Two-Dimensional Planetary Surface Landers

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Dr. Peter Willis (Science Instruments)

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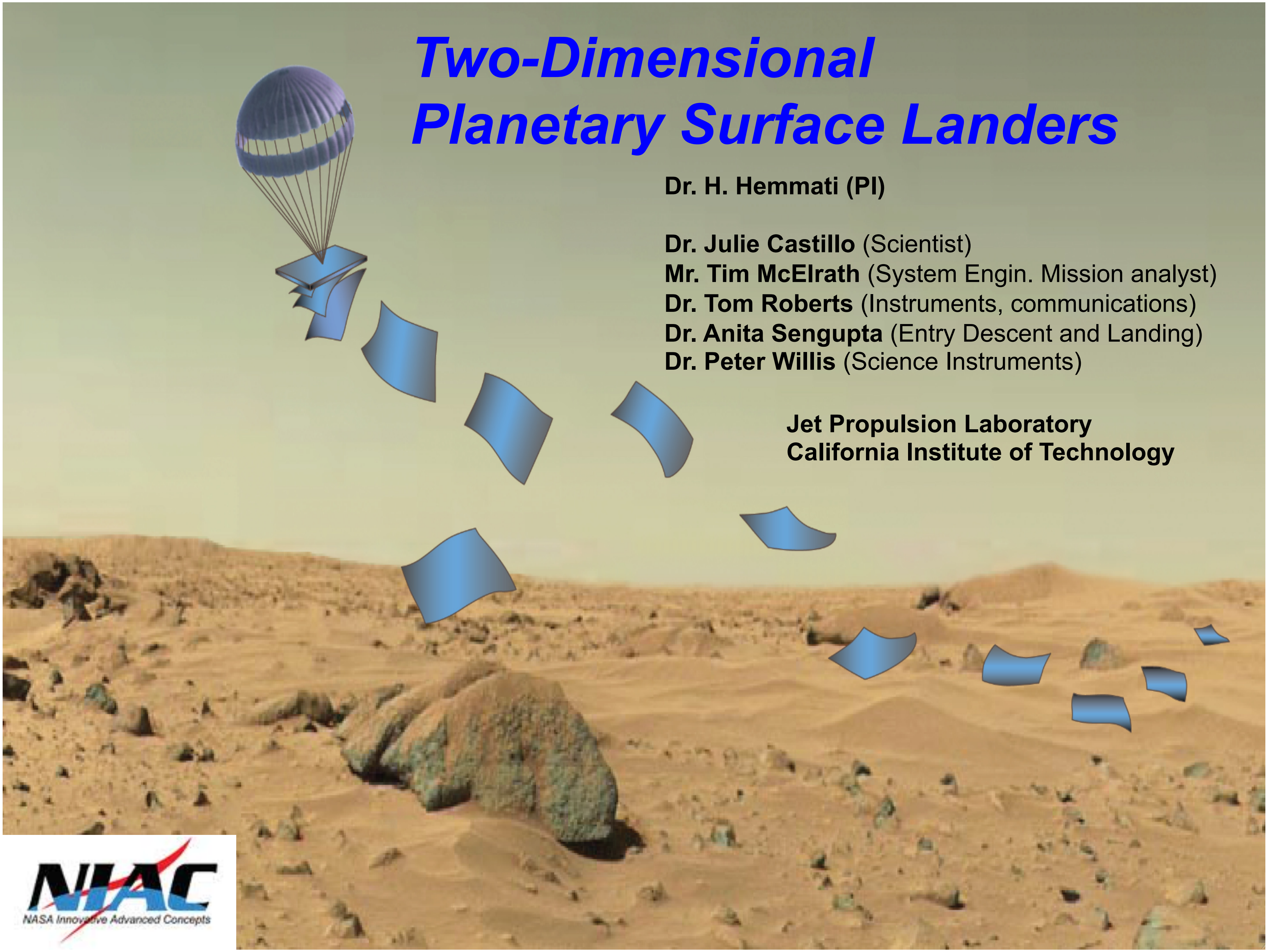
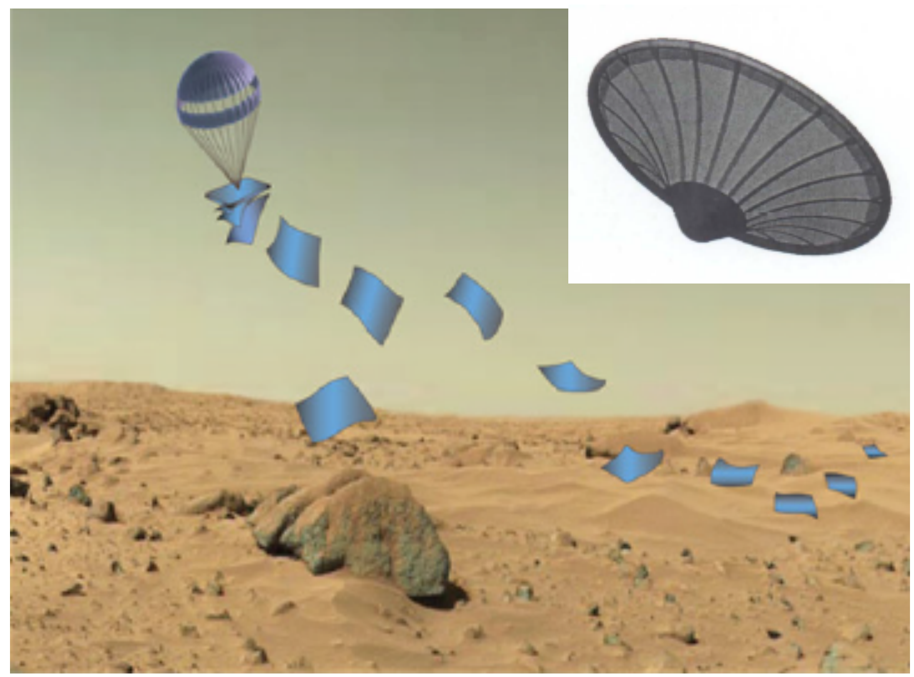


NIAC
NASA Innovative Advanced Concepts

Concept

- **~ 1m x 1m surface area, and < 1cm thick**
  - Form factor allows stacking dozens of landers on a single spacecraft
- **Populated by sensors and avionics on both sides**
  - Surface-mount, low-profile sensors and instruments
  - Surface-mount telecom, solar cells, batteries, processor, and memory
  - Thin flexible electronics, including printable electronics technology

Visiting Locations Otherwise Unimaginable

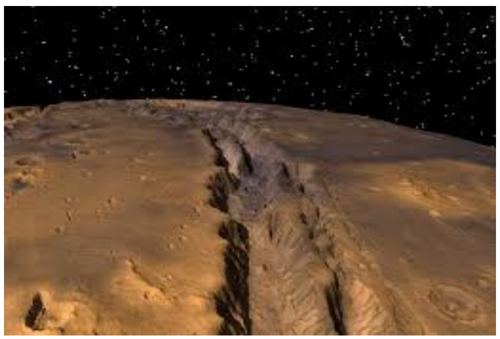


Motivation

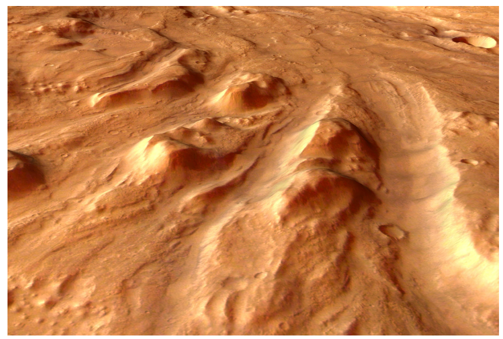
Ability to study multiple locations at once

Ability to take risk in landing on planets

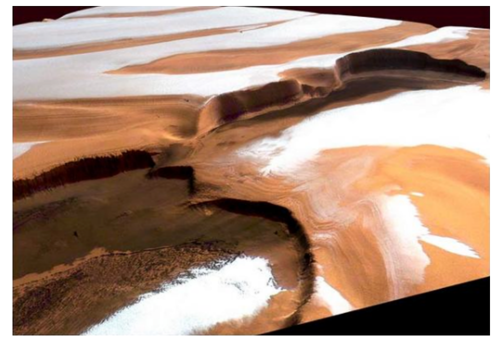
- ***May land on planetary bodies, previously deemed too risky for a single flagship lander/rover, e.g.:***



Depths of Valles Marineris on Mars



Chaotic terrains of Chryse Planitia on Mars



In situ examination of water ice on Mars poles

- **Europa:** Glaciers, geysers, biology, geology, atmosphere
- **Enceladus:** Geysers, biology, geology, atmosphere
- **Titan:** Biology, geology, lakes, rivers, streams, atmosphere
- **Venus:** Geology, atmosphere

- 2D Planetary Landers
- Reference Missions: Mars, Europa, Enceladus, and Titan
- EDL
- Science Instruments
- Lander Infrastructure
- Mobility
- Prototype
- PR, Collaborations, Papers, Spinoffs
- Summary and Future work

Europa

Geysers and Icy Surface Studies

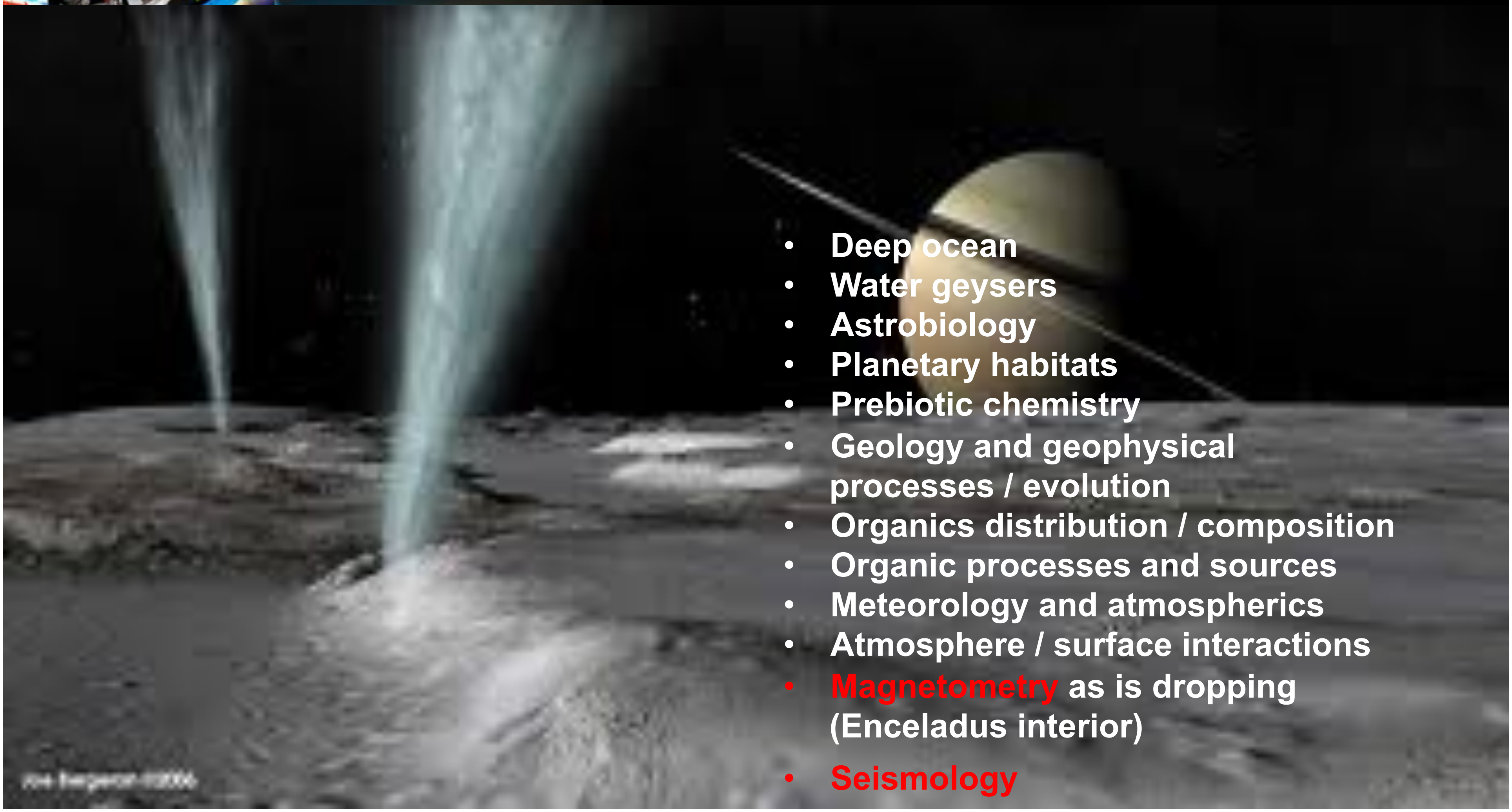
- Deep ocean
- Water geysers
- Astrobiology
- Planetary habitats
- Prebiotic chemistry
- Geology and geophysical processes / evolution
- Organics distribution / composition
- Organic processes and sources
- Meteorology and atmospherics
- Atmosphere / surface interactions
- Magnetometry as is dropping (Europa interior)
- Seismology

Hubble Space Telescope Sees Evidence of Water Vapor Venting Off Jupiter Moon Europa (2013)

> **By far the simplest explanation for this water vapor is that it erupted from plumes on the surface of Europa.**

Enceladus
Plumes and Environment Studies

NIAC NASA Innovative Advanced Concepts



- Deep ocean
- Water geysers
- Astrobiology
- Planetary habitats
- Prebiotic chemistry
- Geology and geophysical processes / evolution
- Organics distribution / composition
- Organic processes and sources
- Meteorology and atmospherics
- Atmosphere / surface interactions
- Magnetometry as is dropping (Enceladus interior)
- Seismology

Cassini Orbiter detected jets of water vapor, ice and dust spewing off the surface of Saturn's moon Enceladus (2005).

Titan
Lakes and Environment Studies

- **Planetary habitats**
- **Prebiotic chemistry**
- **Lakes of hydrocarbons / methane**
- **Hydrological cycle**
- **Geology and geophysical processes / evolution**
- **Organics distribution / composition**
- **Organic processes and sources**
- **Meteorology and atmospherics**
- **Atmosphere / surface interactions**
- **Magnetometry as is dropping (Titan interior)**

Mission Selection

Preliminary

Mission	Science Instruments	Thermal Environment	Power	Telecom	EDL
Asteroids, comets		<-100°C	Solar	RF/Optical	
Enceladus		<-100°C	RHU	RF	Retro-rocket on mother-ship, or Ballistic impact
Moon		<-100°C	Solar	RF/Optical	Retro-rocket on mother-ship, or Ballistic impact
Phobos, Deimos		<-100°C	Solar	RF/Optical	
Europa		<-100°C	Power beaming	RF/Optical	Retro-rocket on mother-ship, or Ballistic impact
Titan		<-100°C	RHU	RF	Parachute and heat shield
Mars		<-100°C	Solar	RF/Optical	Parachute and heat shield
Venus		>+400°C	Solar, Heat - conversion	RF/Optical	

Feasible | Challenging | Difficult | Not Feasible

Electronics failure is primarily due to solder. Solderless approaches to electronics now possible

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EDL Approach

Mission	EDL (*Entry, Descent and Landing*)
Asteroids, comets	Requires anchoring capability post landing
Enceladus	Requires retro-propulsive stage to minimize velocity to <10 m/s, or ballistic impact
Moon,	Requires retro-propulsive stage to minimize velocity to <10 m/s, or ballistic impact
Phobos, Deimos	Requires anchoring capability post landing
Europa	Requires retro-propulsive stage to minimize velocity to <10 m/s, or ballistic impact
Titan	Heat shield and parachute system for terminal descent
Mars	Heat shield and parachute system. Terminal descent on 2D lander. $V_{landing}$ <10 m/s.
Venus	Heat shield and possibly (TBD) parachute system. Terminal descent on 2D lander. $V_{landing}$ <10 m/s.

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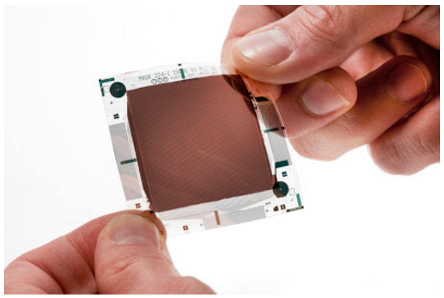
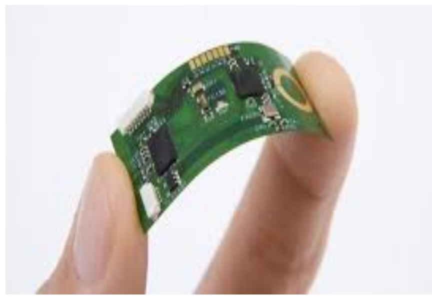
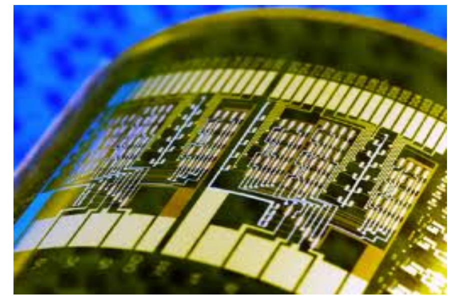
The Era of Thin and Flexible Electronics is Upon Us

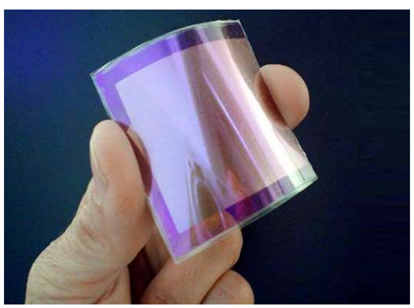
Flexible Image Sensor



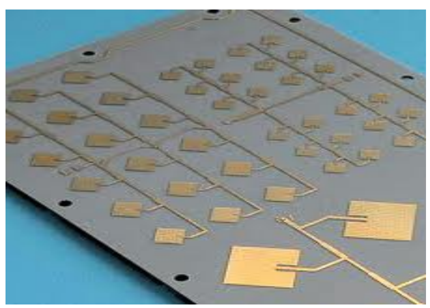




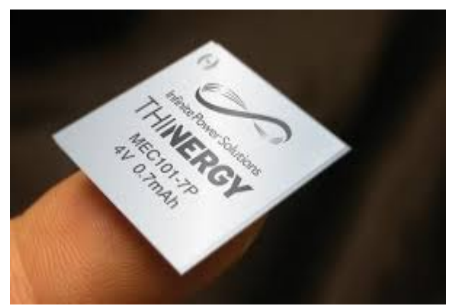
Solar Cells



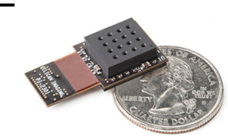
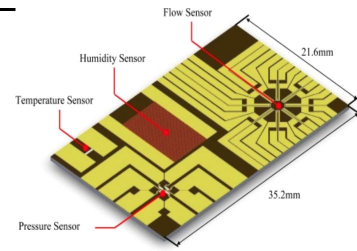
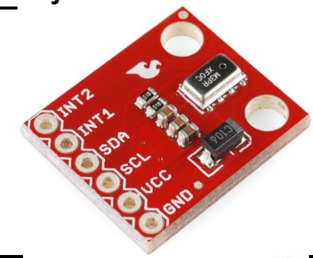
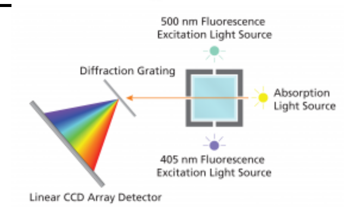
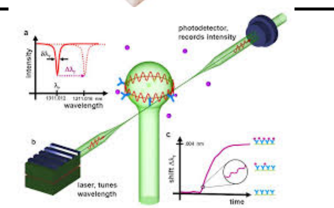
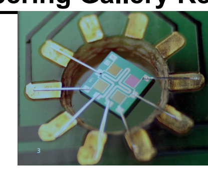
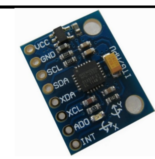
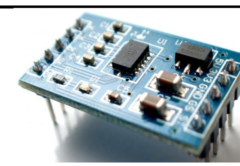
Patch Antenna



Flexible Batteries

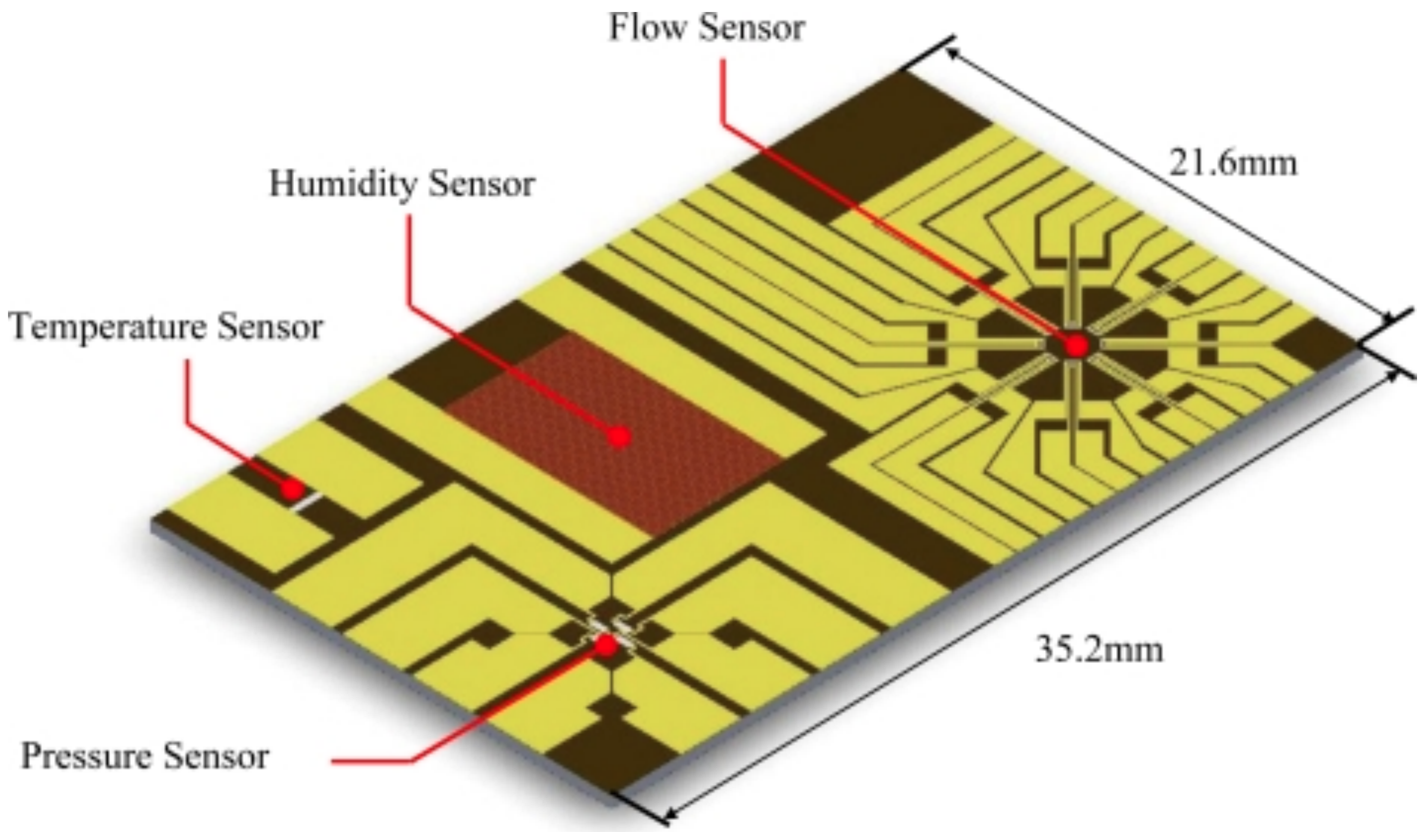


Science Instruments Identified - 1

Instrument	Measurements	Example 1	Example 2
Imaging cameras	**2D and 3D imaging** **Wide-field-of-view imaging**	 **3mm Diameter Camera**	 **Array Camera for 3D Video**
Environment Monitoring (MEMS-based)	**Wind-Speed & Direction, Humidity, Temperature, Altitude, Pressure, Temperature**		
Spectrometer	**Atmospheric constituents** **Prebiotic chemistry** **Astrobiology** **Water**	 **UV LED Fluorescence**	 **Whispering Gallery Resonator**
Gas sensing films	**CO, CO_2, NH_3, NOx, C_xH_y, H_2, H_2S, SO_2, volatile organic compounds (VOCs) – ppb sensitivity**	 **Carbon Nanotube Sensors**	 **Semicond. Sensor Array**
3-axis accelerometer, 3-axis gyroscope, Magnetic-field sensor	**Seismometry** **Magnetometry**	 **Accelerometer & Gyroscope**	 **Magnetic Field Sensor**

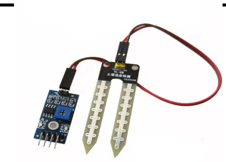
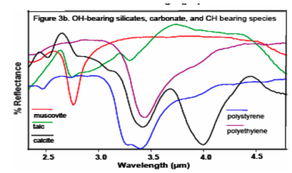
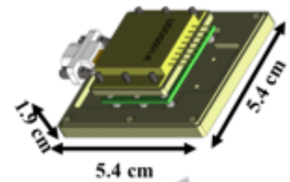
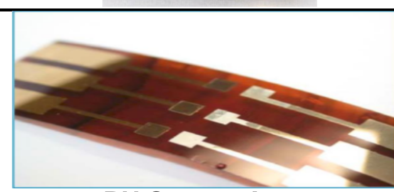
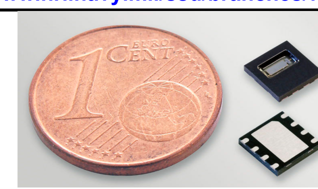
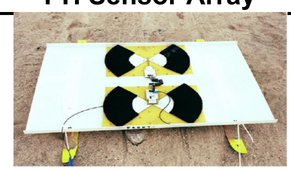
Environmental Sensing

A MEMS-based multi-sensor



Reference: http://openi.nlm.nih.gov/detailedresult.php?img=3231589_sensors-11-02715f2a&req=4

Science Instruments Identified - 2

Instrument	Measurements	Example 1	Example 2
Soil Moisture	**Proof of existance and amount of water in soil**	 **Soil Hygrometer**	 **LED-based Soil Probe**
Radiation Monitoring	**Dosimeter (Gamma, Alpha and Neutron spectroscopy)**		 **http://www.nrl.navy.mil/ssd/branches/7650/MARS**
PH, Humidity	**Measurements of humidity and PH**	 **PH Sensor Array**	 **Humidity Sensor**
Ground Penetrating Radar	**Mapping subsurface Stratigraphy** (50m depth,15m resolution)	 **S. S. Kim et al. (JPL)** 10cmx5cmx1cm, 1W, 45g	
Particle/Dust Analyzer	**Dust particle counting**	 **Miniature, Laser-Based**	

Instruments on Past Mars Landers/Rovers

Lander/Rover: Instrument	MER	MSL	Phoenix	InSight	2D Lander (envisioned)
Cameras	Panoramic	Mast	Surface stereoscopic	120° and 3D video	Panoramic and 3D video
Microscopic imager	Included	Included	Included		Included
Descent imager		Included	Included		Included
Spectrometers and analyzers	Miniature thermal emission	Chemistry and camera	Thermal, evolved gas analyzer		Thermal and gas analyzers. Laser fluorescence and laser spectrometer included
	Mossbauer	Chemistry and mineralogy x-ray diff.	Electrochemistry and conductivity		Miniaturization for low-profile required
	Alpha particle X-ray	Alpha particle X-ray			X
		Mass spectrometer			X
		Gas chromatograph			X
		Tunable laser spectroscopy			A version included
		Sample and gas processor			Gas processor included
Radiation detector		Radiation assessment			Included
		Neutron dynamic albedo			TBD
Grinder/drill	Included	Included		Included	X
Landing radar	Included	Included	Included		Not required. 10s M$
Environmental sensors		Monitoring station		Included	Included
Atmospheric sensor		Entry health monitor.			Included
Meteorological stat.	Included	Included	Included		Included
Seismometer	X	X	X	Included	Included
Radio science	X	X	Included	Included	Included
Robotic arm		Yes	Yes		X

Future Instrument Developments

The following developments will increase science data gathering

- **Miniature mass spectrometer**
- **Miniature Mossbauer spectrometer**
- **Miniature gas chromatograph**
- **Miniature X-ray diffraction instrument**
- **Drills and penetrators**

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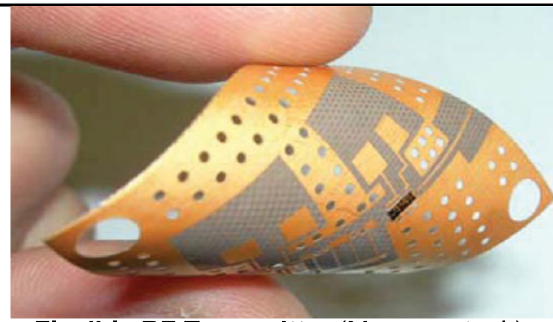
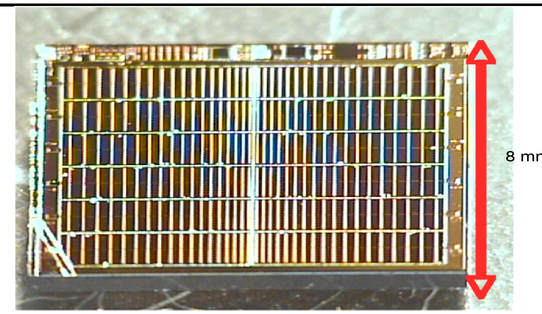
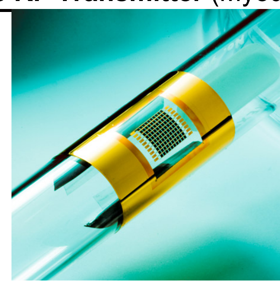
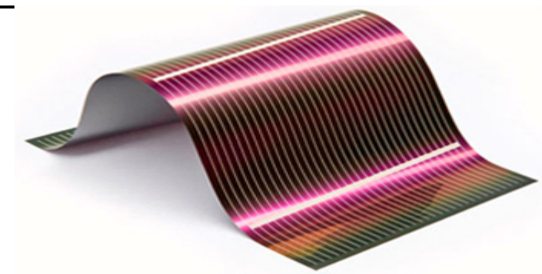
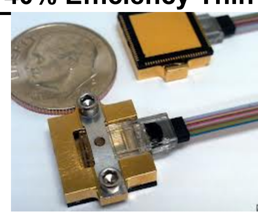
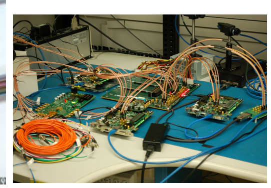
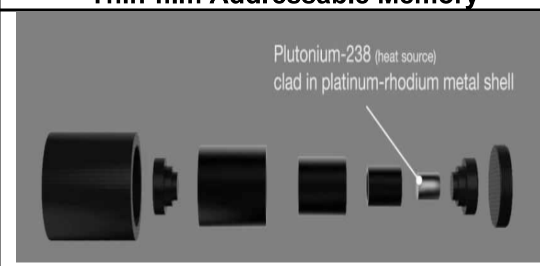
Lander Infrastructure - 1

	Example 1	Example 2
Telecommunications	 **Flexible RF Transmitter** (Myoung et. al.)	 **Modulating (laser) Retro-reflector Array**
Solar Cells	 **40% Efficiency Thin-film GaAs Solar Cells**	 **~30% Efficiency Thin-film Si Solar Cells**
Spacecraft Data Bus	  **Left: Fiberoptic data-bus Nodes. 4 transmit, 4 receive channels in each node.** **Right: JPL proof of concept spacecarft fiber-optics data-bus demo at 10 Gb/s**	 **MSL (Curiosity) Data Bus (2 Mb/s)**

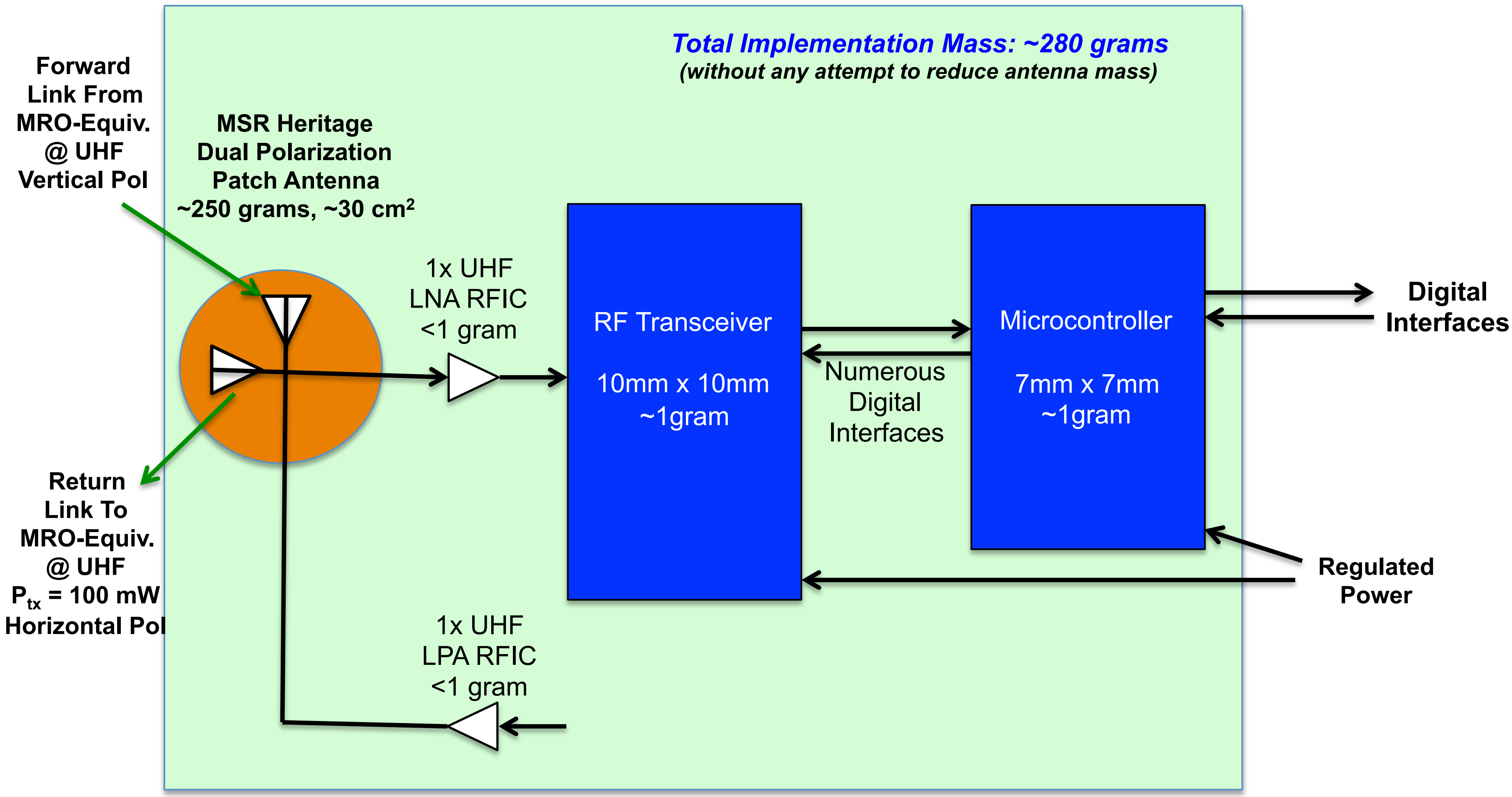
Lander Infrastructure - 2

	Example 1	Example 2
Battery, Memory, …	 400 Wh/kg Flat batteries	 Thin-film Addressable Memory
RHU (Radio-isotope Heater Unit)		 RHUs are commonly used in spacecraft, landers and rovers. May, for example, be used to keep batteries warm (if needed)

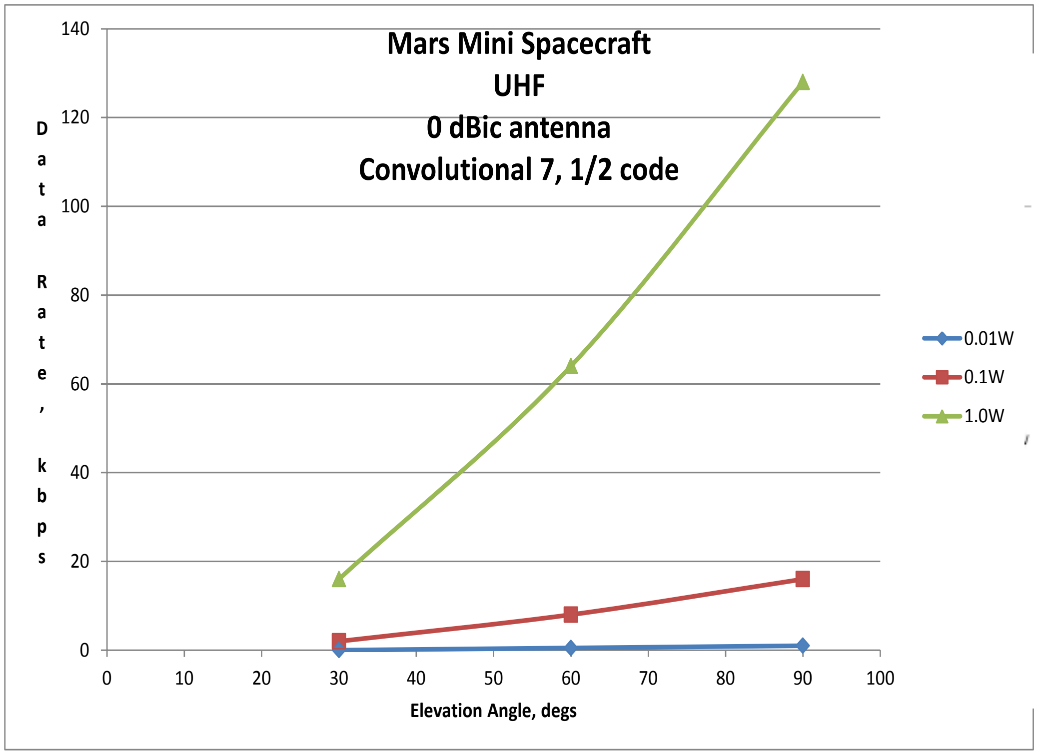
Spacecraft Infrastructure

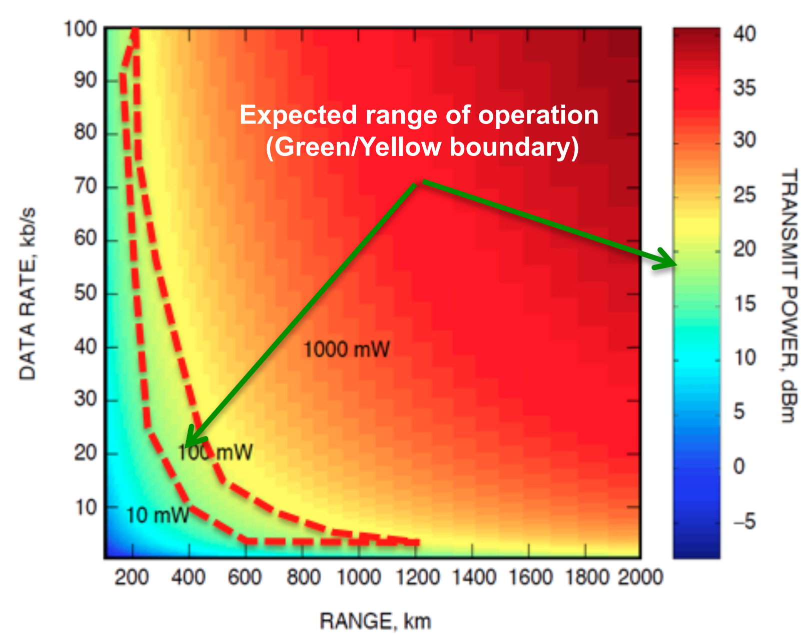
Mission	Power	Telecom	Avionics
Asteroids, comets	Solar and batteries	UHF/X-band, or modulating laser retro-reflector	Copper or fiber data bus both viable + Memory, and Micro-processor
Enceladus	RHU	UHF/X-band, or modulating laser retro-reflector	Copper or fiber data bus both viable + Memory, and Micro-processor
Moon, Phobos, Deimos	Solar and batteries	UHF/X-band, or modulating laser retro-reflector	Copper or fiber data bus both viable + Memory, and Micro-processor
Europa	RHU, Power beaming from S/C to surface	UHF/X-band, or modulating laser retro-reflector	Copper or fiber data bus both viable + Memory, and Micro-processor
Titan	RHU	UHF/X-band relay	Copper or fiber data bus both viable + Memory, and Micro-processor
Mars	Solar and batteries	UHF/X-band, or modulating retro-reflector	Copper or fiber data bus both viable + Memory, and Micro-processor
Venus	Solar and batteries	UHF/X-band relay	Copper or fiber data bus both viable + Memory, and Micro-processor

Telecom Implementation
Configuration with High Performance Antenna



UHF Telecom Performance





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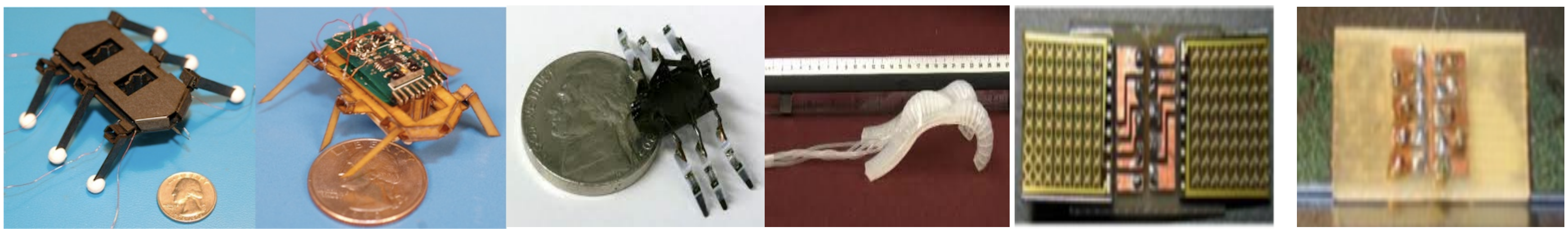
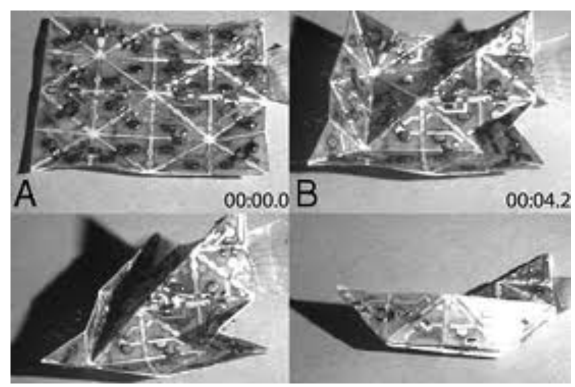
Mobility

- **Inclusion of pop-up legs to enable the landed sheets to crawl**



- **Inclusion of actuators to turn sheets into spheres for wind-driven mobility (e.g. Mars), and back to sheets again**



- **Wind-driven (Mars)**

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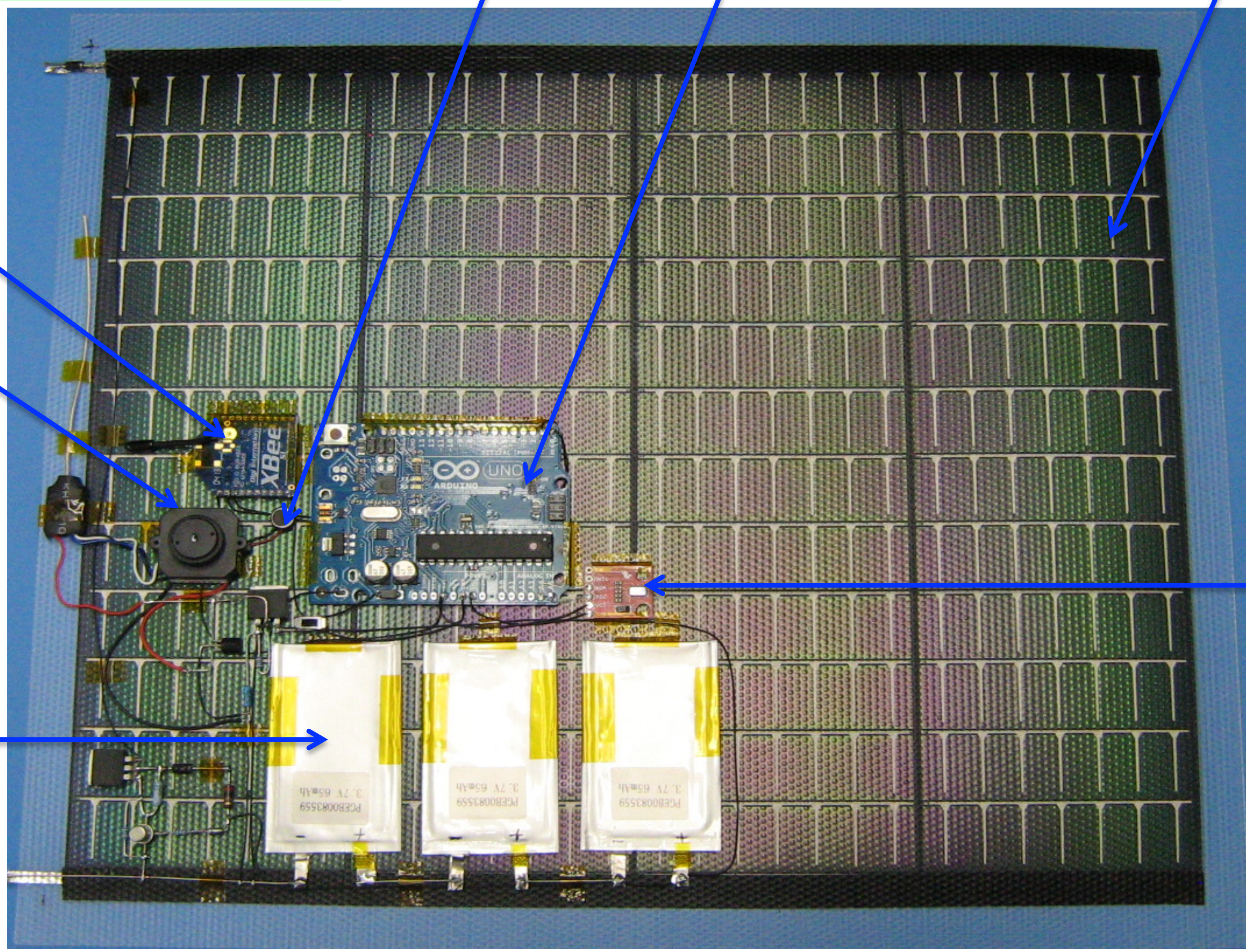
First Hardware Prototype Based on Off-the-Shelf Components

Functional; received images, sound, altitude, pressure, and temperature data nearly 200m away



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PR and Publications

ABC Science

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News in Science

Flat landers get NASA's tick of approval

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2D planet lander and suspended animation get NASA cash

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NASA Funds 'Two-Dimensional Planetary Surface Landers' Project

Landing with a Flutter Rather a Roar and a Bump

Spinoffs and Collaborations

Spinoffs:

- Proposal to DARPA on dropped sensor
- Proposal to multiple branches of Navy for ocean surface sensing

Collaborations:

- Pelican Imaging Corporation: Miniature array camera for 3D video
- University of Idaho students – acquiring students
- MIT students – acquiring students
- Discussions and monitoring progress of following NIAC-funded tasks:
    - Printable Spacecraft, Super Ball Bot, and Transformers-for-Extreme-Environments

Publications:

- Submitting conference papers

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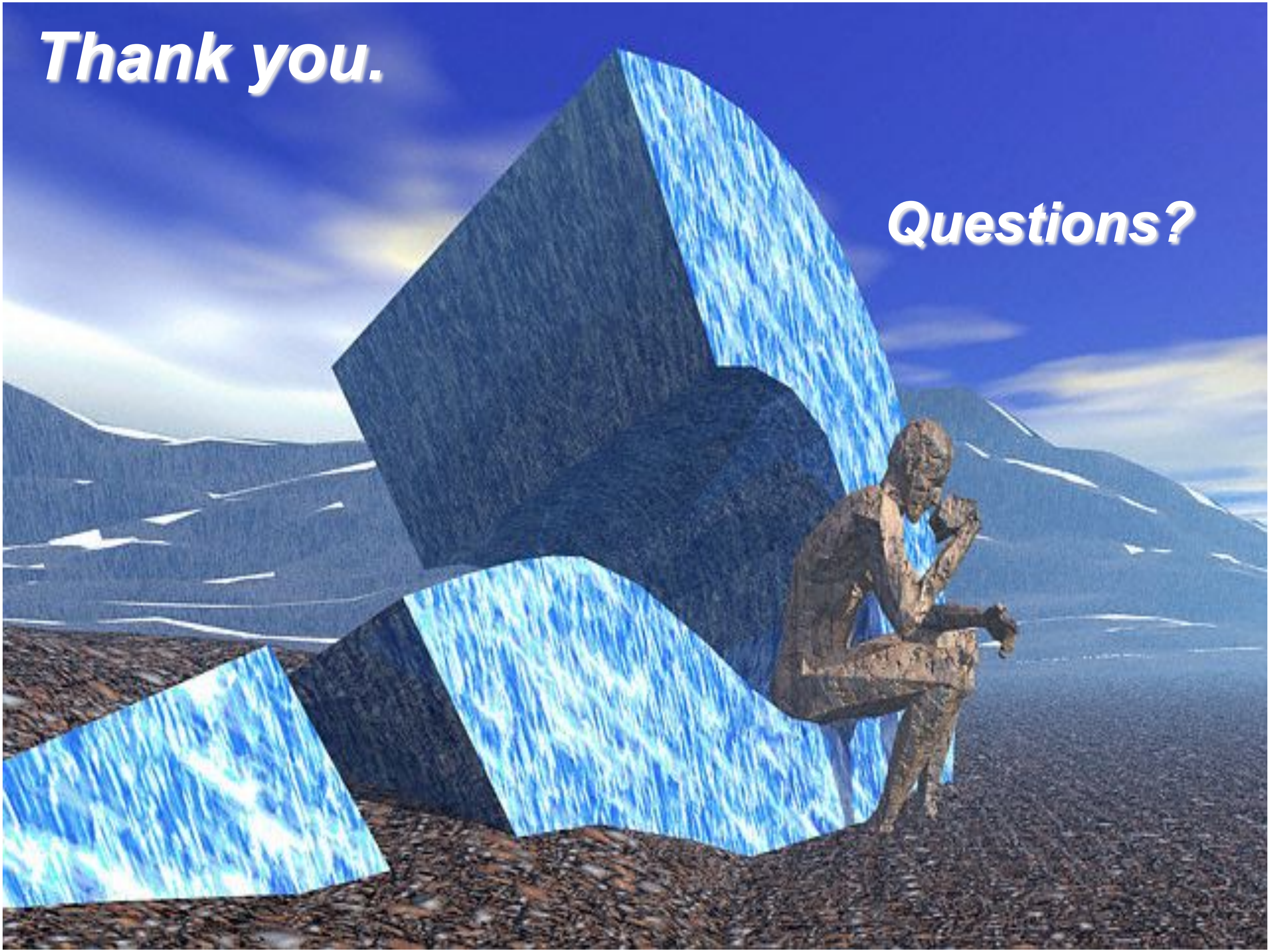
Benefits Summary

- **Significantly reduces development time**
- **Obviates the most complicated, most expensive and highest-risk phase of landing**
- **The flat nature and low mass of these landers allows dozens to be stacked for transport and distributed en masse to the surface.**
  - Simplicity of system testing and validation on Earth.
- **Redundant landers; the mission is not dependent on the success of any particular lander**
- **Even at high attrition rate of 50% would still provide invaluable data and images that currently cannot be obtained in any other way.**
- **Enables certain types of missions such as seismic probing or weather monitoring for which distributed landers are required.**
- **Dual-use benefits civilian and DOD applications**
  - Land, ocean, glacier or forest where it may be difficult to land

Future Work

- Reference mission down-selects
- Complete EDL analysis and approach identification for selected mission(s)
- Complete thermal analysis for descent and upon landing
- Complete telecom link analysis and hardware specification
- Complete mass, power, size determination for a given mission
- Specific point-design. Thorough performance description
  - Lander’s area and mass, power-generation capability
  - EDL approach
  - Thermal management
  - Science gathering capability / performance
  - Telecomm capability and concepts of operation
  - Estimates of cost and lifetime


Thank you.
Questions?

Core Team

	Education		Role	Experience
Julie Castillo, Ph.D.	Geophysics	Co-I	Scientist Mission Selection	Planetary scientist for Dawn, InSight, INSPIRE…
Hamid Hemmati, Ph.D.	Physics	PI	Study Lead, Instruments & Telecom	Electro-optic instruments, planetary communications
Tim McElrath	Aerospace Engineering	Co-I	Mission Analysis Systems Engineering	Mission design and navigation for over 10 NASA missions
Tom Roberts, Ph.D.	Optical Sciences	Co-I	Instrumentation Electro-optic systems	MSL fiberoptic and imaging instrument engineer
Anita Sengupta, Ph.D.	Aerospace Engineering	Co-I	EDL	MSL entry, descent & landing (EDL) systems engineer
Peter Willis, Ph.D.	Chemistry	Co-I	Science Instruments	Materials and fabrication expert. Lab-on-a-chip develop.

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