A MULTISCALE APPROACH TO UNDERSTAND OUTFLOWS FROM HIGH-MASS PROTOSTARS

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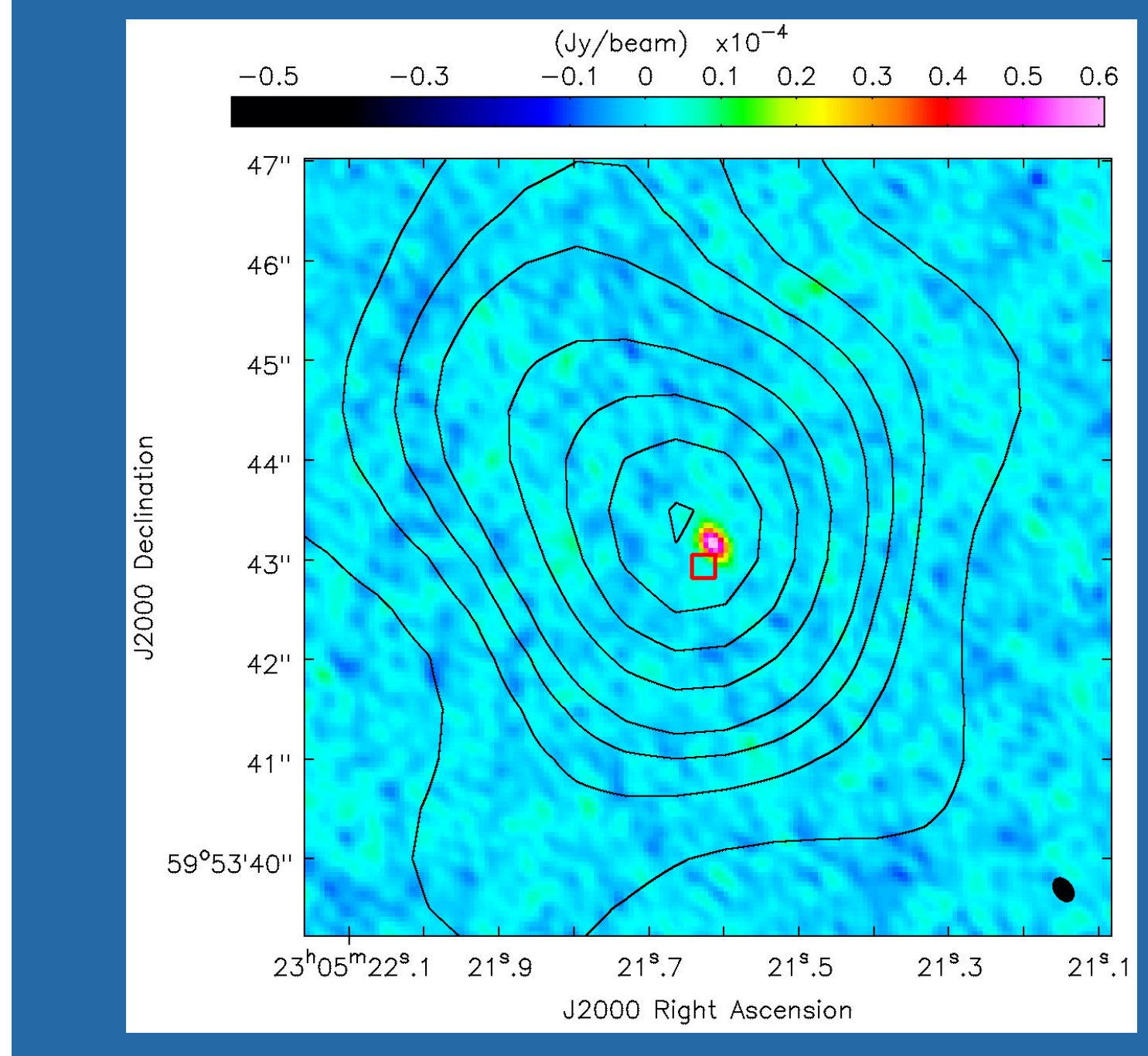


Figure 1: 3.6 cm (color), 1.3 mm (contours) and 7 mm continuum peak position (red square) toward SMM2.

Rodríguez et al. (2021): "Discovery of a Highly Collimated Flow from the High-Mass Protostar ISOSS J23053+5953 SMM2"

- High resolution ($\theta < 1''$) VLA 6, 3.6, and 0.7 cm, and SMA 1.3 mm continuum and CO(2–1) emission ($\theta \sim 3''$).
- 46 $M_\odot$ dust core detected toward SMM2.
- ~1.45 pc bipolar CO outflow centered on SMM2 core.
  - Ionized jet ($\alpha_{cm} = 0.24 \pm 0.15$) detected at base of the outflow.
  - Fast, highly collimated flow with a broader, lower-velocity component.
  - Extremely young ($t_{dyn} \sim 1.5 \times 10^4$ yr) and energetic ($\dot{M}_{CO} = 6 \times 10^{-4}$ $M_\odot$/yr).
  - Kinematics consistent with jet-driven outflow (Fig. 2).

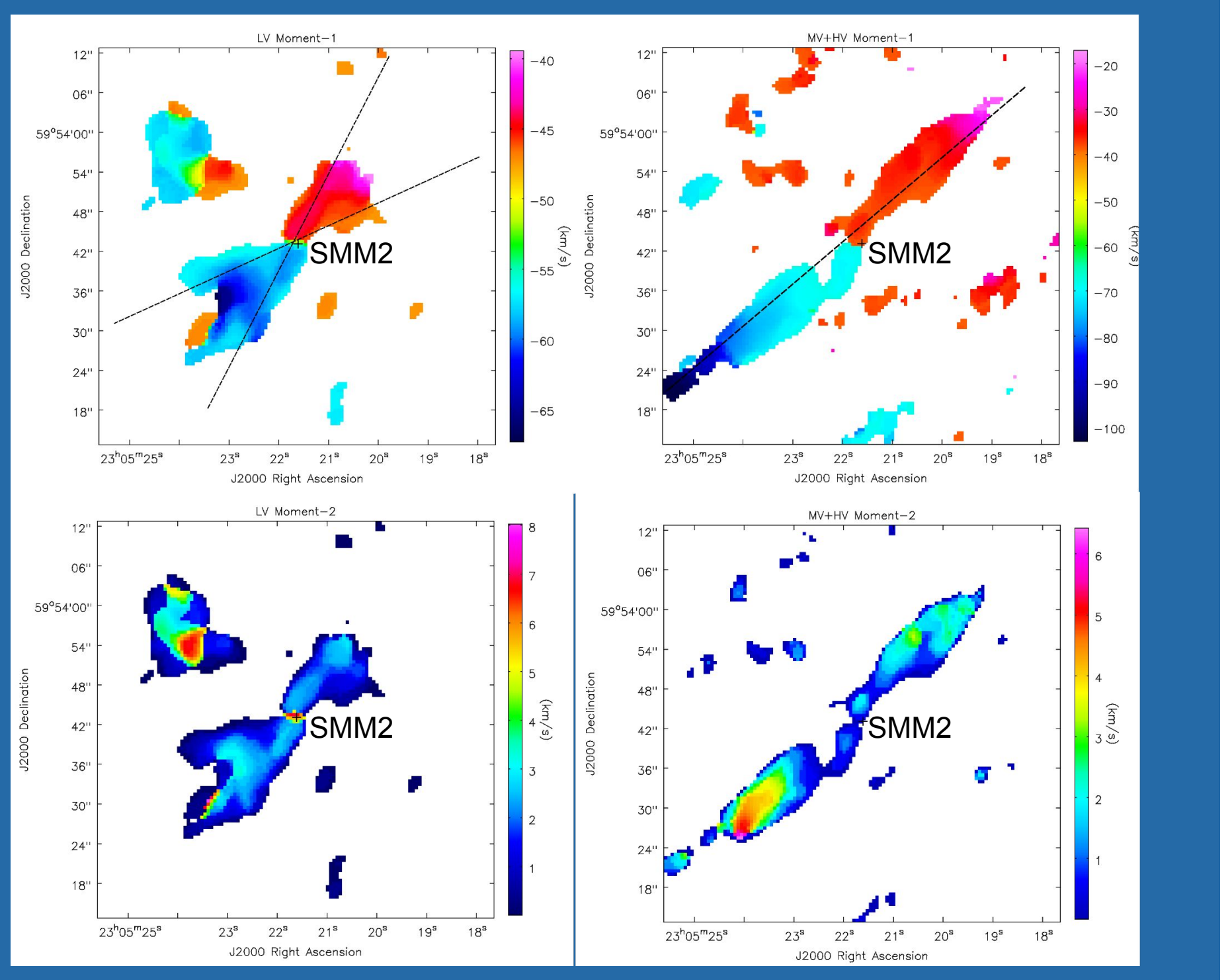


Figure 2: CO(2–1) velocity field (top) and velocity dispersion (bottom) of the low ($|V-V_{LSR}| < 15$ km/s, left) and high velocity (15 km/s $< |V-V_{LSR}| < 52$ km/s, right) gas.

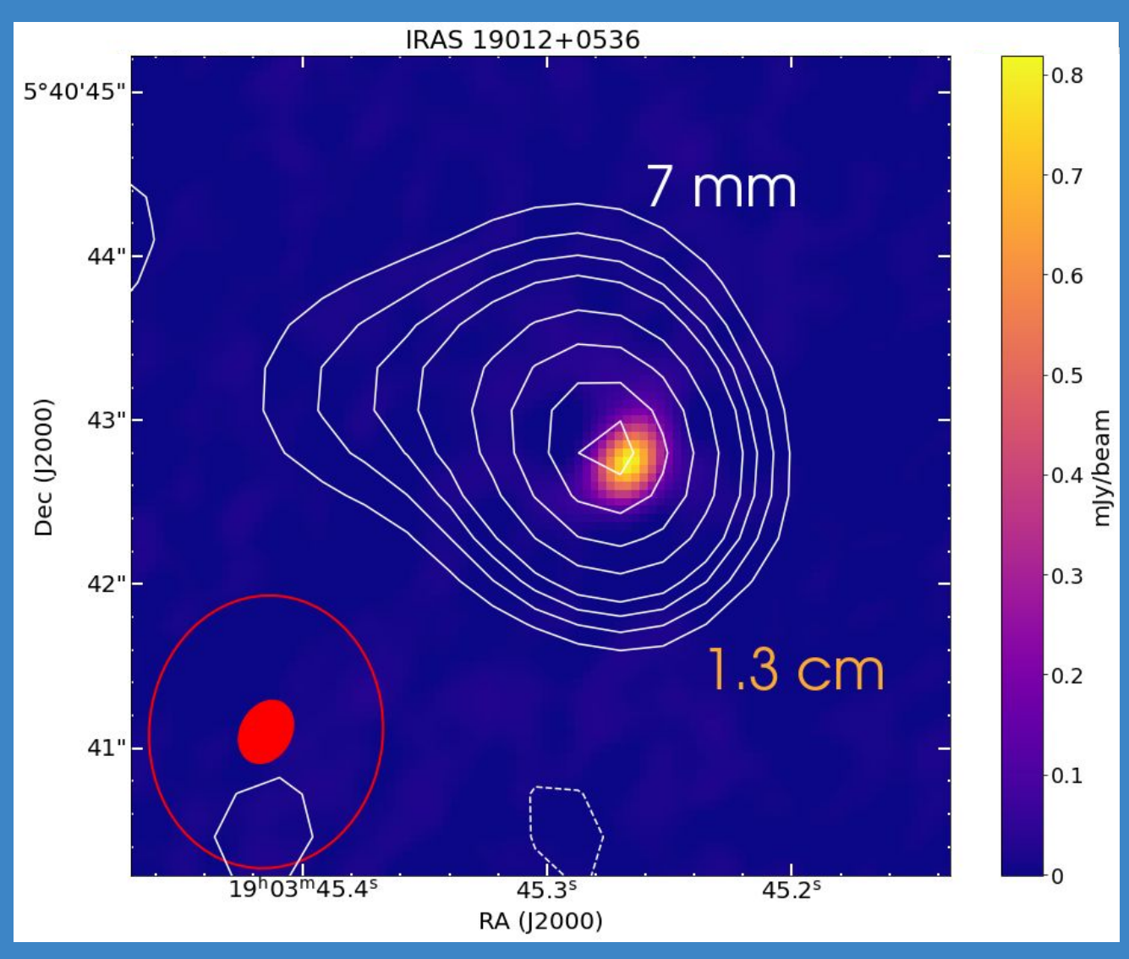


Figure 3: example of ionized jet candidate (1.3 cm, color; Rosero et al. 2016) toward center of 7 mm core (contours).

Rodríguez et al. (2023): "Searching for Molecular Jets from High-Mass Protostars"

- Survey Sample: 10 jet candidates from Rosero et al. (2016, 2019).
  - Goal: investigate jet nature of the 10 unresolved radio sources.
- VLA D configuration 7 mm continuum and SiO(1–0).
- 7 mm cores detected in 90% of the regions.
  - Jet candidates usually toward center of core (Fig. 3).
  - Masses (~100 $M_\odot$) and densities (~10^7 cm^{-3}) consistent with embedded high-mass objects.
- SiO(1–0) jets associated with 60% of the jet candidates (Fig. 4).
  - Jet nature confirmed for 60% of the candidates.

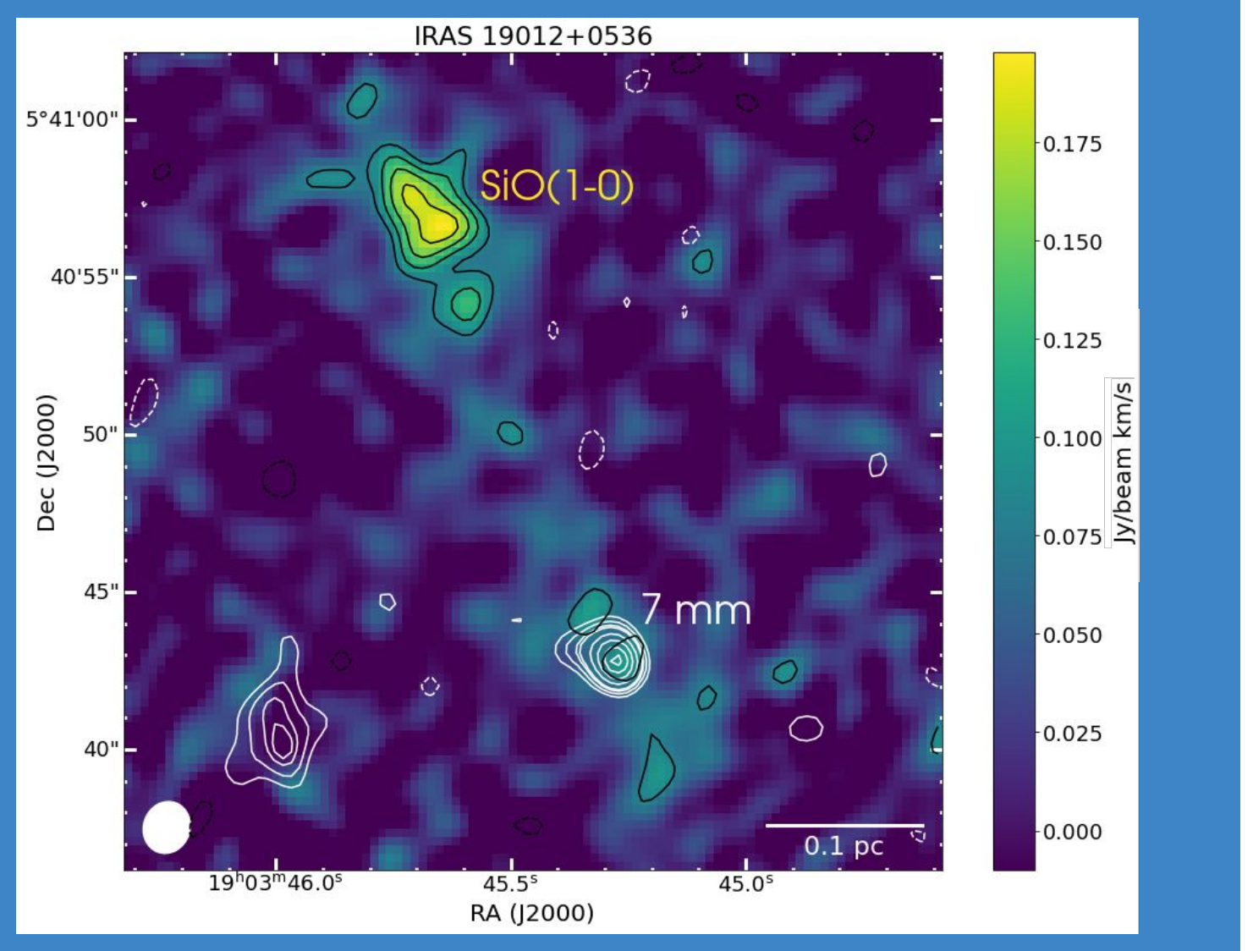


Figure 4: example of SiO jet (color and black contours) emanating from the jet candidate and 7 mm core (white contours) from Fig. 3.

Tan et al. (2020): "High-Sensitivity Observations of Molecular Lines with the Arecibo Telescope"

- Survey Sample: 12 intermediate and high-mass star forming regions.
- Arecibo 6.0 – 7.4 GHz observations, multiple lines, ~5 mJy rms noise, 0.06 – 1.1 km/s channel widths.
- CH_3OH Absorption: 33% detection rate, typically overlapping with strong masers.
- Detection of a CH_3OH maser flare in G45.12+0.13 (Fig. 5).
- Detection of broad blue-shifted 6.0 GHz OH absorption in G34.26+0.15.

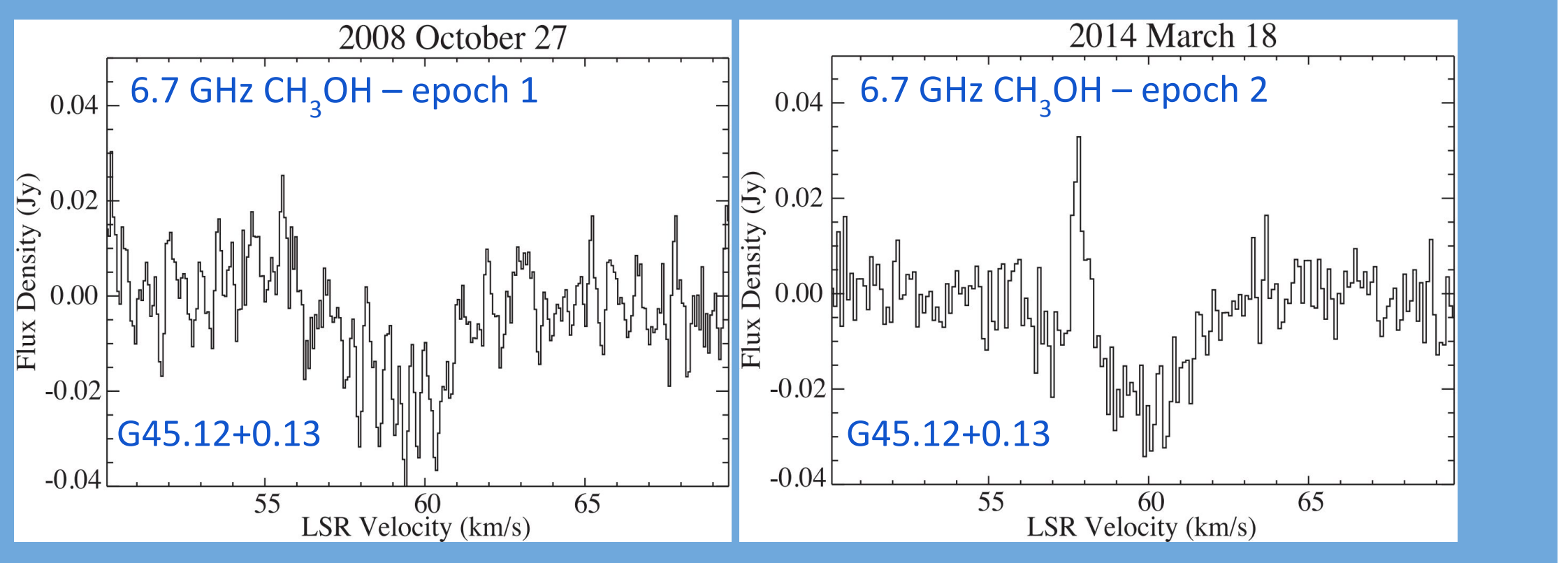


Figure 5: 6.7 GHz CH_3OH recurrent maser flare in G45.12+0.13 in 2 epochs.

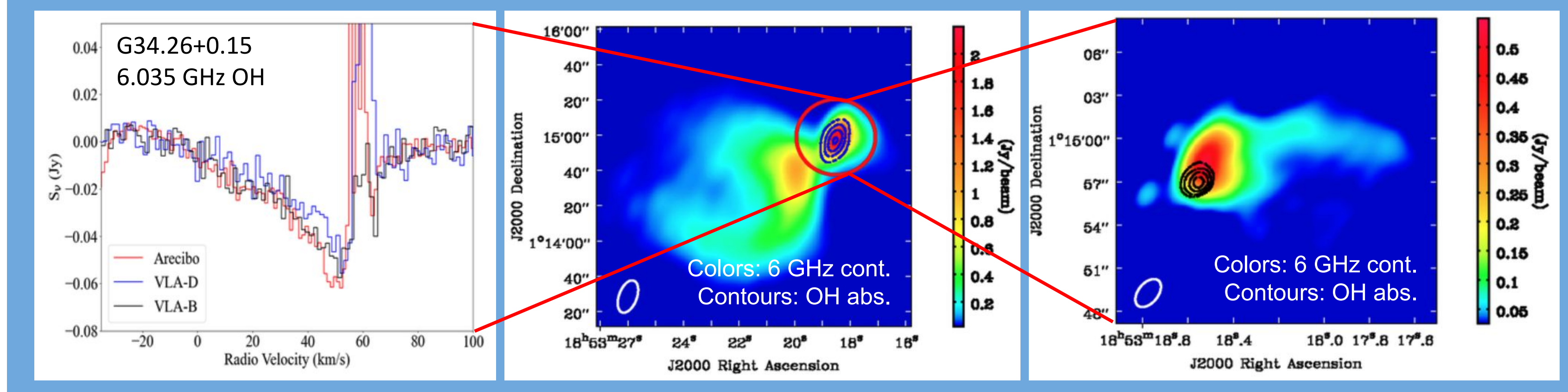
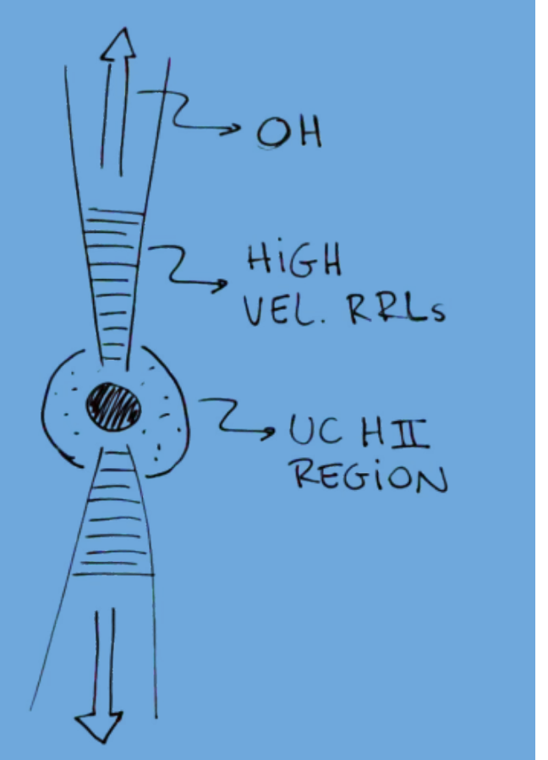


Figure 6: 6035 MHz OH spectra (left) and 6.0 GHz continuum from the VLA D (middle) and B configurations (right). Contours in the continuum plots show the integrated intensity of the OH absorption.

Tan et al. (in prep.): "Excited Hydroxyl Outflow in the High-Mass Star-Forming Region G34.26+0.15"

- Arecibo observations of 4.7 and 6.0 GHz OH transitions.
- VLA observations in D and B configurations of 6.0 GHz OH transitions.
- Detection of unresolved OH absorption at ~2" resolution.
- Association with broad radio recombination line (RRL) emission.
  - Possible inside-out ionization of a pole-on molecular outflow.



Rodríguez et al. (in prep.): "Ionized Jets from High-Mass Protostars: a VLA quest for resolution"

- Survey of 23 jet candidates from the Rosero et al. (2016, 2019) survey.
- Goal: resolve the radio continuum and investigate the jet nature of the ionized emission.
- VLA A-configuration 1.3 cm continuum observations.
  - Linear resolution of 100 ~ 1500 au.
- As byproduct, 22.2 GHz H_2O masers detected in ~60% of the sample.
- Case study paper: "Water Maser Zeeman Splitting in the Ionized Jet IRAS 19035+0641 A" (Fig. 7)

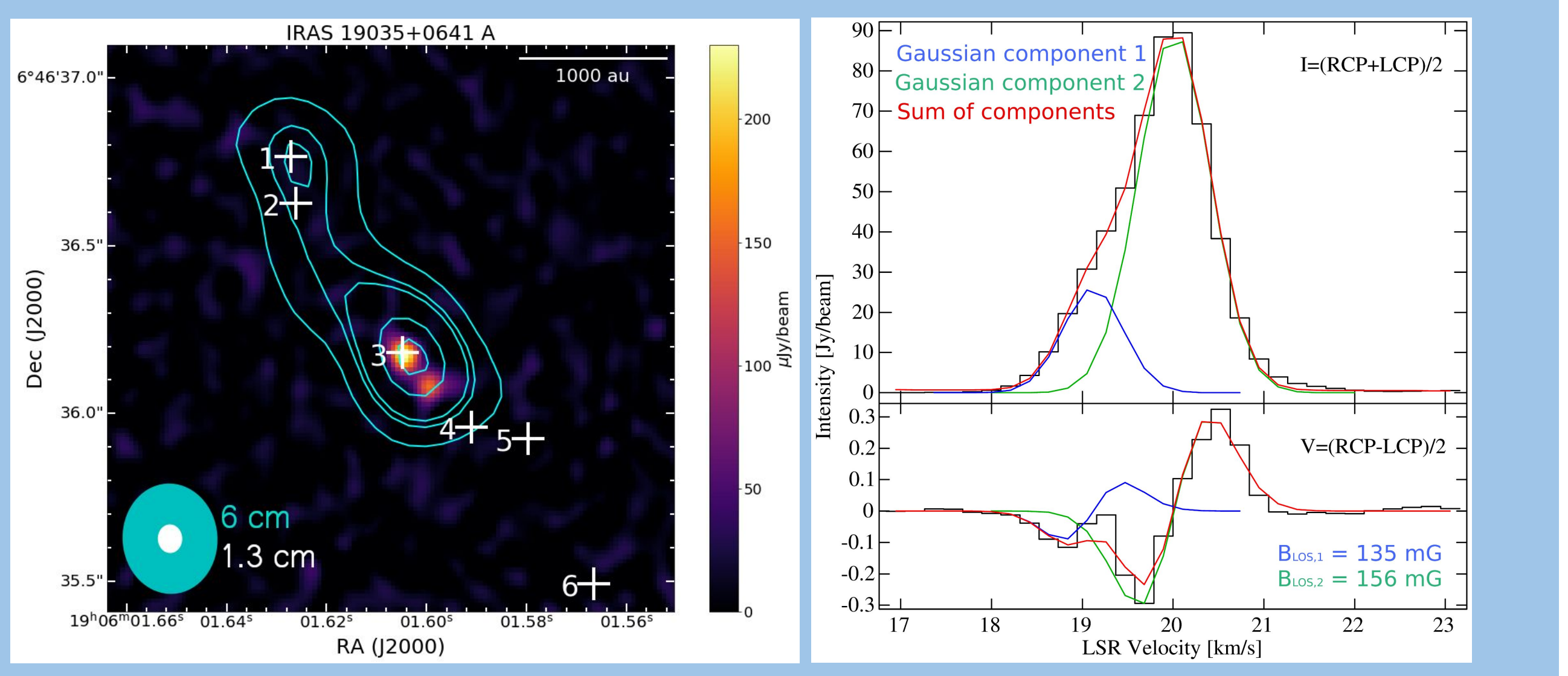


Figure 7: *Left*: 1.3 (color) and 6 cm continuum (contours), and 22.2 H_2O masers (+ symbols) in the IRAS 19035+0641 A jet. *Right:* Stokes I and V profiles of maser #3.

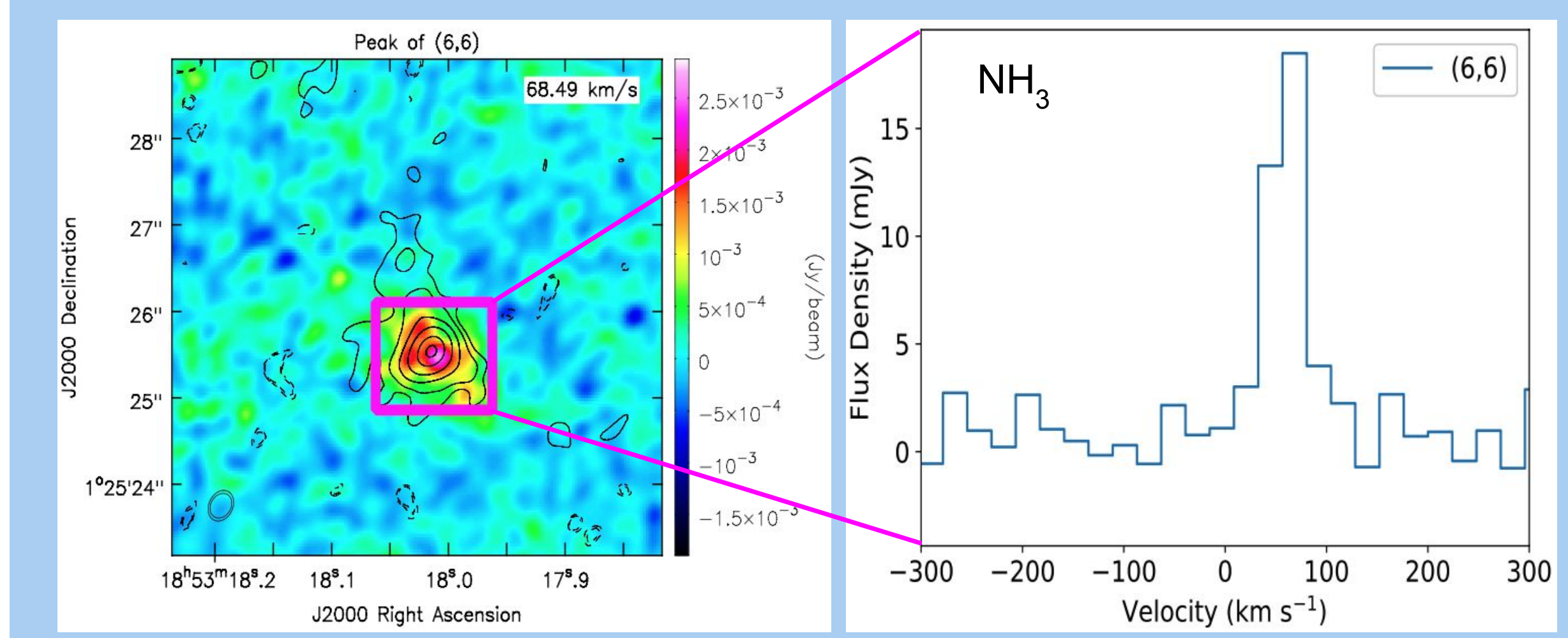


Figure 8: Example of NH_3 (6,6) detection toward G34.43+00.24 mm1 A. The nature of the line (thermal vs maser) is unclear.

Get the script:

Sanchez-Tovar et al. (submitted): "Broadband VLA Spectral Line Survey of a Sample of Ionized Jet Candidates"

- We developed a search and stacking script for spectral lines in continuum data.
- Applied to the Rosero et al. (2016) survey data.
  - Detection of 25 GHz CH_3OH transitions in 10 sources; 5 were also detected in NH_3 (Fig. 8).
  - All detections near ionized jets/jet candidates → shock tracers.
- Non-detection of RRLs, but rms noise decreases following radiometer equation.
  - RRLs might be detected if greater radio continuum and/or more frequency coverage.

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References: • Rodríguez, T.M. et al. 2021, ApJ, 922, 66. • Rodríguez, T.M. et al. 2023, ApJS, 264, 30. • Rosero, V., Hofner, P. et al. 2016, ApJS, 227, 25. • Rosero, V., Hofner, P. et al. 2019, ApJ, 880, 99. • Tan, W., Araya, E.D. et al. 2020, MNRAS, 497, 1348.