Making Human Space Exploration Possible

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Director, Space Systems Department
Engineering Directorate
March 4, 2019

National Aeronautics and Space Administration

NASA

EXPLORE MARSHALL

Ames Research Center
Aerospace and
Small Spacecraft
Moffett Field, Calif.

Armstrong Flight Research Center
Aeronautical Research
and Testing
Edwards, Calif.

Jet Propulsion Laboratory
Deep Space Robotic
Rovers and Science Missions
Pasadena, Calif.

Johnson Space Center
Human Space Flight
Research and Operations
Houston, Texas

Stennis Space Center
Rocket Propulsion Testing
Bay St. Louis, Miss.

Michoud Assembly Facility
Large Vehicle
Manufacturing
New Orleans, La.

Marshall Space Flight Center
Launch Vehicle Development,
Chemical Propulsion, and
Science Instrument
Development
Huntsville, Ala.

Kennedy Space Center
Ground Operations
and Services
Cape Canaveral, Fla.

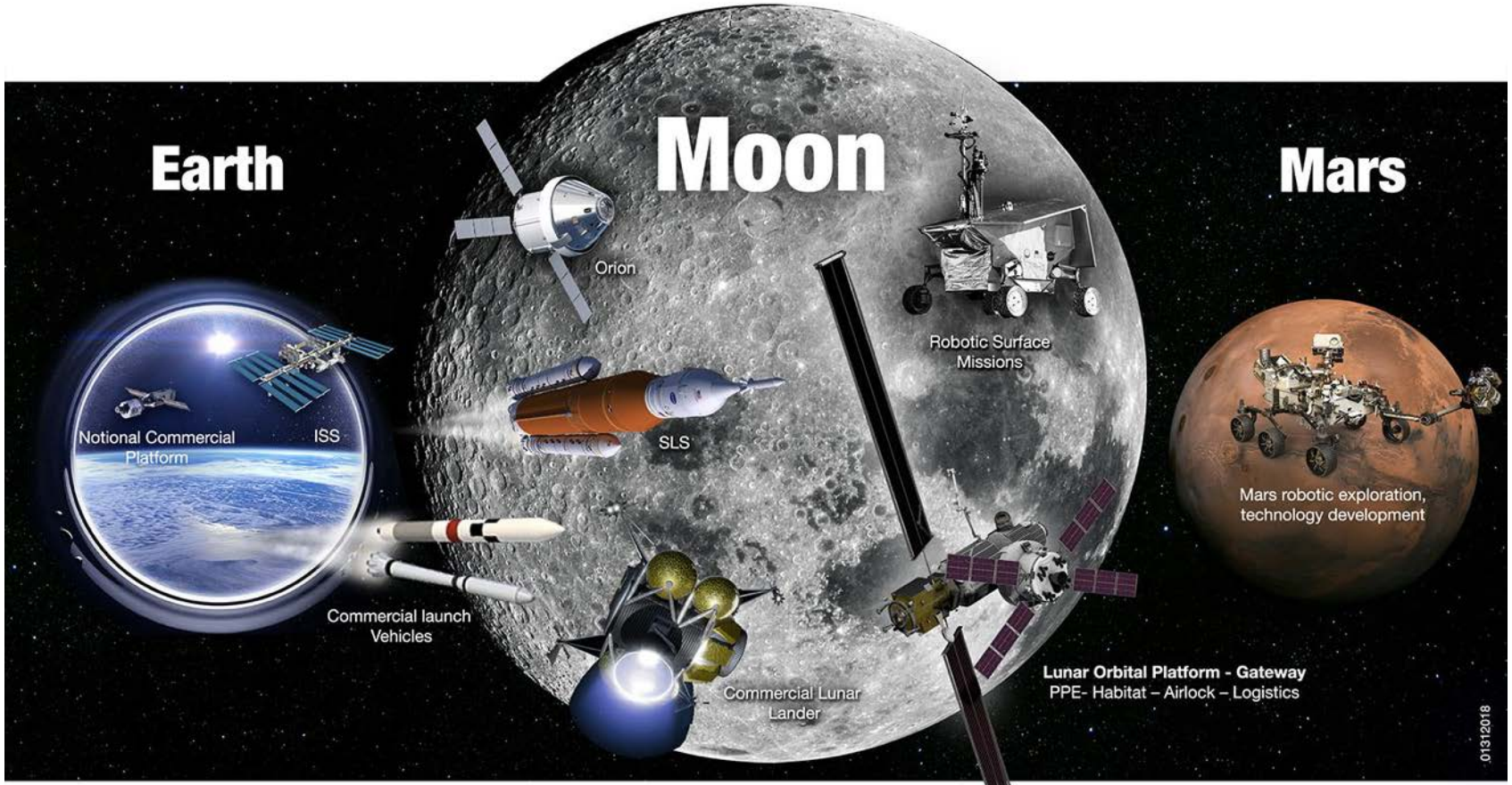
Langley Research Center
Aviation and Space Research
Hampton, Va.

NASA Headquarters
Washington, D.C.

Goddard Space Flight Center
Science Missions
and Telescopes
Greenbelt, Md.

Glenn Research Center
Electric Propulsion and
Small Spacecraft
Technology
Cleveland, Ohio

Marshall Space Flight Center



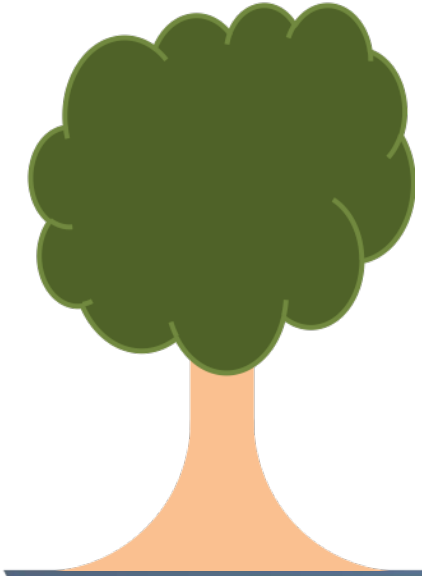
In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

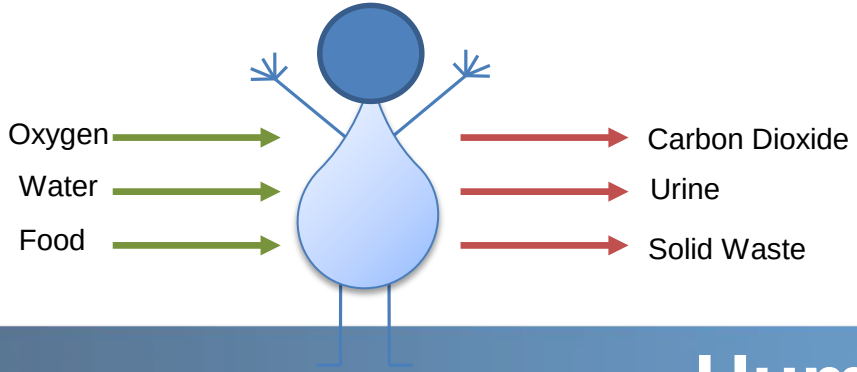
On Mars
Research to inform future crewed missions

Living and Working in Space

Definition:



"…ugly bags of mostly water."
- Microbrain (Star Trek Next Generation 1988)



Humans

"Come with me if you want to live."

- The Terminator (Terminator, 1984)

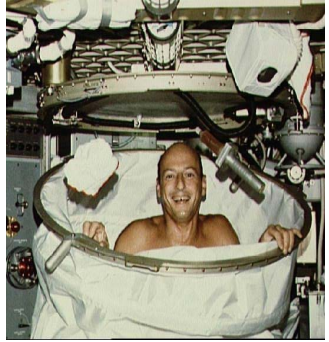
Daily Dose of Narcissism

Adapted from Simplyfantasticbooks.com

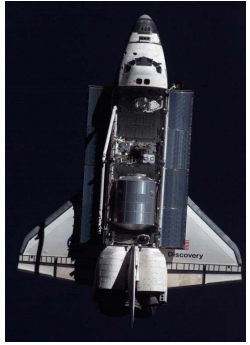
Mercury Astronauts 1961-1963

Saturn V 1968-1979

Lunar Module 1969-1972

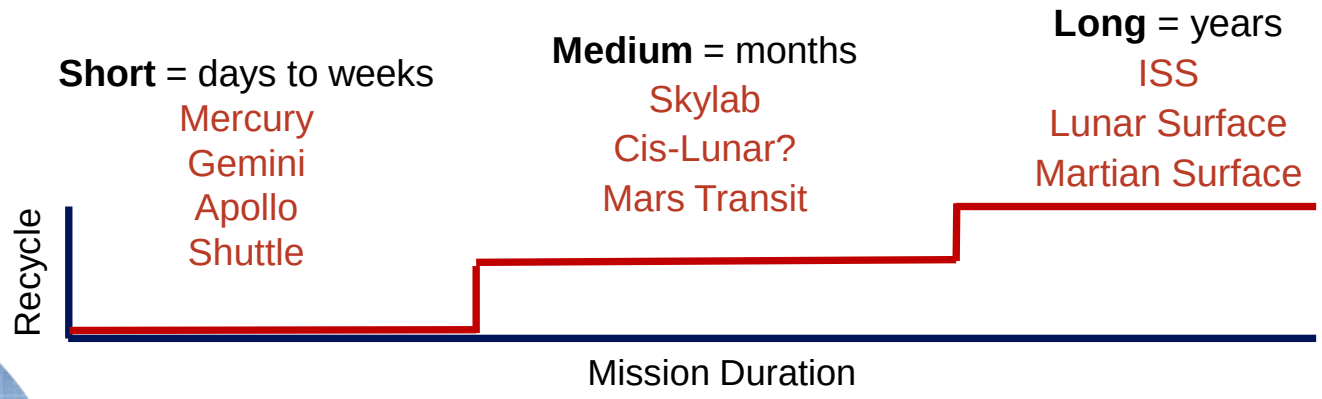


Skylab 1973-1979



Space Shuttle 1981-2011

International Space Station 1981-2011



Mission Definitions

Launch Costs

1lb Water ~$33,000

1 gallon Water = 8.3 lbs

1 gallon Water = $273,900

Crew Reqt's

0.66 gallons potable water consumed/CM-day

0.24 gallons to electrolyze for O_2/CM-day

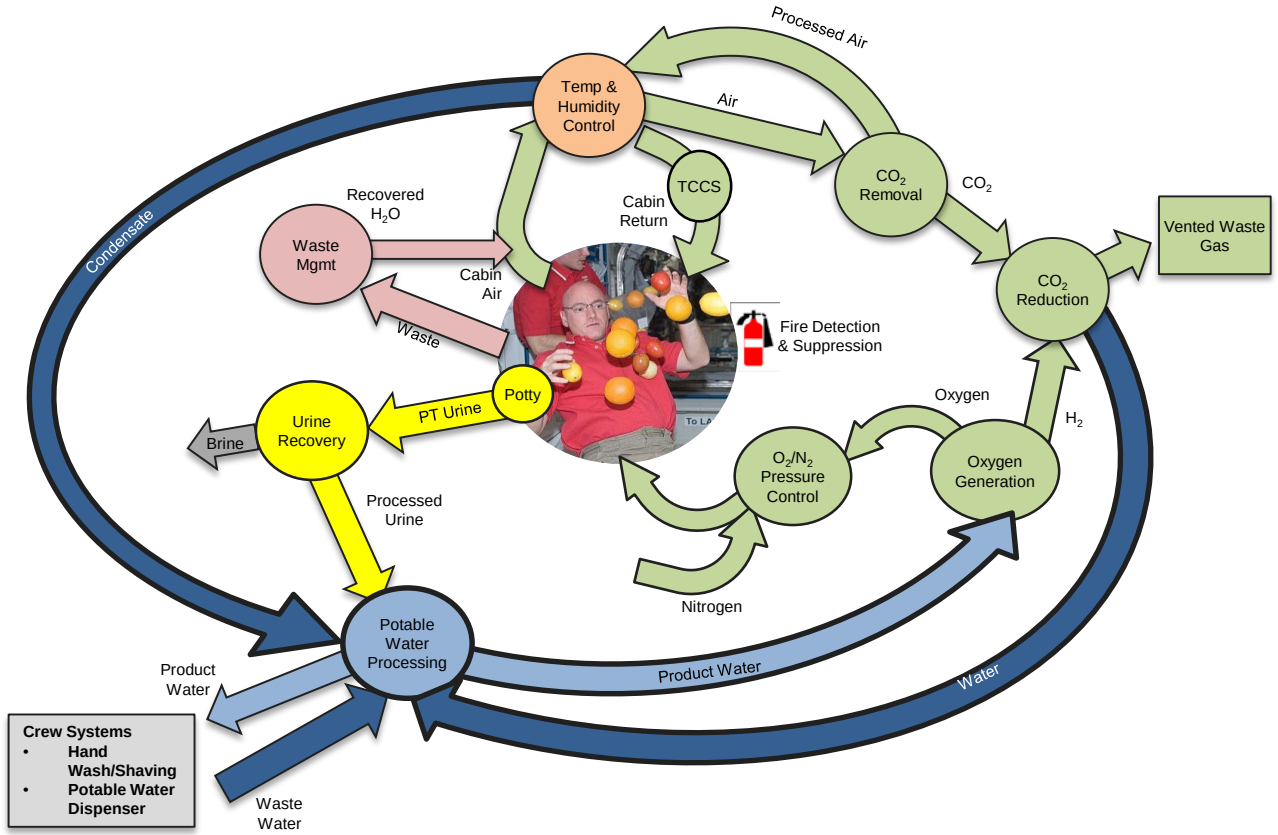
Mission Cost

$247k/CM-day

4-crew = $1M/day

$1.1B for 3yr Mars Mission with 4 crew

Perspective



Life Support Today: ISS

- Continuously occupied since 10/01
- 90-180 day increments typical
- 6 crew typical
- Focus on resource recycling

Combined ~99% H_2O Recovery

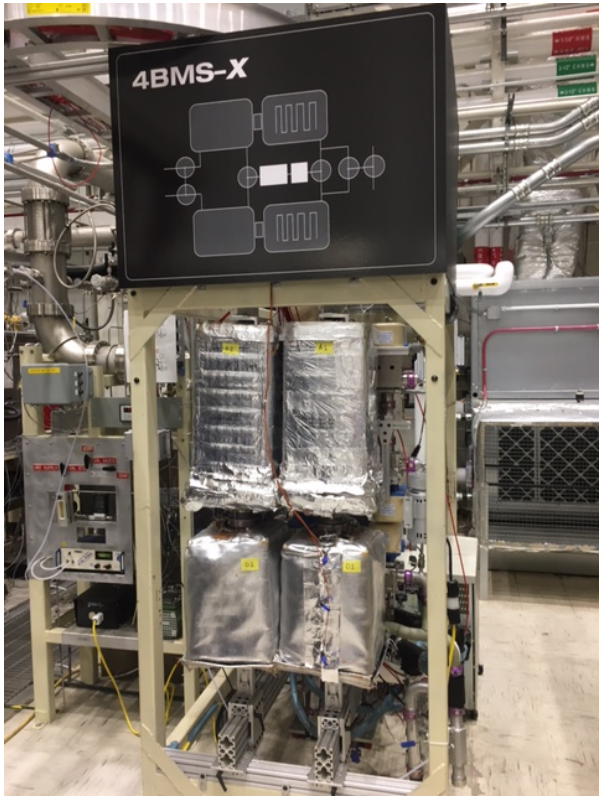
Atmosphere Revitalization System Rack
(Activated Feb 2001)

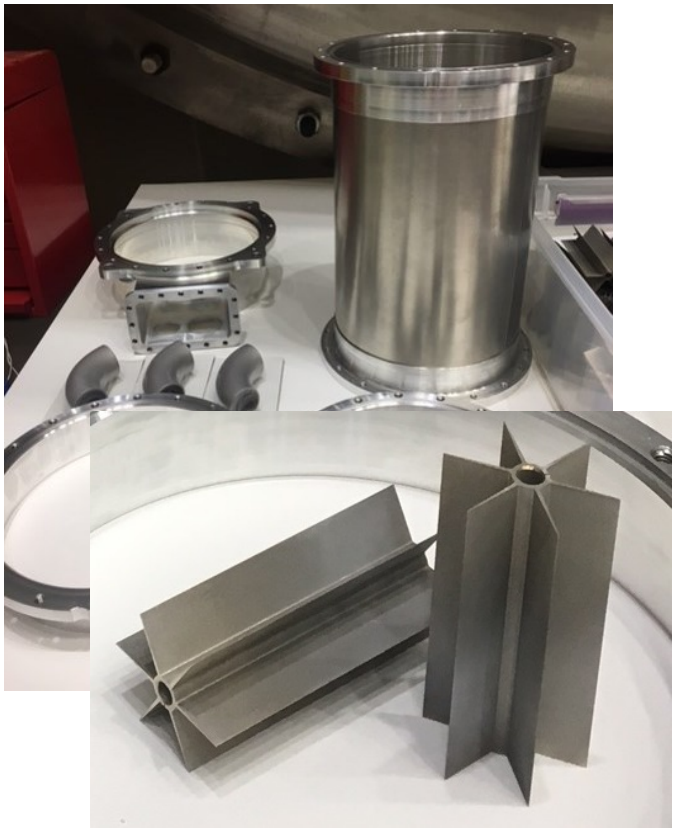
Oxygen Generation System Rack
(OGA Activation July 2007
Sabatier Activation June 2011)

Water Recovery System (WRS) Racks
1 and 2
(Activation March 2009)

$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$

Life Support Today: ISS



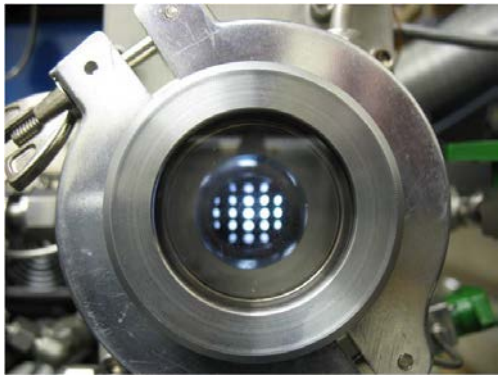


4BMS-X: CO_2 Removal Tech Demo

Sabatier: $CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$

PPA: $2CH_4 \leftrightarrow C_2H_2 + 3H_2$

75-90% O_2 Recovery



PPA: O_2 Recovery Flight Exp

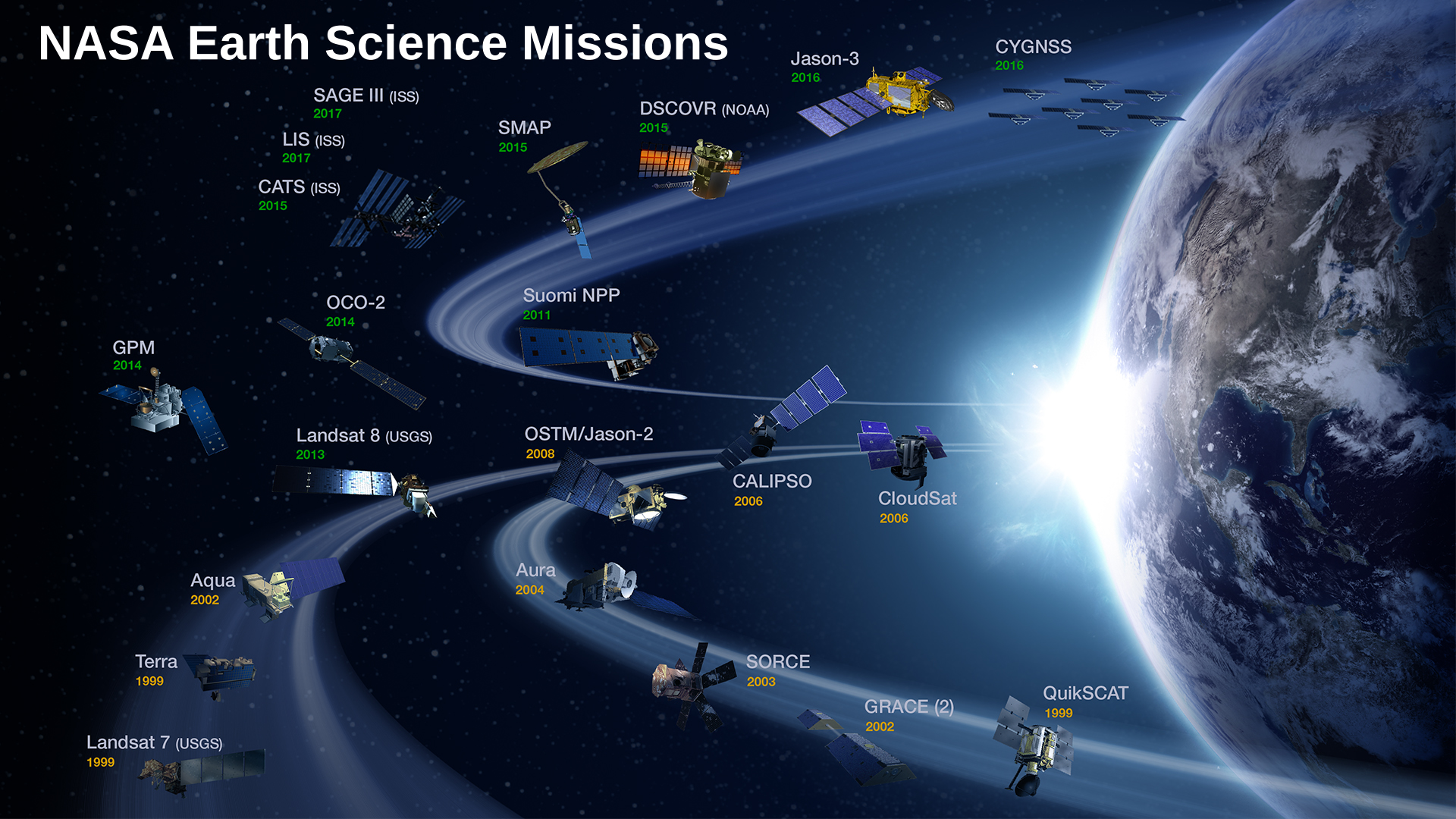
Life Science Glovebox

ISS021E006220

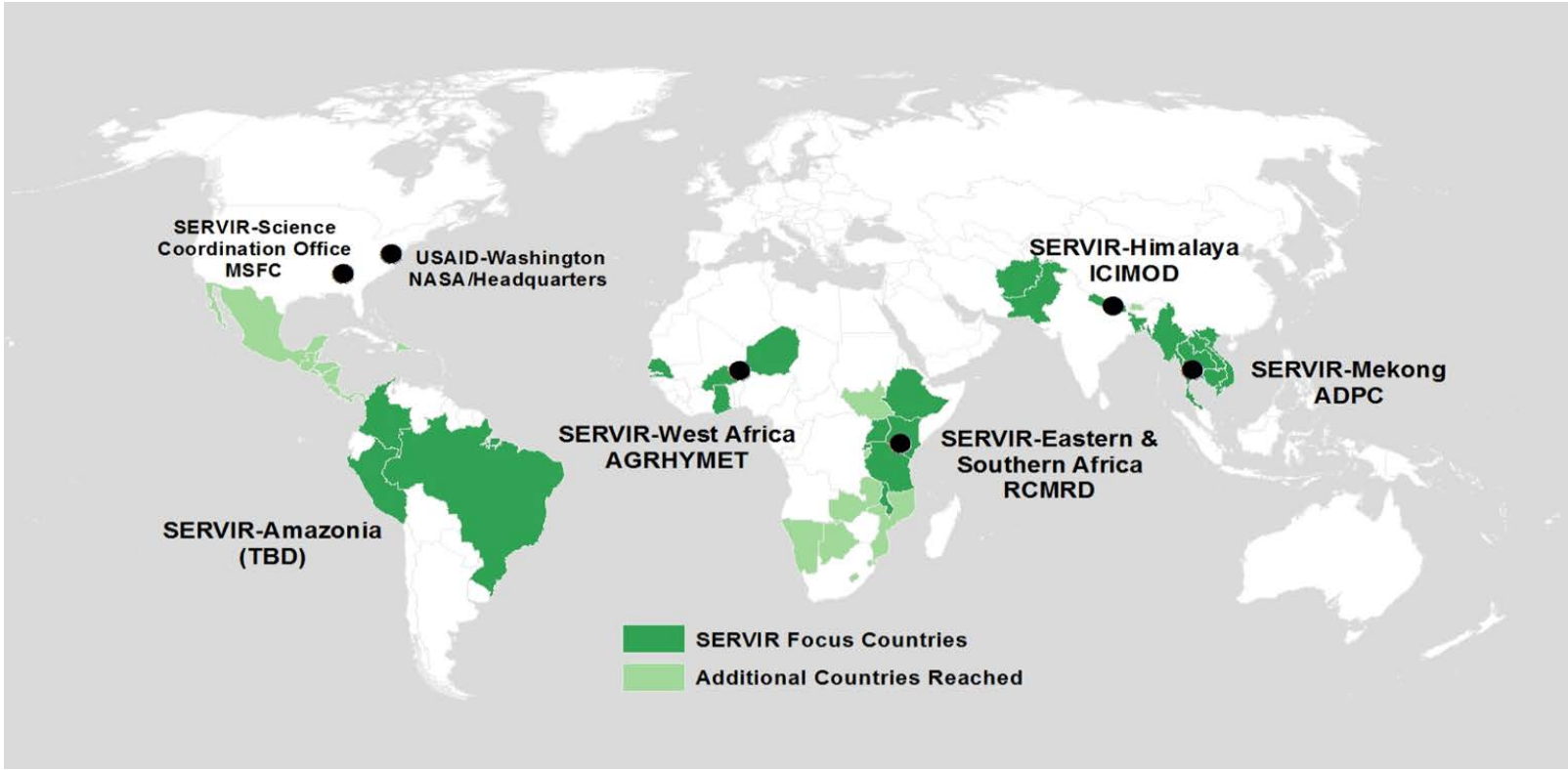
Material Science Research Rack

Understanding Our Home Planet

NASA Earth Science Missions



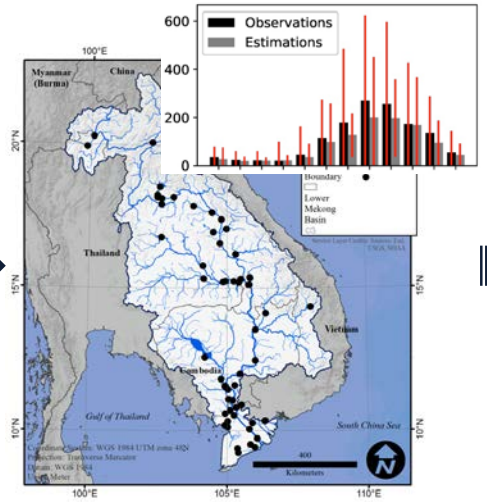
SERVIR connects space to village by helping developing countries use satellite data to address critical challenges in food security, water resources, weather and climate, land use, and natural disasters. A partnership of NASA, USAID, and leading technical organizations, SERVIR develops innovative solutions to improve livelihoods and foster self-reliance in Asia, Africa, and the Americas.



Working in Over 40 Countries

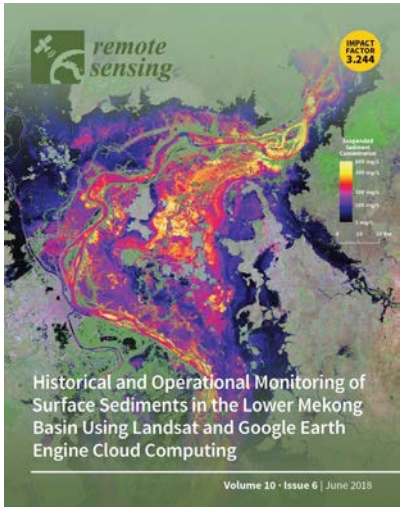
Dam on Nam Theun river in Laos

New dam construction and changes in land cover and land use is having a significant impact on sediment loads and water quality throughout the Lower Mekong basin.



Limited *in situ* sediment measurements sites used to compute model accuracy

Previously, to assess sediment concentration, decision makers had to rely on their sparse network of *in situ* water quality stations in the Mekong River Basin.

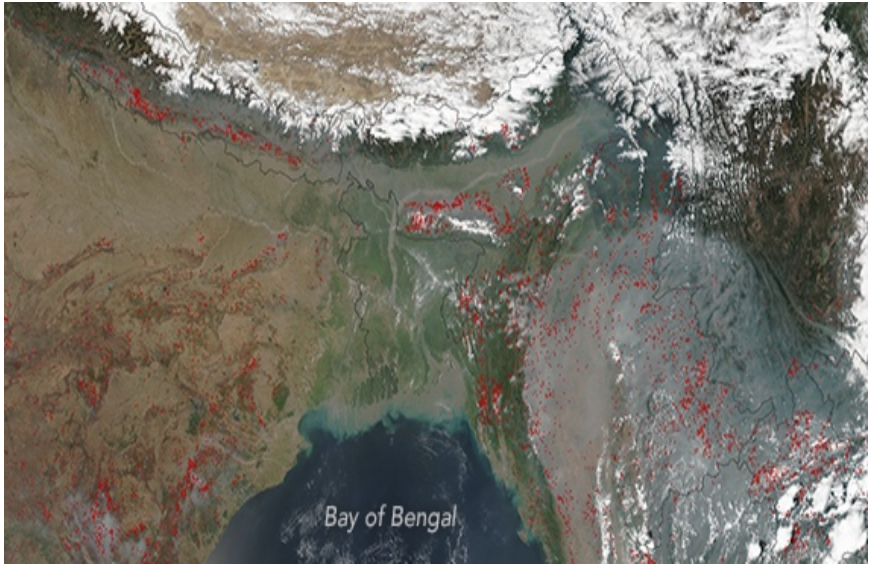


SERVIR's work was featured on the front page of the June issue of Remote Sensing

SERVIR and the Mekong River Commission implemented a model leveraging the entire Landsat archive, allowing users to supplement limited station data with satellite products. The model output enables dam managers to reduce the impact of sedimentation on fisheries downstream.

Monitoring Sedimentation In the Mekong River

SERVIR's Forest Fire Monitoring System displayed in Nepal government lobbies



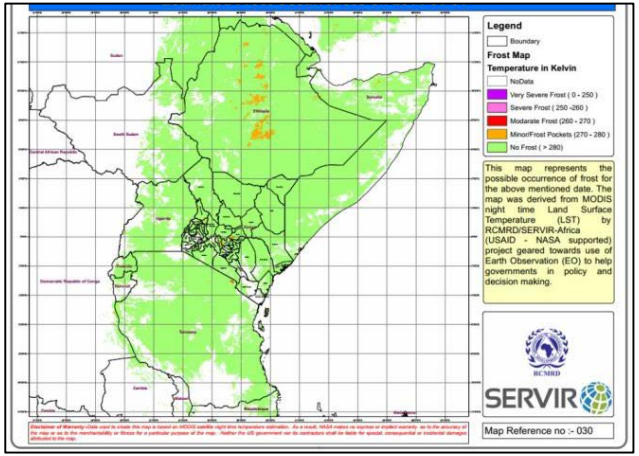
Red dots indicate forest fire hot spots, as detected by the satellite thermal sensors

Through SERVIR's fire monitoring system, use of satellite data is firmly embedded in Nepal's government Forest Department. This system triggers action and response on the ground, especially in remote areas of the country.

Detecting and Responding to Forest Fires in Nepal

SERVIR's satellite-based monitoring and forecasting of frost conditions in the Kenyan tea growing regions has spurred insurance companies to offer new, frost insurance riders to farmers. The satellite data has been used to adjudicate insurance claims and provides great opportunities for taking preventive actions, such as harvesting the tea leaves before a frost. This information is relayed to the farmers at local collection points.

SERVIR team meeting with Kenyan tea farmers to understand possible mitigation options based on frost forecasting information



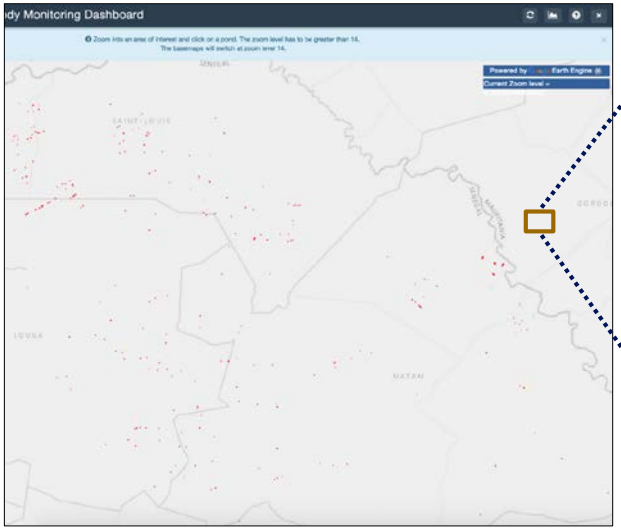
SERVIR frost occurrence map showing affected areas in Kenya (orange areas)

Tea leaves affected by frost

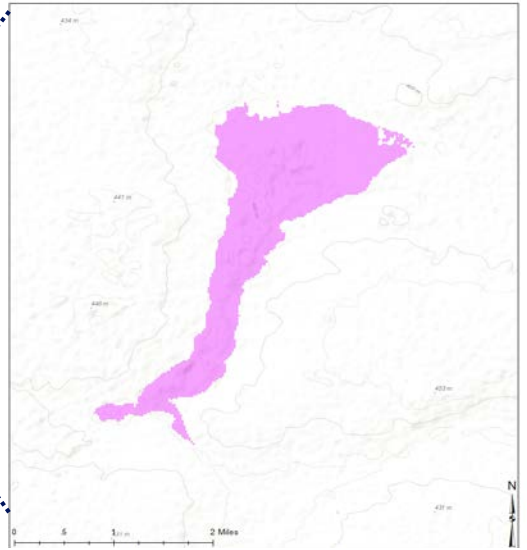
Forecasting and Mapping Frost for Kenyan Tea Farms

Pastoralists in parched West African rangelands are always in search of ponds with water for their livestock. SERVIR has developed a tool that scans the latest satellite data and updates a map of available water in those ponds. This information is relayed to the pastoralists by radio and cellphones.

Pastoralists in West Africa searching for water and forage.

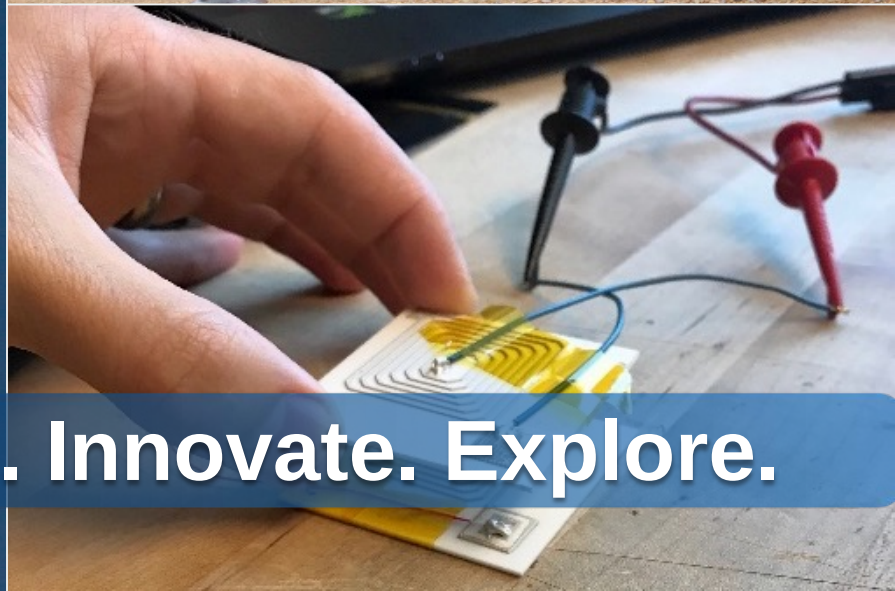


Using latest satellite observations, SERVIR monitors thousands of small ephemeral ponds across the Senegal to determine the availability of water



Monitoring changes in pond water over time

Monitoring Small Water Bodies in West Africa for Pastoralists



Inspire. Innovate. Explore.

Additive Electronics Manufacturing

Optomec High Precision 3D Aerosol Jet Printer

Primary Focus: Utilizing 3D additive dispensing, screen printing, and aerosol jet deposition processes to develop nanoelectronics including but not limited to:

- **Solid State Ultracapacitors**
- **Graphene Superconducting Circuitry**
- **Organic Photovoltaics & LEDs**
- **Electroluminescent Devices**
- **Sensors**
- **PCBs**
- Antennas
- 3D Flexible Interconnects for Area Array Packaging
- Embedded Electronics Packaging
- Advanced Electronic Manufacturing

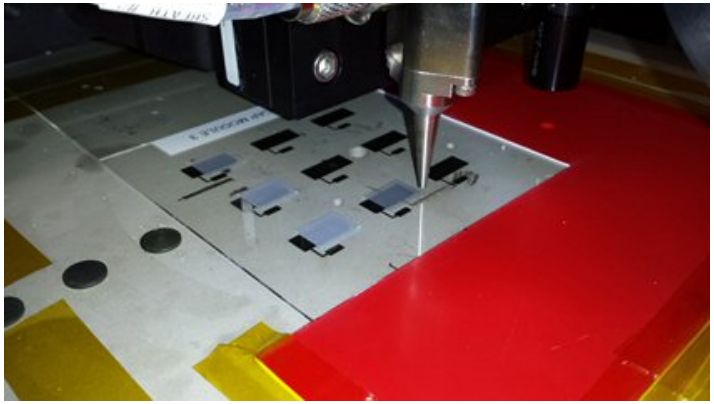
HMI 485 High Precision Screen & Stencil Printer

Hengli Custom 8-Zone HT Sintering Furnace

Hengli Custom 4-Zone LT Sintering Furnace

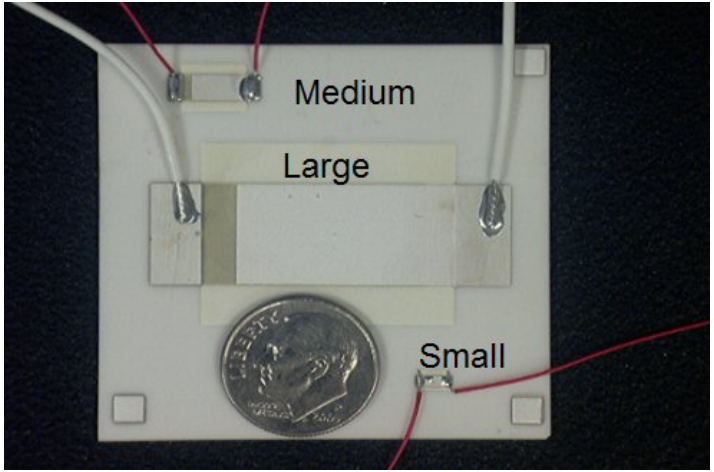
Silverson L5M-A Laboratory Mixer

PVA 350 Tabletop Robotic Dispensing System

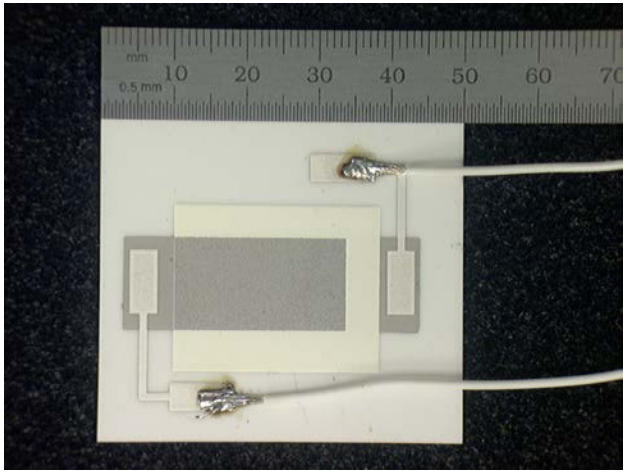


Dielectric ink printing

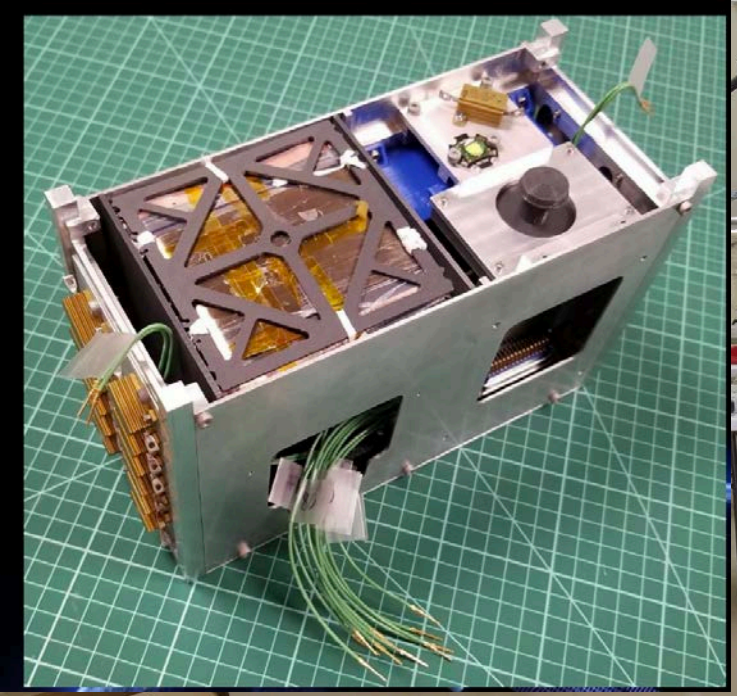
Wireless humidity sensor



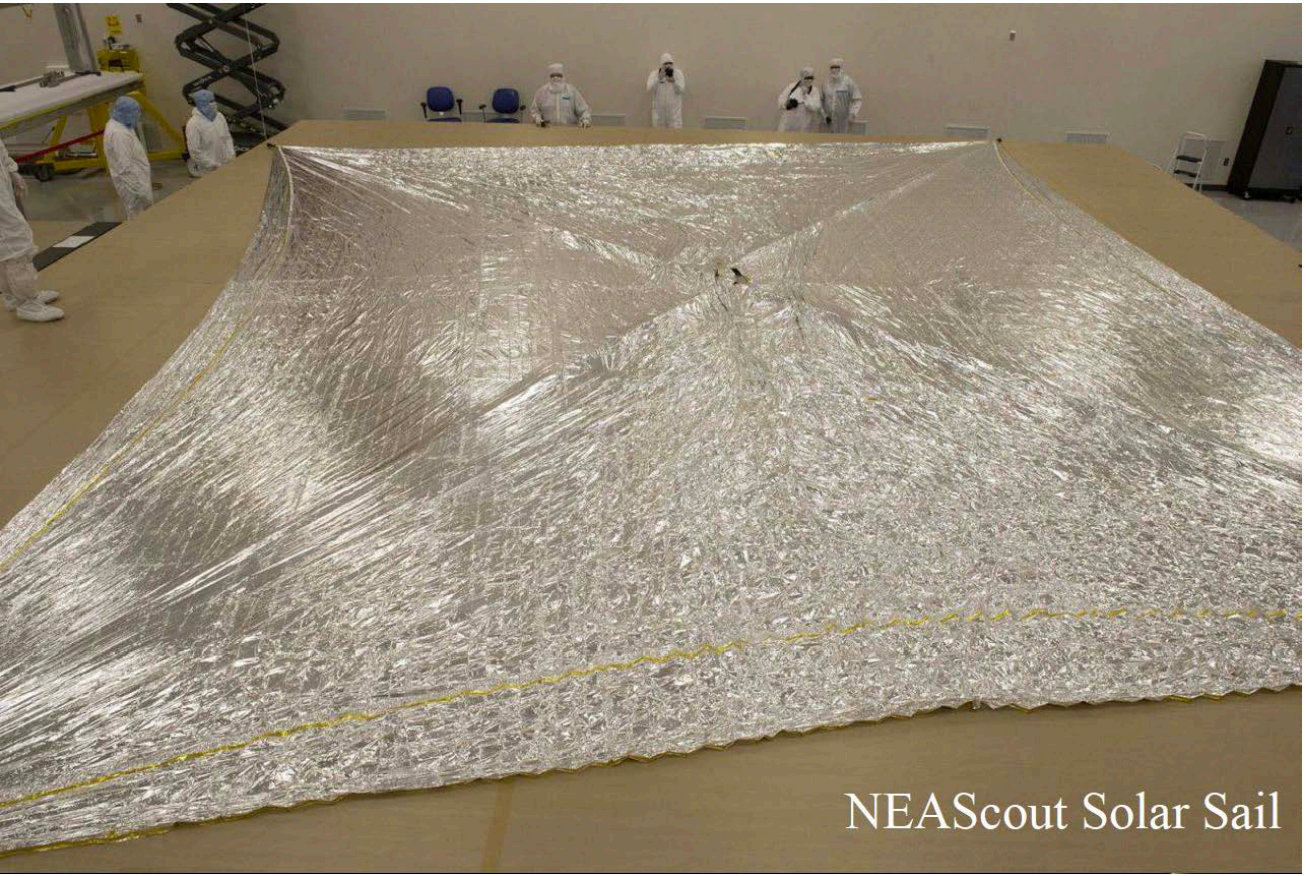
Three different sizes



Ultra cap with leads



The Lightweight Integrated Solar Array and anTenna (LISA-T)

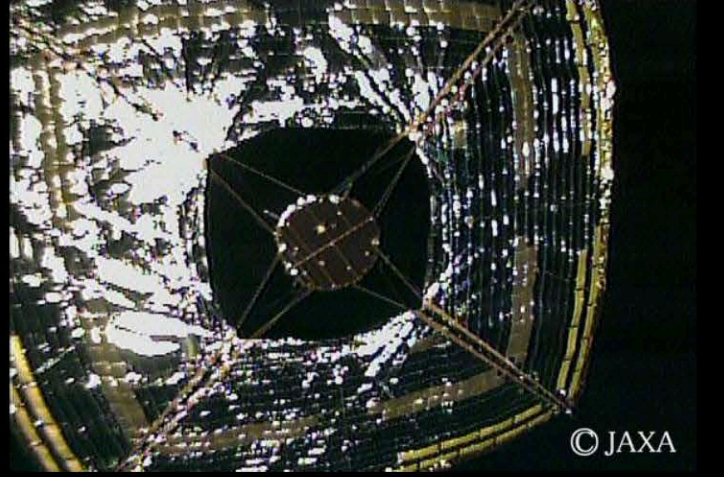

NEAScout Solar Sail

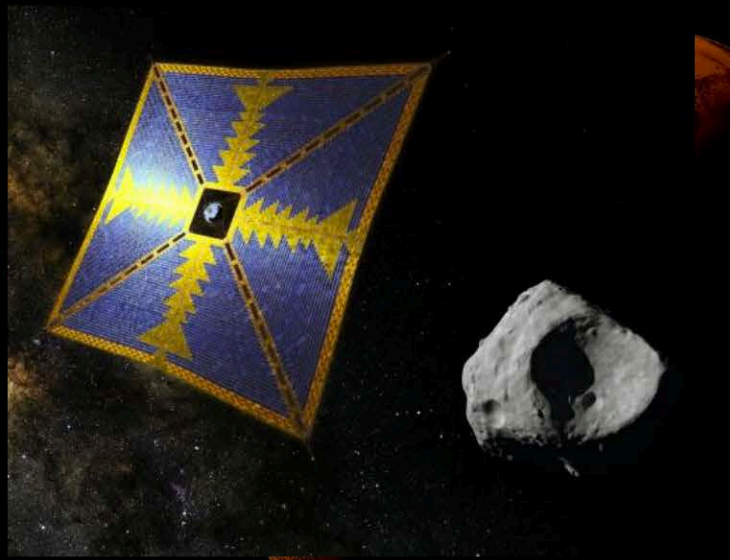
National Aeronautics and Space Administration

[POWER SAIL]

BOL | 28°C | 30% IMM

0.6m² (herein)	-- 200W 1AU | 86W Mars
2.9m² (office desk)	-- 1kW 1AU | 431W Mars
86m² (NeaScout)	-- 23kW 1AU | 250W Saturn
860m² (3.3 tennis courts)	-- 300kW 1AU | 192W Pluto





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Back-Up Charts

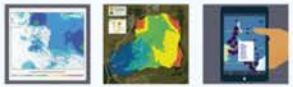
SERVIR

SERVIR connects space to village by making geospatial information useful to developing countries.
SERVIR is a joint development initiative of NASA and USAID, working in partnership with leading regional organizations around the globe.

EXPANDING AROUND THE GLOBE

PRODUCTS, TOOLS, AND SERVICES

88
climate change adaptation and mitigation products developed



1.5M
maps produced interactively on the SERVIR web portal

By the Numbers Thru: 2017

www.servirglobal.net

TRAINING AND INFORMATION SHARING

4719
people trained to use tools and information

353
institutions worldwide with improved capacity to address climate change issues

647
decision-makers and scientists participating in technical exchanges

CONNECTING MORE SCIENCE

28
United States Government science expertise connections (2017)

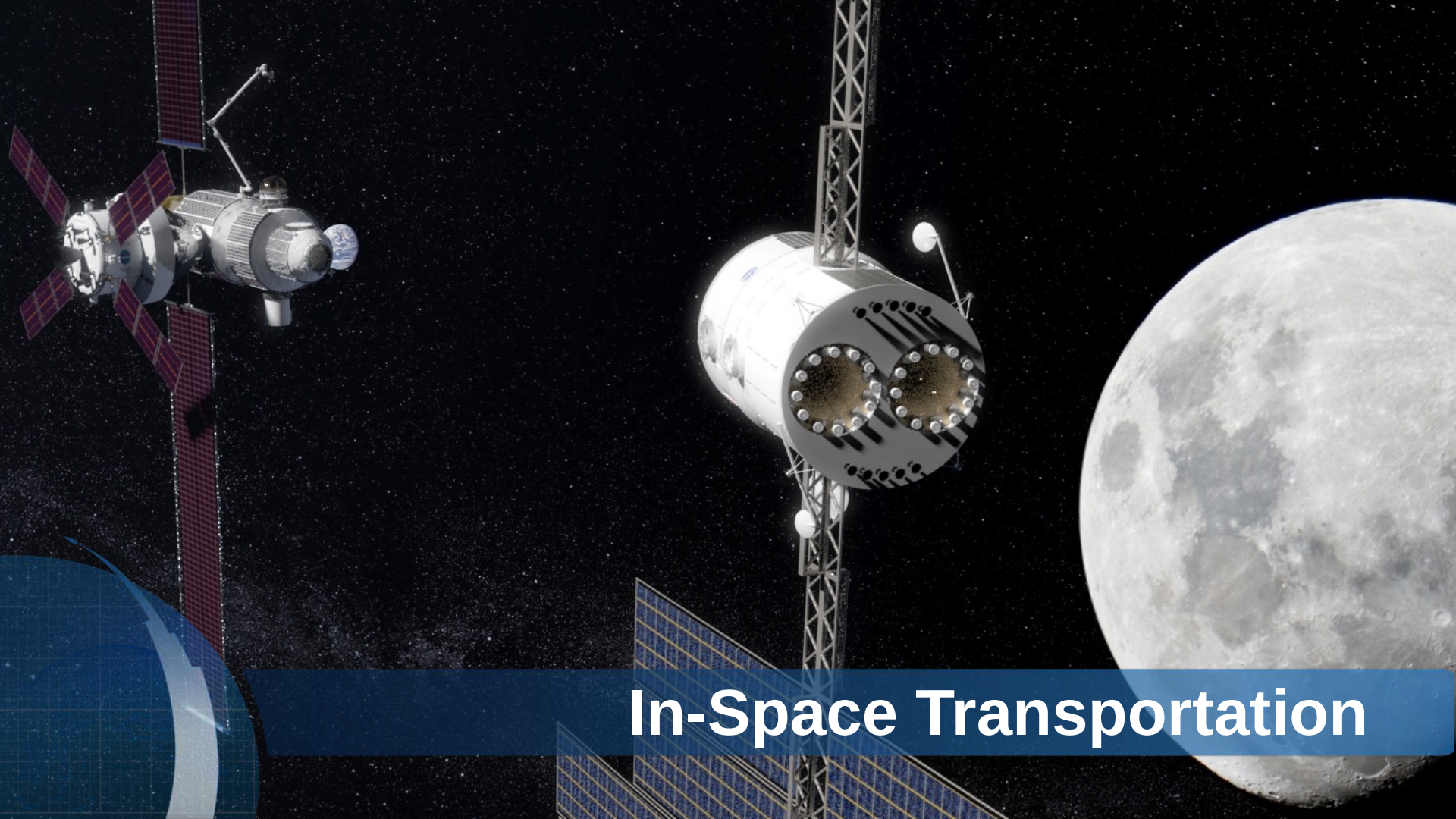
25
SERVIR Applied Sciences Team projects (2017)

USAID FROM THE AMERICAN PEOPLE · NASA · CILSS · RCMRD · ICIMOD · adpc · SERVIR


Space Launch System

Understanding Our World and Beyond


Michoud: Building the Next Generation Rocket


In-Space Transportation

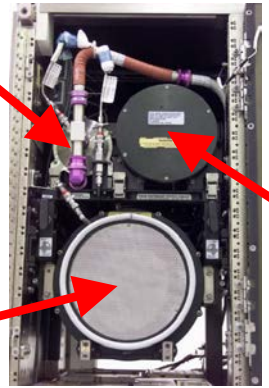
Life Support Today: ARS Rack

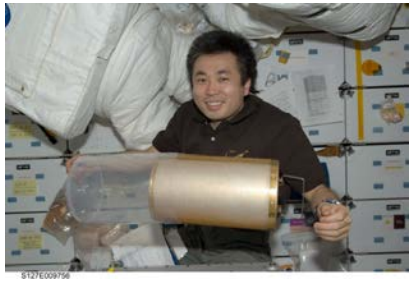
Trace Contaminant Control

3. LiOH Sorbent Bed (acidic oxidation products)

2. High Temperature Catalytic Oxidizer (CH_4, H_2, CO)

1. Charcoal Bed (High MW and NH_3)





JAXA's Koichi Wakata with replaceable LiOH cartridge

CO_2 Removal

5A Zeolite options for CDRA

Insert

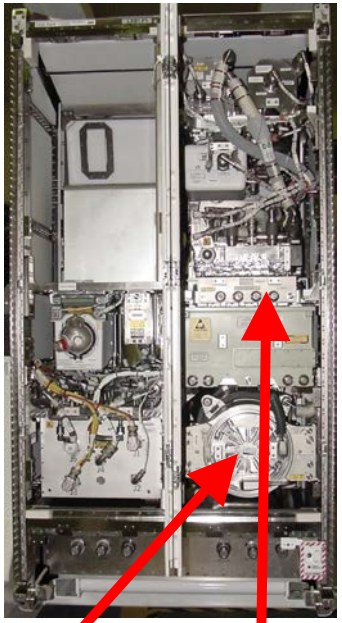
Pressure Plate & Springs

End Cap

CDRA

Life Support Today: OGS Rack

Oxygen Generation Assembly



Cell Stack & Rotary Separator Accumulator

Hydrogen Sensor

Hydrogen ORU without dome

H2 in O2 sensor (150 day life)

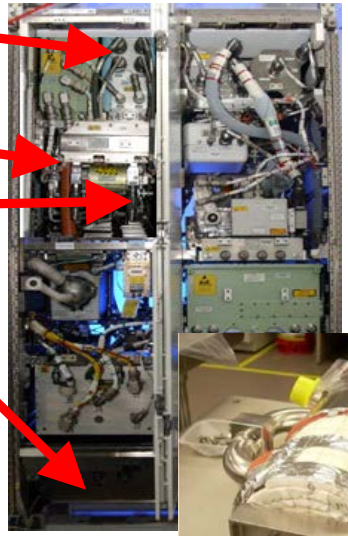
Sabatier CO_2 Reduction

CO_2 Compressor

Reactor

Phase Separator

CO_2 Storage Tanks

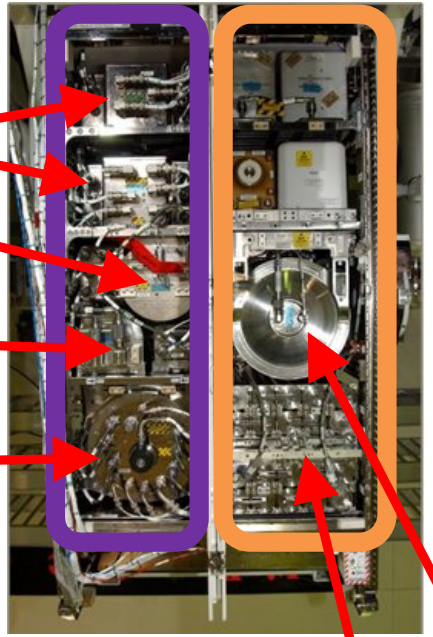


Flight Sabatier Reactor

~50% O_2 Recovery

$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$

Life Support Today: WRS Racks



Urine Processing Assembly

Water Processing Assembly

Pumps

Brine Tank

Urine Storage Tank

Distillation Assembly

Particulate Filter

Catalytic Oxidizer

Product Water Tank

Ion Exchange Bed

Wastewater Tank

Multi-filtration Beds

UPA = ~80% H_2O Recovery

Combined ~88% H_2O Recovery

WPA = >99% H_2O Recovery

Life Support in the Past: Mercury and Gemini

Mercury Astronauts
1961-1963

Redstone Rocket
Launch (first two
flights)

Titan II Rocket

First Spacewalk
Gemini 4
Ed White 1965

- 1-2 astronauts
- 1-14 day missions
- Chlorinated potable water & O_2 stored in tanks
- CO_2 removed from atmosphere w/expendable LiOH
- Wastewater vented overboard

$$LiOH + CO_2 \leftrightarrow Li_2CO_3 + H_2O$$

Life Support in the Past: Apollo

Command Module

- 7-10 day missions
- 3 crew
- Fuel cell by-product water used for drinking, chlorinated manually by crew
- Wastewater vented overboard
- O_2 stored in tanks
- CO_2 scrubbed w/ LiOH
- Rudimentary waste collection

Saturn V Rocket

Lunar Module

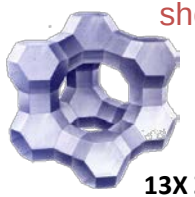
- 1-3 day missions
- 2 crew
- Iodinated potable water stored in tanks
- Wastewater stored in tanks
- Stored O_2
- CO_2 scrubbed w/ LiOH

Life Support in the Past: Skylab

1973-1979

Skylab CO_2 Scrubber

- 3 missions (28, 59, & 84 days)
- 3 crew
- Potable water provided for consumption & hygiene in tanks
- Iodinated potable water stored in tanks (10 x 70-gal tanks)
  - periodic iodine injections by crew
  - manual colorimetric checks
- Wastewater vented overboard
- Stored O_2
- CO_2 scrubbed w/ molecular sieve (13X and 5A) and vented overboard
- Trace contaminant control using a charcoal bed
- Hygiene Facilities including toilet and shower



13X Zeolite

Life Support in the Past: Space Shuttle

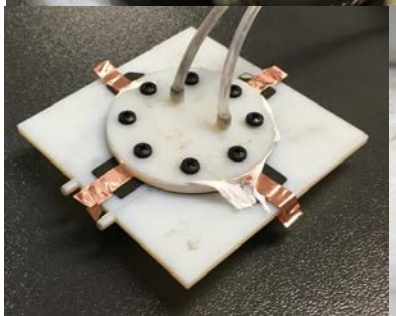
- 7-16 day missions typical
- 6-7 crew typical
- Fuel cell by-product water used for potable water
- Iodine added automatically via flow-thru iodinated resin
- Wastewater vented overboard CO_2 scrubbed w/ LiOH
- Stored (cryo) O_2

Future O_2 Recovery

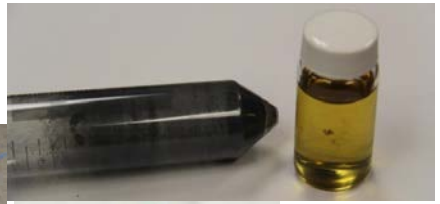
Bosch: $CO_2 + 2H_2 \leftrightarrow C(s) + 2H_2O$

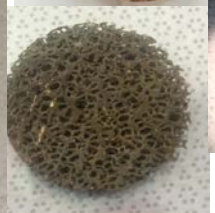
CO_2 Decomposition: $CO_2 \leftrightarrow C(s) + O_2$

Co-Electrolysis: $CO_2 + 2H_2O \leftrightarrow C(s) + 2O_2 + 2H_2$



100% O_2 Recovery





What and Who is SERVIR?

"Connecting space to village"

A joint initiative of USAID and NASA that partners with regional technical institutions around the world to get Earth observation information into the hands of decision-makers to improve development outcomes.

- Societal benefit from space
- 20+ satellites, data free and open
- Major research portfolio
- Limited internationally

- Poverty reduction and resilience
- Working on data-dependent issues in data-scarce places
- International field presence

Regional hubs

Hub partners

Private sector partners:

Research collaborators:
19 universities and research centers located in 14 states (in the U.S.)