Cosmic Masers - from OH to H_0
Proceedings IAU Symposium No. 287, 2012
R.S. Booth, E.M.L. Humphreys & W.H.T. Vlemmings, eds.

doi:10.1017/S1743921312007041

High Resolution Radio and IR Observations of AGB Stars

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Abstract. Asymptotic Giant Branch Stars (AGB) are evolved, mass losing red giants with tenuous molecular envelopes which have been the subject of much recent study using infrared and radio interferometers. In oxygen rich stars, radio SiO masers form in the outer regions of the molecular envelopes and are powerful diagnostics of the extent of these envelopes. Spectroscopically resolved infrared interferometry helps constrain the extent of various species in the molecular layer. We made VLBA 7 mm SiO maser, Keck Interferometer near IR and VLTI/MIDI mid IR high resolution observations of the stars U Ari, W Cnc, RX Tau, RT Aql, S Ser and V Mon. This paper presents evidence that the SiO is depleted from the gas phase and speculate that it is frozen onto Al_2O_3 grains and that radiation pressure on these grains help drive the outflow.

Keywords. masers, stars: AGB and post-AGB, stars: imaging, stars: winds, outflows

1. Introduction

Asymptotic Giant Branch Stars (AGB) are low to intermediate mass stars that have exhausted their nuclear fuel, have become pulsating red giants and are losing most of their mass to become planetary nebulae. The extended, cool envelopes of these stars contain a variety of molecules some of which eventually condense into dust grains. In oxygen rich AGB stars, SiO masers form in the outer parts of the molecular envelope interior to where the silicate dust forms; see Reid & Menton (1997), Danchi *et al.* (1994). Observations by Perrin *et al.* (2004) and Wittkowski *et al.* (2008) have shown that molecules in the envelope occur in shells.

Open questions about AGB stars are how do they sometimes form very asymmetric planetary nebulae and how is the mass loss driven. The observed silicate dust forms too far out in the envelope for radiation pressure on this dust to help drive the outflow. Recent speculation has centered on the role of Al_2O_3 dust which can form at a relatively high temperature (∼1700 K). Wittkowski *et al.* (2007) presented SiO maser and mid-IR

Table 1. Primary IR Opacity Sources

wavelength	Opacity sources
near-IR	photosphere, inner molecular region
7.80 – 9.30 μm	SiO gas
9.37 – 11.50 μm	Silicate dust
11.55 – 13.26 μm	H2O gas

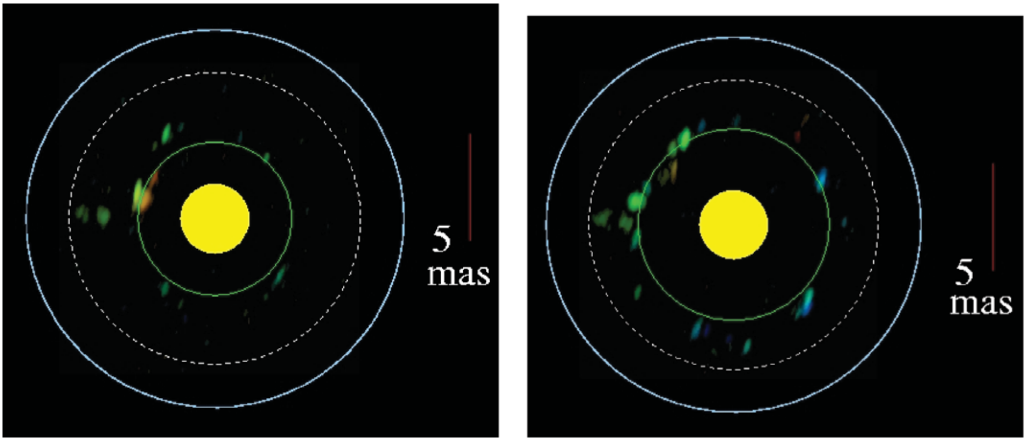

Figure 1. S Ser. On the left is the image in the SiO ν=2, J=1-0 transition. The green circle gives the fitted diameter on the maser ring, the light blue line the fitted size of the IR molecular shell and the dashed white line, the radius at which Al_2O_3 could condense. On the right is the image in the SiO ν=1, J=1-0 transition.

interferometric observations of the AGB star S Ori which they interpreted as showing Al_2O_3 dust forming just interior to the SiO masers.

2. Observations

A sample of AGB stars was observed using the VLBA, VLTI/MIDI and the Keck Interferometer. Multiple snapshot observations of the 7 mm SiO masing ν=1,J=1-0 and ν=2,J=1-0 transitions near 43 GHz were made on 1 July 2007 and 24 February 2008. Observations were analyzed as described in Cotton *et al.* (2006). The diameters of the masing regions were characterized by fitting circular rings.

Observations with the VLTI/MIDI (Leinert *et al.* 2003) measured between 7 and 14 μm; The Keck Interferometer observed S Ser at 2.2 μm. Models were fitted to the IR data to derive sizes of the photosphere and one or more layers needed to characterize the envelope seen in the mid IR. The mid-IR spectrum was modeled by wavelength ranges; the expected principle opacity sources of these are given in Table 1.

3. Results

The observational results are given for S Ser in Fig. 1, W Cnc in Fig. 2, RX Tau in Fig. 3, U Ari in Fig. 4, V Mon in Fig. 5 and RT Aql in Fig. 6. For S Ser, only a single mid IR visibility was measured and a single layer model was fitted to the data. Too few maser spots were deteceted in U Ari and V Mon to reliably fit ring sizes. However, the minimum ring diameter for V Mon is the separation of the two spot groups which is very nearly the same as derived in the mid IR. No IR interferometric data were obtained

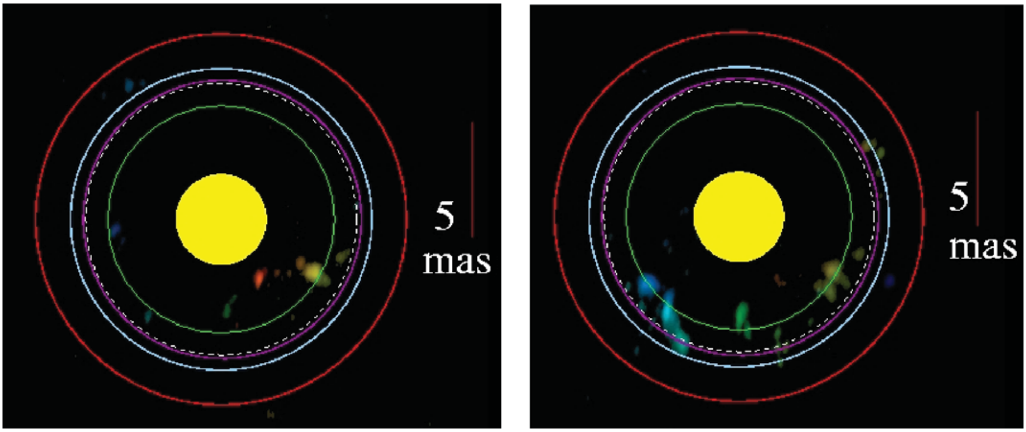

Figure 2. W Cnc. Like figure 1 except that the light blue circle shows the fitted size of the 7.8–9.3 μm data; magenta, the size of the 9.4–11.5 μm and red, 11.6–13.3 μm.

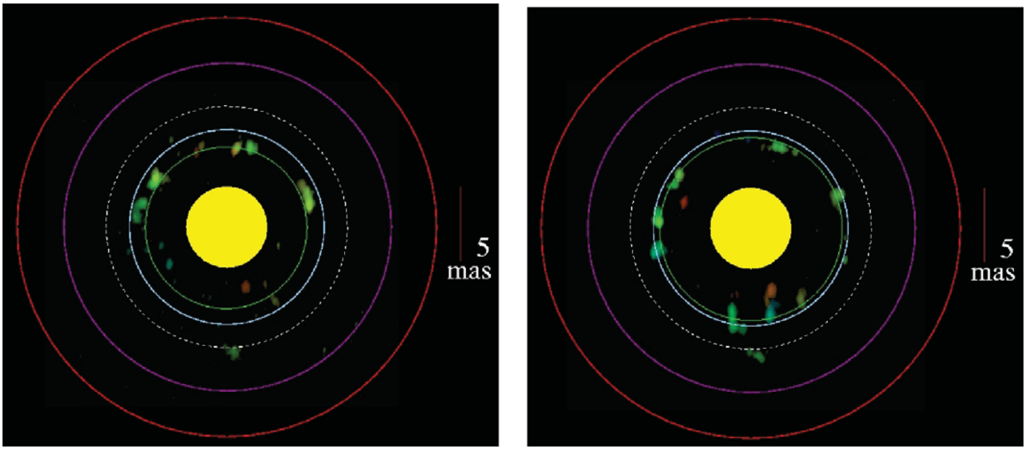

Figure 3. RX Tau. Like figure 2.

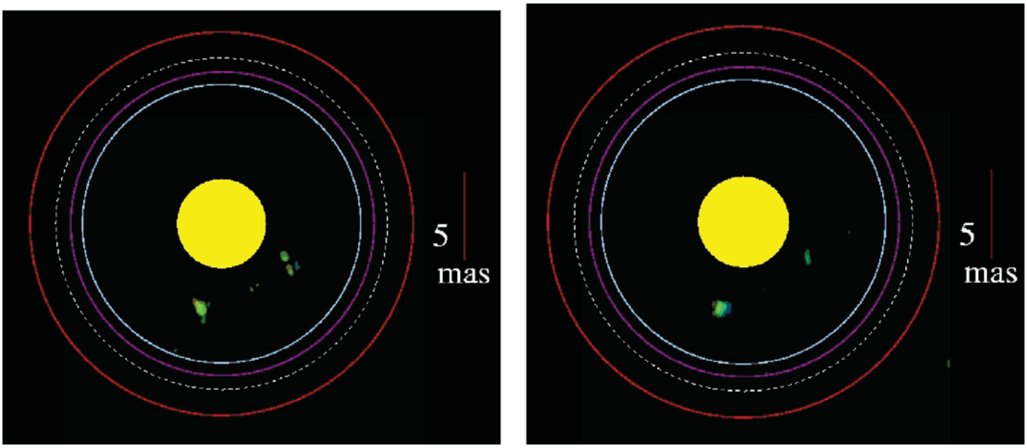

Figure 4. U Ari. Like figure 2 except that insufficient maser emission was present to fit a ring and align with the IR data.

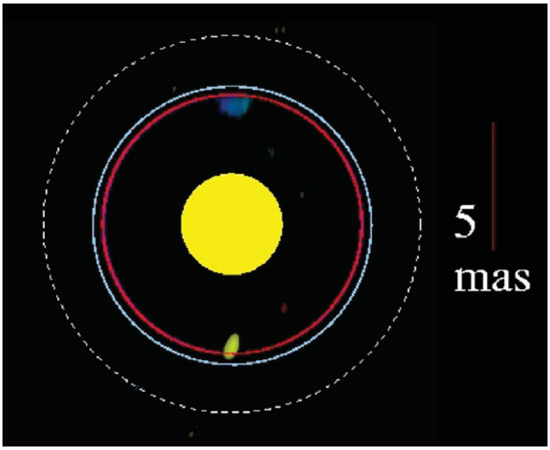

Figure 5. V Mon. Like figure 3 except that maser emission was only detected in the ν=1, J=1-0 transition.

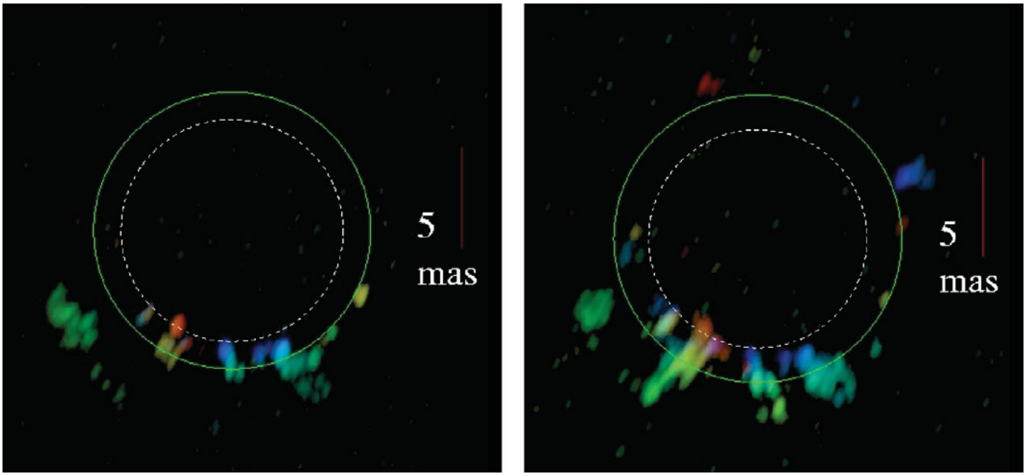

Figure 6. RT Aql. Like figure 2 except no IR interferometric data were obtained.

for RT Aql and the size of the photosphere, hence the anticipated Al_2O_3 condensation distance was based on photometric measurements from the literature.

4. Discussion

In none of the visibility spectra do we detect the strong 9.8 μm silicate feature. Conversion of SiO to silicate must take place exterior to the region probed by this data.

There are two indicators of SiO gas in our data, the SiO masers and the SiO lines in the 7.80 – 9.30 μm spectral region. With the possible exception of RT Aql, none of the stars observed show evidence for either of these diagnostics significantly exterior to the radius at which Al_2O_3 is expected to form (dashed circles in Figures 1–6). There was no IR interferometric data obtained for RT Aql and the photospheric size and the radius of Al_2O_3 condensation were estimated from photometric measurements in the literature. The ratio of the SiO maser ring size to the photospheric size is quite different for RT Aql and the values near 2.0 found in well constrained cases.

Following the suggestion of Verhoelst *et al.* (2006), we propose that the gas phase SiO is condensing onto Al_2O_3 grains soon after these grains form. If this is the case, then the chemical conversion from SiO to silicates must take place on the dust grains. The radiation pressure on these dust grains with SiO mantles relatively close to the photosphere could then help drive the outflow.

References

Cotton, W. D., Vlemmings, W., Mennesson, B., *et al.* 2006, *A&A*, 456, 339

Perrin, G., Coude Du Foresto, V., Ridgway, S. T., *et al.* 2004, *A&A*, 426, 279

Reid, M. J. & Menton, K. M. 1997, *ApJ*, 476, 327

Danchi, W. C., Bester, M., Degaicomi, C. G., Greenhill, L. J., & Townes, C. H. 1997, *AJ*, 107, 1469

Leinert, C., Graser, U, Richichi, A., *et al.* 2003, *The Messenger*, 112, 13

Verhoelst, T., Decin, L., van Malderen, R., *et al.* 2006, *A&A*, 447, 311

Wittkowski, M., Boboltz, D. A., Ohnaka, K., Driebe, T., & Scholz, M. 2007, *A&A*, 470, 191

Wittkowski, M., Boboltz, D. A., Driebe, T., *et al.* 2008, *A&A*, 479, L21