Why Galaxies Care About AGB Stars:
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SMA Spectral Line Survey of the Proto-Planetary Nebula CRL 618

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Abstract. Carbon-rich Asymptotic Giant Branch (AGB) stars are major sources of gas and dust in the interstellar medium. During the brief (∼1000 yr) period in the evolution from AGB to the Planetary Nebula (PN) stage, the molecular composition evolves from mainly diatomic and small polyatomic species to more complex molecules. Using the Submillimeter Array (SMA), we have carried out a spectral line survey of CRL 618, covering a frequency range of 281.9 to 359.4 GHz. More than 1000 lines were detected in the ∼60 GHz range, most of them assigned to HC_3N and c-C_3H_2, and their isotopologues. About 200 lines are unassigned. Lines of CO, HCO^+, and CS show the fast outflow wings, while the majority of line emission arises from a compact region of ∼1" diameter. We have analyzed the lines of HC_3N, c-C_3H_2, CH_3CN, and their isotopologues with rotation temperature diagrams.

Keywords. (stars:) circumstellar matter, molecular processes, stars: AGB and post-AGB, submillimeter, stars: individual (CRL 618)

Earlier studies of the chemical evolution of carbon rich AGB and post-AGB sources with the IRAM 30m, CSO 10m, and ISO telescopes concluded that CO, ^{13}CO, and HCN emission are produced in shocks caused by the fast wind in CRL 618; H_2O and OH form in the inner parts of the envelope; more complex organic molecules appear; and finally as the star reaches the PN stage, molecules are converted to atoms (Herpin *et al.* 2002). By referring to chemical models, it was found that HCN is quickly photodissociated to produce CN; and HCCCN is subsequently produced by reactions of CN with C_2H_2 and C_2H (Cernicharo 2004). Mapping the spatial location of various molecular species is important for comparison with chemical model predictions. Single-dish observations do not have adequate angular resolution (e.g., Pardo *et al.* 2007a). Interferometric observations of CRL 618 are presented in a few studies, but the spectral coverage is limited (Remijan *et al.* 2005, Lee *et al.* 2013, Sanchez-Contreras 2004).

CRL 618 was observed with the SMA with an angular resolution of $0.''5 \sim 2.''5$. The frequency range was 282.0 to 360.0 GHz, with a spectral resolution of ∼0.8 MHz, and rms line sensitivity of ∼0.1 Jy/beam. A sample spectrum covering about 1/4 of the full range is shown in Fig. 1. A total of 1075 lines were detected. About 250 lines remain unassigned. Most of the lines are attributed to c-C_3H_2, and HC_3N and its isotopologues. CS, CN, HCN and CCH are detected in the fast outflow of CRL 618. There are no Si bearing molecules detected except SiO, in contrast to IRC+10216 where molecules such as SiCC are in much greater abundance. Eight hydrogen and two helium recombination lines are detected in the ionized region at the peak continuum emission which remains unresolved even at

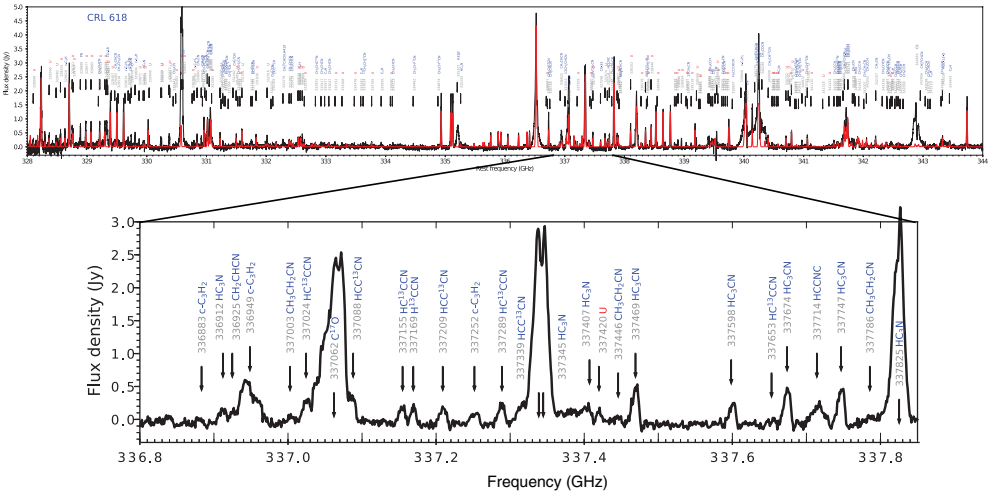

Figure 1. *Top:* Part of the spectrum from the line survey of CRL 618 covering 328 to 344 GHz. The red curve is an LTE model based on identified molecules and isotopologues. *Bottom:* Zoomed spectrum from above, to show details and some of the identifications.

Table 1. Summary of molecules and isotopologues detected in CRL 618

c-C_3H_2	∼150	CH_3CN	21	CN	5	Recombination	
HC_3N	∼ 170	CH_3C_2H	43	^{13}CN	2	lines	
		c-C_3H	11	$^{13}C^{15}N$	2		
$H^{13}CCCN$,		C_2H	3	HCN	4		
$HC^{13}CCN$,	144			$H^{13}CN$	3	H26α	1
$HCC^{13}CN$		H_2CO	6			H27α	1
		$H_2^{13}CO$	3	MgNC	1	H37α	1
$HCCC^{15}N$	1	$H_2C^{18}O$	1			H39α	1
HCCNC	4	CO	1			H33β	1
HC_5N	27	CS	2	^{13}CO	1	H34β	1
		^{13}CS	1	$C^{18}O$	1	H41δ	1
SiO	1			$C^{17}O$	1	H38γ	1
		HCO^+	1				
HCP	1	HCS^+	1	PN	1	He26α	1
CH_2NH	4						
$^{13}CH_2NH$	4						
CH_2CHCN	6						
CH_3CH_2CN	30						

0.″5 resolution. Table 1 summarizes the detected molecules and isotopologues in the line survey. LTE modeling is carried out for several of these molecules and isotopologues (Patel *et al.* 2018, in prep.).

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