Terrestrial Planets

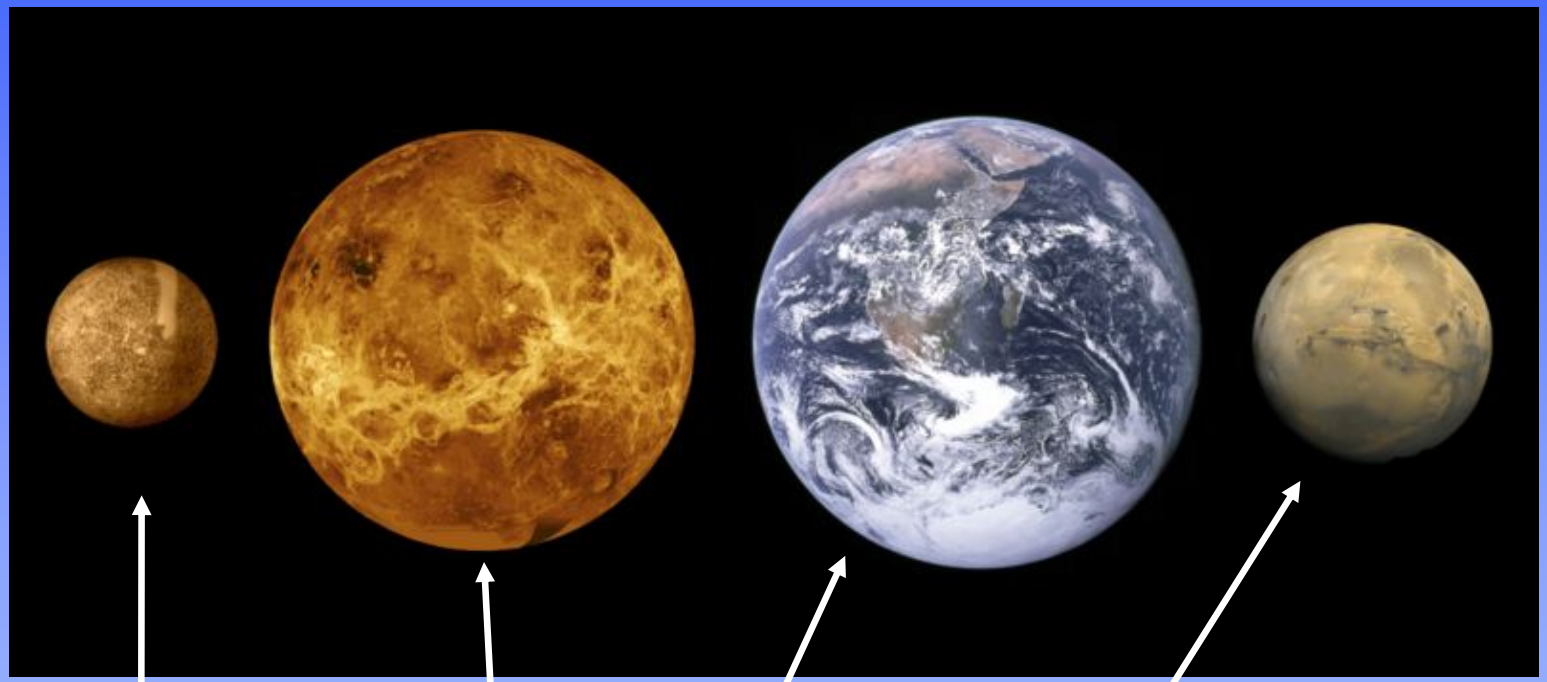
First ever ‘whole Earth’ picture from deep space, taken by Bill Anders on Apollo 8

Apollo 8 crew, Bill Anders centre: courtesy Nasa

- The Earth is just a planet

1- 4 from the Sun

Image courtesy: http://commons.wikimedia.org/wiki/Image:Terrestrial_planet_size_comparisons_edit.jpg



- Mercury, Venus, Earth and Mars are four astonishingly different planets
  - Mercury and Venus have only been seen in any detail within the last 30 years

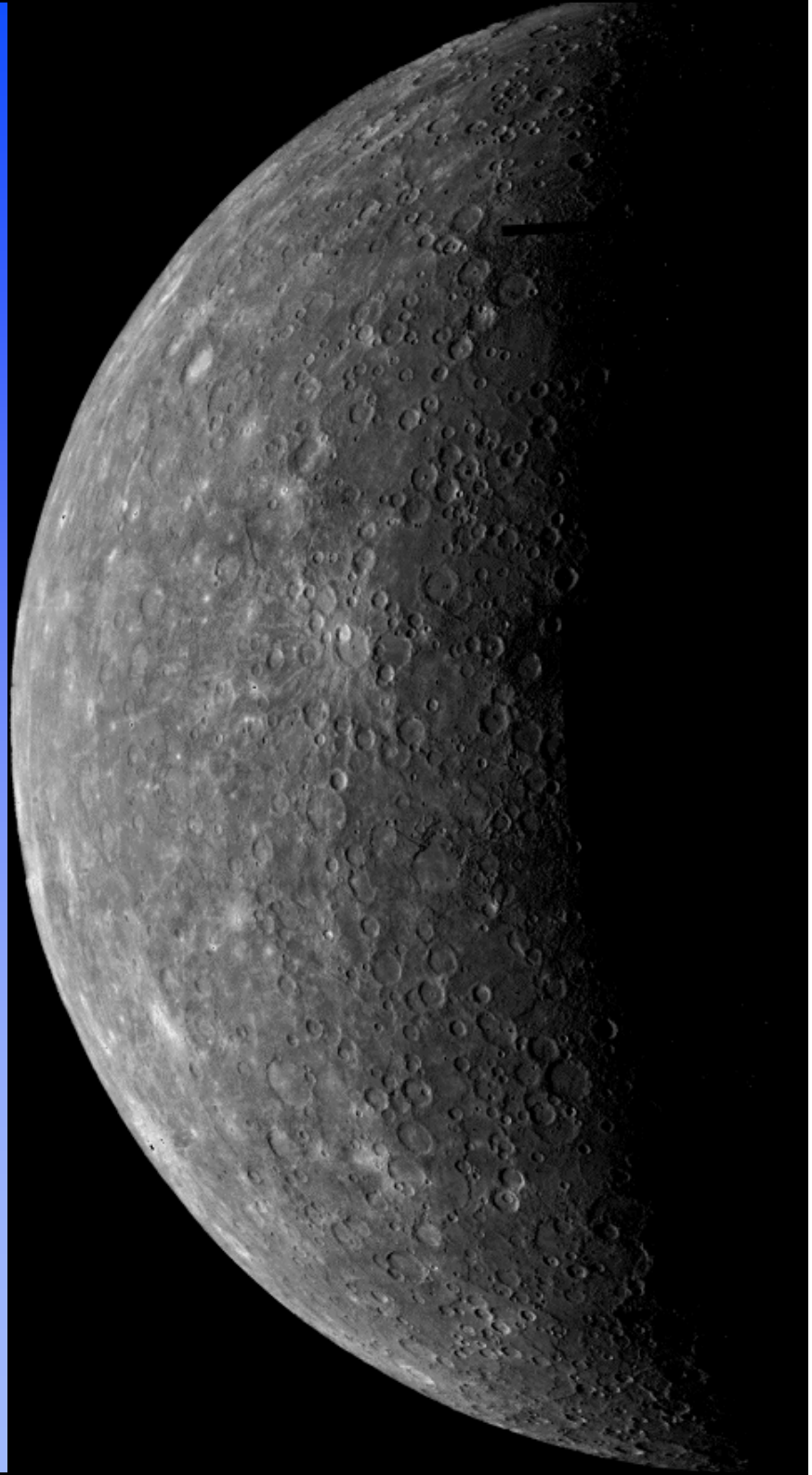
Mercury in sight

Courtesy NASA
(Mariner 10)

- Mercury is visible only soon after the setting sun or shortly before dawn
  - the *Mariner 10* probe (1974/75) is the source of most information about Mercury – *Messenger*, launched 2004, first flypast in 2008 and orbit Mercury in 2011. ESA's BepiColombo, to be launched in 2013

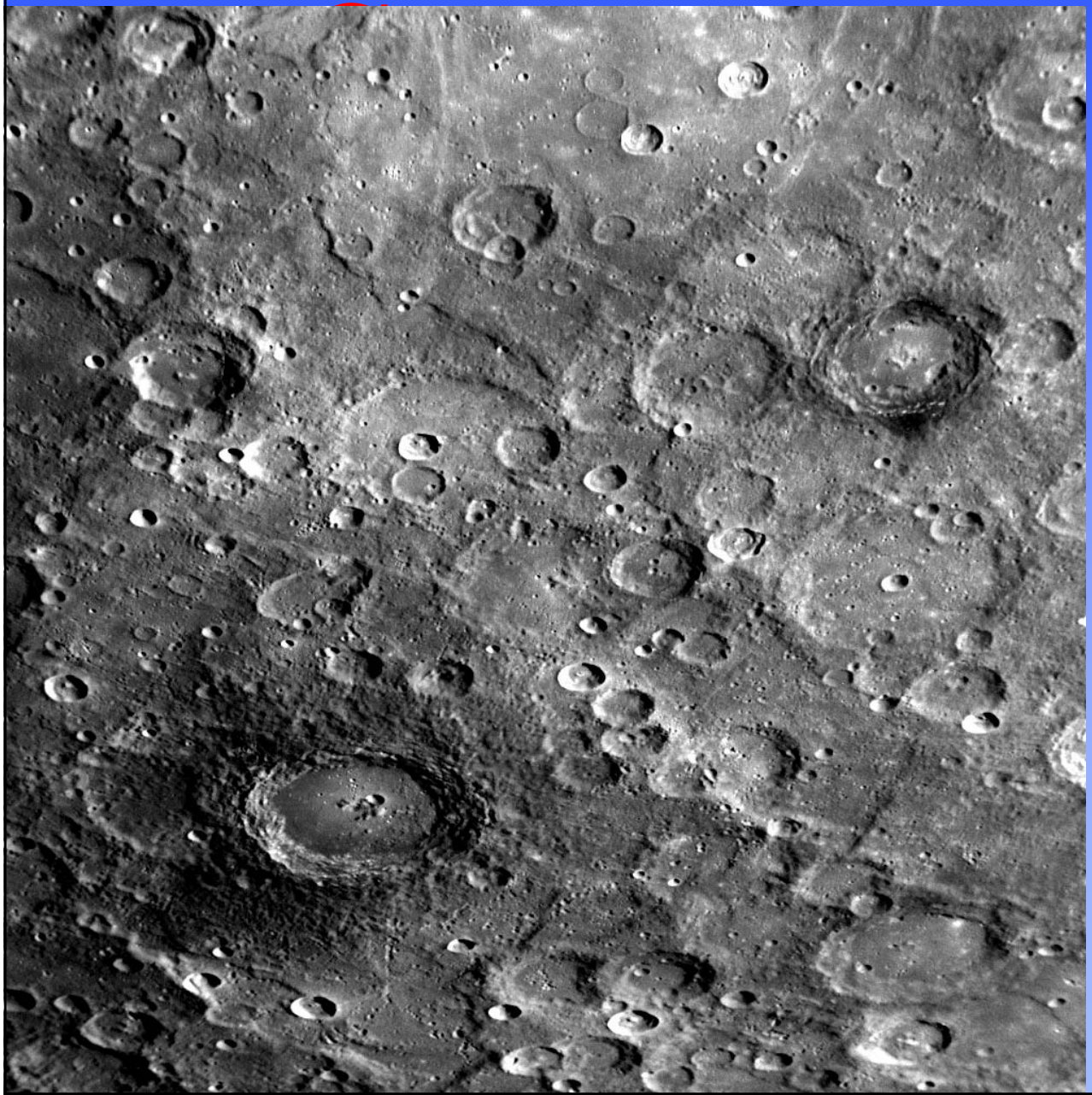
Mercury

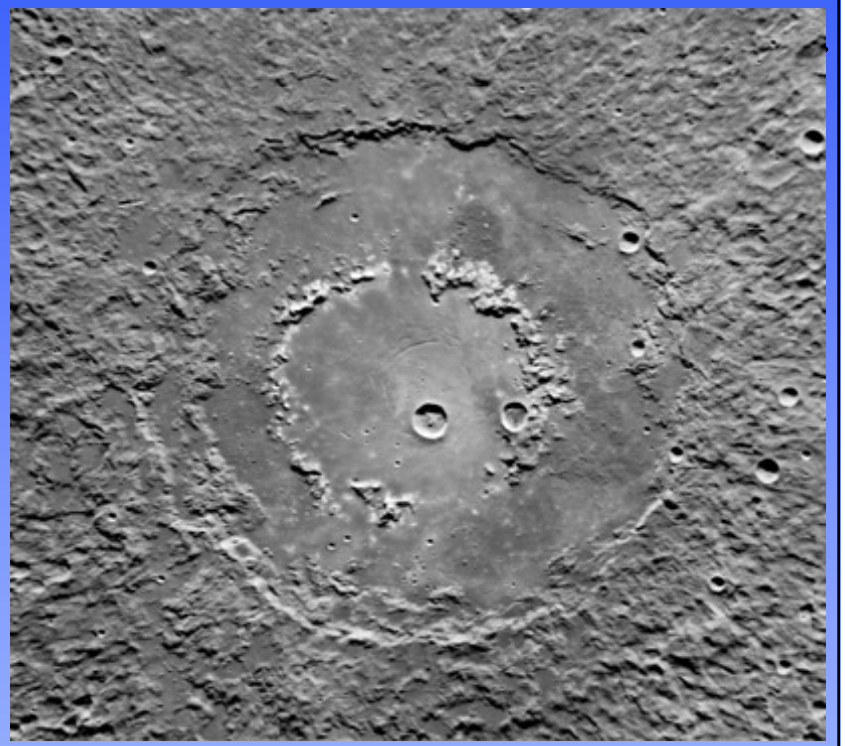
- Mercury is like the Earth inside and the Moon outside
- Mercury has had a cooling and bombardment history similar to the moon
- It appears as cratered lava with scarps
- Its rocks are Earth-like



Mariner 10 image

Messenger images

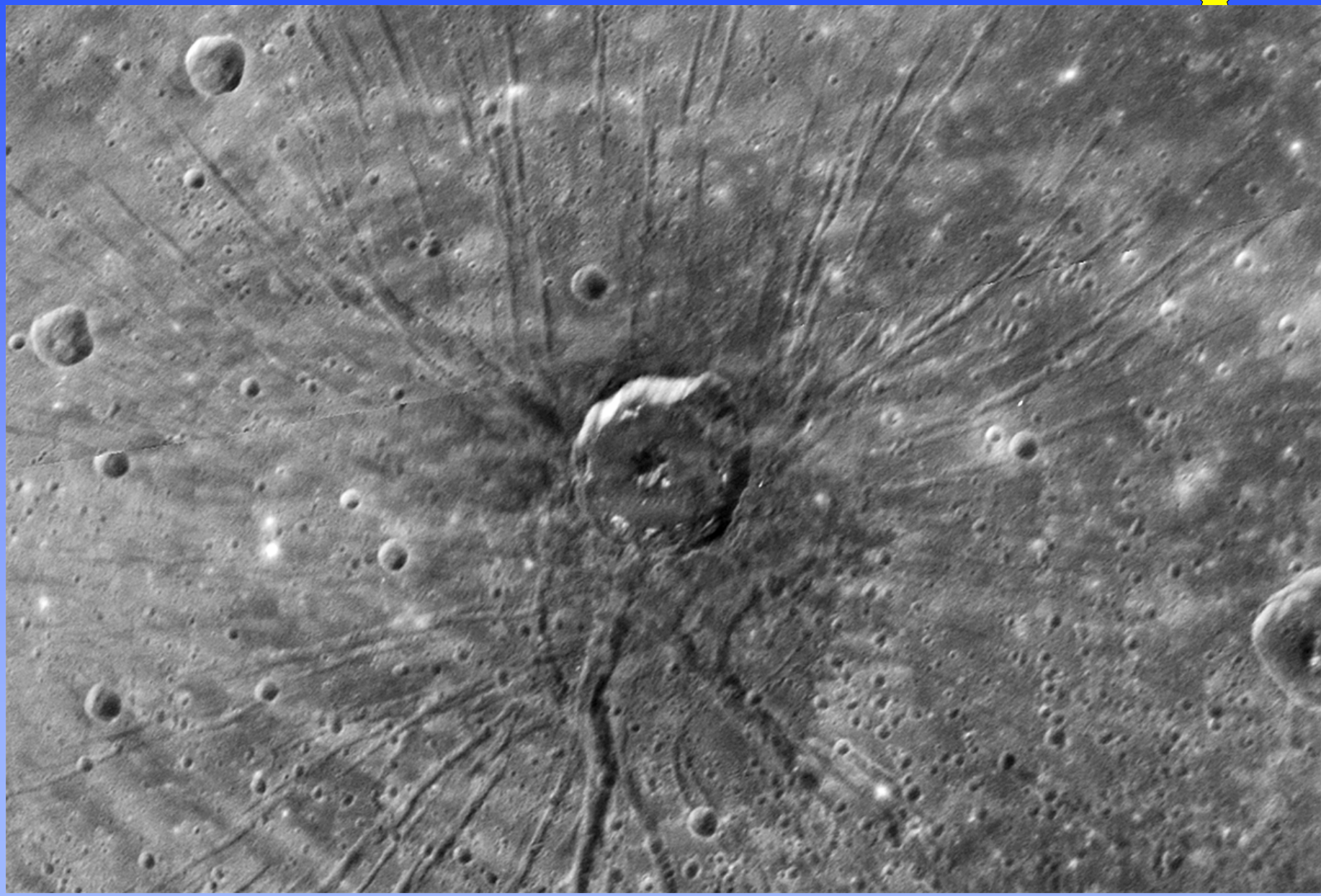




↑ Double-ringed crater – a Mercury feature courtesy: http://messenger.jhuapl.edu/gallery/sciencePhotos/pics/Strom02.jpg

← Courtesy: http://messenger.jhuapl.edu/gallery/sciencePhotos/pics/EN0108828161M.jpg

Messenger image

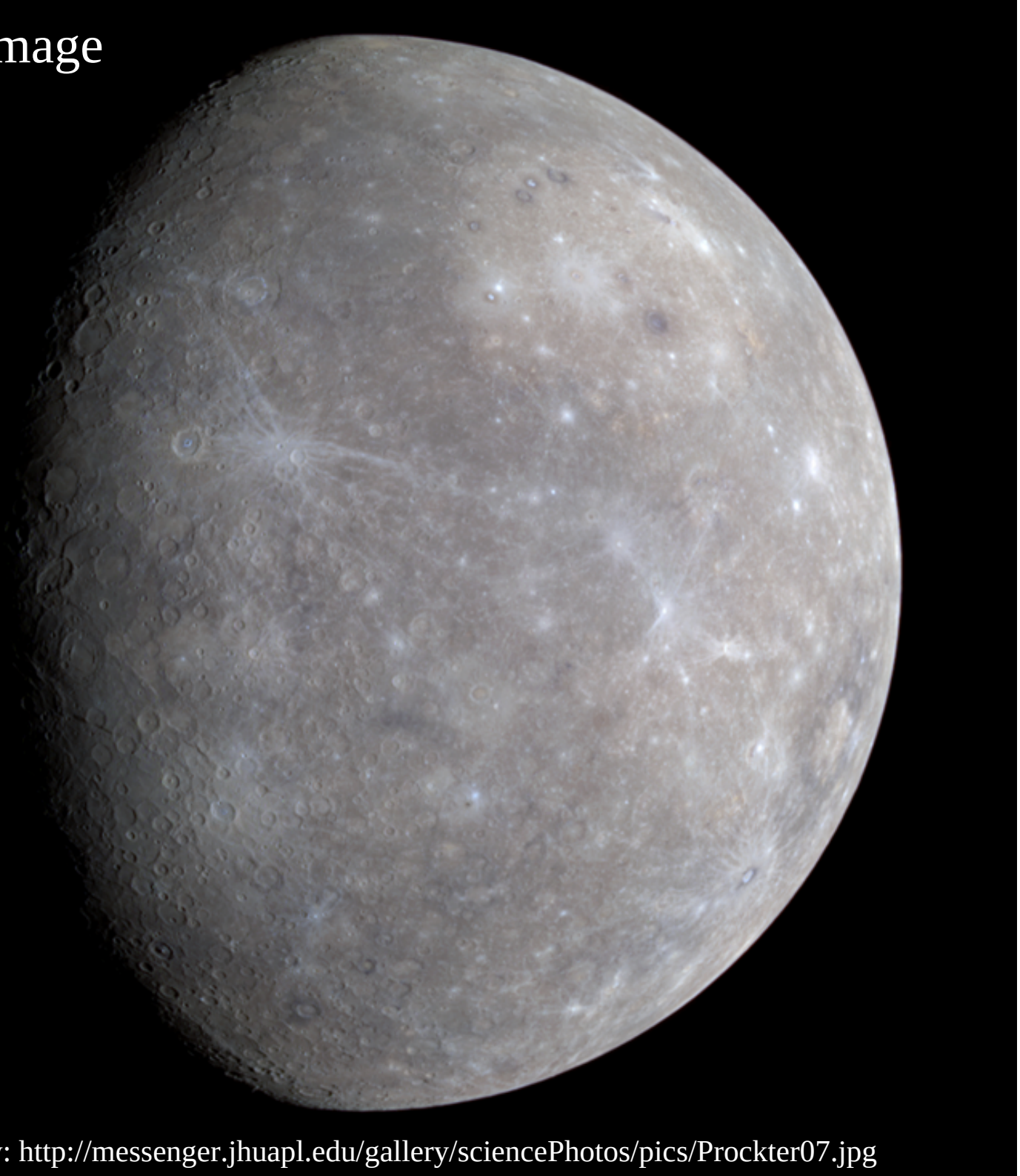


Courtesy: http://messenger.jhuapl.edu/gallery/sciencePhotos/pics/Prockter06.jpg

Mercury Close-up

- Mercury's topography was formed under stronger gravity than on the Moon
- The Caloris basin is an impact crater ~1400 km across, beneath which is thought to be a dense mass
- Mercury's rotation period is exactly $^{2}/_{3}$ of its orbital period of 87.97 days. ('spin-orbit coupling')
- The iron planet? Mercury's mean density 5430 kg m^{-3}
- Mercury has a magnetic field about 1% of the Earth's, which interacts with the solar wind

Messenger image

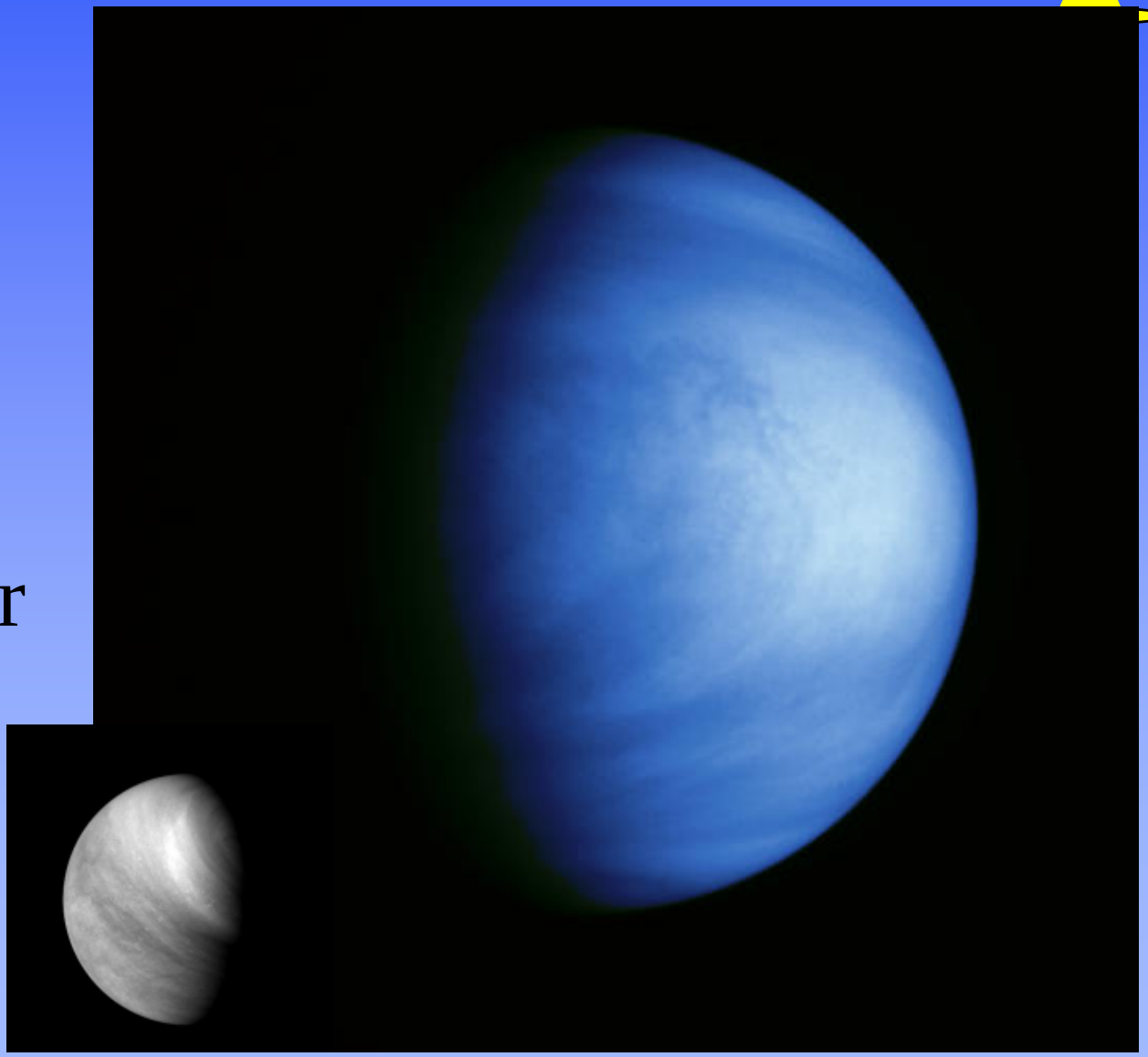


- The caloris basin is the large circular pinkish area near top right

Courtesy: http://messenger.jhuapl.edu/gallery/sciencePhotos/pics/Prockter07.jpg

Venus – Our Neighbour

- Venus is permanently cloud covered
- Clouds seen here through a blue filter are made of H_2SO_4 (sulphuric acid)



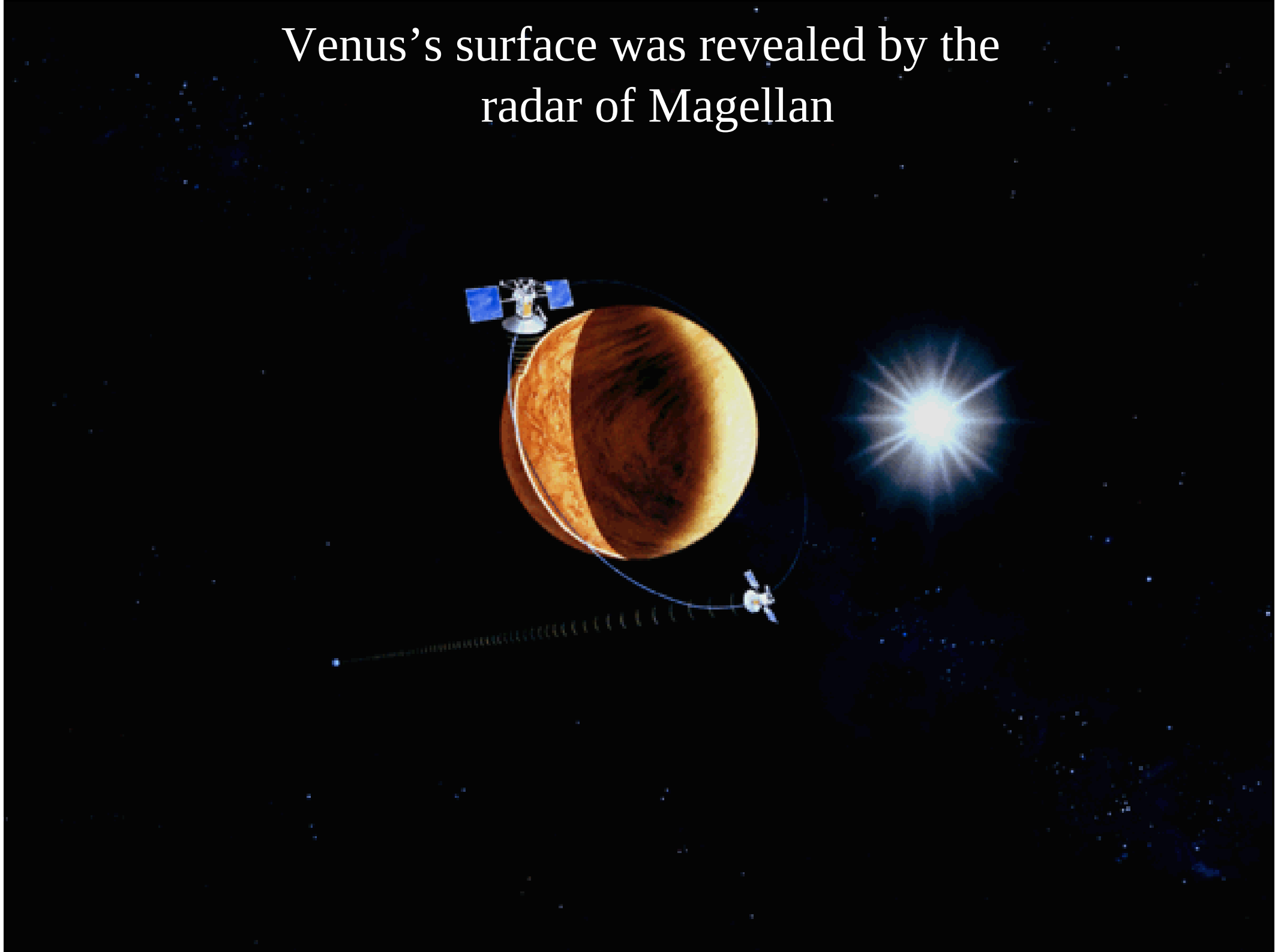
Venus Express approaching
Courtesy ESA

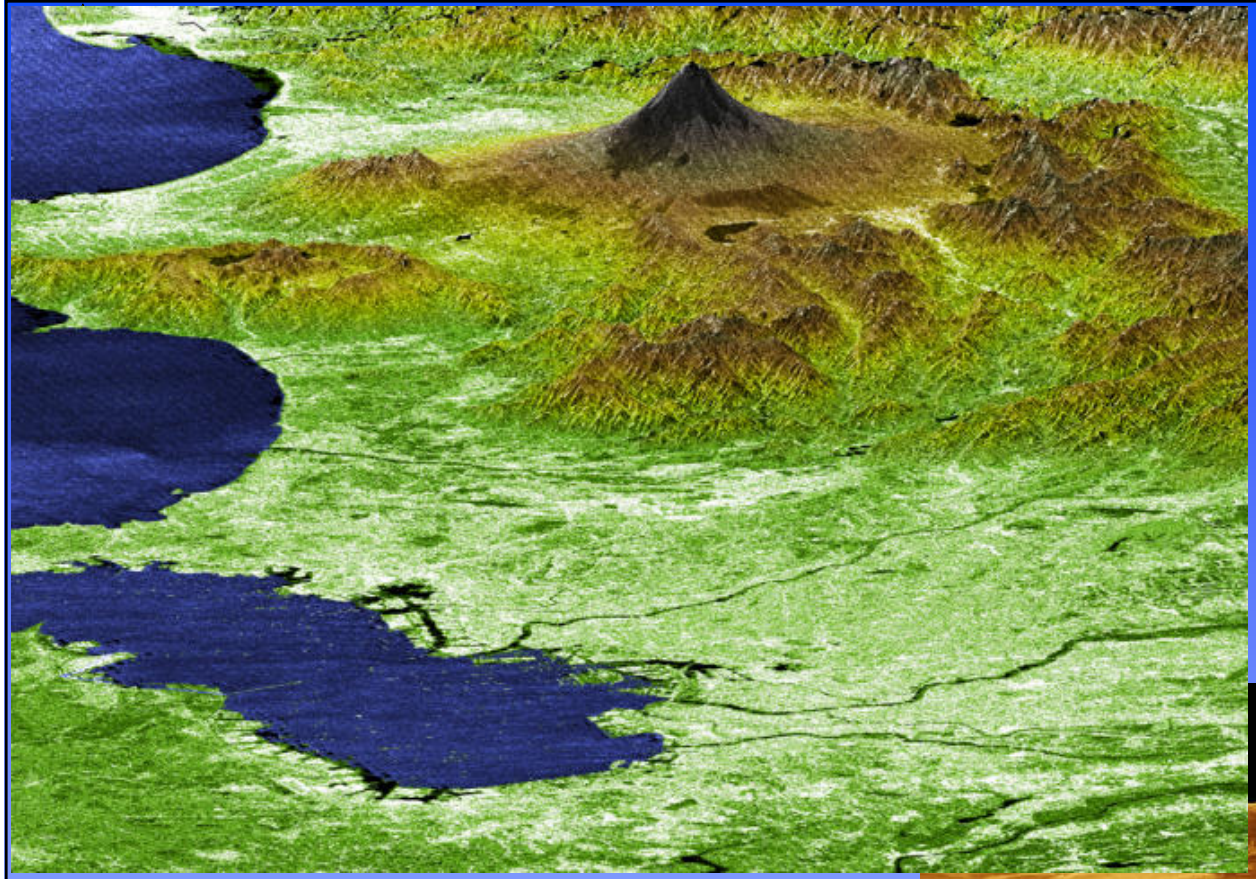
Our Neighbour's Property

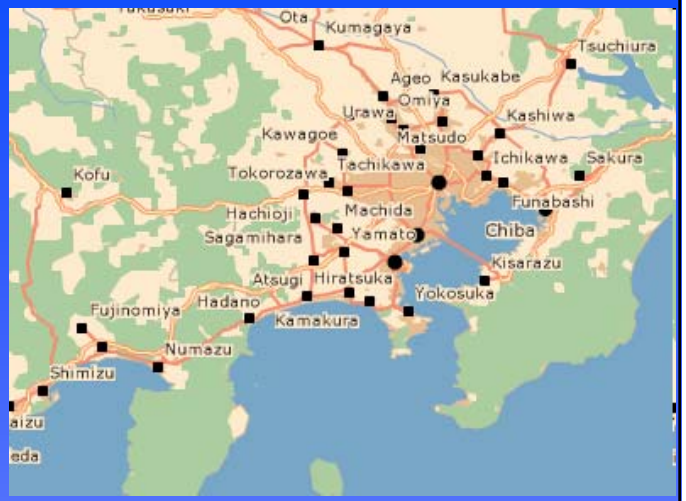
Venera 13

- 95% Earth's diameter; 82% mass; no moon
- Backward rotation of 243 days
- Mapped by radar. Earth-like rocks, 90% surface is rolling lava plains, drier than dust; a thousand craters a few km in diameter
  - highest mountain: volcanic Maat Mons (8km)
  - **no** tectonic plate movement → mountain ranges
  - planet has an Earth-like heavy metal core
  - no magnetic field

Venus’s surface was revealed by the radar of Magellan

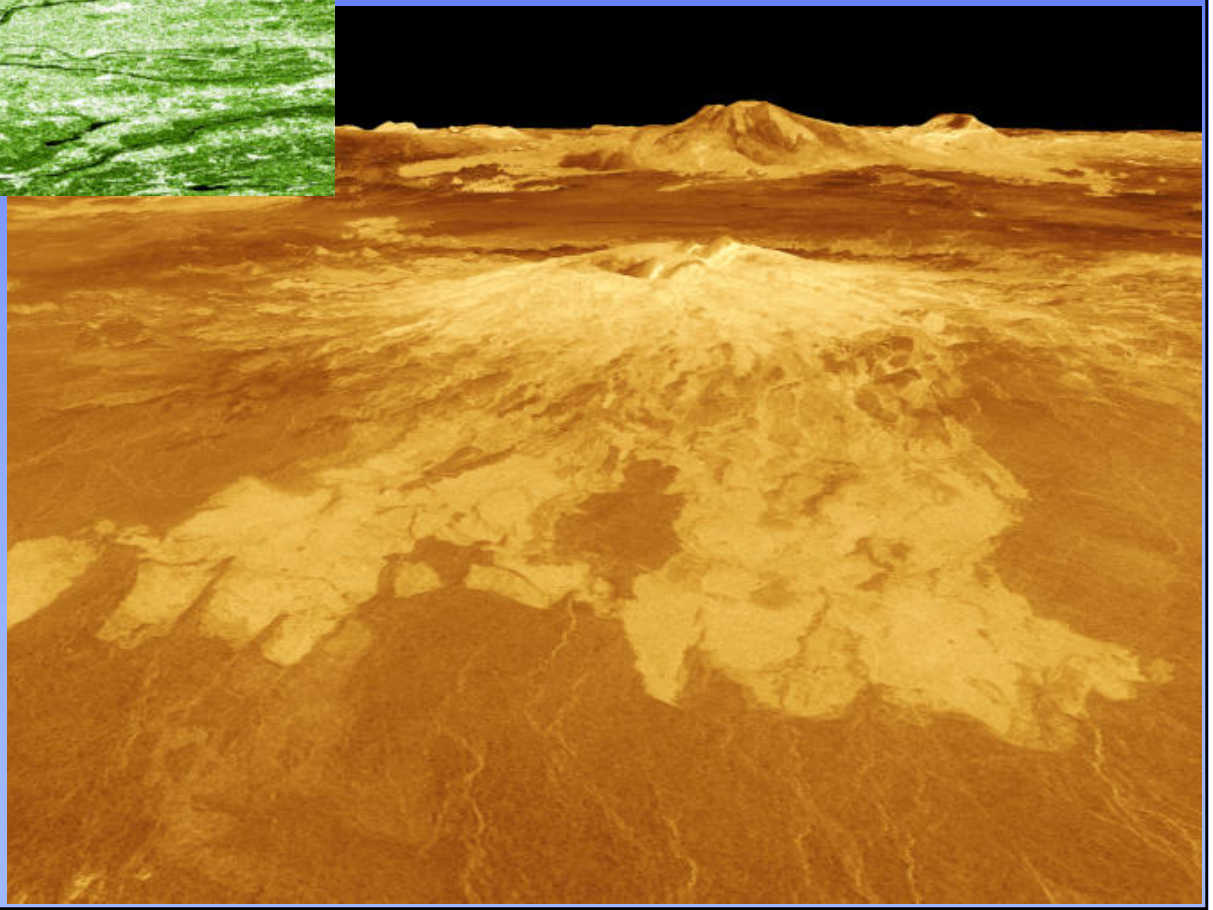




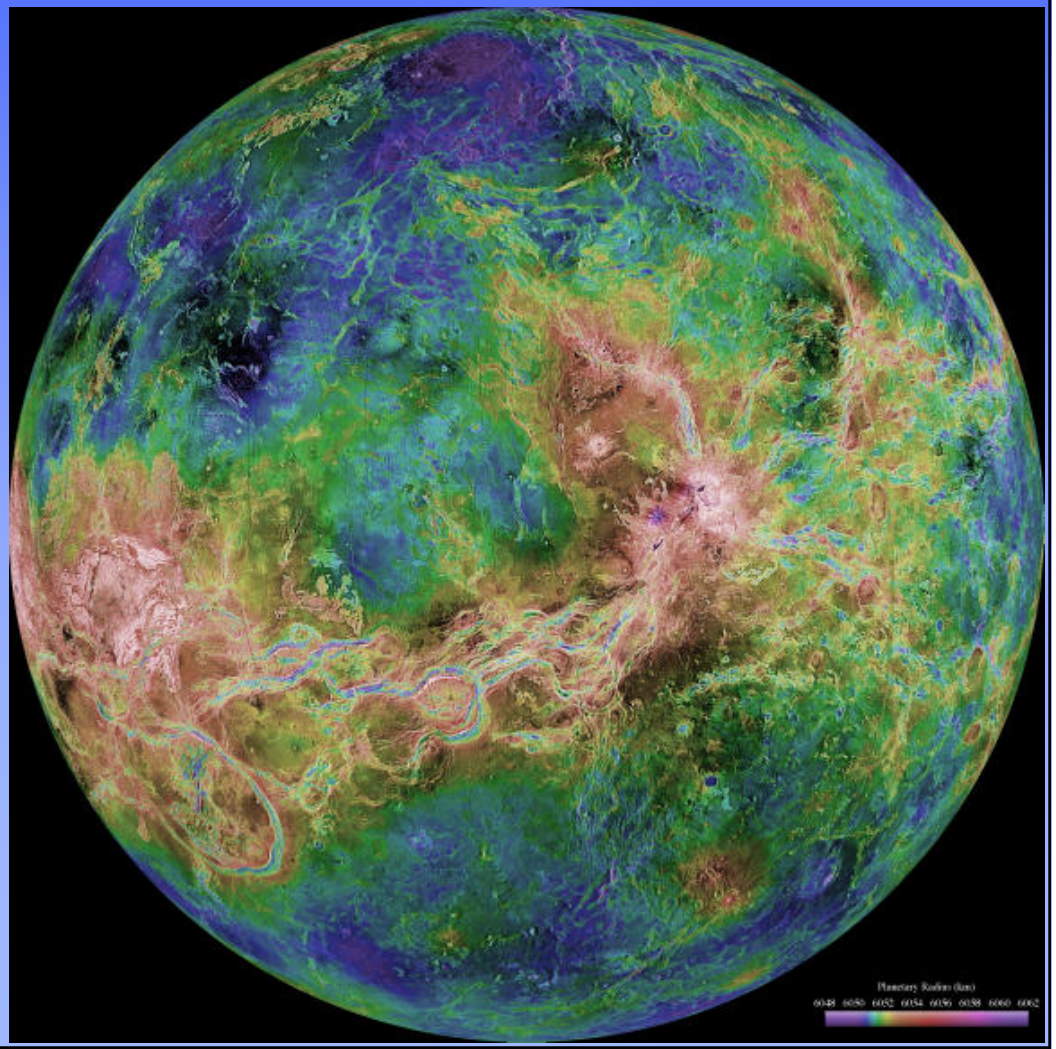


Radar mapping

- Earth: Mt Fuji ↑
- Venus: Sapas Mons →

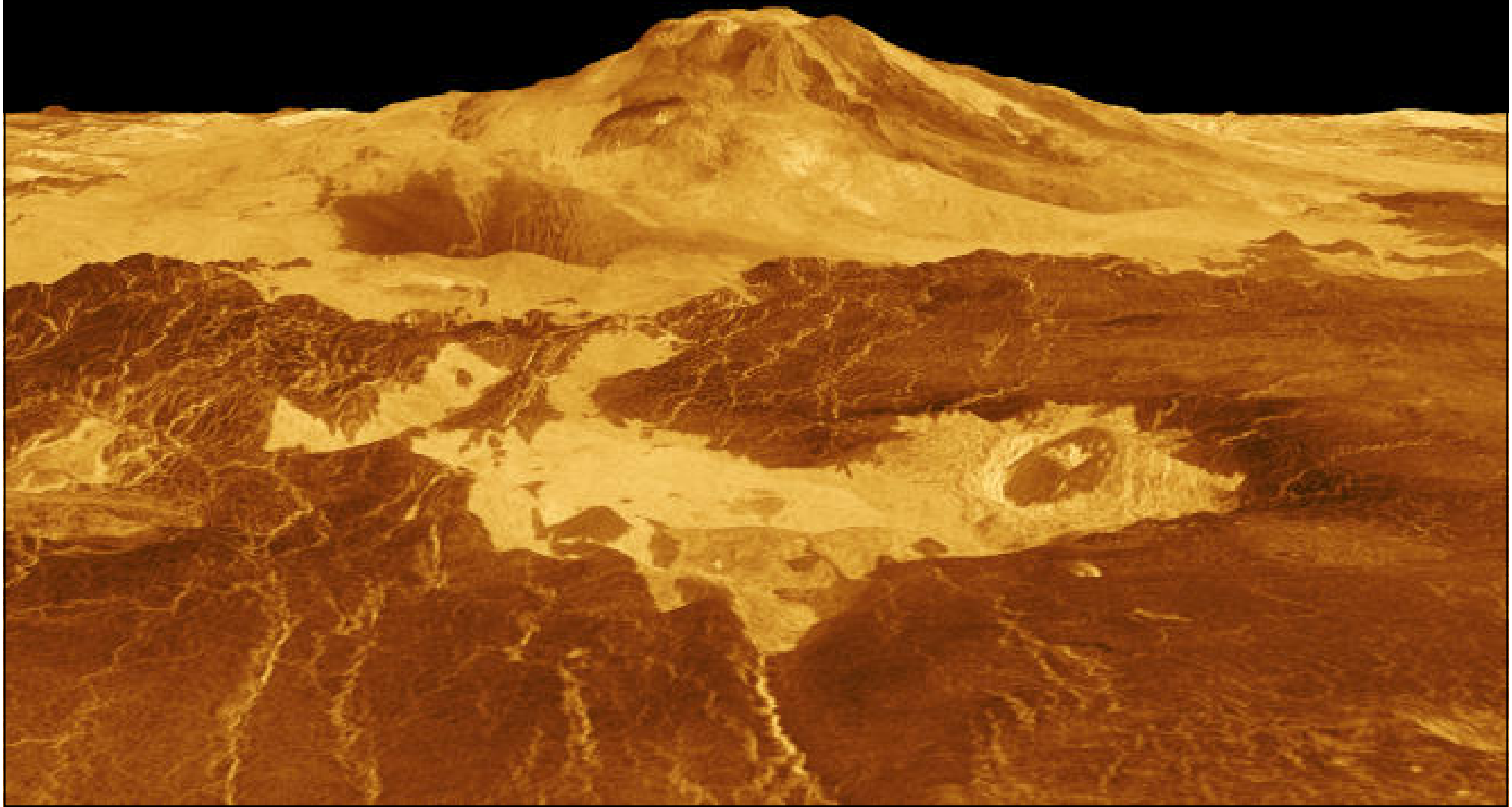


Radar → Contour



Radar ↑ Contour →

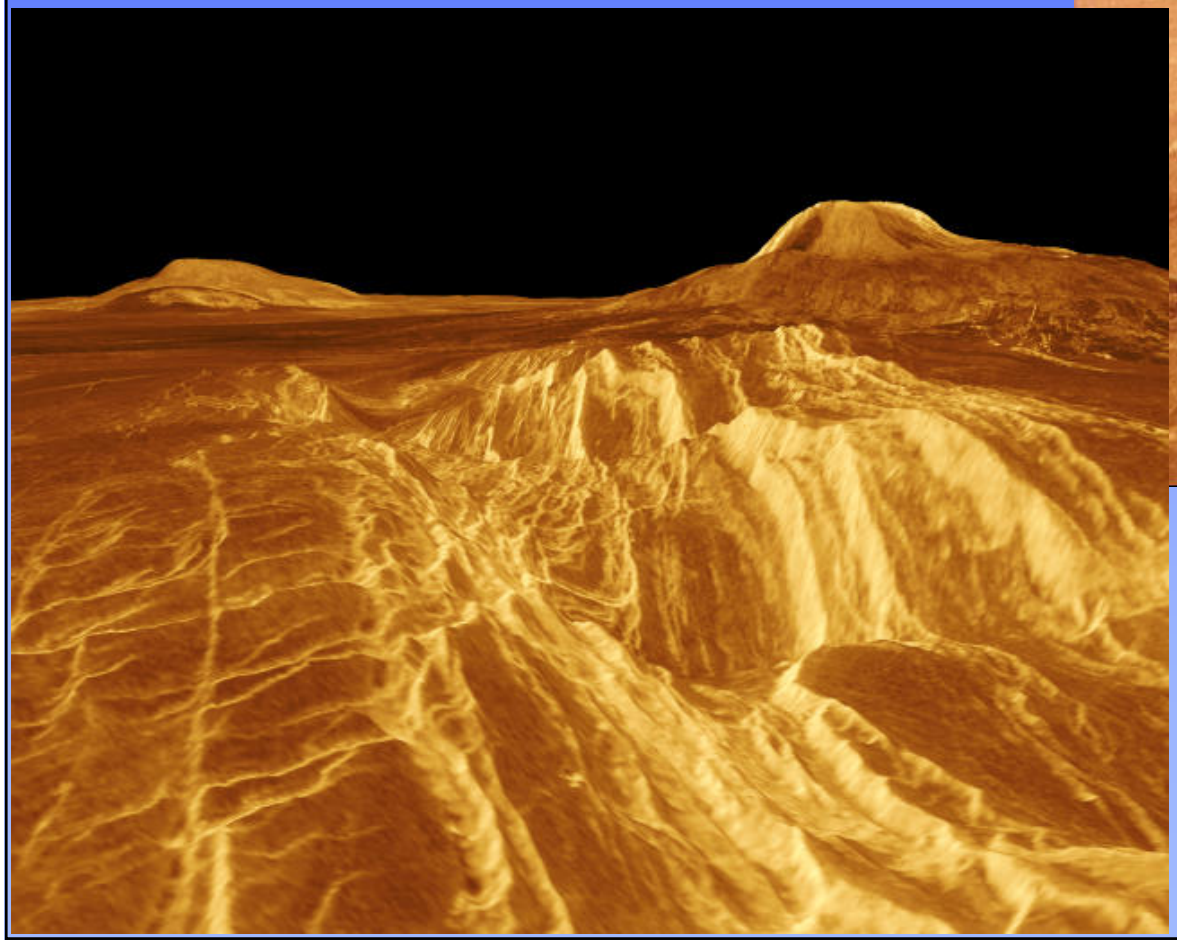
Maat Mons

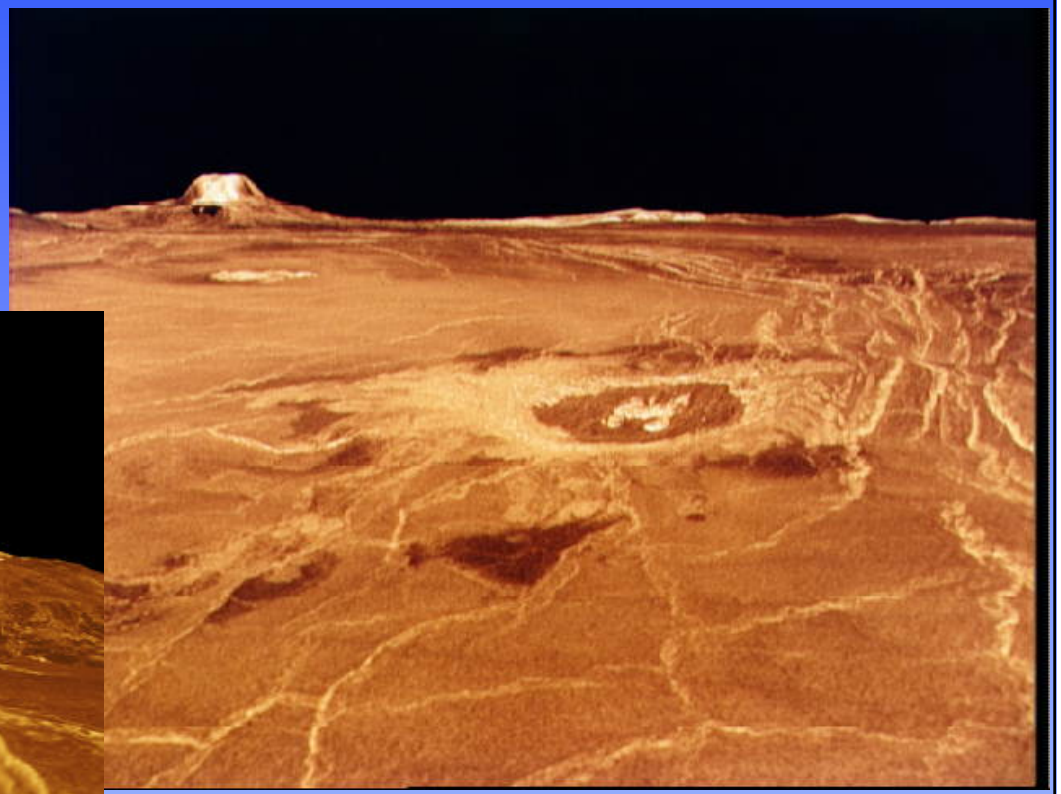


Venusian Landscape

Sif (2 km high) & Gula Mons (3 km)

↓





Volcano and crater ↑

Venus' Hellish Atmosphere

- 96% CO_2, 3.5% N_2, clouds mainly H_2SO_4 with some HCl and H_2O
- At ground level, very dense - 90 bars (bar is a pressure unit of 0.1MPa, approximately Earth's atmospheric pressure)
  - extremely hot (460°C) and still; a yellowish light bathes the planet
  - very high winds in upper atmosphere, 350 km hr^{-1}

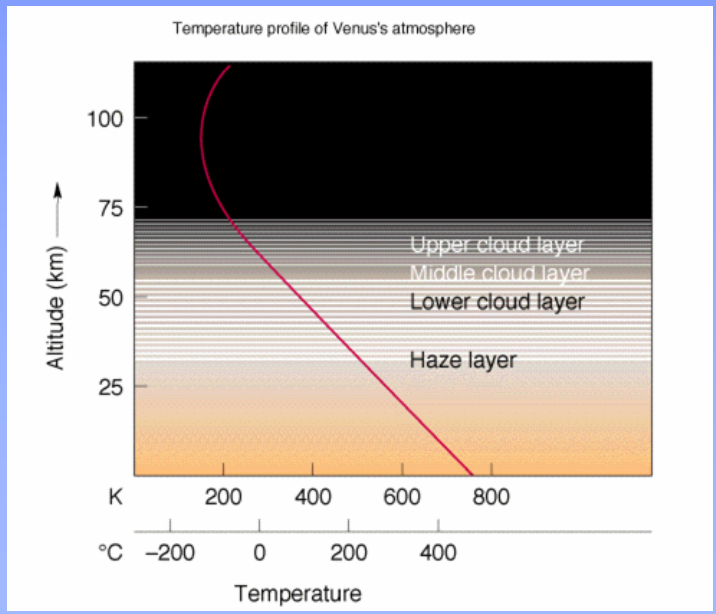


FIG 8.18

The Overheated Greenhouse

- Life on Earth depends on the ‘greenhouse’ effect
- Various atmospheric gases, notably CO_2 and H_2O, blanket the Earth, keeping the biosphere an average of 35°C warmer than it would be without them
- These gases let in sunlight but absorb escaping heat radiation
- The CO_2 on Venus has overcooked the planet

Venus's greenhouse effect

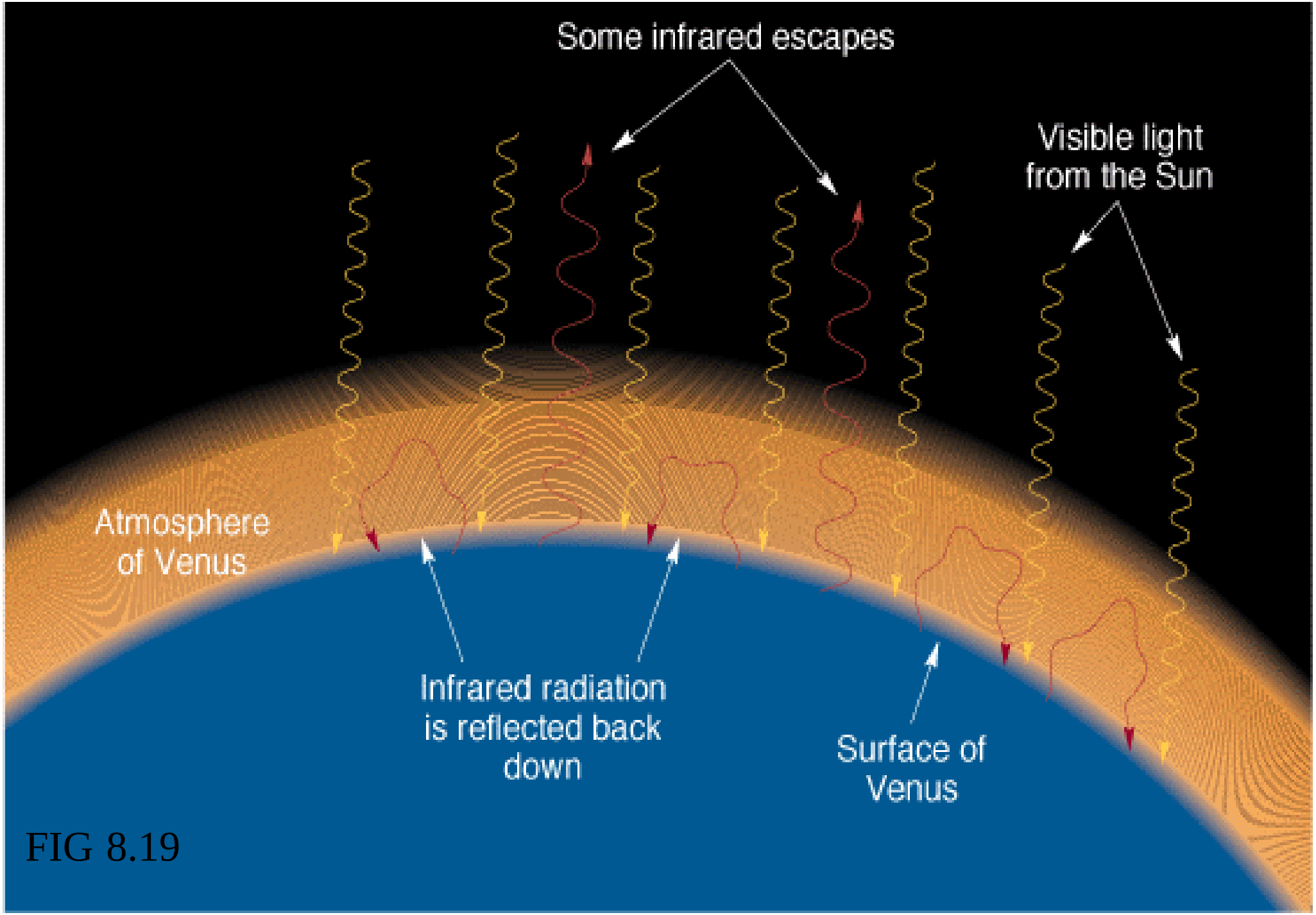
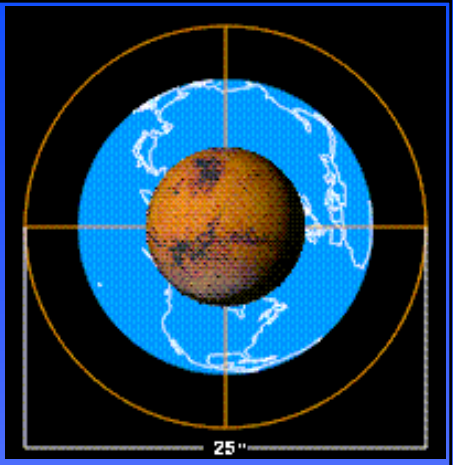
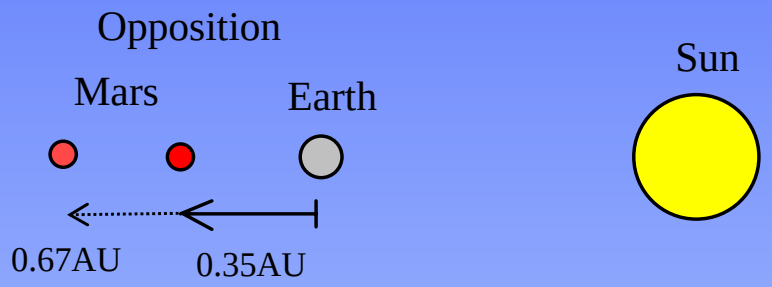


FIG 8.19

Mars from Earth

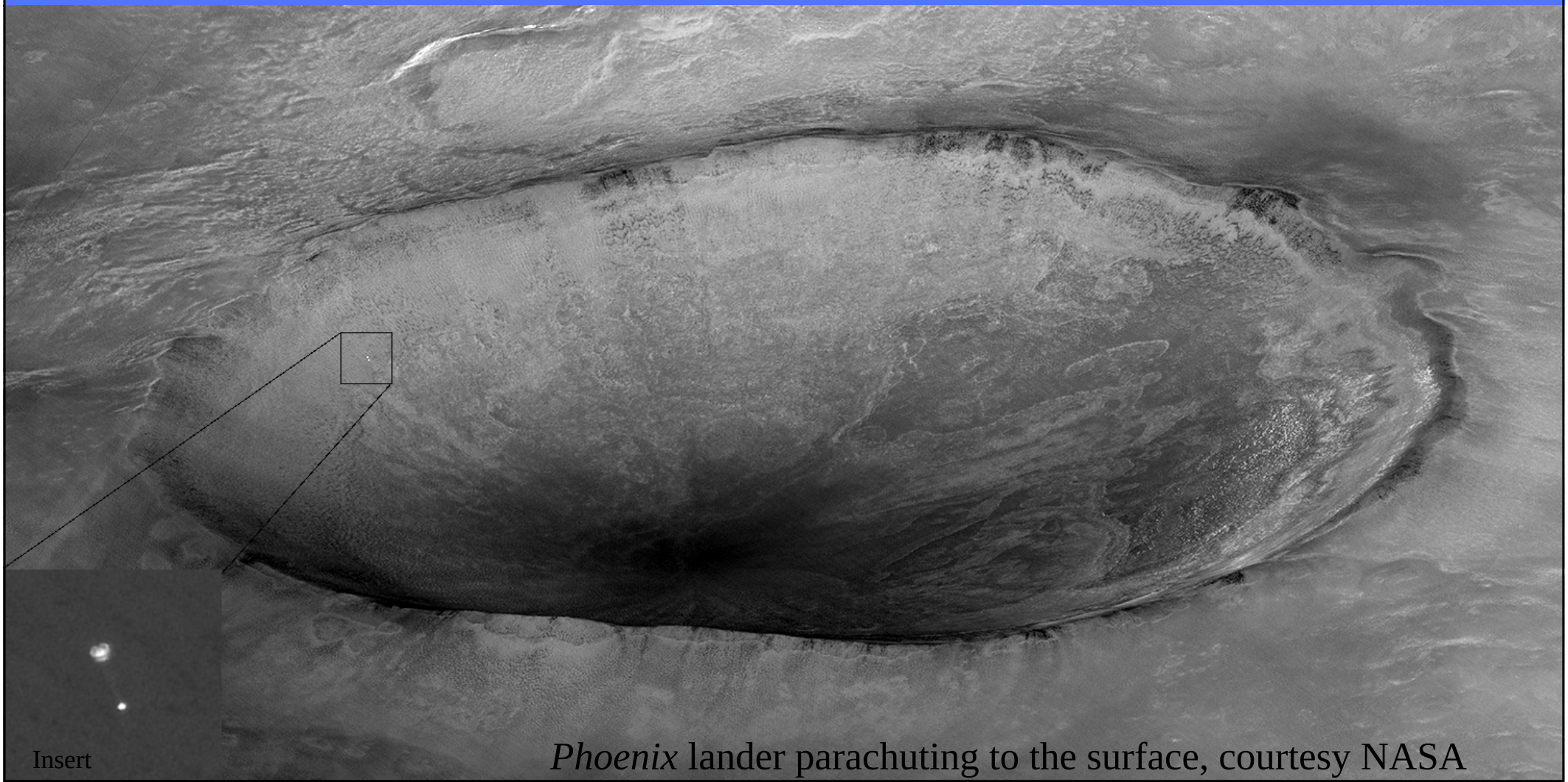


- Next planet out from Sun
  - Mars led Kepler to elliptical orbits
  - eccentricity 0.093 or almost 6 times that of Earth's orbit
- Best seen in opposition



- Small planet approx. half diameter of Earth
- White polar 'dry-ice' caps shrink in summer
- Similar length of day and tilt of ecliptic
  - Martian year is 1.88 Earth years

Mars from Space

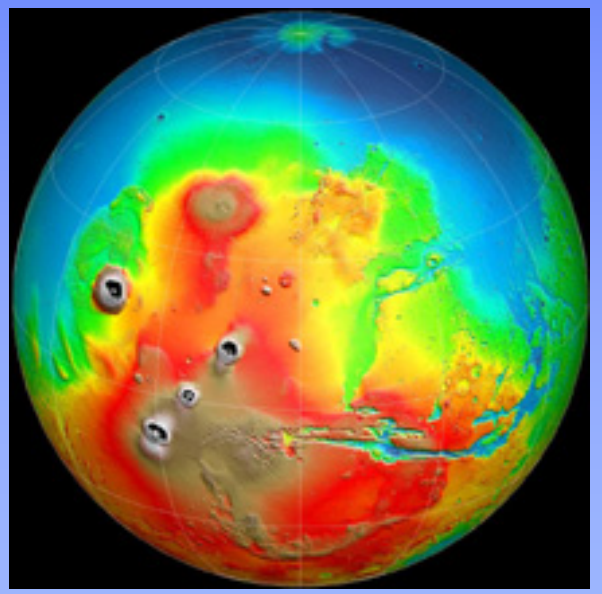


Insert

Phoenix lander parachuting to the surface, courtesy NASA

Mars from Space - 2

- *Mariner* fly-pasts (late 1960s) and orbiter (1971); *Viking* landings (1976), looking for evidence of life; *Pathfinder* (1997); *Global Surveyor*; *Odyssey*; *Rovers*; *Mars Express; Phoenix (2008)*
- Dry dusty planet showing plenty of signs of weathering, past water and present frozen water
- Large dead volcanoes - Olympus Mons
  - no tectonic movement
- Red colour is iron oxide - rust
- Storms of very fine dust at times envelope the planet

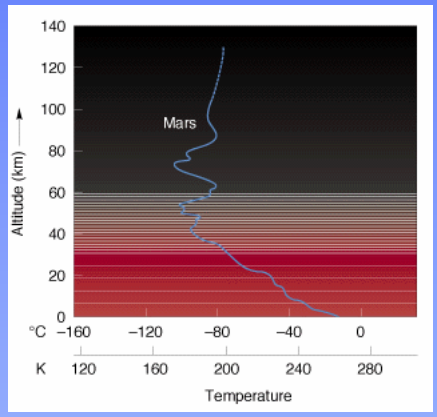


Courtesy NASA MGS.
http://ltpwww.gsfc.nasa.gov/tharsis/mapping_results.html

Atmosphere of Mars

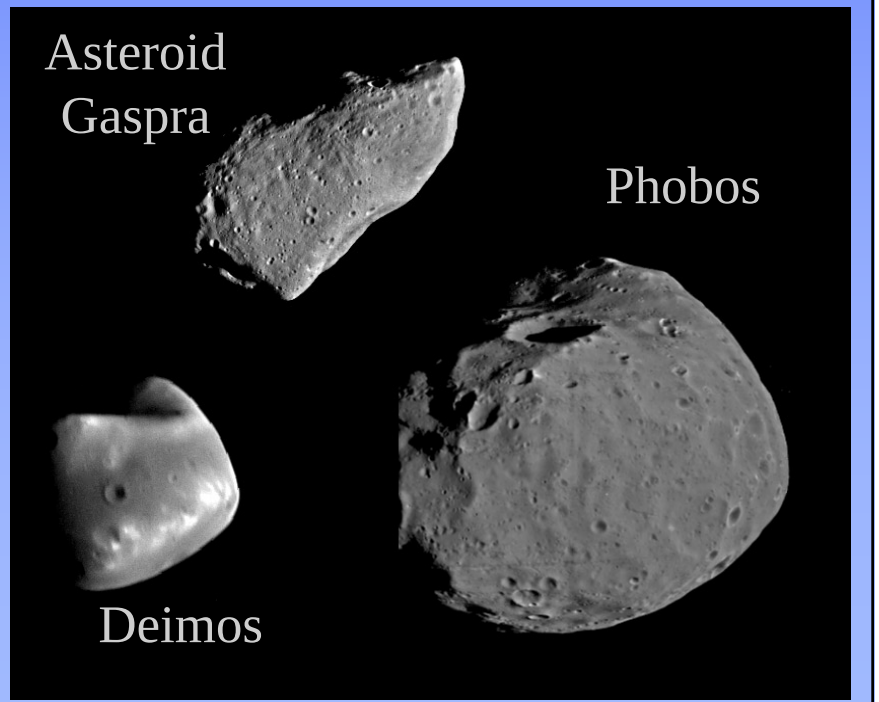
- Atmosphere very thin, about $(^1/200)^{th}$ Earth's
- 95% CO_2 but too little to have a large 'greenhouse effect'
- Night-time temperatures -140°C; day-time can be as high as 20°C
- No ozone layer:- any water vapour can be decomposed into O_2 and H_2, with escape of H_2
- Sometimes clouds of solid CO_2 and dusty haze

Courtesy: K & K



Moons of Mars

- **Phobos** (28 km diameter, period 7.7 hrs) and **Deimos** (23 x 20 x 20 km, period 30.3 hrs)
- Too small to have enough self gravity to make themselves spherical, which is the shape of lowest gravitational energy
- Heavily cratered
- Look like captured asteroids
  - Gaspra shown for comparison



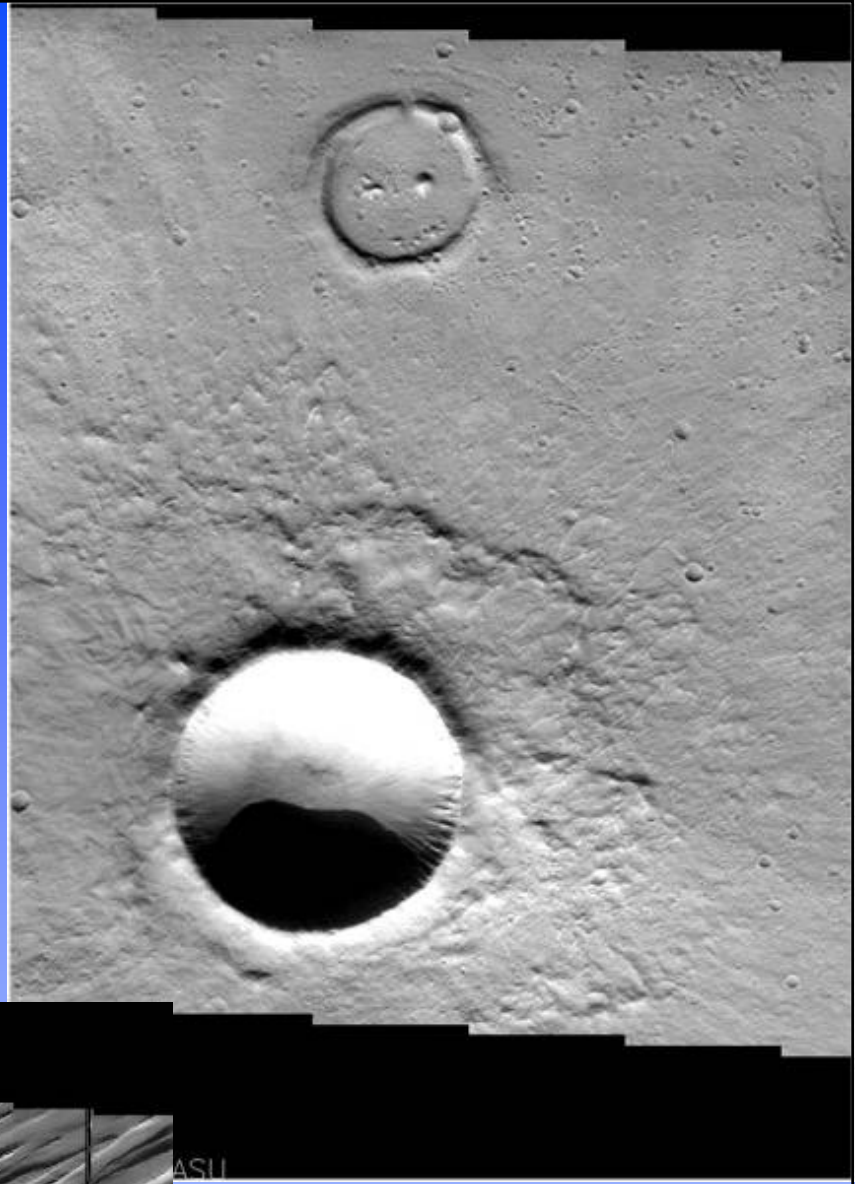
Phobos in Close-up

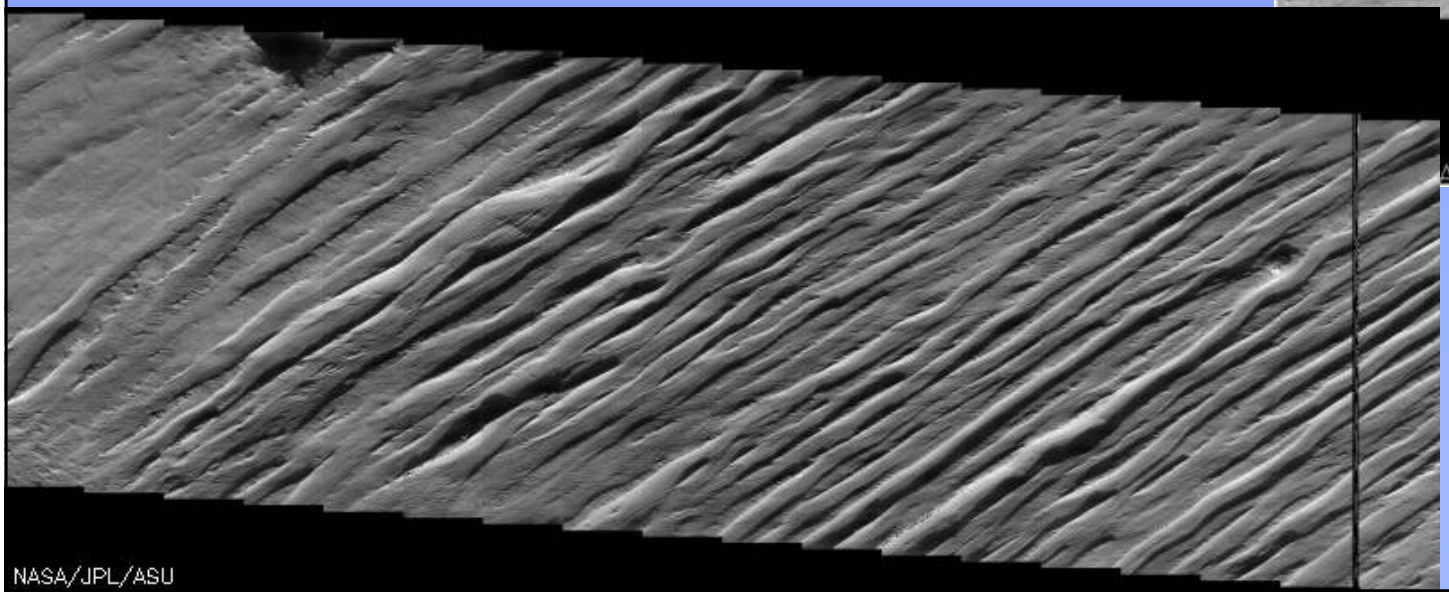
Courtesy NASA

Mars Global Surveyor

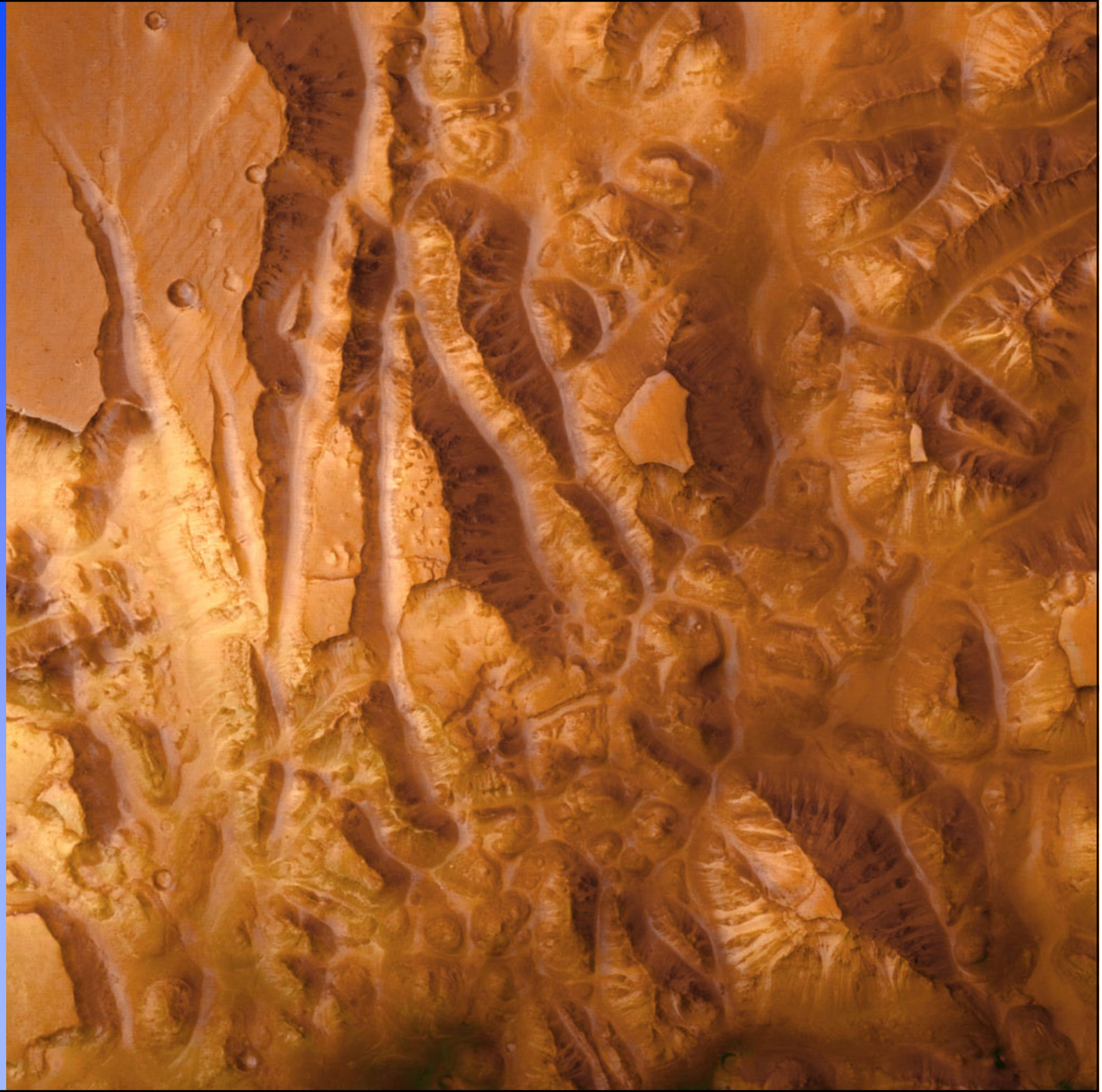
Mars topography

- Old and new craters
  - old crater at top, flooded by lava; newer crater below
- Wind eroded ‘yardangs’





Both pictures courtesy
NASA/JPL/ASU
Odyssey 2001

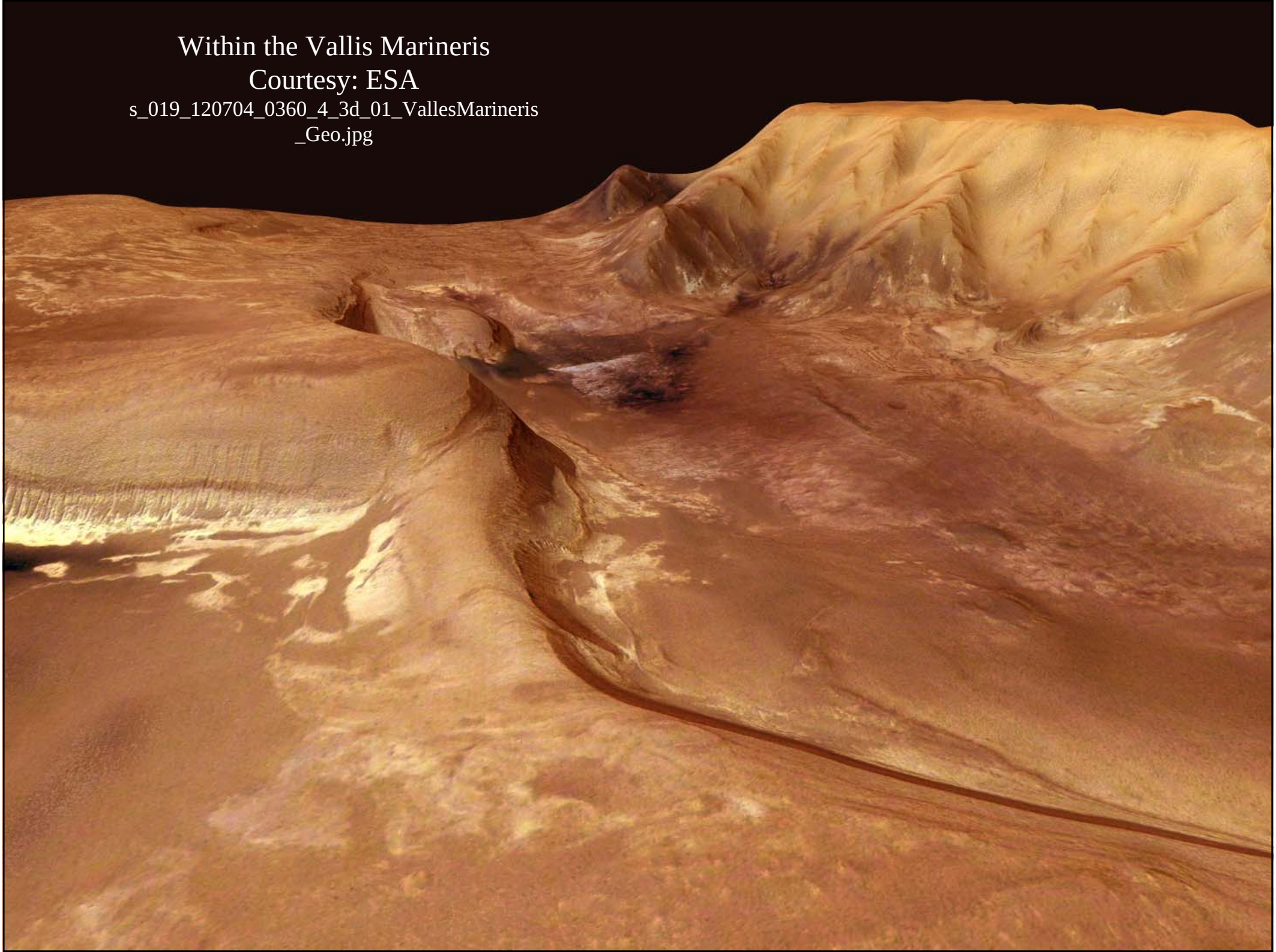


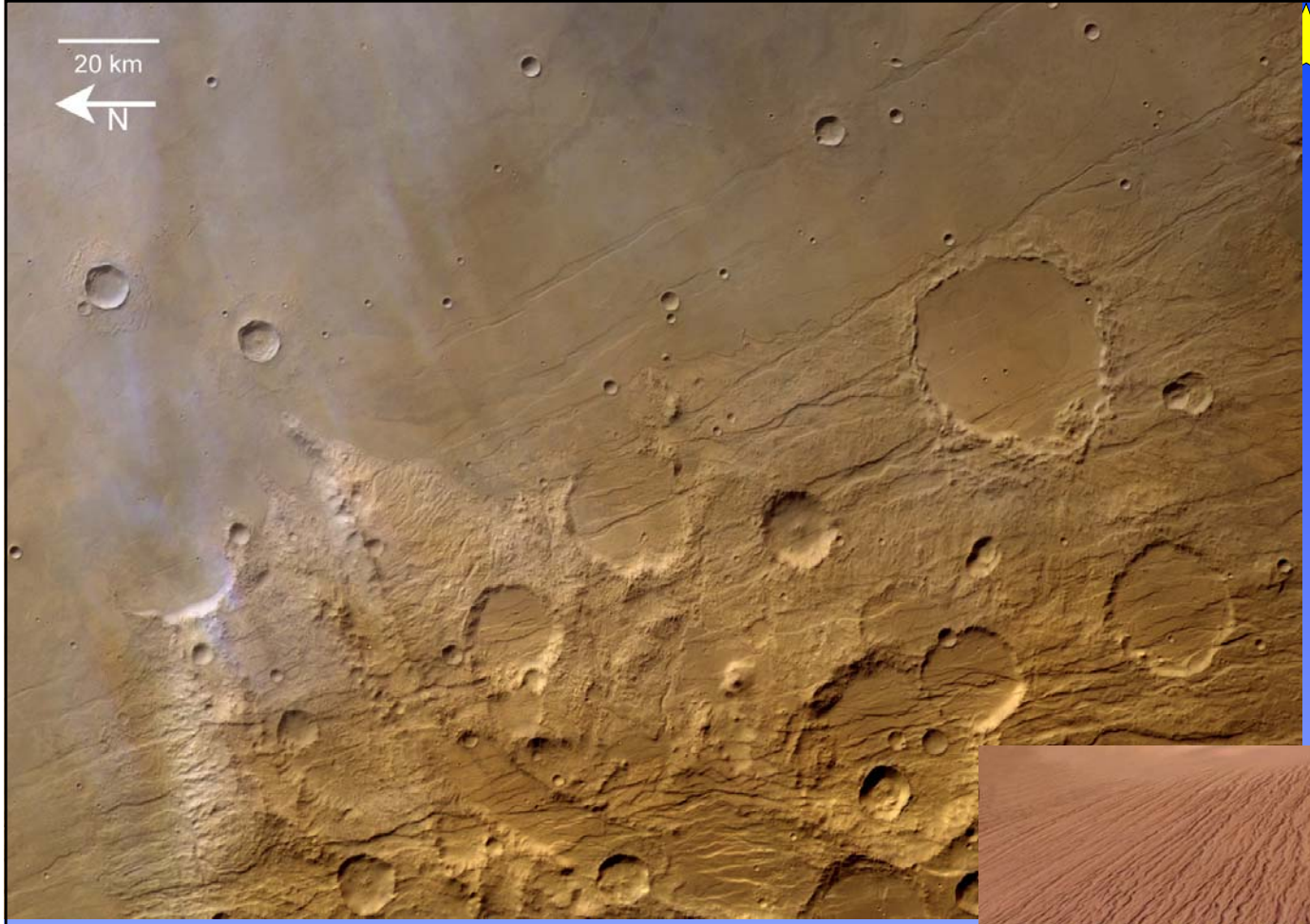
Part of Vallis Marineris

Courtesy: ESA

SEMWU2474OD.jpg

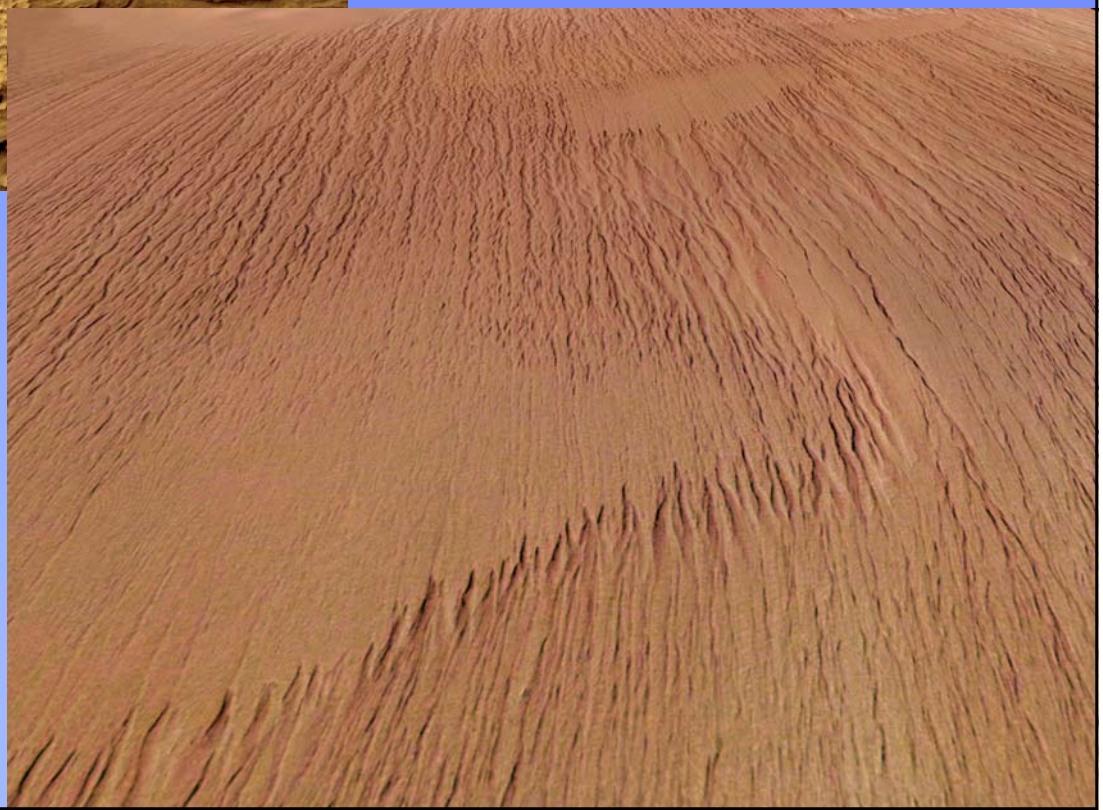
Within the Vallis Marineris
Courtesy: ESA
s_019_120704_0360_4_3d_01_VallesMarineris
_Geo.jpg





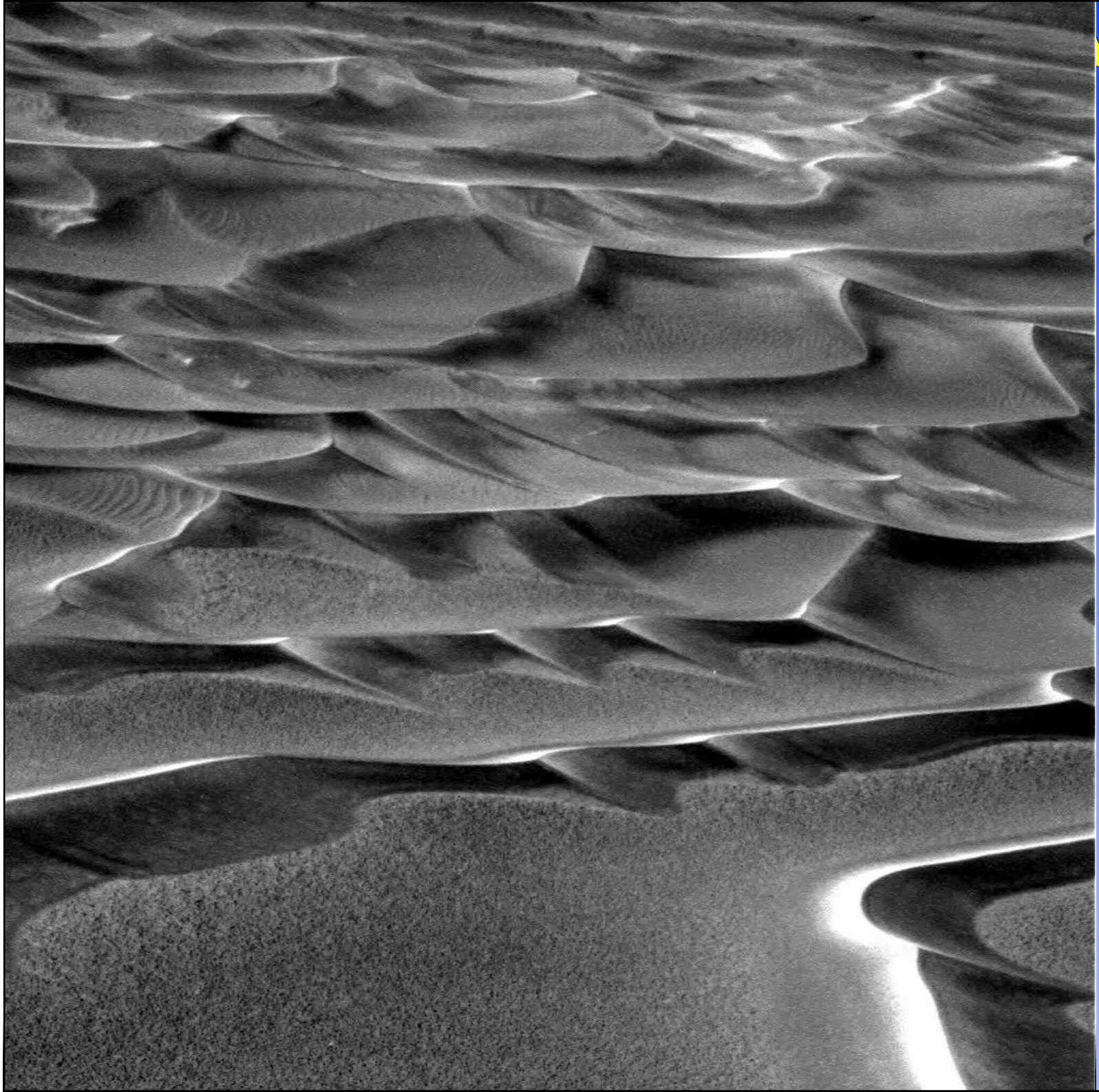
↑ Grabens, courtesy: ESA

GrabensClaritasFossae.jpg



Yardang country near Olympus Mons

Courtesy: ESA OlympusMons_Yardangs.jpg



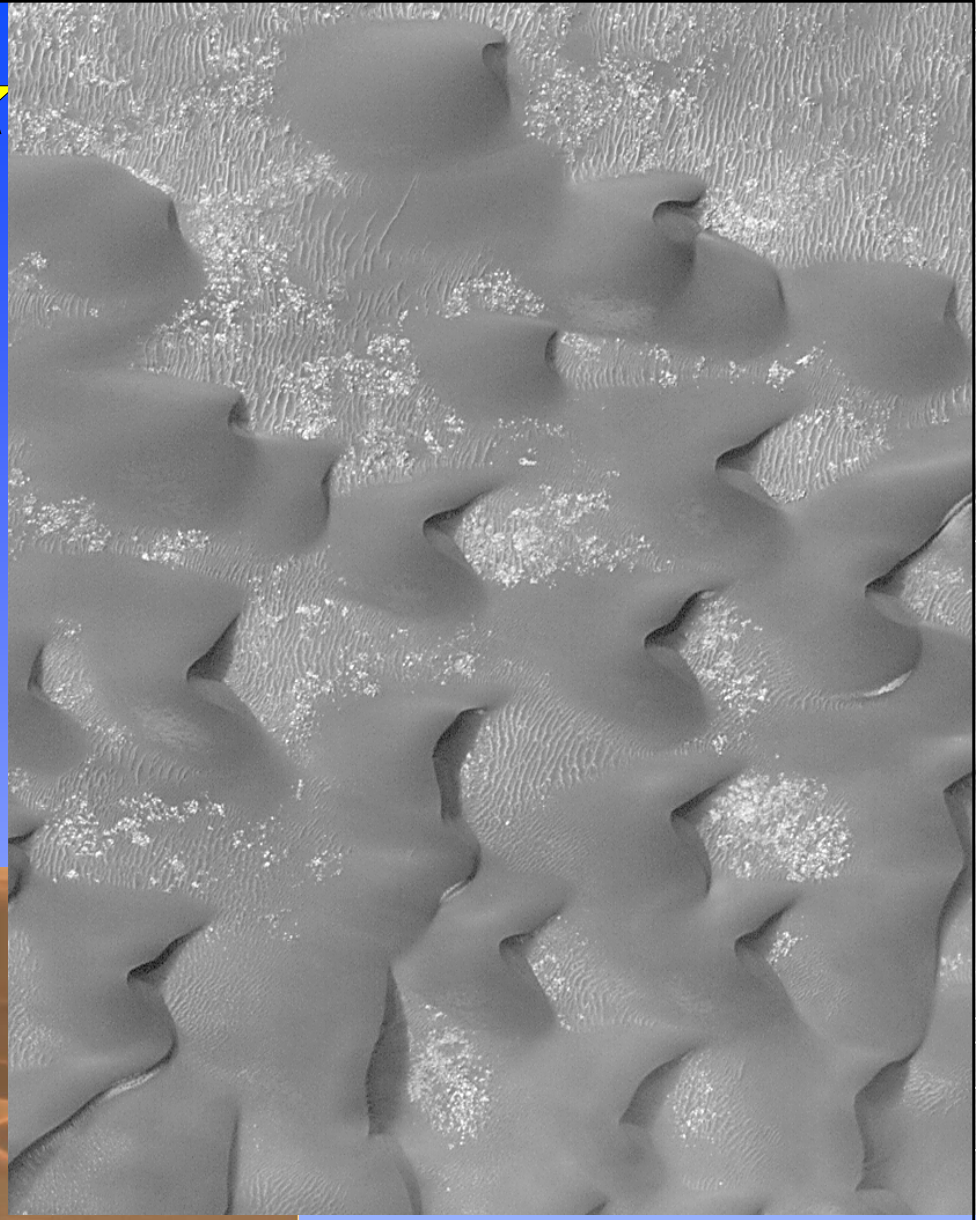
Dunes

Courtesy: NASA

07-OSS-02-Dunes-B202R1_br2.jpg

Dunes 2

M02-04432sub.gif



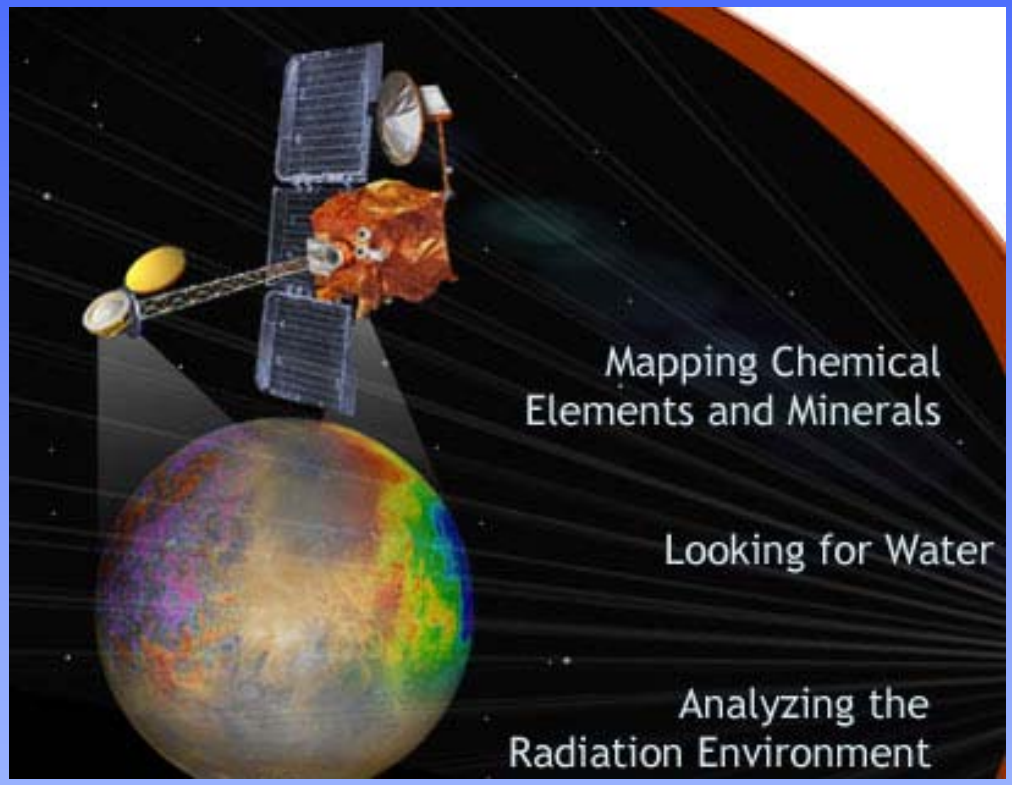
Sol187B_P2546_L456-B187R1.jpg

Dunes in false colour

Sol187B_P2546_L257false-B187R1.jpg

Mars Odyssey - 2001

- Still sending back data
- 3 main instruments
  - multi-spectral IR imager to determine rock types (THEMIS)
  - γ camera to look at distribution of elements
    - neutron detector to look at water distribution
  - incident cosmic radiation detector to monitor health hazard for future astronauts



2004 missions

- ESA's Mars Express
- NASA's Mars exploration rover missions

Mars Express ↓

← Courtesy: http://www.jpl.nasa.gov/images/spacecraft/mars-express-browse.jpg

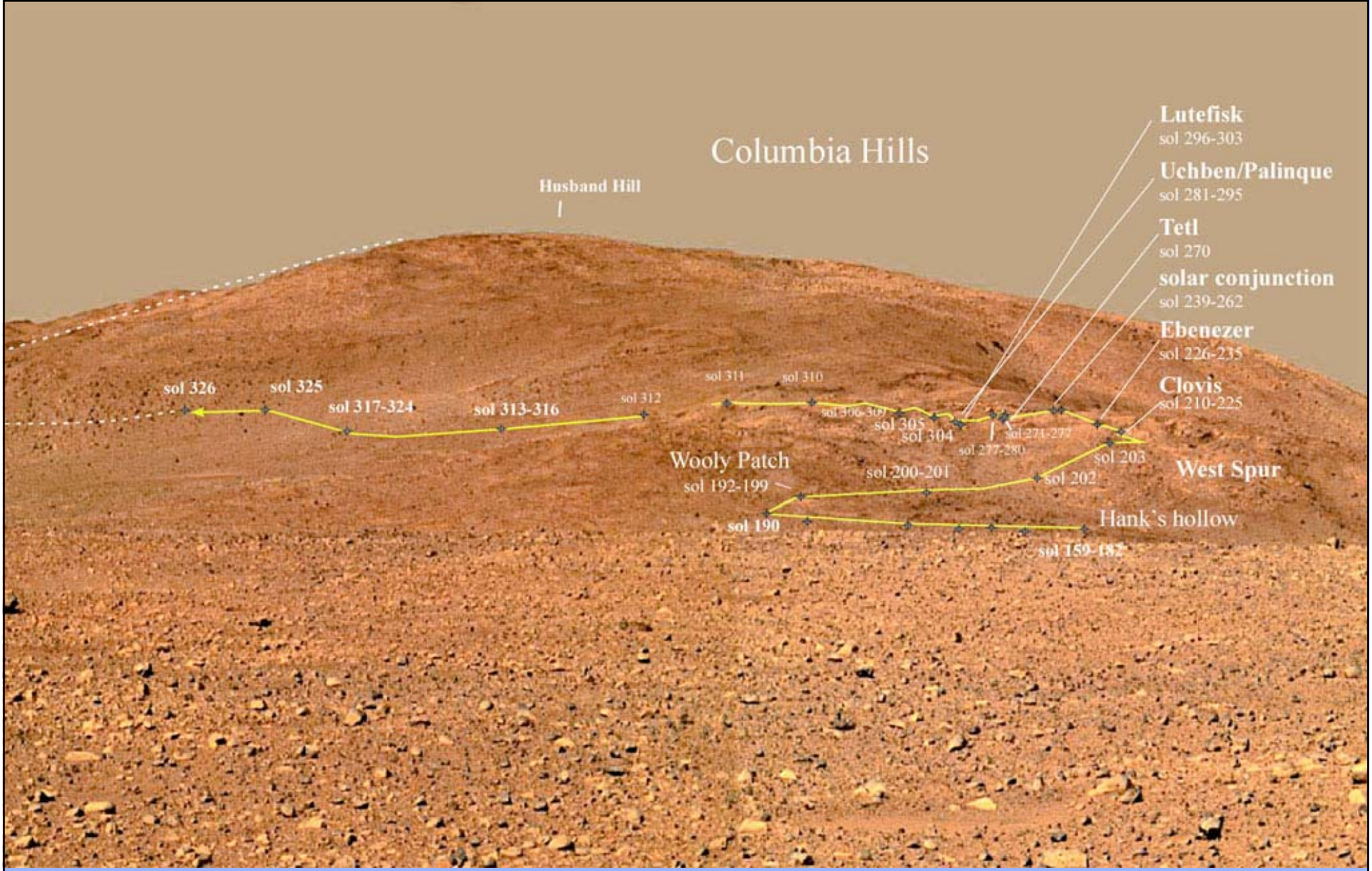
Spirit & Opportunity →

Courtesy: NASA

Spirit’s view

NASA: 08-JT-03-easthills-A094R1_br2.jpg

Animated panorama



Part of Spirit's exploratory track

Outcrop Methuselah 20/04/05

Roving

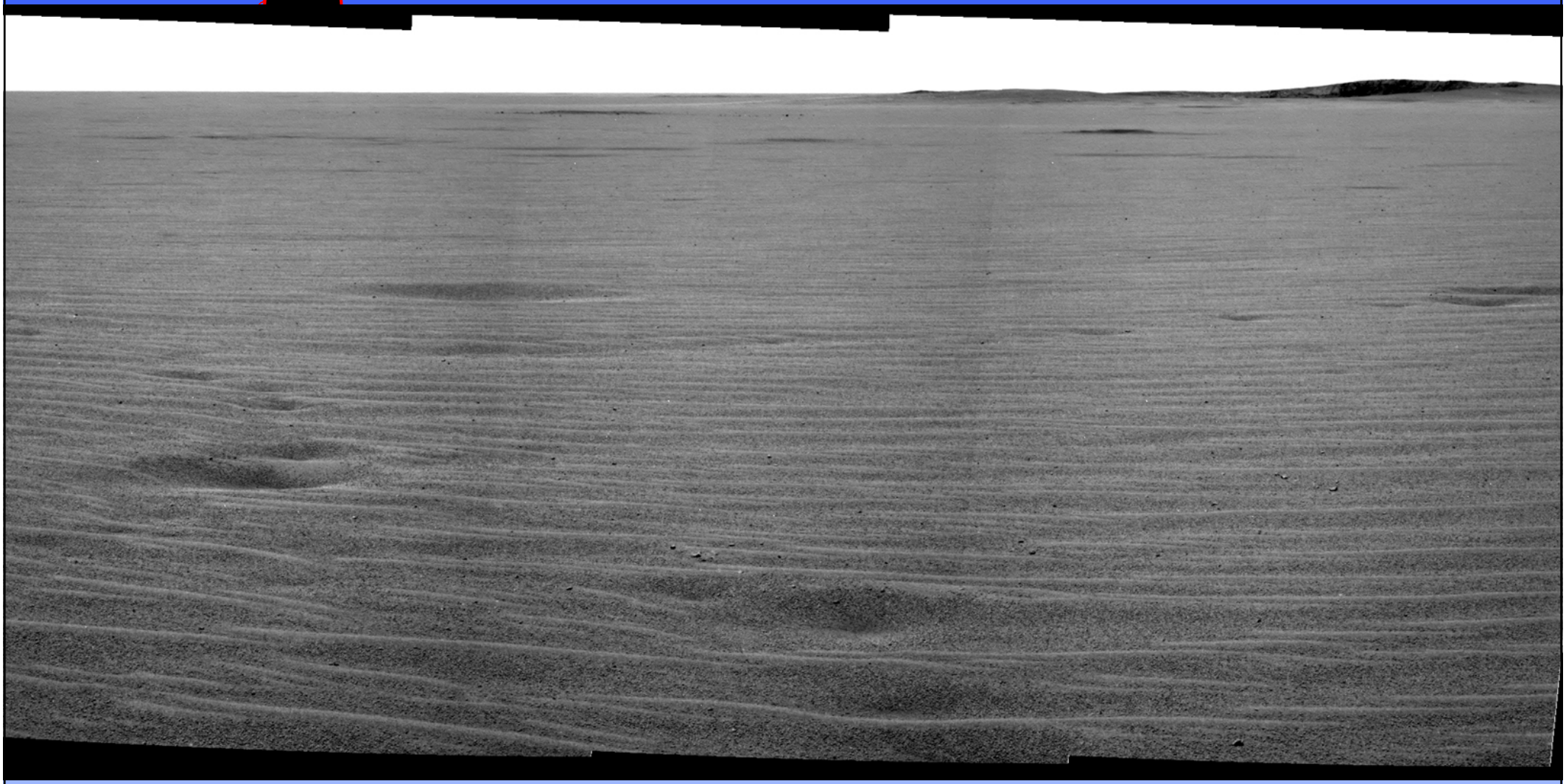
MER

Spirit Navcam

sols: 365, 366, 367,
381, 382, 386, 388, 390

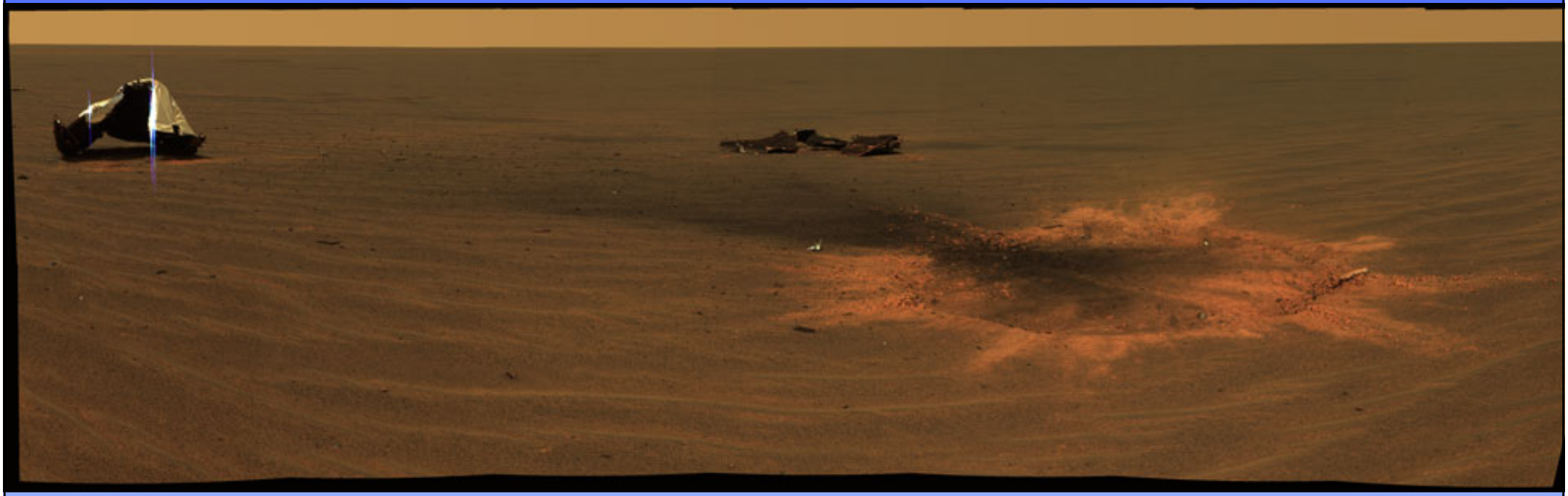
animated GIF

Opportunity's view



NASA: _xpe_pubeng_approved_041504_pan_path_endurance-B081R1_br2.jpg

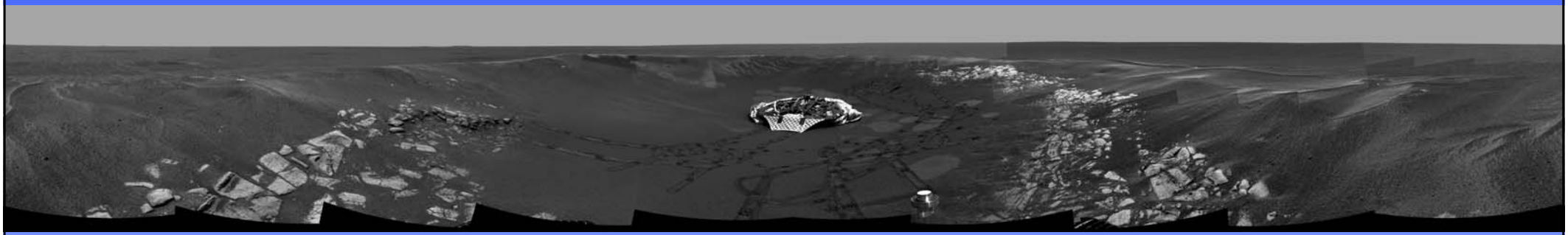
Impact



Opportunity’s heat-shield splash down

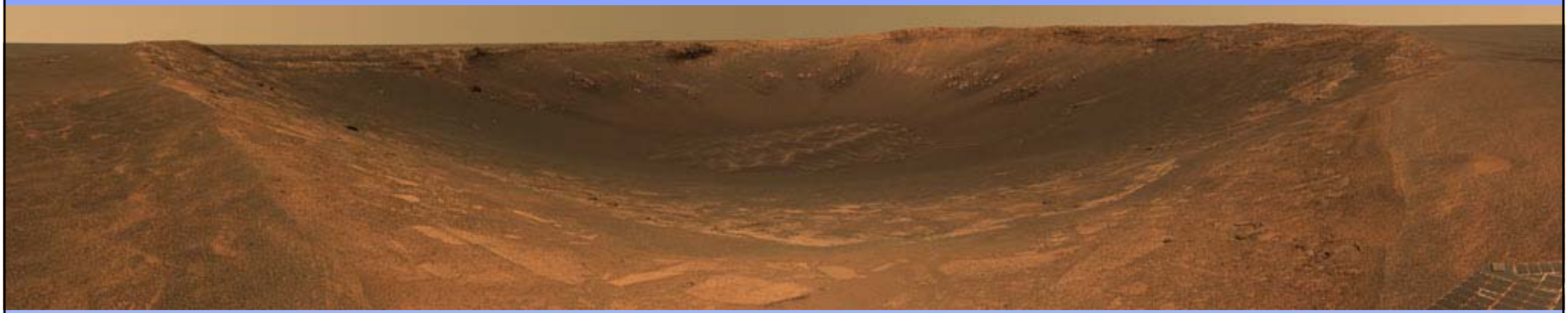
Sol330B_HeatShield_L257-B367R1_br.jpg

Craters

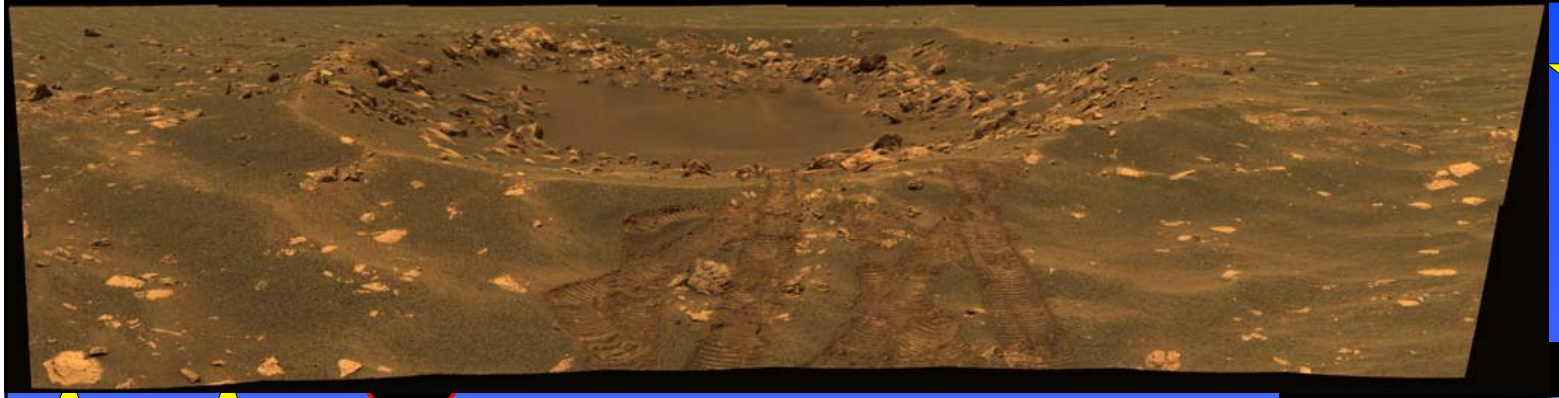


Landing crater

__xpe_pubeng_approved_032104_site5_rim_pan_cyl_jb-B057R1_br2.jpg



01-SS-01-Endurance-B101R1_br.jpg



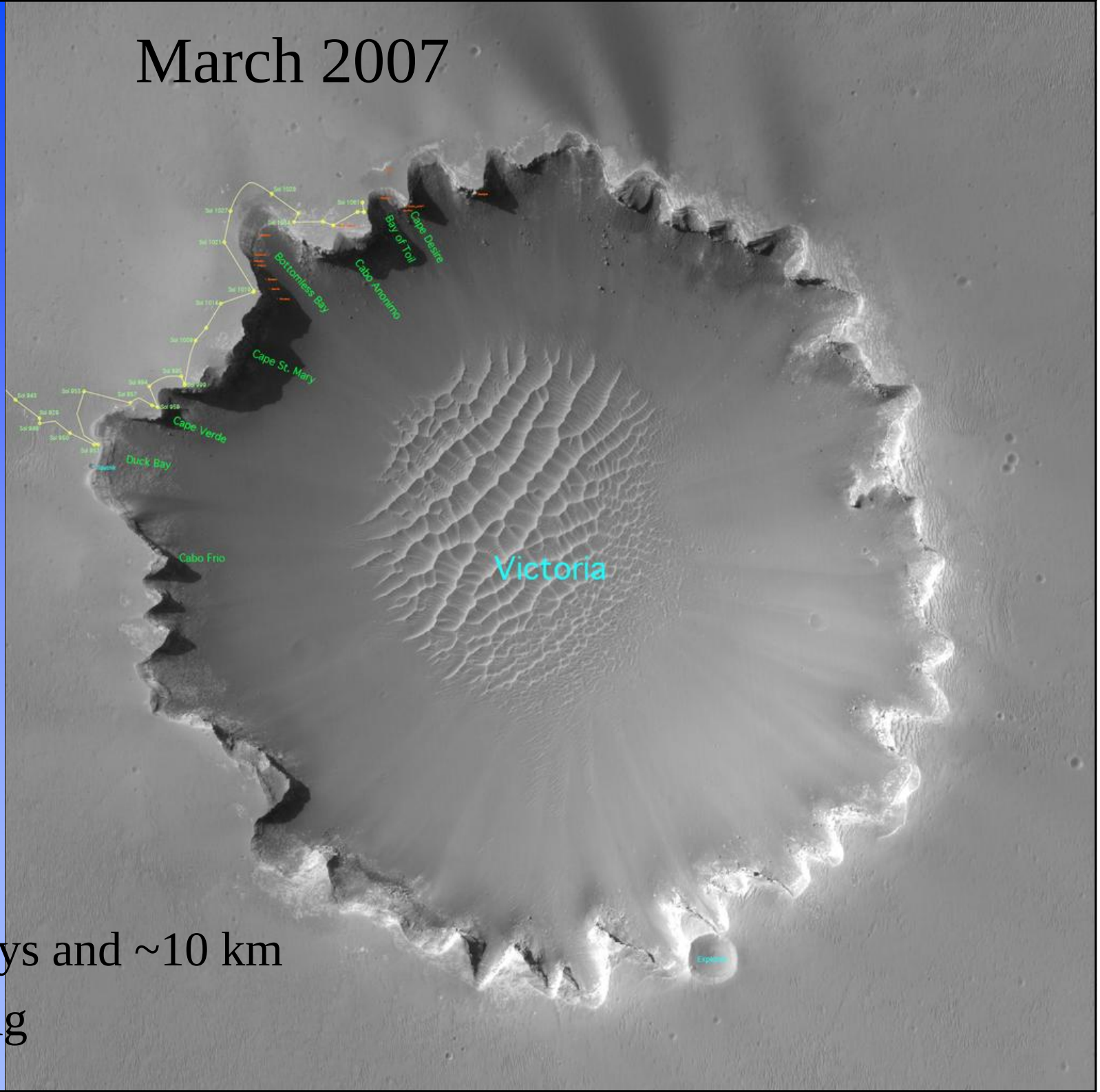
Fram crater
Sol88B_P2285_Fram_L257-B120R1_br.jpg

Within endurance crater
Sol173B_P2401_L257_false-B173R1_br2.jpg

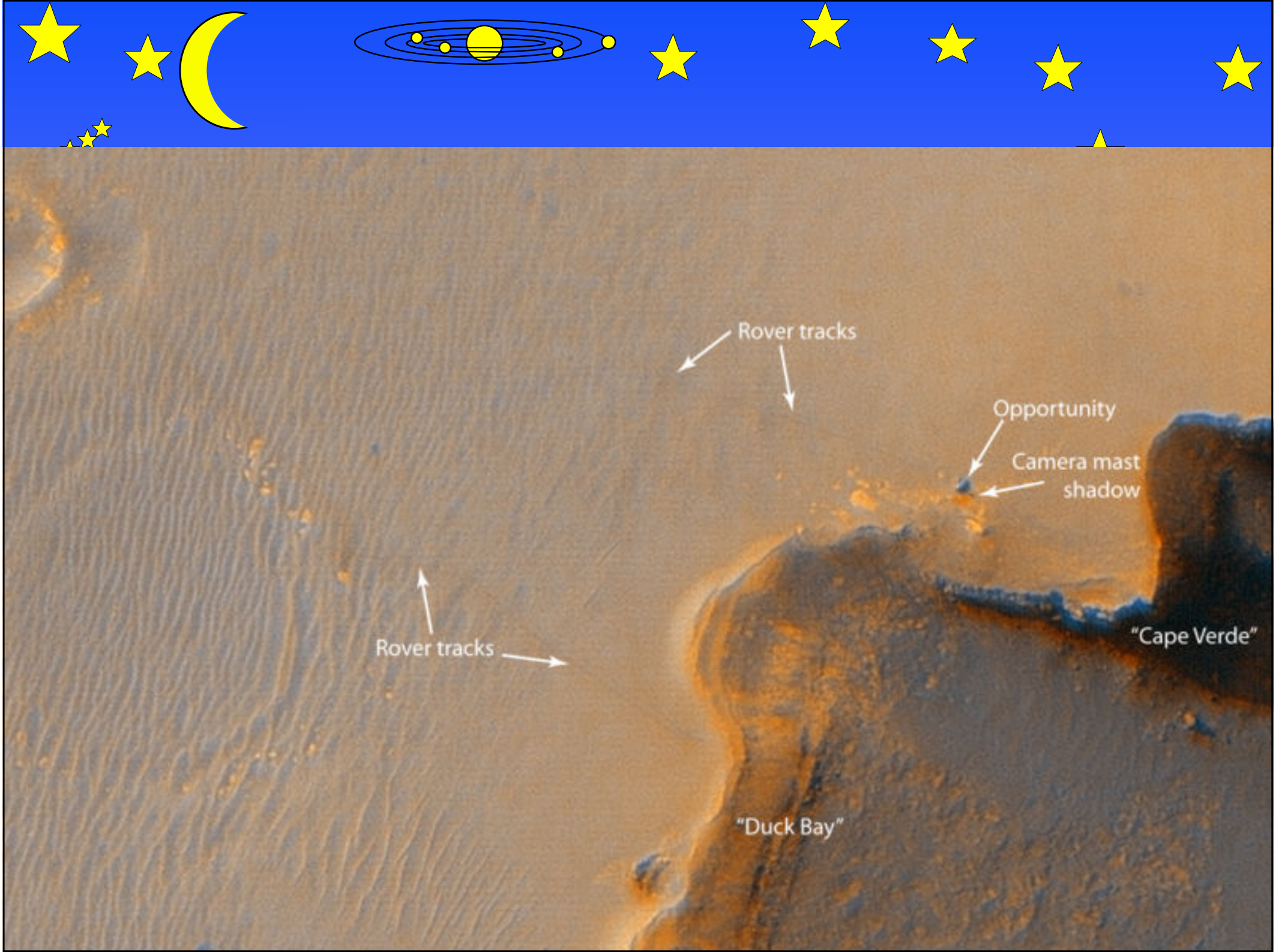
An iron meteorite

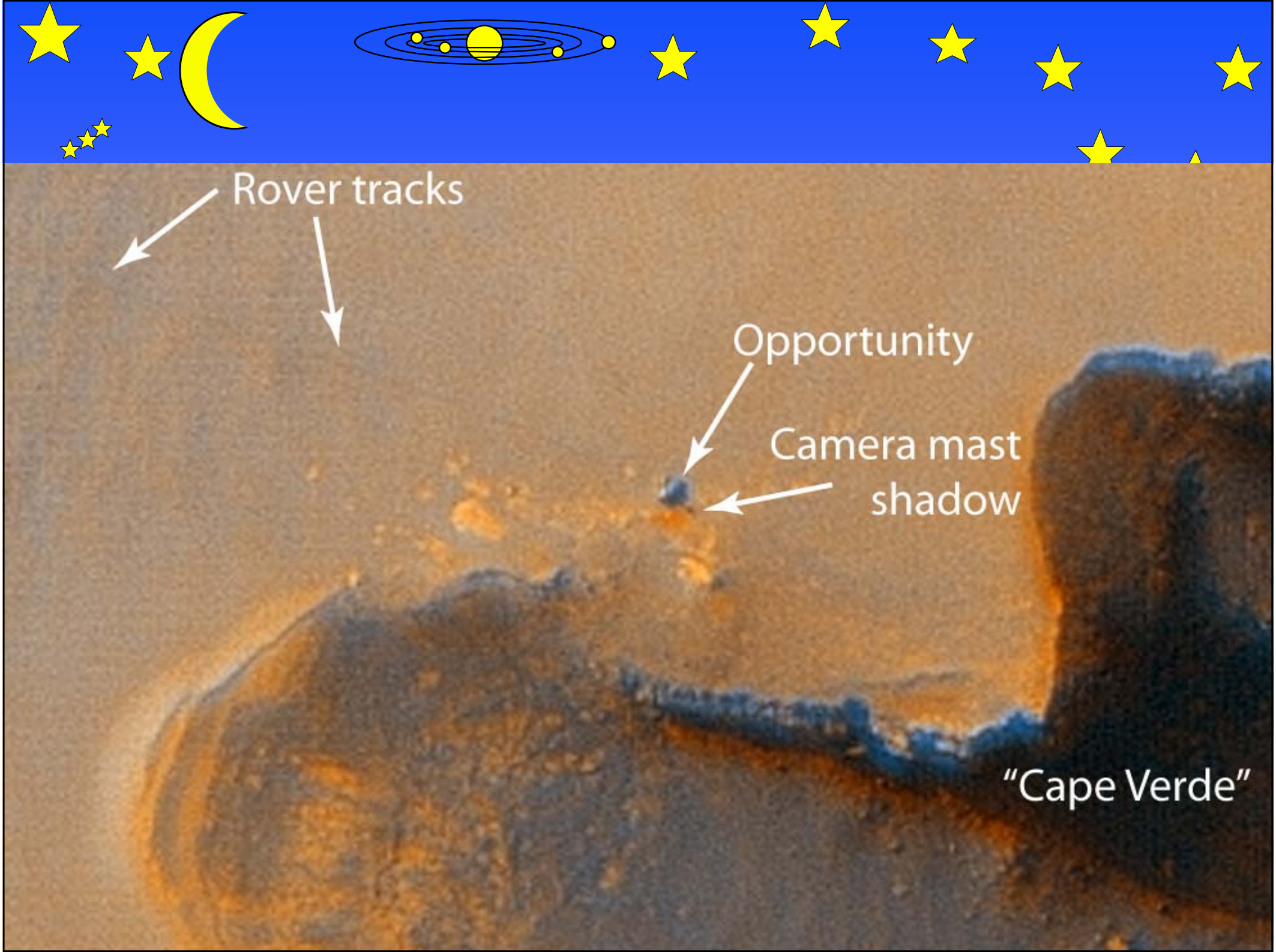
Sol339B_P2581_L456-B352R1_br.jpg

March 2007

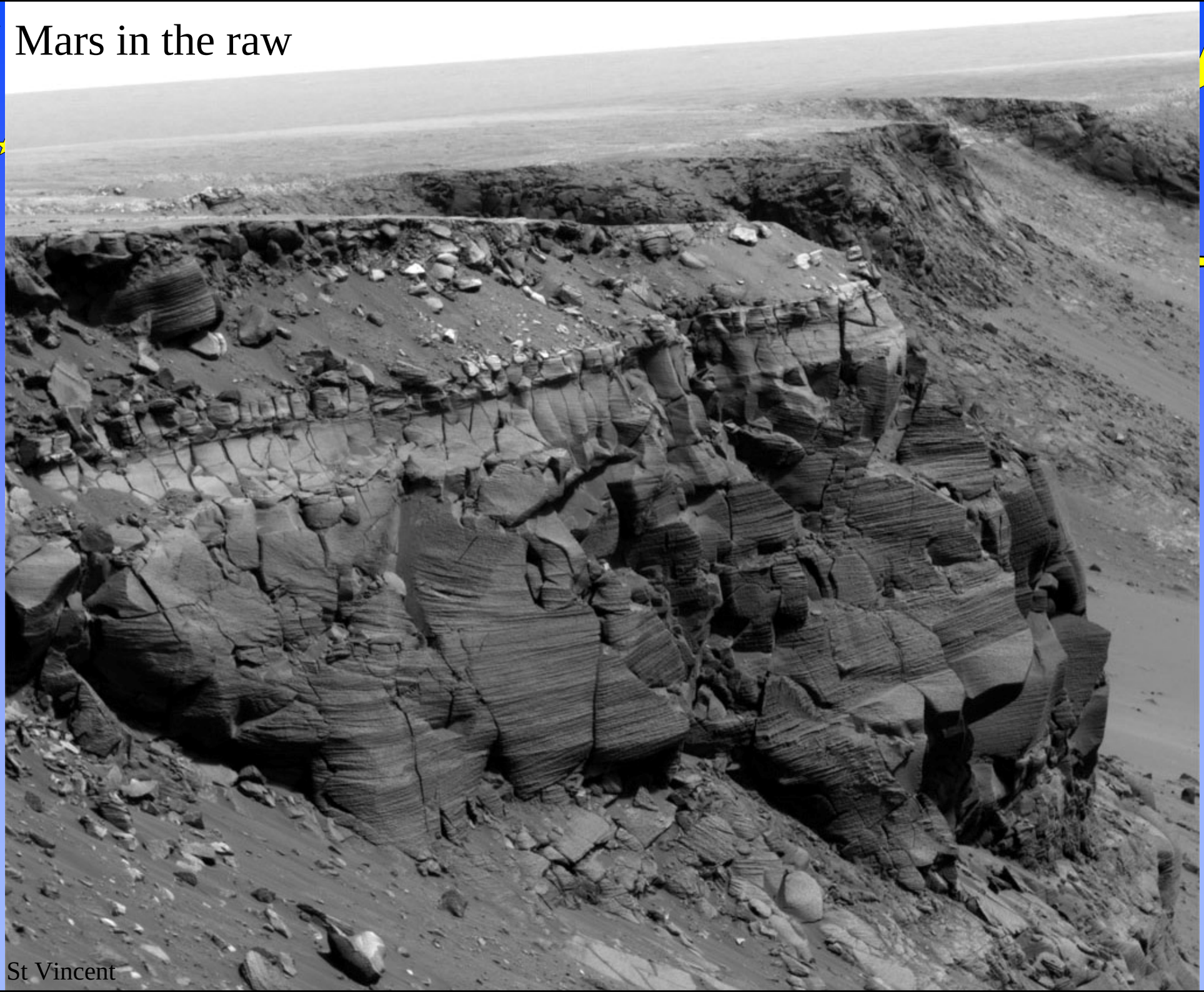


- Over 1000 days and ~10 km
- Overwintering


Rover tracks
Opportunity
Camera mast shadow
Rover tracks
"Cape Verde"
"Duck Bay"

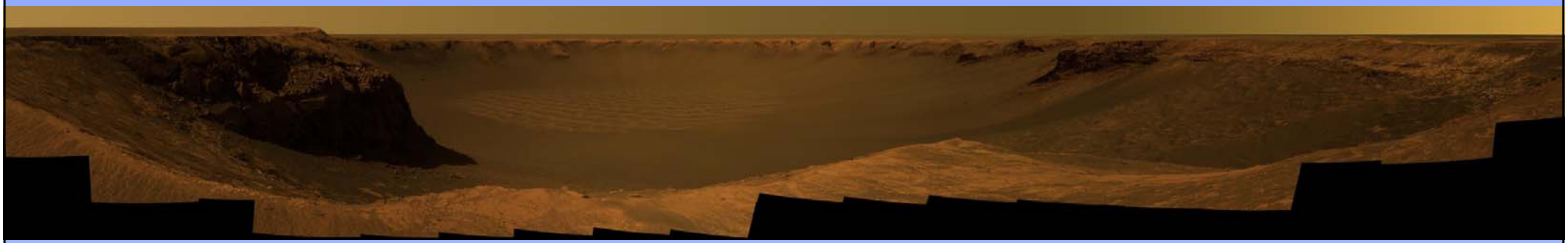

Rover tracks
Opportunity
Camera mast
shadow
"Cape Verde"

Mars in the raw

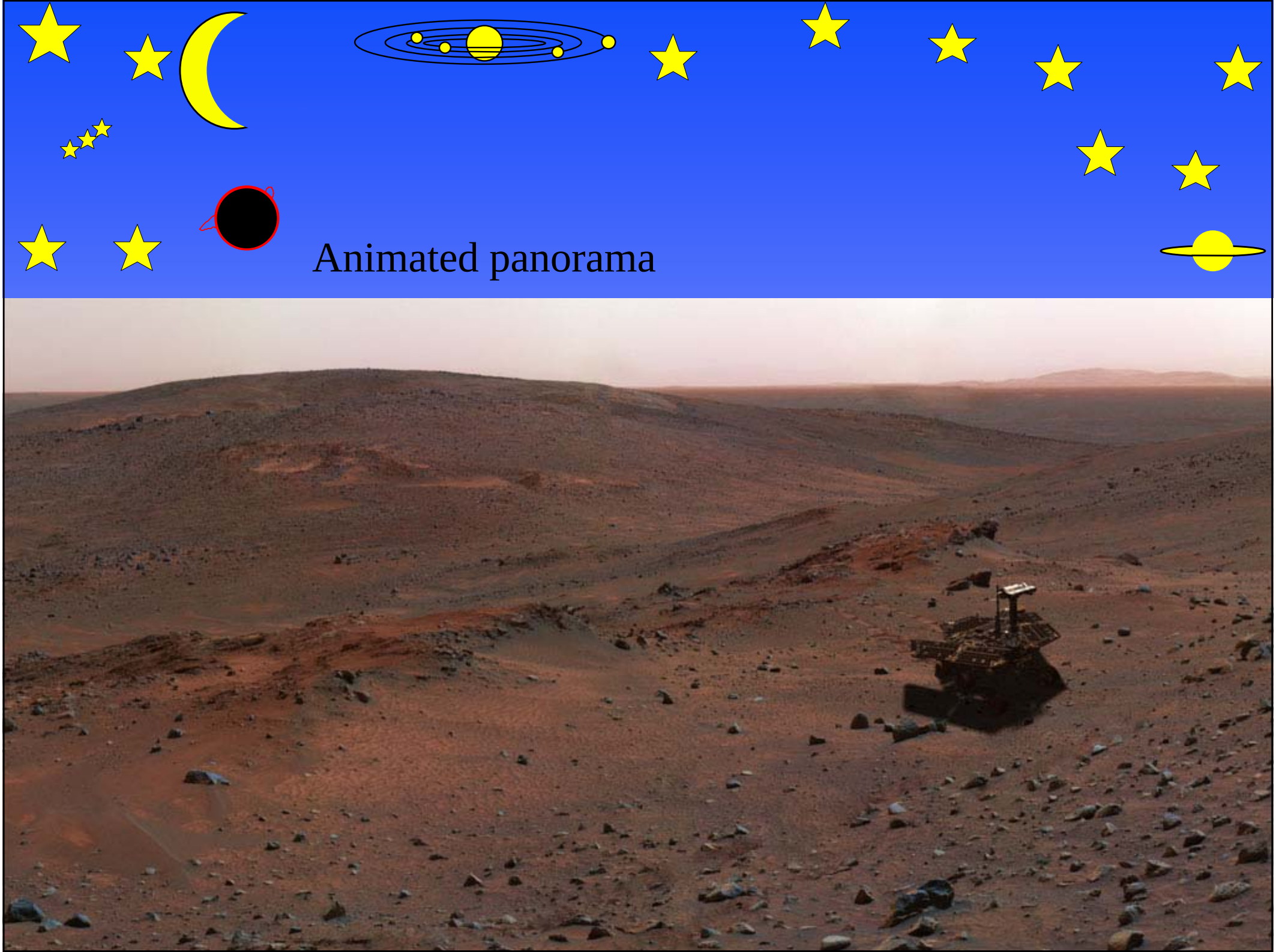


Cape St Vincent

Martian clouds

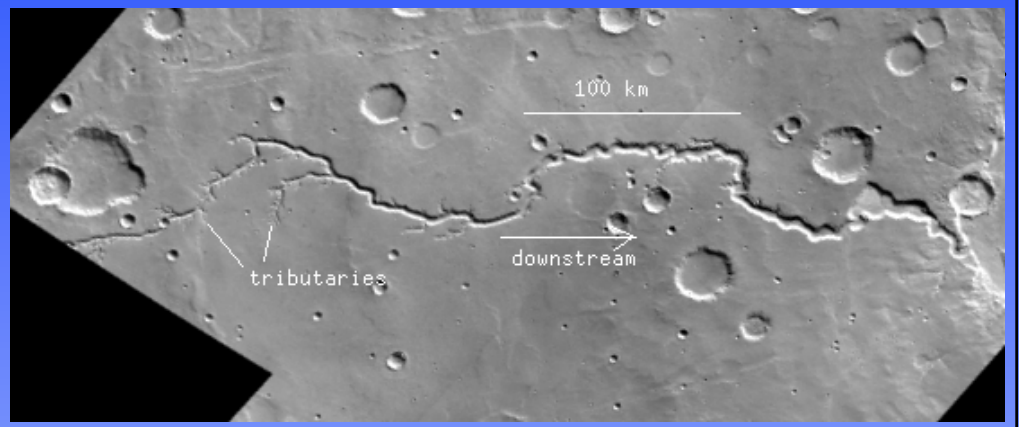


Victoria crater


Animated panorama

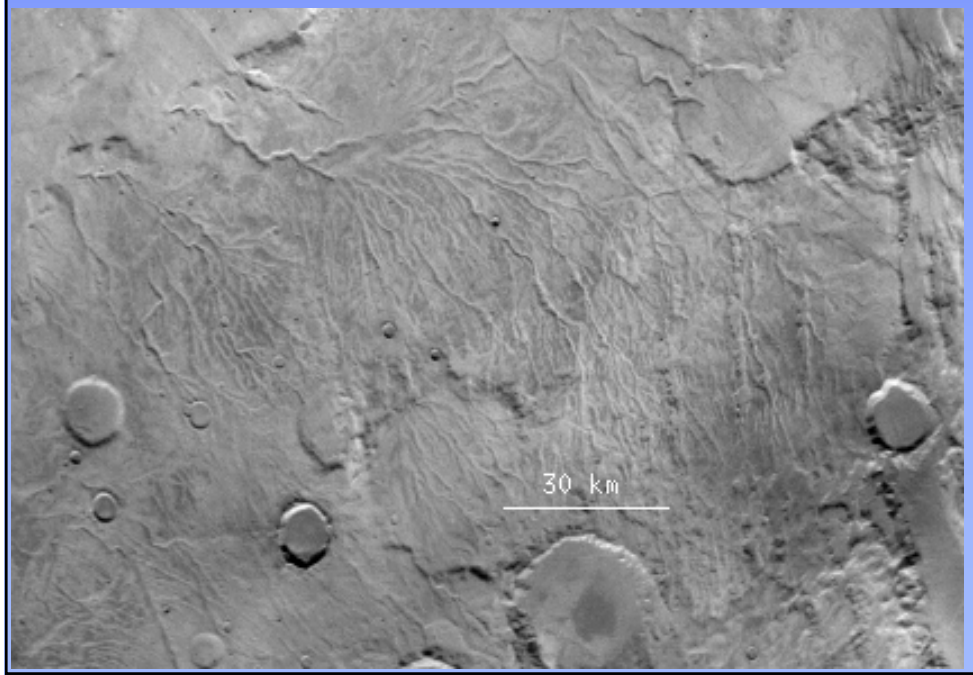
Evidence of Water on Mars

- Many features on the surface of Mars attest to the earlier presence of water

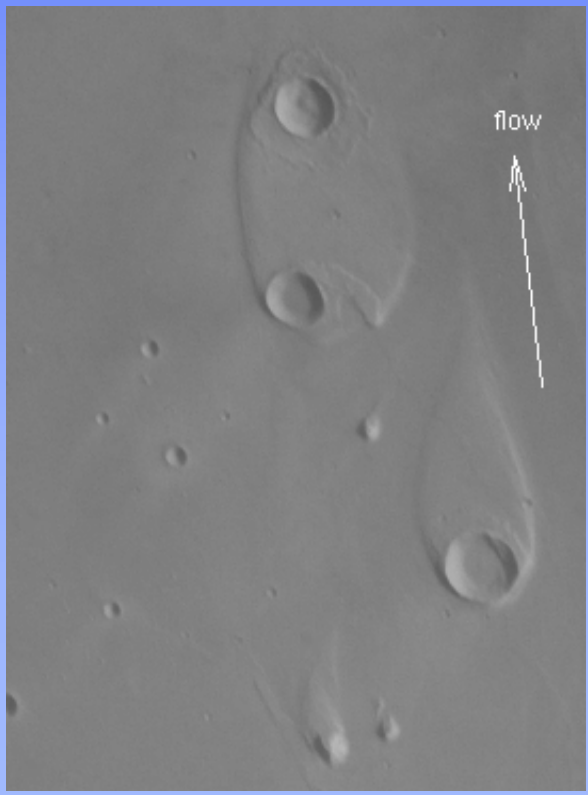


Nirgal Vallis ↑

← "Small" valley network in Thaumasia region



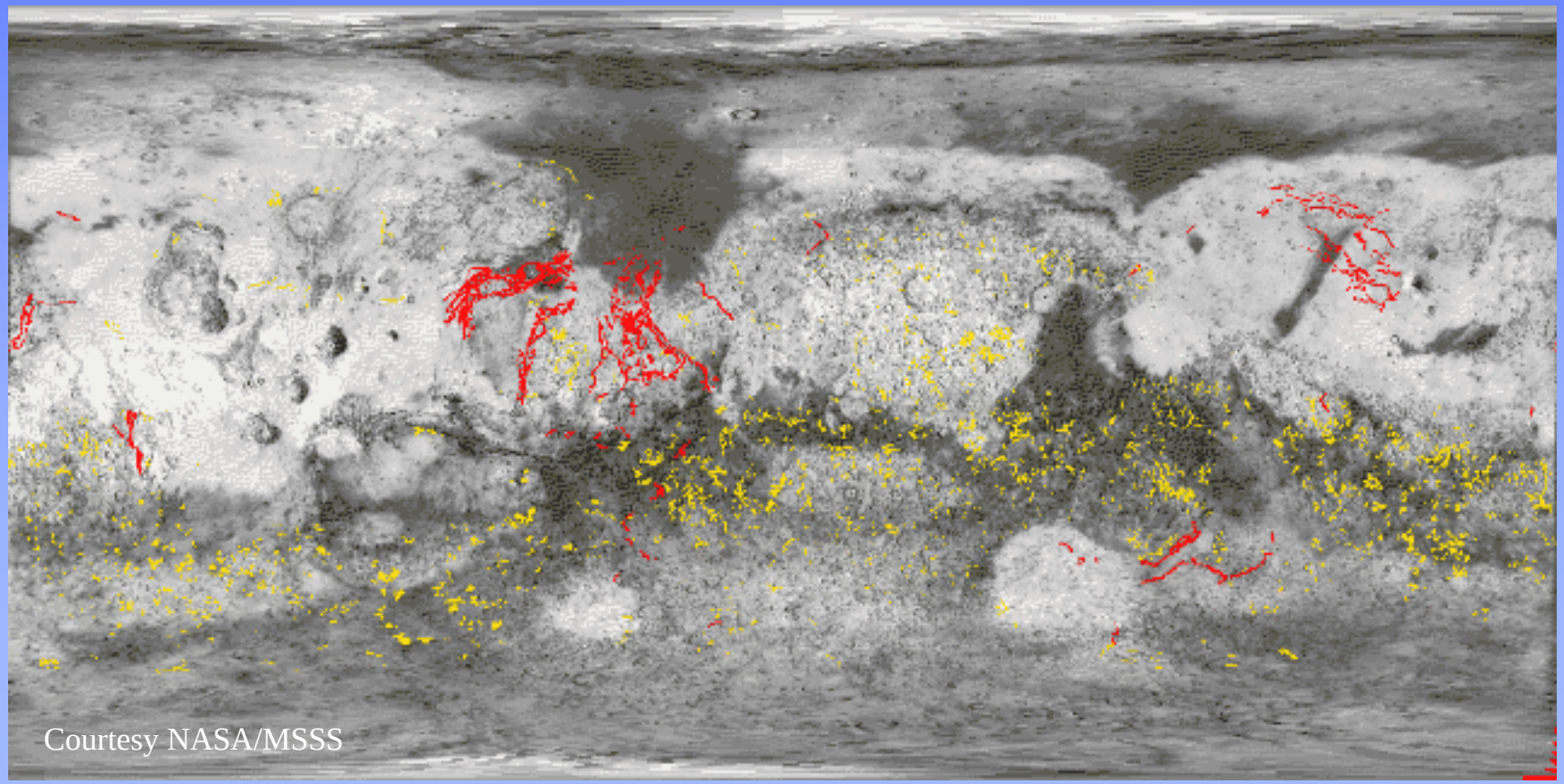
Deposition or reduced erosion around craters in Ares Vallis →



Pictures courtesy NASA/MSSS

Location of Water Channels

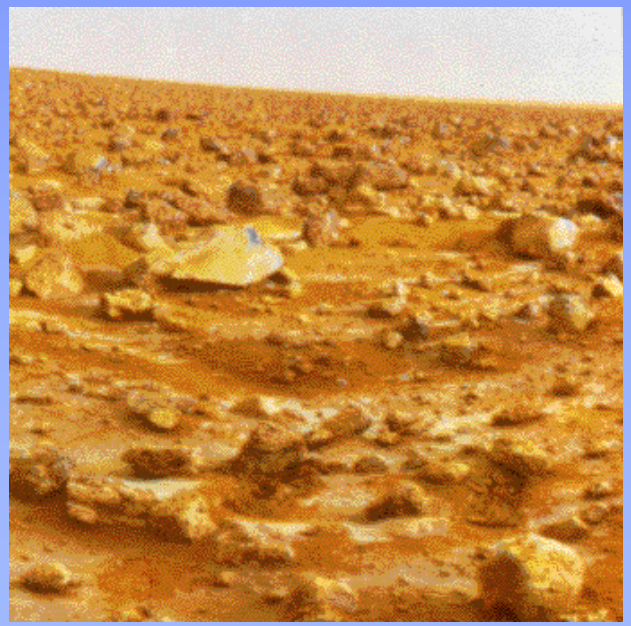
- Mercator map of Mars showing outflow channels (red) and valley networks (yellow)

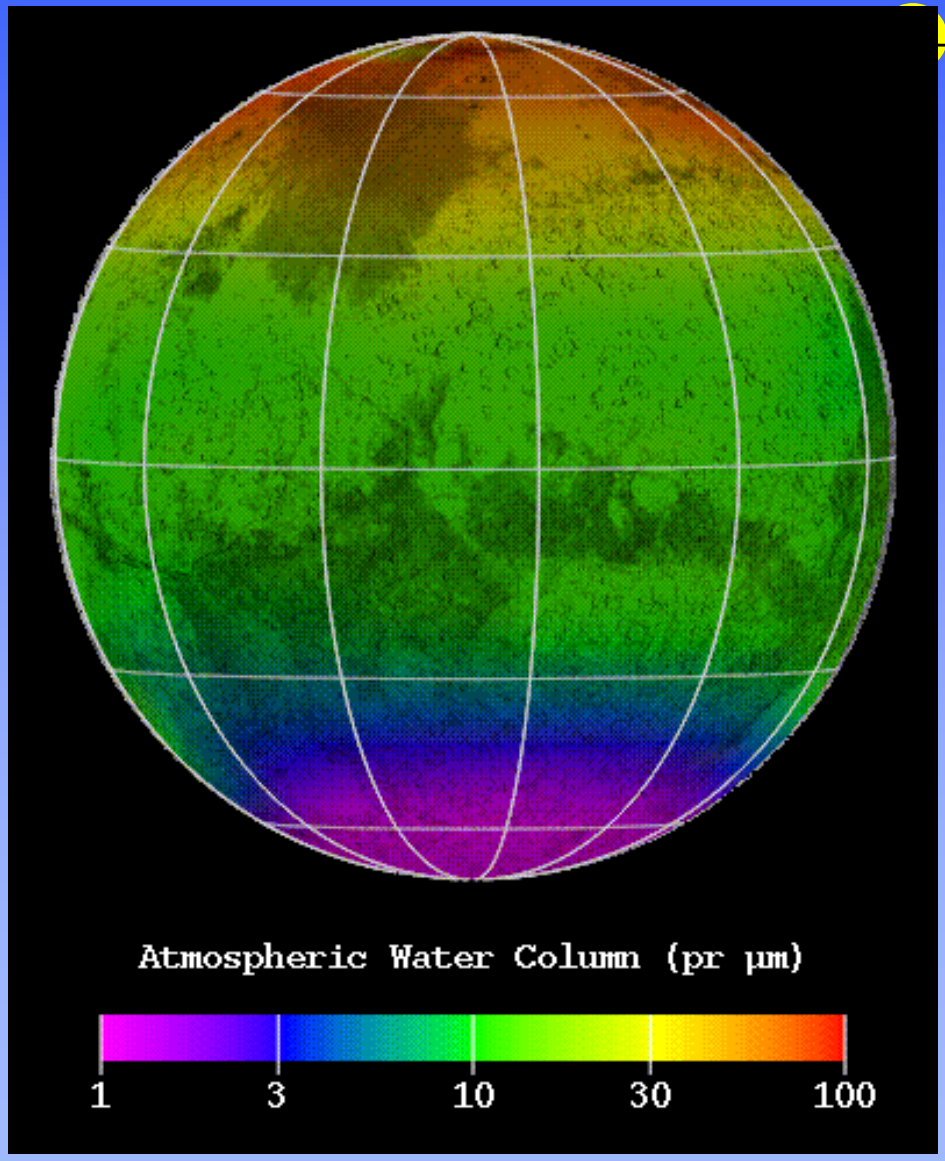


Water now on Mars

- The atmosphere contains very little water
- Frost does form at night
- Water is thought to be present in large quantities beneath the surface

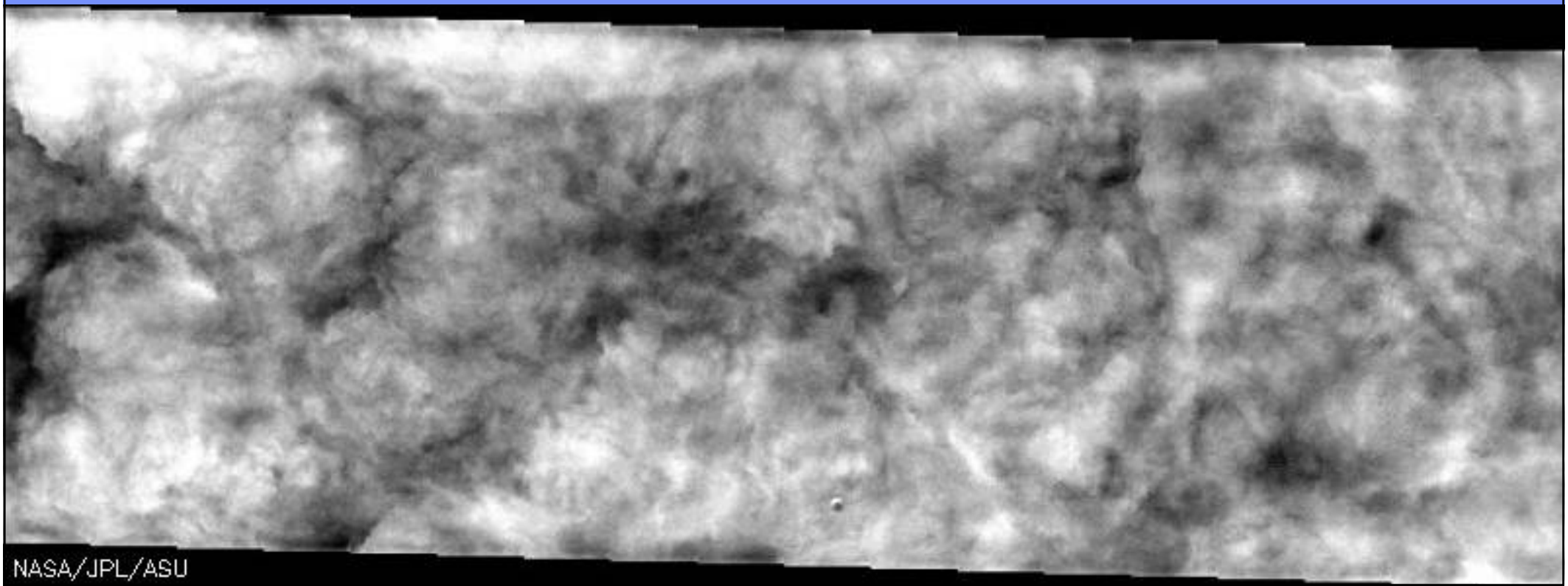
Frost on Mars →





Ice clouds on Mars

- Water ice clouds on Mars observed by the Odyssey probe obscure the surface in Vastitas Borealis



Past Life on Mars

- Famous in the folklore of astronomy are the fictitious *canals* of Mars drawn by Giovanni Schiaparelli & Percival Lowell
- *Viking* landers tested for life (notably with a mass spectrometer) and found none
- Rocks ejected from Mars by impact cratering do reach Earth. Particularly found in Antarctica. They can be recognized by their mineralogy and by the inclusion of gas of same composition as Martian atmosphere. Microscopic structures within one sample looked very like fossil bacteria. Case for life not yet proven but is quite strong. There may have been primitive life on Mars

Future Life on Mars

- Current technology could send a manned mission to Mars within 20 years (see *www.marssociety.org*)

- Unlocking Martian water is the key to long-term survival
- "Terraforming" Mars, including creating an atmosphere and raising its temperature by enhancing the greenhouse effect, will happen

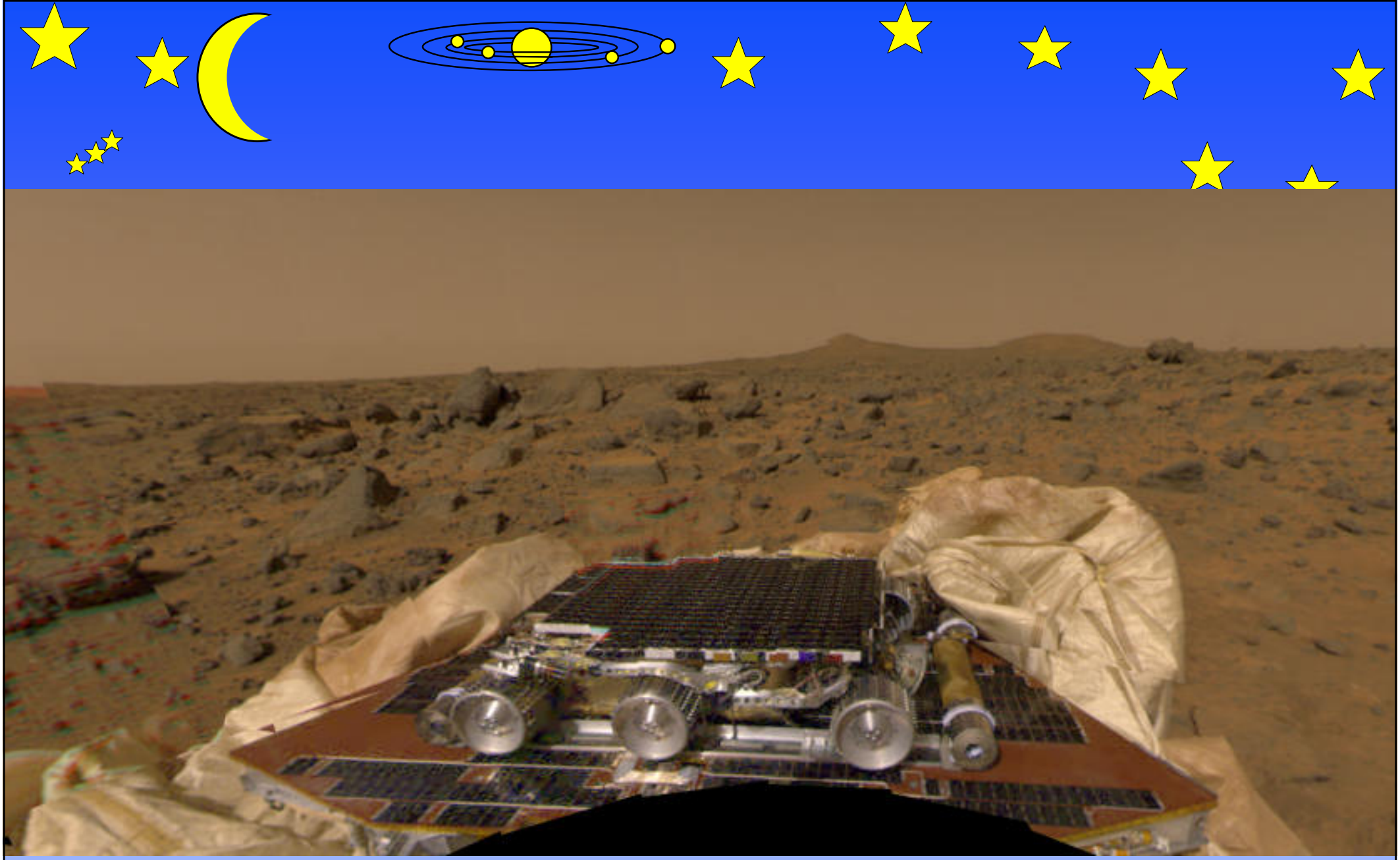
NASA's artwork on a Mars outpost

See:
http://spaceflight.nasa.gov/gallery/images/mars/marsbases/lores/s89_51054.jpg

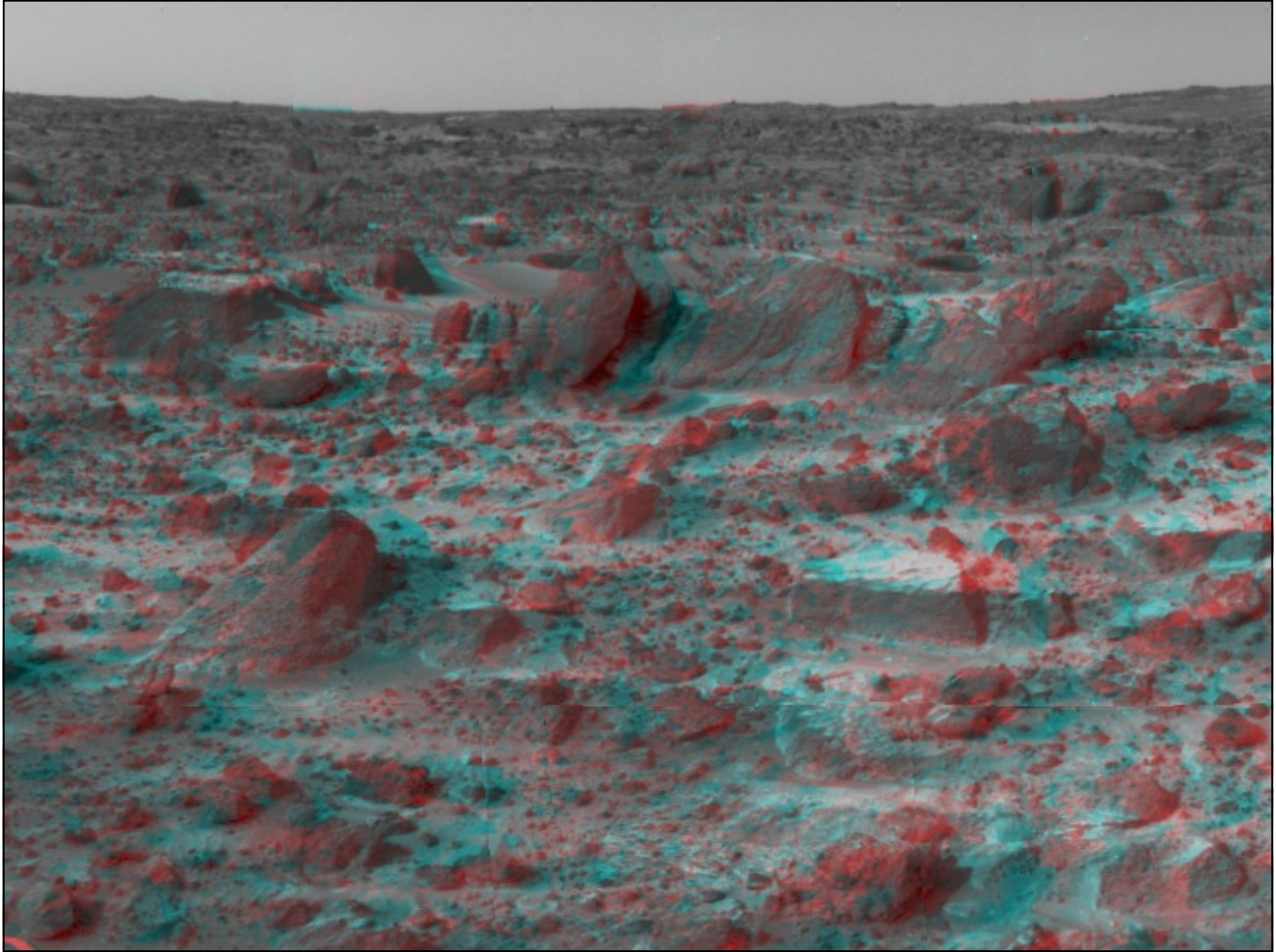
The Surface of Mars

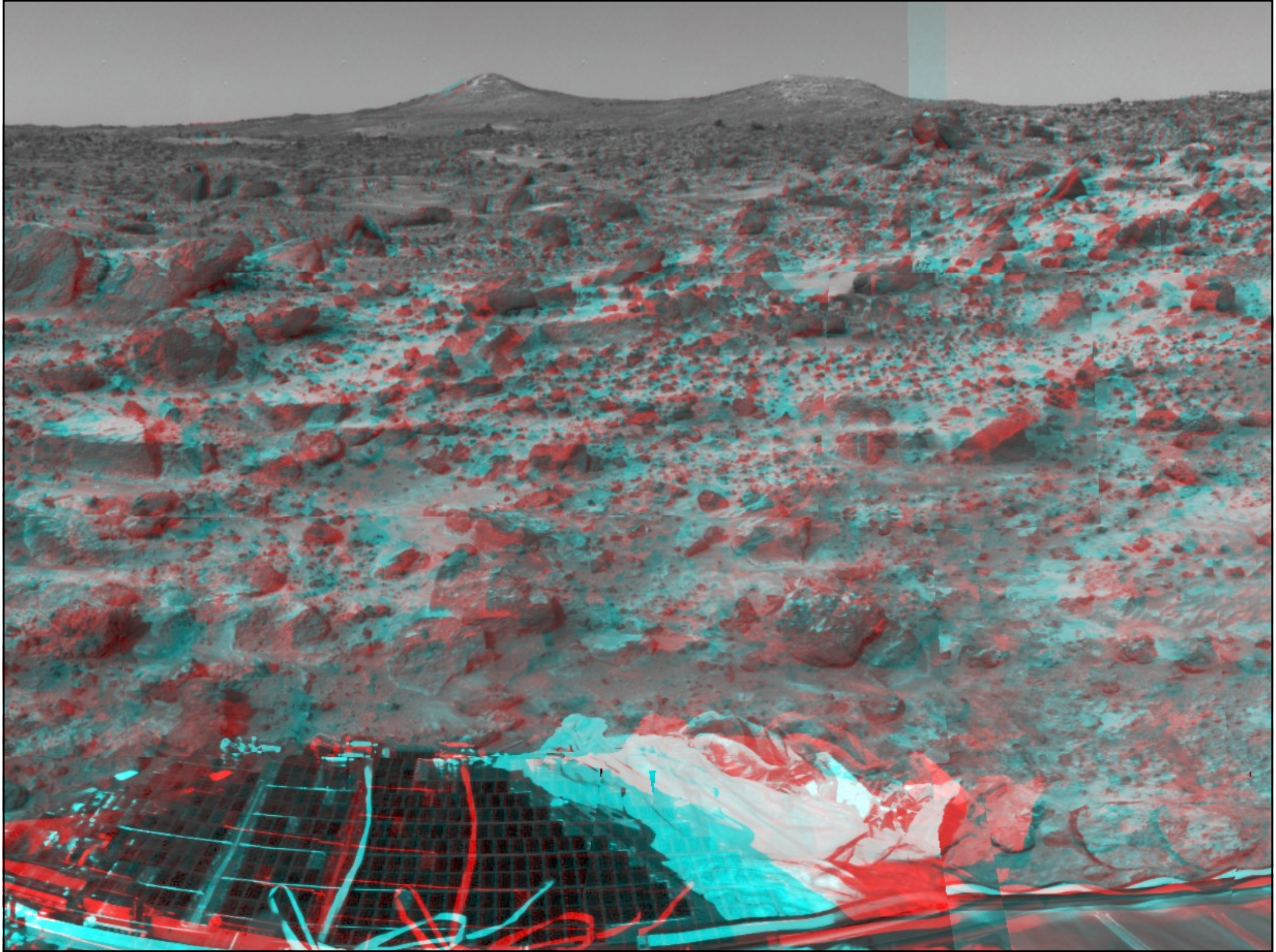
- What would it look like to stand on Mars?
- The following sequence of 3D pictures (anaglyphs) give some idea of the scene explored by the pathfinder mission (red-cyan glasses needed)
  - no rain has fallen on the plain for millions of years
  - the rocks are assorted both in shape and geological composition
  - the first pictures are from Pathfinder; the next from the 2004 - 2008 Mars exploration rover missions

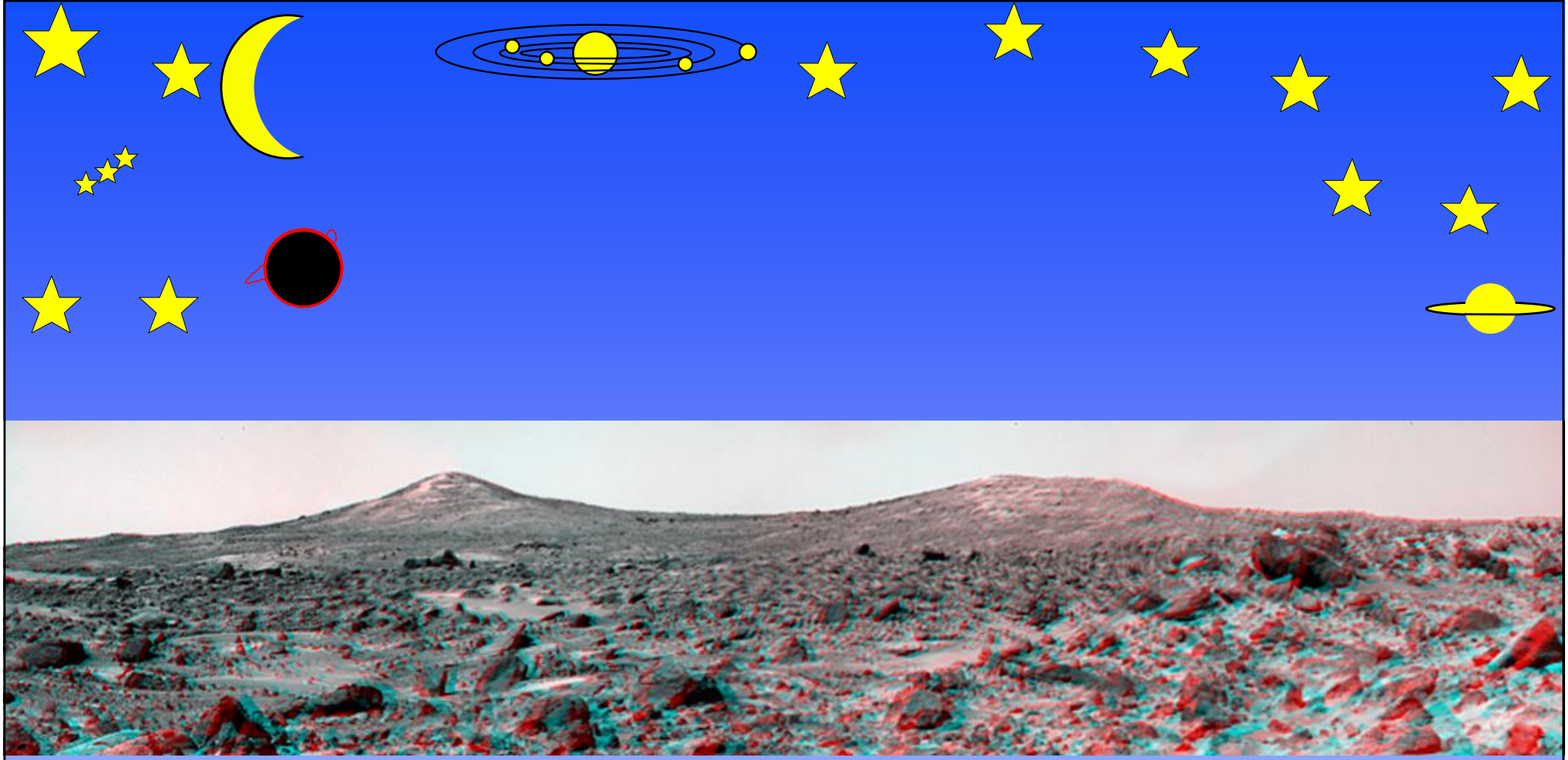
- NASA picture ID nos.: 678; 682; 995; 685; 686; 687; 691; 694;



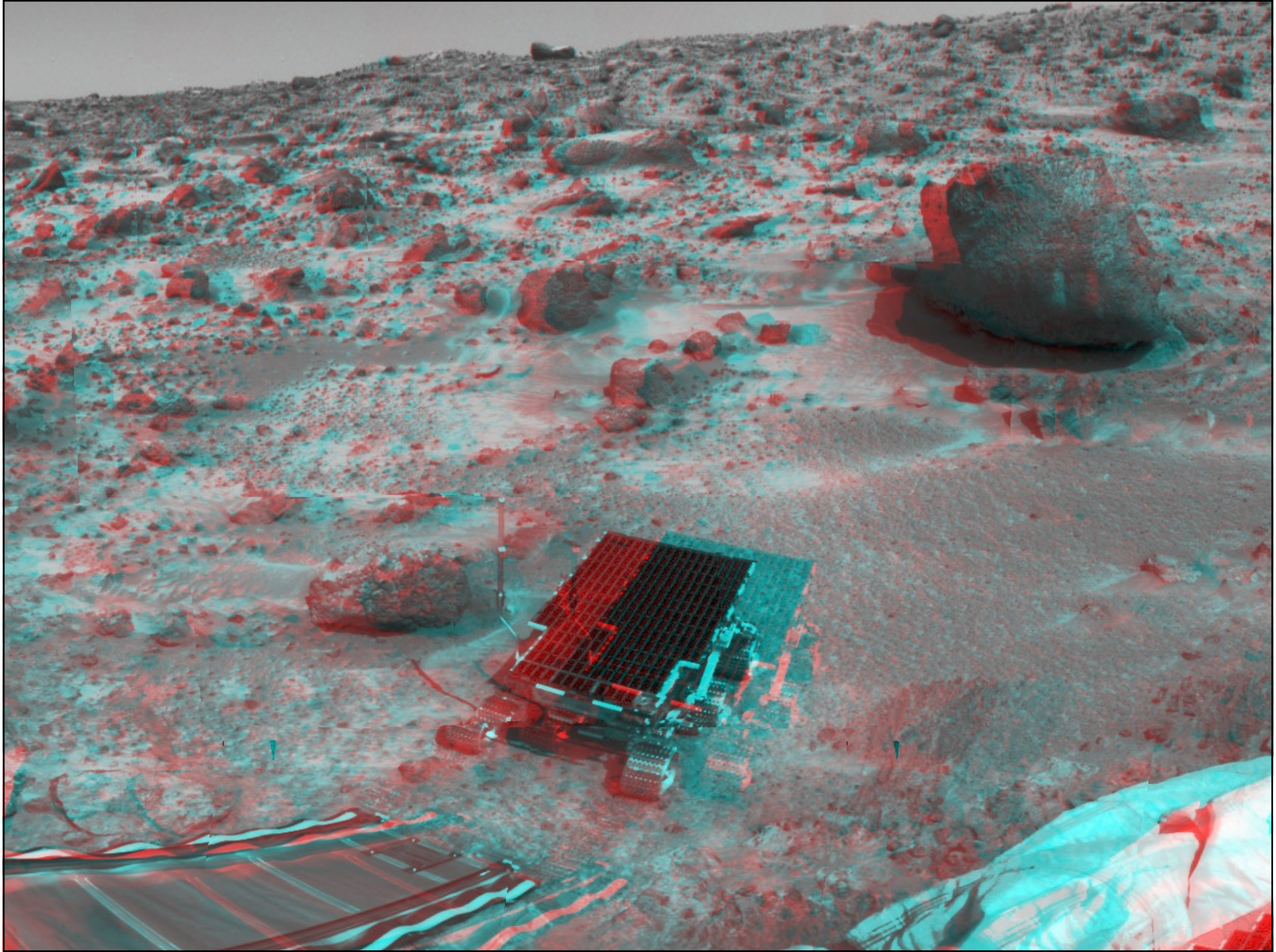
Mars 1997: pathfinder robot rover on its lander

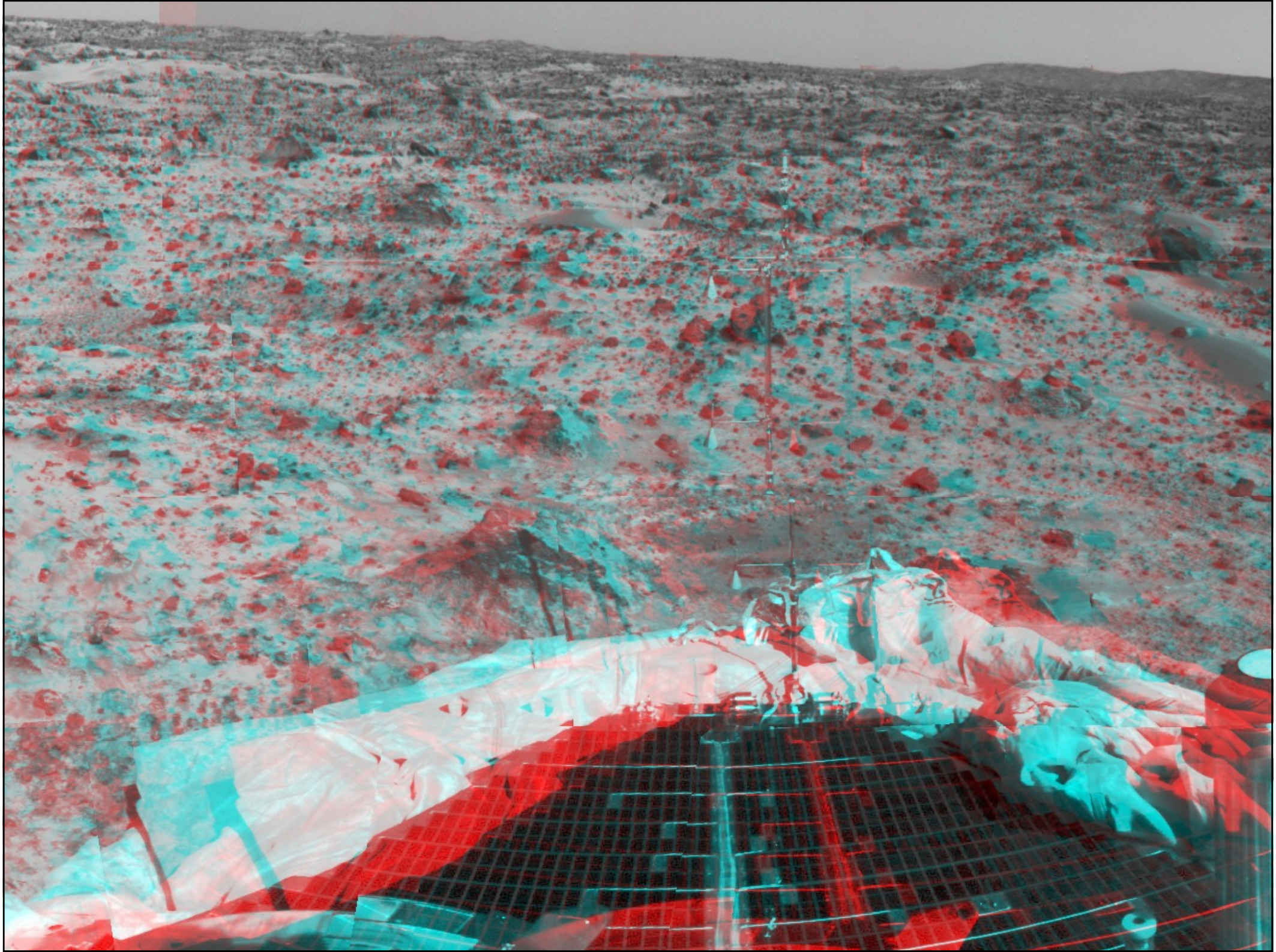


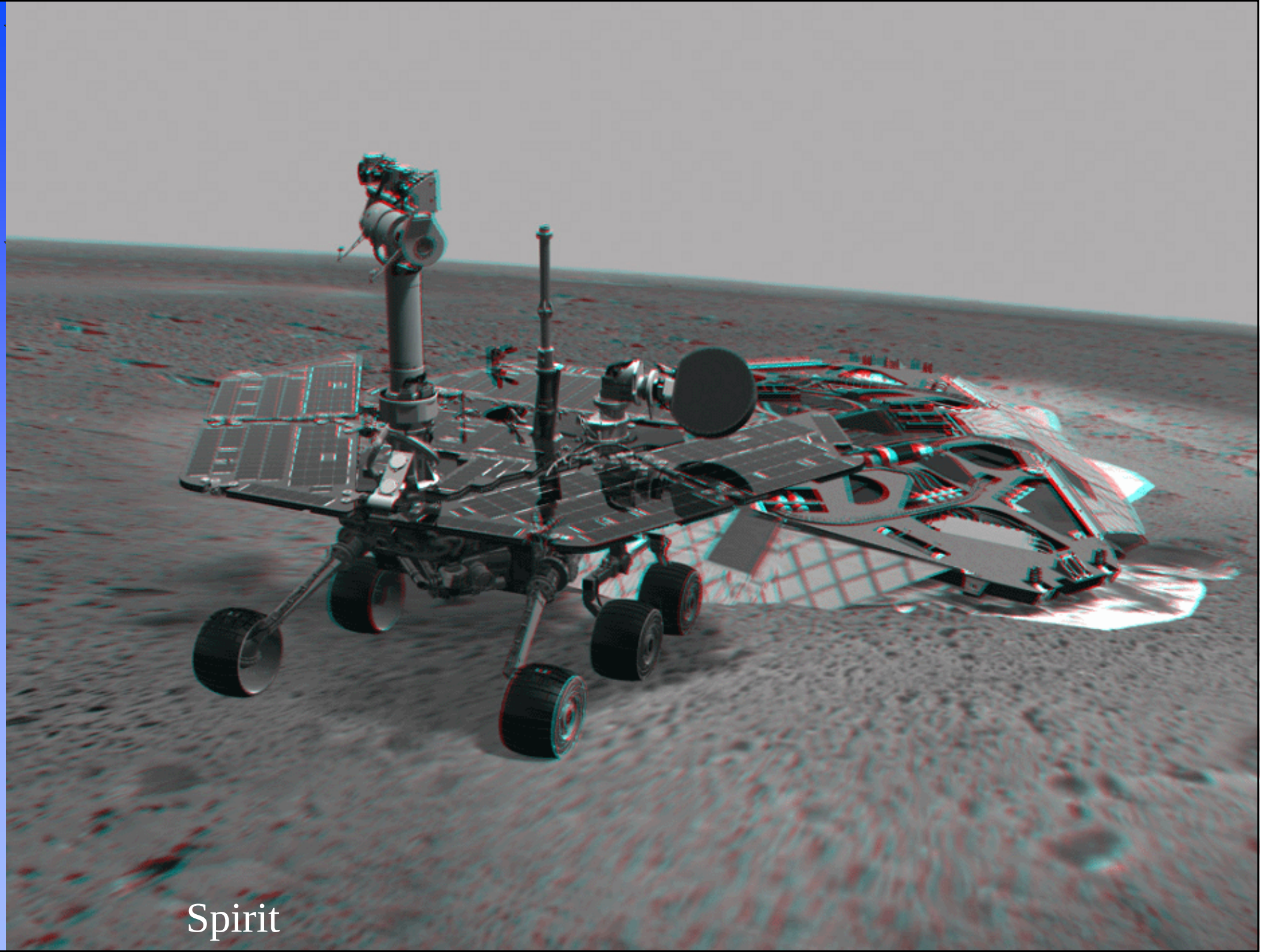


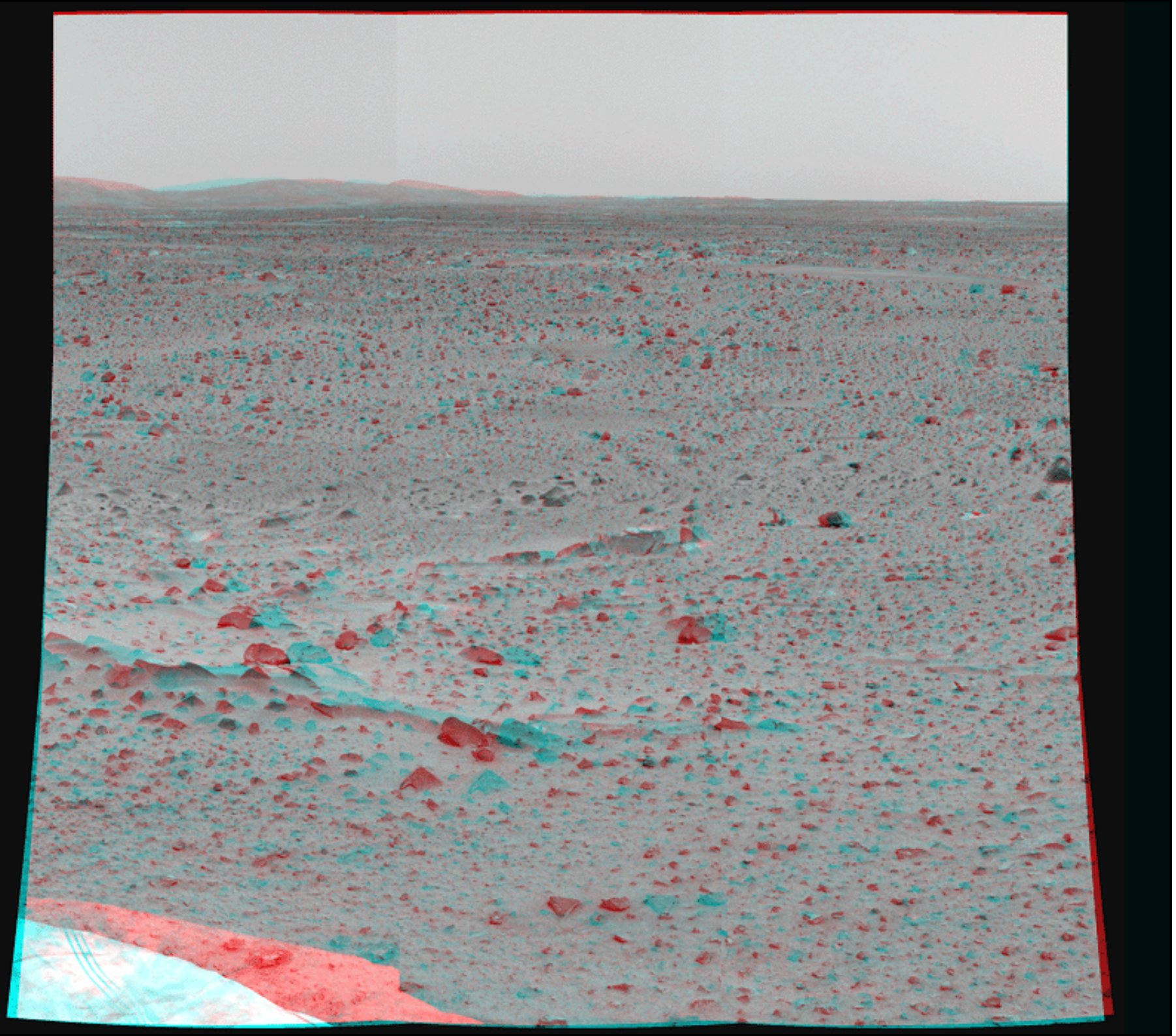


- Twin peaks
  - 0.8 → 1 km distance
  - ~30 m high



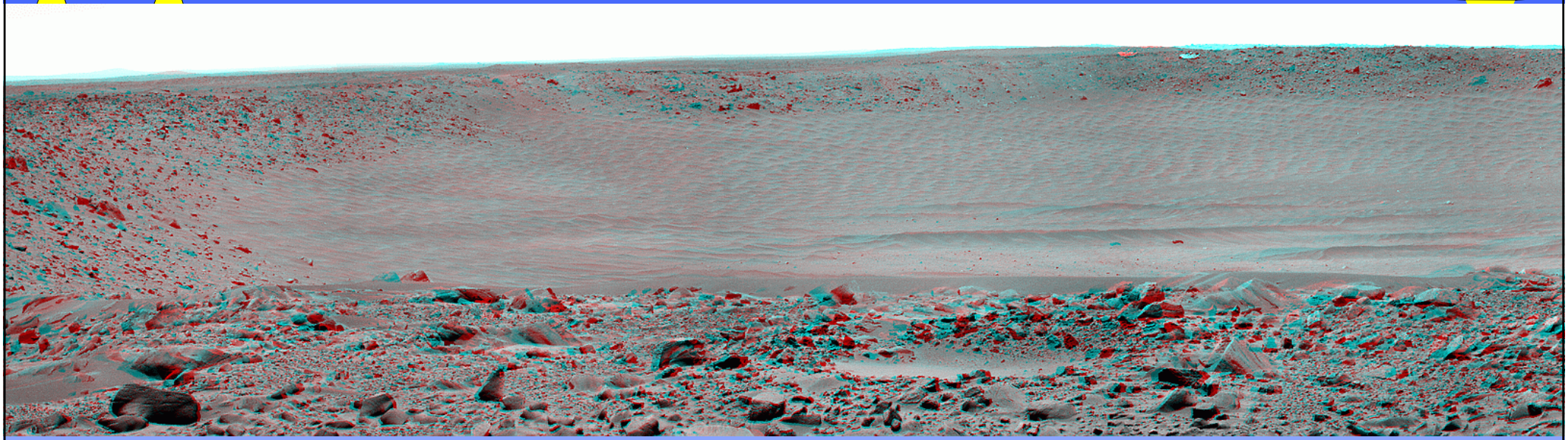


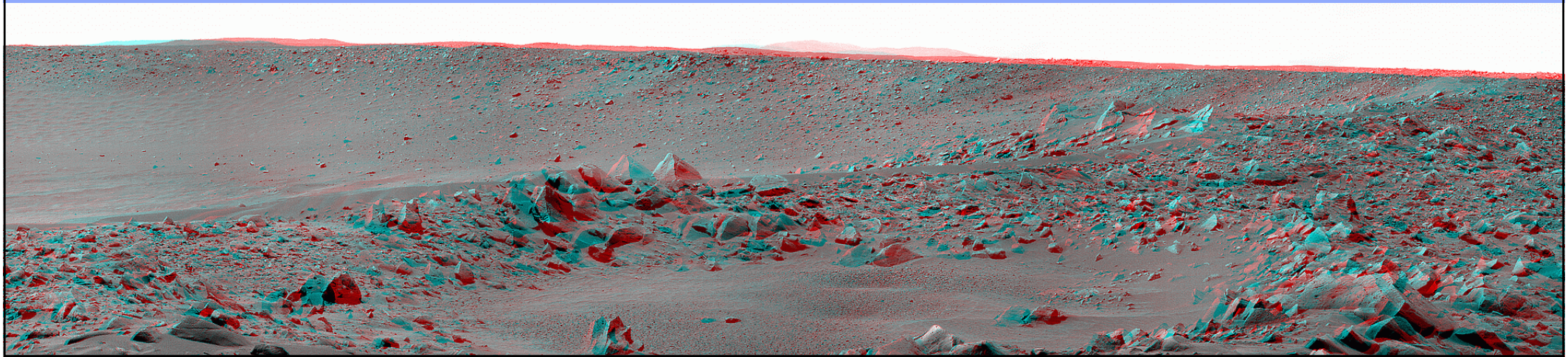

Spirit

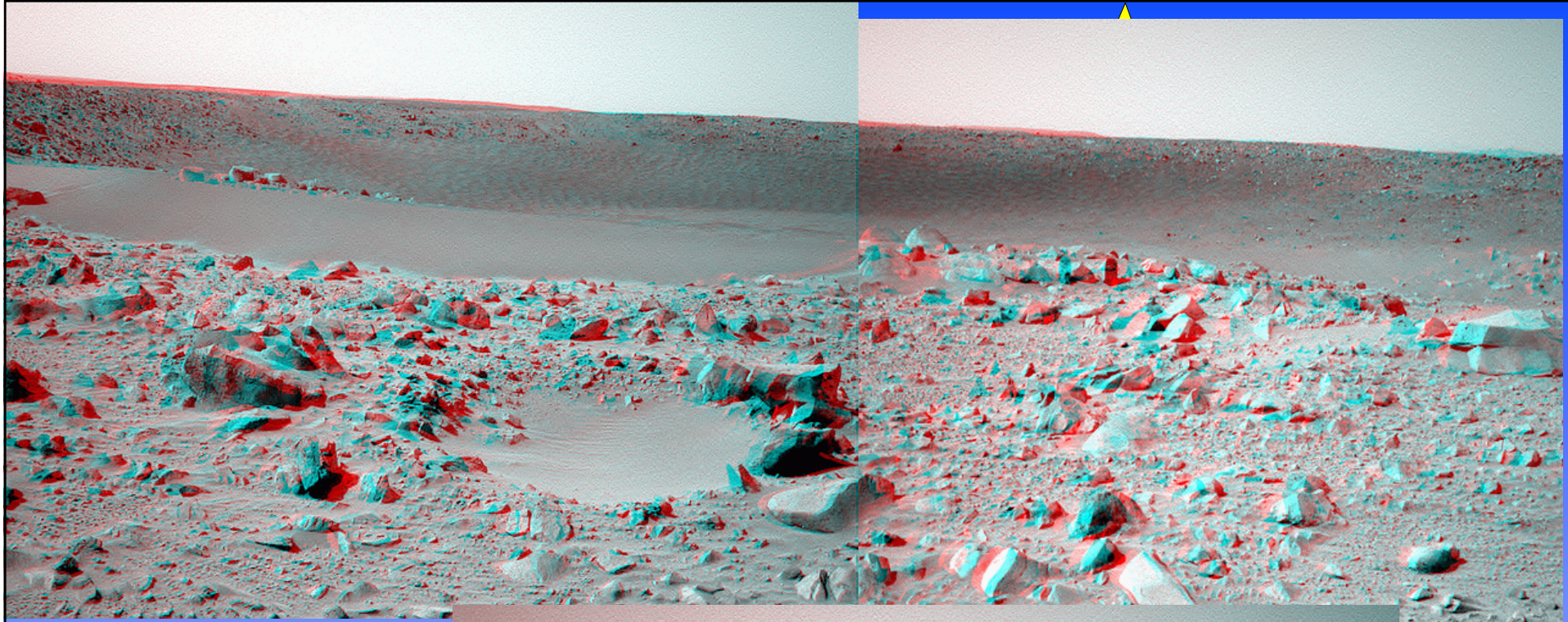


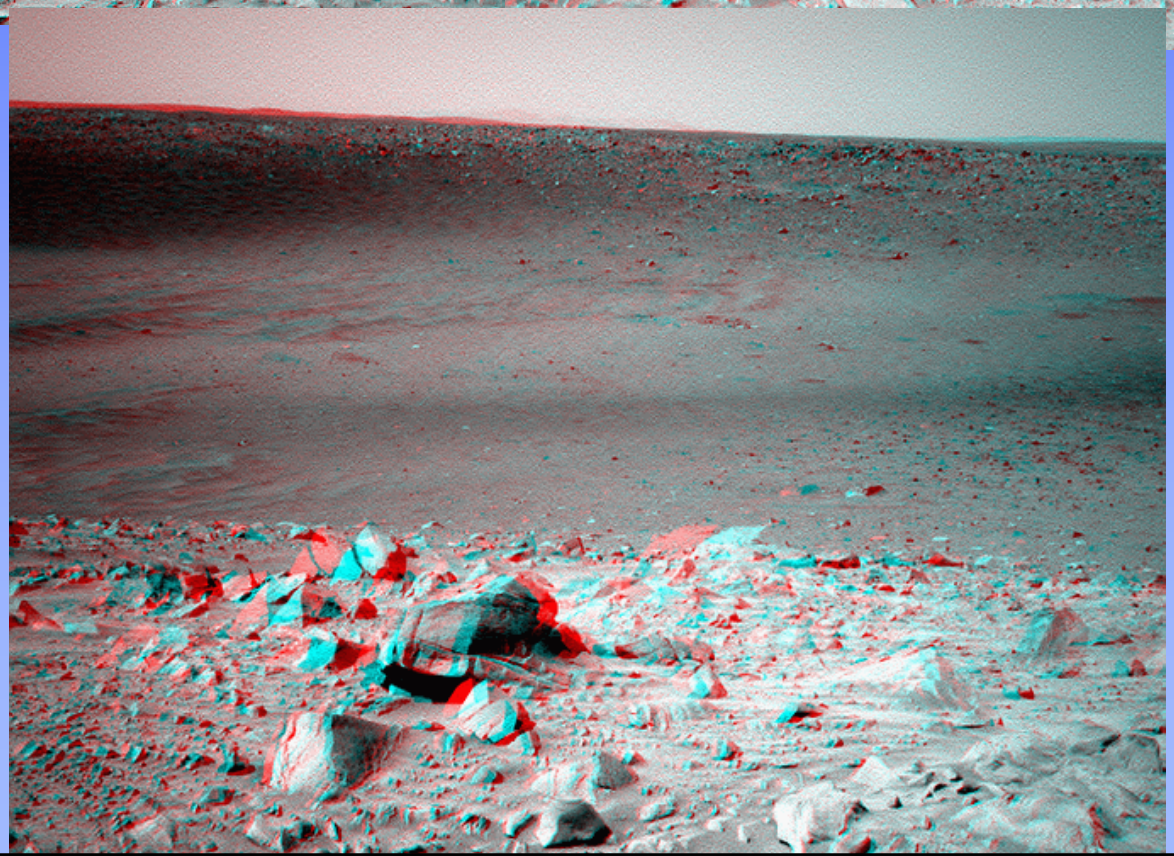
NASA:
3dPIA05008.jpg

Bonneville crater

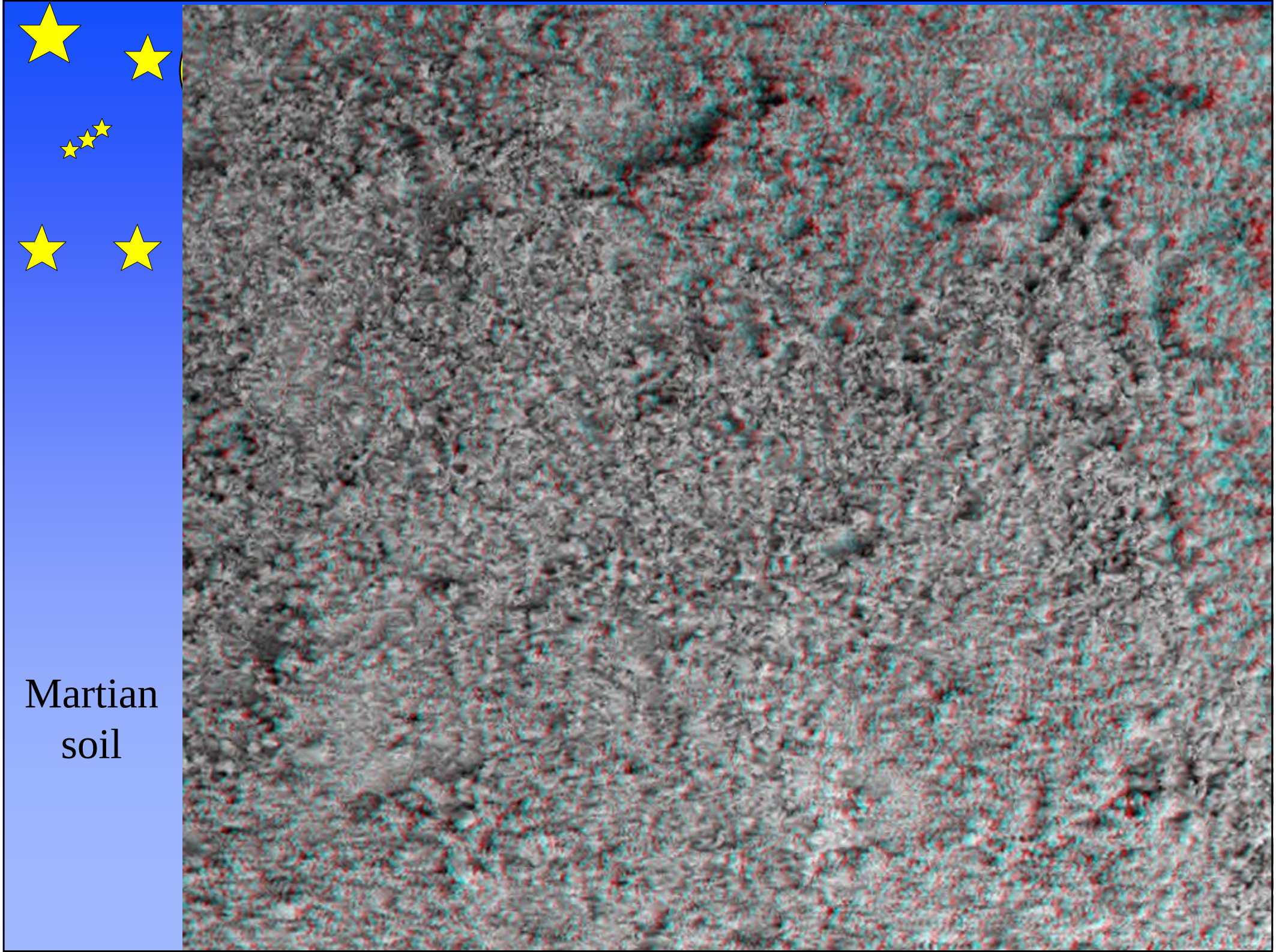




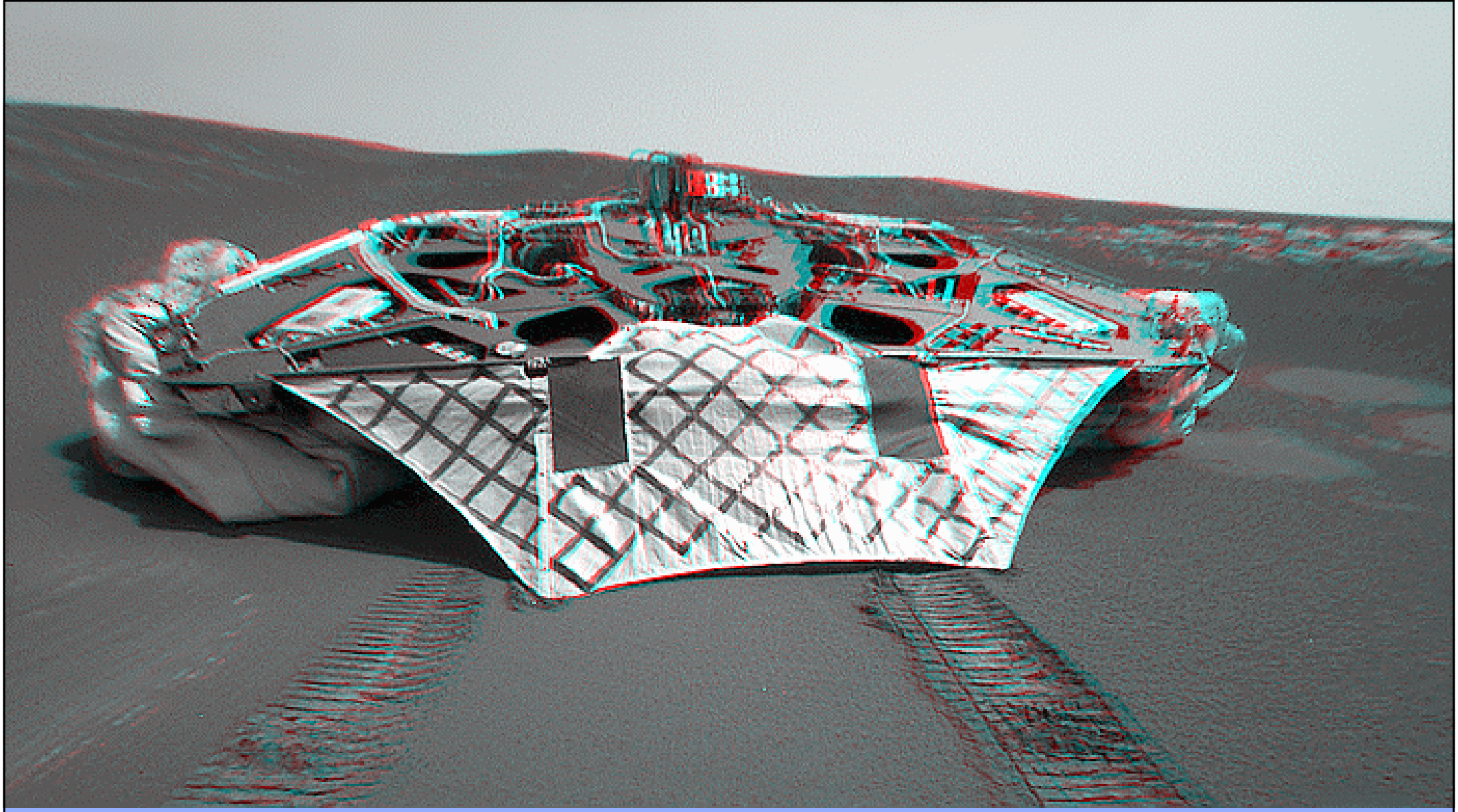




Bonneville crater from Spirit

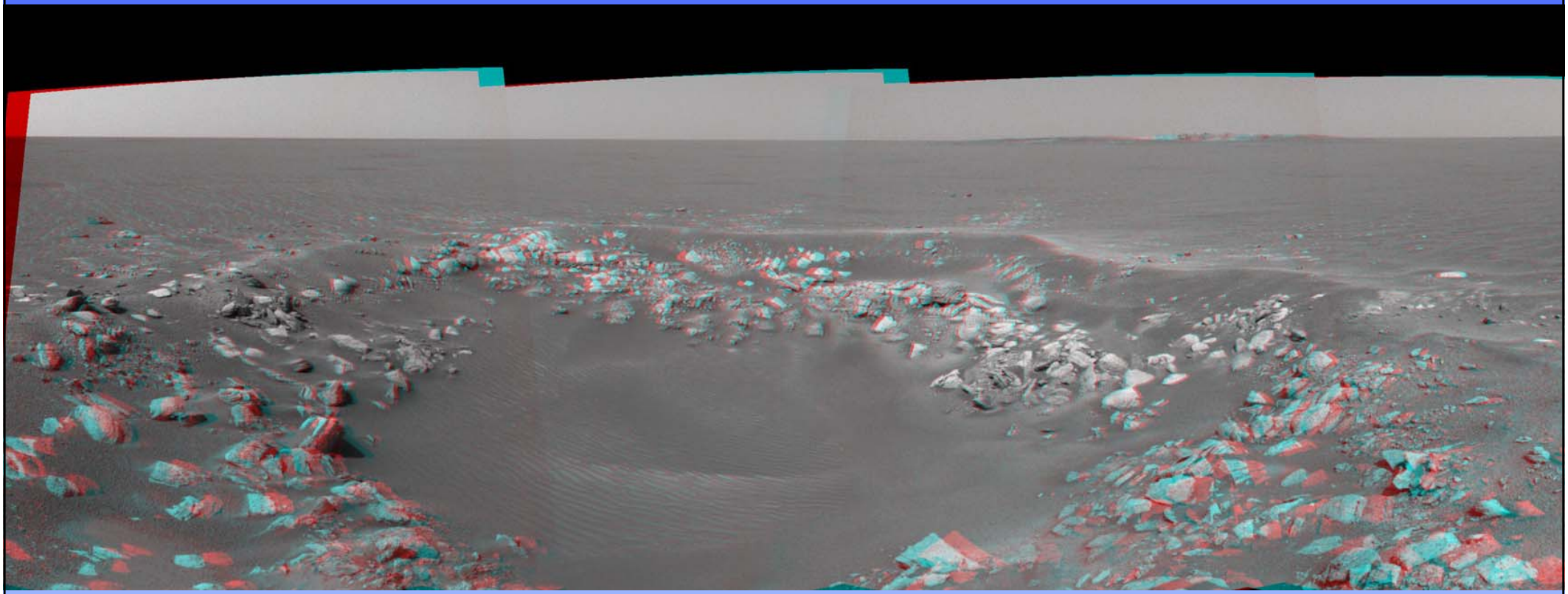


Martian soil



Opportunity

Fram Crater



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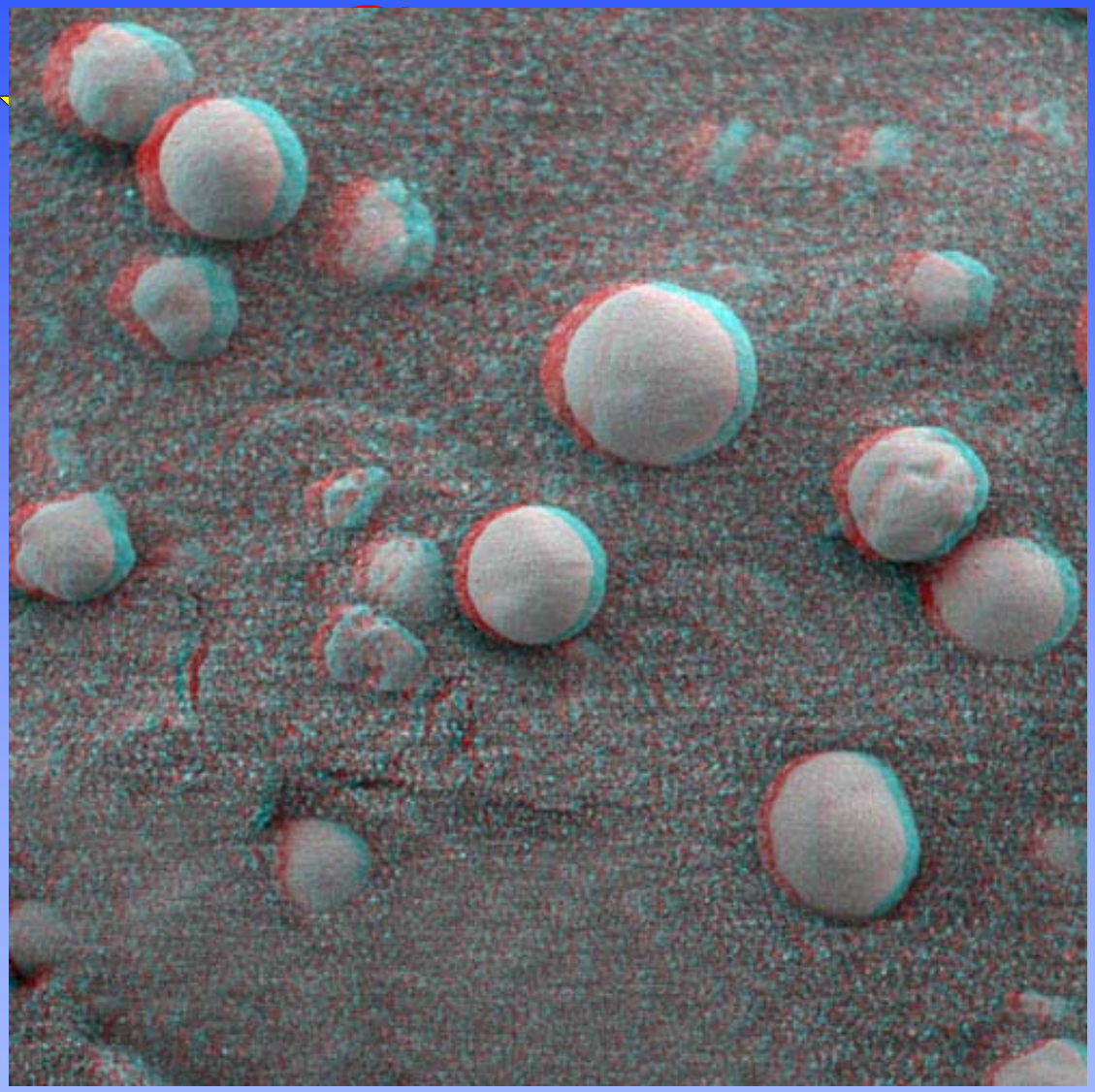
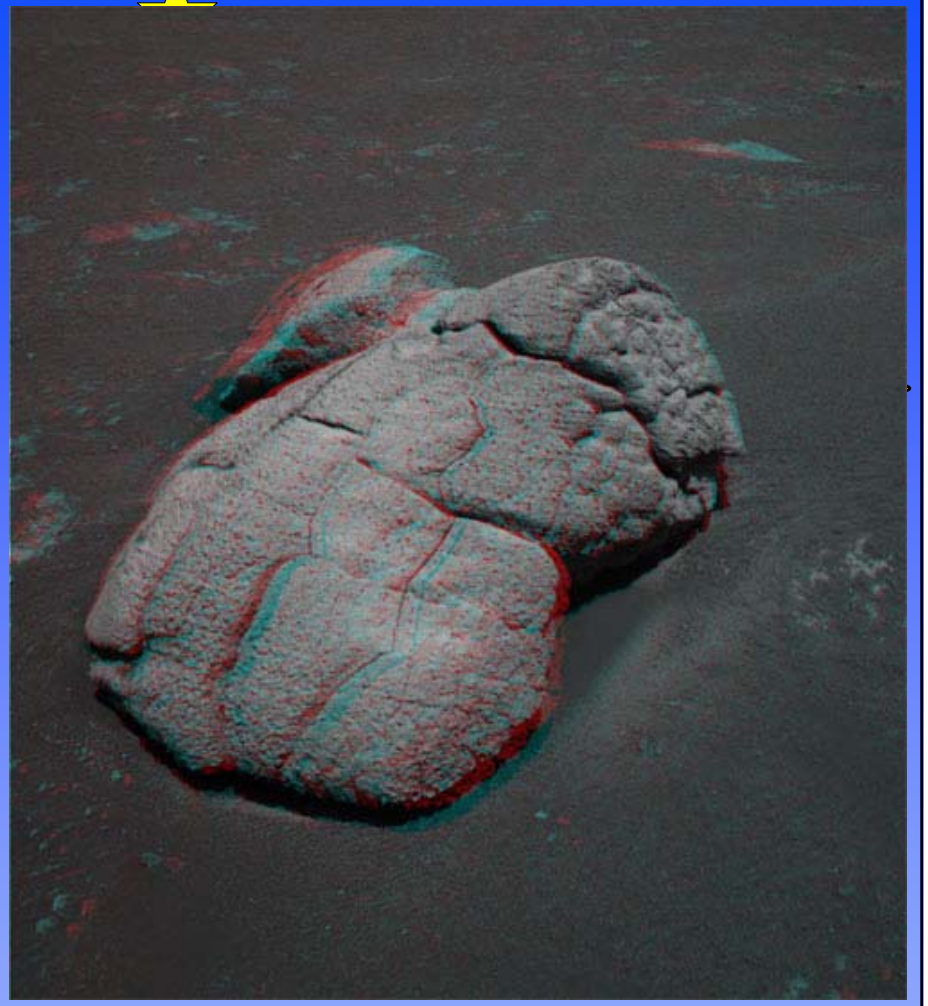
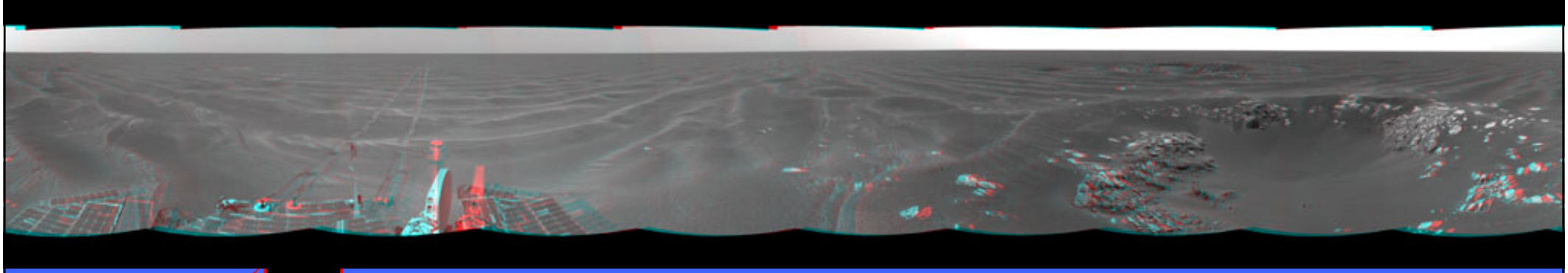


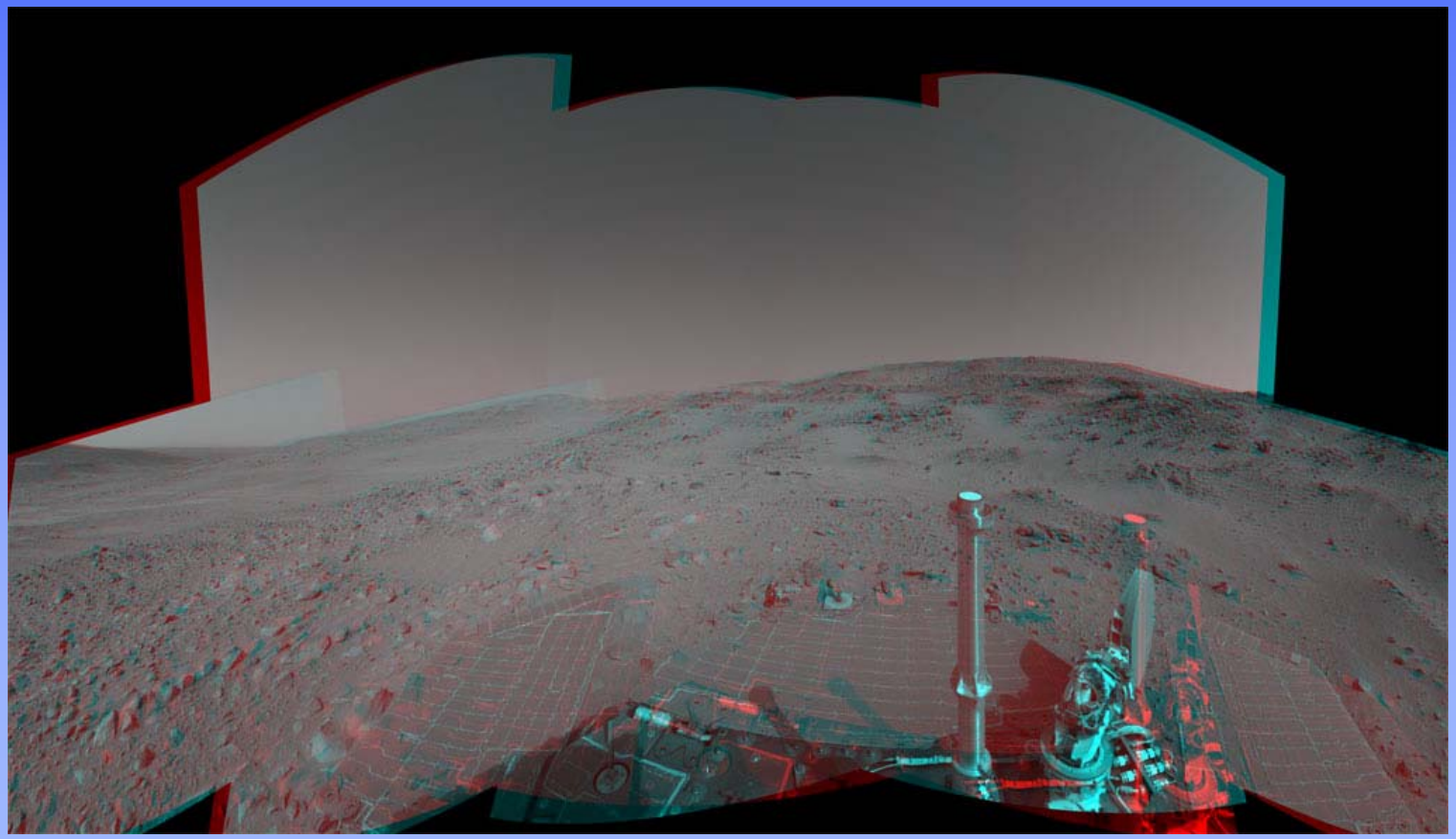
Blueberry granules in rock



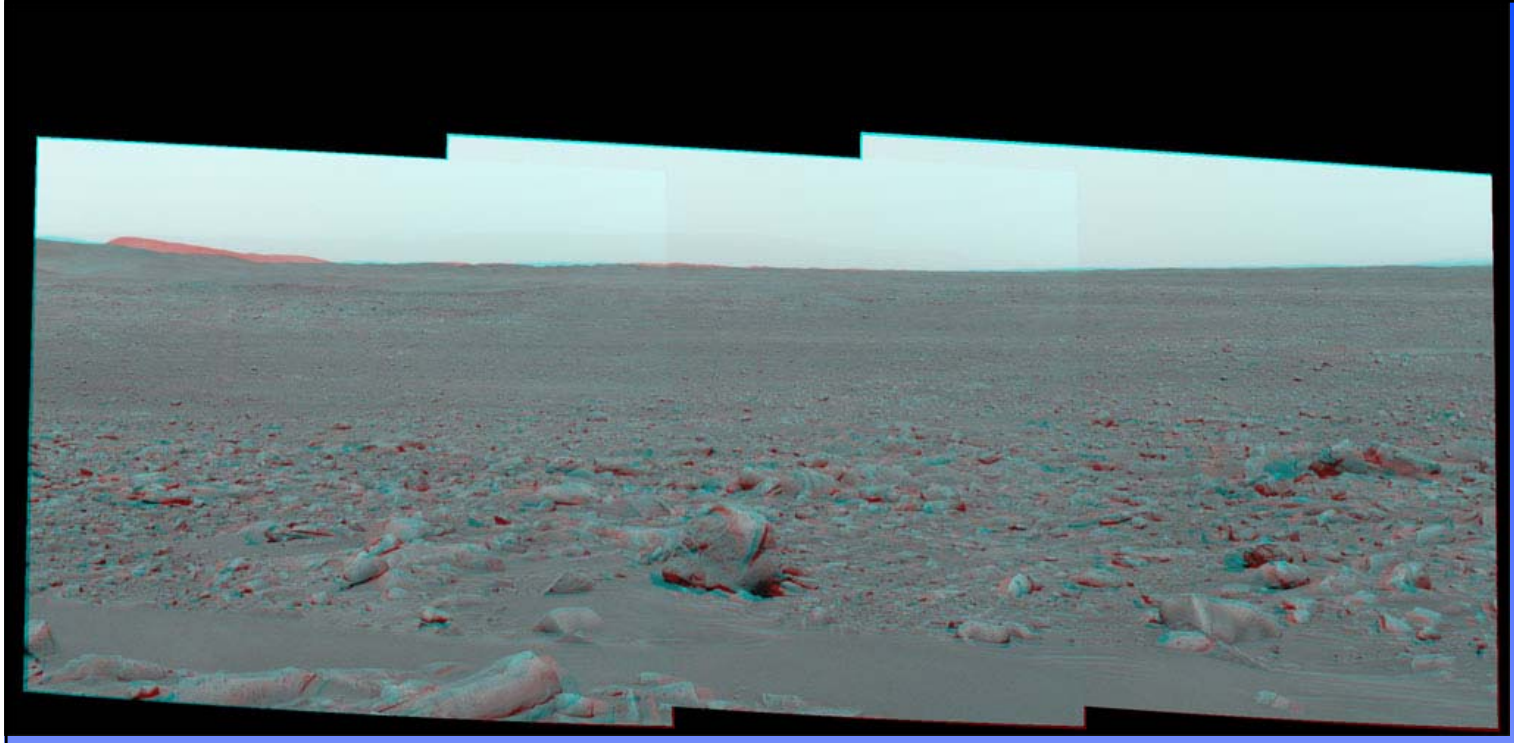
Wopmay – a weathered rock in Endurance crater

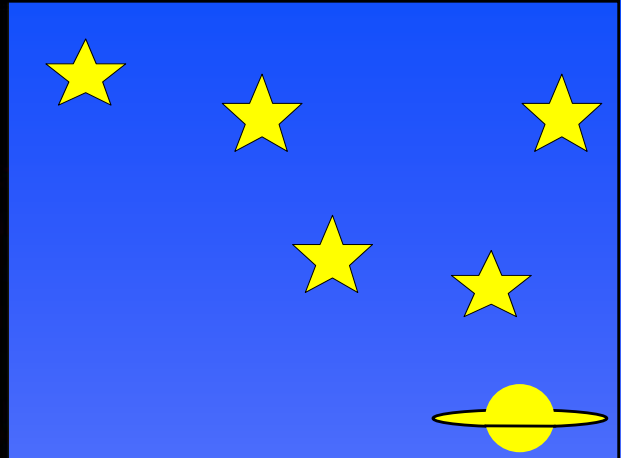


Naturaliste crater from Opportunity



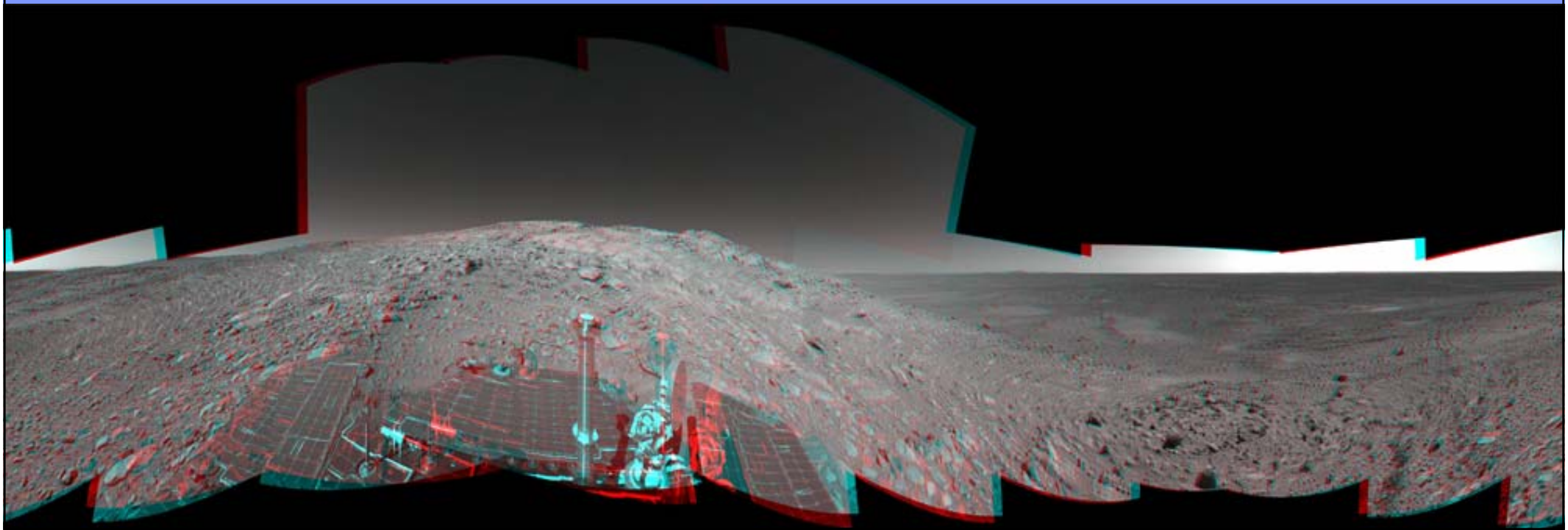
Spirit’s view on sol 399

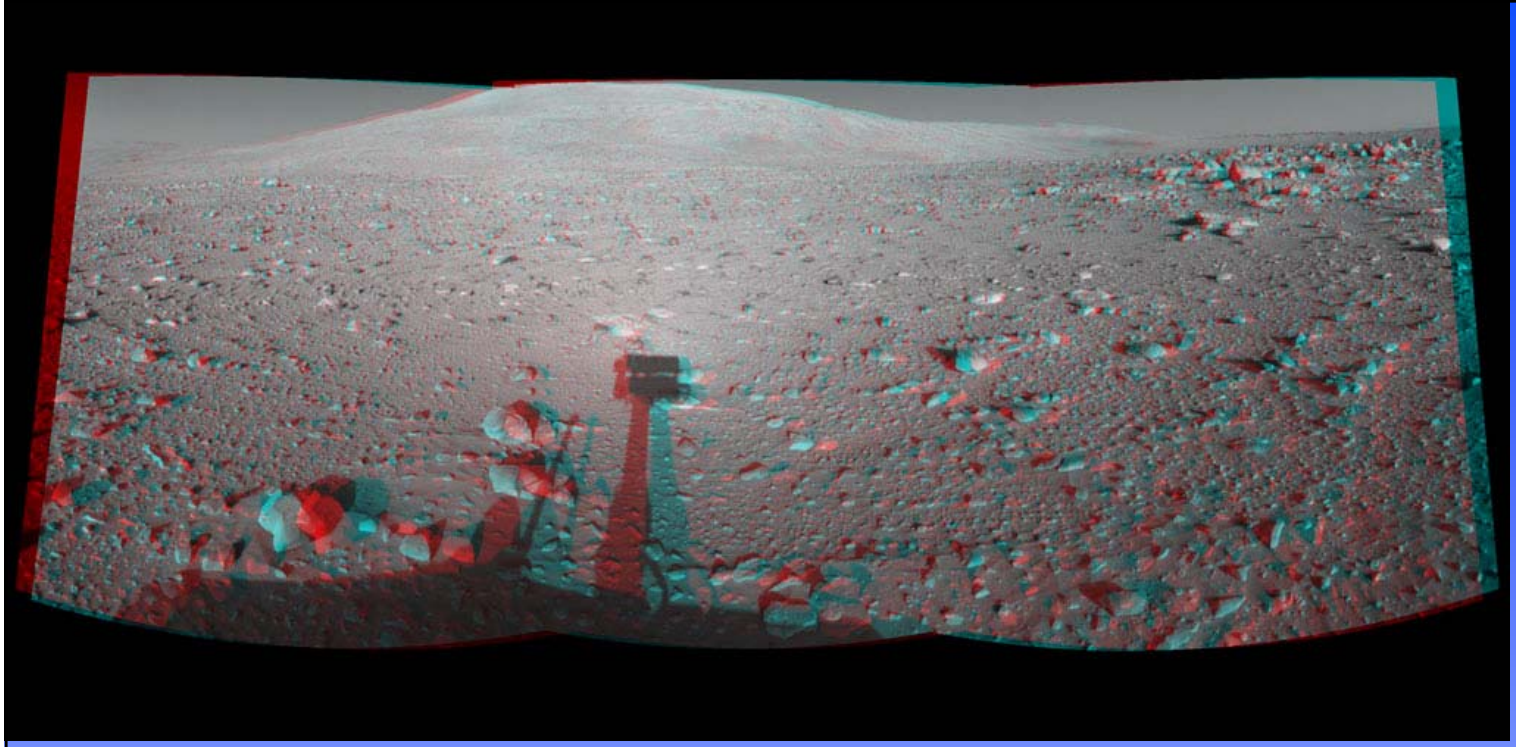




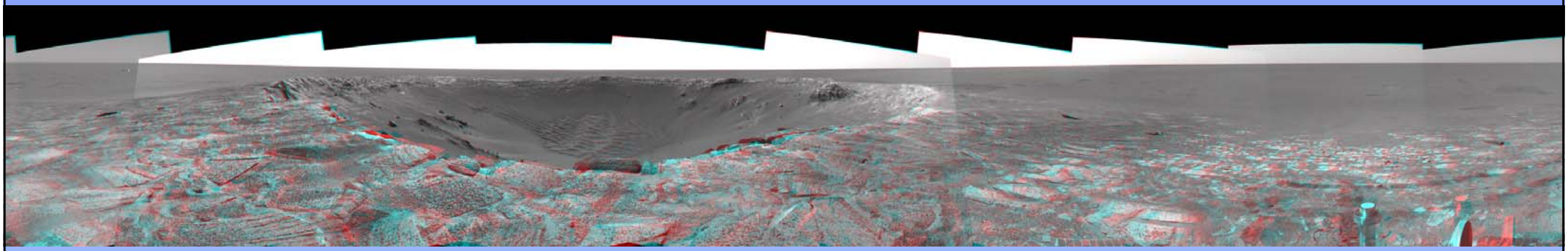
Rim of Bonneville crater

Spirit’s view in Columbia hills ↓



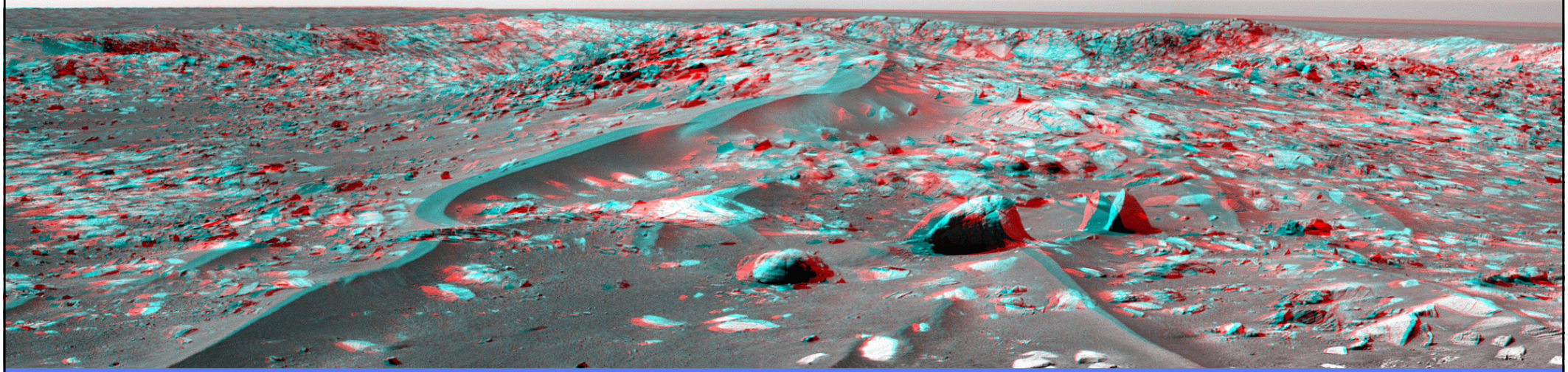


Spirit’s shadow

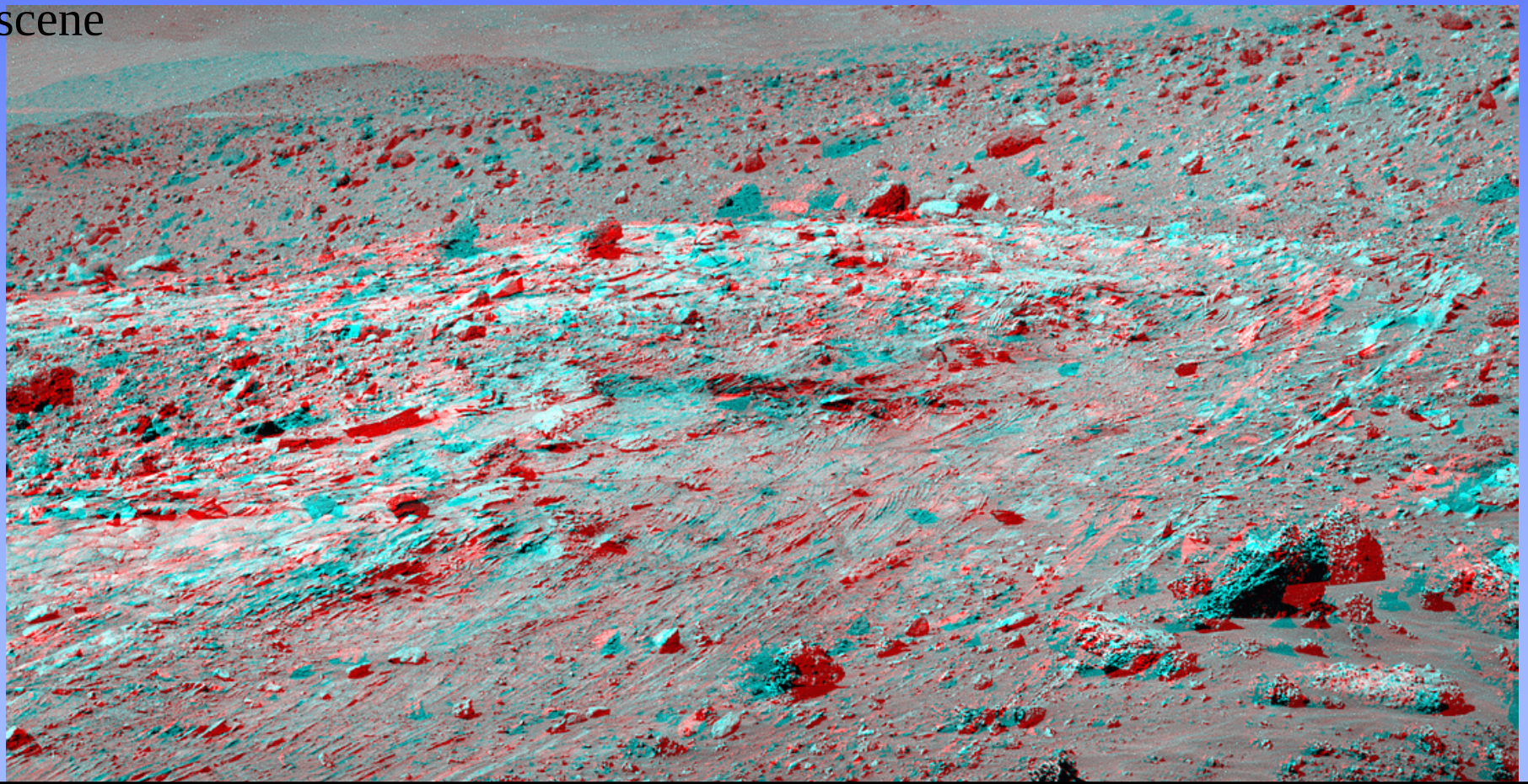


Endurance crater visited by Opportunity

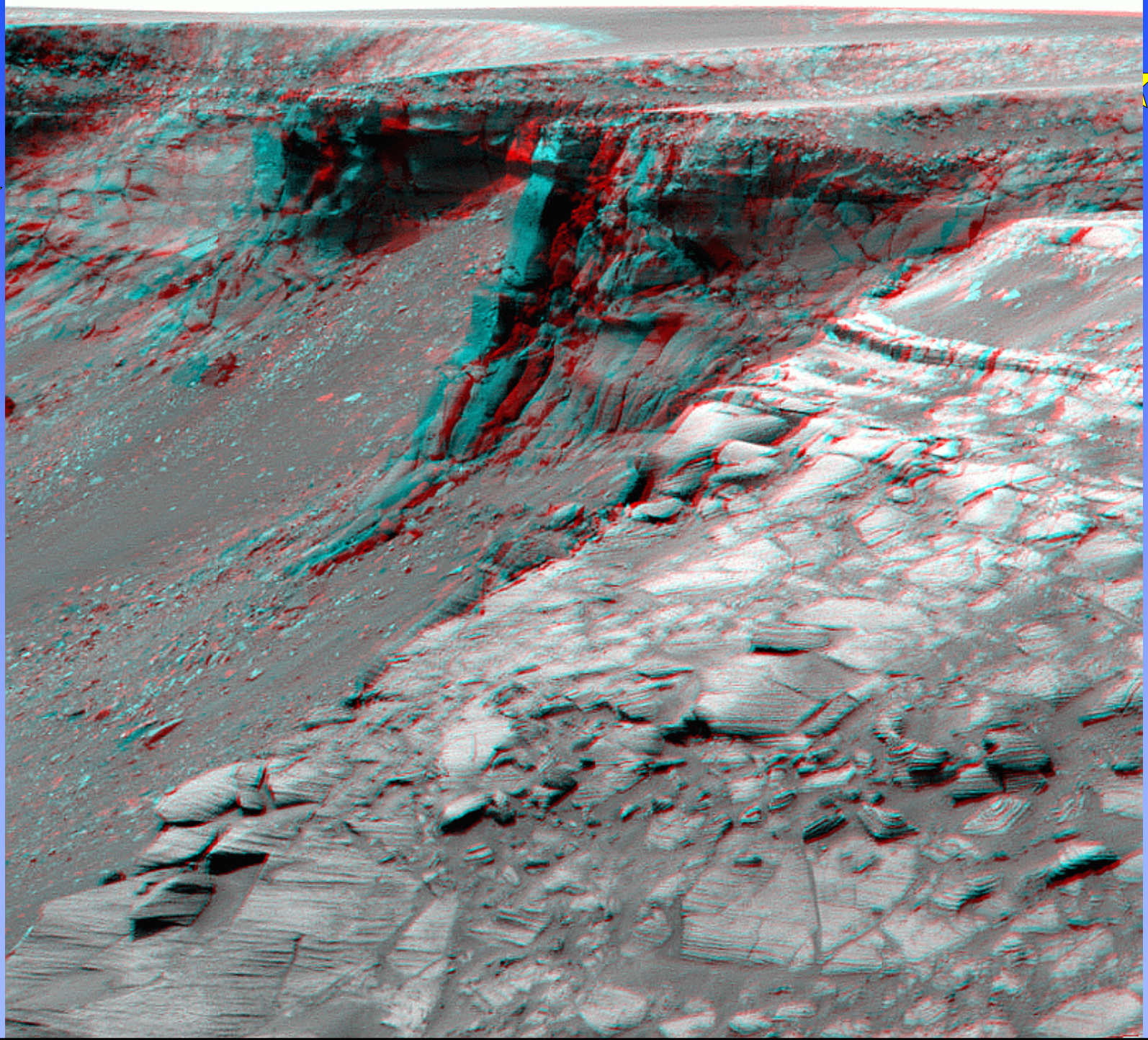
Beagle crater - Opportunity

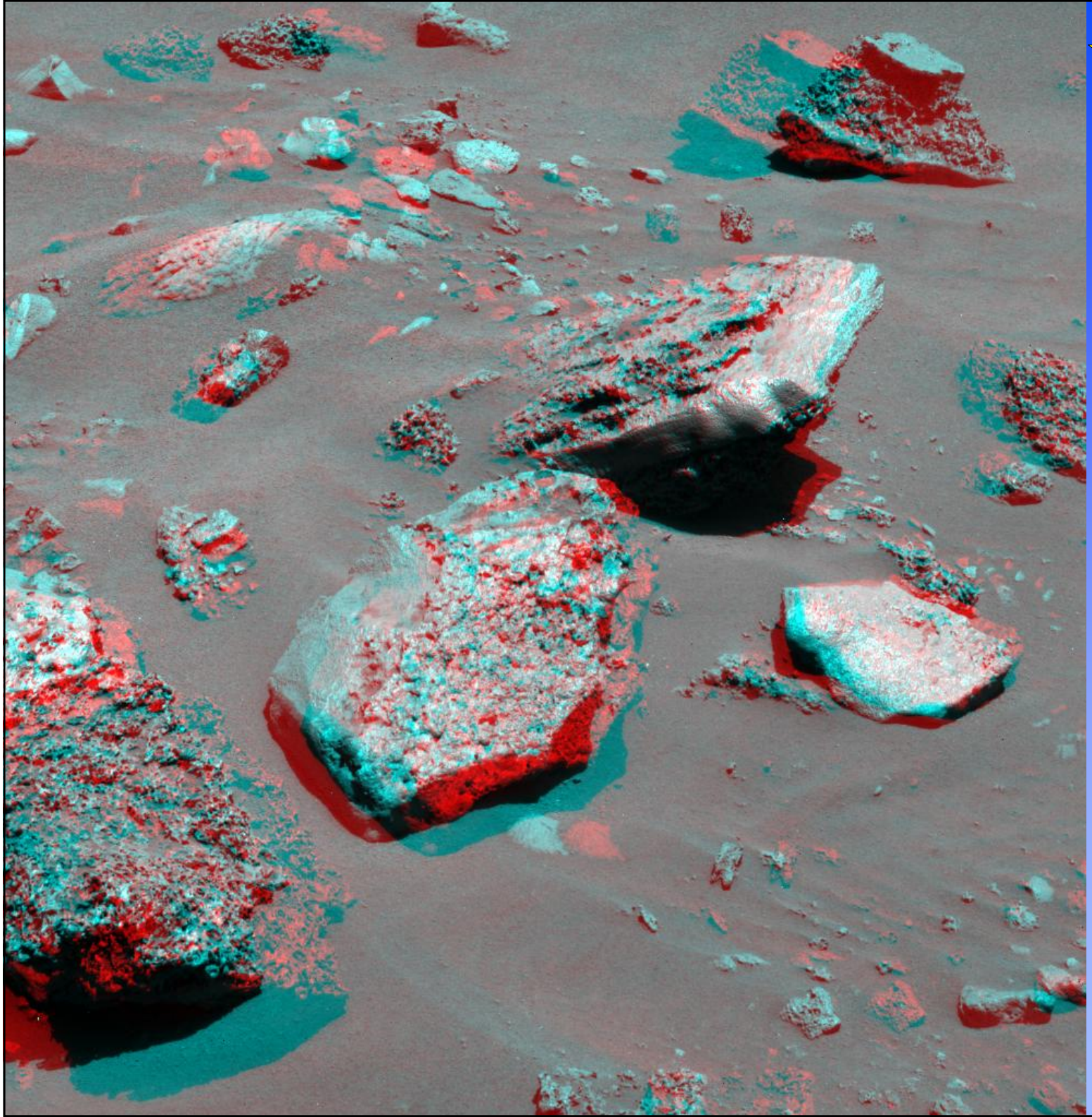


Spirit scene

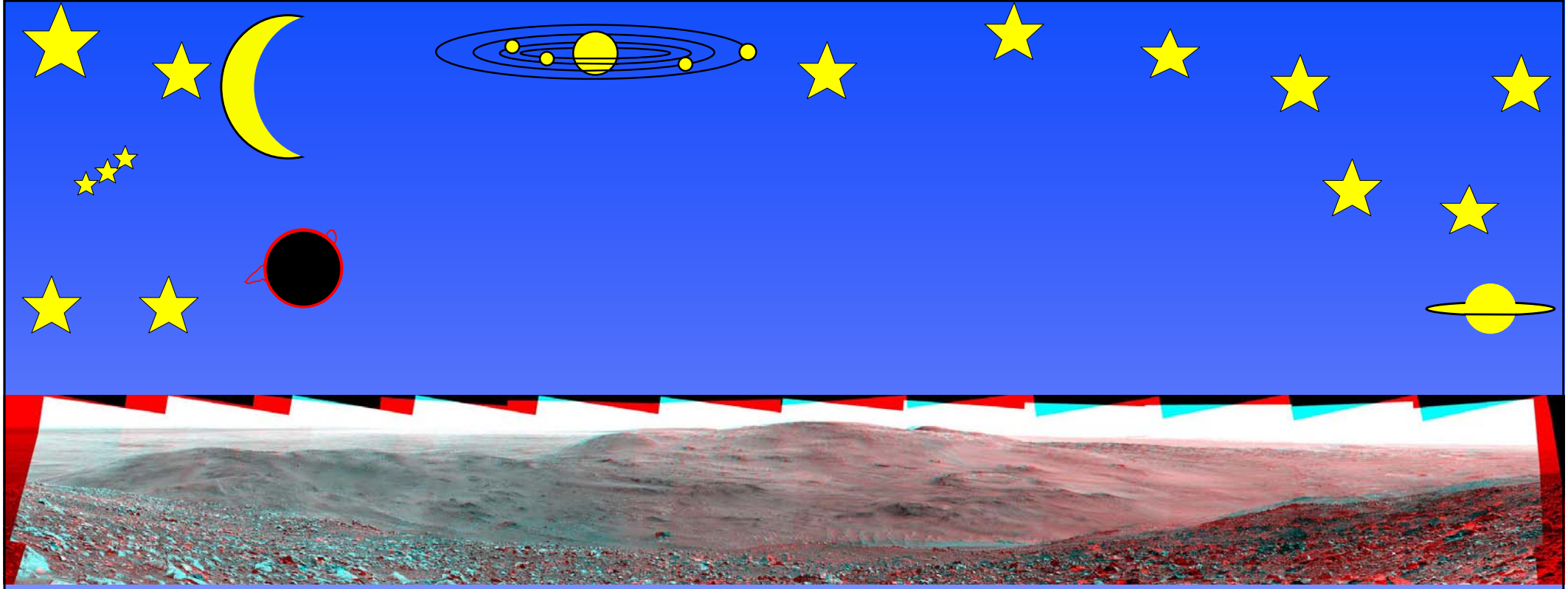


Victoria crater



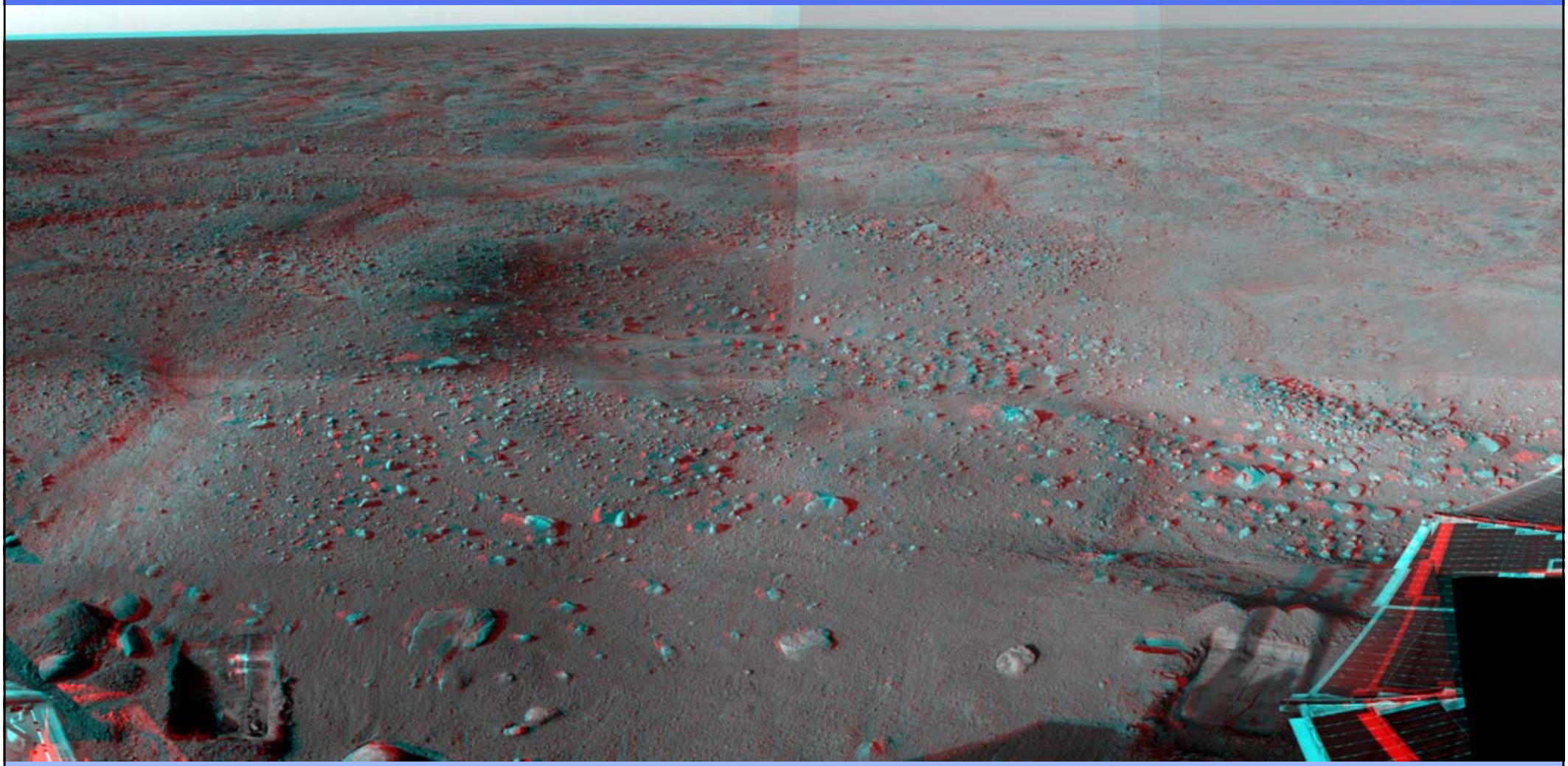


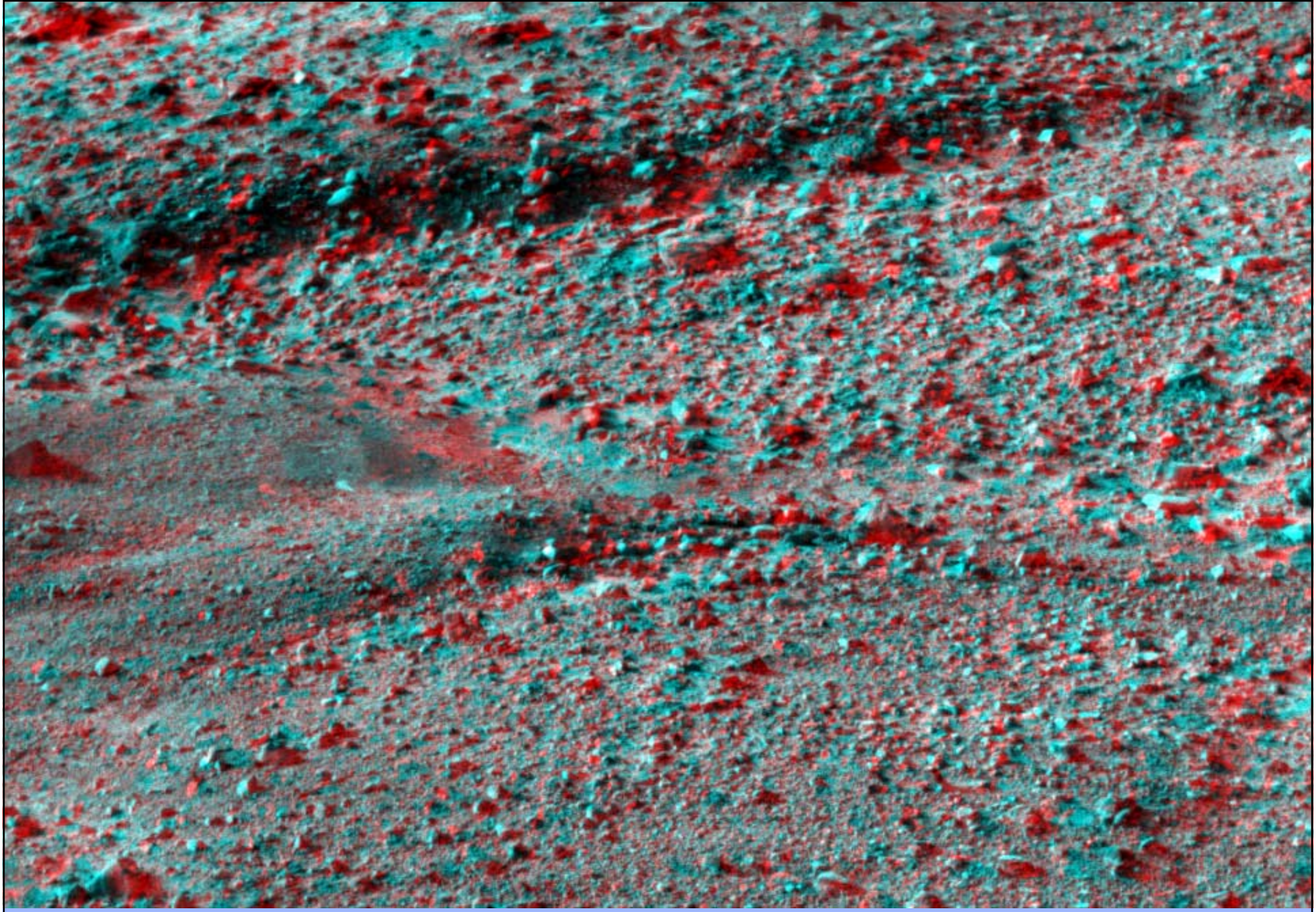
Basaltic rocks with vesicle observed by Spirit in Jan 2006



Spirit’s sweeping view from Columbia hills of Gusev crater (Sept 2005) taken before descending

Phoenix lander view in arctic Mars





Phoenix lander terrain in Martian arctic circle