MIPS In-Orbit Checkout Flux Calibration Implementation Plan

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Abstract

This document describes the way in which stars were selected to support the flux calibration of the MIPS (Multiband Imaging Photometer for SIRTF) instrument during IOC (In Orbit Checkout). The various tests the observations were designed to support are discussed. The procedure for predicting fluxes in the MIPS bands is also described.

1 Purpose and Scope

This document is targeted at the MIPS IT (Instrument Team) and IST (Instrument Support Team). It describes the implementation of the flux calibration plan outlined in the MIPS SDD (System Description Document) and is intended to be used as a description of the existing flux calibration plan and as a guide to altering that plan if (when) it becomes necessary.

This document only covers the period during the IOC and SV (Science Verification) phases, approximately the first 3 months of the SIRTF mission. The calibration of MIPS during the nominal mission is described in the Calibration Implementation Plan written by Jeonghee Rho at the SSC (SIRTF Science Center).

The rules for selection of suitable standards are not discussed here, as they are described in the MIPS SDD and discussed in detail in the SSC's Calibration Implementation Plan.

2 Overview

The main function of the MIPS flux calibration activities is to provide a flux calibration (i.e., the conversion from instrumental units to some physical unit such as Jy) for each MIPS campaign. The per-campaign calibration provides a conversion factor for the science data obtained during that campaign. In addition, the calibration data provide a means of monitoring the long-term properties of the instrument.

During IOC/SV, the calibration data also provide a means of testing other properties of the instrument. These include, but are not limited to, effects on the calibration due to:

- calibrator suitability
- time on various scales
- calibrator spectral type
- source flux density (linearity)
- background level
- integration time
- internal cross-calibration between modes and bands
- cross-calibration between instruments

The calibration data obtained during the life of the instrument will refine these measurements, of course, but the basic properties of the instrument will be ascertained during IOC/SV.

3 Implementation

We will now discuss in more detail how each of the goals listed above will be achieved during IOC/SV. Each time a flux calibrator is measured, it is done in a standard way. All the standards are measured in photometry mode (except during the internal cross-calibration, of course — see § 3.8). The number of cycles used is 2, 3, and 2 (superresolution) at 24, 70, and 160μm, resulting in 30, 30, and 12 images per band, respectively. The integration time is generally 3 seconds, unless the predicted flux is low enough to be less than 1/4 full well in 10s, in which case 10s DCEs are used. The tests described in this section use this standard photometry-mode measurement unless otherwise indicated.

3.1 Campaign Flux Calibration

To ensure that each campaign's data can be calibrated, each campaign should have at least one flux calibrator for each band in which data will be taken in that campaign. This activity starts in campaign D1 at 24μm with the MIPS first light observations. That campaign and all which follow have at least one 24μm calibrator. Similarly, the 70μm and 160μm calibrations begin in campaigns G and H, respectively, and each campaign starting with those has at least one calibrator at 70μm and 160μm.

3.2 Calibrator Suitability

An important goal of the IOC/SV calibration program is to screen the flux calibrators for potential problems. This task is performed explicitly in MIPS-400, but screening should of course be applied to all the calibrators observed during IOC. Some problems will be evident upon inspection of the individual calibrator observations, such as flux that is too high or low, background sources, or spatially-variable background. Other problems will only become evident following inspection of the ensemble of observations. For example, in a plot of counts vs. predicted flux, the stars with disks will lie above the curve defined by most of the observations. Such stars should be flagged and not used for future calibration observations.

3.3 Time-dependent Effects on Calibration

We will measure the calibration repeatability on 4 timescales. The shortest time interval will be 3.5 MIPS seconds, which is obtained with most of the calibrator observations as the interval between DCEs. The repeatability from DCE to DCE will be measured at 24 and 70μm, but is probably too difficult to measure at 160μm. Because the source moves on the array from DCE to DCE, these measurements are subject to flat-field uncertainties and so must be interpreted with caution.

We will measure the repeatability on several-minute timescales at 24μm by rapidly repeating the flux standard measurement, alternating the star measurements with stimulator measurements. This is done in task MIPS-120, which also calibrates the 24μm stimulator in the process. The repeatability of the Ge:Ga calibrators on this timescale is not measured in the current plan, largely because it was not felt to be necessary for any of the arrays (i.e., even the 24μm measurement is simply taking advantage of the stimulator calibration to also measure repeatability).

We will measure the repeatability on several-hour timescales in a few campaigns. The primary measurement is 5 repeats of the 24μm routine calibration, MIPS-920, spread throughout campaign H. The Ge:Ga repeatability on this timescale is less well measured. The current plan contains some campaigns (K, O, P, Q, and R) with 2 repeats each of the Ge:Ga calibrators (which happens either because the routine calibrations, MIPS 922 and 924, are scheduled multiple times in those campaigns, or because MIPS 922 and 924 are scheduled in the same campaigns as MIPS 350, 351, and 352, which also contain the routine calibration targets). I would still like to see the Ge:Ga repeatability measured like the Si:As repeatability, i.e., 5 repeats of MIPS-922 and MIPS-924 spread throughout a campaign. The fact that it is not seems to be an oversight which ought to be corrected if a replanning opportunity presents itself.

We will also measure the repeatability on campaign timescales. The routine calibrators (MIPS-920, 922, and 924, or at the very least the *targets* contained in those tasks) are observed every campaign after the first-light tasks for each array, or soon thereafter. Thus, each band has a single, primary calibrator that is observed throughout IOC and SV. (The 70μm band is an exception to this rule: the original standard, HD050310, was determined to have a poor flux prediction and a poor sky location. Starting in campaign O, this star was replaced by HD163588. The two targets overlap in campaigns G, O, and P, facilitating a comparison of the two.) The 24μm calibrator (and the 70μm calibrator, starting in campaign O) is in the CVZ (Constant Viewing Zone) and can thus be observed throughout the mission if it proves to be suitable. There are fewer Ge:Ga standards available, unfortunately, so non-CVZ stars with large visibility windows were chosen. This does mean, though, that the primary Ge:Ga calibration (160μm only, if the 70μm routine calibrator proves to be a good standard) will have to switch to new targets for part of each year.

3.4 Calibrator Spectral Type Effects on Calibration

We will be using 3 broad spectral types for calibration, each subject to different uncertainties (cf. § 5). We will compare the calibrations obtained with the 3 calibrator types to search for systematic differences. This is done explicitly in the 3 "Flux Calibration" tasks, MIPS 350, 351, and 352. Each of these tasks is designed to highlight one of the 3 types of calibrator: A stars, K giants, and solar analogs (G stars). This is difficult to do at 70 and 160μm, where the A and G stars are typically faint, so the current implementation does not include many A and G stars for the Ge:Ga arrays. Any replan should attempt to include such stars, however, if visibility windows permit.

The flux linearity tasks MIPS-315 and MIPS-400 include a large number of stars of different spectral types and can also be used to compare the calibrations as a function of spectral type.

3.5 Source Flux Density Effects on Calibration (Linearity)

There are sufficient calibrator observations during IOC/SV that we can begin to measure the flux linearity curve for the arrays, i.e., the curve that defines the conversion from counts to Jy. The measurements at 24μm are expected to be linearized by the electronic linearity correction in the pipeline and are not expected to depend on background, so the pipeline-processed Si:As data are expected to follow a linear relation between predicted flux and measured counts. The Ge:Ga arrays, however, are expected to show departures from linearity that may be background-dependent. To keep the IOC/SV measurement of this effect tractable, the current implementation limits the measurement to low-background sources. Flux linearity curves at higher backgrounds will have to be defined gradually throughout the first year, as stars at different backgrounds become visible. This requirement is captured in the SSC's Long-Term Calibration Plan.

The tasks designed to measure linearity are MIPS-315 and MIPS-400, but all the calibrator data taken during IOC/SV can be added to the linearity measurement to improve the S/N somewhat.

3.6 Sky Background Effects on Calibration

Background levels are expected to have little effect on the Si:As calibration, but laboratory tests have indicated that the Ge:Ga calibration is affected by background level. Thus, the 24μm observations of stars against different background are viewed mainly as a check, while the Ge:Ga data are more extensive and will be used to characterize the effect. The tasks used to check for background effects are MIPS-921 and MIPS-315. The early (campaign E) version of MIPS-315 only checks 24μm standards, while the later (campaign R) version includes only Ge:Ga standards.

3.7 Integration Time Effects on Calibration

MIPS flux calibration is not expected to depend on integration time, unless there is some ramp nonlinearity we have not yet accounted for, so comparing observations of calibrators at different integration times is viewed mainly as a check. To save time, most of our calibrators are observed using 3s DCEs. 10s DCEs are only used for fainter standards, most of which can be found in MIPS-400. The logic describing when 10s DCEs are used is found in the MIPS-400 cookbook. Note that there are no explicit calibrator observations using 30s DCEs. However, all the various integration time are tested in the AOT validation tasks (MIPS 320-325), so those data will readily support this test as well, with the advantage that the *same* targets are viewed in all the available integration times. Furthermore, the targets for the AOT validation tasks are also calibrators and can be used to support the other tests discussed in this document.

3.8 Internal Cross-Calibration Between Modes and Bands

The MIPS calibrators are always measured in photometry mode because it is the most efficient way to collect the data. We assume that the calibration will be the same for the other modes which use the wide-field imaging mode, i.e. scan map and total power. This assumption is tested explicitly in MIPS-150, "Observing Mode Relative Throughputs."

The remaining modes, 70μm fine scale and SED (Spectral Energy Distribution), must be calibrated independently because different filters are used and because, in the case of SED, there are slit losses. No data that require flux calibration are taken in these modes until late in SV, so flux calibration of these modes is not performed until campaigns R, V, and W. No separate task exists to calibrate these modes, so we have co-opted the routine 70μm flux calibration task, MIPS-922, to perform this calibration in campaigns R, V, and W by observing the wide-field calibration target in fine-scale and SED modes, too. This requirement is captured in the MIPS-922 cookbook and is reflected in the submitted AORs.

Some attempt has been made to observe several stars in more than one band. This serves two purposes. First, it aids in the relative calibration of the bands by removing one source of uncertainty in the comparison between calibrations of the different bands. For those stars observed in more than one band, the same model can be used to calibrate multiple bands. Second, it aids in the screening process. For example, dust disks that are subtle at 24μm should be bright at 70μm, and a star that is only marginally bad as a calibrator, but is seen to be so in multiple bands can be flagged as bad even when a single band's observation is not enough to condemn the target as bad. The "Flux Calibration" tasks (MIPS 350-352) and the linearity tasks (MIPS 315 and 400) contain stars observed in multiple bands.

3.9 Cross-Calibration Between Instruments

As a further check on our own calibration, we will be observing several sources in common with IRS (InfraRed Spectrograph) at 24μm, where MIPS overlaps with IRS in wavelength. This will be done with both blue and red sources. The blue sources will be stars; through coordination with the SSC's Calibration Working Group and the IRS team, approximately 10 stars will be observed in common between MIPS and IRS. These stars are not found in a specific task, but instead are sprinkled throughout the IOC/SV observing program. A single red source will also be observed in common; this will be the galaxy Mrk 279, found in MIPS-353.

The instrument cross-calibration is the responsibility of the Calibration Working Group, so the MIPS work in this area will consist mainly of reducing the data and reporting the fluxes.

4 Campaign Summary

We now summarize the calibration activities in a chronological fashion on a per-campaign basis. Some calibrators are observed in various tasks but are not part of the formal calibration program; this is indicated in the individual campaign entries.

- D1: The flux calibration activities begin in this campaign with the first-light observations (MIPS-100).
- D2: Flux standards are observed in MIPS-920. Also, the targets in the AOT/PSF tests in MIPS 320 and 121 are calibrators.
- E: Flux standards are observed in MIPS-120. Also, the targets in the AOT/PSF tests in MIPS 315 and 121 are calibrators.
- F: Flux standards are observed in MIPS-920. Also, the targets in the FPS/PSF tests in MIPS 130 and 121 are calibrators.
- G: This campaign marks the 70μm first light. Flux standards are observed in MIPS 920 and 922. Also, the targets in the FPS/AOT tests in MIPS 322, 965, 966, and 130 are calibrators.

- H: This campaign marks the 160μm first light. Flux standards are observed in MIPS 920 and 921, while the AOT test also MIPS-324 also uses a calibrator as a target.

- I: This is a routine campaign, calibration-wise. Flux standards are observed in MIPS 920, 922, and 924.

- J: This is a routine campaign, calibration-wise. Flux calibrators are observed in MIPS 920, 922, and 924.

- K: The routine calibrators are observed twice in this campaign, once in MIPS 920, 922, and 924, then again in MIPS-350 (which observes other stars, too). This campaign marks the end of IOC for MIPS.

- O: Routine flux calibration is achieved through MIPS-351, 920, 922, and 924. Other calibrators are observed multiple times during AOT tests in MIPS 355 and 321.

- P: Routine flux calibration is achieved through MIPS 352, 922, and 924. Other calibrators are observed during AOT tests in MIPS-323.

- Q: Routine flux calibration is achieved through MIPS 920, 922, and 924. This campaign also contains the relative throughput test, MIPS-150.

- R: Routine flux calibration is achieved through MIPS 920, 922, and 924, and a calibrator is observed during the AOT test MIPS-325. Many calibrators are observed in MIPS-315. This campaign marks the transition that adds fine-scale and SED observations to MIPS-922.

- V: Routine flux calibration is achieved through MIPS 920, 922, and 924.

- W: Routine flux calibration is achieved through MIPS 920, 922, and 924, and a calibrator is observed during the PSF test MIPS-337. Many calibrators are observed in MIPS-400.

5 Flux Prediction

As described in the MIPS SDD, 3 types of calibrator stars will be used to calibrate MIPS, under the assumption that the systematic uncertainties will be different for each. In summary, the spectral types we will observe and the methods used to predict their fluxes are:

- A stars extrapolated using Kurucz models

- G stars use direct transfer of solar spectrum

- K stars use templates from Cohen et al., extrapolated using the Engelke function

Table 1: Photometry Zero Points

source	wavelength (μm)	zero point (Jy)	reference reference
2MASS	1.235	1621	[Cohen et al. (2003)]
2MASS	1.681	1041	[Cohen et al. (2003)]
2MASS	2.157	678.1	[Cohen et al. (2003)]
IRAS FSC	12	0.987*	[Cohen et al. (1999)]
IRAS FSC	25	0.941*	[Cohen et al. (1999)]

*The color-corrected data are multiplied by this factor.
N.B.: All zero points in this table have been multiplied by a factor of 1.017 to agree with the adopted 10.6μm zero point, as described in the text.

The data used to normalize the stellar models/spectrum/templates (hereafter referred to generically as "spectra") include optical (preferably Tycho) through NIR (preferably 2MASS) groundbased photometry, and "good" quality IRAS 12 and 25μm data, with less weight given to the optical data. The zero-points used for these measurements are shown in Table 1. The Cohen et al. system does not use all the best measurements at 10.6μm, and thus we will revise their calibration upward by 1.7% (i.e., the adopted 10.6μm flux for Vega is 34.95 Jy, while Cohen et al.'s system sets Vega to 34.375) — see the MIPS SDD for details. Care must be taken to ensure that the photometry used is on a consistent system — since published correction factors exist to put these measurements on the system used by Cohen et al., the easiest procedure may be to use those calibrations and then apply a global correction to all the data to match the 10.6μm zero point. That is the approach adopted here.

MIPS will be calibrated using a 10,000 K blackbody as a reference spectrum to determine color corrections. The corrections required for spectral types less than 10,000 K are small, and so we can ignore them for IOC/SV and compute fluxes at the monochromatic average wavelengths for each filter, which we have calculated to be 23.675, 71.422, and 155.894μm using the definition in W. Reach's "SIRTF Units and Conventions" memo dated June 28, 2002.

Example 1: The star HD50310 has a Cohen et al. composite spectrum ([Cohen et al. (1999)]). Since this template is already calibrated, we need merely multiply the template by the 1.7% factor discussed above to put in on our flux scale. The spectrum ends at 35μm, so we extrapolate it to longer wavelengths using the Engelke ([Engelke (1992)]) function[1]. The effective temperature of the star is taken from [Lang (1992)]. The flux at the average wavelengths discussed above is taken from the Engelke model.

[1] N.B. The second equation in §2.3 of this paper is wrong, so we use the first equation in that section to generate the model.

Example 2: The star HD159330 is a late-type giant star of a type covered by a Cohen et al. composite spectrum, but no composite exists for this particular star. Any composite of matching spectral type can simply be scaled to the available photometry. For this star, for example, 2MASS and IRAS data exist and an average of the ratios (weighted by the uncertainty of the measurements) of the composite to the observations is used to scale the template. The Engelke function is then used as in Example 1 to extrapolate the spectrum and provide the fluxes in the MIPS bandpasses.

Example 3: HD28471 is a G dwarf, similar to the sun. Groundbased photometry (this star is too faint for IRAS) is used as in Example 2 to scale a template, this time the solar template by [Tobiska et al. (2000)]. No extrapolation is necessary, since the solar template extends well beyond the MIPS wavelength range.

Example 4: HD43107 is a late B dwarf, similar to an A0V for which we think we have good models. Groundbased photometry (this star is too faint for IRAS) is used as in Example 2 to scale a template, this time a Kurucz model. No extrapolation is necessary, since the Kurucz model extends to the MIPS wavelength range. Since K. Su and collaborators have already developed the code to produce such fits to support the MIPS science program, I have not developed an independent means of predicting fluxes for such stars. I rely on K. Su for flux predictions for these stars, which I then multiply by the 1.017 factor to put them on the same scale as the other standards.

References

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