CRISM Instrument, Mission, and Data Set Description

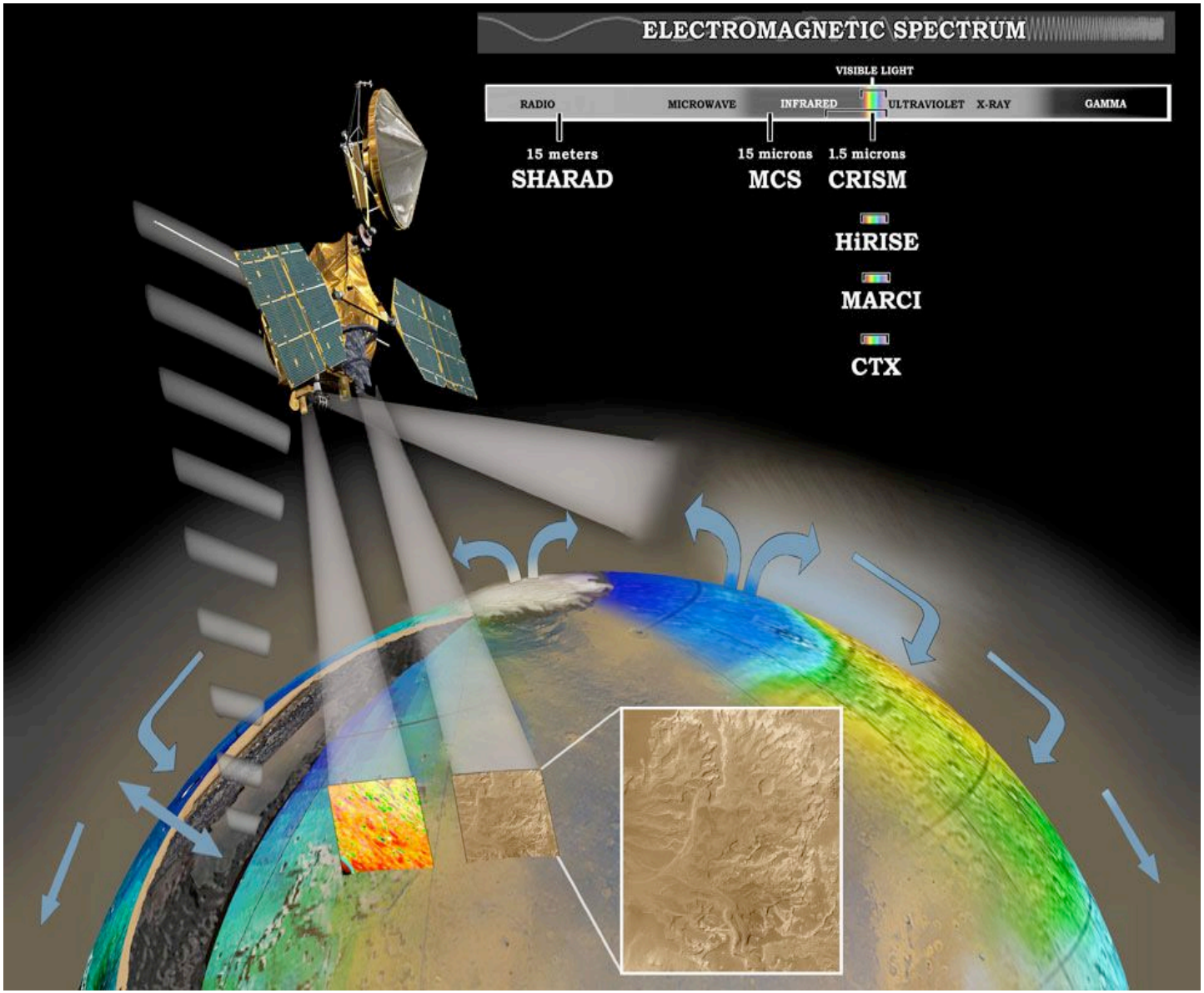
22 March 2009

Scott L. Murchie and the CRISM team

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



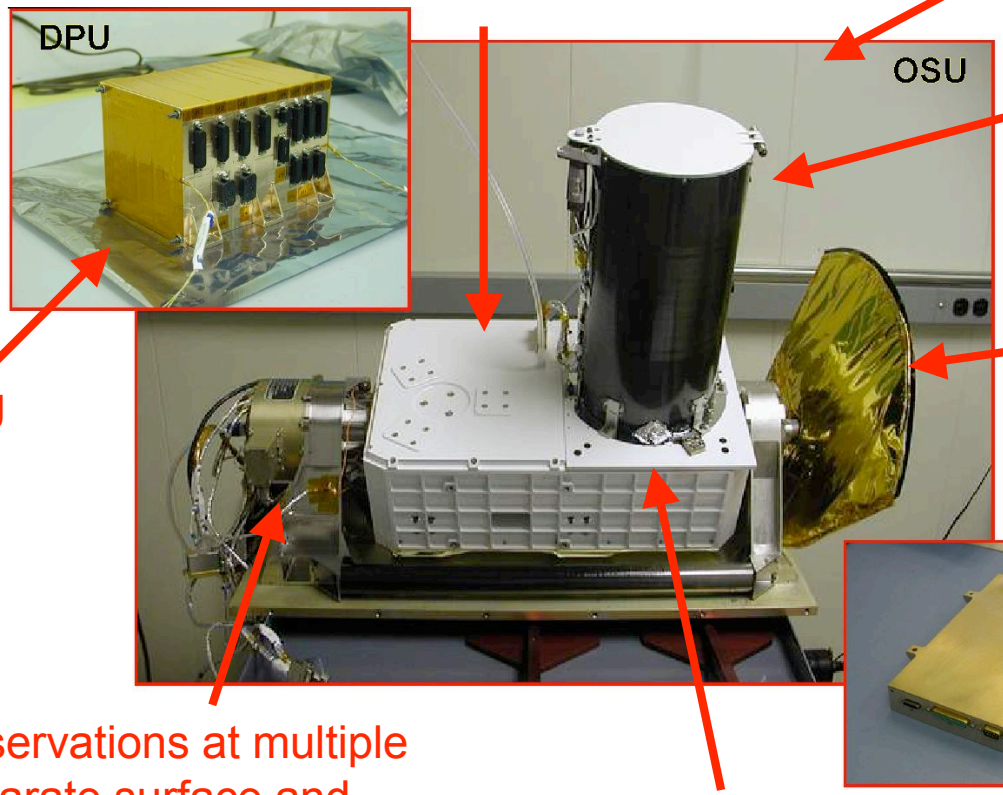
CRISM, HiRISE, and CTX characterize surface geologic features

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

CRISM Hardware Overview

3 cryocoolers keep IR detector at 110-125K to control noise

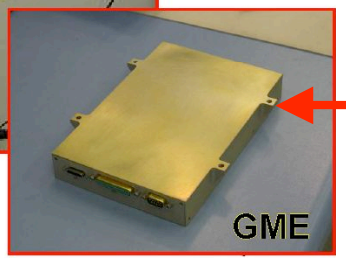
Optical **S**ensor **U**nit



Baffle with 1-time deployed cover cuts out of field stray light

Radiator pointing toward evening terminator cools spectrometer optics to -70C to -80C

Data **P**rocessing **U**nit controls data acquisition, pixel binning, data editing



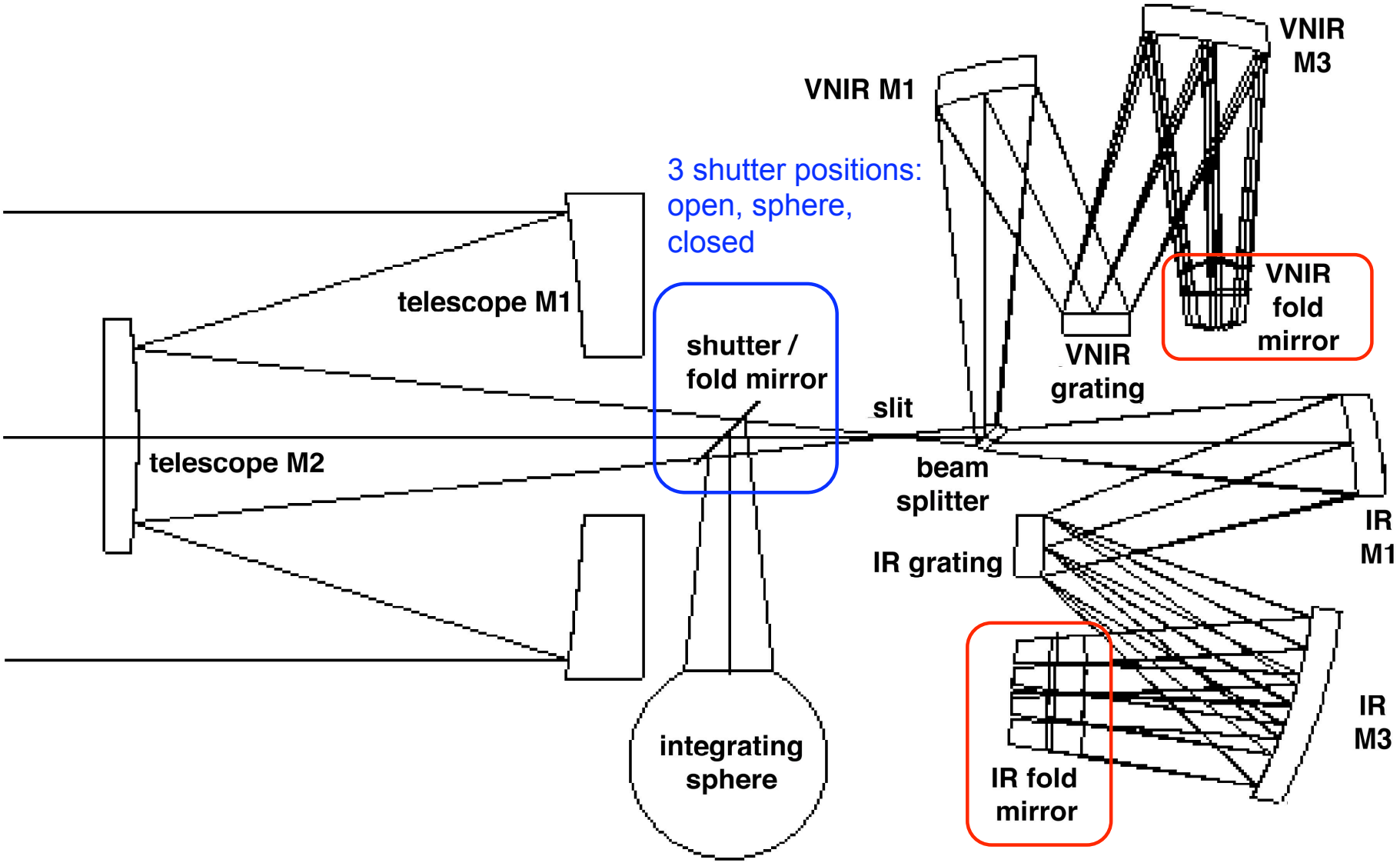
Gimbal **M**otor **E**lectronics controls gimbal

Gimbal allows observations at multiple geometries to separate surface and atmosphere (±60° along-track)

Internal calibration: shutter for dark measurements, integrating sphere for radiometric calibration

Wavelength range	0.4-3.9 μm
Spectral sampling	6.55 nm/channel
Spatial sampling	18 m/pixel from 300 km

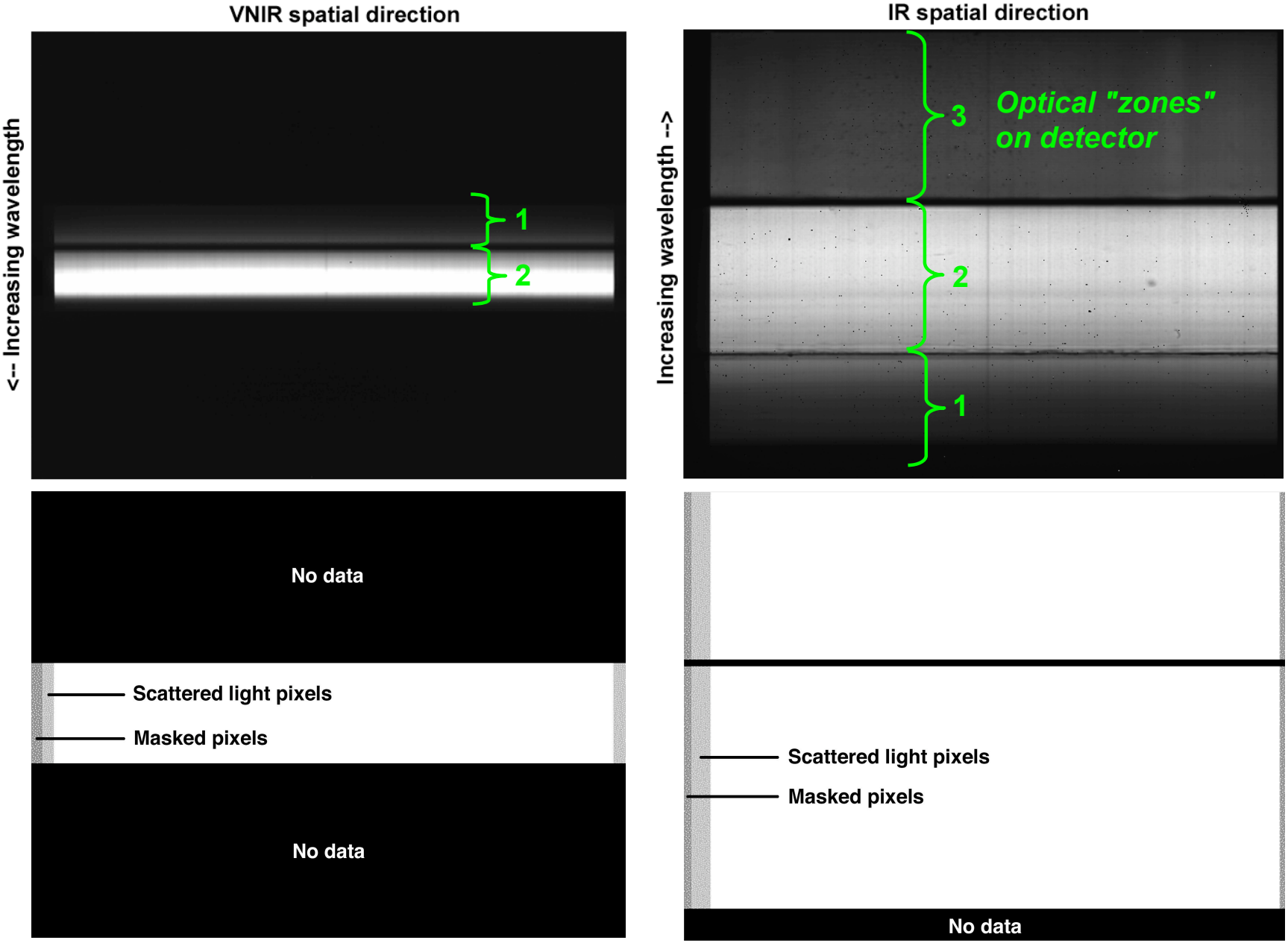
CRISM Optics



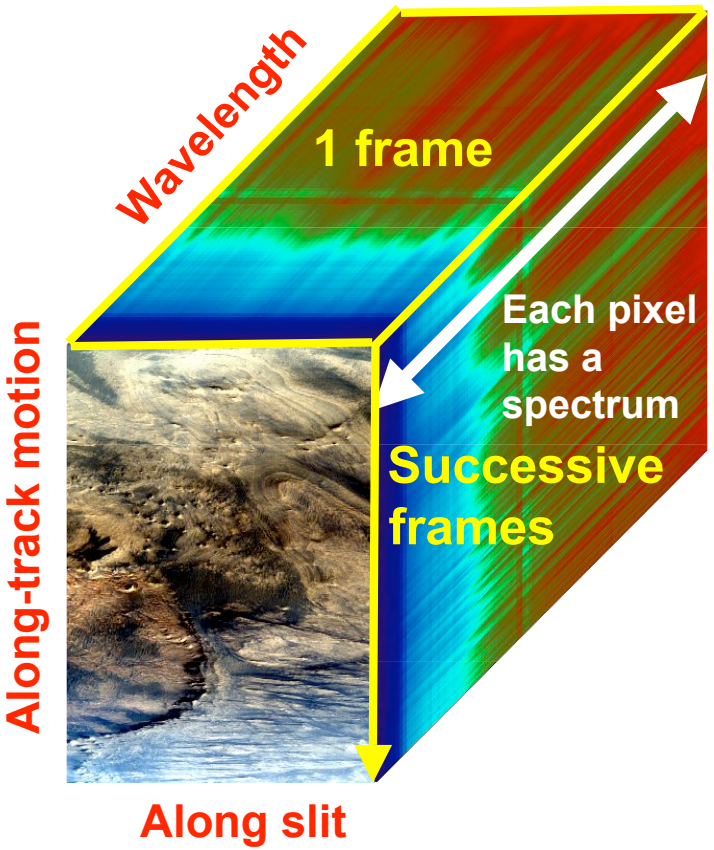
VNIR Detector (0.36-1.05 μm)
IR Detector (1.00-3.92 μm)

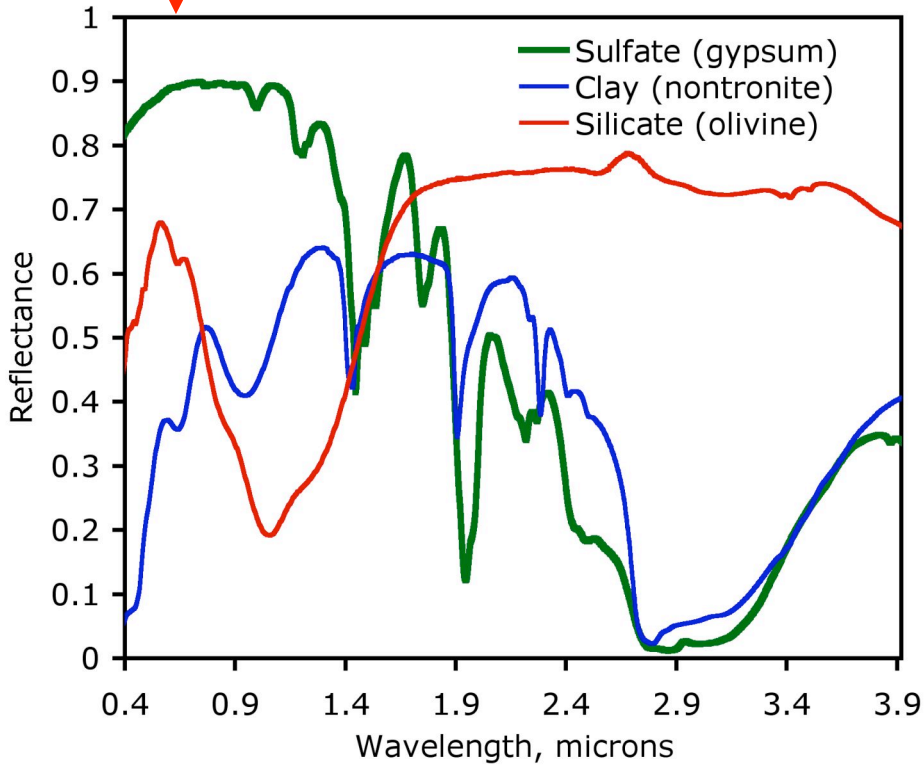
Image brightness

Pixel functions



Basic Structure of the Data: A Cube Composed of Successive Frames Acquired Along Track





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

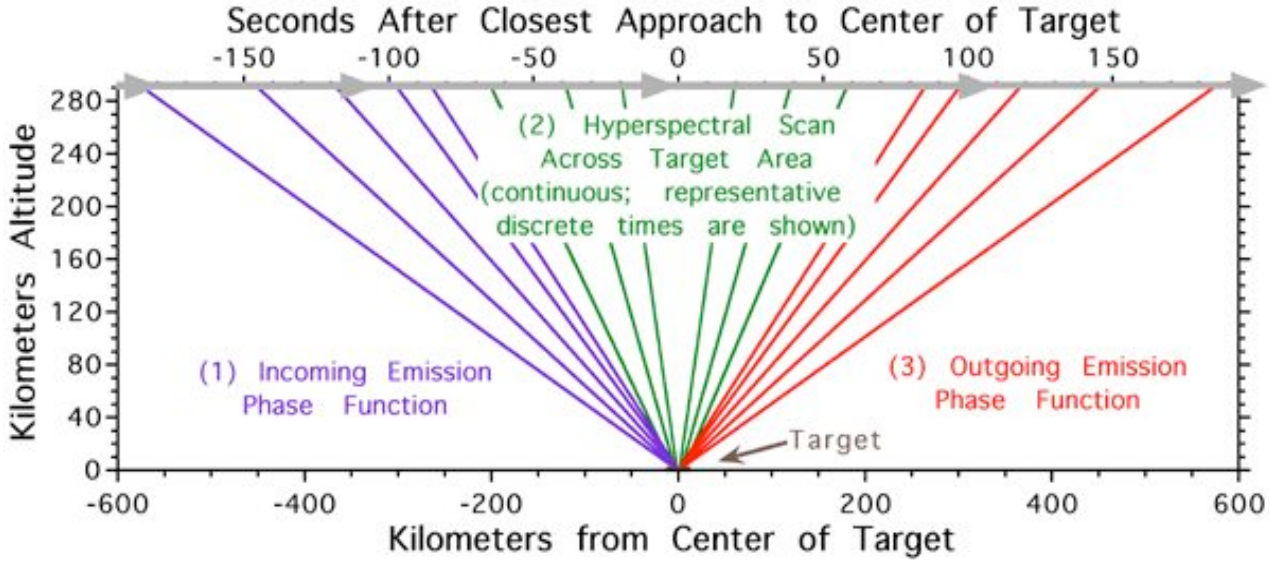
Primary variables that are set to define observation types

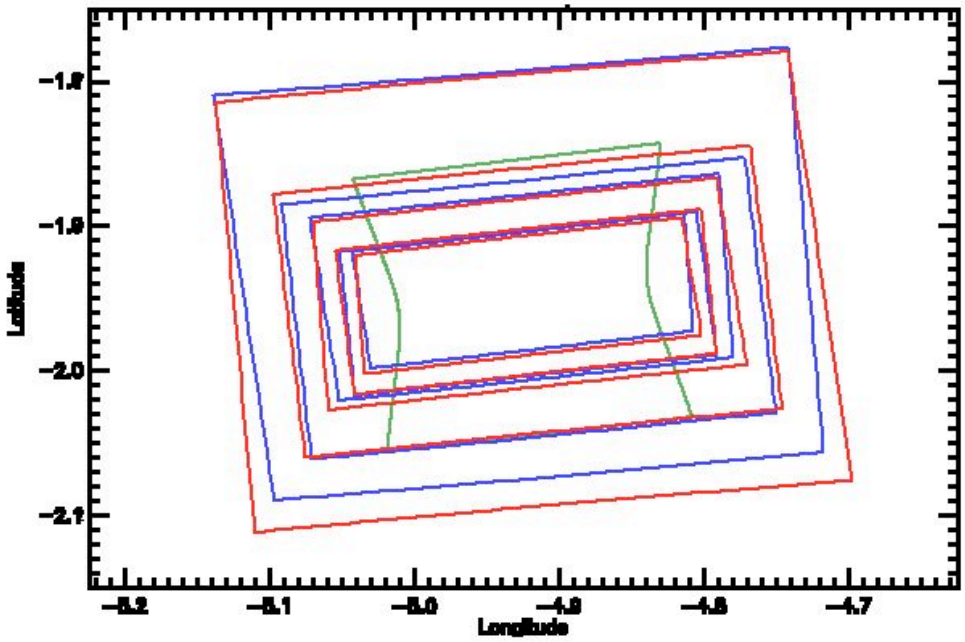
- **Pointing**
  - **Fixed at nadir**
  - **Track a point and repeatedly scan across it**
- **Number of wavelengths**
  - **All 544 with useful data**
  - **3 programmable options (72, 94, or 262 selected wavelengths) for regional/global mapping**

These variables are set to manage data volume and to "square" the pixels

- 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)

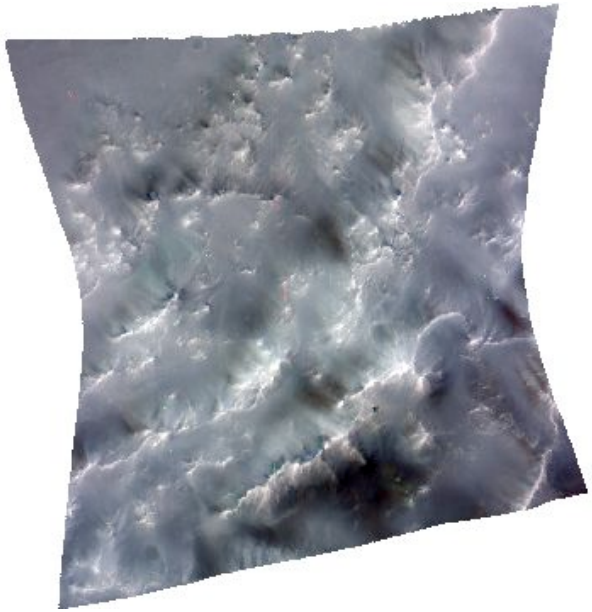




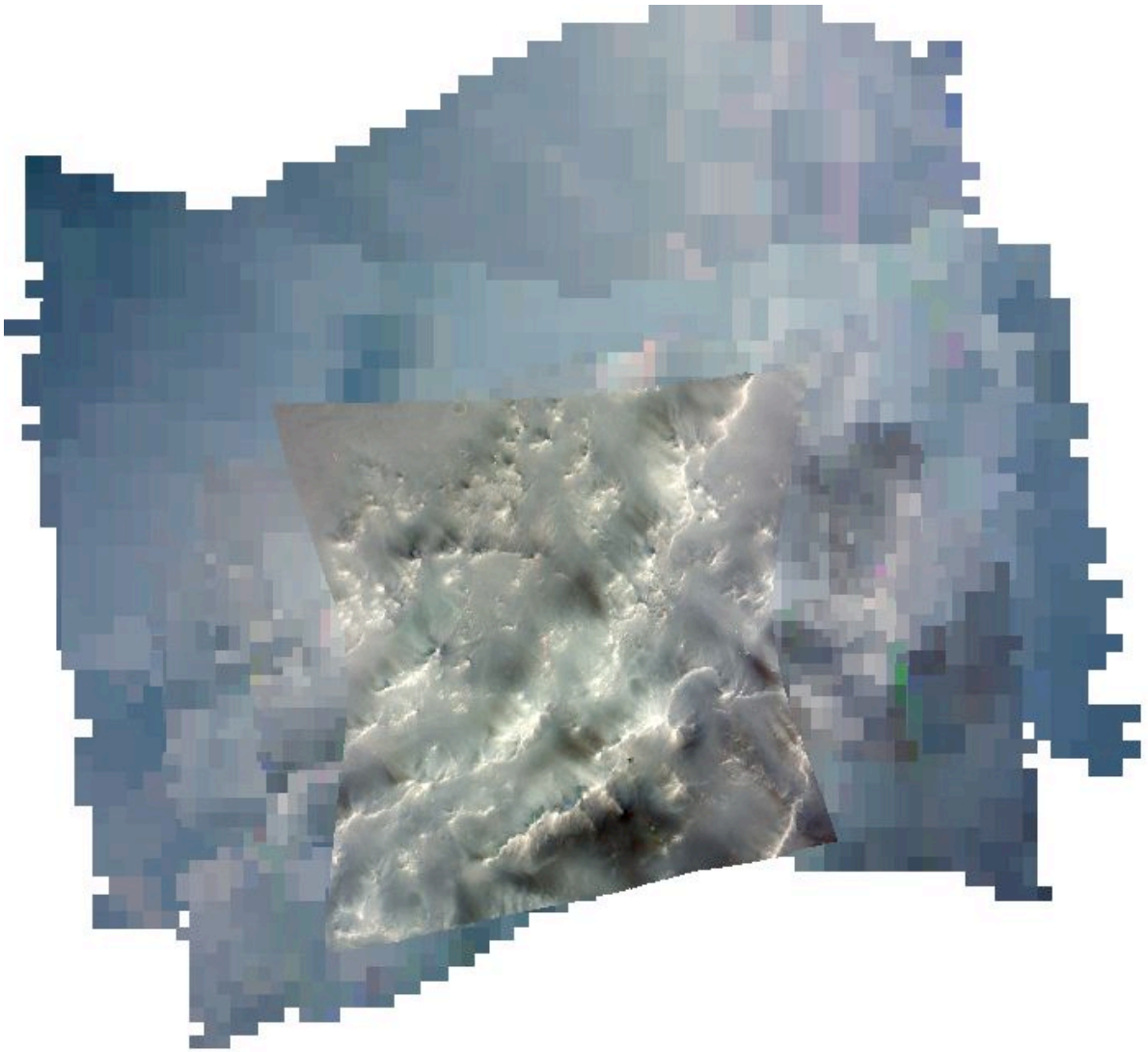
Idealized footprints for target at nadir

- "Targeted" because typically ≥2 instruments participate
- ≥11 images at varying emission angles: <u>"Emission phase function"</u>
- 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

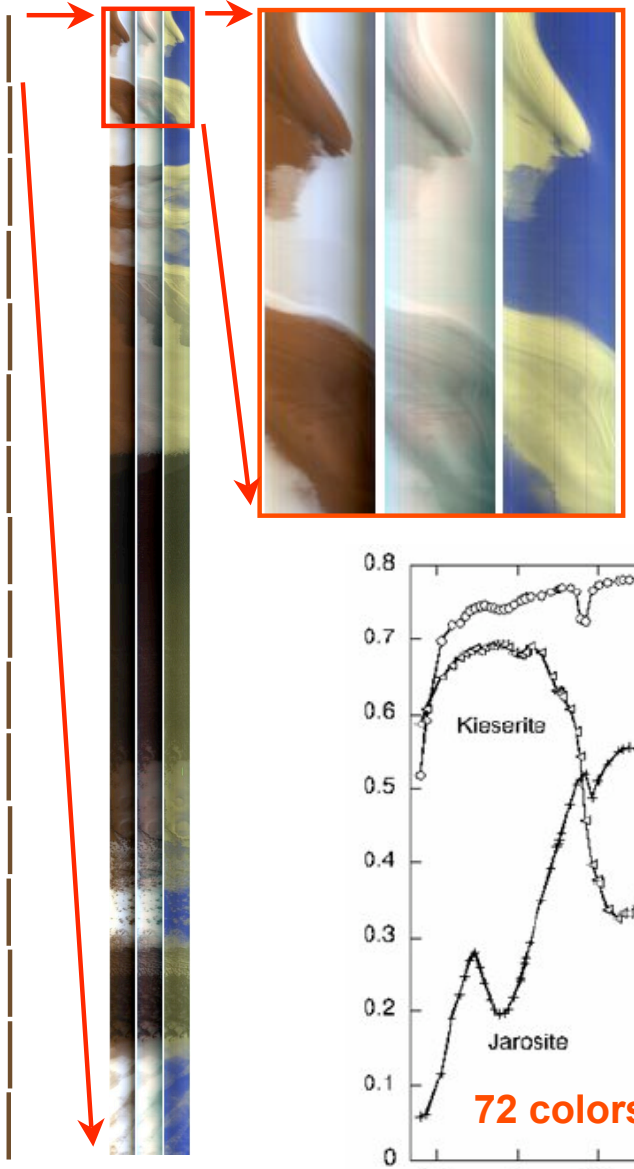


Central swath only



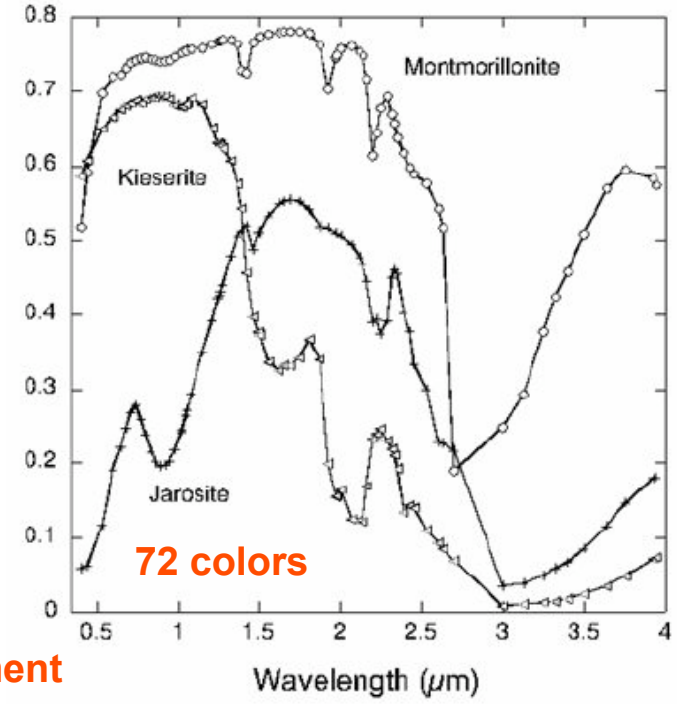
Central swath + EPF sequence

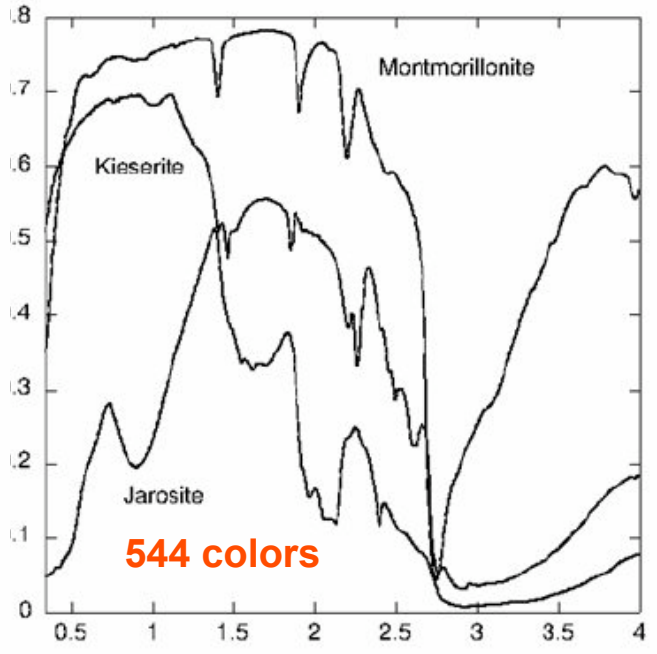
Second Basic Observation Type: Nadir
(example shown is Multispectral Survey)



1 orbit 3-min segment

- 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

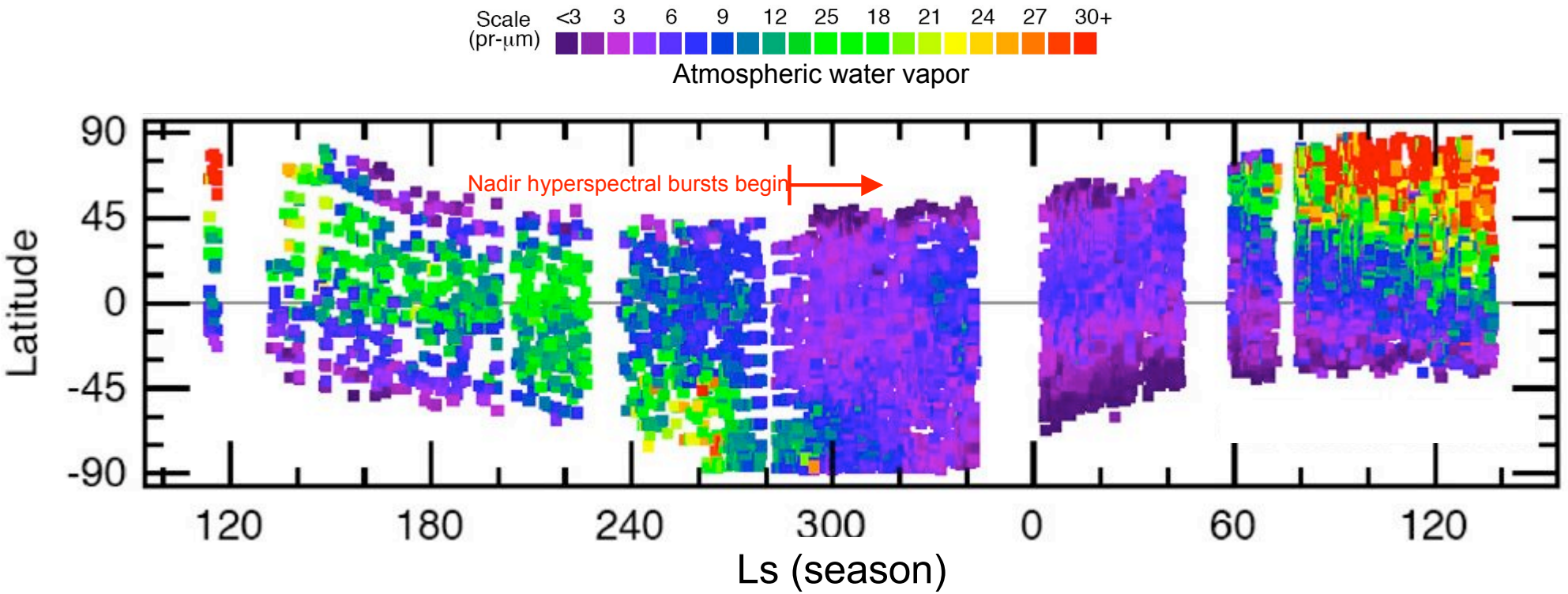




Campaign 1: Multispectral Survey to Provide Global Context and Find Targets

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.

Campaign 2: Monitor Spatial and Seasonal Variations in Aerosols and Trace Gases

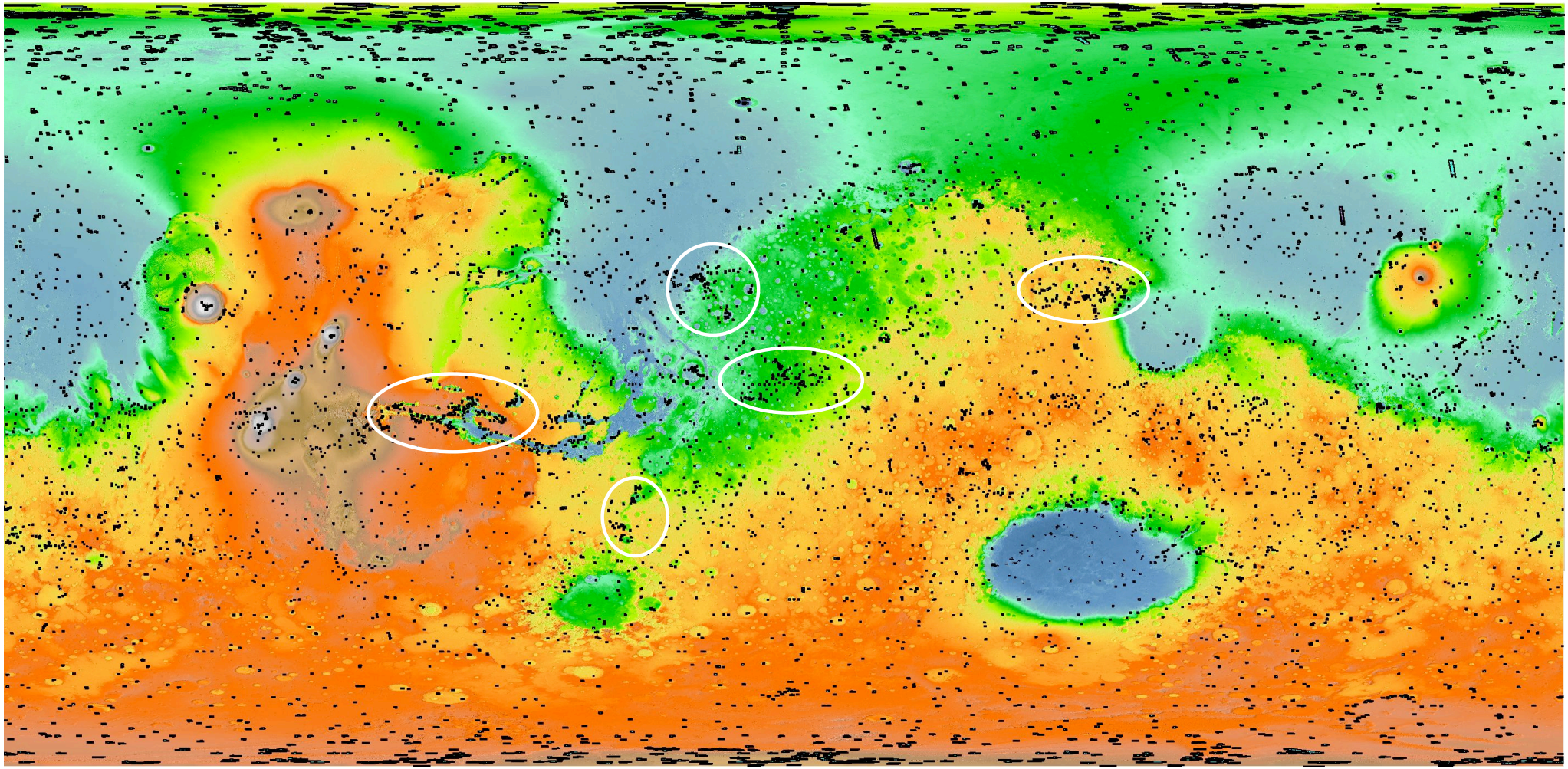


Three types of observations contribute to monitoring the atmosphere

- 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

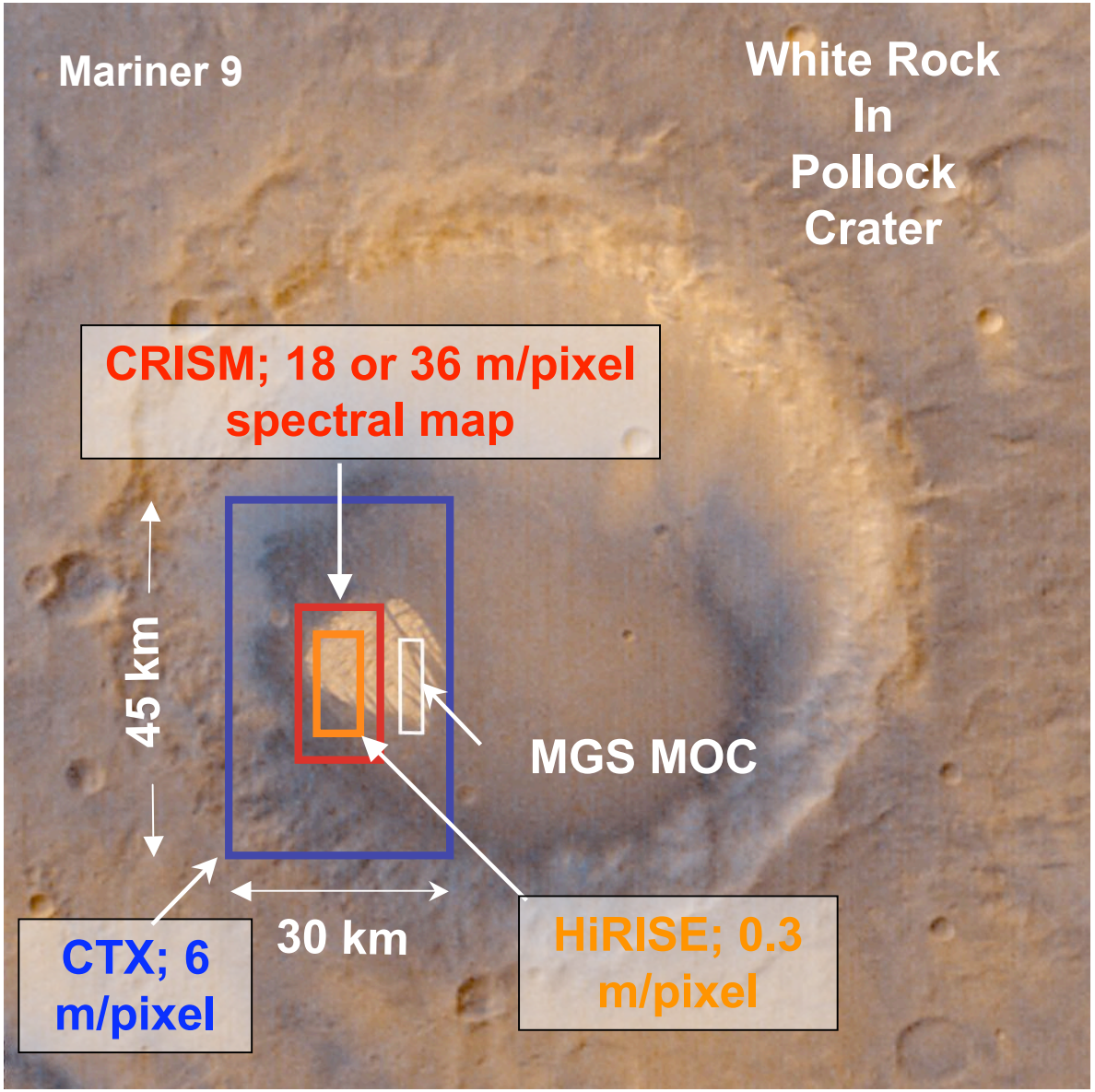
Campaign 3: Targeted Observations Directed at High-Priority Sites

Locations of targeted observations, overlain on MOLA elevation map



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.

Campaign 3: Emphasis on Coordination with HiRISE, CTX



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

Observing Campaign	Gimbal Pointing and Number of Images	Observations Type and Description	Data Product Nomenclature	
Targeted Observations	Gimbal tracks surface with superimposed scan for each image 1 high-resolution image, 10 reduced-resolution EPF images	Full resolution targeted Spatial pixels unbinned for target (18 m/pixel @300 km) Spatial pixels10x binned for EPFs	FRT*	Gimbaled
		Half resolution short targeted Spatial pixels 2x binned for target (36 m/pixel @300 km) Spatial pixels10x binned for EPFs	HRS*	
		Half resolution long targeted Spatial pixels 2x binned for target (36 m/pixel @300 km; 2x swath length as above) Spatial pixels10x binned for EPFs	HRL*	
Atmospheric Survey	Gimbal track surface with superimposed scan for each image 11 or 13 reduced-resolution images	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	EPF*	
	Nadir-pointed; multiple images	Tracking Optical Depth Spatial pixels 10x binned (200x900 m/pixel @300 km)	TOD*	Nadir
Multispectral Survey	Nadir-pointed; multiple images	Multispectral survey 72 channels, spatial pixels 10x binned (~200 m/pixel @300 km)	MSP*	
		Multispectral windows 72 channels, spatial pixels 5x binned (~100 m/pixel @300 km)	MSW*	

Map View / Usage of Different Types of Observations

Gimbaled

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.

EPF: 10-13 images at 180 m/pixel, 544 channels. Free-standing for atmospheric monitoring. Also included with FRT, HRL, HRS.

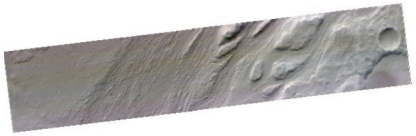
100 km

550 km long

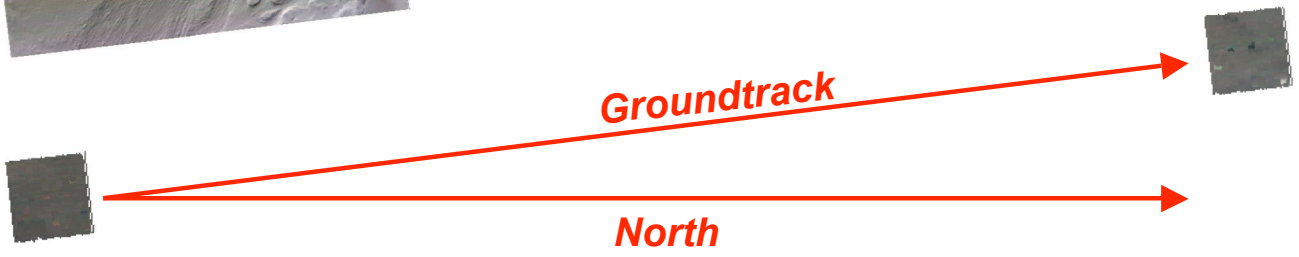
Nadir

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

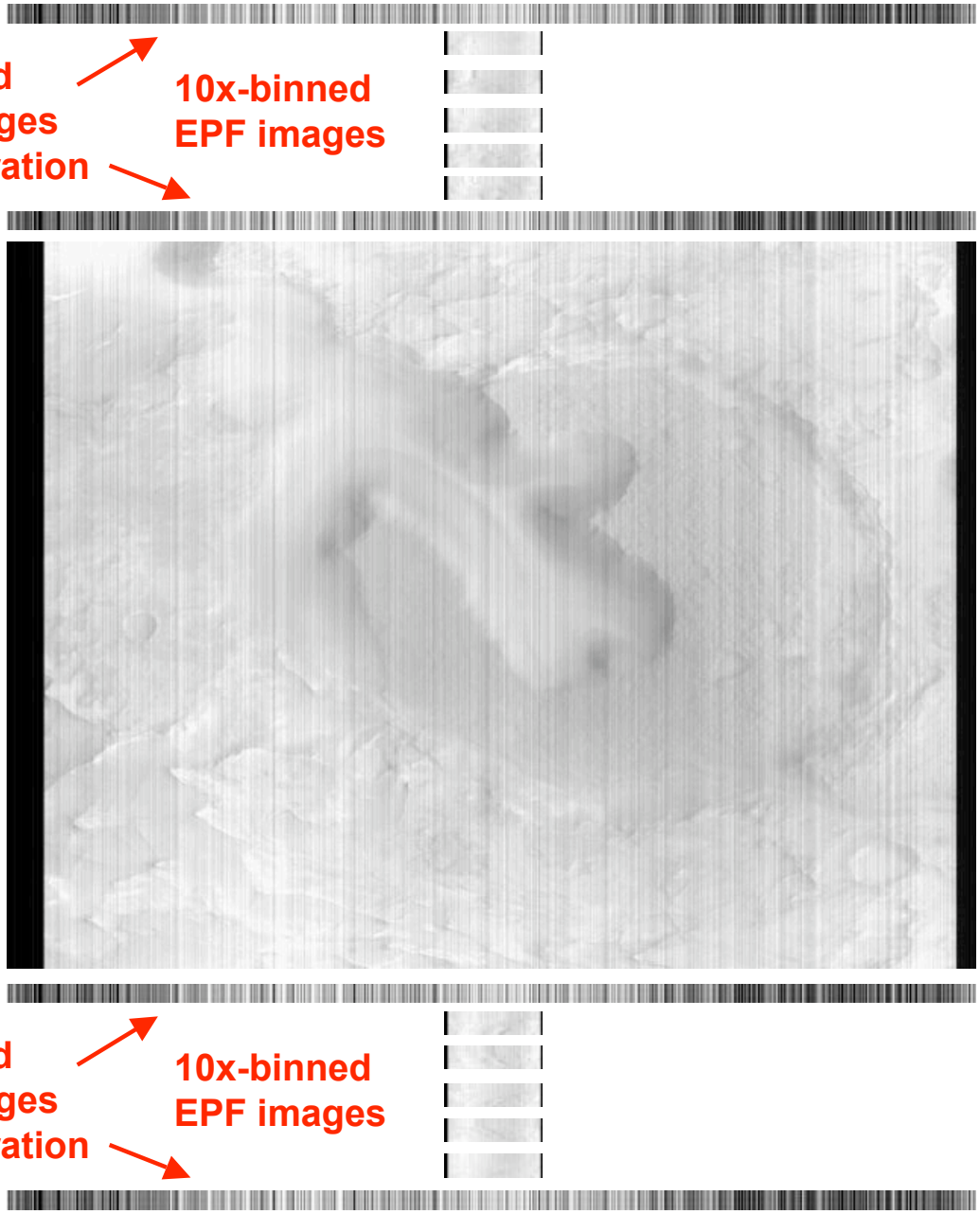
MSW: 100 m/pixel, 72 channels. Ride-alongs with HiRISE when data volume is limited.



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



A Collection of Related Images is an "Observation"



Unbinned dark images for calibration

10x-binned EPF images

Image 00

Images 01-05

Image 06

Image 07

Image 08

Images 00-0D

Image 0E

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

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

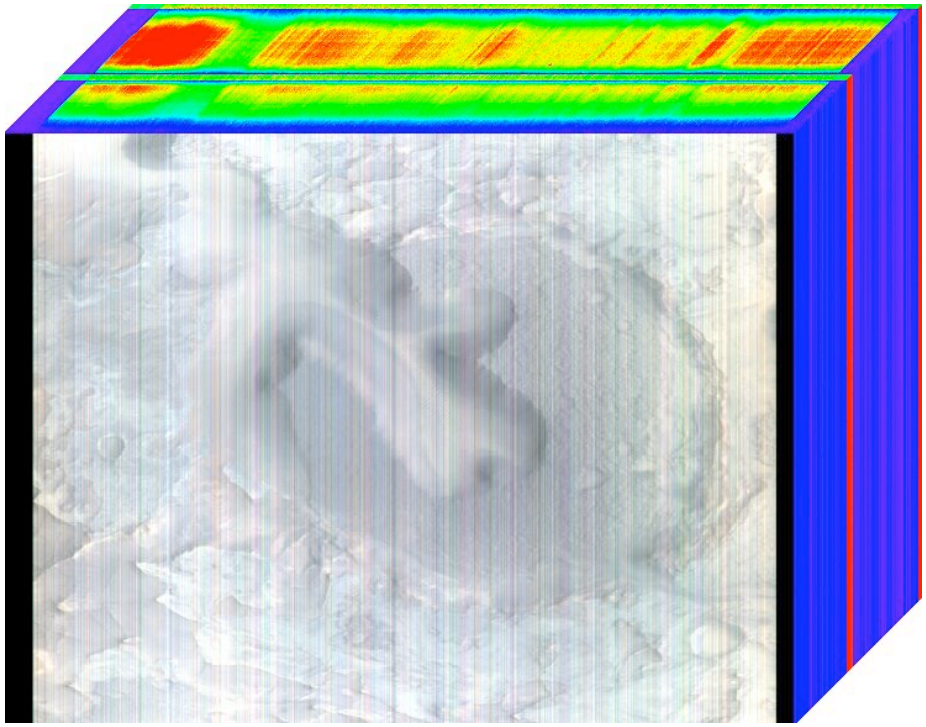
Each of the images has a unique hex counter in the file name (00, 01, …, 0D, 0E)

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 (DDRs)**: "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

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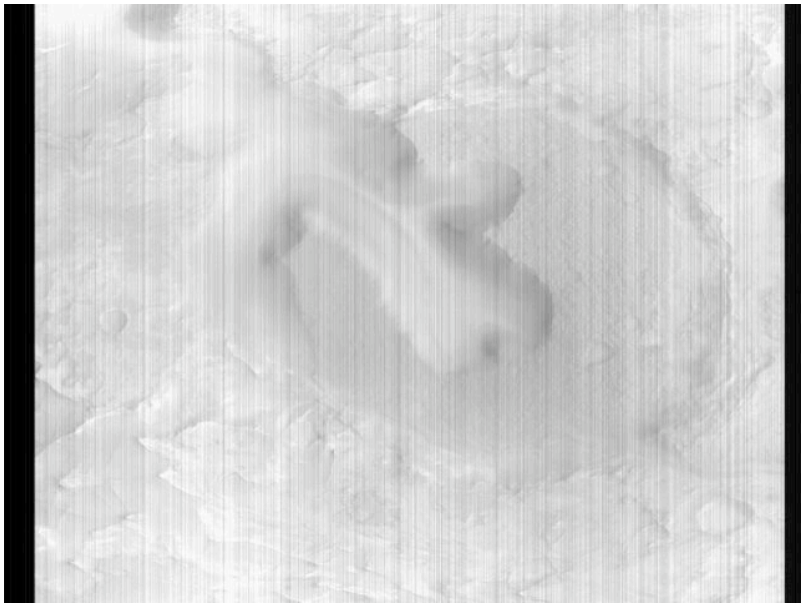
A detached PDS label giving the observation time and setup and the names of the CDRs having information needed to interpret the raw data

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
  - BInnn – 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)

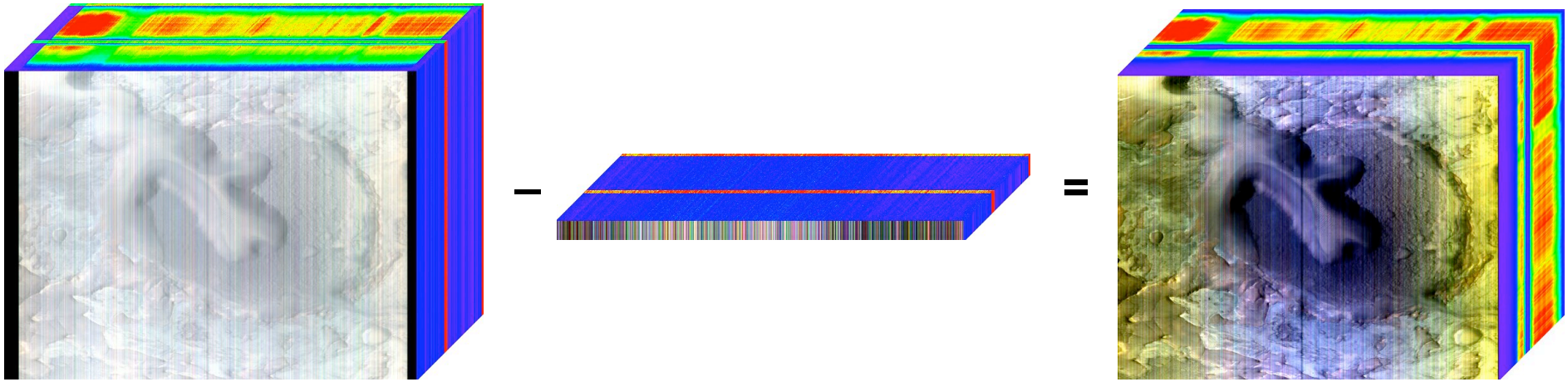


Full-resolution target
Observation 3E12
Counter (central swath = 07)
IR detector
Software version 0

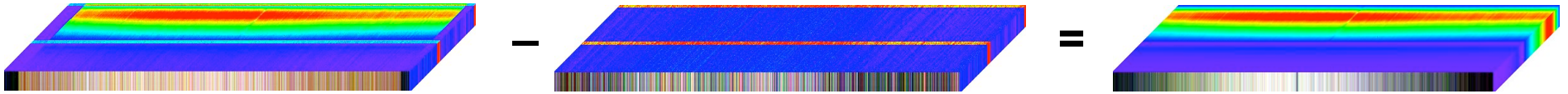
FRT00003E12_07_SC166L_EDR0:
The file name fully describes the type of data, which detector it comes from, the version of the processing, and gives the unique ID and counter

Simplified Calibration Pipeline (1/3)

- **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



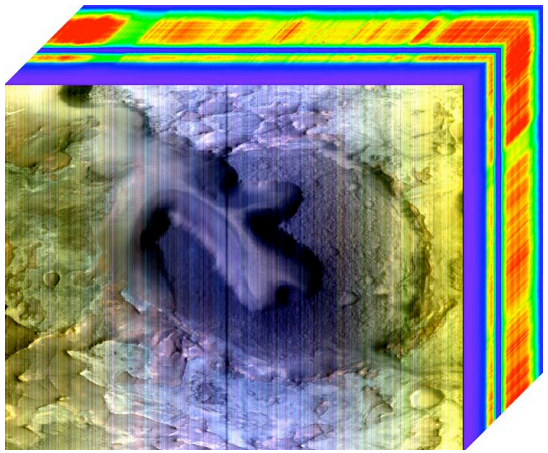
Raw scene image, units DN — Companion dark image, units DN — Corrected scene image, units DN



Raw sphere image, units DN — Companion dark image, units DN — Corrected sphere image, units DN

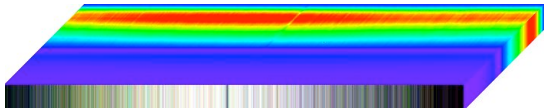
Simplified Calibration Pipeline (2/3)

- 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



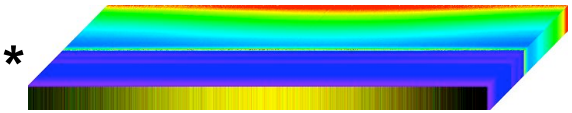
Corrected scene image, units DN

/ exp time



Corrected sphere image, units DN

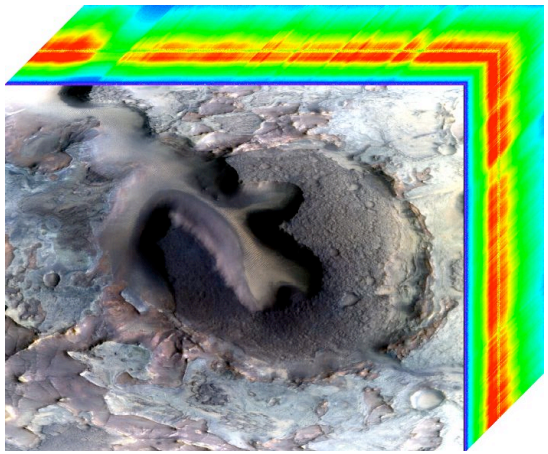
*****



Ground-based model of sphere radiance, units W m^{-2} sr^{-1} μm^{-1}

=

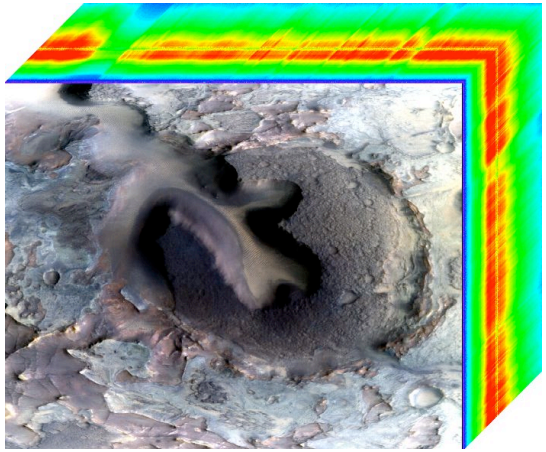
Scene radiance, units W m^{-2} sr^{-1} μm^{-1}



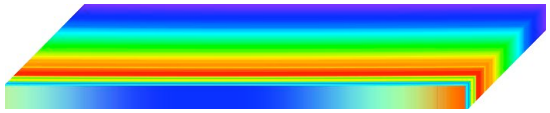
Simplified Calibration Pipeline (3/3)

- 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

Scene radiance,
units W m^{-2} sr^{-1} μm^{-1}



*** solar distance in AU * π**



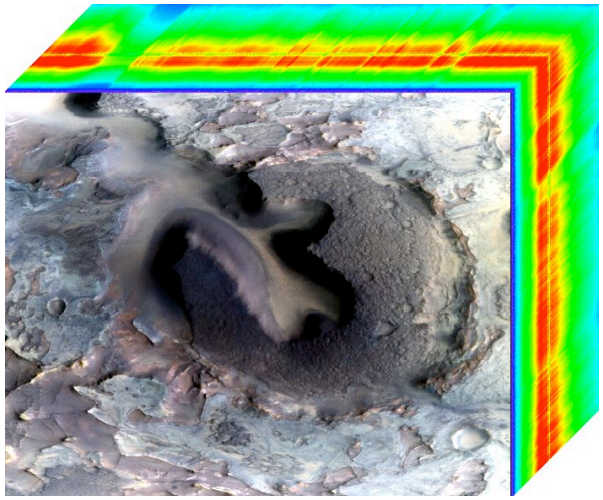
Solar flux at 1 AU,
units W m^{-2} μm^{-1}

=

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 house-keeping from each frame of the data

2163871423,	2835413809,	0.00,	-13275.00,	225.00,
2298090386,	2835413986,	0.00,	-13275.00,	225.00,
2365200485,	2835413764,	0.00,	-13050.00,	225.00,
2365201753,	2835413691,	0.00,	-13050.00,	225.00,
2298094130,	2835413828,	0.00,	-13050.00,	225.00,
2163877667,	2835413775,	0.00,	-13050.00,	225.00,
2365205505,	2835413724,	0.00,	-12825.00,	225.00,
2230989084,	2835413775,	0.00,	-12825.00,	225.00,
2163881483,	2835413764,	0.00,	-12825.00,	225.00,
2289711914,	2835413872,	0.00,	-12825.00,	225.00,
2155495431,	2835413757,	0.00,	-12600.00,	225.00,
2155496715,	2835413815,	0.00,	-12600.00,	225.00,
2222606852,	2835413819,	0.00,	-12600.00,	225.00,
2289717018,	2835413845,	0.00,	-12375.00,	225.00,
2289718298,	2835413795,	0.00,	-12375.00,	225.00,
2155501911,	2835413791,	0.00,	-12375.00,	225.00,
2356829813,	2835413903,	0.00,	-12375.00,	225.00,
2222613388,	2835413848,	0.00,	-12150.00,	225.00,
2356832413,	2835413918,	0.00,	-12150.00,	225.00,
2155507123,	2835413858,	0.00,	-12150.00,	225.00,

```
OBSERVATION_TYPE                = "FRT"
OBSERVATION_ID                  = "16#0000D4DE#"
MRO:OBSERVATION_NUMBER          = 16#07#
MRO:ACTIVITY_ID                 = "IF164"
MRO:SENSOR_ID                   = "L"
MRO:DETECTOR_TEMPERATURE        = -149.765
MRO:OPTICAL_BENCH_TEMPERATURE   = -51.554
MRO:SPECTROMETER_HOUSING_TEMP   = -75.171
MRO:SPHERE_TEMPERATURE          = -51.158
MRO:FPE_TEMPERATURE             =  0.800
PRODUCT_VERSION_ID              = "2"
SOURCE_PRODUCT_ID = {
    "CDR410000000000_DM0000000L_3",
    "CDR410000000000_LL0000000L_3",
    "CDR410000000000_SH0000001L_0",
    "CDR410000000000_SS0000001L_5",
    "CDR410000000000_TD000000S_2",
    "CDR410803692813_SF0000000L_4",
    "CDR420847411200_NU1000001L_4",
    "CDR440910732409_BK0003800L_2",
    "CDR440910732415_UB0003800L_2",
    "CDR440910732449_SP0003801L_2",
    "CDR440910732449_SP00425015_2",
    "CDR440910732471_BK0003800L_2",
    "CDR440910732477_UB0003800L_2",
    "CDR440910736166_BI0000000L_2",
    "CDR440910736205_BI1000000L_2",
    "CDR440910740248_BK1030100L_2",
    "CDR440910740249_UB1030100L_2",
    "CDR440910740371_BK1030100L_2",
    "CDR440910740372_UB1030100L_2",
    "CDR6_1_0000000000_AS_L_0",
    "CDR6_1_0000000000_BS_L_0",
    "CDR6_1_0000000000_DB_L_0",
    "CDR6_1_0000000000_EB_L_0",
    "CDR6_1_0000000000_GH_L_2",
    "CDR6_1_0000000000_HD_J_1",
    "CDR6_1_0000000000_HK_J_1",
    "CDR6_1_0000000000_HV_J_1",
    "CDR6_1_0000000000_LC_L_1",
    "CDR6_1_0000000000_LI_J_0",
    "CDR6_1_0000000000_VL_L_0",
    "CDR6_2_0835294537_PP_L_0",
    "CDR6_4_0910656020_ST_J_0",
    "FRT0000D4DE_07_SC164L_EDR0"
}
```

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)

Full-resolution target
Observation 3E12
Counter
Calibrated to I/F
IR detector
Software version 2

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

```
TARGET_CENTER_DISTANCE       = 3633.060355 <KM>
                               /* distance to Mars center at first frame */
SOLAR_DISTANCE               = 212192706.948812 <KM>
SOLAR_LONGITUDE              = 204.982066 <DEGREES>
MRO:FRAME_RATE               = 3.75 <HZ>
PIXEL_AVERAGING_WIDTH        = 10
MRO:INSTRUMENT_POINTING_MODE = "DYNAMIC POINTING"
SCAN_MODE_ID                 = "LONG"


/* This DDR label describes one data file:                              */
/* 1. A multiple-band backplane image file with wavelength-independent, */
/* spatial pixel-dependent geometric and timing information.            */

/* See the CRISM Data Products SIS for more detailed description.       */

OBJECT                       = FILE
  ^IMAGE                     = "FRT00010DFE_0A_DE157L_DDR1.IMG"
  RECORD_TYPE                = FIXED_LENGTH
  RECORD_BYTES               = 256
  FILE_RECORDS               = 210

  OBJECT                     = IMAGE
    LINES                    = 15
    LINE_SAMPLES             = 64
    SAMPLE_TYPE              = PC_REAL
    SAMPLE_BITS              = 32
    BANDS                    = 14
    BAND_STORAGE_TYPE        = BAND_SEQUENTIAL
    BAND_NAME                = ("INA at areoid, deg",
                                "EMA at areoid, deg",
                                "Phase angle, deg",
                                "Latitude, areocentric, deg N",
                                "Longitude, areocentric, deg E",
                                "INA at surface from MOLA, deg",
                                "EMA at surface from MOLA, deg",
                                "Slope magnitude from MOLA, deg",
                                "MOLA slope azimuth, deg clkwise from N",
                                "Elevation, meters relative to MOLA",
                                "Thermal inertia, J m^-2 K^-1 s^-0.5",
                                "Bolometic albedo",
                                "Local solar time, hours",
                                "Spare")

  END_OBJECT                 = IMAGE

END_OBJECT                   = FILE
```

A detached PDS label gives the companion observation, its time and setup, and describes each layer of the DDR

DDR 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
- **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

Full-resolution target
Observation 3E12
Counter
Derived information
IR detector
Software version 1

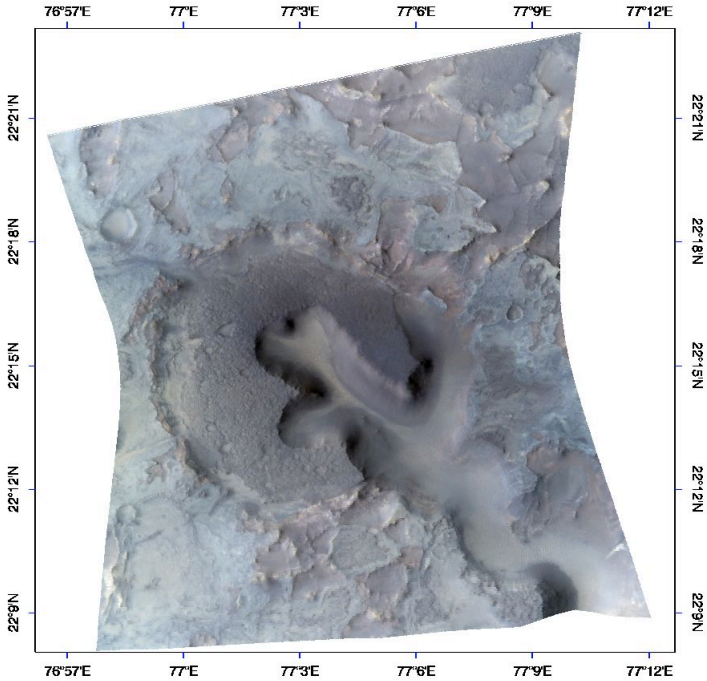
DDR00003E12_07_DE166L_DDR1:
The file name fully describes the companion observation, its type of data, which detector it comes from, and the version of the processing

Usage of DDRs

f (

,

) =



I/F in sensor space

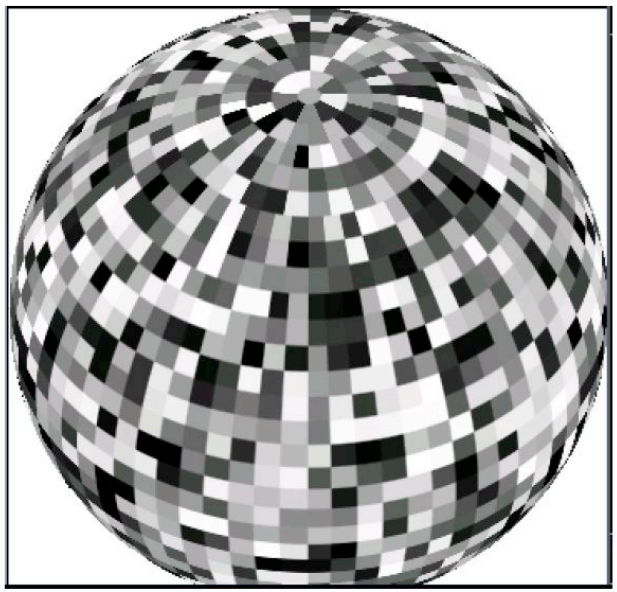
Latitude, longitude, incidence, emission, and phase angle

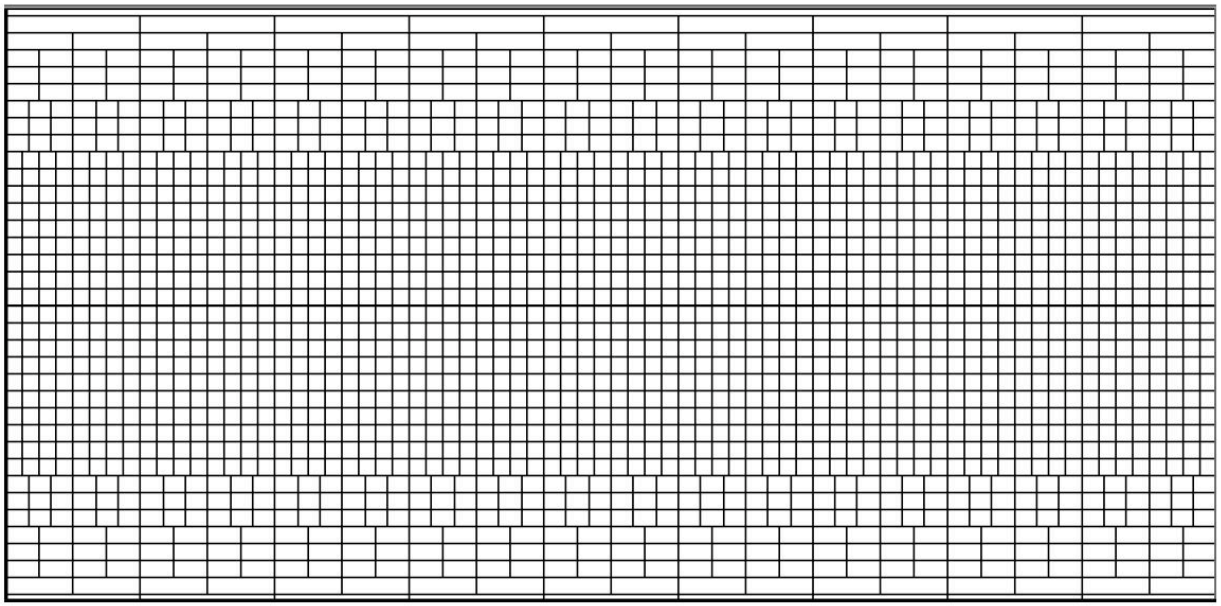
Map-projected, photometrically and atmospherically corrected I/F

Note: Map convention is planetocentric, positive east longitude

MutIspectral Reduced Data Records (MRDRs)

- 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)

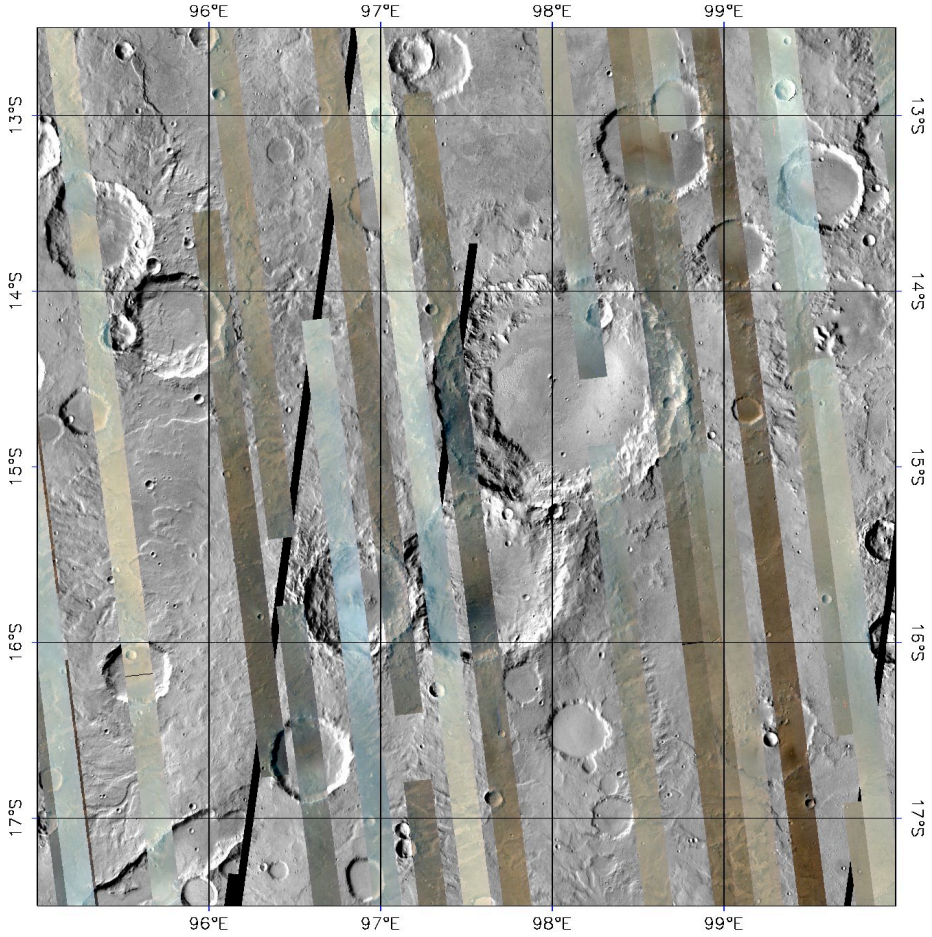




MRDR Format: I/F Data

- 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

```
1,192,  410.12
1,197,  442.63
1,211,  533.74
1,221,  598.86
1,229,  650.99
1,234,  683.59
1,238,  709.68
1,243,  742.30
1,248,  774.92
1,252,  801.04
1,257,  833.68
1,261,  859.81
1,266,  892.48
1,271,  925.16
1,275,  951.31
1,280,  984.01
0,442, 1021.00
1,286, 1023.27
0,438, 1047.20
1,291, 1055.99
0,433, 1079.96
0,422, 1152.06
0,413, 1211.09
0,407, 1250.45
0,406, 1257.01
0,405, 1263.57
0,403, 1276.70
0,395, 1329.21
0,389, 1368.61
0,385, 1394.89
0,380, 1427.73
0,374, 1467.16
0,369, 1500.03
0,368, 1506.61
0,360, 1559.21
0,350, 1625.00
0,345, 1657.91
0,340, 1690.82
```

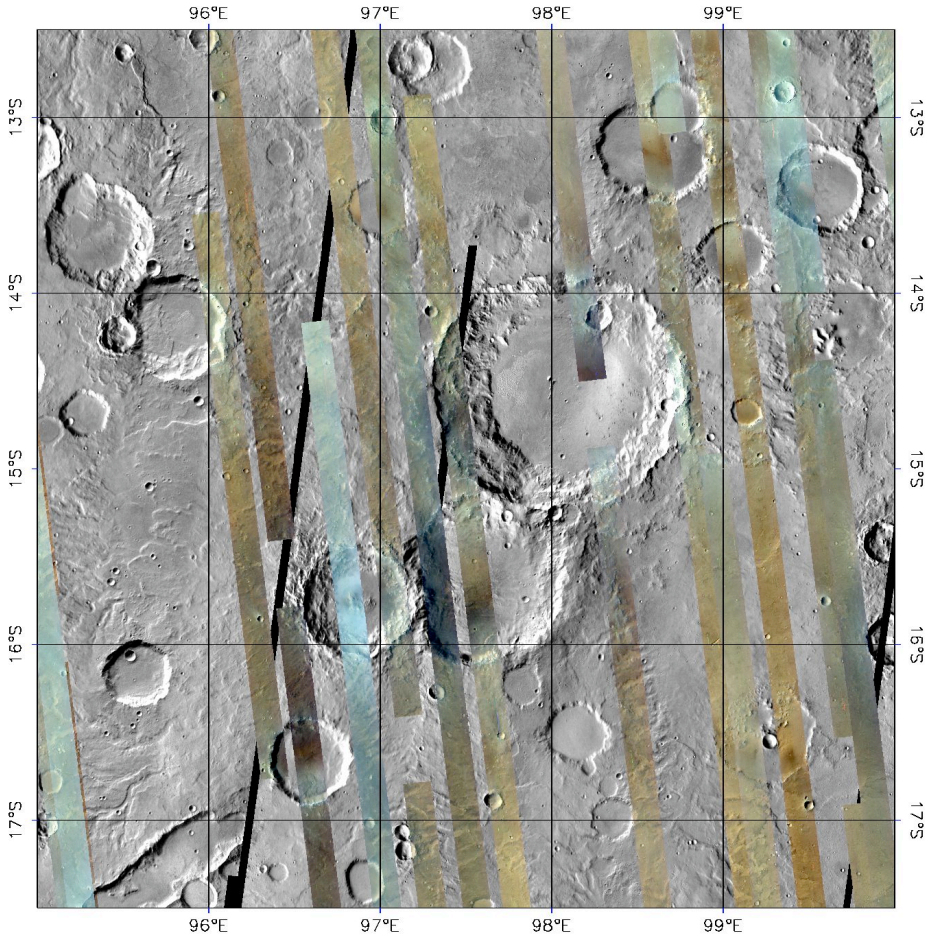
Detached PDS label giving the file history and map projection information

```
OBJECT                       = IMAGE
  LINES                      = 1280
  LINE_SAMPLES               = 1136
  SAMPLE_TYPE                = PC_REAL
  SAMPLE_BITS                = 32
  UNIT                       = "I over F"
  BANDS                      = 72
  BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
END_OBJECT                   = IMAGE

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

OBJECT                       = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION   = "MRR_MAP.CAT"
  MAP_PROJECTION_TYPE        = "EQUIRECTANGULAR"
  A_AXIS_RADIUS              = 3396  <KM>
  B_AXIS_RADIUS              = 3396  <KM>
  C_AXIS_RADIUS              = 3396  <KM>
  FIRST_STANDARD_PARALLEL    = "N/A"
  SECOND_STANDARD_PARALLEL   = "N/A"
  POSITIVE_LONGITUDE_DIRECTION = "EAST"
  CENTER_LATITUDE            =     27.50000 <DEGREE>
  CENTER_LONGITUDE           =     87.50000 <DEGREE>
  REFERENCE_LATITUDE         = "N/A"
  REFERENCE_LONGITUDE        = "N/A"
  LINE_FIRST_PIXEL           = 1      /* North edge */
  LINE_LAST_PIXEL            = 1280   /* South edge */
  SAMPLE_FIRST_PIXEL         = 1      /* West edge */
  SAMPLE_LAST_PIXEL          = 1136   /* East edge */
  MAP_PROJECTION_ROTATION    = 0.0
  MAP_RESOLUTION             = 256 <PIXEL/DEGREE>
  MAP_SCALE                  = 0.231528833585 <KM/PIXEL>
  MAXIMUM_LATITUDE           =     32.50000 <DEGREE>
  MINIMUM_LATITUDE           =     27.50000 <DEGREE>
  WESTERNMOST_LONGITUDE      =     85.00000 <DEGREE>
  EASTERNMOST_LONGITUDE      =     90.00000 <DEGREE>
  LINE_PROJECTION_OFFSET     = 8320.000
  SAMPLE_PROJECTION_OFFSET   = 640.000
  COORDINATE_SYSTEM_TYPE     = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME     = "PLANETOCENTRIC"
END_OBJECT                   = IMAGE_MAP_PROJECTION
```

MRDR Format: Lambert Albedo Data

- 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 overlain on THEMIS day IR)



Detached ASCII file giving wavelengths of each band

```
1,192,  410.12
1,197,  442.63
1,211,  533.74
1,221,  598.86
1,229,  650.99
1,234,  683.59
1,238,  709.68
1,243,  742.30
1,248,  774.92
1,252,  801.04
1,257,  833.68
1,261,  859.81
1,266,  892.48
1,271,  925.16
1,275,  951.31
1,280,  984.01
0,442, 1021.00
1,286, 1023.27
0,438, 1047.20
1,291, 1055.99
0,433, 1079.96
0,422, 1152.06
0,413, 1211.09
0,407, 1250.45
0,406, 1257.01
0,405, 1263.57
0,403, 1276.70
0,395, 1329.21
0,389, 1368.61
0,385, 1394.89
0,380, 1427.73
0,374, 1467.16
0,369, 1500.03
0,368, 1506.61
0,360, 1559.21
0,350, 1625.00
0,345, 1657.91
0,340, 1690.82
```

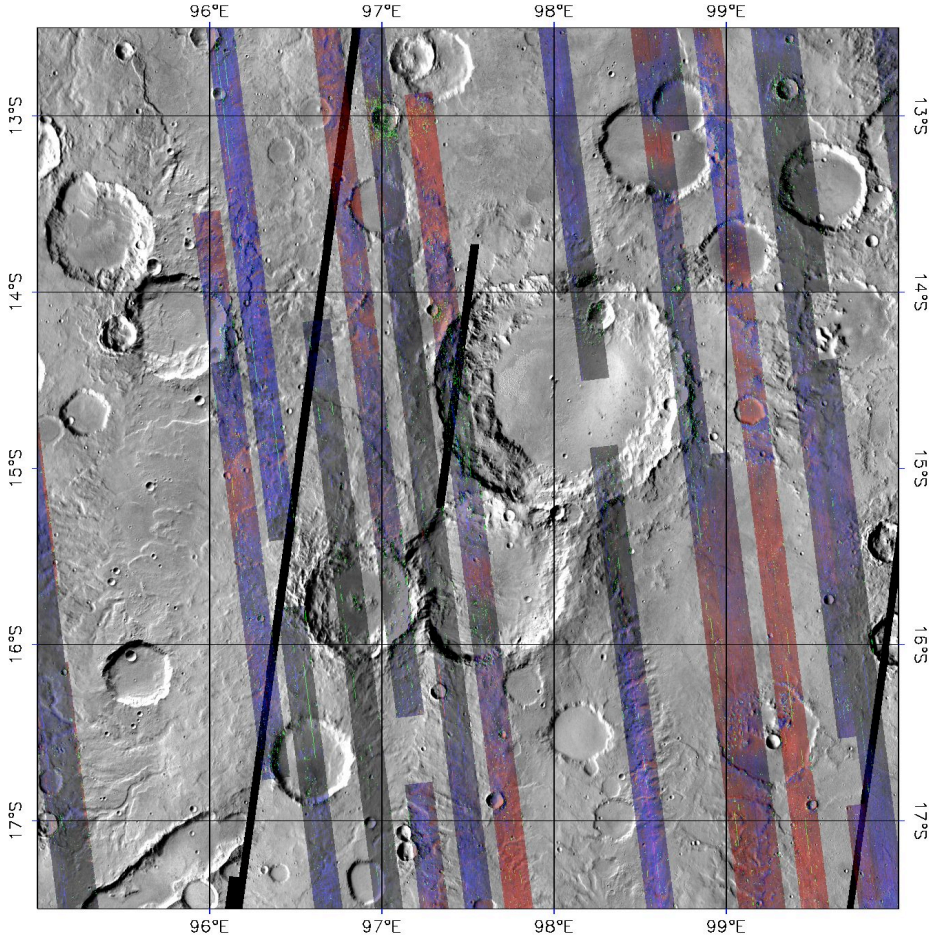
Detached PDS label giving the file history and map projection information

```
OBJECT                          = IMAGE
  LINES                         = 1280
  LINE_SAMPLES                  = 1136
  SAMPLE_TYPE                   = PC_REAL
  SAMPLE_BITS                   = 32
  UNIT                          = "I over F"
  BANDS                         = 72
  BAND_STORAGE_TYPE             = BAND_SEQUENTIAL
END_OBJECT                      = IMAGE

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

OBJECT                          = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION      = "MRR_MAP.CAT"
  MAP_PROJECTION_TYPE           = "EQUIRECTANGULAR"
  A_AXIS_RADIUS                 = 3396  <KM>
  B_AXIS_RADIUS                 = 3396  <KM>
  C_AXIS_RADIUS                 = 3396  <KM>
  FIRST_STANDARD_PARALLEL       = "N/A"
  SECOND_STANDARD_PARALLEL      = "N/A"
  POSITIVE_LONGITUDE_DIRECTION  = "EAST"
  CENTER_LATITUDE               =     27.50000 <DEGREE>
  CENTER_LONGITUDE              =     87.50000 <DEGREE>
  REFERENCE_LATITUDE            = "N/A"
  REFERENCE_LONGITUDE           = "N/A"
  LINE_FIRST_PIXEL              = 1      /* North edge */
  LINE_LAST_PIXEL               = 1280   /* South edge */
  SAMPLE_FIRST_PIXEL            = 1      /* West edge */
  SAMPLE_LAST_PIXEL             = 1136   /* East edge */
  MAP_PROJECTION_ROTATION       = 0.0
  MAP_RESOLUTION                = 256 <PIXEL/DEGREE>
  MAP_SCALE                     = 0.231528833585 <KM/PIXEL>
  MAXIMUM_LATITUDE              =     32.50000 <DEGREE>
  MINIMUM_LATITUDE              =     27.50000 <DEGREE>
  WESTERNMOST_LONGITUDE         =     85.00000 <DEGREE>
  EASTERNMOST_LONGITUDE         =     90.00000 <DEGREE>
  LINE_PROJECTION_OFFSET        = 8320.000
  SAMPLE_PROJECTION_OFFSET      = 640.000
  COORDINATE_SYSTEM_TYPE        = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME        = "PLANETOCENTRIC"
END_OBJECT                      = IMAGE_MAP_PROJECTION
```

MRDR Format: Summary Product Data

- 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)

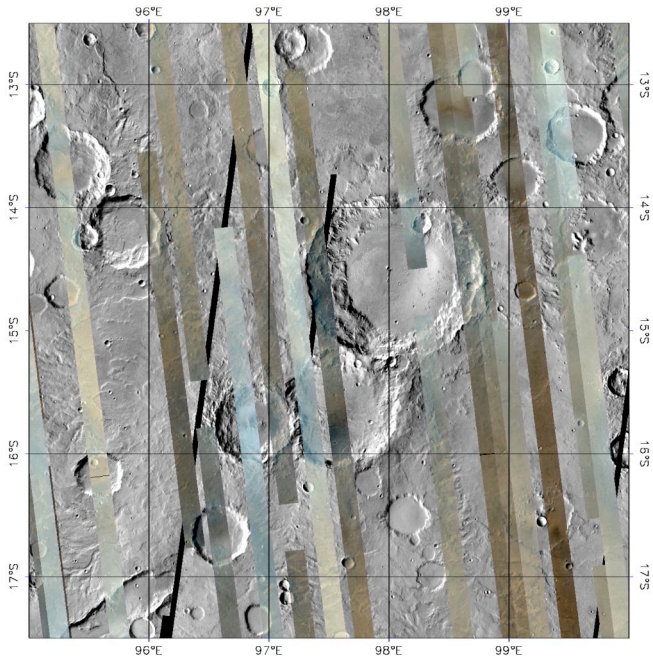


Detached PDS label giving the file history and map projection information

```
/* Description of MAP PROJECTED MULTISPECTRAL RDR RADIANCE IMAGE file */

OBJECT                      = IMAGE
  LINES                     = 1280
  LINE_SAMPLES              = 1250
  SAMPLE_TYPE               = PC_REAL
  SAMPLE_BITS               = 32

  BANDS                     = 45
  BAND_STORAGE_TYPE         = BAND_SEQUENTIAL
  BAND_NAME                 = ("R770",
                               "RBR",
                               "BD530",
                               "SH600",
                               "BD640",
                               "BD860",
                               "BD920",
                               "RPEAK1",
                               "BDI1000VIS",
                               "BDI1000IR",
                               "IRAC",
                               "OLINDEX",
                               "LCPINDEX",
                               "HCPXINDEX",
                               "VAR",
                               "ISLOPE1",
                               "BD1435",
                               "BD1500",
                               "ICER1",
                               "BD1750",
                               "BD1900",
                               "BDI2000",
                               "BD2100",
                               "BD2210",
                               "BD2290",
                               "D2300",
                               "SINDEX",
                               "ICER2",
                               "BDCARB",
                               "BD3000",
                               "BD3100",
                               "BD3200",
                               "BD3400",
                               "CINDEX",
                               "R440",
                               "IRR1",
                               "BD1270O2",
                               "BD1400H2O",
                               "BD2000CO2",
                               "BD2350",
                               "BD2600",
                               "IRR2",
                               "R2700",
                               "BD2700",
                               "IRR3")
END_OBJECT                  = IMAGE
```

MRDR Nomenclature

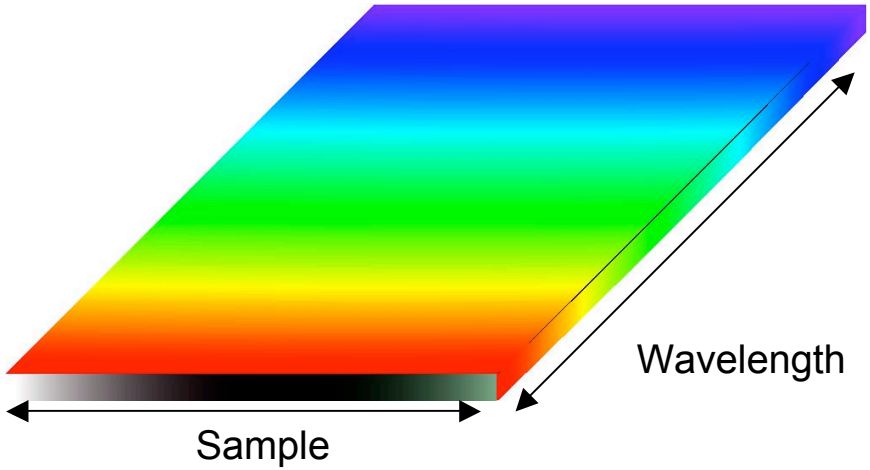
- **T0750** = Tile number with tile 0000 at the south pole, increasing sprialing east and north
- **MRR** = Product Type
- **IF** = Subtype of product, e.g.
  - IF – I/F
  - DE – backplanes for I/F
  - AL – Lambert albedo
  - DL – backplanes for Lambert albedo
  - SU – Summary Products
  - WV – List 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

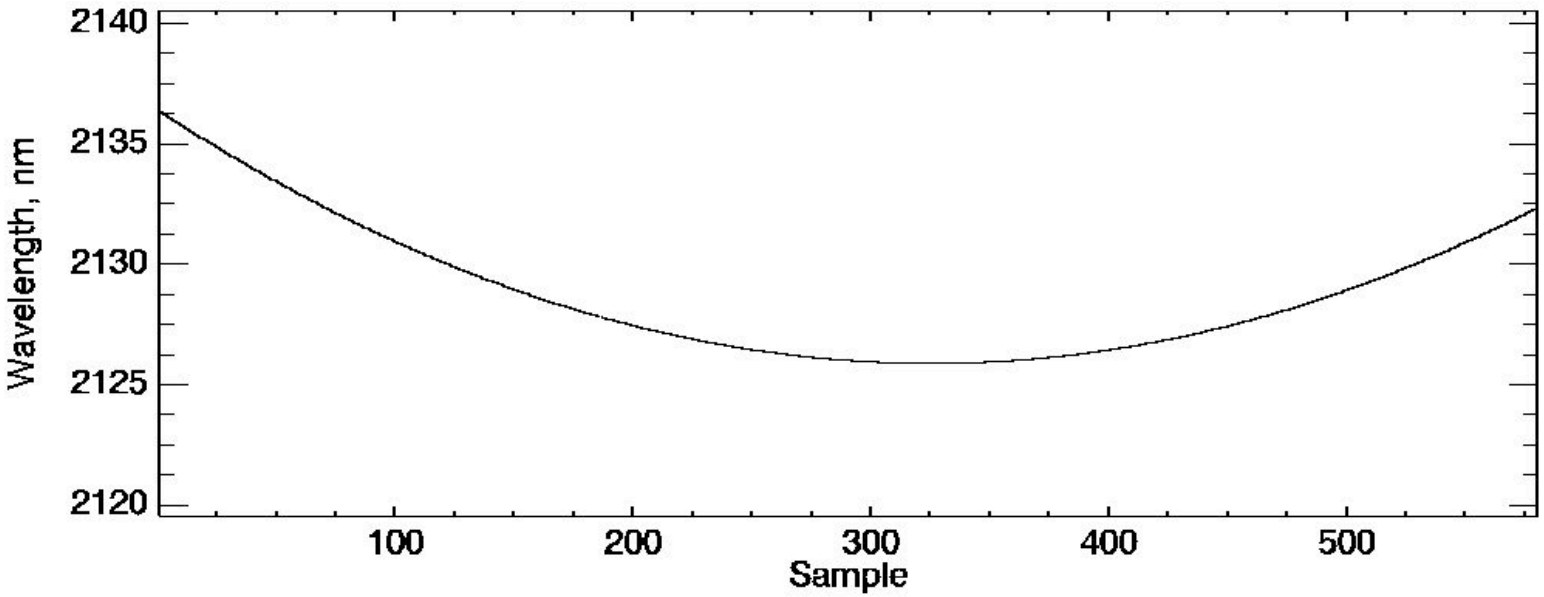


T0750_MRRIF_15S098_0256_1.IMG: The file name fully describes the location of the tile, the level of processing, the map scale, and the version of the data

CDRs Useful for Further Processing: WA

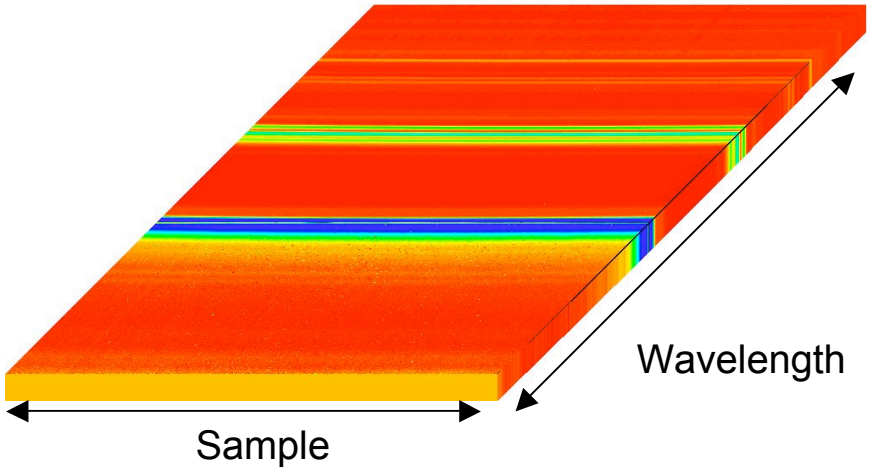
- Several ground- and flight-derived measurements useful for data processing are stored as CDRs
- The name of each CDRs includes a 2-letter designation of its type; machine-readable characters indicate the corresponding start time and instrument configuration
- The WA CDR records "spectral smile," or how each spatial pixel has a slightly different wavelength calibration

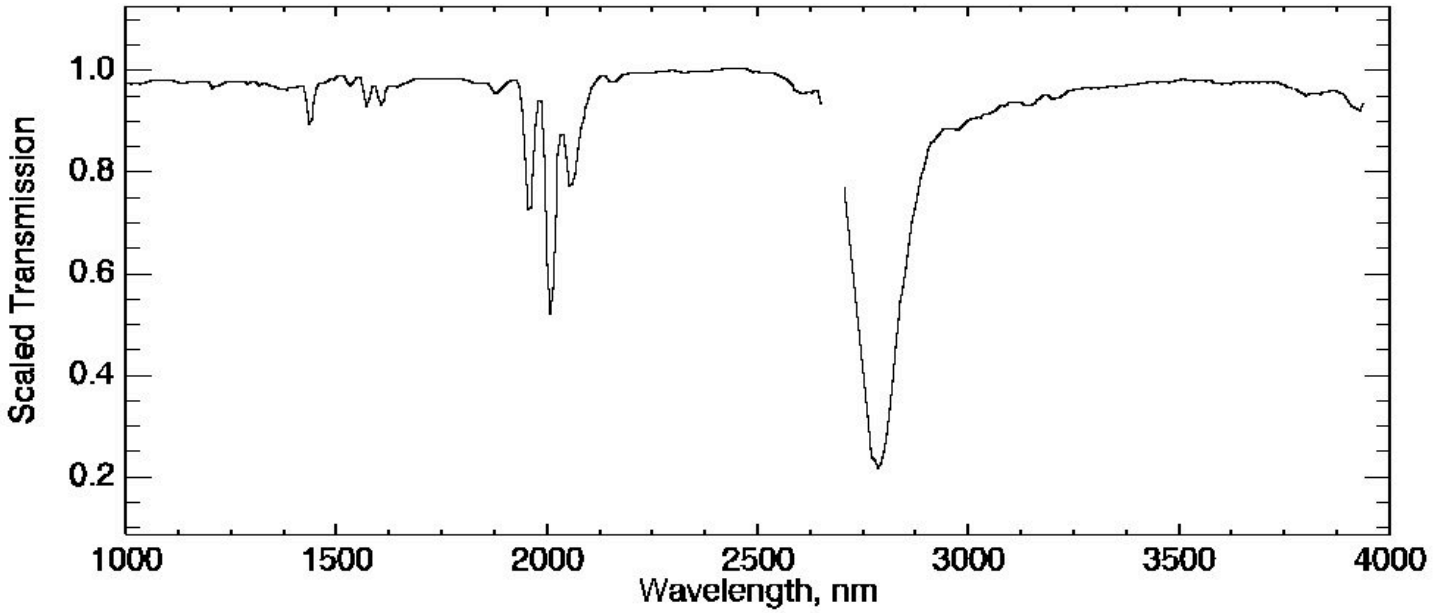




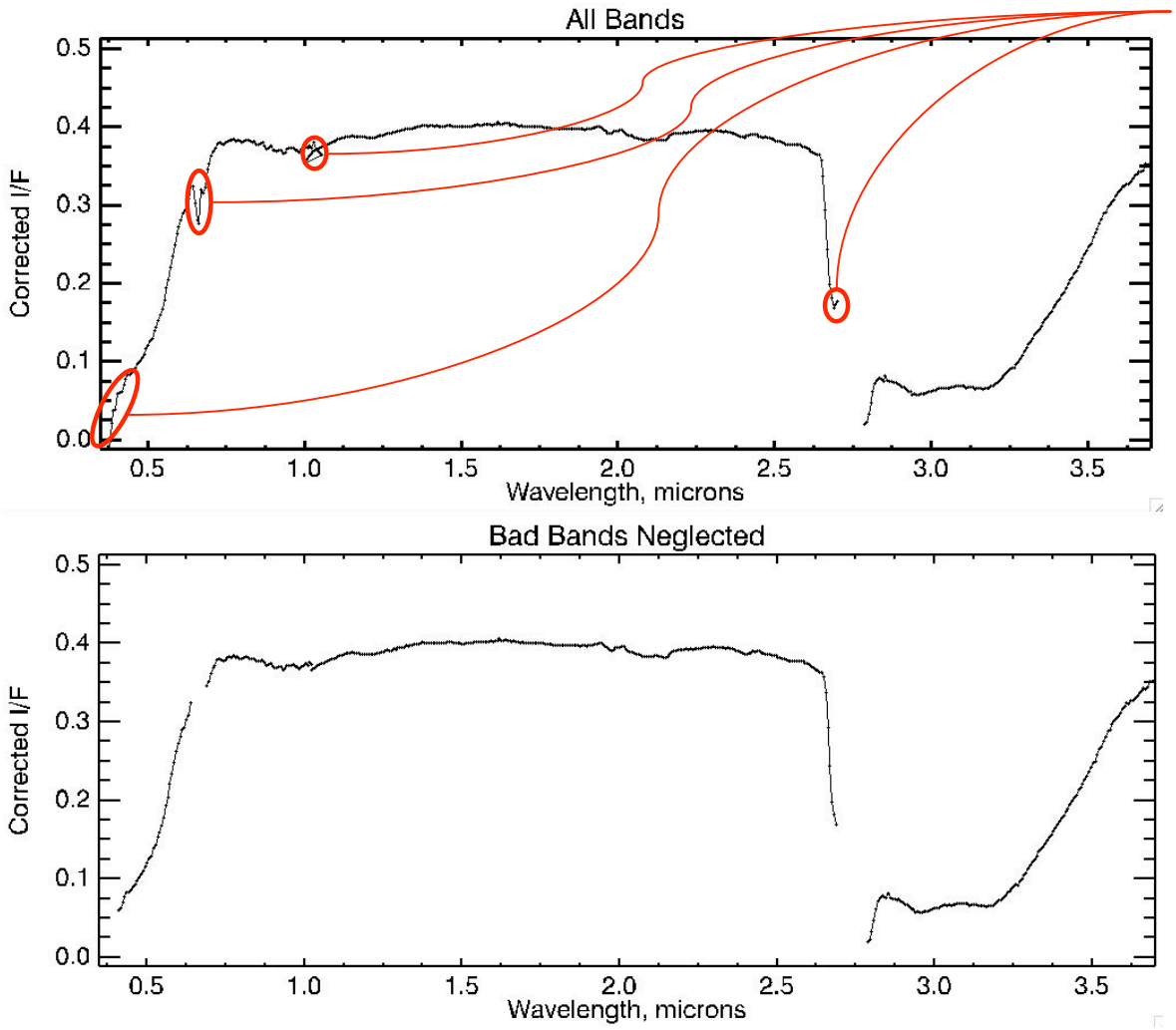
CDRs Useful for Further Processing: AT

- 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
  http://pds-geosciences.wustl.edu/crism-edr01/mro-m-crism-2-edr-v1/mrocr_0001/document/crism_avsis.pdf
  - Descriptions of all CRISM data files
- Pre-print of CRISM instrument paper
  http://pds-geosciences.wustl.edu/crism-edr01/mro-m-crism-2-edr-v1/mrocr_0001/calib/crism_jgr_preprint.pdf
  - Description of the instrument and its functions
  - Overview of performance
  - How observations are commanded
- CRISM Data Product Specification
  http://pds-geosciences.wustl.edu/crism-edr01/mro-m-crism-2-edr-v1/mrocr_0001/document/crism_dpsis.pdf
  - Full detail on contents of all CRISM files
  - Descriptions of all label keywords and housekeeping items
  - Detailed description of radiometric calibration