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ON THE IR VARIABILITY OF SYMBIOTIC STARS: THE CASE OF V1016 CYGNI, HM SAGITTAE, AND V1329 CYGNI

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ABSTRACT

Infrared observations of the peculiar objects V1016 Cyg and HM Sge confirm their periodic variability. A three-component model (Mira, associated dust shell, and external shell) is suggested to account for the infrared spectral variations and for deriving a distance estimate. Much less variability is displayed by V1329 Cyg, but in 1983 May the star appeared to fade by 0.5 mag. A coincidence is suggested with the dip in the optical light curve at phase 0.6–0.7.

Subject headings: infrared: general — stars: combination spectra — stars: individual — stars: variables

I. INTRODUCTION

Since its brightening in 1965, V1016 Cyg has been recognized as an unusual star, and many observational and theoretical efforts have been devoted to understanding its nature. Two basic interpretative models have been proposed in order to account for the complex photometric and spectroscopic behavior of this object: (*a*) the single-star model (e.g., Kwok 1977; Nussbaumer and Schild 1981), in which an evolved star, undergoing mass loss, after some time develops a dense ionized region; and (*b*) the binary model (e.g., Ciatti, Mammano, and Vittone 1978; Puetter *et al.* 1978), which invokes the presence in V1016 Cyg of a hot star and a cold giant companion undergoing mass loss.

Due to the lack of decisive evidence in favor of one of these models, it is not surprising that objects like V1016 Cyg have often been referred to as protoplanetaries as well as symbiotics. In the light of these hypotheses, many authors have discussed observational data to argue for one or the other model. In such a framework Harvey (1974), because the optical spectrum is dominated by the so-called hot component, monitored the star at infrared wavelengths, pointing out the variability and suggesting the presence in V1016 Cyg of a Mira variable on the basis of the observed period length of ~450 days.

Since this work, other observers have engaged in the IR monitoring of V1016 Cyg (Yudin 1982; Taranova and Yudin 1983), confirming the variability. In this paper we present IR observations carried out during a period partially overlapping that discussed in Taranova and Yudin (1983) and extending to 1984 March. A brief discussion of the implications of the observed variability in both color and magnitude follows. In addition, two more objects, HM Sge and V1329 Cyg, are also considered, because they are generally believed to share the nature of V1016 Cyg or at least to be related objects.

II. OBSERVATIONS

The IR photometry in the *J*, *H*, *K*, *L*, and *M* bands has been carried out at the 182 cm telescope of the Asiago Observatory equipped with an InSb detector operating at liquid nitrogen temperature. A detailed description of the instrument is given elsewhere (Lorenzetti *et al.* 1983). Additional observations have been carried out at the Gornergrat 150 cm IR telescope in 1982 October, allowing a crude estimate of the total IR luminosity through the 10 μm photometry carried out with a filter suitably chosen ($\lambda_0 = 8.65\ \mu$; FWHM $= 1.1\ \mu$) to minimize the effect of the silicate feature.

A set of standard stars taken from Strecker, Erickson, and Witteborn (1979) has also been observed, allowing both reduction to absolute fluxes and monitoring of the night sky conditions. Chopping was performed at 21 Hz in the north-south direction with a beam size and throw of 11″ and 18″ respectively. The obtained data are presented in Figures 1, 2, and 3 in the form of light curves, two-color, and color-magnitude diagrams, as well as in Table 1, for ease of comparison with other observations. The errors we report are referred to the reproducibility of the measurements for the magnitude and color determinations, amounting respectively to 0.05 mag and 0.03 mag, where these errors have been estimated each night through the observed standard stars.

III. DISCUSSION

a) Optical Depth and Adopted Model

In the following discussion, the optically thin case is explicitly assumed, so a brief justification is in order. In fact, there are two pieces of observational evidence suggesting such a case. In the 2 μm region, CO and H_2O photospheric absorption bands are seen in both V1016 Cyg and HM Sge (Puetter *et al.* 1978). A measure of the equivalent width could help, by comparison with values quoted by Baldwin, Frogel, and Persson (1973) for late-type stars, in guessing about the circumstellar shell contribution to the continuum as well. However, the reported spectra, though not suited to a reliable estimate of this kind, at least show the shell is thin.

A second piece of evidence is given by the observed silicate emission feature (Puetter *et al.* 1978; Aitken, Roche, and Spenser 1980), which, being related to the radiation transfer regime, suggests an optically thin shell (Mitchell and Robinson 1981; Henning 1983). With this approximation in mind, we shall discuss the light curves of the IR photometry as presented in Figure 1, where the visual magnitudes, taken from the *AAVSO Bull.*, are also shown for comparison. As has been

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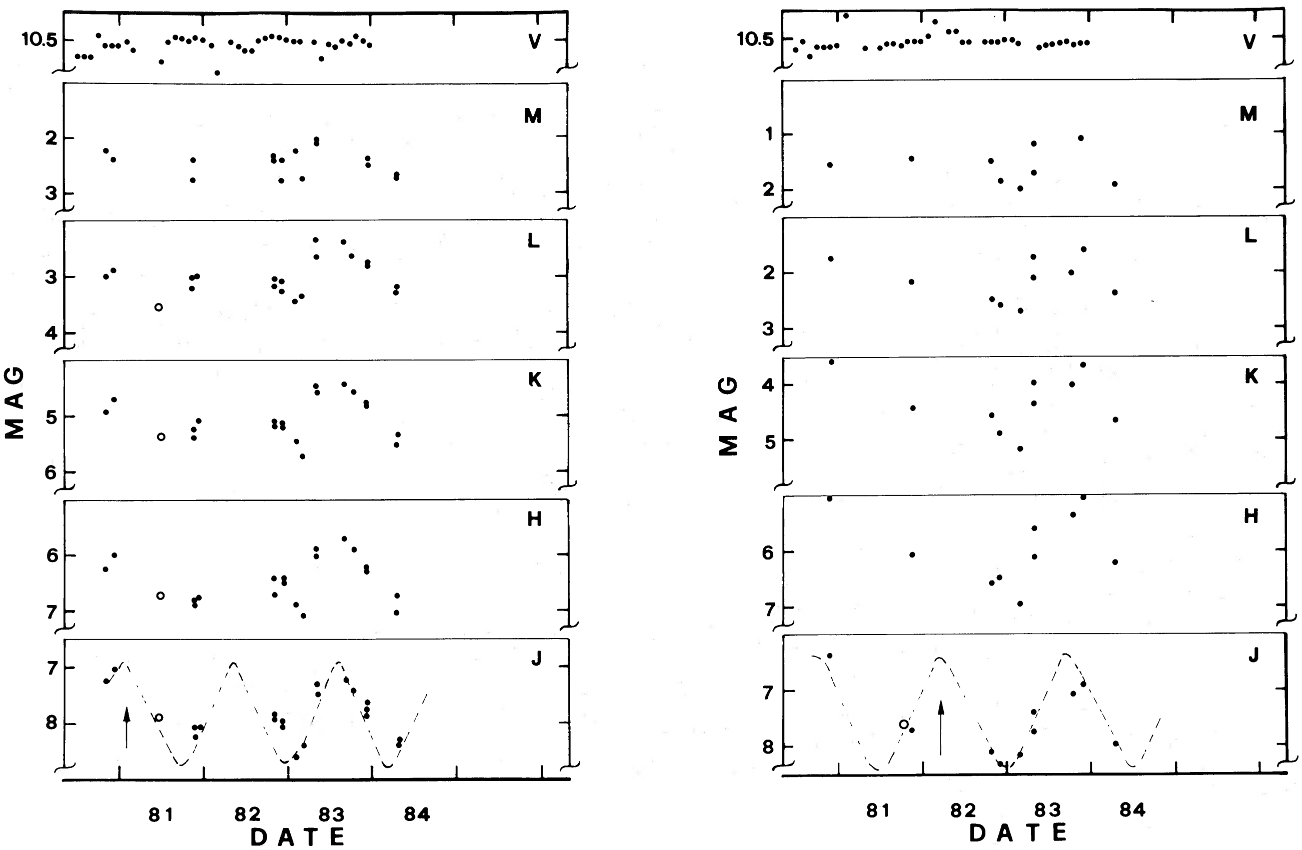

FIG. 1a

FIG. 1b

FIG. 1.—(*a*) Light curves in the *J*, *H*, *K*, *L*, *M*, and *V* photometric bands for V1016 Cyg. The open circle is taken from Taranova and Yudin (1983). A sinusoidal curve of 450 days period is shown for comparison. The arrow indicates the expected maximum according to Taranova and Yudin (1983). (*b*) Same for HM Sge. A sinusoidal curve of 540 days period is shown for comparison.

pointed out by Taranova and Yudin (1983), the circumstance that the IR variation is not accompanied by corresponding antiphase optical variation strongly supports a binary model. The origin of the IR variability, in this framework, should be found in the presence of a late-type star in the Mira stage (Feast, Robertson, and Catchpole 1977) losing mass at variable (Bath 1977) or constant rates (Tielens 1983). This kind of approach makes it possible to relate the observed differences in the IR photometric behavior of symbiotic stars to different mass loss regimes from the late-type component (e.g., Allen 1979). In the following we shall focus our attention on the consistency of the outlined binary model with the observations.

b) *V1016 Cygni*

The IR variability of this object was first noticed by Harvey (1974). In Figure 1 here, a sinusoidal curve is fitted to the observed points, so that a crude estimate of the period can be obtained, showing that the value of ~450 days has not changed since the time of Harvey's observations. Such persistence together with the absence of consistent optical variability point to a composite orgin of the spectrum. A third observational argument is given by the decreasing amplitude with increasing wavelength, implying the object being redder at minimum (see Fig. 3). If the cause of the variation were a cold dust shell, the opposite behavior would be expected, so that the presence of a Mira in V1016 Cyg can hardly be excluded.

The consequences of this case will be reviewed with reference to recent work on the observational properties of Miras. In fact, following the absolute magnitude versus period relations given by Eggen (1975) and Glass and Feast (1982), and assuming that the Mira in V1016 Cyg is essentially similar to those considered in these studies, one obtains for the mean value of the bolometric magnitude $M = -5.47$ and $M = -5.09$ respectively, where the resulting difference is to be considered irrelevant to our discussion. However, in what follows the Glass and Feast relation will be adopted because of its better agreement with the mass-luminosity diagram shown in Figure 1 of Cahn (1980).

Given the bolometric information, T_{eff} can be derived once the effective temperature scale is established, so that, according to Fox and Wood (1982), we obtain 2700 K or 3100 K depending on the adopted scale (Johnson 1966; Ridgway *et al.* 1980). However, apart from this difficulty, the derived *M* allows us to estimate the spectral type as M7 at maximum light (Cahn 1980), in good agreement with Mammano and Ciatti (1975), who on the basis of TiO and VO band observations report a spectral type not later than M6–7. If we further consider that V1016 Cyg has been classified as a D-type symbiotic (Allen 1979), it stands to reason that the presence of dust has to be taken into account.

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In principle, free-free emission powered by the ionized region in symbiotic systems should be included, but it has been shown that this gives a negligible contribution to the near-infrared spectrum, particularly in D-type objects (Kwok 1977; Kwok and Purton 1979; Allen 1982; Tamura 1983). All the above considerations suggest that a very simple model can be adopted as a starting point in this discussion. This consists of a dust component of constant luminosity superposed on a variable component due to a Mira. The ability of this model to account for the IR observations can be judged by considering the two-color diagrams shown in Figure 2. Here the points representative of V1016 Cyg and referred to different phases

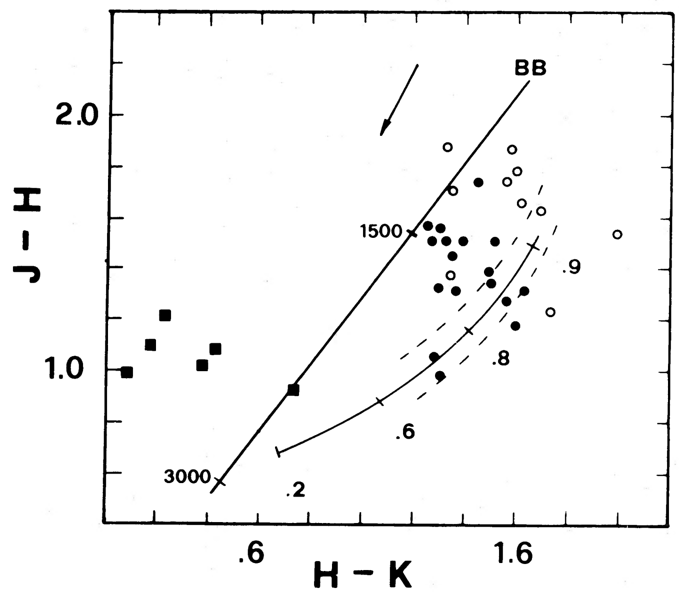

FIG. 2*a*

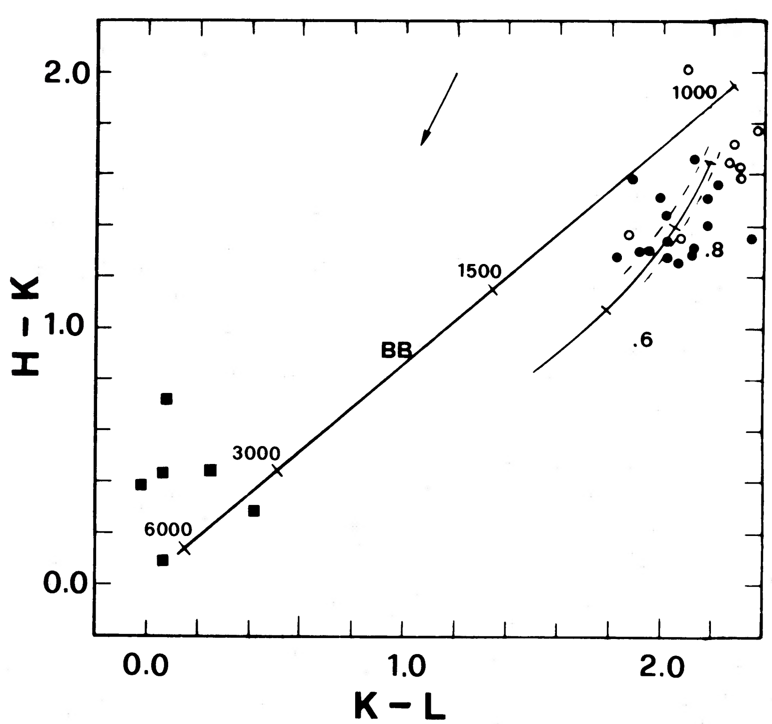

FIG. 2*b*

FIG. 2.—(*a*) $J-H$ vs. $H-K$ diagram showing the positions occupied by V1016 Cyg (*filled circles*), HM Sge (*open circles*), and V1329 Cyg (*filled squares*). The blackbody line (BB) is drawn with some representative temperatures indicated. The locus of the combination of two blackbodies at 2800 and 1000 K is shown by the solid line under the BB line, the dashed lines representing the effect of a temperature variation between 2600 and 3000 K of the first blackbody. The value of the luminosity ratio $L(1000)/[L(1000) + L(2800)]$ is shown along the line. The arrow shows the effect of a dereddening corresponding to $E(B-V) = 1$. (*b*) Same for the $H-K$ vs. $K-L$ colors.

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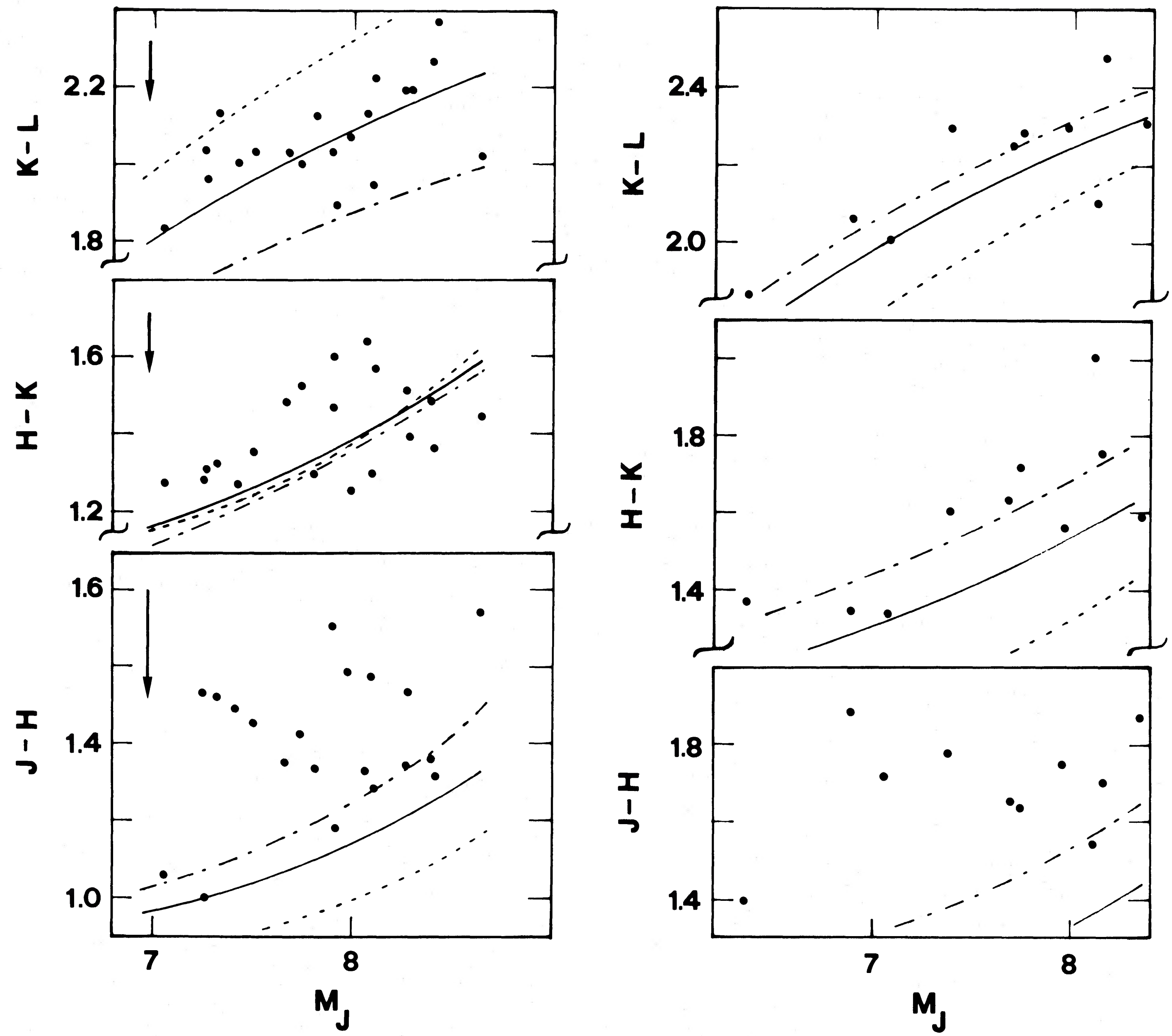

FIG. 3a FIG. 3b

FIG. 3.—(*a*) Color vs. magnitude diagrams for V1016 Cyg. The superposed lines correspond to three different temperatures for the dust associated with the Mira: 1000 K (*solid line*); 900 K (*dashed line*); 1100 K (*dash-dot line*). The Mira temperature at the mean magnitude is taken to be 2800 K, and the relative contribution of the dust to the total IR luminosity is taken to be 0.8. The arrow indicates a dereddening for $E(B-V) = 1$. (*b*) Color vs. magnitude diagrams for HM Sge. Here the superposed lines correspond to different relative contributions of the dust to the total IR luminosity: 0.85 (*solid line*); 0.75 (*dashed line*); 0.9 (*dash-dot line*). The Mira temperature is taken to be 2600 K, and the associated dust is taken to be 1000 K.

cluster in a region of the diagram occupied by the locus of two blackbodies combined at different luminosity ratios (for a discussion of this model see, e.g., Feast, Robertson, and Catchpole 1977; Allen 1982). The temperatures chosen for drawing the solid curve under the BB line are $T_* = 2800$ K and $T_d = 1000$ K, even if this appears to be an oversimplification.

In fact, at least the dust suffers a temperature stratification, and T_d is expected to be variable with the phase, as we shall see below. However, the effect of varying the star or the dust temperature in this diagram is essentially to move the composite blackbody curve into the region under the BB line, as is shown in Figure 2 by the dashed curves, so that, if heavy variable reddening can be excluded, the IR spectrum can be thought of as emerging from the sum of two or more blackbodies. Because of the difficulty in explaining the observed colors as a reddening effect, in what follows the infrared spectrum will be considered as essentially due to (1) the Mira variable; (2) an internal dust shell associated with the Mira that participates in the variability; and (3) an external shell associated with the sytem V1016 Cyg as a whole, playing the role of the constant low-temperature component. The aim of this modeling is to compare observed and computed color-magnitude diagrams

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TABLE 1

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JD (2,440,000+)	K	$J-K$	$H-K$	$K-L$	$K-M$
		V1016 Cygni			
4540	4.95	2.31	1.31	1.96	2.68
4567	4.72	2.33	1.27	1.83	2.32
4918	5.42	2.85	1.51	2.19	2.64
4919	5.26	2.85	1.57	2.22	2.85
4925	5.10	2.97	1.64	2.13	...
5270	5.18	2.63	1.29	2.12	2.72
5273	5.13	2.78	1.60	1.89	2.78
5308	5.15	2.83	1.25	2.07	2.76
5309	5.24	2.86	1.29	1.94	2.43
5366	5.47	3.18	1.44	2.02	3.20
5396	5.74	2.68	1.36	2.37	2.96
5456	4.69	2.80	1.35	2.03	2.50
5457	4.48	2.84	1.32	2.13	2.84
5577	4.44	2.81	1.28	2.03	...
5612	4.66	2.76	1.27	2.00	...
5673	4.78	3.16	1.46	2.03	2.27
5674	4.80	2.83	1.48	2.03	2.38
5676	4.79	2.95	1.52	1.99	2.41
5781	5.37	2.92	1.39	2.19	2.67
5782	5.56	2.84	1.48	2.26	2.85
		HM Sagittae			
4567	3.59	2.76	1.37	1.86	2.03
4919	4.41	3.28	1.63	2.25	2.96
5273	4.58	3.54	2.00	2.10	3.08
5309	4.90	3.45	1.58	2.31	3.05
5396	5.18	3.45	1.75	2.48	3.16
5456	4.39	3.35	1.71	2.28	2.69
5457	4.00	3.38	1.60	2.29	2.83
5628	4.01	3.06	1.34	2.02	...
5673	3.65	3.23	1.34	2.06	2.60
5783	4.65	3.31	1.56	2.30	2.75
		V1329 Cygni			
4541	6.84	1.41	0.38	0.00	...
4567	6.81	1.51	0.43	0.50	...
4919	7.16	1.05	0.06	0.55	...
5308	6.69	1.50	0.27	0.42	...
5457	7.28	1.68	0.74	0.06	...
5986	6.85	1.52	0.41	0.31	...

TABLE 2

DISTANCE MODULI FOR V1016 CYGNI AND HM SAGITTAE

Band	V1016 Cygni $\langle M \rangle$	$\langle m \rangle$	D (kpc)	HM Sagittae $\langle M \rangle$	$\langle m \rangle$	D (kpc)
J	−6.89	8.02	9.8	−7.09	7.57	8.5
H	−7.86	7.07	9.7	−8.05	6.71	8.9
K	−8.19	6.50	8.7	−8.34	6.02	7.4
L	−8.40	5.82	7.0	−8.69	5.26	6.2
M	−8.09	5.78	5.9	−8.28	4.86	4.2

NOTE.—The presence of a Mira is assumed. Symbols are: $\langle M \rangle$, mean absolute magnitude; $\langle m \rangle$, mean observed magnitude corrected for the presence of the two blackbodies at 1000 and 300 K (inner and outer shell; see text).

that, dealing with a periodic light curve, are a better suited tool for clarifying the nature of the variability, relating the color to the phase. Following this guideline and taking as external constraints the observed IR magnitude variations and the Mira temperature variations (2700 K and 2950 K at minimum and maximum respectively, as suggested by Yudin 1982), the expected colors have been computed for different values of the model parameters (see Appendix), with the implicit assumption that the time scale of the dust temperature variations is smaller than the Mira's period.

Some representative cases are presented in Figure 3 for comparison, showing that general agreement is reached between expected and observed colors in the $H-K$ and $K-L$, while in $J-H$ it is less satisfactory. The reasons for this behavior are to be found partially in the adopted simplifications (neglecting of optical depth effects and of the hot component that could play a role in the J band), and partially in the intrinsic complexity of the system. In fact, the scatter in the $J-H$ color diagram could hardly be explained by a periodic phenomenon. However, the simple outlined model allows us to give an estimate of the relative contribution of the dust to the total IR luminosity as being in the range 0.8–0.9. This seems to be a particularly high value if we compare analogous results for symbiotics obtained by Feast, Robertson, and Catchpole (1977) and Feast *et al.* (1983), indicating that we probably deal with an unusually dusty system.

Distance and energy balance.—If an energy balance has to be attempted for V1016 Cyg, the distance determination is a crucial point for identifying in a binary model the source powering the IR emission. Distance determination by means of different methods give values ranging from 2.2 kpc (Nussbaumer and Schild 1981) to 4.5 kpc (Kwok 1977). Here we shall use the presence of a Mira of known absolute magnitude to derive the distance modulus. In fact, the mean bolometric magnitude derived on the basis of the period (Glass and Feast 1982) and the bolometric corrections (Lee 1970; Johnson 1966) allows us to compute the distance modulus at the IR wavelengths if we take into account that, in the adopted model, the observed magnitudes are the result of the contribution of different sources. Incidentally, we note that the difference in effective wavelength between our $L(3.8\ \mu)$ and $M(4.7\ \mu)$ photometry and Johnson's system introduces an error in the bolometric corrections of less than 0.1 mag (Sinton and Tittemore 1984); in this discussion it will be neglected. Taking into account such a correction, the derived distances at different wavelengths are presented in Table 2, where one can note that the distances appear higher than previous determinations, and a definite trend is evident: the longer the wavelength, the closer the object appears. This last point is worthy of further consideration because it is suggestive of a nonnegligible optical depth of the dust shell, pointing up the limit of our approximations. In this respect a recent determination of the color excess for V1016 Cyg has been done by Nussbaumer and Schild (1981), who derive a value of $E(B-V) = 0.28$, too low to be responsible for significant extinction in the IR.

We note, however, that this value is derived on the basis of UV line ratios originating in the hottest region, so that one can argue that the effect of a shell associated with the Mira is not included in their determination. However, despite the fact that this makes it possible to derive a smaller distance, it seems improbable that V1016 Cyg is closer than 5 kpc, because this would require too high an optical depth masking the Mira that, on the contrary, is visible in the greater amplitude of the J light curve.

If this is the case, the N-band photometry allows a crude estimate of the total energy emitted in the IR spectrum, amounting to $2 \times 10^{-15}\ \mathrm{W\ cm^{-2}}$.

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Comparing this luminosity with the Mira's luminosity of 3×10^{30} W and taking into account the fact that the absorption efficiency of grains decreases with wavelength, one can guess that the source powering the IR spectrum cannot simply be the Mira, but the nonvariable hot component must contribute considerably to the dust heating, in particular of the external shell, thus accounting for the observed constancy of the long-wavelength emission.

This kind of situation is suggestive of the symbiotics described by Feast, Robertson, and Catchpole (1977) as *b*-type systems in which the M star is not filling the Roche lobe and the emission lines come from an ionization-bounded region, as pointed out for V1016 Cyg by Nussbaumer and Schild (1981). This conclusion, however, raises some problems, according to Kenyon and Gallagher (1983), as far as the mass transfer rate is concerned, due to the high efficiency required to produce the symbiotic phenomenon.

c) *HM Sagittae*

The relationship between this star and V1016 Cyg has been pointed out by many authors (e.g., Davidson, Humphreys, and Merrill 1978; Puetter *et al.* 1978; Taranova and Yudin 1983; Stauffer 1984), and the IR light curves shown in Figure 1 give evidence of a common periodic behavior, the period of HM Sge being longer (540 days) and the corresponding spectral type being later (M9), according to Cahn (1980). Due to the lack of bolometric corrections specifically derived for spectral types later than M6, and because of the slow dependence of these corrections on spectral type when IR magnitudes are involved (Dyck, Lockwood, and Capps 1974), we adopt the same corrections as for V1016 Cyg. Figures 2 and 3 show how the same approach as that used for V1016 Cyg apparently results in a greater dust contribution to the total IR luminosity.

Taking into account these indications, and following the outlined procedure, the distances presented in Table 2 have been derived, again showing the same trend as V1016 Cyg. If we claim the existence of a nonnegligible extinction in the IR, this could not be due to the $E(B-V) = 0.8$ derived by Davidson, Humphreys, and Merrill (1978), nor to other lower values (Stauffer 1984), so that this may justify the presence of a dust shell associated only with the cool component of the symbiotic system. We must, however, mention that Thronson and Harvey (1981) found that the Brackett hydrogen lines suggest a visual absorption $A = 12$ mag, in sharp disagreement with the aforementioned value obtained from visual lines. The circumstance that these authors exclude the possibility that the discrepancy could be due to a variation of the circumstellar obscuration strengthens the idea of a combined effect of the location of the line-emitting regions and the dust distribution, in agreement with Stauffer's (1984) suggestion. Such a schematic model could well be that shown in Kwok, Bignell, and Purton (1984, Fig. 5) where, adopting an efficiency absorption of the dust grains $Q \propto \lambda^{-1}$ (silicates), the location of the internal shell can be estimated at ~ 6 stellar radii from the Mira. Finally, given a distance of 4 kpc, a lower limit to the IR luminosity of 6×10^{-15} W cm^{-2} (Davidson, Humphreys, and Merrill 1978), and an intrinisic Mira luminosity of 4×10^{30} W, we again conclude that the cool component cannot be the only energy source for the IR emission.

d) *V1329 Cygni*

This star has recently been discussed for its UV variability by Nussbaumer and Schmutz (1983), and relevant references can be found there. On the IR side of the spectrum, V1329 Cyg is classified as an S-type (Allen 1979) because of the lack of an IR excess due to dust. This fact is also evident in Figure 2, where the representative points lie in the region of the M stars. The photometry we present in Table 2, dealing with only few observations, is not suitable for a search for periods. However, it seems worth noting that in 1984 March (J.D. 2,445,457) the star faded by 0.5 mag in the *J*, *H*, *K*, and *L* bands. Whether this is periodic behavior, we do not know; however, we point out that this drop in brightness could be related to the corresponding dip seen between phase 0.6 and 0.7 in the visual light curve of Iijima, Mammano, and Margoni (1981). We emphasize that this is to be regarded only as a tentative interpretation needing further observations for confirmation. Finally, a distance estimate of 3.5 kpc can be obtained if the spectral type M4 III of the cool component (Andrillat 1982) and the bolometric corrections are adopted (Lee 1970).

IV. CONCLUSIONS

The infrared periodicity of V1016 Cyg and HM Sge is confirmed, the periods being 450 days and 540 days respectively and the corresponding spectral type M7 and M9. Assuming the presence of a Mira, the distances have been estimated as approximately 6 kpc and 4 kpc, suggesting the presence of additional extinction by a dust shell associated with the Mira. V1329 Cyg appears much less variable in the infrared, but a fading possibly related to the dip at phase 0.6–0.7 in the optical light curve of Iijima, Mammano, and Margoni (1981) has been observed.

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APPENDIX

If L represents the luminosity, Θ the phase, B Planck's function, S the emitting area, and R the Mira's radius, and denoting with the subscripts *, c, and d respectively quantities referred to the Mira, the internal (associated with the Mira), and the external (associated with the whole system) dust shell, it is easy to derive the following expression for the color index in the blackbody approximation and the optically thin case:

$$C(\lambda_1, \lambda_2) = 2.5 \log \left[\frac{F_{01}}{F_{02}} \frac{B(\lambda_2, T_d)}{B(\lambda_1, T_d)} \frac{1 + \Theta(\lambda_2) + \Psi(\lambda_2)}{1 + \Phi(\lambda_1) + \Psi(\lambda_1)} \right], \tag{1}$$

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where

$$\Phi(\lambda) = \frac{1 - X(0)}{X(0)} \frac{T_d^4 + (S_c/S_d)T_c^4(0)}{T_*^4(0)} \left[\frac{R(\Theta)}{R(0)}\right]^2 \frac{B(\lambda, T_*(\Theta))}{B(\lambda, T_d)},$$

$$\Psi(\lambda) = \left(\frac{S_c}{S_d}\right)\left\{\frac{B[\lambda, T_c(\Theta)]}{B(\lambda, T_d)}\right\},$$

$$\frac{S_c}{S_d} = \left[\frac{Y(0)}{(1 - Y(0))}\right]\left[\frac{T_d}{T_c(0)}\right]^4,$$

$$X = \frac{(L_c + L_d)}{(L_c + L_d + L_*)},$$

$$Y = \frac{L_c}{(L_c + L_d)},$$

and F_{01} and F_{02} are the zero-magnitude fluxes at λ_1 and λ_2 respectively. In the preceding relations, (0) is used for the phase of the mean magnitude $\Theta = 0.25$.

REFERENCES

Allen, D. 1979, in *IAU Colloquium 46, Changing Trends in Variable Star Research*, ed. F. M. Bateson, J. Smak, and I. H. Urch (Hamilton, NZ: University of Waikato), p. 125.
———. 1982, in *IAU Colloquium 70, The Nature of Symbiotic Stars*, ed. M. Friedjung and R. Viotti (Dordrecht: Reidel), p. 27.
Andrillat, Y. 1982, in *IAU Colloquium 70, The Nature of Symbiotic Stars*, ed. M. Friedjung and R. Viotti (Dordrecht: Reidel), p. 173.
Aitken, D. K., Roche, P. F., and Spenser, P. M. 1980, *M.N.R.A.S.*, **193**, 207.
Baldwin, J. R., Frogel, J. A., and Persson, S. E. 1973, *Ap. J.*, **184**, 427.
Bath, G. T. 1977, *M.N.R.A.S.*, **178**, 203.
Cahn, J. H. 1980, *Space Sci. Rev.*, **27**, 457.
Ciatti, F., Mammano, A., and Vittone, A. 1978, *Astr. Ap.*, **68**, 251.
Davidson, K., Humphreys, R. M., and Merrill, K. M. 1978, *Ap. J.*, **220**, 239.
Dyck, H. M., Lockwood, G. W., and Capps, R. W. 1974, *Ap. J.*, **189**, 89.
Eggen, O. J. 1975, *Ap. J.*, **195**, 661.
Feast, M. W., Robertson, B. S. C., and Catchpole, R. M. 1977, *M.N.R.A.S.*, **179**, 499.
Feast, M. W., Whitelock, P. A., Catchpole, R. M., Roberts, G., and Carter, B. S. 1983, *M.N.R.A.S.*, **202**, 951.
Fox, M. W., and Wood, P. R. 1982, *Ap. J.*, **259**, 198.
Glass, I. S., and Feast, M. W. 1982, *M.N.R.A.S.*, **199**, 245.
Harvey, P. M. 1974, *Ap. J.*, **188**, 95.
Henning, T. 1983, *Ap. Space Sci.*, **97**, 405.
Iijima, T., Mammano, A., and Margoni, R. 1981, *Ap. Space Sci.*, **75**, 237.
Johnson, H. L. 1966, *Ann. Rev. Astr. Ap.*, **4**, 193.
Kenyon, S. J., and Gallagher, J. S. 1983, *A.J.*, **88**, 666.
Kwok, S. 1977, *Ap. J.*, **214**, 437.
Kwok, S., Bignell, R. C., and Purton, C. R. 1984, *Ap. J.*, **279**, 188.
Kwok, S., and Purton, C. R. 1979, *Ap. J.*, **229**, 187.
Lee, T. A. 1970, *Ap. J.*, **162**, 217.
Lorenzetti, D., Orfei, R., Saraceno, P., Strafella, F., and Cosmovici, C. B. 1983, *Ap. Space Sci.*, **90**, 171.
Mammano, A., and Ciatti, F. 1975, *Astr. Ap.*, **39**, 405.
Mitchell, R. M., and Robinson, G. 1981, *M.N.R.A.S.*, **196**, 801.
Nussbaumer, H., and Schild, H. 1981, *Astr. Ap.*, **101**, 118.
Nussbaumer, H., and Schmutz, W. 1983, *Astr. Ap.*, **126**, 59.
Puetter, R. C., Russell, R. W., Soifer, B. T., and Willner, S. P. 1978, *Ap. J. (Letters)*, **223**, L93.
Ridgway, S. T., Joyce, R. R., White, N. M., and Wing, R. F. 1980, *Ap. J.*, **235**, 126.
Sinton, W. M., and Tittemore, W. C. 1984, *A.J.*, **89**, 1366.
Stauffer, J. R. 1984, *Ap. J.*, **280**, 695.
Strecker, D. W., Erickson, E. F., and Witteborn, F. C. 1979, *Ap. J. Suppl.*, **41**, 501.
Tamura, S. 1983, *Pub. Astr. Soc. Japan*, **35**, 317.
Taranova, O. G., and Yudin, B. F. 1983, *Astr. Ap.*, **117**, 209.
Thronson, H. A., Jr., and Harvey, P. M. 1981, **248**, 584.
Tielens, A. G. G. M. 1983, *Ap. J.*, **271**, 702.
Yudin, B. F. 1982, *Soviet Astr.*, **26**, 187.

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