

National Aeronautics and
Space Administration



Current Capabilities for Growing Plants in Space.

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Overview

- **PRESENTATION OBJECTIVE:**

Educate and generate interest in the science and engineering **community** with the current state of **Space Plant hardware capabilities**.

- **SPACEFLIGHT HARDWARE PRESENTED:**

- **BRIC-60** (Biological Research In Canisters -60)
- **BRIC-100** (Biological Research In Canisters -100)
- **BRIC-100VC** (Biological Research In Canisters -100 Vacuum Containment)
- **BRIC-PDFU** (Biological Research In Canisters –Petri Dish Fixation Unit)
- **BRIC-LED** (Biological Research In Canisters –Light Emitting Diode)
- **VEGGIE** (**V**egetable **P**roduction **S**ystem)
- **KFT** (Kennedy Fixation Tubes)
- **Apex Growth Chamber**
- **PONDS** (Passive Orbital Nutrient Delivery System; under development)
- **SPECTRUM** (**M**ultispectral **F**luorescent **I**mager)
- **MVP** (Multiuse Variable-G Platform)
- **SABL** (Space Automated Bioproduct Lab)
- **APH** (**A**dvanced **P**lant **H**abitat)
- **CUBES**

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).

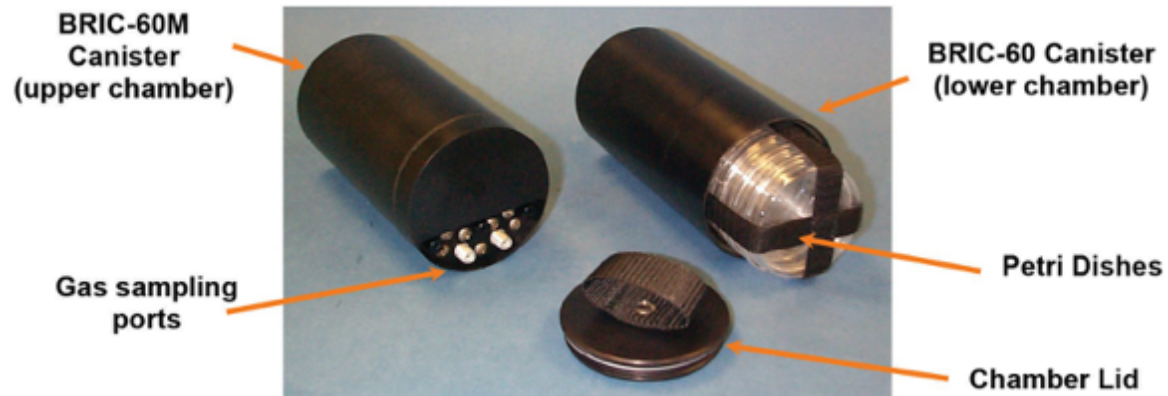


Fig. 1. BRIC-60 & BRIC-60M with petri dish configuration. Teflon sample tubes.

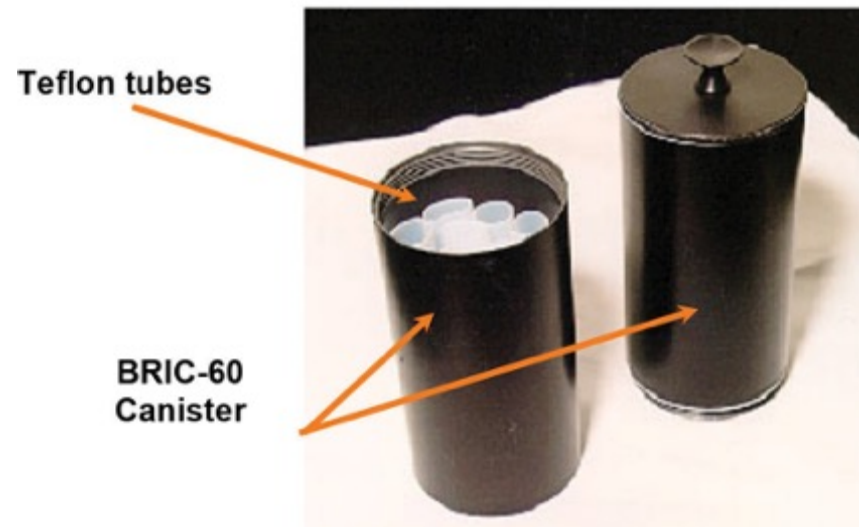
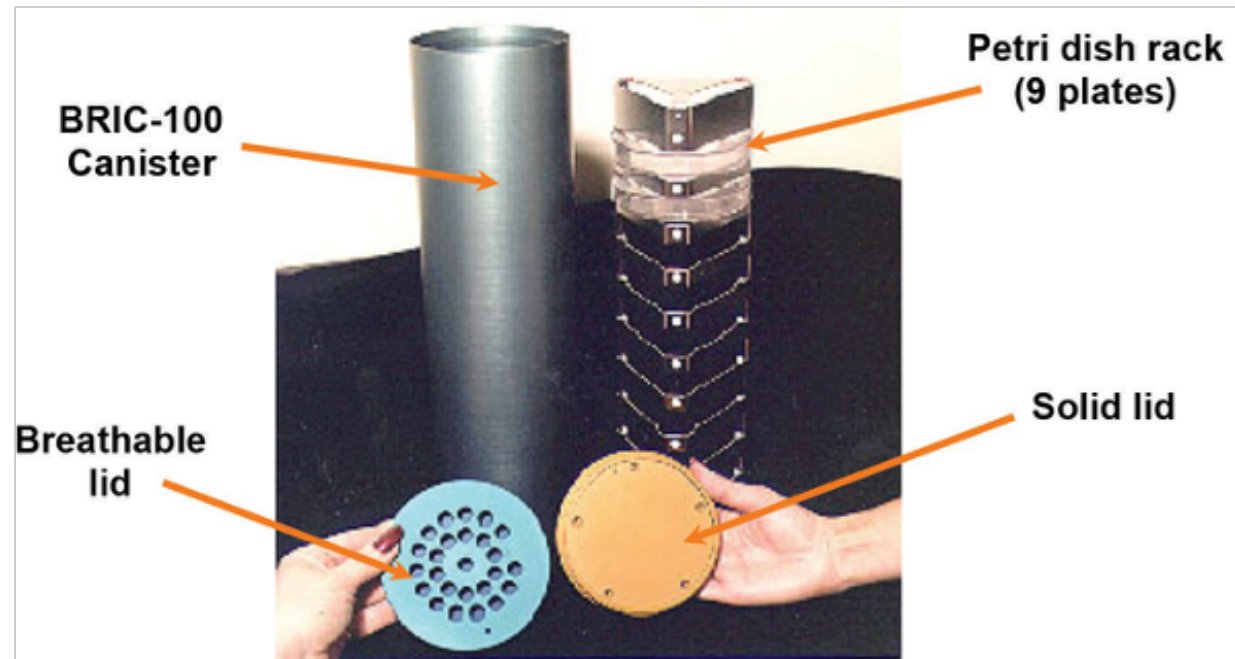


Fig. 2. BRIC-60 containing Teflon sample tubes.

Biological Research In Canisters (BRIC)-100

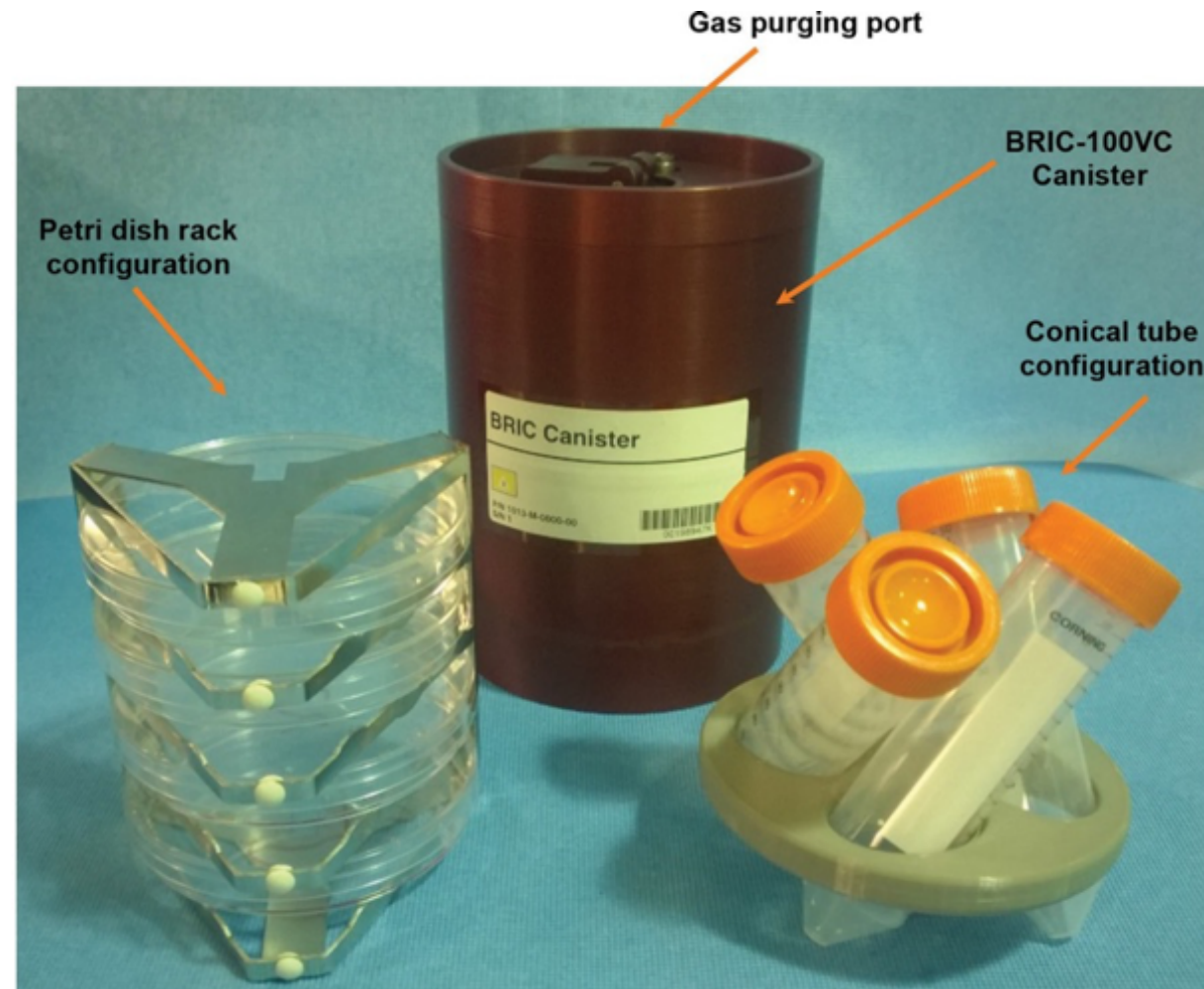
- The Biological Research in Canisters (BRIC) unit is an anodized-aluminum cylinder used to provide passive stowage for investigations into the effects of space flight on small specimens.
- Specimens flown in the BRIC 100 mm petri dish (BRIC-100) include *Manduca sexta* (tobacco hornworm) pupae, *Hemerocallis 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 μ 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% CO₂ 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).

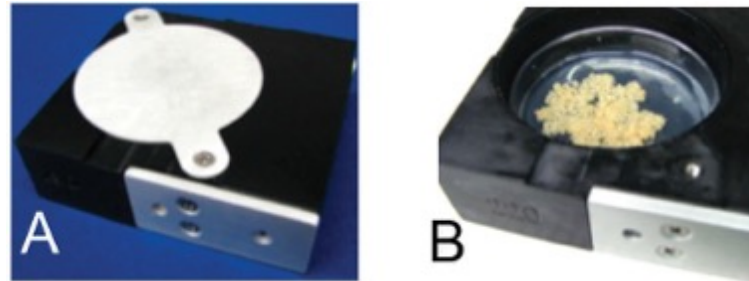


Fig. 1. A. View of an assembled PDFU. B. Callus culture on a 60 mm petri dish within a PDFU prior to closure (courtesy of A.L. Paul).

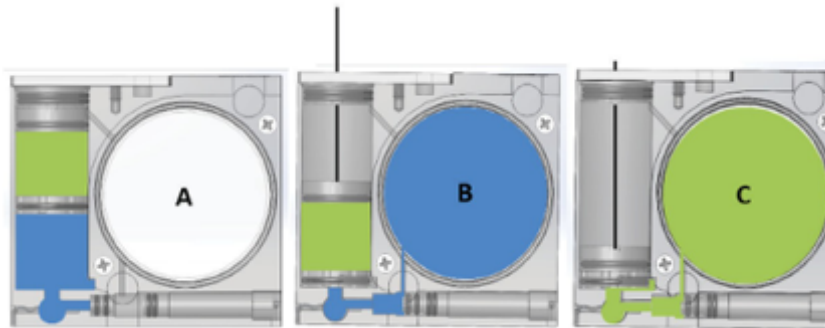


Fig. 2. Injection of Fluids into PDFU Pertri Dishes. A. Liquids 1 & 2 contained within the PDFU reservoir prior to actuation. B. Actuator piston partially depressed to deliver Liquid 1. C. Completion of actuation allows Liquid 2 to be delivered.

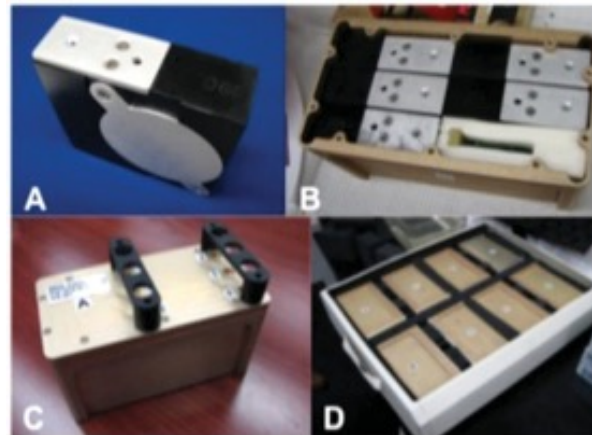


Fig. 3. A. Side View of a PDFU. B. 5 PDFUs plus a temperature logger within a BRIC-PDFU canister prior to closure. C. BRIC-PDFU canister with 2 pin guards attached. D. 8 BRIC-PDFU canisters within an ISS stowage locker.

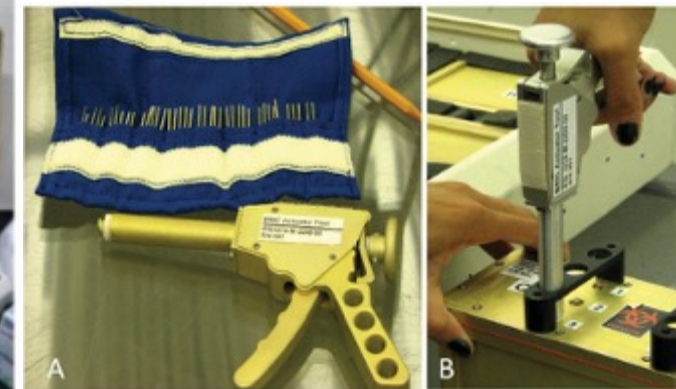
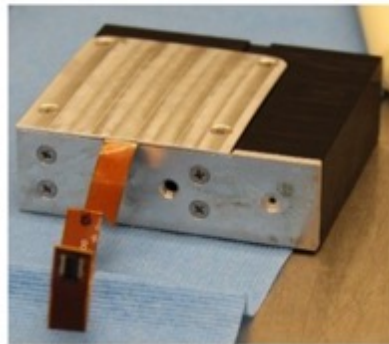


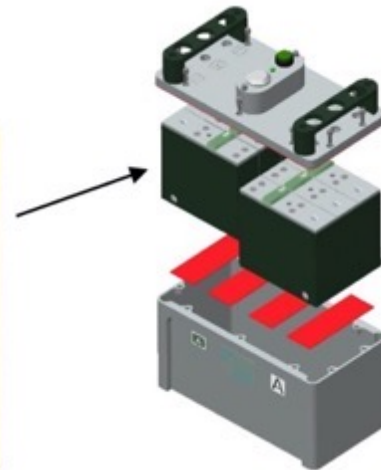
Fig. 4. A. Actuator Rod Kit & Actuator Tool. B. Actuator Tool attached to BRIC-PDFU canister.

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°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.



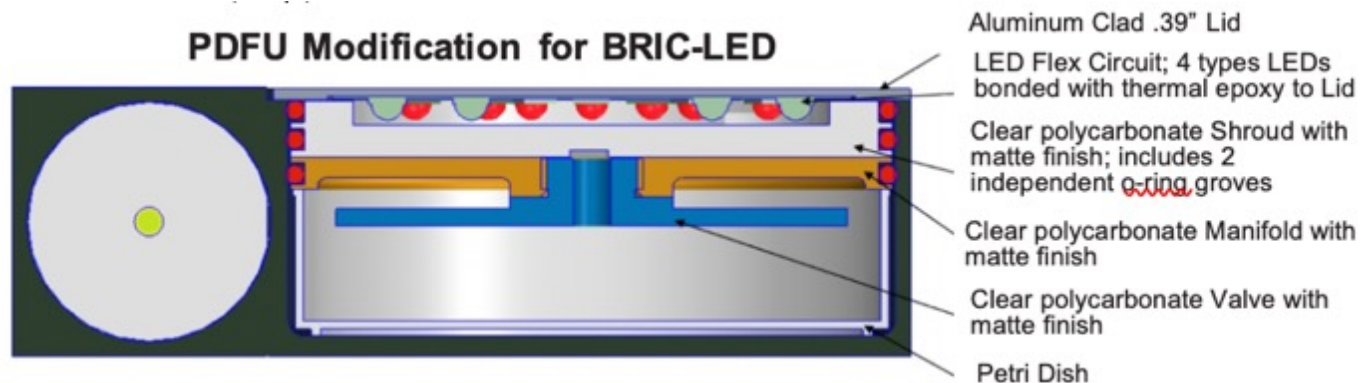
Petri Dish Fixation Unit.



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)

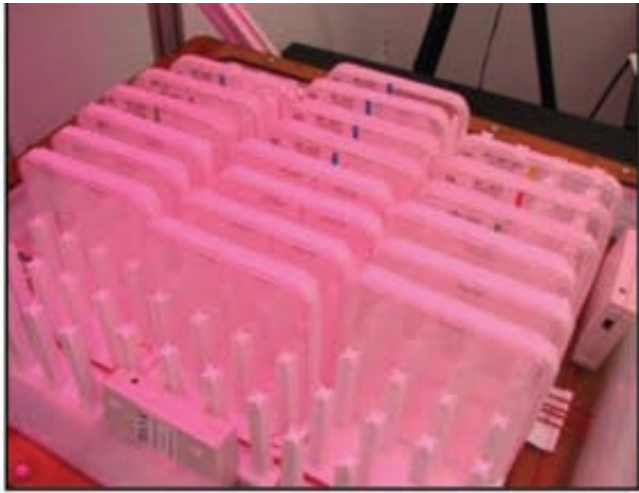
Cabin Air Fan Settings: Low / High / Off

Baseplate Footprint: 29.2 cm x 36.8 cm

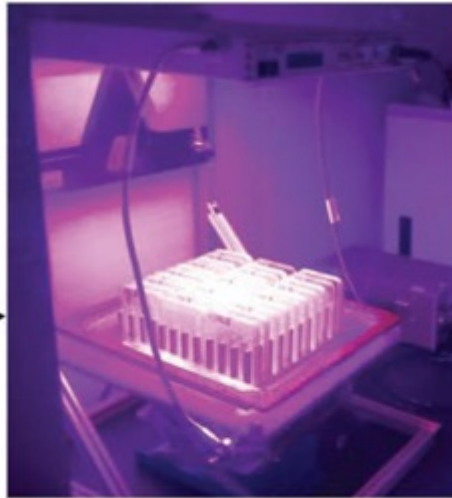
Maximum Height: 47.0 cm empty; 41.9 cm with root mat

Veggie Configured for Petri Plate Science Experiments

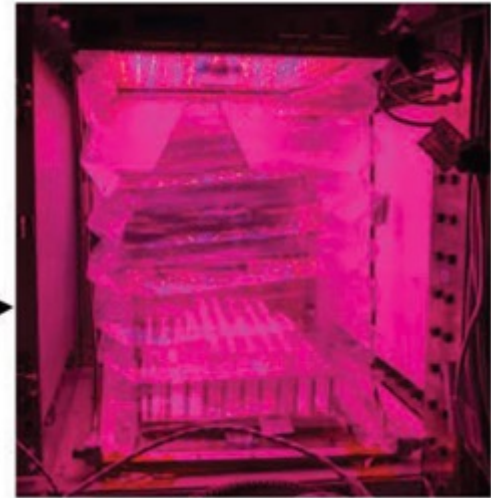
- Veggie has also supported **Petri plate-based science experiments** that have included monocot and dicot plant species that were grown for a pre-determined durations, photographed, harvested, and preserved for return to Earth.
- In some instances, Petri plates have undergone fluorescent microscopy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

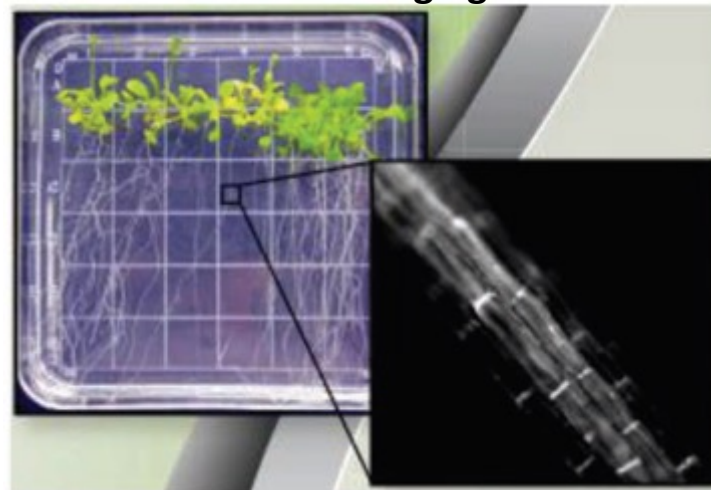


Image of an *Arabidopsis* root taken in the Light Microscopy Module (LMM).

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).

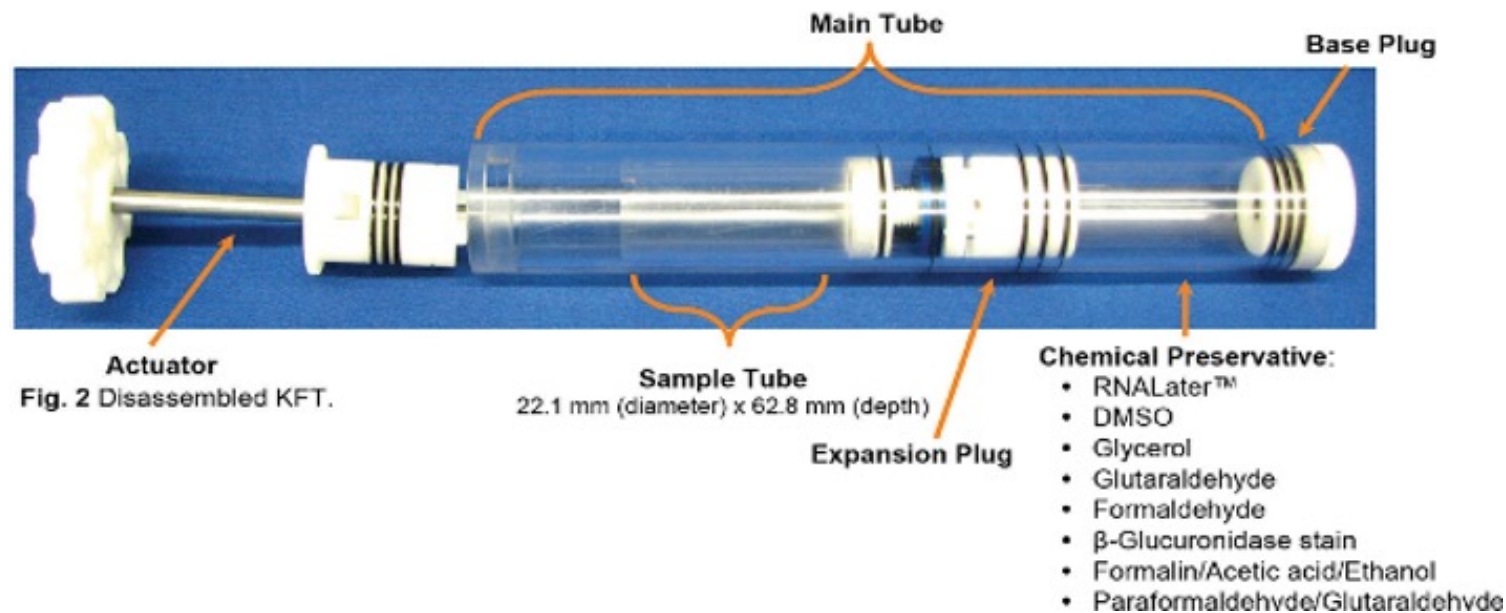
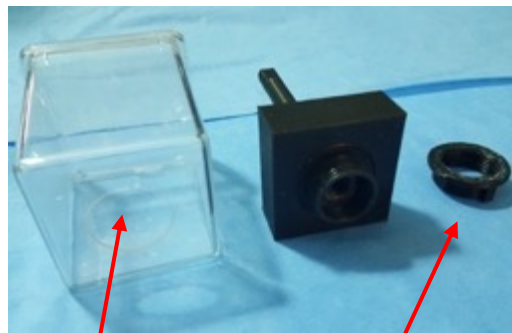


Fig. 2 Disassembled KFT.

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



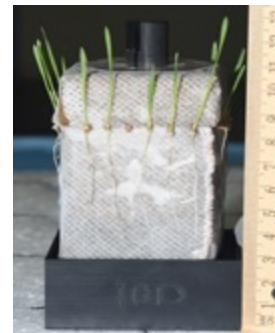
Foam &
Magenta
Top Installed



Nutrient
Solution
Injection



Fully
Loaded
Veggie



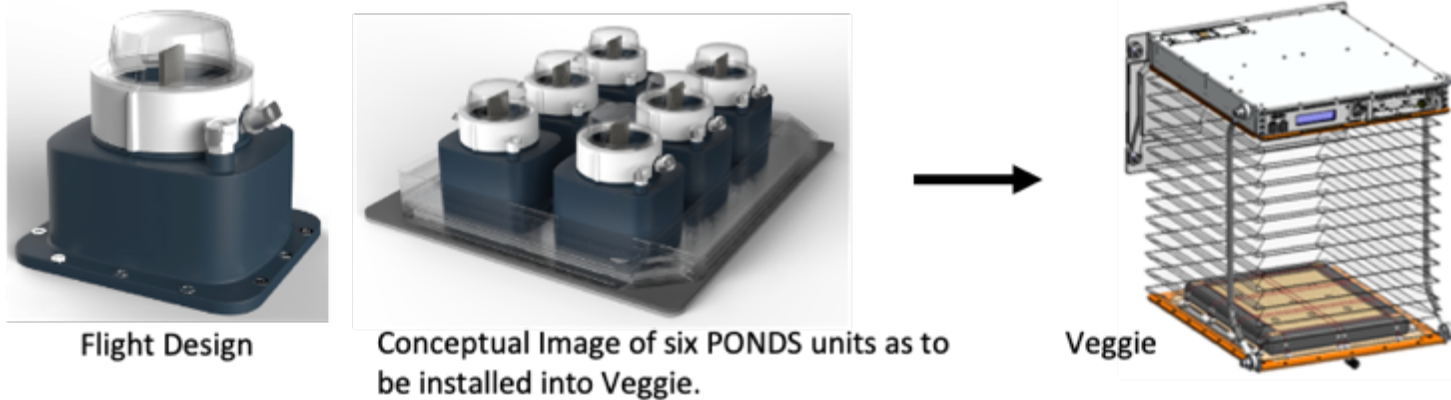
B. Distachyon
growth with
roots visable for
photography.

Passive Orbital Nutrient Delivery System (PONDS)

- 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 μ g conditions
- NOTE: Not yet validated on ISS.**



Flight Unit Development Team: Techshot and Tupperware

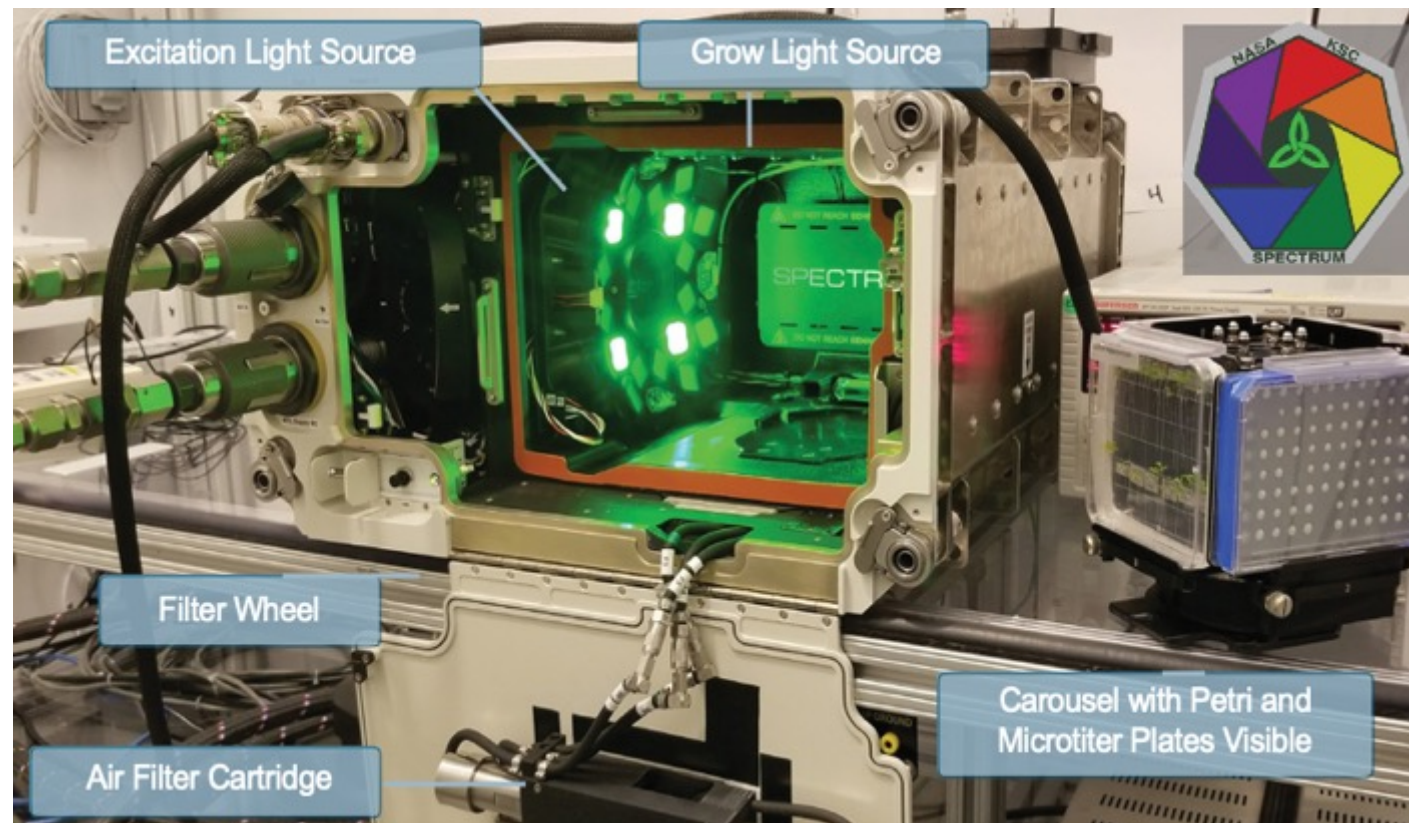


Design Concept:
Exploded View (top).
Cross Sectional View (bottom).

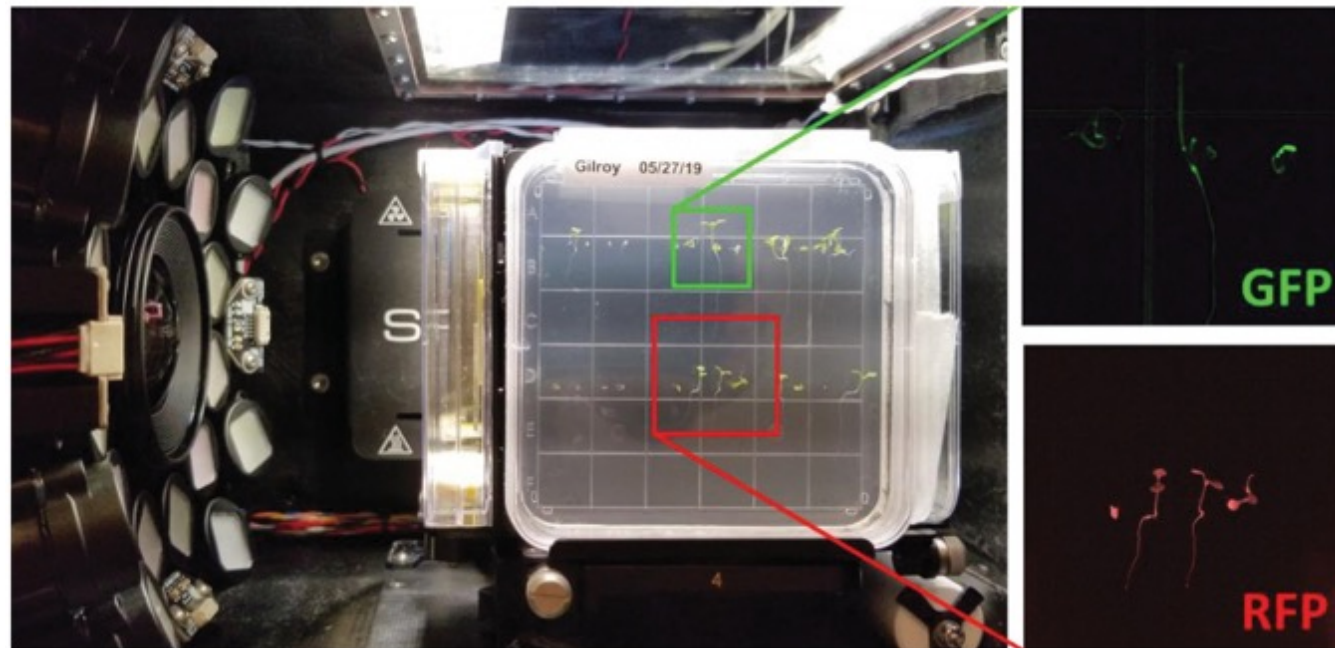
- PONDS on orbit concept of operations is similar to the Veggie plant pillows.
- A clear germination cap maintains high humidity levels during the seed germination phase.
- At harvest the plant cylinder is removed, placed in a bag for cold stowage and returned.
- The PONDS reservoir then has a separate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

SPECTRUM: Multispectral Fluorescent Imager

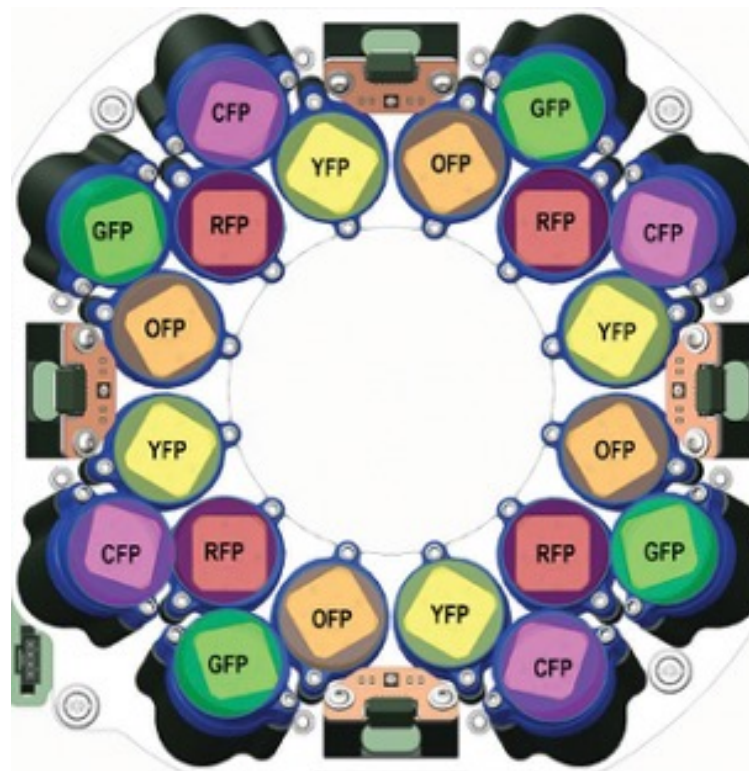
- Spectrum is a multi-spectral fluorescence imaging system designed for capturing *in vivo* genetic expression on ISS.
- Model organisms that may utilize multispectral imaging on ISS include **unicellular organisms (e.g. *Saccharomyces cerevisiae*)**, **plants (e.g. *Arabidopsis thaliana*)**, and **invertebrates (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, CO₂ (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.



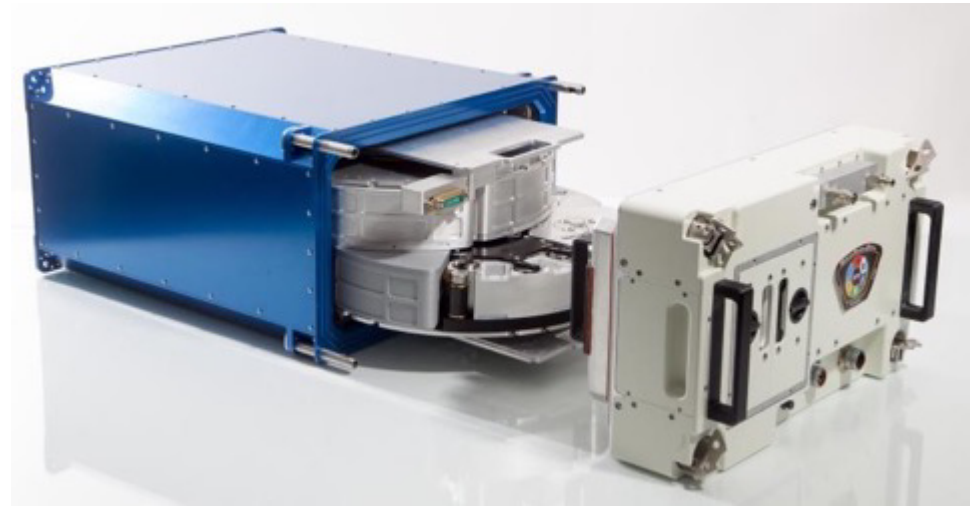
ELS and Carousel Subsystems within the Spectrum Growth Chamber. Insets are images of Arabidopsis plants expressing GFP and RFP fluorescence.



Spectrum ELS mapping by fluorescent protein.

MVP: Multiuse Variable-G Platform (Techshot)

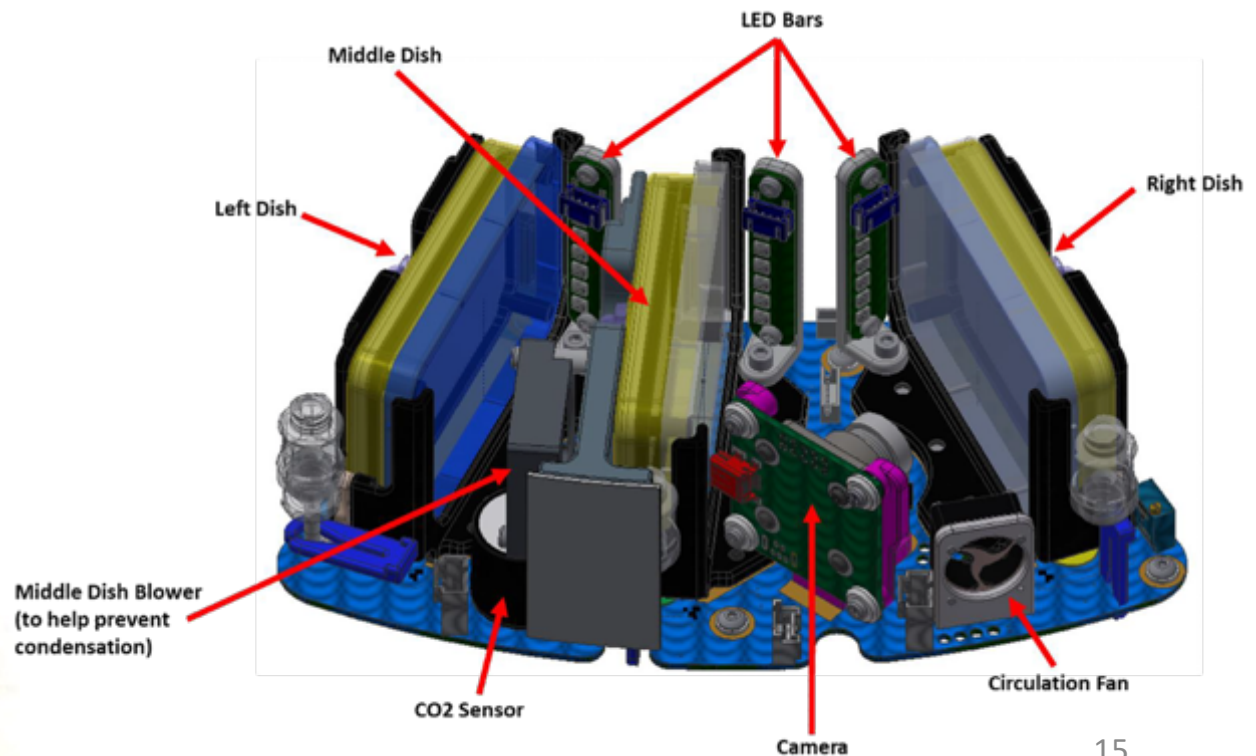
- Dual 390 mm rotors can provide two independent gravity level treatments (0-2g).
- Thermal control & Ground Telemetry/Real-Time Data.
- 12 sample modules (6/centrifuge) with video capability.
- Plants, Bacteria, Cell Cultures, *Drosophila*, *C. elegans*, etc.
- Rotors and sample modules removable on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



Microbe Module

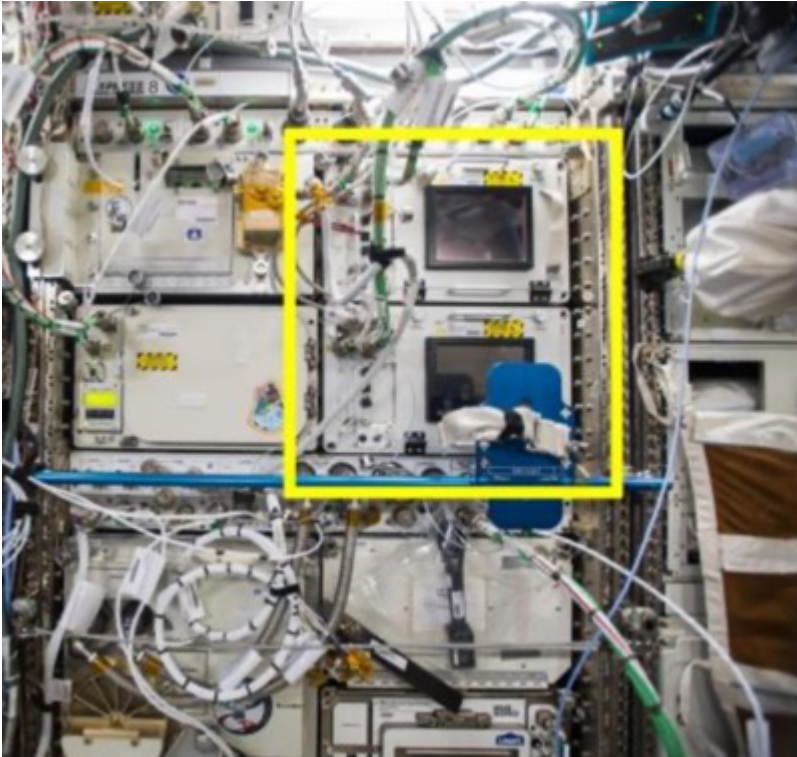


Plant Module

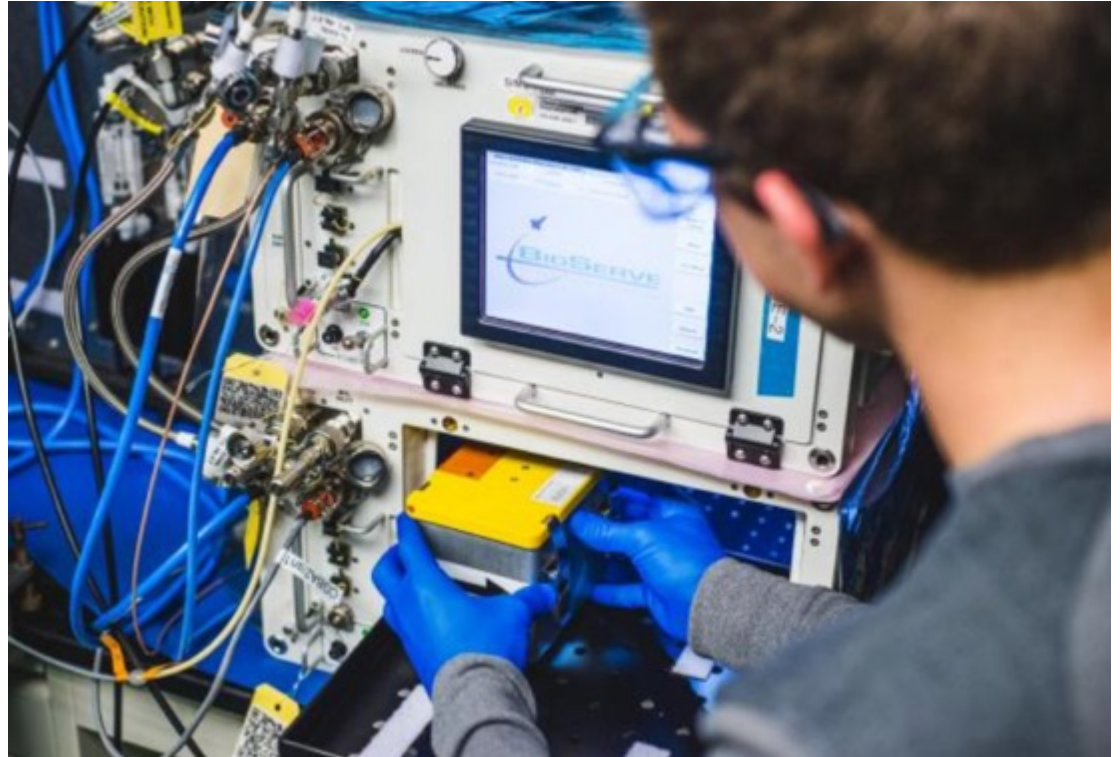


SABL: Space Automated Bioproduct Lab (BioServe)

- 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_2).
- Each unit has over 23 liters of volume for scientific hardware.
- Has 2 USB ports and 2 Ethernet LAN connections.



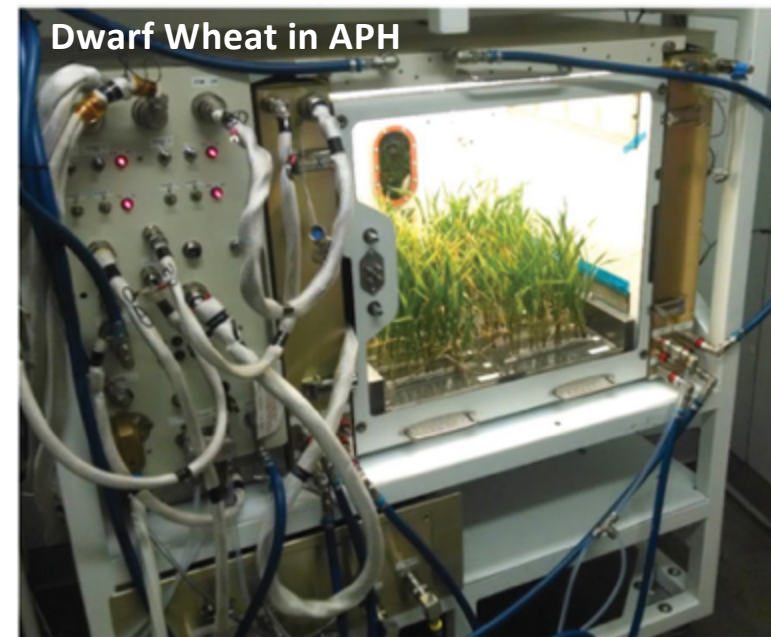
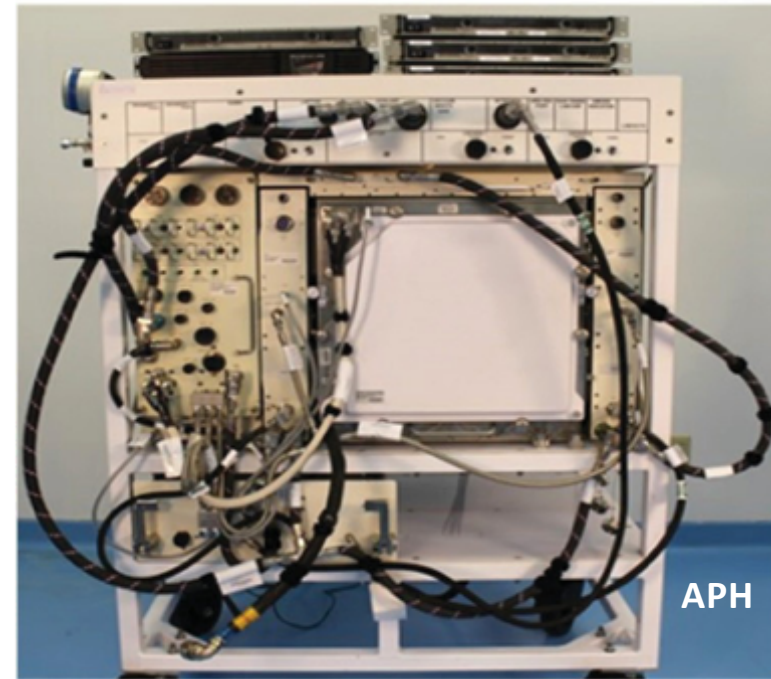
Two SABL units (inside yellow rectangle) aboard ISS.



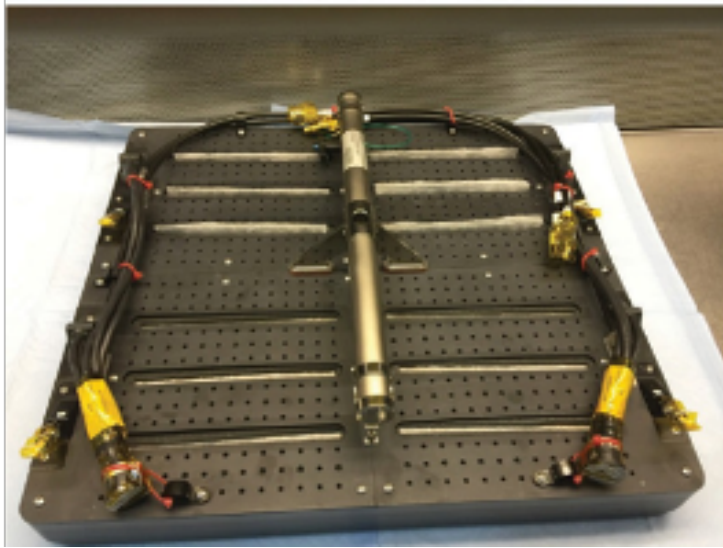
SABL with Color Touch Screen.

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% ($\pm 5\%$), CO₂ concentration 400-5,000 ppm (± 50 ppm or 3%), ethylene scrubbing <25 ppb, air ventilation flow 0.3-1.5 m/s, and O₂ 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 cm² and a growth volume of 112,500 cm³.
 - 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 ± 10 nm), blue (0-400 $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$, 400-500 ± 10 nm), green (0-100 $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$, 525 ± 10 nm), and far-red (0-50 $\mu\text{mol m}^{-2}\text{s}^{-1} \pm 5\%$, 730-750 ± 10 nm) lighting uniformity as measured 15 cm below the growth light assembly and 5 cm away from wall.



Advanced Plant Habitat (cont.)



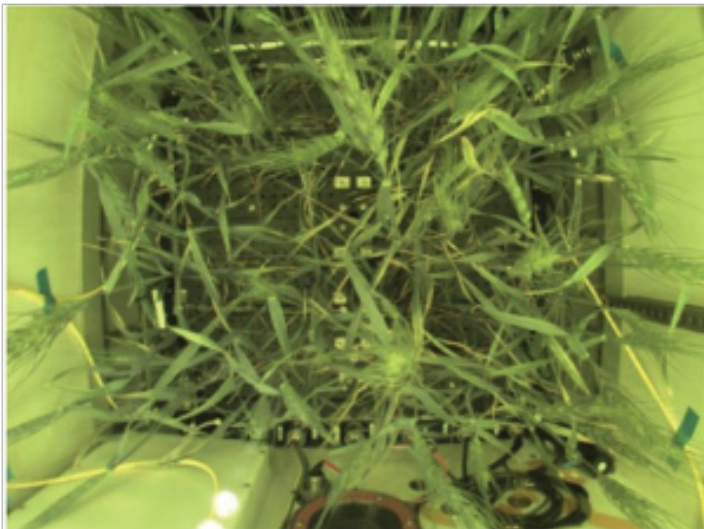
Assembled Science Carrier.



***Arabidopsis thaliana* seedlings.**

The removable science carrier tray has been designed as four independently controllable root modules with each module containing two moisture sensors and one subsurface O₂ 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.

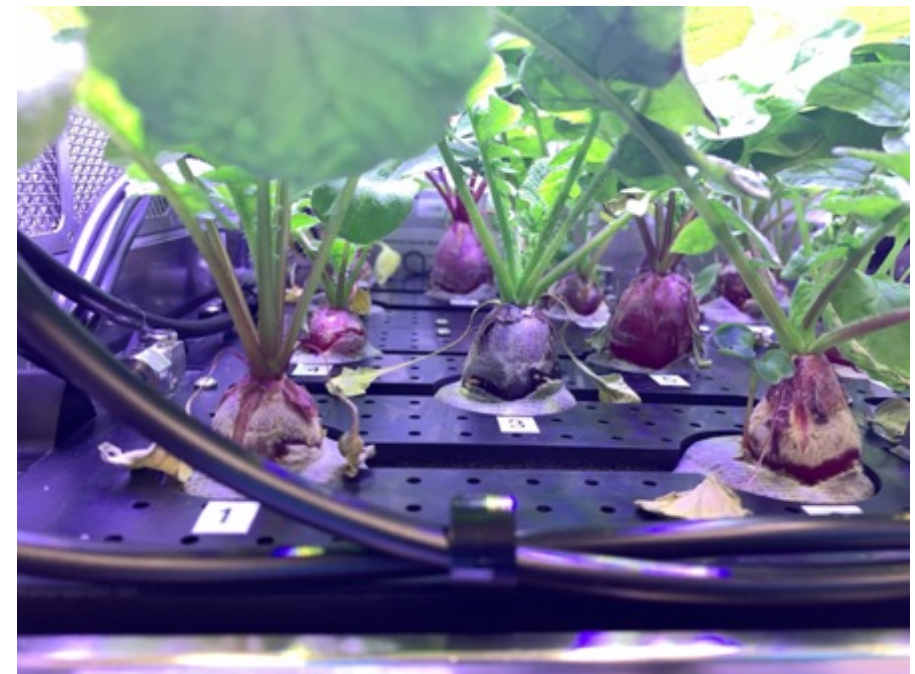
Advanced Plant Habitat (cont.)



APH ISS Validation Test: Arabidopsis & Wheat.



PH-04 Peppers on ISS.

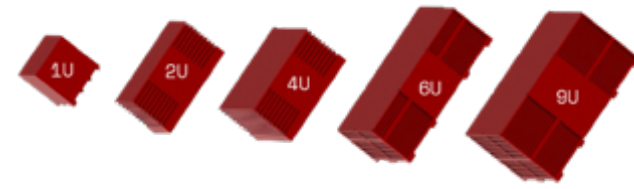


PH-02 Radish Ground Studies (PI K. Hasenstein).

Advanced Plant Habitat (cont.)

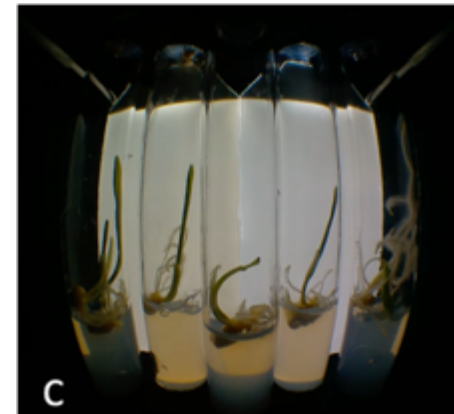
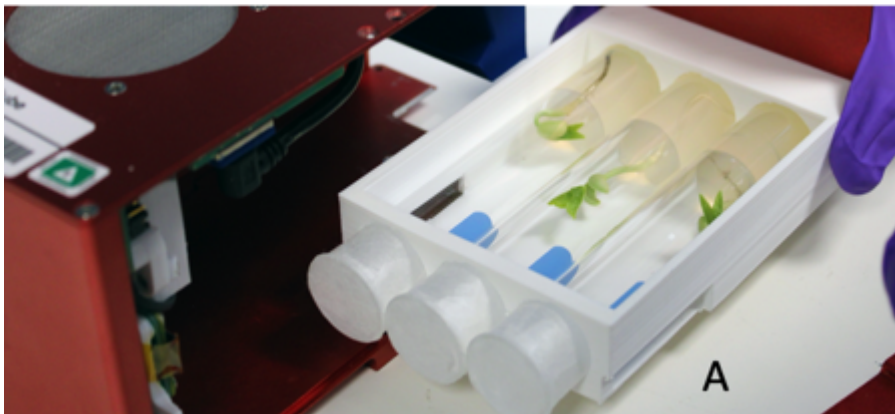
APH At A Glance	
Relative Humidity (RH)	RH Controlled/Monitored: 50-86% ($\pm 5\%$)
	RH Condensate Measured and Recycled
Carbon Dioxide (CO ₂)	CO ₂ Controlled/Monitored: 400-5000 ppm (± 50 ppm)
	Internal CO ₂ Sensor
	CO ₂ Draw-Down Capability
Air Quality	Air Flow: Controlled between 0.3-1.5 m/s
	Ethylene: Scrubbed to ≤ 25 ppb
	Air Filtration
	Air Sampling Ports
Water Quality	Water and Nutrient Delivery
	Water Sampling Ports
Temperature	18-30°C ($\pm 1^\circ\text{C}$)
	Leaf Temperature Sensor
Light Provision	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)
Root and Shoot Zone	Root Zone Moisture Level Controlled/Monitored
	O ₂ Sensors in both Shoot & Root Zone
	Max. Shoot Height: 45 cm
	Root Zone Height: 5 cm
	Growth Area: 1,708 cm ²
	Growth Volume: 112,500 cm ³

Cube Payloads (Space Tango)



Scalable: With 1U (10cm³) as the standard size, CubeLabs can scale to 2U, 4U, 6U, and 9U to accommodate a variety of science and subsystems.

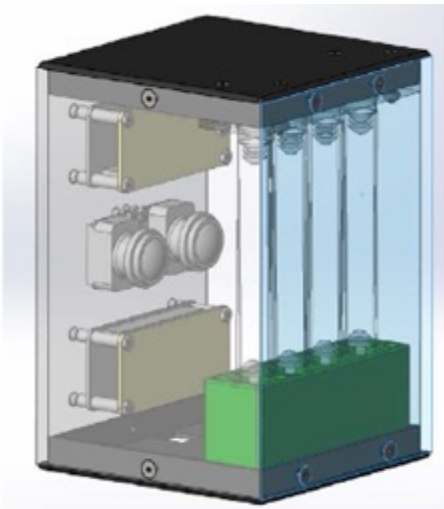
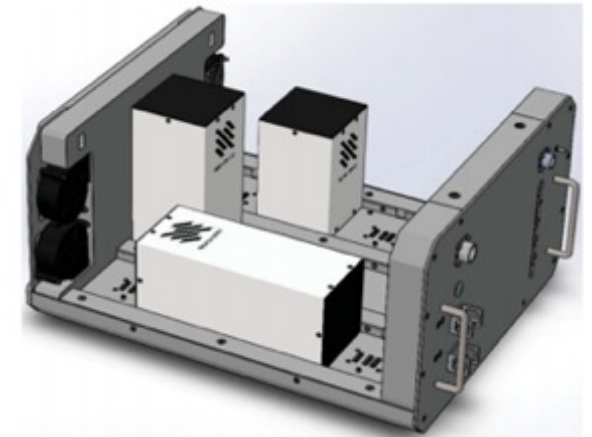
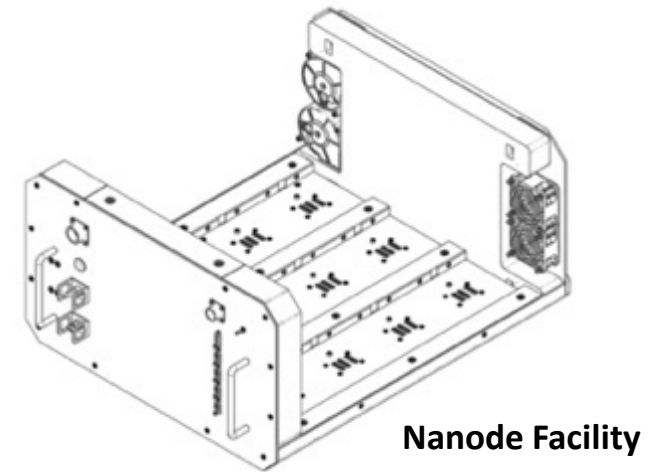
- TangoLab™ facilities are fully automated systems allowing multiple payloads to run simultaneously and independently on orbit.
- They provide a standardized platform and open architecture for payload modules called CubeLabs.
- **CubeLab: Automated hardware that provides a standard platform for science 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)

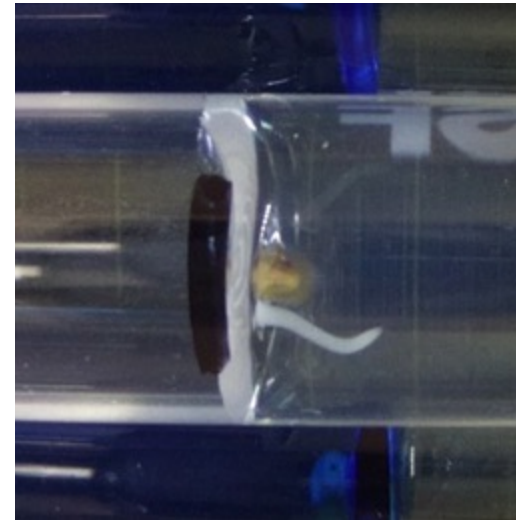
- Nanolabs: low-cost, open sourced, standardized, miniaturized hardware.
- Single Cube size is 10cm x 10cm x 15cm (multiple Cube configurations available).
- Nanolabs have been used for plant growth & other research areas.
- **“Nanode” (launching on NG-15 Spring 2021) is the replacement for 1 of 2 Nanorack 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.



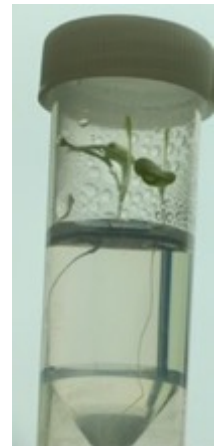
Plants in Space Experiment
(1.5U; 10cm x 10cm x 15cm).



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



Magnified View of
Lettuce Seedling.



Pre-Flight
Ground Test.

Questions?

