

National Aeronautics and  
Space Administration



# Current Hardware Capabilities Relevant to Near-Term Plant and Plant-Microbiome Studies in Space.

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# PRESENTATION OBJECTIVES

- **Educate** and generate interest in the science and engineering **community** with the current state of **Space Plant** and **Plant Microbiome (microbial) hardware capabilities** and the opportunities that lay ahead **relating to:**
  - **Low Earth Orbit (LEO)** e.g. ISS → **Highest Level of Science**
    - Provides Crew Time
    - Provides Science Capabilities
  - **Lunar Orbit** e.g. Gateway → **Moderate Level of Science**
    - Provides periodic short-term Crew Time
    - Hardware Capabilities Limited
  - **Lunar Surface Activities (TBD)** → **Low to Moderate Level of Science**
    - Short-Term No Crew Time & Restricted to Automated Capabilities
    - Long-Term (once human presence established) increased science potential
- **Timeline Focus:** Describe what can be done based on projected opportunities over the **next ten years** with **existing hardware**.
- **Content:** Present overview of **Currently Available** Plant & Microbial Growth **Capabilities** including sampling, fixation, freezing.

# Biological Research In Canisters (BRIC)-60

- The Biological Research in Canisters (BRIC) is an **anodized-aluminum cylinder** used to provide passive stowage for investigations evaluating the effects of space flight on small organisms.
- Specimens flown in the BRIC 60 mm petri dish (BRIC-60) hardware include *Lycopersicon esculentum* (tomato), *Arabidopsis thaliana* (thale cress), *Glycine max* (soybean) seedlings, *Physarum polycephalum* (slime mold) cells, *Poethtria dispar* (gypsy moth) eggs and *Ceratodon purpureus* (moss).
- The BRIC-60 unit requires **no operational power** and consists of both an upper and lower chamber (Fig. 1). Two optional configurations are available with capabilities of flying as a half canister (lower chamber + chamber lid) or full canister (upper chamber + lower chamber + chamber lid).
- The BRIC-60 can hold a maximum of **twelve 60 mm petri dishes per half canister** (a total of twenty-four per full canister) or **thirteen Teflon tubes per half canister** (a total of twenty-six per full canister) (Fig. 2).
- Up to **eight full canisters** or 20 single chamber canisters can be flown in an International Space Station (ISS) **stowage locker** configuration.
- Four **pressure relief vents** in each chamber lid adhere to the rapid depressurization requirements for space flight.
- Vents make a series of unique convoluted turns to maintaining a **light-tight environment** inside.
- The BRIC-60 modified (**BRIC-60M**) includes **2 gas sampling ports** capable of drawing gas from two locations within the sealed canister (Fig. 1).



Fig. 1. BRIC-60 & BRIC-60M with petri dish configuration. Teflon sample tubes.

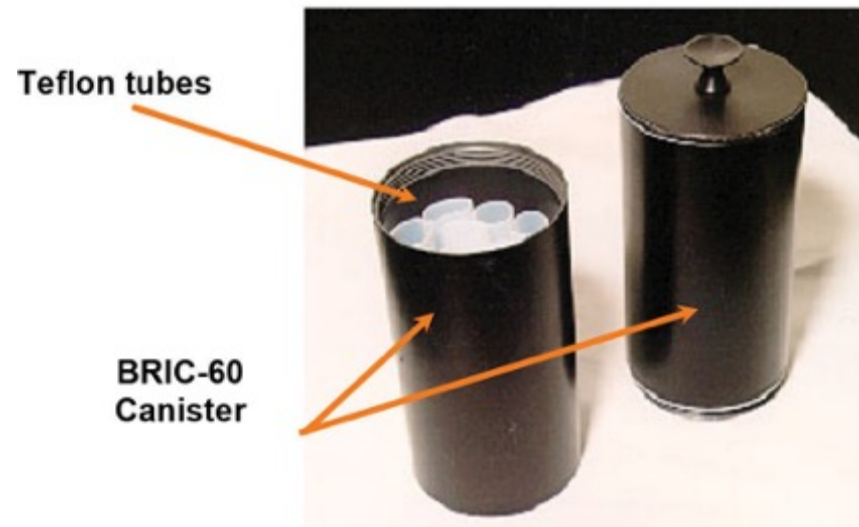
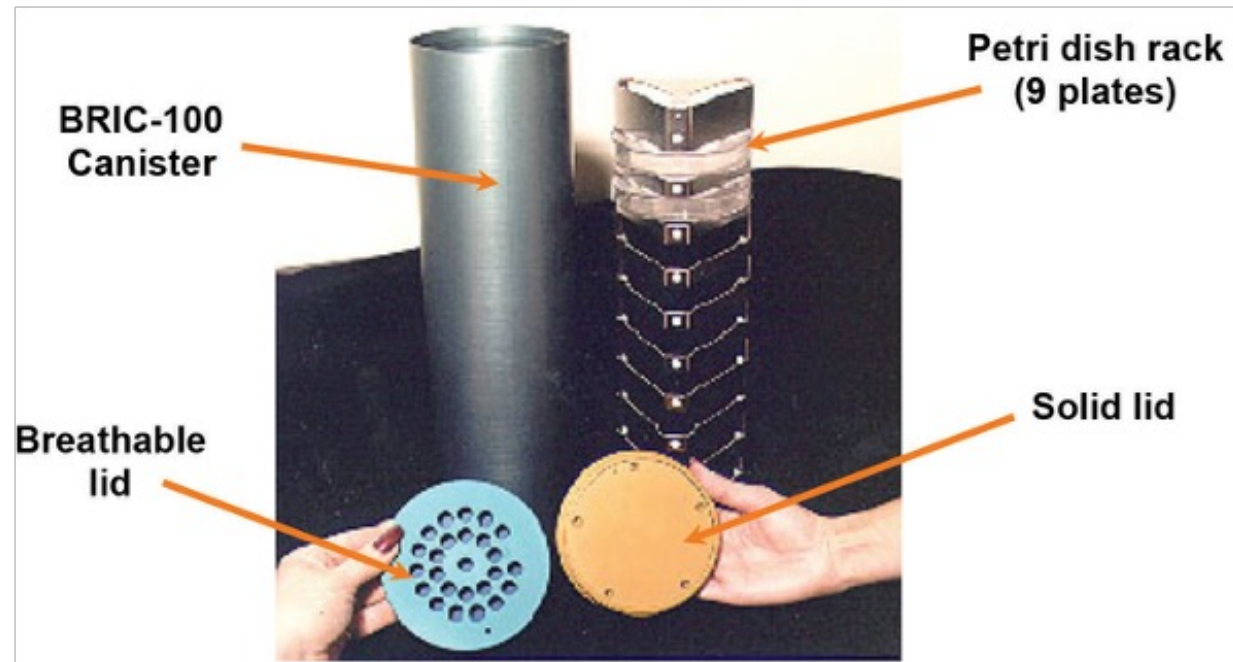


Fig. 2. BRIC-60 containing Teflon sample tubes.

# Biological Research In Canisters (BRIC)-100

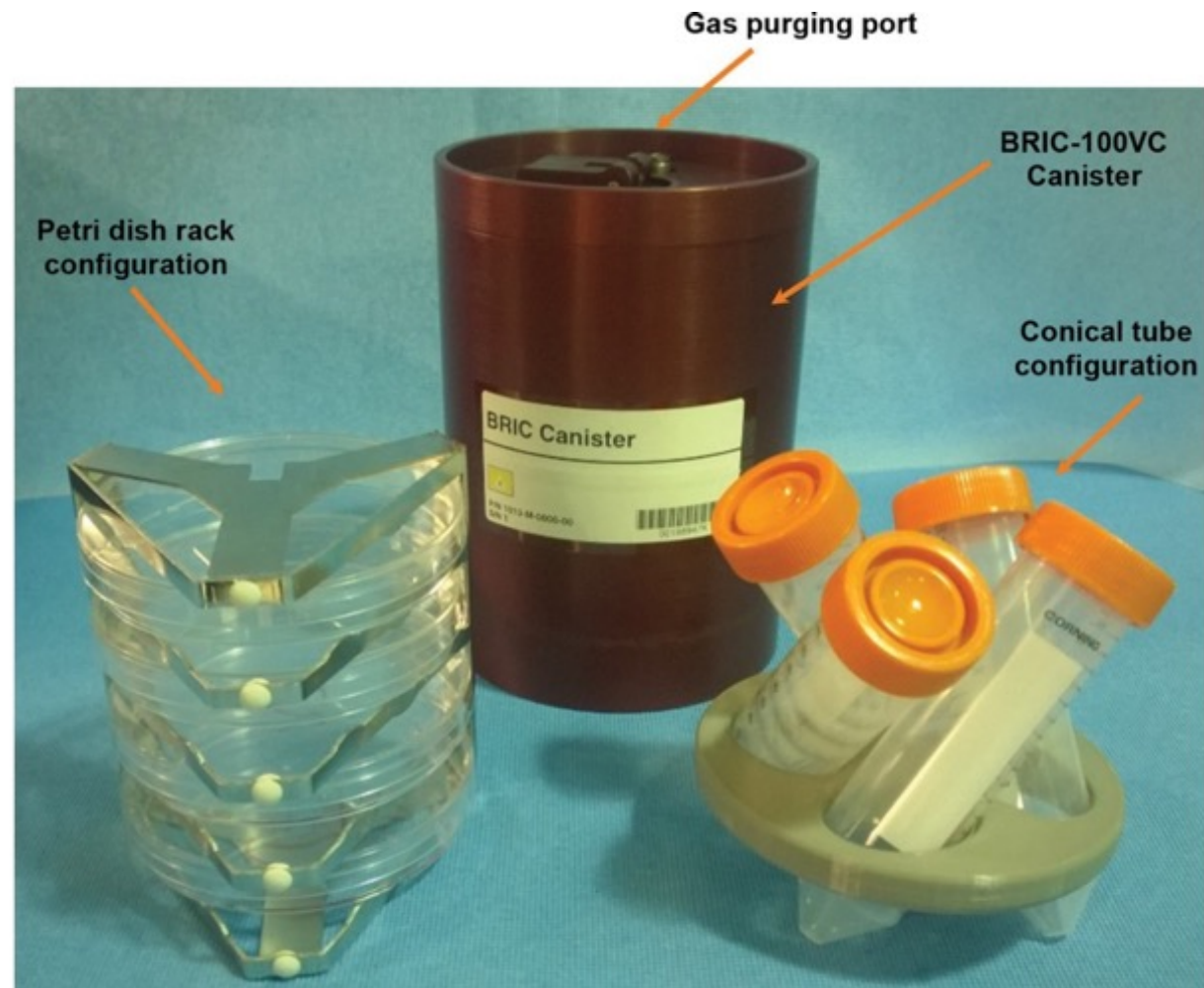
- The Biological Research in Canisters (BRIC) unit is an anodized-aluminum cylinder used to provide passive stowage for investigations into the effects of space flight on small specimens.
- Specimens flown in the BRIC 100 mm petri dish (BRIC-100) include *Manduca sexta* (tobacco hornworm) pupae, *Hemerocallis lillioasphodelus* L. (daylily) and *Dactylis glomerta* L. (orchard grass) embryos.
- BRIC-100 canisters have threaded lids on each end that allow for a **breathable configuration** (Fig. 1).
- This configuration allows passive gas exchange of oxygen and carbon dioxide **through a semi-permeable membrane**.
- **The vented BRIC-100 configuration is not a light-tight container; however if gas exchange is not required, the breathable lid (containing the semi-permeable membrane) can be replaced with a solid lid providing a sealed, closed experimental environment.**
- Bottom & top lids of each breathable canister have twenty-five 1.0 cm holes & a Teflon membrane (pore size 0.5  $\mu\text{m}$ ).
- Two septa located in the lid **allow for gas sampling**.
- BRIC-100 can accommodate **nine 100 mm petri dishes**.
- An ISS **stowage locker** can accommodate up to **three BRIC-100 canisters**.
- The petri dishes inside the canister are held in place by a **petri dish rack** that provides vibration isolation from the other dishes within the canister and air space between each petri dish.
- **If the petri dish rack is not utilized**, the canister is capable of holding up to **21 petri dishes**.



BRIC-100 with both lid options (breathable and solid lids) and petri dish rack.

# Biological Research In Canisters (BRIC)-100VC

- The Biological Research in Canisters (BRIC) is an **anodized-aluminum cylinder** used to provide passive stowage for investigations of the effects of space flight on small specimens.
- The BRIC 100 mm petri dish **vacuum containment** unit (BRIC-100VC) has supported *Dugesia japonica* (flatworm) under normal atmospheric conditions for 29 days in space and *Hemerocallis lilioasphodelus L.* (daylily) somatic embryo development within a 5% CO<sub>2</sub> gaseous environment for 4.5 months in space.
- BRIC-100VC is completely sealed providing containment and structural support of the experimental specimens.
- The top and bottom lids of the canister include **rapid disconnect valves for filling the canister with selected gases**.
- These specialized valves allow for specific atmospheric containment within the canister, providing a PI defined gaseous environment.
- The top lid has a toggle latch and O-ring assembly for prompt sealing and removal of the lid.
- The lower portion of the canister has been equipped with storage space for passive **temperature and relative humidity data loggers**.
- The BRIC- 100VC canister accommodates **standard 100 mm laboratory petri dishes or 50 mL conical tubes**.
- **6-9 canisters** have been flown **within an ISS stowage locker**.



BRIC-100VC with petri dish rack insert (left) and conical tube configuration (right).

# Biological Research In Canisters (BRIC) - Petri Dish Fixation Unit (PDFU)

- BRIC-PDFU allows organisms to be taken to space, chemically **preserved (fixed)**, and returned for post-flight processing using a **minimal amount of crew time**.
- A diverse range of research can be undertaken, including, **plant seedlings, callus cultures, *Caenorhabditis elegans*, microbes, and others**.
- Biological specimens are placed onto (or into) 60 mm petri dishes containing agar-solidified media or using alternative approaches (Fig. 1).
- Each petri dish is placed inside a single PDFU that remains contained within the BRIC canister during all phases of flight operations.
- PDFUs are prepared with **either one or two fluids in the reservoir**.
- Crew members perform up to two in-flight operations per petri dish** to either expose the biology to liquid treatments and/or chemically fix the tissues (e.g., Glutaraldehyde, RNALater, Formaldehyde, or other preservatives) on-orbit prior to return (Fig. 2).
- Five PDFUs plus one temperature data logger are loaded into each BRIC-PDFU** (Fig. 3).
- Actuator equipment** is used to administer fluids (Fig. 4).

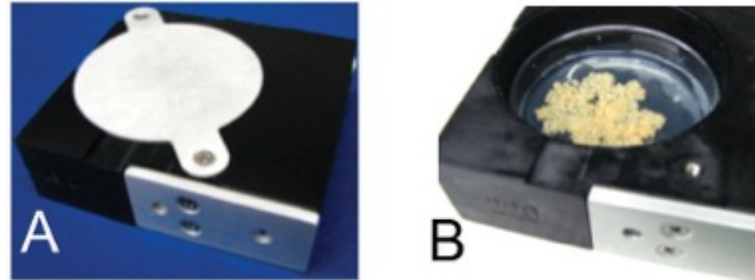


Fig. 1. A. View of an assembled PDFU. B. Callus culture on a 60 mm petri dish within a PDFU prior to closure (courtesy of A.L. Paul).

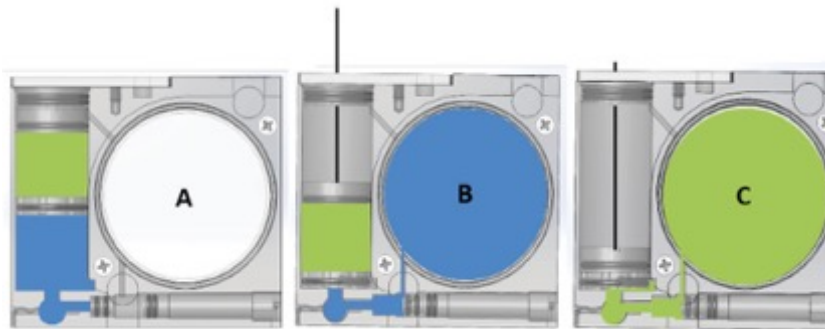


Fig. 2. Injection of Fluids into PDFU Petri Dishes. A. Liquids 1 & 2 contained within the PDFU reservoir prior to actuation. B. Actuator piston partially depressed to deliver Liquid 1. C. Completion of actuation allows Liquid 2 to be delivered.

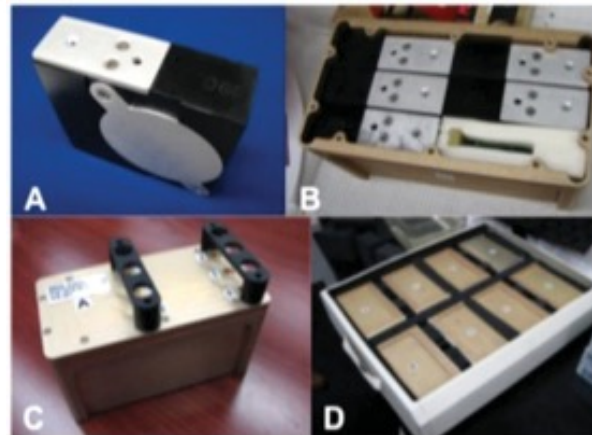


Fig. 3. A. Side View of a PDFU. B. 5 PDFUs plus a temperature logger within a BRIC-PDFU canister prior to closure. C. BRIC-PDFU canister with 2 pin guards attached. D. 8 BRIC-PDFU canisters within an ISS stowage locker.

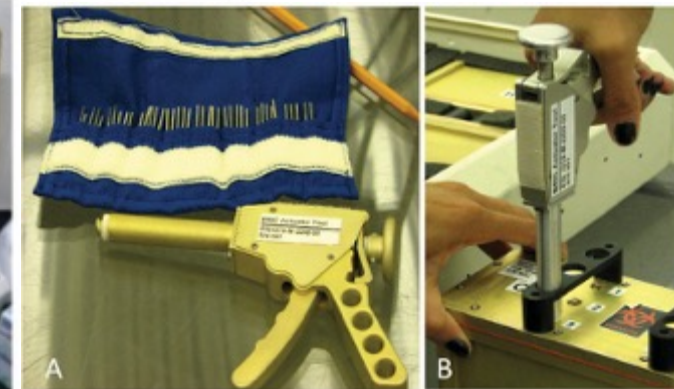
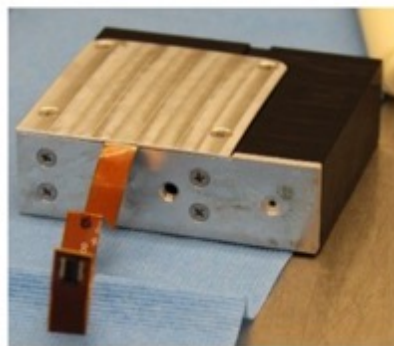


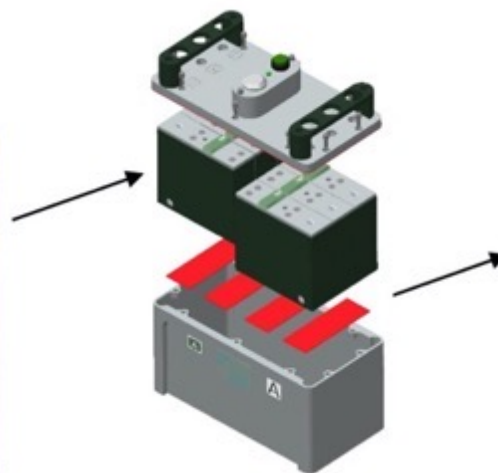
Fig. 4. A. Actuator Rod Kit & Actuator Tool. B. Actuator Tool attached to BRIC-PDFU canister.

# Biological Research In Canisters Light Emitting Diode (BRIC-LED)

- BRIC-LED PDFUs have **customizable LEDs** that illuminate the individual **60 mm petri dishes**.
- Organisms supported include plant seedlings, callus cultures, *Caenorhabditis elegans*, microbes, etc..
- 4 wavelengths of LED's (or more) are available for each petri dish (blue, red, far-red and white).**
- Temperature will be controlled to  $\pm 3^{\circ}\text{C}$  of the surrounding air temperature, with no more than a  $1.5^{\circ}\text{C}$  differential between canisters, using forced air cooling.**
- BRIC-LED provides temperature and LED status, canister pressure and accelerometer data.
- Specimens are placed onto (or into) 60 mm petri dishes containing agar-solidified media (alternative approaches possible).
- Each petri dish is placed inside a single PDFU that remains contained within the BRIC canisters during flight operations.
- PDFUs contain 1-2 fluids in the reservoir.
- Crew members perform 1-2 in-flight operations per petri dish to either expose the biology to liquid treatments and/or chemically fix the tissues on-orbit.
- Each BRIC-LED canister contains 6 PDFUs.
- Actuator used to administer fluids to PDFUs.



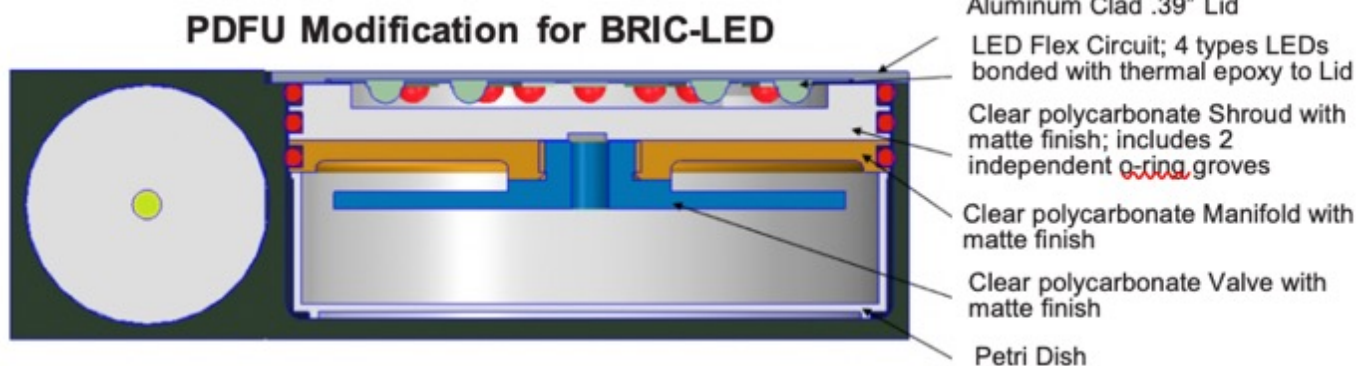
**Petri Dish Fixation Unit.**



**Canister Assembly.**



**Storage Tray Assembly.**



# Veggie: Vegetable Production System

- The Vegetable Production System (Veggie) was **developed to be a simple, easily stowed, and high growth volume yet low resource facility** capable of producing fresh vegetables on ISS.
- **In addition to growing vegetables in space, Veggie supports experiments designed to determine how plants respond to microgravity, provide real-time psychological benefits for the crew, and conduct outreach activities.**
- Veggie provides lighting, water and nutrient delivery for plant growth.
- **It utilizes the cabin environment for temperature control and a source of carbon dioxide for photosynthesis.**
- Veggie contains an **adjustable light emitting diode (LED) light bank** and a reservoir that supplies water via capillary action to root pillows containing substrate, nutrients and seeds.
- Water is administered on-orbit to initiate seed germination and periodically added throughout the growth cycle.

## Veggie Configured for Growth of Lettuce



**Veggie Light Bank.**



**Veggie plant pillow with quick disconnect fitting for adding water.**



**Veggie with 6 plant pillows contained within adjustable bellows.**



**Astronaut Steve Swanson harvesting lettuce on ISS.**



**Astronaut Steve Swanson basking in the glow of Veggie.**



**Astronaut Kjell Lingren (left) and Scott Kelly (right) enjoying freshly harvested lettuce on ISS.**

## Specifications:

### Light Provision

100-500  $\mu\text{mol m}^{-2} \text{s}^{-1}$  photosynthetic photon flux density (PPFD)

Red (630 nm), Blue (455 nm) and Green (530 nm)

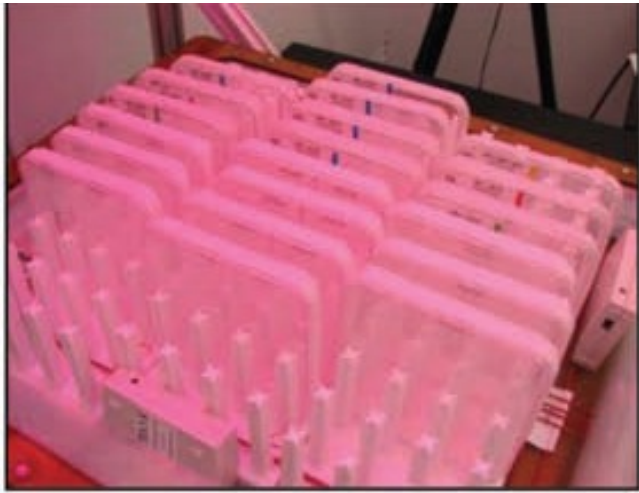
Cabin Air Fan Settings: Low / High / Off

Baseplate Footprint: 29.2 cm x 36.8 cm

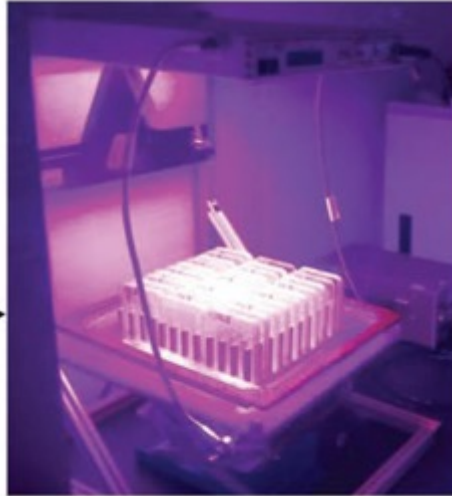
Maximum Height: 47.0 cm empty; 41.9 cm with root mat

# Veggie Configured for Petri Plate Science Experiments

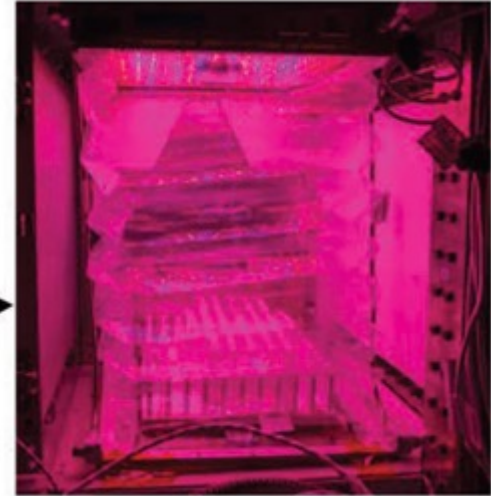
- Veggie has also supported **Petri plate-based science experiments** that have included monocot and dicot plant species that were grown for a pre-determined durations, photographed, harvested, and preserved for return to Earth.
- In some instances, Petri plates have undergone fluorescent microscopy within the **Light Microscopy Module (LMM)**.



Petri plate holder concept containing up to 30 plates.



Plates containing *Arabidopsis* in Veggie (bellows open).



Plates containing *Arabidopsis* in Veggie (bellows closed).

## Plant Fixation



Astronaut Butch Wilmore fixing plants on ISS using a Kennedy Fixation Tube (KFT).

## Plant Imaging

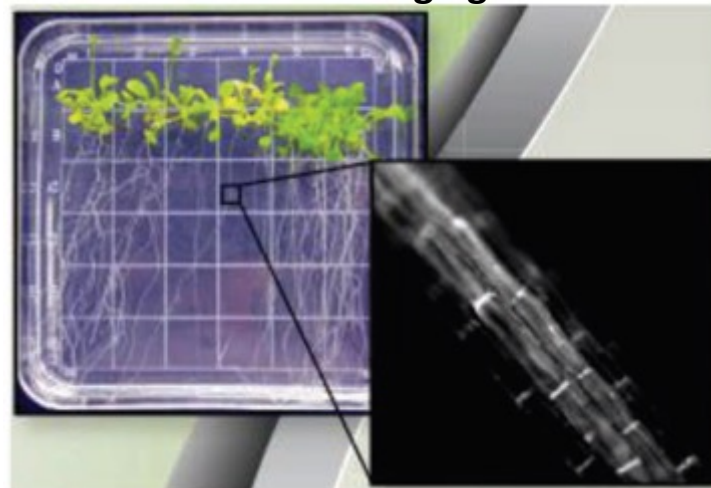


Image of an Arabidopsis root taken in the Light Microscopy Module (LMM).

# Kennedy Space Center Fixation Tube (KFT)

- Experiments performed on ISS frequently require the experimental organisms to be preserved until they can be returned to earth for analysis.
- The Kennedy Fixation Tube (KFT) was developed to allow astronauts to apply fixative, chemical compounds that are often toxic, to biological samples without the use of a glovebox while maintaining three levels of containment (Fig. 1).**
- KFTs have been **used over 200 times on-orbit with no leaks of chemical fixative.**
- The KFT is composed of a polycarbonate **main tube** where the fixative is loaded preflight, the **sample tube** where the plant or other biological specimens is placed during operations, the **expansion plug, actuator, and base plug** that provides fixative containment (Fig. 2).
- The main tube is pre-filled with 25 mL of fixative solution pre-flight.
- When actuated, the specimen contained within the sample tube is immersed with approximately 22 mL of the fixative solution.
- The KFT has been demonstrated to **maintain its containment at ambient temperatures, 4°C refrigeration and -100°C freezing conditions.**



Fig. 1. Astronaut Jeff Williams using KFTs to fix plants on ISS (left) and Astronaut Leland Melvin holding 2 KFTs after fixing plants on ISS (right).

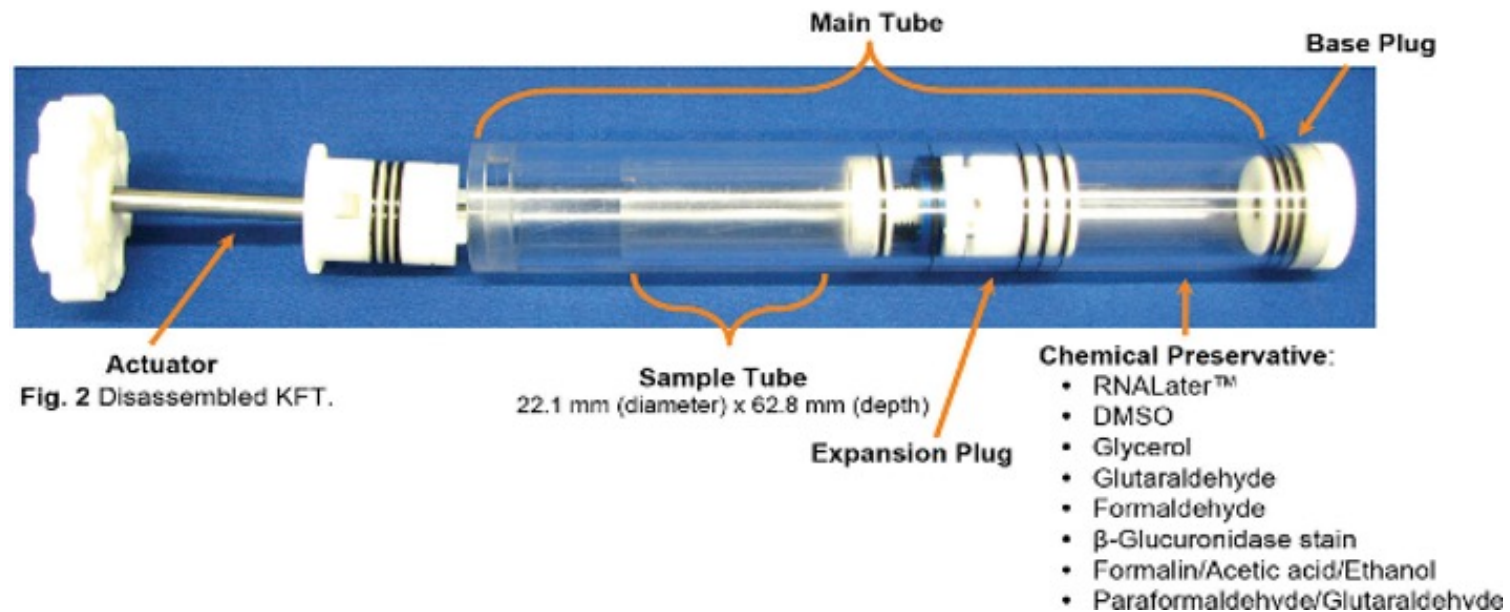
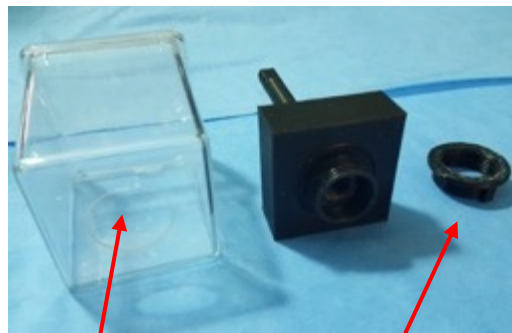


Fig. 2 Disassembled KFT.

# Apex Growth Chamber Plant Growth Assembly

- For **APEX-6** the KSC Payload Development Team designed an alternative **passive, plant culture device for use in Veggie**.
- *Brachypodium distachyon* seeds were germinated within 75mm x 75mm x 2250mm Magenta Jar Growth Assemblies.
- The PI Team will prepare fifteen (15) Magenta Jar Assemblies (12 primary, 3 spare).
- Each **Magenta Jar Assembly contained 20-24 specimens** from three accessions (strains).
- Water is injected through the bottom and absorbed directly into the foam (Oasis RootCube formulation LC-1).
- Watering from the bottom simplifies disassembly on-orbit for harvest.
- The vertical tube both centers the foam and serves as the method for crew removal of the foam for processing.



Retaining Nut

Mounting hole drilled through Magenta Jar bottom



8 Water Delivery Openings



Watering System Installed in Magenta Jar



Retaining Nut Installed



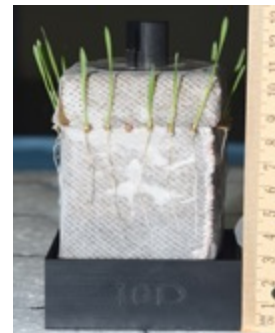
Foam & Magenta Top Installed



Nutrient Solution Injection



Fully Loaded Veggie



*B. Distachyon* growth with roots visible for photography.

# Passive Orbital Nutrient Delivery System (PONDS; under development)

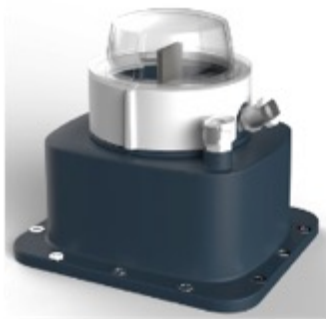
- PONDS is a new plant growth approach that contains both an area for a contained plant growth substrate and a reservoir for water and/or plant nutrient solutions.
  - It was developed to fit under the Veggie light bank.
  - PONDS provides water delivery to seeds for germination and fulfills the requirement to transport water from the reservoir for improved plant growth while providing aeration to the root zone under both 1g and  $\mu$ g conditions
- NOTE: Not yet validated on ISS.**



KSC Prototype  
 →  
 Ground Studies



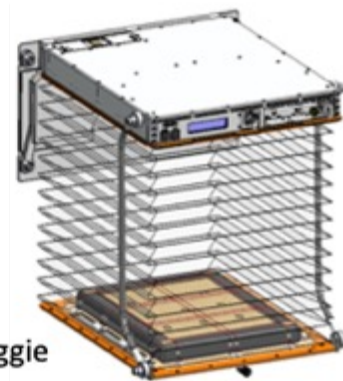
**Flight Unit Development Team:** Techshot and Tupperware



Flight Design



Conceptual Image of six POND units as to be installed into Veggie.



Veggie

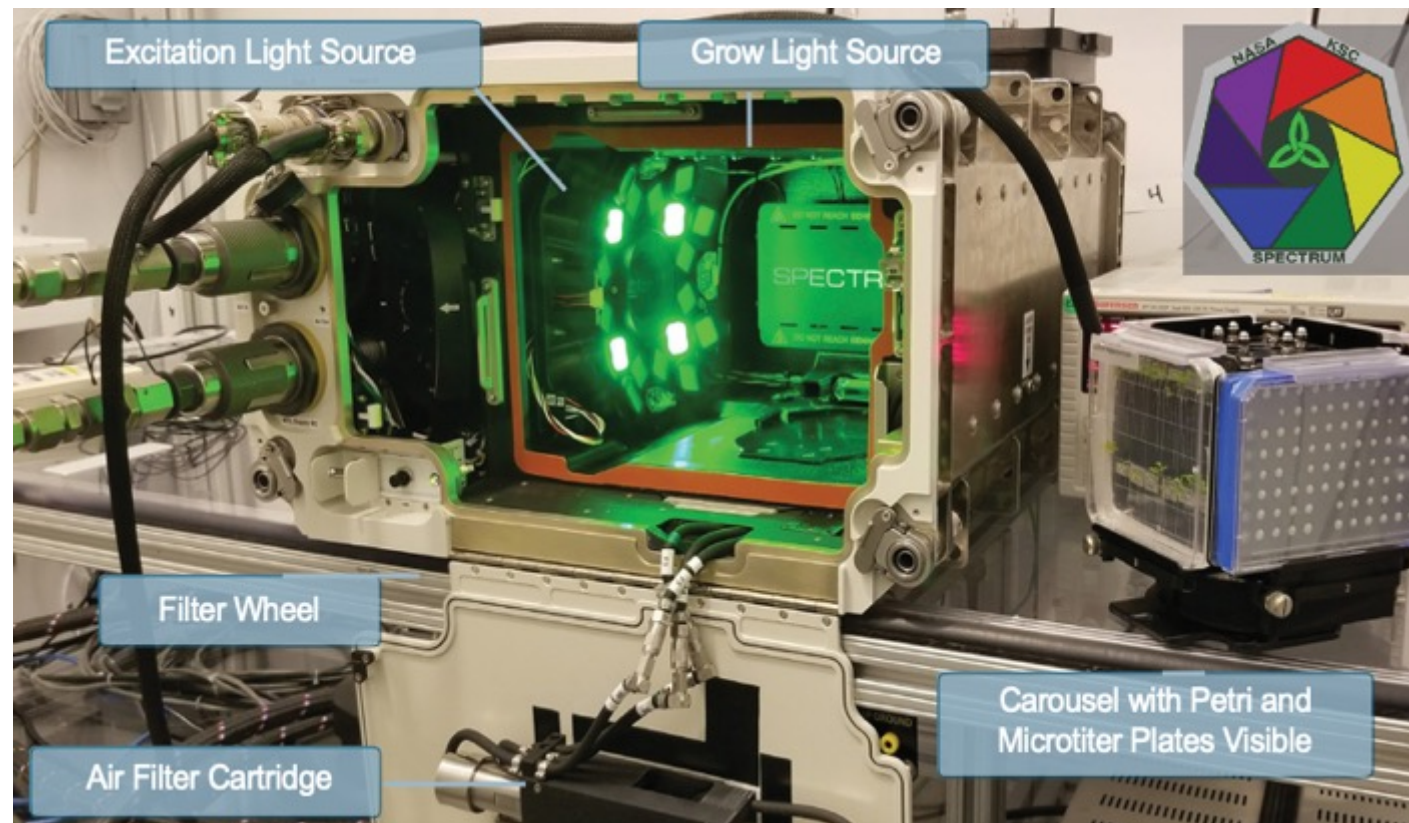


**Design Concept:**  
 Exploded View (top).  
 Cross Sectional View  
 (bottom).

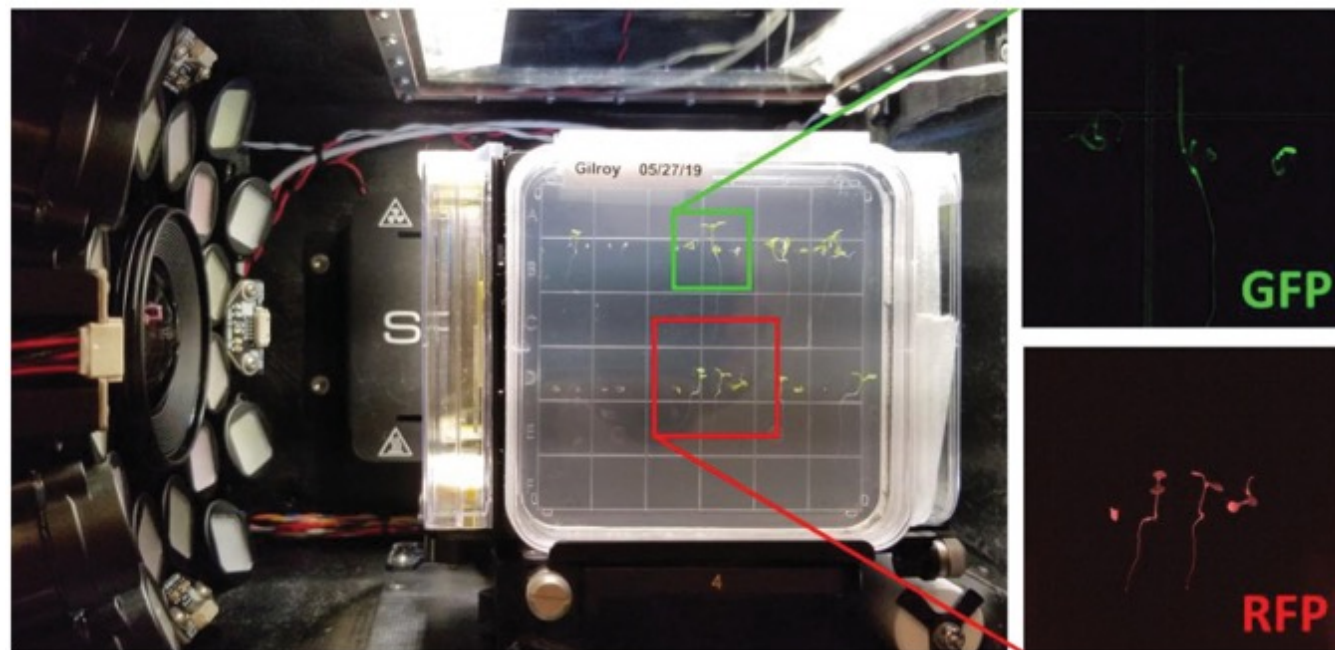
- PONDS on orbit concept of operations is similar to the Veggie plant pillows.
- A clear germination cap maintains high humidity levels during the seed germination phase.
- At harvest the plant cylinder is removed, placed in a bag for cold stowage and returned.
- The POND reservoir then has a separate opaque cap that is installed prior to return.
- Once protocols are validated, POND units may (TBD) be reused for successive grow outs.

# SPECTRUM: Multispectral Fluorescent Imager

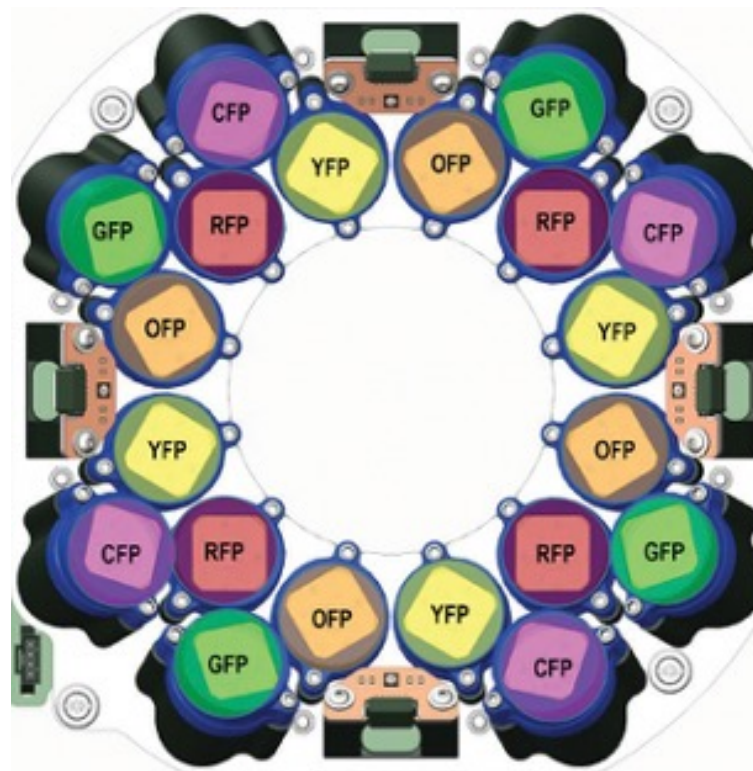
- Spectrum is a multi-spectral fluorescence imaging system designed for capturing *in vivo* genetic expression on ISS.
- Model organisms that may utilize multispectral imaging on ISS include **unicellular organisms (e.g. *Saccharomyces cerevisiae*)**, **plants (e.g. *Arabidopsis thaliana*)**, and **invertebrates (e.g. *Caenorhabditis elegans*)**.
- Accommodates standard 100 mm x 100 mm Petri plates, 128 mm x 82 mm multi-well culture plates, and other custom containers within the growth and imaging chamber.
- Provides automated chamber management & continuous collection of chamber environment information, while capturing 71 megapixel images of fluorescent emission from biological organisms.
- **Controls chamber temperature (18-37°C), humidity, CO<sub>2</sub> (400 ppm up to ISS-ambient levels), volatile organic compounds (ethylene scrubbing < 25 ppb), and growth light characteristics.**
- **Provides high resolution imagery with resolution to 2.5 μm.**
- 10-position motorized filter wheel for fluorescence emission filters paired with **Excitation Light Source (ELS)** using diffusers to achieve 80% uniform illumination of target area.
- Additional filters are provided to support color and infrared images.
- This capability allows researchers to image several fluorescent proteins in a single specimen.



- Growth light cap is equipped with broad-spectrum white (400-750 nm), red (630-660 nm), blue (400-500 nm), and green (520-530 nm) LED's with an intensity range of 0-1000  $\mu\text{mol m}^{-2}\text{s}^{-1}$ .
- LEDs illuminate samples from the top.
- Air ducted through the Carousel to suppress condensation inside Petri plate covers.
- Four 100 mm x 100 mm Petri plates can be mounted and rotation controlled with placement of the Petri plate position to +/- 0.1 degree after rotation.
- **The carousel is capable of continuous rotation for low accelerations up to 33 rpm and is removable.**
- **Can be modified** for new science requirements, including the Excitation Light Source (ELS) and the Emission filters, camera lenses, chamber sensors, carousel assemblies, and the Air Filter Cartridge.
- Commanded from the ground & stores time stamped images with the option to downlink data for near-real time evaluation by the investigator team.
- Software modifiable during flight.



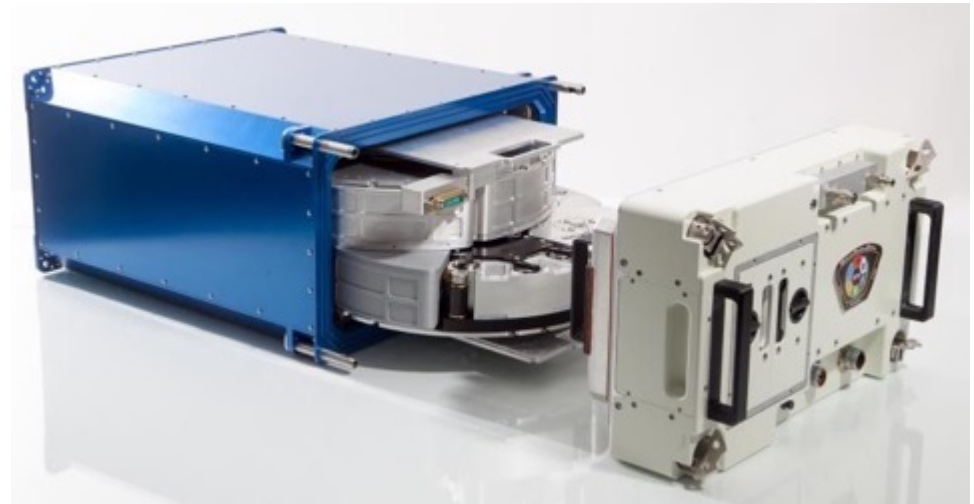
ELS and Carousel Subsystems within the Spectrum Growth Chamber. Insets are images of Arabidopsis plants expressing GFP and RFP fluorescence.



Spectrum ELS mapping by fluorescent protein.

# MVP: Multiuse Variable-G Platform (Redwire)

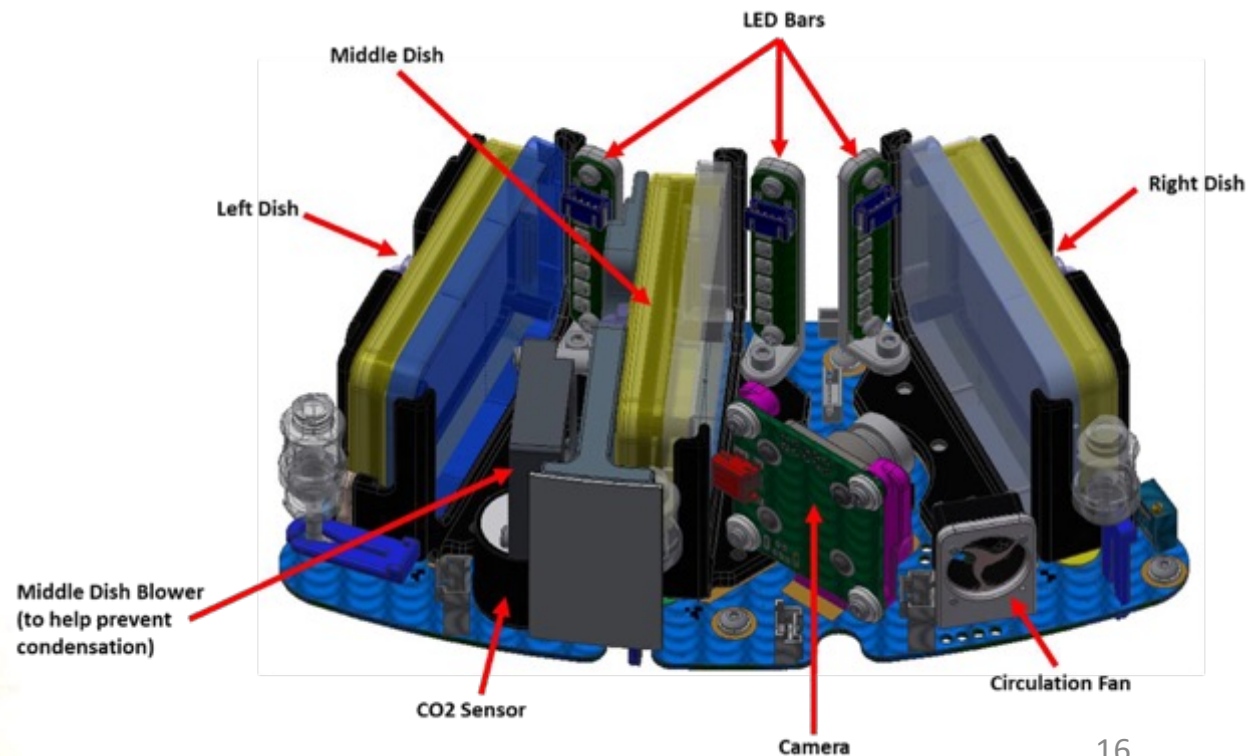
- Dual 390 mm rotors can provide two independent gravity level treatments (0-2g).
- Thermal control & Ground Telemetry/Real-Time Data.
- 12 sample modules (6/centrifuge) with video capability.
- Plants, Bacteria, Cell Cultures, *Drosophila*, *C. elegans*, etc.
- Rotors and sample modules removable on orbit.
- 3 Plant Plates per Module.
- LED Lighting.
- CO2 Sensor
- 1 Camera
- Circulation Fan
- Blower Fan



## Microbe Module



## Plant Module



# ADSEP: ADvanced Space Experiment Processor (Redwire)

- Real time monitoring and control of cassette-based experiments from the ground while in EXPRESS Rack.
- Autonomously and simultaneously conduct research in **three experiment cassettes**.
- **Can be operated during ascent** and/or onboard ISS EXPRESS Rack.
- **Cassettes are swappable on orbit**, can process many cassettes during a mission.
- In bacteria research configuration, up to 24 separate bags in each cassette.
- **Up to six-month experiment duration**.
- **4° - 40° C cassette temperature range**, can be different in each inserted cassette.
- Each cassette can include **video and still imagery**.
- On-board data storage back-up.
- **O<sub>2</sub> and CO<sub>2</sub> monitoring and control**.



**3 ADSEP units available.**



**Open view of an ADSEP locker.**



**Cell Culturing: 50 ml rotating bioreactor, automated feeding, waste & sample collection and fixing.**



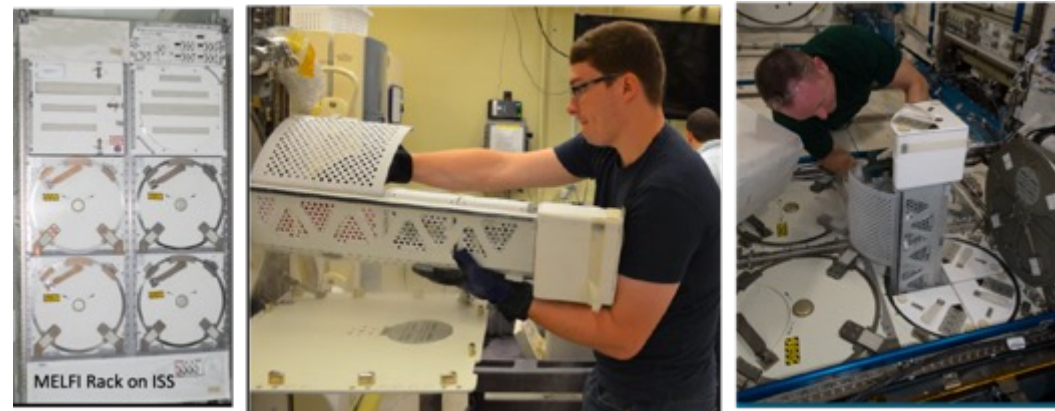
**Pumps, bags & valves in multiple sizes with 24-bag configuration shown on right.**



# Active Cold Stowage Assets

## MELFI: Minus Eighty-Degree Laboratory Freezer for ISS (3 on ISS)

- MELFI consists of four independent dewars which can be set to operate at different temperatures.
- Temperatures of  $-80^{\circ}\text{C}$ ,  $-26^{\circ}\text{C}$ , and  $+4^{\circ}\text{C}$  are used during on-orbit ISS operations.



MELFI (ESA)

## GLACIER (4 on ISS): General Laboratory Active Cryogenic ISS Experiment Refrigerator

- Can be used in an ISS EXPRESS Rack or on a Launching/returning vehicle.
- Temperature Range is  $+4^{\circ}\text{C}$  to  $-160^{\circ}\text{C}$  (using Moderate Temperature Loop for liquid cooling).



GLACIER (Univ. of Alabama, Birmingham)

## POLAR (4 on ISS):

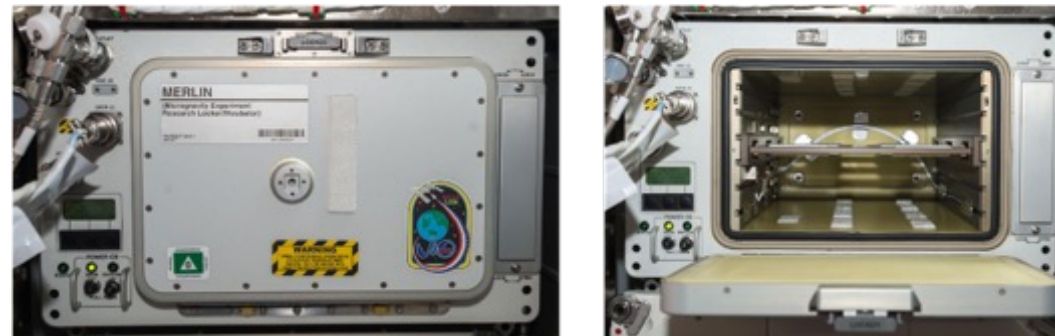
- Can be used in an ISS EXPRESS Rack or on a Launching/returning vehicle to maintain sample temperatures.
- Temperature Range is  $+4^{\circ}\text{C}$  to  $-80^{\circ}\text{C}$ .



POLAR (Univ. of Alabama, Birmingham)

## MERLIN (4 on ISS): Microgravity Experiment Research Locker/Incubator

- MERLIN stores samples at  $-20.0^{\circ}\text{C}$  to  $+48.5^{\circ}\text{C}$  ( $-20^{\circ}\text{C}$  with ISS water cooling;  $-5^{\circ}\text{C}$  with ISS air cooling).
- Can transport for samples to and from ISS (using battery power or vehicle power).
- Can be commanded from the ground.



MERLIN (Univ. of Alabama, Birmingham)

# Passive Cold Stowage Assets

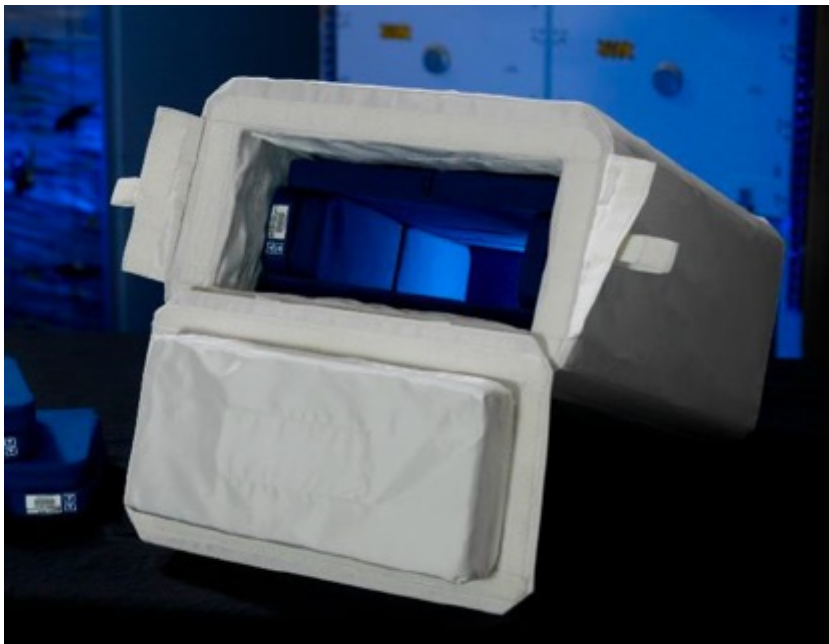
- **Non-Powered Hardware** is utilized to maintain temperatures during transport on a visiting vehicle and between active hardware assets on ISS.
- It includes **Double Coldbags (DCBs), Mini Coldbags (MCBs), Ice Bricks, 3X5 Mesh Bags.**
- **DCBs: Primary means to bring temperature-dependent science to and from ISS.**
- **MCBs:** Used for smaller samples during operations or for return on Soyuz.
- **Preconditioned Ice Bricks** used for temperature control.
- Samples typically remain in 3X5 Mesh Bags for return in DCBs and Active Hardware.
- **Hold times depend on Ice Brick temperatures that are pre-conditioned in active hardware.**
- **Available Ice Brick temperatures include -32°C, -26°C, +4°C, +12°C, +16°C, +25°C, +27°C, +37°C.**



Ice Bricks



Mini Coldbag Closed (top) and with Samples (below)



Double Coldbag (DCB)

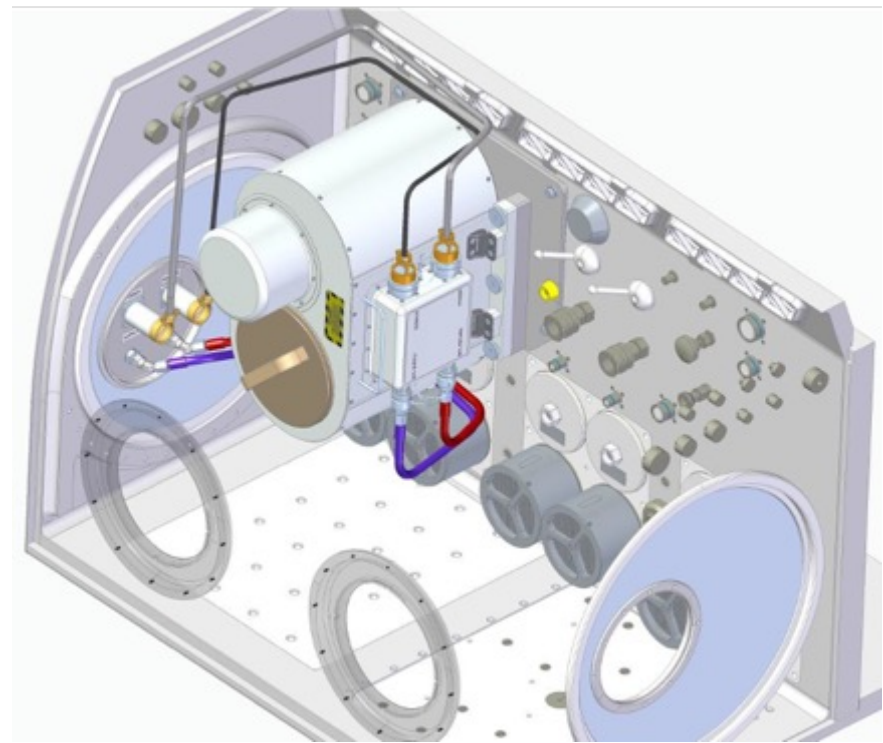


Sample Mesh Bag

# Active Rapid Freezing on ISS

## Glovebox Freezer (Univ. Alabama, Birmingham)

- No LN2 freezing capability exists on ISS today; however, quick freeze solutions using existing assets exist.
- Capability to rapidly freeze biological samples providing a  $-185^{\circ}\text{C}$  interface.
- **3 Locations (LSG, MSG, Express Rack).**
- Can freeze multiple samples over a short period of time.
- Provides consistent freeze rate from sample to sample.
- Interchangeable sample cartridges to accommodate a variety of sample types.



Glovebox Freezer in Microgravity Science Glovebox (MSG)

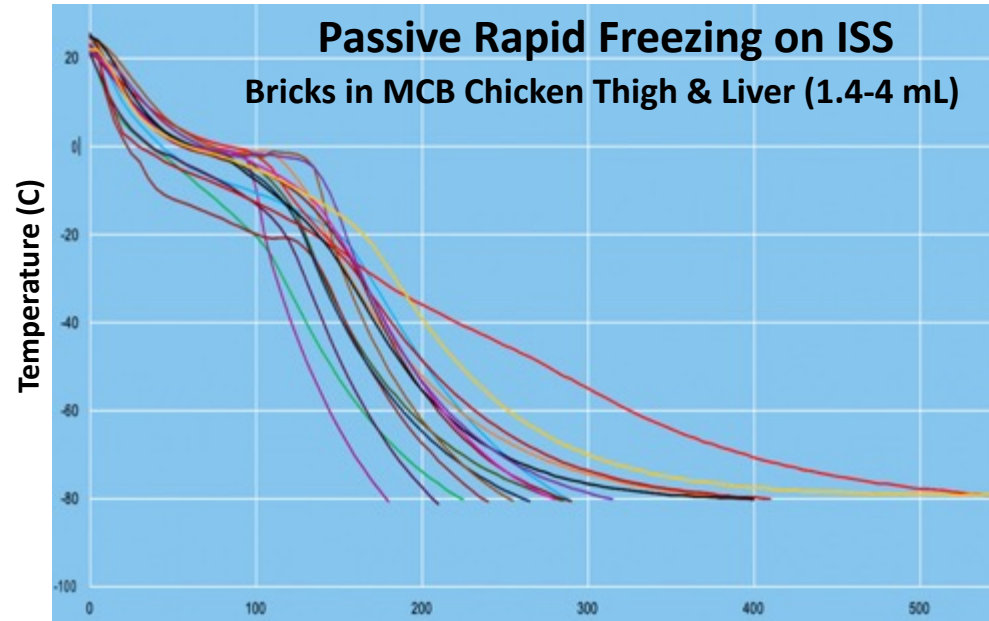
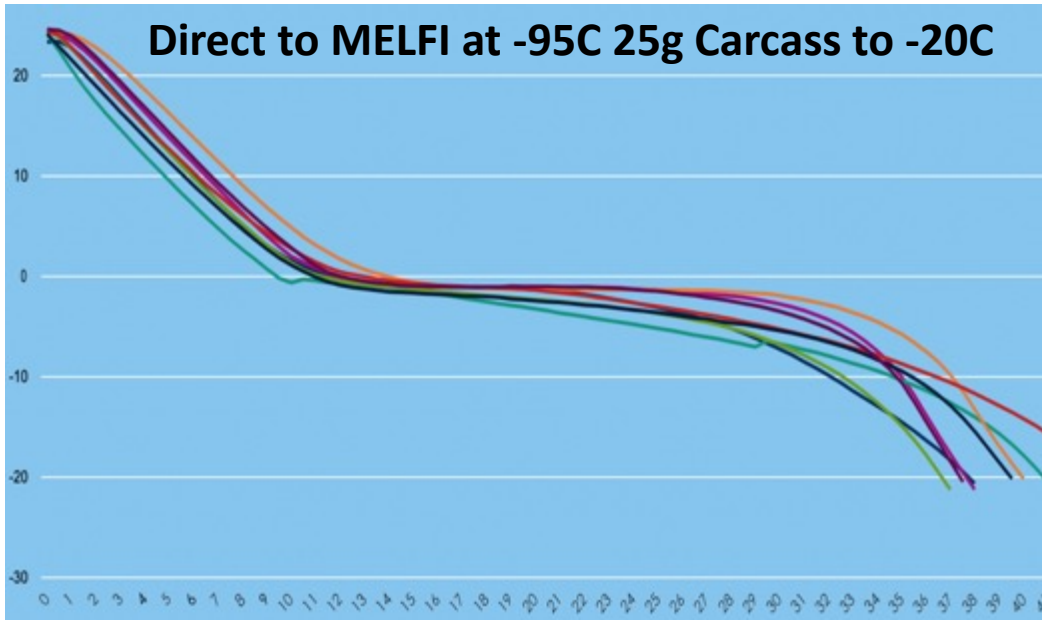
# Passive Rapid Freezing on ISS

- Specimens transferred into labelled foil packets and frozen at  $-150^{\circ}\text{C}$  using a **conditioned  $-150^{\circ}\text{C}$  cold block in a mini cold bag.**
- Transfer to GLACIER or MELFI freezer following harvest completion.
- For harvested plants, insert foil packets with specimens into cold storage asset for return.



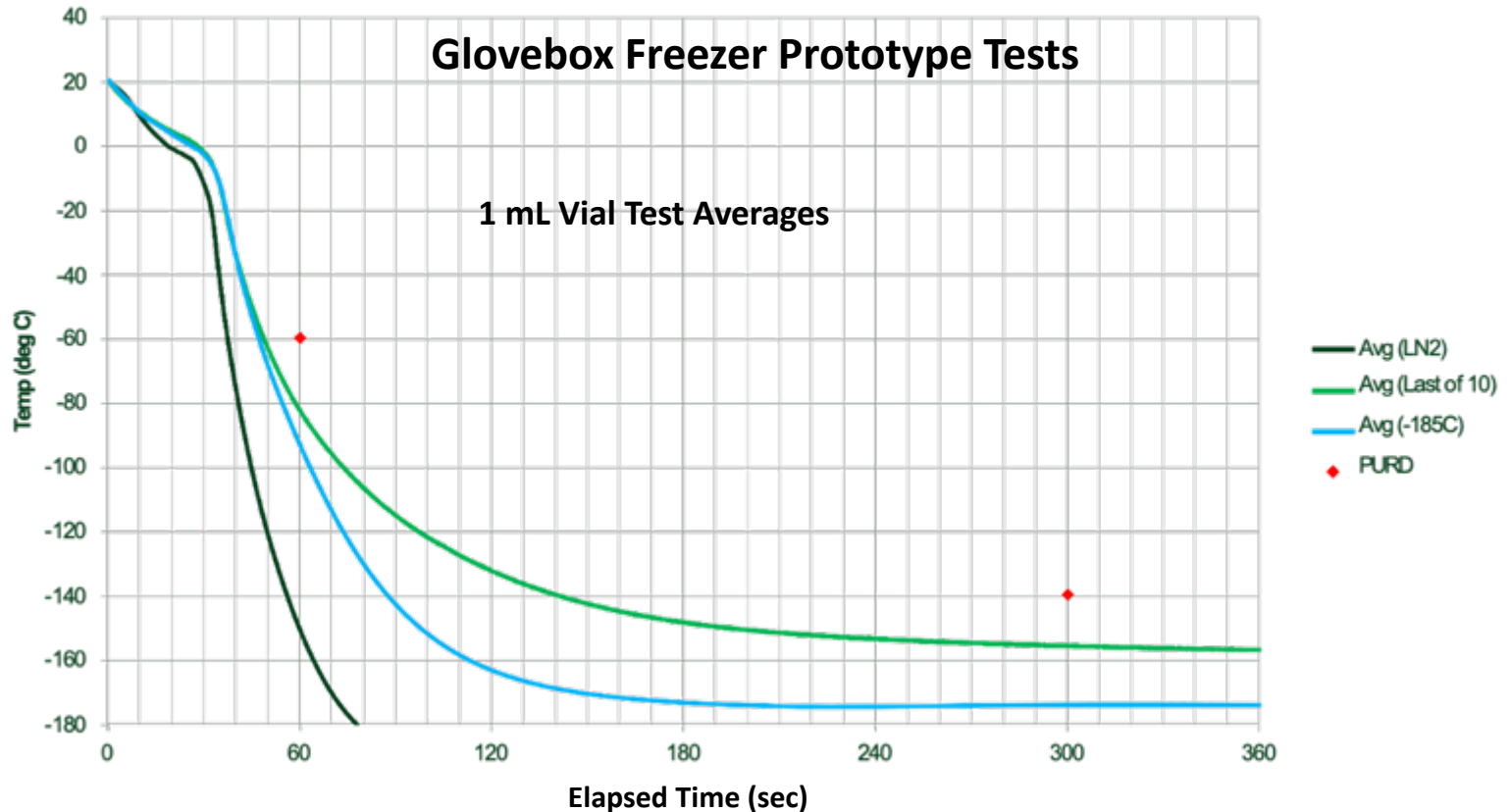
Passive Rapid Freezing in a Mini Cold Bag.

# Freezing Rates: MELFI vs Passive Rapid Freezing vs Glovebox Freezer



Elapsed Time (min)

Elapsed Time (sec)



# GAP-FPA: Group Activation Pack-Fluid Processing Apparatus (BioServe)



A Fluid Processing Apparatus (FPA) is essentially a microgravity test tube that allows controlled, sequential mixing of two, three or four fluids in a weightless environment.

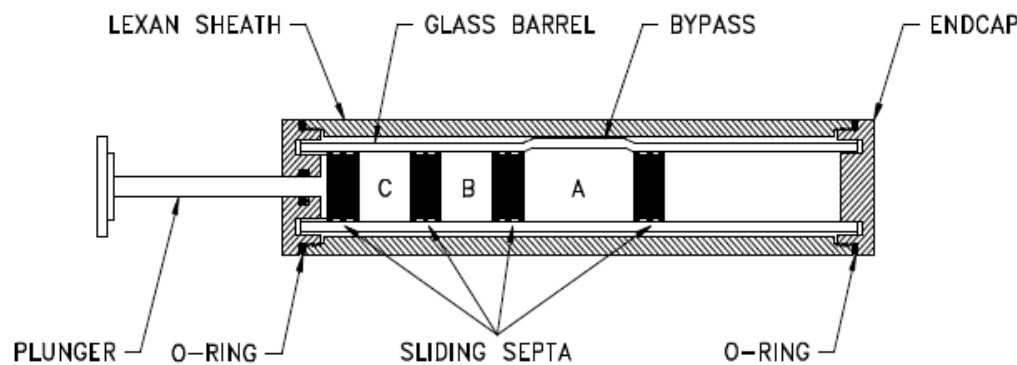


Eight FPAs can be housed in either a hand-operated (see above) or an automated/motorized group activation pack (GAP).



The auto-GAP allows 8 FPAs to be processed simultaneously utilizing a DC motor drive mechanism to automatically initiate and terminate experiments based on preprogrammed instructions.

Activating 8 FPAs inside a manual GAP.

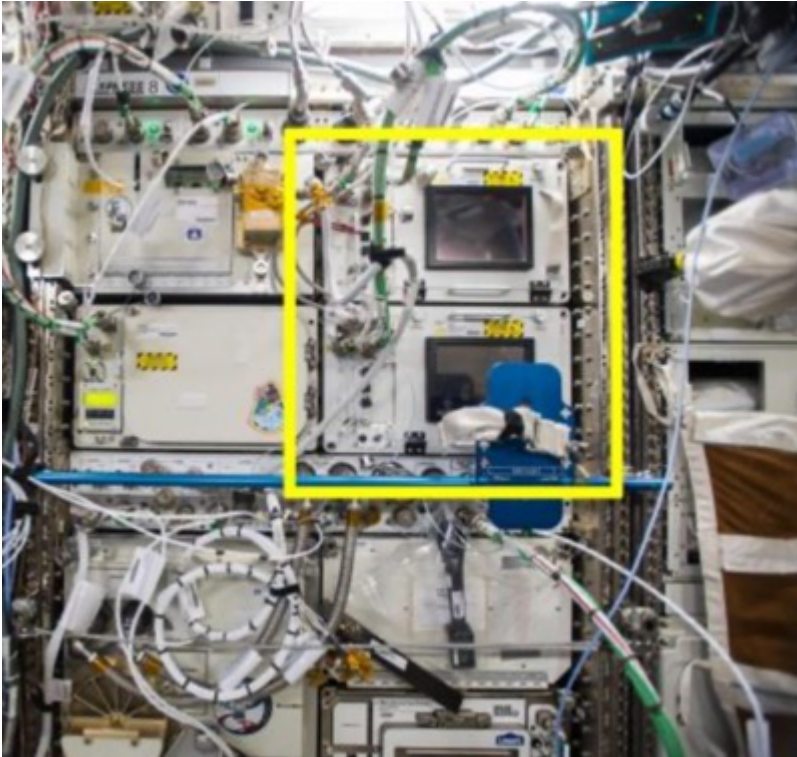


Schematic Diagram of FPA.

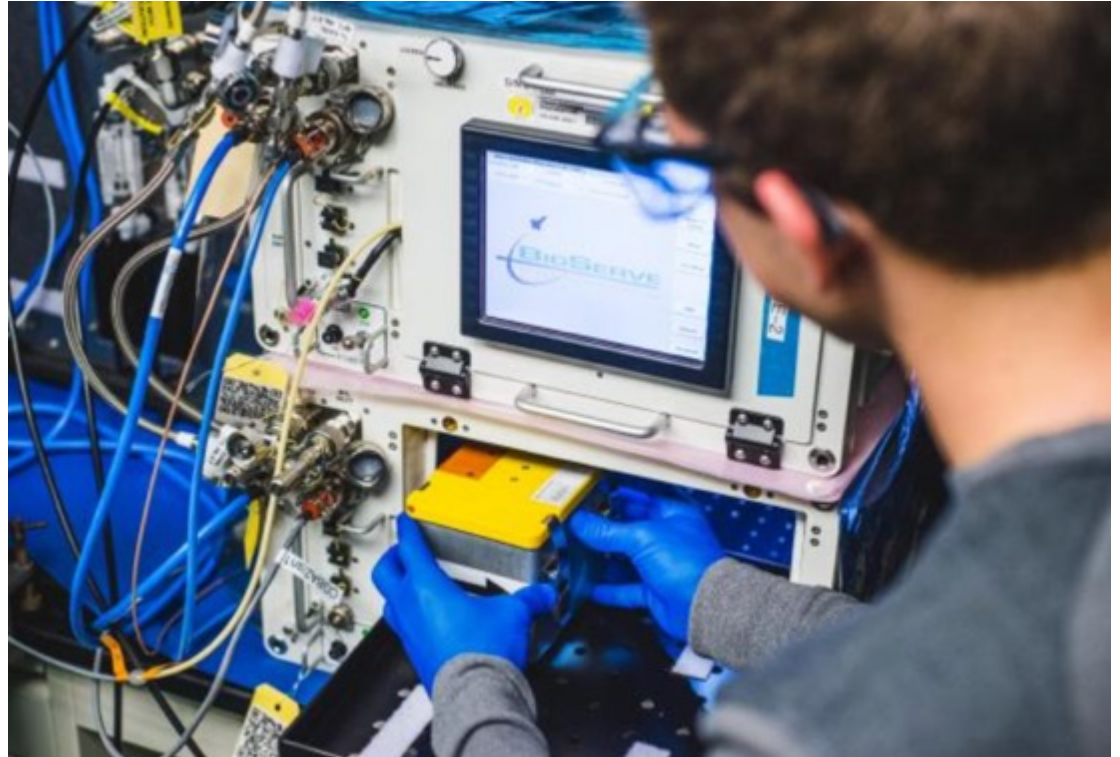


# SABL: Space Automated Bioproduct Lab (BioServe)

- SABL provides researchers with advanced incubator technology for a wide variety of experiment.
- Precise temperature control incubator (-5°C to 43°C).
- **Three units operating on ISS now.**
- **Atmosphere composition control** (e.g. 5% CO<sub>2</sub>).
- Each unit has over 23 liters of volume for scientific hardware.
- Has 2 USB ports and 2 Ethernet LAN connections.



Two SABL units (inside yellow rectangle) aboard ISS.



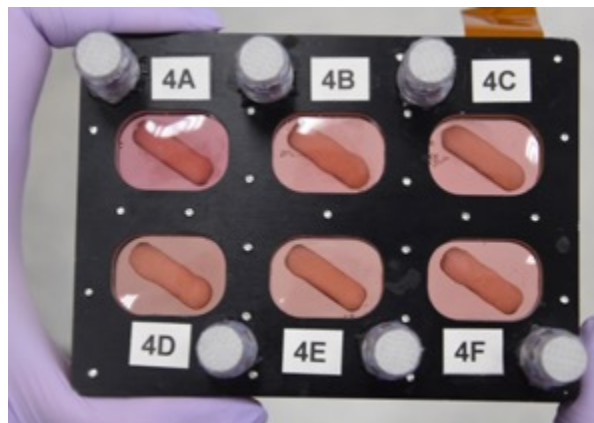
SABL with Color Touch Screen.

# BioCell (BioServe)

- **BioCell is a family of cell culture hardware analogous in function to a typical cell culture flask or multi-well culture plate on ISS (certified for BSL 2 organisms).**
- BioCells have supported numerous flight experiments in tandem with the **SABL incubator**.
- **Both attached and suspended cell cultures** are supported.
- BioCells are available in **three formats: single-well, six-well, and 12-well.**
- BioCells are compatible with the **BioServe Microscope** and the 12-well is compatible with the **Nanoracks Plate Reader**.
- BioCell have **customizable membranes** that can support cellular attachment, cell suspension and gas exchange (typical materials include Teflon FEP, polycarbonate, and polystyrene).
- All BioCell components are readily **autoclavable** or able to be **gamma irradiated** to meet sterility requirements.
- BioCells are **compatible with temperature ranges from -80°C to +43°C.**
- BioCell **have inlet, outlet and sampling ports for fluid injections, media exchanges, fixation, and culture preservation.**
- **Usually fluid manipulations are crew facilitated, but automated fluid exchange mechanisms are available.**
- BioCell models have been fitted with custom coupons to enable studies of biofilm formation on different substrates.



**Single-Well BioCell filled with Growth Medium.**



**6-Well BioCell.**



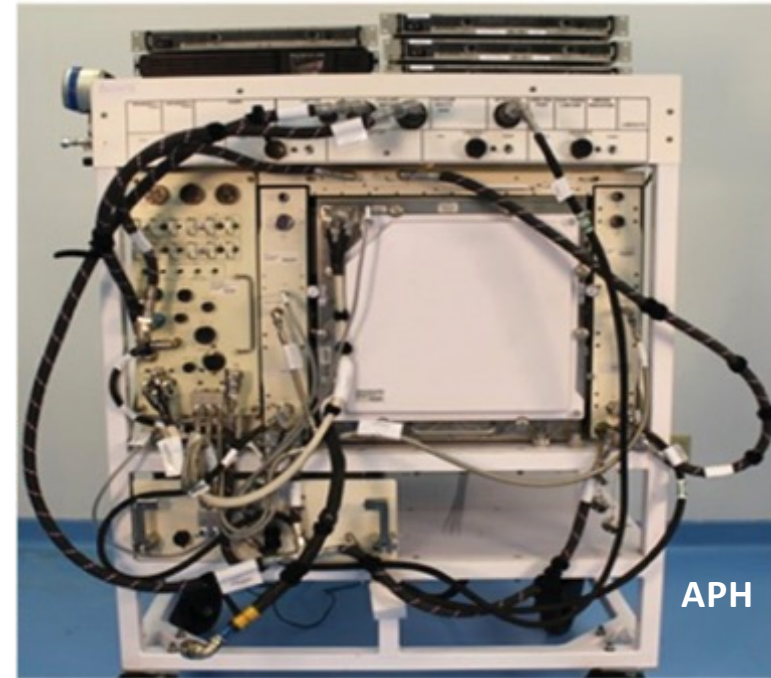
**12-Well BioCell.**

# Advanced Plant Habitat (APH)

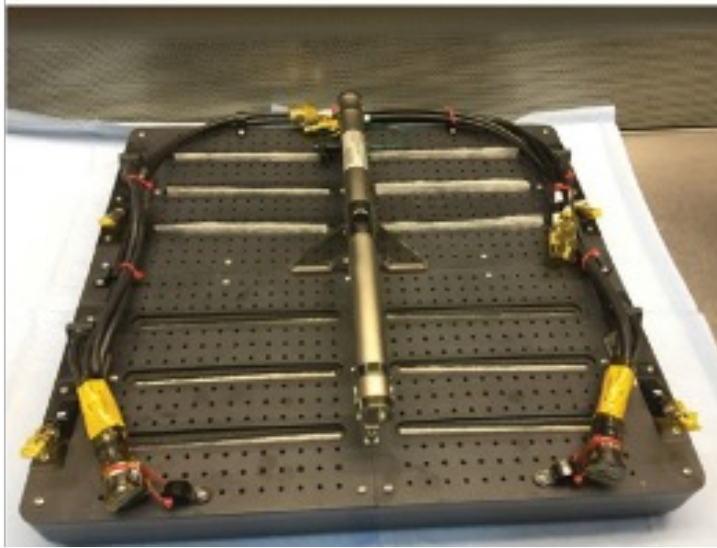
- **APH is a large growth volume habitat** that has been developed for multi-generational and developmental studies on ISS.

APH is equipped with **over 180 calibrated sensors** to ensure the system functions autonomously using a pre-programmed experimental design that provides a suitable growth environment (e.g., temperature, relative humidity, carbon dioxide level, light intensity and spectral quality) for **plant experiments up to 135 days**.

- **APH controls temperature 18-30°C ( $\pm 1^\circ\text{C}$ ), relative humidity 50-90% ( $\pm 5\%$ ), CO<sub>2</sub> concentration 400-5,000 ppm ( $\pm 50$  ppm or 3%), ethylene scrubbing <25 ppb, air ventilation flow 0.3-1.5 m/s, and O<sub>2</sub> concentration (18-24%).**
- The APH growth chamber supports plant growth up to 45 cm (max. shoot height), with a growth area consisting of 1,708 cm<sup>2</sup> and a growth volume of 112,500 cm<sup>3</sup>.
- The modular **science carrier** supports a root zone height up to 5 cm and can be configured with **substrates and nutrients specified by the PI. Water is delivered through porous tubing within the science carrier.**
- Air and water samples can be collected during experimentation.
- **Growth lighting** is designed with a controllable photosynthetic photon flux (PPF) of **0-1000  $\mu\text{mol m}^{-2}\text{s}^{-1}$**  (photosynthetically active radiation 400-750 nm) with a LED light assembly consisting of broad spectrum white (0-600  $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$ , 400-700 nm), red (0-600  $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$ , 630-660  $\pm 10$  nm), blue (0-400  $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$ , 400-500  $\pm 10$  nm), green (0-100  $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$ , 525  $\pm 10$  nm), and far-red (0-50  $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$ , 730-750  $\pm 10$  nm) lighting uniformity as measured 15 cm below the growth light assembly and 5 cm away from wall.



# Advanced Plant Habitat (cont.)



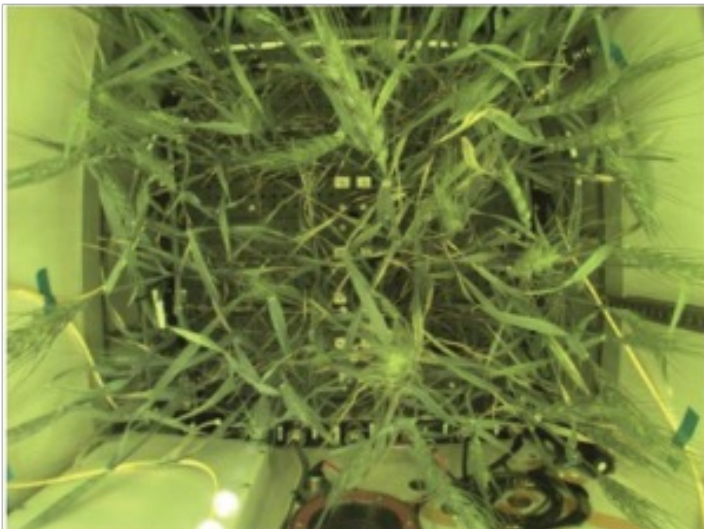
Assembled Science Carrier.



*Arabidopsis thaliana* seedlings in Science Carrier.

The removable science carrier tray has been designed as four independently controllable root modules with each module containing two moisture sensors and one subsurface O<sub>2</sub> sensor with water/nutrient delivery provided through porous tubes in each module.

**Imaging System.** APH contains **two color cameras (top and side views)** and **one infrared camera** (for dark cycle imaging) that are capable of capturing periodic and time lapsed still images for monitoring plant growth.



Top View Color Camera.



Side View Color Camera.

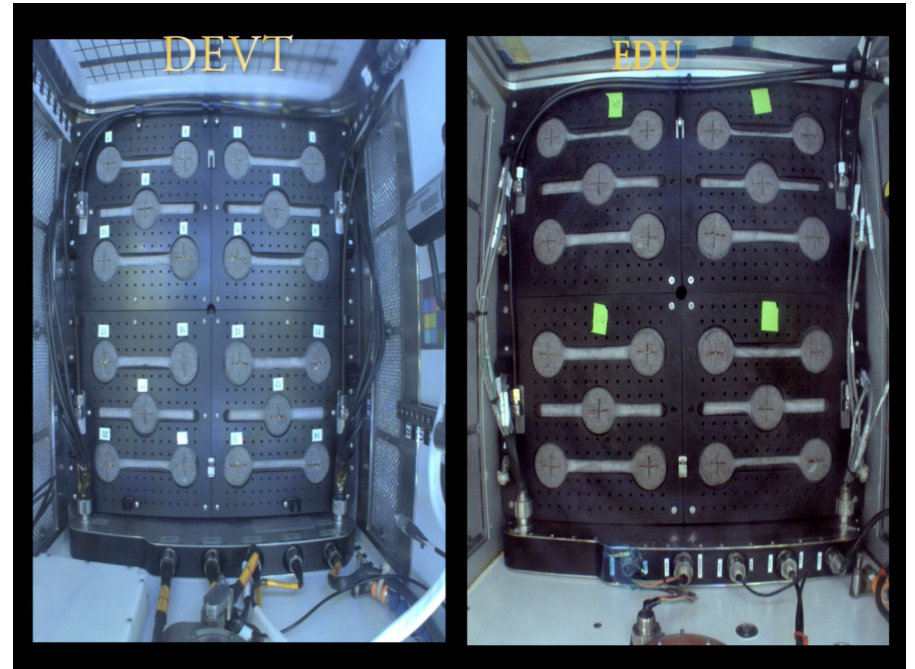


Side View IR Camera.

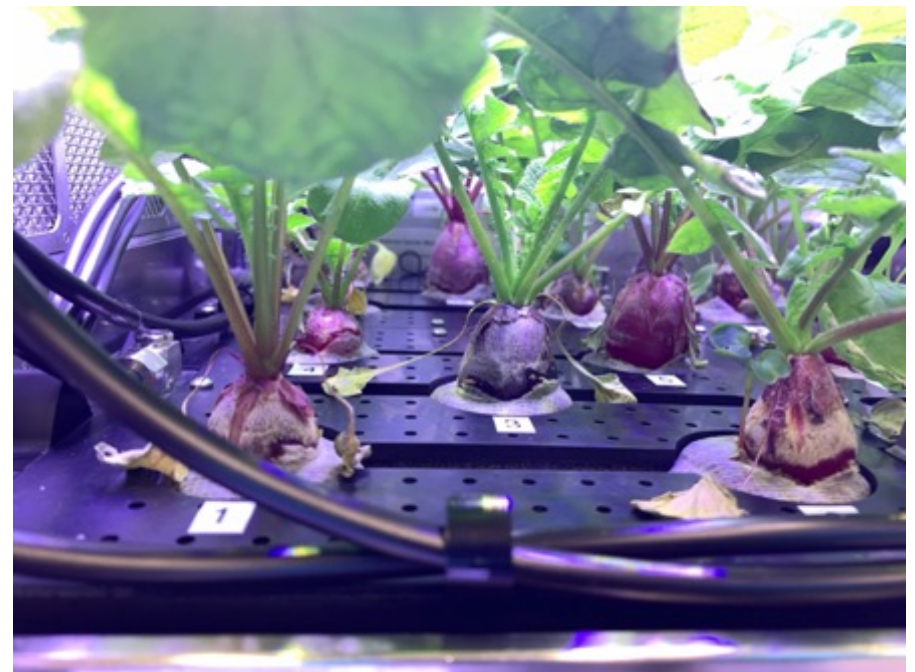
# Advanced Plant Habitat (cont.)



APH ISS Validation Test: Arabidopsis & Wheat.



PH-04 Hatch Chili Peppers on ISS.



PH-02 Radish Ground Studies (PI K. Hasenstein).

# Advanced Plant Habitat (cont.)

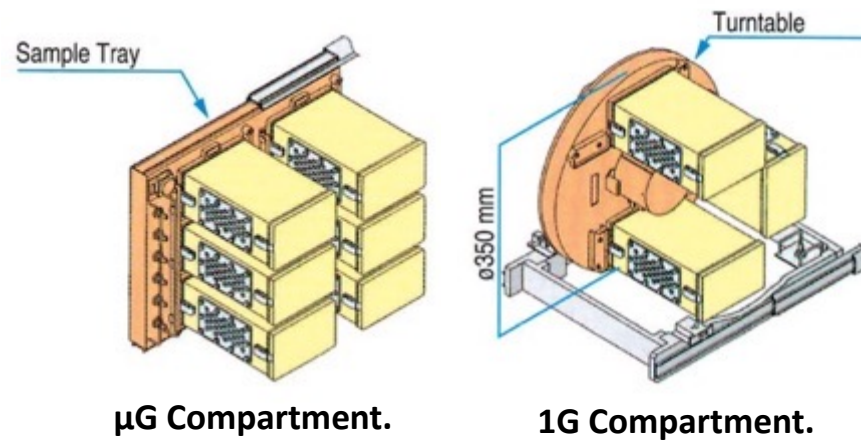
<i>APH At A Glance</i>	
<b>Relative Humidity (RH)</b>	RH Controlled/Monitored: 50-86% ( $\pm 5\%$ )
	RH Condensate Measured and Recycled
<b>Carbon Dioxide (CO<sub>2</sub>)</b>	CO <sub>2</sub> Controlled/Monitored: 400-5000 ppm ( $\pm 50$ ppm)
	Internal CO <sub>2</sub> Sensor
	CO <sub>2</sub> Draw-Down Capability
<b>Air Quality</b>	Air Flow: Controlled between 0.3-1.5 m/s
	Ethylene: Scrubbed to $\leq 25$ ppb
	Air Filtration
	Air Sampling Ports
<b>Water Quality</b>	Water and Nutrient Delivery
	Water Sampling Ports
<b>Temperature</b>	18-30°C ( $\pm 1^\circ\text{C}$ )
	Leaf Temperature Sensor
<b>Light Provision</b>	0-1000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ Photosynthetic Photon Flux (PPF) in incremer of 50 (internal PPF Sensor)
	Red (630-660 nm), Blue (450 $\pm$ 10 nm), Green (525 $\pm$ 10 nm), Far R (730 nm), White
	Uniformity: $\pm 15\%$ (15 cm below light bank, 5 cm in from wall)
<b>Root and Shoot Zone</b>	Root Zone Moisture Level Controlled/Monitored
	O <sub>2</sub> Sensors in both Shoot & Root Zone
	Max. Shoot Height: 45 cm
	Root Zone Height: 5 cm
	Growth Area: 1,708 cm <sup>2</sup>
	Growth Volume: 112,500 cm <sup>3</sup>

# JAXA's Cell Biology Experiment Facility (CBEF)

- CBEF is used for life science experiments such as **cultivating cells and plants** in JAXA's JEM ISS Module.
- Experiment parameters can be set to **run automatically and changed remotely** from the ground.
- CBEF contains an **incubator with a  $\mu$ G and a 1G compartments**.
- 1G compartment has a centrifuge that can control gravity from **0.1 to 2.0G**.
- Incubator can control **temperature (15-40°C), humidity (20-80%) and CO<sub>2</sub> concentration**.



CBEF open showing  $\mu$ G Compartment (top) and 1G Compartment (bottom).



$\mu$ G Compartment.

1G Compartment.

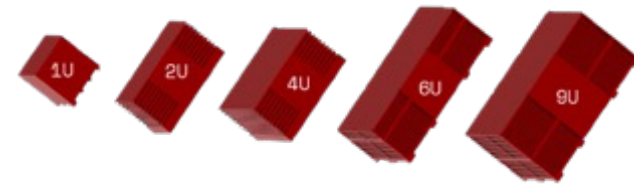


CBEF provides a standard canister for experiments.



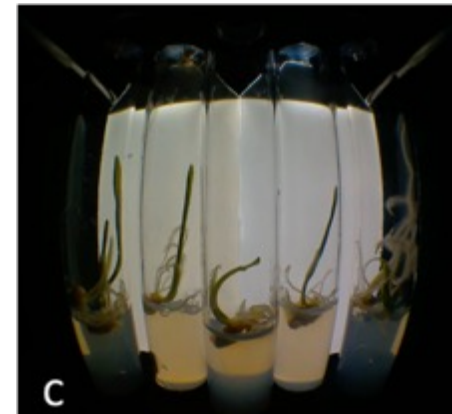
CBEF on ISS.

# Cube Payloads (Space Tango)



**Scalable: With 1U (10cm<sup>3</sup>) as the standard size, CubeLabs can scale to 2U, 4U, 6U, and 9U to accommodate a variety of science and subsystems.**

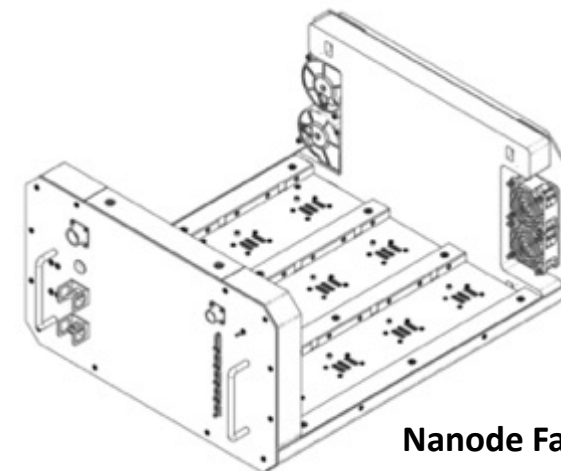
- TangoLab™ facilities are fully automated systems allowing multiple payloads to run simultaneously and independently on orbit.
- They provide a standardized platform and open architecture for payload modules called CubeLabs.
- **CubeLab: Automated hardware that provides a standard platform for science investigations in microgravity.**
- CubeLabs can be managed from Earth with downlink of images and data in near real-time.
- TangoLab architecture also minimizes astronaut interaction.
- TangoLab-1, was installed on ISS in 2016 and TangoLab-2 in 2017.
- Automated facilities on-board the ISS that provides power and data management for CubeLabs.
- **The Powered Ascent Utility Locker (PAUL) can be used to accommodate CubeLabs that need continuous power during launch to orbit.**
- Subsystems include fluid control, temperature control, imaging and observation.
- Customizable Variables: seed/plant species, growth light intensity, growth light cycle, growth medium recipe, imaging/observation intervals and timing.



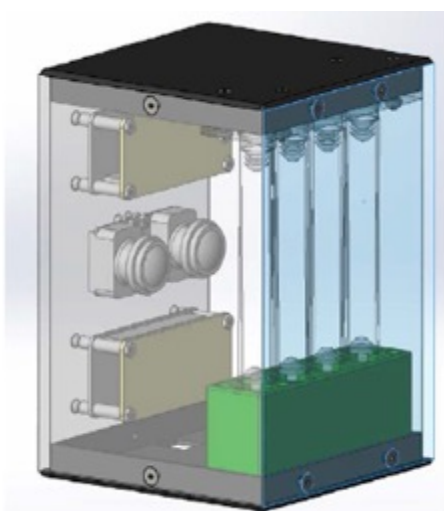
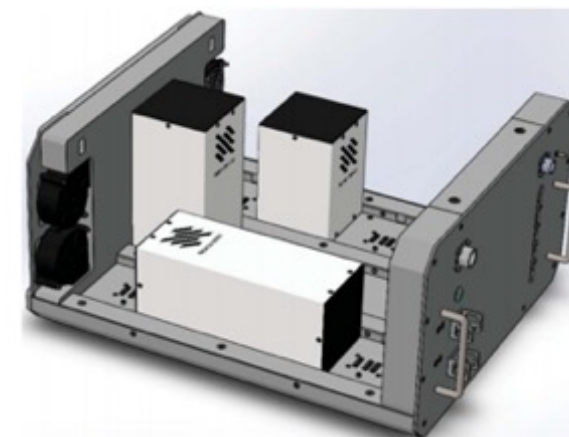
**(A) 2U CubeLab growth chamber installation. (B) Malting CubeLab investigation with fluid and thermal control subsystems. (C) On-Orbit plant growth image.**

# Cube Payloads (Nanoracks)

- Nanolabs: low-cost, open sourced, standardized, miniaturized hardware.
- Single Cube size is 10cm x 10cm x 15cm (multiple Cube configurations available).
- Nanolabs have been used for plant growth & other research areas.
- **“Nanode” (launching on NG-15 Spring 2021) is the replacement for 1 of 2 Nanorack Platforms currently on ISS.**
- **Can accommodate up to 12 single cube experiments.**
- **Unique configurations possible.**
- Cubes connect using USB 3.0 (5V DC @ 900mA), individually controlled.
- Uplink/commanding and downlink through Nanorack’s Mission Operation Center.



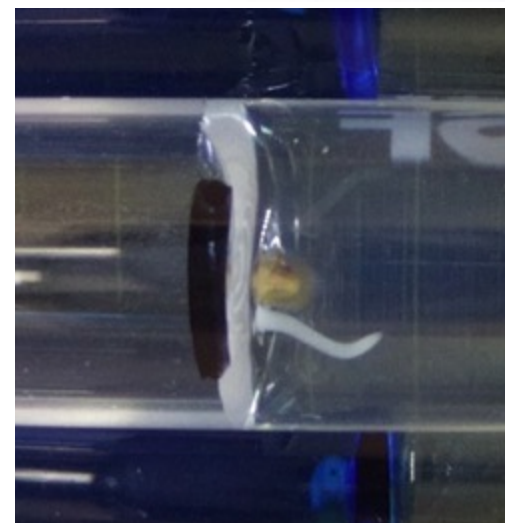
Nanode Facility



Plants in Space Experiment (1.5U; 10cm x 10cm x 15cm).



Image from Space Day 3 of Lettuce Seedlings (*Arugula, *Eruca sativa* 'Rocket'*).

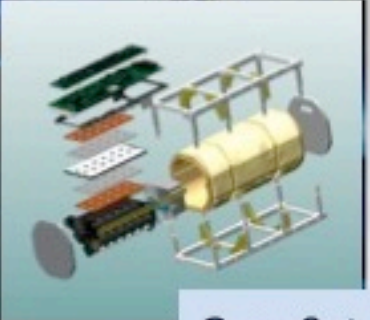
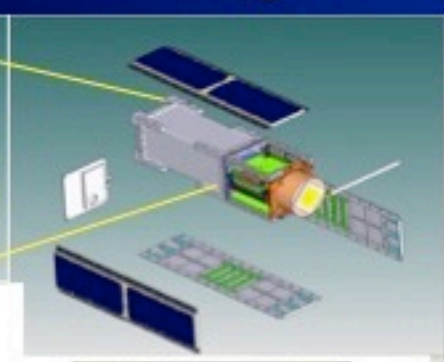
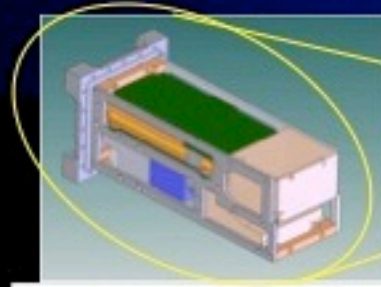
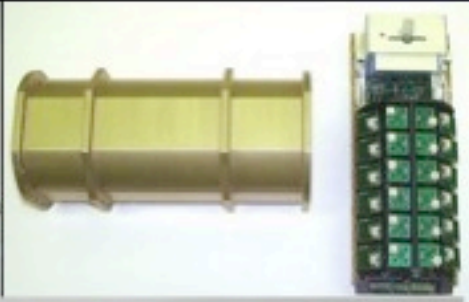
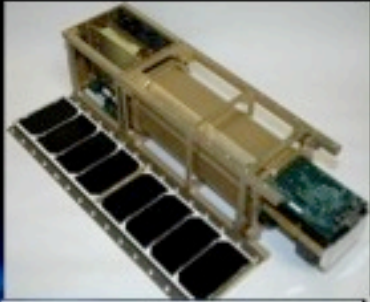


Magnified View of Lettuce Seedling.

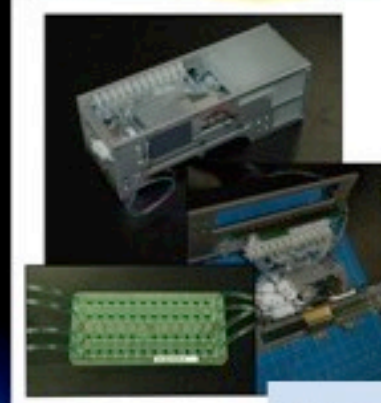


Pre-Flight Ground Test.

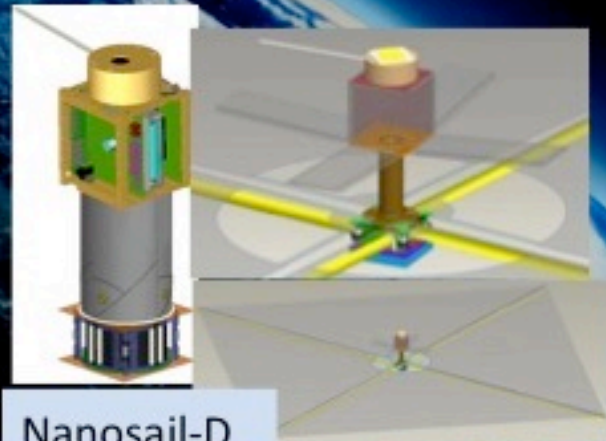
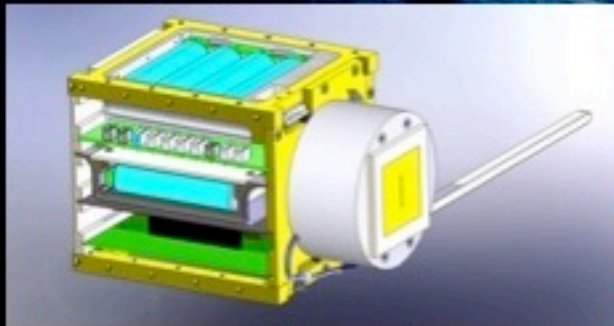
# Free Flying Nanosatellites (Ames Research Center)



GeneSat-1



PharmaSat-1



Nanosail-D

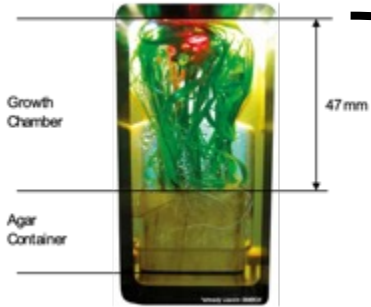


O/OREOS



# YURI for ISS and Free-Flyers (YuriGravity)

The Yuri Greenhouse supports the growth of higher plants under  $\mu\text{G}$ -conditions in solid media (agar or soil). It features LEDs. Gas-permeable membranes and can be placed inside the Yuri Observation Unit.



Yuri Greenhouse



Cell cultures



Fruit flies



Fishes



Science Box (1U)



Type-I Container



Observation Unit



STaARS Facility

- Up to 32 Type-I experiments
- Centrifuge for 1g, Moon and Mars
- Temp between ambient and 39°C



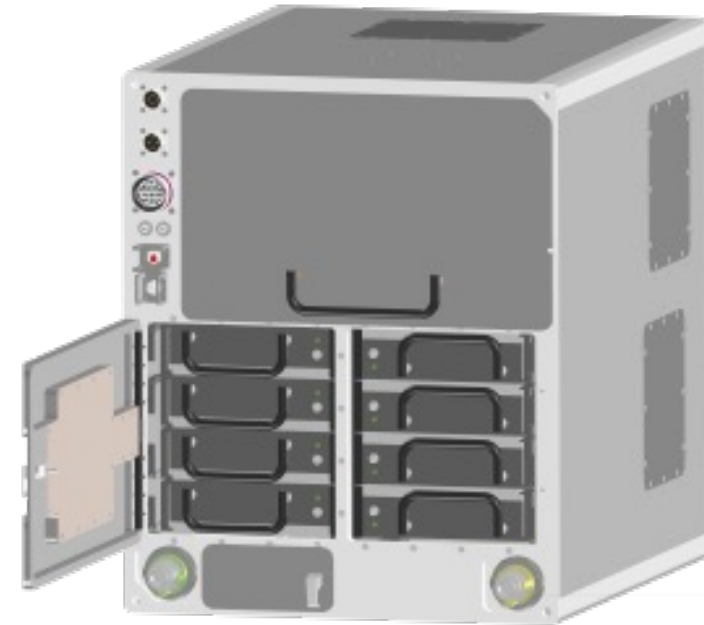
ScienceTaxi Facility (MDL Sized)

- Up to 44 Type-I experiments.
- Centrifuge for 1g, Moon and Mars.
- Temp between 4°C and 40°C.
- Fits on SpaceX Dragon, SNC Dream Chaser, Lunar spacecraft.
- Fully automated.
- Experiment can start just minutes after launch.
- Real-time data monitoring and commanding.
- Independent from ISS.



# Mobile SpaceLab (HNU Photonics)

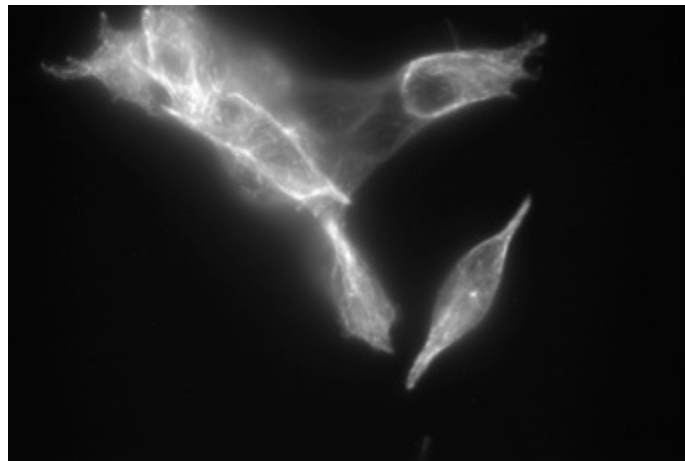
- The Mobile SpaceLab supports quick turn-around live-cell culture experiments for weeks to months on ISS with automated microfluidic delivery of reagents as well as automated phase-contrast and fluorescence microscopy.
- Automated bright-field and/or fluorescent imaging of cells for the duration of the experiment.
- A variety of excitation sources and filters are available to accommodate most, if not all fluorophores.
- Dual GFP and RFP are the standard fluorescence settings.
- Experiments run autonomously from the HNU Photonics Control Center.
- **No crew-time or crew manipulations are required.**
- Automated delivery of reagents via a sophisticated microfluidic network.
  - Multiple media formulations.
  - Fluorescent probes or indicators.
  - Multiple drug formulations and/or concentrations.
  - Multiple reagents to induce differentiation.
- RNA/DNA preservation reagents and/or fixatives for post-flight analysis.



BioChip SpaceLab (**under development**) with Centrifuge Compartment (top) and Microgravity Compartment (Bottom).

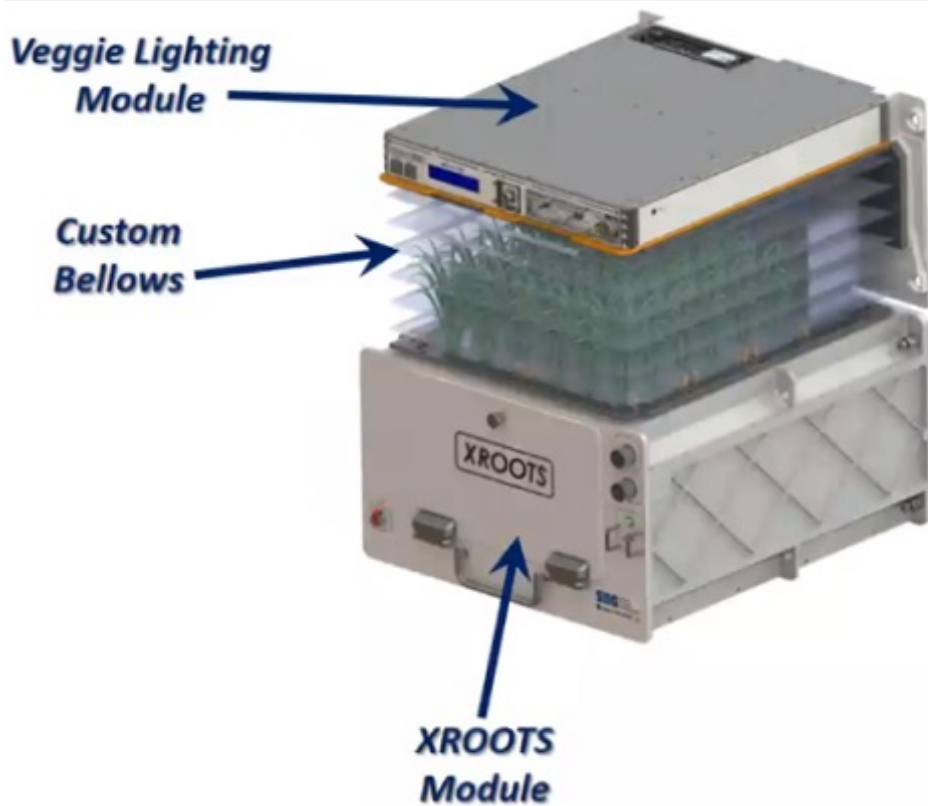


Mobile SpaceLab.



RFP-tagged Microtubules.

# XROOTS (eXposed Root On-Orbit Test System) [Under Development]



XROOTS (eXposed Root On-Orbit Test System). Left: Diagrammatic representation showing XROOTS inserted within Veggie Unit. Right: Radish and Mizuna plants grown within XROOTS with close-up of visible roots (courtesy of Sierra Space).

# Point of Contacts

<b>ADSEP</b>	Redwire: David Reed, <a href="mailto:Dave.Reed@redwirespace.com">Dave.Reed@redwirespace.com</a>
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<b>APH</b>	Redwire: David Reed, <a href="mailto:Dave.Reed@redwirespace.com">Dave.Reed@redwirespace.com</a>
<b>BIOCELL</b>	BioServe Space Technologies: Stephanie Countryman, <a href="mailto:countrym@colorado.edu">countrym@colorado.edu</a>
<b>BIOCHIP</b>	Hnu Photonics: Devin Ridgley, <a href="mailto:drigley@hnuphotonics.com">drigley@hnuphotonics.com</a>
<b>BRICS</b>	AEGIS Aerospace: Lucy Walter, <a href="mailto:lucywalter@aegisaero.com">lucywalter@aegisaero.com</a>
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<b>GAP-FPA</b>	BioServe Space Technologies: Stephanie countryman, <a href="mailto:countrym@colorado.edu">countrym@colorado.edu</a>
<b>KFTS</b>	AEGIS Aerospace: Lucy Walter, <a href="mailto:lucywalter@aegisaero.com">lucywalter@aegisaero.com</a>
<b>Mobile SpaceLab</b>	HNU Photonics: <a href="mailto:info@scorpiov.com">info@scorpiov.com</a> , <a href="http://www.scorpiov.com">www.scorpiov.com</a>
<b>MVP</b>	Redwire: David Reed, <a href="mailto:Dave.Reed@redwirespace.com">Dave.Reed@redwirespace.com</a>
<b>NANOLAB CUBES</b>	Nanorack: Michael Lewis, <a href="mailto:mlewis@nanoracks.com">mlewis@nanoracks.com</a>
<b>NANOSATELLITES</b>	NASA Ames Research Center: Bruce Yost, <a href="mailto:bruce.d.yost@nasa.gov">bruce.d.yost@nasa.gov</a>
<b>PONDS</b>	Redwire: David Reed, <a href="mailto:Dave.Reed@redwirespace.com">Dave.Reed@redwirespace.com</a>
<b>SABL</b>	BioServe Space Technologies: Stephanie countryman, <a href="mailto:countrym@colorado.edu">countrym@colorado.edu</a>
<b>SPECTRUM</b>	AEGIS Aerospace: Lucy Walter, <a href="mailto:lucywalter@aegisaero.com">lucywalter@aegisaero.com</a>
<b>TANGOLAB CUBES</b>	Space Tango: Twyman Clements, <a href="mailto:tclements@spacetango.com">tclements@spacetango.com</a>
<b>VEGGIE</b>	AEGIS Aerospace: Lucy Walter, <a href="mailto:lucywalter@aegisaero.com">lucywalter@aegisaero.com</a>
<b>XROOTS</b>	Sierra Space: Bob Morrow, <a href="mailto:robert.morrow@sncorp.com">robert.morrow@sncorp.com</a>
<b>YURI</b>	YuriGravity, Mark Kugel, <a href="mailto:hello@yurigravity.com">hello@yurigravity.com</a>

# Thanks for Your Participation!

## Questions?



Howard Levine



Jeff Richards