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California Institute of Technology
Pasadena, California

Ground systems in support of space exploration

for

Ground Systems Architectures Workshop

April 3, 2008

Charles Elachi, Director
NASA Jet Propulsion Laboratory
California Institute of Technology

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Ground systems have supported space exploration for a half century

- **1958: Explorer 1 news conference at National Academy with William Pickering, James van Allen, and Werner von Braun**

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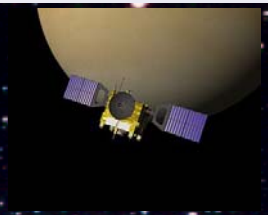
Where are we now? About 58 NASA robotic explorers, plus a number of international missions (some examples)

Spitzer studying stars and galaxies in the infrared

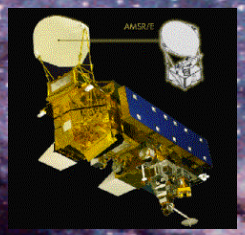
Ulysses studying the sun



ESA Venus Express orbiting Venus

ESA Rosetta to study comet in 2014

Hubble studying the universe



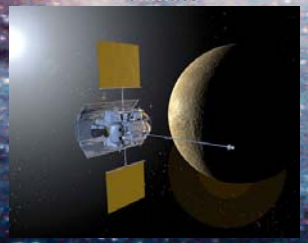
Aqua studying Earth's oceans

Rovers "Spirit" and "Opportunity" studying Mars

CALIPSO studying Earth's climate

Two Voyagers on an interstellar mission

Aura studying Earth's atmosphere



MESSENGER on its way to Mercury

QuikScat, Jason 1, CloudSat, and GRACE (plus ASTER, MISR, AIRS, MLS and TES instruments) monitoring Earth.

Chandra studying the x-ray universe

Japanese SELENE studying Earth's moon

ESA Mars Express orbiting Mars

New Horizons on its way to Pluto

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Now: A continuous robotic presence on and in orbit around Mars

2001 Mars Odyssey

Mars Reconnaissance Orbiter

Mars Express (ESA)

"Do not go where the path may lead, go instead where there is no path and leave a trail."
Emerson.
(Opportunity's tracks in Meridiani Planum)

Spirit

Opportunity

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Mars Reconnaissance Orbiter zooms in on Opportunity at Victoria crater

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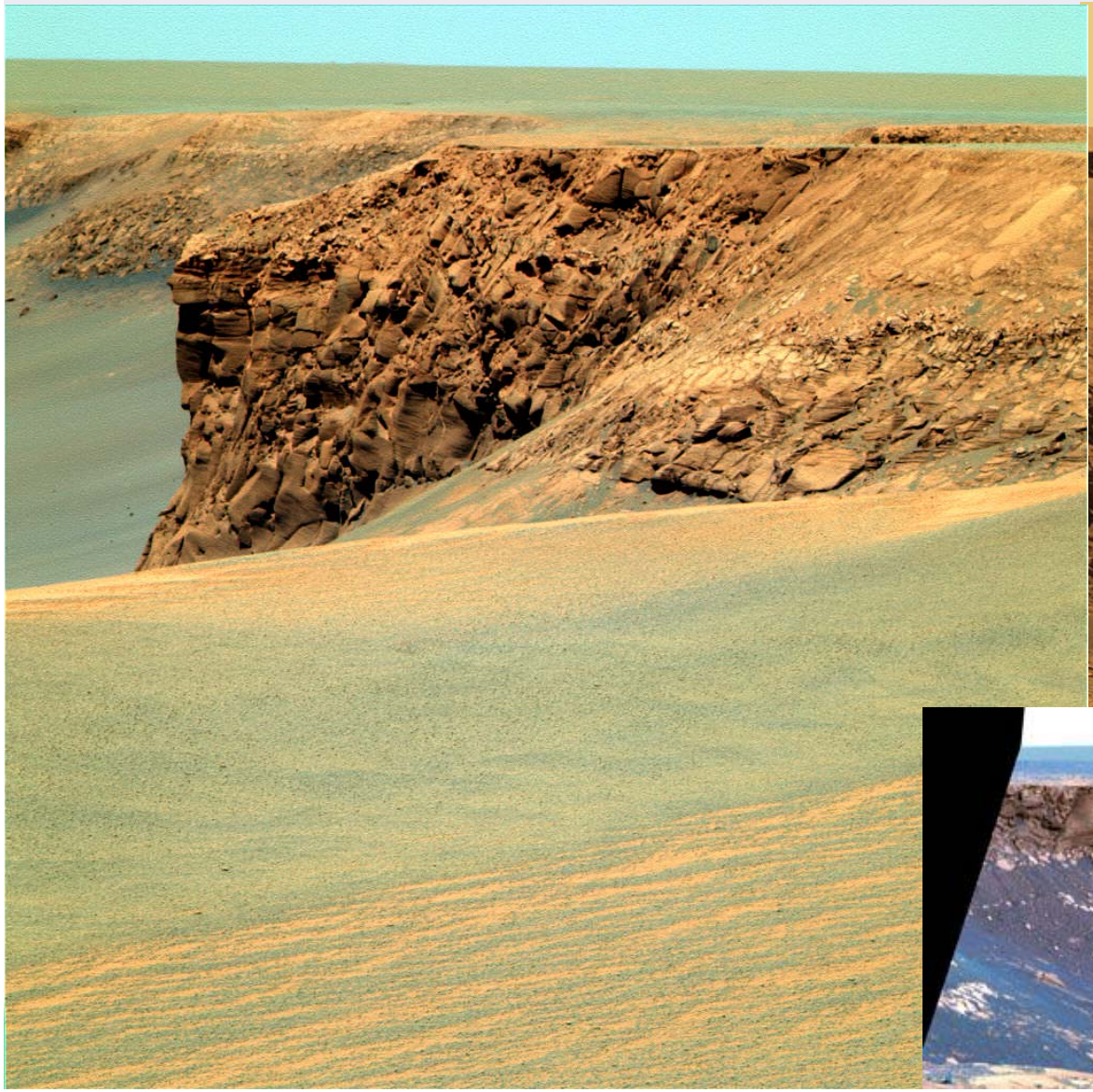
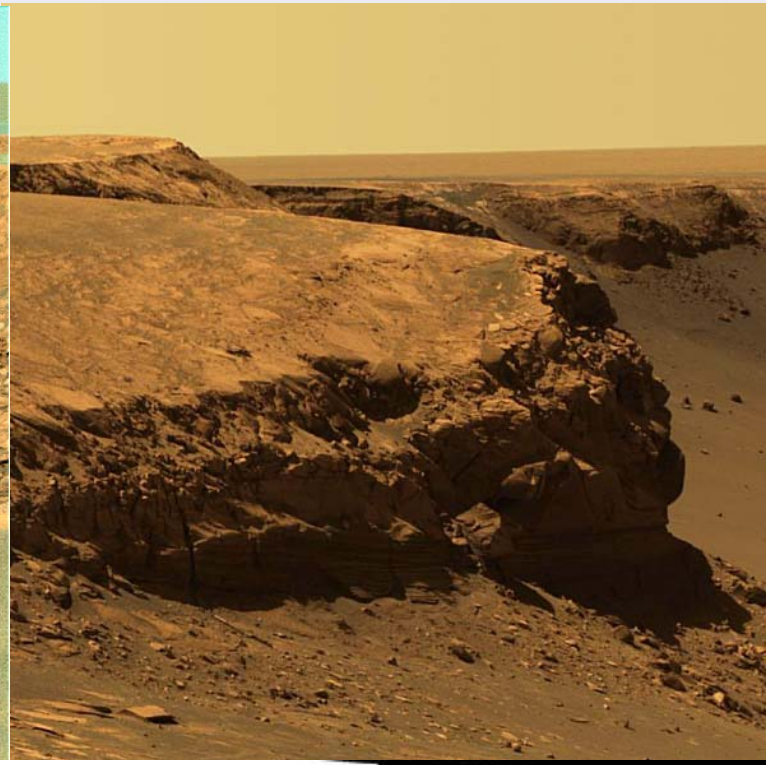
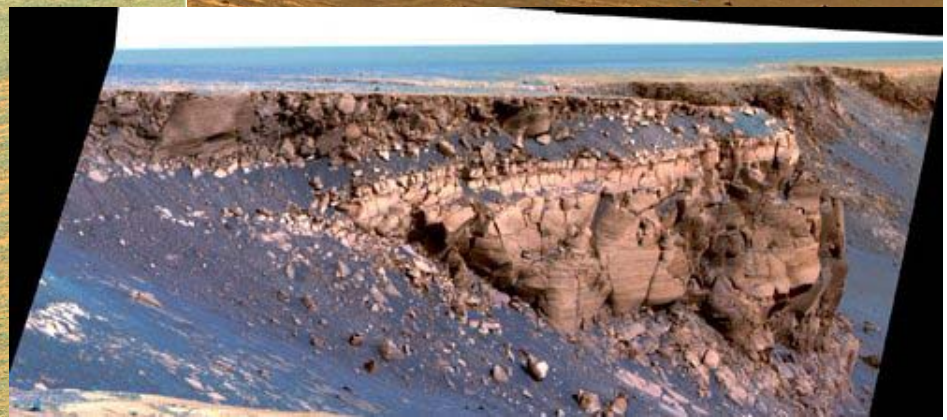
Opportunity's reconnaissance of the cliffs of Victoria Crater







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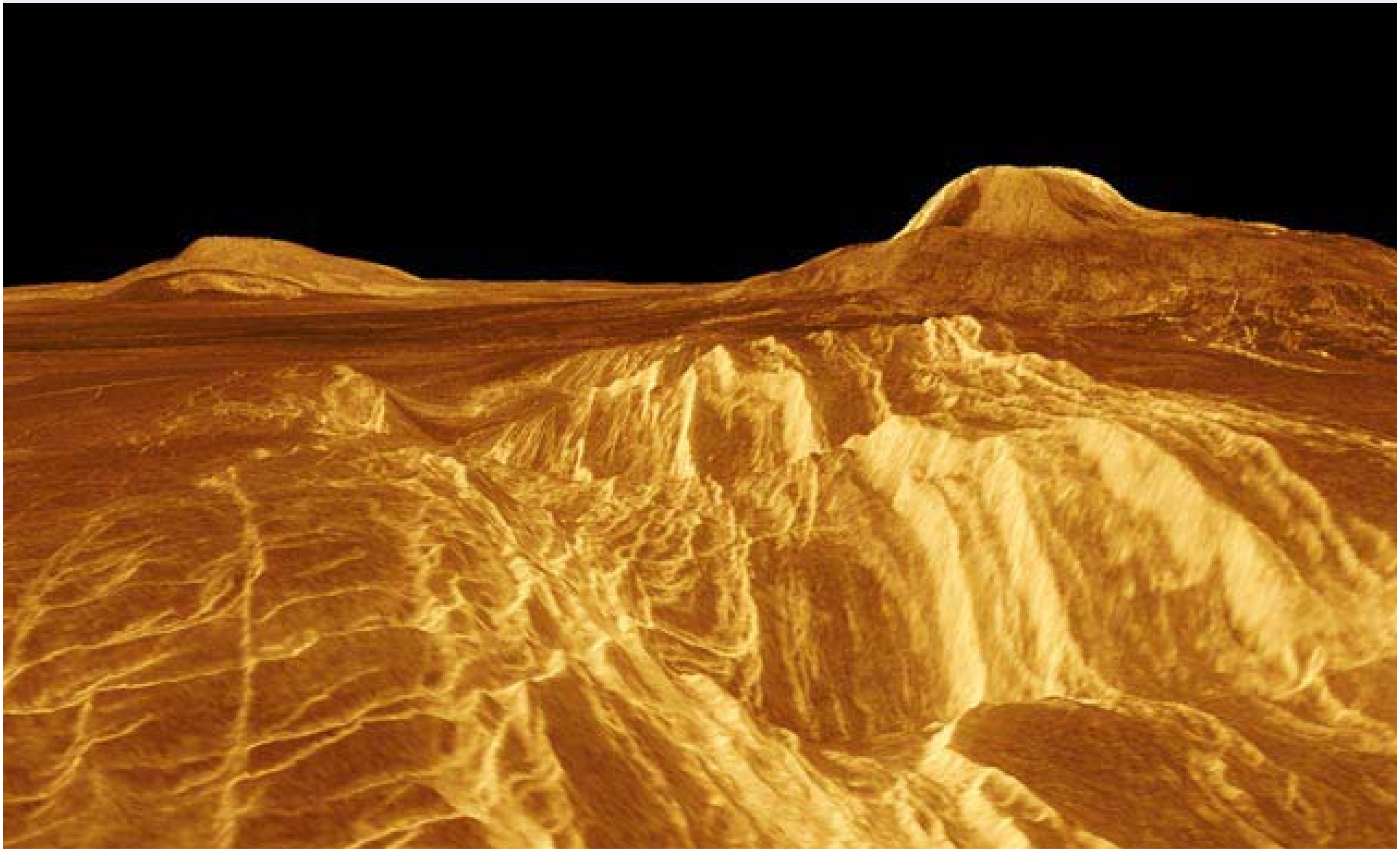
Magellan Venus radar data processed to show topography beneath clouds



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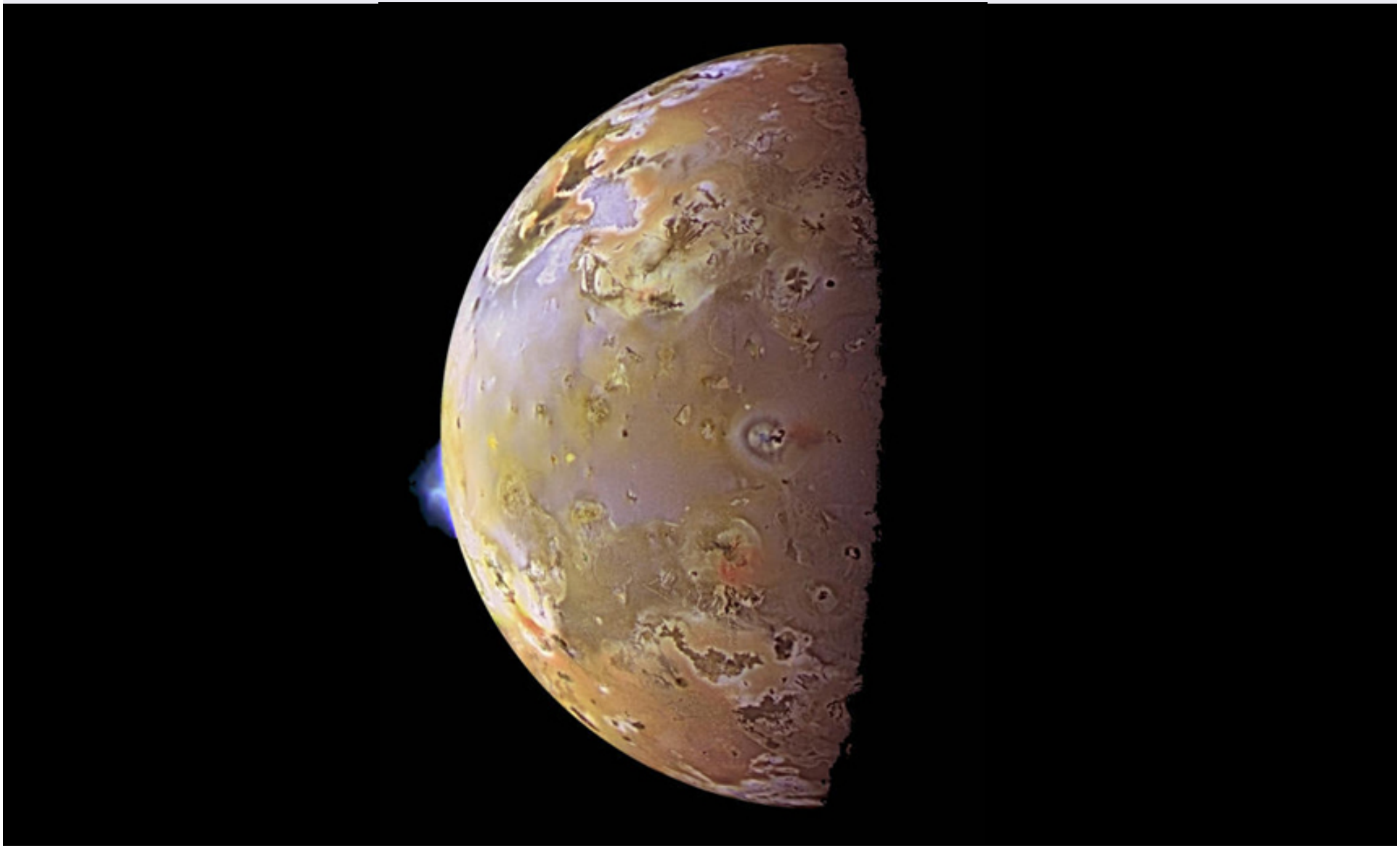
Galileo catches sulfur volcano erupting on Jupiter's moon Io



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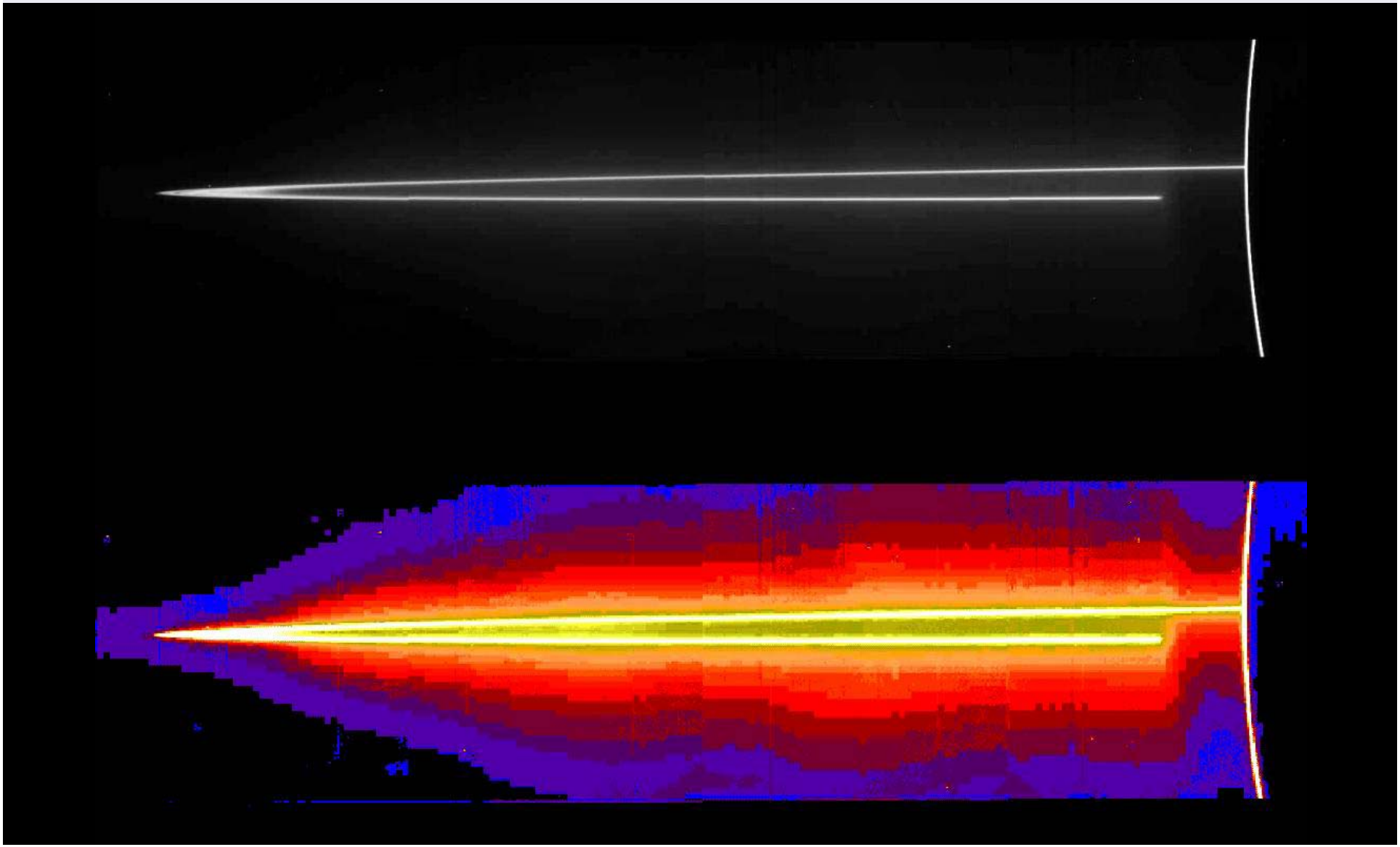
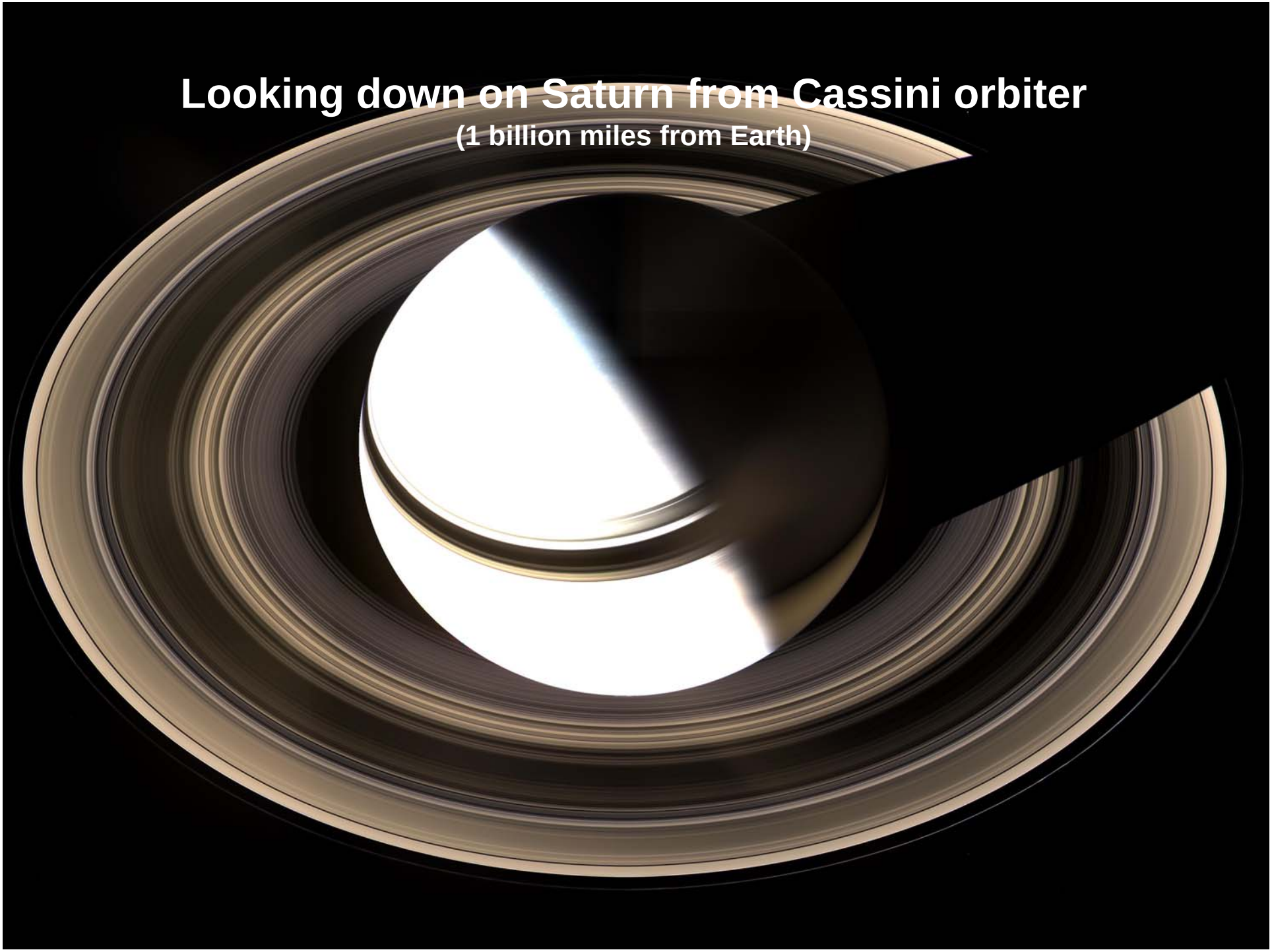
Jupiter's ring and its halo from Galileo




Looking down on Saturn from Cassini orbiter
(1 billion miles from Earth)

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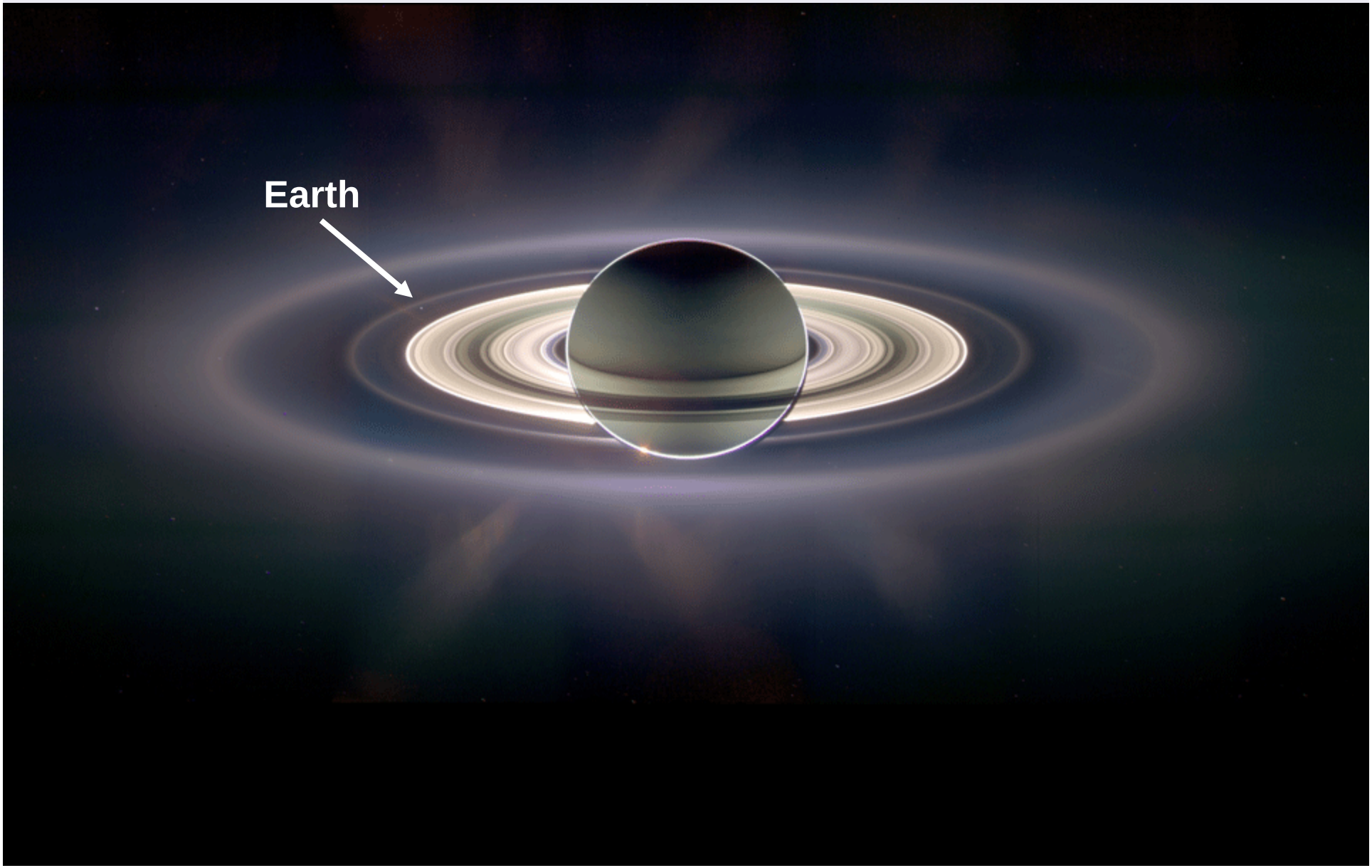
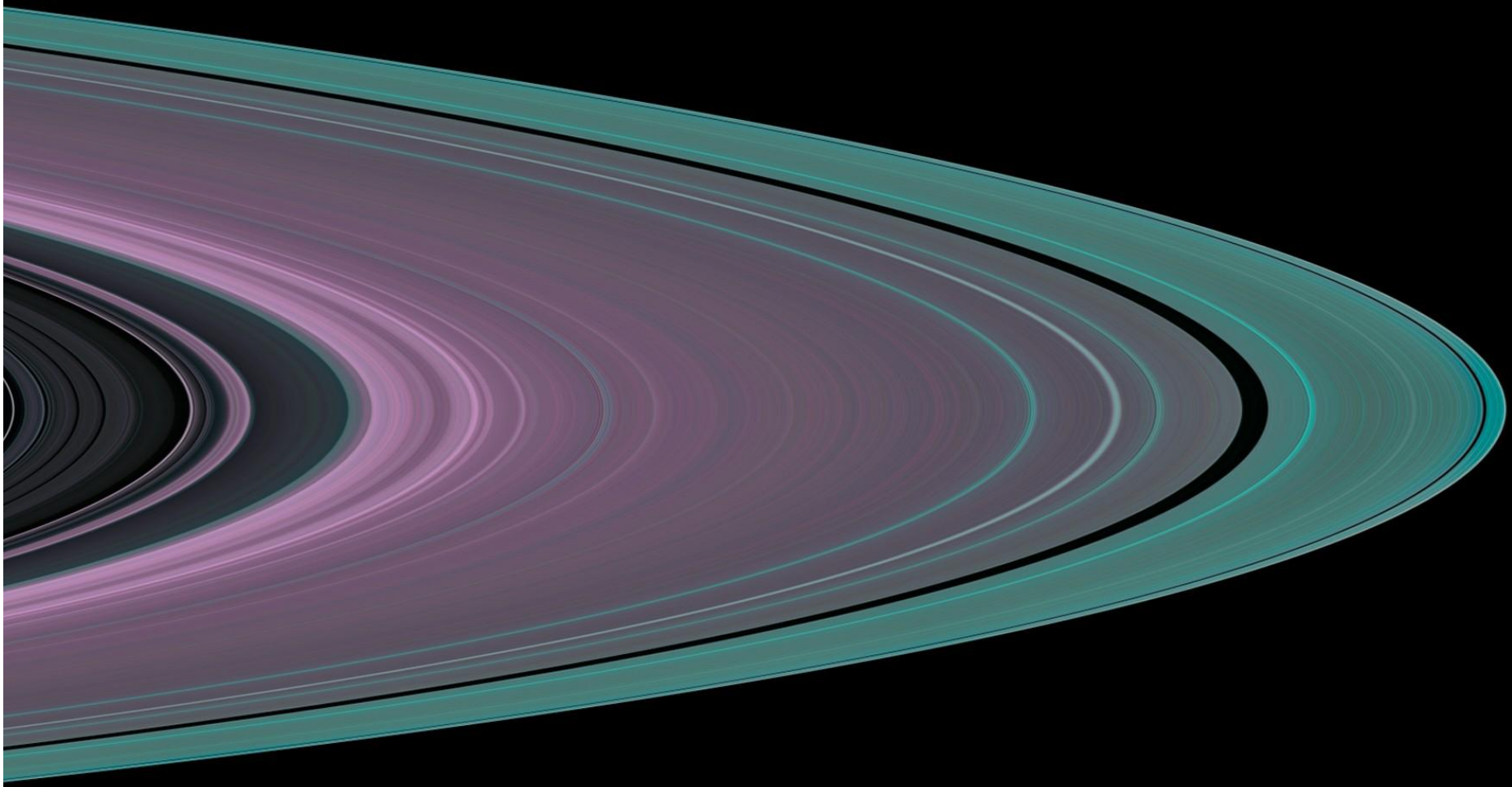
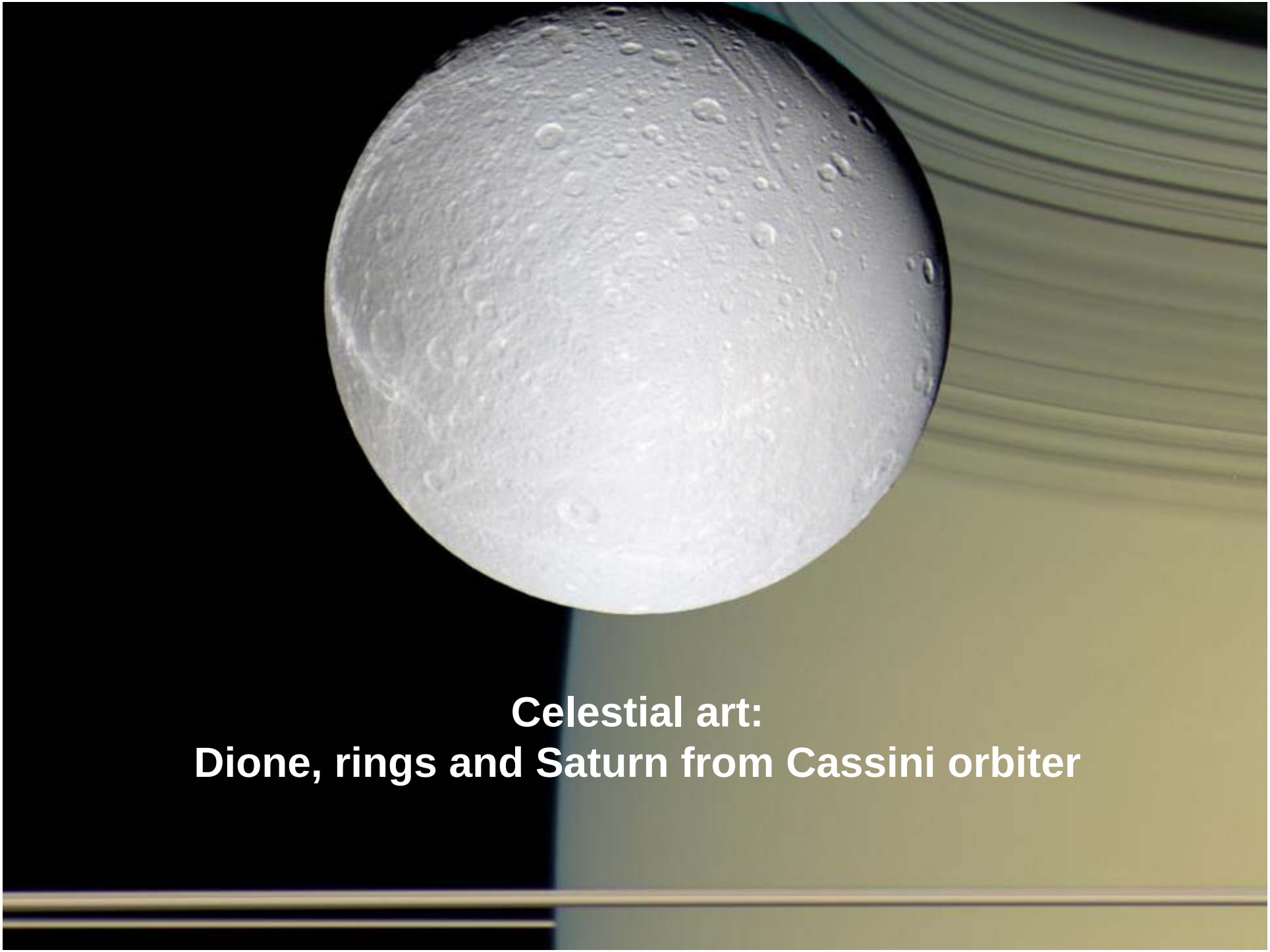
Backlit Saturn from Cassini orbiter



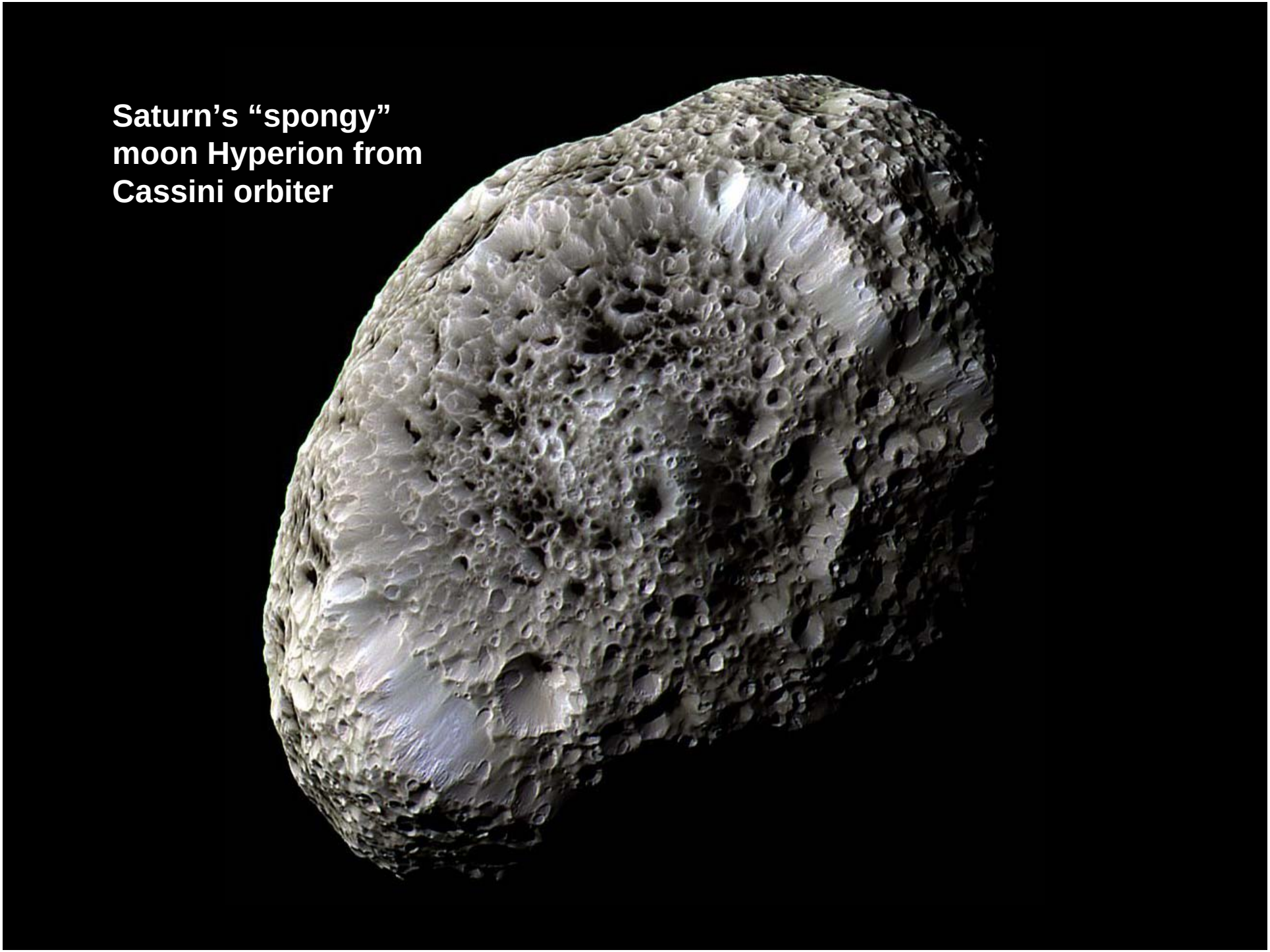
Visions of Saturn’s rings from Cassini orbiter

(Colors indicate particle sizes)

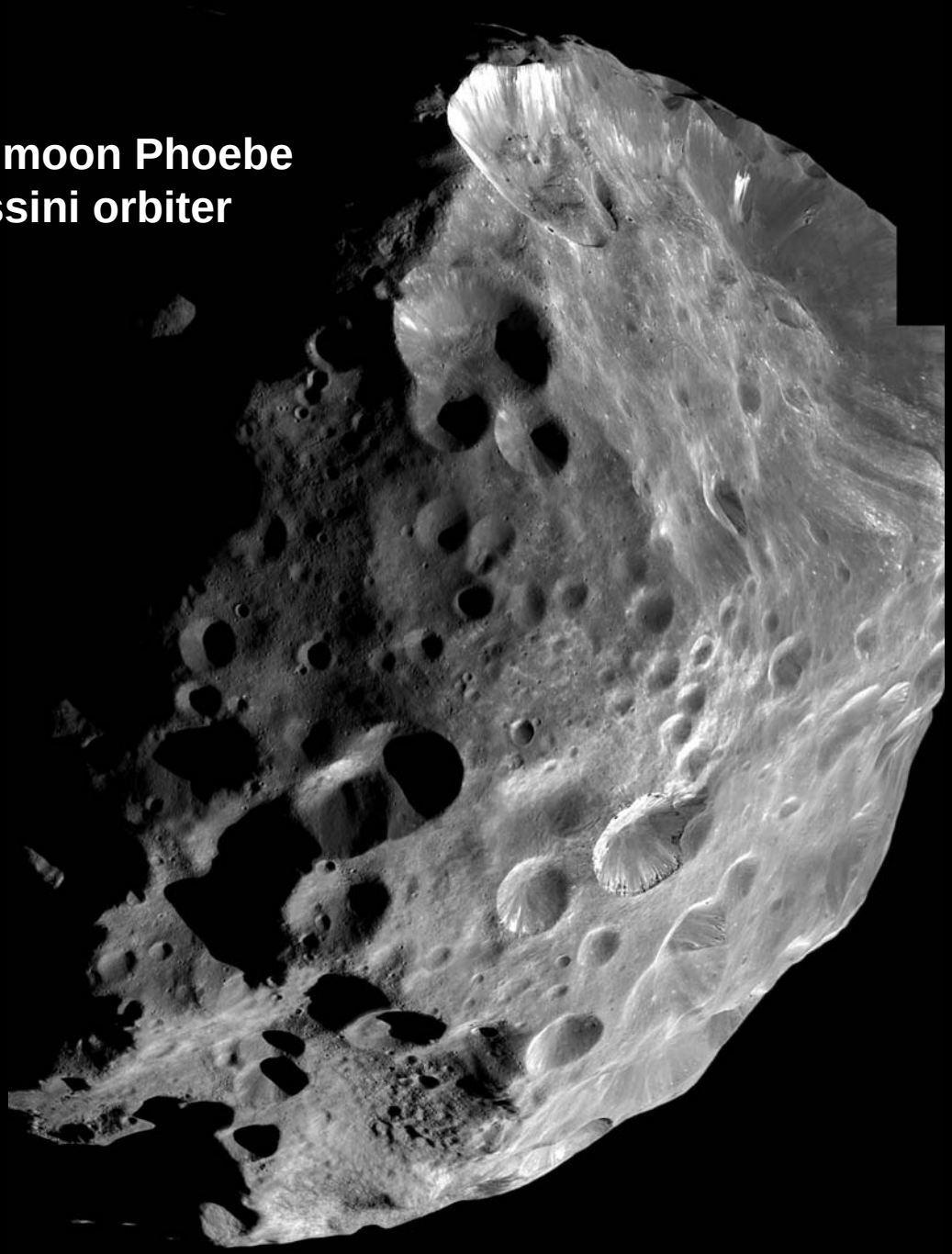




Celestial art:
Dione, rings and Saturn from Cassini orbiter


Saturn's "spongy"
moon Hyperion from
Cassini orbiter

Saturn's moon Phoebe from Cassini orbiter



Saturn's moon Enceledus with "tiger stripe" cracks in ice

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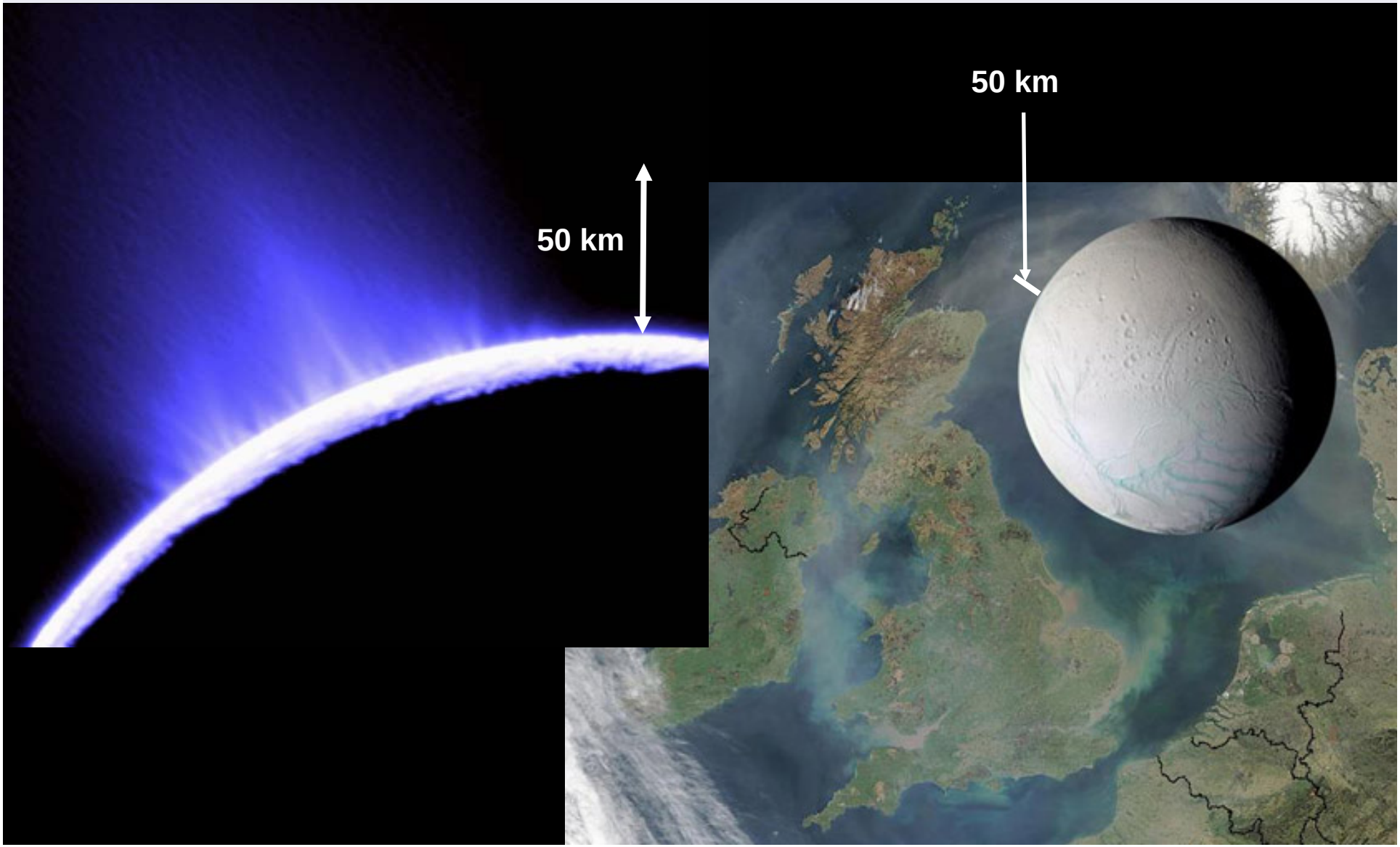
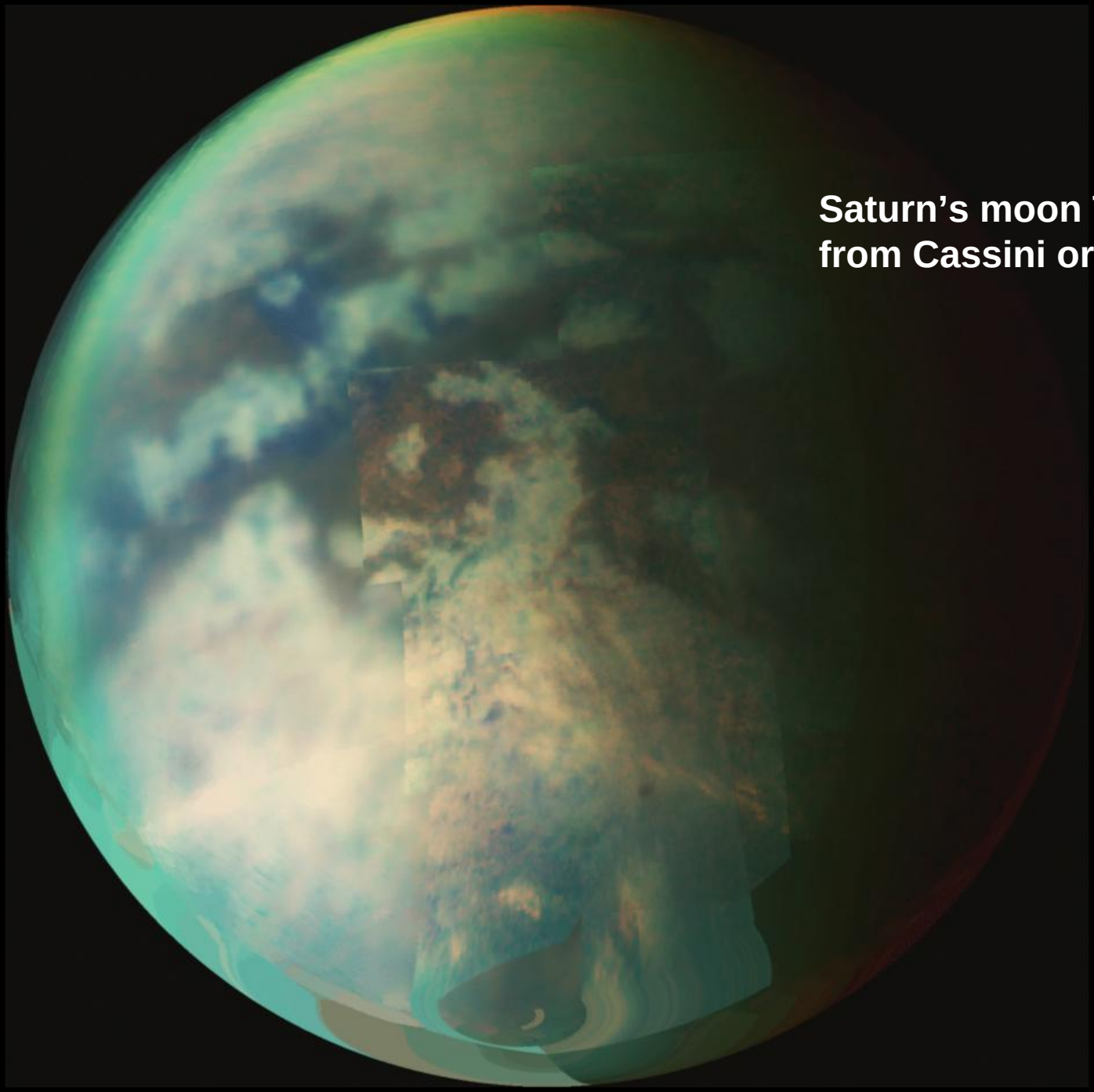
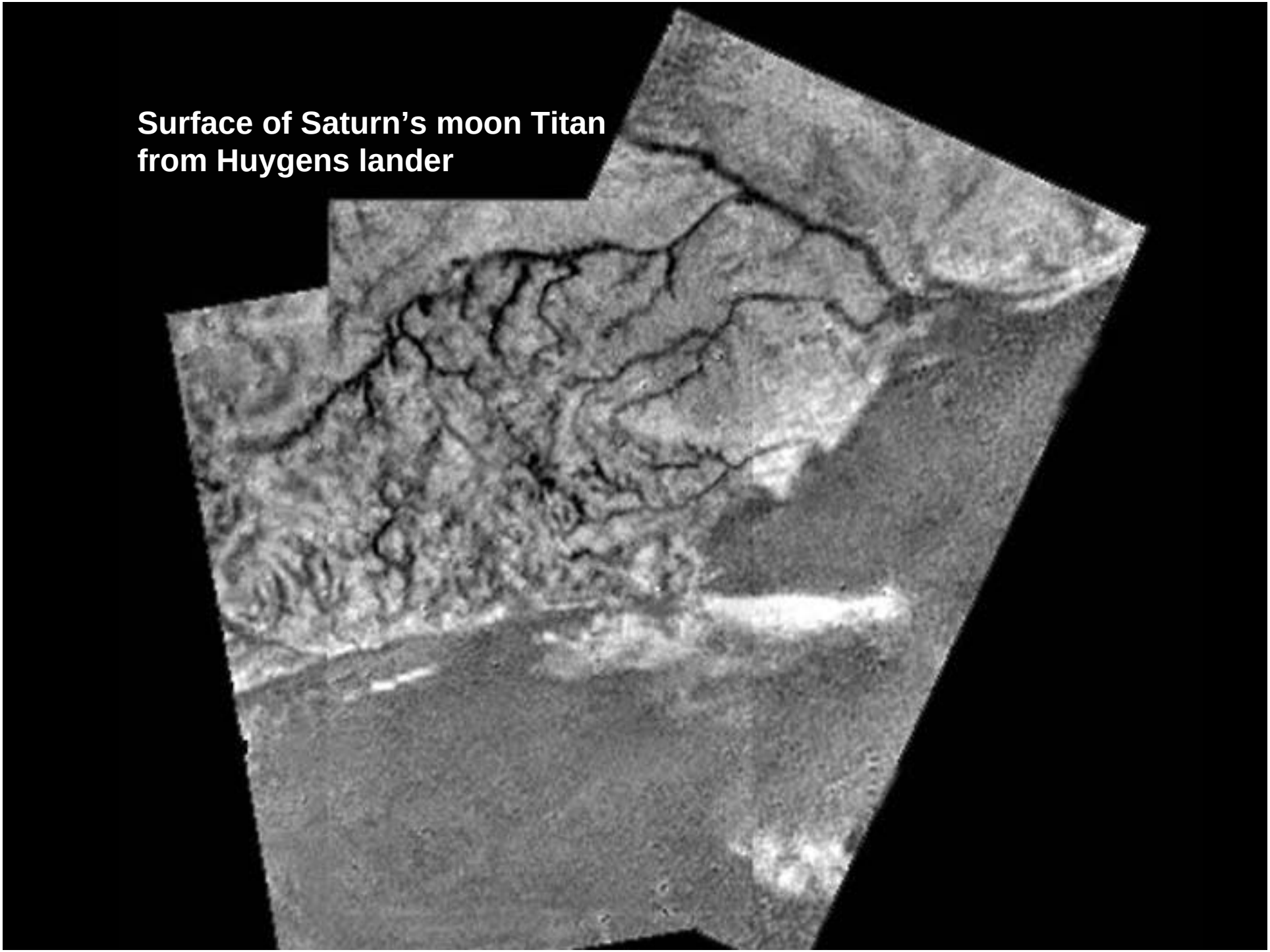
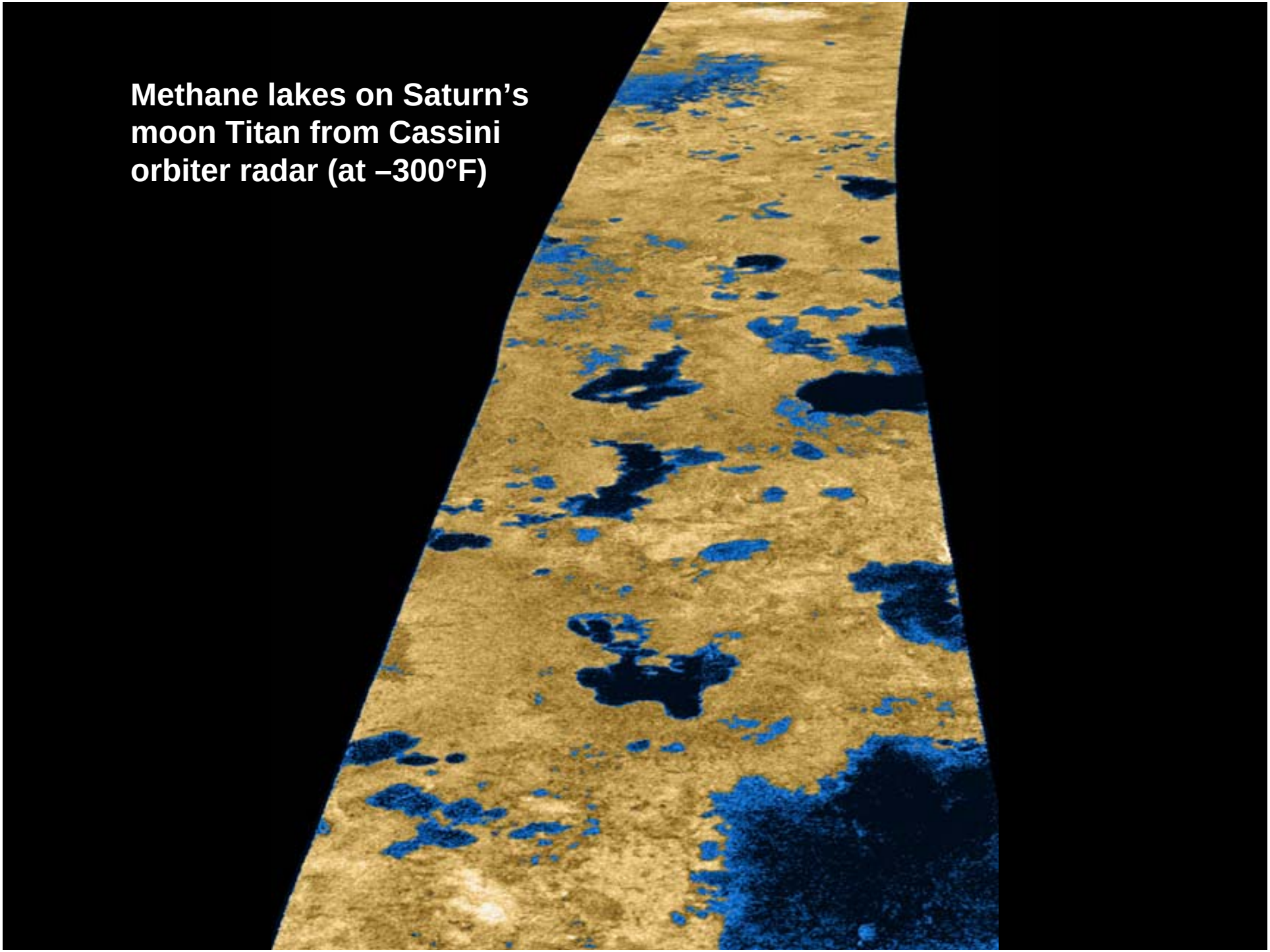
Cassini flew within 50 km of Enceladus on March 12





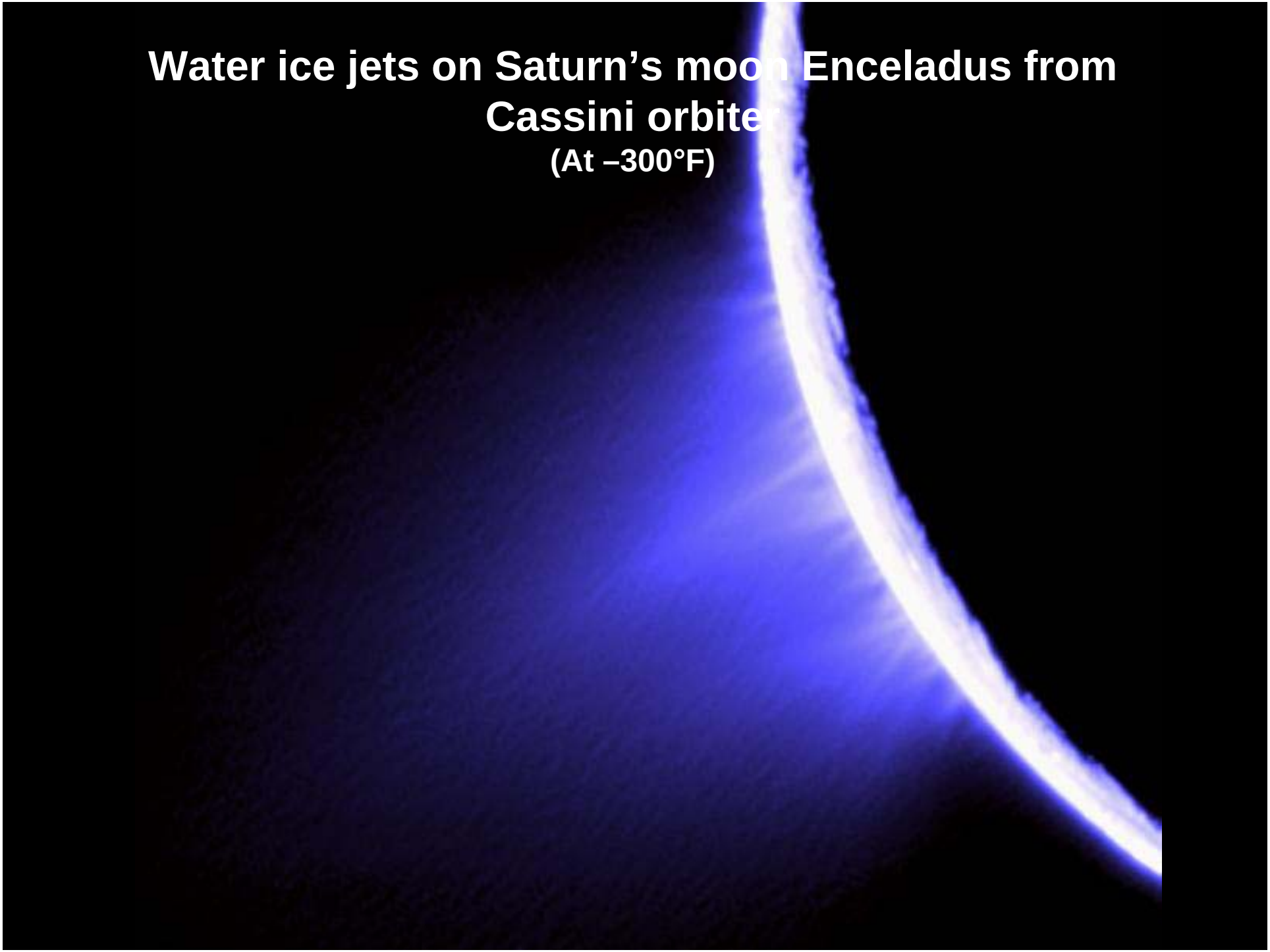
Saturn’s moon Titan from Cassini orbiter


Surface of Saturn's moon Titan
from Huygens lander


Methane lakes on Saturn's moon Titan from Cassini orbiter radar (at –300°F)

Water ice jets on Saturn's moon Enceladus from Cassini orbiter

(At –300°F)



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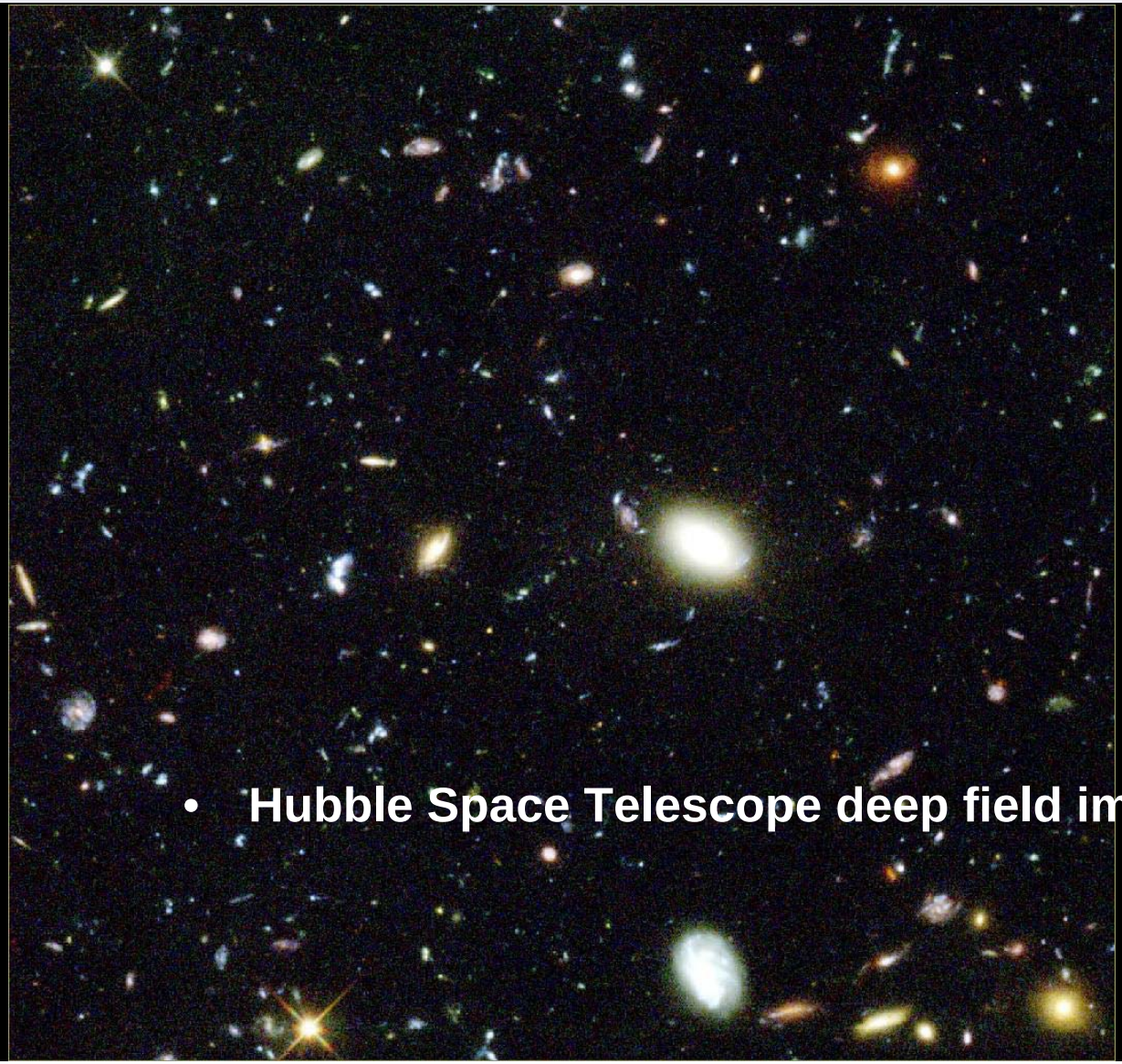
Ground software processes data from the most distant part of the universe



- Hubble Space Telescope deep field image

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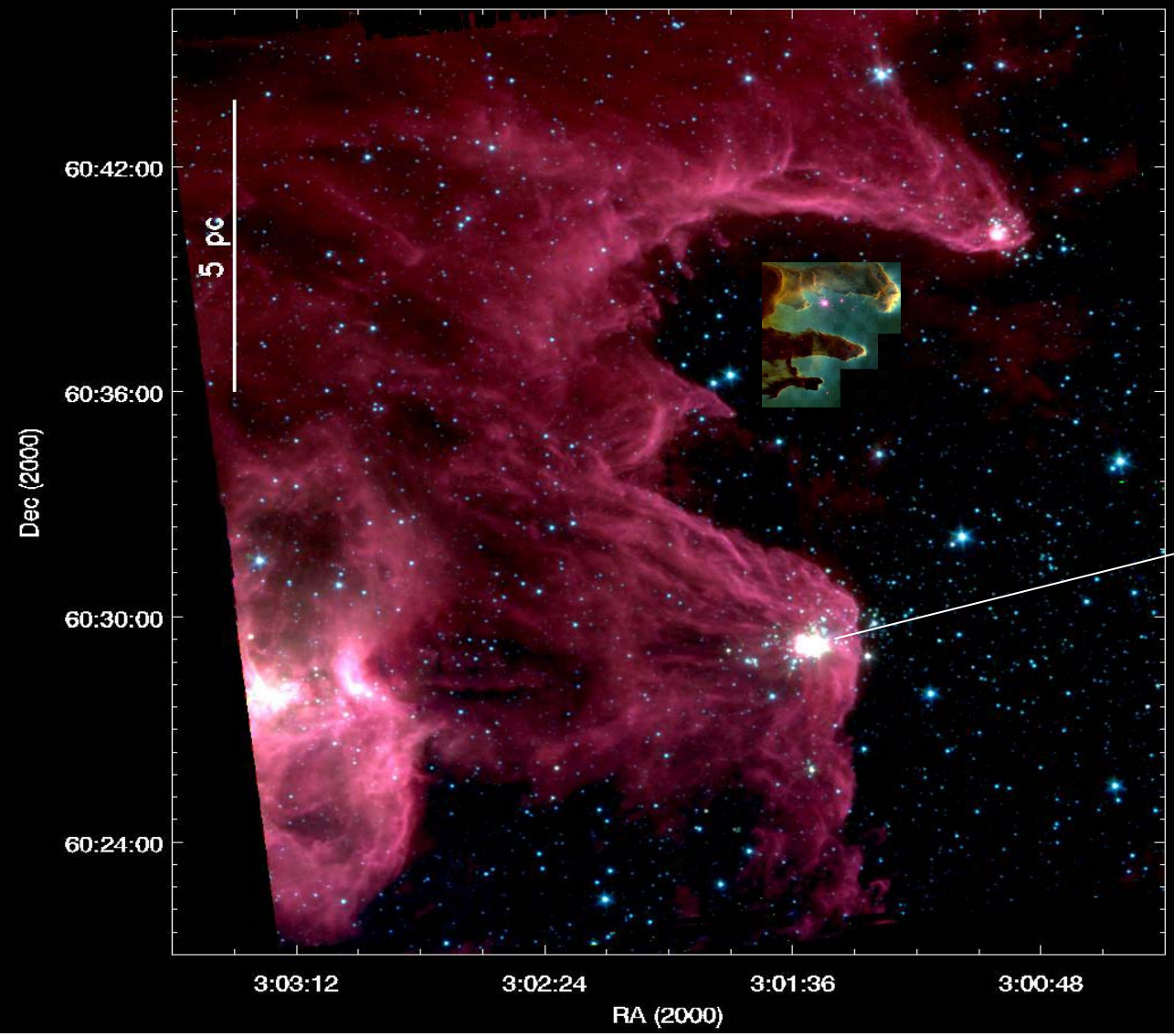
Spitzer views the star-forming "Mountains of Creation"



GL4029
IRAC
[3.6][4.5]

IRAC image

Lori Allen and the IRAC team

AFGL402

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A dying star from Spitzer Space Telescope

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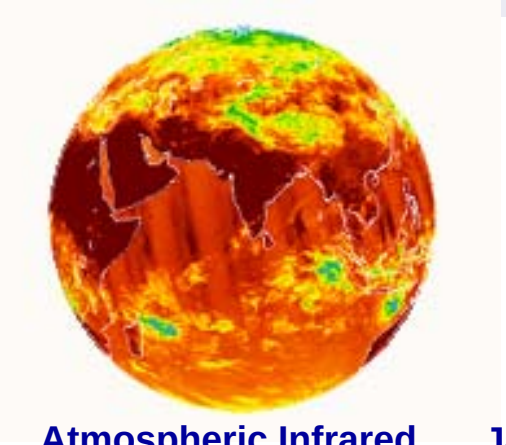
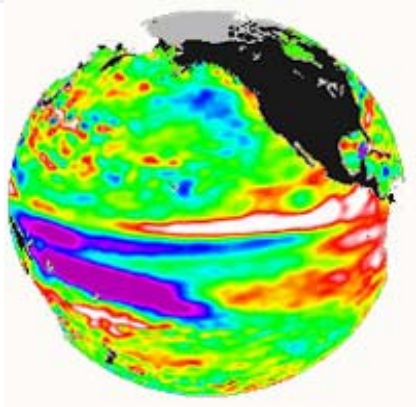
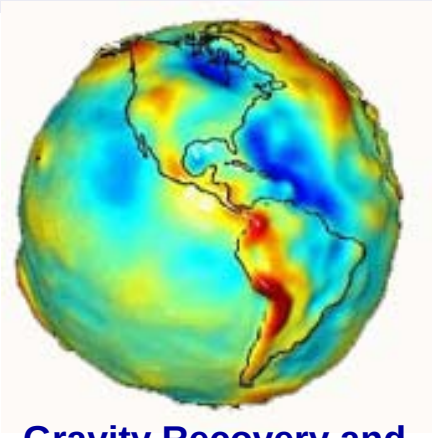
New ways to see a changing Earth with robotic remote sensing



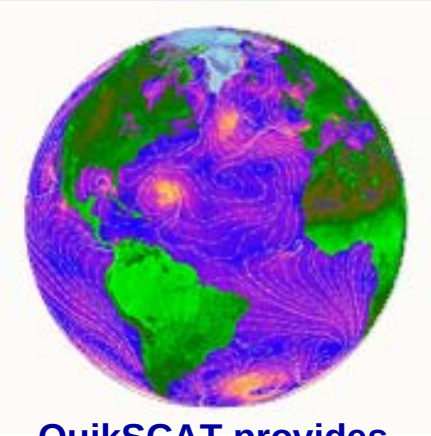
Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps



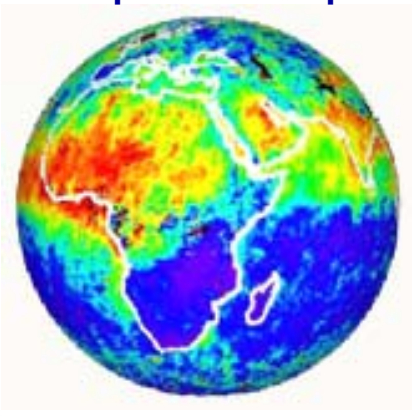
Jason provides global sea surface height maps every 10 days



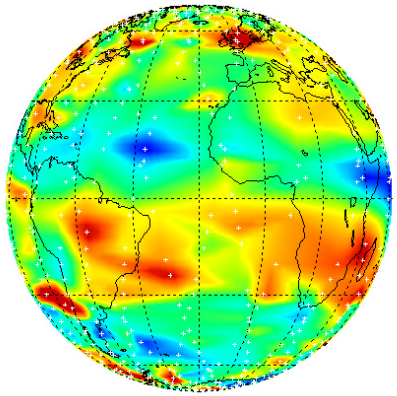
Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth's gravity



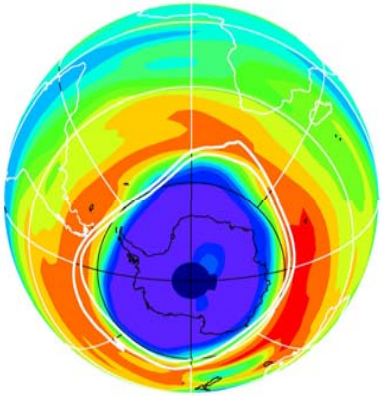
QuikSCAT provides near global (90%) ocean surface wind maps every 24 hours



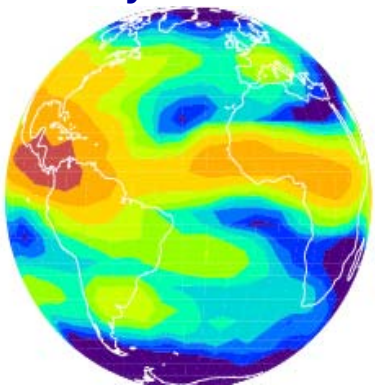
Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps



Tropospheric Emission Spectrometer (TES) provides monthly global maps of Ozone



Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry



CloudSat provides monthly maps of cloud ice water content

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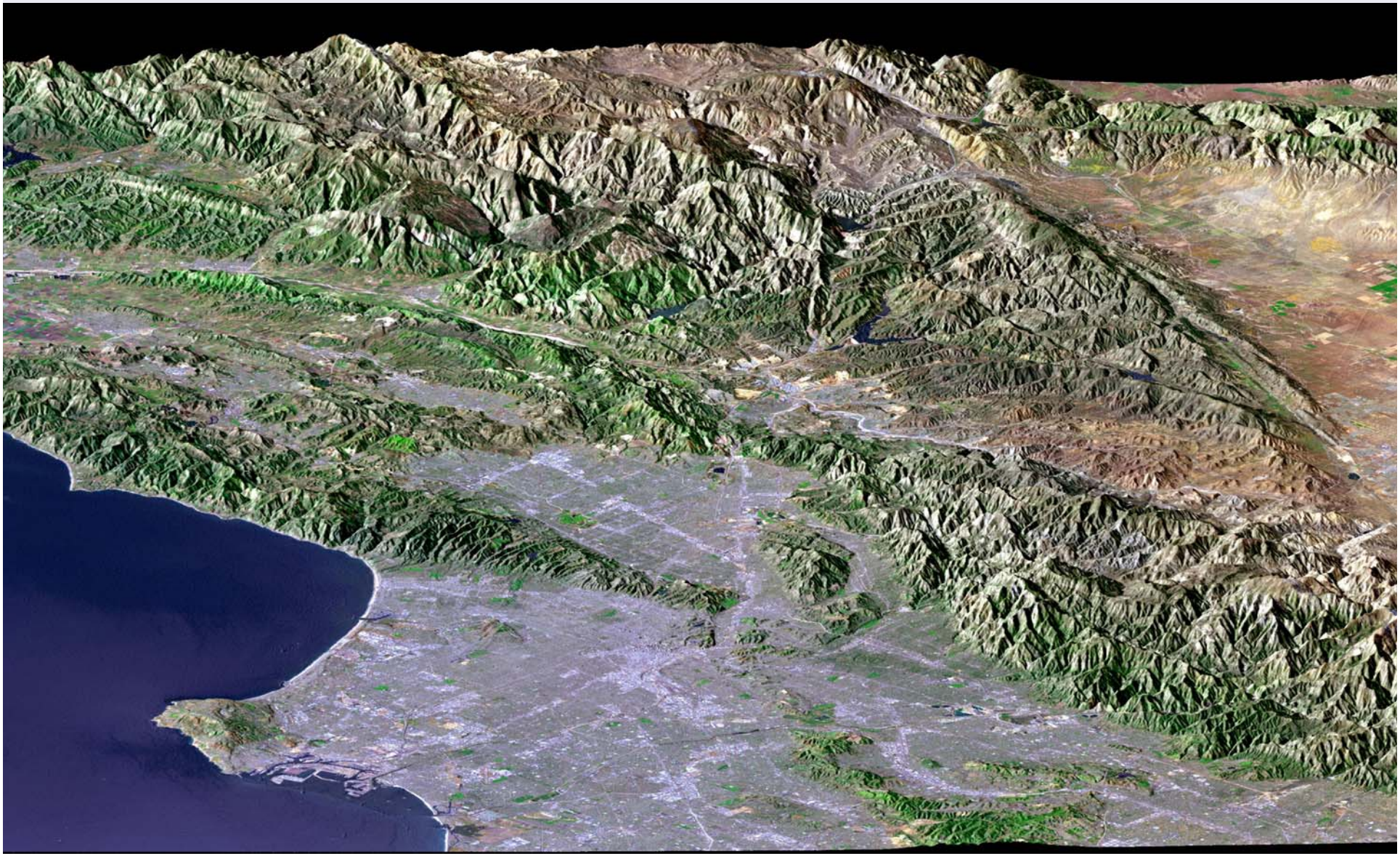
Shuttle Radar Topography Mission (SRTM) image of Los Angeles (2000)



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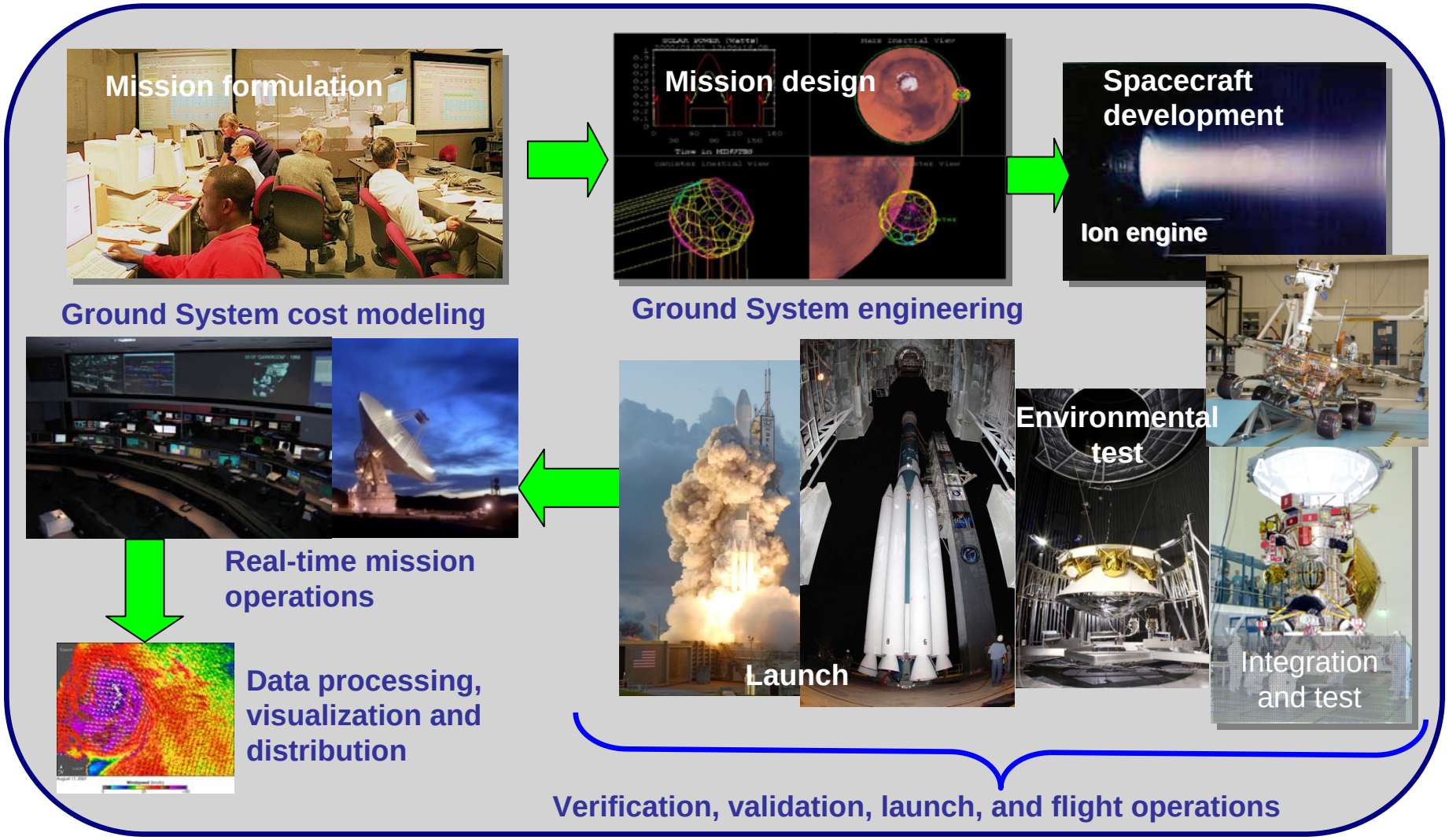
Ground Systems contribute to mission success during all mission life-cycle phases



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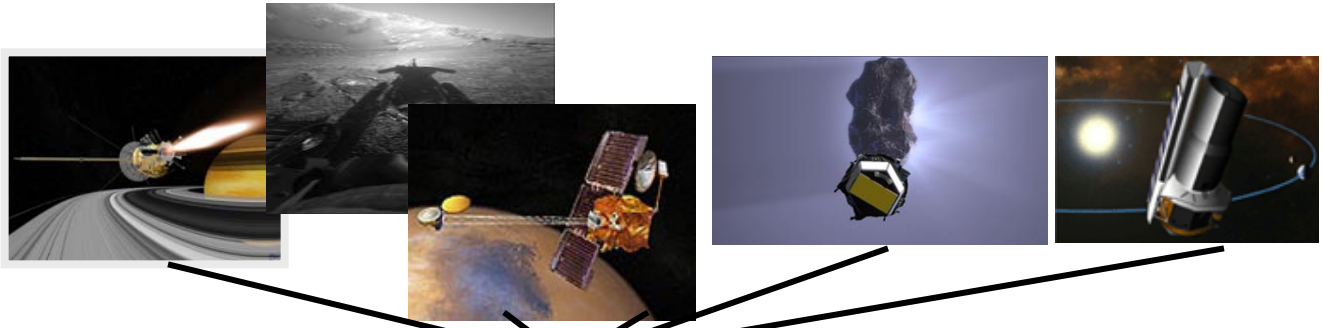
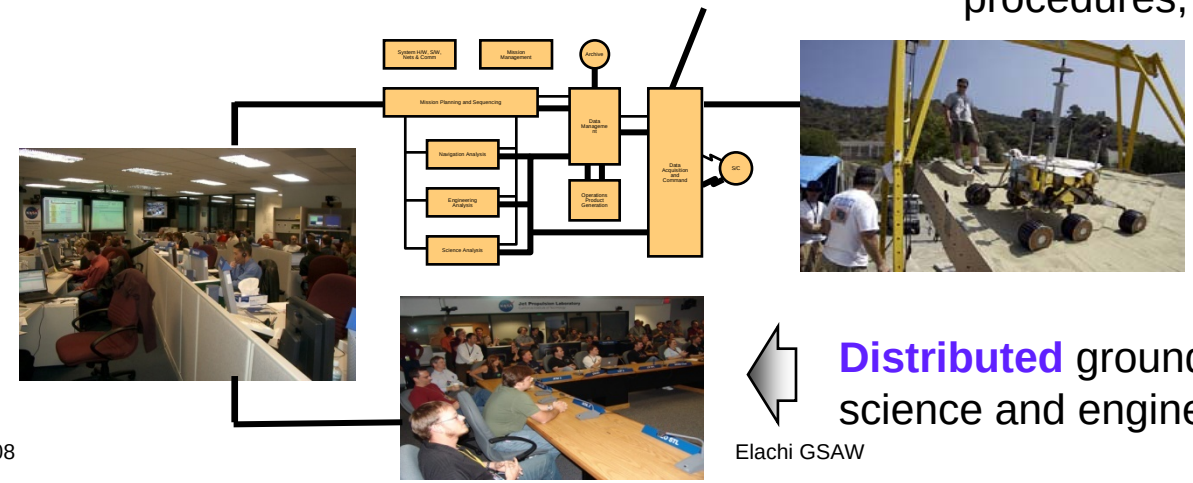
Ground system implementation challenge for JPL missions



Multiple **one-of-a-kind** missions… each with unique challenges

Common tracking, command, telemetry and data management services

Flexible multi-mission operations infrastructure—processes, procedures, teams and facilities



Adaptable multi-mission software systems for mission-unique requirements

Distributed ground system capabilities for science and engineering **interoperability**

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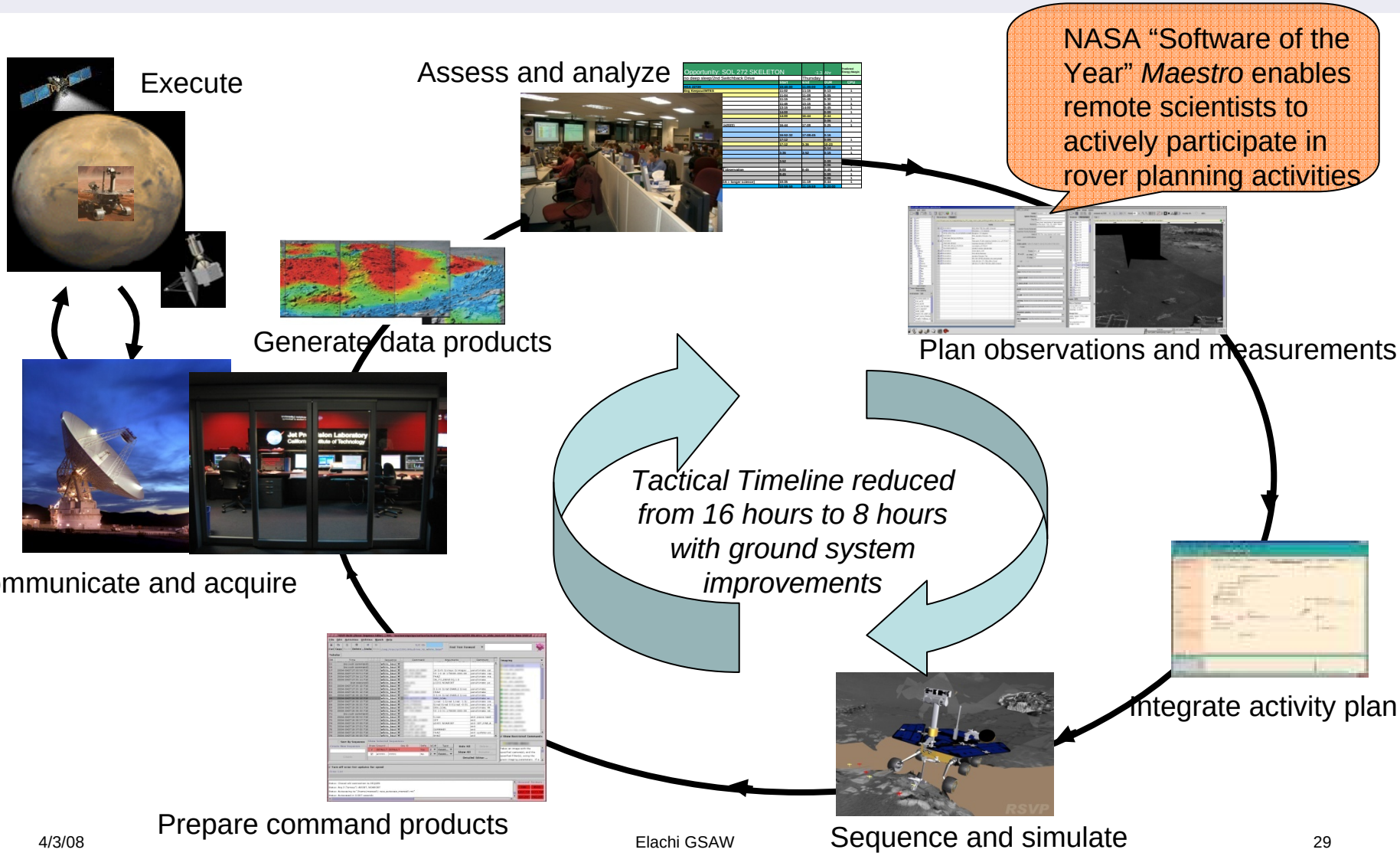
Mars Exploration Rovers: An example of an operationally responsive ground system



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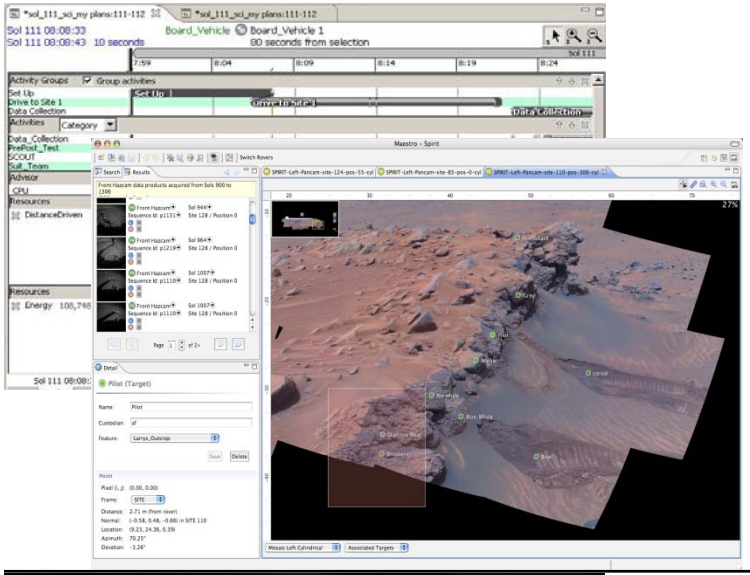
Mars Science Laboratory (MSL): Infusion example of ground system software technologies



MSLICE (MSL Operations Interface)

- Seamless integration of cutting edge visualization and planning tools for Mars surface missions.
- Allows scientists to rapidly search spacecraft data temporally and spatially.
- Automatically validates plans against flight rules and science constraints.
- Enables collaboration by geographically distributed users.

Mission Data Processing System

- Multi-mission, DISA-compliant downlink processing framework.
- Event-driven capabilities enabled by component architecture.
- Supports flight system integration and test through operations, starting with flight software test bed.

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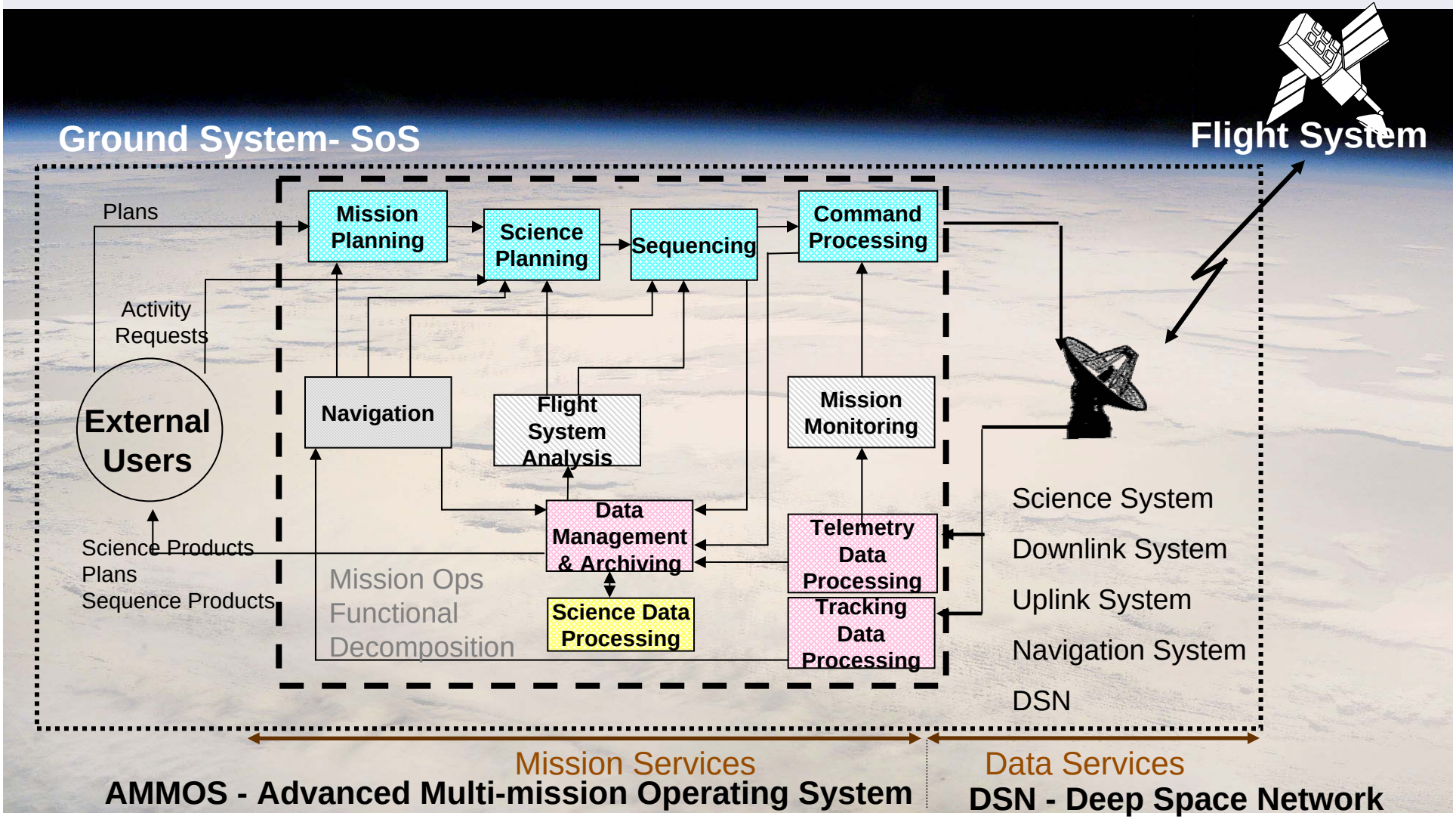
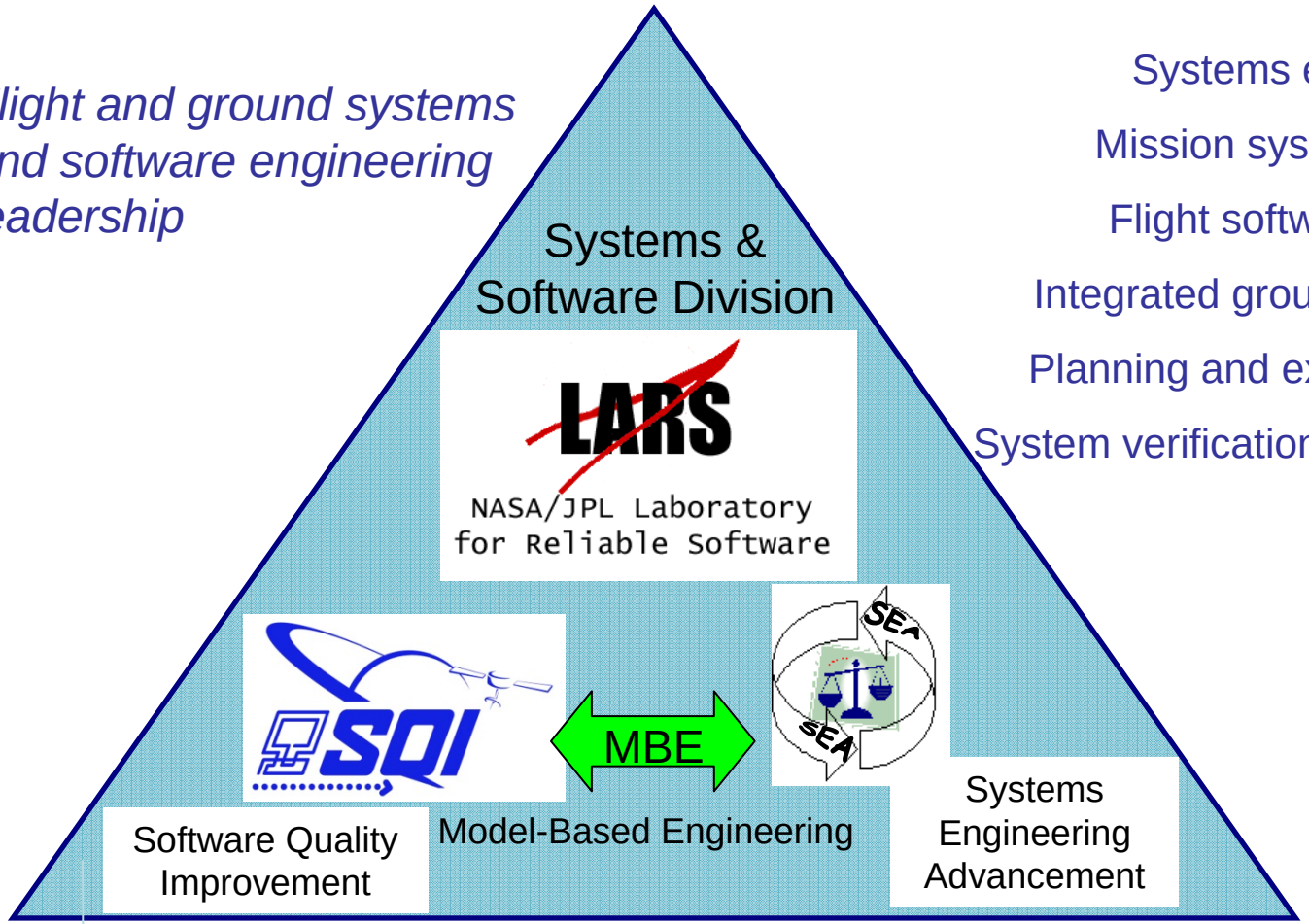
JPL's ground system is the product of a multiple systems integration activity



JPL's Systems and Software Integrated Management and Operability

Flight and ground systems and software engineering leadership



Systems engineering

Mission system concepts

Flight software systems

Integrated ground data systems

Planning and execution systems

System verification, validation and ops

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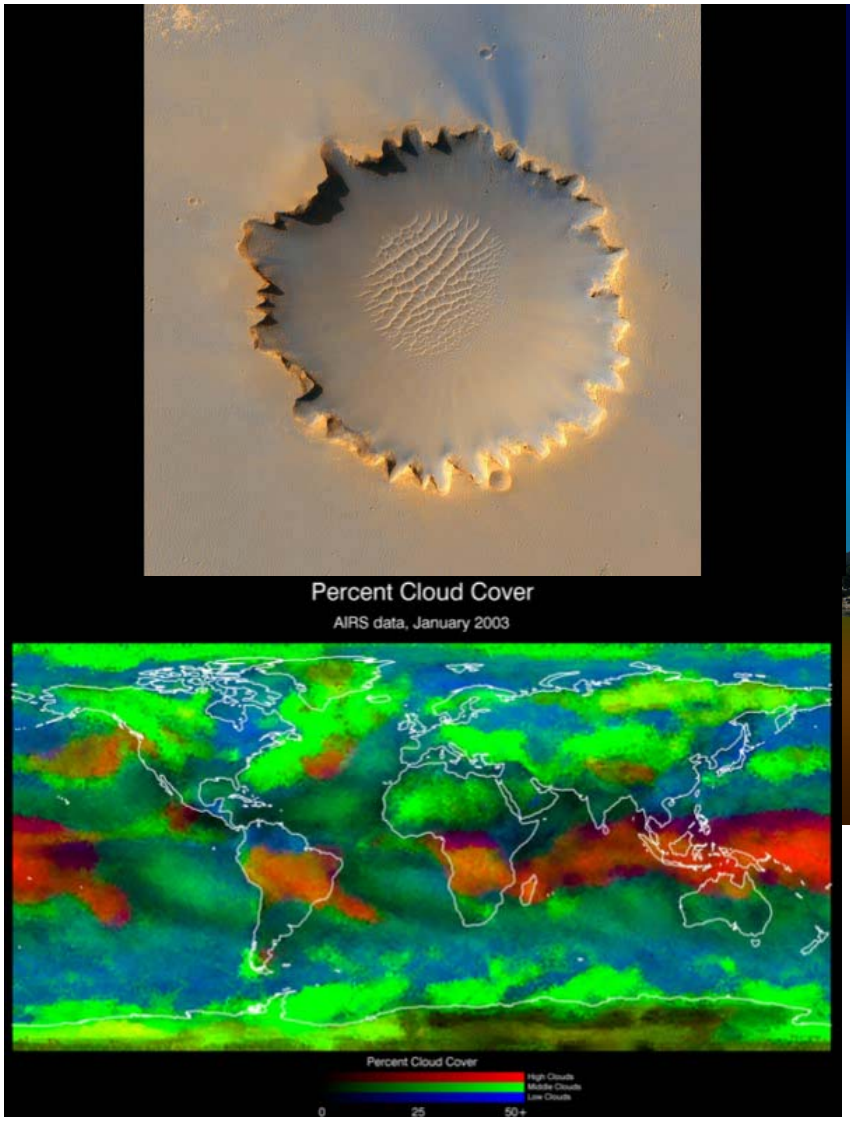
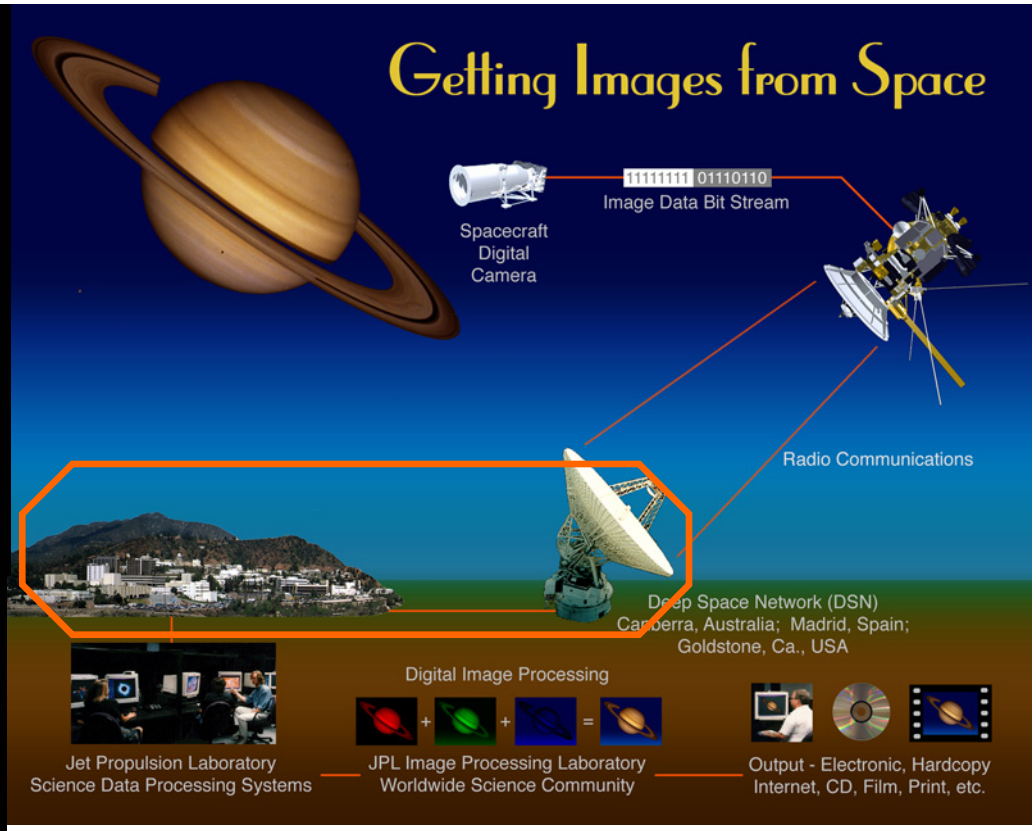
In the end, science application and utilization is what matters.





The Ground System science data processing systems provide both science communities and the public a window into space.

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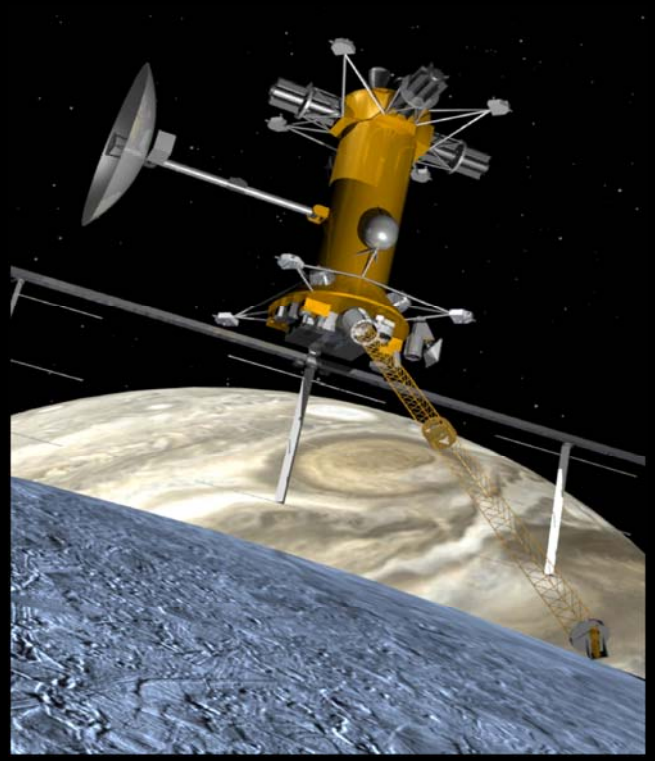
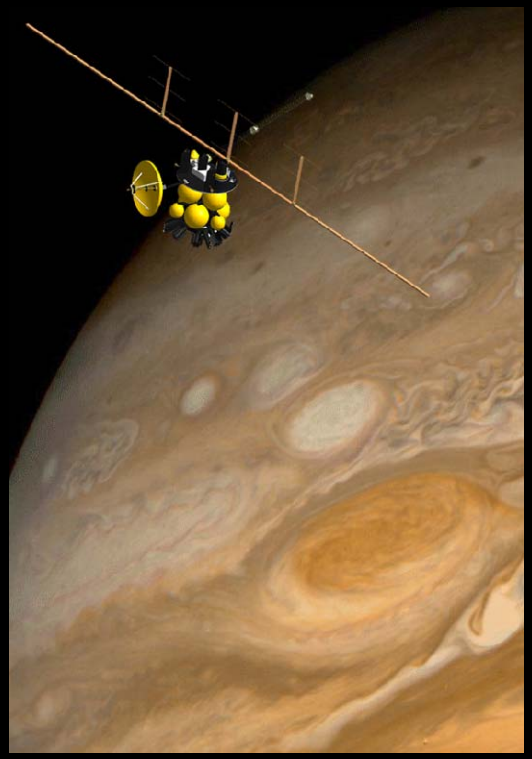
Future solar system exploration: *Flagship Mission Studies*

Europa Explorer



Titan Explorer

Jupiter System Observer



Water, organics, and prebiotic chemistry…
the evolution of habitable environments

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Future Robotic Mars Exploration:
From water, to habitability, to life, and better understanding of Mars' history