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Dana Baylis-Aguirre
New Mexico Institute of Mining and Technology

Michelle J. Creech-Eakman
New Mexico Institute of Mining and Technology

Donald G. Luttermoser
East Tennessee State University, lutter@etsu.edu

Tina Gueth
New Mexico Institute of Mining and Technology

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Blinded by the Lines: Mid-IR Spectra of Mira Variables Taken with Spitzer

Dana Baylis-Aguirre,[1] Michelle J. Creech-Eakman,[1] Donald G. Luttermoser,[2] Tina Güth[1]

[1] Department of Physics, New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA
[2] Department of Physics & Astronomy, East Tennessee State University, Johnson City, Tennessee, USA

Abstract

We present preliminary analysis of mid-infrared spectra of M-type and C-type Mira variables. Due to the brightness of this sample, it is straightforward to monitor changes with phase in the infrared spectral features of these regular pulsators. We have spectra of 25 Mira variables, taken with phase, using the Spitzer Infrared Spectrograph (IRS) high-resolution module. Each star has multiple spectra obtained over a one-year period from 2008-09. This is a rich, unique data set due to multiple observations of each star and the high signal-to-noise ratio from quick exposure times to prevent saturation of the IRS instrument. This paper focuses on the 17.6 and 33.2 micron lines shared by M-types and C-types. These are mostly emission lines that change with phase. We discuss preliminary physical diagnostics for the atmospheres based on the lines, as well as possible line identifications such as fluorescence of metal species.

1 Introduction

One of the most fundamental questions in stellar physics is how stars enrich the interstellar medium with dust and molecules. Much of the answer lies in the complex behavior of Asymptotic Giant Branch (AGB) stars, which are low to intermediate mass stars (0.8 – 8 $M_\odot$) in the final stages of their evolution. AGB stars are characterized by H and He shell burning above a degenerate C/O core. Mira variables are AGB stars that regularly pulsate 200 to 500 days. These pulsations create shock waves that propagate through the atmosphere, contributing to mass loss rates as high as $10^{-6} - 10^{-4}$ $M_\odot yr^{-1}$. The relatively cool (2500-3500 K) atmospheres of Miras allow for the formation of molecules and dust, which enrich the ISM as the star experiences mass loss as seen in Figure 1.

We have mid-IR spectra for 25 Mira variables taken with phase, using the high resolution module of Spitzer's Infrared Spectrograph (IRS) (R$\sim$ 600) (Houck *et al.*, 2004). My dissertation focuses on analyzing the narrow spectral lines of the M-type (C/O $<$ 1) and C-type (C/O $>$ 1) Mira variables in this data set. Here we show preliminary analysis of the 17.6 μm and 33.2 μm features shared by both chemical sub-classes.

2 Data and Analysis

The 25 Mira variables in our data set were carefully chosen to be in a window easily observed with Spitzer, and to survey the M, S, and C chemical sub-classes. This is a unique, rich data set due to multiple observations of each star, and the high SNR from quick exposure times on these bright targets, which prevented saturation of the detector. For data reduction, see Creech-Eakman *et al.* (2012) or Tina Güth's contribution in these conference proceedings.

The spectral lines are being analyzed using the *Image Reduction and Analysis Facility* (IRAF) to create Gaussian fits for the features. Profile fitting includes line center, flux, full-width-half-max (FWHM), and equivalent width. Table 1 presents preliminary values for the 33.2 μm and 17.6 μm features for *SS Cas* and *V Crb*. The Atomic Line List (http://www.pa.uky.edu/~peter/newpage/) is consulted for line identifications.

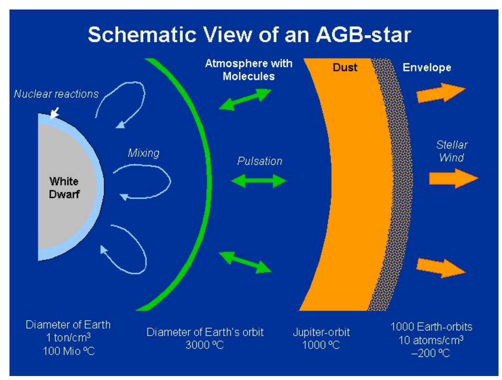
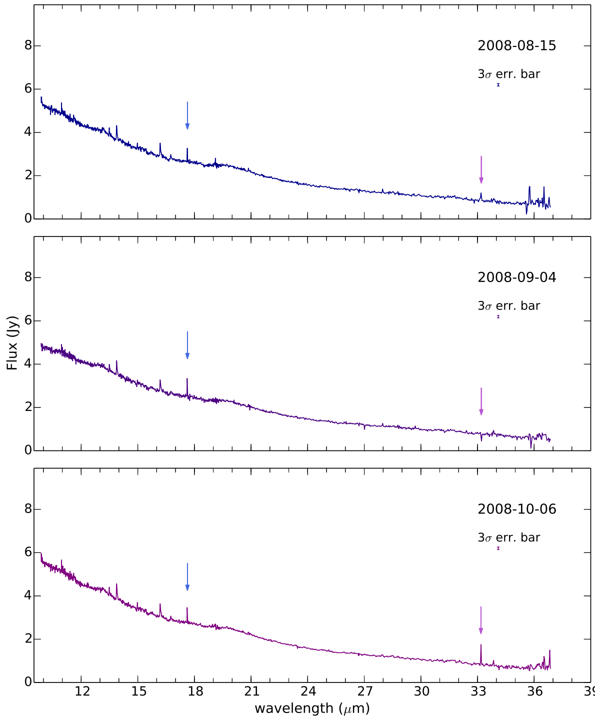


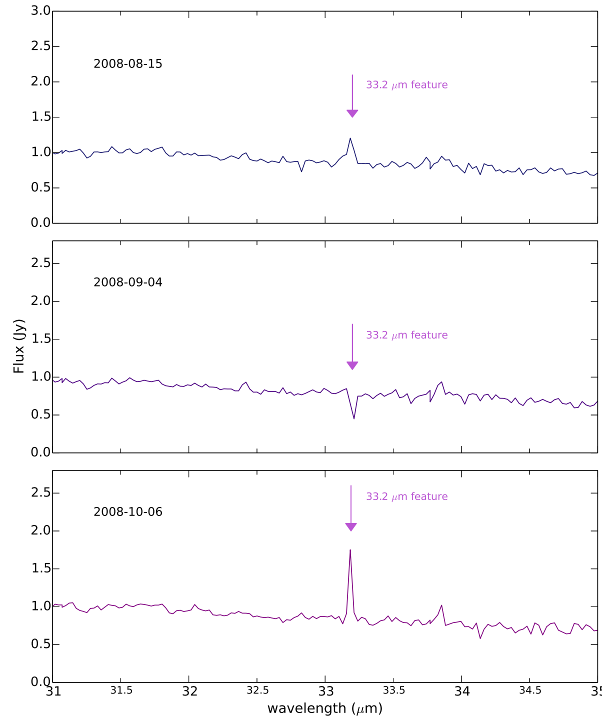
Figure 1: Illustration of AGB star showing the pulsation driven atmosphere and dusty circumstellar environment. (Graphic courtesy of Josef Hron, Univ. of Vienna)

3 Discussion

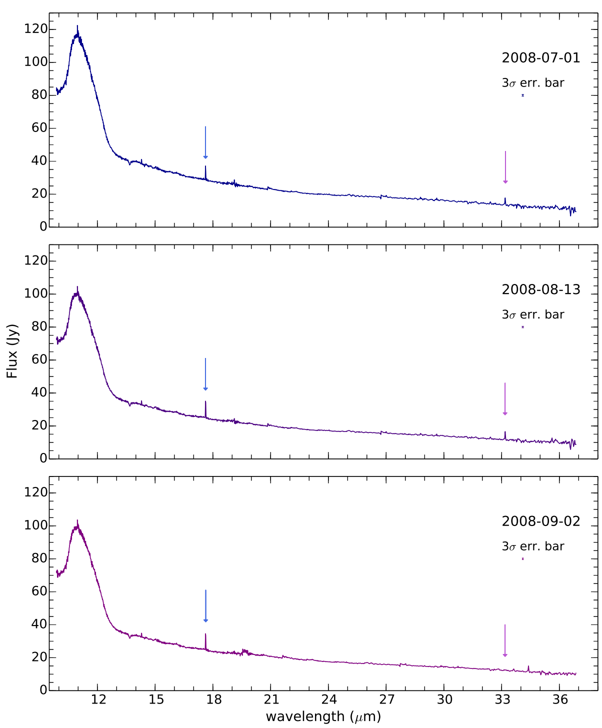
SS Cas and *V Crb* both have long histories in the literature. *V Crb* was first reported by Duner (1899) in a discussion of Class IIIb stars, while SS Cas was reported by Pickering & Fleming (1905) in a discussion of stars with unusual spectra. *SS Cas* has a period of 141 days (Bidelman, 1954; Feuchter, 1967), and has had negative detections for OH and H_2O masers (Sivagnanam *et al.*, 1988; Benson & Little-Marenin, 1996). *V Crb* has a period of 358 days (Bergeat *et al.*, 1976), and has angular size of 7.59 $\pm$ 1.16 mas at phase $\phi = 0.05$,



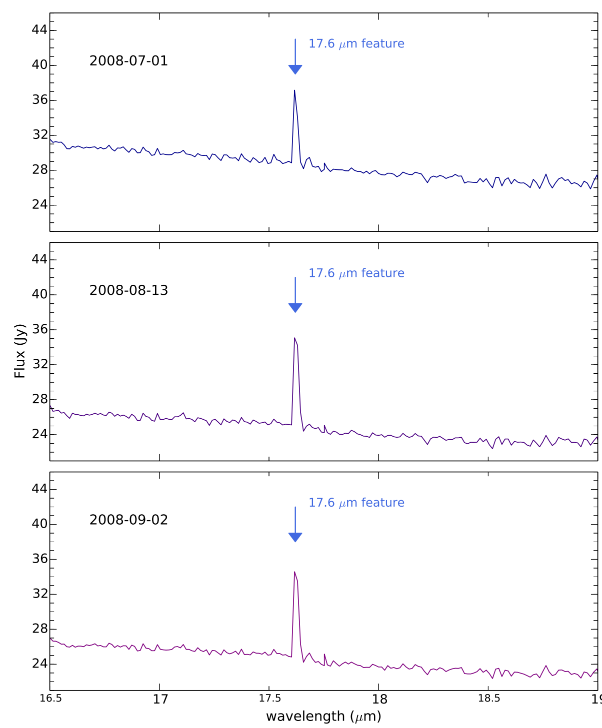
(a) Spitzer spectra for M-type Mira variable called *SS Cas*.



(b) A zoomed in view of the 33.2 μm feature as seen in *SS Cas*. These rapid changes indicate the atmosphere is in NLTE.



(c) Spitzer spectra for C-type Mira variable called *V Crb*.



(d) A zoomed in view of the 17.6 μm feature seen in *V Crb*.

Figure 2: Spitzer High Resolution Spectra for the two Mira variables *SS Cas* and *V Crb*. The dust features are discussed in Tina Güth's contribution in these proceedings.

Table 1: Results from fitting Gaussian profiles to the spectral lines in IRAF. The three values reported for each parameter correspond to the three different observations for each star.

	λ (μm)	Intensity (Jy)	FWHM (μm)	Preliminary Identification
SS Cas	17.6	0.70/0.98/0.80	0.024/0.020/0.020	Ca I, Fe I
	33.2	0.34/-0.36/0.97	0.043/0.036/0.026	Ca I, Fe I
V Crb	17.6	9.5/10.9/11.5	0.019/0.025/0.025	Ca I, Fe I
	33.2	4.43/5.30/–	0.029/0.028/–	Ca I, Fe I

and effective temperature of 2233 K (van Belle *et al.*, 1997).

Understanding the spectral lines shared by both these stars, such as the 17.6 μm and 33.2 μm features, as seen in Figure 2, will help us characterize Mira atmospheres in general. Making rigorous identifications for the 17.6 μm and 33.2 μm features is difficult because the Atomic Line List does not report oscillator strengths for many of the lines in the mid-IR. Ca I and Fe I are both strong candidates because they can be produced via the *s*-process, and they both have many lines in the mid-IR with large oscillator strengths.

We must finish characterizing the 17.6 μm and 33.2 μm features for the rest of the data set; it is possible these are fluorescence features, so we are also seeking potential pumps, such as the Mg II h and k lines, which are significant sources of optical fluorescence in Mira atmospheres (Luttermoser & Mahar, 1998). We will calculate the bolometric flux for the stars in our data set by using the multi-year observations of the Palomar Testbed Interferometer. Determining the phase dependence of the spectral lines will help narrow down possible pumping mechanisms. If Mg II is responsible for pumping these lines then it is possible this is the optical Fe I fluorescence that Willson (1972) described for long period variable stars continuing to cascade down into the infrared. The spectra presented here likely indicate that Mira atmospheres are not in equilibrium. The rapid changes of the 33.2 μm feature in Figure 2b, particularly show that these atmospheres are dynamical and changing with timescales shorter than the pulsation period; therefore we must consider them in non-local thermodynamic equilibrium (NLTE), and the next step is to model them accordingly with *PANDORA*, which solves the radiative transfer equation in NLTE.

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