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Survey Observation of S-bearing Species toward Neptune's Atmosphere to Constrain the Origin of Abundant Volatile Gases

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Abstract

We present our recent sub-mm waveband observation result of CS, CO and HCN gases on Neptune's atmosphere. Obtained abundance of both CO and HCN were comparable to previous observations. In turn, CS gas, which was produced largely after the impact of comet Shoemaker-Levy 9 on Jupiter in 1994 was not detected. Obtained [CS]/[CO] value was at least 300 times more lower than the case of SL9 event while the calculated lifetime of CS gas by thermo-chemical simulation is quite longer than other S-bearing species. The interpretation of the absence of CS bring the new mystery of the origin of trace gases on Neptune's atmosphere.

1. Introduction

On Neptune's atmosphere, abundant volatile gases such as CO and HCN are present[1] and their abundance are larger than other gas giants. Recent observations have shed the new light on their origin. The derived abundance of CO is not uniform with altitude, that the upper stratosphere has several times higher mixing ratio than lower stratosphere and troposphere[2][3]. This result suggests that CO which had been produced above upper stratosphere have been kept transported downward. One of the possible candidate of CO production source is large cometary impact such as SL9 event on Jupiter in 1994, since such impact can produce a large amount of volatile gases[4]. We have tried to constrain this scenario by chemical aspect with new observations. After the SL9 event, a large amount of CS molecule was produced and has kept observed for at least 5 years[4] while other major S-bearing species, such as SO, SO_2, H_2S and OCS have not been detected or lived shortly. Thus, CS molecule may be one of the typical remnant gas of cometary impact on gas giant. In the case CS exists abundantly on Neptune, it would support the hypothesis that cometary impact is the origin of volatile gases on upper atmosphere. We have performed a new observation of CS and other volatile gases on Neptune to verify this scenario.

2. Observation and Results

Observations were performed with Atacama Sub-millimeter Telescope Experiment (ASTE) 10-m single dish telescope of NAOJ in August 2010. CS(J =7-6), CO(J=3-2) and HCN(J=4-3) rotational lines were observed with 2, 1 and 1 hour observation time, respectively. Spectral resolution and bandwidth were 500kHz and 512MHz. The fine emission structure comes from the upper atmosphere of Neptune could be resolved by these frequency resolution.

All of the observations were performed in good weather condition. Thus we could obtain low r.m.s noise level spectra. The emission structure of both CO and HCN were obtained. In turn, while the achieved noise level was low as 6.5 mK, as shown in Figure 1, no spectral features of CS was found.

3. Discussion

Abundance of observed molecule were calculated by 1-D line-by-line radiative transfer model. For CO, assuming the uniform vertical distribution, derived its mixing ratio was 1.2×10^{-6}. Biased distribution model that upper stratosphere has larger mixing ratio than lower stratosphere and troposphere may fit better with observed spectrum. For HCN, assuming that HCN vertical distribution is limited to $p < 2$ mbar, we obtained 8.0×10^{-10} mixing ratio. These values are consistent with previous observations[1][2][3]. This result indicates that both CO and HCN are chemically stable species. On the other hand, assuming CS is uniformly present from p = 1000 mbar to 0.1 mbar, the derived upper limit of CS mixing ratio is low as 6.0×10^{-11}. We modeled a spectrum to derive the upper limit to have its intensity as equivalent to 3-sigma r.m.s. noise level. Since the collision-broadening coefficient of CS gas has not been derived yet, we used the value of HCN(3MHz/torr) instead. Obtained [CS]/[CO] value here shows that CS is 300 times more depleted than the case of Jupiter[4].

Also, we tested the chemical evolution of major S-bearing species on Neptune's atmosphere from just after the large impact to thousands years by using chemical network simulation software Astrochem. Two kind of initial conditions assuming that CS or SO_2 is a dominant S-bearing species were used. As a result, in both cases, throughout from troposphere to stratosphere, CS became the sink source of S-atom. This discrepancy between observation and simulation brings a new mystery about the origin of Neptune's atmospheric composition.

4. Figure

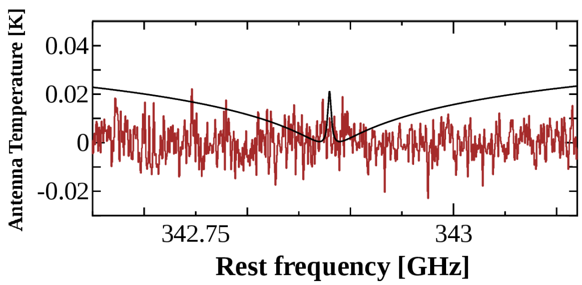

Figure 1: Observed CS(J=7-6) spectrum(red) and modeled spectrum(black). The emission intensity of modeled spectrum is equivalent to 3-sigma r.m.s. noise level of observed spectrum. Derived upper limit of CS was 6.0×10^{-11}.

References

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