National Aeronautics and
Space Administration

EXPLORE
SOLAR SYSTEM & BEYOND

Planetary Science Technology Development

Carolyn Mercer, Len Dudzinski, June Zakrajsek
Manager, Planetary Exploration Science Technology Office (PESTO)
Chief Technologist, Planetary Science Division
Manager, Radioisotope Power Systems Program (RPS)

Decadal Study Briefing
June 4, 2021

Planetary Science Technology Investments

1. Technology Prioritization
   How do we choose what to invest in?

2. Technology Investments
   What are we investing in?

Planetary Science Division Technology Management

PESTO, Radioisotope Power Systems, Mission Specific, STMD Collaborations

PESTO Created in 2017 to:

Recommend Strategic Tech Investments

Manage Technology Programs

Coordinate Investments

Promote Technology Infusion

Joel Kearns
DAA for Exploration

Lori Glaze
PSD Division Director

Kathy Schubert/GRC
Space Flight Systems Director

Jay Jenkins, PE
Brad Bailey, PS

Eric Ianson
PSD Dep. Division Director

Tibor Kremic/GRC
Science Office Chief

Len Dudzinski
PSD Chief Technologist

Planetary Exploration Science Technology Office

Headquarters Office, Managed at GRC

Carolyn Mercer – Propulsion, Power, Autonomy, Ocean Worlds
Catherine Walker – Instruments
Michael Lienhard – Electronics, Venus
Pat Beauchamp – Planetary Protection, Science Liaison
Ryan Stephan – Heat Shields, Ice Mechanisms, Lunar

Instruments: PICASSO, MatISSE, COLDTech, DALI, NPLP

Spacecraft and Ground Tech: COLDTech, NPLP, ARROW, SESAME, Astro-dynamics, HOTTech

Mission Specific

- Mars Program
- Europa Lander

STMD Collaboration

- DSOC
- EESP
- HPSC
- ESM/EDL
- TRN

Radioisotope Power Systems

- RTG
- RPS
- TE/ Conversion

Funded by PSD | Funded by ESSIO | Co-Funded with STMD

PESTO: Technology Recommendation Process

- **Anchored in "Vision and Voyages for Planetary Science in the Decade 2013-2022"**
- **Augmented by Assessment Group (AG) Recommendations**

- Worked with NASA Centers to assess each technology identified by the Decadal and AGs using the following Figures of Merit
  - Critical Technology for Future Mission(s) of Interest
  - Degree of Applicability across PSD Missions/needs
  - Work Required to Complete
  - Opportunity for Cost Sharing
  - Likelihood of Successful Development and Infusion
  - Commercial Sustainability

- Corporate knowledge included previous studies, e.g.:
  - "NASA Planetary Science Division Technology Plan," P. Beauchamp et. al, 12/20/2015
  - "Planetary Science Technology Review Panel," T. Kremic et. al, 7/29/2011
  - "PSD Relevant Technologies," G. Johnston 1/7/2011
  - https://solarsystem.nasa.gov/missions/techreports

- Result: A list of high priority technologies
- **PESTO took that list and decomposed it into quantitative technical goals**

PESTO: Community Technology Inputs – Visions and Voyages

Chapter 4 Primitive Bodies

- ✓ Continue technology developments in several areas including ASRG and thruster packaging and lifetime, thermal protection systems, remote sampling and coring devices, methods of determining that a sample contains ices and organic matter and of preserving it at low temperatures, and electric thrusters mated to advanced power systems.
- ✓ Develop a program to **bridge the TRL 4-6 development gap** for flight instruments.

Chapter 5 Inner Planets

- ✓ Continue current initiatives.
- ✓ Possibly expand incentives to include capabilities for surface access and survivability for challenging environments such as Venus's surface and frigid polar craters on the Moon.

Chapter 6 Mars

- ✓ Key technologies necessary to accomplish Mars Sample Return are Mars ascent vehicle, rendezvous and capture of orbiting sample return container, and planetary protection technologies.

Chapter 7 Giant Planets

- ✓ Continue developments in ASRGs, thermal protection for atmospheric probes, aerocapture and/or nuclear-electric propulsion, and robust deep-space communications capabilities.

Chapter 8 Satellites Technology development

- ✓ Develop the technology necessary to enable Jupiter Europa Orbiter.
- ✓ Address technical readiness of orbital and in situ elements of Titan Saturn System Mission including balloon system, low mass/low-power instruments, and cryogenic surface sampling systems.

PESTO: Community Technology Inputs – Assessment Groups

Visions and Voyages, VEXAG, OPAG, SBAG, Mars Program

Outer Planets input based on the OPAG white paper “Outer Planet “Roadmap of 2009

Reference: Planetary Science Technology Plan, April 9, 2015

	Applicable Technology	NEAR TERM MISSIONS					MID TERM MISSIONS					FAR TERM MISSIONS				
		Small Bodies	Outer Planets	Venus	Mars	Moon	Small Bodies	Outer Planets	Venus	Mars	Moon	Small Bodies	Outer Planets	Venus	Mars	Moon
SYSTEM TECHNOLOGIES	In Space Propulsion															
	Aerocapture/Aeroassist															
	Entry (including at Earth)															
	Descent and Deployment															
	Landing at target object															
	Aerial Platforms															
	Landers - Short Duration															
	Landers - Long Duration															
	Mobile platform - surface, near surface															
	Ascent Vehicle															
	Sample Return															
	Planetary Protection															
SUBSYSTEM TECHNOLOGIES	Energy Storage - Batteries															
	Power Generation - Solar															
	Power Generation - RPS										?					
	Thermal Control - Passive															
	Thermal Control - Active															
	Rad Hard Electronics															
	Extreme Temp Mechanisms															
	Extreme Temp Electronics															
	Communications															
	Autonomous Operations															
	GN&C															
INSTRUMENT	Remote Sensing - Active															
	Remote Sensing - Passive															
	Probe - Aerial Platform															
	In Situ - Space Physics															
	In Situ Surface - Geophysical															
	Sampling															
	In Situ Surface - Long Duration - Mobile															

Colors indicate TRL
(High:Green, Low:Red)

PESTO: Planetary Science Technology Needs Based on Visions and Voyages and Planetary Assessment Groups

PSD invests primarily in:

- Instruments (broad-based calls)
- Radioisotope Power Systems
- Mars Technology
- Extreme Environment Tech (hot and cold)

Instruments
1. Instruments to Locate Regions of Habitability from Orbit/Flyby
2. Technologies to Sample Plumes of Ocean Worlds from Orbit/Flyby
3. Techs to Extract & Process Materials on Ocean Worlds for Life Detection
4. Instruments to Identify Biomarkers from Ocean Worlds
5. Instruments to Identify Microscopic Organisms in Ocean Worlds
6. Instruments to Identify Life Processes on Ocean Worlds
7. Low Volume, Low Mass, Low Power Instruments for Small Spacecraft

Ice Penetration and Sampling
1. Ice Penetration and Sampling: Low-Mass, Low-Power Excavation
2. Ice Penetration and Sampling: Sample Handling and Transport
3. Ice Penetration and Sampling: Deep Ice Penetration

TRN/GNC/EDL –
1. Pinpoint Landing and Hazard Avoidance: Europa
2. Pinpoint Landing and Hazard Avoidance: Titan
3. Pinpoint Landing and Hazard Avoidance: Venus
4. Pinpoint Landing and Hazard Avoidance: Mars
5. Pinpoint Landing and Hazard Avoidance: Planetary Landing

Heat Shield Technologies for Planetary Entry and Sample Return
1. Aerocapture for Ice Giants
2. EDL and Aerocapture for Small Satellites
3. Deployable Aeroshells

Autonomy
1. System Autonomy for Planetary Exploration
2. System Autonomy – Efficient Planetary Surface Science Ops
3. Reactive Science Autonomy
4. Autonomous Interplanetary Navigation

Planetary Protection
1. Expanded Bioburden Reduction Technique Toolbox
2. Modernizing Verification Approaches for Biological Contamination Assessments

High Data Rate Communications
1. High Data Rate Communications: Large Deployable Reflectors
2. High Data Rate Communications: Solid State Power Amplifiers

Small Satellites (ESPA-Class)
1. Small Satellites – Communications
2. Small Satellites – Guidance Navigation and Control
3. Small Satellites – Electric Propulsion
4. Small Satellites – Non-Toxic Chemical Propulsion

Computing and Avionics –
1. Radiation Tolerant, High Performance Computing, and Avionics

Low-Temperature Systems
1. Low Temperature Low Power Rad Hard Electronics
2. Low Temperature Energy Storage
3. Low Temperature Solar Power

High-Temperature Systems
1. High Temperature Electronics
2. Batteries
3. Solar Arrays
4. Alternative Power Generation Systems

Radioisotope Power Systems for Flyby and Orbital Power
1. Fuel for Radioisotope Power Systems
2. Next Gen RTG Technologies for RPS Flyby and Orbital Power
3. Dynamic RPS for Flyby, Orbital and Surface Power
4. Low and Mid TRL Conversion Technologies

PESTO: Planetary Science Technology Goals and Applications

- Created in 2017 bottoms-up across the Agency, vetted by HQ
- Minor updates in 2020
- Used to communicate needs across SMD and STMD, and to inform PSD solicitations
- Major update planned once new Decadal is released

TRN, GNC, and EDL

1/6/2021

Prioritized Technology: Terrain Relative Navigation, Precision/Pinpoint Landing, and Landing Hazard Avoidance

Capability Description

- Terrain Relative Navigation (TRN) estimates position during descent by onboard registration of camera or lidar data to prior reconnaissance maps
- Precision landing uses TRN with a small divert to reach one of several known safe landing sites determined from prior recon
- Pinpoint landing uses TRN with a large divert to reach a single, small landing site (e.g. 100 m) in the unguided landing ellipse
- Landing hazard avoidance (HA) uses onboard lidar and/or camera data to avoid landing hazards not detectable from orbit
- In all cases, sensors are required to estimate horizontal and vertical velocity to enable safe touchdown velocities

Capability Status

- Mars 2020 will do precision landing with TRN with divert of up to 650 m and landing error of < 60 m
  - System uses a descent camera, doppler radar velocimeter, and FPGA coprocessor. This would also address many airless bodies.
- Europa Lander advanced technology program is addressing unique need dual mode lidar altimeter/hazard detection sensor; TRL 6 expected by e FY22. Also developing optical velocimetry to use descent camera instead doppler radar.
- SPLICE program is developing TRN, HA, and navigation doppler lidar (ND velocimetry for robotic and human lunar and other missions
- COLDTech program developed TRN algorithms and guided parafoil conce for the unique conditions at Titan
- Existing TRN and HA methods are insufficient for Venus

Mission Applications

- Current Mars Sample Return architecture calls pinpoint landing with divert of several km, to achieve landing error of < 20 m
- Current Europa Lander architecture requires landing position error < 50 m, velocity error < 0.1 m/s, hazard detection lidar with 5 cm ground pixel spacing a cm elevation error, from 500 m altitude. Lidar SWaP goals of 7 kg, 25000cm^3, 75W
- Landing delivery error for Titan guided descent is limited by resolution of currently available recon imagery to be a few km
- Landing hazard avoidance may be needed for landing in Venus tessera
- Applicable to any planetary landing application, including Moon, Mars, and other solid bodies
  - Some adaptation and/or accommodation may be necessary for particularly demanding environments for individual missions (such as radiation or ther
- Technology has significant overlap with Rendezvous and Docking applications (similar sensors, software, and techniques)

Communications

Last edited 08/10/20

Prioritized Technology: High Data Rate Communications Solid State Power Amplifiers

Technical Goal

Flight qualified solid state power amplifiers for X and Ka bands

- Goals
  - Power levels of 5-50 Watts (maybe up to 100 W)
  - Wall-plug efficiency of > 50% for X-band and > 40% for Ka-band
  - Lower mass and volume than equivalent output power TWTAs
  - Improved manufacturability relative to TWTAs
  - Increased reliability relative to TWTAs

Technical Status

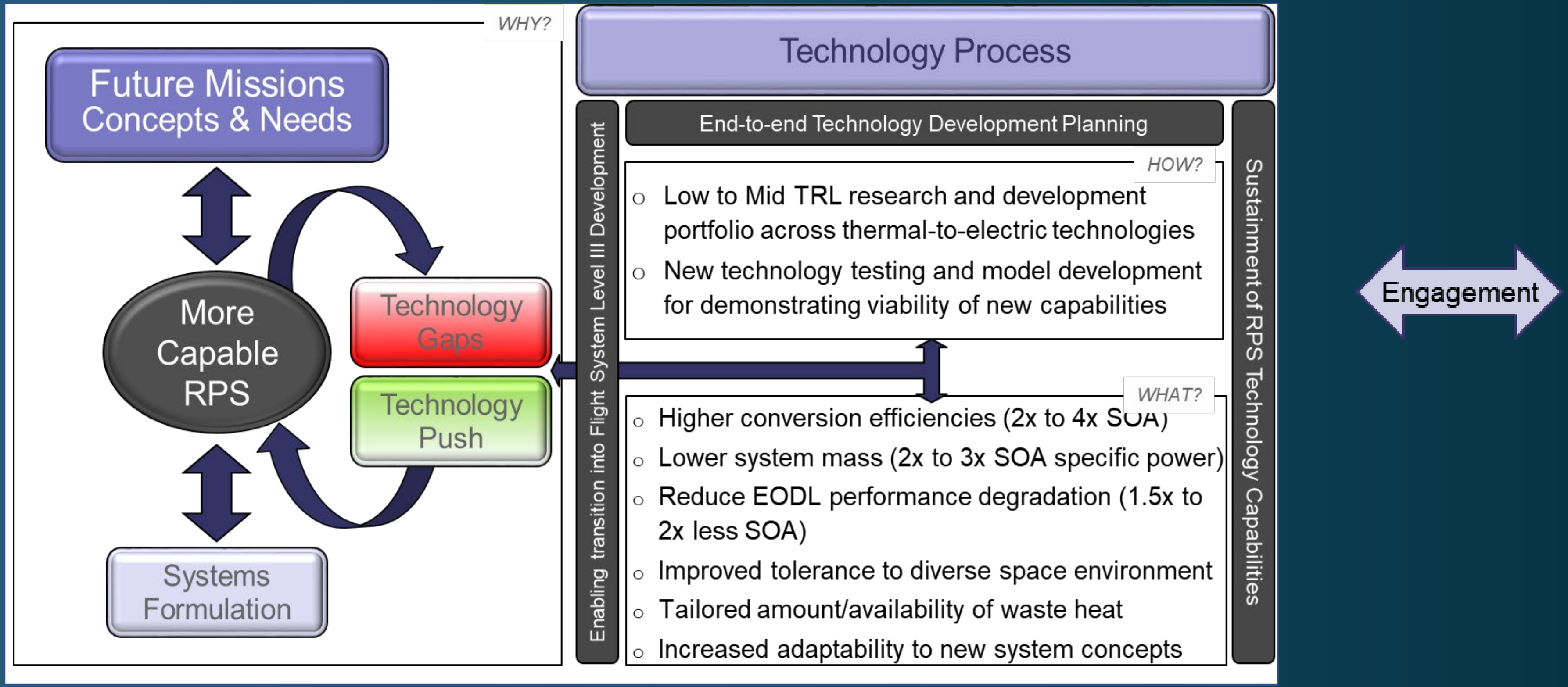
- Travelling Wave Tube Amplifiers (TWTAs) are the workhorse space power amplifier for X and Ka-band
  - Efficiencies of > 50% are typical
  - Power output levels up to at least 200W
- TWTAs require complex power supplies with large voltages (e.g., 300 V)
- TWTs are almost-hand-designed vacuum systems
- Sweet spot for GaN will be <100 W power output
- GaN SSPAs could significantly reduce the mass & volume and increase reliability relative to TWTAs
- Typical "production" GaN amplifiers for Ka-band are in the 10-40 W regime with 25-30% efficiency—lab devices better

Mission Applications

- Cube/SmallSats—requiring small mass and volume as well as power efficiency, usually < 50 W output power
- Outer Planets—limited primarily by prime power so 10-100 W "sweet spot" for GaN is appropriate; lower mass and volume; increased reliability over longer term
- Rovers and landers—requiring small mass and volume as well as power efficiency, usually < 50 W output power; better able to handle the mechanical "shock" of landing and roving.

https://www1.grc.nasa.gov/space/pesto/

RPS: Radioisotope Systems Program Technology Recommendation Process



COMMUNITY

NASA Assessment Groups:
LEAG, OPAG, SBAG, MEPAG…

Decadal

Flight Centers/Missions

Planetary Mission Concepts Studies and NAE/NAS Decadal Surveys

Workshops & Conferences:
NETS,
IEEE Aerospace,
AIAA Power and Propulsion,
Advanced Power Systems for Deep Space Exploration,
International Astronautical Congress,
Lunar and Planetary Science Conference, …

PESTO

RPS: Radioisotope Systems Program
Technology Goals and Performance Estimates

		System Efficiency	System Degradation Rate
State of the Art (SOA)	MMRTG	6.2% at BOL	3.2%/yr*
RPS Program Technology Goals	10-year Goal	10% at BOL	1.9%/yr
	20-year Goal	20% at BOL	1.4%/yr
RPS Technologies Current Best Estimate (CBE) Predictions and Targets	STM	6.65% at BOL	2.1%/yr*
	Next Gen Mod 2	10% at BOL	Target: 1.9%/yr*
	DRPS-FISC (Stirling)	> 20% at BOL	1.3%/yr
	DRPS-SRSC (Stirling)	> 20% at BOL	1.3%/yr
	DRPS-TBC (Turbo-Brayton)	> 20% at BOL	Target: 1.3%/yr
	SmallSTEP (Stirling)	Target: 20% at BOL	Target: 1.3%/yr
	GHOST	Target: > 15% at BOL	Target: 1.9%/yr*
	JTEC (Ericson)	Target: > 30% at BOL	Target: 1.9%/yr

* Based upon exponential rate law

Notes
- Goals are overarching programmatic goals across all technologies
- RPS Program is refining and updating these goals through engagement process
- Targets are for lower level TRLs that we have little data to substantiate CBEs
- BOL represents a deep space case, 250 W_e per GPHS

AMSC – American Semiconductor
FISC – Flexure Isotope Stirling Converter
GHOST – Group for the HOlistic Science of Thermoelectrics (GHOST) Task
JTEC – Johnson Thermo-Electrochemical Converter
SmallSTEP – Small Stirling Technology Exploration Power
SRSC – Sunpower Robust Stirling Converter
STM – Skutterudite Technology Maturation
TAPC – ThermoAcoustic Power Converter
TBC – Turbo-Brayton Converter

Technology Investments

Technology Development for Planetary Science

Science Instruments, Spacecraft Technology

- **Radioisotope Power Systems Program**
  - Next Gen Radioisotope Thermoelectric Generators (RTG)
  - Dynamic Radioisotope Power Systems (RPS)
  - Advanced Thermoelectrics and Conversion Technologies
- **Planetary Exploration Science Technology Office (PESTO)**
  - Science Instruments (PICASSO, MatISSE, DALI, ICEE)
  - High Operating Temperature Technology (HOTTech)
  - Icy Satellites (COLDTech, SESAME, ARROW, Astrodynamics)
- **Mission Specific**
  - Europa Lander
  - Mars 2020, Mars Sample Return
- **Partnerships with STMD**
  - Entry, Descent, and Landing Systems
  - Technology Demonstrations (DSOC, EESP)
  - SBIR
  - EPSCoR

Technology Development for Planetary Science

Radioisotope Power Systems

Next Gen Radioisotope Thermoelectric Generators (RTG)

Next Gen System with a performance no less than the GPHS-RTG system in order to support a 2030 mission: Deliver Mod 0 (refurbished GPHS-RTG); Mod 1 (new capability to produce GPHS-RTGs)

Increase the conversion efficiency as compared to the GPHS-RTG with a goal of 290 We EODL: Lanthanum/Tellurium/Zintl thermoelectric couples

Dynamic Radioisotope Power Systems (DRPS)

Multi-Mission RPS with an efficiency of 20-25% and produce 300-400 W_e of electrical power: Gas Bearing Stirling Convertor; Flexture Stirling Convertor; Controller Maturation; Risk Informed Life Testing, Generator System

Advanced Thermoelectrics and Conversion technologies

Increase system efficiency and decrease system degradation rate: SKD Thermoelectrics; Small Stirling Technology Exploration Power (SmallSTEP); Group for the HOlistic Science of Thermoelectrics (GHOST); Johnson Thermo-Electrochemical Convertor (JTEC)

Technology Development for Planetary Science

PESTO: Scientific Instruments

PICASSO

- Any Science, Low TRL, Annual Solicitation
- 39 active tasks: Spectrometers, Imagers, LIDAR, X-ray Optics, UV Optics, GPR, Seismometers, Radiometers, Sample Capture, Tomography, …

MatISSE

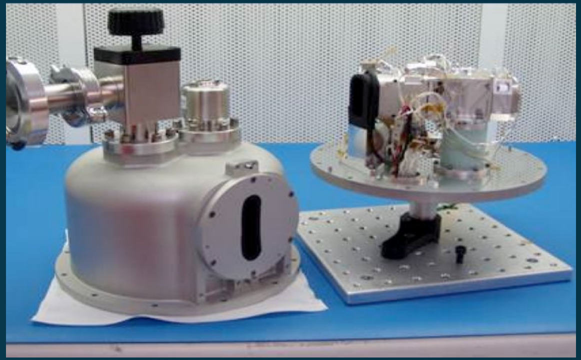
- Any Science, Mid TRL, Bi-annual Solicitation
- 24 active tasks: Accelerometer, Molecular Analyzers, Radiometers, Spectrometers, Radar, LIDAR, Geochronometer, Seismometers, …

DALI

- Lunar Science, Mid TRL, Annual Solicitation
- 20 active tasks: Imaging Spectrometer, Mass Spectrometer, Regolith Analyzers, Seismometers, Geochronometer, Dust Transport

ICEE

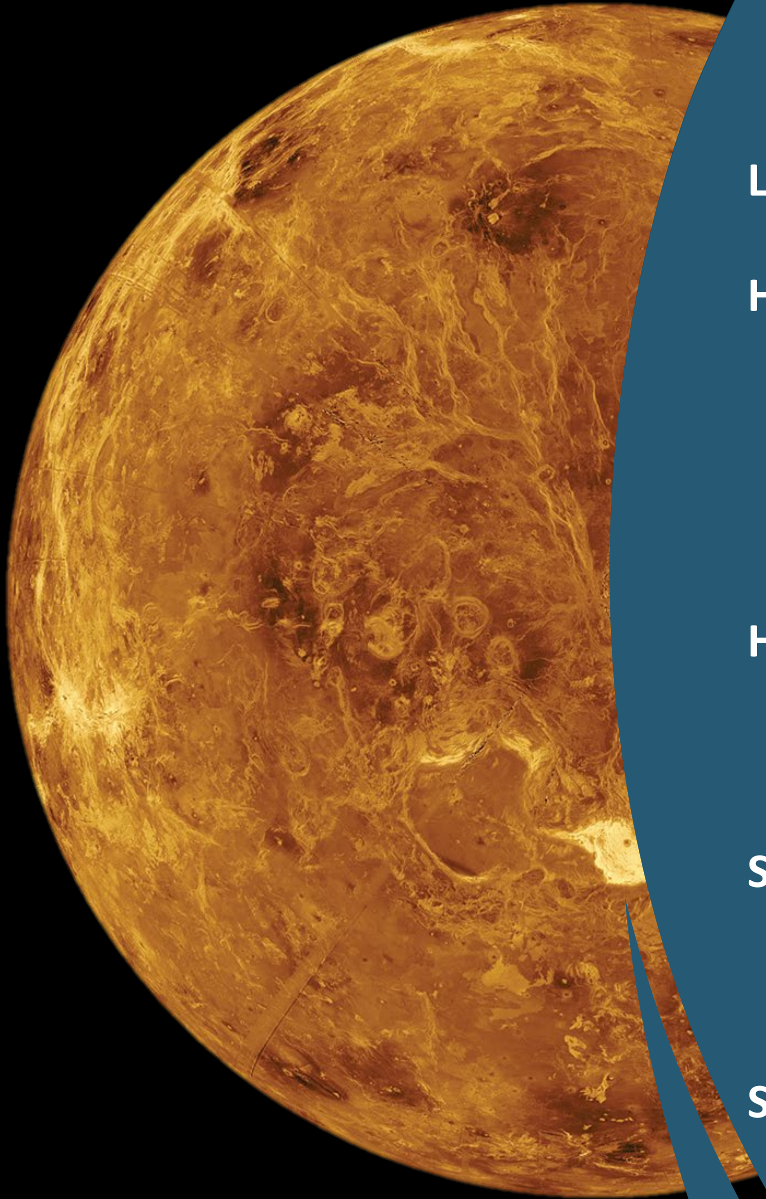
- Ocean World Science, Mid TRL, 2013 & 2018
- 14 tasks recently completed: Seismometers, Imagers, Mass Spectrometers, Raman Spectrometers, Organic Analyzers



MatISSE: Ultra Compact Imaging Spectrometer
PI: Diana Blaney

Technology Development for Planetary Science

PESTO: Venus Surface and Atmosphere



Long-Lived In Situ Solar System Explorer (LLISSE)

Batteries, Electronics, Sensors, Communications

HOTTech-2016

Electronics and Devices for Venus Surface Exploration 12 tasks:

Diamond and GaN Electronics, Memory, Clocks, Electronic Packaging, Motors, Batteries, Sensors, Solar Cells, Surface Power

HOTTech-2021

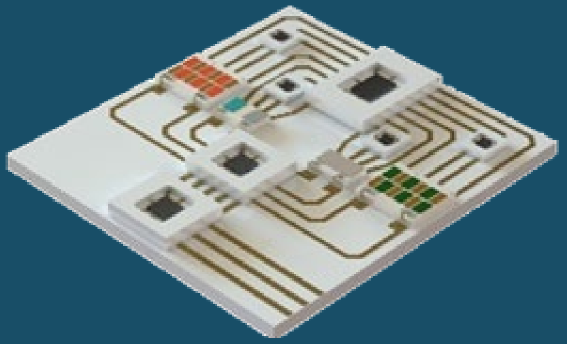
Electrical and Electronic Systems or Components for Venus Surface Exploration

STMD Small Business Innovative Research (SBIR)

Multiple Subtopics, including Venus focus for Aerial Platforms

STMD EPSCoR

Venus Surface and Aerial Platform focus



HOTTech: High Temperature Chemical Sensor
PI: Darby Makel

Technology Development for Planetary Science

PESTO: Icy Satellites

COLDTech-2016

Instruments and Spacecraft Technologies for Surface and Subsurface Exploration. 21 tasks: Detection of evidence of life; Sample acquisition, delivery and analysis systems; Deep-ice access

SESAME

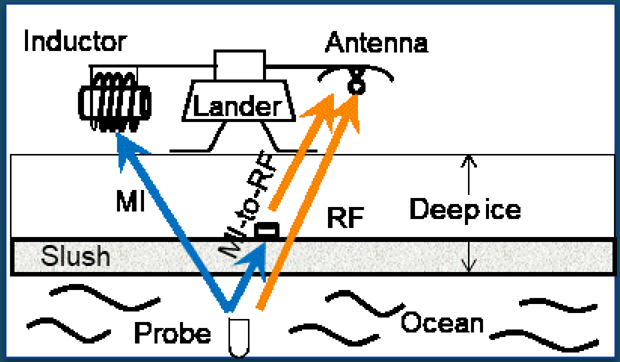
"Tall Pole" technologies for Vertical Ice Transport
5 tasks: Drills, Melt Probes, Communications

ARROW

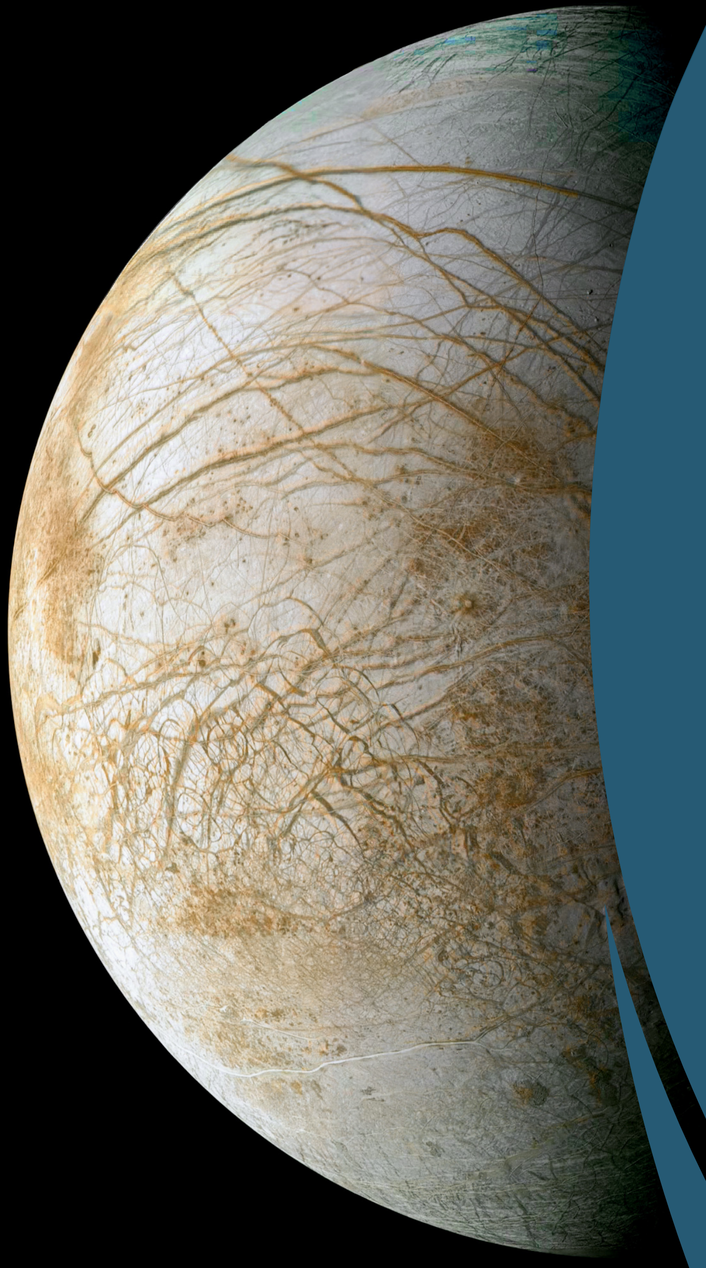
Autonomy for Ocean World Surface Systems
2 tasks: Task Planning, Adaptive Software

COLDTech-2020 (SESAME and ARROW follow-on plus)

11 tasks: Through-the-Ice Communications, Radiation Hard Electronics, Autonomy



COLDTech: Hybrid RF/MI Transceiver for Europa Sub-Ice Communications
PI: Michael Chang



Technology Development for Planetary Science

Mission Specific: Europa Lander

Autonomy

Sampling Autonomy: Develop and validate functional level autonomy for test excavation, sampling, and sample transfer

Surface Mission Autonomy: In-depth exploration of architectural and system issues that enable and constrain onboard autonomy (hardware, software, sensors, etc.)

Communications

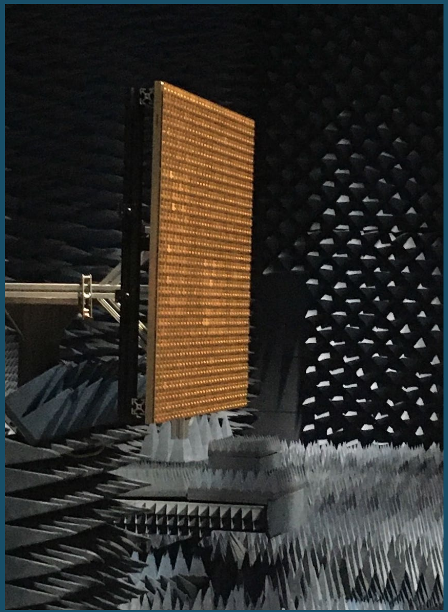
High Gain Antenna: Mature the Europa Lander High Gain Antenna design to TRL-6

Power

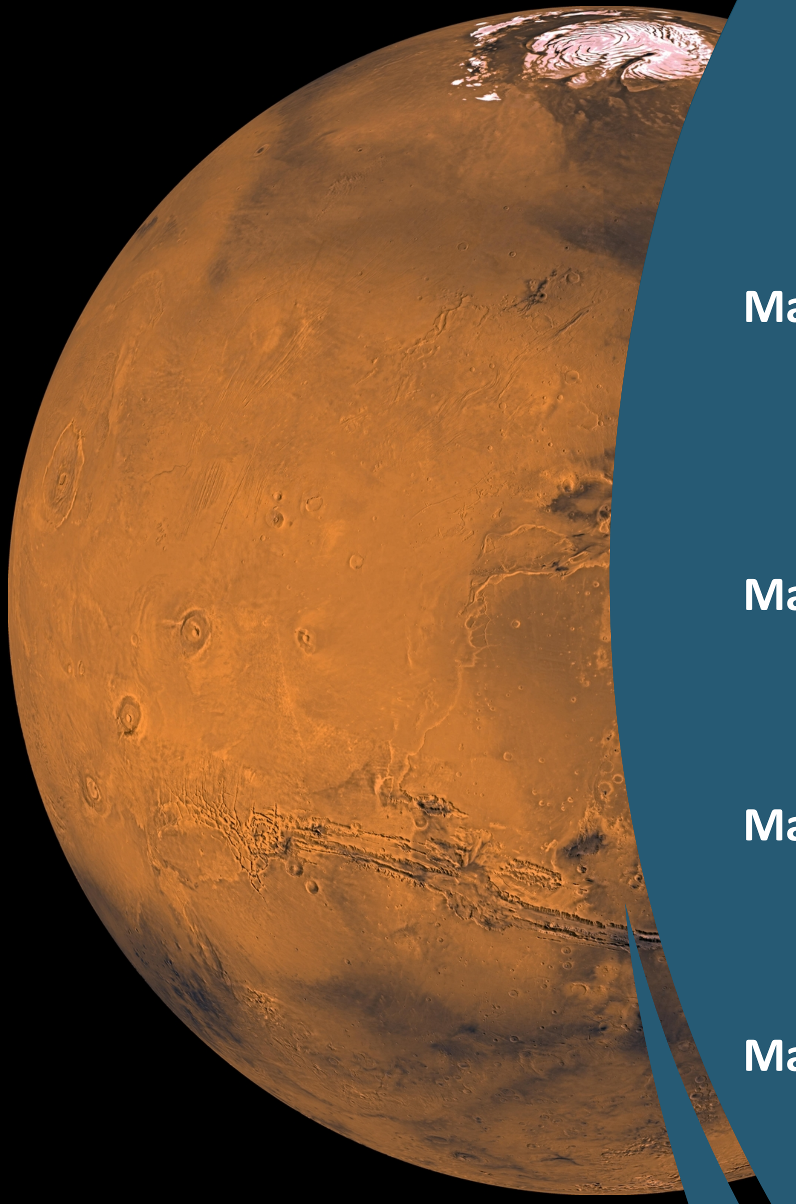
Battery: Evaluate effects of long-term storage and radiation on key cell characteristics (performance, safety, Li/CF_x primary cells)

De-orbit, Descent, Landing (DDL)

LIDAR Systems: Investigate LIDAR-based map-relative localization for Europa DDL



Europa Lander: High Gain Antenna (NASA JPL)



Technology Development for Planetary Science

Mission Specific: Mars

Mars 2020: Mars Helicopter

Co-funded with STMD and Aeronautics

Guidance, navigation and control; IMM solar cell demonstration

Mars 2020: Terrain Relative Navigation

Co-funded with STMD

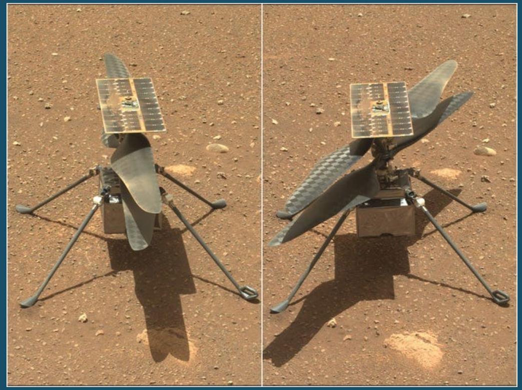
Vision system, Target selection algorithms

Mars 2020: Autonomy

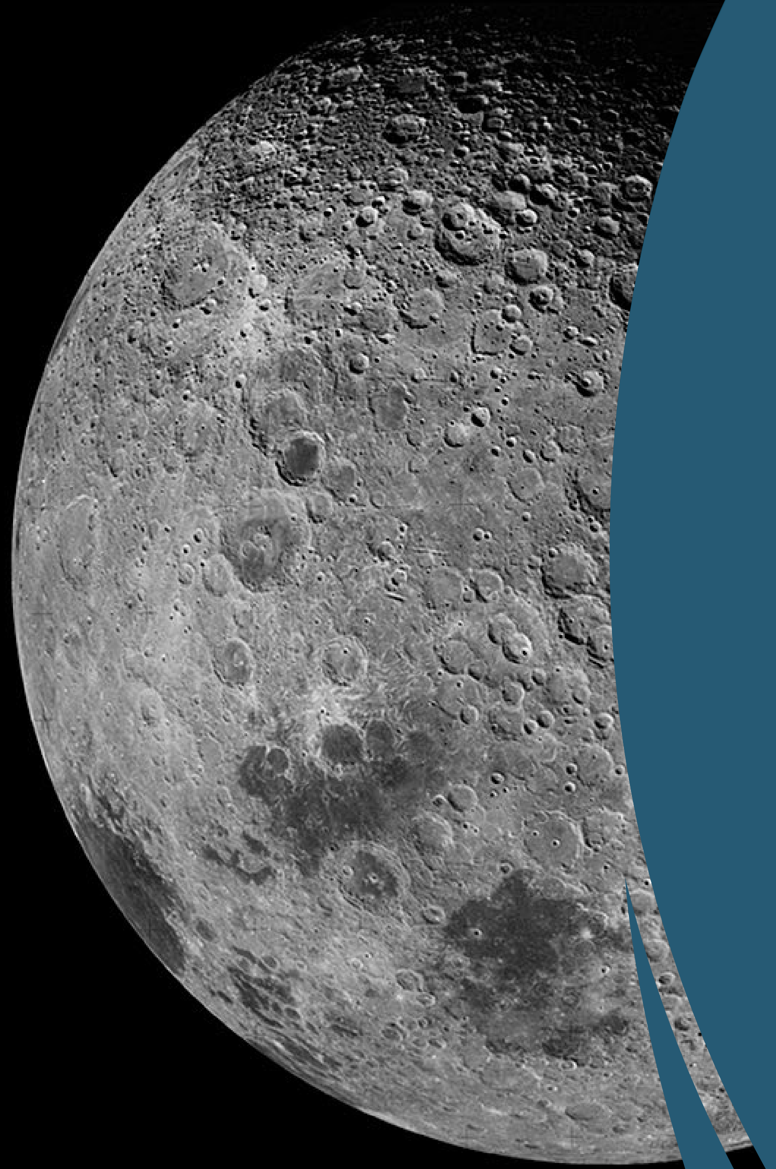
Rover driving, Robotic arm operations, Science instrument operations

Mars Sample Return:

Sample handling, Propulsion, Spring-loaded tires, Heatshield, Brazing technique, Parachute, Impact structure



Ingenuity
(NASA JPL)



Technology Development for Planetary Science

Space Technology Mission Directorate: The Moon and More

Technology Maturation

Lunar Surface Innovation Initiative

Power systems, Dust mitigation systems, Surface excavation systems, Extreme access mobility systems, Mechanisms and Electronics

Game Changing Technology Development Program

Entry Systems Modeling, High Performance Spaceflight Computing, Mars Entry/Descent/Landing Instrumentation, Cooperative Autonomous Distributed Robotic Exploration, Bulk Metallic Glass Gears, Extreme Environment Solar Power

Technology Demonstration Missions

Deep Space Optical Communications, Deep Space Atomic Clock, Laser Communications Relay, Terrain Relative Navigation, Solar Electric Propulsion, Green Propellant, Fission Surface Power

SBIR, EPSCoR, NIAC, ESI

Technology in yellow has flown or will fly on PSD missions

Questions?