Flux Calibration of the *AKARI* Far-Infrared Surveyor (FIS) Data for Extended Emission Sources

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ABSTRACT

We present the preliminary results of the flux calibration for extended sources observed with the Far-Infrared Surveyor (FIS) onboard the *AKARI* satellite. The circumstellar shells of evolved stars (particularly of AGB and post-AGB stars) retain the fossil record of their mass loss in the form of dust/gas density distributions and these shells have the potential to verify/constrain many theoretical aspects of stellar evolution and mass loss. Hence, it is critical to have an accurate surface brightness and flux calibration. The FIS has four photometric bands between 50–180 μm with two types of Ge:Ga array detectors. The Ge:Ga array is long known to have a slow transient response and FIS has already been characterized for point sources. To calibrate for extended sources, we used a method in which photometry is done in a contour aperture of the 3σ detection threshold above the background to encompass more than the PSF core. We show that the revised slow transient corrections for the short wavelength band have a similar functional form as for the point source corrections, whereas for the long wavelength band two distinct functional forms dependent on the source brightness.

1. INTRODUCTION

Mass loss is one of the processes by which stars liberate material into the surrounding space, and lower-mass evolved stars are expected to play a significant role in enriching the ISM with lighter elements as well as molecules and solid-state species (dust) that are critical to life (e.g., Sedlmayr 1994). Unfortunately, our understanding of the evolution of mass loss ejecta in the circumstellar shells remains qualitative at best, and therefore, observational characterization that contains theoretical models is urgently needed.

Probing of the intrinsically cold (below 100 K) circumstellar envelopes (CSEs) in the far-IR began in the 1980's with the *IRAS* satellite (Neugebauer et al. 1984) showing the existence of the CSEs as a consequence of continuous/continual dusty mass loss (Young et al. 1993). In the 1990's, observations made with *ISO* (Kessler et al. 1996) confirmed that these CSEs were rich in molecules and dust (e.g., Yamamura & de Jong 2000) and their far-IR maps showed internal structures as signatures of mass-loss modulations (e.g., Izumiura et al. 1996). Observations made in other wavelengths also indicated that variations in the rate of mass loss resulted in CSEs with multiple shells and axisymmetric structures (e.g., Ueta et al. 2000). In the early 21st century, the next generation of far-IR satellites, *AKARI* (Murakami et al. 2007), *Spitzer* (Werner et al. 2004), and *Herschel* (Pilbratt et al. 2010), became available with higher spatial resolution and greater sensitivities (e.g., Ueta et al. 2009).

2. OBSERVATIONS AND DATA REDUCTION

AKARI is the first Japanese satellite dedicated to infrared astronomy (Murakami et al. 2007). It was launched on 2006 February 21 (UT), began taking data 2006 April 13 and ran out of liquid-helium 2007 August 26. The post-helium mission continued until power failure in May 2011, and the last command to terminate the satellite was sent on 2011 November 24. The diameter of the telescope is 68.5 cm (Kaneda et al. 2007) and is cooled down to 6 K in a liquid-helium cryostat (Nakagawa et al. 2007) for reducing the thermal emission. The Far-Infrared Surveyor (FIS) is one of the two focal-plane instruments onboard *AKARI* (Kawada et al. 2007). It has four photometric bands between 50–180 μm with two types of Ge:Ga array devices: the Short-Wavelength (SW) and the Long-Wavelength (LW) detector.

MLHES (excavating Mass Loss History in Extended dust shells of Evolved Stars, PI: Yamamura) is one of the pointed-observation mission programs and has the primary goal to map the circumstellar shells of low-mass evolved stars in detail to excavate the ancient history of dusty mass loss. The MLHES data set is the largest collection (144 objects) of one of the most sensitive far-infrared (far-IR) images of the cold extended circumstellar dust shells of evolved stars and it is the key to understanding the dusty mass loss phase of stellar evolution.

Due to the intrinsically faint nature of the extended far-IR cold dust shells, it is critical to have an optimized data reduction method to minimize the measurement uncertainties. This was done by using a new imaging tool kit FAST (FIS-*AKARI* Slow-scan Tools). FAST is a program that allows for interactive assessment of the data quality and on-the-fly corrections

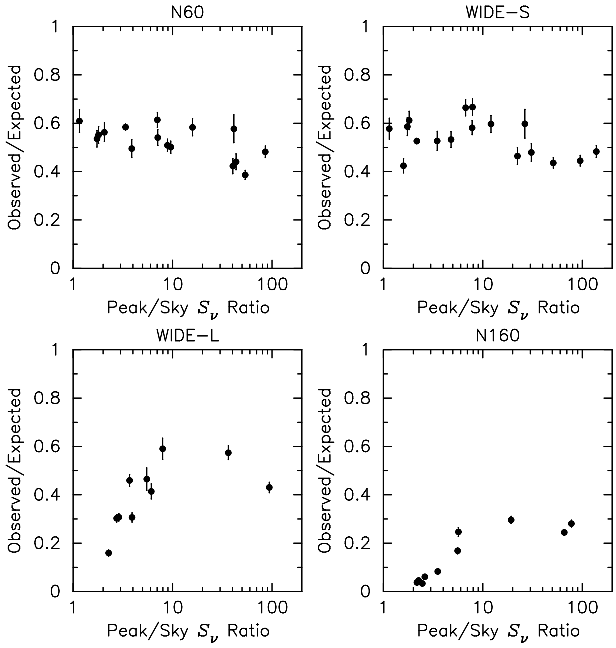

Figure 1. The Observed over Expected flux ratio vs. the Peak/Sky surface brightness ratio shows the effect of the slow transient response from a contour aperture by using a contour aperture to account for extended emission.

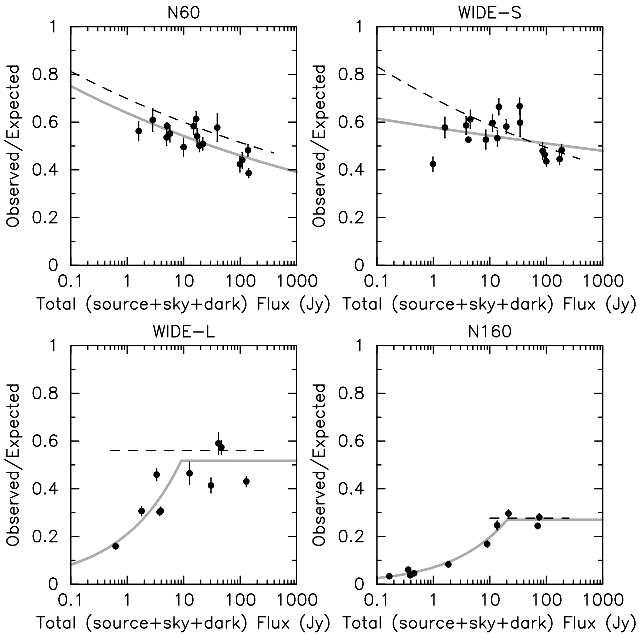

Figure 2. The Observed over Expected flux ratio vs. the Total (Observed plus sky and dark) flux plot. The dashed lines represent the fit determined from Shirahata et al. (2009) and the gray is the fit for extended emission.

to the time-series data on a pixel-by-pixel bases in order to manually correct glitches that would have been missed in the pipeline process.

3. PHOTOMETRIC FLUX CALIBRATION

FIS uses Ge:Ga detectors, which are known to show a slow transient response at low temperature under low background flux conditions, which typically happen in the space environment (Kaneda et al. 2002, and references therein). The slow transient response is a time-delay in the detector response which is caused by quick changes of the incoming flux. The time constant of the slow response is typically 10–100 sec, and depends on both the background and the signal photon fluxes. It is known that the slow transient response is different for point sources and extended sources (Kawada et al. 2007).

Table 1. Preliminary correction functions for SW and LW arrays

SW Band	0 Jy < $(TF) \lesssim$ 400 Jy	LW Band	$(TF) \lesssim$ boundary	boundary $\lesssim (TF)$
N60	$R = 0.638 \times (TF)^{-0.071}$	WIDE-L	$R = 0.210 \times (TF)^{0.409}$	$R = 0.517$
WIDE-S	$R = 0.578 \times (TF)^{-0.027}$	N160	$R = 0.071 \times (TF)^{0.446}$	$R = 0.269$

However it has only been quantified for point sources (Shirahata et al. 2009). For the method described by Shirahata et al. (2009), the point-source fluxes are measured only from the PSF core of the photometric calibration sources (solar system objects and stars) and the flux from the PSF wing is recovered by using an aperture correction scaling factor. Then the slow transient response correction was determined by comparing the ratio between the observed and expected fluxes and the total observed flux. This correction method, by design, works only on point sources because it assumes a specific surface brightness profile (i.e., a Gaussian PSF).

For extended sources, however, the total observed flux is not necessarily a good representation of the transient effect (i.e., a region of strong surface brightnesses may be extended). Thus, to accurately verify the extent of the slow transient response, we elected to use the peak to sky surface brightness ratio instead. Figure 1 shows the relation between the observed-to-expected source flux ratio and the peak-to-sky surface brightness ratio. Note that in our method, a contour aperture with a threshold of 3σ above the background was used to encompass more than the PSF core of the calibration point sources.

This figure suggests that (1) in the N60 and WIDE-S bands, observed fluxes are always underestimated (at about 50–60 %) irrespective of the degree of the slow transient response effect and (2) in the WIDE-L and N160 bands, observed fluxes are always underestimated (at about 50–60 %) for sources with the bright peak (peak/sky $\gtrsim$4 or 5) and the degree of underestimate of the observed flux is dependent on the peak/sky of the peak for faint sources (peak/sky $\lesssim$4 or 5), respectively. When the peak is bright enough the entire PSF (core and wing) is detected by the detector. However, for less sensitive detectors in the WIDE-L and N160 bands, if the peak is not bright, then part of the PSF (most likely wing) may not be detected by the detector (and a larger correction factor is necessary).

To see how this manifests itself in the relationship between the observed/expected flux ratio (R) and the observed total flux (TF; observed plus sky and dark), because we need the correction factor as a function of the measured total flux, flux: Figure 2 displays the relation between R and TF. The dashed lines represent the slow transient correction functions for point sources determined by Shirahata et al. (2009) while the gray lines represent the correction functions for extended sources, resulted from the present analysis.. This figure also indicates that less sensitive WIDE-L and N160 bands are likely to fail to capture emission from the source when a source is not bright enough. This effect for the contour photometry was not properly accounted for in the analysis done by Shirahata et al. (2009). Hence, faint object fluxes will be underestimated if the Shirahata correction method is used in the contour photometry.

We determine that this surface brightness/flux oversight happens for objects with peak/sky $\lesssim$4 or TF $\lesssim$ 9 Jy for the WIDE-L band and peak/sky $\lesssim$ 5 or TF $\lesssim$ 13 Jy for the N160 band. Based on our analysis, we propose to use the following flux correction scheme for extended photometry measurements as shown in Table 1. For the SW band, we suggest the power-law relations (negative exponents) between the total measured flux to the correction factor, while for the LW band we propose two methods, power-law relations (positive exponents) for dim objects and constant factors for bright sources.

RT would like to thank the East Asian and Pacific Summer Institute (EAPSI) fellowship program and NSF/JSPS for the opportunity to conduct part of this research at ISAS/JAXA, and *AKARI* team for allowing a fruitful international collaboration, the SPICA 2013 conference for letting us present our work and the LOC for providing travel funding. This research is based on observations with AKARI, a JAXA project with the participation of ESA.

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