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
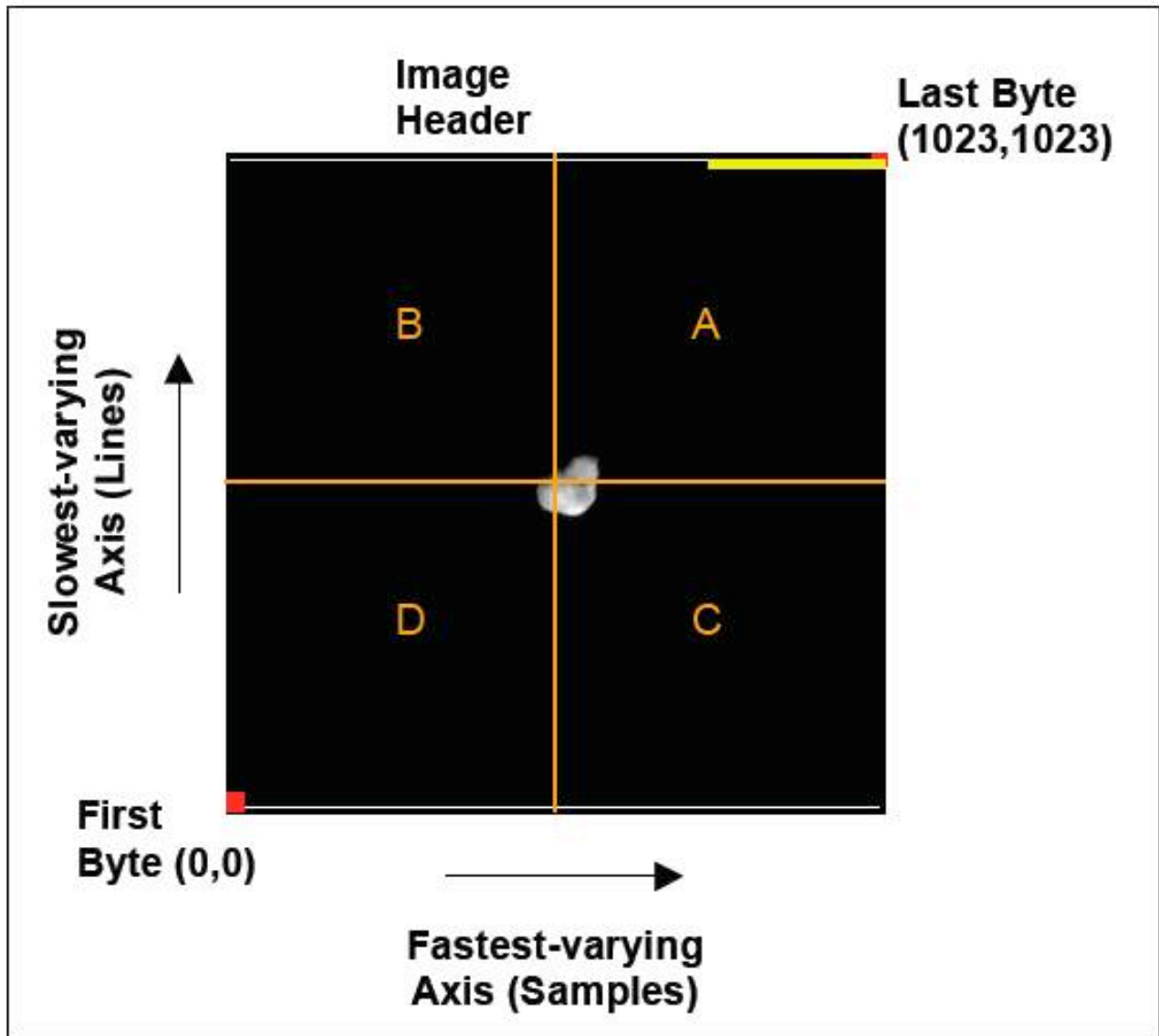is shown in this image.

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
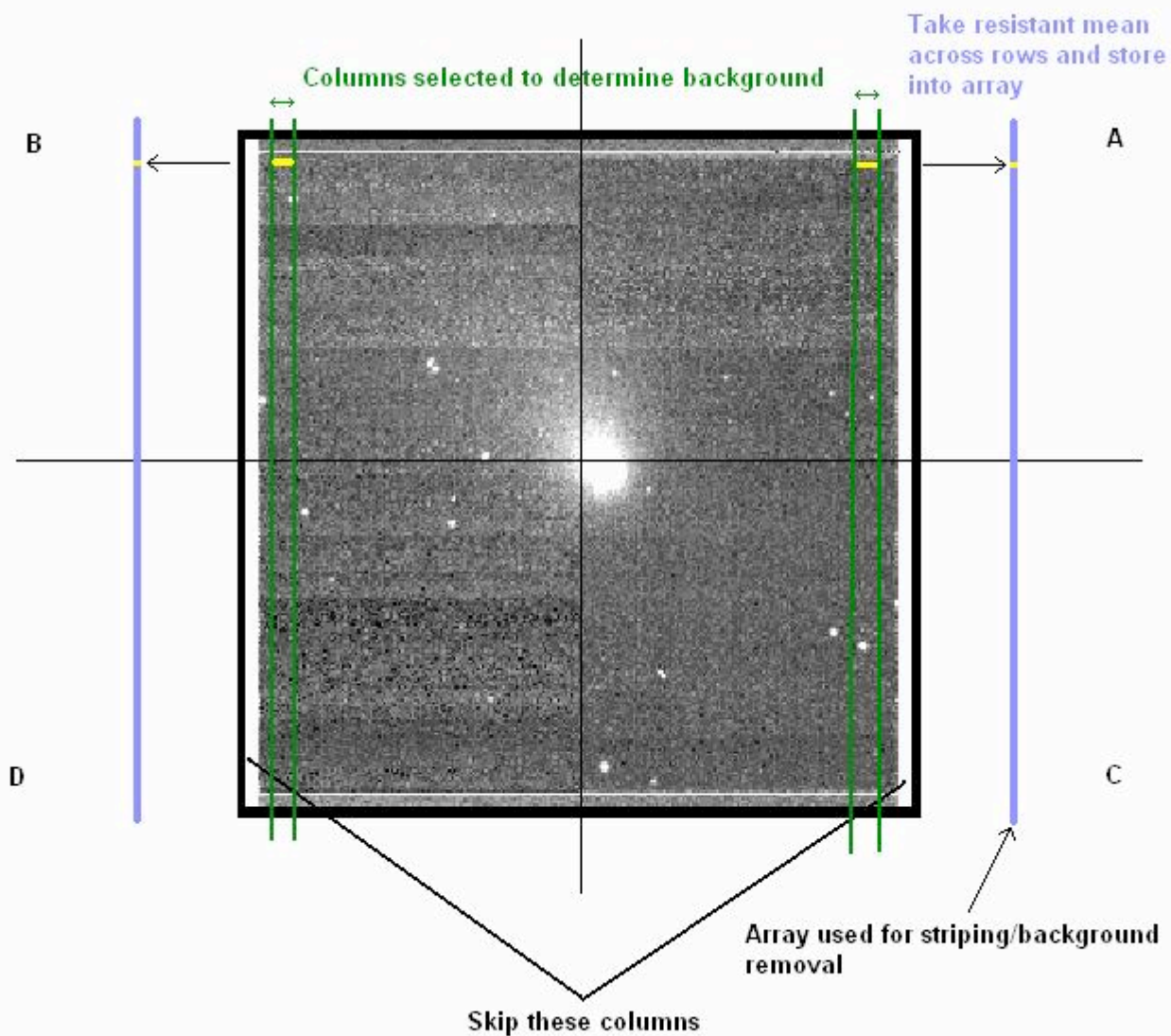interest. Figure 2 illustrates the procedure.

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
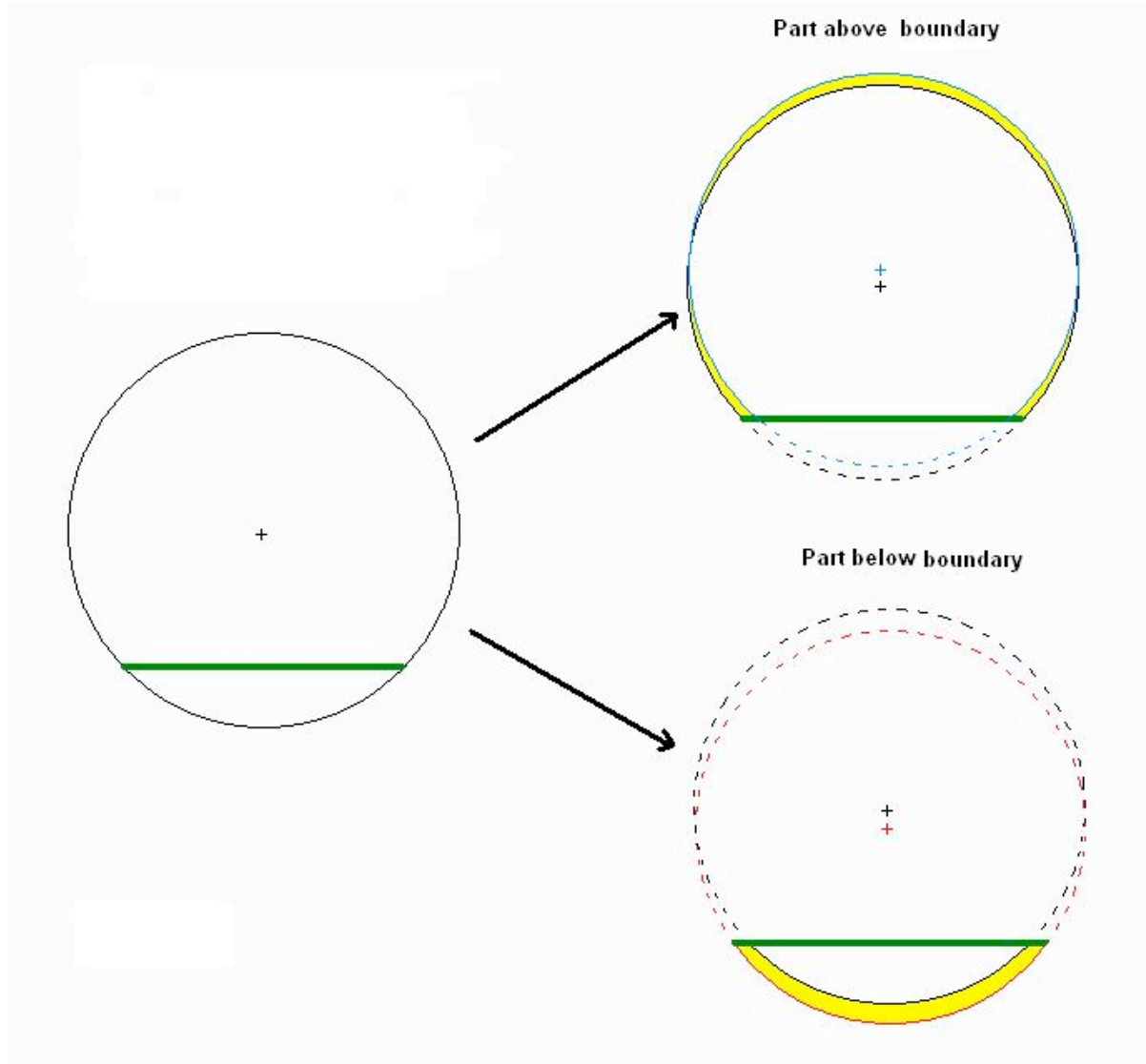is subtracted from the total flux. Figure 3 illustrates this procedure.

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.