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Evolution of Molecular Gas in Planetary Nebulae

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Abstract. Observations of molecular gas at 7 mm are made with the Green Bank Telescope (GBT) in a sample of planetary nebulae (PNe). PNe were selected to test stellar evolution models that include extra mixing processes induced by rotation by directly measuring the isotopic abundance ratios of processed material that has escaped the progenitor star. Moreover, these data are used to probe theories of chemical evolution through a sample of AGB stars, protoplanetary nebulae, and young and evolved PNe. One goal is to constrain the timelines and list of tracers for studying the molecular emission in these sources and examine the role of clumping for different species.

Keywords. radio lines: stars, molecular data

1. Introduction

Surveys of CO at mm wavelengths have revealed that many planetary nebulae (PNe) are surrounded by cold, molecular envelopes (e.g., Huggins & Healy 1989). The molecular gas has been observed by high resolution imaging of CO and molecular hydrogen and the morphology consists of fragmented structures surrounded by ionized gas. Observations of various molecular species in these objects indicates a chemical evolution from the AGB phase to the evolved PNe stage (e.g., Bachiller *et al.* 1997). Measurements of isotopic abundance ratios (e.g., $^{12}C/^{13}C$) from CO in PNe have been used to test stellar evolution models that include extra mixing processes induced by rotation (e.g., Balser *et al.* 2002).

2. Observations

Observations of CS, SiO, H_2CO, HNCO, CH_3OH, and HC_3N at 7 mm were made using the GBT toward 11 PNe. The sample includes AGB stars, protoplanetary nebulae (PPNe), and young and evolved PNe to explore the chemical evolution of molecular gas. We have also chosen some PNe with high Galactic latitude that are likely to be associated with Population II objects and have low-masses to probe extra mixing in these objects. The GBT offers several advantages at 7mm: good spatial resolution ($17''$) coupled with low system temperatures should be well matched to the molecular gas in PNe which has a clumpy morphology; the flexibility of the GBT spectrometer allows us to observe many transitions simultaneously. Figure 1 show several spectra of IRC+10216. We were unable to detect the main lines in most PNe in our sample.

3. Discussion

We have detected and placed limits on a range of molecular species in a sample of objects. These observations are consistent with both other observational studies and with chemical models which indicate that the complex chemistry seen in circumstellar

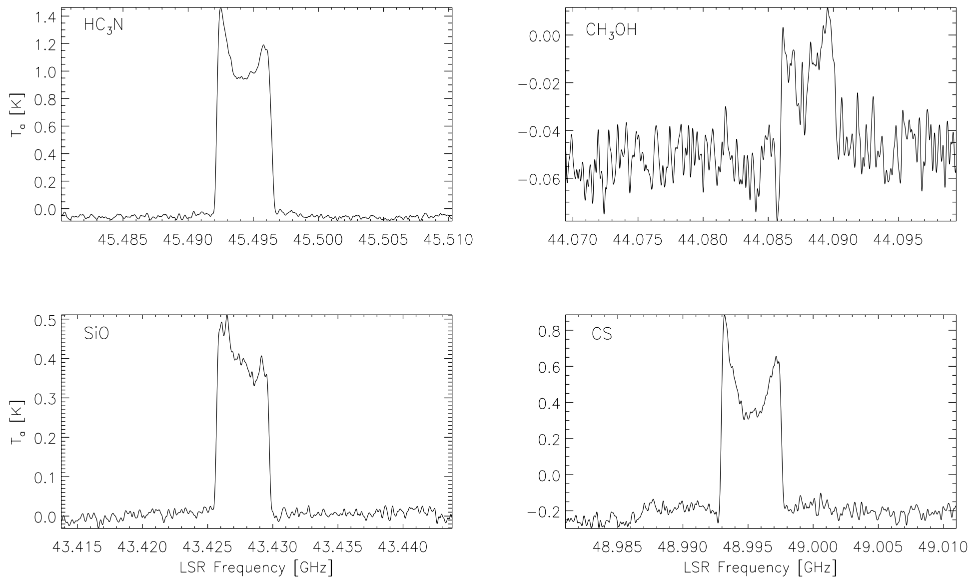

Figure 1. Spectra of several species in IRC+10216. The intensity scale has been calibrated in units of antenna temperature. We have not corrected for the atmosphere or removed the zero level in these "raw" spectra. The data have been smoothed to a velocity resolution of $\sim 1\,\mathrm{km\,s^{-1}}$.

envelopes and AGB stars is quickly quenched through UV photodissociation from the central star. Abundance ratios for our sample will be derived to test and discriminate between the existing models. Previous detections (e.g., CS and H_2CO; Woods & Nyman 2005) indicate that some (smaller) species can persist even in evolved PNe through the shielding effects of clumps. Our failure to detect these species in most of the sources indicates that the shielding effects are not ubiquitous; however stronger limits should be obtained since the anticipated emission is quite low (hundredths of a K).

We were unable to detect isotopic pairs in any of the PNe studied so comparison with the CO ratios was not possible. The derived value of the $^{12}C/^{13}C$ ratio in IRC+10216 is inconsistent with previous efforts (Kahane *et al.* 1988), likely due to opacity effects in the main species; this will be explored further through radiative modeling.

Q-band (40-50 GHz) offers a range of molecular tracers (weak and strong shock indicators, grain chemistry, etc.), with reasonable excitation characteristics for many molecular regions (ISM, star forming, galaxy centers, etc.). However, the peculiar, transient environment of PNe, pares the available molecular material such that these objects are likely best studied through higher frequency observations.

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