Discovery-Driven Science:
Rule or Rarity?

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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 truly “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**
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

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.
Ice Cloud and Land Elevation Satellite (ICESat)

Exploring the third dimension
ICESat 1 km DEM of Antarctica with local area 500m scale DEM as Topographic Reference

Geodetic topography provides DISCOVERY-DRIVEN Science opportunities
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.

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.

Surface lowered 8 m as sub-ice water drained.
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)

**SLA-02 Waveforms**

- Broadleaf Evergreen Forest
- Broadleaf Deciduous
- Mixed Conifer & Broadleaf
- Cultivation
- Woody Grassland

**SLA-02 Sub-orbital track - W. US TVR**

- Elevation along sub-orbital track
- TVR Distributions

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 DESDynl 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*
BEDROCK ON MARS VS VENUS – Discovery Driven Science in action…
Plans for Discovery-Driven Science “evolve” as We plan...

VOIR to Magellan

VOIR
VENUS ORBITING IMAGING RADAR

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…

**But the scale of observation from MOLA (x,y,z) was catalytic and enhanced “DDS”**

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

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 Approach: “Seek, In-Situ, Sample”

Responsive to Discoveries

Seek
Orbital and Airborne Reconnaissance
- Where to look
- How to test
- The context
- The foundation datasets

In-Situ (surface)
Experiments and Reconnaissance
- Ground-truthing
- Surface reconnaissance
- Seeing under the dust
- Subsurface access

Mars Systems Science:
The Context for Biological Potential

Sample
Return rock and soil samples
- Definitive testing of hypotheses
- Experiments to test 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)

Korolev, Mars (MOLA ray trace)

Tycho, Moon (Arecibo DEM)

Popigai, Earth (DTED)
MGS: Discovery-Driven Science

Linking ancient Mars to Earth

Earth (Ikonos): Iran

Mars (MGS/MOC)
Spirit’s High-Silica Discovery
Opportunity Discovers Evidence of Rocks Deposited in a Body of flowing water!
Monitoring very recent impact craters provides statistics on current impact rate (flux) and strengths of planet-crossing asteroids.
MRO see’s where the water flowed... in active gullies

MRO’s HiRISE camera

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

Stereo shows very fluid behavior: low-velocity flow around low obstacles
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…
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
PHOENIX exemplifies how discovery-driven science can be “inserted” into a science-driven, technology enabled Program such as the MEP.
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”
Mars Science Strategies are Linked

Climate

Geology
Evolution or dramatic change?

Persistent liquid water?

Habitable environments?

Hostile surface chemistry?

Carbon chemistry

Processes and their chronology?

Origin of life?

These are the questions we ask about Earth!
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**

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<td>SRTM etc.</td>
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**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...