National Radio Astronomy Observatory

RESOLUTION OF CIRCUMSTELLAR SiO MASERS AROUND LATE TYPE STARS

---CIRCUMSTELLAR SiO---

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I. Observed SiO circumstellar maser transitions:

44 GHz J = 1-0, v = 0,1,2,3
86 GHz J = 2-1, v = 0,1,2
128 GHz J = 3-2, v = 0,1,2
172 GHz J = 4-3, v = 0,1,2
216 GHz J = 5-4, v = 0,1,2

These lines are likely to be observable to very high J values, as stellar masers are likely to be useful to as high a frequency as the millimeter array will work. They can be used for pointing as well as for science in their own right.

Lane (thesis 1982) concludes that within the J = 1 - > 0 rotational state the V = 1, 2, and 3 transitions are quite similar, while the J = 2 - > 1 transitions look quite dissimilar to the J = 1 - > 0 either between the same or different vibrational states. This is a most peculiar state of affairs, as the E/k energy difference between the rotational states, which appear quite different, is only on the order of 1 K while the E/k difference between the vibrational states, which do appear similar, is on the order of 1800 K.

II. Theoretical expectations:

The size of red giant Mira variables is usually taken in the literature as 3×10^{13} cm^{-1}. A recent preprint by Bertschinger and Chevalier estimates the size of these stars and their maser regions as:

size of star $\sim 3\times10^{13}$ M cm (where M is mass in solar masses)
size of SiO $\sim 5.2\times10^{13}$ M cm (Bertschinger and Chevalier 1985)

If the stars are 50 to 1500 pc away, then the maser diameter should be 0.07 M to 0.002 M arcsec, where the size is multiplied by the mass of the star in solar masses (see actual obs. below), where the mass of the stars likely lies in the range 1 - > 30 M for giants and supergiants.

The distances to these stars are measured by a variety of indirect means. Trigonometric parallaxes exist for Mira, with an estimate of 42 pc in the bright star catalog, but other measures yield ranges of 25 to 114 pc, and this number apparently is at the upper limit of useful ground based parallax. Theoretically, one might expect observable effects on the maser from the stellar pulsation, perhaps velocity pulsation (about 30 km s^{-1} max), disruptive effects, abundance and excitation effects. Clark, Troland and Johnson claim that the linear polarization properties of the J = 2 - > 1 transition are continuous between maxima and disrupted maxima. They also claim a small phase dependent velocity pulsation for the SiO emission from W Hya. An observable pulsation of this type, coupled with accurate knowledge of the shock velocity at the distance of the maser from the star, could lead to distance estimates to the stars.

Again, using Bertschinger and Chevalier, the size of the star is expected to be about a factor of two smaller than the maser. Western and Watson's excitation papers do not locate the maser with respect to radius, but do indicate that the SiO maser should be dominantly tangential, and should appear as a ring around the star, with radial or tangential linear polarization on this ring.

Brightness temperatures should be a few billion degrees.

III. Actual Observations of Maser/Stellar angular sizes

Lane (thesis) observes angular sizes of several stellar masers and these are given in the table below. The VLB observations are only of J = 1-0 transition of SiO at 43 GHz. Note that the stellar sizes in arcseconds are actually measured (using "speckled spectra," try picking a peck of those!). Distances to these stars are not well known, and it perhaps is safest to compare measured angular sizes. For example, distances in the literature for Mira range from 25 to 114 pc, R Leo 130 to 1000 pc! Trigonometric parallaxes are quoted for three of these stars in the Yale Bright Star Catalog, 4th edition.

References:

Adair Lane's thesis, FCRAO 191, 1982; Labeyrie et al. 1982, A&A, 106, 235; Labeyrie et al. 1977, Ap. J., 218, L75; Lane 1984 IAU Symp., 110, 329.

Source	Dist# Range pc	Trig Par. pc	Dist used pc	Prdct SiO "/M	Obs. Region "	Obs. Spot "	Prdct Star "	Obs. Star "	Infer Mass M	* type	Obs. Tb SiO K	Ref.
Mira	25-240	42	77	.04			.026	.03-.10	1.1	Mira		Labeyrie 1977 ApJ 218 L75
R Leo	50-1000	50	250	.014	.065	.005-.02	.008	.03-.05	3.8	Mira		Labeyrie 1977, Lane 1984
VX Sgr			1500	.0023	.075	.004-.02			30.4	SG	2x10**10	Lane 1982
R Cas	195-294		230	.015	.085	.008-.02			5.3	Mira	5x10**9	Lane 1982
W Hya	100-240		200	.017		.01-.02				Irr	5x10**9	Lane 1982
IK Tau	270-400					.005-.02					5x10**9	NML Tau. Lane 1982
chi Cyg	71-393	83	83					.023+		S		speckle, Christou & Worden 1980
chi Cyg	71-393							.100+		S		IR speckle, Mariotti et al 1983
u Her	200-450							<=.100		Mira		Mariotti et al 1983
Orion			480	---	.14	.01-.025	--	--		--	5x10**9	Lane 1982

Range of distances quoted in literature
Trigonometric Parallax from Yale Bright Star Catalog, 4th ed.
+ larger size interpreted as stationary shell of Hinkle
Obs. Region is size of the entire region containing "spots"
Obs. Spot is size of maser spots

Labeyrie 1977 ApJ 218 L75
Lane 1982 PhD thesis, U. Mass
Lane 1984 IAU 110, p329.
Christou & Worden 1980 ApJ 85,302.
Mariotti et al 1983 A&A120, 237

Note that I have used Bert. & Chev.'s preprint to calculate masses of these objects, which are extremely uncertain, as are distances. The mass of Mira type variables is typically estimated at about 2 M. The mass of VX Sgr. should be high, as it is reputedly a supergiant, and their calculations may be inappropriate.