# Extreme Expeditionary Architecture (EXP–Arch)


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**NIAC Phase I Fellows Meeting**
**Atlanta, GA**

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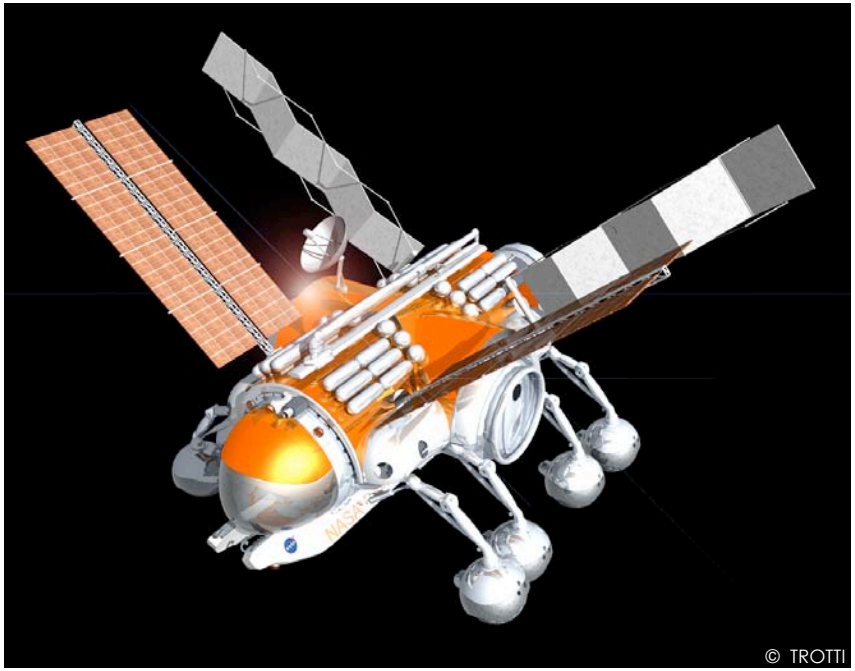
# Expeditionary Architecture Introduction



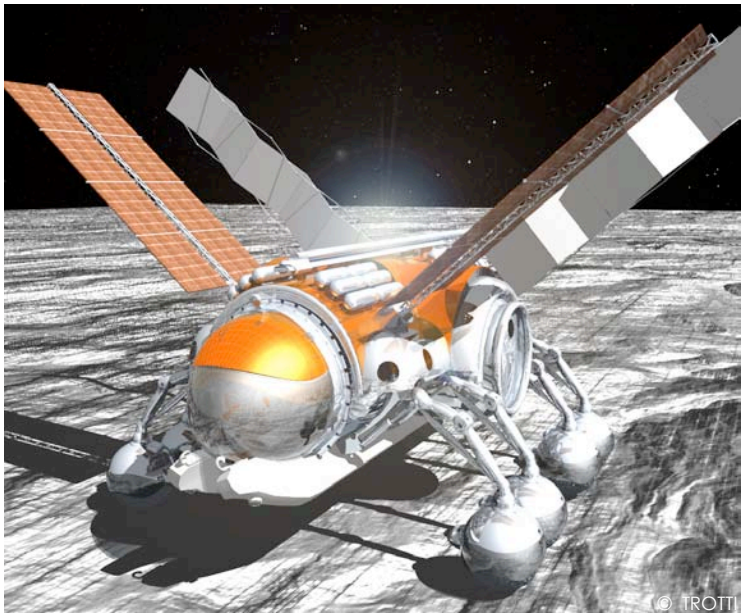

**Introduction**
**Mission Architecture**
**Rover Concepts**
- Mother Ship Rovers
- Mini Rovers

**Expandable Environments**
- Inflatable Structures
- Foldable Structures

**Educational Outreach**
**Conclusions**
**Next steps**

# EXP–Arch Mission Architecture Introduction

**Extreme Expeditionary Architecture: Paradigm Shift – Suite of systems, quickly deployable, transformable, autonomous & human collaboration, explore many diverse sites**

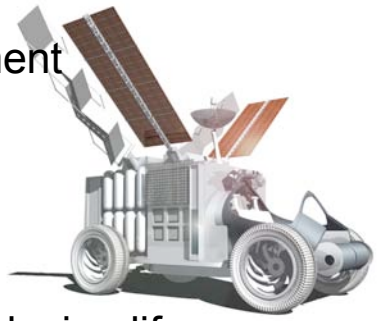




**Mobile "convoy" of rovers:**
- 2 large pressurized rovers,
- 4 small un-pressurized rovers

**Pressurized rovers:**
- 1 habitation; 1 laboratory/exploration
- Inflatable Structures (> 2x volume)
- Crew of 4-8 all supplies and equipment

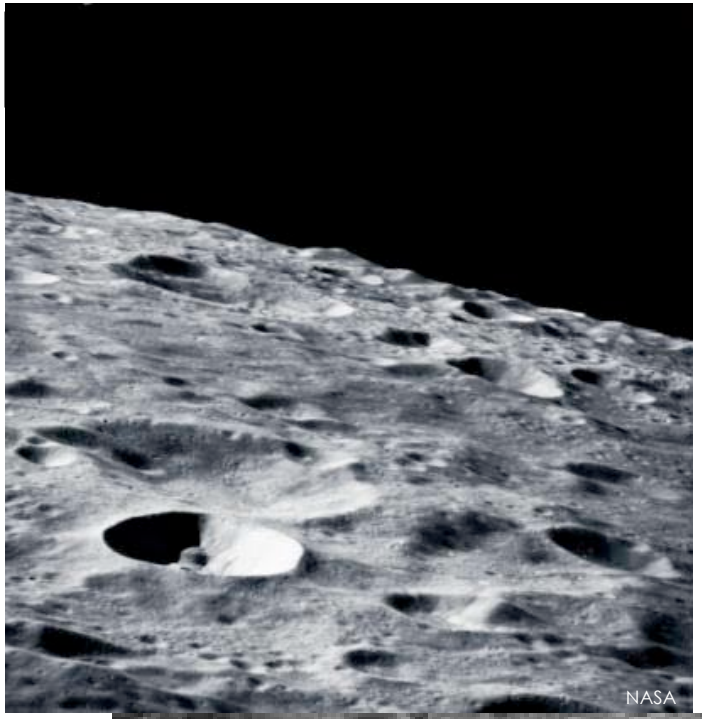
**Un-pressurized rovers:**
- Transport crew and cargo
- Agile exploration
- Regolith moving



**Mission**: weeks–months; 10–12 yr design life

# EXP–Arch Mission Architecture Purpose

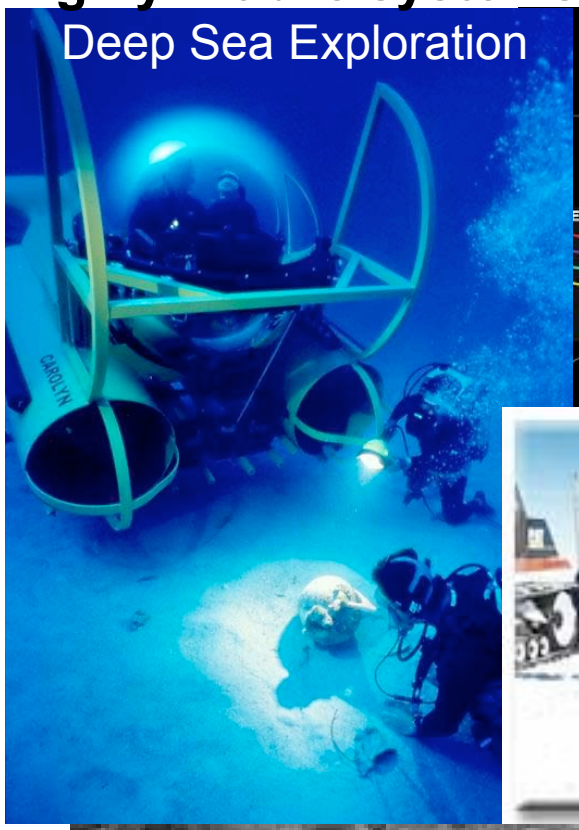
**Go Beyond NASA's Lunar Mission of a Single Outpost, Extensive Infrastructure at the South Pole – EXP-Arch enables us to become a "spacefaring species"**

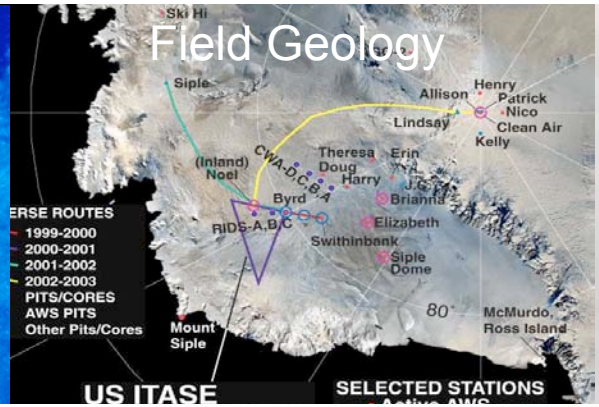



- **Human & Robotic Experience**: Surface operations, Planetary Exploration, Mars Mission Training, Self-Sufficiency
- **Technology Testbeds**: Mining, Construction, Science, Experience, Rapid Excavation and Regolith Movement (for radiation protection), Systems Testing, Mars Mission Testbed
- **Hands-On Lunar Surface Exploration:** Investigate caves/lava tubes, Search for water (ice)
- **Scientific Research:** Selenology, Physics, Astronomy, Geology, Chemistry, & Life Sciences
- **Public Interest/Outreach**: Engage public participation: "The People's Moon"

# Exp-Arch Exploration Analogies

**Historically breakthrough exploration has been accomplished by highly mobile systems**

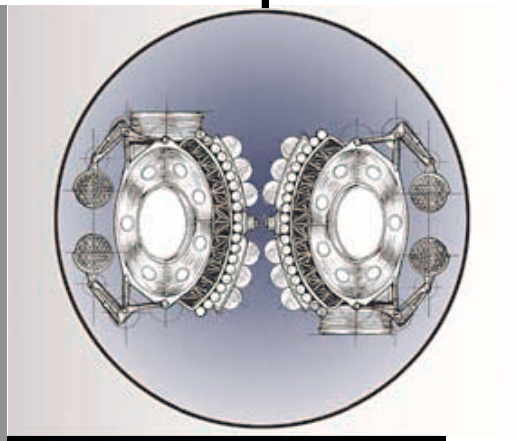




# Transportation Issues

**EXP–Arch mission architecture fully realized on two Ares V class launch vehicles. Operational capability after first launch.**



- Payload Configurations:
  - 1 pressurized rovers (8 mT) and 2 mini-rovers (2 mT)
  - 2 pressurized rovers
  - 4 mini-rovers
- Single launch: 1 pressurized rover and 2 mini–rovers.
- Alternative launch configurations: 2 pressurized rovers or 4 mini-rovers
- Ares V capacity: 65000 kg to the moon and >20 mT payload to the lunar surface.

# Rovers and Vehicle Design Background

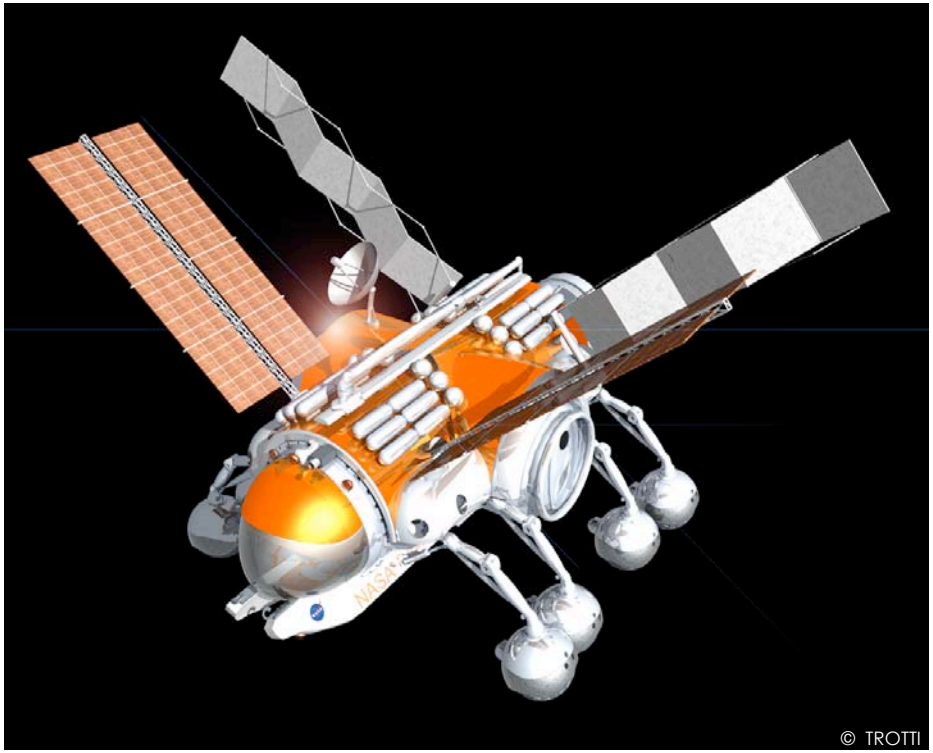
**Advanced automotive, materials, and other industries can be leveraged in planetary exploration concepts. We have researched the new technologies and have applied them to our design.**

There is a paradigm shift on the way we think about planetary rover design and construction.

- Past rover designs
  - Apollo rover
  - NASA past research
- Vehicle design innovations
  - Composites
  - Electrical Motors Propulsion
  - Fuel Cells
  - Hydrogen Storage
  - Power storage
  - Wheel design
  - Joystick control
  - Multidirectional
  - Bio-mimetic systems

# Mother Ship Rover (MSR) Design Criteria

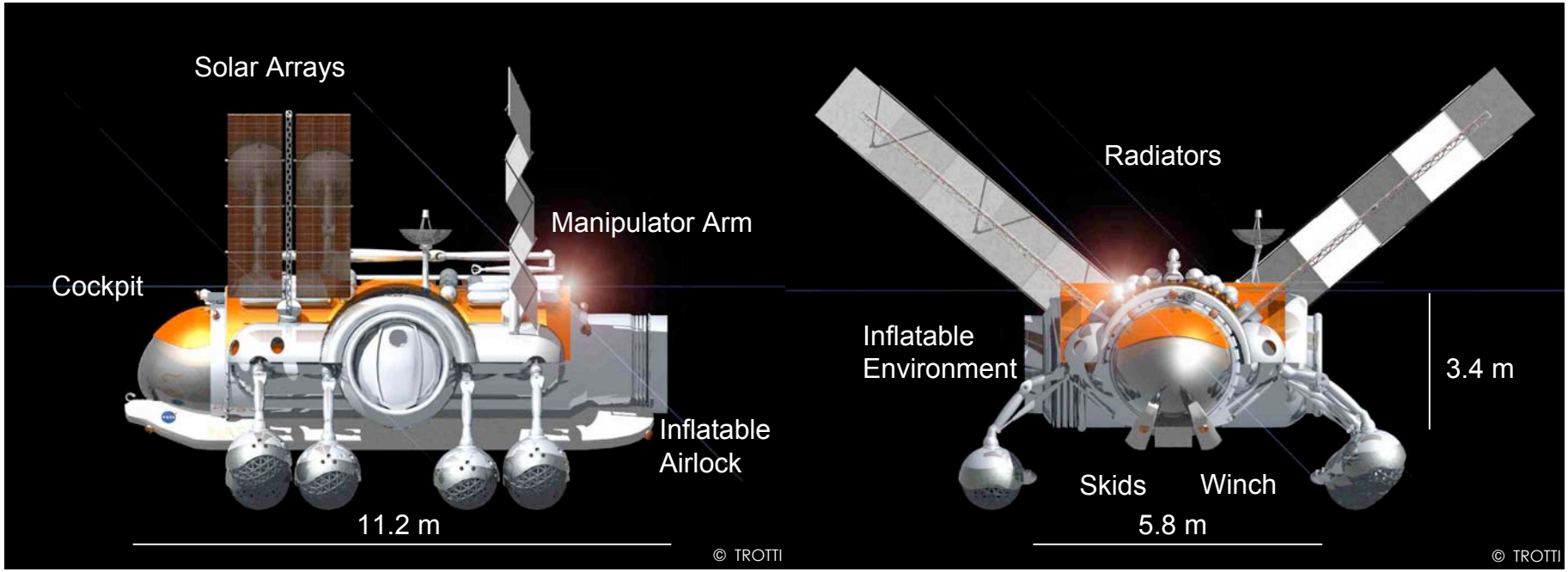
**Highly mobile, smart, autonomous computational system…Trigger!**




Pressurized vehicle and transportable habitat

- All terrain omni-directional vehicle
- Novel 8 wheel traction
- Reduce mass (use of composites /40% less mass)
- Self healing structures
- Passive and active radiation protection
- Crew of 4
- Stereoscopic vision
- Teleoperation and autonomous thinking
- Wireless controls
- Multidirectional telemetry control
- Navigational warning systems
- Docking capabilities
- Re-supply
  - Fuel: Hydrogen - Oxygen
  - Food
  - Tools and equipment
- Maximum mass 10 mT

# Mother Ship Rover Design




**Side View** **Front View**

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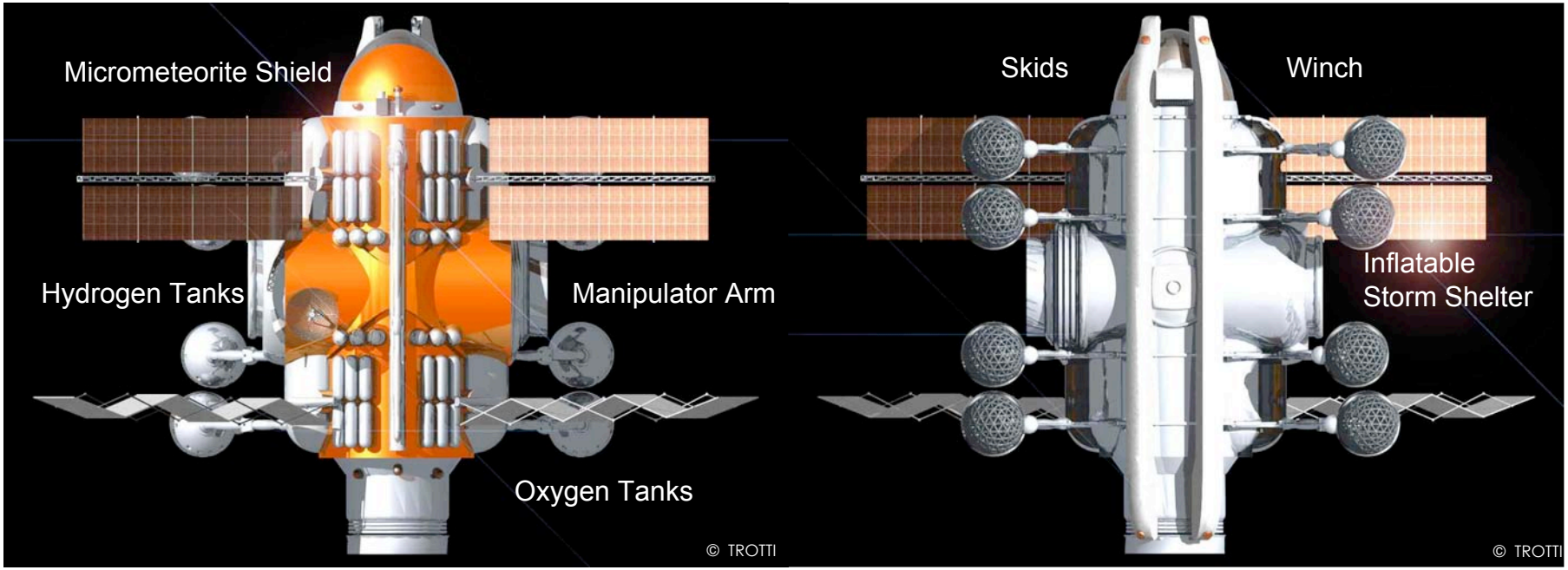
# Mother Ship Rover (MSR) Design

**Equipment layout on the rover's roof enhances radiation protection**

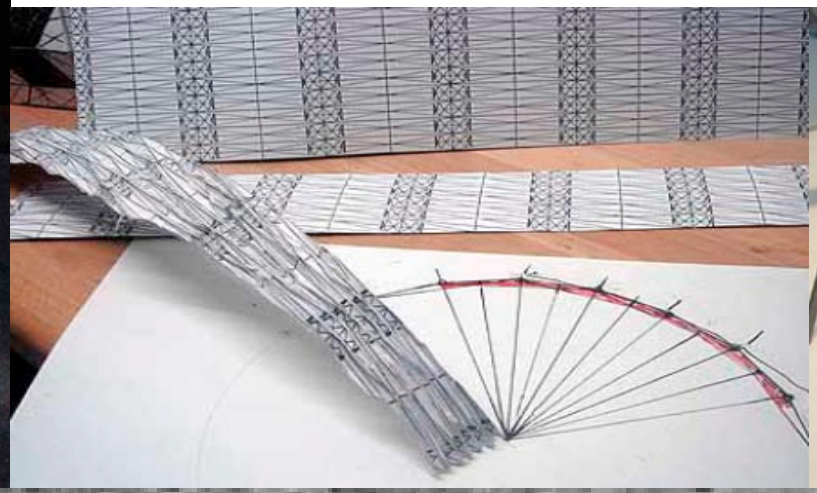



**Top View** **Bottom View**

# Foldable and Inflatable Structures Studies

**The inflatable structures are built of multi-layer para-aramid materials with layers of mylar for thermal and UV radiation protection. NASA and industry have developed and built full scale prototypes (i.e, Spacehab, Honeywell-FTL AIA airlock, Bigelow Enterprises)**

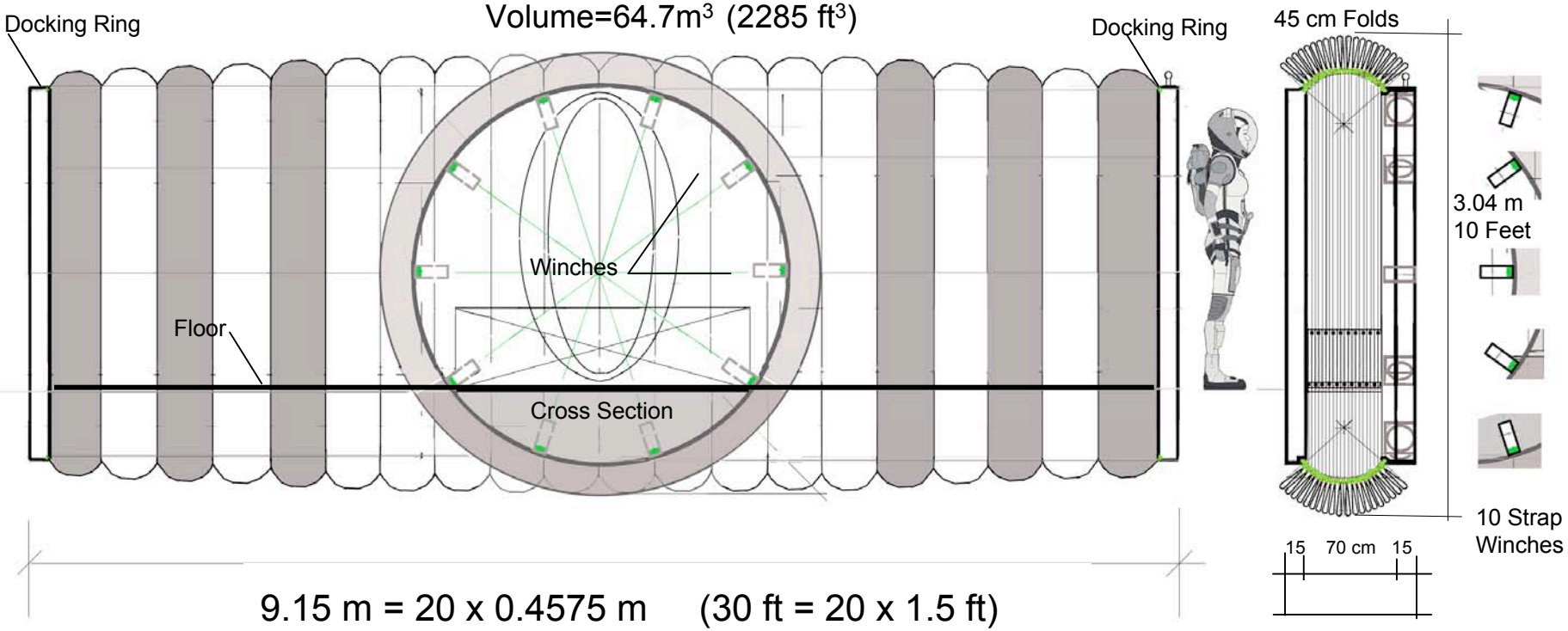

We conducted several studies and constructed several models of **re-deployable structures** using origami principles and fabric folding techniques.



# EXP – Arch Inflatable Habitat Design

**Selected Concept: 20 Sections with 21 section rings, rings are ~2.44 m (~8 ft in dia.) Inflatable Habitat Total Fabric Mass: 857 kg (1890 lb).**

Volume=64.7m$^3$ (2285 ft$^3$)

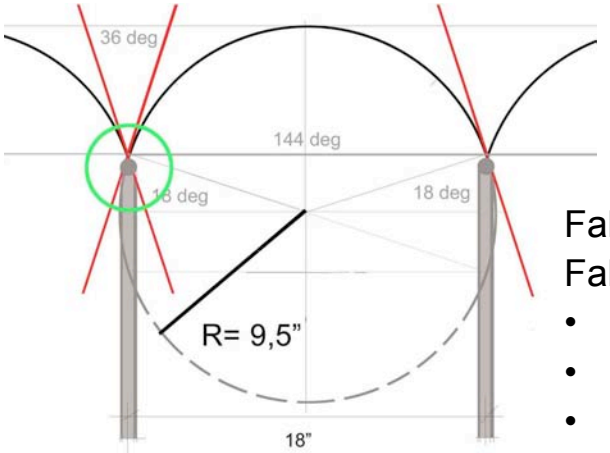



9.15 m = 20 x 0.4575 m (30 ft = 20 x 1.5 ft)

Re-deployable Inflatable Habitat

# Inflatable Details and Airlock Design

## Ring/fabric intersecting geometry

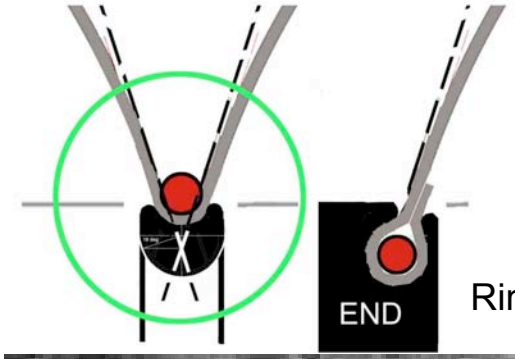



Fabric thickness: 8 mm

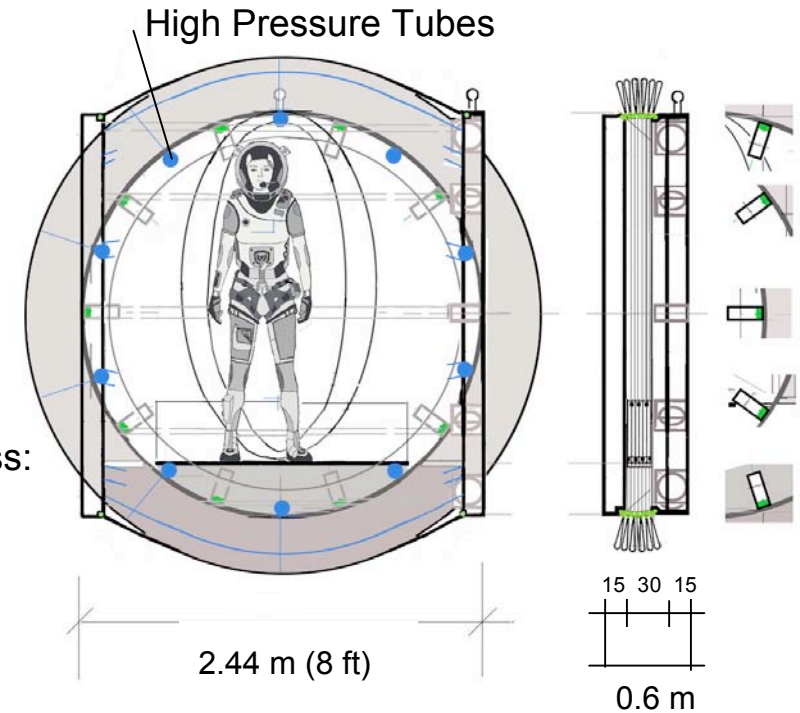
Fabric Layers:

- Pressure bladder
- Thermal blanket
- Abrasion resistant

Airlock Total Fabric Mass: 245 kg (540 lb)



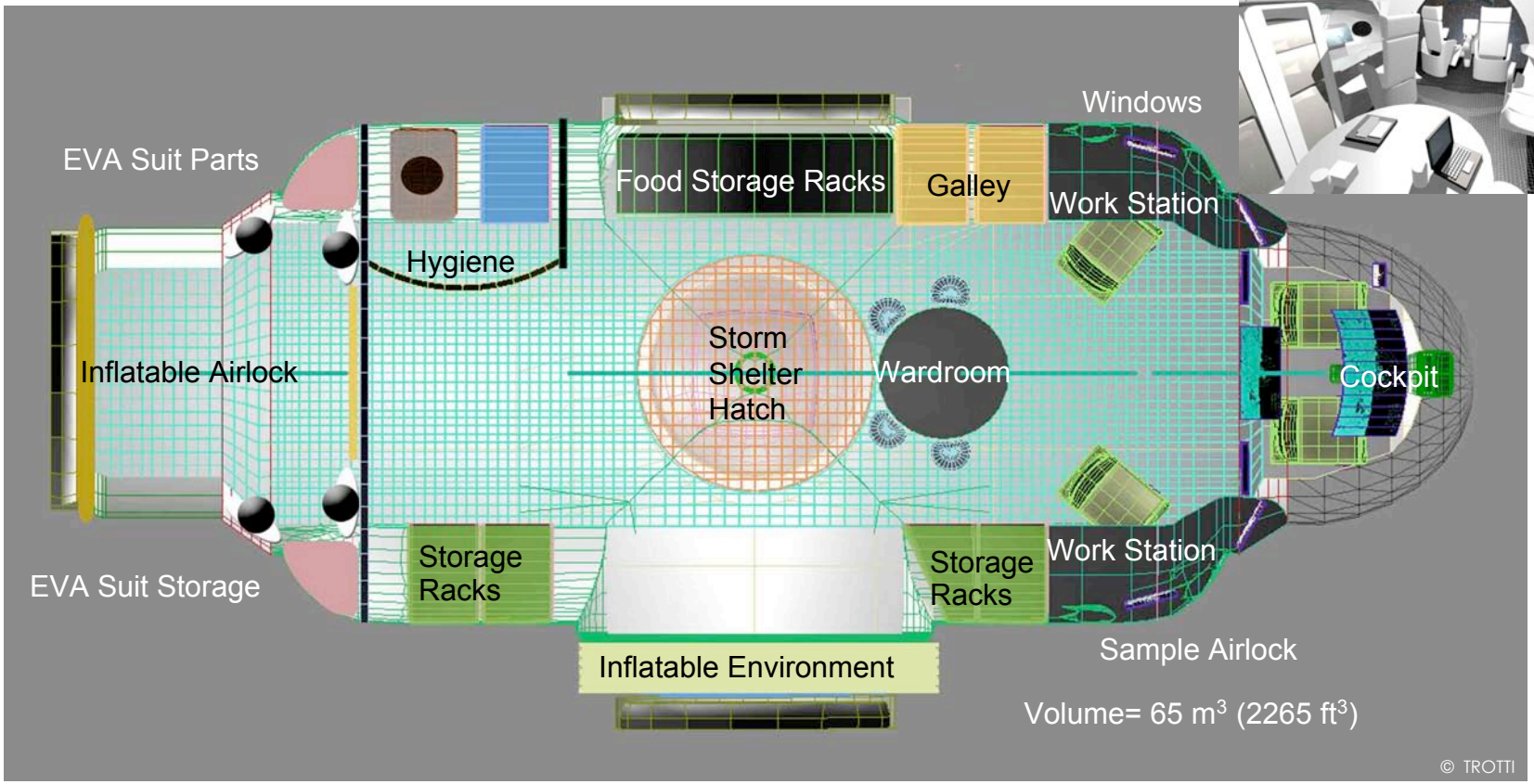

Ring detail




Hatch and Docking Ring Mass: 680 kg (1500 lb) each

# Interior Design Features

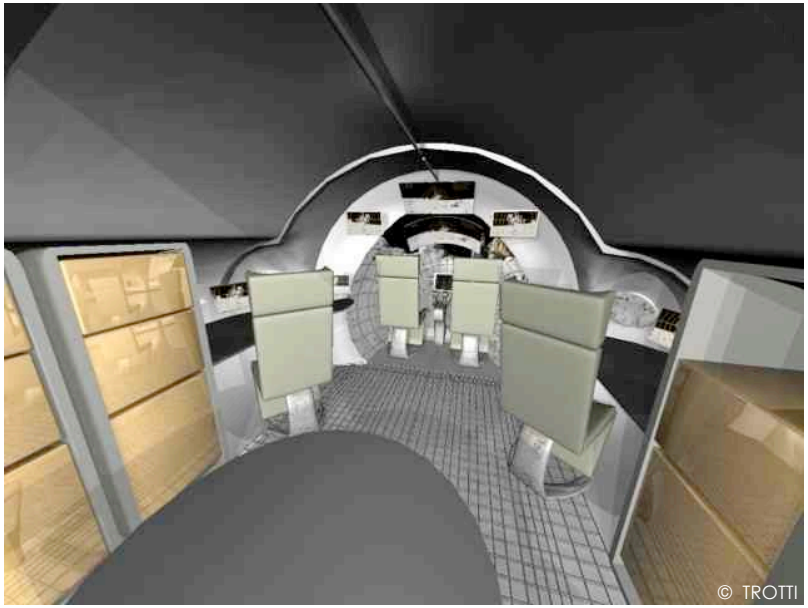
## MSR Floor Plan



# Interior Design Features

**We have made a first analysis of the interior volumes created by the deployed habitat and conclude that it would be sufficient for a crew of 8 to have a productive working and living experience.**

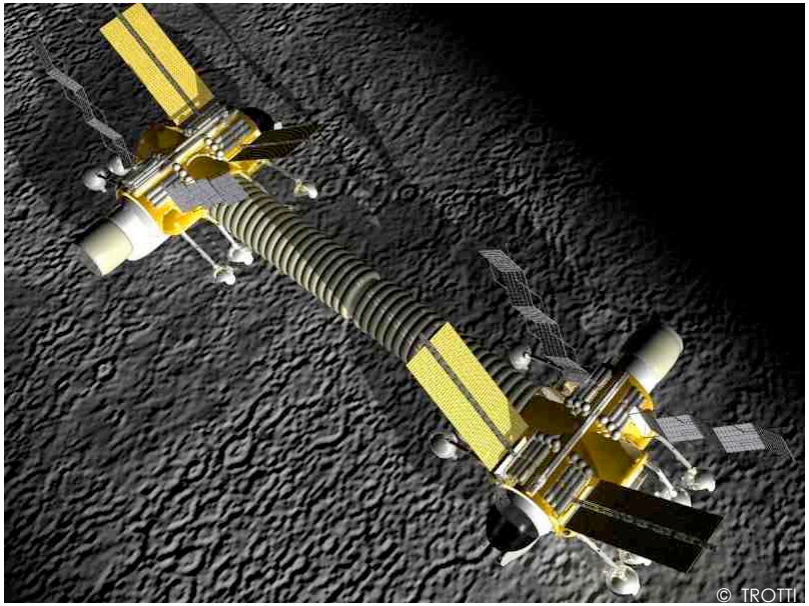
View of Cockpit and workstations

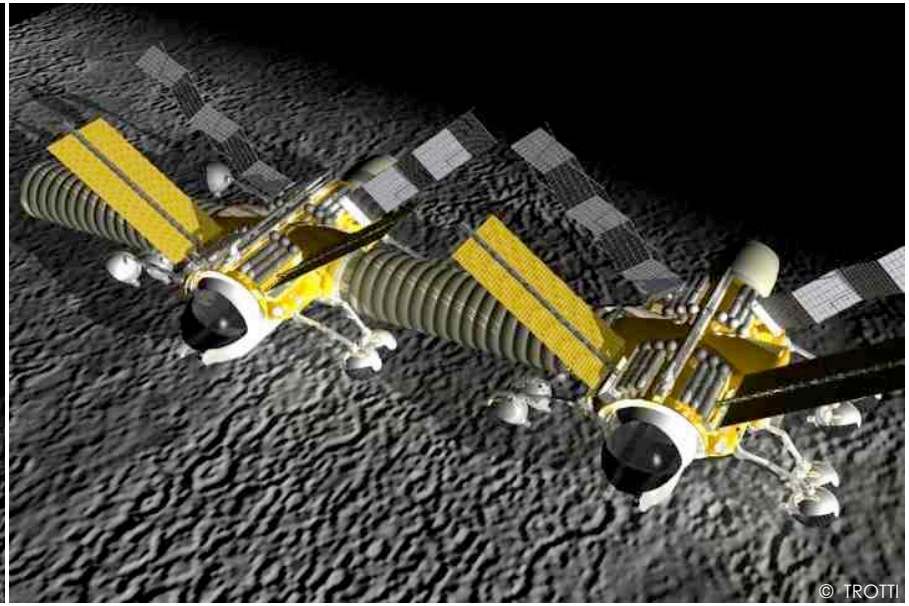



View of Wardroom and Deployed Habitat

# EXP–Arch Campsite Configuration

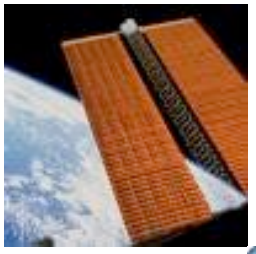
**The two Mother Ships can dock together to make a significant base camp. Two different configurations are possible.**



# Power Generation - Solar Arrays

**Power will be generated by solar arrays during the daytime and by Hydrogen/Oxygen fuel cells during the night.**

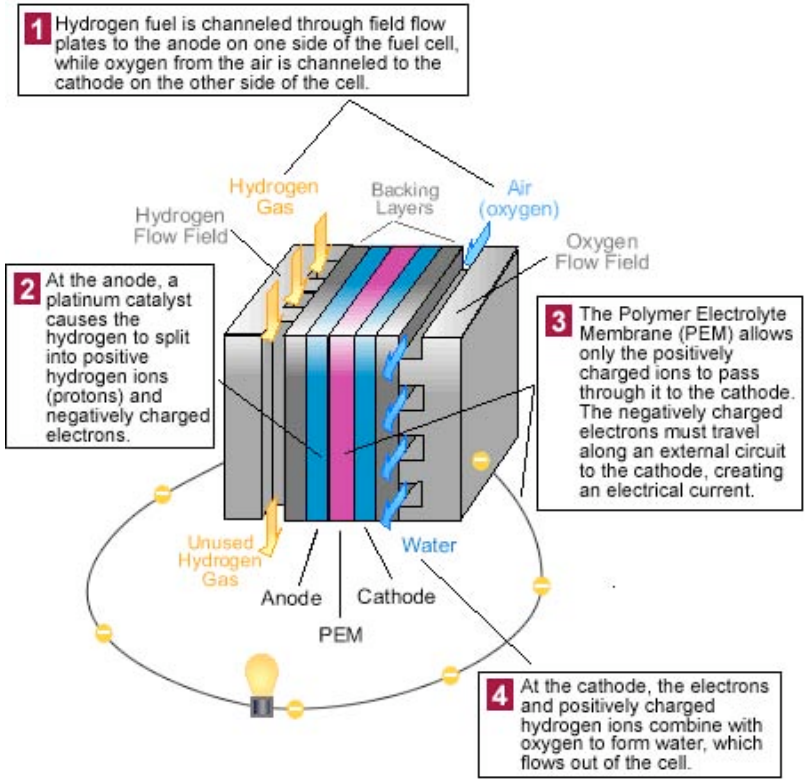


- Solar Array (50 kW each)
- Size: Two Arrays, each 3.75m x 10m long with tracking capability.
- Area: 75 $m^2$ @ 1345 $W/m^2$ insolation
- 50% Efficiency
- Gross Power Out: 50.4 kW
- Angularity Factor: 71% for an average of $45^o$ off-axis
- Conductor Losses: 90%
- Power Conditioner: 75%
- Net Power output during daylight hours: 24 kW to batteries or for instant use.

**Efficiency and reliability of Solar Cells are improving.**

# Power Generation and Heat Rejection

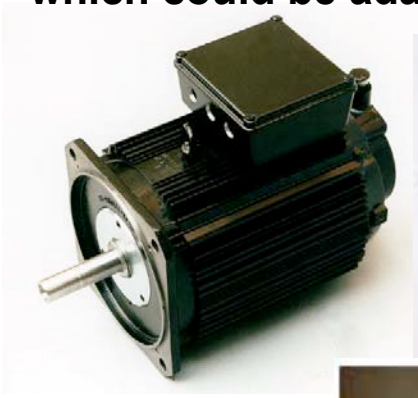
Fuel Cell technology is maturing rapidly and should be readily available by the time we return to the moon.




- 25 kW Hydrogen Fuel Cells based upon electrolyzer / compressor efficiency and vehicle power needs other than locomotion.
- An estimated 9.6 kW available while in motion during daylight.
- Batteries Li-ion,NiCd,NiMH
- Carbon-Carbon (K1100) Radiators (50% lighter than aluminum, 3 times more conductive than copper)

# Drive Motors and Power requirements

**Several high efficiency electrical drive motors are available on the market today which could be adapted for use under the extreme conditions of the Lunar environment.**



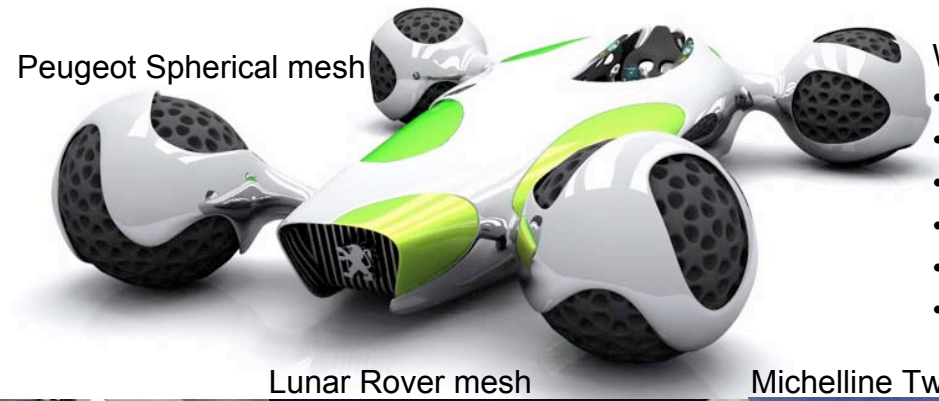

Preliminary requirements:

- <10 mT total mass with 8 wheels
- 17 Km/hr top speed, cruising speed 10 km/hr.
- Ratio on Mass: 14.3 HP= 11 kW power output or
- 1.4 kW output each motor at 75% drive train efficiency.
- Power input per motor: 1.8 kWe or 14.5 kW total drive train.

# Wheel Train Design

**The rovers will be equipped with 'proprioceptive' sensors to determine the position of each joint, the amount of current drawn by each motor, the tilt in 3 dimensions (yaw, pitch, roll) and the load on each wheel.**

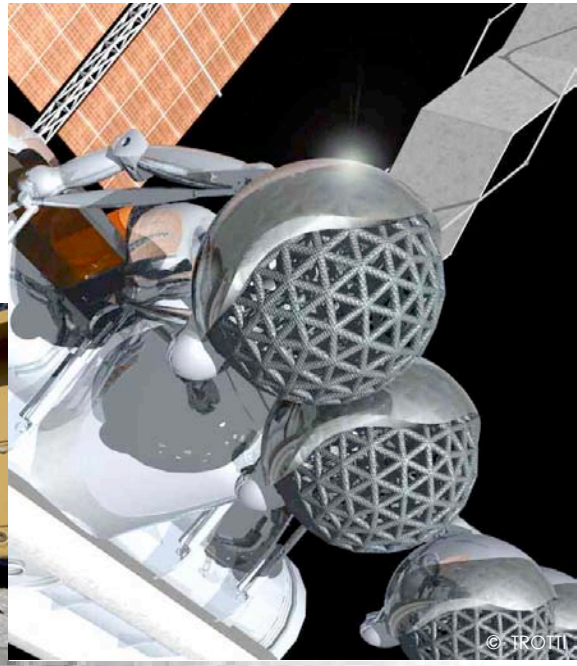
Peugeot Spherical mesh



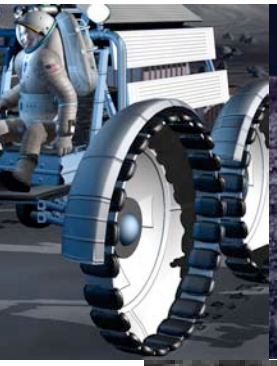
Wheel train features:

- Maximum contact patch
- High traction
- Debris reduction
- Passive suspension
- Nano tubes structure
- Easily replaced

EXP-Arch Nanotube structure design



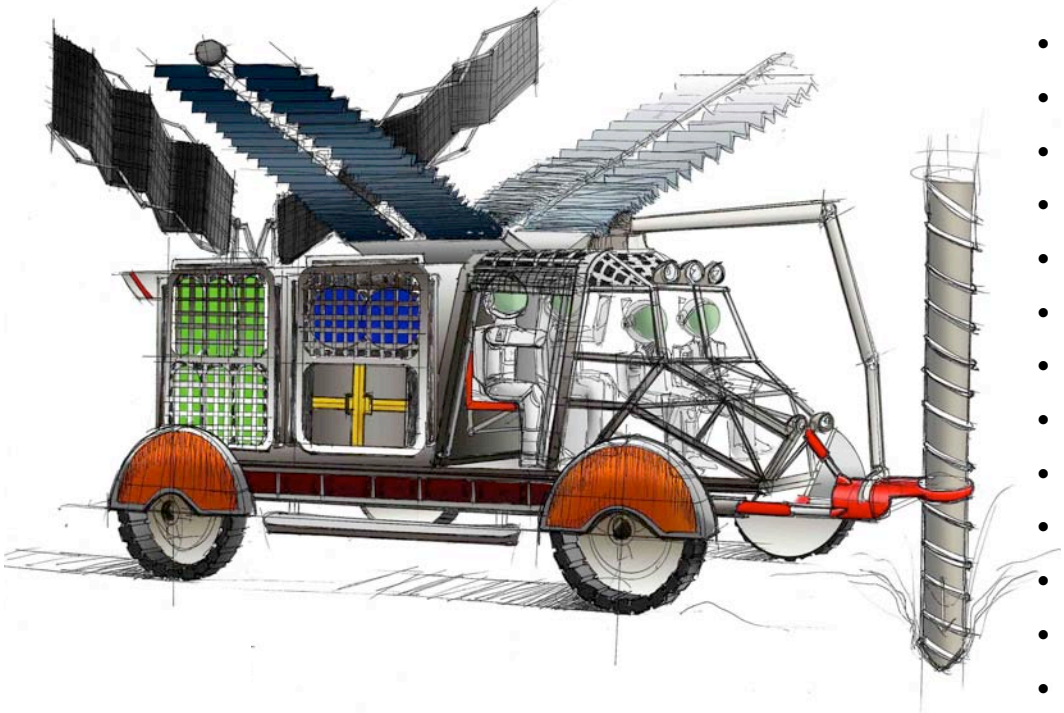

Lunar Rover mesh



Michelline Twheels

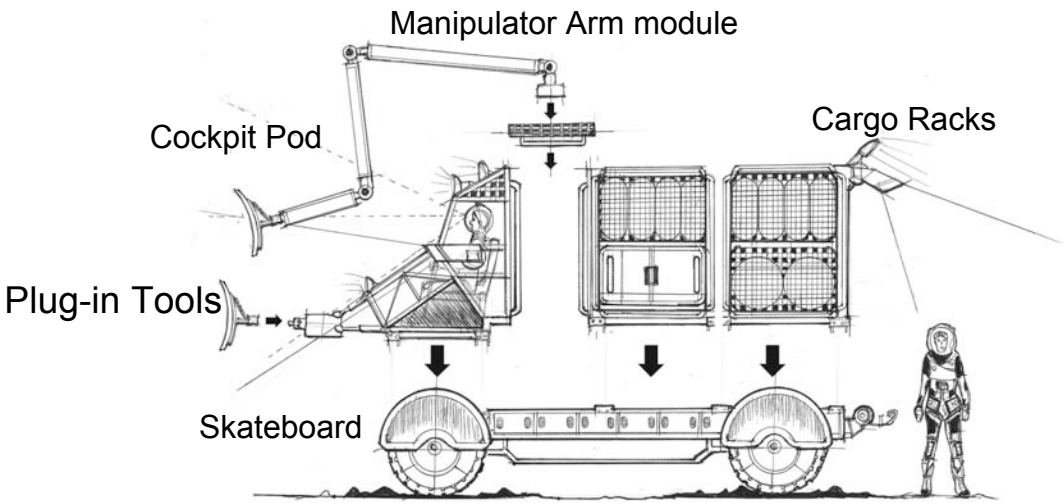
# Mini Rover (MR) Design Criteria

**The Mini Rovers are the agile assistants to the MSR. They move faster and are able to handle a variety of tasks manned or unmanned**

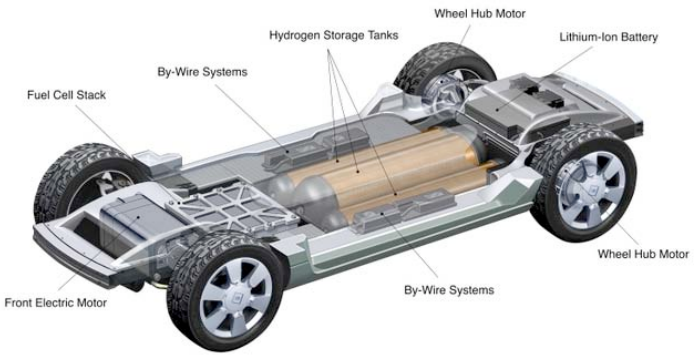


- All Terrain Vehicle
- 4 Wheel drive
- High traction
- Operational during day and night cycles
- Crew Transport (4 Astronauts)
- Cargo Transport
- Regolith mover
- MSR Assistant
- Tele-operation / Joystick control
- Stereoscopic vision
- Wireless controls
- Adaptable to mission requirements
- Mass - 2mT

# Mini Rover design




Skateboard Design

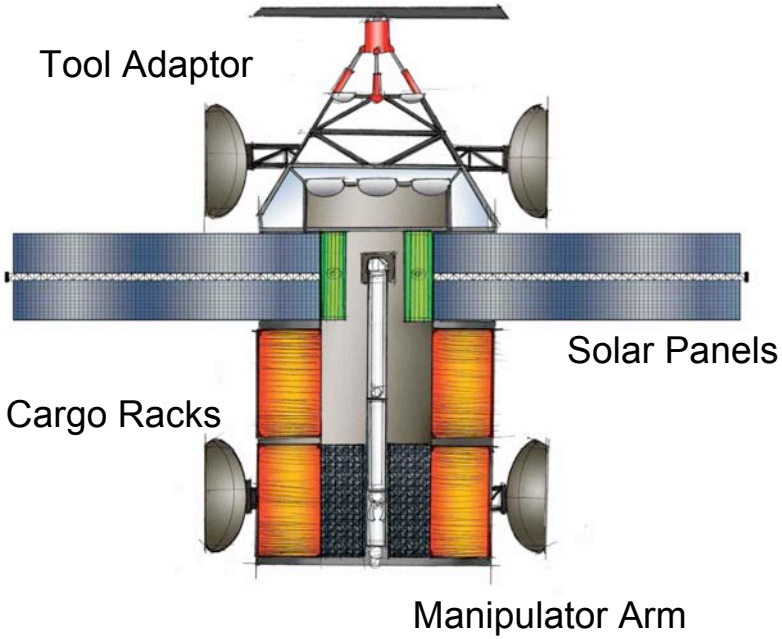



## General Features

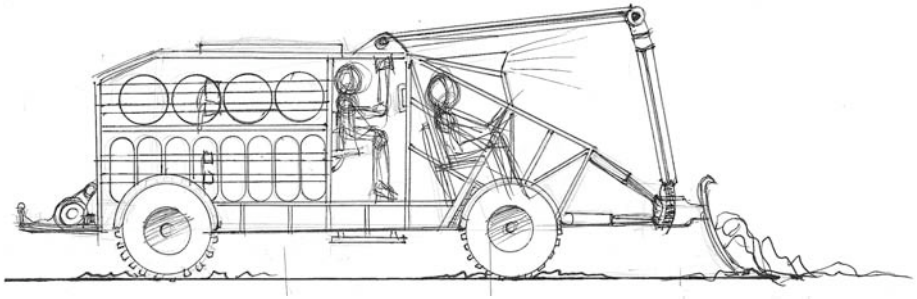
- Skateboard containing batteries, fuel cell, and control systems.
- General Dimensions: 12’ long X 6’ wide X 7’ high 9 (unfolded)
- Launch Configuration: Roof and wheels are foldable to minimize volume during launch.
- Energy: Solar cells, fuel cells, batteries
- Propulsion: 4 independent electric motors.
- Mobility: Four wheels 90 degrees rotation.
- Materials: Composites and aluminum.
- Tools: Winch, plow, drills, manipulator arm, trench digger, auger gun.
- Micrometeorite shielding: The Mini’s will have an aluminum canopy to provide some shielding and mounting of the solar cells.

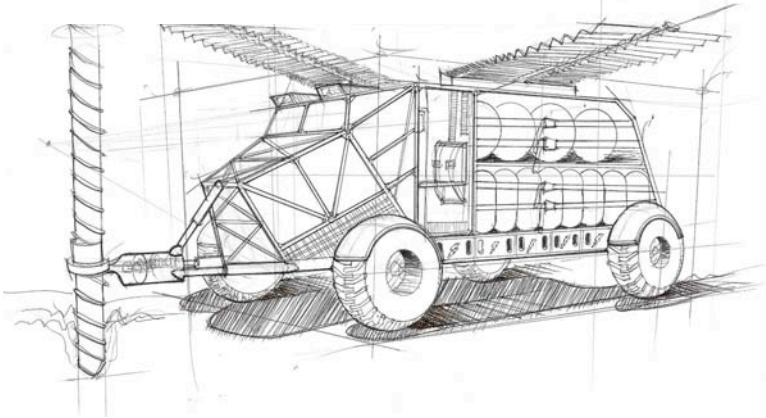
# Mini Rover design

**The Mini Rovers play a critical roll on assisting the MSR during a Solar event**



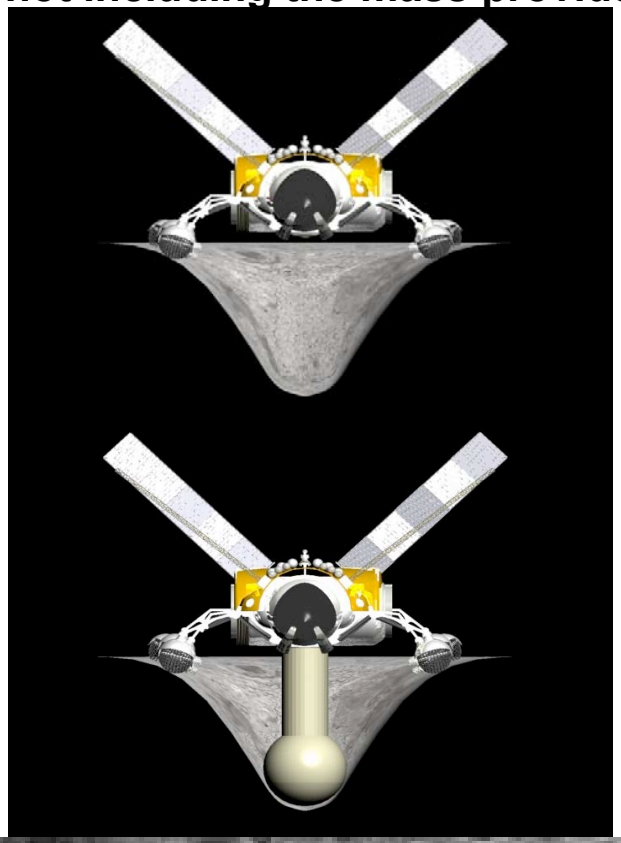

**Mini Rover Plan View**

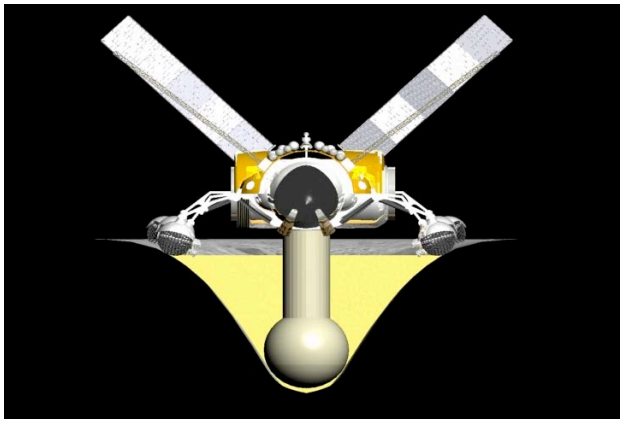




# Radiation Protection Strategies

**The Storm Shelter concept provides a minimum of 3.5 m of regolith shielding not including the mass provided by the vehicle.**





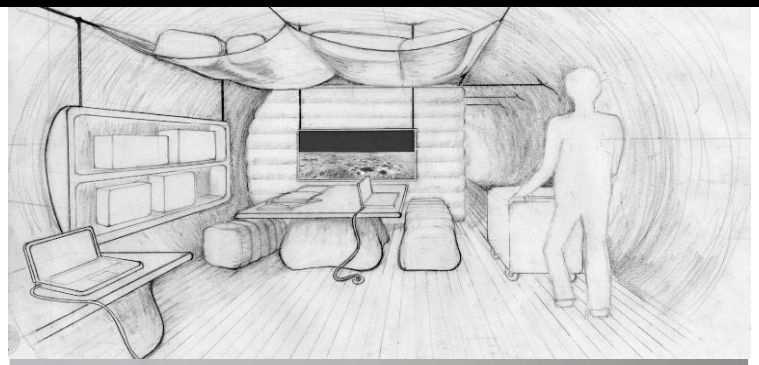
- Rover design/mass allocation
- Storm shelter (maximum depth = 6.2 m)
- Passive shielding - 20 gm/cm$^2$
- Pharmacological measures
- Alert/warning communications infrastructure
- Passive dosimeters on Craft and Astronauts
- Maximum wheel span = 11 m

# Education Outreach: Rhode Island School of Design

*Michael Lye – Design for Extreme Environment Instructor*

## Origami / Foldable Structures Studies

Student: Elizabeth Thelan



*Although only the work of a few of the students is featured here, this project would not have been possible without the efforts of all of the students that were involved with it: Keith Archer, Hyung Yun Choi, Amy Chuang, Rachael Gordon, Myung Hwan Kim, Kris Lee, Juan Martinez, Irene Noh, Eugene Suh, Elizabeth Thelen.*

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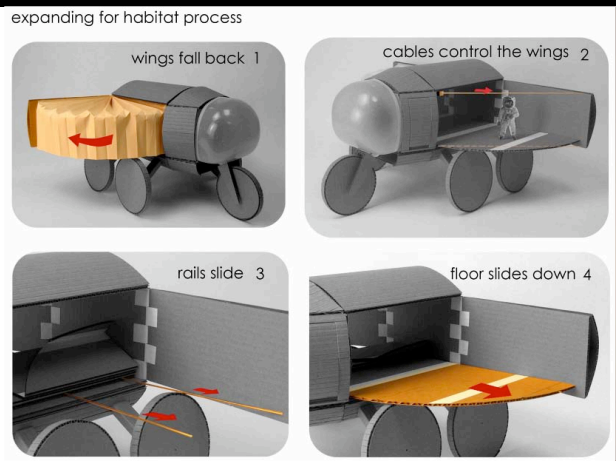
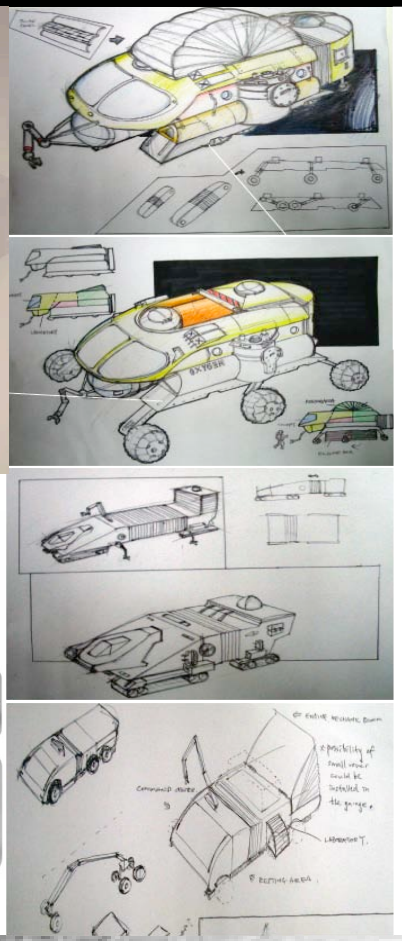
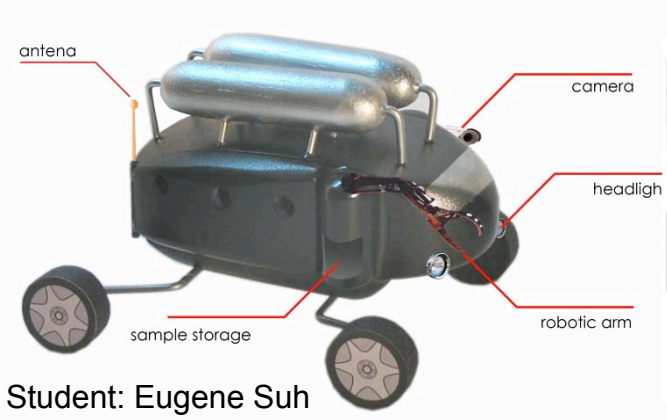
# Education Outreach: Rhode Island School of Design (continued)

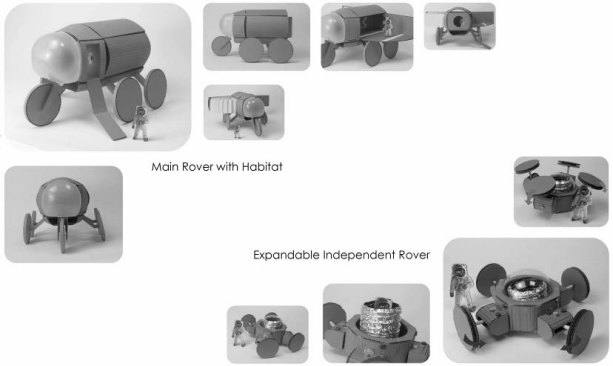





Student: Eugene Suh

Student: Myung Hwan Kim




**Board of Advisors participated in the final design review**

Rhode Island Space Grant Consortium NASA

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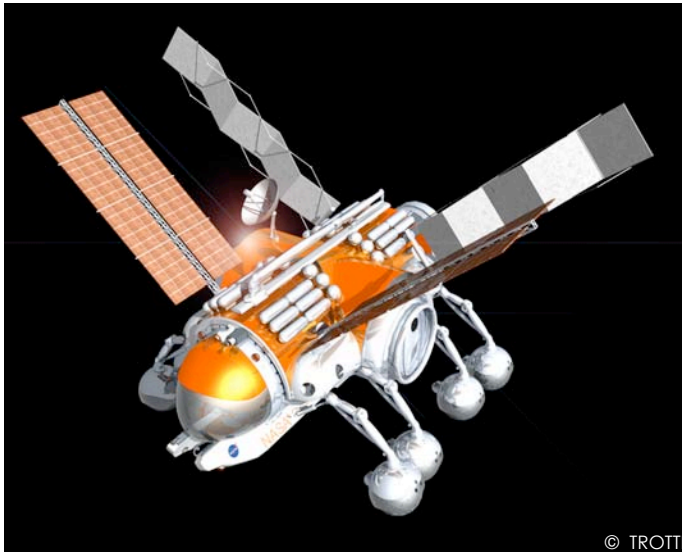
# Conclusions

**Extreme Expeditionary Mission Architecture is a complex System of Systems – re-deployable, transformable, autonomous & human collaboration, explore many diverse sites**




**Creative Design: mobile rover "convoy":**
Pressurized rovers, Un-pressurized mini rovers, Foldable structures, Transformable, Lunar camping

**Human & Robotic Experience**: Surface operations, Planetary Exploration, Mars Mission Training, Self-Sufficiency, Enable "spacefaring species"

**Technology Testbeds**: Mining, Construction, Science, Experience, Rapid Excavation and Regolith Movement (for radiation protection), Systems Testing, Mars Mission Testbed

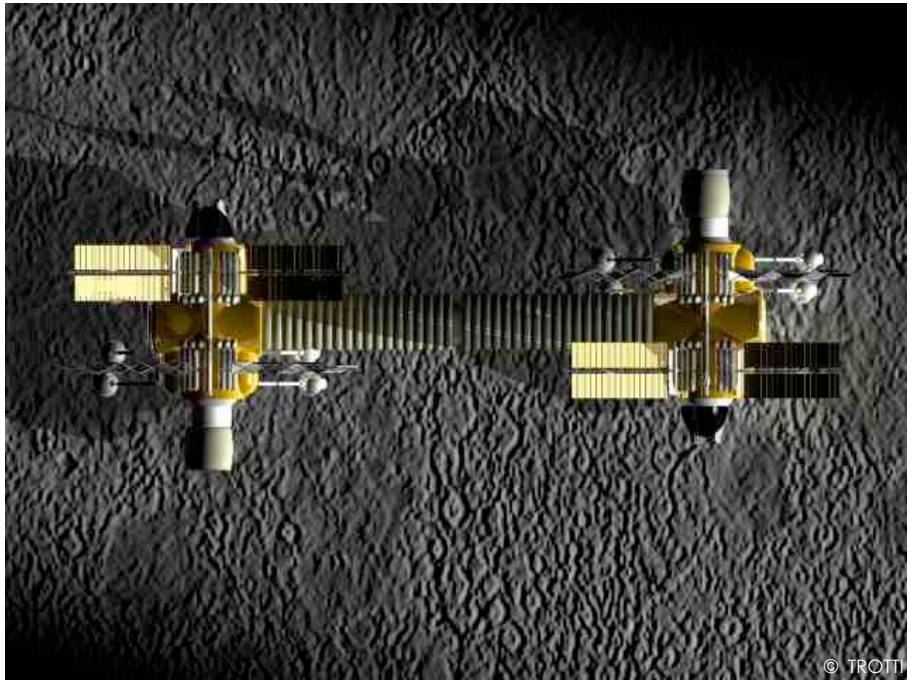
**Lunar Surface Exploration and Science:** Investigate caves/lava tubes, Search for water (ice), Selenology, Physics, Astronomy, Geology, Chemistry, & Life Sciences

**Technology assessment**: Design, Composites, Controls, Robotics, Re-deployable pneumatic structures, Propulsion, Power

**Public Interest/Outreach**: Engage public participation: "The People's Moon", How about a pole to pole race?

# Future Research

## Phase II Emphasis




**Mission Architecture Feasibility**

**Expandable Environments Prototyping**

- Re-deployable Inflatable Structures
- Foldable Structures

**Composite materials research**

**Radiation Protection Development**

- Strategies
- Tools

**Large Robotic Systems Operations**

**Understand Human Performance**

**Technology Roadmap Development**

**Extensive Educational Outreach**

# Acknowledgments

**Advisory Board Members:**
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Thank You!

Questions?