Using JVLA Observations of SiO Masers to Probe the Dynamics of an AGB Star: W Hydrae

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W Hya

- Mira variable, AGB star
- Source of SiO, OH, and H$_2$O masers
- Period of 370 days
- Visual magnitude approx. 5 to 10
- R$_*$ $\sim$ 2.5 AU
- $\sim$115 pc away
- Oxygen-rich
Motivation/context for project

- Silicon monoxide masers typically observed in a region just outside of the “radio photosphere” at \(\sim 2\, R_\star\).
- Lie inside the dust-forming region.
  - AGB stars lose mass through a dust-driven stellar wind.
- Provide indications of physical conditions in this range of the circumstellar envelope (CSE).

adapted from Reid and Menten 1997
Background on masers

- Microwave Amplification by Stimulated Emission of Radiation
  - results from a population inversion (majority of molecules not in ground state)

- Triggered by a pumping process (radiative/collisional)

- Good probe into the temperature/density/kinematic conditions of the environment in which they are formed
Methods

- Data collected from Very Large Array in Socorro, NM in Feb. 2014
  - 11 lines near 43 GHz targeted simultaneously, allowed by capability of upgraded VLA

- Primarily handled with Astronomical Image Processing System (AIPS)

- A number of calibration sources were simultaneously observed with the target W Hya: J1339-2620 (gain calibrator), J1337-1257 (bandpass calibrator), 3C286 (flux calibrator)

- Hanning smoothing applied to correct for Gibbs ringing (caused by strong spectral-line sources), leading to a loss of spectral resolution (to 0.4 km/s resolution)

- Phase and amplitude (iterative) self-calibration of the SiO lines using maser emission as a model
Spectral profiles

Flux density (Jy)

High- and low-velocity “wings”

Outflow velocity ~ 8.8 km/s (Szymczak et al. 1998)

Largest velocity spread ~ 8 km/s

Systemic velocity ~ 41.9 km s⁻¹

Non-detections (not shown) include:
- $^{30}$SiO $v=1$, $v=2$
- $^{29}$SiO $v=1$, $v=2$
- $^{28}$SiO $v=4$
$^{28}\text{SiO } v=1$, epochs 2000 & 2014

East Offset (arcsec)

Reid and Menten 2007
Peak contour: 6400 Jy beam$^{-1}$

$\Phi = 0.25$ cycle

W Hya

$\Phi = 0.71$ cycle

Restoring beam indicated by large circle in lower-left

Peak contour: 928 Jy beam$^{-1}$ m s$^{-1}$

(this work)
Reid and Menten date of observation

~ 370 days

Φ = 0.25

~ 370 days

Observation date, this work

Φ = 0.71
Maser spot maps

$v=2$

W Hya

$v=1$

$28\text{SiO}$

$V_{\text{LSR}}$ (km s$^{-1}$)

RA offset 11.5 AU

Dec offset 100 mas

20 mas 2.3 AU

(size scaled by flux density)
$^{28}\text{SiO } v=0$

Spot maps (size scaled by flux density)

RA offset

Dec offset

60 mas
7.2 AU

$V_{\text{LSR}}$ (km s$^{-1}$)
Spot maps for other isotopologues (size scaled by flux density)
Potential for bipolar outflow in W Hya, as indicated by the $^{28}\text{SiO} \; v=1$ first moment map (intensity-weighted velocity field)

Contour units of $\text{m s}^{-1}$
$^{28}$SiO ground-state, moment 0 map

- Minor axis: 40 AU
- Major axis: 80 AU

Circle, lower right: restoring beam
Red ellipse: photosphere model

Boboltz and Claussen 2004
Results

- Different SiO lines are not co-located
  - e.g., ground-state $^{28}$SiO emission is located a much greater distance from the star than that of the excited states

- Potential of a bipolar outflow is supported by the appearance of a saddle-like structure in the velocity-field map of $v=1$ line, in addition to weaker gradients in velocity in the spot maps for other lines

- SiO ground-state emission was detected in an unusually spatially-extended structure, found to lie approx. 40 AU to 80 AU (~15 R$_*$ to 30 R$_*$) from the star’s center
  - In comparison, 1665-MHz OH (hydroxyl) emission has been previously detected in a shell with radius 80 AU (Szymczak et al. 1998), while the inner radius of the dust shell >50 AU (Zhao-Geisler et al. 2011)
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