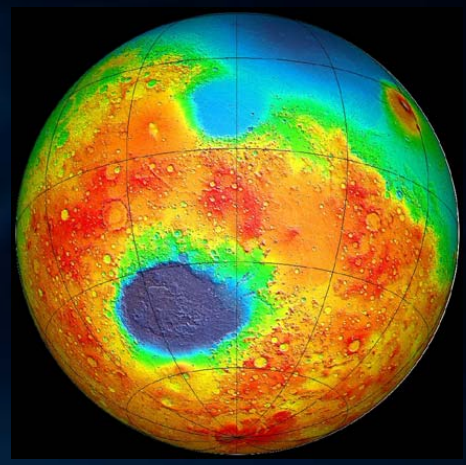
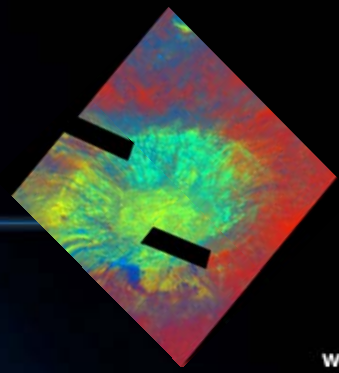
National Aeronautics and Space Administration



Discovery-Driven Science:

Rule or Rarity?

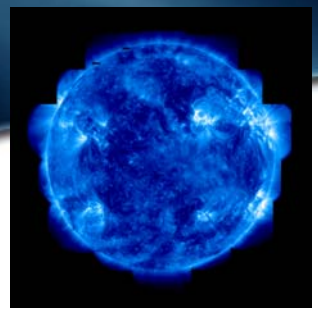


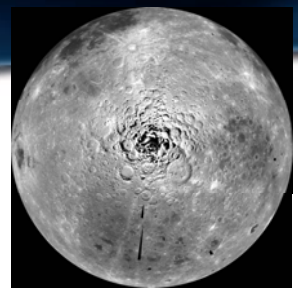
PI Forum, Annapolis MD *2008*

Dr. Jim Garvin
Chief Scientist *(Solar System Exploration)*
NASA Goddard Space Flight Center

www.nasa.gov


Before NASA, *discovery-driven science*
was "human based" (von Braun, '50's)
but that's not how it turned out…





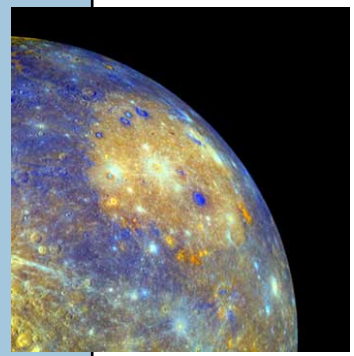
OUTLINE:

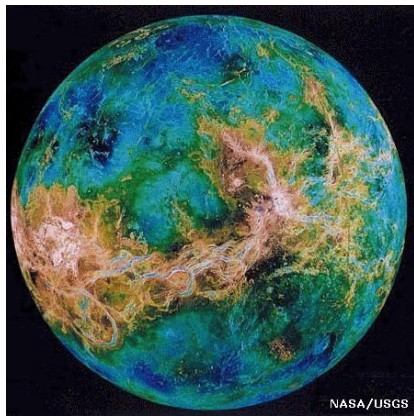
- What “*discovery-driven*” means (*maybe?*)

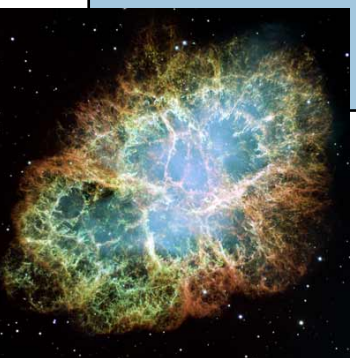
- Examples of “discovery-driven” science

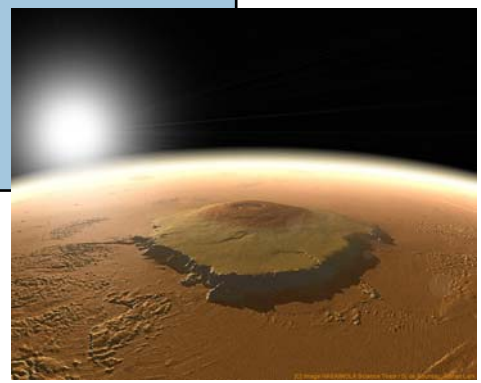
- Future possibilities to consider

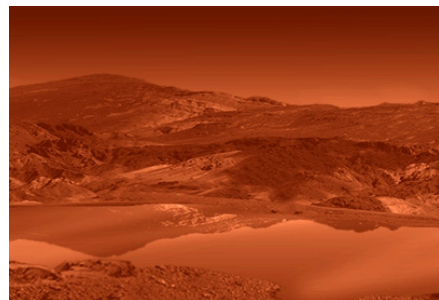
- Lessons learned/Summary

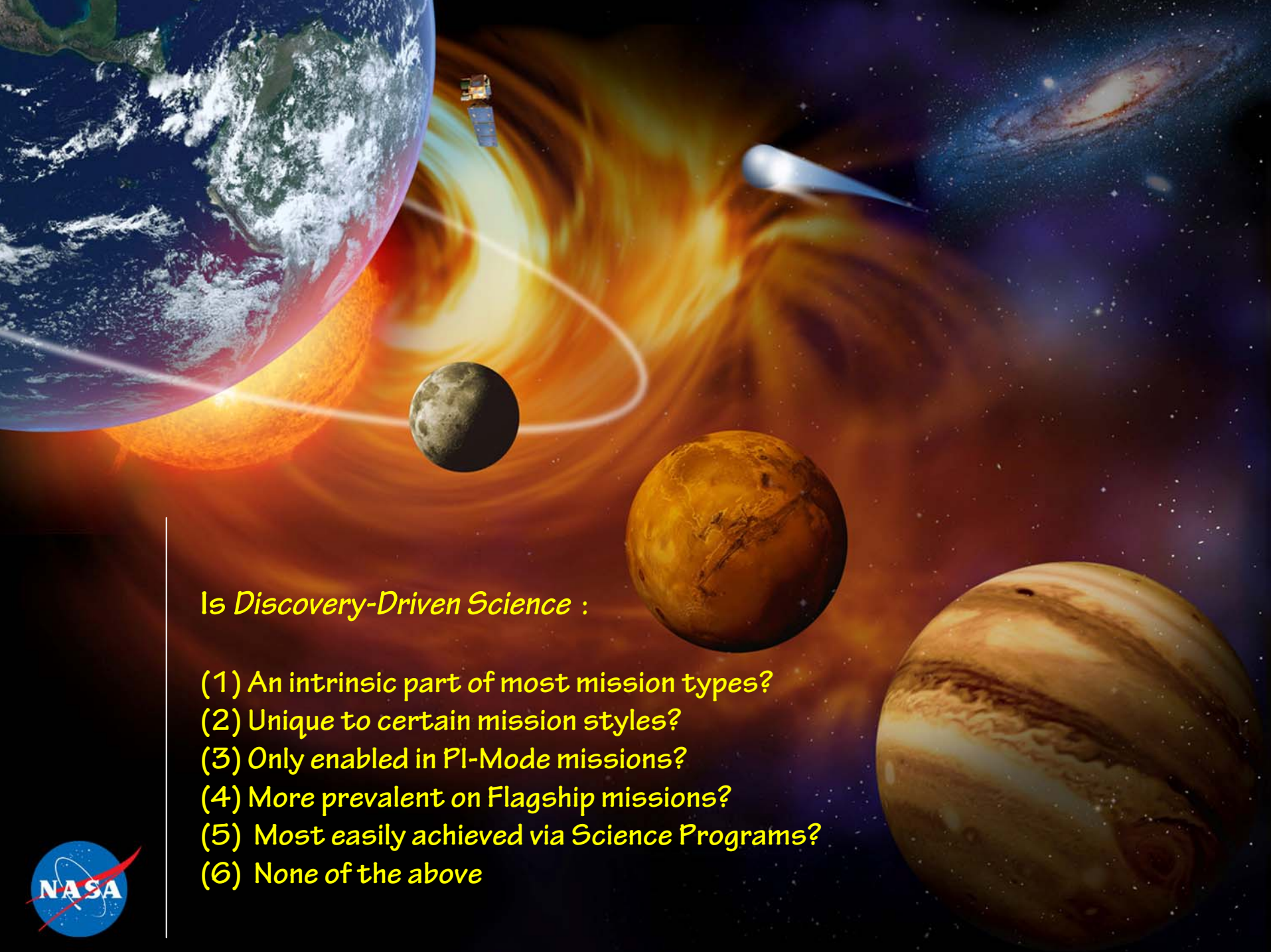












Is *Discovery-Driven Science* :

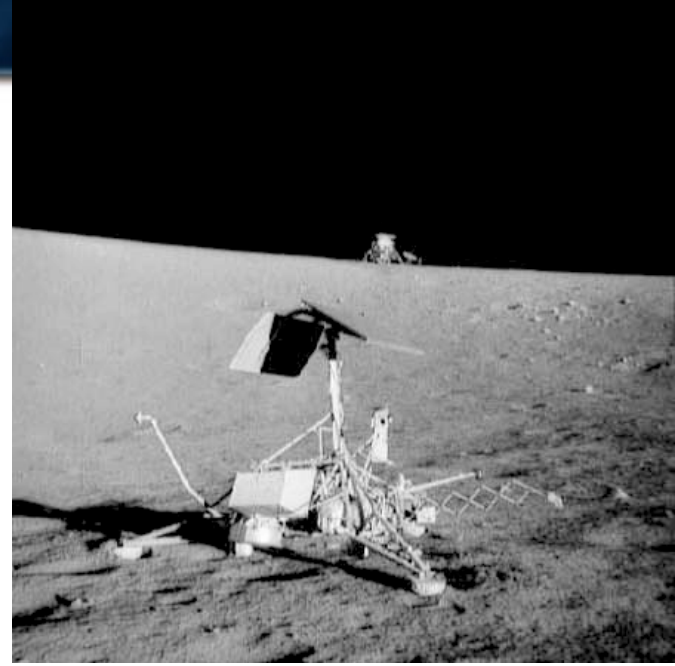
(1) An intrinsic part of most mission types?
(2) Unique to certain mission styles?
(3) Only enabled in PI-Mode missions?
(4) More prevalent on Flagship missions?
(5) Most easily achieved via Science Programs?
(6) None of the above

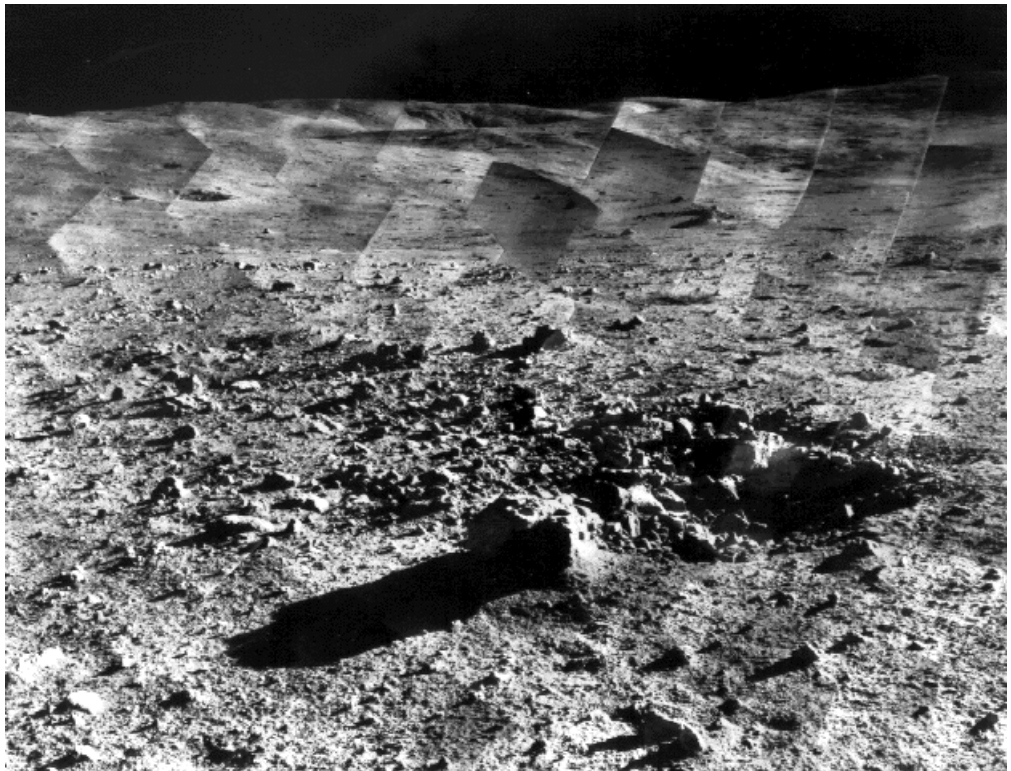
NASA's 1st Robotic Pathfinders:

SURVEYOR

on the Moon…

All observations and measurements were new and provided discoveries in their own right…

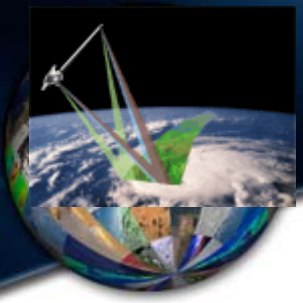




Was the SURVEYOR Program trully "discovery-driven" ?

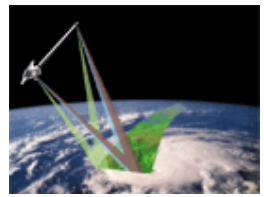
Human exploration of the lunar surface provided a unique opportunity for "discovery-driven" science – discoveries enabled by humans on-site… plus samples returned to Earth for detailed discoveries

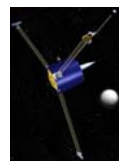
Human adaptation with in situ cognition and dynamic reprogramming

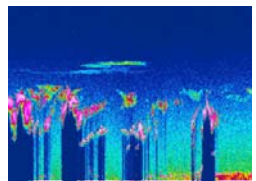


Examples of Discovery-Driven Science in Action:

- GRACE (*first ESSP, PI-mode*)
- SIR-A (*and SIR-B, SIR-C*)
- COBE and WMAP (*MIDEX, PI-mode*)
- Radarsat-1 (*CSA, commercial-science*)
- Venera 13, 14 (USSR to surface of Venus)
- Viking (*Flagship*)
- Mars Global Surveyor (*payload competed with PI's*)
- Mars Exploration Rovers (*payload competed with PI*)
- PHOENIX (*first Mars Scout, PI-Mode*)
- MRO (*payload completed*)
- Cassini (*Flagship*)
- ICESat-1 (*EOS Program mission*)
- SLA (STS-72, STS-85) [*Hitchhiker on STS*]
- Lunar Prospector (*first Discovery, competed in PI-mode*)
- Apollo lunar samples (*science competed*)
- HST (*Flagship*)
- MESSENGER (*Discovery, PI-mode*)
- Stardust (*Discovery, PI-Mode*)
- Calipso (ESSP, PI-mode) … *and so many more*

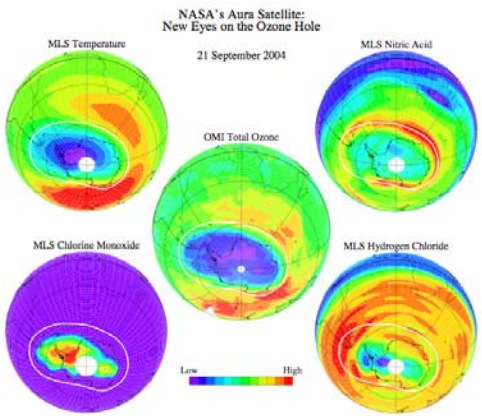


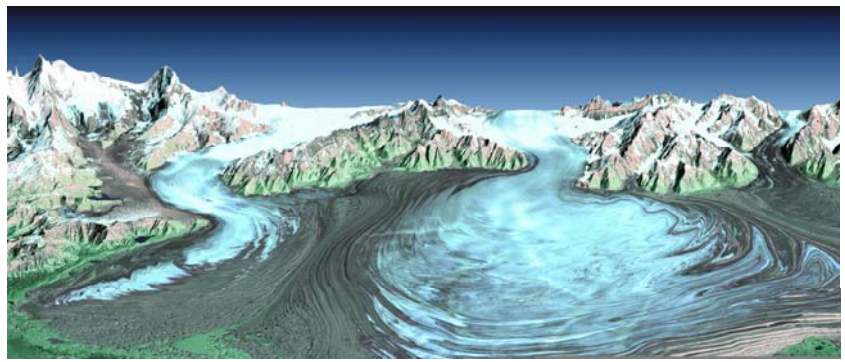




Earth Science Questions

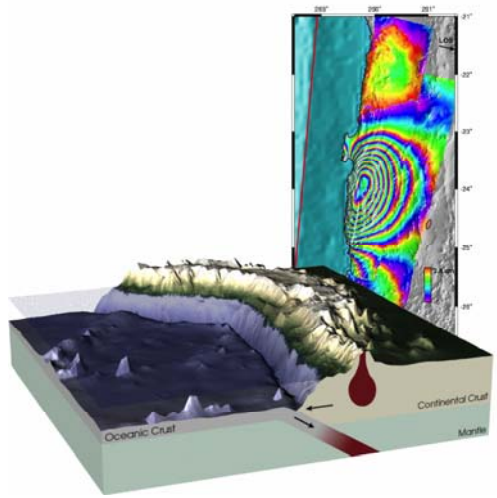
How is Earth changing?





Science Questions:

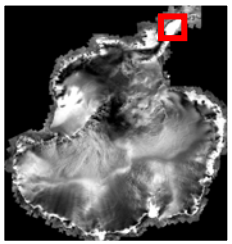
- What changes are taking place in atmosphere-ocean circulation?
- How is land cover and land use changing?
- What changes are taking place in the water and energy cycle? What about the missing Carbon?
- How is atmospheric composition changing?
- How does solar radiation vary?
- How will all of these changes affect climate?

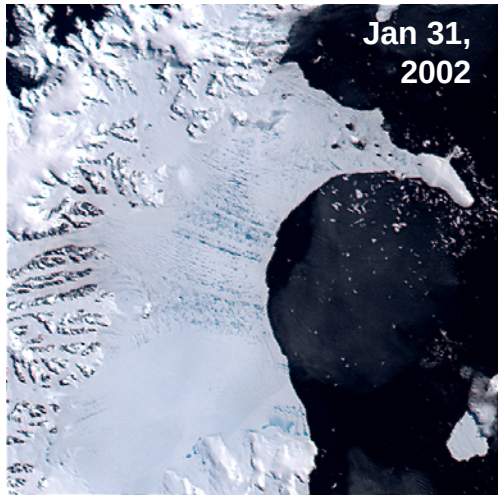


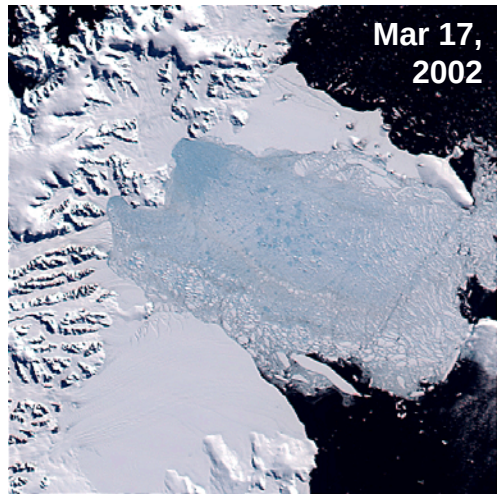
Discovery-Driven Science matters for EARTH !!

E.g., Polar Ice is Changing Dramatically

Antarctica

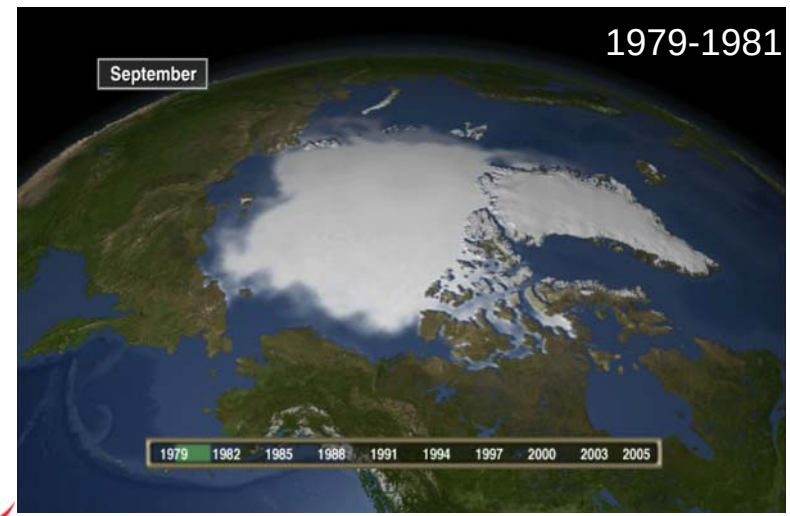


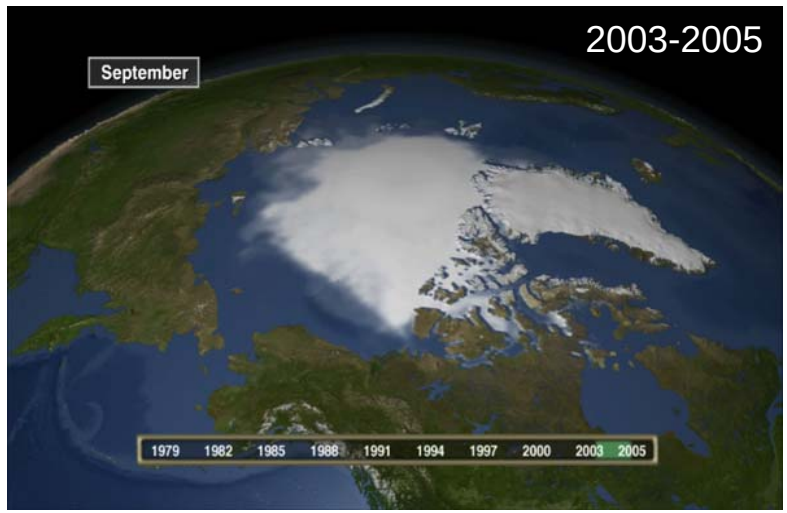




Off the Antarctic Peninsula 3250 sq. km of 12,000 year-old, 700 feet thick ice shelf disappeared in 5 weeks, causing glaciers to accelerate up to 8-fold, flushing their ice into the sea

Arctic perennial ice is shrinking at a rate of nearly 10% per decade





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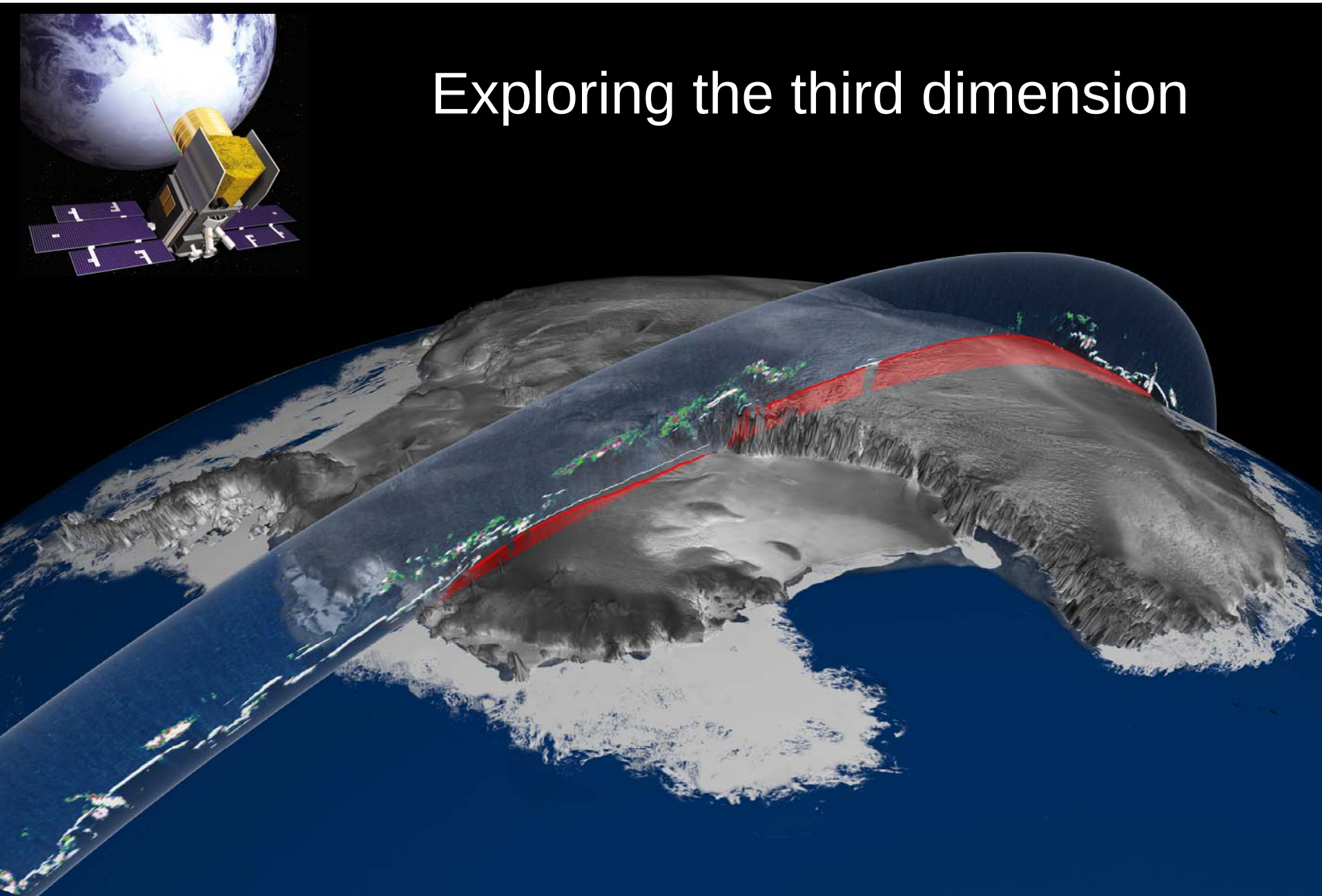
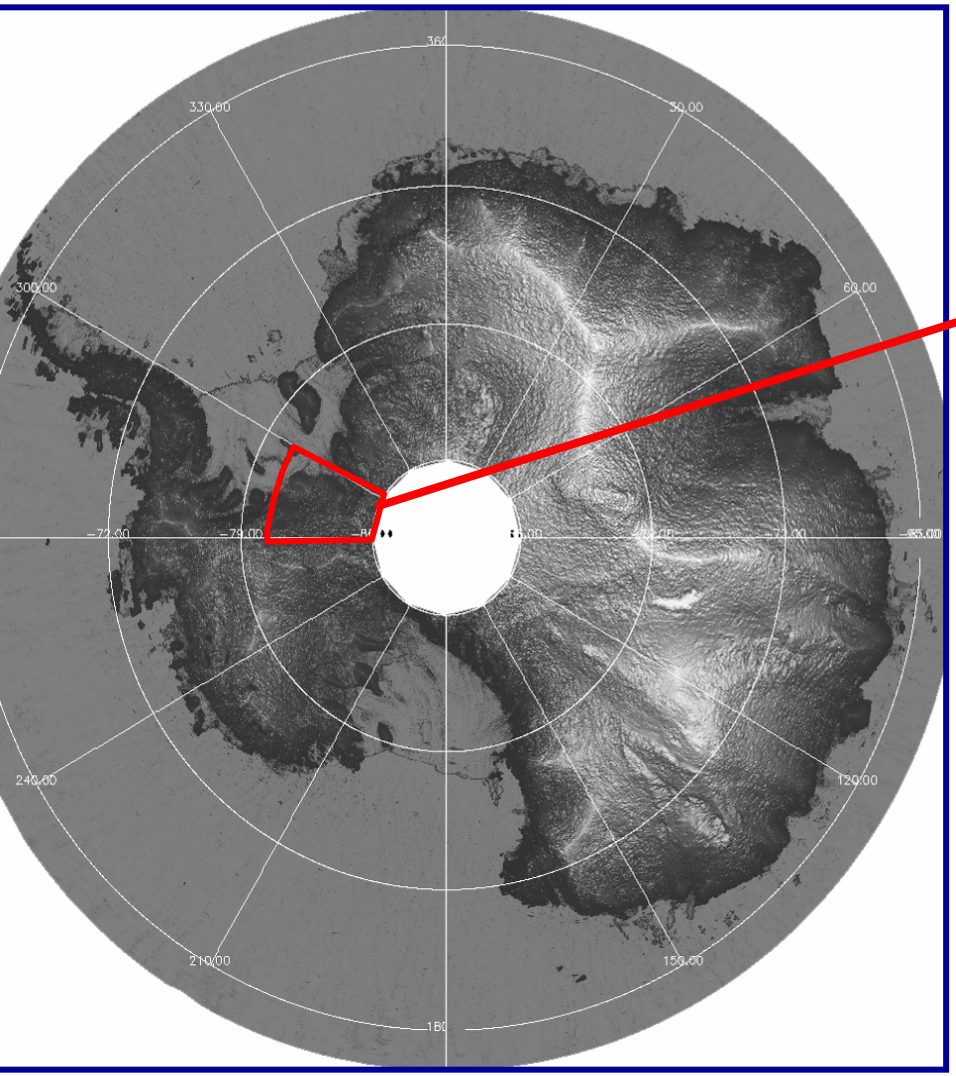
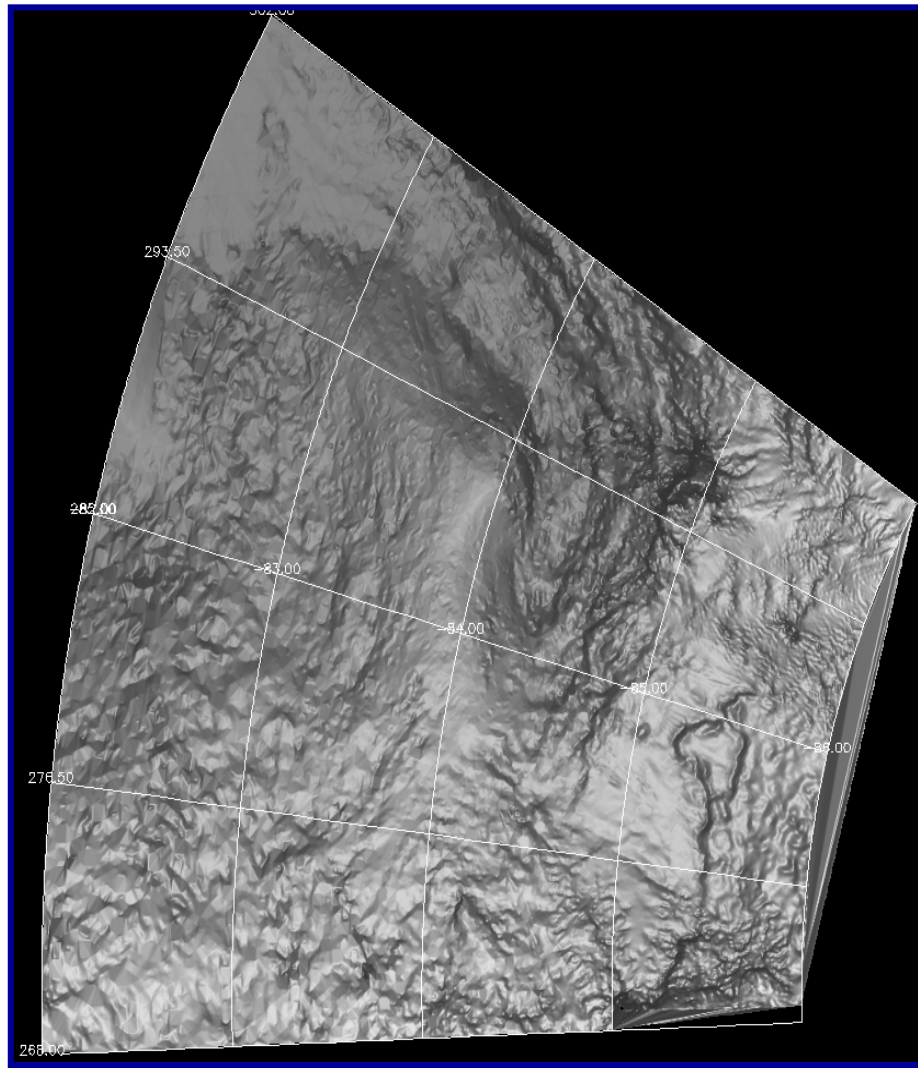
Discoveries enabled by the Earth Science Program with connectivity

Ice Cloud and Land Elevation Satellite (ICESat)



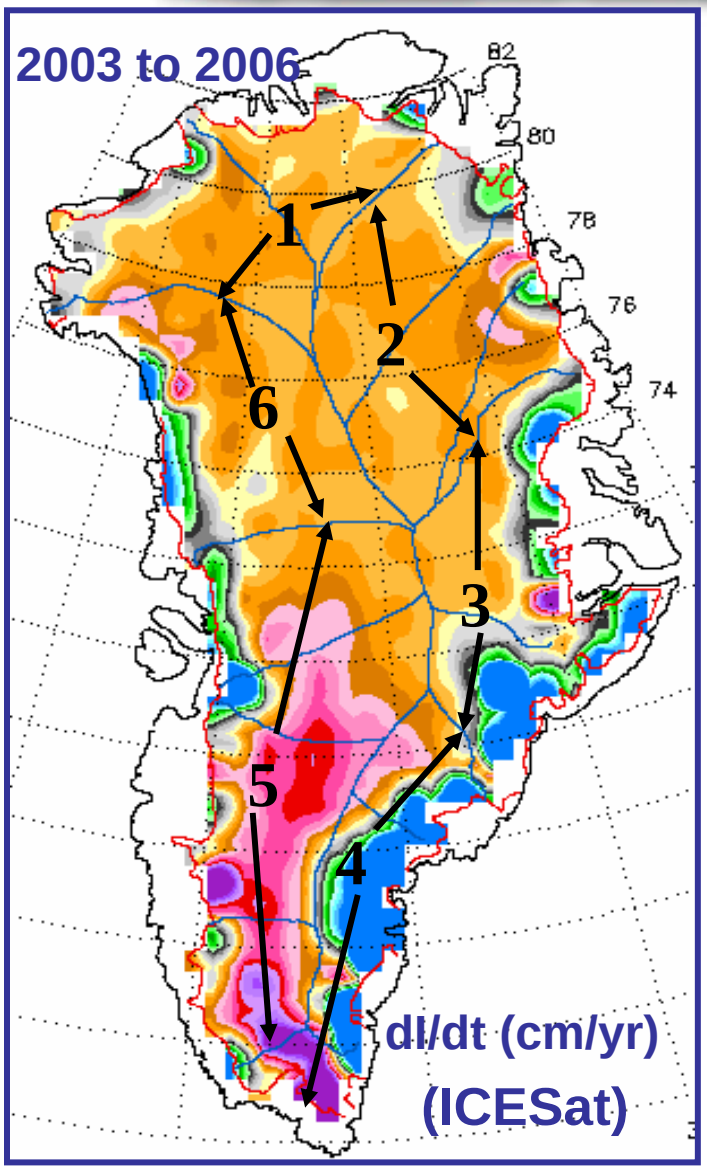
ICESat 1 km DEM of Antarctica with local area 500m scale DEM as Topographic Reference

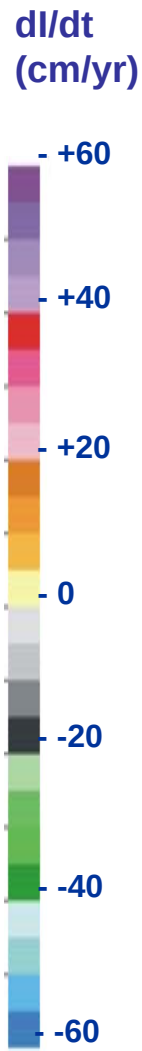




Geodetic topography provides DISCOVERY-DRIVEN Science opportunities

Ice Sheet Thickness Changes from ICESat





- First results from precision repeat-track analysis: a unique capability of ICESat laser altimetry.
- Enhanced thinning at margins and enhanced inland growth since the 1990's.
- Increased net loss of mass since 1990s.
- Provides high-resolution details of increasing ice losses in ice drainage systems 3, 4, upper 5, and 6 where increasing ice quakes have been detected and outlet glaciers have been accelerating.

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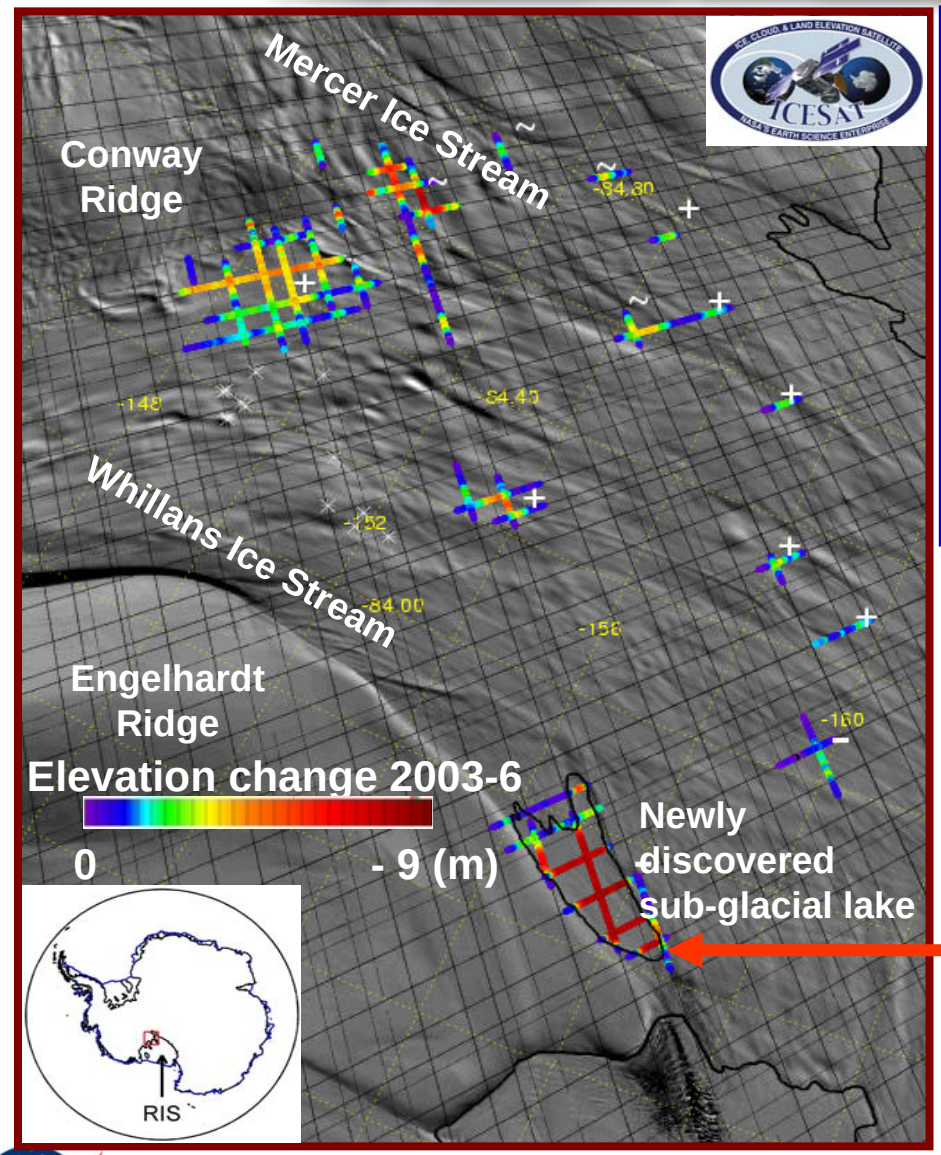
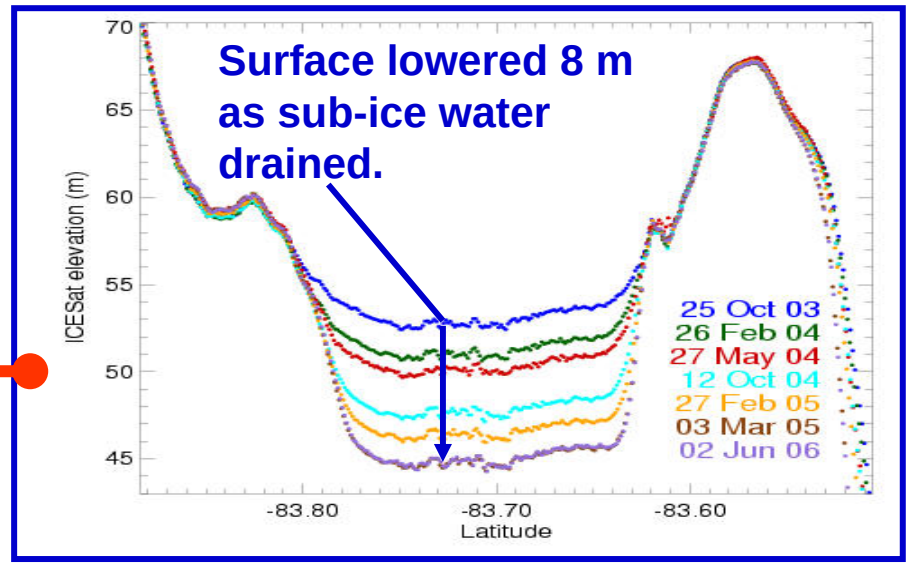
Are these results "discovery-driven"? WHY NOT!

Ice Sheet Science: Sub-glacial hydrology



- ❑ Widespread sub-glacial water system beneath West Antarctic ice streams discovered with ICESat laser altimetry.
- ❑ Surfaces inflate as subglacial lakes fill and deflate as they drain.
- ❑ Providing revolutionary new information on sub-glacial processes that affect rates of ice discharge from polar ice sheets.



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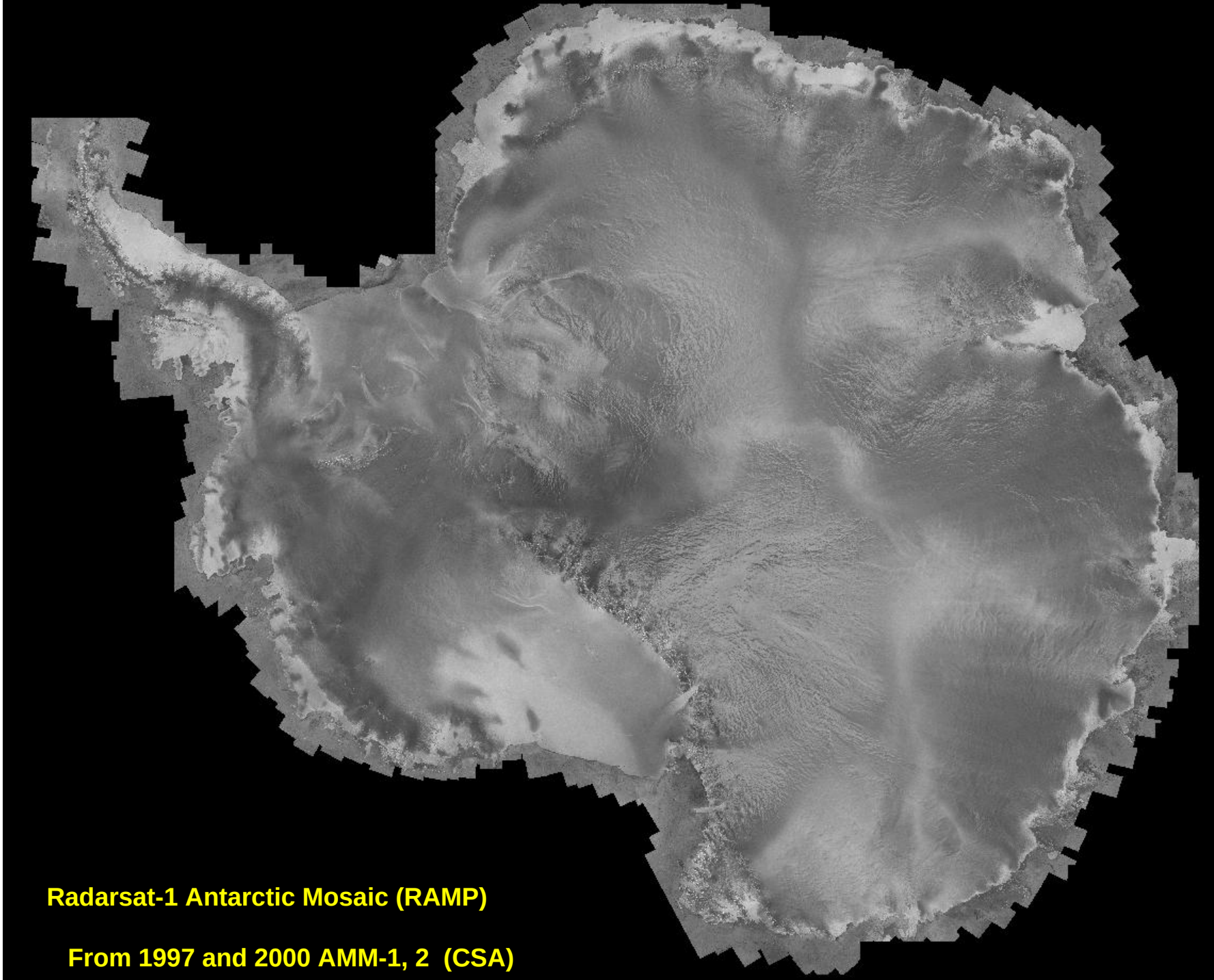
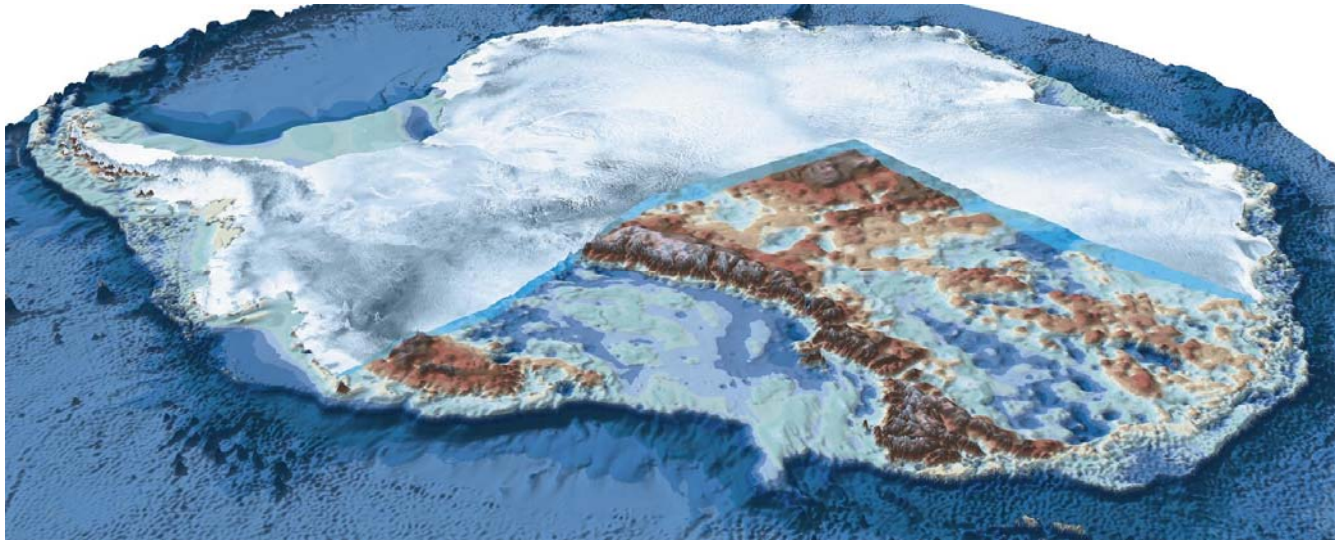
DISCOVERY DRIVEN SCIENCE in ACTION via the EOS "System"



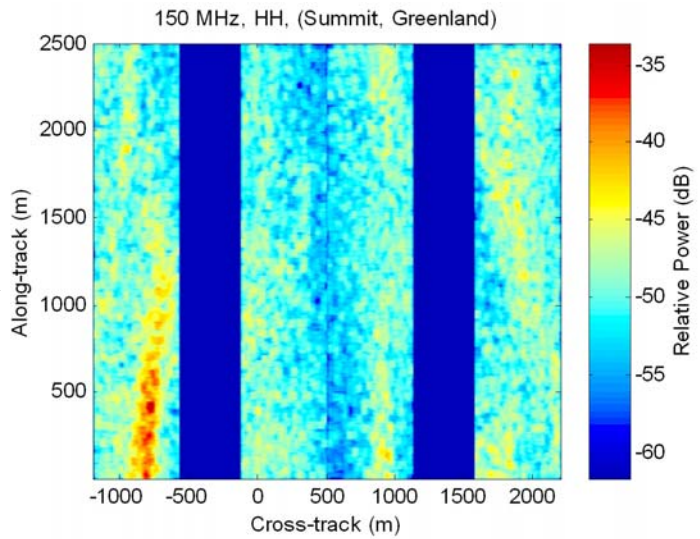
Radarsat-1 Antarctic Mosaic (RAMP)

From 1997 and 2000 AMM-1, 2 (CSA)

What is the topography underlying the Antarctic and Greenland Ice Sheets?



First 150 MHz SAR image of the base of the Greenland ice sheet (*c/o Prasad Gogenini, U. of Kansas)*

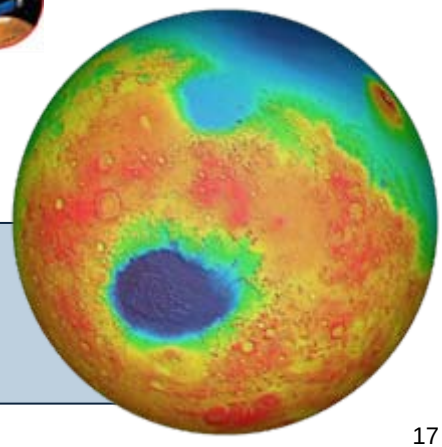


Discovery-Driven Science from Aircraft remote sensing here on Earth


Climatologically we are in unfamiliar territory, and the world's ice cover is responding dramatically
Discovery-Driven Science is required
(i.e., new Missions, new instruments etc.)

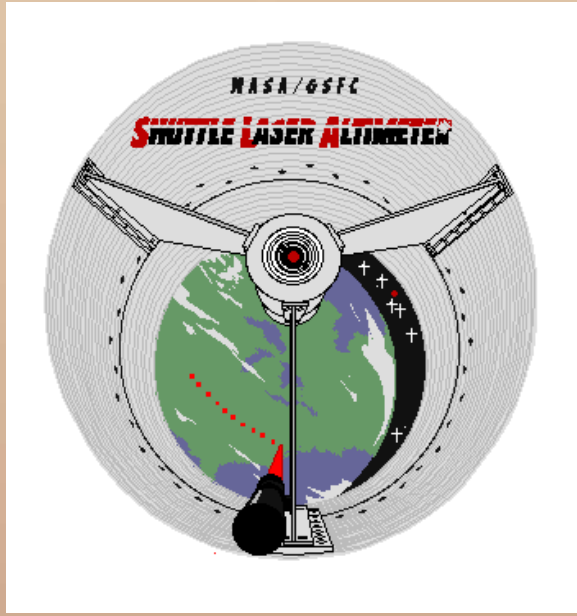
EXAMPLE: ***Discovery-driven science*** **from Shuttle small payloads:**
SLA-01, SLA-02 experiments on STS-72, STS-85:
Measured sub-meter topography and tree heights from space

SLA-1 on *Endeavour*

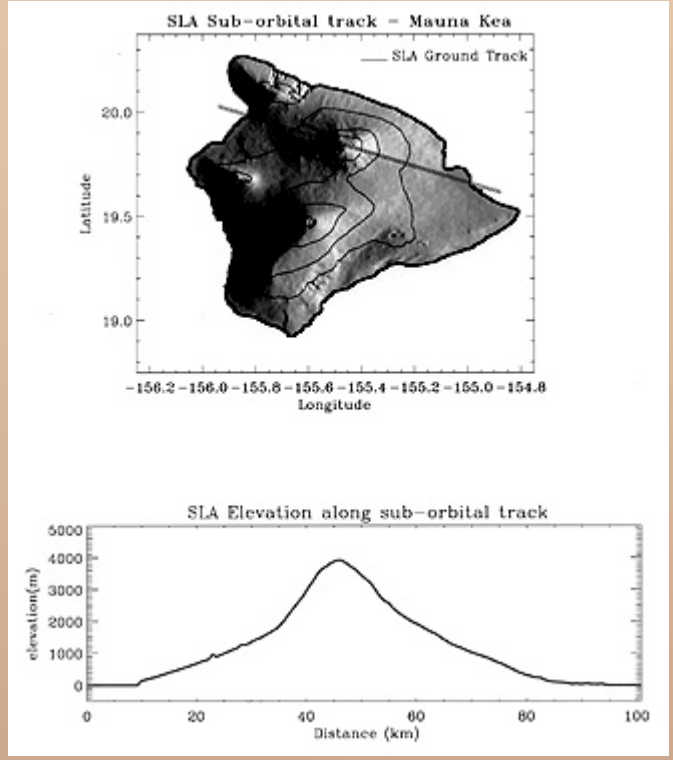


The Shuttle Laser Altimeter (SLA) technology was adapted for several missions including the Mars Global Surveyor which topographically mapped ~ 99% of the Martian surface.

ACCESS TO SPACE Provides DISCOVERY-DRIVEN SCIENCE opportunities



SLA Experiment: sensed the 3D Earth
to prepare for Mars, Moon... And beyond



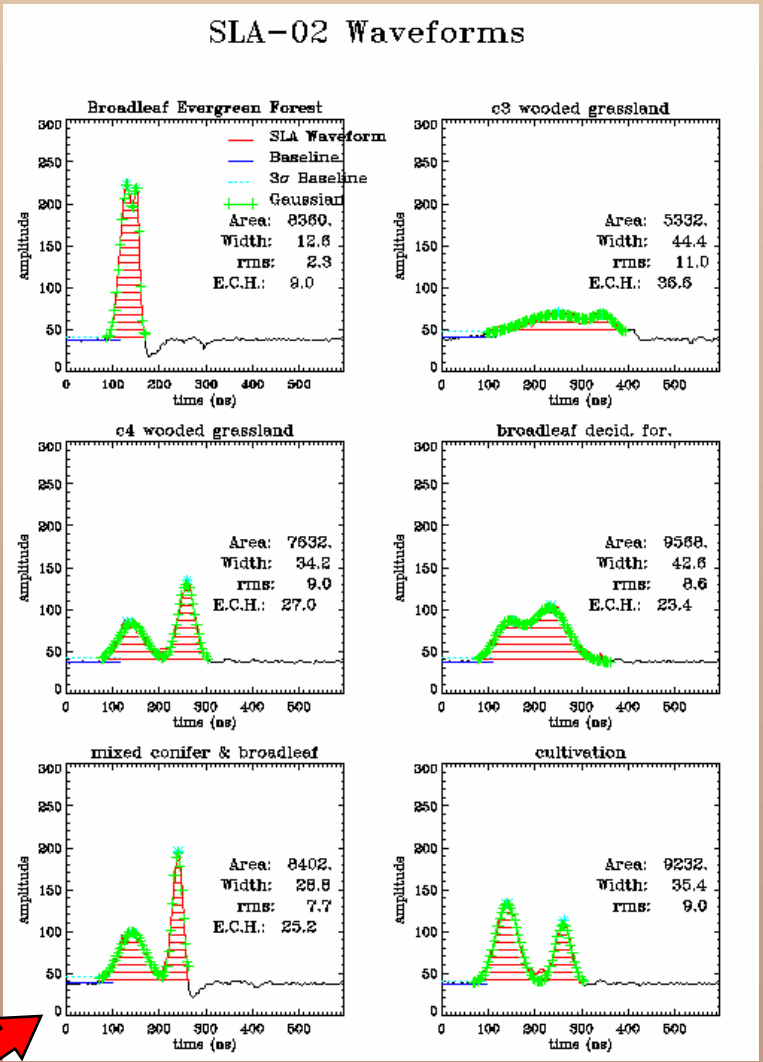
**First "landfall" on STS-72:
We mapped Hawaii at
30 cm scales**

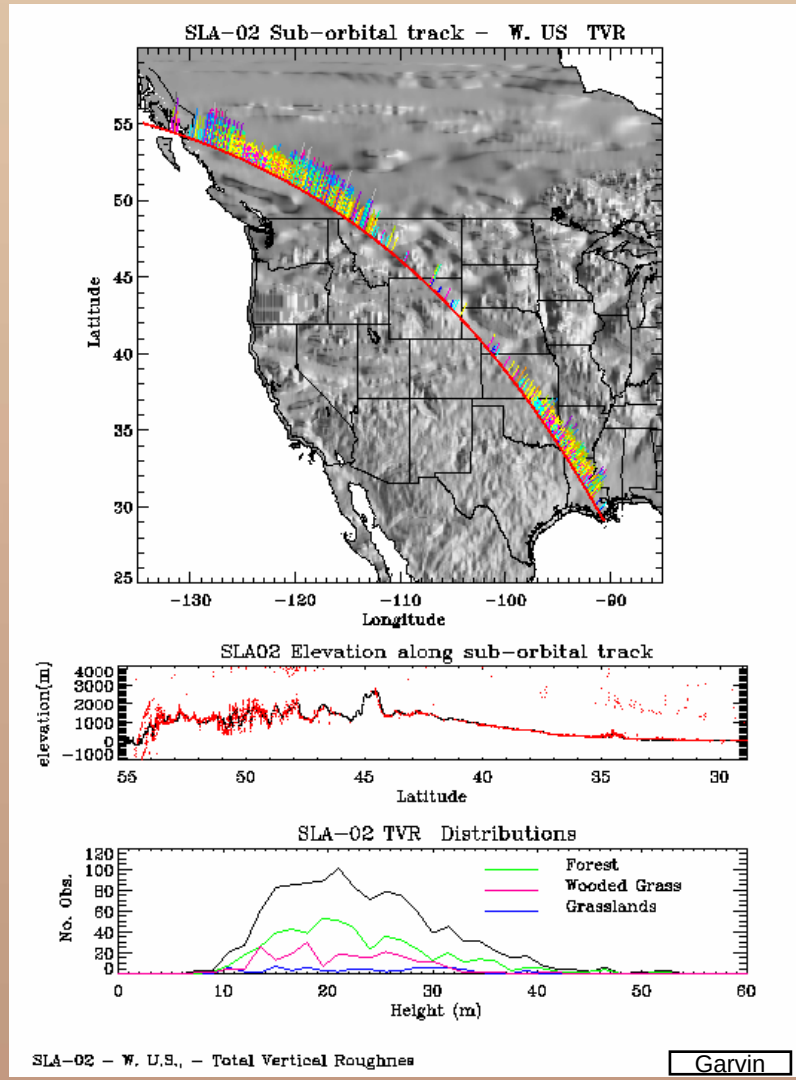
First light: over Pacific Ocean, Jan. 1996

**SLA
Team (GSFC)**

Shuttle Laser Altimeter

Discovered how to map Biomass from Space (3D)



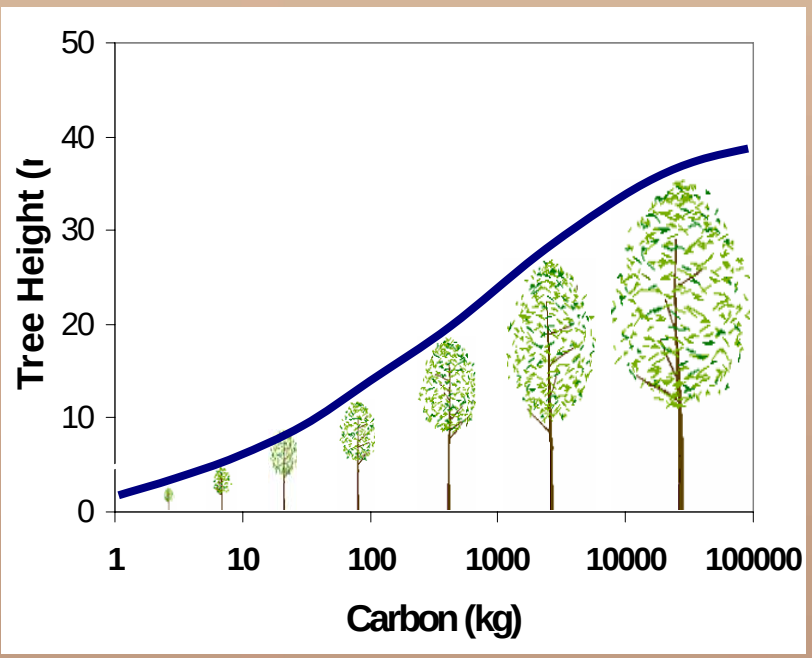


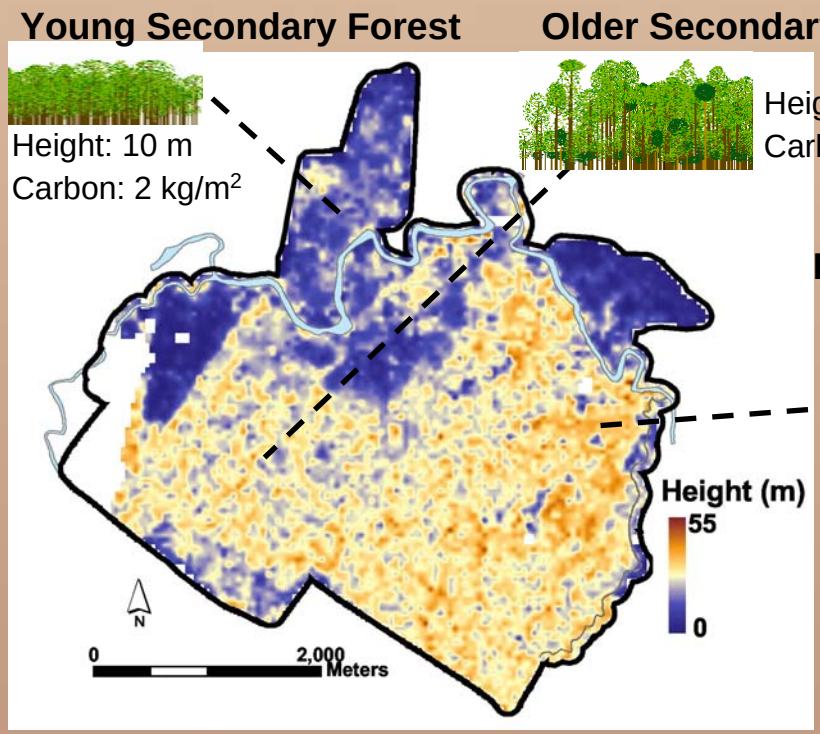
TREE HEIGHTS FROM SPACE!
(25m tall trees observed)

DISCOVERY-DRIVEN SCIENCE:

New Methods to Quantify Earth state variables

- Plant biomass (and carbon) generally increases with height and diameter
- Lidar instruments have accurately estimated height in a variety of terrestrial ecosystems and therefore provide an important metric to estimate aboveground biomass.



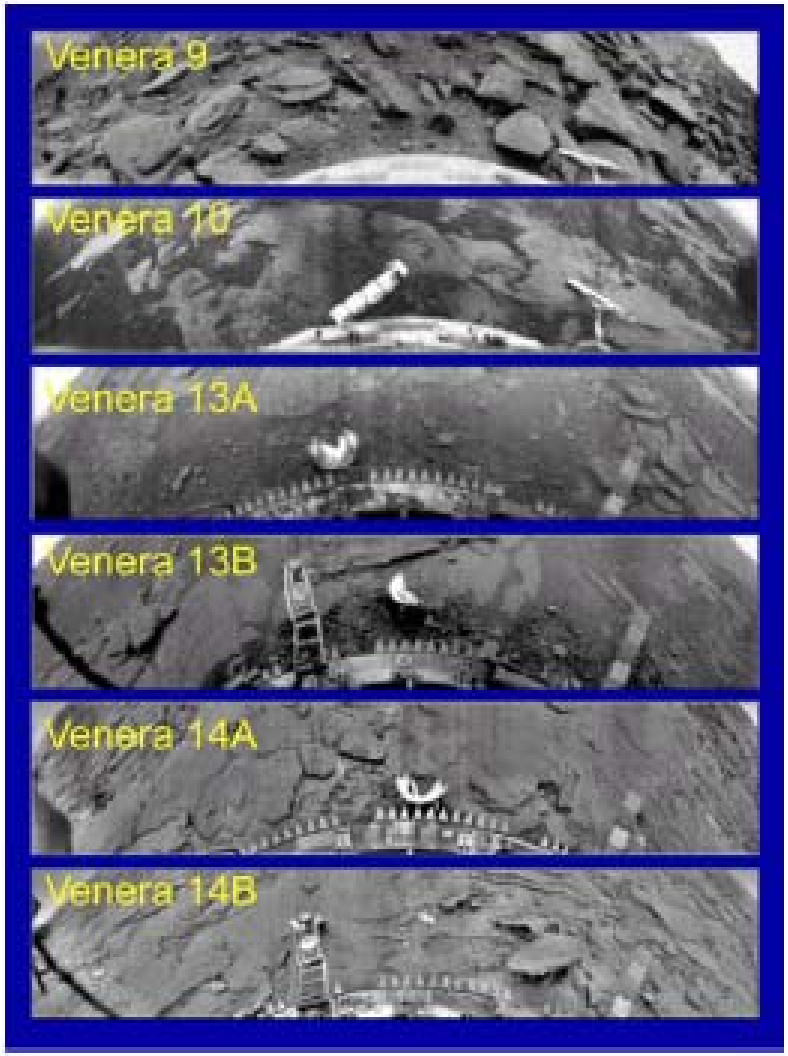


* This is the basis for part of the ES Decadal *DESDynI* mission

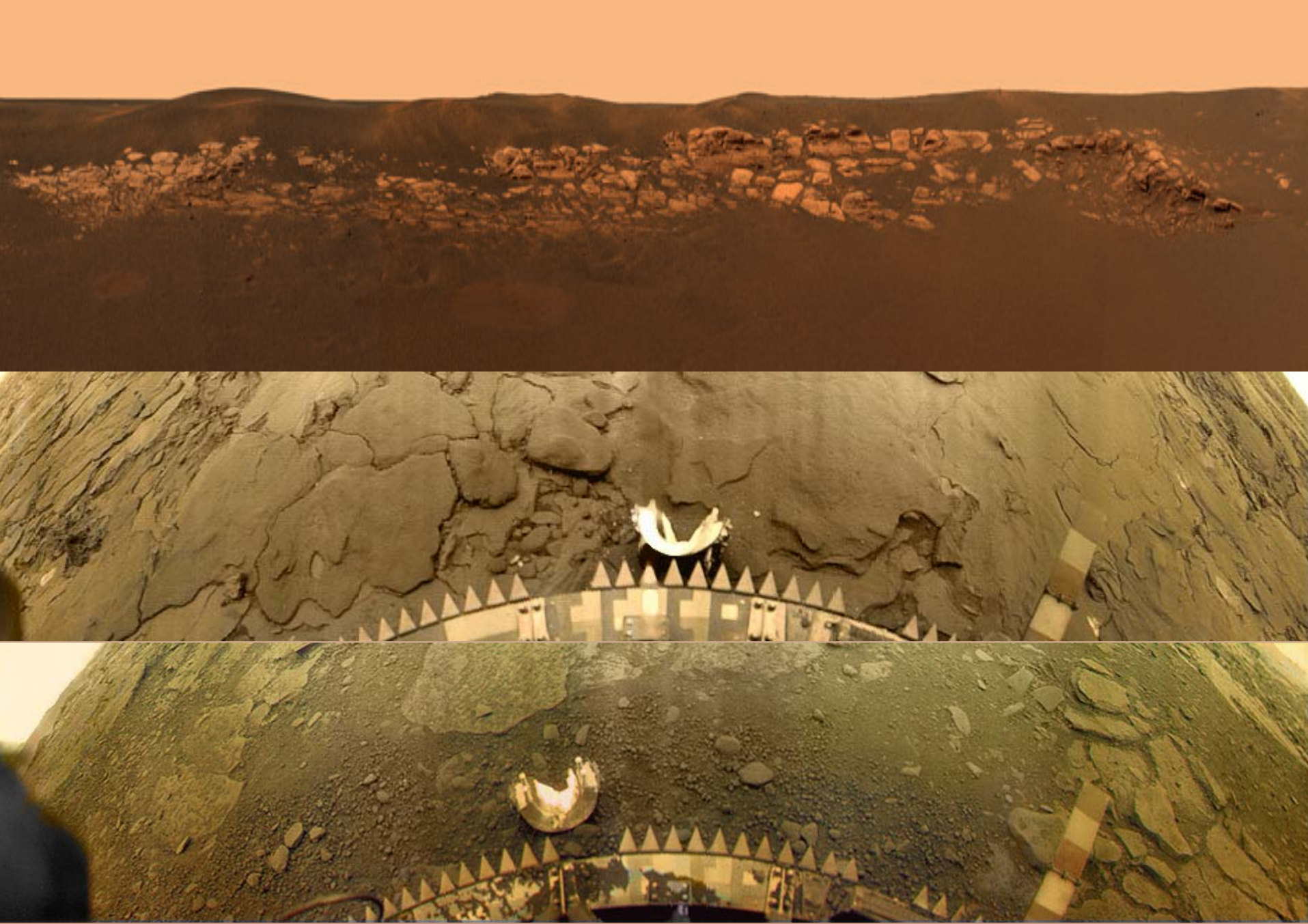
The Surface of VENUS...

Just *being there* enabled unique Discovery-Driven Science

But it left more questions than answers…
So the discovery-driven response was *Magellan*



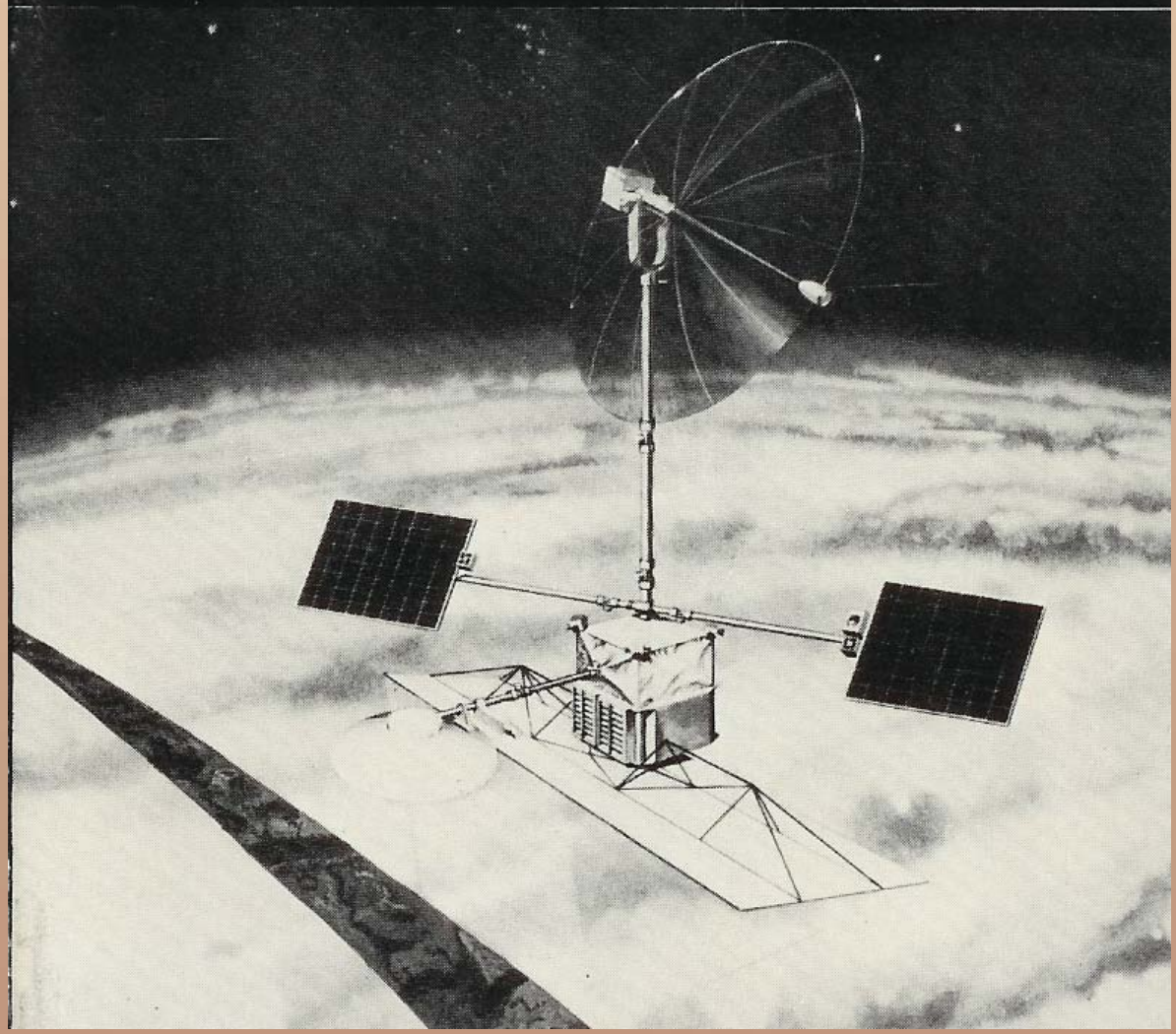
Russian Panaromas of the surface of Venus obtained by the Venera spacecraft.

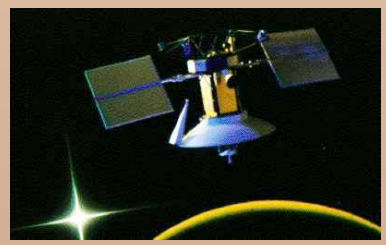


BEDROCK ON MARS VS VENUS – Discovery Driven Science in action…

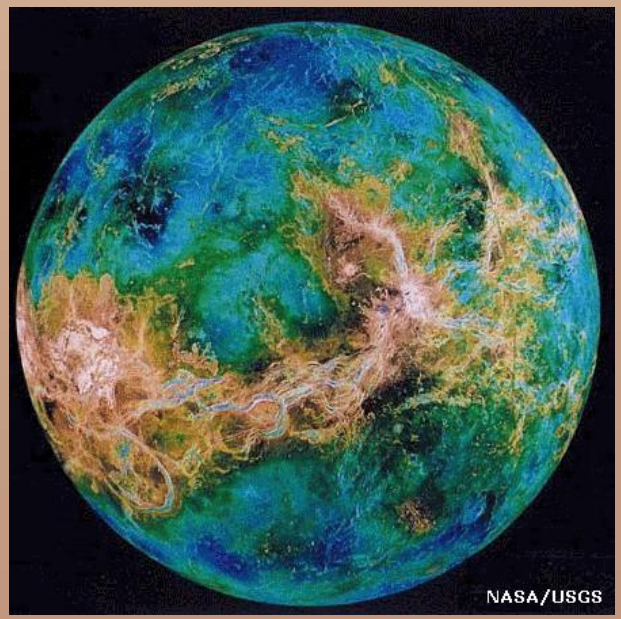
Plans for Discovery-Driven Science "evolve" as We plan…

VOIR to Magellan

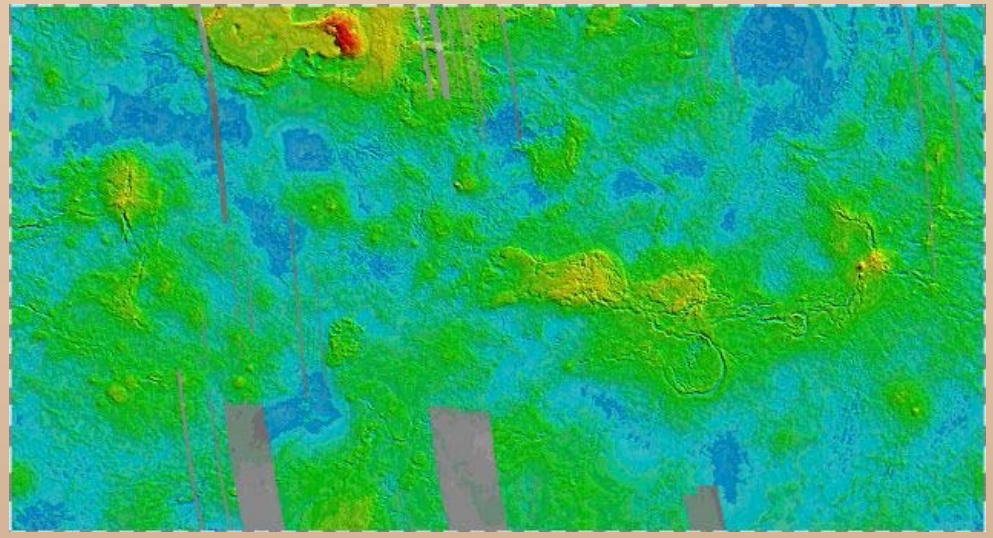




Magellan: Mapped Venus!

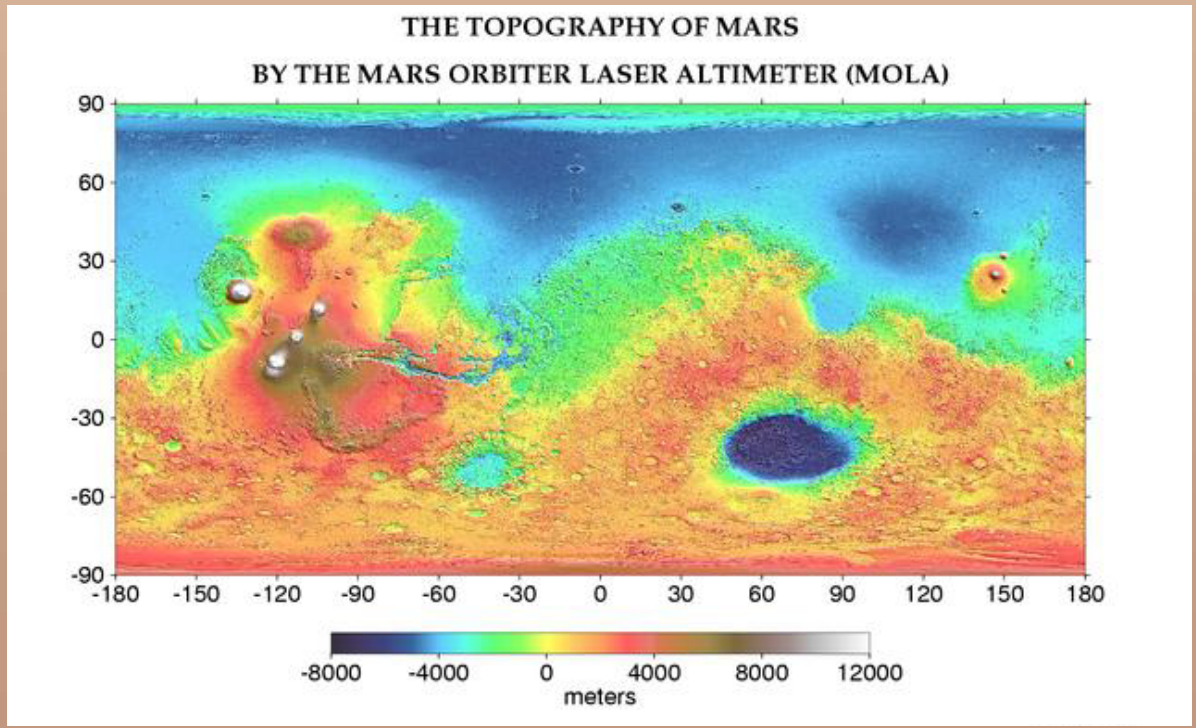


Topography of Venus from *Magellan* Radar Altimeter



Typical grid scale
is ~ 30 km
with ~ 80m vertical
precision
(Magellan Radar Alt.)

BOTH of these
datasets
provided
new discoveries…

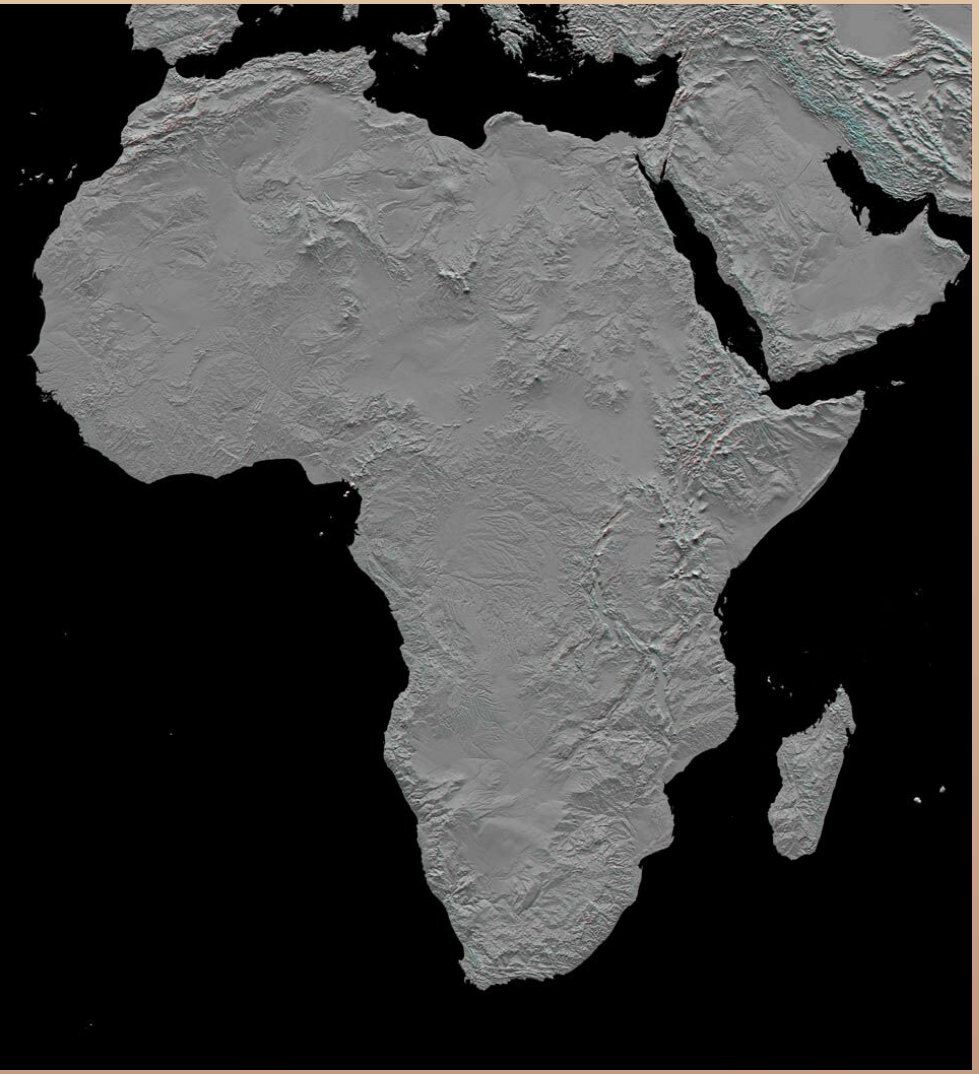


Typical grid scale
is ~ 1-2 km
with ~ 1-3 m vertical
precision

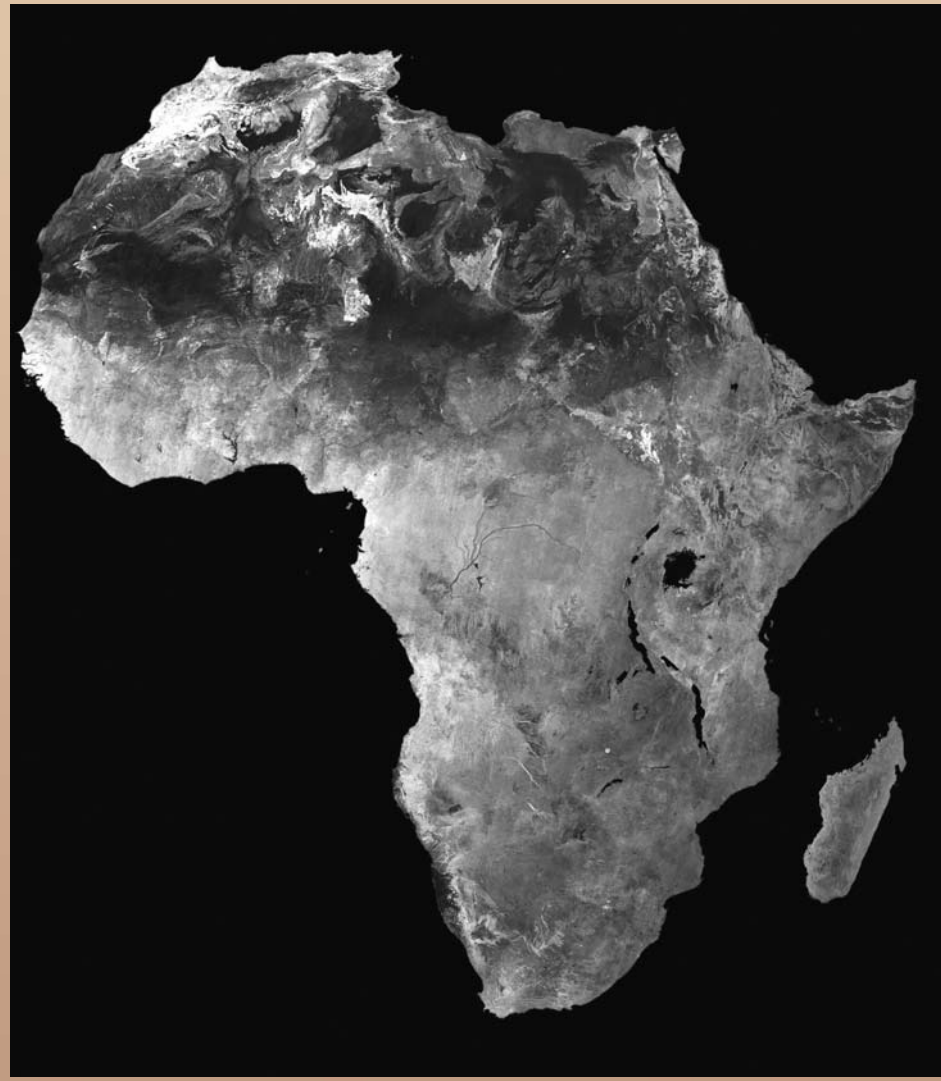
But the
<u>scale of
observation</u>
from MOLA
(x,y,z) was
catalytic
and enhanced
"DDS"

Foundation
Datasets

EARTH Example: Topography (*Left*) vs C-band SAR (*Right*)



SRTM Topography of Africa



Radarsat-1 C-band SAR of Africa

Discovery-driven science can be enabled via FOUNDATION datasets (topography, gravity)

Mars:
Discovery-Driven Science
at a PROGRAM level

Mars Exploration Program

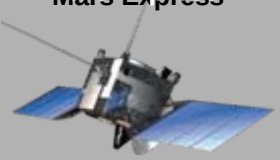
MRO

Rover

MGS

Odyssey

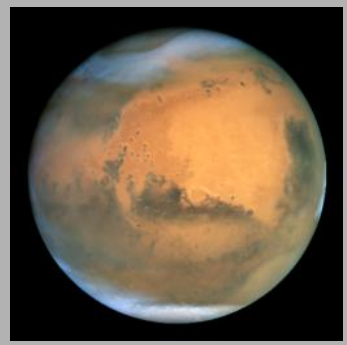
Mars Express



MSR orbiter

Viking Landers

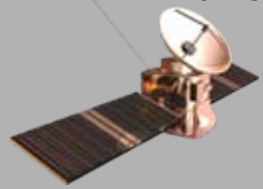
Mars Pathfinder



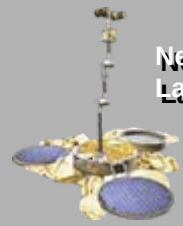
Rover

Phoenix

MAVEN or TGE



Network Lander



ExoMars

Mars Sample Return

Competed Scout

Multi-scout

SCIM

MSO

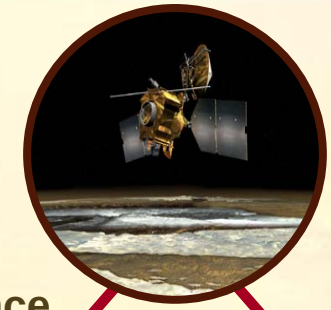
Mars Science Lab

Mars Exploration Program Approach:
"Seek, In-Situ, Sample"

RESPONSIVE to DISCOVERIES

SEEK

Orbital and Airborne Reconnaissance



- Where to look
- How to test
- The context
- The foundation datasets

SAMPLE

Return rock and soil samples

- Definitive testing of hypotheses
- Experiments to test biological potential

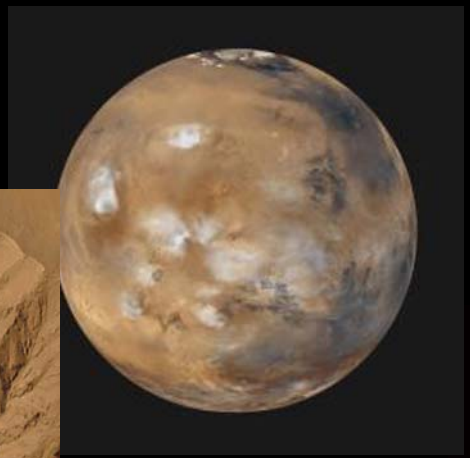
IN-SITU

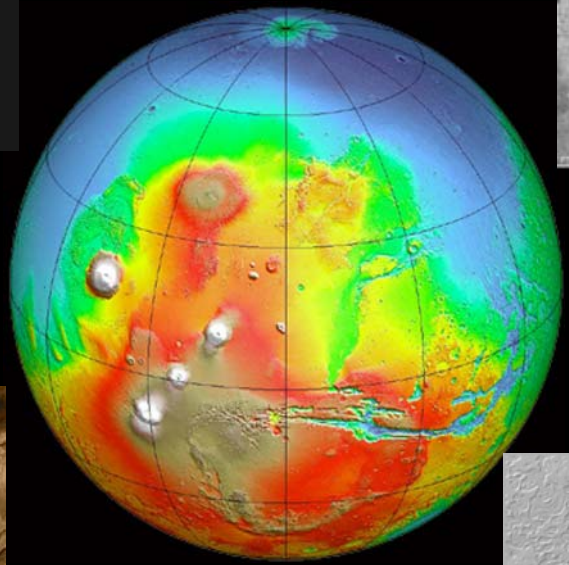
(surface) Experiments and Reconnaissance

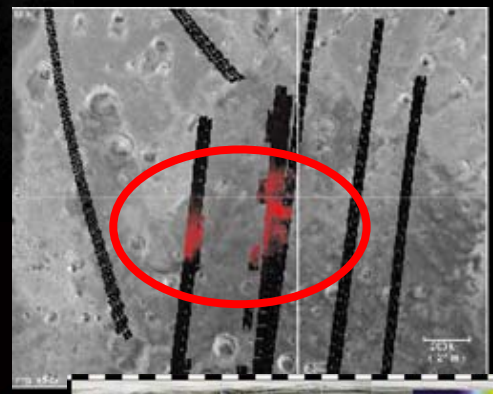
- Ground-truthing
- Surface reconnaissance
- Seeing under the dust
- Subsurface access

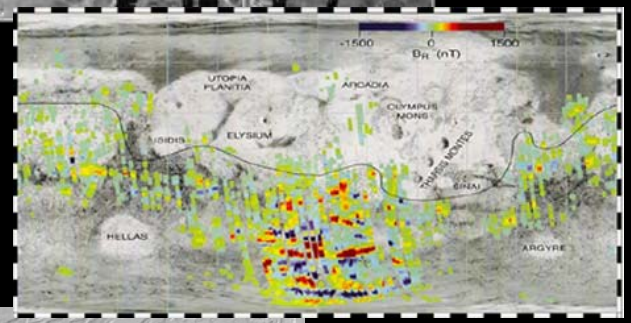
Mars Systems Science: *The Context for Biological Potential*

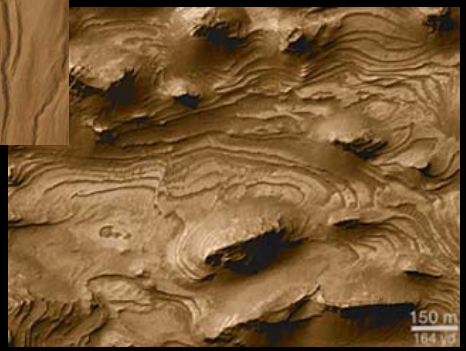
Mars Global Surveyor:
A Science Catalyst for the Mars Exploration Program

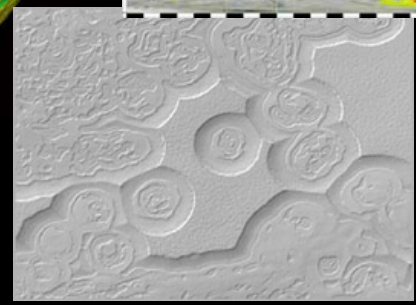






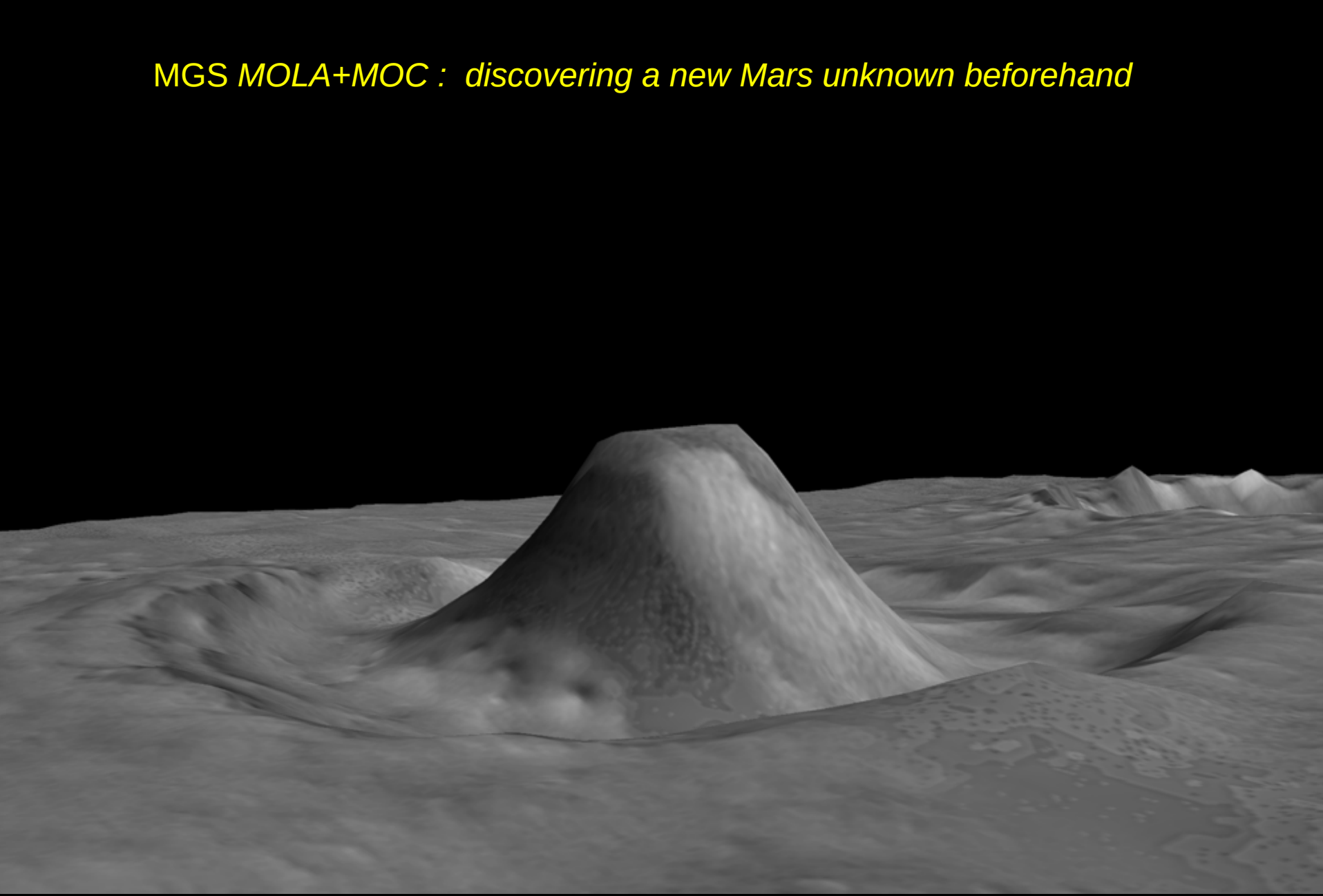






1997-2006

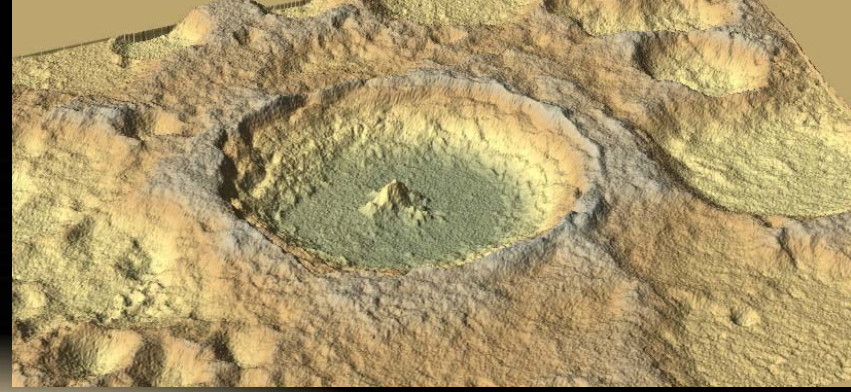
MGS *MOLA+MOC : discovering a new Mars unknown beforehand*



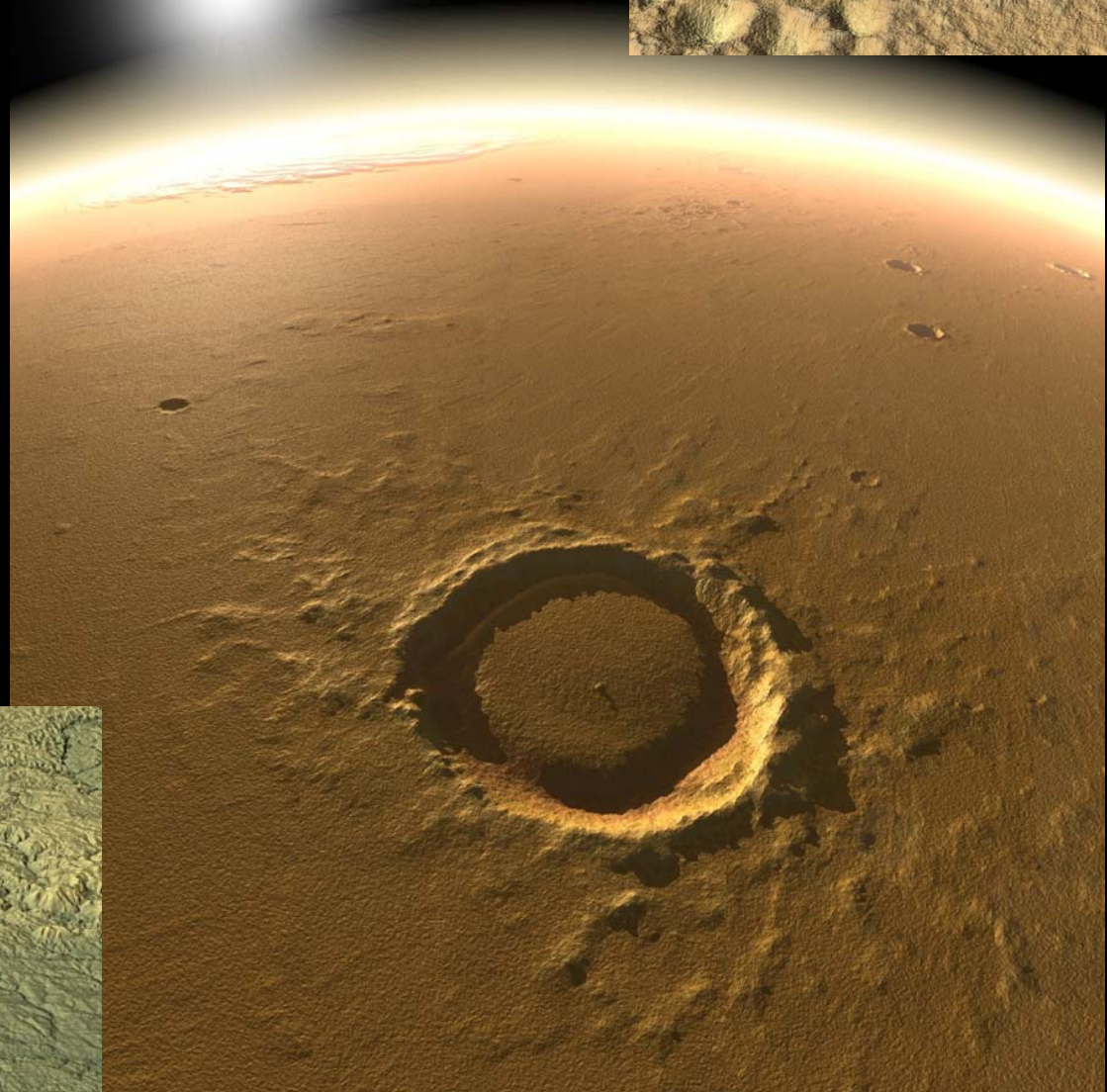
Crater central peaks that rise above rim crests…Western Arabia (12N, 334W)

DISCOVERY-DRIVEN SCIENCE:

Sometimes it Requires Multiple Perspectives (multiple missions)

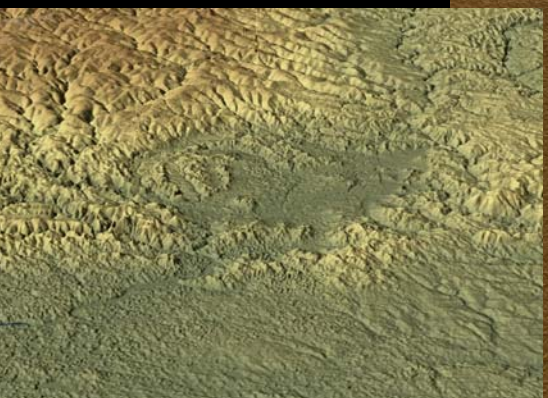


Tycho, Moon
(Arecibo DEM)

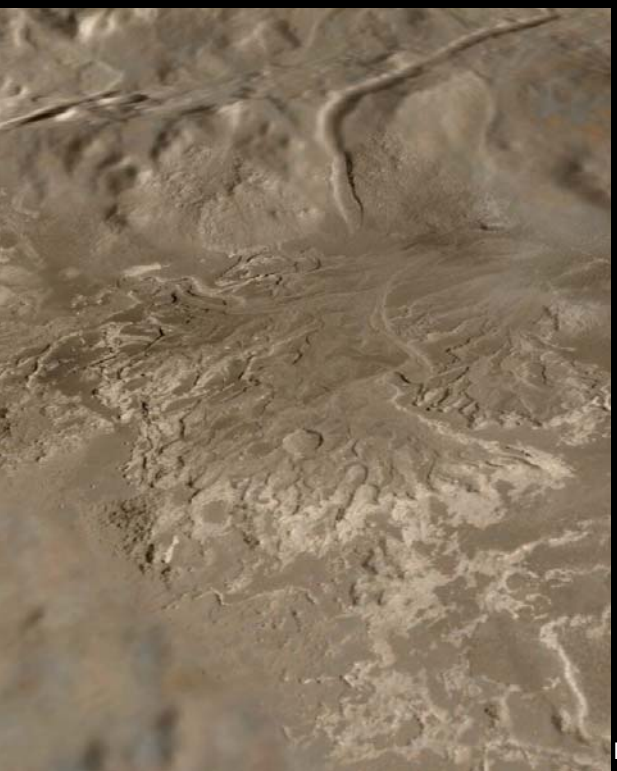


Korolev, Mars
(MOLA ray trace)

Popigai, Earth (DTED)



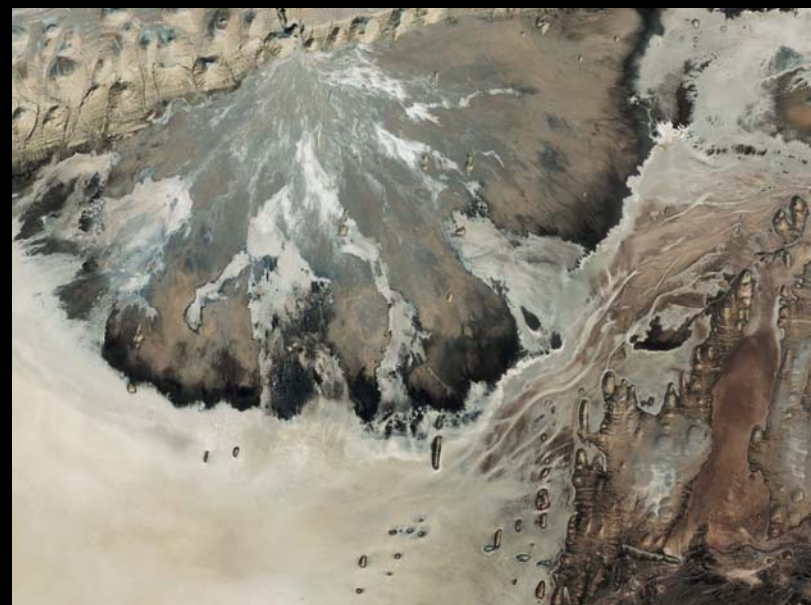
MGS:
Discovery-Driven Science



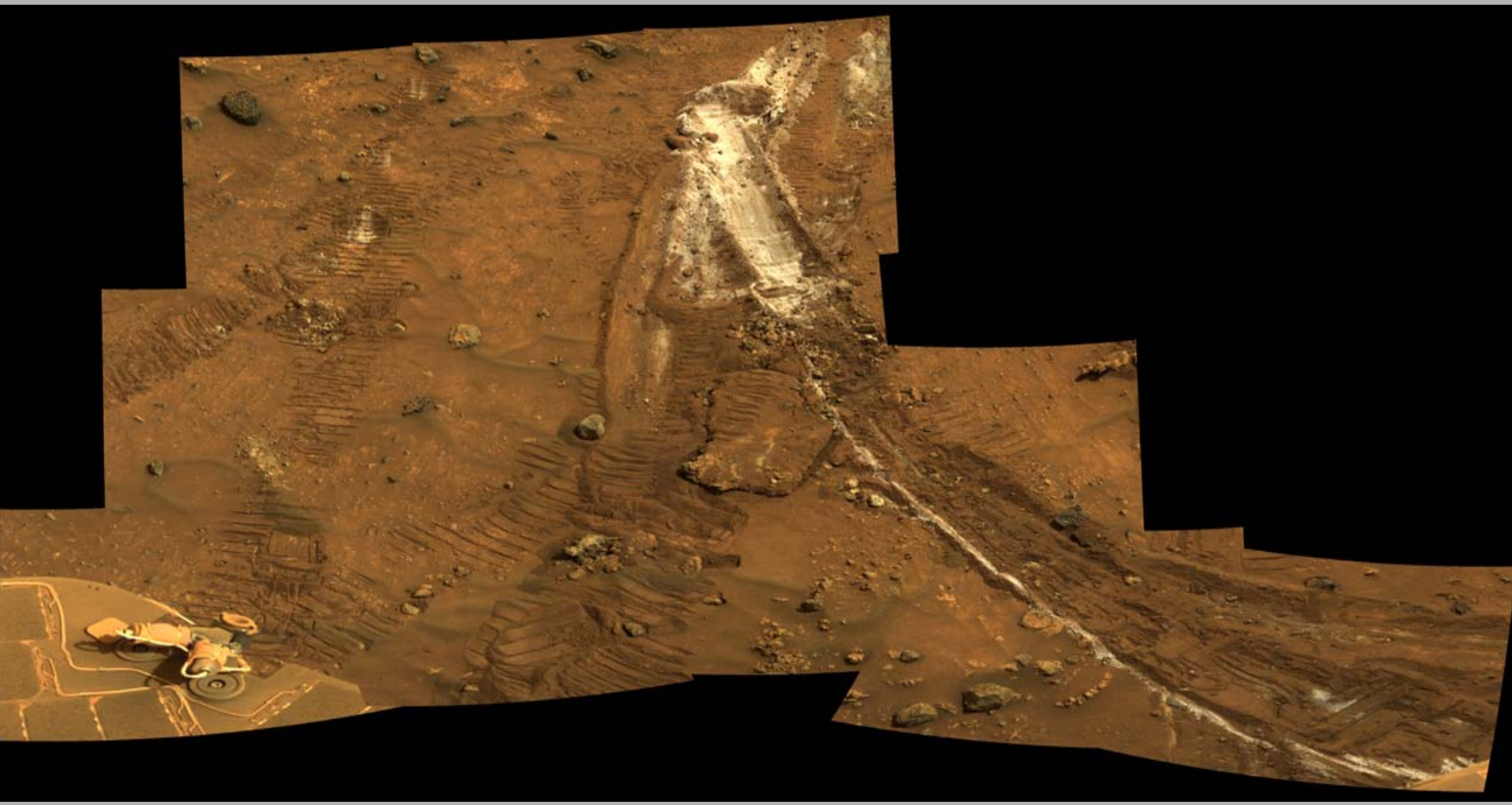
Mars (MGS/MOC)

Earth (Ikonos): Iran

Linking ancient Mars to Earth



Spirit's High-Silica Discovery



Opportunity Discovers Evidence of Rocks Deposited in a Body of flowing water!

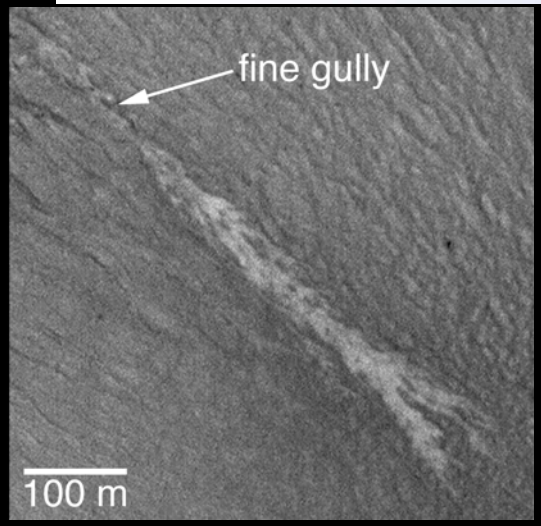
Last Chance

MRO (and MGS before)

Monitoring very recent impact craters provides statistics on current impact rate (flux) and strengths of planet-crossing asteroids

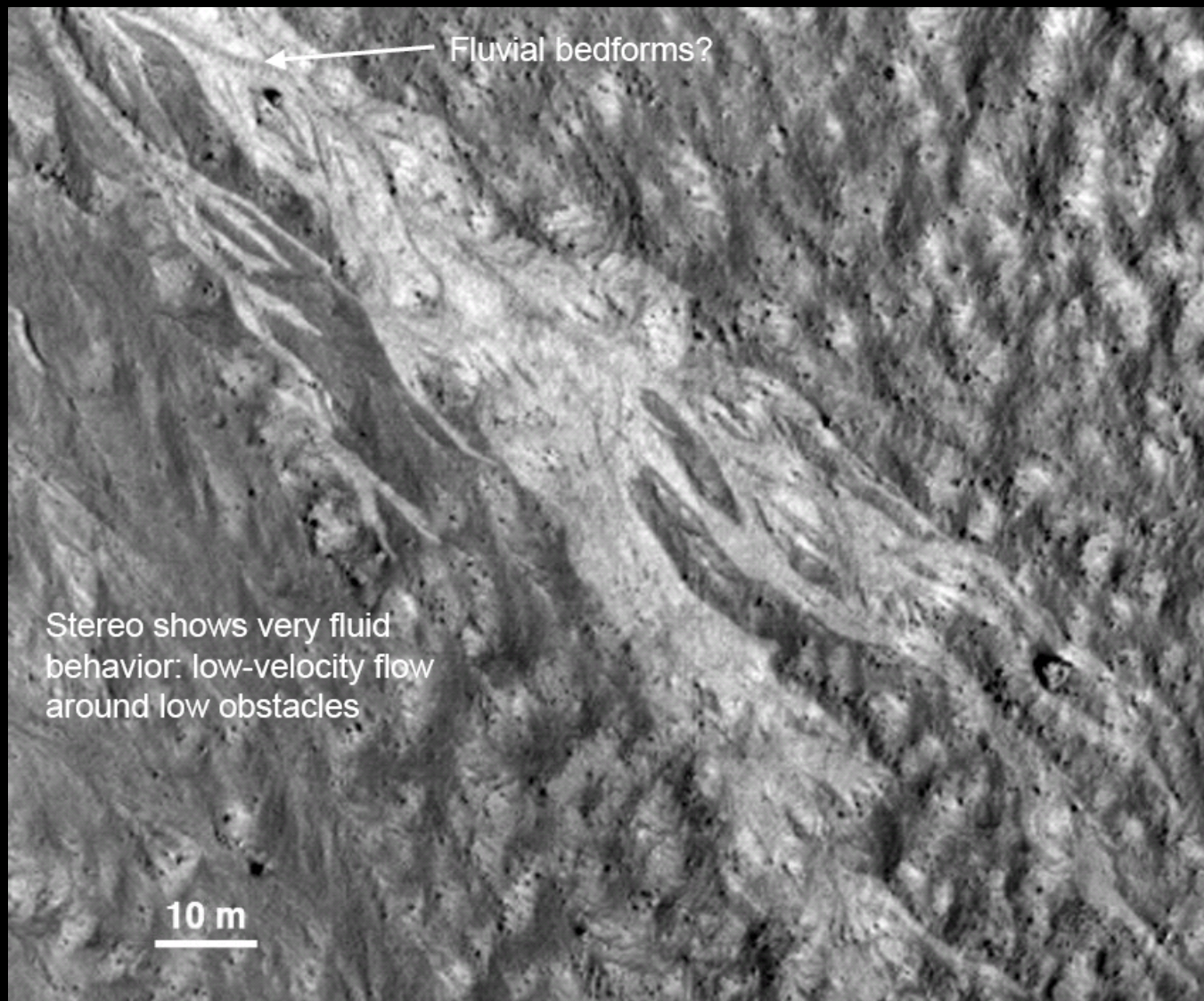
PSP_4038_2005

MRO see's where the water flowed... in active gullies



MGS/MOC

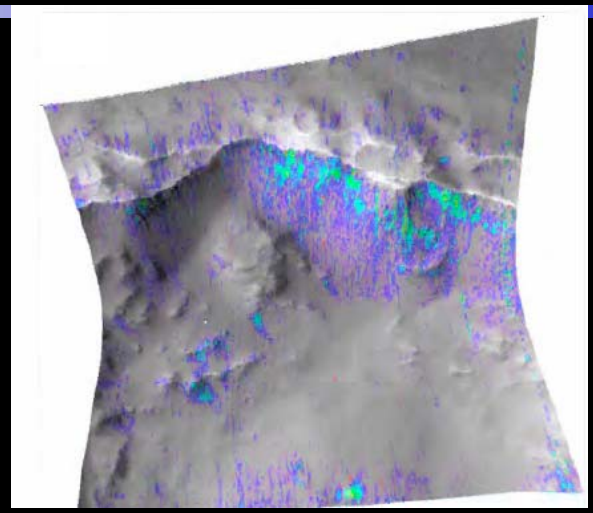
MRO's HiRISE camera



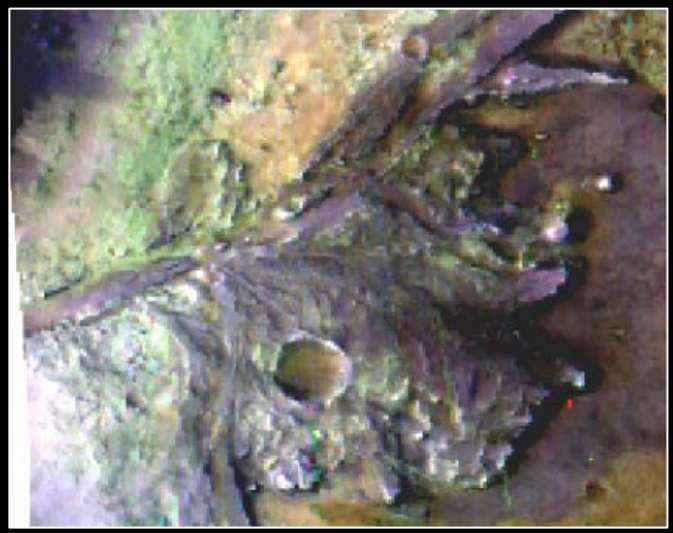
Is systematic reconnaissance at new scales an element of Discovery-Driven Science?

MRO is discovering... new evidence of water

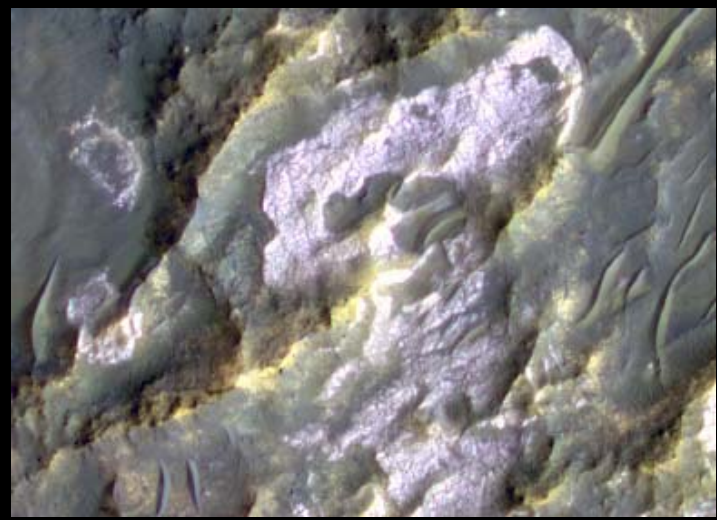
Noachian layered phyllosilicates



Noachian massive phyllosilicates exposed in highland craters, chasma walls



Noachian intra-crater fans with phyllosilicate-rich layers

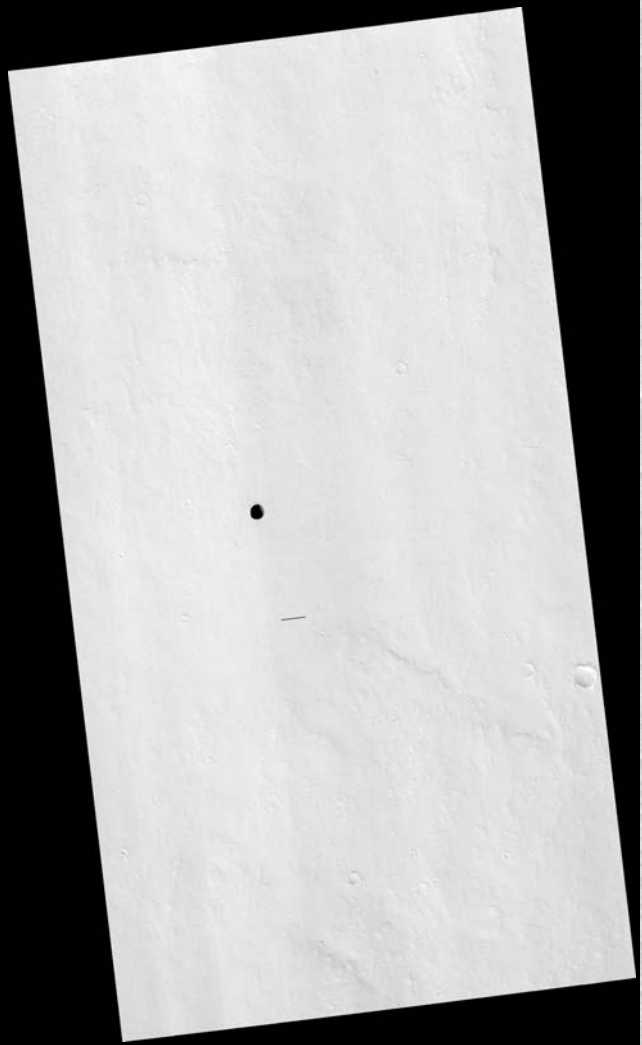


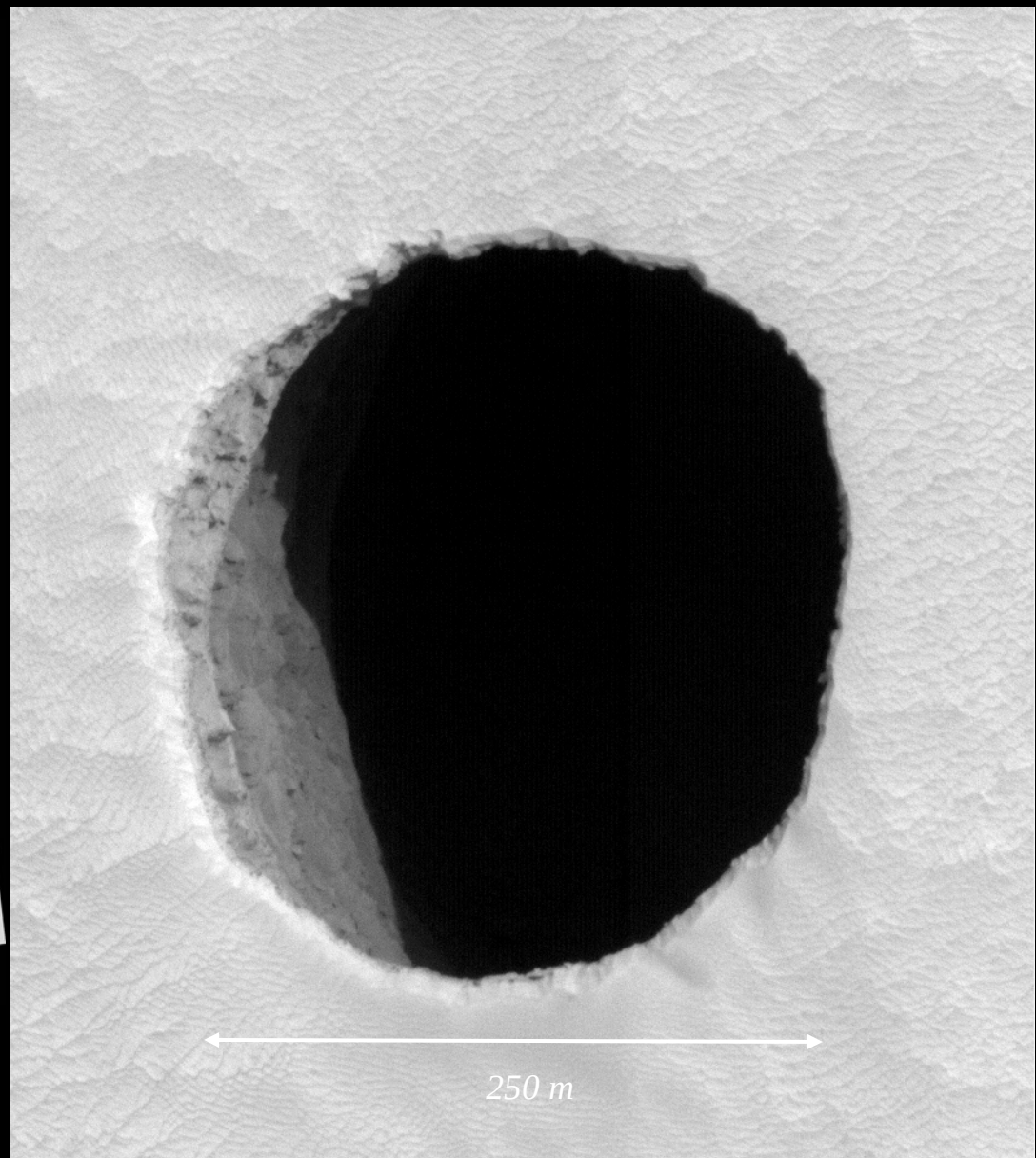
Noachian "glowing terrain" thought to be rich in chlorides

Courtesy S. Murchie/APL (CRISM)

Monitoring active South Polar “Geysers” or CO_2 cold jets

MRO's HiRISE views the "Pit"





Discovering new possibilities…

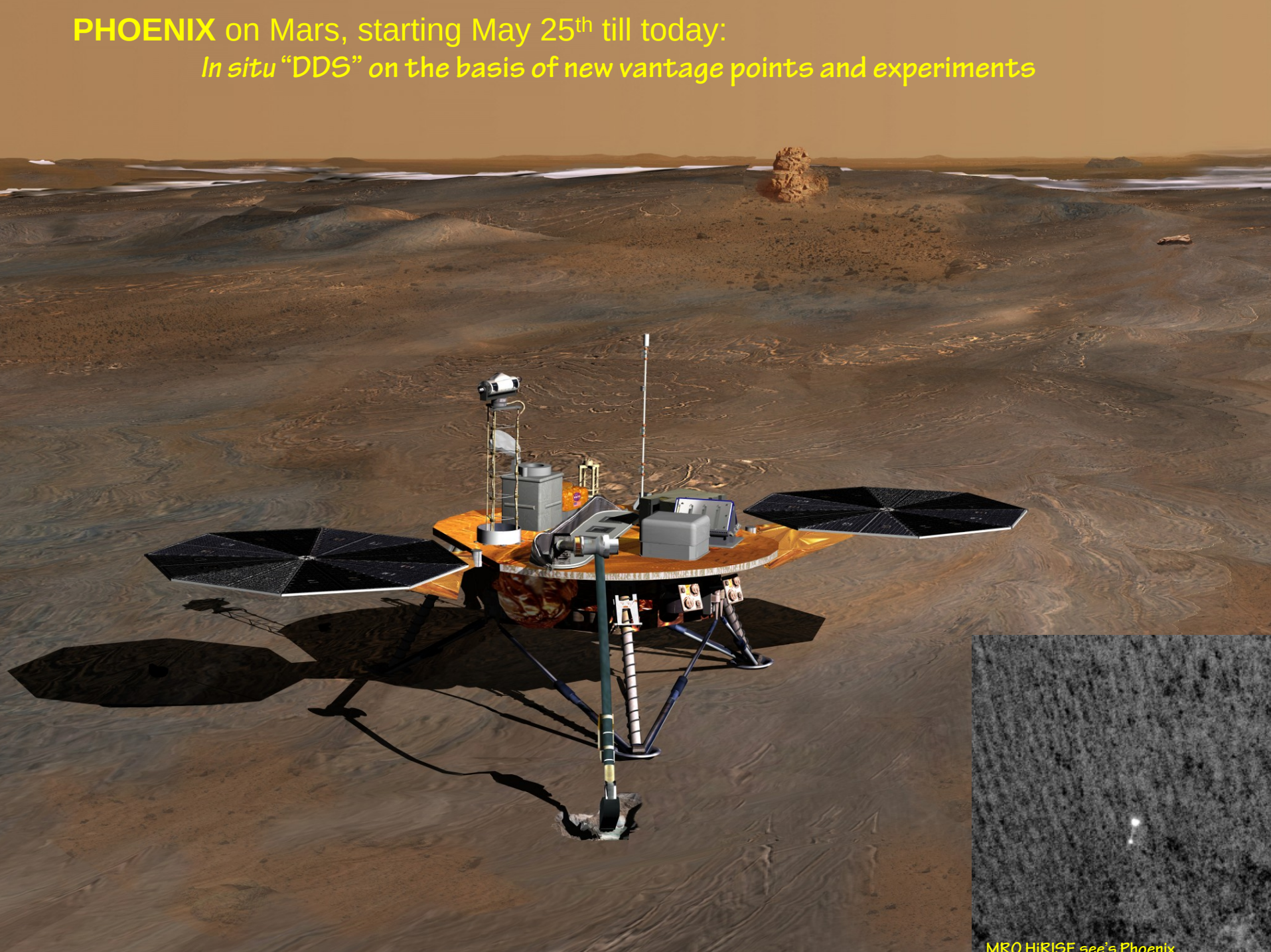
Roger Phillips et al. 2008 paper in *Science* using MRO SHARAD data

Discoveries are enabled via new measurement capabilities and new vantage points

MRO was designed to accentuate "DDS" within the MEP

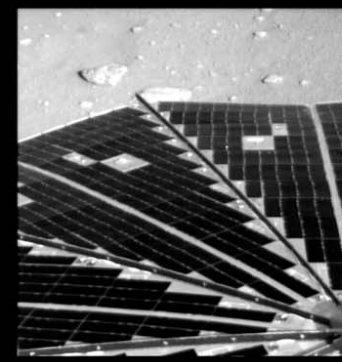
PHOENIX on Mars, starting May 25th till today:

In situ "DDS" on the basis of new vantage points and experiments



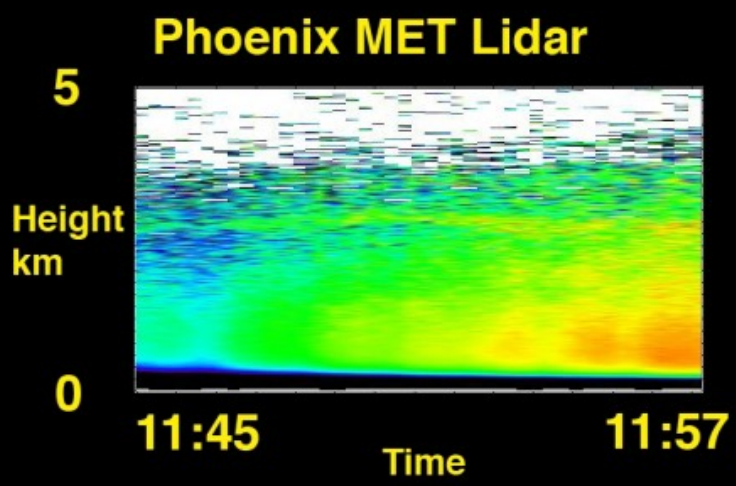
MRO HiRISE see's Phoenix

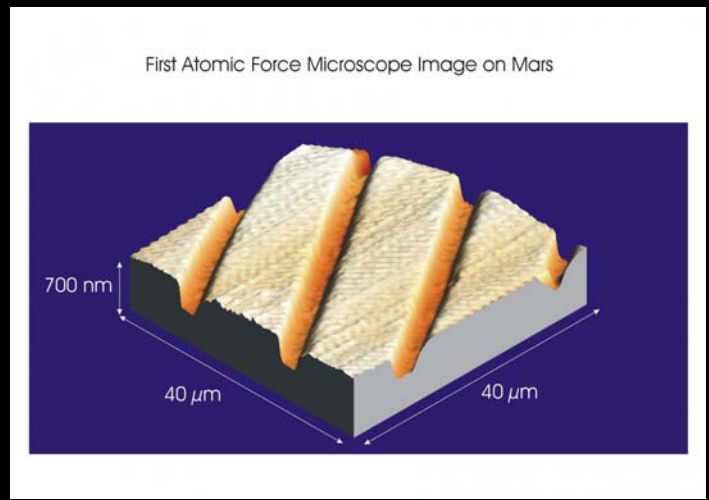
PHOENIX exemplifies how *discovery-driven science* can be "inserted" into a science-driven, technology enabled Program such as the MEP



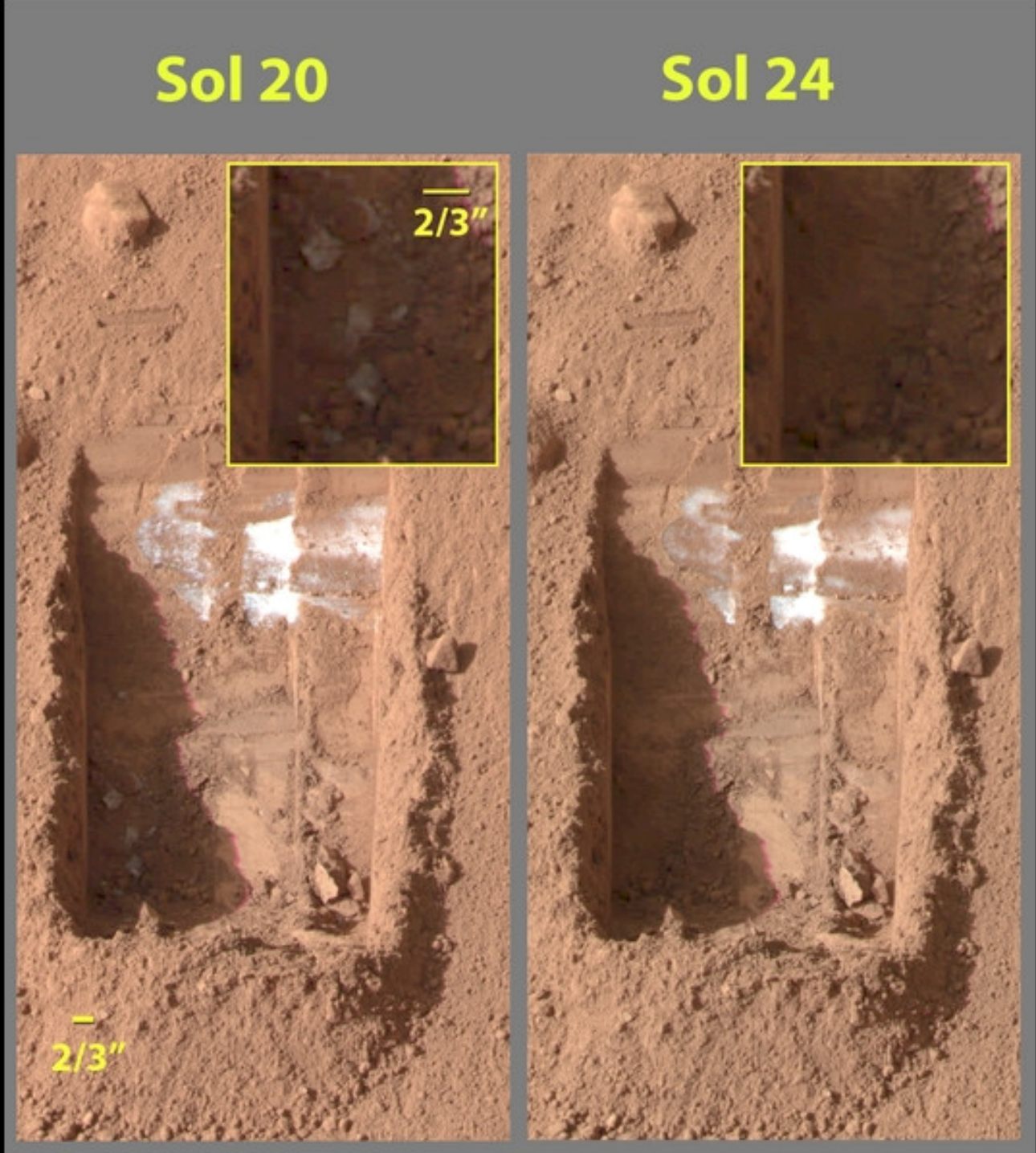
The Phoenix mission is led by the University of Arizona on behalf of NASA. Project management of the mission is by NASA's Jet Propulsion Laboratory. Spacecraft development is by Lockheed Martin Space Systems.

Discoveries enabled by “first-time” capabilities on Mars…

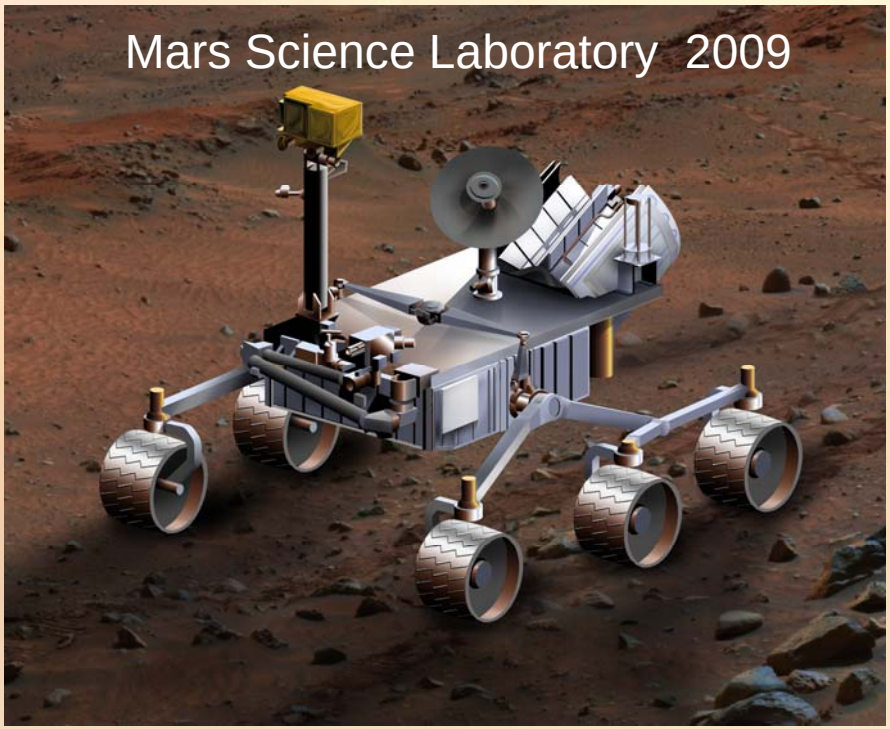




Watching
the water



With an Extensive Instrument Suite, MSL's planned discoveries will influence a next decade of science



Search for past and present habitats

Search for biosignatures

Explore planetary formation and evolution

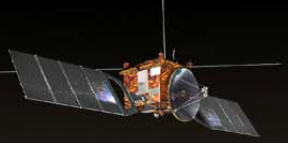
NASA's MEP was designed to be DISCOVERY-DRIVEN and Responsive…
Starting in earnest in 2000 with the restructuring…

NASA MEP was developed in 2000 to be "DDS"

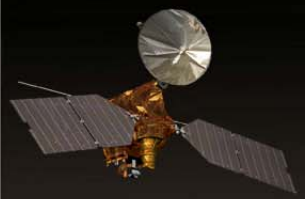
Launch Year

OPERATIONAL | 2007 | 2009

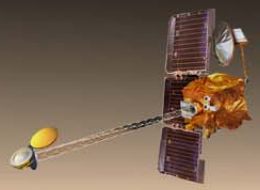
Mars Global Surveyor



ESA
Mars Express



Mars
Reconnaissance
Orbiter



Mars Odyssey

Lost after 10 *productive* years

Beginning Assembly

Science pathways
responsive to discovery

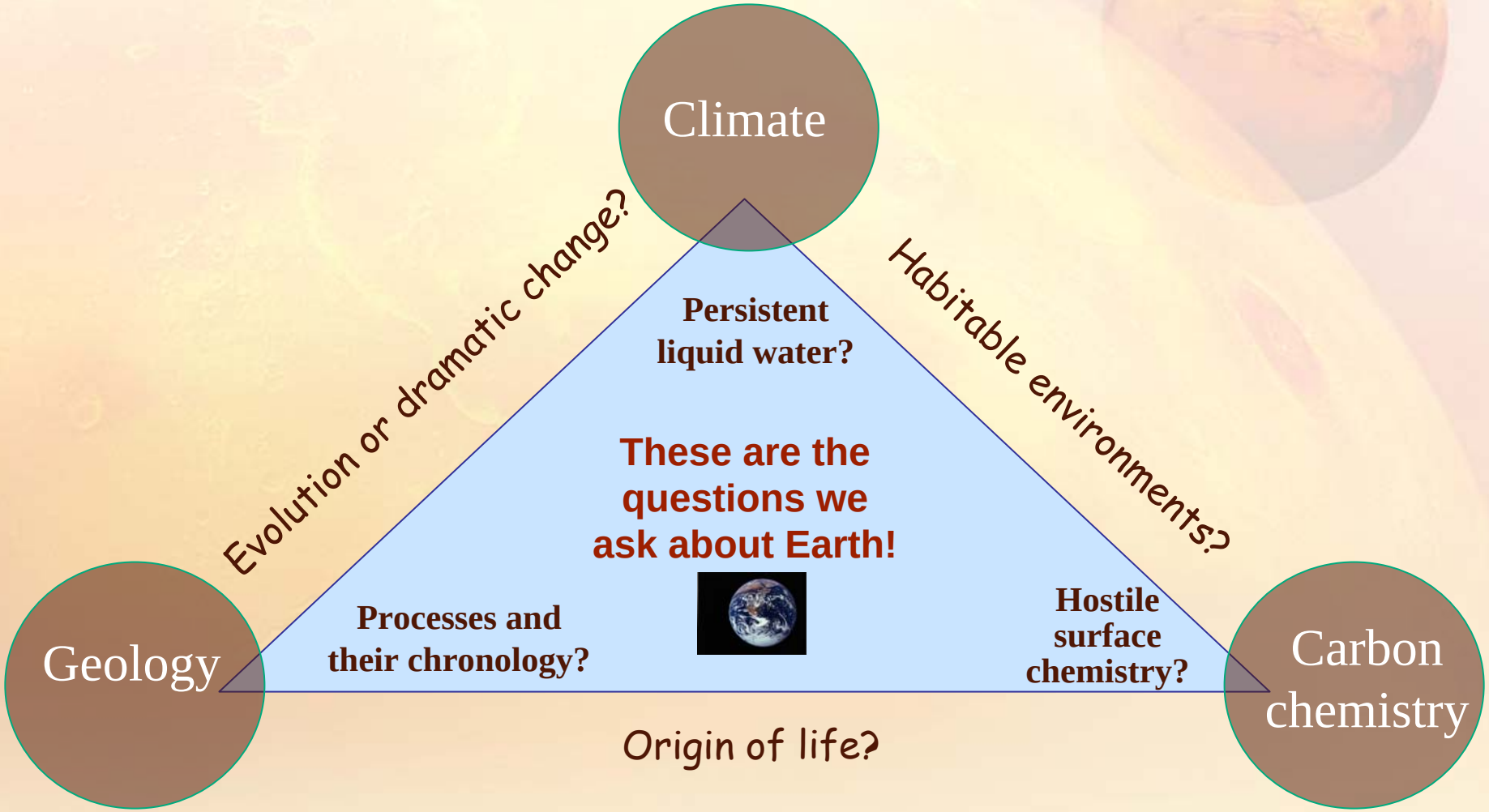
Landed May 2008!!

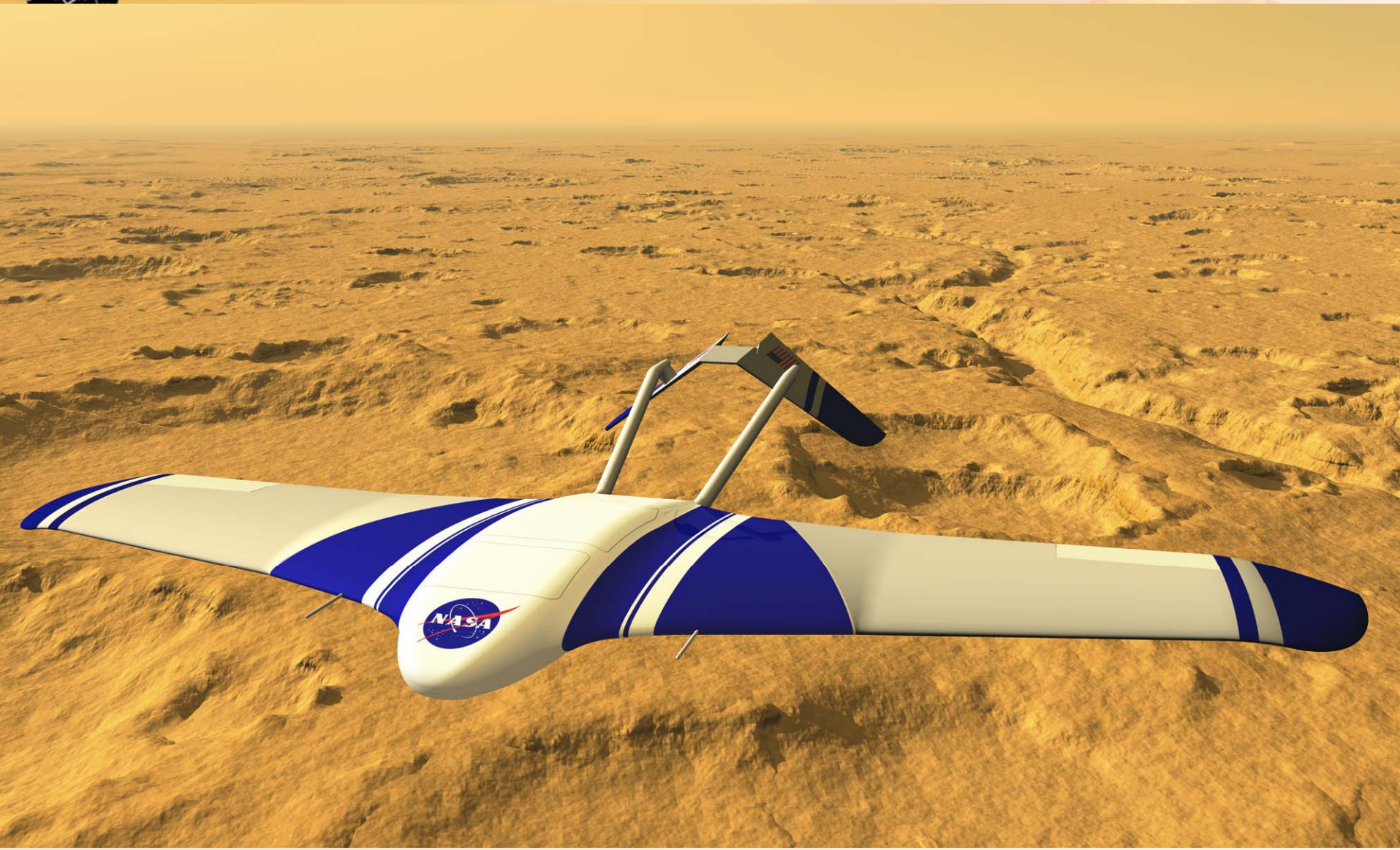
Mars
Exploration
Rovers

Phoenix

Mars Science
Laboratory

Mars Science Strategies are Linked





New Scientific Vantage Points enable NEW SCIENCE...

An Example of Discovery-Driven Science Potential

ARES, Mars
Scout (Levine, LaRC)

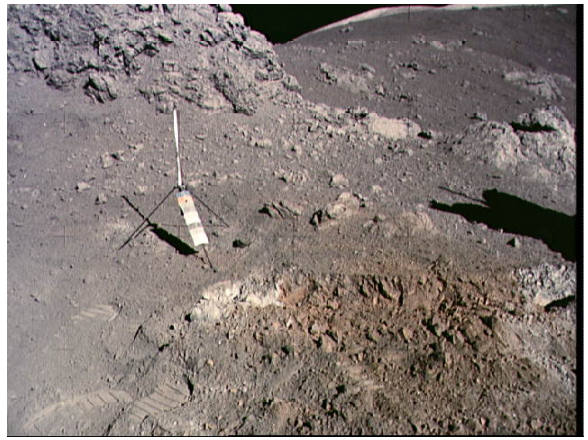
Is this the end-member in Discovery-Driven Science ?

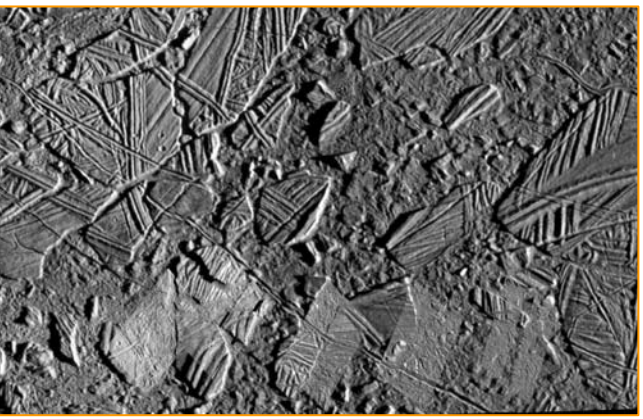
How should we define "*Discovery-Driven Science*" given the past 50 years of NASA and the next 50?

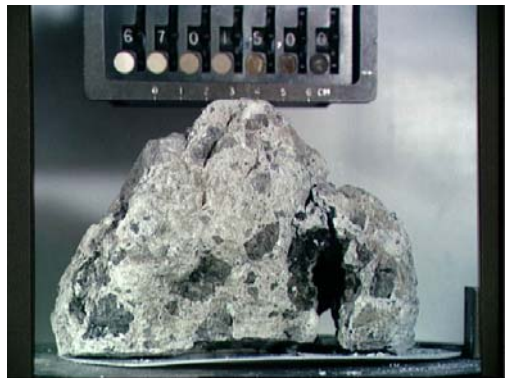
Historical "DDS" Examples

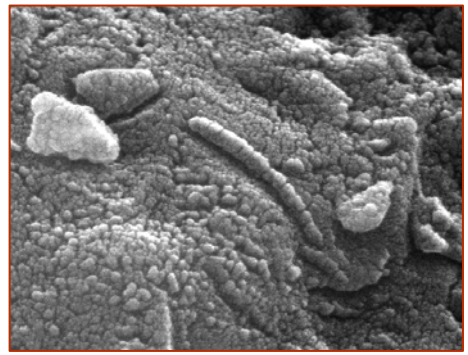
Earth	Sun	Moon	Planets	Universe
• Landsat series • EOS Program • GRACE (ESSP) • Calipso (ESSP) • TOMS series • QuickScat • TRMM • ICESat • Shuttle payloads : *SIR-A, B, C* *LITE* *SLA-1, SLA-2* *SRTM* *etc.*	• ISTP • SOHO • TRACE • STEREO	• Apollo (samples) • Lunar Prospector • Kaguya (*Selene*) • Clementine • Surveyor program	• Mariner 9 • Viking • Voyager • Magellan • MGS • MER • Galileo • Cassini/Hugyens • Phoenix • MRO • Stardust • NEAR • Messenger	• HST • Spitzer • GRO • Chandra • FUSE • COBE • WMAP • IUE

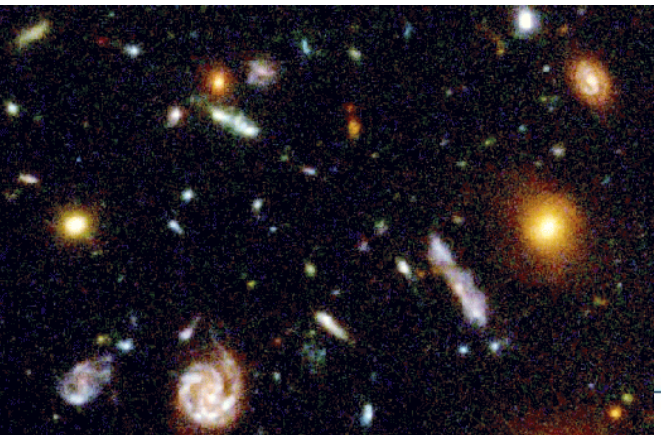
SO WHAT SHOULD COME NEXT? More PI-Mode, more Flagships, or ????



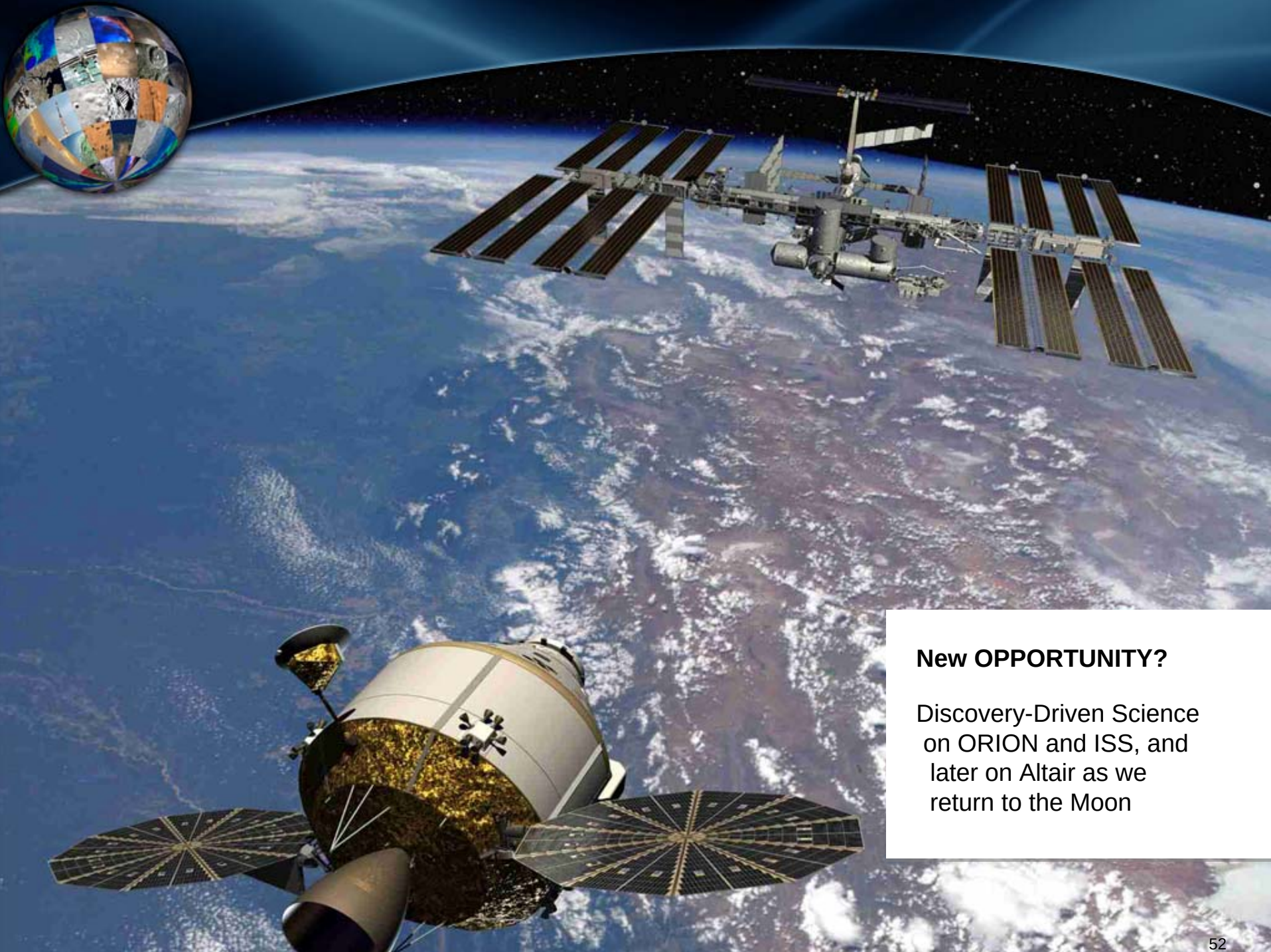








So many discoveries in so many ways…
From telescopes to samples…to unique Recon…



New OPPORTUNITY?

Discovery-Driven Science on ORION and ISS, and later on Altair as we return to the Moon


"As for the future, your task is not to foresee it, but to enable it"
Antoine de Saint-Exupery
Perhaps "DDS" is intrinsic to all NASA's science missions…