DARES Focus Area #6

Astrobiology focused mission approaches and technology development

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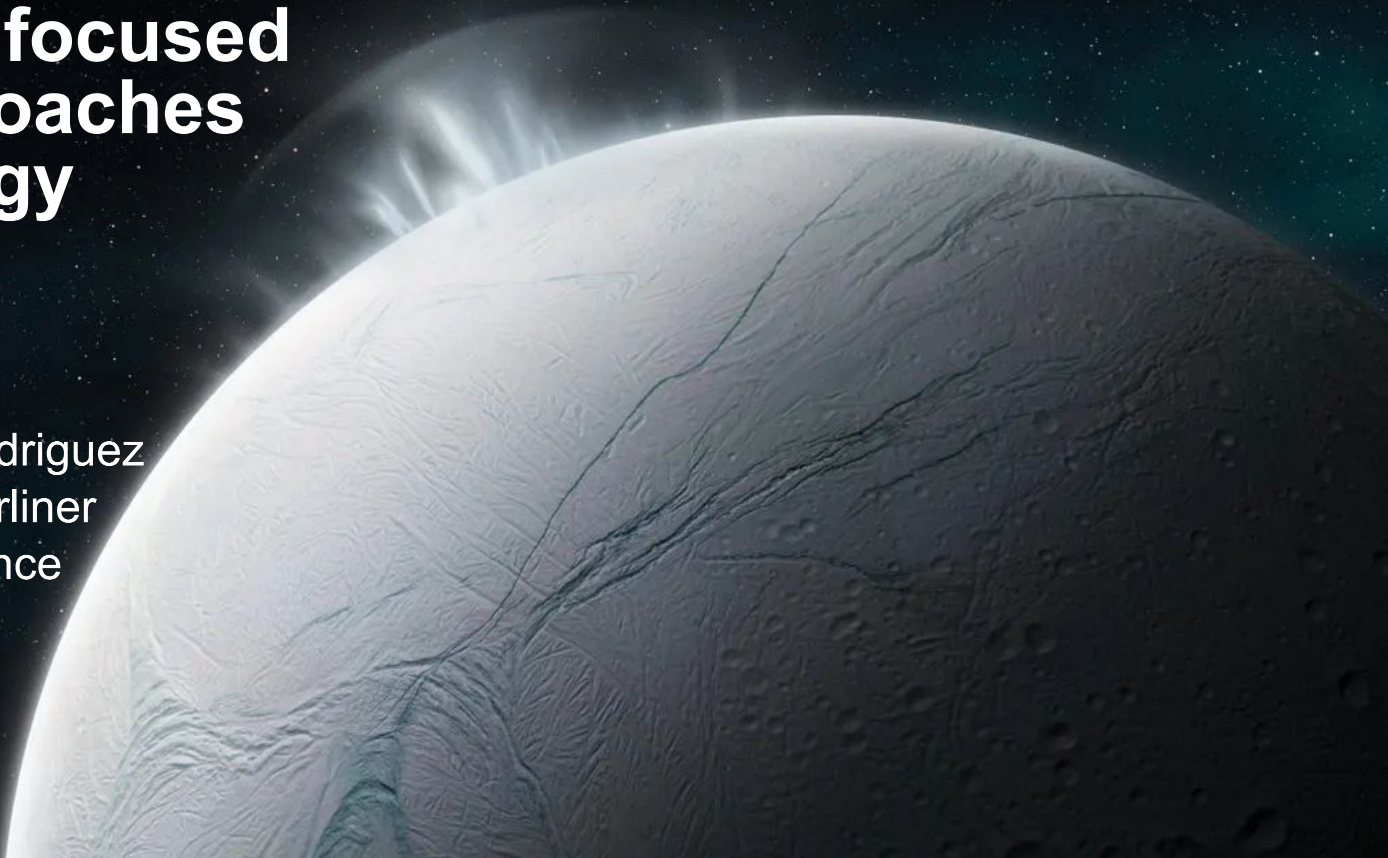
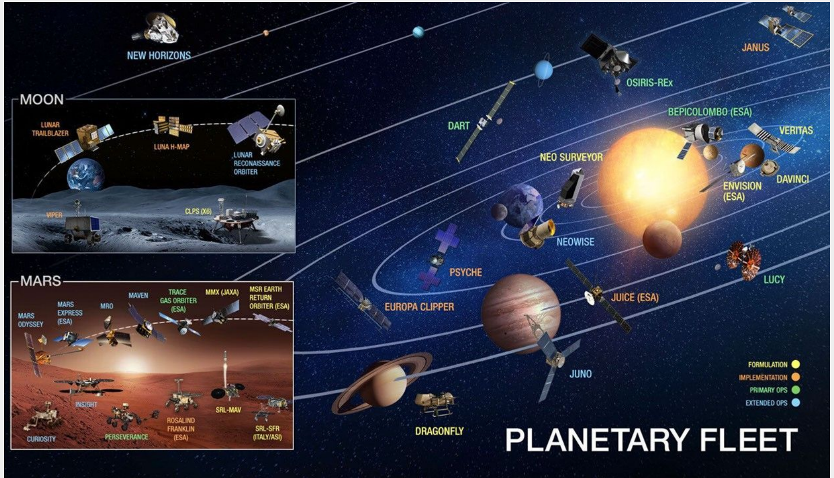


Overview

- Whether they are dedicated to astrobiology or not, the next generation of planetary exploration missions all have the potential to **bridge disciplines** to **maximize scientific return, while minimizing risk**.
- To achieve these optimal results, new **technologies will need to be developed** and missions must be designed, realizing **no single instrument can complete all mission objectives**.
- Mission development span decades, but development must start now to enable missions of the future
  - Missions will be targeting **increasingly complex environments, science operations, and in-situ analysis** in pursuit of life detection *and* habitability assessment.
- As demonstrated by Europa Clipper, JUICE, Dragonfly, and others, **astrobiological science is now firmly cemented in NASA's scientific objectives** and has the potential to cross several NASA divisions.

Credit: NASA



Finding 1: <u>Astrobiology missions will push the limits of traditional human-in-the-loop science operations.</u> The next generation of computing capabilities must be developed to overcome these potential obstacles.

Challenge

- Future astrobiology missions will operate in unique, resource-constrained environments, where **traditional science operations will not be possible**
- Are autonomous mission and science operations **trusted** enough to execute flagship missions?

Credit: NASA

Finding 1: Astrobiology missions will push the limits of traditional human-in-the-loop science operations. <u>The next generation of computing capabilities must be developed to overcome these potential obstacles.</u>

Path Forward

- **Autonomous science judgement and operations** would enable the next generation of planetary missions, operating beyond the constraints of traditional human-in-the-loop operations, especially in resource-constrained environments.
- Several new technology developments could reduce the risk of future missions, while maximizing scientific return:
  - On-board processing
  - AI/ML
  - Autonomous navigation
  - Autonomous science operations
  - Data prioritization in downlink
- Start on Earth: autonomous operations are lower risk, high reward in **Earth analogs**

Credit: NASA

Open Questions

- **Trust must be established** in these technologies through rigorous testing in Earth analogs/labs
- When building autonomy, are we able to properly capture **our own operations and decision making**?

Finding 2: Crewed missions present a unique and valuable opportunity to conduct high-priority science and measure the effects of such missions on a planetary body.

How might human spaceflight benefit astrobiology?

- As NASA returns humans to the Moon (and eventually Mars), it is critical that the astrobiology community evaluates and prioritizes research which would gain **scientific value from crewed operations**
    - Science community gains immense value from crewed operations on ISS

- **Trained astronauts** can make **real-time decisions**:
    - Sample selection
    - Imaging
    - Contextualization of sampling site
    - Consultation with scientists on the ground

- Feedback loop of analysis which facilitates **increased efficiency of follow-up sample collection** → observed in Apollo

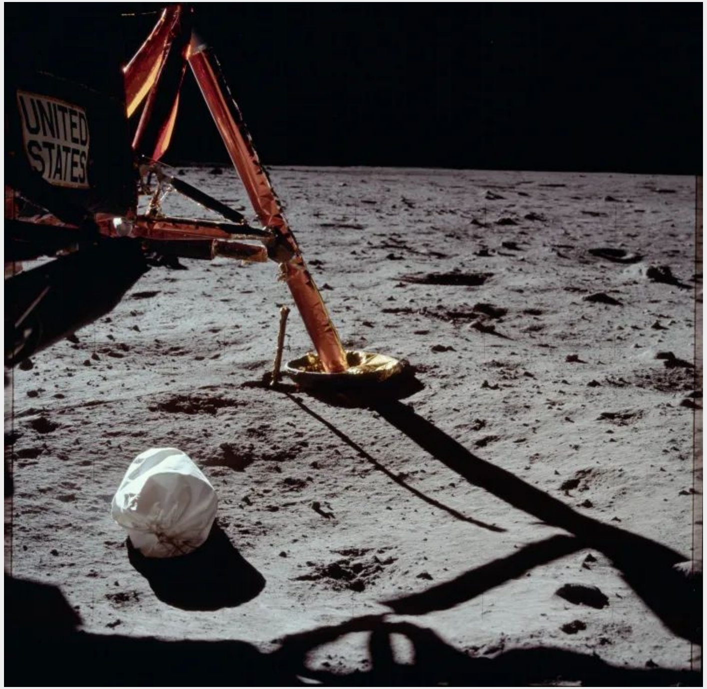
Apollo geology training (Credit: NASA)

Finding 2: Crewed missions present a unique and valuable opportunity to conduct high-priority science and measure the effects of such missions on a planetary body.

How might astrobiology benefit and influence human spaceflight?

- Lunar surface has hosted years of crewed and robotic exploration
- Measure how this **exploration has contaminated a pristine Lunar surface** to gain insight into how **exploration permanently affects a landscape**, which could hold past life, present life, or the building blocks of life
  - What does this mean for crewed missions to Mars, which has years of robotic (only) exploration?

- Technology developed for astrobiological science could facilitate human spaceflight
  - Life detection instruments could monitor environmental conditions on-board crew habitats, spacecraft (aerosol monitoring, biomolecule sequencers)
  - Planetary protection technology and human spaceflight go hand-in-hand



Apollo jettison (trash) bag (Credit: NASA)

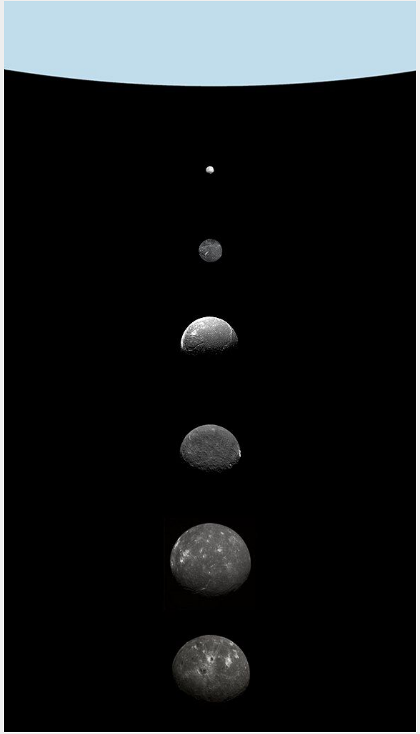
Finding 3: Cross divisional synergies are evident and targets, not always viewed as having astrobiological interest, can provide vital context and reduce risk for future astrobiology exploration (relates to Focus Area #2 F4)

Astrobiology is in all corners of NASA's portfolio

- Across all current and future missions, it is recommended that **astrobiology gets a "seat at the table"** from early stages of mission development to mission end.
- Astrobiology has the potential to **bridge cross-divisional boundaries** and silos
  - BPS, Moon to Mars, astrophysics, crewed missions, heliophysics
- Astrobiology must be viewed as a domain which is **larger than just pure science & research**
  - Astrobiology must be present and considered in:
    - Mission engineering design documents (e.g., sample collection instruments)
    - Mission operations (e.g., site selection)

"Non-traditional" targets are just as important and hold scientific value

- Abiotic targets, and beyond, hold valuable astrobiological opportunities (e.g., cis-Lunar, Terrestrial meteorites, relict ocean worlds)
- **Lunar surface** presents a low-risk proving ground to test instruments and operations before operating in higher-risk environments of particular astrobiological interest
- Include astrobiology on extended mission proposals



Uranian System
(Credit: NASA)

Finding 4: As astrobiology-focused missions progressively get more advanced and target more sensitive environments, especially in-situ operations, <u>planetary protection protocols must be proactive and reflect the increased risks of forward and backward contamination.</u>

- Planetary missions with the **highest potential for scientific return**, often hold the **highest potential for forward and backward contamination**
  - In-situ operations
  - Crewed missions
  - Sample return
- New technologies and operational standards could be able to be **tested in much lower risk environments** (e.g., Lunar surface, asteroid sample handling) before operations in environments of high astrobiological interest and possible habitability (e.g., subsurface oceans, plume sampling).
- **Complementary technologies**, which could be used to detect biosignatures on another planet or monitor aerosols in an operating room, could be developed in conjunction with planetary protection technologies

Credit: NASA

Finding 5: The next generation of world-class astrobiology missions will require technology that currently does not exist.

Technology Development Roadmap

- Support tech development at all phases of TRL
- Develop and test in Earth-based labs and analogs → Test and operate in low risk environments → operate at targets of high-priority science
- Development of new technologies may also see the **infusion of mature technology from other fields** (as observed on ISS):
  - Microfluidics, microbiology, DNA sequencing, environmental monitoring, biohazard mitigation

Technology Gaps

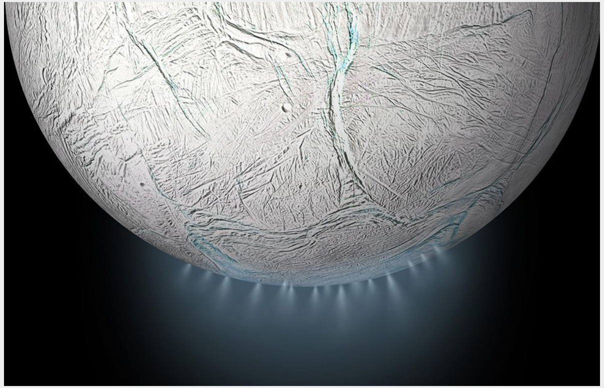
- In-situ operations and analysis (e.g., Europa Lander, Enceladus Orbilander) present the largest technology gaps
  - **Sample collection, preparation, and analysis** instruments in extreme environments (reduced gravity, autonomous operations)
  - Instrument's ability to detect biosignatures at low concentration rates, as low as **parts-per-billion**
- Establish "**finish line**" milestones during tech dev (avoid TRL valley of death)

Credit: NASA

Why this Focus Area Now?

2015 Strategy	Focus Area #6
"While **astrobiology at NASA is a research and analysis activity, rather than mission development and operations**, the advancements made in astrobiology have resulted in an **inseparable link to planetary exploration missions**. Consequently, astrobiology will have a greater focus on such missions."	Astrobiology must be considered as a domain beyond pure science… often, astrobiology now <u>**is**</u> the mission. The "inseparable link" is closer than it's ever been across all missions Missions will be designed around astrobiological science needs: autonomous operations, in-situ instrument analysis
No specific chapter on mission approaches or technology development	Habitability assessment, life detection, biotic/prebiotic chemistry are now focuses of entire missions and instrument suites
[Mission concept → Development → Operations] pipeline can span decades	
"Promote Planetary Stewardship… protections against forward and back biological contamination…Constrain human exploration (minimize adverse impacts on planetary environments)"	Planetary protection is more important than ever, especially since in-situ operations are a growing reality. **Commercial and international exploration** of the Moon and Mars are ongoing and will only expand.
"One of the greatest challenges - and greatest opportunities - faced by the astrobiology community is the need for **collaborative, interdisciplinary research**. The challenge comes in the form of different technical standards and terminology, different sets of expectations for behavior, and sometimes conflicting stakeholder interests." →	Collaborations should be far reaching and begin early in the mission phase
"How does astrobiology research help motivate human spaceflight? How does human spaceflight enable future astrobiological investigations?" →	Human space flight destinations are as **broad and accessible** as ever

Focus Area Landscape



Adapt existing technology and develop new technology

Study Earth as an analog

Test in extreme environments

Bridge divisional boundaries early

Use uninhabitable, accessible bodies as low-risk proving grounds (including crew)

Measure effects of exploration on a planetary body

“Non-traditional” targets hold just as much scientific value

Operate in high-risk environments, of high interest

Maximize scientific return via in-situ sample analysis and operations

Most extreme and resource-constrained environments environments (why the tech was developed)

Focus Area Summary

- Astrobiology is firmly cemented in NASA's scientific objectives
  - More often, astrobiology **is** the mission

- Destinations of the highest astrobiological interest are often the most complex and high risk, requiring:
  - In-situ operations and sample analysis
  - Autonomous science operations
  - Advanced technology development for life detection
  - Planetary protection protocols and technology

- Science of astrobiological relevance can be found in every mission of NASA's portfolio
  - 1. The astrobiology community should seek out these opportunities across all mission targets
  - 2. Presents the ability to cross boundaries and divisions

Backup slides

Strategic Documents

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(continued on next slide)

Strategic Documents

- **OWL relevance**
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Relevant White Papers

- 0006: Implementing Human Missions to Mars to Enhance Astrobiology Science Return (Jakosky et al.)
- 0038: Solar System Surface Technosignatures: Searching for Signs of Artificial Design on Extraterrestrial Terrain (Henrique et al.)
- 0039: Data-Driven Approaches to Searches for Signatures of Extraterrestrial Technology (Lazio and Djorgovski)
- 0065: Science Autonomy using Data Science and Machine Learning for Astrobiology (Da Poian et al.)
- 0077: Doing Astrobiology Before, During and After Crewed Space Missions (Berea et al.)
- 0080: The Importance and Need for Developments in Machine Learning and Artificial Intelligence Applied to Mass Spectrometry Data Interpretation and Decision-Making for Future Life Detection Missions (Nunn et al.)
- 0088: Foundation Models for Astrobiology (Felton et al.)
- 0090: The Astrobiology Data Ecosystem, Open Science, and the AI Era (Gentry et al.)
- 0098: Luna: Earth's Abiotic Partner (Burke et al.)
- 0112: Advancing Synergies in Astrobiology and Space Life Sciences in Service of Human Space Exploration (Farcy et al.)