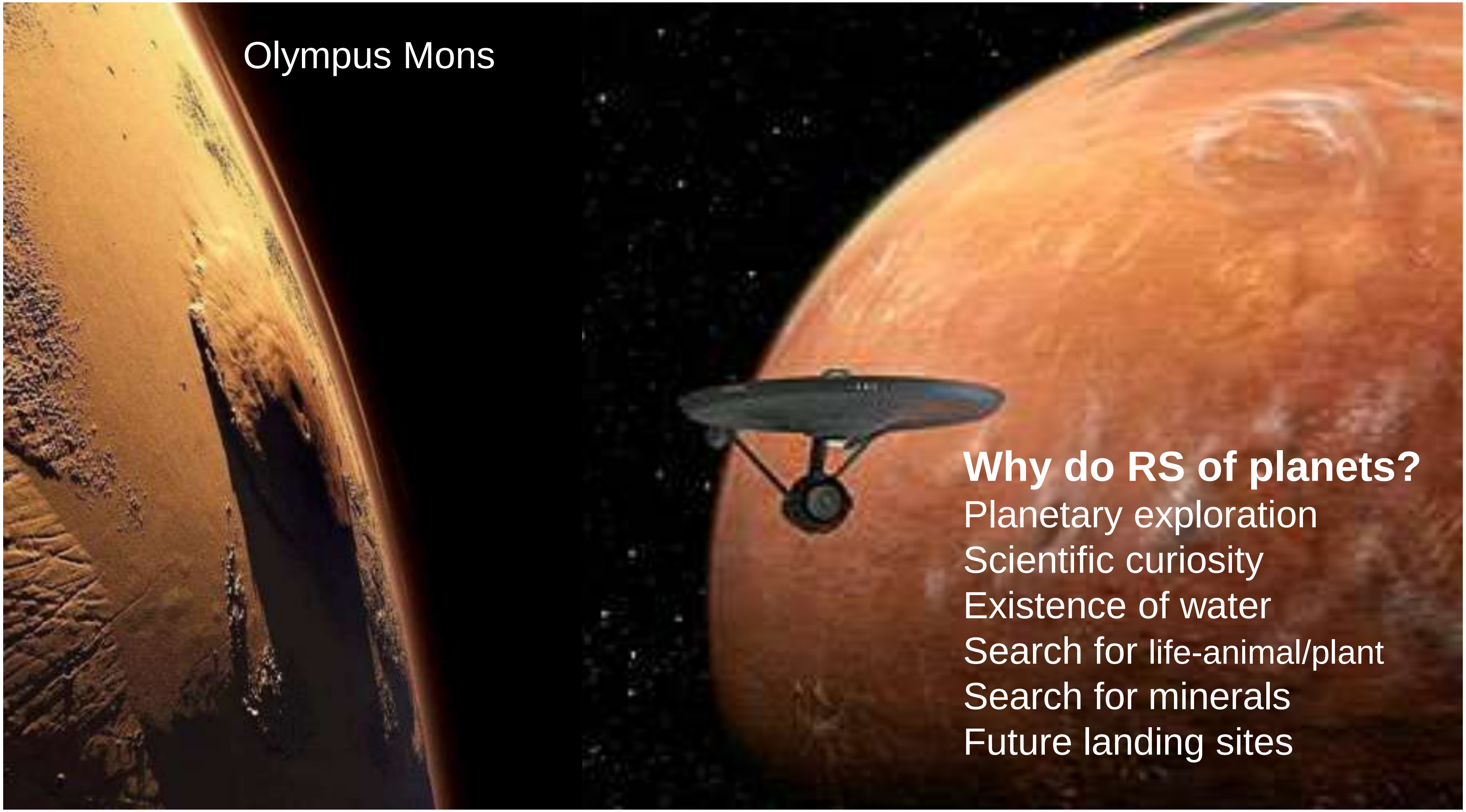
Remote sensing of the planets - the final frontier

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



https://www.gfd-dennou.org/library/wtp/welcome.htm

Methods and wavelengths used on planetary missions - old table

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

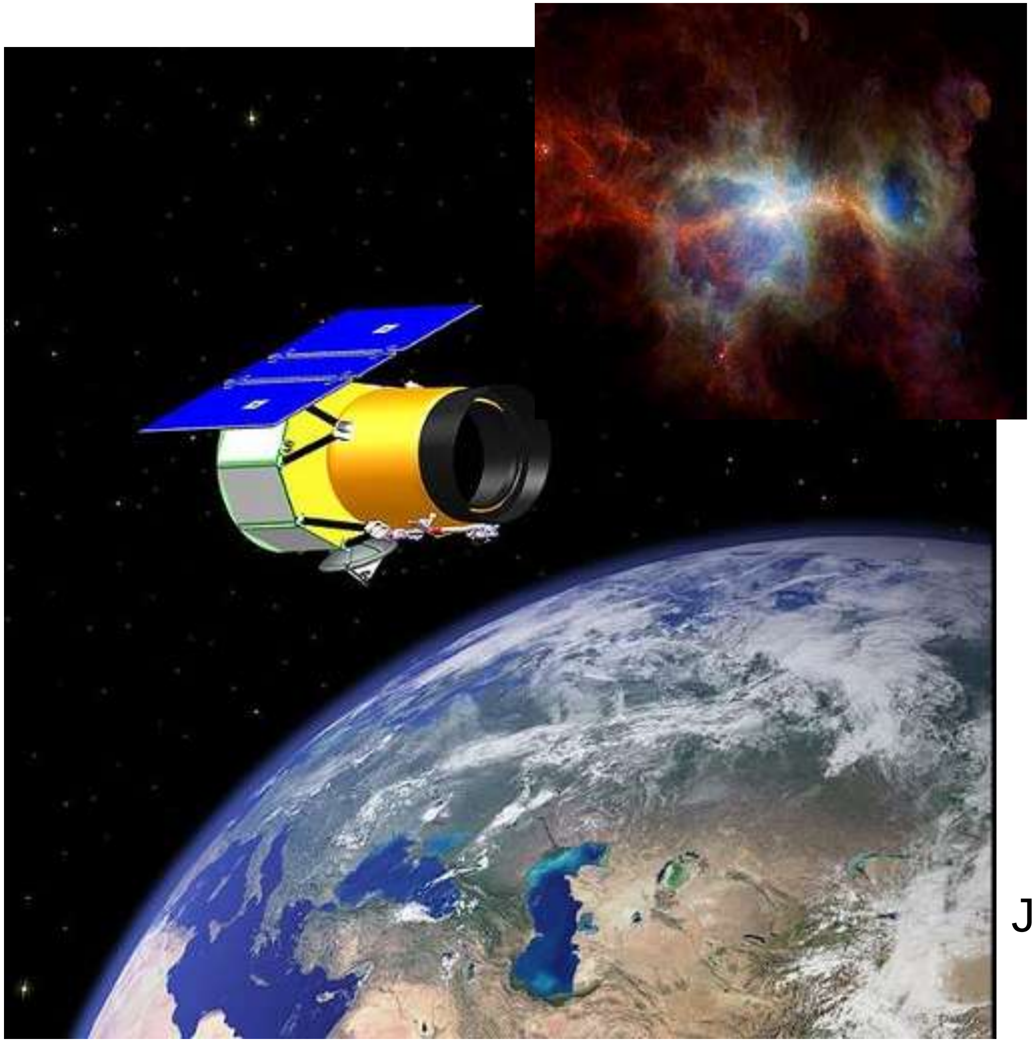
Methods and wavelengths used on planetary missions (continued)

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

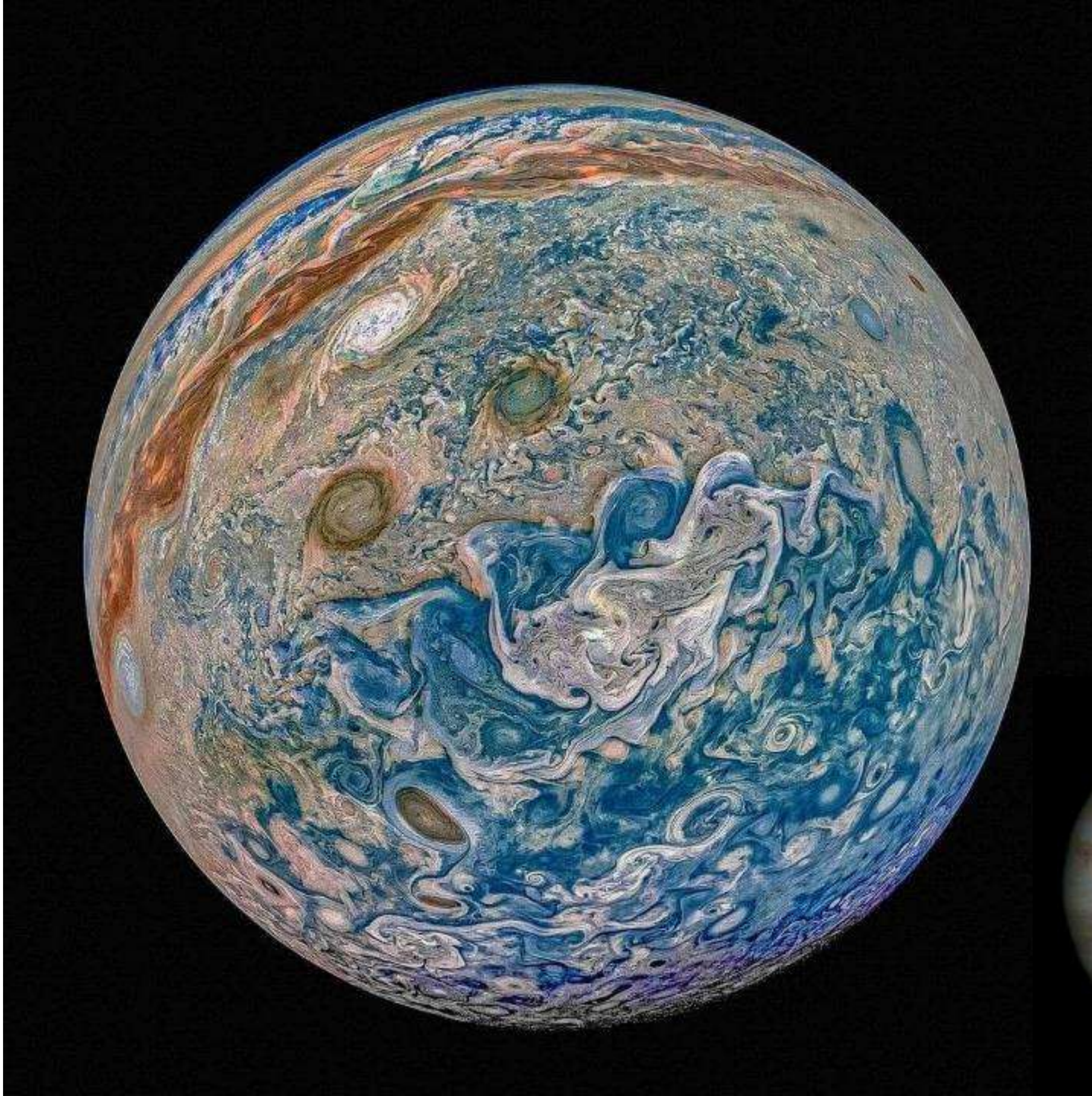
Wide-field Infrared Survey Explorer (WISE) since Nov 20, 2009 ..
Succeeded by NEOWISE (2013) Looking out into space
Detectors at 3.4, 4.6, 12 and 22 microns, chilled to 10 Kelvin



Hubble telescope 1990
0.1 – 0.8 microns, 535km

James Webb Space Telescope
0.6 – 28 microns, 1.5 million km
Launched Dec 25, 2021

https://science.nasa.gov/mission/neowise

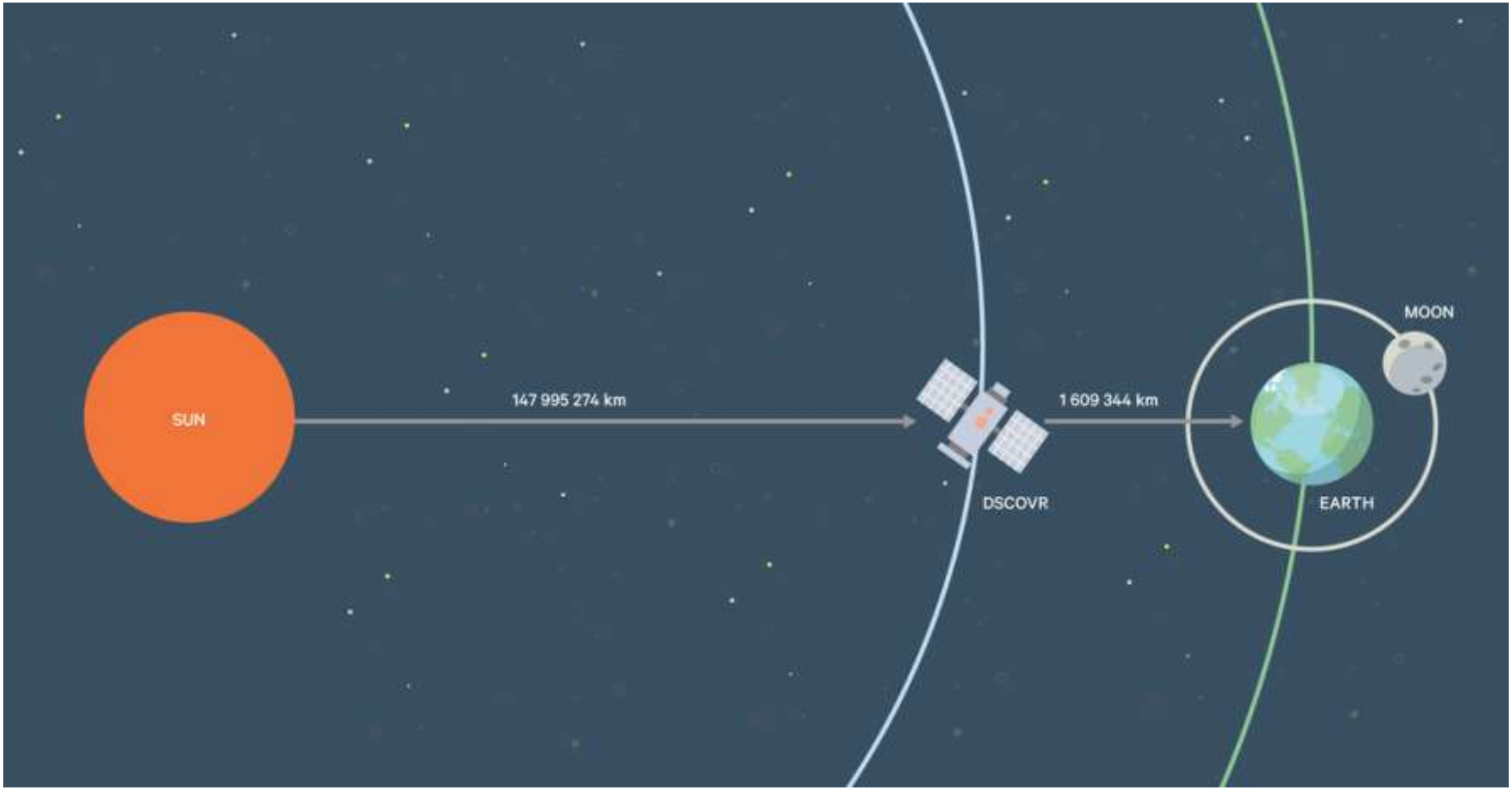


Images of Jupiter

JWST

Hubble

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

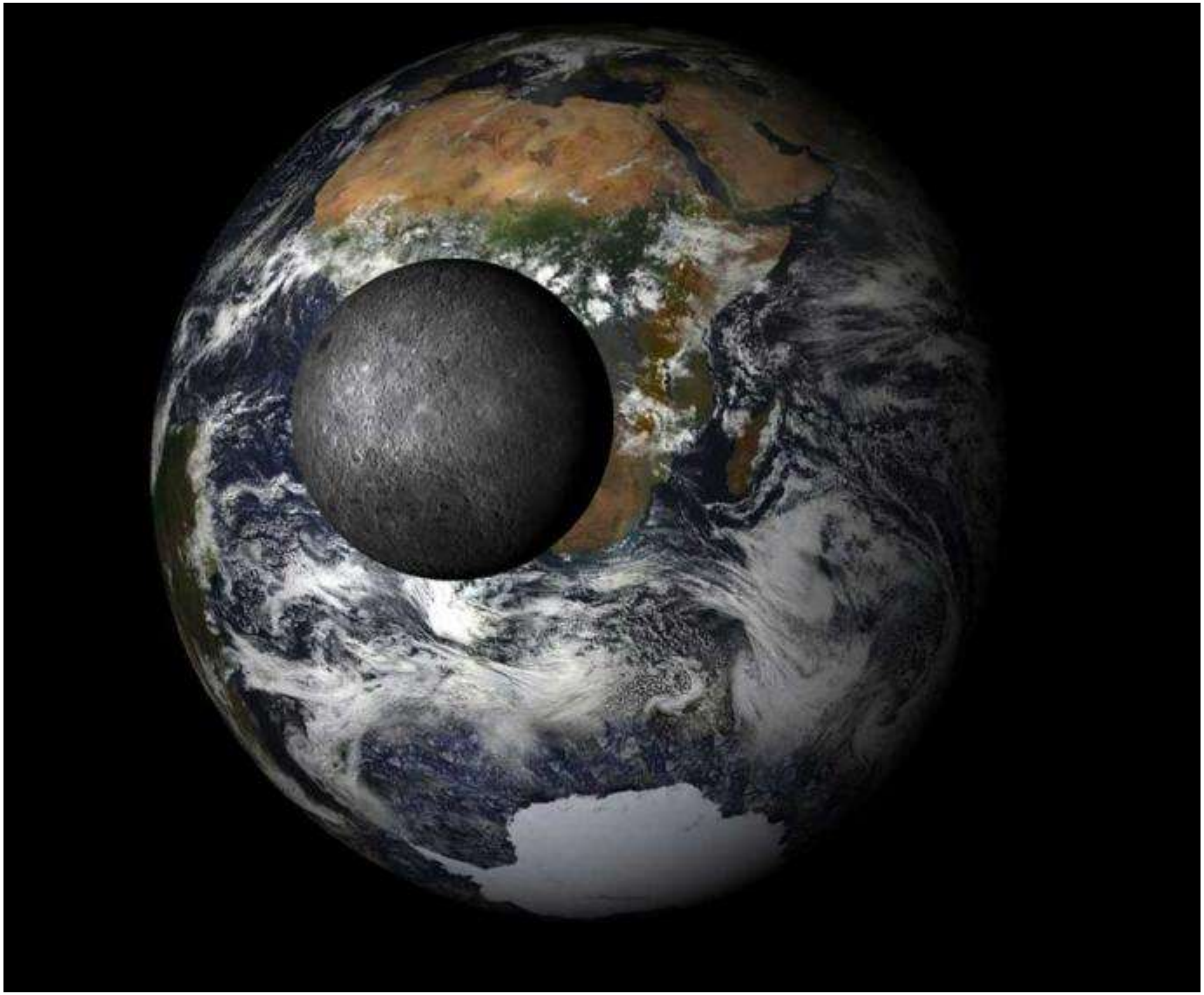


Proposed by Al Gore,1998 to study earth and solar wind
The first satellite orbiting in deep space ….. ‘Goresat’

‘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

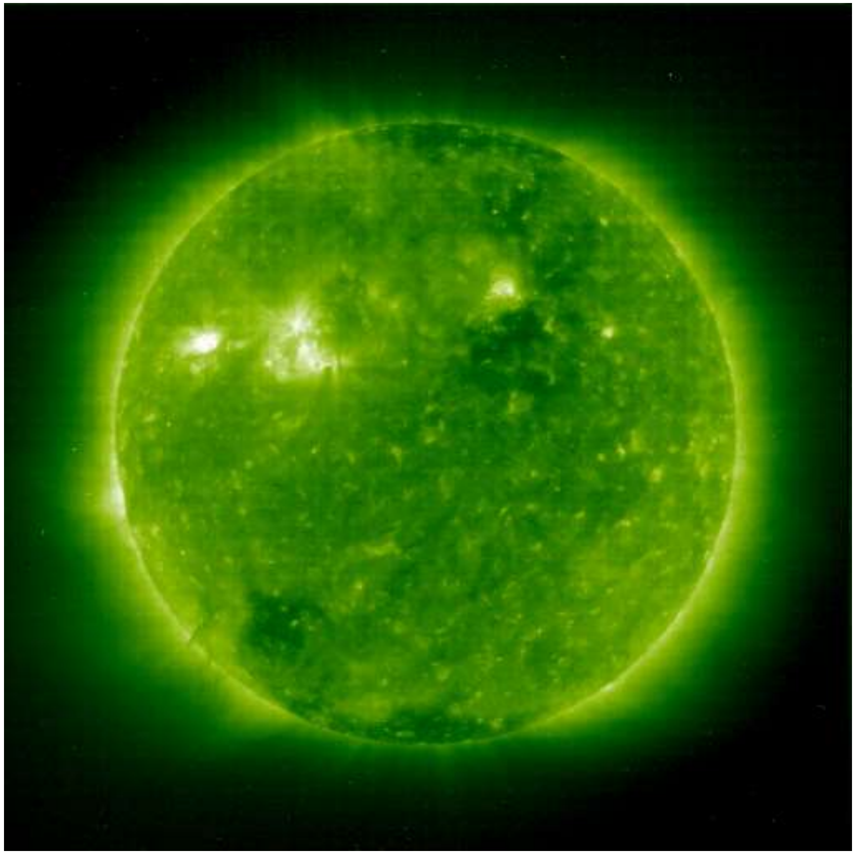
Wavelength(nm)	Full Width (nm)	Primary Application
317.5 ± 0.1	1 ± 0.2	Ozone, SO_2
325 ± 0.1	2 ± 0.2	Ozone
340 ± 0.3	3 ± 0.6	Ozone, Aerosols
388 ± 0.3	3 ± 0.6	Aerosols, Clouds
443 ± 1	3 ± 0.6	Aerosols, Clouds
551 ± 1	3 ± 0.6	Aerosols
680 ± 0.2	3 ± 0.6	Aerosols, Vegetation
687.75 ± 0.2	0.8 ± 0.2	Aerosols, 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-NIR - monitor earth status

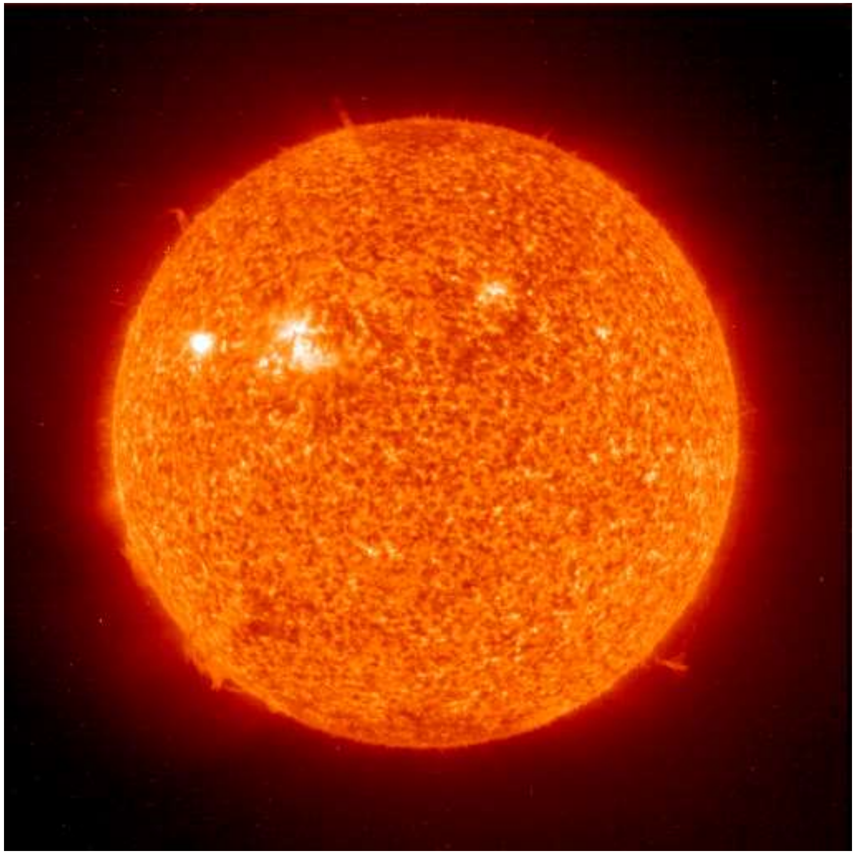
SOHO the Solar & Heliospheric Observatory

.. 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)



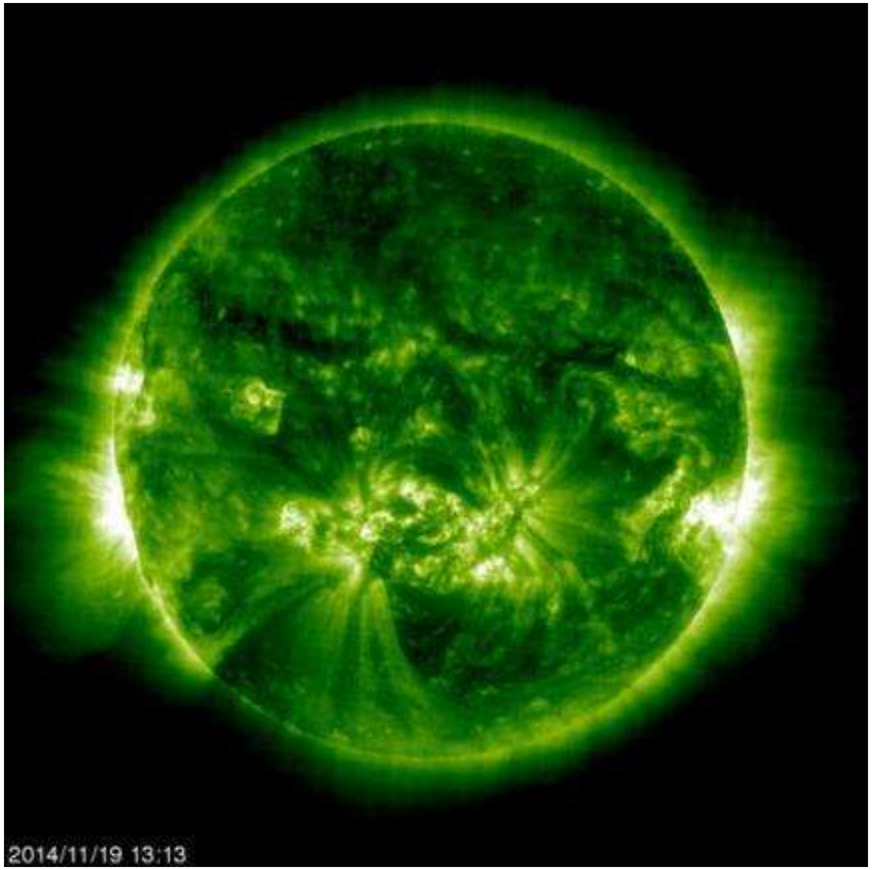
1995, cost €1 billion; Sensor: Extreme ultraviolet Imaging Telescope (EIT)

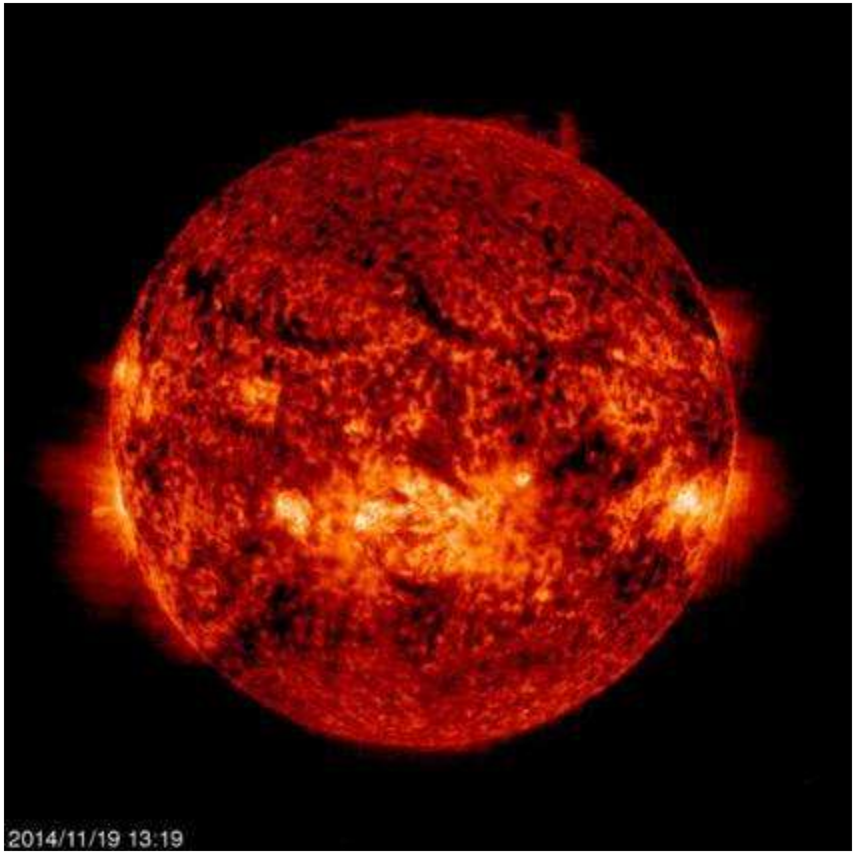
Located at sun-earth L1 gravitational orbit

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.

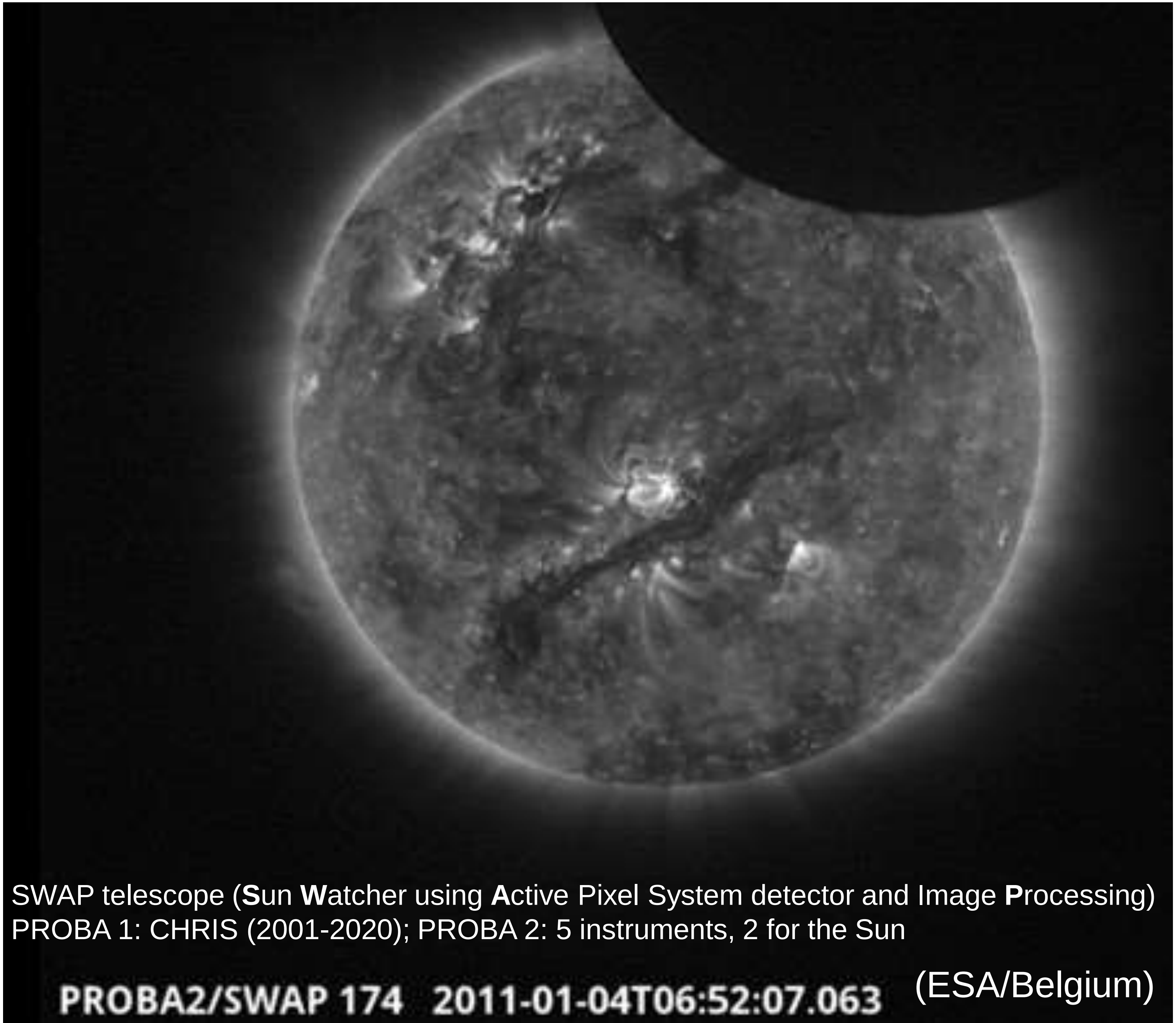
Later images – Nov 19, 2014: 195 nm 304 nm (also 171 and 284)





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

Partial solar eclipse by the Moon



Types of Remote Sensing Missions

- Fly-bys

Mariner Missions, Mercury and Venus

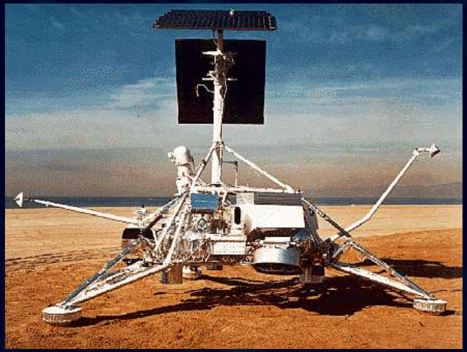
New Horizons 2007, Jupiter and Pluto

- Orbiters

LandSat, Earth

Mars Reconnaissance Orbiter

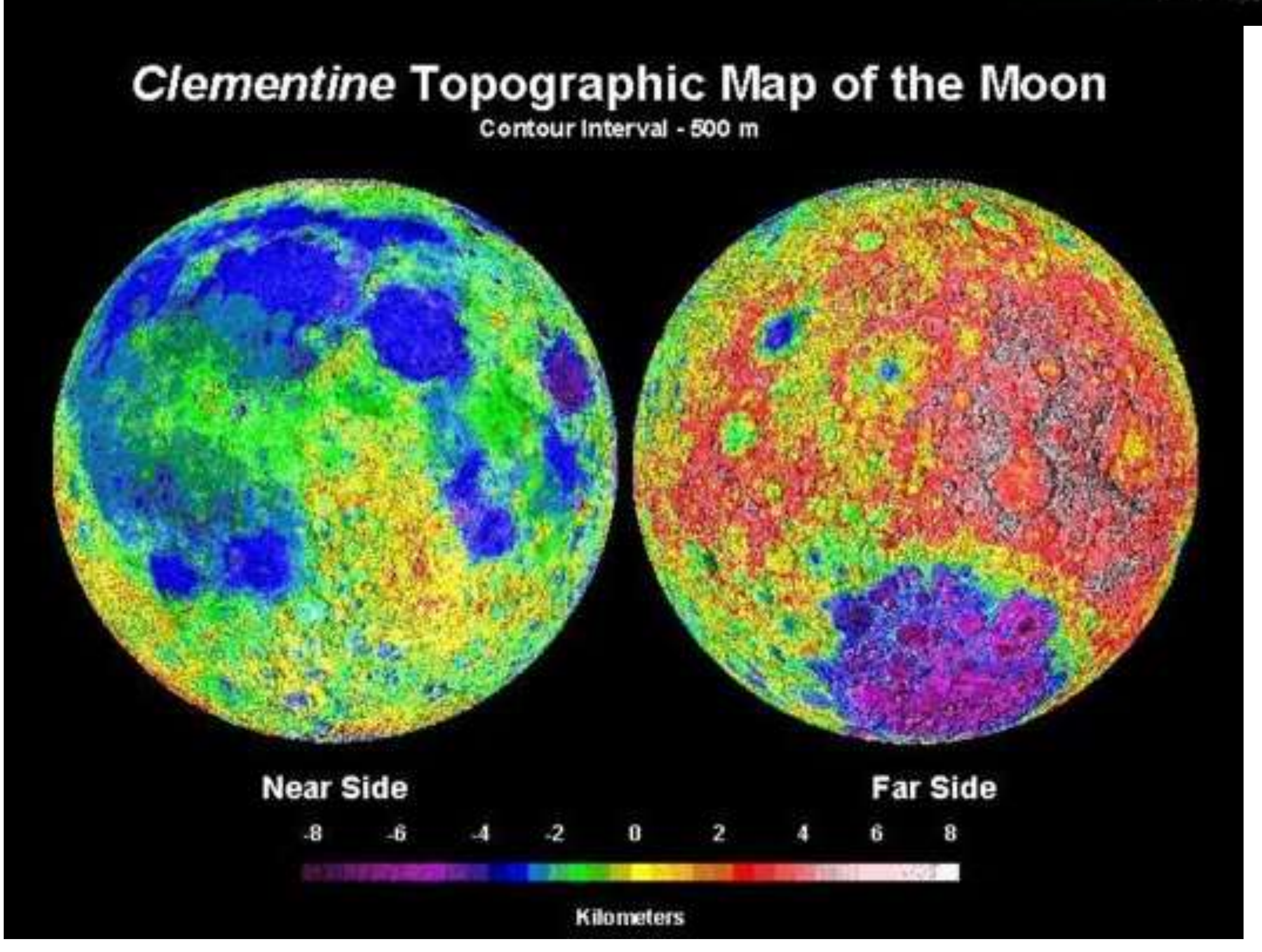
- Landers / Rovers



Surveyor Lunar Lander, 1966

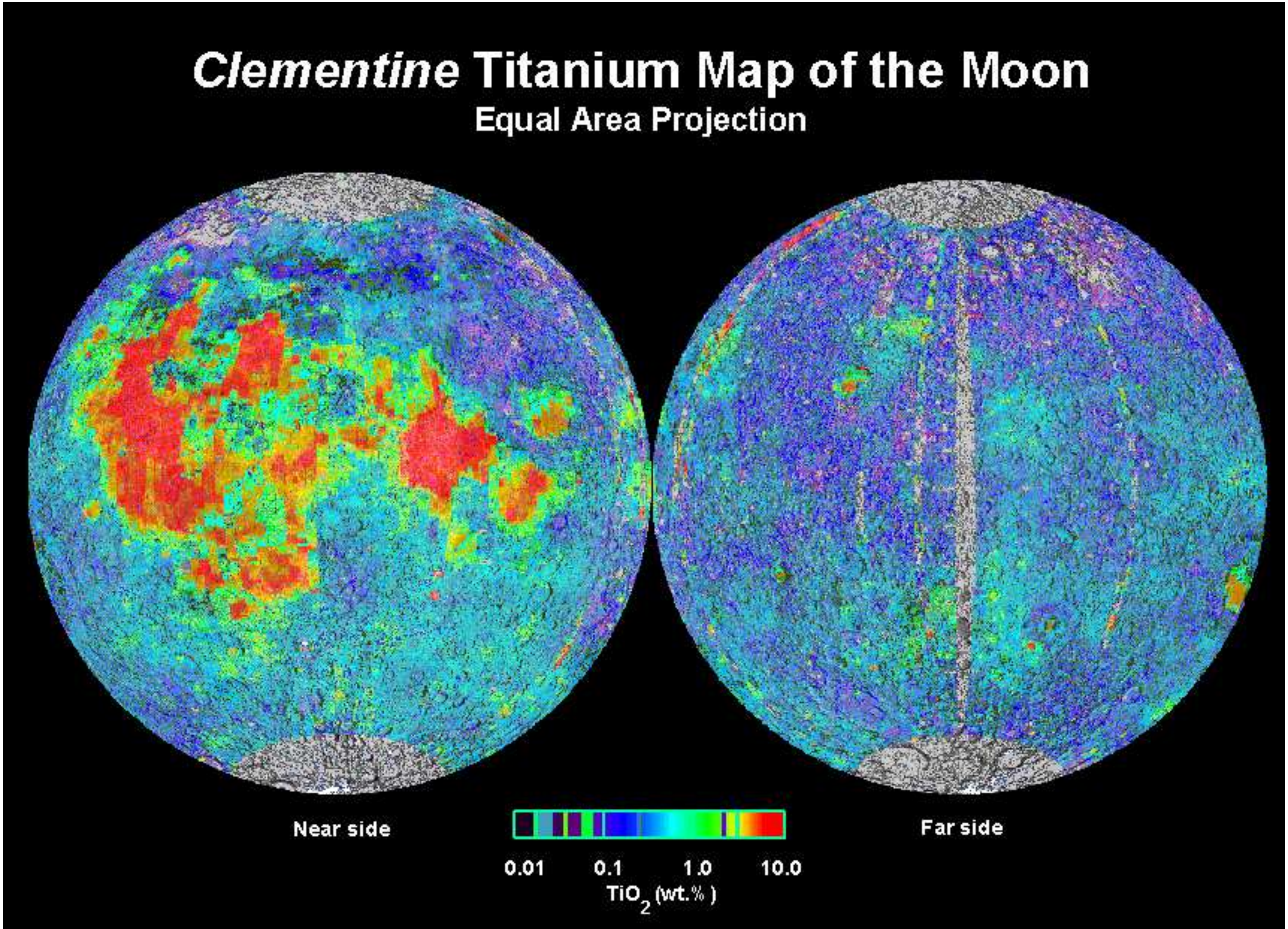
Mars Rovers, 2003

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/

Other specialized products include detailed maps the distribution of several chemical elements, such as iron (Fe) and titanium (Ti), determined by analyzing reflectance variations 750 and 950 nm, where these elements absorb radiation.

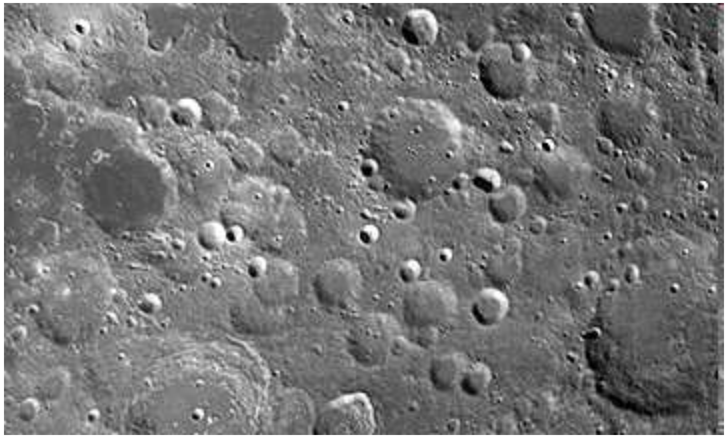


In mid-April 2000, the Terra spacecraft was turned upside down and pointed at the Moon.
This ASTER image was acquired at that time, showing band 3 (NIR) in grayscale.

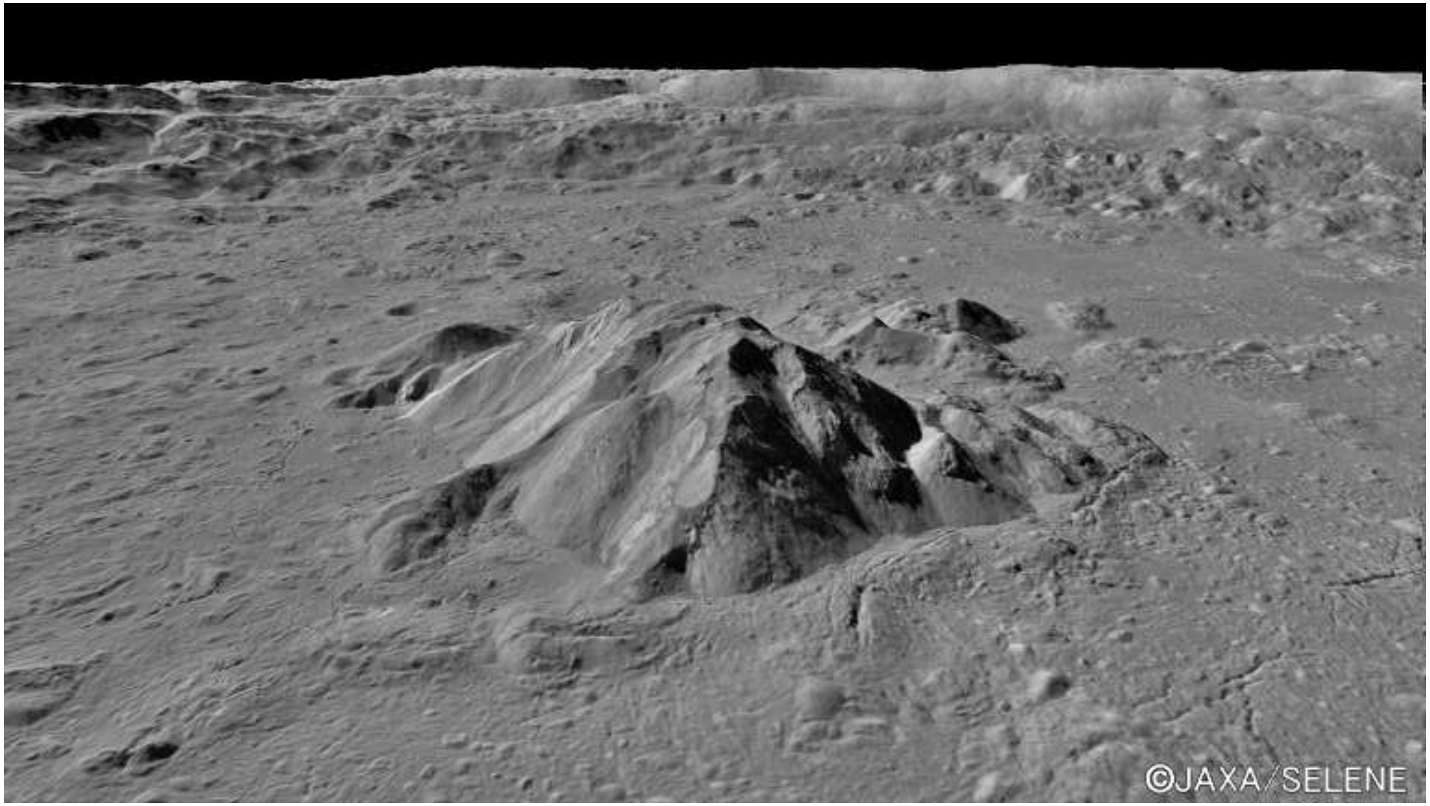
More recent Lunar missions

Right: China: Chang'e-1 (2007)

Chang'e-3 (2013) soft-landed on moon

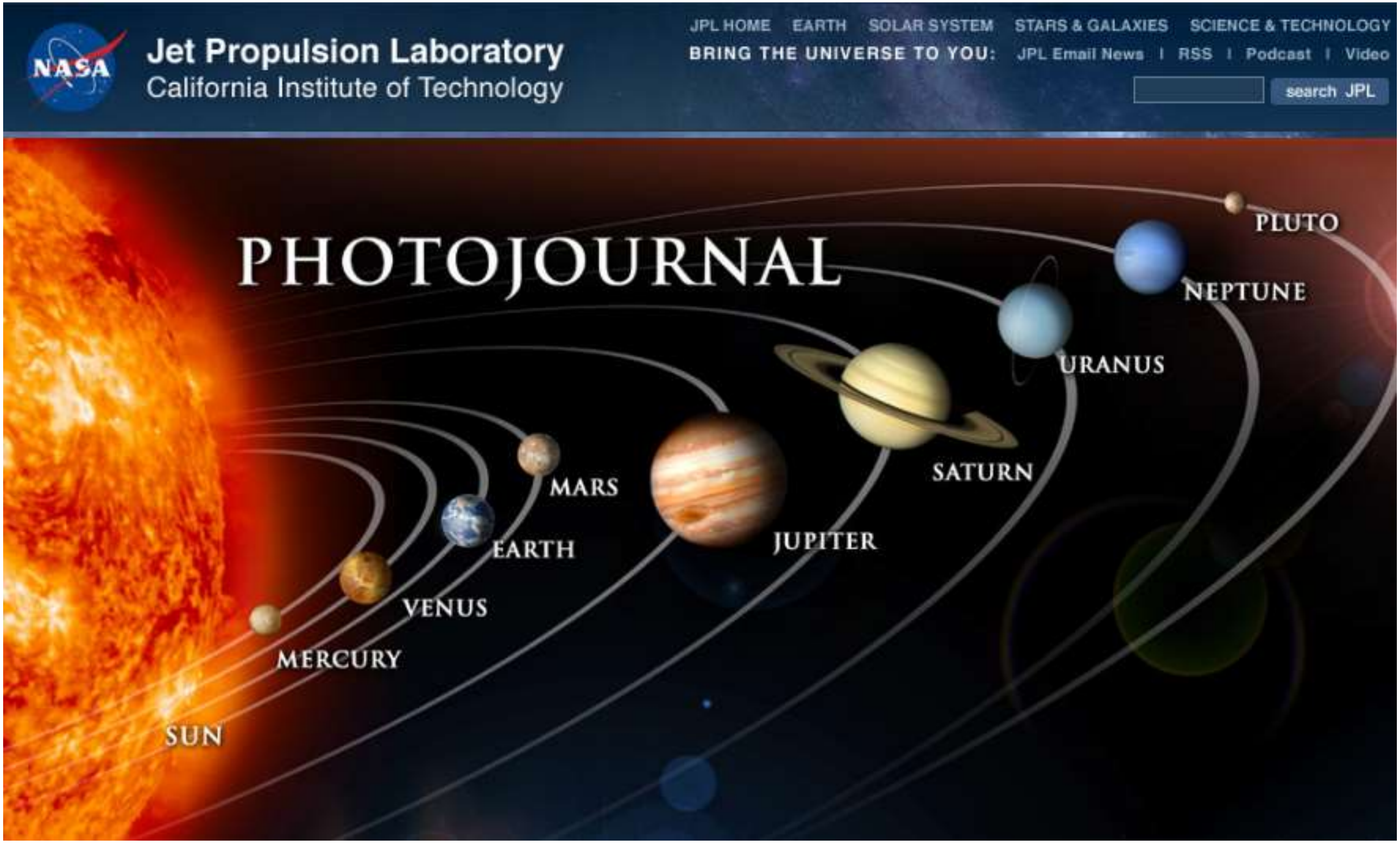


Below: Japan – Kayuga
Launched 2007, impacted on lunar surface 2009 (near South Pole)



India: Aug 2023

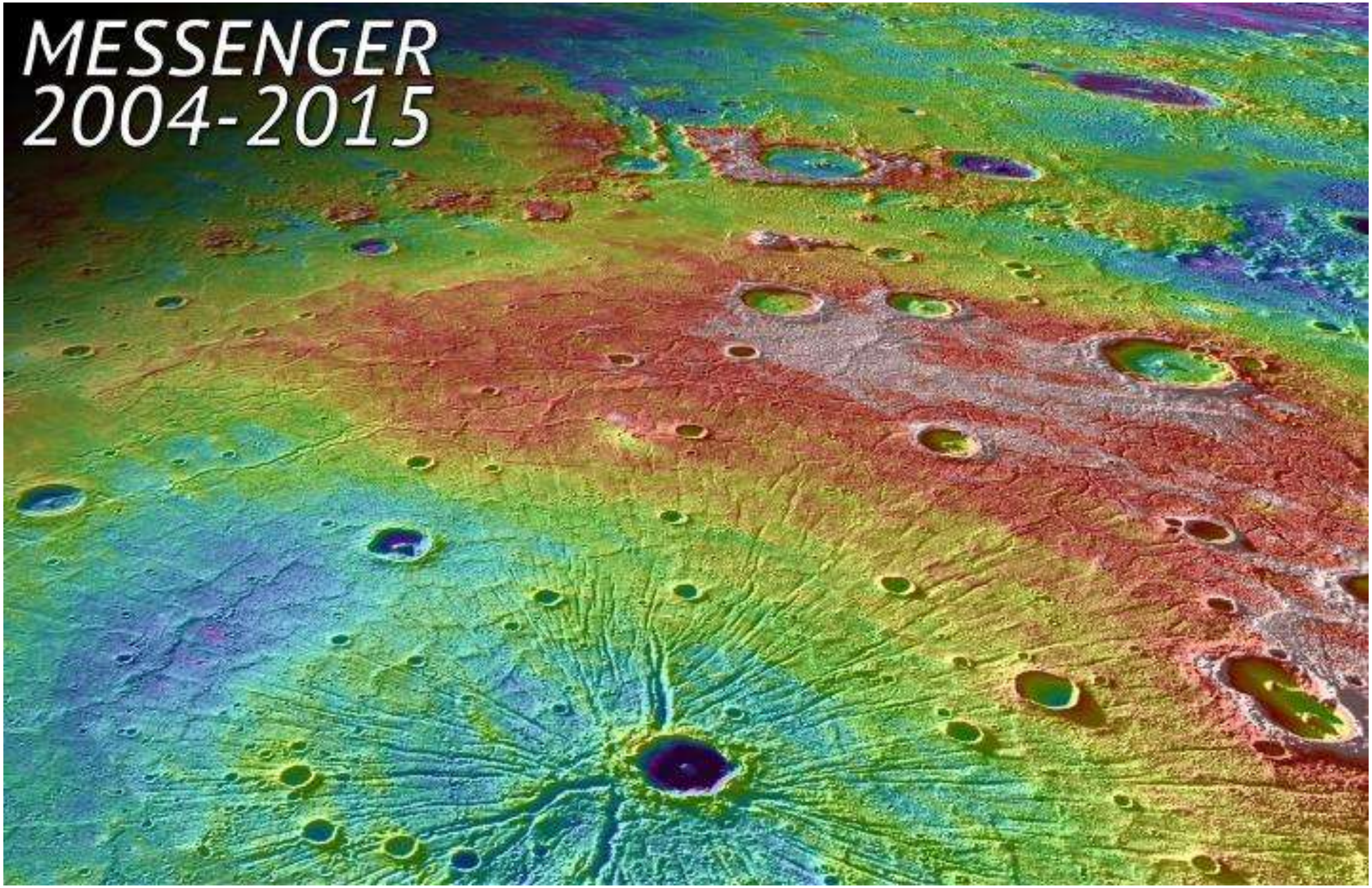
https://www.cnn.com/2023/08/22/world/chandrayaan-3-landing-photos-india-scn/index.html http://photojournal.jpl.nasa.gov/index.html



satellite observation links: Sun 186 Mercury 1315, Venus 153, Earth 2578, Mars 12658, Jupiter 1151, Saturn 3373, Uranus 61, Neptune 89, Dwarf Planets e.g. Pluto 817

Mercury Messenger:

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



Mercury Dual Imaging System (MDIS) and Mercury Laser Altimeter (MLA)- 15m

Venus

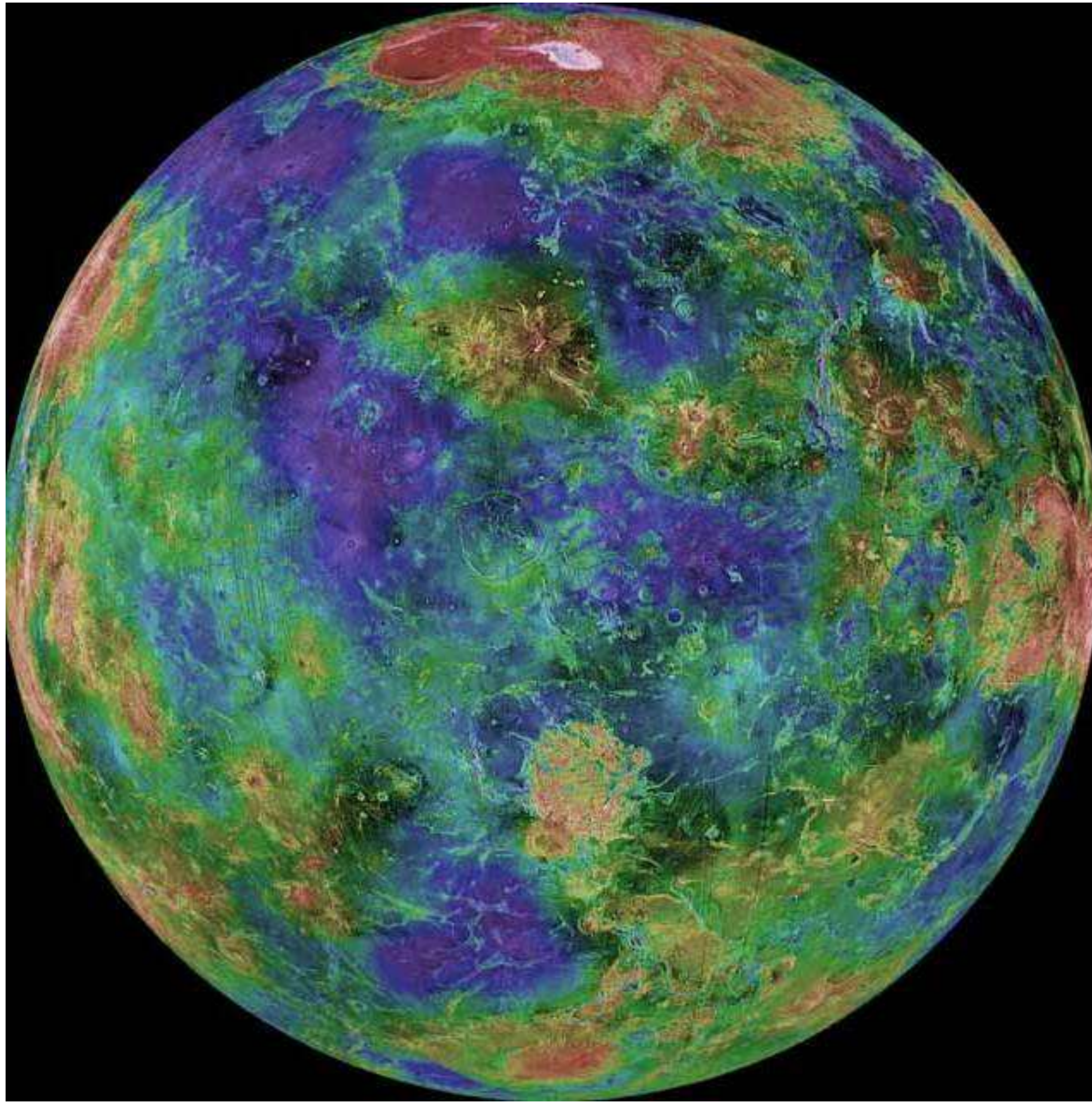
From Magellan

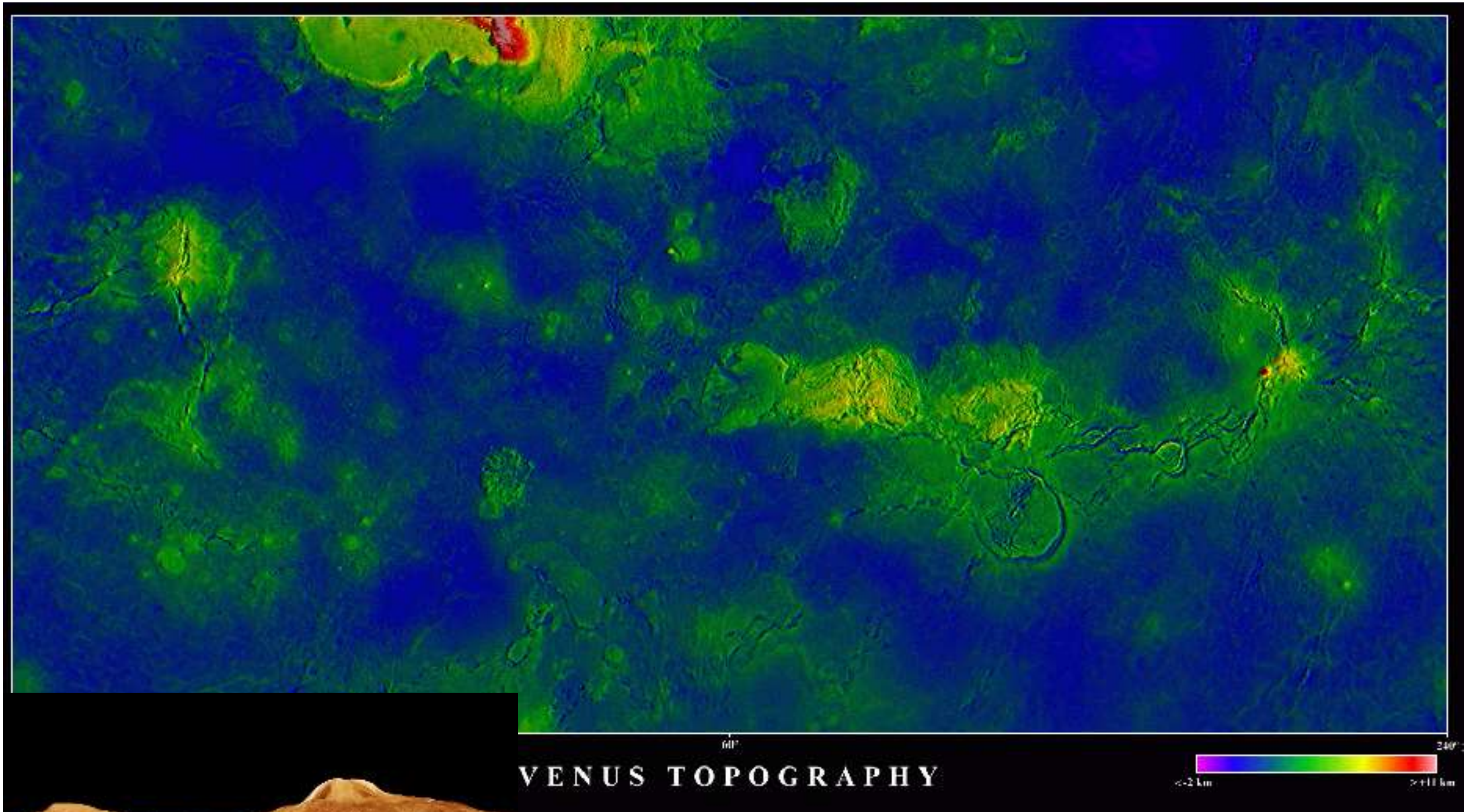
-first imaging device launched from Shuttle 1989

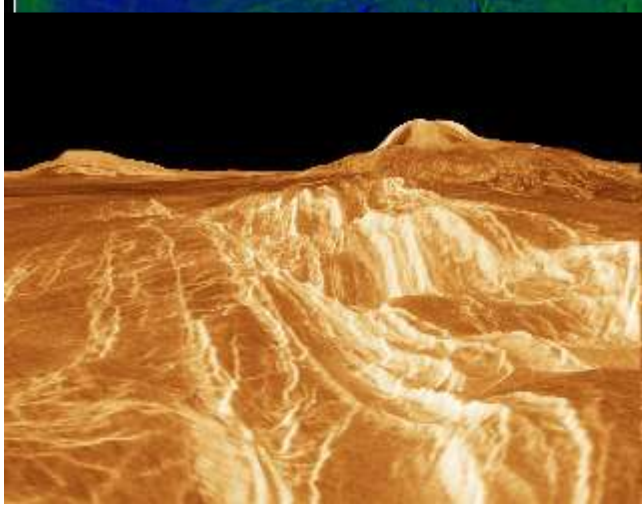
Planet is Cloud covered

Radar 100m

Composite colours based on elevations



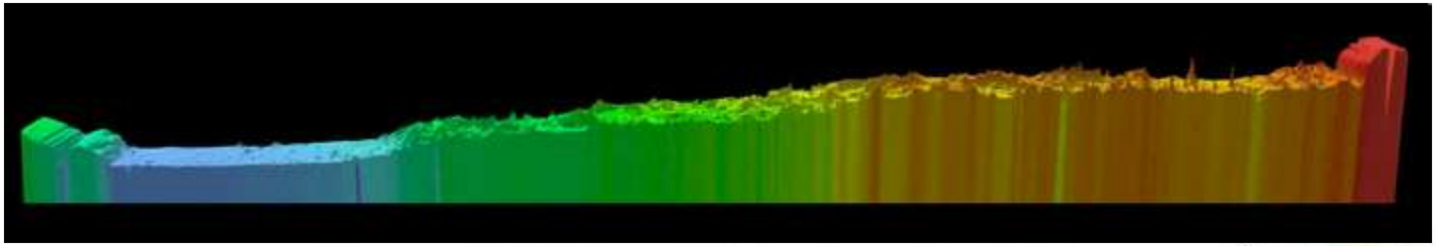


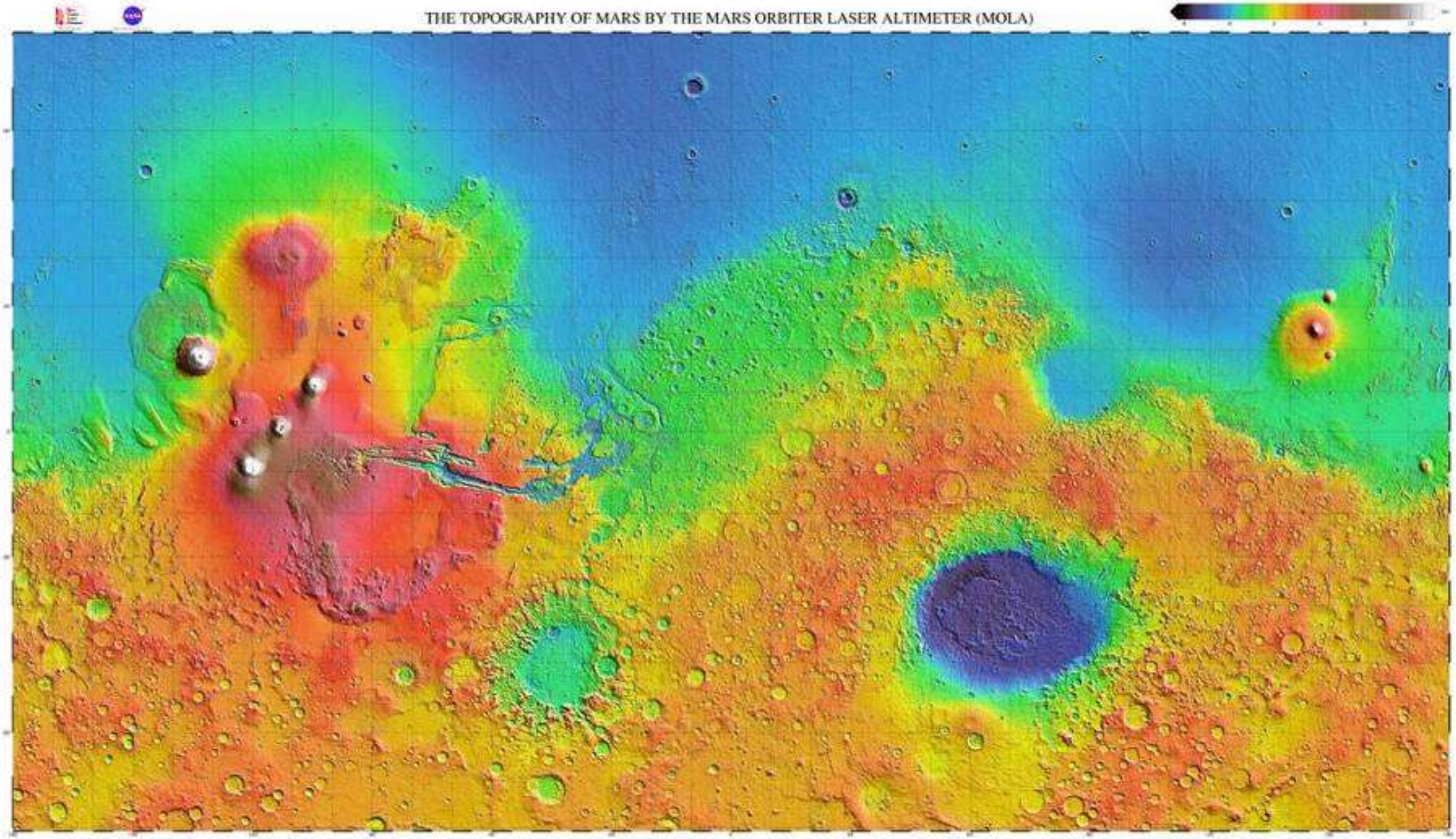


http://www.solarviews.com/eng/venus.htm

Mars Global Surveyor (1996) Instruments

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





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

Elevation, Panchromatic, Thermal

Suspected rock glacier, Mars Orbiter Camera JPL/NASA

Resolution = 1m

- **MOC has produced over 250,000 images to 2020**

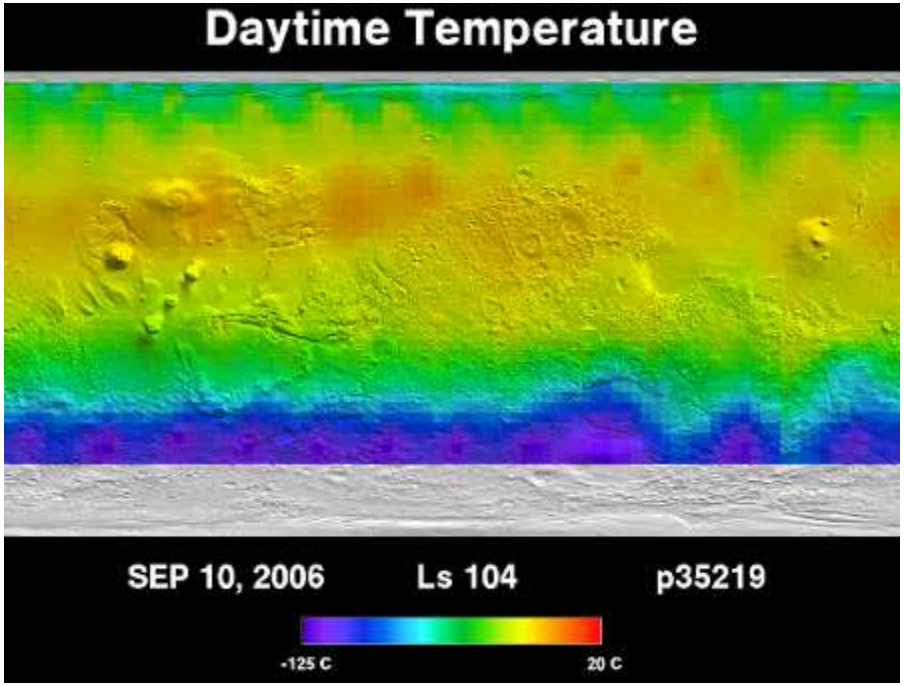
Thermal Emission Spectrometer

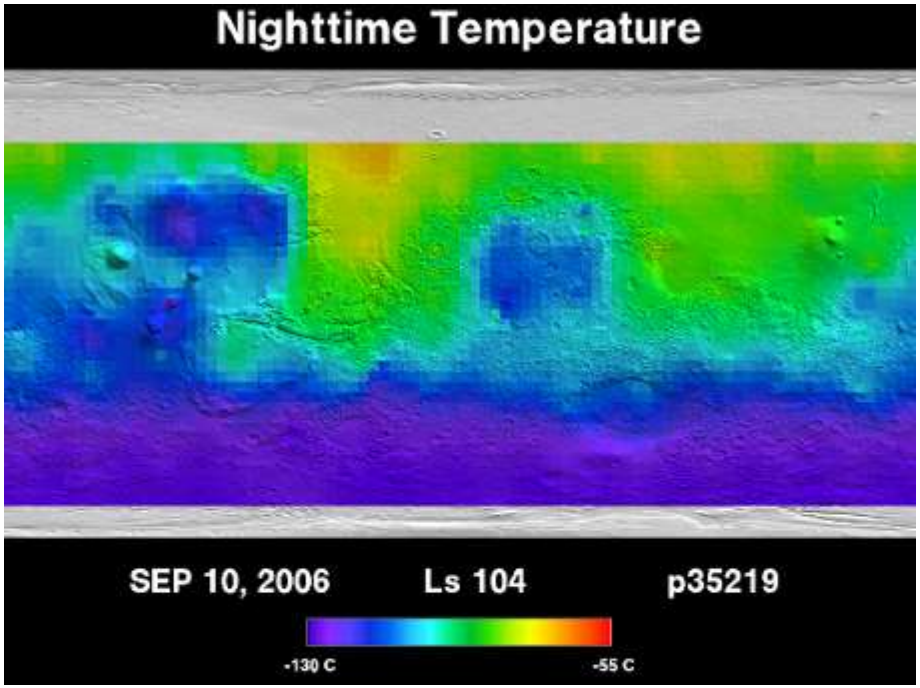
6 to 50 (μm),

143 bands

Onboard Mars Global Surveyor

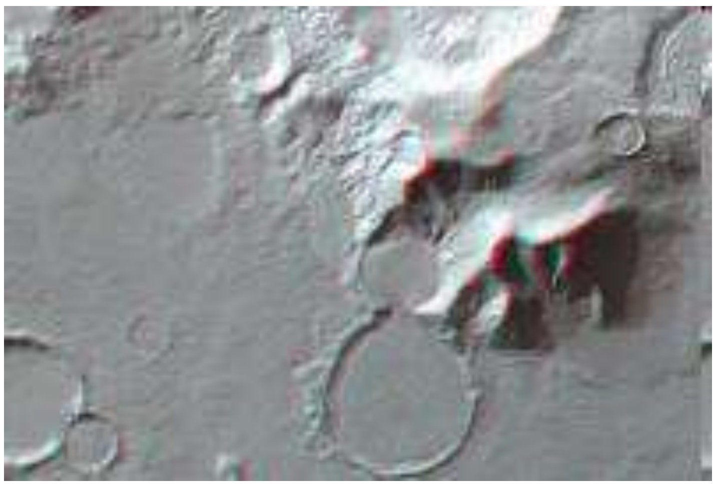
1996-2006

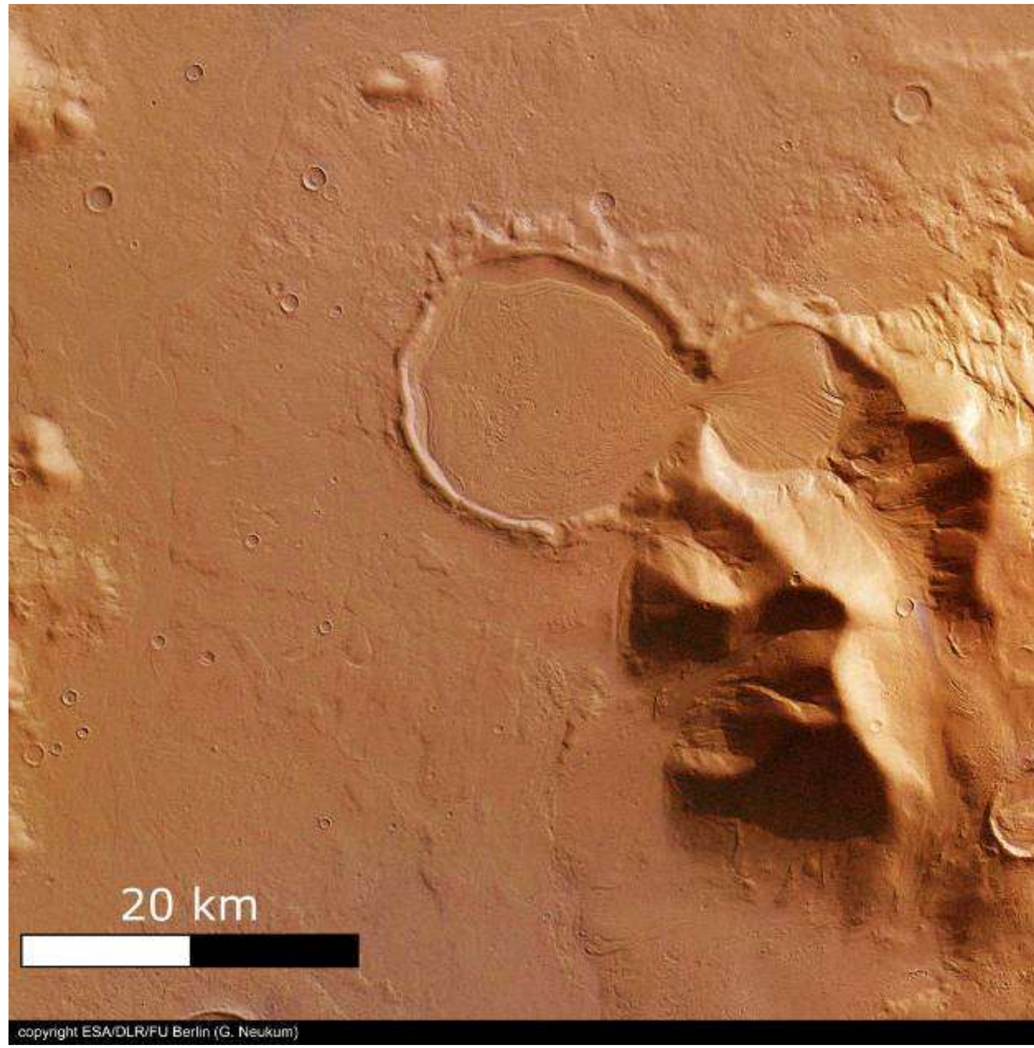




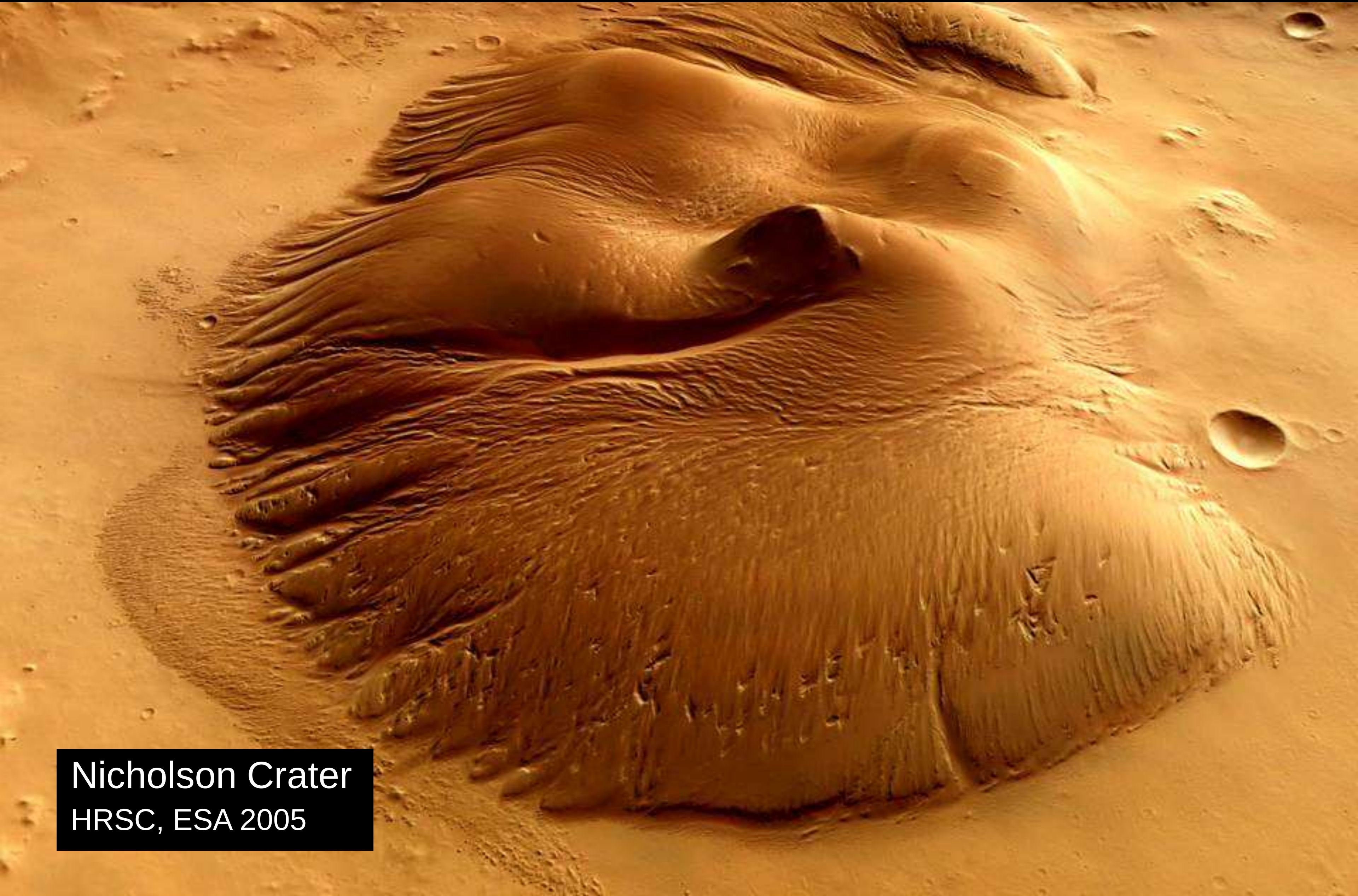
Mars Express (ESA,2003): High Resolution Stereo Camera Resolution 2-10m

The “hourglass” feature
HRSC, ESA

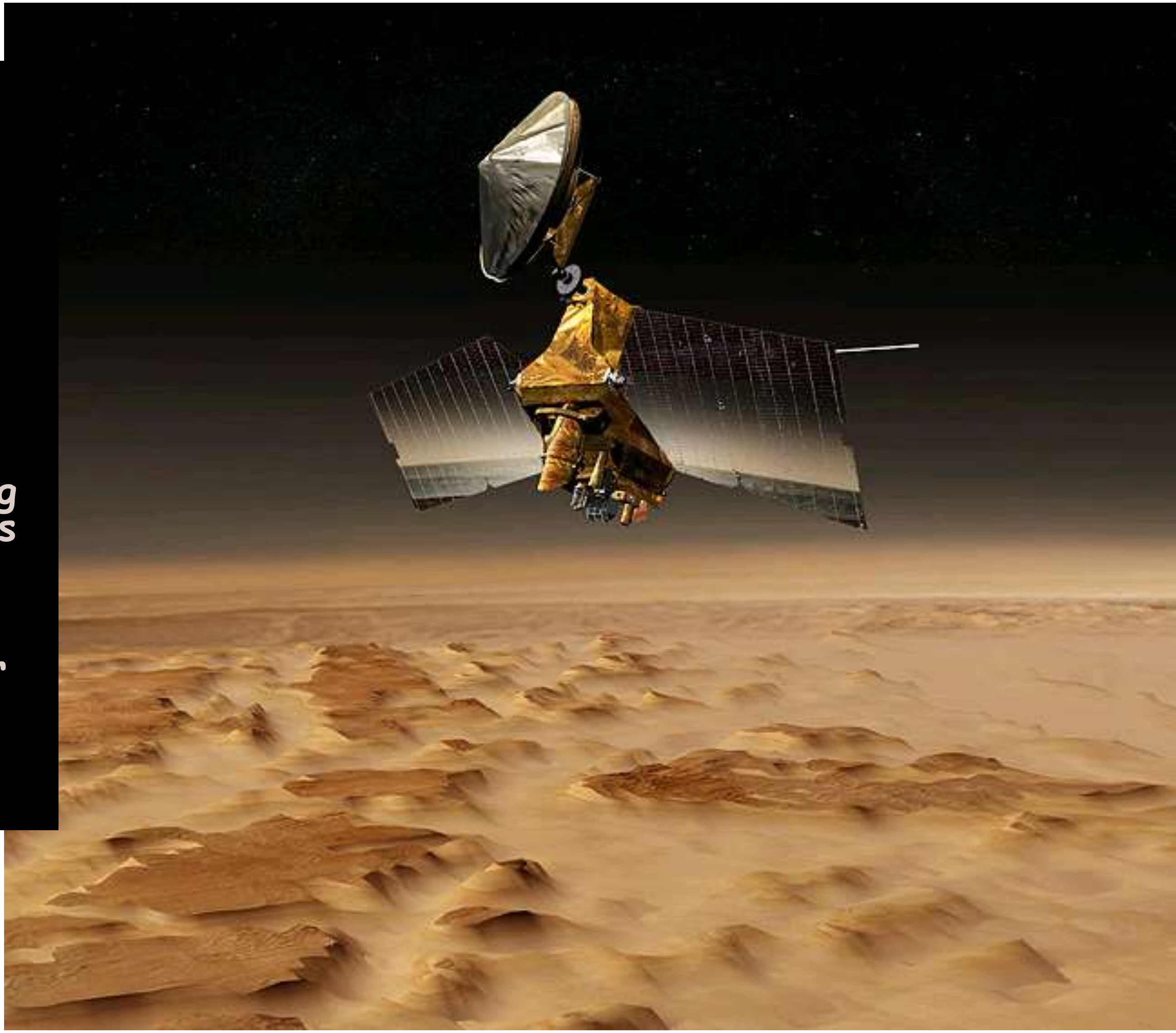




Mars Express: High Resolution Stereo Camera



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

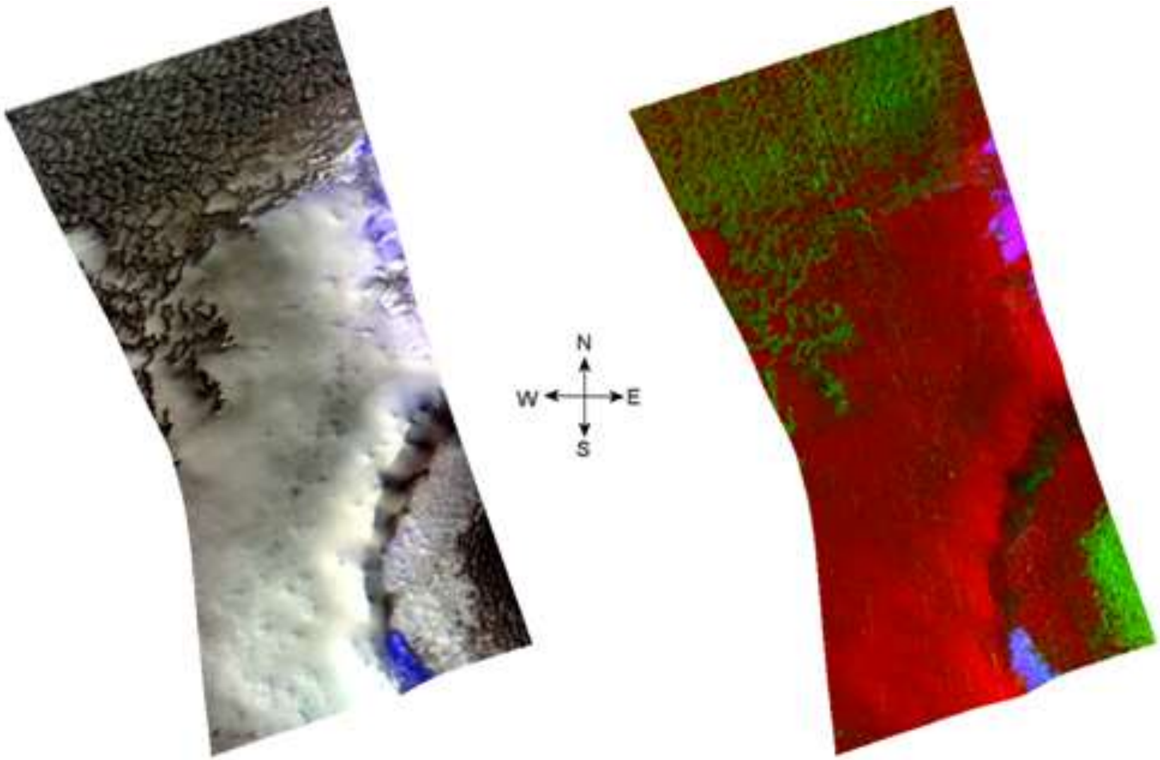
2005-

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

Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on NASA's Mars Reconnaissance Orbiter (2005)

CRISM covers wavelengths from 0.362 to 3.92 microns (362 to 3920 nm) at 6.55 nanometers/channel, to identify a broad range of minerals on the Martian surface.



False colour infrared: Red = dust, blue = water ice

Green = polyhdrated sulphate

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 visible bands: (microns)
0.425, 0.540, 0.654, 0.749, 0.860 microns

10 thermal infrared bands:
6.78, 7.93, 8.56, 9.35,10.21, 11.04, 11.79, 12.57,14.88

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

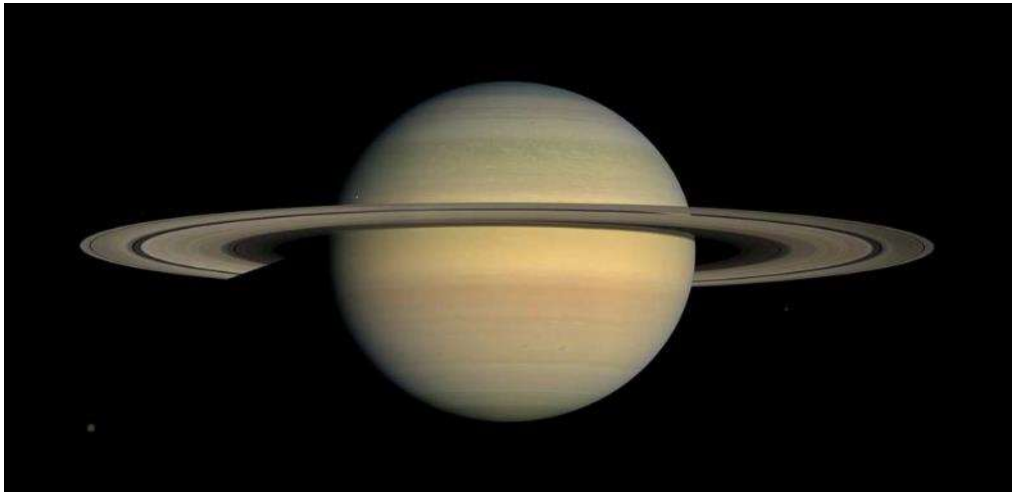
http://themis.asu.edu/gallery

https://youtu.be/JUbQM47QXwQ

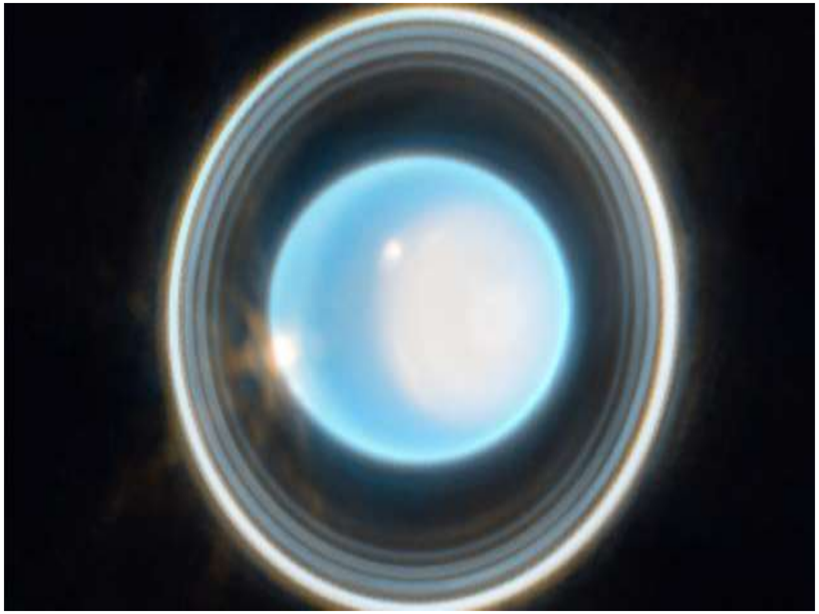
Mars Exploration Rover Missions 2004

https://www.missionjuno.swri.edu

Jupiter- Juno, 2023:

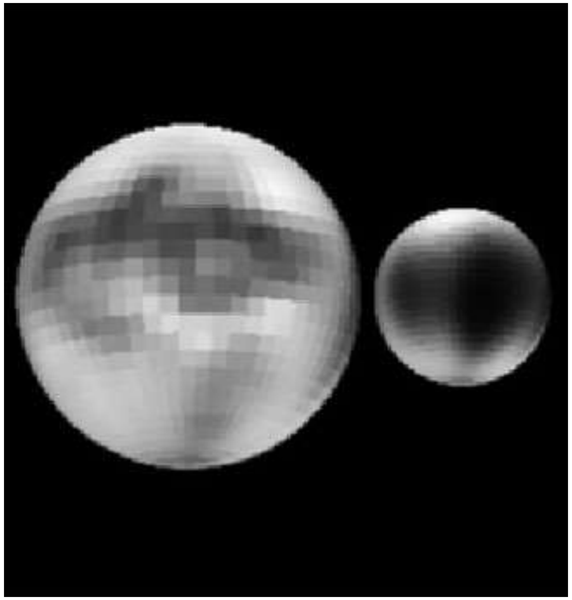


Saturn from Cassini probe, 2016



Neptune / Uranus from Webb telescope, 2022

Pluto and Charon (moon) pre-2015

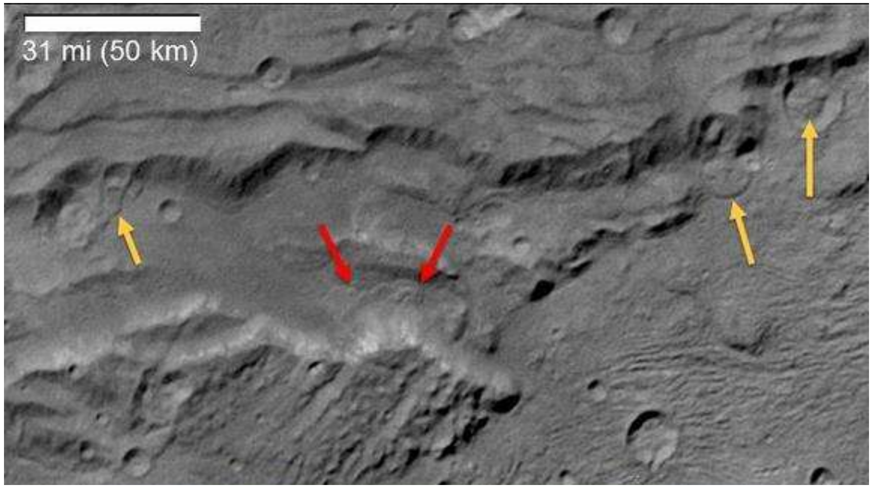


New Horizons Mission 2015

Launched 2006

Alice Ultraviolet sensor and **Ralph** (‘The Honeymooners’)

Landslides on Charon



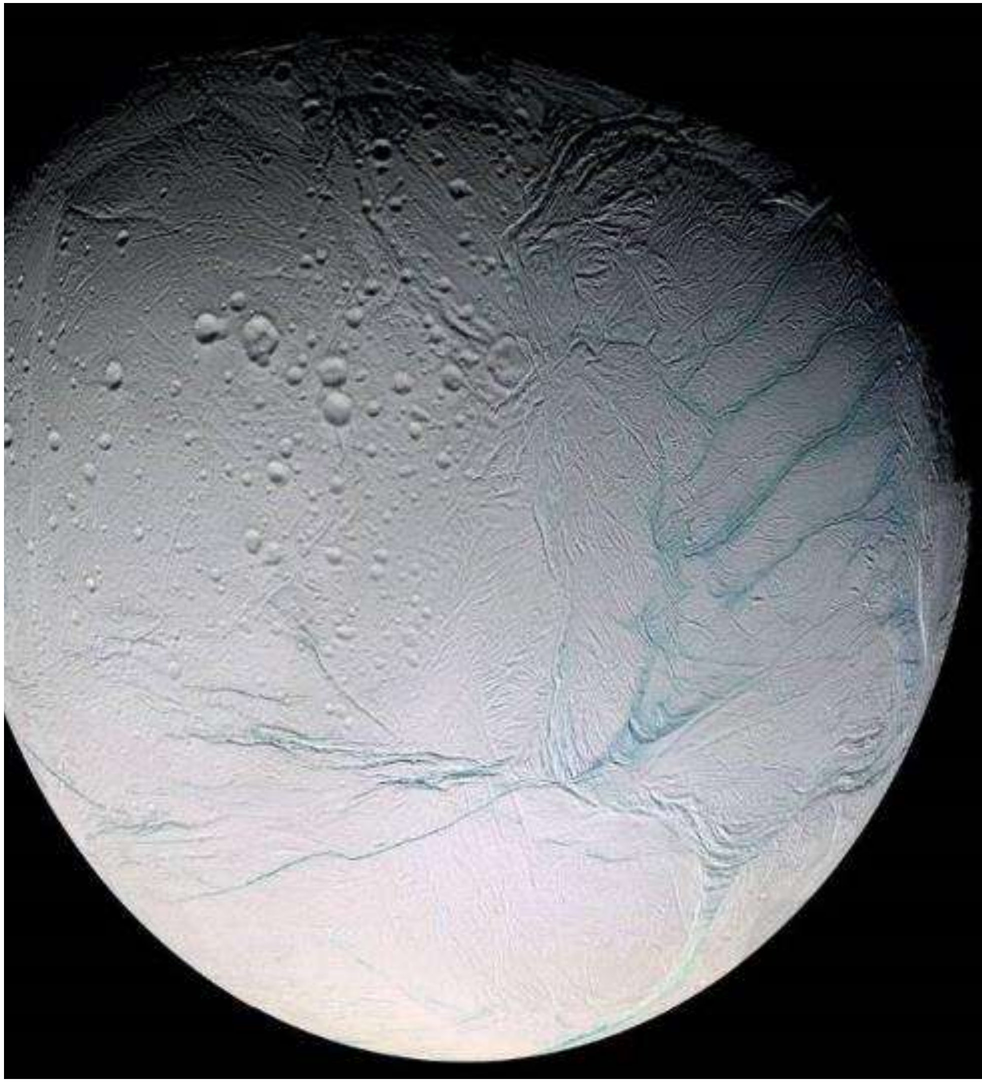
Pluto demoted,
to dwarf planet
2006

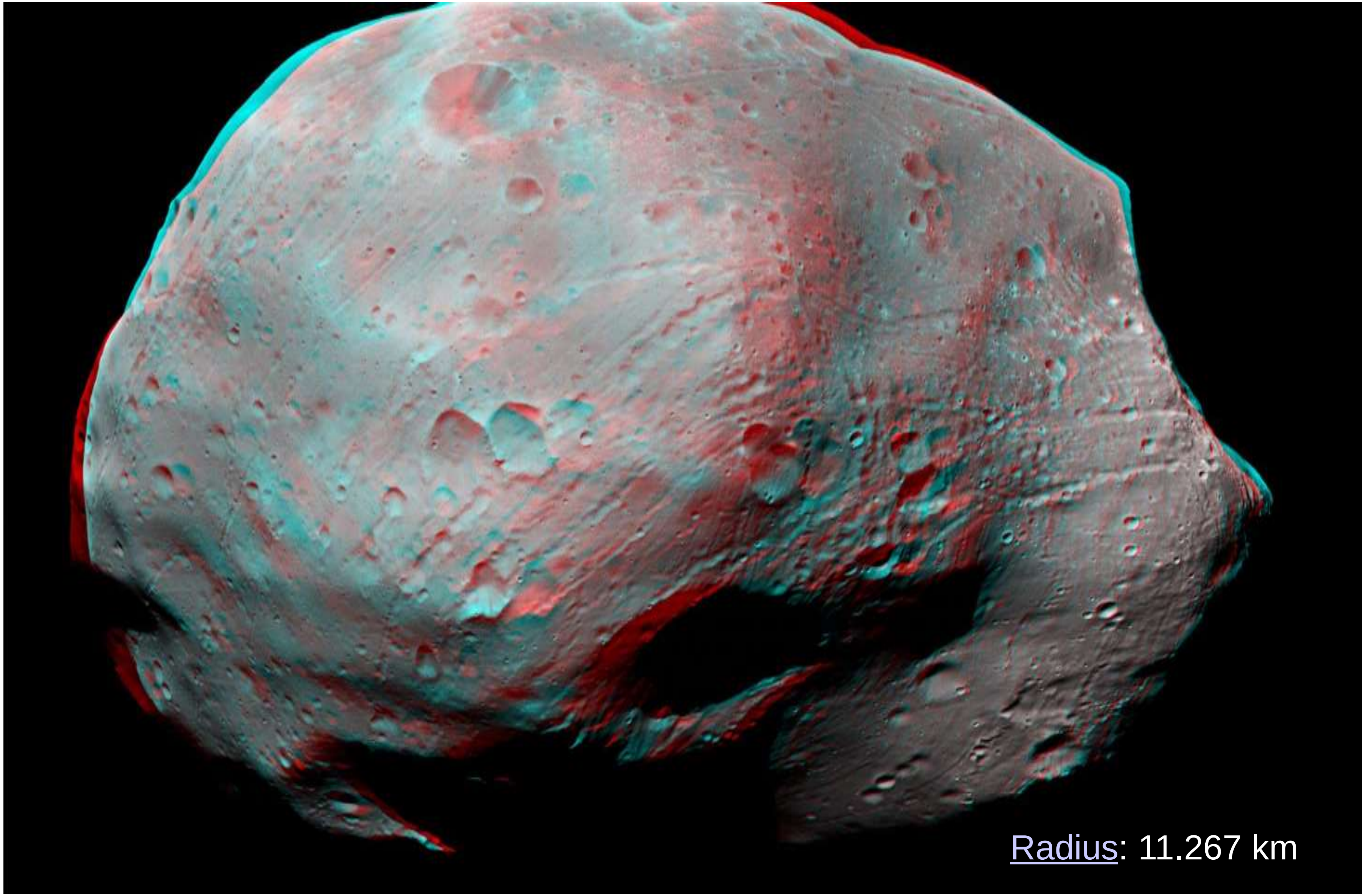
http://www.nineplanets.org/

Pluto was named
in 1930 by
Venetia Burney
(1918-2009)

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



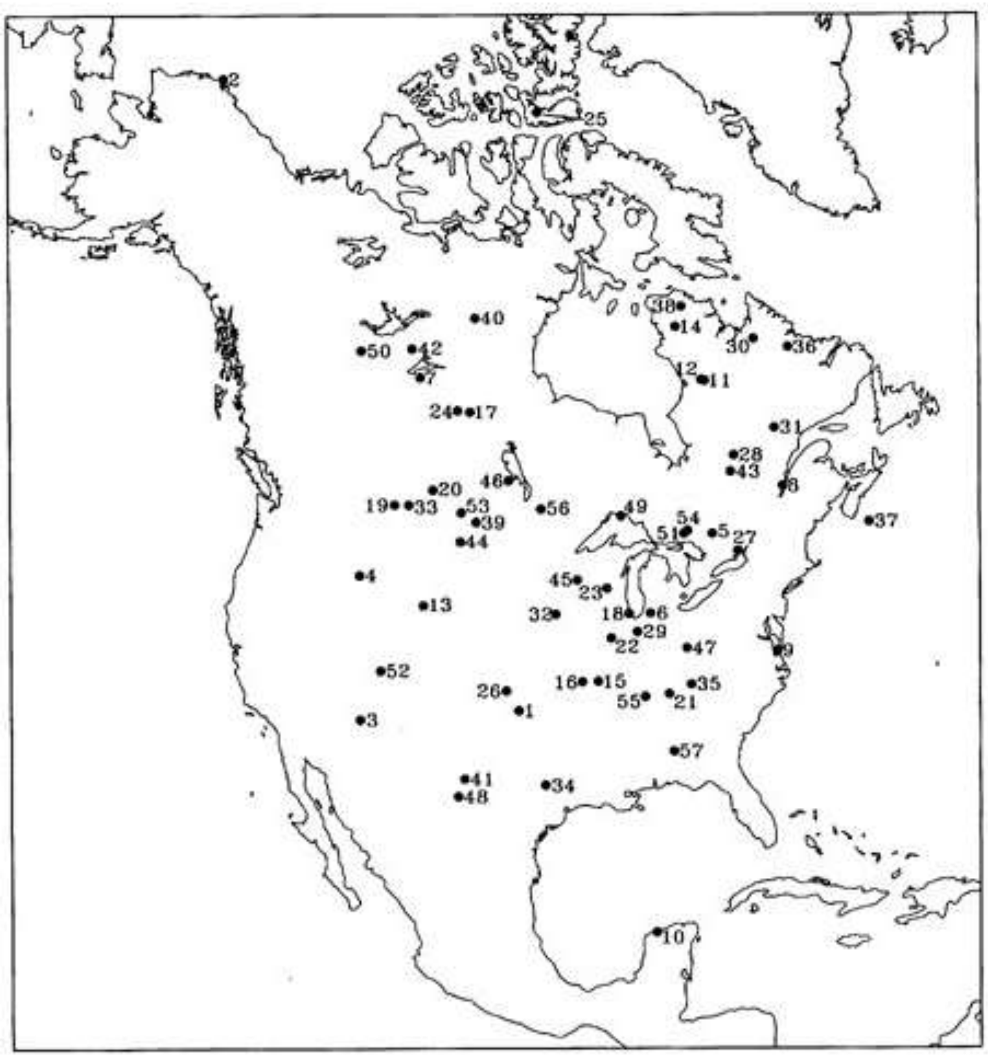


Phobos is the larger of the two natural satellites of Mars, the other being Deimos. The two moons were discovered in 1877. It is named after Phobos, the Greek god of fear and panic, twin brother of Deimos. Mars' two tiny moons – Phobos and Deimos – are the sole survivors of a giant impact on the Red Planet

Meteor and Comet Impact Hazards: North American Impact Craters

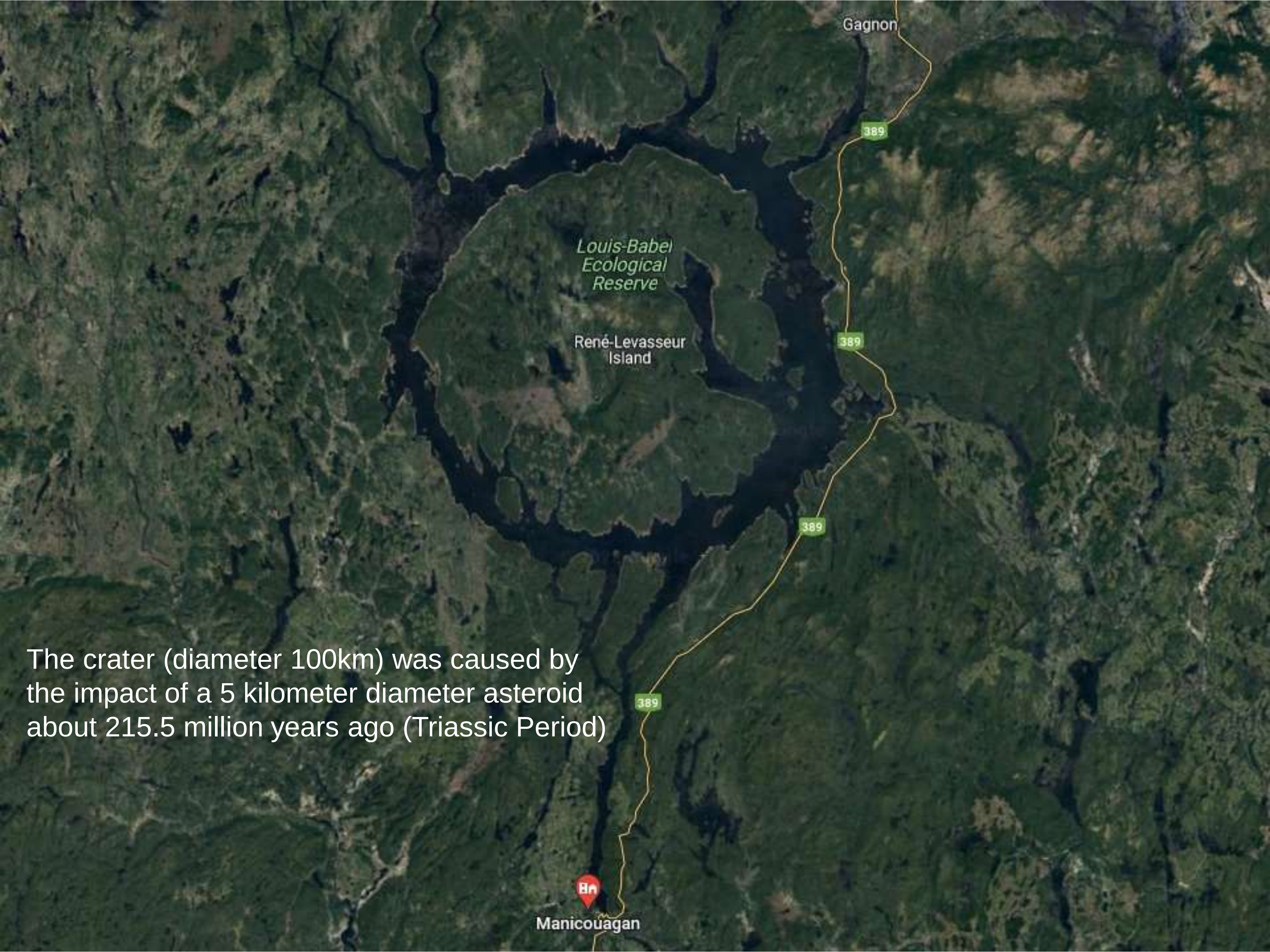
Data from Observer's Handbook 2004, Royal Astronomical Society of Canada

http://astro.wsu.edu/worthey/astro/html/lec-meteor-cc.html



Pingualuit Crater, Northern Quebec

http://earthobservatory.nasa.gov/IOTD/view.php?id=8472



The crater (diameter 100km) was caused by the impact of a 5 kilometer diameter asteroid about 215.5 million years ago (Triassic Period)

Lecture topics for second exam

10-13	~~Feature extraction / *Mid-Term Exam (15%)*~~	*Lab 5: Feature extraction*
16-20	~~Environmental Change / Thermal RS~~	*Lab 6: Environmental Change*
23-27	Glaciers / E~~nv. Change class dem~~os	*Lab 7: Glaciers*
November		
(Oct)30-3	Change detection / DEMs	*Lab 8: Change detection*
6-9	Microwave-RADAR / LiDAR	*Lab 9: DEMs*
13-17	~~Projects~~ / High resolution sensors	*Lab 10: Projects-data*
20-24	Hyperspectral & correction / Planetary RS	*Lab 11: Data processing*
27-Dec 1	RS Software-course review / *Exam2 (10%)*	*Lab 12: project write-up*
Dec 5	Project demos – 5 minutes each	

Evaluation 100%

- Exams: Oct 12, Nov 30 + 5% take-home Quiz 30%
- Environmental Change exercise, Oct 25 10%
- Article review Nov 17 10%
- Lab exercises 5 x 5% 25%
- Final project, Dec 7 25%

Exam 2: Nov 30 (10%) lecture topics since midterm; 10 questions, 1 mark each

Sample exam question (previous): Solar radiation peaks in the visible (green) wavelengths, while terrestrial radiation (emitted by Earth) peaks in the thermal infra-red wavelengths.
Can you explain why this difference occurs?