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# Near-infrared spectroscopy of diffuse Galactic radiation with AKARI/IRC

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We present the results of near-infrared (NIR: 2.5−5 µm) spectroscopy of diffuse Galactic sources on the Galactic plane obtained with the Infrared Camera (IRC) on board AKARI. The spectral region of 2.5−5 µm is rich in various emission and absorption features. In this report, we focus on the $H_2O$ and $CO_2$ ice absorption features at 3.0 and 4.3 µm, respectively, and report a search for features of deuterated polycyclic aromatic hydrocarbons (PAHs) in 4.4−4.6 µm. The column densities of $CO_2$ and $H_2O$ ices show a correlation in agreement with that obtained with ISO observations. The correlation nearly crosses the origin, suggesting that $H_2O$ and $CO_2$ ices form in tandem for a wide range of physical conditions. The ratio of the ice column densities in AFGL2591 along the slit is relatively constant over an area of 30″, also supporting the tandem formation of $H_2O$ and $CO_2$ ices. The $H_2O$ ice column density shows a weak trend with $A_V$ estimated from HI recombination lines, which is in contrast to the clear correlation seen toward quiescent clouds. The weak correlation may be attributed partly to the uncertainty in $A_V$ and/or a range of the environmental conditions in the present targets. Only weak excess emission is seen in 4.4−4.6 µm in the spectra of the Orion bar, M17, and a reflection nebula. From these spectra, the ratio of deuterated PAHs to undeuterated PAHs is estimated as 3% at most. This is significantly smaller than the previously reported value and suggests that missing deuterium must reside in large PAHs that do not emit the 3 µm bands, if it is depleted into PAHs.

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## 1. Introduction

The near-infrared (NIR) spectral range from 2 to 5 µm contains the various interesting features of gaseous and solid species in the interstellar medium (ISM). Absorption features of several major ices are observed at 3 µm ($H_2O$), 4.3 µm ($CO_2$), and 4.6 µm (CO) [13]. These include the fundamental vibration mode of CO gas, several molecular hydrogen lines, and HI recombination lines. In addition, this range contains the emission features of hydrocarbon dust at around 3 µm, which are attributed to stretching vibration modes of aromatic and aliphatic bonds in materials containing polycyclic aromatic hydrocarbons (PAHs) [6]. Deuterated hydrocarbon features are also expected to be present in 4.4–4.6 µm [12]. Despite these interests, however, this spectral range has barely been explored by instruments with high sensitivity.

The Infrared Camera (IRC: [9]) onboard *AKARI* [7] enabled high-sensitivity spectroscopy in the NIR for the first time [8]. Even after the exhaustion of the cryogen, the IRC continued to carry out NIR observations and obtained NIR spectra in various celestial objects [10]. Here we focus on the ice absorption features and report a search for features of deuterated PAHs in the 4 µm region with AKARI/IRC observations. The results of the PAH features are reported separately [6].

## 2. Observations and Results

Observations were made with the long-slit NIR grism spectroscopy mode ($R \sim 100$) of the IRC in the warm mission phase [10]. The present data were obtained in the ISMGN [4] and IPYSO programs. The targets include PDR-HII region complexes and young stellar objects (YSOs) distributed over the Galactic plane. Among $\sim 400$ spectra, we select $\sim 90$ spectra, which show ice absorption features, and analyze them in the following. Details of the data reduction are provided in [6].

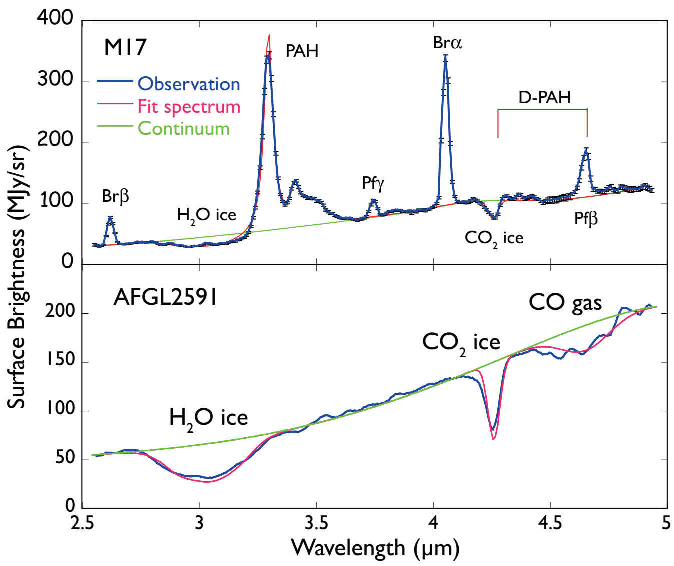


**Figure 1:** IRC spectra of M17 (top) and AFGL 2591 (bottom). Identifications of the features are indicated [11]. The blue, red, and green lines are observed, fitted, and continuum spectra, respectively. AFGL 2591 shows a typical spectrum of a massive YSO [13].

Fig. 1 shows typical examples of spectra of the present sample. The continuum is fitted by a spline curve and then the intensities of the bands and lines are estimated. For the $H_2O$ ice feature, laboratory data at 10K [2] are employed in the fit.

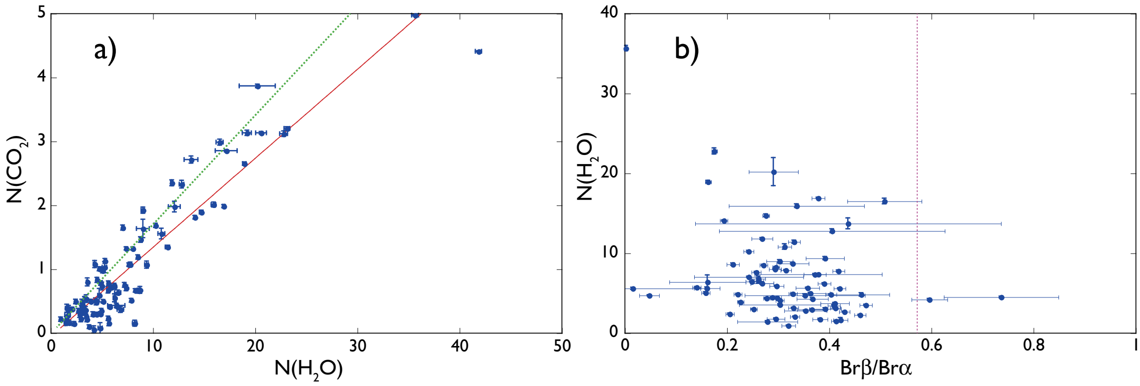


**Figure 2:** (**a**) Column density correlation between $H_2O$ and $CO_2$ ice in units of $10^{17}\,\mathrm{cm}^{-2}$. The red solid line indicates the best fit, while the green dotted line shows a correlation indicated by ISO observations [3]. Data points below the correlation line(s) can be attributed either to foreground contamination or errors in the column density estimate. (**b**) $H_2O$ column density vs. the line ratio of Brβ/Brα. The red vertical line indicates the ratio for the case B condition [14].

Fig. 2a shows the correlation between the $H_2O$ and $CO_2$ column densities of the present sample. The best fit line gives $N(\mathrm{CO_2})[\mathrm{cm}^{-2}] = (0.14 \pm 0.01) \times N(\mathrm{H_2O}) - (0.084 \pm 0.06) \times 10^{17}$ (red line), which is in good agreement with that derived with ISO observations shown by the green line [3]. The best fit line crosses nearly the origin, suggesting that $H_2O$ and $CO_2$ ices form in tandem for a wide range of physical conditions [15].

Fig. 2b plots the $H_2O$ ice column density against the line ratio of Brβ to Brα. The red vertical line indicates the line ratio for the case B conditions (all of the Lyman series transitions are optically thick) with electron density of $10^4\,\mathrm{cm}^{-3}$ and temperature of $10^4$ K [14]. Only a week correlation is seen, which is in contrast to the correlation found toward quiescent clouds [15]. There seems a threshold at around 0.4−0.5 of Brβ/Brα, above which ices are rarely present (Fig. 2b). These ratios correspond to $A_V$ = 4−10 mag assuming case B. The scatter can be attributed partly to the uncertainty in $A_V$ and/or to a wide range of the environmental conditions of the present targets.

The spatial variation of the ice column densities is investigated in AFGL2591 along the slit over an area of 30″. The ratio of the column densities of $CO_2$ to $H_2O$ ices is found to be relatively constant (0.15−0.2). This result further supports the tandem formation of $CO_2$ to $H_2O$ ices.

The fraction of deuterated PAHs is investigated based on the band ratio of 4.4−4.6 µm to that in 3.3−3.5 µm in the Orion bar and M17 regions. As can be seen in Fig. 1, there is no large excess emission in the 4 µm region except for Pfβ. The ratio of the residual emission in 4.4−4.6 µm to the band intensity in 3.3−3.5 µm is found to be 2−3% after subtracting the contribution from ionized gas [11]. To avoid possible contribution from remaining ionized gas component, the spectrum of the reflection nebula GN 18.14.0 is also analyzed, which indicates the band ratio of 2.1 ± 0.2%. These ratios are much smaller than the previously reported value [12], raising a question of the location of missing deuterium in the ISM [5]. If it is depleted in PAHs [1], it must reside in large PAHs that do not emit in the 3 µm bands (see [11] for detailed discussion).

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