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A CORRELATION BETWEEN INFRARED EXCESS AND PERIOD FOR MIRA VARIABLES

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ABSTRACT

The [8.7]–[11.4] infrared color is found to increase monotonically with increasing period for a sample of 41 Mira variables. We conclude that mass loss is not a stochastic process and that for any Mira variable the rate of mass loss is directly linked to the parameters which dictate the period of that variable.

Subject headings: infrared: general — stars: mass loss — stars: variables

I. INTRODUCTION

Kinematic studies (e.g., Feast 1963) imply that the shorter-period Mira variables are Population II stars, while those with longer periods belong to more intermediate populations. These observations suggest that the chemical abundances of Mira variables may be a function of their period. More recently Dickinson, Kollberg, and Yngvesson (1975) have observed that those Mira variables which exhibit OH maser emission characteristically have two separate emission peaks. The separation in radial velocity of these peaks (particularly the 1612 MHz line) is correlated with the photometric period. This velocity difference is now thought to be equal to twice the outflow velocity of circumstellar material (e.g., Dickinson *et al.* 1978). Since the Mira variables are known to have infrared excesses due to emission from circumstellar dust (Woolf and Ney 1969; Gehrz and Woolf 1971; Gillett, Merrill, and Stein 1971), we decided to investigate the relationship between period and infrared excess.

We already had at our disposal a body of data taken in a survey of AFGL sources (Grasdalen, Gehrz, and Hackwell 1980) which included a large number of bright Mira variables. Additional observations of some fainter Mira variables gave us fairly complete coverage in period and showed that the infrared excess, represented by the [8.7]–[11.4] color, increases with increasing period in a well-defined manner. The infrared excess is presumably related to the rates of mass loss and dust formation. We therefore conclude that the mass loss process is not a stochastic property of the Mira variables, but is closely related to the parameters which dictate the period of an individual variable.

II. OBSERVATIONS

All the photometry was obtained at the f/27 Cassegrain focus of the 2.3 m Wyoming Infrared Telescope between 1977 December and 1980 June. The detector used was a multifilter Ga-Ge bolometer. Operation, effective bandpasses, and calibration of the Wyoming photometer have been discussed by Gehrz, Hackwell, and Jones (1974). It should be stressed that the data are internally consistent: all were taken on the same telescope with the same instrument and thus possess a high degree of internal accuracy. Table 1 contains the magnitudes measured for all the Mira variables not in the AFGL catalog. The magnitudes of those which are also AFGL objects will be published elsewhere (Grasdalen, Gehrz, and Hackwell 1980).

III. ANALYSIS

Since the infrared excess of a Mira variable is caused by emission from circumstellar dust, we wanted to choose an infrared color which would indicate the amount of dust. Figure 1 shows some representative spectra from our data, where we have plotted magnitude against λ^{-1}. Three Mira variables of widely different periods and a 2000 K blackbody are shown for comparison. The Mira variables, although appearing fairly black at wavelengths shorter than 8.7 μm, have the emission feature near 10 μm characteristic of silicate grains (e.g., Gillett *et al.* 1975). Note that the height of the silicate feature increases with increasing period. The [8.7]–[11.4] color was chosen to quantify the height of the silicate feature. This particular color emphasizes the change in magnitude due to silicate emission relative to the underlying blackbody distribution.

In Figure 2 we have plotted the [8.7]–[11.4] color against period for our entire sample of Mira variables. Except for those points which have error bars indicated, all the colors in Figure 2 have 1 standard deviation errors less than or equal to 0.05 mag. These errors include random error plus systematic errors arising from guiding and calibration. In the three instances where more than one set of measurements were available, specifically for SS Her, RR Per, and R Vir, the two sets of measurements were averaged. Table 2 contains the name, AFGL number if applicable, period (Kukarkin *et al.* 1969), measured [8.7]–[11.4] color, the date of measurement, and the phase of the measurement if available (Mattei 1980) for the 41 stars in the figure.

Figure 2 shows that the infrared excess increases monotonically with increasing period. The rms scatter in the relationship is approximately 0.16 mag. This is about 3 times the rms errors of the magnitudes. However, since the photometric phase at the time of each

TABLE 1

MAGNITUDES FOR MIRA VARIABLES NOT INCLUDED IN THE GL CATALOG

Star	UT Date	2.3 μm	3.6 μm	4.9 μm	8.7 μm	10 μm	11.4 μm	12.6 μm	19.5 μm
R Boo....	1980 April 14	1.68	+1.27	+0.90	+0.48	+0.32	+0.16	+0.13	−0.33
X CrB....	1980 April 14	3.66	+3.13	+2.80	+2.40	+2.22	+1.99	+1.75	+1.33
R Dra....	1980 April 14	2.04	+1.49	+1.09	+0.66	+0.49	+0.34	+0.26	+0.12
S Gem....	1980 April 18	3.22	+2.55	+2.27	+1.70	...	+1.18	+1.12	+1.20
T Her.....	1980 April 14	2.89	+2.55	+2.29	+1.84	+1.68	+1.55	+1.53	+1.38
RU Her...	1980 April 14	0.60	−0.07	−0.40	−1.05	−1.58	−2.00	−2.02	−2.30
SS Her....	1980 April 14	5.08	+4.60	+4.18	+3.67	+3.49	+3.09	...	...
	1980 June 7	4.96	+4.51	+4.10	+3.41	...	+3.21	...	...
SY Her...	1980 April 18	4.18	+3.73	+3.50	+3.02	...	+2.93	+2.77	...
T Hya....	1980 April 18	2.51	+2.13	+1.95	+1.62	...	+1.37	+1.39	...
W Lyr....	1980 April 14	3.00	+2.70	+2.49	+2.15	+2.03	+1.93	+2.00	+1.98
U Vir.....	1980 April 14	3.78	+3.36	+3.05	+2.65	+2.66	+2.42	...	...

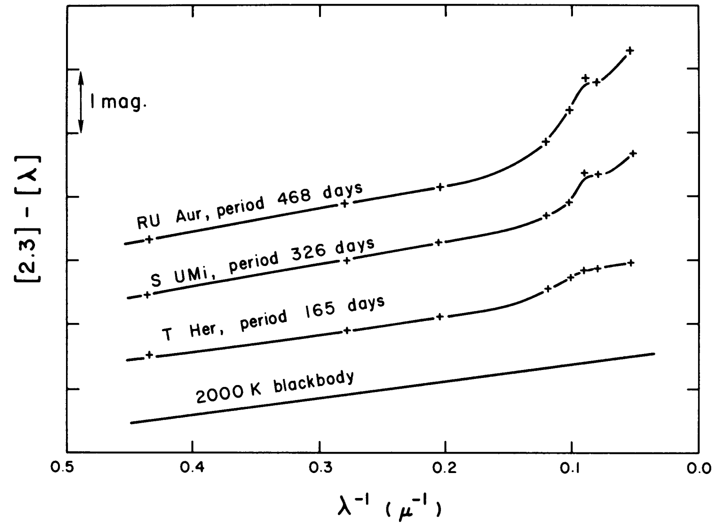

FIG. 1.—Magnitude plotted against inverse wavelength for a 2000 K blackbody and three representative stars of widely different period.

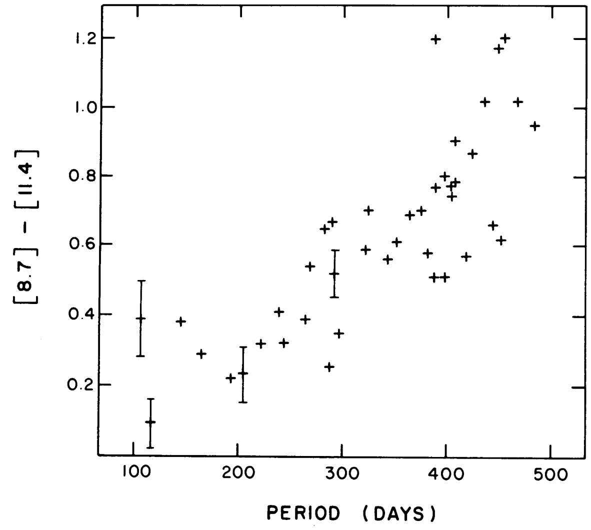

FIG. 2.—A plot of [8.7]–[11.4] color vs. period for 41 Mira variables. Error bars are indicated only if the 1 standard deviation error exceeds ±0.05 mag.

measurement has not been taken into account, some of the scatter may be due to intrinsic variability. Taking the errors and varying phases into account, the amount of scatter in the relationship is remarkably small. The cosmic scatter could be close to zero.

There is no evidence for a sharp change in the relationship at short periods as has been noted in the relationships of kinematic properties (Feast 1963) and absolute magnitude (Clayton and Feast 1969) with period. Neither has such a turnover been found in the relationship between velocity width and period for the OH Mira variables (Dickinson, Kollberg, and Yngvesson 1975).

IV. DISCUSSION

We have shown that the infrared excess of Mira variables is correlated with their period. This is contrary to the accepted notion that the mean mass loss along the giant branch is unpredictable owing to its dependence on some complex set of parameters (e.g., Rood 1973). The real quantities of interest here are the mass loss rate, which we expect to govern the amount of

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material in the shell, and the dust formation rate, which might be related to the chemical composition as well as the surface temperature and luminosity of the star.

The infrared excess is indicative not of the mass in the entire shell, but only of the mass of dust contained in the thermosphere, which extends to that radius in the shell where the dust is sufficiently warm to radiate significantly at 10 μm. On the simplest level, if one assumes two stars to be equal in mass and luminosity and differ only in period and abundance of heavy elements, then a deficiency of heavy elements in the shorter period Population II Mira variable would presumably decrease its infrared excess. Thus the relation in Figure 2 might be interpreted as simply differing metal abundances in differing populations of Mira variables.

To quantify the difference in metal abundances between the short- and long-period Mira variables, we used the relationship derived between $|w|$ and $\delta(U - B)$ given by Eggen, Lynden-Bell, and Sandage (1962). Carney's (1979) recent relationship between $\delta(U - B)$ and [Fe/H] was then used to calibrate a relationship between kinematic properties and the quantity [Fe/H]. Two of Feast's (1963) groups of Mira variables were examined, and the group with periods $149 < P \leq 200$ days was found to be deficient in [Fe/H] by more than one dex relative to the group with periods $350 < P \leq 410$ days. Obviously the metal deficiencies in the short-period Mira variables are substantial.

TABLE 2

COLOR AND PERIOD OF EACH MIRA VARIABLE IN SAMPLE

Star	AFGL Number	Period (days)	[8.7]–[11.4][a]	UT Date	Phase
R And	59	409	0.90	1978 Dec 17	0.74
U Aur	805	408	0.78	1977 Dec 21	0.82
RU Aur	794	468	1.02	1977 Dec 21	0.06
SZ Aur	802	453	0.62	1977 Dec 21	0.66[b]
BU And	3088	382	0.58	1978 Aug 17	0.20[b]
R Boo	...	223	0.32	1980 Apr 14	0.21[b]
T Cas	57	445	0.66	1978 Dec 17	0.33
BT Cas	211	399	0.80	1978 Aug 16	...
BG Cyg	2428	291	0.67	1978 Aug 4	0.83[b]
KZ Cyg	2583	406	0.77	1978 Aug 17	...
V1129 Cyg	2417	270	0.54	1980 Jun 7	...
X CrB	...	241	0.41	1980 Apr 14	0.63[b]
R Dra	...	245	0.32	1980 Apr 14	0.23[b]
S Gem	...	293	0.52±0.07	1980 Apr 18	0.67
XX Gem	1117	384	0.65	1978 Dec 17	0.91[b]
T Her	...	165	0.29	1980 Apr 14	0.22
U Her	1858	405	0.75	1978 Feb 17	0.48
RU Her	...	485	0.95	1980 Apr 14	0.85
SS Her	...	107	0.58±0.12	1980 Apr 14	0.83[b]
	...	107	0.20±0.10	1980 Jun 7	0.33[b]
SY Her	...	117	0.09±0.07	1980 Apr 18	0.21[b]
MW Her	1988	449	1.18	1978 Aug 4	...
R Hya	1627	388	0.51	1978 Mar 27	0.01
T Hya	...	288	0.25	1980 Apr 18	0.98
S Lyn	998	298	0.35	1978 Feb 17	0.25
U Lyn	982	436	1.02	1978 Feb 17	0.38
W Lyr	...	196	0.22	1980 Apr 14	0.29
TW Lyr	2148	376	0.70	1980 Aug 4	0.82[b]
TT Mon	1118	323	0.59	1978 Dec 17	0.27[b]
S Ori	757	419	0.57	1978 Mar 8	0.03
RV Peg	2900	389	1.20	1980 Jun 8	...
SW Peg	2754	396	0.51	1980 Aug 17	0.51[b]
UU Peg	2775	456	1.20	1980 Jun 8	...
RR Per	335	390	0.77	1978 Aug 19	0.87
	335	390	0.77	1978 Aug 20	0.87
R Psc	226	344	0.56	1978 Nov 19	0.84
WW Ser	1777	367	0.69	1978 Mar 26	0.67[b]
WX Ser	1773	425	0.87	1978 Feb 17	...
R Tri	355	266	0.39	1977 Dec 30	0.60
S UMi	326	326	0.70	1978 Apr 4	0.00
R Vir	4157	146	0.44	1977 Dec 29	0.84
	4157	146	0.32	1980 Apr 18	0.57
U Vir	...	207	0.23±0.08	1980 Apr 14	0.10
RS Vir	1710	353	0.61	1978 Feb 17	0.76

[a] Errors are shown only if they exceed ±0.05 mag.

[b] Phase approximate.

The mass loss rate through a differential shell is proportional to the product of the outflow velocity, the dust mass in that shell and some factor related to the percentage of mass present in the form of heavy elements. One can interpret our relationship as an indication that the observed mass of dust in a given thermosphere is an almost linear function of period, although the total shell mass may be approximately constant. The outflow velocity as measured by the OH velocities (Dickinson, Kollberg, and Yngvesson 1975) also increases approximately linearly with period. These considerations appear to imply a relationship of positive slope between period and mass loss rate. Refining this statement will require accurate knowledge of the heavy-element abundances in Miras and the relative efficiency of dust formation as a function of metal content.

Since the period is proportional to $1/(G\rho)^{1/2}$, the mass loss rate is therefore dependent on the star's density, which can be predicted from the knowledge of the mass, temperature, and chemical abundances. Therefore it is clear that mass loss is not a stochastic process, but is predictable for a given Mira variable.

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