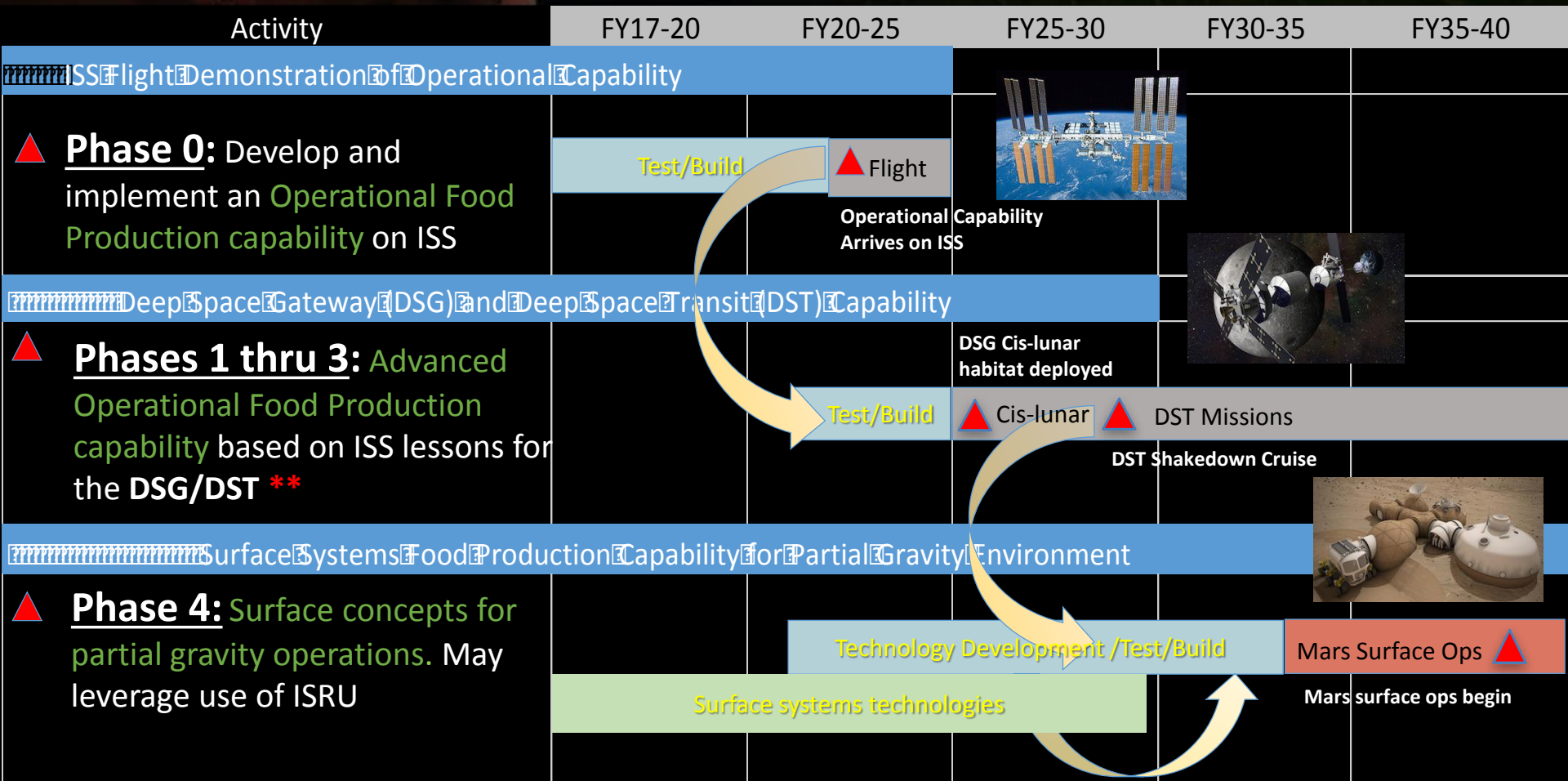




# Future Food Production System Development Pulling From Space Biology Crop Growth Testing in Veggie

Gioia Massa, Matt Romeyn, Ralph Fritsche  
Exploration Research and Technology Programs  
NASA, Kennedy Space Center

# Food Production as an Element of NASA's Deep Space Habitation Strategy



- ▲ Capability online
- Microgravity technology development and implementation
- Partial gravity technology development and implementation

\*\* DSG - Deep Space Gateway  
DST – Deep Space Transport

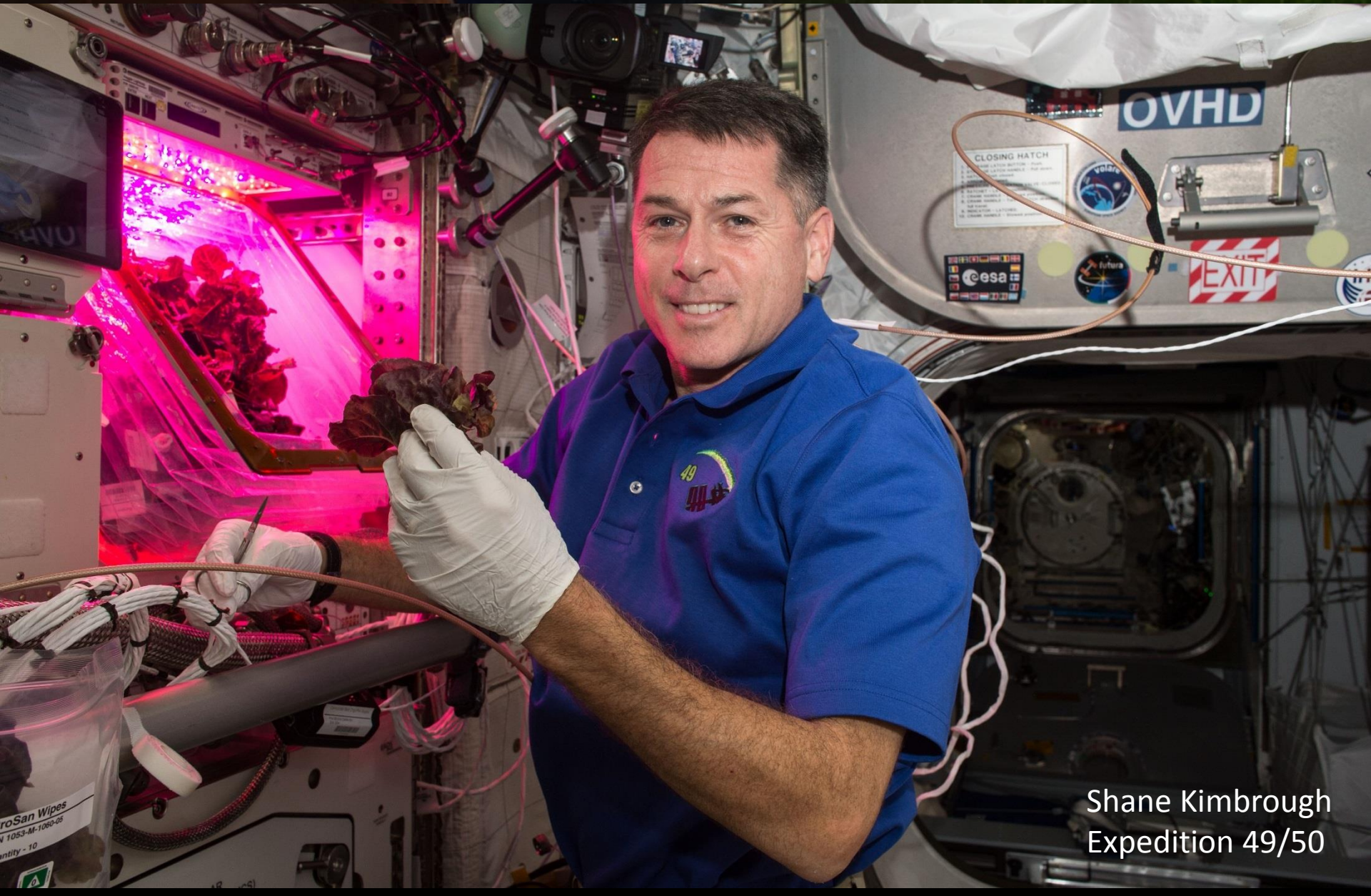
# Technology and Knowledge Gap Focus

- **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<sub>2</sub> 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**

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# Veggie on ISS



Shane Kimbrough  
Expedition 49/50

# Veggie Technology Validation Tests

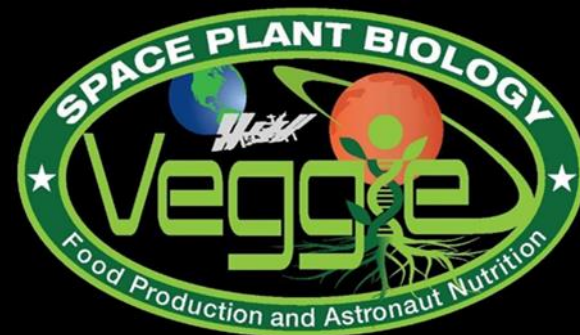
## VEG-01

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



## VEG-03

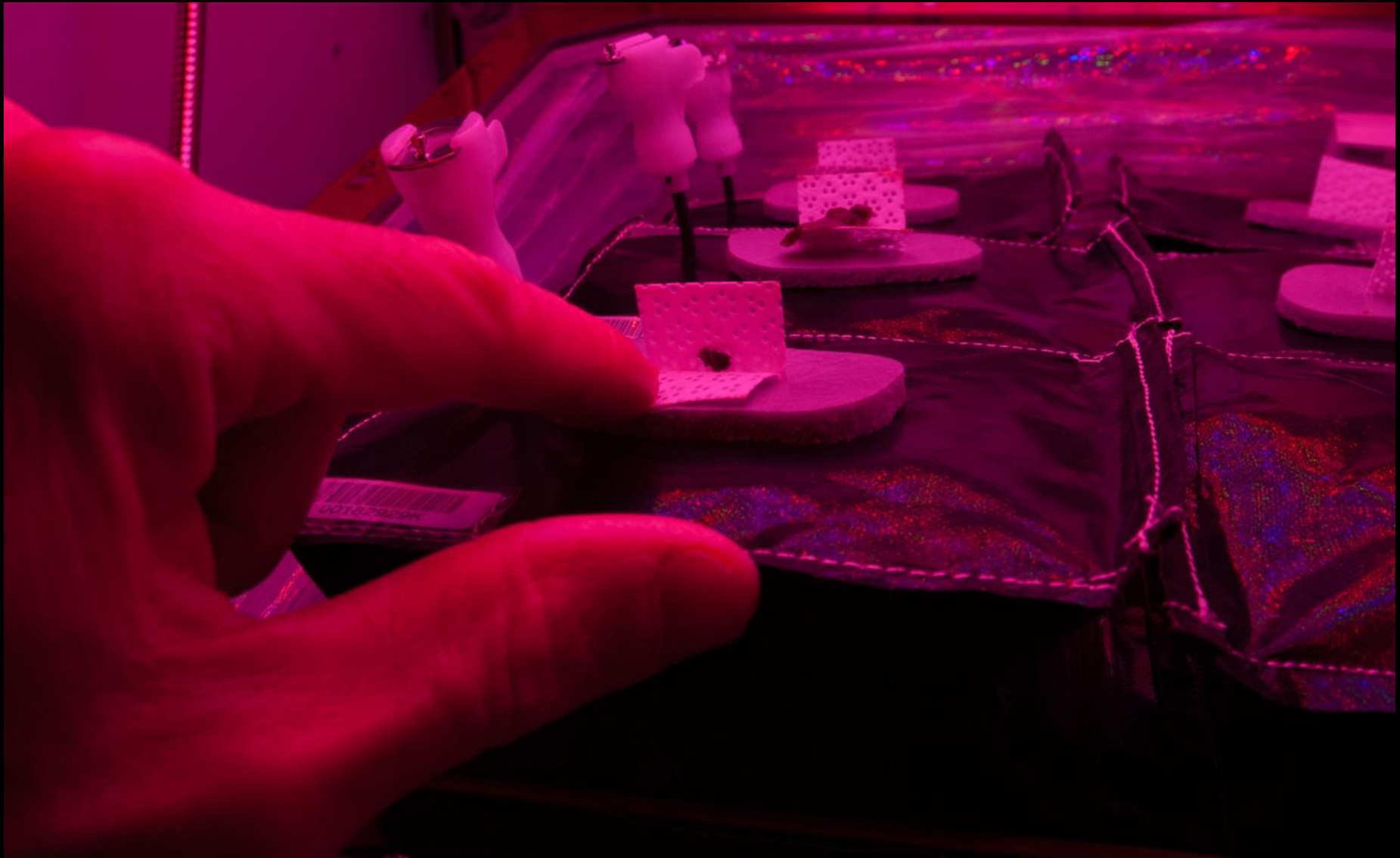
- 2016-Present
- 'Outredgeous' lettuce, 'Tokyo Bekana' Chinese cabbage, Mizuna, 'Waldmann's Green' lettuce
- Cut-and-come-again harvesting
- Mixed cropping



# Food 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

# What's Next

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



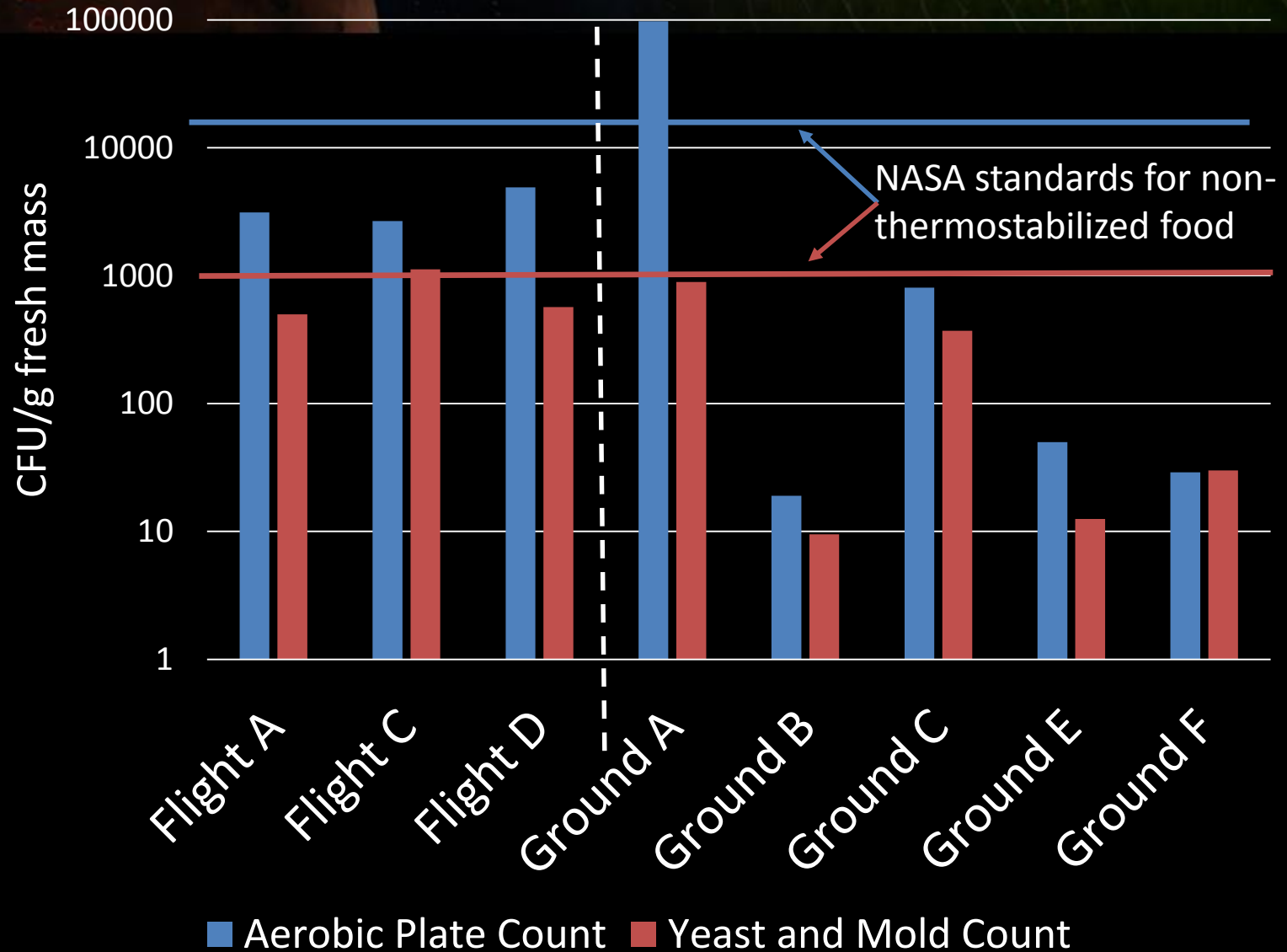
Image courtesy of Techshot and Tupperware Brands

# Food 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

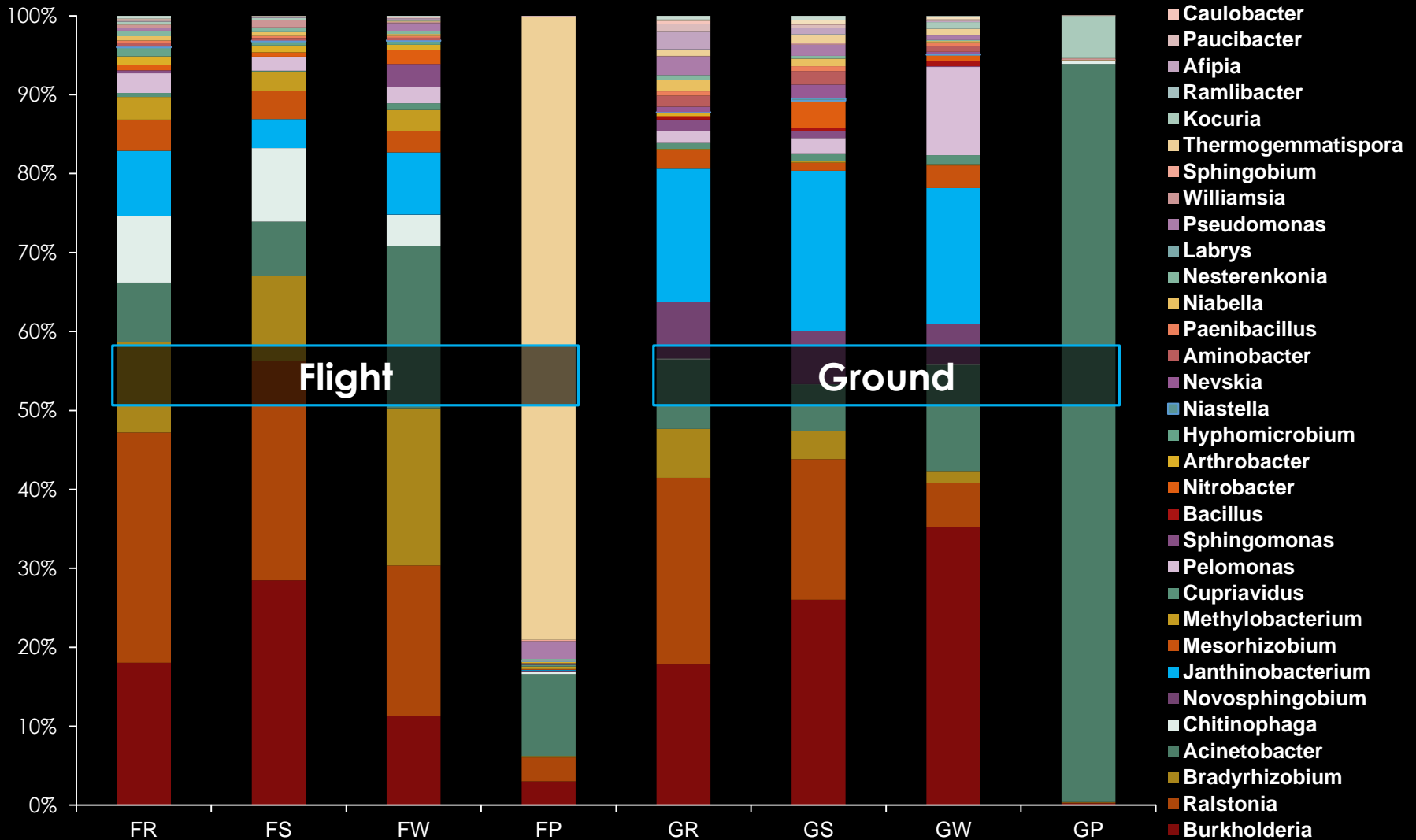
## Plant pathogenesis



# Veggie Microbiology

## Microbiome analysis

### Flight and Ground Community Characterization



# What's Next

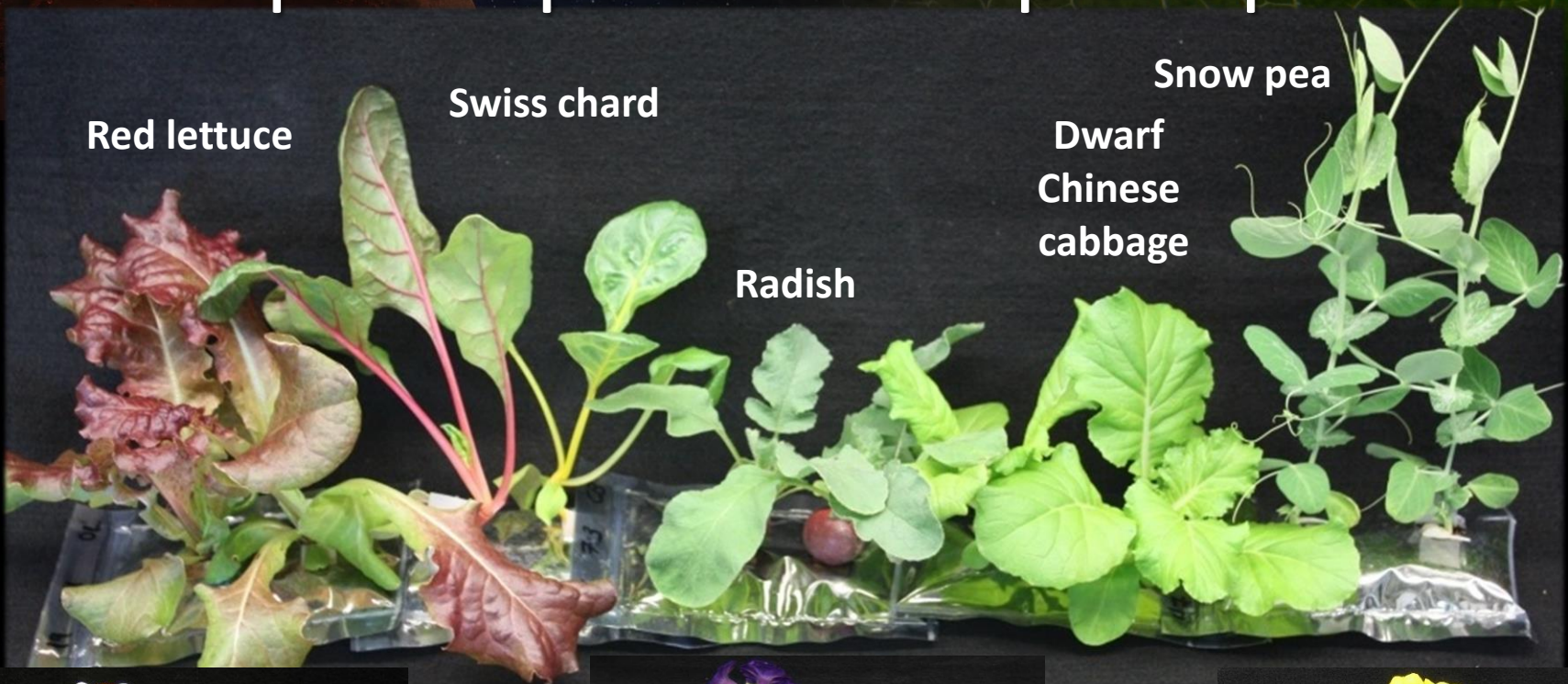
- Conduct ground-based microbial food safety and microbiome testing of candidate crops.
- Develop fresh produce food safety standards for space.
- Use on orbit resources when applicable.
  - Developing process flow for on-orbit sampling of fresh produce microbiome, nucleic acid isolation, library generation,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



# Food Production Challenge

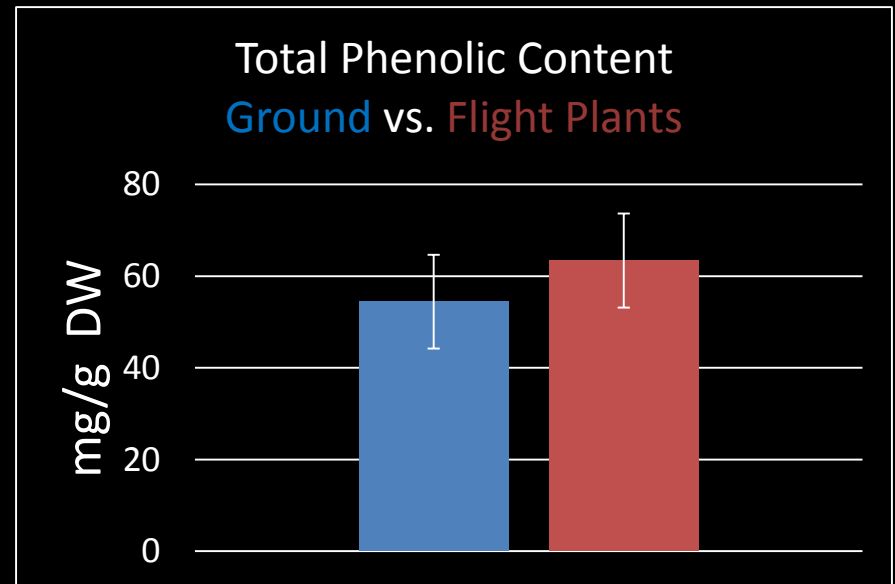
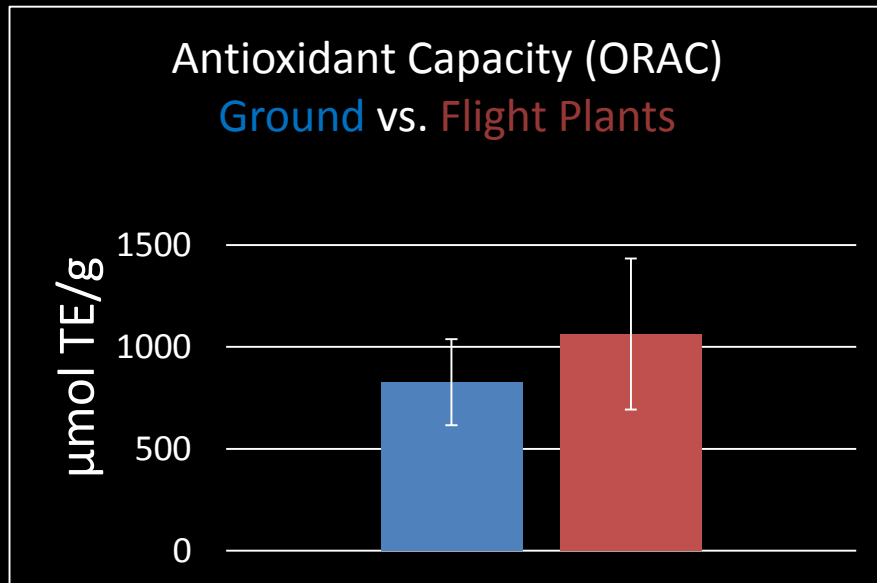
- Identify potential crops:
  - Yield, nutrition, organoleptic attributes, psychosocial benefits
  - Light recipes, elevated CO<sub>2</sub> impacts, fertilizer requirements

# 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 tous les vendredi soirs on se 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



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<sub>2</sub> Impacts on Chinese Cabbage





# What's Next

- Assessing new crop candidates:
  - Preliminary screening at >130 middle and high schools in Fairchild Garden's Growing Beyond Earth Challenge.
  - Down-selected varieties will be tested in high-fidelity environments at KSC.
- Upcoming experiments (VEG-04, VEG-05) include psychosocial and organoleptic evaluations to measure produce impacts on microgravity life.

# Food Production Challenge

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

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

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What's Next: Create capability for 100% automation and crew independence.

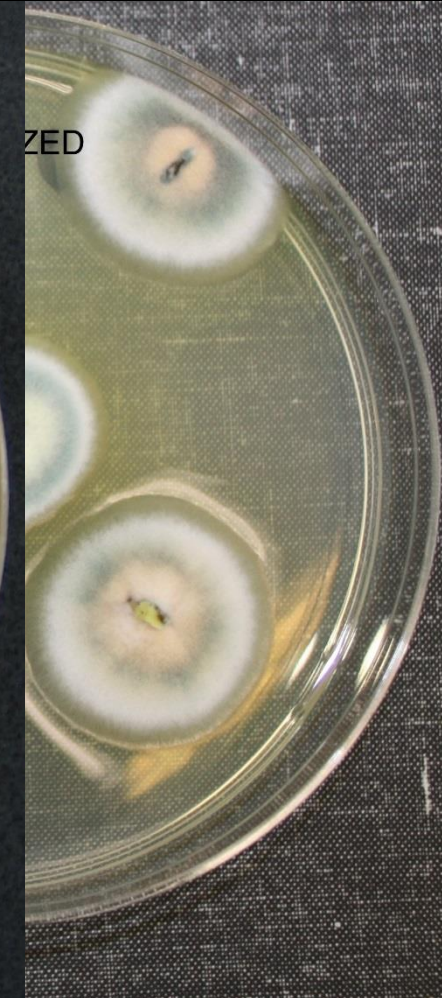
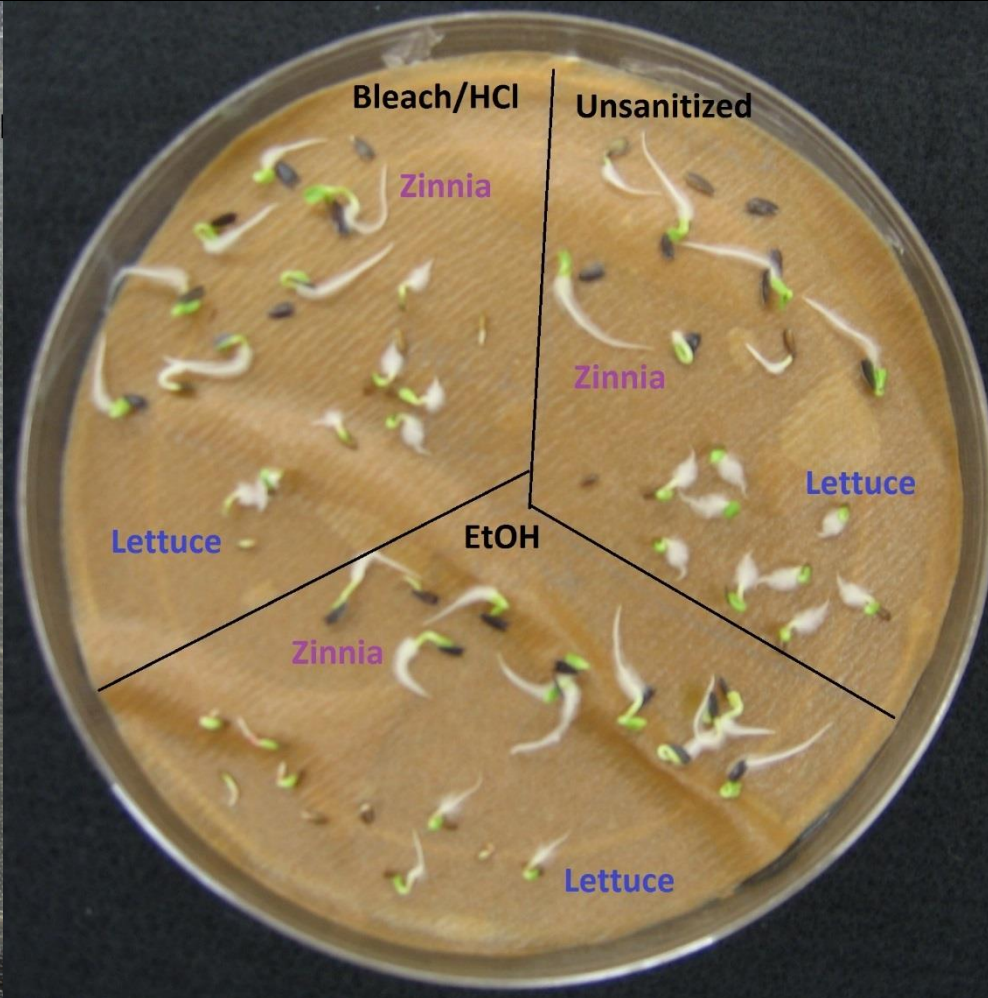
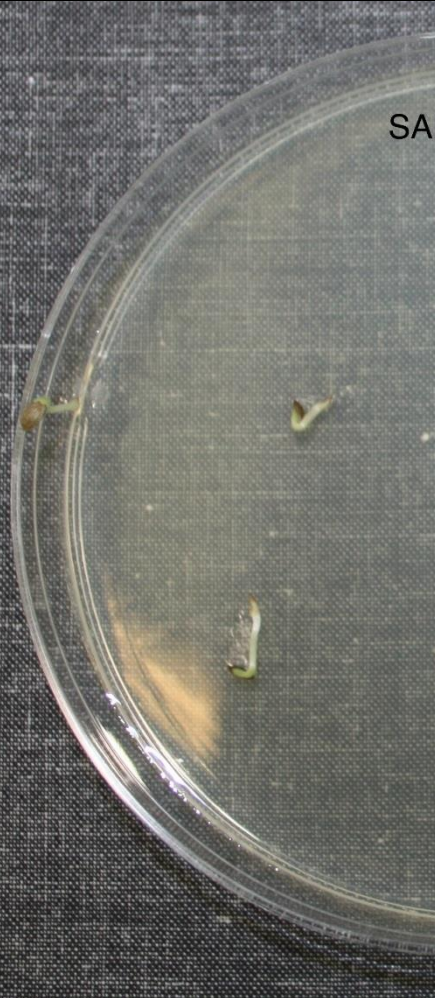
# Food Production Challenge

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



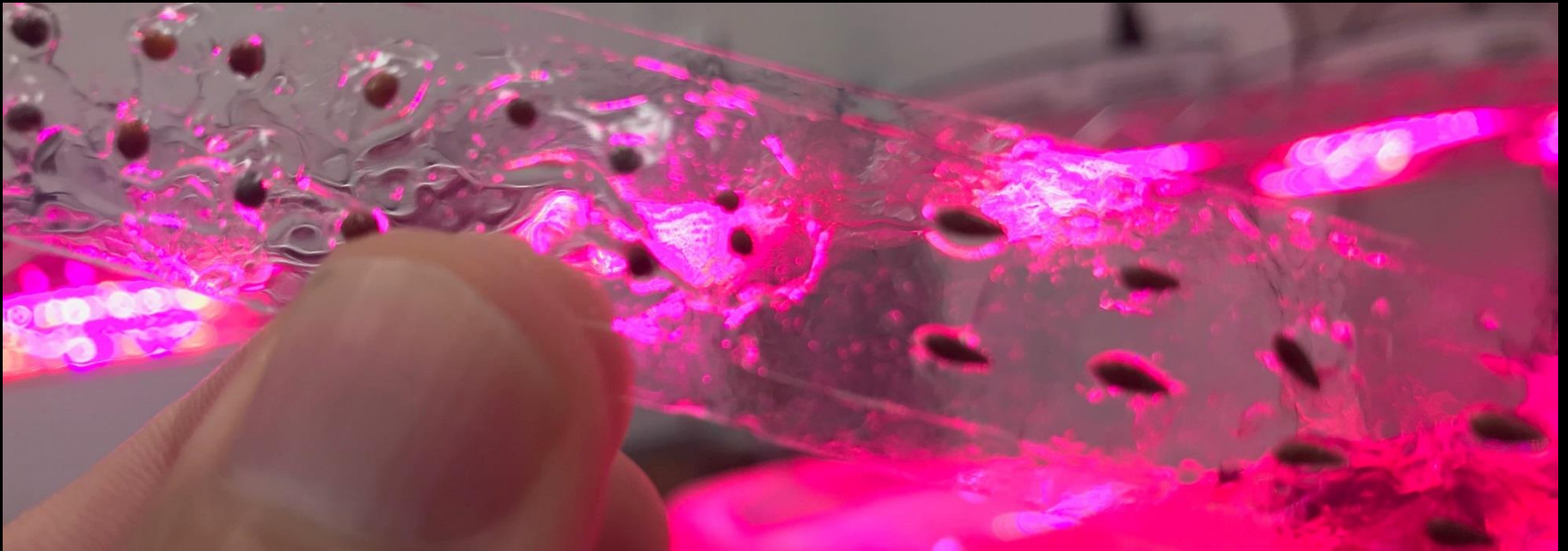
# Veggie Microbiology

## Seed Sanitizing



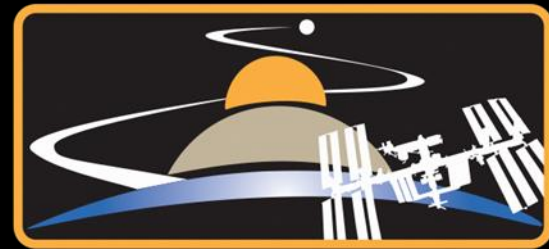
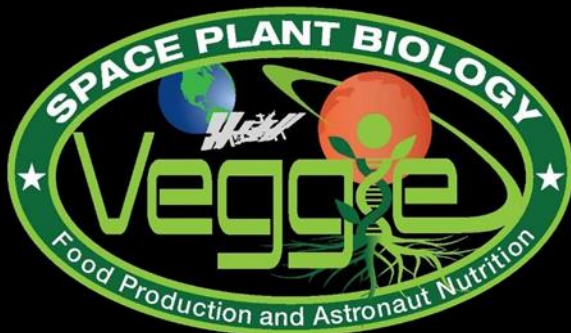
# What's Next

- Testing each new seed type
- Learning from commercial growers and seed producers
- Testing methods to handle and store seeds



# Thank you!

- The Veg-01 and Veggie teams
  - Data from Mary Hummerick, Christina Khodadad, LaShelle Spencer, Trent Smith
- The astronauts!
- KSC's Food Production Team
- Funding from NASA Space Life and Physical Sciences Space Biology Program



**Exploration Research and  
Technology Programs**