SEMI-AUTONOMOUS RODENT HABITAT FOR DEEP SPACE EXPLORATION.

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NASA has flown animals to space as part of trailblazing missions and to understand the biological responses to spaceflight. Mice travelled in the Lunar Module with the Apollo 17 astronauts and now mice are frequent research subjects in LEO on the ISS. The ISS rodent missions have focused on unravelling biological mechanisms, better understanding risks to astronaut health, and testing candidate countermeasures. A critical barrier for longer-duration animal missions is the need for humans-in-the-loop to perform animal husbandry and perform routine tasks during a mission. Using autonomous or telerobotic systems to alleviate some of these tasks would enable longer-duration missions to be performed at the Deep Space Gateway.

Rodent missions performed using the Gateway as a platform could address a number of critical risks identified by the Human Research Program (HRP), as well as Space Biology Program questions identified by NRC Decadal Survey on Biological and Physical Sciences in Space, (2011). HRP risk areas of potentially greatest relevance that the Gateway rodent missions can address include those related to visual impairment (VIIP) and radiation risks to central nervous system, cardiovascular disease, as well as countermeasure testing. Space Biology focus areas addressed by the Gateway rodent missions include mechanisms and combinatorial effects of microgravity and radiation.

The objectives of the work proposed here are to 1) develop capability for semi-autonomous rodent research in cis-lunar orbit, 2) conduct key experiments for testing countermeasures against low gravity and space radiation. The hardware and operations system developed will enable experiments at least one month in duration, which potentially could be extended to one year in duration. To gain novel insights into the health risks to crew of deep space travel (i.e., exposure to space radiation), results obtained from Gateway flight rodents can be compared to ground control groups and separate groups of mice exposed to simulated Galactic Cosmic Radiation (at the NASA Space Radiation Lab). Results can then be compared to identical experiments conducted on the ISS. Together results from Gateway, ground-based, and ISS rodent experiments will provide novel insight into the effects of space radiaiton.

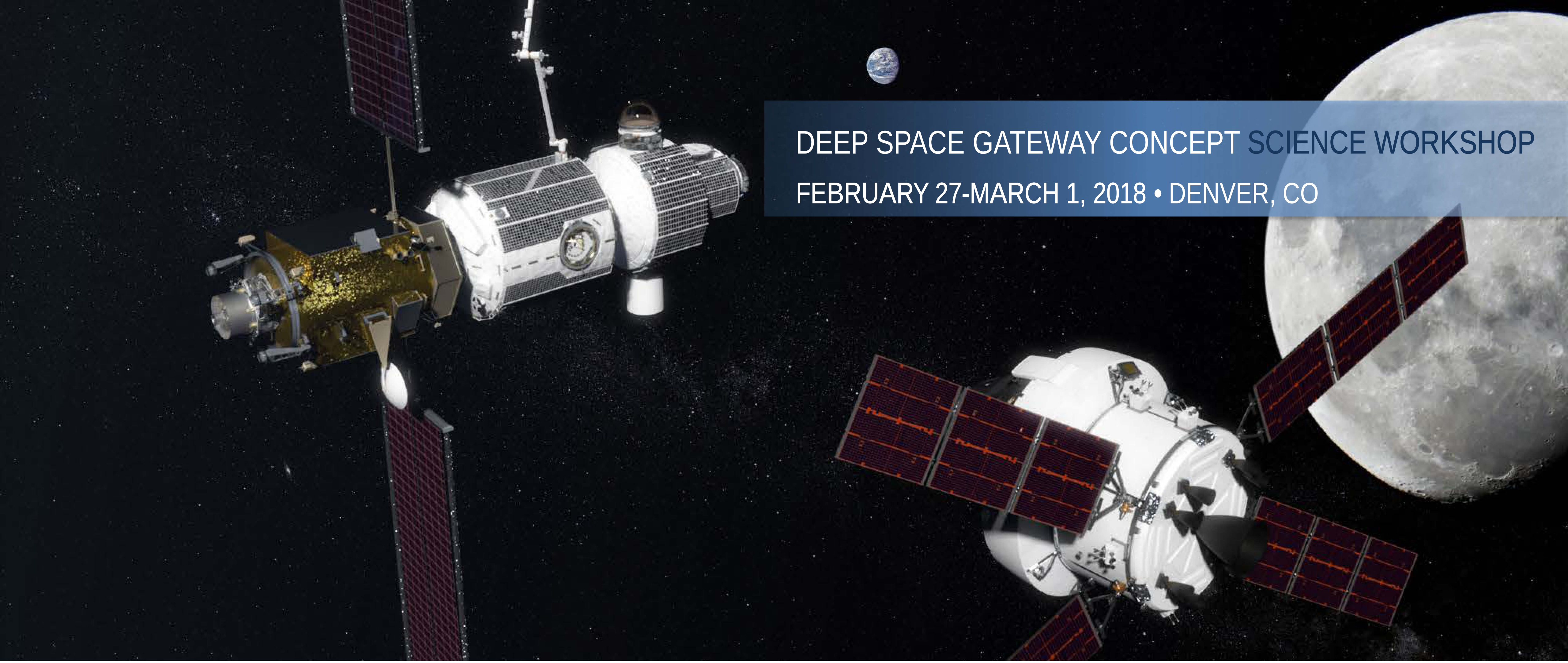
Health checks and telemetry measurements will be collected throughout the mission. Rodents are either euthanized on-board and samples stored until opportunity for return to Earth, or animals are returned live to Earth on return vehicle for later analysis. Samples collected on orbit can be further processed on the Gateway using WetLab-style instruments for molecular biology.

Areas ripe for autonomous, telerobotic, or telemetric monitoring and operations include: monitoring animal health, food delivery, and sample processing. We propose a system be developed to achieve these tasks.

In conclusion, more autonomous rodent research systems will facilitate longer duration experiments to be conducted farther from Earth. The capacity for animal experimentation for biological research, in particular, to determine the effects of space radiation exposure at the Deep Space Gateway, has the potential to complement and enable human exploration of space.

Required Resources: (1 EXPRESS Rack Locker; a second unit could be added to improve sample size.)

- Max. # of mice: ~20 mice (1 locker).
- Mass ~ 60 lbs / 23 kg (with locker)
- Power ~ 75 W
- Volume ~ 8 in. x 19 in. x 21 in.
  (20 cm x 49 cm x 54 cm)
- Temperature Control: 21-30 °C
- CO_2 control: 0.2 in Hg / 5.32 mm Hg (0.7% at 1atm) or lower.
- Oxygen: average 19.5 - 21% (assuming ambient pressure 760 Torr). Oxygen must be greater than 16%.
- Humidity: 30-70%
- Videocamera and Telemetry capacity: TBD
- Other resource needs:
  - Hardware designed to minimize excess noise and vibration and to provide life support conditions equivalent to those provided for astronauts (oxygen, low CO_2).
  - Air flow requirement.
  - Radiation dosimetry.
  - Auxiliary Wetlab-like sample processing capability.



Semi-autonomous Rodent Habitat For Deep Space Exploration

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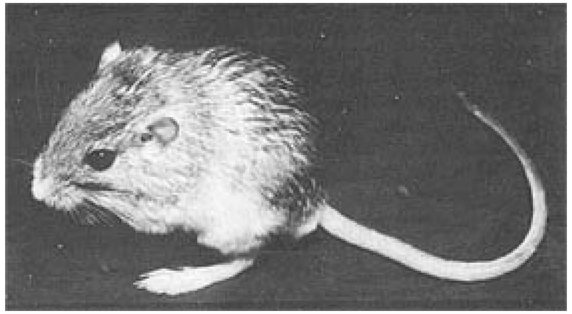
RODENT HAB: Motivation



RODENT HAB: Instrument Function Statement and Gateway Usage

STATEMENT	INSTRUMENT/CONCEPT DETAILS
FUNCTION STATEMENT	The objectives of the work proposed here are to 1) develop capability for semi-autonomous rodent research in cis-lunar orbit, 2) conduct key experiments for testing countermeasures against low gravity and space radiation. The hardware and operations system developed will enable rodent experiments at least one month in duration, which potentially could be extended to one year in duration. To gain novel insights into the health risks to crew of deep space travel, results obtained from Gateway flight rodents can be compared to concurrent ISS experiments AND ground control groups and separate groups of mice exposed to simulated Galactic Cosmic Radiation (at the NASA Space Radiation Lab).
WHY IS THE GATEWAY THE OPTIMAL FACILITY FOR THIS INSTRUMENT/RESEARCH?	More autonomous rodent research systems will facilitate **longer duration experiments** to be conducted farther from Earth. The capacity for animal experimentation for biological research, in particular, to determine the effects of **space radiation exposure** at the Deep Space Gateway, has the potential to **complement and enable** human exploration of space.

RODENT HAB: Mission Designs

Mission Durations (concurrent with ISS to identify unique effects ionizing radiation outside LEO)

I. **Single Hab**
   a. 30 day (verification mission with previous ISS missions)
   b. 90 day
II. **Staggered Habs to extend mission (180-365 days)**

Science Requirements

I. ~20 mice per hab
II. Modular housing at ~ 5/cage to mitigate risk of losing entire cohort
   a. Easy transfer to new habs for extended missions
III. Hydrophobic surfaces to repel waste
IV. Unidirectional and low airflow for ease of waste collection

RODENT HAB: Mission Designs

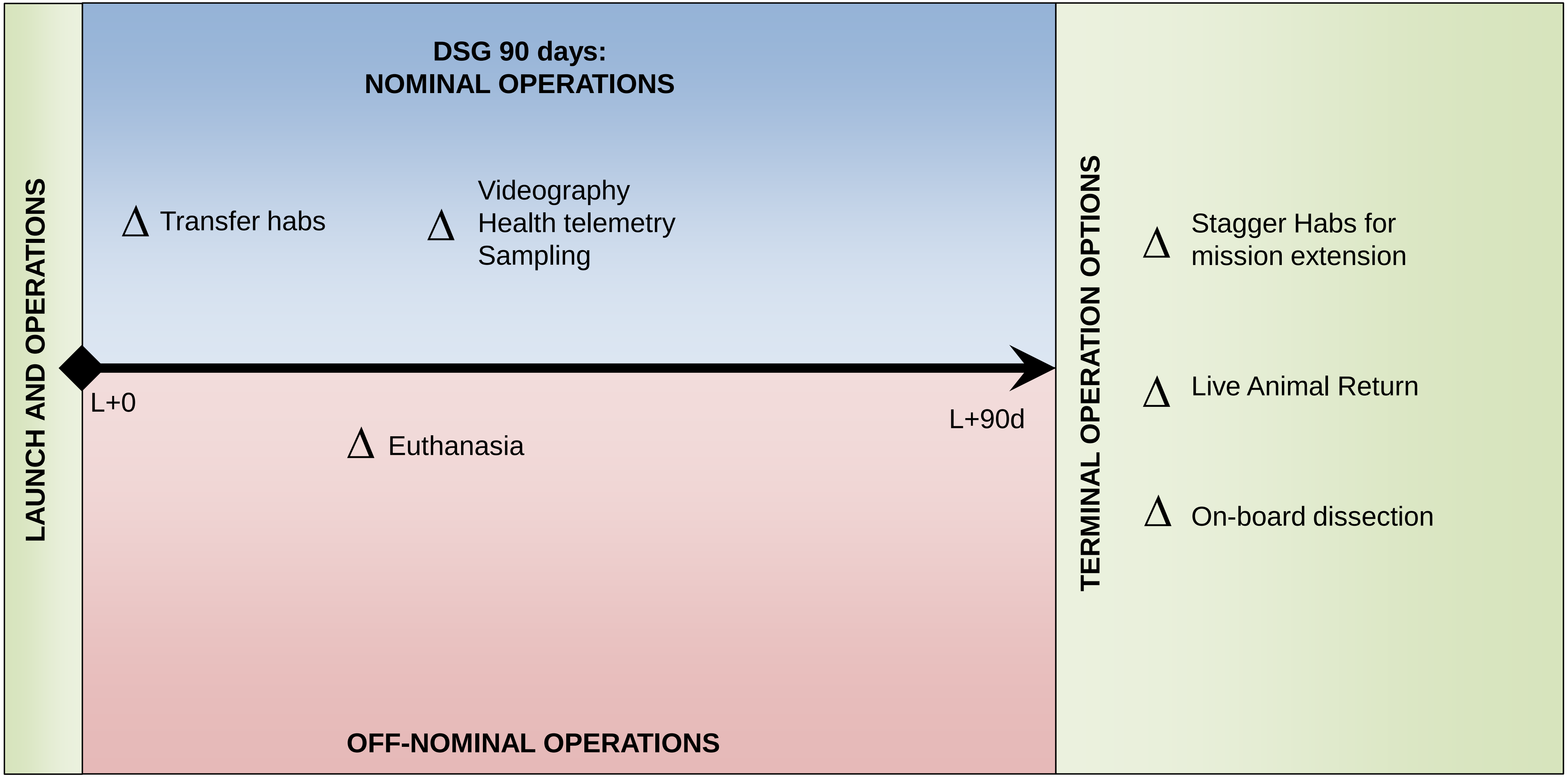
Levels of Automation

I. **Crew involvement in most major aspects**
   I. Videography and health telemetry assessed by ground team

II. **Semi-automated**
   a. Feeding
   b. Off-nominal euthanasia and preservation

III. **Fully-automated**
   a. Live Animal Return
   b. Tele-robotic dissection and sample processing

RODENT HAB: Chronology of Operations



Δ denotes astronaut operation

RODENT HAB: Basic Instrument Parameters

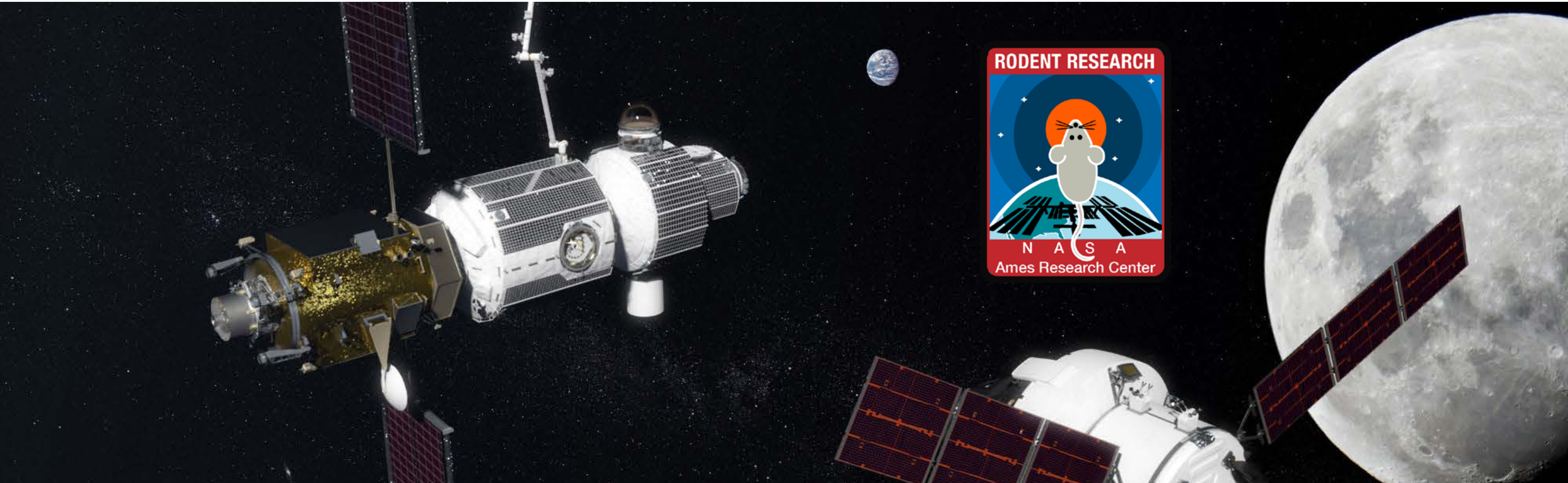
PARAMETER	INSTRUMENT ESTIMATE & ANY COMMENTS
MASS (KG)	~ 25 kg (with locker)
VOLUME (M)	~ 0.20 m x 0.50 m x 0.55 m
POWER (W)	~ 75 W
THERMAL REQUIREMENTS	21 – 30 °C (Inside Hab)
DAILY DATA VOLUME	15 Mb/day telemetry; Video adds an additional 2.7 Gb/hr (with 1 hr minimum per day)
CURRENT TRL	6
WAG COST & BASIS	~$5M (rodent habitat on ISS)
DURATION OF EXPERIMENT	30 days – 1 year
OTHER PARAMETERS	Assumes 1 EXPRESS Rack locker with ~20 mice; can be scaled up to multiple lockers.

RODENT HAB: Instrument Gateway Usage

USAGE	INSTRUMENT REQUIREMENTS & COMMENTS
ORBIT CONSIDERATIONS	N/A
FIELD OF VIEW REQUIREMENTS	N/A
REQUIRES USE OF AIRLOCK	N/A
CREW INTERACTION REQUIRED?	Yes
WILL ASTRONAUT PRESENCE BE DISRUPTIVE?	No
DOES THE INSTRUMENT PRESENT A RISK TO THE CREW	No
OTHER CONSUMABLES REQUIRED	Yes
SPECIAL SAMPLE HANDLING REQUIREMENTS	Yes
NEED FOR TELEROBOTICS?	Possibly
OTHER REQUIREMNTS OF THE GATEWAY?	

RODENT HAB: References and Status of Work in this Field

- **Animal Enclosure Module and ISS Rodent Habitat: 27 successful missions on shuttle and *** on ISS. Numerous (***100s) publications**
- **Childress, et al, 2018, *Life Sciences in Space Research*, DOI: 10.1016/j.lssr.2017.11.002**
- **Moyer, et al, 2016, *npj Microgravity*, https://www.nature.com/articles/npjmgrav20162**
- **Choi, et al, 2016, *PLoS One*, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0167391**



RODENT HAB: Backup/Additional Information