NASA/CP—2007–214565

# Astrobiology Small Payloads
## Workshop Report

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Prepared for John D. Rummel
Astrobiology Small Payloads Workshop
Sponsored by the Science Mission Directorate
Ames Research Center, Moffett Field, California
June 18 – 20, 2007

National Aeronautics and
Space Administration

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**October 2007**

**Acknowledgments**

This report is the final product of a series of activities planned and implemented over the course of several Program focused on the use of microsatellite free flyer platforms. We would like to thank both the planners and participants of the initial Astrobiology Science Focus Group who developed early science concepts as well as provided content on spacecraft platforms, mission architectures, and other technical contributions to the Small Payloads for Astrobiology White Paper. We also appreciate the generous contributions of time and ideas of the many participants, session group leads, and workshop organizers who made the Astrobiology Small Payloads Workshop a success. This entire effort would not have been possible without the technical and programmatic direction of Dr. John D. Rummel and Mr. Pericles D. Stabekis of the Science Mission Directorate at NASA Headquarters whose shared thoughtful insights throughout all phases of this effort are gratefully acknowledged.

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## 1.0 EXECUTIVE SUMMARY

The Astrobiology Small Payloads (ASP) Workshop was held June 18 – 20, 2007 at NASA Ames Research Center. It was convened to solicit additional experiment concepts from the external science community and to further discuss and justify small satellites as an appropriate platform for Astrobiology science. The specific goals of the ASP Workshop were to:

I. Explore science opportunities that address Astrobiology objectives that may be suitably flown on small satellites
   a. Identify required instrument(s), platform, and mission architecture to implement science; delineate experiment scenario(s) and hardware needs/requirements where possible
   b. Estimate timeframe to flight in terms of near (1-3 years), mid (3-5 years), and long (beyond 5 years) given all availability, development, integration, and launch opportunity approximations
   c. Determine extensibility of hardware configurations to support multiple science objectives on a variety of launch opportunities
   d. Validate appropriateness and soundness of these platforms and timeframes to conduct Astrobiology science

II. Review the draft ASP white paper using its concepts and related information as a basis of workshop discussion

III. Contribute additional ideas for consideration in formulating a program - including instruments and techniques, flight opportunities and constraints, impacts, etc.

The workshop was structured to facilitate information exchange between the science and engineering communities, resulting in science concepts vetted with respect to development timeframes and possible launch opportunities. Presentations on the specifics of the different types and capabilities of spacecraft platforms and descriptions of launch vehicles and anticipated launch opportunities provided the participants with basic knowledge of these opportunities. Breakout sessions addressed science scenarios, the refinement and mapping of science ideas, and an engineering assessment of the concepts versus platform opportunities.

A total of 29 different mission concepts were considered during the individual group sessions, and later in the plenary sessions. Each mission concept is summarized in Table 1.0-1 Mission Concepts Considered by the Workshop. Based upon the information contained within the individual engineering assessment checklists, and after assessing the experiment/instruments against known spacecraft systems currently available or in development, engineering teams further classified each mission as being a near-, mid- or long-term development effort. The assigned classification for each mission is indicated in the table referenced above.

Near-term missions are those that can rely on secondary spacecraft designs similar to the 3-Unit (3U) cube-sat configuration (e.g. GeneSat-1), and that also have relatively high instrument Technology Readiness Levels (TRL). The use of existing space platforms, combined with proven and understood instruments results in a mission that could be flown with a minimum of new development. Therefore, the focus of such a project would be on the integration and testing phases, potentially culminating in a mission of opportunity as a secondary payload within a year.
Mid-term missions are estimated to require some modification to spacecraft systems, and typically involve mid-range instrument TRLs, indicating that further development, (most likely testing) will be required. The time for such development is assumed to be less than 2 years for technology maturation and ground testing prior to flight. Wherever possible, heritage or similar systems are assumed to reduce developmental risk and cost.

Long-term missions involve experiments that would require significant development and maturation of either the instrument technology or spacecraft bus capability. An example of a long-term mission might be a sample return mission, which requires technology not in use currently, or an instrument that currently is at a TRL of 2 or 3.

**During the draft white paper and plenary session discussions, four major topic areas were raised and resulting recommendations were made as necessary components for sustaining a small payloads effort in Astrobiology.** The major topic areas discussed were: **1)** the critical need for quick turn around science opportunities, **2)** maintenance of a pipeline of science payloads ready to meet fixed launch platform schedules, **3)** development of mechanisms for sharing existing technologies and hardware systems to keep cost down, and **4)** ability for small payload opportunities to address supporting Ground Control and Test & Integration Support functions and facilities.

Currently the Science Mission Directorate (SMD) has two types of missions, strategic missions and principal investigator (PI) led missions. There is a growing realization within the NASA science community that frequent access to space to perform science on missions of opportunity including suborbital program opportunities is highly desirable. These lower cost platform approaches can yield critical insight into important science questions with possible opportunities to repeat science experiments on a more frequent timescale that advances science knowledge while waiting for the larger class missions to be developed. Suborbital programs in the PI-led mission category offer better opportunities for the Astrobiology science community to advance its knowledge linked to the Astrobiology roadmap goals and objectives. The group discussed the benefits of holding multiple community-specific workshops with scientists and engineers actively participating to understand the launch and payload constraints to be considered when planning a science objective. These science workshops can look for commonality across the themes and allow interaction with engineers to identify commonly needed tools for implementation in missions of opportunity calls. The group recommended a session at the upcoming Astrobiology Science Conference (2008) devoted to small satellites, balloons, and sounding rockets payload opportunities.

TABLE 1.0-1 MISSION CONCEPTS CONSIDERED BY THE WORKSHOP

| Experiment Title/ Objectives | Instrument/ Platform Types[1, 2] | Horizon (Near, Mid, Long) |
|---|---|---|
| **Extended Red Emission (ERE) Mapper** Trace interstellar carbon distribution in the diffuse interstellar medium | Imager<br><br>Microsat | **Near** Instrument is from COTS components; small spacecraft exist to accommodate this experiment |
| **Deuterium Explorer** Determine the deuterium to hydrogen ratio in organics and ices | Imager<br><br>Microsat | **Near** Technologies exist to execute this mission with a smallsat |
| **Dust Telescope** Determine the organic content and its variability in interplanetary and interstellar dust particles | Sensor<br><br>Microsat | **Mid** Instrument TRL = 5. Some development required (Spacecraft and instrument) |
| **Near Earth Object Chemical Analysis Mission (NEOCAM)** Measure the elemental and limited molecular composition of comets | Imager<br><br>Microsat | **Mid** Systems development required, but similar instruments have been flown previously |
| **Detection of Exogenic Organics in the Upper Atmosphere of Earth** Determine the fate exogenic molecules in the atmosphere | Imager<br><br>Microsat | **Near/Mid** Some instrument development needed; small spacecraft exist to accommodate this experiment |
| **Lunar Surface Radiation Dosimeter** Conduct long-term radiation monitoring on the lunar surface as a precursor to manned missions | Sensor<br><br>Lander | **Long** Lunar lander opportunity not known. |
| **Lunar Environment and Dust Reactivity Sensor** Characterize effects of lunar environment (dust) on materials and biological/chemical systems | Incubator<br><br>Lander | **Long** Instrument has high TRL and development behind it. Lander opportunity required, however. |
| **Grain Coagulation** Determine key parameters leading to early-stage particle accretion in the nebula | Sensor<br><br>CubeSat | **Near** Instrument exists and has flight heritage, and is compatible with smallsats. Flown on Shuttle. |
| **Ice Collisions** Determine key parameters leading to early-stage particle accretion in the nebula | Sensor<br><br>CubeSat | **Near** Instrument exists and has flight heritage, and is compatible with smallsats. COLLIDE heritage on Shuttle. |
| **Point and Shoot: Luminescence Survey** Survey and characterize distribution of organics and minerals on planetary surfaces | Sensor<br><br>Lander | **Long** Instrument requires accommodations on a lander/rover |

| **Experiment Title/ Objectives** | **Instrument/ Platform Types[1, 2]** | **Horizon (Near, Mid, Long)** |
|---|---|---|
| **Chemical and Metabolic Activity Calorimeter**<br>Measure the chemical reactivity of dust and identify metabolic processes | Sensor<br><br>Lander | **Long**<br>Mission opportunities for landers/rovers will dictate feasibility**.** |
| **Single Loop for Cell Culture (SLCC)**<br>Expose microbes and/or cells to space environment | Incubator<br><br>CubeSat | **Near/Mid**<br>Smallsats have demonstrated capability to support similar experiments. SLCC hardware has significant development behind it. |
| **O/OREO** Organics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and balloons. | Sensor<br><br>CubeSat | **Near**<br>Instruments exist; heritage spacecraft system available; orbit flexibility will increase launch opportunities |
| **O/OREO w/ Culturing** Organics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and then culture and monitor organisms *in situ* | Incubator<br><br>CubeSat | **Mid**<br>Sensors and spacecraft elements exist; builds on earlier O/OREO concepts; would require some development |
| **Onion/OREO w/ Sample Return** Organics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and then culture organisms and return to Earth | Incubator<br><br>RV | **Mid/Long**<br>Elements of space system exist; reentry technology to be developed; Onion to be developed |
| **Upper Atmosphere Bio-particle Collector**<br>Particle collector spacecraft | Sensor<br><br>RV | **Long**<br>Particle collector will require development; reentry and recovery technologies required |
| **Biological Implications of Atmospheric Stratification**<br>Particle collector on sounding rockets and high altitude balloons | Sensor<br><br>Other | **Near**<br>These types of studies could be mounted almost immediately |
| **Prebiotic Chemistry in Space**<br>Array of combinatorial chemistry reactors exposed to the space environment | Sensor<br><br>CubeSat | **Mid to Long**<br>Instrument development needed; robust spacecraft design which can operate in 10's of °K |
| **XRD/XRF Analysis of Ices at the Lunar Poles**<br>Investigate potential ice/hydrous minerals/clathrate hydrates in permanent lunar shadows | Sensor<br><br>Lander | **Long**<br>Instrument has high heritage, but requires accommodations on a lander/rover. |

| Experiment Title/<br>Objectives | Instrument/<br>Platform<br>Types[1, 2] | Horizon<br>(Near, Mid, Long) |
|---|---|---|
| **Lab-on-a-Chip Application Development-Portable Test System (LOCAD-PTS)**<br>Portable test system for multiple biological and chemical analyses | Sensor<br><br>Lander | **Long**<br>Access to lunar surface and/or sample return required |
| **Lab in a Suitcase**<br>Human tended chemical analyzers | Sensor<br>Other | **Long**<br>Due to Constellation Program schedules |
| **DNA Damage, Repair and Evolution in Bacteria During Interplanetary Transit**<br>Measure rates and spectra of DNA damage of organisms in the deep space environment | Incubator<br><br>Microsat | **Long**<br>Requires return. |
| **Combined Effects of Radiation and Micro-g Biosensor**<br>Culture fruit flies to study the interaction of radiation (cell damage and repair) and microgravity on biological systems | Incubator<br><br>CubeSat | **Near**<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |
| **Lunar Dust Reactivity Biosensor**<br>Measure lunar dust reactivity and toxicity to biological systems | Incubator<br><br>CubeSat | **Near**<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |
| **Response of Intraterrestrial Organisms to Space Conditions**<br>Monitor metabolic activity of microorganisms to the space environment | Incubator<br><br>CubeSat | **Near/Mid**<br>Existing Genesat spacecraft can support these experiments with additional development for the culturing system (rock) |
| **Mutation Rates in the Space Environment**<br>Survey of mutations (rates and mechanisms) in unicellular organisms grown under various conditions in space | Incubator<br><br>CubeSat | **Near**<br>Existing Genesat spacecraft could begin these experiments presently |
| **Experimental Evolution in Drosophila**<br>To understand evolution in a truly novel environment | Incubator<br><br>CubeSat | **NEAR**<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |
| **Adaptation and Acclimation of Microorganisms to Life in Space**<br>Measure gene expression over multiple generations | Incubator<br><br>CubeSat | **Mid**<br>Spacecraft elements exist which can support this mission; development needed for payload/instrument |

| Experiment Title/ Objectives | Instrument/ Platform Types[1, 2] | Horizon (Near, Mid, Long) |
|---|---|---|
| **Establishment of Seed-to-Seed Growth of Plants in a Lunar Environment**<br>Demonstrate that life can function at lunar gravity | Incubator<br><br>Lander | **Long**<br>Lunar lander opportunity not known. However, plant growth hardware has high flight heritage. |

A critical component of building scientific knowledge is the iterative nature of building on previous experimental information. Maintenance of a pipeline of science payloads ready to meet fixed launch platform schedules through the technology development sections of the Research Opportunities in Space and Earth Sciences (ROSES) NASA Research Announcement (NRA) call is a vital component. The technology development programs are critical for experiment development towards flight on small satellite mission opportunities.

With respect to sharing and reusing existing platform bus configurations and experimental hardware systems, the group also discussed several near term strategies that may help facilitate multiple science opportunities for implementing immediate low cost missions with other strategies for expanding existing capabilities for generic use. The group realized the benefits of using lowest price (entry-level) 3-cube hardware configurations for near-term payload launch opportunities in conjunction with the existing common bus configuration so that science experiments and instruments identified as compatible can be flown quickly. This would be a good first step in development of a Small Satellite capability in the Astrobiology Program.

[1] **Instrument Types:**
SENSOR - This type of instrument is designed to make a particular measurement of the environment or sample/specimen.
IMAGER - This class of instruments performs remote sensing functions. They include telescopes and spectrometers.
INCUBATOR - This instrument provides a pressurized environment and other conditions to maintain or sustain biological growth.
OTHER - Classes of instruments not covered above.

[2] **Platform Types:**
CUBESAT - Cubesats are free-flying spaceraft between 5 and 15 kg (kilogram) in mass, up to 15 Watts (W) in power. They are launched as secondary payloads. Cubesats are primarily intended for LEO applications.
MICROSAT - A Microsat can be up to 35-50 kg in mass, with power around 50-75W. They are also free-flyers, and may be launched as secondary payloads. Microsats can be used in low Earth orbit (LEO) and high Earth orbit (HEO), and possibly in lunar orbit.
LANDER/PAYLOAD - A lunar lander is designed to place payload mass on the lunar surface. The experiment may be a payload only as part of a larger lander mission. Landers are typically not mobile once landed, and have severe constraints for payloads on mass and power.
RETURN VEHICLE (RV) - A RV spacecraft is designed to return all or some of the orbited mass to Earth in a controlled, predictable manner. RVs have significant overhead for safety and guidance systems, leaving little resources for payloads.

The group also identified the need for an experimental roadmap where commonality of existing supporting hardware subsystems can be identified and established so that mid to longer-term science experiments may be planned.

Lastly, the group expressed concern over a need for the Agency to provide engineering test and integration and ground control program oversight / support necessary to make these opportunities successful. The group discussed a need for providing some sustaining engineering support along with the small payloads expertise that exists so they can address critical program and engineering functions, including a) coordination of opportunities for NASA participation on various private and government agency rocket launch opportunities, b) assistance in performing engineering reviews and assessments on solicited science payload proposals prior to selection, c) engineering oversight of payloads to ensure readiness to fly on assigned launch window platforms, and d) collaboration with other groups developing spacecraft return technologies and systems to help leverage the program.

The workshop participants found this activity to be most beneficial, particularly the sessions where there was interaction between the NASA Ames Research Center (ARC) Small Spacecraft Division (SSD) engineers and themselves regarding their science experiment ideas and the existing small satellite platforms, payload constraints and the interfaces between these systems and their experiments. Both scientists and engineers were fully engaged in this workshop and welcome the opportunity to help SMD in planning for such an exciting future capability and opportunity to fly science.

**A summary of the group's recommendations made during the workshop is listed below.**

1. SMD hold multiple community-specific workshops with scientists and engineers actively exchanging information to understand the launch and payload constraints to be considered in conjunction with the science objectives. These science workshops can look for commonality across the themes and allow interaction with engineers to identify commonly needed tools for implementation in missions of opportunity calls.

2. Conduct a session at the upcoming Astrobiology Science Conference (2008) on small satellites, balloons, and sounding rockets payload opportunities.

3. Use lowest price (entry-level) 3-cube hardware configurations for near-term payload launch opportunities utilizing the existing common bus configuration so that science experiments and instruments identified as compatible can be flown quickly. As evidenced by the relatively large number of cube-sat based experiments identified during this study and workshop, begin the flight process with selected experiments from the NEAR class. The ideal mission would use an existing spacecraft bus, coupled with a well-known instrument or scientific protocol. These first mission(s) will establish the programmatic baseline for the larger ASP activity.

4. Review the need to identify an experimental roadmap where commonality of existing supporting hardware subsystems can be identified and established so that mid to longer term science experiments can take advantage of these existing hardware subsystem in mission of opportunity calls.

5. Augment or leverage existing technology and instrument development program in SMD to include and address small payload opportunities as they become available. This program (or element of an existing program) should be closely linked to the ASP goals and objectives and will result in a pathway for instruments to mature towards TRL 4 or 5 in preparation for a small payload free-flyer or lander mission.

6. Provide some sustaining engineering support along with the small payloads expertise in NASA to assist the Astrobiology program in a) coordination of opportunities for NASA participation on various private and government agency rocket launch opportunities, b) assistance in performing engineering reviews and assessments on solicited science payload proposals prior to selection and, c) engineering oversight of payloads to ensure readiness to fly on assigned launch window platforms, d) collaboration with other groups developing spacecraft return technologies and systems. It is anticipated that the same technological forces that are currently enabling small, low-cost spacecraft in support of scientific missions, will also accelerate and reduce the cost for the development of sample return spacecraft.

7. Support for a small spacecraft pointing technology study that will collect requirements across science disciplines will benefit the development and qualification of the Microsat platform. Due to the wide utility of these small satellite platforms for supporting scientific disciplines such as Astrophysics, Space Sciences and Earth Sciences, an early investment in this area can result in a number of mid-term missions capable of generating large amounts of science data.

## 2.0 WORKSHOP RATIONALE AND GOALS

The ASP Workshop was held June 18 – 20, 2007 at NASA Ames Research Center. It was convened to solicit additional experiment concepts from the external science community and to further discuss and justify small satellites as an appropriate platform for Astrobiology science.

To this end the specific goals of the ASP Workshop were to:

I. Explore science opportunities that address Astrobiology objectives that may be suitably flown on small satellites
   a. Identify required instrument(s), platform, and mission architecture to implement science; delineate experiment scenario(s) and hardware needs/requirements where possible
   b. Estimate timeframe to flight in terms of near (1-3 years), mid (3-5 years), and long (beyond 5 years) given all availability, development, integration, and launch opportunity approximations
   c. Determine extensibility of hardware configurations to support multiple science objectives on a variety of launch opportunities
   d. Validate appropriateness and soundness of these platforms and timeframes to conduct Astrobiology science

II. Review the draft ASP white paper using its concepts and related information as a basis of workshop discussion

III. Contribute additional ideas for consideration in formulating a program - including instruments and techniques, flight opportunities and constraints, impacts, etc…

Technical guidance in the planning of this workshop was derived from the following documents:

- Life in the Universe: An Assessment of U.S. and International Programs in Astrobiology, National Research Council, 2003.
- NASA Astrobiology Roadmap, September 2003.
- Science Plan for NASA's Science Mission Directorate 2007-2016, January 2007.

## 3.0 WORKSHOP STRUCTURE AND PLENARY OVERVIEW

The workshop was structured to serve an information and data gathering function through the use of brainstorming and more directed data compilation opportunities. The method implemented to facilitate information exchanges included plenary, poster, and breakout sessions. The interaction between the science and engineering communities during each breakout session resulted in many science concepts that were vetted to allow an early idea of development timeframes and possible launch opportunities. Follow-on activities for workshop participants included a request for review of individual science opportunity worksheets and the workshop report.

The plenary session on day one included an overview of the Astrobiology Program's interest in determining the suitability of the small satellite platform to perform targeted research and to develop some new science experiment concepts that might be accommodated on such a platform. Presentations on the specifics of the different types and capabilities of spacecraft platforms in addition to descriptions of launch vehicles and anticipated launch opportunities, information on space environments, and a short brainstorming session on technologies and techniques of interest that might be deployed on small satellites provided the participants with knowledge to use in their discussions. Participants were also invited to present short overviews of their particular science ideas as an introduction prior to the more detailed science scenario brainstorming session. Participant presentations, in addition to other select workshop materials, are available on an accompanying CD-ROM.

## 4.0 BREAKOUT SESSION OVERVIEW

The plenary overview session was followed by a series of 3 breakout sessions spread over the remainder of the two and a half-day workshop. Each breakout session had specific topic areas for discussion and resulting products, summaries of which were presented at the end of each allotted session time by the group leads. A summary of the charter for each breakout is below.

*Session #1 - Brainstorming - Science Scenarios / Storyboards*
- Focus on brainstorming science concepts that may be suitable for small sat platforms
- Initial or continued worksheet development with emphasis on defining science objectives, approach, instrument(s) and measurement parameters, and mission environment

*Session #2 - Refining & Mapping Science Ideas to Astrobiology Goals*

- Focus on refinement of science scenarios and mapping objectives to Astrobiology goals
- Start of early discussion on system / instrument requirements for engineering assessment
- Estimate science experiment readiness timeframe

*Session #3 – Engineering Assessment vs Platform Opportunities*

- Focus on review of science and instrument requirements (as known) to assess development time-frame and launch opportunities
- Review of science concepts in draft white paper

## 4.1 Breakout Session Correlation to ASP Workshop Goals

The brainstorming breakout session was comprised of 2 breakout groups – observational and experimental. Due to the number of experimental scientists present, two experimental groups were formed. Results of the brainstorming activity identified the need to breakout successive sessions by science discipline. These discipline breakouts include: Remote/Observational, Pre-Biotic Chemistry and Planet Formation (Gas-Grain Particle Interactions), Organics in Space, and Biology.

Breakout sessions 1 and 2 were structured to promote the formation of science experiment concepts aligned with Astrobiology goals, to support initial discussions of instruments, preferred mission architectures, follow-on and multiple objective experiments, and to encourage open dialog regarding the appropriateness of the small sat platform for the specific science being discussed. The science concepts formed in sessions 1 and 2 provided the initial information that contributed to achieving all four sub-goals of workshop Goal I - Explore science opportunities that address Astrobiology objectives that may be suitably flown on small satellites. Breakout session 3 was the engineering assessment session that complemented the prior sessions and completes workshop Goal I by providing early estimates of each experiment's development timeframe given current technology and instrument development efforts, technical hurdles, launch opportunities, and testing and integration time frames. Additionally, session 3 provided a forum for the groups to discuss the science in the draft white paper to be used as appropriate to complete workshop Goal II - Review the draft ASP white paper using its concepts and related information as a basis of workshop discussion.

## 4.2 Science Opportunity Summaries

This section provides a summary of the products of breakout sessions 1 and 2. A short description of each science concept discussed over the course of the workshop, along with the name(s) of participants contributing to the concept, the particular Astrobiology goal addressed, and development timeframe are listed below.

**Group 1. Remote / Observational**
**Lead: J. Bregman**

*Title: Mapping the Intragalactic Distribution of the Mysterious Carbon-Rich Carrier of the Extended Red Emission*
*Concept Provided By: Jesse Bregman, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goal 3*
*Development Timeframe: Near to Mid*

The objects which present the Extended Red Emission (ERE) also emit the infrared (IR) features attributed to free polycyclic aromatic hydrocarbon (PAH) molecules, indicating that the carrier is carbon-rich and somehow PAH-related. Furthermore, sensitive IR measurements have shown that PAHs are spread throughout the diffuse regions of the galaxy in what are known as IR Cirrus clouds. Because the radiation environment is reasonably well understood in these diffuse regions, these ERE maps made with the telescope proposed here will probe the connection between PAHs and the carbonaceous ERE carrier. Since these species tie up some 30% to 40% of the cosmic carbon available, this information will provide insight into the nature of a significant fraction of the organic feedstock material that ultimately becomes part of primordial, habitable planets.

The instrument consists of a small (15-20 cm diameter) telescope feeding a low-resolution visible wavelength spectrometer, all parts of which are anticipated to be available as commercial-off-the-shelf (COTS) items. Since this is a mapping mission, the ideal orbit will be a low-earth polar orbit aligned with the day-night terminator. Pointing ability is not as important as pointing reconstruction, which can be done during the data processing stage based on the position of stars picked up during the mapping process. The spacecraft should be 3-axis stabilized with 'to be determined' (TBD) pointing stability.

*Title: IR Astrospectroscopy: Separating False from True Galactic Biomarkers*
*Concept Provided By: Scott Sandford, NASA Ames Research Center*
*Astrobiology Goal(s) addressed: Goals 3 and 7*
*Development Timeframe: Mid*

Deuterium (D) is an isotope of hydrogen (H), with double the mass. The rates of reaction of abiotic processes and biotic processes are very different for H and D because of this large mass ratio. How the H and D are distributed on prebiotic, interstellar carbonaceous species is not known, yet it is crucial in determining whether authentic extraterrestrial samples have an H/D ratio that is scientifically interesting from an astrobiological perspective. In other words, the H/D ratio can serve as an indicator of and likely a discriminator between abiotic or biotic processes, i.e. a false from true biomarker separator.

Additionally, the H/D ratio is of basic and fundamental importance to astrophysics and, as such, also to astrobiology for the following reason. Deuterium was formed in the Big Bang and its abundance provides strong constraints on both the physical conditions in the early universe and the subsequent star and planet formation history of the universe.

The instrument for this reference experiment consists of a moderate (≈50 centimeter [cm] diameter) passively cooled telescope feeding a 2.5-5 micrometer (μm) spectrometer with a resolution of ≥1500 and an indium antimonide detector array. All of these components are currently available as nearly off-the-shelf items. Since the telescope and detectors must be cold to operate (≈45 Kelvin [°K]), the best orbit would be one that slowly drifts away from the earth. It is possible that a low Earth orbit (LEO) orbit could work, but may involve the addition of a closed cycle cooler. This is a pointed mission and will require that the spacecraft point and is stable to a few arc seconds.

*Title: Dust Telescope (Large Area Mass Analyzer + Dust Trajectory Sensor)*
*Concept Provided By: Zoltan Sternovsky, University of Colorado*
*Astrobiology Goal(s) Addressed: Goal 3*
*Development Timeframe: Near to Mid*

The Dust Telescope instrument consists of two parts. The Large Area Mass Analyzer (LAMA) provides an elemental and molecular analysis of the dust and the Dust Trajectory Sensor determines the source of the dust particle (comet, asteroid, interstellar medium [ISM]). The scientific goal is to determine the organic content and composition of the dust from comets, asteroids, and the ISM deposited on the earth that could be incorporated into living systems. Best orbit is a location at Lagrange Point 1 (L1) or L2, or as a lunar lander.

*Title: Near Earth Object Chemical Analysis Mission (NEOCAM)*
*Concept Provided By: Joe Nuth, NASA Goddard Space Flight Center*
*Astrobiology Goal(s) Addressed: Goal 3*
*Development Timeframe: Mid*

Measure ultraviolet (UV) spectra of meteors in storms traceable to those parent bodies. Down-looking slitless UV spectrometer in LEO. Stare at night side of earth at 400 frames/sec. Poor man's sample return mission to a variety of objects. Determine the chemical composition and homogeneity in the parent bodies. Measure the elemental and limited molecular (eg. silicon dioxide, hydroxide) composition of up to 20 comets.

*Title: Detection of Exogenic Organics in the Upper Atmosphere of Earth*
*Concept Provided By: Peter Jenniskens, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goal 3*
*Development Timeframe: Long*

Determines the fate of exogenic organic matter when it is deposited in the earth's atmosphere. This material will ultimately settle to the ground, but in the process of entering the earth's atmosphere, the chemical composition will change. Small mid-IR telescope & spectrometer. Absorption spectroscopy of background stars. Look for the signature of organic material between 80-100 kilometer altitude.

*Title: Lunar Surface Radiation Dosimeter*
*Concept Provided By: Eric Benton, Oklahoma State University; Stevan Spremo NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 4, 5, and 6*
*Development Timeframe: tbd*

Perform never-before collected radiation dosimetry measurements on the Lunar surface essential for managing the radiation exposure of future explorers. Provide the first measurements of dose and dose equivalent rates in tissue (including neutron component) on the Lunar surface by combining silicon detectors with a flight proven Tissue Equivalent Proportional Counter design to develop a radiation dosimeter with easily interpretable data to measure the linear energy transfer spectrum, dose and dose equivalent rates.

**Group 2. Pre-Biotic chemistry and Planet Formation (Gas-Grain Particle Interactions)**
**Lead: A. Mattioda**

*Title: Lunar Environment & Dust Reactivity Sensor (UREY)*
*Concept Provided By: Richard Quinn, SETI Institute*
*Astrobiology Goal(s) Addressed: Goal 5, 6, and 7*
*Development Timeframe: Mid*

This is a mission to characterize the effects of the lunar environment on materials, as well as measure the chemical reactivity of the dust, particularly with respect to biological and chemical systems. This is achieved by a chemometric thin film sensor array comprised of two units, environmental and dust. The environmental unit measures alterations of biological and engineering materials by the ambient lunar environment, while the dust unit characterizes lunar dust reactivity.

*Title: Grain Coagulation in Microgravity: A Microsat Mission for LEO*
*Concept Provided By: John Marshal, SETI Institute*
*Astrobiology Goal(s) Addressed: Goal 1*
*Development Time: Near*

The dust chamber uses key components of proven USML flight hardware, TRL 9

The formation of terrestrial planets is believed to occur in three stages: accretion of small grains (microns to centimeters [cm] in size) into kilometer-size primitive bodies that decouple from the nebula gas; collisional growth of these primitive bodies into lunar-size embryos which dominate their formation regions, and long-term dynamical evolution, with mergers of these embryos into planets. The first stage is the least well understood. Debate rages about how well grains of these small sizes stick, as a function of their relative velocity, and whether their composition plays a role (in particular, organic material has been found to be 'stickier' than silicates). A small number of experiments have shown that the sticking behavior of particles in microgravity is fundamentally different from anything in our terrestrial experience, and has raised many intriguing questions about early-stage accretionary processes. These simple exploratory experiments were too limited to investigate the large range of environmental parameters and timescales needed to confidently extend the results to the solar nebula. This reference experiment will extend grain sticking studies to a more sophisticated range of environmental parameters (gas density and temperature, grain size and composition, ionization state of the ambient gas), and enable much longer-term observations and control experiments. Up to a dozen grain size/composition combinations can be treated (including organic, metal, and silicate particles alone and in mixtures), gas pressures can be varied from near-vacuum through the entire range relevant to the solar nebula, and the gas ionization state can be varied to assess the role of charge longevity. Vapor jet dispersal and gentle mechanical manipulation of cells will be used to vary the grain collisional parameters, which create surface charges. Experiments will be recorded using high-resolution video, buffered into onboard memory, and downlinked as feasible. The setup and mission duration will allow confirmation of, and iteration on, unexpected results under environmental circumstances than can be varied interactively by the team. The entire experiment is estimated to fit under the micro-sat class, operating in the LEO environment. Building on KC135 and two Shuttle missions (USML1,2) this grain coagulation study is at a high TRL, and needs only minor modifications for flight as a small satellite payload.

*Title: Ice Collisions*
*Concept Provided By: John Colwell, University of South Florida*
*Astrobiology Goal(s) Addressed: Goal 1*
*Development Timeframe: Near*

The Ice Collisions in Microgravity uses the microgravity in LEO to simulate nebula conditions where the fundamental coagulation processes of ices are poorly understood. This is achieved by measuring the interparticle sticking forces under a variety of pressure, temperature and plasma conditions. A hand-held version of this instrument has been used by the astronauts aboard the Space Shuttle.

*Title: Point and Shoot Luminescence Surveyor*
*Concept Provided By: Louis Allamandola, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 1, 2, and 3*
*Development Timeframe: Mid*

The Point and Shoot Luminescence Surveyor makes use of the fact that a significant number of organic molecules, as well as some minerals, are luminescent. Using a UV lamp and camera large areas can be surveyed for organic compounds, minerals and ices. The more sophisticated the surveyor, the more detailed the information obtained. The Point and Shoot Luminescence Surveyor can be utilized as an accessory or can be a standalone instrument.

*Title: Chemical and Metabolic Activity Calorimeter*
*Concept Provided By: Andrew Mattioda, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 2,3, and 5*
*Time: Long*

Most chemical reactions/processes either give off energy, in the form of heat, or take in energy. The Chemical and Metabolic Activity Calorimeter is designed to take a sample of dust (from the Moon, Mars, a near-Earth object, etc.) and expose it to a variety of reactants and nutrients. Thus the heat given off the any chemical reaction (i.e. the reactivity) can be measured. Similarly, when the dust sample is exposed to nutrients any heat given off by the metabolic activity of an organism can be detected.

*Title: Single Loop for Cell Culture (SLCC)*
*Concept Provided By: Joe Parrish, Payload Systems Inc*
*Astrobiology Goal(s) Addressed: Goals 2, 3, and 5*
*Development Timeframe: Near*

SLCC is a facility that supports microbial and cell culture, exposing model organisms to the space environment. It is designed for use with multiple platforms, providing automated cell culturing volume, gas exchange, mixing, sub-sampling, and sensing/control.

**Group 3. Organics in Space**
**Leads: C. Conley and B. Yost (summaries by L. Bebout, L. Jahnke, B. Yost)**

*Title: Organics and/or Organisms Exposure to Orbital Stresses (O/OREOs)*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 2, 3, 4, 5, and 6*
*Development Timeframe: Near*

This is the first element of a set of experiments, which scale up in complexity, to provide fundamental information about the effects of the space environment on organic compounds and microorganisms. Conceptually, similar experiments have been carried out by the European Space Agency, however, duration periods have always been relatively short. In order to assess concepts, such as panspermia or survival of space hitchhikers to and from Mars, realistic exposure times are required. These experiments will also be valuable for assessing the effects of exposure on extraterrestrial organics delivered by early bombardment or sample return. The samples to be tested are envisioned to include a variety of 'substrates' which may include more complex samples and experimental scenarios such as endolithic microbial communities or organic impregnated mineral matrices. Important elements of the operational concept include placement of the satellite into a sun synchronous, stabilized LEO, and sufficient duration to space exposure to mimic transit time for Mars-Earth objects (6 months). Samples will be monitored periodically by suitable instrumentation and the data stored for periodic downlink of 'experimental snapshot' and housekeeping information. A major hurdle is launch opportunity. Experimental scenarios can be envisioned with greater orbital flexibility for high Earth Orbit (HEO) and lunar, and balloons. Potential vehicle is the GeneSat.

*Title: O/OREOs with Culturing*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 2, 3, 4, 5, and 6*
*Development Timeframe: Mid*

The objective of this project is to determine the influence of the space environment on the in situ viability of microorganisms. Organisms can be lyophilized (freeze-dried in a vacuum) and maintain potential for viability when exposed to appropriate dehydration media. This operational concept envisioned as a second generation O/OREOs. Lyophilized organisms would be maintained in a stabilized LEO or HEO orbit for periods up to 6 months. Periodically, organisms would be exposed to media to re-hydrate, incubated and monitored to determine germination and/or growth. Data from an optical signal and/or sensor data collected. Snapshots and housekeeping data downloaded periodically, prior to downlink of all raw data. The operational protocol requires moving samples across a pressure barrier and the development of appropriate management and fluidics. Satellite configuration at least a six-unit cubesat.

*Title: O/OREOs with Sample Return (ONION)*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 2, 3, 4, 5, and 6*
*Development Timeframe: Near/Mid*

The objective of this project is to determine the influence of the space environment on the in situ viability of microorganisms. This design concept draws on experience with recent small-scale sample return missions, and would provide the opportunity for more thorough examination of the exposed samples. Organics and/or organisms would be exposed for 6 months within an onion-like, layered matrix to nominal space environmental exposures depending on the orbit (LEO, lunar, HEO). The ONION is housed in a satellite capable of providing safe, guided reentry, and release of the payload (3-4 ONION modules) for hard-landing (Utah salt flats). Modules are recovered for analysis and/or growth of space-exposed organisms. Design places constraints on orbit for recovery. Satellite release control system would have to be developed. Envision Nanosat as possible vehicle.

*Title: Upper Atmospheric Bio-particle Collector**
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 3-7*
*Development Timeframe: Long*

The objective of this project is to determine the fate of exogenic organic molecules in the upper atmosphere of the earth. It involves discrete collection of organic, exogenic particles at various locations in Earth's stratosphere by launching particle collector capabilities through various means including a) balloon loft to upper stratosphere at poles; b) sounding rockets, c) spacecraft to circular LEO. In each case using aseptic low-velocity collectors obtains samples then use propulsion to modify reentry profile and loiter for recovery with subsequent analyses on the ground. Proposed Instrumentation: 35 kilogram (kg) University Nanosat + reentry vehicle, "Particle trap", particle counter, Global Positioning System, and environmental monitors. Readiness level: Balloon Technology = 8, Air sampler = 8, Counting = 5. Challenges to implementation require development in the following areas: 1) Orbital mechanics and mission design, 2) Particle collector design, and 3) Reentry and recovery system, therefore projected time frame to flight is long term.

*Also referred to as "Detection of Exogenic Organics in the Upper Atmosphere of Earth"

*Title: Biological Implications of Atmospheric Stratification*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 3-7*
*Development Timeframe: Near*

This project is similar to the one described above. However it is near term as it will use modular balloon payloads to loft to upper stratosphere (LEO) at poles. Aseptic low-velocity collectors will be used to obtain samples with recovery and analysis on the ground.

*Title: Prebiotic Chemistry in Space*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goal 3*
*Development Timeframe: Mid to Long*

Expose a variety of prebiotic materials to space environments by utilizing an array of combinatorial chemistry reactors. Target exposure conditions include solar radiation, vacuum. Approach will be to use witness plates similar to O/OREO and add spectral sensors (IR, visible, other). Proposed instrumentation, chemical reactors; spectrometer(s) for detection; environmental monitoring included with a spacecraft 6-Unit (6U) cubesat(s) platform (TRL = 4, Environmental monitoring = 5, Spectrometers TRL=5). Implementation will require further development of spectral detectors, and ability to provide very low temperatures. Target mission environments include LEO, HEO and Lunar with and without sample return. Projected time frame to flight is mid to long term. The goals are to provide important platform to address issues of prebiotic chemistry 1) relevant to life in space, and 2) impossible to test in Earth-based experiments. Examples are assessment of survival of polymers in space, and types of damage caused by actual space radiation to biopolymers over long-term exposures to space. Possible targets include a) nucleic acids, b) alternative genomic polymers (e.g. pyranose nucleic acids or peptide nucleic acids) and c) proteins checking to assess relative rates of degradation susceptibility, survival potential. Complementary to prior work on simple organics and spores.

*Title: X-Ray Diffraction/X-Ray Fluorescence (XRD/XRF) Instrument for Analysis of Ices and Hydrous Minerals at Lunar Poles*
*Concept Provided By: David Blake, NASA Ames Research Center;*
*Philippe Sarrazin, inXitu, Inc.*
*Astrobiology Goal(s) Addressed: Goal 2*
*Development Timeframe: Mid*

The objective of this project is to study the history of water on the Moon by investigating potential water ice, hydrous minerals and clathrate hydrates in permanently shadowed regions of the lunar poles. A follow-up of Lunar Prospector's observation of high concentrations of hydrogen in lunar polar regions would provide evidence pro-or-con for cold-trapped water. The moon is exceedingly dry, and this water would have come from cometary impacts. This primordial water would represent one end-point of a continuum of water sources proposed for the origin of life. Robotic exploration of the lunar poles would presage a lunar sample return mission to the same region once such evidence is found. A mineralogical instrument (CheMin) is fitted to a rover or lander deployed at the lunar pole in or near a permanently shadowed crater. Regolith samples are delivered to the instrument for analysis. Solid crystalline materials (minerals, water ice clathrates, water ice) can be analyzed and identified through their diffraction pattens ie. elemental and crystallographic measurements using XRD/XRF. CheMin could also be astronaut-carried as a field geology instrument for other lunar activities. Current laboratory instrument and flight prototype status: CheMin (in a rover configuration) is being prepared for Mars Science Laboratory (MSL) '09 and will be TRL 9 within 2 years. Several versions of laboratory and field instruments are presently in use. CheMin will be tested from -40 Celsius (°C) to +50°C in Mars ambient atmosphere as part of the MSL project. The extreme cold of the lunar poles will probably require survival heaters for the mechanical components and the electronics. Timeframe to Flight: Mid-term. A lunar CheMin flight instrument could be built within 2-3 years utilizing flight heritage components from the MSL CheMin instrument. CheMin has already been proposed for lunar discovery missions twice, and several designs have been considered for deployment on the lunar surface.

*Title: Lab-on-a-Chip Application Development-Portable Test System (LOCAD:PTS)*
*Concept Provided By: Norman Wainwright, Charles River Laboratories*
*Astrobiology Goal(s) Addressed: Goals 2, 3, and 7*
*Development Timeframe: Long*

An adaptation of high-TRL LOCAD-PTS technology for specific lunar surface and general astrobiology research. LOCAD-PTS is a flexible platform for multiple biological / chemical analyses. Capability for point of use operation, by non-expert user, complementary to existing culture-based methods. Multiple chips the size of dimes will be loaded onto Lunar rover platforms (or possibly satellite platforms) to enable detection of (chemical / biological) biosignatures of past or present life. Other potential related uses are: Planetary Protection, Environmental Microbiology, and Crew Health. Astronauts working in space on long-term missions or living in outposts on the Moon or Mars will need the capability of detecting deadly microbes quickly and to stop them from spreading, contributing to studies regarding how life adapts in space. This project is part of the larger "Lab in a suitcase" concept for development of various human operated/associated chemical analyzers. Target missions include 1) Lunar manned mission, 2) Perform O/OREO on the lunar surface autonomously, and 3) Retrieve samples and data. The basic LOCAD-PTS system consists of a handheld analyzer, which provides results within 5 to 15 minutes.

*Title: Lab-in-a-Suitcase*
*Concept Provided By: Group Concept*
*Astrobiology Goal(s) Addressed: Goals 2, 3, and 7*
*Development Timeframe: Long*

Human-tended chemical analyzers. Perform O/OREO on the lunar surface autonomously.

*Title: DNA Damage, Repair, and Evolution in Bacteria during Interplanetary Transit*
*Concept Provided By: Wayne Nicholson, University of Florida/Kennedy Space Center*
*Astrobiology Goal(s) Addressed: Goals 5 and 6*
*Development Timeframe: Long*

Measure rates and spectra of DNA damage of organisms in the deep space environment. Challenge exposed populations with environmental conditions approaching Mars, to select for mutants with enhanced survival/growth properties. Sample return is required.

**Group 4. Biology**
**Leads: O. Santos and L. Bebout**

*Title: Biosensor to Measure the Combined Effect of Radiation and Microgravity During Space Exposure Using Drosophila*
*Concept Provided By: Sharmila Bhattacharya, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 5 and 6*
*Development Timeframe: Near*

Drosophila has been used successfully in recent flight experiments to show that microgravity affects the innate immune system in flies (Space Transportation System 121, PI S. Bhattacharya, July 2006). Ground studies from the same experiment have shown that proton irradiation also affects the innate immune system. There is an increase in visible melanotic tumors caused by blood cells of larvae and adults flies that were proton irradiated during development. These changes are radiation dose dependent and easily measurable by black and white still imaging with optics similar to the prototype camera that has been developed by the Small Satellite/Genesat team (under John Hines' In Situ Genetics Experiments on Nanosatellites program) to visualize Drosophila larvae. So while changes in the immune system are seen in separate studies with microgravity or radiation exposure, the combined study has not yet been done to determine the combined affect of the space environment. Such studies of the effects of different space parameters can only be done in flight experiments and are impossible to reproduce in ground studies. The simple organisms such as Drosophila provides an opportunity to fly small-sized payloads to answer important questions relating to the future of life beyond Earth's environment. Drosophila will be exposed to the increased proton radiation background in low Earth orbits in early studies, and heavy ion radiation of the Galactic Cosmic Rays in higher Earth or lunar orbits in the future. The tumor frequency will be recorded by still photography and the data retrieved on Earth by telemetry. No samples will need to be returned

*Title: A Biosensor to Measure Surface Reactivity and Iron Effects of Lunar Dust*
*Concept Provided By: Sharmila Bhattacharya, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 5 and 6*
*Development Timeframe: Mid*

Nanophase iron is abundant in lunar dust and not present on Earth. Neurons in the brain are highly susceptible to damage due to iron (neuroferritinopathies). We will use wild type Drosophila along with mutant flies that mimic human neurodegenerative diseases (where iron accumulates in target neurons) to compare the effects of the lunar environment on the sensitized mutant backgrounds and wild type flies. Of interest in this context is not only the effect of high iron content in lunar dust, but also the combined effect with the radiation background. Radiation is known to increase reactive oxygen species (ROS) and contributes to further neurodegeneration in the above disease models. The surface of the Moon is exposed to high-level UV radiation, galactic cosmic rays, protons (solar wind and solar particle events), which are likely to generate a charged surface on lunar dust and impart surface reactivity. This surface reactivity can then generate ROS in biological systems causing cell and tissue damage. The specific aims are: 1) Assess the neurodegenerative effects of regolith iron and counteract effects with iron chelators. Use well characterized Drosophila mutants that mimic human neurodegenerative diseases as sensitized background to measure the effects of iron in lunar dust. Iron accumulates in target neurons in these disease conditions and increases severity of neurodegenerative effects and decreased lifespan. Neurodegenerative effects will be detected in flies by following behavioral alterations and lifespan. These parameters are easily measurable in space using short video clips and no sample return is required. 2) Determine the toxic effects of ROS generated by lunar dust by using well-characterized Drosophila mutants with genes encoding potassium channel proteins that act as sensitive in-vivo oxygen sensors. These fly lines have an increased metabolism and a decreased life span, are hyperexcitable and show a locomotor behavior associated with leg shaking. These measurable responses (behavior and lifespan) are exacerbated by ROS and are dose dependent on the amount of ROS present. Overall the operations concept would be to fly a population of fruit flies onto the lunar surface and use short video clips to monitor and measure behavioral movement of the flies periodically. This method has been used extensively in the Bhattacharya lab. Quantification of this data will provide assessment of the degree of reactive oxygen species and iron toxicity effects from the specific fly lines described in Specific Aims 1 and 2.

*Title: Response of Intraterrestrial Microorganisms to Space Conditions*
*Concept Provided By: Alfonso F. Davila, Darlene S. S. Lim, Christopher P. McKay, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 4, 5, and 6*
*Timeframe: Long*

Monitoring the metabolic activity and the survivability of shallow and deep sub-surface microorganisms, to space conditions. Intraterrestrial microorganisms (IM) are strict anaerobes, adapted to extremely low levels of metabolic activity, and ostensibly isolated from surface resources and conditions. IM thrive within rocks and cracks in the shallow and deep subsurface, where they are likely to survive the shock of an impacting meteorite. The same host rock will act as their launching vehicle after a meteorite impact, and as a protecting scaffold during planetary ejection and planetary re-entry. If the size of the ejected particle is sufficiently large, it will act as a shield against harmful radiation, the main factor determining organism survivability during space exposure. Approach / Payload Description: Six iron-rich rocks (RT1…RT6), and six-quartz pebble conglomerate rocks from the deep sub-surface of the Witwatersrand Basin (WB) in South Africa. Each rock (WB1…WB6) has a volume ranging from 50-150 cm3. Samples RT1, RT2 and RT3 will contain a microbial growth module (MGM) with Leptospirillum ferroxidans strain 3.2 and Acidithiobacillus ferrooxidans strain Musta, respectively. Both species have been isolated from the Tinto River. Samples WB1, WB2 and WB3 will contain a MGM with a Desulfovibrio sp. from the Witwatersrand Basin. Three additional rocks from each locality will be equipped with temperature, pressure and radiation sensors both inside and on the surface. These rocks will be used as controls to study the response of the rock material to space conditions. All rocks would be exposed to the space environment in sun-synchronous HEO for extended durations. The MGM consists of a small, cylindershaped, chamber (0.5cm diameter, 5 cm height) with a cubic quartz cuvete, filled with culture medium that provides a closed batch culture environment for microorganisms. The MGM has also the capability to measure bacterial growth by optical density. A light-emitting diode (LED) attached to one side of the cuvete acts as a light source. A photoresistor placed in the opposite side of the cuvete measures the amount of light transmitted through the culture medium which, given the appropriate wave length, is a function of the number of suspended cells. The cuvete, the LED and the photoresistor are protected by an aluminum frame. The temperature of the culture medium and the photoresistor voltage can be continuously monitored with a data acquisition module.

*Title: Determination of Unicellular Organisms Mutation Rates and Mechanisms in Various Space Environments*
*Concept Provided By: Jacob Cohen, NASA Headquarters*
*Astrobiology Goal(s) Addressed: Goal 5*
*Timeframe: Near*

The objective of this project is to determine the fundamental mutation rates and mechanisms employed by unicellular organisms exposed to various space environments and substrates: point mutations, indels, horizontal transfer and population dynamics. Instruments to achieve measurement parameters include optical density, fluorescence, temperature sensors, radiation dosimeters, accelerometers, relative humidity, gas sensors. Use of the GeneSat platform would give a near-term start to this project.

*Title: Experimental Evolution in Drosophila*
*Concept Provided By: Marta L. Wayne, University of Florida; Marty Kreitman, University of Chicago*
*Astrobiology Goal(s) Addressed: Goals 5 and 6*
*Development Timeframe: Near*

Goal: to understand evolution in a truly novel environment. Let selection tell us what genes and alleles are important in the space environment. Artificial selection, in the form of fancy pigeons, was Darwin's inspiration for the theory of natural selection. It is directly analogous to natural selection. Fitness largely defined by experimenter. (Darwinian fitness still involved.) Artificial selection is the deliberate choice of a select group of animals or plants, usually superior for a trait or traits, for breeding. Three major outcomes of artificial selection: change in mean of selected trait, change in variance of selected trait, or change in traits covarying with selected trait. Experimental evolution is artificial selection, but rather than selecting on an individual trait, the experimenter defines the conditions/environment and allows the organism to determine which traits are important to respond. The space environment differs from earth in gravity, radiation, and other unknown factors. Why Drosophila? It is a multicellular eukaryote, but still small and relatively easy to manipulate. It is a model for humans: > 65% genes have human homologues. There is a vast wealth of genetic tools and information, and there is demonstrated success in flight experiments (Bhattacharya and colleagues). Flies have homology to humans for these known astronaut challenges: muscle loss, respiration, immune function (Toll, NF-kappaB, crude Ig), heart, behavior/neurobiology. Experimental design: ground controls are essential to identify genes responding to selection. Multiple replicates of both control and selected lines kept to account for genetic drift. Multiple replicates required for study of correlated response to selection. Immune response will be assessed using a bioassay. The vertically inherited parasite, the sigma virus will be utilized. Resistance to sigma is conferred by the evolutionarily conserved Toll signaling pathway, likely also ribonucleic acid interference (RNAi). Assay for infection by paralysis or death on exposure to carbon dioxide. Evolutionary response to the space environment (data via telemetry): respiration, body size (thorax length, wing length, volume), wing shape, development time, egg-adult fitness/density, activity level. Later experiments would look at: population allele frequency changes, viability, growth, replication, metabolic activity, gene expression, genomic changes, phenotypic changes, and adaptation. Experimental concept: 1) Load embryos in stasis (low oxygen) in 48 isolated wells or chambers - each chamber will contain a distinct isogenic line, 2) Launch, transit, deploy (LEO), 3) Revive & grow, 4) Image: still for morphology & egg - adult viability measurement; video or Fly Minder for behavior (4 weeks), 5) Sensors: Radiation, Temperature, Pressure, Relative Humidity, Acceleration, Gyroscope, Oxygen (respiration.), and 6. Telemeter data.

*Title: Adaptation and Acclimation of Microorganisms to Life in Space*
*Concept Provided By: Andrew Pohorille*
*Astrobiology Goal(s) Addressed: Goals 5 and 6*
*Development Timeframe: Mid*

Examine the survival, genomic alteration, and adaptation of microorganisms and microbial ecosystems to life in space. This will be achieved by measuring gene expression over multiple generations. The payload will be a fully automated, miniaturized unit for measuring gene expression on small spacecraft. The system will support growth of the organism, lyse the organism to release the expressed RNA, amplify this RNA using reverse transcription polymerase chain reaction (RT-PCR) and read the expression levels of a large number of genes by microarray analysis of the PCR product. Other sensors can be added to the instrument.
High throughput approaches, such as deoxyribonucleic acid (DNA) microarrays, are the only way to understand how organisms adapt to space environment by analyzing the whole metabolic and regulatory networks in cells. The proposed instrument can be used for multiple studies along this line. Unit can be assembled that is 7"x7"x3" in size, weights 1-2 pounds, and consumes 5-10 W averaged over a period of 1 hour when gene expression experiment is performed. System needs to be pressurized and requires temperature and humidity control. Studies would be performed in LEO, HEO, and on the lunar surface.

*Title: Establishment and Seed-to-Seed Growth of Plants in a Lunar Environment*
*Concept Provided By: John Hogan, Robert Bowman, Stevan Spremo, NASA Ames Research Center*
*Astrobiology Goal(s) Addressed: Goals 4, 5, and 6*
*Development Timeframe: tbd*

Using a germplasm already developed and demonstrated for 14-day dark/light cycles of the moon, complete the first establishment of prolonged life on a celestial body other than Earth. The project will demonstrate that plants can survive in a moon radiation environment and that sexual reproduction (meiosis) can occur in this environment. The project has direct relevance to enabling future human life support (food, air, water) for human colonization of the moon and Mars. The hardware is at TRL 5-6 and some of the hardware has been demonstrated on TROPI.

### 4.3 Engineering Assessment Objectives and Process

In order to facilitate a rapid assessment of the various experiments and instruments proposed and discussed at the workshop, the engineering team utilized a checklist approach to quickly identify unique design drivers for the proposed investigation. The checklist also attempted to capture suspected or anticipated experiment requirements or constraints, as they are presently known. Because of their unique requirements, a special section was used to address imagers, and a summary of the flight resources was estimated. Table 4.3-1 lists the checklist elements and a brief description of each.

TABLE 4.3 - 1 ENGINEERING ASSESSMENT CHECKLIST ELEMENTS

| Mission Element | Description/Definition |
|---|---|
| Concept of Operations | Overall description of the mission and objectives |
| Experiment Protocol TRL | An estimate of the maturity of the instrument hardware and software needed to make the measurement |
| Instrument Description | Descriptive |
| Space Platform/Bus | Describes high level aspects of the spacecraft needed to accommodate the instrument |
| Orbit | Where the spacecraft needs to be positioned |
| Ground Systems | An estimate of what ground systems will be needed to communicate with and operate the spacecraft/mission |
| Mission Operations and Science Operations Center Locations | If not assumed to be ARC |
| Experimental Requirements and Constraints | Special needs or limitations on the mission design |
| Imaging Platform Requirements | If applicable |
| Estimated Resources Needed | Describes power, mass, data services required from the bus |

Based upon the information contained within the individual checklists, and after assessing the experiment/instruments against known spacecraft systems currently available or in development, the engineering team then further classified the various missions into near-, mid- and long-term categories.

Near-term missions were those that can rely on secondary spacecraft designs similar to the 3U CubeSat configuration (e.g. GeneSat-1), and also had relatively high instrument TRLs. Near term missions are also leveraged by availability of space proven deployers (such as the Poly-Picosat Orbital Deployer (P-POD) used for CubeSats of 1U to 3U). The use of existing space platforms and deployers, combined with proven and understood instruments resulted in a mission that could be flown with a minimum of new development. Therefore, the focus of such a project would be on the integration and testing phases, potentially culminating in a mission of opportunity as a secondary payload within a year.

Mid-term missions were estimated to require some modification to spacecraft systems, and typically involve mid-range instrument TRLs, indicating that further development, (most likely extensive functional performance testing) would be required. The time for such development was assumed to be less than 2 years for technology maturation and ground testing prior to flight. Wherever possible, heritage or similar systems are assumed to reduce developmental risk and cost.

Long-term missions involve experiments that would require significant development and maturation of either the instrument technology or spacecraft bus capability. An example of a long-term mission might be a sample return mission, which requires technology not in use currently, or an instrument that is at a TRL of around 2 or 3.

## 4.4 Science and Engineering Assessment Matrix

The following table, Table 4.4 – 1 Science and Engineering Assessment Matrix, provides a summary of each science concept's objective, identified platform and instrument, experimental approach, technical hurdles, and development timeframe.

TABLE 4.4 – 1 SCIENCE AND ENGINEERING ASSESSMENT MATRIX

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| **Extended Red Emission (ERE) Mapper**<br>Trace interstellar carbon distribution in the diffuse interstellar medium | IMAGER<br><br>MICROSAT | Launch instrument (fast aperture camera/CCD) on a smallsat into LEO<br>Conduct survey of sky (image, reorient, slew)<br>Transmit image data to ground for analysis | Pointing accuracy of smallsat | NEAR<br>Instrument is from COTS components; small spacecraft exist to accommodate this experiment |
| **Deuterium Explorer**<br>Determine the deuterium to hydrogen ratio in organics and ices | IMAGER<br><br>MICROSAT | Launch a small (50cm) telescope into LEO<br>Conduct observations<br>Slew telescope to new observation target and repeat observations<br>Transmit data to ground for analysis | Pointing accuracy of smallsat | NEAR<br>Technologies exist to execute this mission with a smallsat |
| **Dust Telescope**<br>Determine the organic content and its variability in interplanetary and interstellar dust particles | SENSOR<br><br>MICROSAT | Launch spacecraft into LEO, lunar, or L1 orbit.<br>Collect dust particles and analyze immediately (LAMA)<br>Transmit data to ground for analysis | Size of "aperture" affects the rate of particle detection | MID<br>Instrument TRL = 5. Some development required (Spacecraft and instrument) |
| **NEOCAM**<br>Measure the elemental and limited molecular composition of | IMAGER<br><br>MICROSAT | Place spacecraft (with UV instrument) in LEO, facing nadir.<br>Stare at night side of Earth and collect | Requirement to catch fleeting phenomena | MID<br>Systems development required, but similar instruments have been flown previously. |

| **Experiment Title / Objectives** | **Instrument/ Platform Types** [1, 2] | **Concept of Operations** | **Technical Hurdles** | **Horizon (Near, Mid, Long)** |
|---|---|---|---|---|
| comets | | spectra from meteor storms as they enter the atmosphere<br>Transmit spectra data to ground for analysis | | |
| **Detection of Exogenic Organics in the Upper Atmosphere of Earth**<br>Determine the fate exogenic molecules in the atmosphere | IMAGER<br><br>MICROSAT | Launch small mid-infrared telescope/spectrometer instrument into LEO.<br>Monitor spectra of known stars while viewing through the Earth's atmosphere<br>Compare these spectra with known spectra of stars to identify organic compounds | Pointing accuracy of smallsat | NEAR/MID<br>Some instrument development needed; small spacecraft exist to accommodate this experiment |
| **Lunar Surface Radiation Dosimeter**<br>Conduct long-term radiation monitoring on the lunar surface as a precursor to manned missions | SENSOR<br><br>LANDER/ PAYLOAD | Integrate sensor suite onto lunar lander<br>Collect radiation data over an extended period of time<br>Return data to ground for analysis | Opportunity for a lunar lander mission | LONG<br>Lunar lander opportunity not known. |
| **Lunar Environment and Dust reactivity Sensor**<br>Characterize effects of lunar environment (dust) on materials and biological/chemical systems | INCUBATOR<br><br>LANDER/ PAYLOAD | Instrument is integrated onto a lander/rover<br>On the surface, sample (regolith, dust) is introduced onto the sensor<br>Sensor (chemimetric, thin film array) detects alterations of biology and materials.<br>Another sensor element performs dust reactivity chemistry.<br>Data are transmitted to ground for analysis | Opportunity for a lander/rover mission<br>Sample management technologies | LONG<br>Instrument has high TRL and development behind it. Lander opportunity required, however. |
| **Grain Coagulation**<br>Determine key parameters leading to early-stage particle accretion in the nebula | SENSOR<br><br>CUBESAT | Payload is contained in a smallsat and orbited into LEO<br>Under controlled conditions, monitor using video, collisions and interactions of | Achieving "quiet" micro-g ($10^{-6}$g)<br>Varying pressures inflight<br>Management | NEAR<br>Instrument exists and has flight heritage, and is compatible with smallsats. Flown on Shuttle. |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| | | various particles<br>Vary the initial conditions and repeat observations (temperature, pressure, plasmas?)<br>Transmit video images to ground for analysis | of cryogenics | |
| **Ice Collisions**<br>Determine key parameters leading to early-stage particle accretion in the nebula | SENSOR<br><br>CUBESAT | Adapt particle instrument (chamber + video imager) for a smallsat<br>Launch into LEO<br>Measure interparcticle sticking forces under a variety of conditions (temp, pressure, plasma)<br>Transmit video images to ground for analysis | Achieving "quiet" micro-g ($10^{-6}$g)<br>Varying pressures inflight | NEAR<br>Instrument exists and has flight heritage, and is compatible with smallsats. COLLIDE heritage on Shuttle. |
| **Point and Shoot: Luminescence Survey**<br>Survey and characterize distribution of organics and minerals on planetary surfaces | SENSOR<br><br>LANDER/ PAYLOAD | Instrument (UV flash lamp with an imager) is integrated onto a lander/rover vehicle<br>At night, or when conditions permit, areas of surface are illuminated with UV flash and imaged for presence of organics<br>Images are returned for ground analysis | Opportunity for accommodations on a lander/rover mission | LONG<br>Instrument requires accommodations on a lander/rover |
| **Chemical and Metabolic Activity Calorimeter**<br>Measure the chemical reactivity of dust and identify metabolic processes | SENSOR<br><br>LANDER/ PAYLOAD | Integrate calorimeter onto a lander/rover vehicle<br>After arrival on surface, obtain soil (regolith) sample<br>Place sample into reaction chamber and expose to a reactant and/or nutrient<br>Monitor reaction(s) via $\Delta$T measurements<br>Transmit data to ground | Opportunity for a landed mission<br>Sample management technologies development | LONG<br>Mission opportunities for landers/rovers will dictate feasibility. |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| **Single Loop for Cell Culture** Expose microbes and/or cells to space environment | INCUBATOR<br><br>CUBESAT | Launch into LEO (could also be a parasite payload on other spacecraft)<br>Culture organisms<br>Monitor space environment<br>Measure biological parameters, environmental conditions | Sample management<br>Life support for cells | NEAR/MID<br>Smallsats have demonstrated capability to support similar experiments. SLCC hardware has significant development behind it. |
| **O/OREO** Organ-ics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and balloons. | SENSOR<br><br>CUBESAT | Label a substrate with known compounds.<br>Place the substrate/compounds in a satellite into a stabilized LEO, sun synchronous orbit<br>Expose samples for up to 6 months<br>Perform analyses periodically *in situ* and store data.<br>Downlink “snapshot” and housekeeping data to ground periodically.<br>Downlink all raw data | Need space simulators for ground controls<br>Launch orbit opportunities for sun syn-chronous or-bits | NEAR<br>Instruments exist; heritage spacecraft system available; orbit flexibility will increase launch opportunities |
| **O/OREO w/ cultur-ing** Organics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and then culture and monitor organisms in situ | INCUBATOR<br><br>CUBESAT | Preserve (lyophilize) known organisms and attach to substrate on satellite<br>Place satellite into LEO or HEO orbit<br>Expose samples for 6 months<br>Periodically incubate exposed subsets of organisms<br>Detect optical signal (live/dead or metabolic)<br>Downlink “snapshot” and housekeeping data periodically<br>Downlink all raw data | Moving samples across pressure barrier in order to incubate at 1 atmosphere<br>Sample management and life support technologies (fluidics, etc) | MID<br>Sensors and spacecraft elements exist; builds on earlier O/OREO concepts; would require some development |
| **Onion/OREO w/ sample return** Or- | INCUBATOR | Perform an O/OREO mission in LEO (or | Reentry of Onion (safety | MID/LONG<br>Elements of space sys- |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| ganics/and Organisms and/or Endolithic or Other communities exposure in LEO, lunar and HEO and then culture organisms and return to Earth | RV | highly elliptical orbit)<br>Expose specimens for 6 months<br>Command spacecraft to reenter<br>Sample housing (aka "Onion") is separated from the "mother ship" and reenters in a manner analogous to a meterorite (ballistic)<br>Onion impacts in Utah salt flats<br>Locate and recover Onion and analyze samples | implications)<br>Orbit design to be compatible with recovery operations | tem exist; reentry technology to be developed; Onion to be developed |
| **Upper Atmosphere Bio-particle Collector**<br>Particle collector spacecraft | SENSOR<br><br>RV | Spacecraft in LEO collects particulates aseptically.<br>Spacecraft changes altitude and collects more samples<br>Spacecraft is commanded to return<br>Samples are analyzed on the ground | Orbital manipulation<br>Particle collector design<br>Reentry and recovery technologies | LONG<br>Particle collector will require development; reentry and recovery technologies required |
| **Biological Implications of Atmospheric Stratification**<br>Particle collector on sounding rockets and high altitude balloons | SENSOR<br><br>OTHER | Collect particulate samples at various altitudes using balloons and sounding rockets<br>Complements data from orbital sample collection and analysis | None known | NEAR<br>These types of studies could be mounted almost immediately |
| **Prebiotic Chemistry in Space**<br>Array of combinatorial chemistry reactors exposed to the space environment | SENSOR<br><br>CUBESAT | Pre-seed chemical reaction sites (witness plates) on a nanosat with combinations of reactants.<br>Launch nanosat into LEO<br>Expose sample sites to various elements of space environment; solar, cosmic radiation; vacuum, temperature | Spectral detectors development<br>Orbit and spacecraft design needed for very low (cryogenic) reaction temperatures | MID to LONG<br>Instrument development needed; robust spacecraft design which can operate in 10's of °K |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| | | extremes<br>Using onboard spectrometers /instruments, analyze reaction sites n situ | | |
| **XRD/XRF**<br>Analysis of Ices at the Lunar Poles<br>Investigate potential ice/hydrous minerals/clathrate hydrates in permanent lunar shadows | SENSOR<br><br>LANDER/ PAYLOAD | Integrate CHEMIN onto lander/rover and deploy in lunar polar crater.<br>Collect and place samples (regolith) into instrument<br>Perform x-ray diffraction on samples<br>Transmit data to ground for analysis | Opportunity for a lander/rover mission<br>Sample collection technology<br>Extreme temperatures in polar shadows | LONG<br>Instrument has high heritage, but requires accommodations on a lander/rover. |
| **LOCAD-PTS**<br>Portable test system for multiple biological and chemical analyses | SENSOR<br><br>LANDER/ PAYLOAD | Transport a human-tended chem/bio suitcase laboratory to lunar surface<br>Conduct multiple experiments with regolith and lunar dust and/or exposure to space environment<br>Analysis can be done in situ or after return (with crew) | Transport to/from moon is dependent on manned systems | LONG<br>Access to lunar surface and/or sample return required |
| **Lab in a Suitcase**<br>Human tended chemical analyzers | SENSOR<br><br>OTHER | Carried on a manned lunar mission<br>Perform O/OREO on the lunar surface autonomously<br>Return samples and data with crew return | Dependency on manned missions | LONG<br>Due to Constellation Program schedules |
| **DNA Damage, Repair and Evolution in Bacteria During Interplanetary Transit**<br>Measure rates and spectra of DNA damage of organisms in the deep space environment | INCUBATOR<br><br>MICROSAT | Expose endolithic bacteria to HEO simulating Earth-Mars transit.<br>Measure rates and spectra of DNA damage.<br>Using microarrays, assay gene expression response during germination vs. ground | Sample return will require development | LONG<br>Requires return. |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| | | controls.<br>Challenge exposed populations with environmental conditions approaching Mars, to select for mutants with enhanced survival/growth properties | | |
| **Combined Effects of Radiation and Micro-g Biosensor**<br>Culture fruit flies to study the interaction of radiation (cell damage and repair) and microgravity on biological systems | INCUBATOR<br><br>CUBESAT | Place D. melanogaster larvae in nanosat in LEO high radiation orbit (polar or elliptical)<br>Culture larvae<br>Measure local environmental parameters<br>Image developing larvae for generation of tumors<br>Transmit images to ground for analysis | Uniqueness of high radiation orbit | NEAR<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |
| **Lunar Dust Reactivity Biosensor**<br>Measure lunar dust reactivity and toxicity to biological systems | INCUBATOR<br><br>CUBESAT | Use mutant fruit fly larvae which have been sensitized to the toxic effects of lunar dust<br>Place flies with lunar dust simulant into LEO high radiation orbit (polar or elliptical)<br>Culture larvae and then challenge them with dust simulant<br>Monitor larvae's response to dust in the space environment (image larvae)<br>Downlink data for analysis on the ground | Uniqueness of high radiation orbit | NEAR<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |
| **Response of Intra-terrestrial Organisms to Space Conditions**<br>Monitor metabolic activity of | INCUBATOR<br><br>CUBESAT | Instrumented rocks will be inoculated with known bacterial strains<br>Rocks are contained in a nanosatellite which is launched into HEO | Modification of existing culturing system to accommodate rock | NEAR/MID<br>Existing Genesat spacecraft can support these experiments with additional development for the culturing system |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| microorganisms to the space environment | | Monitor radiation and temperature<br>Culture “rocks”<br>Measure bacterial growth and environmental parameters and transmit data to ground for analysis | substrates | (rock) |
| **Mutation Rates in the Space Environment**<br>Survey of mutations (rates and mechanisms) in unicellular organisms grown under various conditions in space | INCUBATOR<br><br>CUBESAT | Use GeneSat platform to incubate various organisms in LEO (multiple flights)<br>Monitor space environment<br>Culture organisms in space<br>Detect genetic changes in cultures<br>Transmit data to ground for analysis<br>Repeat flight for other organisms; alter media, substrates, environmental conditions, etc. | Multi-mission architecture; various orbits, multiple missions | NEAR<br>Existing Genesat spacecraft could begin these experiments presently |
| **Experimental Evolution in Drosophila**<br>To understand evolution in a truly novel environment | INCUBATOR<br><br>CUBESAT | 1. Load embryos in stasis (low oxygen) in 48 isolated wells or chambers. Each chamber will contain a distinct isogenic line<br>2. Launch, transit, deploy (LEO)<br>3. Revive & grow<br>4. Image: still for morphology & egg - adult viability measurement; video or Fly Minder for behavior (4 weeks)<br>5. Sensors: Rad, T, P, RH, Acceleration, Gyroscope, Oxygen (respiration.)<br>6. Telemeter data. | Keep alive environment for biology after loading into hardware. May imply continuous power needed. Relatively high bandwidth for video transmission. | NEAR<br>Spacecraft exists; imaging systems have been demonstrated on the ground for fruit flies |

| Experiment Title / Objectives | Instrument/ Platform Types [1, 2] | Concept of Operations | Technical Hurdles | Horizon (Near, Mid, Long) |
|---|---|---|---|---|
| **Adaptation and Acclimation of Microorganisms to Life in Space**<br>Measure gene expression over multiple generations | INCUBATOR<br><br>CUBESAT | Place incubator/PCR analyzer instrument into LEO or HEO<br>Serially culture organisms, then process the samples for genetic detection<br>Quantify genes of interest<br>Transmit data to ground for analysis | Development of RT/PCR instrument and incubator | MID<br>Spacecraft elements exist which can support this mission; development needed for payload/instrument |
| **Establishment of Seed-to-Seed Growth of Plants in a Lunar Environment**<br>Demonstrate that life can function at lunar gravity | INCUBATOR<br><br>LANDER/ PAYLOAD | Place plant growth unit on lunar lander<br>On lunar surface, activate experiment and supply nutrients and conditions for plant growth<br>Monitor (video) growth<br>Monitor environmental conditions<br>Return video and data to ground for analysis | Opportunity for a lunar lander mission | LONG<br>Lunar lander opportunity not known. However, plant growth hardware has high flight heritage. |

[1] **Instrument Types:**
SENSOR - This type of instrument is designed to make a particular measurement of the environment or sample/specimen.
IMAGER - This class of instruments performs remote sensing functions. They include telescopes and spectrometers.
INCUBATOR - This instrument provides a pressurized environment and other conditions to maintain or sustain biological growth.
OTHER - Classes of instruments not covered above.

[2] **Platform Types:**
CUBESAT - Cubesats are free-flying spaceraft between 5 and 15 kg (kilogram) in mass, up to 15 Watts (W) in power. They are launched as secondary payloads. Cubesats are primarily intended for LEO applications.
MICROSAT - A Microsat can be up to 35-50 kg in mass, with power around 50-75W. They are also free-flyers, and may be launched as secondary payloads. Microsats can be used in low Earth orbit (LEO) and high Earth orbit (HEO), and possibly in lunar orbit.
LANDER/PAYLOAD - A lunar lander is designed to place payload mass on the lunar surface. The experiment may be a payload only as part of a larger lander mission. Landers are typically not mobile once landed, and have severe constraints for payloads on mass and power.
RETURN VEHICLE (RV) - A RV spacecraft is designed to return all or some of the orbited mass to Earth in a controlled, predictable manner. RVs have significant overhead for safety and guidance systems, leaving little resources for payloads.

## 4.5 Engineering Assessment Summary

NEAR Term Missions

A number of NEAR term missions (<18 months to launch) were proposed that leveraged heavily on the CubeSat spacecraft type (GeneSat), and of these many were, not surprisingly, biological in nature. Variations were seen in what kind of sensor is needed to collect the scientific data, but a common theme for a pressurized volume to support life was clearly identified.

Another potentially fruitful area that would strongly complement space measurements is the use of sounding rockets and high altitude research balloons. These suborbital missions can be used as technology risk mitigators for future space missions, or as direct data collection activities concurrent with space measurements. Both the sounding rocket program and balloon program are ongoing currently.

The areas of emphasis to enable NEAR term flights would therefore, be in the sensor or instrument development area. It appears from the number of experiments proposed to use a GeneSat-like spacecraft that the CubeSat bus could be leveraged to support a number of these missions within very short timeframes.

In addition, Microsat missions were identified which use imaging systems on slightly larger platforms than the CubeSat, but still exploit secondary launch accommodations. These experiments could be executed in the NEAR (or MID) timeframe. Much of the instrument technology for these experiments exists or has flight heritage from other programs, and early engineering analyses have shown that the next incremental “size category” of cubesat-derived spacecraft (aka Microsat) could meet these mission requirements.

MID Term Missions

Experiments that were targeted towards CubeSat or MicroSat platforms, but which require specialized instrument development fell into this category. Specifically, sample handling and management and general experimental complexity were key factors driving these experiments to longer development schedules. The required spacecraft technologies to support these experiments, however, appear to be available and sufficient for these missions, with some emphasis on attitude determination and control technologies for imaging platforms.

LONG Term Missions

The LONG-term category is primarily dominated by two spacecraft-related technological needs. The first is to return samples or specimens from orbit. While there are ongoing projects to (re)develop this capability, there are only a few recent examples known (Genesis, Stardust). However, recovery from LEO is possible, and has been successfully demonstrated in the past.

The other feature within the LONG-term classification is the desire to place the instrument or experimental specimens on the lunar surface. The most likely way that this objective can be achieved is for the experiment package to be a “parasite” or guest of the landing vehicle. From an analysis of the instruments proposed, it is feasible that these experiment packages could be adapted and integrated onto landers. However, the pacing element for these missions is the development of the lander vehicles, which are only now in conceptual stage. Therefore, we have classified lunar landers (manned or unmanned) as LONG term endeavors.

Engineering Assessment Conclusions:

1. Augment or leverage an instrument development program to include and address small payload opportunities as they become available. This program (or element of an existing program) should be closely linked to the ASP goals and objectives and will result in a pathway for instruments to mature towards TRL 4 or 5 in preparation for a small payload free-flyer or lander mission.
2. As evidenced by the relatively large number of CubeSat-based experiments identified during this study and workshop, begin the flight process with selected experiments from the NEAR class. The ideal mission would use an existing spacecraft bus and deployer, coupled with a well-known instrument or scientific protocol. These first mission(s) will establish the programmatic baseline for the larger ASP activity.
3. Initiate a small spacecraft technology project that will collaborate with other disciplines on the development and qualification of the Microsat platform, with particular attention to imaging requirements. Due to the wide utility of these platforms for other scientific disciplines such as Astrophysics or Earth Sciences, an early investment in Microsat spacecraft related technologies will result in a number of MID term missions capable of generating large amounts of data and science return.
4. Finally, in parallel to the above 3 recommendations, leverage and collaborate with other groups developing spacecraft return technologies and systems. It is anticipated that the same technological forces that are currently enabling small, low-cost spacecraft in support of scientific missions, will also accelerate and reduce the cost for the development of sample return spacecraft.

## 5.0 WHITE PAPER AND PLENARY DISCUSSIONS AND RECOMMENDATIONS

**During the draft white paper and plenary session discussions, four major topic areas were raised and resulting recommendations were made as necessary components for sustaining a small payloads effort in Astrobiology.** The major topic areas discussed were: **1)** the critical need for quick turn around science opportunities, **2)** maintenance of a pipeline of science payloads ready to meet fixed launch platform schedules, **3)** development of mechanisms for sharing existing technologies and hardware systems to keep cost down, and **4)** ability for small payloads opportunities to address supporting Ground Control and Test & Integration Support functions and facilities.

Currently the SMD has two types of missions, strategic missions and PI-led missions. There is a growing realization within the NASA science community that frequent access to space to perform science on missions of opportunity including suborbital program opportunities is highly desirable. These lower cost platform approaches can yield critical insight into important science questions with possible opportunities to repeat science experiments on a more frequent timescale that advances science knowledge while waiting for the larger class missions to be developed. Suborbital programs in the PI-led mission category offer better opportunities for the Astrobiology science community to advance its knowledge linked to the Astrobiology roadmap goals and objectives. The group discussed the benefits of holding multiple community-specific workshops with scientists and engineers actively participating to understand the launch and payload constraints to be considered when planning a science objective. These science workshops can look for commonality across the themes and allow interaction with engineers to identify commonly needed tools for implementation in missions of opportunity calls. The group recommended a session at the upcoming Astrobiology Science Conference (2008) devoted to small satellites, balloons, and sounding rockets payload opportunities.

A critical component of building scientific knowledge is the iterative nature of building on previous experimental information. Maintenance of a pipeline of science payloads ready to meet fixed launch platform schedules through the technology development sections of the ROSES NRA call is a vital component. The technology development programs are critical for experiment development towards flight on small satellite mission opportunities.

With respect to sharing and reusing existing platform bus configurations and experimental hardware systems, the group also discussed several near term strategies that may help facilitate multiple science opportunities for implementing immediate low cost missions with other strategies for expanding existing capabilities for generic use. The group realized the benefits of using lowest price (entry-level) 3-cube hardware configurations for near-term payload launch opportunities in conjunction with the existing common bus configuration so that science experiments and instruments identified as compatible can be flown quickly. This would be a good first step in development of a Small Satellite capability in the Astrobiology Program. The group also identified the need for an experimental roadmap where commonality of existing supporting hardware subsystems can be identified and established so that mid to longer-term science experiments may be planned.

Lastly, the group expressed concern over a need for the Agency to provide engineering test and integration and ground control program oversight / support necessary to make these opportunities successful. The group discussed a need for providing some sustaining engineering support along with the small payloads expertise that exists so they can address critical program and engineering functions, including a) coordination of opportunities for NASA participation on various private and government agency rocket launch opportunities, b) assistance in performing engineering reviews and assessments on solicited science payload proposals prior to selection, c) engineering oversight of payloads to ensure readiness to fly on assigned launch window platforms, and d) collaboration with other groups developing spacecraft return technologies and systems to help leverage the program.

This final plenary session stimulated discussion in the areas specific to workshop Goal III - Contribute additional ideas for consideration in formulating a program - including instruments and techniques, flight opportunities and constraints, impacts, etc. The workshop participants found this activity to be most beneficial, particularly the sessions where there was interaction between the NASA Ames Research Center SSD engineers and themselves regarding their science experiment ideas and the existing small satellite platforms, payload constraints and the interfaces between these systems and their experiments. Both scientists and engineers were fully engaged in this workshop and welcome the opportunity to help SMD in planning for such an exciting future capability and opportunity to fly science.

**A summary of the group's recommendations made during the workshop is listed below.**

1. SMD hold multiple community-specific workshops with scientists and engineers actively exchanging information to understand the launch and payload constraints to be considered in conjunction with the science objectives. These science workshops can look for commonality across the themes and allow interaction with engineers to identify commonly needed tools for implementation in missions of opportunity calls.

2. Conduct a session at the upcoming Astrobiology Science Conference (2008) on small satellites, balloons, and sounding rockets payload opportunities.

3. Use lowest price (entry-level) 3-cube hardware configurations for near-term payload launch opportunities utilizing the existing common bus configuration so that science experiments and instruments identified as compatible can be flown quickly. As evidenced by the relatively large number of cube-sat based experiments identified during this study and workshop, begin the flight process with selected experiments from the NEAR class. The ideal mission would use an existing spacecraft bus, coupled with a well-known instrument or scientific protocol. These first mission(s) will establish the programmatic baseline for the larger ASP activity.

4. Review the need to identify an experimental roadmap where commonality of existing supporting hardware subsystems can be identified and established so that mid to longer term science experiments can take advantage of these existing hardware subsystem in mission of opportunity calls.

5. Augment or leverage existing technology and instrument development program in SMD to include and address small payload opportunities as they become available. This program (or element of an existing program) should be closely linked to the ASP goals and objectives and will result in a pathway for instruments to mature towards TRL 4 or 5 in preparation for a small payload free-flyer or lander mission.

6. Provide some sustaining engineering support along with the small payloads expertise in NASA to assist the Astrobiology program in a) coordination of opportunities for NASA participation on various private and government agency rocket launch opportunities, b) assistance in performing engineering reviews and assessments on solicited science payload proposals prior to selection and, c) engineering oversight of payloads to ensure readiness to fly on assigned launch window platforms, d) collaboration with other groups developing spacecraft return technologies and systems. It is anticipated that the same technological forces that are currently enabling small, low-cost spacecraft in support of scientific missions, will also accelerate and reduce the cost for the development of sample return spacecraft.

7. Support for a small spacecraft pointing technology study that will collect requirements across science disciplines will benefit the development and qualification of the Microsat platform. Due to the wide utility of these small satellite platforms for supporting scientific disciplines such as Astrophysics, Space Sciences and Earth Sciences, an early investment in this area

can result in a number of mid-term missions capable of generating large amounts of science data.

# 6.0 APPENDIX

## 6.1 Astrobiology Small Payloads White Paper

Draft

# Small Payloads for Astrobiology - A White Paper

April 11, 2007

NASA Ames Research Center
Moffett Field, CA 94035
http://astrobiology.arc.nasa.gov/roadmap

**Small Payloads for Astrobiology**
A White Paper

## 1.0 Executive Summary

To be written after the Astrobiology Small Payloads Workshop

## 2.0 Introduction

*Astrobiology Program Overview*

Astrobiology is the study of the origins, evolution, distribution, and future of life in the universe. It requires fundamental knowledge of life and habitable environments that will help us to recognize biospheres that might be quite different from our own. Astrobiology embraces the search for potentially inhabited planets beyond our Solar System, the exploration of Mars and the outer planets, laboratory and field investigations of the origins and early evolution of life, and studies of the potential of life to adapt to future challenges, both on Earth and in space. Interdisciplinary research is needed that combines molecular biology, ecology, planetary science, astronomy, information science, space exploration technologies, and related disciplines. The broad interdisciplinary character of astrobiology compels us to strive for the most comprehensive and inclusive understanding of biological, planetary and cosmic phenomena.

*Astrobiology Small Payloads Program*

Spaceflight offers a unique opportunity to address these questions in ways that are not possible on Earth. It is not possible to simulate microgravity, Lunar, or Martian gravity environments on Earth, except for very short time periods on parabolic aircraft flights. Spaceflight also provides access to the space radiation environment, including cosmic rays and solar particle events. Ground based accelerators can simulate certain components of this environment, but not the entire spectrum of multi-directional particles.

In order to fully utilize all spaceflight opportunities, NASA is considering an Astrobiology Small Payloads (ASP) Program to fund the development of spaceflight experiments and associated hardware. Particular Astrobiology science that could be accomplished on small satellite and other Lunar flight opportunities include investigations in the fields of exobiology, astrochemistry / planetary science, and astrophysics.

*Purpose of this White Paper and the Astrobiology Small Payloads Workshop*

This paper describes how spaceflight may be used to address the goals of the Astrobiology Roadmap through identification and concept development of reference science experiments in the fields of exobiology, astrochemistry/planetary science, and astrophysics. Reference experiments are presented in terms of their linkage(s) to Astrobiology goals; mission environment(s) suitable to the specific science objectives; particular spacecraft platform(s); payload hardware and instruments required and their associated development status, and available and potential launch opportunities.

To this end, the following ASP Workshop interim and end-products contribute to the recommendations in this white paper:

- Prioritized research areas
- List of possible Astrobiology spaceflight experiments
- Science requirements for mission environments
- Identification of existing spaceflight hardware and determination of priority areas for hardware development
- Science experiments matched to spaceflight opportunities

## 3.0 Background

*The Astrobiology Roadmap*

The NASA Astrobiology Roadmap, <http://astrobiology.arc.nasa.gov/roadmap>, outlines the multiple pathways for research and exploration that are components of Astrobiology and indicates how they might be prioritized and coordinated. The roadmap embodies the efforts of more than 200 scientists and technologists, including NASA employees, academic scientists whose research is partially funded by NASA grants, and many members of the broader community who have no formal association with NASA.

Astrobiology addresses three basic fundamental questions that have been asked in various ways for generations.

- How does life begin and evolve?
- Does life exist elsewhere in the universe?
- What is the future of life on Earth and beyond?

Life is a central theme that unifies NASA's vision and mission. The Astrobiology Roadmap outlines various goals on how to achieve a better fundamental understanding of our own world, and other potentially habitable worlds and life beyond Earth.

The NASA Astrobiology Roadmap provides guidance for research and technology development across the NASA Mission Directorates that encompass the space, Earth and biological sciences. The Roadmap is formulated in terms of seven Science Goals that outline key domains of investigation:

1) Understand the nature and distribution of habitable environments in the Universe,
2) Explore for past or present habitable environments, prebiotic chemistry, and signs of life elsewhere in our Solar System,
3) Understand how life emerges from cosmic and planetary precursors,
4) Understand how past life on Earth interacted with its changing planetary and Solar System environment,
5) Understand the evolutionary mechanisms and environmental limits of life,
6) Understand the principles that will shape the future of life, both on Earth and beyond, and

7) Determine how to recognize signatures of life on other worlds and on early Earth.

*Research Questions Addressed through the Astrobiology Small Payloads Program*

Research relevant to each of the Astrobiology goals can be performed using small satellites. This research will be conducted in the context of NASA's ongoing exploration of our stellar neighborhood and the identification of biosignatures for in situ and remote sensing applications. As a convenient framework for conceptualization, the range of science questions to be addressed can be divided into four categories: Planetary Conditions for Life; Prebiotic Evolution; Early Evolution of Life and the Biosphere; and Evolution of Advanced Life.

Additionally, it is envisioned that appropriate research in the near term will be largely focused on payloads that perform experiments along with demonstration of some remote sensing concepts. Later work may improve our ability to incorporate additional remote sensing and instrument concepts, including suitcase-science payloads to support human exploration needs.

The following sections provide a description of the four science areas identified, and provide example questions for each area.

- Planetary Conditions for Life

Astrophysics is the study of the physical properties, chemical composition, celestial objects, and processes that shape our universe. Astrochemistry and planetary science are concerned with the processes that led to the formation and evolution of planetary systems. Research in these areas seeks to delineate the galactic and planetary conditions conducive to the origin of life. The aspects of astrochemistry and astrophysics that pertain directly to ASP encompass not only observations of extra-solar planets but also include measurements of matter and processes leading to the formation of planets and satellites. Within dense molecular clouds stellar systems are currently forming, providing us with analogs of the early solar nebula and allowing us to study its likely initial chemical composition. Studies on the composition of dust, meteorites, bolides, and the interaction of radiation with matter are also relevant. Of particular relevance to this program will be the elucidation of geological, chemical, and physical processes related to the formation of habitable planets and satellites such as Mars or Europa. Since we regard water and reduced carbon as essential for life, observations relating to hydrospheres and carbon compounds are a natural emphasis of ASP.

Questions

- How does matter condense into planets, satellites, and other objects?
- What is the frequency and nature of extra-solar planetary systems and extra-solar earth-like planets?
- What is the formation, distribution, and fate in space of accessible carbon and other matter essential for a habitable environment?
- What is the nature/quantity of the incoming matter after planet/satellite formation?

- Prebiotic Evolution

Research in the area of prebiotic evolution seeks to understand the pathways and processes leading from the origin of planetary bodies to the origin of life. The strategy is to investigate the planetary and molecular processes that set the physical and chemical conditions within which living systems may have arisen. Studies of carbon chemistry and of the distribution of volatiles, in particular, will help to explain the locations of habitable environments, constrain the origins of life, and facilitate the search for life. Carbon bearing molecules are formed in the outflows of carbon-rich giants, modified during the planetary nebula phase, are further modified during residence in the interstellar medium by ultraviolet (UV) radiation and cosmic rays, and are then incorporated into forming planetary systems. Organic molecules exhibit strong spectral features in the infrared, and are observed both in emission (PAHs) and absorption (e.g., aliphatic molecules, X-CN, methane). Many of these molecules have been seen in comets and meteorites, and likely rained down on the earth during and after its formation, and may have contributed or been incorporated into living systems. Topics potentially approachable using small satellites include the formation of complex organic molecules in space and their delivery to planetary surfaces, exploration of early environments in which organic chemical synthesis could occur, and the forms in which prebiotic organic matter has been preserved in planetary materials.

Questions

- What is the distribution and evolution of organic molecules from their place of origin to their incorporation into proto-planetary systems?
- How was organic material delivered to the early Earth?
- What happens to carbon compounds and biomarkers in the space radiation environment?
- Can we distinguish between abiotic organic chemistry and biomarkers?
- How did biological selectivity for molecular chirality evolve?

- Early Evolution of Life and the Biosphere

The goal of research into the early evolution of life is to determine the nature of the most primitive organisms and the environment in which they evolved. A number of topics are included in this area: i) determine in what setting life first appeared; ii) determine the original nature of biological compounds, including the construction of artificial chemical systems to test hypotheses regarding the original nature of key biological processes; iii) investigate the evolution of genes, pathways, and microbial species subject to long-term environmental change relevant to the origin of life on Earth and the search for life elsewhere; and iv) study the coevolution of microbial communities and the interactions within such communities when presented with novel environmental conditions.

Questions

- Can microorganisms embedded in meteorites survive the journey from one world to another?

– What are the effects of reduced gravitational environments and space radiation on the ecology and population genetics of mixed microbial communities; change, adaptation, and evolution?

- Evolution of Advanced Life

Research on small satellites associated with the study of the evolution of advanced life could be designed to determine the potential distribution of complex life in the universe. This research, using the effects of the spaceflight environment (reduced-gravity and space radiation), will study the functioning of modern biological systems, and will determine how biological factors are important to the emergence of multicellular life. Critical features to be explored include developmental programs, intercellular signaling, programmed cell death, the cytoskeleton, cellular adhesion control, and differentiation.

Questions

– How is photosynthesis in microbes and higher plants altered upon exposure to reduced gravitational environments and space radiation?
– Are known biosignatures altered by long-term exposure to reduced gravitational environments and space radiation?
– How do alterations of the local environment, as derived from planetary environments (*e.g.,* Mars, with reduced gravity and an altered radiation spectrum, etc.) affect biogeochemical models of ecosystems (including isotopic and functional genomics analyses of the constituent parts)?

## 4.0 Target Environments

Three categories of space environments with associated orbital variations that may be accessible to Astrobiology researchers in support of scientific missions, are described below. Other environments may be considered, given the specific nature of the science involved.

*Low Earth Orbit*

Low Earth Orbit (LEO) offers the lowest cost energetically for payloads to operate in the space environment. LEO orbital altitudes are loosely defined from 300 km to 1000 km, and many are circular. A typical LEO orbit has a period around 90 minutes.

Spacecraft need to achieve velocities of ~28,000 km/hr to remain in orbit, and there are a number of launch service providers with a wide variety of launchers that can accurately place satellites into useful orbits. LEO includes circular low inclination orbits (west to east) that can place more mass into space due to the benefit of the Earth's rotation at launch, and polar orbits, which are useful for imaging the planet surface or atmosphere. Polar or high inclination orbits have the added feature of being relatively insensitive to the location of the supporting ground station(s), as the spacecraft will be in sight of the station multiple times per day. In general, communications to spacecraft in LEO are robust allowing for relatively high bandwidth for commanding and data handling capacities.

A variation on a polar orbit is the sun synchronous orbit. This launch profile, properly timed, will place the spacecraft in a permanently sun facing orbit which can be exploited to maximize spacecraft power or to perform specific measurements. In addition, LEO orbits are somewhat "warm" in that temperatures when in eclipse are moderate compared to deep space. The sun and also reflected sunlight re-radiated from the Earth provide for a benign thermal environment. However, other features of being close to Earth are potentially of more concern.

The first is the radiation environment. The Earth's magnetosphere collects and focuses radiation from the Sun, specifically protons into the Van Allen belts. These particles are channeled to the poles and their interaction with the Earth's atmosphere result in phenomena like the Auroras. The South Atlantic Anomaly (SAA) is located between 35° and 60° inclination roughly east of South America and west of Africa. The SAA is a region where the Earth's magnetic field dips closer to the surface than normal. This results in a significantly higher level of protons that are capable of damaging or interfering with space electronic systems. Experiments and spacecraft should avoid orbits through the SAA if possible. A similar threat to spacecraft is the unpredictable discharge of solar material known as Solar Particle Events (SPEs), which can produce a large flux of electrons and protons suddenly, resulting in an elevated radiation environment. SPEs can be lethal to biological systems in LEO spacecraft outside the protective blanket of the Earth's atmosphere.

Some LEO orbits also have the unique distinction of not being entirely out of the Earth's atmosphere. At these altitudes, atomic oxygen is present in sufficient concentrations to be a consideration in the selection of spacecraft materials and optics for missions that may operate for many months. This risk is, of course, dependent on orbital altitude.

Finally, since LEO orbits are "low cost" in terms of boosting energy (orbital velocities), return from LEO should also be less technically challenging requiring less spacecraft propulsion or change in velocity ($\Delta V$) in order to reenter the atmosphere.

*High Earth Orbits and Fly Away Orbits*

High Earth Orbits (HEOs) and flyaway orbits begin with highly elliptical geostationary transfer orbits (GTOs) and continue to Earth trailing orbits where the spacecraft moves further away from Earth over time. For the purposes of this paper, we will only address those orbits that have significantly different characteristics from LEO orbits both in terms of cost to exploit and scientific benefit.

An orbit at an "altitude" of 12 Earth radii (12 $R_E$) was selected to ensure that effects from the Earth's magnetosphere and Van Allen belts are negligible, and is used in this paper for illustrative and discussion purposes. The nature of the spacecraft's local space environment can, therefore, be said to be identical to the broader deep space environment. However, $\Delta V$ requirements to access these orbits are relatively high, requiring more of the spacecraft mass fraction for propulsion, or larger launch vehicles. In addition, due to the large distances from the Earth, communications require careful consideration and data rates may in fact be lower than achievable in LEO.

The HEO radiation environment is dominated by galactic cosmic rays (GCRs), which are heavy particles at relativistic velocities. These include hydrogen, helium, nickel, carbon, and iron nuclei, which can interact with spacecraft or payload systems. However, the dose levels of these particles may be low enough as to not be a major concern for short duration missions.

As spacecraft move away from the Earth, thermal contributions from the Earth onto the spacecraft will diminish. Similarly spacecraft surfaces that remain unexposed to sunlight (facing towards deep space) may reach very low temperatures, depending upon spacecraft design. In addition, deep space viewing instruments may not have to deal with interfering light from the Earth's albedo.

*Lunar Orbits and the Lunar Surface*

Placing a spacecraft into a trans-lunar insertion (TLI) trajectory is not much more expensive energetically than HEO or flyaway orbits. However, some transit scenarios that are efficient in terms of propulsion may require long periods of time (weeks to months) to complete.

In any transit to the moon, a large mass fraction of the spacecraft for propulsion will have to be set aside for the lunar orbit insertion maneuver, and even more for the deorbit and landing sequence for a surface lander. Once the spacecraft is in lunar orbit, additional propulsion will most likely be required to maintain that orbit due to the irregular lunar magnetic field. But since the moon has no atmosphere, very low orbits, down to 10 km in altitude perilune, are possible.

On the lunar surface, and even in orbit, spacecraft will have to operate in the presence of lunar dust, which can interfere with articulated devices or coat optics. At orbital velocities, dust, which is theorized to be transported into the exosphere will have many km/sec velocities relative to the orbiting spacecraft, and upon impact, could result in other types of damage.

Finally, when the spacecraft is in eclipse, temperatures can be as low as tens of degrees Kelvin (°K). This is also when communications are interrupted, unless communications assets have been emplaced around the moon.

The lunar surface has some additional features that must be addressed. During the two-week long lunar night, temperatures on the surface could plummet to 25°K. This presents a significant challenge to hardware systems, especially if the lander architecture is powered by solar energy.

## 5.0 Reference Mission Constraints

*Payload Hardware*

While only a limited number of flight-proven hardware in the nanosat class currently exists, recent flights have demonstrated the technical and programmatic aspects of designing and operating such spacecraft. GeneBox and GeneSat-1 developed by NASA Ames Research Center are currently in orbit and operational. GeneBox is housed inside the Bigelow Aerospace's Genesis test module, which was launched in July of 2006. GeneSat-1 < http://genesat.arc.nasa.gov/ >, a free-flying spacecraft, was launched in December of 2006 from Wallops Flight Facility on a United States Air Force (USAF) Minotaur I. It completed its technical protocols in February of 2006, and is now being operated by students as a training platform.

Other payload hardware systems for biological investigations, physical/chemical science, and astronomy have been developed and flown on various manned and unmanned launch vehicles. The Space Shuttle and International Space Station programs have over many years developed a wide variety of payload hardware systems, some of which are still in flight readiness. Similarly, many types of telescopes and spectrometers and related sensors have been launched or are under development on unmanned vehicles. These heritage payload systems and technologies have both pluses and minuses when considering them for use on small spacecraft missions.

- Legacy Payload Hardware Systems - Pluses
  - High flight heritage
  - Known operations in the space environment
  - Scientific experience with sensors and measurement strategies
  - Development costs incurred by other programs or organizations

- Legacy Payload Hardware Systems - Minuses
  - Systems are large and not well suited for small platforms (mass, power, thermal)
  - Payloads have been tested and qualified for less-stringent manned spaceflight requirements, including launch loads and other environments
  - High costs associated with shrinking/adapting systems into smaller platforms vs. designing to fit

Nonetheless, what has been shown to be a viable approach at least for biological investigations is to start with known laboratory sensors and measurement technologies and to repackage them into the smallsat platform. This same approach may also work for some physical/chemical investigations, but may not be as practical for astronomy. However, technology on all fronts continues to reduce the associated resources required to define, develop, and conduct space-based science.

*Platforms and Access to Space*

The intent of ASP science investigations is to rapidly utilize emerging technologies, such as advanced sensors, small spacecraft platforms, and next generation launch systems, to inexpensively and routinely access space in pursuit of Astrobiology research objectives. This then, provides near term focus on satellites in the Micro-satellite class and smaller, as defined by Surrey Satellite Technology, Limited[1].

- Platform Categories

The emergence of small spacecraft platforms has precipitated the expansion of satellite definitions. The generally accepted categories are shown in Table 5.0-1.

Table 5.0-1 Platform Categories

| **Classification** | **Mass (kg)** | **Cost ($M US)** |
|---|---|---|
| Large Satellite | >1000 | >140 |
| Small Satellite | 500-1000 | 50-140 |
| Mini-Satellite | 100-500 | 10-30 |

| | | |
|---|---|---|
| Micro-Satellite | 10-100 | 3-6 |
| Nano-Satellite | 1-10 | 0.3-1.5 |
| Pico-Satellite | <1 | <0.3 |

Costs indicated in Table 5.0-1 are from year 2002 estimates and do not include launch costs, and are provided for reference only. As there are already programs underway at NASA (Discovery, Explorer) that address the Mini-satellite or larger range, those platforms are not addressed in this paper except by reference. This paper will, therefore, focus on the Micro-satellite and smaller classes, with initial emphasis on low cost platforms that can be rapidly fielded (Micro, Nano, Pico-satellites). Additionally, we can further describe typical development times for Microsats as roughly between 24-36 months, and between 12-18 months for Nanosats. For the purposes of this paper, Micro-, Nano- and Pico-satellite classifications will be generically referred to as smallsats.

As of 2007, a significant number of satellites in the Micro-, Nano-, and to a lesser extent, Pico-range have been successfully demonstrated by a number of countries, space agencies, and companies. The smaller of these satellites generate interest due to their flexible nature and the associated ability to be able to respond to new scientific opportunities. Development cycles have been shown to be less than one year, with significant science return. The shortened development time also translates into reduced budgets required to field and operate this spacecraft. Additionally, short life cycles allow researchers to pose questions and answer those questions in reasonable periods of time, and then repeat the process with the next set of questions. Finally, since smallsat projects are compatible with typical educational timeframes, they provide students at many levels with unique opportunities to train in science and engineering disciplines.

However, even as technologies become smaller and require fewer resources to conduct research, smallsats are not yet substitutes for all classes of larger platforms and spacecraft. Table 5.0-2 lists some of the major benefits and limitations of small spacecraft platforms[2].

Table 5.0-2 Major Benefits and Limitations of Small Spacecraft Platforms

| **Benefits** | **Limitations** |
|---|---|
| Low cost | Limited capacity |
| Short time to scientific return | Limited control |
| Versatile | Short lifetime |
| Rapid development time | Questionable reliability |
| Revitalized scientific community | Questionable profitability |

[1] M. N. Sweeting, Surrey Space Center, University of Surrey, Guildford, Surrey GU2 7XH, UK. *Micro/Nanosatellites – The New World*, 2002.

[2]N. Bovet, J. Hair, G. Kennedy, P. Milani, M. Pavek, R. Schingler, International Space University, Strasbourg, France *The International Space University's Small Satellite Interdisciplinary Survey (ISIS), 2002*

In the current budget constrained era, the capabilities offered by smallsats are still quite attractive, given other alternatives. While it may be some time before a nanosat is capable of conducting an interplanetary mission, say to Mars, there are still many scientific investigations that can be pursued today quickly and for modest resources.

- Access to Space

Within the smallsat categories, there are three primary methods to access space. The first method is to be launched as a primary payload or satellite. The primary dictates the launch parameters, including launch location and time, and orbital insertion specifications. The launch vehicle may be modified to accommodate the satellite, and the majority, if not all of the launch services costs are borne by the payload sponsor.

The next method is to be launched as a piggyback or auxiliary launch. A piggyback spacecraft rides along usually on the launch vehicle, and is delivered to the same orbit as the primary spacecraft. Typically, piggyback spacecraft operate under their own internal resources and there is usually very little interaction, if any at all, between the primary payload and the piggyback spacecraft. The piggyback is almost always treated as a secondary spacecraft, and must not present significant risk to the primary payload's mission.

Finally, secondary spacecraft, which are co-manifested with the primary, do not drive launch parameters and may consist of piggybacks or other payloads that can benefit from the extra mass margin and resources that the primary does not require from a launch vehicle. Secondary accommodations, including deployment operations, are satisfied usually after all of the primary mission's launch objectives have been met.

Due to their small size and quick development cycles, smallsats can readily be accommodated as secondary payloads on existing launchers. This provides multiple opportunities, at fractional costs of the entire launch service package to access the space environment.

- Available Infrastructure

Similarly, ASP will take advantage of existing and planned spacecraft adapter systems in order to inexpensively access secondary launch opportunities. The first of these is the flight proven Poly-Picosat Deployer (PPOD), which has been demonstrated on university Dnepr launches and more recently on an USAF Minotaur I mission. The PPOD standard is open source and a large number of developers are familiar with the interfaces for accommodating spacecraft in these launch adapters. In the spring of 2007, NASA Kennedy Space Center (KSC) initiated a study to investigate providing multiple accommodation points for PPODs on all of the launch vehicles in the NASA livery. This could result in a minimum of two PPODs on each NASA launch, accommodating either two triple cubesat satellites or six single cubesats per launch.

Another key adapter system is the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring, which is designed to lift up to six secondary payloads on EELV. The USAF Space and Missile Center has recently issued a policy that states that the ESPA ring will be flown on all Department of Defense (DoD) missions that have adequate mass margins to accommodate secondary payloads. This means that up to six small spacecraft weighing less than 180kg each are possible on EELV missions.

Other adapters and accommodations systems will be investigated and adopted, as required. For instance, Soft-Ride systems for vibration isolation are commercially available from local vendors, and a number of multi-payload adapter systems are currently in development within NASA and the DoD. ASP will take advantage of any and all of these systems, as mission requirements dictate.

*Launch Systems*

The initial strategy of the ASP flight program will be to use existing hardware systems and platforms to take advantage of secondary launch opportunities. This will allow the various project elements to become familiar with the aspects of conducting Astrobiology research quickly, while demonstrating the value of small platforms for research. In addition to the scientific knowledge gained, technologies, experience, and processes developed using smallsats will be fed forward to larger, more ambitious investigations, as determined by Astrobiology and the Science Mission Directorate.

Figure 5.0-3 is a partial listing of missions that have excess payload capacity, which could be utilized by secondary payloads. In general, many of the launches planned will have at least modest resources for use by nano-satellites (<10 kg) or larger. Launch providers have been requested by KSC to investigate methods of accommodation for multiple nanosat PPODs or similar accommodations on all NASA launch vehicles, and there has been significant resources invested by the USAF on the EELV ESPA and other methods to make dual manifestation of payloads routine and low impact to both the launch vehicle and the primary payload.

Figure 5.0-3 Near Term Launch Opportunities for Secondary Payloads

| | 2007Q1 | 2007Q2 | 2007Q3 | 2007Q4 | 2008Q1 | 2008Q2 | 2008Q3 | 2008Q4 | 2009Q1 | 2009Q2 | 2009Q3 | 2009Q4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NASA | SpaceX Falcon 1 LEO | | Delta II Phoenix Planetary | Delta II GLAST LEO | | | SpaceX Falcon 9 TBD | Atlas V LRO Translunar | Delta IV GOES-P GEO | SpaceX Falcon 9 TBD | SpaceX Falcon 9 TBD | |
| | | Pegasus AIM LEO | | | | | Delta II NOAA-N LEO | Delta II Kepler TBD | | Delta II NPF TBD | | |
| | | Delta II Dawn Planetary | | | | | | | | Delta II WISE TBD | | |
| | | | | | | | | | | | | |
| DoD | | Minotaur 1 NFIRE LEO | Atlas V MDA TBD | Minotaur 1 TacSat-3 LEO | | | Minotaur IV TacSat-4 TBD | Atlas V GPS GEO | | Minotaur IV TBD | | Delta IV GPS GEO |
| | | Atlas V NRO TBD | SpaceX Falcon1 LEO | Delta II STSS LEO | Atlas V GPS GEO | | Delta IV GPS GEO | Atlas V GPS GEO | | Atlas V GPS GEO | | Atlas V GPS GEO |
| | | Atlas V WGS LEO | | Delta II GPS LEO | | Atlas V DMSP LEO | Atlas V SDO TBD | | | | | |
| | | Delta IV DSP-23 GEO | | Delt IV NRO TBD | | Delta II OSTM TBD | | | | | | |
| | | Atlas V NRO TBD | | | | | | | | | | |
| Commercial / International | Dnepr LEO | Delta II COSMO LEO | Atlas V ATV LEO | H2 Selene Lunar | | SpaceX Falcon 9 TBD | | | SpaceX Falcon 1 LEO | | SpaceX Falcon 1 LEO | SpaceX Falcon 1 LEO |
| | Soyuz Globalstar LEO | Dnepr Bigelow LEO | | | Atlas V ICO GEO | | | | | | | |
| | Delta II Geoeye LEO | Dnepr SAR-X LEO | | SpaceX Falcon 1 LEO | | | | | | | | |
| | Proton ANIK F3 GEO | Delta II WV-1 LEO | | | | | | | | | | |
| | | Soyuz Radarsat LEO | | | | | | | | | | |
| | | Soyuz Globalstar LEO | | | | | | | | | | |
| | | Soyuz GIOVE-B LEO | | | | | | | | | | |

Yellow = Secondary opportunities identified by launch services provider;
Blue = Potential opportunities (unproven launch vehicle); Green = Payloads already manifested;
No Color = Scheduled launches

## 6.0 Example Experiments

This section describes example experiments that could be part of an ASP flight activity. They are provided to stimulate similar scientific concepts and to test the feasibility of the associated mission designs. To address the spectrum of technologies and missions envisioned for ASP, example experiments are classified into near, medium, and long-term categories based on their technological or instrument maturity and adaptability for integration and flight, which is reflected by their Technology Readiness Levels (TRL).

Example Experiment categories, TRLs, and projected timeframe categories are listed in Table 6.0-1. High TRL instruments or systems include those that have been previously flown on other space platforms.

Table 6.0-1 Example Experiment Categories

| Category | TRL Definition | Project Life |
|---|---|---|
| Near Term, High TRL | System prototype demonstration in a space environment (TRL $\geq$ 7) | 18 months |
| Medium Term, Mid TRL | Subsystem/system model or prototype demonstration in a relevant environment [ground or space] - (TRL between 4 and 7) | 36 months |
| Long Term, Low TRL | Component and/or breadboard validation in a laboratory environment (TRL $\leq$4) | 5 years or greater |

*Near Term – High TRL / 18 Months*

- Grain Coagulation in Microgravity: A Microsat Mission for LEO

The dust chamber uses key components of proven USML flight hardware, TRL 9

The formation of terrestrial planets is believed to occur in three stages: accretion of small grains (microns to centimeters in size) into kilometer-size primitive bodies that decouple from the nebula gas; collisional growth of these primitive bodies into lunar-size embryos which dominate their formation regions, and long-term dynamical evolution, with mergers of these embryos into planets. The first stage is the least well understood. Debate rages about how well grains of these small sizes stick, as a function of their relative velocity, and whether their composition plays a role (in particular, organic material has been found to be ‘stickier’ than silicates). A small number of experiments have shown that the sticking behavior of particles in microgravity is fundamentally different from anything in our terrestrial experience, and has raised many intriguing questions about early-stage accretionary processes. These simple exploratory experiments were too limited to investigate the large range of environmental parameters and timescales needed to confidently extend the results to the solar nebula. This reference experiment will extend grain sticking studies to a more sophisticated range of environmental parameters (gas density and temperature, grain size and composition, ionization state of the ambient gas), and enable much longer-term observations and control experiments. Up to a dozen grain size/composition combinations can be treated (including organic, metal, and silicate particles alone and in mixtures), gas pressures can be varied from near-vacuum through the entire range relevant to the solar nebula, and the gas ionization state can be varied to assess the role of charge longevity. Vapor jet dispersal and gentle mechanical manipulation of cells will be used to vary the grain collisional parameters, which create surface charges. Experiments will be recorded using high-resolution video, buffered into onboard memory, and downlinked as feasible. The setup and mission duration will allow confirmation of, and iteration on, unexpected results under environmental circumstances than can be varied interactively by the team. The entire experiment is estimated to fit under the micro-sat class, operating in the LEO environment. Building on KC135 and two Shuttle missions (USML1,2) this grain coagulation study is at a high TRL, and needs only minor modifications for flight as a small satellite payload.

The Effects of Radiation on Mirror-Image Organic Compounds

The objective of this experiment is to determine if space microgravity and radiation conditions found in HEO could influence the origin of chiral selectivity now seen in all life forms on Earth (i.e., all nucleic acids use D sugars and all proteins use L amino acids). This experiment will investigate whether organic compound destruction could be a plausible causal factor in enantiomer availability. The goal is to determine if radiation from the sun and/or interstellar space destroys enantiomers at different rates, i.e., is there at least a small amount of asymmetric radiation present near Earth. The approach will be to expose 50:50 enantiomer mixtures of organic compounds to space radiation for a brief period of time. In situ analyses using polarimetric light sources and filters is highly feasible.

- Comparisons of Organics Pre & Post Exposure (COppE)

Since carbon compounds are ubiquitous, essential for life, and fragile, studies of the photo-chemistry of organic molecules are important both for understanding the survival of biomarkers on Solar System objects and to better understand the prebiotic chemistry that is key to the formation of a habitable environment. The aim of this reference experiment is to conduct an infrared spectroscopic pre- and post- analysis of organic samples (amino acids, polycyclic aromatic hydrocarbons [PAHs], polycyclic aromatic nitrogen heterocycles [PANHs]) exposed to space radiation. This experiment can be launched on a small satellite equipped with a small infrared spectrometer as well as multiple sample chambers (one for each type of compound investigated). Once in orbit, an initial spectra of each sample will be collected. Over the course of the flight infrared spectra of each sample will be collected and compared with the initial spectrum. Through the spectroscopic measurements the destruction rate of the initial compounds as well as the by-products of their destruction will be deduced. Sensors will provide exact doses and temperatures. This experiment builds off of previous exposure experiments (e.g., Biopan and CNES Perseus-Exobiologie.) and will employ small spectrometers being developed for flight by ASTID and other programs.

- Microbial Ecology in Mixed Communities

This reference experiment will examine the effect of microgravity conditions in LEO on a mixed community of two types of microorganisms. Of interest are changes in how the organisms interact, and changes in the percentage make-up of the two organisms over time. By selecting organisms that naturally fluoresce at different wavelengths, analyses can be carried out on-orbit using video microscopy. Follow-on experiments would include examining the effects of microgravity and space radiation in HEO, additional analytical techniques to monitor gene expression to answer population genetics questions, and the examination of more complex populations. Martian and Lunar gravity levels could also be examined by spinning spacecraft or using on-board centrifuges. In addition to the astrobiology implications, these questions are critical for future life support technologies that utilize microorganisms.

- ISGEN: A Small Critter-Sat Concep

The (In-Situ Genetics Experiments on Nanosatellites) ISGEN project is designing and developing miniature biological stasis, growth, and analysis systems along with the necessary life support (culturing) capabilities to study gene and protein expression in model small/micro organisms. The system is fully self-contained and autonomous, telemetering results to Earth, requiring no specimen return. The main project components are technology-demonstration subsystems including quantitative fluorescent imagers, microfluidic networks, liquid arrays for the replicate study of multiple genetic constructs, and miniature environmental control and power management systems.

Each 20 – 50 µL microwell contains a population of a model organism, with the option to include replicates and/or genetic variants in the different wells. A permeable membrane covering each well provides gas exchange, and an optical surface on the other face allows (imaging) fluorescence, luminescence, or absorbance-based assay of gene or protein expression, as well as population enumeration via counting or optical density measurement.

Details at: http://www.nasa.gov/centers/ames/research/technology-onepagers/isgen.html

- Photosynthesis is a critical process for creating the biosphere on Earth. The photosystems used to PAMSat: Photosynthesis in Orbit

Photosynthesis is a critical process for creating the biosphere on Earth. The photosystems used to capture light energy are also susceptible to damage and degradation from space radiation. Well-studied models of photosynthesis (cyanobacteria) can be flown easily, and detailed information regarding photosynthetic efficiency, degradation, or repair after deleterious space radiation exposures, under a variety of microgravity, or temperature regimes can be gathered using pulse amplitude modulated (PAM) fluorometry.  PAM fluorometery will be used to measure fundamental photosynthesis parameters in situ in cultures of cyanobacteria during exposure to microgravity and radiation conditions in LEO or HEO.  Cultures can be maintained at 20 or 25C and be kept in stasis indefinitely until desired experimental onset, to capture effects specific radiative events.

*Medium Term – Mid-TRL / 36 Months*

- Mapping the Intragalactic Distribution of the Mysterious Carbon-Rich Carrier of the Extended Red Emission

The objects which present the Extended Red Emission (ERE) also emit the infrared (IR) features attributed to free PAH molecules, indicating that the carrier is carbon-rich and somehow PAH-related. Furthermore, sensitive IR measurements have shown that PAHs are spread throughout the diffuse regions of the galaxy in what are known as IR Cirrus clouds. Because the radiation environment is reasonably well understood in these diffuse regions, these ERE maps made with the telescope proposed here will probe the connection between PAHs and the carbonaceous ERE carrier. Since these species tie up some 30% to 40% of the cosmic carbon available, this information will provide insight into the nature of a significant fraction of the organic feedstock material that ultimately becomes part of primordial, habitable planets.

The instrument consists of a small (15-20 cm diameter) telescope feeding a low-resolution visible wavelength spectrometer, all parts of which are anticipated to be available as commercial off-the shelf items. Since this is a mapping mission, the ideal orbit will be a low-earth polar orbit aligned with the day-night terminator. Pointing ability is not as important as pointing reconstruction, which can be done during the data processing stage based on the position of stars picked up during the mapping process. The spacecraft should be 3-axis stabilized with TBD pointing stability.

- IR Astrospectroscopy: Separating False from True Galactic Biomarkers

Deuterium (D) is an isotope of hydrogen (H), with double the mass. The rates of reaction of abiotic processes and biotic processes are very different for H and D because of this large mass ratio. How the H and D are distributed on prebiotic, interstellar carbonaceous species is not known, yet it is crucial in determining whether authentic extraterrestrial samples have an H/D ratio that is scientifically interesting from an astrobiological perspective. In other words, the H/D ratio can serve as an indicator of and likely a discriminator between abiotic or biotic processes, i.e. a false from true biomarker separator.

Additionally, the H/D ratio is of basic and fundamental importance to astrophysics and, as such, also to astrobiology for the following reason. Deuterium was formed in the Big Bang and its abundance provides strong constraints on both the physical conditions in the early universe and the subsequent star and planet formation history of the universe.

The instrument for this reference experiment consists of a moderate (≈50 cm diameter) passively cooled telescope feeding a 2.5-5 µm spectrometer with a resolution of ≥1500 and an InSb detector array. All of these components are currently available as nearly off-the-shelf items. Since the telescope and detectors must be cold to operate (≈45 K), the best orbit would be one that slowly drifts away from the earth. It is possible that a LEO orbit could work, but may involve the addition of a closed cycle cooler. This is a pointed mission and will require that the spacecraft point and is stable to a few arc seconds.

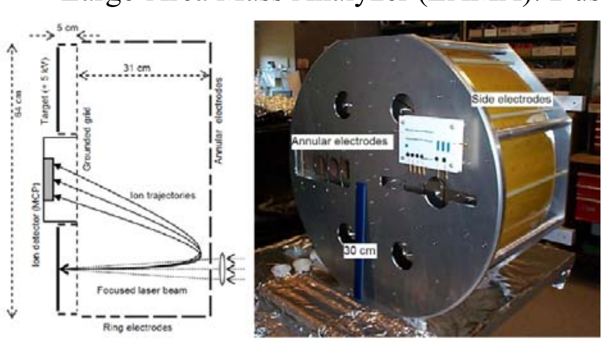
- Effect of Space Radiation on the Survival of Organic Biomolecules

Future missions to Mars and Europa include the detection and characterization of organic molecules as potential biosignatures. Some biological compounds are known to survive for billons of years on Earth and provide valuable information about early life. Little information is available to understand the potential effect of high UV and space radiation on the carbon skeletons of significant biomarker molecules. This reference experiment proposes to examine the effects of exposure to space radiation on the structure of microbial organics. Organic material has clearly reached the surface of extraterrestrial bodies through meteoritic input. The question is identification of abiotic from biotic sources. Information gathered on the effect of radiation on biomarker chemical structure is necessary to fully assess potential survival of bioorganic molecules and degradation process in order to recognize biosignatures from abiotic sources for future analysis of in situ or sample returns. The approach will be to expose both microorganisms known to contain molecules such as hopanoids, branch alkanes, isoprenoids, and purified molecules extracted from microbes to space radiation. Samples will be presented both as exposed (in transparent sample vials) and embedded in a rock matrix. The goal is to determine whether suspension in a mineral matrix is sufficient to retard potential deleterious effects. Remote analyses with development of in situ Raman analytical capabilities from HEO is targeted for this experiment.

- Meteorite Colonization Simulation

Organisms which have colonized sub-surface environments and the interior of rocks (endoliths) are likely to survive a meteorite impact, interstellar travel and planet re-entry, as suggested by panspermia theories. These organisms are therefore good candidates to test the possibility that life may have spread in our Solar System by being transported from one planet to another in meteorites. The instrument consists of a small (20-25 cm diameter) capsule hosting a natural rock of similar dimensions colonized by endolithic or sub-surface biota. All of the parts are anticipated to be available as commercial off-the shelf items. The rock will be fully exposed to interstellar conditions for a minimum period of time of 6 months. The survivability of organisms will be tested with live/dead staining and video microscopy. The ideal orbit will be a HEO or cis-lunar, since these orbits fulfill the conditions that organisms have to face in interstellar travels. The proposed mission complements previous tests such as Biopan, but are conceived in a more realistic manner, both in terms of sample size and time of exposure.

- Large-Area Mass Analyzer (LAMA): Dust Analyzer for Orbit or Lunar Surface




**Left: The schematic diagram of the prototype LAMA instrument with illustrating ion trajectories. Right: The laboratory prototype instrument. The annular electrodes are covered by an aluminum disk.**

Dust is thought to have contributed to the atmosphere, hydrosphere and carbon chemistry of the Earth. Thus, describing the composition and effects of the influx of dust is essential to understanding how planets become habitable. Dust particles, entering the Earth-Moon system can come from comets and asteroids, or even outside the Solar System. As a result dust, like photons, carry information from remote sites in space and time; this approach could be called 'Dust Astronomy.' Finally, dust is a potential hazard for humans during space exploration. The lunar surface provides an ideal platform for a large-scale Dust Observatory to investigate the interplanetary and interstellar dust environment. The dust particle enters the LAMA (Figure 1) through transparent annular disk electrodes and another (grounded) grid and impacts a solid disc target with an opening to the ion detector. The ions from the impact are accelerated away from the target and, essentially the mass of the ions is given by their flight taking into account the geometry of the instrument. The design of the LAMA was optimized for mass resolution, spatial focusing of ions with the minimum required number of biased electrodes. The LAMA can be reconfigured for the detection of negative ions simply by switching the polarity of the applied bias voltages. The LAMA has been tested in the lab using a laser to generate small puffs of plasmas from pure target materials including silver, brass, lead, and a graphite target. Engineers and students at the University of Colorado are working on a smaller version, about 40 cm diameter and < 30 cm tall, less than 15 kg total, ~ 10 W power. The technology readiness level will soon be 5 or greater as the result of this development. The University of Colorado is developing this reduced size LAMA exactly for small satellites and missions of opportunities. LAMA would also work well on the lunar surface, measuring the composition of the incoming micrometeorites.

*Long Term – Low TRL / 5 Years or Greater*

- IDP Organic Analysis

Interstellar Dust Particles (IDP) are some of the most primitive materials in our solar system. These particles also carry pristine information of the amount and diversity of organic particles in other planets of our Solar System. Although some isotopic characterization of these particles has been accomplished, little is still known about their flux into our planet and their internal composition. The capture and return of IDPs from LEO, HEO or cis-lunar transit will provide the science community an opportunity to garner information about the evolution of our solar system and about the delivery of (pre-)biotic material on Earth.

The instrument used in this experiment will mimic or be based on the same technology used in the Stardust mission. All of the parts are anticipated to be available as commercial off-the shelf items. The mission will last a total of 4 weeks. This is preferably a sample return mission, as laboratory techniques allow for more detailed and varied analysis of the samples, and technology on the ground will have much more power in terms of resolution and sensitivity. A sample return mission of captured IDPs would enable researchers the chance to run comprehensive volatile analyses using mass spectrometry, gas chromatography/mass spectrometry, chemical reaction analysis, auger electron analysis, and infrared spectroscopy. As well, the determination of the elemental composition of the grains, their internal isotopic composition of carbon, hydrogen, oxygen, and mineralogical and textural character could be accomplished. A LEO mission with sample collection at different latitudes (North-Pole, Equator, South-Pole) would provide more realistic data to estimate the total flux of IDPs. It would also enable an understanding of the influence of the geomagnetic field in the survivability of these particles upon entrance into the atmosphere.

- 'Point and Shoot' Radiation Induced Luminescence Surveyor

The objective of this reference experiment is to survey large surface areas surrounding a Micro Lunar Lander or Rover, for luminescent organic, biomarker, and mineral materials. By adding a simple a UV flash lamp onto a smallsat such as the Micro Lunar Lander, the standard cameras could take 'UV flash' photographs of the nearby surroundings during periods of darkness. Many astrobiologically important organic molecules and some minerals luminesce strongly when exposed to UV light. These photographs could then be overlaid with the photos taken when the area is sunlit. Depending on the strength of the lamp, areas of several hundred to several thousand square meters surrounding the spacecraft could be rapidly surveyed for luminescent materials in this way.

Many tons of organic rich materials fall on planetary surfaces monthly. This material is not protected from the harsh radiation environment and is perhaps badly degraded on the surface. However, degradation is much less likely slightly below the surface. The surface disturbed by the landing or positioning of the smallsat will expose this material and slight subsurface radiation induced luminescence (RIL) measurements can be made with a 'Point and Shoot RIL Surveyor' without adding extra instrumental capabilities. An inherent advantage of this approach is that large areas can be surveyed quickly. This is in sharp contrast with the more finely tuned, complex and sophisticated instruments which can sample and analyze a specific site of a few square cm. Such a rapid radiation induced luminescence survey can greatly guide site selection for those instruments that perform more in-depth analyses. More information could also be obtained by simply filtering the flash lamp. For example, flashes of light from 100 to 200 nm, 200 to 300, or 300 to 400 nm, obtained using simple filters, would induce a different spectral and time response from most materials and this, in turn, would reveal much about the bonding nature of emitting species, placing additional important constraints on the carrier. The instrument concept proposed here is well suited to NASA's Vision for Space Exploration as it represents a significant and new step towards being able to rapidly perform a zero order survey of the organic and inorganic inventory of a large area surrounding a landing site.

- Laser Induced Fluorescence Subsurface Surveyor (LIFSS)

The goal of this reference experiment is to carry out a deep subsurface survey for luminescent organic, biomarker, and mineral materials and to characterize soil type surrounding a Micro Lunar Lander or Rover. These data would then be combined to produce a three dimensional subsurface picture of the soil type and organic distribution. Combining laser-induced fluorescence with a penetrometer makes it possible to map subsurface soil type and engineering properties as well as the distribution of subsurface organic compounds. By equipping a penetrometer probe with strain gauges for the measurement of tip resistance and sleeve friction, an advancing probe provides a continuous detailed delineation of subsurface data/soils. By coupling this with laser induced fluorescent capabilities, as the probe advances, luminescent hydrocarbons are detected in real time. This fluorescent signal is collected by the probe and returned to a miniature spectrometer on board the lander/rover. This data is then combined to produce a three dimensional subsurface picture of the soil type and organic distribution. No other space-qualified instrument can provide this information. By designing the penetrometer to sample sandy, rocky, or sedementary soils (instead of hard rock) makes the design far simpler than most previously considered. This would be an ideal instrument to probe alluvial fans and sedimentary basins on other worlds, precisely the places where water seepage could promote interesting chemistry.

The LIFSS represents a new way to search for, detect, and characterize organics below planetary surfaces to depths of tens of meters below a rover or lander. Since many different classes of organic molecules show very strong fluorescence, and we know that tons of extraterrestrial material lands on planetary surfaces monthly, the LIFSS would be a unique subsurface organic tracer in precisely those regions in which interesting subsurface chemistry is likely to occur. In general it would help assess the organic inventory surrounding a landing site in an unprecedented manner.

The LIFSS instrument, as with the Laser Induced Fluorescence Telescope (LIFT) concept mentioned separately, requires laboratory scale studies to define the critical optical parameters and then size scale down. All of the laboratory scale instruments have miniature counterparts available as off-the shelf items. Some of these individual, off-the-shelf miniature components are now being space qualified for some early lunar missions. The penetrometer, its strain gauges and luminescence optics are a mature technology (see American Society for Testing and Materials method ASTM-D-3441-86), which will only need to be modified and qualified for use in space.

- Lunar Plant Growth Module

The ability to grow plants at Lunar gravity levels transfers directly to Mars plant growth for human sustainability. Investigations will sequentially address factors which could affect plant growth in the space environment: microgravity, space radiation and exposure to lunar regolith. Each factor will be assessed individually and with possible synergistic affects, using a combination of stationary or tethered rotational satellites, with appropriate controls.

## 7.0 Appendix

Table 7.0-1 Summary of Reference Experiments Mapped to Astrobiology Roadmap Objectives

| AB Roadmap Goal | Near-Term | Mid-Term | Long-Term |
|---|---|---|---|
| 1) Understand the nature and distribution of habitable environments in the Universe | Grain Coagulation in Microgravity: A Microsat Mission for LEO | | |
| 2) Explore for past or present habitable environments, prebiotic chemistry, and signs of life elsewhere in our Solar System | | | 'Point and Shoot' Radiation Induced Luminescence Surveyor |
| | | | IDP Organic Analysis |
| | | Meteorite Colonization Simulation | Laser Induced Fluorescence Subsurface Surveyor LIFSS |
| 3) Understand how life emerges from cosmic and planetary precursors | The Effects of Radiation on Mirror-image Organic Compounds | Mapping the Intra-galactic Distribution of the Mysterious carbon-rich carrier of the ERE | |
| | | IR Astrospectroscopy: Separating False from True Galactic Biomarkers | |
| | | Large-Area Mass Analyzer (LAMA): Dust Analyzer for orbit or Lunar surface | |
| 4) Understand how past life on Earth interacted with its changing planetary and Solar System environment | | | |
| 5) Understand the evolutionary mechanisms and environmental limits of life | Microbial Ecology in Mixed Communities | | |
| 6) Understand the principles that will shape the future of life, both on Earth | PAMsat: Photosynthesis on Or- | | Lunar Plant Growth Module |

| **AB Roadmap Goal** | **Near-Term** | **Mid-Term** | **Long-Term** |
|---|---|---|---|
| and beyond | bit | | |
| 7) Determine how to recognize signatures of life on other worlds and on early Earth | Comparisons of Organics Pre & Post Exposure | Effect of Space Radiation on the Survival of Organic Biomolecules | |

### 6.2 Participant Presentations and Science Opportunity Worksheets (CD-ROM)

### 6.3 Select Workshop Plenary Charts (CD ROM)

### 6.4 Workshop Agenda

Monday, June 18

| | | |
|---|---|---|
| 7:45-8:30AM | Registration / Continental Breakfast | Eagle Room |
| 8:30-8:40AM | Welcome | Michael Bicay /Pete Kulpar |
| 8:45-9:30AM | Introduction to ASP Workshop Objectives, Workshop Flow | Mark Fonda /John Rummel |
| | Overview of Astrobiology Program, Small Payloads Participants Charter and Draft White Paper | John Rummel |
| 9:35-10:15AM | Introduction to Small Satellite Platforms, Reference Missions | Bruce Yost |
| 10:15-10:30AM | Break | |
| 10:30-11:00AM | Launch Opportunities | Bruce Yost |
| 11:00-12:30N | Participant Opportunity to Present Ideas *(Opportunity for invitees to present their ideas worked on before mtg.)* | Invitees |
| 12:30-1:15PM | Catered Lunch | Eagle Room |
| 1:15-2:00PM | Technologies / Instruments / Techniques for Small Satellites | Bruce Yost/Team |

*Session #1 – Experiment Scenarios/Storyboards – Brainstorming Session*

| | | |
|---|---|---|
| 2:05-2:20PM | Charter to Session #1 | Mark Fonda |
| | *Product – Preliminary experiment scenario descriptions (storyboards). Identify science objective, instrument hardware, mission environment,* | |

| | | |
|---|---|---|
| | *anticipated readiness timeframe.* | |
| 2:25-4:00PM | Experiment Scenarios (2-4 groups) | |
| | 1. Remote Sensing / Observational | Bregman/Mattioda |
| | 2. Laboratory Experiments (2) | Santos/Bebout |
| 4:05-5:00PM | 15-Minute Report Outs | Bregman/Santos |
| 5:00-6:00PM | Reception Wine and Cheese / Poster Session | |

Tuesday, June 19

| | | |
|---|---|---|
| 7:45-8:30AM | Continental Breakfast | Eagle Room |

*Session #2 – Mapping Science Ideas to Astrobiology Goals*

| | | |
|---|---|---|
| 8:30-8:40AM | Charter to Session #2 | Mark Fonda |
| | *Product: Discussion and documentation of science experiment scenarios (objectives) mapped to Astrobiology goals; unique opportunities provided by Small Sat vs other flight and ground opportunities. Identify opportunities as near, mid, long-term for Session #3.* | |
| 8:45-11:10AM | Science Experiment Scenarios | Bregman/Mattioda /Conley/Bebout/Santos |
| | Astrobiology Goals Refinement | |
| | 1. Remote / Observational | Bregman |
| | 2. Experimental / Gas-Grain | Mattioda |
| | 3. Organics in Space | Conley |
| | 4. Biology | Bebout/Santos |
| 11:15-12:00N | 15-Minute Report Outs | Bregman/Mattioda/ Conley/ Bebout/Santos |
| 12:00-1:10PM | Catered Lunch | Eagle Room |

*Session #3 – Engineering Assessment vs Platform Opportunities*

| | | |
|---|---|---|
| 1:15-1:25PM | Charter to Session #3 | Mark Fonda |
| | *Product: White paper experiment* | |

| | | |
|---|---|---|
| | *sections updated with refined experiment scenarios. Discussion focus is for an engineering assessment of hardware readiness of ideas vs opportunities /platforms.* | |
| 1:30-4:00PM | Near, Mid, Long-Term<br>Experiment Assessments & White Paper<br>Platform Review<br><br>Same breakouts as Session #2 | Bruce Yost Team |
| 4:05-5:00PM | 15-Minute Report Outs | Bruce Yost Team |
| 5:00PM | Adjourn | |

Wendesday, June 20

| | | |
|---|---|---|
| 7:45-8:30AM | Continental Breakfast | Eagle Room |
| 8:35-10:05AM | Plenary Discussion<br><br>*Validation / Appropriateness of Small Satellites as a Platform for Astrobiology Science* | Rummel/Stabekis<br>/Fonda |
| 10:10-10:30 | Break | |
| 10:30-12:00 | Follow On Work, Next Steps<br><br>General Discussion | Rummel/Stabekis<br>/Fonda |

Adjourn

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## 6.6 Acronym List

| | |
|---|---|
| 3U, 6U | 3-Unit, 6-Unit |
| ARC | Ames Research Center |
| ASP | Astrobiology Small Payloads |
| °C | Celsius |
| CM | Centimeter |
| COTS | Commercial-off-the-Shelf |
| D | Deuterium |
| DNA | Deoxyribonucleic Acid |
| ERE | Extended Red Emission |
| H | Hydrogen |
| HEO | High Earth Orbit |
| IM | Intraterrestrial microorganisms |
| IR | Infrared |
| ISM | Interstellar Medium |
| °K | Kelvin |
| KG | Kilogram |
| L1, L2 | Lagrange Points |
| LAMA | Large Area Mass Analyzer |
| LED | Light-Emitting Diode |
| LEO | Low Earth Orbit |
| LOCAD:PTS | Lab-on-a-Chip Application Development-Portable Test System |
| MID | Midterm |
| MGM | Microbial Growth Module |
| μm | Micrometer |
| MSL | Mars Science Laboratory |
| NRA | NASA Research Announcement |
| NEOCAM | Near Earth Object Chemical Analysis Mission |
| O/OREO | Organics and/or Organisms Exposure to Orbital Stresses |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PI | Principal Investigator |
| P-POD | Poly-Picosat Orbital Deployer |
| RNAi | Ribonucleic Acid Interference |
| ROS | Reactive Oxygen Species |
| ROSES | Research Opportunities in Space and Earth Sciences |
| RT-PCR | Reverse Transcription - Polymerase Chain Reaction |
| RV | Return Vehicle |
| SLCC | Single Loop for Cell Culture |
| SMD | Science Mission Directorate |
| TBD | To be Determined |
| TRL | Technology Readiness Level |
| UV | Ultraviolet |
| W | Watt |
| WB | Witwatersrand Basin |
| XRD/XRF | X-Ray Diffraction/X-Ray Fluorescence |