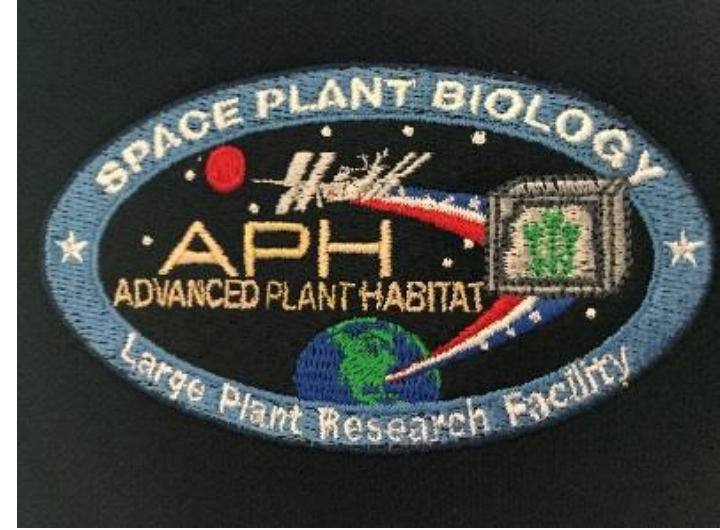


# Hardware Validation Test of the Advanced Plant Habitat

- Oscar Monje, Jeffrey T. Richards
  - AECOM – LASSO KSC
- Dinah I. Dimapilis
  - Jacobs – TOSC KSC
- Guillermo M. Tellez-Giron, Matthew De Mars
  - Sierra Nevada (formerly Orbitec)
- Nicole F. Dufour, Howard G. Levine, and Bryan G. Onate
  - NASA / KSC

34th Annual Meeting of the American Society for  
Gravitational and Space Research, Bethesda Maryland,  
Nov 3 2018



Astronaut "Ricky" Arnold



# Advanced Plant Habitat

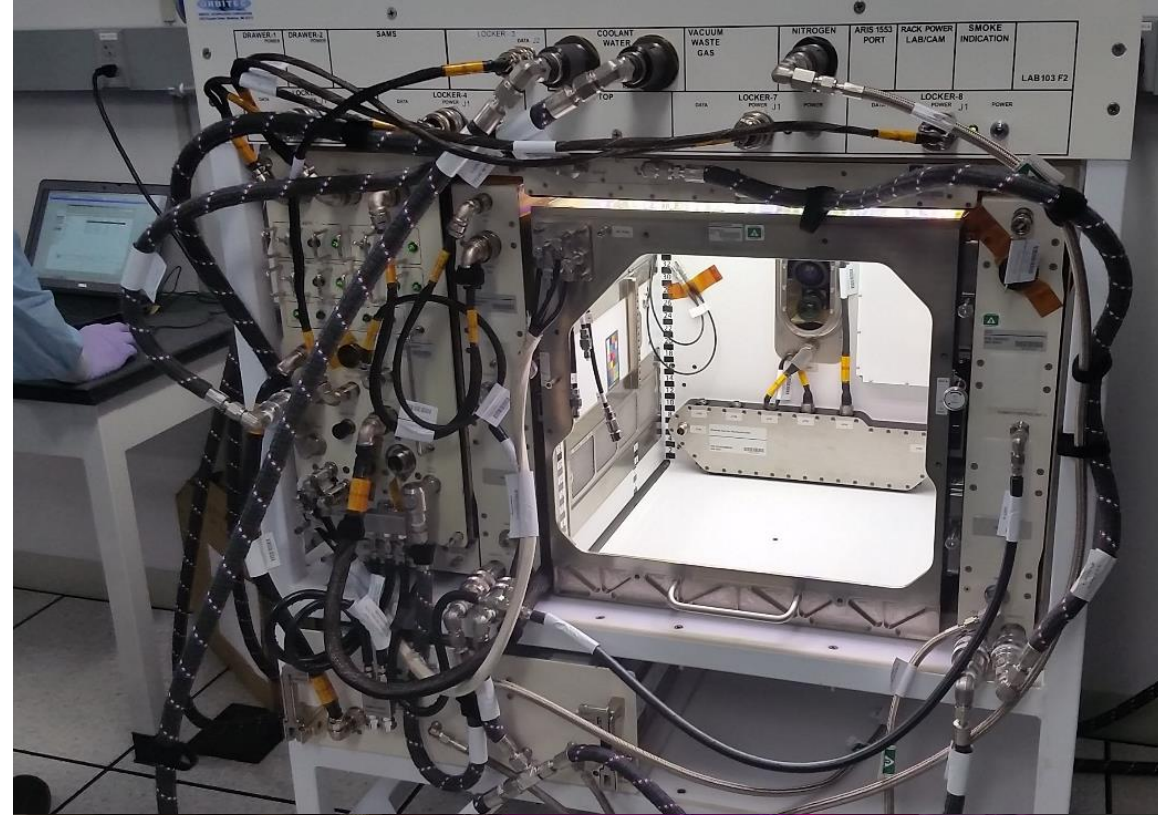
An automated plant growth facility for conducting plant research supporting space biology and food production projects on the International Space Station (ISS).

Plants are grown in the Science Carrier (SC) of the APH, (0.2 m<sup>2</sup> instrumented) root module.

The SC is packed with media, seeded on Earth, and transferred dry to the APH facility on ISS. The plant experiments are initiated when the SC is installed in the APH growth chamber and it is fully wetted.

The planting and germination protocols for growing wheat (cv Apogee) and Arabidopsis (cv Columbia) were developed and tested at KSC in the APH Engineering Development Unit (EDU). Protocols were tested on orbit during the post-installation growth checkout of APH on ISS.

## Hardware Validation – 1<sup>st</sup> plant growth test



# APH Facility – Assembly / Functional Test



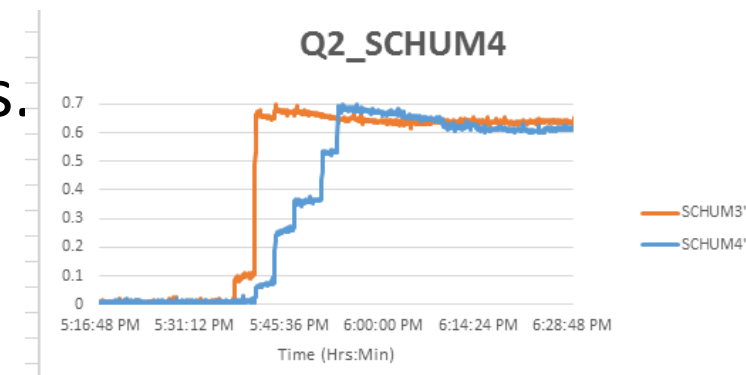
Astronaut Joe Acaba

- APH - transported to ISS on SpaceX 11 and OA-7.
- APH - assembled on the Kibo Module in 27Oct17.
- First power-up and 5-day functional test - 27Nov to 1Dec 2017 tested:
  - commanding, telemetry, and data retrieval from PHARMER.
  - T/RH control modules at 23 C/70% RH, 18 C/50% RH, 18 C/90% RH, 30 C/90% RH, and 30 C/50% RH.
  - Light levels
  - CO<sub>2</sub> scrubbing, CO<sub>2</sub> injection, Ethylene Scrubbing functions
  - Experiment Profile scripts (T, RH, CO<sub>2</sub>, Pictures).
- An acoustic test was completed on 8Dec17.



# APH Facility – Validation Schedule

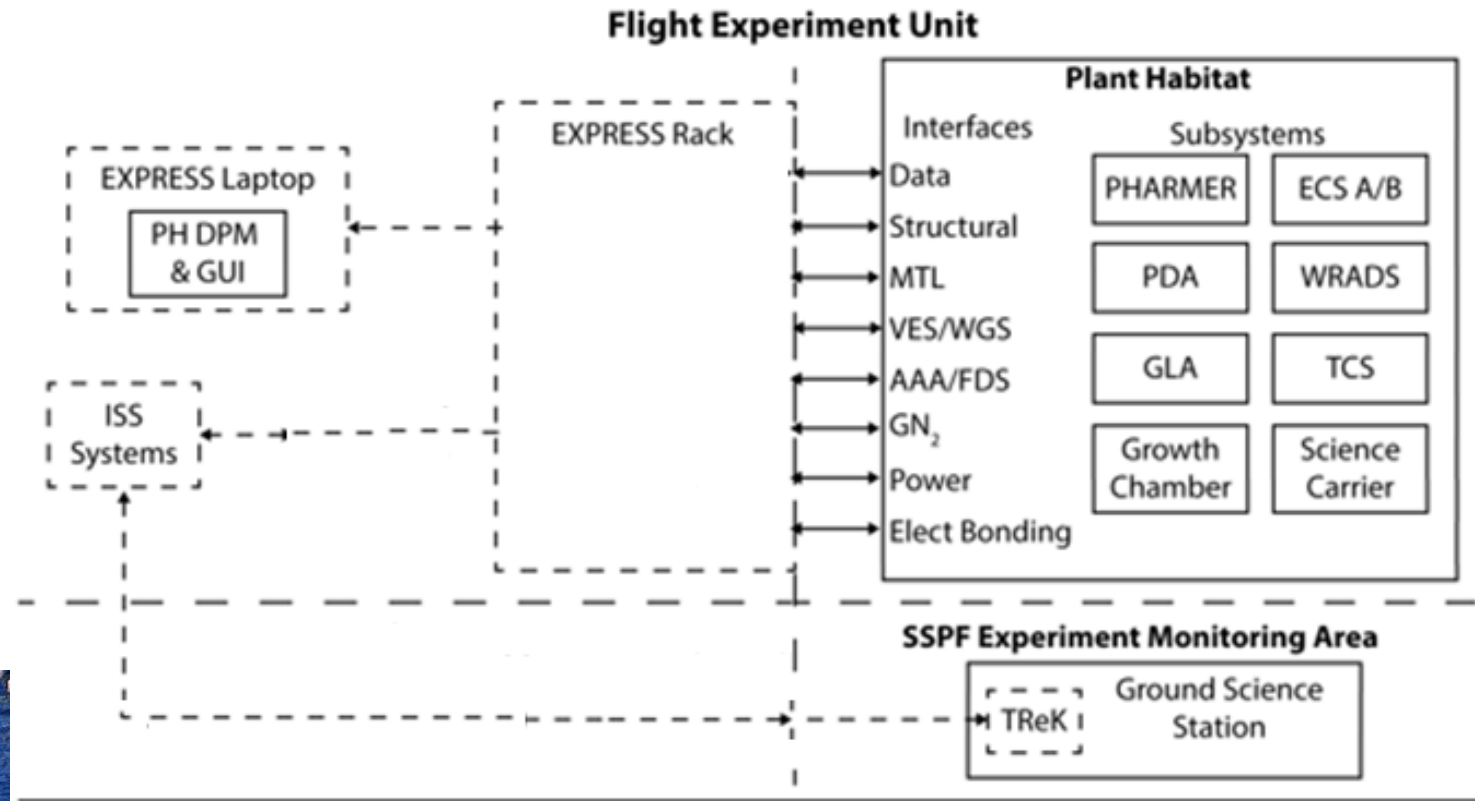
- Activated APH 19Jan18
- Initiated First Plant Test on 22Jan18 - verify that science is supported on APH hardware.
  - Install pre-planted SC: WT Arabidopsis and Apogee semi-dwarf wheat
  - Two week growth of WT Arabidopsis and 33 days of wheat conducted to demonstrate adequate plant growth for future science experiments.
  - Demonstrate and evaluate performance of on-orbit watering protocols.
- WT Arabidopsis – verify planting protocols of PH-01 Experiment.
- Wheat Plants – provide a biological ‘load’ on the system.
- Demonstrate on-orbit watering protocol.
- Demonstrate on-orbit germination / harvest protocols.
- Demonstrate experiment profile scripts



# APH - Subsystems

The APH communicates with crew via a laptop

Ground commands from the KSC Experiment Monitoring Area



## Non Plant Habitat Systems

AAA	Avionics Air Assembly
FDS	Fire Detection System
GN <sub>2</sub>	Gaseous Nitrogen
MTL	Moderate Temperature Loop
PEHB	Payload Ethernet Hub/Bridge
PLMDM	Payload Multiplexer/Demultiplexer
RIC	Rack Interface Controller
TReK	Telescience Resource Kit

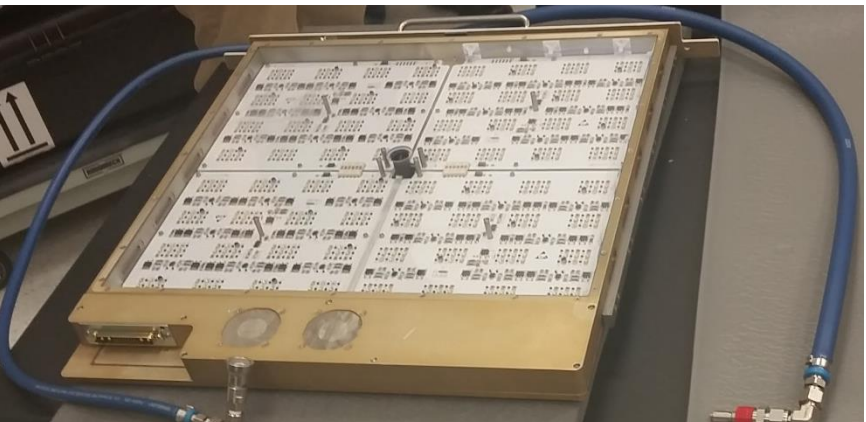
—— Within PH Teams Control  
 - - - - Outside PH Teams Control

## Plant Habitat Subsystems

DPM	Data Processing Module
ECS	Environmental Control Subassembly
GLA	Growth Light Assembly
GUI	Graphical User Interface
PDA	Power Distribution Assembly
PHARMER	Plant Habitat Avionics Realtime Manager in EXPRESS Rack
SMA	Structural Mounting Assembly
TCS	Thermal Control Subsystem
WRADS	Water Recovery and Distribution Subsystem

## Flight Experiment Unit Technical Boundaries

Growth Light Assembly



# Subsystems

ISIS Drawers



Power Distribution Assembly



Growth Chamber



# APH – User Interface

Plant Habitat GSS User Interface

File Settings View About

Ku-Band Operational Mode Experiment Profile Growth Chamber Door Status Closed GSS Mode Flight GSS Time 19Jul18 12:47:50

Subsystems

Power Module TCS ECS-A ECS-B Growth Light Growth Chamber Water Module Science Carrier Data Module

Packet Time Stamp 19Jul18 17:48:01

Home

Subsystems

Payload Commanding

Log

Help

Exit

Growth Chamber Subsystem Status ■

**Control Settings**

Air Pressure Control Switch  Off  
 Ethylene Control Switch  On  
 Oxygen Control Switch  On  
 CO<sub>2</sub> Control Switch  On  
 CO<sub>2</sub> Scrubbing Switch  On  
 CO<sub>2</sub> Setpoint 400 ppm

**Status**

Faulted   
 Air Pressure Control Inhibited   
 Ethylene Control Inhibited   
 Oxygen Control Inhibited   
 CO<sub>2</sub> Control Inhibited

**CO<sub>2</sub> Control**

Primary Sensor FE003 395 ppm  
 Secondary Sensor FE010 418 ppm  
 Idle   
 Sensor Warm-Up   
 Injecting   
 Timed Inject   
 Injection Inhibited   
 Scrubbing   
 Scrubbing Inhibited   
 CO<sub>2</sub> Injection Pressure FE005 150.9 kPa<sub>a</sub>

**Oxygen/Air Pressure Control**

Oxygen Sensor 1 FE004 21.6 %  
 Oxygen Sensor 2 FE006 22.0 %  
 GN<sub>2</sub> Pressure FE007 230.5 kPa<sub>a</sub>  
 Chamber Pressure 1 FE001 98.2 kPa<sub>a</sub>  
 Chamber Pressure 2 FE002 98.5 kPa<sub>a</sub>  
 Chamber dP FE003 -23 Pa

Science Carrier Subsystem Status ■

PAR Visible Light  μmoles/m<sup>2</sup>/s  
 Far Red Light  μmoles/m<sup>2</sup>/s

Water Module Subsystem Status ■

CO<sub>2</sub> Bottle Pressure FE001 5593 kPa<sub>a</sub>

Plant Habitat GSS User Interface

File Settings View About

Ku-Band Operational Mode Experiment Profile Growth Chamber Door Status Closed GSS Mode Flight GSS Time 19Jul18 12:48:24

Home

Setpoint File Name APH001.csv Setpoint File Line 3 Packet Time Stamp 19Jul18 17:48:34

Home

Subsystems

Payload Commanding

Log

Help

Exit

	Current Value	Setpoint
Growth Chamber Air Temperature	°C 20.9	21.0
Growth Chamber Humidity	% rH 65.1	65
Growth Chamber Air Pressure	kPa 98.2	
Light Level	umoles/m <sup>2</sup> /s 286.2	
Science Carrier Pressure Quadrant 1	kPa 0.28	-0.4
Science Carrier Pressure Quadrant 2	kPa -0.61	-0.4
Science Carrier Pressure Quadrant 3	kPa 0.56	-0.4
Science Carrier Pressure Quadrant 4	kPa 0.04	-0.4
Soil Moisture Quadrant 1	% 48.2	
Soil Moisture Quadrant 2	% 48.8	
Soil Moisture Quadrant 3	% 51.2	
Soil Moisture Quadrant 4	% 47.8	
CO <sub>2</sub> Concentration	ppm 391	400
CO <sub>2</sub> Injected	grams 5.2	
Oxygen Concentration	% 21.6	
Leaf Temperature	°C 24.2	

**Distribution Reservoir**

0.545 L

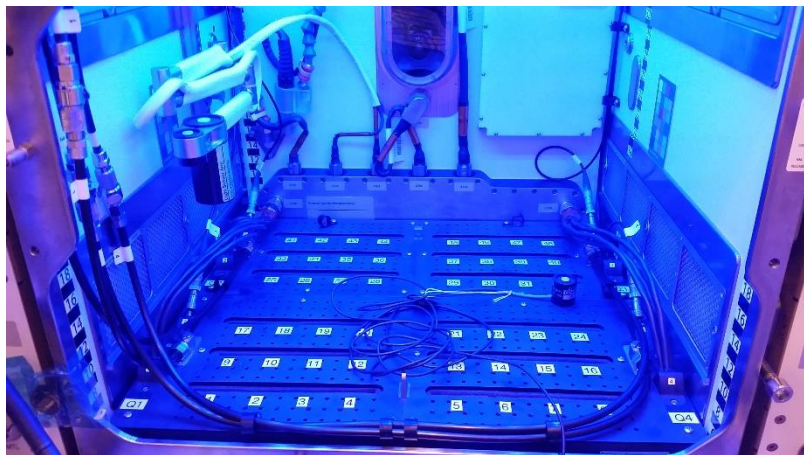
2.100 -  
2.050 - Max Fill Level

**Recovery Reservoir**

0.664 L

1.100 -  
1.050 - Max Fill Level

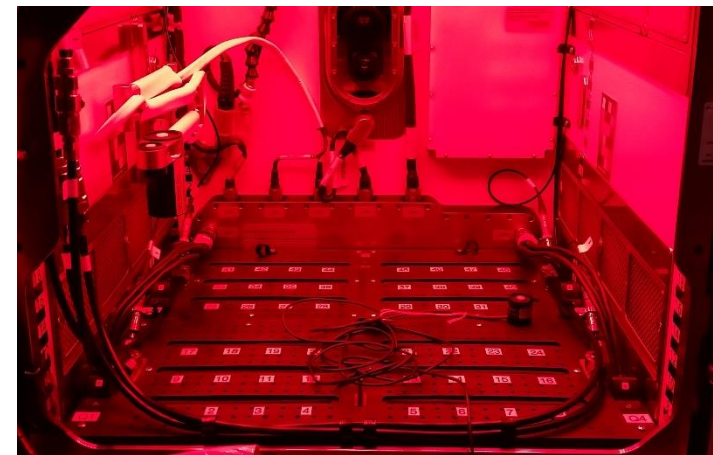
# GLA - Spectral Quality & Intensity



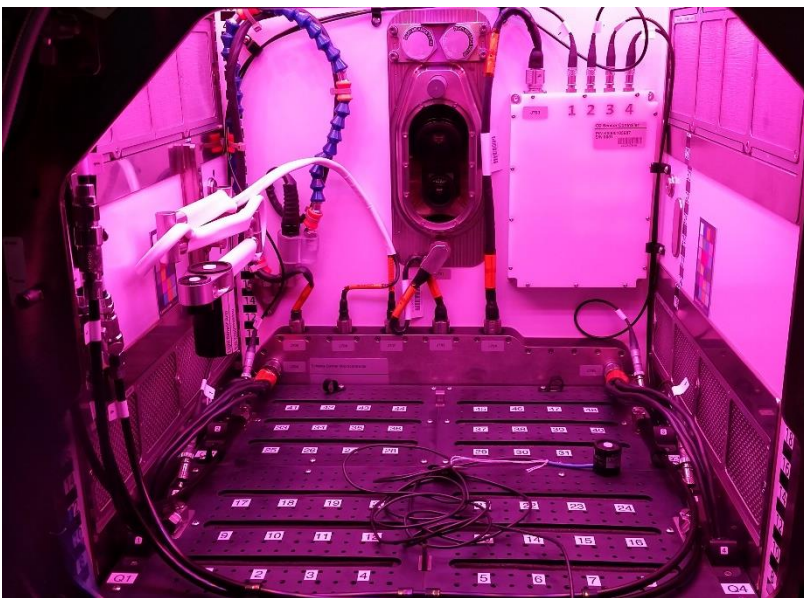
0-400  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 450 nm  $\pm 10$  nm



0-100  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 525 nm  $\pm 10$  nm



0-600  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 630 nm  $\pm 10$  nm



PI Mixture



IR 0-50  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 735 nm  $\pm 10$  nm

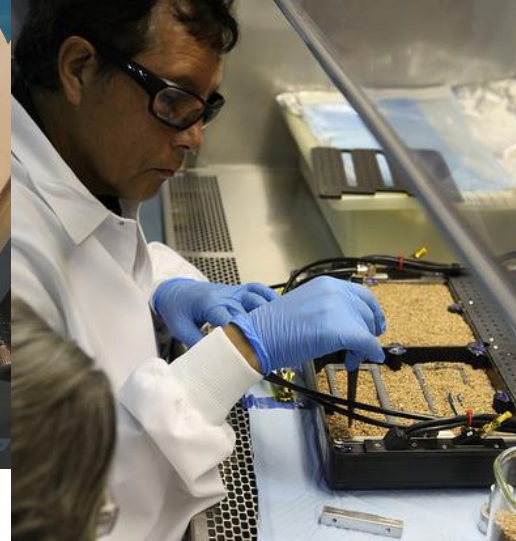
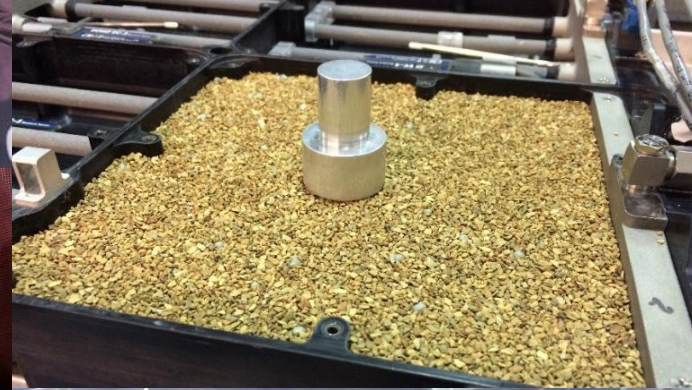
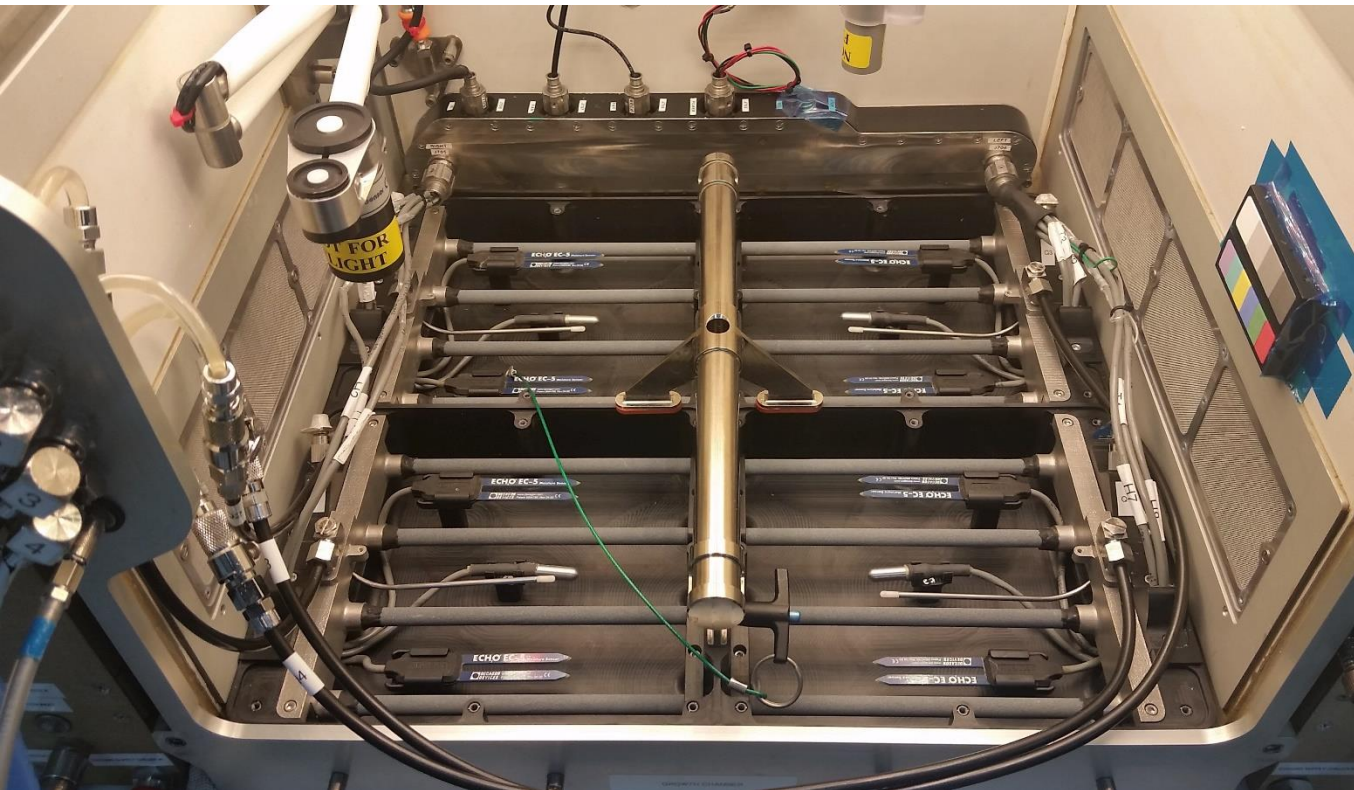


W 0-600  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 400-700 nm



# APH Science Carrier

- Four quadrants – independent moisture control
- Baseline – TRL-9 porous substrate / slow release fertilizer
- Pre-planted / Contains water and substrate



# Planting and Germination

planting protocols (**launch vibration**):

- Preparing the planting media, foam – sift, autoclave
- **Packing (legacy to Mir, BPS)**
- Seeding the SC (immobilize seeds).

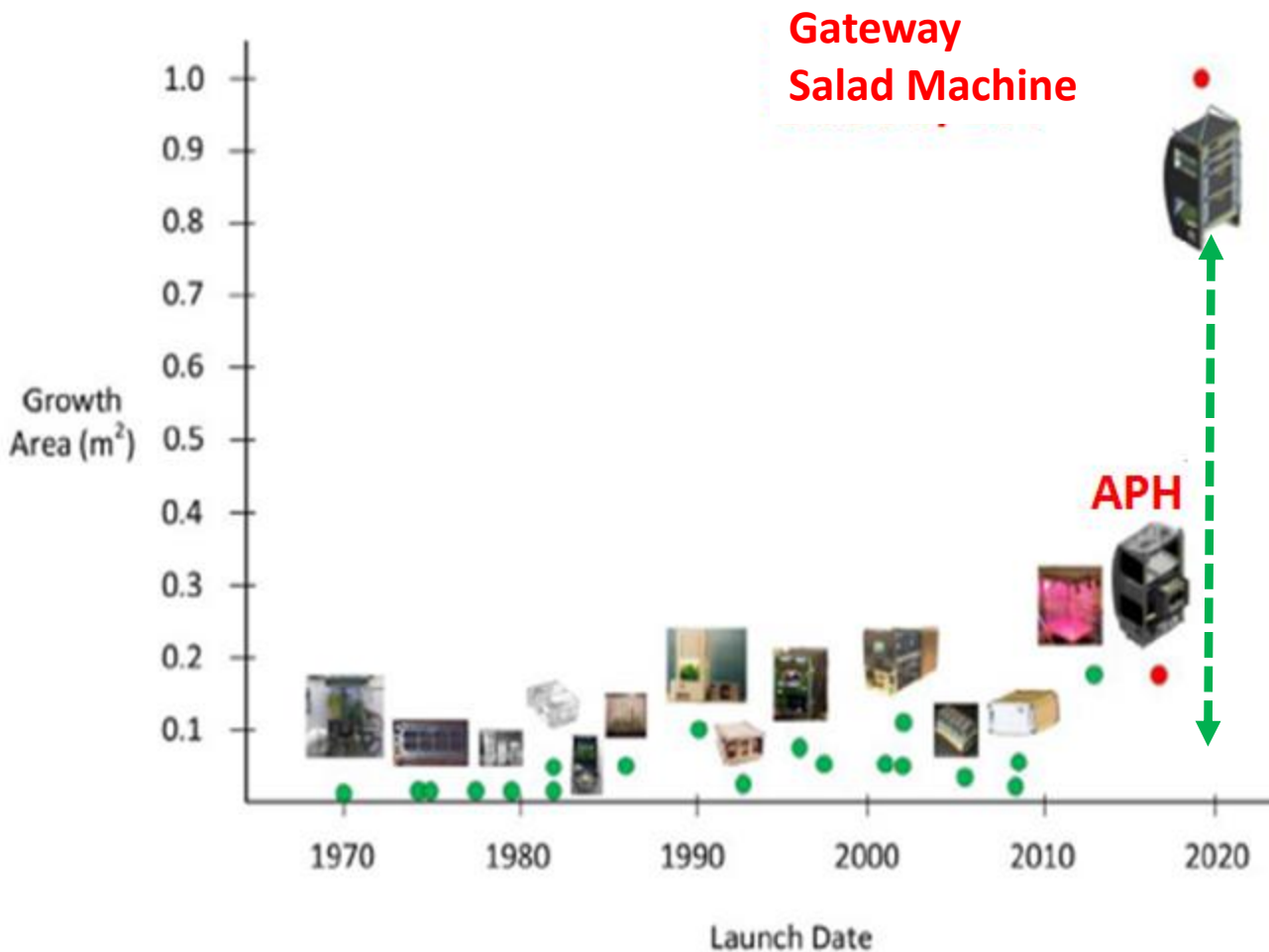
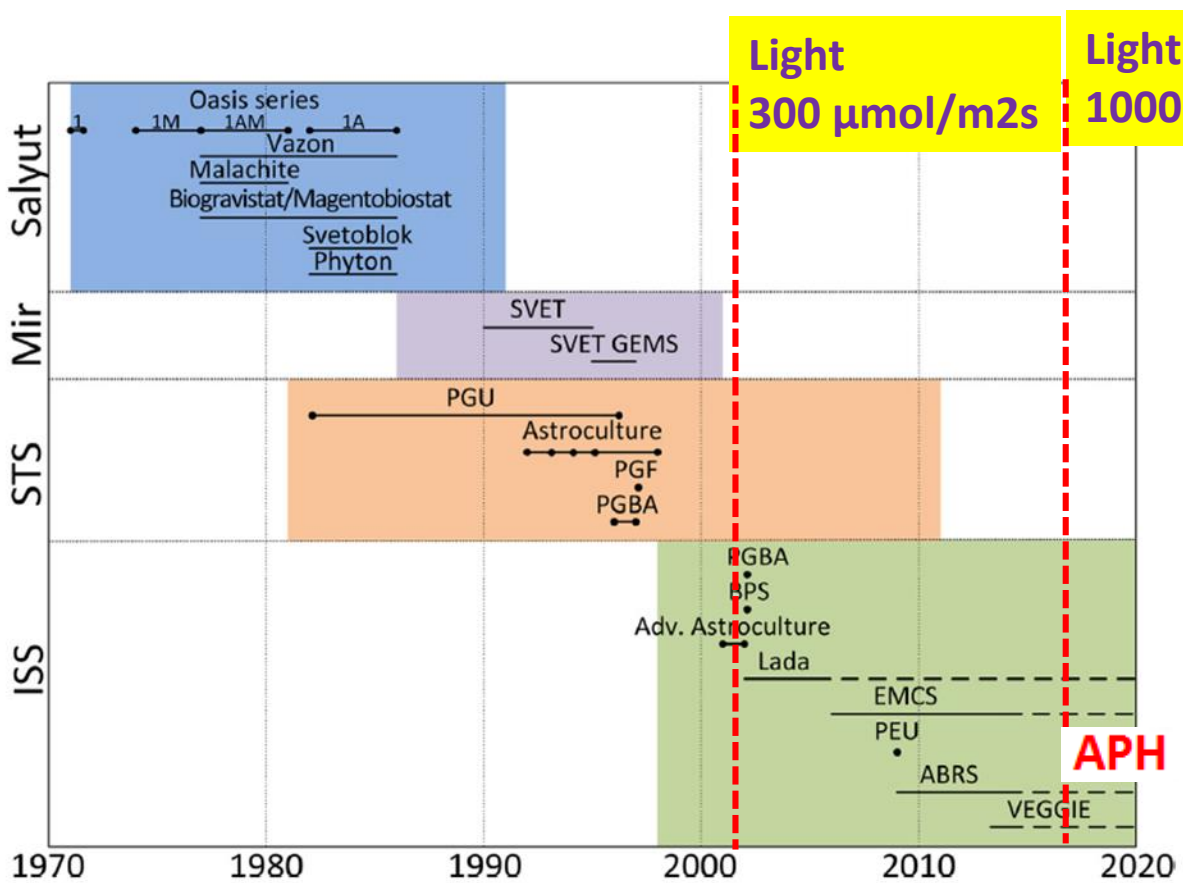
germination protocols:

- **Seed sterilization**
- **Determining the wicking system used to germinate seeds**
- **Determine environmental conditions to ensure germination**
- **Thinning as needed**





# Context: Spaceflight Plant Growth Systems



# APH – current capabilities

- Automated substrate-based watering system – 0.2 m<sup>2</sup> - Active
- Cultural Conditions
  - LED lighting: 0 to 1000  $\mu\text{mol}/\text{m}^2\text{s}$ , photoperiod
  - Spectral bands: white, blue, green, red, far red
  - Environmental control: CO<sub>2</sub>, T<sub>air</sub>, RH, soil moisture, ventilation
  - Teleoperation via commanding: manual mode, scripts, real time GUI
  - Crew tended functions: planting, harvest, sensors, maintenance
  - Imagery: aerial growth rates, health, watering, food safety - hyperspectral

# Future Studies – deep space

- Watering system:
  - microgravity independent, reusable, modular, light weight, no substrate
- Autonomous:
  - firmware, troubleshooting, scheduler, robotic farmer arms, AI
- Crew/Inputs:
  - installation, sample return, consumer, fertilizer, seeds, water
- Enable Science:
  - Platform for molecular tests, fundamental biology
  - radiation exposure, crop production rates, food quality

APH commanding logs are data for designing a 'fully' automated plant chamber

Space farming is multidisciplinary – science, engineers, robotics

# APH Facility – First Plant Test



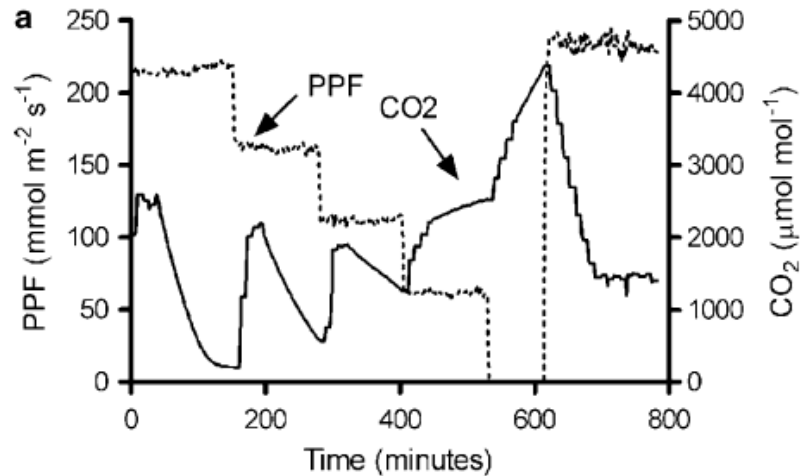
Arabidopsis (Quadrants 2 & 3) initiated on 1/22/18.

Apogee wheat (Quadrants 1 & 4) Initiated on 2/7-8/18.

**Feb 22, 26, harvest Mar 6, 9, 12 2018** - Arabidopsis harvested on Mar 6 – observed debris containment. Apogee wheat (Quadrants 1 & 4) was 32 days old on Mar12.

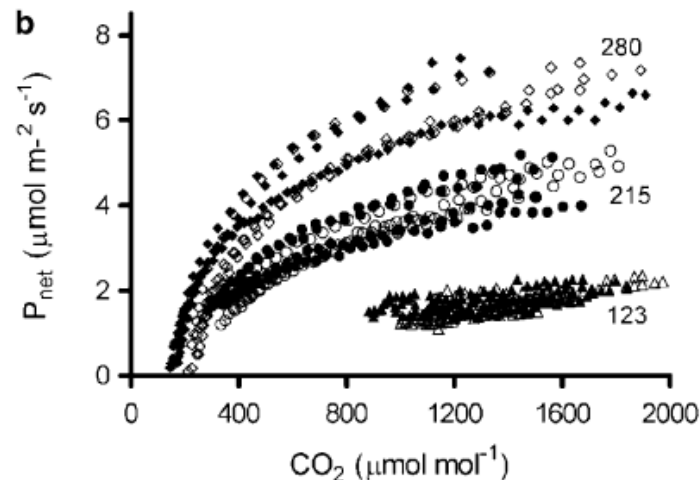
# Nondestructive data – Gas exchange

- APH measures nondestructive growth data – C fluxes.
- Example: CO<sub>2</sub> Response Curves from 20 day old wheat



## CO<sub>2</sub> Drawdown Technique:

- Change the light level, disable CO<sub>2</sub> control, and photosynthesis consumes chamber CO<sub>2</sub> - drawdown.
- Allows Light response curves to be measured as well.
- Daily Growth – Lights come on.



## ISS 2002 - BPS – Biomass Production System

PESTO - Photosynthesis Experiment Subsystem Testing and Operations - PI\_G. Stutte

Stutte et al. Planta (2005)



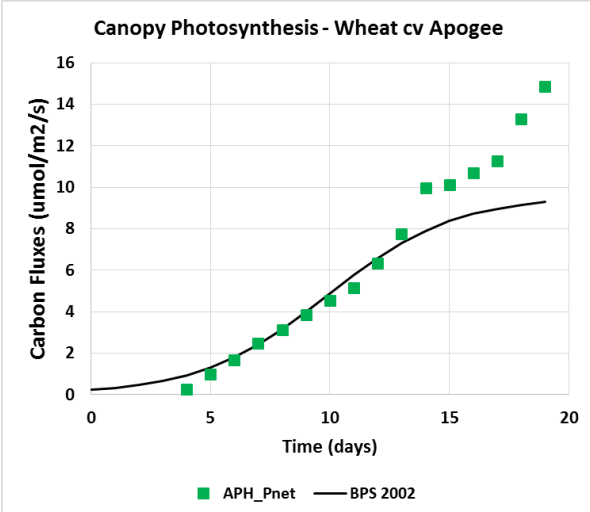
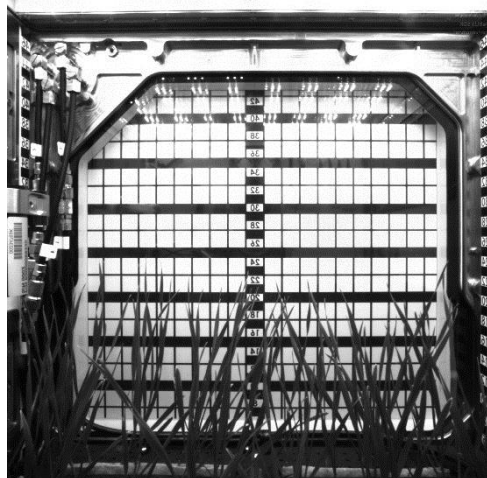
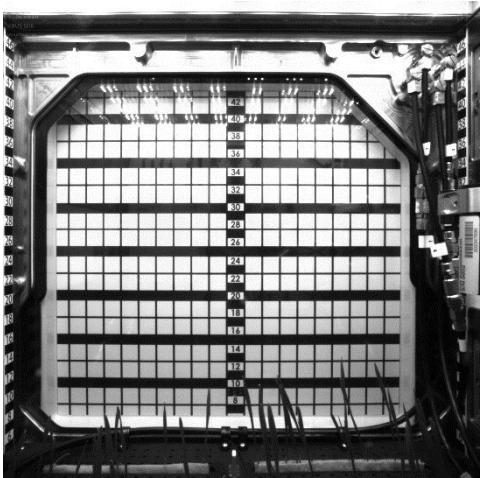
5

11

20

25

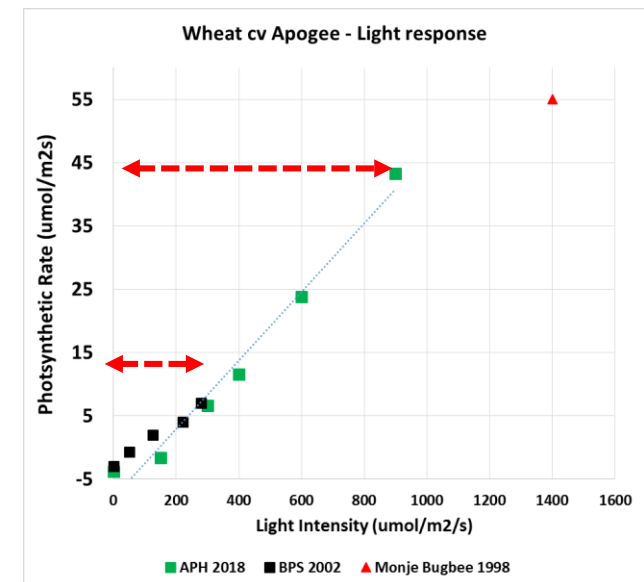
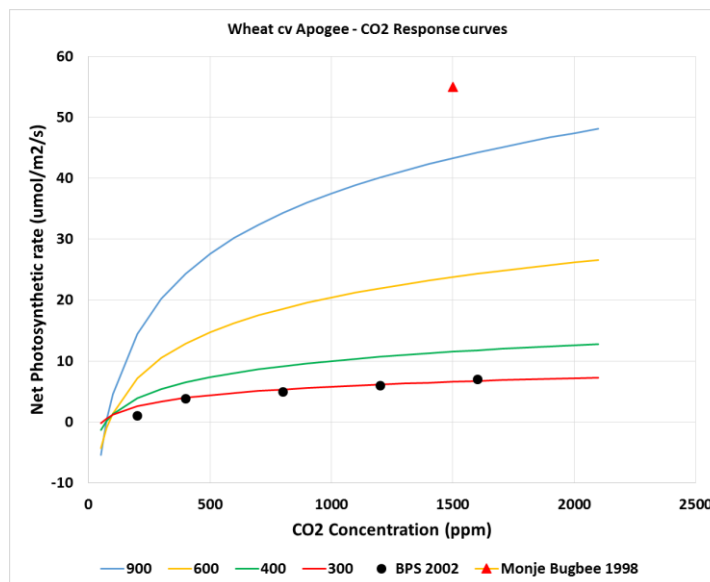
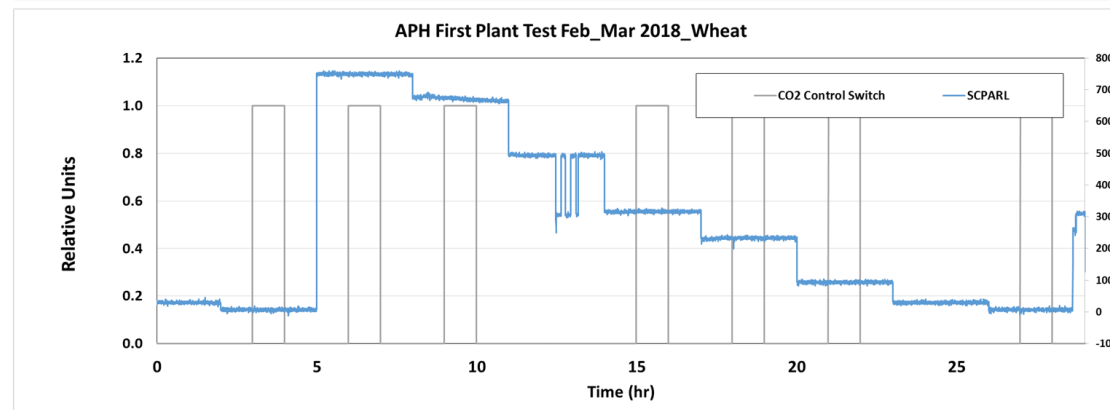
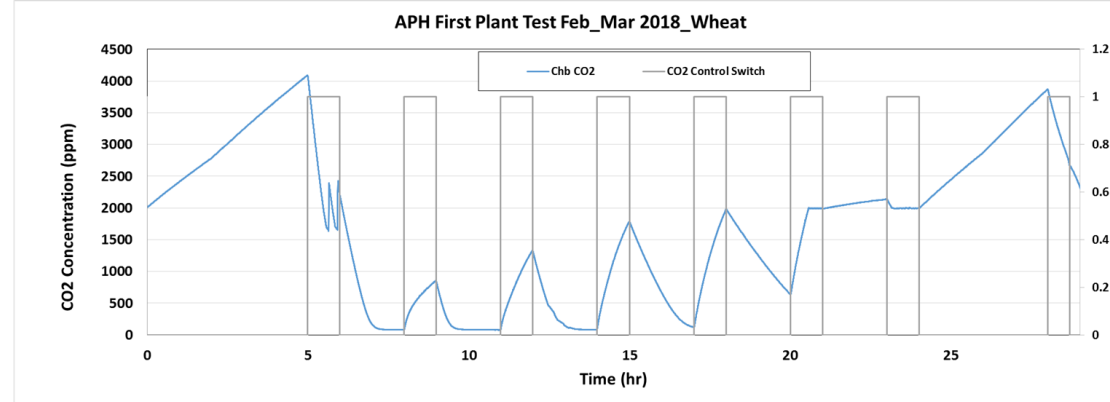
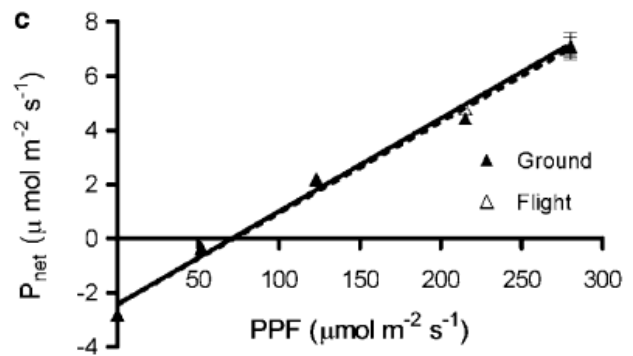
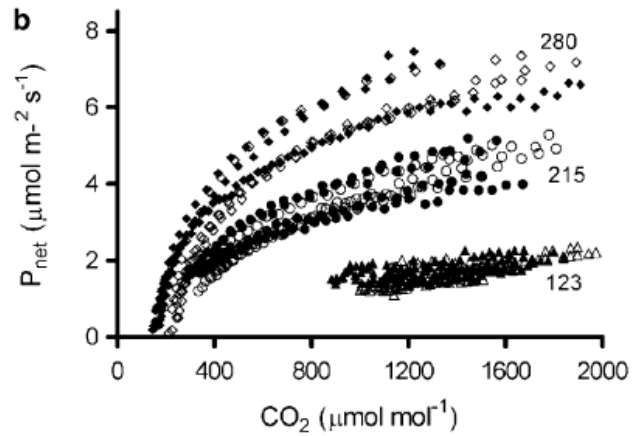
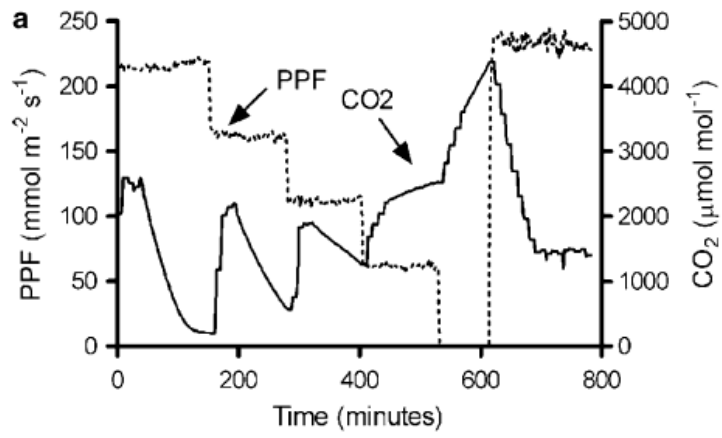
31



Daily CO<sub>2</sub> DrawDown Data

Monje et al. Planta (2005)





Measuring CO<sub>2</sub> and light response curves of wheat plants in microgravity



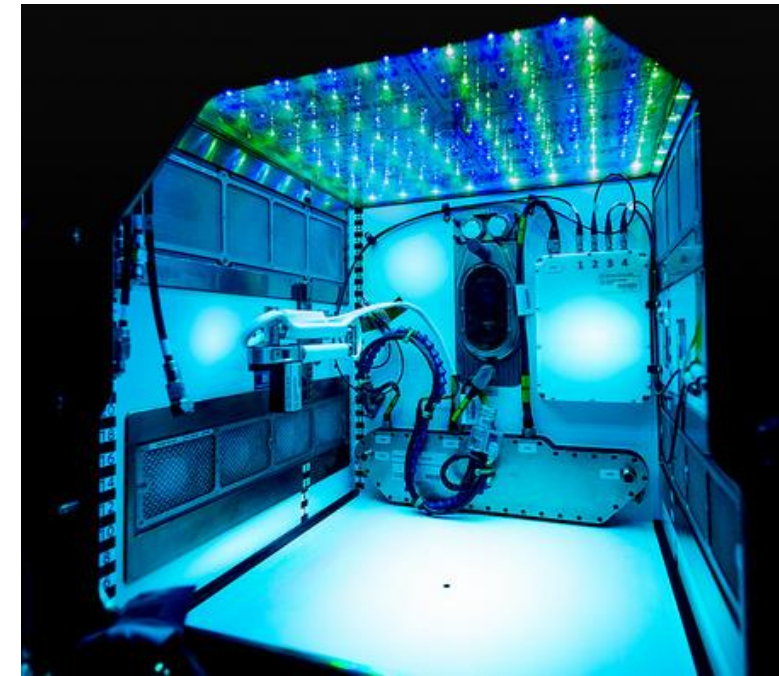
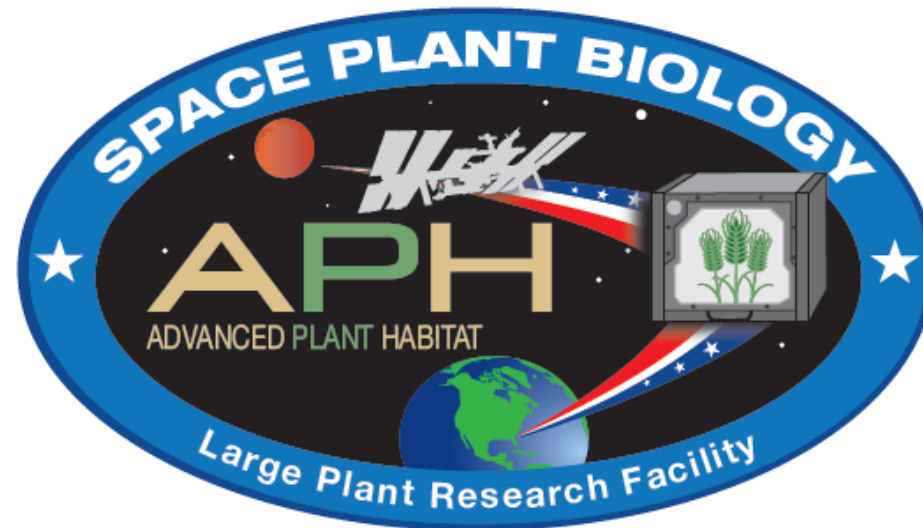
- Wheat harvest was conducted by removing the SC - Astronaut Norishige “Nemo” Kanai



# Conclusions

- APH Facility was installed, assembled and validated for conducting plant research on ISS.
- Two species – Wheat and Arabidopsis plants were successfully grown from seed and harvested after 30 days of growth on ISS.
- Validated planting, germination and watering protocols.
- Collected environmental data and nondestructive plant growth data.
- Hardware supports science.

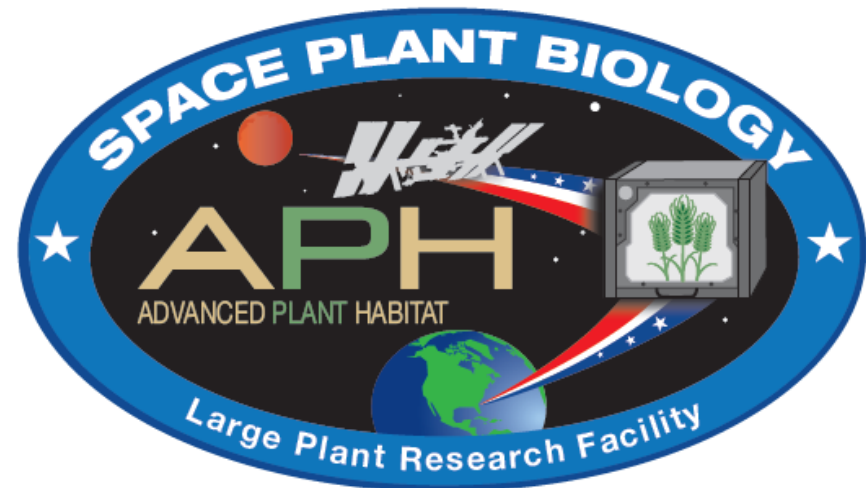
**Go APH!**



# Acknowledgements

APH was sponsored by NASA's ISS Program and Space Life and Physical Sciences Research and Applications Division (SLPSRA) and co-developed by NASA and Sierra Nevada Corp. (formerly ORBITEC) of Madison, Wisconsin.

APH is available to support SLPSRA selected fundamental biology plus U.S. National Laboratory investigations sponsored by the Center for the Advancement of Science in Space.



# Questions?

