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

Patrick Kamieneski
Bowdoin College
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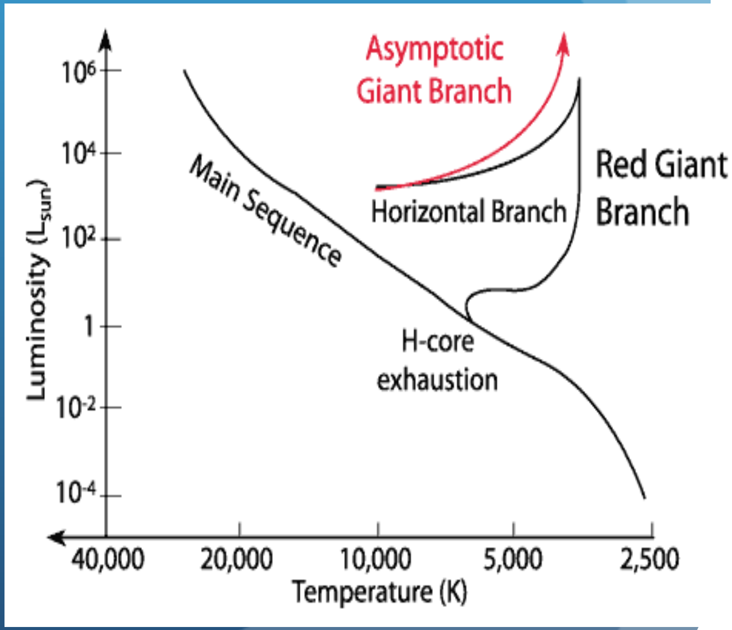
Mentor: L.D. Matthews

W Hya

- Mira variable, AGB star
- Source of SiO, OH, and H_2O masers
- Period of 370 days
- Visual magnitude approx. 5 to 10
- $R_* \sim 2.5$ AU
- ~115 pc away
- Oxygen-rich

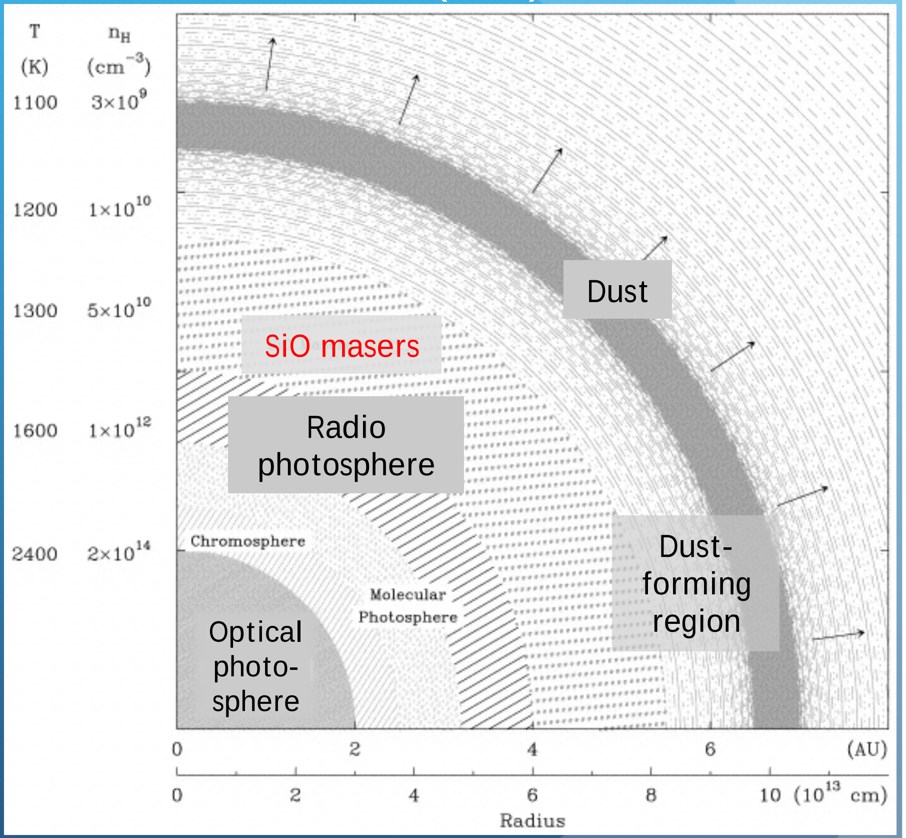


NOAO

Motivation/context for project

- Silicon monoxide masers typically observed in a region just outside of the "radio photosphere" at ~2 R_*
- 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)

Model cross-section for Long-Period Variable (LPV) star:



adapted from Reid and Menten 1997

Background on masers

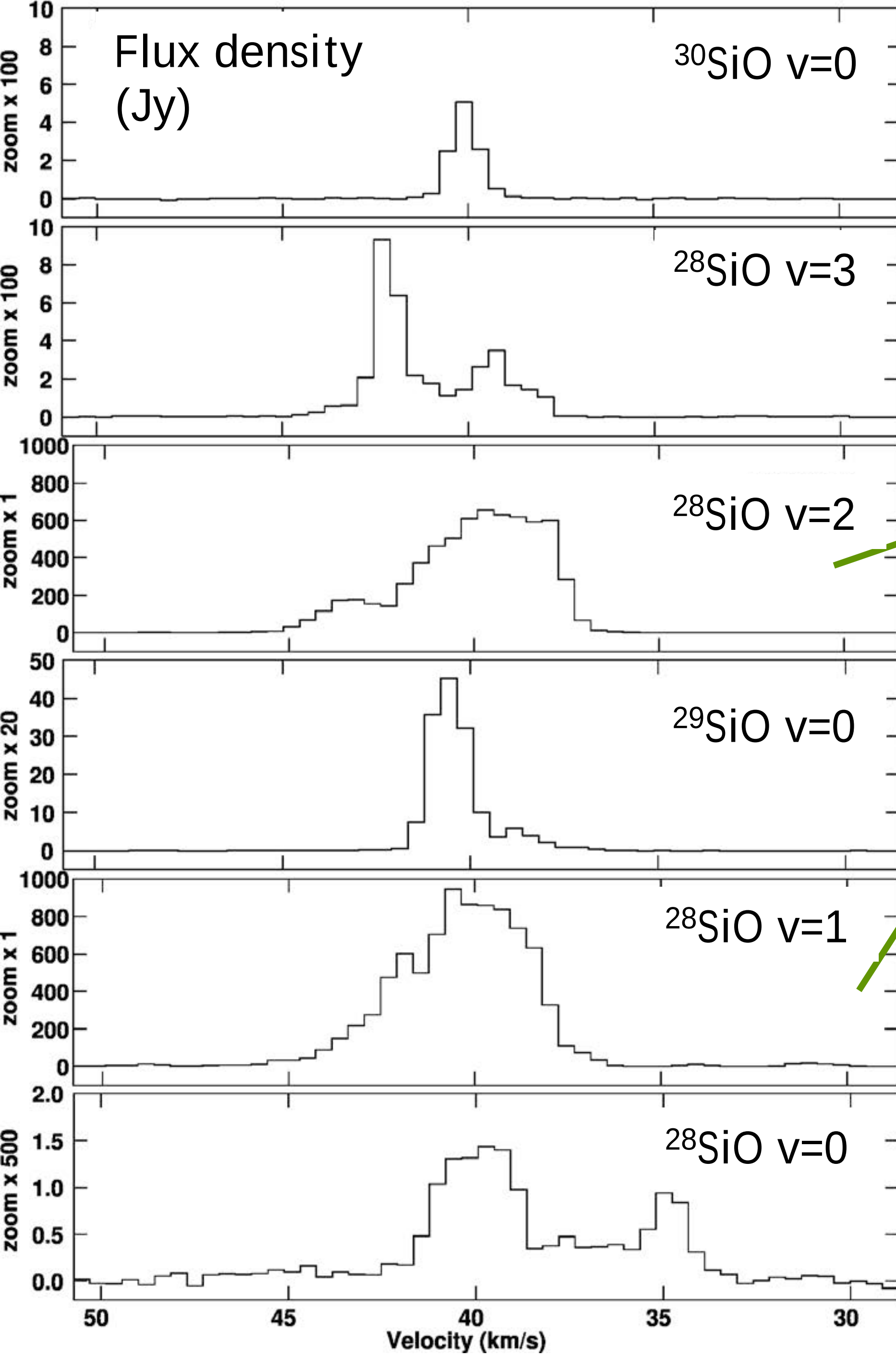
- Microwave Amplification by Stimulated Emission of Radiation
  - results from a population inversion (majority of molecules not in ground state)
- Triggered by a pumping process (radiative/collisional)
- Good probe into the temperature/density/kinematic conditions of the environment in which they are formed

NRAO

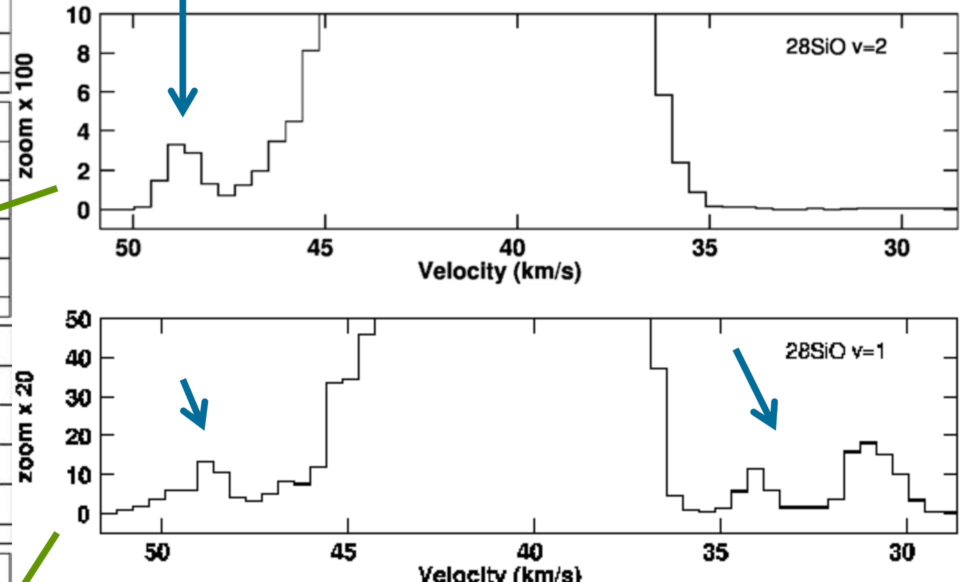
Methods

- 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



High- and low-velocity "wings"



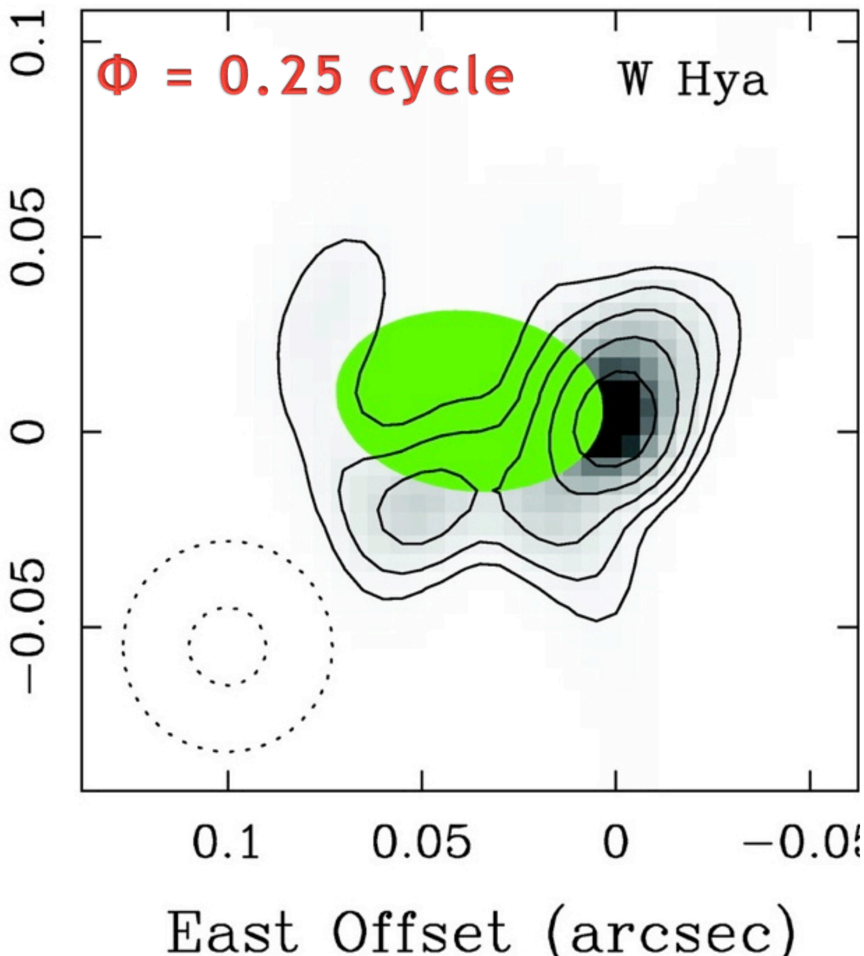
Non-detections (not shown) include:
^{30}SiO v=1, v=2
^{29}SiO v=1, v=2
^{28}SiO v=4

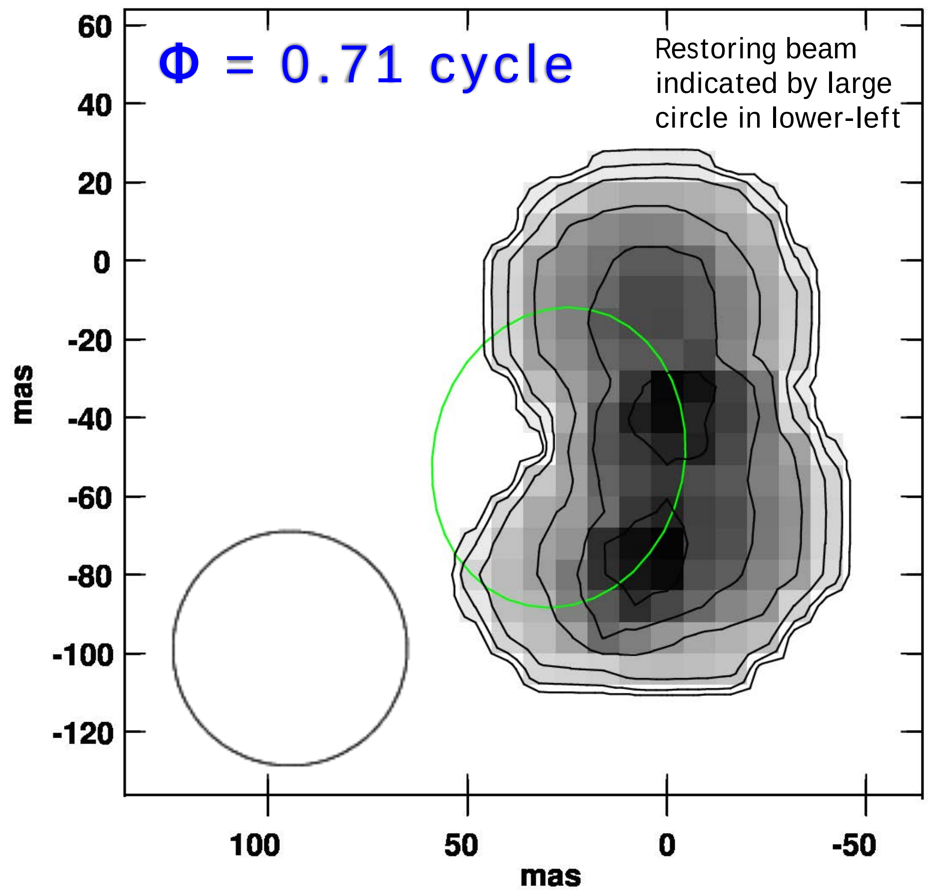
Outflow velocity ~ 8.8 km/s
(Szymczak et al. 1998)

Largest velocity spread ~ 8 km/s

Systemic velocity ~ 41.9 km s^{-1}

^{28}SiO v=1, epochs 2000 & 2014





Reid and Menten 2007

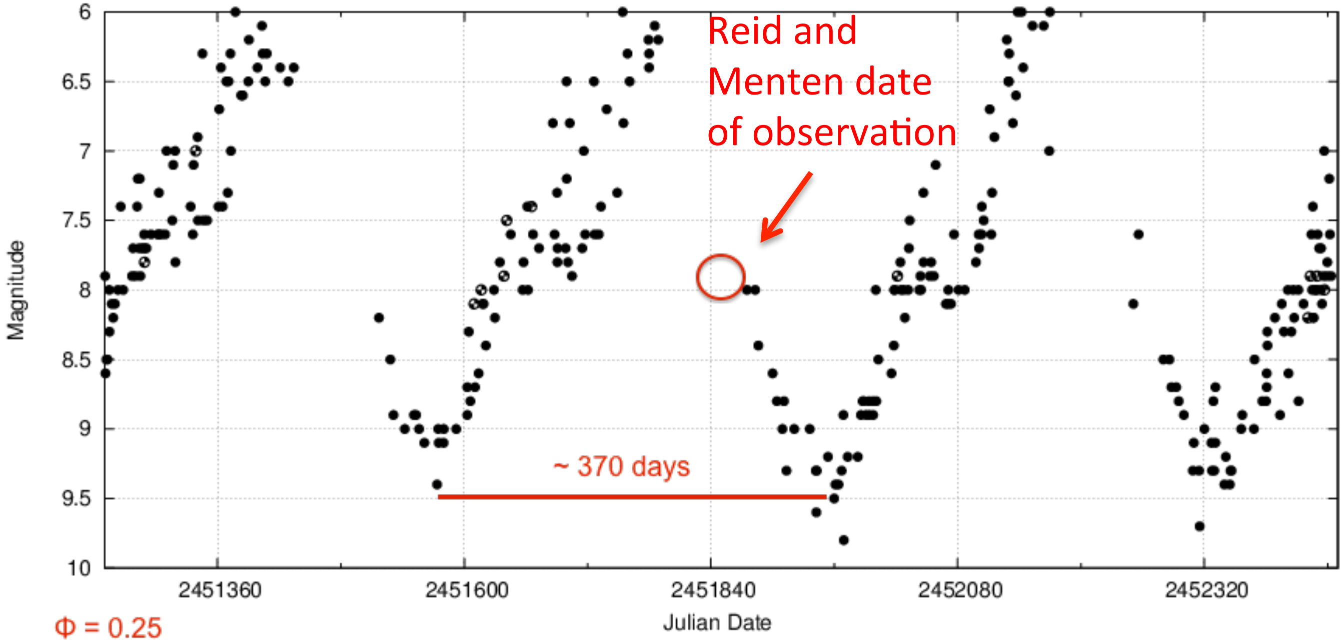
Peak contour: 6400 Jy beam^{-1}

(this work)

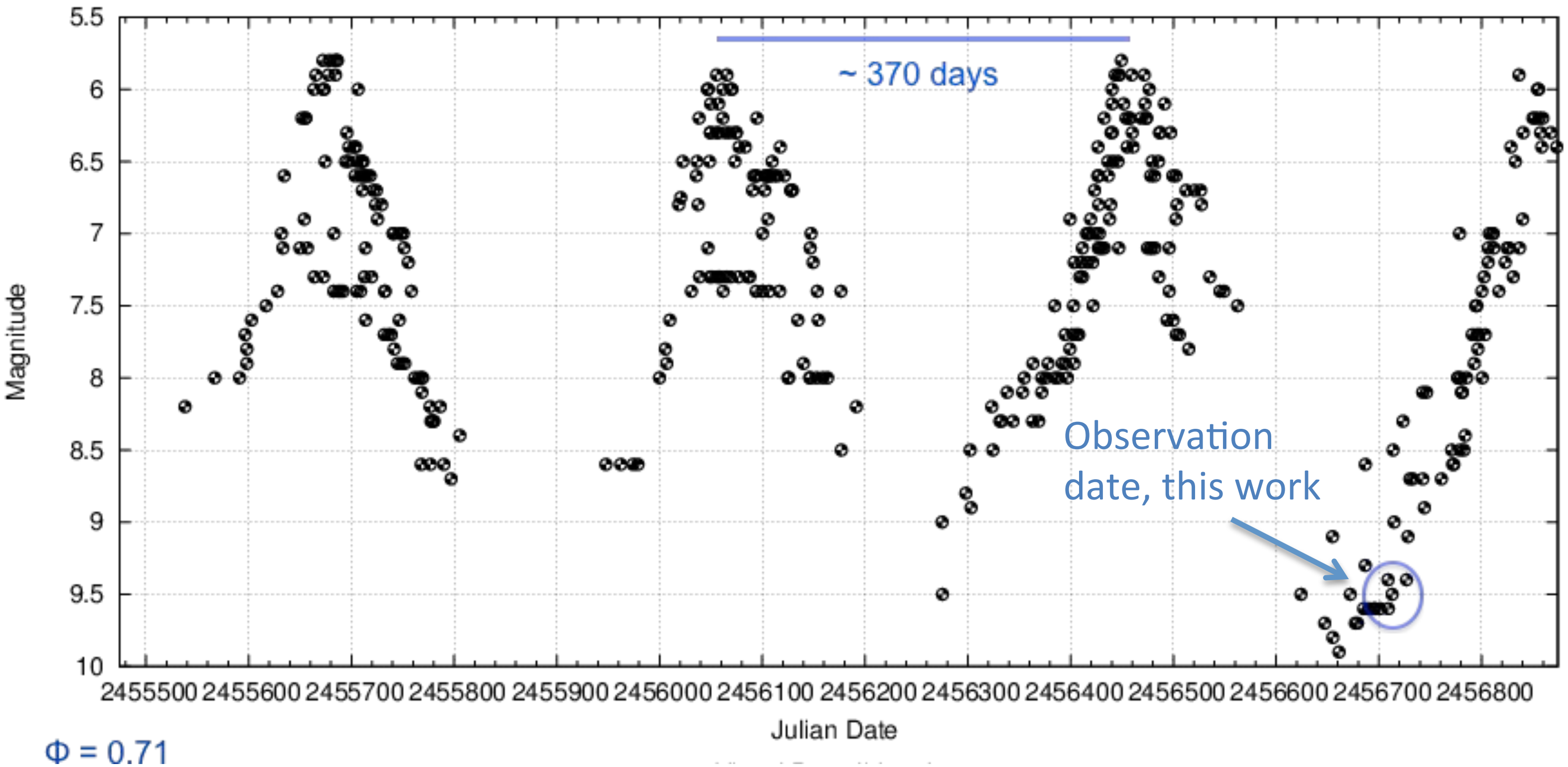
Peak contour: 928 Jy beam^{-1} m s^{-1}

Visual Light Curves, AAVSO

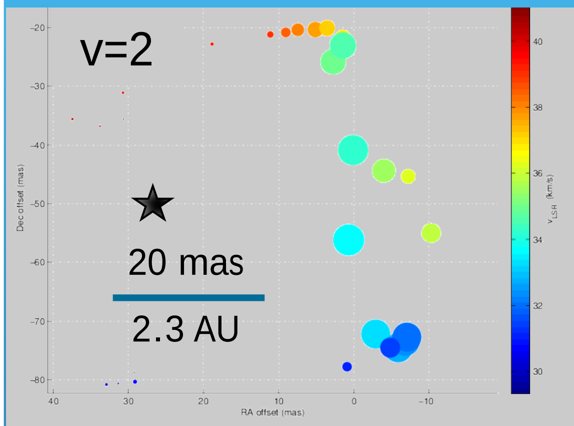
2000



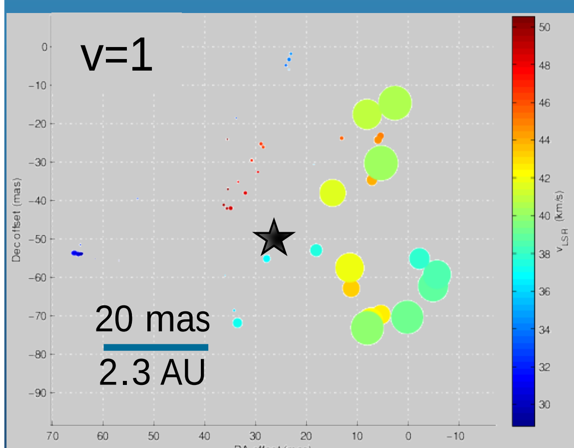
2014

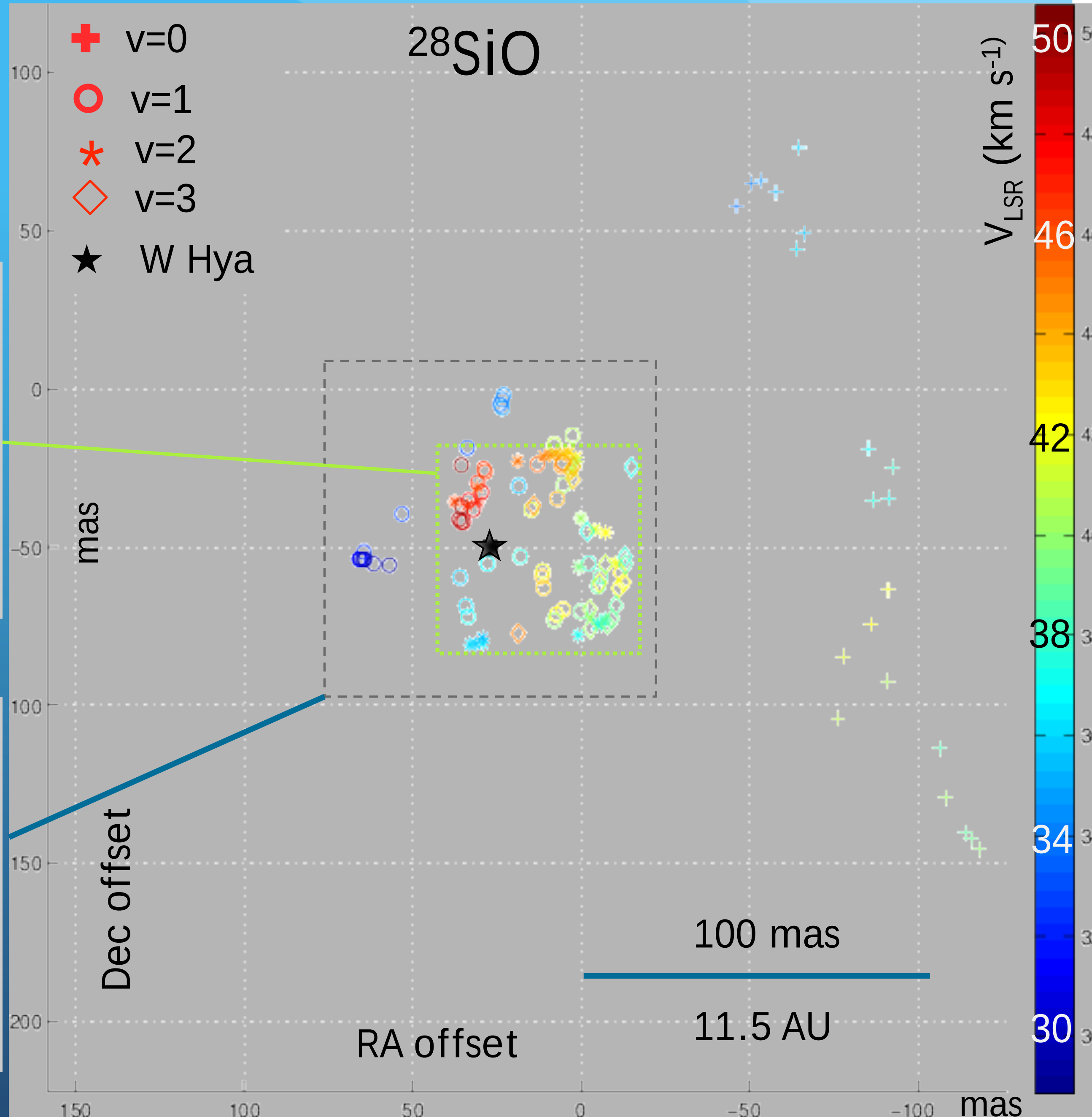


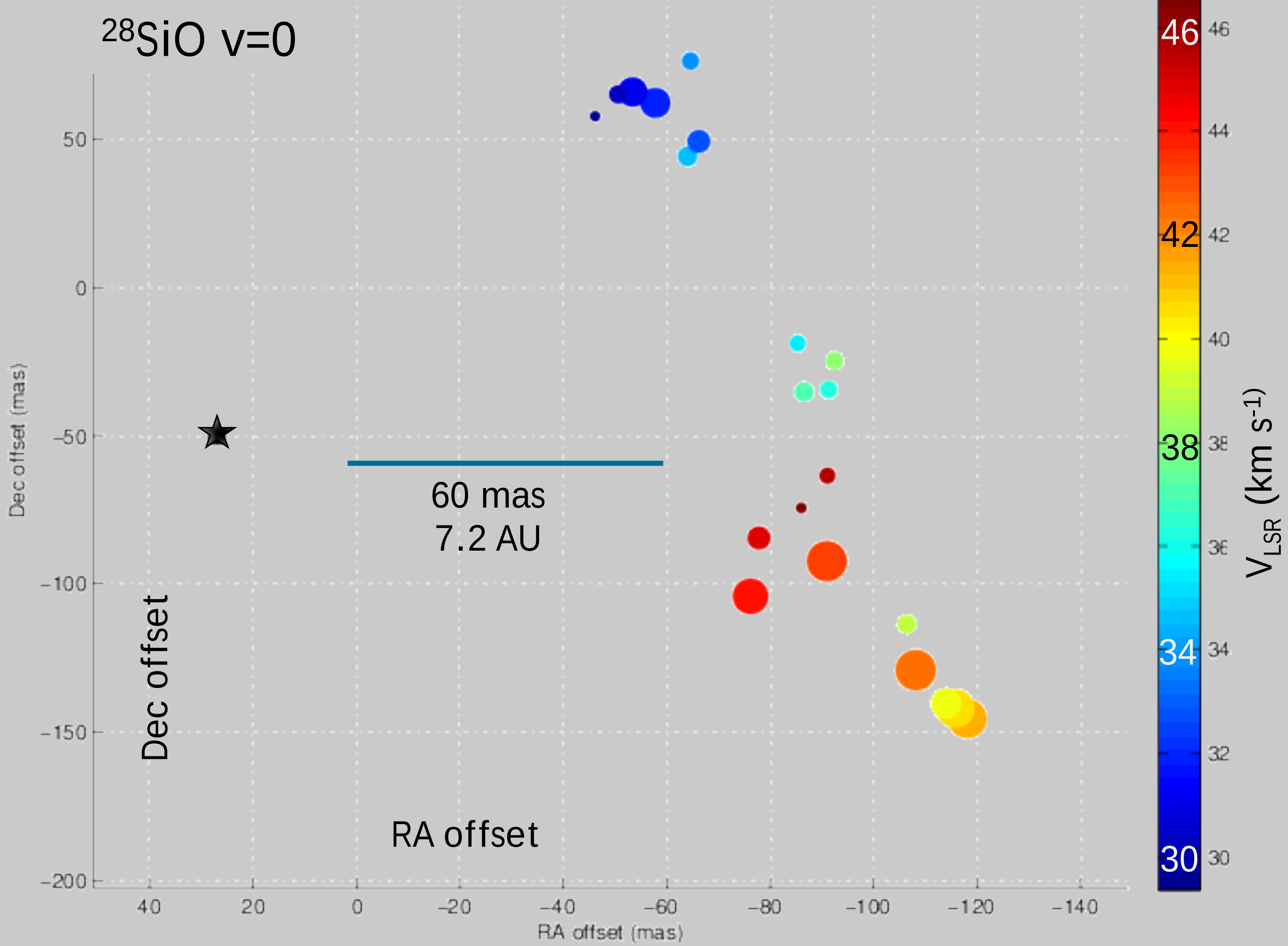
Maser spot maps



(size scaled by flux density)



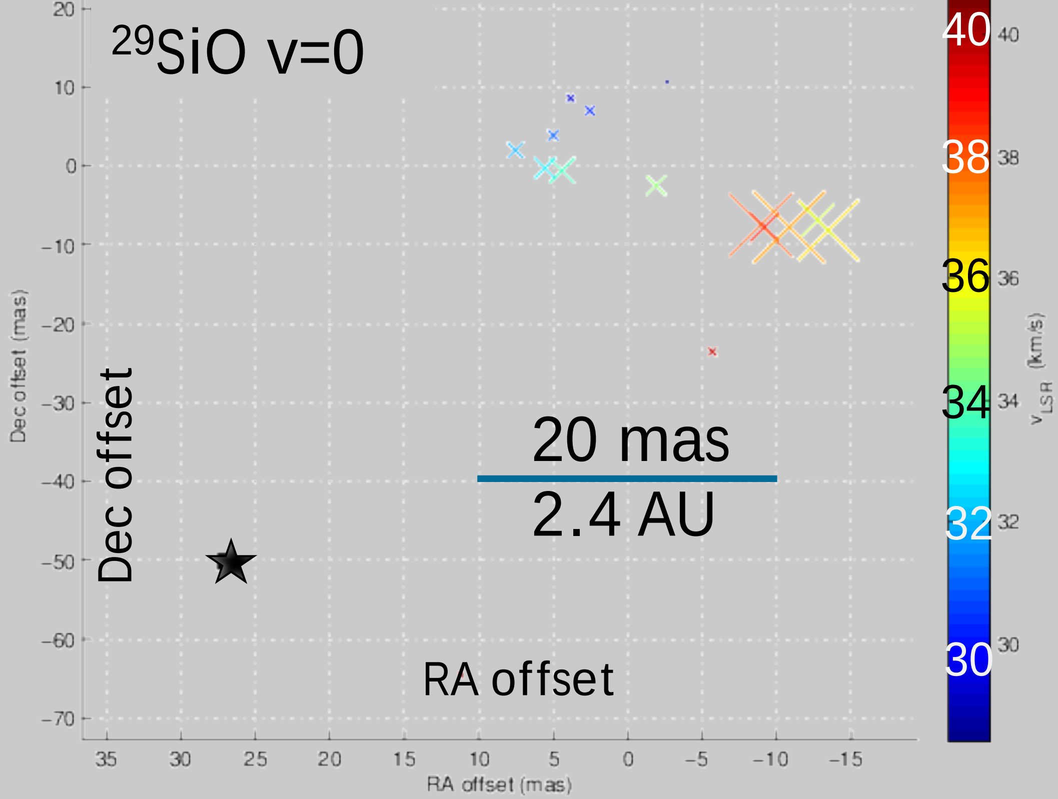


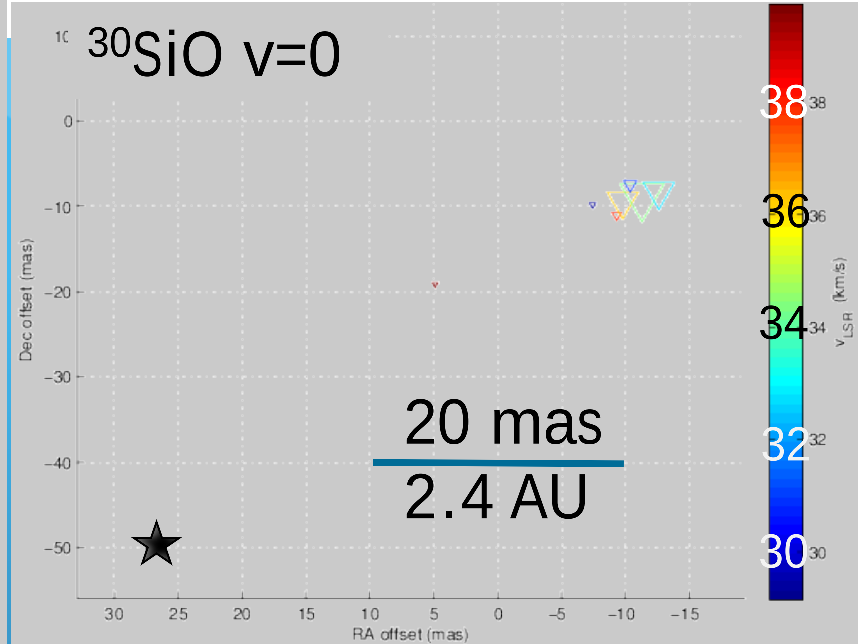


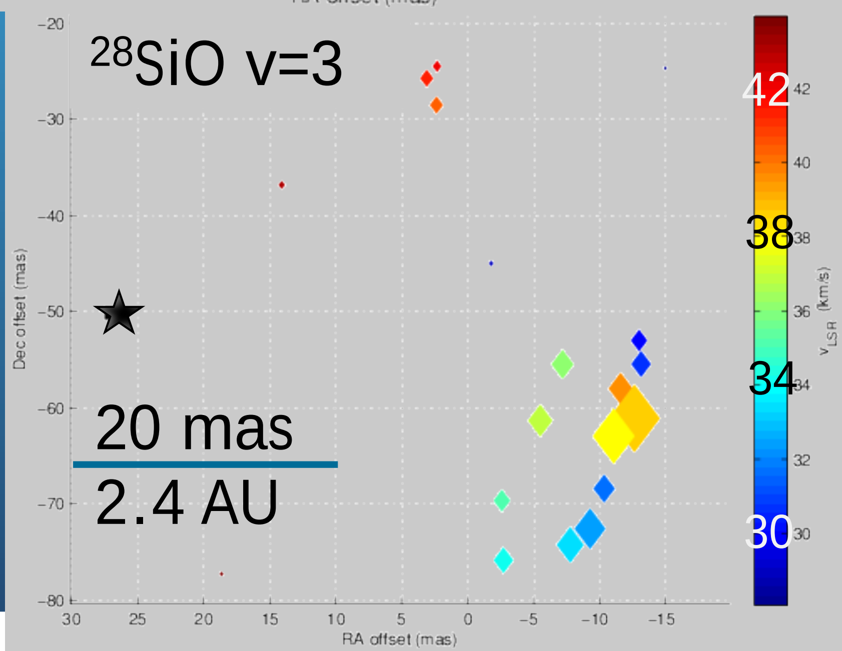
Spot maps (size scaled by flux density)

Spot maps for other isotopologues

(size scaled by flux density)

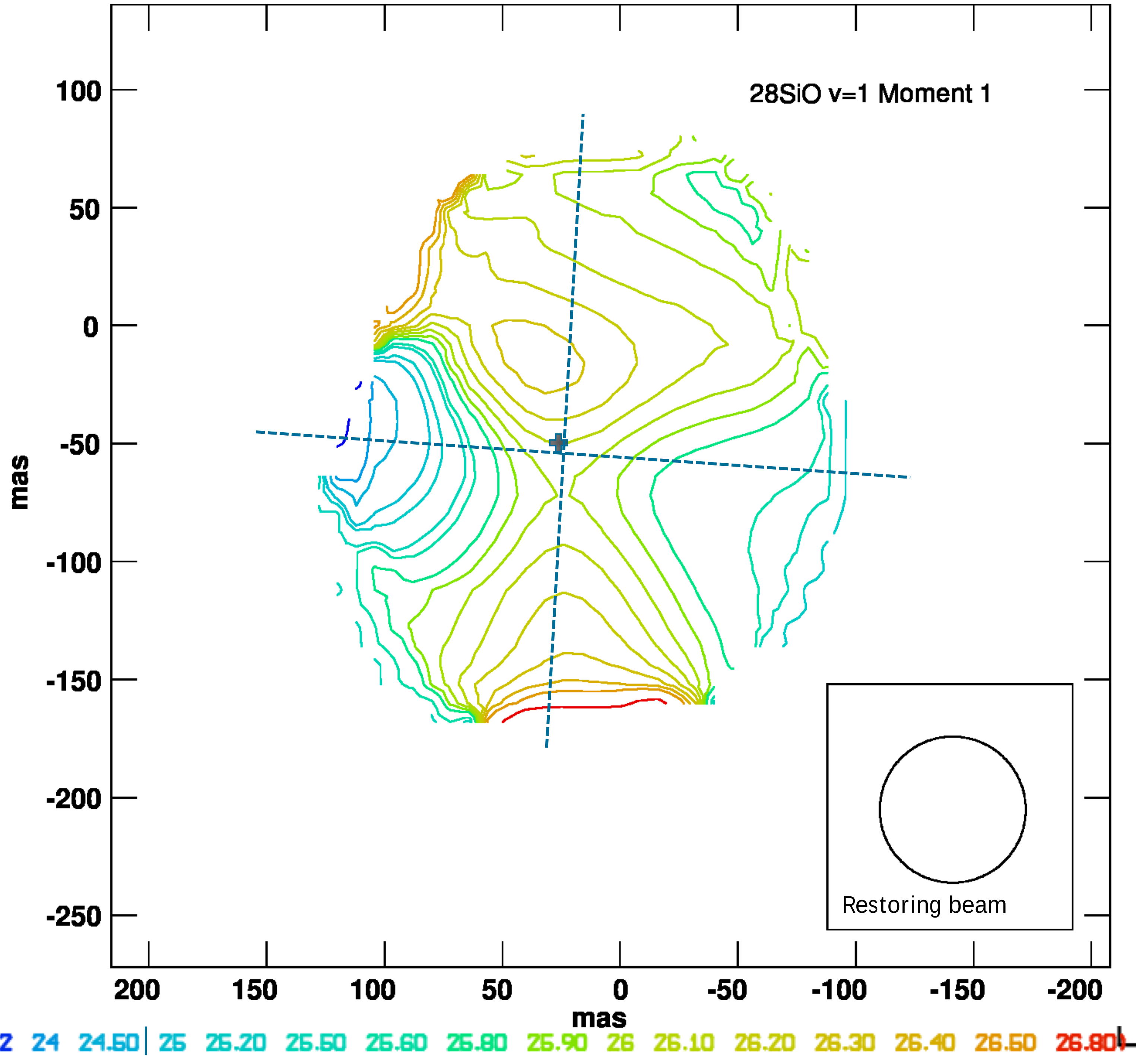




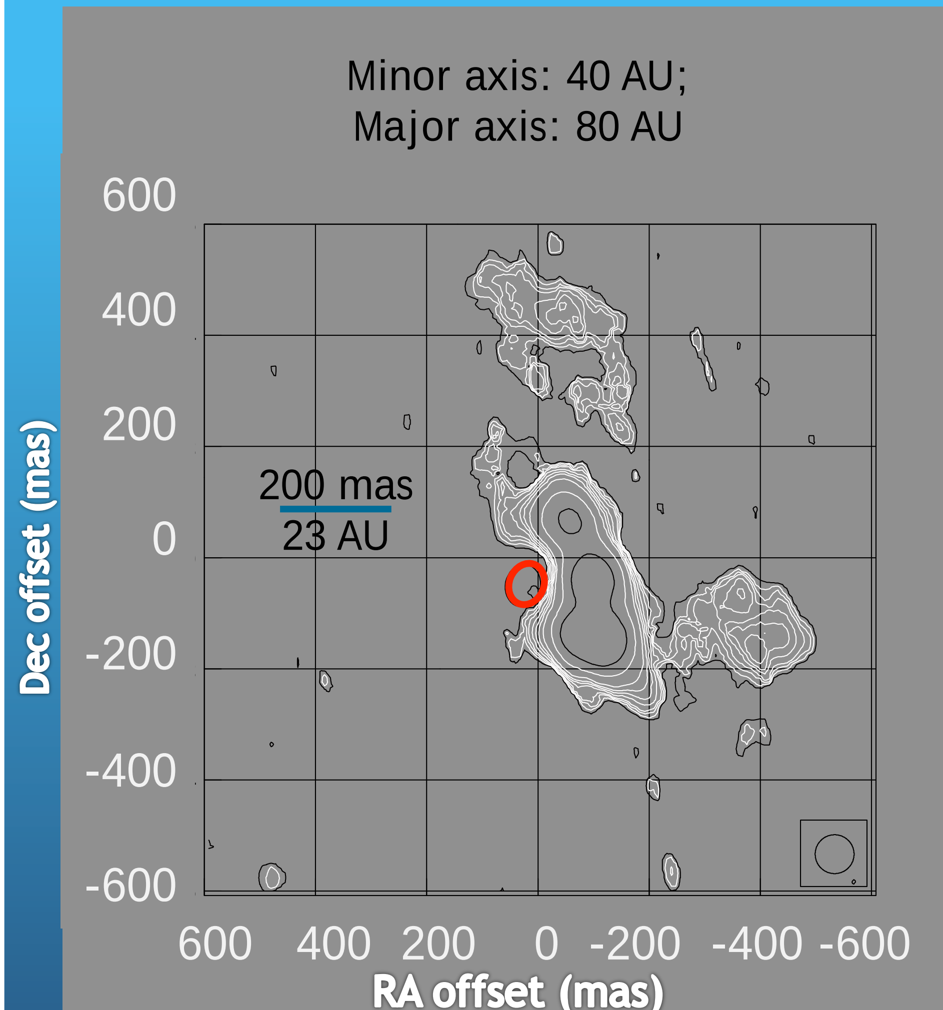


Potential for bipolar outflow in W Hya, as indicated by the ^{28}SiO v=1 first moment map (intensity-weighted velocity field)

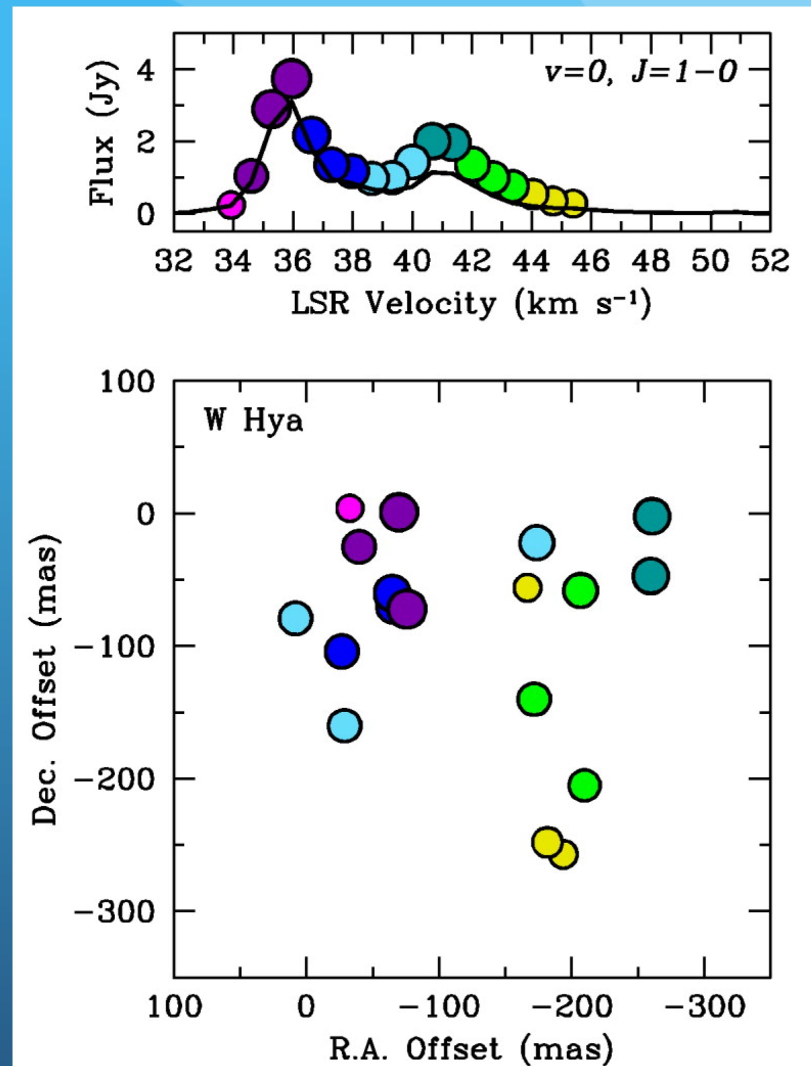
Contour units of $m\ s^{-1}$



^{28}SiO ground-state, moment 0 map



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)

Acknowledgments

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