The *AKARI* Phase 3 Near-infrared Spectroscopic Catalog of the Large Magellanic Cloud and the Stellar Spectroscopic Variability

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ABSTRACT

We performed the data reduction of the *AKARI* Phase 3 near-infrared spectroscopy (2–5.5 μm with prism) of the LMC, which covers almost the same regions as in Phase 1&2 (~10 deg^2). A new spectroscopic catalog which includes ~350 contamination free (~200 new) sources and ~1200 not heavily contaminated (~700 new) sources is created. The time intervals between Phase 1&2 observations and the corresponding Phase 3 observations are more than 200 days, allowing us to analyze the spectroscopic variabilities of YSOs and carbon stars. In this paper, we report the details of the current version of the Phase 3 spectroscopic catalog as well as some of the results so far obtained.

Keywords: catalogs, infrared: stars, Magellanic Clouds, surveys, techniques: spectroscopic

1. INTRODUCTION

Since the distance from the Large Magellanic Cloud (LMC) to the Galaxy is ~50 kpc (Alves 2004), details of individual stars in the LMC could be investigated. The metallicity of the LMC is about half of the solar neighborhood metallicity (Luck et al. 1998). The LMC has been observed in many surveys, such as the *AKARI* LSLMC (Ita et al. 2008), the *Spitzer* SAGE (Meixner et al. 2006), the IRSF/SIRIUS survey (Kato et al. 2007) and the Magellanic Clouds optical photometric survey (Zaritsky et al. 2004).

The early stage of stellar evolution corresponds to the young stellar object (YSO). Compared with the temperature of a main sequence star, that of a YSO is relatively low. A YSO mainly radiates infrared. In the circumstellar environments of embedded YSOs, there are a lot of ices which have near-infrared absorption features in the spectra (e.g., Gibb et al. 2004). YSOs have absorption features of H_2O ice (3.05 μm), CO_2 ice (4.27 μm) and CO ice (4.67 μm) in 2.0–5.5 μm.

There are few analyses of the spectroscopic variabilities of YSOs. The ice chemistry around YSOs are not clearly understood. Variations in the absorption features could provide useful information to study the processing of ices.

The late evolution stage of a star with low or intermediate mass corresponds to the asymptotic giant branch (AGB) star. Typically, the temperatures of AGB stars are lower than those of main sequence stars. AGB stars are also important infrared sources. C-rich AGB stars have the near-infrared absorption features of HCN + C_2H_2 (3.1 μm), C_2H_2 (3.8 μm) and CO (4.6 μm).

Obvious changes in the infrared spectra of AGB stars could be caused by the atmospheric pulsations and the molecule or dust formation (e.g., Hron et al. 1998). AGB stars provide interstellar environments with large amounts of materials by mass-loss processes associated with stellar pulsations. Spectroscopic variabilities are useful to study the mass-loss processes. The spectra are very useful for separating the variations of continua from the variations of absorption features.

Sources can usually be classified with color-magnitude diagrams (CMDs) and color-color diagrams (CCDs) based on the photometric data (e.g., Whitney et al. 2008). However, only with the photometric data, it is not easy to distinguish YSOs from dusty carbon stars since they are located in similar regions in CMDs or CCDs. For identifying YSOs, the ice absorption features are very useful (Shimonishi et al. 2008). More than 10 YSOs are confirmed with the spectra in the *AKARI* LSLMC P1&2 near-infrared spectroscopic catalog (Shimonishi et al. 2010; Shimonishi et al. 2013).

By analyzing the *AKARI* Phase 3 data, we create a new spectroscopic catalog of the LMC. Since the number of confirmed massive young stellar objects is not large, we search for YSOs in the LMC with the new catalog. By comparing the spectra in Phase 1&2 and Phase 3, the spectroscopic variabilities can be investigated, and useful information of stellar evolution could be obtained. YSOs and carbon stars are important infrared sources. We analyze the spectroscopic variabilities of them in this research.

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2. OBSERVATIONS

The Large-area Survey of the LMC was carried out from May 2006 to July 2007, including ~600 pointed observations with the Infrared Camera (IRC; Onaka et al. 2007). Based on the Phase 1&2 data, a point-source catalog (Ita et al. 2008; Kato et al. 2012) and a near-infrared spectroscopic catalog (Shimonishi et al. 2013) have been created.

From March 2008 to June 2009, 548 pointed observations were carried out with the *N3* filter and the NP prism in the LSLMC P3. The *N3* filter covers 2.7–3.8 μm with the reference wavelength of 3.2 μm. The NP prism covers 2.0–5.5 μm with the dispersion of 0.06 μm/pixel at 3.5 μm. The areas of 465 pointed observations were surveyed in Phase 1&2. 83 pointed observations surveyed new areas, which covers the LMC-N11 region.

There are important differences between them. The liquid Helium was used up before Phase 3. Thus only the near-infared data were obtained in the LSLMC P3. The spectral dispersion direction was designed to rotate by 180° between the corresponding observations in Phase 1&2 and Phase 3. This caused the different overlapping parts of spectra. More information could be extracted with careful analyses, which could not be obtained only by using the Phase 1&2 data.

3. DATA REDUCTION

The basic data reduction were performed by using the IRC toolkit to get the stacked *N3* images and stacked NP images. The positions of the sources obtained from the *N3* images are used to check the overlaps of spectra. Contaminations are checked by using the Phase 3 *N3* fluxes. The criteria used for creating the Phase 1&2 spectroscopic catalog (Shimonishi et al. 2013) are used to select contamination free spectra and not heavily contaminated spectra.

4. RESULTS

There are ~9000 sources with Phase 3 *N3* fluxes in the range of 10–500 mJy. ~350 spectra are contamination free, including 200 spectra of new sources. ~1200 spectra are not heavily contaminated, including 700 spectra of new sources.

A new spectroscopic catalog of the LMC is created. More than 1500 near-infrared spectra and the Phase 3 *N3* data, Phase 1&2 IRC data (Kato et al. 2012), 2MASS data (Skrutskie et al. 2006) and *Spitzer* IRAC data (Meixner et al. 2006) are included in it. 1-dimensional and 2-dimensional spectra in the range of 2.5–5.0 μm are plotted for preview.

5. DISCUSSION

5.1. Spectroscopic variabilities of YSOs

About 17000 spectra with the *N3* fluxes in the range of 5–500 mJy are checked with the visual inspection for searching for YSOs in the LMC. We find 10 YSOs which have obvious ice absorption features of H_2O (3.05 μm), CO_2 (4.27 μm) and CO (4.67 μm). All the 10 YSOs were observed with the NG grism spectroscopy of the IRC (Shimonishi et al. 2010). 7 of them were also observed with the NP prism spectroscopy in Phase 1&2. The Phase 3 NG spectra and the Phase 1&2 NP spectra of the YSOs are contamination free. But for the Phase 3 NP spectra, only ST14 is contamination free, and ST5 and ST10 are not heavily contaminated.

We investigate the variabilities of continua by visually inspecting the NP spectra and the NG spectra. The variabilities of ice features of H_2O and CO_2 are investigated by comparing the absorption strengths. The spectral resolution of the grism is ~80 while that of the prism is ~20. Since the absorption features could not be resolved in the NP spectra, the equivalent widths (EWs) are calculated to compare the absorption strengths. Here we use ST5 and ST14 as examples to discuss the spectroscopic variabilities of YSOs. Figure 1 shows the spectra of ST5, and Figure 2 shows the spectra of ST14. The calculated EWs are displayed in Table 1.

For ST5, we find the variation of the continuum. Within the error bar, the variation of ice absorption feature of CO_2 is not found. The calculated EW of H_2O is smaller at the Phase 3 NP observation, which is the brighter phase. However, the continuum near the absorption feature of H_2O (3.05 μm) is relatively low, while the calculated EW is strongly related to the continuum. Small differences of the continuum could cause relatively large differences of the calculated EW. If the variation of H_2O absorption feature is real, it may be explained that because the luminosity of central star increases, the H_2O ice located in the relatively inner region sublimates. CO_2 ice is not strongly affected since H_2O ice is located nearer the star compared with CO_2 ice and absorbs more energy.

For ST14, the Phase 1&2 NP spectrum is not available. The NP and NG spectra in Phase 3 are compared, and we find the variation of the continuum. Within the error bar, the variation of ice absorption feature of CO_2 is not found. Because the resolutions of the NG spectroscopy and NP spectroscopy are different, the variation of H_2O absorption feature needs to be checked by adjusting the resolution.

5.2. Spectroscopic variabilities of carbon stars

By matching the Phase 1&2 spectroscopic catalog with the Phase 3 spectroscopic catalog, 23 spectra of carbon stars are selected.

With the visual inspection of the continua in the NP spectra, the variability trends of near-infrared fluxes are found. To investigate the variabilities of the absorption features of HCN + C_2H_2 at 3.1 μm, C_2H_2 at 3.8 μm and CO at 4.6 μm, we calculate and compare the equivalent widths.

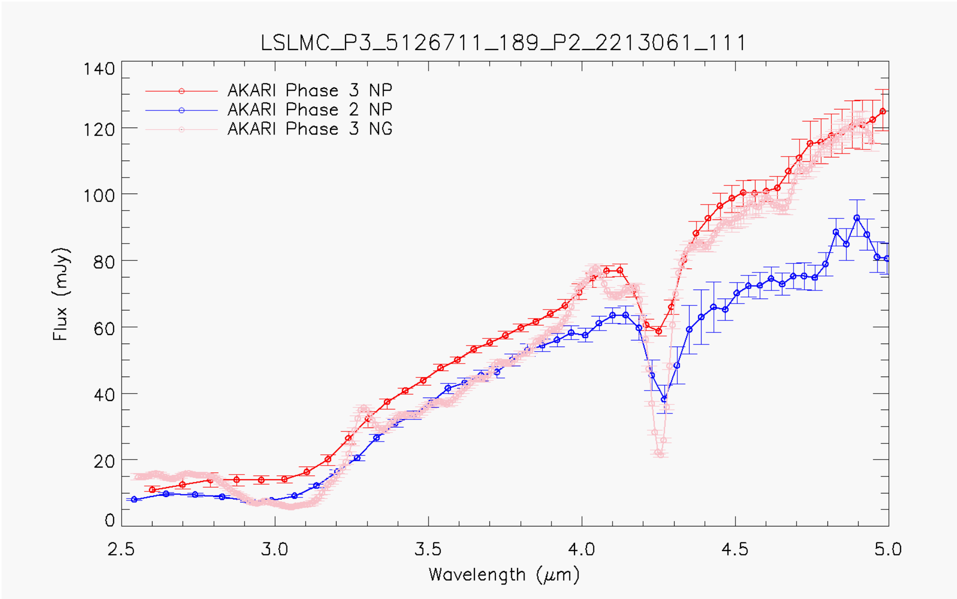

Figure 1. Near-infrared spectra of ST5 obtained by the IRC.

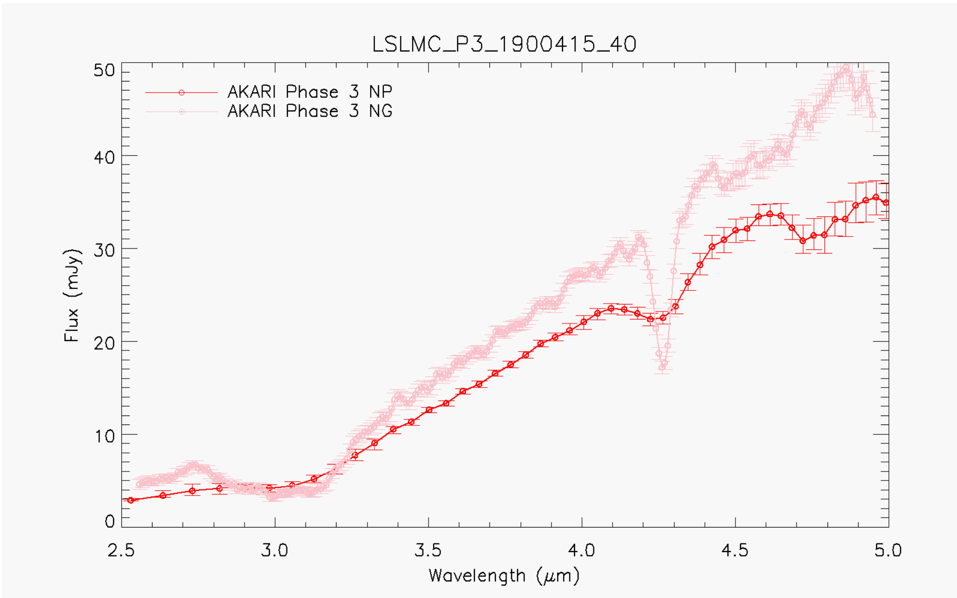

Figure 2. Near-infrared spectra of ST14 obtained by the IRC.

Table 1. Equivalent Widths of Ice Absorption Features of ST5 and ST14

Number	P3 NP	P1&2 NP	P3 NG	P3 NP	P1&2 NP	P3 NG
	EW_{H2O} (nm)	EW_{H2O} (nm)	EW_{H2O} (nm)	EW_{CO2} (nm)	EW_{CO2} (nm)	EW_{CO2} (nm)
ST5	228 ± 20	314 ± 11	271 ± 3.4	48.4 ± 3.8	52.6 ± 11	51.8 ± 0.67
ST14	201 ± 22	N/A	243 ± 7.7	32.0 ± 5.3	N/A	33.6 ± 1.2

For finding the relations of the variability trends, the continua and the calculated EWs are compared. We find that the HCN + C_2H_2 absorption strengths of 11 carbon stars and 12 carbon stars increase as the continua increase and decrease, respectively. It indicates that the stellar variabilities of carbon stars are complex. More detailed investigations are useful for analyzing the pulsations, mass-loss processes and the structure of photosphere.

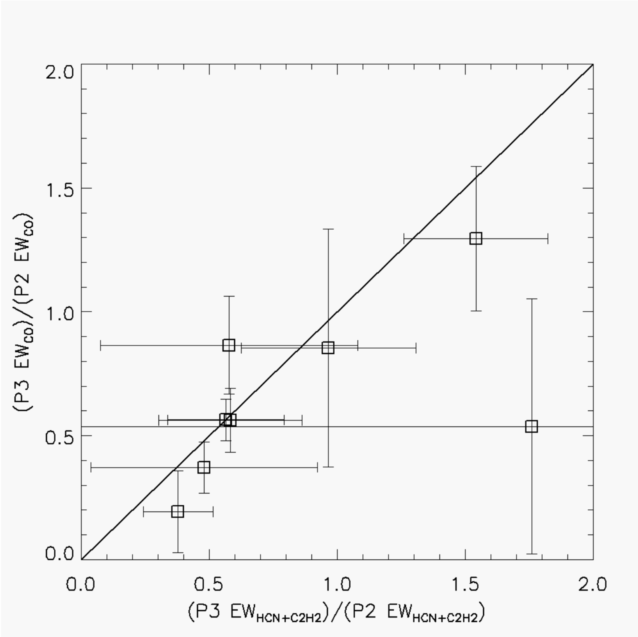

Figure 3. (P3 EW_{CO} / P1&2 EW_{CO}) vs. (P3 $EW_{HCN+C2H2}$ / P1&2 $EW_{HCN+C2H2}$).

For each absorption feature, we calculate the ratio of the EW in Phase 3 to the EW in Phase 1&2. The ratios are also compared. Figure 3 shows the comparison of the ratios between CO and HCN + C_2H_2. The absorption strength variation of CO is similar to that of HCN + C_2H_2. It may indicate that they are in the similar physical region.

6. SUMMARY

By analyzing the near-infrared data in 548 pointed observations in Phase 3, a new spectroscopic catalog of the LMC is created, including ~350 contamination free (~200 new) spectra and ~1200 not heavily contaminated (~700 new) spectra. 10 YSOs are found with the Phase 3 data. New YSO is not found. We also find the variation of continuum and probably that of H_2O ice absorption. CO_2 ice is not strongly affected by the variation of the luminosity. It may indicate that compared with CO_2 ice, H_2O ice absorbs more energy and is located nearer the star. We analyze the NP spectra of 23 carbon stars. Obvious relation between the near-infrared flux variation and HCN + C_2H_2 absorption strength variation is not found. It indicates that the stellar variabilities are complex. The variation of absorption strength of HCN + C_2H_2 is similar to that of CO, which may indicate that they are located in the similar physical region. Higher spectral resolution data of more sources can be useful to investigate the spectroscopic variabilities.

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