*Organic Matter in Space*
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# Molecular lines in the envelopes of evolved stars

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**Abstract.** We report a spectral line survey of the circumstellar envelopes of evolved stars at millimeter wavelengths. The data allow us to investigate the chemical processes in different physical environments and evolutionary stages. A total of more than 500 emission features (mostly rotational transitions of molecules) are detected in the survey. Our observations show that the sources in different evolutionary stages have remarkably different chemical composition. As a star evolves from AGB stage to proto-planetary nebula, the abundances of Si-bearing molecules (SiO, SiCC, and SiS) decrease, while the abundances of some long-chain molecules, such as $CH_3CN$, $C_4H$, and $HC_3N$, increase. After further evolution to planetary nebula, the abundances of neutral molecules dramatically decrease, and the emission from molecular ions becomes more intense. These differences can be attributed to the changes of the role that dust, stellar winds, shock waves, and UV/X-rays from the central star play in different evolutionary stages. These results will provide significant constraints on models of circumstellar chemistry.

**Keywords.** Stars: AGB and post-AGB, line: identification, ISM: molecules, radio lines: ISM

## 1. Introduction

Since 1970, more than 60 molecular species, including many organic molecules, have been detected in the circumstellar envelopes of evolved stars. Asymptotic giant branch (AGB) stars, their descendant planetary nebulae (PNs), and the transition objects between the two phases, proto-planetary nebulae (PPNs), therefore represent major sites of molecular synthesis. Since the evolutionary time scales of these phases are very short ($10^4$–$10^5$ yr, $< 10^3$ yr, $10^3$–$10^4$ yr for AGB stars, PPNs, and PNs, respectively), chemical reaction time scales are very well constrained by these time scales. The study of the changing chemical composition and molecular abundance between objects in consecutive phases of evolution provides useful information on the chemical pathways of molecular synthesis. Furthermore, these comparisons can lead us to a better understanding of the roles of dust, shock waves, and UV and X-ray radiation on the chemical processes. For this purpose, we present a molecular line survey in a sample of evolved stars.

## 2. Observations

Our sample consists of three AGB stars (IRC+10216, CRL 3068, and CIT 6), one PPN (CRL 2688), and one young PN (NGC 7027). The spectral survey was carried out between 2005 April and 2008 January using the Arizona Radio Observatory 12 m and 10 m telescopes, covering the frequency ranges from 71–161 GHz and 218–268 GHz, respectively. The typical sensitivity is $T_{\rm R} < 10$ mK at a spectral resolution of 1 MHz. The spectra are presented in Figure 1. The temperature scales at the ARO 12 m and 10 m are $T_R^*$ and $T_A^*$, respectively. The main beam brightness temperatures were derived through

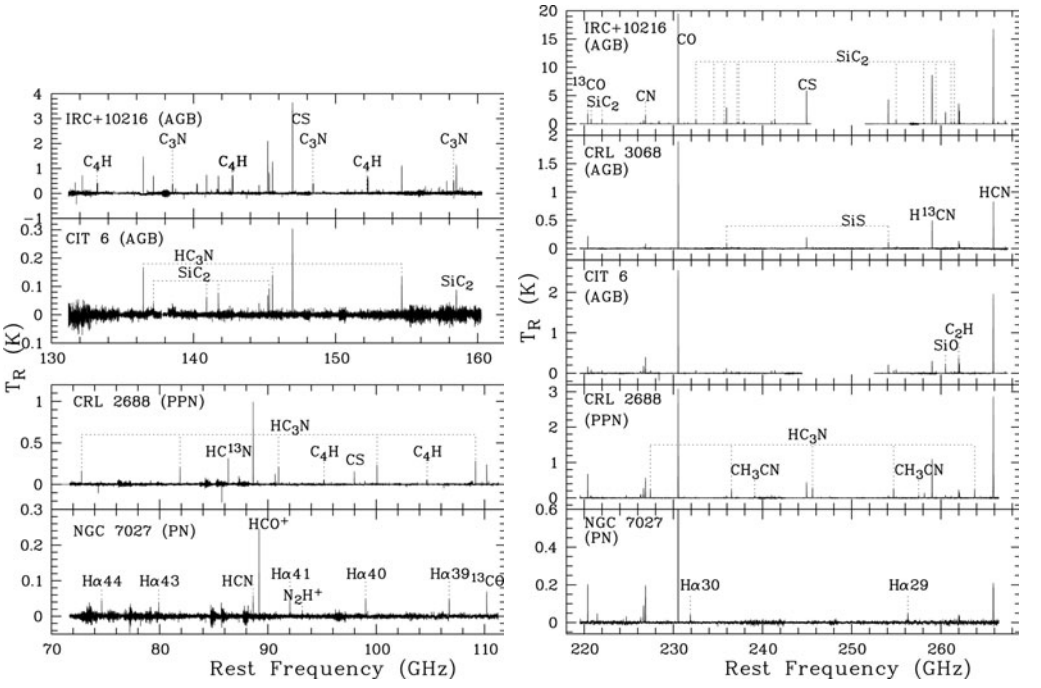


**Figure 1.** *Left panel*: The 12 m data; *Right panel*: The 10 m data.

$T_R = T_R^*/\eta_m^*$ and $T_R = T_A^*/\eta_{mb}$, where $\eta_m^*$ is the corrected beam efficiency and $\eta_{mb}$ the beam efficiency.

## 3. Conclusions

A systematic comparison of the molecular emission in the five objects has revealed the following spectral differences:

a) Refractory metal- and Si-bearing species, which are plentifully present in IRC+10216, show weak or no emission in the other objects. These molecules may be depleted onto dust grains with stellar evolution.

b) Compared to the other objects, CRL 2688 has stronger $C_4H$, $HC_3N$ and $CH_3CN$ emission, suggesting that these species are rapidly reprocessed during the evolution from AGB to PPN.

c) Compared to other objects, CIT 6 has a large CN/HCN intensity ratio due to photodissociation of HCN into CN. However, the CN/HCN ratios in CRL 2688 and NGC 7027 are relatively low, indicating that CN and/or HNC may be efficiently transferred into HCN in hot environments.

d) Emissions from neutral molecules in NGC 7027 are fainter compared to those in other objects. This is partly due to the destruction of neutral molecules caused by strong shocks and UV radiation in the young PN.

e) For our observations, NGC 7027 is the only source in which we have detected ionized species ($HCO^+$, $HCS^+$, and $N_2H^+$) and recombination lines. This is attributed to photoionization by the much stronger UV radiation from the central star.

Further observations are underway to expand the evolutionary coverage in order to better constrain the relation between chemical abundance and physical conditions.

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