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PURDUE UNIVERSITY

UCONN UNIVERSITY OF CONNECTICUT

HARVARD UNIVERSITY

UTSA The University of Texas at San Antonio

NASA

Funded by the National Aeronautics and Space Administration under award number 80NSSC19K1076.

The RETH *institute*

Professor Shirley Dyke

LSIC Meeting September 2020

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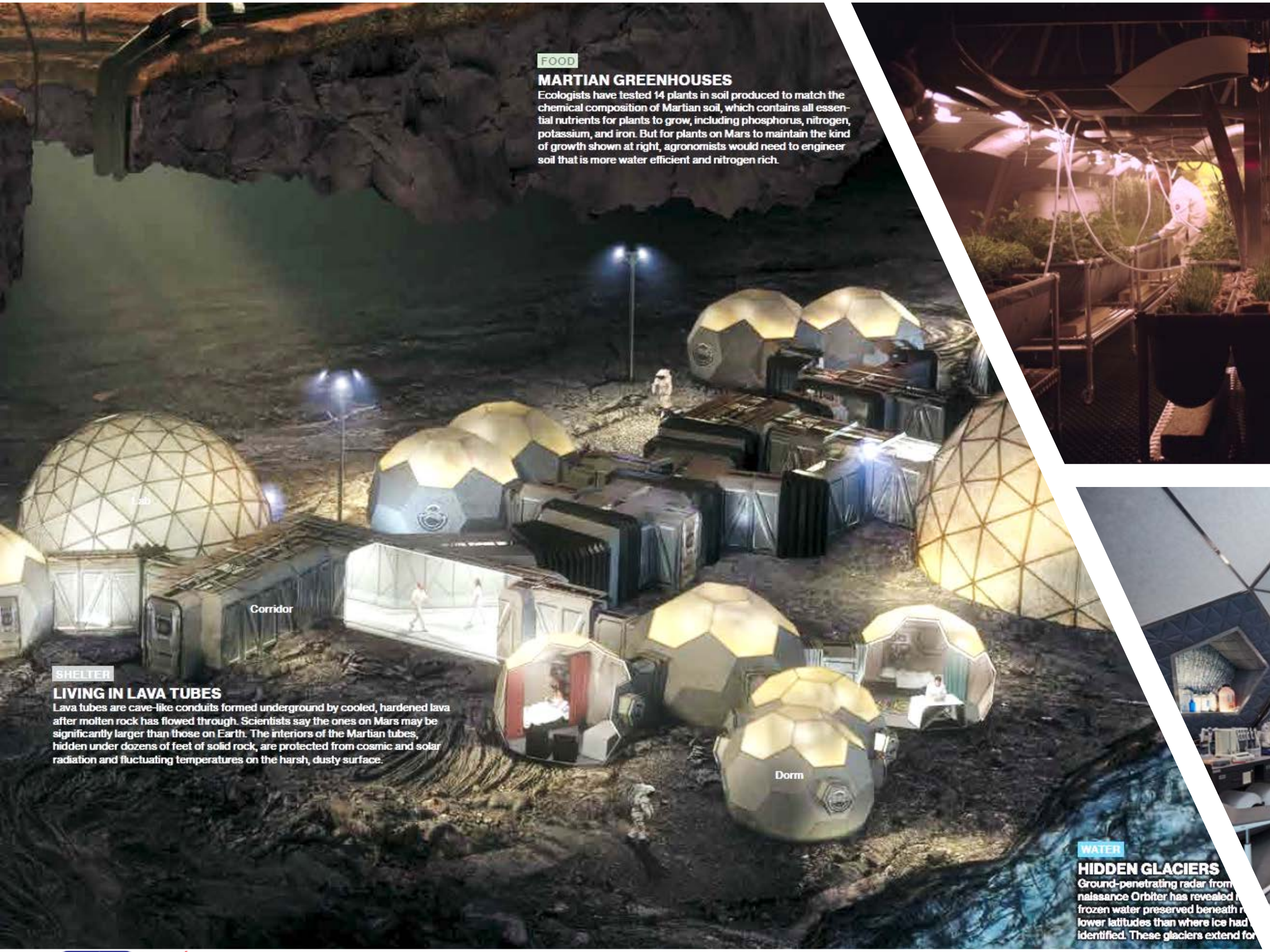
Where will we live?

Credit: National Geographic



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How we design on Earth

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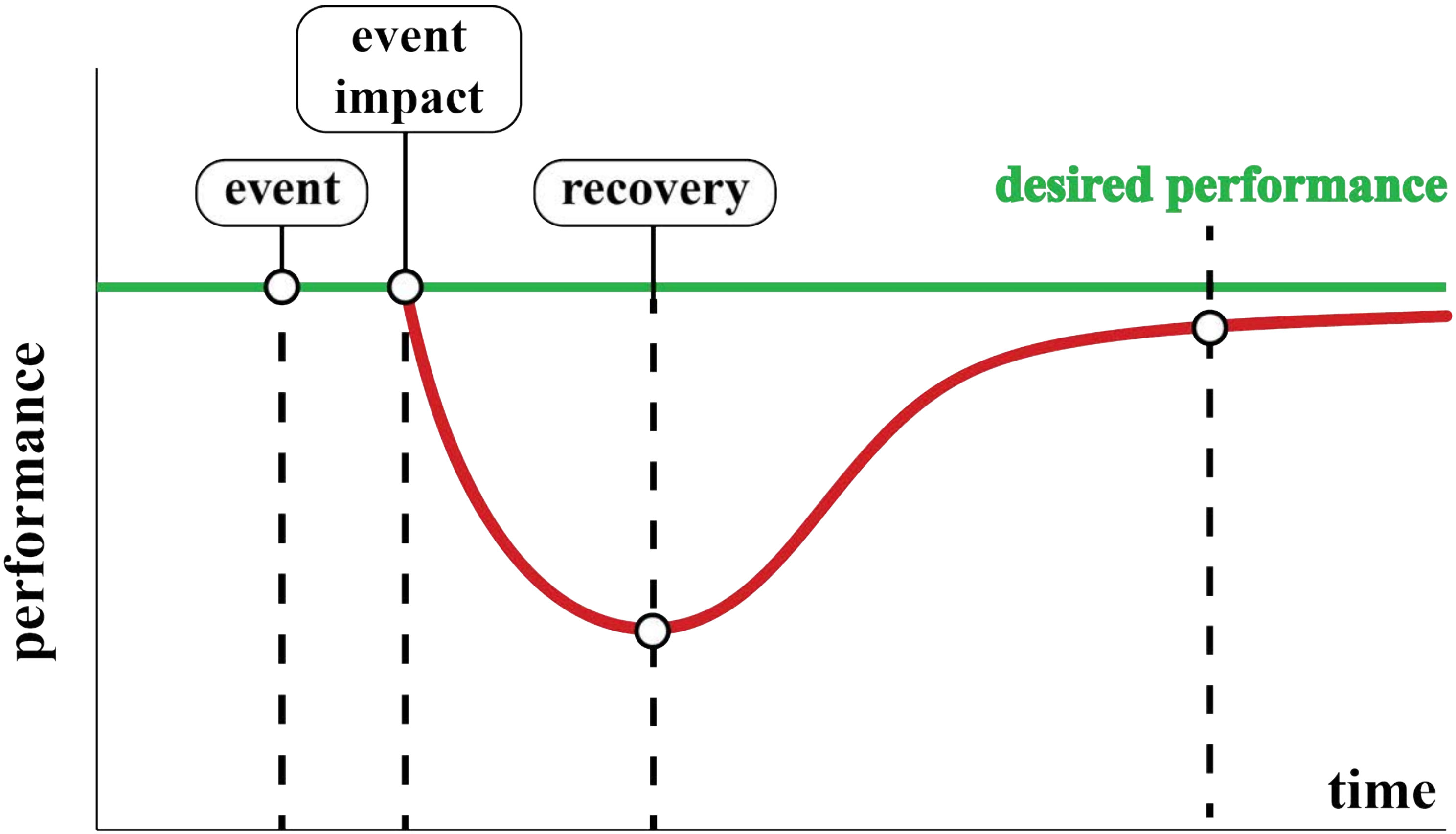
Then Katrina…. systems approach

Resilient Design



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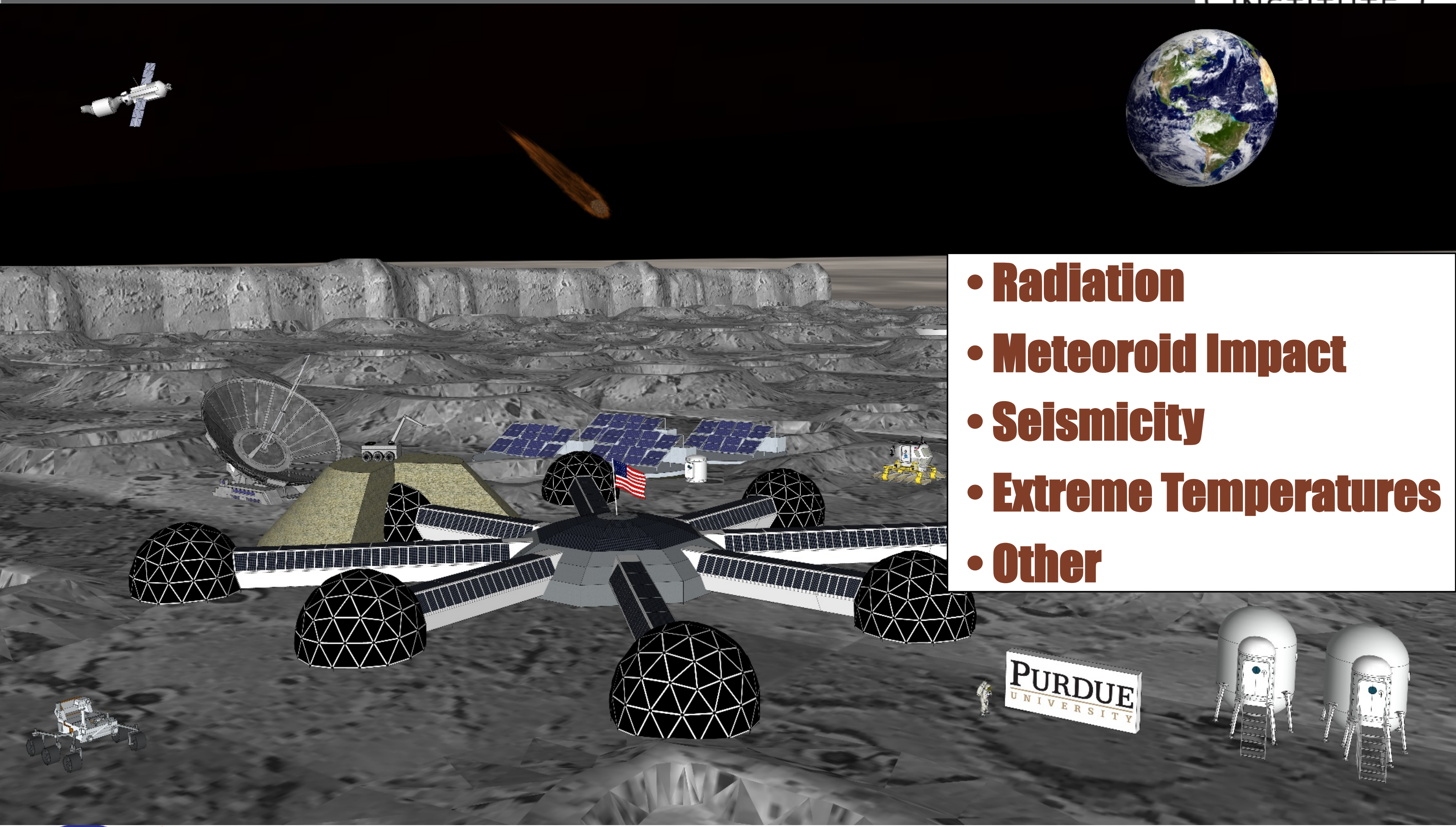
If humans are to live and work out there, they must be prepared to deal with an array of hazards



- Radiation
- Meteoroid Impact
- Seismicity
- Extreme Temperatures
- Other

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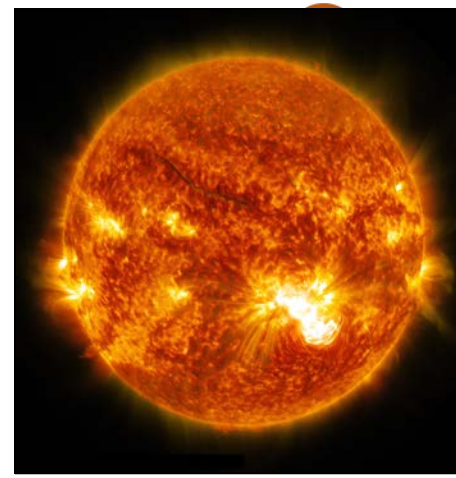
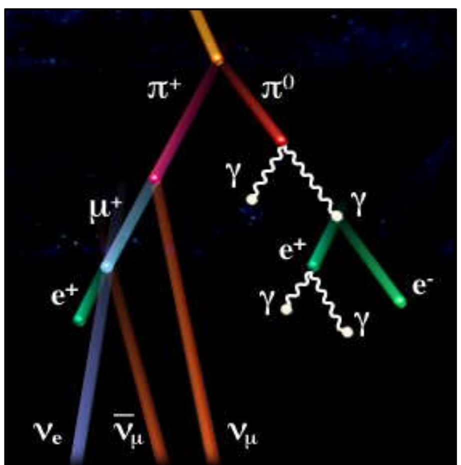
Radiation (several types)

Galactic Cosmic Rays (GCR)

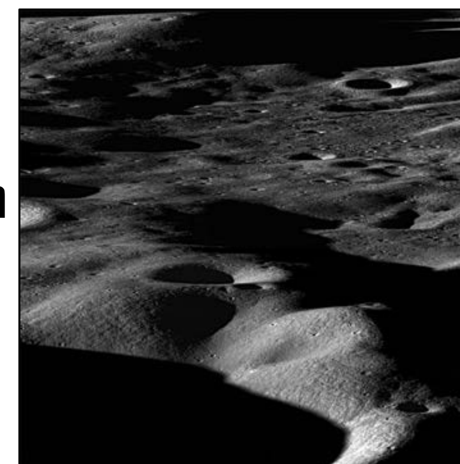
Solar Particle Events (SPE)





Secondary Particles

Lunar Regolith (Soil)



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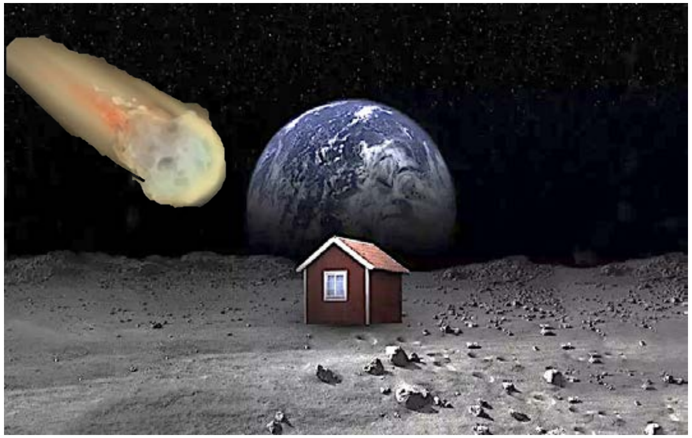
Meteoroid Impact

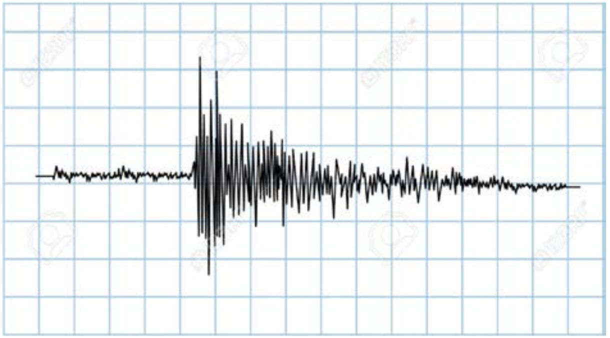
Primary impact:



Direct damage

Secondary impact:

Ejected particles



Seismic activity

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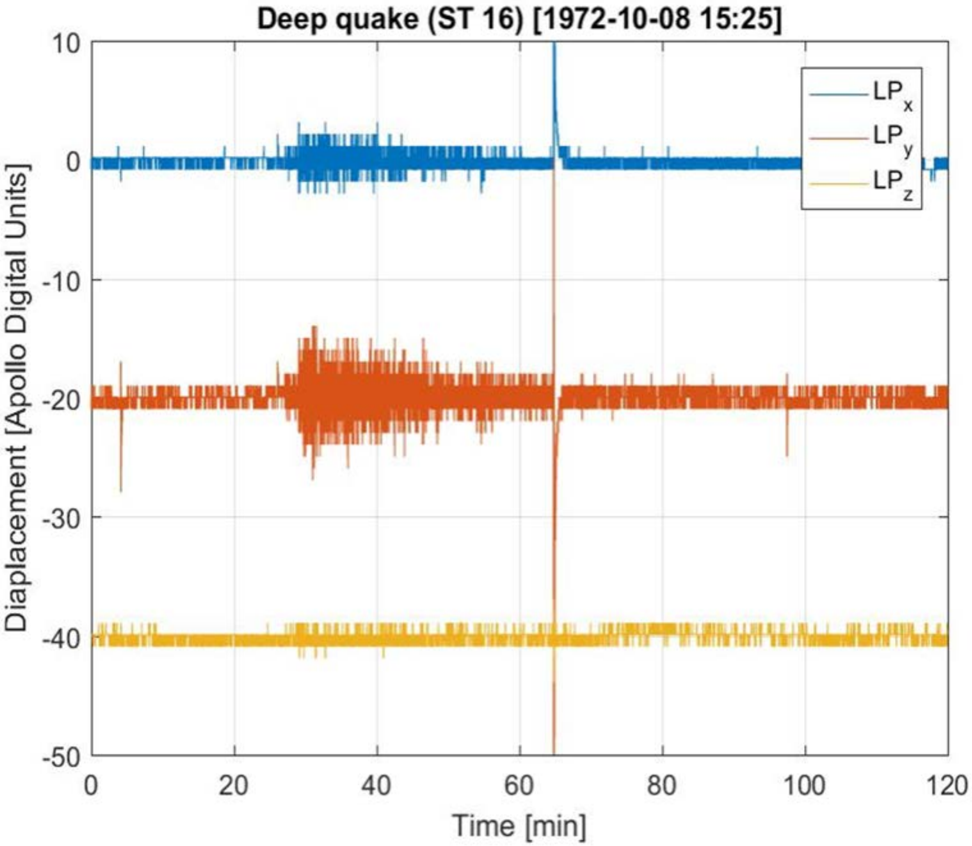
Moonquakes / Marsquakes

Deep moonquakes:

- **At depths of 700 - 1000 km.**
- **Frequent events, but low energy**
- **Most less than magnitude 2**
- **Terrestrial tidal forces influence the occurrence and periodicity of deep events.**
- **7000 events identified!!!**



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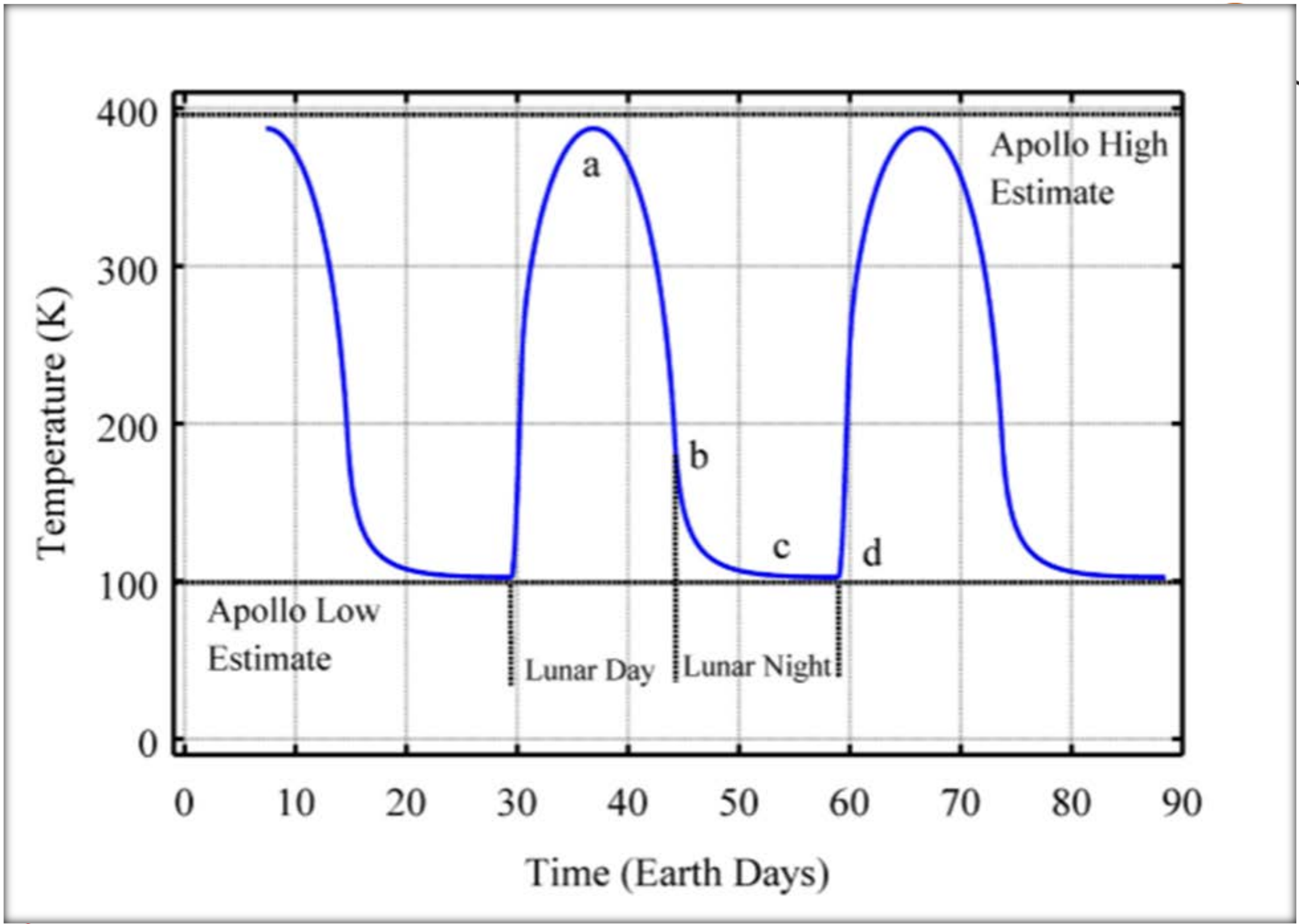
Extreme Temperatures



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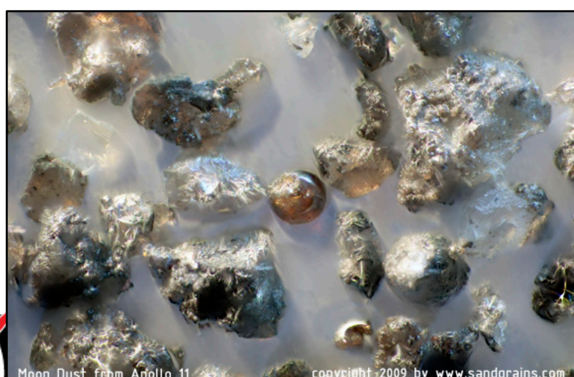
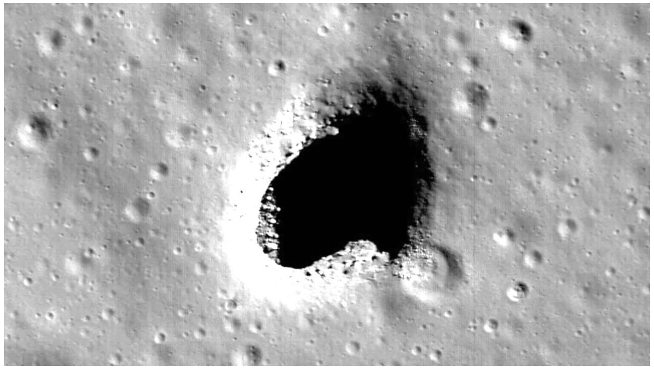
Lunar Dust gets into everything

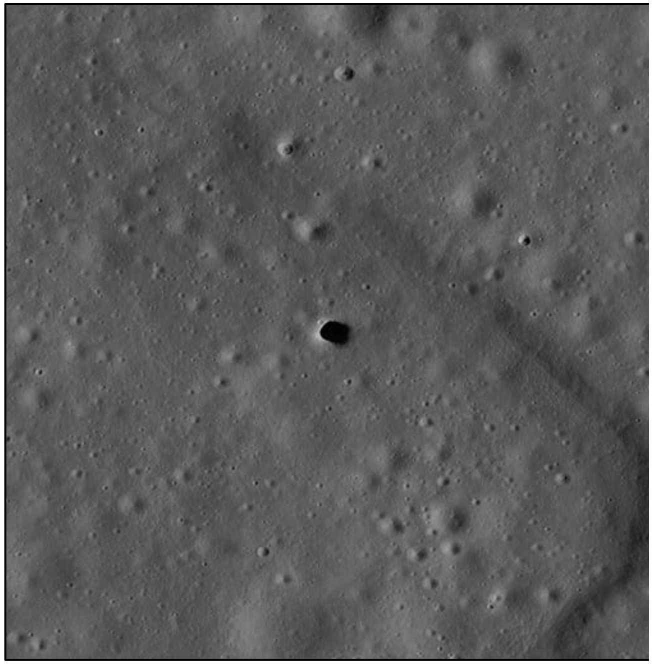


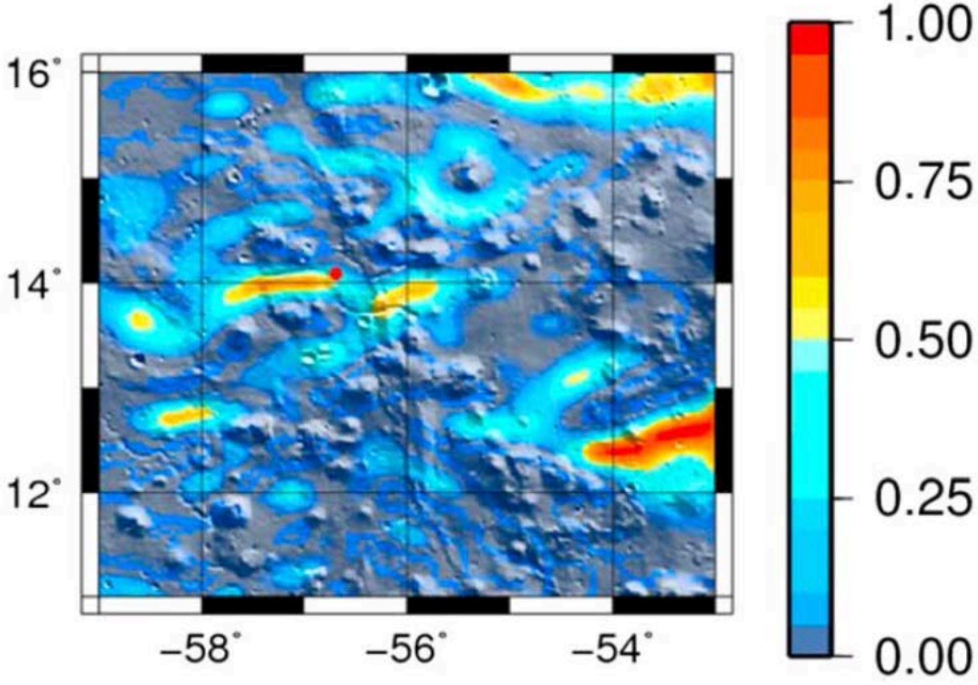
Large Lava Tubes on the Moon



GRAIL Players from AAE and EAPS:

Rohan Sood, Loic Chappaz, Jay Melosh, Kathleen Howell, David Blair, Colleen Milbury





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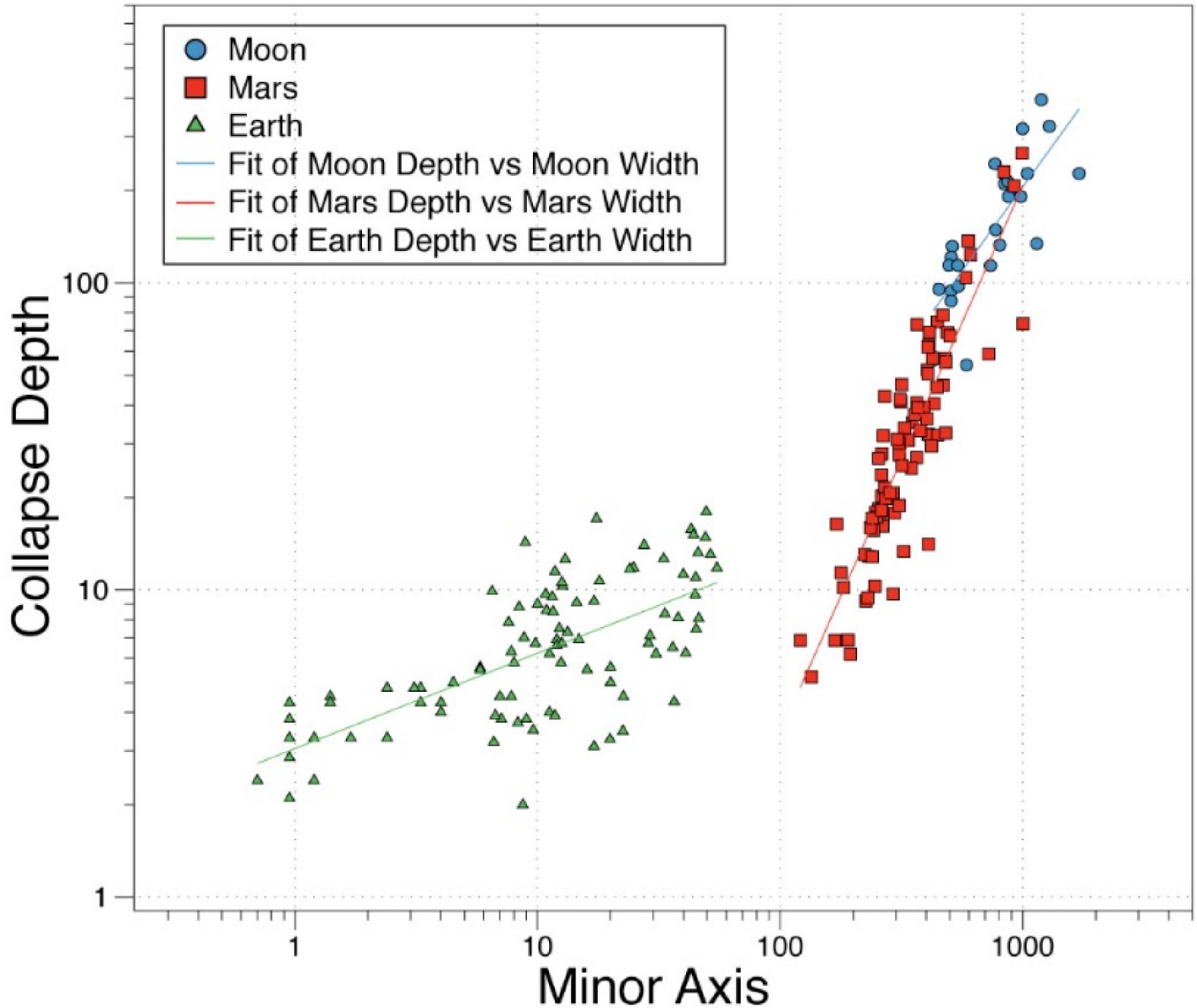
Moon, Mars, Earth Lava Tubes

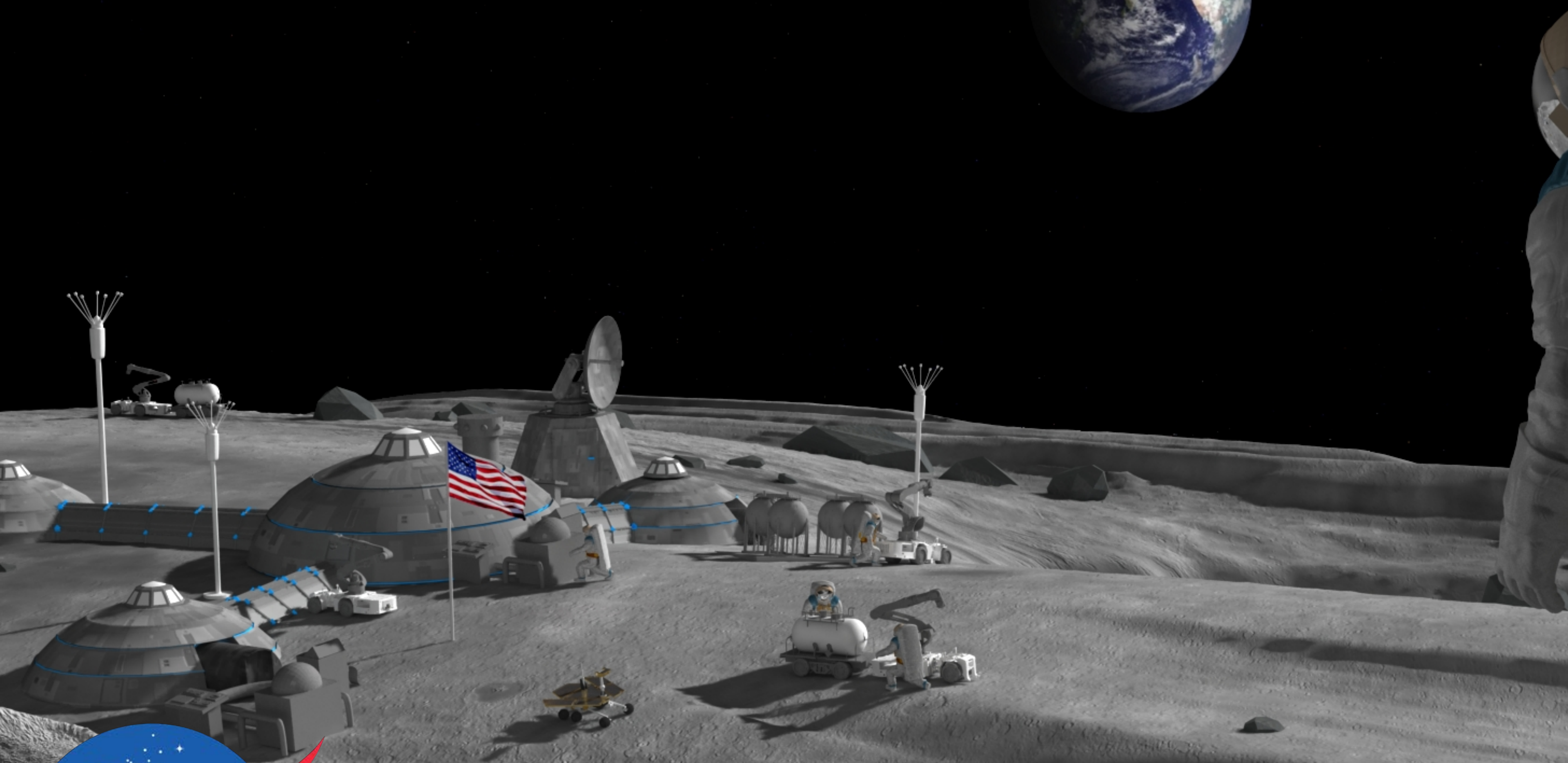


Sauro et al. (2018)

International Workshop, Oct 2018

https://www.purdue.edu/reth/

Vision: Enable the design and realization of smart and resilient space habitats.



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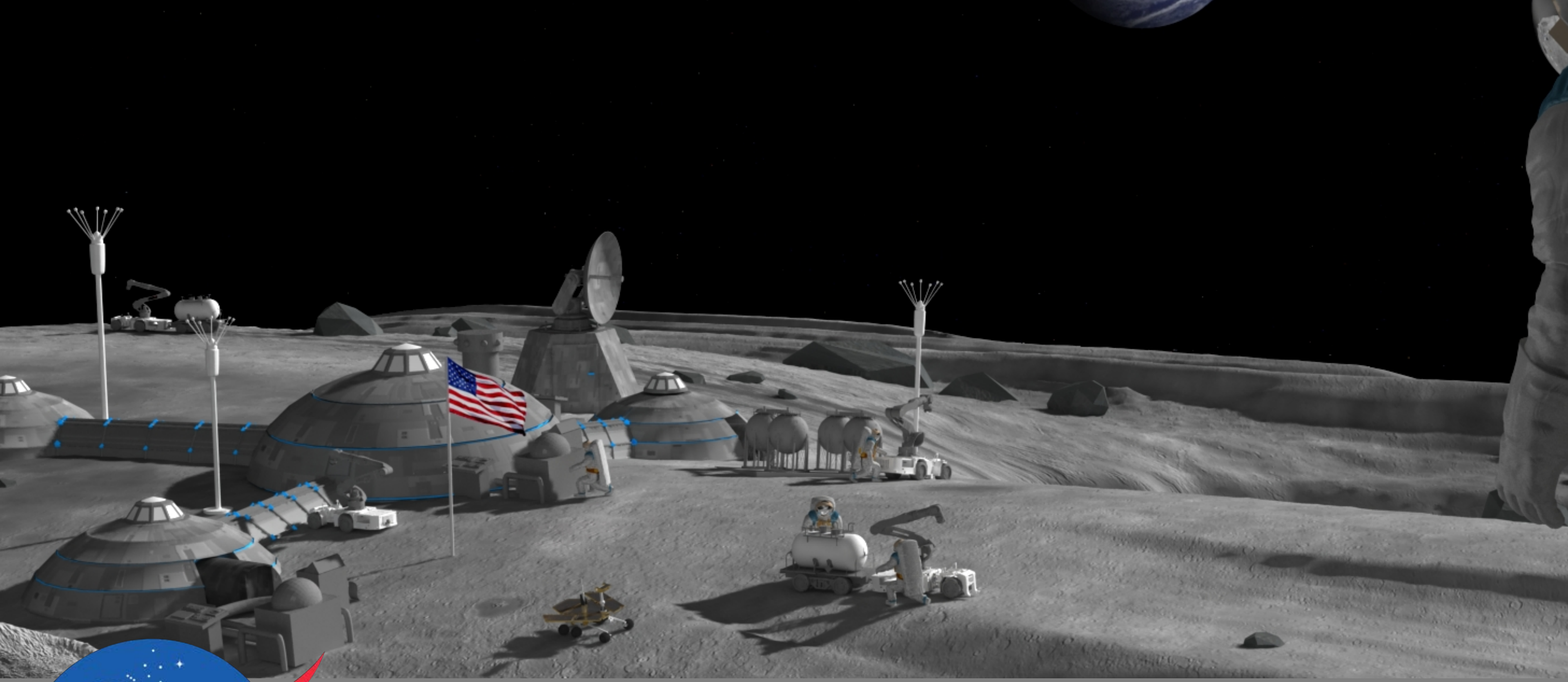
This material is based upon work supported by NASA under grant or cooperative agreement award number 80NSSC19K1076.

Mission*: To propel space exploration forward by developing new knowledge, technologies and techniques and collaborating with other NASA centers and industry to establish the knowhow to create smart and resilient extraterrestrial habitats.*



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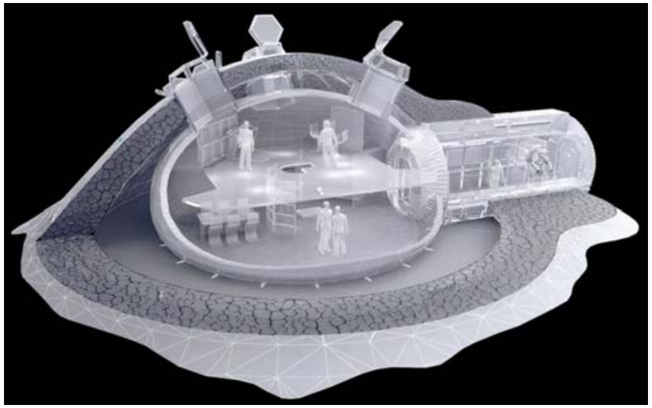
Resilience is not robustness, reliability or redundancy …

- Risk analysis, risk management and health management are widely used to support system performance and reliability

- Existing approaches are driven by avoiding or minimizing the occurrence of known/anticipated faults.

- For long term space habitat system this is inadequate:
    - high reliability is inefficient and costly
    - disruptions are inevitable, yet difficult to predict
    - humans will not always be present



European Space Agency

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Objectives

***Resilience**: The ability to adapt, absorb and rapidly recover from expected and unexpected disruptions without fundamental changes in function or sacrifices in safety*

- Establish a *comprehensive systems resilience framework* to support design, operation, and management of efficient and effective long-term deep space habitats
- Develop ***SmartHabs*** that *autonomously sense, anticipate, respond to*, and *learn from* disruptions
- Develop *decision-making techniques* for complex interconnected, interdependent habitat systems

- *Educate* the next generation of engineers and scientists

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Leadership Team

Shirley Dyke

Karen Marais

Ramesh Malla

Dan Zehner

Justin Werfel

Ilias Bilionis

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Modular Coupled Virtual Testbed

- A **simulation environment** to enable our team to carry out a wide array of quantitative research related to the resilience and autonomous operation of extraterrestrial habitats
- Main capabilities include:
  - Damageable/repairable subsystem models
  - ECLSS: temperature/pressure control
  - Robotic agents
  - Health management (includes: fault detection)
  - Crewed / Dormant configurations
  - Systematic approach to capture interactions

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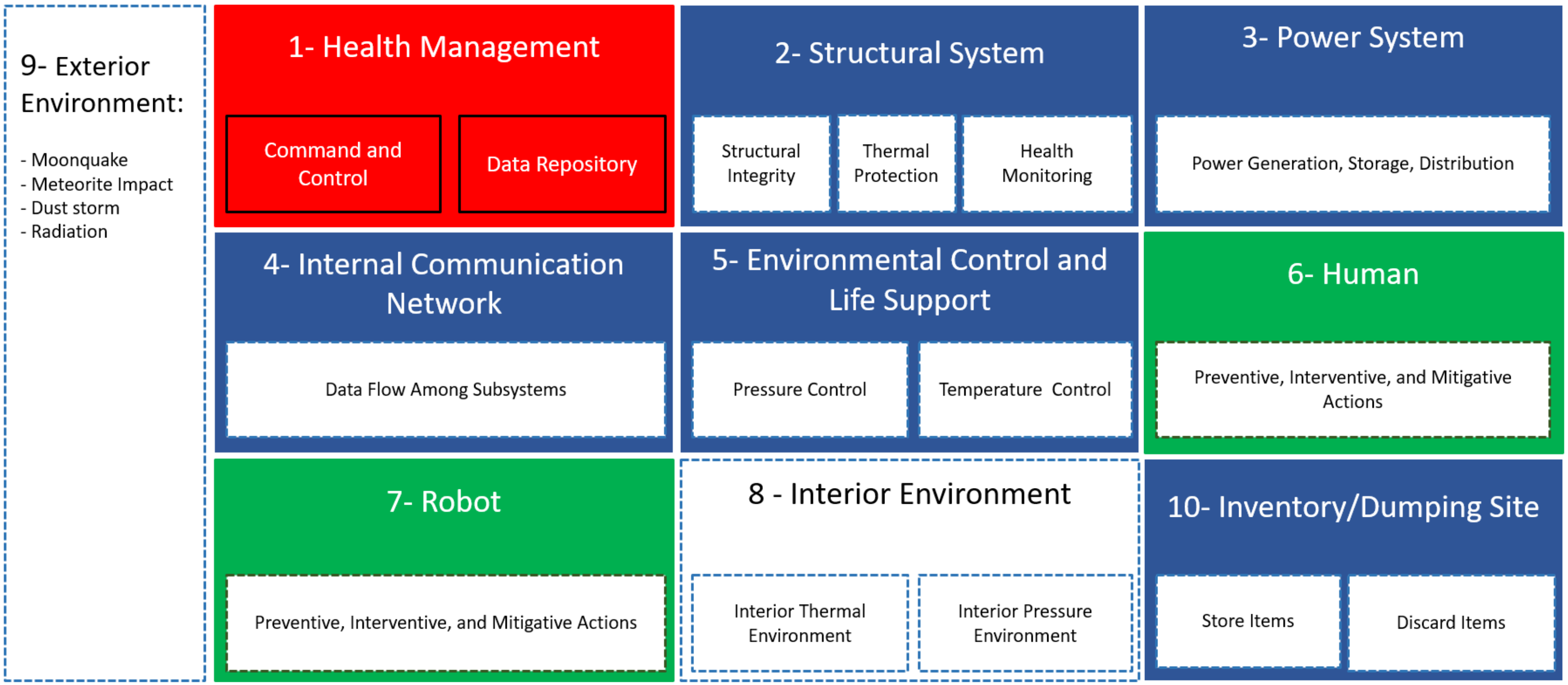
Modular Coupled Virtual Testbed



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Resilient-oriented Design

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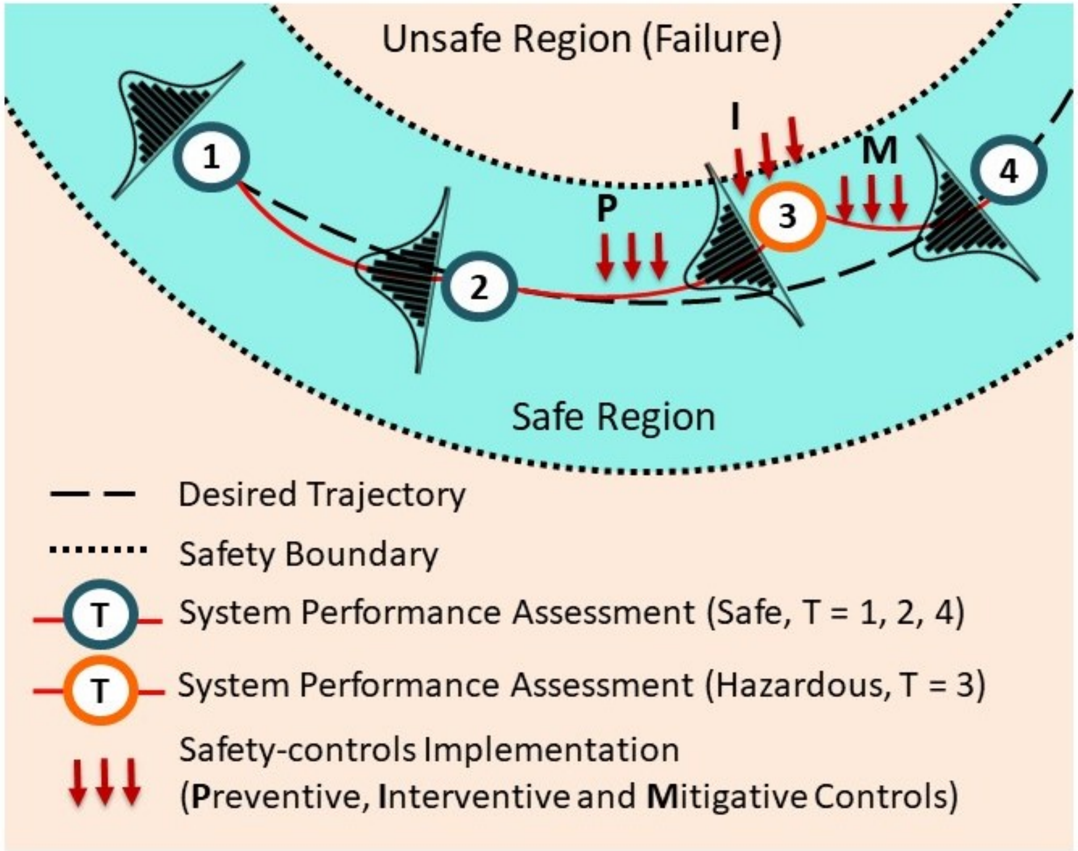
1
State estimation, assessment of performance or function. Within boundary.
2

Safety-controls act (passive)

3
State estimation, identification of undesirable trajectory. Action must be taken. *Decision* made.

Safety-controls act (adaptive)

4
State estimation, assessment of performance or function. Within boundary.



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Generate New Knowledge

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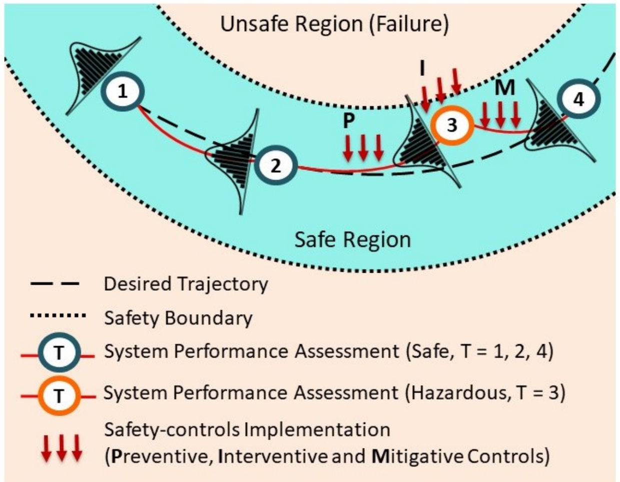
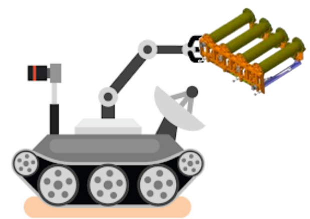
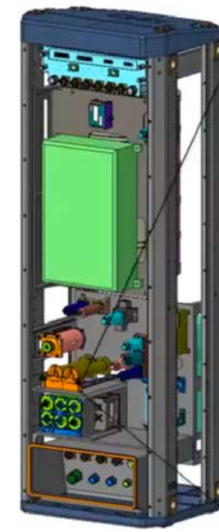
Control-theoretic Resilience

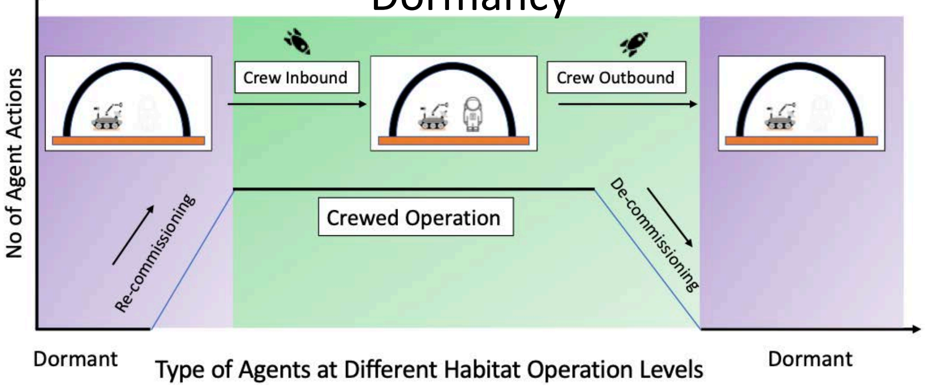


Design for Robotic Operations

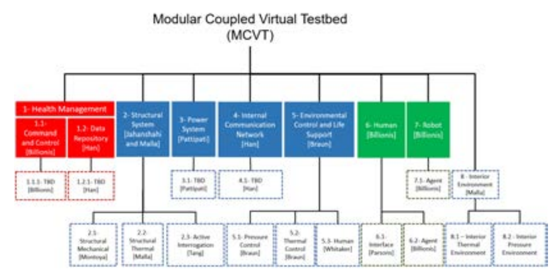




Dormancy



Complex Systems



Modular Coupled Virtual Testbed

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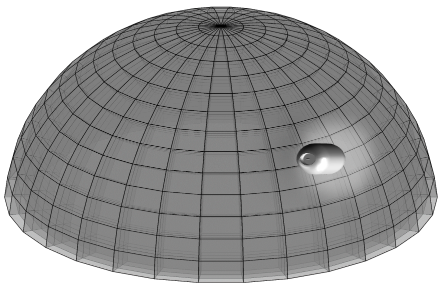
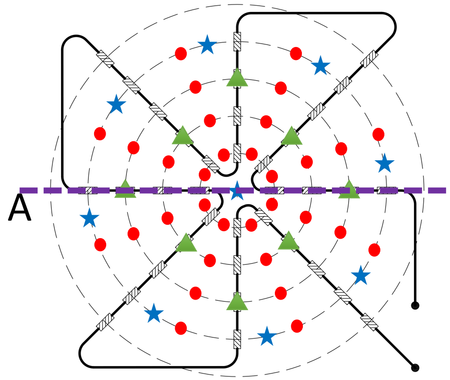
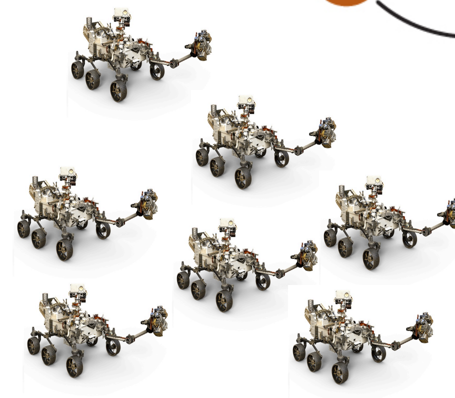
New Technologies and Techniques

Fault Detection

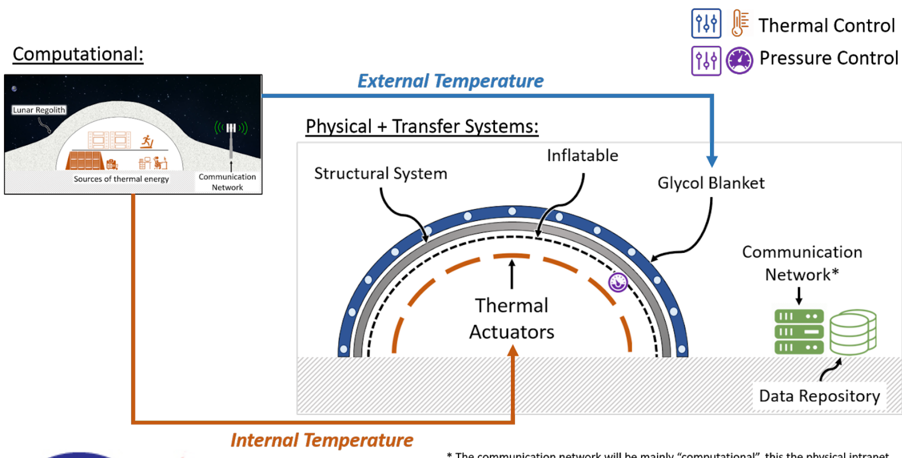




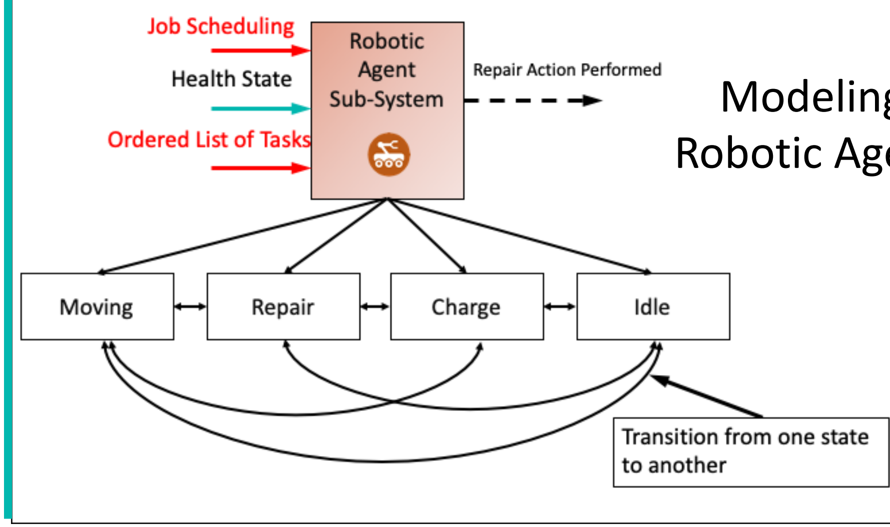
Perception, Navigation, Manipulation



Cyber-physical Testing



Modeling of Robotic Agents



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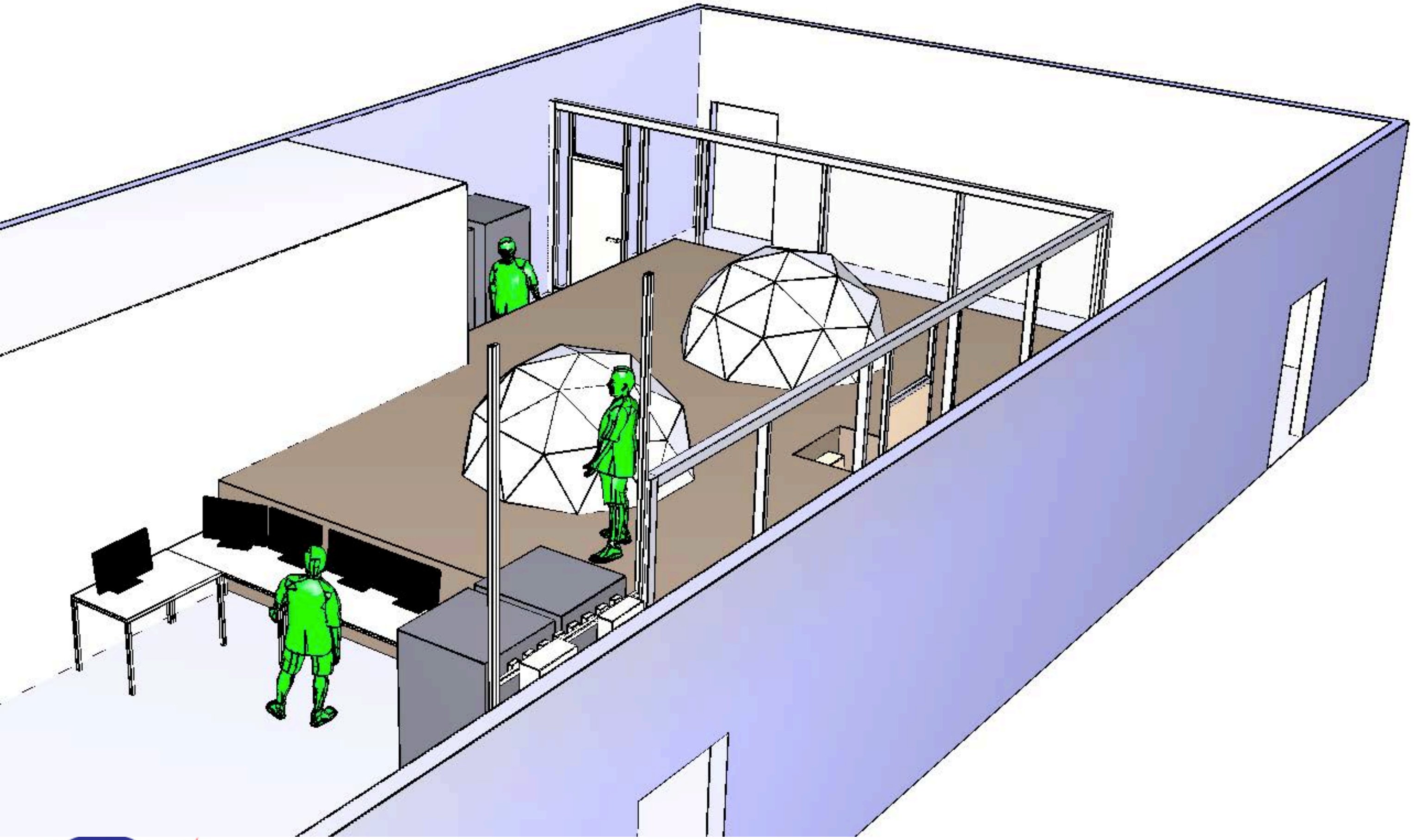
Cyber-physical Testbed

- We can emulate various conditions, operating modes, and configurations
- We can examine resilience under various faults, deterioration, etc.



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