MRO CRISM

Map Projected Targeted Reduced Data Records (MTRDRs):

Data Processing Pipeline and Product Set

CRISM Data User's Workshop

03/18/12

F. Seelos, S. Murchie, CRISM SOC

What is an MTRDR?

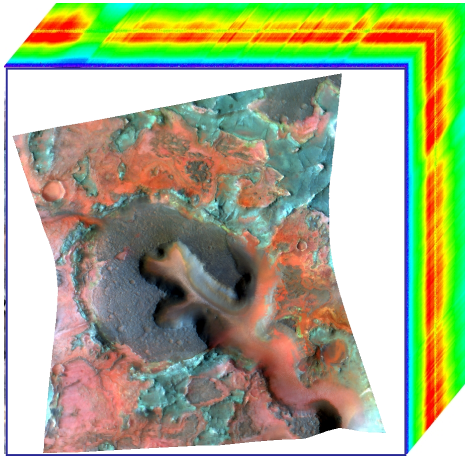
1) Hyperspectral targeted observation central scan TRR3 I/F image cube with additional systematic data processing:
   - [PHT] Lambertian photometric correction
   - [ATM] Revised empirical correction for atmospheric gas absorptions
     - [RSC] Post-ATM mitigation of introduced column-dependent residuals
   - [EGN] Empirical normalization of observation geometric dependencies (e.g. atmospheric scattering) to the nearest-nadir sampled geometry
   - [ESC] Empirical modeling and correction of residual cross-track optical distortions (spectral smile)
   - VNIR data transformed to the IR data sensor space
   - “Bad bands” removed
   - Map projected to a global standard
     - Equirectangular with rolling center latitude of projection
     - Polar stereographic poleward of +/- 65 degrees latitude
2) An image cube of spectral indices (“summary parameters”) derived from these corrected, normalized data
3) An image cube of map-projected geometric information from the DDRs

The current best available “whole observation” correction to what an idealized gimbal-free version of CRISM would acquire

Corrected, Map-Projected Data= MTRDRs* 3 Component Image Cubes

*** Map-Projected Targeted Reduced Data Records**

Scene I/F, unitless



Multiband image of corrected I/F; VNIR transformed to IR; map projected; “bad bands” removed

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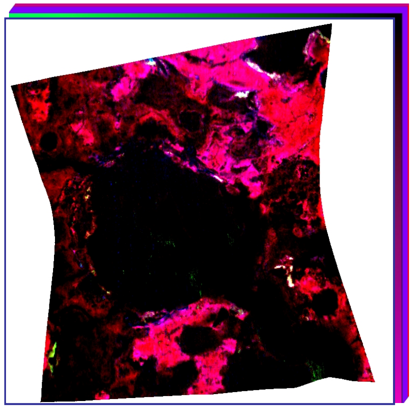
INSTRUMENT_NAME                = "COMPACT RECONNAISSANCE IMAGING
                                      SPECTROMETER FOR MARS"
INSTRUMENT_ID                  = CRISM
TARGET_NAME                    = MARS
PRODUCT_TYPE                   = MPTARGETED_RDR
PRODUCT_CREATION_TIME          = 2010-11-21T17:44:07
START_TIME                     = 2008-08-21T17:20:57.794
STOP_TIME                      = 2008-08-21T17:22:57.529
SPACECRAFT_CLOCK_START_COUNT   = "4/0903806478.04596"
SPACECRAFT_CLOCK_STOP_COUNT    = "4/0903806597.52710"
ORBIT_NUMBER                   = "NULL"
OBSERVATION_TYPE               = "FRT"
OBSERVATION_ID                 = 16#0000C202#
MRO:OBSERVATION_NUMBER         = 16#07#
MRO:ACTIVITY_ID                = "IF165"
MRO:SENSOR_ID                  = "J"

/* Detector and FPE temperature refer to IR component of observation */

MRO:DETECTOR_TEMPERATURE       = -152.306
MRO:OPTICAL_BENCH_TEMPERATURE  = -52.930
MRO:SPECTROMETER_HOUSING_TEMP  = -76.728
MRO:SPHERE_TEMPERATURE         = -52.672
MRO:FPE_TEMPERATURE            = 0.718
PRODUCT_VERSION_ID             = 3
```

Detached PDS label describing the source files, corrections performed, with map projection information

Summary products, I/F or unitless



Multiband image of various summary parameters; VNIR transformed to IR; map projected

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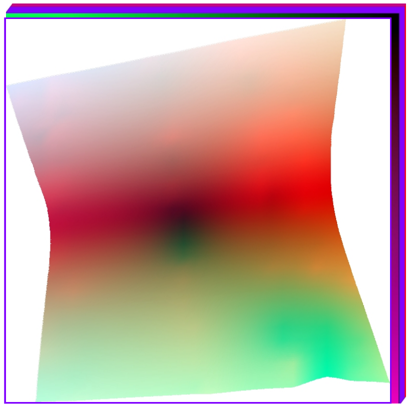
INSTRUMENT_NAME                = "COMPACT RECONNAISSANCE IMAGING
                                  SPECTROMETER FOR MARS"
INSTRUMENT_ID                  = CRISM
TARGET_NAME                    = MARS
PRODUCT_TYPE                   = MAP_PROJECTED_SUMMARY_PRODUCTS
PRODUCT_CREATION_TIME          = 2008-08-29T16:16:47
START_TIME                     = 2008-08-21T17:20:57.794
STOP_TIME                      = 2008-08-21T17:22:57.528
SPACECRAFT_CLOCK_START_COUNT   = "4/903806478:4596"
SPACECRAFT_CLOCK_STOP_COUNT    = "4/903806597:52710"

ORBIT_NUMBER                   = "0"
OBSERVATION_TYPE               = "FRT"
OBSERVATION_ID                 = 16#0000C202#
MRO:OBSERVATION_NUMBER         = 16#07#
MRO:ACTIVITY_ID                = "SU165"
MRO:SENSOR_ID                  = "L"
PRODUCT_VERSION_ID             = "1"
SOURCE_PRODUCT_ID              = {
    "FRT0000C202_07_DE165L_DDR1"
}

PRODUCER_INSTITUTION_NAME      = "APPLIED PHYSICS LABORATORY"
SOFTWARE_NAME                  = "mtrdr_pipeline"
SOFTWARE_VERSION_ID            = "1.0"
```

Detached PDS label describing the source I/F cube, listing the bands, with map projection information

Map-projected info from DDR, various units



Multiband image of IR DDR image planes, map projected (elevation, slopes, photometry)

```
INSTRUMENT_HOST_NAME           = "MARS RECONNAISSANCE ORBITER"
SPACECRAFT_ID                  = MRO
INSTRUMENT_NAME                = "COMPACT RECONNAISSANCE IMAGING
                                  SPECTROMETER FOR MARS"
INSTRUMENT_ID                  = CRISM
TARGET_NAME                    = MARS
PRODUCT_TYPE                   = MAP_PROJECTED_DDR
PRODUCT_CREATION_TIME          = 2008-08-29T16:16:47
START_TIME                     = 2008-08-21T17:20:57.794
STOP_TIME                      = 2008-08-21T17:22:57.528
SPACECRAFT_CLOCK_START_COUNT   = "4/903806478:4596"
SPACECRAFT_CLOCK_STOP_COUNT    = "4/903806597:52710"

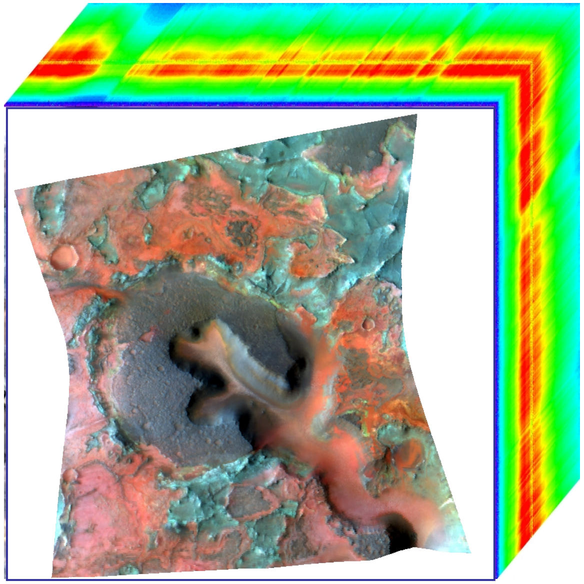
ORBIT_NUMBER                   = "0"
OBSERVATION_TYPE               = "FRT"
OBSERVATION_ID                 = 16#0000C202#
MRO:OBSERVATION_NUMBER         = 16#07#
MRO:ACTIVITY_ID                = "DE165"
MRO:SENSOR_ID                  = "L"
PRODUCT_VERSION_ID             = "1"
SOURCE_PRODUCT_ID              = {
    "FRT0000C202_07_DE165L_DDR1"
}

PRODUCER_INSTITUTION_NAME      = "APPLIED PHYSICS LABORATORY"
```

Detached PDS label describing the source DDR, listing the bands, with map projection information

MTRDR Nomenclature

- **FRT =** Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long Targeted Observation)
  - HRS (Half Resolution Short Targeted Observation)
- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter for image within observation
- **IF166** = Processing, internal command macro used
  - IFnnn – I/F / Macro #
  - SUnnn – Summary products / Macro #
  - DEnnn – Derived data / Macro #
- **J** = Sensor ID
  - J for joined (for IF and SU)
  - L for IR (for DE)
- **MTR3** = MTRDR, calibration version = 3
- **IMG** = file extension
  - IMG for binary image data
  - LBL for detached ASCII PDS label



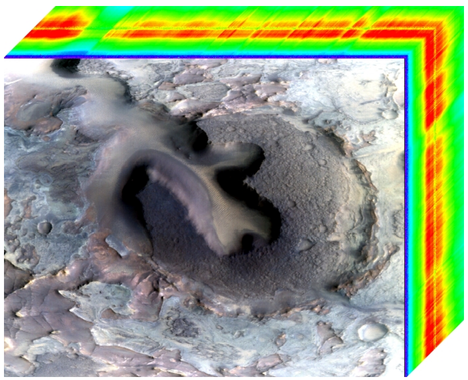
Full-resolution targeted
Observation 0x3E12
Counter
Calibrated to I/F
Joined VNIR+IR data
Software version 3

FRT00003E12_07_IF166J_MTR3.IMG

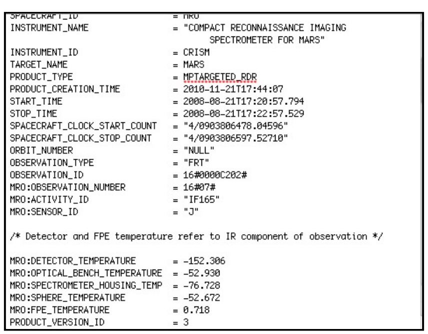
The file name describes the type of data, an overview of the processing, and gives the unique ID and counter

A non-Map Projected Version of the Corrected Data will also be PDS-Delivered

Scene I/F, unitless



Multiband image of corrected I/F; VNIR transformed to IR; “bad bands” **still present**



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SPACECRAFT_ID                 = MRO
INSTRUMENT_NAME               = "COMPACT RECONNAISSANCE IMAGING
                                   SPECTROMETER FOR MARS"
INSTRUMENT_ID                 = CRISM
TARGET_NAME                   = MARS
PRODUCT_TYPE                  = MPTARGETED_RDR
PRODUCT_CREATION_TIME         = 2010-11-21T17:44:07
START_TIME                    = 2008-08-21T17:20:57.794
STOP_TIME                     = 2008-08-21T17:22:57.529
SPACECRAFT_CLOCK_START_COUNT  = "4/0903806478.04596"
SPACECRAFT_CLOCK_STOP_COUNT   = "4/0903806597.52710"
ORBIT_NUMBER                  = "NULL"
OBSERVATION_TYPE              = "FRT"
OBSERVATION_ID                = 16#0000C202#
MRO:OBSERVATION_NUMBER        = 16#07#
MRO:ACTIVITY_ID               = "IF165"
MRO:SENSOR_ID                 = "J"

/* Detector and FPE temperature refer to IR component of observation */

MRO:DETECTOR_TEMPERATURE      = -152.306
MRO:OPTICAL_BENCH_TEMPERATURE = -52.930
MRO:SPECTROMETER_HOUSING_TEMP = -76.728
MRO:SPHERE_TEMPERATURE        = -52.672
MRO:FPE_TEMPERATURE           = 0.718
PRODUCT_VERSION_ID            = 3
```

Detached PDS label describing the source files, corrections performed

TER = Targeted Empirical Record

- **FRT =** Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long Targeted)
  - HRS (Half Resolution Short Targeted)
- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter within observation
- **IF166** = Processing, internal macro used
  - IFnnn – I/F / Macro #
- **J** = Sensor ID
  - J for joined
- **TER3** = TER, calibration version = 3
- **IMG** = file extension
  - IMG for binary image data
  - LBL for detached ASCII PDS label

Full-resolution targeted
Observation 0x3E12
Counter
Calibrated to I/F
Joined VNIR+IR data
Software version 3

FRT00003E12_07_IF166J_TER3.IMG

Each Type of I/F File is Accompanied by a Wavelength Table

```
0,196,  436.13
0,197,  442.63
0,198,  449.14
0,199,  455.64
0,200,  462.15
0,201,  468.65
0,202,  475.16
0,203,  481.67
0,204,  488.17
0,205,  494.68
0,206,  501.19
0,207,  507.70
0,208,  514.21
0,209,  520.72
0,210,  527.23
0,211,  533.74
0,212,  540.25
0,213,  546.76
0,214,  553.27
0,215,  559.78
0,216,  566.29
0,217,  572.81
0,218,  579.32
0,219,  585.83
0,220,  592.35
0,221,  598.86
0,222,  605.38
0,223,  611.89
0,224,  618.41
0,225,  624.92
0,226,  631.44
0,238,  709.68
0,239,  716.20
0,240,  722.72
0,241,  729.25
0,242,  735.77
0,243,  742.30
0,244,  748.82
```

ASCII table indicating source detector, detector row number, and wavelengths

```
INSTRUMENT_NAME                 = "COMPACT RECONNAISSANCE IMAGING
                                   SPECTROMETER FOR MARS"
INSTRUMENT_ID                   = CRISM
TARGET_NAME                     = MARS
PRODUCT_TYPE                    = MPTARGETED_RDR
PRODUCT_CREATION_TIME           = 2012-03-14T03:47:40
START_TIME                      = "N/A"
STOP_TIME                       = "N/A"
SPACECRAFT_CLOCK_START_COUNT    = "N/A"
SPACECRAFT_CLOCK_STOP_COUNT     = "N/A"

PRODUCT_VERSION_ID              = "3"
PRODUCER_INSTITUTION_NAME       = "JOHNS HOPKINS UNIVERSITY
                                    APPLIED PHYSICS LABORATORY"
SOFTWARE_NAME                   = "mtrdr_pipeline"
SOFTWARE_VERSION_ID             = "1.0"

/*    A listfile including detector row numbers and wavelengths in the */
/*    Targeted Empirical Record and Map-Projected Targeted RDR images. */

OBJECT                  = WAVELENGTH_SOURCE_TABLE
  NAME                  = "CRISM JOINED WAVELENGTH TABLE"
  INTERCHANGE_FORMAT    = "ASCII"
  ROWS                  = 674
  COLUMNS               = 3
  ROW_BYTES             = 14
  DESCRIPTION           = "CRISM JOINED WAVELENGTH table"
  OBJECT                = COLUMN
    COLUMN_NUMBER       = 1
    NAME                = SPECT_ID
    DATA_TYPE           = ASCII_INTEGER
    START_BYTE          = 1
    BYTES               = 1
    DESCRIPTION         = "Spectrometer identifier; 0 = IR; 1 = VNIR"
  END_OBJECT            = COLUMN
  OBJECT                = COLUMN
    COLUMN_NUMBER       = 2
    NAME                = ROWNUM
```

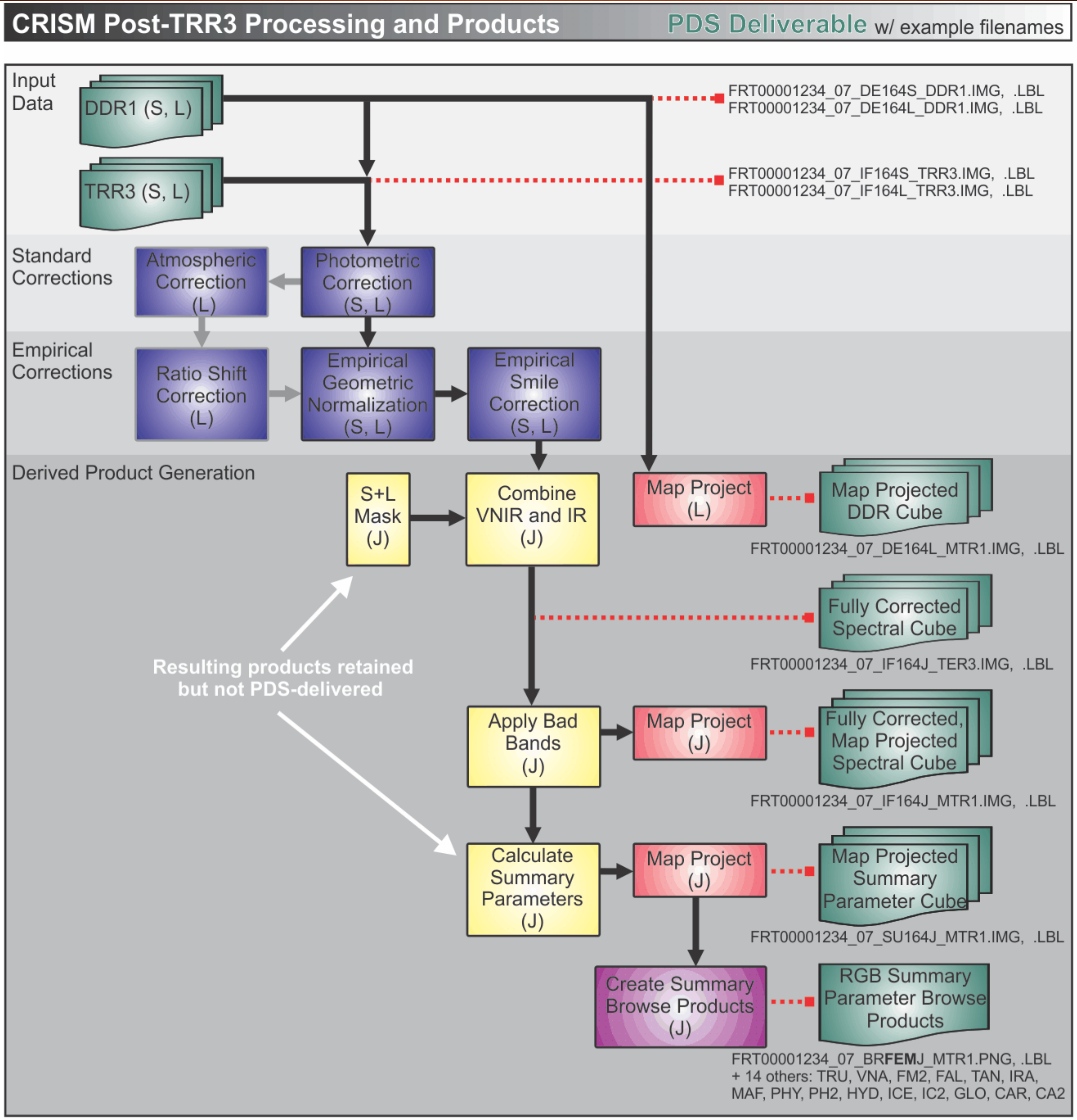
Detached PDS label describing the table

- **FRT =** Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long Targeted)
  - HRS (Half Resolution Short Targeted)
- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter within observation
- **WV166** = Processing, internal macro used
  - WVnnn – Wavelength / Macro #
- **J** = Sensor ID
  - J for joined
- **TER3** = Product type and calibration version
  - TER, calibration version = 3
  - MTR, calibration version = 3
- **TAB**= file extension
  - TAB for table of wavelengths
  - LBL for detached ASCII PDS label

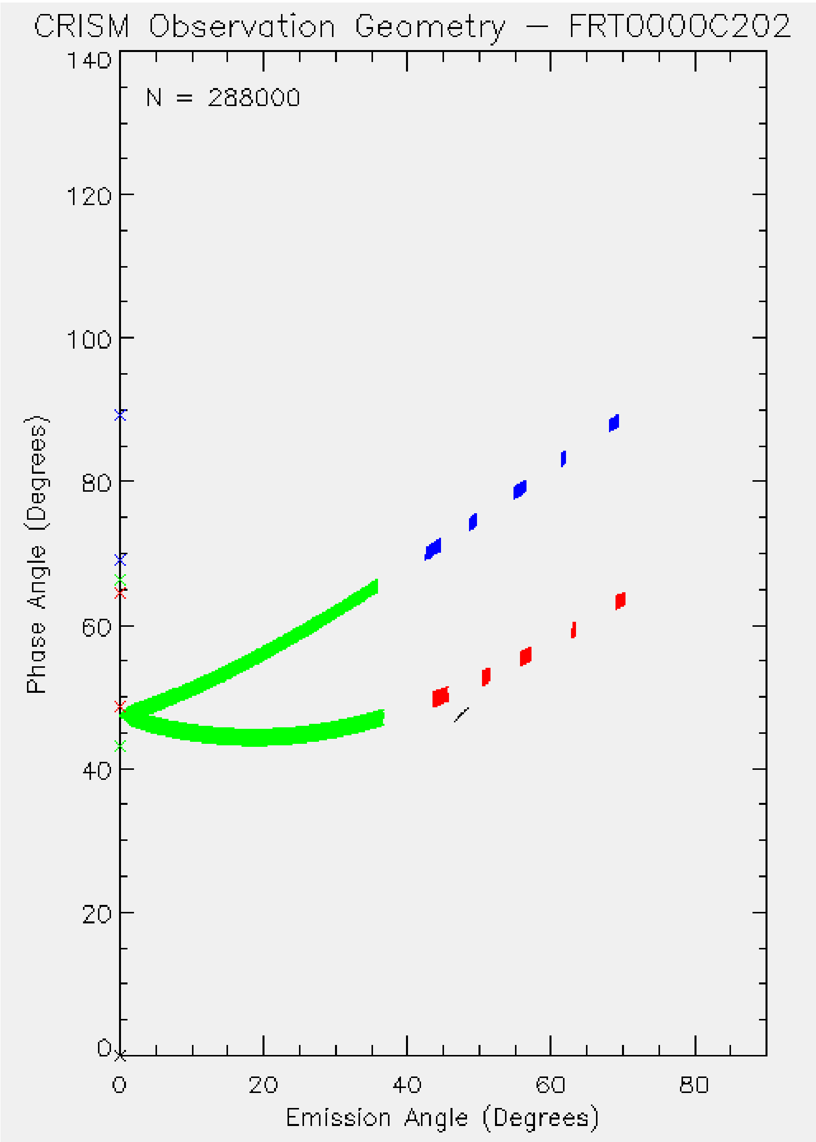
Full-resolution target
Observation 0x3E12
Counter
Wavelength table
Joined VNIR+IR data
Software version 3

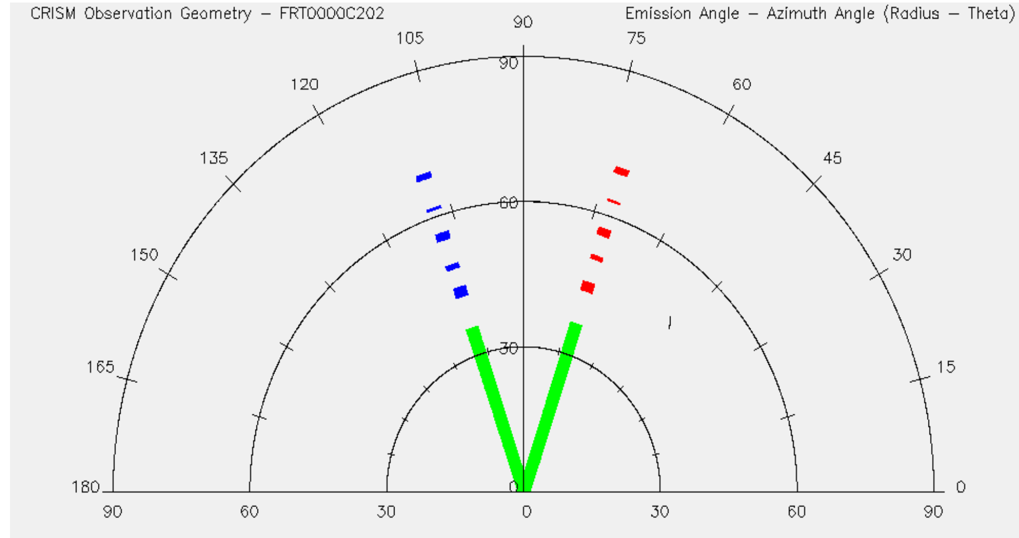
FRT00003E12_07_WV166J_TER3.TAB

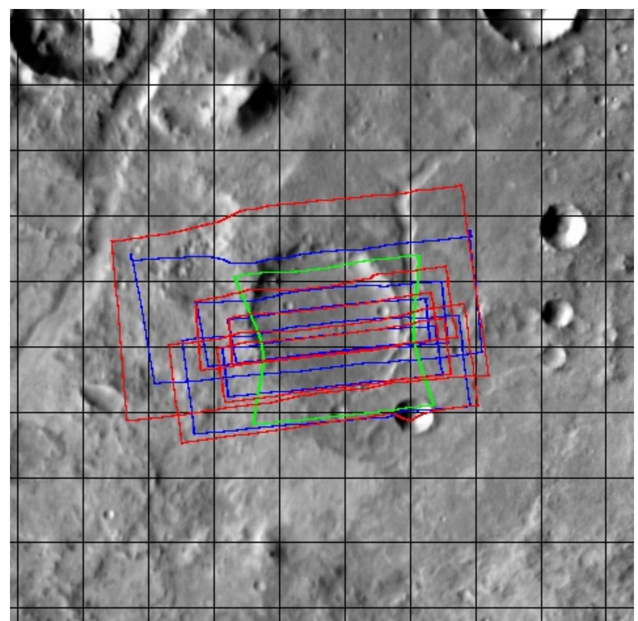
MTRDR Data Processing Pipeline



CRISM Gimbaled Observation Geometry FRT0000C202



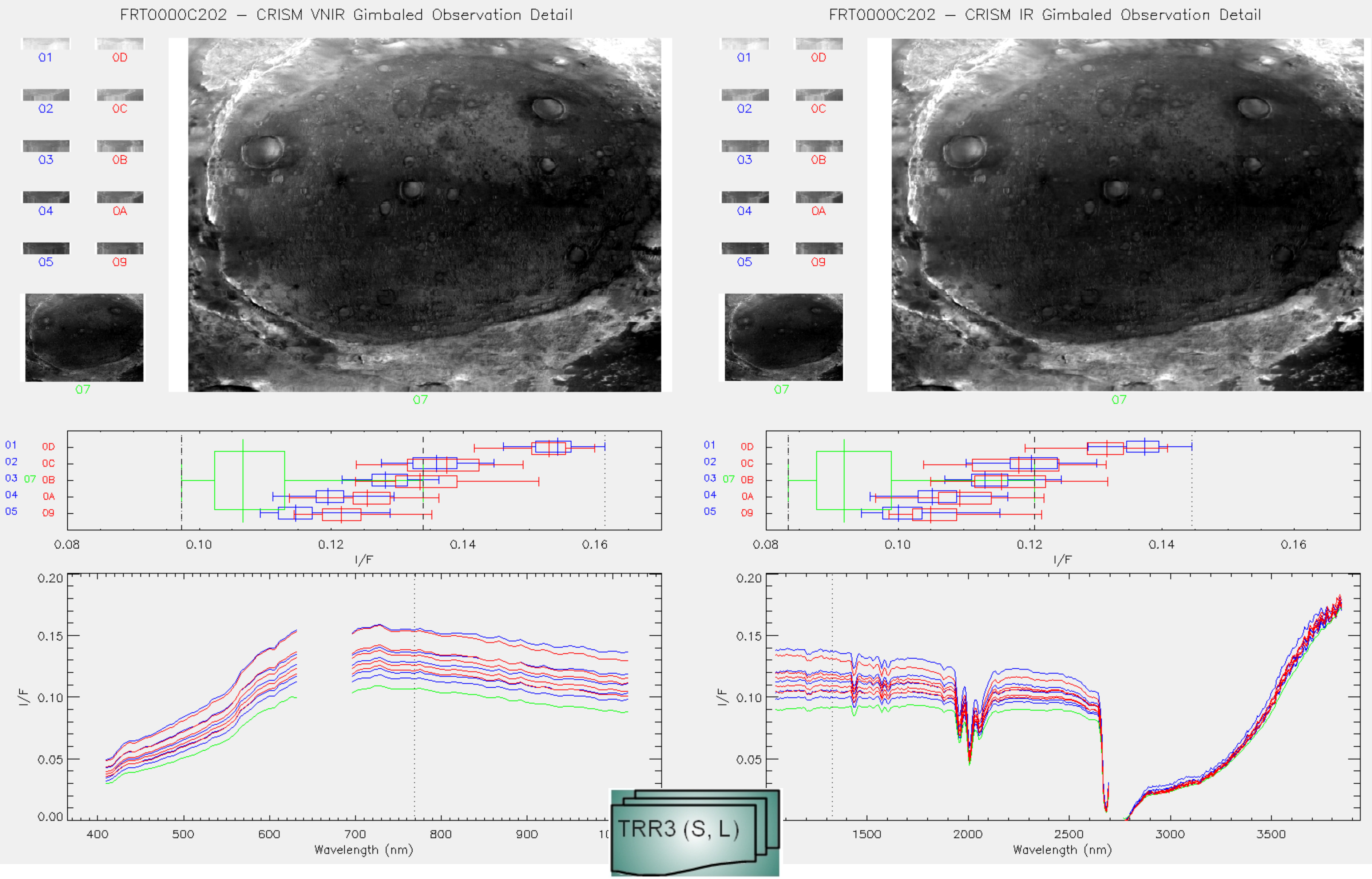




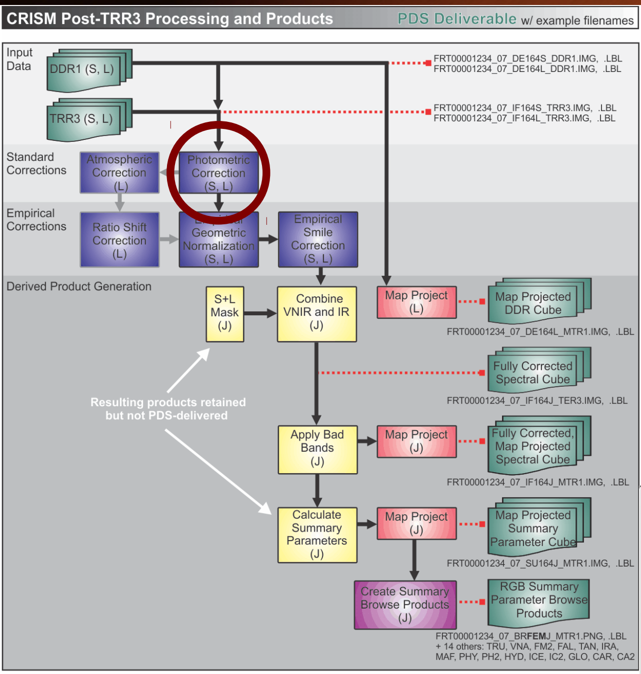
THEMIS DAY IR
5 km grid

DDR1 (S, L)

CRISM Gimbaled Observation Detail
FRT0000C202



Lambertian Photometric Correction [PHT]



- The Lambertian (cos[i]) photometric correction assumes the simplest reasonable surface bidirectional reflectance function and corrects the data to a normal illumination geometry
- Allows observations acquired at varying incidence angles to be more readily compared

INA ~ 60°
cos(INA) ~ 0.5

FRT00003192 - Columbia Hills, Gusev Crater (MER-A)

Lambertian
Photometric Correction [PHT]

Photometric Correction (S, L)

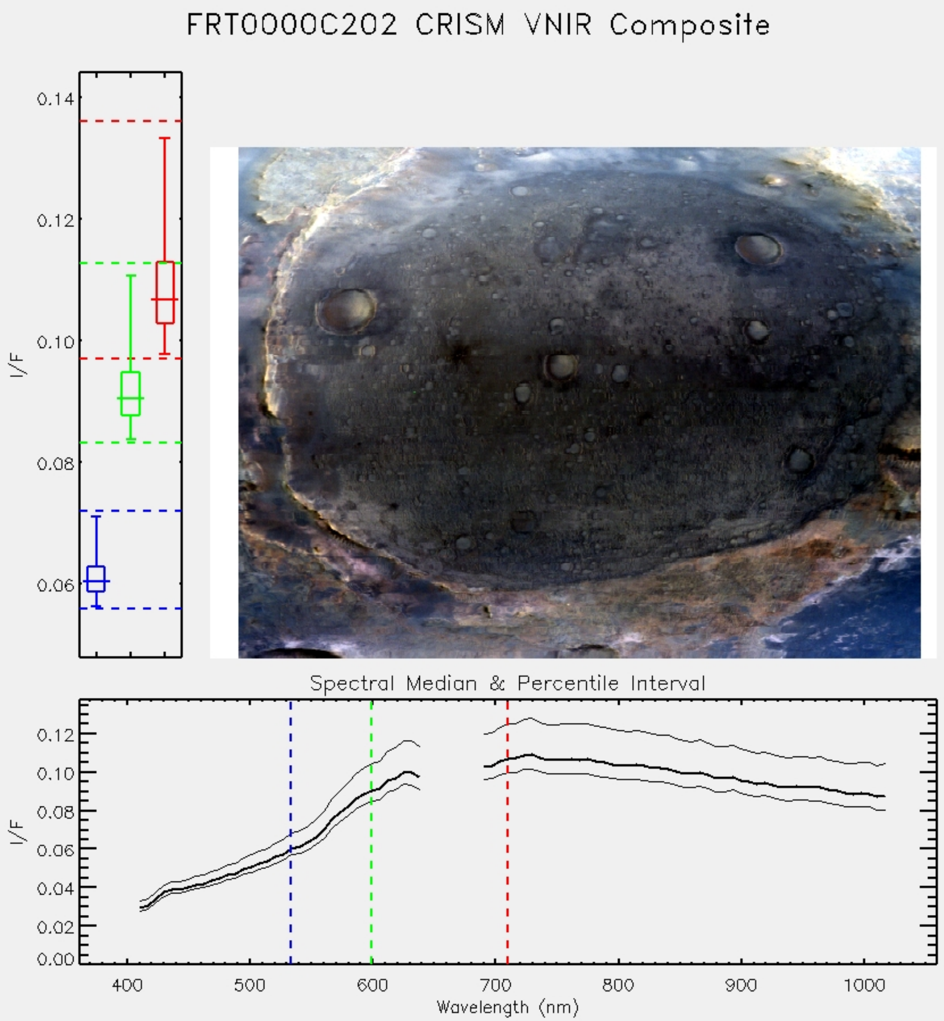
- Lambertian (cos[i]) photometric correction w/r/t the MOLA areoid
- MOLA MEGA source product - gridded degree and order 50 spherical harmonic expansion (16 ppd)
- CRISM DDR incidence angle (INA) band oversamples the areoid data

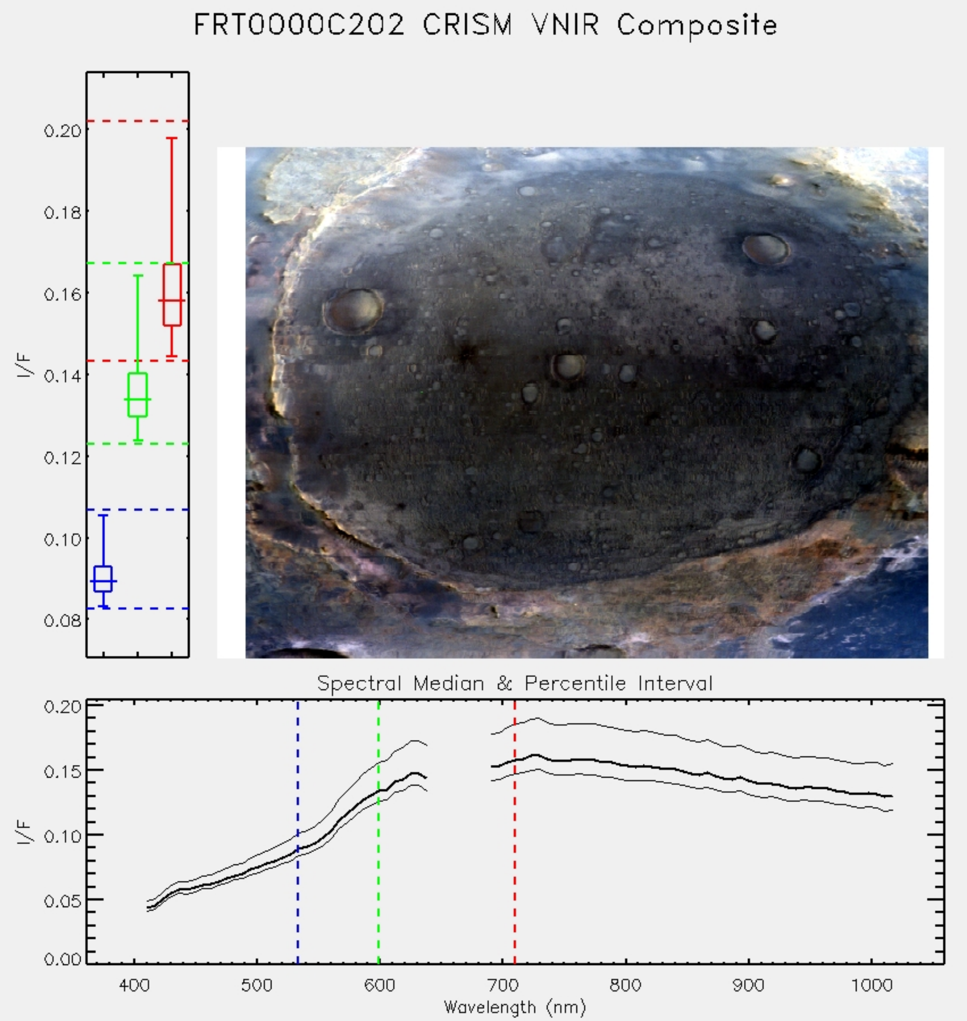
- Smooth fit to areoid INA data
- Two dimensional quadratic model

Lambertian Photometric Correction [PHT]

Photometric Correction (S, L)

VNIR TRR3 RGB → VNIR TRR3 PHT RGB

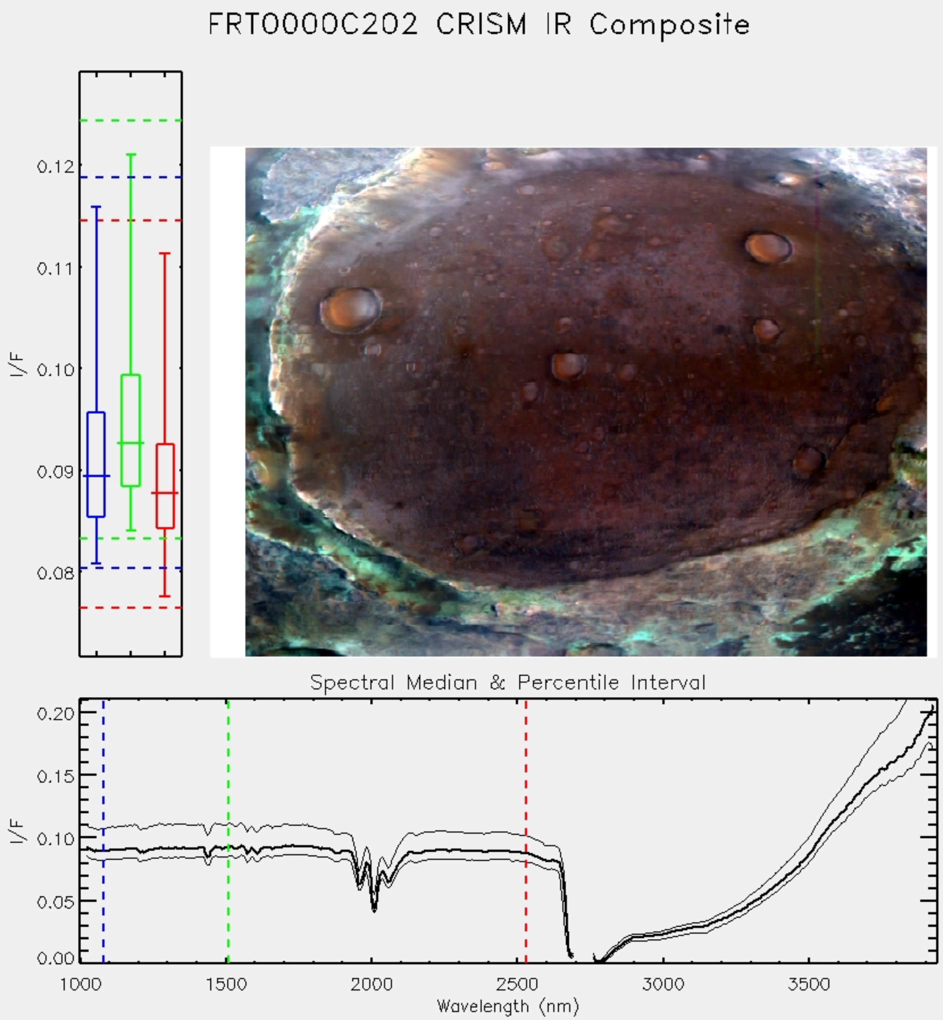


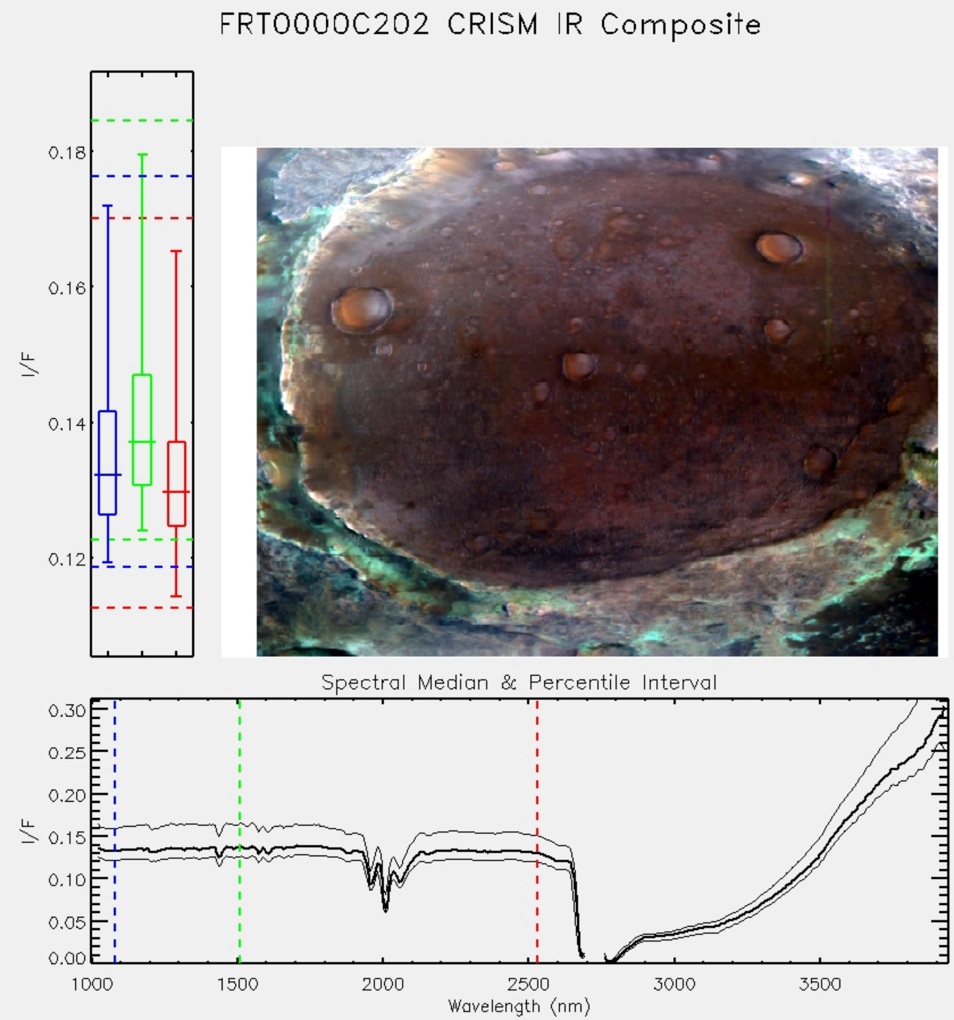


Lambertian
Photometric Correction [PHT]

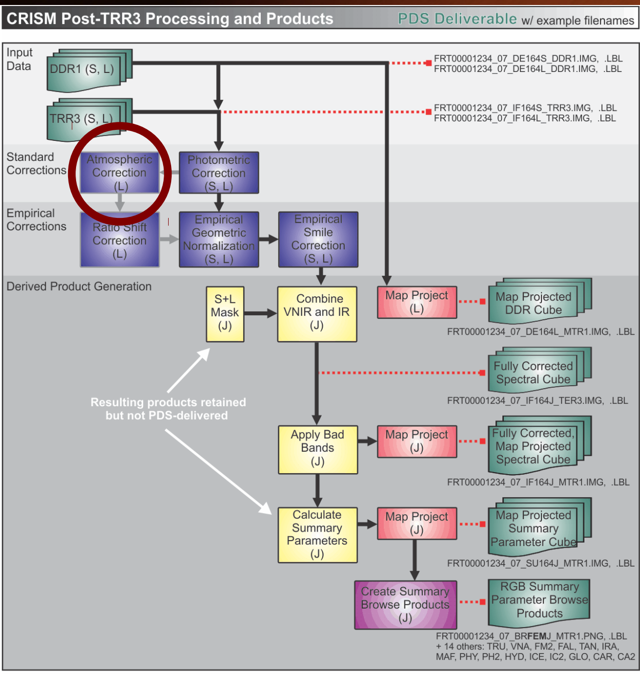
Photometric Correction (S, L)

IR TRR3 RGB → IR TRR3 PHT RGB

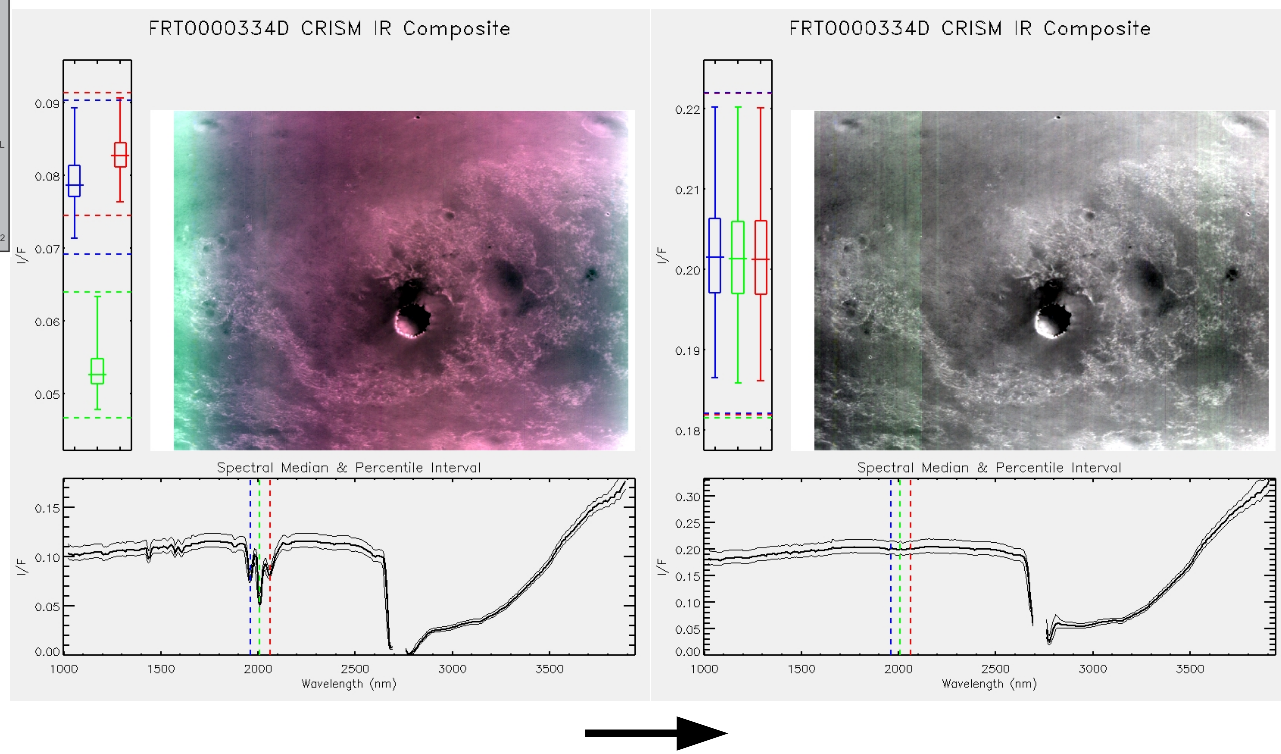




Modified Volcano Scan Atmospheric Correction [ATM]



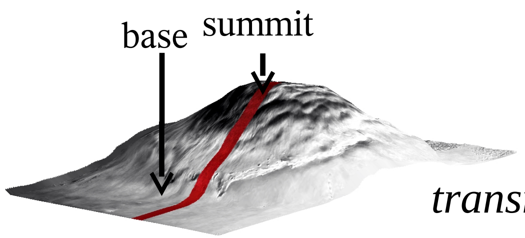
- The volcano scan atmospheric correction uses an empirically derived atmospheric transmission spectrum to characterize and remove spectral structure attributable to atmospheric gas absorptions
- The ATM procedure is only applied to CRISM IR data



FRT0000334D - Victoria Crater, Meridiani Planum (MER-B)

Volcano Scan Correction

- Observations contain atmospheric CO_2 absorption
- Derive transmission from Olympus Mons "volcano scan"

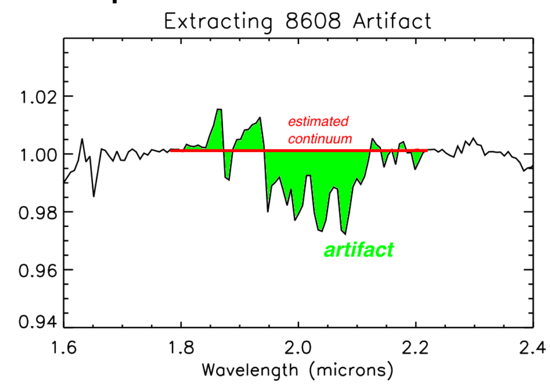


$$transmission = \frac{base}{summit}$$

- Scale transmission to match absorption in scene spectrum, divide to remove atmosphere

Artifact Correction

- Correction leaves a bowl-shaped artifact at 2 microns
  - Related to P/T dependence of CO_2 spectrum
- Apply correction to VS base spectrum; assume linear continuum; difference is "artifact spectrum"

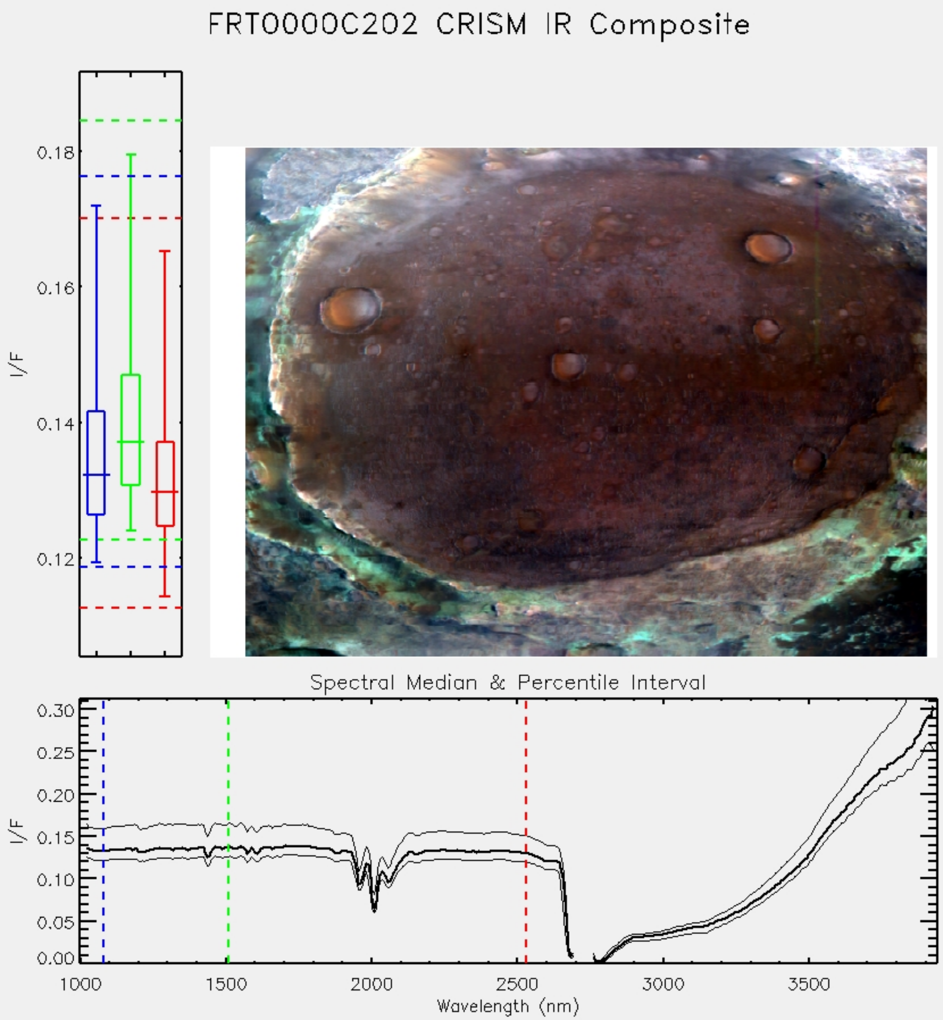


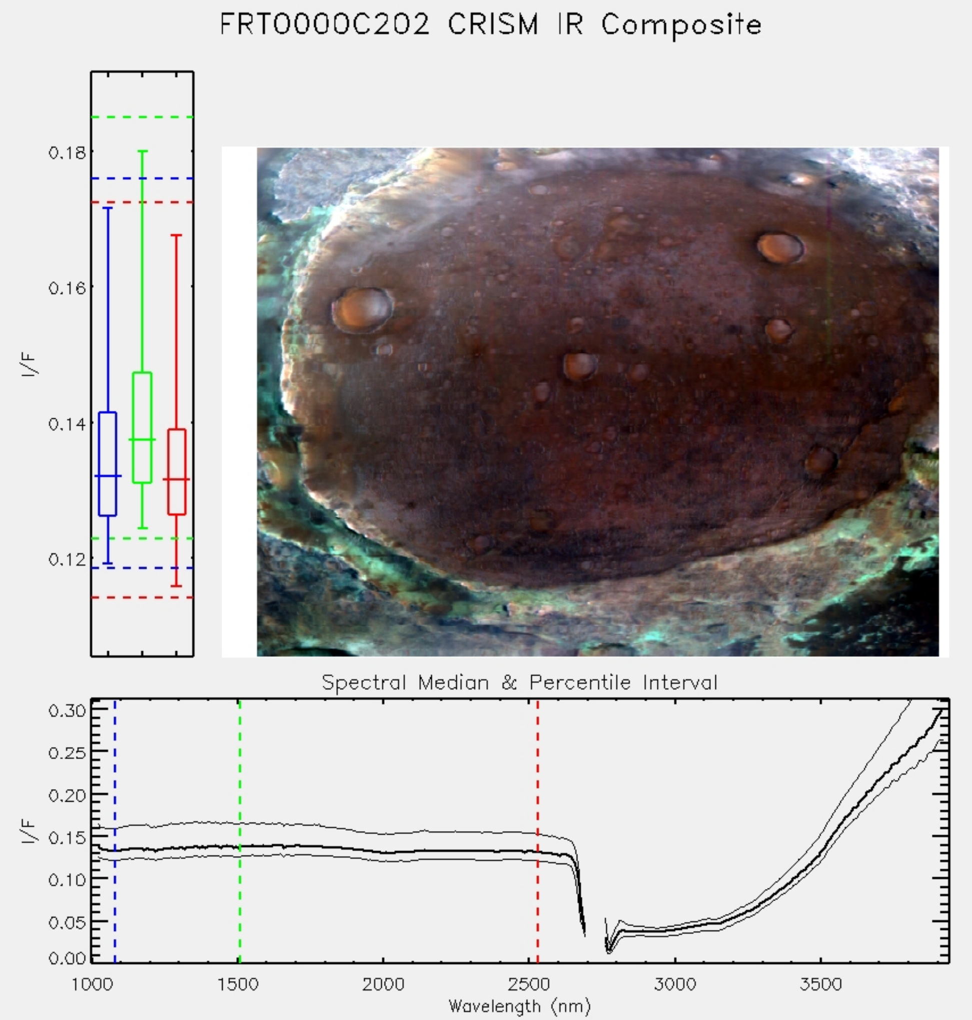
- Add artifact to corrected spectrum after scaling to minimize correlation between artifact and corrected spectrum

Modified Volcano Scan
Atmospheric Correction [ATM]

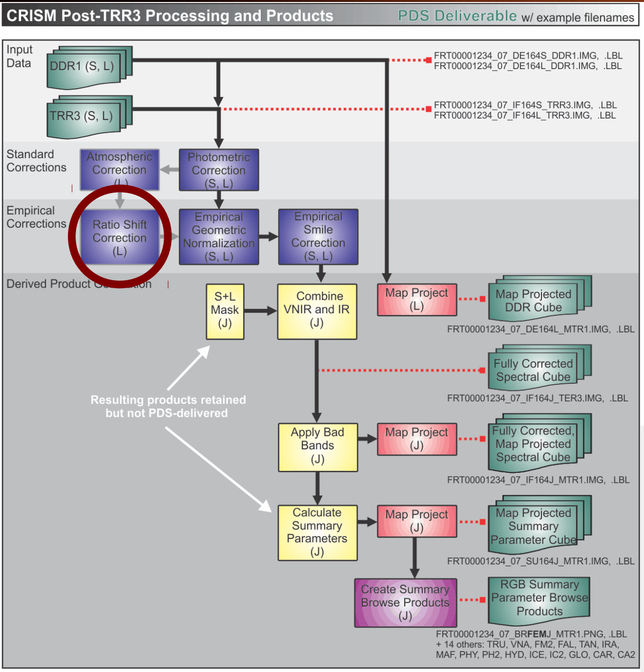
Atmospheric Correction (L)

IR TRR3 PHT RGB → IR TRR3 PHT ATM RGB

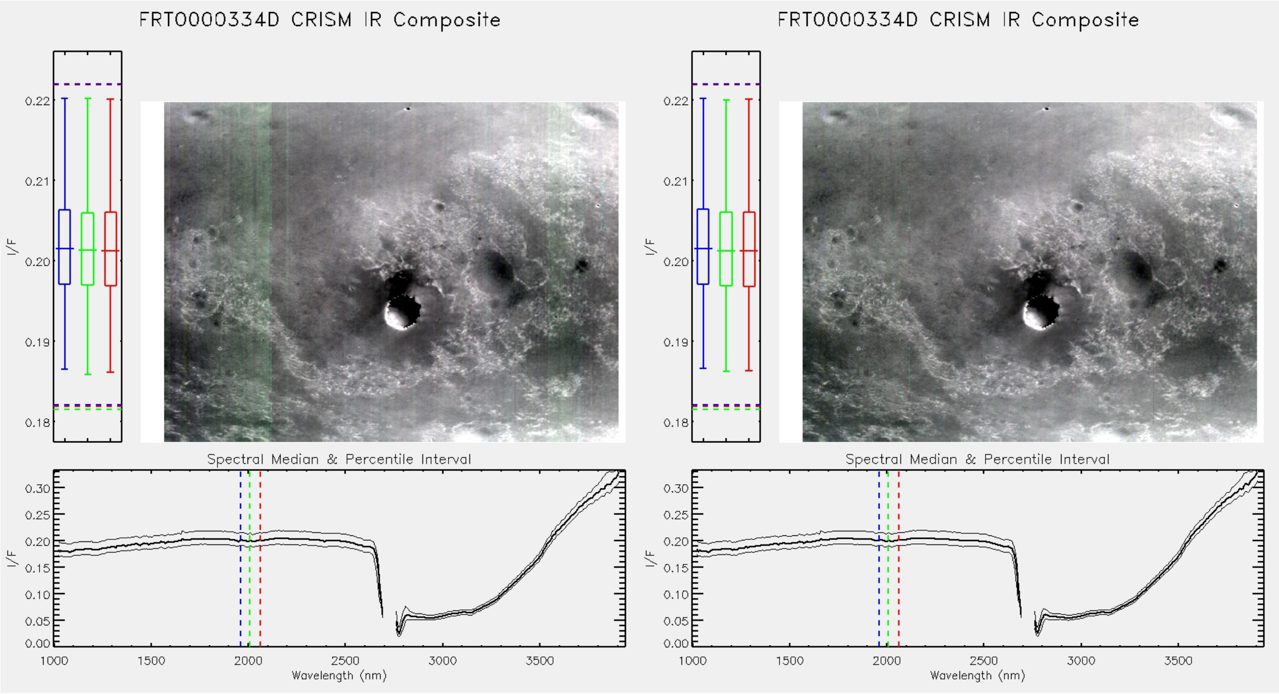




Ratio Shift Correction [RSC]



- The Ratio Shift Correction quantifies systematic cross-track residual structure (ground plane along-track striping) and develops a correction frame from the evaluation of inter-column ratio statistics
- Statistically supported cross-track structure is retained

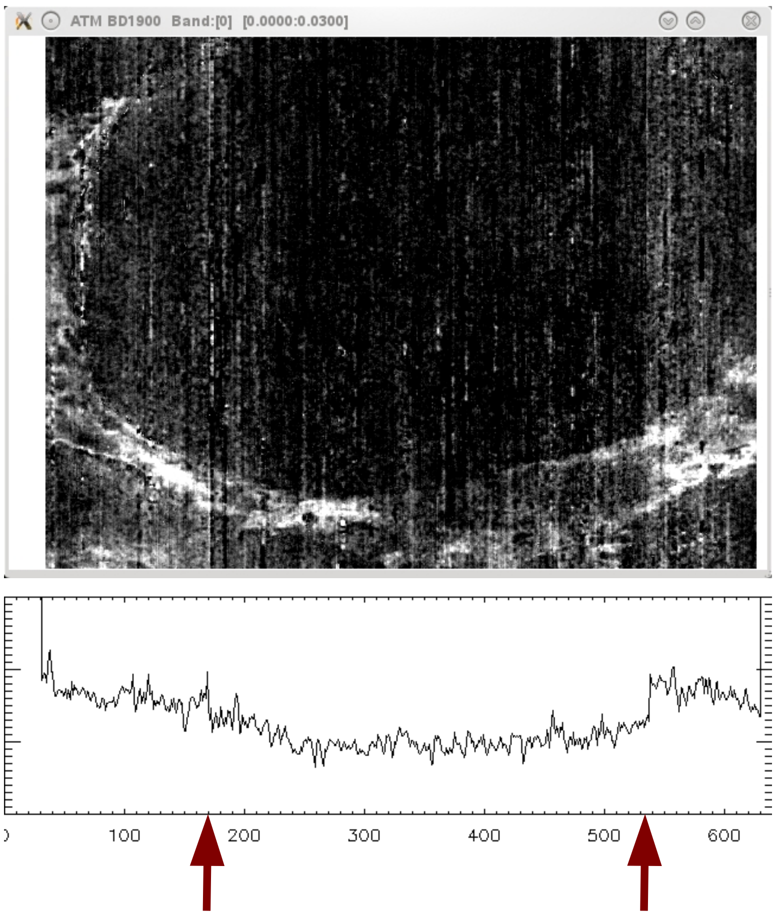


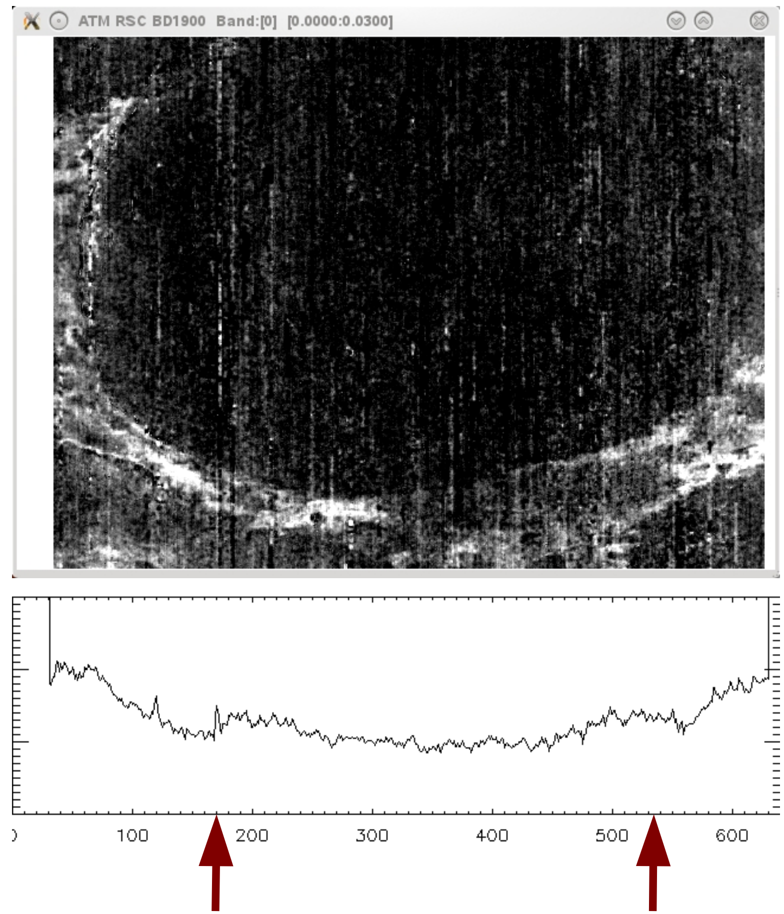
FRT0000334D - Victoria Crater, Meridiani Planum (MER-B)

Ratio Shift Correction [RSC]

Ratio Shift Correction (L)

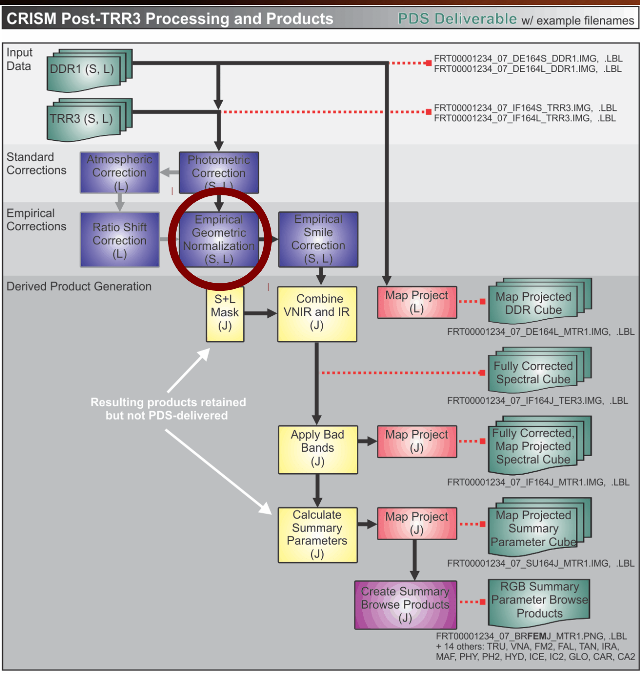
IR TRR3 PHT ATM BD1900 → IR TRR3 PHT ATM RSC BD1900



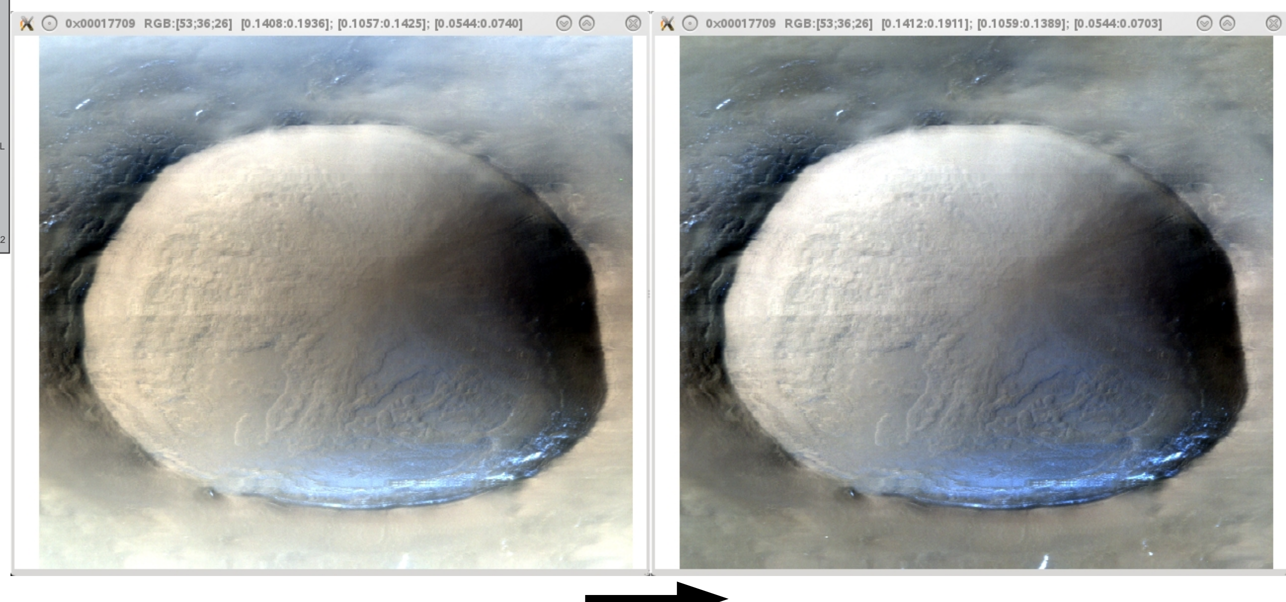


Parameterization of 0xC202 1900 nm spectral region highlights ATM residual

Empirical Geometric Normalization [EGN]



- The Empirical Geometric Normalization characterizes and develops a correction for the geometric dependencies that result from the continuously varying geometry of CRISM targeted observations
- Correction of characteristic wavelength-dependent along-track gradients



FRT00017709 - Heimdall crater, Northern Plains (PHX)

Empirical Geometric Normalization [EGN]

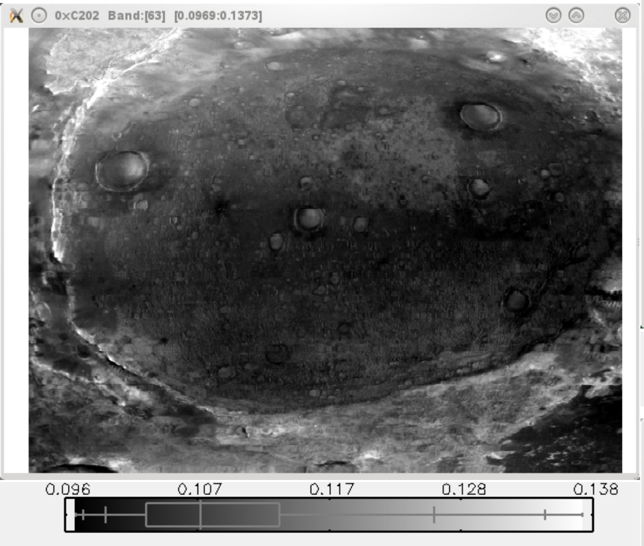
Empirical Geometric Normalization (S, L)

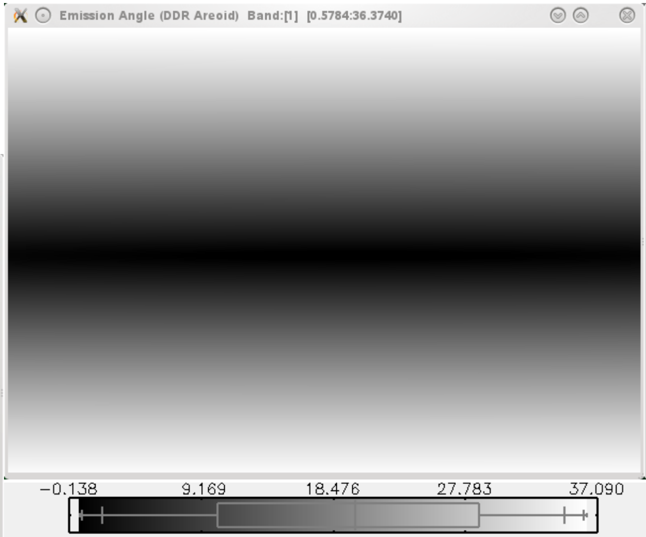
Characterize and Mitigate Geometric Dependencies

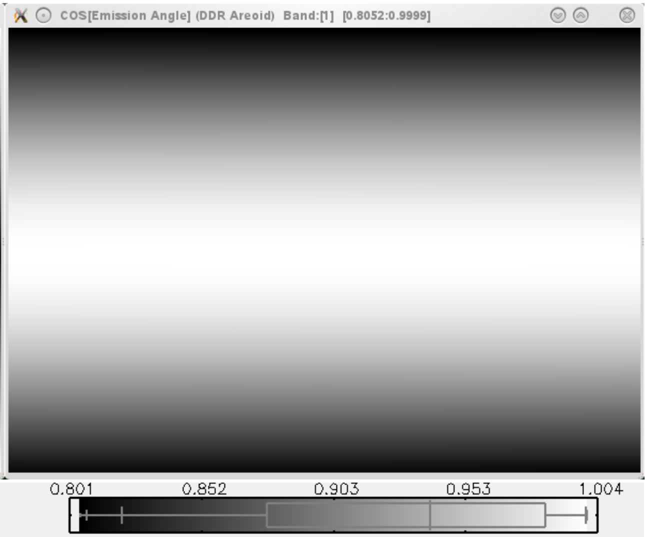
- Spectral data sampled with respect to the observation geometry
  - Targeted observation central scan and associated EPFs
  - Default is [cos(e), g]; 1 degree sampling
  - Robust statistics – sample bin median and MAD weighting
- Sampled I/F data modeled as a low-order two-dimensional polynomial
  - Independent model for each spectral band
  - Default model order is [2, 2] – can be overridden
  - Least-squares optimized using Levenberg-Marquardt algorithm
- Forward model spectral cube normalized to the model spectrum at the minimum sampled emission angle (minimum atmospheric path length)
  - Spectral stability enforced in the normalized correction cube
- Spectrum for each spatial pixel divided by the corresponding normalized/stabilized forward model spectrum
- 'Kitchen Sink Correction' – atmospheric aerosol scattering, atmospheric path length, surface photometric effects

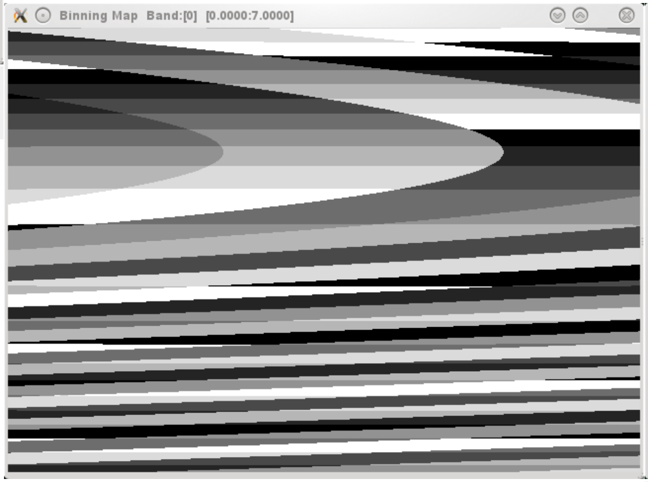
Empirical Geometric Normalization [EGN]

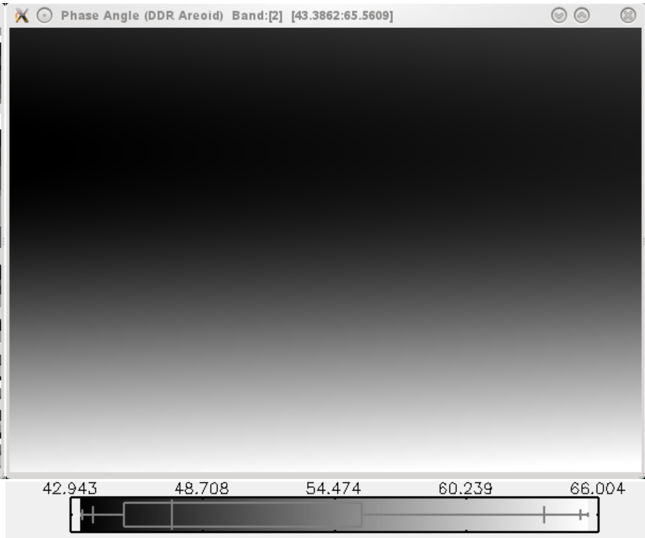
Empirical Geometric Normalization (S, L)







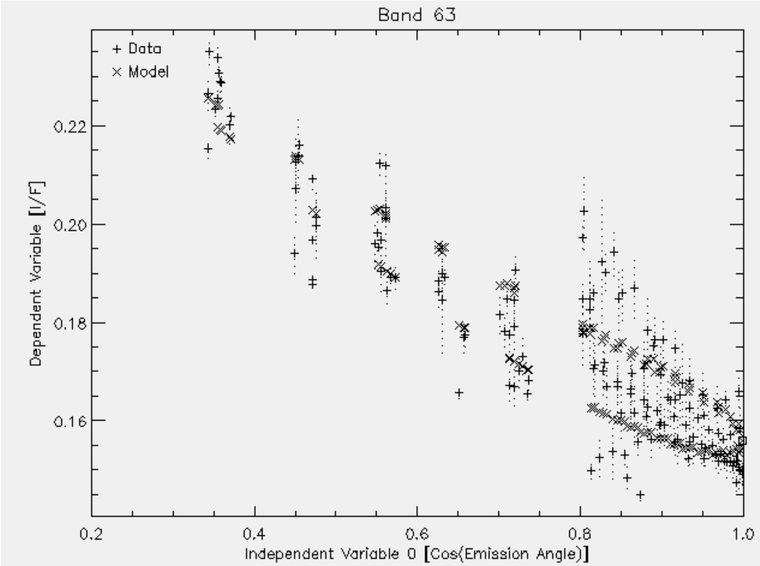


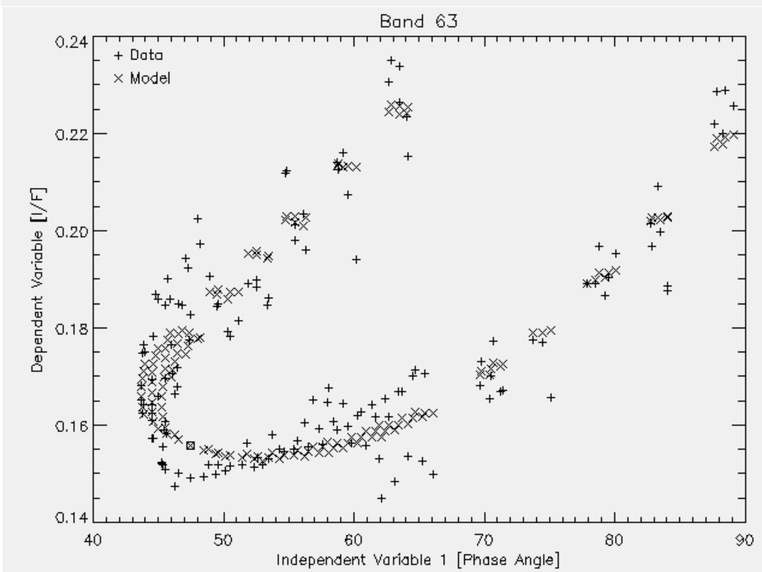


Empirical Geometric Normalization [EGN]

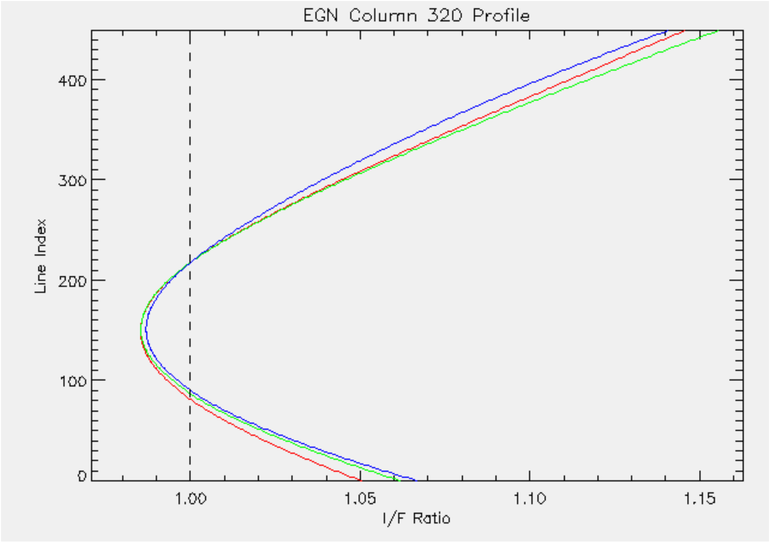
Empirical Geometric Normalization (S, L)

EGN 0xC202 VNIR modeling [775 nm]





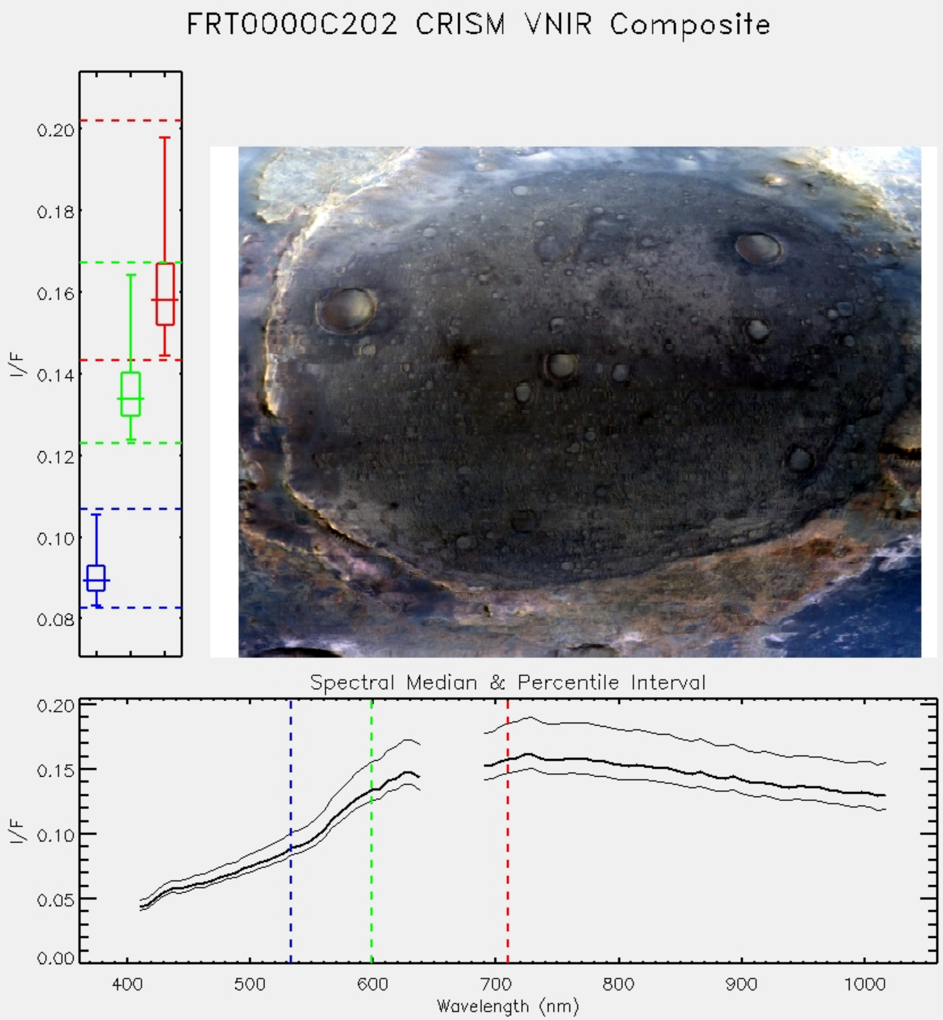
EGN 0xC202 VNIR correction profiles

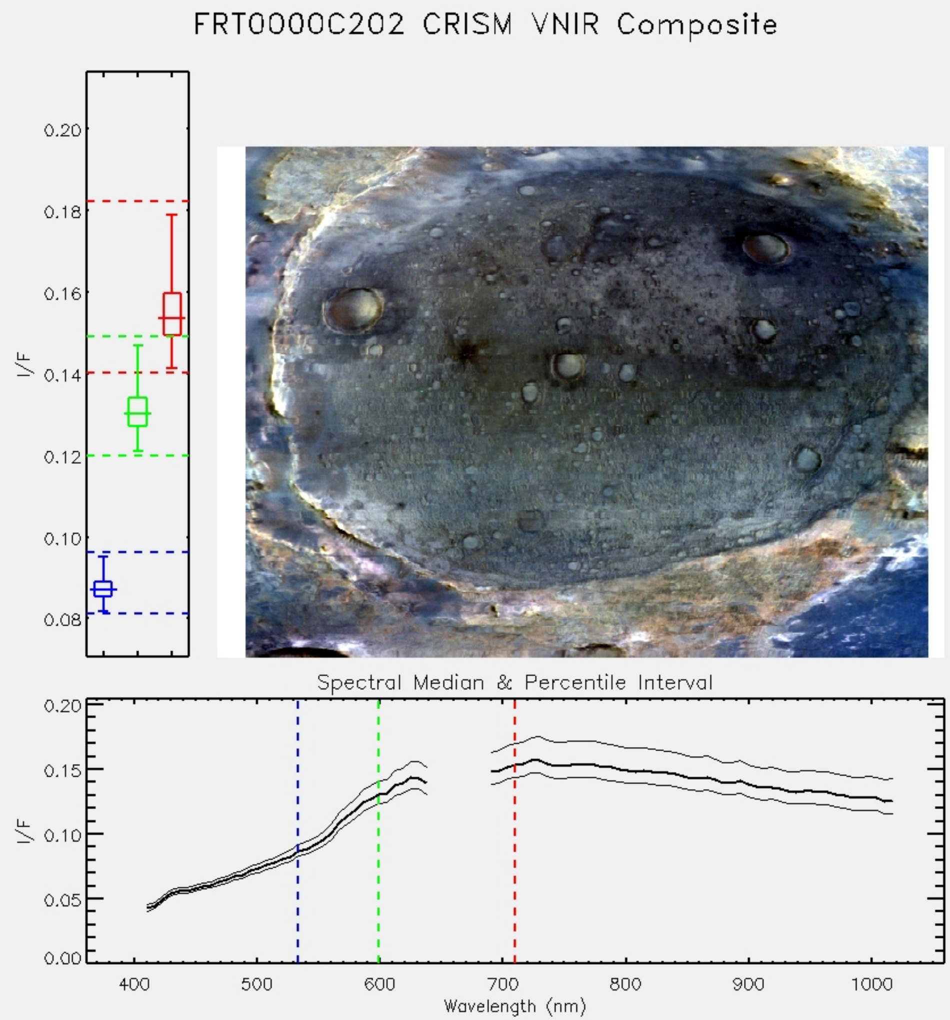


Empirical Geometric Normalization [EGN]

Empirical Geometric Normalization (S, L)

VNIR TRR3 PHT RGB → VNIR TRR3 PHT EGN RGB

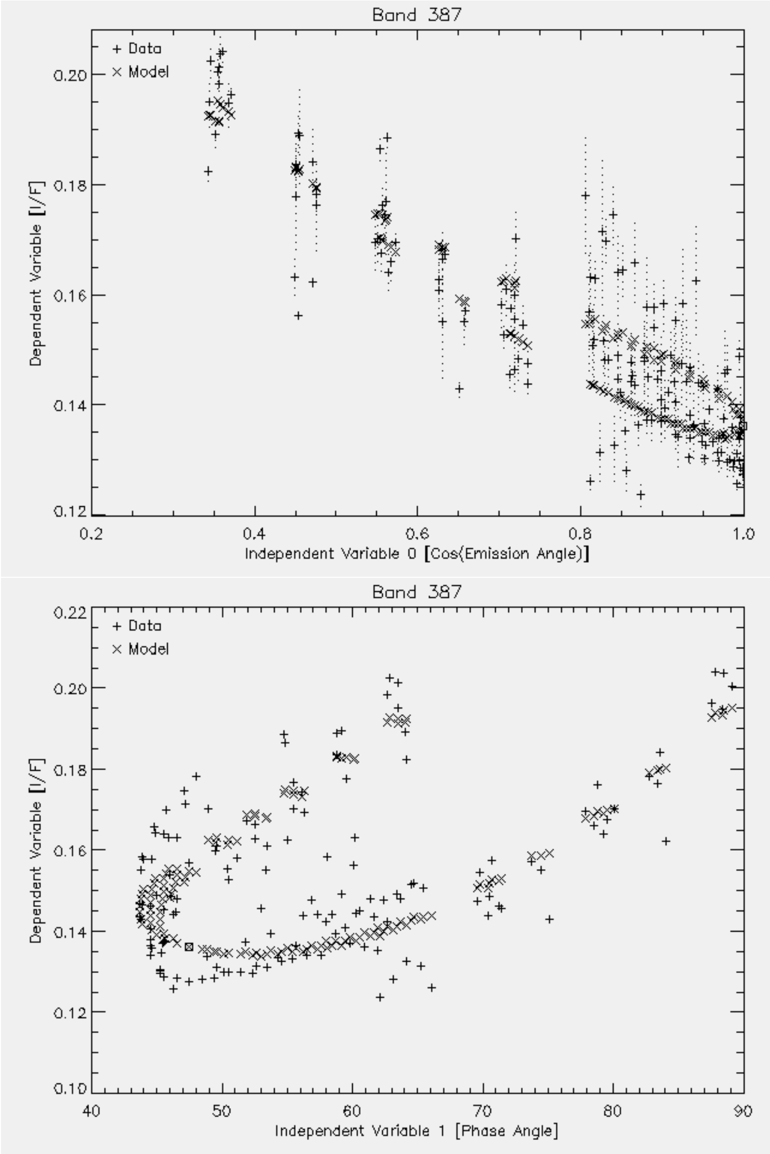




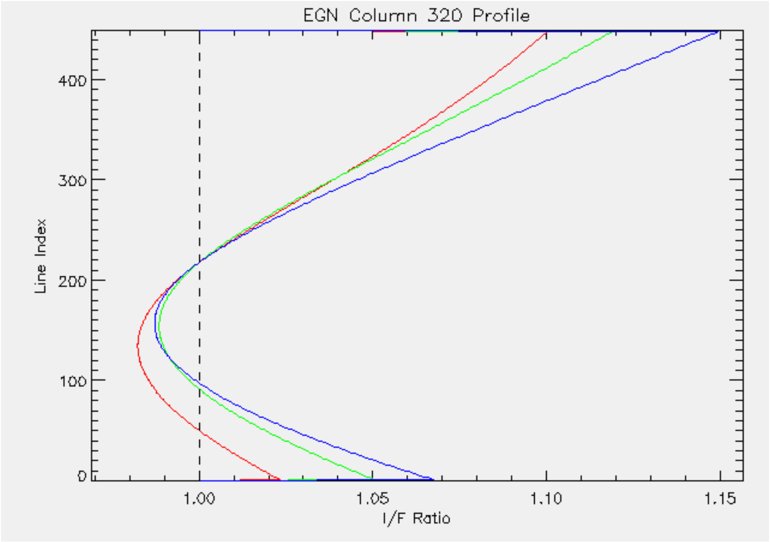
Empirical Geometric Normalization [EGN]

Empirical Geometric Normalization (S, L)

EGN 0xC202 IR modeling [1330 nm]



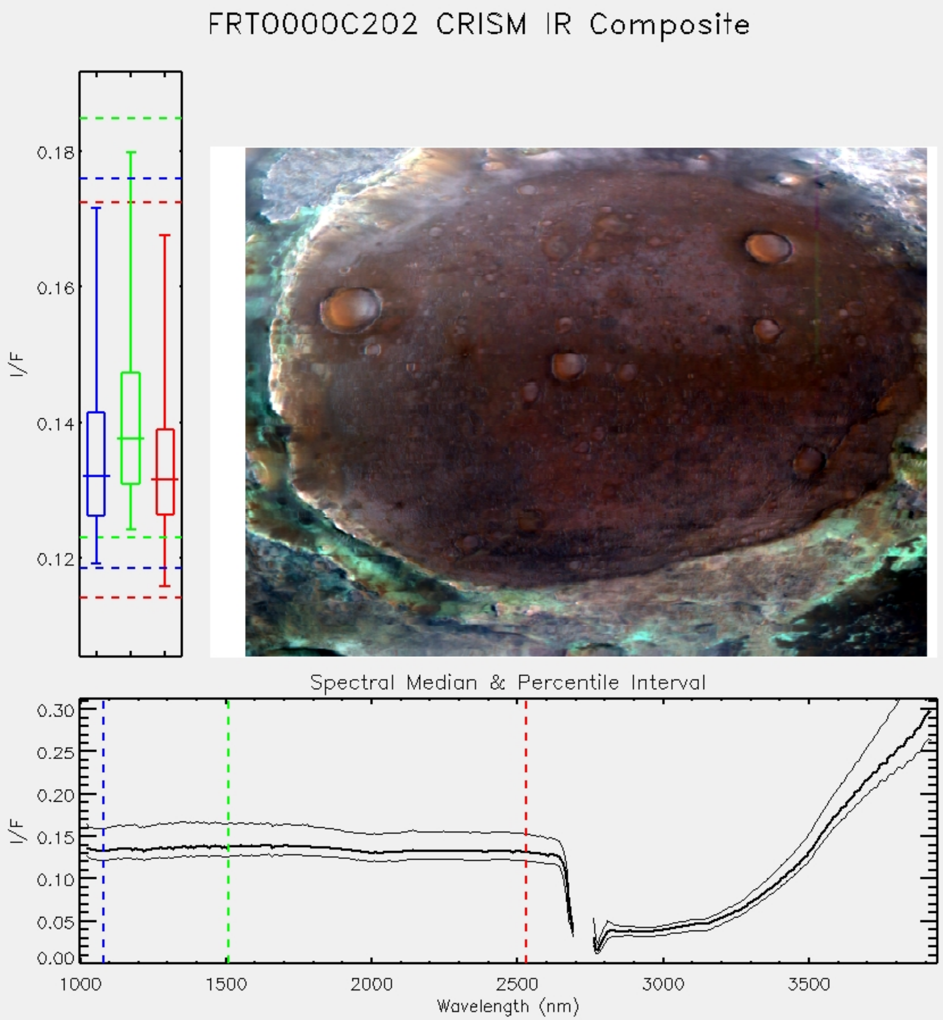
EGN 0xC202 IR correction profiles

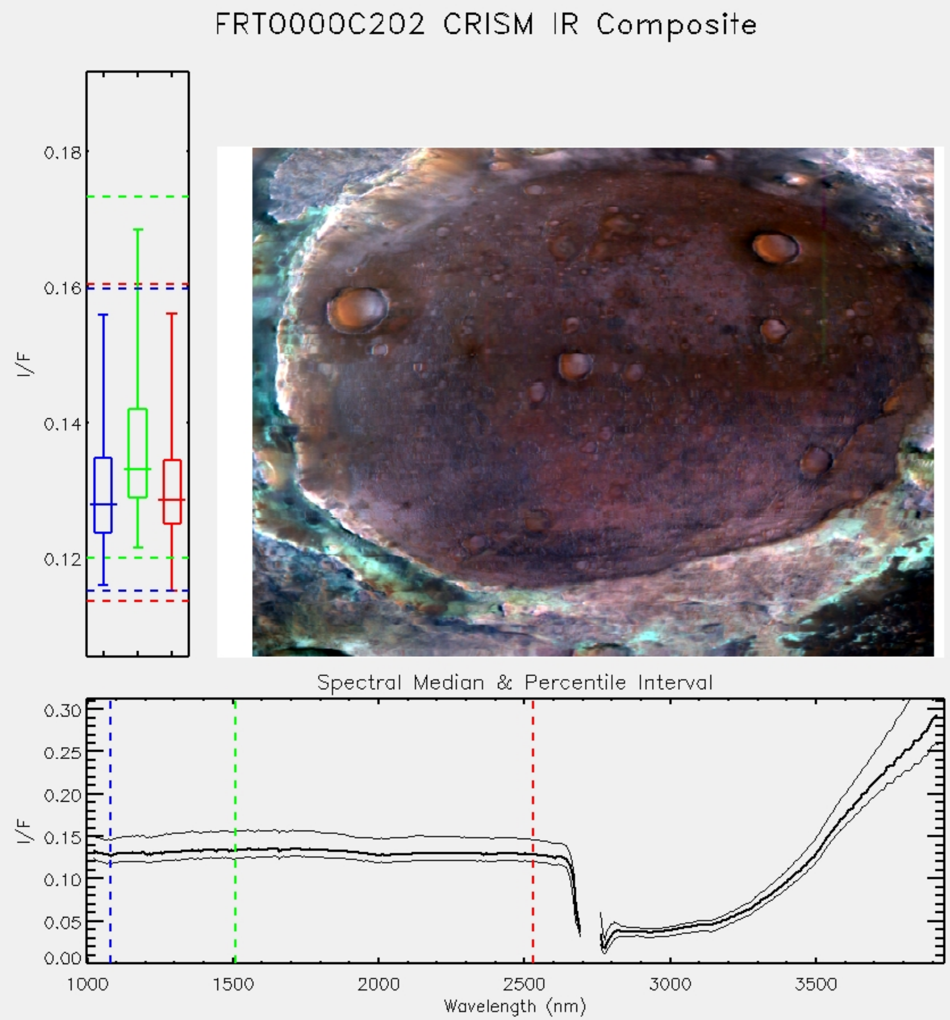


Empirical Geometric Normalization [EGN]

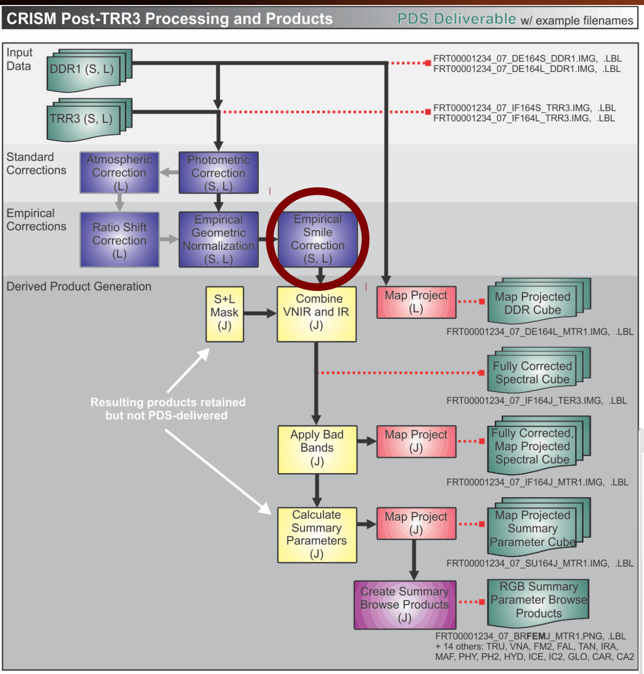
Empirical Geometric Normalization (S, L)

IR TRR3 PHT ATM RSC RGB → IR TRR3 PHT ATM RSC EGN RGB

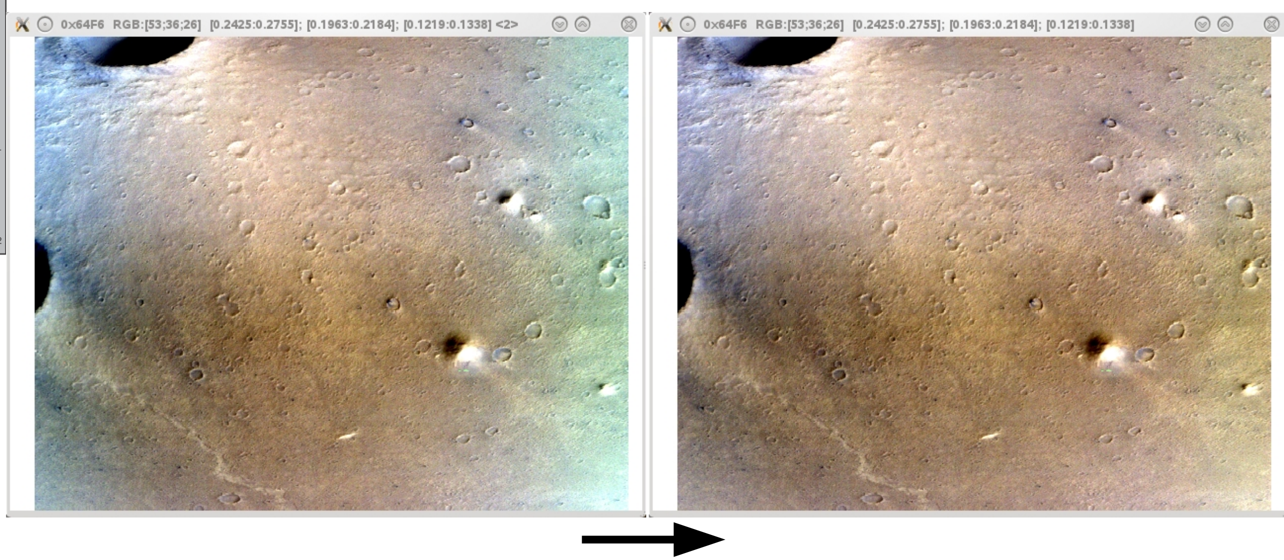




Empirical Smile Correction [ESC]



- The Empirical Smile Correction characterizes and develops a correction for a radiometric residual related to spectral smile - an instrument optical artifact
- Correction of wavelength-dependent asymmetric cross-track gradients



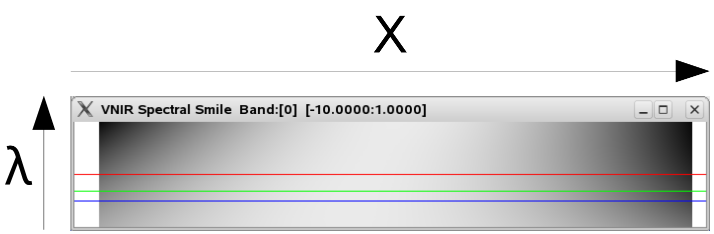
High atmospheric opacity observation (τ_{dust} ~ 1.4)

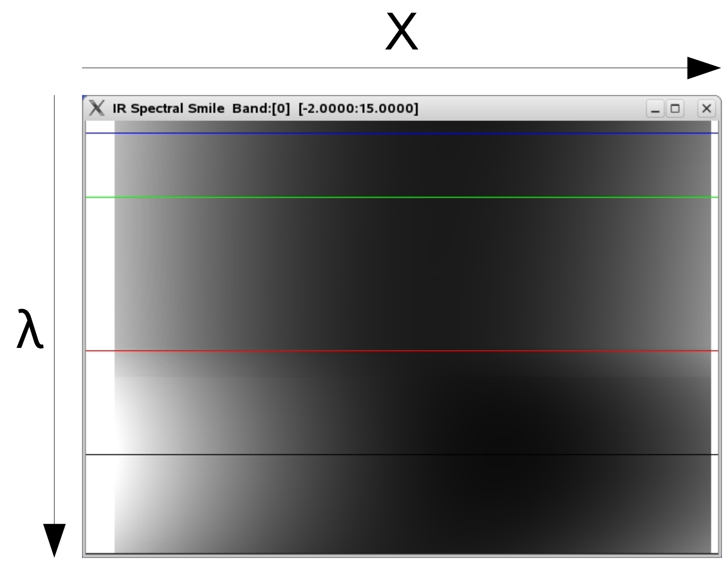
FRT000064F6 - Ares Vallis (MPF)

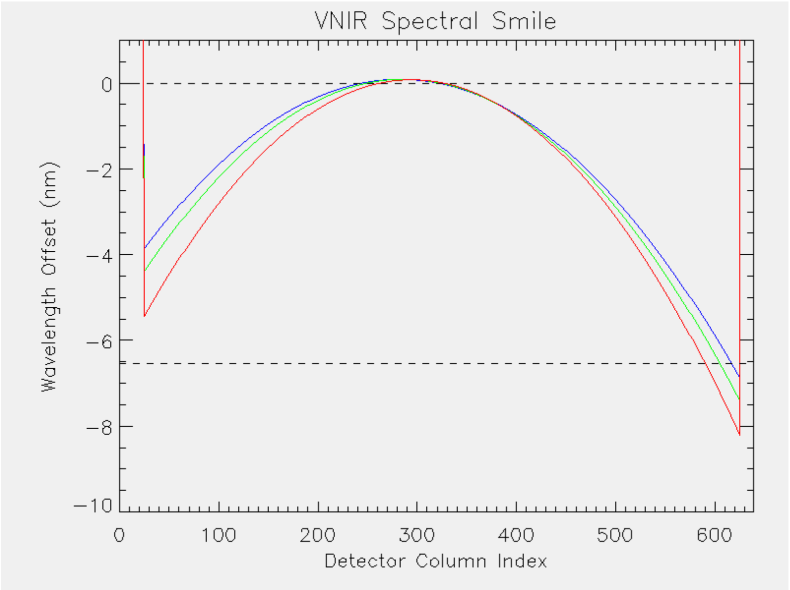
Empirical Smile Correction [ESC]

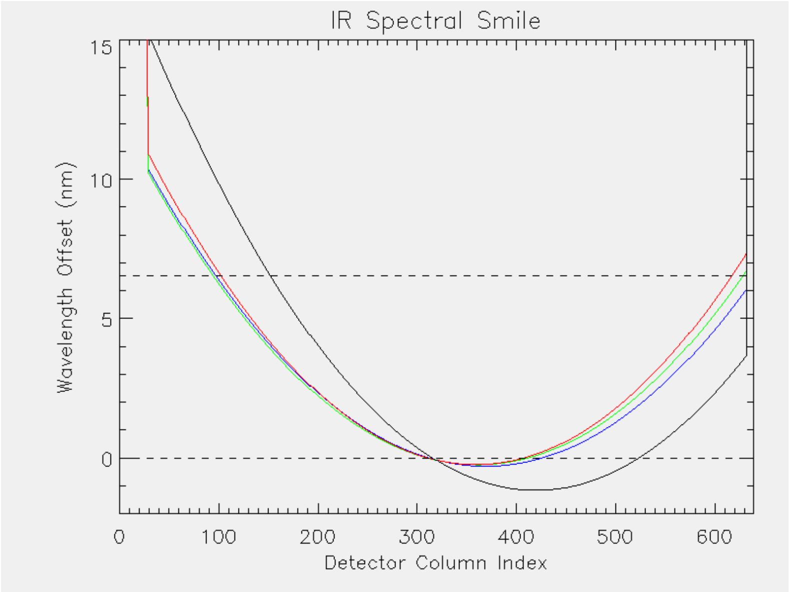
Empirical Smile Correction (S, L)

CRISM Spectral Smile









Empirical Smile Correction [ESC]

Empirical Smile Correction (S, L)

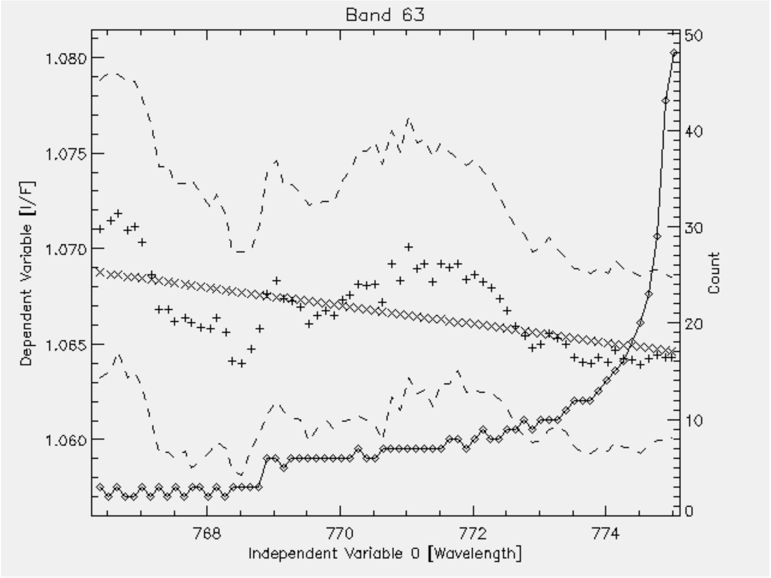
Characterize and Mitigate Optical Artifact Radiometric Residual

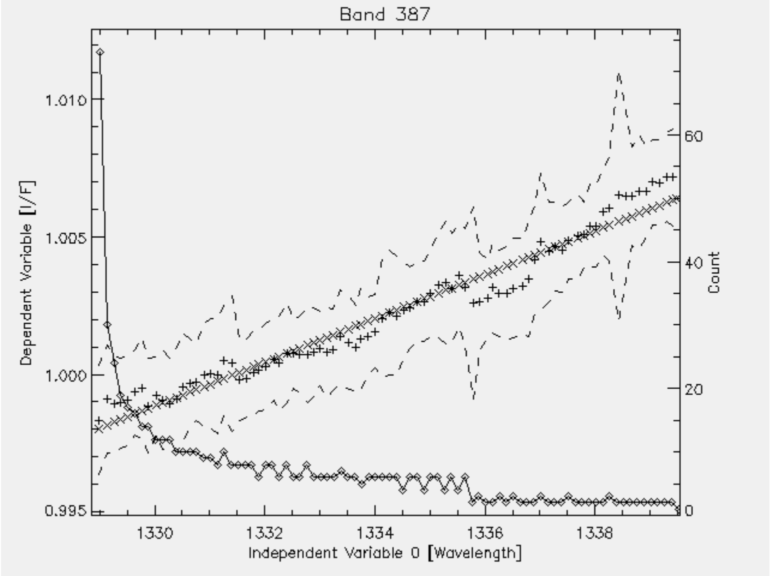
- Albedo normalization – low spectral frequency reference cube divided out of the input I/F spectral data
  - Prevents albedo "spoofing" in the empirical model
- Column sampling histogram calculated from the detector wavelength map
  - Default bin size is 0.125 nm (FRT); 0.250 nm (HRL, HRS)
  - One histogram for each detector row (spectral band)
- Robust statistics
  - Median normalized I/F and MAD for each wavelength bin
- Optimal weighted linear model calculated for the sample values as a function of wavelength
  - Weighting is a function of the reference histogram and data spread
- Detector smile/frown forward model normalized to the model value at the "sweet spot" wavelength near the center of the field of view
- Data value for each pixel divided by the normalized forward model
- Minor correction – typically order of magnitude smaller than EGN

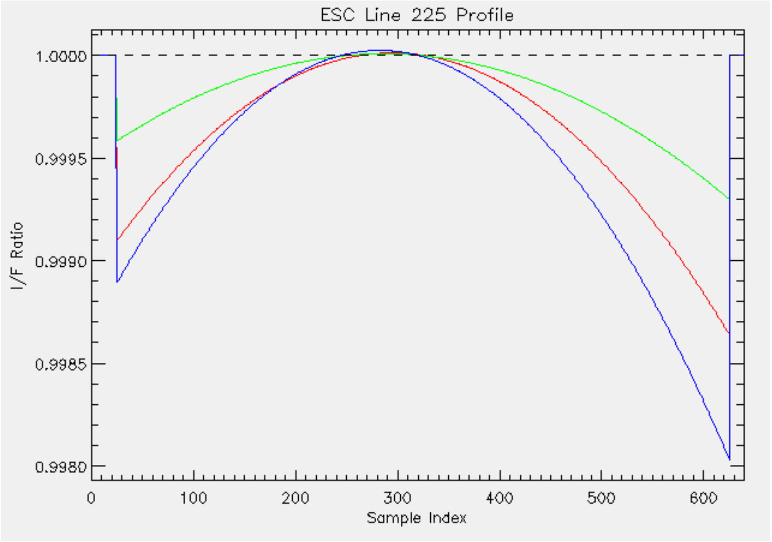
Empirical Smile Correction [ESC]

Empirical Smile Correction (S, L)

ESC 0xC202 modeling [775 nm; 1330 nm]

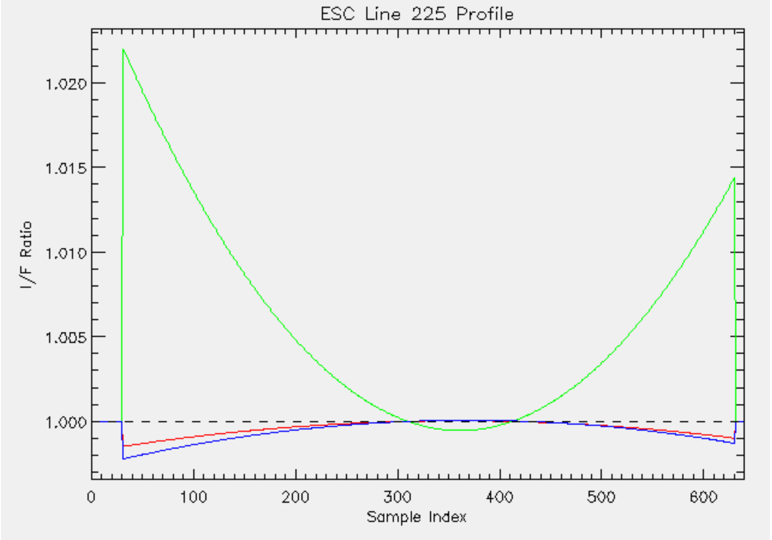






VNIR

ESC 0xC202 correction profiles

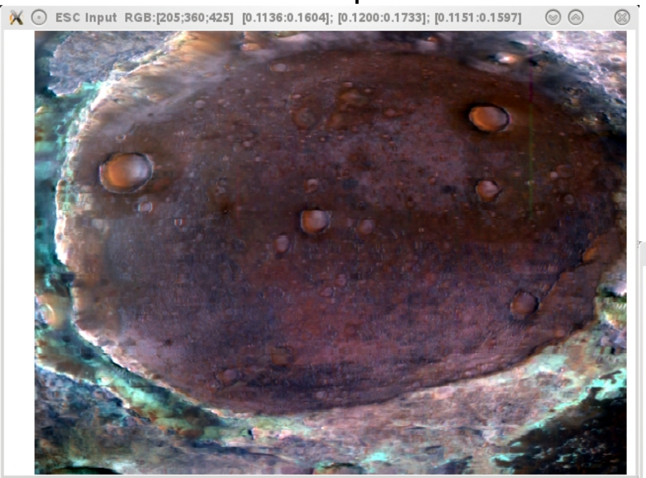


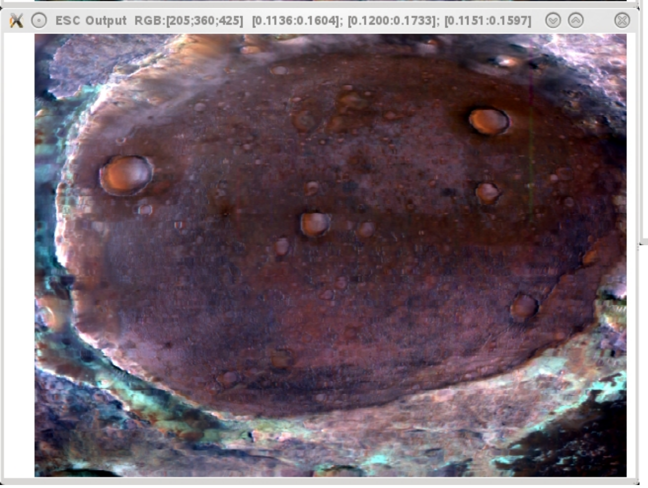
IR

Empirical Smile Correction [ESC]

Empirical Smile Correction (S, L)

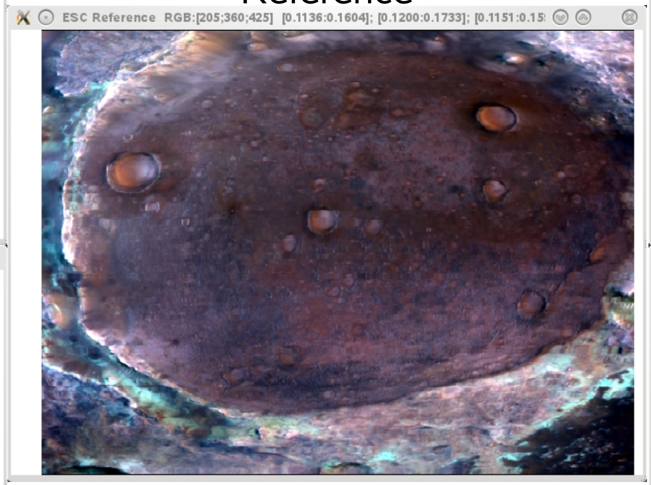
ESC Input



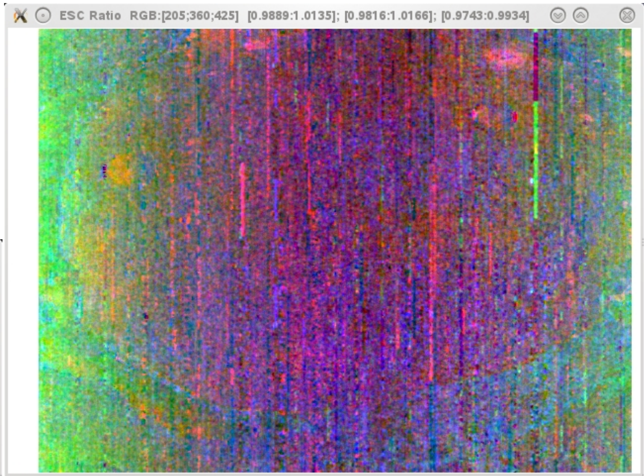


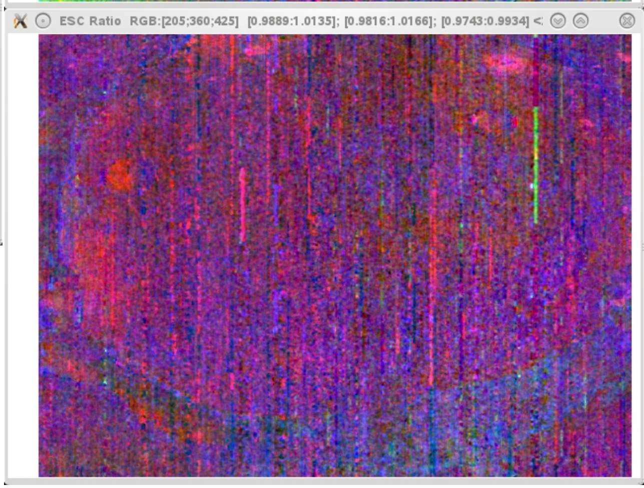
ESC Output

Reference



Ratio



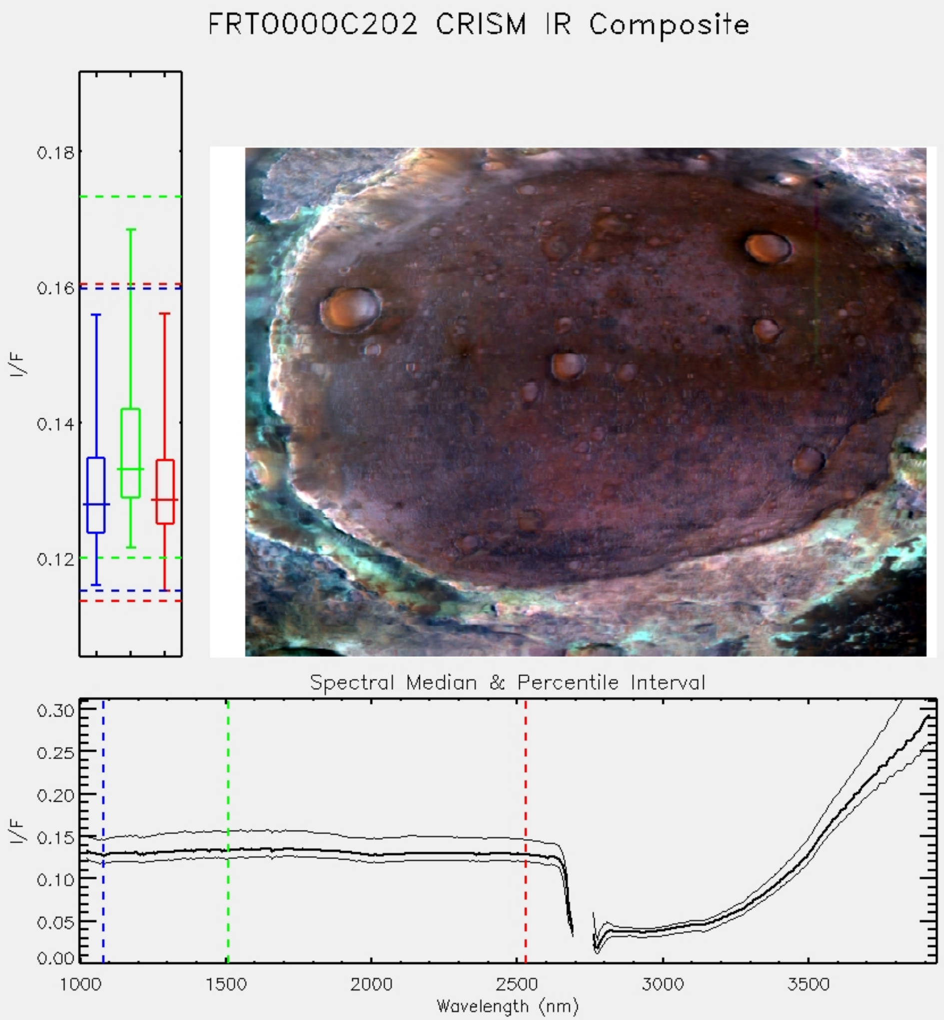


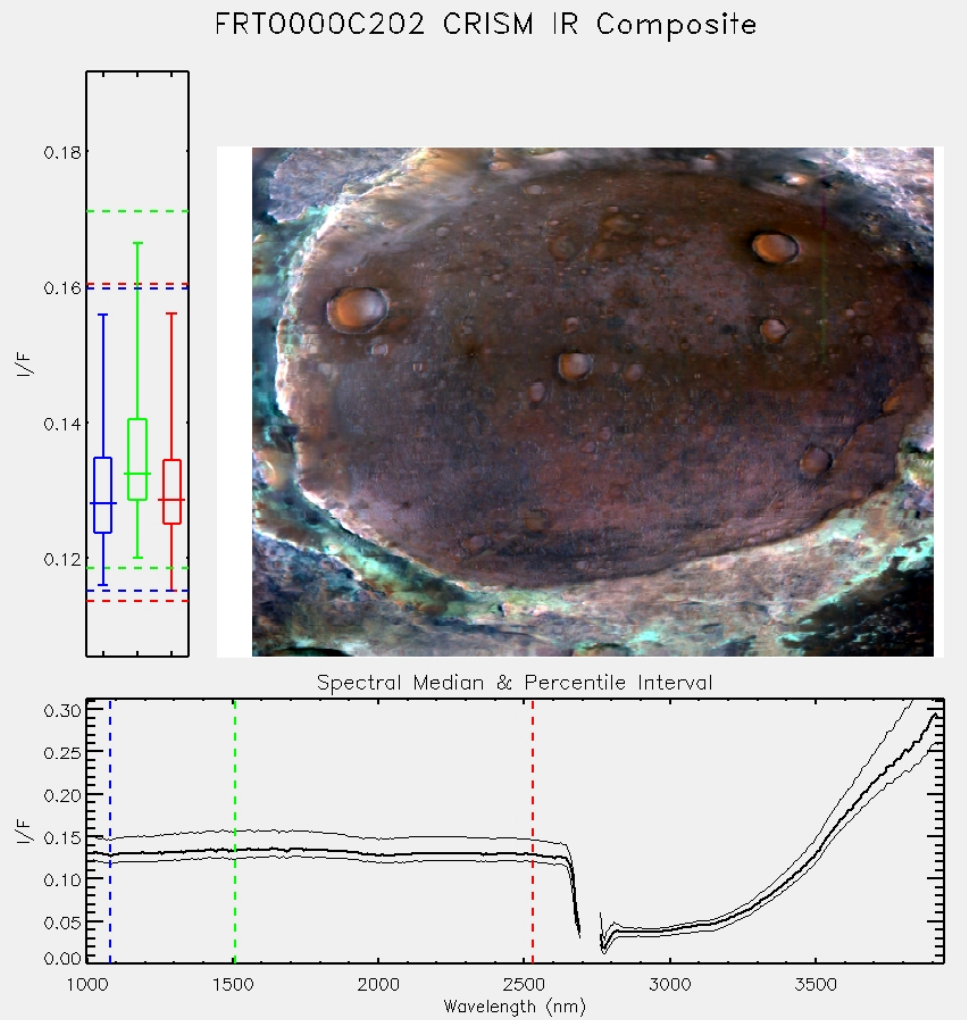
Corrected Ratio

Empirical Smile Correction [ESC]

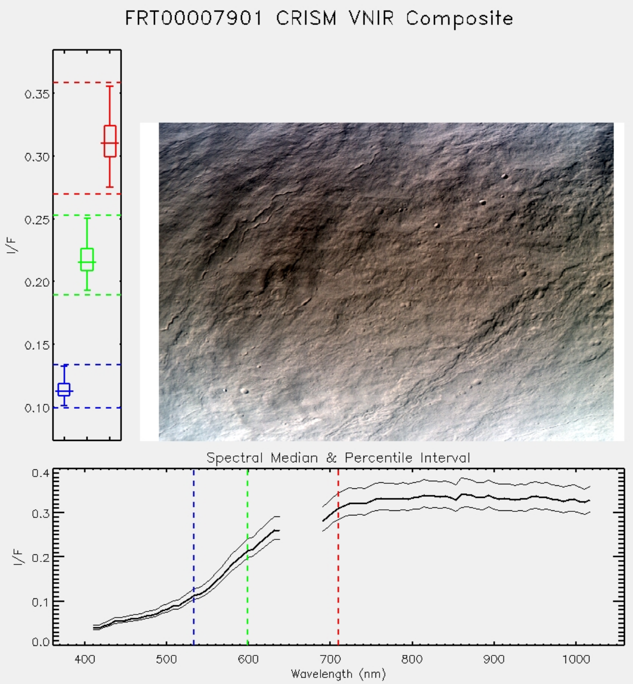
Empirical Smile Correction (S, L)

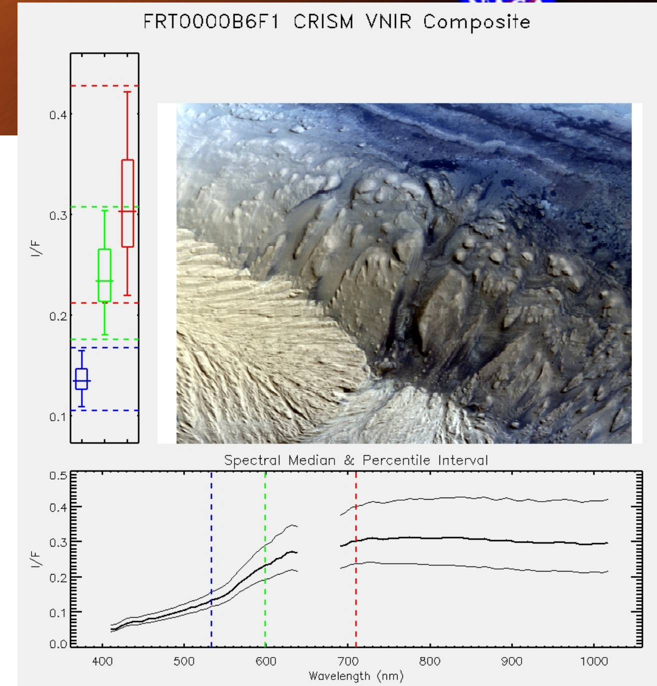
IR TRR3 PHT ATM RSC EGN RGB → IR TRR3 PHT ATM RSC EGN ESC RGB





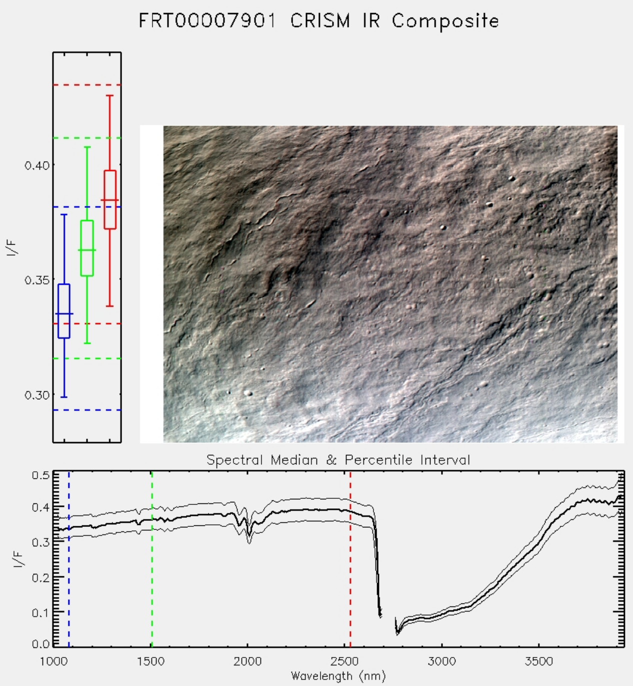
MTRDR Composite Gallery

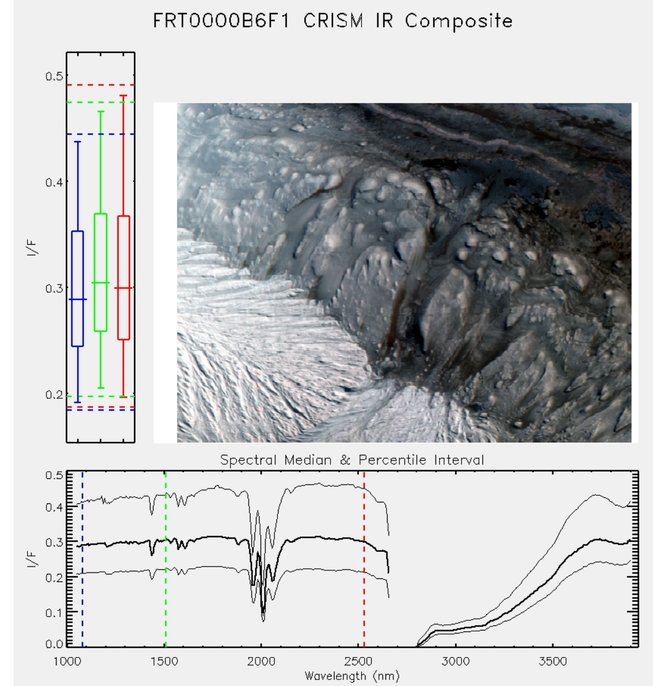




FRT00007901	FRT0000B6F1
Olympus Mons	Gale Crater
Low Spectral Contrast	High Spectral Contrast
Shorter Path Length	Longer Path Length

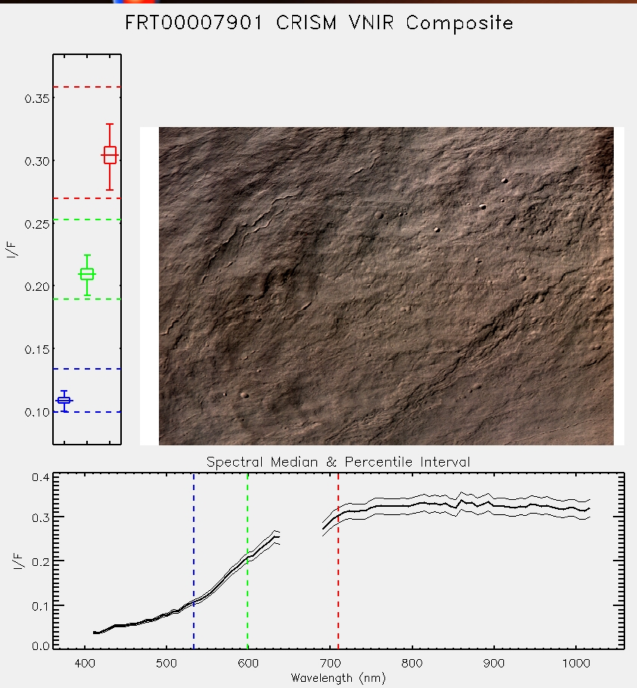
VNIR TRR3
PHT RGB

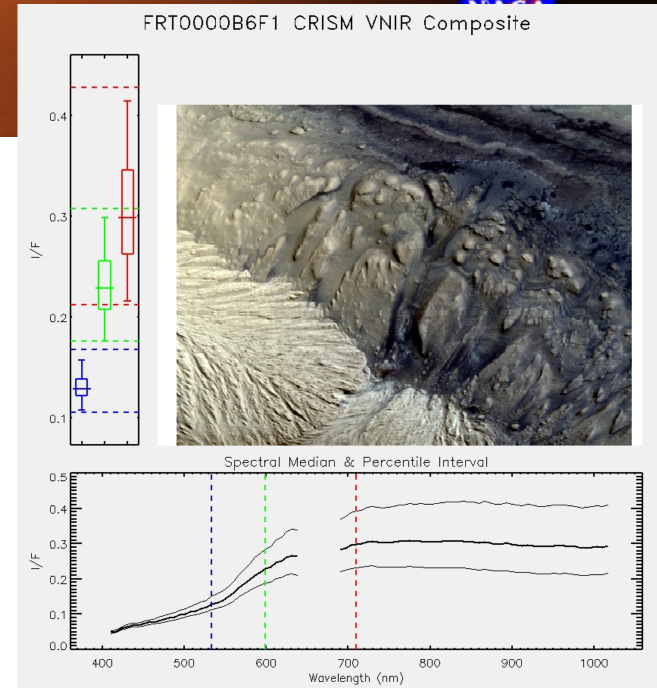




IR TRR3
PHT RGB

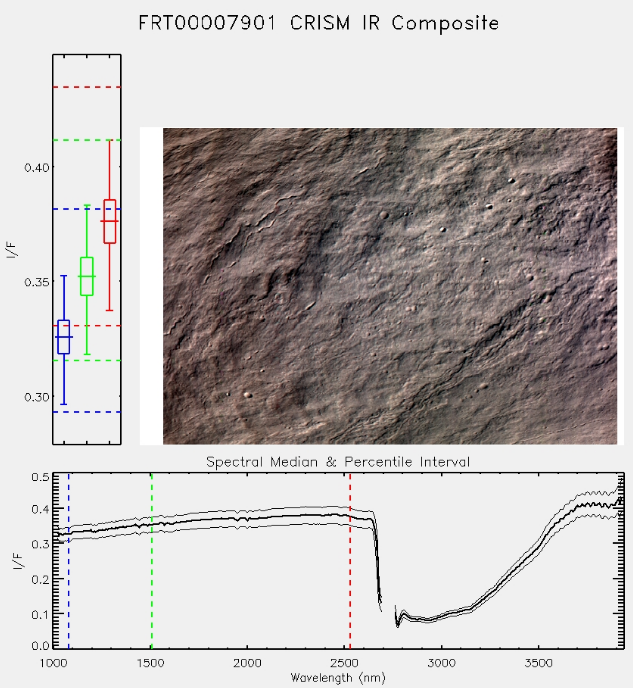
MTRDR Composite Gallery

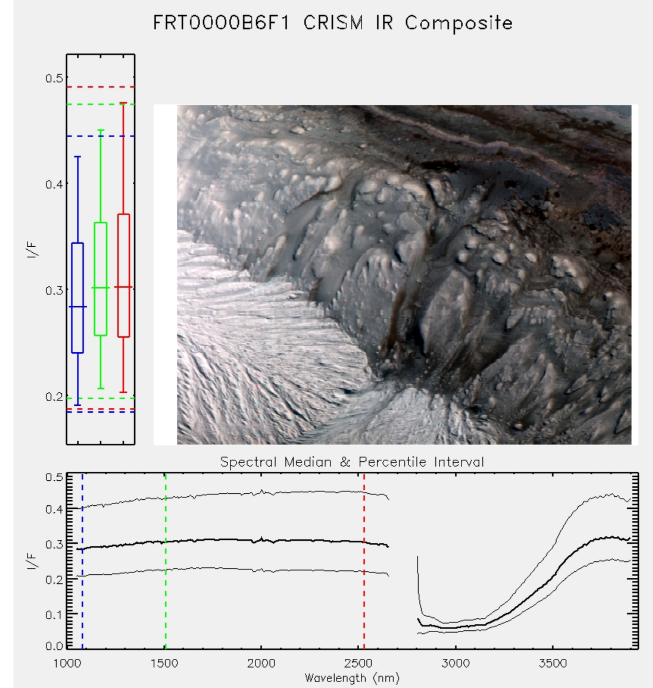




FRT00007901 Olympus Mons	FRT0000B6F1 Gale Crater
Low Spectral Contrast	High Spectral Contrast
Shorter Path Length	Longer Path Length

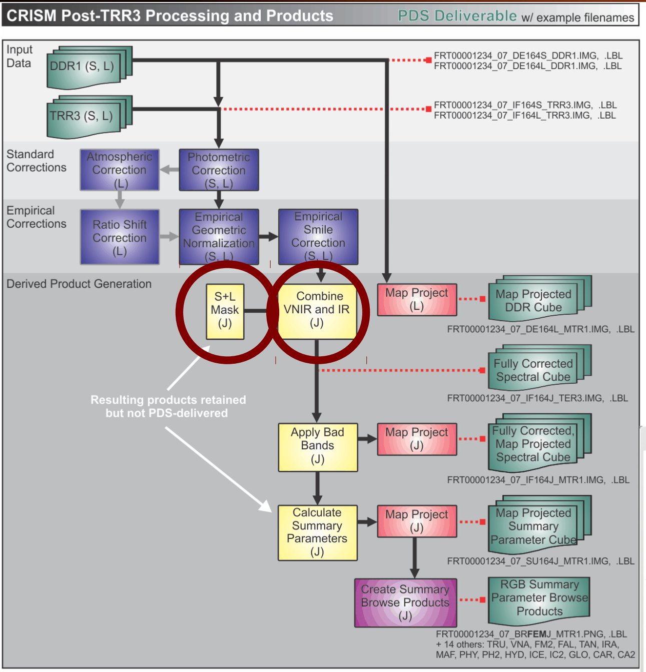
VNIR TRR3
PHT EGN ESC RGB



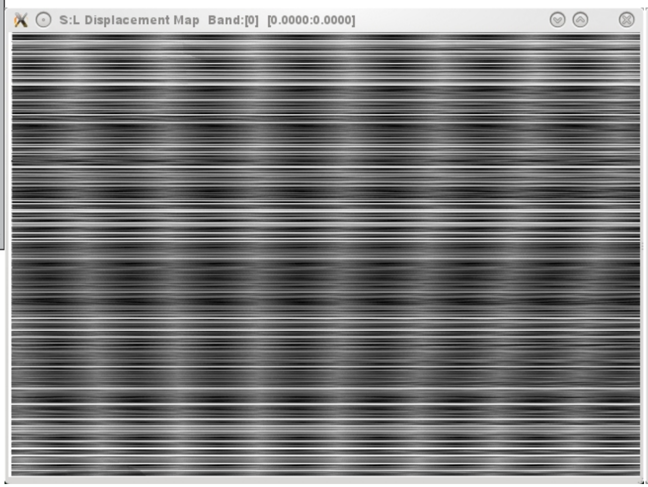


IR TRR3
PHT ATM RSC EGN ESC RGB

Combine VNIR and IR



- Sensor space transform maps VNIR (S-detector) data into the IR (L-detector) sensor space using DDR latitude and longitude information
- Intersection of transformed S data and L data valid pixel masks applied to the joined (J) data cube



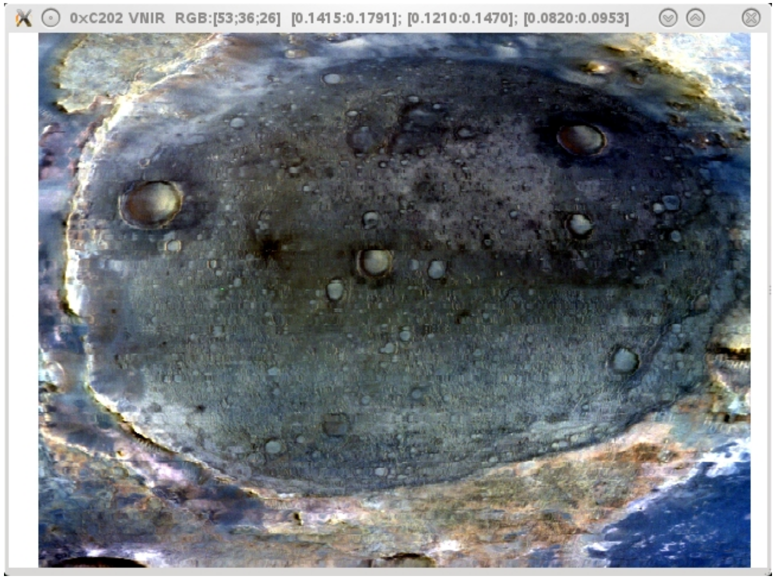
- IR (L) detector sensor space map
- DN indicates displacement to nearest VNIR (S) detector pixel

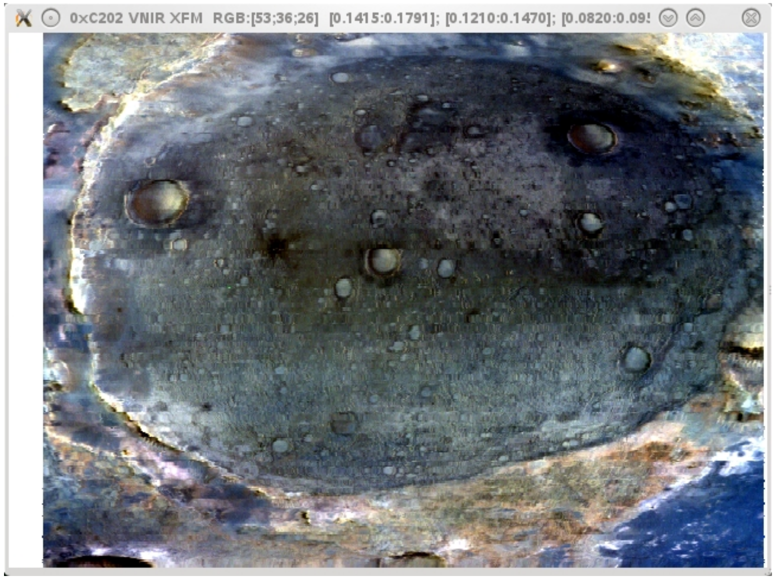
- S_valid ∩ L_valid = J_valid

Combine VNIR and IR
VNIR:IR sensor space transform

Combine VNIR and IR (J)

VNIR TRR3 PHT EGN ESC RGB → VNIR TRR3 PHT EGN ESC XFM RGB





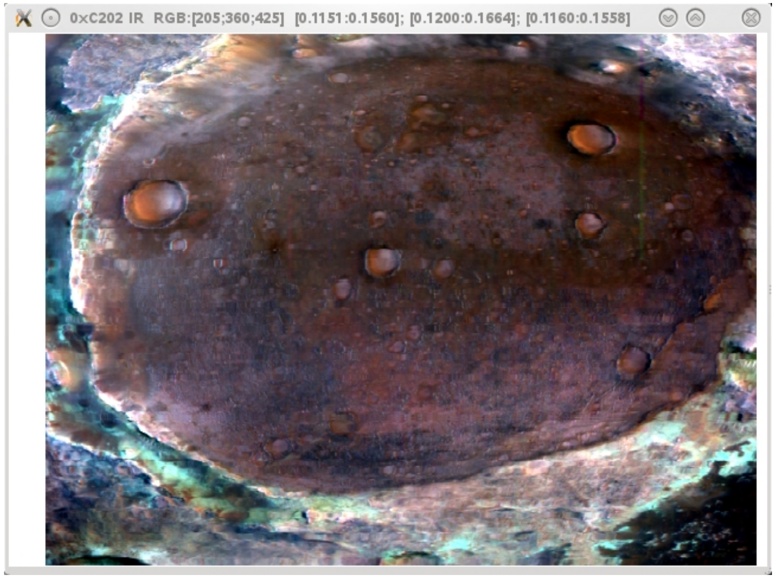
- VNIR → IR transform is nearest neighbor – no spectral averaging
- VNIR and IR systems have different spatial sampling functions
- VNIR and IR detectors are operated at different frame rates

- Even after the VNIR → IR transformation differences in how the VNIR and IR systems sample the surface may be apparent
- VNIR/IR spectral offset at sharp albedo boundaries

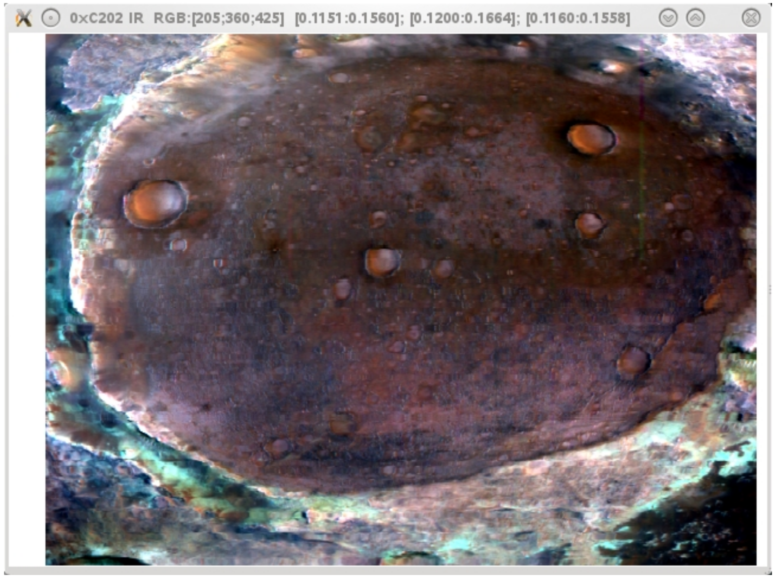
Combine VNIR and IR
VNIR:IR sensor space transform

Combine VNIR and IR (J)

IR TRR3 PHT ATM RSC EGN ESC RGB



IR TRR3 PHT ATM RSC EGN ESC RGB



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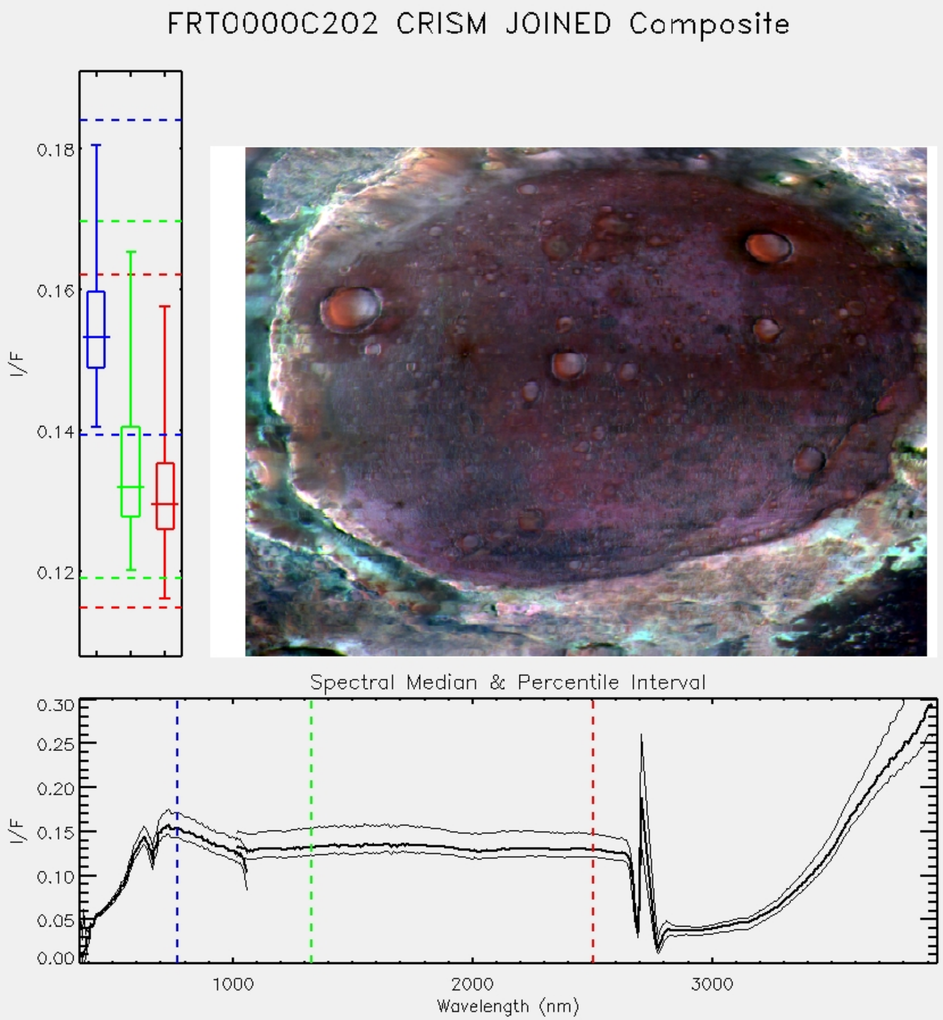
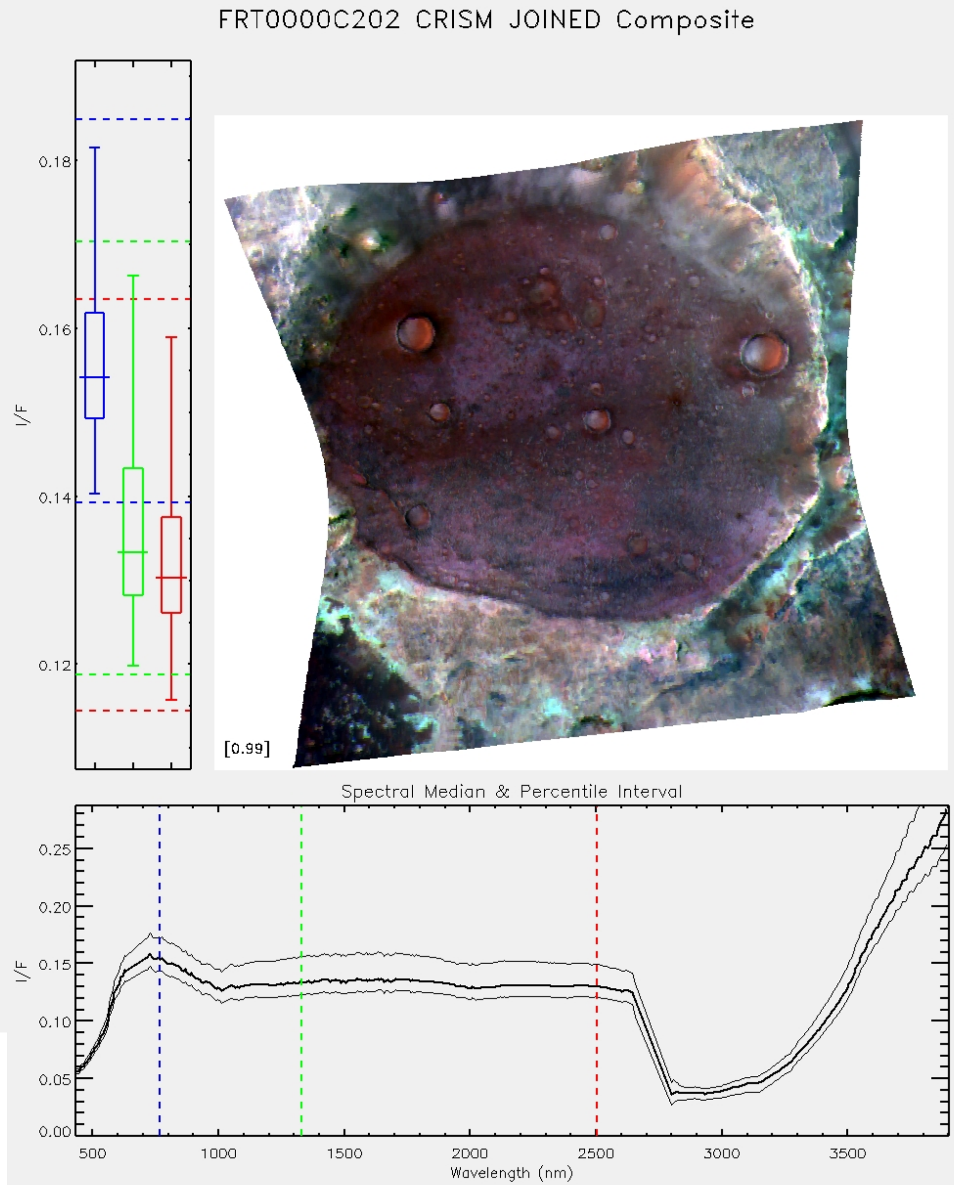
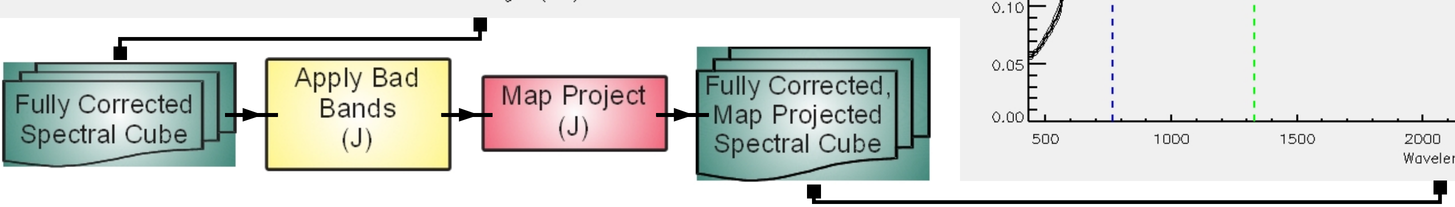
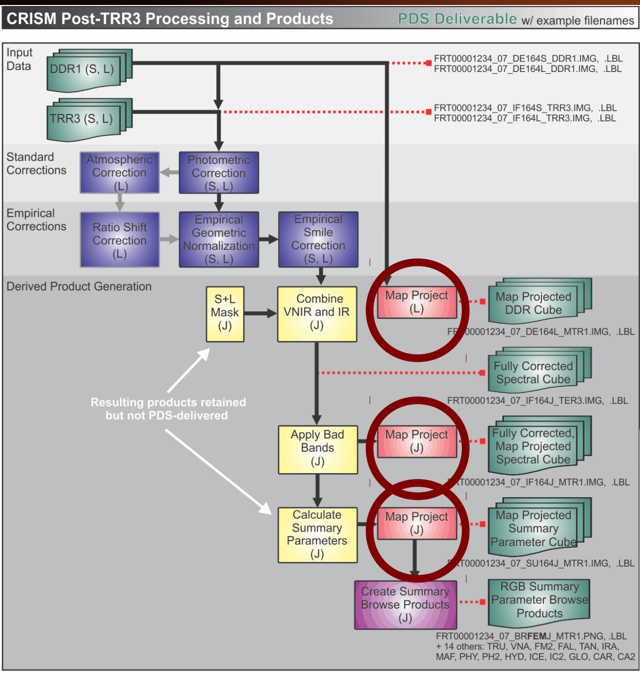
CRISM Full Spectral Range Data Products



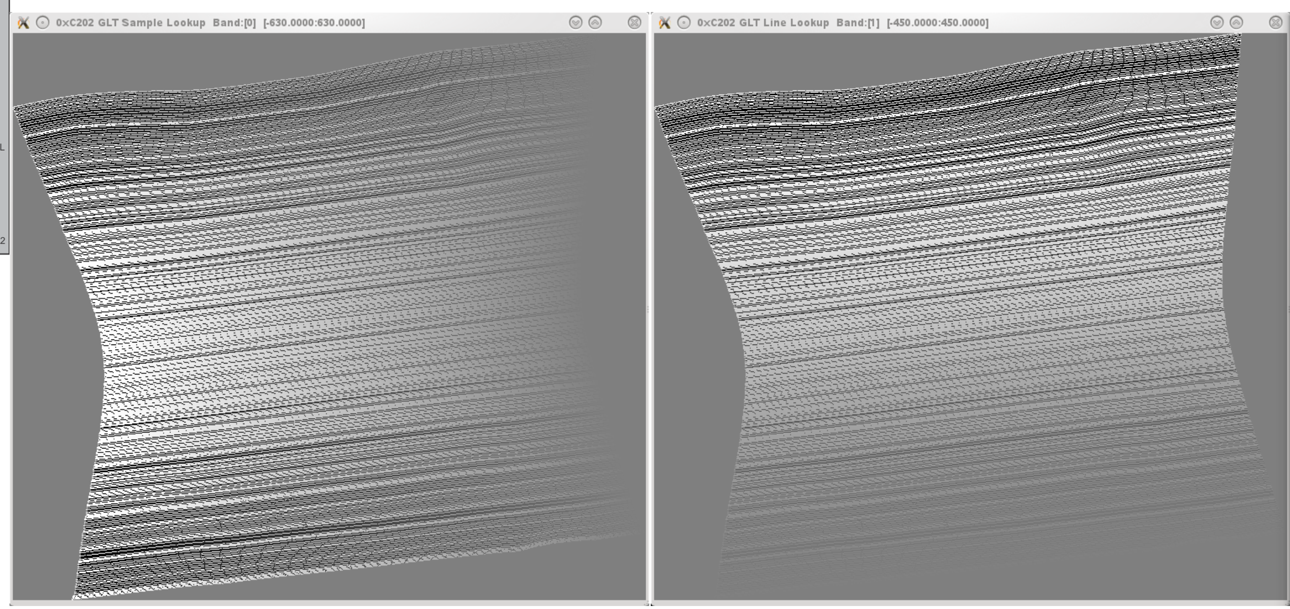




MTRDR Product Map Projection



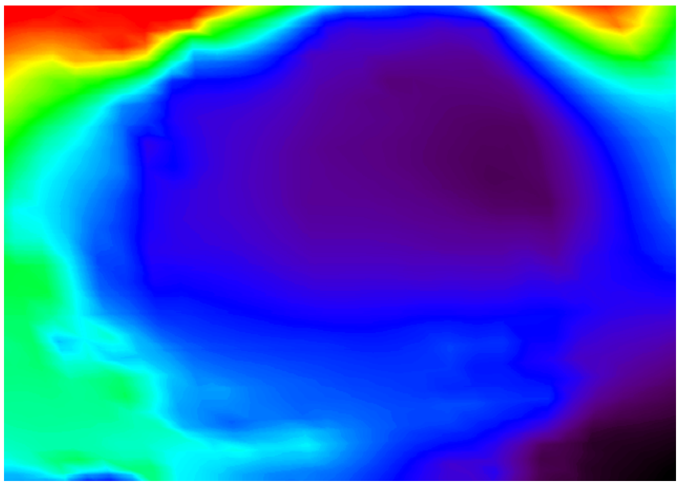
- Geographic Lookup Table (GLT) based map projection
- Encodes line/sample pixel mapping from unprojected (sensor) space to map projected space
- The same GLT is used to generate all MTR products for a given source observation



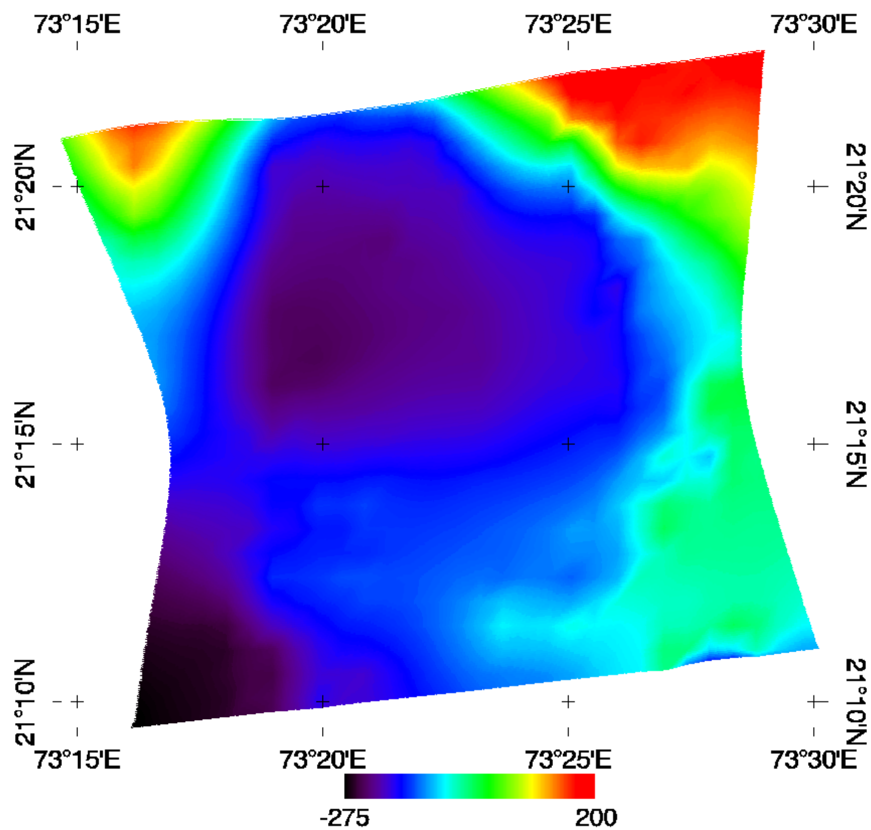
Map Projected DDR Data Product

Map Project
(L)

FRT0000C202 IR DE DDR Mola Elevation

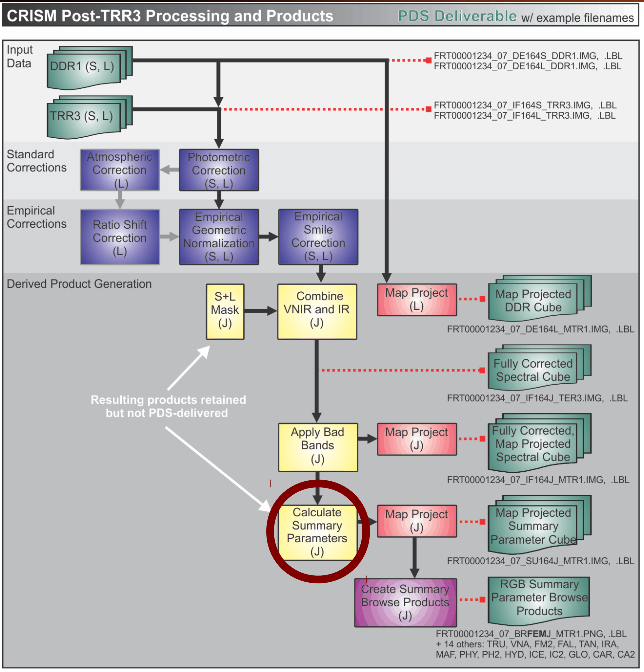


FRT0000C202 IR DE MTR Mola Elevation

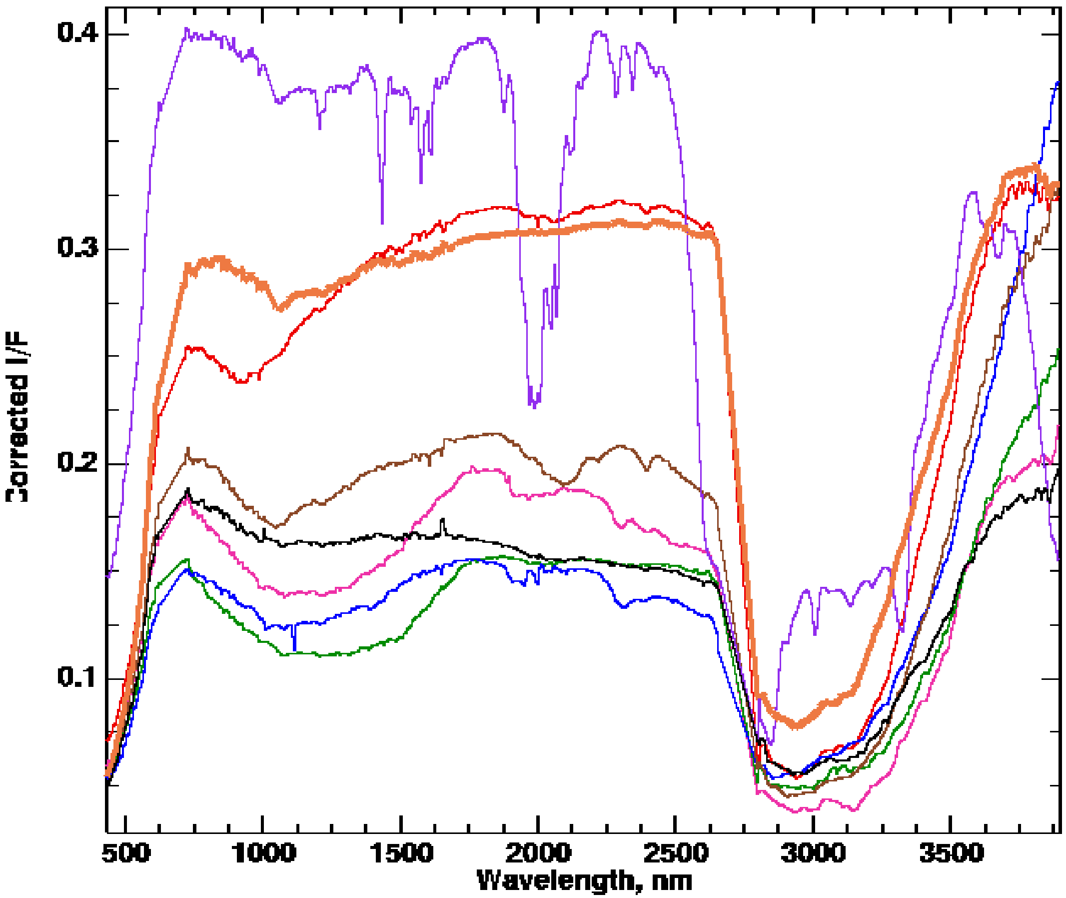


Map Projected
DDR Cube

Spectral Summary Parameters



- Selected highlights of the CRISM data set



Hematite + Monohydrated Sulfate, Candor Chasma

Magnesite; Nili Fossae

Olivine; Nili Fossae

Fe/Mg smectite; Nili Fossae

Monohydrated (Fe) sulfate; Juventae Chasma

Fresh CO2 ice; S polar cap

Bright soil, Gusev crater

El Dorado sand, Gusev Crater

What is a Spectral Summary Parameter?

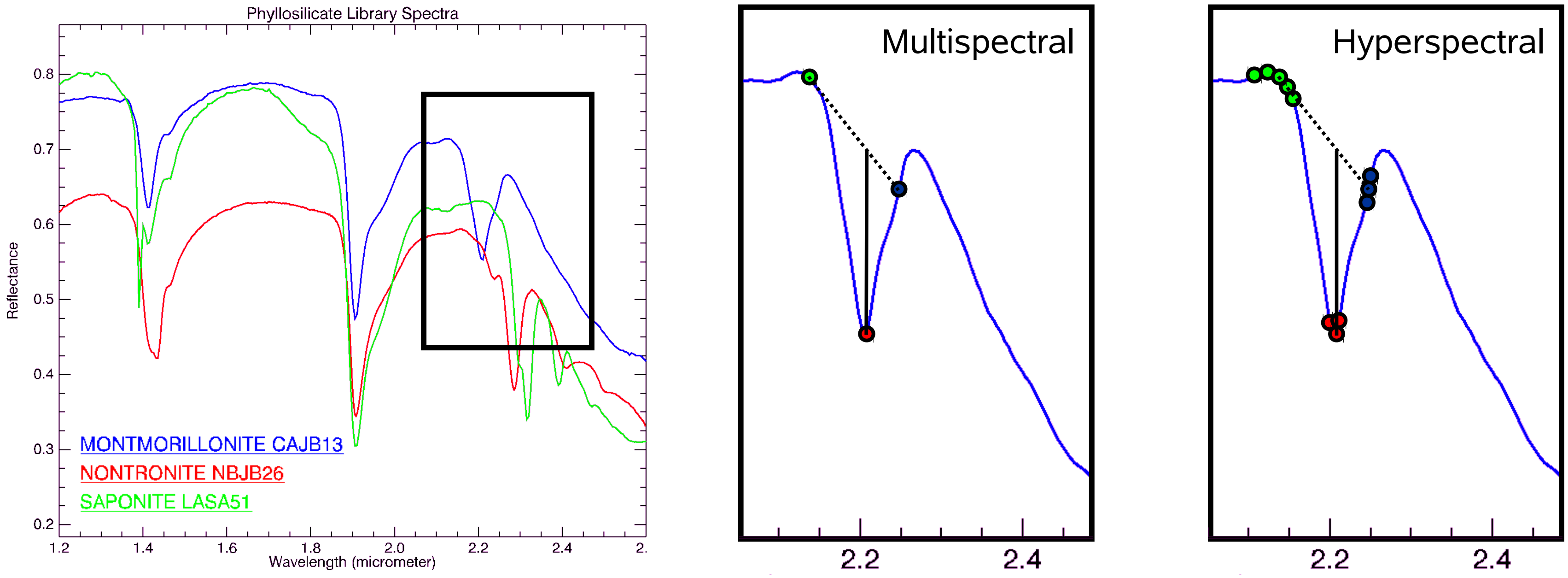
Calculate Summary Parameters (J)

- The spectra on the previous slide show some of the most outstanding mineral exposures in the CRISM data set
- They are buried among 4 billion spectra in targeted observations and another 4 billion spectra in the global mapping data
- To find and visualize the occurrences of mineral exposures, we create synthetic images that parameterize diagnostic, indicative, or informative spectral structure
- These are called **summary parameters**

Example – Calculation of BD2210

Calculate Summary Parameters (J)

- MTRDR spectral summary parameter calculations take advantage of CRISM targeted observation hyperspectral sampling
- The effective I/F value at parameter reference wavelengths is a function of a neighborhood of spectral values around each reference wavelength
  - Spectral kernel size and interpolating function tuned for each parameter
  - Kernel size typically 1, 3, 5 samples - larger in limited cases
  - Kernel median; boxcar smooth; polynomial model



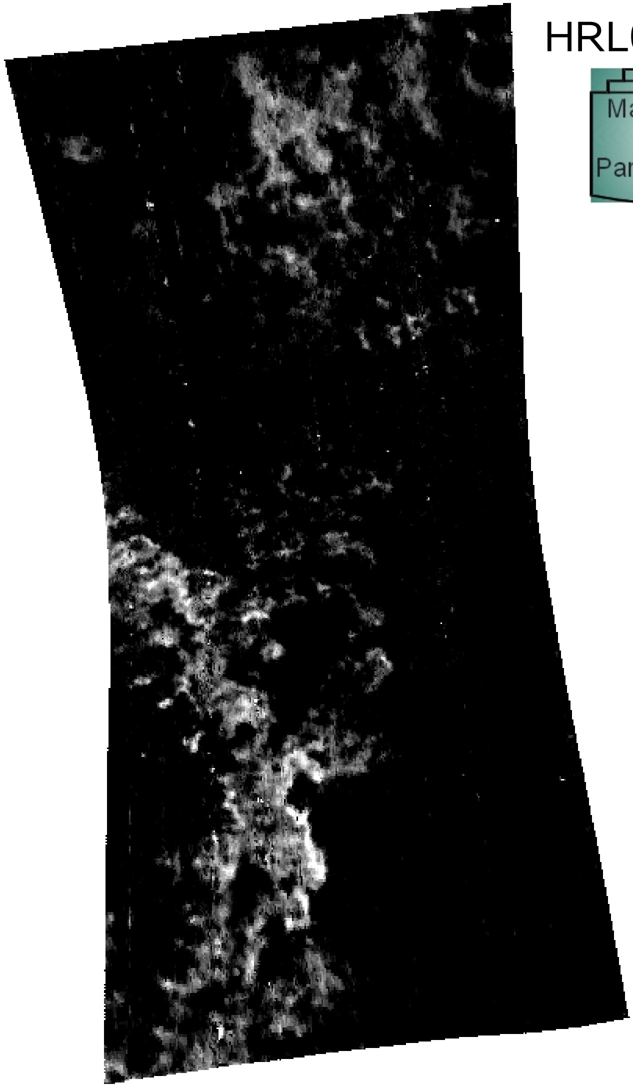
Example – Mapping of BD2210

Calculate Summary Parameters (J)

HRL000043EC

Map Projected Summary Parameter Cube

I/F in source spectral data



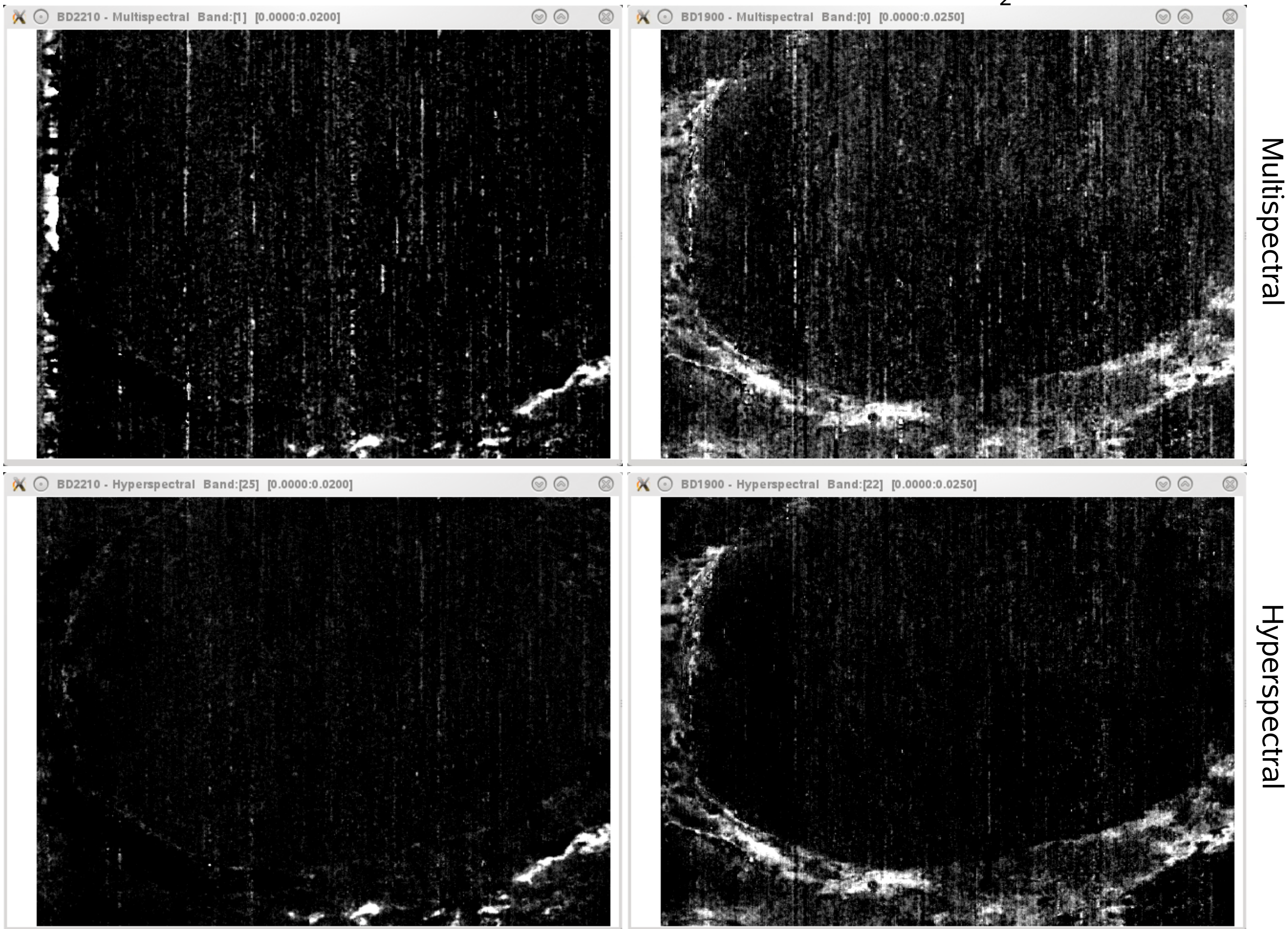
Strength of Al-OH band @ 2210 nm

Hyperspectral Summaray Parameters

Calculate Summary Parameters (J)

BD2210 – Al-OH

BD1900 – H_2O



Key VNIR Spectral Summary Parameters

Calculate Summary Parameters (J)

Name	Description	Derivation:	Higher values detect...
R770	Reference VNIR brightness image	Reflectance at 770 nm	Brighter materials or sunward facing slopes
RBR	Slope of VNIR "red edge"	770/440 nm reflectance ratio	Dustier surface
BD530	530-nm band depth	Relative to continuum between 440, 709 nm	Greater content or larger particles of ferric oxide
SH600	Height of 600-nm "shoulder"	Relative to continuum between 530, 709 nm	Dust coatings on dark rock, or olivine
BD920	Depth of 920-nm band	Relative to continuum between 800, 984 nm	Crystalline Fe minerals (esp. hematite, pyroxene)
BDI1000VIS	Integrated depth of 1-μm band at VNIR wavelengths	Area between spectrum and horizontal line tangent to peak reflectance	Stronger 1-μm band due to Fe in pyroxene, olivine

Key IR Spectral Summary Parameters (1/2)

Calculate Summary Parameters (J)

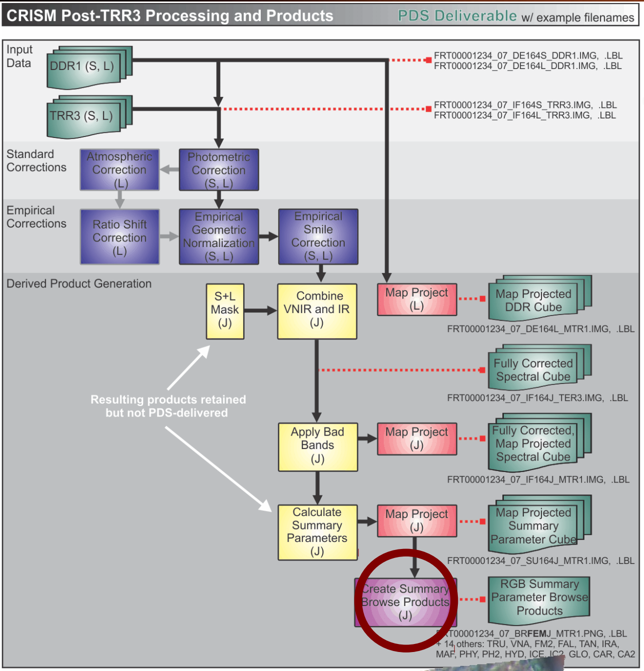
Name	Description	Derivation:	Higher values detect...
IRA	Reference IR brightness image	Reflectance at 1330 nm	Brighter materials or sunward facing slopes
OLINDEX2	Strength of broad Fe absorption with shoulder at 1.7 μm	Area between spectrum and line fit to wavelengths 1700-2500 nm	Olivine and/or Fe-containing phyllosilicates
LCPINDEX	Indicator of low-Ca pyroxene	3-point curvature index (1050,1330,1815 nm)	Pyroxene, favors low-Ca type
HCPINDEX	Indicator of high-Ca pyroxene	3-point curvature index (1050,1470, 2067 nm)	Pyroxene, favors high-Ca type
ISLOPE1	NIR spectral slope	Slope evaluated between 1815, 2530 nm	Ferric coating on dark rock, or atmospheric aerosols
BD1435	1435-nm CO_2 ice band depth	Relative to continuum between 1370, 1470 nm	CO_2 frost on surface
BD1500	1500-nm H_2O ice band depth	Relative to to continuum between 1367, 1808 nm	H_2O ice on surface or in atmospheric aerosols
BD1900	1900-nm H_2O band depth	Relative to continuum between 1875, 2067 nm	Bound H_2O in hydrated phyllosilicate, zeolite, sulfate, carbonate, silica
BD2100	2100-nm shifted H_2O band depth	Relative to continuum between 1930, 2250 nm	Monohydrated sulfate

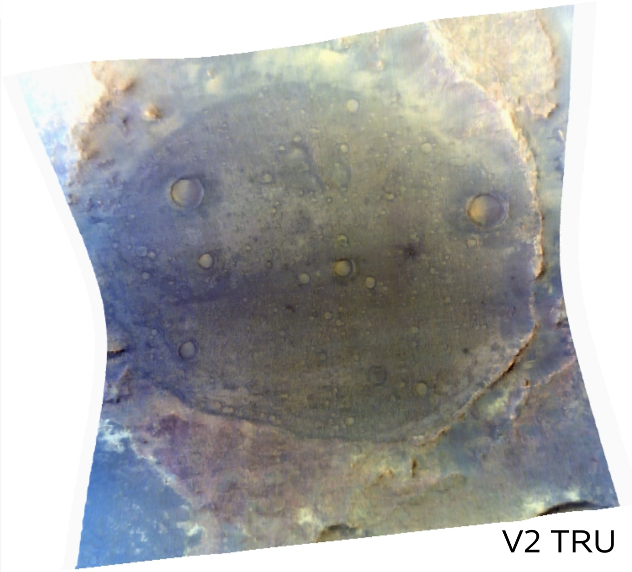
Key IR Spectral Summary Parameters (2/2)

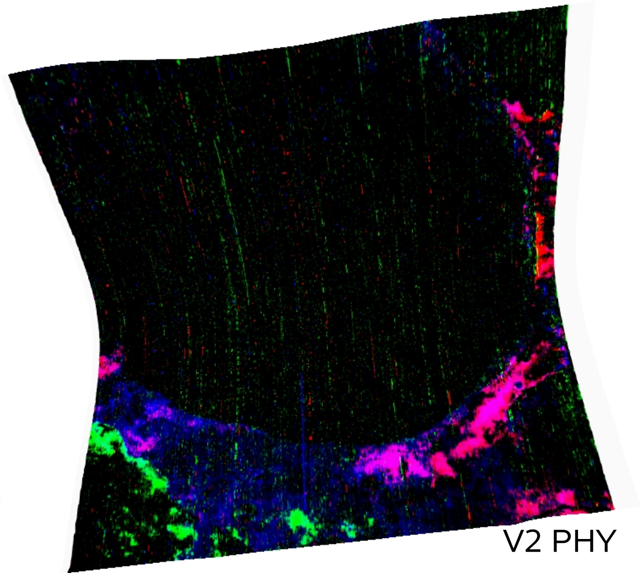
Calculate Summary Parameters (J)

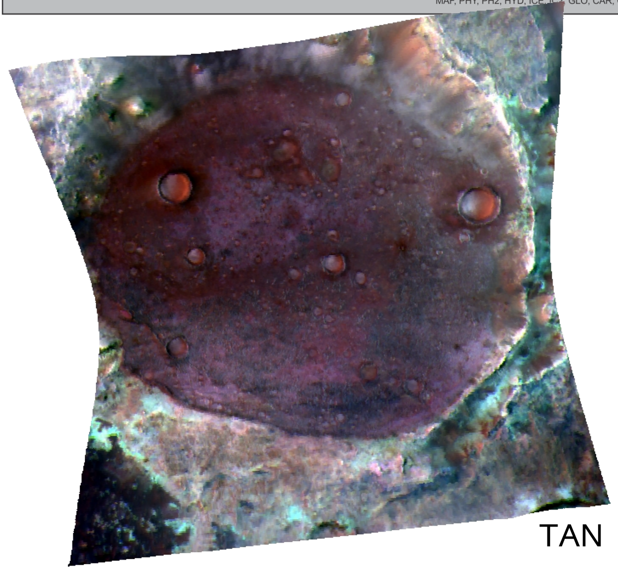
Name	Description	Derivation:	Higher values detect...
BD2210	2210-nm Al/Si-OH band depth	Relative to continuum between 2140, 2250 nm	Al-phyllosilicates and hydrated silica
D2300	Dropoff into 2300-nm band	Relative to reflectance at 2140-2210 nm	Fe/Mg phyllosilicates, Mg carbonate
SINDEX	Convexity due to bands at 1900-2100 & 2400 nm	3-point curvature index (2100, 2290, 2400 nm)	Mono- and poly-hydrated sulfates
BDCARB	Depth of overtone bands in Ca/Fe carbonate	Sqrt of product of depth of bands at 2330 and 250 nm	Ca/Fe carbonate
BD3000	3000-nm H2O band depth	Relative to continuum extrapolated from 2210, 2530 nm	Adsorbed and bound H2O
CINDEX	1-sided depth of 3890-nm carbonate band	Relative to continuum extrapolated from 3630, 3750 nm	Carbonate
BD2350	Depth of 2350-nm band	Relative to continuum between 2290, 2430 nm	Serpentine, chlorite
IRR2	NIR continuum	2530/2210 reflectance ratio	Ice vs. dust clouds, surface dust / dust-bearing deposits

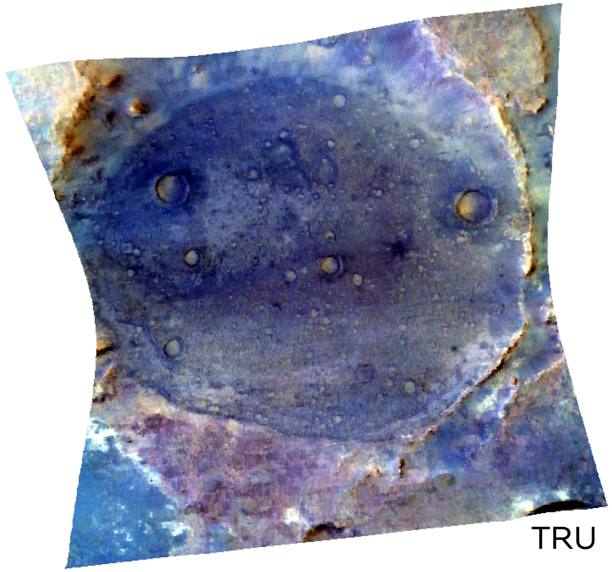
CRISM MTRDR Browse Products

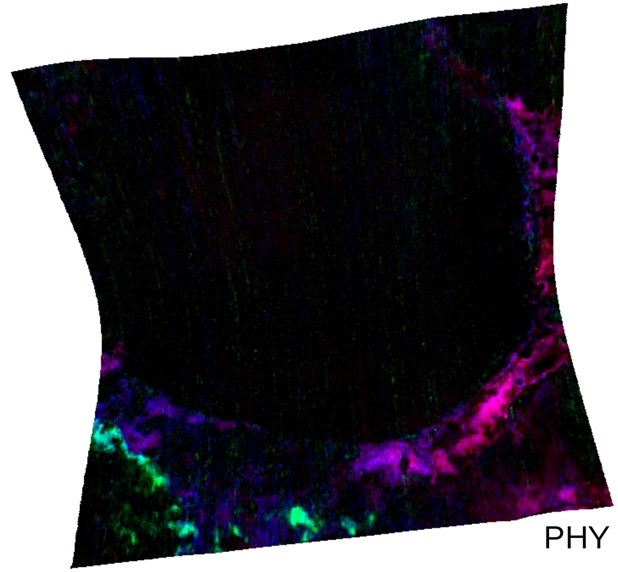












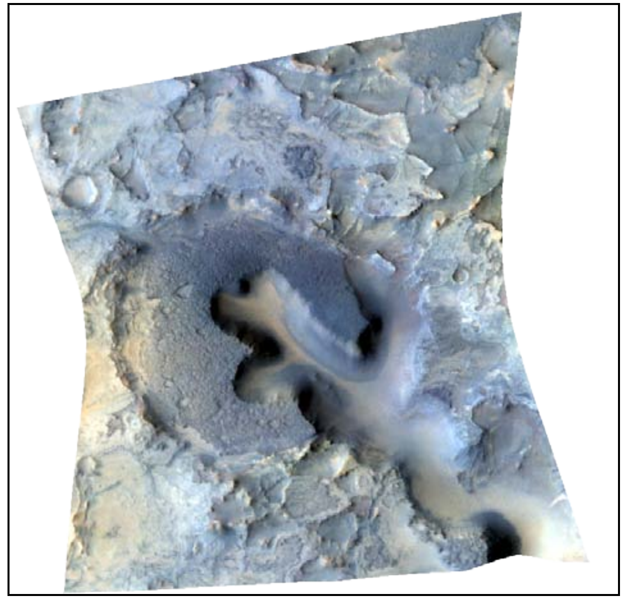
What is a Browse Product?

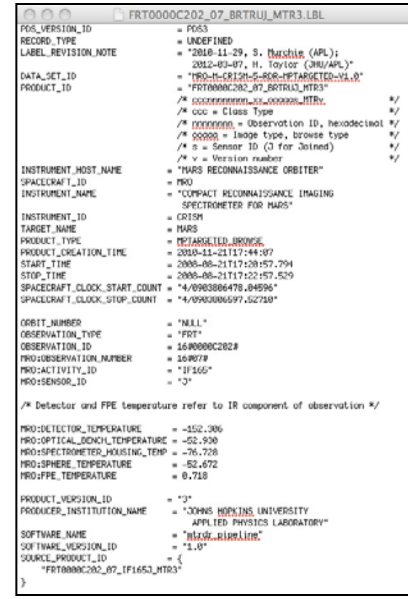
- Browse products are 14 “flavors” of PNGs with scaled combinations of 1-3 summary products – many are bland, but a fraction identify geologically significant mineral exposures
- **The objective is to follow up by analyzing the full I/F data**
- Each browse product has a theme (color, a mineral class, etc.)
- In the PDS, each browse product will have a PDS label describing scaling of the component RGB bands and map projection information
- Here is a **preview** of MTRDR browse products…details are still being finalized

- We also CURRENTLY provide a subset of the browse products described here at crism-map.jhuapl.edu
- The set described here will have:
  - Much lower noise
  - Much lesser artifacts
  - More “flavors” to better detect a greater variety of mineral exposures

MTRDR Browse Product Nomenclature

- **FRT =** Class Type
  - FRT (Full Resolution Targeted Observation)
  - HRL (Half Resolution Long)
  - HRS (Half Resolution Short)
- **00003E12** = 8-digit hexadecimal Observation ID
- **07** = Hex counter within observation
- **BRxxx** = Browse and theme
  - See following slides for 3-character strings
- **J** = Sensor ID
  - J for Joined
- **MTR3** = MTRDR, calibration = v3
- **IMG** = file extension
  - PNG for binary image data
  - LBL for detached ASCII PDS label





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                                 /* ccc = Class Type                         */
                                 /* nnnnnnnn = Observation ID, hexadecimal   */
                                 /* ooooo = Image type, browse type          */
                                 /* s = Sensor ID (J for Joined)             */
                                 /* v = Version number                       */
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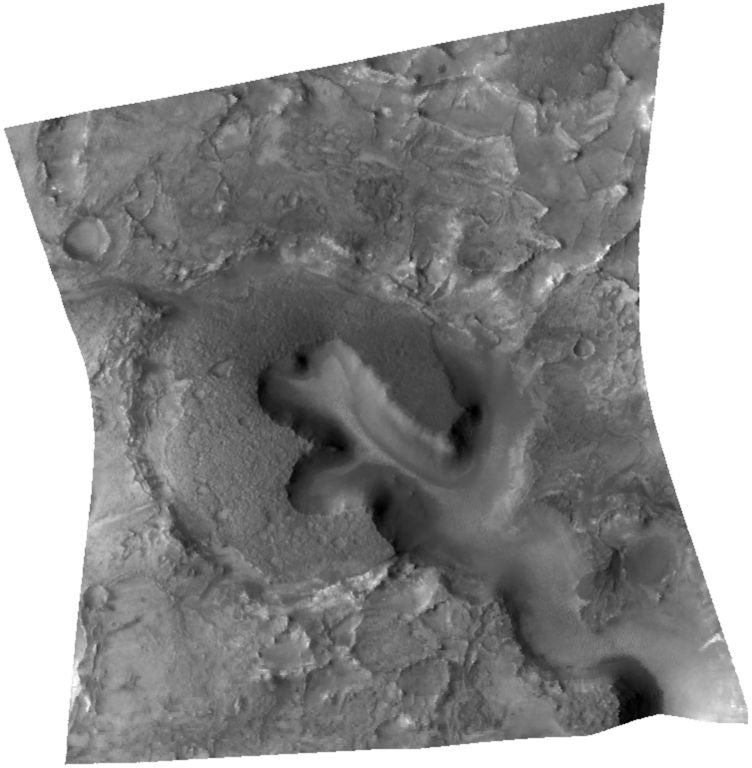
Full-resolution target
Observation 3E12
Counter
Derived information
Joined detectors
Software version 3

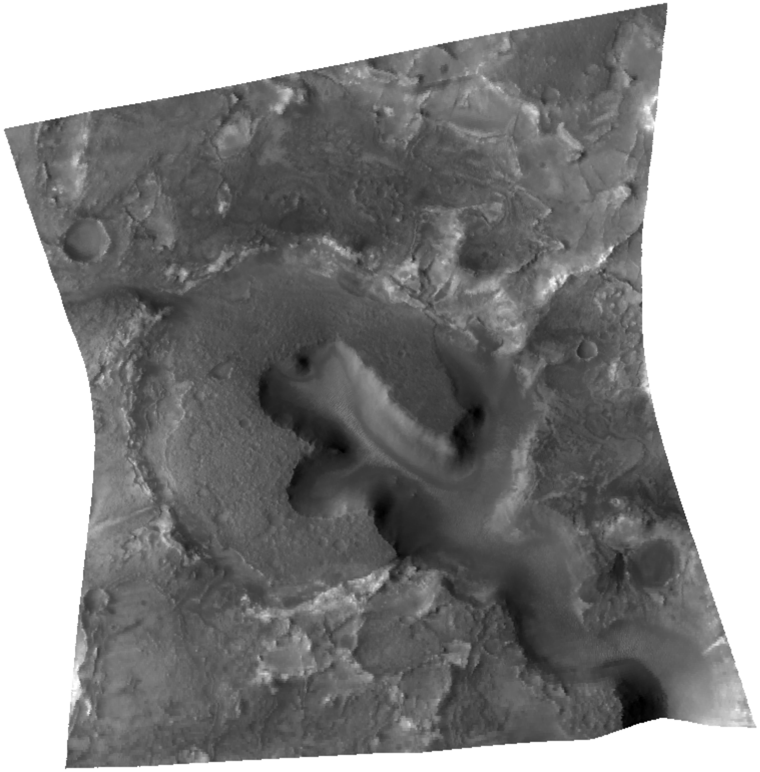
FRT00003E12_07_BR**TRU**J_MTR3.PNG

VNIR and IR Reference Albedo

- To correlate spectral variations with morphology
- **VNA**: Corrected I/F at 770 nm
- **IRA**: Corrected I/F at 1330 nm



VNA

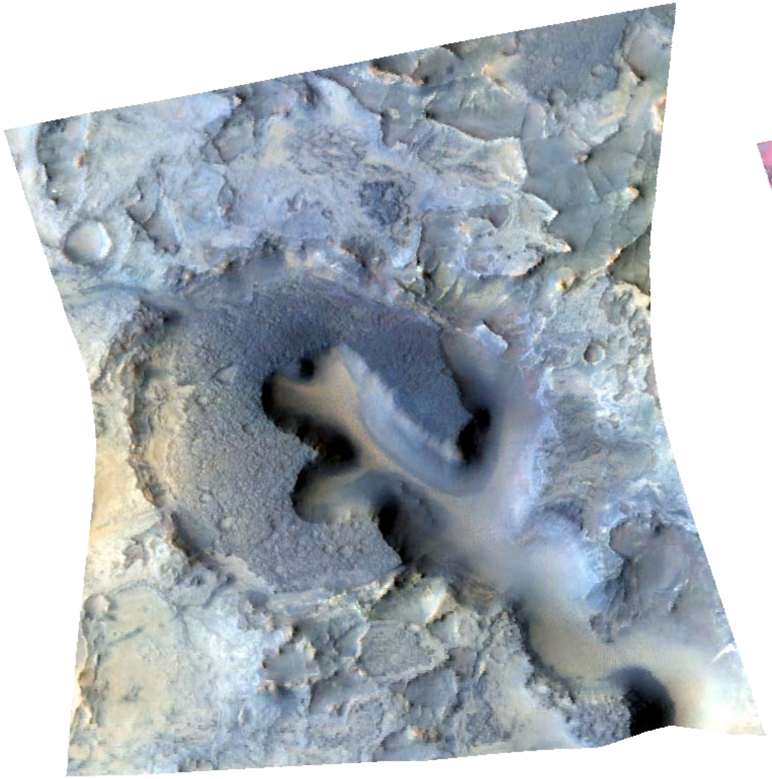


IRA

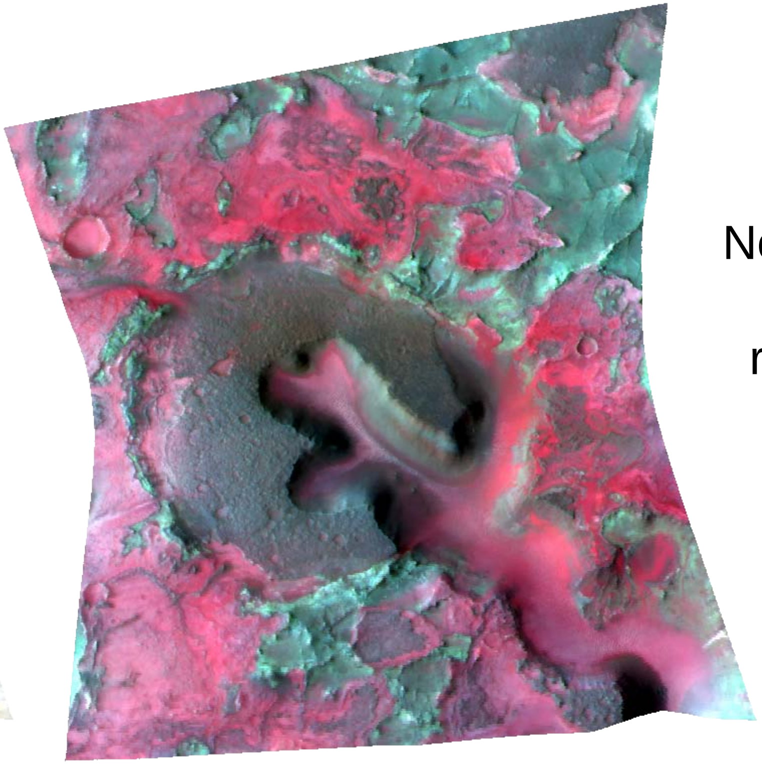
FRT00003E12: Olivine, phyllosilicate, dark basaltic material in Nili Fossae

VNIR and IR Color

- Color variations, to help locate mineral exposures geographically
- **TRU**: VNIR enhanced color, R=600-nm I/F, G=530-nm I/F, B=440-nm I/F
- **TAN**: VNIR+IR enhanced color, R=2529-nm I/F, G=1330-nm I/F, B=770-nm I/F
- **FAL**: IR enhanced color, R=2529-nm I/F, G=1506-nm I/F, B=1080-nm I/F



TRU



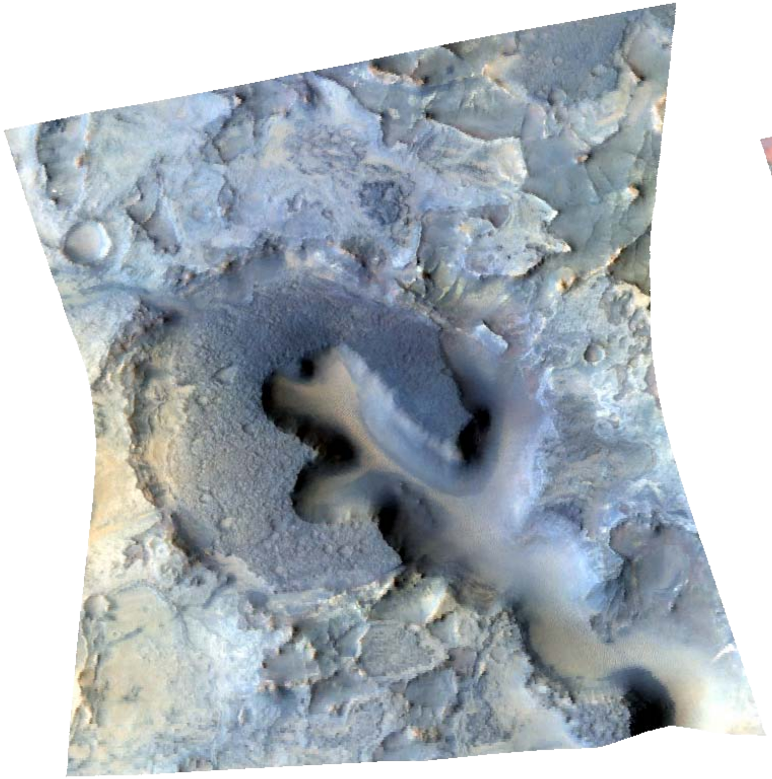
TAN

Note excellent VNIR-IR registration!

FRT00003E12: Olivine, phyllosilicate, dark basaltic material in Nili Fossae

VNIR and IR Color

- Color variations, to help locate mineral exposures geographically
- **TRU**: VNIR enhanced color, R=600-nm I/F, G=530-nm I/F, B=440-nm I/F
- **TAN**: VNIR+IR enhanced color, R=2529-nm I/F, G=1330-nm I/F, B=770-nm I/F
- **FAL**: IR enhanced color, R=2529-nm I/F, G=1506-nm I/F, B=1080-nm I/F



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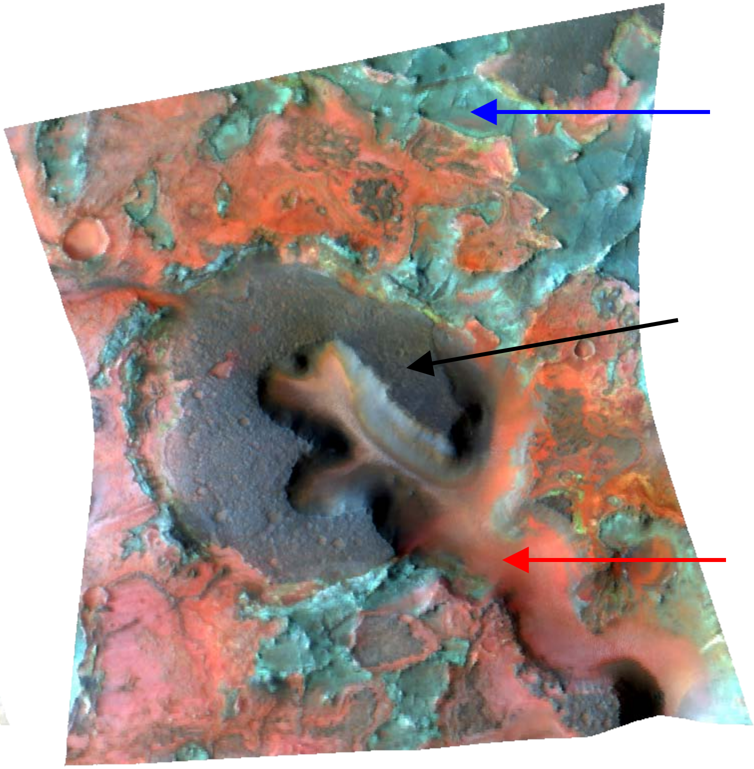
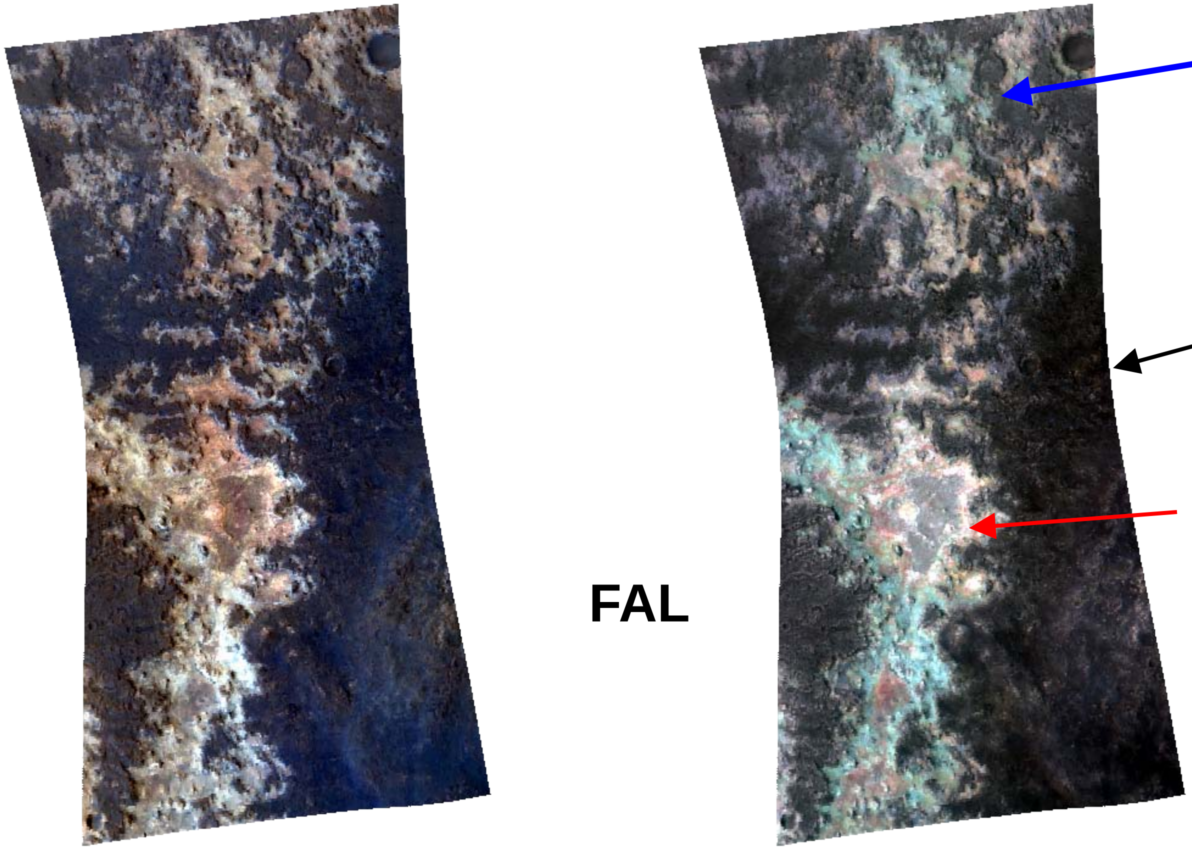


FAL

FRT00003E12: Olivine, phyllosilicate, dark basaltic material in Nili Fossae

VNIR and IR Color

- Color variations help to locate mineral absorption features geographically
- **TRU**: VNIR enhanced color, R=600-nm I/F, G=530-nm I/F, B=440-nm I/F
- **FAL**: IR enhanced color, R=2529-nm I/F, G=1506-nm I/F, B=1080-nm I/F



TRU

FAL

Carbonate and clay often blue-green

Basaltic material often gray-brown

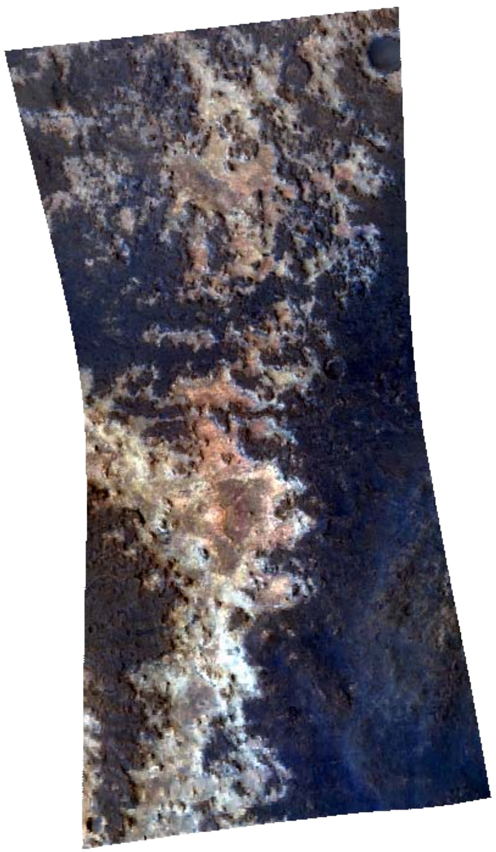
Fe-phyllosilicates commonly reddish

HRL000043EC: Layered clays in Mawrth Vallis region

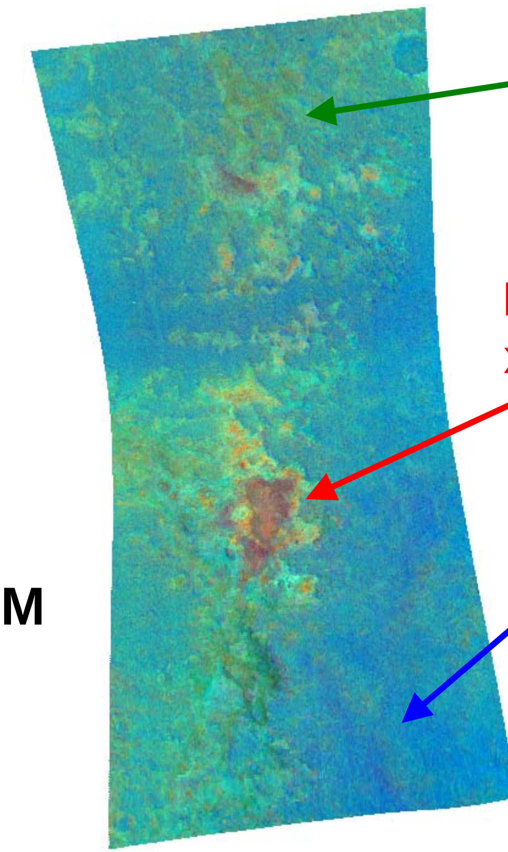
FEM – VNIR Spectral Shape

- Curvature of VNIR spectrum due to
  - Ferric and ferrous mineral absorptions
  - Negative slope due to dust-on-rock coatings or compacted dust texture
- R=BD530, G=SH600, B=BDI1000VIS

TRU



FEM



Green= textural effects

Red= nanophase or xtalline ferric oxides

Blue = cleaner/more mafic surfaces

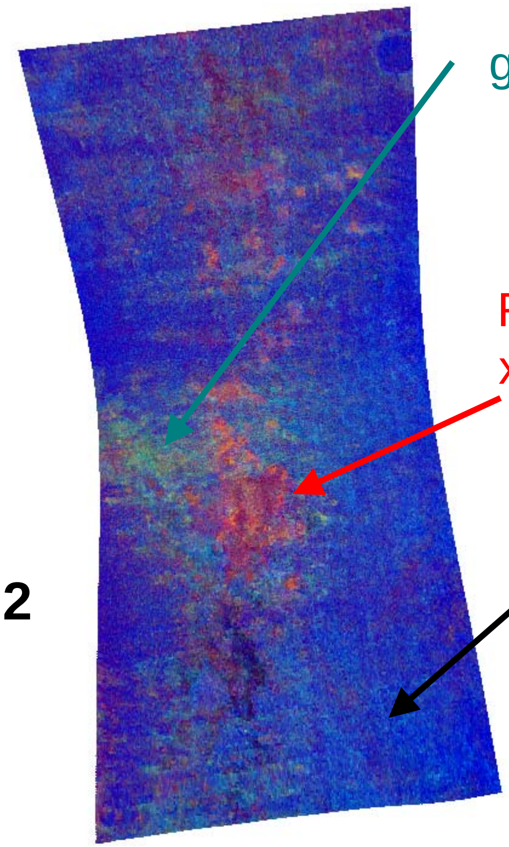
HRL000043EC: Layered clays in Mawrth Vallis region

FM2 – Fe Minerals

- Absorption bands due to
  - Olivine and pyroxene (1000 nm)
  - Nanophase ferric oxide (530 nm) and xtalline ferric/ferrous minerals (~920 nm)
- R=BD530, G=BD920, B=BDI1000VIS

TRU

FM2



Green= coarser-grained Fe minerals

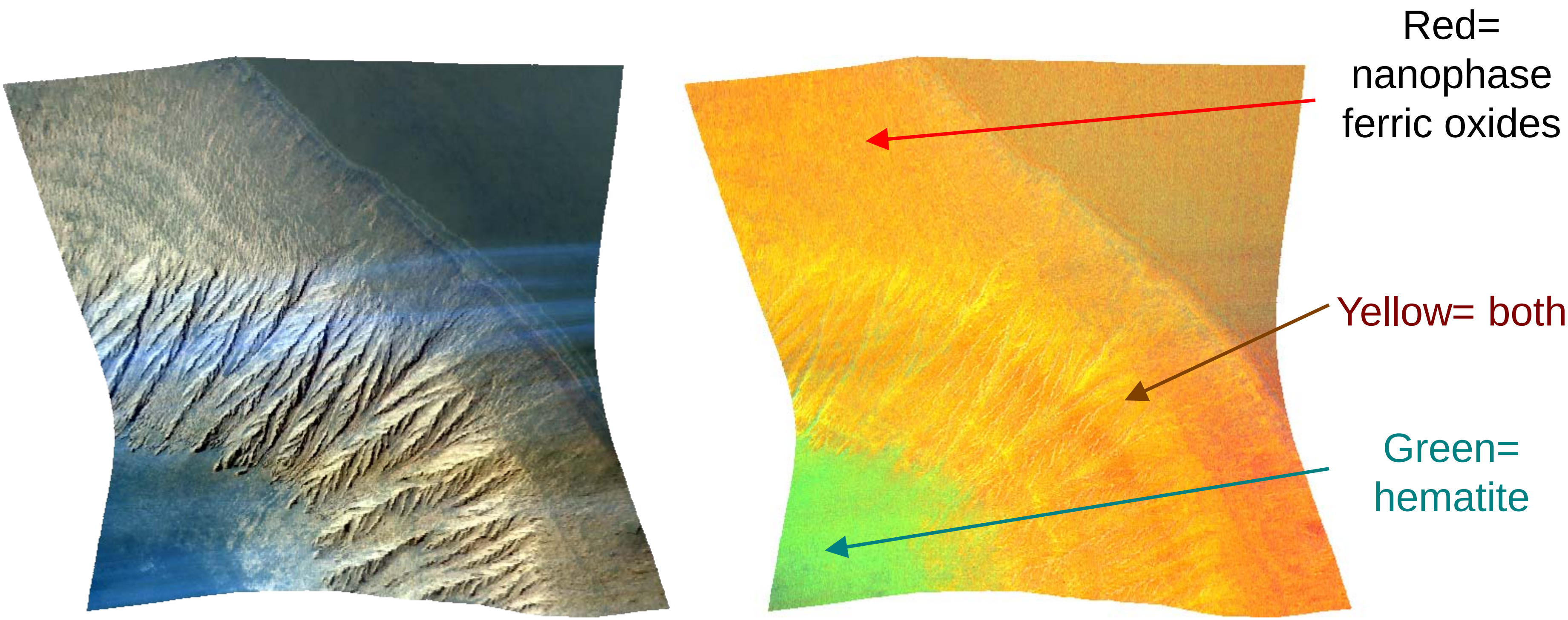
Red= nanophase or xtalline ferric oxides

Blue = cleaner /more mafic surfaces

HRL000043EC: Layered clays in Mawrth Vallis region

FM2 – Fe Minerals

- Dramatic response in/around crystalline hematite deposits
- R=BD530, G=BD920, B=BDI1000VIS

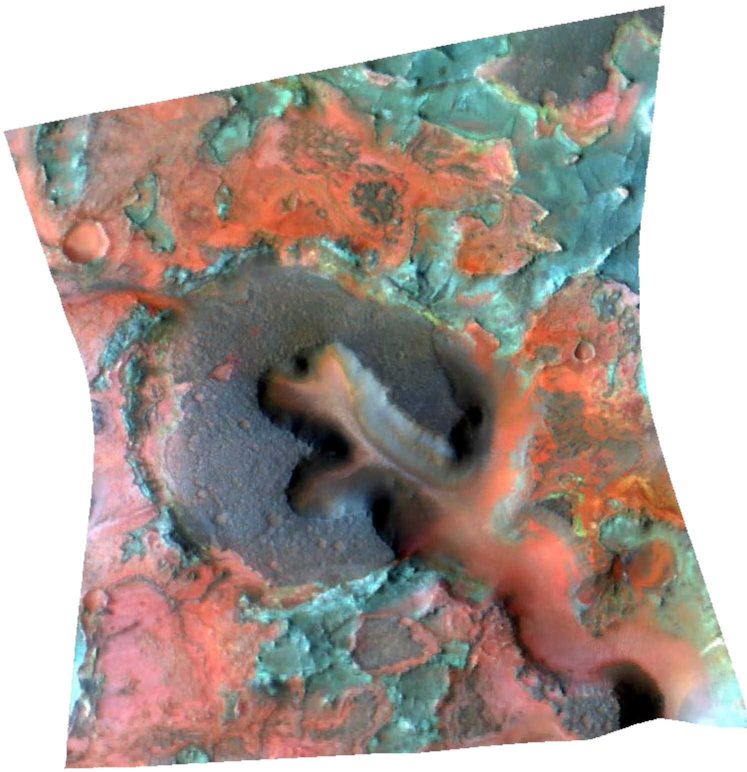


TRU **FM2**

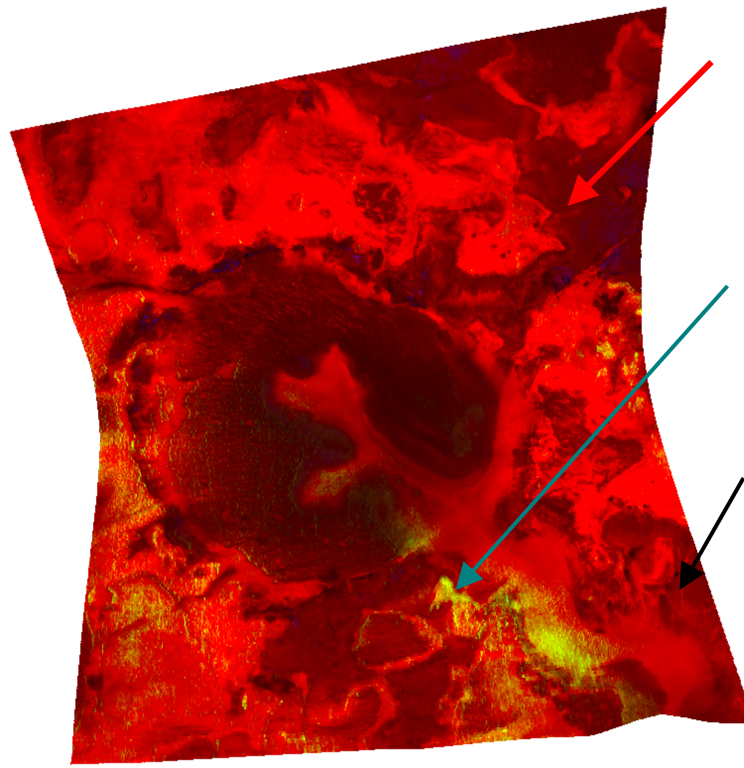
FRT00009CB6: "gray" hematite mass wasting from layered deposits in Candor Chasma

MAF–Fe^{2+} in Olivine, Pyroxene, Phyllosilicate

- NIR spectral curvature due to absorptions from
  - Low- and high-Ca pyroxene (~1000- and ~2000-nm)
  - 1000-1700 nm feature due to olivine and Fe-phyllosilicates
- R=OLINDEX2, G=LCPINDEX, B=HCPINDEX



FAL



Red=olivine

Green=low-Ca pyroxene

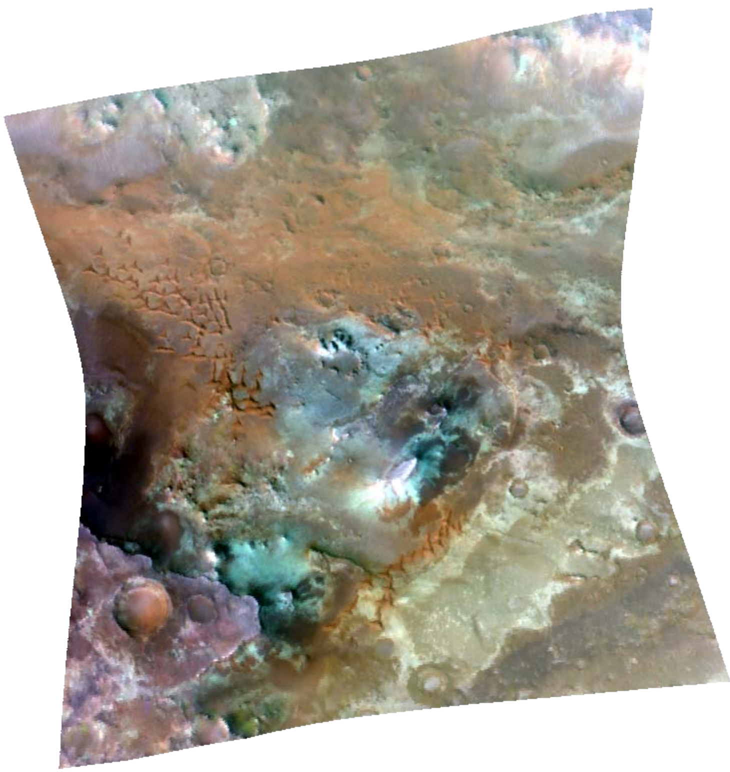
Gray=weak bands

MAF

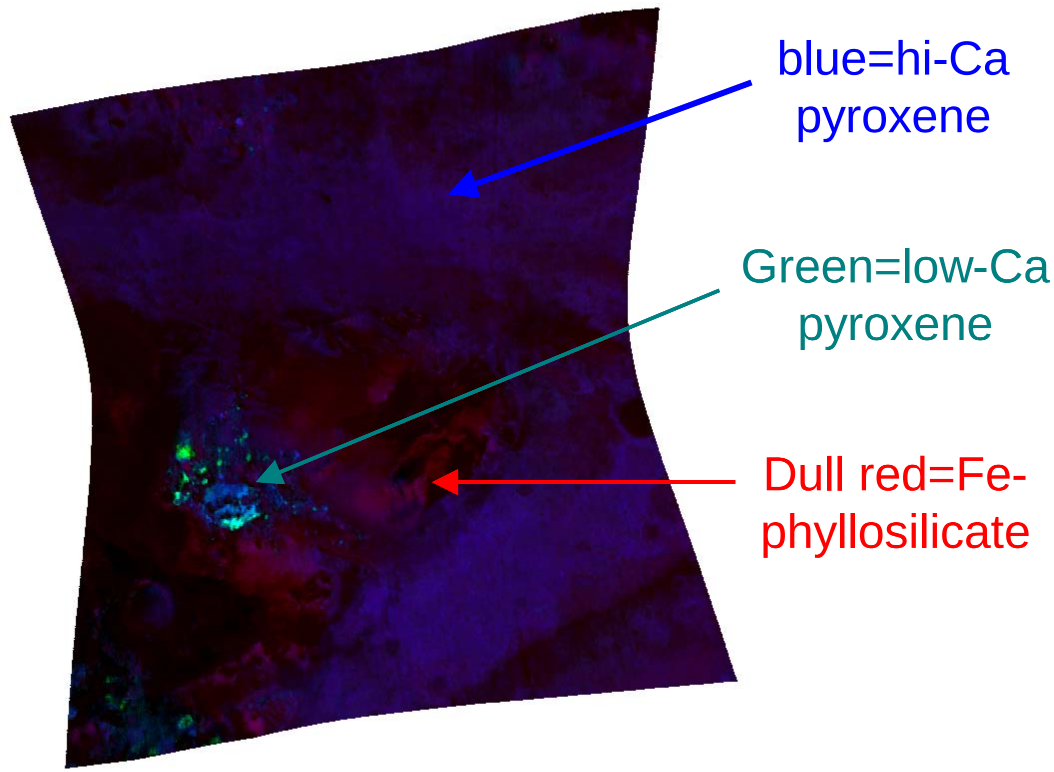
FRT00003E12: Olivine, phyllosilicate, dark basaltic material in Nili Fossae

MAF–Fe^{2+} in Olivine, Pyroxene, Phyllosilicate

- NIR spectral curvature due to absorption bands from
  - Low- and high-Ca pyroxene (~1000- and ~2000-nm)
  - 1000-1700 nm feature due to olivine and Fe-phyllosilicates
- R=OLINDEX2, G=LCPINDEX, B=HCPINDEX



FAL



MAF

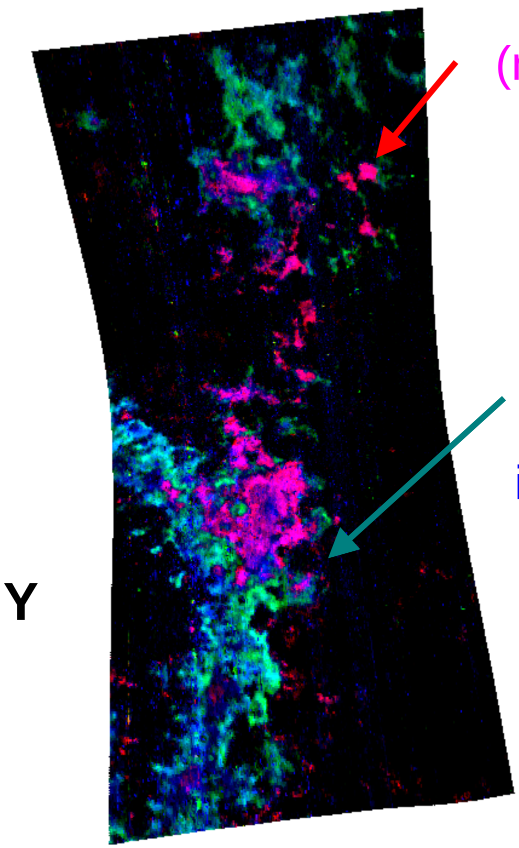
FRT000064D9: Lo- and hi-Ca pyroxene, olivine in Nili Fossae

PHY– Phyllosilicates (v1)

- Common metal-OH absorption bands and state of hydration
  - Al/Si-OH (2210 nm) or Mg/Fe-OH (~2300 nm)
  - Chemically bound H_2O (~1900 nm)
- R=D2300, G=BD2210, B=BD1900

FAL

PHY



Red=Mg/Fe-clay (magenta where it's more hydrated)

Green= Al-clay or hydrated silica (blue-green where it's more hydrated)

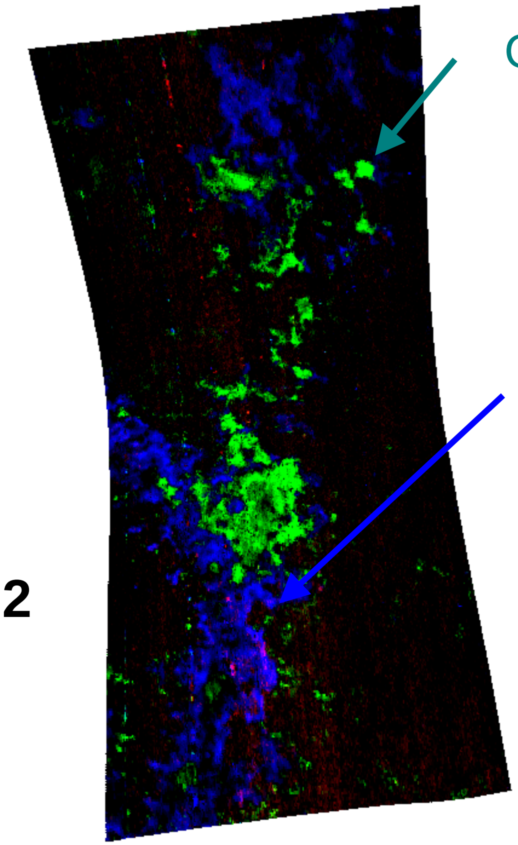
HRL000043EC: Layered clays in Mawrth Vallis region

PH2 – Phyllosilicates (v2)

- Wavelength position of 2200-2350 nm metal-OH absorption band
  - Blue ~ near 2210 nm, green ~ near 2300 nm, red ~ near 2350 nm
  - Relates to cation composition and silicate type
- R=BD2350, G=D2300, B=BD2210

FAL

PH2

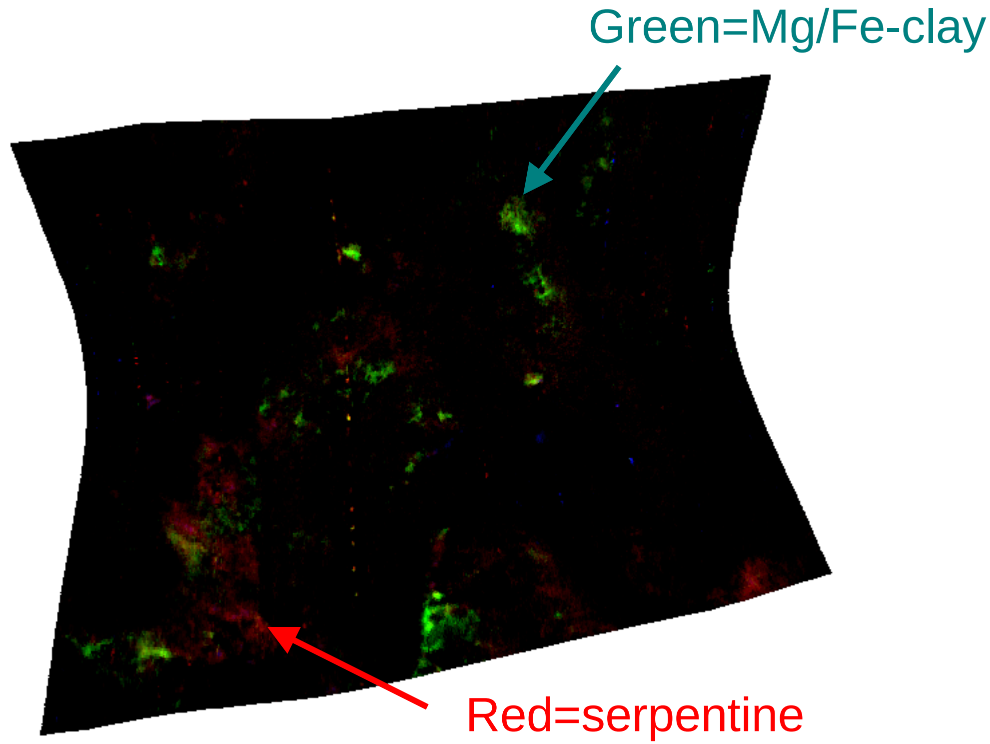


HRL000043EC: Layered clays in Mawrth Vallis region

PH2 – Phyllosilicates (v2)

- Wavelength position of 2200-2350 nm metal-OH absorption band
  - Blue ~ near 2210 nm, green ~ near 2300 nm, red ~ near 2350 nm
  - Relates to cation composition and silicate type
- R=BD2350, G=D2300, B=BD2210

FAL

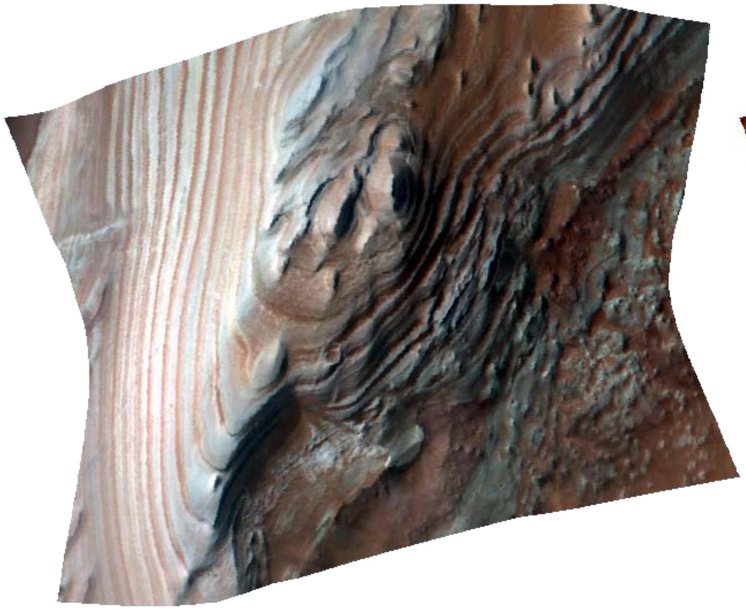


PH2

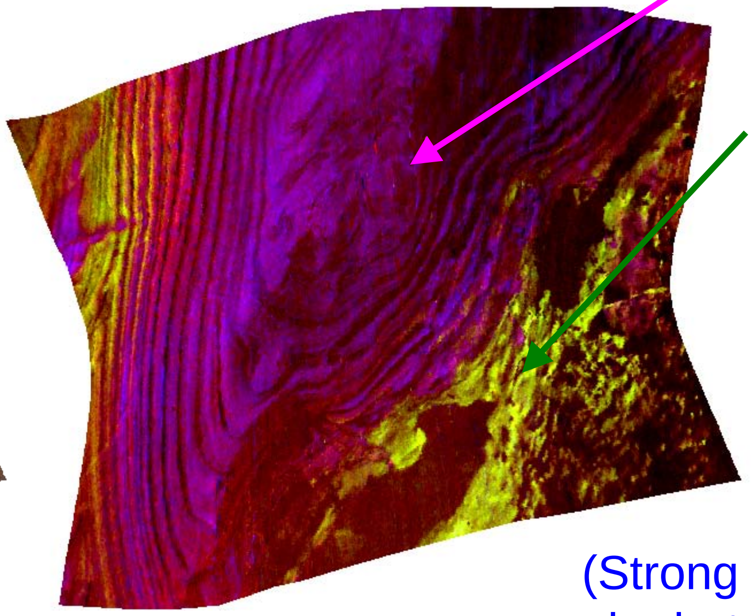
FRT0000634B: Fe/Mg clays and serpentine in Claritas Fossae

HYD – Hydrated Sulfates

- Absorption bands in hydrated sulfates
  - Monohydrated sulfates (strong 2100-nm and weak 2400-nm band)
  - Polyhydrated sulfates (strong 1900-nm and strong 2400-nm band)
- R=SINDEX, G=BD2100, B=BD1900



FAL

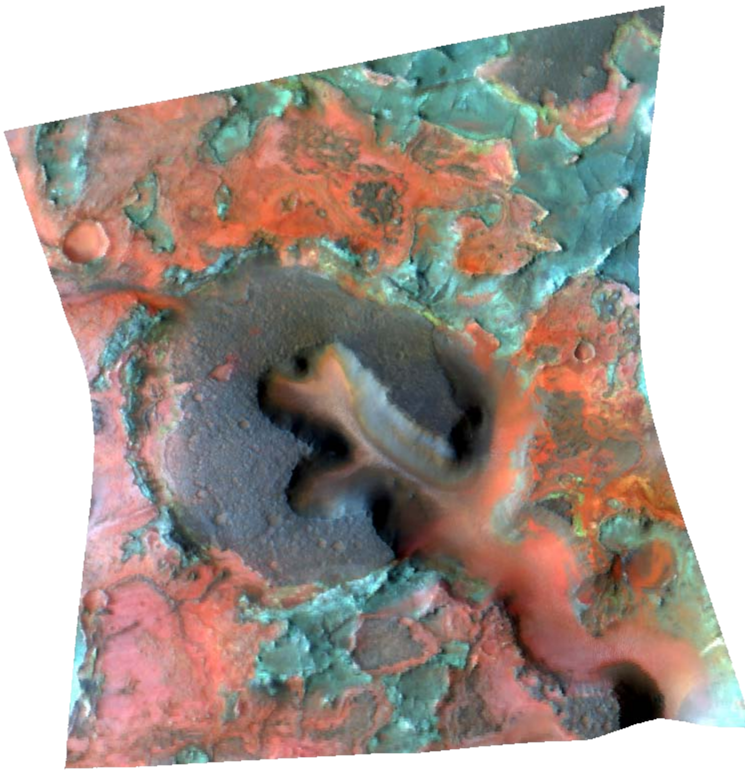


HYD

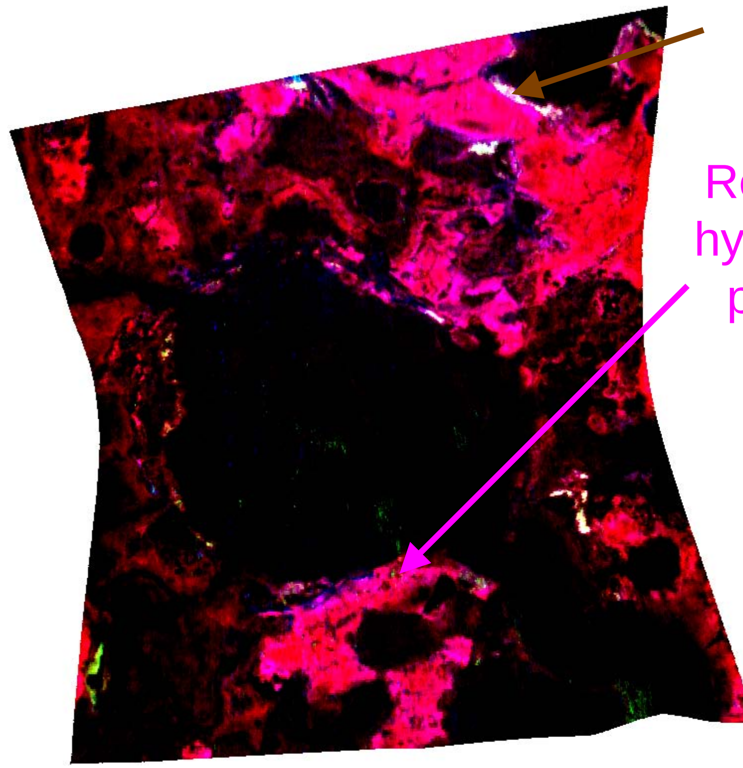
FRT00009C0A: Hydrated sulfates in Juventae Chasma

CAR – Mg Carbonate

- Absorption bands in hydrated Mg carbonate
  - 2300-nm, 2500-nm carbonate overtones
  - 1900-nm bound H_2O band
- R=D2300, G=BD2500H, B=BD1900



FAL

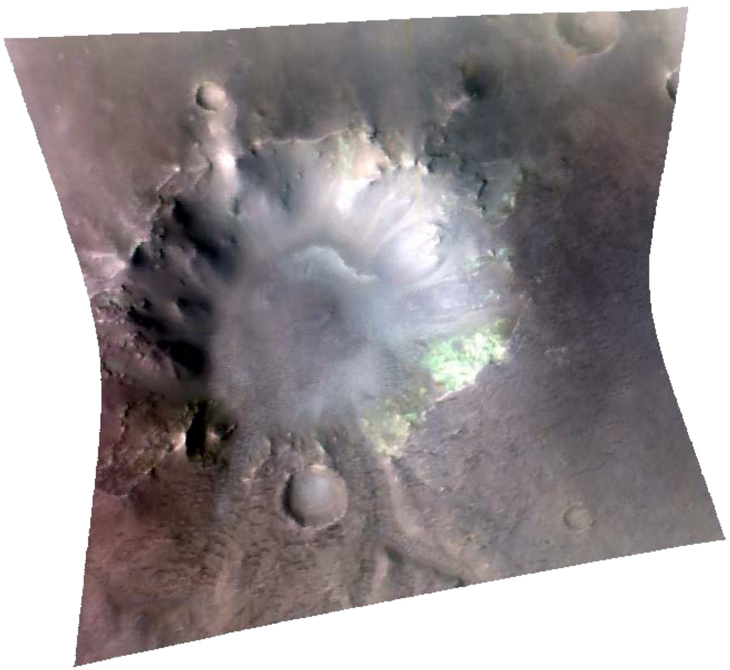


CAR

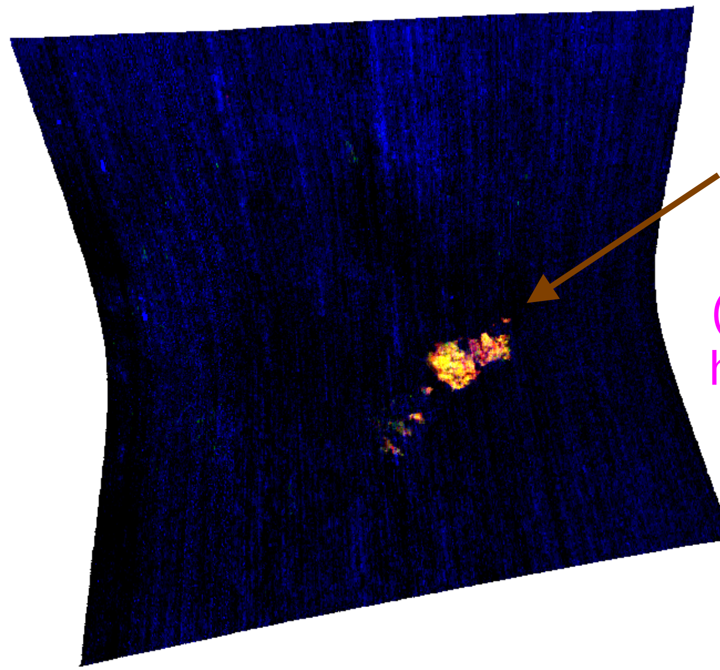
FRT00003E12: Thin Mg carbonate layer in Nili Fossae

CR2 – Ca/Fe Carbonate

- Absorption bands in Ca and/or Fe carbonate
  - 2330-nm, 2530-nm carbonate overtones
  - 3890 carbonate fundamental
- R=D2300, G=BDCARB, B=CINDEX



FAL



Pale yellow= Ca/Fe carbonate

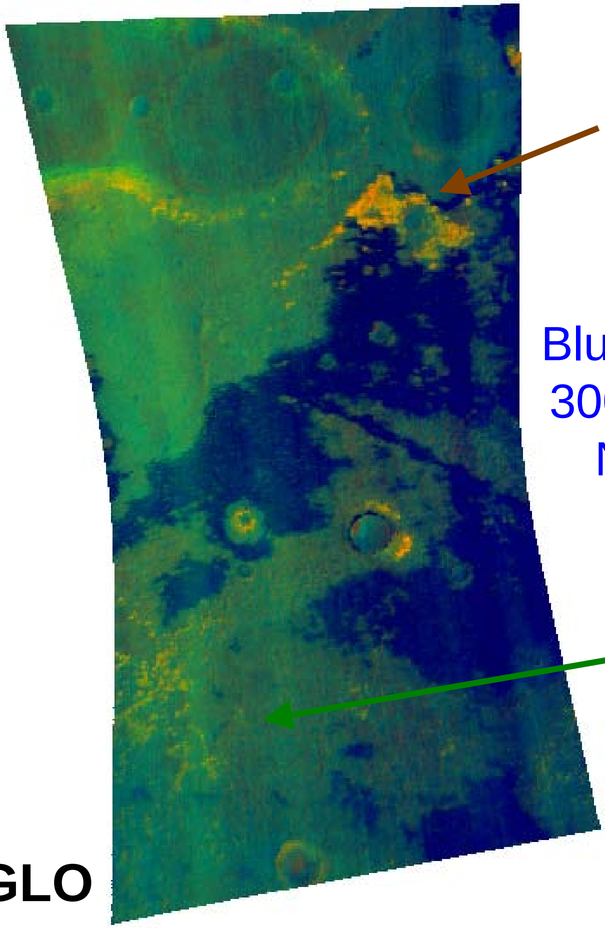
(Red/magenta= hydrated Mg/Fe phyllosilicate)

CAR

FRT00124B3: Excavated Ca/Fe carbonate in Tyrrhena Terra

GLO - "THEMIS Glowing Terrain"

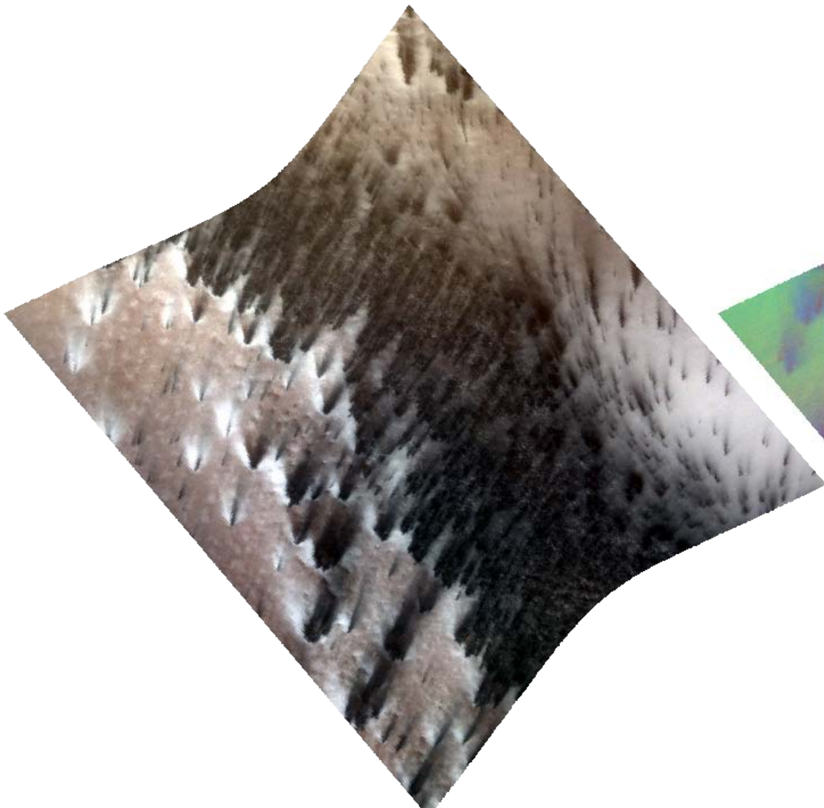
- Spectral continuum and 3000-nm band strength distinguish putative chlorides and associated materials
- R=ISLOPE, G=BD3000, B=IRR2



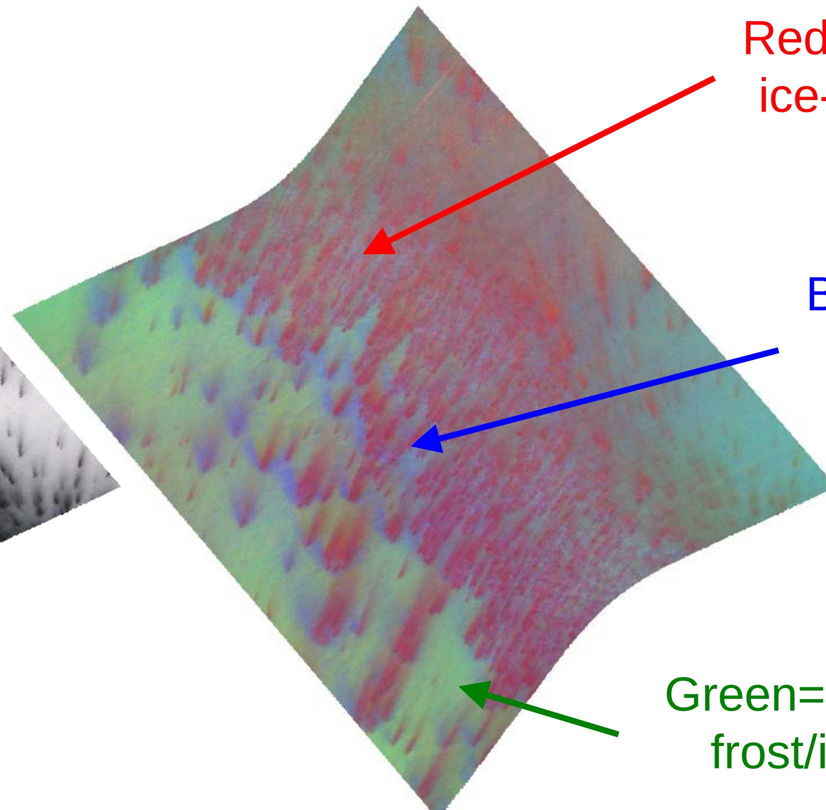
HRL0000860C: Chlorides and phyllosilicate in Terra Sirenum

IC2 – H_2O ice, CO_2 ice, dust

- CO_2 ice from 1435-nm band, H_2O ice from 1500-nm band, dust from MIR brightness
- R=R3920, G=BD150, B=BD1435



TRU



Red=exposed ice-free dust

Blue = CO2 frost/ice

Green=H2O frost/ice

IC2

FRT000059E2: CO_2 fans on dust and H_2O ice, S polar cap