DARES Focus Area 7: Investment in astrobiology physical and digital architecture

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Overview: Future astrobiology research will require resources, facilities, and protocols to enable collaborations and to provide new technological capabilities.

Why is this important to NASA Astrobiology?

- The astrobiology community is geographically dispersed and requires physical places to interact and conduct research.
- Many disciplines within astrobiology have emerging needs for **specialized facilities and computational capabilities.**
- NASA's physical infrastructure is at or beyond its designed lifetime (NASEM 2024).
- Some of these resources are already in development but are not necessarily being developed explicitly for astrobiology goals.

Physical Architecture

F1: There is a widespread need for physical resources and facilities dedicated for astrobiology research

- Example Recommendations:
  - Astrobiology-specific **sample repository** (Pontefract et al., 2025) modeled on existing NASA repositories (astromaterials, BISC, PMD).
  - Astrobiology analog **field stations** (e.g. Antarctica, Arctic, caves, deserts, deep drill sites, etc.).
  - Laboratory **facilities** for research in astrobiology-relevant conditions (e.g. extremes in temperature and pressure, clean rooms for low-biomass research, early evolution simulations).
  - Flight missions rely on NASA's assembly, test, launch, and communications **infrastructure**. Astrobiology could be more explicitly incorporated into this infrastructure, which must be maintained and improved.

Conceptual Figure for an Astrobiology and Planetary Analogs Curation Facility

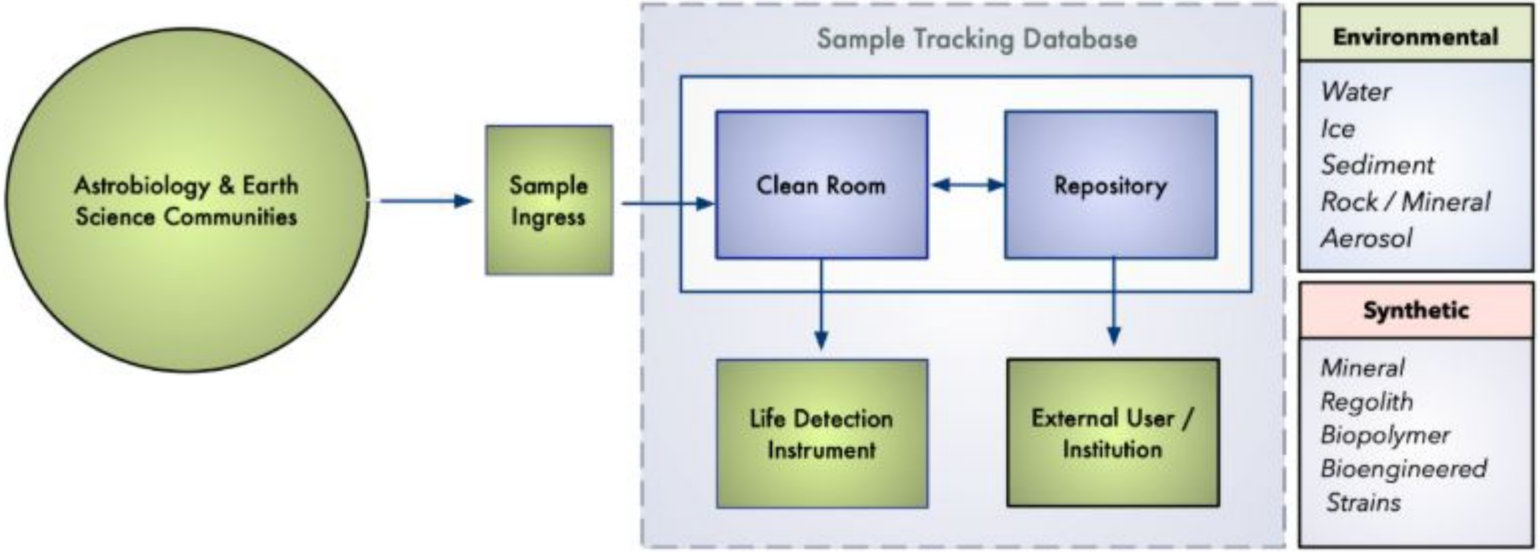


***Figure 1**. Concept facility for the Astrobiology and Planetary Analogs Sample Collection. Arrows detail sample ingress and egress, as well as the role of the clean room in sample processing as well as instrument testing. Examples of potential sample types are listed on the right, spanning environmental analog samples to synthetic (lab-generated) samples.*

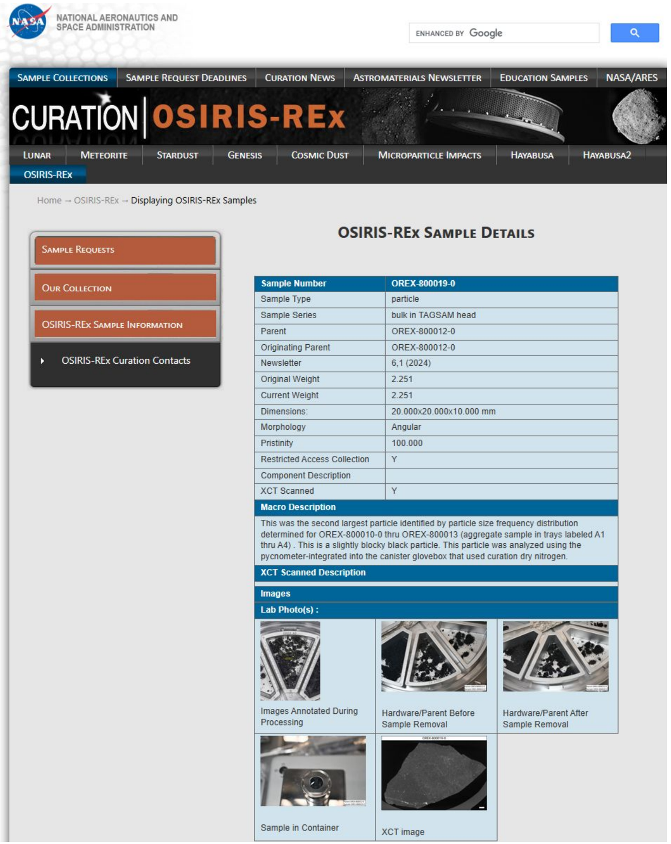
Pontefract et al. White Paper 0094

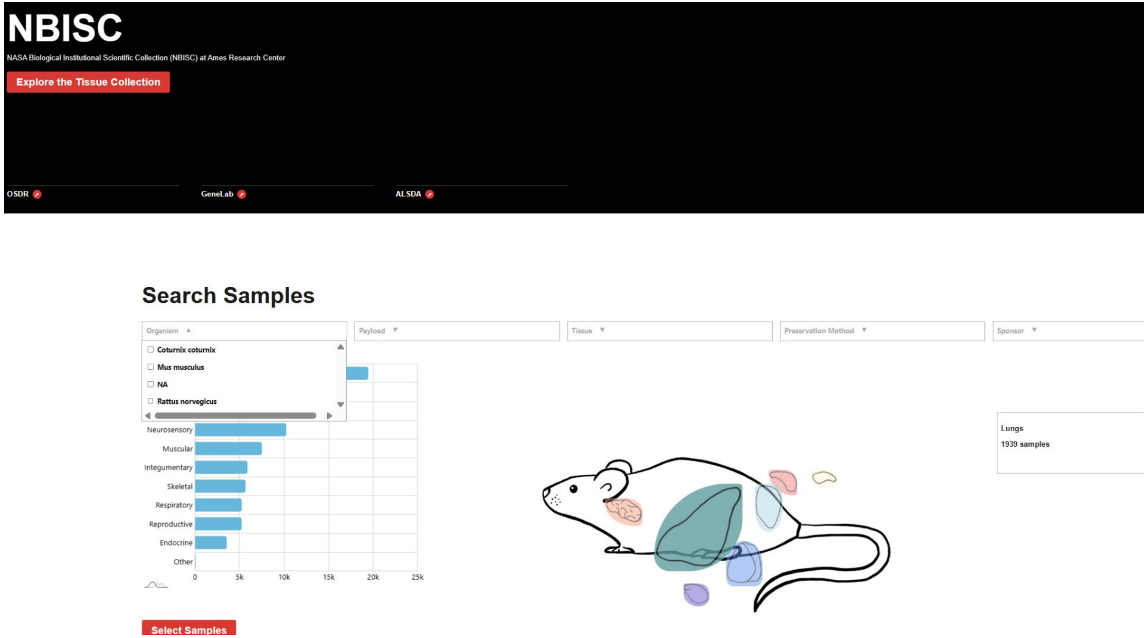
Digital Architecture

F2: Digital resources are required to facilitate collaborative research and to take full advantage of AI/ML technologies.

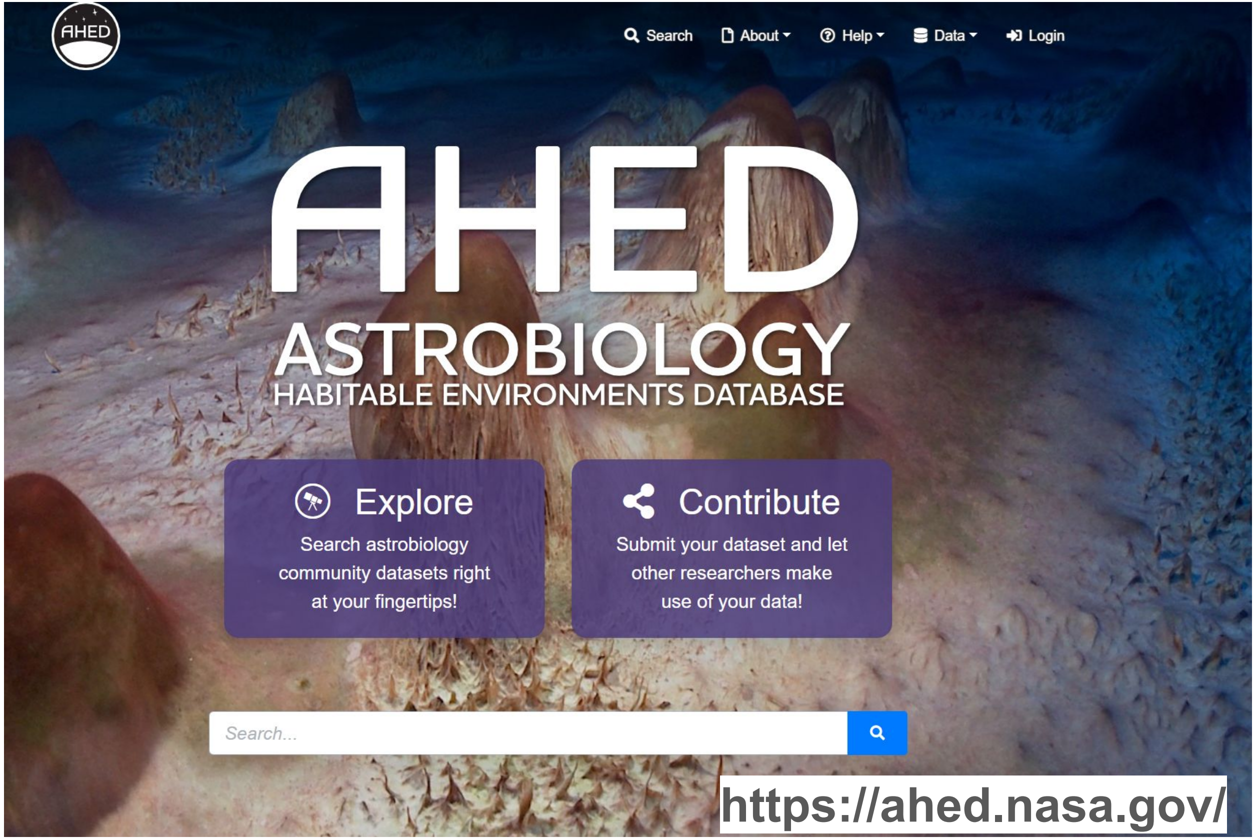
- Astrobiology-specific **databases** are required to preserve, curate, and facilitate sharing of large and cross-divisional datasets
- Contributes to NASA's goals of Open Science
- Unifying disparate datasets in common formats and databases is required to take full advantage of **AI/ML technologies** that could enable breakthroughs in all astrobiology disciplines from genomics to exoplanet and technosignature detection.
- Current funding structures are not conducive for the **longevity of databases**
- **Examples** that could be developed further toward these goals:
  - Astrobiology and Habitable Environments Database
  - Astromaterials Data System
  - Astrobiology Spectral Database
  - Planetary Data System

Sample Database Examples for Physical Samples





Database Example for Digital Data



https://ahed.nasa.gov/

Differences from 2015 Astrobiology Strategy

- Field stations, sample repositories, and common-use facilities were not mentioned in 2015 Strategy.
- Computational approaches were only briefly mentioned in 2015, but are a common theme in many 2025 white papers.

Why this Focus Area now?

- New technological needs (challenging samples, computational approaches) recognized in NAS OWL 2023.
- Needs for databases and computational resources also highlighted in NAS Astrobiology Strategy 2019, Astro2020, BPS Decadal 2023, PESTO 2024, Mars 2024, Heliophysics Decadal 2024, IODP-NASA Workshop 2024.
- The need for infrastructure reflects the maturing of astrobiology research.

Focus Area Landscape

Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Area 8
Area 9

Area 7: Infrastructure

Summary

There is a clear community need for physical and digital infrastructure to connect the astrobiology community and enable research.

Potential Topics For Discussion

- **Top-down or bottom-up?** The need for physical and digital resources to connect the astrobiology community is clear, but in which cases should NASA provide these resources and in which cases should researchers be supported to develop their own?

- **Environmental impact of AI**. Many implementations of AI consume large amounts of energy and water (Ligozat et al. 2022). How should we evaluate these costs when planning research?

Relevant White Papers

- 0016: Expanding Nasa's Concept Of Astrobiology Through The Creation Of A Lunar Biorepository
- 0030: National Ocean Worlds Analog Test Facility and Field Station
- 0039: Data-Driven Approaches to Searches for Signatures of Extraterrestrial Technology
- 0068: The need for comparative analog studies for astrobiology
- 0087: Caves as natural laboratories for astrobiology research
- 0090: The Astrobiology Data Ecosystem, Open Science, and the AI Era
- 0091: Set up and Maintenance of Laboratory Studies for Astrobiology Research
- 0094: Community need for an Astrobiology Sample Repository and Sample Reference Suite
- 0104: The Need for Intra-Model Comparisons and Data in Assessing Habitable Environments and Interpreting Potential Biosignatures
- 0122: Development of an Open Science Strategy for the Next Decade of Astrobiology.

Foundational Documents

- 2018 Exoplanet Science STrategy
  - Strengthen support for RCN’s to include research funding
  - Recommendation: Building on the NExSS model, NASA should support a cross-divisional exoplanet research coordination network that includes additional membership opportunities via dedicated proposal calls for interdisciplinary research.
- Astrobiology Strategy 2019: Search for Life in the Universe
  - 5. Evolution in the Technology and Programmatic Landscape
    - **Finding:** Rapid progress in the development of artificial intelligence machine learning algorithms has the potential to improve analysis of the large, complex data sets increasingly common to astrobiology.
- Astro2020 Decadal Survey: Pathways to Discovery
  - 4.5 THE DATA FOUNDATION
    - 4.5.1 Data Archiving, Curation, and Pipelines
    - 4.5.2 Software Development
    - 4.5.3 High-Performance and High-Throughput Computing
    - 4.5.4 Data Science and Machine Learning
    - **Recommendation**: NASA and the National Science Foundation should explore mechanisms to improve coordination among U.S. archive centers and to create a centralized nexus for interacting with the international archive communities. The goals of this effort should be informed by the broad scientific needs of the astronomical community.
    - H.2.1 Investment in Archives and Joint Analyses

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Foundational Documents

- Origins, Worlds, and Life A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (2023)
    - 20 INFRASTRUCTURE FOR PLANETARY SCIENCE AND EXPLORATION
        - **Finding:** An index covering all planetary science, astrobiology, and field sample databases, would assist in data sharing and analysis. This index could include links to relevant spectral databases (e.g., USGS SpecLib, RELAB, GEISA, HIITRAN), other dedicated data archives (e.g., MAST, ASTROMAT), and sample archives that are available for outside users and/or collaboration.
        - **Finding:** A clear plan for the preservation and sharing of planetary model input and output data, involving both the PDS and planetary modeling communities, is needed to develop a network of discipline-specific, community-recognized repositories, rather than via rigorous, costly, and often unnecessary archiving.
        - **Finding:** Already established, and newly emerging, mechanisms for facility and data collaborations across other federal science agencies can serve as a good model for future NASA collaborations. Such partnerships ought to span from theoretical modeling and simulations to data ecosystems to data analysis, laboratory experiments, and field investigations across multiple entities.
    - 21 TECHNOLOGY
        - **Finding:** Cold/cryogenic sample return requires significant development of technologies to enable the acquisition, containment, and preservation of cold/cryogenic volatile materials at ambient sampling conditions. Such technologies are needed to be employed during all phases of the mission in order to preserve and maintain the scientific integrity of the samples.

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Foundational Documents

- 2023 BPS Decadal: Thriving in Space
  - Finding 2-2: The increased sophistication of required measurement, sample process, and cellular manipulation in space suggests that the future will require support for space-based large-scale synthesis, molecular/cellular biology, and biological measurement backed by significant data systems.
  - Finding 2-3: Technology developed to advance scientific inquiry on Earth has advanced rapidly in the past decade. Lagging incorporation into research infrastructure for space environments has the potential to reduce scientific and technical impact of space-based research in the coming decade.
  - Ch. 7 Strategy and Challenges for Disciplinary Balance, Infrastructure, and Access and a Vibrantly Sustained Space Science Community
  - Develop the essential ground- and space-based technologies (instruments, vehicles, and data analysis tools); reusable infrastructures (i.e., physics and biology laboratories and new “cassettes” that hold different classes of experimental types that can operate within them), driven by the highest-priority science identified in (1); and properly subsidized protocols for ensuring their usability by both the core BPS and research campaign scientists
  - Recommendation 7-6: NASA should continue to expand the investment in open and shared computational infrastructure (CI) to support storage, analysis, and dissemination of its biological and physical data, while ensuring linkage to the original and archived samples. NASA should recognize the need for long-term investment to maintain, update, and improve such community-serving CI and physical repositories over time.
  - Finding 7-9: Spaceflight experiments can generate additional tissues and materials that are useful beyond the original scientific objectives of primary studies. Additional facilities, support personnel, and user protocols are needed for storage, handling, and availability of spaceflight-specific samples and tissues to maximize use of these materials for research.
- 2024 NASA PESTO Technology Strategy
  - Advance DEIA & Open Science
    - Foster inclusion, accessibility, and early-career support
    - Require Open Science Data Management Plans (OSDMPs)

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Foundational Document

- 2024 NASA Mars Future Plan
    - Core Infrastructure Serving All Missions: Enable infrastructural advancements that no single mission could likely achieve alone and that lower the costs and risks of, and increase benefits for, all Mars missions. Actively consider opportunities to buy commercial services to address MEP infrastructure goals.
    - Data Infrastructure, Visualization, and Analysis: Support strategic investments in data access, visualization, and analysis to expand research opportunities and to capitalize on existing and future mission data, the return of which will be orders of magnitude higher with the implementation of other infrastructure investments.
- 2024 Heliophysics Decadal
    - Recommendation 5-11: The National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA) should continue to support the development of modern cyberinfrastructure to enable effective sharing and utilization of heterogeneous data produced across the integrated HelioSystems Laboratory. Future investments should consider the following agency roles and approaches:
    - Automated methods to alleviate the burden of data annotation and curation, including the use of AI methods to create labeled data for machine learning
- 2024 NASA-IODP Workshop
    - Analogs
    - 4.5.1.1 Interagency Partnership Pathway: Analogue Sites for Tectonics Associated with Plume Volcanism.
    - 4.5.1.3 Interagency Partnership Pathway: Definition of “Analogue Site”
    - 4.5.1.4 Interagency Partnership Pathway: Analogue Site Opportunities. Analogue site studies should incorporate interdisciplinary/multidisciplinary opportunities.
    - 4.6.1.3 Interagency Partnership Pathway: Integrating Data Sets. Connecting technologies/instrumentation used to characterize cores with those used for satellite measurements could be a way of integrating NASA and ocean drilling data (e.g., same spectral measurements,etc.).
    - 4.6.1.4 Interagency Partnership Pathway: Maximizing Ocean Drilling Legacy Data. Tools need to be generated for exploration of existing legacy collection to maximize their use (e.g. Google Earth of IODP holes that is interactive with site/drilling data).