MicroStrat
A Cross-Continental High Altitude Balloon Mission for Astrobiology Research

Research Associates: NASA Ames Space Life Sciences Training Program (SLSTP) 2017
PI: David J. Smith (NASA Ames Research Center)
Eclipse Ballooning Project Director: Angela Desjardins (Montana State University)
Co-Is: Parag Vaishampayan and Arman Seulemezian (Jet Propulsion Laboratory)
Co-Is: Chris Mason, Alexa McIntyre (Weill Cornell Medicine)

Photo Credit: EBARC Henry-1
Astrobiology is the study of the origin, evolution, distribution, and future of life in the universe.

https://astrobiology.nasa.gov
The stratosphere is part of a Radiation Continuum
(Ground < Near Space < Low Earth Orbit < Deep Space)

This is where balloons fly
(Near Space radiation)

This is where most NASA radiation research occurs (low Earth orbit)

This is where we want to go
(deep space radiation)

Ground radiation simulations
Using the stratosphere as a Mars analog environment
Overview of Near Space Conditions

There are two sources of cosmic rays: (1) the ever-present galactic cosmic rays (GCR), with origins outside the solar system; (2) solar energetic particles (SEP) (or solar cosmic rays).

<table>
<thead>
<tr>
<th>Location</th>
<th>UVB Total (W m⁻²) 280-315 nm</th>
<th>UVC Total (W m⁻²) 100-280 nm</th>
<th>Ionizing Radiation (mGy/d)</th>
<th>Pressure (kPa)</th>
<th>Temp (°C)</th>
<th>RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Mexico</td>
<td>10.6</td>
<td>2.60</td>
<td>0.066</td>
<td>2.84</td>
<td>-30</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>(35 km ASL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>8.38</td>
<td>3.18</td>
<td>0.200</td>
<td>0.700</td>
<td>-53</td>
<td>&lt;&lt; 1</td>
</tr>
<tr>
<td>(surface)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Values averaged from Nicholson et al. (2002), Hassler et al. (2014), Mertens et al. (2017), Khodadad et al. (2017)*

Energetic particle radiation from space continuously bombards the Earth’s atmosphere. Cosmic radiation has sufficient energy to penetrate deep within the atmosphere and adversely affect biology.
Limitation of Ground Based Facilities

● (1) Expensive to perform, (2) volume limited, and (3) unable to accurately mimic dynamic sunlight levels

● Short-lasting, small in size, and limited by acute doses of radiation; secondary scattering difficult to simulate

● The NASA Space Radiation Laboratory (NSRL) is capable of generating a range of ions from protons to uranium at relevant energies observed beyond LEO (from 50 MeV to 1000 MeV). Beam target size is limited to about 20 x 20 cm². The need to perform studies at very low dose rates to replicate the space environment is not always practical at NSRL due to access limitations and cost.
E-MIST: Recent Results

An 8-hour stratospheric flight on the NASA E-MIST balloon killed off even the hardiest microbes.

David J. Smith/NASA

UV light could easily kill microbial stowaways to Mars

By Joshua Sokol
Mar. 28, 2017, 2:15 PM

Stratosphere Conditions Inactivate Bacterial Endospores from a Mars Spacecraft Assembly Facility

Christina L. Khoddadad, Gregory M. Wong, Leandro M. James, Pritpal J. Thakrar, Michael A. Lane, John A. Catsicas, and David J. Smith

Abstract

Every spacecraft sent to Mars is allowed to land viable microbial bioburden, including hardy endospore-forming bacteria resistant to environmental extremes. Earth’s stratosphere is severely cold, dry, irradiated, and oligotrophic; it can be used as a stand-in location for predicting how stowaway microbes might respond to the martian surface. We launched E-MIST, a high-altitude NASA balloon payload on 10 October 2015 carrying known quantities of viable Bacillus pumilus SAFR-032 (4.07 × 10^7 spores per sample), a radiation-tolerant strain collected from a spacecraft assembly facility. The payload spent 8 h at ~31 km above sea level, exposing bacterial spores to the stratosphere. We found that within 120 and 240 min, spore viability was significantly reduced by 2 and 4 orders of magnitude, respectively. By 480 min, <0.001% of spores carried to the stratosphere remained viable. Our balloon flight results predict that most terrestrial bacteria would be inactivated within the first sol on Mars if contaminated spacecraft surfaces receive direct sunlight. Unfortunately, an instrument malfunction prevented the acquisition of UV light measurements during our balloon mission. To make up for the absence of radiometer data, we calculated a stratosphere UV model and conducted ground tests with a 271.1 nm UVC light source (0.5 W/m^2), observing a similarly rapid inactivation rate when using a lower number of contaminant spores (640 spores per sample). The starting concentration of spores and microconfiguration on hardware surfaces appeared to influence survivability outcomes in both experiments. With the relatively few spores that survived the stratosphere, we performed a resequencing analysis and identified three single nucleotide polymorphisms compared to unexposed controls. It is therefore plausible that bacteria enduring radiation-rich environments (e.g., Earth’s upper atmosphere, interplanetary space, or the surface of Mars) may be pushed in evolutionarily consequential directions.


http://online.liebertpub.com/doi/full/10.1089/ast.2016.1549
A New Mission of Opportunity

August 21st, 2017:
A total solar eclipse occurred across the United States from Oregon to South Carolina.

Student-built High Altitude Balloons (HABs) were launched from across the country through the Eclipse Ballooning Project run by Montana State (Eclipse.montana.edu) with the main purpose of photographing the eclipse and taking environmental measurements.

Credit: MSU Eclipse Ballooning Project / Creative Commons
MicroStrat =
10 States
34 Teams
39 Balloons
200+ Students
100,000 ft ASL
2 Primary Questions…
Question 1: During a full solar eclipse, is the stratosphere an even better Mars analog?

<table>
<thead>
<tr>
<th></th>
<th>Earth’s Middle Stratosphere (~36 km)</th>
<th>Martian Surface (by Curiosity Rover)</th>
<th>Earth’s Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pressure</strong></td>
<td>0.962 kPa</td>
<td>0.7kPa</td>
<td>101.325 kPa</td>
</tr>
<tr>
<td><strong>UVA (315-400nm)</strong></td>
<td>84.3 W m(^{-2})</td>
<td>39.0 W m(^{-2})</td>
<td>2.0 W m(^{-2})</td>
</tr>
<tr>
<td><strong>UVB (280-315nm)</strong></td>
<td>10.6 W m(^{-2})</td>
<td>8.38 W m(^{-2})</td>
<td>.007 W m(^{-2})</td>
</tr>
<tr>
<td><strong>UVC (100-280nm)</strong></td>
<td>2.6 W m(^{-2})</td>
<td>3.18 W m(^{-2})</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Ionizing Radiation</strong></td>
<td>.066 mGy/d</td>
<td>.200 mGy/d</td>
<td>.0161 mGy/d (FAA max)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>-60°C → 0°C</td>
<td>-80°C → 0°C</td>
<td>0 → 30°C</td>
</tr>
<tr>
<td><strong>Relative Humidity</strong></td>
<td>&lt;10%</td>
<td>&lt;1%</td>
<td>Variable</td>
</tr>
</tbody>
</table>
Question 2: How are microbes affected by Mars-like conditions?

Exposing Microorganisms in the Stratosphere (E-MIST) – Previously-Flown NASA Mission

- Filies hardy bacterial strains to upper atmosphere in order to measure resistance to environmental extremes.
- **Astrobiology:**
  - Defining the limits of habitability
- **Planetary Protection:**
  - Understanding the bio-burden we inadvertently carry into space

Credit: David J. Smith (NASA)
Post-flight Plan for MicroStrat

1. Effect of exposure conditions (duration, temperature, UV, altitude) on spore survival rates

2. Genomic differences pre- & post-flight
   SNPs, indels, fatal mutations

3. Epigenetic changes:
   DNA methylation: spore vs. vegetative states & effect of stratospheric conditions

4. RNA expression: spore vs. vegetative states
**What Flew?**

*Paenibacillus xerothermodurans*

- Spore Forming
- Extremely resistant to heat
- Found in the soil
- Non hazardous - BSL1 bacteria

Isolated from soil outside of spacecraft assembly clean room at Kennedy Space Center

Credit: David J. Smith & Joey Varelas (NASA)
Experimental Coupons

- 10 aliquots (20µL) of samples in sterile water. Roughly $10^7$ spores per aliquot.

- Post Flight PVA Peel

- Use liquid PVA solution to peel bacteria off coupon for subsequent analysis.

- Coupon weight: <1g
Field Kits Sent to All Participating Teams

- Sterile Petri Dish with experimental coupons
- Forceps
- Alcohol disinfecting wipes
- Nitrile gloves
- Sterile Prep Pad
- Industrial Velcro (pre-attached)
- Standard Operating Procedure (w/ pictures for simplicity)
- SDS for all materials
Risks and Challenges

- Descent can be violent, coupon could be dislodged
- Adhesive can fail at subzero temperatures
- May take multiple hours to reclaim payload
- Payloads may be unrecoverable
- Some payload data forfeited
- Contamination of samples is almost inevitable
Photos from the Field (Oregon Team)

Photo Credit: Daniela Bezdan
Photos from the Field (Oregon Team)

Photo Credit: Daniela Bezdan

OIT microstrat balloon
Photos from the Field (Oregon Team)

<table>
<thead>
<tr>
<th>IMEI</th>
<th>Time-UTC</th>
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<th>Latitude</th>
<th>Location</th>
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<td>2017-8-21</td>
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<td>2017-8-21</td>
<td>44.4647667-12</td>
<td></td>
</tr>
</tbody>
</table>

Photo Credit: Daniela Bezdan
Some Contamination Issues

● “The payload landed in a soybean field. The coupon came in direct contact with the soybeans and the soil.” – Kentucky

● “Control coupon dropped spore side down from roof of car to dusty dirt road.” – Washington

● “Since the payload landed in the alfalfa field, it made contact with the plants and soil surrounding it.” – Nebraska

● “Still looking for the payload in the pacific” – Oregon

● “The payload containing the coupon landing upside down in mud/cow feces.” – Montana
Available Metadata

- Number of Samples
- Returned Sample Metadata Intersection
- Photo_video
- Temperature
- Altitude
- Pressure
- Speed
- Ionizing_radition
- UV
- Irradience
- Humidity
- Methane
- CO2
- Turbulence
- Turbulence
- Methane
- Methane
- Humidity
- Humidity
- Irradience
- Irradience
- UV
- UV
- Ionizing_radition
- Ionizing_radition
- Speed
- Speed
- Pressure
- Pressure
- Altitude
- Altitude
- Temperature
- Temperature
- Photo_video
- Photo_video

Number of Samples: 0, 5, 10, 15
MicroStrat Timeline and Progress to Date

June 13th-24th
- Designated roles for project

July 10th-28th
- Prepare all field kits

July 14th
- Plate bacteria

July 3rd
- Adhesion stress test, feedback for experimental design

July 27th
- NASA press release!

August 1st
- All kits will be shipped, with SOP and SDS

August 22nd
- Coupons shipped to Cornell for Analysis

August 21st
- Solar Eclipse!

September +
- Analysis underway
Analysis Underway
Analysis Underway
Student Flight Opportunities on Large NASA Balloons

http://laspace.lsu.edu/hasp/

The High Altitude Student Platform (HASP) is designed to carry up to twelve student payloads to an altitude of about 36 kilometers with flight durations of 15 to 20 hours using a small volume, zero pressure balloon. It is anticipated that the payloads carried by HASP will be designed and built by students and will be used to flight-test compact satellites or prototypes and to fly other small experiments.

HASP includes a standard mechanical, power and communication interface for the student payload, based upon a flight tested design. This simplifies integration, allows the student payloads to be fully exercised, and minimizes platform development / operation costs. In addition, HASP is lightweight and has simple mission requirements, thus providing maximum flexibility in the launch schedule.
Acknowledgements

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Photo credit: Shepherd Kruse
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