



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



# **The RETH *institute***

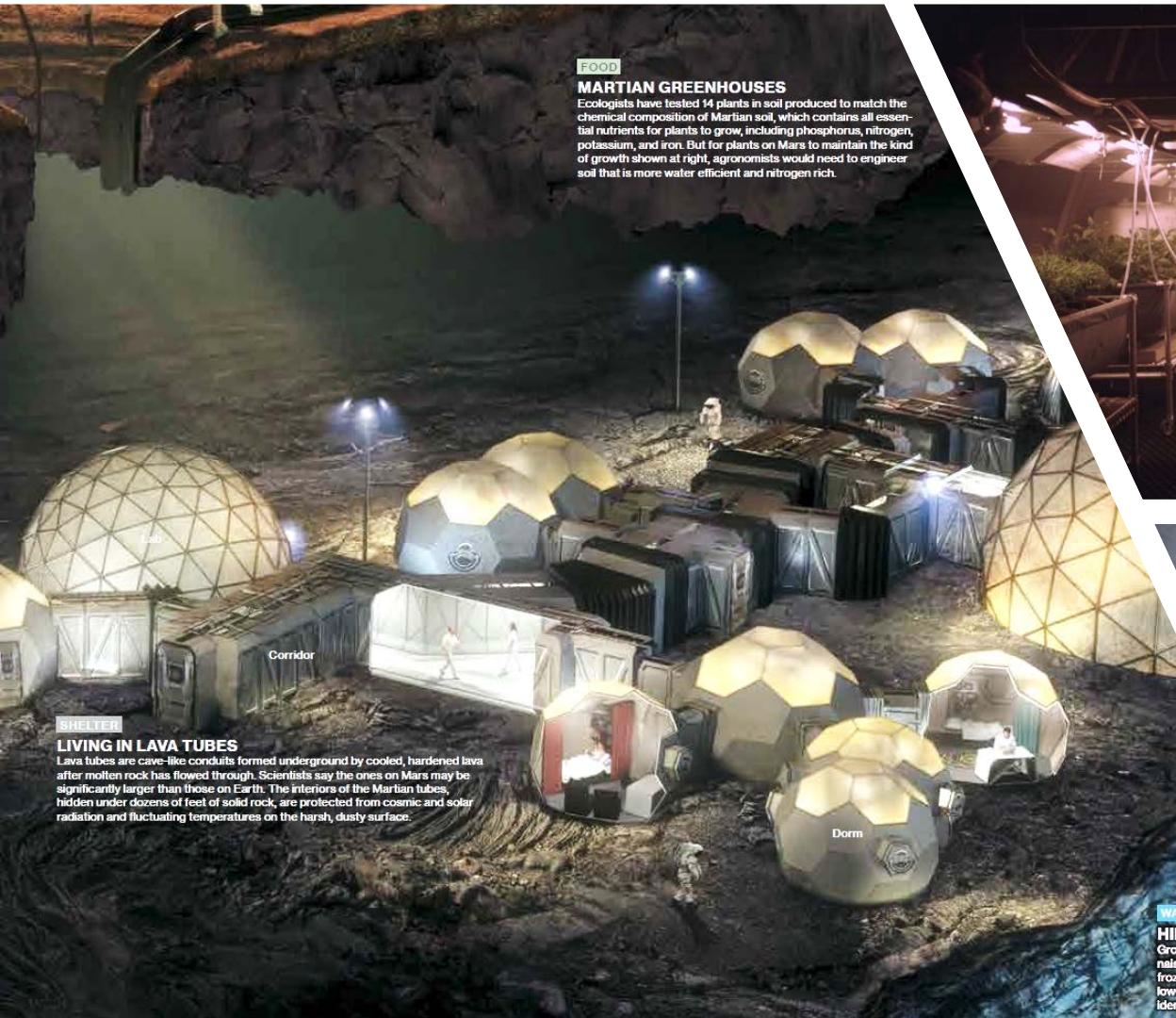
Professor Shirley Dyke  
LSIC Meeting September 2020



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# Where will we live?

Credit: National Geographic



## FOOD

### MARTIAN GREENHOUSES

Ecologists have tested 14 plants in soil produced to match the chemical composition of Martian soil, which contains all essential nutrients for plants to grow, including phosphorus, nitrogen, potassium, and iron. But for plants on Mars to maintain the kind of growth shown at right, agronomists would need to engineer soil that is more water efficient and nitrogen rich.



## SHELTER

### LIVING IN LAVA TUBES

Lava tubes are cave-like conduits formed underground by cooled, hardened lava after molten rock has flowed through. Scientists say the ones on Mars may be significantly larger than those on Earth. The interiors of the Martian tubes, hidden under dozens of feet of solid rock, are protected from cosmic and solar radiation and fluctuating temperatures on the harsh, dusty surface.

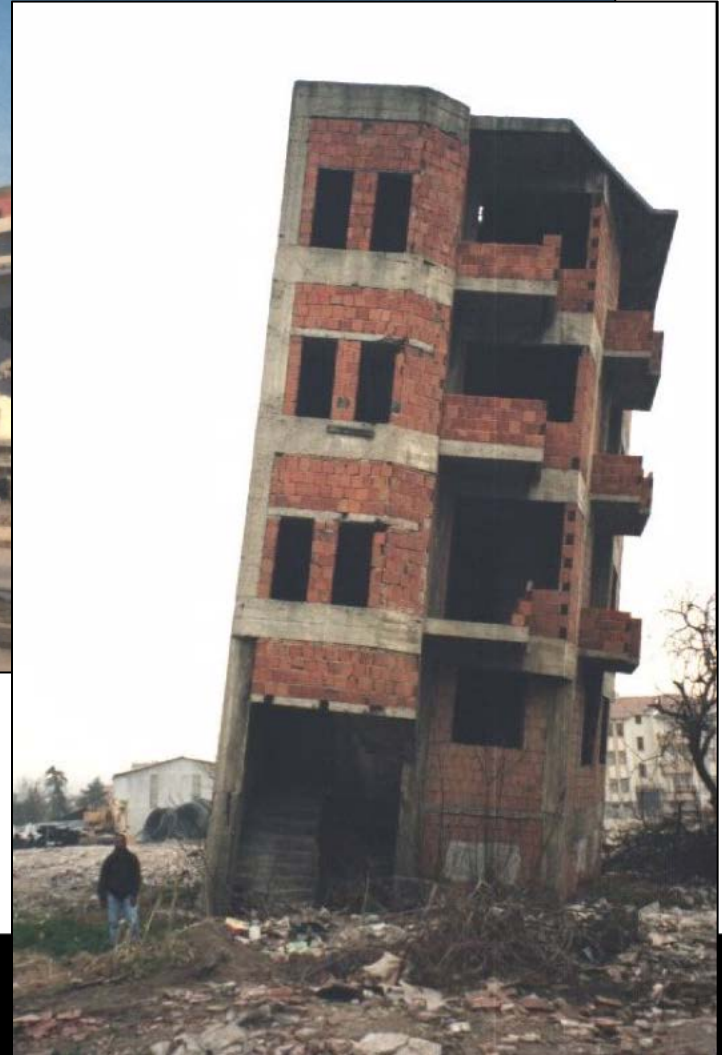


## WATER

### HIDDEN GLACIERS

Ground-penetrating radar from the Mars Reconnaissance Orbiter has revealed frozen water preserved beneath the surface at lower latitudes than where ice had previously been identified. These glaciers extend for

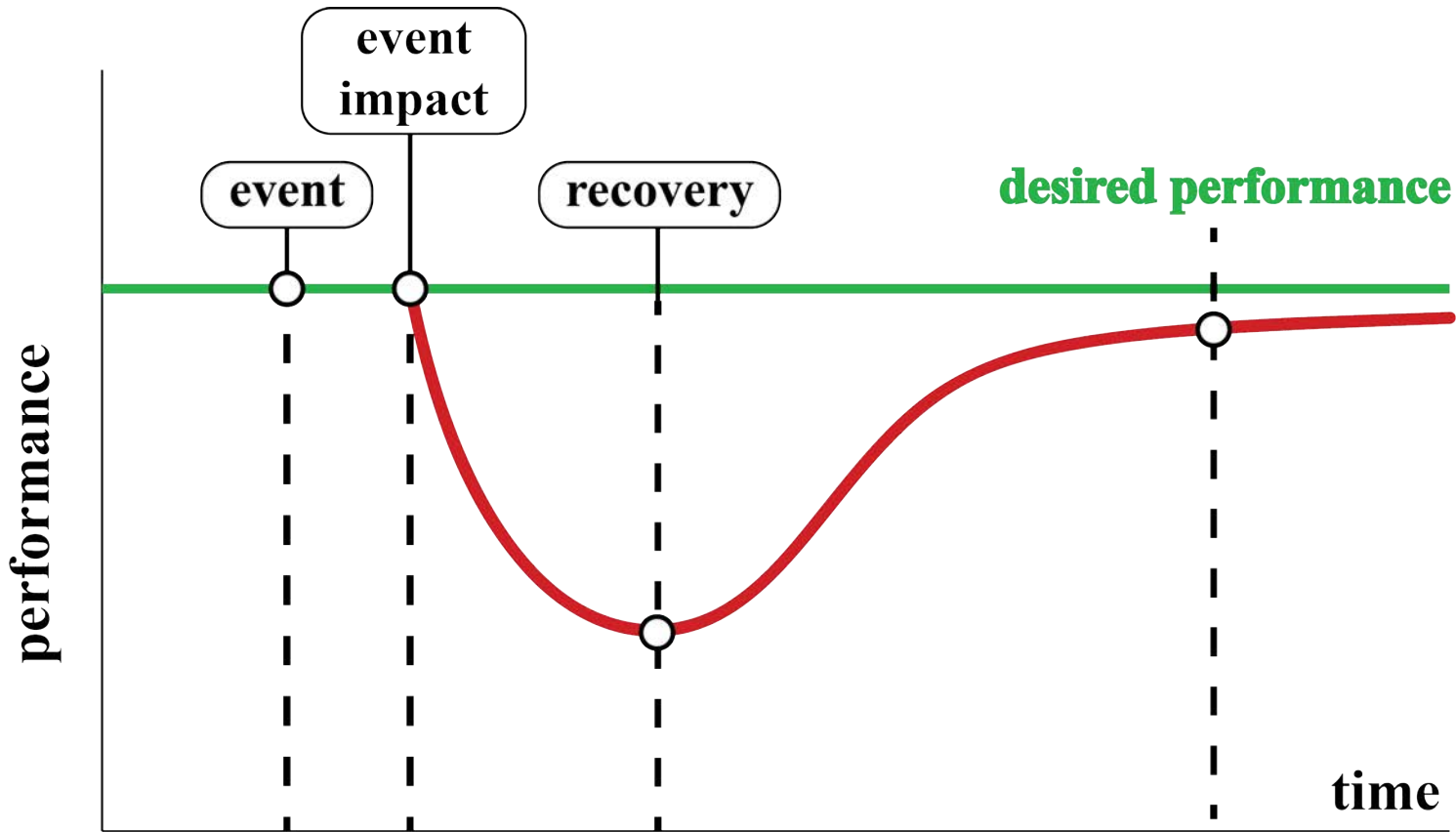
# How we design on Earth



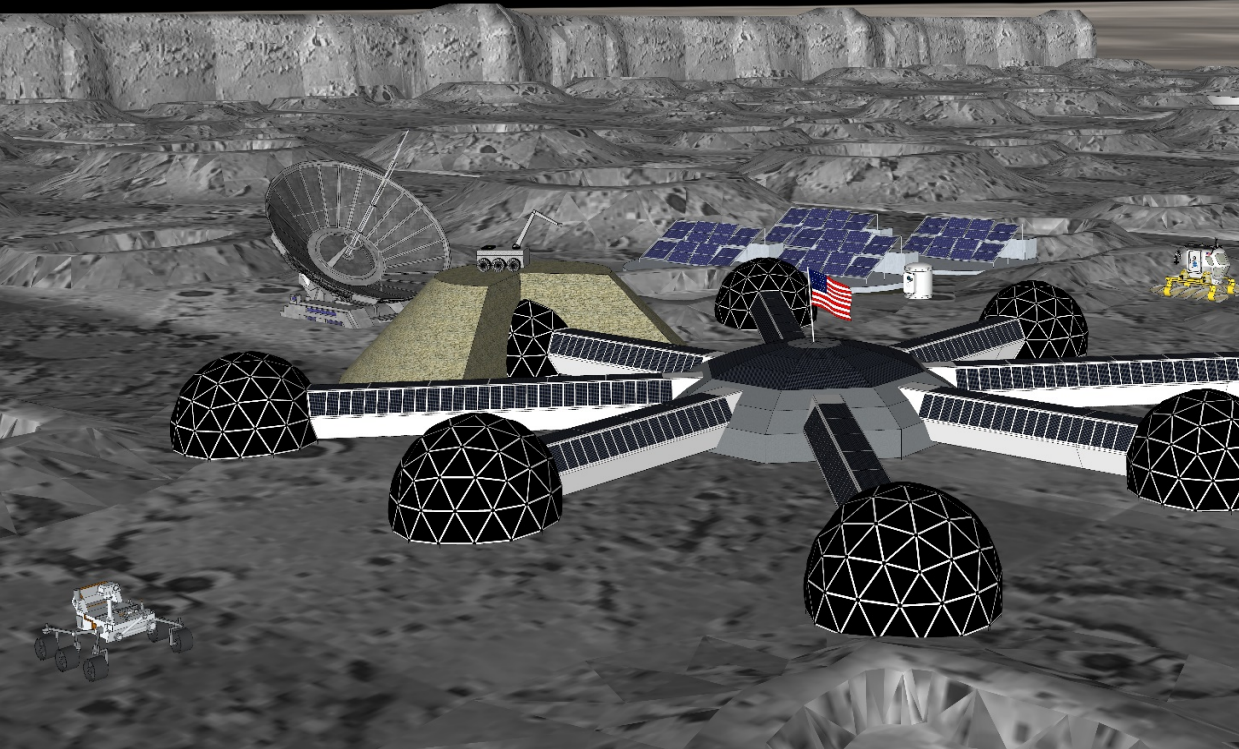
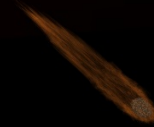
# Then Katrina.... systems approach



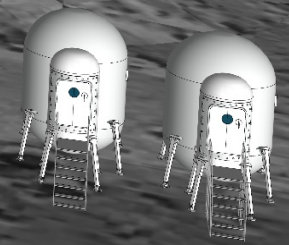
# Resilient Design



**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**



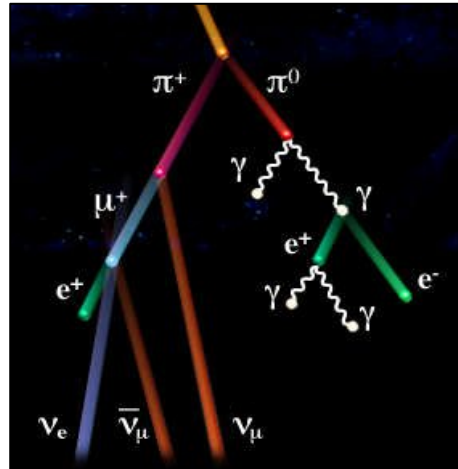
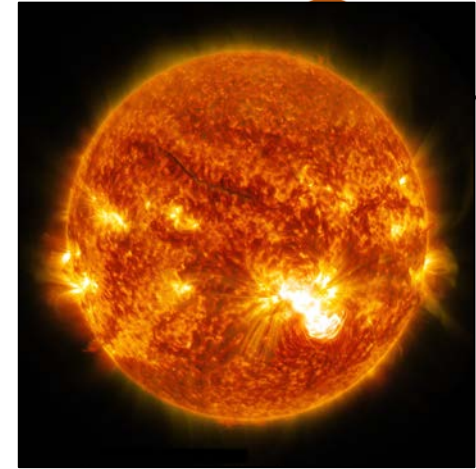
*Funded by the National Aeronautics and Space Administration*

# Radiation (several types)



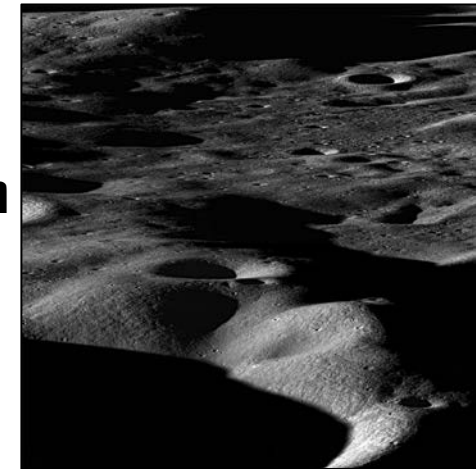
**Galactic Cosmic Rays (GCR)**

**Solar Particle Events (SPE)**



**Secondary Particles**

**Lunar Regolith (Soil)**





# Meteoroid Impact



## Primary impact:

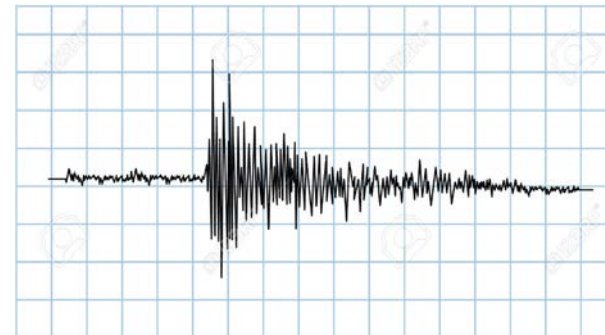


## Direct damage

## Secondary impact:



## Ejected particles



## Seismic activity

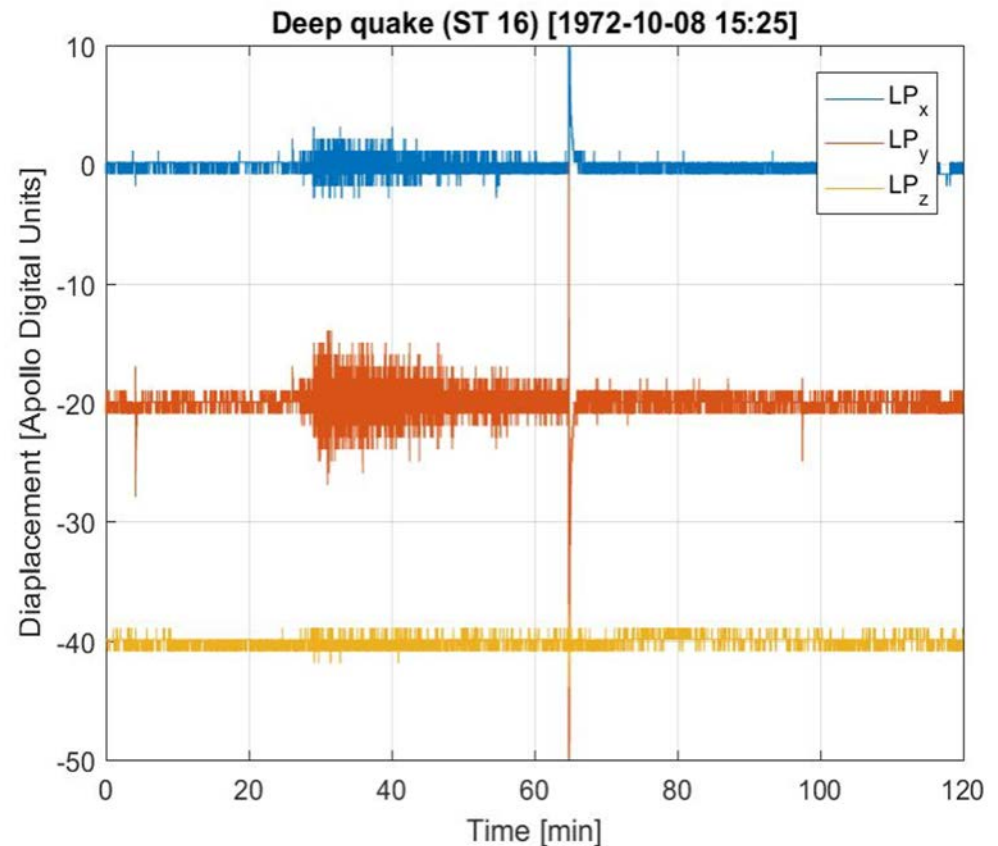


# Moonquakes / Marsquakes

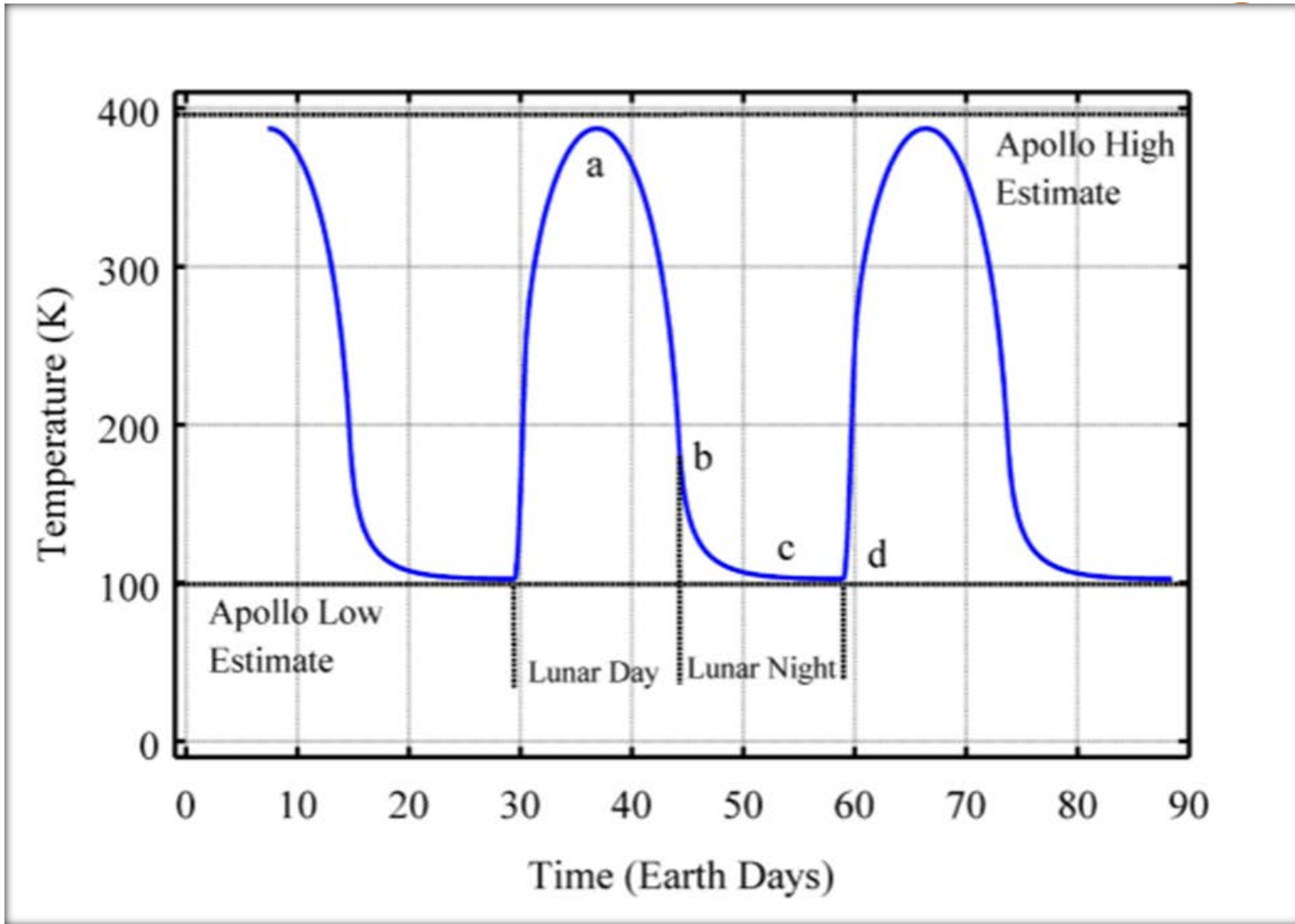


## Deep moonquakes:

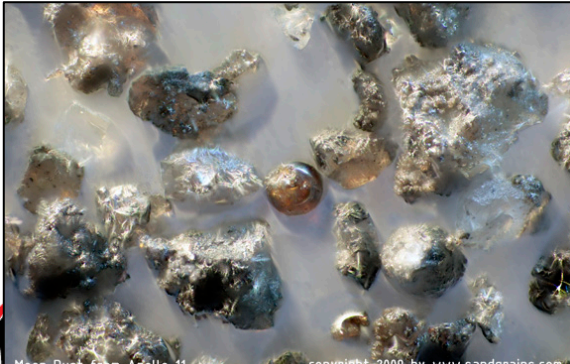
- **At depths of 700 - 1000 km.**
- **Frequent events, but low energy**
- **Most less than magnitude 2**
- **Terrestrial tidal forces influence the occurrence and periodicity of deep events.**
- **7000 events identified!!!**



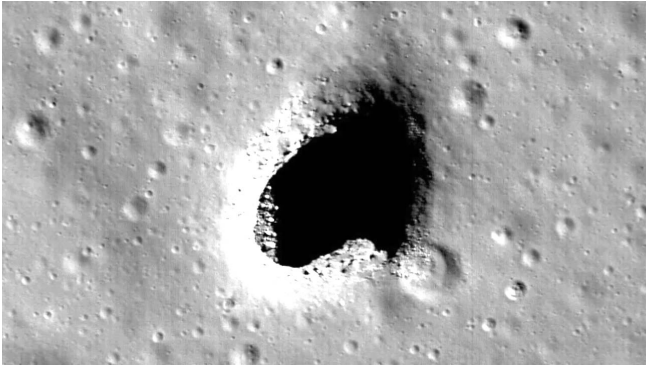
# Extreme Temperatures



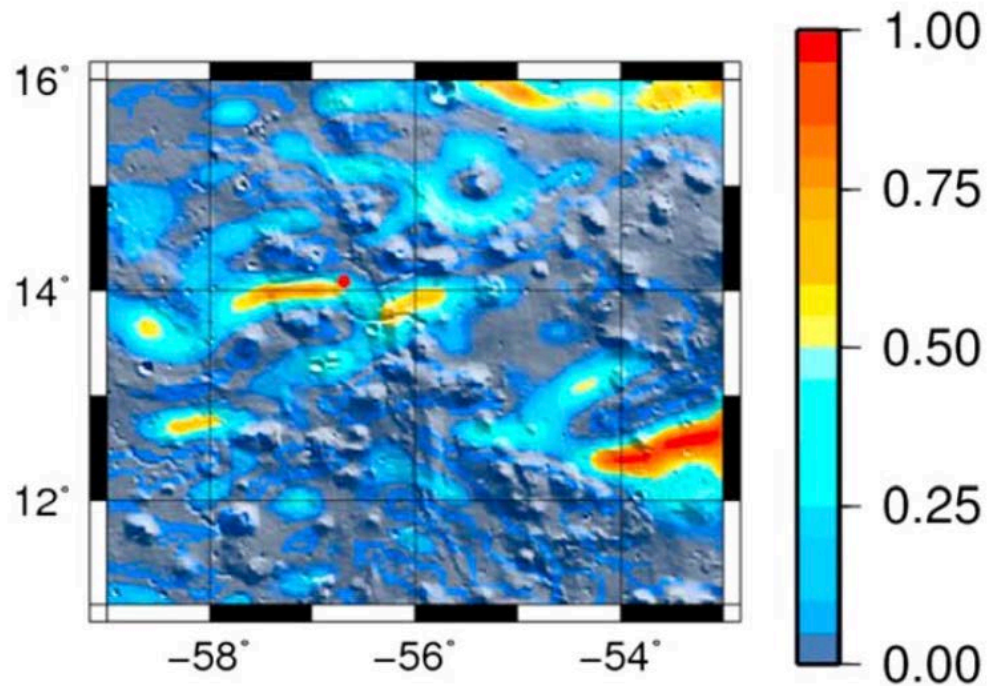
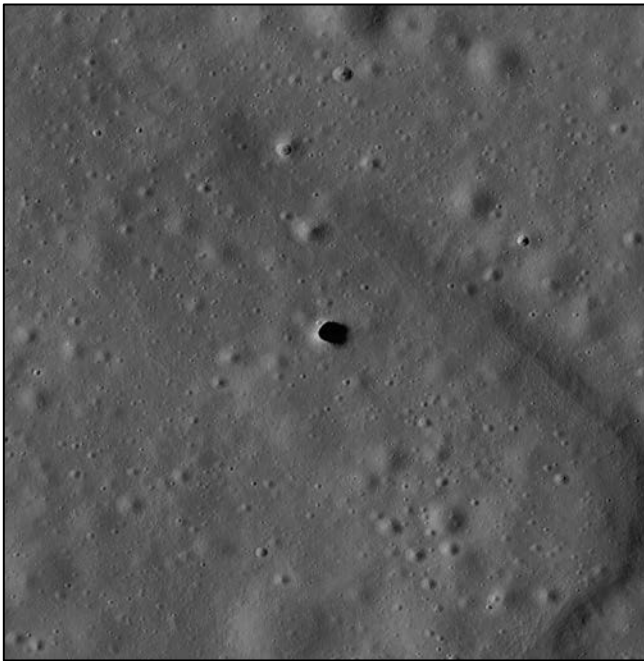
# Lunar Dust gets into everything



# Large Lava Tubes on the Moon



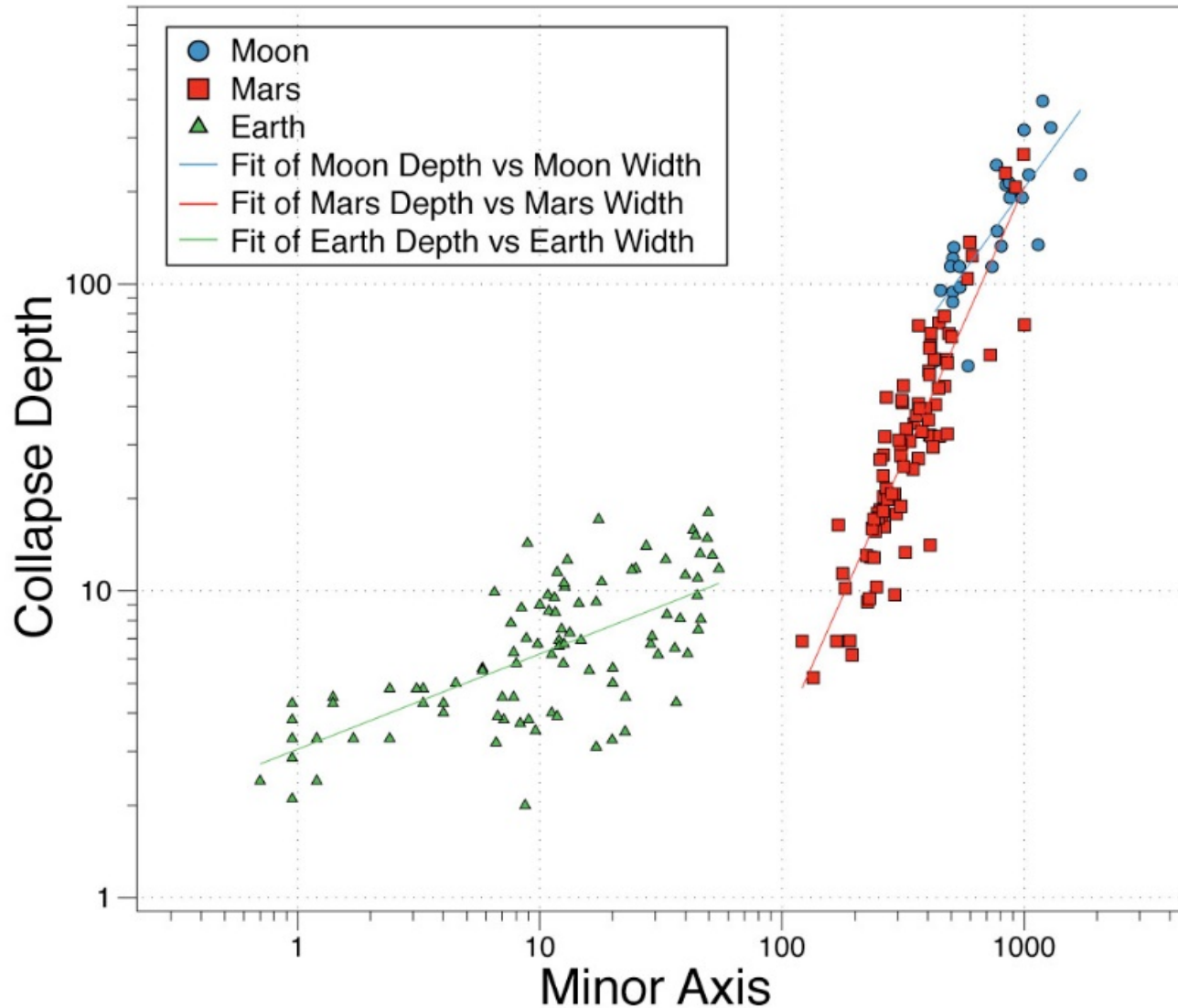
**GRAIL Players from AAE and EAPS:  
Rohan Sood, Loic Chappaz, Jay Melosh, Kathleen Howell,  
David Blair, Colleen Milbury**



# Moon, Mars, Earth Lava Tubes



Sauro et al. (2018)



# International Workshop, Oct 2018



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



## 2018 International RETH Workshop

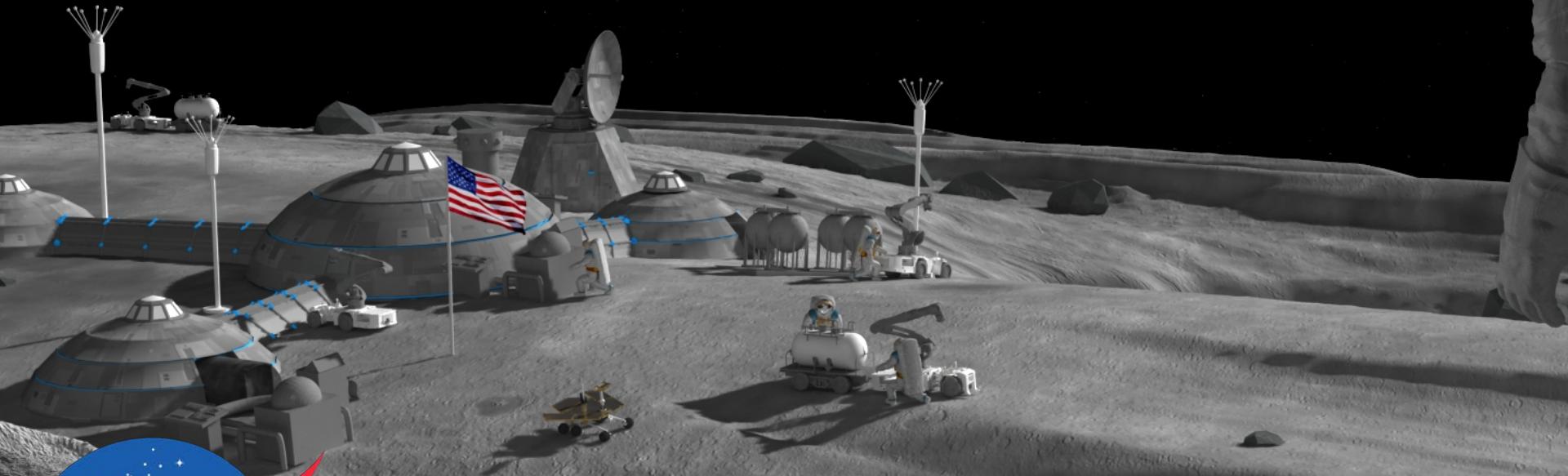
**Row 1 Left to Right:** Audai (Ed) Theinat, Jay Melosh, Junichi Haruyama, Barry Finger, Bill O'Hara, Larry Toups, Dan Dumbacher, Mike Grichnik, Anita Gale, Shirley Dyke, Lindsay Aitchison

**Row 2 Left to Right:** Ibrahim Emre Gunduz, Monsi Roman, Glenn White, Tatjana Paunesku, Hunain Alkhateb, Babajide Onanuga, Danielli Moura, Jared Atkinson, Anahita Modiriasari, Nicholas Schmerr, Elizabeth A. Silber, Riccardo Pozzobon

**Row 3 Left to Right:** Aryan Noroozi, Dawn Whitaker, Ramesh B. Malla, Michael Kosson, Florence Sanchez, Joseph Biernacki, Cary Mitchell, Kelsey Young, Daniel Gomez, Pablo Zavattieri, Anthony Boener

**October 22-23, Purdue**

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



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UNIVERSITY

**UConn**  
UNIVERSITY OF CONNECTICUT



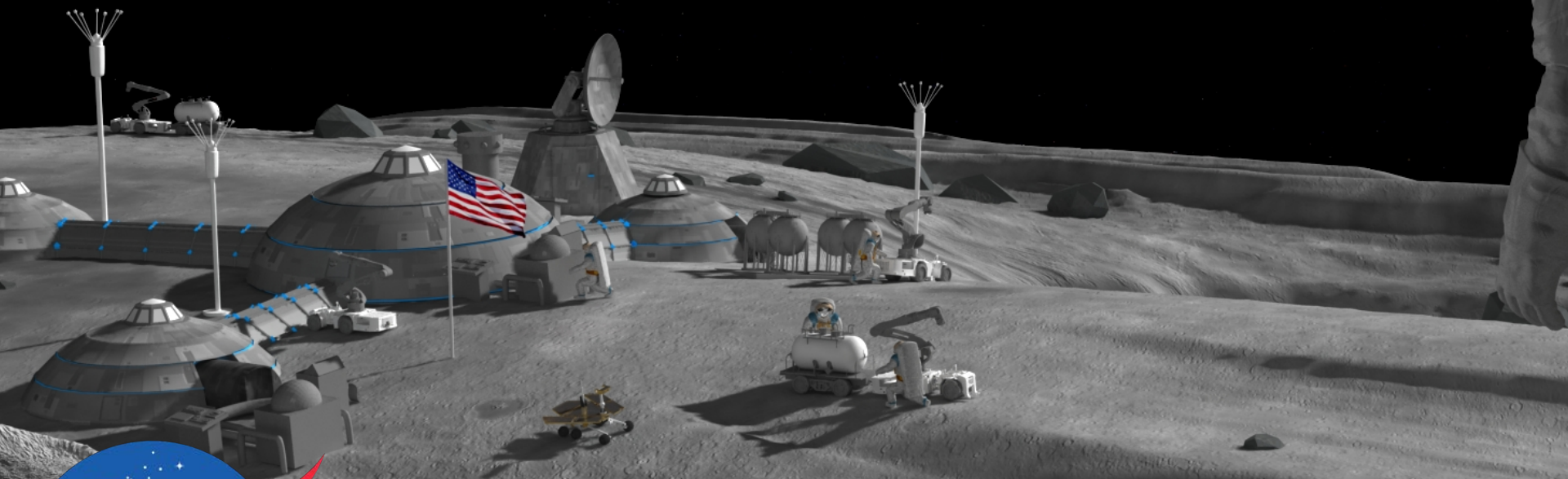
**HARVARD**  
UNIVERSITY

**UTSA**  
The University of Texas  
at San Antonio

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.*



**PURDUE**  
UNIVERSITY.

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UNIVERSITY OF CONNECTICUT



**HARVARD**  
UNIVERSITY

**UTSA**

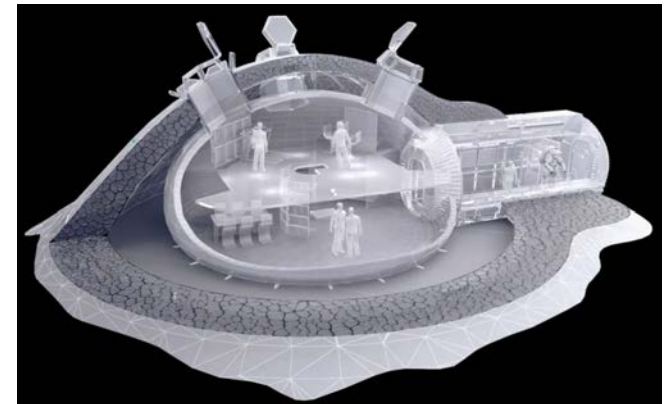
The University of Texas  
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# Resilience is not robustness, reliability or redundancy ...



- 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*



# 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



# Leadership Team



Shirley Dyke



Ramesh Malla



Dan Zehner



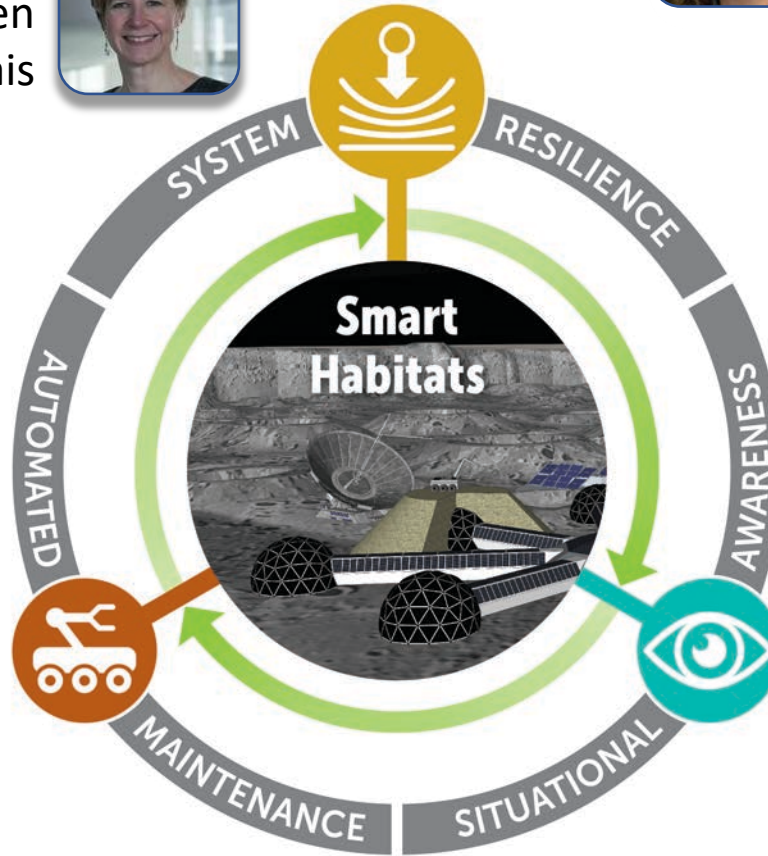
Ilias Billionis



Karen Marais



Justin Werfel



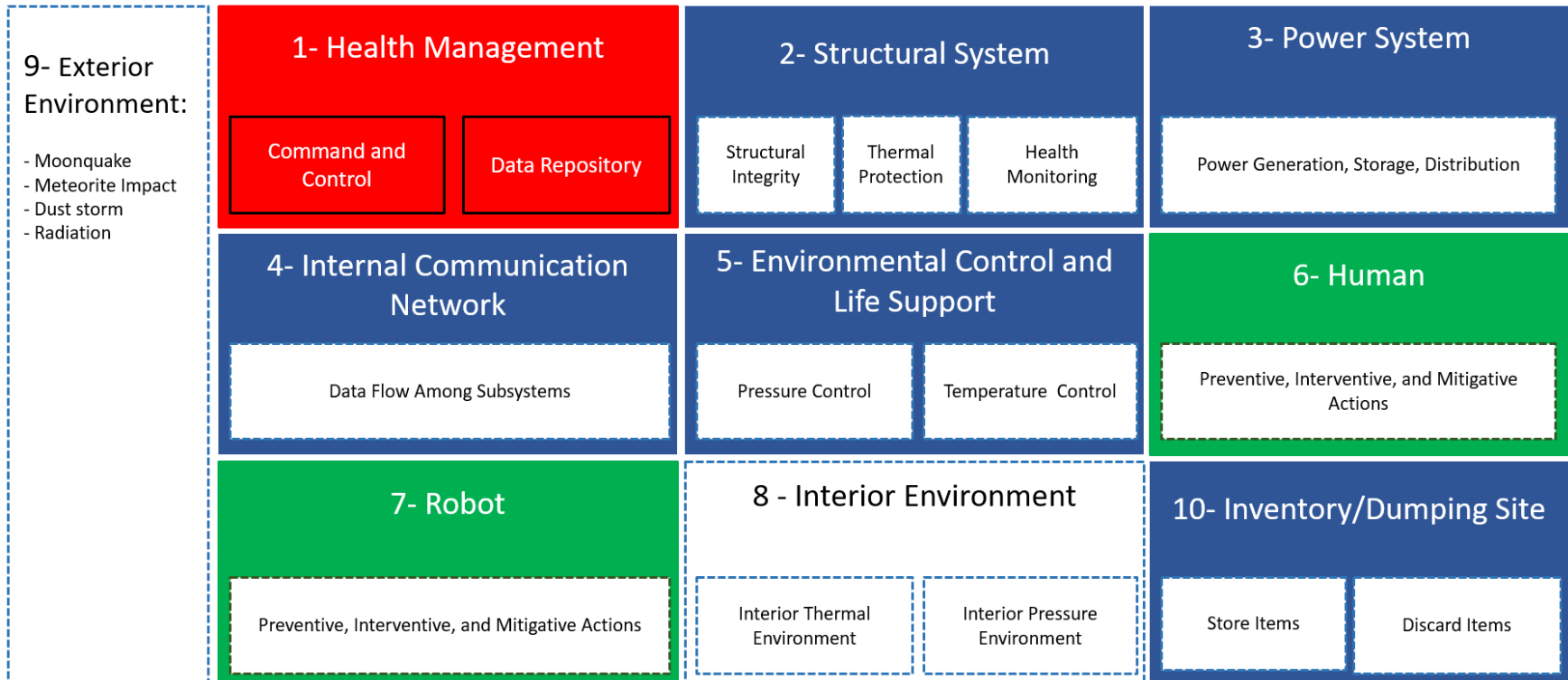
# Modular Coupled Virtual Testbed



- 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



# Modular Coupled Virtual Testbed



# Resilient-oriented Design



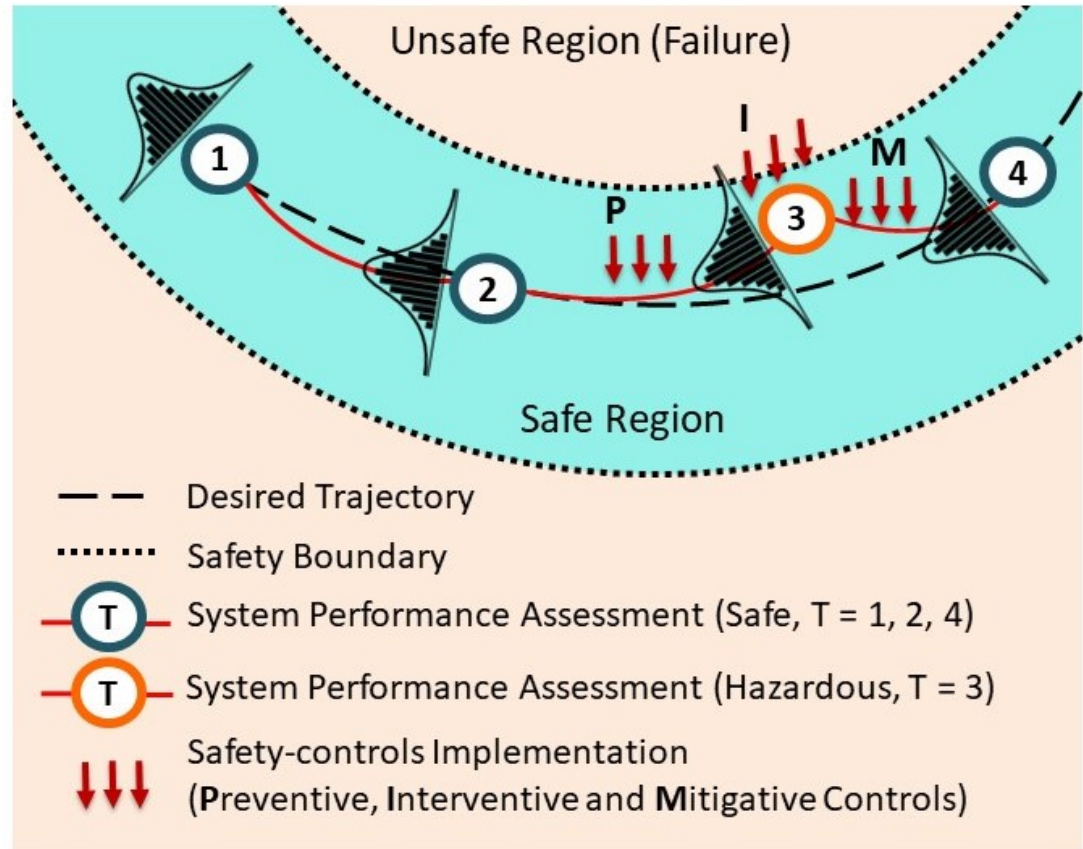
- 1 State estimation, assessment of performance or function. Within boundary.
- 2

↓ ↓ ↓ Safety-controls act (passive)

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

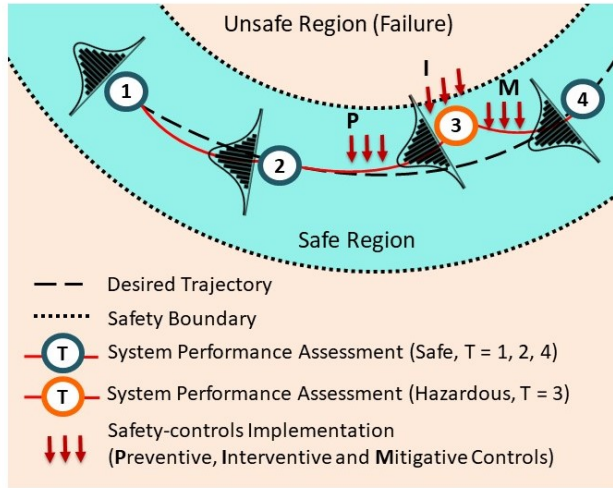
↓ ↓ ↓ Safety-controls act (adaptive)

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

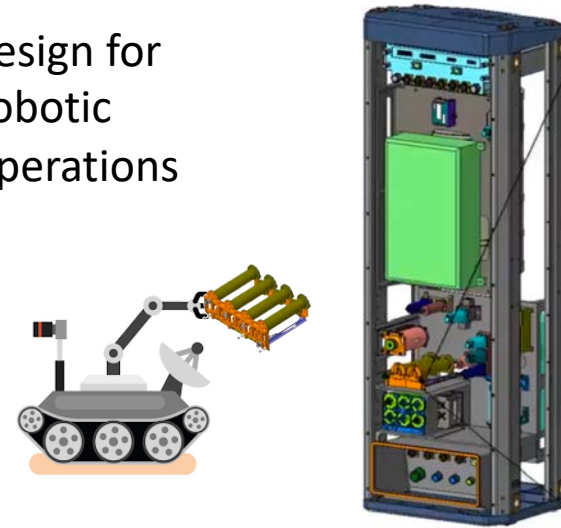


# Generate New Knowledge

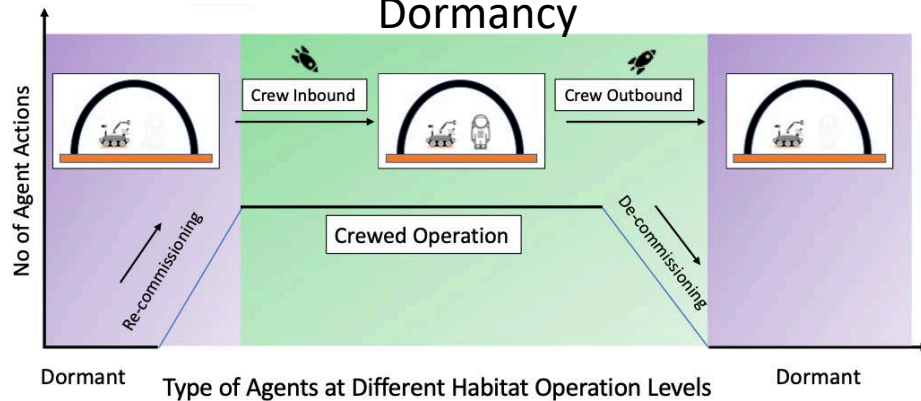
## Control-theoretic Resilience



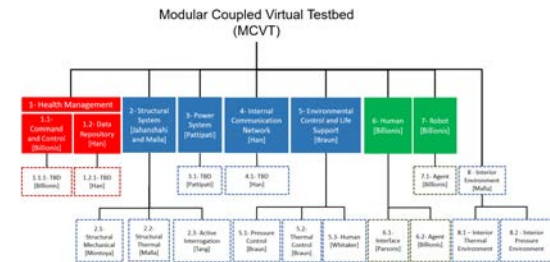
## Design for Robotic Operations



## Dormancy



## Complex Systems



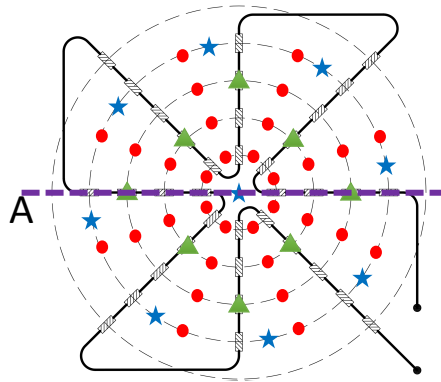
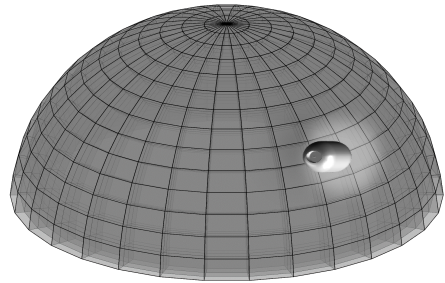
Modular Coupled Virtual Testbed



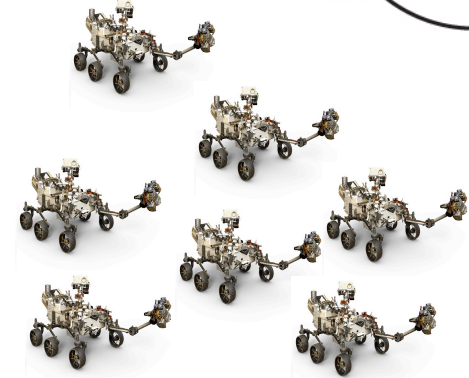
# New Technologies and Techniques



## Fault Detection

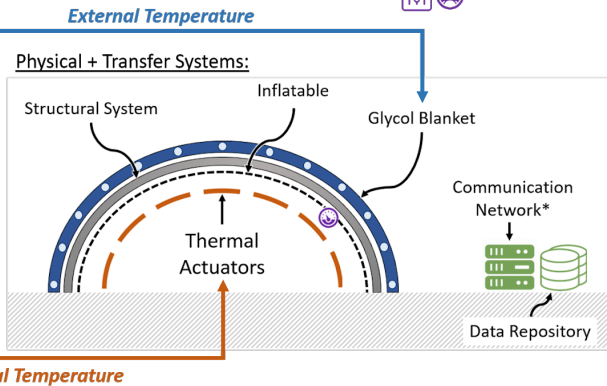
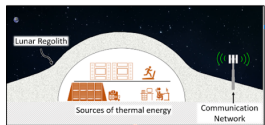


## Perception, Navigation, Manipulation



## Cyber-physical Testing

Computational:



- Thermal Control
- Pressure Control

\* The communication network will be mainly "computational", this the physical intranet.

Job Scheduling

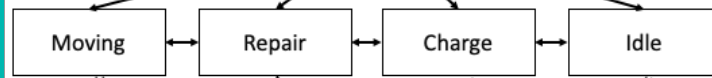
Health State

Ordered List of Tasks



Repair Action Performed

## Modeling of Robotic Agents



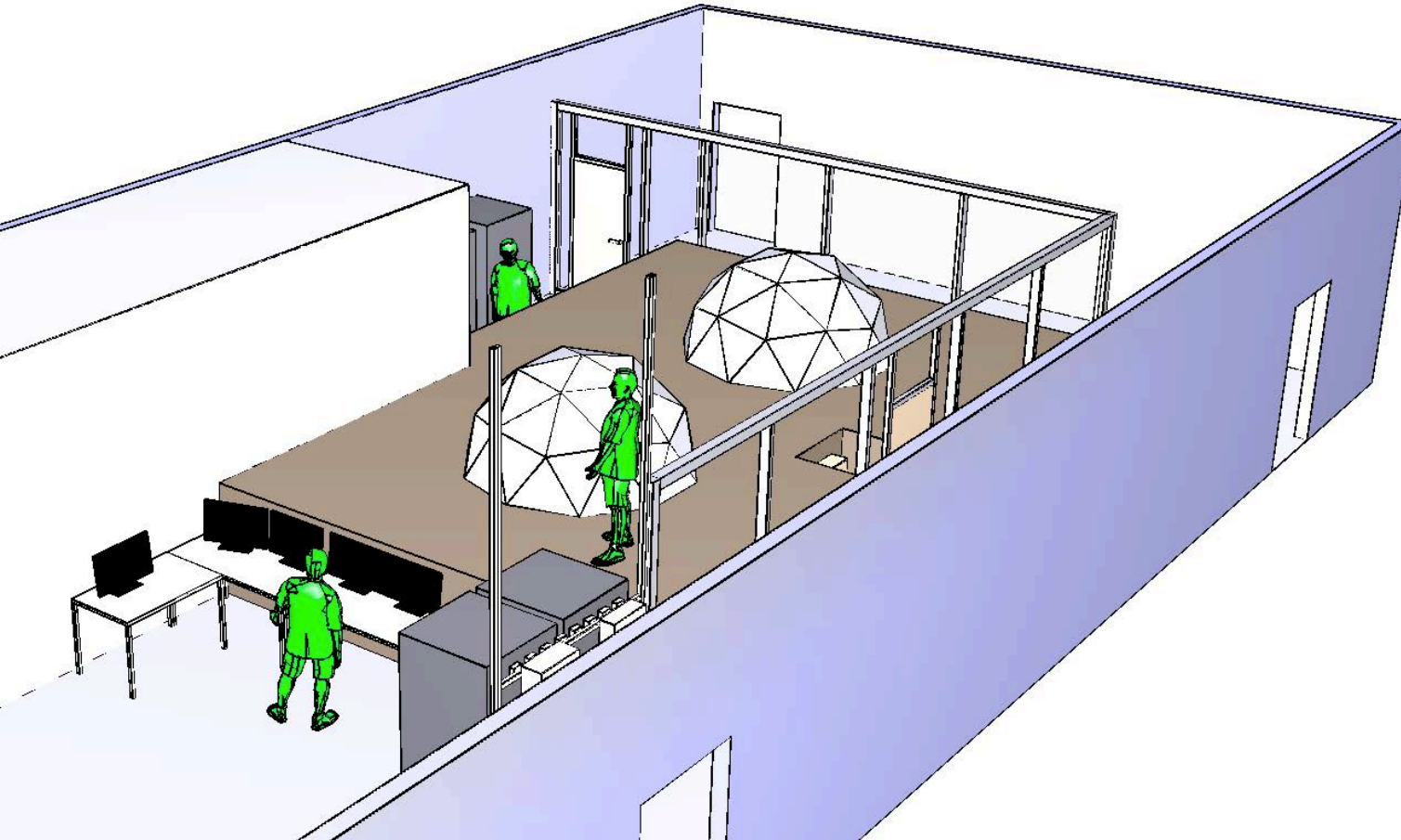
Transition from one state to another



# Cyber-physical Testbed



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





<https://www.purdue.edu/rethi/>



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