Exploring Space In Partnership

Using the International Space Station

Exploring Space In Partnership

Operating in the Lunar Vicinity

2020s

Leaving the Earth-Moon System and Reaching Mars Orbit

2030s

Now

Phase 0
Solve exploration mission challenges through research and systems testing on the ISS. Understand if and when lunar resources are available

Phase 1
Conduct missions in cislunar space; assemble Deep Space Gateway and Deep Space Transport

Phase 2
Complete Deep Space Transport and conduct Mars verification mission

Phases 3 and 4
Missions to the Mars system, the surface of Mars

Advancing technologies, discovery and creating economic opportunities
Human Exploration of Mars is Hard

- **20-30 tons** Ability to land large payloads needed
- **130 tons** Heavy-lift mass means **multiple** launches per mission
- **13.5 km/s** Earth re-entry speed
- **800-1100 days away from** Earth in micro gravity and high levels of radiation
- **44 minute max** two-way communication delay
- **2-week blackout** every 26 months when Earth and Mars are on opposite sides of the sun
- **20 tons** of oxygen needed for ascent to orbit: In-Situ Resource Utilization (ISRU)

**Reliable in-space transportation:** Total continuous transportation power

**Thin atmosphere and dusty conditions for surface operations.**
Specific Deep Space Habitation Systems Objectives

Habitation Systems Elements

1. LIFE SUPPORT
   - Atmosphere Management
   - Waste Management
   - Water Management
   - Microbes
   - Moisture
   - Pressure
   - O₂ & N₂

2. ENVIRONMENTAL MONITORING
   - Pressurized CO₂ & N₂
   - Moisture
   - Particles
   - Microbes
   - Chemicals
   - Sound

3. CREW HEALTH
   - Monitoring
   - Exercise
   - Diagnostics
   - Treatment
   - Food Storage & Management

4. EVA: EXTRA-VEHICULAR ACTIVITY
   - Mobility
   - Life Support
   - Science and Exploration

TODAY
- ISS
- 42% O₂ Recovery from CO₂
- 90% H₂O Recovery
- < 6 mo mean time before failure (for some components)

FUTURE
- Deep Space
- 75%+ O₂ Recovery from CO₂
- 98%+ H₂O Recovery
- >30 mo mean time before failure

Limited, crew-intensive on-board capability
- Reliance on sample return to Earth for analysis

On-board analysis capability with no sample return
- Identify and quantify species and organisms in air & water

Bulky fitness equipment
- Limited medical capability
- Frequent food system resupply

Smaller, efficient equipment
- Onboard medical capability
- Long-duration food system

High upper body mobility for limited sizing range
- Low interval between maintenance, contamination sensitive, and consumables limit EVA time
- Construction and repair focused tools; excessive inventory of unique tools

Full body mobility for expanded sizing range
- Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time
- Geological sampling and surveying equipment; common generic tool kit
Specific Habitation Systems Objectives

Habitation Systems Elements

**Radiation Protection**
- Monitoring
- Tracking
- Modeling
- Mitigation

**Fire Safety**
- Detection
- Protection
- Suppression
- Cleanup

**Logistics**
- Tracking
- Clothing
- Packaging
- Trash

**Cross-Cutting Technologies**
- Robotics
- Communication
- Avionics, Autonomy & Software
- Power
- Docking
- Thermal
- Materials

**Today**
- Space Station
  - Node 2 crew quarters (CQ) w/ polyethylene reduce impacts of proton irradiation.
  - RAD, REM – real-time dosimetry, monitoring, tracking, model validation & verification
  - TEPC, IVTEPC – real-time dosimetry
  - CPD, RAM – passive dosimeters

**Future**
- Deep Space
  - Solar particle event storm shelter, optimized position of on-board materials and CQ
  - Distributed REM/HERA system for real-time monitoring & tracking
  - CPAD – real-time dosimeter

- **Today**
  - **CROSS-CUTTING TECHNOLOGIES**
    - Tracking
    - Trash
    - Power
    - Docking
    - Thermal
    - Materials

- **Future**
  - **Logistics**
    - Tracking
    - Packaging
    - Trash

- **Today**
  - **Fire Safety**
    - Detection
    - Suppression
    - Cleanup

- **Future**
  - **Fire Safety**
    - Obsolete combustion prod. sensor
    - Only depress/repress clean-up

- **Today**
  - **Radiation Protection**
    - Modeling

- **Future**
  - **Radiation Protection**
    - Minimal on-board autonomy
    - Near-continuous ground-crew comm
    - Some common interfaces, modules controlled separately

- **Today**
  - **Radiation Protection**
    - Monitoring
    - Tracking
    - Modeling
    - Mitigation

- **Future**
  - **Radiation Protection**
    - Ops independent of Earth & crew
    - Up to 40-minute comm delay
    - Widespread common interfaces, modules/systems integrated
    - Manufacture replacement parts in space
Exploration ECLSS Diagram

Crew Systems
- Hygiene water
- Potable Water Dispenser

Ag Biocide

Water Quality Monitors

Water

Oxygen Generation
- 
- 

O$_2$/N$_2$ Control
- 
- 

Particulate Monitor

Atmosphere Monitors

Fire Detection & Suppression

Microbial Monitor (Water & Surfaces)

Nitrogen

CO$_2$ Reduction

CO$_2$ Removal

CO$_2$

By-products

Oxygen

H$_2$

Water

Potable Water Processing

Product Water

Waste Water

Ag Biocide

Processed Urine

Brine water

Brine & Urine Sensors

Urine Recovery

PT Urine

Recovered H$_2$O

Waste

Waste Mgmt

Cabin Air

Cabin Return

Filtration & Heavy VOC Removal

TCCS

Temp & Humidity Control

Air

Condensate
Current ISS Capabilities and Challenges: Atmosphere Management

- **Circulation**
  - ISS: Fans (cabin & intermodule), valves, ducting, mufflers, expendable HEPA filter elements
  - Challenges: Quiet fans, filters for surface dust

- **Remove CO₂ and contaminants**
  - ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO₂ for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  - Challenges: Reliability, ppCO₂ <2 mmHg, commercial sorbents

- **Remove humidity**
  - ISS: Condensing heat exchangers with anti-microbial hydrophilic coatings requiring periodic dryout, catalyze siloxane compounds.
  - Challenge: Durable, inert, anti-microbial coatings that do not require dry-out

- **Supply O₂**
  - ISS: Oxygen Generation Assembly (H₂O electrolysis, ambient pressure); high pressure stored O₂ for EVA
  - Challenge: Provide high pressure/high purity O₂ for EVA replenishment & medical use

- **Recovery of O₂ from CO₂**
  - ISS: Sabatier process reactor, recovers 42% O₂ from CO₂
  - Challenge: >75% recovery of O₂ from CO₂
Current ISS Capabilities and Challenges: Water Management

• Water Storage & biocide
  – ISS: Bellows tanks, collapsible bags, iodine for microbial control
  – Challenges: Common biocide (silver) that does not need to be removed prior to crew consumption; dormancy

• Urine Processing
  – ISS: Urine Processing Assembly (vapor compression distillation), currently recovers 80% (brine is stored for disposal)
  – Challenges: 85-90% recovery (expected with alt pretreat formulation just implemented); reliability; recovery of urine brine water

• Water Processing
  – ISS: Water Processor Assembly (filtration, adsorption, ion exchange, catalytic oxidation, gas/liquid membrane separators), 100% recovery, 0.11 lbs consumables + limited life hw/lb water processed.
  – Challenges: Reduced expendables; reliability
Current ISS Capabilities and Challenges: Waste Management

- **Logistical Waste** (packaging, containers, etc.)
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Reduce &/or repurpose

- **Trash**
  - ISS: Gather & store; dispose (in re-entry craft)
  - Challenge: Compaction, stabilization, resource recovery

- **Metabolic Waste**
  - ISS: Russian Commode, sealed canister, disposal in re-entry craft
  - Challenge: Long-duration stabilization, potential resource recovery, volume and expendable reduction
Current ISS Capabilities and Challenges: Environmental Monitoring

- **Water Monitoring**
  - ISS: On-line conductivity; Off-line total organic carbon, iodine; Samples returned to earth for full analysis
  - Challenge: On-orbit identification and quantification of specific organic, inorganic compounds.

- **Microbial**
  - ISS: Culture-based plate count, no identification, 1.7 hrs crew time/sample, 48 hr response time; samples returned to earth.
  - Challenge: On-orbit, non culture-based monitor with identification & quantification, faster response time and minimal crew time

- **Atmosphere**
  - ISS: Major Constituent Analyzer (mass spectrometry – 6 constituents); COTS Atmosphere Quality Monitors (GC/DMS) measure ammonia and some additional trace gases; remainder of trace gases via grab sample return; Combustion Product Analyzer (CSA-CP, parts now obsolete)
  - Challenges: On-board trace gas capability that does not rely on sample return, optical targeted gas analyzer

- **Particulate**
  - ISS: N/A
  - Challenge: On-orbit monitor for respiratory particulate hazards

- **Acoustic**
  - SOA: Hand held sound level meter, manual crew assays
  - Challenge: Continuous acoustic monitoring with alerting
## ECLSS & Environmental Monitoring Capability Gaps

<table>
<thead>
<tr>
<th>Function</th>
<th>Capability Gaps</th>
<th>Gap Criticality as applicable to μg transit Hab</th>
<th>Orion Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Removal</td>
<td>Bed and valve reliability; ppCO₂ &lt; 2 mmHg</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>O₂ recovery from CO₂</td>
<td>Recover &gt; 75% O₂ from CO₂</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Urine brine processing</td>
<td>Water recovery from urine brine &gt; 85%</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Metabolic solid waste collection</td>
<td>Low-mass, universal waste collection</td>
<td>5</td>
<td>X</td>
</tr>
<tr>
<td>Trace Contaminant Control</td>
<td>Replace obsolete sorbents w/ higher capacity; siloxane removal</td>
<td>4</td>
<td>X</td>
</tr>
<tr>
<td>Condensing Heat Exchanger</td>
<td>Durable, chemically-inert hydrophilic surfaces with antimicrobial properties</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Water microbial control</td>
<td>Common silver biocide with on-orbit redosing</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Contingency urine collection</td>
<td>Backup, no moving parts urine separator</td>
<td>4</td>
<td>X</td>
</tr>
<tr>
<td>Urine processing</td>
<td>Reliability, 85% water from urine, dormancy survival</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Atmosphere monitoring</td>
<td>Small, reliable atmosphere monitor for major constituents, trace gases, targeted gases</td>
<td>4</td>
<td>X</td>
</tr>
<tr>
<td>Water monitoring</td>
<td>In-flight identification &amp; quantification of species in water</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Microbial monitoring</td>
<td>Non-culture based in-flight monitor with species identification &amp; quantification</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>O₂ generation</td>
<td>Smaller, reduced complexity, alternate H₂ sensor</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>High pressure O₂</td>
<td>High pressure (3000 psi) O₂ for EVA/on-demand O₂ supply for contingency medical</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Wastewater processing (WPA)</td>
<td>Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Non-metabolic solid waste</td>
<td>Volume reduction, stabilization, resource recovery</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Particulate monitoring</td>
<td>On-board measurement of particulate hazards</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Particulate Filtration</td>
<td>Surface dust pre-filter; regen filter</td>
<td>2</td>
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</tr>
<tr>
<td>Atmosphere circulation</td>
<td>Quiet fans</td>
<td>2</td>
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<tr>
<td>Logistics Reduction</td>
<td>10:1 volume reduction logistical and clothing</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Metabolic solid waste treatment</td>
<td>Useful products from metabolic waste</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Current Status – Atmosphere Management

• **CO2 Removal**
  – Have initiated work on early thermal amine ISS flight demo targeted for 2018
  – Downselect among all options planned end of 2017
    • Using NRA thrust area announcement to ensure all options considered

• **Oxygen Generation & High Press O₂**
  – Testing to reduce complexity complete; team to assess ISS OGA recommended upgrades as a result

• **Oxygen Recovery/CO₂ Reduction**
  – STMD awarded two Phase II oxygen recovery projects:
    • Honeywell methane pyrolysis
    • Umpqua continuous Bosch
  – NASA development of methane plasma pyrolysis continues
  – ISS on-orbit Sabatier degrading; planning for return and troubleshooting
    • 2 of 3 oxygen recovery options include Sabatier
Current Status – Atmosphere Management, cont.

• Condensing Heat Exchanger
  – Several options under assessment with downselect in early FY19 for flight demonstration
  – Received NRA thrust area proposals – SMT evaluating

• Trace Contaminant Control
  – Alternate commercial sorbent testing
  – Supporting efforts to solve ISS siloxane problem

• Particulate Filtration
  – Pre-filter and regenerable filter development ongoing
Current Status – Water Management

- **Urine processing**
  - New pretreat formula on ISS improves recovery to 85-90%
  - Pump reliability improved by change to planetary gear
  - Improvements to distillation assembly in work

- **Water processing**
  - Improved catalyst development
  - Operational filter life extension
  - Alternate technology/reverse osmosis testing & trade

- **Brine processing**
  - ISS flight demonstration by Paragon in development – flies in 2018

- **Silver biocide**
  - Development of on orbit injection capability through SBIR projects
Capillary Structures for Exploration Life Support (SpX-11 manifest)

Investigation Summary

• Current life-support systems on the International Space Station require special equipment to separate liquids and gases, including rotating or moving devices that could cause contamination if they break or fail.

• The Capillary Structures investigation studies a new method using structures of specific shapes to manage fluid and gas mixtures.

• The investigation studies water recycling and carbon dioxide removal, benefiting future efforts to design lightweight, more reliable life support systems for future space missions.

Alexander Gerst conducts a session with the Capillary Flow Experiment (CFE-2).

Samantha Cristoforetti takes a sip of espresso from the Capillary Beverage investigation.
Featured Investigation
Capillary Structures

Partially wetting fluids that are in contact with air and solid surfaces want to minimize their total surface energy by:

**Maximizing the amount of surface area in contact with the solid surface**

**Minimizing the amount of surface area in contact with air**
Featured Investigation
Capillary Structures

Capillary Brine Residual in Containment (CapiBRIC)

• designed to passively recover water from brine
• characterizes both containment and evaporation performance of the capillary structure within the CapiBRIC, called the “Capillary Evaporator”

Large amount of surface area exposed to air, large amount of surface area in contact with solid surface

Capillary Evaporator:
evaluates effectiveness of various shapes/structures and fluid stability of sample components. A non-toxic ersatz used to mimic ISS wastewater brine.
Featured Investigation
Capillary Structures

Capillary Liquid CO2 Sorbent System (CapiSorb)

- designed to remove CO2 from air using a liquid sorbent, and to regenerate the sorbent

- focuses on evaluating flow across manifolded capillary channels as a function of total system liquid volume, and pump speed

CapiSorb - proof of concept of the microgravity regenerable liquid sorbent system.

Capillary flow can be integrated into a recirculating loop.
Progress – Waste Management

• **Commode**
  – Minimum mass fecal container development

• **Fecal processing**
  – Torrefaction SBIR development

• **Trash management**
  – Heat melt compactor and trash to gas development

• **Logistics Reduction**
  – Long wear clothing demonstrated on ISS
  – Repurposing of packaging and cargo bags
• **RFID Enabled Autonomous Logistics Management (REALM)**
  - 6 RFID readers and 24 antennas (REALM-1) were launched on HTV6 in December and deployed in February
  - Successfully demonstrated end-end data transfer and down linked over 600 million tag reads from over 3,000 unique tags
  - Responded to unplanned real-time ISS request to locate missing cargo bag slated for SpX-10 return. Manually searched data to predict missing bag location which demonstrated ‘find’ capability
  - A mobile RFID reader (REALM-2) for the Astrobee free flyer is under development for FY19
Current Status – Environmental Monitoring

• **Atmosphere Monitoring**
  – Spacecraft Atmosphere Monitor (SAM) micro GC/MS for major constituents and trace gases ISS tech demo planned (2018)
  – Laser-based monitors for combustion products and targeted gases planned for Saffire demonstration, upgrade of ISS combustion products monitor and Orion Anomaly Gas Analyzer implementation
  – Improved mass spec for ISS & Orion use

• **Water Monitoring**
  – Requirements in development
  – Front end to atmosphere monitor for water samples
Microbial Monitoring

• RAZOR
  – COTS Polymerase Chain Reaction (PCR) unit launched to ISS in July 2016 aboard SpX-9 – detect & identify microorganisms
  – First device to perform quantitative PCR using ISS water samples in the microgravity environment of space – “sample to answer”
  – 9 successful test runs completed Sept 2016 – March 2017

• Mini-PCR DNA sequencer demonstrated on ISS as part of Genes in Space
Current Status – Environmental Monitoring, cont

- **Particulate Monitor**
  - Aerosol sampler (flown on OA-5) just completed ISS ops, samples just returned on SpaceX-10.
    - Analysis will begin immediately upon return and will include a variety of microscopic techniques to determine particle morphology, composition, and long-term average concentrations
    - Data will inform the design of particulate monitors for future long-term missions
  - SBIR particulate monitor development expected to lead to future ISS tech demo
ISS actively working on integration concepts for Exploration ECLSS

- Water system will be evolution of current ISS Water Recovery System in Node 3
  - Upgrades to WPA and UPA could require retrofit in a rack space nearby
- Air system must be co-located and may incorporate new CO2 removal/reduction technologies – plan is to move to USL as Node 3 cannot accommodate this string
  - Oxygen Generation System rack must move to USL to enable integration in adjacent rack space(s)
  - Will require racks in USL to be moved to other locations