First VLBI mapping of ^{29}SiO emission in a circumstellar envelope

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SiO maser emission in circumstellar envelopes of AGB stars

- Maser emission in three different isotopic substitutions: ^{28}SiO, ^{29}SiO and ^{30}SiO.

- ^{28}SiO masers in hundreds of variable stars: $v=1$ to $v=4$ and $J=1-0$ up to $J=8-7$ (single dish).

  Variability
  Typical phase lag between SiO and optical maxima $\sim$ 0,1 periods
  $f_{8\mu m} \sim 5\, f_{SiO}$

  VLBI has studied in detail ^{28}SiO transitions at 43 GHz towards Mira-type variables.

  ^{28}SiO $v=1$ $J=2-1$ transition at 86 GHz mapped successfully in R Leo, χ Cyg and IRC +10011.

- ^{29}SiO maser lines:

  - detected in tens of sources and in a few rotational transitions of the $v=0,1,2$ states (single dish).

  - Some properties associated to ^{28}SiO: time variability + correlation with 8μm stellar radiation.

This is the first VLBI mapping of ^{29}SiO maser emission in an evolved star (IRC +10011)

Observations: IRC +10011

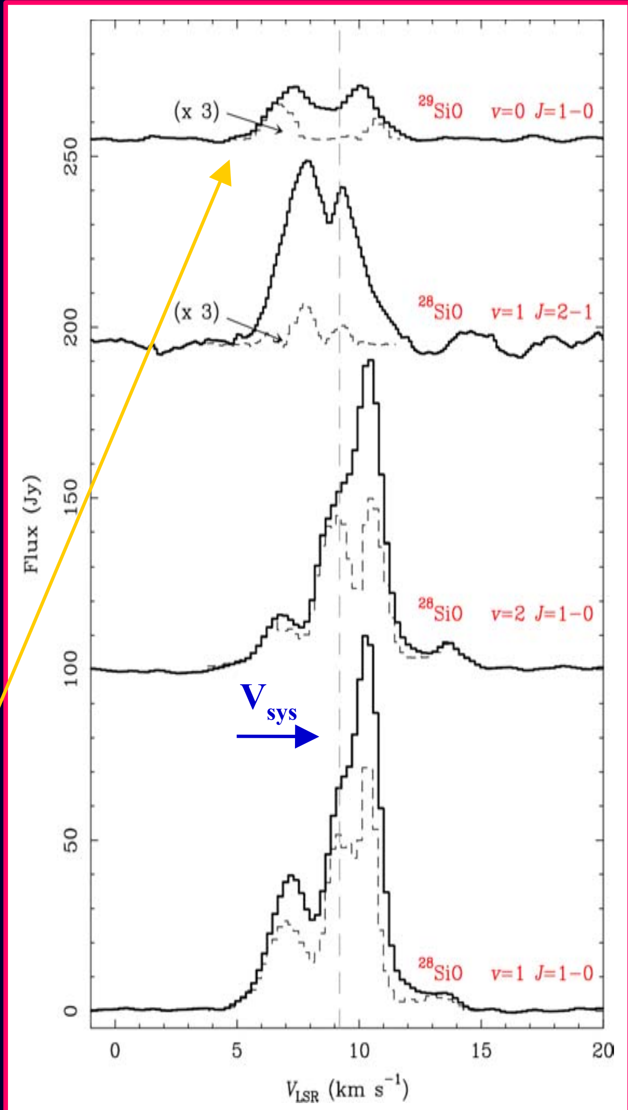
species	maser transition	rest frequency (MHz)	restoring beam (mas)	R_{in} (mas)	R_{out} (mas)
^{29}SiO	$v = 0$ $J = 1\text{-}0$	42879.916	0.97 x 0.73	11.80	15.26
^{28}SiO	$v = 1$ $J = 2\text{-}1$	86243.442	0.58 x 0.47	15.33	16.92
^{28}SiO	$v = 1$ $J = 1\text{-}0$	43122.080	0.80 x 0.53	10.07	13.09
	$v = 2$ $J = 1\text{-}0$	42820.587	0.85 x 0.35	8.81	12.35

The $v = 1$ and $v = 2$ $J = 1\text{–}0$ ^{28}SiO lines present similar line profiles. About 70% of the emission was recovered.

The $v = 1$ $J = 2\text{–}1$ ^{28}SiO is composed of two peaks (50 Jy). 10% of the emission recovered.

The $v = 0$ $J = 1\text{–}0$ ^{29}SiO maser transition has an intensity of 16 Jy, being the weakest. About 25% of the emission recovered.

Total power vs. Recovered flux



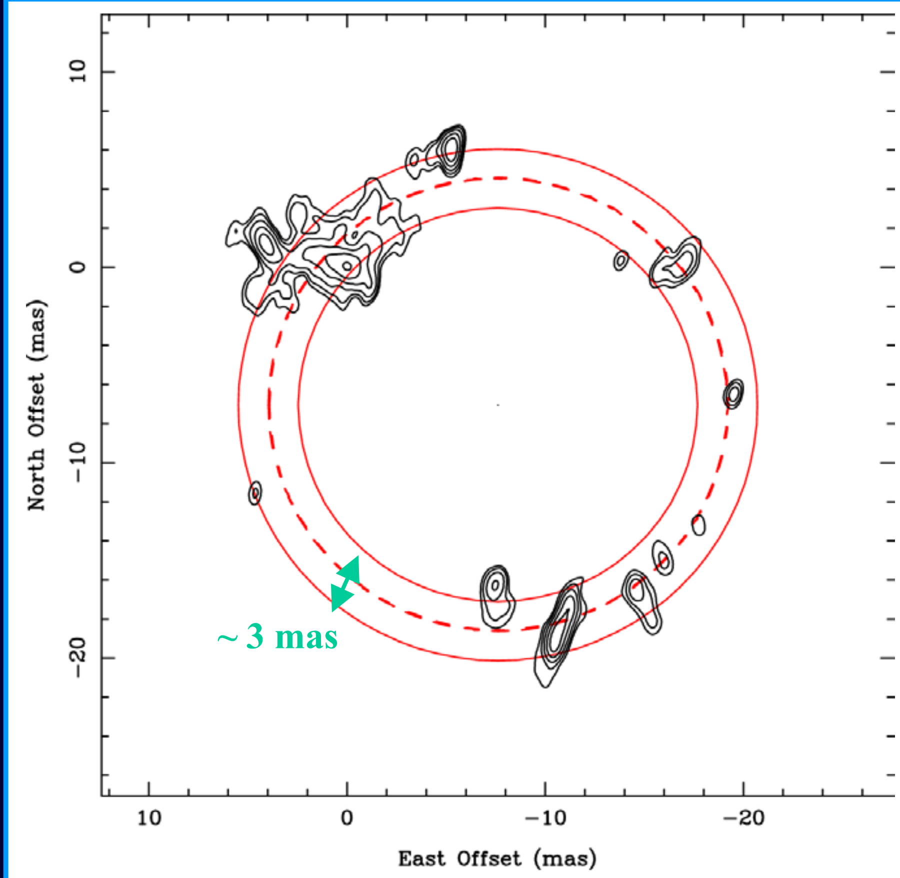
Results I: ^{28}SiO $v=1$ $J=1-0$

IRC +10011

To compare the VLBA maps, we fit a ring to our observational data, selecting the maser spots with a SNR ≥ 6 and those appearing on at least 3 consecutive spectral channels.

We derive the center, the width (ΔR) and the mean radius (<R>) of the ring.

$$R_{in} = \langle R \rangle - 1/2\ \Delta R$$
$$R_{out} = \langle R \rangle + 1/2\ \Delta R$$



Contour levels: 0.28, 0.57, 1.14, 2.28, 4.16 and 8.34 Jy/beam·km/s
Peak flux: 9.14 Jy/beam·km/s

The map is composed of multiple maser spots forming a ring with a mean radius of ~ 11.6 mas.

Results consistent with Desmurs et al. (2000) and Soria-Ruiz et al. (2004).

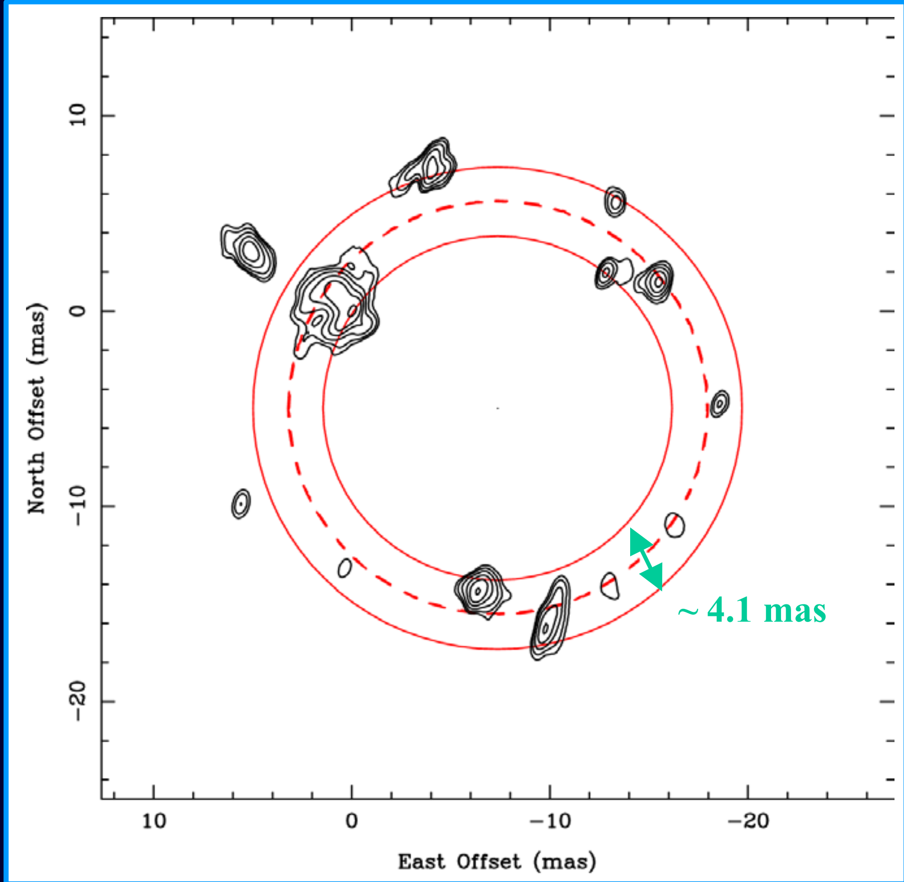
Results II: ^{28}SiO $v=2$ $J=1-0$

IRC +10011

The ring-like structure has a mean radius of ~ 10.6 mas.

Compared to the $v=1$, the $v=2$ $J=1-0$ is located in an inner region of the envelope (~ 1 mas).

This result is consistent with previous studies by Desmurs et al. (2000), Cotton et al. (2004) and Soria-Ruiz et al. (2004) .



Contour levels: 0.28, 0.57, 1.14, 2.28, 4.16 and 8.34 Jy/beam·km/s
Peak flux: 9.74 Jy/beam·km/s

Results III: ^{28}SiO v=1 J=2−1

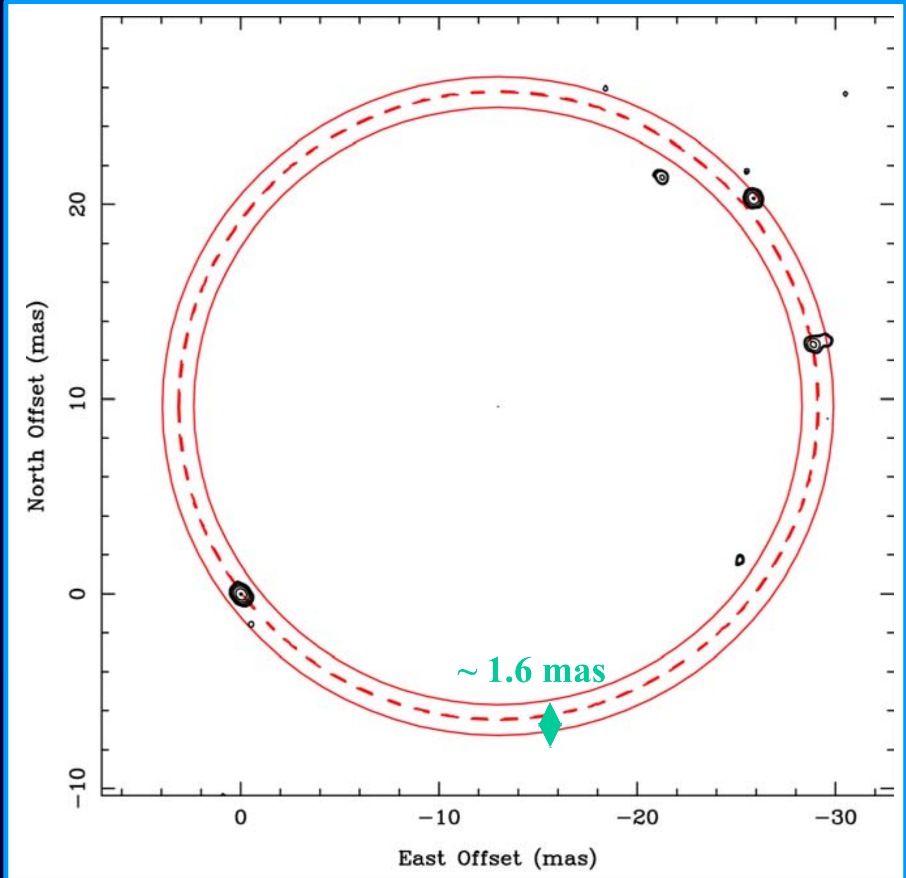
IRC +10011

The map is composed of a few maser spots forming a ring with a mean radius of ~ 16.1 mas.

The emission is located in an outer region of the circumstellar envelope.

Consistent with Soria-Ruiz et al. (2004).

Similar result in R Cas by Winter et al. (2002) and Phillips et al. (2003) and OH231.8+4.2 by Desmurs et al. (these proceedings).



Contour levels: 0.10, 0.12, 0.14, 0.28, 0.57, 1.14 and 2.28 Jy/beam·km/s
Peak flux: 2.41 Jy/beam·km/s

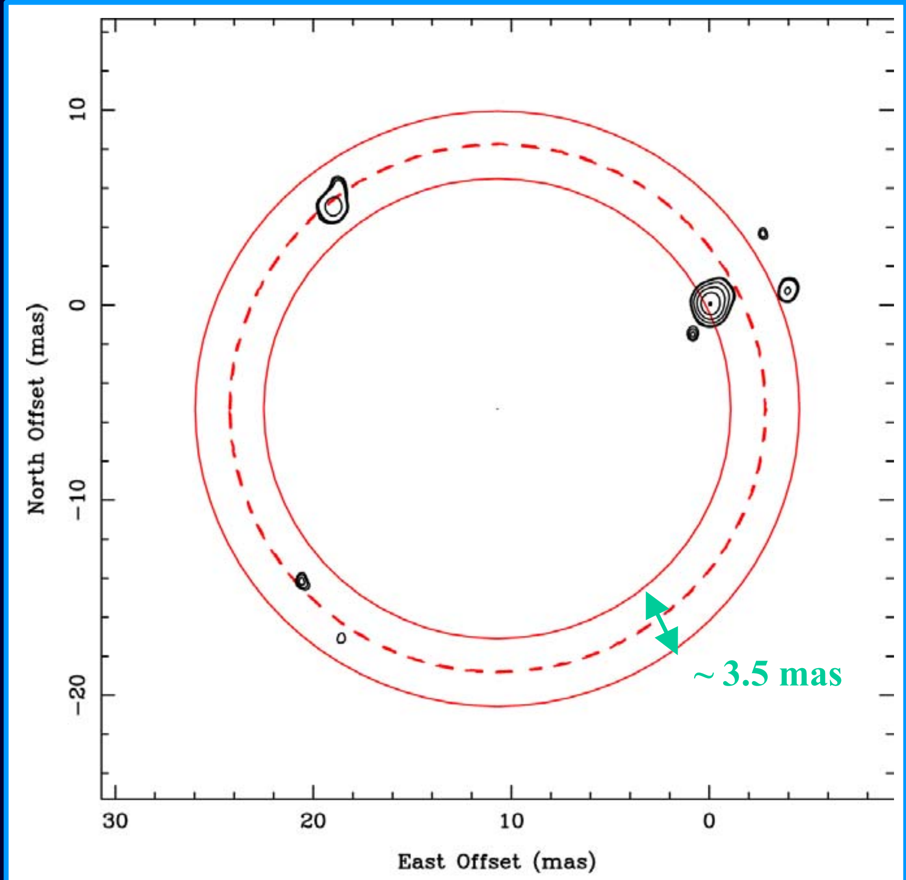
Results IV: ^{29}SiO v=0 J=1−0

IRC +10011

<u>First VLBI map</u> of the ^{29}SiO v = 0 J = 1–0 maser transition in a circumstellar envelope using VLBI.

The map is composed of a few spots forming a ring, though incomplete, with a mean radius of ~ 13.5 mas, suggesting <u>tangential amplification</u>, as in other ^{28}SiO masers studied.

The ^{29}SiO masing layer is <u>located in between</u> the ^{28}SiO v = 1 J = 1–0 and J = 2–1 rings.

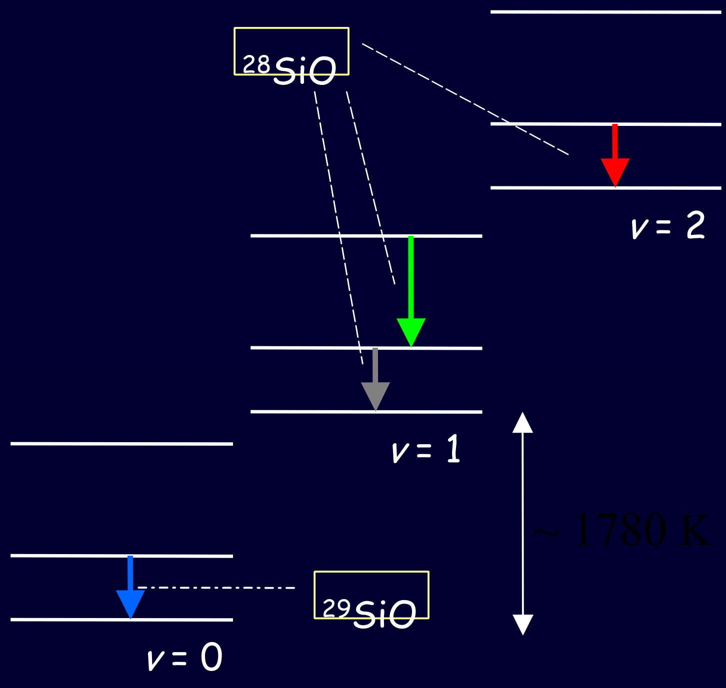


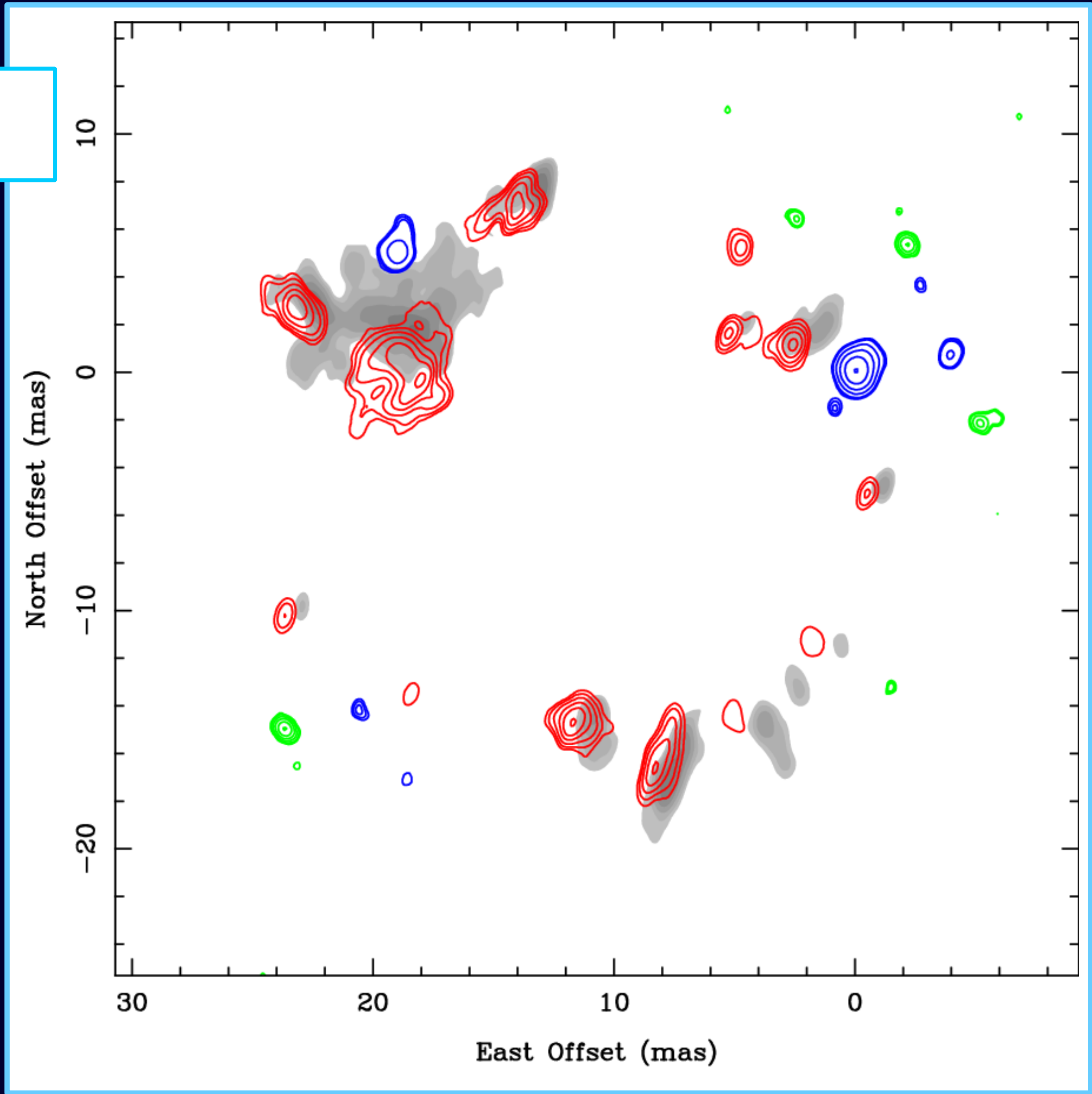
Contour levels: 0.08, 0.10, 0.12, 0.23, 0.46, 0.92 and 1.76 Jy/beam·km/s
Peak flux: 1.77 Jy/beam·km/s

The entire SiO masing shell is ~ **7 – 9 mas** width !

^{29}SiO v = 0 J = 1–0 ^{28}SiO v = 1 J = 2–1

^{28}SiO v = 1 J = 1–0 ^{28}SiO v = 2 J = 1–0

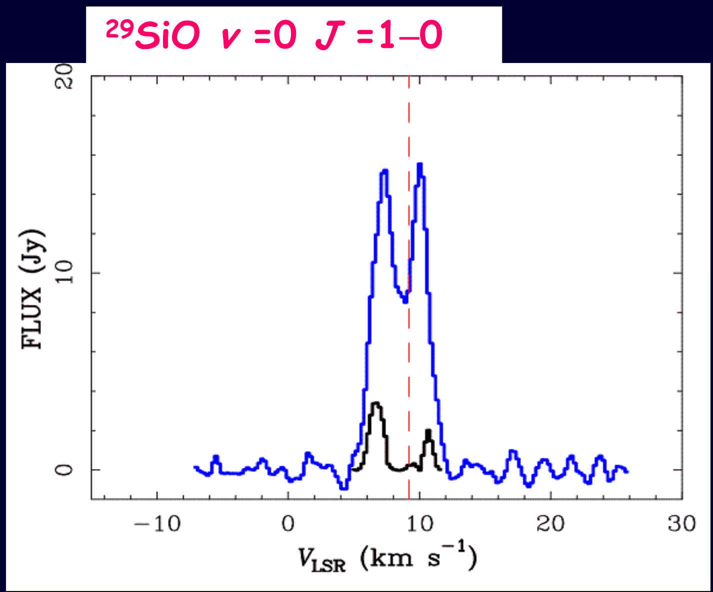


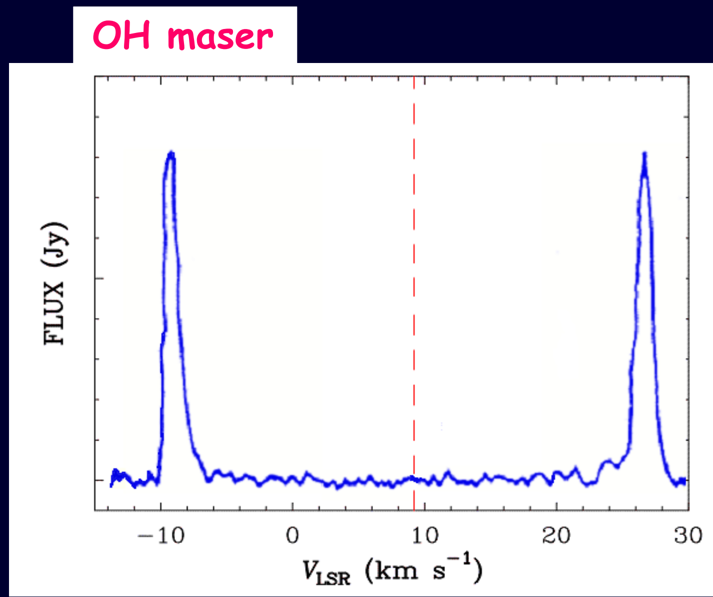


^{29}SiO pumping models

Robinson & Van Blerkom (1981): produced when there is an asymetry in the radiation trapping. The opacity along the radial direction is higher than the mean opacity, in an expanding low acceleration regime. The line profiles are composed of two peaks separated twice the expansion velocity of the envelope, similar to those observed in OH masers.

This model does not reproduce the observed line shapes and obviously our ring-like geometry, an indication of not radial but tangential amplification !!



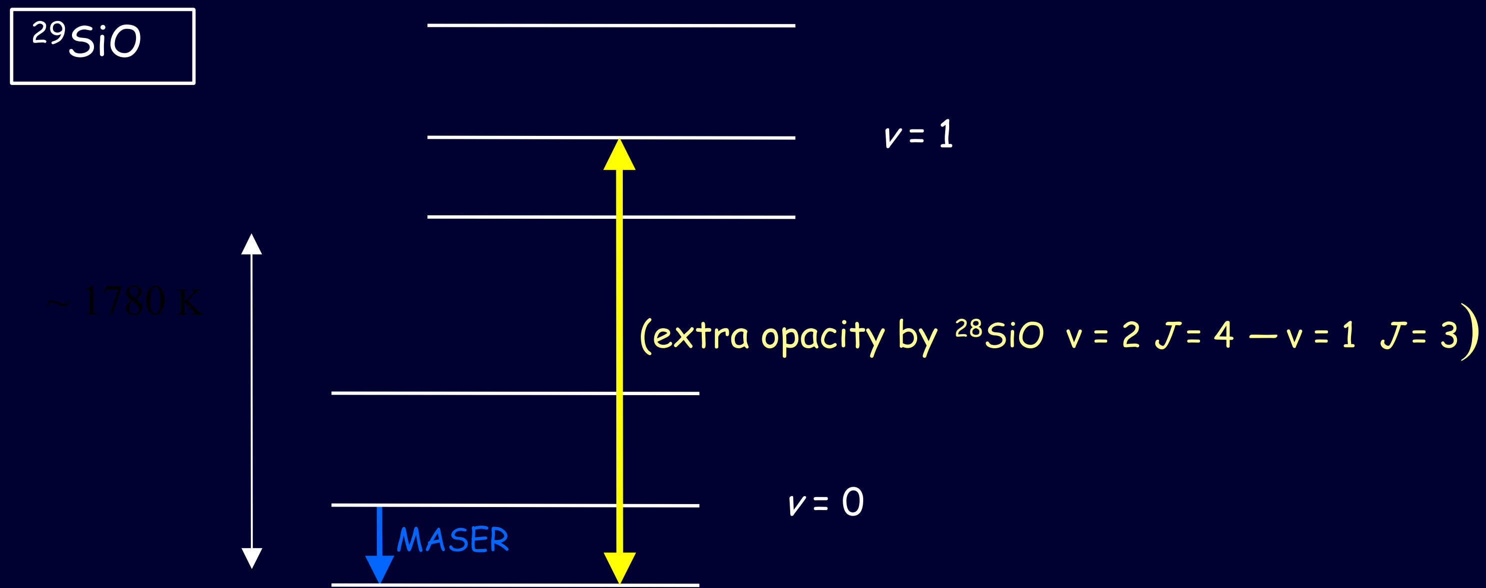


Olofsson et al. (1981): line overlaps between ro-vibrational transitions of ^{28}SiO and ^{29}SiO.

→ González-Alfonso & Cernicharo (1997): ^{28}SiO v = 2 J = 4 — v = 1 J = 3

^{29}SiO v = 1 J = 1 — v = 0 J = 0

This model does not explain how the line overlap affects the location and spatial distribution of the different SiO maser transitions !!



CONCLUSIONS

- We have mapped for the first time the <u>^{29}SiO $v = 0$ $J = 1–0$</u> maser transition in a CSE.
  The emission forms an incomplete ring, suggesting <u>tangential amplification</u>, as other ^{28}SiO maser lines.
- The ^{29}SiO maser shell is confined <u>in a region in between</u> the ^{28}SiO $v = 1$ $J = 1–0$ and $J = 2–1$, indicating that it requires high excitation temperatures ($T_{ex} \geq 1700$ K).
- The pumping of the ^{29}SiO maser transitions remains <u>uncertain</u>. The proposed theories do not explain the observed distributions and line shapes. Overlaps between infrared lines ?.

Our results confirm that:

- The ^{28}SiO $v = 1$ $J = 2–1$ (3mm) maser in IRC +10011 is produced further away than the $J = 1–0$ (7mm), as in Soria-Ruiz et al (2004).
- The ^{28}SiO $J = 1–0$ (7mm) $v = 1$ and $v = 2$ maps are displaced ~ 1 mas, being the $v = 2$ located in an inner region of the circumstellar envelope, as in Desmurs et al (2000) and Cotton et al (2004).

- Multiple SiO maser lines observations allow us to compare different physical conditions of the envelope.
- The multi-transitional studies help in determining the width of the whole SiO masing shell (~ 7– 9 mas).

Work in progress

- A similar multi-transitional observational study by means of VLBI has been performed in the variable sources: R Leo, χ Cyg and TX Cam.

- In our preliminary results we have found a new detection of the ^{29}SiO $v = 0$ $J = 1-0$ maser transition also in R Leo.

- We are also introducing the proposed line overlap in the theoretical pumping calculations of the excitation of the ^{29}SiO maser emission.