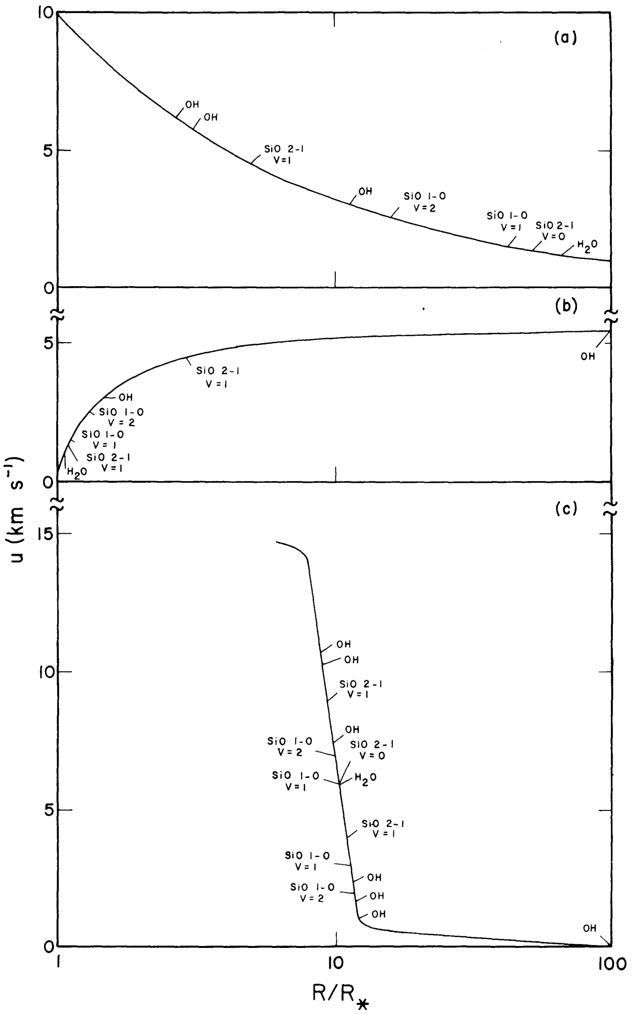

FIG. 2—R Cas radial velocities as a function of radius for (a) symmetric model and a pulsation driven flow, and (b) symmetric model with radiation pressure driven flow and $u_\infty = u_{\mathrm{circ}}$. For comparison (c) illustrates a possible shock wave linear model.

and the velocity system of maser emission from the observer's side of the flow may be represented by Figure 2a. The $v = 2$ line which has a typical excitation temperature $T_x \sim 3400$ K originates from closer to the star, the probable pump source, than the $T_x \sim 1700$ K $v = 1$ line. The H_2O then comes from the outer region of the flow while the OH is from near the star perhaps reflecting the higher OH/H_2O ratio in hotter regions. (Note: if the flow is driven by radiation pressure, $u_0 = 0$, $u(r) = u_\infty\,[1 - (R_\infty/r)]^{1/2}$ and the picture reverses with H_2O being closest to the star as shown in Fig. 2b.) For comparison, Figure 2c illustrates the arrangement of masers about a shock front in the linear model. While this geometry is not physically excluded, it is certainly less plausible than the symmetric model with a pulsation driven flow.

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