Probing the Dust Formation Zone in IRC+10216 with the SMA

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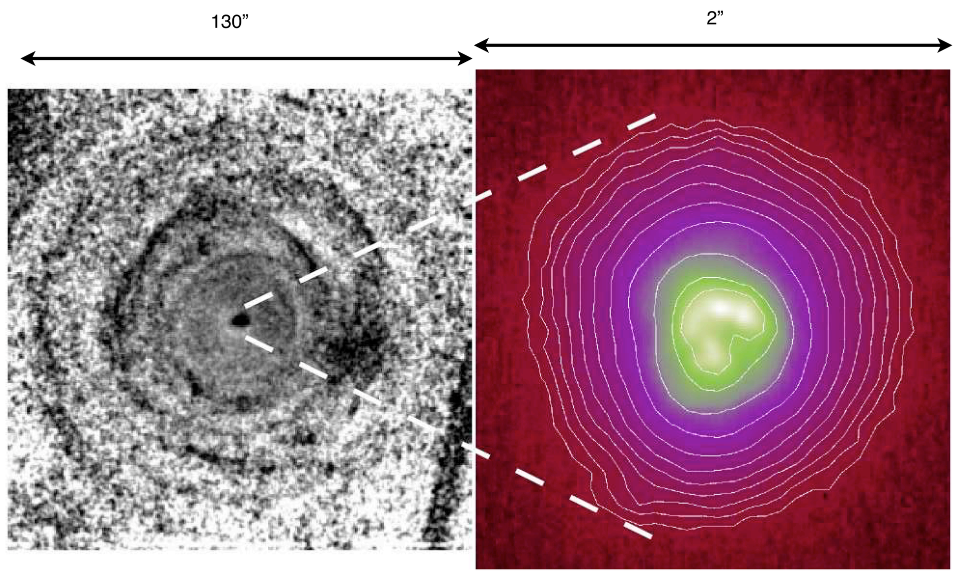
IRC+10216 (CW LEO)

- Nearest and brightest Carbon-rich AGB star (distance: $\sim$ 150 pc)
- Discovered in 1969 by Neugebauer & Leighton from an unbiased IR sky survey
- Spectral type: C9.5, Mira variable, 649 day period
- Velocity w.r.t. LSR: -26 km s^{-1}, wind velocity: 14.5 km s^{-1}.
- Mass-loss rate = several $\times 10^{-5} M_{\odot}$yr^{-1}



Left: optical image of dusty shells around IRC+10216 imaged with the CFHT (Mauron & Huggins (1999). Right: Adaptive Optics VLT image of the inner envelope of IRC +10216 at 2 microns (Menut et al. 2002). See also, talk by Michel Guelin at this conference.

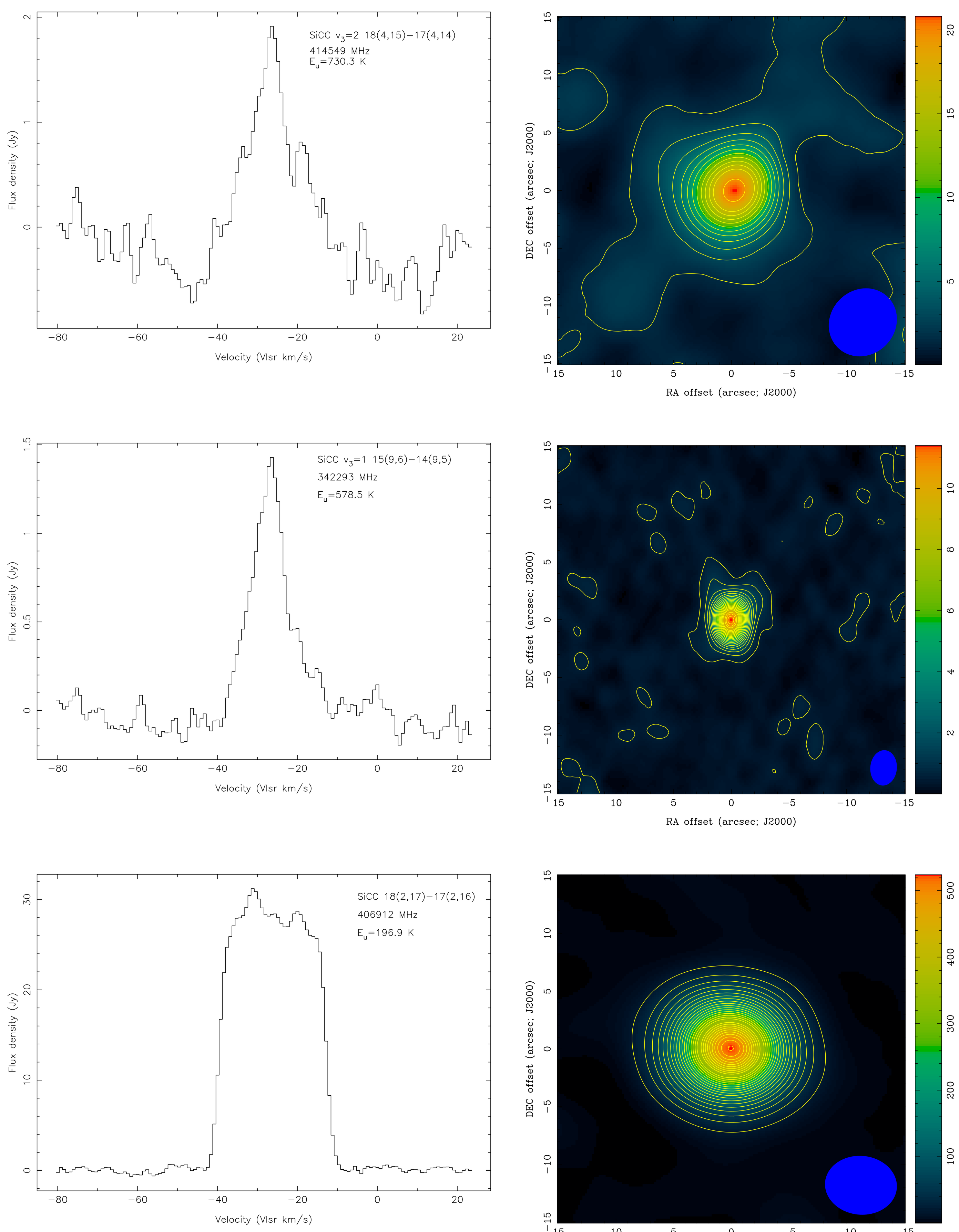


Figure 1. *Left:* Sample spectra of 3 rotational transitions of SiCC from levels with excitation energies (E_u) between 196 and 730 K above ground. The line profiles change from rectangular to narrow triangular shape with increasing E_u. *Right:* Integrated emission with a 3″ diameter beam of the 3 lines in the left hand panel, showing a progression from spatially extended to point-like unresolved emission as a function of E_u.

Introduction & Motivation

Interstellar dust grains are thought to evolve in the colder regions of space from the gas and solids present in the outflows from Asymptotic Giant Branch (AGB) stars. IRC+10216 is an ideal source to study the physical and chemical processes that occur in the circumstellar envelopes of carbon-rich AGB stars, because it is close to the Sun ($\sim$150 pc), the mass loss is high, and it is very rich in molecules. Summarized here are some interferometric spectral line measurements of a few small Si, Al, and Na bearing molecules included in recent models of the chemistry and dynamics of the inner envelope of IRC+10216.

- The formation of silicon carbide dust ("SiC") in the inner envelope of AGB stars is not well understood (Parker et al. 2013; Yasuda et al. 2012; Speck et al. 2009).
- Most prior measurements of the gaseous silicon carbides (SiC_n) were made with single antennas at low angular resolution of typically $10'' - 30''$.
- Direct observation of small metal bearing molecules in the inner envelope of AGB stars is becoming feasible with sensitive interferometers in the submillimeter band.
- In the past couple of years, we have measured many lines of SiCC in IRC+10216 in the 345 GHz and 400 GHz bands at high angular resolution with the SMA (see Figure 1) (Patel et al. 2011).
- Of the 4 silicon carbides observed with radio telescopes (SiC, SiCC, cyclic SiC_3, and SiC_4), only SiCC is observed in the inner envelope of IRC+10216 (the other 3 are in shells $\geq 4''$ from the star).
- The measured line widths confirm that we are directly observing SiCC in the dust condensation region close to the star (see Figure 2) (Patel et al. 2009).

Present Plans and Future Goals:

- Derive the abundances of small metal bearing molecules believed to be relevant for dust formation from our measurements.
- Compare the derived abundances with published chemical model calculations of the abundances versus radius.
- Critically assess current models of the non-equilibrium chemistry in the dust formation zone, and estimates of depletion of metal bearing molecules from the gas phase (Cherchneff 2012; Agúndez et al. 2012; Glassgold 1996).
- Continue interferometric measurements of metal bearing molecules at increased angular resolution to advance the determination of the physics and chemistry in the inner envelope of AGB stars.

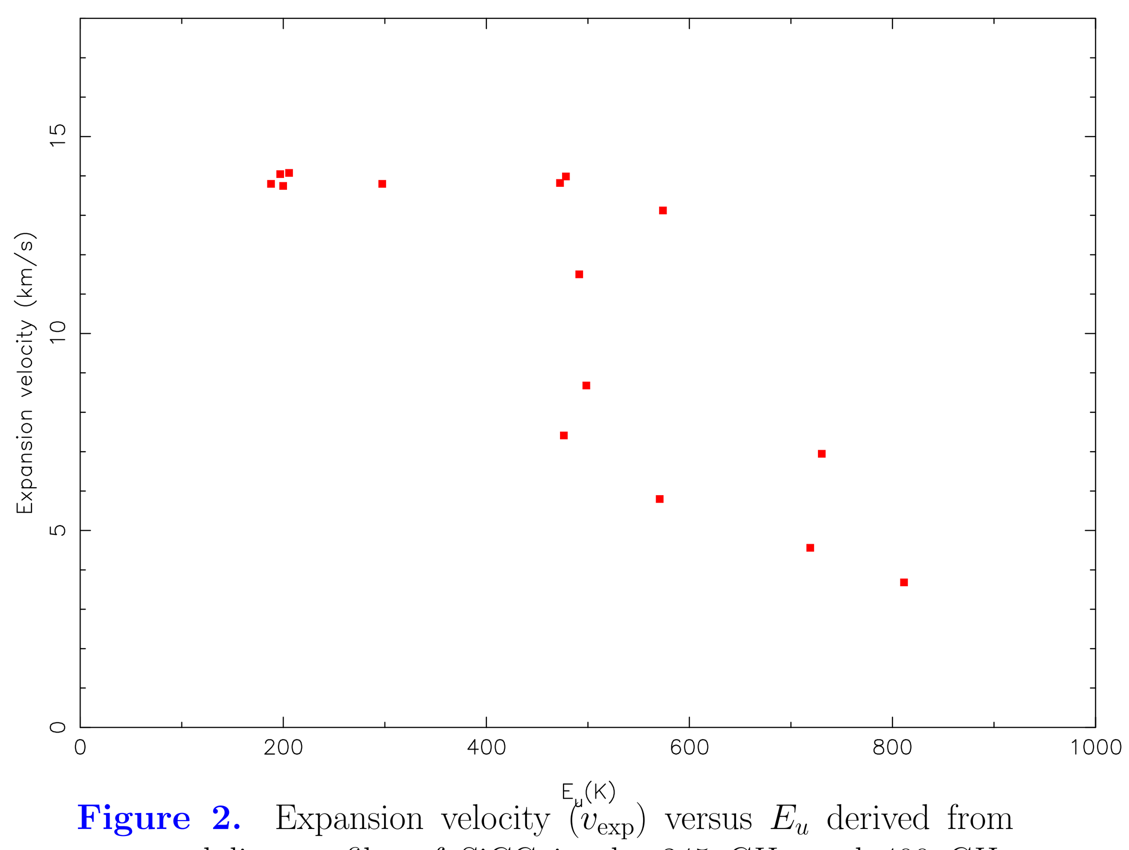


Figure 2. Expansion velocity (v_{exp}) versus E_u derived from measured line profiles of SiCC in the 345 GHz and 400 GHz bands. For $E_u < 400$ K, v_{exp} is comparable to the terminal velocity of 14.5 km s^{-1}, but v_{exp} decreases at higher E_u approaching 5 km s^{-1} (the velocity in the dust condensation region) for $E_u = 700 - 800$ K.

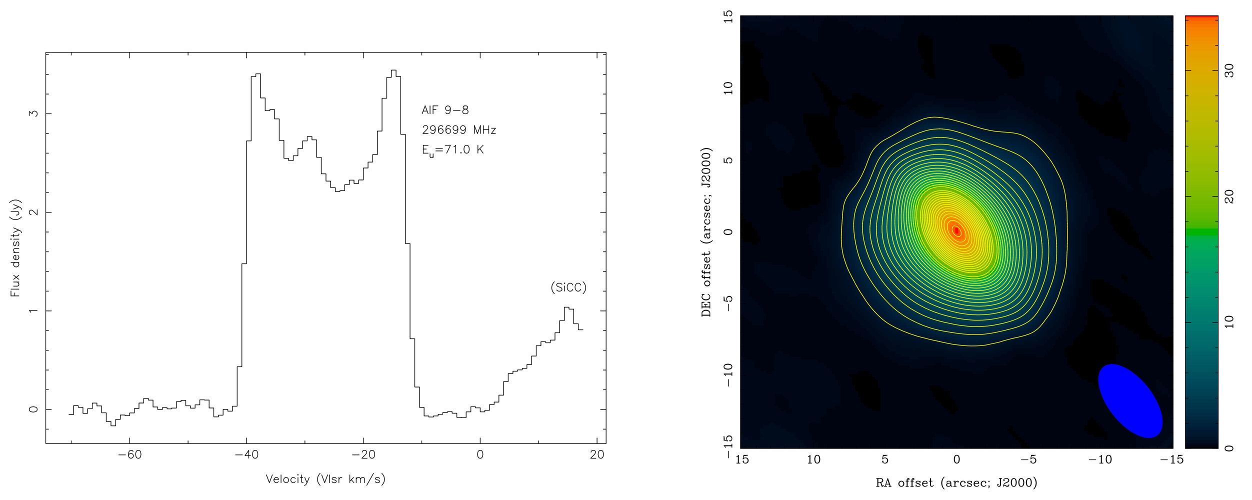


Figure 5. Spectrum and map of integrated emission of AlF near 296 GHz. The map confirms that there are two spatial components — a spatially unresolved, and a very compact shell just barely resolved with our 3″ beam. A similar angular distribution is observed in AlCl (not shown here).

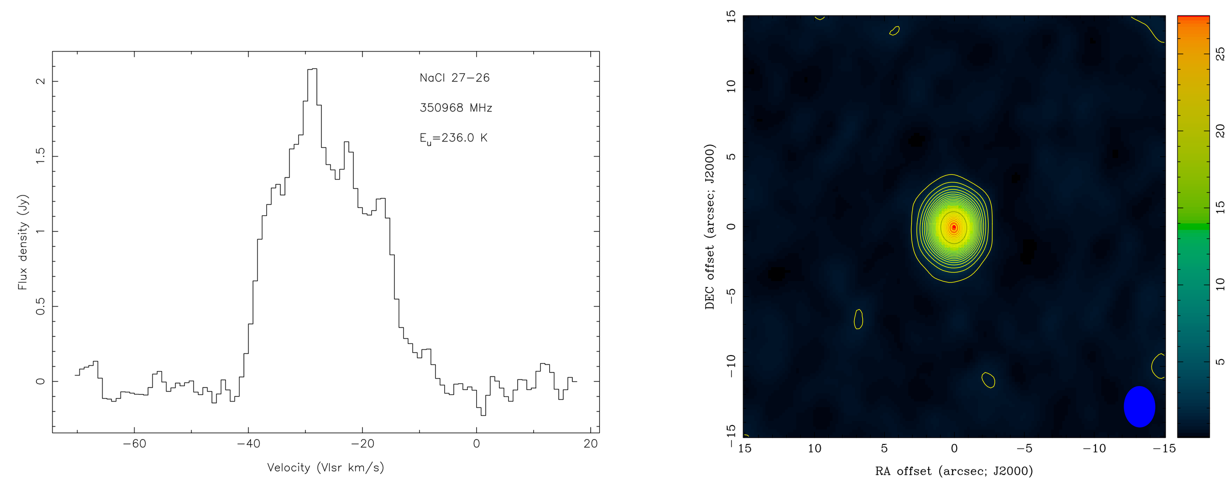


Figure 6. Spectrum and map of integrated emission of NaCl near 351 GHz. The NaCl (and KCl not shown here) appears very close to the star (within a few arcseconds), but some of the gas reaches the terminal expansion velocity.

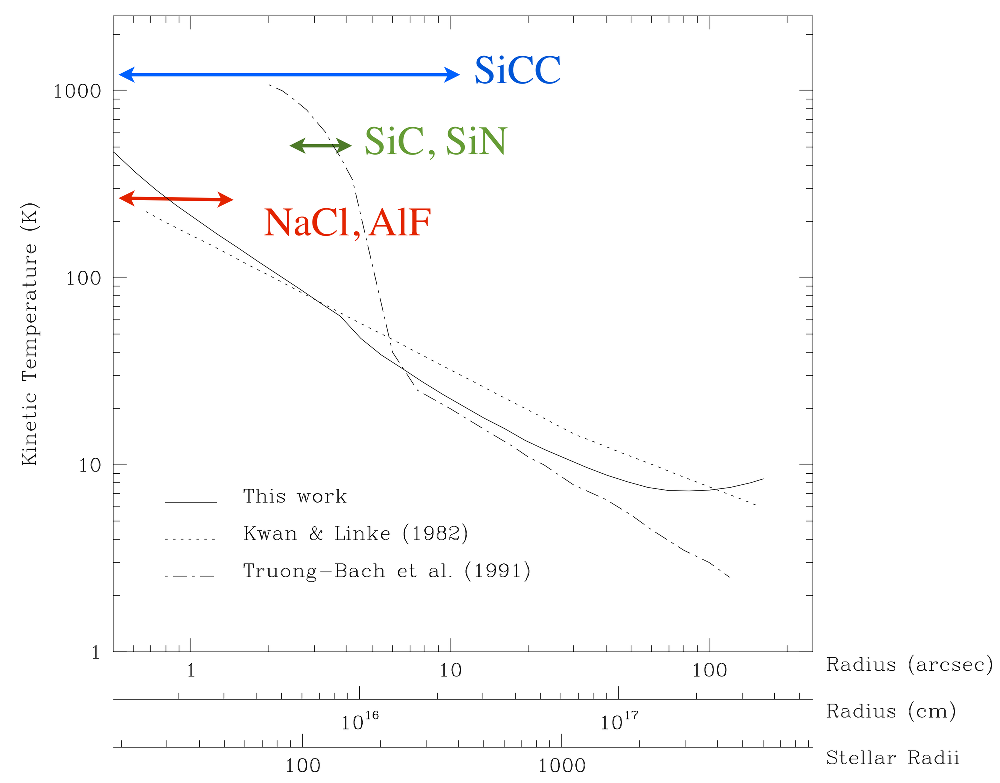


Figure 7. Figure from Crosas & Menten (1997) (see their Fig. 7) that shows the kinetic temperature as a function of radial distance from the star, derived from a model constrained by measurements of submillimeter-wave rotational lines of CO and ^{13}CO. The radial distribution of the metal bearing molecules observed with the SMA are shown with colored arrows.

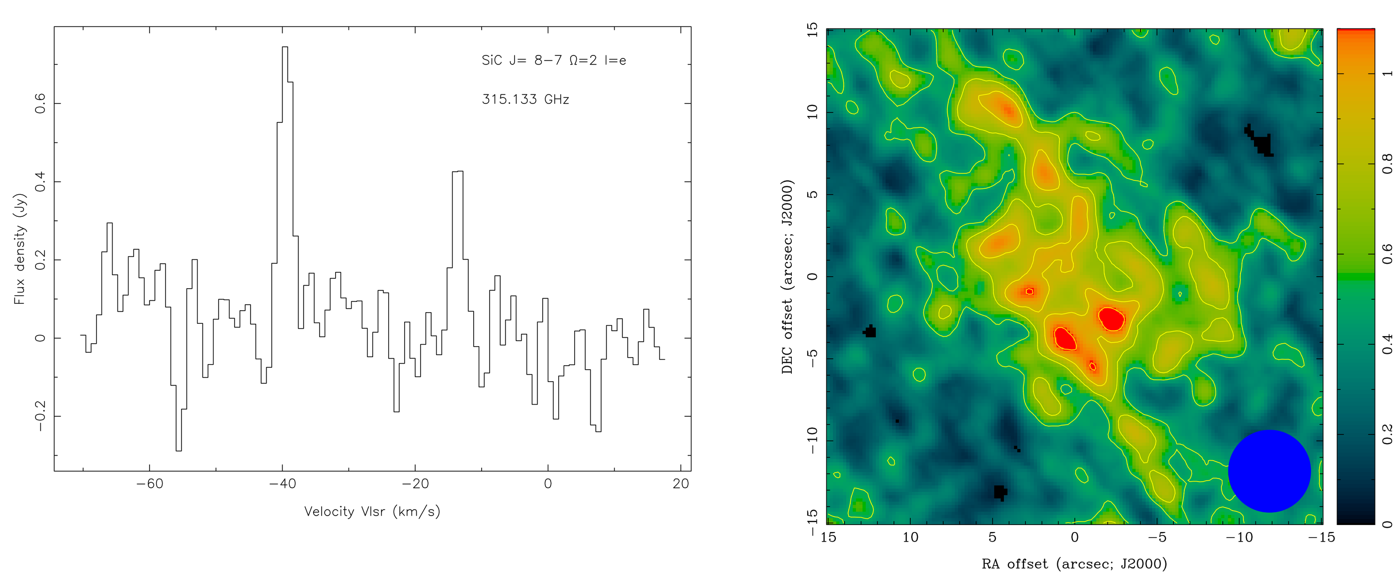


Figure 3. Spectrum and map of integrated emission of SiC near 315 GHz. The map confirms that (1) SiC is localized in an asymmetrical extended shell-like structure with an approximate radius from the star of about 4″, and (2) there is no evidence for SiC within the dust condensation radius of 0.1″.

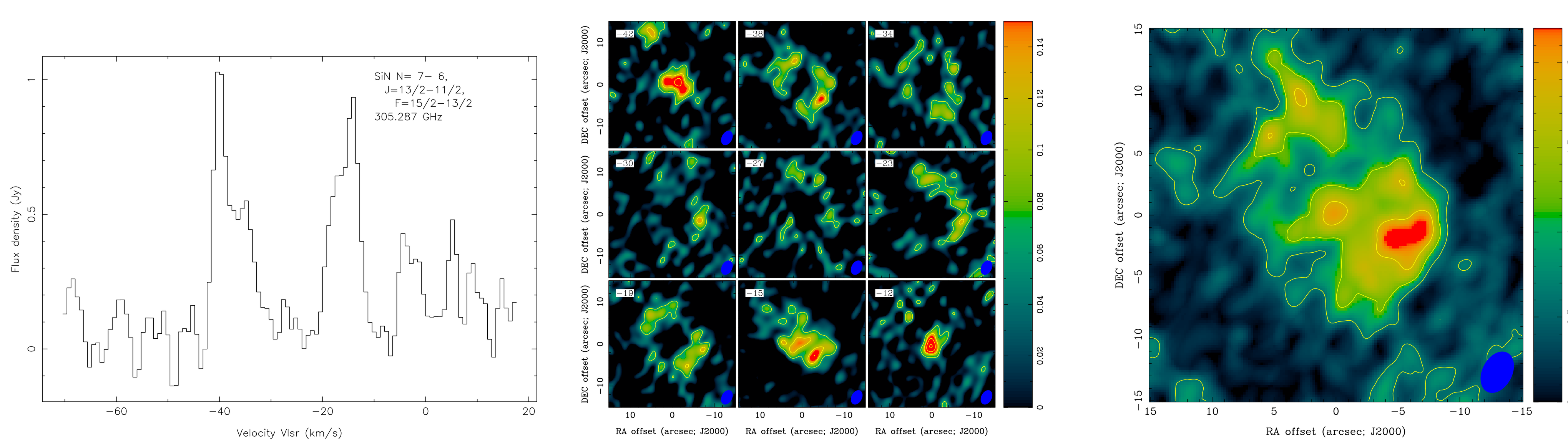


Figure 4. Spectrum, velocity channel maps, and map of integrated emission of SiN near 305 GHz. The map of SiN is very similar to that of SiC shown in Figure 3.

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