Characterization and Improvement of the Image Quality of the Data Taken with the Infrared Camera (IRC) Mid-Infrared Channels on Board AKARI

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ABSTRACT. Mid-infrared images frequently suffer artifacts and extended point-spread functions (PSFs). We investigate the characteristics of the artifacts and the PSFs in images obtained with the infrared camera (IRC) on board AKARI at four mid-infrared bands of the S7 (7 μm), S11 (11 μm), L15 (15 μm), and L24 (24 μm). Removal of the artifacts significantly improves the reliability of the reference data for flat-fielding at the L15 and L24 bands. A set of models of the IRC PSFs is also constructed from on-orbit data. These PSFs have extended components that come from diffraction and scattering within the detector arrays. We estimate the aperture correction factors for point sources and the surface brightness correction factors for diffuse sources. We conclude that the surface brightness correction factors range from 0.95 to 0.8, taking account of the extended component of the PSFs. To correct for the extended PSF effects for the study of faint structures, we also develop an image reconstruction method, which consists of the deconvolution with the PSF and the convolution with an appropriate Gaussian. The appropriate removal of the artifacts, improved flat-fielding, and image reconstruction with the extended PSFs enable us to investigate detailed structures of extended sources in IRC mid-infrared images.

Online material: color figures

1. INTRODUCTION

Mid-infrared multiband imaging data offer a useful tool to study dusty stellar objects (e.g., Meixner 2008; Ita et al. 2008) as well as the interstellar medium (ISM; e.g., Bernard et al. 2008; Onaka et al. 2010). However, mid-infrared observations frequently suffer from various instrumental effects, such as the anomalies in the detector performance (Pipher et al. 2004), the extended point-spread functions (PSFs) due to the diffraction of light, and artifacts. The corrections for these annoying effects should become crucial, particularly when we are interested in the faint diffuse objects adjacent to bright objects. In this article we report detailed investigations on the qualities of the mid-infrared imaging data taken with the infrared camera on board the Japanese AKARI satellite to evaluate their artifacts and to

Fig. 1.—Example of the MIR-S artifact at S11 for CRL 618 (pointing ID: 4080002.1). The secondary and tertiary artifacts, which come from the primary and secondary artifacts, are also seen. The image is displayed in a logarithmic scale.
offer useful information needed for the advanced data reduction procedures to users of the AKARI mid-infrared data, which are now publicly available from the data archive server.

The infrared satellite AKARI carried out about 5000 pointed observations in addition to the all-sky survey at the mid- to far-infrared bands during its cold phase (until 2008 August 24) (Murakami et al. 2007). The infrared camera (IRC; Onaka et al. 2007) on board AKARI made near- to mid-infrared (2–26 μm) imaging, as well as spectroscopic observations in the pointed observation mode. The IRC has three channels: NIR, MIR-S, and MIR-L, which cover the spectral ranges of 1.8–5.5 μm, 4.6–13.4 μm, and 12.6–26.5 μm, respectively. Each channel has a field of view of about 10′ × 10′ and is equipped with three medium-band filters for imaging observations (see Onaka et al. 2007 for details).

When a bright object comes into the field of view, several artifacts, often termed as “ghosts,” appear in MIR images of

| Observation ID | AOT | Date       | Object       | Note           |
|---------------|-----|------------|--------------|----------------|
| 4080002.1     | IRC03 | 2007 Mar 05 | CRL618       | PSF & SCL     |
| 4080019.1     | IRC03 | 2007 Mar 05 | CRL618       | PSF           |
| 4080007.1     | IRC03 | 2006 Sep 28 | Red Rectangle| PSF & SCL     |
| 4080006.1     | IRC03 | 2006 Sep 28 | Red Rectangle| PSF           |
| 1800623.1     | IRC02 | 2007 May 10 | HIP 28909    | PSF           |
| 5124007.1     | IRC03 | 2006 Jun 24 | KP01T4       | PSF           |
| 5124019.1     | IRC03 | 2006 Aug 03 | KF03T2       | PSF           |
| 1400229.1     | IRC04 | 2007 Feb 06 | CAR 057T0005 | SCL           |
| 1401033.1     | IRC04 | 2007 Apr 06 | CRU 032 S003 | SCL           |
| 5020484.1     | IRC04 | 2006 Apr 29 | NGC6543      | SCL           |
| 1711365.1     | IRC02 | 2007 May 12 | IRAS 22396-4708 | PSF & SCL |
| 4080019.1     | IRC03 | 2007 Mar 05 | CRL618       | SCL           |
| 4080002.1     | IRC03 | 2007 Mar 05 | CRL618       | PSF & SCL     |
| 5124105.1     | IRC03 | 2007 Jul 12 | IRAS F06009-6636 | PSF & flat |
| 5124089.1     | IRC03 | 2007 Jun 19 | IRAS F06009-6636 | PSF & flat |
| 5124090.1     | IRC03 | 2007 Jun 22 | IRAS F06009-6636 | PSF & flat |
| 5124091.1     | IRC03 | 2007 Jun 22 | IRAS F06009-6636 | PSF & flat |
| 5124099.1     | IRC03 | 2007 Jul 4  | IRAS F06009-6636 | PSF & flat |
| 5124092.1     | IRC03 | 2007 Jul 21 | IRAS F06009-6636 | PSF & flat |
| 5124098.1     | IRC03 | 2007 Jul 4  | IRAS F06009-6636 | PSF & flat |
| 5124097.1     | IRC03 | 2007 Jul 1  | IRAS F06009-6636 | PSF & flat |
| 5124100.1     | IRC03 | 2007 Jul 5  | IRAS F06009-6636 | PSF & flat |
| 5124083.1     | IRC03 | 2007 Jun 1  | IRAS F06009-6636 | Flat         |
| 5124081.1     | IRC03 | 2007 Jun 2  | IRAS F06009-6636 | Flat         |
| 5124082.1     | IRC03 | 2007 Jun 2  | IRAS F06009-6636 | Flat         |
| 5124084.1     | IRC03 | 2007 Jun 7  | IRAS F06009-6636 | Flat         |
| 5124085.1     | IRC03 | 2007 Jun 12 | IRAS F06009-6636 | Flat         |
| 5124087.1     | IRC03 | 2007 Jun 13 | IRAS F06009-6636 | Flat         |
| 5124086.1     | IRC03 | 2007 Jun 14 | IRAS F06009-6636 | Flat         |
| 5124088.1     | IRC03 | 2007 Jun 18 | IRAS F06009-6636 | Flat         |
| 5124094.1     | IRC03 | 2007 Jun 26 | IRAS F06009-6636 | Flat         |
| 5124095.1     | IRC03 | 2007 Jun 27 | IRAS F06009-6636 | Flat         |
| 5124093.1     | IRC03 | 2007 Jun 29 | IRAS F06009-6636 | Flat         |
| 5124096.1     | IRC03 | 2007 Jun 30 | IRAS F06009-6636 | Flat         |
| 5124101.1     | IRC03 | 2007 Jul 8  | IRAS F06009-6636 | Flat         |
| 5124102.1     | IRC03 | 2007 Jul 8  | IRAS F06009-6636 | Flat         |
| 5124103.1     | IRC03 | 2007 Jul 9  | IRAS F06009-6636 | Flat         |
| 5124104.1     | IRC03 | 2007 Jul 12 | IRAS F06009-6636 | Flat         |

*a Astronomical Observation Template for the IRC and Far-Infrared Survey observations. See the ASTRO-F Observer's Manual for details of the parameters (http://www.ir.isas.jaxa.jp/AKARI/Observation/).

*b PSF indicates the data that were used to derive the PSF. SCL indicates those used to estimate the scattered light contribution (artifacts). Flat indicates those used to estimate the reference data for flat-fielding at L15 and L24.

See http://www.ir.isas.jaxa.jp/ASTRO-F/Observation/.
S7 (7 μm), S11 (11 μm), L15 (15 μm), and L24 (24 μm) bands due to reflections among the optical elements. The scattering of light internal to the Si:As detector arrays of the AKARI also spreads out the signals from the object over the entire array. This scattering, together with the diffraction, produces very extended components in the PSFs. It is not straightforward to separate artifacts from the PSF unambiguously. In this article, we define artifacts as components that move differently from the real object in the image or those showing very distinct, asymmetric patterns (§ 2.1). In our definition, anomalies of the detector array and the effects of diffraction are included in the PSF. We present high dynamic range (HDR) PSFs, aperture correction factors, and surface brightness correction factors for diffuse sources at S7, S11, L15, and L24 bands (§ 2.2). The obtained HDR PSFs are useful in the process of image reconstruction (see § 3), which enable us to not just carry out an accurate photometry of point sources, but also to get much improved information on the structures and surface brightness of diffuse extended sources. We also obtain the revised reference data for flat-fielding (hereafter, flat data) for L15 and L24 that are free from the effects of the artifacts (see § 2.3).

Among the information obtained in this study, the information commonly used in the process of data reduction (e.g., new flat data set for L15 and L24) is included in the latest update of the imaging toolkit version 20110225. On the other hand, further advanced data reduction procedures, beyond the treatments made with the standard pipeline, may be necessary for the data of relatively faint extended sources and for those affected by artifacts due to an inclusion of bright objects in the field of view. This article aims to provide the information needed in the course of such advanced data reduction procedures to the general users of the AKARI MIR data sets and to demonstrate the method of imaging reconstruction and its

**TABLE 2**

| Object          | S7                  | S11                  |
|-----------------|---------------------|----------------------|
| A-type stara    | 0.0065 ± 0.0008     | 0.016 ± 0.002        |
| K-type starb    | 0.0073 ± 0.0006     | 0.024 ± 0.004        |
| Zodiacal lightc | <0.0027             | 0.023 ± 0.008        |

a HD 28909 (A0 star).  
b KF01T4 (K1.5III star).  
c Calculated from the slit image.

**TABLE 3**

| Artifacts | a (pixels) | b (pixels) |
|-----------|------------|------------|
| A         | 0.364 × (1 ± 0.051) | 0.194 × (1 ± 0.012) |
| B and C   | −1.426 × (1 ± 0.0049) | −1.272 × (1 ± 0.0026) |

a The fit parameters in eq. (1).
application to the AKARI MIR data of M81 to exemplify the usage of information newly given in this article.

2. DETAILED EXAMINATION ON THE IMAGE QUALITIES OF AKARI/IRC DATA

2.1. Artifacts in IRC Images

2.1.1. MIR-S Artifacts

In the MIR-S channel, a pointlike artifact appears with an interval of about 24 pixels from the corresponding real point source in the scan direction (hereafter, defined as the Y-axis), which is attributed to internal reflections in the beam splitter, since it does not split the light perfectly (Fig. 1). We employ archival data of CRL618 and Red Rectangle Nebula of open time programs as a calibration source for the artifact, which are listed in Table 1. The outskirts of the PSF are fairly symmetric about the central source, and the artifact shows a distinct pointlike pattern. Using this characteristic, we derive the artifact patterns at the S7 and S11 bands by subtracting the signals 24 pixels away from the real source in the opposite side from the image as the background. No significant difference is noticed in the spatial pattern of the artifact between the two objects.

Despite the consistency in the spatial pattern of the artifact, the ratio of the intensity of the artifact to that of the original object varies among objects. Since the degree of imperfection varies with wavelength, the intensity of the artifacts can have

![Fig. 4.—PSF and artifacts at L15. The object is located at the center (128 pixels, 128 pixels). The arrows in the right two figures indicate the direction of the relative movement. All images are displayed in a logarithmic scale with the object signal within 7.5 pixel radius normalized as unity. See the electronic edition of the PASP for a color version of this figure.](image)

![Fig. 5.—PSF and artifacts at L24. The layout is the same as in Fig. 4. See the electronic edition of the PASP for a color version of this figure.](image)
We investigate the wavelength dependence of the artifact by using spectroscopic data sets. The IRC has a narrow slit (Ns) for spectroscopy of diffuse emission (Onaka et al. 2007; Ohyama et al. 2007). The dispersion direction is along the Y-axis and the artifact of an emission line appears at a different wavelength. Three data sets of spectroscopic observations of two Galactic H II regions and a planetary nebula are employed to investigate the spectral dependence (see Table 1). We use the lines of [Ar III] 8.99 μm, [S IV] 10.51 μm, and [Ne II] 12.81 μm and the unidentified infrared (UIR) band at 11.3 μm. The relative intensity of the artifact varies with the wavelength of the incident photon from 1% to 4.5% for 9 to 13 μm (see Fig. 2). The tendency of the wavelength dependence is roughly consistent with the wavelength dependence of transmission of the beam splitter (Fig. 5 of Onaka et al. 2007). Because of this characteristic, the intensity of the artifact depends on the spectrum of the object and

| Artifact | Total signal to the object signal | Typical radius (pixels) | Surface brightness per pixel relative to the object signal |
|----------|----------------------------------|-------------------------|--------------------------------------------------------|
|          |                                  |                         | L15                                                    |
| A ....... | 2.5 × 10^-2                     | 100                     | 1 × 10^-6                                             |
| B ....... | 1.8 × 10^-2                     | 30                      | 2 × 10^-6                                             |
| C ....... | 3.0 × 10^-2                     | 150                     | 6 × 10^-7                                             |
|          |                                  |                         | L24                                                    |
| A ....... | 6.8 × 10^-2                     | 100                     | 2.4 × 10^-6                                           |
| B ....... | 4.9 × 10^-2                     | 30                      | 1.8 × 10^-5                                           |
| C ....... | 4.9 × 10^-2                     | 150                     | 1 × 10^-6                                             |

**TABLE 4:** PROPERTIES OF THE ARTIFACTS AT L15 AND L24

Fig. 6.—Example of the individual dithered images with the artifacts of U Ant at L24 (ID: 1710071.1). The central region of field of view (160 × 150 pixels) is shown. The scales are in units of ADU per pixel and all figures are displayed in a logarithmic scale. See the electronic edition of the *PASP* for a color version of this figure.
cannot be estimated straightforwardly. In practice, the estimate of the intensity of this artifact has to be made interactively. Examples of the relative intensity of the artifacts for various objects are given in Table 2. The contributions of the artifacts to the total input signals are measured to be less than 1% at S7 and about 1–3% at S11, the latter of which is consistent with the values obtained from the spectroscopic data.

2.1.2. MIR-L Artifacts

MIR-L images are severely affected by artifacts originating in reflections among the optical elements and the surface of the detector array because of the imperfect AR coating. There are at least three types of artifacts (A, B, and C) overlapped with the extended PSF (§ 4) in MIR-L images (Fig. 3), one relatively compact (artifact B) and the others quite extended (artifacts A and C). The optical path of each artifact is identified by ray-tracing calculations. Their major paths are the reflection between the surface of the detector array and the KRS-5 lenses, whose AR coating is not perfect, particularly at the longer wavelength edge of the spectral range of the MIR-L. Thus, the artifacts appear more strongly at L24 than at L15. The artifact images from a point source are not focused onto a point, but appear as a diffuse pattern. We examine the properties of these artifacts and derive the surface brightnesses and the positions relative to the original object using the on-orbit data listed in Table 1. Artifacts A and C and the PSFs (see § 2.2.1) are very extended, and the subtraction of the background sky needs to be made with high accuracy. There is no appropriate position for the estimate of the background sky in the image, and we use the data taken at a near sky position that do not have bright objects in their field of view as the sky background.

During an pointed observation carried out with AOT IRC02 (Onaka et al. 2007), a dithering operation was carried out to settle the target at three different positions on the detector array.

Fig. 7.—Example of the images of U Ant at L24 after the artifact removal. All figures are displayed in a logarithmic scale. See the electronic edition of the PASP for a color version of this figure.
Fig. 8.—PSFs of AKARI/IRC imaging bands at (a) S7, (b) S11, (c) L15, and (d) L24. All figures are displayed in a logarithmic scale with the total intensity of unity. The contour levels are set as $2^{n+1} \times 10^{-5}$ of the total intensity. See the electronic edition of the PASP for a color version of this figure.
Using these dithered data, the movement of the artifacts is estimated by a least-squares fit for the region, where each component of the artifacts does not overlap with each other. The relative movement of each artifact is assumed to be proportional to the movement of the original object. Thus, the relative movement of the reference position of each artifact \((x_r, y_r)\) from the origin \((x_o, y_o)\) is given by the position of the incident object \((x_i, y_i)\) as

\[
(x_r - x_o, y_r - y_o) = (a(x_i - x_o), b(y_i - y_o)),
\]

where \(a\) and \(b\) are the fitting parameters. We set the origin as the center of the array, \((x_o, y_o) = (128 \text{ pixels}, 128 \text{ pixels})\). The artifact patterns do not change with the position of the object in the field of view, and thus the reference position \((x_r, y_r)\) is defined as a position near the center of the artifact. For real objects and their PSFs in the image, \(a\) and \(b\) should be unity, but these are not for the artifacts. By the difference in the relative movement, the artifacts can be separated from the PSF pattern. The derived fitting parameters are listed in Table 3.

The artifacts on L15 images are too faint to derive reliable position movements, and the fit is made only for L24 images. We assume the same values of \(a\) and \(b\) for L15 as derived for L24, since the positions are determined by internal reflections and the spectral dependence is thought to be negligible. The parameters \(a\) and \(b\) for artifact A are both positive, and thus artifact A moves in the same direction as the real object. Artifacts B and C, on the other hand, move in the opposite direction relative to the real object with the same amount on the image. Taking account of the difference in the movement on the image, we determine the patterns of artifacts A, B, and C and the PSFs at both L15 and L24 (Figs. 4 and 5). The spider patterns and the banding structures from the detectors are included in the PSFs (see § 2.2.1). Because they move with the same amount in the same direction, artifacts B and C cannot be separated uniquely from the relative movement. The relative intensities between these two artifacts, however, vary between L15 and L24 (see Table 4). Each artifact image is shifted and stacked by median average, excluding the maximum value to remove the other artifacts from the output image. Artifact A in the L15 image is very diffuse and fully overlaps with the extended component of the PSF, which makes it difficult to extract. We assume the same pattern at L24 as for the low frequency (>25 pixels) of artifact A at L15. Artifact C is much fainter than artifact A at L24 and we assume the same pattern at L24 as at L15.

The characteristics of artifacts A, B, and C are summarized in Table 4. The total contributions of the artifacts to the input signals are 7.3% and 16.1% at L15 and L24, respectively. The spectral dependence of the intensity of the artifacts relative to the original object cannot be investigated with accuracy because of the lack of sufficient data. We assume fixed relative intensities of the artifacts, as given in Table 4, where the artifact signals are normalized by the signal of the target point source within a radius of 7.5 pixels. Among the MIR-L images we have investigated, the spectral dependence of the relative intensity of the artifacts is less than 15%. Corrections for the artifacts have to be made for each dithered image, since the artifacts move differently from real objects. Figures 6 and 7 show examples of the original images with the artifacts and those of the artifacts removed for the carbon star U Antliae at L24, respectively (pointing ID: 1710071.1; Arimatsu et al. 2011). They show that the artifacts seen in Figure 6 are subtracted almost perfectly after the removal process (Fig. 7), demonstrating the applicability of the artifact patterns at L15 and L24 derived in the present study.

### 2.2. Extended PSFs of IRC Images

#### 2.2.1. Extended PSFs

In general, the PSFs of mid-infrared instruments tend to be extended due to the diffraction and the scattering within the detector arrays (Holo et al. 2004). We determine the PSFs over the entire field of view of the four imaging bands (S7, S11, L15, and L24) by subtracting the artifacts from calibration and science observations of stars. The observations used to determine the PSFs are listed in Table 1. To obtain HDR PSFs, we use targets with a wide range of brightness. We also employ short-exposure and long-exposure images, the latter of which was taken with 28-times-longer exposure time than the former. Images after the artifact subtraction at each dithering position are shifted and combined with an accuracy of 0.1 pixels to produce a brightness map, and we determine the extended component of the PSFs down to \(10^{-6}\) of the total intensity. Figure 8 shows the PSFs, which indicate significant morphological differences among the imaging bands. Especially in the PSFs at S7 and L15, a banding structure along the cross-scan direction (hereafter, defined as the \(X\)-direction) is seen in addition to the structures produced by the

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**TABLE 5**

| IRC band | FWHM (') |
|----------|----------|
| S7       | 2.9      |
| S11      | 3.3      |
| L15      | 4.6      |
| L24      | 6.7      |

**TABLE 6**

| IRC band | \(A^a\) | \(B^a\) | \(C^a\) |
|----------|--------|--------|--------|
| S7       | 0.776  | 0.371  | 0.906  |
| S11      | 0.804  | 0.428  | 0.926  |
| L15      | 1.671  | 0.417  | 0.843  |
| L24      | 1.764  | 0.396  | 0.817  |

\(^a\)The fit parameters in eq. (2).
secondary mirror spiders separated by 120°. A similar banding pattern is seen in Spitzer/IRAC images, which is attributed to light scattering inside the detector (Pipher et al. 2004). The banding shows a strong spectral dependence, and the morphological differences can be attributed partly to the internal reflections in the Si:As detector and/or to diffraction of light. Uniform offsets that appear under high incoming photon conditions (Pipher et al. 2004) are not recognized in the IRC PSF object images when they are compared with the reference sky images (§ 2.1.2).

The full width at half-maximum (FWHM) of the obtained PSFs are listed in Table 5. The obtained values of the FWHM are smaller than the published values (Table 2 of Onaka et al. 2007) at the short-wavelength channels. The present values are consistent with the diffraction-limited performance at 7.3 μm (Kaneda et al. 2007). The published values are derived from a number of stellar images, and the averaging process could increase the FWHM. In other words, they provide “average” FWHM when the standard reduction toolkit is used. On the other hand, the PSFs in the present study are derived from the data that are carefully shifted and stacked. This process requires data with sufficient signal-to-noise ratios. When the present HDR PSF is applied to a standard processed image, the inner parts of the new PSFs need to be adjusted to the individual image, which might be degraded by a less accurate stacking process, while the outer parts provide proper information on the extended component of the PSFs.

2.2.2. Aperture Corrections

The extended component of the PSFs can be characterized quantitatively by the encircled energy. It is also useful for practical applications to calculate the aperture correction factor AF, which is defined as the reciprocal of the encircled energy normalized at a given radius (Reach et al. 2005). We set the reference radius as 7.5 pixels, with which the absolute calibration of the MIR-S and MIR-L data is carried out (Tanabé et al. 2008). This radius corresponds to 17.55″ for the MIR-S and 1 7.88″ for the MIR-L channel, respectively. According to Jarrett, we approximate AF as a function of the radius \( r \) from the center of the object as

\[
AF(r) = A \exp(-r^B) + C, \tag{2}
\]

where \( r \) is in pixels, and \( A, B, \) and \( C \) are the fitting parameters. They are given in Table 6, and \( AF(r) \) is plotted in Figure 9. Figure 9 indicates that equation (2) provides good fits for \( r > 7.5 \) pixels.

The calibration for diffuse emission needs to take account of the fact that a large fraction of the incident photons spread over the detector array. The correction for diffuse emission can be given by equation (2) with \( r \to \infty \). Thus, parameter \( C \) gives the correction factor for diffuse emission (Cohen et al. 2007). As indicated in Table 6, the correction factor has spectral dependence. Scattering within the detector array is known to have strong spectral dependence, peaking in the 5–6 μm region (Pipher et al. 2004). It explains part of the dependence in the MIR-S bands. For the MIR-L bands, diffraction of light is likely to make a significant contribution.

2.3. Revised Flat Frames for MIR-L Images

Diffuse emission images are affected not only by the artifacts and the extended PSF components produced by bright objects in the field of view, but also by those produced by diffuse sky background. Signals of the artifacts produced by the diffuse background in each pixel are small, but the total amount of the signals integrated over the entire array becomes significant. Flat data for mid-infrared instruments are usually produced from the sky background data. Previous flat data for the MIR-L channel are created from a large number of background sky images. Thus, the artifacts at L15 and L24 can affect the derived flat data. In fact, they show strange patterns, which are attributed to the artifact effects. The flat data show a steep decline at the edges of the field of view (Fig. 10a). It is most likely that the decline is produced by the effect of the artifacts, especially artifact A.

To investigate the effects of the artifacts on the flat data, we carried out observations of the MIR-L standard star IRAS F06009-6636 at 25 different positions of a 5 \( \times \) 5 grid separated by \( \sim 2° \) in the field of view of the MIR-L (Table 1) and compare

\[ \text{See http://www.ir.isas.jaxa.jp/ASTRO-F/Observation/} \]
Fig. 10.—(a) Previous flat data of L24. (b) Artifact A predicted from a uniform background. (c) Artifact B and C patterns predicted from a uniform sky. (d) Flat data of L24 corrected for the artifacts. The entire detector array (256 × 256 pixels) is shown. See the electronic edition of the PASP for a color version of this figure.
the variation in the signal with the flat data. The flux of the star is measured with aperture photometry with a radius of 7.5" and is derived for each dithered image. The comparison indicates that the previous flat data overcorrect the flux of a point source at an edge of the field of view by 15%, at most, at L24 (Figs. 11b and 12b). The standard deviation of the flux variation increases from 3.8% (without flat-fielding) to 6.4% if the flat correction is made. These observations were useful to estimate the accuracy of the previous flat-fielding process of MIR-L images, but did not have sufficient spatial information to produce new flat data.

We produce new flat data for L15 and L24 from the previous flat data by correcting for the artifacts derived in § 2.1.2. First, we assume that the sky background is uniform over the entire field of view and integrate the contribution from the signal of each position to obtain the artifact pattern that is produced by the uniform background. Next, the artifact pattern is searched for in the previous flat data and the amplitude of the artifact is estimated. The scaled artifact pattern is then subtracted from the previous flat data. The artifact-subtracted flat data are renormalized at the center position to keep the present absolute calibration valid, since most of the standard stars are observed around the center of the field of view (Tanabé et al. 2008). Finally, we apply the newly derived flat data to the 5 × 5 standard star observations. The results indicate that the accuracy of the flat fielding is significantly improved in the Y-direction (Fig. 11c), but there still remains a shallow decline around the edge in the X-direction (Fig. 11c). There may still be a very diffuse artifact that remains uncorrected. We fit the pattern in the X-direction with a quadratic function of the position and apply it to the flat data to create the final flat data (Fig. 10d). With the final artifact-subtracted and slope-corrected flat data, the standard deviation of the flux variation of the standard star decreases from 3.8% to 2.8% for L24 (see Figs. 11d and 12d).

For the L15 band, a similar trend is seen in the previous flat data. The same procedure is applied as for the L24 band to obtain new flat data after the slope correction in the X-direction.

Fig. 11.—Comparison of the aperture photometry of the same point source (F06009-6636) at 25 different positions at the L24 band. All the plots are made along the X-axis of the image. (a) The photometric data without flat-fielding. (b) Those corrected with the previous flat data. (c) Those corrected with the artifact-subtracted flat data. (d) Those corrected with the artifact-subtracted flat data with the slope correction shown in (c) (see text). The photometry is all carried out with the standard aperture size (7.5 pixels in radius) and the flux is normalized by the average of the fluxes of the data taken at the center position. See the electronic edition of the PASP for a color version of this figure.
The standard deviation of the flux variation of the standard star improves from 3.2% (without flat-fielding) to 1.2% (with the artifact-subtracted flat data with the slope correction) for the L15 band.

3. DATA REDUCTION TECHNIQUES BEYOND THE IMAGING PIPELINE PROCEDURES FOR THE ADVANCED ANALYSES OF DIFFUSE SOURCES

A significant fraction of IRC observations in the cold phase were made with the S7, S11, L15, and L24 bands, which provide us useful information to characterize the emission properties of the interstellar matter (e.g., Onaka et al. 2009, 2010; Sakon et al. 2007). However, the differences in the PSF sizes, as well as in the distinct patterns in a large scale, as shown in Table 5 and Figure 8, hamper us from directly making color analyses among those bands, especially for extended objects such as ISM structures of nearby galaxies. Figure 13 compares the radial profile of the PSF at L24 and that at S11 convolved with a Gaussian to have the same FWHM as the L24 PSF (6.7″, see Table 5). It shows that the radial profile of the adjusted PSF of S11 is different from that of L24, especially at larger radii.
Fig. 14.—Example of the image reconstruction process of the IRC mid-infrared data investigated in the present study (M81: pointing ID 5020062.1 and 5020063.1). (a) Artifact-subtracted image of S11. (b) S11 image reconstructed with eq. (4). (c) Artifact-subtracted image of L24. (d) L24 image reconstructed with eq. (4). (e) L24/S11 color map produced from the L24 image (c) and the S11 image (a) convolved with a simple Gaussian to adjust the FWHM to 6.7″ (line in Fig. 13), and (f) L24/S11 color map produced from the reconstructed images (b) and (d). Arrows indicate bright H II regions and the galactic center of M81, where ringlike artifacts appear in (c) and (e). After the image reconstruction procedure, the ringlike artifacts seen in (c) and (e) disappear in (d) and (f). The line in region A overlaid on (c) and (d) indicates the position of the surface brightness profiles shown in Fig. 15 and the boxes indicate the regions used to estimate the general fluctuation level (see § 3). See the electronic edition of the PASP for a color version of this figure.
Figure 14 shows how the reconstruction procedure described previously improves the image quality taken with the IRC. For example, some discrete H II regions are seen as bright pointlike spots over the relatively faint diffuse emission from the ISM in the M81 in the L24 image in Figure 14c. Due to the extended component of the PSF, especially to the diffraction ring structure of the PSF at L24, the diffuse emission around such bright sources are overlapped by the extended artifacts that come from the bright sources. Figure 15 shows the surface brightness profiles along a certain selected line defined in both images of region A before and after processing the present image reconstruction (see Figs. 14c and 14d, respectively). A typical level of the diffuse emission in region A is about 0.7 M Jy sr\(^{-1}\) if the area that is not affected by bright sources. On the other hand, a bright infrared pointlike source centered at \(\Delta Y = 12.5\) with a flux density of 0.02 Jy at L24, for example, produces the ringlike pattern that makes a false contribution to the surface brightness as bright as 2 M Jy sr\(^{-1}\) in the profile ranges of \(\Delta Y = 7–9\) and \(\Delta Y = 16–18\) (see Fig. 15). In this case, about one-third of all pixels in region A are almost comparably affected by the extended PSF components from the bright sources, which makes it difficult to estimate the emission from the diffuse sources of concern. These artifacts are properly removed by the reconstruction procedure, as shown in Figures 14d and 15, which offers significant improvement in accurate photometry of the surface brightness of diffuse sources located at an even closer region to a point source. After the present image reconstruction, the surface brightness of the diffuse emission can be measured with an accuracy of 0.2 M Jy sr\(^{-1}\) at L24 if there are no sources brighter than 0.1 Jy within 5 pixels from the region in question. We note that the present methods do not take account of the changes in PSF shapes within the field of view. Thus, the accuracy of the present image reconstruction may be slightly degraded for diffuse sources around a point source located in the corner of the field of view. Figures 14e and 14f indicate that the image reconstruction significantly improves the quality of the comparative study of four-band images. As shown in the reconstructed L24/S11 color map (Fig. 14f), the ringlike structures disappear and the contrast of the L24/S11 flux ratio is clearly enhanced compared with the original color map (Fig. 14e).

4. SUMMARY

Mid-infrared images taken with the IRC onboard *AKARI* suffer artifacts and extended PSFs. The artifacts are investigated at four IRC bands, whose contributions to the total input signal are measured to be about less than 1%, 1–3%, 7%, and 16% at S7, S11, L15, and L24, respectively. These artifacts affect the flat-fielding reference data, and new flat data are derived by removing the effects of the artifacts. The PSFs and the aperture correction factors for point and diffuse sources are obtained at S7, S11, L15, and L24. To adjust the spatial resolution at different bands, an image reconstruction method is developed. The
present investigation enables us to carry out the comparative study of four-band mid-infrared images taken with the IRC. The artifacts and extended PSFs of the IRC data have common characteristics inherent in mid-infrared instruments. The present analysis will be useful not only for the analysis of IRC MIR data, but also for the design, ground tests, on-orbit calibration plans, and data analyses of mid-infrared instruments of future facilities. The image reconstruction developed here can also be applied to data taken with other instruments. The MIR-L ghost patterns, the new flat data of L15 and L24, and the HDR PSFs of S7, S11, L15, and L24 are available online. The new flat data are included in the latest version of the imaging toolkit (version 20110225). The validity of the absolute calibration is confirmed with the data of standard stars in the LMC (Tanabé et al. 2008) processed with the latest imaging toolkit with the new flat data.

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