The property of star-forming regions in ULIRGs probed with NIR absorption bands

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ABSTRACT

We observed near-infrared (NIR) absorption bands in 48 ultraluminous infrared galaxies (ULIRGs) to study physical conditions in star-forming regions. We focus on two absorption features in this study: the H_2O ice absorption at 3.0 μm, which traces dark clouds (A_V > a few mag), and the aliphatic carbon absorption at 3.4 μm, which traces diffuse clouds ($A_V < 1$ mag). Spectral analysis shows that optical depths of H_2O ice and aliphatic carbon in most of the ULIRGs are similar to those in diffuse clouds in the Galaxy when normalized by silicate optical depth, and ULIRGs do NOT consist of dark clouds. This suggests that the star-forming regions in ULIRGs have more intense radiation field than typical dark clouds in the Galaxy. We also examined the profile of H_2O ice for objects showing relatively deep absorption. The observed profiles of H_2O ice in ULIRGs sometimes show a sign of saturated absorption, while the continuum emission is not completely absorbed by the feature. This suggests that the dark clouds, where H_2O ice resides, do not cover the background sources entirely. These results imply that the dark clouds are sparsely distributed in ULIRGs.

Keywords: galaxies: ISM — galaxies: starburst — infrared: galaxies

1. INTRODUCTION

Ultraluminous Infrared Galaxies (ULIRGs; $L_{IR} > 10^{12} L_\odot$) are IR luminous. This means ULIRGs have quite a large amount of dust, hence high star formation rates (SFR). ULIRGs are an interesting subject to study not only due to their high SFR, but also that they are thought to be being at the summit of star-formation activity during their lifetime (Hopkins et al. 2008). It is therefore important to understand physical properties in star-forming regions in ULIRGs. UV environment is one of them since it links to regulation on cloud temperature. H_2O ice and aliphatic carbon are useful for investigating UV environment because in the Galaxy they reside in 2 types of regions which have quite different UV environment: H_2O ice exclusively resides in dark clouds defined as A_V > a few mag (e.g., Whittet et al. 1988), and aliphatic carbon in diffuse clouds which is defined as $A_V < 1$ mag (e.g., Pendleton & Chiar 1997). H_2O ice and aliphatic carbon appear as absorptions in the NIR region (3.0 μm for H_2O ice, 3.4 μm for aliphatic carbon). Estimating these absorptions are somewhat challenging, especially from ground-based telescopes. It is because the emission at 3.3 μm originating from C–H bonds of polycyclic aromatic hydrocarbon (PAH; e.g., Duley & Williams 1981) overlaps with these absorptions, and the shorter side of the ice absorption is difficult to observe due to telluric absorption. Therefore 2.5–4.0 μm spectra are essential to estimate these absorptions. *AKARI* Infrared Camera NIR grism spectroscopy, which covers 2.5–5.0 μm, thus offers good opportunity to do so.

2. OBSERVATION AND ANALYSIS

AKARI NIR spectra of 48 local ULIRGs obtained in the *AKARI* mission program named AGNUL (P.I. T. Nakagawa) are used in this study. These spectra are fit with a simple function: $F_\nu(\lambda) = (continuum + lines) \times \exp(-a_{ice}\tau_{ice}(\lambda)) \times \exp(-a_{ali}\tau_{ali}(\lambda))$. We assumed *continuum* as a 3rd polynomial. *lines* include the PAH emission at 3.3 μm and its accompanying weaker features at 3.41 μm and 3.48 μm (Mori et al. 2014), and hydrogen recombination lines within this wavelength range. The shape of $\tau_{ice}(\lambda)$ is taken from laboratory spectrum (H_2O:NH_3 = 100:20, 10 K; Gerakines et al. 1996) and $\tau_{ali}(\lambda)$ from the profile observed in IRAS 08572+3915. Free parameters are the coefficients of the 3rd polynomial, PAH intensity, Brβ intensity, a_{ice}, and a_{ali}.

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Figure 1 shows an example of spectral fitting. Thanks to *AKARI*, we can use a wide spectrum to estimate the H_2O ice and aliphatic carbon absorptions and results in successful fitting.

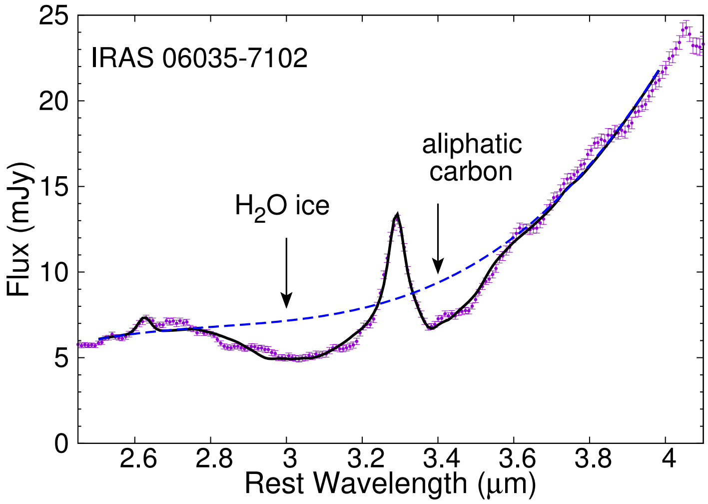

Figure 1. An example of spectral fitting. The purple points represent observed fluxes, the black line the best-fit spectrum, and the blue dashed line its continuum component.

3. DISCUSSION

3.1. UV environment in star-forming regions

We successfully estimated optical depths ($\tau_{3.0}$ for H_2O ice, $\tau_{3.4}$ for aliphatic carbon) by spectral fitting. Then the fraction of dark/diffuse clouds to the total amount of dust can be estimated by normalizing $\tau_{3.0}$ and $\tau_{3.4}$ by $\tau_{9.7}$ which traces rather refractory silicate dust. Figure 2 shows this $\tau_{3.0}/\tau_{9.7} - \tau_{3.4}/\tau_{9.7}$ distribution. Galactic values for dark clouds and diffuse clouds are also shown along with ULIRGs. All the ULIRGs show lower $\tau_{3.0}/\tau_{9.7}$ than dark clouds. In the Galaxy stars are born in dark clouds, and therefore low $\tau_{3.0}/\tau_{9.7}$ indicates that star-forming regions in ULIRGs have more intense UV environment than those in the Galaxy. Moreover, some ULIRGs show quite low $\tau_{3.4}/\tau_{9.7}$. This implies that some ULIRGs may have even intense UV environment, because too strong UV radiation destroys not only H_2O ice but also aliphatic carbon (Mennella et al. 2011)

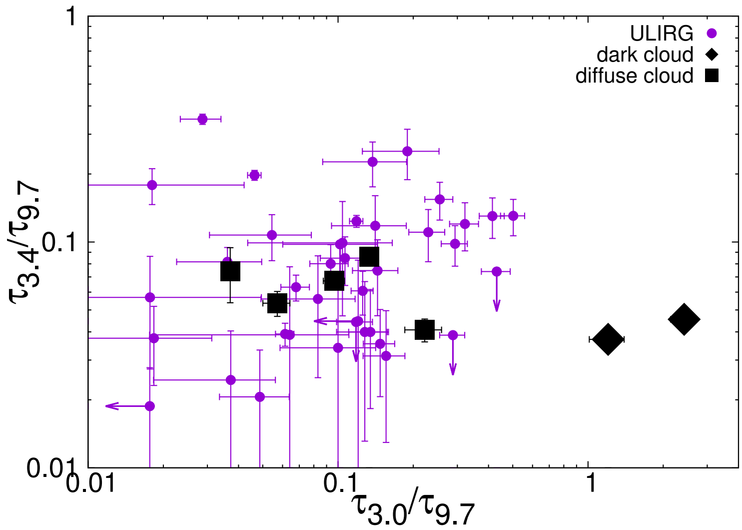

Figure 2. Distribution of $\tau_{3.0}/\tau_{9.7}$ and $\tau_{3.4}/\tau_{9.7}$. The purple circles are for ULIRGs, the black diamonds for Galactic dark clouds, the black squares for Galactic diffuse clouds.

3.2. H_2O ice absorption profile

AKARI provides unique chance to study the H_2O ice absorption free from telluric absorption. Making most of this opportunity, we investigate the ice absorption profile in detail. As shown in Figure 3, we then found that some ULIRGs show excess absorption around 2.8 μm, which is not observed in Galactic sources. This feature can be explained by neither mixtures in ice nor ice temperature. These ULIRGs seem to have large optical depth at 2.8 μm but moderate flux at the absorption peak. Therefore we think this excess as a sign of saturated, partially covering H_2O ice (i.e., area covering factor $C_f < 100\%$). We then reanalysis those spectra including the effect of area covering factor. Figure 4 shows a χ^2 map on the $C_f - \tau_{3.0}$ plane, obtained by the reanalysis. The map strongly supports this saturated and partially covering H_2O ice scenario and indicates that in some ULIRGs dark clouds with extremely large column density ($\tau_{3.0} > 1$) are sparsely distributed ($C_f < 50\%$).

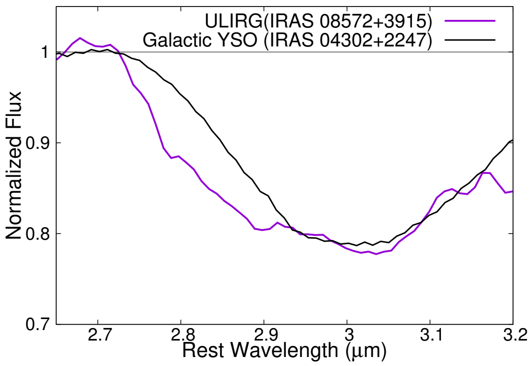

Figure 3. Comparison of the observed H_2O ice profiles in a ULIRG IRAS 08572+3915 with a Galactic YSO IRAS 04302+2247.

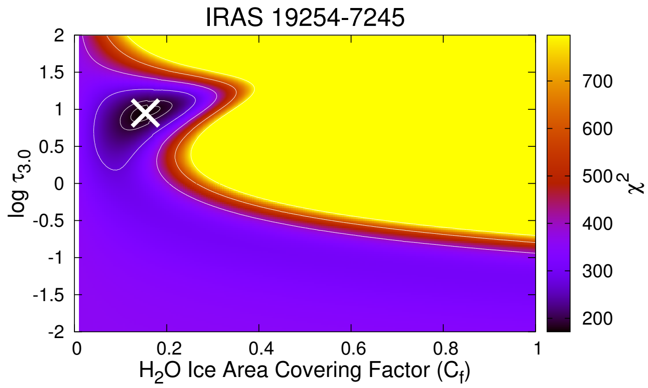

Figure 4. An example of χ^2 map for IRAS 19254−7245. The white cross denotes the least χ^2 point. Confidence contours shown in white line correspond to 3σ, 5σ, 10σ, 15σ and 20σ level.

ACKNOWLEDGMENTS

This research is based on observations with *AKARI*, a JAXA project with the participation of ESA.

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