PROCEEDINGS OF SCIENCE

Probing the dust formation zone in IRC+10216 with the SMA

Nimesh A. Patel
Harvard-Smithsonian Center for Astrophysics
E-mail: npatel@cfa.harvard.edu

Carl Gottlieb
Harvard-Smithsonian Center for Astrophysics
E-mail: cgottlieb@cfa.harvard.edu

Ken Young
Harvard-Smithsonian Center for Astrophysics
E-mail: kyoung@cfa.harvard.edu

Submillimeter imaging of high-excitation molecular rotational lines provides a powerful probe of the dust formation and acceleration region ($R \leq 5 \times 10^{16}$ cm) in the extreme carbon-rich star IRC+10216. We present Submillimeter Array (SMA) observations of several rotational lines of SiCC from our 345 and 400 GHz spectral-line surveys, showing a progression from rectangular to narrow triangular line-profiles, and spatially extended to point-like unresolved emission, as a function of increasing energy $E_{\rm u}$. Maps of SiC and SiN emission show asymmetrical extended shell-like structures. These results are compared with published chemical model calculations of the radial abundances of molecules believed to be relevant for dust formation.

The Life Cycle of Dust in the Universe: Observations, Theory, and Laboratory Experiments - LCDU 2013, 18-22 November 2013
Taipei, Taiwan

PoS(LCDU 2013)098

1. 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. Spectral line-surveys allow us to identify new molecules, and from multiple transitions of the same molecule, we can also infer the physical conditions of the circumstellar gas. Direct observation of small metal bearing molecules in the inner envelope of AGB stars is becoming feasible with sensitive interferometers in the submillimeter band [1, 2]. These recent studies show that higher excitation submillimeter wavelength rotational lines are powerful probes, particularly with interferometry, of the inner envelope of IRC+10216 in the regions of dust formation and acceleration of the outflow.

2. Silicon carbide and silicon nitride in IRC+10216

Silicon carbide is a well known constituent of solid particles in circumstellar envelopes. Pre-solar SiC grains found in meteorites are believed to have originated in carbon stars [3, 4]. Chemical equilibrium calculations on the production of these molecules have been carried out in the last few decades [5] and also more recently [6, 7]. But very little is known from observations about the spatial distribution of SiC in gas phase.

Two successive rotational transitions of SiC at 315 and 354 GHz were observed in the ground $^3\Pi_2$ fine structure component with the SMA [1]. Prior to this, lines of gaseous SiC in the $^3\Pi$ ground electronic state were observed in the 157—283 GHz range with single antennas [8, 9, 10], at low angular resolution of typically $10'' - 30''$. Figure 1 shows the SiC spectrum and map of the 315 GHz line observed with the SMA at $3''$ resolution. In spectra observed both with single antennas and the SMA, the line profiles are very narrow with distinct horns, where we find that the FWHM $\sim$2.5 km s^{-1} and $V_{\rm exp}$ = 12.8 km s^{-1} is close to the terminal velocity. The flux observed with the SMA (1.2 Jy km s^{-1} at 315 GHz, and 1.4 Jy km s^{-1} at 354 GHz) is comparable to that observed in transitions at a slightly lower frequency of 275.7 GHz with the 10 m ARO antenna ($27''$ diameter beam [10]). Although the flux is not very high, there is no evidence for SiC in the dust formation zone within a few arcsec of the star as Figure 1 shows. Cernicharo et al. [8] concluded on the basis of the line profile shapes that SiC is confined to the outer envelope with an estimated column density of 6×10^{13} cm^{-2} averaged over their $17''$ diameter antenna beam. Our derived column density of 2.4×10^{13} cm^{-2} is comparable to this original estimate, but the fractional abundance (w.r.t. H_2) of 1.5×10^{-9} is significantly higher than chemical model predictions [6] and the calculated radial distribution of SiC [11] is not consistent with our measurements which establish that the gaseous SiC is about ten times closer to the star. However, similar maps of lower excitation lines are needed to confirm this. Results for SiN are similar, as shown in Figure 2. The channel maps confirm that the emission arises from an expanding shell. We estimate the column density for SiN $\sim 3.2 \times 10^{13}$ cm^{-2} and fractional abundance of 2.0×10^{-9}, with $T_{\rm ex} \sim 40$ K. Our SiN column density is in good agreement with the value quoted by Turner in his detection paper [12].

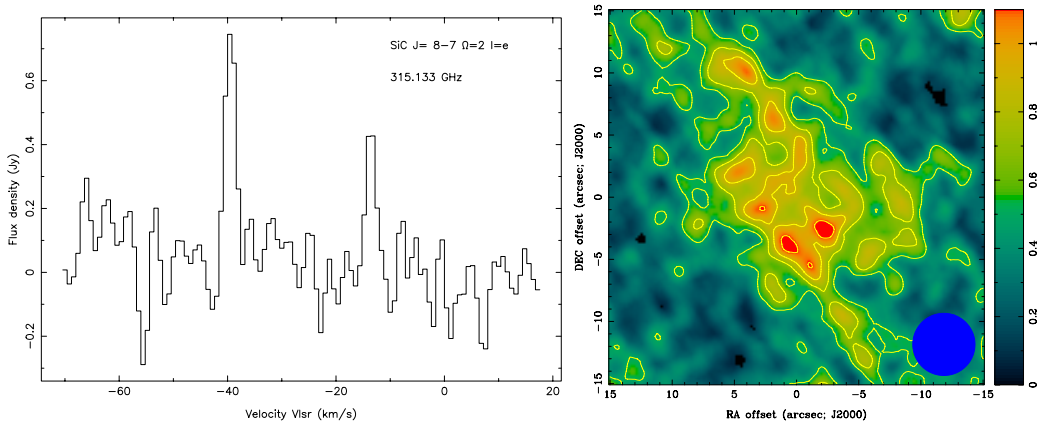

Figure 1: Spectrum and map of integrated emission of SiC near 315 GHz. The map suggests that (1) SiC is localized in an asymmetrical extended shell-like structure with an approximate radius from the star of about $4''$, and (2) there is no evidence for SiC within the dust condensation radius of $0.1''$.

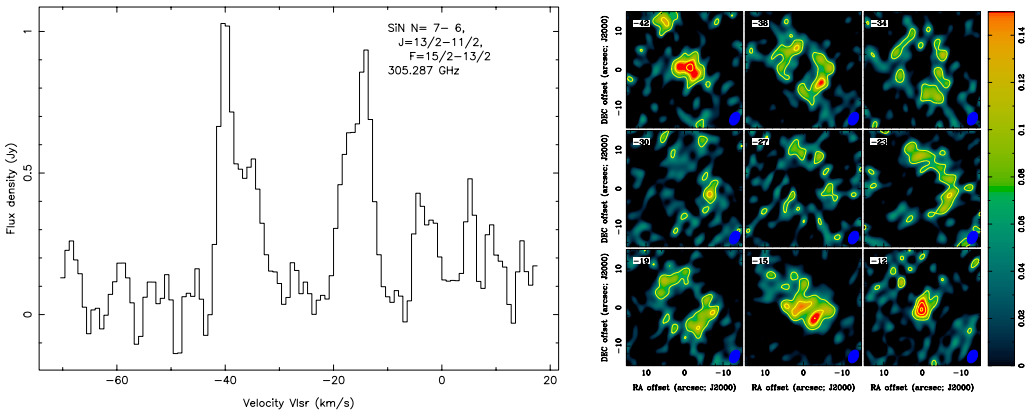

Figure 2: Spectrum and channel map of SiN emission near 305 GHz.

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 [1, 13]. 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. The line profiles change from rectangular to narrow triangular shape with increasing E_u. The expansion velocities derived from the line widths are plotted vs E_u in Figure 3, showing a transition at $\sim$ 500 K.

3. Salts and metal halides

Spectra and maps of salts NaCl and KCl at $\sim$ 351 GHz (not shown here) confirm that the emission appears symmetrical and confined to within a few arcseconds around the star, but some of

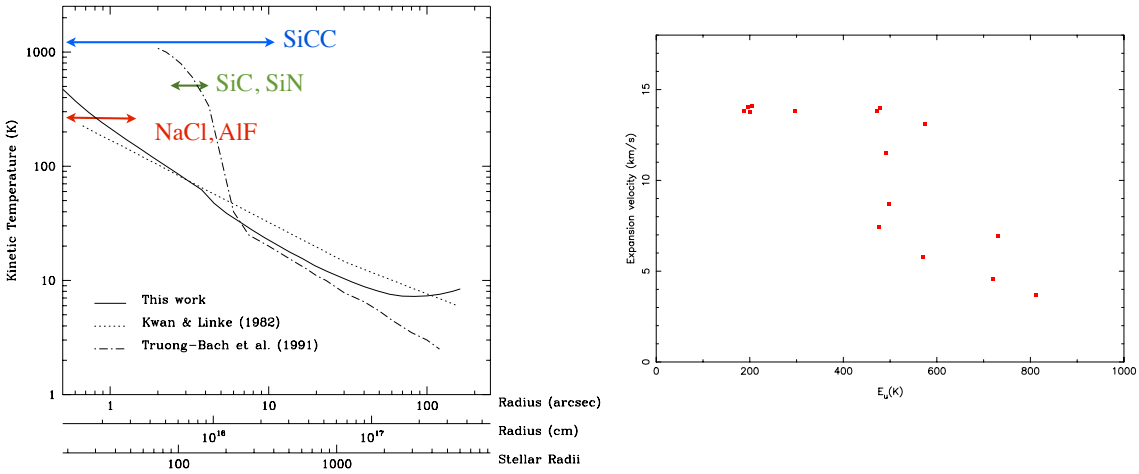

Figure 3: *Left:* This figure (from [14]) shows the kinetic temperature as a function of radial distance from the star. The radial distribution of various molecules as suggested from SMA results, are shown with colored arrows. *Right:* Expansion velocity ($v_{\rm exp}$) versus $E_{\rm u}$ derived from measured line profiles of SiCC in the 345 GHz and 400 GHz bands. For $E_{\rm u} < 400$ K, $v_{\rm exp}$ is comparable to the terminal velocity of 14.5 km s^{-1}, but $v_{\rm exp}$ decreases at higher $E_{\rm u}$ approaching 5 km s^{-1} (the velocity in the dust condensation region) for $E_{\rm u} = 700 - 800$ K.

the gas reaches the terminal velocity. AlF and AlCl (near 296 GHz) show two spatial components — a spatially unresolved, and a very compact shell just barely resolved with our 3″ beam.

References

[1] N. A. Patel, K. H. Young, C. A. Gottlieb, et al. 2011, ApJS, 191, 17

[2] J. Cernicharo, F. Daniel, A. Castro-Carrizo, et al., 2013, ApJ, 778, L25

[3] D. S. N. Parker, A. V. Wilson, R. I. Kaiser, et al. 2013, ApJ, 770, 33

[4] Y. Yasuda, & T. Kozasa 2012, ApJ, 745, 159

[5] A. Glassgold, 1996, Annu. Rev. Astron. Astrophys, 34, 241

[6] I. Cherchneff 2012, A&A, 545, A12

[7] M. Agúndez, J. P. Fonfría, J. Cernicharo, et al. 2012, A&A, 543, A48

[8] J. Cernicharo, C. Gottlieb, M. Guélin, et al. 1989, ApJ, 341, L25

[9] J. Cernicharo, M. Guélin, C. Kahane, 2000, A&AS,142,181

[10] E. Tenenbaum, J. Dodd, S. Milam, et al., 2010, ApJ, 720, 102

[11] D. MacKay & S. Charnley, 1999, MNRAS, 302,793

[12] B. Turner, 1992, ApJ, 388, L35

[13] N. A. Patel, K. H. Young, S. Brünken, et al. 2009, ApJ, 692, 1205

[14] M. Crosas & K. Menten, 1997, ApJ, 483, 913