Crop Production in Support Exploration

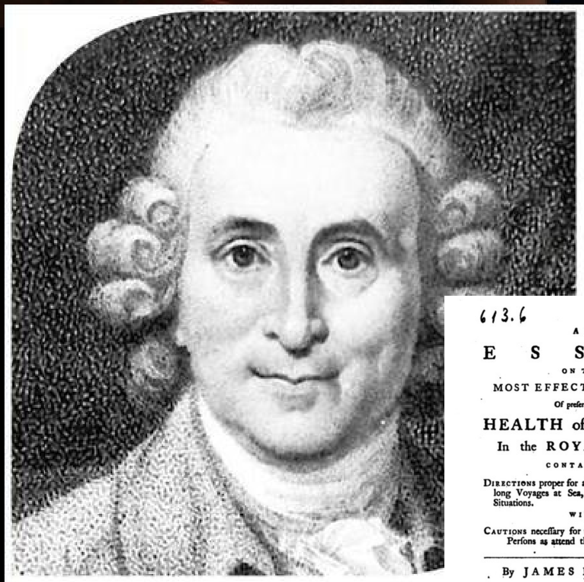
"Feeding Exploration and Enabling Earth Independence"

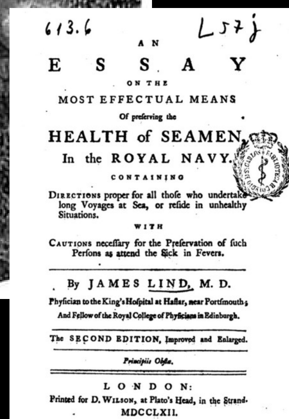
Mr. Ralph Fritsche
NASA, Kennedy Space Center, FL

The Long History of Food and Exploration

- Before the invention of refrigeration and canning explorers like Columbus, Magellan and Cook carried dried foods and foods preserved in salt and brine
- They also brought crops familiar to them and central to their European diet
- On his second voyage, Columbus introduced wheat, rice, barley, oats, coffee, sugar cane, citrus fruits and melons to the Americas
- Over time, the cultivation of wheat and other European foodstuffs would drastically change the cultural and ecological landscape of the Americas

Food and the Health and Welfare of the Crew





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AN

ESSAY

ON THE

MOST EFFECTUAL MEANS

Of preſerving the

HEALTH of SEAMEN,

In the ROYAL NAVY.

CONTAINING

Directions proper for all thoſe who undertake long Voyages at Sea, or reſide in unhealthy Situations.

WITH

Cautions neceſſary for the Preſervation of ſuch Perſons as attend the Sick in Fevers.

By JAMES LIND, M. D.

Phyſician to the King's Hoſpital at Haſlar, near Portſmouth; And Fellow of the Royal College of Phyſicians in Edinburgh.

The SECOND EDITION, Improved and Enlarged.

Principiis Obſta.

LONDON:

Printed for D. Wilson, at Plato's Head, in the Strand.

MDCCLXII.

- James Lind was a Scottish Doctor and pioneer of naval hygiene for the Royal Navy In the mid 18th century
- He was responsible for some of the first clinical trials which led to his theory that citrus fruits cured scurvy.
- *Lind was also a strong proponent for growing and incorporating fresh vegetables in the diet of seamen in order to maintain crew health and performance.*

To a Crew replete in Health, what Enterprize too dangerous? What Atchievement too great?

NASA Space Food Then and Now

- John Glenn was the first American to eat in space aboard Friendship 7 in 1962
- At that time it was not known if ingestion and absorption of nutrients were possible in a state of zero gravity.
- Glenn ate applesauce, packed in a tube, and xylose sugar tablets with water he demonstrated that people could eat, swallow, and digest food in a weightless environment.

International Space Station Food System

- No refrigerators or freezers for food storage
- All food processed and prepackaged
- Eight day menu cycle for 6 month mission
- Fresh food only available at resupply
- Testing of "Pick-and-Eat" food grown in space

We can grow more than just food!
Zinnia Action Shot

The Space Crop Production Vision

Ensure Food System Security on Long Duration Missions Beyond Low Earth Orbit (LEO)*

- ***Food and nutrition are the first line of defense for crew health and performance***
- **Provide safe, nutritious and acceptable fresh food**
- **Add variety to crew diet**
- **Enhance morale**

* Food security is the condition in which crew have continuous access to sufficient safe and nutritious food which meets both their dietary needs and food preferences in order to maintain peak health and performance.

Near Term Goal

Nutrient Supplementation of the Prepackaged Food System

It is possible to support life for 7-8 months upon a diet of canned food; but after this period there is something in the human system which makes it refuse to utilize the elements of nutrition contained in tins. Against such food, even for a short period, the stomach protests…" - FA Cook (1900)

- **Fresh produce supplements vitamins (B_1, K, C) and bioactive compounds that degrade in the stored food system on multi-year exploration missions**
- **"Pick-and-Eat" crops that require no processing and minimal preparation will provide variety, customization, and psychological appeal**
- **Enable testing and demonstration of dependable crop production before reliance on system.**
- **Limiting factors are vehicle resources mass, power, volume, water, air, crew time**

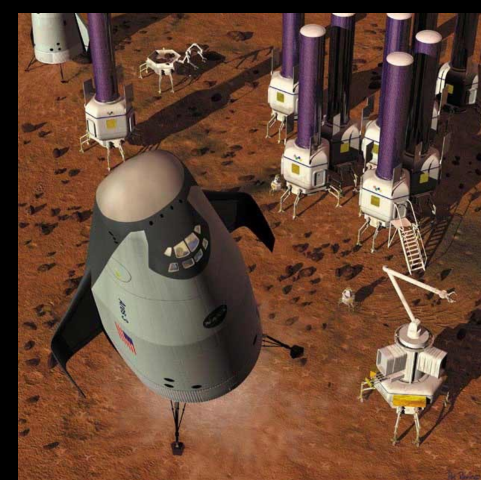
Needed for: Deep Space Transport

Long Term Goal

Caloric Replacement to Facilitate Earth Independence

- **Reduce up-mass associated with pre-packaged food**
- **In addition to "pick and eat" crops, include staple crops that require processing and preparation**
- **Bioregenerative capability will be required for long duration surface missions**

Needed for: Long duration Surface missions on the Moon and Mars



SPACE CROP PRODUCTION ROADMAP FOR EXPLORATION

ISS (*Plant Research and H/W Technology*)

µg · Mag Field

Identify challenges and solutions for growing pick and eat crops in µg to support crew nutrition

Scale: Single Locker to EXPRESS Rack (8 Lockers)

GATEWAY (*Plant Research*)

µg · Rad Field

Proving Ground to study the effect of deep space radiation on pick and eat crops in µg

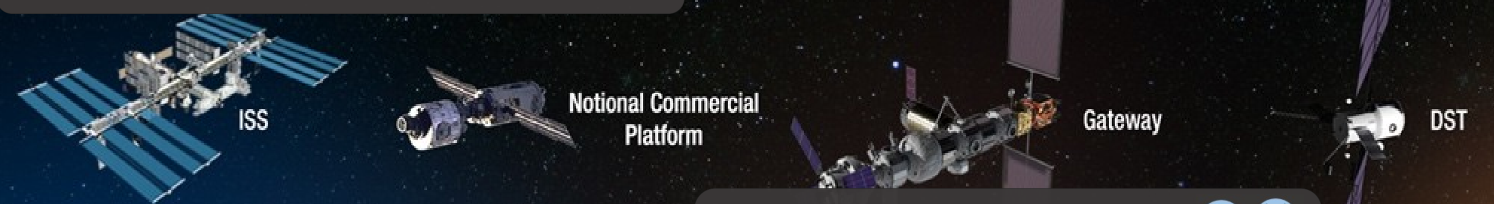
Scale: Single Locker

MARS TRANSIT (*Crop Production*)

µg · Rad Field

Operational µg Food Production capability for pick and eat crops to supplement crew diet

Scale: One to Two EXPRESS Racks (8-16 Lockers)



Ground (*Plant Research and H/W Technology*)

1g · Mag Field

Develop space crop production concepts and strategies in support of destinations along the exploration roadmap

Scale: Single Locker to Module

LUNAR SURFACE (*Research/Production*)

g/6 · Rad Field

Develop and deploy operational partial gravity systems for both nutritional support and caloric replacement as both a source of food for long duration lunar missions and as a demonstration for Mars

Scale: Single Locker to Module

MARTIAN SURFACE (*Production*)

g/3 · Rad Field

Leverage Lunar Surface experience in Food Production systems to extend Earth Independence for Mars missions

Scale: Single Locker to Module

Environment

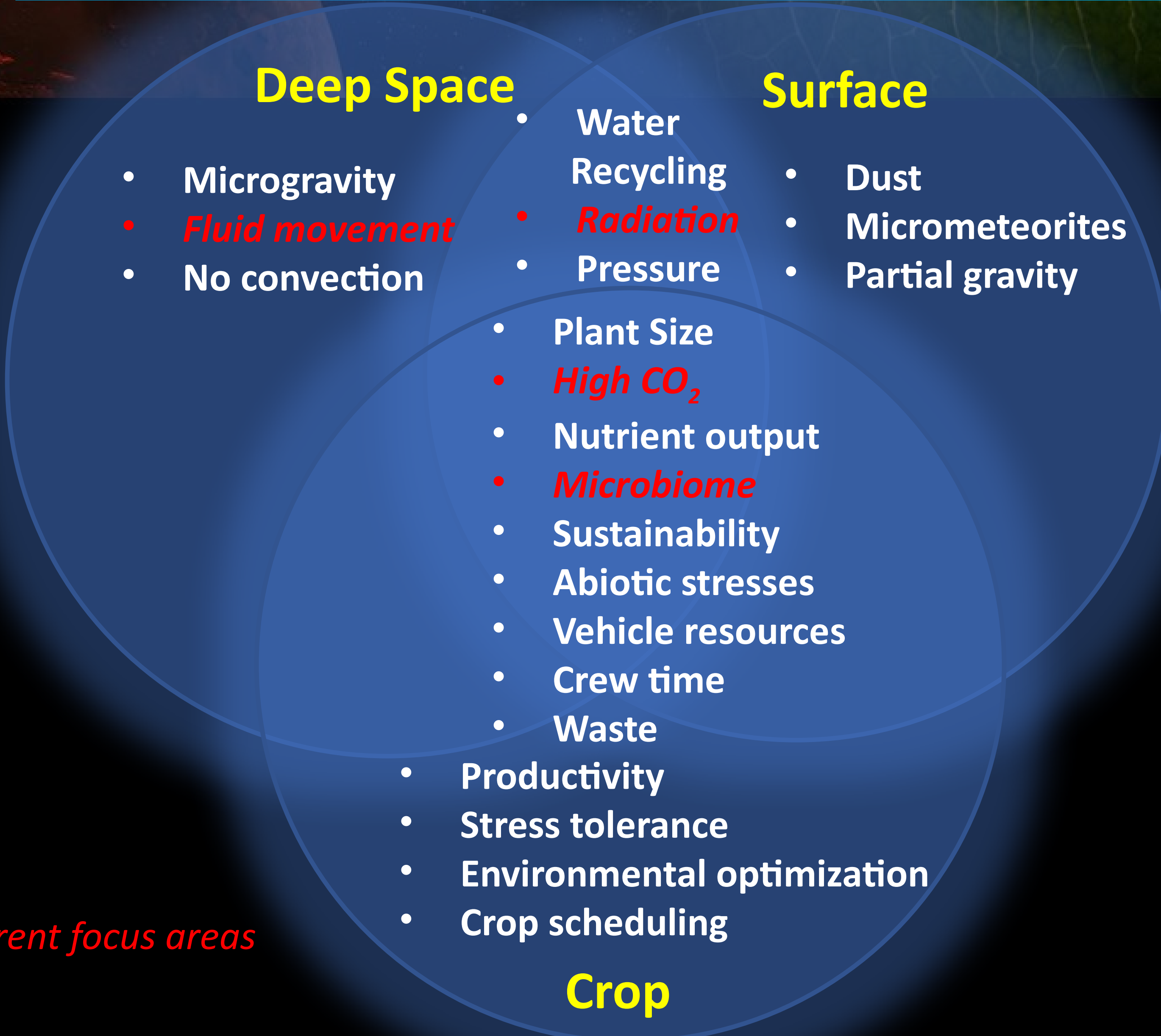
- 1g Gravity
- Mag Field
- Rad Field

Current Food System Challenges

- Packaged diet is diverse but low in several key nutrients
- Vitamins and quality degrade over time
- We do not currently have a diet that will support lunar or Mars missions
- Menu fatigue over longer mission durations (currently at 200 items)
- Psychological support
- Bioavailable nutrients

Food safety is paramount but we do not have standards for fresh produce

Space Crop "*Production*" Challenges



- *Current focus areas*

Technology and Knowledge Gap Focus

- **Identify and demonstrate effective options to provide both water and oxygen to the root zone in microgravity**
  - **Investigate benefits of both passive and active systems**
- **Understand the deep space radiation impacts on seeds and plants**
- **Investigate the relationship between microbiomes and food safety**
  - **Effectively sanitize produce with few consumables and low inputs**
  - **Control biotic stresses and pathogens**
  - **Use the microbiome to protect crops or enhance growth**
- **Identify potential crops**
  - **Yield, nutrition, organoleptic attributes, psychosocial benefits**
  - **Light recipes, elevated CO_2 impacts, fertilizer requirements**
  - **Custom space crops**
- **Automation and human factors**
  - **Identify operations and capabilities that require automation**
  - **Understand which crew activities are desirable and at what scale**
- **Storage and handling of seeds to ensure they are viable, free of contaminants and long-lived**
- **Scalability for different concepts and architectures**

Technology and Knowledge Gap Focus

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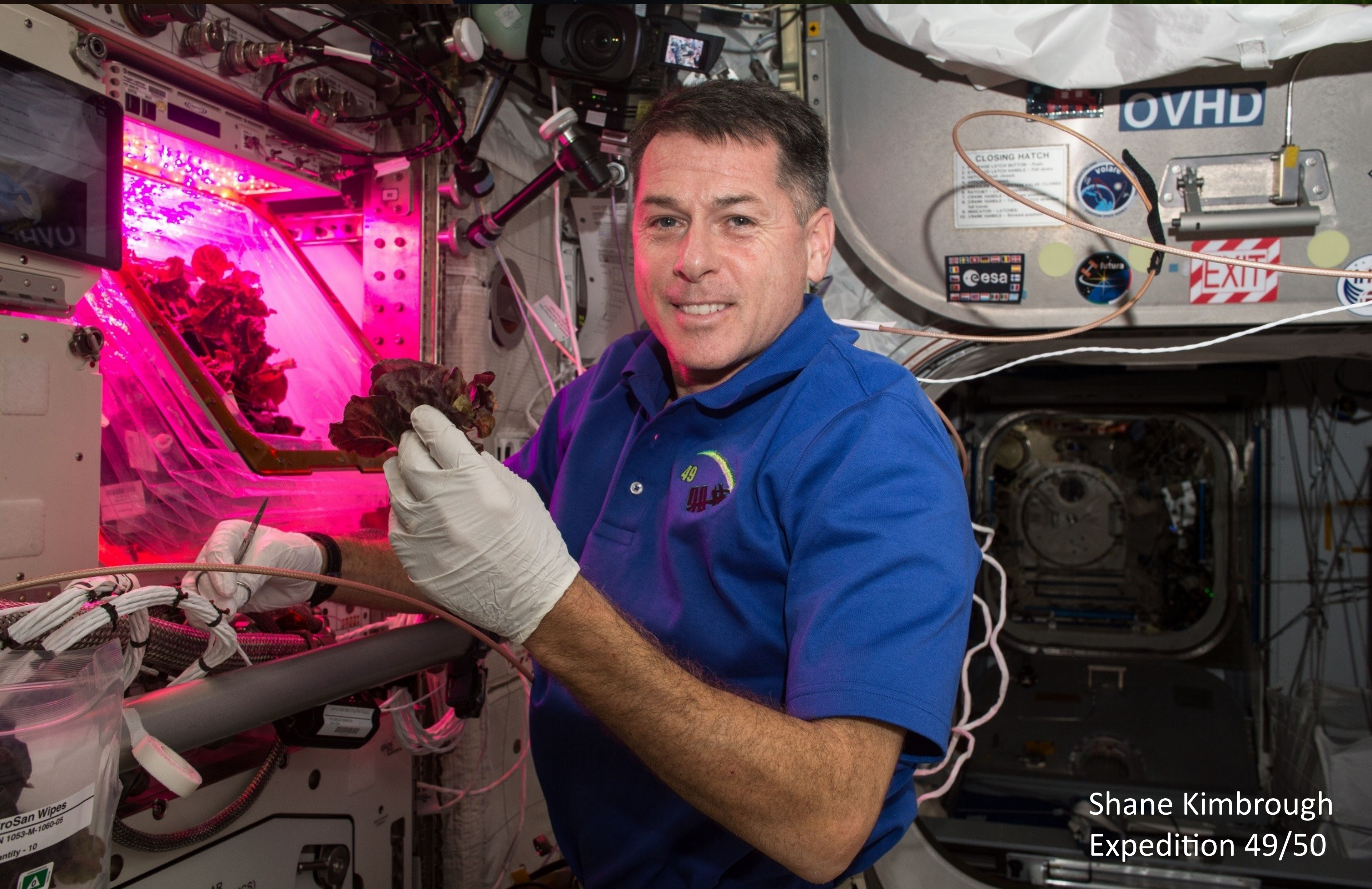
Veggie on ISS



Shane Kimbrough
Expedition 49/50

Veggie Technology Validation Tests

VEG-01

- 2014-2016
- 'Outredgeous' lettuce and 'Profusion' Zinnia
- Crew consumption approval
- Watering challenges
- Fungus

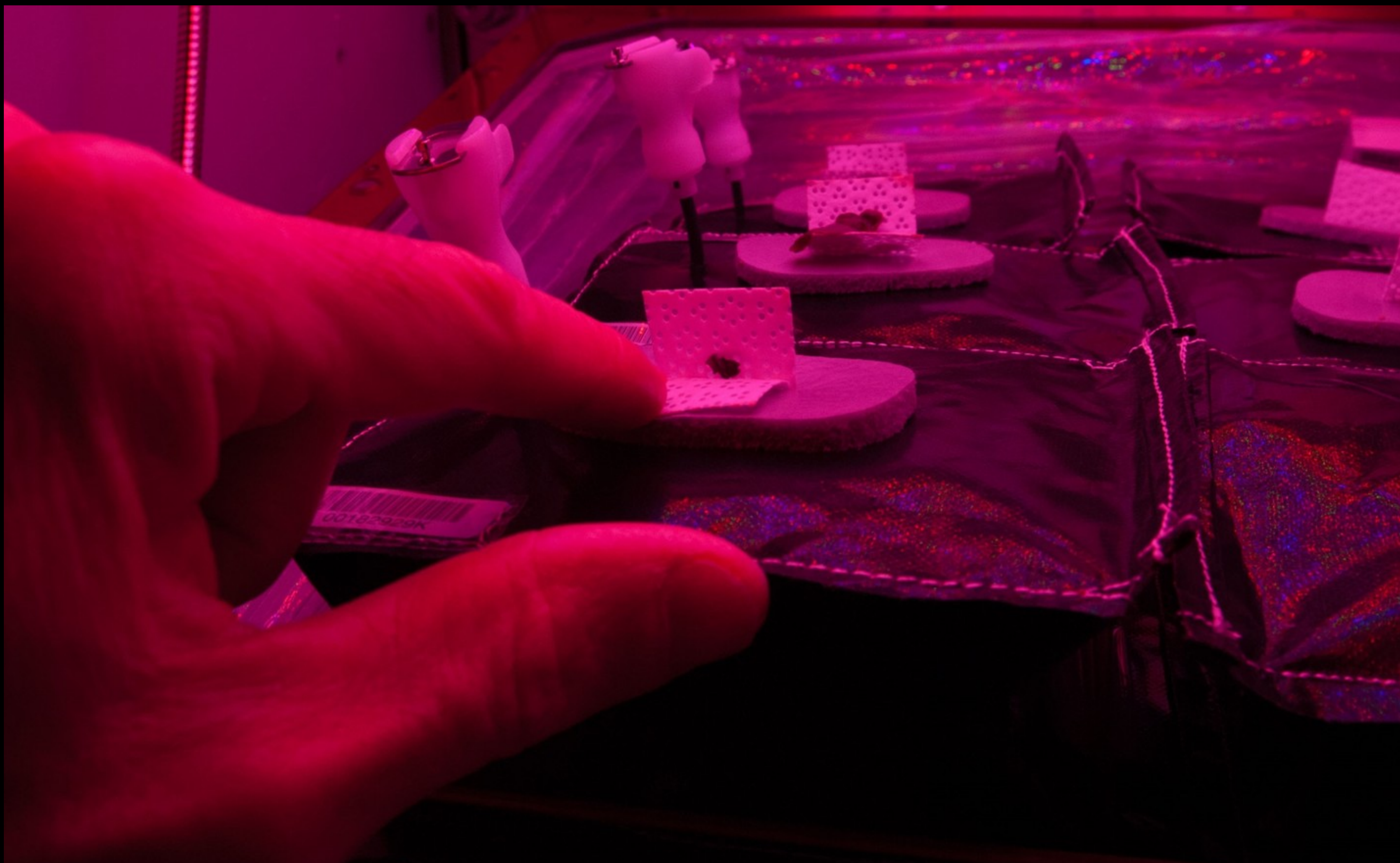
VEG-03

- 2016-Present
- 'Outredgeous' lettuce, 'Tokyo Bekana' Chinese cabbage, Mizuna, 'Waldmann's Green' lettuce, 'Red Russian' kale, 'Dragoon' lettuce, 'Wasabi' mustard, 'Extra dwarf' Pak Choi
- Cut-and-come-again harvesting
- Mixed cropping

Crop Production Challenge

- Identify and demonstrate effective options to provide both water and oxygen to the root zone in microgravity.

Root Zone Water – Insufficient



Root Zone Water – Excess

Condensation on Bellows

Stunting and Chlorosis

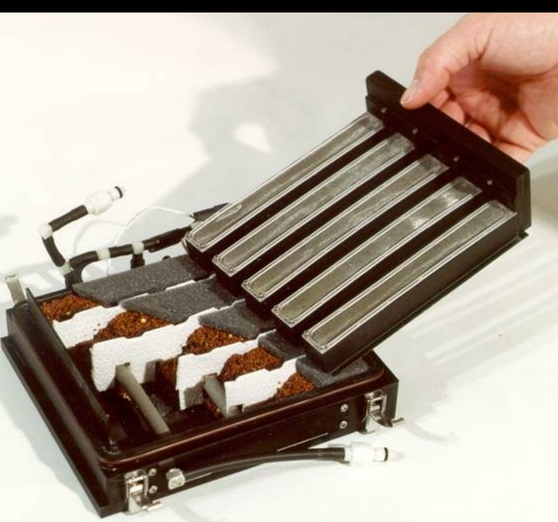
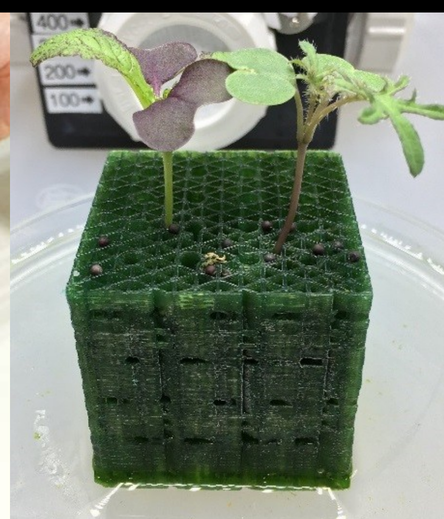
Root Zone Water – Excess

Guttation and Leaf Curling

Abnormal Growth

Current and Future Activities

- Testing in ground-based Food Production Demonstration Unit test bed to evaluate and compare candidate solutions.
- Testing active and passive concepts
- Collaborative work between plant scientists, microgravity fluid physicists, and engineers with student design teams also participating.

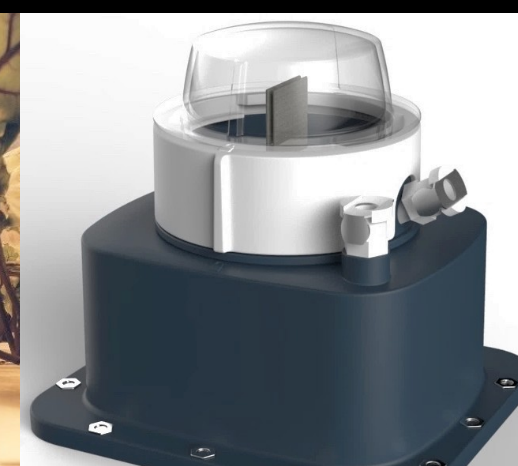



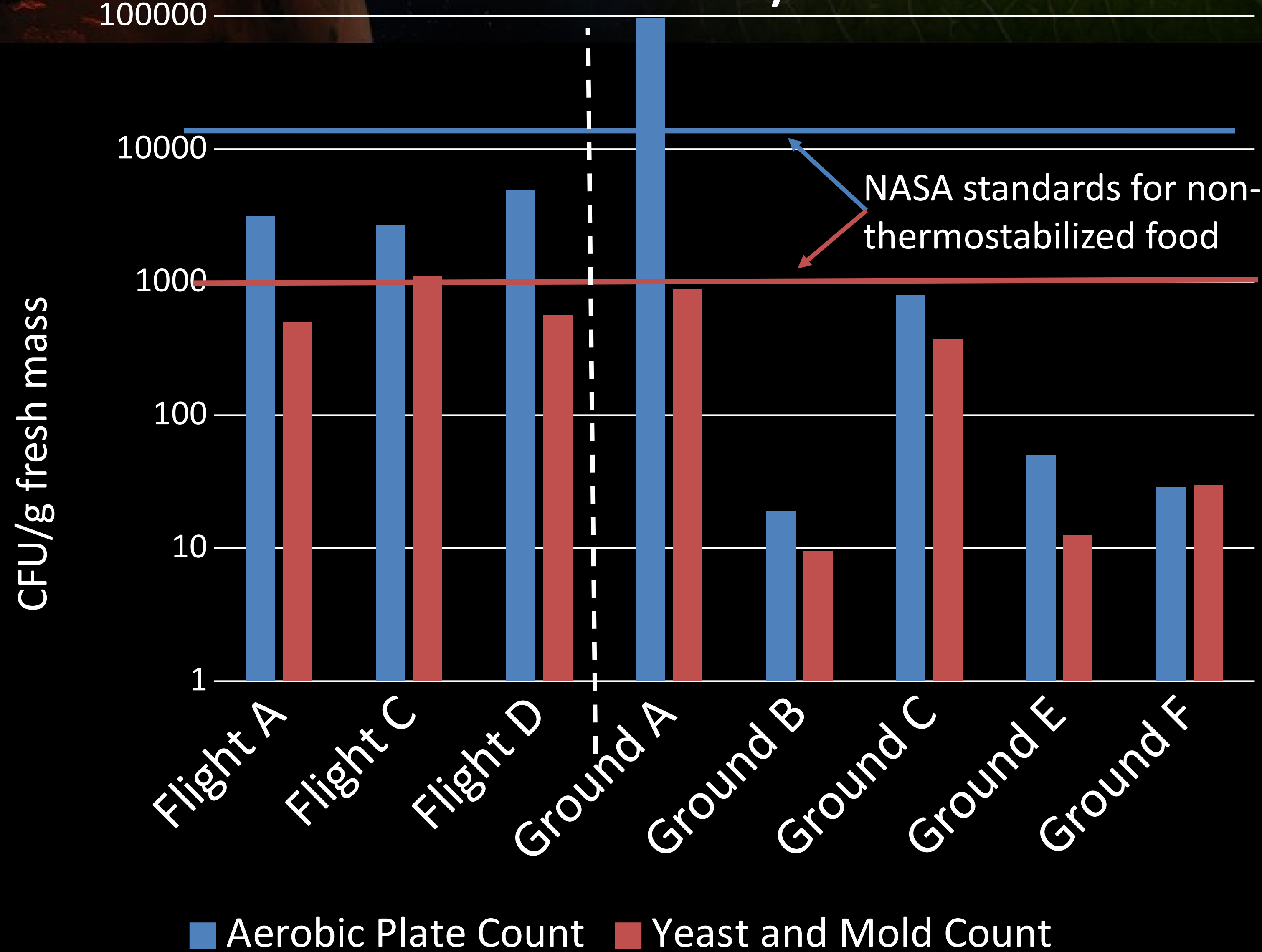
Image courtesy of Techshot and Tupperware Brands

Crop Production Challenge

- Investigate the relationship between microbiomes and food safety:
  - Effectively sanitize produce with few consumables and low inputs
  - Control biotic stresses and pathogens
  - Use the microbiome to protect crops or enhance growth.

Veggie Microbiology

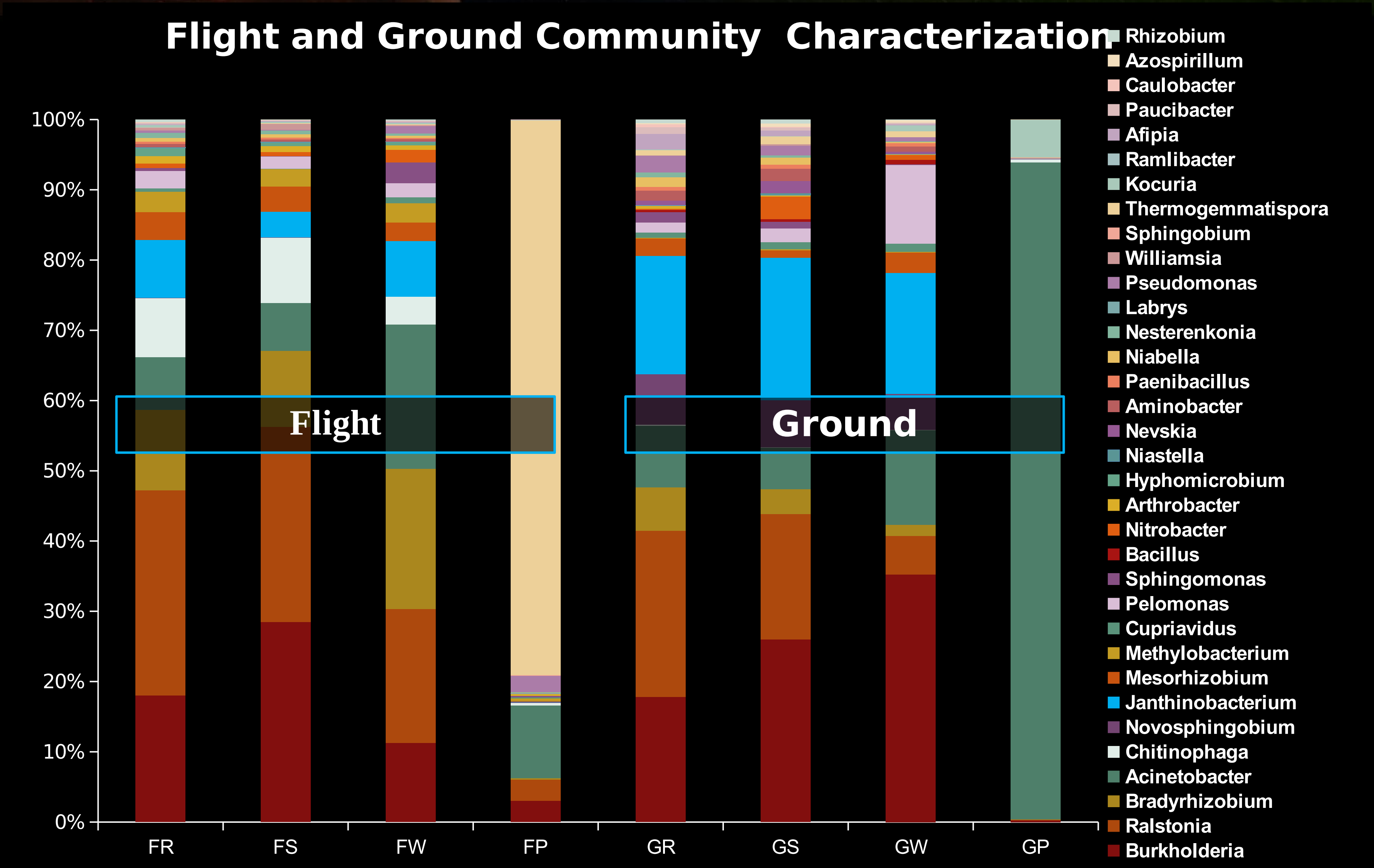
Food Safety



Veggie Microbiology
Plant pathogenesis

Veggie Microbiology

Microbiome analysis



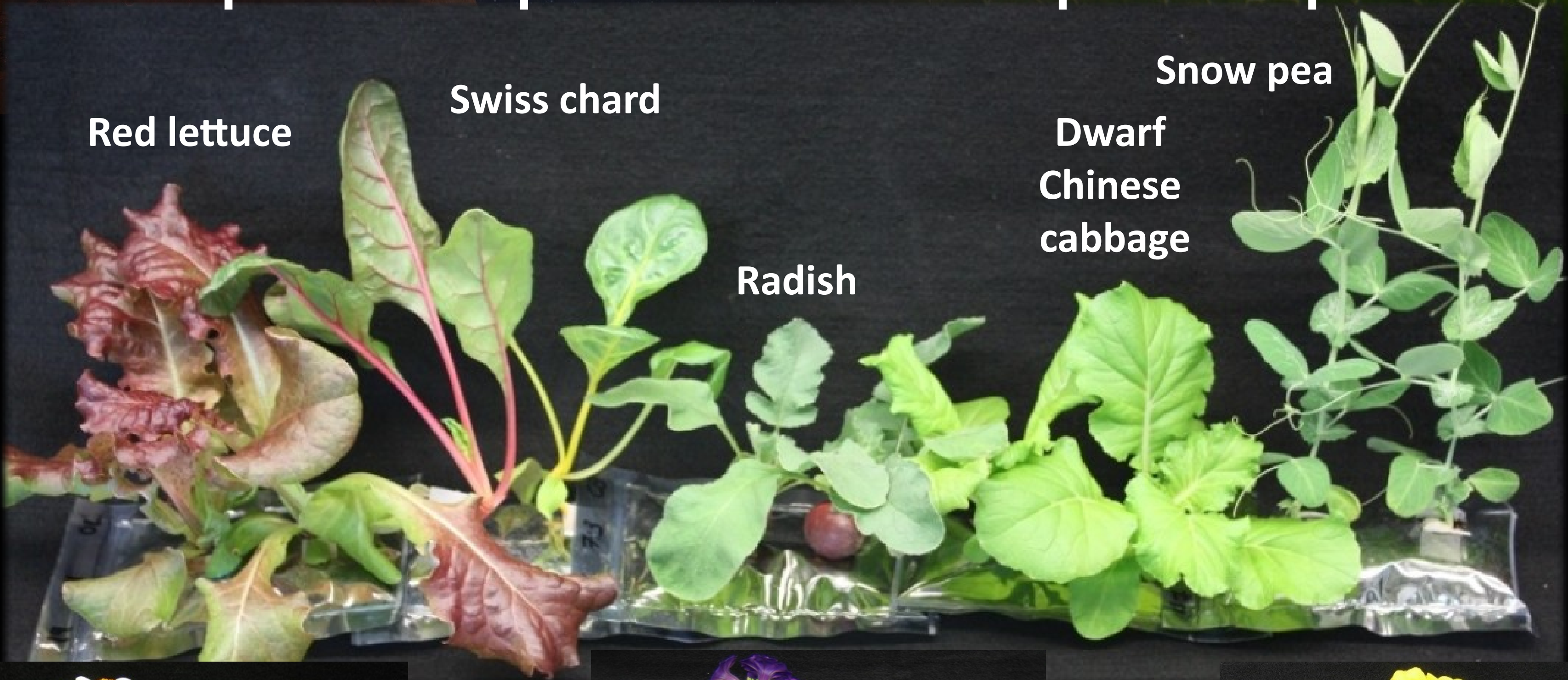
Current and Future Activities

- Conducting ground-based microbial food safety and microbiome testing of candidate crops.
- Developing fresh produce food safety standards for space.
- Use of on orbit resources when applicable.
  - Developing process flow for on-orbit sampling of fresh produce microbiome, nucleic acid isolation, library generation, sequencing, and data analysis

Crop Production Challenge

- Identify potential crops:
  - Yield, nutrition, organoleptic attributes, psychosocial benefits
  - Light recipes, elevated CO_2 impacts, fertilizer requirements

Example crops tested in plant pillows



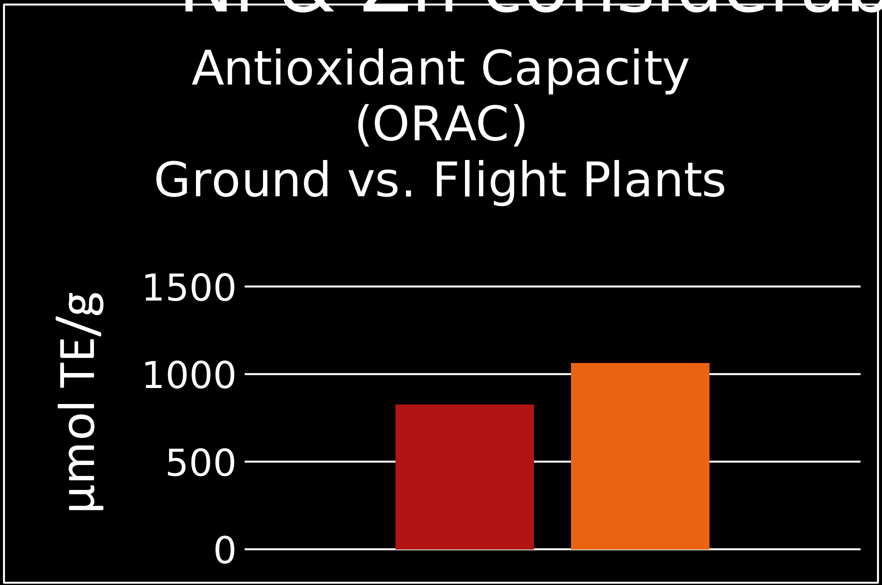
Nutrient Levels – Veg-01 lettuce

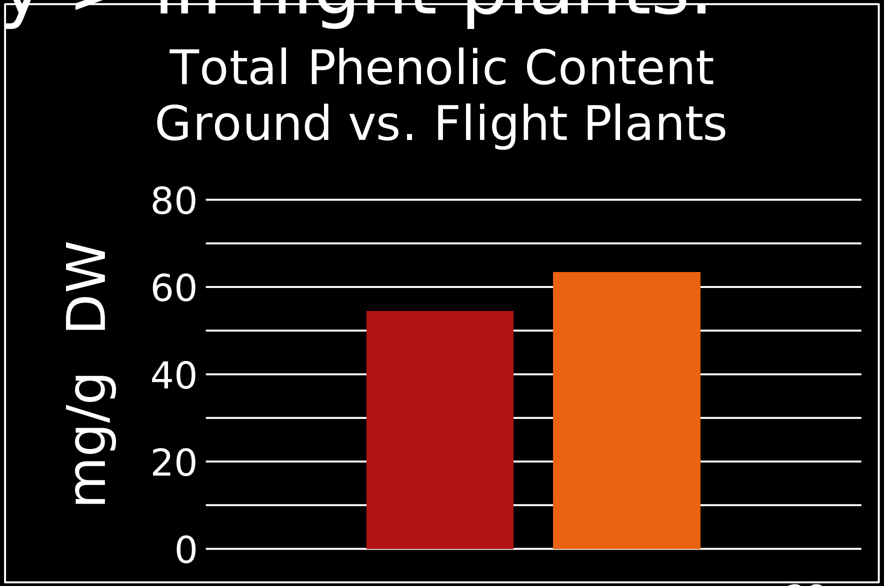
– Fe, Ca, Mo & P and Anthocynains = between flight and ground.

– B, Cu, Mg, Mn, Na & S were slightly > in flight plants.

– K slightly > in ground plants.

– Ni & Zn considerably > in flight plants.





Happy Crew


Thomas Pesquet
@Thom_astro
#TGIF! On Fri
best food item
lettuce with lol
-chef @AstroF
RETWEETS
199
LIKES
725
11:18 AM - 16 Dec 2016


Thomas Pesquet
#TGIF! Comme tou
vendredi soirs on s
retrouve tous pour
nos meilleurs plats.
menu ici: salade sp
par @AstroPeggy


ISS Research
@ISS_Research
"Better than any
on the ground."
space farming is
0:00


Peggy Whitson
@AstroPeggy
I am growing cabbage on station. I love gardening on Earth, and it is just as fun in space... I just need more room to plant more!

LED and Elevated CO_2 Impacts on Chinese Cabbage

Current and Future Activities

- Assessing new crop candidates:
  - Preliminary screening at >230 middle and high schools in Fairchild Garden's Growing Beyond Earth Challenge.
  - Down-selected varieties will be tested in high-fidelity environments at KSC.
  - Two student-selected varieties have flown in Veggie
- Recent and upcoming experiments (VEG-04, VEG-05) include psychosocial and organoleptic evaluations to measure produce impacts on

Crop Production Challenge

- Automation and human factors:
  - Understand which crew activities are desirable and at what scale

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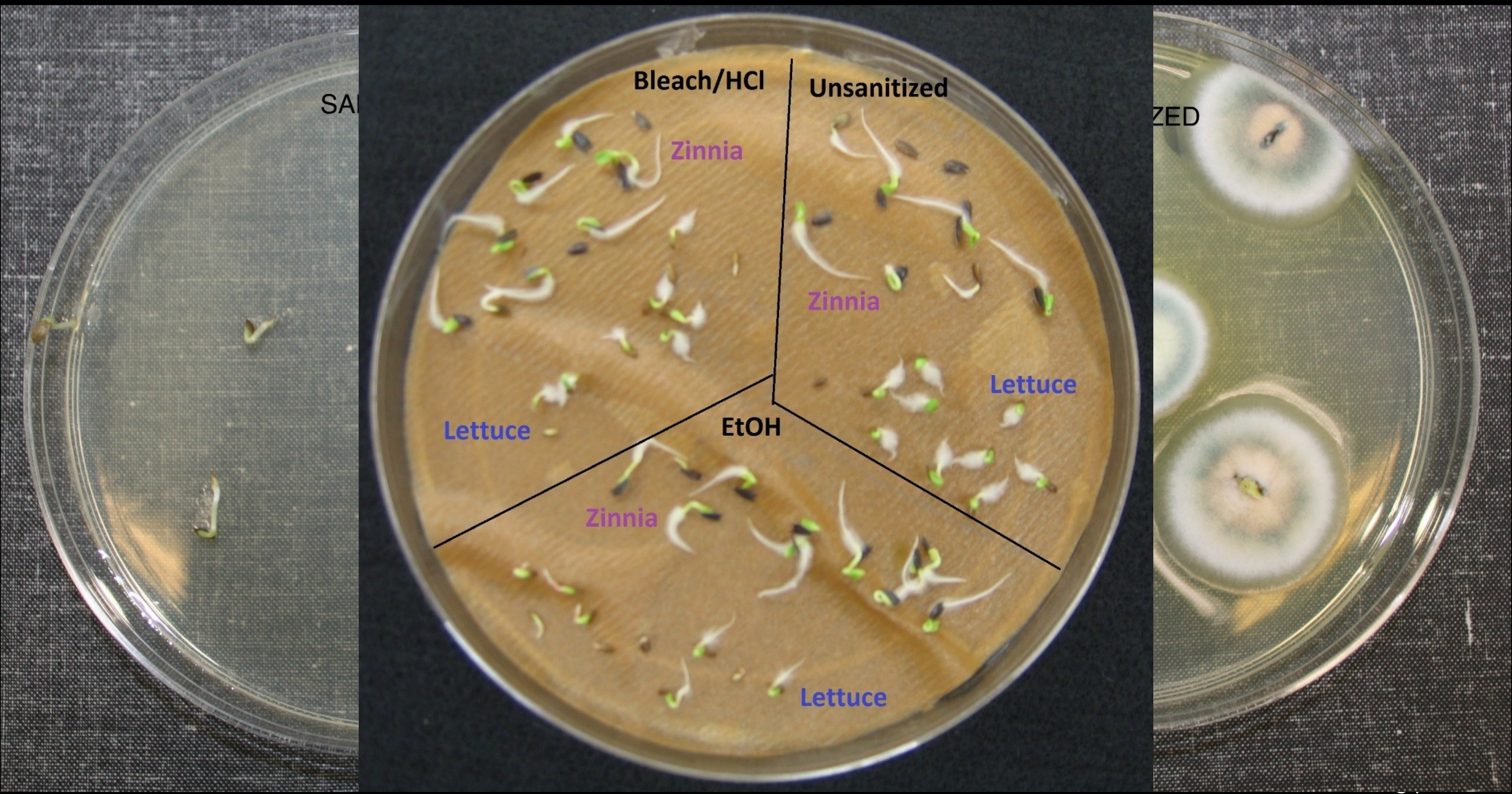
- ➢ Estimate crew time and compare activities with estimates
- ➢ Gather data in crew debriefs

What's Next: Create capability for

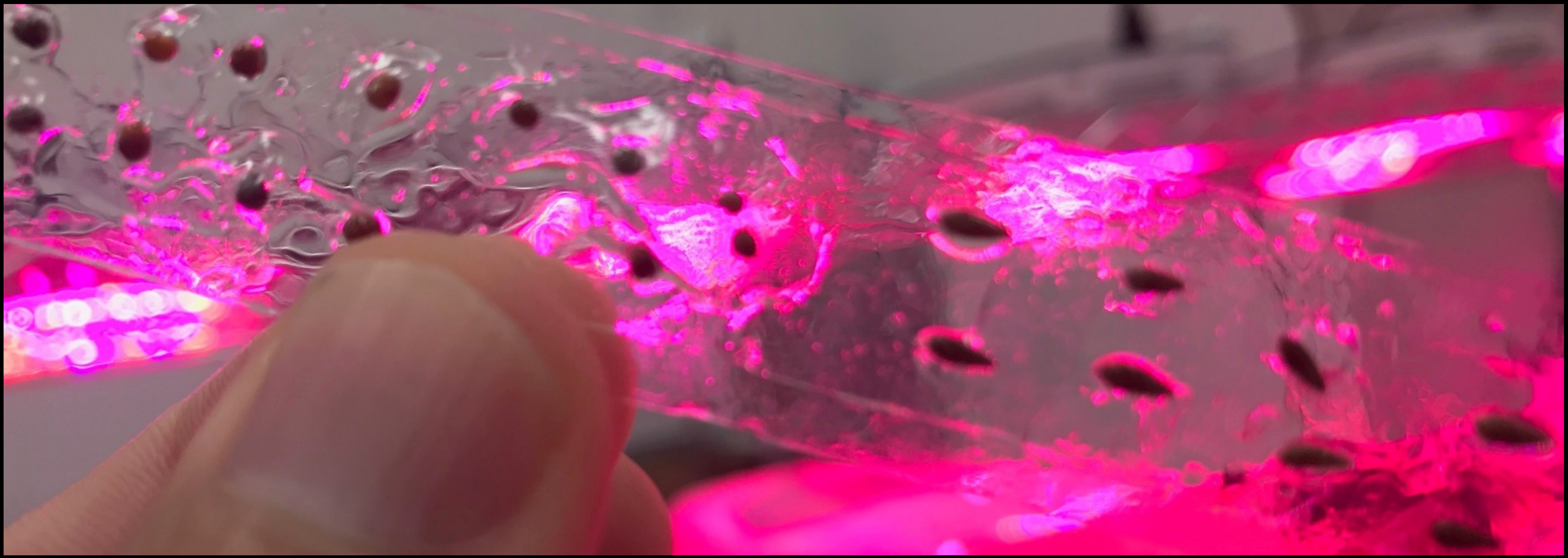
Crop Production Challenge

- Storage and handling of seeds to ensure they are viable, free of contaminants and long-lived.

Veggie Microbiology
Seed Sanitizing



Current and Future Activities

- Testing each new seed type with different sanitation approaches (chlorine gas, ethanol, plasma)
- Learning from commercial growers and seed producers
- 

Crop Production Challenge
Operations Beyond Low Earth Orbit (LEO)

LEO Operations Overview

- Hardware is designed around ORU's and spares sent from the ground
- Operations are controlled and monitored from the ground with crew Acting in the role of technicians
- Continuous presence of crew is assumed

As Distances Increase Access Decreases

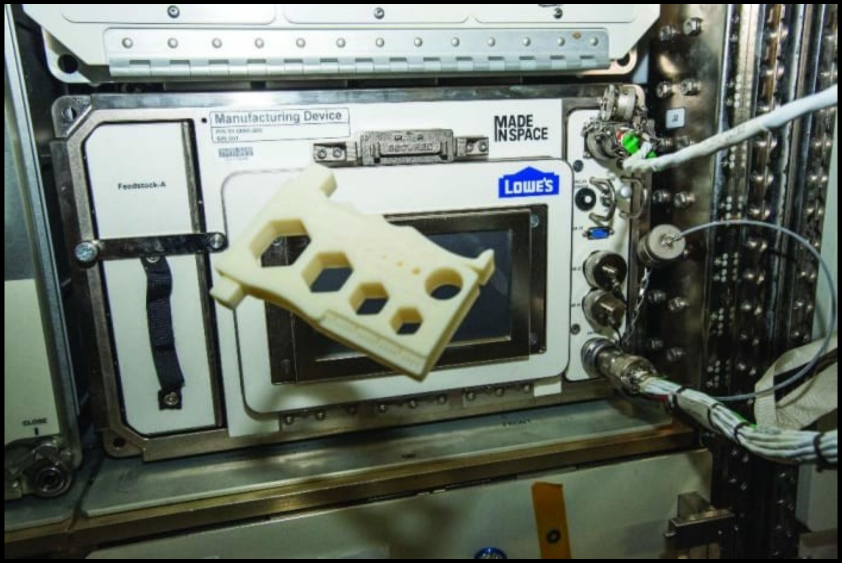
- The return journey from ISS (LEO) takes **Hours**
- From the moon **Days**
- From Mars **Years**

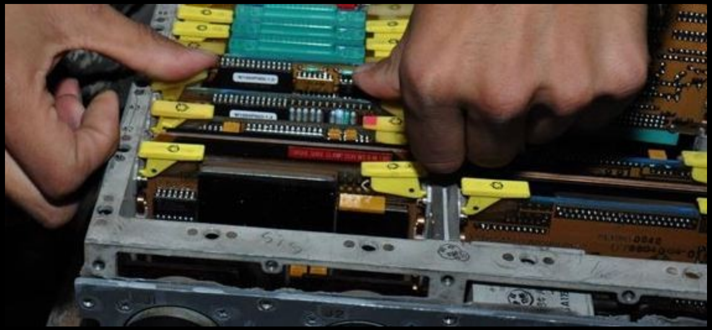
As Distances Increase Communications are Delayed

- LEO virtually instantaneous
- Moon **2.5 seconds** round trip
- Mars between **6 – 44 *minutes*** round trip depending on distance
- Reduce reliance on permanently staffed ground control centers

As Distances Increase the Focus Must Change from Replacement to Repair

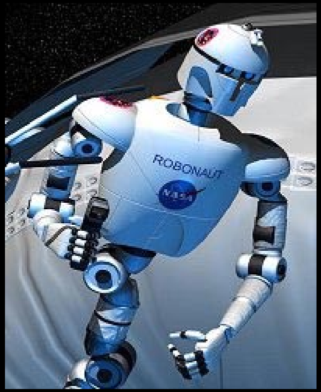
- Systems designed with repair in mind
- Leverage in space manufacturing for repair
- Minimize non-reusable components
- Reduce reliance on non renewable consumable commodities





As Distances Increase Systems and Software Controls will need to Detect, Decide and Do

- Autonomy and robotics will be widely incorporated into all facets of crop production operations
- Smart sensors will collect and provide real time information on plant health



As Distances Increase Systems must be Evolvable

- Initial systems capabilities must ensure core functions are provided
- Enhancements should be iterative and not require system replacement

As Distances Increase System Dormancy will be a Design Driver

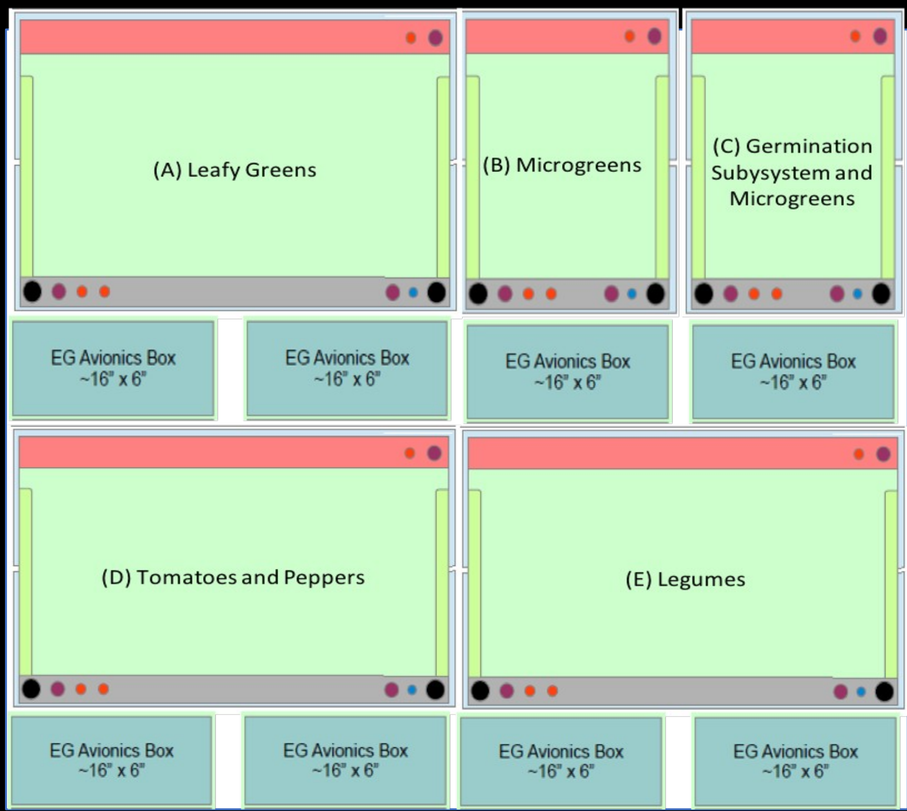
- For early exploration missions there will be long durations of time when crews will not be present nor systems powered

Lunar Surface: The Moon as an Analog for Mars

- **Early opportunities to perform research in the radiation and partial gravity environment are a priority**
- **Initial crop production capability will likely be an adaptation of the microgravity hydroponic systems developed on the ISS**
- **A lunar outpost three days from Earth will provide needed practice for "living off the land" before making the long trek to Mars**
- **A lunar habitat will serve to demonstrate technologies for a future Mars habitat**
- **Start with pick-and-eat crops and eventually include staple crops**

Deep Space Transit Crop Production System

- Based on hardware concepts currently under development for the ISS
- Chambers designed to accommodate a variety of Pick-and-Eat Crops
- Hydroponic growth systems
- Reliable for 2.5 to 3 year mission duration



Mars Surface: Crop Production as a Component of a Bioregenerative Life Support System

- **Will use systems demonstrated and proven on the lunar surface and the trip to Mars**

- **Long term presence on Mars will result in a permanent bioregenerative capability as a part of a life support system**

- **Benefits of a bioregenerative system:**
  - Lower food stowage mass
  - Water and waste treatment
  - Air revitalization
  - Improved nutrition and acceptability
  - Personalized preparation
  - Psychosocial benefit

Crop Production and Bioregenerative Life Support

- Challenges of a bio-regenerative system:
  - Hydroponic verses regolith based systems
  - Envision dedicated module(s) to produce both Pick-and-Eat and Staple Crops
  - Long term radiation effect on nutrition and acceptability
  - Safe handling and advanced micro testing
  - Additional hardware required for food preparation and storage
  - Crew time

<u>Staple Crop Candidates</u>

Rice	Soybeans
Beans	Peanuts
Wheat Berries	Wheat

How Space Crop Research Benefits Earth

History

- LED lighting for plants was patented through NASA funding

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

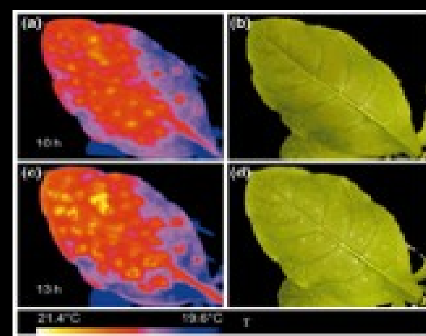
- NASA use of Nutrient Film Technique (NFT) for Potato production led to the development of production techniques for seed potatoes

Similar Challenges

- Limited Resources
- Need for Reliable, Efficient Production
- Time as a Resource (Humans Vs. Automation)
- Importance of Early Detection of Issues

Hardware and Growth System Technology

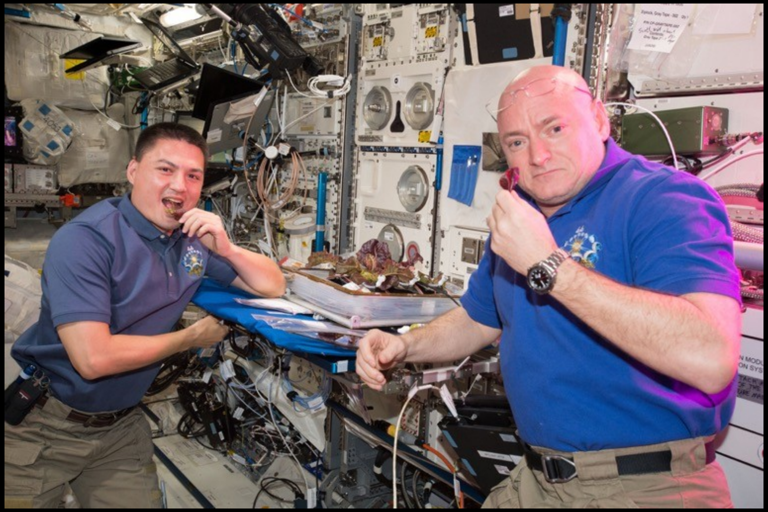
- **Lighting Advancements**
- **Imaging Systems for Plant Health and Food Safety Monitoring (NDVI, Hyperspectral Imagery, Fluorescence)**
- **Component Reliability, Maintenance and Miniaturization**
- **Sensor Development**
- **Autonomy and Robotics**
- **Sensor Fusion**
- **Control Systems Development**



- **NASA Approach to System Selection for Specialized Applications**

Horticulture and Growth System Operations

- Cultivar selection (Edible Biomass, Yield Verses Volume)
- Genetic Engineering (Environmental Stress Tolerance)
- Microbiome (Plant, Growth System, Vehicle and Crew)
- Optimized Growth Recipes
- Food Safety



VEG-03H – (March-April 2019)