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AKARI NIR spectroscopy of interstellar ices

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Abstract. The Infrared Camera (IRC) onboard *AKARI* has a near-infrared (2–5 μm) spectroscopic capability with high sensitivity that allows us to study the major ice components in various objects. In particular, H_2O and CO_2 ice absorption features have been detected towards nearby galaxies, including several young stellar objects (YSOs) in the Large Magellanic Cloud (LMC), as well as a number of HII region-PDR complexes for the first time by IRC spectroscopy. While observations in the LMC show a high ratio (~ 0.34) of the CO_2 to H_2O ice column densities, the ratios in Galactic HII-region-PDR complexes are in the range of 0.1–0.2, being compatible with those found in Galactic massive YSOs in previous studies. The good correlation supports concurrent formation of the two ice species on the grain surface and the higher ratio in the low-metallicity LMC suggests possible environmental effects in the formation process.

Keywords. (ISM:) dust, extinction, ISM: lines and bands, infrared: ISM, astrochemistry

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Ices of various species play important roles in interstellar chemistry (e.g., van Dishoeck 2014). Characteristic bands of ice species reside in the near- to mid-infrared (2–20 μm) and thus infrared observations are the most efficient means for the study of ices in the interstellar medium (ISM). *ISO* and *Spitzer* studied ice features towards deeply embedded young stellar objects (YSOs) and stars behind molecular clouds, making significant progress in our understanding of interstellar ices (e.g., Gibb *et al.* 2004; Pontoppidan *et al.* 2008). They indicate good correlations between the column densities of H_2O and CO_2 ices, suggesting concurrent formation of the two ice species on the grain surface (Ippolo *et al.* 2011; Oba *et al.* 2012).

The Infrared Camera (IRC) onboard *AKARI* offered high-sensitivity spectroscopy in 2.5–5 μm (Onaka *et al.* 2007), where major ice species have strong absorption bands, such as H_2O at 3.05 μm, CO_2 at 4.27 μm, XCN at 4.62 μm, and CO at 4.67 μm. The IRC allows us to study ice absorption features in faint objects, including nearby galaxies and relatively evolved diffuse objects. A recent study of ices in nearby galaxies with the IRC suggests no clear correlation between H_2O and CO_2 ices, which may be attributed to the relatively large beam ($\sim 5''$) that contains various components on the line-of-sight (Yamagishi et at. 2015). Studies of ice absorption towards YSOs in the Large Magellanic Cloud (LMC) with the IRC, on the other hand, show by a factor of 2 larger column densities of CO_2 ice relative to H_2O ice than towards Galactic massive YSOs, which must be related to the low-metallicity condition of the LMC and give important implication on the ice formation process (Shimonishi *et al.* 2008, 2010). A study of Galactic molecular clouds with the IRC further suggests multi-stage ice formation (Noble *et al.* 2013).

In this report, we present latest results of NIR spectroscopy of ice species in Galactic HII-photodissociation region (PDR) complexes made with the IRC. Those targets are extended and relatively evolved compared to YSOs in previous studies and thus may

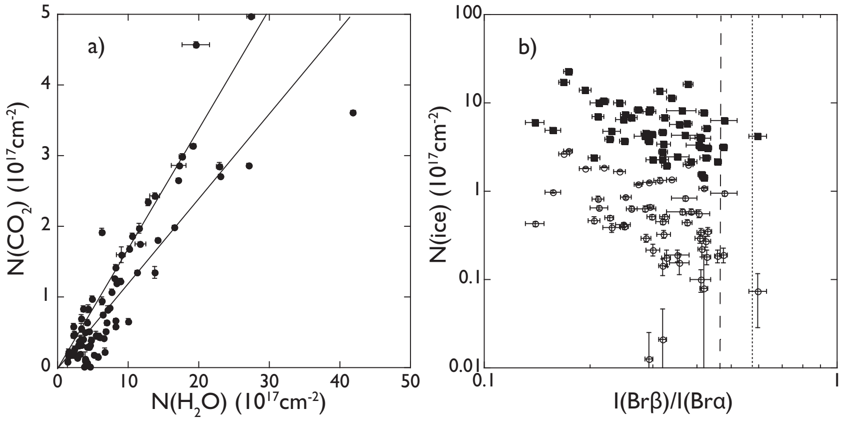

Figure 1. (a) Correlation of the column densities of CO_2 and H_2O ices for HII-PDR complexes observed with the IRC. The solid lines of the slopes of 0.17 and 0.12 are indicated as reference. The slope of 0.17 is suggested for Galactic massive YSOs in previous studies. (b) Correlations of the ice column densities and the ratio of Brβ to Brα line intensities. The filled squares show H_2O ice, while the open circles indicate CO_2 ice. The dotted line shows the ratio for Case B with the electron density of 10^4 cm^{-3} and the temperature of 10^4 K. The dashed line suggests a possible threshold for the presence of the two ice species, which corresponds to $A_v \sim 5$.

indicate evidence for interstellar processing of ice species. Previous studies of the emission bands related to polycyclic aromatic hydrocarbons (PAHs) indicate that IRC spectra of those objects indeed show ice absorption features (Mori *et al.*2014; Onaka *et al.* 2014). Figure 1a shows the correlation of the column densities between CO_2 and H_2O ices for the present samples, which is in agreement with previous results for Galactic massive YSOs except for several data located below the correlation line(s), suggesting possible interstellar processing. Figure 1b plots the ice column densities against the HI line intensity ratio, which suggests a threshold for the presence of these ices. The suggested threshold is $A_v \sim 5 \pm 1$, being compatible with those found in the Taurus cloud (Whittet *et al.* 2001, 2007). The new IRC results support concurrent formation of CO_2 and H_2O ices and suggest common physical conditions present for ice formation in the ISM.

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