

Thermal Emission Imaging System
2001 Mars Odyssey

**THEMIS GEOMETRIC PROCESSING
USER'S GUIDE**

January 1, 2010

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January 1, 2010

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

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ACRONYMS

ASU	Arizona State University
DCS	DeCorrelation Stretch product
EDR	Experiment Data Record
GEO	Geometrically registered record
IR	Infrared
ISIS	Integrated Software for Imaging Spectrometers
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
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 and IR-DCS) are spatially registered, image products generated from the IR-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, 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 Architecture, *internet documentation*: http://isis.astrogeology.usgs.gov/Isis2/isis-bin/isis_arch.cgi.
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.

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]. Each qube file is composed of an ASCII label attached to one or more data objects, such as a HISTORY object and the qube data object. A three-dimensional qube file, with two spatial dimensions and one spectral dimension, is referred to specifically as an ISIS CUBE file. A complete description of ISIS qube files can be found in *Overview of ISIS Architecture* [6].

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>). All aspects of the ISIS-THEMIS tools are discussed in *Mars Odyssey THEMIS Geometry Processing with ISIS* [4].

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 cross-track by 192 lines down-track, 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:

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

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			VISIBLE BANDS		
Band Numbers	Center (μm)	FWHM (μm)	Band Numbers	Center (μm)	FWHM (μm)
IR-1	6.78	1.01	V-1	0.425	0.049
IR-2	6.78	1.01	V-2	0.540	0.051
IR-3	7.93	1.09	V-3	0.654	0.053
IR-4	8.56	1.16	V-4	0.749	0.053
IR-5	9.35	1.20	V-5	0.860	0.045
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			

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 per image in a multispectral ISIS CUBE file. 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 and IR-DCS) are generated by additional processing of the IR-GEO products. The IR-PBT products are one band IMAGE files, which conform to the same format standards as the IR-BTR products. The IR-DCS products are stored as simple PNG image products, similar to the PDS standard BROWSE images.

2. GEOMETRIC PROCESSING

2.1 THEMIS Into 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 *THM2ISIS* tool is used to convert the PDS formatted IR-RDR or VIS-RDR image into an LEV-CUBE image that can be manipulated by subsequent ISIS software tools. At this time the label is initialized with geometric parameters, but the data values and image dimensions remain fundamentally unchanged.

When necessary, the default behavior of *THM2ISIS* can be modified for an image. The most common change is the selection of the kernels which define the orientation of the spacecraft during the acquisition of each image; the kernels used are specified in the ISIS_GEOMETRY object. The PDS2ISIS and LEVINIT HISTORY objects are generated during *THM2ISIS* 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 (Section 2.1) and the geometric projection products are completed by projecting the image into standard Mars coordinates. 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 3.3); some significant label entries are highlighted throughout this section using [].

2.2.1 THMIRMC

The ISIS *THMIRMC* tool is used to project the ISIS formatted modified IR-RDR data into a geometrically registered image cube. This tool translates the radiance values into the desired map projection by applying a bilinear interpolation algorithm [DNINTERP = “BILINEAR”, GEOM object], which incorporates the values of the four pixels closest to each mapped position. The spatial transformation is performed following the projection parameters defined for each image based on the conditions shown in Table 2.2.

Table 2.2: IR-GEO Map parameters

Map Parameter	Value	Application Conditions
kmres	0.1 km/pix	SPATIAL_SUMMING = 1
lonsys	180	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358
	360	2 < CENTER_LONGITUDE < 358
mappars	SINU:lon,OCENTRIC (where lon = default center longitude)	-70 < LATITUDE < 70
	POLA:+90,0	LATITUDE > 60
	POLA:-90,0	LATITUDE < -60

Unless otherwise noted, the infrared geometry product generated by these parameters is identified IooooonnnGGG.CUB.gz (see Section 3.1), where the value of “GGG” is the projection abbreviation.

2.2.2 Additional 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 3.4.3), as shown in Appendix 1.4.

The *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 *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. 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 may result in spatial distortions that are reversible using the parameters provided in the *RECTIFY* HISTORY object and the *RECONSTITUTE* algorithm.

The *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 *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.

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 IMGAGE objects, almost identical to the IR-BTR products; the only differences being that several of the important parameters from the IR-GEO History objects are available as keywords in the IR-PBT label (see Appendix A.2).

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 220 K and a minimum of eight bands (bands 3-10 required).

To generate a IR-DCS image, two final noise filters are applied to all available bands, 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 *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 (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 3.3); some significant label entries are highlighted throughout this section using [].

2.5.1 THMVISM

The ISIS *THMVISM* tool is used to project the ISIS formatted VIS-RDR data into a geometrically registered image cube. The spatial transformation is performed following the parameters defined for each image. Individual visible framelets are projected independently then mosaicked together per band, with the overlapping pixels taking the value of the downtrack framelets [TOP = “YES”]. Calibrated radiance values are translated into the desired map projection by applying a bilinear interpolation algorithm [DNINTERP = “BILINEAR”, GEOM object], which incorporates the values of the four pixels closest to each mapped position.

The map parameters used to project each visible image are determined by the conditions shown in Table 2.3. Unless otherwise noted, the visible geometry product generated by these parameters is identified VooooonnnLOC.CUB (see Section 3.1), where the abbreviation “LOC” recognizes that this is a local-latitude appropriate projection.

Table 2.5: VIS-GEO Local map parameters

Map Parameter	Value	Application Conditions
kmres	0.018 km/pix 0.036 km/pix 0.072 km/pix	SPATIAL_SUMMING = 1 SPATIAL_SUMMING = 2 SPATIAL_SUMMING = 4
lonsys	180 360	CENTER_LONGITUDE < 2 or CENTER_LONGITUDE > 358 2 < CENTER_LONGITUDE < 358
mappars	SINU:lon,OCENTRIC (where lon = default center longitude) POLA:+90,lon (where lon = meridian longitude) POLA:-90,lon (where lon = meridian longitude)	-60 < LATITUDE < 60 LATITUDE > 60 LATITUDE < -60

2.5.2 Additional Processing

Additional image processing may be applied to the VIS-GEO projected image cube. Each process described in this section generates a HISTORY object in the detached PDS label (see Section 3.4.3), as shown in Appendix 1.4.

The *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 *THMVISMIC* projection. When applied, all source VIS-RDR radiance values are significantly modified.

The *FEATHER* process is applied to cosmetically enhance the discontinuities along the overlapping framelet boundaries of a projected visible image. This cosmetic filter is applied in concert with the *THMVISMIC* projection of the visible framelets of each band, before they are mosaicked together into the final cube file. 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.

3. GEOMETRIC PRODUCT SPECIFICATIONS

3.1 Geometry Product Naming and Identification

3.1.1 Naming Conventions

Each THEMIS geometry image 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 3.3). The combinations used with the THEMIS geometry products are

- 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
- LOC.CUB identifies the VIS-GEO data product: a local-latitude appropriate projection, stored in a multi-spectral ISIS image cube
- LOC.LBL identifies the PDS detached label file for a 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 an IR-GEO data product: a polar projection, stored in a multi-spectral ISIS image cube
- POL.LBL identifies the PDS detached label file for an IR-GEO data product
- SNU.CUB identifies an IR-GEO data product: a sinusoidal projection, stored in a multi-spectral ISIS image cube
- SNU.LBL identifies the PDS detached label file for an IR-GEO 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` or `ODTIVGREL.CAT`), and by modifying records as necessary in the indexes (`INDEX_ODTxx`, `THMIDX_IR`, or `THMIDX_VIS`). See Appendix A.3 for label keyword definitions and the *THEMIS Archive SIS* [2] for document specifications.

3.2 Standards Used in Generating Geometry Products

3.2.1 PDS Standards & Data Processing Level

The THEMIS GEO 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.

3.2.2 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`.

3.2.3 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.1-3) in both 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. The Planet and Instrument kernels are static, and only the current version is used. The Spacecraft and Camera-matrix kernels are time dependant, 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.

3.2.4 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>.

3.3 Image Formats

The THEMIS geometry images maintain the ISIS CUBE format of the software from which they were generated [6]. Each CUBE is composed of an ASCII label attached to a core of uncompressed, binary, band-sequential qubes of scaled, 16-bit integer data.

Like the unprojected equivalent IR-BTR images, the THEMIS IR-PBT images are PDS standard IMAGE objects. See Section 2.3.3 of the *THEMIS Standard Data Products SIS* [5] for a description of this THEMIS file format.

3.3.1 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. Additional information may be stored in “suffix” planes (back, side, or bottom) as shown in Figure 1b. 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 CUBE

The data format of the THM-GEO CUBE is similar to the source THM-RDR QUBE, and both are stored as floating point values, scaled into 16-bit integers. To recover the floating point values, apply the following function to each data value per band (x_i)

$$y = m \cdot x + b$$

where m is the CORE_MULTIPLIER value and b is the CORE_BASE value, given in the CUBE label.

Missing image pixels and padding around the image data to square up the spatial dimensions are set to the CORE_NULL value. The total count of missing lines in an IR-GEO image is stored in the MISSING_SCAN_LINES keyword of the detached label.

3.3.2 ISIS CUBE Label Object

The CUBE object has an attached label containing pertinent observation information, and header data objects (Figure 2). A “keyword=value” text format, similar to the structure of the PDS Object Definition Language (ODL), define the CUBE structure, the CORE and suffix parameters, the geographic projection parameters, and the ISIS History. See the *Overview of ISIS Architecture* [7] for examples of the elements in this label.

Figure 2: Example of a ISIS CUBE: attached label, header data object, and image data

3.4 GEO Label Format

A PDS label describes the structure, content, and observation specifications of the data. It is a discrete ASCII text available with each image file. Information in the label is stored in a “keyword=value” text format and structured in the Object Definition Language (ODL) of PDS. Example labels are shown in Appendices A.1-A.2; individual keyword items are defined in Appendices A.3.

3.4.1 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.3 for a detailed description of these keywords.

3.4.2 QUBE Object Label

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.3 for a detailed description of the keywords used in the QUBE label.

3.4.3 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.4 for a detailed description of the entries and keywords used with THM-GEO HISTORY objects.

3.5 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 VIS-GEO images will be a factor of 1-4 larger than the source VIS-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 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. 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.

A. APPENDICES

Appendices A.1-2 contain example detached labels from THEMIS IR-GEO and VIS-GEO, with definitions of individual label keywords given in Appendix A.3. “Valid values” for each item are shown in [] at end of each description, as appropriate. Appendix A.4 contains definitions for the basic HISTORY keywords and example geometric HISTORY objects. Appendix A.5 contains geometric parameter fields available in the THEMIS indexes.

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-V1.0"  
PRODUCT_CREATION_TIME = 2009-03-25T17:41:41  
PRODUCT_VERSION_ID = "1.0"  
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
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)

/* Core Description */

CORE_ITEMS = (352,321,10)
CORE_NAME = "CALIBRATED_SPECTRAL_RADIANCE"
CORE_ITEM_BYTES = 4
CORE_ITEM_TYPE = PC_REAL
CORE_BASE = 0.000000e+00
CORE_MULTIPLIER = 1.000000e+00
CORE_UNIT = "WATT*CM**-2*SR**-1*UM**-1"
CORE_NULL = -32768
CORE_VALID_MINIMUM = -32752
CORE_LOW_REPR_SATURATION = -32767
CORE_LOW_INSTR_SATURATION = -32766
CORE_HIGH_REPR_SATURATION = -32765
CORE_HIGH_INSTR_SATURATION = -32764

/* Suffix Description */

SUFFIX_ITEMS = (1,0,0)
SUFFIX_BYTES = 4
SAMPLE_SUFFIX_NAME = RECTIFY_LEFTEDGE
SAMPLE_SUFFIX_ITEM_BYTES = 4
SAMPLE_SUFFIX_ITEM_TYPE = LSB_INTEGER
SAMPLE_SUFFIX_BASE = 0.000000
SAMPLE_SUFFIX_MULTIPLIER = 1.000000
SAMPLE_SUFFIX_VALID_MINIMUM = 16#FF7FFFA#
SAMPLE_SUFFIX_NULL = 16#FF7FFFB#
SAMPLE_SUFFIX_LOW_REPR_SAT = 16#FF7FFFC#
SAMPLE_SUFFIX_LOW_INSTR_SAT = 16#FF7FFFD#
SAMPLE_SUFFIX_HIGH_REPR_SAT = 16#FF7FFFF#
SAMPLE_SUFFIX_HIGH_INSTR_SAT = 16#FF7FFFE#

```

/* 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

END

```

A.2 Example Label: IR-PBT

An example IR-PBT label is shown below:

```

PDS_VERSION_ID = PDS3
FILE_NAME = "I33413035PBT.IMG"
RECORD_TYPE = "FIXED_LENGTH"
RECORD_BYTES = 419
FILE_RECORDS = 336
LABEL_RECORDS = 6
^IMAGE = 7

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,-20,0)
SPACECRAFT_POINTING_MODE = "HGA_MITIGATION_R-20"
^SPACECRAFT_POINTING_MODE_DESC = "ODY_ORIENT_POINT.TXT"
TARGET_NAME = "MARS"
PRODUCT_ID = "I33413035PBT"
PRODUCER_ID = "ODY_THM_TEAM"
DATA_SET_ID = "ODY-M-THM-5-IRPBT-V1.0"
PRODUCT_CREATION_TIME = 2009-07-07T20:28:08
PRODUCT_VERSION_ID = "1.0"
SOURCE_PRODUCT_VERSION_ID = "1.0"
RELEASE_ID = "0028"
START_TIME = 2009-06-26T13:39:06.870
STOP_TIME = 2009-06-26T13:39:15.936
SPACECRAFT_CLOCK_START_COUNT = "930491180.025"
SPACECRAFT_CLOCK_STOP_COUNT = "930491189.042"
START_TIME_ET = 299295613.1
STOP_TIME_ET = 299295622.1
UNCORRECTED_SCLK_START_COUNT = "930491180.025"
IMAGE_DURATION = 9.067
ORBIT_NUMBER = 33413

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

GEOMETRY_SOURCE_DESC = "Reconstructed"
PDS2ISIS_VERSION = "2004-05-28"
GEOM_VERSION = "2004-06-17"
CUBEIT_VERSION = "2004-06-17"
LONGITUDE_SYSTEM = 360
MINIMUM_LATITUDE = 70.3685
MAXIMUM_LATITUDE = 70.905
CENTER_LONGITUDE = 55
WESTERNMOST_LONGITUDE = 53.408
EASTERNMOST_LONGITUDE = 55.5926
MAP_RESOLUTION = 592.747
MAP_SCALE = 0.1
MAP_PROJECTION_TYPE = "SINUSOIDAL"
PROJECTION_LATITUDE_TYPE = "PLANETOCENTRIC"
LINE_PROJECTION_OFFSET = -42028.5
SAMPLE_PROJECTION_OFFSET = -317.5

```
ASU_PROCESSES = "PROJECT; RECTIFY; RECONSTITUTE"  
MINIMUM_BRIGHTNESS_TEMPERATURE = 152.701  
MAXIMUM_BRIGHTNESS_TEMPERATURE = 163.601
```

```
OBJECT = IMAGE  
  LINES = 330  
  LINE_SAMPLES = 419  
  SAMPLE_TYPE = UNSIGNED_INTEGER  
  SAMPLE_BITS = 8  
  SAMPLE_NAME = "BRIGHTNESS_TEMPERATURE"  
  SAMPLE_UNIT = K  
  NULL_CONSTANT = 0  
  OFFSET = 152.701  
  SCALING_FACTOR = 0.042744  
  MD5_CHECKSUM = "dea37efdfefd89e7195171bf33c3dbc5"  
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 = ("V01001004.loc.cub")  
^QUBE = ("V01001004.loc.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 = "V01001004LOC"
DATA_SET_ID = "ODY-M-THM-5-VISGEO-V1.0"
PRODUCT_CREATION_TIME = 2004-12-07T13:28:26
PRODUCT_VERSION_ID = "1.0"
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
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

END

A.4 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.

^SPACECRAFT_POINTING_MODE_DESC

Pointer to 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. [“Aooooonnggg”]

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-V1.0”, “ODY-M-THM-5-VISGEO-V1.0”]

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 THM-GEO image.

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 THM-GEO image.

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.

ORBIT_NUMBER

Spacecraft orbit during which this image was observed.

HISTORY STRUCTURE

See Appendix A.4

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)]

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. [MSB_INTEGER]

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.

SUFFIX DESCRIPTION (IR-GEO QUBEs only)

SUFFIX_ITEMS

The dimensions of available suffix planes following the order given in AXIS_NAME keyword. [(1, 1, 0)]

SUFFIX_BYTES

The allocation in bytes of each suffix plane defined. [4]

AXIS_SUFFIX_NAME

Name of “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [HORIZONTAL_DESTRIPE (for SAMPLE suffix planes) or VERTICAL_DESTRIPE (for LINE suffix planes)]

AXIS_SUFFIX_ITEM_BYTES

Size of “axis” suffix plane elements in bytes, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [2]

AXIS_SUFFIX_ITEM_TYPE

“Axis” suffix plane element type, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [LSB_INTEGER]

AXIS_SUFFIX_BASE

Base value of “axis” suffix plane item scaling, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs.

AXIS_SUFFIX_MULTIPLIER

Multiplier for “axis” suffix plane item scaling, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs.

AXIS_SUFFIX_VALID_MINIMUM

Value of the minimum valid “axis” suffix plane data, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFA#]

AXIS_SUFFIX_NULL

Value assigned to “invalid” or missing data in an “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFB#]

AXIS_SUFFIX_LOW_REPR_SATURATION

Value of representation saturation at the low end in an “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFC#]

AXIS_SUFFIX_LOW_INSTR_SATURATION

Value of instrument saturation at the low end in an “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFD#]

AXIS_SUFFIX_HIGH_REPR_SATURATION

Value of representation saturation at the high end in an “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFF#]

AXIS_SUFFIX_HIGH_INSTR_SATURATION

Value of instrument saturation at the high end in an “axis” suffix plane, where “axis” can be either SAMPLE or LINE in IRRDR QUBEs. [16#FF7FFFFE#]

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 data portion of the QUBE. Corruption of the data QUBE 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).

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).

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 STRUCTURE & GEOMETRIC PARAMETERS (IMAGEs only)

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"]

PDS2ISIS_VERSION

Version of ISIS software algorithm PDS2ISIS used during the projection of this image ["yyyy-mm-dd"].

GEOM_VERSION

Version of ISIS software algorithm GEOM used during the projection of this image ["yyyy-mm-dd"].

CUBEIT_VERSION

Version of ISIS software algorithm CUBEIT used during the projection of this image ["yyyy-mm-dd"].

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.

MINIMUM_LATITUDE

The northernmost latitude on the planet Mars of the image.

MAXIMUM_LATITUDE

The southernmost latitude on the planet Mars of the image.

CENTER_LONGITUDE

Approximate longitude on the planet Mars at the image center.

WESTERNMOST_LONGITUDE

The longitude on the planet Mars at the image western edge.

EASTERNMOST_LONGITUDE

The longitude on the planet Mars at the image eastern edge.

MAP_RESOLUTION

The scale of the image in pixels per degree.

MAP_SCALE

The scale of the image in kilometers per pixel.

MAP_PROJECTION_TYPE

The type of projection applied to this image ["SINUSOIDAL"].

PROJECTION_LATITUDE_TYPE

The type of latitude that is sample in equal increments by successive image lines ["PLANETOCENTRIC"].

LINE_PROJECTION_OFFSET

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

SAMPLE_PROJECTION_OFFSET

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

ASU_PROCESSES

Simple list identifying the ASU processes that have been applied to this image; a more complete description of these processes may be available in the Appendix A.5 examples.

RECTIFY_WIDTH

Parameter of the ASU Rectify process which describes the original width of the projected image.

RECTIFY_ANGLE

Parameter of the ASU Rectify process which describes the amount of rotation required to make the top line of a projected image parallel to the x-axis of 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.

SAMPLE_NAME

Identifies the scientific meaning of each pixel value
["BRIGHTNESS_TEMPERATURE"] .

SAMPLE_UNIT

Identifies the scientific unit of each pixel value [K].

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.

A.5 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	= <i>The name of the program that generated the history entry.</i>
DATE_TIME	= <i>Date and time, in UTC standard format, that the program was executed. [yyyy-mm-ddThh:mm:ss]</i>
SOFTWARE_DESC	= <i>Program generated description and execution notes.</i>
VERSION_ID	= <i>Program version number.</i>
USER_NAME	= <i>Username and name of computer. [“marvin@mars”]</i>
USER_NOTE	= <i>User supplied brief description of program; may be blank.</i>
GROUP	= <i>Used to delineate the statements specifying the parameters of the program; will not be present if additional keywords are not required.</i>
	[PARAMETERS]
KEYWORD	= <i>Value.</i>
END_GROUP	= [PARAMETERS]
END_GROUP	= <i>The name of the program that generated the history entry.</i>
END	

THM-GEO labels contain the cumulative processing history of the observation. The HISTORY objects generated during THEMIS standard data processing (THM-EDR, THM-RDR, THM-BTR, or THM-ABR) 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 PROJECTION HISTORY OBJECT

GROUP = ISIS_PROJECTION

DATE_TIME = 2004-12-07T13:28:26

SOFTWARE_DESC = "ISIS geometric projection of a THEMIS QUBE.

Process includes translation of file formats (PDS2ISIS and LEVINIT); determining the valid core data range (DSK2DSK); geometric transformation of image planes (GEOM); and merging the individual bands back together (MOSAIC and CUBEIT). See header of resulting ISIS cube for more details of projection.

The ISIS_COMMAND parameter may also include additional processing steps that are described in other HISTORY groups in this label."

VERSION_ID = "2003-07-23T23:51:07-7"

USER_NAME = "marvin@mars"

USER_NOTE = ""

GROUP = PARAMETERS

GEOMETRY_SOURCE_DESC = "Reconstructed"

ISIS_COMMAND = "feather.dv V010XXRDR/V01001002RDR.QUB \
SINU:315,OCENTRIC 0.018 --"

PDS2ISIS_VERSION = " 2003-06-17"

GEOM_VERSION = "1995-06-16"

MOSAIC_VERSION = " 2003-07-01"

LONGITUDE_SYSTEM = 360

MINIMUM_LATITUDE = -9.0765104

MAXIMUM_LATITUDE = -8.0947313

CENTER_LONGITUDE = 315.0000000

WESTERNMOST_LONGITUDE = 315.2828979

EASTERNMOST_LONGITUDE = 315.7157593

MAP_RESOLUTION = 3293.0387513

MAP_SCALE = 0.0180000

MAP_PROJECTION_TYPE = "SINUSOIDAL_EQUAL-AREA"

PROJECTION_LATITUDE_TYPE = "PLANETOCENTRIC"

LINE_PROJECTION_OFFSET = 26656.000000

SAMPLE_PROJECTION_OFFSET = 920.000000

END_GROUP = PARAMETERS

END_GROUP = ISIS_PROJECTION

IR-GEO UDDW HISTORY OBJECT

GROUP = ASU_PROCESS_UDDW
DATE_TIME = 2009-03-25T17:41:41
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."
VERSION_ID = 1.80
USER_NAME = "thmproc@c145.mars.asu.edu"
END_GROUP = ASU_PROCESS_UDDW

IR-GEO RECTIFY HISTORY OBJECT

GROUP = ASU_PROCESS_RECTIFY
DATE_TIME = 2008-12-31T2hh: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 may result in spatial distortions that are reversible using the parameters provided."
VERSION_ID = 2005.07
USER_NAME = "thmproc@c145.mars.asu.edu"
USER_NOTE = ""
GROUP = PARAMETERS
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

IR-GEO Auto-RADCOR HISTORY OBJECT

GROUP = ASU_PROCESS_ARADCOR
DATE_TIME = 2008-12-31T3hh: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 = 2005.07
USER_NAME = "thmproc@c145.mars.asu.edu"
USER_NOTE = ""
END_GROUP = ASU_PROCESS_DCS

VIS-GEO COFF HISTORY OBJECT

GROUP = ASU_PROCESS_COFF
DATE_TIME = 2005-08-19T17:00:
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 = 2005.07
USER_NAME = "smith@mars"
USER_NOTE = ""
GROUP = PARAMETERS
FLATFIELD_FILE = "/themis/data/flat_frames12.profl.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 = 2004-12-07T13:28:26
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, if necessary, ramps brightness differences back towards the start of the framelet. All values in the resulting cube may have been significantly modified from the source VIS-RDR values."
VERSION_ID = 2003.11
USER_NAME = "smith@mars"
USER_NOTE = ""
END_GROUP = ASU_PROCESS_FEATHER

ERRATA HISTORY OBJECT

GROUP = ERRATA_ODTVG_0001_1_1
DATE_TIME = "2005-09-01T00:00:00"
SOFTWARE_DESC = "Description of the change which required the regeneration of this product.

Associated ERRATA_ID: ODTVR_0001-1.5"
ERRATA_ID = "ODTIG-0011-1.1"
USER_NAME = "marvin@mars"
USER_NOTE = ""
END_GROUP = ERRATA_ODTVG_0001_1_1

A.6 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

