PROCESSING OF AMICA AND NIRS OBSERVATIONS OF ASTEROID ITOKAWA FROM THE HAYABUSA MISSION.
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Introduction: The goal of this work is to restore data from the Hayabusa spacecraft that is currently available in the Planetary Data System (PDS) Small Bodies Node. The archived Itokawa AMICA (Asteroid Multi-Band Imaging Camera) images are not radiometrically calibrated and photometrically corrected (corrected from the effect of varying viewing geometry). Therefore, this PDS dataset is not directly usable for analysis of the reflectance of Itokawa's surface. For processing images from AMICA and spectra from the NIRS (Near-InfraRed Spectrometer) instrument we used the Integrated Software for Imagers and Spectrometers (ISIS) system version 3. Our main objective is to process the AMICA mutliband and NIRS (point spectrometer) data to create global mosaics, perform photometric modeling on the calibrated data, apply photometric corrections, and extract mineralogical parameters. The end results of this effort will be the creation of pyroxene chemistry and olivine/pyroxene ratio maps of Itokawa using combined NIRS and AMICA map products. All the products/maps from this work will be archived in the PDS. All newly implemented ISIS3 applications and map projections from this work will be distributed via ISIS3 public releases.

AMICA images: The processing of clear and color images starts with the ingestion of the images in ISIS3 using the application *amica2isis* and the attachments of the right SPICE kernels using *spiceinit* to get geometric, pointing and trajectory information. Then, the AMICA start time needs to be updated due to a discrepancy between the start times in the label of the PDS label and the start times retrieved by StereoPhotoClinometry (SPC) modeling and stored in resulting SUMFILEs. The AMICA start times were known to have a 12 second uncertainty where some have been corrected by Gaskell and retained in the SUMFILEs.

S/C trajectory and AMICA pointing: We implemented a new ISIS3 application called *sumspice* that can update s/c trajectory and pointing information. This application was developed to apply ephemeris pointing and spacecraft position data to individual images using SUMFILEs, a byproduct of digital elevation modeling (DEM) processes. It has been designed to also apply timing corrections contained within the SUMFILEs to image observation start times. We discovered this discrepancy when evaluating geometric alignment with the Itokawa DEM. This issue was resolved with additional functionality added to *sumspice* to apply the start times in the Gaskell SUMFILEs to each image and is a selectable user option in the application. Testing of this application as applied to AMICA images of Itokawa shows very good alignment after application of timing, pointing and spacecraft position updates. It did, however, reveal a very slight scale difference. This has been tracked to the AMICA camera distortion model. The model as documented in the instrument manuscript was initially added to the ISIS camera model. It appears there was no distortion model applied during SPC modeling work. Therefore, we have removed the distortion parameter from the ISIS AMICA camera model.

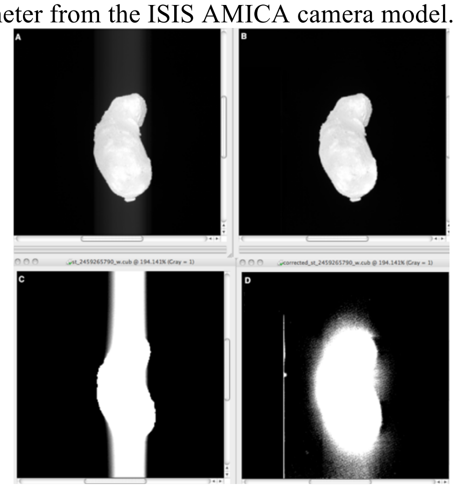

Figure 1: Image A shows the raw unprocessed image. Image B is the calibrated image. To demonstrate the smear removal aspect of the calibration, Image C shows a hard stretch of the raw image that highlights the smear component of the data. Image D is calibrated.

For the processing itself, we first ran *sumspice* to modify the start time then *spiceinit* needs to be reran to update the target body position and orientation. Finally, *sumspice* is applied again but with different parameters in order to update the pointing and trajectory information for each image. The *sumspice* application has been completed and distributed to the community in the ISIS 3.4.12 release. Alternatively, if smithed CK and SPK kernels with more precise ephemeris were built from the updated images, rerunning *spiceinit* after the first run of sumspice would have the same result. We can also provide the adjusted start times in the new AMICA labels of the raw image in the PDS archive.

Basic calibration. Radiometric calibration is processed using the application *amicacal.* The most noticeable effect of the calibration is smear correction as demonstrated by the hard stretch shown in Fig. 1. Calibration steps based on [1] include multiplication by 16 for lossy data, substraction of the bias, linearity correction, removal of hot pixels, read out smear removal (smear correction was processed correctly onboard until Oct. 2005), division by exposure time. It also has an option to remove the pixels corresponding to the polarizing filters on the left side of the image. In addition, *amicacal* can be applied to subframes and binned images.

Conversion to radiance and reflectance. The v band images can be converted from DN to radiance using the conversion factor given in table 9 in [1]. For the ul, b, w, x, p filters, the scale factors in the same paper are used to convert from DN to normalized reflectance. We calibrated the filter zs by deriving a scale factor using Itokawa spectrum from [2]. However, the phase angle is different between the color calibration set used in [1] and this ground-based spectrum. We can compare to NIRS spectra acquired at the same time with similar phase angle (Fig. 2). Unlike the AMICA images we used, NIRS footprints do not cover the full disk of Itokawa, which could account for the differences.

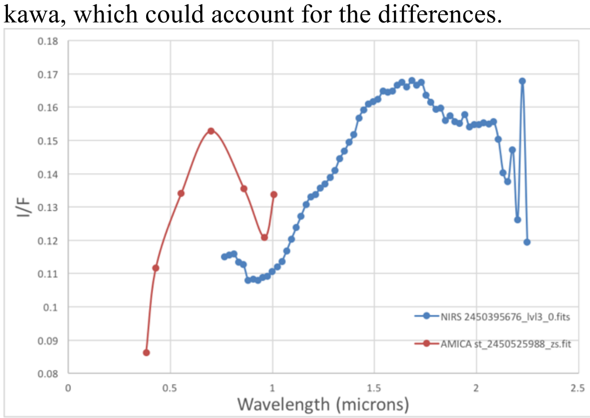

Figure 2: Comparison of AMICA reflectance data averaged on Itokawa full disk with a NIRS average spectrum taken at the same date.

Point Spread function (PSF) and scattered light. The last version of the PSF published by [3] includes correction for the effect of scattered light. This effect can add 10% level in error and the PSF is affecting mostly the longer wavelength filters such as p (Fig. 3) and zs.

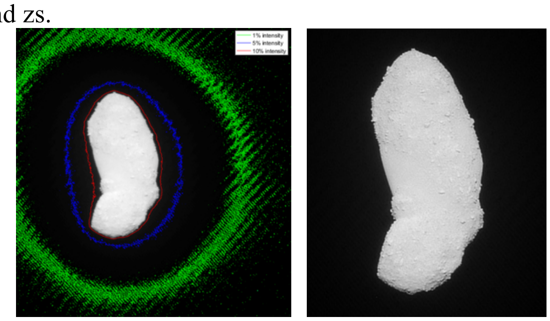

Figure 3: (Left) Original image after basic calibration showing the level of brightness in the sky background due to scattered light. (Right) Image after scattered light removal and sharpening.

The Hayabusa team used the color data for six of the filters for scientific analysis after correcting for the scattered light. We are currently testing how to correct for scattered light with deconvolution and comparing with methods from [3]. Image sharpness can be improved significantly using the narrow PSF with Richardson-Lucy algorithm as done in [1]. If scattered light correction is implemented, scale factors for conversion from DNs to radiance would need to be recalculated.

Mosaics. Images are reprojected using *cam2map* and are assembled together to create global or local mosaics (Fig. 4) with the application *automos*.

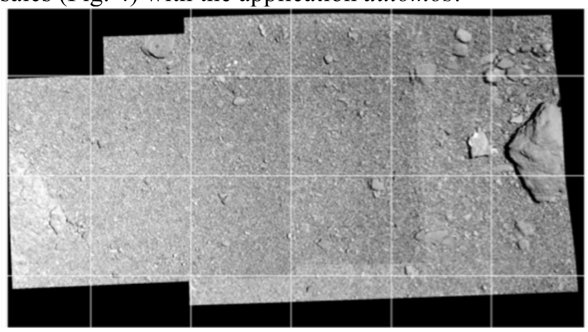

Figure 4: Projected images using *cam2map* (including orthorectification with the DSK). The mosaic is an equirectangular projection at 5.3 cm/pixel, some of the highest resolution images in this dataset.

NIRS spectra: We developed a new application in ISIS3, *nirs2isis* to import NIRS data from the PDS. *nirs2isis* translates parameters from the PDS label, computes the wavelengths in microns and reorders the channels by increasing wavelength. We also added the NIRS camera model in ISIS in order to be able to reproject the data with *pixel2map* using the full field-of-view (FOV) for the entire exposure time. The FOV is derived from a user specified number of instantateous FOVs (IFOV) that are computed at evenly spaced time increments of the pixel exposure duration. After building NIRS mosaics of Itokawa, we will correct to standard geometry and extract the band parameters for all the NIRS data using the new mineral calibration developed in [4].

New projection:. The difficulty for an object with irregular shape such as Itokawa is the presentation of the data on maps with geographic projections. Some projections are better suited to minimize distortion but it cannot be completely eliminated with any standard projection. A new projection is being added to the ISIS3 system that is specifically designed to work well with small oblate bodies. It is well suited for small bodies that rotate about one of the short axes. The Upturned Ellipsoid Transverse Azimuthal projection have been developed and is in the final stages of testing.

References: [1] Ishiguro et al. (2010) *Icarus, 207,* 714–731. [2] Binzel et al. (2001) *Meteoritics & Planet. Sci., 36,* 1167–1172. [3] Ishiguro et al. (2014), *Publications of the Astron. Soc. of Japan*, 66, 3. [4] Bhatt et al. (2015), *Icarus*, 262,124-130.

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