Mars Express HRSC Experiment Overview

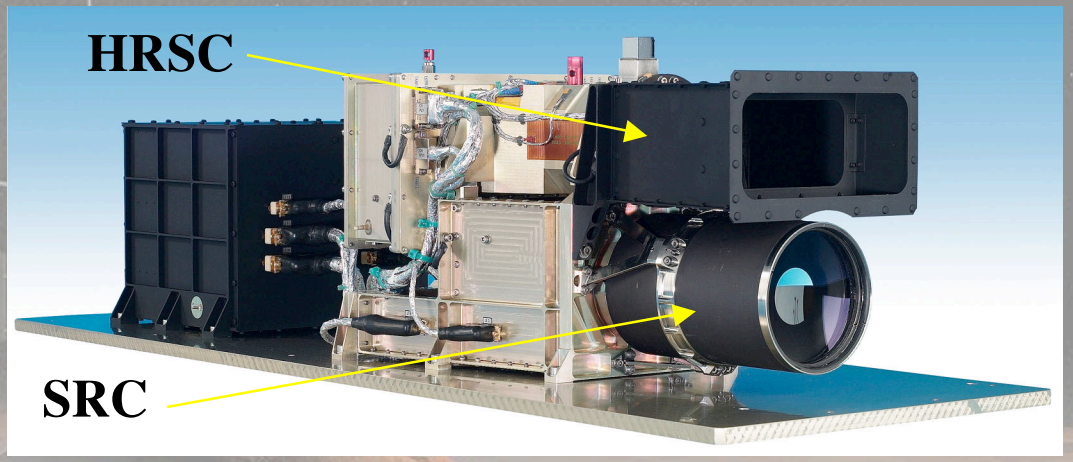
David A. Williams

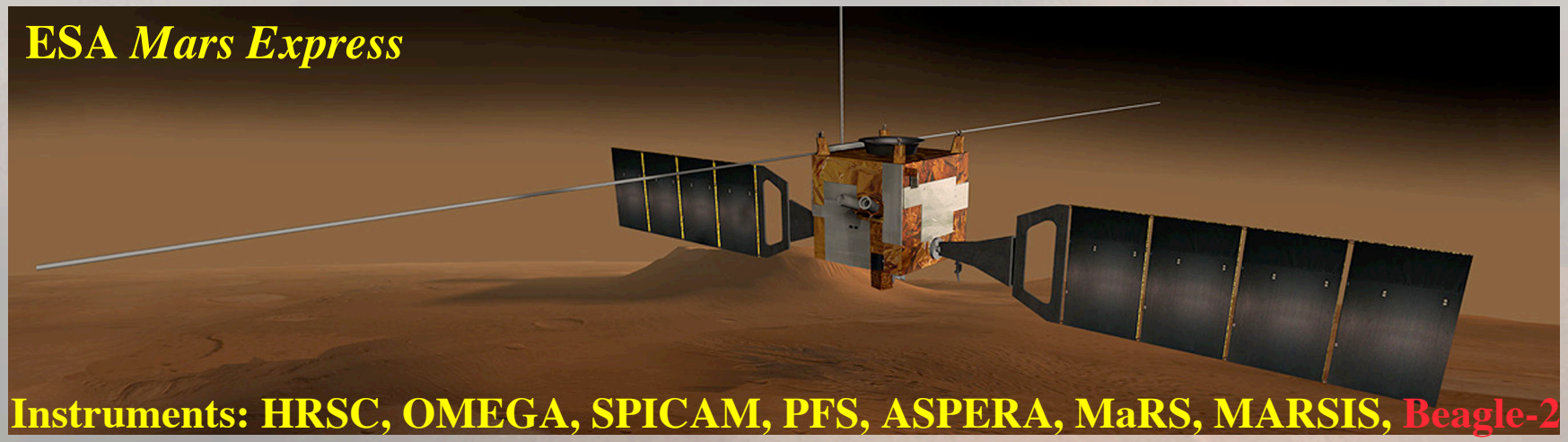
School of Earth and Space Exploration
Arizona State University
Tempe, Arizona

School of Earth & Space Exploration
Arizona State University

Outline

- HRSC Science Objectives
- HRSC Experiment
- Overview of Results
- Comments on Processing

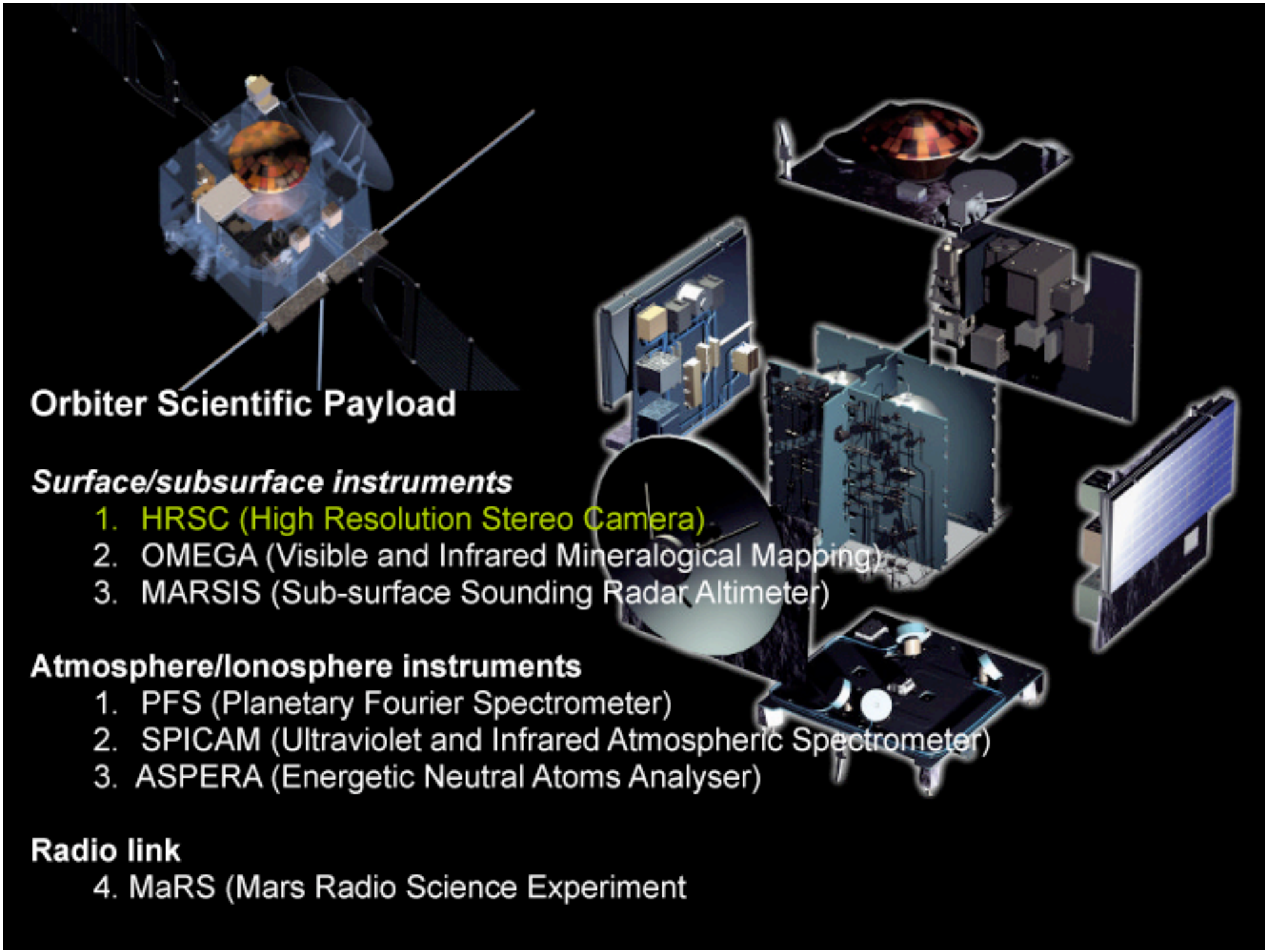




HRSC Science Objectives

- Characterize surface structure & morphology at high spatial resolution (≥10 m/pixel)
- Characterize surface topography at high spatial & vertical resolution
- Perform color imaging at high spatial resolution for terrain classification
- Refine geodetic control network & cartographic base
- Determine the evolution of surface processes and their influence on the martian environment

Neukum, G., R. Jaumann, and the HRSC Co-Investigator & Experiment Team, 2004, HRSC: the High Resolution Stereo Camera of *Mars Express*, ESA Special Publication 1240, p. 17-36



Orbiter Scientific Payload

Surface/subsurface instruments

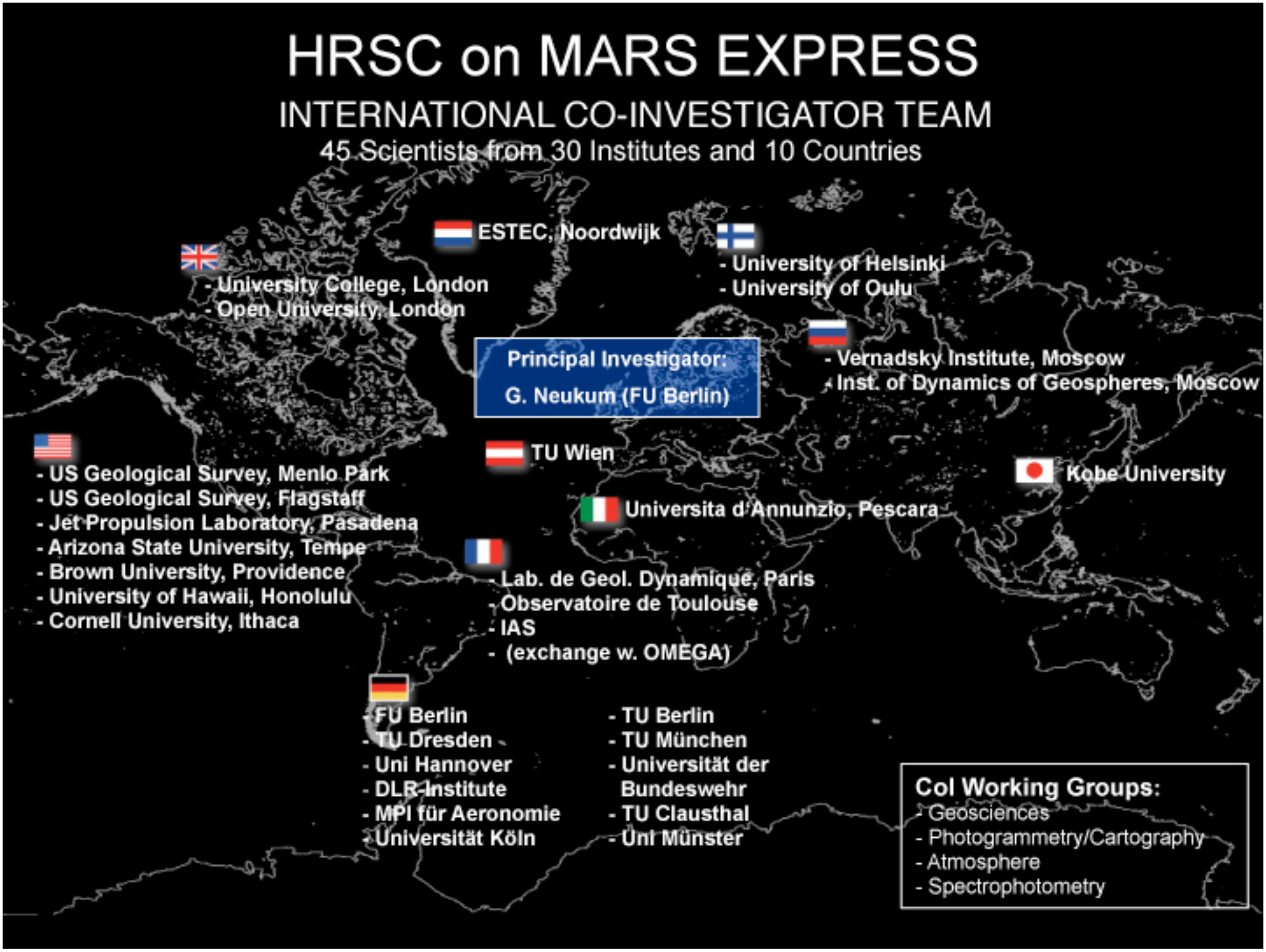
1. HRSC (High Resolution Stereo Camera)
2. OMEGA (Visible and Infrared Mineralogical Mapping)
3. MARSIS (Sub-surface Sounding Radar Altimeter)

Atmosphere/Ionosphere instruments

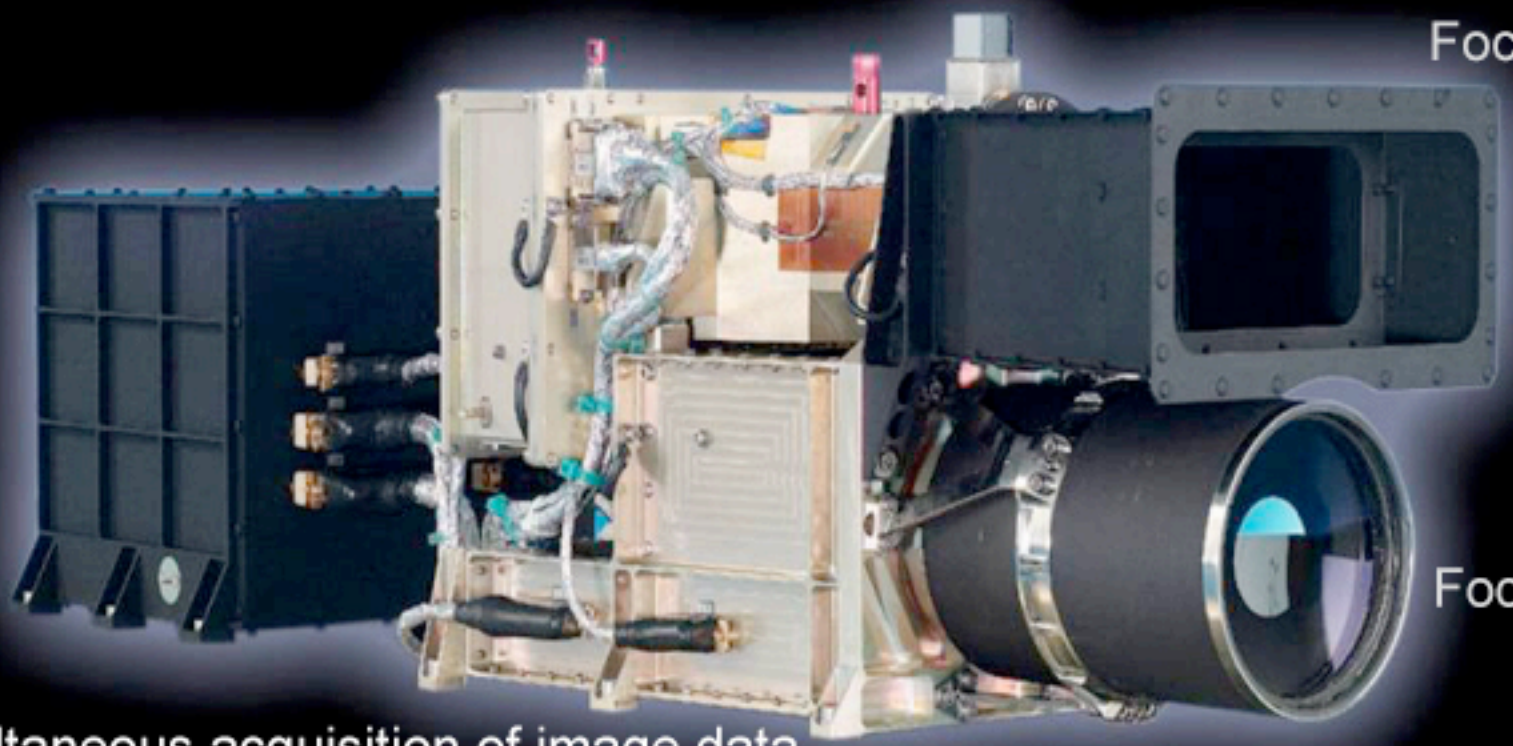
1. PFS (Planetary Fourier Spectrometer)
2. SPICAM (Ultraviolet and Infrared Atmospheric Spectrometer)
3. ASPERA (Energetic Neutral Atoms Analyser)

Radio link

4. MaRS (Mars Radio Science Experiment


HRSC on MARS EXPRESS
INTERNATIONAL CO-INVESTIGATOR TEAM
45 Scientists from 30 Institutes and 10 Countries
ESTEC, Noordwijk
- University College, London
- Open University, London
- University of Helsinki
- University of Oulu
Principal Investigator:
G. Neukum (FU Berlin)
- Vernadsky Institute, Moscow
- Inst. of Dynamics of Geospheres, Moscow
TU Wien
- US Geological Survey, Menlo Park
- US Geological Survey, Flagstaff
- Jet Propulsion Laboratory, Pasadena
- Arizona State University, Tempe
- Brown University, Providence
- University of Hawaii, Honolulu
- Cornell University, Ithaca
Kobe University
Universita d'Annunzio, Pescara
- Lab. de Geol. Dynamique, Paris
- Observatoire de Toulouse
- IAS
- (exchange w. OMEGA)
- FU Berlin
- TU Dresden
- Uni Hannover
- DLR-Institute
- MPI für Aeronomie
- Universität Köln
- TU Berlin
- TU München
- Universität der Bundeswehr
- TU Clausthal
- Uni Münster
CoI Working Groups:
- Geosciences
- Photogrammetry/Cartography
- Atmosphere
- Spectrophotometry

HRSC and SRC – Technical Parameters

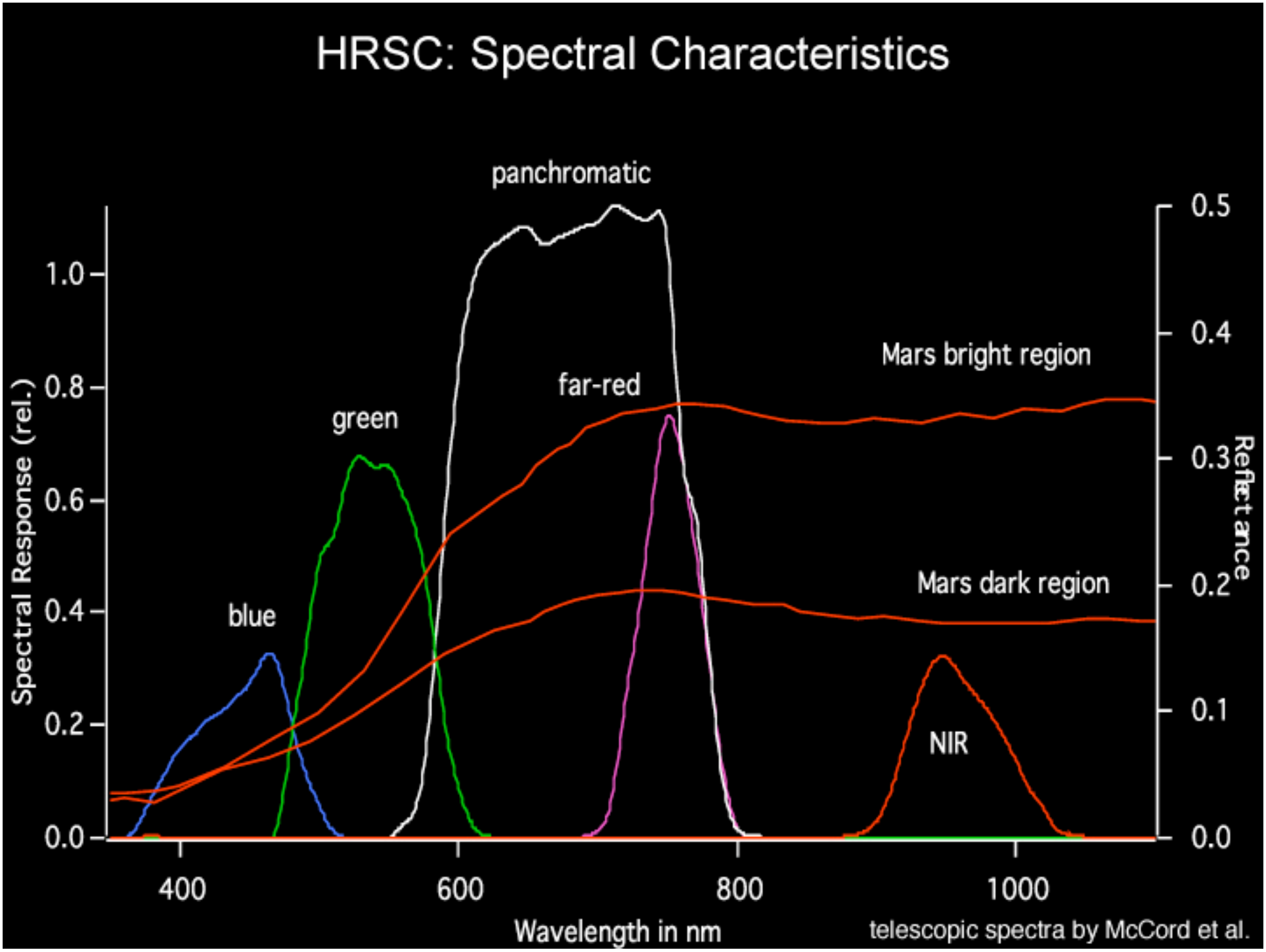


HRSC:
Focal length
175 mm

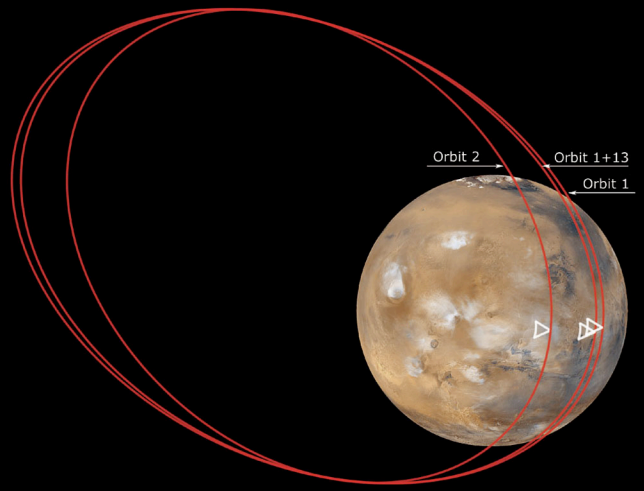
SRC:
Focal length
975 mm

Simultaneous acquisition of image data

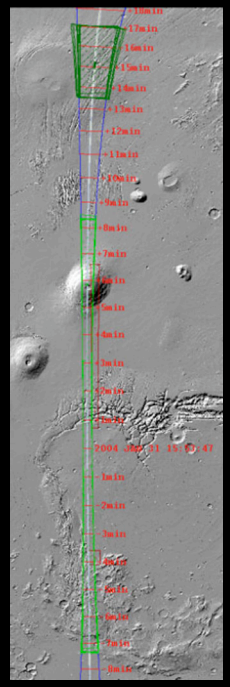
- High resolution : Nadir-Sensor, 10 m/Pixel from 250 km Altitude
- Stereo: 4 Sensors, 10-20 m/Pixel from 250 km Altitude
- Color: 4 Sensors, red,green,blue,near Infrared
- Max. Resolution (SRC): 2.3 m/Pixel from 250 km
- Output Datarate: 25 Mbit/s, Online-Compression
- Mass: 19.6 kg

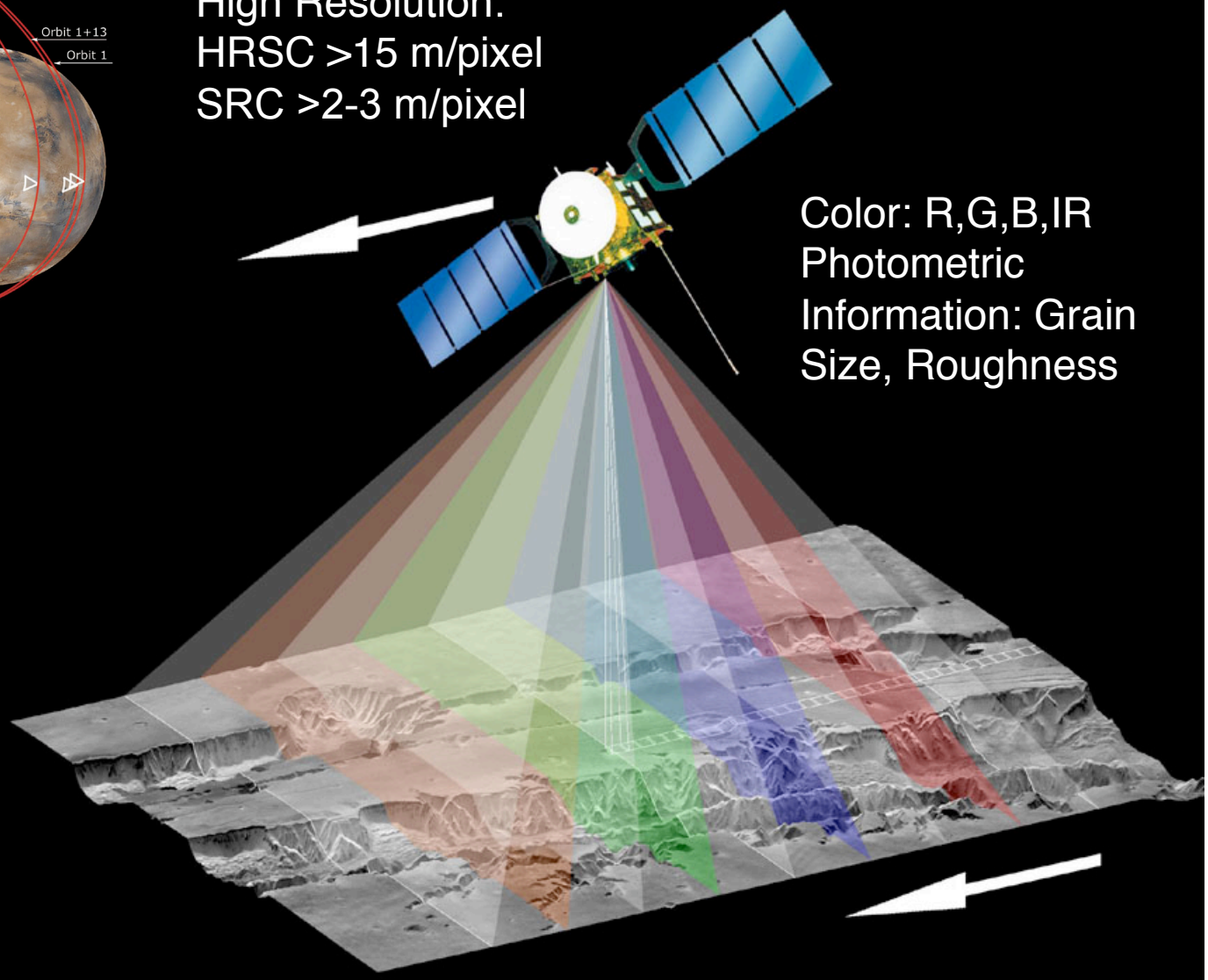

HRSC: Spectral Characteristics
panchromatic
green
blue
far-red
NIR
Mars bright region
Mars dark region
Spectral Response (rel.)
Reflectance
Wavelength in nm
1.0
0.8
0.6
0.4
0.2
0.0
0.5
0.4
0.3
0.2
0.1
0.0
400
600
800
1000
telescopic spectra by McCord et al.

HRSC Imaging Principle



Stereo (height) Information:
High Resolution:
HRSC >15 m/pixel
SRC >2-3 m/pixel





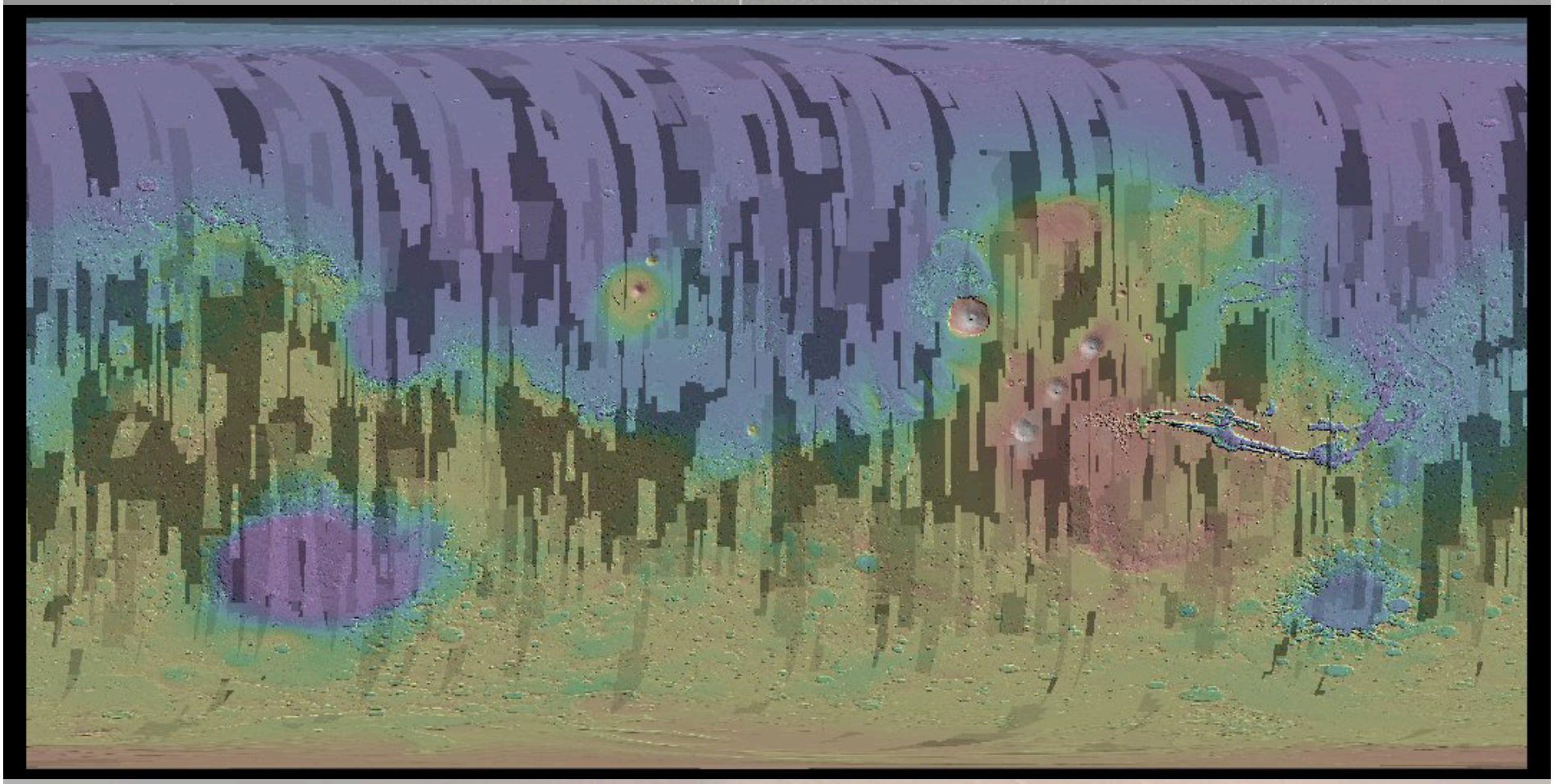
Color: R,G,B,IR
Photometric
Information: Grain
Size, Roughness

Tab. 2. The 16 main **m**acro**p**ixel-**f**ormats (MPF) of HRSC. The figures in the columns for the different CCD lines indicate sampling density, e.g., „1x1“ means that each pixel will be recorded individually along and across flight direction (highest resolution), „8x8“ means that 8x8 pixels will be summed up (lowest resolution; data volume reduced by factor 64). MPF modes marked in light gray will be used most frequently to assure homogeneous imagery. See text for details on data volume and SRC imaging.

Nr	MacroPixelFormat (MPF)	Nadir 1 CCD	Stereo 2 CCD	Color 4 CCD	Phot. 2 CCD	Data Vol. Mbit comp.	SRC Spot	SRC Raster/Contig.
1	Mapping Stereo	1x1	2x2	8x8	4x4	183	possible	w/o Col. or Pho
2	Mapping Stereo Color	1x1	2x2	4x4	4x4	204	possible	w/o Col. or Pho
3	Mapping SpecPhot	1x1	4x4	4x4	4x4	163	possible	possible
4	Mapping Large Area	1x1	4x4	8x8	4x4	143	possible	possible
5	Stereo High-Res.	1x1	1x1	-	2x2	381	possible	w/o Pho
6	Stereo Quint.	1x1	2x2	8x8	2x2	224	possible	w/o Col.
7	Stereo Triple	1x1	1x1	8x8	8x8	340	possible	w/o Pho + Col
8	Stereo Color	1x1	2x2	4x4	2x2	245	possible	w/o Col or Pho
8a	Spectrophotometry	1x1	4x4	2x2	4x4	245	possible	no
9	Color	-	-	1x1	-	435	possible	If only 3 color
10	Color Stereo	1x1	2x2	2x2	-	272	possible	no
11	Map. Med.-Res.	2x2	2x2	8x8	4x4	102	possible	w/o Col or Pho
12	Med.-Res. SpecPhot	2x2	4x4	4x4	4x4	82	possible	possible
13	Med.-Res. Stereo	2x2	2x2	8x8	2x2	143	possible	w/o Col.
14	Mapping Med.-Res. Large Area	2x2	4x4	8x8	4x4	62	possible	possible
15	Mapping Low-Res.	4x4	4x4	8x8	4x4	41	possible	possible
16	Limb sounding	1x1	-	-	-	109	possible	possible

School of Earth & Space Exploration
Arizona State University

HRSC Coverage through April 2008



HRSC Coverage of Mars
(by orbit)

The purpose of this document is to briefly describe (by orbit number) the surficial coverage of Mars by the High Resolution Stereo Camera (HRSC) on the ESA *Mars Express* orbiter. This document is a compliation of emails sent by David A. Williams to the members of the Planetary Geology Group at ASU during the *Mars Express* mission (January 2004-Present). Data releases are done periodically throughout the year (since 2006, daily) by the PI Gerhard Neukum of the Free University (Berlin, Germany), after which HRSC Level 2 and Level 3 data are downloaded from JPL and the Vienna database, respectively.

The format of the coverage summaries is to give a sample image file name for each orbit (initially I used a lower-resolution color image, but switched to the full-resolution nadir image by orbit 68), followed by image size (line x sample), range of coverage (latitude range and longitude range), center coordinates of image (lat, long), resolution of image (m/px), names of primary surface features that are covered, and the number and quality of any Super Resolution Channel (SRC) frames obtained. After the June 2004 HRSC Team Meeting (after orbit 600), David Williams of ASU was directed to produce simple SRC mosaics of images from each orbit where obtained, and provide VICAR and TIFF versions to the Team Website at FU-Berlin. Early orbit summaries are less detailed, but become more formalized as the mission progressed.

Location of all HRSC images at ASU: /export/Projects/hrsc/

Orbit 0008
Sample Image: h0008_0000.bl2.01, 4280 lines x 640 samples (**POOR QUALITY**)
Center Coordinates (CC): -31, 90 E
Range (R): -22 to -39, 89-92 E
SRC: 189 images, generally of low quality

Orbit 0010
h0010_0009.gr2.10, 6832 lines x 640 samples
CC: -1, 90 E
R: -8 to +1, 89-92 E
Contents: Old cratered terrain south of Isidis Basin
SRC: 189 images, variable quality

Orbit 0016
h0016_0008.gr2.04, 15,136 lines x 640 samples
CC: 6, 256 E
R: -5 to +10, 255-257 E
Contents: N. Noctis Labyrinthis to Ascraeus Mons, good canyons & pit chains
SRC: 15 images, good quality

Orbit 0018 (First Press Release came from these data)
h0018_0000.gr2.08, 19,440 lines x 640 samples
CC: -1, 323 E

Orbit 5549
FRI: h5549_0000.nd3.01 48,630 l x 17,539 s
R: 72 to 83˚, 215-236˚E Res: 12.5 m/px
CC: 78˚, 230˚E
Cov: Vastitas Borealis

Orbit 5551
FRI: h5551_0000.nd3.01 48,465 l x 22,400 s
R: 75 to 86˚, 358-34˚E Res: 12.5 m/px
CC: 80˚, 25˚E
Cov: Vastitas Borealis to Planum Boreum

Orbit 5554
FRI: h5554_0000.nd3.01 45,722 l x 20,823 s
R: 74 to 84˚, 64-94˚E Res: 12.5 m/px
CC: 80˚, 85˚E
Cov: Vastitas Borealis to Planum Boreum

Orbit 5555
FRI: h5555_0000.nd3.01 40,199 l x 12,262 s
R: 68 to 77˚, 348-358˚E Res: 12.5 m/px
CC: 73˚, 354˚E
Cov: Vastitas Borealis

Orbit 5557
FRI: h5557_0000.nd3.00 53,296 l x 27,522 s
R: 75 to 86˚, 105-153˚E Res: 12.5 m/px
CC: 81˚, 142˚E
Cov: Vastitas Borealis to Planum Boreum

Orbit 5560
FRI: h5560_0000.nd3.01 46,241 l x 17,270 s
R: 70 to 80˚, 198-214˚E Res: 12.5 m/px
CC: 77˚, 209˚E
Cov: Vastitas Borealis

Orbit 5562
FRI: h5562_0000.nd3.01 47,321 l x 2,721 s
R: 76 to 87˚, 318-12˚E Res: 12.5 m/px
CC: 82˚, 360˚E
Cov: Vastitas Borealis to Planum Boreum

HRSC Data in PDS

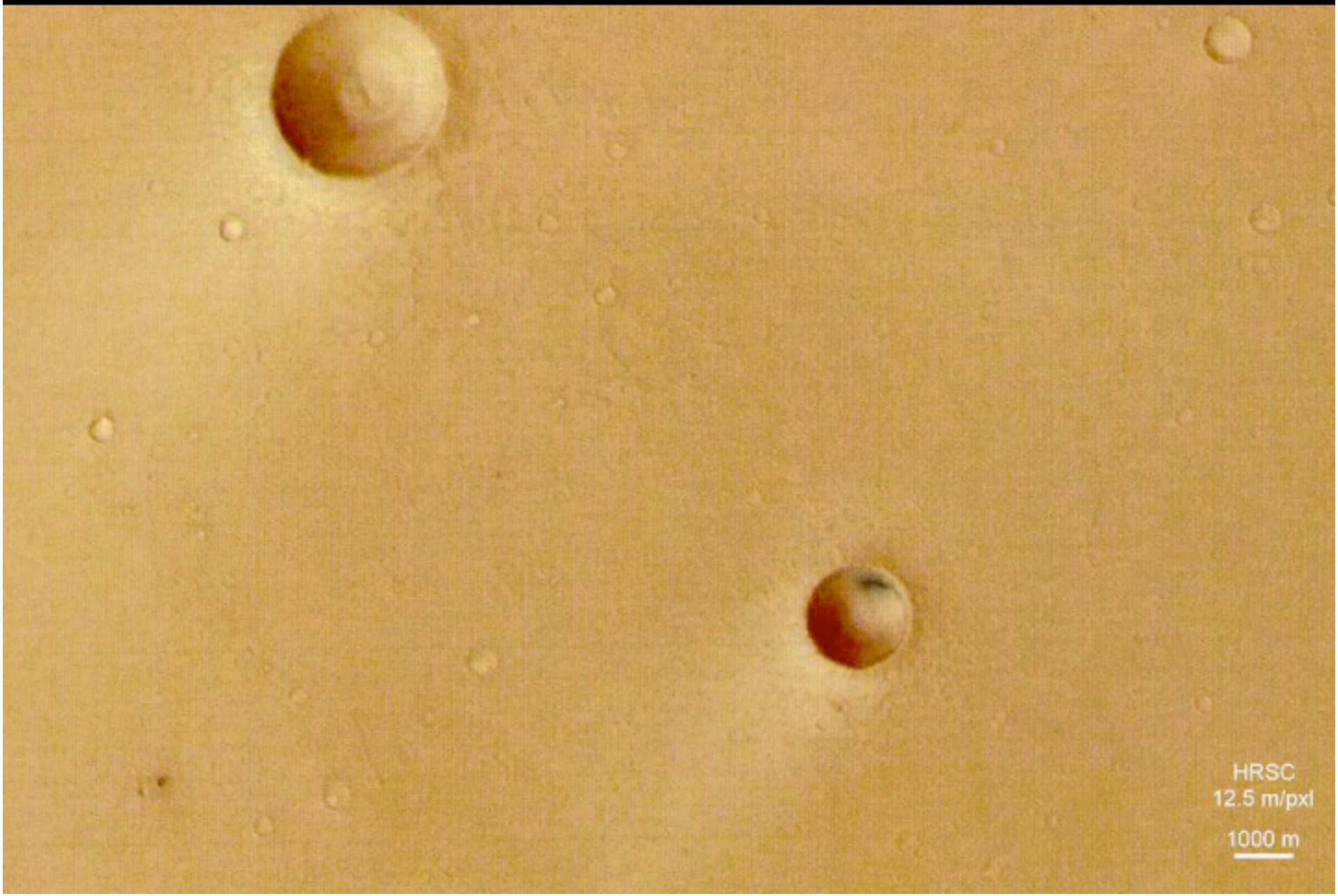
Level-2: Orbits 0010-4479 (In PDS as of March 18, 2008)
Radiometrically-corrected, NOT map-projected

Level-3: Orbits 0010-4479 (In PDS as of March 28, 2008)
Radiometrically-corrected and map-projected
(Sinusoidal, lat < ±80°; Polar Stereographic, lat ≥ ±80°)

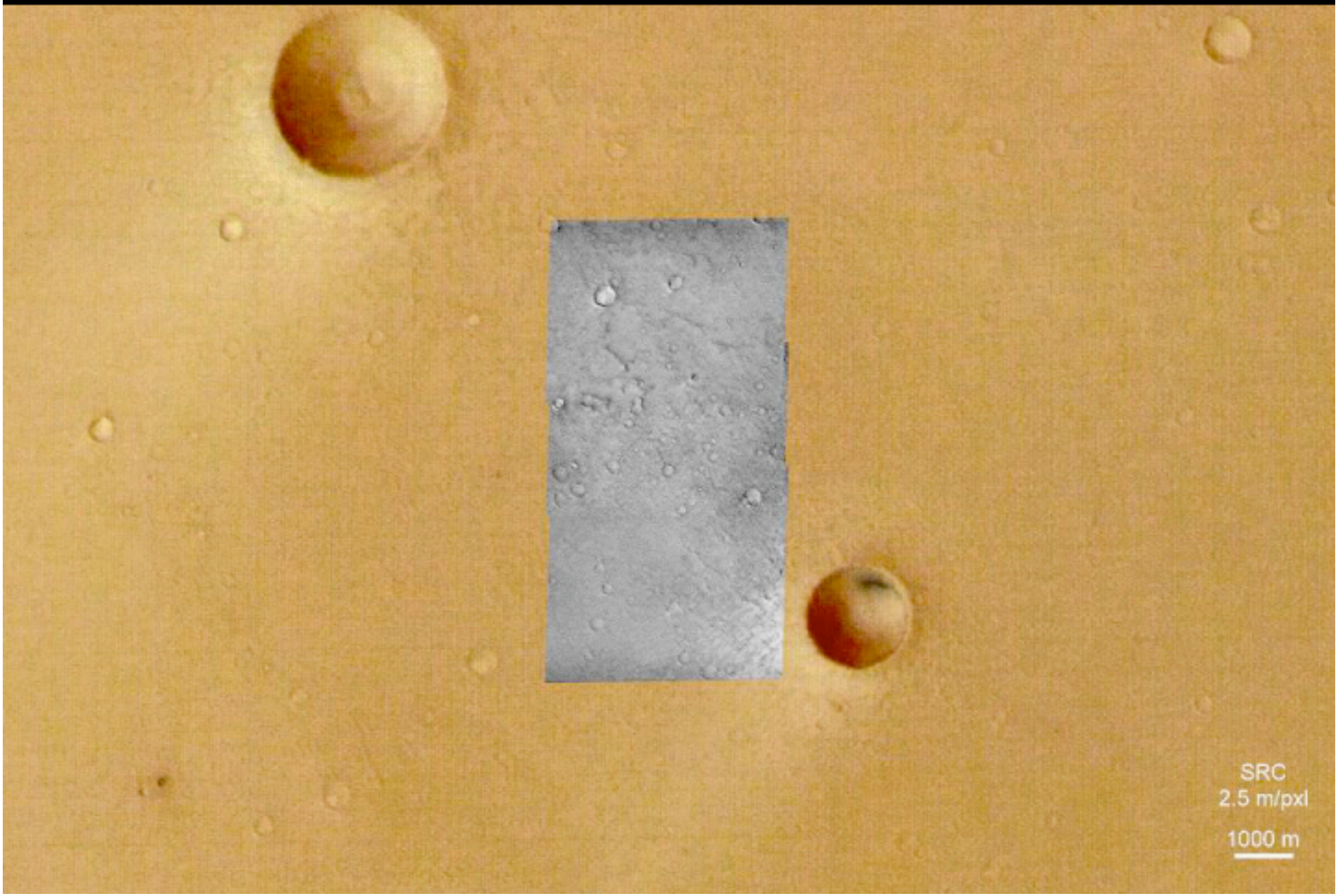
Level-4: Orbits 0010-1961 (In PDS as of ~May 21, 2008)
Orthorectified nadir, stereo, & color images with
'archival' HRSC DTM

New data added every six months

Comparison HRSC / SRC

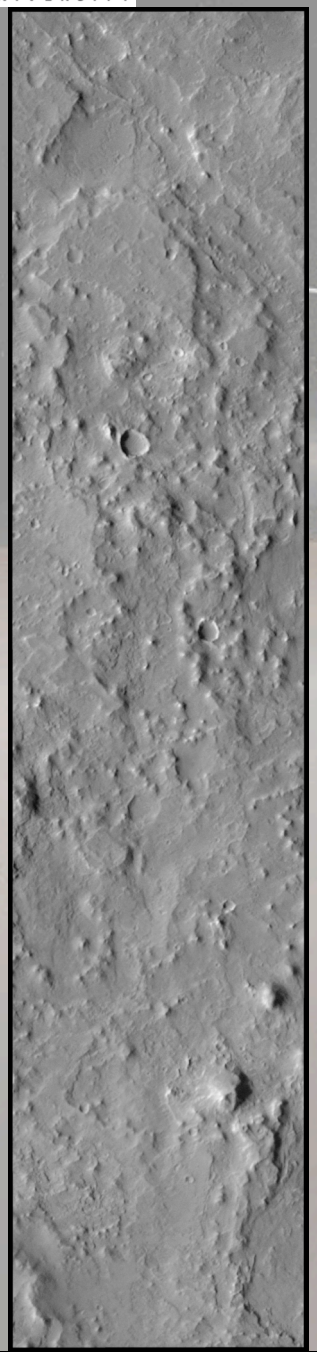


Comparison HRSC / SRC

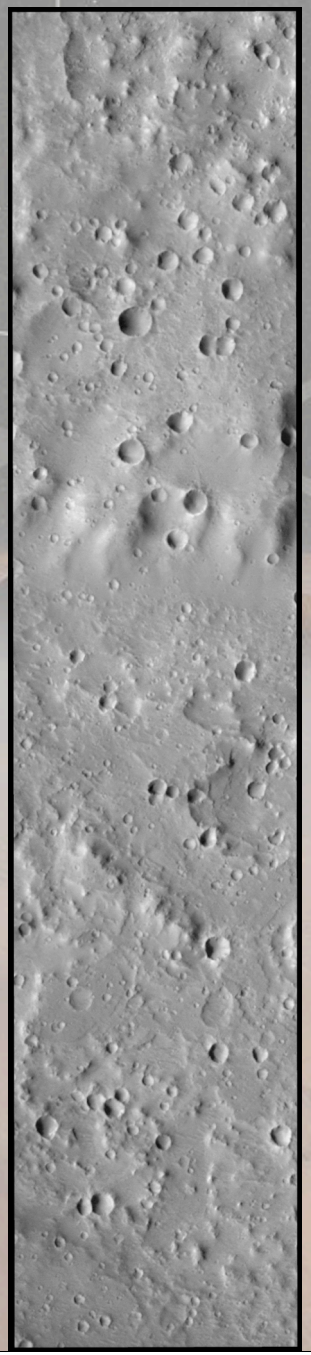


Recent SRC Mosaics

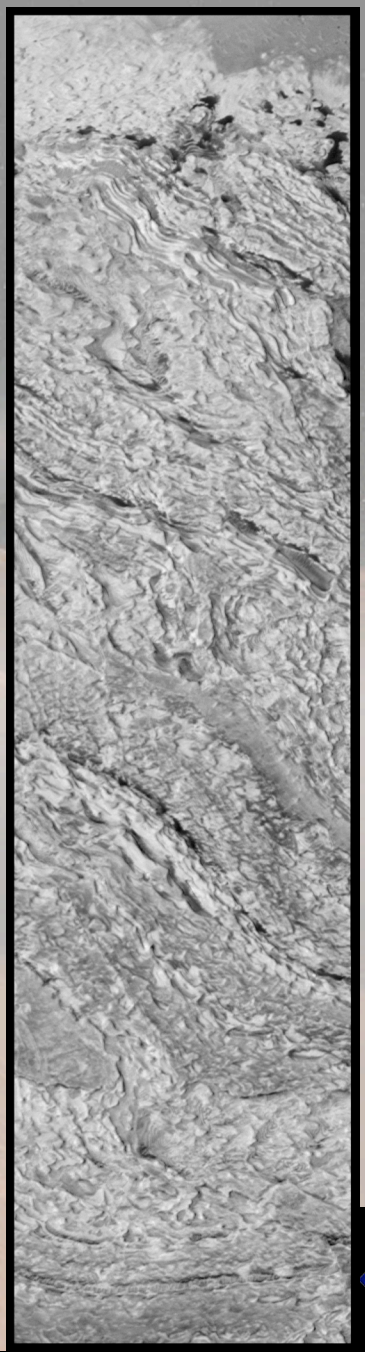
h5145
Arabia
Terra



h5163
Arabia
Terra

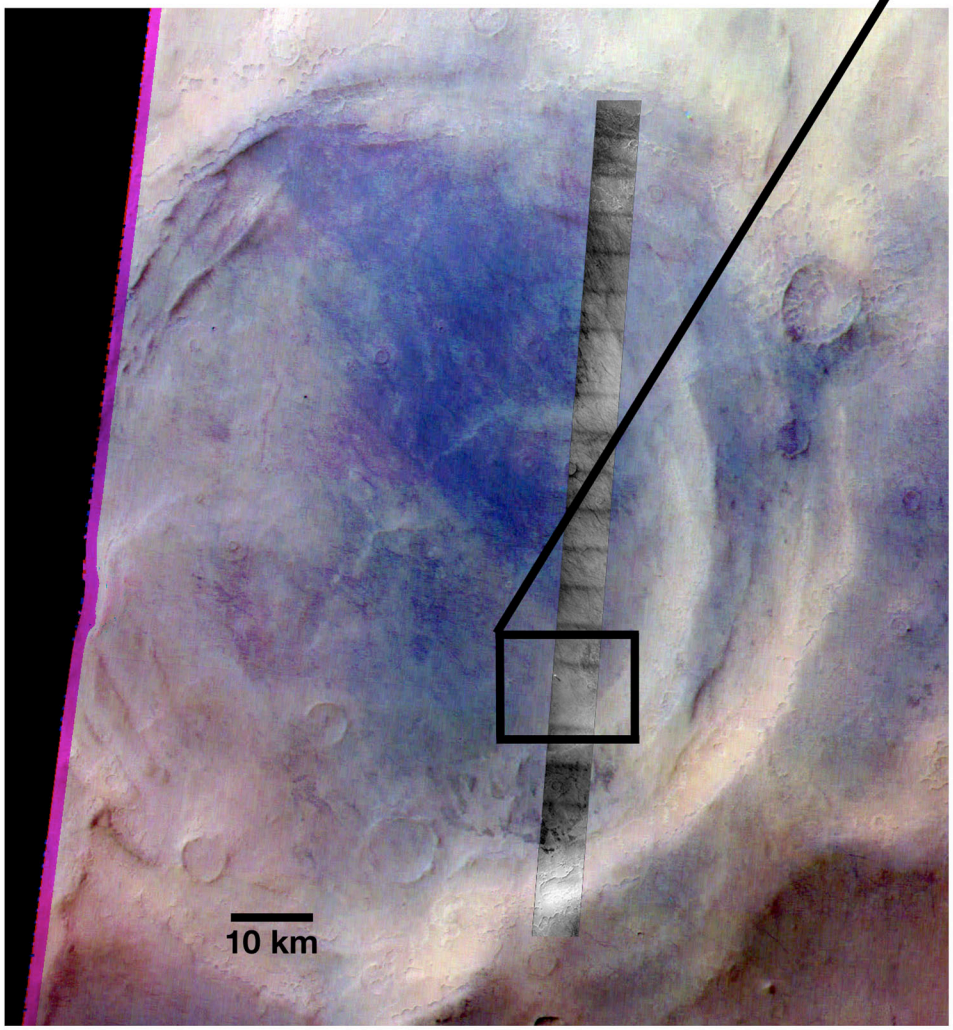


h5350
Arabia
Terra

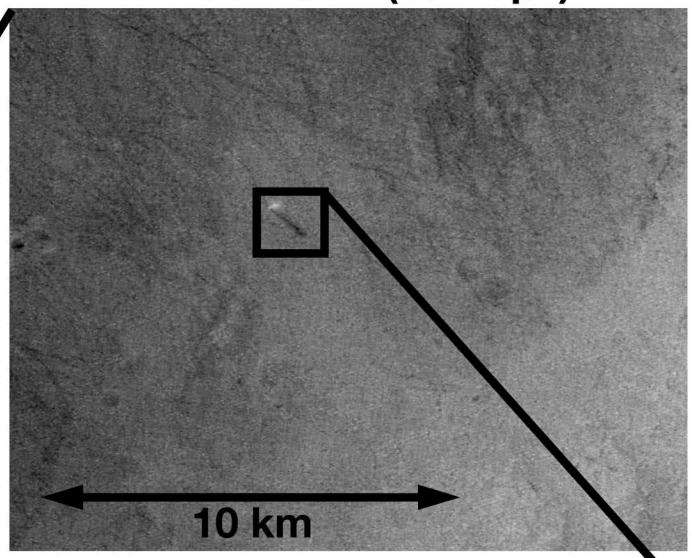


Active Dust Devil detected in Peneus Patera Caldera
Orbit 2133, 11 September 2005

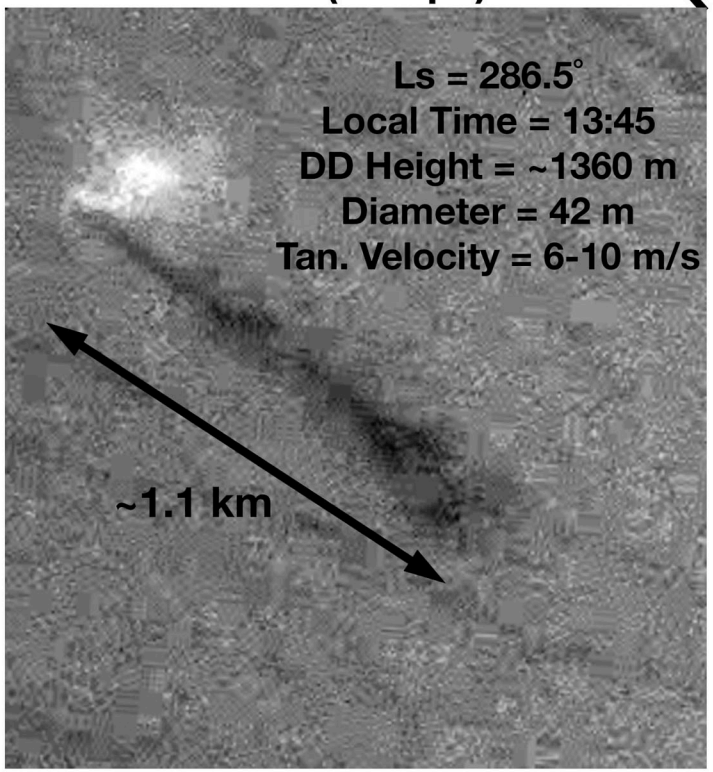
HRSC RGB Color, stretched (100 m/px) w/SRC



HRSC Nadir (25 m/px)



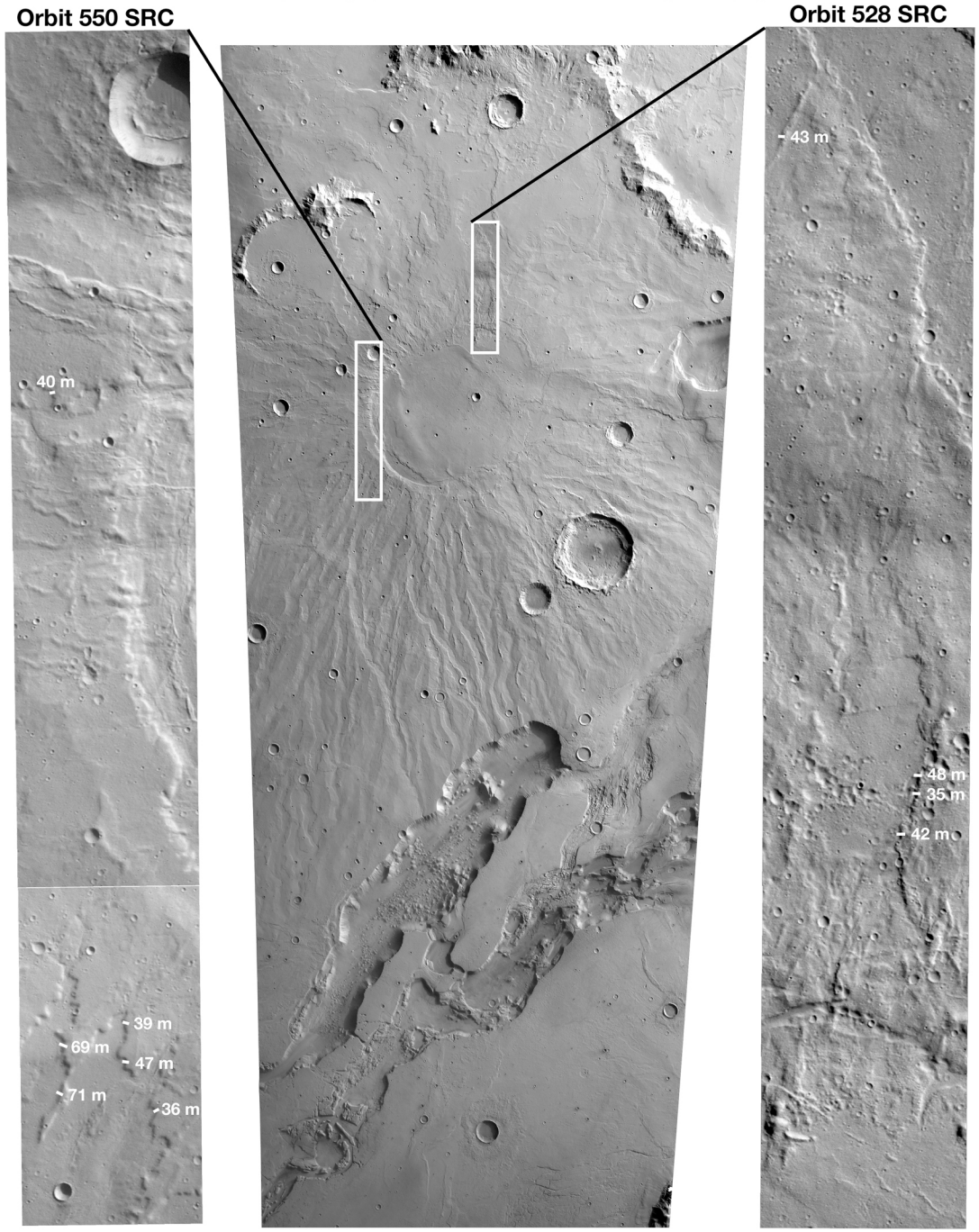
SRC (5 m/px)



Credit: Arizona State University/University of Cologne

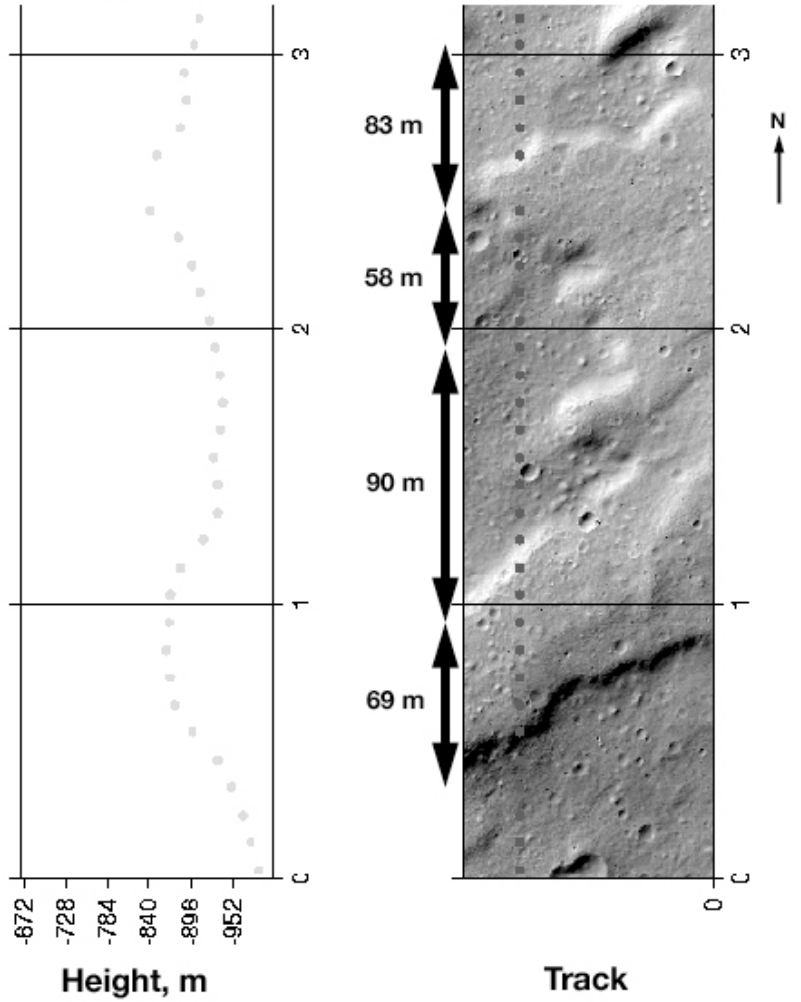
Hadriaca Patera

SRC Mosaics (10 m/px) in Orbit 550 HRSC Nadir (50 m/px) Context



MOC-NA E03-00036 w/MOLA Track

Upper West Flank of Hadriaca Patera, W of Caldera Rim



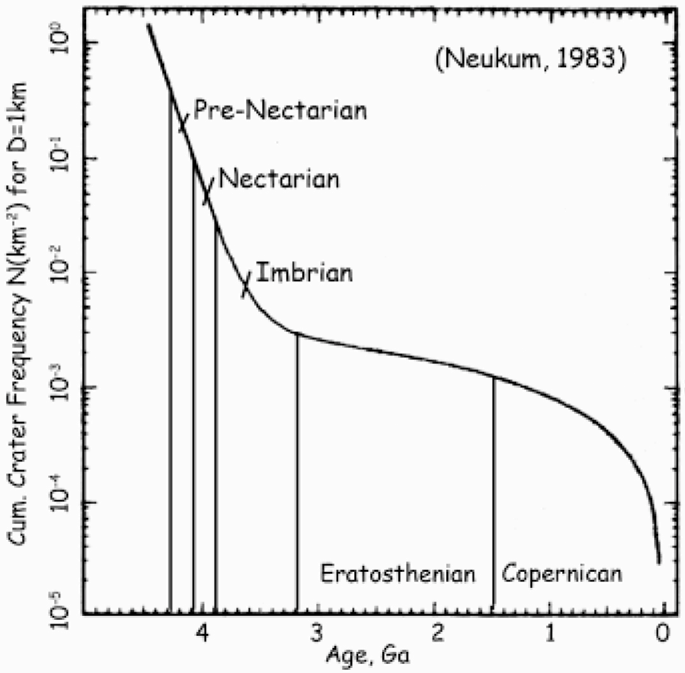
The Martian Cratering Record

Transfer of the Lunar Cratering Chronology to Mars

Martian basins and correlation of volcanic ages with meteorite ages support this approach

Werner & Neukum (2004) LPSC; Nyquist et al. (2001) SSR; Hartmann et al. (1998) Nature

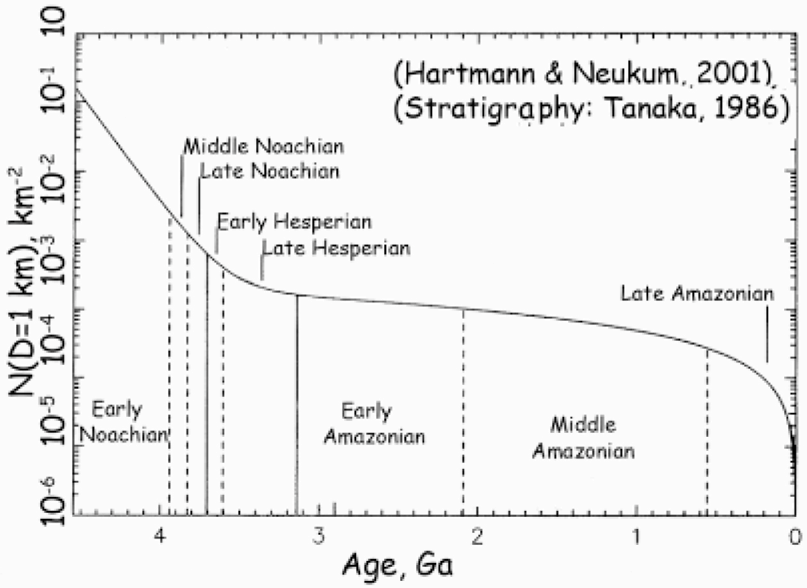
Lunar Cratering Chronology



Model

(Adjustment of the relative cratering rates Moon/Mars, impact mechanics; assumption of the same time dependence)

Martian Cratering Chronology



$N\ (1km) = 5.44\ 10^{-14}\ (\exp(6.93t_A)-1) + 8.38\ 10^{-4}t_A$

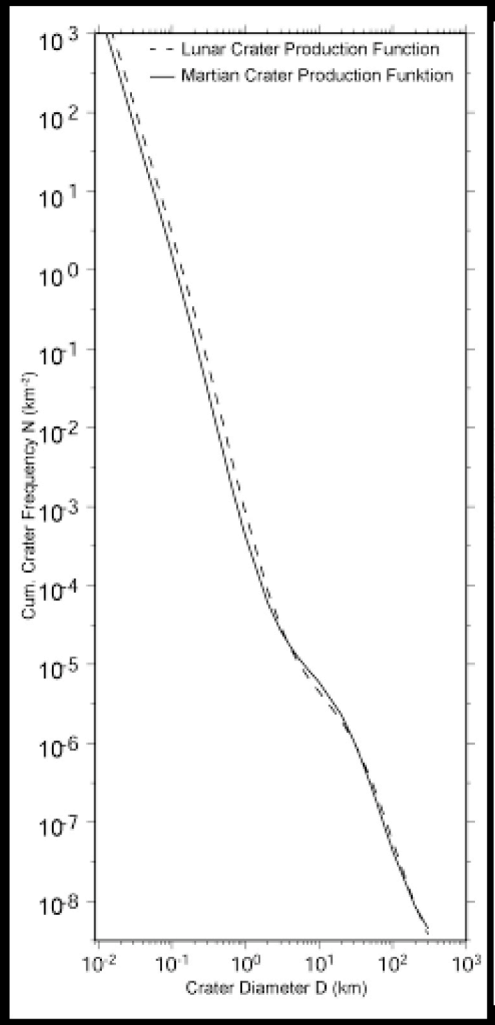
$N\ (1km) = 2.68\ 10^{-14}\ (\exp(6.93t_A)-1) + 4.1310^{-4}t_A$

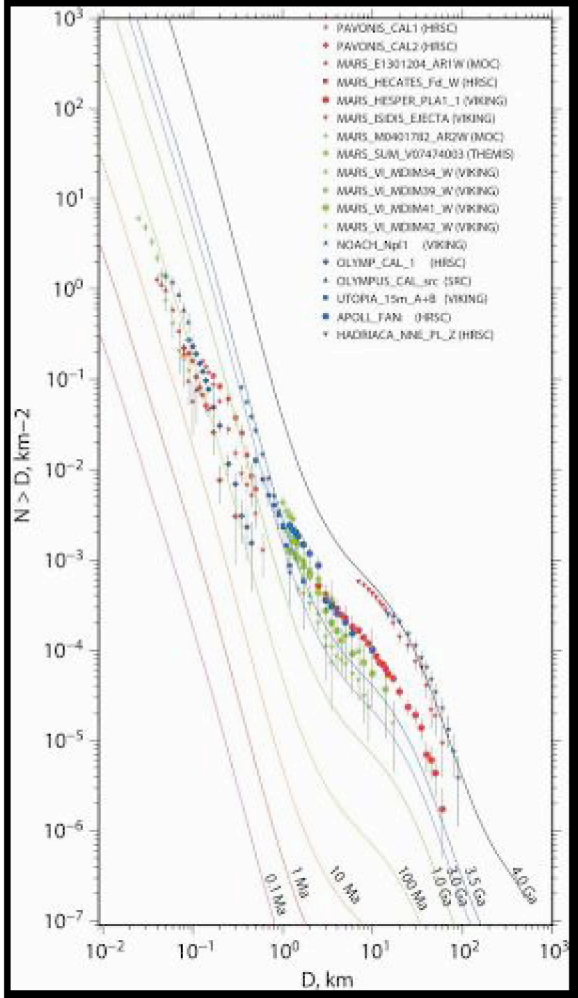
N (1km): cumulative crater frequency for craters of diameter equal to and larger than 1km

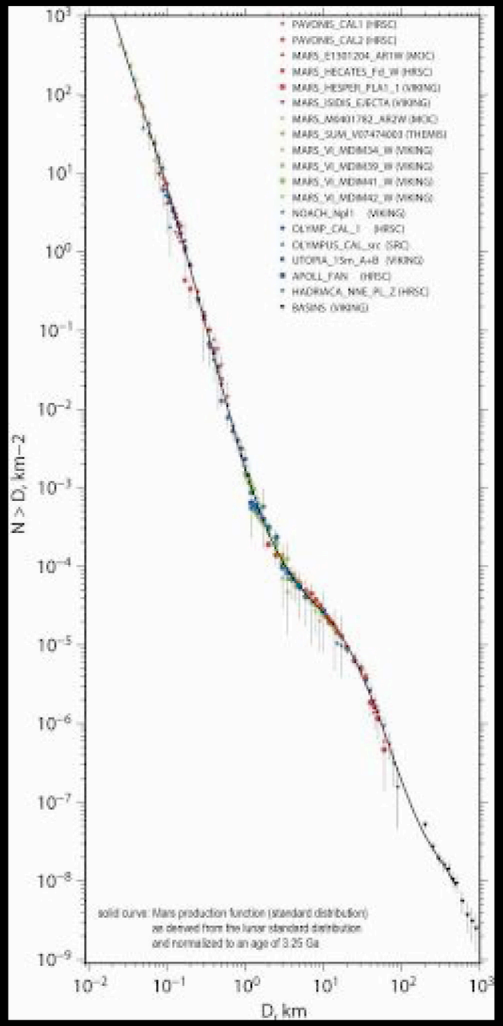
t_A : age of the measured surface in billion years (Ga)

The Martian Production Size-Frequency Distribution

Werner (2005) Dissertation





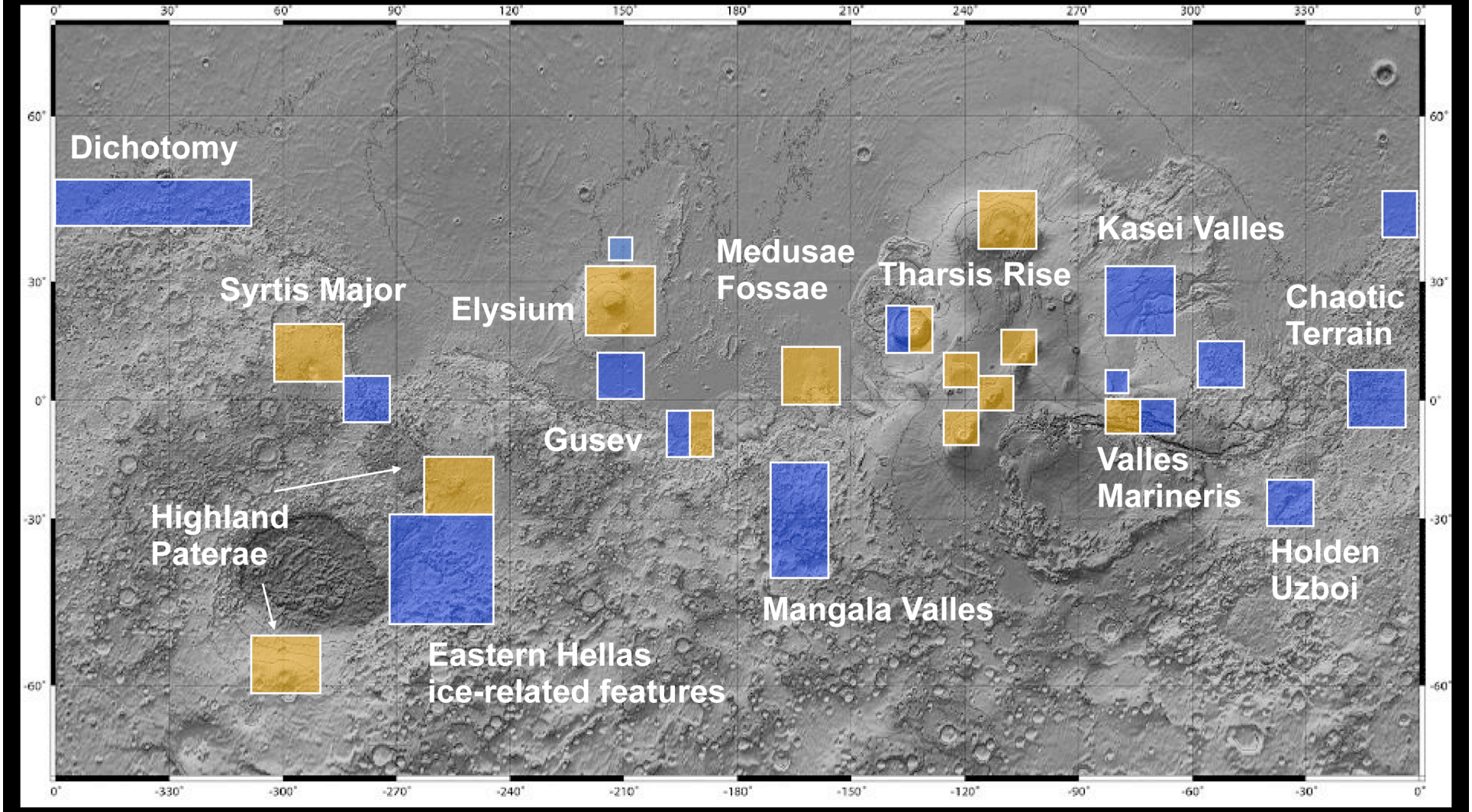


Lunar and Martian SFD
Transfer via crater scaling laws

Measurements on
Various-aged surface units
at different image resolutions

3.25 Ga Isochron

Current Working Fields on Fluvial/Glacial and Volcanic Processes



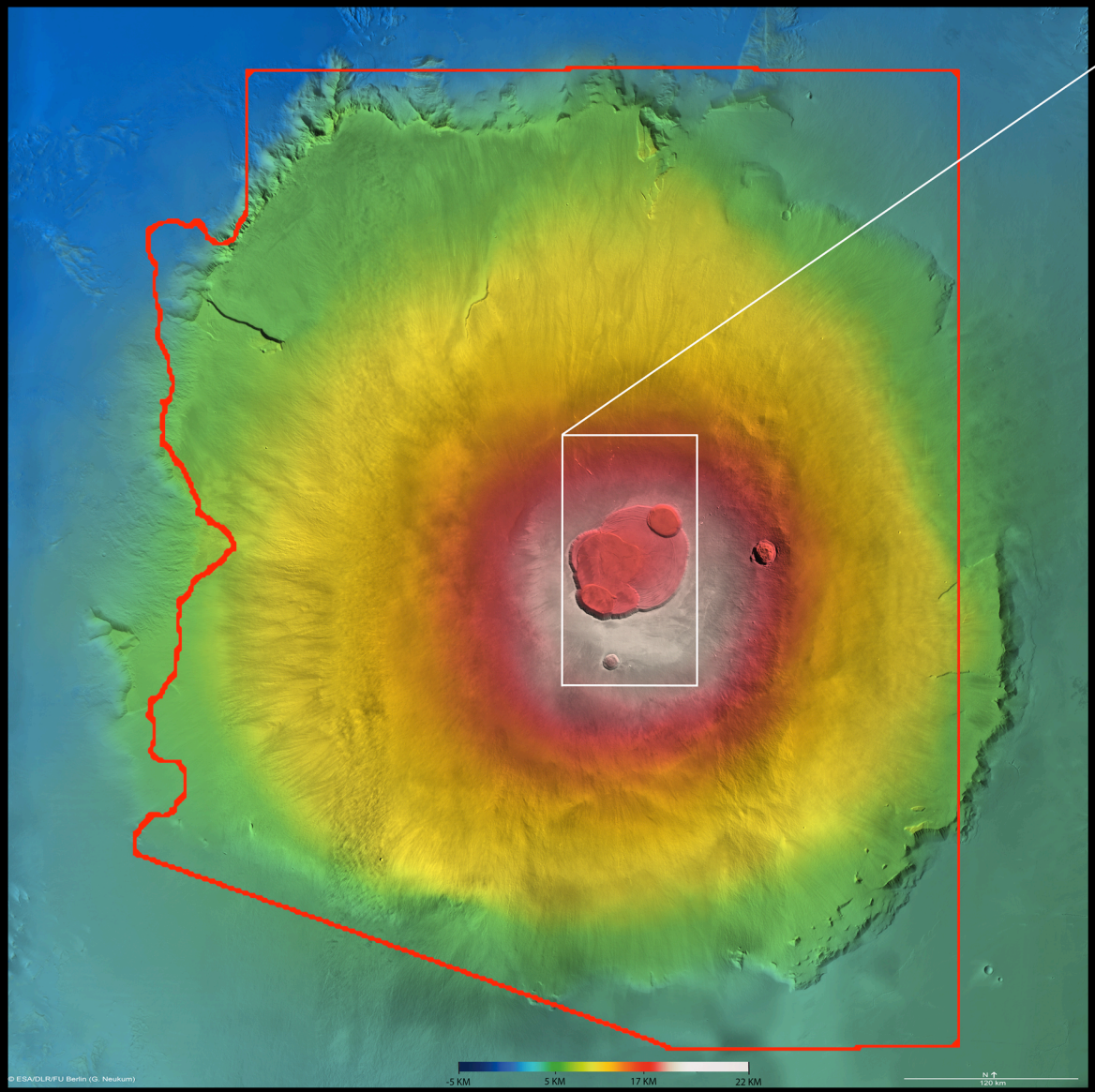
- fluvial/glacial processes
- volcanic processes

Olympus Mons Shield Volcano, Mars

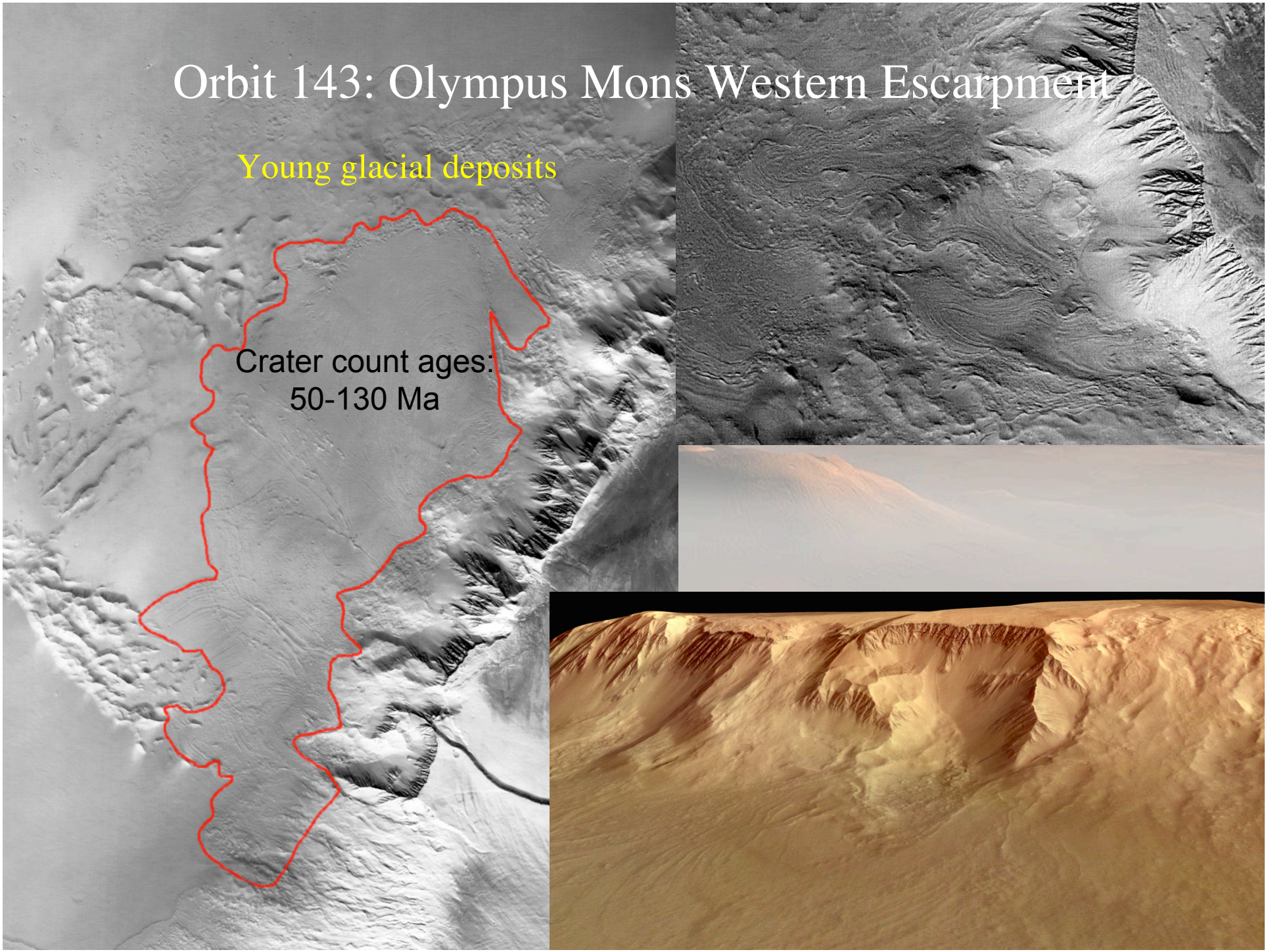
ESA *Mars Express* HRSC Mosaic and False Color Digital Terrain Model with Arizona Border

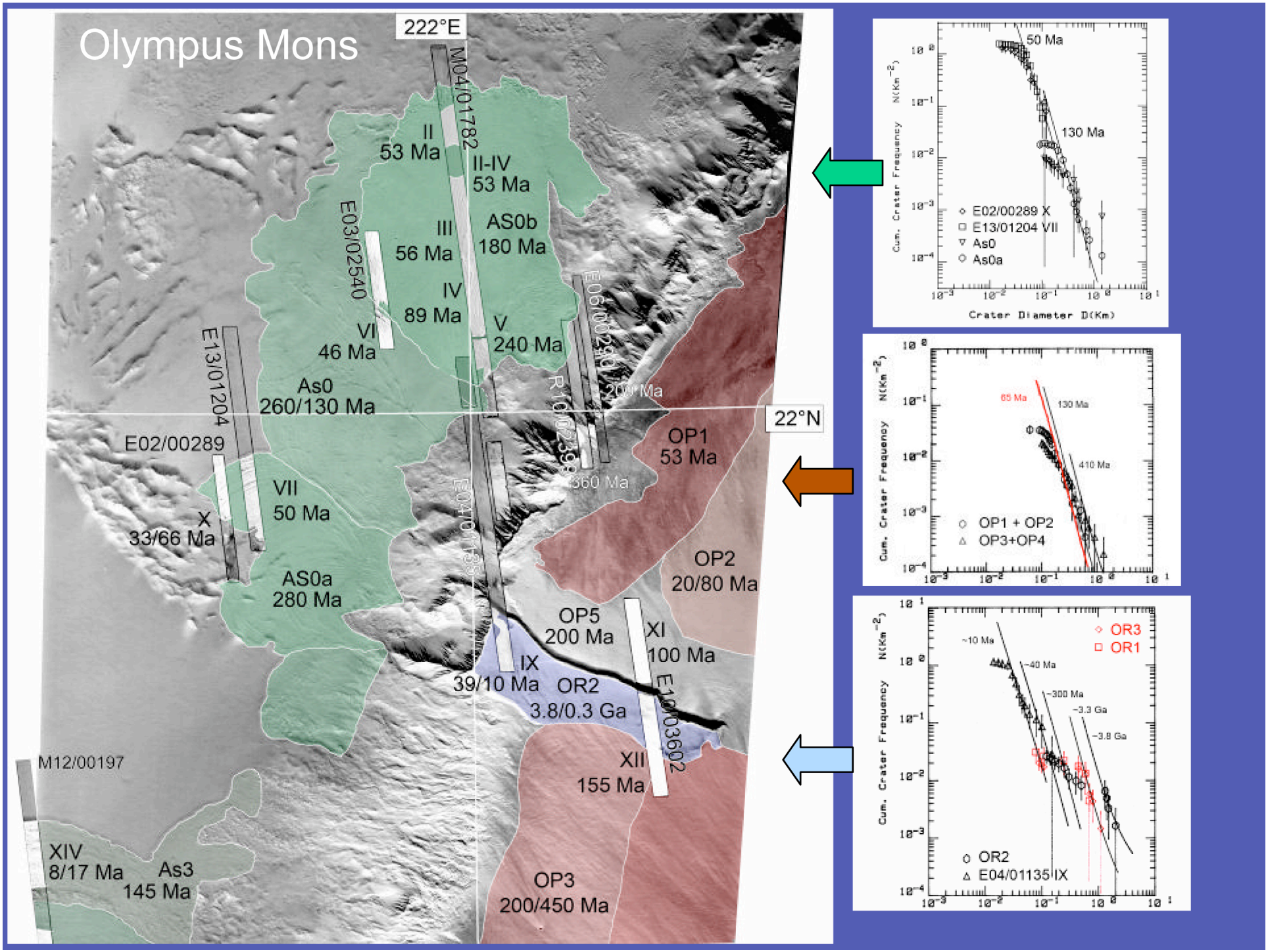
Inset: HRSC True Color Image of Caldera with Phoenix Metropolitan Area to Scale

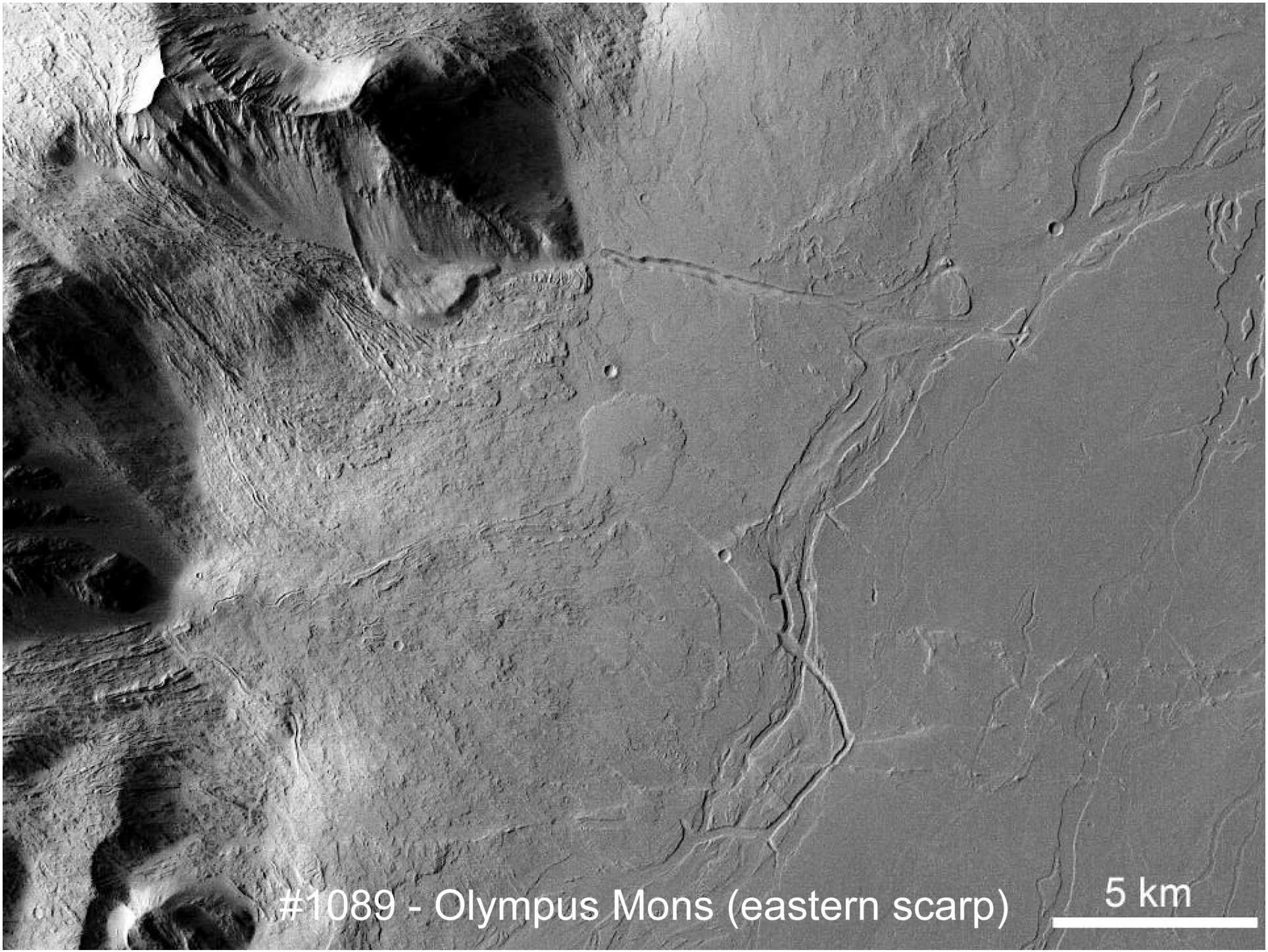
DTM Spatial Resolution: 50 m/pixel, Height Accuracy: 10 m

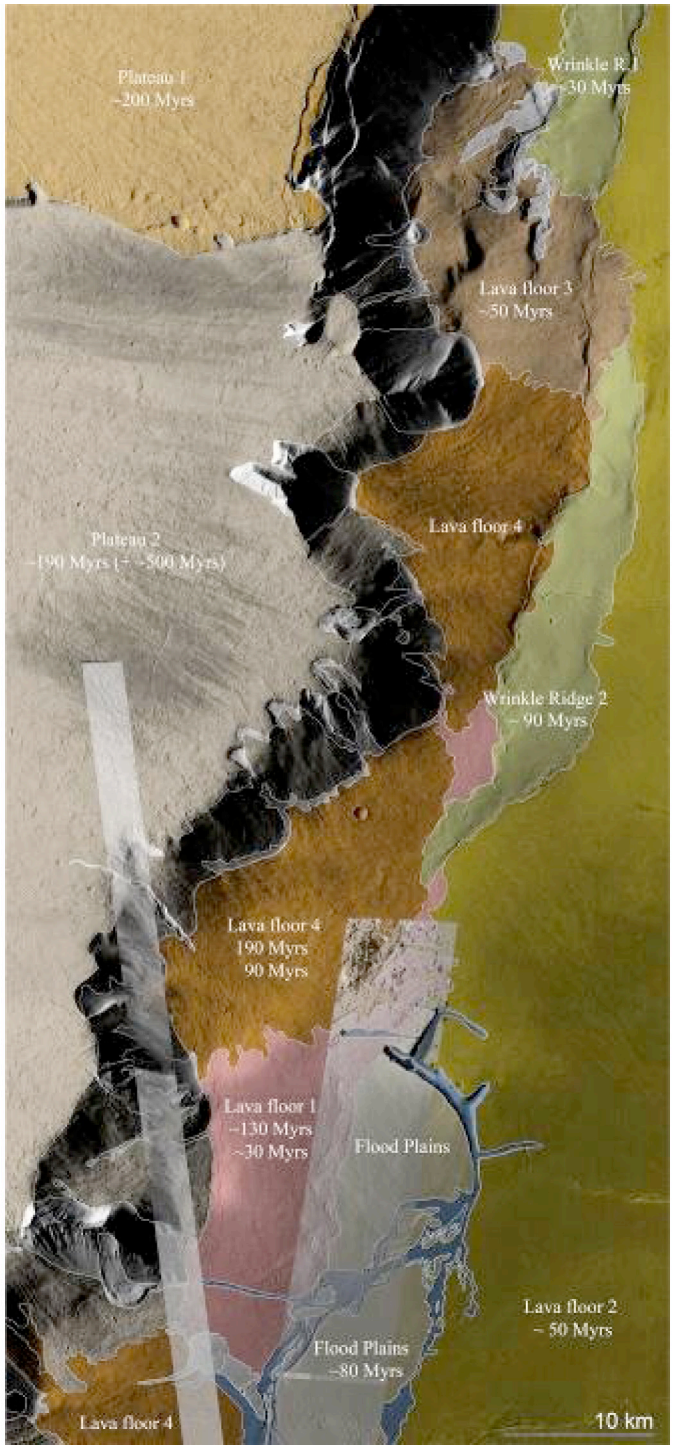


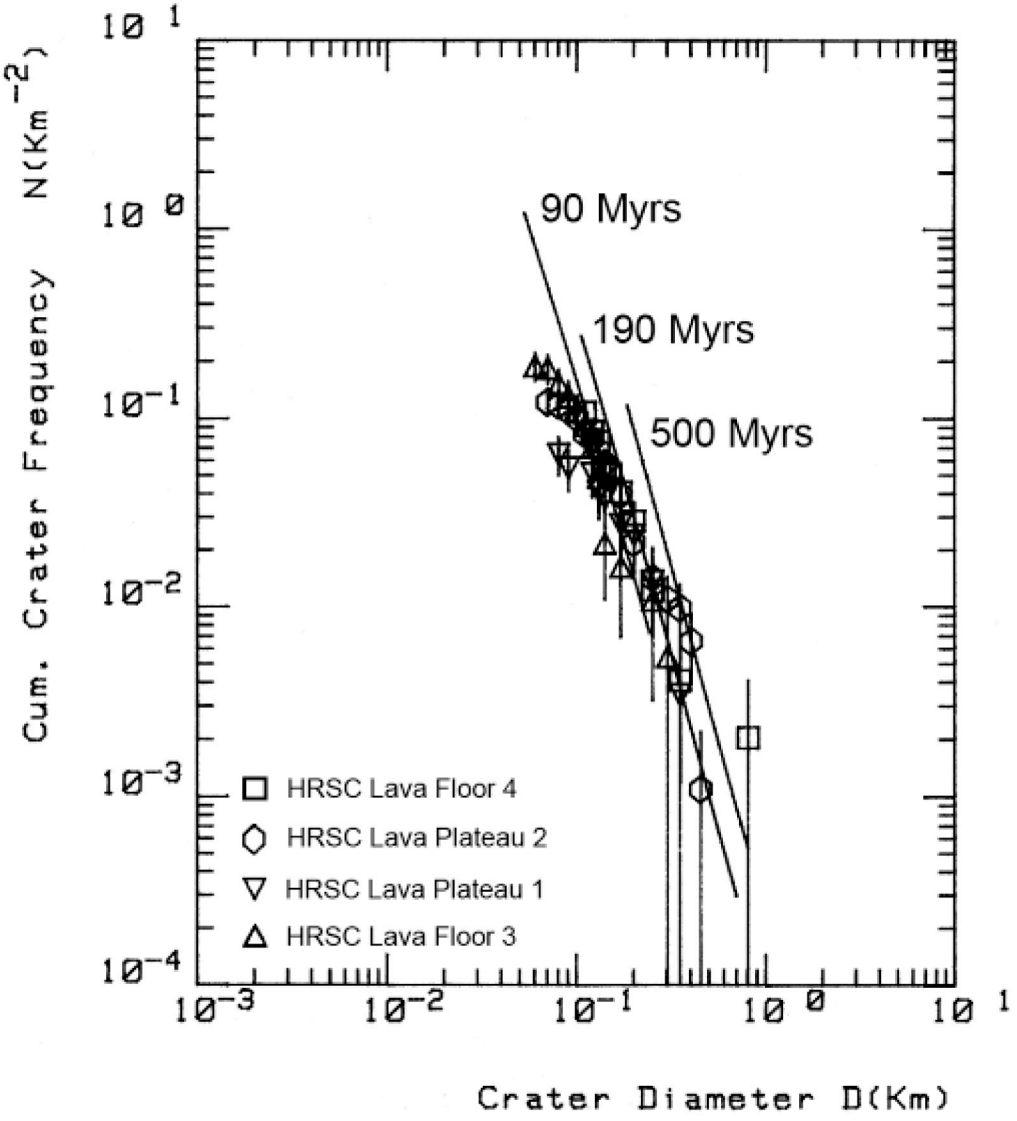
Orbit 143: Olympus Mons Western Escarpment



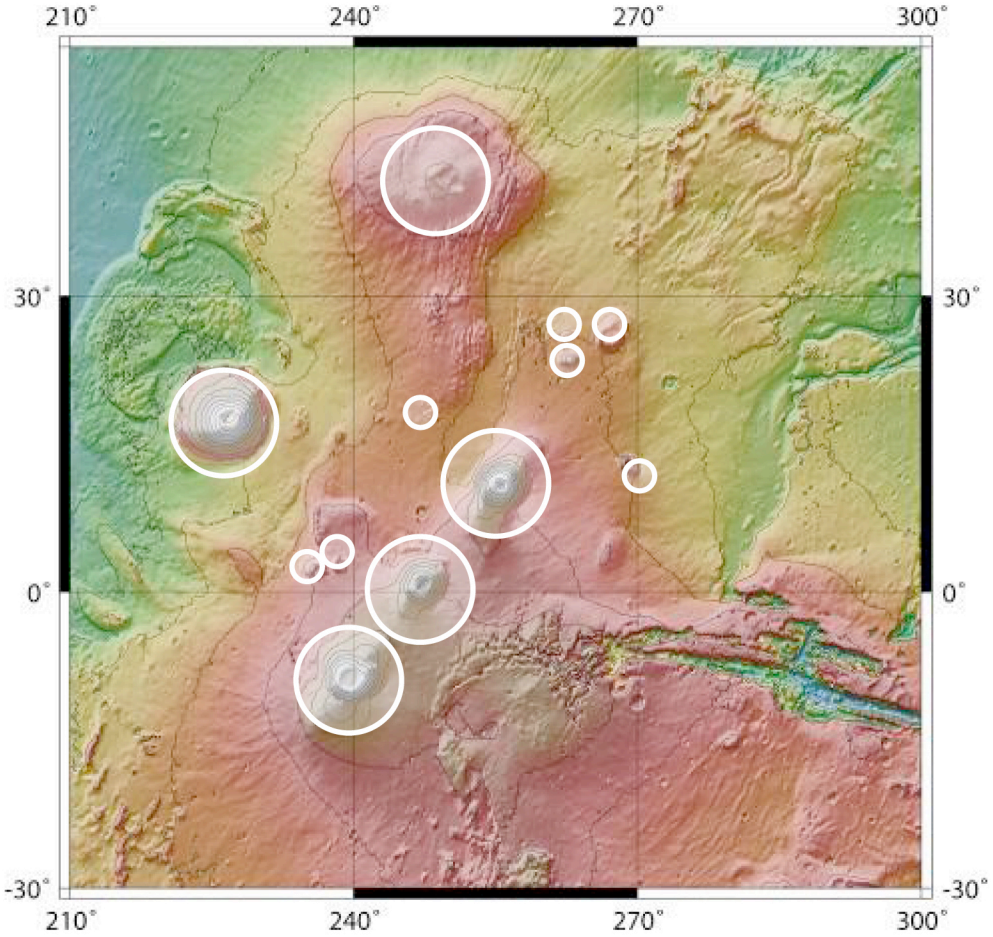

Olympus Mons
222°E
22°N
M04/01782
E03/02540
E13/01204
E02/00289
E06/02360
E04/01135
E19/03602
M12/00197
II
53 Ma
II-IV
53 Ma
III
56 Ma
AS0b
180 Ma
IV
89 Ma
V
240 Ma
VI
46 Ma
As0
260/130 Ma
VII
50 Ma
X
33/66 Ma
AS0a
280 Ma
OP1
53 Ma
OP2
20/80 Ma
OP5
200 Ma
XI
100 Ma
IX
39/10 Ma
OR2
3.8/0.3 Ga
XII
155 Ma
XIV
8/17 Ma
As3
145 Ma
OP3
200/450 Ma
50 Ma
130 Ma
E02/00289 X
E13/01204 VII
As0
As0a
Cum. Crater Frequency N(Km⁻²)
Crater Diameter D(Km)
65 Ma
130 Ma
410 Ma
OP1 + OP2
OP3+OP4
~10 Ma
~40 Ma
~300 Ma
~3.3 Ga
~3.8 Ga
OR3
OR1
OR2
E04/01135 IX


#1089 - Olympus Mons (eastern scarp)
5 km


Plateau 1
~200 Myrs
Wrinkle R. 1
~30 Myrs
Lava floor 3
~50 Myrs
Lava floor 4
Plateau 2
~190 Myrs (+ ~500 Myrs)
Wrinkle Ridge 2
~ 90 Myrs
Lava floor 4
190 Myrs
90 Myrs
Lava floor 1
~130 Myrs
~30 Myrs
Flood Plains
Lava floor 2
~ 50 Myrs
Flood Plains
~80 Myrs
Lava floor 4
10 km


OLYMPUS MONS EAST *HRSC* VOLCANIC
Cum. Crater Frequency N(Km^{-2})
Crater Diameter D(Km)
90 Myrs
190 Myrs
500 Myrs
HRSC Lava Floor 4
HRSC Lava Plateau 2
HRSC Lava Plateau 1
HRSC Lava Floor 3

Tharsis Volcanoes



Olympus and Arsia Montes

episodic activity, most recent caldera activity as young as ~150 Myr

Ascraeus and Pavonis Montes

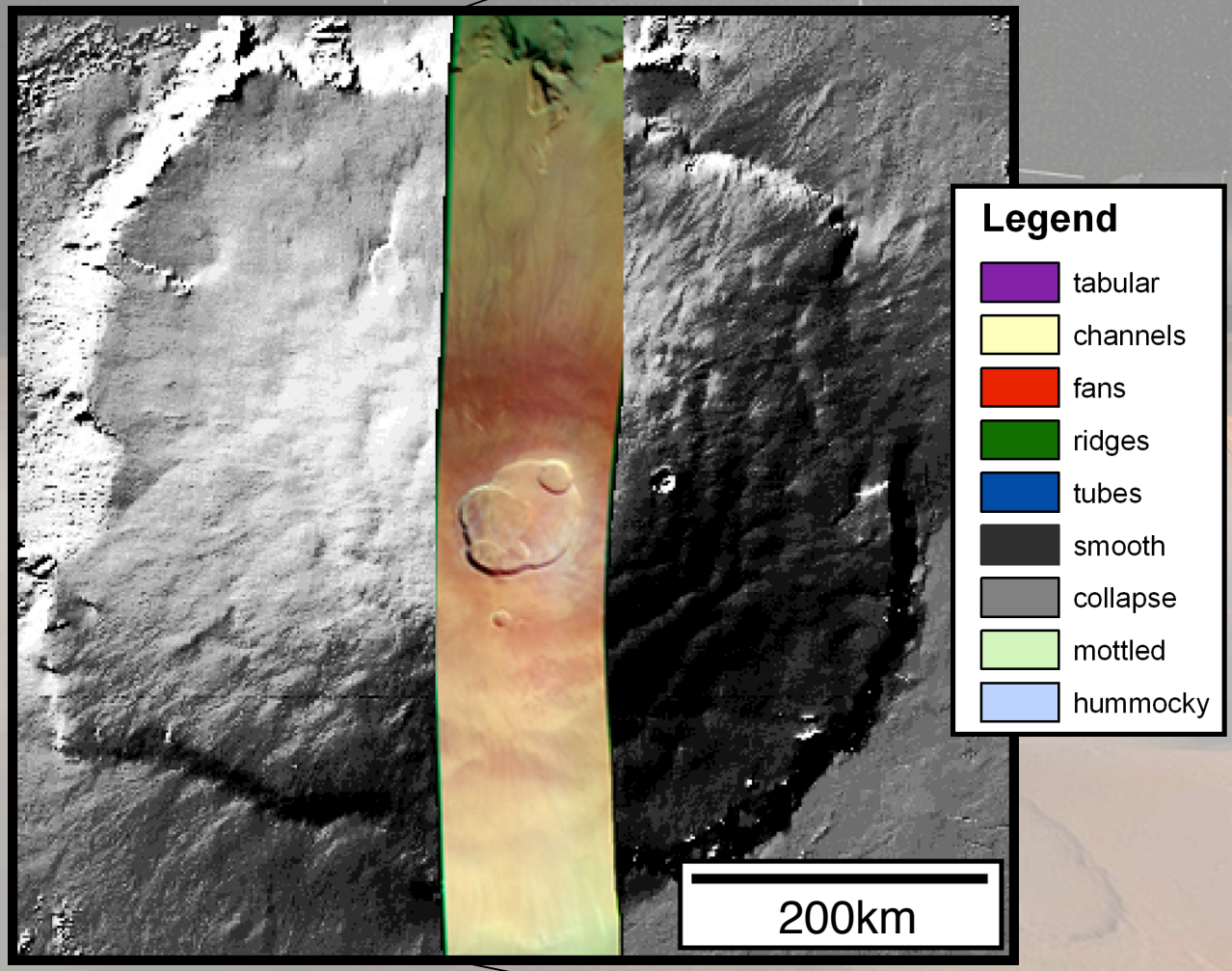
episodic activity in Martian history, latest caldera activity as young as ~150 Myr.

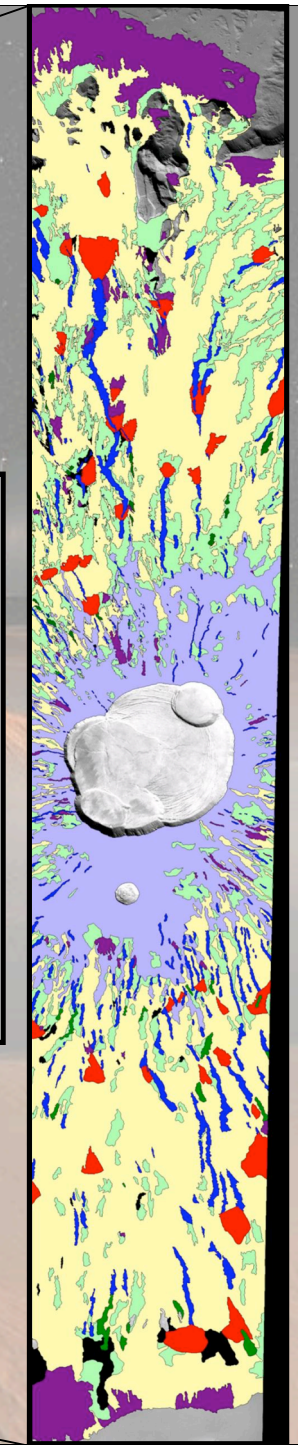
Paterae and Tholi

activity started ~4 Gyr ago
and ended at ~3.7 Gyr

ASU School of Earth & Space Exploration
ARIZONA STATE UNIVERSITY

Geologic Mapping of Volcanic Feature on the Tharsis Montes

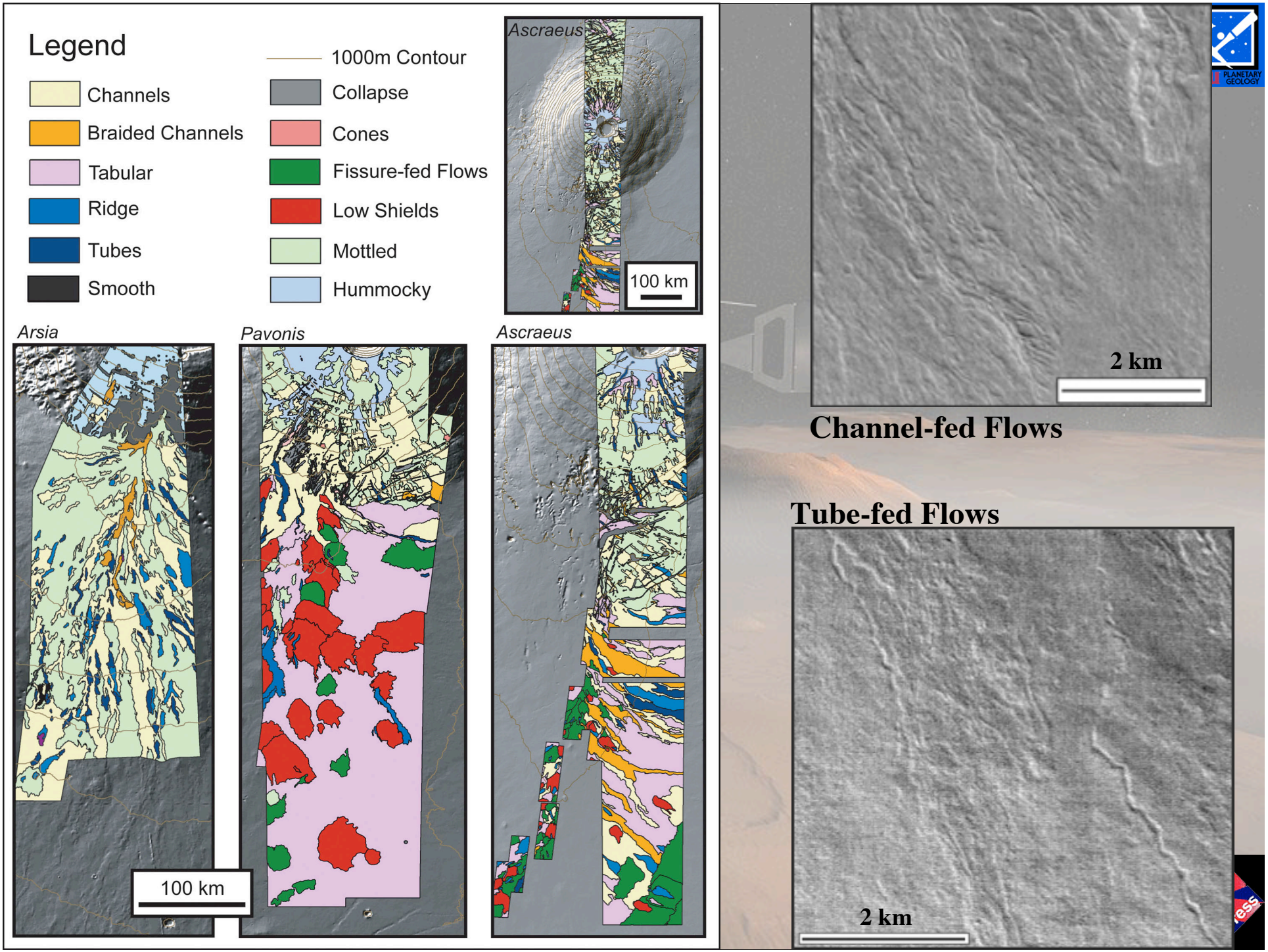




Legend

- tabular
- channels
- fans
- ridges
- tubes
- smooth
- collapse
- mottled
- hummocky

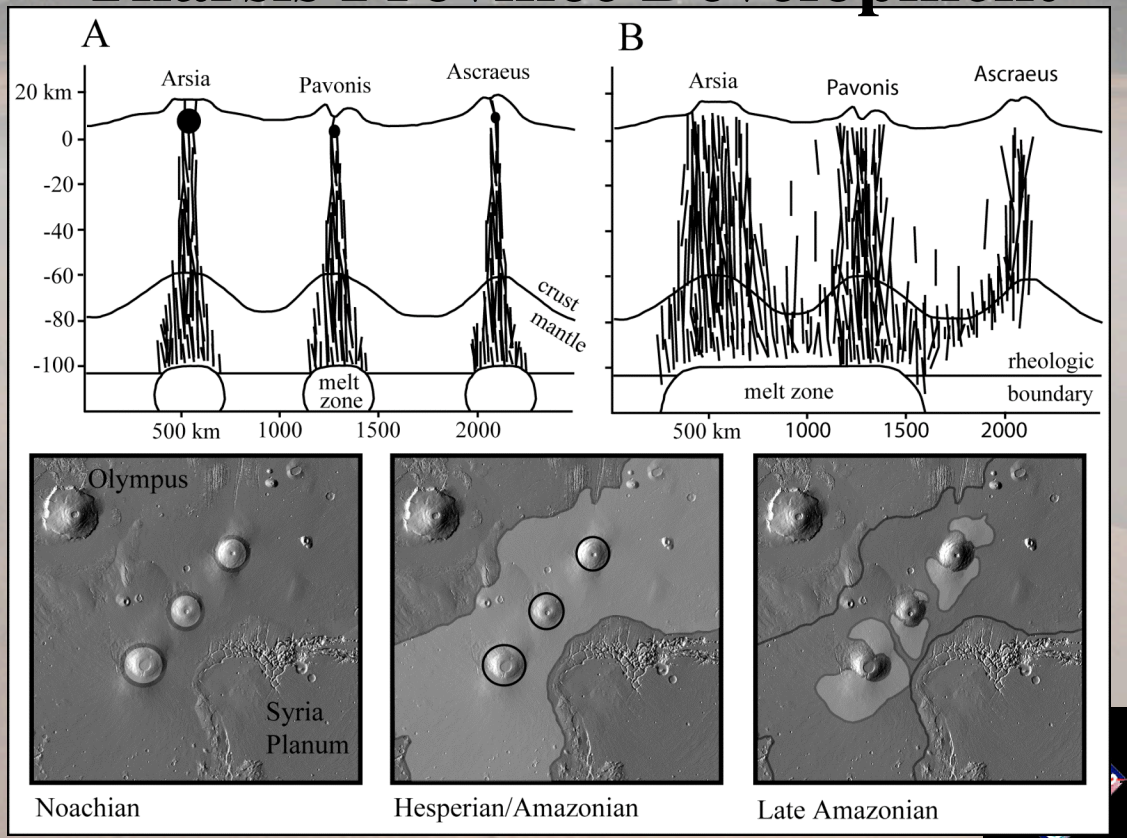
h0037


Legend
1000m Contour
Channels
Collapse
Braided Channels
Cones
Tabular
Fissure-fed Flows
Ridge
Low Shields
Tubes
Mottled
Smooth
Hummocky
Ascraeus
100 km
Arsia
Pavonis
Ascraeus
100 km
2 km
Channel-fed Flows
Tube-fed Flows
2 km

Results: Geologic Mapping of Tharsis Shields

- Olympus Mons: Older tube-fed flows embayed by younger channel-fed flows; Major rift zones did not develop
- OM experienced change in eruptive style in late Amazonian; Similar to evolution of Hawaiian shields
- Tharsis Montes: Similar transition observed on main flanks
- TM rift aprons: Tubes not consistently embayed by channels
- RA trends suggest most recent activity in TM from single, shared magma source
- Change in magma production from main flank phase

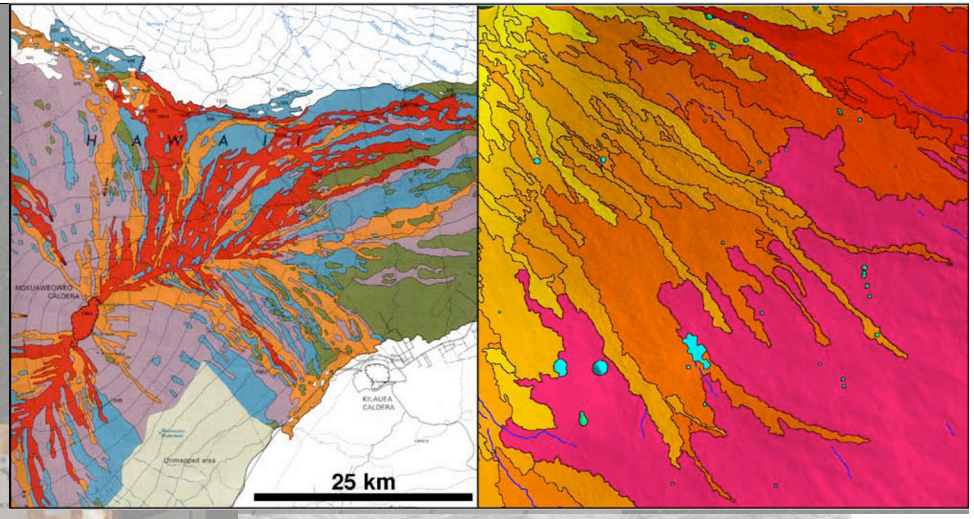
Tharsis Province Development

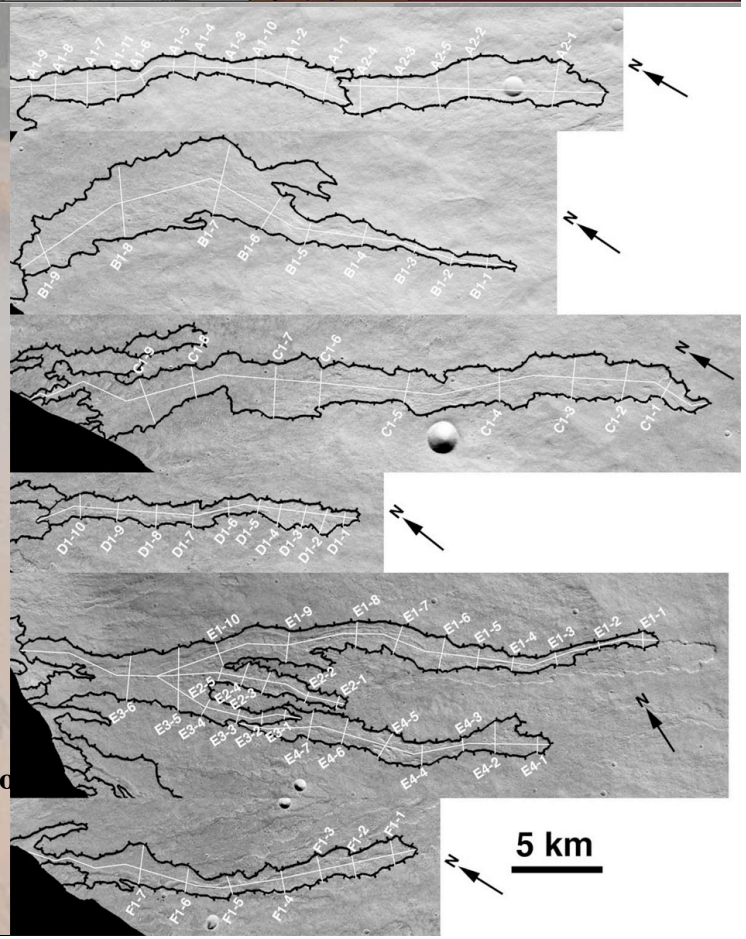


ASU School of Earth & Space Exploration
Arizona State University

Ascraeus Mons Flows

- Objective: Assess rheological properties of AM flows using models for viscosity, yield strength, effusion rate as function of flow dimensions
- Mapped 25 late-stage flows
- Lengths ~4-38 km, widths ~0.5-2 km, depths ~5-24 m, slopes ~1.5-6.7°
- Yield strengths ~2.1 x 10^4 Pa, similar to terrestrial basaltic flows
- Effusion rates 23-400 m^3/s, similar to those of Kilauea and Mauna Loa
- Average time to emplace flows ~26 days
- Viscosities ~1.8 x 10^4-4.2 x 10^7 Pa s, similar to terrestrial basaltic/andesitic flows

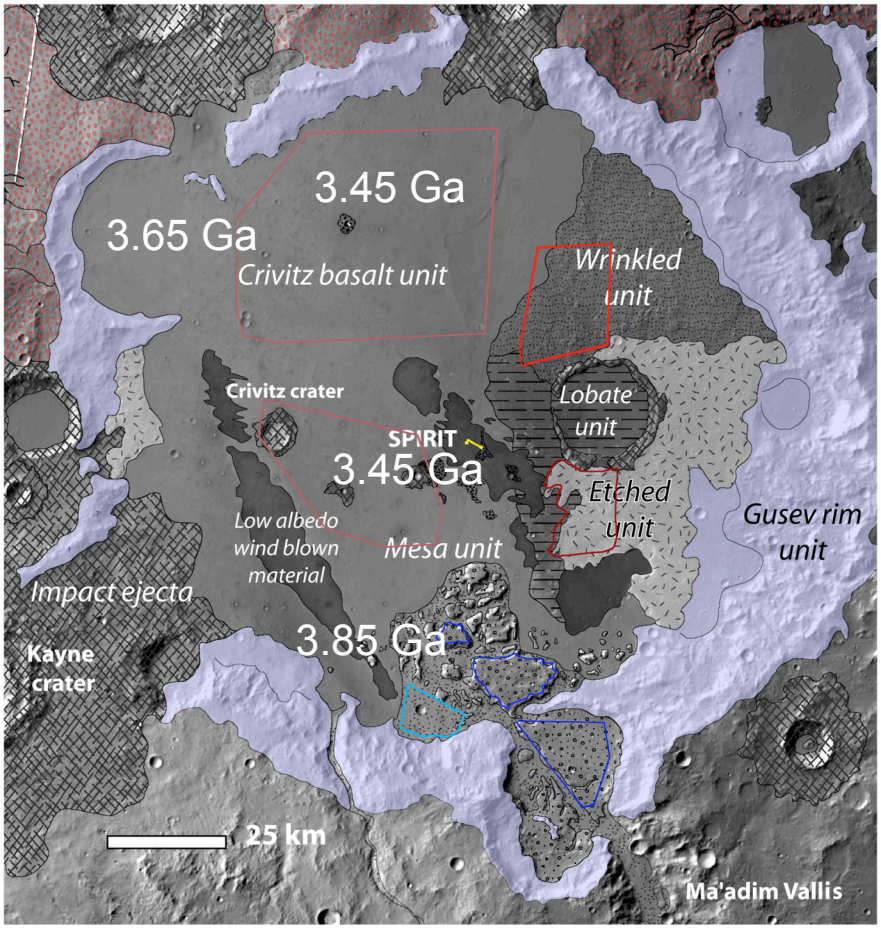




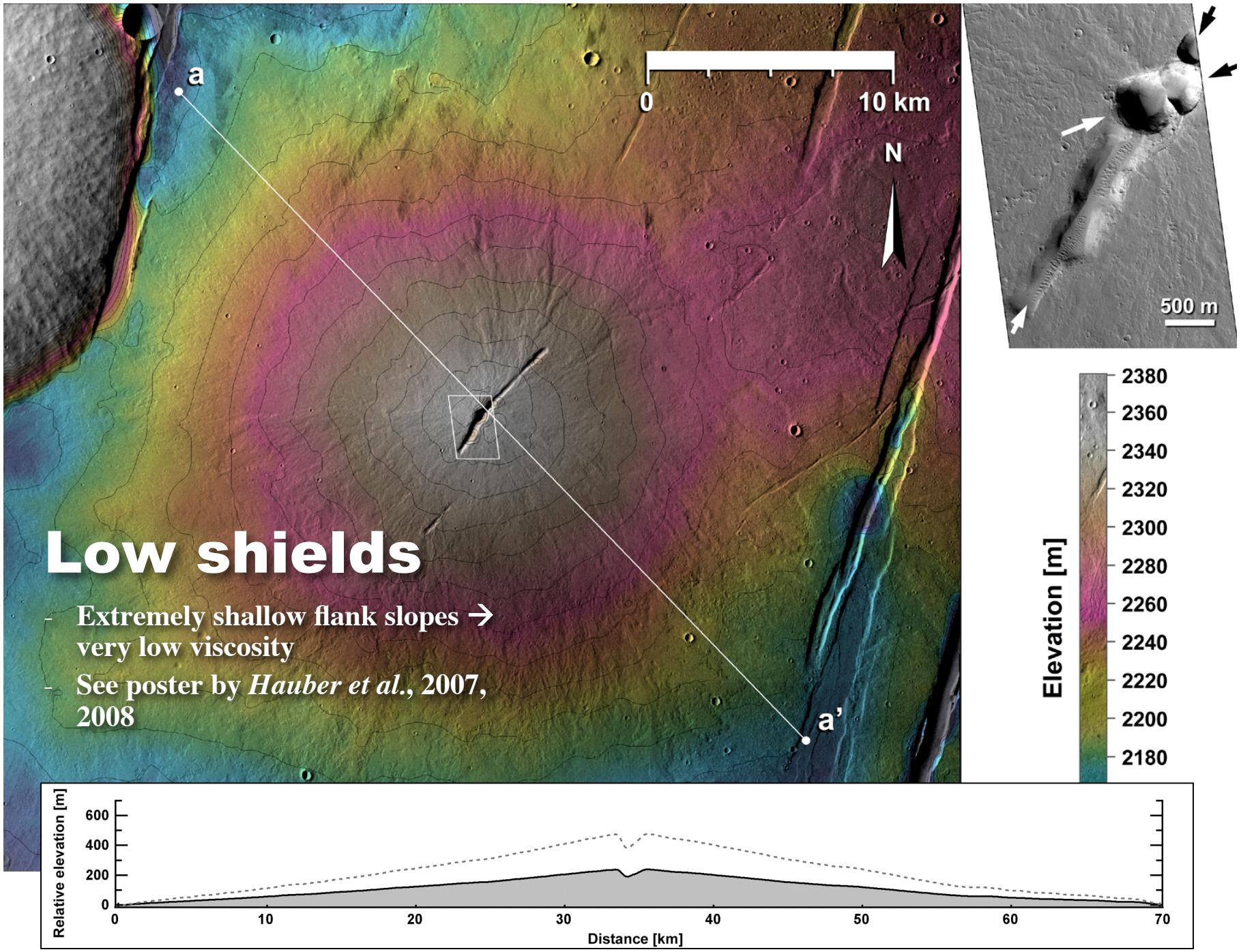
Hiesinger, H., J. W. Head and G. Neukum (2007), Young lava flows on the eastern flank of Ascraeus Mons: Rheological properties derived from High Resolution Stereo Camera (HRSC) images and Mars Orbiter Laser Altimeter (MOLA) data, *Journal of Geophysical Research (Planets)*, 112, E05011, doi:10.1029/2006JE002717

Gusev Crater Basalts

- Objective: Assess geologic history of Gusev crater
- Evaluate lava flows using compositions from MER-*Spirit*
- Unlike Tharsis flows, Gusev flows have compositions and viscosities more like terrestrial high-Mg basalts
- Likely emplaced as very fluid lavas
- Gusev formed ~4 Ga
- Ancient fluvial activity in Ma'adim Vallis ended between 3.85-3.65 Ga
- Volcanic resurfacing after Ma'adim flooding ~3.45 Ga



v. Kan (2004) Diploma thesis; Zegers et al. (2005) 1st MEX Sci. Conf.; Ivanov et al (2005) 1st MEX Sci. Conf
Greeley et al. (2005); Werner (2005) Dissertation

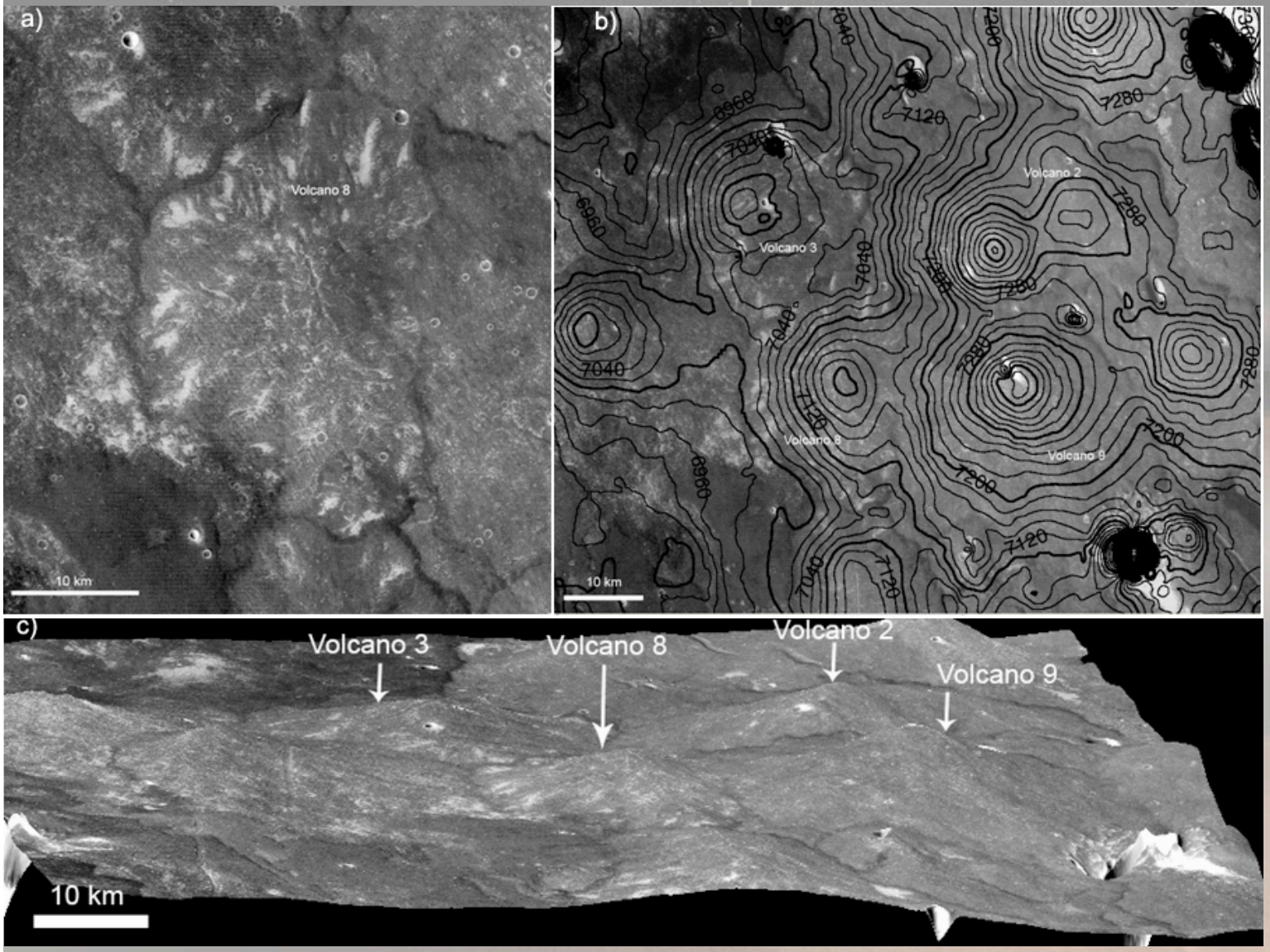


Low shields

- Extremely shallow flank slopes → very low viscosity
- See poster by *Hauber et al.*, 2007, 2008

SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY

Results: Syria Planum



Contour lines – spaced of 20 m

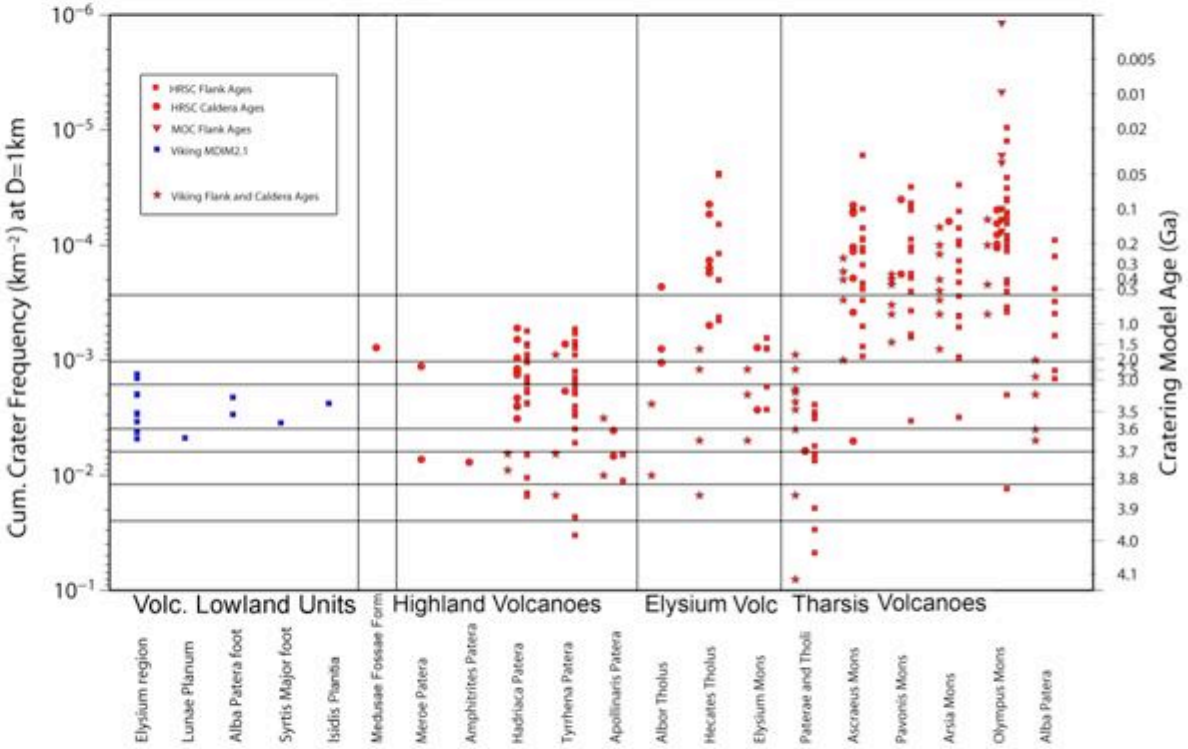
Detail of some coalesced shield volcanoes

3D representation

Baptista, A., N. Mangold, V. Ansan, P. Lognonne, D. Williams, J. Bleacher, P. Masson, G. Neukum, 2007, A swarm of small shield volcanoes on Syria Planum, Mars, analyzed using *Mars Express* HRSC data, *J. Geophys. Res.*, in press.

Ages of Volcanic Constructs and Related Landforms

- Highland volcanoes formed before 4.0 – 3.7 Ga ago and latest activity ended ~1.5 Ga ago
- Hadriaca and Tyrrhena Paterae show effusive later phases ~1.5 Ga ago correlated with fluvial activity
- Elysium volcanoes formed before 3.6 Ga ago, Elysium Mons activity ended 1.5 Ga ago; subsequent activity over the past 2 Ga, Hecates Tholus even past 1 Ga until ~100 Ma ago
- Tharsis Paterae and Tholi formed before 4 Ga ago in major parts, activity ended 3.7 Ga ago
- Tharsis Montes, Alba Patera and Olympus Mons formed before 3.5 Ga ago, have been episodically active until very recently (2 Ma, Olympus Mons)
- Possible correlation with SNC ages (Nyquist et al. (2001) SSR): ~1.5 Ga and 150-200 Ma ages in volcanic activity
- Medusae Fossae deposits formed ~1.6 Ga ago, when most highland volcanoes were active last (~1.5 Ga ago)



Neukum & Hiller (1981) JGR; Neukum et al. (2004) Nature; Werner (2005) Dissertation; Werner et al. (2005) LPSC, EGU; Zuschneid (2005) Diploma thesis


ASU SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY
ASU PLANETARY GEOLOGY
Switch to
Non-volcanics
PDF
Mars Express

HRSC Processing

- HRSC image processing software developed from JPL VICAR software
- HRSC Co-Investigator Team has “Full” DLR-VICAR package
- PSA-PDS has “mini-VICAR” with limited capabilities
  - XVD window for viewing images, DTMs
  - Level-2 to Level-3 map projection software (hrortho, frameortho)
  - Red-blue anaglyph production
- Learn about other useful software
  - HRSCView
  - CRATERSTATS
  - Convert VICAR image format to those readable by Adobe™ Photoshop™

ASU School of Earth & Space Exploration
Arizona State University

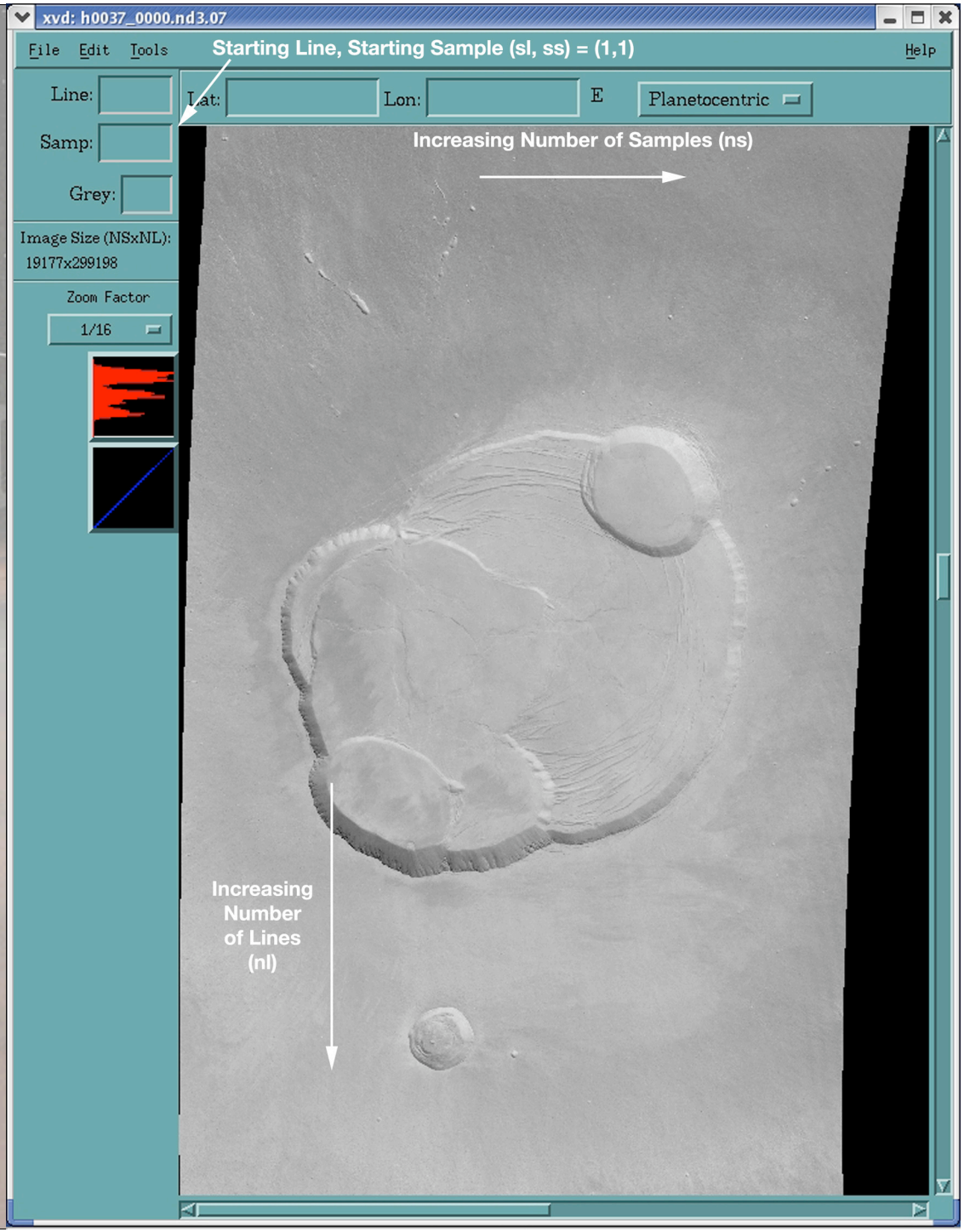
HRSC Naming Convention

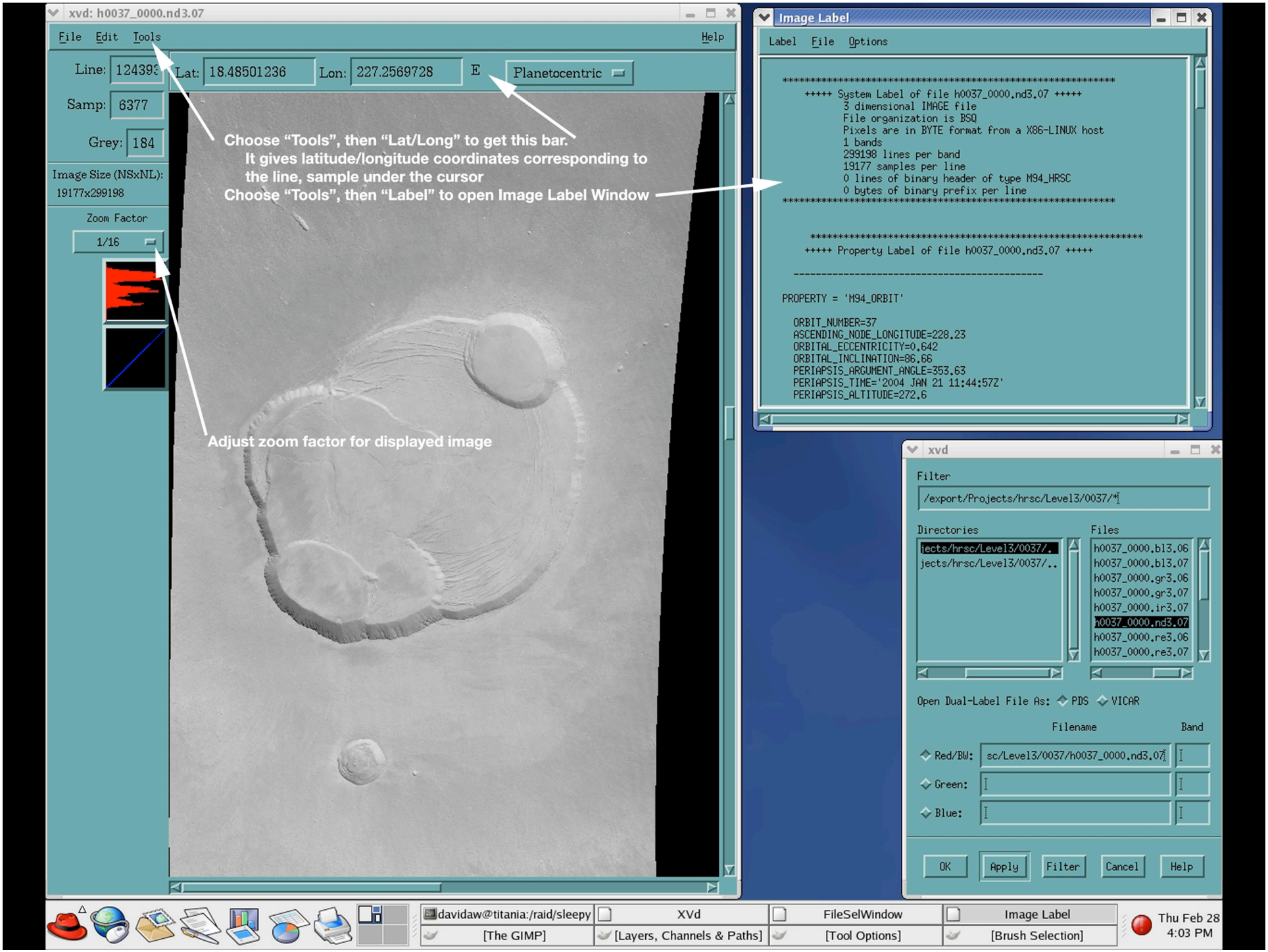
hoooo_mmmm.ddl.vv

oooo = orbit number
mmmm = image number
dd = detector id:

nd = nadir channel
s1 = stereo 1 channel
s2 = stereo 2 channel
p1 = photometry 1 channel
p2 = photometry 2 channel
re = red channel
ir = infrared channel
gr = green channel
bl = blue channel
sr = super resolution channel

l = level (0,1,2,3,4)
vv = version number




xvd: h0037_0000.nd3.07
File Edit Tools Help
Line: 124393
Samp: 6377
Grey: 184
Lat: 18.48501236
Lon: 227.2569728
E
Planetocentric
Image Size (NSxNL):
19177x299198
Zoom Factor
1/16
Choose "Tools", then "Lat/Long" to get this bar.
It gives latitude/longitude coordinates corresponding to the line, sample under the cursor
Choose "Tools", then "Label" to open Image Label Window
Adjust zoom factor for displayed image
Image Label
Label File Options
***** System Label of file h0037_0000.nd3.07 *****
3 dimensional IMAGE file
File organization is BSQ
Pixels are in BYTE format from a X86-LINUX host
1 bands
299198 lines per band
19177 samples per line
0 lines of binary header of type M94_HRSC
0 bytes of binary prefix per line
***** Property Label of file h0037_0000.nd3.07 *****
PROPERTY = 'M94_ORBIT'
ORBIT_NUMBER=37
ASCENDING_NODE_LONGITUDE=228.23
ORBITAL_ECCENTRICITY=0.642
ORBITAL_INCLINATION=86.66
PERIAPSIS_ARGUMENT_ANGLE=353.63
PERIAPSIS_TIME='2004 JAN 21 11:44:57Z'
PERIAPSIS_ALTITUDE=272.6
xvd
Filter
/export/Projects/hrsc/Level3/0037/*
Directories
jects/hrsc/Level3/0037/.
jects/hrsc/Level3/0037/..
Files
h0037_0000.bl3.06
h0037_0000.bl3.07
h0037_0000.gr3.06
h0037_0000.gr3.07
h0037_0000.ir3.07
h0037_0000.nd3.07
h0037_0000.re3.06
h0037_0000.re3.07
Open Dual-Label File As: PDS VICAR
Filename
Band
Red/BW: sc/Level3/0037/h0037_0000.nd3.07
Green:
Blue:
OK Apply Filter Cancel Help
davidaw@titania:/raid/sleepy
XVd
FileSelWindow
Image Label
[The GIMP]
[Layers, Channels & Paths]
[Tool Options]
[Brush Selection]
Thu Feb 28
4:03 PM

References

Bleacher, J., R. Greeley, D. Williams, S. Cave and G. Nekum (2007), Trends in effusive style at the Tharsis Montes, Mars, and implications for the development of the Tharsis province, Journal of Geophysical Research (Planets), 112,E09005, doi:10.1029/2006JE002873

Hiesinger, H., J. W. Head and G. Neukum (2007), Young lava flows on the eastern flank of Ascraeus Mons: Rheological properties derived from High Resolution Stereo Camera (HRSC) images and Mars Orbiter Laser Altimeter (MOLA) data, Journal of Geophysical Research (Planets), 112, E05011, doi:10.1029/2006JE002717

Bleacher, J.E., R. Greeley, D.A. Williams, S. Werner, G. Neukum (2007), Olympus Mons, Mars: Inferred changes in late Amazonian-aged effusive activity from lava flow mapping of *Mars Express* High Resolution Stereo Camera data, Journal of Geophysical Research (Planets), 112, E04003, doi:10.1029/2006JE002826.

Basilevsky, A. T., S. Werner, G. Neukum, J. Head, S. v. Gasselt, K. Gwinner, and B. Ivanov (2006), Geologically recent tectonic, volcanic and fluvial activity on the eastern flank of the Olympus Mons volcano, Mars, Geophys. Res. Lett., 33, L13201, doi:10.1029/2006GL026396.

Head, J. W., L. Wilson, J. Dickson, and G. Neukum (2006), The Huygens-Hellas giant dike system on Mars: Implications for late Noachian - early Hesperian volcanic resurfacing and climatic evolution, Geology, 34, 4, 285-288, doi:10.1130/G22163.1.

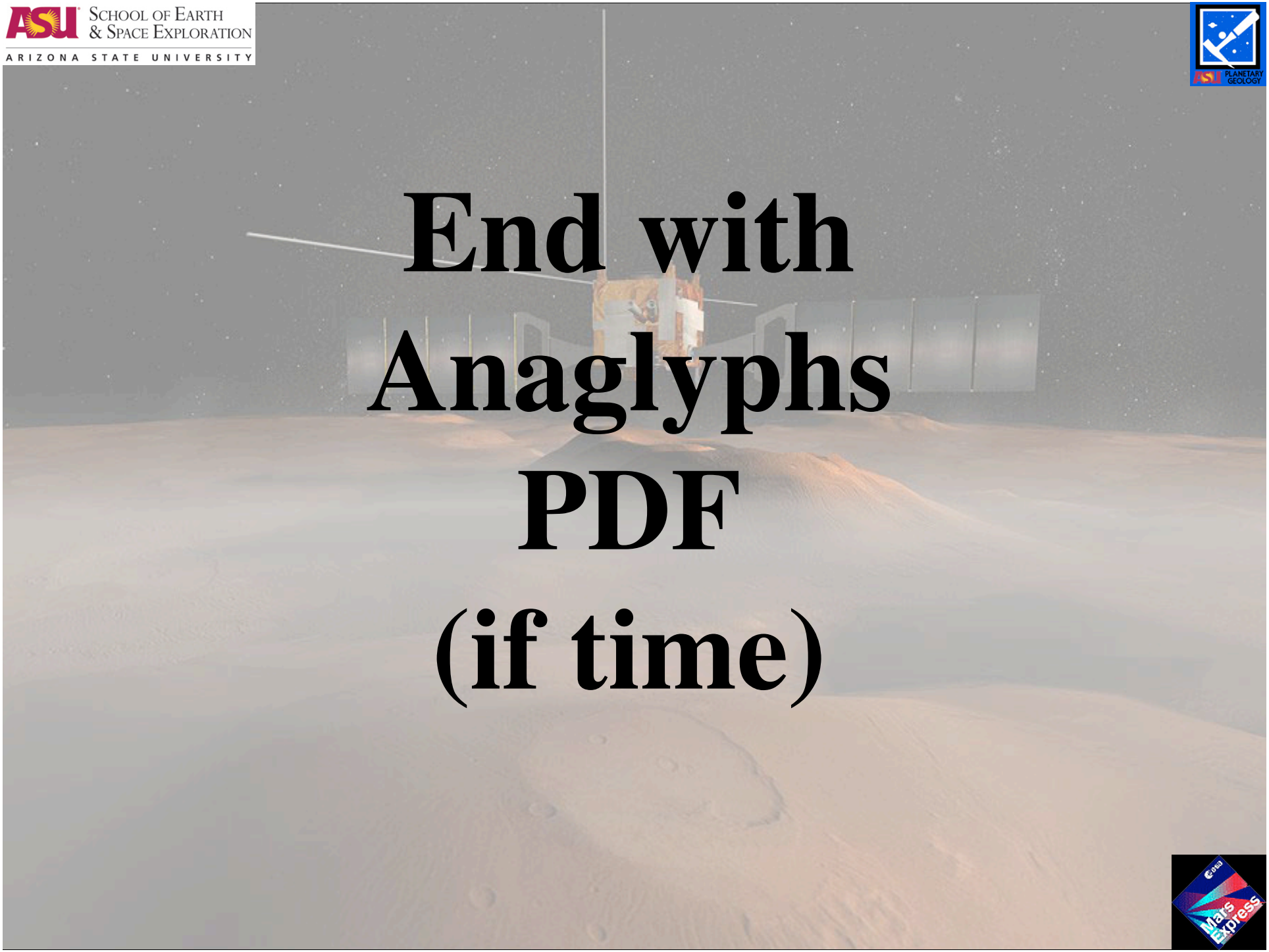
Basilevsky, A. T.,G. Neukum, B. A. Ivanov, S. K. Werner, S. van Gasselt, J. W. Head, T. Denk, R. Jaumann, H. Hoffmann, E. Hauber, and T. McCord (2005), Morphology and geological structure of the western part of the Olympus Mons volcano on Mars from the analysis of the Mars Express HRSC imagery, Solar System Research, 39, 2, 85-101(117), doi:10.1007/s11208-005-0025-2.

Greeley, R., B. H. Foing, H. Y. McSween, G. Neukum, P. Pinet, M. van Kan, S. C. Werner, D. A. Williams, and T. E. Zegers (2005), Fluid lava flows in Gusev crater, Mars, J. Geophys. Res., 110, E05008, doi:10.1029/2005JE002401.

Hauber, E., S. van Gasselt, B. Ivanov, S. Werner, J. W. Head, G. Neukum, R. Jaumann, R. Greeley, K. L. Mitchell, P. Muller, and the HRSC Co-Investigator Team (2005), Discovery of a flank caldera and very young glacial activity at Hecates Tholus, Mars, Nature, 434, 356-361, doi: 10.1038/nature03423.

Williams, D. A., R. Greeley, E. Hauber, K. Gwinner, and G. Neukum (2005), Erosion by flowing Martian lava: New insights for Hecates Tholus from Mars Express and MER data, J. Geophys. Res., 110, E05006, doi:10.1029/2004JE002377.

Neukum, G., R. Jaumann, H. Hoffmann, E. Hauber, J. W. Head, A. T. Basilevsky, B. A. Ivanov, S. C. Werner, S. van Gasselt, J. B. Murray, T. McCord, and the HRSC Co-Investigator Team (2004), Recent and episodic volcanic and glacial activity on Mars revealed b[illegible] High Resolution Stereo Camera, Nature, 432, 971-979, 10.1038/nature03231.


ASU SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY
ASU PLANETARY GEOLOGY
End with Anaglyphs PDF (if time)
Mars Express