Thermal Emission Imaging System
2001 Mars Odyssey

THEMIS GEOMETRIC PROCESSING USER'S GUIDE

April 1, 2022

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April 1, 2022

DOCUMENT CHANGE LOG

Date	Description	Sections affected
01/01/06	Initial draft	All
07/15/09	Descriptions of IR products	All
01/01/10	Accumulated updates to instrument & product descriptions Full projection format change to IR-PBT and IR-DCS products	Section 1.3.1, Appx A.4 Sections 2.3, 2.4, 3.1.1, and Appx A.2
07/01/12	Description of VIS DESPECK processing Addition of new peer-reviewed reference	Section 2.5.2, Appx A.5 Section 1.1
10/01/12	Geometry Quality HISTORY object	Appx A.7
07/31/14	GEO version-2 with upgrade to ISIS version 3.x.x Modified IR-PBT Header Description of new VIS-ALB and VIS-RGB products	All Appx A.2 Section 2.6-2.7, Insert new Appx A.4
07/17/15	Minor label changes related to ISIS version 3.4.9	Section 2.1 and Appx A.5 & A.6
04/01/16	Band selection for ALB images Corrected typographical errors in section numbering	Section 2.6 Section 3.3
04/01/17	GEO-LBL Mars Radius units	Appendix A.5
07/01/17	Data format and label changes for IR-PBT and VIS-ALB products	Section 2.3, 3.4.3, and Appx A.2, A.4, & A.5
07/01/20	Revisions to Geometry Quality Assessment and HISTORY Object	Appx A.8
04/01/22	Addition of SCLKERNEL keyword to headers	Section 3.3.2 and Appendices

CONTENTS

ACRONYMS

ALB	ALBedo record
ASU	Arizona State University
DCS	DeCorrelation Stretch product
EDR	Experiment Data Record
GEO	Geometrically registered record
IR	Infrared
ISIS-2	Integrated Software for Imaging Spectrometers, version 2 (discontinued 7/2014)
ISIS-3	Integrated Software for Imaging Spectrometers, version 3 (in use 7/2014)
JPL	Jet Propulsion Laboratory
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PBT	Projected Brightness Temperature record
PDS	Planetary Data System
RDR	Reduced Data Record
RGB	(Red Green Blue) false color composite image
ODY	2001 Mars Odyssey
SIS	Software Interface Specification
SPICE	Spacecraft, Planet, Instrument, Camera-matrix, Events
THEMIS	THermal EMission Imaging System
VIS	Visible

1. INTRODUCTION

1.1 Purpose and Contents

The purpose of this document is to provide scientists using the Thermal Emission Imaging System (THEMIS) Visible and Infrared special geometry products with enough information to enable them to read and understand the data products. Topics discussed in this document include an introduction to the ISIS software used to geometrically project the images, a description of the processing algorithm used to generate the images, a description of the data product format, and the contents of available ancillary labels and files.

THEMIS geometry products (IR-GEO and VIS-GEO) are spatially registered, spectral image CUBEs derived from the THEMIS calibrated radiance products (IR-RDR and VIS-RDR). Each image file is accompanied by a detached ASCII label describing the data format, contents, and processing history. THEMIS derived geometry products (IR-PBT, IR-DCS, VIS-ALB, and VIS-RGB) are spatially registered, image products generated from the appropriate IR-GEO or VIS-GEO products.

For additional information, the user is referred to the following documents available in the THEMIS archive, unless otherwise noted:

1. Calibration Report for the Thermal Emission Imaging System (THEMIS) for the 2001 Mars Odyssey Mission, P.R. Christensen.
2. Mars Odyssey THEMIS: Archive SIS.
3. Mars Odyssey THEMIS: Data Processing User's Guide, P.R. Christensen.
4. Mars Odyssey THEMIS Geometry Processing with ISIS-2, J. Torson, *internet documentation:* http://isis.astrogeology.usgs.gov/Isis2/isis-bin/themis_processing.cgi .
5. Mars Odyssey THEMIS: Standard Data Products SIS.
6. Overview of ISIS-3, *internet documentation:* http://isis.astrogeology.usgs.gov/UserDocs/index.html .
7. Planetary Data System Data Standards Reference, October 30, 2002, Version 3.5, JPL D-7669, Part 2.
8. The Thermal Emission Imaging System (THEMIS) for the Mars 2001 Odyssey Mission, P.R. Christensen, et. Al., *Space Science Review*, Vol. 110, pp 85-130, 2004.
9. Edwards, C. S., K. J. Nowicki, P. R. Christensen, J. Hill, N. Gorelick, and K. Murray (2011), Mosaicking of global planetary image datasets: 1. Techniques and data processing for Thermal Emission Imaging System (THEMIS) multi-spectral data, J. Geophys. Res., 116 (E10), E10008, doi:10010.11029/12010JE003755.
10. Edwards, C. S., P. R. Christensen, and J. Hill (2011), Mosaicking of global planetary image datasets: 2. Modeling of wind streak thicknesses observed in Thermal Emission Imaging System (THEMIS) daytime and nighttime infrared data, J. Geophys. Res., 116, E10005, doi:10.1029/2011JE003857.

11. Christensen, P.R., et. Al. (2001), The Mars Global Surveyor Thermal Emission Spectrometer experiment: Initial description and surface science results, J. Geophys. Res., 106 (E10), doi:10.1029/2000JE01370.
12. Mars Odyssey THEMIS: Data Set Map Projection (EQR, POL, SNU).

1.2 ISIS Overview

1.2.1 Software and Product Overview

ISIS (Integrated System for Imagers and Spectrometers) is a specialized image processing software package developed by the Astrogeology Program of the United States Geological Survey (USGS, Flagstaff Arizona). The software package includes the standard tools desired for the digital processing of multi-spectral image datasets, as well as instrument specific tools to convert between raw camera geometry and standardized map coordinate systems. Cartographic conversions are made possible by incorporating spacecraft and camera models into the ISIS software. The software and complete documentation is available for download from the ISIS website: http://isis.astrogeology.usgs.gov.

The ISIS software manipulates and stores image data in multi-dimensional qube files, formatted similar to the standard Planetary Data System (PDS) QUBE data object [7]. A three-dimensional qube file, with two spatial dimensions and one spectral dimension, is referred to specifically as an ISIS CUBE file. Each CUBE file is composed of an ASCII label attached to one or more data objects, such as TABLE objects, a HISTORY object, and the qube data object. An overview of the ISIS CUBE file format is provided in Section 3.3 of this document; a more complete description of can be found in the *Overview of ISIS-3* [6] documentation.

The transition to replace ISIS version 2 (ISIS-2) with ISIS version 3 (ISIS-3) began at the USGS Flagstaff ISIS facility several years prior to its full use in the THEMIS geometric product processing. The rationale for the change from the software perspective is available in the *Overview of ISIS-3* [6] documentation. From the THEMIS perspective, a major revision to the IR camera model, which significantly improves the band-to-band registration, is only available in ISIS-3. Additional changes to the ISIS-3 core code also improve the quality of the projected visible images, elevating it as the preferred software for projecting all THEMIS images. However, there are significant differences between ISIS-2 and ISIS-3, making many descriptions of the former obsolete in the latter. This document will specify the appropriate version whenever differences between the versions could cause confusion.

1.2.2 THEMIS Specific Software Overview

Several essential tools have been developed to allow the ISIS software to process and geometrically project THEMIS standard data products. First, the ISIS software was given the ability to ingest the THEMIS QUBE data products. Although the PDS QUBE and ISIS CUBE formats are similar, they are different enough to require a translation tool. Second, the conversion parameters between the raw raster coordinate systems of the THEMIS cameras and a standardized Mars coordinate system were used to define several specialized projection tools. The projection capability is facilitated with the geometry information in Mars Odyssey SPICE kernels available from NAIF (http://naif.jpl.nasa.gov/naif). Many aspects of the ISIS-THEMIS tools are discussed in *Mars Odyssey THEMIS Geometry Processing with ISIS-2* [4]; although this document specifically references ISIS-2, the general concepts are still relevant to processing with ISIS-3. All ISIS-3 commands are documented in the *Overview of ISIS-3* [6] Software Manual.

1.3 THEMIS Overview

1.3.1 Instrument Overview

The THEMIS instrument is a combined infrared (IR) and visible (VIS) multi-spectral pushbroom imager. The imaging system is comprised of a three-mirror, off-axis, reflecting telescope in a rugged enclosure, a visible/infrared beamsplitter, a silicon focal plane for visible detection, and a microbolometer for infrared detection. The telescope has a 12-cm effective aperture, speed of f/1.6, and co-aligned VIS-IR detector arrays. A major feature of this instrument is the uncooled IR microbolometer array which can be operated at ambient temperature. A small thermal electric (TE) cooler is used to stabilize the detector temperature to ±0.001 K. The calibration flag is the only moving part in the instrument, allowing for thermal calibration and protection of the detectors from unintentional direct Sun illumination when the instrument is not in use.

THEMIS IR images are acquired at selectable image lengths and in combinations of ten selectable bands. The image width is 320 pixels (32 km, based on the nominal 400 km mapping orbit) and the length is variable, in multiples of 256 line increments, with a minimum and maximum image lengths of 272 and 65,296 lines respectively (27.2 km and 6,530 km, based on the nominal mapping orbit). The IR focal plane is covered by ten ~1 μm-bandwidth strip filters (Table 1a), producing ten band images with bands 1 and 2 having the same wavelength range.

THEMIS VIS images are acquired in framelets of size 1024 pixels crosstrack by 192 lines downtrack, for a total image size of 3.734 Mbytes or less. The number of framelets is determined by the number of bands selected (five available, Table 1b) and the spatial resolution selected (three summing modes available). The size of an image is given by:

$$[((1024 * 192) * \#framelets * \#bands) \div summing^2] \leq 3.734 \text{ Mbytes}$$

For example, if spatial summing is not applied (summing=1), either a single-band, 19-framelet (65.6 km) image or a 5-band 3-framelet (10.3 km) image can be collected. Each VIS image collected is stored in the THEMIS internal buffer and must be transferred to the spacecraft computer before a subsequent image can be acquired. VIS images may be compressed with one of two available compression algorithms before storage on the spacecraft computer.

VIS images can be acquired simultaneously with IR images, but the spacecraft can only transfer data from one of the two THEMIS imagers at a time. The IR imager transfers data as it is being collected, while the VIS images are stored within an internal THEMIS buffer for later transfer to the spacecraft computer. Before storage of IR images on the spacecraft, one or more data reduction techniques may be selected. The time-delay integration (TDI) algorithm may be applied to improve the signal-to-noise ratio of each pixel by co-adding 16 independent measurements of each point on the ground. Lossless data compression may be applied to the image by the hardware Rice algorithm chip.

Tables 1a&b: THEMIS available bands

INFRARED BANDS		
Band Numbers	Center (μm)	FWHM (μm)
IR-1	6.78	1.01
IR-2	6.78	1.01
IR-3	7.93	1.09
IR-4	8.56	1.16
IR-5	9.35	1.20
IR-6	10.21	1.10
IR-7	11.04	1.19
IR-8	11.79	1.07
IR-9	12.57	0.81
IR-10	14.88	0.87

VISIBLE BANDS		
Band Numbers	Center (μm)	FWHM (μm)
V-1	0.425	0.049
V-2	0.540	0.051
V-3	0.654	0.053
V-4	0.749	0.053
V-5	0.860	0.045

The IR and VIS cameras share the instrument optics and housing, but have independent power and data interfaces to the spacecraft. In Spring 2006, a software patch was loaded into the spacecraft memory to apply spatial summing to IR images before downlink; use of this patch decreases the effective bandwidth of the IR camera, and allows for the collection of additional IR images. Final data stream formatting for both the IR and VIS data is performed by the spacecraft processor. Further information about onboard processing is available in the THEMIS *Space Science Review* paper [8].

1.3.2 Data Products Overview

THEMIS standard data products include experimental, reduced, and calibrated data files. The experimental and reduced products (VIS-EDR, IR-EDR, VIS-RDR, and IR-RDR) are spectral image QUBEs containing one layer per each visible or infrared band collected. The calibrated products (VIS-ABR and IR-BTR) are one band IMAGE files produced from the reduced data products. A detailed description of the format and content for each of the standard data products is provided in the *THEMIS Standard Data Products SIS* [5].

The THM-RDR data products are uncompressed, binary, band-sequential QUBEs of 16-bit integer data. The image width is fixed (320 pixels for IR, 1024 pixels for VIS), but the length varies proportional to the duration of the observation. Calibration algorithms used to generate each THM-RDR are described in the *THEMIS Data Processing User's Guide* [3] and each execution adds an entry in the cumulative HISTORY object contained in the ASCII header of the QUBE. The THM-RDR QUBE images are not spatially registered, and bands (layers) within a single image can be out of registration with each other by up to 10 lines and/or columns.

The THEMIS geometric data products will be generated by the staff at the ASU Mars Space Flight Facility and be distributed in conjunction with their standard data product counterparts. Geometric projection of the IR-RDR and VIS-RDR standard data products may be augmented with additional manipulation of the images, which may invalidate the calibrated radiance values inherited from the source RDR product. Geometric data products will be stored as one projection in a multispectral ISIS CUBE file, with multiple projections per image possibly available. All processing performed on the GEO cube will be recorded in the HISTORY object of the detached PDS label.

THEMIS derived geometric data products (IR-PBT, IR-DCS, VIS-ALB, and VIS-RGB) are generated by additional processing of the IR-GEO and VIS-GEO products, respectively. The IR-PBT and VIS-ALB products are one band PDS IMAGE files, which similar in many ways to the IR-BTR or VIS-ABR products. The IR-DCS and VIS-RGB products are stored as simple PNG image products, similar to the PDS standard BROWSE images.

2. GEOMETRIC PROCESSING

2.1 THEMIS to ISIS

In order to generate the geometric projections from the calibrated radiance images, the THEMIS RDR.QUBE format must be modified so that it can be ingested into the standard ISIS projection software. The ISIS-3 *THM2ISIS* command is used to convert the PDS formatted IR-RDR or VIS-RDR image into an LEV1 CUBE image that can be manipulated by subsequent ISIS software tools. Application of the *THM2ISIS* command converts only the label to ISIS-3 standards; the image remains unprojected in the original camera coordinates. In the THEMIS IR images, the data values and image dimensions remain fundamentally unchanged. In the THEMIS VIS, alternating framelets are split into two separate files: “odd.cub” and “even.cub”; all subsequent projection steps must be executed on both files until they are merged back together using some kind of “mosaic” command.

The ISIS-3 *THM2ISIS* command translates the THEMIS RDR band keywords into several new keywords within the BandBin label group. The ISIS-3 keywords FilterNumber, Center, and Width have the same values as the RDR keywords BAND_BIN_FILTER_NUMBER, BAND_BIN_CENTER, and BAND_BIN_WIDTH respectively. The ISIS-3 keyword BandNumber, available after version 3.4.8 (2014), has the same value as the RDR keyword BAND_BIN_BAND_NUMBER. The default value of the ISIS-3 keyword OriginalBand is a confusing re-mapping of the THEMIS camera band designations, which does not correlate to any RDR keyword value, and actually may cause problems during later processing steps. Therefore, the THEMIS Team resets the ISIS-3 OriginalBand values to be equal to the RDR keyword BAND_BIN_BAND_NUMBER values before continuing with additional processing.

2.2 Infrared GEO Products

The generation of infrared projected images (IR-GEO) includes multiple processing steps. First, a post-calibration filter is applied to the infrared calibrated radiance images (IR-RDR). Next, these modified radiance images are ingested into ISIS-3 and the geometric projection products are completed by projecting the image into standard Mars coordinates (Section 2.1). Finally, additional image processing is applied to complete the process.

These IR-GEO products contain geometrically registered and atmospherically corrected calibrated radiance, making them ideal for use in surface studies and for use with other projected Mars datasets. For these purposes, two derived products may be generated from the geometric projection with further processing: a projected brightness temperature product (IR-PBT), and a decorrelation stretch product (IR-DCS). Parameters of each process, applied by default or request, are recorded in the label of the final product as “keyword = values” pairs (see section 3.5); some significant label entries are highlighted throughout this section using [ ].

2.2.1 ISIS-3 IR Projection Processing

Three ISIS-3 commands used in succession are required to project the ISIS-3 formatted IR-RDR data into a geometrically registered image cube: 1) *SPICEINIT, 2) MAPTEMPLATE*, and *3) CAM2MAP*. ISIS-3 *SPICEINIT* is used to select the appropriate SPICE kernels for use with this image. This command adds the KERNELS group and several TABLE objects to the LEV1 CUBE label, as well as the SPICEINIT HISTORY object.

ISIS-3 *MAPTEMPLATE* is used to create a temporary file which defines the projection parameters appropriate for this image; this information is saved in the MAPPING group in the CUBE label. Table 2.2 shows the possible image observation conditions and the resulting *MAPTEMPLATE* parameter values.

The ISIS-3 *CAM2MAP* command is used to project the ISIS-3 formatted camera data into a geometrically registered image cube. This command translates the radiance values into the desired map projection by applying a bilinear interpolation algorithm [INTERP = BILINEAR], which incorporates the values of the four pixels closest to each mapped position. The spatial transformation is performed based on the projection parameters in the file generated by *MAPTEMPLATE*. This command adds the CAM2MAP HISTORY object to the CUBE.

Table 2.2: IR-GEO MAPTEMPLATE parameters

Map Projection Abbreviation	**ISIS-3 *MAPTEMPLATE* Parameter**	**Value**	**Image Observation Conditions**
EQR	projection	Equirectangular	-70 < CENTER_LATITUDE CENTER_LATITUDE < 70
POL	projection	PolarStereographic	max(LATITUDE) > 60 max(LATITUDE) < -60
SNU	projection	Sinusoidal	-70 < CENTER_LATITUDE CENTER_LATITUDE < 70
EQR	clon	180 0	where londom=360 where londom=180
POL	clon	(MeridianLon)	Calculated from image
SNU	clon	(CenterLon)	Equal to image CENTER_LONGITUDE value
EQR	clat	(see Table 3.2)	Calculated from image CENTER_LATITUDE value
POL	clat	+90 or -90	Closest pole to image
SNU	clat	0	Default for all images
(any)	resolution	100 m/pix 100*summing m/pix	SPATIAL_SUMMING = 1 SPATIAL SUMMING > 1
(any)	londom	180 360	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358 2 < CENTER_LONGITUDE CENTER_LONGITUDE < 358
(any)	londir	PositiveEast	Default for all images
(any)	lattype	Planetocentric	Default for all images

2.2.2 Additional IR Processing

Additional image processing may be applied to the IR-GEO image cube either before or after the ISIS projection steps. Each process described in this section generates a HISTORY object in the detached PDS label (see Section 3.5.3), as shown in Appendix A.5.

The ASU *UDDW* (Undrift and Dewobble) filter is applied to the IR-RDR QUBE before the image is projected, and is designed to correct for time-dependent signal offsets which are highly correlated in the original image coordinates. It removes undesirable data value fluctuations resulting from changes in the temperature of the IR detector array during image collection. This filter alters the calibrated radiance values of bands 1 - 9 (where available), but does not change the radiance values of band 10.

The ASU *RECTIFY* algorithm is applied to the projected infrared image to minimize the null space around the image and to prepare the data for additional processing. If necessary, the image data is first rotated to align the top line of the projected image with the horizontal edge (x axis) of the image frame; then each image line is shifted left to align with the vertical edge (y axis) of the image frame. This process will result in spatial distortions that are reversible using the parameters provided in the *RECTIFY* HISTORY object and the ASU *RECONSTITUTE* algorithm.

The ASU *DEPLAID* algorithm applies a specialized, high-pass filter to projected and rectified infrared radiance images. These filters attempt to remove the effects of both column and row correlated, band independent noise that would otherwise dominate a decorrelation stretch image. The noise originates from voltage fluctuations in the THEMIS instrument during image collection; this noise is minimized, but not completely removed, during the IR-RDR calibration *DESTRIPE* process (see *THEMIS: Data Processing User's Guide* [3]). Validation of the results of this algorithm confirm that the average spectra from a 50 x 50 pixel sample area remains unchanged.

The ASU *ARADCOR* (Automated RADiance CORrection) algorithm attempts to remove the atmospheric radiance component from the projected and filtered infrared image. The correction value is based on multiple 50 x 50 pixel samples identified throughout the image which meet several temperature and quality criteria; if these samples cannot be found, then the algorithm is not applied. Radiance correction of the image may still be possible, but will require hand processing by an interested user.

2.3 Infrared PBT Products

Projected Brightness Temperature (PBT) images are available as the projected equivalent product of the standard IR-BTR images. To generate an IR-PBT product, the brightness temperature algorithm described in *THEMIS: Data Processing User's Guide* [3], Section 2.2.11 is applied to the projected and rectified IR-GEO product. Then the resulting image is restored to the full projection dimensions using the *RECONSTITUTE* algorithm for ease of viewing. The IR-PBT products are available as standard PDS IMAGE objects (see Section 3.4.3), with the temperatures stored as full 4-byte float values and an IMAGE_MAP_PROJECTION object, similar to that available in the IR-GEO label, embedded in the ascii header (see Appendix A.2).

A comparison between the temperatures recorded in the IR-BTR and IR-PBT images will show a notable difference between the same pixels at the highest and lowest extremes of the image temperature range, but only a slight difference for the bulk of the image pixels. The slight temperature difference has been attributed to the data manipulation that occurs during the translation from camera-coordinates (RDR) to projection coordinates (GEO). The larger temperature difference arises during the scaling of the IR-BTR data to reformat it for compressed storage, at which time the extreme ends are also truncated to improve the display quality of the image. On average, the IR-BTR maximum temperatures are 5 degrees lower than the same IR-PBT image. Since the IR-PBT temperature values are not scaled nor truncated, these products are recommended for use in quantitative scientific studies.

2.4 Infrared DCS Products

The decorrelation stretch (DCS) method maximizes the differences between bands in order to highlight the compositional information in the image. THEMIS IR-DCS products provide a quick preview of the potential compositional variation available in an infrared image. They are generated from the IR-GEO images with an average surface temperature greater than 225 K and a minimum of eight bands (bands 3-10 required).

To generate an IR-DCS image, two final noise filters are applied to all available bands in an IR-GEO product, then the DCS algorithm is applied, and the results are saved as a simple image (PNG format). First, any residual uncorrelated noise is removed by applying the ASU *DESTREAK* and *WHITE_NOISE* algorithms. These filters are useful for reducing the anomalous noise in the qualitative DCS image, but are not appropriate for application on a quantitative radiance product. Next, three bands of the radiance image are selected for decorrelation and displayed in color as variations of red, green, and blue. The THEMIS IR-DCS images are executed on three standard RGB band combinations: bands 6, 4, and 2; bands 8, 7, and 5; and bands 9, 6, and 4. The results are made available individually in full projection dimensions (using *RECONSTITUTE*), and also available combined together side-by-side in rectified dimensions with a brightness temperature image for contrast (see Section 3.1).

2.5 Visible GEO Products

After the visible calibrated radiance images (VIS-RDR) are ingested into ISIS-3 (Section 2.1), the geometric projection products are completed by projecting the image into standard Mars coordinates, and then applying any additional image processing. Parameters of each process, applied by default or request, are recorded in the label of the final projected image as "keyword = values" pairs (see section 3.5); some significant label entries are highlighted throughout this section using [ ].

Most of the VIS-GEO standard products include the application of a cosmetic filter (*FEATHER*) which renders them undesirable for rigorous spectroscopic studies. Two VIS-GEO derived products may be available to assist users interested in using the THM-VIS image is more quantitative work. The projected visible albedo product (VIS-ALB) is generated directly from the VIS-RDR calibrated radiance, and the resulting albedo values compare favorably with albedo measurements from the Mars Global Surveyor TES instrument (see Section 2.6). The projected visible false color composite images (VIS-RGB) are an alternative view of three bands of the multi-band visible images (see Section 2.7).

2.5.1 ISIS-3 VIS Projection Processing

The same three ISIS-3 commands used to project THM-IR images are also used to project THM-VIS images: 1) *SPICEINIT, 2) MAPTEMPLATE*, and *3) CAM2MAP*. ISIS-3 *SPICEINIT* is used to select the appropriate SPICE kernels for use with this image; it must be applied to both the "odd.cub" and "even.cub" files generated when ISIS-3 *THM2ISIS* is executed on a VIS-RDR. This command adds the KERNELS group and several TABLE objects to the LEV1 CUBE label, as well as the SPICEINIT HISTORY object.

ISIS-3 *MAPTEMPLATE* is used to create a single file which defines the projection parameters appropriate for use with both the "odd.cub" and "even.cub" files; this information is saved in the MAPPING group in the CUBE label. It is important to project both even/odd image halves with the exact same projection parameters, otherwise they will not mosaic back into a single image post-projection. Table 2.5 shows the possible image observation conditions and the resulting *MAPTEMPLATE* parameter values.

Table 2.5: VIS-GEO MAPTEMPLATE parameters

Map Projection Abbreviation	**ISIS-3 *MAPTEMPLATE* Parameter**	**Value**	**Image Observation Conditions**
EQR	projection	Equirectangular	-60 < CENTER_LATITUDE < 60
POL	projection	PolarStereographic	max(LATITUDE) > 60 max(LATITUDE) < -60
SNU	projection	Sinusoidal	-60 < CENTER_LATITUDE < 60
EQR	clon	180 0	where londom=360 where londom=180
POL	clon	(MeridianLon)	Calculated from image
SNU	clon	(CenterLon)	Equal to image CENTER_LONGITUDE value
EQR	clat	(see Table 3.2)	Calculated from image CENTER_LATITUDE value
POL	clat	+90 or -90	Closest pole to image
SNU	clat	0	Default for all images
(any)	resolution	18 m/pix 36 m/pix 72 m/pix	SPATIAL_SUMMING = 1 SPATIAL SUMMING = 2 SPATIAL SUMMING = 4
(any)	londom	180	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358

Map Projection Abbreviation	ISIS-3 *MAPTEMPLATE* Parameter	Value	Image Observation Conditions
		360	2 < CENTER_LONGITUDE < 358
(any)	londir	PositiveEast	Default for all images
(any)	lattype	Planetocentric	Default for all images

The ISIS-3 *CAM2MAP* command is again used, this time to independently project both the ISIS-3 formatted camera “even.cub” and “odd.cub” data files into a geometrically registered image cubes. This command translates the radiance values into the desired map projection by applying a bilinear interpolation algorithm [INTERP = BILINEAR], which incorporates the values of the four pixels closest to each mapped position. The spatial transformation is performed based on the projection parameters in the file generated by *MAPTEMPLATE*. This command adds the CAM2MAP HISTORY object to the CUBE.

Several options are available to mosaic the two halves, “odd.cub” and “even.cub”, back into a single, projected VIS-GEO product. Two ISIS-3 commands are available for this purpose: ISIS-3 *THMNOSEAM,* used rarely in VIS-GEO products, is similar in purpose to the ASU process *FEATHER* described below; ISIS-3 *AUTOMOS* is used occasionally in conjunction with other ASU processes as described below.

2.5.2 VIS Pre-projection Processing

The generation of many VIS-GEO projected images includes one or more cosmetic corrections that are most easily applied before the ISIS-3 projection steps. Each process described in this section generates a HISTORY object in the detached PDS label (see Section 3.5.3), as shown in Appendix A.5.

The ASU *DESPECKLE* process is a cosmetic correction applied to selected VIS-RDR QUBEs before the image is projected. On occasion, temporary radiation disruptions in the camera electronics produce anomalously bright or dark pixels scattered throughout the image. The distribution and intensity of this pixel “speckling” varies between each radiation event, but the corrupt pixels are usually concentrated either along the framelet edges, or within the more saturated areas of the image. This algorithm identifies the corrupt pixels based on an image specific DN threshold [THRESHOLD_VALUE = #], and then replaces it with a value matching the average of the surrounding valid pixels. This process alters the calibrated radiance values of the selected pixels in the corrected bands.

The ASU *COFF* (Cosmetically Optimized Flat-Field) process is applied to maintain the overall radiance level of each framelet in the VIS-GEO image. This is accomplished by removing an optimized flat-field from each framelet before the ISIS-3 *THM2ISIS* step. When applied, all source VIS-RDR radiance values are significantly modified.

The ISIS-3 *TRIMVISTRIM* command is used to remove the specified number of lines from the top and bottom of each visible framelet. Nominal image collection results in multiple lines of overlap between each framelet; the extreme edges of which are frequently noisy. Trimming off the worst of these lines improves the appearance of the image without otherwise affecting the image contents.

2.5.3 VIS Post-projection Processing

VIS-GEO standard processing includes application of one of two post-projection commands in order to mosaic the two halves, “odd.cub” and “even.cub” back into a single projected image: the ASU *FEATHER* algorithm (most commonly used), or the ISIS-3 *AUTOMOS* command. Both processes include many image-dependent parameters which are recorded in the appropriate HISTORY object in the label (see Section 3.5.4), as shown in Appendix A.5.

The ASU *FEATHER* process is applied to cosmetically enhance the discontinuities along the overlapping framelet boundaries of a projected visible image. This cosmetic filter is applied simultaneously with mosaicking the “odd.cub” and “even.cub” framelets back together into the final VIS-GEO cube file. The most common parameters that may be adjusted per image include the size of the filter [FILTER_DIMENSIONS = (x, y)], special handling of the boundary between the first and second framelets [FRAMELET1_NOTE = (description)], and temporary changes to the image orientation to facilitate the processing [ROTATION = (#,#)]. Because of the nature of this algorithm, all values in the resulting projected image may have been significantly modified from the source VIS-RDR calibrated radiance values.

Although the ISIS-3 *AUTOMOS* command can be used alone to complete the VIS-GEO projection processing, the algorithm has limited options to how it handles the overlapping data between framelets: overlay all pixels from one framelet set, or average all pixels of both framelet sets. In practice, the data located at the trailing framelet edge (as collected) usually includes a noticeable signal “roll-off” that should be replaced by the better data in the overlapping, leading edge of the successive framelet; in other words, the framelets should be assembled interleaved like louvered window panes. To achieve this effect, first the ASU *FRAMECLIP* process is applied to remove the overlapping data along all the trailing edges in the overlaid framelet set, then the ISIS-3 *ATUOMOS* command is executed with the option selected to place the appropriate “clipped” framelet set ONTOP. Both commands generate separate HISTORY objects in the label.

2.6 Visible ALB Products

Projected Lambert albedo (ALB) images are generated by calculating albedo from the calibrated visible radiance (VIS-RDR), projecting the data as described above, and storing the results for a single band in a standard PDS IMAGE object (see Section 3.4.3). Lambert albedo (L) is calculated from the THEMIS visible radiance using

$$L = R/(J/d^2\pi)(\cos(i))$$

where R is the calibrated spectral radiance data (VIS-RDR) in [W m^{-2} st^{-1} μm^{-1}],
J is the solar irradiance in [W m^{-2} μm^{-1}] at the Mars-Sun distance (d) in AU,
and i is the incidence angle of the Sun on the surface of Mars.

The solar distance (d) and incidence angle (i) are computed at the image center using the ISIS-3 *CAMPT* function and stored in the ALB image header (see Appendix A.4). The solar irradiance values were convolved to the THEMIS visible wavelengths and are given in Table 2.6. This albedo equation does not account for topography or shadows, so the calculated values are most accurate for surfaces with low to no slopes.

VIS-ALB images are generated for a single band of most available VIS-RDR images with an incidence angle less than 80º, and located between +/- 75º latitude. VIS-ALB images are usually derived from Band-3; if it is not available, Band-4 or the first available band may be used. Similar to the VIS-ABR images, the albedo data is stored as scaled, 16-bit integer images in the standard PDS IMAGE object format as described in Section 3.4.3; an example of the attached header is provided in Appendix A.4. In addition to the usual observation and processing keywords, the ALB header includes several parameters describing the equivalent MGS-TES measured albedo of this image. The footprint of the THEMIS VIS image is projected onto the TES Albedo 8ppd map [11], and the statistics of the TES albedo values in the overlapping area are stored in the keywords TES_ALBEDO_MINIMUM, TES_ALBEDO_MAXIMUM, TES_ALBEDO_AVERAGE, and TES_ALBEDO_SIGMA.

Using selected THEMIS images, a linear correlation between the TES_ALBEDO_AVERAGE with the THEMIS AVERAGE_ALBEDO was established. The images were selected from orbits 816-54299, having a center latitude between +/- 60º and incidence angle less than 75º, and displaying "good" calculated albedo values (albedo values between 0 and 1.0 and albedo sigma <0.05). The number of qualifying images is shown in Table 2.6, along with the linear fit parameters for:

$$\text{THM-AVG\_ALB} = m * \text{TES\_AVG\_ALB} + b$$

Table 2.6: Various THM VIS-ALB per band parameters

THM Band	J [W m^{-2} μm^{-1}]	b (offset)	m (slope)	R^2 Error	Images Used
1	1714.882	0.0728	0.0198	0.0055	4,924
2	1854.915	0.1196	0.2175	0.2877	5,545
3	1567.595	0.1350	0.9355	0.7968	77,542
4	1268.324	0.1334	1.3175	0.8026	4,328
5	981.8372	0.1798	0.5432	0.3889	317

The linear offset between the two instruments is due primarily to the design differences of the two instruments: TES was a broadband spectrometer, spanning ~0.4-2.7 µm, while the THEMIS individual bands are much narrower, for example band-3 is at ~0.654 µm (Table 1b).

2.7 Visible RGB Products

Most multiple band visible images can be used to generate a false color composite image, or VIS-RGB image. After projection, a linear stretch is applied to each band, and then each of the three bands is assigned to the three color channels (red, green, blue). The final image results from displaying visible band-4 (or if not available, band-3) in the red channel, band-2 in the green channel, and band-1 in the blue channel (see Section 1.3, Table 1b for the visible camera band configuration). These RGB products are useful for assessing the magnitude of the color variations across the available bandpasses at this image location, but it should be noted that these products also tend to highlight filter edge and straylight effects (along the east/west edges) or low frequency variations (down the length of the image); a discussion of visible camera issues is available in the *THEMIS Data Processing User's Guide, Part 2 - Visible* [3].

3. GEOMETRIC PRODUCT SPECIFICATIONS

3.1 Geometry Product Naming and Identification

3.1.1 Naming Conventions

Each THEMIS projected product is named using the THEMIS standard data product naming convention, which follows the pattern "AooooonnnGGG.EXT". As established in the standard documentation, the PRODUCT_ID pattern is defined as

A	is a 1-letter description of the type of image collected; [V = visible image; I = infrared image]
ooooo	is a 5-digit mission orbit number when the image was collected; [01000 = mapping orbit number example]
nnn	is a 3-digit image sequence number indicating the order that images were collected each orbit; [001 = first image collected in the xxxxx orbit]

The suffix-extension "GGG.EXT" value identifies the geometry product type and the file format standards (see Section 3.4). The combinations used with the THEMIS geometry products are

ALB.IMG	identifies the VIS-ALB data product; both data and label information are available in this file
D###.PNG	identifies a single, full projection IR-DCS browse image, where the numeric value lists the IR bands represented in red, green, and blue respectively
DCS.PNG	identifies a multiple panel IR-DCS browse image, composed of the following side-by-side, rectified images: D875, D964, D642 (if available), and brightness temperature
EQR.CUB	identifies a GEO data product: an equirectangular (cylindrical) projection, stored in a multi-spectral ISIS image cube
EQR.LBL	identifies the PDS detached label file for a EQR.CUB data product
LOC.CUB	identifies an ISIS-2 version VIS-GEO data product; these products have been superseded by the ISIS-3 POL or SNU products
LOC.LBL	identifies the PDS detached label file for an ISIS-2 version VIS-GEO data product
PBT.IMG	identifies the IR-PBT data product; both data and label information are available in this file
POL.CUB	identifies a GEO data product: a polar stereographic projection, stored in a multi-spectral ISIS image cube
POL.LBL	identifies the PDS detached label file for a POL.CUB data product
RGB.PNG	identifies a single, full projection VIS-RGB browse image, where three of the available VIS bands are represented in each color (red, green, and blue) to create a single, false color composite image
SNU.CUB	identifies a GEO data product: a sinusoidal projection, stored in a multi-spectral ISIS image cube
SNU.LBL	identifies the PDS detached label file for a SNU.CUB data product

3.1.2 Revision Conventions

As with the THEMIS standard data products, a revision to the geometry product after the initial public release may be warranted. At that time, the PRODUCT_VERSION_ID keyword in the product label will be incremented, an ERRATA_ID will be established, and the change made will be documented. The ERRATA_ID will take the form ODTxx_rrrr_v.v, where xx is the image and dataset abbreviation, rrrr is the original RELEASE_ID number, and v.v is the PRODUCT_VERSION_ID value. Each revision will be documented in the label HISTORY object, the ERRATA.TXT and the appropriate release catalog (ODTIGREL.CAT, ODTIVGREL.CAT, ODTIPREL.CAT, or ODTVAREL.CAT), and by modifying records as necessary in the indexes (INDEX_ODTxx, THMIDX_IR, or THMIDX_VIS). See Appendix A.5 for label keyword definitions and the *THEMIS Archive SIS* [2] for document specifications.

The transition to using ISIS-3 in the generation of THEMIS projected products is concurrent with the roll of the Odyssey THEMIS Projected Products (ODTGEO) archive VOLUME_VERSION_ID to 2.0. All ISIS-3 projected products will start at PRODUCT_VERSION_ID = 2.0, regardless of the previous release or revision value; this is also true for new data releases available only as ISIS-3 products.

3.2 Overview of Cartographic Standards

The THEMIS Projected Products are compliant with the cartographic standards defined in the *DATA SET MAP PROJECTION* [12] catalog objects provided with this archive. The areal coverage of most THEMIS images make them ideal candidates for projection using either the Sinusoidal or Polar Stereographic standards, dependent on local latitude. However, the THEMIS team recognizes the common use of these images as a background to the other, higher resolution Mars images currently available. Therefore, an Equirectangular projection of many non-polar images will be provided to more easily facilitate this usage. The THEMIS implementation of each of the three projections is discussed below.

3.2.1 Equirectangular (EQR)

The Equirectangular projection is commonly referred to as the "Simple Cylindrical" projection when the CenterLatitude is fixed at the equator. In general, both projections are chosen for their ease of use in two dimensional maps of relatively small areas. When used with THEMIS images, however, caution is warranted as these cylindrical projections tend to cause distortion of size, especially at points increasing in distance away from the center of projection. The ISIS-3 implementation of the Equirectangular projection is based on the formula for a sphere, as described in the *DSMAP_EQR.CAT* [12] document. The sphere is defined by the radius at the CenterLatitude of the projection, the value of which is being calculated and stored as both the LocalRadius keyword in the Mapping Group of the ISIS-3 CUBE label, and also as the value of all three EQR.LBL keywords: A_AXIS_RADIUS, B_AXIS_RADIUS, and C_AXIS_RADIUS. The values for scale and resolution are true at the CenterLatitude of the projection.

To minimize the distortion per image, the center of the Equirectangular projection is based on the observed center of the THEMIS image. The CenterLongitude (CLON) of the projection is set to the observed center longitude of the image; the CenterLatitude (CLAT) value is based on where the observed center latitude falls within the 5-degree latitude grid shown in Table 3.2:

Table 3.2: Equirectangular Center Latitude grid

Image Latitude Range	Projection CLAT	Image Latitude Range	Projection CLAT
65 to 70	65	-65 to -70	-65
60 to 65	60	-60 to -65	-60
55 to 60	55	-55 to -60	-55
50 to 55	50	-50 to -55	-50
45 to 50	45	-45 to -50	-45
40 to 45	40	-40 to -45	-40
35 to 40	35	-35 to -40	-35
30 to 35	30	-30 to -35	-30
25 to 30	25	-25 to -30	-25
20 to 25	20	-20 to -25	-20
15 to 20	15	-15 to -20	-15
10 to 15	10	-10 to -15	-10
5 to 10	5	-5 to -10	-5
0 to 5	0	0 to -5	0

When attempting to mosaic a THEMIS EQR.CUB with another overlapping image, it may be necessary to adjust the center of projection of the THEMIS image to match that of the other image; this is easily done with minimal impact on the integrity of the calibrated data values by using the ISIS-3 *MAP2MAP* command. Furthermore, the user should also consider cropping THEMIS images that are significantly longer than the desired final mosaic.

3.2.2 Polar Stereographic (POL)

THEMIS images with a center latitude greater than 60 degrees or less than -60 are projected using the Polar Stereographic standards to give a true perspective of the surface features. The Polar Stereographic projection as defined in ISIS-3 uses the ellipsoid form of the standard equation which may cause issues in other cartographic software; see the *DSMAP_POL.CAT* [12] document for a complete discussion, including the equations necessary to translate between the two standards.

The center of each THEMIS polar projection is defined by the image location: the CenterLatitude (CLAT) is set to either +90 or -90 latitude, whichever pole is closest in proximity to the image; the CenterLongitude (CLON) is set to the “Meridian Longitude” as calculated from the start and end points of the image. The result of using these parameters is that the image length is approximately vertical in the projected file, with the data collected at the start of the image at the “top” of the projection. While use of the Meridian Longitude reduces the final file size of the resulting cube and simplifies several of the THEMIS post-projection processing algorithms, it may cause issues when attempting to mosaic individual polar images into a single scene or with other Mars imagery. To circumvent this problem, the user should simply modify the Center Longitude (i.e. using the ISIS-3 *MAP2MAP* command) to match the mosaic center.

3.2.3 Sinusoidal (SNU)

The Sinusoidal projection is an equal area, partially equidistant projection where latitude lines are drawn as parallel lines, the center meridian is a straight, vertical line, and the remaining longitude lines curve with increasing distance away from the center. THEMIS sinusoidal projected products use the nominal ISIS-3 standards for this projection (*DSMAP_SNU.CAT* [12]), with the observed center longitude used to define the CenterLongitude (CLON) of the image projection. By default, the CenterLatitude is always the Equator (CLAT = 0). All other adjustable parameters for resolution, longitude domain and direction, and latitude type are as shown above in Tables 2.2 and 2.5.

3.3 Standards Used in Generating Geometry Products

3.3.1 PDS Standards & Data Processing Level

The THEMIS GEO ISIS CUBE products are similar to Planetary Data System QUBE data product in file format and label structure; however, they are not intended to meet all of the standards specified in the PDS Standards Reference [7]. The detached label associated with each image CUBE does comply with Planetary Data System standards for file labels. The THEMIS geometric products are NASA processing Level 2 images, derived from the THM-RDR products (Level-1A) and adjusted for instrument location, pointing, and sampling.

The THEMIS PBT and ALB derived products are Planetary Data System IMAGE data products which include a single band of image data with an attached label. These products are NASA processing Level 2 images, derived from the THM-RDR products, projected for instrument location, and further transformed by additional computations.

3.3.2 Time Standards

All time stamps stored in the GEO label are extracted from the source THM-RDR image; a full description of the time standards used with THEMIS data products is available in the *THEMIS Standard Data Products SIS* [5], Section 2.3.4.

The time stamp (SPACECRAFT_CLOCK_START_COUNT) stored with each geometry product is the value of the spacecraft clock at the time of data acquisition of the leading edge of the first detector in the array (filter 1), even if filter 1 is not downlinked. For visible images, this time is calculated from the UNCORRECTED_SCLK_START_COUNT and may differ by as much as 4 seconds, depending on which bands are acquired in the observation. The stop time stamp, SPACECRAFT_CLOCK_STOP_COUNT, is calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION. Depending on which bands are acquired in a visible image, the difference of the start and stop time stamps may not be equivalent to IMAGE_DURATION.

The spacecraft clock value is equal to the number of seconds since 12:00 a.m. 1/01/1980 GMT. This number can vary from the number of seconds recorded on earth due to variations in the spacecraft's oscillator or relativistic effects. For convenience, all data products also contain time values in UTC (Universal Time Coordinated) and ET (Ephemeris Time) formats, translated from the SCLK spacecraft event times when the raw data (EDR) is generated; the SPICE kernel used in the translation is tracked in the SCLKERNEL keyword. UTC is the date (year, month, day) and time (hour, minute, second) in GMT. ET is the time in seconds since January 1, 2000 at 12:00:00 in Barycentric Dynamical Time (TDB)

3.3.3 Coordinate Systems

All geometric values are based on Mars IAU 2000 areocentric model with east positive longitude. The geographic map projection for each data product is identified in the MAP_PROJECTION_TYPE keyword (see Appendices A.1-4) in all labels and defined in detail in the ISIS attached cube label.

ISIS requires the precise geometric locations of the Odyssey spacecraft, THEMIS camera, and Mars in order to correctly project each image. This information is referenced from the Mars Odyssey SPICE kernels published by the navigation team (http://naif.jpl.nasa.gov/naif), and the kernels actually used are recorded in the label of the ISIS CUBE and in the associated HISTORY object in the GEO.LBL. The Planet and Instrument kernels are static, and only the current version is used. The Spacecraft and Camera-matrix kernels are time dependent, constructed from measurements made by the spacecraft; the kernel corresponding to the image acquisition time is used. The camera-matrix kernels contain intermittent time gaps which occasionally overlap with the imaging times; when this happens, a substitute kernel is used which assumes a known and fixed camera-matrix geometry.

3.3.4 Compression Standards

Due to the potential for large file sizes, many THEMIS GEO products are routinely compressed using the GZIP utility. The ".gz" extension on any product filename (see Section 3.1.3 above) indicates that the gzip compression has been applied. For more information, or to download this free software, visit http://www.gzip.org.

3.4 Image Formats

The THEMIS geometry products maintain the ISIS-3 CUBE format of the software from which they were generated [6]. Each CUBE is composed of an ASCII label attached to the core of an uncompressed, binary cube of 32-bit float data. There are significant differences between the ISIS-2 and ISIS-3 CUBE formats; unless otherwise noted, the following sections describe the format of the ISIS-3 CUBE files.

Like the unprojected equivalent IR-BTR and VIS-ABR images, the THEMIS IR-PBT and VIS-ALB images are PDS standard IMAGE objects. See Section 3.4.3 below for a description of this THEMIS file format (also available in the *THEMIS Standard Data Products SIS* [5].)

3.4.1 ISIS CUBE Data Object

The CUBE core is an array of sample values in three dimensions: two spatial dimensions (samples and lines) and one spectral dimension (bands), as shown conceptually in Figure 1a. For ISIS-2 cubes, additional information may be stored in "suffix" planes (back, side, or bottom) as shown in Figure 1b; suffix planes are not available in ISIS-3 cubes. This format allows each CUBE to be simultaneously a set of images (at different wavelengths) of the same target area, and also a multi-point spectrum at each spatially registered pixel in the target area. The spectral dimension of each THM-GEO cube is identical to the source THM-RDR image, but the spatial dimensions are expanded to accommodate the projected data.

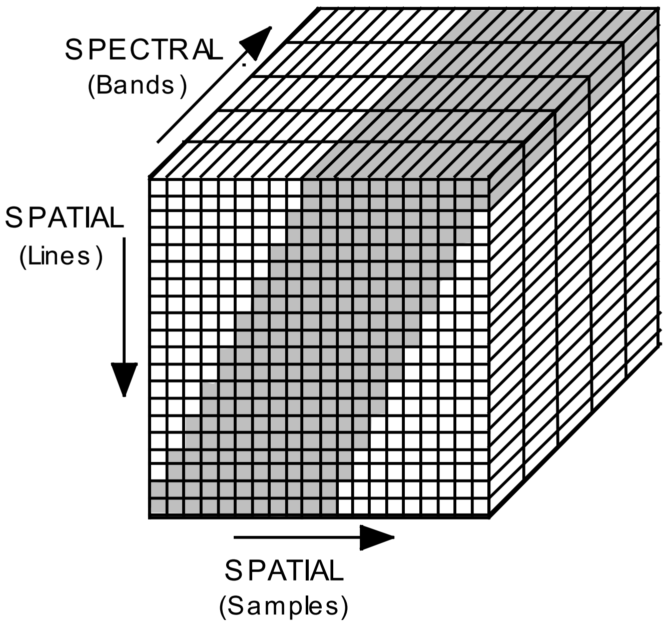

Figure 1a: ISIS CUBE core structure with projected data pixels shown in gray

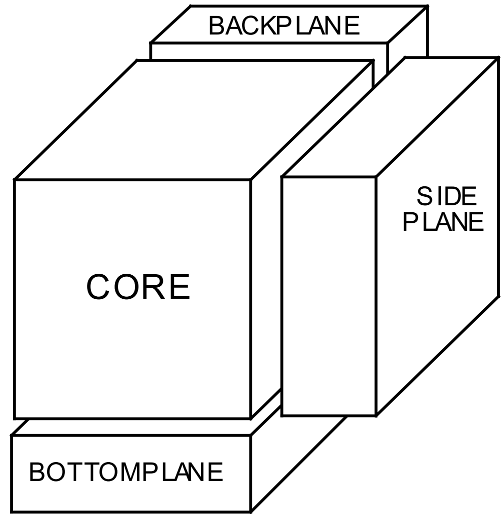

Figure 1b. Exploded view of ISIS-2 CUBE

There are two available formats for the data organization within the ISIS-3 CUBE core array: BAND_STORAGE_TYPE = BAND_SEQUENTIAL or BAND_STORAGE_TYPE = TILE. In a band sequential cube with CORE_ITEMS = (X ,Y, Z), the data from band=1 is stored in the first (X*Y*CORE_ITEM_BYTES) bytes of the CUBE core array, followed by the data from band=2, etc. In a tiled CUBE, the tile dimensions (TileSamples, TileLines) are listed in the attached CUBE label and are usually smaller than the image dimensions (CORE_ITEMS or Lines and Samples). The data from each band is stored in multiple tiles, with NULL data padding as necessary to completely fill an integer number of tiles.

The THM-GEO data is modified calibrated radiance stored as 32-bit, floating point integer values, as described in the attached ISIS-3 CUBE label, Pixels Group. Although unusual, if the data has been scaled, apply the following function to each data value per band (x_i)

$$y = m * x + b$$

where m is the Multiplier value and b is the Base value (m=1.0 and b=0.0 for unscaled data).

Missing image pixels and padding around the image data to square up the spatial dimensions are set to the standard ISIS-3 NULL value, -3.40282 e+38. The total count of missing lines in an IR-GEO image is stored in the MISSING_SCAN_LINES keyword of the detached label.

3.4.2 ISIS-3 *CUBE Label, Table, and History Objects*

The CUBE object usually includes a header Label, one or more header Table data, the Core data cube, and the trailing History (Figure 2). Each of the Label, Table, and History elements contain pertinent structure, observation, and projection information organized into Objects with one or more Groups of multiple "Keyword = Value" pairs of details. This text format is fully described *Overview of ISIS-3* [6] Label Dictionary and is similar to the PDS Object Definition Language

(ODL). One formatting difference between the ISIS-3 and PDS standards that is repeated in this document is the capitalization practice: the PDS keywords are presented in all capitals (like KEYWORD), while the ISIS-3 keywords are presented in start case capitalization (like FirstKeyword).

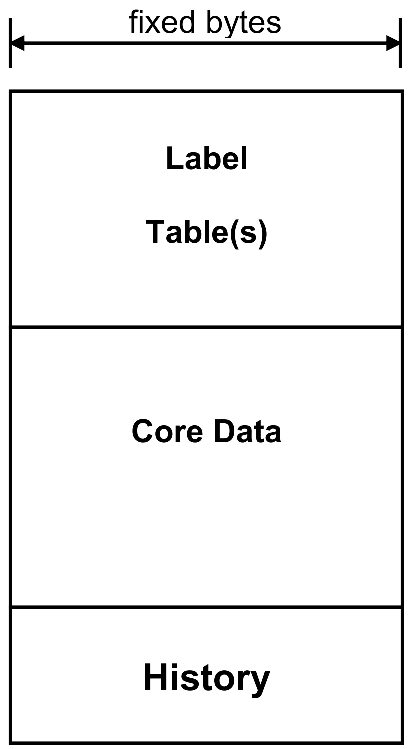

Figure 2: Example of an ISIS-3 CUBE: image data and attached ASCII elements

3.4.3 PDS Image Object

THEMIS IR-PBT and VIS-ALB make use of the PDS IMAGE object defined in the PDS Standards Reference [7]. An IMAGE is a two-dimensional array of values organized as line_samples and lines. A THEMIS IMAGE is derived from a single band of a GEO CUBE and has the same dimensions as that band. Each THEMIS IMAGE has an attached label, shown conceptually in Figure 3, containing structure details and a summary of observation information in the "keyword=value" format.

The IMAGE object label describes the size and format of the image data. THEMIS image data available in the UNSIGNED_INTEGER (2-byte) format is usually scaled before storage; those available in the PC_REAL (4-byte) format are not scaled. When scaling has been applied to the data before storage, the true values can be restored using

$$y = mx + b$$

where m is the SCALING_FACTOR value and b is the OFFSET value available in the label. If no scaling has been applied, the keywords will be available with the appropriate values: SCALING_FACTOR=1 and OFFSET=0.

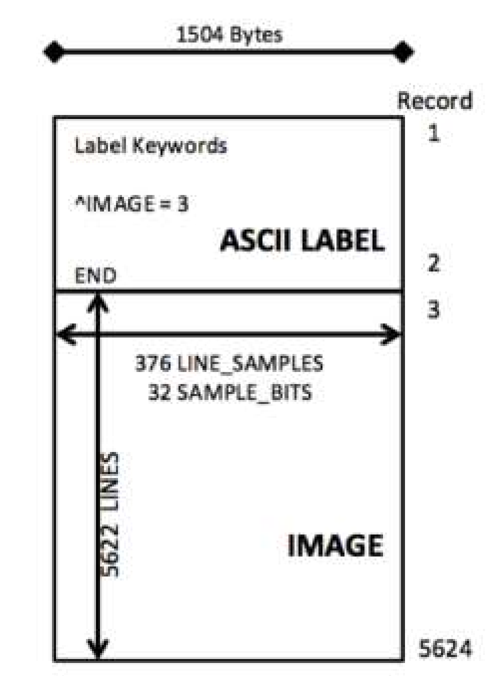

Figure 3: Example of a PDS IMAGE: attached label and image data

3.5 GEO Label Format

A PDS label describes the structure, content, and observation specifications of the data, duplicating the contents of Label and History elements embedded in the ISIS-3 cube. It is a discrete ASCII text available with each cube file. Information in the label is stored in a "keyword=value" text format and structured in the Object Definition Language (ODL) of PDS. Example GEO labels are shown in Appendices A.1 and A.3; individual keyword items are defined in Appendices A.5 and A.6.

3.5.1 File Identification and Structure Label

The first lines of the label are the "File Identification Keywords" and associated values. Next are the file structure keywords, which define the number and size of records in the associated ISIS CUBE data file. The pointer keywords define the filename and start byte of the HISTORY (in the PDS label) and the header and image data objects in the ISIS CUBE file. Finally, "Identification Data Elements" define parameters of the mission, spacecraft, instrument team, and data stream. See Appendix A.5 for a detailed description of these keywords.

3.5.2 QUBE or CUBE Object

The generalized, multidimensional data array is identified within the PDS Standards Reference [7] as a QUBE object, while the current ISIS-3 standards adopted the CUBE spelling to identify the same object. For THEMIS Projected Products, the terms QUBE and CUBE are used interchangeably, with the QUBE spelling primarily found in the detached GEO.LBL files, to maintain PDS compliance, and the CUBE spelling found in the data files themselves (GEO.cub) to maintain the ISIS-3 compliance.

In the GEO.LBL files, the QUBE object keywords are organized by the following sub-structure descriptions:

QUBE structure	- parameters of the multidimensional array (image)
CORE description	- parameters of the array elements (pixels)
Observation parameters	- operational modes of the instrument for this image
Band-bins	- parameters of the layers (bands) in the array

See Appendix A.5 for a detailed description of the keywords used in the QUBE label.

3.5.3 IMAGE MAP PROJECTION Object

The IMAGE_MAP PROJECTION object keywords summarize the critical parameters of the geographical projection applied to this THM-GEO image. The object includes a pointer to the *DATA SET MAP PROJECTION* [12] catalog object which fully describes the standards for this projection. See Appendix A.5 for a detailed description of all the keywords in this object.

3.5.4 HISTORY Object

A cumulative HISTORY object is available in each geometry label. The HISTORY object structure keywords define the size and format of the data object stored later in the label. The HISTORY object itself is a structured series of text entries identifying all previous computer manipulations of the data in the file; the format is not intended to be compliant with PDS-ODL standards. HISTORY entries may include identification of source data, processes performed, processing parameters, and dates and times of processing. See Appendix A.6 for a detailed description of the entries and keywords used with GEO.LBL HISTORY objects.

3.6 Data Product Archive

The special geometry data products will be generated and validated at the ASU Mars Space Flight Facility. The size of individual geometry products depends on several factors: image type (VIS vs. IR), length of an image, number of bands in the image, and map projection. Within these parameters, most projected images will be a factor of 1-4 larger than the source RDR. Validation will be conducted using the latest, best-effort algorithms available.

Standard data products will be archived and released following the agreement outlined in the *THEMIS Archive SIS* [2]. Starting in January 2006, the special ISIS-2 geometry data products will be released concurrent with their source THM-RDR images; geometry products for previously released THM-RDR images will be added to the archive as available. Starting July 2014, the special ISIS-3 geometry data products will be released with their concurrent source THM-RDR images. Previously released ISIS-2 geometry products will be maintained in the Odyssey THEMIS Projected Products, Version-1 (ODTGEO_v1) for archive purposes, but will be superseded by the ISIS-3 version available in the Version-2 release (ODTGEO_v2).

Due to the large volume of data products expected from the mission, physical copies will be made for PDS long-term archive purposes only. All other data distribution will be facilitated through an online THEMIS data archive service, maintained by the ASU Mars Space Flight Facility.

4. APPLICABLE SOFTWARE

The THEMIS team uses the software tools DAVINCI and ISIS to generate, display, and analyze the THM-RDR and THM-GEO images. DAVINCI is a data analysis package for working with multispectral images. DAVINCI is distributed by ASU and is available at

http://davinici.asu.edu/software .

ISIS is an image processing package produced by USGS - Flagstaff and is available at

http://isis.astrogeology.usgs.gov .

Since THEMIS images are stored and labeled using a standard and known structure, any tool that can be taught to understand that structure should be able to view them. The processing options used when generating the standard THM-GEO products were carefully chosen to satisfy the majority of users and minimize the need for adjustments to the files. If minor file format or geospatial translations are desired, the THEMIS team recommends the GDAL software, as an alternative to the more robust multispectral data tools listed above. The GDAL software is available at

http://www.gdal.org .

A. APPENDICIES

Appendices A.1-4 contain example labels from THEMIS IR-GEO, THEMIS IR-PBT, VIS-GEO, and VIS-ALB, with definitions of individual label keywords given in Appendix A.5. “Valid values” for each item are shown in [ ] at end of each description, as appropriate. Appendix A.6 contains definitions for the basic HISTORY keywords and example geometric HISTORY objects. Appendix A.7 contains geometric parameter fields available in the THEMIS indexes. Appendix A.8 describes the geometric quality assessment and associated HISTORY object.

A.1 Example Label: IR-GEO

An example IR-GEO label is shown below:

```
PDS_VERSION_ID = PDS3

/* File Identification and Structure */
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES =  512
FILE_RECORDS =  8922

/* Pointers to Data Objects */
^HISTORY = 3480 <BYTES>
^HEADER = ("I31099044SNU.CUB")
^QUBE = ("I31099044SNU.CUB", 67 )

/* Identification Data Elements */
MISSION_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_HOST_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_NAME = "THERMAL EMISSION IMAGING SYSTEM"
INSTRUMENT_ID = "THEMIS"
DETECTOR_ID = "IR"
MISSION_PHASE_NAME = "EXTENDED-3"
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0, 0, 0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = "I31099044SNU"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-IRGEO-V2.0"
PRODUCT_CREATION_TIME = 2014-07-25T17:41:41
PRODUCT_VERSION_ID = "2.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0028"
START_TIME = 2008-12-18T00:44:50.791
STOP_TIME = 2008-12-18T00:44:59.858
SPACECRAFT_CLOCK_START_COUNT = "914028697.153"
```

```
SPACECRAFT_CLOCK_STOP_COUNT = "914028706.170"
START_TIME_ET = 282833156.000
STOP_TIME_ET = 282833165.000
SCLKERNEL = "ORB1_SCLKSCET.00277.tsc"
ORBIT_NUMBER = 31099

/* History Object Structure */
OBJECT = HISTORY
   BYTES = 7615
   HISTORY_TYPE = CUSTOM
   INTERCHANGE_FORMAT = ASCII
END_OBJECT = HISTORY

OBJECT = QUBE

   /* QUBE Structure */
   AXES = 3
   AXIS_NAME = (SAMPLE, LINE, BAND)
   BAND_STORAGE_TYPE = BAND_SEQUENTIAL

   /* Core Description */
   CORE_ITEMS =  (352,321,10)
   CORE_NAME = "CALIBRATED_SPECTRAL_RADIANCE"
   CORE_ITEM_BYTES =  4
   CORE_ITEM_TYPE = PC_REAL
   CORE_BASE = 0.0
   CORE_MULTIPLIER = 1.0
   CORE_UNIT = "WATT*CM**-2*SR**-1*UM**-1"
   CORE_NULL = -3.40282e+38
   CORE_VALID_MINIMUM = -32752
   CORE_LOW_REPR_SATURATION = -32767
   CORE_LOW_INSTR_SATURATION = -32766
   CORE_HIGH_REPR_SATURATION = -32765
   CORE_HIGH_INSTR_SATURATION = -32764

   /* Observation Parameters */
   FLIGHT_SOFTWARE_VERSION_ID = "1.00"
   COMMAND_SEQUENCE_NUMBER = 31099
   IMAGE_ID = 44
   DESCRIPTION = "35 deg day atmos"
   INST_CMPRS_RATIO = 2.72
   UNCORRECTED_SCLK_START_COUNT = "914028697.153"
   IMAGE_DURATION = 9.067
   GAIN_NUMBER = 16
   OFFSET_NUMBER = 2
   TIME_DELAY_INTEGRATION_FLAG = "ENABLED"
```

```
   RICE_FLAG = "ENABLED"
   SPATIAL_SUMMING = 1
   PARTIAL_SUM_LINES = "N/A"
   MISSING_SCAN_LINES = 0
   MD5_CHECKSUM = "ed9c27074865056d8d5f1edcfb2737a8"

   /* Band Bins */
   GROUP = BAND_BIN
      BAND_BIN_FILTER_NUMBER = (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
      BAND_BIN_BAND_NUMBER = (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
      BAND_BIN_CENTER = (6.78, 6.78, 7.93, 8.56, 9.35, 10.21, 11.04,
                  11.79, 12.57, 14.88)
      BAND_BIN_WIDTH = (1.01, 1.01, 1.09, 1.16, 1.20, 1.10, 1.19,
                  1.07, 0.81, 0.87)
      BAND_BIN_UNIT = "MICROMETER"
   END_GROUP = BAND_BIN
END_OBJECT = QUBE

OBJECT = IMAGE_MAP_PROJECTION
   ^DATA_SET_MAP_PROJECTION = “DSMAP_EQR.CAT”
   GEOMETRY_SOURCE_DESC = “RECONSTRUCTED”
   COORDINATE_SYSTEM_TYPE = “BODY-FIXED ROTATING”
   COORDINATE_SYSTEM_NAME = “PLANETOCENTRIC”
   MAP_PROJECTION_TYPE = “SINUSOIDAL”
   MAP_PROJECTION_ROTATION = 0
   MAP_LONGITUDE_SYSTEM = 360
   A_AXIS_RADIUS = 3396190.000
   B_AXIS_RADIUS = 3396190.000
   C_AXIS_RADIUS = 3396190.000
   FIRST_STANDARD_PARALLEL = “N/A”
   SECOND_STANDARD_PARALLEL = “N/A”
   POSITIVE_LONGITUDE_DIRECTION = “EAST”
   REFERENCE_LATITUDE = “N/A”
   REFERENCE_LONGITUDE = “N/A”
   CENTER_LATITUDE = 34.505
   CENTER_LONGITUDE = 50.000
   MINIMUM_LATITUDE = = 34.310
   MAXIMUM_LATITUDE = = 34.815
   WESTERNMOST_LONGITUDE = 50.291
   EASTERNMOST_LONGITUDE = 51.074
   MAP_SCALE = 0.100
   MAP_RESOLUTION = 592.74
   SAMPLE_PROJECTION_OFFSET = 141.500
   LINE_PROJECTION_OFFSET = -20636.500
   SAMPLE_FIRST_PIXEL = 1
   LINE_FIRST_PIXEL = 1
```

```
    SAMPLE_LAST_PIXEL = 352
    LINE_LAST_PIXEL = 321
END_OBJECT = IMAGE_MAP_PROJECTION
END
```

A.2 Example Label: IR-PBT

An example IR-PBT label is shown below:

```
PDS_VERSION_ID = PDS3
FILE_NAME = "I65600003PBT.IMG"
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES = 1504
FILE_RECORDS = 5624
LABEL_RECORDS = 2
^IMAGE = 3

MISSION_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_HOST_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_NAME = "THERMAL EMISSION IMAGING SYSTEM"
INSTRUMENT_ID = "THEMIS"
DETECTOR_ID = "IR"
MISSION_PHASE_NAME = "EXTENDED-6"
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0,0,0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = " I65600003PBT"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-IRPBT-V2.0"
PRODUCT_CREATION_TIME = 2017-05-12T00:39:06
PRODUCT_VERSION_ID = "2.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0060"
START_TIME = 2016-09-27T08:23:49.031
STOP_TIME = 2016-09-27T08:26:48.762
SPACECRAFT_CLOCK_START_COUNT = "1159432444.02"
SPACECRAFT_CLOCK_STOP_COUNT = "1159432623.212"
START_TIME_ET = 528236697.2
STOP_TIME_ET = 528236876.9
UNCORRECTED_SCLK_START_COUNT = "1159432444.025"
IMAGE_DURATION = 179.733
SCLKERNEL = “ORB1_SCLKSCET.00277.tsc”
ORBIT_NUMBER = 65600

ODY:ASU_PROCESSES = “UDDW; ISIS3-PROJECT”
ODY:ISIS_VERSION = "3.4.9.6114"

ODY:SPICEINIT_VERSION = "2014-04-27"
ODY:CAM2MAP_VERSION = "2013-07-11"
```

```
OBJECT = IMAGE_MAP_PROJECTION
   ^DATA_SET_MAP_PROJECTION = "DSMAP_POL.CAT"
   GEOMETRY_SOURCE_DESC = "Reconstructed"
   COORDINATE_SYSTEM_TYPE = "BODY-FIXED ROTATING"
   COORDINATE_SYSTEM_NAME = "PLANETOCENTRIC"
   MAP_PROJECTION_TYPE = "POLAR_STEREOGRAPHIC"
   MAP_PROJECTION_ROTATION = 0
   MAP_LONGITUDE_SYSTEM = 360
   A_AXIS_RADIUS = 3396.190
   B_AXIS_RADIUS = "N/A"
   C_AXIS_RADIUS = 3376.2
   FIRST_STANDARD_PARALLEL = "N/A"
   SECOND_STANDARD_PARALLEL = "N/A"
   POSITIVE_LONGITUDE_DIRECTION = "EAST"
   REFERENCE_LATITUDE = "N/A"
   REFERENCE_LONGITUDE = "N/A"
   CENTER_LATITUDE = -90.000
   CENTER_LONGITUDE = 319.281
   MINIMUM_LATITUDE = -75.983
   MAXIMUM_LATITUDE = -66.788
   WESTERNMOST_LONGITUDE = 146.528
   EASTERNMOST_LONGITUDE = 153.933
   MAP_SCALE = 0.100
   MAP_RESOLUTION = 589.258
   SAMPLE_PROJECTION_OFFSET = 2120.500
   LINE_PROJECTION_OFFSET = -8093.500
   SAMPLE_FIRST_PIXEL = 1
   LINE_FIRST_PIXEL = 1
   SAMPLE_LAST_PIXEL = 376
   LINE_LAST_PIXEL = 5622
END_OBJECT = IMAGE_MAP_PROJECTION

INCIDENCE_ANGLE = 63.464
EMISSION_ANGLE = 1.714
LOCAL_TIME = 7.766
SOLAR_LONGITUDE = 230.784

MINIMUM_BRIGHTNESS_TEMPERATURE = 139.270
MAXIMUM_BRIGHTNESS_TEMPERATURE = 227.467

BAND_NUMBER = 9
BAND_CENTER = 12.57 <MICROMETERS>
SPATIAL_SUMMING = 1

OBJECT = IMAGE
   LINES = 5622
```

```
   LINE_SAMPLES = 376
   SAMPLE_TYPE = PC_REAL
   SAMPLE_BITS = 32
   ODY:SAMPLE_NAME = "BRIGHTNESS_TEMPERATURE"
   ODY:SAMPLE_UNIT = "KELVIN"
   NULL_CONSTANT = 0
   OFFSET = 0
   SCALING_FACTOR = 1
   MD5_CHECKSUM = "d7c30bd6352e3ec38296459de648b743"
END_OBJECT = IMAGE
END
```

A.3 Example Label: VIS-GEO

An example VIS-GEO label is shown below:

```
PDS_VERSION_ID = PDS3

/* File Identification and Structure */
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES =  512
FILE_RECORDS =  17934

/* Pointers to Data Objects */
^HISTORY = 4131 <BYTES>
^HEADER = ("V01001004SNU.CUB")
^QUBE = ("V01001004SNU.CUB", 59 )

/* Identification Data Elements */
MISSION_NAME = “2001 MARS ODYSSEY”
INSTRUMENT_HOST_NAME  = “2001 MARS ODYSSEY”
INSTRUMENT_NAME  = “THERMAL EMISSION IMAGING SYSTEM”
INSTRUMENT_ID  = “THEMIS”
DETECTOR_ID = “VIS”
MISSION_PHASE_NAME = “MAPPING”
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0, 0, 0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = “MARS”
PRODUCT_ID = “V01001004SNU”
DATA_SET_ID = "ODY-M-THM-5-VISGEO-V2.0"
PRODUCT_CREATION_TIME =  2014-12-07T13:28:26
PRODUCT_VERSION_ID = "2.0"
SOURCE_PRODUCT_VERSION_ID = "1.5"
RELEASE_ID = "0011"
START_TIME = 2002-03-06T22:46:31.259
STOP_TIME = 2002-03-06T22:46:50.259
SPACECRAFT_CLOCK_START_COUNT = "699922043.000"
SPACECRAFT_CLOCK_STOP_COUNT = "699922062.000"
START_TIME_ET = 68726855.445
STOP_TIME_ET = 68726874.444
SCLKERNEL = “ORB1_SCLKSCET.00277.tsc”
ORBIT_NUMBER = 01001

/* History Object Structure */
OBJECT = HISTORY
   BYTES = 5126
   HISTORY_TYPE = CUSTOM
```

```
    INTERCHANGE_FORMAT = ASCII
END_OBJECT = HISTORY

OBJECT = QUBE
    /* QUBE Structure */
    AXES = 3
    AXIS_NAME = (SAMPLE, LINE, BAND)

    /* Core Description */
    CORE_ITEMS =  (1415,3234,1)
    CORE_NAME = "CALIBRATED_SPECTRAL_RADIANCE"
    CORE_ITEM_BYTES = 2
    CORE_ITEM_TYPE = LSB_INTEGER
    CORE_BASE = 4.302270e-03
    CORE_MULTIPLIER = 3.629682e-08
    CORE_UNIT = "WATT*CM**-2*SR**-1*UM**-1"
    CORE_NULL = -32768
    CORE_VALID_MINIMUM = -32752
    CORE_LOW_INSTR_SATURATION = -32766
    CORE_LOW_REPR_SATURATION = -32767
    CORE_HIGH_INSTR_SATURATION = -32765
    CORE_HIGH_REPR_SATURATION = -32764

    /* Observation Parameters */
    FLIGHT_SOFTWARE_VERSION_ID = “1.00”
    COMMAND_SEQUENCE_NUMBER = 1001
    IMAGE_ID = 4
    DESCRIPTION = “Example VIS image”
    INST_CMPRS_RATIO = 1.96
    UNCORRECTED_START_SCLK_COUNT = “699922045.000”
    IMAGE_DURATION = 19.000
    INST_CMPRS_NAME = “PREDICTIVE”
    FOCAL_PLANE_TEMPERATURE = 1.05
    EXPOSURE_DURATION = 4.000
    INTERFRAME_DELAY = 1.000
    SPATIAL_SUMMING = 1
    MD5_CHECKSUM = “5d0ee743130781de5fbd73d5a7cb98ef”

    /*Band Bins */
    GROUP = BAND_BIN
        BAND_BIN_FILTER_NUMBER = (2, 5, 3, 4, 1)
        BAND_BIN_ BAND_NUMBER = (1, 2, 3, 4, 5)
        BAND_BIN_CENTER = (0.425, 0.540, 0.654, 0.749, 0.860)
        BAND_BIN_WIDTH = ( 0.049, 0.051, 0.053, 0.053, 0.045 )
        BAND_BIN_UNIT = “MICROMETER”
    END_GROUP = BAND_BIN
```

```
END_OBJECT = QUBE

OBJECT = IMAGE_MAP_PROJECTION
   ^DATA_SET_MAP_PROJECTION =  “DSMAP_EQR.CAT”
   GEOMETRY_SOURCE_DESC = “RECONSTRUCTED”
   COORDINATE_SYSTEM_TYPE = “BODY-FIXED ROTATING”
   COORDINATE_SYSTEM_NAME = “PLANETOCENTRIC”
   MAP_PROJECTION_TYPE = “SINUSOIDAL”
   MAP_PROJECTION_ROTATION = 0
   MAP_LONGITUDE_SYSTEM = 360
   A_AXIS_RADIUS = 3396190.000
   B_AXIS_RADIUS = 3396190.000
   C_AXIS_RADIUS = 3396190.000
   FIRST_STANDARD_PARALLEL = “N/A”
   SECOND_STANDARD_PARALLEL = “N/A”
   POSITIVE_LONGITUDE_DIRECTION = “EAST”
   REFERENCE_LATITUDE = “N/A”
   REFERENCE_LONGITUDE = “N/A”
   CENTER_LATITUDE = -8.085
   CENTER_LONGITUDE = 315.000
   MINIMUM_LATITUDE = -9.076
   MAXIMUM_LATITUDE = -8.095
   WESTERNMOST_LONGITUDE = 315.284
   EASTERNMOST_LONGITUDE = 315.714
   MAP_SCALE = 0.018
   MAP_RESOLUTION = 3289.55
   SAMPLE_PROJECTION_OFFSET = 924.500
   LINE_PROJECTION_OFFSET = 26657.500
   SAMPLE_FIRST_PIXEL = 1
   LINE_FIRST_PIXEL = 1
   SAMPLE_LAST_PIXEL = 1415
   LINE_LAST_PIXEL = 3234
END_OBJECT = IMAGE_MAP_PROJECTION
END
```

A.4 Example Label: VIS-ALB

An example VIS-ALB label is shown below:

```
PDS_VERSION_ID = PDS3
FILE_NAME = "V65600004ALB.IMG"
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES = 1232
FILE_RECORDS = 5570
LABEL_RECORDS = 3
^IMAGE = 4

MISSION_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_HOST_NAME = "2001 MARS ODYSSEY"
INSTRUMENT_NAME = "THERMAL EMISSION IMAGING SYSTEM"
INSTRUMENT_ID = "THEMIS"
DETECTOR_ID = "VIS"
MISSION_PHASE_NAME = "EXTENDED-6"
SPACECRAFT_ORIENTATION_DESC = (PITCH, ROLL, YAW)
SPACECRAFT_ORIENTATION = (0,0,0)
SPACECRAFT_POINTING_MODE = "NADIR"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = " V65600004ALB"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-VISALB-V2.0"
PRODUCT_CREATION_TIME = 2017-05-24T21:06:53
PRODUCT_VERSION_ID = "2.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0060"
START_TIME = 2016-09-27T08:24:14.730
STOP_TIME = 2016-09-27T08:26:23.535
SPACECRAFT_CLOCK_START_COUNT = "1159432469.204"
SPACECRAFT_CLOCK_STOP_COUNT = "1159432598.154"
START_TIME_ET = 528236722.9
STOP_TIME_ET = 528236851.7
UNCORRECTED_SCLK_START_COUNT = "1159432470.153"
IMAGE_DURATION = 128.800
SCLKERNEL = “ORB1_SCLKSCET.00277.tsc”
ORBIT_NUMBER = 65600

ODY:ISIS_VERSION = "3.4.9.6114"
ODY:SPICEINIT_VERSION = "2014-04-27"
ODY:CAM2MAP_VERSION = "2013-07-11"

OBJECT = IMAGE_MAP_PROJECTION
   ^DATA_SET_MAP_PROJECTION = "DSMAP_POL.CAT"
   GEOMETRY_SOURCE_DESC = "Reconstructed"
```

```
    COORDINATE_SYSTEM_TYPE = "BODY-FIXED ROTATING"
    COORDINATE_SYSTEM_NAME = "PLANETOCENTRIC"
    MAP_PROJECTION_TYPE = "POLAR_STEREOGRAPHIC"
    MAP_PROJECTION_ROTATION = 0
    MAP_LONGITUDE_SYSTEM = 360
    A_AXIS_RADIUS = 3396.190
    B_AXIS_RADIUS = "N/A"
    C_AXIS_RADIUS = 3376.2
    FIRST_STANDARD_PARALLEL = "N/A"
    SECOND_STANDARD_PARALLEL = "N/A"
    POSITIVE_LONGITUDE_DIRECTION = "EAST"
    REFERENCE_LATITUDE = "N/A"
    REFERENCE_LONGITUDE = "N/A"
    CENTER_LATITUDE = -90.000
    CENTER_LONGITUDE = 319.296
    MINIMUM_LATITUDE = -74.820
    MAXIMUM_LATITUDE = -68.265
    WESTERNMOST_LONGITUDE = 147.430
    EASTERNMOST_LONGITUDE = 152.397
    MAP_SCALE = 0.072
    MAP_RESOLUTION = 818.414
    SAMPLE_PROJECTION_OFFSET = 2847.500
    LINE_PROJECTION_OFFSET = -12219.500
    SAMPLE_FIRST_PIXEL = 1
    LINE_FIRST_PIXEL = 1
    SAMPLE_LAST_PIXEL = 308
    LINE_LAST_PIXEL = 5567
END_OBJECT = IMAGE_MAP_PROJECTION

INCIDENCE_ANGLE = 63.490
EMISSION_ANGLE = 0.766
LOCAL_TIME = 7.768
SOLAR_LONGITUDE = 230.784
SOLAR_DISTANCE = 1.389 <AU>
ODY:MINIMUM_ALBEDO = 0.003
ODY:MAXIMUM_ALBEDO = 0.663
ODY:AVERAGE_ALBEDO = 0.436
ODY:TES_ALBEDO_MINIMUM = 0.115
ODY:TES_ALBEDO_MAXIMUM = 0.228
ODY:TES_ALBEDO_AVERAGE = 0.179
ODY:TES_ALBEDO_SIGMA = 0.016

BAND_NUMBER = 3
BAND_CENTER = 0.654 <MICROMETERS>
EXPOSURE_DURATION = 2.000 <MSEC>
INTERFRAME_DELAY = 0.800 <SEC>
```

```
SPATIAL_SUMMING = 4

OBJECT = IMAGE
   LINES = 5567
   LINE_SAMPLES = 308
   SAMPLE_TYPE = PC_REAL
   SAMPLE_BITS = 32
   ODY:SAMPLE_NAME = "LAMBERT_ALBEDO"
   ODY:SAMPLE_UNIT = “DIMENSIONLESS”
   NULL_CONSTANT = 0
   OFFSET = 0
   SCALING_FACTOR = 1
   MD5_CHECKSUM = "18e2d1cde40e75871fdbd5f685ecb3b6"
END_OBJECT = IMAGE

END
```

A.5 Label Keyword Descriptions

FILE AND DATA IDENTIFICATION ELEMENTS

PDS_VERSION_ID
PDS version number for the label format. [PDS3]

RECORD_TYPE
Style of records in this label file. [“FIXED_LENGTH”]

RECORD_BYTES
Number of bytes per record in ISIS CUBE file.

FILE_RECORDS
Number of records in ISIS CUBE file, including labels and data.

Pointer to HISTORY
Start byte location of HISTORY object in this detached THM-GEO label; units given in < >.

Pointer to HEADER
Filename and start byte location of the ISIS CUBE label object; byte =1 is implied if no byte location is given.

Pointer to IMAGE
Start byte location of the image data object.

Pointer to QUBE
Filename and start byte location of the ISIS CUBE data object.

MISSION_NAME
Name of the mission including the THEMIS instrument. [“2001 MARS ODYSSEY”]

INSTRUMENT_HOST_NAME
Name of the host spacecraft for the THEMIS instrument. [“2001 MARS ODYSSEY”]

INSTRUMENT_NAME
Proper name of the instrument. [“THERMAL EMISSION IMAGING SYSTEM”]

INSTRUMENT_ID
Abbreviated name of instrument used to collect this image. [“THEMIS”]

DETECTOR_ID
Abbreviated name of camera used to collect this image. [“IR” or “VIS”]

MISSION_PHASE_NAME
Mission phase during which this image was collected. [“MAPPING”, “EXTENDED-1”]

SPACECRAFT_ORIENTATION_DESC
Description of rotation axis corresponding to values of SPACECRAFT_ORIENTATION keyword. [(PITCH,ROLL,YAW)]

SPACECRAFT_ORIENTATION
Odyssey orientation during which this image was collected; described as a angle (in degrees) of rotation away from nadir around the three axes spacecraft frame of reference; see given in SPACECRAFT_POINTING_MODE_DESC value for more information. [(#,#,#)]

SPACECRAFT_POINTING_MODE
Description of the Odyssey pointing mode during which this image was collected; see text given in SPACECRAFT_POINTING_MODE_DESC value for definitions of valid modes.

Pointer to SPACECRAFT_POINTING_MODE_DESC
Text file describing valid Odyssey orientation values and pointing modes; text file is in the DOCUMENT directory. [“ODY_ORIENT_POINT.TXT”]

TARGET_NAME
The name of the target observed in the image. [“MARS”]

PRODUCT_ID
Unique identifier for this THM-GEO image. [“Aooooonnnggg”]

PRODUCER_ID
Identity of the producer of this dataset. [“ODY_THM_TEAM”]

DATA_SET_ID
Unique alphanumeric identifier of this dataset. [“ODY-M-THM-5-IRGEO-V2.0”, “ODY-M-THM-5-VISGEO-V2.0”, “ODY-M-THM-5-IRPBT-V2.0”, “ODY-M-THM-5-VISALB-V2.0”]

PRODUCT_CREATION_TIME
Time of creation of this QUBE on the ground (in UTC). [yyyy-mm-ddThh:mm:ss]

PRODUCT_VERSION_ID
Version identification of this THEMIS image product.

SOURCE_PRODUCT_VERSION_ID
Version identification of the THM-RDR QUBE from which this product was derived.

RELEASE_ID
Identification of the original public release of this THEMIS image product.

START_TIME
The time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of STOP_TIME minus START_TIME may not be equivalent to IMAGE_DURATION. Value given in spacecraft event time (SCET), UTC format. [yyyy-mm-ddThh:mm:ss.fff]

STOP_TIME
The time of the end of data acquisition calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION; given in spacecraft event time (SCET), UTC format. [yyyy-mm-ddThh:mm:ss.fff]

SPACECRAFT_CLOCK_START_COUNT
The value of the spacecraft clock at the time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of

SPACECRAFT_CLOCK_STOP_COUNT minus SPACECRAFT_CLOCK _START_COUNT may not be equivalent to IMAGE_DURATION. Value given in seconds.

SPACECRAFT_CLOCK_STOP_COUNT
: The time on the spacecraft clock at the end of data acquisition (in seconds) calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION.

START_TIME_ET
: The time of data acquisition of the leading edge of the detector array (filter 1), even if filter 1 is not downlinked; the difference of STOP_TIME_ET minus START_TIME_ET may not be equivalent to IMAGE_DURATION. Value given in spacecraft event time (SCET), ET format.

STOP_TIME_ET
: The time of the end of data acquisition calculated from the sum of the UNCORRECTED_SCLK_START_COUNT and IMAGE_DURATION; given in spacecraft event time (SCET), ET format.

SCLKERNEL
: The filename of the SPICE SCL-Kernel used when the EDR is created to translate between the fixed spacecraft clock (SCLK) and spacecraft ephemeris time (SCET) time systems. Both observation time values are propagated forward (not recalculated) during each successive processing step. [“ORB1_SCLKSCET.00###.tsc”]

ORBIT_NUMBER
: Spacecraft orbit during which this image was observed.

HISTORY STRUCTURE

See Appendix A.5

QUBE STRUCTURE & CORE DESCRIPTION

AXES
: Number of dimensions (axes) of the QUBE. [3]

AXIS_NAME
: Names of axes in physical storage order. [(SAMPLE, LINE, BAND)]

BAND_STORAGE_TYPE
: The storage sequence of lines, samples, and bands in the projected cube; the tile line and sample dimensions are available in the label attached to the ISIS-3 cube. [BAND_SEQUENTIAL, TILE]

CORE_ITEMS
: The length of each of the three axes of the core in pixels.

CORE_NAME
: Name of the data value stored in core of ISIS CUBE. [“CALIBRATED_SPECTRAL_RADIANCE”]

CORE_ITEM_BYTES
: Core element size in bytes. [2]

CORE_ITEM_TYPE
Core element type. [PC_REAL]

CORE_BASE
The offset value of the stored data; the CORE_BASE value is added to the scaled data (see CORE_MULTIPLIER) to reproduce the true data.

CORE_MULTIPLIER
The constant value by which the stored data is multiplied to produce the scaled data; the CORE_BASE value is added to the scaled data to reproduce the true data.

CORE_UNIT
Unit of the value stored in the core of QUBE. [“WATT*CM**-2*SR**-1*UM**-1”]

CORE_NULL
Value assigned to missing data and padding of projected image.

CORE_VALID_MINIMUM
Value of the minimum valid core data in an RDR QUBE.

CORE_LOW_REPR_SATURATION
Value of representation saturation at the low end in an RDR QUBE.

CORE_LOW_INSTR_SATURATION
Value of instrument saturation at the low end in an RDR QUBE.

CORE_HIGH_REPR_SATURATION
Value of representation saturation at the high end in an RDR QUBE.

CORE_HIGH_INSTR_SATURATION
Value of instrument saturation at the high end in an RDR QUBE.

OBSERVATION PARAMETERS

FLIGHT_SOFTWARE_VERSION_ID
Indicates version of instrument flight software used to acquire image. [“1.00”]

COMMAND_SEQUENCE_NUMBER
Numeric identifier for the sequence of commands sent to the spacecraft which include this image.

IMAGE_ID
Numeric identifier for this image within the onboard command sequence.

DESCRIPTION
Description of image written by mission planner.

INST_CMPRS_RATIO
The ratio of the size, in bytes, of the uncompressed data file to the compressed data file.

UNCORRECTED_SCLK_START_COUNT
The spacecraft clock value (in seconds) when the instrument was commanded to acquire an observation. This can differ from the SPACECRAFT_CLOCK_START_COUNT (or the other START_TIME keywords) by as much as 4 seconds, depending on which bands are acquired in the image.

IMAGE_DURATION
The length of time (in seconds) required to collect all frames of all bands in the downlinked image.

INST_CMPRS_NAME
The type of compression applied to the VIS data and removed before storage in the image QUBE. [“NONE” or “DCT” or “PREDICTIVE”]

FOCAL_PLANE TEMPERATURE
Temperature in Kelvin of the VIS camera focal plane array at the time of the observation.

EXPOSURE_DURATION
The length of time the VIS detector array is exposed per frame in an image; given in milliseconds.

INTERFRAME_DELAY
The time between successive frames of a VIS image; given in seconds.

SPATIAL_SUMMING
Onboard spatial average of NxN set of pixels, where N is the value of the keyword. SPATIAL_SUMMING = 1 implies that no spatial averaging has been applied to the image. [VIS: 1 or 2 or 4; IR: 1 through 320]

PARTIAL_SUM_LINES
The number of lines in a summed IR image which were produced by averaging less than N lines of the original non-summed image, where N is the value of the SPATIAL_SUMMING keyword. [“N/A” for spatial_summing=1 or integer for spatial_summing > 1]

MISSING_SCAN_LINES
The total number of scan lines missing from an IR image when it was received at Earth.

GAIN_NUMBER
The gain value of the THEMIS IR camera; a multiplicative factor used in the analog to digital conversion.

OFFSET_NUMBER
The offset value of the THEMIS IR camera; the offset value multiplied by a constant voltage is added to the measured voltage in the analog to digital conversion.

TIME_DELAY_INTEGRATION_FLAG
Status of onboard algorithm which applies a temporal average of successive lines in an IR image; when enabled, THEMIS TDI averages 16 detector rows to equal one line in an IR image. [“ENABLED” or “DISABLED”]

MISSING_SCAN_LINES
The total number of scan lines missing from an IR image when it was received at Earth.

MD5_CHECKSUM
A 128-bit checksum identification of the entire ISIS-3 CUBE file (this differs from the usage in other THEMIS products). Corruption of the file will result in a different value when the MD5 algorithm is reapplied as compared to the value stored in the keyword. An example of the source code applied by ASU is available in SRC/BIN/md5_qube.pl. A

complete definition of the MD5 algorithm is available at http://www.ietf.org/rfc/rfc1321.txt . ["fd2781d05bdc0215dc87a0f41035ad77"]

BAND-BINS or BAND INFORMATION

BAND_NUMBER
Identifies from which band in the source RDR this image was derived; see Table 1, Section 2.2 of this document (THM-SDPSIS). Note that CUBs generated using ISIS-3.4.8 or higher, may include the keyword BandNumber whose value is equivalent to the BAND_BIN_BAND_NUMBER from the source RDR.

BAND_BIN_FILTER_NUMBER
List of filter numbers corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images. The filter number describes the physical location of the band in the detector array; filter 1 is on the leading edge of the detector array.

BAND_BIN _BAND_NUMBER
List of band numbers corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images. The band number is equivalent to the instrument band number listed in Table 1, Section 2.2 of this document (THM-SDPSIS). Note that the default value of the ISIS-3 keyword OriginalBand has been reset to match the value of this keyword.

BAND_CENTER
The wavelength value of the band contained in the image; units are given in < > with the value.

BAND_BIN_CENTER
List of wavelength values corresponding to each layer (band) contained in the image; up to 10 entries possible for IR images and up to 5 entries possible for VIS images.

BAND_BIN_WIDTH
Calculated full width, half maximum (in micrometers) for each band listed in the BAND_BIN_ BAND_NUMBER.

BAND_BIN_UNIT
Unit which applies to the values of the BAND_BIN_CENTER keyword. ["MICROMETER"]

IMAGE MAP PROJECTION PARAMETERS

Pointer to DATA_SET_MAP_PROJECTION
Text file describing valid standards of the projection used; text file is in the CATALOG directory. ["DSMAP_???.TXT"]

GEOMETRY_SOURCE_DESC
Description of the geometry kernels used by the ISIS software when generating geometric information for this image. ["Not Available", "Predicted", "Reconstructed", "Nadir pointing assumed", or "Off Nadir pointing assumed"]

COORDINATE_SYSTEM_TYPE

Defines the coordinate system used with this projection; the body-fixe rotating system is standard for planets and satellites. [BODY-FIXED ROTATING]

COORDINATE_SYSTEM_NAME

The coordinate system to which the state vectors are referenced. The planetocentric system has an origin at the center of mass of the planet; latitude angles are measured between a vector connecting a point of interest to this origin and the equatorial plane [“PLANETOCENTRIC”].

MAP_PROJECTION_TYPE

The type of projection characteristic of this image [“SINUSOIDAL”, “EQUIRECTANGULAR”, “POLAR_STEREOGRAPHIC”]

MAP_PROJECTION_ROTATION

The clockwise rotation, in degrees, of the line and sample coordinates with respect to the map projection origin. [0]

MAP_LONGITUDE_SYSTEM

Longitude system standards in place during the projection of this image, where a value of 180 indicates that longitude is measured from 0 to +180 east of the meridian and 0 to -180 west of the meridian; a value of 360 indicates that longitude is measured from 0 to 360 degrees from the meridian in the positive longitude direction.

A_AXIS_RADIUS

The semi-major axis of the ellipsoid that defines the approximate shape of the Mars planet; given in kilometers. [3396.1900]

B_AXIS_RADIUS

The intermediate axis of the ellipsoid that defines the approximate shape of the Mars planet; given in kilometers. [3396.1900]

C_AXIS_RADIUS

The semi-minor axis of the ellipsoid that defines the approximate shape of the Mars planet; given in kilometers. [3396.1900]

FIRST_STANDARD_PARALLEL

Used in conic projections. [N/A]

SECOND_STANDARD_PARALLEL

Used in conic projections. [N/A]

POSITIVE_LONGITUDE_DIRECTION

The direction of positive longitude for this projected image. [“EAST”]

REFERENCE_LATITUDE

The zero latitude in a rotated spherical coordinate system. [N/A]

REFERENCE_LONGITUDE

The zero longitude in a rotated spherical coordinate system. [N/A]

CENTER_LATITUDE

The reference latitude of the map projection for this image; the map_scale is defined at this location.

CENTER_LONGITUDE
The reference longitude of the map projection for this image; the map_scale is defined at this location.

MINIMUM_LATITUDE
The northernmost latitude on the planet Mars of the image; includes any NULL padding in the image.

MAXIMUM_LATITUDE
The southernmost latitude on the planet Mars of the image; includes any NULL padding in the image.

WESTERNMOST_LONGITUDE
The longitude on the planet Mars at the image western edge; includes any NULL padding in the image.

EASTERNMOST_LONGITUDE
The longitude on the planet Mars at the image eastern edge; includes any NULL padding in the image.

MAP_SCALE
The scale of the image is the ratio of the actual distance between two points on the Martian surface and corresponding points in the projected image; given in kilometers per pixel. Note: this is the ISIS-3 keyword *PixelResolution*.

MAP_RESOLUTION
The resolution of the image is similar to the scale of the image, expressed in different units; resolution is given in pixels per degree. Note: this is the ISIS-3 keyword *Scale.*

SAMPLE_PROJECTION_OFFSET
The sample offset value between the map projection origin and the upper left corner of the image.

LINE_PROJECTION_OFFSET
The line offset value between the map projection origin and the upper left corner of the image.

SAMPLE_FIRST_PIXEL
The sample index for the first pixel that was physically recorded at the beginning of the image. [1]

LINE_FIRST_PIXEL
The line index for the first pixel that was physically recorded at the beginning of the image. [1]

SAMPLE_LAST_PIXEL
The sample index for the last pixel that was physically recorded at the end of the image. [#]

LINE_LAST_PIXEL
The line index for the last pixel that was physically recorded at the end of the image. [#]

IMAGE STRUCTURE & GEOMETRIC PARAMTERS (IMAGEs only)

ODY:ASU_PROCESSES
: Simple list identifying the ASU processes that have been applied to this image; see Section 2 for a complete description of the listed processes.

ODY:ISIS_VERSION
: Version of ISIS software used during the projection of this image [“(3.#.#)”].

ODY:SPICEINIT_VERSION
: Version of ISIS software algorithm SPICEINIT used during the projection of this image [“yyyy-mm-dd”].

ODY:CAM2MAP_VERSION
: Version of ISIS software algorithm CAM2MAP used during the projection of this image [“yyyy-mm-dd”].

GEOMETRY_SOURCE_DESC
: Description of the geometry kernels used by the ISIS software when generating geometric information for this image. [“Not Available”, “Predicted”, “Reconstructed”, “Nadir pointing assumed”, or “Off Nadir pointing assumed”]

INCIDENCE_ANGLE
: The angle between the Sun and a 'normal' drawn perpendicular to the surface of the planet at the center of the image for the time the image was acquired. A value of 0 degrees indicates that the Sun was directly overhead at the time the image was acquired.

EMISSION_ANGLE
: The angle between THEMIS and a 'normal' drawn perpendicular to the planet surface at the center of the image. For nadir observations, this value will be approximately 0 degrees.

LOCAL_TIME
: The local time on Mars at the center of the image, given as the division of the Martian day into 24 equal parts; for example, 12.00 represents high noon.

SOLAR_LONGITUDE
: The position of Mars relative to the Sun as measured from the vernal equinox; also known as heliocentric longitude.

SOLAR_DISTANCE
: The distance between Mars and the Sun at the time this image was acquired; given in Astronomical Units.

ODY:MINIMUM_ALBEDO
: Minimum Lambert Albedo value calculated for this band of the image.

ODY:MAXIMUM_ALBEDO
: Maximum Lambert Albedo value calculated for this band of the image.

ODY:AVERAGE_ALBEDO
: Average Lambert Albedo value calculated for this band of the image.

ODY:TES_ALBEDO_MINIMUM
MGS-TES minimum measured albedo for the same Mars surface area as the image.

ODY:TES_ALBEDO_MAXIMUM
MGS-TES maximum measured albedo for the same Mars surface area as the image.

ODY:TES_ALBEDO_AVERAGE
MGS-TES average measured albedo for the same Mars surface area as the image.

ODY:TES_ALBEDO_SIGMA
The standard deviation of the MGS-TES measured albedo for the same Mars surface area as the image.

MAXIMUM_BRIGHTNESS_TEMPERATURE
Maximum brightness temperature value measured within the image.

MINIMUM_BRIGHTNESS_TEMPERATURE
Minimum brightness temperature value measured within the image.

LINES
Total number of data pixels along the vertical axis of the image.

LINE_SAMPLES
Total number of data pixels along the horizontal axis of the image.

SAMPLE_TYPE
Data storage representation of a pixel value [UNSIGNED_INTEGER]

SAMPLE_BITS
Stored number of bits in a single pixel value.

ODY:SAMPLE_NAME
Identifies the scientific meaning of each pixel value ["BRIGHTNESS_TEMPERATURE", “LAMBERT_ALBEDO”] .

ODY:SAMPLE_UNIT
Identifies the scientific unit of each pixel value [“KELVIN”,”DIMENSIONLESS”].

NULL_CONSTANT
Numeric value used to represent NULL data.

OFFSET
The offset value of the stored data; the offset value is added to the scaled data to reproduce the true data.

SCALING_FACTOR
The constant value by which the stored data is multiplied to produce the scaled data; the offset value is added to the scaled data to reproduce the true data.

MD5_CHECKSUM
A 128-bit checksum identification of the data portion of the IMAGE.

A.6 HISTORY Object Items and Examples

The HISTORY data object is described within the THM-GEO labels by the following keywords:

BYTES
: Number of bytes in the HISTORY object.

HISTORY_TYPE
: Identifies the software compliance of the HISTORY object format. [CUSTOM]

INTERCHANGE_FORMAT
: Identifies the manner in which the HISTORY object data items are stored. [ASCII]

Each program that operates on the data product will generate a new "history entry" and will concatenate the new entry onto the existing HISTORY object. All HISTORY objects follow this basic format, where the values have been replaced with keyword descriptions:

```
  GROUP                = The name of the program that generated the history entry.
    DATE_TIME          = Date and time, in UTC standard format, that the program
                         was executed. [yyyy-mm-ddThh:mm:ss]
    SOFTWARE_DESC      = Program generated description and execution notes.
    VERSION_ID         = Program version number.
    USER_NAME          = Username and name of computer. ["marvin@mars"]
    USER_NOTE          = User supplied brief description of program; may be blank.
    GROUP                = Used to delineate the statements specifying the
                           parameters of the program; will not be present if
                           additional keywords are not required.
                           [PARAMETERS]
      KEYWORD            = Value.
    END_GROUP            = [PARAMETERS]
  END_GROUP            = The name of the program that generated the history entry.
END
```

THM-GEO labels contain the cumulative processing history of the observation. The HISTORY objects generated during THEMIS standard data processing (THM-EDR and THM-RDR) are described in Appendix 8 of the *THEMIS Standard Data Products SIS* [5]. Examples of the HISTORY objects added during geometric processing are shown below.

ISIS-3 PROJECTION HISTORY OBJECTs

One or more of the following HISTORY groups may be present in a THM-GEO LBL documenting the details of the ISIS-3 command executed on the image.

```
GROUP = THM2ISIS
    IsisVersion = "3.4.9.6114 stable | 2015-03-26"
    ProgramVersion = 2008-03-20
    ProgramPath = /mars/common/isis3/3.4.9_64/isis/bin/
    ExecutionDateTime = 2015-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = "Import a Themis IR/VIS RDR or EDR"
    GROUP = PARAMETERS
        FROM = [filenameRDR]
        TO = [filename.cub]
        TIMEOFFSET = 0
    END_GROUP = PARAMETERS
END_GROUP = THM2ISIS


GROUP = THMVISTRIM
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2008-03-20
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = "Trims data from framelets on THEMIS VIS images"
    GROUP = PARAMETERS
        FROM_EVEN = [filename.even.cub]
        FROM_ODD = [filename.odd.cub]
        TO_EVEN = [filename2.even.cub]
        TO_ODD = [filename2.odd.cub]
        TOPTRIM = 4
        BOTTOMTRIM = 4
        LEFTTRIM = 0
        RIGHTTRIM = 0
    END_GROUP = PARAMETERS
END_GROUP = THMVISTRIM
```

```
GROUP = SPICEINIT
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2013-02-26
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = "Determine SPICE kernels for a camera cube"
    GROUP = PARAMETERS
        FROM = [filename]
        WEB = FALSE
        ATTACH = TRUE
        CKSMITHED = FALSE
        CKRECON = YES
        CKPREDICTED = FALSE
        CKNADIR = NO
        SPKSMITHED = FALSE
        SPKRECON = TRUE
        SPKPREDICTED = FALSE
        SPHAPE = SYSTEM
        STARTPAD = 0
        ENDPAD = 0
        URL = http://services.isis.astrogeology.usgs.gov/cgi-bin/spiceinit.cgi
        PORT = 80
    END_GROUP = PARAMETERS
```

[*The KERNELS group is extracted from the ISIS-3 CUBE header and added to the SPICINIT History object for completeness of documentation.]*

```
    GROUP = KERNELS
        NaifFrameCode = -53031
        LeapSecond = $base/kernels/lsk/naif0010.tls
        TargetAttitudeShape = $base/kernels/pck/pck00009.tpc
        TargetPosition = (Table, $base/kernels/spk/de405.bsp)
        InstrumentPointing = (Table, /themis/naif/ck/m01_sc_ext37.bc,
                                    $odyssey/kernels/fk/m01_v29.tf)
        Instrument = Null
        SpacecraftClock = $odyssey/kernels/sclk/ORB1_SCLKSCET.00200.tsc
        InstrumentPosition = (Table, /themis/naif/spk/spk_m_od52525-52603_rec_v1.bsp
        InstrumentAddendum = $odyssey/kernels/iak/themisAddendum003.ti
        ShapeModel = $base/dems/molaMarsPlanetaryRadius0005.cub
        InstrumentPositionQuality = Reconstructed
        CameraVersion = 2
    END_GROUP = KERNELS
END_GROUP = SPICEINIT
```

```
GROUP = CAM2MAP
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2012-10-11
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = “Convert camera image to a map projection”
    GROUP = PARAMETERS
        FROM = [filename]
        MAP = [filename.maptemplate]
        TO = [filename.proj]
        MATCHMAP = FALSE
        PIXRES = MAP
        DEFAULTRANGE = MINIMIZE
        LONSEAM = AUTO
        INTERP = BILINEAR
        WARPALGORITHM = AUTOMATIC
    END_GROUP = PARAMETERS
```

[*The MAPPING group is extracted from the ISIS-3 CUBE header and added to the CAM2MAP History object for completeness of documentation.]*

```
    GROUP = MAPPING
        ProjectionName = Sinusoidal
        CenterLongitude = #
        TargetName = MARS
        EquatorialRadius = 3.9619e+06
        PolarRadius = 3.762e+06
        LatitudeType = Planetocentric
        LongitudeDirection = PositiveEast
        LonigtudeDomain = 360
        MinimumLatitude = 29.253
        MaximumLatitude = 29.7627
        MinimumLongitude = 207.284
        MaximumLongitude = 208.036
        UpperLeftCornerX = -20200
        UpperLeftCornerY = 1.7642e+06
        PixelResolution = 100
        Scale = 592.747
        LocalRadius = 3.39619e+06
    GROUP = MAPPING
    END_GROUP = PARAMETERS
END_GROUP = CAM2MAP
```

```
GROUP = AUTOMOS
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2012-09-18
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = “Create a mosaic using a list of map projected cubes”
    GROUP = PARAMETERS
        FROMLIST = [filename]
        MOSAIC = [filename2]
        PRIORITY = ONTOP
        GRANGE = AUTO
        TRACK = FALSE
        MATCHBANDBIN = TRUE
        MATCHDEM = FALSE
        HIGHSATURATION = FALSE
        LOWSATURATION = FALSE
        NULL = FALSE
    END_GROUP = PARAMETERS
END_GROUP = AUTOMOS


GROUP = SPECPIX
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2011-08-31
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = “Replaces user specified values with ISIS special pixel values”
    GROUP = PARAMETERS
        FROM = [filename]
        TO = [filename2]
        NULLMIN = -32770.0
        NULLMAX = -1.0
    END_GROUP = PARAMETERS
END_GROUP = SPECPIX


GROUP = CUBATT
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2012-07-03
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
```

```
    UserName = marvin
    Description = “Cube attribute editor”
    GROUP = PARAMETERS
        FROM = [filename]
        TO = [filename2]
        PROPTABLES = TRUE
    END_GROUP = PARAMETERS
END_GROUP = CUBATT


GROUP = EDITLAB
    IsisVersion = "3.4.3.5155 stable | 2013-03-19"
    ProgramVersion = 2012-12-20
    ProgramPath = /mars/common/isis3/3.4_64/isis/bin/
    ExecutionDateTime = 2014-07-14Thh:mm:ss
    HostName = mvc10a
    UserName = marvin
    Description = “Modifies cube labels’
    GROUP = PARAMETERS
        FROM = [filename]
        OPTIONS = addkey
        GRPNAME = Mapping
        KEYWORD = LocalRadius
        VALUE = [#]
    END_GROUP = PARAMETERS
END_GROUP = EDITLAB


GROUP = DAVINCI_TO_ISIS3
    DavinciVersion = “davinci Version #2.09”
    DavinciIsis3ModuleVersion = "0.9.5 (ISIS 3.4.x)”
    ExecutionDateTime = "2014-07-23T23:50:07"
    HostName = "mvc10a"
    UserName = "marvin"
    Description = "ISIS3 cube written from davinci after [named] processing step."
END_GROUP = DAVINCI_TO_ISIS3


GROUP = DAVISIS3
    DavinciVersion = “davinci Version #2.09”
    DavinciIsis3ModuleVersion = "0.9.5 (ISIS 3.4.x)”
    ExecutionDateTime = "2014-07-23T23:51:07"
    HostName = "mvc10a"
    UserName = "marvin"
    Description = "ISIS3 cube written from davinci."
END_GROUP = DAVISIS3
```

IR-GEO UDDW HISTORY OBJECT

```
GROUP = ASU_PROCESS_UDDW
  DATE_TIME = 2014-07-25T17:41:41
  SOFTWARE_DESC = "The Undrift-Dewobble filter was applied to this THEMIS IR-
                   RDR QUBE to remove data value fluctuations caused by
                   changes in the temperature of the IR detector array.   Band 10
                   values remain unchanged.  See Bandfield, et. al,
                   doi:10.1029/2004JE002289."
  VERSION_ID = 1.84
  USER_NAME = "thmproc@c145.mars.asu.edu"
END_GROUP = ASU_PROCESS_UDDW
```

IR-GEO RECTIFY HISTORY OBJECT

```
GROUP = ASU_PROCESS_RECTIFY
  DATE_TIME = 2014-07-31T2hh:mm:ss
  SOFTWARE_DESC = "The Rectify algorithm was applied to this THEMIS IR-GEO
                   cube to minimize null space around the image data and to
                   prepare the data for the Deplaid algorithm.  This process was
                   then reversed with the Reconstitute algorithm to restore the data
                   to the fully projected orientation."
  VERSION_ID = 2005.07
  DAVINCI_VERSION = 2.09
  USER_NAME = "thmproc@c145.mars.asu.edu"
  USER_NOTE = ""
  GROUP = PARAMETERS
    CORNERS = 385.000000
    WIDTH = 385.000000
    ANGLE = 3.084812
  END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_RECTIFY
```

IR-GEO DEPLAID HISTORY OBJECT

```
GROUP = ASU_PROCESS_DEPLAID
  DATE_TIME = 2008-12-31T3hh:mm:ss
  SOFTWARE_DESC = " Deplaid is a specialized, high-pass filter which was applied to
                    remove row and line radiance spikes from the THEMIS IR-
                    RDR data in this projection. Validation of the resulting spectral
                    image confirms that the average spectra from a 50 x 50 pixel
                    sample area remains unchanged."
  VERSION_ID = 2005.07
  USER_NAME = "thmproc@c145.mars.asu.edu"
  USER_NOTE = ""
END_GROUP = ASU_PROCESS_DEPLAID

GROUP = ASU_PROCESS_NIGHT_DEPLAID
  DATE_TIME = 2014-07-14T3hh:mm:ss
  SOFTWARE_DESC = "THM.Deplaid was executed two times on this NIGHT IR image:
                    first run removes the nighttime specific TEHMIS IR plaid
                    pattern from each band based on the temperature mask
                    parameters.  Second run removes the general plaid pattern of
                    row and line radiance spikes from the data. "
  VERSION_ID = 2005.12
  USER_NAME = "thmproc@c145.mars.asu.edu"
  USER_NOTE = ""
  GROUP = PARAMETERS
    TMASK_MIN = 0.05
    TMASK_MAX = 5.5
    B10 = 0
    IGNORE = -32768.0
  END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_NIGHT_DEPLAID
```

IR-GEO AUTORADCOR HISTORY OBJECT

```
GROUP = ASU_PROCESS_ARADCOR
  DATE_TIME = 2014-07-31T3hh:mm:ss
  SOFTWARE_DESC = "An automated radiance correction algorithm was applied to the
                    THEMIS IR-RDR data in this projection to remove the
                    atmospheric radiance component.  The correction value is based
                    on multiple 50 x 50 pixel samples located throughout the image
                    which meet several temperature and emissivity criteria."
  VERSION_ID = 2013.07
  DAVINCI_VERISON = 2.09
  USER_NAME = "mvc10a"
  USER_NOTE = ""
END_GROUP = ASU_PROCESS_ARADCOR
```

VIS-GEO DESPECKLE HISTORY OBJECT

```
GROUP = ASU_PROCESS_DESPECKLE
    DATE_TIME = 2012-07-01Thh:mm:ss
    SOFTWARE_DESC = "The Despeckle filter was applied after calibration of this
                     THEMIS VIS-RDR QUBE.  This cosmetic filter uses the
                     method below to identify anomalously bright (or dark) pixels;
                     all values from the original RDR exceeding the threshold value
                     have been replaced.  The replacement value is calculated by
                     filtering the surrounding good pixels."
    VERSION_ID = 1.0
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        METHOD = "STANDARD DEVIATION"
        METHOD_LIMIT = # or ( #, #, #, #, # )
        FILTER = "filter name”
        FILTER_SIZE = #
        THRESHOLD_VALUE = # or ( #, #, #, #, # )
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_DESPECKLE
```

VIS-GEO COFF HISTORY OBJECT

```
GROUP = ASU_PROCESS_COFF
    DATE_TIME = 2014-07-19T17:00:
    SOFTWARE_DESC = "The radiance values of this THEMIS VIS-RDR QUBE were
                     modified before geometric projection.  This is a cosmetic
                     correction which removes an optimized flat-field from each
                     framelet in the image.  The process maintains the overall
                     radiance level of each framelet at the expense of significantly
                     modifying the source VIS-RDR radiance values"
    VERSION_ID = 2013.03
    DAVINCI_VERSION = 2.09
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        FLATFIELD_FILE = "/themis/data/flat_frames12.prof1.fits"
        FLATFIELD_FILE_DATE = 2005-03-16T04:54:55
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_COFF
```

VIS-GEO FEATHER HISTORY OBJECT

```
GROUP = ASU_PROCESS_FEATHER
    DATE_TIME = 2014-07-07T13:28:26
    SOFTWARE_DESC = "The Feather filter was applied during the geometric projection of
                     this THEMIS VIS-RDR QUBE.  This cosmetic filter blends the
                     data in the overlapping lines between framelets, and ramps
                     brightness differences back towards the start of the framelet.
                     Many values in the resulting cube may have been significantly
                     modified from the source VIS-RDR values."
    VERSION_ID = 2014.05
    DAVINCI_VERSION = 2.09
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        CURRENT_PROJECTION = “Equirectangular”
        ROTATION = (#, #)
        FILTER_DIMENSIONS = (#, #)
        FRAMELET1_NOTE = “N/A”
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_FEATHER
```

VIS-GEO FRAMECLIP HISTORY OBJECT

```
GROUP = ASU_PROCESS_FRAMECLIP
    DATE_TIME = 2014-07-07T13:28:26
    SOFTWARE_DESC = "Frameclip was used to manipulate the overlapping data between
                     framelets in preparation for mosaicking the even framelets on
                     top of the odd framelets.  Pixels in the trailing edge of even
                     numbered framelets was replaced with the values from the
                     overlapping odd numbered framelet; then overlapping pixels in
                     the odd framelet were removed."
    VERSION_ID = 2014.05
    DAVINCI_VERSION = 2.09
    USER_NAME = "smith@mars"
    USER_NOTE = ""
    GROUP = PARAMETERS
        ONTOP = EVEN
        ROTATION = (#, #)
    END_GROUP = PARAMETERS
END_GROUP = ASU_PROCESS_FRAMECLIP
```

ERRATA HISTORY OBJECT

```
GROUP                   = ERRATA_ODTVG_0001_2_1
    DATE_TIME           = "2015-09-01T00:00:00"
    SOFTWARE_DESC       = "Description of the change which required the regeneration
                          of this product.

                          Associated ERRATA_ID: ODTVR_0001-1.5"
    ERRATA_ID           = "ODTIG-0011-2.1"
    USER_NAME           = "marvin@mars"
    USER_NOTE           = ""
END_GROUP               = ERRATA_ODTVG_0001_2_1
```

A.7 Geometry Indexes

Index files, available in the archive volume INDEX directory (*THEMIS Archive SIS* [2], Section 2.7), contain release information for the THM-GEO products. The INDEX_ODTIG and INDEX_ODTVG files contain one record of release information per geometry data product, including product creation time, version identification, and map projection type. See the appropriate label for a list of all columns and their descriptions.

In addition, selected geometric parameters of each observation are included in the general THEMIS indexes, THMIDX_IR or THMIDX_VIS. The column descriptions for these parameters have been reproduced here; the complete labels (THMIDX_*.LBL) are available in the archive INDEX directory. Note that the column number for each index is given for reference only following the syntax

COLUMN_NUMBER = [thmidx_ir = #, thmidx_vis =#].

All geometry parameter values are calculated using the basic ISIS processing for the first available band in the observation.

```
OBJECT                  = COLUMN
    NAME                = GEOMETRY_SOURCE
    COLUMN_NUMBER       = [ thmidx_ir = 25, thmidx_vis =19 ]
    DATA_TYPE           = CHARACTER
    BYTES               = 1
    DESCRIPTION         = "Description of the geometry kernels used by the ISIS
                          software when generating the geometry information for
                          this image:
                              P = Predicted using NAIF tools (some parameters
                                  may be unavailable)
                              R = Reconstructed
                              N = Nadir pointing assumed
                              U = Geometry unavailable; parameters filled with
                                  UNKNOWN_CONSTANT"
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
    NAME                = SAMPLE_RESOLUTION
    COLUMN_NUMBER       = [ thmidx_ir = 26, thmidx_vis = 20 ]
    DATA_TYPE           = ASCII_REAL
    BYTES               = 5
    UNKNOWN_CONSTANT    = 32767
    UNIT                = "KM"
    DESCRIPTION         = "The horizontal size of a pixel at the center of the image
                          as projected onto the surface of the target."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
    NAME                = LINE_RESOLUTION
    COLUMN_NUMBER       = [ thmidx_ir = 27, thmidx_vis = 21 ]
```

```
    DATA_TYPE           =  ASCII_REAL
    BYTES               =  5
    UNKNOWN_CONSTANT    =  32767
    UNIT                =  "KM"
    DESCRIPTION         =  "The vertical size of a pixel at the center of the image as
                           projected onto the surface of the target."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
    NAME                =  PIXEL_ASPECT_RATIO
    COLUMN_NUMBER       =  [ thmidx_ir = 28, thmidx_vis = 22 ]
    DATA_TYPE           =  ASCII_REAL
    BYTES               =  5
    UNKNOWN_CONSTANT    =  32767
    UNIT                =  "DIMENSIONLESS"
    DESCRIPTION         =  "Ratio of the height to the width of the projection of the
                           center pixel onto the surface of the target."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
    NAME                =  CENTER_LATITUDE
    COLUMN_NUMBER       =  [ thmidx_ir = 29, thmidx_vis = 23 ]
    DATA_TYPE           =  ASCII_REAL
    BYTES               =  7
    UNKNOWN_CONSTANT    =  32767
    UNIT                =  "DEGREE"
    DESCRIPTION         =  "Latitude on Mars at the image center."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
    NAME                =  CENTER_LONGITUDE
    COLUMN_NUMBER       =  [ thmidx_ir = 30, thmidx_vis = 24 ]
    DATA_TYPE           =  ASCII_REAL
    BYTES               =  7
    UNKNOWN_CONSTANT    =  32767
    UNIT                =  "DEGREE"
    DESCRIPTION         =  "Longitude on Mars at the image center using an east
                           positive coordinate system."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
    NAME                =  UPPER_LEFT_LATITUDE
    COLUMN_NUMBER       =  [ thmidx_ir = 31, thmidx_vis = 25 ]
    DATA_TYPE           =  ASCII_REAL
    BYTES               =  7
    UNKNOWN_CONSTANT    =  32767
```

```
    UNIT                  =  "DEGREE"
    DESCRIPTION           =  "Latitude on Mars at the upper left corner of the image."
END_OBJECT                =  COLUMN

OBJECT                    =  COLUMN
    NAME                  =  UPPER_LEFT_LONGITUDE
    COLUMN_NUMBER         =  [ thmidx_ir = 32, thmidx_vis = 26 ]
    DATA_TYPE             =  ASCII_REAL
    BYTES                 =  7
    UNKNOWN_CONSTANT      =  32767
    UNIT                  =  "DEGREE"
    DESCRIPTION           =  "Longitude on Mars at the upper left corner of the
                             image."
END_OBJECT                =  COLUMN

OBJECT                    =  COLUMN
    NAME                  =  UPPER_RIGHT_LATITUDE
    COLUMN_NUMBER         =  [ thmidx_ir = 33, thmidx_vis = 27 ]
    DATA_TYPE             =  ASCII_REAL
    BYTES                 =  7
    UNKNOWN_CONSTANT      =  32767
    UNIT                  =  "DEGREE"
    DESCRIPTION           =  "Latitude on Mars at the upper right corner of the image."
END_OBJECT                =  COLUMN

OBJECT                    =  COLUMN
    NAME                  =  UPPER_RIGHT_LONGITUDE
    COLUMN_NUMBER         =  [ thmidx_ir = 34, thmidx_vis = 28 ]
    DATA_TYPE             =  ASCII_REAL
    BYTES                 =  7
    UNKNOWN_CONSTANT      =  32767
    UNIT                  =  "DEGREE"
    DESCRIPTION           =  "Longitude on Mars at the upper right corner of the
                             image."
END_OBJECT                =  COLUMN

OBJECT                    =  COLUMN
    NAME                  =  LOWER_LEFT_LATITUDE
    COLUMN_NUMBER         =  [ thmidx_ir = 35, thmidx_vis = 29 ]
    DATA_TYPE             =  ASCII_REAL
    BYTES                 =  7
    UNKNOWN_CONSTANT      =  32767
    UNIT                  =  "DEGREE"
    DESCRIPTION           =  "Latitude on Mars at the lower left corner of the image."
END_OBJECT                =  COLUMN
```

```
OBJECT                  =  COLUMN
  NAME                  =  LOWER_LEFT_LONGITUDE
  COLUMN_NUMBER         =  [ thmidx_ir = 36, thmidx_vis = 30 ]
  DATA_TYPE             =  ASCII_REAL
  BYTES                 =  7
  UNKNOWN_CONSTANT      =  32767
  UNIT                  =  "DEGREE"
  DESCRIPTION           =  "Longitude on Mars at the lower left corner of the
                           image."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  LOWER_RIGHT_LATITUDE
  COLUMN_NUMBER         =  [ thmidx_ir = 37, thmidx_vis = 31 ]
  DATA_TYPE             =  ASCII_REAL
  BYTES                 =  7
  UNKNOWN_CONSTANT      =  32767
  UNIT                  =  "DEGREE"
  DESCRIPTION           =  "Latitude on Mars at the lower right corner of the image."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  LOWER_RIGHT_LONGITUDE
  COLUMN_NUMBER         =  [ thmidx_ir = 38, thmidx_vis = 32 ]
  DATA_TYPE             =  ASCII_REAL
  BYTES                 =  7
  UNKNOWN_CONSTANT      =  32767
  UNIT                  =  "DEGREE"
  DESCRIPTION           =  "Longitude on Mars at the lower right corner of the
                           image."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  PHASE_ANGLE
  COLUMN_NUMBER         =  [ thmidx_ir = 39, thmidx_vis = 33
  DATA_TYPE             =  ASCII_REAL
  BYTES                 =  7
  UNKNOWN_CONSTANT      =  32767
  UNIT                  =  "DEGREE"
  DESCRIPTION           =  "The angle between the surface-to-Sun vector and the
                           surface-to-THEMIS vector drawn at the center of the
                           image for the time the image was acquired."
END_OBJECT              =  COLUMN

OBJECT                  =  COLUMN
  NAME                  =  INCIDENCE_ANGLE
```

```
    COLUMN_NUMBER      = [ thmidx_ir = 40, thmidx_vis = 34 ]
    DATA_TYPE          = ASCII_REAL
    BYTES              = 7
    UNKNOWN_CONSTANT   = 32767
    UNIT               = "DEGREE"
    DESCRIPTION        = "The angle between the Sun and a 'normal' drawn
                         perpendicular to the surface of the planet at the center of
                         the image for the time the image was acquired.  A value
                         of 0 degrees indicates that the Sun was directly overhead
                         at the time the image was acquired."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
    NAME               = EMISSION_ANGLE
    COLUMN_NUMBER      = [ thmidx_ir = 41, thmidx_vis = 35 ]
    DATA_TYPE          = ASCII_REAL
    BYTES              = 6
    UNKNOWN_CONSTANT   = 32767
    UNIT               = "DEGREE"
    DESCRIPTION        = "The angle between THEMIS and a 'normal' drawn
                         perpendicular to the planet surface at the center of the
                         image.  For nadir observations, this value will be
                         approximately 0 degrees."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
    NAME               = NORTH_AZIMUTH
    COLUMN_NUMBER      = [ thmidx_ir = 42, thmidx_vis = 36 ]
    DATA_TYPE          = ASCII_REAL
    BYTES              = 7
    UNKNOWN_CONSTANT   = 32767
    UNIT               = "DEGREE"
    DESCRIPTION        = "The clockwise angle from an imaginary three o'clock
                         axis to the North polar axis, where the origin of both axes
                         is at the center of the image."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
    NAME               = SLANT_DISTANCE
    COLUMN_NUMBER      = [ thmidx_ir = 43, thmidx_vis = 37 ]
    DATA_TYPE          = ASCII_REAL
    BYTES              = 8
    UNKNOWN_CONSTANT   = 32767
    UNIT               = "KM"
```

```
    DESCRIPTION           = "A measure of the distance from the spacecraft to the
                            target body at the center of the image;  this value is the
                            spacecraft altitude if the emission angle is 0 degrees."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = LOCAL_TIME
    COLUMN_NUMBER         = [ thmidx_ir = 44, thmidx_vis = 38 ]
    DATA_TYPE             = CHARACTER
    BYTES                 = 6
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "HOUR"
    DESCRIPTION           = "The local time on Mars at the center of the image, given
                            as the division of the Martian day into 24 equal parts; for
                            example, 12.00 represents high noon."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = SOLAR_LONGITUDE
    COLUMN_NUMBER         = [ thmidx_ir = 45, thmidx_vis = 39 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 7
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "DEGREE"
    DESCRIPTION           = "The position of Mars relative to the Sun as measured
                            from the vernal equinox;  also known as heliocentric
                            longitude."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
    NAME                  = SUB_SOLAR_AZIMUTH
    COLUMN_NUMBER         = [ thmidx_ir = 46, thmidx_vis = 40 ]
    DATA_TYPE             = ASCII_REAL
    BYTES                 = 7
    UNKNOWN_CONSTANT      = 32767
    UNIT                  = "DEGREE"
    DESCRIPTION           = "The clockwise angle from an imaginary three o'clock
                            axis to the Sun at the time the image was acquired, where
                            the origin of both axes is at the center of the image."
END_OBJECT                = COLUMN
```

A.8 Geometric Quality Assessment and HISTORY Object

After a decade of in-flight operations, the Inertia Measurement Unit (IMU) on the Odyssey Spacecraft Side-A (primary) began to show end-of-life warning signs. The IMU is the basis for the Gyro based attitude determination operational mode. After considering all the options, the M01 Odyssey Project and Spacecraft teams decided to switch to the All-Stellar based attitude determination operational mode, in order to preserve some functionality of the IMU. Testing and on-board demos of All-Stellar mode were conducted in January 2012, and full time operations in All-Stellar mode ran from March to June 2012, when the spacecraft transitioned to the redundant Spacecraft Side-B. The Gyro based attitude determination operational mode was available for several years on the redundant IMU. Operations in All-Stellar attitude determination mode on Side-B began in late 2019, with short returns to Gyro mode as needed. While the behavior in general of the primary and redundant systems are not identical, in this case they are similar enough and the differences do not significantly change the effects on THEMIS images; there will be no additional distinction between the two All-Stellar operational periods in the following discussion.

Not surprising, the attitude control in All-Stellar mode is slightly looser than in Gyro mode. All-Stellar operations are characterized by a constant “jitter” motion that can be measured in degrees of rotation around the spacecraft axes: pitch, roll, and yaw. Most of the time, this background motion is well under the tolerance levels of the THEMIS camera systems; however, certain routine spacecraft operations have the potential to induce higher degrees of motion that could negatively impact the quality of a concurrently collected THEMIS image. Therefore, during All-Stellar mode, the THEMIS Operations team may avoid targeting high priority images during periods of anticipated high levels of motion and may shorten the duration of all images to minimize the total motion experienced during image collection. Additionally, starting at orbit 44500 (December 2011) all RDR and GEO product labels will include a GEOMETRY_QUALITY History object (shown below) that will document the assessed spacecraft attitude stability and the geometric accuracy of the projected image.

Through extensive validation it has been determined that highly accurate geometric results, as well as very poor geometric results, can be obtained during either Gyro or All-Stellar attitude modes. The following is a brief description of the various parameters that may affect the geometric accuracy of any THEMIS image. Since not all research requires the same degree of attitude stability and geometric accuracy, the measured impact of these parameters is provided per image in the GEOMETRY_QUALITY History object to allow the scientist to assess their total impact on the image in the context of a specific study.

Spacecraft Telemetry Quality. The values for most of the parameters presented in this appendix are extracted from various spacecraft telemetry values. Like any other downlinked data product, spacecraft telemetry can contain data gaps. When THEMIS image acquisition intersects a gap in the spacecraft telemetry, the status of the various parameters described below will be unknown and may compromise our ability to predict the cumulative effects on the geometric accuracy. This situation will be reflected in the SPACECRAFT_TELEMETRY_GAP = “YES” and may also result in a GEOMETRY_QUALITY_RATING = “N/A”.

Geometry Kernel Source. Regardless of the attitude determination mode in use, the spacecraft position and trajectory kernels (respectively, SPK and NAIF-CK kernels) are only as accurate as the onboard navigational system knowledge. Since these kernels are absolutely required for execution of the ISIS geometric projection software, the THEMIS data processing team assumes their content to be valid, unless contrary information is available that would challenge their use. The accuracy of these kernels may be best assessed using the image coregistration method discussed below.

Whenever possible, "RECONSTRUCTED" spacecraft trajectory kernels are provided to ISIS for use in calculating the geometric projection of each image. These kernels are generated from various downlinked telemetry, which can contain data gaps that intersect the image. In these cases, a simulated kernel ("ASSUMED_NADIR") is used which assumes that the spacecraft is fixed in a perfectly nadir position. During Gyro based operations, use of these kernels produces results with accuracy similar to that obtained by using the "RECONSTRUCTED" kernels. During All-Stellar based operations, geometric accuracy when using these kernels is more unpredictable.

Star Camera Mode. Both attitude determination modes depend on solutions from the Star Camera in the attitude control logic; obviously, All-Stellar is more dependent on the results, and therefore, more susceptible to severe Star Camera outages. The Star Camera normally operates in "TRACKING" mode; when an anomaly is encountered, the camera autonomously transitions to "ACQUISTION" mode until the conditions for an acceptable solution are met. Brief outages, where the spacecraft spends less than 200 total seconds in ACQUISITION mode, are expected during nominal spacecraft operations and usually have minimal effect on attitude. Longer outages can affect attitude stability, depending on how far the spacecraft attitude has strayed during the outage. When in All-Stellar mode, severe outages (no solution after 180 seconds) will automatically transition the spacecraft to Gyro mode.

Spacecraft Attitude Determination Error. Attitude is continuously monitored onboard the Odyssey spacecraft and the various measurements are used in the attitude control algorithms. The spacecraft attitude determination error is calculated from the difference between the commanded and estimated spacecraft attitude, and quantifies the amount of offset around the each of the three axes of the spacecraft body frame. Typical spacecraft attitude error measurements during GYRO based operations are routinely lower than during All-Stellar based operations, especially around the spacecraft pitch axis. The spacecraft attitude determination error measured during image collection is recorded in the GEOMETRY_QUALITY History object, however, there is only a weak correlation between this error measurement and actual wobbles in pitch, roll, and yaw of the spacecraft orbital attitude.

Angular Momentum Desaturation. Angular Momentum Desaturation (AMD or DESAT) events are required to maintain spacecraft attitude and stability. The events typically last 50 minutes with about 30 total minutes of notable motion divided between two phases of the event period. Timing between sequential DESAT events slowly changes throughout the Mars year, but there is never more than one event scheduled per orbit. Testing during the early Odyssey Mapping Phase of the mission concluded that THEMIS images were less sensitive to DESAT events during GYRO based operations, however, all DESATs are marked both by heightened spacecraft attitude error values and by significant spacecraft attitude motion, especially around the pitch and roll axes. The scientist is encouraged to review all available GEOMETRY_QUALITY parameter values, since images collected during the quiet, middle phase of the DESAT may experience no unusual motion at all.

Coregistration of Image to Mars Basemap. Validation studies have shown that the only way to reliably know the geometric accuracy of an image is to project the image, use feature registration to align the image to an accurate Mars basemap, and measure any image offset. Intensive THEMIS imaging campaigns early in the Odyssey mission resulted in complete coverage of the Martian surface and allowed for the creation of two global mosaics: (1) a Daytime Infrared mosaic ["thm_dir_100m_v11_11"] and (2) a Nighttime Infrared mosaic ["thm_nir_100m_v13_3"]. Both mosaics are available at 100 m/pixel resolution and are suitable for use as a basemap against which to coregister other THEMIS infrared images. To date, the THEMIS data processing team has yet to identify a basemap with significant coverage and resolution against which to coregister the THEMIS visible images.

During Odyssey Extended Mission 6 (2014-2016), the spacecraft changed the local time of the orbital plane:

- in the early Mission, THEMIS acquired "daytime" (2pm-6pm) images on the descending orbital node and acquired "nighttime" (2am-6am) images on the ascending orbital node.
- in the late Mission, THEMIS acquired "nighttime" (7pm-9pm) images on the descending orbital node and acquired "daytime" (7am-9am) images on the ascending orbital node.

The Infrared Global mosaics also reflect this pattern, with the Daytime Infrared mosaic primarily composed of images collected on the descending orbit node, and the Nighttime Infrared mosaic composed of images collected on the ascending orbit node. There is a known, and as of yet unresolved, offset observed when attempting to align THEMIS images of the same location but collected on opposite orbital nodes. This anomaly, added to the orbital change, makes coregistration of late Mission collected images against the early Mission Global mosaics difficult; therefore, this coregistration method for determining geometric accuracy is usually not available for images collected after orbit 55000 (May 2014).

For images where coregistration is possible and produces acceptable results (ASU_BASEMAP_COREG = YES), a GEOMETRIC_QUALITY_RATING of "GOOD", "OKAY", or "BAD" is reported, corresponding to the amount of pixel offset required: none, minimal, or significant. For images where coregistration is not possible, the other parameters discussed in this section are used to suggest the final geometric accuracy of the image: a GEOMETRIC_QUALITY_RATING of "NO-ISSUES", "CAUTION", or "WARNING" corresponds to the predicted equivalent of none, minimal, or significant pixel offsets required to accurately locate this image on Mars. Unfortunately, these parameters are not perfect predictors of geometric accuracy, so the scientist is forewarned that approximately 78% of the predictions turn out to be true (i.e. when coregistered, an image with a NO-ISSUES prediction results in a GOOD quality rating), and approximately 7% of the predictions turn out to be false (i.e. when coregistered, an image with a WARNING prediction results in a GOOD quality rating).

Spacecraft Attitude Stability. Another area of concern, particularly during All-Stellar mode operations, is the stability of the spacecraft pointing during THEMIS image collection. Stability can be assessed by differencing the reported spacecraft attitude compared to true nadir, as measured in degrees of rotation around the three body axes, where

- pitch is rotation around the orbit normal direction
- roll is rotation around the velocity vector

- yaw is rotation around the nadir vector.

Yaw and roll rotations are most easily observed as anomalies in the ground projected "shape" of an individual image. Yaw rotations will be manifest as infrared line or visible framelet rotations in the projected image. Roll rotations will be manifest as cross-track variations in the projected image. Both instabilities will affect the pixel sampling in the collected image but will likely be mitigated by the geometric projection processing.

Pitch rotations are harder to observe in an individual image; this motion causes lengthening or shortening of the image in the along-track direction, but also has the potential to significantly impact the spectral integrity of the image. A pitch rotation of 0.5 degree is the surface equivalent of one full VIS image framelet or 35 lines of an IR image. For the THEMIS visible camera, a framing imaging spectrometer, changes to pitch direction during image collection will affect the size and location of the surface exposed to each framelet-band set and could result in questionable band-to-band alignment of individual pixels. For the THEMIS infrared camera, the nominal spectral resolution is achieved, in part, by engaging Time Delay Integration (TDI), an on-board compression algorithm that averages successive lines of scanned data before downlink. Changes to pitch direction during infrared image collection will affect the size and location of the surface exposed to each scanned line, and potentially will be further compounded during the TDI processing, resulting in spectrally smeared pixels that vary from band-to-band.

Additional spacecraft attitude information is available in the image label keywords of SPACECRAFT_POINTING_MODE and SPACECRAFT_ORIENTATION, as described in the ODY_ORIENT_POINT.txt. The nominal values of these keywords, respectively "NADIR" and "(0,0,0)", will not likely change due to the relatively small spacecraft stability anomalies discussed here. The same NAIF tool (frmdiff) used to calculate the (pitch, roll, yaw) orientation values of various Odyssey maneuvers is also used to monitor the spacecraft attitude. The total change in attitude throughout the duration of each image is summed per axis and reported in the SPACECRAFT_ATTITUDE_CHANGE parameter. (For example, if the pitch direction changed from -0.5 to +0.5 during an image, the reported total pitch SPACECRAFT_ATTITUDE _CHANGE value is 1.0.) The characteristics of the THEMIS camera system and the spacecraft attitude control were considered in order to assign a qualitative assessment of stability based on these total change values. The majority of THEMIS images collected during All-Stellar attitude determination mode (91%), were collected during minimal attitude change and are tagged with an ATTITUDE_QUALITY_RATING = "STABLE". Images tagged with the ratings of "CHECK-STABILITY" or "UNSTABLE" were collected during more significant attitude changes but still may be useful in some studies; therefore, the scientist is encouraged to review the image itself and all the parameters in the GEOMETRY_QUALITY object in order to determine the suitability of a specific image for their work.

GEOMETRIC QUALITY HISTORY OBJECT

GROUP = GEOMETRIC_QUALITY
DATE_TIME = *YYYY-MM-DDTmm:hh:ss*
SOFTWARE_DESC = "The quality of the projected location of a THEMIS image can be affected by multiple factors, which are summarized here along with the assessed GEOMETRY_QUALITY_RATING. See the GEOMETRY/GEOMETRY.PDF for a full discussion of the individual parameters."
USER_NAME = "marvin@mars"
USER_NOTE = ""
GROUP = PARAMETERS
[*see parameter keyword list with definitions and valid values below*]
END_GROUP = PARAMETERS
END_GROUP = GEOMETRIC_QUALITY

GEOEMTRIC QUALITY PARAMETERS

GEOMETRY_SOURCE_DESC

Description of the geometry kernels used by the ISIS software when generating geometric information for this image. [“PREDICTED”, “RECONSTRUCTED”, or “ASSUMED-NADIR”]

SPACECRAFT_ORBITAL_NODE

Description of the portion of the orbit during which this image was acquired. The Odyssey spacecraft flies towards the south pole on the DESCENDING node and back towards the north pole on the ASCENDING node. If the spacecraft changes direction due to flying over the pole, the cross-polar qualifier is included. [“DESCENDING”, ”ASCENDING”, “DESC_CROSSPOLAR”, ”ASC_CROSSPOLAR”]

SPACECRAFT_ATTITUDE_DESC

Two part description of the attitude control mode during collection of this image: Attitude Determination mode and Star Camera mode. [(“GYRO” or “ALLSTAR, “TRACKING” or “ACQUISITION”)]

SPACECRAFT_ATTITUDE_ERROR

Maximum spacecraft attitude error during collection of this image; given in degrees as (pitch, roll, yaw) around the spacecraft body frame. [“N/A”, or (#.#, #.#, #.#)]

SPACECRAFT_DESAT_EVENT

Results from testing if this image was collected during an angular momentum desaturation event. [“N/A”, “YES”, or “NO”]

SPACECRAFT_TELEMETRY_GAP

Results from testing if this image coincides with a data gap in the downlinked spacecraft telemetry. [“N/A”, “YES”, or “NO”]

ASU_BASEMAP_NAME

Identification of the Mars basemap used for a sucessful coregistration quality assessment. [“N/A”, “thm_dir_100m_v11_11”, “thm_nir_100m_v13_3”]

ASU_BASEMAP_COREG

Results from testing for success when attempting to coregister this ISIS projected image against the Mars basemap listed. The ASSOC_IR value indicates that the IR image collected concurrently with this VIS image was successfully coregistered. [“N/A”, “YES”, “NO”, or “ASSOC_IR”]

SPACECRAFT_ATTITUDE_CHANGE

Cumulative change in attitude experienced by THEMIS while collecting this image; measured in degrees (pitch, roll, yaw). [“N/A” or (#.#, #.#, #.#)]

ATTITUDE_QUALITY_RATING

Assessed quality of spacecraft attitude stability based on total attitude change from all three axis. [“N/A”, “STABLE”, “CHECK-STABILITY”, “UNSTABLE”]

GEOMETRIC_QUALITY_RATING

Assessed quality of geometric values when projected using appropriate NAIF kernels and ISIS software. [“N/A”, “GOOD”, “OKAY”, ”BAD”, “NO-ISSUES”, “CAUTION”, “WARNING”]