Why Galaxies Care About AGB Stars: A Continuing Challenge through Cosmic Time
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The Structure of the Inner Circumstellar Shell in Miras

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Abstract. We have measured CO line profiles in a time series of 42 high-resolution 1.6 - 2.5 μm spectra of R Cas. The low-excitation CO first overtone lines have a contribution from a ~1000 K region. We show that this region undergoes a periodic changes on time scales many times longer than the photospheric pulsation. Comparison with interferometry and models suggests that the ~1000 K region is at ~2 R_* and cospatial with the region of SiO masers and grain condensation. The CO lines are entirely in absorption requiring formation in a layer thin compared to the stellar diameter. The CO excitation temperature has been measured as low as 600 K suggesting that grains with a variety of compositions condense at ~2 R_*.

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Low-mass stars undergo most of their mass loss on the AGB with this accounting for ~75% of the mass returned to the Milky Way ISM. AGB mass loss results from the combined effects of stellar pulsation and radiation pressure on dust. We report here on observations of low-excitation CO first overtone lines in the mira R Cas. The lines have multiple velocity components one of which is formed in cool, infalling gas. The temperature and velocity of the cool, low-excitation component are significantly different than that of high-excitation CO lines formed in the stellar photosphere.

The presence of multiple velocity components in low-excitation 2-0 lines has been known for decades (Hinkle 1978, Hinkle *et al.* 1982). However, previous time series were insufficient to reveal the nature of the variability (Hinkle & Barnes 1979). We report here on part of an extensive time series of near-IR mira spectra. In most spectra the 2-0 lines are blends but on rare occasions the photospheric and ~1000 K gas have opposite velocities and the two components can be resolved.

Figure 1 shows velocities measured from low-excitation 2-0 CO lines. The CO probes a region that undergoes long term, aperiodic variations. These are very different from the periodic variations seen in the CO second overtone lines and tied to the light curve (Hinkle *et al.* 1984). For spectra where the velocity components are well separated we have measured excitation temperatures. The CO excitation temperature was measured dropping from ~1100 K to ~600 K over ~300 days. This velocity component then disappeared, probably as the result of transversing a shock. This kind of behavior appears in a number of recent models for regions at $\gtrsim$2 R_* (Ireland *et al.* 2011, Gail *et al.* 2016, Liljegren *et al.* 2017).

Direct evidence that the ~1000 K CO is at ~2 R_* comes from VLTI/AMBER R=12000 K-band spectral-spatial interferometry (Ohnaka *et al.* 2017). The AMBER data show CO extending to ~3 R_*. Assaf *et al.* (2011) has shown that the R Cas SiO masers have a maximum concentration at ~2 R_*. ALMA observations by Wong *et al.* (2016)

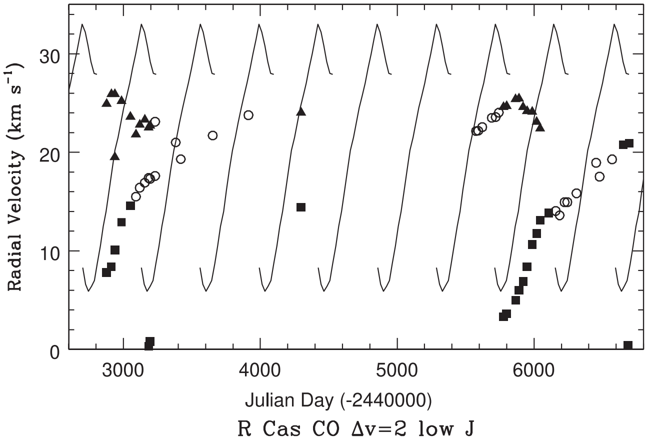

Figure 1. R Cas CO Δ v=2 low-excitation line velocities as a function of time. The points shown as filled squares have a high excitation temperature, the open circles are blends of high and low temperatures, and the filled triangles are at low-excitation temperature. The solid line is the mean velocity curve for the higher excitation CO Δ v=3 lines. The center of mass velocity of R Cas is 16.4 km s^{-1} so the cool gas is falling.

detect a ∼1000 K molecular layer at ∼2 R_*. The lack of P-Cyg type profiles in our observations show that the CO layer is thin. The line widths suggest the existence of large scale inhomogeneities that are also apparent in the SiO maser and ALMA results. An intriguing possibility is that the CO ∼1000 K component is formed in clouds that also can produce SiO masers. The maser clouds are preferentially seen tangentially while the CO layer is seen in absorption against the stellar photosphere.

The CO observations reported here show temperatures low enough for SiO condensation on grains. Models by Gail *et al.* (2016) and Liljegren *et al.* (2017) show SiO dust formation in descending clouds. On the other hand, Wong *et al.* (2016) argues that silicon can not be significantly depleted on grains in the SiO maser region. Al_2O_3 (corundum) grain formation occurs at ∼1000 K (Ohnaka *et al.* 2017). However, corundum is transparent to mira flux peak radiation (Woitke 2006) requiring the deposition of an opaque coating on the grain seeds if the grains are to be accelerated by radiation pressure (Bladh *et al.* 2015). Given the inhomogeneous nature of the 2 R_* region and our discovery of gas as cool as 600 K, grains with a variety of compositions should originate in this region.

References

Assaf, K.A., Diamond, P.J., Richards, A.M.S., *et al.* 2011 MNRAS 415 1083
Bladh, S., Höfner, S., Aringer, B., *et al.* 2015 A&A 557 A105
Gail, H.-P., Scholz, M., & Pucci, A. 2016 A&A 591 A17
Hinkle, K.H. 1978, ApJ, 220, 210
Hinkle, K.H. & Barnes, T.G. 1979, ApJ, 227, 923
Hinkle, K.H., Hall, D.N.B., & Ridgway, S.T. 1982, ApJ, 252, 697
Hinkle, K.H., Scharlach, W.W.G., & Hall, D.N.B. 1984, ApJS, 56, 1
Ireland, M.J., Scholz, M., & Wood, P.R. 2011 MNRAS 418 114
Liljegren, S., Höfner, S., Eriksson, K., *et al.* 2017 A&A 606 A6
Ohnaka, K., Weigelt, G., Hofmann, K.-H. 2017 A&A 597 A20
Woitke, P. 2006 A&A 460, L9
Wong, K.T., Kamiński, T., Menten, K.M., *et al.* 2016 A&A 590 A127

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