The Velocity Range of Mira's SiO Maser Emission

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Abstract

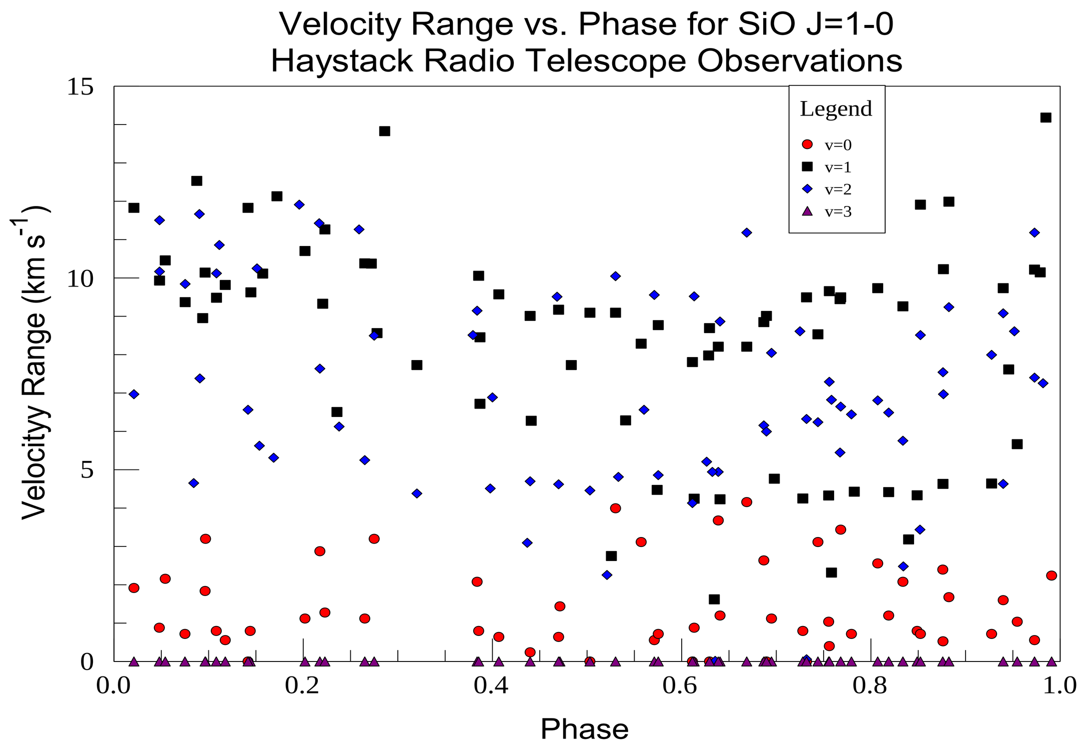
The SiO maser emission from Mira was observed using the Haystack Radio Telescope from 2001 until 2006. These observations were carried out in the v=0, v=1, and v=2, J=1-0 transitions. The v=3, J=1-0 transition was search for but not detected. The Mopra Telescope of the Australia Telescope National Facility observed SiO maser spectra from Mira, and a large number of other sources, from 2008 until earlier this year. Mopra observed the v=1, J=1-0 (J10) and the v=1, J=2-1 (J21) transitions. The velocity range of emission versus stellar phase has been determined for these various transitions and is compared with existing theory.

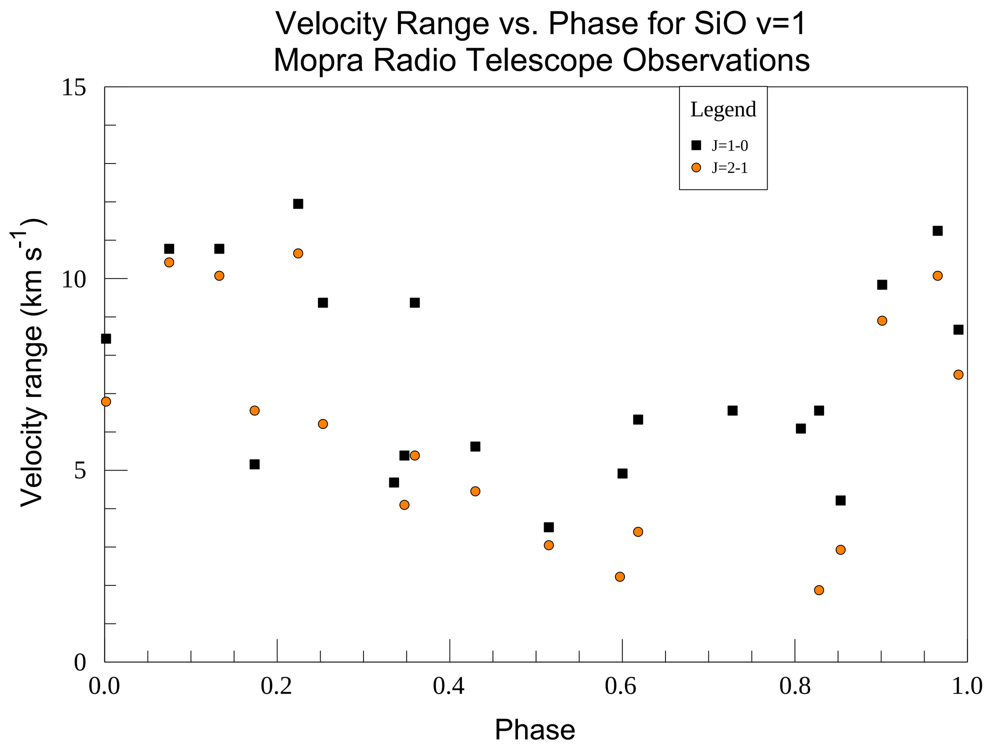
Background

Humphrey et al. (2002) show J10 SiO maser spectra for each 0.05 of stellar phase. In these spectra the velocity range of emission varies from approximately 4 km s^{-1} to 20 km s^{-1}. The spectra indicate a broad, weak plateau of emission with a range of about 20 km s^{-1}. For about half of the variation period this plateau emission is a large part or all of the emission.

More recently Gray et al. (2009) investigated the dynamics of the circumstellar region in which the SiO masers originate and have provided the most thoroughly developed theory for the maser spectra in long period variables such as Mira. They model a shock traveling out from the star generating different velocities at different distances from the star. As the shock travels out the velocities change as a function of distance from the star and phase. They indicate

- a J10 velocity range of emission of ~10 km s^{-1}
- no emission at a phase of 0.4 in any transition except the J10
- no v=0 masers at any phase
- weak v=3 emission being strongest in the J21 transition at a phase of 0.1
- the J21 transition is generally narrower than the J10 transition, but the difference is phase dependent and difficult to quantify.





Observations

Observations were carried out using the Haystack Radio Telescope, Westford, MA, between over approximately 2.6 periods of the star. The velocity resolution of the original observations was 0.005 km s^{-1}. For analysis the weaker v = 0 and 3 transitions were smoothed to 0.080 km s^{-1}. Later observations of the v=1 and 2 transitions were also smoothed to 0.080 km s^{-1}.

Spectra were collected over a period of 24 to 48 hours and averaged. Pointing and focus corrections were updated approximately hourly. Planetary calibration indicated a system sensitivity of 11 Jy K^{-1}. Typical rms noise values were 0.5 to 1.5 Jy

The 22-m Mopra radio telescope, New South Wales, Australia observed SiO maser sources between 2008 and early 2012. The velocity resolution was 0.23 km s^{-1} (J10) and 0.12 km s^{-1} (J21) .

At Mopra each maser source is first pointed on to ascertain adequate positioning inside the beam. The observations are then executed as 16 cycles on and 16 cycles off observation, thus lasting 32 seconds per source. For J21 observations the rms noise was about 1.8 Jy. For J10 observations the rms noise was about 0.6 Jy.

The Range of Emission

The velocity range of emission is calculated to be the region where the signal exceeds three times the rms of the background noise. The rms is determined from the variation in velocity channels far from the emission range of the source.

The Phase

Mira's phase was determined from publications of the maxima by the American Association of Variable Star Observers (AAVSO 2011).

Observational Conclusions

- There is no evidence of a continuous, broad plateau of emission.
- The J10 emission shows a larger velocity range of emission than the J21 emission. This result is consistent with the predictions of Gray et al. (2009).
- During some cycles the velocity range of emission decreases between phases of 0.3 to 0.7 for the J10 and J21 transitions.
- Various masers are observed at a phase of 0.4.
- The v=0, J=1-0 maser was observed in all phase ranges.
- The v=3, J=1-0 was not observed at any phase.

References

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