Asymptotic Giant Branch Stars
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ISOSWS Spectral Variations of Oxygen-Rich Miras

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Abstract. In conjunction with an extensive ground-based monitoring program of 32 oxygen-rich Mira variables, a subset of this sample has been monitored with phase using ISO's Short Wavelength Spectrometer (ISOSWS) and ground-based mid-infrared spectrometers. Some of the six sources will be presented here in 2.5–45 μm ISOSWS spectra and 7.5–13.5 μm ground-based spectra using CGS3. Discussion of the spectral features of SiO, CO, H_2O, and silicates will be presented. These data are considered in the context of recent demonstrations of variations in the spectral features with phase of the Miras.

1. Introduction and background

This study was initiated based on classifications of silicate features of oxygen-rich Mira variables from the IRAS LRS database first assembled by Little-Marenin & Little (1990, hereafter LML). Sloan & Price (1995) later reclassified the LML features using statistical fits of black body curves modified to account for SiO absorption near 8 μm. They demonstrated that a sequence of color of the 10 μm features was evident by examining the colors of the black-body subtracted IRAS LRS spectra. Stencel et al. (1990), based on a paper by Lewis (1989), concluded that the silicate emission features when taken in conjunction with SiO, OH and H_2O masers implied an evolutionary sequence for M Miras. Based on this information, we undertook a photometric campaign of the 5 to 20 μm region to study the silicate features of the Miras to determine if these features changed with phase, and if more information on an evolutionary sequence could be obtained (Creech-Eakman 1997).

As part of the research, we proposed to study a sub-group of the sources in our photometric study with ISO's Short Wavelength Spectrometer (ISOSWS). Three epochs of each source were to be taken over the course of ISO's initial mission. The sources were chosen to span the LML classification scheme and to complement the Central Programme. Unfortunately, not all the allocated time was ultimately scheduled on the sources. Thus only two of the six sources had

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more than one epoch of ISOSWS data obtained. Concurrently, ground-based observations were obtained with CGS3 as part of the UKIRT Service Program on this same group of sources, so that between three and seven spectra exist for each of the sources in the 7–14 μm region over about 3 years.

2. Data reduction

2.1. ISOSWS data

ISOSWS AOT01 data were taken for six stars, two at more than one epoch (Table 1). The data were reduced using the SIA interactive software written by scientists at ESA and IPAC. Each scan was reduced from its ERD using the pipeline 7 reduction and was interactively dark subtracted, flat fielded, masked and corrected for anomalies in the up and down scans before being converted to flux values. Each scan was further reduced in ISAP by 2.0 sigma clipping and Gaussian smoothing at half the native resolution for each band. Finally, the data bands were merged together, rebinned onto a 0.005 μm grid and Gaussian smoothed at 0.02 μm. Some of the data are of low S/N and need more work; hence not all data will be shown here.

Star	IRAS	(Jy)		Obs. Date	Phase	Sil Class
	12 μm	25 μm	60 μm			
TW Cyg	10.96	4.27	0.79	03/12/96	0.73	No Feature
ER Cyg	14.20	5.59	1.31	05/12/96	0.38*	Broad
U Dra	18.51	7.24	1.27	20/12/96	0.01	Broad
				23/04/97	0.40	
				10/10/97	0.94	
SV And	12.67	4.89	0.79	17/01/97	0.15	S Feature
				31/01/98	1.35	
RY And	23.97	11.55	2.01	03/12/96	0.26	Sil +
AU Her	17.31	10.41	2.53	12/02/97	0.61*	Sil

Table 1. Sources observed in the mcreeche ISOSWS program. Included here are the color-corrected IRAS fluxes assuming a 2 500 K color-correction. Epochs and periods were taken from AAVSO data. Those marked by an asterisk were taken from the GCVS.

2.2. CGS3 data

Through the UKIRT Service Observing program Cooled Grating Spectrometer 3 (CGS3) has been used to conduct ground-based observations of the sources in Table 1 prior to and throughout the ISO mission. These observations were taken at a variety of variable star phases in the 10 μm and, when weather permitted, 20 μm windows at a resolving power of about 50. The observations were taken by J. K. Davies and standards from Cohen & Davies (1995) taken close in airmass and time were used for all the data reduction. We were supplied with completely reduced spectra, the entire collection of which will be published in an upcoming paper.

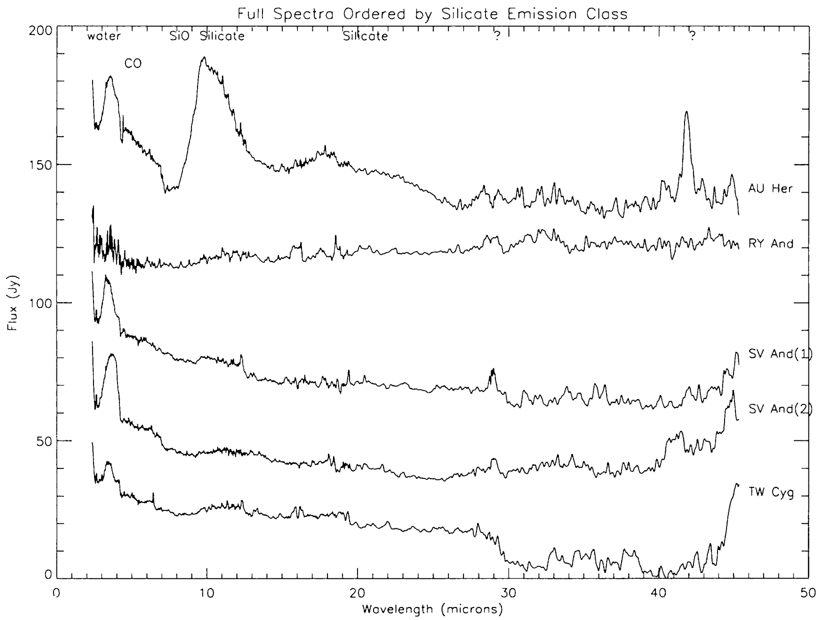

Figure 1. ISOSWS spectra of 4 M Miras - AU Her, RY And, SV And (2 epochs) and TW Cyg. Offsets of 120, 105, 35, 20 and 0 Jy have been applied to the data for plotting purposes.

3. Data and analysis

In Fig. 1 we show the complete ISOSWS spectrum for four different M Miras, AU Her, RY And, SV And (2 epochs) and TW Cyg, ordered from top to bottom by silicate class. It is clear that AU Her has pronounced 10 and 18 μm silicate features of both amorphous and crystalline nature. Based on the IRAS LRS spectrum of RY And, one would expect more pronounced silicates in this source. The ISOSWS spectrum is further evidence of the changing nature of the silicate features and general spectrum of M Miras with phase of the star (see also Little-Marenin et al. 1996, Creech-Eakman et al. 1997).

Also evident in these sources are a wealth of short wavelength features from CO and SiO gases and water present in these atmospheres. In some sources, there is a hint of the 13 μm feature attributable to Al_2O_3 (Begemann et al. 1997). While the spectra get considerably noisier past about 27 μm, there are two interesting long-wavelength features, at 29 μm (in all the sources) and 42 μm (in only AU Her). Based on the width of the features, it is likely they are related to crystalline solid state complexes of silicate dust (see for example Waters et al. 1998). It is possible, however, that the features near 30 μm are not real, caused by band mismatches when merging data from different detectors, so care must be taken in identifications at those wavelengths.

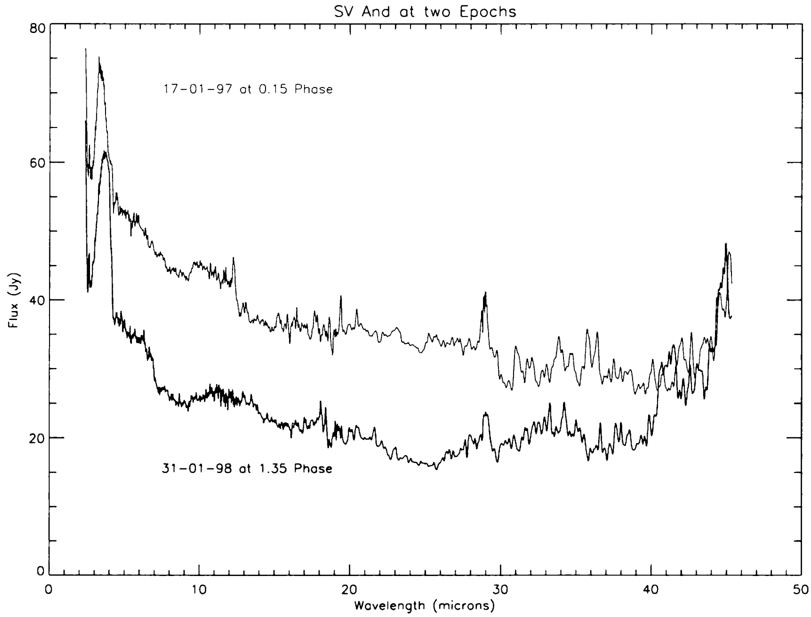

Figure 2. ISOSWS spectra of SV And at 2 epochs.

In Fig. 2 we show ISOSWS spectra of SV And at two epochs. While there is a change of nearly 20 Jy in overall level of the spectrum from the first to the second epoch, there are more pronounced changes in the individual spectra. In particular, the depth of the features near 3 μm, mainly attributable to H_2O and CO, are different by about 25%. Second, the silicate features at 10 and 18 μm and the SiO absorption at 7.5 μm combine to give an overall change in the appearance of the dust with phase. Finally the appearance of the 13 μm feature at only one epoch suggests dust formation processes on time scales of less than a pulsation period.

In Fig. 3 we show the 7.5–13.5 μm spectra from ISOSWS and CGS3 of SV And over a 3 year period. The top 2 spectra are from ISOSWS, while the bottom 3 are from CGS3. While it is possible that the CGS3 spectra are depressed with respect to the ISOSWS spectra due to telluric absorption, great care was taken in the calibration and reduction of this data to mitigate telluric effects. These data are presented to show that the character and flux level of the spectra change markedly with phase and do not precisely follow the visual light curve of the Mira. For instance, note the appearance of the spectral features from 9.5 to 10.5 μm and around 12 μm. Spectral features in these regions are most often associated with silicate dust. Changes in these regions are possibly indicative of short-time scale dust growth and destruction. Modeling of the

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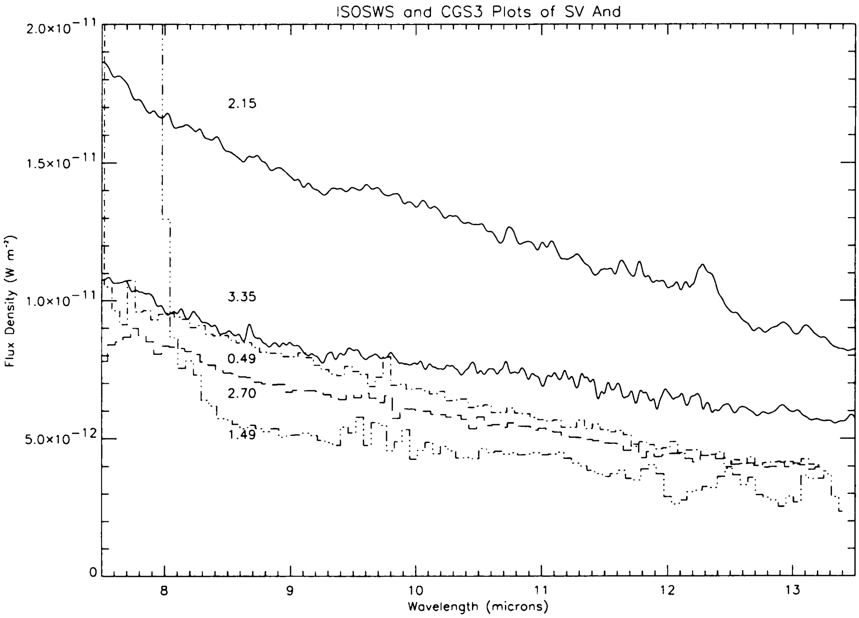

Figure 3. ISOSWS and CGS3 spectra of SV And over a 3 year time period demonstrate marked variability with phase. Epochs and phase were determined with concurrent AAVSO data.

major gas and dust constituents will help determine whether the changes seen are principally due to radiation and optical depth effects, or whether they indicate gross changes in the silicate dust.

4. Conclusions

In this paper, we have shown that marked variation exists among M Miras in the appearance of their spectral features throughout the 2.5–45 μm region. Along with differences among the various silicate emission features classes, individual stars show differences from one phase to the next, as is demonstrated by SV And. It is likely that the changes seen in the silicate features arise from formation, annealing and destruction of the dust during the stellar pulsation cycle (Creech-Eakman & Stencel 1998). Radiative hydrodynamical modeling with silicate dust formation will likely be needed to adequately reproduce the variations seen in these spectra.

Ongoing work in the form of both mid-IR photometry and near and mid-IR spectroscopy continues for some of these sources. In particular, we are currently trying to determine whether the short-term variations in M Miras reported by de Laverny et al. (1998) in the HIPPARCOS data are present at other wavelengths, in particular in the silicate dust and in the SiO and CO gas features. It is hoped that the new information presented here will encourage other groups to undertake dedicated photometric and spectroscopic monitoring of these sources.

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