CRISM Instrument, Mission, and Data Set Description

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Topics to be Discussed

• Instrument characteristics
  – Hardware overview
  – Data configuration and characteristics
  – Basic instrument operation
• Observing strategies / campaigns
  – Global Mapping Campaign
  – Atmospheric / Seasonal Change Campaign
  – Targeted Observations
• Observing modes and observation types
  – Gimbaled: FRT, HRL, HRS, EPF
  – Nadir: MSP, MSW, TOD
• Calibration pipeline
• CRISM data set description (EDR, DDR, TRDR, MRDR, CDR)
CRISM is 1 of 6 MRO Instruments to Map Mars’ Surface and Atmosphere

CRISM, HiRISE, and CTX characterize surface geologic features.

MARCI, MCS, and CRISM track spatial and seasonal variations in the atmosphere.
CRISM Hardware Overview

- **Optical Sensor Unit**
- Baffle with 1-time deployed cover cuts out of field stray light
- Radiator pointing toward evening terminator cools spectrometer optics to -70°C to -80°C
- **Gimbal Motor Electronics** controls gimbal
- Internal calibration: shutter for dark measurements, integrating sphere for radiometric calibration

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<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Wavelength range</strong></td>
<td>0.4-3.9 µm</td>
</tr>
<tr>
<td><strong>Spectral sampling</strong></td>
<td>6.55 nm/channel</td>
</tr>
<tr>
<td><strong>Spatial sampling</strong></td>
<td>18 m/pixel from 300 km</td>
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</tbody>
</table>
CRISM Optics

Detectors are located out of the optical plane.

3 shutter positions: open, sphere, closed

Detectors are located out of the optical plane.
VNIR Detector (0.36-1.05 μm)
IR Detector (1.00-3.92 μm)

Image brightness

Pixel functions

No data

Scattered light pixels

Masked pixels

No data

Optical "zones" on detector
Each readout of the detector is 1 line of a spatial image. The whole image is built as MRO moves along its ground track.

Each pixel has a spectrum whose absorptions can be compared with minerals.
Key Instrument Settings Control the Type of Observation being Taken

- **Pointing**
  - Fixed at nadir
  - Track a point and repeatedly scan across it

- **Number of wavelengths**
  - All 544 with useful data
  - 3 programmable options (72, 94, or 262 selected wavelengths) for regional/global mapping

- **Frame rate**
  - 1 Hz (for internal calibration)
  - 3.75 Hz (hyperspectral observations)
  - 15 or 30 Hz (multispectral mapping)

- **Spatial pixel binning**
  - None (18 m) or 2x (36 m) for high-resolution observations
  - 5x (100 m) or 10x (200 m) for global mapping
First Basic Observation Type: Gimbaled
(example shown is Full-Resolution Targeted)

- "Targeted" because typically ≥2 instruments participate
- ≥11 images at varying emission angles:
  "Emission phase function"
- Central image may be unbinned (18 m/pixel), 2x binned (36 m/pixel), or 10x binned (~180 m/pixel)
- 1st 5 and last 5 are 10x binned
- Central high-resolution image for geology; whole set to separate surface/atmosphere
Gimbaled Observation Actual Footprints

Central swath only

Central swath + EPF sequence
Second Basic Observation Type: Nadir
(example shown is Multispectral Survey)

- Lower-resolution global map to provide context and to find new targets
- 72 selected wavelengths, 10x-binned spatially to 200 m/pixel
- Multispectral "noodles" mosaicked to create global map

1 orbit 3-min segment

72 colors 544 colors
Campaign 1: Multispectral Survey to Provide Global Context and Find Targets

This is implemented using nadir pointing, collecting 72 colors at 200 m/pixel. During MRO's Primary Science Phase 55% of Mars was mapped at low atmospheric opacity.
Three types of observations contribute to monitoring the atmosphere

- A globally distributed grid of fully 10x-binned EPFs every ~9° of Ls measures aerosols and trace gases.
- The EPFs accompanying targeted observations increase spatial and temporal sampling.
- During the time between targeted observations, EPFs, and mapping observations, periodic bursts of nadir-pointed hyperspectral data monitor trace gases.
9,514 targeted observations were taken during MRO's PSP. 6,674 were at full resolution (18 m/pixel) and 2,840 were at half resolution (36 m/pixel). The highest concentrations are at phyllosilicate, sulfate, and chloride deposits discovered by OMEGA and THEMIS.
As many CRISM observations as possible are taken with coordinated HiRISE and/or CTX images so that both spectral properties and morphology are characterized.

Where data volumes prohibit CRISM hyperspectral targeted observations being coordinated with HiRISE, 100 or 200 m/pixel multispectral data are taken.
**Different Types of Observations Result from the Instrument Settings**

<table>
<thead>
<tr>
<th>Observing Campaign</th>
<th>Gimbal Pointing and Number of Images</th>
<th>Observations Type and Description</th>
<th>Data Product Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Targeted Observations</strong></td>
<td>Gimbal tracks surface with superimposed scan for each image 1 high-resolution image, 10 reduced-resolution EPF images</td>
<td>Full resolution targeted Spatial pixels unbinned for target (18 m/pixel @300 km) Spatial pixels 10x binned for EPFs</td>
<td>FRT*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Half resolution short targeted Spatial pixels 2x binned for target (36 m/pixel @300 km) Spatial pixels 10x binned for EPFs</td>
<td>HRS*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Half resolution long targeted Spatial pixels 2x binned for target (36 m/pixel @300 km; 2x swath length as above) Spatial pixels 10x binned for EPFs</td>
<td>HRL*</td>
</tr>
<tr>
<td><strong>Atmospheric Survey</strong></td>
<td>Gimbal track surface with superimposed scan for each image 11 or 13 reduced-resolution images</td>
<td>EPF; spatial pixels 10x binned (~200 m/pixel @300 km) 9° lon. x 11° lat. grid every ~36° of Ls 27° lon. x 11° lat. grid every ~5° of Ls</td>
<td>EPF*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nadir-pointed; multiple images</td>
<td>Tracking Optical Depth Spatial pixels 10x binned (200x900 m/pixel @300 km)</td>
</tr>
<tr>
<td><strong>Multispectral Survey</strong></td>
<td>Nadir-pointed; multiple images</td>
<td>Multispectral survey 72 channels, spatial pixels 10x binned (~200 m/pixel @300 km)</td>
<td>MSP*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multispectral windows 72 channels, spatial pixels 5x binned (~100 m/pixel @300 km)</td>
<td>MSW*</td>
</tr>
</tbody>
</table>
Map View / Usage of Different Types of Observations

FRT: 18 m/pixel, 544 channels. High-priority targets.

HRS: 36 m/pixel, 544 channels. Where data volume is limited.

HRL: 36 m/pixel, 544 channels. Where coverage is more important than high resolution.

MSP: 200 m/pixel, ≥72 channels. Long strips for global mapping.

MSW: 100 m/pixel, 72 channels. Ride-alongs with HiRISE when data volume is limited.

TOD: 180x900 m/pixel, 544 channels. Hyperspectral samples of atmospheric transmission to monitor trace gases.

EPF: 10-13 images at 180 m/pixel, 544 channels. Free-standing for atmospheric monitoring. Also included with FRT, HRL, HRS.
A Collection of Related Images is an "Observation"

The central image is unbinned so this is a Full-Resolution Targeted Observation (FRT)

File names for all the images share a unique 8-digit hex target ID, e.g., 00003E12

Each of the images has a unique hex counter in the file name (00, 01, …, 0D, 0E)
Each Observation is Processed to Multiple Levels

- All images in all observations:
  - **Experiment Data Records (EDRs):** raw data

- Shutter-open images aimed at Mars:
  - **Targeted Reduced Data Records (TRDRs):** calibrated to radiance and I/F
  - **Derived Data Records (DDR):** "backplanes" with latitude, longitude, photometric angles, and other information for each image pixel in the TRDRs. Lat/lon support map projection, and photometric angles and ancillary information support correction for illumination and atmospheric effects.

- Images of the integrating sphere, or dark images embedded within Mars observations:
  - **Calibration Data Records (CDRs):** matrices used to calibrate scene data.
  - Other CDRs are derived from ground calibrations.

- NOTE: The calibration process is complicated and users are not recommended to attempt to redo processing themselves. EDRs and CDRs are provided for archival purposes. The main data of interest are TRDRs and DDRs.
Raw Data Format (EDR)
Separate VNIR and IR EDRs

A multiband image of raw data formatted from the telemetry stream; assembled from multiple frames

A separate ASCII table giving the instrument housekeeping associated with each frame of the data

A detached PDS label giving the observation time and setup and the names of the CDRs having information needed to interpret the raw data
EDR Nomenclature

- **FRT** = Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long Targeted Observation)
  - HRS (Half Resolution Short Targeted Observation)
  - EPF (Atmospheric Survey EPF)
  - TOD (Tracking Optical Depth Observation)
  - MSP (Multispectral Survey)
  - MSW (Multispectral Window)
  - CAL (Generic calibration; internal)
  - ICL (Integrating sphere calibration; internal)
  - FFC (Flat Field Calibration; Mars-pointed)
- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter for image number within observation
- **SC166** = Activity and the internal command macro used
  - Blnnn – Bias measurements / Macro#
  - DFnnn – Dark field measurements / Macro#
  - SPnnn – Sphere measurements / Macro #
  - SCnnn – Scene measurements / Macro #
- **L** = Sensor ID
  - S for VNIR
  - L for IR
- **EDR0** = EDR, version 0
- **IMG** = file extension
  - IMG for binary image data
  - LBL for detached ASCII PDS label
  - TAB for detached ASCII table of instrument housekeeping (EDR and TRDR only)

**FRT00003E12_07_SC166L_EDR0:**
The file name fully describes the type of data, which detector it comes from, the version of the processing, and gives the unique ID and counter.
• **The current version of radiometric calibration is v2**
  • All scene images are calibrated to radiance using internal calibrations to remove time-variable instrumental effects
  • The first correction is to subtract shutter-closed dark measurements from the scene and from a sphere measurement taken close in time
  • The scattered light columns are used to estimate and remove grating glare
• The corrected scene and sphere images are both divided by exposure time to yield values linearly related to radiance.
• The scene is ratioed to the sphere, and multiplied by a ground-based model of the sphere's radiance.
• The result is scene radiance.

\[
\frac{\text{Corrected sphere image, units DN}}{\text{exp time}} \times \frac{\text{Corrected scene image, units DN}}{\text{exp time}} = \text{Scene radiance, units W m}^{-2} \text{ sr}^{-1} \text{ m}^{-1}
\]
Simplified Calibration Pipeline (3/3)

- To convert radiance to I/F, the solar flux at 1 AU is convolved with the bandpasses for each CRISM pixel
- The radiance is divided by the solar flux scaled to Mars' solar distance
- The result is I/F

\[
\text{Scene radiance, units } \frac{\text{W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}}{\text{solar distance in AU} \times \pi}
\]

\[
= \frac{\text{Solar flux at 1 AU, units } \frac{\text{W m}^{-2} \mu\text{m}^{-1}}}{\text{Scene I/F, unitless}}
\]
Calibrated Data Format (TRDRs)
Separate VNIR and IR TRDRs

Scene radiance, units W m⁻² sr⁻¹ μm⁻¹

Multiband image of radiance; assembled from multiple frames

A separate ASCII table with housekeeping from each frame of the data

Detached PDS label for each image, giving the observation time and setup, and all the CDRs used to process the data

Scene I/F, unitless

Multiband image of I/F; assembled from multiple frames
TRDR Nomenclature

- **FRT** = Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long Targeted Observation)
  - HRS (Half Resolution Short Targeted Observation)
  - EPF (Atmospheric Survey EPF)
  - TOD (Tracking Optical Depth Observation)
  - MSP (Multispectral Survey)
  - MSW (Multispectral Window)

- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter for image number within observation
- **IF166** = Processing and the internal command macro used
  - RAnnn – Radiance / Macro#
  - IFnnn – I/F / Macro#

- **L** = Sensor ID
  - S for VNIR
  - L for IR

- **TRR0** = TRDR, current version = 2

- **IMG** = file extension
  - IMG for binary image data
  - LBL for detached ASCII PDS label
  - TAB for detached ASCII table of instrument housekeeping (EDR and TRDR only)

**FRT00003E12_07_IF166L_TRR2**: The file name fully describes the type of data, which detector it comes from, the version of the processing, and gives the unique ID and counter.
Format of Backplanes (DDRs)
Separate VNIR and IR DDRs

- Core information in the DDRs includes lat, lon, i, e, and g for every pixel, used for map projection and photometric correction
- Additional information includes elevation, slope magnitude and azimuth, and TES bolometric albedo and thermal inertia for correction of thermal and atmospheric contributions

Backplanes, various units

Multiband images of backplanes; one-for-one correspondence with spatial position in TRDR

A detached PDS label gives the companion observation, its time and setup, and describes each layer of the DDR
• **FRT** = Class Type
  – FRT (Full Resolution Targeted Observation)
  – HRL (Half Resolution Long Targeted Observation)
  – HRS (Half Resolution Short Targeted Observation)
  – EPF (Atmospheric Survey EPF)
  – TOD (Tracking Optical Depth Observation)
  – MSP (Multispectral Survey)
  – MSW (Multispectral Window)
• **00003E12** = 8-digit hexadecimal Observation ID
• **07** = Hex counter for image number within observation
• **DE166** = Processing and the internal command macro used
  – DEnnn – Derived information / Macro#
• **L** = Sensor ID
  – S for VNIR
  – L for IR
• **DDR1** = DDR, current version = 1
• **IMG** = file extension
  – IMG for binary image data
  – LBL for detached ASCII PDS label

**DDR00003E12_07_DE166L_DDR1**: The file name fully describes the companion observation, its type of data, which detector it comes from, and the version of the processing
Usage of DDRs

$I/F$ in sensor space

Latitude, longitude, incidence, emission, and phase angle

Map-projected, photometrically and atmospherically corrected $I/F$

Note: Map convention is planetocentric, positive east longitude
• CRISM's global multispectral survey mapping exists at the TRDR level as about 64,000 distinct TRDRs each with a companion DDR.
• The data are projected into 1,964 "tiles" organized by Mars charts (MC01-MC30) divided into 5° latitude tiles with variable longitude width.
• 3 parallel products:
  – I/F with backplanes, and the table of included wavelengths
  – Atmospherically corrected Lambert albedo, with backplanes for data used
  – "Summary products" (spectral indices derived from Lambert albedo)
MRDR Format: I/F Data

- The most basic version of the MRDRs simply has map-projected I/F, stacked so that lowest incidence angle is on top.
- There is a companion file with DDR information for each strip to support data mining and corrections.

Multiband image of map-projected I/F (shown with lat/lon grid and overlain on THEMIS day IR) Detached ASCII file giving wavelengths of each band Detached PDS label giving the file history and map projection information

```
1,192, 419.12
1,197, 442.63
1,211, 533.74
1,224, 590.86
1,229, 658.09
1,234, 683.89
1,238, 769.68
1,243, 742.59
1,248, 774.52
1,252, 801.64
1,257, 833.60
1,261, 859.62
1,266, 892.48
1,271, 925.46
1,278, 951.32
1,280, 984.81
0,442, 1021.80
1,286, 1023.27
8,430, 1870.20
1,291, 1855.09
8,433, 1879.06
0,442, 1882.86
0,443, 1211.49
0,447, 1258.46
0,446, 1257.61
0,445, 1263.57
0,443, 1275.70
0,395, 1329.22
0,389, 1368.61
0,388, 1394.89
0,388, 1427.73
0,374, 1467.16
0,369, 1509.03
0,360, 1586.61
0,360, 1559.21
0,350, 1625.09
0,345, 1652.92
0,340, 1698.82
```

/* Map projection information about this RDR is in the IMAGE_MAP_PROJECTION */
/* object below.*/

```
DECRET = IMAGE
LINES = 1280
LINE_SAMPLES = 3436
SAMPLE_TYPE = 255
SAMPLE_BITS = 32
UNIT = "I over F"
BAND = 72
BAND_STORAGE_TYPE = BANDSEQUENTIAL
END_OBJECT = IMAGE

/* Data set map projection */
DATA_SET_MAP_PROJECTION = "MRDR_MAP.BAT"
PRJ_TYPE = "EQUIDISTANT"
LAT_RADIUS = 2296.456
LONG_RADIUS = 2296.456
FIRST_STANDARD_PARALLEL = "N/A"
SECOND_STANDARD_PARALLEL = "N/A"
CENTER_LATITUDE = 22.560000 <DEGREES>
CENTER_LONGITUDE = 87.560000 <DEGREES>
REFERENCE_LATITUDE = "N/A"
REFERENCE_LONGITUDE = "N/A"
LINE_FIRST_PIXEL = 1
LINE_LAST_PIXEL = 1280
SAMPLE_FIRST_PIXEL = 1
SAMPLE_LAST_PIXEL = 1280
MAP_RESOLUTION = 8.0
SCALE = 235 <PIXEL/DEGREE>
MAX_LATITUDE = 22.560000 <DEGREES>
MIN_LATITUDE = 22.560000 <DEGREES>
WESTERNMOST_LONGITUDE = 87.560000 <DEGREES>
EASTERNMOST_LONGITUDE = 87.560000 <DEGREES>
LINE_PROJECTION_OFFSET = 0
SAMPLE_PROJECTION_OFFSET = 0
COORDINATE_SYSTEM_TYPE = "PLANETOCENTRIC"
END_OBJECT = IMAGE_MAP_PROJECTION
```
A parallel version has data corrected for photometric and atmospheric effects to "Lambert albedo."

There is a companion file with DDR information for each strip to support data mining. There are fewer strips than in the I/F data.

Multiband image of map-projected Lambert albedo (shown with lat/lon grid and overlaid on THEMIS day IR) Detached ASCII file giving wavelengths of each band Detached PDS label giving the file history and map projection information
• The final version includes spectral indices ("summary products") that show variations in absorptions due to mineralogic and atmospheric species.
• Filtering is applied in sensor space prior to map projection to reduce noise.

Multiband image of spectral indices (shown with lat/lon grid and overlain on THEMIS day IR)

Detached PDS label giving the file history and map projection information
MRDR Nomenclature

- **T0750** = Tile number with tile 0000 at the south pole, increasing spiraling east and north
- **MRR** = Product Type
- **IF** = Subtype of product, e.g.
  - IF – I/F
  - DE – backplanes for I/F
  - AL – Lambert albedo
  - DL – backplanes for Lambert albedo
  - SU – Summary Products
  - WV – List of wavelengths in I/F and Lambert albedo
- **15** = Planetocentric latitude of upper left corner
- **S** = Hemisphere
  - N for north latitude
  - S for south latitude
- **098** = East longitude of upper left corner
- **0256** = Resolution, in map-projected pixels per degree
- **1** = version
- **IMG** = file extension
  - IMG for binary image data
  - LBL for detached ASCII PDS label
  - TAB for table of wavelengths

The file name fully describes the location of the tile, the level of processing, the map scale, and the version of the data.
• Several ground- and flight-derived measurements useful for data processing are stored as CDRs.
• The name of each CDRs includes a 2-letter designation of its type; machine-readable characters indicate the corresponding start time and instrument configuration.
• The WA CDR records "spectral smile," or how each spatial pixel has a slightly different wavelength calibration.
CDRs Useful for Further Processing: AT

- The AT CDR records the scaled atmospheric transmissivity as a function of wavelength.
- Measured using the base and summit of Olympus Mons.
- This is used to correct for attenuation due to atmospheric gases.
Caveats to the Current Calibration: "Bad Channels"

- At boundaries of detector zones, wavelengths with calibration uncertainties can be excluded:
  - VNIR: <410, 644-684 nm, >1023 nm.
  - IR: <1021 nm, 2694 and 2701 nm, and >3924 nm.
  - IR surrounding 3180 nm if a sharp peak or trough occurs.

- Between-scene comparisons of the following wavelengths are suspect, but intra-scene relative variations are valid:
  - VNIR: <442 nm, ≥ 970 nm
  - IR: <1047 nm, 2660-2800 nm >3700 nm

- Calibration v. 3 (late 2009) will improve some artifacts.
Where to Find More Information

- **Pre-print of CRISM PSP Investigation summary** ("Murchie_CRISMPSP_submit.pdf")
  - As-flown Primary Science Phase investigation
  - Intermediate level of detail on instrument and calibration
  - Data processing
  - Data accuracy and precision, and significant artifacts and caveats

**Also:**

- **CRISM Data Set Specification**
  - Descriptions of all CRISM data files

- **Pre-print of CRISM instrument paper**
  - Description of the instrument and its functions
  - Overview of performance
  - How observations are commanded

- **CRISM Data Product Specification**
  - Full detail on contents of all CRISM files
  - Descriptions of all label keywords and housekeeping items
  - Detailed description of radiometric calibration