National Aeronautics and Space Administration

Astrochemistry with the Deep Space Network (DSN)

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Program: FY22 R&TD Innovative Spontaneous Concepts

Objectives: The Astronomy and Physics Directorate (7X) recently started strategy discussions on astrochemistry science and programmatics, including JPL capabilities and gaps. One strategic topic "Path Toward Habitability" includes DSN radio observations of gas-phase complex organic molecules in astrophysical sources and their connection to Solar System and exoplanet environments. A Deep Space Network pilot program to detect organic molecules in a protostellar core was conducted to assess the potential for the DSN to contribute to NASA's abiogenesis, the origins of life, program.

Background: To date over 240 molecules, the majority organic, have been detected through their spectral signatures. *Rosetta* showed that cometary ice composition is very similar to that of low-mass star-forming regions, suggesting that interstellar clouds could be a cradle for prebiotic molecules delivered to the early Earth by comets. Unfortunately, the organically important aromatic hydrocarbons are nonpolar and have no allowed radio frequency transitions. However, benzonitrile c-C6H5CN (Figure 1), a derivative of benzene (CN substituted for an H), has radio transitions and is an excellent candidate for radio-frequency searches to confirm the presence of these ring molecules in cores.

Approach and Results: Using the 70-m Canberra DSN telescope, we searched for benzonitrile emission in the class 0 protostar Cha-MMS1 and the prestellar core Cha-C2 in the Chamaeleon cloud complex, which are targets of the JWST "Ice Age" ERS program. Several molecular species were detected (Figure 2). We demonstrated that the DSN Canberra can reach a rms of ~4 mK (T_{mb}) in most sub-bands, in a 30.5 kHz channel, in 20 hours of on-source observing time. A much lower rms of 1.0 mK (T_{mb}) was demonstrated in a stacked spectrum of 30 benzonitrile lines within the DSN frequency range (Figure 3). To support astrochemical studies with the DSN, we developed a gas-grain chemical network starting from the public chemical network kida.uva.2014. The predicted benzonitrile abundance in TMC-1 is an order magnitude lower than the observed abundance. The chemistry in TMC-1 clearly favors planar carbon structures (as opposed to linear ones). Consequently, the observed aromatic chemistry in TMC-1 is much richer than that predicted by the model, but the details are not well understood. The non-detection of benzonitrile emission in Cha-MMS1 and Cha-C2 suggests that the abundance of benzonitrile is lower than that in TMC-1. Our findings suggests that the high benzonitrile abundance in TMC-1 may be specific to this source and that its production is not well understood.

Significance/Benefits to JPL and NASA: Our preliminary results clearly demonstrate the potential of the DSN 70-m Canberra telescope for astrochemistry studies in the Southern Hemisphere. DSN observations of complex organic molecules in the gas phase will be highly complementary to the James Webb Space Telescope MIRI and NIRSpec spectroscopic studies of the composition of interstellar ices in star-forming regions. This synergy will enable successful long-term JWST observing programs by JPL researchers, thus enhancing the scientific return on the JPL investment in the MIRI instrument.

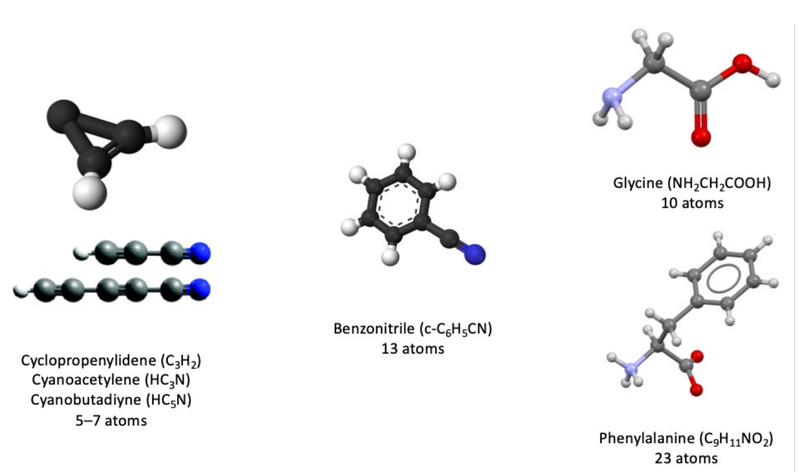

Figure 1. Chemical structure of the most complex species detected in the short DSN observation of Cha-MMS1 (left; 5–7 atoms), the ring molecule that was a target of the observations (middle; 13 atoms), and simple amino acids (right; 10–23 atoms).

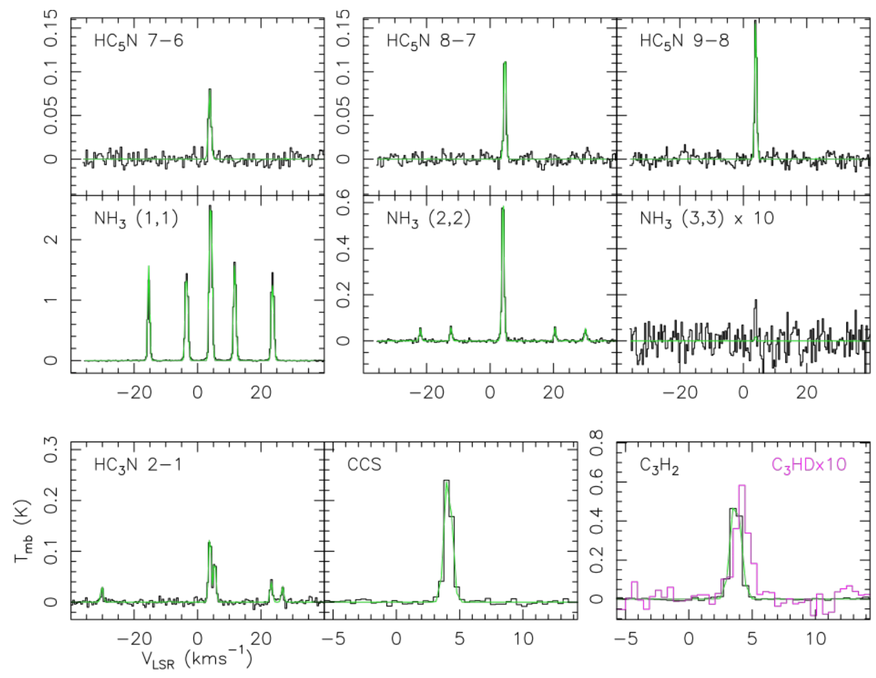

Figure 2. Spectra of molecular lines toward Cha-MMS1. The intensity scale is the main beam brightness temperature. The hyperfine splitting is clearly detected for ammonia and HC_3N. The green line is the hyperfine structure fit to the spectra, except for CCS and C_3H_2, where it represents a Gaussian fit.

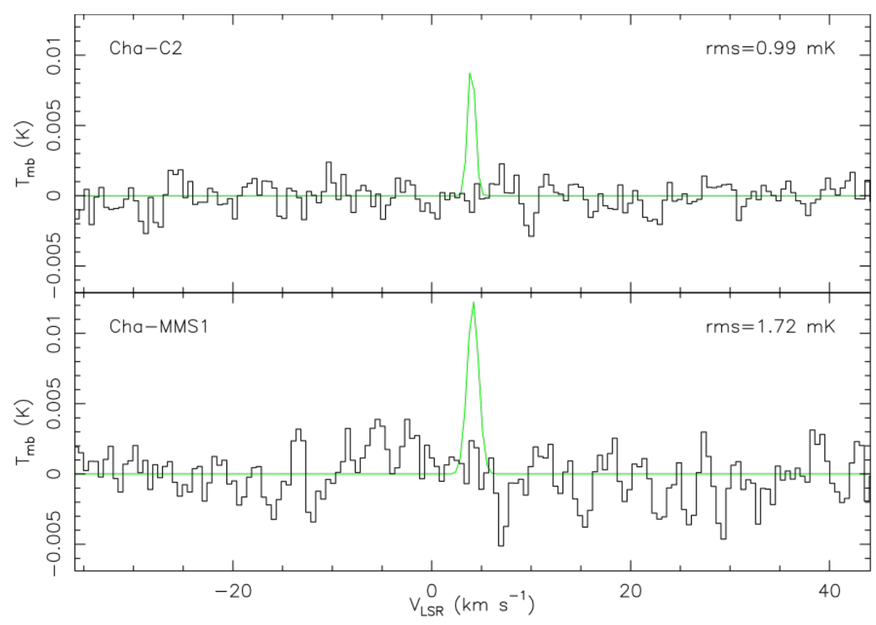

Figure 3. Stacked spectra of benzonitrile in Cha-C2 and Cha-MMS1 (black histograms, top and bottom panels, respectively). The spectra of individual lines were scaled to the intensity of the brightest line and averaged with $1/\sigma^2$ weighting. The green line shows a Gaussian fit to the HC_7N spectrum, which has been used as a reference in previous benzonitrile studies. HC_7N is clearly detected (6.4σ) in both sources (average of the 4 brightest lines in the DSN frequency range). No benzonitrile emission is detected in either source.

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Publications:

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