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LONG-PERIOD VARIABLES: CORRELATION OF STELLAR PERIOD WITH OH RADIAL-VELOCITY PATTERN

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ABSTRACT

The OH radio spectrum seen in variable stars shows two distinct groups of emission features well separated in radial velocity. In this paper we show that the separation is directly proportional to the period.

Subject headings: long-period variables — molecules

Hydroxyl microwave emission has been observed in about 50 long-period variable stars (cf. Wilson and Barrett 1972). The ground-state radio frequencies of the OH molecule are at 1612, 1665, 1667, and 1720 MHz. These stars are usually strong 1612-MHz emitters, although a number are stronger in the "main lines" (1665 and 1667 MHz). They are, in fact, maser emission sources (cf. Litvak and Dickinson 1972). Emission at 1720 MHz is never seen. In all of these stars the OH emission features occur in two distinct and separate velocity groups. As an example, figure 1 shows the 1612-MHz spectrum of PZ Cas, a star in which we recently detected OH.

We present evidence in figure 2 for a strong, approximately linear, correlation between the stellar period and the velocity separation of the two OH microwave groups. The correlation appears to hold over a range of velocities from 0 to 53 km s^{-1} and periods from 160 to 900 days. Table 1 lists data for 22 of these stars whose periods are established. The velocity separation was taken between the peaks of the outermost radio features. Periods for optical variables were taken from Kukarkin *et al.* (1969); those for infrared stars were generously supplied by Drs. Eric Becklin and Paul Harvey.

A regression line has been fitted by the method of least squares and is shown in figure 2. The star R Crt (IRC—20222), the one OH-variable star that shows only one radio emission group, was not included in the fit. Note, however, that if it is taken to have a zero-velocity separation, R Crt is consistent with the regression line and suggests that the nonzero intercept is, indeed, real.

Optical observers have long been aware that optical emission and absorption lines in long-period variables are also separated in velocity, the absorption lines always being at the higher velocity (cf. Merrill 1923, 1941). Because both the radio and optical lines appear in two distinct velocity groups, it seems probable that a simple moving-shell geometry is not the correct picture. A shell that emits over most of its surface would produce emission over a broad, continuous range because of the changing component of expansion velocity along the observer's line of sight. These OH and optical emission regions are apt to be much more localized. Also, because the OH velocity-period correlation exists, the observable emission regions must have the same relative position for each star with respect to the observer's line of sight. If this were not so, the OH velocity vector would be modified differently in each case by projection along the line of sight, completely destroying the correlation.

Both the radio and optical data suggest two distinct velocity regimes, which might be produced by a shock front propagating outward from the star. In this picture,

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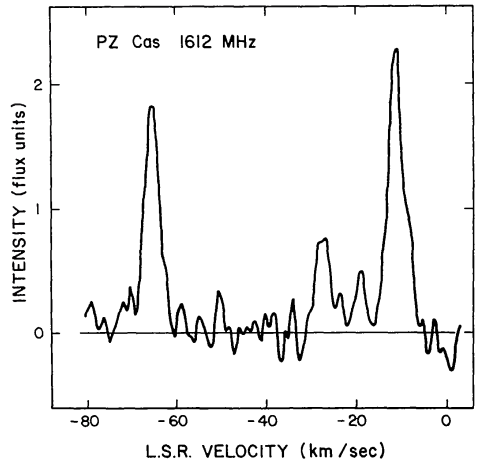

FIG. 1

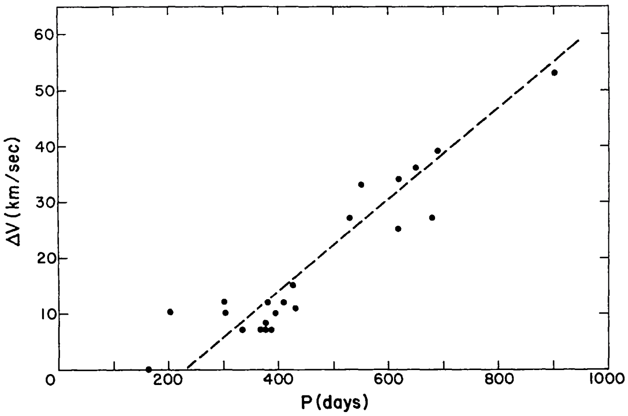

FIG. 2

FIG. 1.—1612-MHz spectrum of PZ Cas.

FIG. 2.—OH radial-velocity separation versus stellar period of 22 long-period variables.

the optical absorption lines (and one OH component) would be formed in the quiescent gas ahead of the shock front. The optical emission lines and the relatively blue-shifted OH would be formed in the gas behind the shock, which flows away from the star and may provide the excitation for the hot optical emission lines. This inter-

TABLE 1

STELLAR PERIODS AND OH VELOCITY SEPARATIONS

STAR	PERIOD (days)	VELOCITY SEPARATION (km s^{-1})		COMMENTS
		1612 MHz	Main Lines	
PZ Cas	900	53	...	N(—22, —75)
VX Sgr	688	39	...	SR
IRC—10529	680	26	29	IR
IRC+10011	650	36	37	IR
IRC+50137	620	34	...	IR
IRC—20197	620	25	...	IR
NML Tau	550	33	...	IR
IRC—20540	530	27	...	IR
R Cas	431	...	11	M
WX Ser	425	16	14	M
U Her	406	...	12	M
RR Aql	394	10	...	M
W Hya	382	...	8	SR
V Mic	381	12	...	M
R Peg	378	7	...	M
R LMi	372	7	...	M
U Ori	372	...	7	M
RU Hya	333	7	...	M
V Ant	303	10	...	M, N(—9.5, 1)
R Aql	300	13	11	M
GY Aql	204	10	...	SR
R Crt	160	0	...	SR

COMMENTS.—IR = infrared period, M = Mira variable, SR = semiregular variable, N(...) = new data (heliocentric velocities).

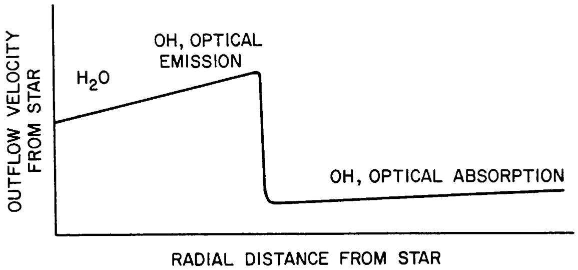

FIG. 3.—Schematic view of the gas outflow from a star showing the relative places of formation for different lines.

pretation would also be consistent with observations showing that the Balmer series lines are partially absorbed by various atomic species (cf. Joy 1947; Merrill 1945).

Joy (1926), Merrill (1923, 1945), and others have noted that both absorption and emission lines from states with higher excitation potential have slightly greater velocities than their counterparts that originate from the ground state. This suggests a gradual increase in the velocity of outflow from the star in both velocity regions (fig. 3). The lines of higher excitation would thus be formed closer to the stars in a, presumably, somewhat hotter layer.

Water-vapor emission (1.35 cm), which is seen in many OH-IR stars, requires substantially greater excitation than OH and would be formed still closer to the star than either OH component and would, in this picture, possess a velocity intermediate to both. (Observationally, the water emission always lies between the OH components.) In the one case where excited-state OH emission is seen, NML Cyg (Zuckerman *et al.* 1972), its velocity is also intermediate to both OH features and lies near the H_2O emission.

A number of interesting puzzles remain, such as the bright emission-line spectra from these rather cool ($\sim$2000° K) objects, the appearance of a maximum in $H\epsilon$ and $H\eta$ several months after the light curve maximum (Joy 1926), and the basic mechanism responsible for pulsation, A good quantitative model for these much-studied stars will be difficult to formulate.

In preparing this paper, we made several new detections (and probable detections) of OH emission from variable stars. They include: DH Cyg, R Ari, RW Lyr, PZ Cas, V Ant, U CVn, X Cep, V Cas, RT Cyg, and TW Peg. Only PZ Cas and V Ant were included in this study because of poor signal-to-noise ratios. Observations were made with the 84-foot antenna of the George R. Agassiz Station, Harvard, Massachusetts, and the 140-foot antenna of the National Radio Astronomy Observatory, Green Bank, West Virginia.[1]

We wish to thank Professor Cecilia Payne-Gaposchkin for directing us to the early work of Merrill (1923, 1941), who noted a similar relation, over a smaller range of periods, involving the velocity separation of the optical absorption and emission lines.

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