

# **Data Product and Archive Volume Software Interface Specifications**

## **EPOXI**

### **Raw and Calibrated Science Data Products for**

### **Hi-Res IR Spectrometer (HRII) Hi-Res Visible CCD (HRIV) Medium-Res Visible CCD (MRI)**

**Prepared by:**

**EPOXI Archive Team  
University of Maryland, Astronomy Department  
College Park, MD 20742**

**October 22, 2007  
Last Revised September 7, 2011**

## Modification History

Date	Name	Description
2007-10-11	S. McLaughlin	Created draft
2008-05-21	S. McLaughlin	Updated many sections
2008-06-21	S. McLaughlin	Updated many sections
2008-07-25	S. McLaughlin	Updated phase dates; section 3.5.3
2008-07-31	S. McLaughlin	Updated typo in INTEGRATION_DURATION
2008-09-30	S. McLaughlin	Inserted new labels, add dataset IDs for NAV to DIXI section 3.5.3, discuss and list higher-level datasets (check my Standard Values Keyword list), update some label keyword definitions.
2009-01-02	S. McLaughlin	Fix typos; Add missing keyword definitions.
2009-04-29	S. McLaughlin	Updated several sections to reflect latest version of the PDS labels
2009-09-09	S. McLaughlin	Updated several sections to resolve liens from the peer review of the EPOXI/EPOCH datasets held on 23 Jul 2009
2010-08-01	S. McLaughlin	Updated several sections to reflect the archive of data acquired during the second cruise phase from 2009-01-01 through 2010-08-31: EPOCH Earth North/South Pole and Mars observations, and MOA-2009-BLG-266 imaging, and EPOXI/DIXI calibrations and tests.
2010-08-19	S. McLaughlin	Improved explanation of how the value UNK is used for geometry-related elements in the PDS labels. Revised description for spacecraft clock string format.
2010-10-16	S. McLaughlin	Fixed three typos per Sep 2010 PDS peer review; clarified wording in 4.3.4 for times used to compute observational geometry.
2011-06-24	S. McLaughlin	Revised DIXI/Hartley2 archive.
2011-09-07	S. McLaughlin	Edited per per Aug 2011 PDS peer review for Hartley 2 datasets. Fixed typo (MRIV → MRI) in table on page 27. Added minimum, maximum, median, standard_deviation to the keywords table in Section 4.5. Correct year to 2011 for Cruise3 in Table 1. Added scientific references [21] and [22]. Noted the cal pipeline accounts for varying readouts, tied to image modes, for the IR detector. Noted overscan area was removed from (overwritten with 0 in) RAD VIS products. Noted different reset/read timing for IR ALTF mode.

# Table of Contents

<b>1 INTRODUCTION.....</b>	<b>6</b>
<b>1.1 PURPOSE AND SCOPE.....</b>	<b>6</b>
<b>1.2 APPLICABLE DOCUMENTS.....</b>	<b>6</b>
1.2.1 EXTERNAL STANDARD REFERENCES.....	6
1.2.2 PROJECT DOCUMENTS.....	6
1.2.3 SCIENTIFIC REFERENCES.....	8
<b>1.3 CONTACT NAMES AND ADDRESSES.....</b>	<b>8</b>
<b>2 MISSION AND INSTRUMENT OVERVIEW.....</b>	<b>9</b>
<b>2.1 MISSION OVERVIEW AND TIMELINE .....</b>	<b>9</b>
<b>2.2 IR SPECTROMETER (HRII).....</b>	<b>10</b>
2.2.1 SPECTROMETER IMAGING MODES.....	13
<b>2.3 HIGH- AND MEDIUM-RESOLUTION VISIBLE CCDs .....</b>	<b>13</b>
2.3.1 HRI VISIBLE CCD (HRIV).....	13
2.3.2 MRI VISIBLE CCD (MRI) .....	16
2.3.3 CCD IMAGING MODES.....	18
2.3.4 CCD FILTERS.....	19
<b>2.4 ALIGNMENT OF INSTRUMENTS .....</b>	<b>20</b>
<b>3 ARCHIVE OVERVIEW.....</b>	<b>21</b>
<b>3.1 DATASET AND DATA VOLUME ORGANIZATION .....</b>	<b>21</b>
3.1.1 CALIB DIRECTORY .....	21
3.1.2 CATALOG DIRECTORY .....	21
3.1.3 DATA DIRECTORY .....	22
3.1.4 DOCUMENT DIRECTORY .....	22
3.1.5 EXTRAS DIRECTORY .....	23
3.1.6 GEOMETRY DIRECTORY.....	23
3.1.7 INDEX DIRECTORY.....	23
<b>3.2 EXPECTED DATASETS.....</b>	<b>23</b>
3.2.1 IN-FLIGHT CALIBRATIONS .....	23
3.2.2 EPOCH .....	24
3.2.3 DIXI/HARTLEY 2 ENCOUNTER .....	27
3.2.4 HIGHER-LEVEL DATASETS FOR EPOCH AND DIXI .....	28
<b>4 SCIENCE DATA PRODUCTS .....</b>	<b>29</b>
<b>4.1 OVERVIEW OF DATA PRODUCTS.....</b>	<b>29</b>
4.1.1 RAW FITS DATA PRODUCT (EDR).....	29
4.1.2 CALIBRATED FITS DATA PRODUCT (RDR).....	30

4.1.3	QUALITY FLAGS MAP (FITS EXTENSION) .....	31
4.1.4	SIGNAL-TO-NOISE RATIO MAP (FITS EXTENSION) .....	31
4.1.5	IR SPECTRAL WAVELENGTH MAP (FITS EXTENSION).....	32
4.1.6	IR SPECTRAL BANDWIDTH MAP (FITS EXTENSION) .....	32
4.1.7	VIS DE-STRIPE VALUES (FITS EXTENSION) .....	32
4.1.8	PIPELINE CALIBRATION FILES .....	32
<b>4.2</b>	<b>DATA PRODUCT GENERATION AND LABELING .....</b>	<b>35</b>
4.2.1	DATA PIPELINE OVERVIEW .....	35
4.2.2	CALIBRATION PROCESS – PRIOR TO AUGUST 2010 .....	35
4.2.3	CALIBRATION PROCESS – AS OF JUNE 2011 .....	36
4.2.4	IMAGE ORIENTATION AND PIXEL READOUT ORDER.....	36
4.2.5	DATA FILE NAMING CONVENTIONS AND PRODUCT IDS .....	41
<b>4.3</b>	<b>STANDARDS USED IN DATA PRODUCT GENERATION .....</b>	<b>41</b>
4.3.1	PDS STANDARDS .....	41
4.3.2	TIME STANDARDS .....	41
4.3.3	REFERENCE FRAME STANDARDS .....	41
4.3.4	TIME- AND GEOMETRY-RELATED KEYWORDS.....	42
4.3.5	IMAGE ORIENTATION .....	42
<b>4.4</b>	<b>SAMPLE PDS LABELS.....</b>	<b>43</b>
4.4.1	LEVEL 2 RAW HRII SCIENCE DATA PRODUCT.....	43
4.4.2	LEVEL 2 RAW HRIV/MRI SCIENCE DATA PRODUCT.....	53
4.4.3	LEVEL 3/4 CALIBRATED HRII SCIENCE DATA PRODUCT .....	63
4.4.4	LEVEL 3/4 CALIBRATED HRIV/MRI SCIENCE DATA PRODUCT.....	79
<b>4.5</b>	<b>PDS OBJECT AND KEYWORD DEFINITIONS .....</b>	<b>93</b>
<b>5</b>	<b>USING THE DATA PRODUCTS.....</b>	<b>116</b>
5.1	INDEX AND IMAGE PARAMETERS FILES .....	116
5.2	RELATED DEEP IMPACT DATASETS.....	116
5.3	FLIGHT HARDWARE CONSIDERATIONS.....	117
5.4	LIMITATIONS AND KNOWN ANOMALIES .....	117
5.5	RECOMMENDED SOFTWARE TO READ DATA PRODUCTS .....	117
5.5.1	IDL.....	117
5.5.2	PDS-SBN TOOLS.....	117
5.6	RAW IMAGE COMPRESSION .....	118
5.7	ACCESSING QUALITY FLAGS MAP VIA IDL .....	118
<b>6</b>	<b>TECHNICAL/PROGRAMMING INFORMATION .....</b>	<b>120</b>
6.1	BRIEF DESCRIPTION OF ODL USED FOR PDS LABELS .....	120
6.2	ARCHITECTURE NOTES.....	120
6.2.1	INTERNAL REPRESENTATION OF DATA TYPES .....	120
6.2.2	FILE SYSTEM (ISO 9660).....	120
6.3	NAIF/SPICE.....	121

<b>7</b>	<b>APPENDICES .....</b>	<b>122</b>
<b>7.1</b>	<b>GLOSSARY .....</b>	<b>122</b>
<b>7.2</b>	<b>ACRONYMS .....</b>	<b>123</b>
<b>7.3</b>	<b>DATA PROCESSING LEVELS .....</b>	<b>124</b>

# 1 Introduction

## 1.1 Purpose and Scope

The purpose and scope of this document is to describe the Level 2 (raw) and Level 3/4 (calibrated) science data products generated by the Cornell Science Data Center (SDC) pipeline for the three EPOXI instruments as well as the format and content of the PDS archival datasets. The processing levels are defined in Appendix 7.3. This document is intended to provide enough information to enable users to understand and use the data products, and it includes examples of the science data products and information about how the data were processed, formatted, and labeled.

This document is not intended to provide a detailed description of the EPOXI instruments nor does it provide methods for interpreting the scientific data. For a thorough discussion of the EPOXI instruments, see Hampton, et al. 2005 [4]. The Deep Impact Instrument Calibration paper by Klaasen, et al. 2008 [7] describes the existing Deep Impact calibration pipeline that was implemented for EPOXI and used to process data acquired from October 2007 through July 2010. The *EPOXI - Hartley2 Calibration Pipeline Summary* [17] and *EPOXI Instrument Calibration* by Klaasen, et al. 2011 [20] describe how the pipeline was improved in June 2011 for processing data acquired during the Hartley2 phase of the mission from August 2010 to February 2011. For overviews of the Deep Impact flyby spacecraft and the autonomous navigation system, see A'Hearn, et al. 2005 [5], Blume, 2005 [6], and Mastrodemos, et al. 2005 [8].

## 1.2 Applicable Documents

### 1.2.1 External Standard References

- [1] PDS Standards Reference, JPL, D-7669, Version 3.7, March 20, 2006.
- [2] PDS Data Dictionary, JPL, D-7116, Revision E, August 28, 2002 and the EPOXI Local Data Dictionary created from the PDS Full Data Dictionary generated on January 21, 2009.

### 1.2.2 Project Documents

The following project-related publications are included in the documentation for the PDS archive. Please note the publishers allowed only *drafts* of [4] through [9] to be included in the archive documentation. Documents [10] to [18] are written by the EPOXI team specifically for inclusion in the archive.

- [3] EPOXI Data Management and Archiving Plan, JPL, D-39796.

- [4] An Overview of the Instrument Suite for the Deep Impact Mission, Hampton et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3390-8.
- [5] Deep Impact: A Large-Scale Active Experiment on a Cometary Nucleus, A'Hearn, et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3387-3.
- [6] Deep Impact Mission Design, Blume, Space Science Reviews, 2005, DOI:10.1007/s11214-005-3386-4.
- [7] Deep Impact Instrument Calibration, Klaasen, et al., Review of Scientific Instruments, American Institute of Physics, 79, 091301, 2008, DOI: 10.1063/1.2972112, Permalink: <http://link.aip.org/link/?RSINAK/79/091301/1>.
- [8] Autonomous Navigation for the Deep Impact Mission Encounter with Comet Tempel 1, Mastrodemos, et al., Space Science Reviews, 2005, DOI:10.1007/s11214-005-3394-4.
- [9] Deep Impact: The Anticipated Flight Data, Klaasen, et al., Space Science Reviews, 2005.
- [10] Deep Impact - Navigation Images Report, Project Documentation, Carcich, 2006.
- [11] Deep Impact Spacecraft Clock Correlation, Project Documentation, Carcich, 2006.
- [12] Deep Impact and EPOXI Instrument Thermal Sensor Atlas, Hampton, 2008.
- [13] Deep Impact - Limitations of the HRI-IR Instrument, Groussin and Klaasen, 2006.
- [14] EPOXI Data Archive: FITS Keyword Descriptions for the Primary Image Header, Carcich, 2009.
- [15] Report on the Calibration of EPOXI spacecraft timing and reduction to Barycentric Julian Date, Hewagama, 2009.
- [16] Deep Impact Spacecraft Clock 0-40ms Errors, Carcich, 2011.
- [17] EPOXI – Hartley 2 Calibration Pipeline Summary, EPOXI team, 2011.
- [18] EPOXI In-Flight Calibrations Summary, EPOXI team, 2011.

Additional project-related publications that could not be included in the documentation for the PDS archive are but are available from the publishers:

- [19] Restoration of Images of Comet 9P/Tempel 1 Taken with the Deep Impact High Resolution Instrument, Lindler, et al., PASP, 2007.
- [20] EPOXI Instrument Calibration, Klaasen, et al., 2011, in preparation for publication.
- [21] Stardust-NExT, Deep Impact, and the accelerating spin of 9P/Tempel 1, Belton, et al. Icarus, Volume 213, Issue 1, 2011, DOI:10.1016/j.icarus.2011.01.006.
- [22] Development of a Point Spread Function for the Extrasolar Planet Observation Characterization and the Deep Impact Extended Investigation Missions, Barry, et al., Space Telescopes and Instrumentation 2010: Optical, Infrared, and Millimeter, Proceedings of SPIE, Volume 7731, 2010.

### **1.2.3 Scientific References**

Scientific references, including those from Deep Impact, relevant to EPOXI are listed here.

- [A] Deep Impact: Excavating Comet Tempel 1, A'Hearn, et al., 2005, Science, 310, 258-264, DOI:10.1126/science.1118923.
- [B] The Extrasolar Planets Encyclopedia, <http://exoplanet.eu>, J. Schneider, CNRS/LUTH Paris Observatory.
- [C] EPOXI at Comet Hartley 2, A'Hearn, et al., 2005, Science, 332, 1396-1400, DOI:10.1126/science.1204054.

### **1.3 Contact Names and Addresses**

Michael A'Hearn  
EPOXI Principal Investigator and PDS Small Bodies Node Manager  
Department of Astronomy  
University of Maryland  
College Park, MD 20742

Drake Deming  
EPOXI Deputy Principal Investigator and EPOCH Principal Investigator  
Goddard Space Flight Center  
Mail Code 693.0  
Greenbelt, MD 20771

Jessica Sunshine  
DIXI Deputy Principal Investigator  
Department of Astronomy  
University of Maryland  
College Park, MD 20742

Brian Carcich  
EPOXI Science Data Center Manager  
Department of Astronomy  
Cornell University  
Ithaca, NY 14853

Stephanie McLaughlin  
EPOXI Archive Team and PDS Small Bodies Node Staff  
Department of Astronomy  
University of Maryland  
College Park, MD 20742



## **2 Mission and Instrument Overview**

An overview of the EPOXI mission and its three instruments is provided here. The user of the EPOXI data archive is strongly encouraged to read project documents [4], [7], [17], and [19] for thorough discussions of the instruments and their calibration.

### **2.1 Mission Overview and Timeline**

The EPOXI mission is the combination of two independently proposed scientific investigations using the flyby spacecraft of Deep Impact in an extended mission. EPOCH (Extrasolar Planet Observation and Characterization) will utilize the HRI CCD and IR spectrometer on the DI flyby spacecraft to a) observe transits by known extrasolar planets (hot Jupiters) to look for perturbations due to terrestrial planets in low-order resonances, b) search those same systems for secondary occultations of the hot Jupiter by the star, and c) characterize the Earth as a remotely sensed planet. DIXI (Deep Impact eXtended Investigation) consists of a flyby of 103P/Hartley 2 in order to study a second short-period comet with the same set of instrumentation as was used at 9P/Tempel 1. The original target was 85P/Boethin. When the comet could not definitively be recovered after extensive observations during 2007, the mission selected the backup, 103P/Hartley 2, as the new target.

The EPOCH phase of the mission in 2008 consisted of imaging eight known transiting exoplanetary systems for several weeks at a time. During the second cruise phase of the mission in 2009 and the first half of 2010, the project performed additional observations for EPOCH including imaging Earth at northern and southern latitudes and Mars to supplement its remote sensing of planets. EPOCH also imaged a planetary microlensing event known as MOA-2009-BLG-2006.

The DIXI phase of the mission consisted of continuous imaging of comet 103P/Hartley 2 from September through November 2010 with a closest approach on 4 November. In-flight calibrations were performed throughout the EPOXI mission from October 2007 to February 2011. Table 1 presents a high-level timeline for the mission.

Phase	Start Date	End Date	Targets
CRUISE 1	01 Sep 2007	21 Jan 2008	
Earth Flyby	31 Dec 2007	31 Dec 2007	Moon and calibration sources
In-flight Calibrations	04 Oct 2007	21 Jan 2008	Calibration sources
EPOCH	22 Jan 2008	31 Aug 2008	
Exoplanet Transit Obs	22 Jan 2008	31 Aug 2008	HAT-P-4, XO-3, TrES-3, XO-2, GJ 436, TrES-2, WASP-3, and HAT-P-7
Earth Obs #1	18 Mar 2008	19 Mar 2008	Earth (as a remotely-sensed planet)
Earth Obs #2 and 3	Apr/May 2008	Apr/May 2008	Cancelled due to telecom anomaly
Earth Obs #4	28 May 2008	29 May 2008	Earth (as a remotely-sensed planet)
Earth Obs #5	04 Jun 2008	05 Jun 2008	Earth (as a remotely-sensed planet)
In-flight Calibrations	22 Jan 2008	31 Aug 2008	Calibration sources
CRUISE 2	01 Sep 2008	03 Sep 2010	
EPOCH Earth North	27 Mar 2009	28 Mar 2009	High northern latitudes
EPOCH Earth South	27 Sep 2009	05 Oct 2009	High southern latitudes
EPOCH Microlens Obs	05 Oct 2009	08 Oct 2009	Planetary transit MOA-2009-BLG-266
EPOCH Mars Obs	24 Nov 2009	25 Nov 2009	Mars (as a remotely-sensed planet)
Earth Flybys	Jun/Dec 2009	Jun/Dec 2009	Moon and calibration sources
In-flight Calibrations	01 Sep 2008	31 Jul 2010	Calibration sources
DIXI/Hartley 2	01 Aug 2010	28 Nov 2010	
Hartley 2 Approach	04 Sep 2010	03 Nov 2010	103/P Hartley 2
Hartley 2 Encounter	04 Nov 2010	04 Nov 2010	103/P Hartley 2
Lookback Imaging	04 Nov 2010	26 Nov 2010	103/P Hartley 2
In-flight Calibrations	01 Aug 2010	28 Nov 2010	Calibration sources
CRUISE 3	28 Nov 2010	06 Feb 2011	
In-flight Calibration	05 Feb 2011	06 Feb 2011	Calibration source

Table 1 – High-level timeline for the EPOXI mission

## 2.2 IR Spectrometer (HRII)

The High Resolution Imager (HRI) consists of a long-focal-length telescope followed by a dichroic beam splitter that reflects (0.3 to 1.0 microns) light through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near infrared (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV (High Resolution Visible CCD) and HRII (High Resolution IR spectrometer), sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture:	30.0 cm diameter, round
Primary focal ratio:	4.5
Secondary Obscuration:	9.7 cm diameter, round
Secondary magnification:	7.8x (net Cassegrain focal length 1050 cm)
Back focal distance:	30.0 cm

The dichroic beam-splitter has equal transmission and reflection occurring at about 1.05 microns and is placed in front of the telescope focal plane. The spectrometer is a 2-prism

design, one of calcium fluoride (CaF<sub>2</sub>) and one of zinc selenide (ZnSe) to maximize etendue and minimize problems with order separation. The camera and collimator lead to a net demagnification of 3x, for an effective focal ratio of f/12 and effective focal length of 360 cm in the final beam. The entrance slit subtends on the sky 2.53 milliradians by 10 microradians (0.145 degrees by 2 arcseconds), filling the 512-pixel height of the IR array. The slit width matches the binned pixel (2x2) mode used for most observations.

The near-infrared detector is a 1024 (wavelength) x 512 (spatial) pixel mercury cadmium telluride (HgCdTe) device manufactured by Rockwell using the multiplexer originally developed under contract from the University of Hawaii for use in the WFC3 on HST. Physically, it is a 1024 x 1024 device, but only half of the device is active. Pixels are 18 microns square and normal operations include 2x2 binning (post-readout). Spectral resolving power, because of the 2-prism design, varies from greater than 740 at 1.04 microns down to 210 at 2.6 microns, and back up to 385 at 4.8 microns. Due to saturation problems in warm areas of a cometary nucleus, the central quarter of the detector is covered with a neutral density filter.

When operated in the 512 x 256 pixel, 2x2 binning mode, the HR II instrument has the following field-of-view characteristics:

Spatial

Physical Pixel Size :	36 micrometers
Effective Pixel FOV :	10.0 microradians or 2.06265 arcseconds
Effective FOV :	2.5 milliradians or 0.15 degrees

Spectral

Effective Pixel FOV :	10.0 microradians
Effective FOV :	10.0 microradians (slitwidth)

The spectrometer includes an internal stimulator lamp for calibrating between the two quadrants of the spectrometer (i.e., not as a standard calibrator). However the lamp was broken during one of the ground thermal-vacuum tests and was not replaced. Therefore this lamp was never used during the Deep Impact and EPOXI missions.

It is important to note that the readout order of the IR detector affects the timing of the spectra. When a HR II spectral image is displayed using the true-sky convention, the wavelength increases horizontally to the right and the spatial or along-slit direction is vertical. In this orientation, the IR detector was read out from the left and right edges and toward the center and starting with the first row at the bottom and ending with the last row at the top of the display. Since the detector is reset and read out on a pixel-by-pixel basis, the read out order affects the time at which each pixel is exposed, although each pixel has the same exposure duration except for the ALTF mode that has different read and reset timing causing the effective exposure time to vary with line number, i.e., along the slit in the spatial direction (see the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17]). The calibration pipeline accounts for these timing effects. Additionally, the end of the spectrometer slit that always points roughly towards the sun is the first line to be readout and

the last line to be read out is furthest from the sun, assuming the spacecraft is in its usual orientation with the solar panels pointing roughly toward the sun.

The three instruments on the flyby spacecraft, HRII, HRIV, and MRI (Medium Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. 2008 [7] and Klaasen, et al. 2011 [20].

### Instrument Calibration & Flight Performance

The HRII instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV1, TV2, and TV4) performed in 2002 and 2003. In-flight calibrations continued through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. 2008 [7]. This shared version of the pipeline was used to calibrate EPOXI data (exoplanets, Earth, and Mars). The science team improved the calibration process in June 2011. This version was used to process the Hartley 2 data archived as version 1.0 in PDS. For more information see the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17] or Klaasen, et al. 2011 [20].

The HRII instrument generally performed as expected during flight. During Deep Impact, small changes in instrumental temperatures affected the dark current more than expected from ground thermal-vacuum tests. This effect continues for EPOXI and is discussed in the Deep Impact instrument calibration paper by Klaasen, et al. 2008 [7]. Also for the prime mission in 2005, about 1.15% of the IR pixels were bad. Calibration data acquired throughout EPOXI showed changes to the linearity constants and increases to the numbers of bad pixels. Also a new flat field that corrected for the anti-saturation filter was constructed. Therefore new calibration files and constants were incorporated into the calibration pipeline for EPOXI processing; additional improvements such as the timing for certain imaging modes are discussed by Klaasen, et al. (2011) [20].

later in 2008 for EPOXI show the fraction of bad pixels has increased to about 1.48%. Therefore new bad pixel maps were generated and incorporated into the calibration pipeline for EPOXI processing. See the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17] for more information.

During the Deep Impact mission, early images of stars acquired by the HRIV CCD indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the HRIV CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels in a HRIV frame. This focus problem had only a nominal effect on the HRII instrument. For a detailed discussion about the focus of the HRI telescope, please see Klaasen, et al. 2008 [7] and Lindler, et al. (2007) [19].

## 2.2.1 Spectrometer Imaging Modes

The imaging modes for the HRII instrument are provided in Table 2.

#	Mode Mnemonic	Mode	Stored Image Size (x, y)	Minimum Exposure Time (sec)	Frame to Frame Time for Minimum Exposure (sec)
1	BINFF	Binned Full Frame	512 x 256	2.86	2.862
2	BINSF1	Binned Sub-Frame 1	512 x 128	1.43	1.432
3	BINSF2	Binned Sub-Frame 2	512 x 64	0.71	0.717
4	UBFF	Un-binned Full Frame	1024 x 512	2.86	2.862
5	ALTFF	Alternating Binned Full Frame	512 x 256	1.43	2.868
6	DIAG	Diagnostic: One reset frame followed by a read frame	1024 x 512 (each frame)	1.43 (each frame)	1.432 (each frame)
7	MEMCK	Memory Check	1024 x 512	N/A	2.862

Table 2 - IR Spectrometer (HRII) Imaging Modes

For diagnostic mode 6, a reset frame is acquired first, then a read (i.e., data) frame. Each frame is stored as a separate file. Both data files use the same exposure ID with consecutive image numbers (e.g., exposure ID 1021000 and image number 001 for the reset frame and 002 for the read frame).

The IR detector has several reference columns (line samples) and rows (lines) around the edge of the array. **Pixels in the reference areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the number of reference rows and columns for each instrument mode.

## 2.3 High- and Medium-Resolution Visible CCDs

### 2.3.1 HRI Visible CCD (HRIV)

The High Resolution Imager (HRI) consists of a long-focal-length telescope with a dichroic beam splitter located in front of the focal plane that reflected visible light (0.3 to 1.0 microns) through a filter wheel to a CCD for direct, optical imaging. The beam splitter transmits the near-infrared light (1 to 5 microns) to a 2-prism spectrometer. For convenience, we consider these as two separate instruments, HRIV (High Resolution Visible CCD) and HRII (High

Resolution IR spectrometer), sharing the telescope since the two focal planes operate in parallel asynchronously. The HRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture: 30.0 cm diameter, round  
Primary focal ratio: 4.5  
Secondary Obscuration: 9.7 cm diameter, round  
Secondary magnification: 7.8x (net Cassegrain focal length 10.5 m)  
Back focal distance: 30.0 cm

The dichroic beam-splitter has equal transmission and reflection occurring at about 1.05 microns. The filter wheel contains two clear apertures and 7 filters. Five of the filters are roughly 100 nanometers in bandwidth, centered at 450, 550, 650, 750, and 850 nanometers. The shortest-wavelength filter is effectively a short-wavelength pass filter starting at 400 nanometers and limited to about 340 nanometers on the short end by the rapid decline in beamsplitter reflectivity. The longest wavelength filter is a long-pass filter starting at 900 nanometers that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The visible detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels, with each quadrant read out through a separate amplifier. The electronics allow readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two, shielded areas, is about 5.2 milliseconds. Readout time for a full frame is about 1.8 seconds.

The HRIV instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

Pixel Size: 21 micrometers  
Pixel FOV: 2.0 microradians or 0.41253 arcseconds  
Instrument FOV: 2.0 milliradians or 0.118 degrees  
Surface Scale: 1.4 meters/pixel at 700 kilometers

The HRIV instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD. The lamp is not a standard calibrator. One of its in-flight uses is to improve the photometry from the EPOXI exoplanet transit observations.

The three instruments on the flyby spacecraft, HRII, HRIV, and MRI (Medium Resolution Visible CCD), are mounted on a separate instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. 2008 [7] and Klaasen, et al. 2011 [20].

## Instrument Calibration & Flight Performance

The HRIV instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during thermal-vacuum tests (TV2 and TV4) performed in 2002 and 2003. In-flight calibrations continued through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. 2008 [7]. This shared version of the pipeline was used to calibrate EPOCH data (exoplanets, Earth, and Mars). The science team improved the calibration process in June 2011. This version was used to process the Hartley 2 data archived as version 1.0 in PDS. For more information see the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17] or Klaasen, et al. 2011 [20].

Calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the HRIV CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from HRIV images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows; this is only a problem for aperture photometry. See Belton, et al. (2011) [21] for a discussion of how the central horizontal gap was handled for aperture photometry of comet 9P/Tempel 1 for Deep Impact.

The HRIV instrument generally performed as expected during flight. However, images of stars acquired early in the Deep Impact mission indicated the HRI telescope was out of focus. An analysis showed the focus was forward of the CCD, so bakeouts were performed in late February and early March 2005 to improve the focus. The bakeouts reduced the defocus from 1.0 cm to 0.6 cm, which caused the width of star images to decrease from about 12 pixels to about 9 pixels. Star images continued to have a three-fold symmetry (six points) resulting from the three-point mounting of the primary and secondary mirrors. Most of the expected resolution can be regained by applying algorithms to deconvolve the HRIV images as described by Lindler, et al. 2007 [19]. The EPOXI mission takes advantage of the poor focus characteristic that increases the point spread function of measurements, enabling high-precision photometry of known extrasolar planetary systems. For a detailed discussion about the focus of the HRI telescope, see Klaasen, et al. 2008 [7] and Lindler, et al. 2007 [19]. During the EPOXI mission, new target-specific point spread functions (PSFs) were produced from data acquired in 2008 of exoplanet transit targets such as GJ 436 and stellar calibrators such as Canopus. See Barry, et al., (2010) [22] for more information. These PSFs are archived as a data set in the PDS: DIF-CAL-HRIV-6-EPOXI-STELLAR-PSFS-V1.0.

Calibration data acquired in 2008 for EPOXI show a 6% increase in the response of the HRIV 950-nm filter (#5) and changes to the electronic crosstalk between the CCD quadrants since 2005. Therefore new calibration constants for the 950-nm filter and new crosstalk coefficients were calculated and incorporated into the calibration pipeline for EPOXI processing.

### **2.3.2 MRI Visible CCD (MRI)**

The Medium Resolution Imager consists of an f/17.5 Cassegrain telescope followed by a filter wheel feeding directly onto a CCD for direct, optical imaging. The MRI telescope is a classical Cassegrain design with the following parameters:

Primary aperture: 12.0 cm diameter, round  
Primary focal ratio: 3.75  
Secondary Obscuration: 6.6 cm diameter, round  
Secondary magnification: 4.75x (net Cassegrain focal length 210 cm)  
Back focal distance: 30.0 cm

The filter wheel contains two clear apertures and 8 filters. The filters include duplicates of some of the medium-band filters in the High Resolution Images and filters that isolate OH, CN, and C2 as well as the green and violet continuum. These narrow-band filters are designed to match the Hale-Bopp filter sets used for ground-based programs since 1996. The longest wavelength filter is actually a long-pass filter that uses the CCD response to define the long-wavelength cutoff at about 960 nanometers.

The detector is a 1024 x 1024 split-frame, frame-transfer CCD with 21-micron-square pixels. The electronics allows readout of centered sub-frames in multiples of 2: 64x64, 128x128, and so on, with or without rows of overscan. Transfer time, to move the two halves of the image from the exposing area to the two shielded areas, is about 5.2 milliseconds. There are readout amplifiers in each of the four quadrants. Readout time for a full frame is about 1.8 seconds. Net pixel scale is 10 microradians/pixel (2 arcseconds/pixel).

The MRI instrument in full-frame 1024 x 1024 mode has the following field-of-view characteristics:

Pixel Size: 21 micrometers  
Pixel FOV: 10.0 microradians or 2.06265 arcseconds  
Instrument FOV: 10.0 milliradians or 0.587 degrees  
Surface Scale: 7 meters/pixel at 700 kilometers

The MRI instrument includes an internal stimulator lamp for calibrating between the four quadrants of the CCD; it is not a standard calibrator.

The three instruments on the flyby spacecraft, MRI, HRII (High Resolution IR Imaging Spectrometer), and HRIV (High Resolution Visible CCD), are mounted on a separate



instrument platform together with the star trackers. The three instruments are nominally co-aligned as described by Klaasen, et al. 2008 [7] and Klaasen, et al. 2011 [20].

### Instrument Calibration & Flight Performance

The MRI instrument was originally calibrated by using in-flight data acquired during Deep Impact as well as pre-launch data taken during a thermal-vacuum test (TV4) performed in 2003. In-flight calibrations continued through the EPOXI mission to monitor performance and to provide additional data for refining the data calibration pipeline. Instrument calibration as well as the pipeline that is shared by Deep Impact and EPOXI is discussed by Klaasen, et al. 2008 [7]. This shared version of the pipeline was used to calibrate EPOCh data (exoplanets, Earth, and Mars). The science team improved the calibration process in June 2011. This version was used to process the Hartley 2 data archived as version 1.0 in PDS. For more information see the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17] or Klaasen, et al. 2011 [20].

Calibration analysis combining Deep Impact and early EPOXI data determined the two halves of the MRI CCD - the boundary being the two horizontal central lines 511 and 512 (zero based) - while physically consistent across the boundary, are biased during integration so that the centers of the two halves are apparently 1/6 pixel closer to the center, and the two boundary rows show a decrease in sensitivity of 1/6. Reconstructed image files space all lines evenly, so the true image is erroneously vertically pushed apart by 1/3 pixel at its center in these reconstructions. When making science measurements from MRI images, one must therefore be very careful to properly account for the two flaws introduced by the apparently narrow central lines on the CCD - a geometric error that separates the image by an extra 1/3 pixel at the horizontal quadrant boundary, and 2) insertion of extra total radiance into calibrated images due to the flat-field correction, which corrects for an apparent radiance deficit in the two central rows because of the smaller number of photons actually incident on those rows; this is only a problem for aperture photometry. See Belton, et al. (2011) [21] for a discussion of how the central horizontal gap was handled for aperture photometry of comet 9P/Tempel 1 for Deep Impact.

The MRI instrument generally performed as expected during flight. However calibration data acquired in 2008 for EPOXI show changes to the electronic crosstalk between the CCD quadrants since 2005. Therefore new crosstalk coefficients were calculated and incorporated into the calibration pipeline for EPOXI processing.

### 2.3.3 CCD Imaging Modes

The imaging modes for the HRIV and MRI CCD instruments are provided in Table 2. Modes where the light blocker opens and closes are identified by ‘shuttered’ in the Mode column. Modes where the light blocker remained open for each image are identified by ‘unshuttered’.

#	Mode Mnemonic	Mode	Stored Image Size (x & y)	# Serial Over-Clock Cols (x)	# Parallel Over-Clock Rows (y)	Minimum Commanded Exposure (ms)	Frame to Frame Time (sec)
1	FF	Full Frame (shuttered)	1024	8	8	0	1.634
2	SF1	Sub-Frame 1 (shuttered)	512	4	4	0	0.737
3	SF2S	Sub-Frame 2 (shuttered)	256	4	4	0	0.430
4	SF2N	Sub-Frame 2 (unshuttered)	256	4	4	4	0.232
5	SF3S	Sub-Frame 3 (shuttered)	128	2	2	0	0.312
6	SF3N	Sub-Frame 3 (unshuttered)	128	2	2	4	0.113
7	SF4O	Sub-Frame 4 (unshuttered)	64	0	1	4	0.062
8	SF4NO	Sub-Frame 4 (unshuttered)	64	0	0	4	0.062
9	FFD	Full-Frame Diagnostic (shuttered)	1024	8	8	0	1.634

Table 3 - Visible CCD (HRIV and MRI) Imaging Modes

The CCD arrays have several serial overclock columns (line samples) and several parallel overclock rows (lines) located around the edge of the array and the resulting images. **Pixels in the overclock areas are excluded from the MINIMUM and MAXIMUM values in the PDS labels.** See Hampton, et al. 2005 [4] for more details about the instrument modes and the overclock rows and columns.

### 2.3.4 CCD Filters

The filter characteristics for the HRIV and MRI CCD instruments are shown in Table 4. The characteristics of the filters for the HRIV and MRI instruments were:

Filter Wheel Position	MRI Center Wavelength (nm)	MRI Filter Width (nm)	MRI Filter Target Measurement	HRIV Center Wavelength (nm)	HRIV Filter Width (nm)
1	650	>700 <sup>a</sup>	Context	650	>700 <sup>a</sup>
2	514	11.8	C2 in coma	450	100
3	526	5.6	Dust in coma	550	100
4	750	100	Context	350	100 <sup>c</sup>
5	950	100 <sup>b</sup>	Context	950	100 <sup>b</sup>
6	650	>700 <sup>a</sup>	Context	650	>700 <sup>a</sup>
7	387	6.2	CN in coma	750	100
8	345	6.8	Dust in coma	850	100
9	309	6.2	OH in coma	650	100

<sup>a</sup>Filters in position 1 & 6 are uncoated fused silica and not band limited.

<sup>b</sup>The 950 nm filter is longpass.

<sup>c</sup>The coating on the 350 nm filter is shortpass; the substrate limits the short wavelength to about 320 nm. The dichroic beamsplitter limits the short cutoff to about 300 nm (for HRIV only).

Table 4 - HRIV and MRI Filters

## 2.4 Alignment of Instruments

The HRII, HRIV, and MRI instruments are nominally co-aligned as described by Klaasen, et al. 2011 [20]. Although the alignments changed slightly during EPOXI, Figure 1 illustrates the alignments as determined during flight for the Deep Impact mission. the figure is taken from Klaasen, et al. 2008 [7].

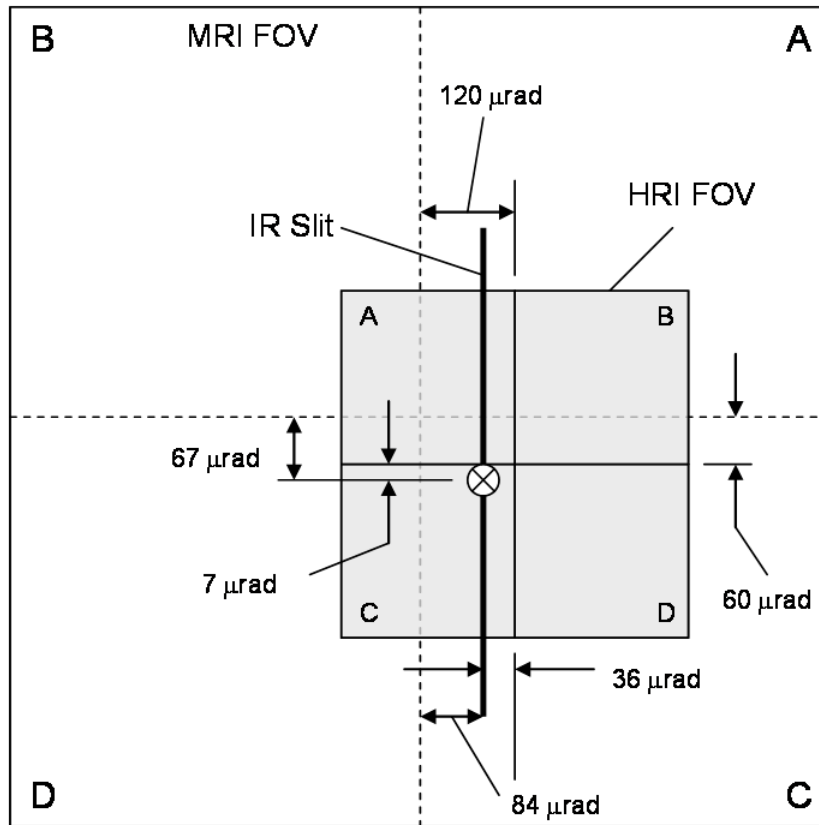


Figure 1 – Relative locations of the slit of the HRII spectrometer with respect to the fields of view for the HRIV and MRI CCDs as measured during flight of the Deep Impact mission. Please note the offsets are not to scale: only 25% of the IR slit is shown along with the central 120x120-pixel subarea of the MRI FOV and the central 250x250-pixel subarea of the HRIV FOV.

## 3 Archive Overview

### 3.1 Dataset and Data Volume Organization

For the EPOXI archive, the science data products generated by the SDC pipeline are grouped into PDS datasets by target (EPOCH exoplanet and planetary microlensing transits, EPOCH Earth, EPOCH Mars, comet Hartley 2, or calibrations), instrument (HRII, HRIV, or MRI), and reduction level (raw or calibrated). The EPOXI science datasets are organized using the subdirectories recommended by the PDS standards:

- CALIB
- CATALOG
- DATA
- DOCUMENT
- EXTRAS (optional)
- GEOMETRY (optional)
- INDEX

#### 3.1.1 CALIB Directory

The CALIB directory is included only in the calibrated datasets and provides the files used by the SDC pipeline to calibrate raw data for the exoplanet and planetary microlensing transit, Earth, and Mars observations for EPOXI and the DIXI Hartley 2 observations. The PROCESSING\_HISTORY\_TEXT keyword in the PDS data labels lists the calibration files from the CALIB directory that the pipeline used.

The EPOXI science team produces the calibration files as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations acquired during EPOXI.

#### 3.1.2 CATALOG Directory

The CATALOG directory contains catalog files required by PDS:

- DATASET.CAT - Description of the dataset (required reading)
- DIF.CAT - Description of the Flyby spacecraft
- <instrument.CAT> - Description of each instrument: HRII.CAT, HRIV.CAT or MRI.CAT
- EPOXI.CAT - Description of the mission
- PERSON.CAT - Contact information for personnel who created the dataset
- REF.CAT - List of publications cited in the catalog files
- <target>.CAT - One file for each mission target, for example, HAT\_P\_2.CAT, XO\_3.CAT, EARTH.CAT, and 103P\_HARTLEY\_2\_1986\_E2.CAT. Datasets

containing calibration target data include the CALIBRATION.CAT file. It is a generic catalog file for all calibration targets, where the TARGET\_DESC keyword in the PDS data labels provides the specific target name such as CANOPUS or DARK.

### 3.1.3 DATA Directory

The DATA directory contains the raw or calibrated science image data grouped by level of calibration, by target, then by the year and day of year of the UTC mid-point of the observation:

<DATA>/<level><target>/<year>/<day of year>

where:

- level is RADREV for calibrated but uncleaned data in units of radiance (calibration steps can be reversed to get back to the raw DN) or RAD for calibrated and irreversibly cleaned data in units of radiance; the RADREV and RAD products from the HRIV and MRI CCDs include a multiplicative factor for converting from units of radiance to I-over-F (unitless)
- target is only used for raw and calibrated EPOCH exoplanet observations datasets
- year is 4 digits
- day of year is 3 digits

### 3.1.4 DOCUMENT Directory

The DOCUMENT directory provides only the most relevant documentation and supplementary information pertaining to the raw and calibrated science datasets. It nominally includes:

- Project documents listed in section 1.2.2
- Image parameters tables
- A description of the quaternion found in the PDS labels
- Perpetual and leap year day-of-year calendars
- A report about the known limitations of the VIS and IR calibration pipeline and the resulting reduced data
- The EPOXI local Data Dictionary which consists of the full PDS Data Dictionary plus keywords specific to EPOXI, such as EPOXI:IMAGE\_MID\_TIME
- The EPOXI Data Management and Archive Plan [3]
- This Software Interface Specifications Document

Documentation for Deep Impact was extensive. Instead of maintaining documents for each Deep Impact dataset, the latest version of each document was gathered into a separate PDS dataset for the Deep Impact archive, DI-C-HRIV/MRI/ITS-6-DOC-SET-V1.0. Since documentation for EPOXI complements that for Deep Impact, the most current documentation for both missions is gathered and included in an updated version of the Deep

Impact and EPOXI Documentation Dataset, DI-C-HR2/HRIV/MRI/ITS-6-DOC-SET-V3.0 (effective for data acquisition through December 2010).

### **3.1.5 EXTRAS Directory**

The EXTRAS directory is optional. If present, the EXTRAS directory for an EPOCH dataset contains one JPEG image for each target. If present for the DIXI/Hartley2 encounter datasets, the EXTRAS directory contains a thumbnail file and a full-size JPEG file of each image found in the DATA directory and are grouped by the observation day of year. This directory may also be located in the DOCUMENT directory for permanent archiving.

### **3.1.6 GEOMETRY Directory**

The GEOMETRY directory is optional and is typically not included in an EPOXI science dataset because the project delivers a separate PDS dataset of SPICE kernels. However the project may include ASCII text tables of improved geometry and timing values for each observation if the corresponding values in the data product labels are based on older SPICE kernels.

### **3.1.7 INDEX Directory**

This directory contains a comma-separated, fixed-width, ASCII table for locating data products. Index files are required by PDS and include some values found in the data label that are relevant to science, such as TARGET\_NAME and START\_TIME.

## **3.2 Expected Datasets**

### **3.2.1 In-Flight Calibrations**

All raw (EDR), in-flight calibration data acquired during the various phases of the EPOXI mission are accumulated over time and grouped into datasets by instrument for the PDS archive. In-flight calibrations include:

- Lunar observations acquired during flybys of Earth by all three instruments,
- HRIV darks and STIM lamp frames to aid calibration of the EPOCH exoplanet transit and Earth observations,
- HRIV and MRI darks interspersed with DIXI observations of comet Hartley 2,
- Standard EPOXI cruise calibrations for all three instruments, and
- Additional calibrations designed to further test or retest a specific instrument or observing scenario, such as instrument checkout, as described in the DATASET.CAT file in the CATALOG directory and the *EPOXI In-Flight Calibration Summary* report [19] included in the datasets.

Calibration data acquired before August 2010 were archived as version 1.0 datasets. These have been superseded by version 2.0 which in-flight calibration data for the entire mission.

Instr. ID	Data Set ID	Volume Set ID	Data Products
HRII	DIF-CAL-HRII-2-EPOXI-CALIBRATIONS-V2.0	EPXCAL_0004	EDR: Raw, in-flight calibrations from Oct 2007 to Feb 2011
HRIV	DIF-CAL-HRIV-2-EPOXI-CALIBRATIONS-V2.0	EPXCAL_0005	EDR: Raw, in-flight calibrations from Oct 2007 to Feb 2011
MRI	DIF-CAL-MRI-2-EPOXI-CALIBRATIONS-V2.0	EPXCAL_0006	EDR: Raw, in-flight calibrations from Oct 2007 to Feb 2011

Instr. ID	Superseded Data Set ID	Volume Set ID	Data Products
HRII	DIF-CAL-HRII-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0001	EDR: Raw, in-flight calibrations from Oct 2007 through Jul 2010
HRIV	DIF-CAL-HRIV-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0002	EDR: Raw, in-flight calibrations from Oct 2007 through Jul 2010
MRI	DIF-CAL-MRI-2-EPOXI-CALIBRATIONS-V1.0	EPXCAL_0003	EDR: Raw, in-flight calibrations from Oct 2007 through Jul 2010

For these datasets, the TARGET\_NAME in the PDS labels is always set to the value “CALIBRATION”. The actual name of the target such as “CANOPUS” or “DARK” is provided by the TARGET\_DESC keyword in the labels.

If the SDC pipeline is modified after version 1.0 of the calibration datasets are delivered to PDS for review in 2009, then the project will redeliver all calibration-related data as version 2.0 at a later time. Also raw calibration data are acquired for the DIXI phase of the mission will be appended to the most current version of these datasets, and the version number will be incremented.

### 3.2.2 EPOCH

For the EPOCH phase of the mission, the following types of data will be archived by instrument into datasets by the reduction level:

- Raw (EDR) observations of eight stars with known transits by extra-solar planets and one planetary microlensing target as acquired by the HRIV instrument: Time series of continuous 50-second integrations were used with the clear #6 filter to observe each system for about three weeks, typically covering five or more transits as well as secondary eclipses. The stars observed for exoplanet transits are GJ 436, HAT-P-4, HAT-P-7, TRES-2, TRES-3, WASP-3, XO-2, XO-3, and MOA-2009-BLG-266 (microlensing target),
- Calibrated RADREV (RDR) observations of eight stars with known transits by extra-solar planets and one planetary microlensing target as acquired by the HRIV instrument,
- Raw (EDR) observations of Earth as acquired by the HRII, HRIV, and MRI instruments: Each observing period lasted approximately 24 hours to capture a full



rotation where the HRII spectra were acquired twice per hour and HRIV images were acquired every 15 minutes with the 450-, 550-, 650-, and 850-nm filters and once per hour with the filters centered on 350, 750 and 950 nm; MRI images were occasionally acquired as context images for the HRII spectra,

- Calibrated RADREV and RAD (RDR) observations of Earth as acquired by the HRII, HRIV, and MRI instruments. As noted in section 4.1.2, the RADREV and RAD products for HRIV and MRI include a multiplicative factor for converting from units of radiance to I-over-F (unitless),
- Raw (EDR) observations of Mars acquired by the HRII, HRIV, and MRI instruments using same image sequencing as the Earth observations, and
- Calibrated RADREV and RAD (RDR) observations of Mars acquired by the HRII, HRIV, and MRI instruments. As noted in section 4.1.2, the RADREV and RAD products for HRIV include a multiplicative factor for converting from units of radiance to I-over-F (unitless).

The EPOCH datasets are:

Instr. ID	Data Set ID	Volume ID	Data Products
HRIV	DIF-X-HRIV-2-EPOXI-EXOPLANETS-V1.0	EPXEXO_0001	EDR: Raw exoplanet transit observations grouped by target, then mid-observation date
	DIF-X-HRIV-3-EPOXI-EXOPLANETS-V1.0	EPXEXO_0002	RDR: Calibrated (RADREV only) exoplanet transit observations, grouped by target then mid- observation date
HRII	DIF-E-HRII-2-EPOXI-EARTH-V1.0	EPXEAR_0001	EDR: Raw Earth observations grouped by mid- observation date
	DIF-E-HRII-3/4-EPOXI-EARTH-V1.0	EPXEAR_0002	RDR: Calibrated (RADREV and RAD) Earth observations grouped by mid-observation date
HRIV	DIF-E-HRIV-2-EPOXI-EARTH-V1.0	EPXEAR_0003	EDR: Raw Earth observations grouped by mid-observation date
	DIF-E-HRIV-3/4-EPOXI-EARTH-V1.0	EPXEAR_0004	RDR: Calibrated (RADREV and RAD) Earth observations grouped by reduction level then mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
MRI	DIF-E-MRI-2-EPOXI-EARTH-V1.0	EPXEAR_0005	EDR: Raw Earth observations grouped by mid-observation date

	DIF-E-MRI-3/4-EPOXI-EARTH-V1.0	EPXEAR_0006	RDR: Calibrated (RADREV and RAD) Earth observations grouped by reduction level then mid-observation date. The MRI labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
HRII	DIF-M-HRII-2-EPOXI-MARS-V1.0	EPXMAR_0001	EDR: Raw Mars observations grouped by mid- observation date
	DIF-M-HRII-3/4-EPOXI-MARS-V1.0	EPXMAR_0002	RDR: Calibrated (RADREV and RAD) Mars observations grouped by mid-observation date
HRIV	DIF-M-HRIV-2-EPOXI-MARS-V1.0	EPXMAR_0003	EDR: Raw Mars observations grouped by mid-observation date
	DIF-M-HRIV-3/4-EPOXI-MARS-V1.0	EPXMAR_0004	RDR: Calibrated (RADREV and RAD) Mars observations grouped by reduction level then mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
MRI	DIF-M-MRI-2-EPOXI-MARS-V1.0	EPXMAR_0005	EDR: Raw Mars observations grouped by mid-observation date
	DIF-M-MRI-3/4-EPOXI-MARS-V1.0	EPXMAR_0006	RDR: Calibrated (RADREV and RAD) Mars observations grouped by reduction level then mid-observation date. The MRI labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.

If the SDC pipeline is modified after version 1.0 of these datasets are delivered to PDS for review in 2009, then the project may redeliver datasets as version 2.0 at a later time.

### 3.2.3 DIXI/Hartley 2 Encounter

During the DIXI/Hartley 2 Encounter phase of the mission, the following types of data will be acquired and archived by instrument into Hartley2-specific datasets of raw data (EDR) and calibrated data (RDR – RADREV and RAD with a multiplicative factor in the labels for converting CCD radiance data to unitless I-over-F):

- Approach imaging of comet 103P/Hartley 2 by the HRIV and MRI CCDs beginning 60 days before the encounter (E-60) and by the HRII spectrometer beginning at E-34 days,
- Imaging of comet 103P/Hartley 2 by all three instrument during the flyby encounter, and
- Lookback imaging of Hartley 2 by all three instrument extending to 21 days after the encounter (E+21).

The DIXI science datasets are:

Instr. ID	Data Set ID	Volume ID	Data Products
HRII	DIF-C-HRII-2-EPOXI-HARTLEY2-V1.0	EPXH2_0001	EDR: Raw Hartley 2 observations grouped by mid- observation date
	DIF-C-HRII-3/4-EPOXI-HARTLEY2-V1.0	EPXH2_0002	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date
HRIV	DIF-C-HRIV-2-EPOXI-HARTLEY2-V1.0	EPXH2_0003	EDR: Raw Hartley 2 observations grouped by mid-observation date
	DIF-C-HRIV-3/4-EPOXI-HARTLEY2-V1.0	EPXH2_0004	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date. The HRIV labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.
MRI	DIF-C-MRI-2-EPOXI-HARTLEY2-V1.0	EPXH2_0005	EDR: Raw Hartley 2 observations grouped by mid-observation date
	DIF-C-MRI-3/4-EPOXI-HARTLEY2-V1.0	EPXH2_0006	RDR: Calibrated (RADREV and RAD) Hartley 2 observations grouped by mid-observation date. The MRI labels and FITS headers include a multiplicative factor for converting from radiance units to I-over-F; see section 4.1.2 for more information.

### 3.2.4 Higher-Level Datasets for EPOCH and DIXI

Several higher-level products such as instrument temperatures, photometry tables, shape models, and SPICE kernels generated by the mission or the science teams are archived into the PDS. The proposed datasets are listed below. These datasets are typically simple and self-explanatory and are thus not described in this document.

Instr. ID	Data Set ID	Volume ID	Data Products
HRII, HRIV, MRI (and ITS)	DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V3.0 DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V2.0	DIDOC_0003 DIDOC_0002	Deep Impact and EPOXI documentation.  Version 3.0 is effective for the entire EPOXI mission from Oct 2007 to Feb 2011. It supersedes version 2.0 that is effective only through Dec 2008.
HRII, HRIV, MRI	DIF-C/E/X-SPICE-6 -V1.0	EPXSP_0001	SPICE kernels for the EPOXI mission.
HRII, HRIV, MRI	DIF-CAL-HRII/HRIV/MRI-6-EPOXI-TEMPS-V2.0 DIF-CAL-HRII/HRIV/MRI-6-EPOXI-TEMPS-V1.0	EPXTMP_0002 EPXTMP_0001	ASCII tables of averaged instrument sensor temperatures from telemetry.  Version 2.0 covers the entire mission from 2007 to 2011. It supersedes version 1.0 that contains data only from 2007 and 2008.
HRIV	DIF-X-HRIV-5-EPOXI-EXOPLANETS-PHOT-V1.0	EPXEXO_0003	ASCII and binary tables of photometry derived from EPOCH observations of exoplanet transits
HRIV	DIF-CAL-HRIV-6-EPOXI-STELLAR-PSFS-V1.0	EPXPSF_0001	Point spread functions for EPOXI calibrator stars provided as FITS images.
HRIV, MRI	DIF-C-HRIV/MRI-5-HARTLEY2-SHAPE-V1.0	EPXH2_0007	Shape model of comet 103P/Hartley 2 derived from HRIV and MRI images
HRII	DIF-C-HRII-5-HARTLEY2-THERMAL-MAPS-V1.0	EPXH2_0008	Temperature maps of the surface of 103P/Hartley 2 derived from HRII spectra
MRI	DIF-C-MRI-5-HARTLEY2-PHOTOMETRY-V1.0	EPXH2_0009	ASCII table of photometry derived from MRI science and Nav images of 103P/Hartley 2

## 4 Science Data Products

This section describes the raw Level 2 (EDR) and the calibrated Level 3 and 4 (RDR) data products generated by the SDC pipeline and included in the science datasets listed previously in sections 3.2.1, 3.2.2, and 3.2.3. We define science data products as the raw and calibrated HRII spectral and HRIV and MRI CCD visible image data acquired during the entire EPOXI mission.

### 4.1 Overview of Data Products

#### 4.1.1 Raw FITS Data Product (EDR)

A raw science data product consists of a detached PDS label that points to a FITS file composed of 1) a two-dimensional primary image array with a header and 2) a two-dimensional image extension with a header that provides a pixel-by-pixel quality map. In particular,

**For HRII:** The raw FITS file (\*.fit) consists of a two-dimensional spectral image in units of data number (raw counts) and one image extension for a pixel-by-pixel quality flags map described in section 4.1.3. Fastest varying axis provides increasing wavelengths from about 1.05 to about 4.8 microns. The slowest varying axis is in the spatial direction.

**For HRIV and MRI:** The raw FITS file (\*.fit) consists of a two-dimensional CCD image in units of data number (raw counts) and one image extension for a pixel-by-pixel quality flags map described in section 4.1.3.

Raw data are archived as received on the ground, either as uncompressed (i.e., never compressed) or compressed integer data. Image data could be compressed by means of a look-up table that converted 14-bit data to 8-bit values onboard the spacecraft. Raw, compressed data are stored in the FITS files as FITS files as 8-bit unsigned integers (i.e., exactly as received on the ground).

For the HRII instrument, uncompressed data consist of 14-bit signed integers stored in the FITS files as 16-bit signed integers with no offset. For the HRIV and MRI instruments, uncompressed data consist of 16-bit unsigned integers stored in the FITS files as 16-bit signed integers with an offset of 32768. The byte order for all FITS files in this archive is most significant bit first (MSB).

One raw product is archived for each frame acquired by the HRII, HRIV, and MRI instruments of the EPOCH and DIXI targets (extrasolar targets, Earth, Mars, and Hartley 2) as well as the calibration sources (e.g., dark frames and standard stars).

## 4.1.2 Calibrated FITS Data Product (RDR)

Identical to the raw science data product, a calibrated Level 3 or 4 data product also consists of a detached PDS label that points to a FITS file (\*.fit) composed of 1) a two-dimensional primary image array with a header and 2) a two-dimensional image extension with a header that provides a pixel-by-pixel quality map and 3) these additional two-dimensional image extensions depending on the instrument:

**For HRII:** The FITS file includes image extensions and headers for a spectral wavelength map, a spectral bandwidth map, and a signal-to-noise ratio map (\*.fit). These extensions are described in sections 4.1.4 through 4.1.6.

**For HRIV and MRI:** The FITS file includes an image extension and header for a signal-to-noise ratio map, (\*.fit). This extension is described in section 4.1.4. For Hartley 2 images, the pipeline includes an image extension that captures the DN values used to de-stripe the data. It is described in section 4.1.7.

The calibration process creates two types of reduced data products (that is, primary image arrays and accompanying extension) that are archived for EPOXI:

**RADREV:** These Level 3 uncleaned radiance image data, designated by the mnemonic 'RADREV', are provided in units of radiance as Watts/(meter\*\*2 steradian micron). These data are considered reversible because the applied calibrations can be removed to get back to the original, raw data numbers. This type of calibrated product is archived for data of the EPOCH and DIXI targets (extrasolar targets, Earth, Mars, and Hartley 2) acquired by the HRII, HRIV, and MRI instruments mission.

**RAD:** These Level 4, irreversibly cleaned, radiance data are designated by the mnemonic 'RAD' and are provided in units of radiance as Watts/(meter\*\*2 steradian ). These data have been cleaned in such a way (interpolation over bad pixels, cosmic ray removal, etc.) such that the applied calibrations cannot be backed out. This type of calibrated product is archived only for EPOCH Earth/Mars data and DIXI Hartley 2 data acquired by the HRII, HRIV, and MRI. Please note that all overscan rows and columns that border the active area of the VIS CCDs have been removed from (overwritten with 0 in) in the RAD HRIV and MRI products.

Additionally the RADREV and RAD products for HRIV and MRI can be converted to unitless I-over-F data by multiplying the calibrated image by the value provided by the EPOXI:DATA\_TO\_IOVERF\_MULTIPLIER keyword in the PDS label (or the MULT2IOF keyword in the FITS header). This multiplier is only provided for VIS data.

Calibrated spectral and CCD image data are stored as 32-bit IEEE signed real numbers in the FITS files. The byte order is most significant bit first (MSB).

### 4.1.3 Quality Flags Map (FITS Extension)

The Quality Flags map is the first FITS header and image extension in a raw or reduced science data product. Produced by the SDC pipeline for HRII, HRIV, and MRI data, this extension provides one byte of eight data quality flags or bits for each pixel in the primary image array. For each byte in the map, representing one pixel in the primary image array, each bit acts as a flag that is set to 1 if the given criterion is met for that pixel. These flags or bits are described next and are listed from the least-significant (0 or right-most) to most-significant (7 or left-most) within a byte:

MSB				LSB			
7	6	5	4	3	2	1	0

- 0. Bad Pixel - This pixel is a known bad pixel.
- 1. Missing - The datum for this pixel was not received from the spacecraft.
- 2. Despiked - This pixel was modified by the despiking routine.
- 3. Interpolated - This pixel was reclaimed by interpolating from its neighbors.
- 4. Some Saturated - The raw value for this pixel is above the point where pixels are partially full-well saturated. For VIS instruments, this occurs at 11,000 DN, while for the IR spectrometer, this occurs at 8,000 DN.
- 5. Most Saturated - The raw value for this pixel is above the point where pixels are full-well saturated. For VIS instruments, this occurs at 15,000 DN, while for the IR spectrometer, this occurs at 11,000 DN. Bit flag 4 (above) will also be set in this case because raw value exceeded the limit for that flag, too.
- 6. ADC Saturation - The analog-to-digital converter (ADC) was saturated for this pixel.
- 7. Ultra Compressed - The raw value for this pixel was in a compression bin so large that the value contains very little useful information.

For example, if the pixel is bad and has been reclaimed by interpolation, the decimal value in the quality map will be  $2^0 + 2^3 = 9$ . In the normal FITS format for the calibrated image, this map exists as the first image extension. Section 5.7 explains how to use IDL to access the information in this map.

For a raw image, only the missing data bit (#1) is turned on (set to 1). The remaining seven bits are set by the calibration pipeline for calibrated images only and are thus set to zero for all raw images.

### 4.1.4 Signal-to-Noise Ratio Map (FITS Extension)

The Signal-to-Noise Ratio map is the last FITS header and image extension in a Level 3 or 4 calibrated science data product. Produced by the SDC calibration pipeline for HRII, HRIV, and MRI data, this extension provides the signal-to-noise ratio as calculated by the pipeline for each pixel in the primary image array. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers.

#### **4.1.5 IR Spectral Wavelength Map (FITS Extension)**

The IR Spectral Wavelength map is the second FITS header and image extension in a Level 3 or 4 calibrated HRII science data product. Produced by the SDC calibration pipeline only for HRII data, this extension provides the spectral registration or wavelength for each pixel in the primary image. This extension is required because the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers.

#### **4.1.6 IR Spectral Bandwidth Map (FITS Extension)**

The IR Spectral Bandwidth map is the third FITS header and image extension in a Level 3 or 4 calibrated HRII science data product. Produced by the SDC calibration pipeline only for HRII data, this extension provides the spectral bandwidth for each pixel in the primary image. This extension is required because the wavelength for each pixel shifts with thermal changes within the instrument. The image extension has the same dimensions as the primary image array. Data values are stored as 32-bit IEEE real numbers.

#### **4.1.7 VIS De-stripe Values (FITS Extension)**

The VIS de-stripe values is the third FITS header and image extension in a Level 3 or 4 calibrated HRIV or MRI science data product. Produced by the SDC calibration pipeline only for Hartley 2 VIS images, this extension contains the two columns of DNs subtracted from every non-overclock column in the left and right halves of the primary image array by the destriping module of the Hartley2 calibration pipeline. If the pipeline determined that stripe removal was not necessary for an image then DN values in this extension will be set to 0. Data values are stored as IEEE real numbers.

#### **4.1.8 Pipeline Calibration Files**

Files used by the SDC pipeline to generate the calibrated science data products are produced by the EPOXI science team as a result of analyses of thermal-vacuum and in-flight calibration data from Deep Impact and in-flight calibrations from EPOXI. Calibration files are provided as FITS image files (\*.fit) or as flat ASCII tables (\*.tab) with detached PDS labels and are packaged in the CALIB directory of the appropriate calibrated datasets. A PDS label for a calibrated science data product includes the PROCESSING\_HISTORY\_TEXT keyword that provides a list of the calibration files the pipeline used.

##### **4.1.8.1 HRII Calibration Files**

**ABSCALIR** - This subdirectory contains tables of the absolute calibration constants for all instrument (image) modes. The first column specifies the wavelength for the reading. The second column specifies the conversion factor for areas not under the anti-saturation filter. The last column contains the conversion factors for areas under the anti-saturation filter.



Two identical files, one with a placeholder of '000' and another with '999' were created for the pipeline to allow existing processes to correctly execute.

**ADCLUT** - This subdirectory contains a look up table for the correction of uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

**BADPIX** - This subdirectory contains maps that identify bad pixels for all instrument modes. These are master maps where a pixel is flagged bad if it was determined to be bad in the four in-flight science calibrations. Bad pixels are set to a value of 1. Also, the reference rows and columns around the edges of the array are set to 1. Good pixels are set to 0.

**BIAS** - This subdirectory contains a dummy bias correction map for each instrument mode. All bias maps are set to zero to prevent the automated calibration pipeline from changing data.

**DECOMPRS** - This subdirectory contains the four lossy look up tables used to decompress raw data.

**DRKMODEL** - This subdirectory contains master dark frames for all instrument modes.

**FLAT** - This subdirectory contains flat fields for the IR instrument.

**LINDN** - This subdirectory contains mode-specific maps of the four coefficients used in a polynomial to linearize the raw data numbers. Mode 5 must use the mode 1 file. Modes 6 and 7 must use the mode 4 file.

**PSF** - This subdirectory contains a default point-spread function used by the calibration pipeline. This file is a placeholder that simply provides a centered delta function to prevent the pipeline from making any changes to the data. The project does not plan to improve it.

**QE** - This subdirectory contains the quantum efficiency curve for the IR focal plane array.

**SPECMAP** - This subdirectory contains temperature-dependent, pixel-by-pixel, spectral registration maps for each instrument mode. The first dimension provides the wavelength; the second provides the spectral resolution (delta wavelength). The temperature string in the file names refers to the temperature of the IR spectrometer for which a map is applicable.

**XTALK** - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the two quadrants of the IR array. There is one table for each instrument mode. The crosstalk between IR quadrants is negligible, thus the table values are set to zero to keep the automated calibration pipeline from changing data.

### 4.1.8.2 HRIV and MRI Calibration Files

**ABSCALVS** - This subdirectory contains ASCII text tables of the absolute calibration constants for all instrument (image) modes. The first column in a table specifies the constant for converting raw data numbers to units of radiance,  $W/(m^2 \text{ sr } \mu m)$ . The second column specifies the constant for converting from units of radiance to units of reflectance (i.e., I-over-F or the observed radiance over the input solar radiance, unitless).

**ADCLUT** - This subdirectory contains a look up table for the correction of uneven bit weighting caused by the analog-to-digital conversion. The single table applies to all instrument modes. As of this archive, the corrections had not been derived. Therefore, the input pixel values are the same as the output values to prevent the automated calibration pipeline from changing the data.

**BADPIX** - This subdirectory contains maps that identify bad pixels for all instrument modes. Bad pixels are set to a value of 1. Good pixels are set to 0. Pixels in the serial and parallel overclock columns and rows are flagged as good (0). For each image mode, there is one row of warm pixels near the top and bottom edge. These rows are flagged as bad (1).

**BIAS** - This subdirectory contains bias correction maps for instrument modes 7 and 8 that do not have overlocks (that are used for bias subtraction for modes 1-6, and 9).

**DECOMPRS** - This subdirectory contains the four lossy look up tables used to decompress raw data.

**DRKMODEL** - This subdirectory contains mode-dependent files of physical parameters of the CCD for modeling the dark current.

**FILTERS** - This subdirectory contains one transmission profile table each HRIV or MRI filter.

**FLAT** - This subdirectory contains flat fields for every combination of instrument mode and filter.

**PSF** - This subdirectory contains maps of the point-spread function for all HRIV or MRI filters. For MRI, the PSF is simply a centered-delta function to prevent the pipeline from changing the data, and the project does not plan to improve it. For HRIV, the PSF files can be used to deconvolve an out-of-focus HRIV image. Also for HRIV, PSFs for each EPOCH extrasolar target and stellar calibration targets will be included if available.

**QE** - This subdirectory contains the quantum efficiency curves for the HRIV or MRI CCD.

**XTALK** - This subdirectory contains tables that specify the amount of gain from electronic cross talk that occurs between all possible combinations of the four quadrants of the CCD. There is one table for each instrument mode.

## **4.2 Data Product Generation and Labeling**

### **4.2.1 Data Pipeline Overview**

All raw and calibrated science data products (FITS files and PDS labels) described in this document are generated by a data and calibration pipeline that is maintained by the DI/EPOXI Science Data Center SDC at Cornell University. The pipeline takes raw telemetry with embedded data, as downloaded from the DI flyby spacecraft, and constructs raw FITS spectral or visible image files and PDS labels. Images that were compressed onboard the spacecraft are received on the ground in the compressed format. The data pipeline keeps the associated raw FITS images in the same compressed format, and these data are archived in the *compressed* format.

Next, the pipeline inputs the raw FITS files, decompresses any compressed data, calibrates the data through the RADREV and RAD streams, and outputs calibrated data as radiance FITS files (RADREV and RAD). For the HRIV and MRI instruments, the I/F stream in the pipeline calculates a multiplicative factor to convert a RADREV radiance image to unitless IFREV or RAD radiance image to unitless IF. This multiplicative factor is provided in the PDS labels (see section 4.1.2 for more information). The calibration process is briefly described below. For details about the SDC, the flow of data, and the calibration pipeline refer to the EPOXI Data Management and Archive Plan [3], Klaasen, et al. 2005 [5], and Klaasen, et al. 2008 [7].

Calibration files, such as bad pixel maps, are the result of various analyses by the science teams of ground-based thermal-vacuum and in-flight calibration data from Deep Impact as well as in-flight calibrations acquired throughout the EPOXI mission. Calibration files are stored at the DI/EPOXI SDC and are used by the calibration portion of the pipeline. The files used by the pipeline to calibrate raw HRIV, HRIV, and MRI data are included in the reduced EPOXI datasets.

PDS data labels are generated by the data pipeline using information stored in the FITS primary and extension headers. All PDS data labels are detached. (Many values in a label are extracted from FITS image header keywords which are defined in 'EPOXI Data Archive: FITS Keyword Descriptions for the Primary Image Header' by Carcich, 2009 [14] located in the Deep Impact and EPOXI documentation set.)

### **4.2.2 Calibration Process – Prior to August 2010**

The version of the calibration pipeline used to process data acquired from October 2007 through July 2010, including version 1.0 of EPOCH datasets, was a duplicate the final version of the pipeline for the Deep Impact mission. However several minor improvements were applied to the base pipeline before data were processed:

- New bad pixel maps for HR11 to account for an increase from 1.15% to 1.48% in the fraction of anomalous pixels since DI,
- New calibration constants for the HR14 950-nm (#5) filter to account for a 6% increase of its response since DI, and
- New crosstalk coefficients both the HR14 and MRI instruments to account for changes in the electronic crosstalk between the CCD quadrants since DI.

The goal of the data calibration process for the HR11, HR14, and MRI instruments is to:

- Convert the raw data numbers (DNs) returned from each pixel in each image or spectrum to absolute scientific units of scene radiance (reversible RADREV or irreversible RAD).
- Calculate a multiplicative factor to convert or scale HR14 and MRI radiance products (RADREV and RAD) to units of reflectance (I/F).
- Determine from where in the scene or its surroundings the photons originated that produced the signal in each pixel.

For a thorough discussion of this version of the pipeline and its processing steps, refer to the draft of Klaasen, et al. 2008 [7] included in the version 1.0 calibrated EPOCH datasets. Please note that various steps within the calibration pipeline can be turned on or off. The DATASET.CAT file in the CATALOG directory of each calibrated dataset provides a list of the processes that were active in the pipeline.

#### **4.2.3 Calibration Process – As of June 2011**

The EPOCH calibration pipeline was improved in June 2011 for data acquired during the DIXI/Hartley 2 phase of the mission. This version was used to produce version 1.0 of the calibrated Hartley 2 science datasets for the HR11, HR14, and MRI instruments.

The pipeline and its processing steps are described in the project report *EPOCH – Hartley 2 Calibration Pipeline Summary* [19] included in the DOCUMENT directory of the calibrated datasets. The report also discusses known limitations of the pipeline as of June 2011. Please note that various steps within the calibration pipeline can be turned on or off. The DATASET.CAT file in the CATALOG directory of each calibrated dataset provides a list of the processes that were active in the pipeline.

#### **4.2.4 Image Orientation and Pixel Readout Order**

This section was excerpted from an incomplete draft of the DI Calibration Pipeline paper [7].

In order to understand the data from the instruments at the level of calibrations, it is important to understand both the way in which pixels are read out from the detector and also the way in which they are stored in the resultant FITS/PDS images. Throughout this paper we identify the four physical quadrants of the detectors as A through D (or just A and B in

the case of the IR detector, which only uses 2 of the quadrants on the physical detector). The nomenclature in Figures 2a, 2b, and 3 assumes the standard convention for displaying FITS files: the faster-varying index in the data file (for line samples) is displayed to the right and the slower varying index (for lines) is displayed up (in PDS images the directions are controlled by keywords, which for our images are set to match the standard FITS display). Thus, the first byte of the FITS/PDS file appears in the lower-left corner of the window and the last byte in the FITS/PDS file appears in the upper-right. All FITS/PDS archival images are structured to display a true image of the sky, with arbitrary rotation about the center of the image (ecliptic north is to the right in this particular image), rather than a mirror image of the sky. The image header information in the downlinked data is always written in the first 100 bytes of quadrant A.

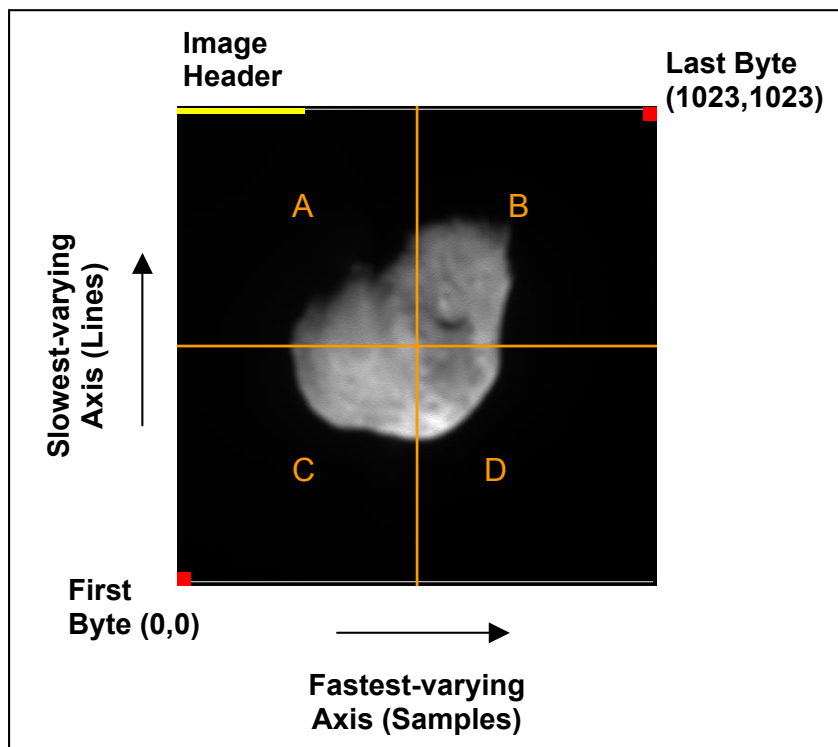


Figure 2a - A full-frame, HRI-VIS image taken shortly before impact, displayed with the FITS convention. This orientation reproduces a true sky image. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

Figure 2a shows an inflight, visible image from HRI, in which the directions in the labels are referred to by the order of the bytes (pixels) in the archived data files. The images from the thermal-vacuum calibrations have the same orientation. For MRI, the different number of reflections in the optical path of the instruments lead to a right-left mirroring between the physical quadrants and the image of the sky and also a mirroring between the thermal-vacuum calibrations and the inflight data. Since the quadrant labeling refers to physical

quadrants, the thermal-vacuum calibrations have the same orientation of the quadrants for all three instruments (A in upper left and D in lower right), but they have different orientations for inflight data, i.e., the inflight data for MRI have quadrant A in the upper right and quadrant D in the lower left for normally displayed FITS images. Thus the quadrants for inflight images from MRI are shown in Figure 2b.

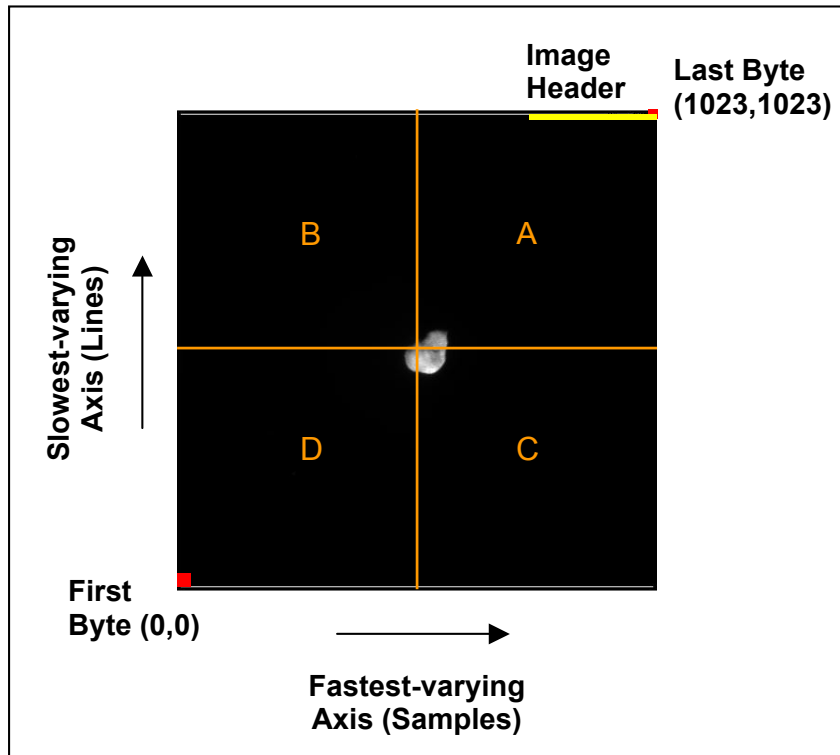


Figure 2b - A full-frame, MRI image taken at nearly the same time as the HRI-VIS image in Figure 2a. Displayed with the FITS convention, a true sky image is reproduced. The first and last bytes are those read from the FITS file and are not connected with the order of readout. Quadrants A, B, C and D noted throughout this paper are labeled in the image.

The readout order of the pixels is independent of the order of bytes in the FITS images since each quadrant is read out independently in parallel, and the bytes are then rearranged into an image. The direction of the split-frame rapid transfer is up and down in Figures 2a and 2b, symmetric about the centerline. This affects the smear of bright sources in short exposures. After shifting to the shielded region of the detector, the top and bottom rows are read out first (top and bottom of the relevant subframe when only a subframe is read), and in each of these rows the outermost pixels are read out first. The rows immediately above and below the centerline are read out last, and within these two rows, the pixels immediately adjacent to the centerline are read out last. The header information is overwritten on the first 100 bytes of quadrant A (upper left quadrant for HRI inflight images and upper right quadrant for in-flight images with MRI) after the image is constructed. Overclocked pixels and rows are read out

after the true pixels, but they are moved to the outside of the FITS/PDS image to preserve the contiguity of the image in normal displays.

The situation for the IR spectrometer is shown in Figure 3. The normally displayed image, whether using the FITS standard display convention or displaying via the relevant PDS keywords, will have wavelength increasing from left to right and the long spatial dimension of the slit oriented vertically. The vertical spatial direction in the spectrometer image is the same as in the HRI visible image, terminator at the top and limb at the bottom for a spectrum at the time of Figure 2a. There are only two quadrants used (as shown in Figure 4), although the actual detector has two additional quadrants that are not exposed to light and are not read out. The orientation is the same both for inflight data and for thermal-vacuum calibrations, with A is on the left in a standard FITS/PDS display and B is on the right. When the image is constructed, the header information is overwritten on the first 100 bytes of quadrant A.

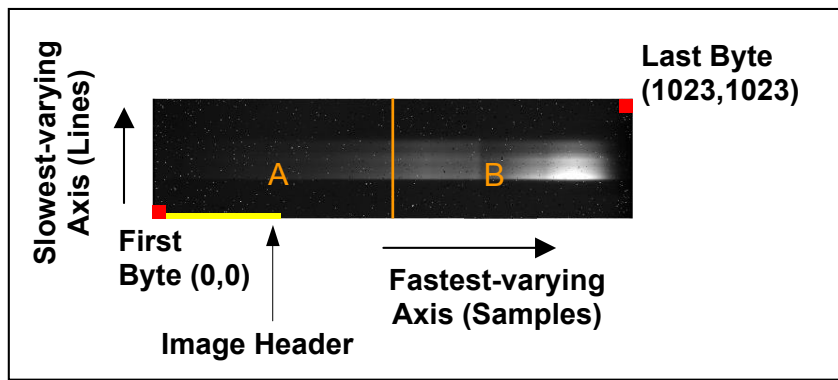


Figure 3 - A full-frame, HRIIR image taken shortly before impact, displayed with the FITS convention. For this FITS display, the wavelength increases as the fastest-varying axis increases to the right. The slowest-varying axis is the spatial direction along the slit. The first and last bytes are those read from the FITS file and are not connected with the order of readout. IR quadrants A and B noted throughout this paper are labeled in the image.

Since the IR detector is reset and read out on a pixel-by-pixel basis, the readout order affects the actual time at which a pixel is exposed, unlike the situation for the visible CCDs. Each pixel has the same exposure duration, but the exposure of the last pair of pixels read out does not start until one integration delay time plus  $\sim 2$  ms before the first pair of pixels is read out – except for the ALTF mode that has different read and reset timing causing the effective exposure time to vary with line number, i.e., along the slit in the spatial direction (see the project report *EPOXI – Hartley 2 Calibration Pipeline Summary* [17]). As with the lower half of the visible images, the bottom row is read out first, and within that row the outermost (leftmost and rightmost) pixels are read out first. The spectral row at the upper end of the slit in this standard display is read out last, and within that row the two pixels on either side of the center line are read out last. The header information is again written over the first 100 bytes of quadrant A, now in the lower left of a normal display.

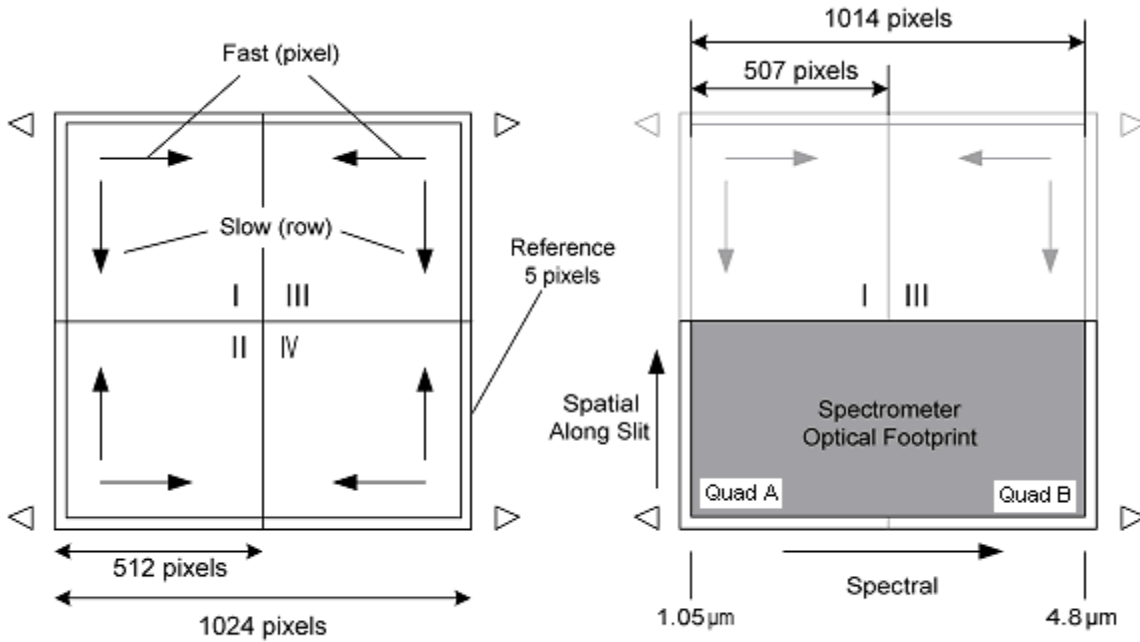


Figure 4 - IR focal plane array architecture ([4], used with permission). The left panel shows the architecture for the full IR FPA. The right panel shows the spectrometer mapping onto the FPA. Only Quads II (A) and IV (B) are used; Quads I and III are not used.



## 4.2.5 Data File Naming Conventions and Product IDs

The naming convention for the products in the data directory for the raw and calibrated datasets is:

iiYYMMDDHH\_eeeeee\_nnn{\_xx}.fit or .lbl

where:

- ii = instrument mnemonic: “hi” for the HRI IR Spectrometer, “hv” for the HRI Visible CCD, and “mv” for the MRI Visible CCD
- YYMMDDHH = Abbreviated UTC time stamp for the mid-point of the observation: YY is the last two digits of the year, MM is the month, DD is the day, and HH is the hour (00 to 23)
- eeeeeee = exposure ID
- nnn = image number within the exposure ID
- xx = identifies the level of calibration: “rr” for RADREV, “r” for RAD, and “if” for I-over-F (reflectance); not used for RAW

This convention guarantees unique file names within a PDS dataset. The value for the PRODUCT\_ID keyword in the PDS data labels is formed from the FITS file name where the period before the extension is replaced with an underscore character. PRODUCT\_IDs are unique within each dataset as required by PDS.

## 4.3 Standards Used in Data Product Generation

### 4.3.1 PDS Standards

The version 3, PDS3, of the PDS Standards Reference [1] and revision E of the PDS Data Dictionary and the EPOXI Local Data Dictionary [2] were followed when generating the data products.

### 4.3.2 Time Standards

Times given in the PDS labels are UTC at the EPOXI spacecraft, unless otherwise specified.

### 4.3.3 Reference Frame Standards

PDS labels for raw and calibrated science FITS data products contain keywords that provide geometry-related values based on the inertial reference frame, Earth mean equator J2000 (EMEJ2000). The exception is the ECLIP\_NORTH\_CLOCK\_ANGLE keyword that is in

the Ecliptic J2000 frame (ECLIPJ2000). Definitions of geometry keywords found in the raw and calibrated science labels are found in section 4.5 of this document.

#### **4.3.4 Time- and Geometry-Related Keywords**

All time-related keywords in the data labels, except `EARTH_OBSERVER_MID_TIME`, are based on the clock on board the flyby spacecraft. `EARTH_OBSERVER_MID_TIME` provides the UTC when an Earth-based observer should have been able to see an event recorded by the instrument.

The SDC pipeline was not able to automatically determine the proper geometric information for the target of choice in some cases. When these parameters could not be computed, the corresponding keywords in the data labels are set to a value of unknown, 'UNK'. Also if `GEOMETRY_QUALITY_FLAG` is set to 'BAD' or `GEOMETRY_TYPE` is set to 'PREDICTED' in the PDS labels, then this indicates the geometry values are not accurate and should be used with caution. The value 'N/A' is used for some geometry-related keywords in the data labels because these parameters are not applicable for certain calibration targets.

Observational geometry values are based on the mid-obs time (`IMAGE_MID_TIME`) and are corrected for light time and stellar aberration. Target-to-sun values were computed at the time the light left the target that reached the spacecraft at the mid-obs time. Earth-observer-to-target values were computed at the time the light that left the target, which reached the spacecraft at the mid-obs time, reached Earth.

#### **4.3.5 Image Orientation**

The raw and calibrated science FITS images in this PDS archive are those produced by the data pipeline and analyzed by the science team. These images are oriented such that the fastest-varying FITS axis (samples) increases to the right of and the slowest-varying FITS axis (lines) increases to the top such that the first pixel read from the FITS file is displayed in the lower-left corner of a graphics window and the last pixel in the upper-right. These sample and line directions are provided by the `LINE_DISPLAY_DIRECTION` and `SAMPLE_DISPLAY_DIRECTION` keywords in the PDS labels.

This orientation provides views “as seen” from the spacecraft and places ecliptic north approximately to the right and the sun towards the bottom for all images from the beginning of EPOXI through the approach and shield mode portions for the Hartley 2 encounter of DIXI. As the spacecraft comes out of shield mode, it will turn back and continue imaging the comet. Therefore, all DIXI/Hartley 2 lookback images have ecliptic north approximately to the left and the sun approximately towards the top. See section 4.3.4 for more information.

The directions to celestial north, ecliptic north, the Sun, and the body positive pole position (for Hartley 2 observations only) are provided in data labels by

CELESTIAL\_NORTH\_CLOCK\_ANGLE, ECLIPTIC\_NORTH\_CLOCK\_ANGLE, SUN\_DIRECTION\_CLOCK\_ANGLE, and BODY\_POSITIVE\_POLE\_CLOCK\_ANGLE keywords and are measured clockwise from the top of the image when is displayed in the correct orientation defined by SAMPLE\_DISPLAY\_DIRECTION and LINE\_DISPLAY\_DIRECTION. Please note the aspect of the North celestial pole in an image can be computed by adding 90 degrees to the boresight declination given by DECLINATION in the data labels.

Also it is important to note that the slit of the HRII spectrometer is oriented vertically such that the top of the slit in an HRII image corresponds to the top of an HRIV or MRI image.

## 4.4 Sample PDS Labels

This section provides sample PDS labels for raw and calibrated science data products for the HRII spectrometer and the HRIV and MRI CCDs.

### 4.4.1 Level 2 Raw HRII Science Data Product

The raw science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a raw HRII FITS data file is provided below. Units for the primary image array are data number.

Although the format of the HRII raw data product did not change between EPOCH and Hartley 2, an example of a label from each mission phase is provided next.

#### 4.4.1.1 EPOCH Label

```
PDS_VERSION_ID      = PDS3
RECORD_TYPE         = "FIXED_LENGTH"
RECORD_BYTES        = 2880
FILE_RECORDS        = 84

^HEADER = ("HI08052904_1001003_004.FIT",1)
^IMAGE = ("HI08052904_1001003_004.FIT",15)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004.FIT",61)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004.FIT",62)

DATA_SET_ID          = "DIF-E-HRII-2-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID  = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI08052904_1001003_004_FIT"
```

```

PRODUCT_CREATION_TIME = 2009-02-09T23:15:12
PRODUCT_TYPE          = "RAW"

/***** TIME INFORMATION *****/
START_TIME            = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME = 2008-05-29T04:21:04.702
STOP_TIME             = 2008-05-29T04:21:05.420
START_JULIAN_DATE_VALUE = 2454615.6812961
MID_JULIAN_DATE_VALUE  = 2454615.6813044
STOP_JULIAN_DATE_VALUE = 2454615.6813127
SPACECRAFT_CLOCK_START_COUNT    = "1/0265306167.104"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0265306168.032"
SPACECRAFT_CLOCK_STOP_COUNT     = "1/0265306168.216"
EPOXI:EARTH_OBSERVER_MID_TIME   = 2008-05-29T04:23:49.914

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME      = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE = "EARTHOB"
EPOXI:OBSERVATION_DESC  = "RADIOMETRY; N/S SCANS 5B"
EPOXI:POINTING_DESC     = "IR EARTH SCAN B"
TARGET_NAME             = "EARTH"
TARGET_DESC             = "EARTH"
INSTRUMENT_MODE_ID     = 2
EPOXI:INSTRUMENT_MODE_NAME = "BINSF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID          = "N/A"
EPOXI:OBSERVATION_ID   = "1001003"
EPOXI:IMAGE_NUMBER     = "004"
EPOXI:COMMANDED_IMAGE_COUNT = 8
FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH = "N/A"
EPOXI:INTEGRATION_DURATION = 1435.6400000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 304.1247840 <K>
, 304.1247840 <K>
, 299.3939680 <K>
, 302.5192480 <K>
, 283.5592160 <K>
, 163.1479276 <K>
, 137.5605760 <K>
, 137.2787488 <K>
, 132.1110720 <K>
, 135.9330490 <K>
, 83.9405000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"

```

```

, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2052597 <V>
, 1.2162471 <V>
, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = "N/A"
VERTICAL_PIXEL_SCALE = 495388.309 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE = "
Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
system used to specify observational geometry. Geometric parameters are
based on the best available SPICE data at the time of product creation.
Refer to the EPOXI SPICE archive for the most current observational
geometry. The observation midpoint was used to derive the geometry.
All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "PREDICTED"
RIGHT_ASCENSION = 172.418745200 <DEG>
DECLINATION = 0.064255500 <DEG>

```

```

CELESTIAL_NORTH_CLOCK_ANGLE      = 112.5549 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 89.2999 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 179.9771 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 112.5610 <DEG>
SOLAR_ELONGATION                  = 85.9196 <DEG>
PHASE_ANGLE                        = 75.065 <DEG>
TARGET_CENTER_DISTANCE             = 49538830.8946 <KM>
TARGET_HELIOCENTRIC_DISTANCE       = 151638590.527 <KM>
TARGET_GEOCENTRIC_DISTANCE         = 0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE     = 146888525.712 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE       = 49529487.895 <KM>
QUATERNION_DESC                   = "QUATERNION_DESC.ASC"
QUATERNION                         =
( 0.683177600000
, 0.092082800000
, -0.700685400000
, -0.183927000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( -4.919866894210e-05 <RAD/S>
, -3.682750220260e-04 <RAD/S>
, -1.543913646210e-04 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR   =
( 49118869.452 <KM>
, -6428890.231 <KM>
, -319061.962 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR   =
( 2.806568 <KM/S>
, 7.298245 <KM/S>
, 0.847287 <KM/S>
)
TARGET_SUN_POSITION_VECTOR        =
( 56669336.529 <KM>
, 129046247.358 <KM>
, 55945638.589 <KM>
)
TARGET_SUN_VELOCITY_VECTOR        =
( -27.144124 <KM/S>
, 10.326189 <KM/S>
, 4.477789 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR      =
( 0.000 <KM>
, 0.000 <KM>
, 0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR      =
( 0.000000 <KM/S>
, 0.000000 <KM/S>
, 0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR            =
( 7550467.077 <KM>
, 135475137.589 <KM>
, 56264700.551 <KM>
)

```

```

)
SC_EARTH_POSITION_VECTOR      =
(  -49109933.310 <KM>
,    6425187.955 <KM>
,    318717.944 <KM>
)
SUB_SPACECRAFT_LONGITUDE      =    41.0630015 <DEG>
SUB_SPACECRAFT_LATITUDE       =    -0.3225872 <DEG>
SUB_SOLAR_LONGITUDE           =   114.8285460 <DEG>
SUB_SOLAR_LATITUDE            =    21.6690802 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE        = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME        = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004.FIT"
PROCESSING_HISTORY_TEXT       = "RAW"

OBJECT      = HEADER
  BYTES      = 40320
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS    = 14
  DESCRIPTION = "FITS format defined in
    NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT      = IMAGE
  LINE_SAMPLES = 512
  LINES        = 128
  SAMPLE_BITS  = 16
  SAMPLE_TYPE  = "MSB_INTEGER"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET       = 0
  SCALING_FACTOR = 1
  UNIT         = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM = -126
  EPOXI:DERIVED_MAXIMUM = 16168
  EPOXI:DERIVED_MEDIAN   = 986.0
  EPOXI:DERIVED_STANDARD_DEVIATION = 414.7
END_OBJECT = IMAGE

OBJECT      = EXT_QUALITY_FLAGS_HEADER
  BYTES      = 2880
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS    = 1
  DESCRIPTION = "This extension provides quality flags for
    each pixel in the primary image array.  Each of the one-byte pixels
    in this map is composed of eight bits.  Each bit represents a specific
    characteristic about the corresponding pixel in the primary image
    array.  For a raw image, only the bit for a missing data value is set
    (bit 1 below).  The remaining 7 bits apply only to a calibrated image
    and are thus set to zero for a raw image.  The bits are described below
    and are listed from the least-significant (0) to most-significant (7):

```

```

    0 = Bad
    1 = Data for this pixel was not received from the spacecraft or
        this pixel is one of the image header bytes.
    2 = Despiked
    3 = Interpolated
    4 = Partially saturated
    5 = Mostly saturated
    6 = ADC saturated
    7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT          = EXT_QUALITY_FLAGS_IMAGE
LINE_SAMPLES   = 512
LINES          = 128
SAMPLE_BITS    = 8
SAMPLE_TYPE    = "MSB_UNSIGNED_INTEGER"
AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT     = EXT_QUALITY_FLAGS_IMAGE

END

```

#### 4.4.1.2 Hartley 2 Label

```

PDS_VERSION_ID   = PDS3
RECORD_TYPE      = "FIXED_LENGTH"
RECORD_BYTES     = 2880
FILE_RECORDS     = 154

^HEADER = ("HI10110413_5001000_001.FIT",1)
^IMAGE = ("HI10110413_5001000_001.FIT",16)
^EXT_QUALITY_FLAGS_HEADER = ("HI10110413_5001000_001.FIT",108)
^EXT_QUALITY_FLAGS_IMAGE = ("HI10110413_5001000_001.FIT",109)

DATA_SET_ID      = "DIF-C-HRII-2-EPOXI-HARTLEY2-V1.0"
MISSION_NAME     = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID = "DIF"
INSTRUMENT_NAME  =
    "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID    = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID       = "HI10110413_5001000_001_FIT"
PRODUCT_CREATION_TIME = 2011-06-10T01:17:11
PRODUCT_TYPE     = "RAW"

/***** TIME INFORMATION *****/
START_TIME       = 2010-11-04T13:42:16.135
EPOXI:IMAGE_MID_TIME = 2010-11-04T13:42:16.855
STOP_TIME        = 2010-11-04T13:42:17.575
START_JULIAN_DATE_VALUE = 2455505.0710201
MID_JULIAN_DATE_VALUE  = 2455505.0710284
STOP_JULIAN_DATE_VALUE = 2455505.0710367
SPACECRAFT_CLOCK_START_COUNT = "1/0342148252.143"

```



```

EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0342148253.071"
SPACECRAFT_CLOCK_STOP_COUNT      = "1/0342148254.000"
EPOXI:EARTH_OBSERVER_MID_TIME    = 2010-11-04T13:43:34.791

```

```

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME                = "HARTLEY 2 ENCOUNTER"
EPOXI:MISSION_ACTIVITY_TYPE       = "FLYBY"
EPOXI:OBSERVATION_DESC           = "E-14MIN SCAN"
EPOXI:POINTING_DESC              = "IR SCAN"
TARGET_NAME                       = "103P/HARTLEY 2 (1986 E2)"
TARGET_DESC                      = "103P/HARTLEY 2 (1986 E2)"
INSTRUMENT_MODE_ID               = "5"
EPOXI:INSTRUMENT_MODE_NAME       = "ALTF"
EPOXI:COMPRESSED_IMAGE_VALUE     = "UNCOMPRESSED"
COMPRESSOR_ID                    = "N/A"
EPOXI:OBSERVATION_ID            = "5001000"
EPOXI:IMAGE_NUMBER              = "001"
EPOXI:COMMANDED_IMAGE_COUNT     = 116
FILTER_NUMBER                    = "N/A"
FILTER_NAME                      = "N/A"
CENTER_FILTER_WAVELENGTH         = "N/A"
EPOXI:INTEGRATION_DURATION      = 1440.6150000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID   = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 307.6177440 <K>
, 307.7525600 <K>
, 300.5215200 <K>
, 305.9999520 <K>
, 272.3694880 <K>
, 164.1697126 <K>
, 137.1305376 <K>
, 136.8047616 <K>
, 131.3707728 <K>
, 135.6087342 <K>
, 84.0855000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2131950 <V>
, 1.2049545 <V>
, 1.2162471 <V>
, 5.1241209 <V>
, 5.1233263 <V>
, 5.1106113 <V>

```

```

, 5.1058432 <V>
, 5.0311429 <V>
, -5.0231961 <V>
, 5.0073024 <V>
, -9.1961593 <V>
, 0.2433761 <V>
, 0.7386894 <V>
, 3.4023738 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = "N/A"
VERTICAL_PIXEL_SCALE = 129.609 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE = "
Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
system used to specify observational geometry. Geometric parameters are
based on the best available SPICE data at the time of product creation.
Refer to the EPOXI SPICE archive for the most current observational
geometry. The observation midpoint was used to derive the geometry.
All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "RECONSTRUCTED"
RIGHT_ASCENSION = 310.068586600 <DEG>
DECLINATION = 40.314566400 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE = 83.7637 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 110.7587 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 190.1930 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 20.0543 <DEG>
SOLAR_ELONGATION = 94.3798 <DEG>
PHASE_ANGLE = 85.584 <DEG>
TARGET_CENTER_DISTANCE = 12960.8968 <KM>
TARGET_HELIOCENTRIC_DISTANCE = 159105528.689 <KM>
TARGET_GEOCENTRIC_DISTANCE = 23356658.282 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE = 159104531.168 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE = 23364722.058 <KM>

```

```

QUATERNION_DESC = "QUATERNION_DESC.ASC"
QUATERNION =
( 0.337702200000
, 0.370662600000
, -0.197781300000
, 0.842288000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( 3.396454105520e-05 <RAD/S>
, 3.208269299830e-05 <RAD/S>
, 3.283639342790e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( -6371.957 <KM>
, 7560.351 <KM>
, -8379.982 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 6.376873 <KM/S>
, -7.454455 <KM/S>
, 7.454289 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( -103730026.758 <KM>
, -113065341.255 <KM>
, -42081818.104 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( 26.375673 <KM/S>
, -26.702505 <KM/S>
, -1.988183 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( -6745868.379 <KM>
, 22199555.735 <KM>
, 2684487.124 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( -6.002527 <KM/S>
, 6.441482 <KM/S>
, -6.794060 <KM/S>
)
SC_SUN_POSITION_VECTOR =
( -103723654.800 <KM>
, -113072901.606 <KM>
, -42073438.122 <KM>
)
SC_EARTH_POSITION_VECTOR =
( 6751924.232 <KM>
, -22207131.852 <KM>
, -2676761.275 <KM>
)
SUB_SPACECRAFT_LONGITUDE = "N/A"
SUB_SPACECRAFT_LATITUDE = "N/A"
SUB_SOLAR_LONGITUDE = "N/A"
SUB_SOLAR_LATITUDE = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */

```

COORDINATE\_SYSTEM\_TYPE = "N/A"  
COORDINATE\_SYSTEM\_NAME = "N/A"

/\*\*\*\*\* PROCESSING HISTORY \*\*\*\*\*/

EPOXI:SDC\_PIPELINE\_FILE\_NAME = "HI0342148253\_5001000\_001.FIT"  
PROCESSING\_HISTORY\_TEXT = "RAW"

OBJECT = HEADER  
BYTES = 43200  
HEADER\_TYPE = "FITS"  
INTERCHANGE\_FORMAT = "BINARY"  
RECORDS = 15  
DESCRIPTION = "FITS format defined in  
NASA/Science Office Standards Technology 100-1.0"  
END\_OBJECT = HEADER

OBJECT = IMAGE  
LINE\_SAMPLES = 512  
LINES = 256  
SAMPLE\_BITS = 16  
SAMPLE\_TYPE = "MSB\_INTEGER"  
AXIS\_ORDER\_TYPE = "FIRST\_INDEX\_FASTEST"  
LINE\_DISPLAY\_DIRECTION = "UP"  
SAMPLE\_DISPLAY\_DIRECTION = "RIGHT"  
OFFSET = 0  
SCALING\_FACTOR = 1  
UNIT = "DATA\_NUMBER"  
EPOXI:DERIVED\_MINIMUM = -78  
EPOXI:DERIVED\_MAXIMUM = 16128  
EPOXI:DERIVED\_MEDIAN = 890.0  
EPOXI:DERIVED\_STANDARD\_DEVIATION = 253.0  
END\_OBJECT = IMAGE

OBJECT = EXT\_QUALITY\_FLAGS\_HEADER  
BYTES = 2880  
HEADER\_TYPE = "FITS"  
INTERCHANGE\_FORMAT = "BINARY"  
RECORDS = 1  
DESCRIPTION = "This extension provides quality flags for  
each pixel in the primary image array. Each of the one-byte pixels  
in this map is composed of eight bits. Each bit represents a specific  
characteristic about the corresponding pixel in the primary image  
array. For a raw image, only the bit for a missing data value is set  
(bit 1 below). The remaining 7 bits apply only to a calibrated image  
and are thus set to zero for a raw image. The bits are described below  
and are listed from the least-significant (0) to most-significant (7):  
0 = Bad  
1 = Data for this pixel was not received from the spacecraft or  
this pixel is one of the image header bytes.  
2 = Despiked  
3 = Interpolated  
4 = Partially saturated  
5 = Mostly saturated  
6 = ADC saturated  
7 = Ultra compressed"  
END\_OBJECT = EXT\_QUALITY\_FLAGS\_HEADER

```

OBJECT          = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES  = 512
  LINES         = 256
  SAMPLE_BITS   = 8
  SAMPLE_TYPE   = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT      = EXT_QUALITY_FLAGS_IMAGE

END

```

## 4.4.2 Level 2 Raw HRIV/MRI Science Data Product

The raw science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for a raw HRIV FITS data file is provided below. Units for the primary image array are data number.

Although the format of the HRII raw data product did not change between EPOCH and Hartley 2, an example of a label from each mission phase is provided next.

### 4.4.2.1 EPOCH Label

```

PDS_VERSION_ID = PDS3
RECORD_TYPE    = "FIXED_LENGTH"
RECORD_BYTES   = 2880
FILE_RECORDS   = 291

^HEADER = ("HV08060416_1000001_001.FIT",1)
^IMAGE  = ("HV08060416_1000001_001.FIT",16)
^EXT_QUALITY_FLAGS_HEADER = ("HV08060416_1000001_001.FIT",199)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08060416_1000001_001.FIT",200)

DATA_SET_ID      = "DIF-E-HRIV-2-EPOXI-EARTH-V1.0"
MISSION_NAME     = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME    =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID     = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID        = "HV08060416_1000001_001_FIT"
PRODUCT_CREATION_TIME = 2009-01-15T11:47:49
PRODUCT_TYPE      = "RAW"

/***** TIME INFORMATION *****/
START_TIME        = 2008-06-04T16:57:24.642
EPOXI:IMAGE_MID_TIME = 2008-06-04T16:57:24.649
STOP_TIME        = 2008-06-04T16:57:24.656
START_JULIAN_DATE_VALUE = 2454622.2065352
MID_JULIAN_DATE_VALUE  = 2454622.2065353

```

```

STOP_JULIAN_DATE_VALUE = 2454622.2065354
SPACECRAFT_CLOCK_START_COUNT = "1/0265869939.131"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0265869939.132"
SPACECRAFT_CLOCK_STOP_COUNT = "1/0265869939.134"
EPOXI:EARTH_OBSERVER_MID_TIME = 2008-06-04T17:00:12.888

```

```

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE = "EARTH OBS"
EPOXI:OBSERVATION_DESC = "HRIV RADIOMETRY 1A"
EPOXI:POINTING_DESC = "TO EARTH"
TARGET_NAME = "EARTH"
TARGET_DESC = "EARTH"
INSTRUMENT_MODE_ID = 2
EPOXI:INSTRUMENT_MODE_NAME = "SF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID = "N/A"
EPOXI:OBSERVATION_ID = "1000001"
EPOXI:IMAGE_NUMBER = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER = 2
FILTER_NAME = "BLUE"
CENTER_FILTER_WAVELENGTH = 450 <NM>
EPOXI:INTEGRATION_DURATION = 13.500000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 303.9532000 <K>
, 303.9899680 <K>
, 296.2441760 <K>
, 302.0412640 <K>
, 283.4121440 <K>
, 163.2127061 <K>
, 137.3380562 <K>
, 137.1009052 <K>
, 131.8059846 <K>
, 135.7561008 <K>
, 84.1435000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2049545 <V>
, 1.2159419 <V>
, 5.1249156 <V>
)

```

```

, 5.1233263 <V>
, 5.1106113 <V>
, 5.1050485 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0104812 <V>
, -9.2021797 <V>
, 0.2458221 <V>
, 0.7423583 <V>
, 3.4060428 <V>
, "UNK"
)

```

```

INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

```

```

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = 100893.168 <M/PIXEL>
VERTICAL_PIXEL_SCALE = 100893.168 <M/PIXEL>

```

```

/***** GEOMETRY PARAMETERS *****/
NOTE = "

```

Earth Mean Equator and Vernal Equinox J2000 is the inertial reference system used to specify observational geometry. Geometric parameters are based on the best available SPICE data at the time of product creation. Refer to the EPOXI SPICE archive for the most current observational geometry. The observation midpoint was used to derive the geometry. All positions are relative to body centers."

```

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "RECONSTRUCTED"
RIGHT_ASCENSION = 177.489792500 <DEG>
DECLINATION = -0.215176100 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE = 113.1337 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 89.7128 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 180.0005 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 113.1357 <DEG>
SOLAR_ELONGATION = 84.1632 <DEG>
PHASE_ANGLE = 76.533 <DEG>
TARGET_CENTER_DISTANCE = 50446583.8460 <KM>
TARGET_HELIOCENTRIC_DISTANCE = 151789311.363 <KM>
TARGET_GEOCENTRIC_DISTANCE = 0.000 <KM>

```

```

EPOXI:SC_HELIOCENTRIC_DISTANCE = 148385381.127 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE = 50436998.201 <KM>
QUATERNION_DESC = "QUATERNION_DESC.ASC"
QUATERNION =
( 0.688178800000
, 0.126812100000
, -0.696991000000
, -0.156627400000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( -6.193104793090e-07 <RAD/S>
, 5.662622783320e-07 <RAD/S>
, -2.666095006670e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( 50397729.649 <KM>
, -2211519.755 <KM>
, 189336.499 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 1.724195 <KM/S>
, 7.629346 <KM/S>
, 0.946928 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( 41049886.647 <KM>
, 134075548.433 <KM>
, 58126148.701 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( -28.206501 <KM/S>
, 7.494698 <KM/S>
, 3.248512 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( 0.000 <KM>
, 0.000 <KM>
, 0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( 0.000000 <KM/S>
, 0.000000 <KM/S>
, 0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR =
( -9347843.002 <KM>
, 136287068.188 <KM>
, 57936812.202 <KM>
)
SC_EARTH_POSITION_VECTOR =
( -50388265.569 <KM>
, 2208512.122 <KM>
, -189617.362 <KM>
)
SUB_SPACECRAFT_LONGITUDE = 210.5053179 <DEG>
SUB_SPACECRAFT_LATITUDE = 0.2619271 <DEG>
SUB_SOLAR_LONGITUDE = 286.0135359 <DEG>

```



```

SUB_SOLAR_LATITUDE          =      22.5295803 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE     = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME     = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0265869939_1000001_001.FIT"
PROCESSING_HISTORY_TEXT     = "RAW"

OBJECT      = HEADER
  BYTES      = 43200
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS    = 15
  DESCRIPTION = "FITS format defined in
                NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT      = IMAGE
  LINE_SAMPLES = 512
  LINES        = 512
  SAMPLE_BITS  = 16
  SAMPLE_TYPE  = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  OFFSET       = 32768
  SCALING_FACTOR = 1
  UNIT         = "DATA_NUMBER"
  EPOXI:DERIVED_MINIMUM = 361
  EPOXI:DERIVED_MAXIMUM = 5060
  EPOXI:DERIVED_MEDIAN   = 376.0
  EPOXI:DERIVED_STANDARD_DEVIATION = 278.7
END_OBJECT = IMAGE

OBJECT      = EXT_QUALITY_FLAGS_HEADER
  BYTES      = 2880
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS    = 1
  DESCRIPTION = "This extension provides quality flags for
                each pixel in the primary image array.  Each of the one-byte pixels
                in this map is composed of eight bits.  Each bit represents a specific
                characteristic about the corresponding pixel in the primary image
                array.  For a raw image, only the bit for a missing data value is set
                (bit 1 below).  The remaining 7 bits apply only to a calibrated image
                and are thus set to zero for a raw image.  The bits are described below
                and are listed from the least-significant (0) to most-significant (7):
                0 = Bad
                1 = Data for this pixel was not received from the spacecraft or
                   this pixel is one of the image header bytes.
                2 = Despiked
                3 = Interpolated
                4 = Partially saturated
                5 = Mostly saturated
                6 = ADC saturated
                7 = Ultra compressed"

```

```

END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT      = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES = 512
  LINES       = 512
  SAMPLE_BITS = 8
  SAMPLE_TYPE = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT  = EXT_QUALITY_FLAGS_IMAGE

END

```

#### 4.4.2.2 Hartley 2 Label

```

PDS_VERSION_ID = PDS3
RECORD_TYPE    = "FIXED_LENGTH"
RECORD_BYTES   = 2880
FILE_RECORDS   = 85

^HEADER = ("HV10110412_5000000_001.FIT",1)
^IMAGE  = ("HV10110412_5000000_001.FIT",16)
^EXT_QUALITY_FLAGS_HEADER = ("HV10110412_5000000_001.FIT",62)
^EXT_QUALITY_FLAGS_IMAGE = ("HV10110412_5000000_001.FIT",63)

DATA_SET_ID      = "DIF-C-HRIV-2-EPOXI-HARTLEY2-V1.0"
MISSION_NAME     = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME    =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID     = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID        = "HV10110412_5000000_001_FIT"
PRODUCT_CREATION_TIME = 2011-06-09T20:11:08
PRODUCT_TYPE      = "RAW"

/***** TIME INFORMATION *****/
START_TIME        = 2010-11-04T12:03:13.125
EPOXI:IMAGE_MID_TIME = 2010-11-04T12:03:14.125
STOP_TIME         = 2010-11-04T12:03:15.125
START_JULIAN_DATE_VALUE = 2455505.0022352
MID_JULIAN_DATE_VALUE  = 2455505.0022468
STOP_JULIAN_DATE_VALUE = 2455505.0022584
SPACECRAFT_CLOCK_START_COUNT   = "1/0342142309.163"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0342142310.163"
SPACECRAFT_CLOCK_STOP_COUNT    = "1/0342142311.163"
EPOXI:EARTH_OBSERVER_MID_TIME  = 2010-11-04T12:04:32.081

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME = "HARTLEY 2 ENCOUNTER"
EPOXI:MISSION_ACTIVITY_TYPE = "FLYBY"
EPOXI:OBSERVATION_DESC    = "E-2HR"
EPOXI:POINTING_DESC       = "TO HARTLEY"

```

```

TARGET_NAME                = "103P/HARTLEY 2 (1986 E2)"
TARGET_DESC                = "103P/HARTLEY 2 (1986 E2)"
INSTRUMENT_MODE_ID        = "3"
EPOXI:INSTRUMENT_MODE_NAME = "SF2S"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID              = "N/A"
EPOXI:OBSERVATION_ID      = "5000000"
EPOXI:IMAGE_NUMBER        = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER              = "1"
FILTER_NAME                = "CLEAR1"
CENTER_FILTER_WAVELENGTH   = 650 <NM>
EPOXI:INTEGRATION_DURATION = 2000.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 307.5564640 <K>
, 307.6790240 <K>
, 300.5582880 <K>
, 305.9264160 <K>
, 272.1488800 <K>
, 163.3098984 <K>
, 136.9972176 <K>
, 136.6716040 <K>
, 131.2548410 <K>
, 135.4909000 <K>
, 84.0420000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2058701 <V>
, 1.2135002 <V>
, 1.2040388 <V>
, 1.2168575 <V>
, 5.1257103 <V>
, 5.1209422 <V>
, 5.1122007 <V>
, 5.1042538 <V>
, 5.0295536 <V>
, -5.0216067 <V>
, 5.0041237 <V>
, -9.1901389 <V>
, 0.2445991 <V>
, 0.7411353 <V>
, 3.4035968 <V>
, "UNK"
)

```

```

)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = 172.327 <M/PIXEL>
VERTICAL_PIXEL_SCALE = 172.327 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE = "
Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
system used to specify observational geometry. Geometric parameters are
based on the best available SPICE data at the time of product creation.
Refer to the EPOXI SPICE archive for the most current observational
geometry. The observation midpoint was used to derive the geometry.
All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "RECONSTRUCTED"
RIGHT_ASCENSION = 310.478316600 <DEG>
DECLINATION = 37.691773900 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE = 73.6859 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 99.2005 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 179.9952 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 12.4447 <DEG>
SOLAR_ELONGATION = 93.9799 <DEG>
PHASE_ANGLE = 85.985 <DEG>
TARGET_CENTER_DISTANCE = 86163.7134 <KM>
TARGET_HELIOCENTRIC_DISTANCE = 159091889.765 <KM>
TARGET_GEOCENTRIC_DISTANCE = 23314661.089 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE = 159085880.630 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE = 23370621.570 <KM>
QUATERNION_DESC = "QUATERNION_DESC.ASC"
QUATERNION =
( 0.256494300000
, 0.370018900000
, -0.239539800000
, 0.860184500000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( 1.306664244630e-06 <RAD/S>

```

```

, 1.989385378040e-06 <RAD/S>
, 9.226216507660e-07 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( -44267.991 <KM>
, 51860.155 <KM>
, -52678.789 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 6.376261 <KM/S>
, -7.453739 <KM/S>
, 7.453570 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( -103886716.314 <KM>
, -112906583.167 <KM>
, -42069977.895 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( 26.358407 <KM/S>
, -26.721306 <KM/S>
, -1.995183 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( -6710175.992 <KM>
, 22161273.756 <KM>
, 2724867.959 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( -6.009372 <KM/S>
, 6.442536 <KM/S>
, -6.795851 <KM/S>
)
SC_SUN_POSITION_VECTOR =
( -103842448.323 <KM>
, -112958443.322 <KM>
, -42017299.106 <KM>
)
SC_EARTH_POSITION_VECTOR =
( 6754121.985 <KM>
, -22213141.696 <KM>
, -2672849.558 <KM>
)
SUB_SPACECRAFT_LONGITUDE = "N/A"
SUB_SPACECRAFT_LATITUDE = "N/A"
SUB_SOLAR_LONGITUDE = "N/A"
SUB_SOLAR_LATITUDE = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE = "N/A"
COORDINATE_SYSTEM_NAME = "N/A"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0342142310_5000000_001.FIT"
PROCESSING_HISTORY_TEXT = "RAW"

OBJECT = HEADER
BYTES = 43200

```

```

HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
RECORDS              = 15
DESCRIPTION          = "FITS format defined in
      NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

OBJECT               = IMAGE
LINE_SAMPLES        = 256
LINES               = 256
SAMPLE_BITS         = 16
SAMPLE_TYPE         = "MSB_UNSIGNED_INTEGER"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
OFFSET              = 32768
SCALING_FACTOR      = 1
UNIT                = "DATA_NUMBER"
EPOXI:DERIVED_MINIMUM      = 383
EPOXI:DERIVED_MAXIMUM      = 6924
EPOXI:DERIVED_MEDIAN       = 409.0
EPOXI:DERIVED_STANDARD_DEVIATION = 242.7
END_OBJECT               = IMAGE

OBJECT      = EXT_QUALITY_FLAGS_HEADER
BYTES       = 2880
HEADER_TYPE = "FITS"
INTERCHANGE_FORMAT = "BINARY"
RECORDS      = 1
DESCRIPTION   = "This extension provides quality flags for
each pixel in the primary image array.  Each of the one-byte pixels
in this map is composed of eight bits.  Each bit represents a specific
characteristic about the corresponding pixel in the primary image
array.  For a raw image, only the bit for a missing data value is set
(bit 1 below).  The remaining 7 bits apply only to a calibrated image
and are thus set to zero for a raw image.  The bits are described below
and are listed from the least-significant (0) to most-significant (7):
  0 = Bad
  1 = Data for this pixel was not received from the spacecraft or
      this pixel is one of the image header bytes.
  2 = Despiked
  3 = Interpolated
  4 = Partially saturated
  5 = Mostly saturated
  6 = ADC saturated
  7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT      = EXT_QUALITY_FLAGS_IMAGE
LINE_SAMPLES = 256
LINES       = 256
SAMPLE_BITS = 8
SAMPLE_TYPE = "MSB_UNSIGNED_INTEGER"
AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT = EXT_QUALITY_FLAGS_IMAGE

```

END

### 4.4.3 Level 3/4 Calibrated HRII Science Data Product

The calibrated science data products for the HRII instrument have self-consistent formats. An example of a PDS label for a reversible, calibrated HRII FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) science images have the same format.

The calibration pipeline was improved to handle HRII spectra for the Hartley 2 encounter. In particular the master dark process was modified; several keywords were added to PROCESSING\_HISTORY\_TEXT to capture the parameters used for the revised dark process. Therefore an example of an EPOCH label (without a de-stripping extension) and a Hartley 2 label are provided next.

#### 4.4.3.1 EPOCH Label

```
PDS_VERSION_ID      = PDS3
RECORD_TYPE         = "FIXED_LENGTH"
RECORD_BYTES        = 2880
FILE_RECORDS        = 412

^HEADER = ("HI08052904_1001003_004_RR.FIT",1)
^IMAGE = ("HI08052904_1001003_004_RR.FIT",18)
^EXT_QUALITY_FLAGS_HEADER = ("HI08052904_1001003_004_RR.FIT",110)
^EXT_QUALITY_FLAGS_IMAGE = ("HI08052904_1001003_004_RR.FIT",111)
^EXT_WAVELENGTH_HEADER = ("HI08052904_1001003_004_RR.FIT",134)
^EXT_WAVELENGTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",135)
^EXT_SPEC_BANDWIDTH_HEADER = ("HI08052904_1001003_004_RR.FIT",227)
^EXT_SPEC_BANDWIDTH_IMAGE = ("HI08052904_1001003_004_RR.FIT",228)
^EXT_SNR_HEADER = ("HI08052904_1001003_004_RR.FIT",320)
^EXT_SNR_IMAGE = ("HI08052904_1001003_004_RR.FIT",321)

DATA_SET_ID          = "DIF-E-HRII-3/4-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID   = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HRII"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI08052904_1001003_004_RR_FIT"
PRODUCT_CREATION_TIME = 2009-02-09T23:15:12
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-05-29T04:21:03.984
EPOXI:IMAGE_MID_TIME = 2008-05-29T04:21:04.702
STOP_TIME            = 2008-05-29T04:21:05.420
```

START\_JULIAN\_DATE\_VALUE = 2454615.6812961  
MID\_JULIAN\_DATE\_VALUE = 2454615.6813044  
STOP\_JULIAN\_DATE\_VALUE = 2454615.6813127  
SPACECRAFT\_CLOCK\_START\_COUNT = "1/0265306167.104"  
EPOXI:SPACECRAFT\_CLOCK\_MID\_COUNT = "1/0265306168.032"  
SPACECRAFT\_CLOCK\_STOP\_COUNT = "1/0265306168.216"  
EPOXI:EARTH\_OBSERVER\_MID\_TIME = 2008-05-29T04:23:49.914

/\*\*\*\*\*\* OBSERVATION INFORMATION \*\*\*\*\*/

MISSION\_PHASE\_NAME = "EPOCH"  
EPOXI:MISSION\_ACTIVITY\_TYPE = "EARTHOBBS"  
EPOXI:OBSERVATION\_DESC = "RADIOMETRY; N/S SCANS 5B"  
EPOXI:POINTING\_DESC = "IR EARTH SCAN B"  
TARGET\_NAME = "EARTH"  
INSTRUMENT\_MODE\_ID = 2  
EPOXI:INSTRUMENT\_MODE\_NAME = "BINSF1"  
EPOXI:COMPRESSED\_IMAGE\_VALUE = "UNCOMPRESSED"  
COMPRESSOR\_ID = "N/A"  
EPOXI:OBSERVATION\_ID = "1001003"  
EPOXI:IMAGE\_NUMBER = "004"  
EPOXI:COMMANDED\_IMAGE\_COUNT = 8  
FILTER\_NUMBER = "N/A"  
FILTER\_NAME = "N/A"  
CENTER\_FILTER\_WAVELENGTH = "N/A"  
EPOXI:INTEGRATION\_DURATION = 1435.640000 <MS>  
EPOXI:SPACECRAFT\_PROCESSOR\_ID = "SCU-A"  
INSTRUMENT\_TEMPERATURE =  
( 304.1247840 <K>  
, 304.1247840 <K>  
, 299.3939680 <K>  
, 302.5192480 <K>  
, 283.5592160 <K>  
, 163.1479276 <K>  
, 137.5605760 <K>  
, 137.2787488 <K>  
, 132.1110720 <K>  
, 135.9330490 <K>  
, 83.9405000 <K>  
)  
INSTRUMENT\_TEMPERATURE\_POINT =  
( "INSTRUMENT CONTROLLER PROCESSING BOARD"  
, "CCD SIGNAL PROCESSING BOARD"  
, "IR SIGNAL PROCESSING BOARD"  
, "LVPS SIGNAL PROCESSING BOARD"  
, "CCD PREAMP BOX"  
, "CCD ON-CHIP SENSOR"  
, "PRISMS"  
, "PRIMARY MIRROR"  
, "SECONDARY MIRROR"  
, "SPECTRAL IMAGING MODULE COVER"  
, "IR FPA ON-CHIP SENSOR"  
)  
INSTRUMENT\_VOLTAGE =  
( 1.2067857 <V>  
, 1.2128898 <V>  
, 1.2052597 <V>  
, 1.2162471 <V>



```

, 5.1249156 <V>
, 5.1233263 <V>
, 5.1098166 <V>
, 5.1058432 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0120705 <V>
, -9.2021797 <V>
, 0.2421531 <V>
, 0.7374664 <V>
, 3.4035968 <V>
, "UNK"
)

```

```

INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALLEL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

```

```

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = "N/A"
VERTICAL_PIXEL_SCALE = 495388.309 <M/PIXEL>

```

```

/***** GEOMETRY PARAMETERS *****/
NOTE = "

```

Earth Mean Equator and Vernal Equinox J2000 is the inertial reference system used to specify observational geometry. Geometric parameters are based on the best available SPICE data at the time of product creation. Refer to the EPOXI SPICE archive for the most current observational geometry. The observation midpoint was used to derive the geometry. All positions are relative to body centers."

```

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "PREDICTED"
SPICE_FILE_NAME = ( "NAIF0009.TLS",
                    "PCK00008.TPC",
                    "DIF_SCLKSCET.00036.TSC",
                    "DI_V17.TF",
                    "DIF_HRI_V10.TI",
                    "DIF_MRI_V10.TI",
                    "DIF_PREDICT_050112_050809.BC",
                    "DIF_EPOXI_PREDICT_V20081206.BC",
                    "DIF_PRED_EARTHOB4_1.BC",
                    "DIF_SC_050112_050809.BC",

```

```

        "DIF_SC_050225_HIGHRATE.BC",
        "DIF_SC_050704_HIGHRATE.BC",
        "JUP164_20YEAR.BSP",
        "SPK_OD221_FULLL.BSP" )
RIGHT_ASCENSION      = 172.418745200 <DEG>
DECLINATION          =  0.064255500 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE = 112.5549 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 89.2999 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 179.9771 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 112.5610 <DEG>
SOLAR_ELONGATION    = 85.9196 <DEG>
PHASE_ANGLE         = 75.065 <DEG>
TARGET_CENTER_DISTANCE = 49538830.8946 <KM>
TARGET_HELIOCENTRIC_DISTANCE = 151638590.527 <KM>
TARGET_GEOCENTRIC_DISTANCE = 0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE = 146888525.712 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE = 49529487.895 <KM>
QUATERNION_DESC     = "QUATERNION_DESC.ASC"
QUATERNION          =
( 0.683177600000
, 0.092082800000
, -0.700685400000
, -0.183927000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( -4.919866894210e-05 <RAD/S>
, -3.682750220260e-04 <RAD/S>
, -1.543913646210e-04 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( 49118869.452 <KM>
, -6428890.231 <KM>
, -319061.962 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 2.806568 <KM/S>
, 7.298245 <KM/S>
, 0.847287 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( 56669336.529 <KM>
, 129046247.358 <KM>
, 55945638.589 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( -27.144124 <KM/S>
, 10.326189 <KM/S>
, 4.477789 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( 0.000 <KM>
, 0.000 <KM>
, 0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( 0.000000 <KM/S>
, 0.000000 <KM/S>

```

```

,    0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR      =
(    7550467.077 <KM>
,   135475137.589 <KM>
,   56264700.551 <KM>
)
SC_EARTH_POSITION_VECTOR   =
(   -49109933.310 <KM>
,    6425187.955 <KM>
,    318717.944 <KM>
)
SUB_SPACECRAFT_LONGITUDE   =    41.0630015 <DEG>
SUB_SPACECRAFT_LATITUDE   =    -0.3225872 <DEG>
SUB_SOLAR_LONGITUDE       =   114.8285460 <DEG>
SUB_SOLAR_LATITUDE       =    21.6690802 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE    = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME    = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0265306168_1001003_004_RR.FIT"
PROCESSING_HISTORY_TEXT     = ""
FILEVERN=                   1.1000000 / Version number of file format
PGMNAME = 'DICAL'           / Program name that produced this file
PGMVERN =                   5.0000000 / Version number of the above program
DATAQUAL=                   -999 / Data quality
TMPVLTUP=                   F / Physical temps and voltages updated(T/F)
TMPVLTV = ' '              / Valid date of physical temps, volts used
SMOBENT =                   -1.0000000 / Smoothed over time version of OPTBENT[K]
CMPRESSN=                   F / Decompression performed (T/F)
LUTTABLE= ' '              / Lossy lookup table/algorithm applied
CMPRMETH=                   -999 / Decompress method. 1
SATPIX =                    T / Saturated pixels flagged (T/F)
SMSATVL =                   8000 / DN value where some pixels are saturated
MSTSATVL=                   11000 / DN value where most pixels are saturated
ADCSATVL=                   16383 / DN value where the ADC encoder is
saturated
BITCORR =                   F / Uneven bit weighting corrected (T/F)
BITLUT = ' '              / Bit weighting lookup table used
DARKCORR=                   T / Dark subtraction (T/F)
DARKALG = 'MODEL'         / Algorithm used to create dark
DARKFN = 'HRIIR_050620_1_2.FIT' / File name for frame/model used
BIASFN = ' '              / Filename of bias frame used
XTALK =                    T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIIR_050112_1_2.FIT' / Filename of crosstalk gains used
GAINCORR=                   F / Quadrant Gain correction performed (T/F)
GAINFN = ' '              / Filename of gain values used
FLATCORR=                   F / Flat fielded
FLATFILE= ' '              / Name of flat field applied
BPIXFL =                    T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIIR_080528_1_2_999.FIT' / Name of bad pixel map applied
CLEAN =                    F / Cleaned/fill small gaps (T/F)
CLEANV =                   -999 / Max filled gap size; -999999
CLNBAD =                    F / Bad pixels cleaned
CLNMISS =                   F / Missing data cleaned
DESPIKE =                   F / Despiking applied (T/F)

```

```

DESPIKET= -999 / Despiking threshold used (sigma)
DESPIKEI= -999 / Number of iterations of despiking
DESPIKEB= -999 / Boxsize for despiking
DESPIKEM= ' ' / Metric used for despiking.Mean or Median
DENOISE = F / Denoising applied (T/F)
DENOISEV= ' ' / Denoise parameter applied
DECON = F / Deconvolution performed (T/F)
DECONPSF= ' ' / Deconvolution psf used
DECONALG= ' ' / Deconvolution algorithm used
DECONV = ' ' / Deconvolution algorithm-specific param
LINEARIZ= T / Linearization applied (T/F)
LINAC0 = 'HRIIR_050115_3_2.FIT' / Quad A additive constant to linearize
LINAC1 = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x term
LINAC2 = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-squared term
LINAC3 = 'HRIIR_050115_3_2.FIT' / Quad A coefficient for x-cubed term
LINAC4 = -999.0000000 / Quad A coefficient for x-4th term
LINBC0 = 'HRIIR_050115_3_2.FIT' / Quad B additive constant to linearize
LINBC1 = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x term
LINBC2 = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-squared term
LINBC3 = 'HRIIR_050115_3_2.FIT' / Quad B coefficient for x-cubed term
LINBC4 = -999.0000000 / Quad B coefficient for x-4th term
MDARKVER= 2.0000000 / Master dark frame version
DRKPMODE= 2 / Mode of the previous set taken
DARKISG = 636.6120000 / Inter-sequence gap [msec]
DARKA0 = 3.0060000E+10 / Dark level temp coef A_0
DARKA1 = -3384.4000000 / Dark level temp coef A_1
DARKB0 = 65630000.0000000 / Dark level temp coef B_0
DARKB1 = -2002.0000000 / Dark level temp coef B_1
DARKC0 = 0.0583000 / Dark level temp coef C_0
DRKTMSCl= 1.0000000 / Dark scaling factor for time dependency
DARKPLAT= T / Dark plateau reached
DARKMSCl= -999.0000000 / Manually derived scaling factor
CALCORR = T / Calibration Applied (T/F)
CALCONST= -999.0000000 / Calibration Constant Applied
CALNUMB0= 0 / Number of ZERO calibration factors found
CALMAP1 = 'HRIIR_050112_9_2_999.FIT' / Calib constant map interped (1)
CALMAP2 = 'HRIIR_050112_9_2_000.FIT' / Calib constant map interped (2)
SPECMAP1= ' ' / Spectral map interpolated over (1)
SPECMAP2= ' ' / Spectral map interpolated over (2)
HLUTFN = ' ' / H lambda lookup table used
"

```

```

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT = 5680
EPOXI:MISSING_PIXEL_COUNT = 50
EPOXI:DESPIKED_PIXEL_COUNT = 0
EPOXI:INTERPOLATED_PIXEL_COUNT = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 16
EPOXI:SATURATED_PIXEL_COUNT = 10
EPOXI:ADC_SATURATED_PIXEL_COUNT = 0
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT = 0

```

```

OBJECT = HEADER
BYTES = 48960
HEADER_TYPE = "FITS"
INTERCHANGE_FORMAT = "BINARY"
RECORDS = 17

```

```
DESCRIPTION          = "FITS format defined in
  NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER
```

```
OBJECT              = IMAGE
LINE_SAMPLES        = 512
LINES                = 128
SAMPLE_BITS         = 32
SAMPLE_TYPE         = "IEEE_REAL"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT                = "W/(m**2*sr*um)"
EPOXI:MINIMUM       = -1.70204000000e+01
EPOXI:MAXIMUM       = 1.58491000000e+02
EPOXI:MEDIAN        = -6.84000000000e-03
EPOXI:STANDARD_DEVIATION = 3.06571000000e+00
END_OBJECT          = IMAGE
```

```
OBJECT              = EXT_QUALITY_FLAGS_HEADER
BYTES                = 2880
HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
RECORDS              = 1
DESCRIPTION          = "This extension provides quality flags for
  each pixel in the primary image array.  Each of the one-byte pixels
  in this map is composed of eight bits.  Each bit represents a specific
  characteristic about the corresponding pixel in the primary image
  array.  For a raw image, only the bit for a missing data value is set
  (bit 1 below).  The remaining 7 bits apply only to a calibrated image
  and are thus set to zero for a raw image.  The bits are described below
  and are listed from the least-significant (0) to most-significant (7):
  0 = Bad
  1 = Data for this pixel was not received from the spacecraft or
    this pixel is one of the image header bytes.
  2 = Despiked
  3 = Interpolated
  4 = Partially saturated
  5 = Mostly saturated
  6 = ADC saturated
  7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER
```

```
OBJECT              = EXT_QUALITY_FLAGS_IMAGE
LINE_SAMPLES        = 512
LINES                = 128
SAMPLE_BITS         = 8
SAMPLE_TYPE         = "MSB_UNSIGNED_INTEGER"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_QUALITY_FLAGS_IMAGE
```

```
OBJECT              = EXT_WAVELENGTH_HEADER
BYTES                = 2880
HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
```

```

RECORDS          = 1
DESCRIPTION      = "This extension provides the spectral
  wavelength for each pixel in the primary image array."
END_OBJECT = EXT_WAVELENGTH_HEADER

OBJECT           = EXT_WAVELENGTH_IMAGE
LINE_SAMPLES    = 512
LINES           = 128
SAMPLE_BITS     = 32
SAMPLE_TYPE     = "IEEE_REAL"
AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT            = "MICROMETER"
END_OBJECT      = EXT_WAVELENGTH_IMAGE

OBJECT           = EXT_SPEC_BANDWIDTH_HEADER
BYTES           = 2880
HEADER_TYPE     = "FITS"
INTERCHANGE_FORMAT = "BINARY"
RECORDS        = 1
DESCRIPTION     = "This extension provides the spectral
  bandwidth for each pixel in the primary image array."
END_OBJECT = EXT_SPEC_BANDWIDTH_HEADER

OBJECT           = EXT_SPEC_BANDWIDTH_IMAGE
LINE_SAMPLES    = 512
LINES           = 128
SAMPLE_BITS     = 32
SAMPLE_TYPE     = "IEEE_REAL"
AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT            = "MICROMETER"
END_OBJECT      = EXT_SPEC_BANDWIDTH_IMAGE

OBJECT           = EXT_SNR_HEADER
BYTES           = 2880
HEADER_TYPE     = "FITS"
INTERCHANGE_FORMAT = "BINARY"
RECORDS        = 1
DESCRIPTION     = "This extension is the signal-to-noise ratio
  for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT           = EXT_SNR_IMAGE
LINE_SAMPLES    = 512
LINES           = 128
SAMPLE_BITS     = 32
SAMPLE_TYPE     = "IEEE_REAL"
AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT      = EXT_SNR_IMAGE

END

```

### 4.4.3.2 Hartley 2 Label

```
PDS_VERSION_ID      = PDS3
RECORD_TYPE         = "FIXED_LENGTH"
RECORD_BYTES        = 2880
FILE_RECORDS        = 801

^HEADER = ("HI10110413_5001000_001_RR.FIT",1)
^IMAGE = ("HI10110413_5001000_001_RR.FIT",20)
^EXT_QUALITY_FLAGS_HEADER = ("HI10110413_5001000_001_RR.FIT",203)
^EXT_QUALITY_FLAGS_IMAGE = ("HI10110413_5001000_001_RR.FIT",204)
^EXT_WAVELENGTH_HEADER = ("HI10110413_5001000_001_RR.FIT",250)
^EXT_WAVELENGTH_IMAGE = ("HI10110413_5001000_001_RR.FIT",251)
^EXT_SPEC_BANDWIDTH_HEADER = ("HI10110413_5001000_001_RR.FIT",434)
^EXT_SPEC_BANDWIDTH_IMAGE = ("HI10110413_5001000_001_RR.FIT",435)
^EXT_SNR_HEADER = ("HI10110413_5001000_001_RR.FIT",618)
^EXT_SNR_IMAGE = ("HI10110413_5001000_001_RR.FIT",619)

DATA_SET_ID          = "DIF-C-HR11-3/4-EPOXI-HARTLEY2-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID  = "DIF"
INSTRUMENT_NAME      =
    "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - IR SPECTROMETER"
INSTRUMENT_ID        = "HR11"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HI10110413_5001000_001_RR_FIT"
PRODUCT_CREATION_TIME = 2011-06-18T12:57:01
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2010-11-04T13:42:16.135
EPOXI:IMAGE_MID_TIME = 2010-11-04T13:42:16.855
STOP_TIME            = 2010-11-04T13:42:17.575
START_JULIAN_DATE_VALUE = 2455505.0710201
MID_JULIAN_DATE_VALUE  = 2455505.0710284
STOP_JULIAN_DATE_VALUE = 2455505.0710367
SPACECRAFT_CLOCK_START_COUNT      = "1/0342148252.143"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT  = "1/0342148253.071"
SPACECRAFT_CLOCK_STOP_COUNT       = "1/0342148254.000"
EPOXI:EARTH_OBSERVER_MID_TIME     = 2010-11-04T13:43:34.791

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME      = "HARTLEY 2 ENCOUNTER"
EPOXI:MISSION_ACTIVITY_TYPE = "FLYBY"
EPOXI:OBSERVATION_DESC  = "E-14MIN SCAN"
EPOXI:POINTING_DESC     = "IR SCAN"
TARGET_NAME             = "103P/HARTLEY 2 (1986 E2)"
INSTRUMENT_MODE_ID      = "5"
EPOXI:INSTRUMENT_MODE_NAME = "ALTFF"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID           = "N/A"
EPOXI:OBSERVATION_ID    = "5001000"
EPOXI:IMAGE_NUMBER      = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 116
```

```

FILTER_NUMBER          = "N/A"
FILTER_NAME            = "N/A"
CENTER_FILTER_WAVELENGTH = "N/A"
EPOXI:INTEGRATION_DURATION = 1440.6150000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 307.6177440 <K>
, 307.7525600 <K>
, 300.5215200 <K>
, 305.9999520 <K>
, 272.3694880 <K>
, 164.1697126 <K>
, 137.1305376 <K>
, 136.8047616 <K>
, 131.3707728 <K>
, 135.6087342 <K>
, 84.0855000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2131950 <V>
, 1.2049545 <V>
, 1.2162471 <V>
, 5.1241209 <V>
, 5.1233263 <V>
, 5.1106113 <V>
, 5.1058432 <V>
, 5.0311429 <V>
, -5.0231961 <V>
, 5.0073024 <V>
, -9.1961593 <V>
, 0.2433761 <V>
, 0.7386894 <V>
, 3.4023738 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"

```



```

, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

```

```

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = "N/A"
VERTICAL_PIXEL_SCALE   = 129.609 <M/PIXEL>

```

```

/***** GEOMETRY PARAMETERS *****/
NOTE = "

```

Earth Mean Equator and Vernal Equinox J2000 is the inertial reference system used to specify observational geometry. Geometric parameters are based on the best available SPICE data at the time of product creation. Refer to the EPOXI SPICE archive for the most current observational geometry. The observation midpoint was used to derive the geometry. All positions are relative to body centers."

```

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE        = "RECONSTRUCTED"
SPICE_FILE_NAME            = ( "NAIF0009.TLS",
                              "PCK00008.TPC",
                              "DI_TEMPEL1_V01.TPC",
                              "DI_HARTLEY_2_V01.TPC",
                              "DIF_SCLKSCET_00084_SCIENCE.TSC",
                              "DI_V18.TF",
                              "DIF_HRI_V10.TI",
                              "DIF_MRI_V10.TI",
                              "DIF_SC_090101_110228_V2.BC",
                              "DIF_SC_101104_HIGHRATE.BC",
                              "HARTLEY_2_2005_2020.BSP",
                              "SPK_MARS_DRM232.BSP",
                              "JUP164_20YEAR.BSP",
                              "DIF_PREENC174_NAV_V1.BSP",
                              "DI_FINALENC_NAV_V3_TO2006048.BSP",
                              "DIF_DIXI_NAV_V1.BSP" )
RIGHT_ASCENSION             = 310.068586600 <DEG>
DECLINATION                 = 40.314566400 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE = 83.7637 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 110.7587 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 190.1930 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 20.0543 <DEG>
SOLAR_ELONGATION           = 94.3798 <DEG>
PHASE_ANGLE                 = 85.584 <DEG>
TARGET_CENTER_DISTANCE      = 12960.8968 <KM>
TARGET_HELIOCENTRIC_DISTANCE = 159105528.689 <KM>
TARGET_GEOCENTRIC_DISTANCE  = 23356658.282 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE = 159104531.168 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE  = 23364722.058 <KM>
QUATERNION_DESC             = "QUATERNION_DESC.ASC"
QUATERNION                   =

```

```

( 0.337702200000
, 0.370662600000
, -0.197781300000
, 0.842288000000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( 3.396454105520e-05 <RAD/S>
, 3.208269299830e-05 <RAD/S>
, 3.283639342790e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( -6371.957 <KM>
, 7560.351 <KM>
, -8379.982 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 6.376873 <KM/S>
, -7.454455 <KM/S>
, 7.454289 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( -103730026.758 <KM>
, -113065341.255 <KM>
, -42081818.104 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( 26.375673 <KM/S>
, -26.702505 <KM/S>
, -1.988183 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( -6745868.379 <KM>
, 22199555.735 <KM>
, 2684487.124 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( -6.002527 <KM/S>
, 6.441482 <KM/S>
, -6.794060 <KM/S>
)
SC_SUN_POSITION_VECTOR =
( -103723654.800 <KM>
, -113072901.606 <KM>
, -42073438.122 <KM>
)
SC_EARTH_POSITION_VECTOR =
( 6751924.232 <KM>
, -22207131.852 <KM>
, -2676761.275 <KM>
)
SUB_SPACECRAFT_LONGITUDE = "N/A"
SUB_SPACECRAFT_LATITUDE = "N/A"
SUB_SOLAR_LONGITUDE = "N/A"
SUB_SOLAR_LATITUDE = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE = "N/A"
COORDINATE_SYSTEM_NAME = "N/A"

```

```

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HI0342148253_5001000_001_RR.FIT"
PROCESSING_HISTORY_TEXT      = "
FILEVERN=                1.1300000 / Version number of file format
PGMNAME = 'DICAL'         ' / Program name that produced this file
PGMVERN =                5.0800000 / Version number of the above program
DATAQUAL=                -999 / Data quality (1)
TMPVLTUP=                F / Physical temps and voltages updated
(T/F)
TMPVLTV = ' '           ' / Valid date of physical temps, voltages
used
SMOBENT =                -1.0000000 / Smoothed over time version of OPTBENT
[K]
CMPRESSN=                F / Decompression performed (T/F)
LUTTABLE= ' '           ' / Lossy lookup table/algorithm applied
CMPRMETH=                -999 / Decompress method. 1
SATPIX =                 T / Saturated pixels flagged (T/F)
SMSATVL =                8000 / DN value where some pixels are saturated
MSTSATVL=               11000 / DN value where most pixels are saturated
ADCSATVL=               16383 / DN value where the ADC encoder is
saturated
BITCORR =                F / Uneven bit weighting corrected (T/F)
BITLUT = ' '           ' / Bit weighting lookup table used
DARKCORR=                T / Dark subtraction (T/F)
DARKALG = 'MODEL'        ' / Algorithm used to create dark
DARKFN = 'HRIIR_071004_1_5.FIT' / File name for frame/model used
BIASFN = ' '           ' / Filename of bias frame used
XTALK =                  T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIIR_050112_1_5.FIT' / Filename of crosstalk gains used
GAINCORR=                F / Quadrant Gain correction performed (T/F)
GAINFN = ' '           ' / Filename of gain values used
FLATCORR=                T / Flat fielded
FLATFILE= 'HRIIR_050112_4_0_0.FIT' / Name of flat field applied
BPIXFL =                 T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIIR_100928_1_5_999.FIT' / Name of bad pixel map applied
CLEAN =                  F / Cleaned/fill small gaps (T/F)
CLEANV =                 -999 / Max filled gap size; -999999
CLNBAD =                 F / Bad pixels cleaned
CLNMISS =                F / Missing data cleaned
DESPIKE =                F / Despiking applied (T/F)
DESPIKET=               -999 / Despiking threshold used (sigma)
DESPIKEI=               -999 / Number of iterations of despiking
DESPIKEB=               -999 / Boxsize for despiking
DESPIKEM= ' '           ' / Metric used for despiking. Mean or
Median
DENOISE =                F / Denoising applied (T/F)
DENOISEV= ' '           ' / Denoise parameter applied
DECON =                  F / Deconvolution performed (T/F)
DECONPSF= ' '           ' / Deconvolution psf used
DECONALG= ' '           ' / Deconvolution algorithm used
DECONV = ' '           ' / Deconvolution algorithm-specific
parameter
LINEARIZ=                T / Linearization applied (T/F)
LINAC0 =                 1.01820 / Quad A additive constant for
linearization
LINAC1 =                 -5.21680E-06 / Quad A coefficient for x term

```

```

LINAC2 =          1.63150E-10 / Quad A coefficient for x-squared term
LINAC3 =         -3.66660E-14 / Quad A coefficient for x-cubed term
LINAC4 =        -999.0000000 / Quad A coefficient for x-4th term
LINBC0 =          1.01790 / Quad B additive constant for
linearization
LINBC1 =         -5.21490E-06 / Quad B coefficient for x term
LINBC2 =          1.80100E-10 / Quad B coefficient for x-squared term
LINBC3 =         -3.73680E-14 / Quad B coefficient for x-cubed term
LINBC4 =        -999.0000000 / Quad B coefficient for x-4th term
MDARKVER=          3.0000000 / Master dark frame version
DRKPMODE=           0 / Mode of the previous set taken
DARKISG =         -0.9990000 / Inter-sequence gap [msec]
DARKA0 =          3.0060000E+10 / Dark level temp coef A_0
DARKA1 =         -3384.4000000 / Dark level temp coef A_1
DARKB0 =          65630000.0000000 / Dark level temp coef B_0
DARKB1 =         -2002.0000000 / Dark level temp coef B_1
DARKC0 =           0.0583000 / Dark level temp coef C_0
DRKTMSCl=          0.9650000 / Dark scaling factor for time dependency
DARKPLAT=           F / Dark plateau reached
DARKMSCl=        -999.0000000 / Manually derived scaling factor
DRKTOOHI=           F / Modeled dark too high (T/F)
DARK99 =           F / Dark scaled back to 99% of dark region
(T/F)
DRKIRPRO= 'HRIIR_071004_4_0.pro' / DARKIR_PRO - IDL code used
TEMPFPA =          84.0850000 / [KELVINS] Tfpa temperature used
TEMPSIM =         137.1310000 / [KELVINS] Tsim temperature used
TEMPSCAL=          0.6361000 / Scaling
[A0*EXP(A1/Tfpa)+B0*EXP(B1/Tsim)]
FLATTYPE= 'IR_FARNHAM_MASTER_FLAT_V201009' / Flat type identifier
FASFCORR=           T / Flat corrects ASF
CASFCORR=           F / Cal Const corrects ASF
ASFSTAT = 'FLAT      ' / ASF corrected by
CALCORR =           T / Calibration Applied (T/F)
CALCONST=        -999.0000000 / Calibration Constant Applied
CALNUMB0=          1075 / Number of ZERO calibration factors found
CALMAP1 = 'HRIIR_050112_13_5_999.FIT' / Calibration constant map interped
(1)
CALMAP2 = 'HRIIR_050112_13_5_000.FIT' / Calibration constant map interped
(2)
SPECMAP1= '      ' / Spectral map interpolated over (1)
SPECMAP2= '      ' / Spectral map interpolated over (2)
HLUTFN = '      ' / H lambda lookup table used
"

/***** IMAGE STATISTICS *****/
EPOXI:BAD_PIXEL_COUNT           = 10051
EPOXI:MISSING_PIXEL_COUNT       = 50
EPOXI:DESPIKED_PIXEL_COUNT      = 0
EPOXI:INTERPOLATED_PIXEL_COUNT  = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 16
EPOXI:SATURATED_PIXEL_COUNT     = 8
EPOXI:ADC_SATURATED_PIXEL_COUNT = 0
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT = 0

OBJECT      = HEADER
  BYTES     = 54720
  HEADER_TYPE = "FITS"

```

```

INTERCHANGE_FORMAT = "BINARY"
RECORDS             = 19
DESCRIPTION         = "FITS format defined in
NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

```

```

OBJECT              = IMAGE
LINE_SAMPLES       = 512
LINES              = 256
SAMPLE_BITS        = 32
SAMPLE_TYPE        = "IEEE_REAL"
AXIS_ORDER_TYPE    = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT               = "W/(m**2*sr*um)"
EPOXI:MINIMUM      = -6.53858000000e+01
EPOXI:MAXIMUM      = 9.64768000000e+01
EPOXI:MEDIAN       = 3.49900000000e-04
EPOXI:STANDARD_DEVIATION = 9.54982000000e-01
END_OBJECT         = IMAGE

```

```

OBJECT              = EXT_QUALITY_FLAGS_HEADER
BYTES               = 2880
HEADER_TYPE         = "FITS"
INTERCHANGE_FORMAT = "BINARY"
RECORDS             = 1
DESCRIPTION         = "This extension provides quality flags for
each pixel in the primary image array. Each of the one-byte pixels
in this map is composed of eight bits. Each bit represents a specific
characteristic about the corresponding pixel in the primary image
array. For a raw image, only the bit for a missing data value is set
(bit 1 below). The remaining 7 bits apply only to a calibrated image
and are thus set to zero for a raw image. The bits are described below
and are listed from the least-significant (0) to most-significant (7):
0 = Bad
1 = Data for this pixel was not received from the spacecraft or
this pixel is one of the image header bytes.
2 = Despiked
3 = Interpolated
4 = Partially saturated
5 = Mostly saturated
6 = ADC saturated
7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

```

```

OBJECT              = EXT_QUALITY_FLAGS_IMAGE
LINE_SAMPLES       = 512
LINES              = 256
SAMPLE_BITS        = 8
SAMPLE_TYPE        = "MSB_UNSIGNED_INTEGER"
AXIS_ORDER_TYPE    = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT         = EXT_QUALITY_FLAGS_IMAGE

```

```

OBJECT              = EXT_WAVELENGTH_HEADER
BYTES               = 2880

```

```

HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
RECORDS              = 1
DESCRIPTION          = "This extension provides the spectral
                        wavelength for each pixel in the primary image array."
END_OBJECT = EXT_WAVELENGTH_HEADER

OBJECT               = EXT_WAVELENGTH_IMAGE
LINE_SAMPLES        = 512
LINES                = 256
SAMPLE_BITS         = 32
SAMPLE_TYPE         = "IEEE_REAL"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT                = "MICROMETER"
END_OBJECT          = EXT_WAVELENGTH_IMAGE

OBJECT               = EXT_SPEC_BANDWIDTH_HEADER
BYTES                = 2880
HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
RECORDS              = 1
DESCRIPTION          = "This extension provides the spectral
                        bandwidth for each pixel in the primary image array."
END_OBJECT = EXT_SPEC_BANDWIDTH_HEADER

OBJECT               = EXT_SPEC_BANDWIDTH_IMAGE
LINE_SAMPLES        = 512
LINES                = 256
SAMPLE_BITS         = 32
SAMPLE_TYPE         = "IEEE_REAL"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
UNIT                = "MICROMETER"
END_OBJECT          = EXT_SPEC_BANDWIDTH_IMAGE

OBJECT               = EXT_SNR_HEADER
BYTES                = 2880
HEADER_TYPE          = "FITS"
INTERCHANGE_FORMAT  = "BINARY"
RECORDS              = 1
DESCRIPTION          = "This extension is the signal-to-noise ratio
                        for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT               = EXT_SNR_IMAGE
LINE_SAMPLES        = 512
LINES                = 256
SAMPLE_BITS         = 32
SAMPLE_TYPE         = "IEEE_REAL"
AXIS_ORDER_TYPE     = "FIRST_INDEX_FASTEST"
LINE_DISPLAY_DIRECTION = "UP"
SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_SNR_IMAGE

```

END

#### 4.4.4 Level 3/4 Calibrated HRIV/MRI Science Data Product

The calibrated science data products for the HRIV and MRI instruments have self-consistent formats. Therefore, only an example of a PDS label for reversible, calibrated HRIV FITS science image in units of radiance (RADREV, not cleaned) is provided below. Labels for RAD (radiance units, cleaned) science images have the same format. As noted in section 4.1.2, the RADREV and RAD products for HRIV and MRI include a multiplicative factor for converting from units of radiance to unitless I-over-F:

EPOXI:DATA\_TO\_IOVERF\_MULTIPLIER in the PDS labels or MULT2IOF in the FITS headers.

The calibration pipeline was improved to handle de-stripping of HRIV and MRI image for the Hartley 2 encounter and to capture the de-stripping values in a new FITS extension. Therefore an example of an EPOCH label (without a de-stripping extension) and a Hartley 2 label are provided next.

##### 4.4.4.1 EPOCH Label

```
PDS_VERSION_ID      = PDS3
RECORD_TYPE         = "FIXED_LENGTH"
RECORD_BYTES        = 2880
FILE_RECORDS        = 842

^HEADER = ("HV08060416_1000001_001_RR.FIT",1)
^IMAGE = ("HV08060416_1000001_001_RR.FIT",19)
^EXT_QUALITY_FLAGS_HEADER = ("HV08060416_1000001_001_RR.FIT",384)
^EXT_QUALITY_FLAGS_IMAGE = ("HV08060416_1000001_001_RR.FIT",385)
^EXT_SNR_HEADER = ("HV08060416_1000001_001_RR.FIT",477)
^EXT_SNR_IMAGE = ("HV08060416_1000001_001_RR.FIT",478)

DATA_SET_ID          = "DIF-E-HRIV-3/4-EPOXI-EARTH-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID  = "DIF"
INSTRUMENT_NAME      =
  "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV08060416_1000001_001_RR_FIT"
PRODUCT_CREATION_TIME = 2009-03-12T00:44:08
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2008-06-04T16:57:24.642
EPOXI:IMAGE_MID_TIME = 2008-06-04T16:57:24.649
STOP_TIME            = 2008-06-04T16:57:24.656
START_JULIAN_DATE_VALUE = 2454622.2065352
```

```

MID_JULIAN_DATE_VALUE    = 2454622.2065353
STOP_JULIAN_DATE_VALUE   = 2454622.2065354
SPACECRAFT_CLOCK_START_COUNT    = "1/0265869939.131"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0265869939.132"
SPACECRAFT_CLOCK_STOP_COUNT     = "1/0265869939.134"
EPOXI:EARTH_OBSERVER_MID_TIME   = 2008-06-04T17:00:12.888

```

```

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME      = "EPOCH"
EPOXI:MISSION_ACTIVITY_TYPE = "EARTH OBS"
EPOXI:OBSERVATION_DESC  = "HRIV RADIOMETRY 1A"
EPOXI:POINTING_DESC     = "TO EARTH"
TARGET_NAME             = "EARTH"
INSTRUMENT_MODE_ID      = 2
EPOXI:INSTRUMENT_MODE_NAME = "SF1"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID           = "N/A"
EPOXI:OBSERVATION_ID    = "1000001"
EPOXI:IMAGE_NUMBER      = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER           = 2
FILTER_NAME              = "BLUE"
CENTER_FILTER_WAVELENGTH = 450 <NM>
EPOXI:INTEGRATION_DURATION = 13.500000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 303.9532000 <K>
, 303.9899680 <K>
, 296.2441760 <K>
, 302.0412640 <K>
, 283.4121440 <K>
, 163.2127061 <K>
, 137.3380562 <K>
, 137.1009052 <K>
, 131.8059846 <K>
, 135.7561008 <K>
, 84.1435000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2067857 <V>
, 1.2128898 <V>
, 1.2049545 <V>
, 1.2159419 <V>
, 5.1249156 <V>

```



```

, 5.1233263 <V>
, 5.1106113 <V>
, 5.1050485 <V>
, 5.0335270 <V>
, -5.0287589 <V>
, 5.0104812 <V>
, -9.2021797 <V>
, 0.2458221 <V>
, 0.7423583 <V>
, 3.4060428 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

/***** IMAGE INFORMATION *****/
HORIZONTAL_PIXEL_SCALE = 100893.168 <M/PIXEL>
VERTICAL_PIXEL_SCALE = 100893.168 <M/PIXEL>

/***** GEOMETRY PARAMETERS *****/
NOTE = "
Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
system used to specify observational geometry. Geometric parameters are
based on the best available SPICE data at the time of product creation.
Refer to the EPOXI SPICE archive for the most current observational
geometry. The observation midpoint was used to derive the geometry.
All positions are relative to body centers."

EPOXI:GEOMETRY_QUALITY_FLAG = "OK"
EPOXI:GEOMETRY_TYPE = "RECONSTRUCTED"
SPICE_FILE_NAME = ( "NAIF0009.TLS",
" PCK00008.TPC",
" DIF_SCLKSCET.00035.TSC",
" DI_V17.TF",
" DIF_HRI_V10.TI",
" DIF_MRI_V10.TI",
" DIF_SC_050112_050809.BC",
" DIF_SC_050225_HIGHRATE.BC",
" DIF_SC_050704_HIGHRATE.BC",
" DIF_SC_2008_06_04.BC",
" JUP164_20YEAR.BSP",

```

```

                                "SPK_OD221_FULL.BSP" )
RIGHT_ASCENSION                = 177.489792500 <DEG>
DECLINATION                    = -0.215176100 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE  = 113.1337 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 89.7128 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE = 180.0005 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 113.1357 <DEG>
SOLAR_ELONGATION              = 84.1632 <DEG>
PHASE_ANGLE                   = 76.533 <DEG>
TARGET_CENTER_DISTANCE        = 50446583.8460 <KM>
TARGET_HELIOCENTRIC_DISTANCE  = 151789311.363 <KM>
TARGET_GEOCENTRIC_DISTANCE    = 0.000 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE = 148385381.127 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE  = 50436998.201 <KM>
QUATERNION_DESC               = "QUATERNION_DESC.ASC"
QUATERNION                    =
( 0.688178800000
, 0.126812100000
, -0.696991000000
, -0.156627400000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( -6.193104793090e-07 <RAD/S>
, 5.662622783320e-07 <RAD/S>
, -2.666095006670e-06 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( 50397729.649 <KM>
, -2211519.755 <KM>
, 189336.499 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 1.724195 <KM/S>
, 7.629346 <KM/S>
, 0.946928 <KM/S>
)
TARGET_SUN_POSITION_VECTOR     =
( 41049886.647 <KM>
, 134075548.433 <KM>
, 58126148.701 <KM>
)
TARGET_SUN_VELOCITY_VECTOR     =
( -28.206501 <KM/S>
, 7.494698 <KM/S>
, 3.248512 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR   =
( 0.000 <KM>
, 0.000 <KM>
, 0.000 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR   =
( 0.000000 <KM/S>
, 0.000000 <KM/S>
, 0.000000 <KM/S>
)
SC_SUN_POSITION_VECTOR        =

```

```

(   -9347843.002 <KM>
,   136287068.188 <KM>
,   57936812.202 <KM>
)
SC_EARTH_POSITION_VECTOR      =
(   -50388265.569 <KM>
,   2208512.122 <KM>
,   -189617.362 <KM>
)
SUB_SPACECRAFT_LONGITUDE      = 210.5053179 <DEG>
SUB_SPACECRAFT_LATITUDE       = 0.2619271 <DEG>
SUB_SOLAR_LONGITUDE           = 286.0135359 <DEG>
SUB_SOLAR_LATITUDE            = 22.5295803 <DEG>
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE        = "BODY-FIXED ROTATING"
COORDINATE_SYSTEM_NAME        = "PLANETOCENTRIC"

/***** PROCESSING HISTORY *****/
EPOXI:SDC_PIPELINE_FILE_NAME = "HV0265869939_1000001_001_RR.FIT"
EPOXI:DATA_TO_IOVERF_MULTPLIPLIER = 0.0017237002
EPOXI:DATA_TO_RADIANCE_MULTPLIPLIER = 1.0
EPOXI:DATA_TO_DN_MULTPLIPLIER = 14.030347
PROCESSING_HISTORY_TEXT      = "
FILEVERN= 1.1000000 / Version number of file format
PGMNAME = 'DICAL' / Program name that produced this file
PGMVERN = 5.0000000 / Version number of the above program
DATAQUAL= -999 / Data quality (1)
TMPVLTUP= F / Physical temps, voltages updated (T/F)
TMPVLTV = ' ' / Valid date of physical temps, volts used
SMOBENT = -1.0000000 / Smoothed over time version of OPTBENT[K]
CMPRESSN= F / Decompression performed (T/F)
LUTTABLE= ' ' / Lossy lookup table/algorithm applied
CMPRMETH= -999 / Decompress method. 1
SATPIX = T / Saturated pixels flagged (T/F)
SMSATVL = 11000 / DN value where some pixels are saturated
MSTSATVL= 15000 / DN value where most pixels are saturated
ADCSATVL= 16383 / DN value where ADC encoder is saturated
BITCORR = F / Uneven bit weighting corrected (T/F)
BITLUT = ' ' / Bit weighting lookup table used
DARKCORR= T / Dark subtraction (T/F)
DARKALG = 'MODEL' / Algorithm used to create dark
DARKFN = 'HRIVIS_020601_2_2.FIT' / File name for frame/model used
BIASFN = 'SERIAL OVERCLOCK' / Filename of bias frame used
XTALK = T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIVIS_071004_1_2.FIT' / Filename of crosstalk gains used
GAINCORR= F / Quadrant Gain correction performed (T/F)
GAINFN = ' ' / Filename of gain values used
FLATCORR= T / Flat fielded
FLATFILE= 'HRIVIS_050701_1_2_2.FIT' / Name of flat field applied
BPIXFL = T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIVIS_020601_2_2_999.FIT' / Name of bad pixel map applied
CLEAN = F / Cleaned/fill small gaps (T/F)
CLEANV = -999 / Max filled gap size; -999999
CLNBAD = F / Bad pixels cleaned
CLNMISS = F / Missing data cleaned
DESPIKE = F / Despiking applied (T/F)
DESPIKET= -999 / Despiking threshold used (sigma)

```

```

DESPIKEI=          -999 / Number of iterations of despiking
DESPIKEB=          -999 / Boxsize for despiking
DESPIKEM= '      ' / Metric used for despiking.Mean or Median
DENOISE =          F / Denoising applied (T/F)
DENOISEV= '      ' / Denoise parameter applied
DECON  =          F / Deconvolution performed (T/F)
DECONPSF= '      ' / Deconvolution psf used
DECONALG= '      ' / Deconvolution algorithm used
DECONV = '      ' / Deconvolution algorithm-specific param
SMEAR  =          T / Frame-transfer smear removed (T/F)
SMEARV = 'POC ROWS' / Smear removal algorithm applied
RADCAL =          T / Radiance calibration applied (T/F)
RADCALV =          0.0009622 / Rad cal const used[W/(m^2 sr um)/(DN/s)]
RADCALW =          452.48 / Radiance calib - wavelength used [nm]
IOFCAL =          F / I/F calibration applied (T/F)
IOFCALV =          1876.3752000 / I/F cal const used[W/(m^2 sr um) @ 1 AU]
IOFCALW =          454.19 / I/F calib - wavelength used [nm]
IOFCALD =          1.0146489 / I/F calib - Distance used [AU]
MULT2RAD=          1 / Multiplier to convert data to Radiance
MULT2IOF=          0.0017237002 / Multiplier to convert data to I/F
MULT2DN =          14.030347 / Multiplier to convert data to DN
GEOMCAL =          F / Geometric calibration performed (T/F)
GEOMFILE= '      ' / File used for geometric calibration
"

```

/\*\*\*\*\* IMAGE STATISTICS \*\*\*\*\*/

```

EPOXI:BAD_PIXEL_COUNT          = 1024
EPOXI:MISSING_PIXEL_COUNT     = 50
EPOXI:DESPIKED_PIXEL_COUNT    = 0
EPOXI:INTERPOLATED_PIXEL_COUNT = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 971
EPOXI:SATURATED_PIXEL_COUNT   = 948
EPOXI:ADC_SATURATED_PIXEL_COUNT = 900
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT = 0

```

```

OBJECT      = HEADER
  BYTES          = 51840
  HEADER_TYPE    = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS       = 18
  DESCRIPTION    = "FITS format defined in
    NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

```

```

OBJECT      = IMAGE
  LINE_SAMPLES = 512
  LINES       = 512
  SAMPLE_BITS = 32
  SAMPLE_TYPE = "IEEE_REAL"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT          = "W/(m**2*sr*um)"
  EPOXI:MINIMUM = -7.44281000000e-01
  EPOXI:MAXIMUM = 3.11041000000e+02
  EPOXI:MEDIAN  = 4.86289000000e-02
  EPOXI:STANDARD_DEVIATION = 1.90605000000e+01

```

```

END_OBJECT          = IMAGE

OBJECT              = EXT_QUALITY_FLAGS_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension provides quality flags for
each pixel in the primary image array.  Each of the one-byte pixels
in this map is composed of eight bits.  Each bit represents a specific
characteristic about the corresponding pixel in the primary image
array.  For a raw image, only the bit for a missing data value is set
(bit 1 below).  The remaining 7 bits apply only to a calibrated image
and are thus set to zero for a raw image.  The bits are described below
and are listed from the least-significant (0) to most-significant (7):
  0 = Bad
  1 = Data for this pixel was not received from the spacecraft or
this pixel is one of the image header bytes.
  2 = Despiked
  3 = Interpolated
  4 = Partially saturated
  5 = Mostly saturated
  6 = ADC saturated
  7 = Ultra compressed"
END_OBJECT = EXT_QUALITY_FLAGS_HEADER

OBJECT              = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES      = 512
  LINES              = 512
  SAMPLE_BITS        = 8
  SAMPLE_TYPE        = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE    = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_QUALITY_FLAGS_IMAGE

OBJECT              = EXT_SNR_HEADER
  BYTES              = 2880
  HEADER_TYPE        = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS            = 1
  DESCRIPTION        = "This extension is the signal-to-noise ratio
for each pixel in the primary image array."
END_OBJECT = EXT_SNR_HEADER

OBJECT              = EXT_SNR_IMAGE
  LINE_SAMPLES      = 512
  LINES              = 512
  SAMPLE_BITS        = 32
  SAMPLE_TYPE        = "IEEE_REAL"
  AXIS_ORDER_TYPE    = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT          = EXT_SNR_IMAGE

END

```

#### 4.4.4.2 Hartley 2 Label

```
PDS_VERSION_ID      = PDS3
RECORD_TYPE         = "FIXED_LENGTH"
RECORD_BYTES        = 2880
FILE_RECORDS        = 229

^HEADER = ("HV10110412_5000000_001_RR.FIT",1)
^IMAGE = ("HV10110412_5000000_001_RR.FIT",19)
^EXT_QUALITY_FLAGS_HEADER = ("HV10110412_5000000_001_RR.FIT",111)
^EXT_QUALITY_FLAGS_IMAGE = ("HV10110412_5000000_001_RR.FIT",112)
^EXT_SNR_HEADER = ("HV10110412_5000000_001_RR.FIT",135)
^EXT_SNR_IMAGE = ("HV10110412_5000000_001_RR.FIT",136)
^EXT_DESTRIPE_HEADER = ("HV10110412_5000000_001_RR.FIT",228)
^EXT_DESTRIPE_IMAGE = ("HV10110412_5000000_001_RR.FIT",229)

DATA_SET_ID          = "DIF-C-HRIV-3/4-EPOXI-HARTLEY2-V1.0"
MISSION_NAME         = "EPOXI"
INSTRUMENT_HOST_NAME = "DEEP IMPACT FLYBY SPACECRAFT"
INSTRUMENT_HOST_ID  = "DIF"
INSTRUMENT_NAME      =
    "DEEP IMPACT HIGH RESOLUTION INSTRUMENT - VISIBLE CCD"
INSTRUMENT_ID        = "HRIV"

/***** PRODUCT INFORMATION *****/
PRODUCT_ID           = "HV10110412_5000000_001_RR_FIT"
PRODUCT_CREATION_TIME = 2011-06-10T01:11:12
PRODUCT_TYPE         = "RADIANCE_REVERSIBLE"

/***** TIME INFORMATION *****/
START_TIME           = 2010-11-04T12:03:13.125
EPOXI:IMAGE_MID_TIME = 2010-11-04T12:03:14.125
STOP_TIME            = 2010-11-04T12:03:15.125
START_JULIAN_DATE_VALUE = 2455505.0022352
MID_JULIAN_DATE_VALUE  = 2455505.0022468
STOP_JULIAN_DATE_VALUE = 2455505.0022584
SPACECRAFT_CLOCK_START_COUNT = "1/0342142309.163"
EPOXI:SPACECRAFT_CLOCK_MID_COUNT = "1/0342142310.163"
SPACECRAFT_CLOCK_STOP_COUNT = "1/0342142311.163"
EPOXI:EARTH_OBSERVER_MID_TIME = 2010-11-04T12:04:32.081

/***** OBSERVATION INFORMATION *****/
MISSION_PHASE_NAME   = "HARTLEY 2 ENCOUNTER"
EPOXI:MISSION_ACTIVITY_TYPE = "FLYBY"
EPOXI:OBSERVATION_DESC = "E-2HR"
EPOXI:POINTING_DESC  = "TO HARTLEY"
TARGET_NAME          = "103P/HARTLEY 2 (1986 E2)"
INSTRUMENT_MODE_ID   = "3"
EPOXI:INSTRUMENT_MODE_NAME = "SF2S"
EPOXI:COMPRESSED_IMAGE_VALUE = "UNCOMPRESSED"
COMPRESSOR_ID        = "N/A"
EPOXI:OBSERVATION_ID = "5000000"
EPOXI:IMAGE_NUMBER   = "001"
EPOXI:COMMANDED_IMAGE_COUNT = 1
FILTER_NUMBER        = "1"
FILTER_NAME          = "CLEAR1"
```

```

CENTER_FILTER_WAVELENGTH      = 650 <NM>
EPOXI:INTEGRATION_DURATION    = 2000.5000000 <MS>
EPOXI:SPACECRAFT_PROCESSOR_ID = "SCU-A"
INSTRUMENT_TEMPERATURE =
( 307.5564640 <K>
, 307.6790240 <K>
, 300.5582880 <K>
, 305.9264160 <K>
, 272.1488800 <K>
, 163.3098984 <K>
, 136.9972176 <K>
, 136.6716040 <K>
, 131.2548410 <K>
, 135.4909000 <K>
, 84.0420000 <K>
)
INSTRUMENT_TEMPERATURE_POINT =
( "INSTRUMENT CONTROLLER PROCESSING BOARD"
, "CCD SIGNAL PROCESSING BOARD"
, "IR SIGNAL PROCESSING BOARD"
, "LVPS SIGNAL PROCESSING BOARD"
, "CCD PREAMP BOX"
, "CCD ON-CHIP SENSOR"
, "PRISMS"
, "PRIMARY MIRROR"
, "SECONDARY MIRROR"
, "SPECTRAL IMAGING MODULE COVER"
, "IR FPA ON-CHIP SENSOR"
)
INSTRUMENT_VOLTAGE =
( 1.2058701 <V>
, 1.2135002 <V>
, 1.2040388 <V>
, 1.2168575 <V>
, 5.1257103 <V>
, 5.1209422 <V>
, 5.1122007 <V>
, 5.1042538 <V>
, 5.0295536 <V>
, -5.0216067 <V>
, 5.0041237 <V>
, -9.1901389 <V>
, 0.2445991 <V>
, 0.7411353 <V>
, 3.4035968 <V>
, "UNK"
)
INSTRUMENT_VOLTAGE_POINT =
( "CCD OFFSET FROM ADC REF QUAD A"
, "CCD OFFSET FROM ADC REF QUAD B"
, "CCD OFFSET FROM ADC REF QUAD C"
, "CCD OFFSET FROM ADC REF QUAD D"
, "CCD OUTPUT AMP DRAIN QUAD A"
, "CCD OUTPUT AMP DRAIN QUAD B"
, "CCD OUTPUT AMP DRAIN QUAD C"
, "CCD OUTPUT AMP DRAIN QUAD D"
, "CCD SERIAL CLOCK POSITIVE"
)

```

```

, "CCD SERIAL CLOCK NEGATIVE"
, "CCD PARALLEL CLOCK POSITIVE"
, "CCD PARALELL CLOCK NEGATIVE"
, "IR RESET"
, "IR SUBSTRATE"
, "IR BIASGATE"
, "IR CALIB LAMP"
)

```

```

/***** IMAGE INFORMATION *****/

```

```

HORIZONTAL_PIXEL_SCALE = 172.327 <M/PIXEL>
VERTICAL_PIXEL_SCALE   = 172.327 <M/PIXEL>

```

```

/***** GEOMETRY PARAMETERS *****/

```

```

NOTE = "

```

```

Earth Mean Equator and Vernal Equinox J2000 is the inertial reference
system used to specify observational geometry. Geometric parameters are
based on the best available SPICE data at the time of product creation.
Refer to the EPOXI SPICE archive for the most current observational
geometry. The observation midpoint was used to derive the geometry.
All positions are relative to body centers."

```

```

EPOXI:GEOMETRY_QUALITY_FLAG      = "OK"
EPOXI:GEOMETRY_TYPE              = "RECONSTRUCTED"
SPICE_FILE_NAME                  = ( "NAIF0009.TLS",
                                     "PCK00008.TPC",
                                     "DI_TEMPEL1_V01.TPC",
                                     "DI_HARTLEY_2_V01.TPC",
                                     "DIF_SCLKSCET_00084_SCIENCE.TSC",
                                     "DI_V18.TF",
                                     "DIF_HRI_V10.TI",
                                     "DIF_MRI_V10.TI",
                                     "DIF_SC_090101_110228_V2.BC",
                                     "DIF_SC_101104_HIGHRATE.BC",
                                     "HARTLEY_2_2005_2020.BSP",
                                     "SPK_MARS_DRM232.BSP",
                                     "JUP164_20YEAR.BSP",
                                     "DIF_PREENC174_NAV_V1.BSP",
                                     "DI_FINALENC_NAV_V3_TO2006048.BSP",
                                     "DIF_DIXI_NAV_V1.BSP" )
RIGHT_ASCENSION                   = 310.478316600 <DEG>
DECLINATION                       = 37.691773900 <DEG>
CELESTIAL_NORTH_CLOCK_ANGLE      = 73.6859 <DEG>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE = 99.2005 <DEG>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE  = 179.9952 <DEG>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE = 12.4447 <DEG>
SOLAR_ELONGATION                 = 93.9799 <DEG>
PHASE_ANGLE                      = 85.985 <DEG>
TARGET_CENTER_DISTANCE           = 86163.7134 <KM>
TARGET_HELIOCENTRIC_DISTANCE     = 159091889.765 <KM>
TARGET_GEOCENTRIC_DISTANCE       = 23314661.089 <KM>
EPOXI:SC_HELIOCENTRIC_DISTANCE   = 159085880.630 <KM>
EPOXI:SC_GEOCENTRIC_DISTANCE     = 23370621.570 <KM>
QUATERNION_DESC                  = "QUATERNION_DESC.ASC"
QUATERNION                       =
( 0.256494300000
, 0.370018900000

```



```

, -0.239539800000
, 0.860184500000
)
EPOXI:SC_ROTATION_VELOCITY_VECTOR =
( 1.306664244630e-06 <RAD/S>
, 1.989385378040e-06 <RAD/S>
, 9.226216507660e-07 <RAD/S>
)
EPOXI:TARGET_SC_POSITION_VECTOR =
( -44267.991 <KM>
, 51860.155 <KM>
, -52678.789 <KM>
)
EPOXI:TARGET_SC_VELOCITY_VECTOR =
( 6.376261 <KM/S>
, -7.453739 <KM/S>
, 7.453570 <KM/S>
)
TARGET_SUN_POSITION_VECTOR =
( -103886716.314 <KM>
, -112906583.167 <KM>
, -42069977.895 <KM>
)
TARGET_SUN_VELOCITY_VECTOR =
( 26.358407 <KM/S>
, -26.721306 <KM/S>
, -1.995183 <KM/S>
)
EARTH_TARGET_POSITION_VECTOR =
( -6710175.992 <KM>
, 22161273.756 <KM>
, 2724867.959 <KM>
)
EARTH_TARGET_VELOCITY_VECTOR =
( -6.009372 <KM/S>
, 6.442536 <KM/S>
, -6.795851 <KM/S>
)
SC_SUN_POSITION_VECTOR =
( -103842448.323 <KM>
, -112958443.322 <KM>
, -42017299.106 <KM>
)
SC_EARTH_POSITION_VECTOR =
( 6754121.985 <KM>
, -22213141.696 <KM>
, -2672849.558 <KM>
)
SUB_SPACECRAFT_LONGITUDE = "N/A"
SUB_SPACECRAFT_LATITUDE = "N/A"
SUB_SOLAR_LONGITUDE = "N/A"
SUB_SOLAR_LATITUDE = "N/A"
/* Coordinate system for sub-spacecraft and sub-solar values */
COORDINATE_SYSTEM_TYPE = "N/A"
COORDINATE_SYSTEM_NAME = "N/A"

/***** PROCESSING HISTORY *****/

```

```

EPOXI:SDC_PIPELINE_FILE_NAME = "HV0342142310_5000000_001_RR.FIT"
EPOXI:DATA_TO_IOVERF_MULTIPLIER = 0.0024160
EPOXI:DATA_TO_RADIANCE_MULTIPLIER = 1.0
EPOXI:DATA_TO_DN_MULTIPLIER = 16543.7220000
PROCESSING_HISTORY_TEXT = "
FILEVERN= 1.1000000 / Version number of file format
PGMNAME = 'DICAL ' / Program name that produced this file
PGMVERN = 5.0400000 / Version number of the above program
DATAQUAL= -999 / Data quality (1)
TMPVLTUP= F / Physical temps and voltages updated
(T/F)
TMPVLTV = ' ' / Valid date of physical temps, voltages
used
SMOBENT = -1.0000000 / Smoothed over time version of OPTBENT
[K]
CMPRESSN= F / Decompression performed (T/F)
LUTTABLE= ' ' / Lossy lookup table/algorithm applied
CMPRMETH= -999 / Decompress method. 1
SATPIX = T / Saturated pixels flagged (T/F)
SMSATVL = 11000 / DN value where some pixels are saturated
MSTSATVL= 15000 / DN value where most pixels are saturated
ADCSATVL= 16383 / DN value where the ADC encoder is
saturated
BITCORR = F / Uneven bit weighting corrected (T/F)
BITLUT = ' ' / Bit weighting lookup table used
DARKCORR= T / Dark subtraction (T/F)
DARKALG = 'MODEL ' / Algorithm used to create dark
DARKFN = 'HRIVIS_020601_2_3.FIT' / File name for frame/model used
BIASFN = 'SERIAL_OVERCLOCK' / Filename of bias frame used
XTALK = T / Electrical crosstalk removed (T/F)
XTALKFN = 'HRIVIS_071004_3_3.FIT' / Filename of crosstalk gains used
GAINCORR= F / Quadrant Gain correction performed (T/F)
GAINFN = ' ' / Filename of gain values used
FLATCORR= T / Flat fielded
FLATFILE= 'HRIVIS_100201_1_3_1.FIT' / Name of flat field applied
BPIXFL = T / Bad pixels flagged (T/F)
BPIXFILE= 'HRIVIS_020601_2_3_999.FIT' / Name of bad pixel map applied
CLEAN = F / Cleaned/fill small gaps (T/F)
CLEANV = -999 / Max filled gap size; -999999
CLNBAD = F / Bad pixels cleaned
CLNMISS = F / Missing data cleaned
DESPIKE = F / Despiking applied (T/F)
DESPIKET= -999 / Despiking threshold used (sigma)
DESPIKEI= -999 / Number of iterations of despiking
DESPIKEB= -999 / Boxsize for despiking
DESPIKEM= ' ' / Metric used for despiking. Mean or
Median
DENOISE = F / Denoising applied (T/F)
DENOISEV= ' ' / Denoise parameter applied
DECON = F / Deconvolution performed (T/F)
DECONPSF= ' ' / Deconvolution psf used
DECONALG= ' ' / Deconvolution algorithm used
DECONV = ' ' / Deconvolution algorithm-specific
parameter
RMSTRIPE= F / Stripe removal algorithm applied (T/F)
SMEAR = T / Frame-transfer smear removed (T/F)
SMEARV = 'POC ROWS' / Smear removal algorithm applied

```

```

RADCAL = T / Radiance calibration applied (T/F)
RADCALV = 0.0001209 / Rad cal constant used [W/(m^2 sr
um)/(DN/s)]
RADCALW = 653.02 / Radiance calib - wavelength used [nm]
IOFCAL = F / I/F calibration applied (T/F)
IOFCALV = 1470.5860000 / I/F cal constant used [W/(m^2 sr um) @ 1
AU]
IOFCALW = 624.52 / I/F calib - wavelength used [nm]
IOFCALD = 1.0634636 / I/F calib - Distance used [AU]
MULT2RAD= 1.0000000 / Multiplier to convert data to Radiance
MULT2IOF= 0.0024160 / Multiplier to convert data to I/F
MULT2DN = 16543.7220000 / Multiplier to convert data to DN
GEOMCAL = F / Geometric calibration performed (T/F)
GEOMFILE= ' ' / File used for geometric calibration
"

```

```

/***** IMAGE STATISTICS *****/

```

```

EPOXI:BAD_PIXEL_COUNT = 512
EPOXI:MISSING_PIXEL_COUNT = 50
EPOXI:DESPIKED_PIXEL_COUNT = 0
EPOXI:INTERPOLATED_PIXEL_COUNT = 0
EPOXI:PARTIAL_SATURATED_PIXEL_COUNT = 459
EPOXI:SATURATED_PIXEL_COUNT = 447
EPOXI:ADC_SATURATED_PIXEL_COUNT = 446
EPOXI:ULTRA_COMPRESSED_PIXEL_COUNT = 0

```

```

OBJECT = HEADER
  BYTES = 51840
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS = 18
  DESCRIPTION = "FITS format defined in
  NASA/Science Office Standards Technology 100-1.0"
END_OBJECT = HEADER

```

```

OBJECT = IMAGE
  LINE_SAMPLES = 256
  LINES = 256
  SAMPLE_BITS = 32
  SAMPLE_TYPE = "IEEE_REAL"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT = "W/(m**2*sr*um)"
  EPOXI:MINIMUM = 4.540000000000e-04
  EPOXI:MAXIMUM = 3.757030000000e-01
  EPOXI:MEDIAN = 2.536800000000e-03
  EPOXI:STANDARD_DEVIATION = 1.473100000000e-02
END_OBJECT = IMAGE

```

```

OBJECT = EXT_QUALITY_FLAGS_HEADER
  BYTES = 2880
  HEADER_TYPE = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS = 1
  DESCRIPTION = "This extension provides quality flags for
  each pixel in the primary image array. Each of the one-byte pixels

```

in this map is composed of eight bits. Each bit represents a specific characteristic about the corresponding pixel in the primary image array. For a raw image, only the bit for a missing data value is set (bit 1 below). The remaining 7 bits apply only to a calibrated image and are thus set to zero for a raw image. The bits are described below and are listed from the least-significant (0) to most-significant (7):

- 0 = Bad
- 1 = Data for this pixel was not received from the spacecraft or this pixel is one of the image header bytes.
- 2 = Despiked
- 3 = Interpolated
- 4 = Partially saturated
- 5 = Mostly saturated
- 6 = ADC saturated
- 7 = Ultra compressed"

END\_OBJECT = EXT\_QUALITY\_FLAGS\_HEADER

```
OBJECT          = EXT_QUALITY_FLAGS_IMAGE
  LINE_SAMPLES  = 256
  LINES         = 256
  SAMPLE_BITS   = 8
  SAMPLE_TYPE   = "MSB_UNSIGNED_INTEGER"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT      = EXT_QUALITY_FLAGS_IMAGE
```

```
OBJECT          = EXT_SNR_HEADER
  BYTES          = 2880
  HEADER_TYPE    = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS        = 1
  DESCRIPTION    = "This extension is the signal-to-noise ratio
  for each pixel in the primary image array."
END_OBJECT      = EXT_SNR_HEADER
```

```
OBJECT          = EXT_SNR_IMAGE
  LINE_SAMPLES  = 256
  LINES         = 256
  SAMPLE_BITS   = 32
  SAMPLE_TYPE   = "IEEE_REAL"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
END_OBJECT      = EXT_SNR_IMAGE
```

```
OBJECT          = EXT_DESTRIPE_HEADER
  BYTES          = 2880
  HEADER_TYPE    = "FITS"
  INTERCHANGE_FORMAT = "BINARY"
  RECORDS        = 1
  DESCRIPTION    = "This extension contains the two columns of DNs
  which have been subtracted from every non-overclock column in the
  left and right halves of the primary image array by the destripping
  module of the calibration pipeline.
```

See the comments in this FITS header for more details."

```

END_OBJECT = EXT_DESTRIPE_HEADER

OBJECT      = EXT_DESTRIPE_IMAGE
  LINE_SAMPLES = 2
  LINES      = 256
  SAMPLE_BITS = 32
  SAMPLE_TYPE = "IEEE_REAL"
  AXIS_ORDER_TYPE = "FIRST_INDEX_FASTEST"
  LINE_DISPLAY_DIRECTION = "UP"
  SAMPLE_DISPLAY_DIRECTION = "RIGHT"
  UNIT      = "DATA_NUMBER"
END_OBJECT = EXT_DESTRIPE_IMAGE

END

```

## 4.5 PDS Object and Keyword Definitions

This section provides definitions for the objects and keywords found in the PDS labels for raw and calibrated FITS science data products. Definitions are ordered following the label examples provided in the previous sections. (FITS keyword definitions are provided in 'EPOXI Data Archive: FITS Keyword Descriptions for the Primary Image Header' by Carcich, 2009 [14] located in the Deep Impact and EPOXI documentation set.)

All time- and geometry-related keyword values are based on the time at the spacecraft, except EARTH\_OBSERVER\_MID\_TIME that provides the UTC of the image mid-time for an observer on Earth. All values for geometry-related keywords were calculated for the mid-point of an image at the spacecraft *except for “target-to-sun” and “earth -to-target” keywords*. The values for target-to-sun were calculated for the time (with respect to image mid-time) when the light arrived at the target while the values for earth-to-target were calculated for the time when the light left the target.

PDS Keyword or Object	Definition
PDS_VERSION_ID	Represents the version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for Deep Impact data products.
RECORD_TYPE	Indicates the record format of a file. The value FIXED_LENGTH is for FITS data products. The physical record length (RECORD_BYTES) corresponds directly to the logical record length of the data objects (that is, one physical record for each image line, or one physical record for each row of a table).
RECORD_BYTES	Indicates the number of bytes in a physical file record, including record terminators and separators. For FITS data products, the value is 2880.
FILE_RECORDS	Indicates the number of physical file records, including both label records and data records. Note: In the PDS, the use of the file_records keyword along with other file-related data elements is fully described in the PDS Standards Reference.

<b>/** OBJECT POINTERS **/</b>	
^HEADER	This object identifies the attributes of the FITS header for the primary image array (see ^IMAGE below). The use of bytes within the header object refers to the number of bytes for the entire header, not a single record,
^IMAGE	This object defines the primary, two-dimensional FITS image array of sample values. Images are composed of LINES and SAMPLES.
^EXT_QUALITY_FLAGS_HEADER	This object identifies the attributes of the header for the quality map, an image extension in all raw and reduced FITS files.
^EXT_QUALITY_FLAGS_IMAGE	This object provides the quality map, an image extension in all raw and reduced FITS files. The map or array is the same size as the primary image and provides information about the quality of each pixel in the primary image array.
^EXT_WAVELENGTH_HEADER	Used only for calibrated, HR11 images. This object identifies the attributes of the header for the pixel-by-pixel spectral wavelength map.
^EXT_WAVELENGTH_IMAGE	Used only for calibrated HR11 images. This object provides the pixel-by-pixel spectral wavelength map. The array provides the wavelength for each pixel in the primary image array.
^EXT_SPEC_BANDWIDTH_HEADER	Used only for calibrated HR11 images. This object identifies and defines the attributes of the header for the pixel-by-pixel spectral bandwidth map.
^EXT_SPEC_BANDWIDTH_IMAGE	Used only for calibrated HR11 images. The object provides the pixel-by-pixel spectral bandwidth map. The array provides the spectral bandwidth for each pixel in the primary image array.
^EXT_SNR_HEADER	Used only for calibrated images. This object identifies the attributes of the header for the pixel-by-pixel, signal-to-noise ratio (SNR) map.
^EXT_SNR_IMAGE	Used only for calibrated images. The object provides the pixel-by-pixel SNR map. The array provides a signal-to-noise ratio for each pixel in the primary image array.
^EXT_DESTRIPE_HEADER	<b>Used only for VIS calibrated images comet Hartley 2.</b> This object identifies the attributes of the header for the VIS destripe values.
EXT_DESTRIPE_IMAGE	<b>Used only for VIS calibrated images comet Hartley 2.</b> The object provides the DN values used by the calibration pipeline to remove horizontal/row striping in calibrated VIS images of Hartley2. Values of 0 indicate the pipeline did not perform stripe removal.

/** DATASET INFORMATION **/	
DATA_SET_ID	Provides a unique alphanumeric identifier for a dataset or a data product. The DATA_SET_ID is constructed according to instructions outlined in the PDS Standards Reference. Source: Hardcoded.
MISSION_NAME	Provides the name of the mission: EPOXI. Source: FITS header keyword MISSION.
INSTRUMENT_HOST_NAME	Provides the full name of the host on which an instrument is based. For EPOXI, there is only one value: Deep Impact Flyby Spacecraft. Source: Derived from FITS header keyword OBSERVAT.
INSTRUMENT_HOST_ID	Provides a unique identifier for the host where an instrument is located. For EPOXI, there is only one value: DIF = DI flyby spacecraft. Source: Derived from FITS header keyword OBSERVAT.
INSTRUMENT_NAME	Provides the full name of an instrument based on the value for INSTRUMENT_ID: <ul style="list-style-type: none"> <li>- Deep Impact High-Resolution Instrument - Infrared Spectrometer</li> <li>- Deep Impact High-Resolution Instrument - Visible CCD</li> <li>- Deep Impact Medium-Resolution Instrument - Visible CCD</li> </ul> Source: FITS header keyword INSTRUME converted to one of the above values.
INSTRUMENT_ID	Provides an abbreviated name or acronym that identifies an instrument. The possible values are HRIL, HRIV, and MRI. Source: FITS header keyword INSTRUME converted from HRIIR, HRIVIS, or MRIVIS to HRIL, HRIV, or MRI, respectively.

/** PRODUCT INFORMATION **/	
PRODUCT_ID	Represents a permanent, unique identifier assigned to a data product by its producer. Note: In the PDS, the value assigned to PRODUCT_ID must be unique within its dataset. Source: FITS file name with the period converted to an underscore.
PRODUCT_CREATION_TIME	Defines the UTC system format time when a product label was created. Formation rule: YYYY-MM-DDThh:mm:ss. Source: FITS header keyword DATE.
PRODUCT_TYPE	Provides the type or category of a product within a dataset. The possible values are: RAW = Raw data record RADIANCE_REVERSIBLE = Reversibly calibrated radiance data record RADIANCE_CLEANED = Irreversibly cleaned, calibrated radiance data record Source: Hardcode based on the level of data reduction.



/** TIME INFORMATION **/	
START_TIME	Provides the date and time at the spacecraft for the beginning of an observation in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSDATE.
EPOXI: IMAGE_MID_TIME	Provides the UTC date and time at the spacecraft of the midpoint between the start and end times. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSMIDDT.
STOP_TIME	Provides the date and time at the spacecraft or the end of an observation in UTC system format. Formation rule: YYYY-MM-DDThh:mm:ss.fff. Source: FITS header keyword OBSENDDT.
START_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC START_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn. Source: FITS header keyword OBSJD.
MID_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC EPOXI:IMAGE_MID_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn. Source: FITS header keyword OBSMIDJD.
STOP_JULIAN_DATE_VALUE	Provides the full Julian date corresponding to the UTC STOP_TIME of an exposure. Formation rule: nnnnnnn.nnnnnnn. Source: FITS header keyword OBENDJD.
SPACECRAFT_CLOCK_START_COUNT	Provides the value of the spacecraft clock at the beginning of an observation. Formulation rule: p/sssssssss.fff where p is clock partition, ssssssssss is the clock seconds count, fff is the top 8 microseconds bits (values range from 0 to 244.14). Source: FITS header keyword SCSTART.
EPOXI: SPACECRAFT_CLOCK_MID_COUNT	Provides the value of the spacecraft clock at the midpoint of an observation. Formulation rule: p/sssssssss.fff where p is clock partition, ssssssssss is the clock seconds count, fff is the top 8 microseconds bits (values range from 0 to 244.14). Source: FITS header keyword ADCTIME.
SPACECRAFT_CLOCK_STOP_COUNT	Provides the value of the spacecraft clock at the end of an observation. Formulation rule: p/sssssssss.fff where p is clock partition, ssssssssss is the clock seconds count, fff is the top 8 microseconds bits (values range from 0 to 244.14). Source: FITS header keyword SCSTOP.
EPOXI:EARTH_OBSERVER_MID_TIME	Provides the calendar UTC time when light from the target, which left the target at the same time as light reached the Deep Impact spacecraft at the UTC mid-point of the observation (IMAGE_MID_TIME), reaches the center of Earth. Formation rule: YYYY-MM-DDThh:mm:ss[.fff]; will be set to "UNK" if geometry is bad or not available. Source: FITS header keyword EAROBSDT.

/** OBSERVATION INFORMATION **/	
MISSION_PHASE_NAME	Identifies the mission phase: CRUISE 1 EPOCH CRUISE 2 HARTLEY 2 ENCOUNTER CRUISE 3 Source: Hardcoded.
EPOXI: MISSION_ACTIVITY_TYPE	Identifies the mission activity such as “Instrument Checkout”. Source: FITS header keyword KPKIMNTL.
EPOXI:OBSERVATION_DESC	Provides a description of the observation or image such as “Radiometry”. Source: FITS header keyword KPKICMMT.
EPOXI:POINTING_DESC	Provides the planned instrument pointing as described in an imaging sequence. Source: FITS header keyword KPKPCMMT.
TARGET_NAME	Identifies the intended mission target, such as “CALIBRATION”, “GJ 436”, or “103P/HARTLEY 2 (1986 E2)”. For raw data, TARGET_DESC provides the name of a “CALIBRATION” target. Source: Derived from FITS header keyword OBJECT.
TARGET_DESC	Used only for raw data, identifies a specific calibration target, such as “CANOPUS” or “DARK”. For mission targets, this keyword is set to the value of TARGET_NAME. This keyword allows the user to more easily search for raw calibration data. Source: FITS header keyword OBJECT.
INSTRUMENT_MODE_ID	Provides an instrument-dependent designation of operating mode. For the HR II instrument, valid modes are 1-7. For the HR IV and MRI instruments, the valid modes are 1-9. Source: FITS header keyword IMGH030.
EPOXI:INSTRUMENT_MODE_NAME	Provides the common name used by the mission for INSTRUMENT_MODE_ID. Source: FITS header keyword IMGMODEN.
EPOXI: COMPRESSED_IMAGE_VALUE	Identifies a compressed or decompressed image: UNCOMPRESSED = Image is not compressed COMPRESSED = Raw image is compressed as received from the spacecraft DECOMPRESSED = Reduced image is decompressed; all raw, compressed images are decompressed at the beginning of the calibration pipeline Source: FITS header keyword COMPRESS.
COMPRESSOR_ID	Identifies the look-up table (compressor number) used to compress an image onboard the spacecraft and to decompress an image the calibration. Valid values are 0-3. Images that were never compressed in-flight this keyword set to “N/A”. Source: If the file is compressed (if FNCMPRSS = “C” in FITS header), then set to FITS header keyword IMGH0001.

EPOXI:OBSERVATION_ID	<p>Identifies a set of images, also known as a sequence, taken by the same command using a 7-digit value. Also known as exposure ID. It is used with IMAGE_NUMBER. For example, exposure ID 9000000 and image number 2 identifies the second image taken for the commanded exposure ID.</p> <p>Source: FITS header keyword EXPID.</p>																																																																																
EPOXI:IMAGE_NUMBER	<p>A three-digit value that identifies the order of an image within an exposure ID (see OBSERVATION_ID). Values are 001 through 999. One HRII OBSERVATION_ID typically consists of several, thus IMAGE_NUMBER is incremented for each frame in the sequence.</p> <p>Source: FITS header keyword IMGH026.</p>																																																																																
EPOXI:COMMANDED_IMAGE_COUNT	<p>Provides to total number of images commanded for a specific observation (exposure) ID. See OBSERVATION_ID and IMAGE_NUMBER.</p> <p>Source: FITS header keyword IMGH027.</p>																																																																																
FILTER_NUMBER	<p>Provides the number, an integer, of the filter used for this observation. The Hall Sensor location was sourced because it was the best indicator of the actual filter used for a given observation. A value of UNK indicates the filter could not be determined (is unknown). The HRII instrument did not have filter wheels, so this keyword is set to N/A (not applicable).</p> <p>HRIV</p> <table border="1" data-bbox="764 1031 1333 1402"> <thead> <tr> <th>#</th> <th>Name</th> <th>Center <math>\lambda</math> (nm)</th> <th>Width (nm)</th> </tr> </thead> <tbody> <tr><td>1</td><td>CLEAR1</td><td>650</td><td>&gt;700</td></tr> <tr><td>2</td><td>BLUE</td><td>450</td><td>100</td></tr> <tr><td>3</td><td>GREEN</td><td>550</td><td>100</td></tr> <tr><td>4</td><td>VIOLET</td><td>350</td><td>100 (cut-on is ~320 nm)</td></tr> <tr><td>5</td><td>IR</td><td>950</td><td>100 (longpass)</td></tr> <tr><td>6</td><td>CLEAR6</td><td>650</td><td>&gt;700</td></tr> <tr><td>7</td><td>RED</td><td>750</td><td>100</td></tr> <tr><td>8</td><td>NIR</td><td>850</td><td>100</td></tr> <tr><td>9</td><td>ORANGE</td><td>950</td><td>100</td></tr> </tbody> </table> <p>MRI</p> <table border="1" data-bbox="764 1465 1333 1837"> <thead> <tr> <th>#</th> <th>Name</th> <th>Center <math>\lambda</math> (nm)</th> <th>Width (nm)</th> </tr> </thead> <tbody> <tr><td>1</td><td>CLEAR1</td><td>650</td><td>&gt;700</td></tr> <tr><td>2</td><td>C2</td><td>514</td><td>11.8</td></tr> <tr><td>3</td><td>GREEN_CONT</td><td>526</td><td>5.6</td></tr> <tr><td>4</td><td>RED</td><td>750</td><td>100</td></tr> <tr><td>5</td><td>IR</td><td>950</td><td>100 (longpass)</td></tr> <tr><td>6</td><td>CLEAR6</td><td>650</td><td>&gt;700</td></tr> <tr><td>7</td><td>CN</td><td>387</td><td>6.2</td></tr> <tr><td>8</td><td>VIOLET_CONT</td><td>345</td><td>6.8</td></tr> <tr><td>9</td><td>OH</td><td>309</td><td>6.2</td></tr> </tbody> </table> <p>Source: Decode FITS header keyword FILTER.</p>	#	Name	Center $\lambda$ (nm)	Width (nm)	1	CLEAR1	650	>700	2	BLUE	450	100	3	GREEN	550	100	4	VIOLET	350	100 (cut-on is ~320 nm)	5	IR	950	100 (longpass)	6	CLEAR6	650	>700	7	RED	750	100	8	NIR	850	100	9	ORANGE	950	100	#	Name	Center $\lambda$ (nm)	Width (nm)	1	CLEAR1	650	>700	2	C2	514	11.8	3	GREEN_CONT	526	5.6	4	RED	750	100	5	IR	950	100 (longpass)	6	CLEAR6	650	>700	7	CN	387	6.2	8	VIOLET_CONT	345	6.8	9	OH	309	6.2
#	Name	Center $\lambda$ (nm)	Width (nm)																																																																														
1	CLEAR1	650	>700																																																																														
2	BLUE	450	100																																																																														
3	GREEN	550	100																																																																														
4	VIOLET	350	100 (cut-on is ~320 nm)																																																																														
5	IR	950	100 (longpass)																																																																														
6	CLEAR6	650	>700																																																																														
7	RED	750	100																																																																														
8	NIR	850	100																																																																														
9	ORANGE	950	100																																																																														
#	Name	Center $\lambda$ (nm)	Width (nm)																																																																														
1	CLEAR1	650	>700																																																																														
2	C2	514	11.8																																																																														
3	GREEN_CONT	526	5.6																																																																														
4	RED	750	100																																																																														
5	IR	950	100 (longpass)																																																																														
6	CLEAR6	650	>700																																																																														
7	CN	387	6.2																																																																														
8	VIOLET_CONT	345	6.8																																																																														
9	OH	309	6.2																																																																														

FILTER_NAME	Provides the name of the filter used for this observation. The Hall Sensor location was used because it was the best indicator of the actual filter used. A value of “UNK” indicates the filter could not be determined. This keyword is not applicable for HR11 and is set to “N/A”. Source: FITS header keyword FILTER.
CENTER_FILTER_WAVELENGTH	Provides the wavelength for the center of a filter bandpass in microns. A value of “UNK” indicates the filter could not be determined. This keyword is not applicable for HR11 and is set to “N/A”. Source: FITS header keyword FILTERCW.
EPOXI: INTEGRATION_DURATION	Provides the total integration time for the image in units of milliseconds. Integration duration is calculated as follows: For HR11, all modes: $integration\_duration = minimum\_exposure\_duration + commanded\_exposure\_duration$ For HR1V and MRI shuttered modes (1, 2, 3, 5, and 9): $integration\_duration = minimum\_exposure\_duration + commanded\_exposure\_duration$ For HR1V and MRI unshuttered modes (4, 6, 7, and 8): $integration\_duration = minimum\_exposure\_duration + commanded\_exposure\_duration + interframe\_delay\_duration + (0.5\ ms\ if\ interframe\_delay\_duration > 0)$ Minimum exposure times are given in Tables 1 and 2. Source: FITS header keyword INTTIME.
EPOXI:SPACECRAFT_PROCESSOR_ID	Identifies one of two processor units onboard the DI spacecraft the processed and stored the image file. Source: FITS header keyword SCUPROCU.
INSTRUMENT_TEMPERATURE	<b><i>NOTE: For HR11 analysis, the most reliable detector temperatures can be found in the EPOXI instrument thermal telemetry dataset, DIF-CAL-HR11/HR1V/MR1-6-EPOXI-TEMPS-V2.0 .</i></b>  Provides the temperature, in degrees Kelvin, of an instrument or some part of an instrument. Multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values.  The temperature values were extracted from the original image headers that were generated onboard the spacecraft. Values from the nearest thermal telemetry were put in the image headers. For HR11, the best temperatures are in the thermal telemetry dataset for the flyby spacecraft, DIF-CAL-HR11/HR1V/MR1-6-TEMPS-V1.0  A value of “N/A” means the measurement was not applicable. A value of “UNK” indicated the measurement

	<p>could not be determined or did not exist.</p> <p>Source: FITS header keywords ICT590T, CCD590T, IR590T, LVPS590T, CCDPRET, CCDT, OPTBENT, PRIMIRT, SECMIRT, COVERT, and IRFPAT.</p>
--	--

INSTRUMENT_TEMPERATURE_POINT	<p>Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_TEMPERATURE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_TEMPERATURE list with a corresponding item in the INSTRUMENT_TEMPERATURE_POINT sequence of values.</p> <p>Values used for HRII and HRIV are:  INSTRUMENT CONTROLLER PROCESSING BOARD  CCD SIGNAL PROCESSING BOARD  IR SIGNAL PROCESSING BOARD  LVPS SIGNAL PROCESSING BOARD  CCD PREAMP BOX  CCD ON-CHIP SENSOR  PRISMS  PRIMARY MIRROR  SECONDARY MIRROR  SPECTRAL IMAGING MODULE COVER  IR FPA ON-CHIP SENSOR</p> <p>Values used for MRI are:  INSTRUMENT CONTROLLER PROCESSING BOARD  CCD SIGNAL PROCESSING BOARD  IR SIGNAL PROCESSING BOARD  LVPS SIGNAL PROCESSING BOARD  CCD PREAMP BOX  CCD ON-CHIP SENSOR  OPTICAL BENCH  PRIMARY MIRROR  SECONDARY MIRROR  STRUCTURE COVER  IR FPA ON-CHIP SENSOR</p> <p>Source: Hardcoded.</p>
------------------------------	--

INSTRUMENT_VOLTAGE	<p>Provides the voltage, in volts, of an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE_POINT to more fully describe either single or multiple voltages at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each voltage measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values.</p> <p>A value of “N/A” means the measurement was not applicable. A value of “UNK” indicated the measurement could not be determined or did not exist.</p> <p>Source: FITS header keywords CCDOFSAV, CCDOFSBV, CCDOFSCV, CCDOFSDV, CCDOUTAV, CCDOUTBV, CCDOUTCV, CCDOUTDC, CCDSERP, CCDSERNV, CCDPARPV, CCDPARNV, IRRESETV, IRSUBSTV, IRBIASGV, and ALLAMPV.</p>
INSTRUMENT_VOLTAGE_POINT	<p>Identifies the measurement point or location on an instrument or some part of an instrument. This keyword may be used in conjunction with INSTRUMENT_VOLTAGE to more fully describe either single or multiple temperatures at various locations within a single instrument. If there is more than one measurement taken for a given instrument, a multi-value ordered set of values (i.e., sequence) may be constructed to associate each temperature measurement in the INSTRUMENT_VOLTAGE list with a corresponding item in the INSTRUMENT_VOLTAGE_POINT sequence of values.</p> <p>The following values are used for all instruments:</p> <p>CCD OFFSET FROM ADC REF QUAD A  CCD OFFSET FROM ADC REF QUAD B  CCD OFFSET FROM ADC REF QUAD C  CCD OFFSET FROM ADC REF QUAD D  CCD OUTPUT AMP DRAIN QUAD A  CCD OUTPUT AMP DRAIN QUAD B  CCD OUTPUT AMP DRAIN QUAD C  CCD OUTPUT AMP DRAIN QUAD D  CCD SERIAL CLOCK POSITIVE  CCD SERIAL CLOCK NEGATIVE  CCD PARALLEL CLOCK POSITIVE  CCD PARALELL CLOCK NEGATIVE  IR RESET  IR SUBSTRATE  IR BIASGATE  IR CALIB LAMP</p> <p>Source: Hardcoded.</p>

/** IMAGE INFORMATION**/	
HORIZONTAL_PIXEL_SCALE	Indicates the horizontal picture scale in units of meters per pixel for the HRIV and MRI instruments. This keyword is set to "N/A" for HRII images. For non-planetary, calibration targets, this element is set to "N/A". If geometry is bad or not available, it is set to "UNK". Source: FITS header keyword PXLSCALE.
VERTICAL_PIXEL_SCALE	Indicates the vertical picture scale in units of meters per pixel for the HRII, HRIV, and MRI instruments. . For non-planetary, calibration targets, this element is set to "N/A". If geometry is bad or not available, it is set to "UNK". Source: FITS header keyword PXLSCALE.
/** GEOMETRY PARAMETERS **/	
NOTE	States that the Earth Mean Equator and Vernal Equinox J2000 (EME J2000) is the inertial reference frame, unless otherwise specified. Geometric parameters are based on the best available SPICE data at the time a product was produced. The observation midpoint was used to derive the geometry, and all positions are relative to body centers. Source: Hardcoded.
EPOXI:GEOMETRY_QUALITY_FLAG	Indicates the quality of the geometry values. "OK" indicates geometry is good. "BAD" indicates the geometry values should be used with caution or are not available. Source: FITS header keyword GEOMSTAT.
EPOXI:GEOMETRY_TYPE	Indicates if preliminary ('PREDICTED') or finalized ('RECONSTRUCTED') SPICE kernels were used to generate geometry values. Source: FITS header keyword GEOMQUAL.
SPICE_FILE_NAME	Provides a list of the SPICE kernels used to calculate the values for the geometry-related. The kernels are listed in the order they were loaded for processing. Source: FITS header keywords RECK0001 through RECK00nn if GEOMETRY_TYPE is 'RECONSTRUCTED' or NOMK0001 through NOMK00nn if GEOMETRY_TYPE is 'PREDICTED'.
RIGHT_ASCENSION	Provides the right ascension, in the EME J2000 reference, where the boresight was pointing, in degrees. Source: FITS header keyword BORERA for mission targets or "UNK" for calibration targets or if geometry is bad or not available.
DECLINATION	Provides the declination, in the EME J2000 reference, where the boresight was pointing, in degrees. Source: FITS header keyword BOREDEC for mission targets or "UNK" for calibration targets or if geometry is bad or not available.



CELESTIAL_NORTH_CLOCK_ANGLE	<p>Specifies the direction of celestial north at the center of an image. It is measured from the 'upward' direction, clockwise to the direction toward celestial north (declination = +90 degrees), when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. The epoch of the celestial coordinate system is J2000 unless otherwise indicated. For images pointed near either pole, the value varies significantly across the image; in these cases, the element is very sensitive to the accuracy of the pointing information.</p> <p>Source: FITS header keyword CELESTN for mission targets or "UNK" for calibration targets or if geometry is bad or not available.</p>
EPOXI:ECLIPTIC_NORTH_CLOCK_ANGLE	<p>Specifies the direction of ecliptic north at the center of the image. It is measured from the 'upward' direction, clockwise to the direction toward ecliptic north when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. The epoch of the coordinate system is J2000 unless otherwise indicated.</p> <p>Source: FITS header keyword ECLN for mission targets or "UNK" for calibration targets or if geometry is bad or not available.</p>
EPOXI:SUN_DIRECTION_CLOCK_ANGLE	<p>Specifies the direction to the Sun at the center of the image. It is measured from the 'upward' direction, clockwise to the direction of the sun as projected into the image when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements.</p> <p>Source: FITS header keyword SOLARCLK for mission targets or "UNK" for calibration targets or if geometry is bad or not available.</p>
EPOXI:BODY_POSITIVE_POLE_CLOCK_ANGLE	<p>Specifies the direction of the target body's positive rotation axis in the image plane. It is measured from the 'upward' direction, clockwise to the direction of the positive rotational pole as projected into the image plane when the image is displayed as defined by the SAMPLE_DISPLAY_DIRECTION and LINE_DISPLAY_DIRECTION elements. Note: In some cases, knowledge of the inertial orientation of the rotational axis improves with time. This keyword necessarily reflects the state of knowledge of the rotational axis at the time of preparing the data product as given by the POLE_DECLINATION and POLE_RIGHT_ASCENSION values in the dataset or target catalog file.</p> <p>Source: FITS header keyword RECPAPZ or NOMPPAZ for Earth or comet Hartley 2 frames only, otherwise "UNK" for other targets or if geometry is bad or not available.</p>

SOLAR_ELONGATION	Provides the angle, in degrees, between the target and the Sun as viewed by the observer at the mid-point of an observation. For some cases it may be the angle between the instrument boresight and the vector from the observer to the Sun. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword SOLARELO.
PHASE_ANGLE	Provides the angle, in degrees, between the Sun, the target, and the observer at the mid-point of an observation. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword PHANGLE.
TARGET_CENTER_DISTANCE	Provides the distance between the spacecraft and the center of the target, in units of kilometers, at mid-obs time. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword TARSCR.
TARGET_HELIOCENTRIC_DISTANCE	Provides the distance between the target and the Sun, in units of kilometers, at the time light left the target that reached the spacecraft at mid-obs time. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword TARSUNR.
TARGET_GEOCENTRIC_DISTANCE	Provides the distance between the target and the Earth, in units of kilometers, at the time the light that left the target, which reached the spacecraft at the mid-obs, reached Earth. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword EARTARR.
EPOXI:SC_HELIOCENTRIC_DISTANCE	Provides the distance between the spacecraft and the Sun, in units of kilometers. Source: FITS header keyword SCSUNR. For solar system targets, if SCSUNR is > 1.0E9 then this element is set to “UNK”. For targets outside the solar system, it is set to “N/A”. If geometry is bad or not available, it is set to “UNK”.
EPOXI:SC_GEOCENTRIC_DISTANCE	Provides the distance between the spacecraft and the Earth, in units of kilometers. For targets outside the solar system, this element is set to “N/A”. If geometry is bad or not available, it is set to “UNK”. Source: FITS header keyword SCEARR.

QUATERNION_DESC	Provides a pointer to an accompanying quaternion description file used to describe the formation rules for the quaternion and the specific rotation accomplished by application of that quaternion. This keyword is required to be used in conjunction with the QUATERNION keyword. The file to which this keyword points is to be included in the /document subdirectory of an archive product. Source: Hardcoded to 'QUATERNION_DESC.ASC'.
QUATERNION	Provides four-component representation of a rotation matrix. This quaternion rotates vectors defined in the instrument frame into the EME J2000 reference frame. If geometry is bad or not available, the components of this element are set to "UNK". Source: FITS header keywords ADCQA, ADCQB, ADCQC, and ADCQD.
EPOXI: SC_ROTATION_VELOCITY_VECTOR	Provides the x-, y-, z-components of the angular velocity of the spacecraft about axes of the EME J2000 reference frame. If geometry is bad or not available, the components of this element are set to "UNK". Source: FITS header keywords ADCVX, ADCVY, and ADCVZ.
EPOXI: TARGET_SC_POSITION_VECTOR	Provides the (x, y, z) components of the position vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers. For targets outside the solar system, the components of this vector are set to "N/A". If geometry is bad or not available, the components are set to "UNK". Source: FITS header keywords TARSCRX, TARSCRY, and TARSCRZ.
EPOXI: TARGET_SC_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector, at image mid-time, from the target to the spacecraft expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers/second. For targets outside the solar system, the components of this vector are set to "N/A". If geometry is bad or not available, the components are set to "UNK". Source: FITS header keywords TARSCVX, TARSCVY, and TARSCVZ.

TARGET_SUN_POSITION_VECTOR	Provides the (x, y, z) components of the position vector from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the time light left the target that reached the spacecraft at mid-obs time. The units are kilometers. For targets outside the solar system, the components of this vector are set to "N/A". If geometry is bad or not available, the components are set to "UNK". Source: FITS header keywords TARSUNRX, TARSUNRY, and TARSUNRZ.
TARGET_SUN_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector from the target to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the time light left the target that reached the spacecraft at mid-obs time. The units are kilometers/second. For targets outside the solar system, the components of this vector are set to "N/A". If geometry is bad or not available, the components are set to "UNK". Source: FITS header keywords TARSUNVX, TARSUNVY, and TARSUNVZ.
EARTH_TARGET_POSITION_VECTOR	Provides the (x, y, z) components of the position vector from the target to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the time the light that left the target, which reached the spacecraft at mid-obs time, reached Earth. The units are kilometers. For targets outside the solar system, the components of this vector are set to "N/A". If geometry is bad or not available, the components are set to "UNK". Source: FITS header keywords EARTARRX, EARTARRY, and EARTARRZ.
EARTH_TARGET_VELOCITY_VECTOR	Provides the (x, y, z) components of the velocity vector from the target to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the time the light that left the target, which reached the spacecraft at mid-obs time, reached Earth. The units are kilometers/second. For targets outside the solar system, the components of this vector are set to "N/A". If geometry was not available, the components are set to "UNK". Source: FITS header keywords EARTARVX, EARTARVY, and EARTARVZ.

SC_SUN_POSITION_VECTOR	<p>Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Sun expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers.</p> <p>Source: FITS header keyword SCSUNRX, SCSUNRY, and SCSUNRZ. If SCSUNR is &gt; 1.0E9 or the geometry is bad or not available, the components of this vector are set to "UNK".</p>
SC_EARTH_POSITION_VECTOR	<p>Defines the (x, y, z) components of the position vector, at image mid-time, from the spacecraft to the Earth expressed in the EME J2000 coordinate frame, corrected for light travel time and stellar aberration, and evaluated at the epoch at which the data were taken (J2000). The units are kilometers.</p> <p>Source: FITS header keywords SCEARRX, SCEARRY, and SCEARRZ. If the geometry is bad or not available, the components of this vector are set to "UNK".</p>
SUB_SPACECRAFT_LONGITUDE	<p>Provides the longitude of the sub-spacecraft point, the point on a body that lies directly beneath the spacecraft. <b><i>For Hartley 2 and targets outside the solar system, this element is set to "N/A".</i></b> If geometry is bad or not available, it is set to "UNK".</p> <p>Source: FITS header keywords RECSCOLON or NOMSCOLON.</p>
SUB_SPACECRAFT_LATITUDE	<p>Provides the latitude of the sub-spacecraft point, the point on a body that lies directly beneath the spacecraft. <b><i>For Hartley 2 and targets outside the solar system, this element is set to "N/A".</i></b> If geometry is bad or not available, it is set to "UNK".</p> <p>Source: FITS header keywords RECSCLAT or NOMSCLAT.</p>
SUB_SOLAR_LONGITUDE	<p>Provides the longitude of the sub-solar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. <b><i>For Hartley 2 and targets outside the solar system, this element is set to "N/A".</i></b> If geometry is bad or not available, it is set to "UNK".</p> <p>Source: FITS header keywords RECSOLON or NOMSOLON.</p>
SUB_SOLAR_LATITUDE	<p>Provides the latitude of the sub-solar point, the point on a body's reference surface where a line from the body center to the sun center intersects that surface. This keyword is used in conjunction with coordinate_system_type. <b><i>For Hartley 2 and targets outside the solar system, this element is set to "N/A".</i></b> If geometry is bad or not available, it is set to "UNK".</p> <p>Source: FITS header keywords RECSOLAT or NOMSOLAT.</p>

COORDINATE_SYSTEM_TYPE	<p>Specifies the type of coordinate system used for the sub_spacecraft_longitude/latitude and sub_solar_longitude/latitude.</p> <p>Source: Hardcoded to “BODY-FIXED ROTATING” if sub_spacecraft* and sub_solar* keywords are set to numeric values. <b><i>For Hartley 2 and targets outside the solar system, this element is set to “N/A”.</i></b> If geometry is bad or not available, it is also set to “N/A”.</p>
COORDINATE_SYSTEM_NAME	<p>Provides the full name of the coordinate system associated with coordinate_system_type, sub_spacecraft_longitude/latitude, and sub_solar_longitude/latitude keywords.</p> <p>Source: Hardcoded to “PLANETOCENTRIC” if sub_spacecraft* and sub_solar* keywords are set to numeric values. <b><i>For Hartley 2 and targets outside the solar system, this element is set to “N/A”.</i></b> If geometry is bad or not available, it is set to “N/A”.</p>

<b>/** PROCESSING HISTORY **/</b>	
EPOXI:SDC_PIPELINE_FILE_NAME	Provides the actual filename used in the data pipeline for this data file. The EPOXI project elected to modify and shorten the filename for the PDS archive.
EPOXI:DATA_TO_IOVERF_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to unitless I-over-F data. A value of 1 indicates the current image is already in I-over-F units. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2IOF.
EPOXI:DATA_TO_RADIANCE_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to radiance data, $W/(m^2 \cdot \mu m \cdot sr)$ . A value of 1 indicates the current image is already in units of radiance. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2RAD.
EPOXI:DATA_TO_DN_MULTIPLIER	Provides the multiplicative (scaling) factor for converting the image data from the currently specified unit to calibrated data numbers (before the conversion to radiance). A value of 1 indicates the current image is already in raw data counts. This keyword is calculated and provided only for calibrated HRIV and MRI observations. Source: FITS header keyword MULT2DN.
PROCESSING_HISTORY_TEXT	For a calibrated data file, lists the steps performed by the calibration process. Includes the names of the calibration files, such as the dark frame, used to reduce a data file. For raw, uncalibrated data, this keyword is set to RAW. Source: FITS header keywords for calibration steps and files applied..

/** IMAGE STATISTICS **/	
EPOXI: BAD_PIXEL_COUNT	Provides a count of the number of known bad pixels in the image array, as identified by the calibration pipeline. Source: FITS header keyword BADPXCT.
EPOXI: MISSING_PIXEL_COUNT	Provides a count of the number of pixels that were not received from the spacecraft. Source: FITS header keyword MISSPXCT.
EPOXI: DESPIKED_PIXEL_COUNT	Provides a count of the number of pixels that were modified by the despiking routine in the calibration pipeline. Source: FITS header keyword DESPIKCT.
EPOXI: INTERPOLATED_PIXEL_COUNT	Provides a count of the number of pixels that were reclaimed, in the calibration pipeline, by interpolating from the values of neighboring good pixels. Source: FITS header keyword INTERPCZT.
EPOXI: PARTIAL_SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the raw value is above the point where some pixels have reached partial saturation. For HRIV and MRI, this occurs at 11,000 DN. For HRII, this occurs at 8,000 DN. Source: FITS header keyword PSATPXCT.
EPOXI: SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the raw value is above the point where most pixels have reached full-well saturation. For HRIV and MRI, this occurs at 15,000 DN. For HRII, this occurs at 11,000 DN. Source: FITS header keyword SATPXCT.
EPOXI: ADC_SATURATED_PIXEL_COUNT	Provides a count of the number of pixels where the analog-to-digital converter (ADC) was saturated. Source: FITS header keyword ASATPXXCT.
EPOXI: ULTRA_COMPRESSED_PIXEL_COUNT	Provides a count of the number of pixels where the raw DN is in a compression bin so large that the resulting value contains very little information. Source: FITS header keyword ULTCMPCT.



<b>/** OBJECT-RELATED KEYWORDS **/</b>	
BYTES	Indicates the number of bytes allocated for a particular data representation. Source: Hardcoded to 2880.
HEADER_TYPE	Identifies a specific type of header data structure. For example: FITS. Note: In the PDS, HEADER_TYPE is used to indicate non-PDS headers. Source: Hardcoded to FIXED.
INTERCHANGE_FORMAT	Represents the manner in which data items are stored. Example values: BINARY, ASCII. Source: Hardcoded to BINARY.
RECORDS	Identifies the number of physical records in a file or other data object. Source: Derived from the size of the FITS primary or extension image.
DESCRIPTION	Provides a free-form, unlimited-length character string that represents or gives an account of something. Source: Hardcoded.
LINE_SAMPLES	Indicates the total integer number of data instances along the horizontal axis of an image. Source: FITS header keyword NAXIS1.
LINES	Indicates the total integer number of data instances along the vertical axis of an image. Source: FITS header keyword NAXIS2.
SAMPLE_BITS	Indicates the stored number of bits, or units of binary information, contained in a line sample value. Source: Derived from FITS header keyword BITPIX.
SAMPLE_TYPE	Indicates the data storage representation of sample value such MSB_INTEGER, MSB_UNSIGNED_INTEGER, or IEEE_REAL. Source: Derived from FITS header keyword BITPIX.

AXIS_ORDER_TYPE	Identifies the storage order for elements of a multidimensional ARRAY object. The default storage order for an ARRAY object presumes the rightmost or last index of a sequence varies the fastest. This is the ordering used in the C programming language and is equivalent to ROW_MAJOR storage order for COLUMN elements within tables. Source: Hardcoded to FIRST_INDEX_FASTEST.
LINE_DISPLAY_DIRECTION	Identifies the preferred orientation of lines within an image for viewing on a display device. See also SAMPLE_DISPLAY_DIRECTION. Source: Hardcoded to "UP" meaning lines must be displayed and viewed the bottom to the top in the graphics window.
SAMPLE_DISPLAY_DIRECTION	Identifies the preferred orientation of samples within a line for viewing on a display device. See also LINE_DISPLAY_DIRECTION. Source: Hardcoded to "RIGHT" meaning samples must be displayed and viewed from left to right in the graphics window.
UNIT	Provides the full name or standard abbreviation of a unit of measurement in which a value is expressed: <ul style="list-style-type: none"> <li>• DATA NUMBER = Data number for RAW FITS</li> <li>• W/(m**2 sr um) = Radiance units of Watts per meter-squared per steradian per micron; this values applicable only for the RAD and RADREV reduction types</li> </ul> Source: FITS header keyword BUNIT.
OFFSET	Used for EDR (raw) data products only; Provides the shift or displacement of a stored data value: True data value = OFFSET + (SCALING_FACTOR * Stored data value). Source: FITS header keyword BZERO.
SCALING_FACTOR	Used for EDR (raw) data products only; Provides the constant value by which the stored data value is multiplied: True data value = OFFSET + (SCALING_FACTOR * Stored data value). Source: FITS header keyword BSCALE.

EPOXI:DERIVED_MINIMUM and EPOXI:MINIMUM (same definition)	Provides the smallest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword DATAMIN.
EPOXI:DERIVED_MAXIMUM and EPOXI:MAXIMUM (same definition)	Provides the largest value occurring in a given instance of the primary image array after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword DATAMAX.
EPOXI:DERIVED_MEDIAN and EPOXI:MEDIAN (same definition)	Provides the median value (middle) occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword MEDPVAL.
EPOXI:DERIVED_STANDARD_DEVIATION and EPOXI:STANDARD_DEVIATION (same definition)	Provides the standard deviation occurring in a given instance of the data object after the application of any scaling factor and/or offset. Note: For EPOXI, pixels in the overclock areas bordering the HRIV and MRI CCD or pixels in the reference rows and columns bordering the HRI IR spectrometer are included in the image object but are excluded from this value. Source: FITS header keyword STDPVAL.

## 5 Using the Data Products

### 5.1 Index and Image Parameters Files

As noted in section 3, the index file in the INDEX subdirectory can be used to locate data products within a dataset and are required by PDS. The image parameters tables in the DOCUMENT subdirectory provide values from the PDS labels that are relevant to science such as FILTER\_NAME and INTEGRATION\_DURATION.

### 5.2 Related Deep Impact Datasets

Several raw, calibration-related datasets in the Deep Impact archive at the PDS may be useful for further analyses of instrument performance and calibration.

PDS Data Set ID	DI Mission Phase(s)	Dataset Description
DI-C-HR2/HRIV/MRI/ITS-6-DOC-SET-V1.0	All	Deep Impact documentation set
DIF-C-HR2/HRIV/MRI-6-TEMPS-V1.0	Cruise and Encounter	Instrument temperatures from telemetry (not the data headers)
DI-C-SPICE-6-V1.0	Cruise and Encounter	SPICE kernels
DIF-CAL-HR2-2-GROUND-TV1-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV1: June-July 2002
DIF-CAL-HR2/HRIV-2-GROUND-TV2-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV2: August-September 2002
DIF-CAL-HR2/HRIV/MRI-2-GROUND-TV4-V1.0	Ground Calibrations	Raw FITS data from thermal-vacuum test TV4: February-March 2003
DIF-CAL-HR2-2-9P-CRUISE-V1.0	Cruise	HR2 raw in-flight calibration data from January-April 2005
DIF-CAL-HRIV-2-9P-CRUISE-V1.0	Cruise	HRIV raw in-flight calibration data from January-April 2005
DIF-CAL-MRI-2-9P-CRUISE-V1.0	Cruise	MRI raw in-flight calibration data from January-April 2005
DIF-C-HR2-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional HR2 raw in-flight calibration data from May-July 2005
DIF-C-HRIV-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional HRIV raw in-flight calibration data from May-July 2005
DIF-C-MRI-2-9P-ENCOUNTER-V1.0	Encounter	Includes additional MRI raw in-flight calibration data from May-July 2005

### **5.3 Flight Hardware Considerations**

For reference, please note that during the Deep Impact prime mission, analysis of impact data indicated a 1- to 2-second discrepancy between the spacecraft clocks for the flyby, spacecraft, the impactor spacecraft, UTC, and ground-based observations. This discrepancy still applies to data archived for Deep Impact and is discussed in the Deep Impact spacecraft clock correlation report by Carcich, 2006 [11] which is included in the Deep Impact and EPOXI documentation set.

The Deep Impact flyby spacecraft clock SPICE kernels (SCLK) used to convert to UTC and to calculate geometry-related parameters for EPOXI data have a known accuracy of no better than 0.5 seconds. The latest DIF SCLK (science version 84) applied to the Hartley 2 encounter data is good to within 0.01 seconds for converting the Deep Impact flyby spacecraft timestamps to ephemeris time for observations *acquired around closest approach*. Please note that the DIF SCLK (version 65) used to compute UTC values and geometry for calibration data acquired from January 2009 through July 2010 has known discontinuities of up to a second. (Those discontinuities have been corrected in the latest DIF SCLK, science version 84, applied to Hartley data.)

### **5.4 Limitations and Known Anomalies**

Limitations of the different versions of the calibration pipeline are discussed documents [7] and [19].

Any anomalies identified in the archived data products are listed in the ERRATA.TXT file in the root directory or in the limitations section of the DATASET.CAT file of each dataset.

### **5.5 Recommended Software to Read Data Products**

#### **5.5.1 IDL**

Standard routines in the IDL astronomy library can be used to read the FITS data files. The `LINE_DISPLAY_DIRECTION` and `SAMPLE_DISPLAY_DIRECTION` keywords in the product labels describe how the data should be displayed in a graphics window, and the values are set to the IDL convention where samples are displayed from left to right and lines from bottom to top.

#### **5.5.2 PDS-SBN Tools**

The EPOXI project recommends an IDL-based tool, called READPDS, to display and analyze data products. This tool was developed by the PDS SBN and is available at the SBN

website, <http://pdssbn.astro.umd.edu>. The purpose of this tool is to enable users to display and examine data products (i.e., a detached PDS labels and its data file) archived at the SBN.

## 5.6 Raw Image Compression

Some raw science images in the EPOXI archive are stored in a compressed format (8-bit unsigned integers). These data were compressed by software onboard the spacecraft using one of four, simple, instrument-specific lookup tables and received on the ground, processed by the data pipeline, and archived in the same format. Values in the compressed, raw FITS images vary from 0 to 255 DN. The first step in the calibration pipeline uncompresses these data using the appropriate decompression lookup table. These tables are provided as ASCII tables with detached PDS labels in CALIB/ directory of the raw and reduced science datasets. For more information, see Klaasen, et al. 2008 [7].

## 5.7 Accessing Quality Flags Map via IDL

This section explains how to use IDL to access the information in the pixel-by-pixel Quality Flags Map described in section 4.1.3.

Because each pixel in the quality map is a collection of 8 bits, one must think binary when interrogating the bits. For example if an image pixel is only flagged as bad by the quality flags map, then only the right-most bit (bit 0 or the least-significant bit) in the corresponding quality pixel will be turned on and its value will be  $2^0$  or 1. If the calibration pipeline determined the *raw* value of the pixel was above the limit where some pixels saturate and no other flag has been set, then the fifth bit from the right (bit 4) will be turned on and the value of the corresponding pixel in the quality flags map will be  $2^4$  or 16. For an example using an IR image pixel with a raw value of 12000 DN, a value of 49 (=1+16+32) in a quality pixel indicates three things:

- 1) The pixel is bad ( $2^0 = 1$ ),
- 2) The raw pixel value is above the point (8000 DN for IR) where some pixels are full-well saturated ( $2^4 = 16$ ), and
- 3) The raw pixel value is above the point (11000 DN for IR ) where most pixels are full-well saturated ( $2^5 = 32$ ).

If a pixel is rather saturated, the calibration pipeline sets bits 4 and 5 because the pixel first failed the "some pixels saturated" test then it failed the "most pixels saturated" test. It is important to note that if this quality pixel was interrogated as an unsigned integer instead of by its individual bits, then any odd integer value indicates only a bad pixel.

Here is a sample of IDL code that can be used to interrogate the 8-bit quality flag pixels. The code sets variables that can be used to check. If you print each variable, you will see the resulting *bit* values:

```

; Set variables for checking individual quality flags.
print,FLAG_BAD = ishft(1,0)           ; = 2^0 = 1
print,FLAG_GAP = ishft(1,1)          ; = 2^1 = 2
print,FLAG_SPIKE = ishft(1,2)        ; = 2^2 = 4
print,FLAG_INTERP = ishft(1,3)       ; = 2^3 = 8
print,FLAG_SOMEFULLWELL= ishft(1,4)   ; = 2^4 = 16
print,FLAG_MOSTFULLWELL = ishft(1,5)  ; = 2^5 = 32
print,FLAG_ADCSAT = ishft(1,6)       ; = 2^6 = 64
print,FLAG_ULTRACOMPRESS = ishft(1,7) ; = 2^7 = 128

```

To check if a pixel is bad, use IDL's bitwise AND operator on the quality pixel (qualmap) and the FLAG\_BAD variable and compare the result to 0 (the note at the end of the attached IDL program explains why the result must be compared to 0):

```

if (qualmap[25,18] and flag_bad) ne 0 then print,'Bit 0 is on; Bad pix'

```

To locate the good and bad pixels, use:

```

badpix  = where((qualmap and flag_bad) ne 0)
goodpix = where((qualmap and flag_bad) eq 0)

```

To locate pixels with raw values that were above the point where most IR pixels are full-well saturated (11000 raw DN), use:

```

mostsat = where((qualmap and flag_mostfullwell) ne 0)

```

In IDL, the AND is a bit-by-bit logical AND operation. It does all the bits. However, if the result is used in an IF statement or WHERE call in IDL, it will return FALSE because the least-significant bit of the result is 0. Therefore, the result must be compared to "NE 0" to produce the correct results for an IF or WHERE in IDL.

## 6 Technical/Programming Information

### 6.1 Brief Description of ODL used for PDS Labels

ODL is an object description language used to describe the structure or contents of a file. The following is an example of an ODL label that describes a data file that contains an image:

```
FILE_TYPE = FIXED
OBJECT    = IMAGE
  LINES      = 1024
  LINE_SAMPLES = 1024
  ...
END_OBJECT = IMAGE
  ...
END
```

The ODL label describes each meaningful section of data. PDS labels use ODL conventions. For more information about ODL and PDS labels, refer the PDS Standards Reference [1].

### 6.2 Architecture Notes

#### 6.2.1 Internal Representation of Data Types

The following internal representation of data types are used:

- IEEE\_REAL, IEEE-format, floating-point numbers
- MSB\_INTEGER, signed integers using Most Significant Byte first (MSB) order
- MSB\_UNSIGNED\_INTEGER, unsigned integers using Most Significant Byte first (MSB) order

For more information about these internal representations, refer the Appendix C of the PDS Standards Reference [1].

#### 6.2.2 File System (ISO 9660)

The ISO 9660 Level 2 file system is used including these PDS conventions:

- There are no more than eight nested directory levels
- File names are a maximum of 31 characters long, with no more than three characters in the suffix (i.e., 27.3).



### **6.3 NAIF/SPICE**

Geometry values found in the PDS data labels and FITS data headers were computed using the mid-observation time and the best available SPICE files, also known as kernels, at the time the products were generated by the data pipeline. The SPICE kernels were produced by NAIF for EPOXI and are archived as a separate dataset. For the latest and best version of the SPICE kernels is available online at the NAIF website, <http://naif.jpl.nasa.gov/naif/data.html>.

The SPICE system used to compute geometry information is available at the <http://naif.jpl.nasa.gov/naif/toolkit.html>. The system is available in several programming languages (FORTRAN, C, IDL, and MATLAB) and for most computer platforms such as Sun Solaris, Mac, PC Linux, and PC Windows. The SPICE software, mostly in the form of subroutines, allows users to read SPICE kernels and compute desired observation geometry such as lighting angles, distances, and latitudes or longitudes. Documentation for the SPICE system is available from the NAIF website, <http://naif.jpl.nasa.gov/naif/>.

## 7 Appendices

### 7.1 Glossary

**Archive** - An archive consists of one or more datasets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

**Archive Volume, Archive Volume Set** - A volume is a unit of media on which data products are stored; for example, one DVD. An archive volume is a physical volume containing all or part of an archive; that is, one or more datasets plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone. For EPOXI, one archive volume equates to one dataset.

**Catalog Information** - Descriptive information about a dataset (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) that is suitable for loading into a PDS catalog.

**Data Product** - A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. Examples of a data product are a planetary image, a spectrum table, or a time series table.

**Dataset** - An accumulation of data products. A dataset together with supporting documentation and ancillary files is an archive.

**Standard Data Product** - A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in pipeline fashion. Data products that are generated in a nonstandard way are sometimes called special data products.

## 7.2 Acronyms

ADC	Analog-to-Digital Converter
ASCII	American Standard Code for Information Interchange
CODMAC	Committee on Data Management and Computing
DN	Data number
DI	Deep Impact
DIXI	Deep Impact eXtended Investigation
EDR	Edited Data Record (raw data counts)
EME J2000	Inertial reference frame for the Earth Mean Equator (EME) and Vernal Equinox J2000
EPOCh	Extrasolar Planet Observation and Characterization investigation
EPOXI	EPOCh + DIXI
FOV	Field of View
FITS	Flexible Image Transport System
HRI	High Resolution Instrument/Telescope
HRII	High Resolution Instrument, Infrared Spectrometer
HRIV	High Resolution Instrument, Visual CCD
IEEE	Institute of Electrical and Electronics Engineers
IF	Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of reflectance, also known as I-over-F or I/F, and defined as the radiance divided by the solar spectrum multiplied by pi; For Deep Impact and EPOXI, I/F data are unitless
IFREV	Nomenclature for irreversibly calibrated data (CODMAC level 3) in units of reflectance, also known as I-over-F or I/F, and defined as the radiance divided by the solar spectrum multiplied by pi; For Deep Impact and EPOXI, I/F data are unitless and are not cleaned
IDL	Interactive Data Language, a data visualization and analysis platform
IR	Infrared
MRI	Medium Resolution Instrument, Visual CCD
ODL	Object Description Language
PDS	NASA Planetary Data System
PI	Principle Investigator
FITS	Flexible Image Transport System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
RAW	Nomenclature for edited, raw data (CODMAC level 2) in units of DN
RAD	Nomenclature for irreversibly cleaned, calibrated data (CODMAC level 4) in units of radiance, Watts/(meter**2 steradian micron)
RADREV	Nomenclature for reversibly calibrated data (CODMAC level 3) in units of radiance, Watts/(meter**2 steradian micron); data are not cleaned
RDR	Reduced Data Record (calibrated to physical units)
SBN	Small Bodies Node of the PDS
SDC	Deep Impact and EPOXI Science Data Center at Cornell University
SIS	Software Interface Specifications
SPICE	Spacecraft, Planet, Instrument, Pointing C-matrix, and Event kernels (a historical acronym for NAIF)
TV	Thermal-vacuum Test (ground calibrations)

### 7.3 Data Processing Levels

<b>CODMAC Level</b>	<b>Proc. Type</b>	<b>Data Processing Level Description</b>
<b>1</b>	Raw Data	Telemetry with data embedded.
<b>2</b>	Edited Data	Corrected for telemetry errors and split or decommutated into a dataset for a given instrument. Sometimes called Experimental Data Record (EDR). Data are also tagged with time and location of acquisition. Corresponds to NASA Level 0 data.
<b>3</b>	Calibrated Data	Edited data that are in units produced by instrument, but have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed. Corresponds to NASA Level 1A.
<b>4</b>	Resampled data	Data that have been resampled in the time or space domains in such a way that the original edited data cannot be reconstructed. Could be calibrated in addition to being resampled. Corresponds to NASA Level 1B.
<b>5</b>	Derived Data	Derived results, as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5.
<b>6</b>	Ancillary Data	Non-Science data needed to generate calibrated or resampled datasets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
<b>7</b>	Correlative Data	Other science data needed to interpret space-borne datasets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
<b>8</b>	User Description	Description of why the data were required, any peculiarities associated with the datasets, and enough documentation to allow secondary user to extract information from the data.
<b>n</b>	n	Not Applicable