Mineralogy on Mars and Future Missions with MIMOS II

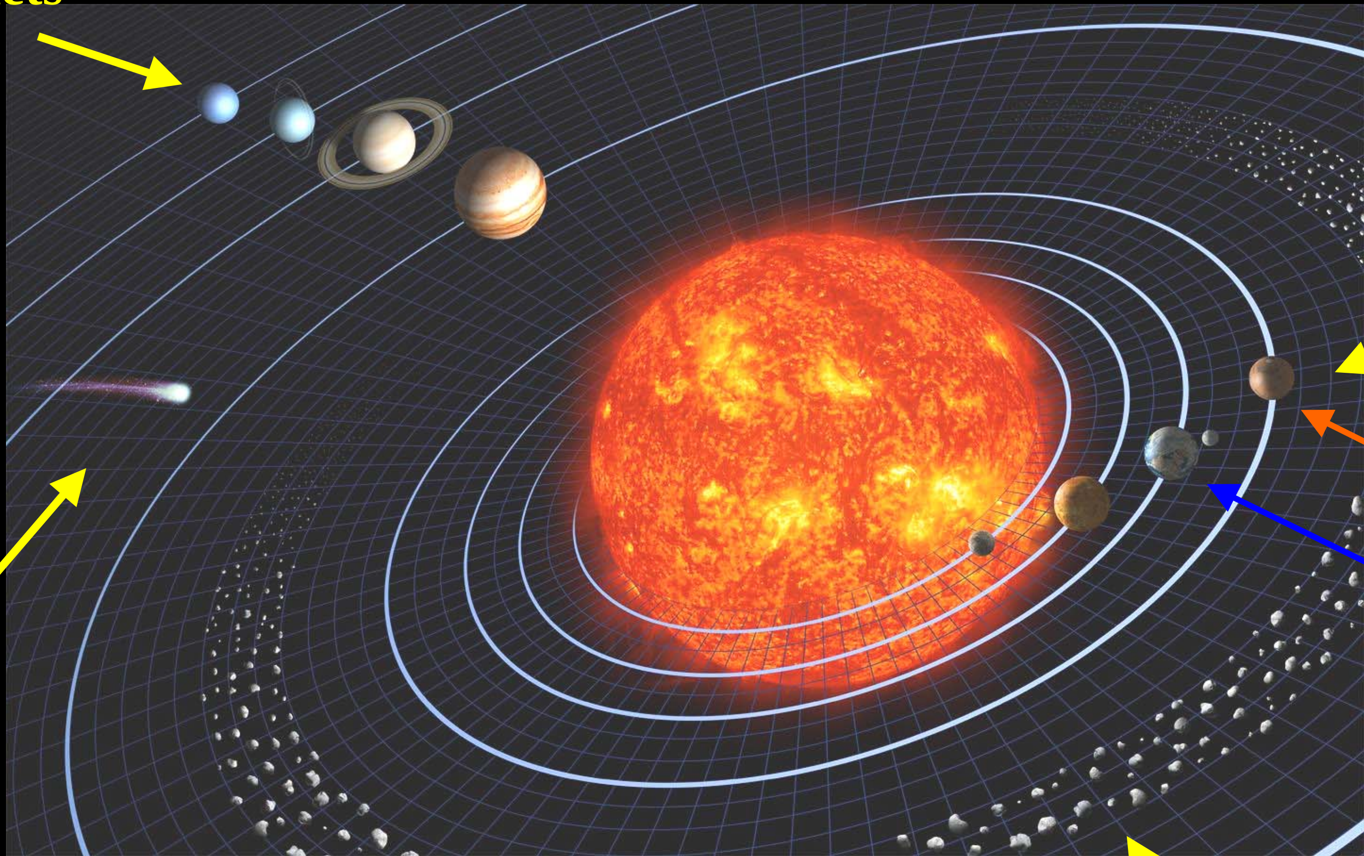
Göstar Klingelhöfer & MIMOS II Team

50th Anniversary MB

9.-10.October 08/Garching

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

The Solar System (not to scale)



Mars: the red planet

~ 1/3 the gravity of the Earth

atmosphere: CO_2 (nearly 100 %)

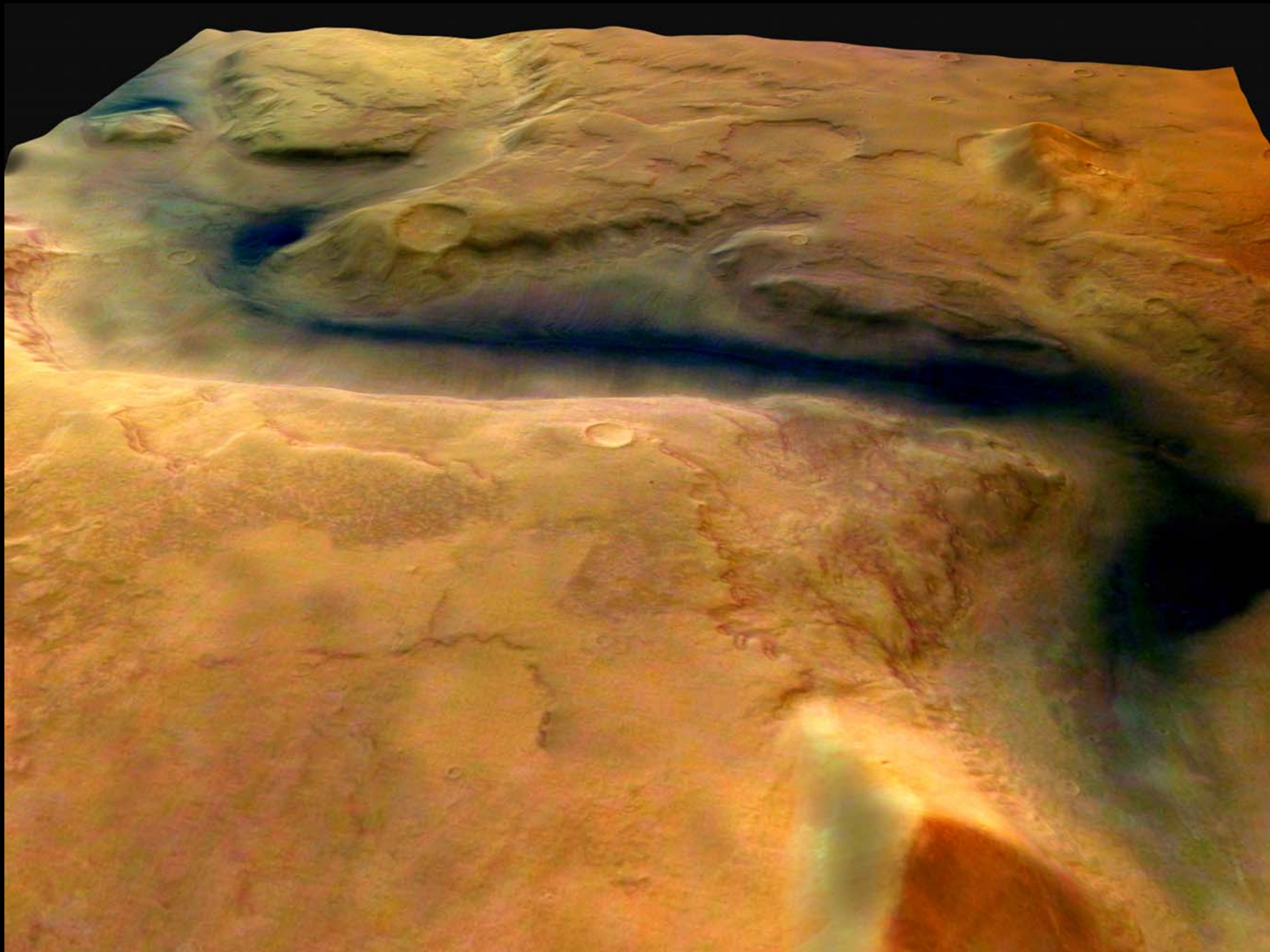
~ 1 % the density of the Earth atmosphere

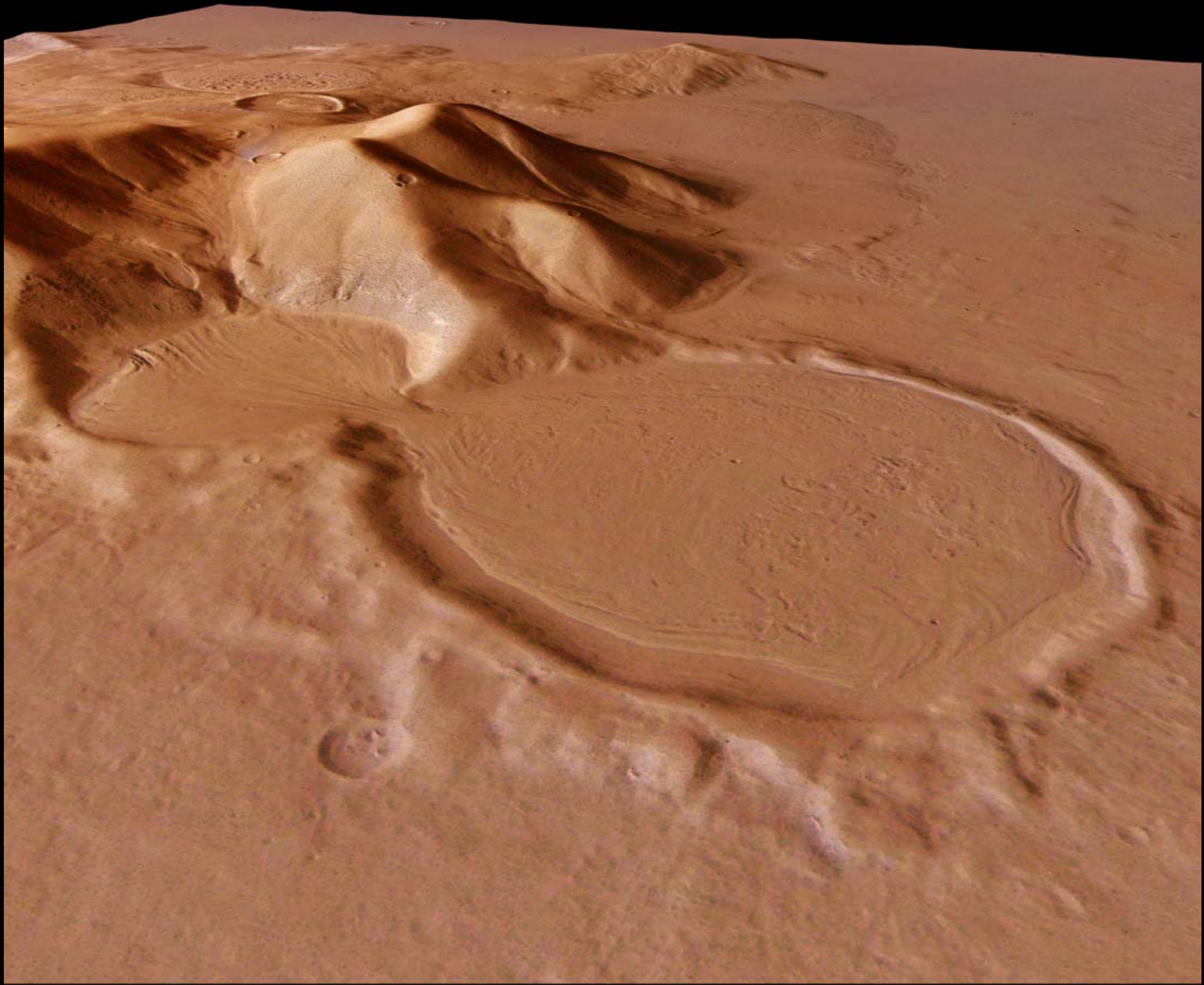
One Mars day is 24 h 39 min.

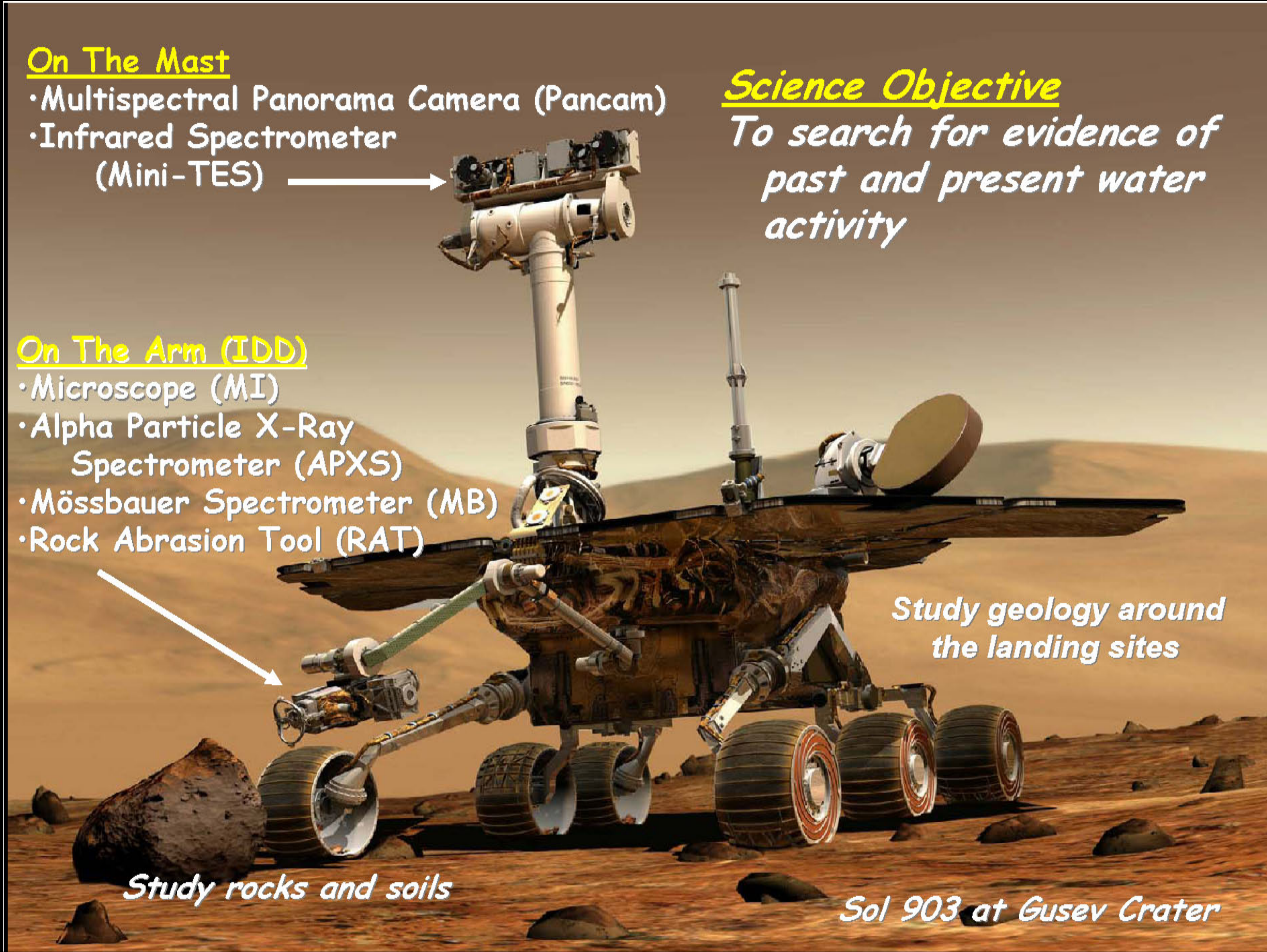
One Mars year last ~ 2 Earth years (~686 days)

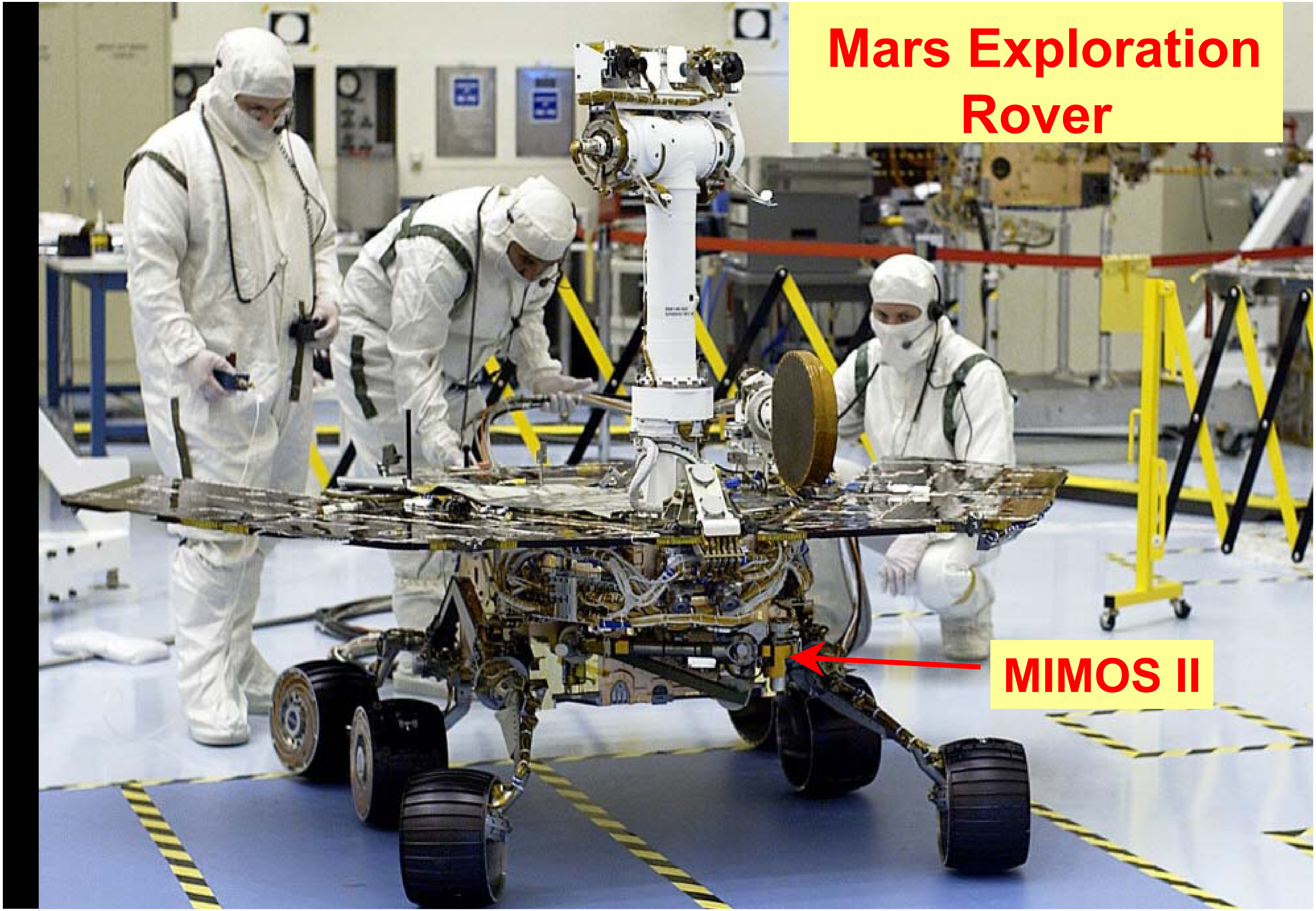
temperature on Mars: ca. +20°C (day) to - 120°C (night)

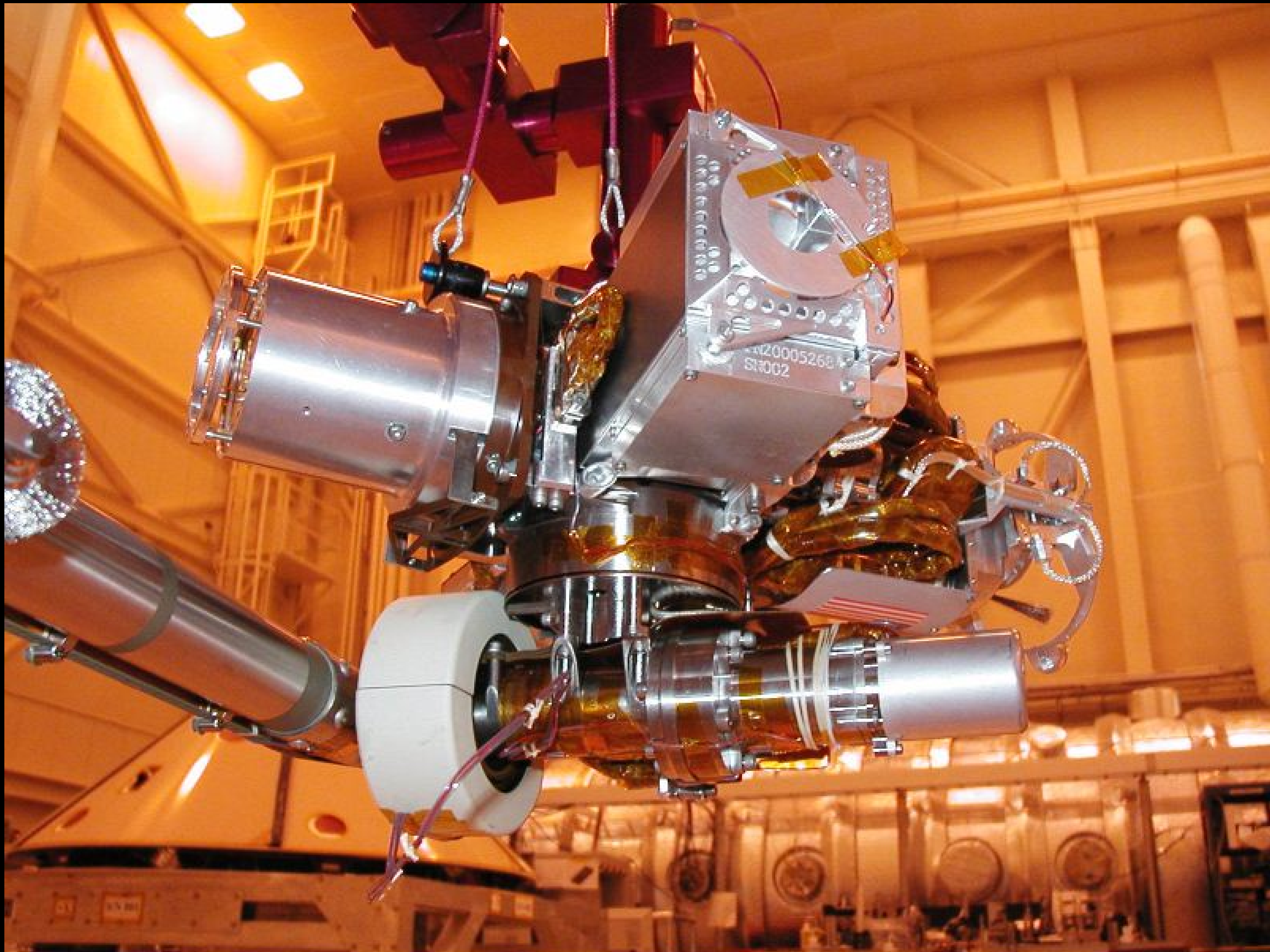
ESA Mars-Express Orbiter / HRSC photo, DLR Berlin, Prof. Neukum

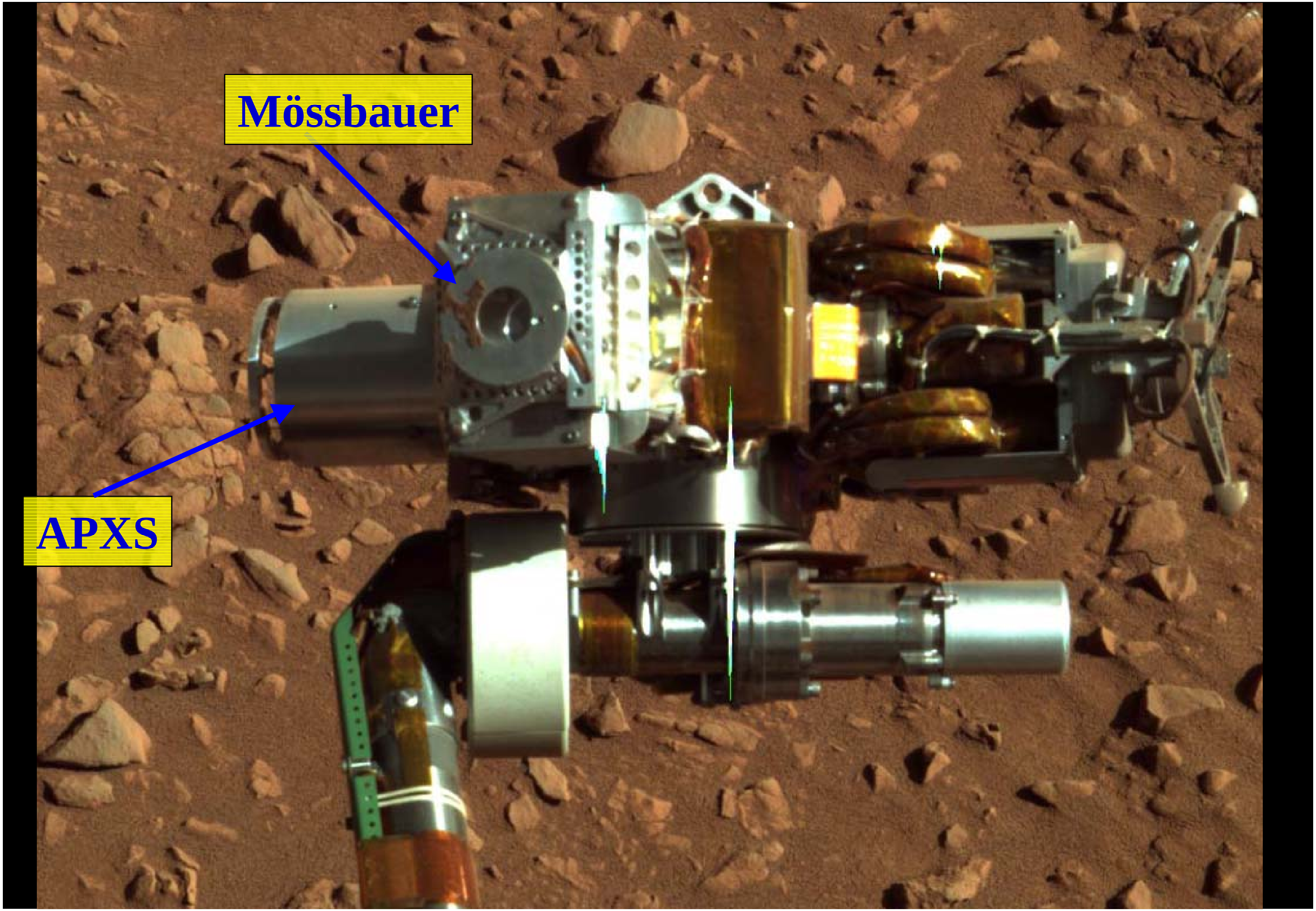




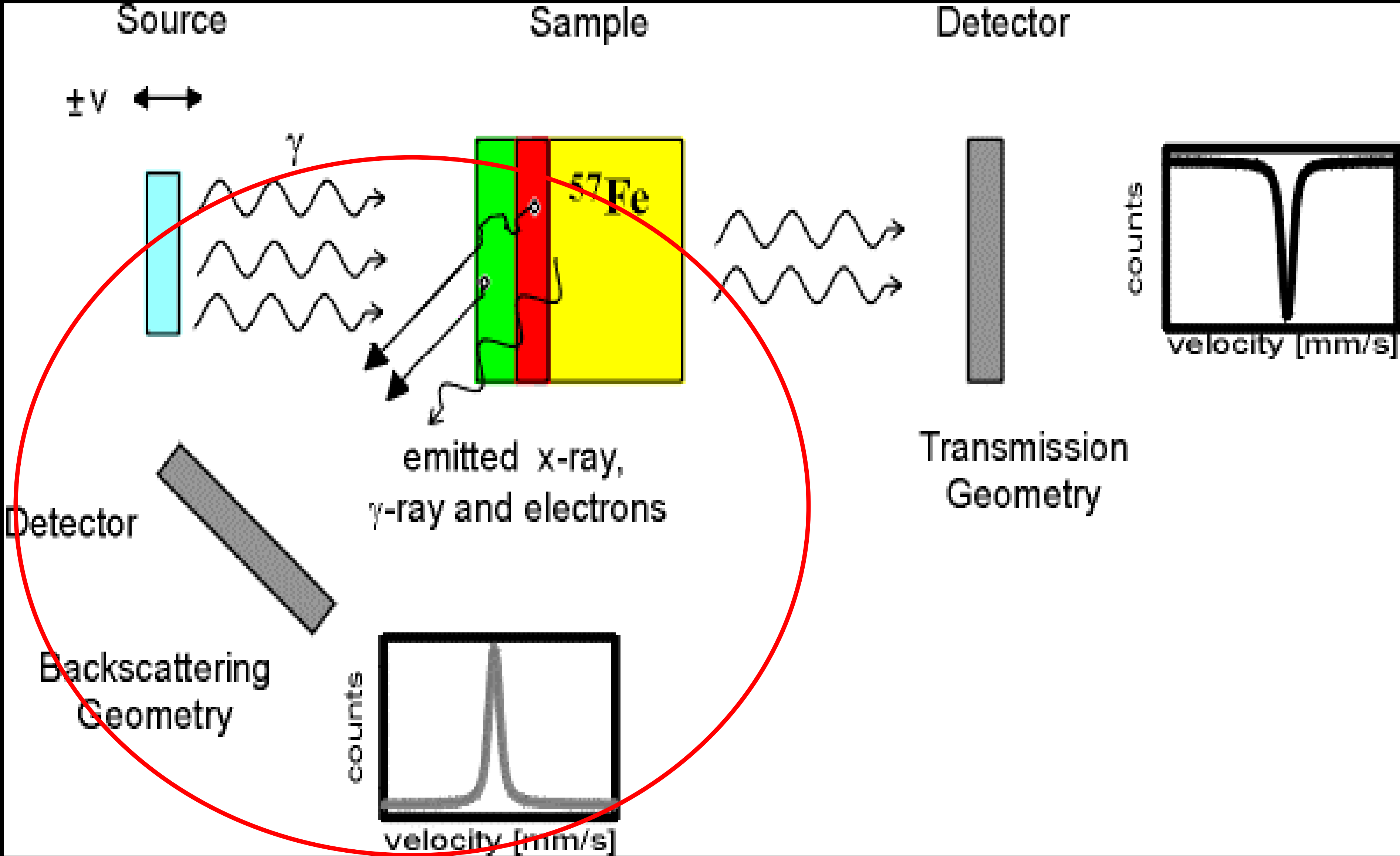

On The Mast
·Multispectral Panorama Camera (Pancam)
·Infrared Spectrometer (Mini-TES)
Science Objective
To search for evidence of past and present water activity
On The Arm (IDD)
·Microscope (MI)
·Alpha Particle X-Ray Spectrometer (APXS)
·Mössbauer Spectrometer (MB)
·Rock Abrasion Tool (RAT)
Study geology around the landing sites
Study rocks and soils
Sol 903 at Gusev Crater


Mars Exploration Rover
MIMOS II

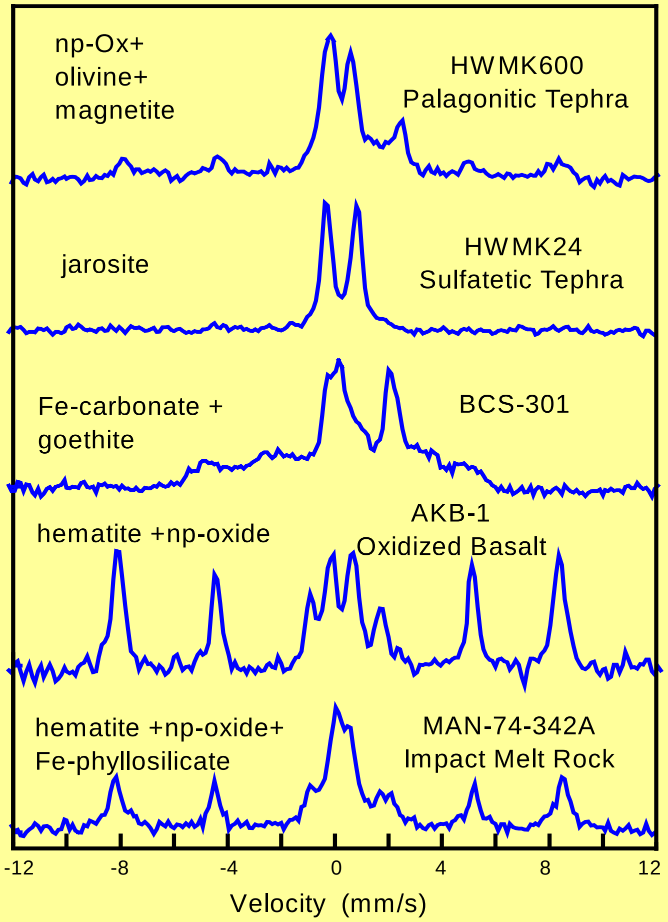


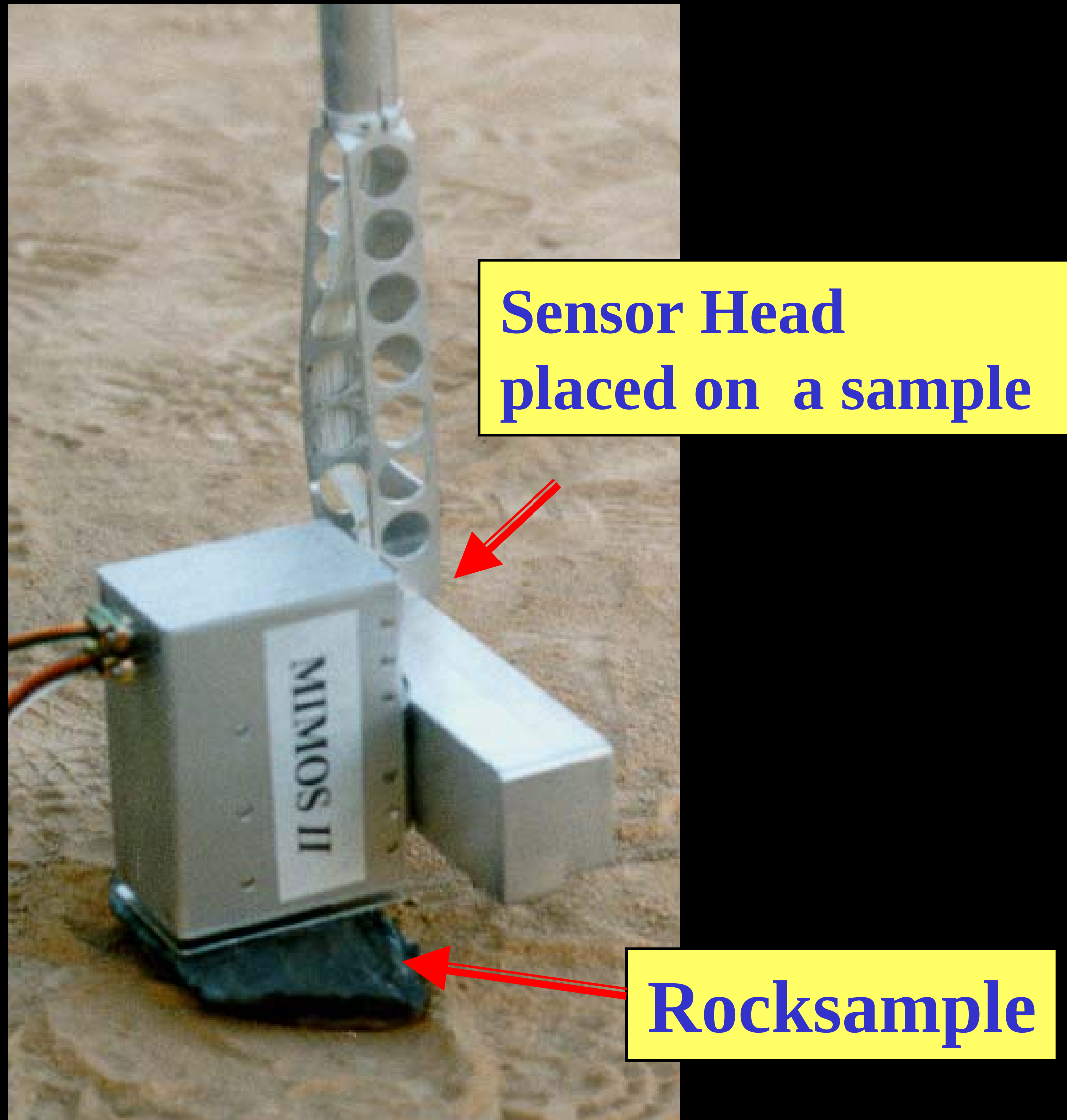

Mössbauer
APXS

Mössbauer Spectroscopy:



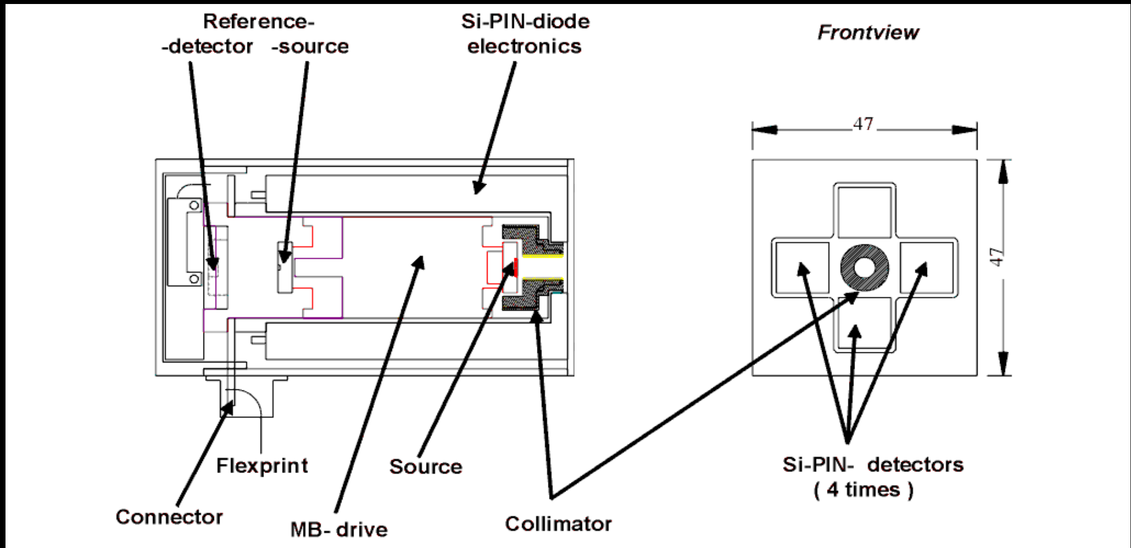
Backscatter Mossbauer Spectra (293 K) Obtained with MIMOS II Instrument for Martian Surface Analogues

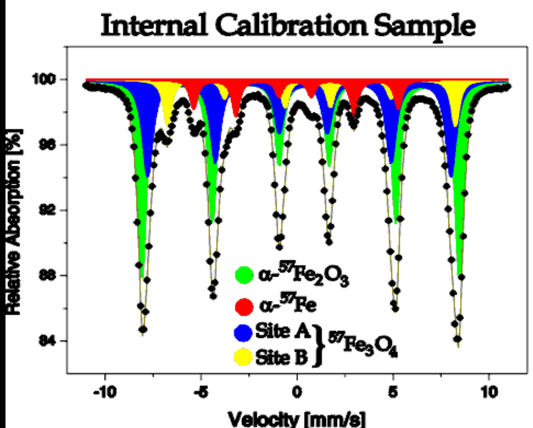


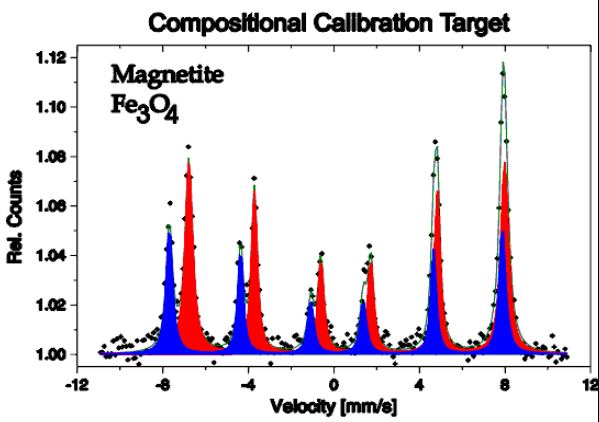


MIMOS II Sensor head

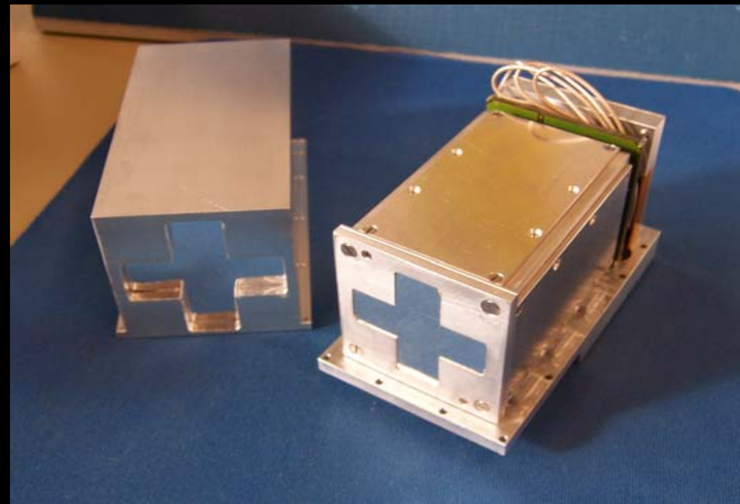
Scheme of Sensor Head



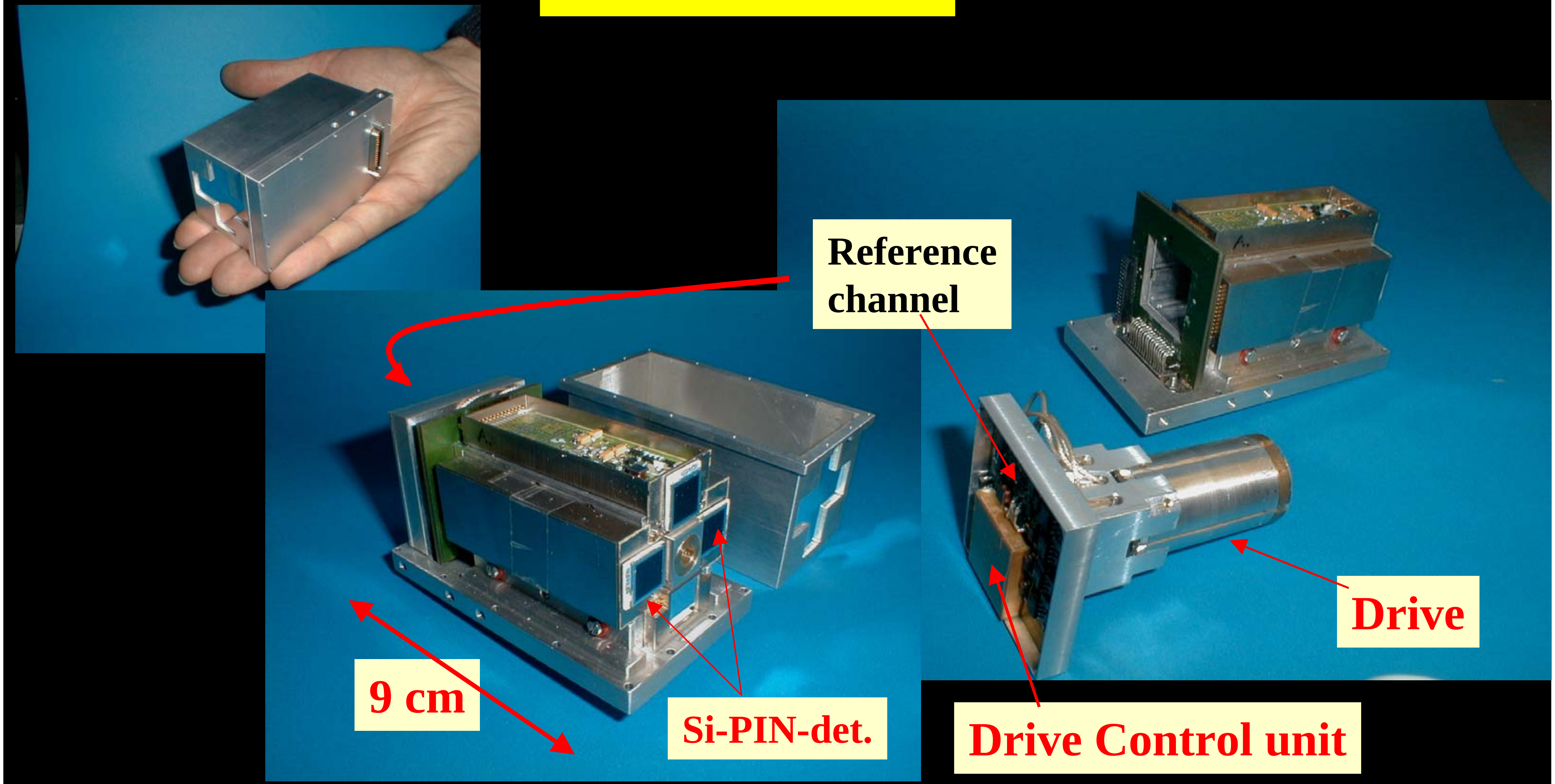


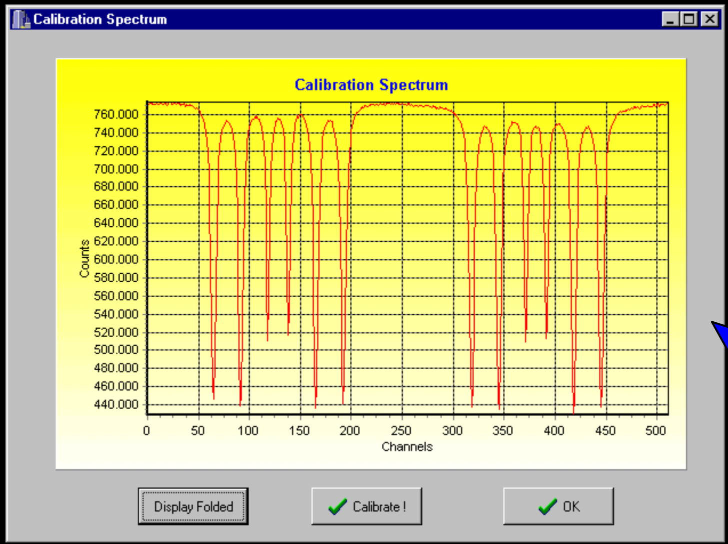


Sensor Head (actual design)



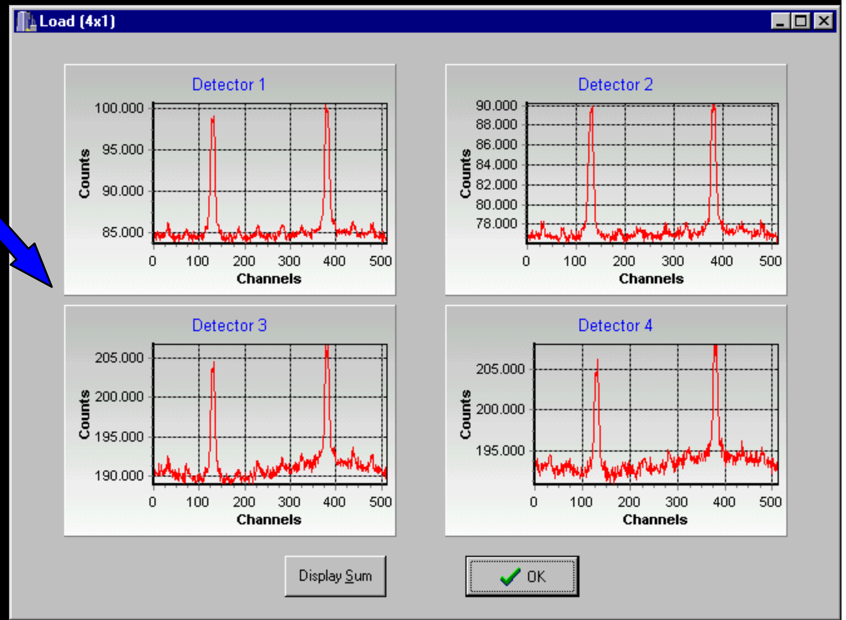
Sensor Head





Calibration

Sample

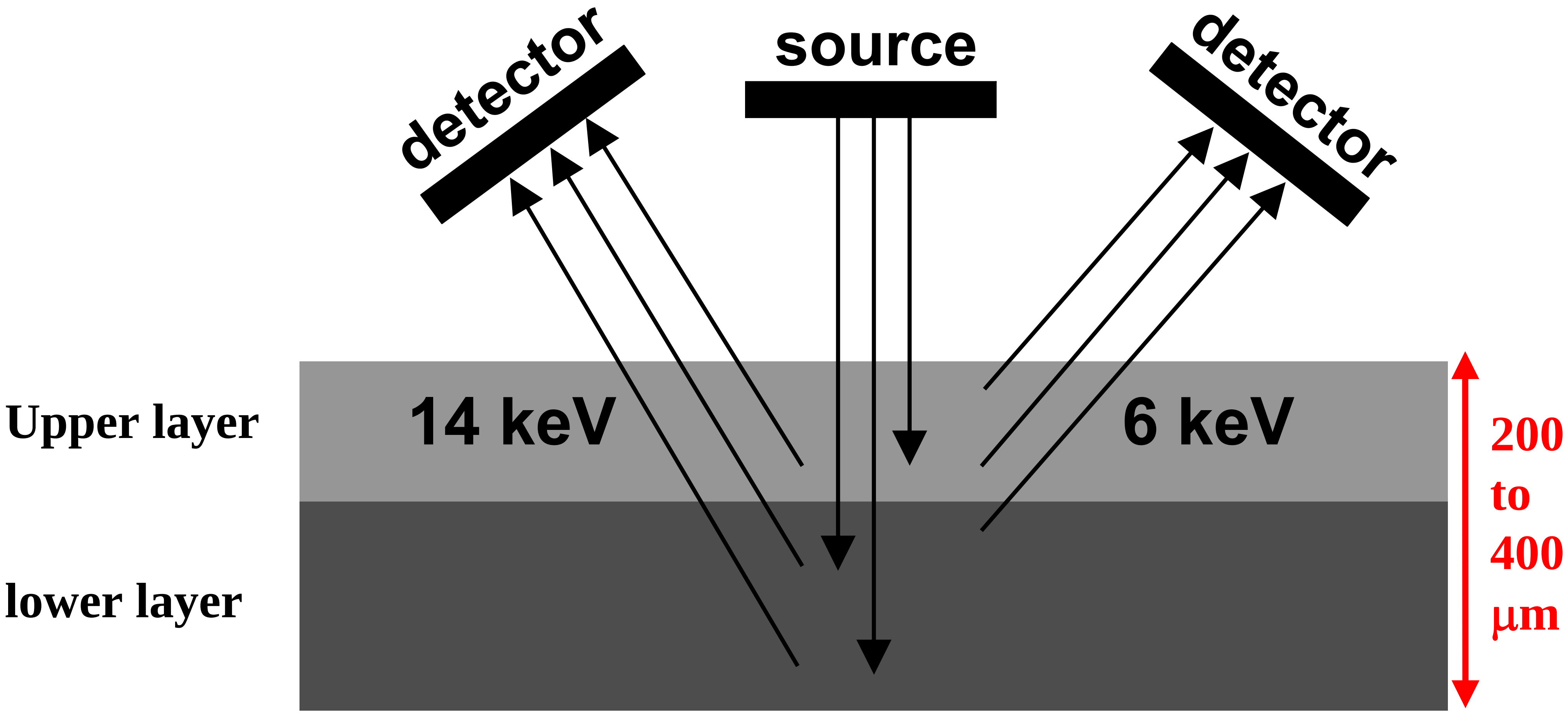


4 MB Spectra 14.4 keV
4 MB Spektra 6.4 keV
1 MB Reference Spectrum
up to 13 Temperature windows

and: (i)Energy spectra Si-detectors; (ii) Drive error signal

DEPTH SELECTIVITY

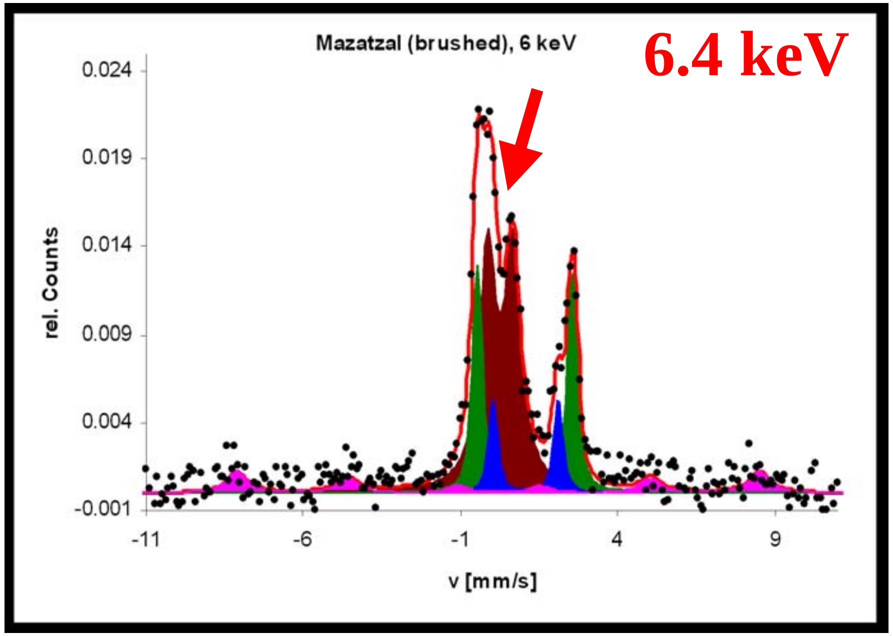
6.4 kev and 14.41 keV Mössbauer Spectroscopy

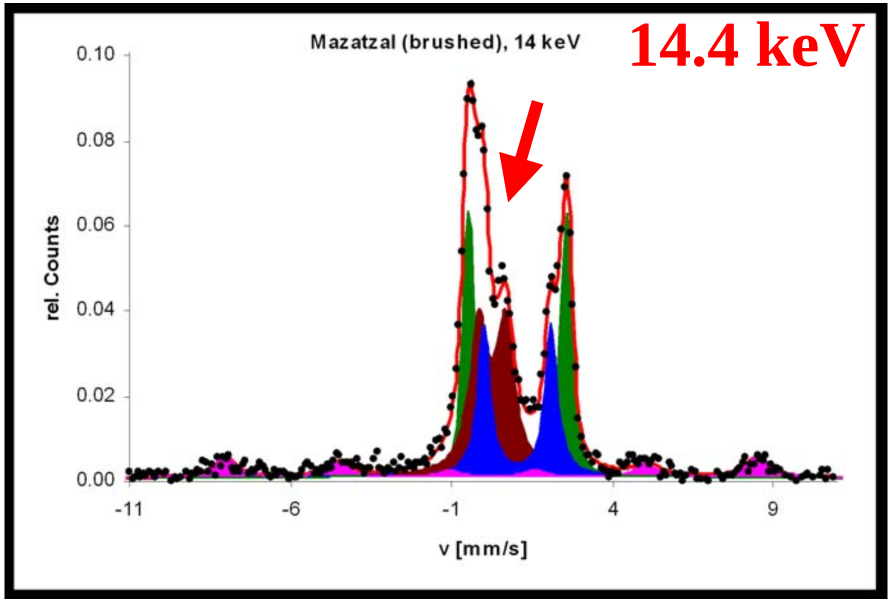


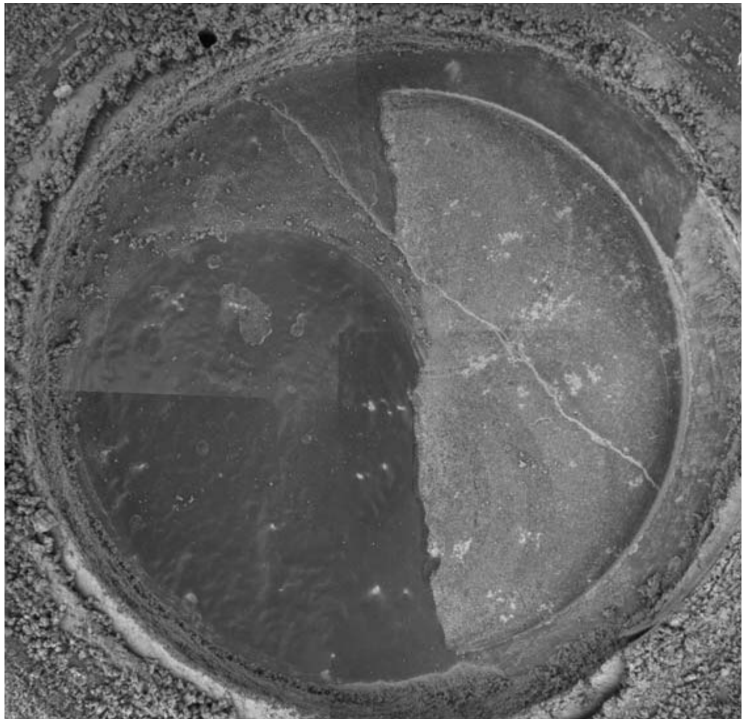
Early Mars – northern sea?

Early Earth
ocean-covered

MAZATZAL(Gusev)



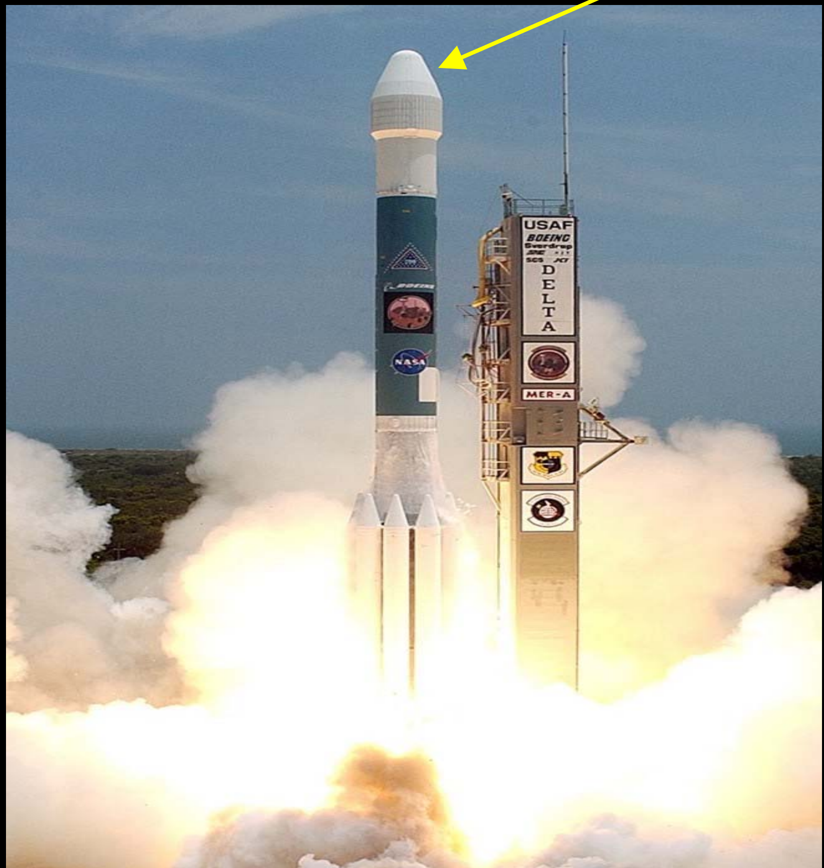


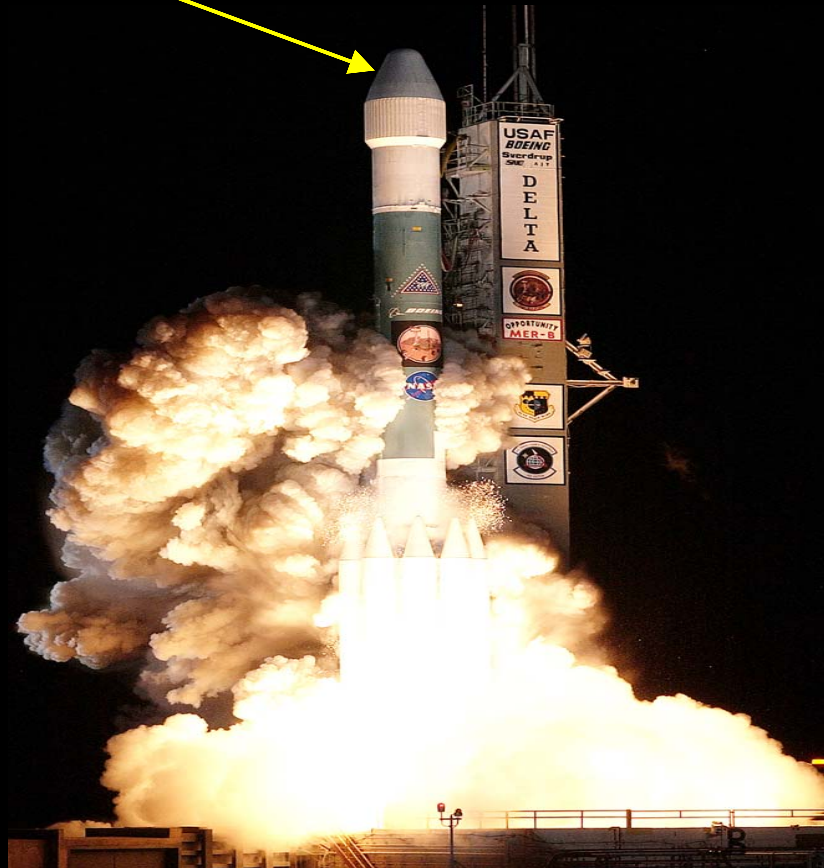


Mineral	relative intensity	
	6 keV	14 keV
Pyroxene (blue)	11 %	24 %
Olivine (green)	27 %	33 %
Np oxides (brown)	51 %	33 %
Magn. Phases (magenta)	11 %	10 %

Launch of Spirit and Opportunity

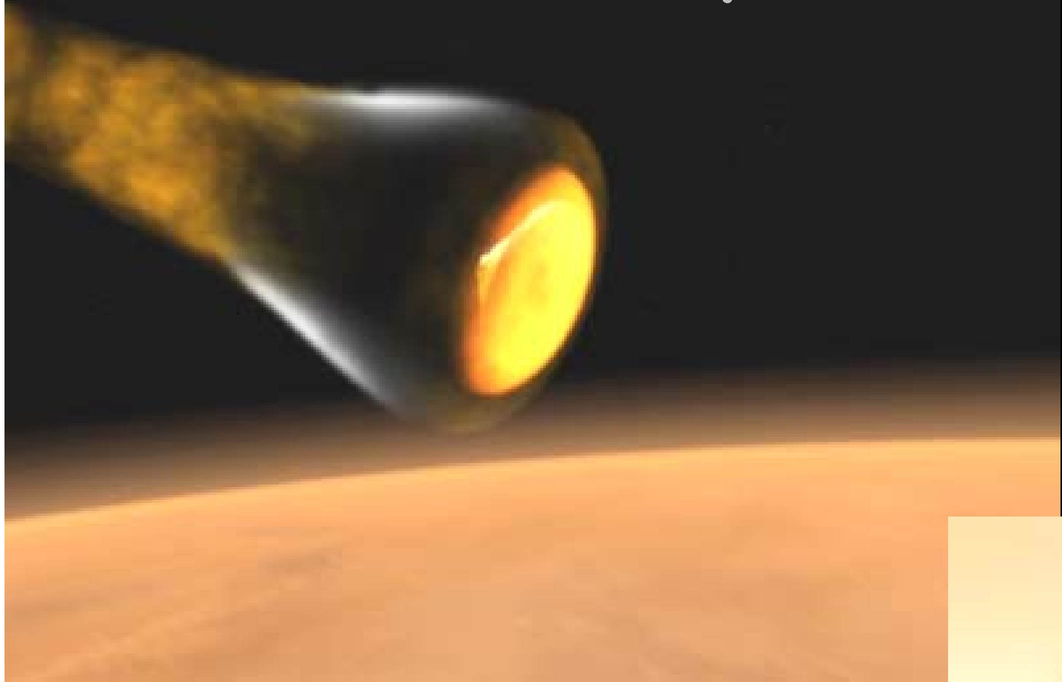
- and MIMOS II



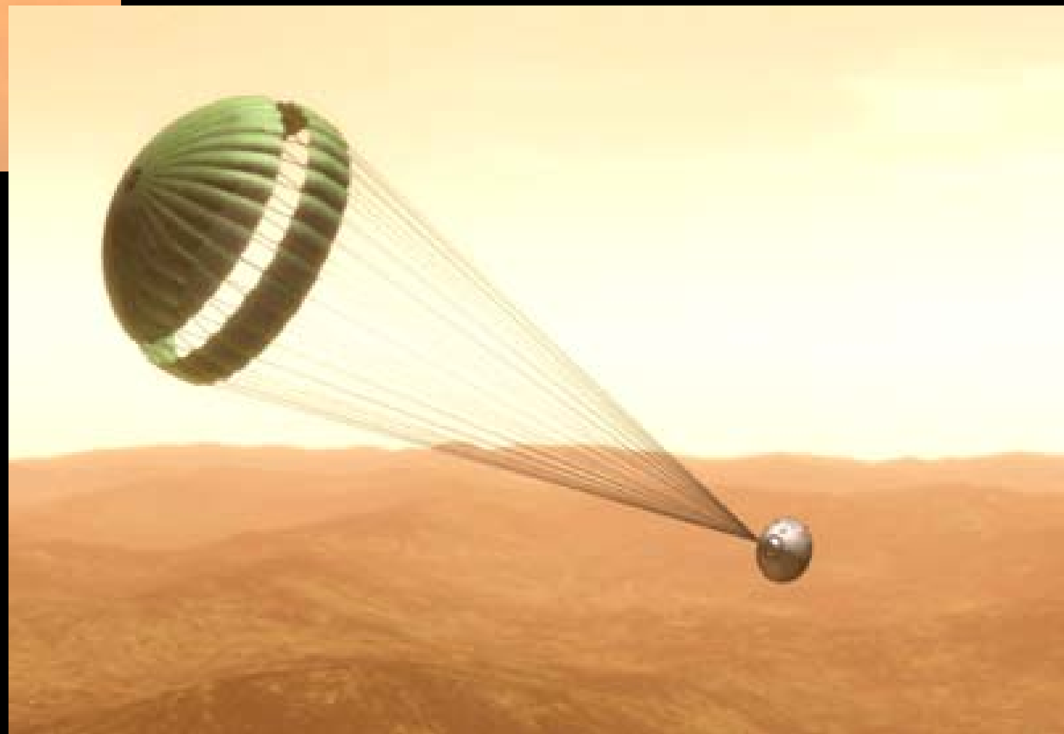


at Kennedy Space Center, Florida, USA

Direct Entry



Parachute Phase



!! Successful Landings !!

Spirit : 3. January 04

Opportunity : 25. January 04

MER- Statistics (10.October 2008)

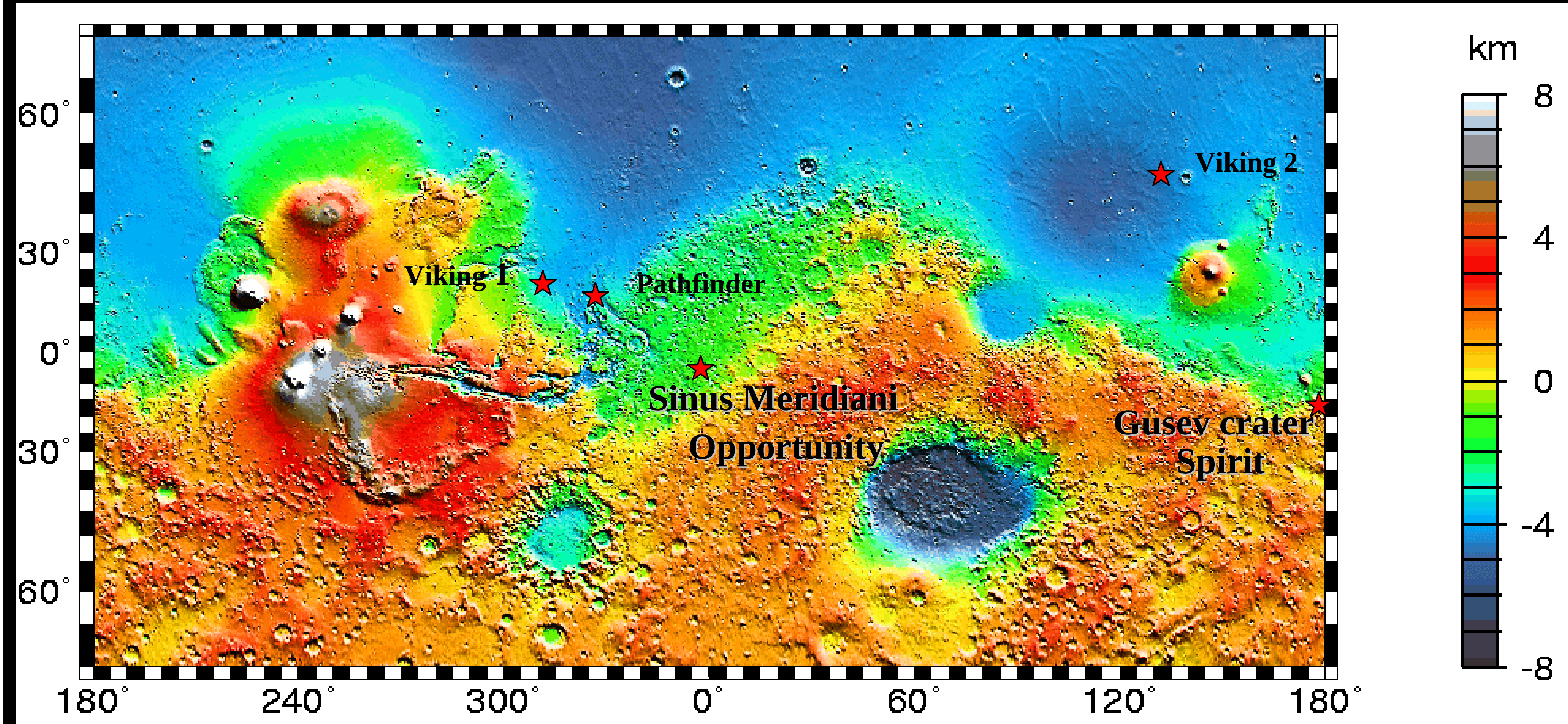
Spirit, Gusev-krater

- 1697 Sols (initial goal: 90 Sols)
- ~7 km traveled (initial goal: 600 m)
- 161 sets of spectra of rocks and soil targets (initial goal: 1 rock, 1 soil target, 1 extra)
- ~ 6 Half-life periods of the Co-sources since the landing

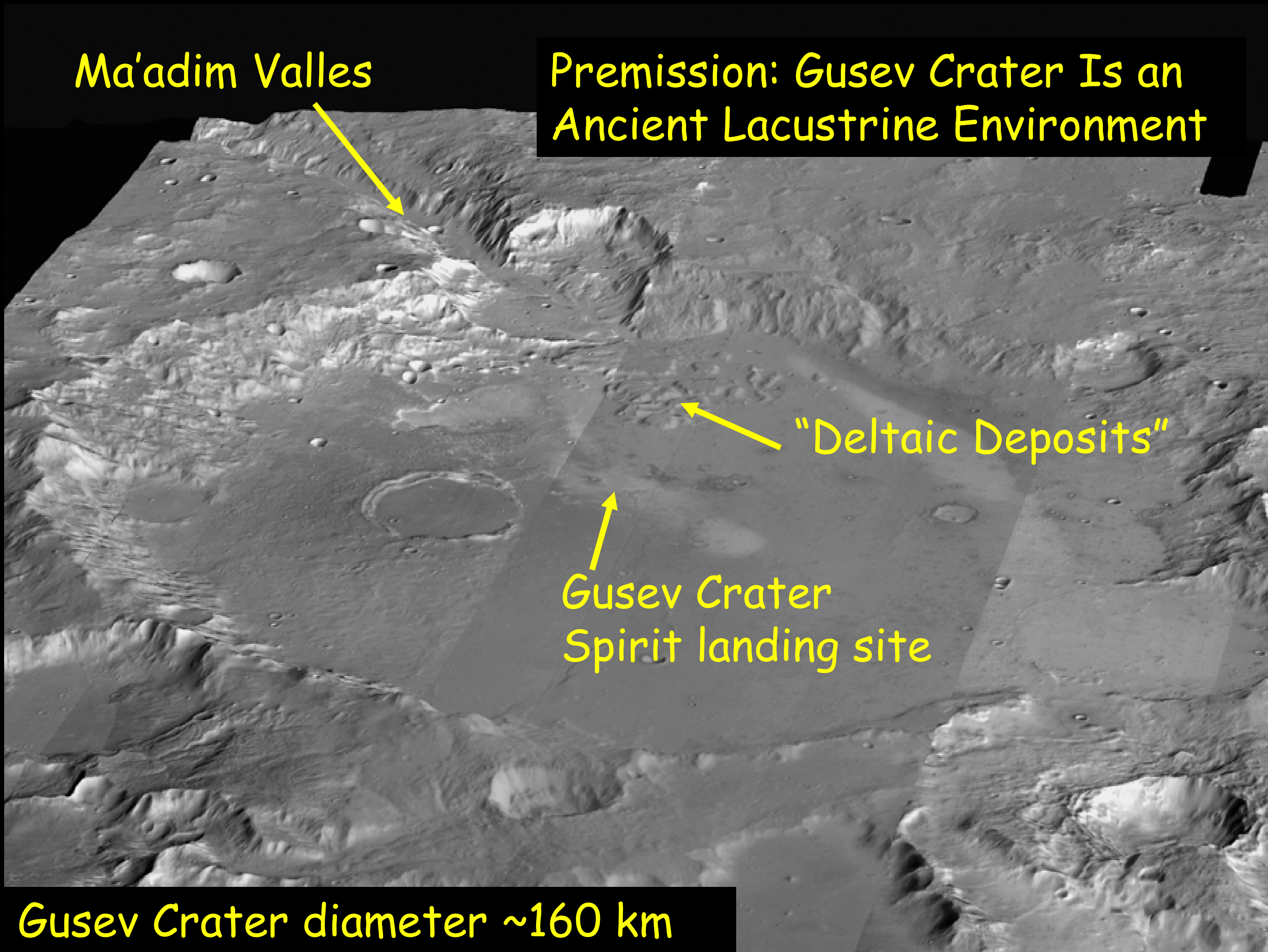
Opportunity, Meridiani Planum

- 1674 Sols (initial goal: 90 Sols)
- ~11 km traveled (initial goal: 600 m)
- 139 sets of spectra of rocks and soil targets (initial goal: 1 rock, 1 soil target, 1 extra)
- ~ 6 Half-life periods of the Co-sources since the landing

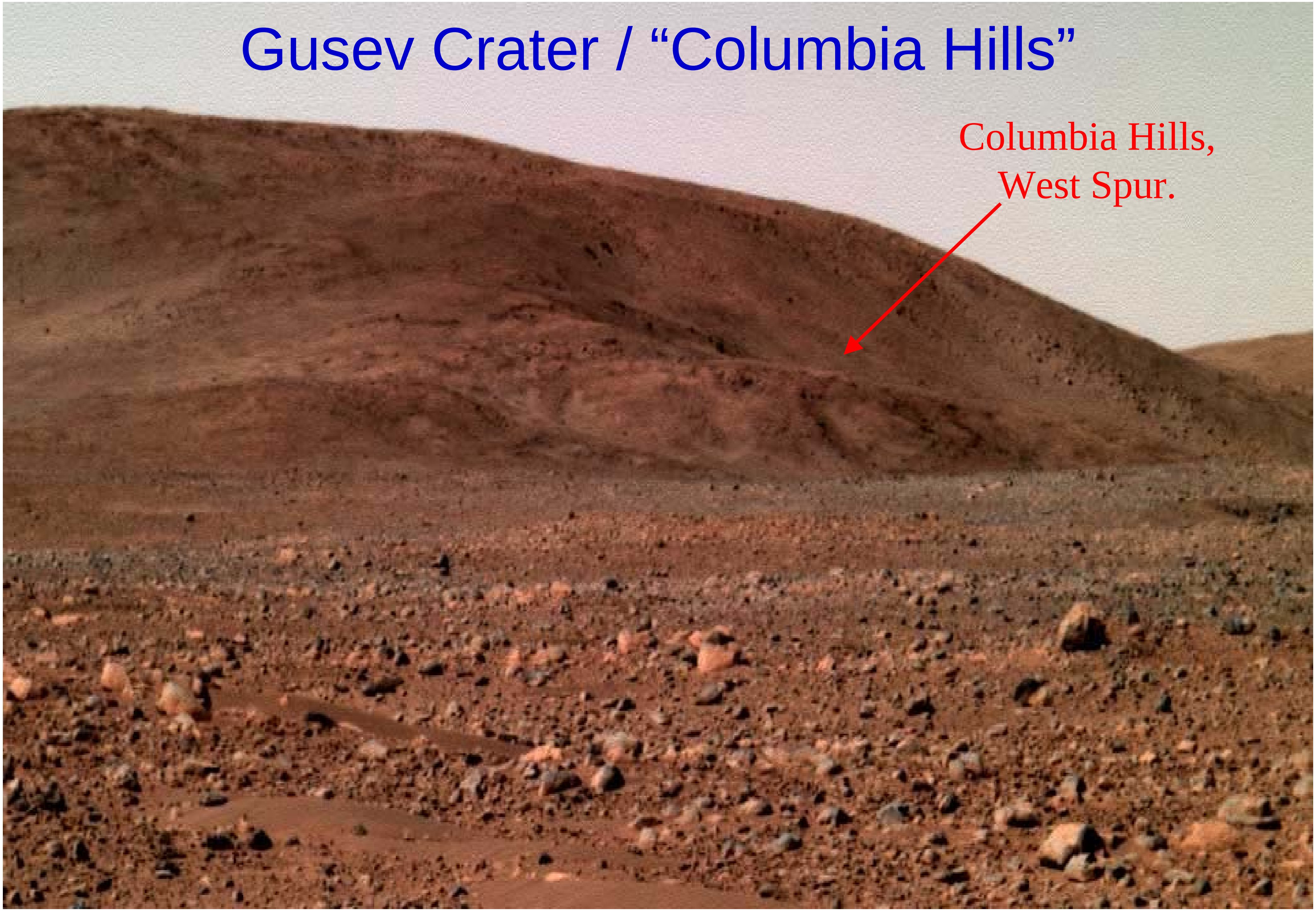
Landing sites on Mars:
Follow the water !



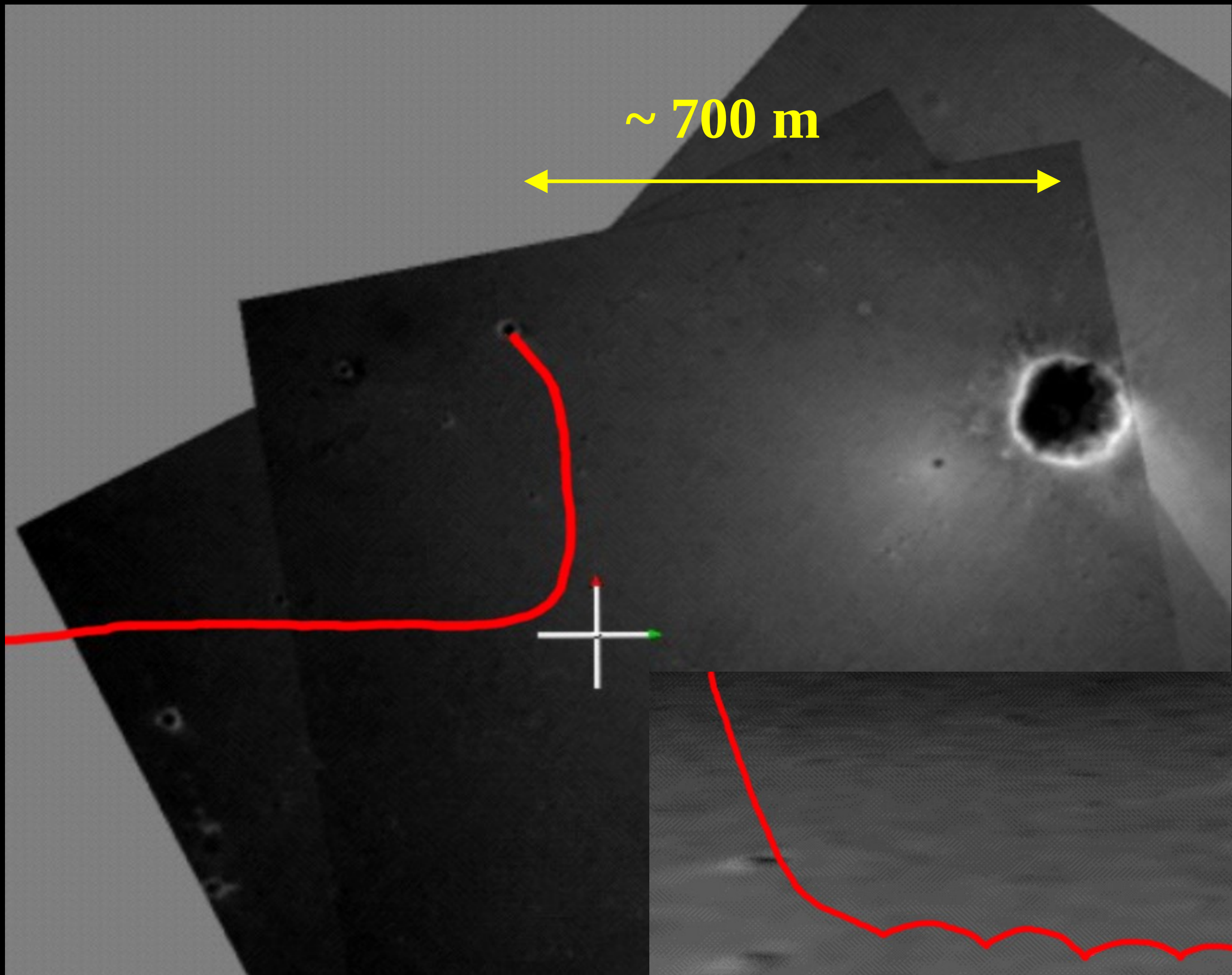
Gusev Crater, Mars

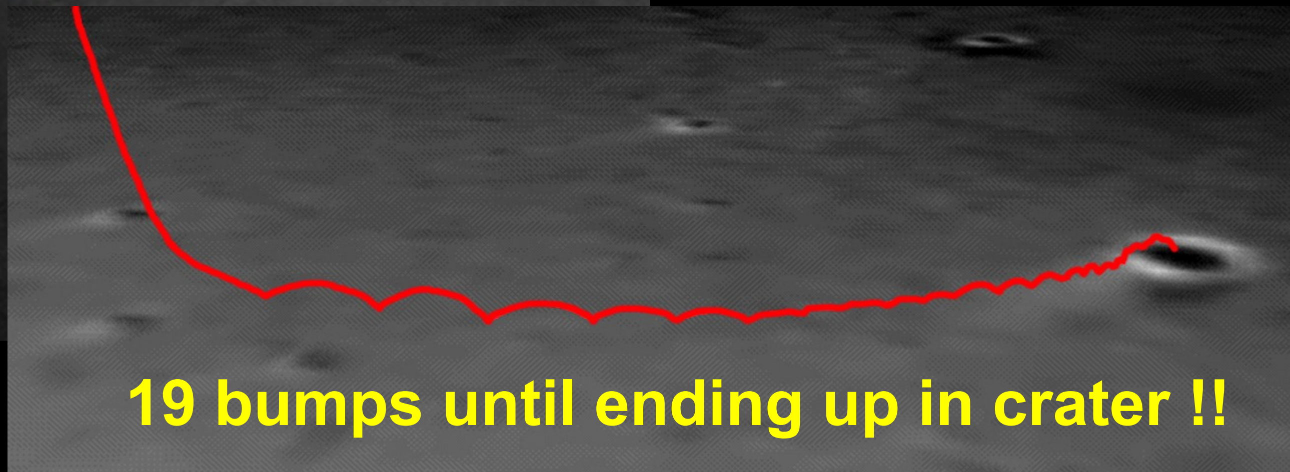


Gusev Crater / “Columbia Hills”

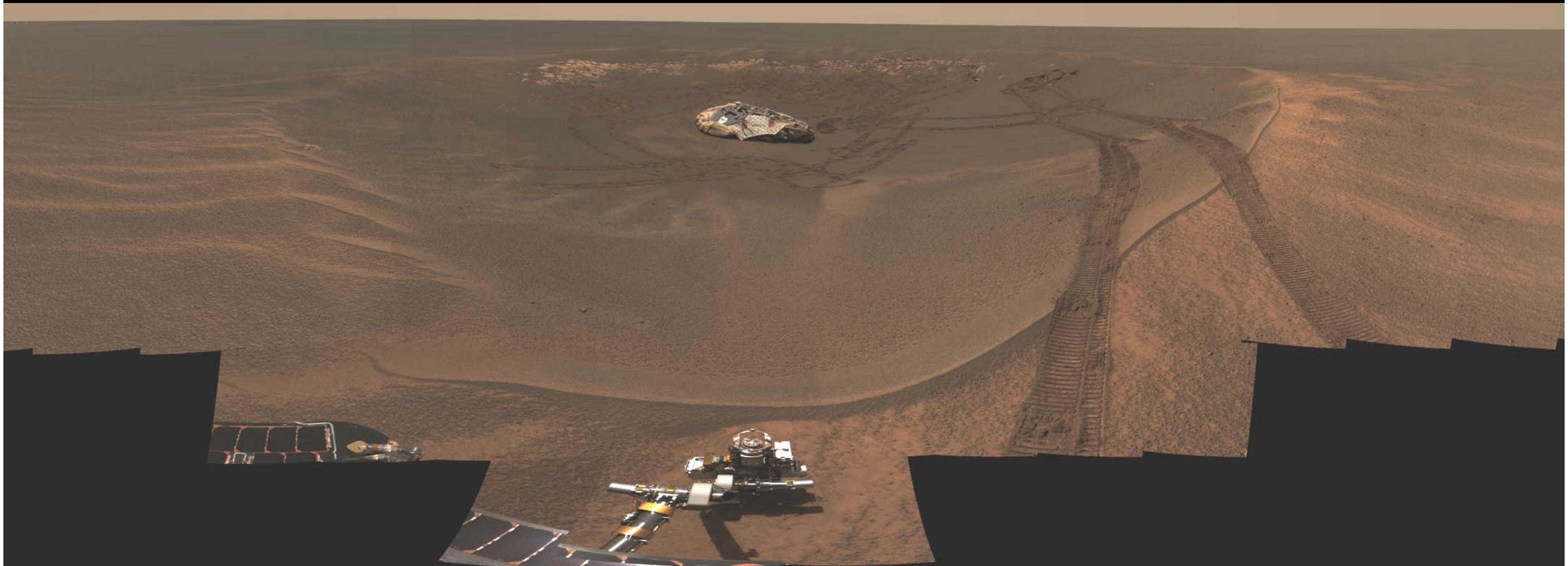


Landing- Trajectory (according to real data)





Landing site ‘Eagle crater‘ / Meridiani Planum

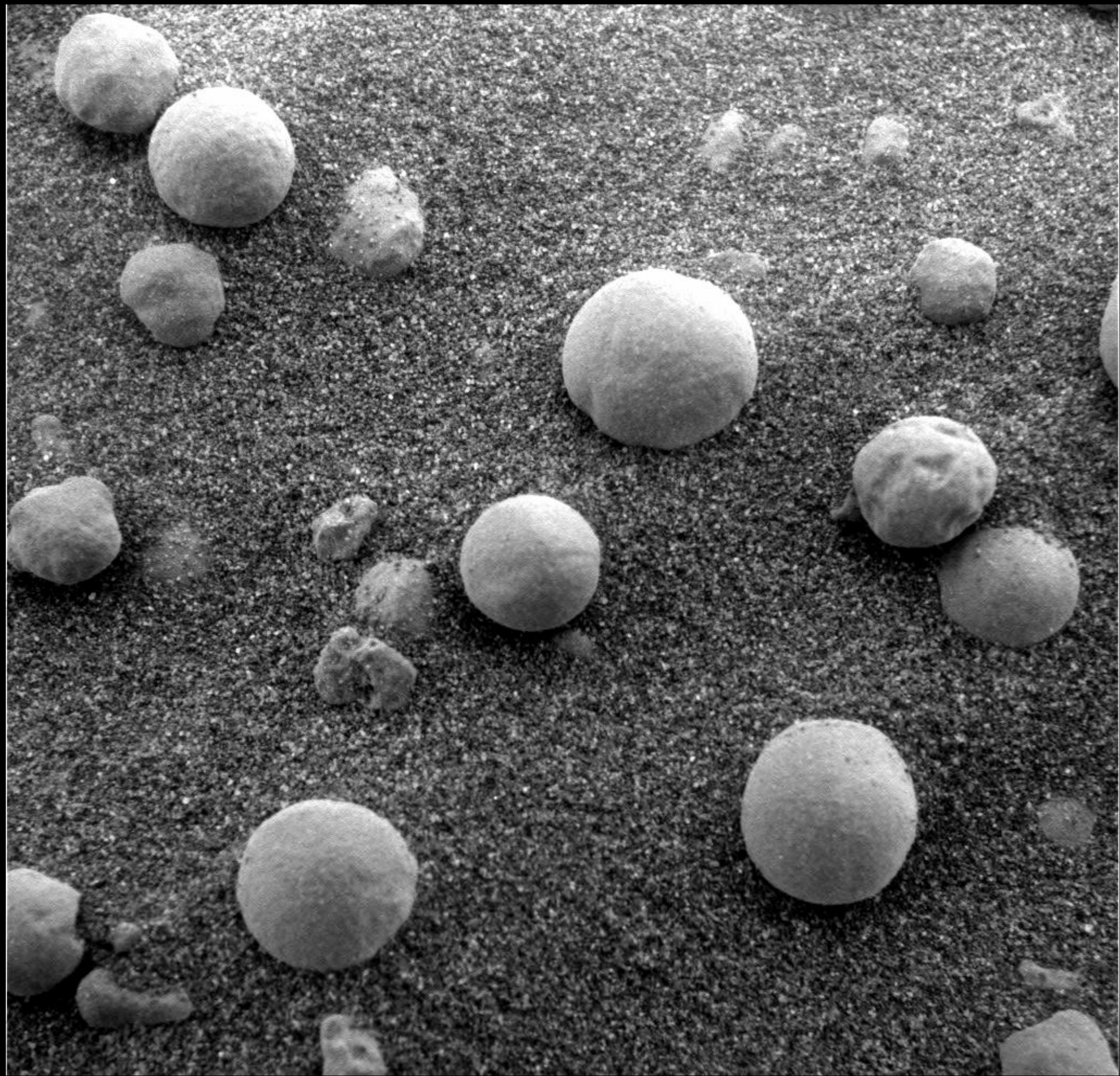


Opportunity, Meridiani Planum
0 400 800
m
Victoria Crater
Cha
Sol 968-991
Endurance Crater
Beagle Crater
Erebus Crater
Baltra
Sol 894-895
Cheyenne
Sol 819-820
Eagle Crater
Olympia
Sol 633-730
OSU Mapping and GIS Laboratory

Spherules

Blueberries

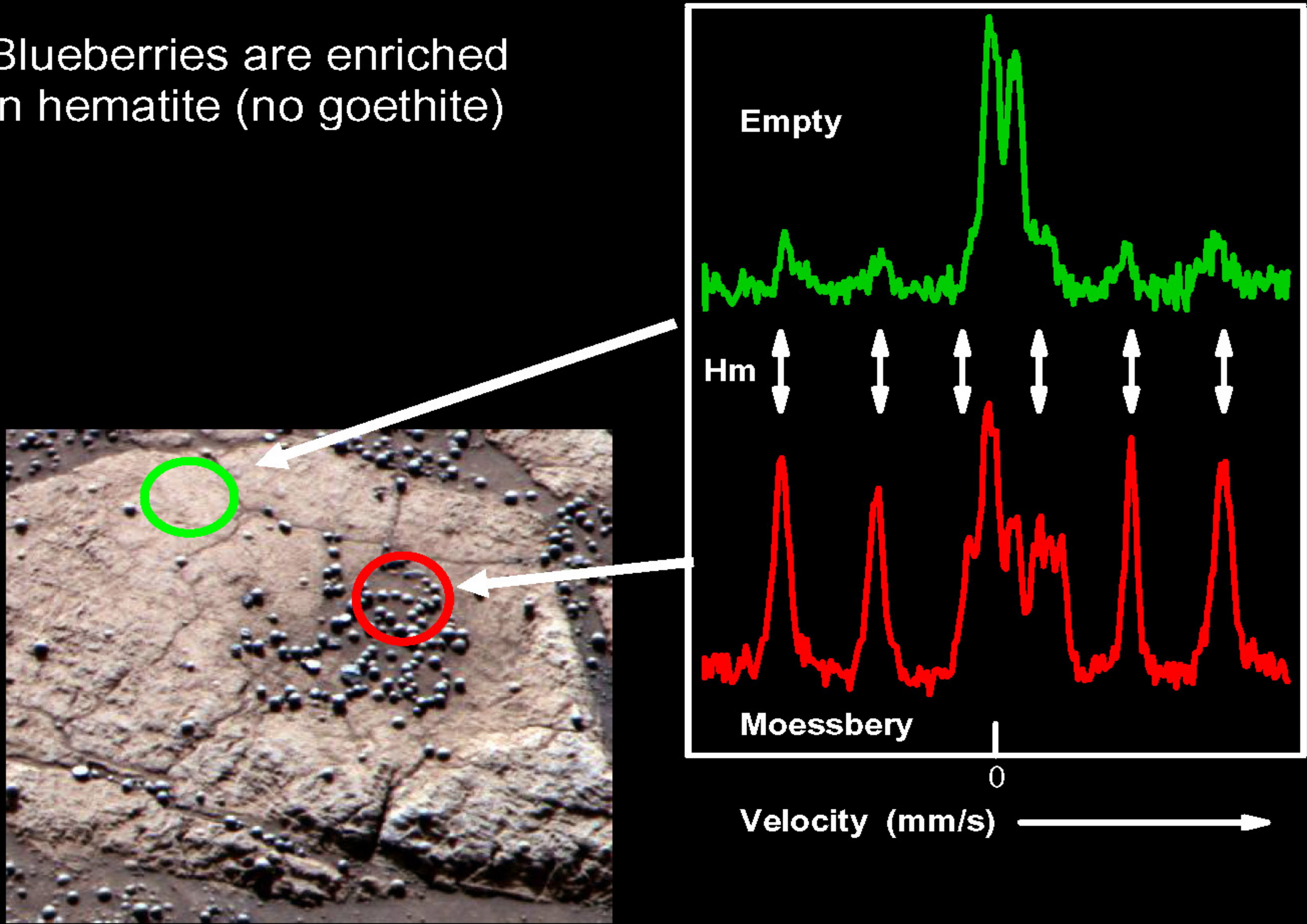
everywhere !!



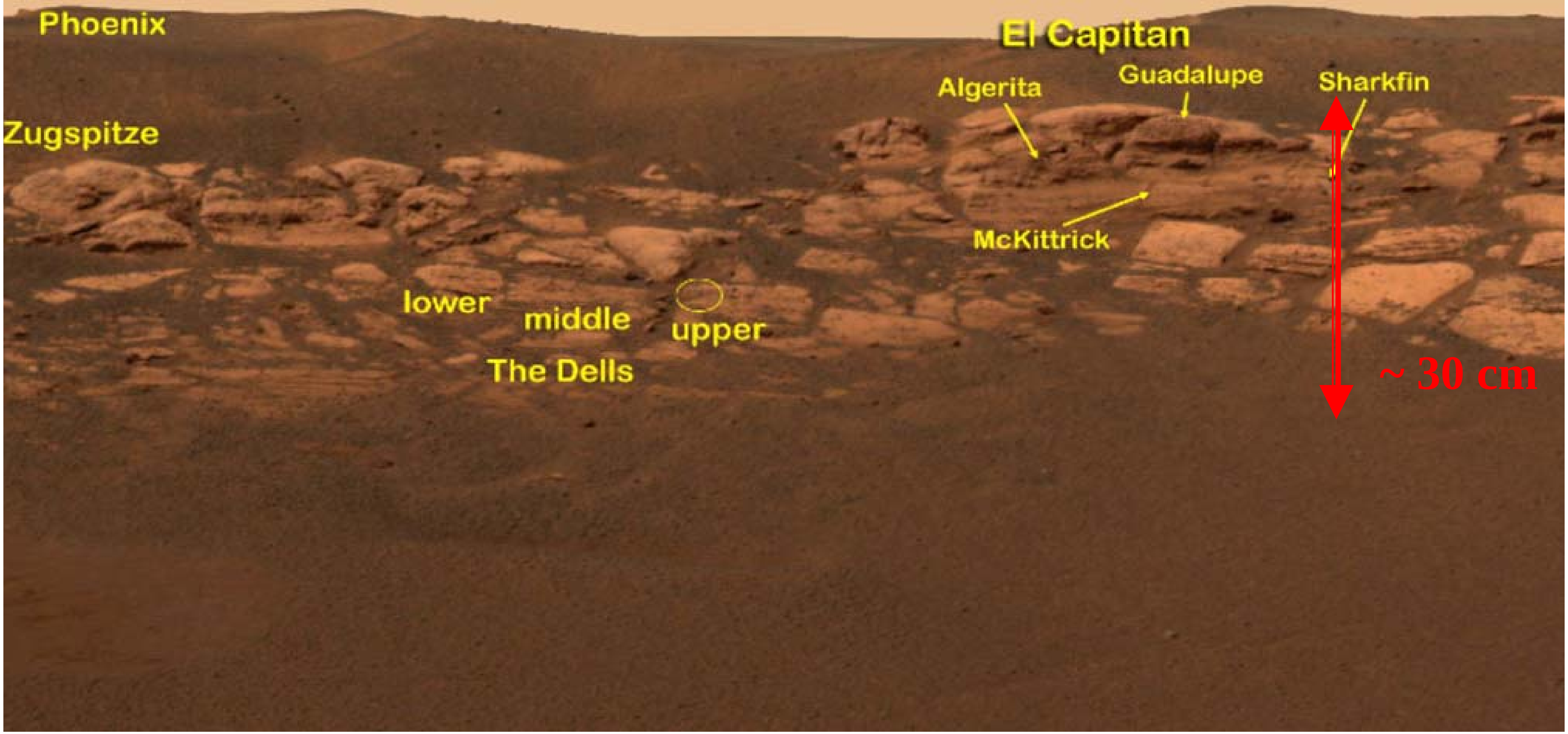
~ 3cm

What is the mineralogical composition of the “Blueberries“?

Blueberries are enriched in hematite (no goethite)

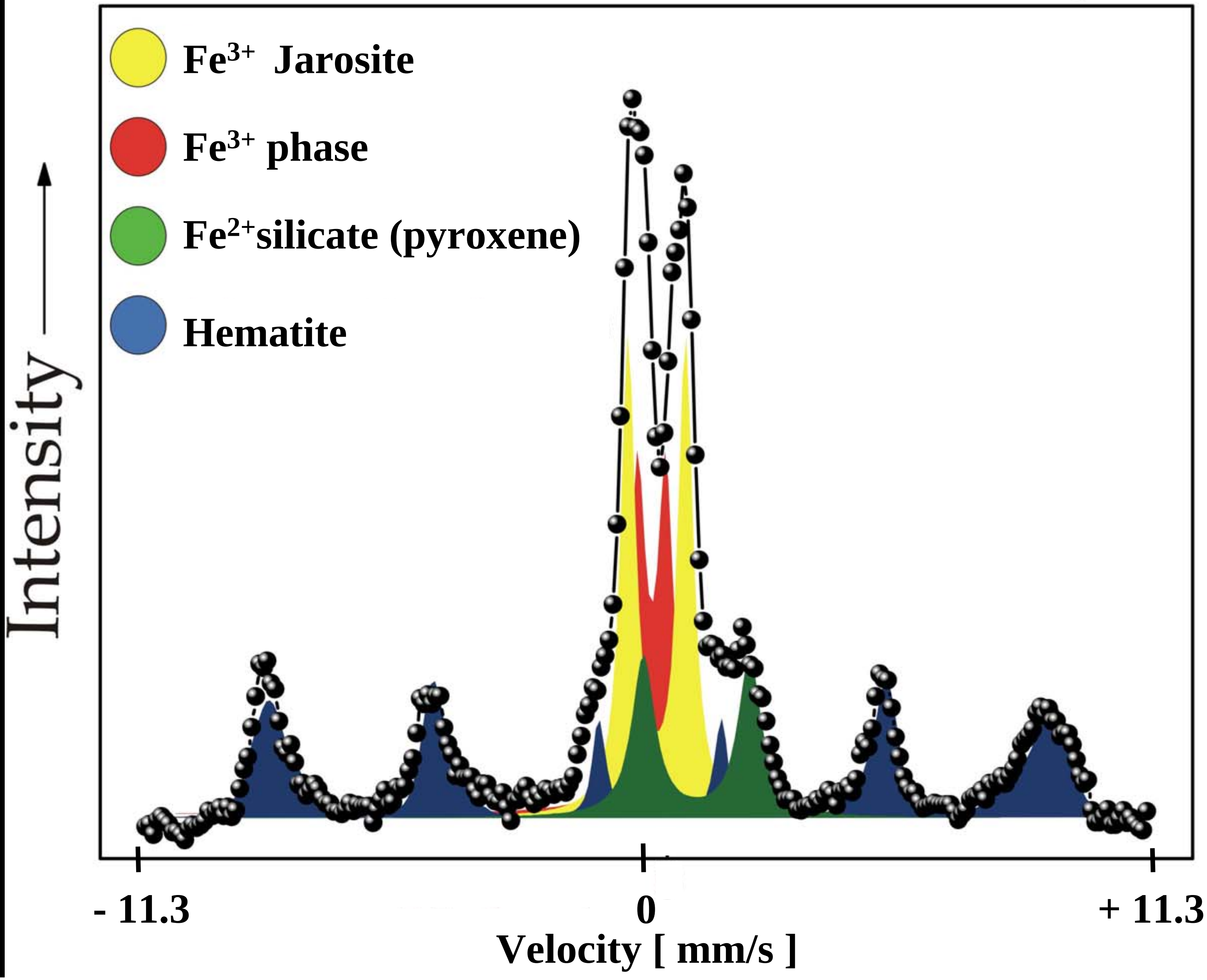


Meridiani Planum - Opportunity in Eagle crater



Mössbauer spectrum of El Capitan: Meridiani Planum

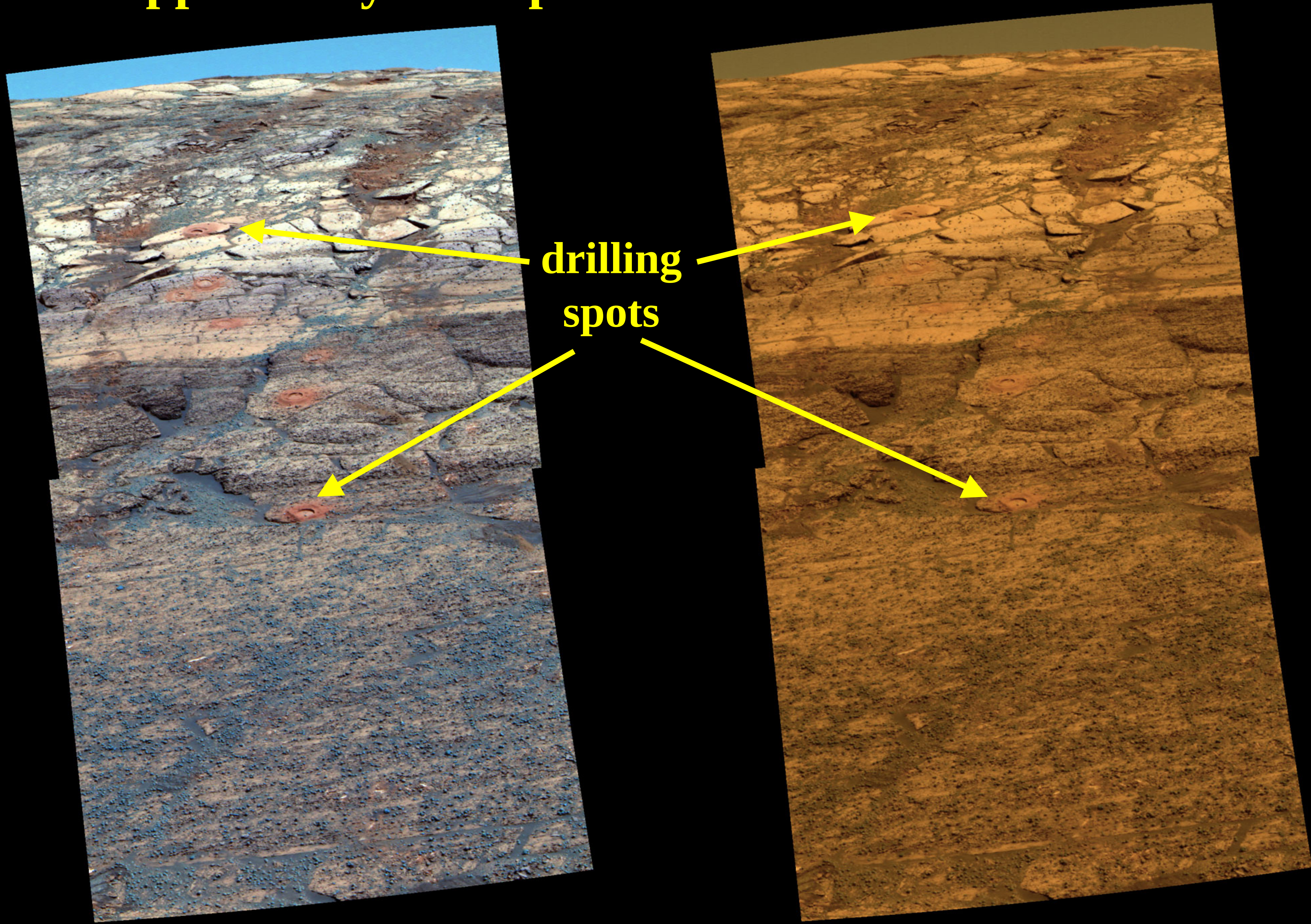
Jarosite: $(K, Na, X^{+1})Fe_3(SO_4)_2(OH)_6$



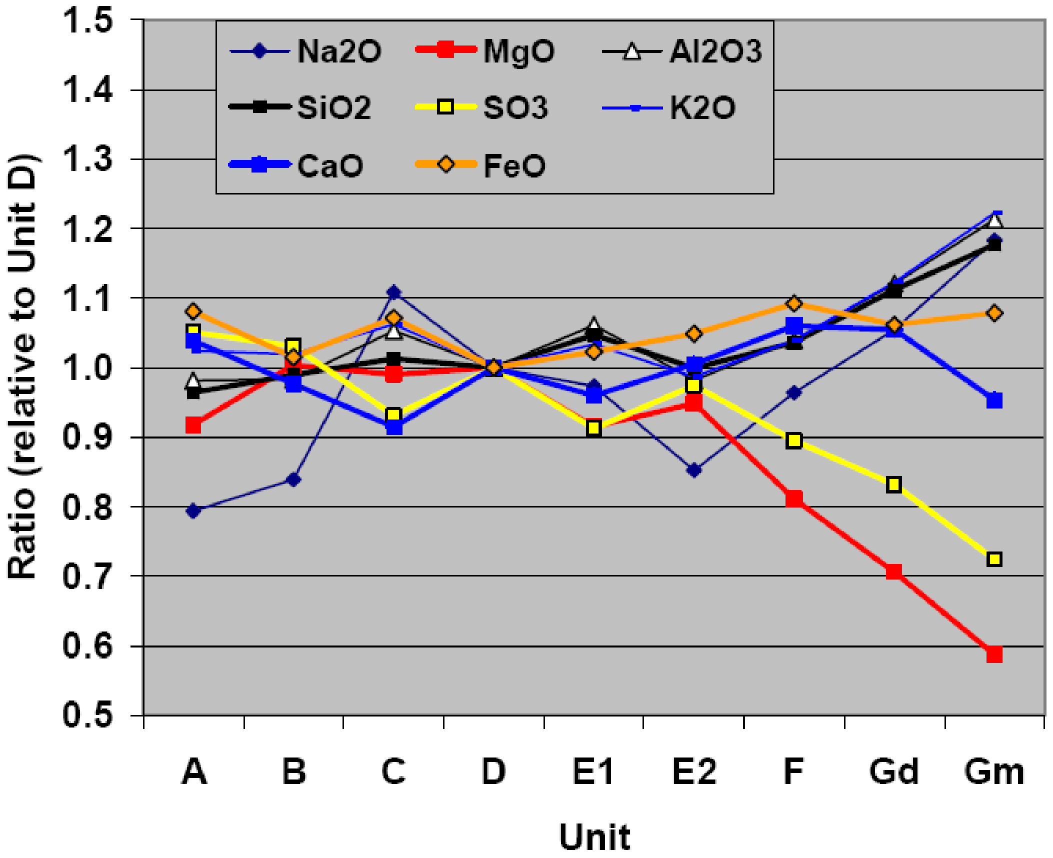
Endurance Crater
Opportunity Sol ~ 133

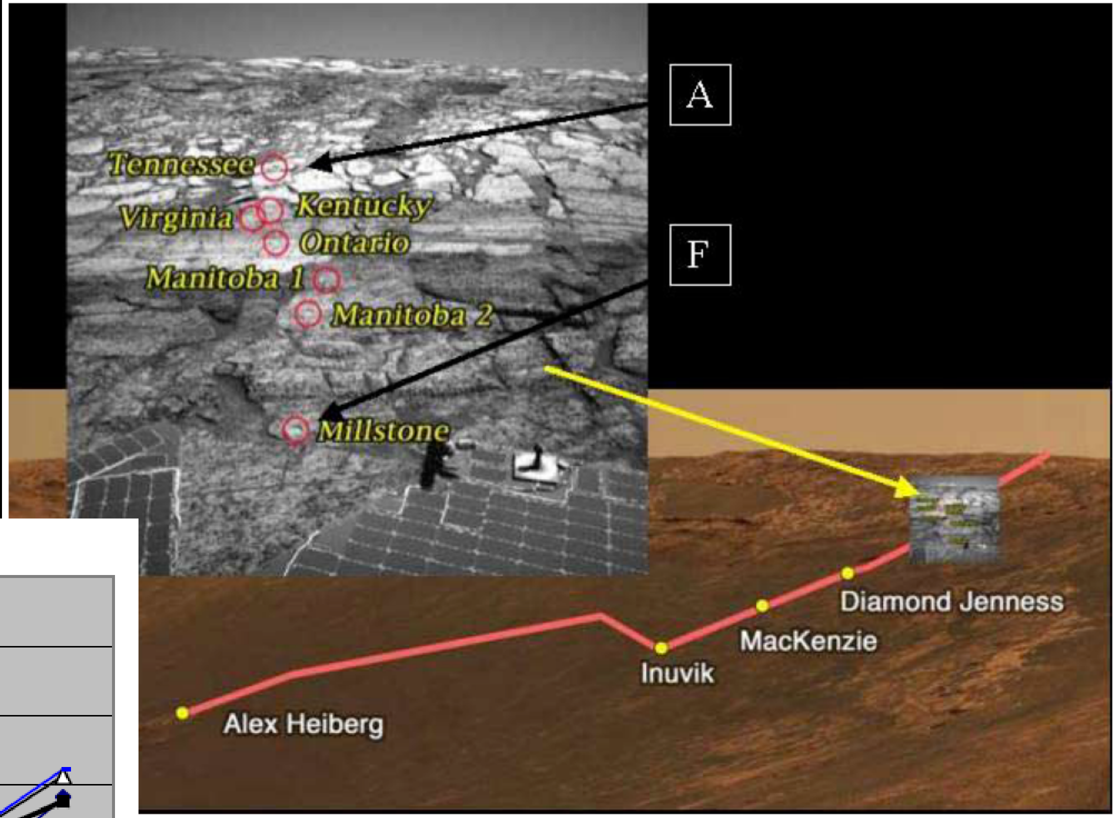
Opportunity drive path into Endurance crater

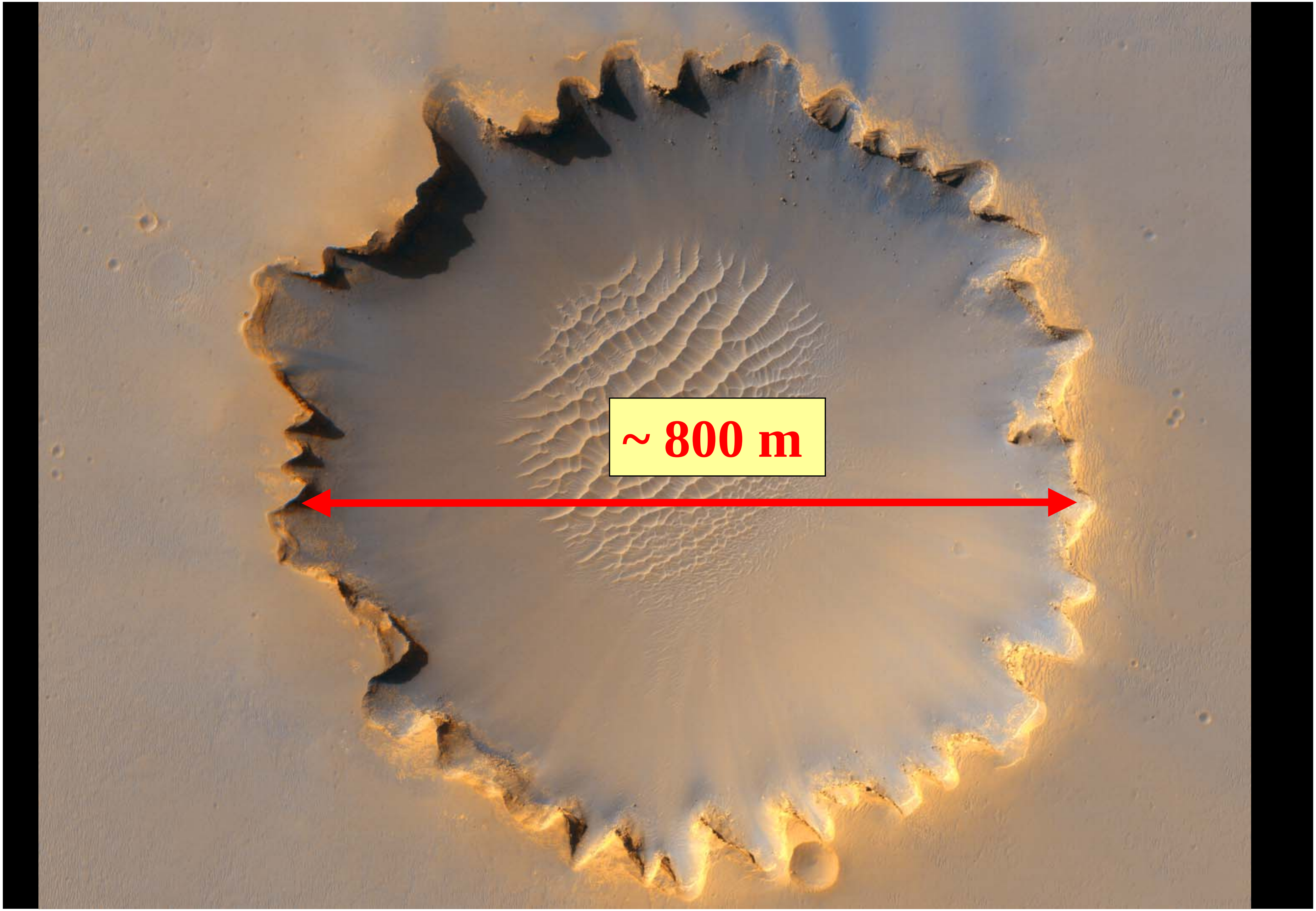
Sol 173

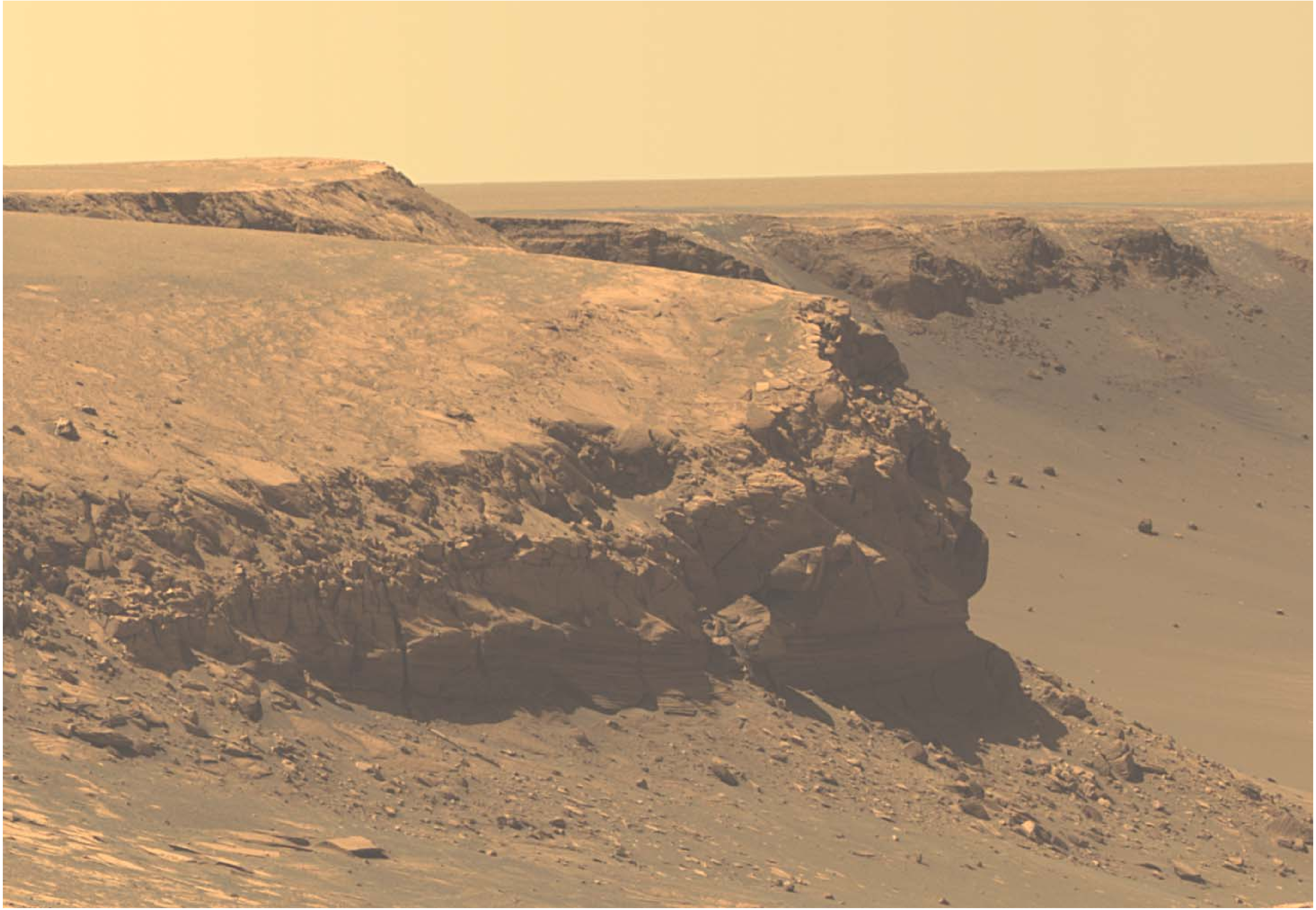


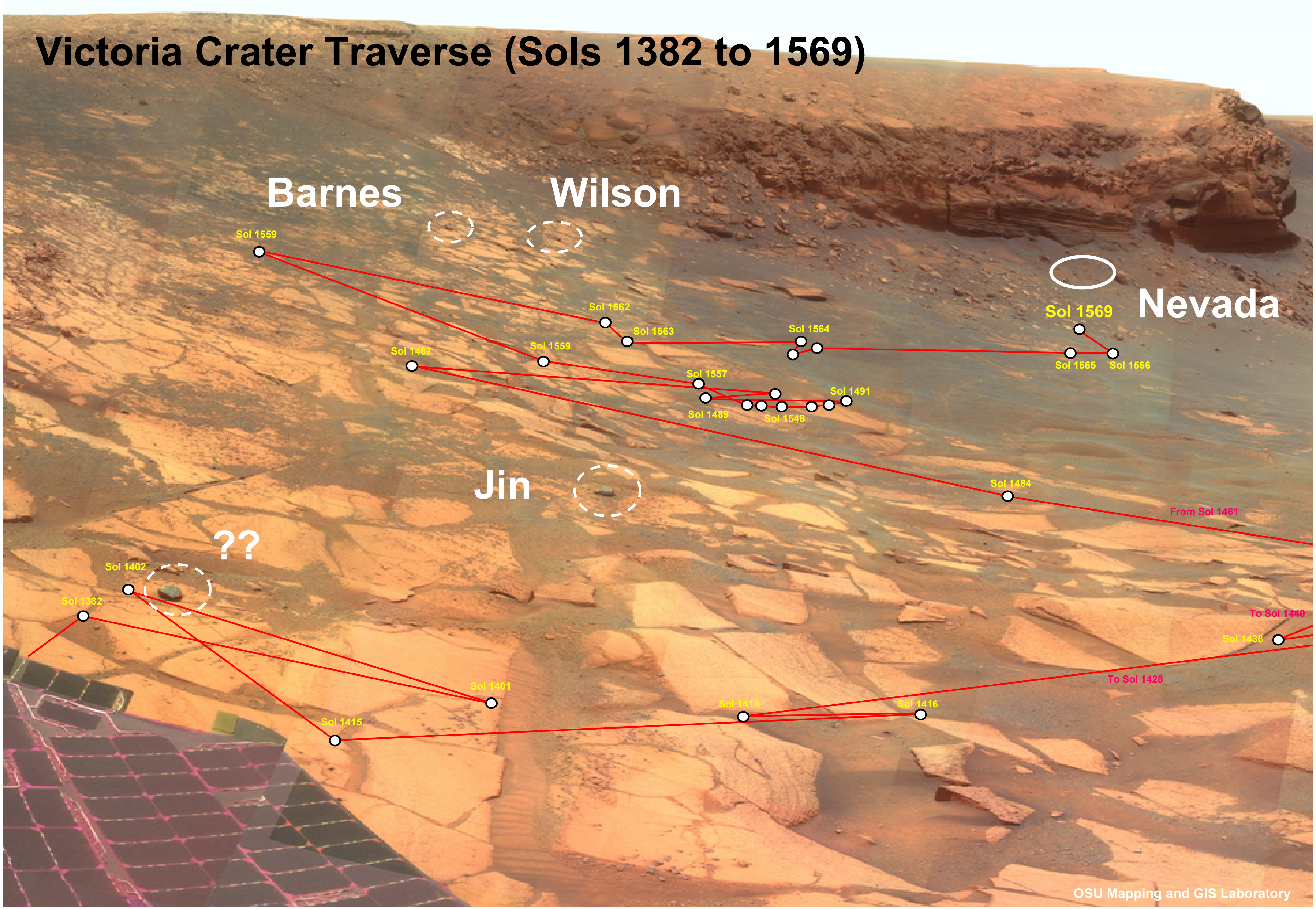
changes of element – distribution (relativ to unit D)






~ 800 m

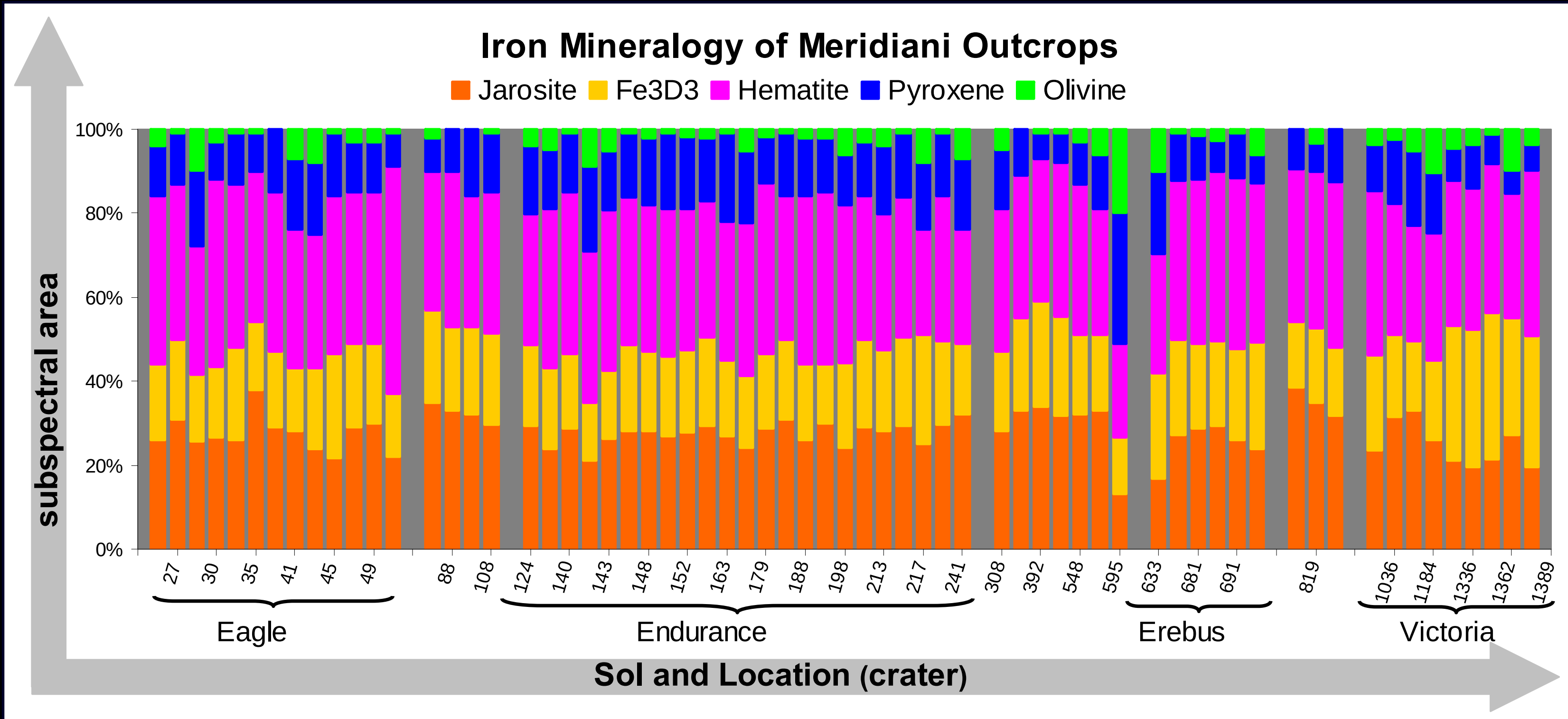


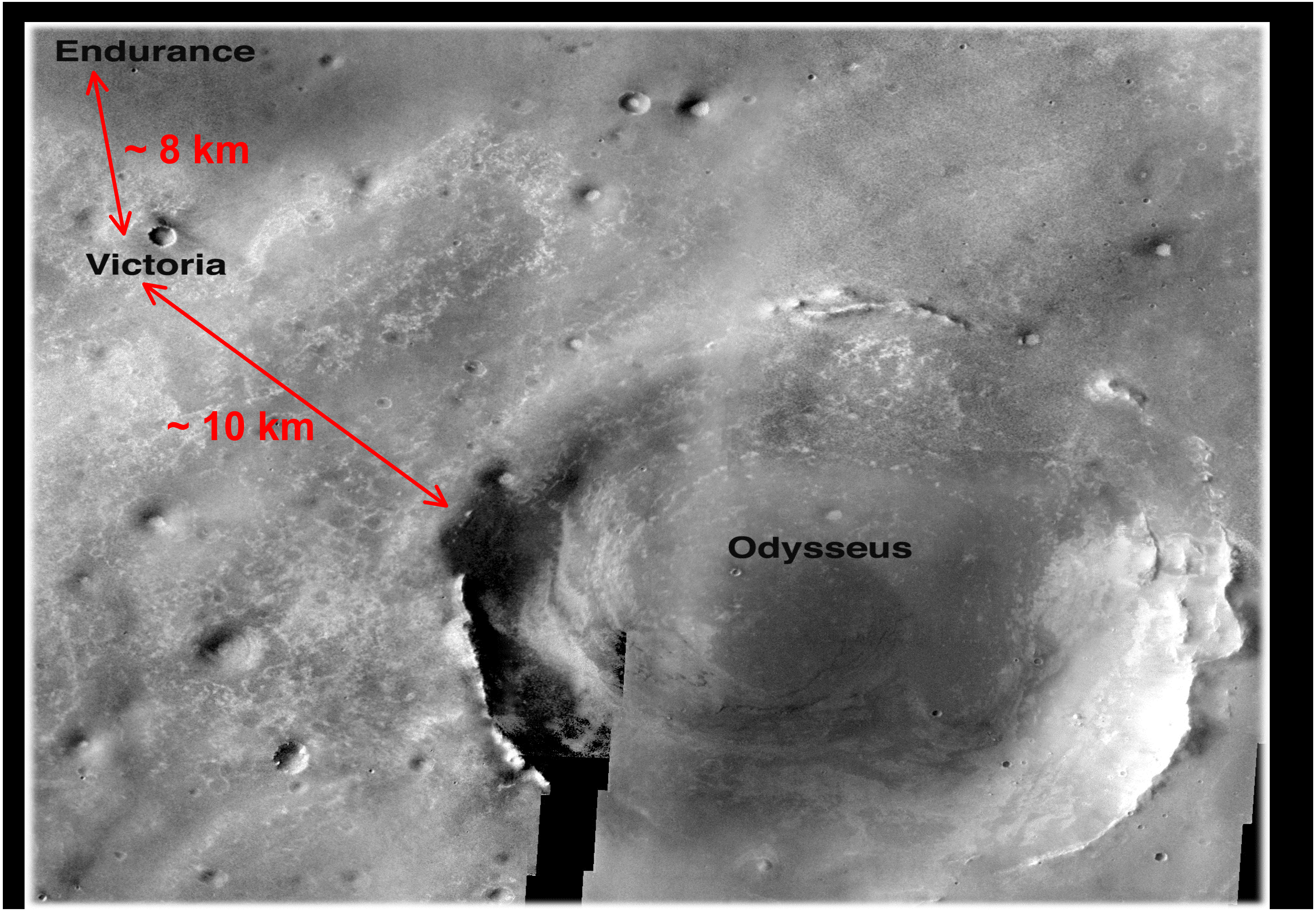


Victoria Crater Traverse (Sols 1382 to 1569)
Barnes
Wilson
Nevada
Sol 1559
Sol 1562
Sol 1563
Sol 1564
Sol 1569
Sol 1565
Sol 1566
Sol 1487
Sol 1559
Sol 1557
Sol 1491
Sol 1489
Sol 1548
Jin
Sol 1484
From Sol 1461
??
Sol 1402
Sol 1382
To Sol 1440
Sol 1438
To Sol 1428
Sol 1401
Sol 1418
Sol 1416
Sol 1415
OSU Mapping and GIS Laboratory

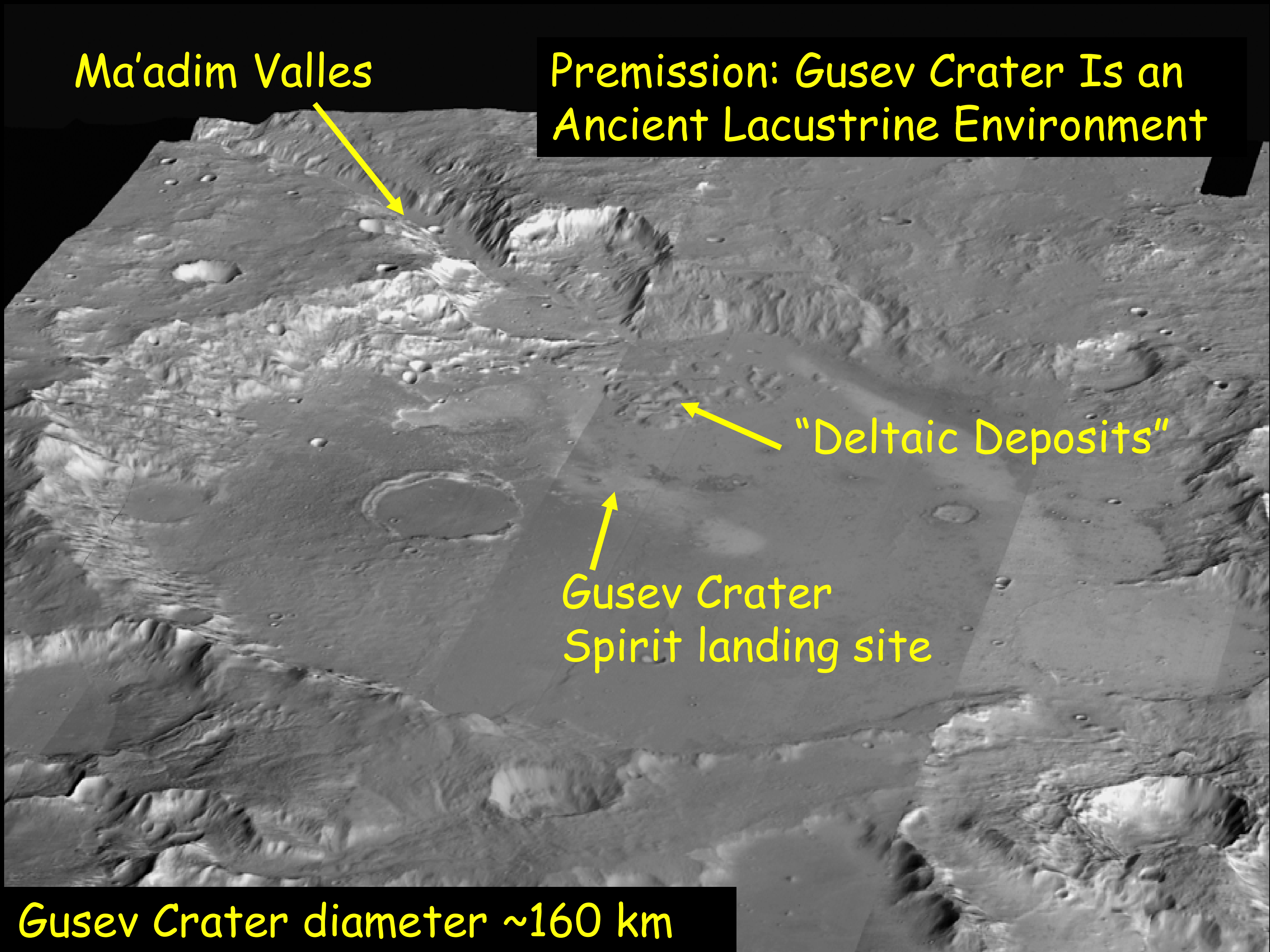
Sulfates at Meridiani Planum, Mars

Jarosite Distribution

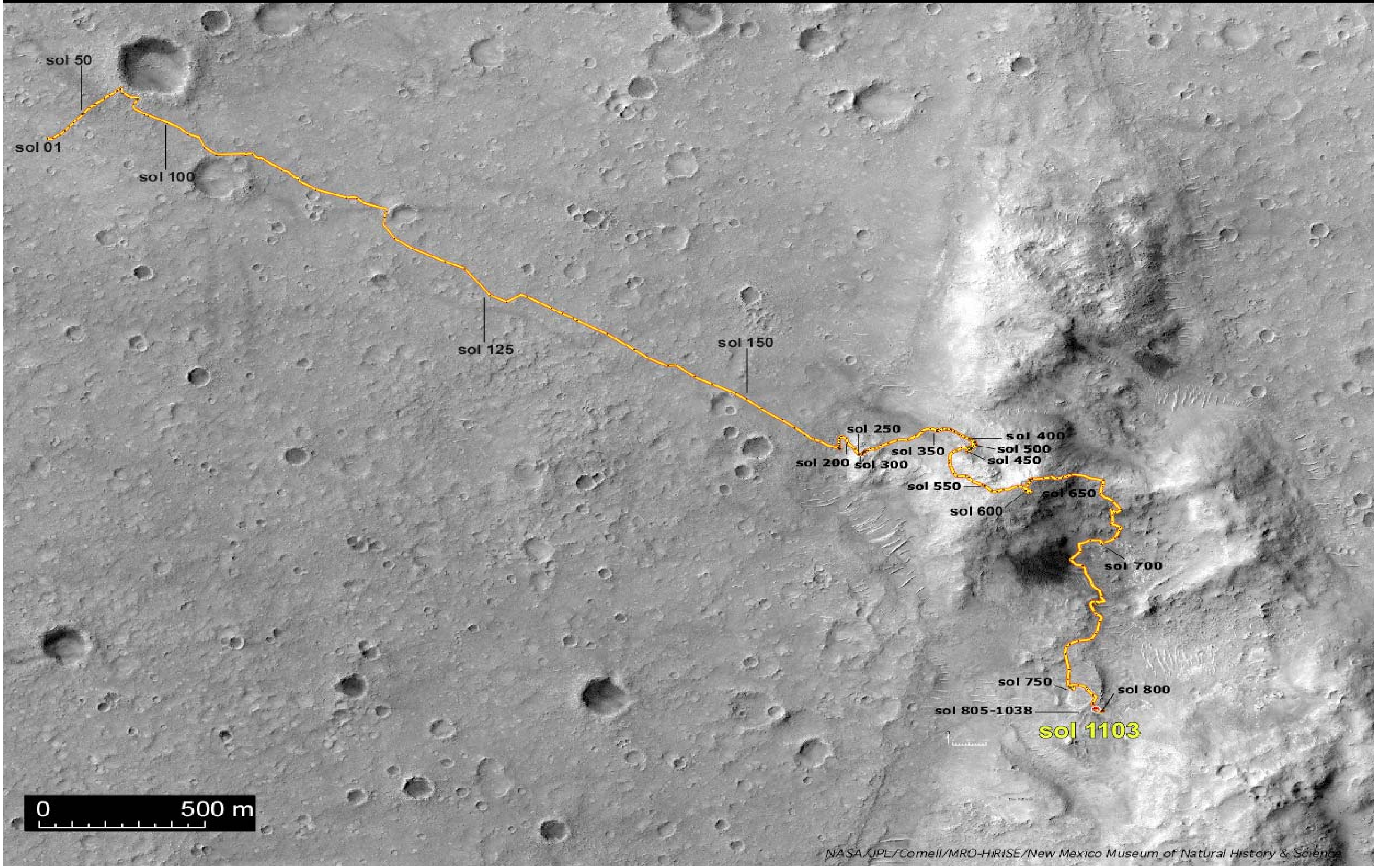



Endurance
~ 8 km
Victoria
~ 10 km
Odysseus

Gusev Crater, Mars

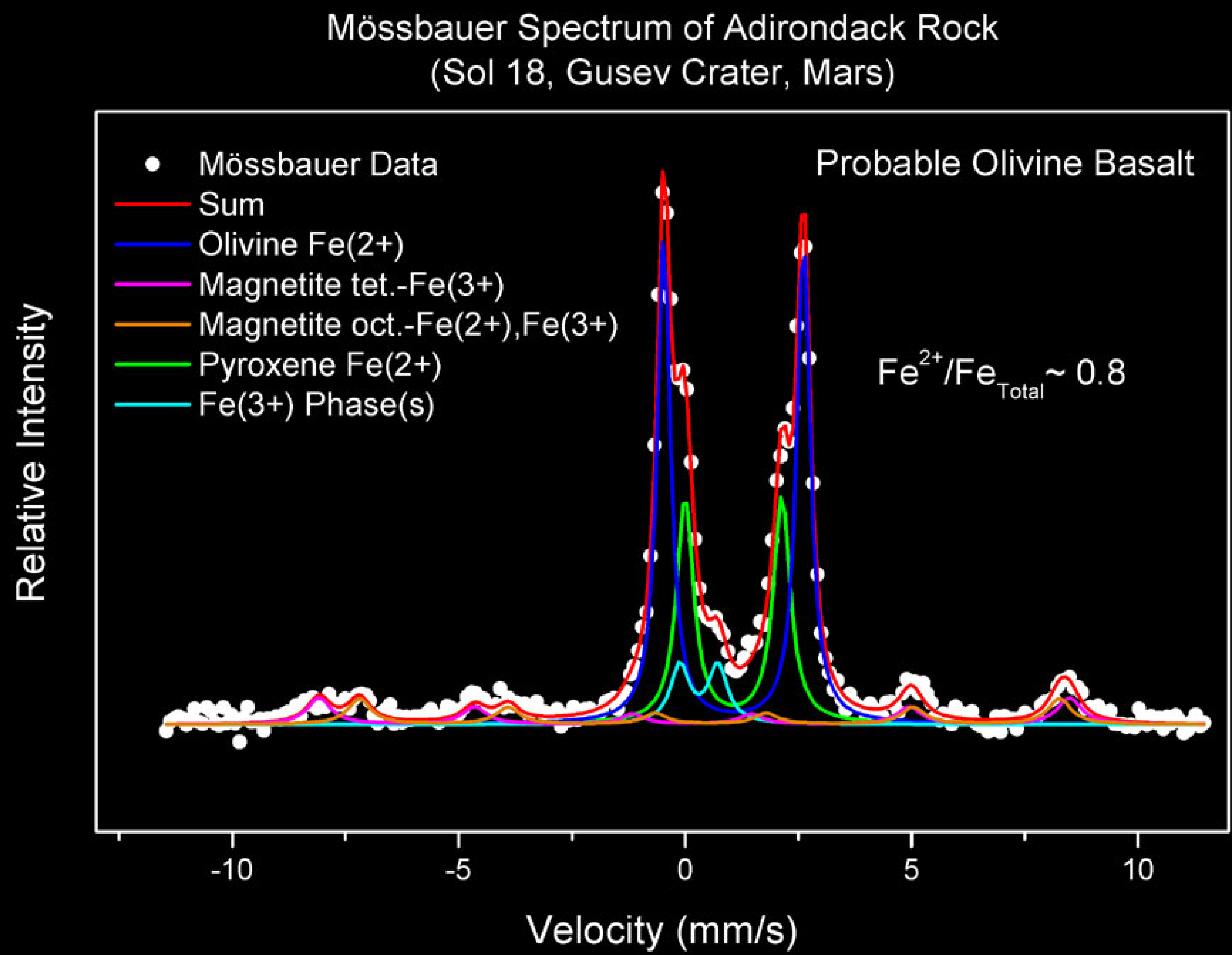


Spirit in Gusev Crater



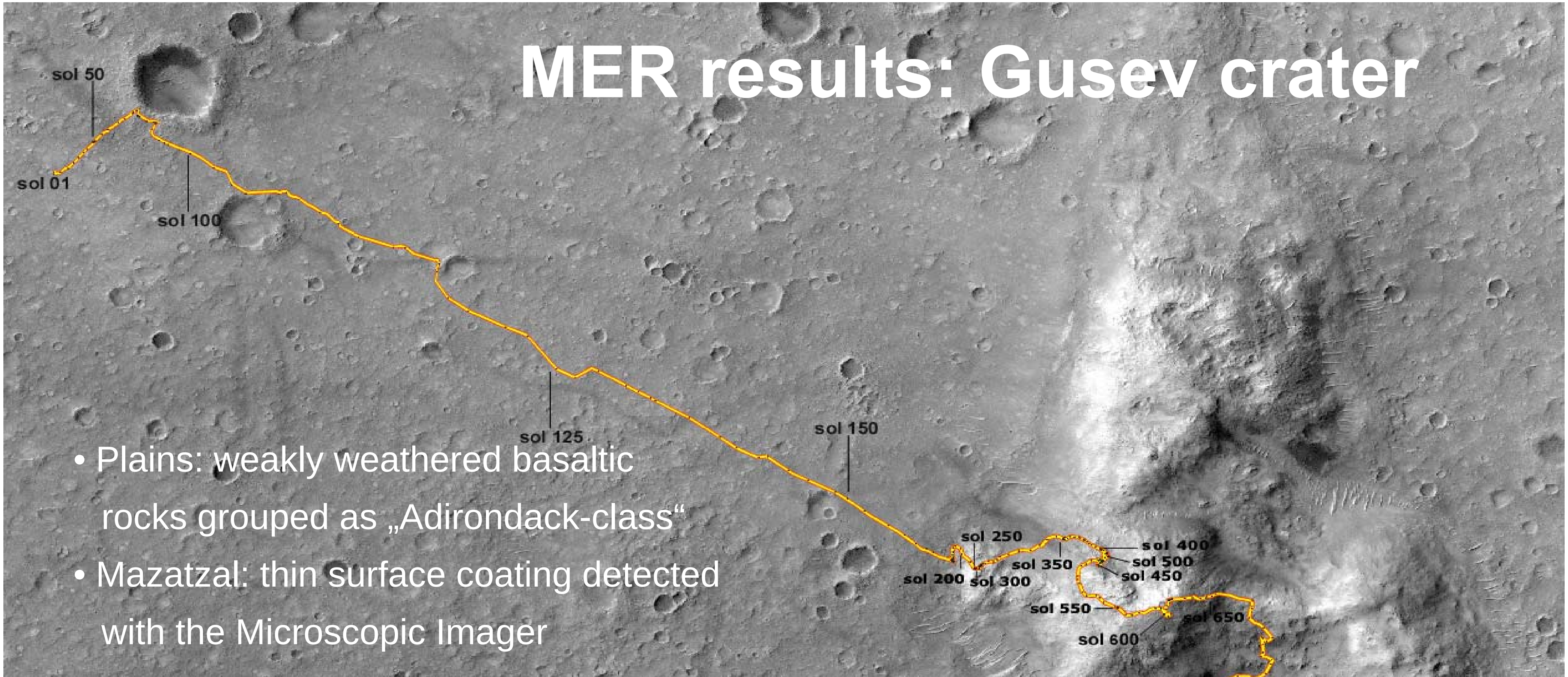
Sol 55 Brushing at rock ‘Humphrey‘ / lots of dust !!

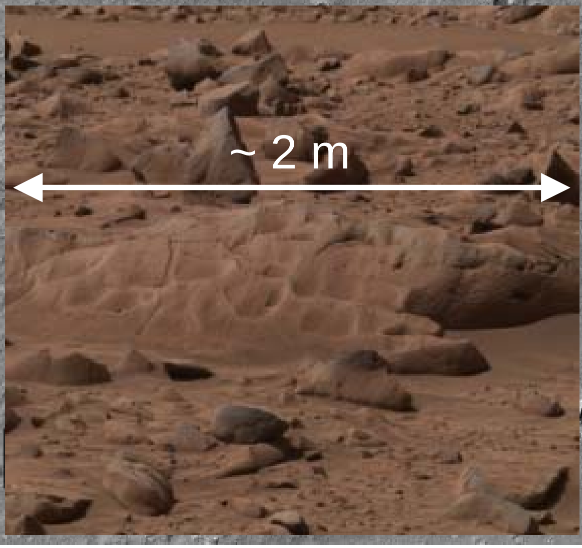
Mössbauer Spectrum of "Adirondack"

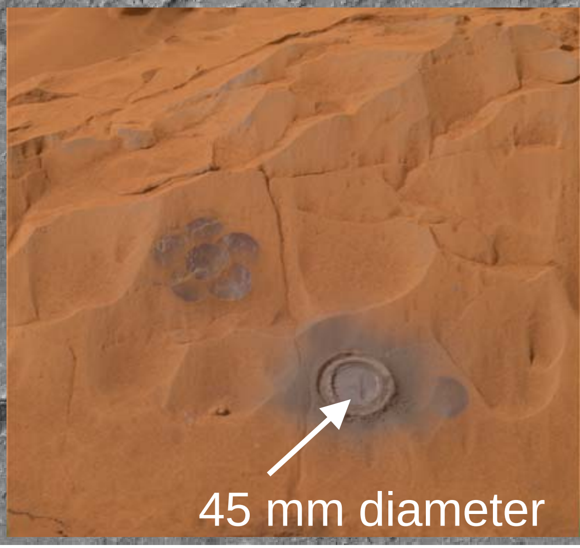


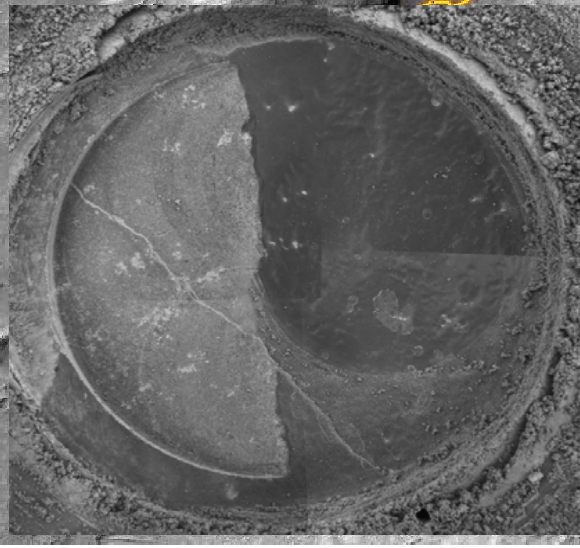
MER results: Gusev crater

- Plains: weakly weathered basaltic rocks grouped as „Adirondack-class“
- Mazatzal: thin surface coating detected with the Microscopic Imager

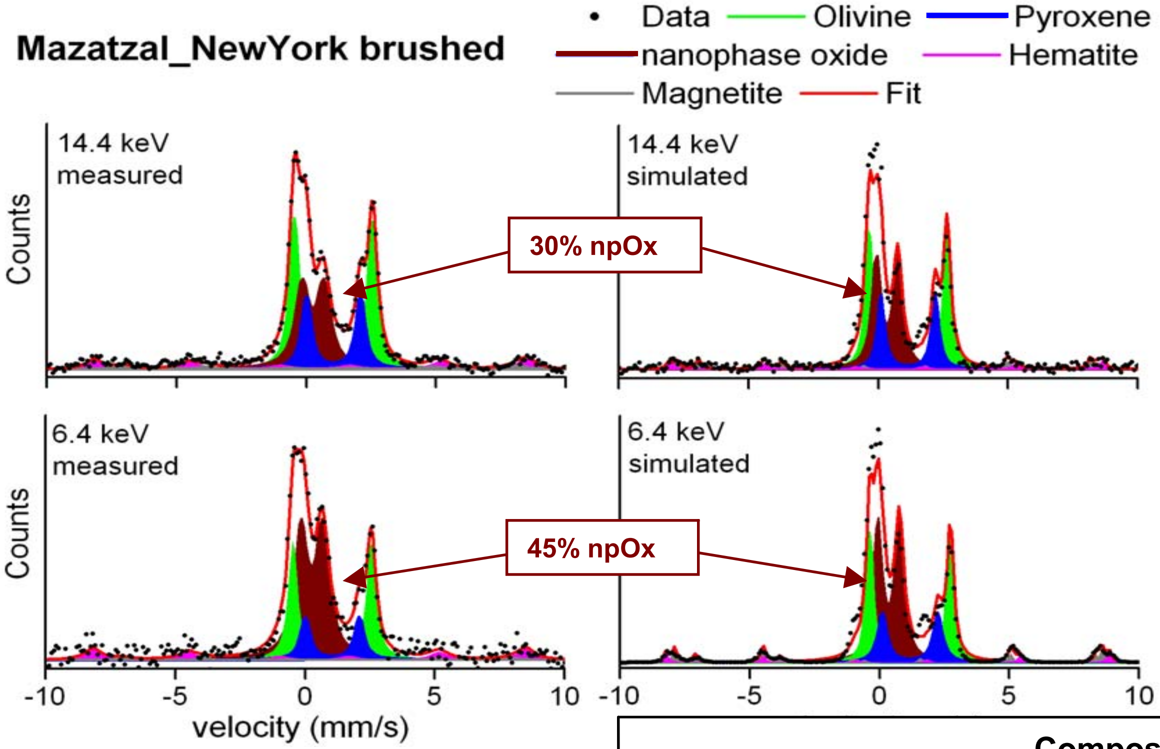








Mazatzal



npOx: weathering product

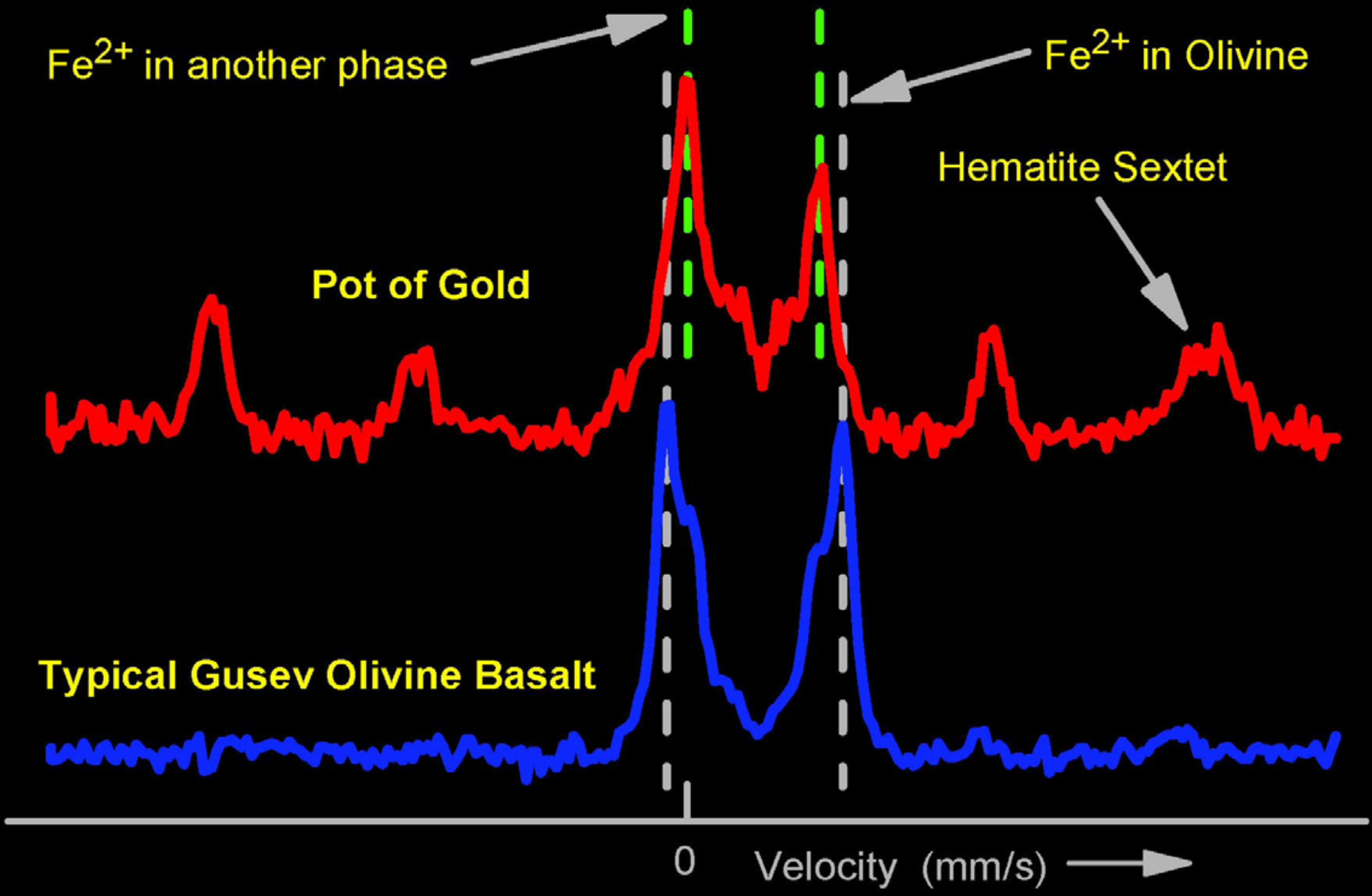
Simulation of a coating with **10 µm** thickness compares best to measured spectra

Simulation uses SiO_2 to account for Fe-absent phases

Composition of Mazatzal (wt %)		
Mineral	**Interior**	**Coating**
Olivine (50% Fe_2SiO_4 + 50% Mg_2SiO_4)	40%	-
Pyroxene (33%$CaFeSi_2O_6$ + 33%$CaMgSi_2O_6$+ 33%$MgFeSi_2O_6$)	30%	-
Nanophase Oxide (50%Fe_2O_3+50%SiO_2)	20%	80%
Magnetite (50%Fe_3O_4+50%SiO_2)	5%	10%
Hematite (50%Fe_2O_3+50%SiO_2)	5%	10%

Rotten Rock at Columbia Hills / Spirit _Gusev Crater

Moessbauer Spectrum of Pot of Gold

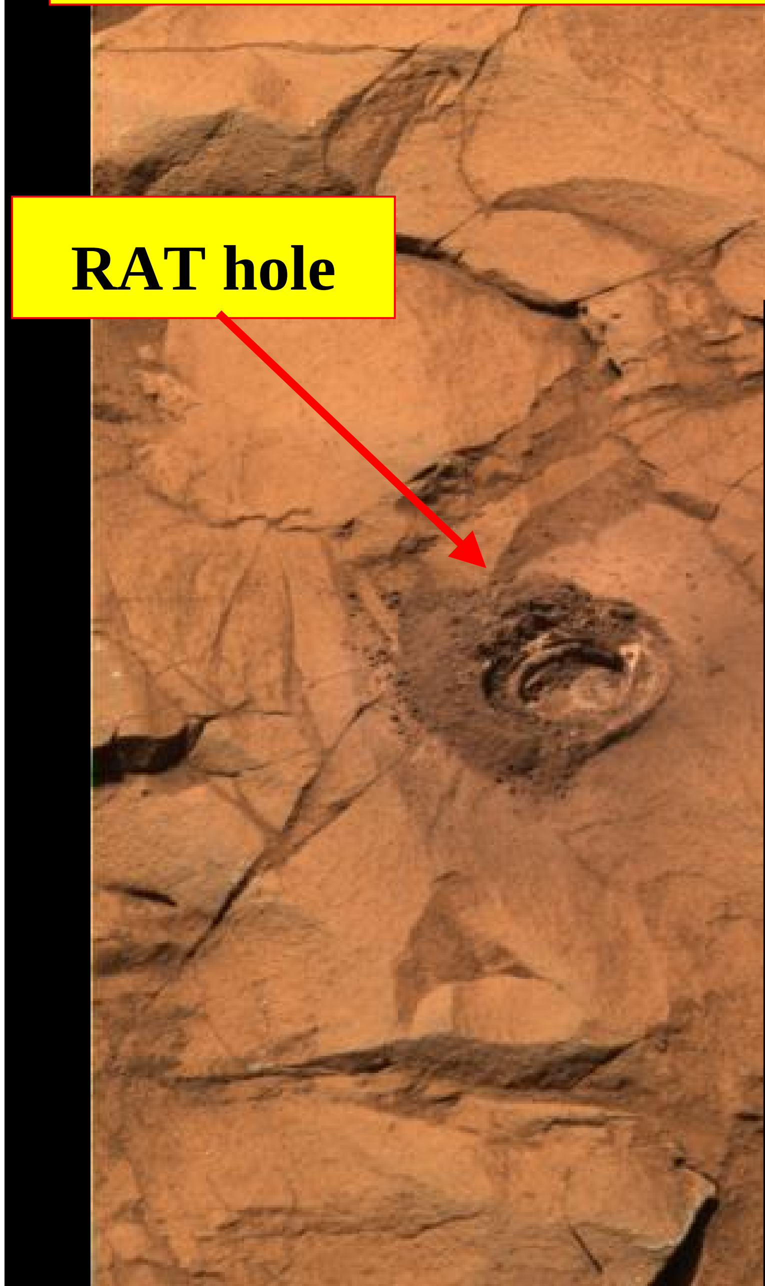


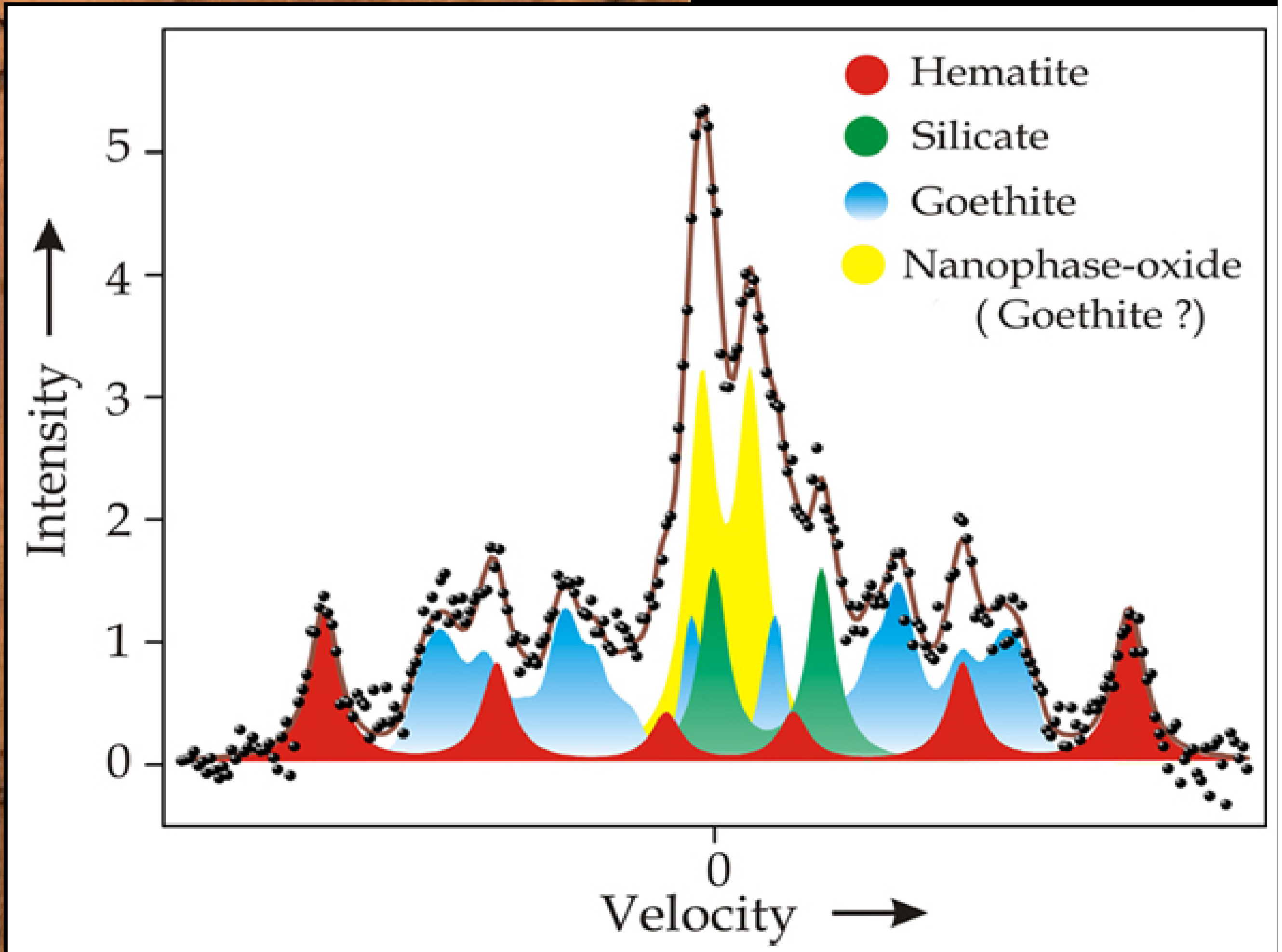
Intense Signal of hematite, no magnetite !! No Olivine !!

‚Clovis‘ in the Columb

Goethite in Columbia Hills:

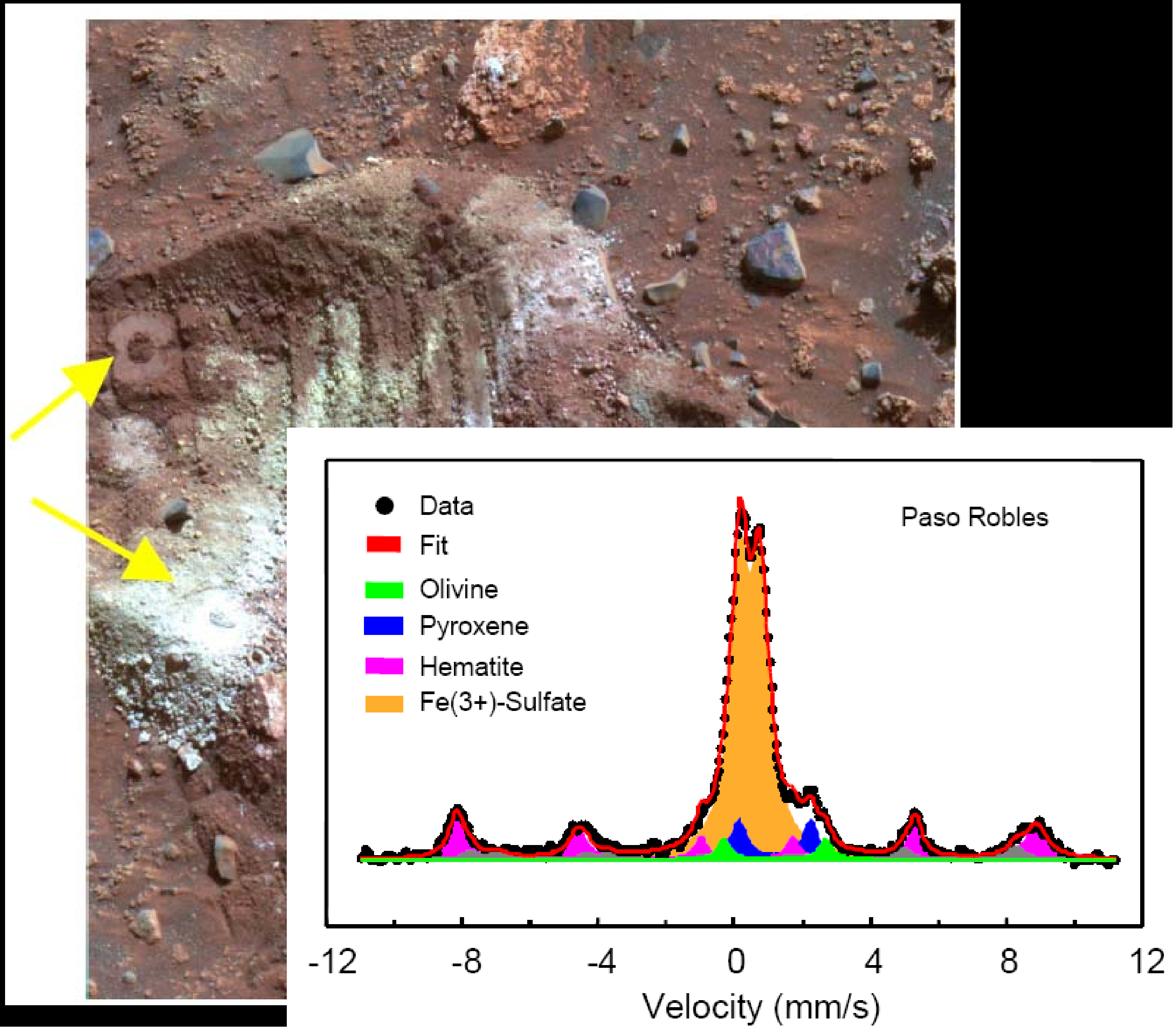
- alpha- FeOOH
- forms only in presence of water

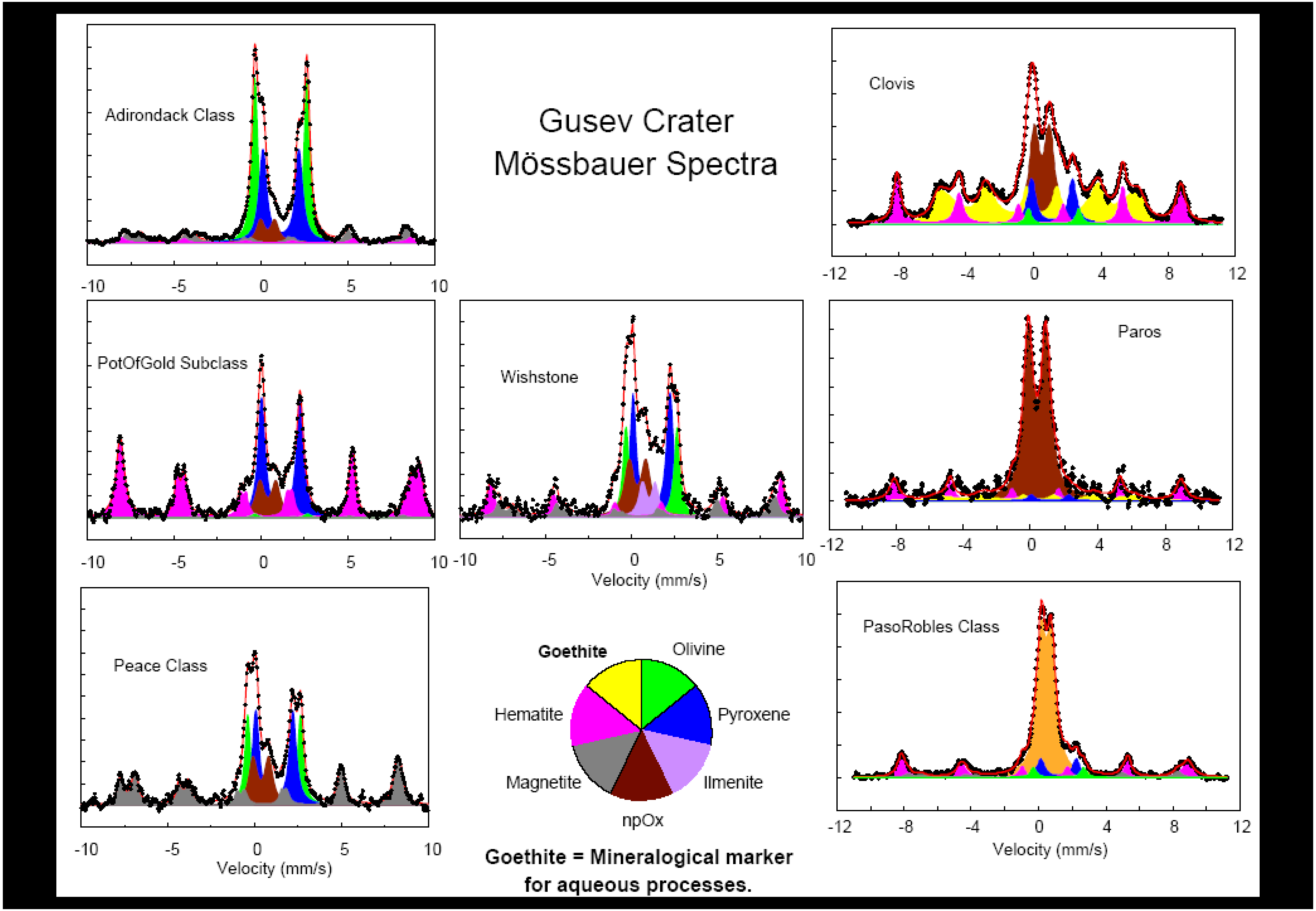


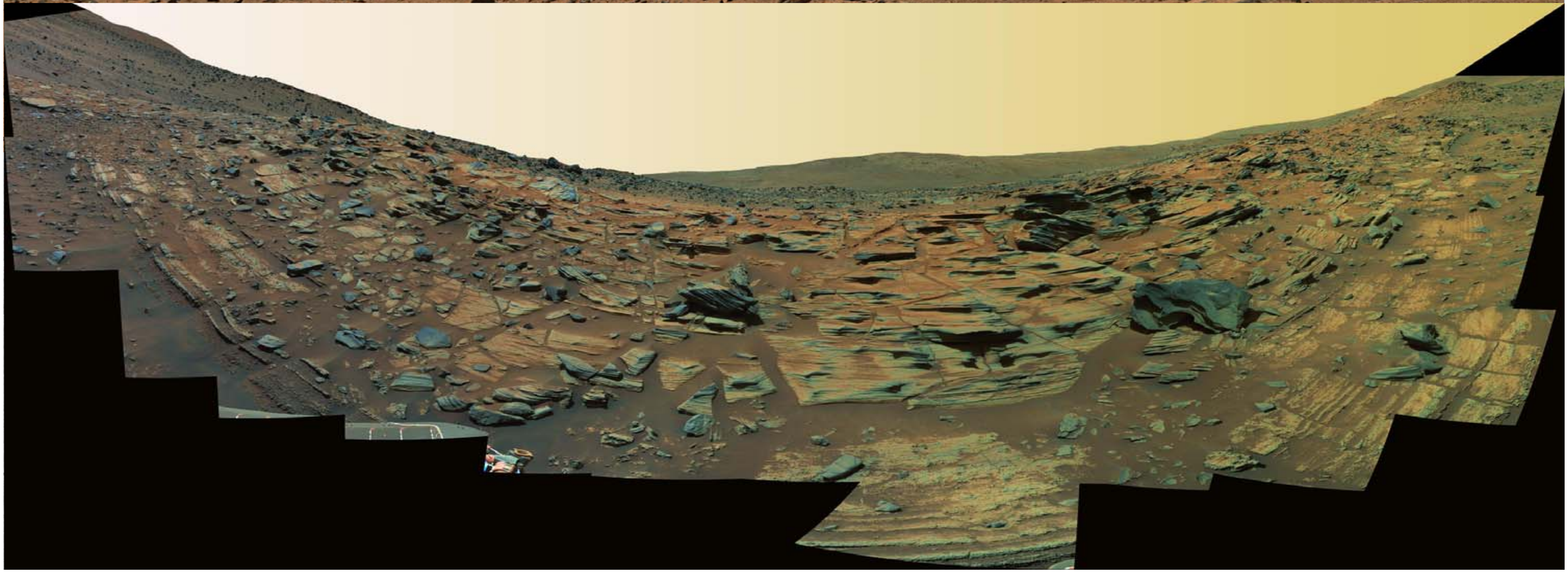


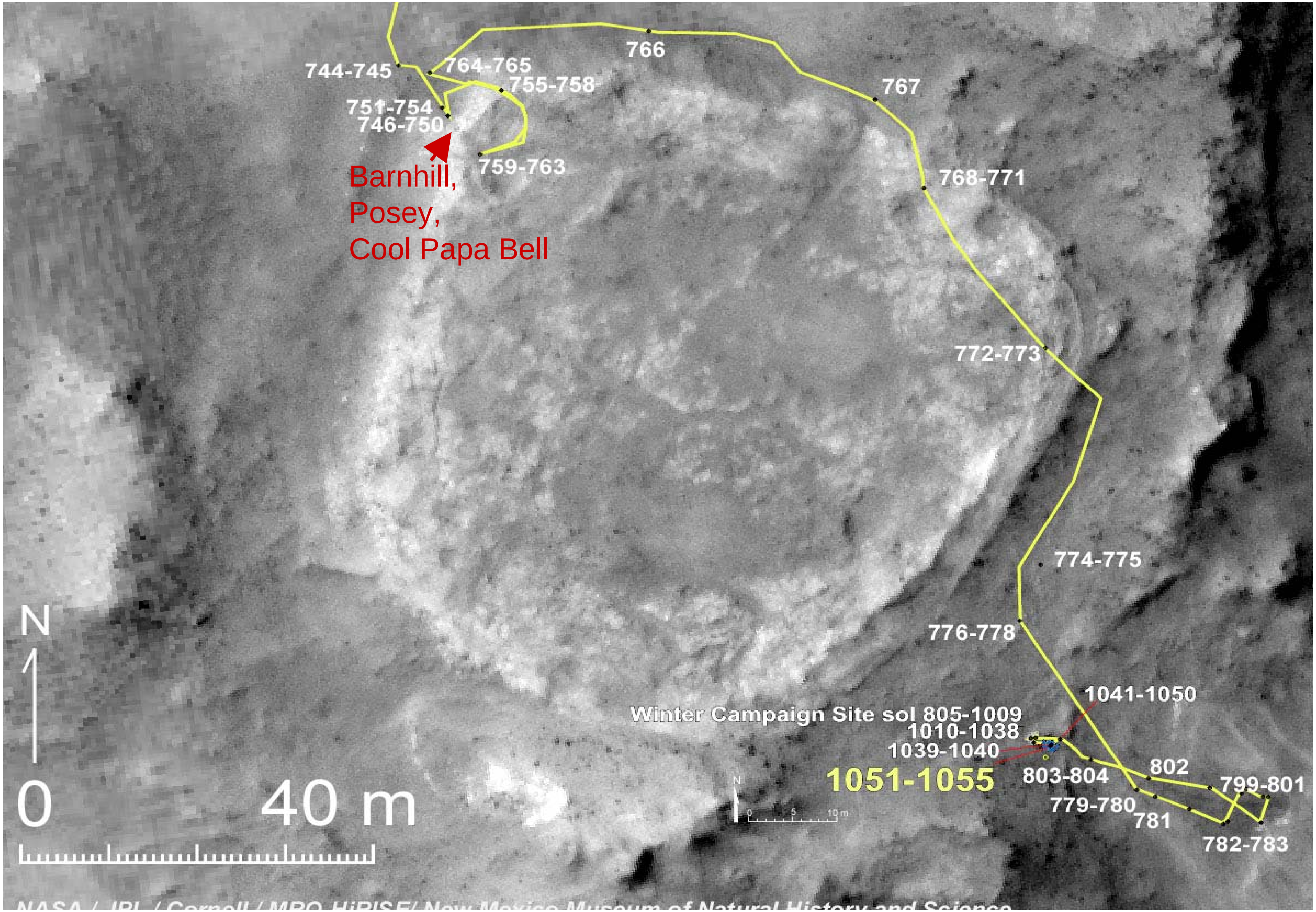
Fe^{3+}-Sulfate Mars- soil (Paso Robles) at 'Husband Hill'

MIMOS II
'nose print'




Gusev Crater
Mössbauer Spectra
Adirondack Class
PotOfGold Subclass
Wishstone
Peace Class
Clovis
Paros
PasoRobles Class
-10
-5
0
5
10
-12
-8
-4
0
4
8
12
Velocity (mm/s)
Goethite
Olivine
Hematite
Pyroxene
Magnetite
Ilmenite
npOx
Goethite = Mineralogical marker
for aqueous processes.


744-745
764-765
766
755-758
767
751-754
746-750
759-763
Barnhill,
Posey,
Cool Papa Bell
768-771
772-773
774-775
N
776-778
1041-1050
Winter Campaign Site sol 805-1009
1010-1038
1039-1040
1051-1055
803-804
802
799-801
0
40 m
779-780
781
782-783
NASA / JPL / Cornell / MRO-HiRISE/ New Mexico Museum of Natural History and Science

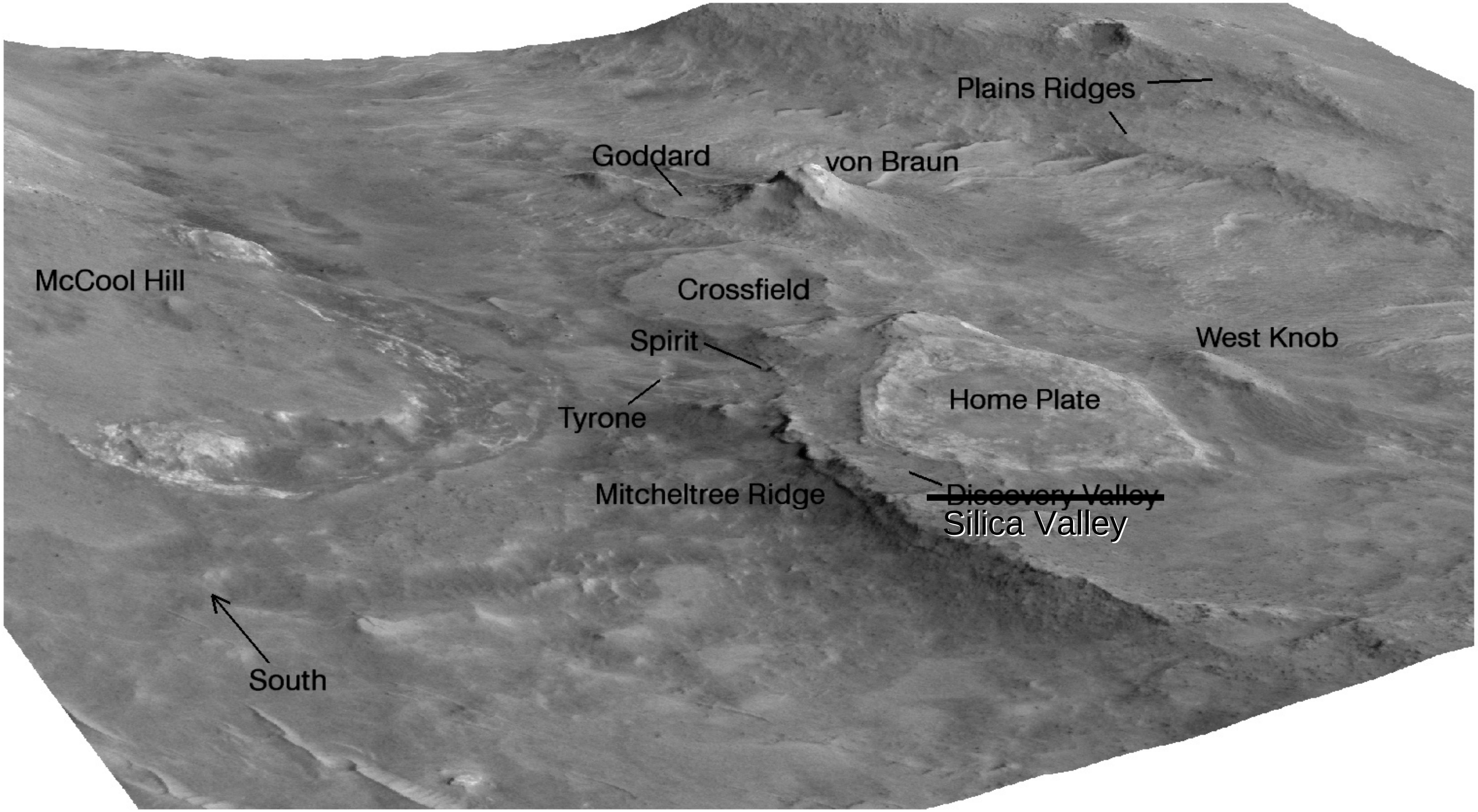
Spirit

dragging the Wheel........

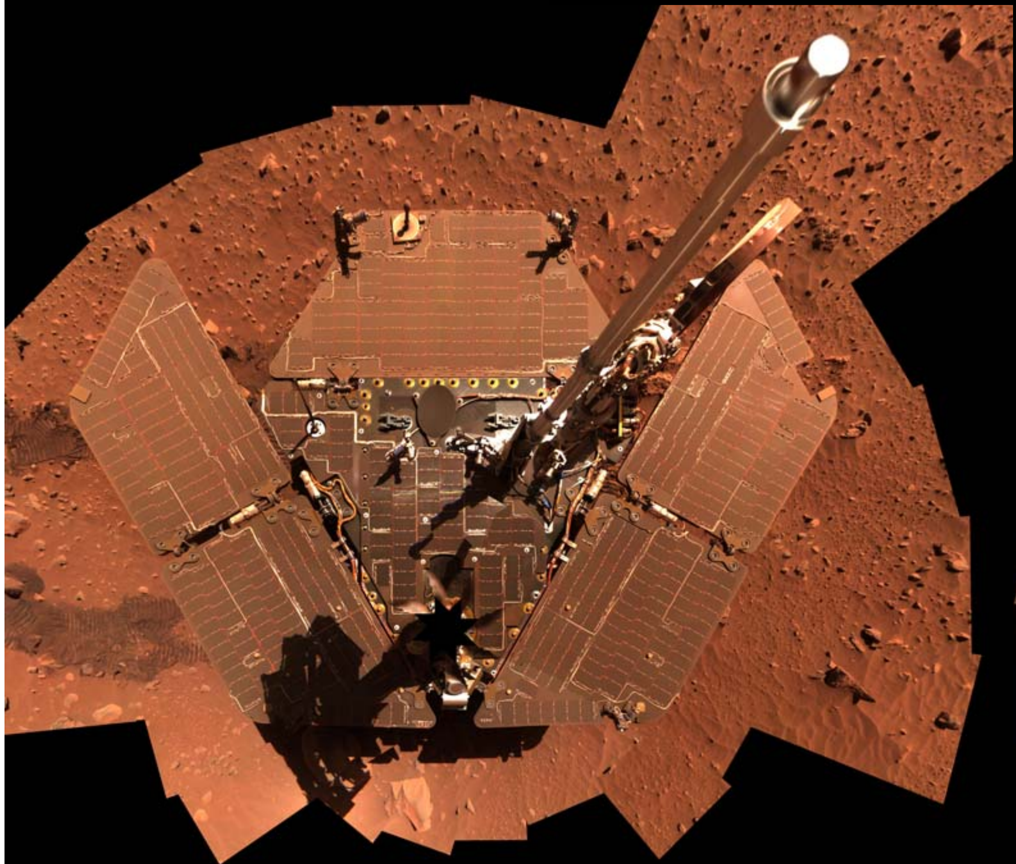
‘white‘ sands

rich in Silica (~ 70 wt%)!!

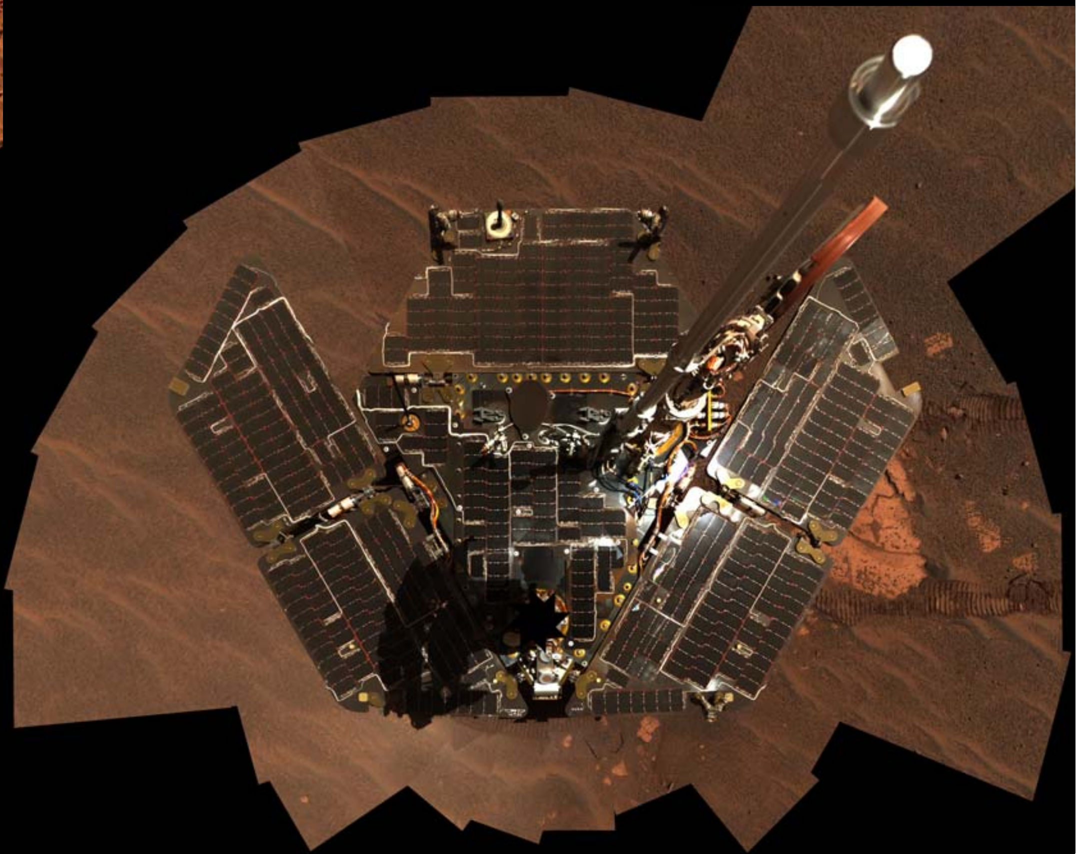
Silica Valley is where most of the high silica targets are located



Dust and Energy



Dusty rover



Clean rover

dust on Mars and the ‘dust devils‘

Car wash on Mars

before the ‘dust devil‘

Car wash on Mars

before the ‘dust devil‘ **after the ‘dust devil‘**

Summary (1): Mössbauer Mineralogy at Meridiani Planum

- 8 Fe-bearing phases were identified:
  - Primary igneous phases: olivine [$(Fe,Mg)_2SiO_4$], pyroxene [$(Fe,Mg)SiO_3$],magnetite [Fe_3O_4].
  - Alteration products: npOx, hematite [α-Fe_2O_3], jarosite [(K,Na)Fe3(SO4)2(OH)6], and Fe^{3+}-sulfate.
- Jarosite [(K,Na)Fe3(SO4)2(OH)6] identified as a mineralogical marker for aqueous process.
- Direct support for NASA's "follow the water" exploration theme and strategy. MB results will constrain Martian climate history (e.g., jarosite identification)

Summary (2): Mössbauer Mineralogy at Gusev Crater

- Identification of 9 (10) Fe-bearing phases were identified:
  - Primary igneous phases: olivine [$(Fe,Mg)_2SiO_4$], pyroxene [$(Fe,Mg)SiO_3$], ilmenite [$FeTiO_3$], magnetite [Fe_3O_4], and chromite [$Fe(Cr,Fe)_2O_4$].
  - Alteration products: npOx, hematite [α-Fe_2O_3], goethite [FeOOH], and Fe^{3+}-sulfate.

- Ilmenite, chromite, magnetite, hematite, goethite, and Fe^{3+}-sulfate were not unequivocally identified by any other MER instrument at Gusev crater.

- Magnetite established as the primary magnetic phase in martian soil and rock.

- Goethite (FeOOH) identified as a mineralogical marker for aqueous process. The phase has the equivalent of ~10% H_2O and can be formed only in H_2O-bearing environments.

- Direct support for NASA's "follow the water" exploration theme and strategy.

- MB results will constrain Martian climate history (e.g., goethite found only in very old terrain.)

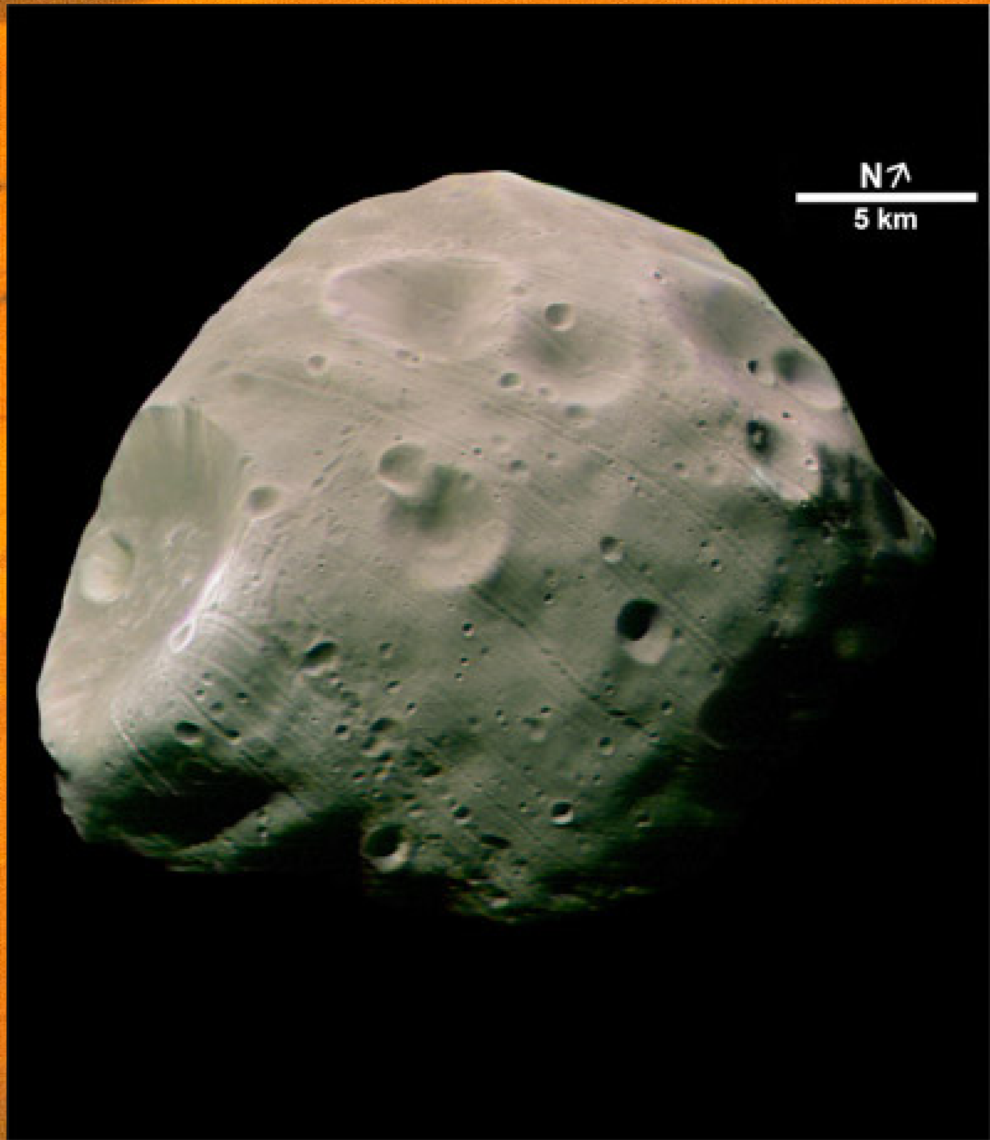
The Future:

(1) Current Projects:

MIMOS II advanced for:

- **‘Phobos Soil‘ in 2009 (Russia)**
- **‘ExoMars‘ in 2013 (Europe/ESA)**

Phobos Sample Return Mission



Mars moon „Phobos“

- 1/1000 of Earth gravity
- troughs / crater chains possibly due to material ejected from Mars (ESA Mars-Express).
- bluer material may be fresher than other parts of surface.
- origin: asteroid, caught by Mars?
- C-typ (high Carbon)?
- low density -> mixture of rock & ice?

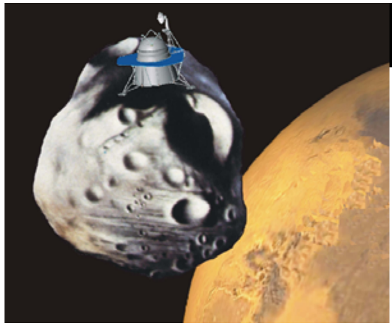
Credit: NASA/JPL-Caltech/University of Arizona

HiRISE camera on NASA's Mars Reconnaissance Orbiter; March 23, 2008. distance of about 5,800 kilometers; about 21 kilometers across.
Most prominent feature: crater Stickney (lower right); diameter: 9 kilometers.

According to the current understanding the Martian moons Phobos and Deimos are captured asteroids and so they are samples of relict matter of the Solar system.

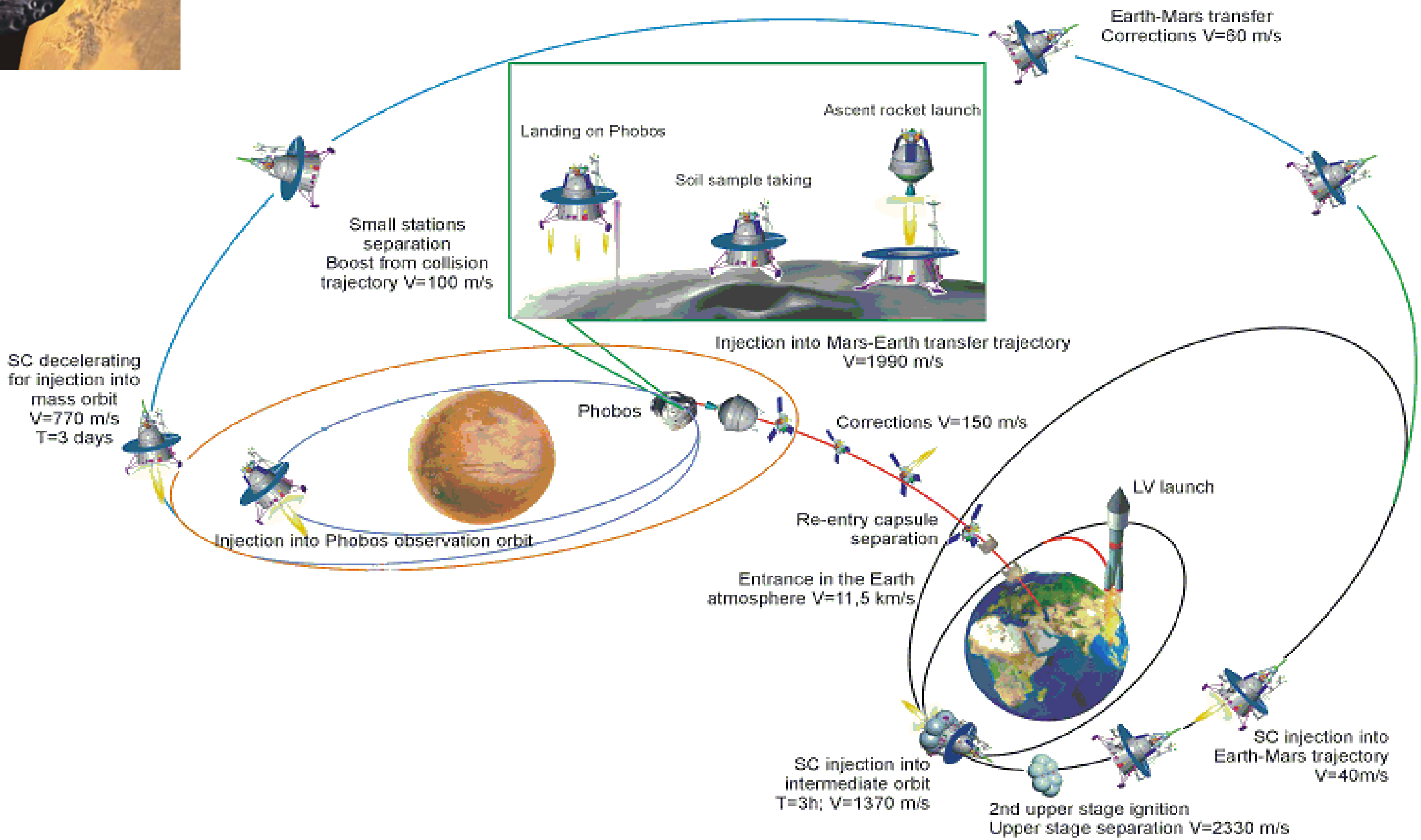
Choice of Phobos and Deimos as an object of investigation for the next planetary mission bases on following reasons:

- **Delivery to the Earth of samples of relict matter** and its investigation in the laboratories is one of the most important task of current Solar system exploration;
- Phobos and Deimos are the most accessible small bodies for space research from the technical point of view;



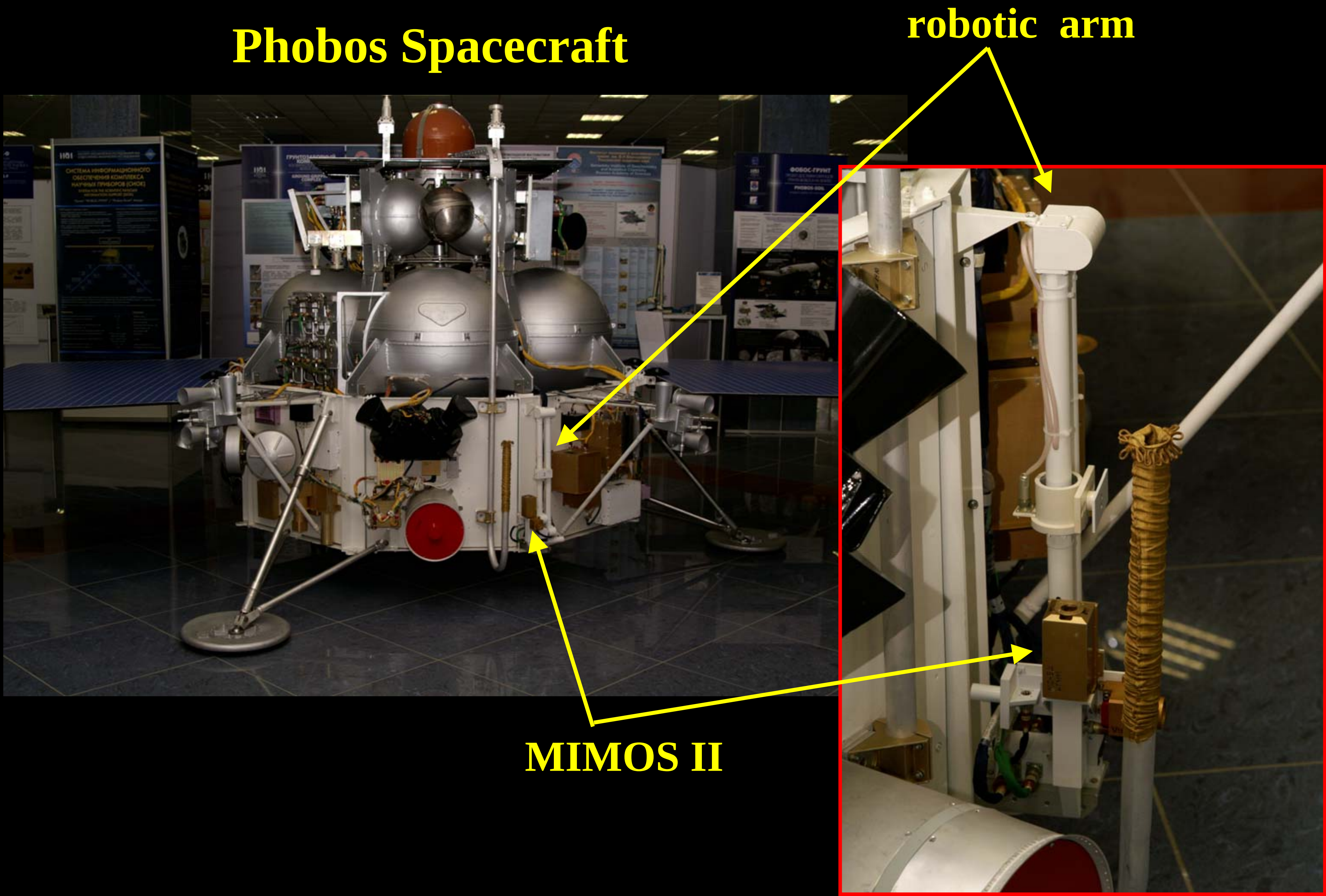
PHOBOS-GRUNT 2009

MISSION PROFILE



BABAKIN SCIENCE AND RESEARCH SPACE CENTER

Phobos Spacecraft



ExoMars Mission

Launch Window: 19th April to 9th May 2013 on Soyuz 2b from Kourou

Arrival: March 2015 after Mars Global Dust Season (GDS) using HEO and Delayed Transfer strategies

S/C Composite: Carrier Module plus Descent Module (including Rover and GEP *subject to technical feasibility*)

Landing: Following ballistic entry from hyperbolic arrival trajectory - EDLS based of Heat Shield, Parachute, Retro-rockets and Airbags

Landing Range: Latitudes between –15° and +45°, all longitudes
Altitude ≤ 0 m relative to the MOLA zero level

Payload:

<u>Rover and its Pasteur Payload</u>: Mass 150-180 kg, includes:
Drill (up to 2 m depth) & SPDS
Instruments ~8 kg
Mobility ~10 km

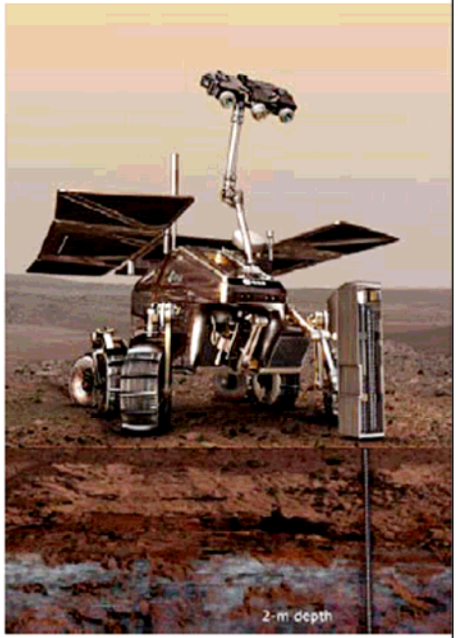
<u>Geophysics/Environment Package (GEP)</u>: Mass ≤ 20 kg, includes:
Instruments (4-5 kg TBC)

Data Relay: To be provided by NASA (MRO or equivalent orbital asset)

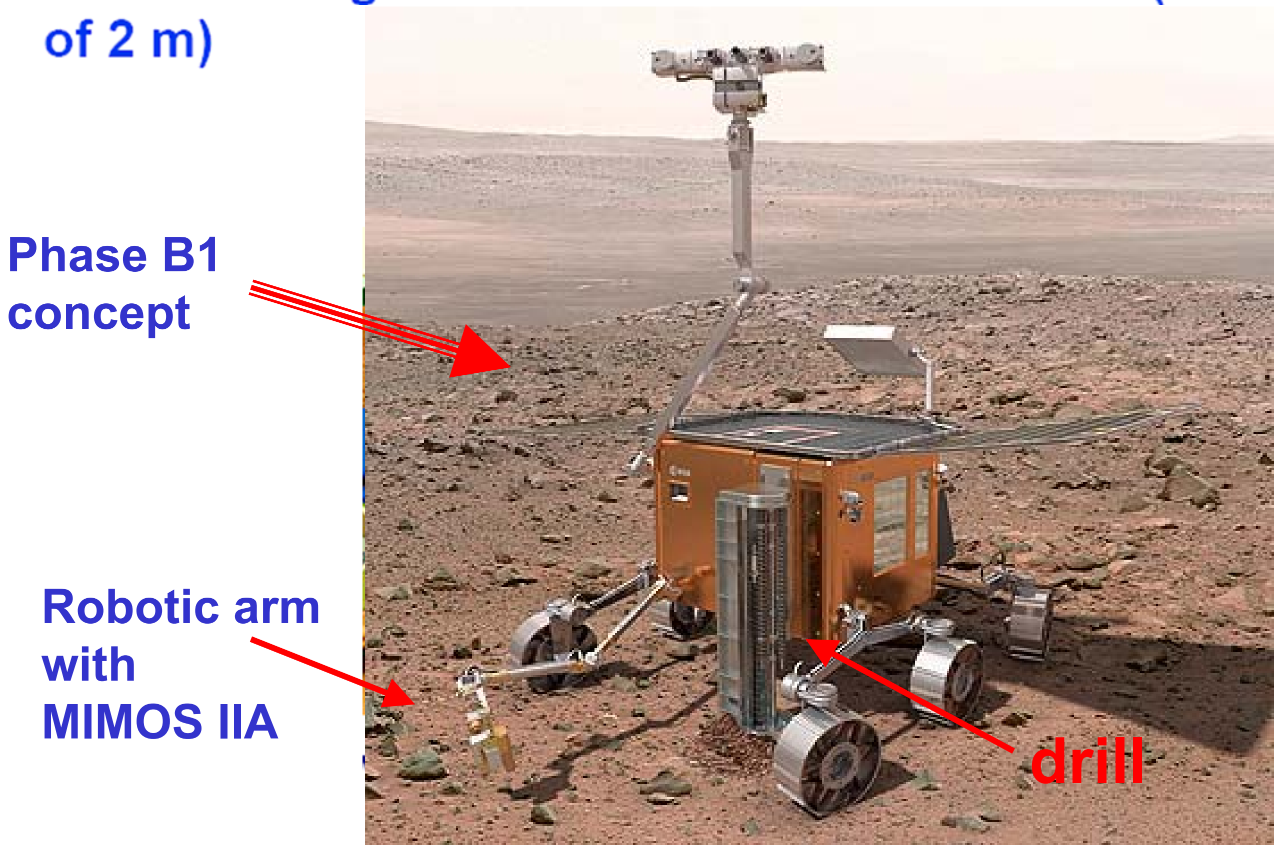
MOPs and GS: MOC at ESOC (up to Rover egress TBC); ROC (& MTS) at ALTEC (afterwards)

ExoMars-2013

Baseline Mission:
Rover



- The Rover will ensure regional mobility (several km) to the Pasteur Payload as well as power, communications etc.
- The Rover also includes a Drill-based Sample acquisition Preparation and Distribution System (SPDS) which will allow for accessing Mars surface and sub-surface (down to a depth of 2 m)



Current baseline

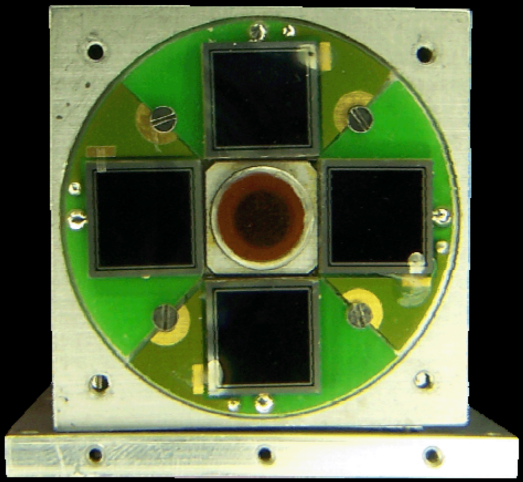
- Mass ~ 180 kg
- Average Power ~ 120 W (by Solar Array assuming RHUs availability)
- X-band communication link for DTE and UHF band for link with MRO

Important to look into the „Subsurface“

Credit:
„Space is a funny place“
by Colin Pillinger 2007

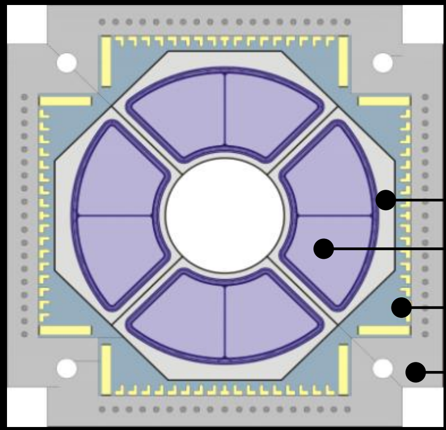
“Old“

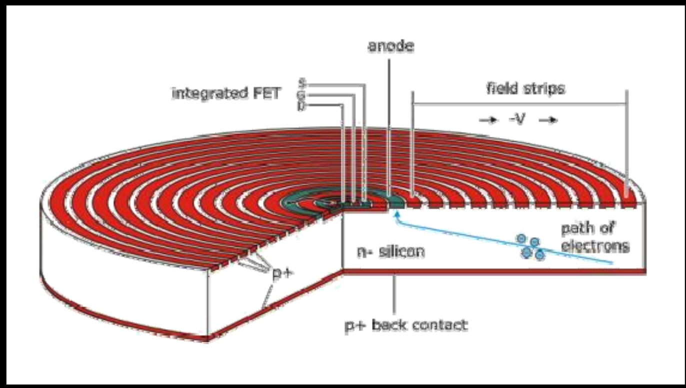
Si-PIN detector system (MER)



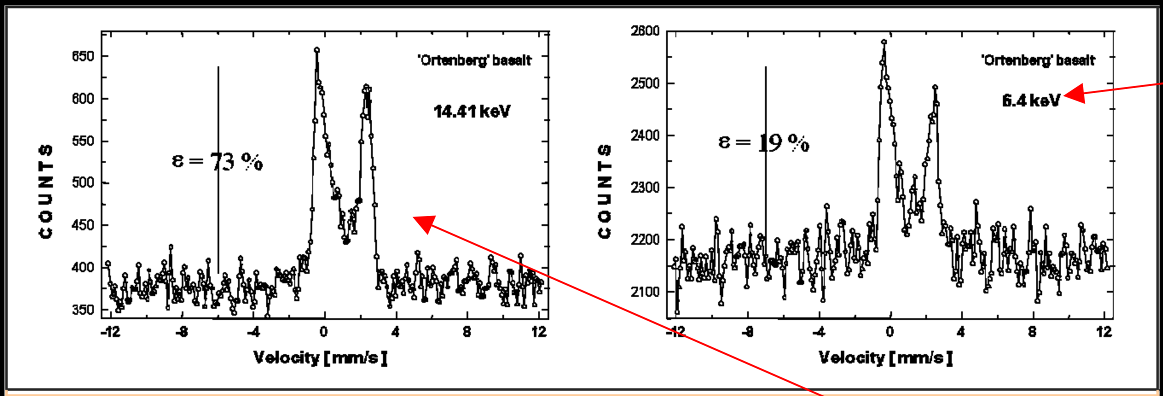
“New“

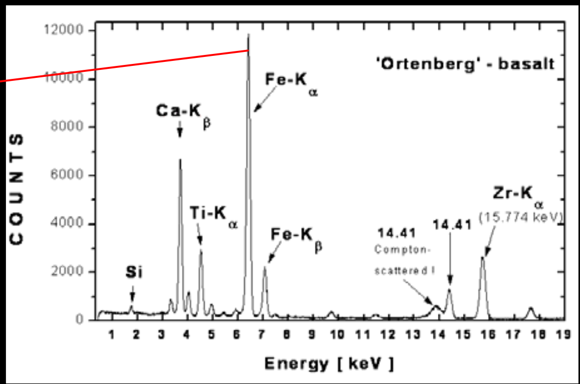
Si-Drift detectors SDD





SDD detector: Mössbauer AND XRF on Basalt:





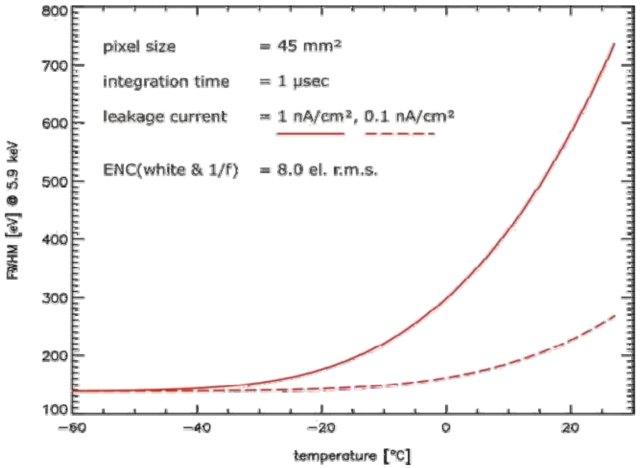
Resolution: 150-200 ev at 5.9 keV

Peak/Background at 14.4 keV: 73% (only ~5% Si-PIN on MER)

G.Klingelhöfer, *The miniaturized MB spektrometer*…..,in: Mössbauer Spectroscopy in Materials Science, eds. M.Miglierini and D.Petridis, Kluwer Academic Publishers 1999.

Silicon Drift Detector, SDD

Expected performance



range of expected energy resolution (FWHM @ 5.9 keV) vs. temperature

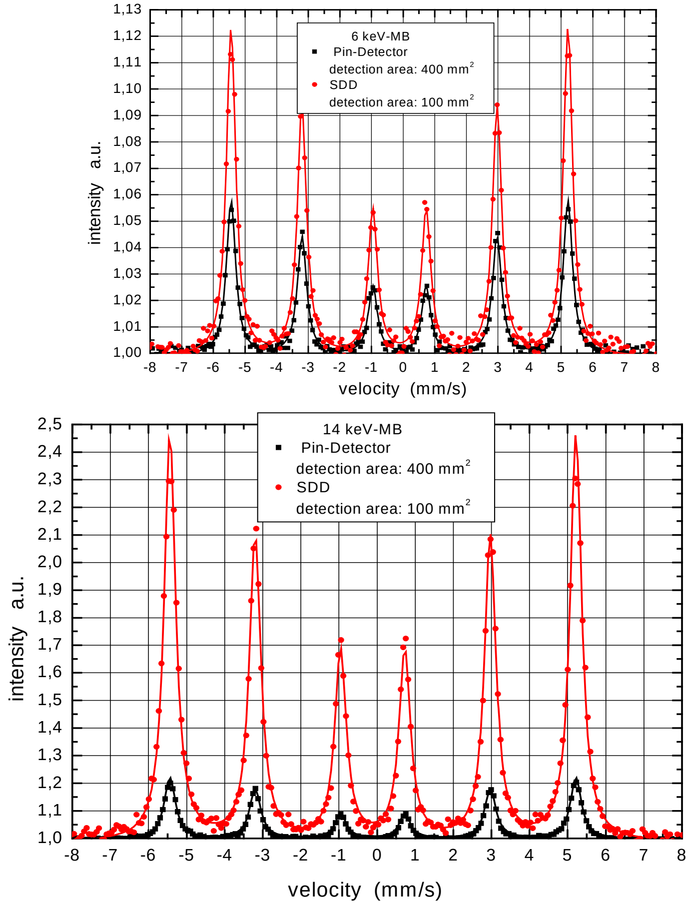
- **For temperatures < 250 K the energy resolution is < 150 eV**
- **Significant reduction of integration time**
- **Possibility of simultaneous acquisition of an X-ray fluorescence spectrum (element analysis)**

Preliminary studies

Results:

- **14.4 keV MB radiation: SDD gives a factor of 7 better signal to noise ratio**

Backscatter Mössbauer-spectra of an Fe-foil taken with MIMOS II standard e-board and a high resolution SDD



Field test at Rio Tinto / Spain

1- Valladolid

2- Cúllar (Granada)

3- Jaroso-Sorbas-Cabo de Gata (see details in the text)

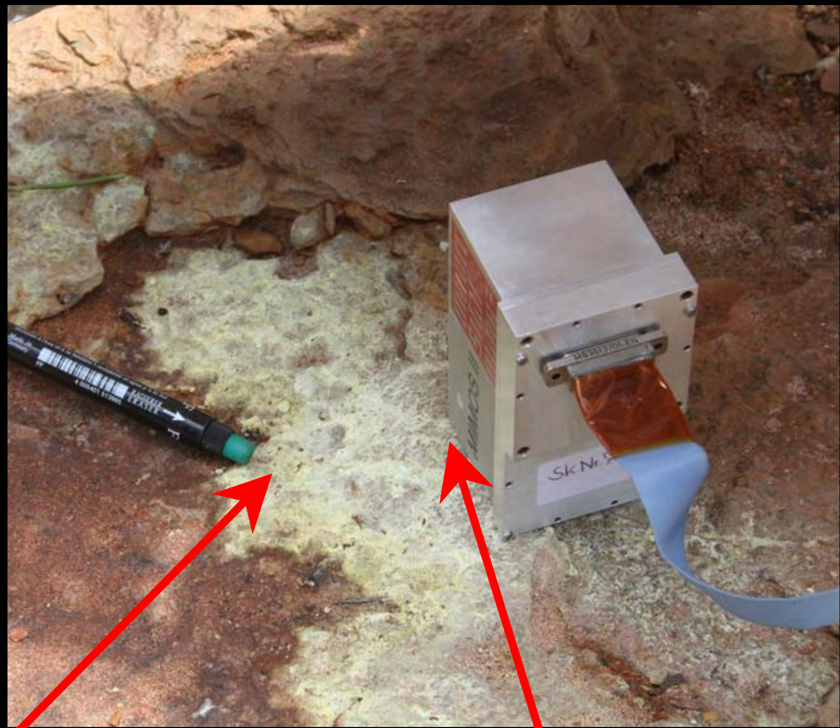
4- Almuñecar (Granada)

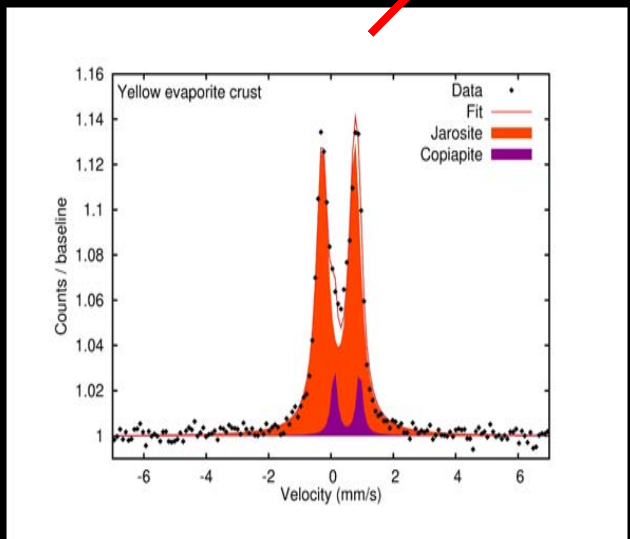
5- Rio Tinto (see details in the text)

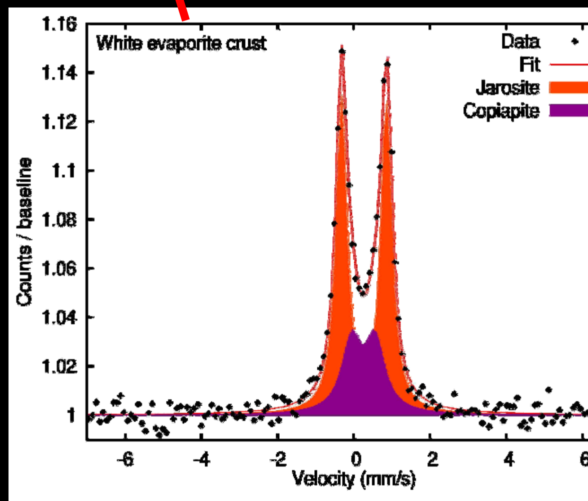
6- Return to Madrid

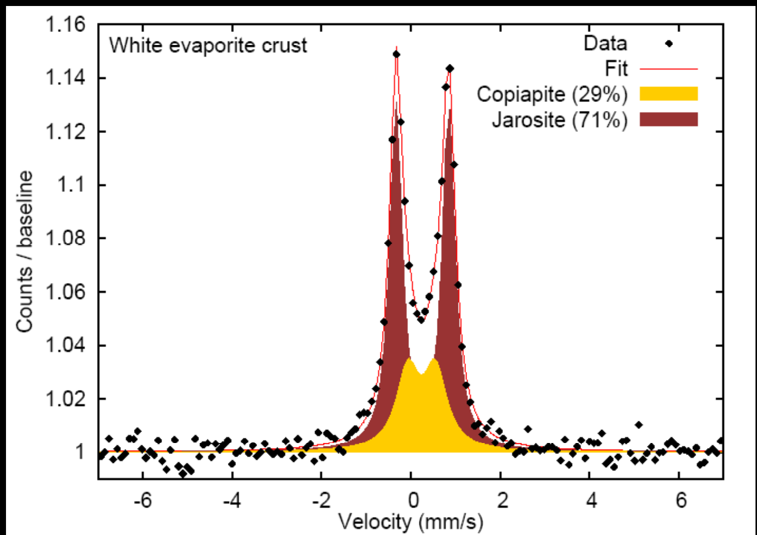
Rio Tinto field campaigne June 2008

Field test at Rio Tinto / Spain

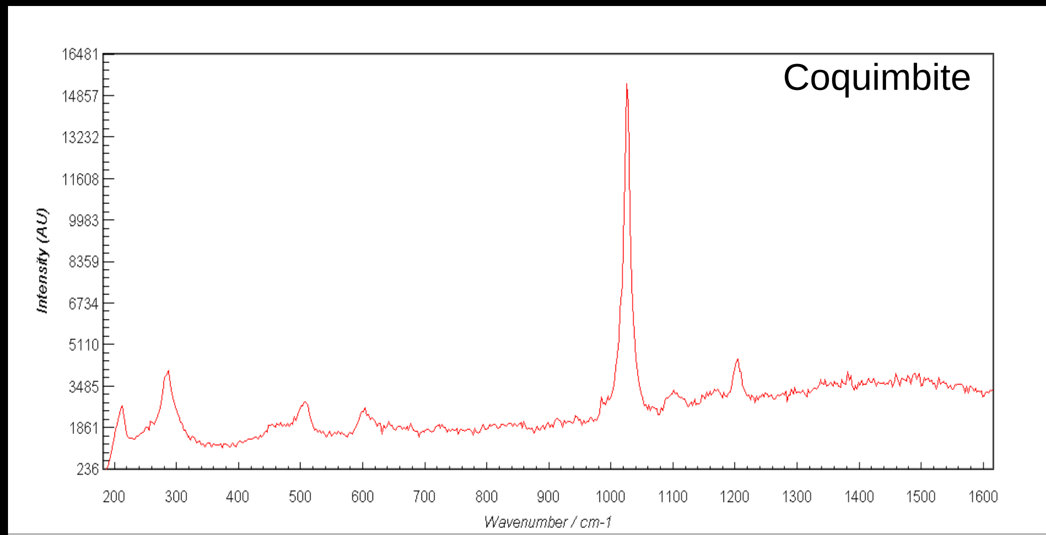








Mössbauer: substrate (jarosite) is visible through the crust (copiapite; possibly with coquimbite).



Raman: white coquimbite crust

Future Plans (& Dreams):

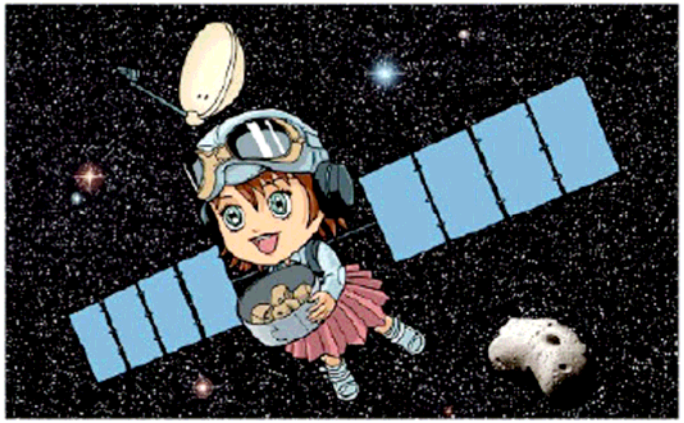
MIMOS II ‚advanced‘ for:

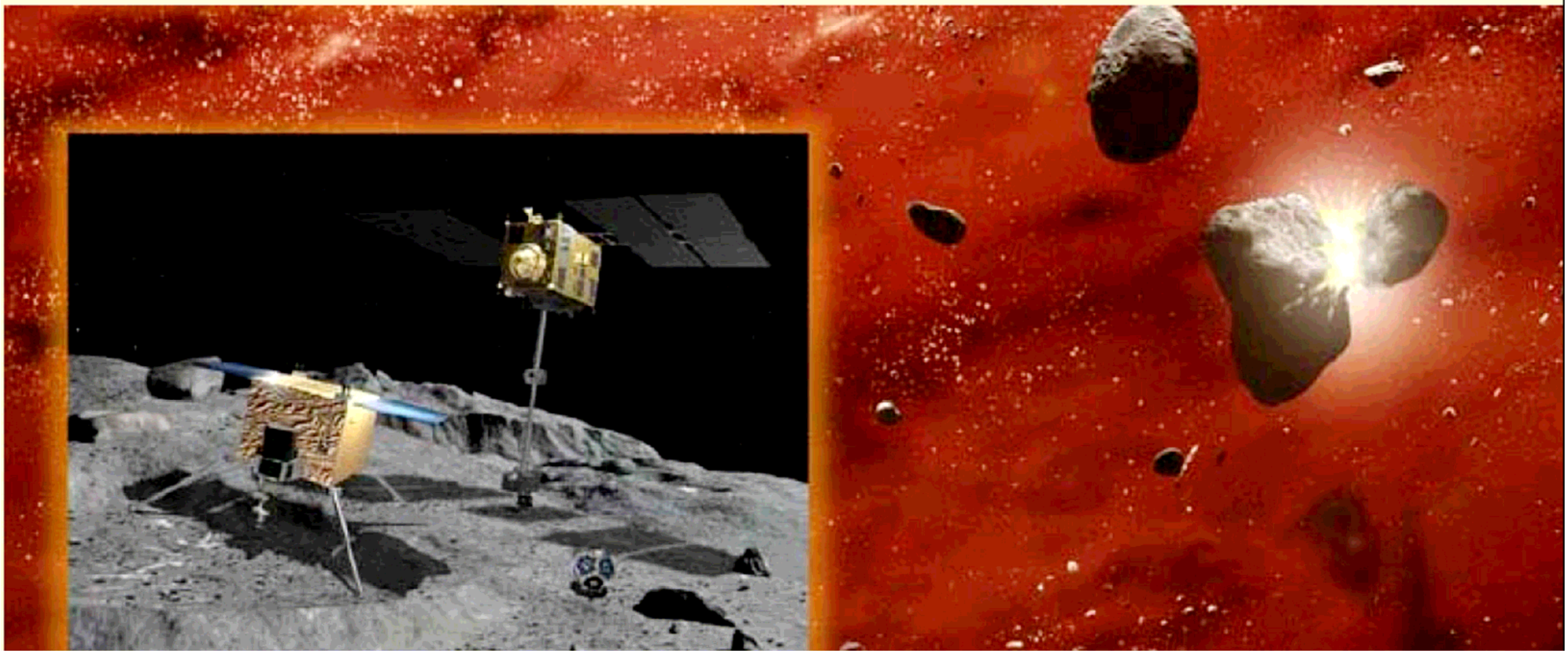
- **Asteroid Sample Return mission:**
  “Marco Polo“

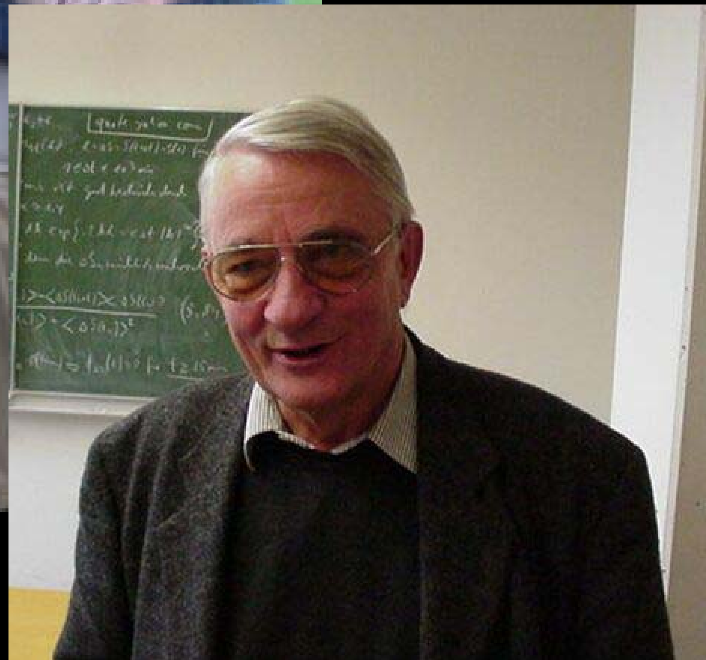
(ESA Cosmic Vision / after 2017)

Marco Polo

- Sample return from a *primitive* asteroid
- Collaboration with Japan
- Proposed by Antonella Barucci, Obs. Paris (+ ca. 400 scientists)







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