Survey of CO$_2$ in 18 comets with the Japanese Infrared Satellite _AKARI_

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Abstract

We performed the survey of cometary volatiles by the Japanese Infrared satellite _AKARI_ with the Infrared Camera (IRC) in the wavelength range from 2.5 – 5 $\mu$m from 2008 to 2009. In our survey, both Oort-cloud comets and Jupiter-family comets were observed, and observations were carried out twice or more in some cases. Most prominent emission bands were the fundamental vibrational bands of water (H$_2$O) at 2.7 $\mu$m and carbon dioxide (CO$_2$) at 4.3 $\mu$m in our spectra. The fundamental vibrational band of carbon monoxide (CO) at 4.7 $\mu$m was also recognized in some comets as well as broad emission features probably related to C-H bearing molecules around 3.4 – 3.5 $\mu$m region. Especially, CO$_2$ in comets can be observed from the space only. Our dataset provides the largest and homogeneously analyzed database of CO$_2$/H$_2$O ratios in comets at present. The mixing ratios of CO$_2$ span from a few to ~30 % among the comets.

1. Introduction

Comets are the most primordial objects in the solar system. One of the important characters of comet is the mixing ratio, especially for organic volatiles relative to H$_2$O. Mixing ratios are thought as clues to the chemical evolution in the proto-planetary disk of the Sun. CO$_2$ is the most abundant volatile in the cometary coma except water. However, because of the severe absorption of telluric CO$_2$ in the atmosphere, we cannot access the cometary CO$_2$ by ground-based observations. To date, the daughter species of CO$_2$ has been used to determine the mixing ratio of CO$_2$, or direct measurements by satellites or spacecrafts were available only in some cases. In this paper, we will present the results of our survey of CO$_2$ mixing ratio in 18 comets by using Japanese Infrared satellite _AKARI_.

2. Observations

Japanese Infrared satellite _AKARI_ [5] is equipped with a 68.5 cm telescope and two scientific instruments. We used Infrared Camera (IRC) [4] for our survey. _AKARI_ was launched on 2006 February 21 UT, and its liquid helium cryogen boiled off on 2007 August. Our survey started in the post-liquid helium phase (called as “phase 3”) as the “SOSOS Mission Program”. We observed 18 comets by the _AKARI_. The effective spectral resolution is R < 100 at 3.6 $\mu$m. Data was analyzed with the toolkit customized for diffused object [6]. An example of calibrated spectrum is shown in Figure 1. Since the “dust continuum” has to be subtracted from the calibrated spectra to measure the flux of molecular emissions, we fit the continuum component by polynomial functions.

![Calibrated spectrum of comet C/2007 N3 (Lulin). No CO was detected in this comet.](image)

Figure 1: Calibrated spectrum of comet C/2007 N3 (Lulin). No CO was detected in this comet.

3. Results

Mixing ratios of CO$_2$ and CO relative to H$_2$O are defined as the ratios of production rates of those molecules (Q(X)/Q(H$_2$O), X=CO$_2$ or CO).
Production rates were calculated by comparing observed molecular band flux with the g-factor multiplied by the total number of the molecules within the aperture, calculated based on the following formula:

\[ n_x = \frac{Q_x}{4\pi v_{\text{exp}} \rho^2} \exp \left( -\frac{\rho}{v_{\text{exp}} \tau_x} \right) \]  

(1)

Here, \( Q_x \) is the production rate of molecule “X”, \( \rho \) denoted nucleocentric distance, \( \tau_x \) denotes the lifetime of “X”, \( v_{\text{exp}} \) denotes the expansion velocity. The band g-factors are taken from [1]. Obtained mixing ratios of CO\(_2\) are summarized in Figure 2.

4. Discussion and Conclusions

In figure 2, the mixing ratios of CO\(_2\) are systematically higher for the comets observed at further distances from the Sun (> ~3 AU). This could be explained by that water could not sublimate efficiently at such further distances from the Sun. The surface temperature of the nucleus could be comparable or lower than that for the sublimation of H\(_2\)O (~150 K) while hyper volatiles such as CO\(_2\) and CO could sublimate sufficiently even at such further distances. Therefore, the gas production rate ratios of CO\(_2\) and CO with respect to H\(_2\)O observed at further than 3 AU should be considered as upper limits of the mixing ratios of the cometary ice. On the other hand, around 1 AU from the Sun, H\(_2\)O can evaporate efficiently and the gas production rate ratios are considered as good indicators for the composition of the cometary ice. Our results show that the CO\(_2\) mixing ratios in the 18 comets are in the range from several to ~30 % and this ratios are consistent with the previous measurements of CO\(_2\), including indirect observations, as illustrated in Figure 12 of [2]. The wide variety can be found in the CO mixing ratios (only upper limits could be obtained in most cases) as already investigated by radio and near-infrared observations in the past [2]. Obtained CO/CO\(_2\) ratios are summarized in Figure 3. Although most of them were determined as upper limit. CO/CO\(_2\) ratios are smaller than unity. Our results did not agree with the CO/CO\(_2\) ratio measured in interstellar ice (CO/CO\(_2\) > 1). This fact implies that the nebula processing (e.g., gas phase formation mechanism of CO\(_2\)) occurred in the proto-planetary disk.

Figure 2: Mixing ratios of CO\(_2\) in 18 comets versus heliocentric distances at the observations.

Figure 3: Mixing ratios of CO\(_2\) versus mixing ratios of CO in 18 comets.

References