CO observations of short period Miras

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Abstract. CO observations are reported of Miras with periods shorter than 400 days.

1 Introduction

In two previous contributions (Groenewegen 1995a, b) it was found from modeling the spectral energy distributions (SEDs) of carbon-rich Mira variables with a dust radiative transfer code (Groenewegen 1993) that there exists a tight relation between mass loss rate (MLR) and pulsation period for periods $\gtrsim$ 400 days, but that the MLRs appear to be significantly lower for periods $\lesssim$ 400 days (see Fig. 1, crosses). This was interpreted as an observational signature that radiation pressure on dust is less effective at these relatively low luminosities, in qualitative agreement with model calculations by e.g. Habing et al. (1994).

More observations were needed (in particular CO) to confirm this trend at short periods, and, at the same time, the question was raised if a similar trend could be observed among oxygen-rich Miras. To this end we have made CO observations of a sample of C- and O-rich Miras with periods below 400 days.

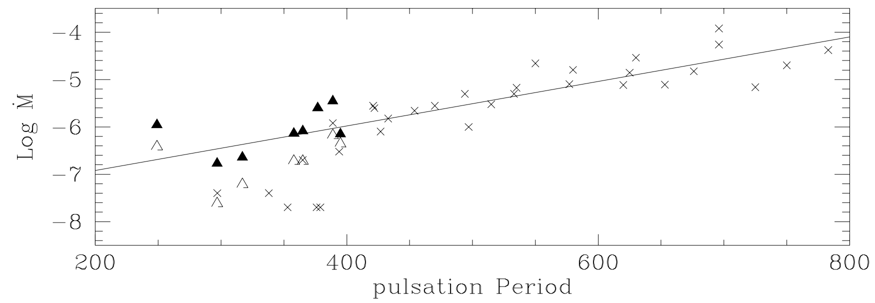

Fig. 1. $\dot{M}-P$ relation for carbon Miras derived from modeling the dust shells (crosses). The line is a fit to the crosses wich represent periods longer than 400 days. The new CO data is indicated (filled $\triangle$ = 2-1, open $\triangle$ = 1-0 transition)

2 Observations

Observations were performed in Dec. 1994 (IRAM, CO J=1-0, 2-1, observers MG & JB), Jan. 1995 (IRAM, J=1-0, 2-1, 3-2, by MG), Aug. 1995 (IRAM, J=1-0, 2-1, by EJ) and Aug. 1995 (JCMT, J= 2-1, 3-2, partly ^{13}CO as well, by FB & RT). Among carbon Miras, 19 were observed and 10 detected; among O-rich Miras, 24 were observed and 19 detected. Many are new detections. The different detection rates are simply due to the available numbers in the General Catalog of Variable Stars (GCVS). Among carbon stars, ALL stars north of δ = –30^o (and P $<$ 400 days) were observed, while there are so many such O-rich Miras in the GCVS that we have picked the brightest in IRAS, to increase the detection probability.

Two things are remarkable. First, some of the stars have very small expansion velocities, down to 6 km s^{-1}. Often these stars also have the lowest MLRs. This could indicate that radiation pressure on dust in stars with short periods (= low luminosities) can not drive the outflow to the typical outflow velocities of 10-15 km s^{-1} observed in most AGB stars. Second, the ratio between the 2-1 and 1-0 peak temperatures are sometimes very large. In 'normal' AGB stars with 'high' MLRs and expansion velocities near 10-15 km s^{-1} this ratio is about 2. In the present sample, we find ratios which are almost always larger than 2, even up to 10. This could indicate that the excitation of CO may be very different. Possibly, radiative excitation in these very optically thin dust shells is much more important than collisional excitation. An example of a star with such a high ratio and low expansion velocity is the 356 day period O-Mira R Ser (Fig. 2).

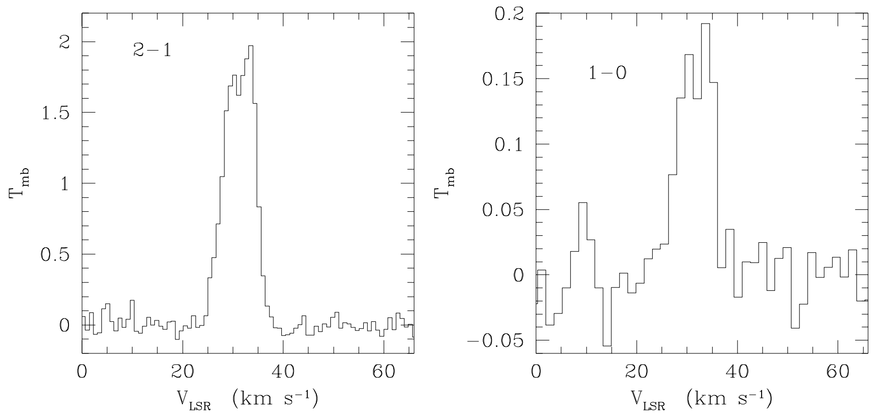

Fig. 2. R Ser

3 Analysis

Luminosities are derived from the period-luminosity relation of Feast et al. (1989) for O-rich Miras, and a newly derived one (Groenewegen, MNRAS submitted) for C-rich Miras. Distances are estimated from the IRAS 12 and 25 μm flux-densities using a pre-calculated grid of dust models, basically giving the bolometric correction at 25 μm as a function of S_{25}/S_{12}. In the future it is planned to model the SEDs of individual stars to accurately determine the dust MLR and the distance.

The (gas) MLRs are calculated from the standard Knapp & Morris (1985; KM85) formula (also see Van der Veen & Oloffson 1990) relating MLR to peak temperature, distance, expansion velocity, beam width and transition. Especially in view of the a-normal line ratios it could very well be that the simple KM85 formula does not apply. The MLRs based on the 2-1 line are systematically higher than those based on the 1-0 line. In the future, it is planned to model the CO line profiles in detail using the model of Groenewegen (1994). For a discussion on the applicability of the KM85 formula when there is strong chromospheric or interstellar UV radiation, see Josselin et al. (1996).

The lowest MLR among the C-stars is 1.6 10^{-7} $M_\odot$ yr^{-1} in V Oph which has the lowest period as well, and an expansion velocity of 7.0 km s^{-1}. Among O-stars the "record holder" is R Aqr with a MLR of 1.5 10^{-8} $M_\odot$ yr^{-1}.

Final conclusions regarding the MLR must await detailed modeling. However, the first impression of the new CO data for carbon stars with periods below 400 days is that there is better agreement with the extension of the $\dot{M}$-P relation than with the dust MLRs (see Fig. 1). For the moment we list the preliminary results in Table 1, where the name, period, expansion velocity and the (uncertain) mass loss rate based on the 2-1 and 1-0 line are given. Observed but not detected are the carbon Miras UV Aur, R CMi, V390 Cas, PT Cas, CN Per, GY Per, VX Gem, AO Lac, LS Cas, and the oxygen-rich Miras BD Eri, RS Eri, T Lep, R Peg, S Scl.

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Table 1. Results

Name	Period (days)	v_{exp} (km s^{-1})	$\dot{M}$(2-1) (10^{-7} $M_\odot$ yr^{-1})	$\dot{M}$(1-0) (10^{-7} $M_\odot$ yr^{-1})
		carbon Miras		
Y Per	249	7.2	11	3.8
V Oph	297	7.0	1.6	0.24
ZZ Gem	317	6.8	2.3	0.61
R Cap	345	10.5	76.	–
V Aur	353	20(:)	15.	<6
V Crb	358	8.2	7.3	1.9
R Pyx	365	8.5	8.2	1.9
R Ori	377	10(:)	25.	<8
R For	389	16.9	35.	6.6
AX Cep	395	13.2	7.1	4.4
		oxygen Miras		
R Cet	166	9.0	14.	–
Z Cyg	264	7.5	41.	–
X Hya	301	6.8	2.2	–
R Leo	310	7.3	0.49	0.05
R Tau	321	6.0	11.	–
TU Peg	322	9.0	15.	–
RT Aqr	327	6.0	25.	–
X Oph	329	6.3	1.2	–
W Peg	345	11.0	19.	–
RU Cap	347	7.5	48.	–
RS Vir	354	6.2	57.	4.6
R Ser	356	6.4	7.9	0.56
U Ori	368	7.5	1.5	0.10
RT Eri	372	8.5	5.5	–
R LMi	372	8.0	6.3	0.74
W Eri	377	10.0	23.	–
R Peg	378	6.3	4.7	0.44
R Aqr	387	16.7	0.15	–
BQ Cyg	420	7.5	50.	–