Briefly: Hyperspectral remote sensing

.. Theory and Application (spectrometry)

Planetary Remote sensing

Wavelengths and sensors

Sun and Moon

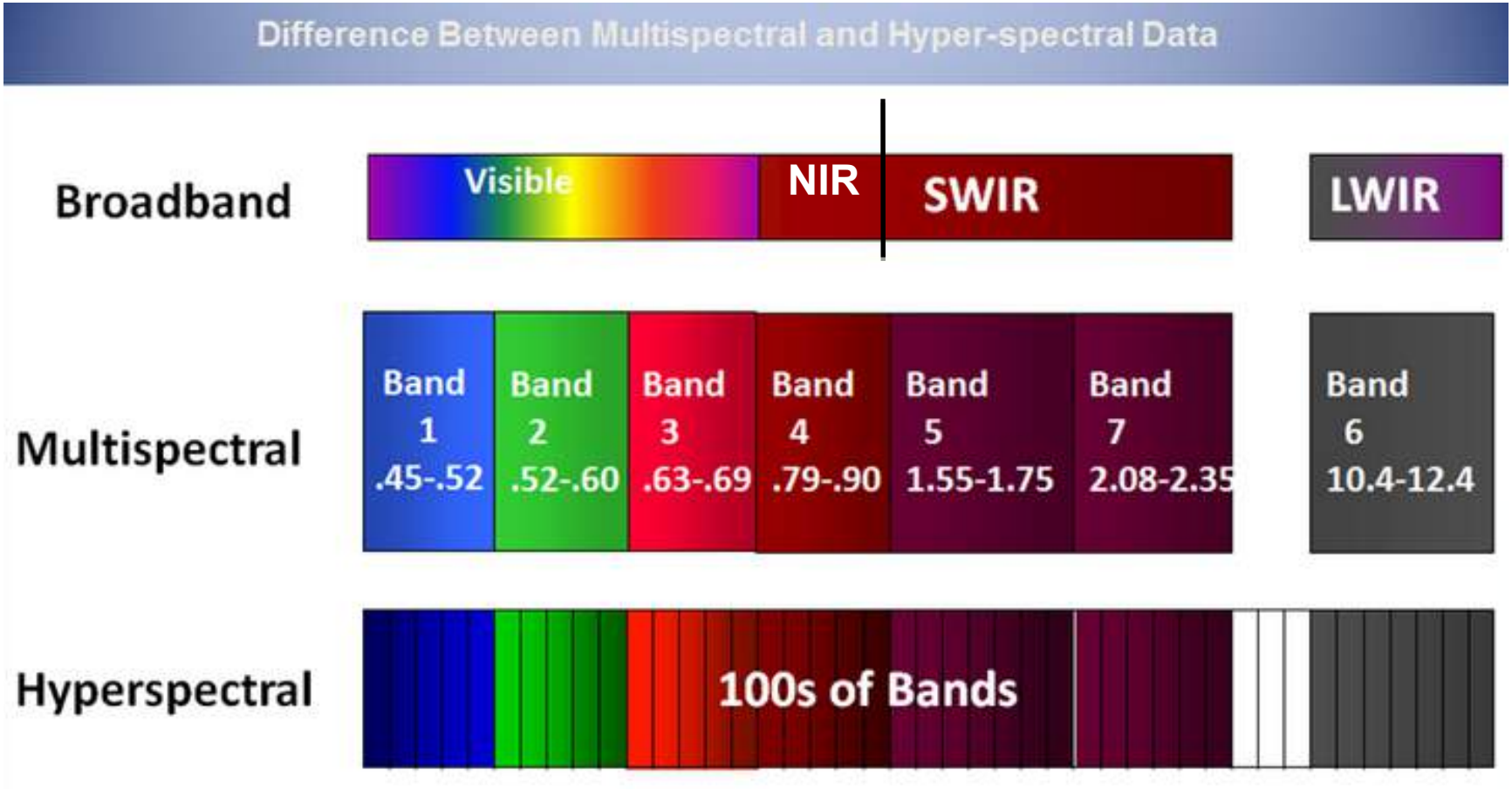
9 Planets: Mercury …Mars ….. (Pluto) + moons

Hyperspectral remote sensing ('Image spectroscopy')

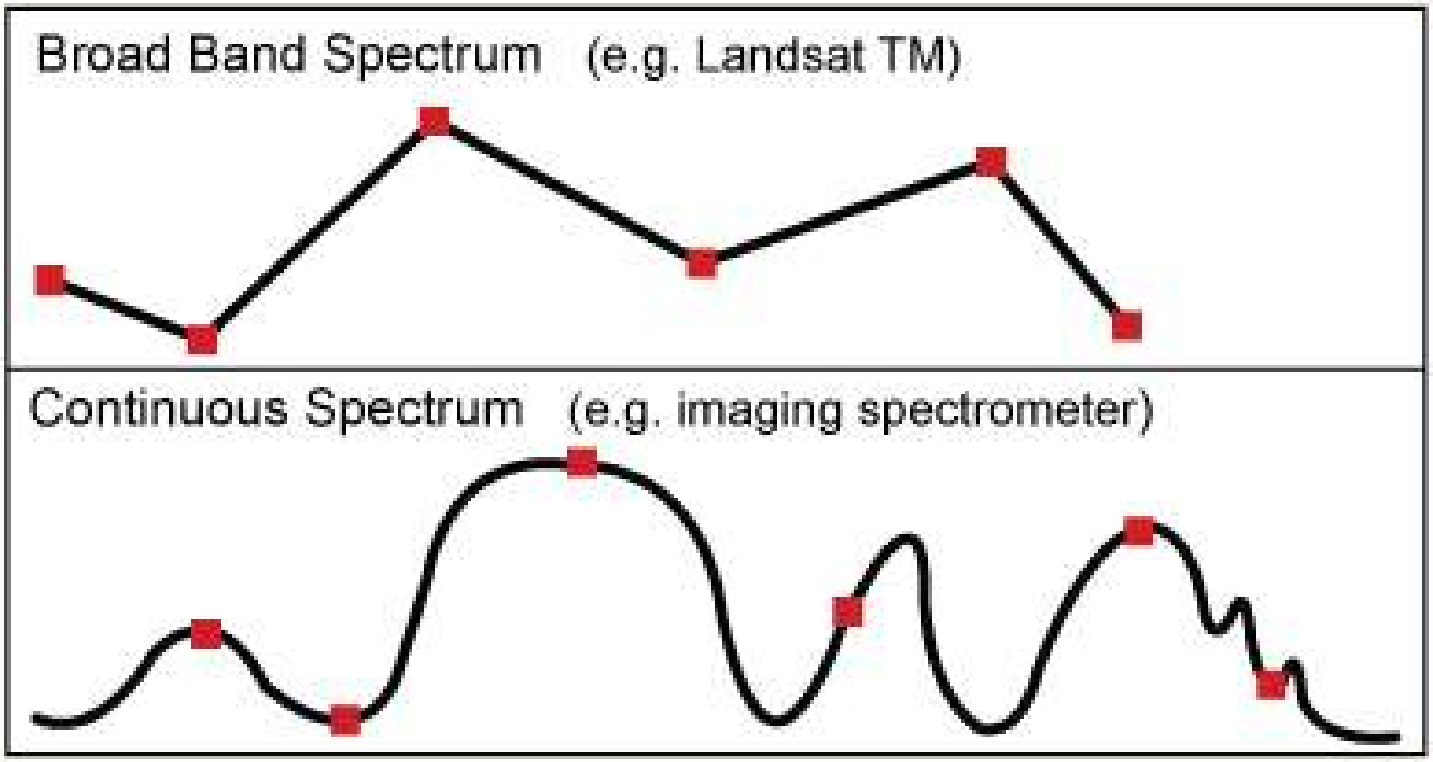
Multispectral systems contain~4-15 bands, 70-400 nm wide

Superspectral: 16-60 (*e.g.* MODIS)

Hyperspectral : 100- 200+ bands 0.38 - 2.5µm, 5-10nm each
Bands are contiguous and high spectral resolution

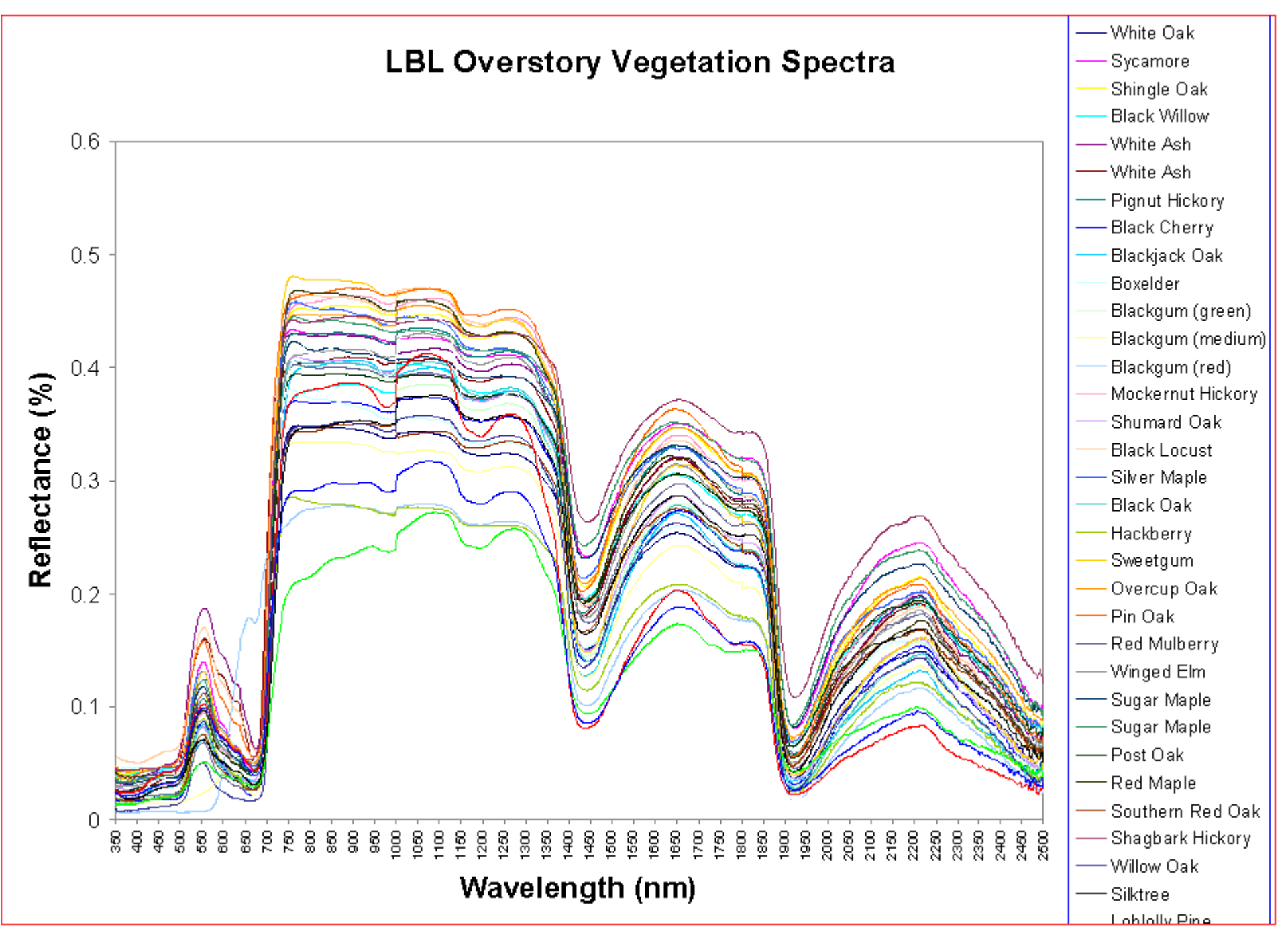


Spectral signatures: Landsat TM v hyperspectral



Above: Spectral comparison between hyperspectral and broad-band data.

http://www.ccrs.nrcan.gc.ca/hyperspectral/isst_e.php



http://www.murraystate.edu/qacd/cos/marc/projects/nasa98/veg_library/lblspec.gif

Currently there are airborne systems and spaceborne.

Coming 'soon' …….

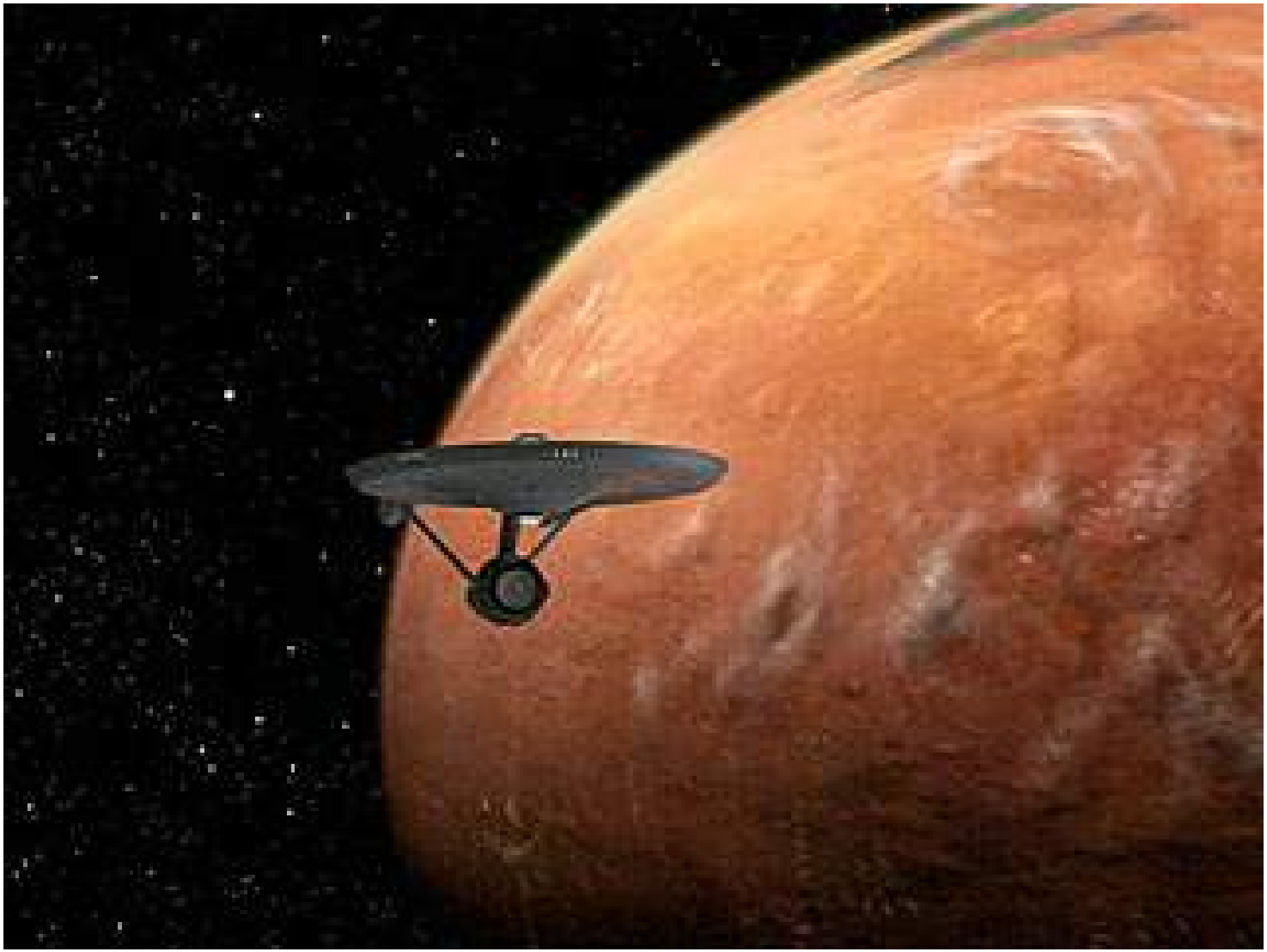
2021: Spaceborne Hyperspectral Applicative Land and Ocean Mission (SHALOM)

… is a joint mission by the Israeli Space Agency and the Italian Space Agency to develop two commercial hyperspectral satellites

Shalom is a Hebrew word meaning peace, harmony, and wholeness

Remote sensing of the planets

A vast literature and methodology exists in optical and radar astronomy that parallels and often exceeds our methods used in remote sensing



Space – the final RS frontier

Methods and wavelengths used on planetary missions

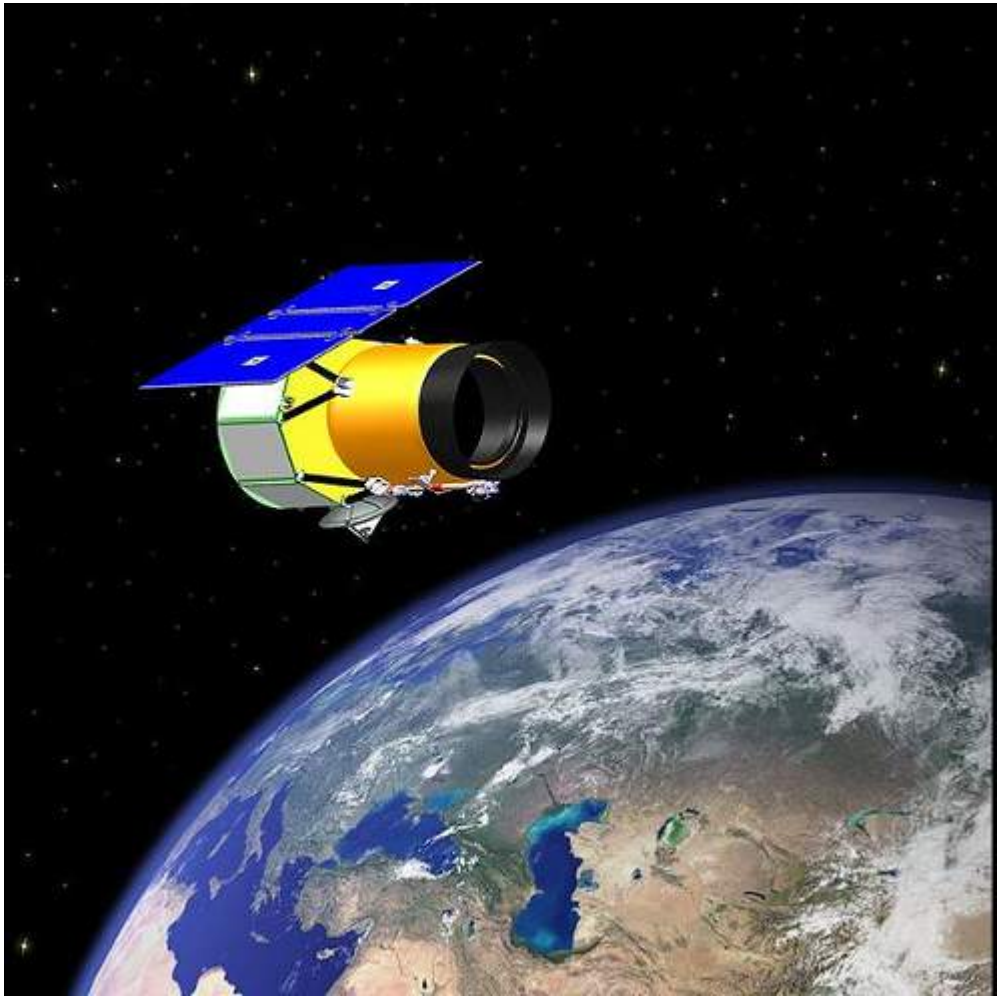
METHOD	EM SPECTRUM	INFORMATION	INTERPRETATION	MISSION
Gamma-Ray Spectroscopy	Gamma rays	Gamma spectrum	K, U, Th Abundances	Apollo 15, 16: Venera
X-ray Fluorescence spectrometry	X-rays	Characteristic Wavelengths	Surface mineral/ chemical comp.	Apollo; Viking Landers
Ultraviolet Spectrometry	UV	Spectrum of Reflected sunlight	Atmospheric Composition: H,He,CO_2	Mariner; Pioneer; voyager
Photometry	UV, Visible	Albedo	Nature of Surface; Composition	Earth Telescopes; Pioneer
Multispectral Imagers	UV, Visible, IR	Spectral and Spatial	Surface Features; Composition	On most missions
Reflectance Spectrometers	Visible, IR	Spectral intensities of reflected solar radiation	Surface Chemistry; mineralogy; processes	Telescopes; Apollo
Laser Altimeter	Visible	Time delay between emitted and reflected pulses	Surface Relief	Apollo 15,16,17
Polarimeter	Visible	Surface Polarization	Surface Texture; Composition	Pioneer; Voyager

Infrared Radiometer (includes scanners)	Infrared	Thermal radiant intensities	Surface and atmospheric temperatures; compos.	Apollo; Mariner; Viking; Voyager
Microwave Radiometer	Microwave	Passive microwave emission	Atmosphere/Surface temperatures; structure	Mariner; Pioneer Venus
Bistatic Radar	Microwave	Surface reflection profiles	Surface Heights; roughness	Apollo 14,15,16; Viking
Imaging Radar	Microwave	Reflections from swath	Topography and roughness	Magellan; Earth systems
Lunar Sounder	Radar	Multifrequency Doppler Shifts	Surface Profiling and imaging; conductivity	Apollo 17
S-Band Transponder	Radio	Doppler shift single frequency	Gravity data	Apollo
Radio Occultation	Radio	Frequency and intensity change	Atmospheric density and pressure	Flybys and Orbiters

* Adapted from Billy P. Glass, *Introduction to Planetary Geology*, 1982, Cambridge University, Press

Hyperspectral	visible-NIR	Reflected solar radiation	Surface	Mars

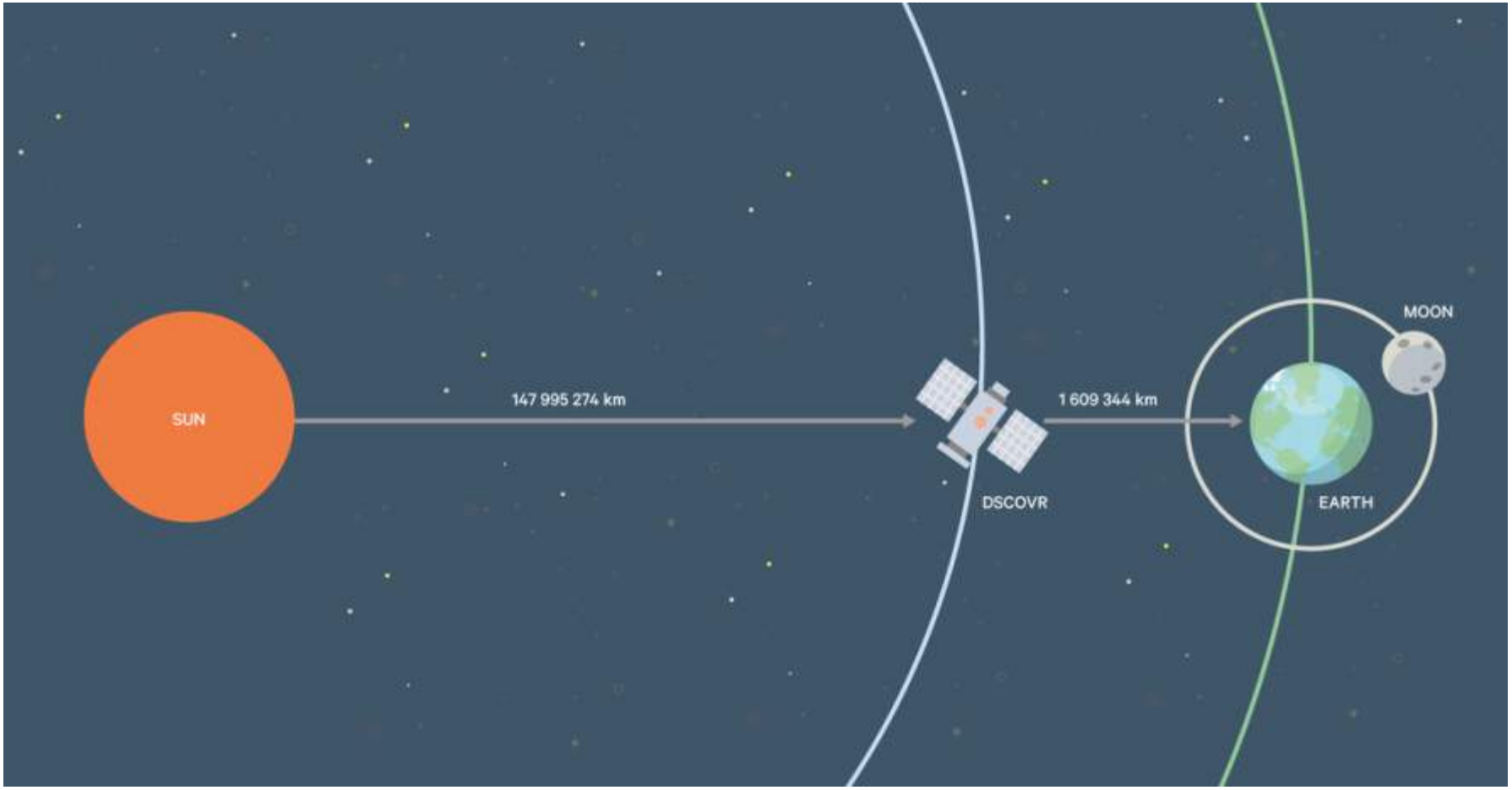
Wide-field Infrared Survey Explorer (WISE) since Nov 20, 2009
Looking out into space; Detectors at 3.4, 4.6, 12 and 22 microns



https://www.nasa.gov/mission_pages/WISE/main/index.html

Infrared Echoes of a Black Hole Eating a Star

DSCOVR: Deep Space Climate Observatory - 2015
1 million miles away – ~10km resolution
– orbiting at 'Lagrange point L1 = gravitational pull



Proposed by Al Gore,1998 to study earth and solar wind
The first satellite orbiting in deep space ….. 'Goresat'

'Dark side of the Moon' crossing Earth from DSCOVR satellite

daily images from EPIC

Earth Polychromatic Imaging Camera (EPIC)

http://epic.gsfc.nasa.gov/

1. EPIC: Earth Polychromatic Imaging Camera, 10 bands

EPIC Wavelengths and main data products

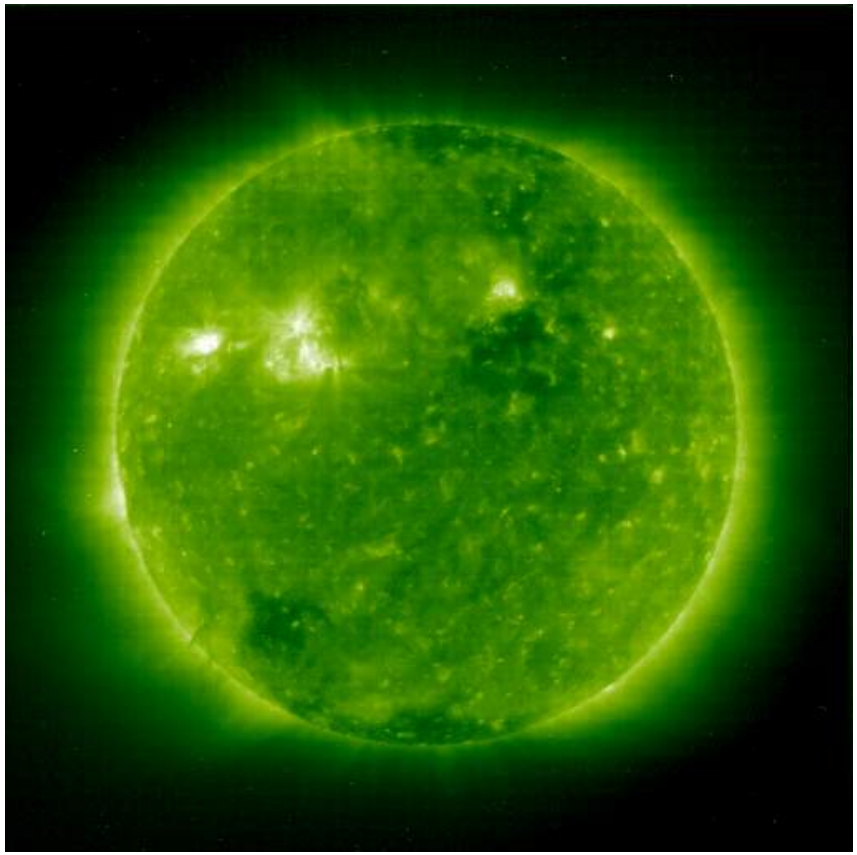
Wavelength(nm)	Full Width (nm)	Primary Application
317.5 ± 0.1	1 ± 0.2	Ozone, SO_2
325 ± 0.1	2 ± 0.2	Ozone
340 ± 0.3	3 ± 0.6	Ozone, Aerosols
388 ± 0.3	3 ± 0.6	Aerosols, Clouds
443 ± 1	3 ± 0.6	Aerosols, Clouds
551 ± 1	3 ± 0.6	Aerosols
680 ± 0.2	3 ± 0.6	Aerosols, Vegetation
687.75 ± 0.2	0.8 ± 0.2	Aerosols, Vegetation, Clouds
764 ± 0.2	1 ± 0.2	Cloud Height
779.5 ± 0.3	2 ± 0.4	Clouds, Vegetation

2. NISTAR Radiometer to measure radiance UV-TIR, 0.2 - 100 microns – to monitor earth temperature and reflected solar radiation

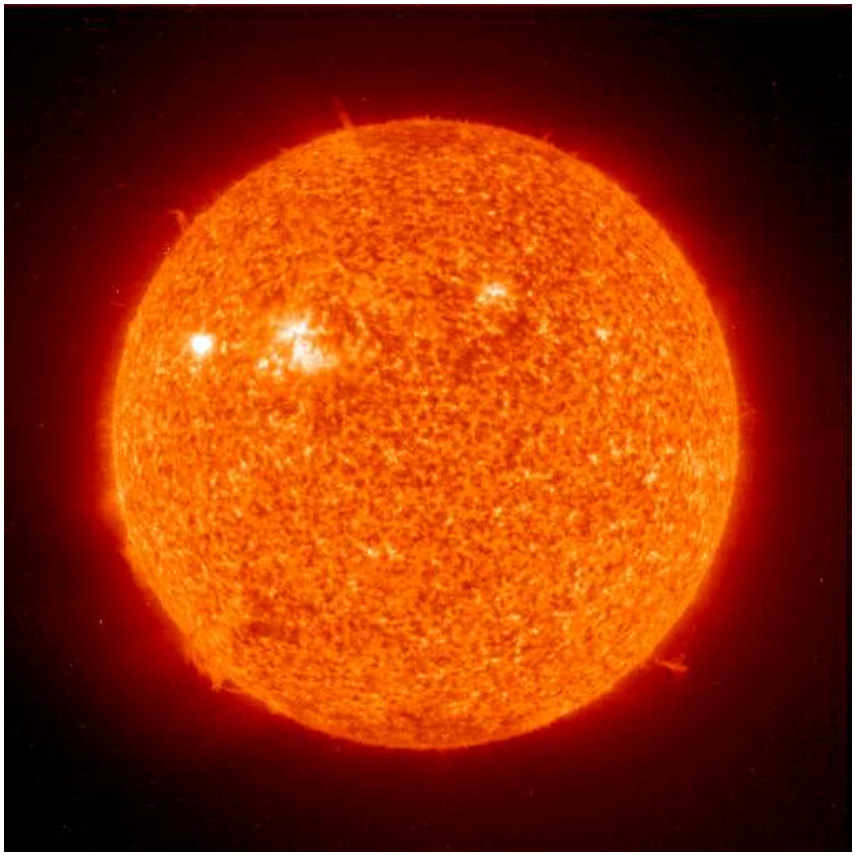
SOHO the Solar & Heliospheric Observatory

.. is a project of international collaboration between ESA and NASA to study the Sun from its core to the outer corona and the solar wind.

Nov 18, 2009: 195 nm



304 nm (also 171 and 284)



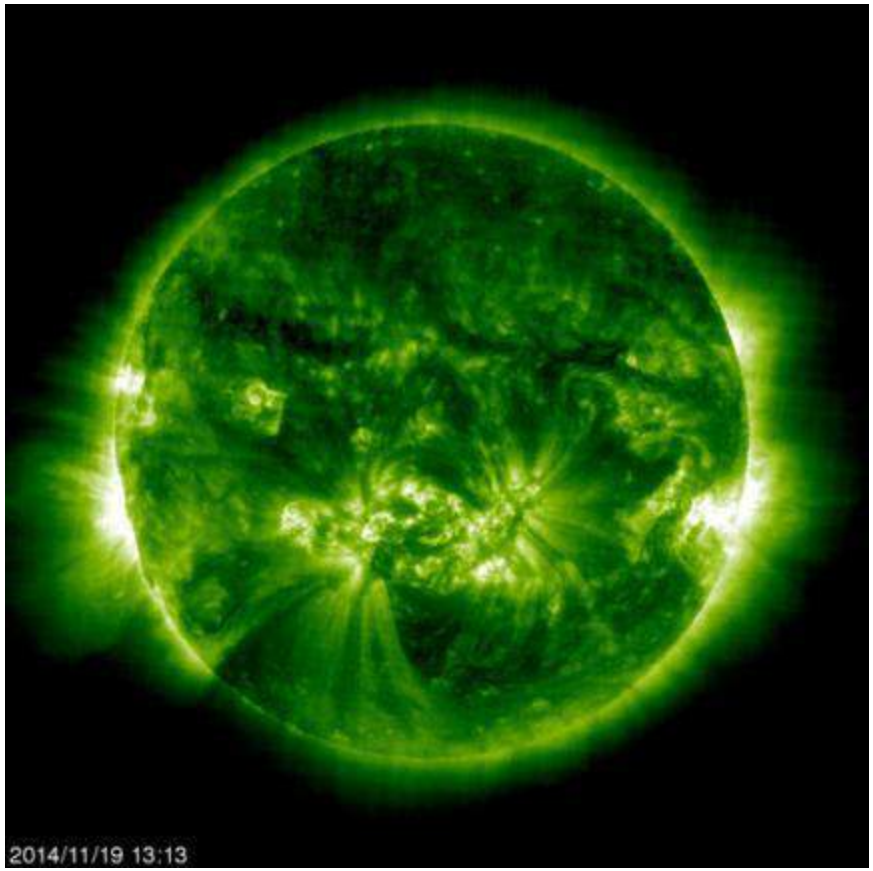
1995, cost €1 billion; Sensor: Extreme ultraviolet Imaging Telescope (EIT)

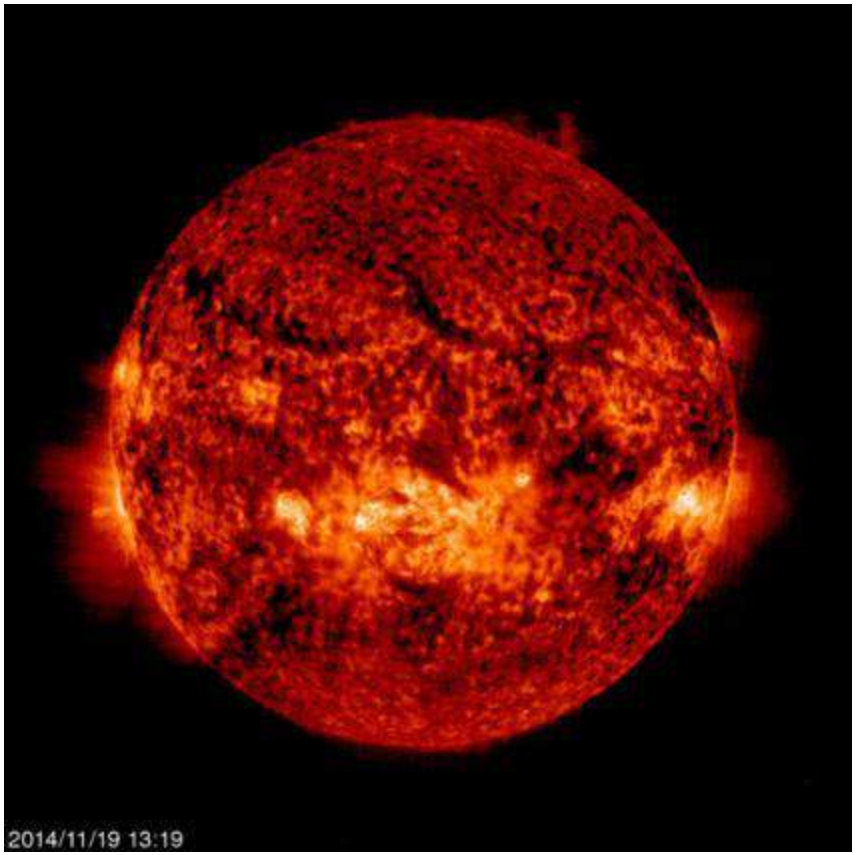
Located at sun-earth L1 gravitational orbit

SOHO, the Solar & Heliospheric Observatory

.. is a project of international collaboration between ESA and NASA to study the Sun from its core to the outer corona and the solar wind.

Later images – Nov 19, 2014: 195 nm 304 nm (also 171 and 284)





Launched 1995, cost €1 billion; Sensor: Extreme ultraviolet Imaging Telescope (EIT)

Daily images: https://umbra.nascom.nasa.gov/newsite/images.html

Types of Remote Sensing Missions

- Fly-bys

Mariner Missions, Mercury and Venus

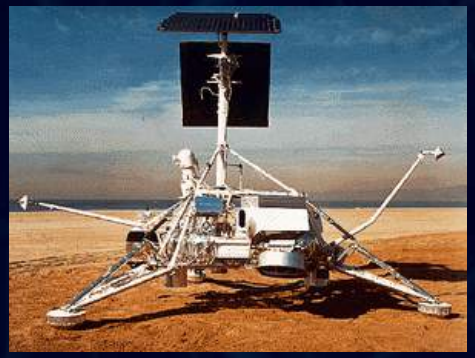
New Horizons 2007, Jupiter and Pluto

- Orbiters

LandSat, Earth

Mars Reconnaissance Orbiter

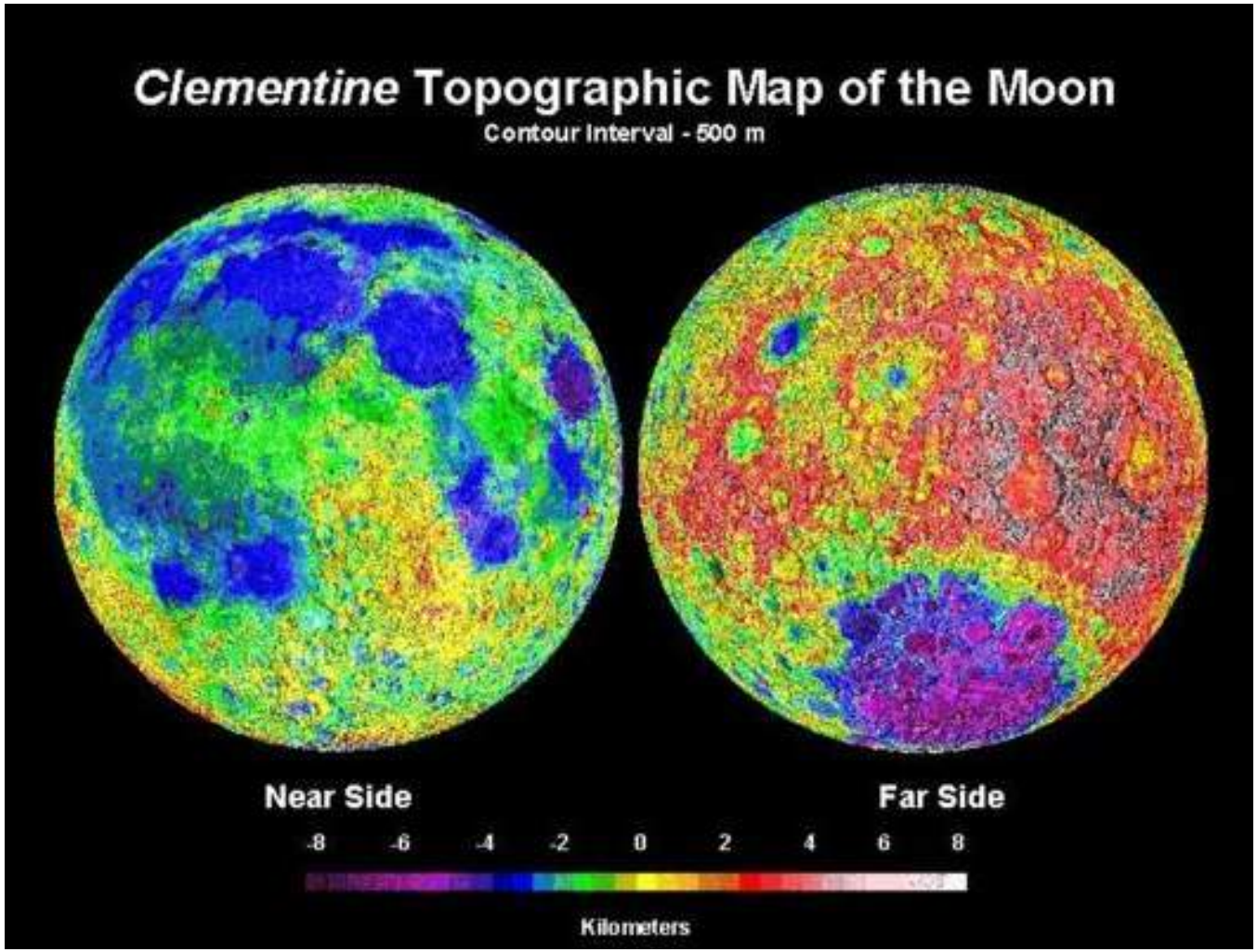
- Landers / Rovers



Surveyor Lunar Lander, 1966

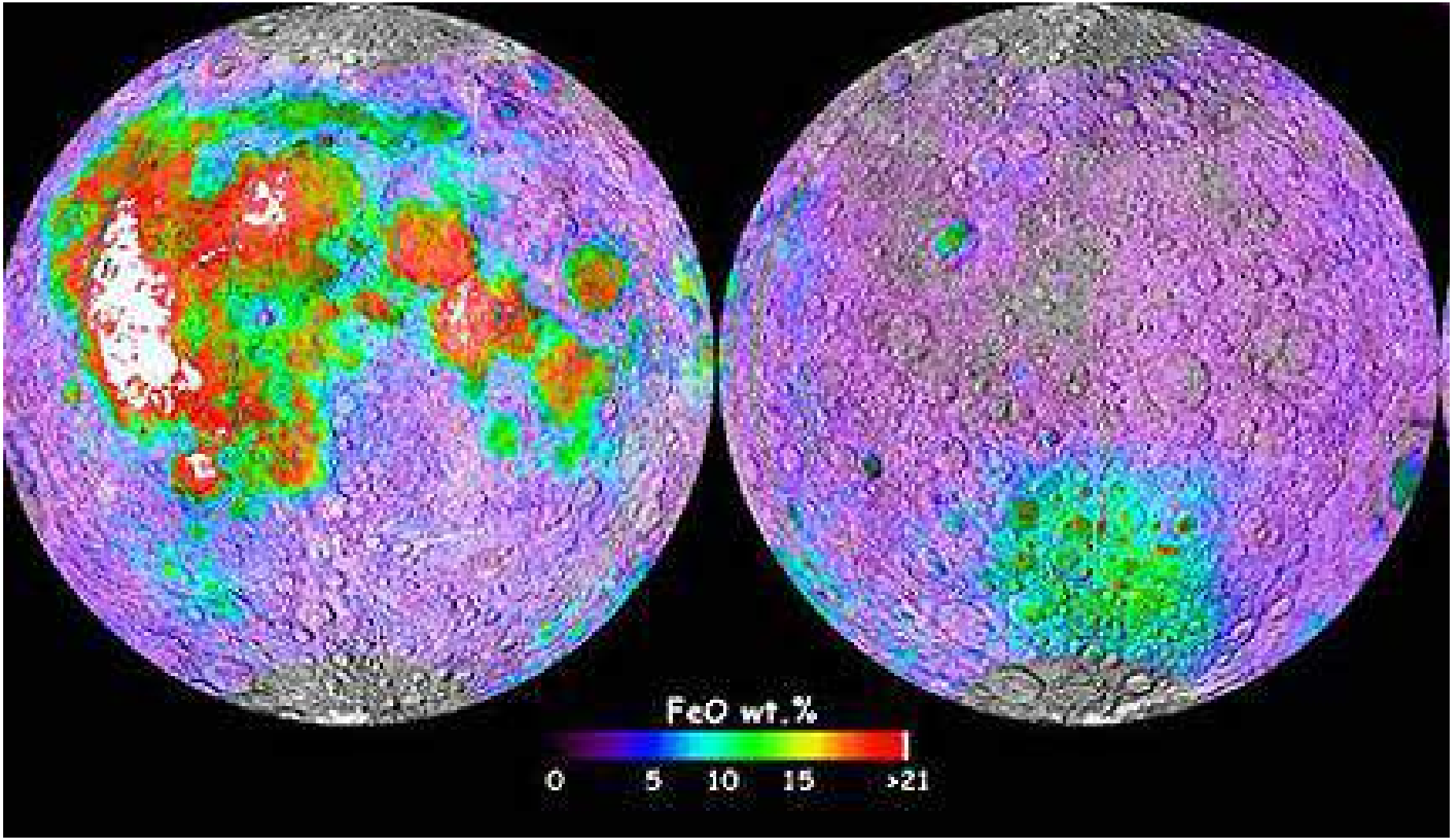
Mars Rovers, 2003

After Apollo (1972), the Moon was not revisited until an unmanned spacecraft, Clementine orbited to conduct mapping studies February 19 - April 21, 1994, using UV/Visible, Near IR, and Lidar



https://www.google.ca/moon/

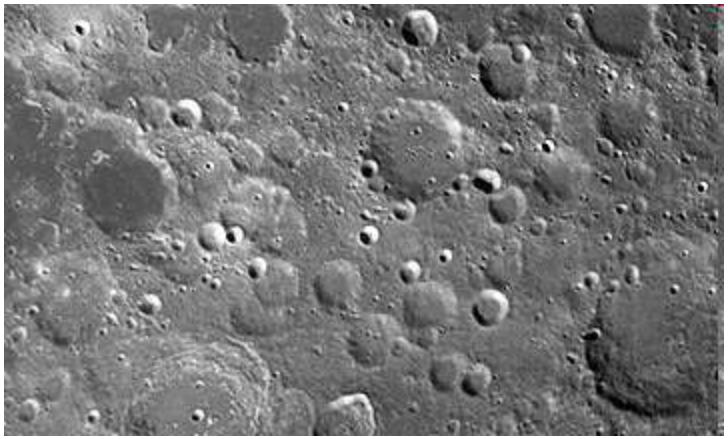
specialized products include detailed maps of lunar topography and the distribution of several chemical elements, such as iron (Fe) and titanium (Ti), determined by analyzing reflectance variations at 0.75 mu and 0.95 mu, where these elements absorb radiation.



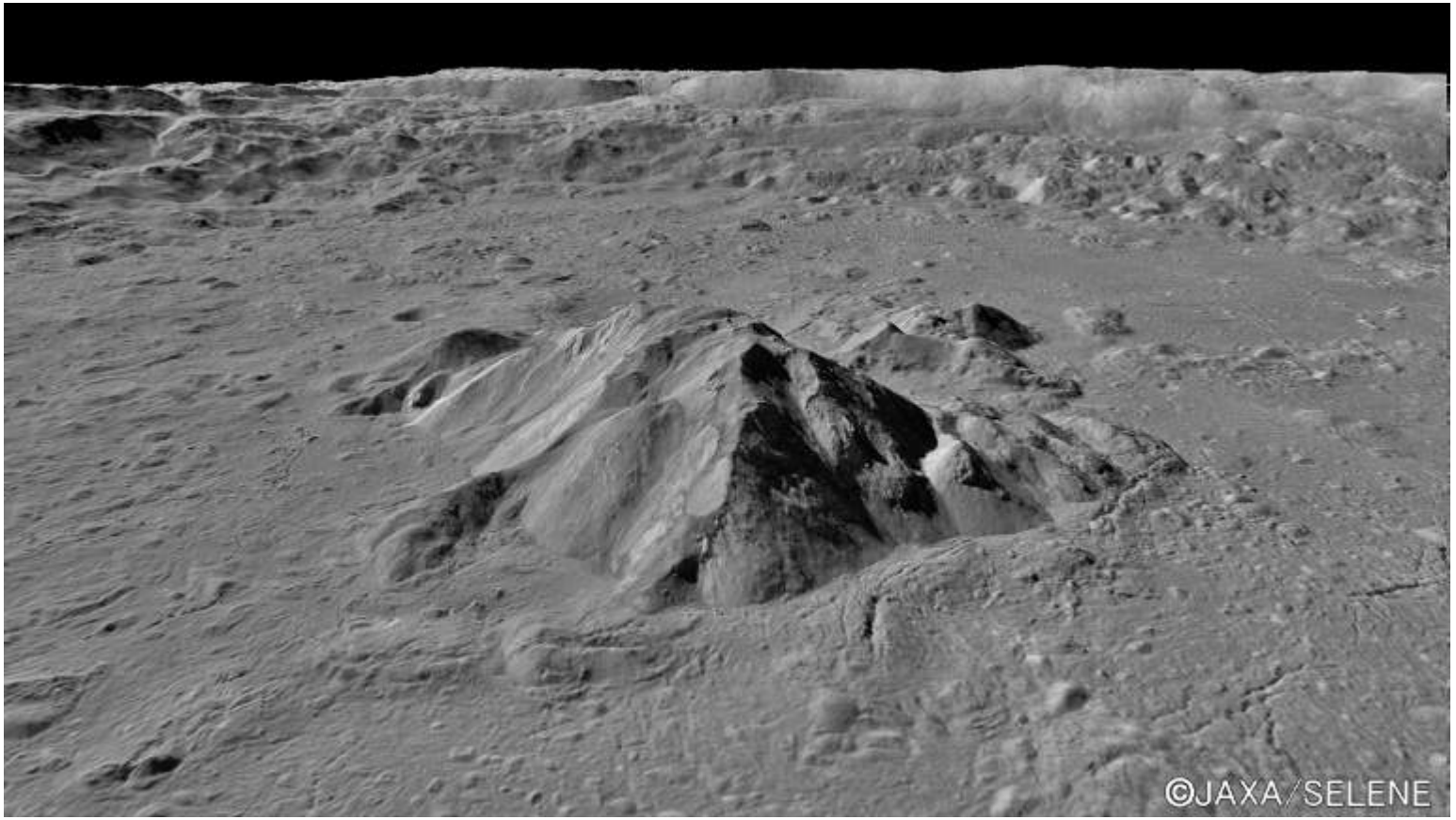
In mid-April 2000, the Terra spacecraft was turned upside down and pointed at the Moon. This ASTER image was acquired at that time, showing band 3 in black and white.

Recent Lunar missions

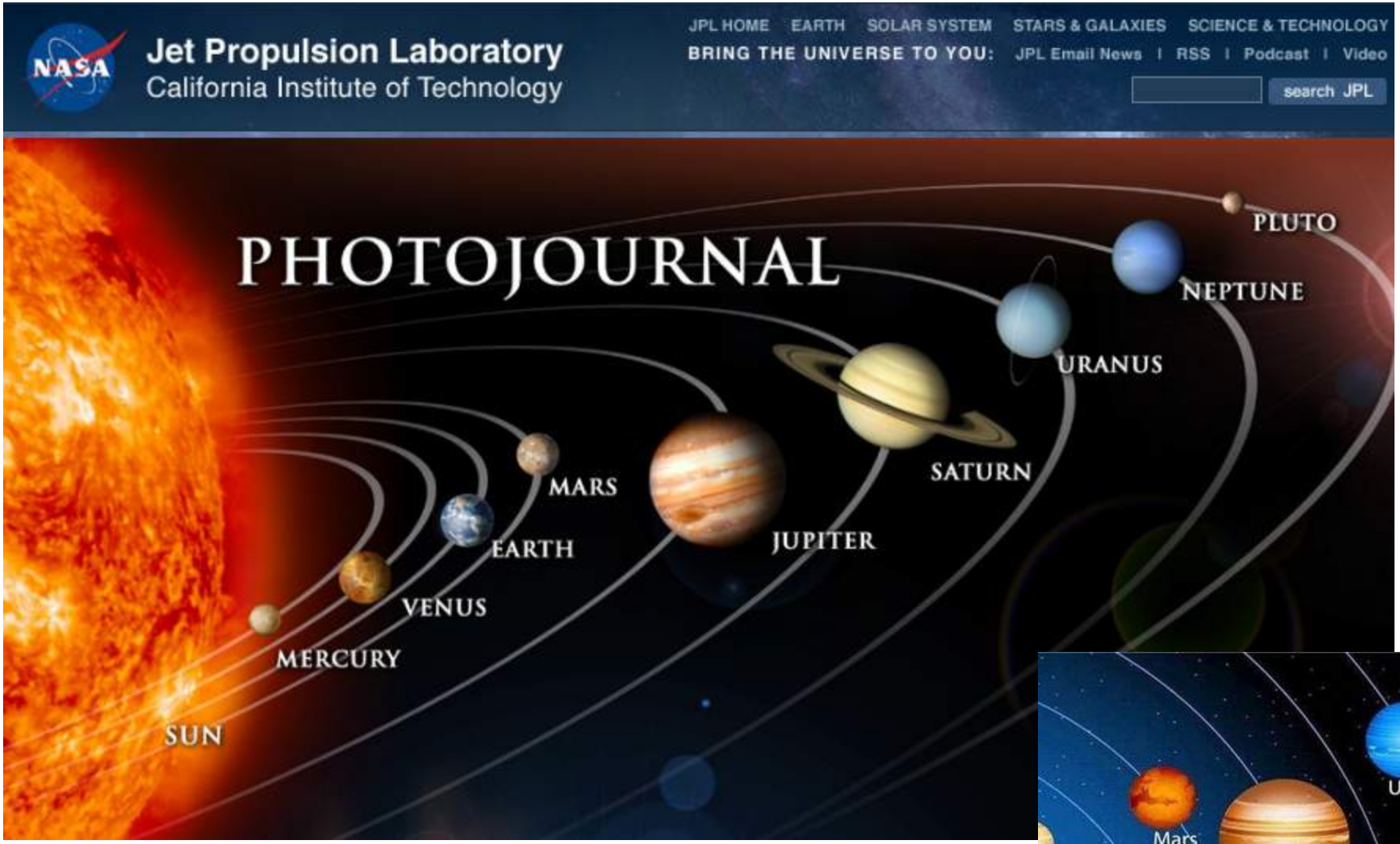
Right: China: Chang'e-1 (2007)
Chang'e-3 (2013) landed on moon
Chang'e-5 (2020) – lander on Moon



Below: Japan – Kayuga
Launched 2007, impacted on lunar surface 2009 (near South Pole)



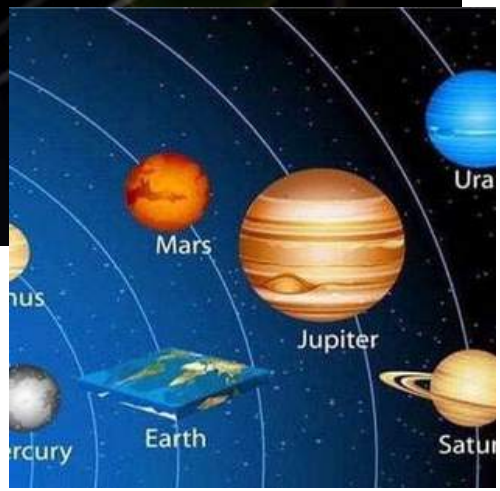
http://photojournal.jpl.nasa.gov/index.html



Imaging links (2015): Sun 23, Mercury 281, Venus 149, Mars 6327

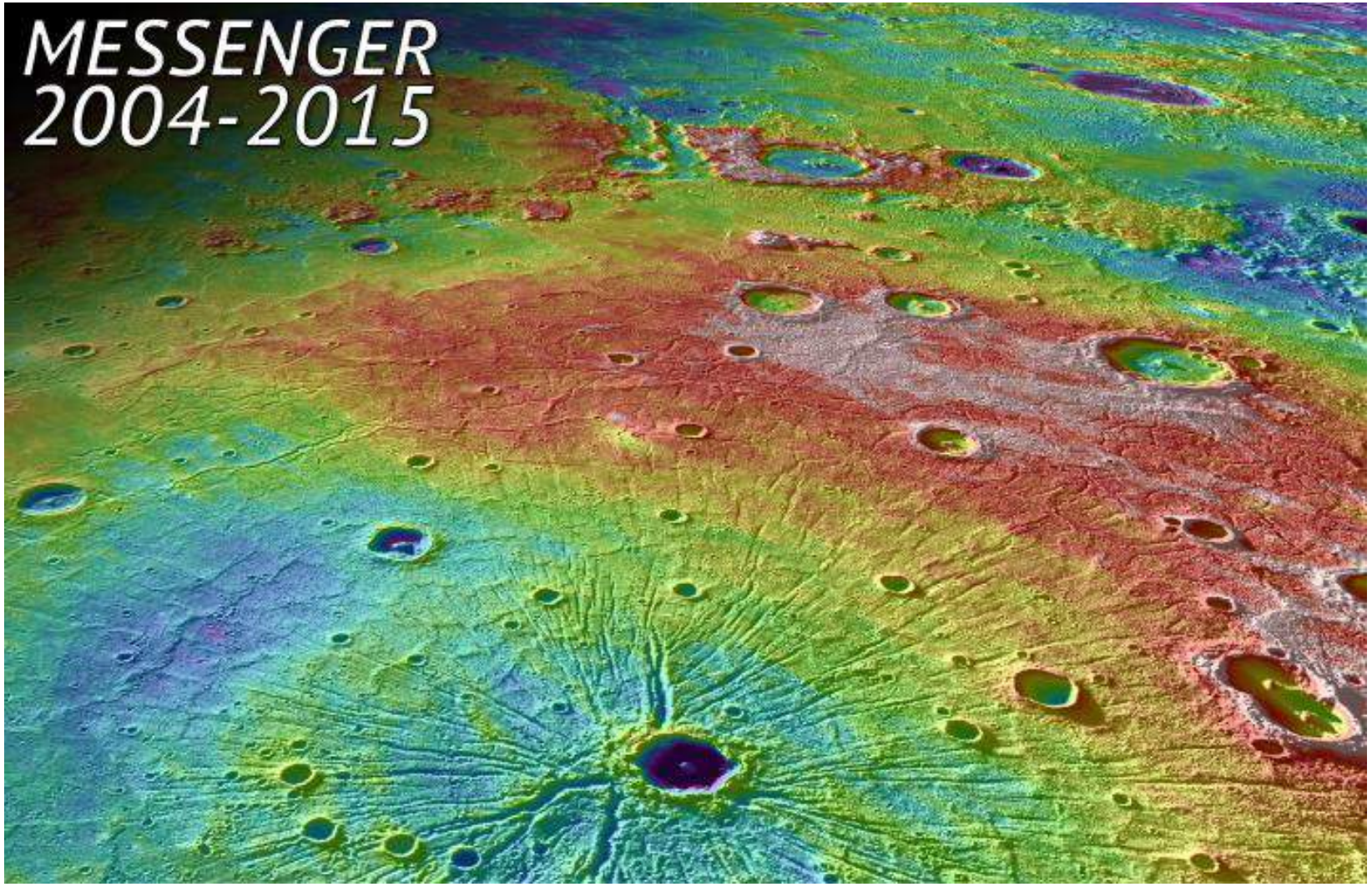
Jupiter 817, Saturn 2291, Uranus 55, Neptune 80, Pluto 7

For Flat Earthers -->



Mercury Messenger:

Mercury **S**urface**, S**pace **Environment, Ge**ochemistry**, &** **R**anging



Mercury Dual Imaging System (MDIS) and Mercury Laser Altimeter (MLA)

Venus

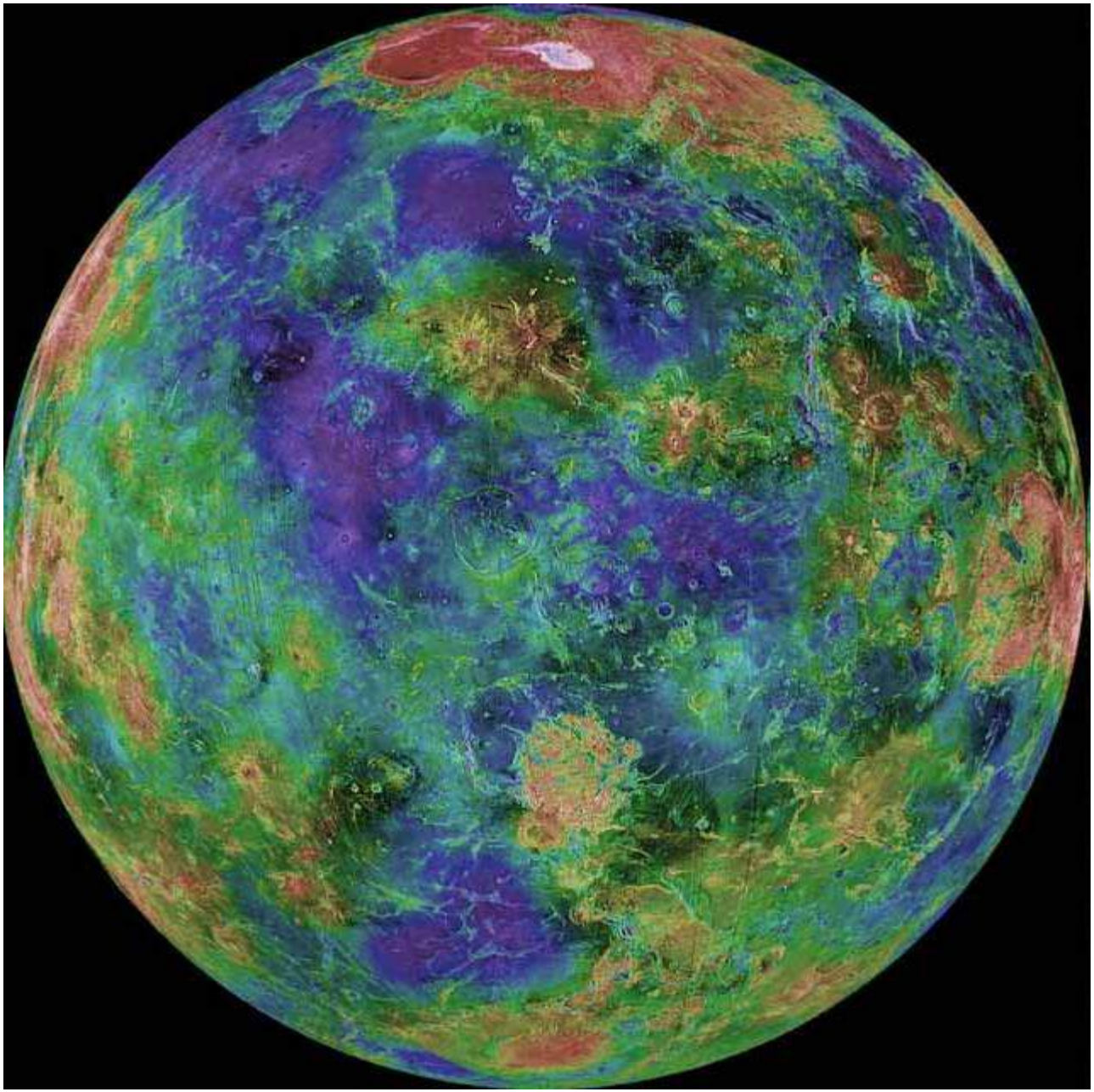
From Magellan

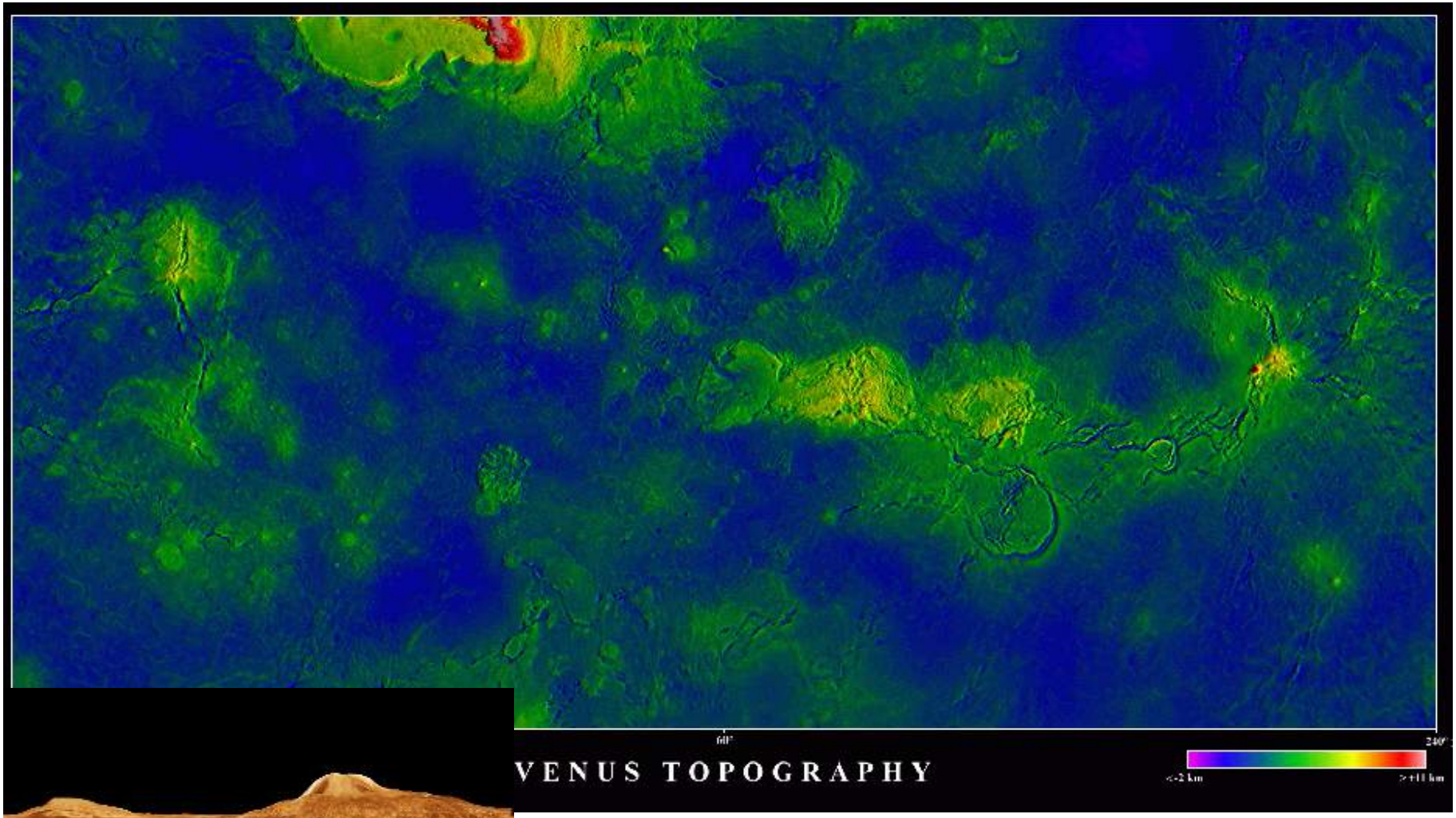
-first imaging device launched from Shuttle 1989

Planet is Cloud covered

Radar 100m

Composite colours based on elevations

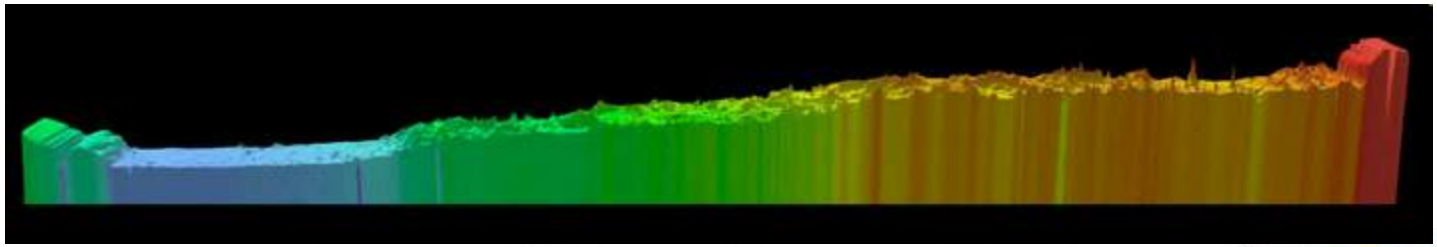


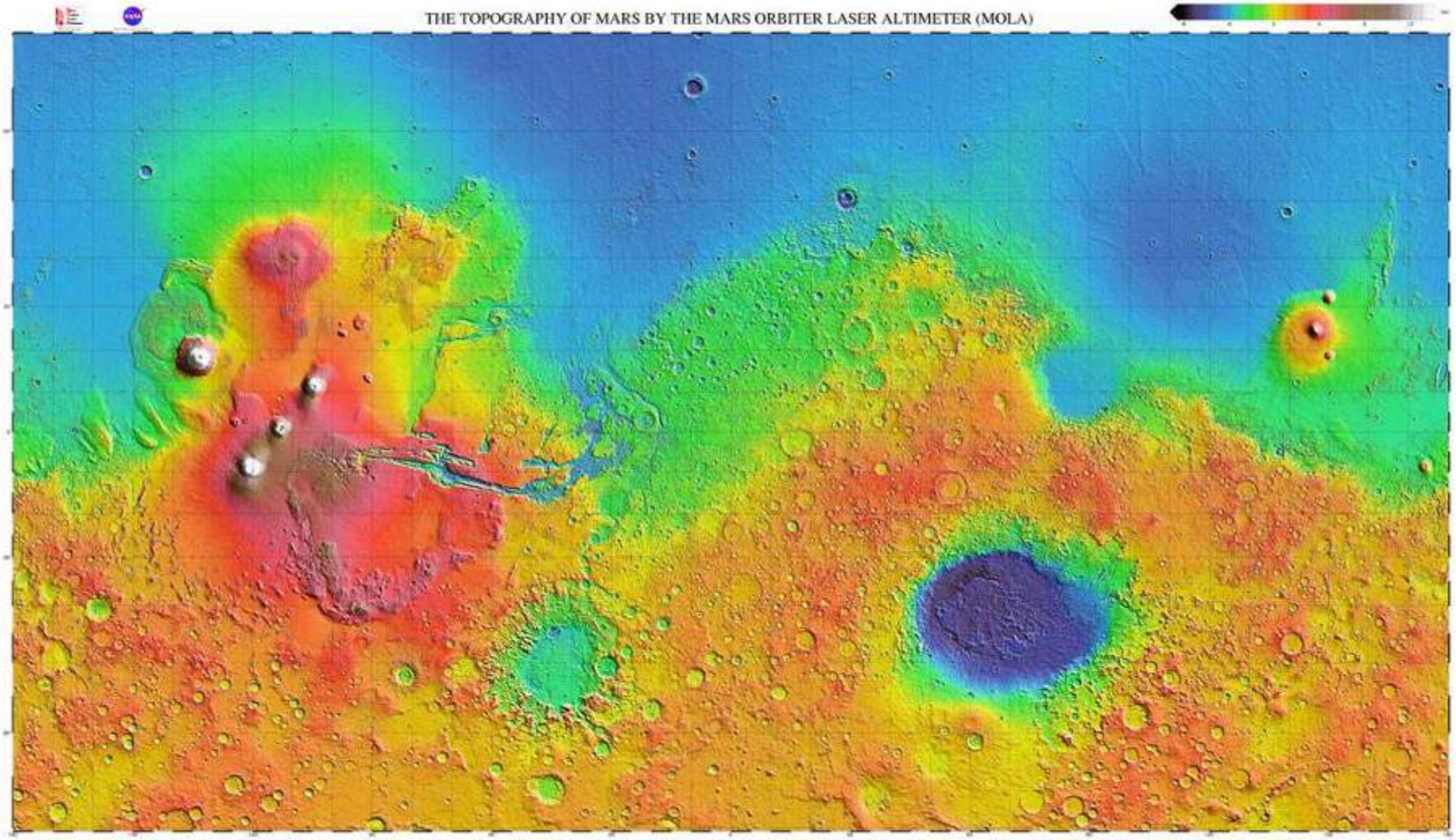


http://www.solarviews.com/eng/venus.htm

Mars Global Surveyor (1996) Instruments

DEM resolution in z = 30cm ! (N. Pole to S. Pole transect)





https://www.google.ca/mars/

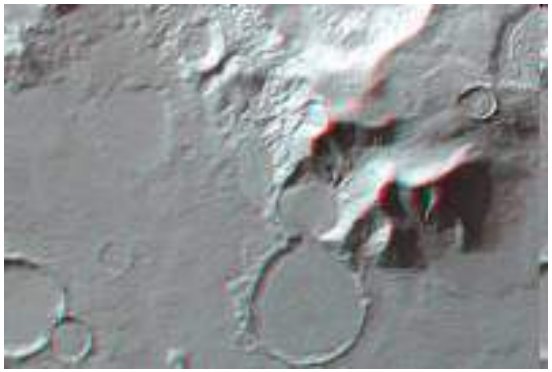
Suspected rock glacier, Mars Orbiter Camera JPL/NASA

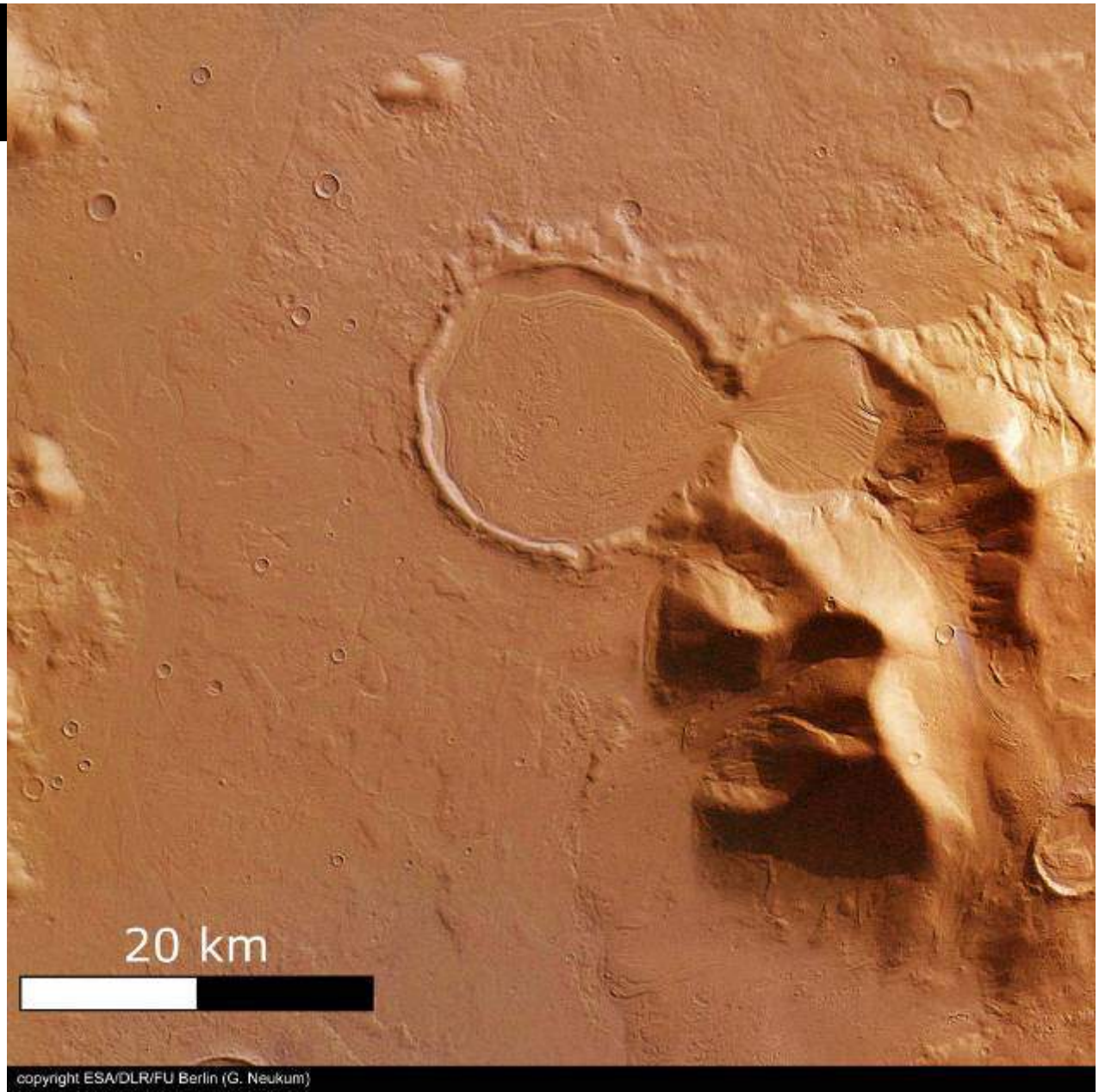
Resolution = 1.4 m PAN, 230m Red-Blue

- **MOC has produced over 250,000 images to date**

Mars Express (ESA,2003): High Resolution Stereo Camera Res.2-10m

The “hourglass” feature
HRSC, ESA





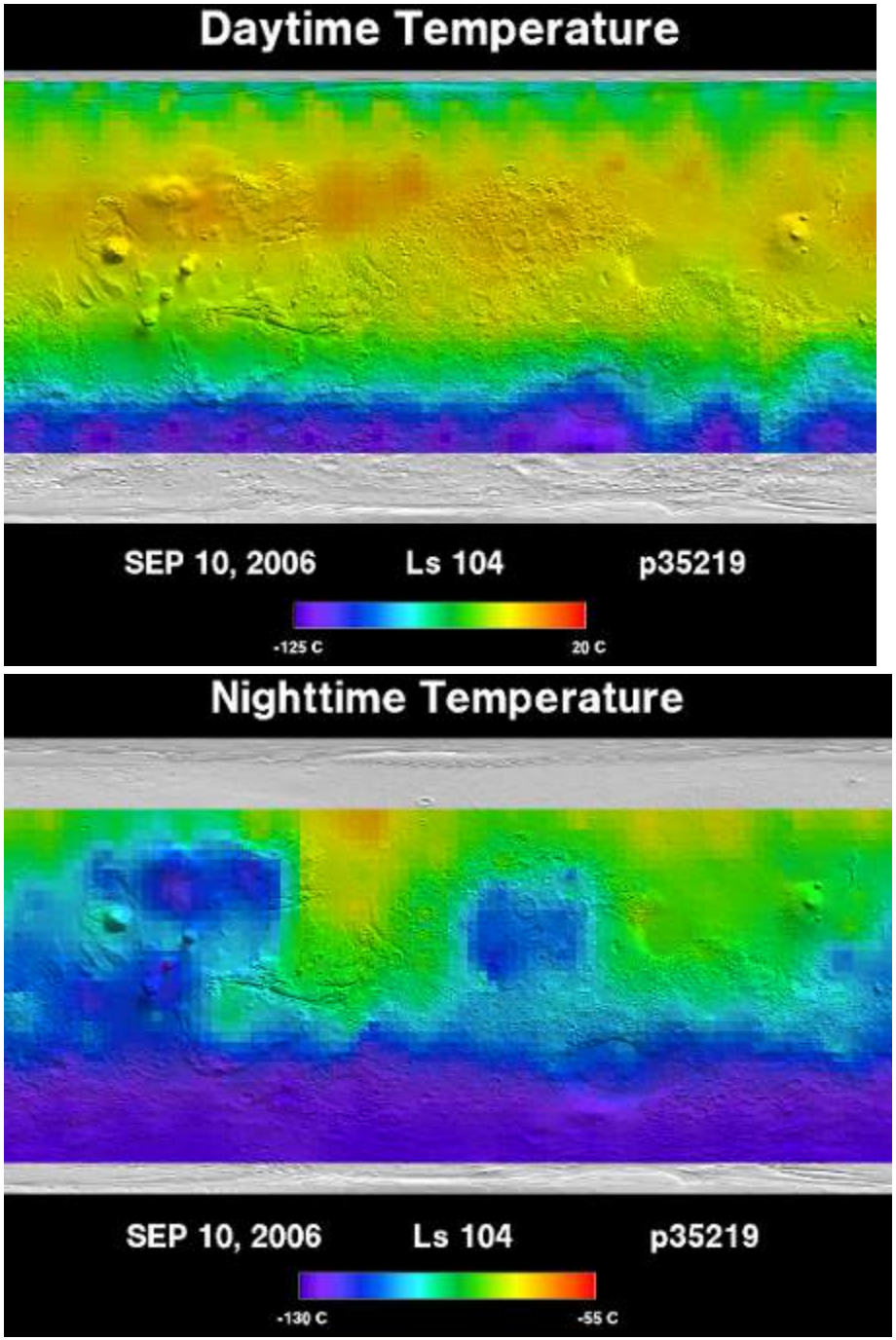
Thermal Emission Spectrometer

6 to 50 (μm),

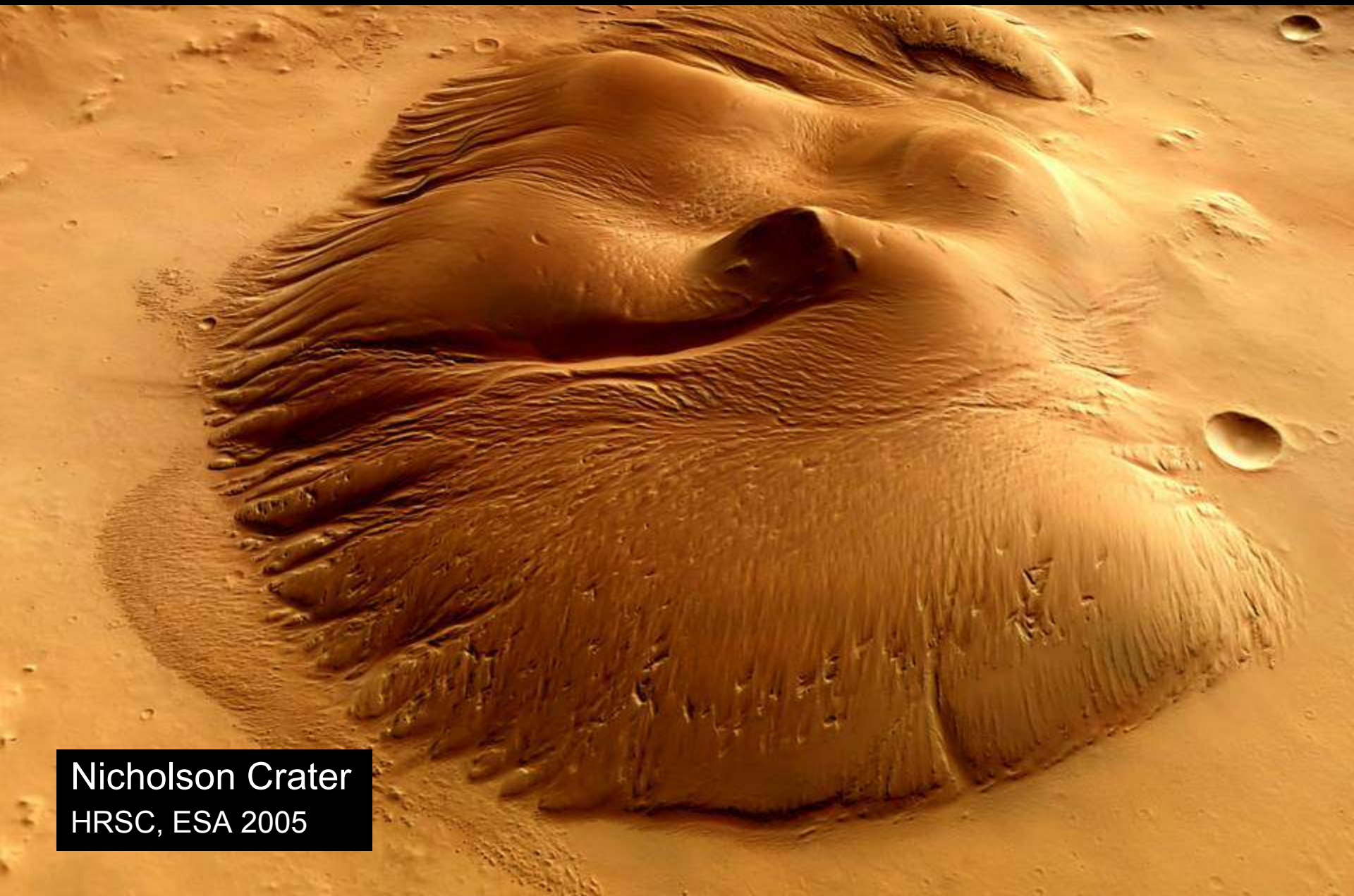
143 bands

On Mars Global Surveyor

1996-2006



Mars Express: High Resolution Stereo Camera

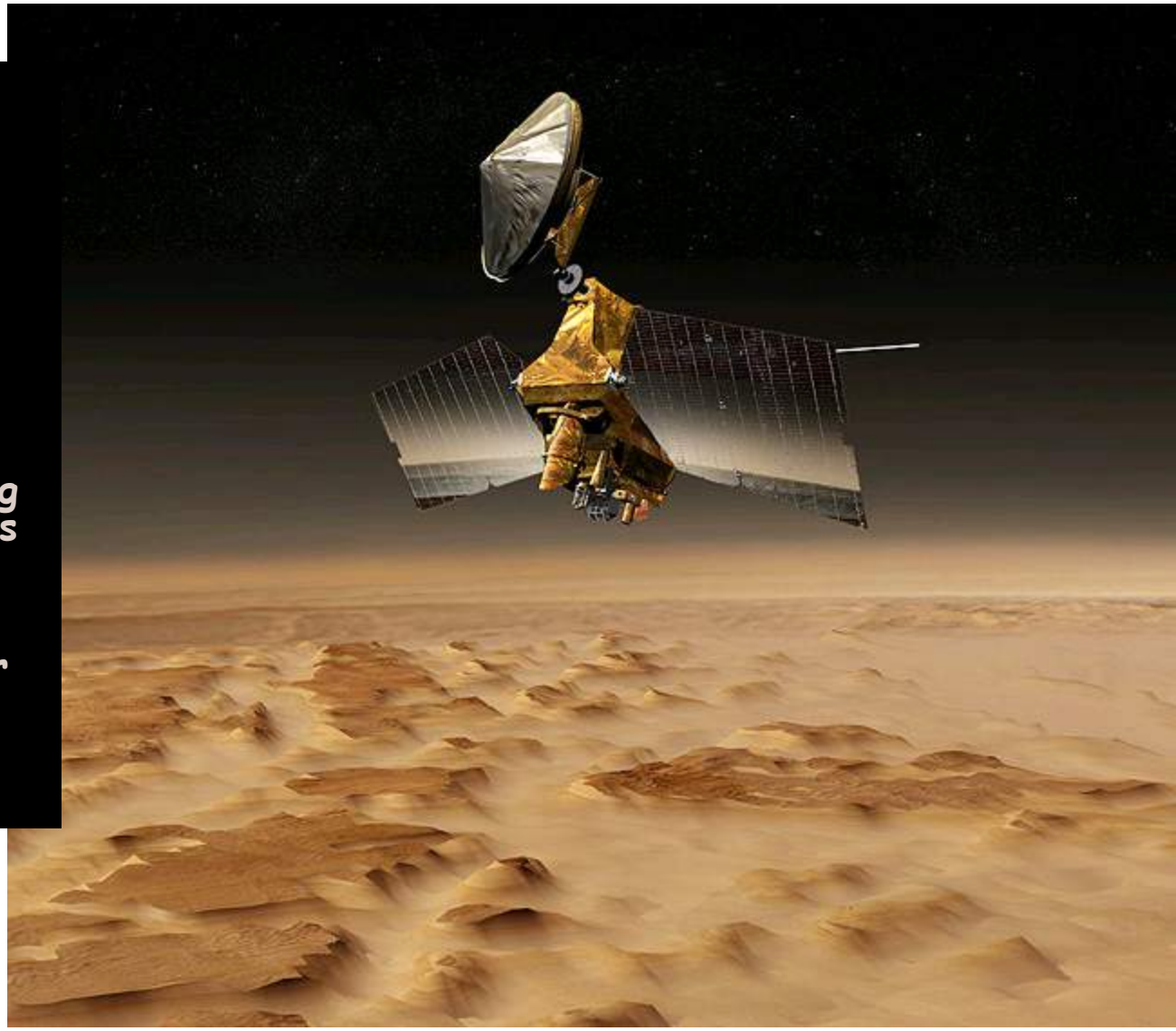


Nicholson Crater
HRSC, ESA 2005

Mars Reconnaissance Orbiter (2005)

Onboard:

- HiRISE - High Resolution Imaging Science Experiment (Visible and infrared wavelengths)
- CRISM - Compact Reconnaissance Imaging Spectrometer for Mars
- CTX - Context Imager Takes low resolution overview images for geological context



Mars Reconnaissance Orbiter: HiRISE

2005-

MRO HIGH RESOLUTION IMAGING SCIENCE EXPERIMENT (HIRISE) -1 foot (0.3m)
three bands, 400–600 nm (blue-green), 550–850 nm (red) 800–1,000 nm (near infrared)

http://hirise.lpl.arizona.edu/nea.php http://marsoweb.nas.nasa.gov/HiRISE/hirise_images/

Thermal Emission Imaging System (THEMIS) 2001

This is a special camera on the Mars Odyssey spacecraft (2001). Its main tasks are mapping rock mineralogies and detecting heat, which yields information on the Martian surface.

THEMIS is a multi-wavelength camera

5 visual bands:
0.425 microns, 0.540 microns, 0.654 microns, 0.749 microns, 0.860 microns

10 infrared bands:
6.78 microns (used twice), 7.93 microns, 8.56 microns, 9.35 microns,10.21 microns, 11.04 microns, 11.79 microns, 12.57 microns, 14.88 microns

Resolution:
visual images, 59 feet (18 meters) per pixel
infrared images, 328 feet (100 meters) per pixel

http://themis.asu.edu/gallery

MARS ODYSSEY MISSION

THEMIS

THERMAL EMISSION IMAGING SYSTEM

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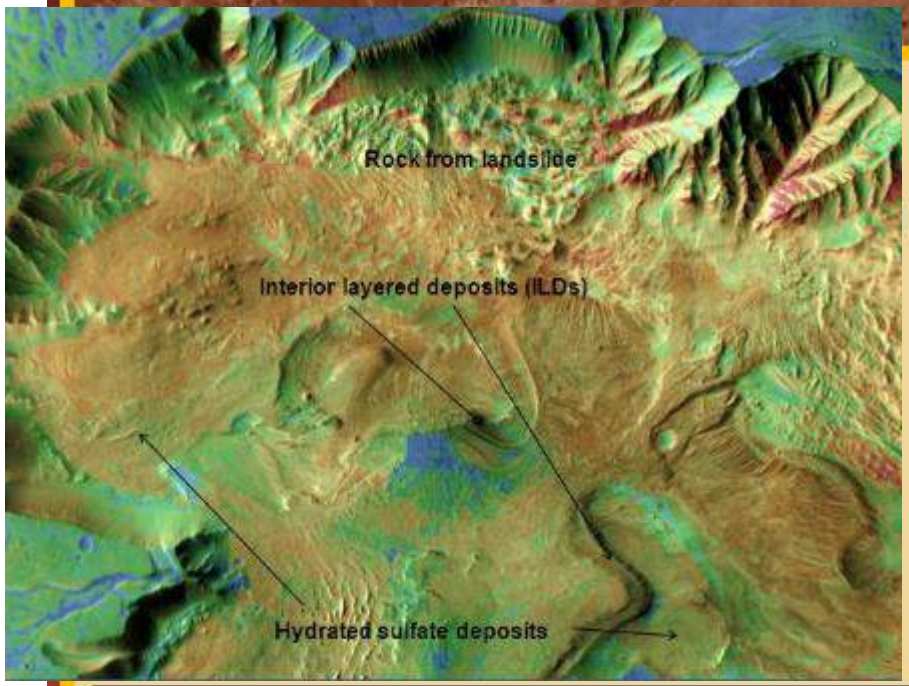
Flight Into Mariner Valley: The Movie



Watch the Movie

Watch on Google Video (low bandwidth)

MPEG1 (872x540: 56MB)

bittorrent

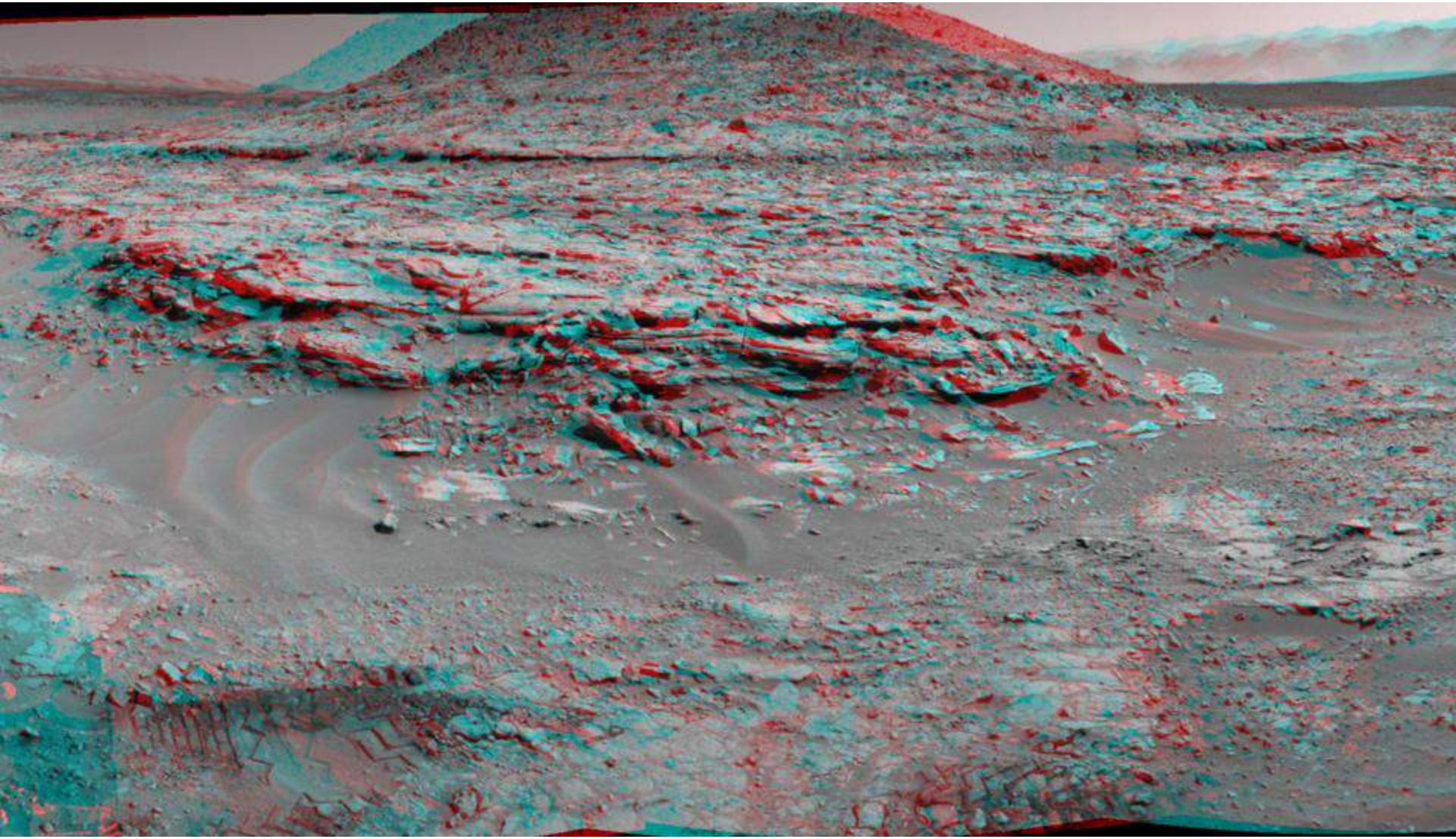
download

Windows Video (960x540: 122MB)

The Grandest Canyon of all isn't on Earth, it's on the planet Mars - Valles Marineris, or Mariner Valley.

http://themis.asu.edu/valles_video
http://themis.asu.edu/maps

Mars Exploration Rover Missions 2004



http://mars.nasa.gov/mars3d/

http://pds.jpl.nasa.gov/planets/

The Nine Planets

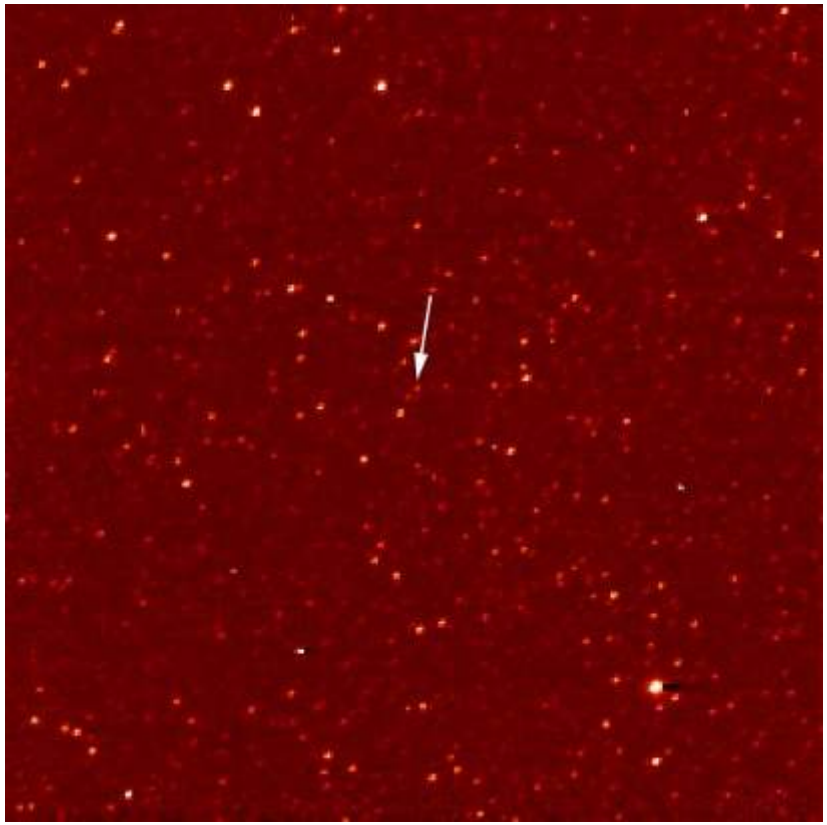
A Multimedia Tour of the Solar System:

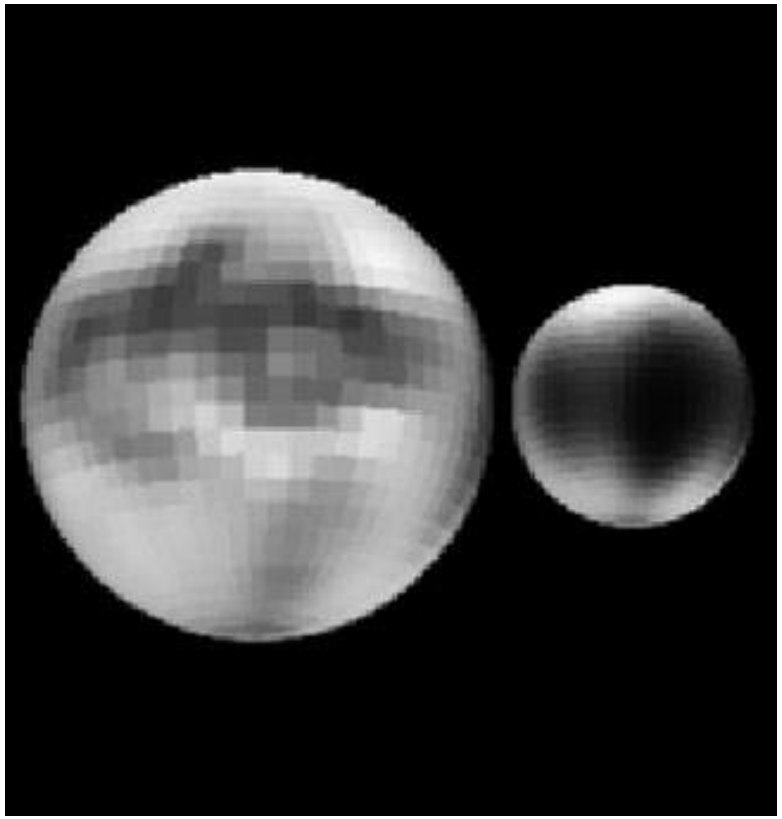
one star, eight planets, and more

by Bill Arnett

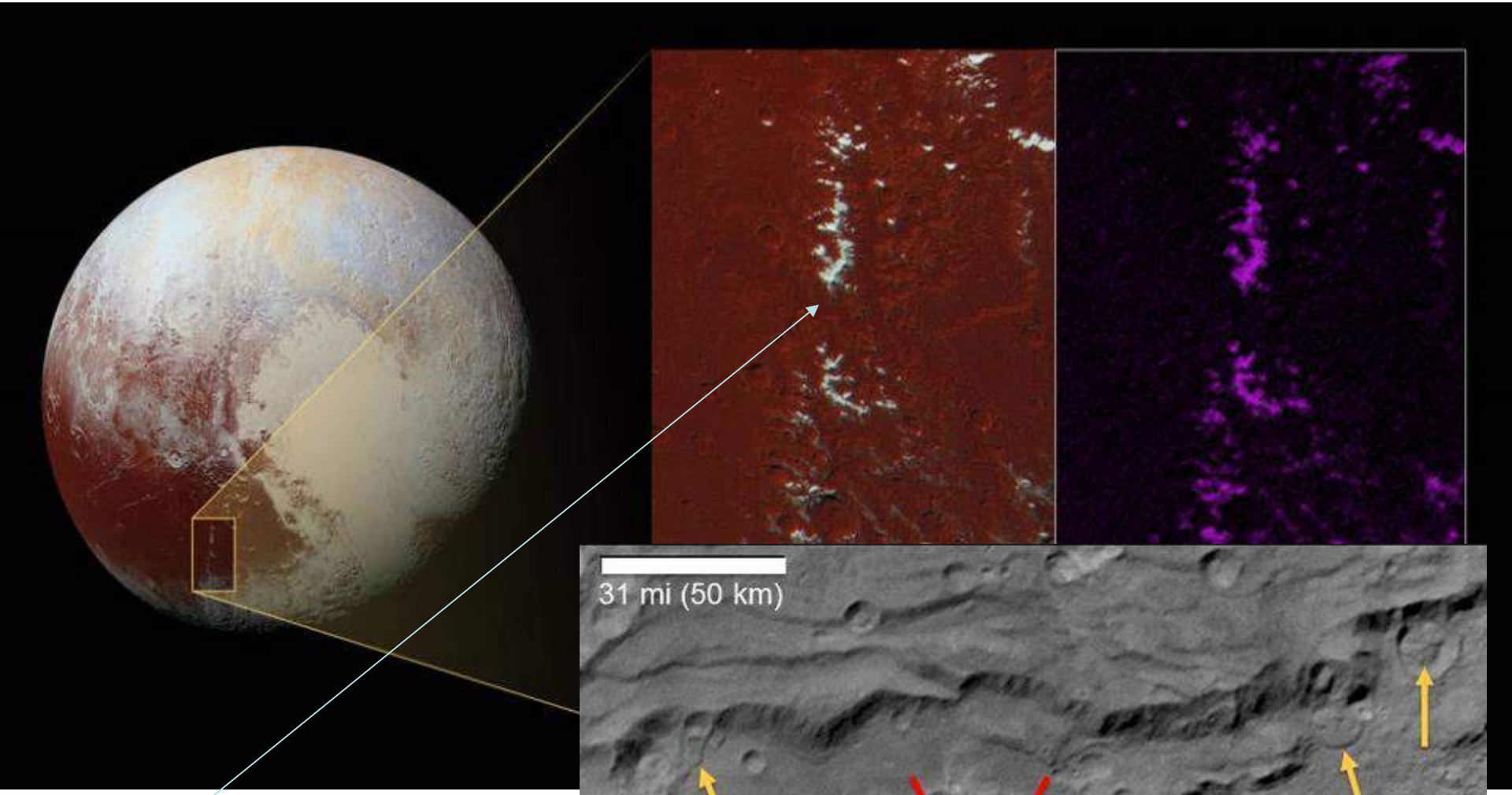
http://www.nineplanets.org/

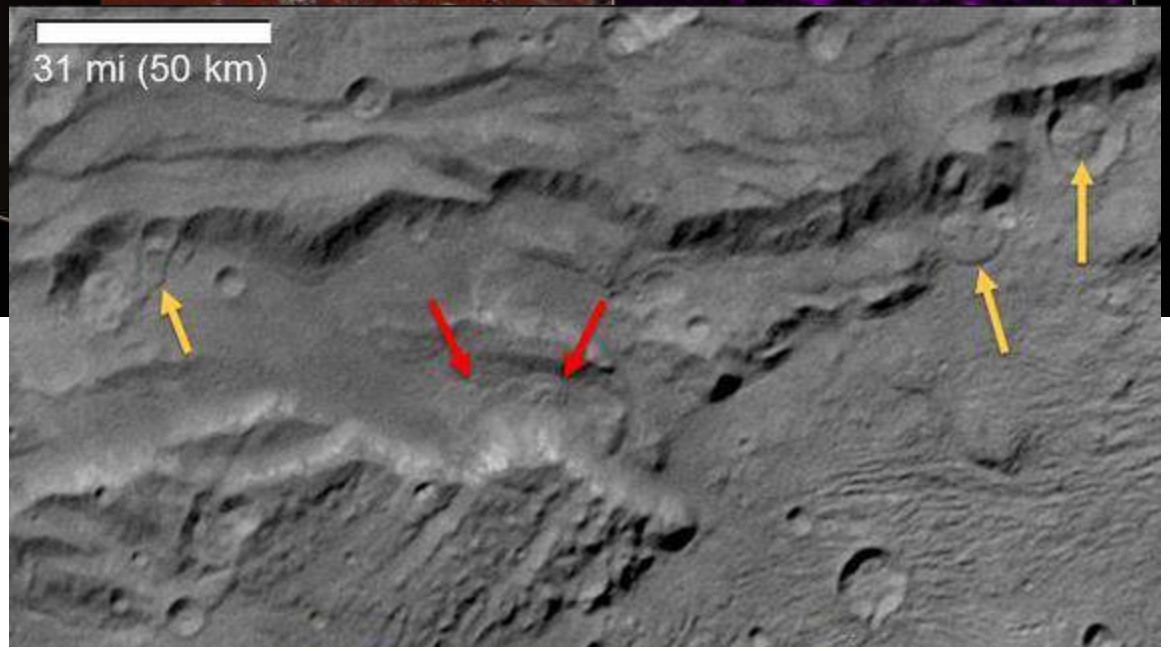
Pluto and Charon (pre-2015)





New Horizons 2015, launched 2006





Snow clad mountains on Pluto

Landslides on Charon ⟶

The Planets and Their Moons		
PLANET	**MOONS**	**MOON NAMES**
Mercury	0	
Venus	0	
Earth	1	Moon
Mars	2	Phobos, Deimos
Jupiter	62	Io, Europa, Ganymede, Callisto, Amalthea, Himalia, Elara, Pasiphae, Sinope, Lysithea, Carme, Ananke, Leda, Metis, Adrastea, Thebe, Callirrhoe, Themisto, Kalyke, Iocaste, Erinome, Harpalyke, Isonoe, Praxidike, Megaclite, Taygete, Chaldene, Autonoe, Thyone, Hermippe, Eurydome, Sponde, Pasithee, Euanthe, Kale, Orthosie, Euporie, Aitne, plus others yet to receive names
Saturn	33	Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas, Hyperion, Prometheus, Pandora, Phoebe, Janus, Epimetheus, Helene, Telesto, Calypso, Atlas, Pan, Ymir, Paaliaq, Siarnaq, Tarvos, Kiviuq, Ijiraq, Thrym, Skadi, Mundilfari, Erriapo, Albiorix, Suttung, plus others yet to receive names
Uranus	27	Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Belinda, Puck, Miranda, Ariel, Umbriel, Titania, Oberon, Caliban, Sycorax, Prospero, Setebos, Stephano, Trinculo, plus others yet to receive names
Neptune	13	Triton, Nereid, Naiad, Thalassa, Despina, Galatea, Larissa, Proteus, plus others yet to receive names
Pluto	1	Charon
TOTAL	**139**	

Enceladus, Moon of Saturn, by Cassini Orbiter, 2005