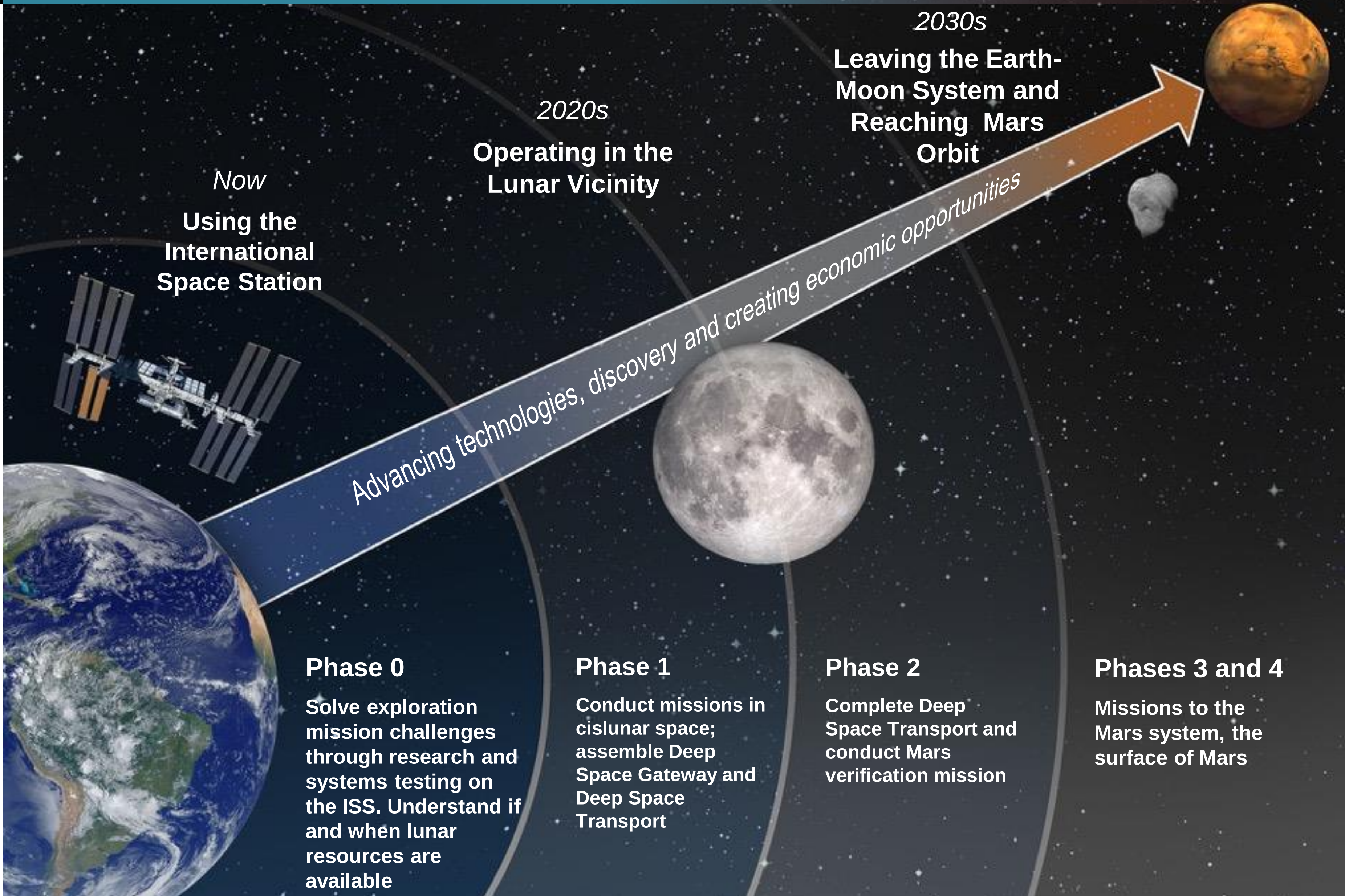
Environmental Control & Life Support Systems for Human Spaceflight

Exploration Systems Interface with Biological and Physical Sciences Symposium
March 29, 2017

Robyn Gatens
Deputy Director, International Space Station Division
Human Exploration and Operations Mission Directorate

Exploring Space In Partnership

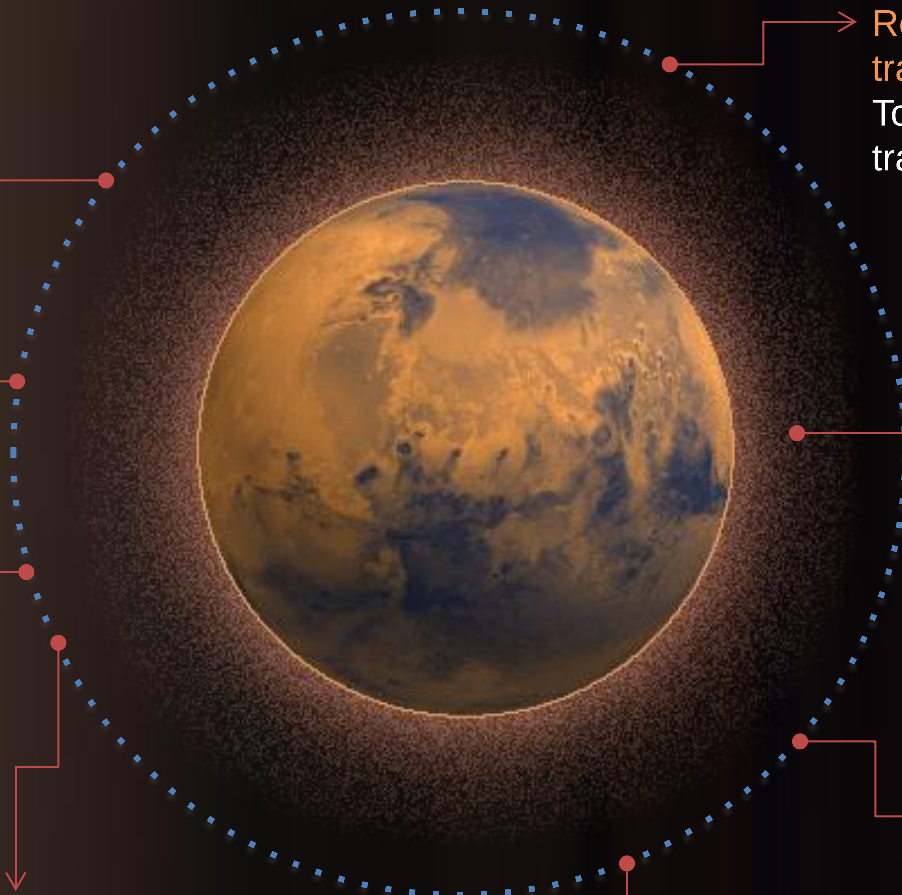


Human Exploration of Mars is Hard

20-30 tons
Ability to land large payloads needed

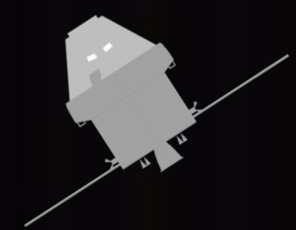
130 tons
Heavy-lift mass means **multiple** launches per mission

13.5 km/s Earth re-entry speed



Reliable in-space transportation:
Total continuous transportation power

Thin atmosphere and dusty conditions for surface operations.



44 minute max two-way communication delay
2-week blackout every 26 months when Earth and Mars are on opposite sides of the sun

800-1100 days away from Earth in micro gravity and high levels of radiation

20 tons of oxygen needed for ascent to orbit: In-Situ Resource Utilization (ISRU)

Specific Deep Space Habitation Systems Objectives

Habitation Systems Elements

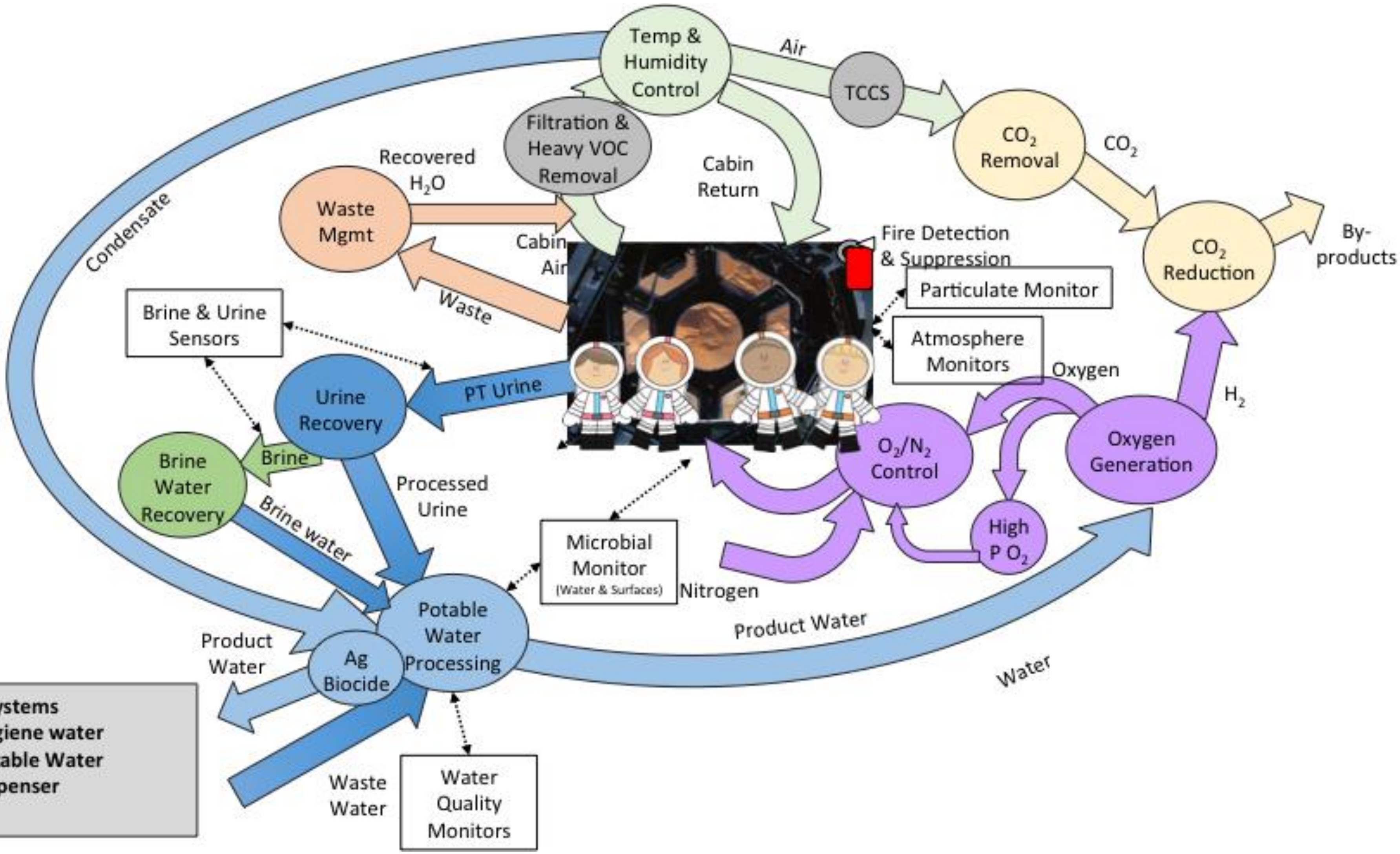
Habitation Systems Elements	TODAY ISS	FUTURE Deep Space
1 LIFE SUPPORT: Atmosphere Management, Water Management, Waste Management	42% O_2 Recovery from CO_2; 90% H_2O Recovery; < 6 mo mean time before failure (for some components)	75%+ O_2 Recovery from CO_2; 98%+ H_2O Recovery; >30 mo mean time before failure
2 ENVIRONMENTAL MONITORING: Pressure O_2 & N_2, Moisture, Particles, Microbes, Chemicals, Sound	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
3 CREW HEALTH: Monitoring, Exercise, Diagnostics, Treatment, Food Storage & Management	Bulky fitness equipment; Limited medical capability; Frequent food system resupply	Smaller, efficient equipment; Onboard medical capability; Long-duration food system
4 EVA: EXTRA-VEHICULAR ACTIVITY: Mobility, Life Support, Science and Exploration	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

		TODAY Space Station	FUTURE Deep Space
RADIATION PROTECTION	Monitoring, Tracking, Modeling, Mitigation	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	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
FIRE SAFETY	Detection, Protection, Suppression, Cleanup	Large CO_2 Suppressant Tanks 2-cartridge mask Obsolete combustion prod. sensor Only depress/repress clean-up	Water Mist portable fire extinguisher Single Cartridge Mask Exploration combustion product monitor Smoke eater
LOGISTICS	Tracking, Clothing, Packaging, Trash	Manual scans, displaced items Disposable cotton clothing Packaging disposed Bag and discard	Automatic, autonomous RFID Long-wear clothing/laundry Bags/foam repurposed w/3D printer Resource recovery, then disposal
CROSS-CUTTING TECHNOLOGIES	Robotics, Power, Communication, Docking, Avionics, Autonomy & Software, Thermal, Materials	Minimal on-board autonomy Near-continuous ground-crew comm Some common interfaces, modules controlled separately	Ops independent of Earth & crew Up to 40-minute comm delay Widespread common interfaces, modules/systems integrated Manufacture replacement parts in space

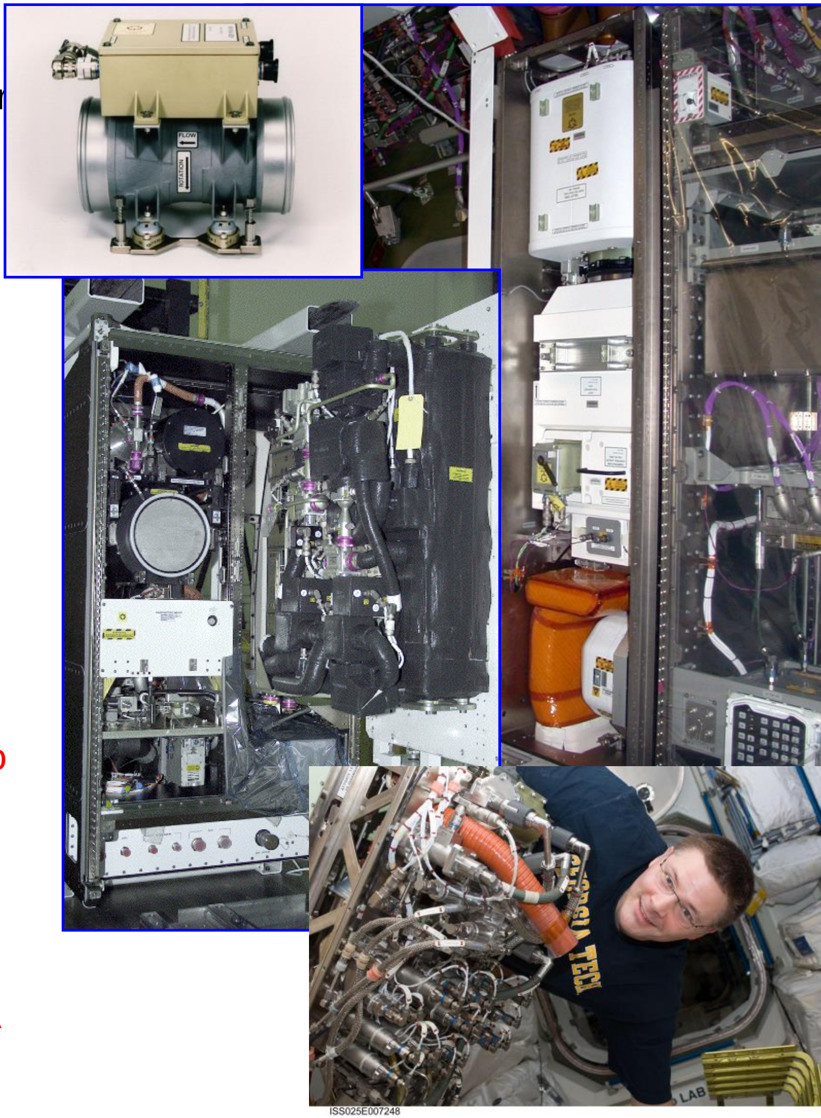
Exploration ECLSS Diagram



Crew Systems
- Hygiene water
- Potable Water Dispenser

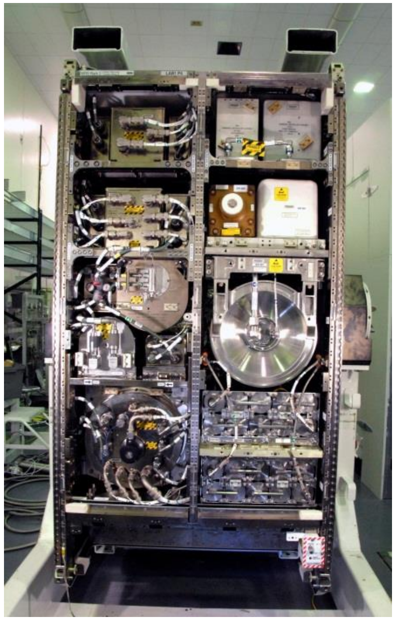
Current ISS Capabilities and Challenges: Atmosphere Management

- **Circulation**
  - ISS: Fans (cabin & intermodule), valves, ducting, muffler expendable HEPA filter elements
  - Challenges: Quiet fans, filters for surface dust
- **Remove CO_2 and contaminants**
  - ISS: Regenerative zeolite CDRA, supports ~2.3 mmHg ppCO2 for 4 crew. MTBF <6 months. Obsolete contaminant sorbents.
  - Challenges: Reliability, ppCO_2 <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 O_2**
  - ISS: Oxygen Generation Assembly (H_2O electrolysis, ambient pressure); high pressure stored O_2 for EVA
  - Challenge: Provide high pressure/high purity O_2 for EVA replenishment & medical use
- **Recovery of O_2 from CO_2**
  - ISS: Sabatier process reactor, recovers 42% O_2 from CO_2
  - Challenge: >75% recovery of O_2 from CO_2



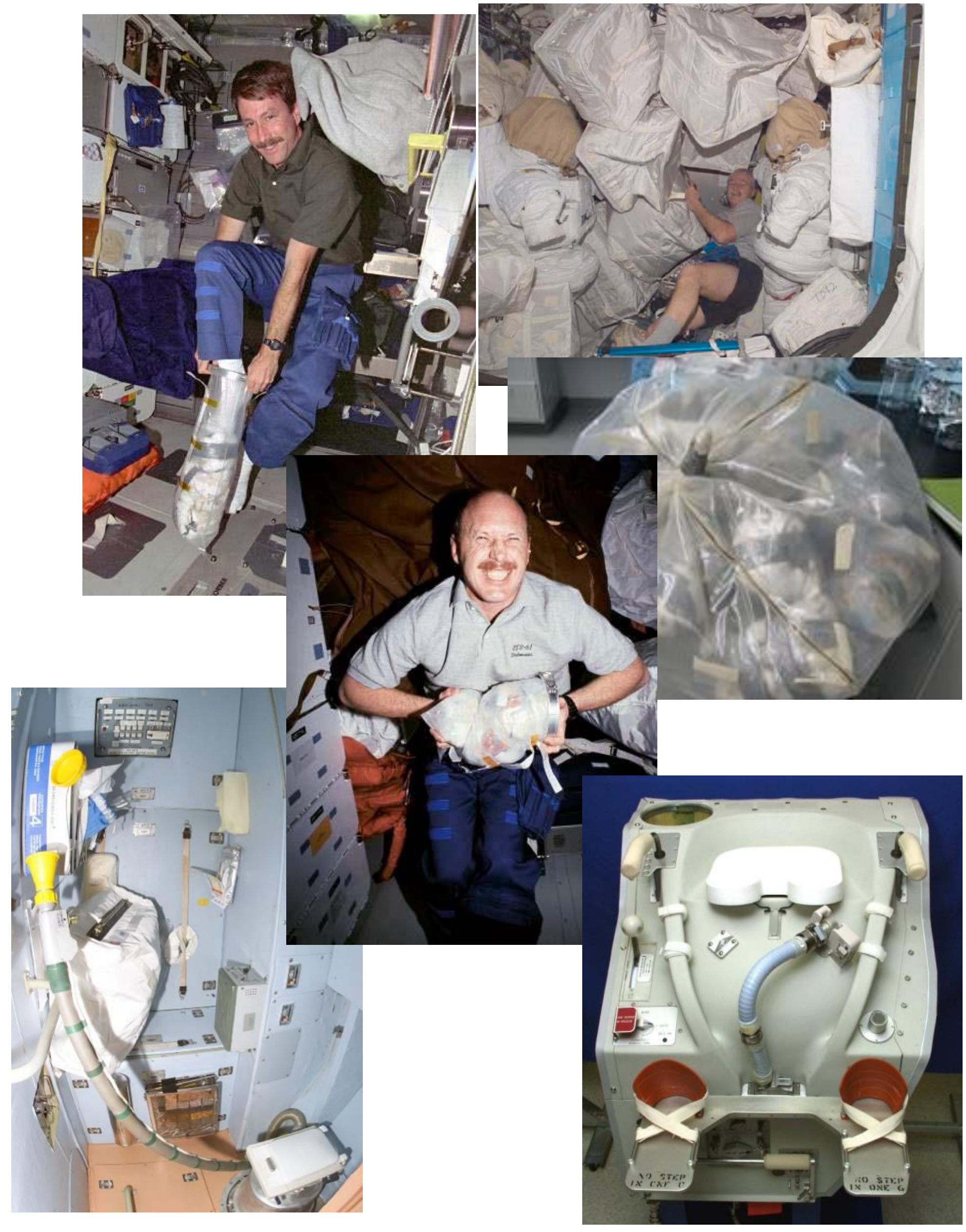
Current ISS Capabilities and Challenges:
Water Management

- **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



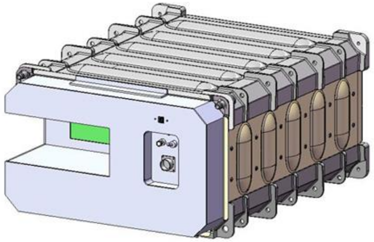
Current ISS Capabilities and Challenges: Waste Management

- **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

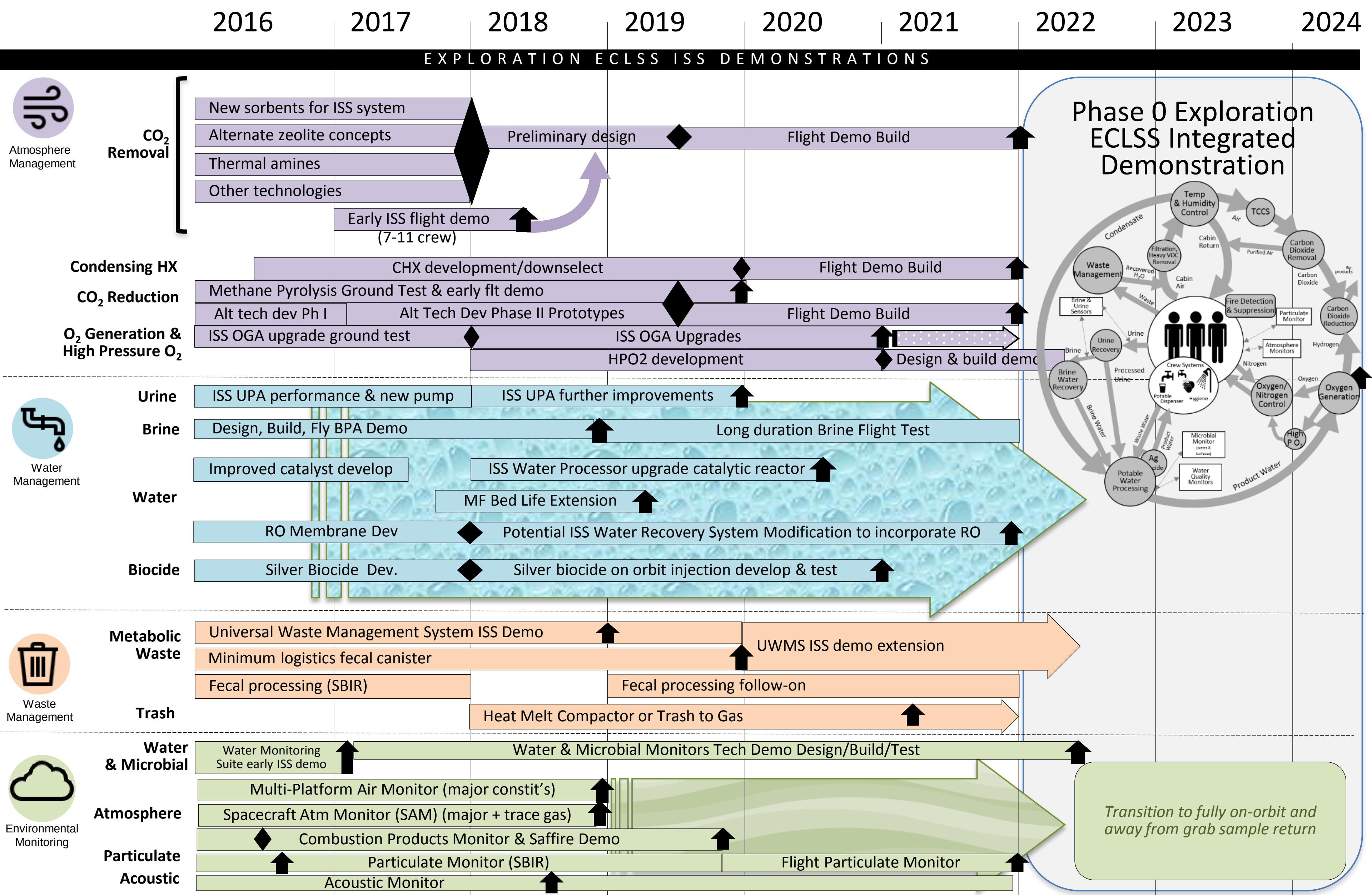


ECLSS & Environmental Monitoring Capability Gaps

Gap Criticality:
5 = high
1 = low

Function	Capability Gaps	Gap criticality as applicable to μg transit Hab	Orion Need
CO_2 Removal	Bed and valve reliability; $ppCO_2$ <2 mmHg	5	
O_2 recovery from CO_2	Recover >75% O_2 from CO_2	5	
Urine brine processing	Water recovery from urine brine >85%	5	
Metabolic solid waste collection	Low-mass, universal waste collection	5	X
Trace Contaminant Control	Replace obsolete sorbents w/ higher capacity; siloxane removal	4	X
Condensing Heat Exchanger	Durable, chemically-inert hydrophilic surfaces with antimicrobial properties	4	
Water microbial control	Common silver biocide with on-orbit redosing	4	
Contingency urine collection	Backup, no moving parts urine separator	4	X
Urine processing	Reliability, 85% water from urine, dormancy survival	4	
Atmosphere monitoring	Small, reliable atmosphere monitor for major constituents, trace gases, targeted gases	4	X
Water monitoring	In-flight identification & quantification of species in water	4	
Microbial monitoring	Non-culture based in-flight monitor with species identification & quantification	4	
O_2 generation	Smaller, reduced complexity, alternate H_2 sensor	3	
High pressure O_2	High pressure (3000 psi) O_2 for EVA/on-demand O_2 supply for contingency medical	3	
Wastewater processing (WPA)	Reliability (ambient temp, reduced pressure catalyst), reduced expendables, dormancy survival	3	
Non-metabolic solid waste	Volume reduction, stabilization, resource recovery	3	
Particulate monitoring	On-board measurement of particulate hazards	3	
Particulate Filtration	Surface dust pre-filter; regen filter	2	
Atmosphere circulation	Quiet fans	2	
Logistics Reduction	10:1 volume reduction logistical and clothing	2	
Metabolic solid waste treatment	Useful products from metabolic waste	1	

Exploration ECLSS Roadmap



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 O_2**
  - Testing to reduce complexity complete; team to assess ISS OGA recommended upgrades as a result
- **Oxygen Recovery/CO_2 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.

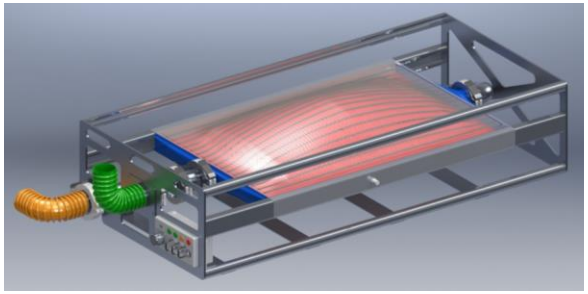
- **Condensing Heat Exchanger**
  - Several options under assessment with downselect in early FY19 for flight demonstration
  - Received NRA thrust area proposals – SMT evaluating
- **Trace Contaminant Control**
  - Alternate commercial sorbent testing
  - Supporting efforts to solve ISS siloxane problem
- **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

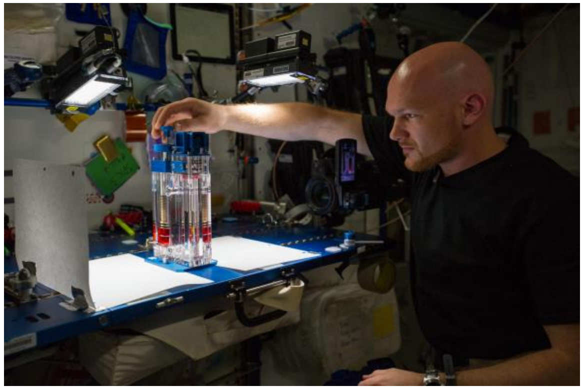
- **Water processing**
  - Improved catalyst development
  - Operational filter life extension
  - Alternate technology/reverse osmosis testing & trade

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



- **Silver biocide**
  - development of on orbit injection capability through SBIR projects

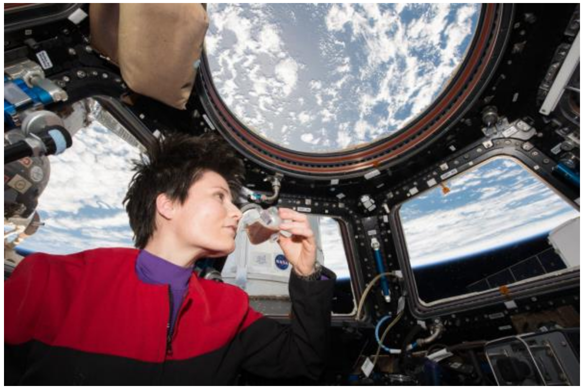
Capillary Structures for Exploration Life Support (SpX-11 manifest)



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

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



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

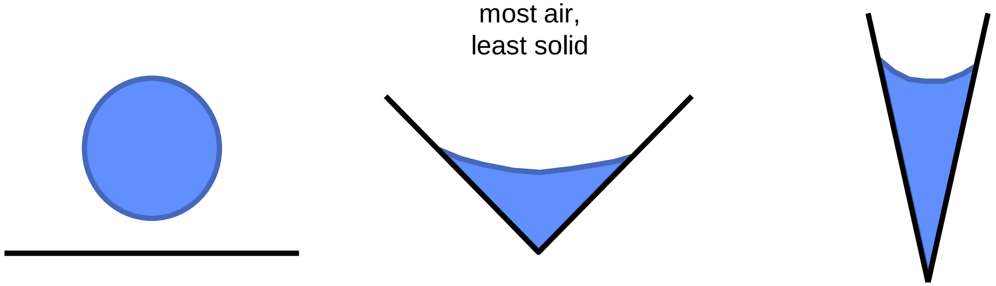
Partially wetting fluids that are in contact with air and solid surfaces want to minimize their total surface energy by:

<u>Maximizing</u> the amount of surface area in contact with the <u>solid surface</u>

<u>Minimizing</u> the amount of surface area in contact with <u>air</u>

least air,
most solid

most air,
least solid



Stable, but this configuration has the most surface energy

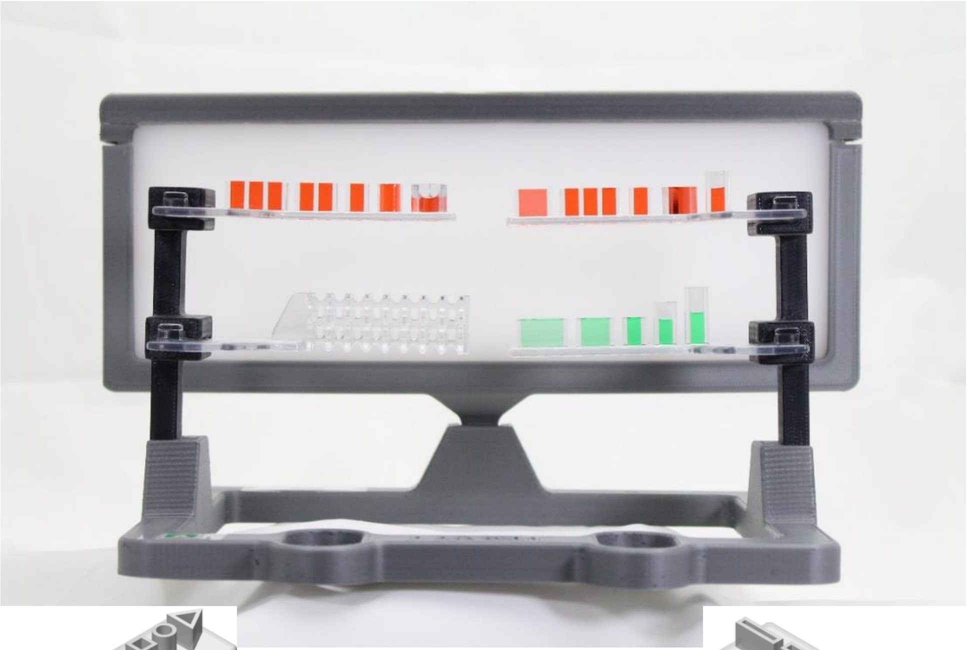
Less surface energy

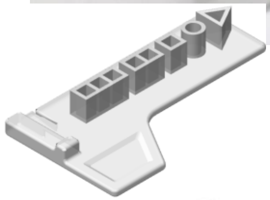
Least amount of surface energy. Fluids will naturally flow from any other configuration to places like this

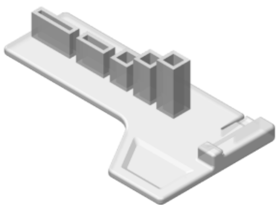
Featured Investigation
Capillary Structures

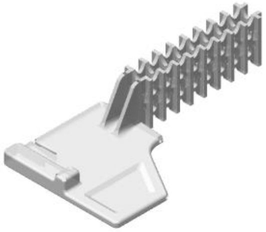
Capillary Brine Residual in Containment (CapiBRIC)

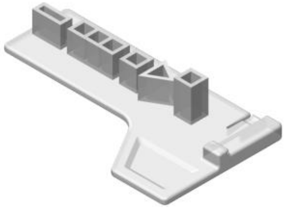
- ***designed to passively recover water from brine***
- ***characterizes both containment and evaporation performance of the capillary structure within the CapiBRIC, called the "Capillary Evaporator"***



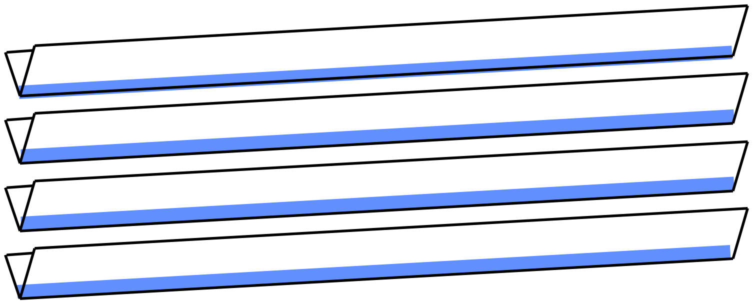








Capillary Evaporator: evaluates effectiveness of various shapes/structures and fluid stability of sample components. A non-toxic ersatz used to mimic ISS wastewater brine.



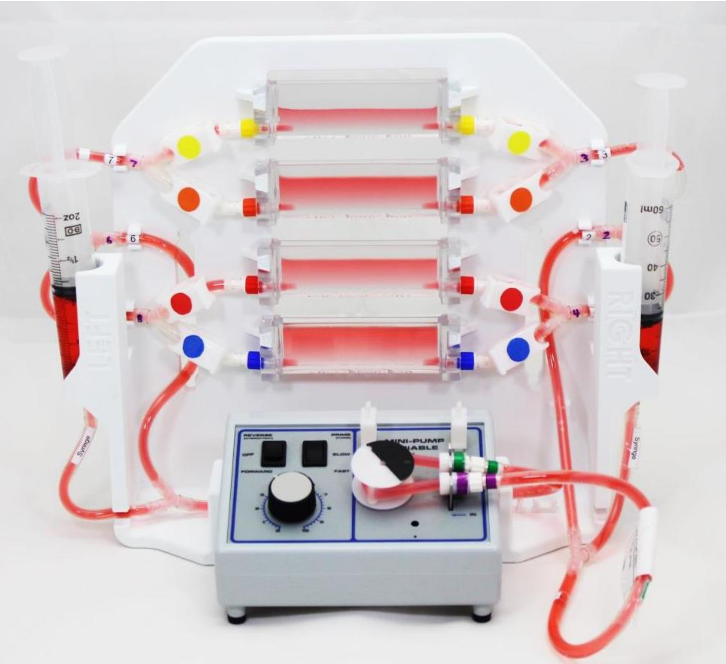
Large amount of surface area exposed to air, large amount of surface area in contact with solid surface

Featured Investigation
Capillary Structures

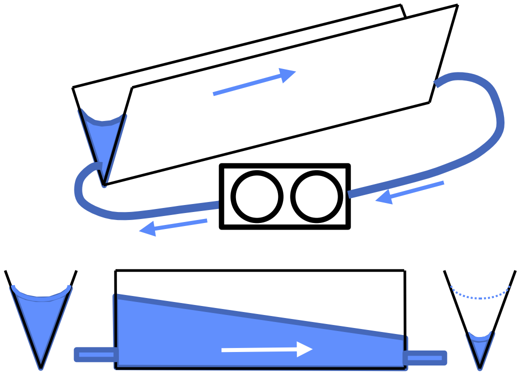
Capillary Liquid CO_2 Sorbent System (CapiSorb)

-designed to remove CO_2 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.



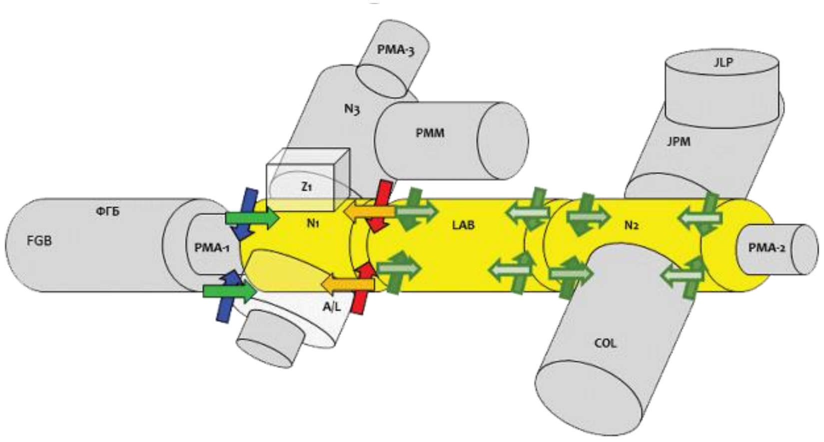
Capillary flow can be integrated into a recirculating loop.

Progress – Waste Management

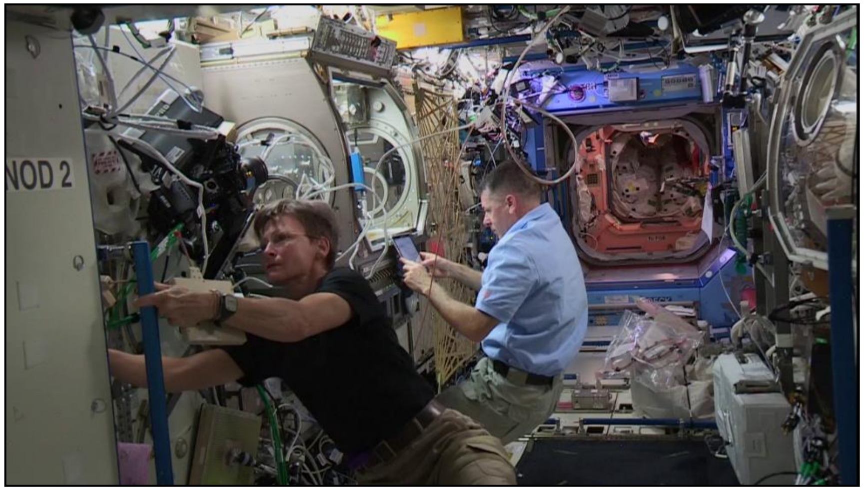
- **Commode**
  - Universal waste management system for ISS demo & Orion (2018) – ISS working integration for permanent ISS installation side by side with current Waste & Hygiene Compartment/Russian Commode
  - Minimum mass fecal container development
- **Fecal processing**
  - Torrefaction SBIR development
- **Trash management**
  - Heat melt compactor and trash to gas development
- **Logistics Reduction**
  - Long wear clothing demonstrated on ISS
  - Repurposing of packaging and cargo bags

Progress – Waste Management, cont

- **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



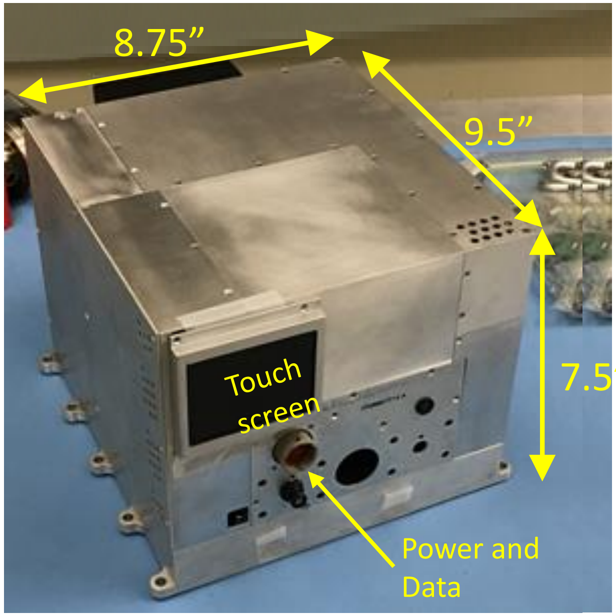
Location of 24 REALM-1 antennas in Node 1, US Lab, and Node 2



Astronaut Peggy Whitson installing 1 of 24 REALM-1 antennas (tan square in her left hand)

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



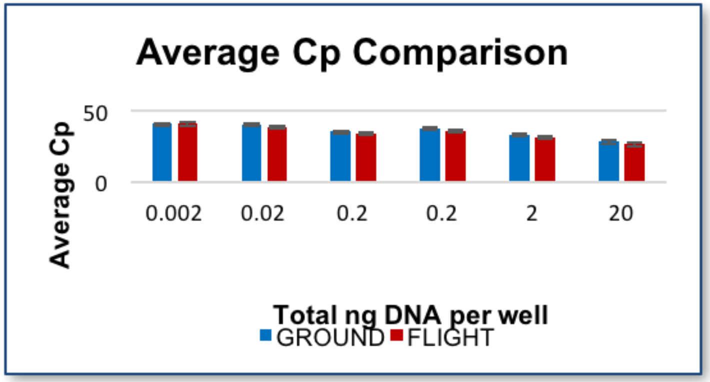
Development Model of the Spacecraft Atmosphere Monitor (Front-View)

Current Status – Environmental Monitoring, cont

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

Flight testing of RAZOR hardware on 9/20/2016. NASA image iss049e007041

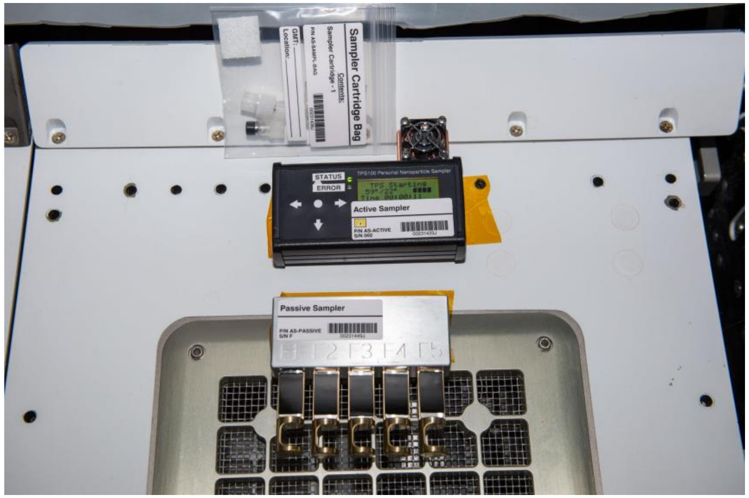


- **Mini-PCR DNA sequencer demonstrated on ISS as part of Genes in Space**

COTS Oxford Nanopore Technologies MinION™ DNA Sequencer

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



Progress – ISS Integration

- **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