



NASA Science Technology Development Programs for Ocean Worlds Exploration

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A vibrant space-themed background featuring a large blue circle on the left containing a detailed view of Earth's horizon. The rest of the background is a deep blue space filled with stars, a bright yellow sun, and several planets, including Saturn with its rings, Mars, and a large blue planet. The text is overlaid on the right side of the image.

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Planetary Science Decadal Guidance

Visions and Voyages 2013-2022

Basic motivations for planetary science:

- Building new worlds—understanding solar system beginnings
- **Planetary habitats—searching for the requirements for life**
- Workings of solar systems—revealing planetary processes through time.

Planetary habitats

- What were the primordial sources of organic matter, and where does organic synthesis continue today?
Important objects for study: comets, asteroids, Trojans, Kuiper belt objects, **Enceladus, Europa, Titan**, Mars, and uranian satellites.
- Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?

Important objects for study: **Enceladus, Europa, Titan**, Mars.

NASA's Science Plan

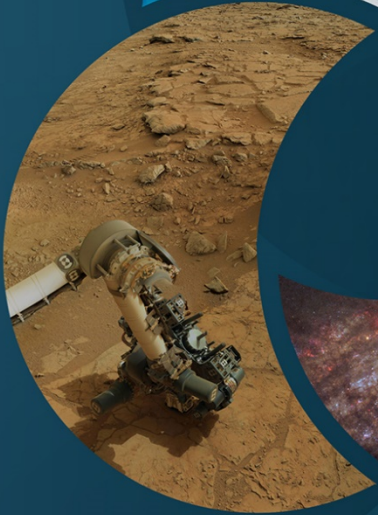
Science 2020-2024:

A Vision for Scientific Excellence

KEY SCIENCE THEMES



Protect & Improve
Life on Earth



Search for
Life Elsewhere



Discover Secrets
of the Universe



Ocean Worlds Technology Development Instruments and Spacecraft Technology to Prepare for Future Missions

Instrument Development Solicitations

- 2013 Instrument Concepts for Europa Exploration (ICEE-1)
- 2016 Concepts for Ocean Worlds Life Detection Technology (COLDTech-1)
- 2018 Instrument Concepts for Europa Exploration (ICEE-2)
- Every 2 years:
Maturation of Instruments for Solar System Exploration (MatISSE)

Spacecraft Platform/Ground Support Solicitations

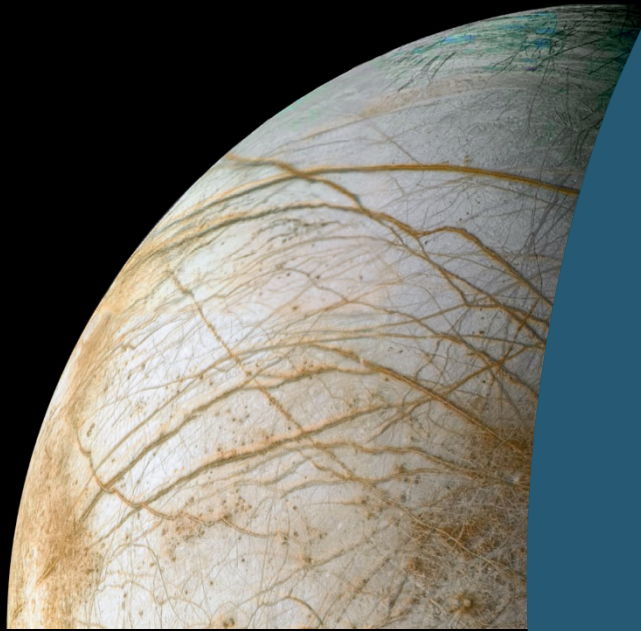
- 2016 Concepts for Ocean Worlds Life Detection Technology (COLDTech-1)
- 2018 Astrodynamics in Support of Icy Worlds
- 2018 Scientific Exploration Subsurface Access Mechanism for Europa (SESAME)
- 2019 Autonomous Robotics Research for Ocean Worlds (AISR:ARROW)
- 2020 Concepts for Ocean Worlds Life Detection Technology (COLDTech-2)

Spacecraft Platform/Ground Support Directed Work

- Europa Lander
- Radiation Hard Electronics
- Autonomy Testbeds

Instrument Concepts for Europa Exploration (ICEE-1)

Solicited in 2013



Program Objective:

- Development of spacecraft-based **instruments** for a Europa orbiter

15 Awards: Imagers, Mass Spectrometers, Spectrometers, Altimeter, Plasma Instruments, Dust Analyzer, Magnetometer, Ice Penetrating Radar, Radiometer

- SIRSE: Spectral Imager/ Spectrometer for Europa
- Thermal Imager for Europa Reconnaissance (TIMER) - Technology Maturation and Risk Mitigation
- Technology Development for a Topographic Imager on the NASA Europa Clipper Mission
- Topographic and Reconnaissance Imaging for Europa Exploration
- Mass Analyzer for Real-time Investigation of Neutrals at Europa (MARINE)
- Technical development of the MASPEX instrument for Europa Exploration
- Europa Short Wavelength Infrared Spectrometer- Radiation and Planetary protection Maturation (ESWIRS-RPM)
- CIRIS: A near- and mid-infrared Fourier transform spectrometer for investigations of the surface composition and habitability of Europa
- Plasma Instrument for Magnetic Sounding (PIMS)
- A Probe For Europa's Plasma Interaction
- Extended Range Laser Altimeter (ERLA)
- Maturing the Surface Dust Analyzer (**SUDA**) for Europa Exploration
- Development and Testing of an Integrated Magnetic Mapping Package for the Europa Clipper Mission
- Ice Penetrating Radar (IPR) for Europa Exploration
- Development of Large Format Rad-Hard Focal Plane Arrays and Readouts for Thermal Radiometer for Europa Clipper Mission



SUDA dust analyzer – S. Kempf/LASP

Instrument Concepts for Europa Exploration (ICEE-2)

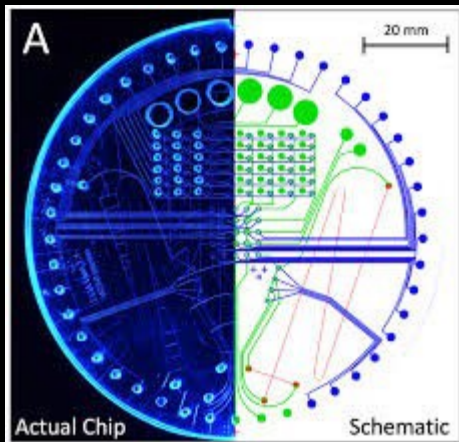
Solicited in 2018

Program Objective:

- Development of **instruments** for Europa surface exploration
- **Collaboration required** with the Europa Lander pre-project to co-develop the instruments, sampling acquisition and delivery system, and spacecraft accommodation.

14 Awards: Imagers, Mass Spectrometers, Raman Spectrometers, Organic Analyzers, Seismometers

- Cold-Lightweight Imagers for Europa (C-LIFE)
- Europa Lander Stereo Spectral Imaging Experiment (ELSSIE)
- Europa Luminescence Microscope (ELM)
- CORALS: Characterization of Ocean Residues and Life Signatures
- Mass Spectrometer for Planetary Exploration-Organic Composition Analyzer (MASPEX-ORCA) for Europa Lander
- Collaborative Acceptance and Distribution for Measuring European Samples (CADMES) System
- MICA: Microfluidic Ice-World Chemistry Analyzer
- Microfluidic Organic Analyzer for Biosignatures (**MOAB**)
- European Molecular Indicators of Life Investigation (EMILI)
- Compact Integrated Raman Spectrometer (CIRS)
- Seismometer to Investigate Ice and Ocean Structure (SIOS)
- Europa Seismic Package
- Reduced SWAP+C Radiation Tolerant Magnetometer for Europa Lander
- Europa Magnetotelluric Sounder (EMS)



MOAB – R. Mathies/UC Berkeley

Maturation of Instruments for Solar System Exploration (MatISSE)

Solicited every 2 years

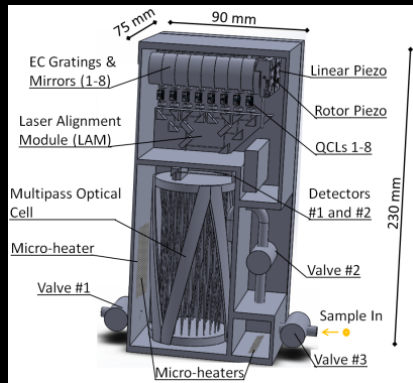
Program Objective:

- Significantly improve **instrument** measurement capabilities for future planetary science missions

7 Awards relevant to ocean worlds:

Imagers, Spectrometers, Organic Analyzers, Seismometers

- Maturation of a Hypertunable IR Laser Spectrometer for In Situ Planetary Exploration
- In-situ Spectroscopic Europa Explorer (iSEE)
- Compact, High Dynamic Range Ultraviolet Imaging Spectrometer
- Picture this SELFI: A Maturation Project for a Submillimeter Enceladus Life Finder Instrument (SELFI)
- Ion/Liquid Chromatography for Exploration of Solar System (ILCESS)
- The Enceladus Organic Analyzer (EOA)
- A Planetary Broadband Seismometer for the Lunar Geophysical Network and the Ocean Worlds



IR Spectrometer – S. Rafkin/SwRI

Concepts for Ocean Worlds Life Detection Technology (COLDTech) Solicited in 2016

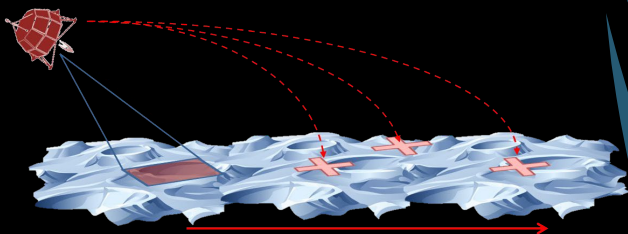
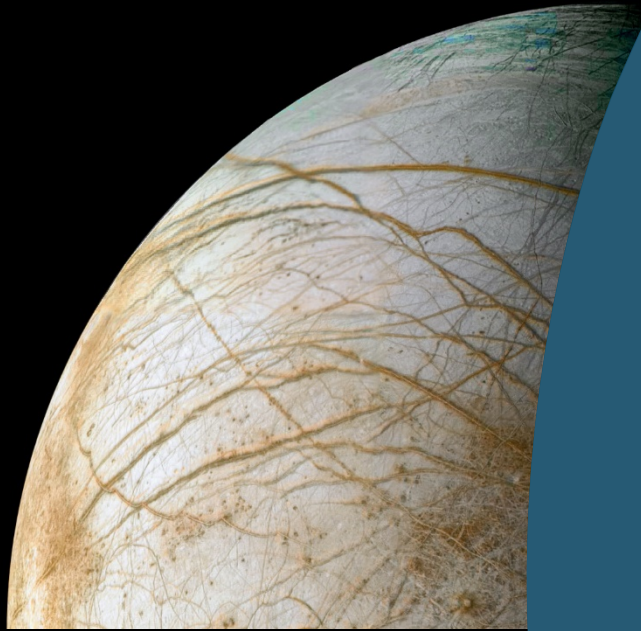
Program Objective:

Develop **instrument and spacecraft technologies** for surface and subsurface exploration of ocean worlds (e.g. Europa, Enceladus, Titan)

- Instrument development emphasis on the detection of evidence of life
- Sample acquisition, delivery and analysis systems
- Spacecraft technologies to access the oceans

21 Awards: Instruments, Sample Handlers, Spacecraft Technologies

- Plumbing Europa: A magnetotelluric sounder to characterize water layers and habitability within the ice shell of an ocean world
- Seismometers for Exploring the Subsurface of Europa (SESE)
- Cold-Lightweight Imagers for Europa (C-LIFE)
- Microfluidic Wet Chemistry Laboratory (mWCL) for Assessing Habitability of Ocean Worlds by Analysis of Surface or Plume Samples
- LIFE: Luminescence Imager for Exploration
- Development of Nanopore Sequencing for Automated Ocean World Life Detection
- NMR Detection of Extant Life
- Micro Fabricated Optical Seismometer "FROSTY"
- European Molecular Indicators of Life Investigation (EMILI)
- Supercritical CO₂ Extraction and Chiral Supercritical Fluid Chromatography for Ocean Worlds
- Advancing Nanomotion Sensor Technology to Provide Evidence for Active Life in Ocean Worlds
- Sample Processor for Life on Icy Worlds (SPLIce)
- Integrated Sample Acquisition Drill and Pneumatic Sample Delivery for Ocean Worlds
- EFun: the Plume Sampling System for Enceladus
- Ocean Worlds Lander Imager
- Precise Landing on Titan
- ICICLES: Intelligence for Choosing Icy Landing and Exploration Sites
- Cold Survivable Distributed Motor Controller (CSDMC)
- Autonomous Melt-Probe Penetration of Dirty Ice with Clean Sampling for Life Detection
- ARCHIMEDES (A Really Cool High Impact Method for Exploring Down into European Subsurface)
- Advanced Spacecraft Technologies to Explore the Ocean Worlds for the Detection of Extant Life



ICICLES—U. Wong/SGT Inc.



Astrodynamics in Support of Icy Worlds

Solicited in 2018

Program Objective:

Formulation, maturation, and validation of astrodynamics analysis tools to uncover new mission concepts, motivate entirely new classes of missions that may not have been previously considered, improve the efficiency of missions, and/or extend mission life.

4 Awards:

- Falcon: Automating the Search and Design Process for Icy World Trajectories
- Enhancements to The NASA Evolutionary Mission Trajectory Generator
- ASSET: Astrodynamics Software and Science Enabling Toolkit
- Quasi-periodic orbit computational tools for mission design

Scientific Exploration Subsurface Access Mechanism for Europa (SESAME) Solicited in 2018

Program Objective:

Formulation and maturation of **system concepts and the associated technologies** capable of penetrating ice and accessing the subsurface liquid water on ocean worlds such as Europa

5 Awards:

- PROMETHEUS: Nuclear-Powered Robotic Mechanism Technology for Hot-water Exploration of Under-Ice Space
- **SLUSH**: Search for Life Using Submersible Heated drill
- Cryobot For Ocean Worlds Exploration
- Vertical Entry Robot for Navigating Europa (VERNE)
- Europa STI- Exploring Communication Techniques and Strategies for Sending Signals Through the Ice (STI) for an Ice-Ocean Probe



Ocean Worlds Technology Development

Directed: 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

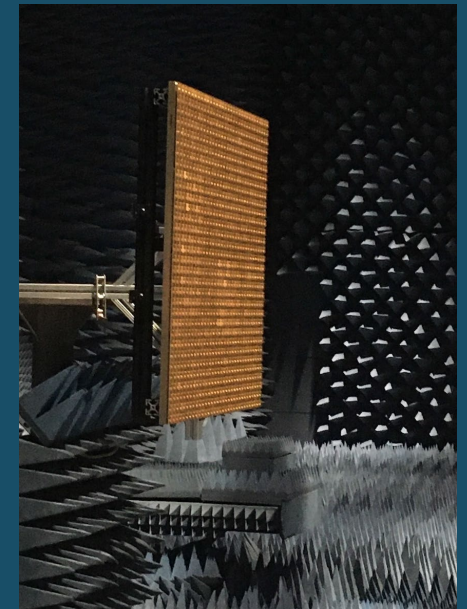
High Gain Antenna: Mature the Europa Lander High Gain Antenna design to TRL-6

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)

Ocean Worlds Technology Development

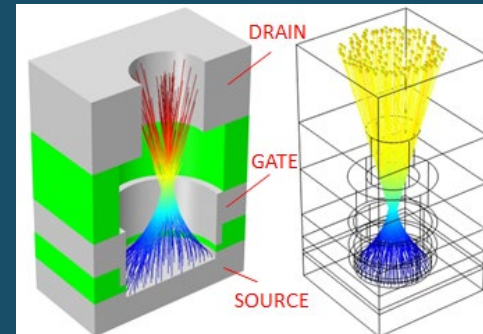
Directed: Radiation Hard Electronics

Objective:

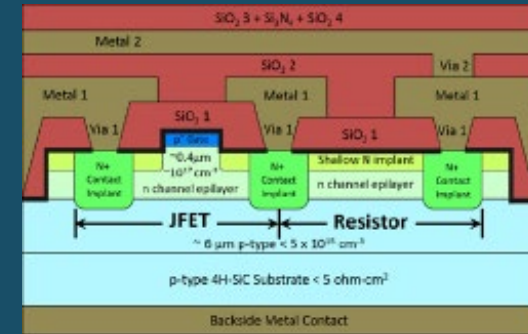
Develop **digital electronics devices** to operate in the high radiation Jovian environment

2 Activities:

- Nanoscale vacuum channel transistors (prior lunar development)
- Silicon carbide (SiC) transistors (prior Venus development)



NVCT – M. Meyyappan/NASA Ames



SiC – P. Neudeck/NASA GRC

Ocean Worlds Technology Development

Directed: Autonomy Testbeds

Objective:

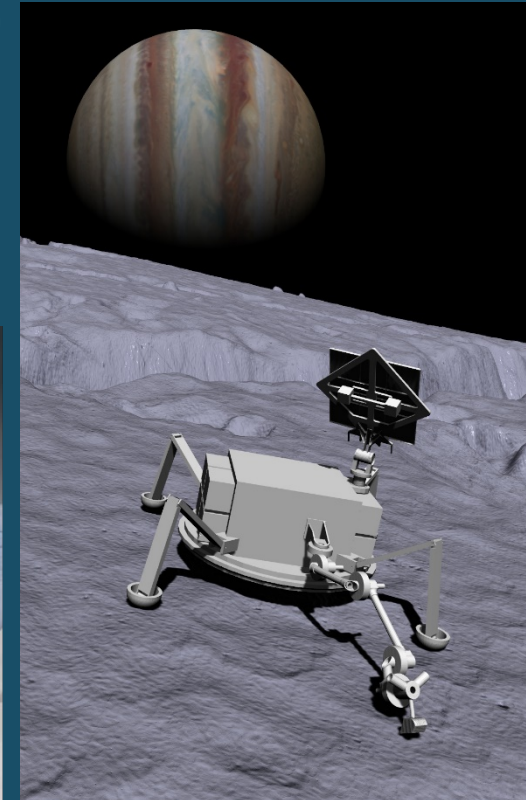
Develop testbeds to provide a common platform for competed autonomy task development and validation

2 Activities:

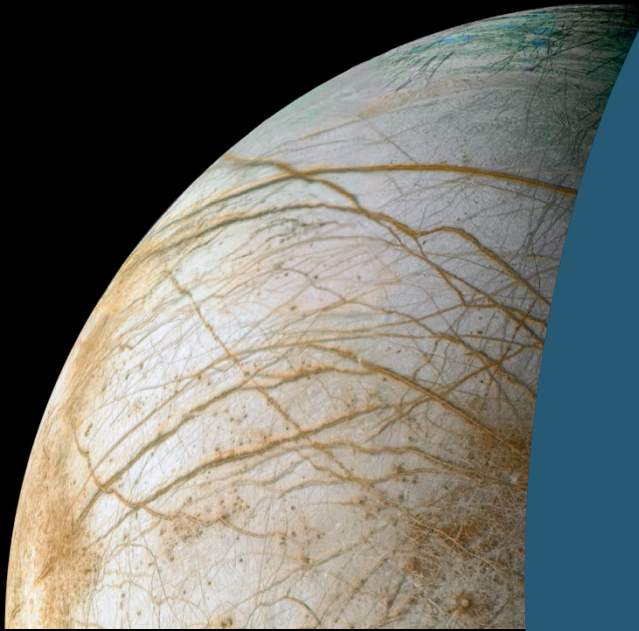
- Physical: Ocean Worlds Lander Autonomy Testbed (OWLAT)
- Virtual: Ocean Worlds Autonomy Testbed for Exploration Research and Simulation (OCEANWaters)



OWLAT – NASA JPL



OCEANWaters – NASA Ames



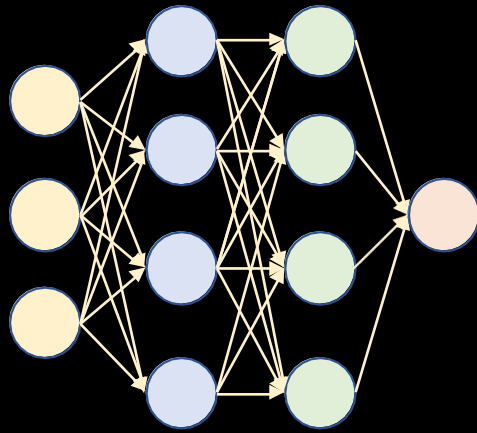
Autonomous Robotics Research for Ocean Worlds (AISR:ARROW) Solicited in 2019

Program Objective:

Development of functional and system-level **autonomous capabilities** for the surface exploration of ocean worlds

2 Awards:

- Robust Autonomy for Planetary Sampling
- RASPBERRY SI: Resource Adaptive Software Purpose-Built for Extraordinary Robotic Research Yields - Science Instruments



Concepts for Ocean Worlds Life Detection Technology (COLDTech-2) Solicited in 2020

Program Objective:

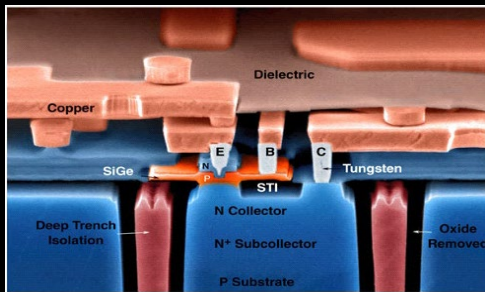
Develop **spacecraft technologies** for surface and subsurface exploration of ocean worlds (e.g. Europa and Enceladus)

Scope was limited to:

- **Autonomy** for landed operations
- Radiation-hard **digital devices**
- Technology to enable **communications** through many kilometers of ice thickness

11 Awards:

- Causal and Reinforcement Learning (CARL)
- Adaptive, Resilient Learning-Enabled Ocean World Autonomy (DRILLAWAY)
- Robust, Explainable Autonomy for Scientific Icy Moon Operations (REASIMO)
- Expert-Informed Autonomous Science Planning for In-situ Observations and Discoveries
- Environmentally-Invariant Silicon-Germanium Electronics for On-Surface Ocean Worlds Exploration
- A Radiation-Hardened Analog-to-Digital Converter for Outer Planetary Missions
- Tether based communication system for the Search for Life Using Submersible Heated drill (SLUSH) Europa probe
- Puck-Based Data Transmission Using Adaptive Radio Modems for Through-Ice Communications (PARTI Pucks)
- Technology for Sending Signals Through the Ice on Ocean Worlds (STI Tech)
- Hybrid Radio Frequency (RF) and Magneto-Inductive (MI) Transceiver for Europa Sub-Ice Communications
- Maturation and demonstration of technology to enable through deep-ice communication (CryoComm) on Europa



SiGe Transistor – J. Cressler/GA Tech

Scientific Instruments



Summary

Motivated by the *Visions and Voyages for Planetary Science in the Decade 2013-2022* to search for the requirements for life, a substantial investment has been made in the development of ocean world technologies

These include scientific instruments, and spacecraft technology focused on operating autonomously in the cold, high-radiation environment and accessing oceans under deep ice.

The newly-released *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* continues to emphasize the exploration of habitability and expands to include the search for life elsewhere.