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Determination of $^{14}N/^{15}N$ of CH_3CN in Titan's atmosphere with ALMA

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Abstract

We have successfully detected rotational transitions of gaseous Acetonitrile molecule $CH_3C^{15}N$ (J = 19–18) locate at 338.88 – 338.92 GHz along with its isotopologue CH_3CN (J = 18–17) at 330.75 – 330.95 GHz in Titan atmosphere by analysing ALMA archival data. Spatial resolution was larger than Titan's disk, so we obtained the disk-averaged spectra of both isotopologues. The observation was carried out in April 2015. Since it is known that $^{14}N/^{15}N$ in Titan's nitriles such as N_2, HCN and HC_3N show large variations, isotopic fractionation processes induced by the atmospheric chemistry have been expected in Titan's atmosphere. A new determination of $^{14}N/^{15}N$ in CH_3CN may present a new information on the fractionation processes.

1. Introduction

Titan has a thick N_2 atmosphere with CH_4 and other various nitriles and hydrocarbons (i.e., organic gases), which makes this moon very unique in our solar system. The presence of the complex organic species raises a fundamental question of how such an atmosphere has evolved over Titan's history.

Among many observational methods, a spectroscopic determination of nitrogen isotopic ratio $^{14}N/^{15}N$ gives us essential information in terms of the atmospheric chemistry because nitrogen is easily fractionated with respect to the chemical reaction processes.

Recently, a new theoretical study [1] has highlighted a more critical importance of $^{14}N/^{15}N$ in some nitrogen-bearing species. It predicted that the production process of CH_3CN is sensitive to the Galactic Cosmic Rays (GCR) influx, whereas other major nitriles such as HCN and HC_3N are rather sensitive to the magnetospheric electrons.

Previously measured $^{14}N/^{15}N$ values in HCN and HC_3N are in a range of $\sim$56–94 (HCN, e.g., [2][3][4]) and 67$\pm$14 (HC_3N, [5]), which is in good agreement with the theoretical result by [1]. In turn, CH_3CN is proposed to exhibit a higher $^{14}N/^{15}N$ value of $\sim$120 at a 200 km altitude because of GCR induced fractionation by the same theoretical calculations. A precise measurement of $^{14}N/^{15}N$ in CH_3CN could give an effective constraint on the role of GCR induced fractionation process for changing Titan's atmospheric environment. There has been no dedicated observation of $CH_3C^{15}N$ so far, and therefore, we are to reveal the production process of CH_3CN molecules by a new determination of its $^{14}N/^{15}N$ value.

2 Analysis of ALMA archival data

We searched all the public-released Titan data (including the calibrator-purpose data) in the ALMA science archive, and found one data set (2013.1.00033.S) which contains both $CH_3C^{15}N$ (J = 19–18) and CH_3CN (J = 18–17) spectra taken quasi-simultaneously. It is noted that (quasi-)simultaneous data acquisition of CH_3CN and $CH_3C^{15}N$ is necessary to avoid a potential error due to strong seasonal variation of CH_3CN abundance.

Observations were carried out in April 2015. Synthesized beam size of $CH_3C^{15}N$ and CH_3CN observations were 1.19 $\times$ 0.62 arcsec and 1.08 $\times$ 0.8 arcsec, respectively. Figure 1 shows disk-averaged spectra of CH_3CN (top panel) and $CH_3C^{15}N$ (bottom panel). Both isotopologues were detected with relatively high S/N even for $CH_3C^{15}N$.

We analyzed $CH_3CN/CH_3C^{15}N$ using these data by means of radiative transfer modeling of the Titan atmosphere. The model used in this study is that of used for analysis of previous $Herschel$ observations [6]. A vertical profile of CH_3CN was retrieved for a disk-averaged measurement spectrum (Figure 2). As the temperature profile and a priori profile of CH_3CN, a result presented by a previous ALMA [7] and IRAM [2] observations were employed, respectively.

3 Results

As shown in an upper panel of Figure 1, we succeeded to fit the observed CH_3CN spectrum with our modeled one within the measurement noise range. Assuming the obtained CH_3CN vertical profile, we attempted to fit the $CH_3C^{15}N$ spectrum by scaling the CH_3CN abundance. A red line in bottom panel of Figure 1 indicates the best-fit spectrum of $CH_3C^{15}N$. As the initial result, the obtained $^{14}N/^{15}N$ value roughly agrees with that of measured in HCN and HC_3N.

4. Figures

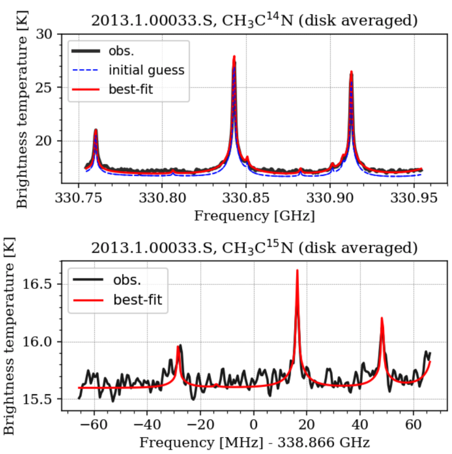

Figure 1: top: Observed (black), modeled with a priori profile (blue), and the best-fit spectra of CH_3CN. bottom: Observed (black) and modeled (red) spectra of $CH_3C^{15}N$.

Acknowledgements

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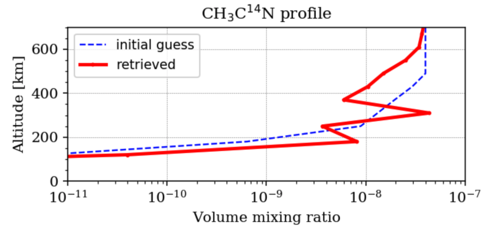

Figure 2: A test retrieval of CH_3CN vertical profile from the disk-averaged spectrum. A priori (blue) and retrieved (red, preliminary result) profiles are shown.

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