Description of the Deep Impact MRI Photometry of Comet 9P/Tempel 1

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I. Introduction

Photometric measurements of comet 9P/Tempel 1 were performed on images taken with the Medium Resolution CCD Instrument during the approach phase of the Deep Impact mission, from 1 May 2005 to approximately 6 hours before impact on 4 July 2005. A total of 3014 images were analyzed: 595 science images and 2419 optical navigation images. These data are based on circular apertures ranging from 5 to 30 pixels in diameter. Results of this analysis will permit a more detailed analysis of the rotation state of the comet and facilitate the search for cometary outburst events.

II. Instruments

The images used in this analysis were taken with the Medium Resolution Instrument on the Deep Impact flyby spacecraft. The MRI is a Cassegrain telescope with a 12 cm aperture and a 2.1 m focal length. The clear filters have a center wavelength of 650 nm; they are uncoated and not band limited (Hampton et al., 2005).

III. Data

The data on which measurements were performed consist of science images taken with the clear 1 and clear 6 filters and of optical navigation images taken with the clear 1 filter. The following description assumes the images are displayed with lines increasing up and samples to the right. Figure 1 (Klaasen et al., in review) shows a full frame MRI image displayed with this FITS convention. The quadrant nomenclature used later in this report is shown in this image.

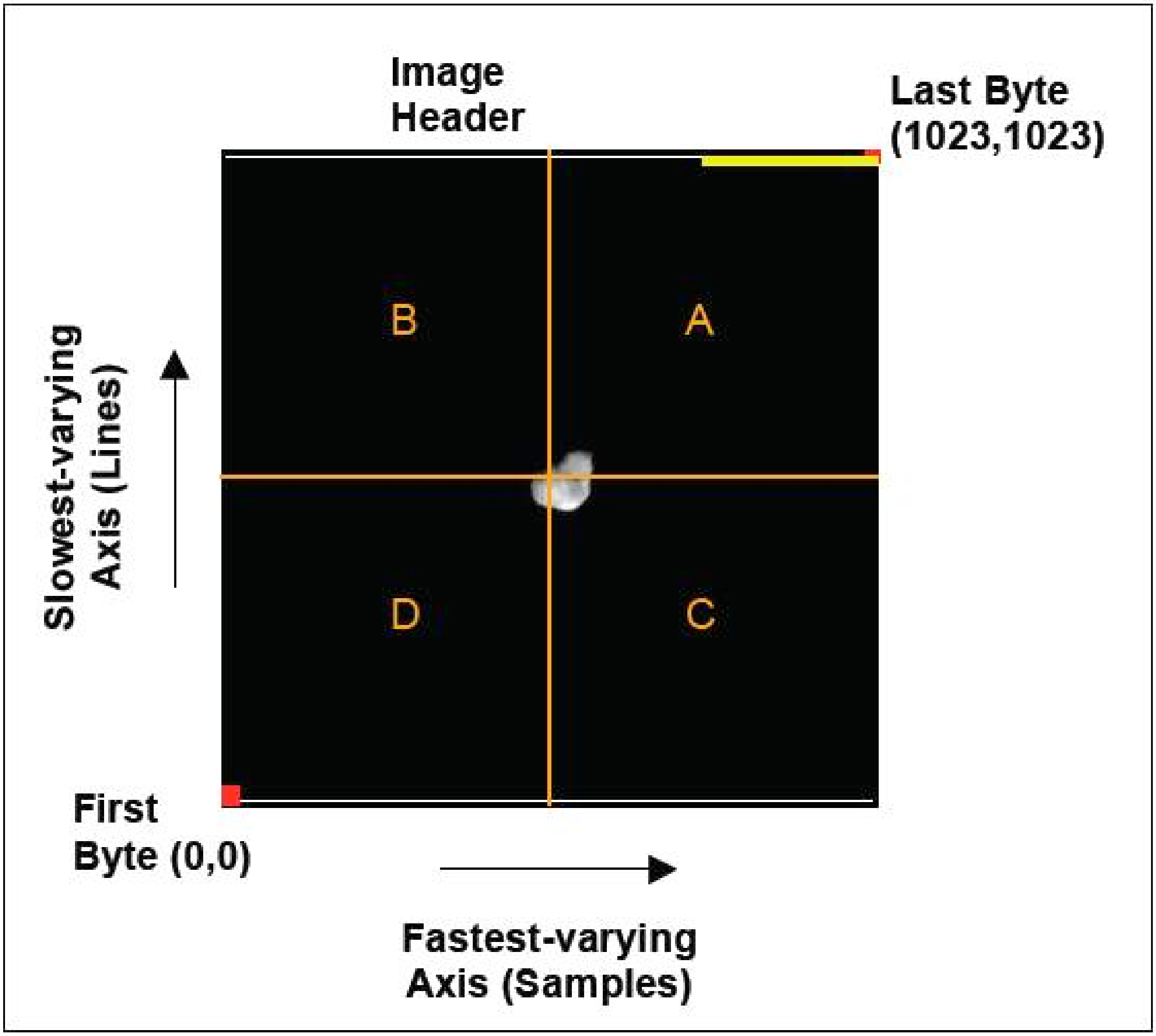

Figure 1: A full frame MRI image with quadrant nomenclature.

A] Science Data

Photometric measurements were derived from the reversibly calibrated ("RADREV") science images. These images have had the standard pipeline corrections applied to them: bias and dark frame subtraction, flat-field corrections, etc. They have not, however, been "cleaned" to remove artifacts such as cosmic rays. All images were taken in one of two sub-frame modes: 256x256 pixels for most of the approach sequence, and 512x512 pixels for the last 1.7 days of approach. Impact is defined as 05:44:34.265 UT 4 July 2005 at the flyby spacecraft.

All images are affected by a horizontal striping of a few DN in amplitude caused by electrical interference. This noise, if not removed, introduces an offset between measurements performed on images taken through the clear 6 filter and those taken through the clear 1 filter. The early approach images are primarily affected by this noise.

The pixels in the two rows surrounding the horizontal boundary between the upper and lower halves of the CCD are each 1/6 of a pixel smaller than the other pixels of the CCD. This increases the point spread function of objects that overlap this boundary by 1/3 of a pixel. Flux measurements similarly tend to be greater at the boundary. In approximately 80% of the images, the comet centroid lies within 20 pixels of this region; images taken through the clear 6 filter are particularly affected. Thus, most of the photometric measurements need to be corrected for this effect.

B] Navigation Data

The raw optical navigation images are in a different format from the science images. Each image consists of a number of square "snippets", each less than 400x400 pixels in size. Each "snippet" is centered on an object deemed interesting by the navigation team, usually a star or comet 9P/Tempel 1. Each set of snippets is integrated into a single image that is 1008x1008 pixels in size; the nav data have neither serial-overclock nor parallel-overclock pixels. Therefore, quadrant bias must be determined via other methods. For a more detailed description of the navigation data, please see the Deep Impact Navigation Images Report included in the Deep Impact documentation dataset, DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V1.0, which is archived by the PDS.

The optical navigation data suffers from the same striping noise as the science data. However, because these data are in a different format from the science data, a different algorithm was applied to the nav data. This procedure was also used to remove the bias. For the navigation data, the centroid position of the comet was sufficiently far away (more than 30 pixels, on average) from the horizontal boundary between the upper and lower halves of the CCD for the photometric measurements to not be affected by the narrower pixels in this region.

IV. Photometry

A] Science Data

The general procedure for the analysis of the science data is as follows:

1. Start with RADREV calibrated data
2. Convert the images to DN/s
3. Remove the horizontal striping
4. Measure the photometry
5. Correct the flux measurements (as needed) for the effect of lying close to the quadrant boundary

In order to remove the horizontal striping, the image is first divided into two halves: quadrants B and D to one side and quadrants A and C to the other. The process is similar for each half: begin by defining the region, avoiding the overclock pixels, that will be used to determine the background. This is a two-dimensional array that, in this case, is 25 pixels wide; the length depends on the size of the image (256 pixels or 512 pixels). Take the resistant mean across each row of this array and store into a new array that is 1 pixel wide and 256 pixels or 512 pixels long. Subtract this final array from each column of the half-image of interest. Figure 2 illustrates the procedure.

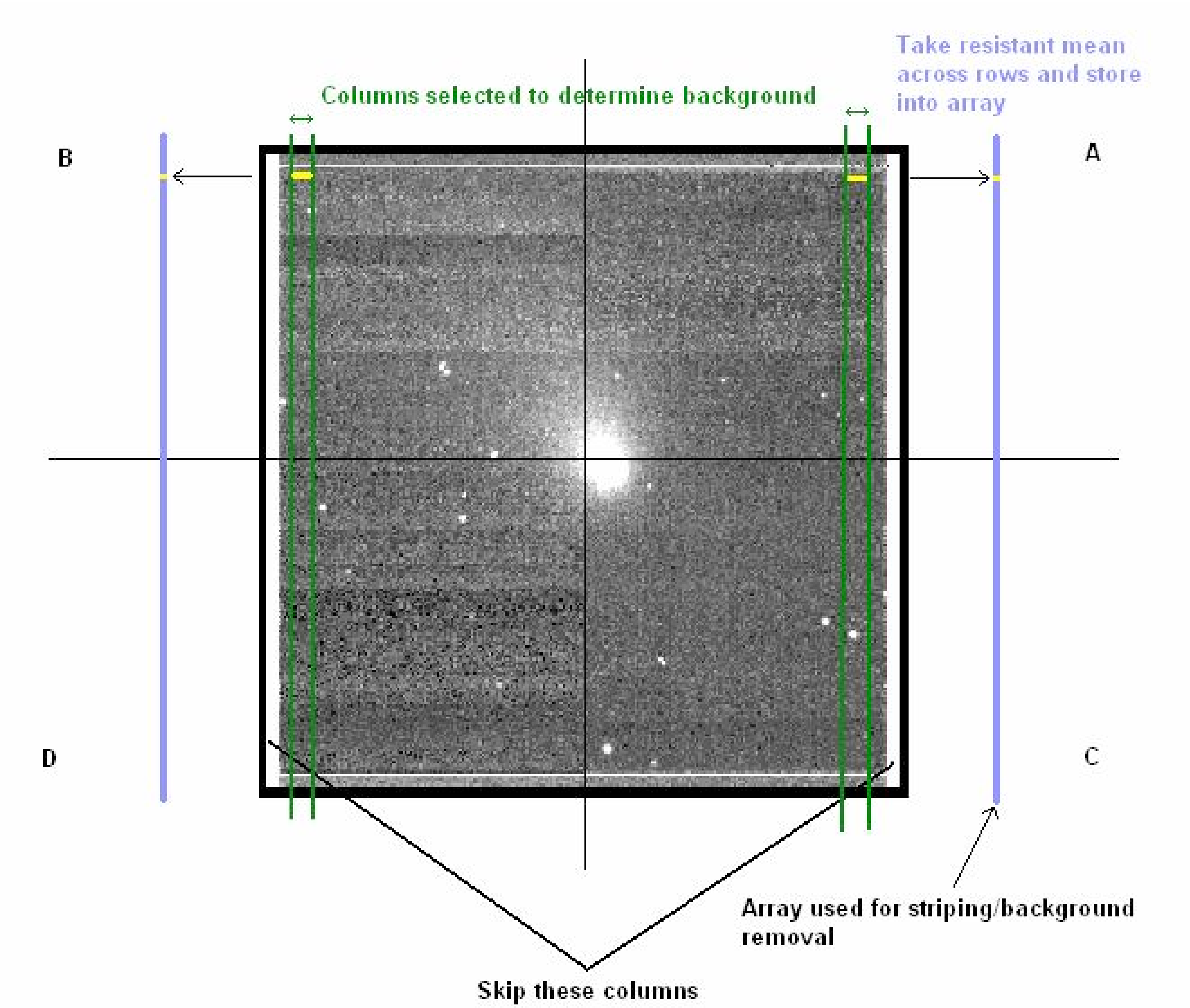

Figure 2: Illustration of the procedure used to create a uniform background in the science images.

Once the background noise is removed, circular aperture photometry is performed with apertures ranging in size from 5 pixels to 30 pixels in diameter. If the aperture falls across the boundary between the upper and lower halves of the CCD, the following procedure is used to correct the flux: create a subimage centered on the comet that is slightly larger than the aperture. This subimage is then divided into two parts: part 1 is the portion of the image located above the quadrant boundary (rows 512 and up, assuming a 1024x1024 frame and that the pixel at the lower left corner of the image is at (0,0), and part 2 corresponds to the part below the boundary (rows 511 and down). Begin by taking part 1 and measuring the flux contained within the original aperture (i.e. with the center of the aperture at the original centroid position). Shift the centroid position by 1/6 of a pixel, and again measure the flux. Subtract this latter measurement from the former, and add this to the total flux. Repeat the procedure for part 2, only this time shift the centroid position down by 1/6 of a pixel. Next, take the two central rows of the CCD (rows 511 and 512), and measure the flux from these two rows contained within the aperture. 1/3 of this value is subtracted from the total flux. Figure 3 illustrates this procedure.

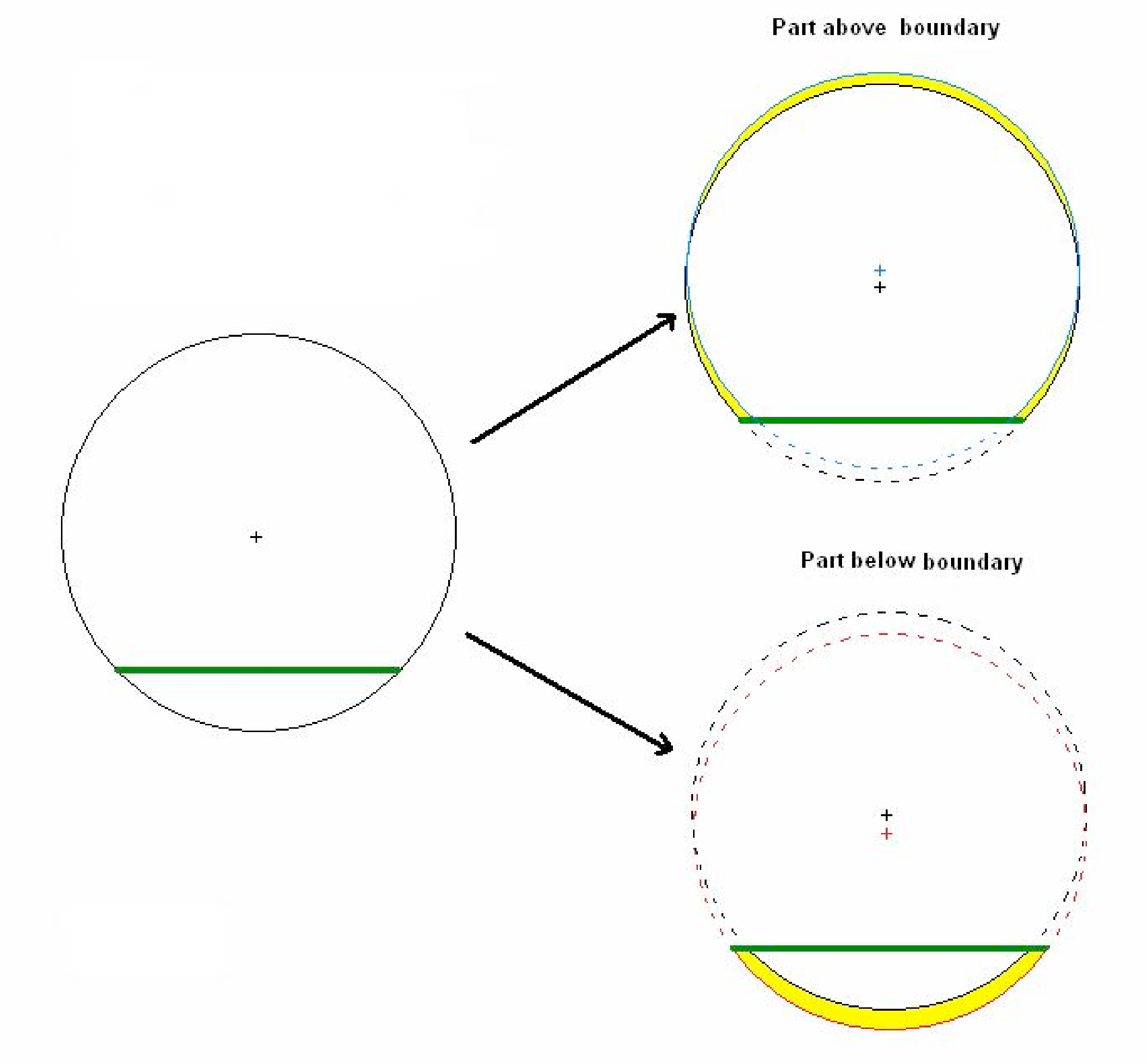

Figure 3: Procedure used to correct flux measurements for the quadrant boundary effect. The cross at the center of the aperture corresponds to the comet's centroid position. The green line represents the quadrant boundary. The correction consists of subtracting 1/3 of the flux from the rows at the boundary. The yellow shaded areas illustrate what is added back in.

B] Navigation Data

The optical navigation images were processed similarly to the science images:

1. Start with raw images
2. Concert to DN/s
3. Remove background and horizontal striping
4. Measure photometry

The background removal algorithm applied to the navigation images is similar to that used for the science images, except that the edge of the relevant snippet is used instead of the edge of the image. Since the apertures used do not cross quadrant boundaries, it is only necessary to use one edge of the snippet. This procedure not only determines the value of the background in the snippet but also measures the bias.

This procedure does not work, however, for images taken during the last week of approach. At this point, the comet's coma contaminates the entire snippet centered on the comet, and rarely are there any other snippets within the same quadrant. Therefore, for this time frame, the value of the background is measured from the raw science images taken closest in time to the navigation image of interest. Additionally, a slightly different bias value is subtracted from the navigation images (358.5 DN) than from the science images (359 DN); however since the bias values applied to the science data are only determined to the nearest full DN, these two numbers are consistent with one another. Note that the horizontal striping is not removed from images taken during this time frame; at this point, the comet is bright enough for the effect to be negligible.

In only 12 cases did the comet lie close enough to the quadrant boundary to require that the flux be corrected. Since this comprises less than 0.5% of the total number of navigation images, these data were simply omitted from this analysis.

V. References

Hampton, D.L., Baer, J.W., Huisjen, M.A., Varner, C.C., Delamere, A., Wellnitz, D.D., A'Hearn, M.F., Klaasen, K.P., 2005, An Overview of the Instrument Suite for the Deep Impact Mission, Space Science Reviews, 117, 43-93.

Klaasen, K.P., A'Hearn, M.F., Baca, M., Delamere, A., Desnoyer, M., Farnham, T., Groussin, O., Hampton, D., Ipatov, S., Li, J.-Y., Lisse, C., Mastrodemos, N., McLaughlin, S., Sunshine, J., Thomas, P., Wellnitz, D.D., 2006, Deep Impact Instrument Calibration, Optical Engineering, submitted.

Carcich, B., 2006, Deep Impact - Navigation Images Report.

These three references are included in the Deep Impact Documentation data set DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V1.0, available online at http://pdssbn.astro.umd.edu.