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ETHYL CYANIDE ON TITAN: SPECTROSCOPIC DETECTION AND MAPPING USING ALMA

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ABSTRACT
We report the first spectroscopic detection of ethyl cyanide (C2H5CN) in Titan’s atmosphere, obtained using spectrally and spatially resolved observations of multiple emission lines with the Atacama Large Millimeter/submillimeter Array (ALMA). The presence of C2H5CN in Titan’s ionosphere was previously inferred from Cassini ion mass spectrometry measurements of C2H5CN+. Here we report the detection of 27 rotational lines from C2H5CN (in 19 separate emission features detected at >3σ confidence) in the frequency range 222–241 GHz. Simultaneous detections of multiple emission lines from HC3N, CH3CN, and CH3CCH were also obtained. In contrast to HC3N, CH3CN, and CH3CCH, which peak in Titan’s stratosphere and above, vertical column densities are found to be in the range (1–5) × 1012 cm−2.

Key words: planets and satellites: individual (Titan) – techniques: interferometric – planets and satellites: atmospheres – techniques: imaging spectroscopy

1. INTRODUCTION

Saturn’s largest moon Titan has a thick (1.45 bar) atmosphere composed primarily of molecular nitrogen (98%) and methane (approximately 2%). Remote and in situ measurements (see the review by Bézard et al. 2014) have also revealed the presence of a diverse population of trace hydrocarbons and nitrogen-bearing compounds, the presence of which can be explained as a consequence of the complex gas-phase photochemistry, driven by photodissociation/ionization and cosmic rays (Wilson & Atreya 2004).

Multiple studies have predicted the existence of ethyl cyanide (C2H5CN, also known as propionitrile) on Titan, but a firm confirmation of its presence has been elusive until now. Capone et al. (1981) suggested that C2H5CN could be formed as a recombination product of complex nitrile ions produced in three-body association reactions in the dense, lower atmosphere. More recent photochemical models by Krasnopolsky (2009) and Loison et al. (2015) predict C2H5CN to be abundant throughout the atmosphere. In laboratory plasma-discharge experiments designed to simulate Titan’s photochemistry, C2H5CN is among the most abundant molecules produced (e.g., Thompson et al. 1991; Coll et al. 1999; Fujii & Arai 1999), and crystalline C2H5CN has been suggested as an explanation for the broad emission feature at 221 cm−1 seen in the Voyager IRIS data (Khanna 2005). Nevertheless, previous spectroscopic studies have failed to find gas-phase ethyl cyanide; abundance upper limits have been obtained of 8 × 10−9 from the Cassini Composite Infrared Spectrometer (CIRS) and 2 × 10−9 from the IRAM 30 m microwave spectroscopy (de Kok et al. 2008 and Marten et al. 2002, respectively).

The presence of C2H5CN was strongly implied by the detection of C2H5CN+ by the Cassini Ion and Neutral Mass Spectrometer (INMS; Vuitton et al. 2007). This nitrile ion was theorized to form primarily by proton transfer from HCNH+ and C2H5+ to neutral C2H5CN. A spectroscopic detection of C2H5CN would provide the first conclusive proof for the presence of ethyl cyanide in Titan’s atmosphere and help validate the conclusions of the INMS studies. Gas-phase synthesis of C2H5CN is not well understood, and the chemical models of Krasnopolsky (2009) and Loison et al. (2015) differ in their predicted abundances by two to three orders of magnitude. Accurate measurements of the C2H5CN atmospheric distribution are required in order to constrain models for the formation of nitriles and other large organic molecules, which will lead to improvements in our understanding of the complex photochemistry occurring on Titan and on other bodies with nitrogen- and methane-rich atmospheres.

In this study, we employ millimeter-wave data obtained from the Atacama Large Millimeter/submillimeter Array (ALMA) Science Archive9 to search for and map rotational emission lines from C2H5CN in Titan’s atmosphere and compare the spatial distribution of C2H5CN emission with that of other, previously identified molecules.

2. OBSERVATIONS

Interferometric observations of Titan were made between UT 2012 July 03 23:22:14 and 2012 July 04 01:06:18 as part of ALMA project 2011.0.00319.S (for the purpose of flux

9 https://almascience.nrao.edu/alma-data/archive
Two 4 minute integrations were obtained using the dual-sideband Band 6 receiver, with 20 12 m antennas in the telescope array, providing baselines in the range 21–402 m. Due to the high sensitivity of ALMA, even these short integrations permitted the detection of weak spectral lines on Titan. The correlator was configured to observe four basebands, with frequencies 221.48–223.35 and 223.48–225.35 GHz in the lower sideband and 236.48–238.36 and 239.48–241.36 GHz in the upper sideband, with 3840 channels per spectral window. The channel spacing was 488 kHz, which (after Hanning smoothing by the correlator) leads to a spectral resolution of 976 kHz (or 1.3 km s\(^{-1}\) at 224 GHz). Weather conditions were good, with 1.7 mm of precipitable water vapor at zenith. The bright quasar 3C 279 was observed for bandpass calibration. The telescope was configured to track Titan’s ephemeral position, updating the coordinates of the phase center in real-time.

The data obtained from the ALMA Science Archive were already processed using the standard scripts and protocols provided by the Joint ALMA Observatory. This included routine flagging, bandpass calibration, and complex gain calibration. The measured continuum flux density for each baseline was scaled to match the Butler-JPL-Horizons 2010 Titan flux model (see ALMA Memo #594\(^{10}\)), which is expected to be accurate to within 15%. Continuum-subtraction of the visibility amplitudes was performed using the uvcontsub task in the NRAO CASA software (version 4.2.1; McMullin et al. 2007), and imaging was carried out using the clean task. Deconvolution of the point-spread function (PSF) was performed for each spectral channel using the Hognbom algorithm, with natural visibility weighting and a threshold flux level of twice the expected rms noise. The image pixel sizes were set to 0\(^{″}\)1 × 0\(^{″}\)1. The resulting spatial resolution (FWHM of the Gaussian restoring beam at 223.5 GHz) was 0\(^{″}\)85 × 0\(^{″}\)67 (long axis 57.3° clockwise from celestial north). This resolution element corresponds to 5860 × 4620 km at Titan’s geocentric distance of 9.51 AU at the time of observation (compared with Titan’s 5150 km diameter).

The images were transformed from equatorial coordinates to (projected) linear distances with respect to the center of Titan, and the spectral coordinate scale of each image was Doppler-shifted to Titan’s restframe using the JPL Horizons Topocentric radial velocity.

### 3. RESULTS

The observed spectra recorded in each of the four basebands are shown in Figure 1. These were obtained by integrating the reduced ALMA data cubes within a circular region of radius 1°1' from the center of Titan (7500 km at Titan’s distance). This circle enclosed the flux within 2\(σ_{\text{PSF}}\) of Titan’s surface, where \(σ_{\text{PSF}}\) is the standard deviation of the major axis of the restoring beam. Negligible flux was found to lie outside of this region.

Spectral peaks were assigned using the Splatalogue database for astronomical spectroscopy,\(^{11}\) with frequencies obtained from the Cologne Database for Molecular Spectroscopy (Müller et al. 2001) and the JPL catalog.\(^{12}\) The detected transitions are given in Table 1. The spectra are sufficiently uncrowded that unambiguous assignments were possible for all detected lines. Nineteen separate C\(_2\)H\(_5\)CN rotational emission features (many of which are blends of several transitions) were detected at greater than 3\(σ\) confidence. Emission from HC\(_3\)N, vibrationally excited CH\(_3\)CN, and CH\(_3\)CCH was also detected. An additional 153 C\(_2\)H\(_5\)CN lines lie within the observed spectral range, but these were too weak to be detected individually.

Contour maps showing the spatial distributions of emission from the observed species are shown in Figure 2, overlaid upon the 221–225 GHz continuum flux (shown in each panel as an orange bitmap). The contour maps were obtained by integrating over the strongest line(s) observed for each species. For C\(_2\)H\(_5\)CN, the strongest six lines in the range 223.9–224.1 GHz (shown in Figure 3(b)), were summed to improve the signal-to-noise ratio of the map. For HC\(_3\)N, only the strongest (\(J = 26–25\)) line was used and for CH\(_3\)CN and CH\(_3\)CCH, integration was performed over the blended multiplets at 239.8 and 222.1 GHz, respectively. The peak signal-to-noise ratios of the resulting maps were as follows: C\(_2\)H\(_5\)CN: 15, HC\(_3\)N: 40, CH\(_3\)CN: 17, CH\(_3\)CCH: 29.

Adopting a similar strategy to Cordiner et al. (2014), the spatially integrated C\(_2\)H\(_5\)CN emission lines in the range 223.9–224.2 GHz were modeled using the line-by-line radiative transfer module of the NEMESIS atmospheric retrieval code (Irwin et al. 2008). There are 13 C\(_2\)H\(_5\)CN transitions in this range (see Table 1), spanning a broad range of upper-state energies (150–300 K) and providing sufficient information on the C\(_2\)H\(_5\)CN abundance and excitation to adequately constrain our models. A lack of interloping lines from other species in this range facilitated accurate abundance retrievals. The atmospheric temperature profile was generated from a combination of Cassini CIRS and HASI measurements (Flasar et al. 2005; Fulchignoni et al. 2005), and the abundances of nitrogen and methane isotopologues and aerosols were the same as used by Teanby et al. (2013). Spectral line parameters and partition functions were taken from the JPL catalog. The Lorentzian broadening half-width at 296 K was assumed to be 0.075 cm atm\(^{-1}\), with a temperature-dependence exponent of 0.50.

Under the assumption that the model temperature/abundance/aerosol profiles profiles do not vary with latitude and longitude, the integrated flux per spectral channel was calculated using a 10 point trapezium-rule integration from the center of Titan’s disk to the edge of the model atmosphere (at an altitude of 1000 km). Initially, least-squares fits to the observed spectra were performed using C\(_2\)H\(_5\)CN abundance profiles with constant mixing ratio above a specified cutoff altitude \(z_c\) and zero abundance below. In these “step” models, \(z_c\) values in the range 100–400 km were tried, and the best-fitting abundances for each are given in Table 2. Reduced \(χ^2\) values are also given, and the corresponding continuum-subtracted spectral models are shown in Figure 3.

The \(z_c\) are 300 and 400 km models (green and magenta solid curves, respectively), provide a near-perfect fit to the observations, accurately reproducing the intensities, frequencies, and widths of all the spectral features attributed to C\(_2\)H\(_5\)CN. The quality of these fits confirms that our C\(_2\)H\(_5\)CN line assignments are secure. As can be seen from the close-up spectral region in Figure 3(c), our models show that pressure-broadening wings begin to become significant for \(z_c \lesssim 200\) km, but no clear wings are apparent above the noise level in the observed spectra.

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\(^{10}\) http://science.nrao.edu/facilities/alma/aboutALMA/Technology/ALMA_Memo_Series/alma594/memo594.pdf
\(^{11}\) http://www.cv.nrao.edu/php/splat/
\(^{12}\) http://spec.jpl.nasa.gov/
indicating that the majority of Titan’s \(\text{C}_2\text{H}_5\text{CN}\) must be confined to higher altitudes. Accordingly, the \(z_c = 100 \text{ km}\) model (orange dashed curve) provides a poor fit to the observations.

Due to vertical mixing, model profiles with an abrupt abundance cutoff are unlikely to represent the true \(\text{C}_2\text{H}_5\text{CN}\) profile, so the spectrum was also fitted using a more realistic two-parameter “gradient” model, in which the abundance varies smoothly as a function of altitude. The free parameters in this model were the abundance at a reference altitude \(z_r = 292 \text{ km}\) and the slope, given as a fraction \((f_H)\) of the atmospheric pressure scale height. Condensation of \(\text{C}_2\text{H}_5\text{CN}\) was assumed to occur at altitudes \(\leq 100 \text{ km}\) based on the saturated vapor pressure curve of Lide & Kehiaian (1994). The best-fitting abundance at \(z_r\) was found to be \(1.3 \pm 0.4 \) ppb, with a retrieved fractional scale height of \(f_H = 4.6 \pm 1.1\). Despite slightly stronger line wings, this model (blue solid curve) also matches the observations extremely well.

Vertical column densities \((N)\) for the four models are given in Table 2. The models that fit the data well have values in the range \((1–5) \times 10^{14} \text{ cm}^{-2}\).

### 4. DISCUSSION

#### 4.1. \(\text{C}_2\text{H}_5\text{CN}\) Vertical Mixing Ratio Profile

Confirmation of the presence of ethyl cyanide in Titan’s atmosphere provides an important test and validation of the Cassini INMS result. Although a near-perfect fit to our observed ALMA spectrum was obtained using a step model for the \(\text{C}_2\text{H}_5\text{CN}\) VMR profile (with cutoff altitude at 300 km), a smoothly varying profile is expected to be more realistic. The shape of the retrieved “gradient” profile (shown by the solid blue curve in Figure 3(a)) is constrained primarily by the requirement of a low abundance at \(z \leq 200 \text{ km}\), and is largely unconstrained at altitudes above about 600 km, where the atmospheric density is low. Similar to the case of HNC (Moreno et al. 2012; Cordiner et al. 2014), the steep vertical abundance gradient for \(\text{C}_2\text{H}_5\text{CN}\) and its concentration at altitudes \(\geq 200 \text{ km}\) are consistent with production in the upper atmosphere, combined with a relatively short chemical lifetime that prevents it from building up at lower altitudes through vertical mixing.

A plausible alternative to the best-fitting gradient profile above 700 km is indicated with a dotted vertical line in
Table 1
Detected Transitions and Upper-state Energies

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency (GHz)</th>
<th>Transition</th>
<th>$E_u$ (K)</th>
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<td>75</td>
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Note. Primary spectroscopic sources for molecular line frequencies: C$_2$H$_5$CN—Brauer et al. (2009), HC$_3$N—Thorwirth et al. (2000), CH$_2$CN—Boucher et al. (1980), CH$_3$CCH—Dubrulle et al. (1978).
in photochemical product species, theorized to result from the combined effects of Titan’s atmospheric chemistry and circulation (Coustenis & Bézard 1995; Teanby et al. 2008, 2012; Coustenis et al. 2010; Vinatier et al. 2010).

The $\text{C}_2\text{H}_5\text{CN}$ emission map (Figure 2(a)) shows a surprising spatial distribution with a significant (7$\sigma$) flux enhancement over the southern pole relative to the north. This is the opposite trend to that observed for the other three species, which show clear enhancements in the northern hemisphere. Differences in stratospheric temperature between Titan’s northern and southern hemispheres have been found to be generally $\lesssim$15% (Coustenis & Bézard 1995; Flasar et al. 2005; Achterberg et al. 2008). Our observed emission lines are relatively invariant to such small temperature changes, so spatial variations in the gas temperature are an unlikely explanation for the observed asymmetries. Molecular abundance peaks near Titan’s north pole have previously been identified for HC$_3$N and CH$_3$CCH (during northern winter), so it seems plausible that the emission structures observed with ALMA are due to intrinsic latitudinal abundance variations. As a caveat, the temperatures in Titan’s polar mesosphere are known to vary on rapid timescales (e.g., Teanby et al. 2012; de Kok et al. 2014), and temperature information for the epoch of our observations is lacking, so further work will be needed to firmly establish the relative distributions of these species.

An explanation for the southerly $\text{C}_2\text{H}_5\text{CN}$ peak is due to the transition of Titan’s seasons from northern winter in 2002 to (late) northern spring in 2012. During this time, the reversal of Titan’s main atmospheric circulation cell is expected to channel fresh photochemical products from mid-latitudes toward the south pole (Teanby et al. 2012). Meanwhile, gases transported north during the previous season remain concentrated around the north pole, undergoing slow photochemical destruction. Following the northern winter, species with longer chemical lifetimes should remain in the north for longer while those with shorter lifetimes disappear and then re-appear in the south. Our maps therefore suggest a shorter chemical lifetime for $\text{C}_2\text{H}_5\text{CN}$ than for HC$_3$N, CH$_3$CN, and CH$_3$CCH. This hypothesis can be tested by observing the evolution of the distributions of these species over the coming years, particularly during the transition from northern spring to the summer solstice in 2017.

Figure 2. Integrated emission contour maps for $\text{C}_2\text{H}_5\text{CN}$, HC$_3$N, CH$_3$CN, and CH$_3$CCH. The 221–225 GHz continuum is shown in orange. The coordinate scale is in Titan-projected distances (white cross denotes the position of the phase center). Axes are aligned in the equatorial coordinate system. Contour intervals (in units of $\sigma$ —the rms noise level of each map), are as follows: $\text{C}_2\text{H}_5\text{CN}$: 3$\sigma$, HC$_3$N: 8$\sigma$, CH$_3$CN: 3$\sigma$, CH$_3$CCH: 5$\sigma$. The blue circle represents Titan’s surface (dashed white curve is the equator), and the dotted–dashed blue line is the polar axis, oriented 2.0° clockwise from vertical, with the north pole tilted toward the observer by 12.7°. Titan’s Earth-facing hemisphere was almost fully illuminated at the time of observation, with a (Sun-target-observer) phase angle of 5.9°. The FWHM of the Gaussian restoring beam (0°85 × 0°67) and its orientation are shown as hatched ellipses.
is consistent with production in the upper atmosphere, combined with a relatively short chemical lifetime that inhibits downward mixing. The observed C$_2$H$_5$CN emission maps suggest a higher abundance in the south polar region than in the north (in contrast to HC$_3$N, CH$_3$CN, and CH$_3$CCH, which peak in the north), again consistent with a relatively short chemical lifetime for C$_2$H$_5$CN and south polar subsidence. This possibility can be verified through future measurements of temporal variations in the spatial distributions of the observed species with respect to Titan’s changing seasons.

In order to help ascertain the origin of ethyl cyanide on Titan (and in other astrophysical environments), new laboratory studies of possible gas-phase routes to C$_2$H$_5$CN are required.

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REFERENCES

Boucher, D., Burie, J., Dubrulle, A., & Demaison, J. 1980, IJPCRD, 9, 659
Coustenis, A., & Bézard, B. 1995, Icar, 115, 126
de Kok, R., Irwin, P. G. J., & Teanby, N. A. 2008, Icar, 197, 572
Dubrulle, A., Boucher, D., Burie, J., & Demaison, J. 1978, IJPCRD, 9, 659
Khanna, R. K. 2005, Icar, 177, 116

5. SUMMARY

Nineteen separate emission features from 27 rotational transitions of C$_2$H$_5$CN were detected in Titan’s atmosphere using ALMA archival spectra recorded in 2012 July.

Radiative transfer modeling indicates that most of the observed C$_2$H$_5$CN is concentrated at altitudes >200 km. This
Krasnopolsky, V. A. 2009, Icar, 201, 226
Lide, D., & Kehiaian, H. 1994, CRC Handbook of Thermophysical and Thermochemical Data (Boca Raton, FL: CRC Press)
Marten, A., Hidayat, T., Biraud, Y., & Moreno, R. 2002, Icar, 158, 532
Thorwirth, S., Müller, H. S. P., & Winnewisser, G. 2000, JMoSp, 204, 133
Wilson, E. H., & Atreya, S. K. 2004, JGR, 109, 6002