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IR and SiO Maser Observations of Miras

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Abstract. Preliminary results of a coordinated program of near IR and SiO maser interferometric observations of Mira variables are reported. The 2.2 and 3.6 micron results are from the FLUOR interferometer on the IOTA array and the SiO maser observations from the VLBA. The ratio of the SiO ring diameter to the apparent diameter at 2.2 microns for stars in our sample cluster around 2, whereas the 3.6 micron diameters range from slightly larger than the 2.2 micron diameter to approximately

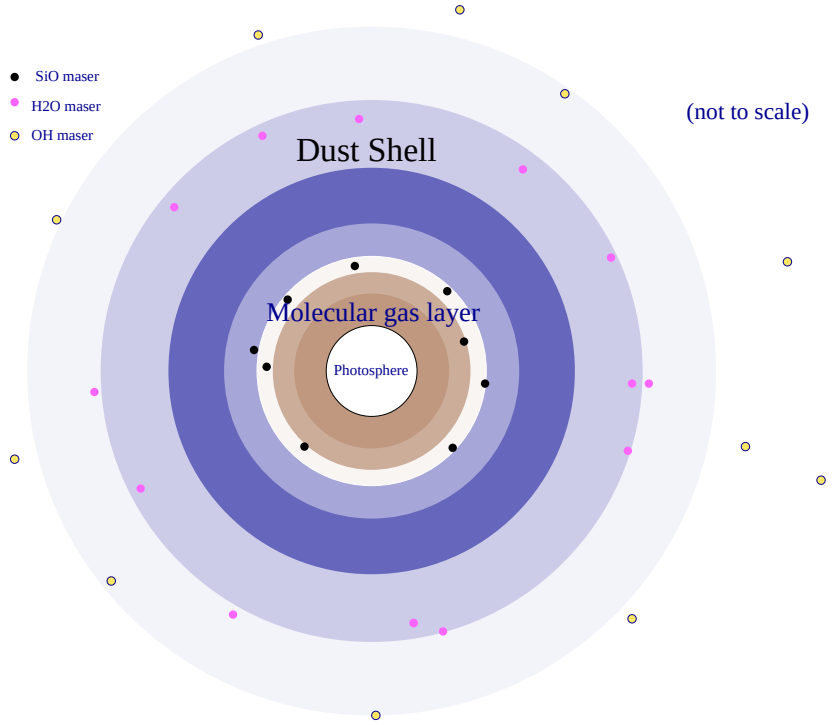

Figure 1. A cartoon showing some of the features of the circumstellar envelope of Mira stars.

the SiO ring diameter. This may be due to differences in the opacity of the molecular envelope at 3.6 microns.

1. Introduction

Stars on the Asymptotic Giant Branch (AGB) are low to intermediate mass evolved stars which are shedding much of their mass to the ISM. As such, they are one of the major sources of replenishing gas and dust to the ISM. The detailed structure of the circumstellar envelopes around these stars and the mass loss mechanism are not well understood. Oxygen rich AGB stars frequently exhibit molecular masers; in particular SiO masers near 43 GHz occur in the molecular layer close to the photosphere. Most AGB stars are pulsationally unstable but Mira type stars are periodic and have very large variations, 5 magnitudes or more, in the visual. A cartoon of the circumstellar envelope of a Mira star is shown in Figure 1. This paper is a preliminary report on the VLBA observations of the SiO masers observed in Miras as part of a coordinated radio-IR program. A detailed description of the maser observations is given in (Cotton et al. 2003). The IR interferometric results are reported in (Mennesson et al. 2002).

2. Observations

The VLBA plus a single VLA antenna was used in four 18 hour sessions, on Jan. 25, Apr. 29, Aug. 4 and 10 Nov. 2001. Dual circular polarizations were recorded with 4 MHz bands covering the 42.820587 and 43.122027 GHz, ν=2, J=1-0 and ν=1, J=1-0 masing transitions of SiO. Data were sampled to two bits and 128 frequency channels used for each transition and polarization. The stars observed in one or more of these sessions were R Andromadae, omicron Ceti (Mira), U Orionis, R Leonis, W Hydrae, S Coronae Boralis, U Herculis, R Aquarii and R Cassopeiae.

The infrared observations were made using the FLUOR and TISIS interferometers on the CFA IOTA array on Mt. Hopkins, Arizona, USA. The observations are described in detail in (Mennesson et al. 2002).

3. Maser Results

3.1. Variations of SiO Maser Ring diameters

SiO masers appear in incomplete rings around the photosphere of the star as illustrated in Figure 1. For each star and each epoch, a circular ring diameter and width was estimated jointly from the two transitions subject to the constraint that the two transition have a common center. The mean and RMS variation of the mean is shown in Table 1 for those stars observed in all four epochs. The typical period of a Mira is approximately a year so the observations reported here covered most of a pulsation cycle. Most of the stars had variations on the order of 5-10%, consistent with the models of (Humphreys et al., 2002). However, U Orionis showed almost no variation in the size of the SiO maser ring.

Table 1. SiO Ring Diameter Variations

Star	Mean[1] (mas)	RMS[1] (mas)	percent[1] (%)	Mean[2] (mas)	RMS[2] (%)	percent[2]
omicron Ceti	70.3	7.0	10	68.3	5.0	7
U Orionis	29.3	1.0	3	27.5	0.2	0.7
R Leonis	57.4	4.3	8	54.5	5.3	10
S Coronae Boralis	20.6	1.9	9	18.9	0.5	3
U Herculis	25.3	1.6	9	22.6	1.7	8

[1] ν=1, J=1-0 transition of SiO at 43.1 GHz.
[2] ν=2, J=1-0 transition of SiO at 42.8 GHz.

3.2. Comparision of SiO Maser Ring and IR diameters

The distances to most Miras are poorly known so the best comparison of sizes is by diameter ratios. Ratios of 2.2 and 3.6 μm diameters to that of the SiO maser ring is shown in Figure 2. The ratio of 2.2 μm to SiO diameter is relatively constant but the 3.6 μm to SiO diameter is not. Both the IR measurements are sensitive to molecular line emission, 3.6 3.6 μm more than 2.2 μm. U Ori and R Aqr stand out from the others in having apparent sizes at 3.6 μm of

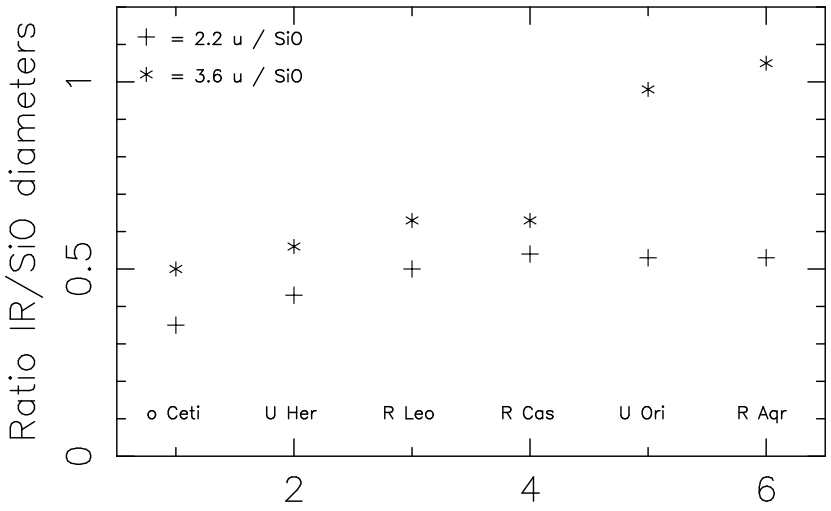

Figure 2. Ratio of IR diameters to SiO maser ring diameters for a number of Mira stars.

approximately that of the SiO maser ring. These stars are also different in that the inner diameter of the dust shell inferred by (Danchi et al., 1994) from earlier 10 μm data is much larger than for the others. These observations suggest a different temperature and/or opacity structure in the circumstellar envelopes of these stars (Perrin et al., 2003).

3.3. Possible Molecular Disk Around R Aquarii

The velocity field of the masers around R Aquarii was found to be consistent with rotation with a period of $\approx$22 years, this was in agreement with the finding of (Hollis et al, 2001). Furthermore, in the January 2001 data there is evidence for an equatorial molecular disk whose rotation velocity decreases away from the star as $r^{-1.8}$.

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