DETECTION OF THE 3.3 μm AROMATIC FEATURE IN THE SUPERNOVA REMNANT N49 WITH AKARI

Ji Yeon Seok1, Bon-Chul Koo1, and Takashi Onaka2

1 Department of Physics and Astronomy, Seoul National University, Seoul 151-742, Republic of Korea; jyseok@astro.snu.ac.kr
2 Department of Astronomy, Graduate School of Science, University of Tokyo, Bunkyo-ku, Tokyo 113-0033, Japan

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ABSTRACT

We present an infrared (IR) study of the supernova remnant (SNR) N49 in the Large Magellanic Cloud with the near-IR (NIR; 2.5–5 μm) spectroscopic observations performed by AKARI. The observations were performed as a coarse spectral mapping to cover most of the bright region in the east, which enables us to compare the distribution of various line emissions and to examine their correlation. We detect the 3.3 μm aromatic feature in the remnant, which is the first time the presence of the 3.3 μm aromatic feature related to an SNR has been reported. In the line maps of the H2 1–0 O(3), the 3.3 μm feature, and the Brα, the distribution of the aromatic feature shows overall correlation with those of other emissions together with regional differences that reflect the local physical conditions. By comparing other archival imaging data at different wavelengths, the association of the aromatic emission with other ionic/molecular emissions is clarified. We examine the archival Spitzer Infrared Spectrograph data of N49 and find signatures of other polycyclic aromatic hydrocarbon (PAH) features at 6.2, 7.7, and 11.3 μm corresponding to the 3.3 μm aromatic feature. Based on the band ratios of the PAHs, we find that the PAHs in N49 are not only dominantly neutral, but they are also small in size. We discuss the origin of the PAH emission in N49 and conclude that the emission is either from the PAHs that have survived the shock or from the PAHs in the preshock gas that was heated by the radiative precursor.

Key words: dust, extinction – infrared: ISM – ISM: supernova remnants – Magellanic Clouds

Online-only material: color figures

1. INTRODUCTION

Over the past 20 years, various types of research on polycyclic aromatic hydrocarbon (PAH) in the interstellar medium (ISM) have been conducted both observationally and theoretically. PAHs are revealed as abundant, ubiquitous, and dominant in the ISM of galaxies (Tielens 2008 and references therein), and PAHs are one of the main resources of infrared (IR) emission from near- to mid-IR wavebands. There have been a number of observations that show a variety of PAH features at different wavelengths. Several major emission features are usually detected in diverse objects such as the 3.3 μm C–H stretching band, the 6.2 and 7.7 μm C–C stretching bands, and the 8.6 and 11.3 μm C–H in- and out-of-plane bending bands.

In PAH processing, interstellar shocks are known to play a crucial role. It is largely accepted that PAHs could be either the remaining dust condensation nuclei that escaped the grain growth process in asymptotic giant branch ejecta or the fragmentation of dust grains through a shattering collision in fast interstellar shocks (e.g., Tielens 2008; Jones et al. 1996). Also, interstellar shock waves have been considered one of the main mechanisms that destroy PAH molecules. In spite of plentiful observational evidences of PAH features, however, there are still unanswered questions on the role of interstellar shocks in the evolution of PAHs. In particular, the effect of supernova shocks on the PAH molecules has barely been explored. Detection of PAH features in supernova remnants (SNRs) is unexpectedly rare, although one type of their formation process is related to interstellar shocks.

A considerable amount of literature has dealt with the survivability of PAH molecules in shocked environments. In particular, since PAH emission has been categorized as one of the IR emission components expected for SNRs based on the Spitzer imaging data (Reach et al. 2006), substantial efforts have been made to search for observational evidence of PAH emission in SNRs. By using the Spitzer Infrared Spectrograph (IRS) observations, Tappe et al. (2006) reported the first detection of the 15–20 μm hump attributed to the C–C–C bending modes of large PAHs (∼4000 C-atoms) with the weakly detected 11.3 μm PAH feature in SNR N132D, which is located in the Large Magellanic Cloud (LMC). Based on the lack of PAH features at 6–9 μm and the large ratio of the 15–20 μm hump to the 11.3 μm feature, they interpreted that small PAHs are rapidly destroyed by thermal sputtering in the supernova blast wave. Among the Spitzer/IRS spectra of several galactic SNRs, some in Neufeld et al. (2007) and Hewitt et al. (2009) also show the major PAH features with strong ionic and/or molecular lines, yet both authors did not mention the association of the features with the SNRs in their papers. In most cases when the PAH emission is observed in SNRs, no convincing evidence for the PAH emission intrinsic to the SNRs has been reported. This lack of detection of PAH features in SNRs results from the difficulty of discriminating between the PAH emission from SNRs and that from other back/foreground sources.

In this respect, the best place to observe the PAH emission from SNRs could be the LMC since it is located away from the Galactic disk. Moreover, since PAH molecules in shock regions are supposed to be able to survive only in those with dense clumps (Micelotta et al. 2010a), SNRs interacting with dense circumstellar or interstellar material would be good candidates for detecting the PAH emission. Thus, we have targeted the SNR N49, one of the SNRs interacting with the ambient molecular clouds in the LMC, with the AKARI infrared space telescope (Murakami et al. 2007). N49 (SNR 0525–66.1) is a middle-aged SNR (∼6600 yr; Park et al. 2003), and the surrounding dense ambient medium, which includes complex filamentary structures, suggests that the progenitor of the SNR is a B-type star without a strong stellar wind (Shull 1983). Thanks to its
We performed spectroscopic observations of N49 (SNR 0525–66.1) using the Infrared Camera (IRC; Onaka et al. 2007) on board AKARI. These observations are part of several AKARI mission programs, and the details of the observations are listed in Table 1. The data were taken with a grism in the IRC NIR channel, NG (2.5–5 μm), in the common mode of slit spectroscopy (Ns) during the post-He phase (cooled by the onboard cryocooler). The dispersion (wavelength increment per pixel) is ~0.01 μm, and the slit width is 5″, which gives a spectral resolution of R ~ 100 at 3 μm (Onaka et al. 2007). As a coarse spectral mapping, we made 14 pointed observations to the SNR covering a bright wedge-shaped feature in the east as well as a relatively IR faint region at the west. To obtain a background spectrum, we also carried out two independent observations toward neighboring regions to avoid diffuse emission from the remnant, Figure 1 shows the positions of the IRC NG/Ns slits superposed on the IRC N3 band (2.7–3.8 μm) image that was taken as part of the AKARI large-scale survey of the LMC.

2. OBSERVATIONS

We performed spectroscopic observations of N49 (SNR 0525–66.1) using the Infrared Camera (IRC; Onaka et al. 2007) on board AKARI. These observations are part of several AKARI mission programs, and the details of the observations are listed in Table 1. The data were taken with a grism in the IRC NIR channel, NG (2.5–5 μm), in the common mode of slit spectroscopy (Ns) during the post-He phase (cooled by the onboard cryocooler). The dispersion (wavelength increment per pixel) is ~0.01 μm, and the slit width is 5″, which gives a spectral resolution of R ~ 100 at 3 μm (Onaka et al. 2007). As a coarse spectral mapping, we made 14 pointed observations to the SNR covering a bright wedge-shaped feature in the east as well as a relatively IR faint region at the west. To obtain a background spectrum, we also carried out two independent observations toward neighboring regions to avoid diffuse emission from the remnant.
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we did not subtract it from the final spectra so as not to degrade

ground spectrum does not show any line or continuum emission,
background spectrum, are shown in Figure 2. Since the back-
ning region for the final spectra. The final spectra, including the
point sources and to average the resultant spectra in the overlap-
the signal-to-noise ratio (S

Center and the length of extraction were determined to maximize
areas observed with more than one slit position, and finally five
regions, named “P1” to “P5” from east to west, are chosen and
marked in Figure 1 (white rectangles). To extract each spec-
trum, we integrated 21 pixels along the slit for source spectra
(corresponding to about 31′ and 25′, respectively. For the “P5”
spectrum, we extracted it from a shorter aperture (13 pixels cor-
responding to 19′) to avoid low surface brightness regions. The
center and the length of extraction were determined to maximize
the signal-to-noise ratio (S/N) to avoid contamination from any
point sources and to average the resultant spectra in the overlap-
ing region for the final spectra. The final spectra, including the
background spectrum, are shown in Figure 2. Since the back-
ground spectrum does not show any line or continuum emission,
we did not subtract it from the final spectra so as not to degrade
the S/N.

3. IR SPECTRUM OF N49

3.1. AKARI/IRC NG Spectrum

We examined the IRC NG spectra for the SNR N49, and
the detected lines are given in Table 2. The mid-IR emission
in N49 is dominated by ionic line emission (Williams et al.
2007). However, there is no strong ionic line within this
IRC NG wavelength coverage, so we could not detect any ionic
lines except for a marginal detection of [Fe II] λ 4.889 μm. The
most prominent lines are hydrogen recombination lines such as
Brαλ 4.052 μm and Brβλ 2.626 μm, which are seen at all
spectra, except spectrum P1 (Figure 2). Since P1 is extracted
from just outside of the bright Hz region, there is no strong
recombination line emission, only an interesting feature at
3.3 μm (see below). Although the H2 molecular lines are not
as distinct as the recombination lines, several rotational lines
such as the H2 1–0 O(3) and 0–0 S(11) lines are also clearly
detected.

For the lines detected in most spectra, we measured their
intensities by fitting Gaussians with linear baselines. The in-
tensities with uncertainties are given in Table 2. The uncertain-
ties are the 1σ errors from the line fits, and the upper limits
at the 2σ level are given if the line emission is not apparent.
Most lines in Table 2 are not blended with others, yet there
are a few lines that stand close to their neighboring line (i.e.,
H2 1–0 O(5), Pfδ at 3.235, 3.297 μm and Pfβ, H2 0–0 S(9)
at 4.654, 4.695 μm). For those cases, we applied two Gaussian
fits to estimate their intensities together with either the
peak wavelength or the FWHM fixed if necessary. In addition,
we fixed the peak wavelengths or FWHMs for a few relatively
weak lines.

In the case of the P1 to P3 spectra, we notice that the feature
at 3.3 μm could largely originate from the well-known aromatic
C–H stretching transition at 3.3 μm rather than Pfδ at 3.297 μm.
To be attributable to the Pfδ emission, its intensity is abnormally
stronger than the theoretical value (≤10% of the Brα intensity
in Case B), while the other Brγ and Pf lines are generally consistent
with the expected values (see Table 2). Moreover, the intensities
of the 3.3 μm feature do not vary with the Brα intensities
(see Figure 2), and the measured widths of the feature appear
to be wider (FWHM ~ 0.04–0.05 μm) than those of other
ionic/molecular lines (FWHM ~ 0.03 μm on average) that
correspond to the instrumental width (Onaka et al. 2007).
These widths are consistent with the typical width (~0.04 μm)
of the 3.3 μm aromatic emission (van Diedenhoven et al. 2004).
Hence, we consider that the 3.3 μm feature mainly arises from
the aromatic hydrocarbon emission due to the C–H stretching
mode, which is the first time that we have detected this aromatic
feature associated with an SNR. Although this 3.3 μm feature
does not require a polycyclic molecular structure, it is referred
to as a 3.3 μm PAH feature en bloc hereafter.

There are several minor PAH features near the 3.3 μm feature
such as the weak 3.4 μm band or the broad plateau
at 3.2–3.6 μm (e.g., Tielens 2008). In the IRC spectra, these
minor PAH features are not obvious (Figure 2). We could
only find features at the 3.4–3.5 μm range from P2 and P3,
but they do not look similar to each other (i.e., they have
different peak positions), and there seems to be no such feature
at P1. We measured their intensities, which may be regarded
as an upper limit of the minor 3.4 μm PAH feature intensity,
considering that other minor features and/or the underlying
plateau might be included (Table 2). Despite our ambiguous
detection, the presence/absence of the 3.4 μm feature could be
an interesting issue because this feature can give a constraint
on the band carriers, which is still controversial. There are two
interpretations for this feature: overtones (i.e., anharmonicity of
hot bands; Allamandola et al. 1989; Geballe et al. 1989) and
the C–H stretching emission from the aliphatic side groups attached
to PAHs (Joblin et al. 1996; Tielens 2008, and references
therein). The excited PAH bands of the C–H stretching transition
can be shifted to longer wavelengths due to anharmonicity. In

![Figure 2. Final spectra together with the background spectrum. For convenience, the spectra are shifted by 1, 2, 3, and 4 × 10^-6 W m^-2 μm^-1 sr^-1 for P2 to P5, respectively. The background spectrum is shown in the bottom (shifted by -1 × 10^-6 W m^-2 μm^-1 sr^-1). Noticeable lines are labeled at their vacuum wavelengths.](image-url)
that case, the 3.4 μm intensity increases if the excitation gets higher. Besides, smaller PAHs tend to have a higher ratio of the 3.4–3.3 μm bands for the same internal excitation energy (Geballe et al. 1989). Meanwhile, the presence of aliphatic bonds may delineate a balance between reactions with C_2, C_3-, and H-producing aliphatic groups and the photodissociation of these peripheral groups. When the UV radiation is strong, the dehydrogenation of PAHs severely proceeds so that the 3.4 μm emission becomes weak. However, Tielens et al. (1994) suggested that the ion bombardment can form the aliphatic bonds by hydrogenation of an amorphized graphite surface in interstellar shocks. Although its detection is tentative, the possible presence of the 3.4 μm feature at P2 and P3 but not at P1 may indicate that the PAHs inside the SNR are generally smaller with a strong UV field or that the aliphatic bonds are more abundant due to shock processing compared with a preshock region. Further investigation with a higher sensitivity and spectral resolution would be needed to understand this point more clearly.

3.2. Brightness Distribution of PAH, Hα, and H2 Emission

Although the 3.3 μm feature can be attributed to the PAH emission, it is important to confirm whether the PAH emission is really associated with the SNR. For this purpose, maps of the H2, PAH, and Brα emissions are constructed from all spectra covering the PAH-bright area in the east (Figure 3). The pixel size of the map is the same as the original pixel size of the slit (1′.46 × 1′.46), and the intensity at each pixel is calculated by resampling them with a nearest-neighbor interpolation method and averaging the data values that fall on the pixel. Then, the line maps are smoothed with a three-pixel Gaussian. The resultant line maps reveal the distribution of a 3.3 μm PAH or Pfβ emission. Due to the ambiguous identification, the measured intensities can be regarded as an upper limit of the 3.4 μm feature intensity.

| Line ID | λ_{em}[^a] | P1 | P2 | P3 | P4 | P5 |
|---------|------------|----|----|----|----|----|
| Brγ     | 2.626      | ≤0.34 | 1.58 ± 0.30 | 2.73 ± 0.27 | 2.47 ± 0.53 | 0.77 ± 0.34 |
| H2 1–0 O(3) | 2.803 | 0.27 ± 0.15[^b] | 0.31 ± 0.25 | 1.38 ± 0.23 | 0.85 ± 0.40 | ≤0.47 |
| H2 1–0 O(5) | 3.235 | 0.32 ± 0.15[^b] | 0.75 ± 0.38 | 0.58 ± 0.12[^b] | 0.42 ± 0.24[^b] | ≤0.57 |
| Pfβ+PAH[^c] | 3.297 | 1.72 ± 0.31[^d] | 2.16 ± 0.51 | 1.42 ± 0.25[^d] | 0.79 ± 0.37[^d] | ≤0.73 |
| PAH[^c] | 3.300 | 1.67 ± 0.33 | 1.87 ± 0.53 | 1.04 ± 0.28 | 0.39 ± 0.45 | ... |
| PAH[^c] | 3.400 | ... | 0.61 ± 0.36[^f] | 0.80 ± 0.34[^f] | ... | ... |
| Pfγ[^a] | 3.741 | ≤0.24 | 0.22 ± 0.09[^b] | 0.51 ± 0.13 | ≤0.44 | ≤0.45 |
| Brα | 4.052 | 0.50 ± 0.16 | 2.94 ± 0.15 | 3.83 ± 0.13 | 4.03 ± 0.25 | 1.52 ± 0.17 |
| H2 0–0 S(11) | 4.181 | ≤0.09 | 0.23 ± 0.08[^b] | 0.50 ± 0.11 | 0.42 ± 0.14[^b] | ≤0.48 |
| H2 0–0 S(10) | 4.410 | ≤0.20 | 0.20 ± 0.09[^b] | 0.35 ± 0.14 | ≤0.51 | ≤0.29 |
| Pfβ | 4.654 | ≤0.57 | 0.84 ± 0.11[^b] | 0.79 ± 0.11[^b] | 0.88 ± 0.17[^b] | 0.64 ± 0.24 |
| H2 0–0 S(9) | 4.695 | ≤0.44 | 0.26 ± 0.20[^d] | 1.29 ± 0.23[^d] | 1.17 ± 0.35[^d] | ≤0.55 |

**Table 2**

Detected Lines and Their Intensities from the AKARI/IRC Data for N49

| Line ID | λ_{em}[^a] | P1 | P2 | P3 | P4 | P5 |
|---------|------------|----|----|----|----|----|
| Brγ/Brα | 0.60 | ≤0.68 | 0.54 ± 0.11 | 0.71 ± 0.07 | 0.61 ± 0.14 | 0.51 ± 0.23 |
| Pfβ/Brα | 0.10 | 3.44 ± 1.26 | 0.73 ± 0.18 | 0.37 ± 0.07 | 0.20 ± 0.09 | ≤0.48 |
| Pfγ/Brα | 0.135 | ≤0.48 | 0.07 ± 0.03 | 0.13 ± 0.03 | ≤0.11 | ≤0.30 |
| Pfβ/Brα | 0.20 | ≤0.57 | 0.29 ± 0.04 | 0.21 ± 0.03 | 0.22 ± 0.04 | 0.42 ± 0.16 |

Notes. Intensities with errors of detected lines are given. Upper limits are at the 2σ level.

[^a]: Vacuum wavelength of a line in μm.
[^b]: FWHM fixed to the instrumental width (∼0.03 μm) for a Gaussian fit.
[^c]: Total intensity of the feature at 3.3 μm, which can be mainly contributed by either the 3.3 μm PAH or Pfβ emission.
[^d]: Central wavelength fixed for a Gaussian fit.
[^e]: Estimation of the PAH intensity by subtracting the total intensity of the 3.3 μm feature by the scaled Brγ intensity (i.e., 10% of the Brγ intensity).
[^f]: Intensity of a minor PAH feature at 3.4 μm. Because of the curvature around the feature, the baseline is fitted by using a second-order polynomial.
[^g]: Theoretical recombination line ratio in the case of “on-the-spot” approximation (the so-called Case B) with n_e ∼ 10^{2–3} cm^{-3} and T_e ∼ 5–30 × 10^{3} K (Hummer & Storey 1987).
tip of the wedge-shaped region, which is at the center of the interacting molecular cloud (i.e., P1 and P2 in Figure 1). The two clumps of the PAH emission in the south (white crosses in Figure 3) could be seen at the coincident positions in the H2 map. Meanwhile, the peak position of the PAH emission is not matched with that of the H2 emission but rather closer to that of the Brα emission. In addition, it is interesting that the relatively weak PAH emission is observed where the H2 emission is the strongest.

Figure 4 compares the average intensities of the representative emission lines in individual slits from P1 (east) to P4 (west). Since the intensities (listed in Table 2) are those averaged over the slits, they may not directly describe the spatial variation but, quantitatively, they show their trend. The peak intensity of the PAH emission appears at P2 (more eastward) unlike the others, and the emission at P1 (outside the shock boundary) still has a comparable intensity to that of the PAH emission at P2. We could not see any tight correlations of the PAH emission with either the H recombination or the H2 molecular line emission, but it is notable that the recombination line intensity rapidly increases over the boundary (P2), whereas the molecular line intensity is steady at the east (even inside the boundary) and becomes stronger at P3.

In addition to the emission intensities, we examined the variation of the physical quantities such as the column densities, \( N(\text{H}_2) \), and the gas temperatures, \( T_{\text{gas}} \), with respect to the four spectra, assuming local thermodynamic equilibrium (LTE) estimated from the intensities of the H2 molecular lines. The H2 line intensities can directly provide the column density, \( N(J_u) \), of each upper state of the transitions, \( J_u \). An extinction correction is not applied because the extinction toward N49 is negligible.
Figure 5. Images of N49 in (a) H2 2.12 μm (Dickel et al. 1995), (b) IRAC 8.0 μm, (c) smoothed Hα, and (d) original Hα (Bilikova et al. 2007). (c) Hα image is convolved to the spatial resolution of the AKARI N3 image (FWHM ∼0.0′′). Contours overlaid in all of the images are from the PAH 3.3 μm map of Figure 3, whose levels are at 6, 7, 8, and 9 × 10^{-19} W m^{-2} arcsec^{-2}. North is up and east is to the left. Positions of the Spitzer/IRS SL resolution slits are marked in (b) and (d). (A color version of this figure is available in the online journal.)

according to the measured E(B − V) = 0.37 (Vancura et al. 1992) and the extinction curve of the “average” LMC model (Weingartner & Draine 2001). Performing a one-temperature LTE fits to the observed H2 transitional lines with a given ortho-to-para ratio = 3, we find that N(H2) varies from ∼1 to 5 × 10^{16} cm^{-2} (Figure 4), while T_{gas} steadily remains at ∼2000 K. The column densities we derived are much lower than the typical total column densities for SNRs (∼10^{20} cm^{-2}, e.g., Hewitt et al. 2009). This is probably because only H2 lines of a high upper state transition are used for our estimation. In the case for SNRs, an ankle-like curve is representativey seen in the H2 level populations (e.g., Shinn et al. 2010), so that H2 pure rotational lines with low upper states such as H2 S(0)—S(2) transitional lines mainly determine the total column density. Then, what we derived is likely to be the column density of a hot component (T_{gas} ∼ 2000 K) within the SNR. Therefore, with the current observations, we cannot explore the relation between total H2 and PAH.

The morphological characteristics of the PAH emission with respect to the molecular and ionic gas would be reconfirmed and clarified by comparing them with the narrow filter images with a higher spatial resolution. As a complement, we use preexisting data, the H2 1–0 S(0) at 2.12 μm taken with the Anglo-Australian Telescope (AAT; Dickel et al. 1995), the Spitzer Infrared Array Camera (IRAC) 8 μm (Williams et al. 2007), and the Hubble Space Telescope (HST) Hα image (Bilikova et al. 2007). The 2.12 μm and the Hα images generally show a consistent distribution with the H2 O(3) and Brα maps in Figure 3, respectively. In Figure 5, we can confirm the features described above. The eastern boundaries of the 2.12 μm and the PAH emission show a good agreement, and both emissions are almost absent in the western part of the SNR where the optical
filaments are comparably bright, as seen in the P5 spectrum (Figure 2). The peak of the PAH emission, however, corresponds better to the Hα emission rather than the 2.12 μm emission. It is certain that the PAH emission exists beyond the Hα boundary in the east. Thus, the other observations of N49 similarly show the same morphological characteristics as our AKARI line maps.

The characteristics of the PAH emission in N49 may be summarized as follows. (1) The overall morphology of the 3.3 μm PAH emission is similar to the H2 emission in the sense that both are spatially confined. In contrast, the peak of the PAH emission is located rather closer to that of the Brγ emission. (2) Toward the region with the brightest H2 emission, however, the PAH emission is relatively faint. (3) There is PAH emission beyond the shock front in the east, i.e., beyond the east boundary in the optical image, and its peak position is near the center of the interacting molecular cloud (Figure 1). In addition, it is interesting that the distribution of the PAHs shows a good agreement with the bright emission seen in the IRAC 8 μm image. A noticeable feature in the 8 μm image, not covered by our AKARI observation, is the bright emission beyond the eastern boundary. The nature of this feature is described in more detail in Section 3.3.

3.3. Spitzer/IRS Spectrum

The detection of the PAH emission at 3.3 μm implies the possibility of other major PAH band emissions such as the 6.2, 7.7, and 11.3 μm features. We examined the Spitzer/IRS archival data for the PAH emission (AOR 6586112; Williams et al. 2007). The IRS slits are centered on the brightest tip of the wedge-shaped region (Figure 5(b)), and they partially overlap with the IRC slits (P2 and P3). Retrieving the IRS low-resolution (SL: 5.2–14.5 μm) Post-Base Calibrated Data (PBCD) from the Spitzer archive, we have extracted spectra by using the standard SPICE package with a full aperture for an extended source (slit width: 3.7′, aperture length: 50′/4 (28 pixels)). We have applied background subtraction by using different orders of spectra. One of the benefits of the background subtraction is that the residual of the instrumental pattern (the so-called jail-bar pattern) seen weakly in the PBCD data can be efficiently removed without much loss of S/N. The final IRS spectrum is shown in Figure 6. It is almost the same as the one published by Williams et al. (2007), but it shows small differences probably due to background subtraction. The strong ionic lines such as [Fe II] and [Ne II] at λλ 5.32 μm and 12.83 μm are detected together with several H2 transitional lines up to 0–0 S(2) λ 12.30 μm (Figure 6(a)). As in Williams et al. (2007), a non-zero background level is seen, presumably because the background level varies. A close look at the PAH bands in the spectra helps us identify several PAH features (Figures 6(b)–(d)). The PAH emission of the C–H out-of-plane bending mode at 11.3 μm is clearly detected, and weak C–C stretching features at 6.2 μm and 7.7 μm with an ambiguous 8.6 μm emission of the C–H in-plane bending mode can also be seen. We derive the intensities of the PAH band features by simple summations with a linear baseline fit over the entire order. The intensities of the 6.2, 7.7, and 11.3 μm PAH features are estimated as 1.0±0.5, 2.0±0.4, and 1.6±0.1 in units of 10⁻¹⁶ W m⁻², respectively. The quoted errors include the calibration uncertainty and 1σ fluctuation in the baseline spectra.

For the clearly detected 11.3 μm PAH feature, we compare its spatial distribution with those of the H2 0–0 S(2) λ 12.3 μm and [Ne II] λ 12.8 μm along the slit (Figure 7). For comparison, the spatial profile of the Hα emission that was extracted from the HST image is also shown. Although a sharp jump in the Hα intensity is not seen, a shock front might be located near the place where the Hα intensity rapidly increases. A dashed line in Figure 7 can be regarded as the SNR boundary. The emission outside of the shock front could originate from ambient gas heated by radiative precursors, and the hint of the radiative precursor can be found in the Hα emission in the zoomed profile at the lower intensity level (Figure 7, bottom). Beyond the SNR boundary, continuous decreases of the 11.3 μm PAH and H2 S(2) emission are seen up to the position around the pixel zero. The

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Figure 6. (a) IRS SL spectra of N49 with the Spitzer/IRAC spectral response curves. “Nod 1” position spectra are used only. The [Ne II] line at 12.8 μm is truncated for clarity. Dominant emission lines are labeled. (b–d) Profiles of the PAH band emission features at 6.2, 11.3, and 7–9 μm are extracted from the IRS spectra. The extracted ranges are overplotted in (a). Detected PAH bands with H2 emission lines are also marked. Error bars at the left bottom of each panel represent the typical error for the spectra.

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4 See irsa.ipac.caltech.edu/data/SPITZER/docs/irs/irsinstruments/handbook/61/
The bump of the PAH emission at −4 pixels in the preshock area is more likely due to a background fluctuation (the bump is located outside of the southern boundary of Figure 5(b)). The profile of the PAHs shows a smooth decrease near the shock front like that of H$_2$, but there is better agreement with [Ne II] beyond the peak to the downstream. This is consistent with the morphological characteristics of the PAH emission seen in the line maps. A similar distribution between the 11.3 $\mu$m PAH emission and the [Ne II] has been observed toward several objects. For example, in the planetary nebula, BD +30 3639, Matsumoto et al. (2008) detected the coexistence of PAHs and ionized gas, which has been attributed to a slow destruction of PAHs in the ionized gas. There is a non-zero continuum level in the IRS spectrum in Figure 6 that we attributed to the residual of the background subtraction. The dust emission and synchrotron (or free–free) emission from the SNR should be negligible at this wavelength, so that even if the non-zero continuum is real, it should come from an unrelated object. Although we cannot completely exclude the contamination from the general ISM, we conclude that the good spatial correspondence is mainly due to the 7–9 $\mu$m PAH emission in the IRAC 8 $\mu$m band.

4. DISCUSSION

4.1. Physical Properties of PAHs in N49

The PAH emission features are expected to reflect the local physical conditions. In particular, the relative strength variations among the PAH features at different wavelengths are mainly attributed to their different charge states (e.g., Bakes et al. 2001). The PAH emission from the C–H modes, such as the 3.3 and 11.3 $\mu$m features, becomes stronger in a neutral state, whereas others from the C–C modes, such as the 6.2 and 7.7 $\mu$m features, become stronger in an ionic state. Generally, comparisons of the intensities of 3.3 $\mu$m and 11.3 $\mu$m, both normalized with 6.2 $\mu$m, are regarded as an indicator for the degree of ionization of PAHs (e.g., TieLens 2008, and references therein). Similarly, the intensity ratios of 6.2 $\mu$m to 11.3 $\mu$m and 7.7 $\mu$m to 11.3 $\mu$m are often used as well. In our observations, the intensities of the 3.3 $\mu$m bands cannot be directly compared with those of other PAH bands in the IRS spectra. But, from the IRS spectra we calculate band ratios among the 6.2, 7.7, and 11.3 $\mu$m PAH emissions: $I_{6.2}/I_{11.3} \approx 0.63 \pm 0.31$, $I_{7.7}/I_{11.3} \approx 1.25 \pm 0.26$.

Our ratios show unusually weak 6–8 $\mu$m PAH features relative to an 11.3 $\mu$m feature in comparison with the median of the ratios from the star-forming galaxies ($I_{7.7}/I_{11.3} \approx 3.6$ in Smith et al. 2007) or those for a Galactic diffuse emission ($I_{7.7}/I_{11.3} \approx 2.0–3.3$ in Sakon et al. 2004). Such low PAH 7.7/11.3 ratios have been reported in some of the elliptical galaxies, which is reasonably interpreted as a result of a larger fraction of neutral PAHs due to a soft radiation field from evolved stars (e.g., $I_{7.7}/I_{11.3} \approx 1$–2 in Kaneda et al. 2008). Similarly, our ratios indicate that the PAHs in N49 are dominantly neutral, even though the environmental cause is different. Figure 8 is a diagram of the PAH band ratios ($I_{6.2}/I_{11.3}$ versus $I_{7.7}/I_{11.3}$) from various objects in the literature, which shows that these PAH band ratios are linearly correlated regardless of the object type. Note that the PAHs are mainly neutral in the lower left and mainly ionized in the upper right. Interestingly, our ratios also follow the universal linear correlation between the two ratios. As far as we know, N49 is the only SNR where both the $I_{6.2}/I_{11.3}$ and $I_{7.7}/I_{11.3}$ ratios are obtained. In N31D, which is another SNR with a PAH emission, only an upper limit of $I_{6.2}/I_{11.3}$ ratio could have been derived (Tappe et al. 2006), and it is marked in Figure 8. This upper limit suggests that the ionization fraction of PAHs in N31D is not high, which is consistent with the

Figure 7. Top: IRS SL line profiles of PAH $\lambda$ 11.3 $\mu$m (black solid), H$_2$ 0–0 S(2) $\lambda$ 12.3 $\mu$m (dotted), and [Ne II] $\lambda$ 12.8 $\mu$m (dash dot). For comparison, a one-dimensional cut of the H$\alpha$ emission along the IRS slits (gray solid) is extracted from the HST image smoothed to the pixel scale of the IRS. Bottom: the same profile of H$\alpha$, but zoomed in for variation at the lower levels. The dashed line represents the SNR boundary (the probable location of the shock front). One pixel corresponds to 1"/8, and the coordinate of the position for the zero pixel is ($\alpha, \delta$) = (05$^{h}$26$^{m}$05$^{s}$, −66 05'28") J2000.0). The negative and the positive correspond to south and north, respectively.
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The theoretical expectation that PAHs can become neutral within a short timescale in the postshock layer (see Figure 5 in Micelotta et al. 2010a). It is known that the charge states of PAHs are determined by the balance between the photoionization and electron/ion collisions. The charge state is proportional to the quantity \( G_0 \sqrt{T/n_e} \) (for a review, see Tielens 2008), where \( G_0 \) is the intensity of the radiation field in units of the Habing field (1.6 \( \times 10^{-6} \) W m\(^{-2}\)), \( T \) is the gas temperature, and \( n_e \) is the electron density. The ones with a small \( I_{6.2}/I_{11.3} \) ratio (or with neutral PAHs) represent a region where \( G_0 \sqrt{T/n_e} \) is small. For a few well-studied photodissociation regions, Galliano et al. (2008) have empirically interpreted the PAH band ratio with the above physical properties, \( I_{6.2}/I_{11.3} \approx \left[ G_0/304n_0(\text{cm}^{-3}) \right] \left( T_{\text{gas}}/10^3 \text{ K} \right)^{1/2} \).5 valid in the range \( 400 \lesssim G_0/\langle n_e \rangle/1 \text{ cm}^{-3} \), \( T_{\text{gas}}/10^3 \text{ K} \)^{1/2} \( \lesssim 4000 \).

As we will discuss in the next section, the detected PAH emission is probably either from the PAHs in the shocked molecular gas and/or from the PAHs in the preshock gas that is heated by the radiative precursor. In dense molecular clouds, PAHs usually exist in a neutral (and anionic) state. Even after they experience continuous (C-type) shock waves, neutral PAHs predominate in all charged states because photoionization is not significant in these circumstances (Flower & Pineau des Forêts 2003). The PAH emission could also be from PAHs in preshock gas that is heated by the radiative precursor. In N49, by modeling the UV and optical spectrum, Vancura et al. (1992) find that preshock densities of 20–940 cm\(^{-3}\) in the velocity range, 40–270 km s\(^{-1}\), are required for the denser regions with radiative emission. The strength of the UV precursor in radiative shocks (30 km s\(^{-1}\) \( \lesssim v_s \lesssim 200 \) km s\(^{-1}\)) is calculated that \( G_0 \approx 1.6n_0v_{s,7} \), where \( v_{s,7} \) is the shock velocity per 100 km s\(^{-1}\) and \( n_0 \) is the preshock hydrogen nucleus density (McKee et al. 1987, and references therein). The coefficient varies with the shock velocity, and it is 1.6 when \( v_s = 100 \) km s\(^{-1}\). Then, adopting a preshock density as 150 cm\(^{-3}\) at \( v_s = 100 \) km s\(^{-1}\) under the requirement that \( G_0v_{s,7}^2 \) remains constant (Vancura et al. 1992), \( G_0 \) becomes 240. This UV radiation heats a column of 10\(^{19} \) cm\(^{-2}\) hydrogen nuclei to \( \sim 5000 \) K and fully ionizes it (e.g., the case of \( n_0 = 100 \) cm\(^{-3}\) and \( v_s = 100 \) km s\(^{-1}\) in Allen et al. 2008). In this radiative precursor region, the ratio \( G_0\sqrt{T/n_e} \) will be small (\( \sim 110 \)) so that the PAHs will be neutral. If we extrapolate the empirical relation of Galliano et al. (2008), we obtain \( I_{6.2}/I_{11.3} \approx 0.53 \), which is consistent with the observed ratio.

Meanwhile, the observed band ratio can be compared with theoretical studies by Draine & Li (2001), which show how the charge state and size of the PAHs affect the relative strengths of the three-band emission, 6.2 \( \mu \text{m}/7.7 \mu \text{m} \) versus 11.3 \( \mu \text{m}/7.7 \mu \text{m} \) (see Figure 16 in their paper). Our observed fluxes give \( I_{6.2}/I_{7.7} \approx 0.50 \pm 0.27 \) and \( I_{11.3}/I_{7.7} \approx 0.80 \pm 0.15 \), which are located near the line for neutral PAHs. More interestingly, our high \( I_{6.2}/I_{7.7} \) ratio indicates that small PAHs are dominant in N49, although the error is large. The existence of small PAHs can also be verified by the \( I_{3.3}/I_{11.3} \) ratio since larger PAHs produce a relatively strong 11.3 \( \mu \text{m} \) feature, while the 3.3 \( \mu \text{m} \) emission is enhanced by small PAHs (e.g., Schutte et al. 1993). It is not simple to directly derive the \( I_{3.3}/I_{11.3} \) ratio from our data because the 3.3 \( \mu \text{m} \) and 11.3 \( \mu \text{m} \) fluxes are observed by different telescopes and positions. However, we make a rough estimation to obtain both the surface brightness at the peak and the integrated intensity with the full aperture (50\(\prime\)4) along the IRS slit from the AKARI 3.3 \( \mu \text{m} \) line map (Figure 3) and the Spitzer spectrum (see the slit position in Figure 5). The \( I_{3.3}/I_{11.3} \) ratios of the peak brightness and the total intensity are measured as \( \sim 0.43 \) and \( \sim 0.30 \), respectively. These ratios are at a high end of the observed range (in general, 0.2–0.3), which can be accounted for by small PAHs unless the radiation is hard enough to excite large PAHs (Mori et al. 2011). For 100 km s\(^{-1}\) radiative shocks, the UV radiation from the shock is mostly in Ly\(\alpha \) photons (McKee et al. 1987), so it might be difficult to directly compare the shock radiation with the radiation from a central source. However, no detectable PAH feature at longer wavelengths, which are easily produced by large PAHs (e.g., 16.2 or 17.4 \( \mu \text{m} \) features), is more likely produced by large PAHs (e.g., 16.2 or 17.4 \( \mu \text{m} \) features), is more likely to support a small contribution of large PAHs to the 3.3 \( \mu \text{m} \) feature (see Figure 9 of Williams et al. 2007). Therefore, the observed \( I_{6.2}/I_{7.7} \) and \( I_{3.3}/I_{11.3} \) ratios indicate the presence of small PAHs, which is consistent with the PAH formation by the fragmentation from larger carbonaceous grains but not with the preferential destruction of small PAHs in shocked gas.

### 4.2. Origin of PAH Emission

PAH emission has been detected toward a few shock-associated regions. Due to the limited observational evidence, it is poorly understood how shocks play a role in PAH processing. Generally, there are two sides to the SNR shocks in terms of the PAH processing, i.e., shocks can produce PAH molecules by shattering larger dust grains (e.g., Jones et al. 1996), but shocks can also destroy them by colliding with energetic particles in shocked gas (e.g., Micelotta et al. 2010a). Micelotta et al. (2010b) show that the destruction mechanism in a hot gas (\( T \gtrsim 3 \times 10^4 \) K) is dominated by an electron collision for small/medium size PAHs (50–200 C-atom). They describe a PAH lifetime in a hot gas as \( t_0 = N_C/J_nH/e \), where \( N_C \) is the initial PAH size, \( J \) is the rate constant for electrons, nuclear, and electronic interactions, and \( nH/e \) is the hydrogen/electron...
diffuse intercloud medium (preshock density $X$-ray emission is generated by the fast shock propagating in the medium from which different emission arises. The hot gas with kinds of environments related to the characteristics of the conditions inside the remnant should significantly vary in low-PAH emission depending on the local shock condition. Hence, it is necessary for the PAH emission could also be produced outside of the shocked same processing as the survived ones soon after. Meanwhile, the newly formed PAHs undergo the difference between newly formed and survived PAHs is not obvious, but it is supposed that the newly formed PAHs undergo the same processing as the survived ones soon after. Meanwhile, the PAH emission could also be produced outside of the shocked region by radiative precursors of the shocks. Hence, it is necessary to separately examine the dominant mechanism for the PAH emission depending on the local shock condition.

The complex structures of N49 imply that physical conditions inside the remnant should significantly vary in localities. This remnant can be largely divided up into three kinds of environments related to the characteristics of the medium from which different emission arises. The hot gas with X-ray emission is generated by the fast shock propagating in the diffuse intercloud medium (preshock density $n_0 = 0.9 \text{ cm}^{-3}$, $n_e = 27$–2300 $\text{cm}^{-3}$, $T \gtrsim 7 \times 10^6 \text{ K}$, and $v_s \sim 730 \text{ km s}^{-1}$ in Park et al. 2003). The dense ambient medium produces the bright optical filaments (i.e., the ionization line emission) by shocks of $v \lesssim 140 \text{ km s}^{-1}$ ($n_0 = 20$–940 $\text{cm}^{-3}$, $T \sim 10^4 \text{ K}$ in Vancura et al. 1992). The electron densities of the filaments vary from $n_e \simeq 70$ to 515 $\text{cm}^{-3}$, and the densest regions have densities of $1000$–$1800 \text{ cm}^{-3}$ (Bilikova et al. 2007; Vancura et al. 1992). Last, the molecular line emission such as those in H$_2$ lines can arise from the dense clumps where slow (non-dissociative) shocks are propagating (in general, $n_0 \gtrsim 30 \text{ cm}^{-3}$, $v_s \lesssim 50 \text{ km s}^{-1}$ in Draine & McKee 1993). Interestingly, in N49, both the shocked molecular and ionic gases show analogous distributions, and the PAH emission is likely to be associated with both gases. This is not surprising in the sense that N49 is known to interact with a nearby molecular cloud (Banas et al. 1997). The coexistence of both the molecular and ionic shocks in a single SNR is occasionally seen in SNRs interacting with molecular clouds, since the shocked dense clumps emitting the H$_2$ transitional line emission are immersed in a less dense medium that emits various ionic line emissions after being swept up by shocks (e.g., Chevalier 1999).

In the hot diffuse medium of N49 ($n_0 = 27 \text{ cm}^{-3}$, $T = 7 \times 10^6 \text{ K}$), the lifetime of the PAHs with $N_C = 200$ is $\sim 1$ month by adopting the analytical fits to the rate constant ($J \sim 2.7 \times 10^{-6} \text{ cm}^{-3} \text{s}^{-1}$; Table 2 in Micelotta et al. 2010b). Even for the large-sized PAHs or PAH clusters, the lifetime is not long enough to be detected (e.g., $\sim 20$ months for $N_C = 1000$; Figure 8 in Micelotta et al. 2010b). To explain the observed PAH emission, protective environments in N49 are necessary, which have already been noticed in optical spectroscopic observations (Vancura et al. 1992; Bilikova et al. 2007). By using the echelle observations with the HST image (see Figure 3 in Bilikova et al. 2007), some broad emission features in the echellegrams reveal a “head-tail” structure, whose bright emission at the head has a smaller radial velocity offset from the systemic velocity compared with the fainter emission in the tail. This type of structure could originate from the shocks that encounter the dense gas. While a shock is propagating through the preshock gas in the inner part of the dense bright regions, the shock velocity drops so that the gas deep inside the dense filament can avoid being swept up by shocks, thus staying unshocked. The observed H$_\alpha$ recombination lines at the systemic velocity in the optical spectrum support this.

Based on the above discussion, we propose a schematic model of the PAH emitting condition in N49 in Figure 9. Since a shock...
is retarded by a dense gas (Region II and shocked Region III), the temperature of the postshock gas can substantially decrease ($T_{\text{gas}} \propto v_i^2$). The PAH lifetime can significantly increase under these circumstances because the rate constant rapidly declines below $10^5$ K (Micleotta et al. 2010b). Vancura et al. (1992) have measured electron densities and electron temperatures for the bright optical filament of N49 as $\sim 1 \times 10^3$ cm$^{-3}$ and $\sim 1 \times 10^4$ K, respectively. These quantities lead to the lifetime of $1.2 \times 10^9$ yr for 200 C-atom PAHs (cf. $J \sim 5.2 \times 10^{-15}$ cm$^3$ s$^{-1}$), which is much longer than the age of the SNR. The PAHs in the central region (unshocked Region III) of the molecular clumps (and the dense filaments) can be heated by UV photons that mainly originate from the radiative shell, more precisely in this case, the knotty optical filaments around the clumps. In the case of the PAH emission observed outside of the shock front (seen eastward at the tip in Figure 3), it is most likely that the preexisting PAH molecules are heated by the radiative precursors and produce the emission features. When the shock velocity is greater than 80 km s$^{-1}$, the ionizing UV fluxes produced by the precursor become effective (Shull & McKee 1979). The bulk range of the shock velocity in N49 is measured as $\lesssim 140$ km s$^{-1}$ (Vancura et al. 1992), and we indeed see the hint of the radiative precursor in the zoomed H$\alpha$ line profile (Figure 7). In summary, the PAH emission can be associated with shocked ionic gas (Region II) or (shocked) molecular gas (Region III) when the shock is sufficiently retarded with the existence of a heating source such as UV photons (Figure 9). Also, because a shock is propagated and retarded inside the dense region, the shocked ionic and molecular gas can hierarchically exist together with the PAH emission. Then, the morphological correlation of the PAH emission to other emissions would depend on the shock velocity and the preshock density.

The absence of the PAH emission at the peak of the H$\alpha$ emission is interesting. In Figure 5, the region with the brightest H$\alpha$ emission seems to coincide with one of the bright H$\alpha$ filaments. In particular, we find that the filament shows the most extreme difference among the H$\alpha$, [S$\text{ii}$], and [O$\text{iii}$] emissions in the optical; the [O$\text{iii}$] emission is absent, while the [S$\text{ii}$] emission is relatively stronger than H$\alpha$ (see Figure 1 in Bilikova et al. 2007; Vancura et al. 1992). According to shock models in Vancura et al. (1992), the [O$\text{iii}$] emission is generally produced by faster shocks and cannot be produced for shocks with velocities $\leq 80$ km s$^{-1}$. Meanwhile, as the shock velocity decreases, the intensities of [S$\text{ii}$] show an increasing tendency with respect to that of H$\beta$ in the model calculation. In this context, it is likely that relatively slow shocks ($\leq 80$ km s$^{-1}$) have reached the filament and have resulted in these differences in the optical spectra. If so, the faint PAH emission can be explained, because the shocks with $v_i \leq 80$ km s$^{-1}$ cannot produce sufficient UV radiation (Shull & McKee 1979) at the outer layer of the filament, which is necessary to heat the PAH molecules. For the H$\alpha$ emission, however, hydrogen molecules can be collisionally excited by shocks with those velocity ranges and produce a bright emission. For $v_i \gtrsim 25$–30 km s$^{-1}$, the line intensity is sensitive to the preshock density, not to the shock velocity (Burton et al. 1992). Hence, even if the PAHs can survive, they might not generate a detectable emission due to the lack of heating sources, although it is possible to produce a bright H$\alpha$ emission in the same environment. This may also explain the interaction between the IRS spectra of the Galactic SNRs and the molecular clouds, where the H$\alpha$ emission is prominent but the PAH emission is absent (e.g., Hewitt et al. 2009).

The detection of the 3.3 $\mu$m PAH band feature from N49 is surprising in a sense that only small PAHs with $<100$ C-atoms or a size $<6 \mu$m can notably produce the feature (Draine & Li 2007), while small PAHs can easily be destroyed by strong shocks. Even elliptical galaxies showing low PAH 7.7/11.3 $\mu$m ratios (i.e., mainly neutral PAHs) seem to have no significant 3.3 $\mu$m PAH emission due to the lack of small PAHs (Kaneda et al. 2007). Meanwhile, the comparison between our PAH band ratios ($I_{6.2}/I_{7.7}$ and $I_{11.3}/I_{11.1}$) and the numerical studies (Draine & Li 2001; Mori et al. 2011) supports that small PAHs are dominant in N49. In addition, there is no indication of the 15–20 $\mu$m feature in the IRS spectrum by Williams et al. (2007) (see their Figure 9), which is a signature of large PAHs. In the case of N132D, however, the relatively strong 15–20 $\mu$m hump compared with the 6–11.3 $\mu$m PAH features suggests that the large PAHs are dominant, which was interpreted as evidence for the survival of large PAHs behind a fast shock (Tuppe et al. 2006). Thus, the PAH processing in N49 and N132D is likely to differ from each other. This difference in PAH sizes can be explained by the different environments and evolutionary stages of the two SNRs: N49 is a middle-aged SNR (~6600 yr; Park et al. 2003) and is interacting with a nearby molecular cloud with a radiative shock ($v_i \approx 100$ km s$^{-1}$), while N132D is relatively young (~2500 yr; Morse et al. 1996) and still has a fast shock in a less dense environment ($v_i \approx 800$ km s$^{-1}$; Morse et al. 1996). In a dense gas with a moderately low temperature ($\lesssim 3 \times 10^4$ K), PAHs would survive regardless of their size. This is because the nuclear interaction with helium is the dominant process of destruction in that situation, and it does not significantly depend on the size of PAHs (see Figure 5 in Micelotta et al. 2010b). Hence, small PAHs are not preferentially destroyed in N49, which can reasonably explain our detection of the 3.3 $\mu$m PAH feature in the postshock region with the relatively low temperature. This might imply that a wide range of PAH properties can be found in SNRs.

Based on our observations, it might be difficult to understand in detail, for example, what is a dominant heating mechanism for emitting PAH features in the SNR, and whether the PAHs are newly formed or not. Nevertheless, it seems obvious that one of the essential conditions for the survival/(re)formation of PAHs is the existence of a dense ambient medium around an SNR that directly influences the evolution of shocks such as the shock velocity. In addition to this, a sufficient heating source, such as UV radiation, is necessary for survived PAHs to produce an observable PAH emission from an SNR.

5. SUMMARY

We have carried out an IR spectroscopic study on the SNR N49 in the LMC by using the AKARI/IRC NG observations that cover most of the bright eastern regions, including distinct filaments. Since the observations have been performed as a coarse spectral mapping, we are able to make spectral line maps and have compared the distribution of the different emission features. In the AKARI/IRC spectra (2.5–5 $\mu$m), we detect 3.3 $\mu$m PAH band features with several strong hydrogen recombinations lines and moderate H$\alpha$ molecular lines. To our knowledge, this is the first time that the presence of the 3.3 $\mu$m PAH feature related to an SNR has been observed. Our main results are summarized below.

1. The 3.3 $\mu$m PAH feature in the spectra is clearly distinguished from other shocked ionic/molecular lines in terms
of the line width and the intensity variation with position. In the AKARI line maps, the distribution of the 3.3 μm PAH emission shows an overall association with those of the other emissions such as Brα and H2 1–0 O(3), which indicates that the PAH emission originates from the SNR and is associated with both the ionic and molecular emissions. In addition, there are morphological dissimilarities among the line maps in a local scale that reflect the different physical conditions such as shock velocity and preshock density in each region. The morphological characteristics are also clarified and confirmed by comparing them with the archival Spitzer 8 μm, HST Hα, and H2 2.12 μm images obtained at AAT.

2. The overall distribution of the 3.3 μm PAH emission is more similar to that of the H2 emission in a sense that the H2 emission is spatially confined, but the Brα emission is extended over a large area. In addition, the 3.3 μm PAH emission extends beyond the eastern shock boundary with an intensity comparable with those in the inner regions. These indicate that the PAH emission is possibly associated with the interacting molecular cloud, the center of which nearly coincides with the bright PAH emission region. Meanwhile, the peak position of the PAH emission is not matched with that of the H2 emission, but it is rather close to that of the Brα emission. In addition, the PAH emission is relatively faint at the peak of the H2 emission.

3. We find signatures of other PAH features, C–C stretching modes at 6.2 and 7.7 μm, and the C–H out-of-plane bending mode at 11.3 μm in the archival Spitzer/IRS SL spectra (5.2–14.5 μm). We derive the band ratios of PAHs, I6.2/11.3, and I7.7/11.3 from the IRS spectra (I6.2/I11.3 = 0.63 ± 0.31, I7.7/I11.3 = 1.25 ± 0.26), which implies that the PAHs in N49 are dominantly neutral. This is consistent with the theoretical expectation for the shocked PAHs in dense molecular clouds. We also find that the ratios follow the universal linear correlation between the two ratios in the literature. We try to associate the I6.2/I11.3 ratio with the physical quantity G0 √T/n_e by using the empirical relation in Galliano et al. (2008) under the assumption that the shock radiation is the dominant heating mechanism of the PAHs in a very dense clump. In addition, the relatively high I6.2/I7.7 and I13/I11.3 ratios (0.50 ± 0.27 and ~0.36, respectively) indicate the existence of small PAHs according to the numerical studies (Draine & Li 2001; Mori et al. 2011). These results are consistent with the PAH formation by fragmentation from larger carbonaceous grains but not with the preferential destruction of small PAHs in the shocked gas.

4. The morphological features of the PAH emission can be attributed to the different mechanisms of the SNR shocks in terms of the PAH processing. For the PAH emission associated with either the shocked H2 gas or (shocked) ionic gas, or both, the PAHs must exist in dense gas where the shocks have been sufficiently retarded (even terminated) to avoid complete destruction. Depending on the shock velocity and the preshock density, the PAH emission can be associated with either the ionic gas or the molecular gas. Although PAHs can survive a slow shock, a detectable PAH emission may not arise due to the lack of UV radiation in certain conditions. For the PAH emission outside of the SNR, the radiative precursor could be responsible for the excitation. For PAHs to exist and radiate in SNRs, an ambient dense medium and a sufficient heating source around the medium most likely are required.

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