Vibration-Rotation CO in Intermediate Population Miras

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Introduction

The short period Miras seem to form in many ways a distinct group of objects. Beside the shorter period this group is also remarkable in its scale height perpendicular to the galactic plane, which is much larger than for Mira variables with longer periods. Therefore these variables are thought to include older, metal poor objects (Hron 1991). For these – we will call them intermediate population – Miras up to now only kinematic and infrared photometric investigations exist. Variations in the infrared spectrum of these stars, which would show pulsational properties much clearer than optical variations do, have not yet been investigated in detail. These properties, especially the amplitude of the radial velocity variations, could help to decide whether there is a difference in the pulsating mode of these objects and the long period Miras as discussed by Willson et al. (1982). So we decided to observe the radial velocity variations of these stars in the infrared. Therefore we used lines of CO (Δv=2) at 2.3μm which have already been used successfully by Hinkle (1978) and Hinkle et al.(1982, 1984) for the same investigation of Miras with longer periods.

Observations

We got time series of infrared spectra for the four intermediate population Miras RT Cyg, R Vir, SS Oph und Z Oph. Beside these a few single spectra of RY Oph, R Cet and X Mon were added to our analysis. Despite its longer period we included the star Z Oph mainly because of its very early maximum spectral type and its high radial velocity, which might be a hint that this star is a metal poor object.
The spectra used in this work were obtained with the Mayall 4m telescope at Kitt Peak National Observatory with the Fourier Transform Spectrometer. The S/N ratio for the spectra ranges from 10 to more than 100. For most of the spectra we achieved a resolution of about 60000 or better. For the measurment of the radial velocities we used the positions (line cores) of high and low excitation lines of CO (Δv=2) and some Titanium lines for the stars with time series.

Results

The resulting radial velocities are plotted in Fig. 1 against the phase. Most of the data were taken from only one or two adjacent cycles. The velocity of the

low excitation CO lines is the mean of 13 to 15 lines, the velocity of the high excitation CO lines was calculated from 4 to 5 lines. About 6 lines were used for each Titanium data point.
Line doubling of CO lines was present in some of the spectra and one example is plotted for RT Cyg at phase 0.77. Three of the investigated objects show a similar behavior of the variations. For these objects the low excitation lines show only very little variations in radial velocity. In RT Cyg and SS Oph these changes are more prominent than in Z Oph. The high excitation CO lines show a well defined S-shaped radial velocity curve with an amplitude of 20 to 25 km/s. There seems to be no significant shift beween the maximum of the visual light curve and the minimum radial velocity. The behavior of the Titanium lines seems to be similar to the one of the high excitation lines, the velocities of these indicators are almost the same at many phases. For R Cet and X Mon a radial velocity amplitude could be estimated from cross correlation data. For R Cet it seems to be compareable with the results from RT Cyg, but for X Mon we estimate an amplitude of only about 10 to 15 km/s.
R Vir behaves a little bit different. There we find a nice S-shaped variation of the low excitation CO lines, but with the minimum velocity near the visual light minimum. The amplitude of this variation is significantly larger (about 15 km/s) than for the low excitation CO lines of the other three stars (5 to 7 km/s). In the high excitation CO and the Ti lines of R Vir a very complex variation can be seen. Line doubling is present in the Ti lines at many phases. One group of Ti lines is almost constant over the cycle at a velocity of about -20 km/s. The other component shows variations similar to those of the low excitation CO lines. But the lines are very weak in the spectra of this star and were difficult to measure.
To measure the carbon isotopic ratios, the central depths of all the unblended lines of $^{12}C^{16}O$ and $^{13}C^{16}O$ in the 4200 to 4360 cm^{-1} region were measured. The method to investigate the carbon isotopic ratio has been previously described by Hinkle et al.(1982). The values we got from this analysis (on the order of 10 to 20) are typical for bright, thin disk Miras. For R Cet we got a value of only 4. The resulting excitation temperatures are in the range of 2750 to 3500 K.

Discussion and Conclusions

Compared with the results for metal rich Miras (Hinkle et al. 1982) the radial velocity amplitude in the infrared of the high excitation CO lines is almost the same for the intermediate population Miras. Therefore a different pulsation mode for these objects seems to be very doubtful. Both in metal poor and metal rich Miras the low excitation CO lines show only small radial velocity variations and probably no periodic changes except in R Vir. The similarity suggests also a similar structure of the atmosphere of these variables and that also the indicators of the different layers can be used in an analogous way.
We have no definite explanation for the strange behavior of the lines in the

spectra of R Vir at the moment. Further work on this star to explain this behavior is in progress.
Z Oph remains a strange object. With the data available its evolutionary status cannot be determined exactly. It is the only Mira listed in the GCVS with a spectral type in maximum earlier than M0 and a period of more than 300 days. If we asume that the star is metal poor ($Z/Z_{\odot}= 0.3$) with a mass between 0.6 and 0.8 solar masses and has an effective temperature of 3500 K (from J-K and the stars mean spectral type) it is only slightly brighter than the calculated AGB-tip (Vassiliadis & Wood 1993). As the calculation of the AGB brightness included mass loss this difference could be explained by the assumption that Z Oph has a very low mass loss rate for its period so that the star could stay longer on the AGB. The low mass loss is evident from the IRAS colours of this star indicating no circumstellar shell.
The research presented in this paper allows two conclusions: (1) The amplitude of the radial velocity variations is almost independent from the period for periods between 350 and 150 days. (2) The amplitude does not depend on metallicity. Due to the small number of objects currently observed better data provided by longer time series or a larger sample of objects would be interesting. More complete photometric data sets for these objects are needed, too.

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Figure 1: Radial velocity variations in low and high excitation CO lines (Δv=2) and in Ti lines for our four program stars with time series.