Plants in Space and Space Crop Production

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Exploration Research & Technology Programs

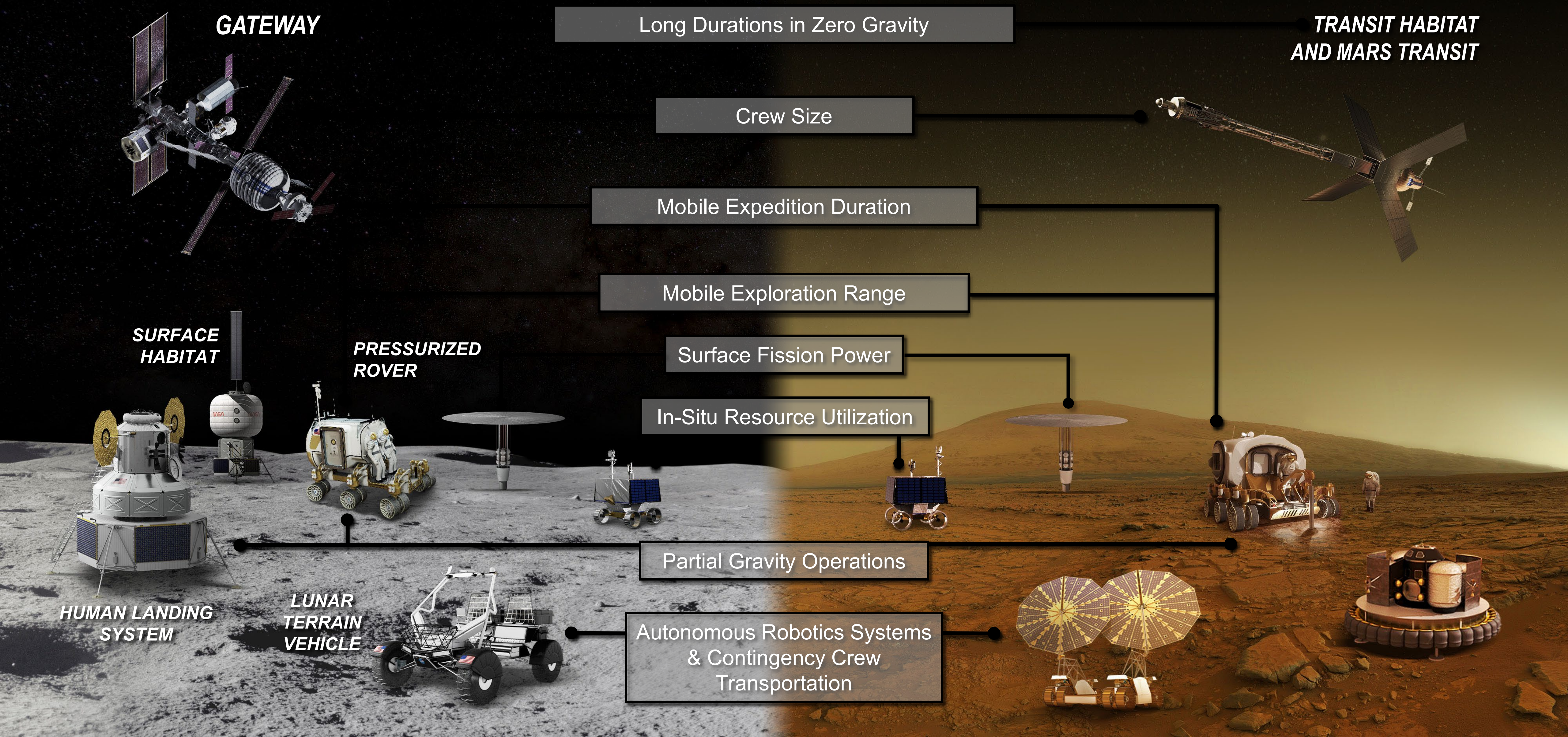
NASA, Kennedy Space Center

Earth and beyond: Plants in extreme environments

Australian Society of Plant Scientists Conference 2023

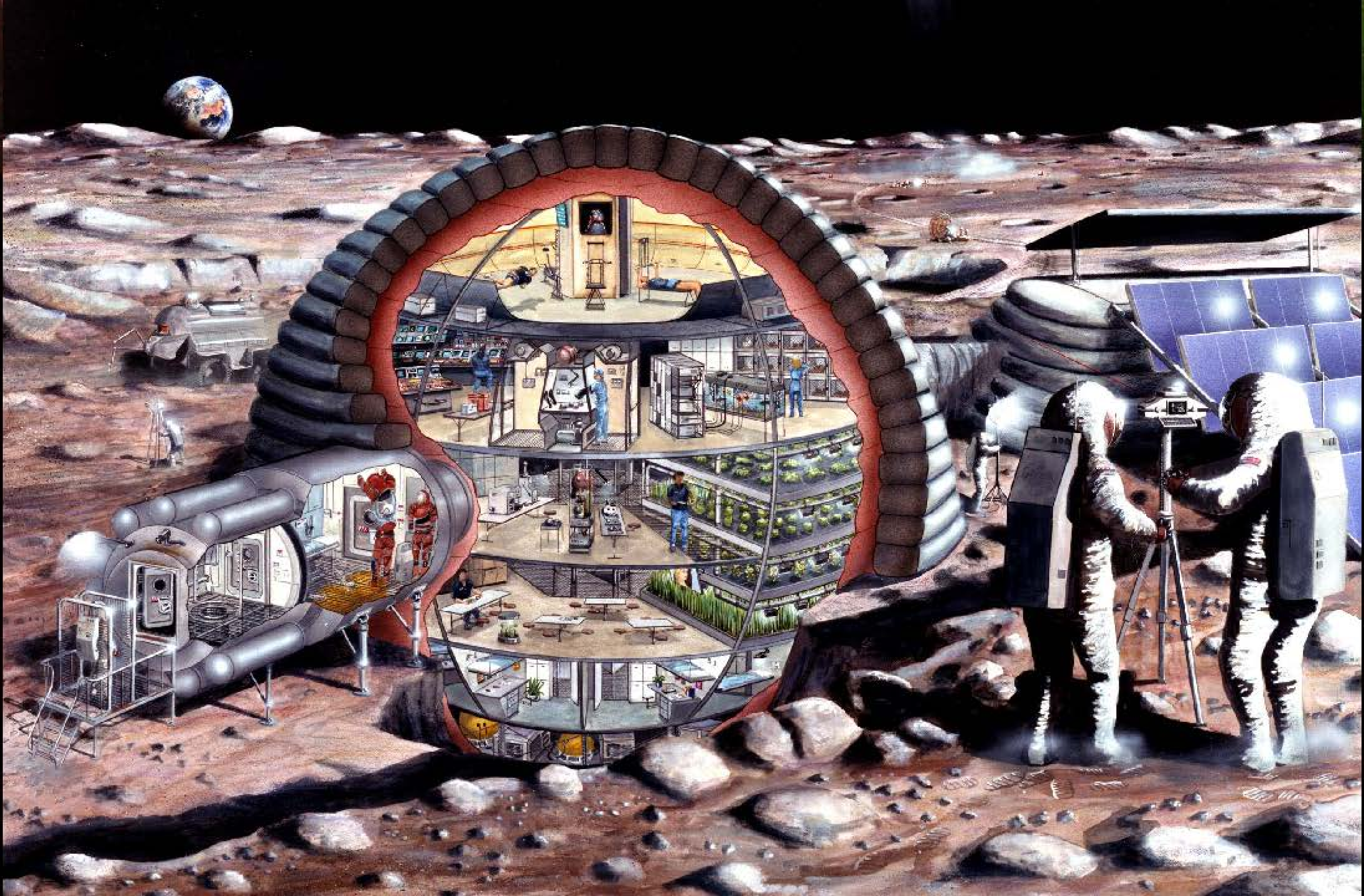
MOON AND MARS EXPLORATION

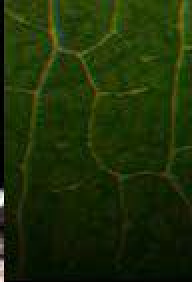
Operations on and around the Moon will help prepare for the first human mission to Mars



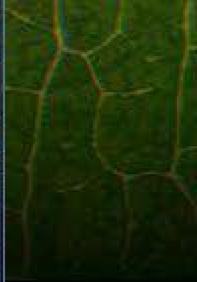
Why grow plants in space?

- Food
- Psychological well being
- Atmosphere
- Water









EDEN ISS Antarctic Greenhouse

The EDEN ISS greenhouse, developed by the German Aerospace Center; DLR, in Antarctica since 2018.
Credit: Hanno Müller, AWI

Jess Buncheck – KSC scientist
Tending plants in EDEN ISS, 2021

NASA's Space Crop Production Vision

Ensure Food System Security on Long Duration Missions Beyond LEO

Near-Term Goal
Nutrient Supplementation of Prepackaged Food

Long-Term Goal
Caloric Replacement to Facilitate Earth Independence

Space Crop Production Candidates

Salad

Leafy Greens
Tomato
Pepper
Radish
Strawberry
Green Onion
Pea
Carrot

Lettuce, Chinese cabbage, Swiss chard, Mizuna, Spinach

Microgreens

CONSUMED FRESH WITHOUT PROCESSING

Herbs

Basil
Mint
Chives
Dill

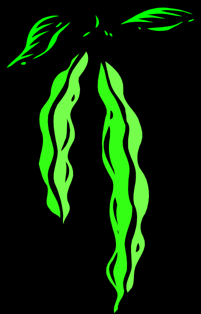
Staple Crops

White Potato
Sweet Potato

MINIMAL PREPARATION / COOKING

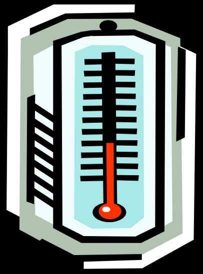
Rice
Wheat
Dried Bean
Soybean
Peanut

SIGNIFICANT PREPARATION / COOKING

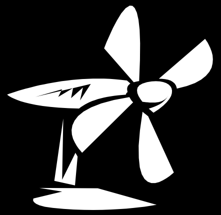


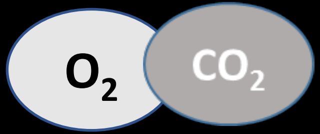
The Space Environment

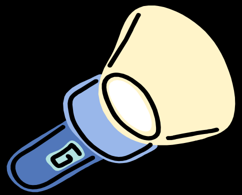
….and how these work with and without <u>Gravity!</u>



No natural convection without gravity so need to mix the air







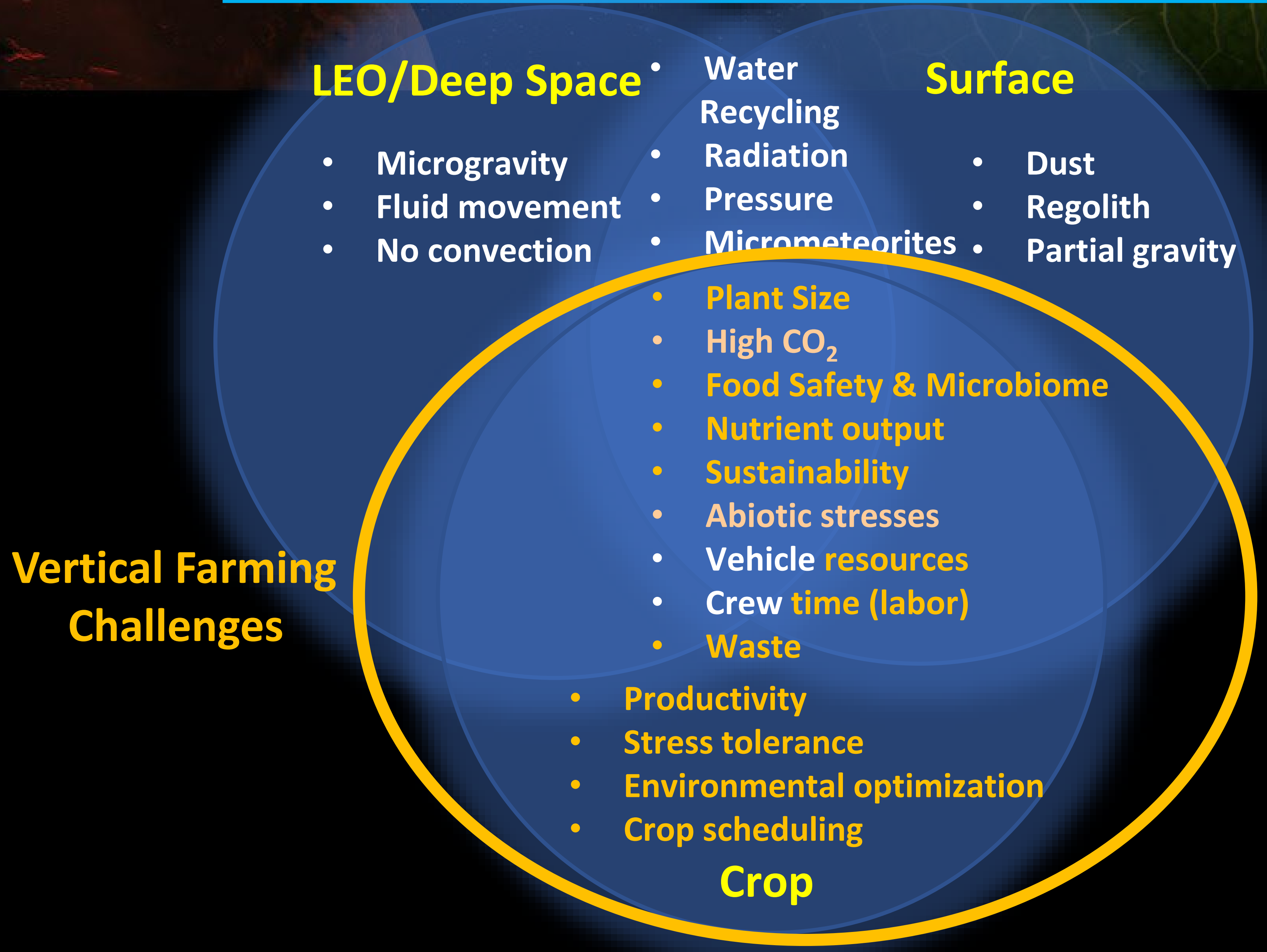
Key plant characteristics may be modified with novel light recipes

Water forms a ball, and water and air don't mix well, and roots need both!

Fertilizer is heavy to launch so we need to learn how to recycle plant (and other) wastes!

Space Crop Production Challenges

Space Crop Production Challenges



Space Crop Production Roadmap For Exploration

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

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

GATEWAY *(Plant Research)*

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

MARS TRANSIT *(Crop Production)*

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

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

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

LUNAR SURFACE *(Research/Production)*

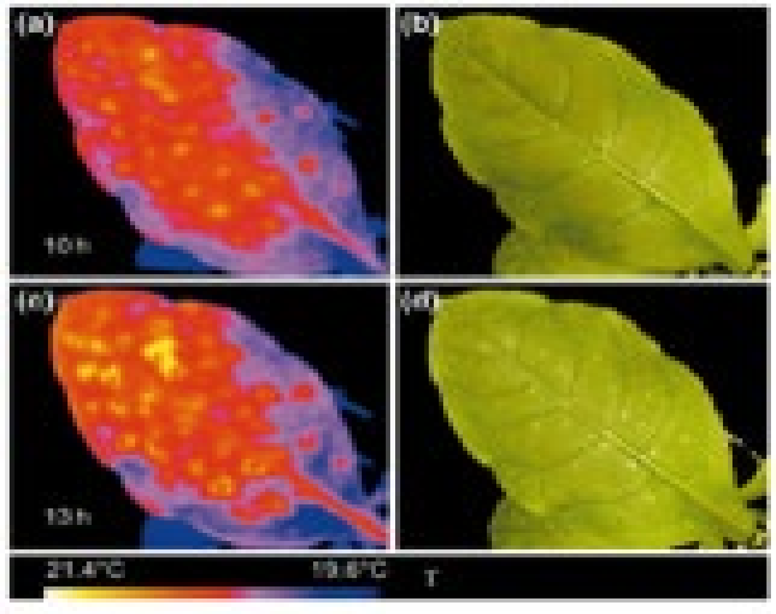
Develop and deploy operational partial gravity systems for both nutritional support and caloric replacement as both a source of food for long duration lunar missions and as a demonstration for Mars

MARTIAN SURFACE *(Production)*

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

Hardware and Technology Needs

- Sensor Selection and Development
  - Need a suite of non-destructive sensors
- Imaging Systems for Plant Health and Microbial Monitoring (Hyperspectral, Multispectral, Fluorescence, Thermal)
- Integrated Sensor Control Systems

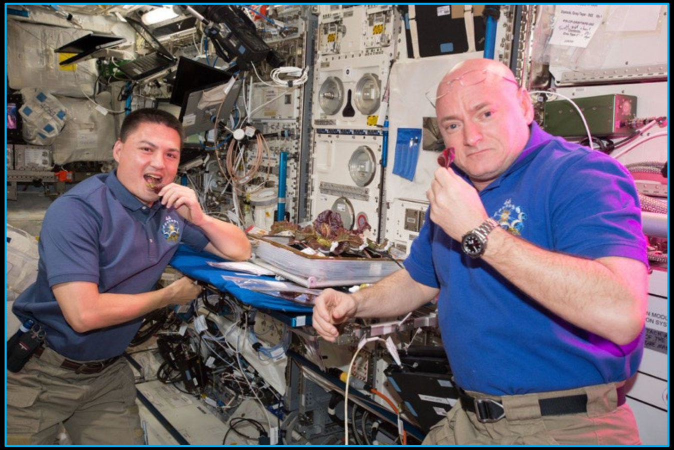


Hardware and Technology Needs

- Autonomy and Robotics
- "Smart" Farmer: AI Control Systems and Predictive Algorithms
- Advanced Lighting
- Component Reliability, Maintenance, and Miniaturization
- Sustainable Operations
  - e.g. Inedible biomass recycling approaches

Horticulture Needs

- Crop selection (Edible Biomass, Yield verses Volume, Nutrients, Acceptability, Crop Readiness Levels)
- Optimized growth recipes
- Microbiome (Plants, Growth System, Vehicle, Crew)
  - Food Safety (HACCP)
  - Space IPM
- Crop Breeding and Engineering



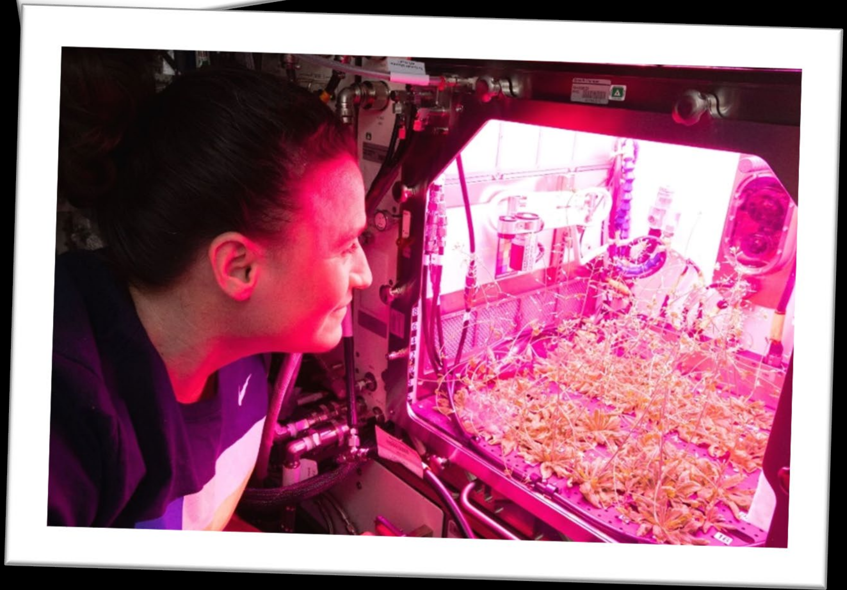
Crop Readiness Levels

CRL	Title	Description
1	Crop Identification	Identification of candidate crop at cultivar level. Preliminary assessment of morphology, consumable yield, germination, and mission application.
2	Cultivar Screening	Detailed assessment of plant dimensions at maximal growth, pollination and germination requirements identified, harvest index quantified.
3	Relevant Environmental Testing	Testing at spaceflight simulated environmental conditions. Currently this is ISS-relevant: ~3000 ppm CO_2, 21-24^{o} C, 38-44% RH, and LED lighting with no UV. Candidates are screened for robust performance or adverse physiological responses.
4	Chemistry & Organoleptic	Elemental and mission-specific nutritional testing conducted at flight-like conditions Organoleptic and sensory analysis
5	Baseline Microbiology	Baseline microbiological and food safety characterization conducted under flight-like conditions
6	Seed / Propagule Sanitization	Identification of acceptable seed surface sterilization or plant propagule sanitization protocols
7	Flight-like Testing	Testing in flight or flight-analog hardware at flight environmental setpoints
8	Grown in Space	Crop successfully grown to maturity in space
9	Consumed in Space	Good growth in space and consumption by crew with acceptability

Modified from Romeyn et al., 2019, Crop Readiness Level (CRL): A Scale to Track Progression of Crop Testing for Space

Current NASA Large Plant Research Capabilities On ISS

SPACE PLANT BIOLOGY
Veggie
Food Production and Astronaut Nutrition



SPACE PLANT BIOLOGY
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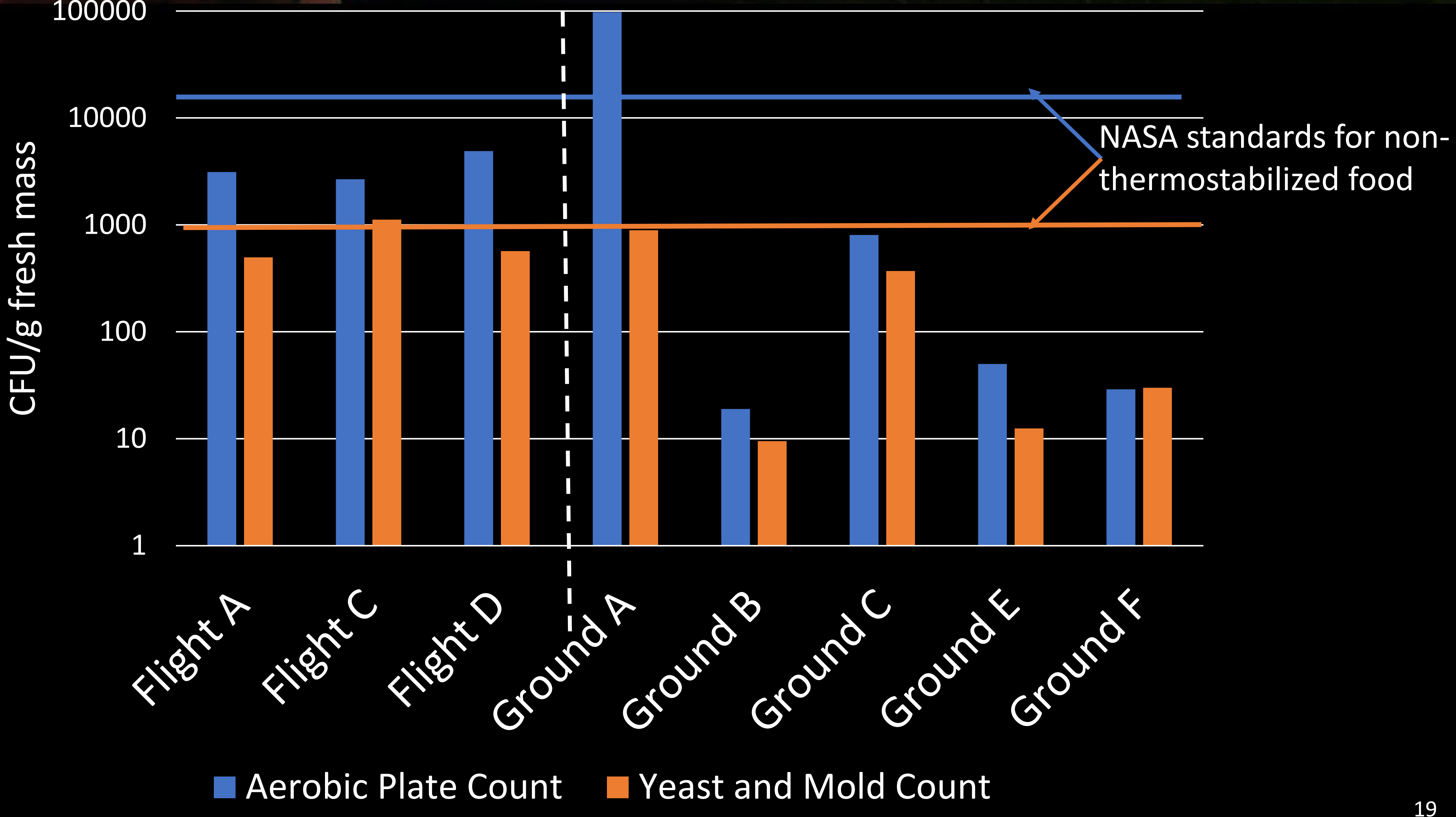
ADVANCED PLANT HABITAT
Large Plant Research Facility

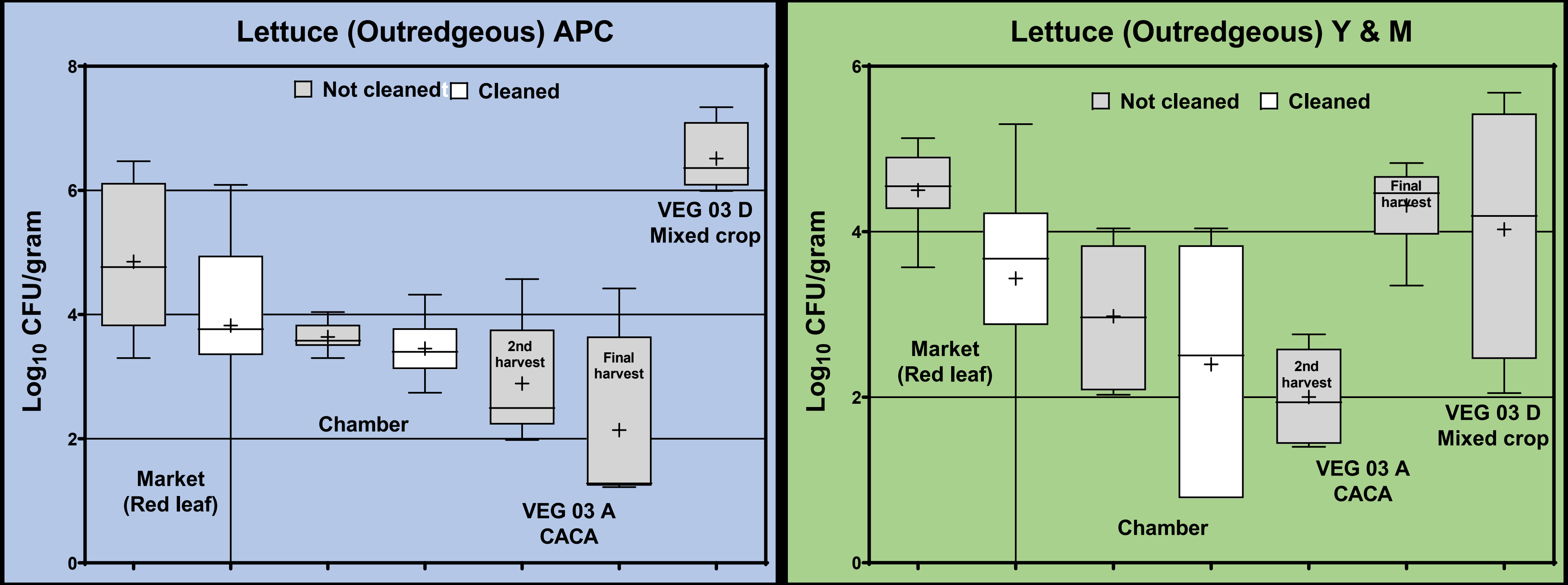
VEG-01B Harvest (August 2015)

Veggie Microbiology

Food Safety

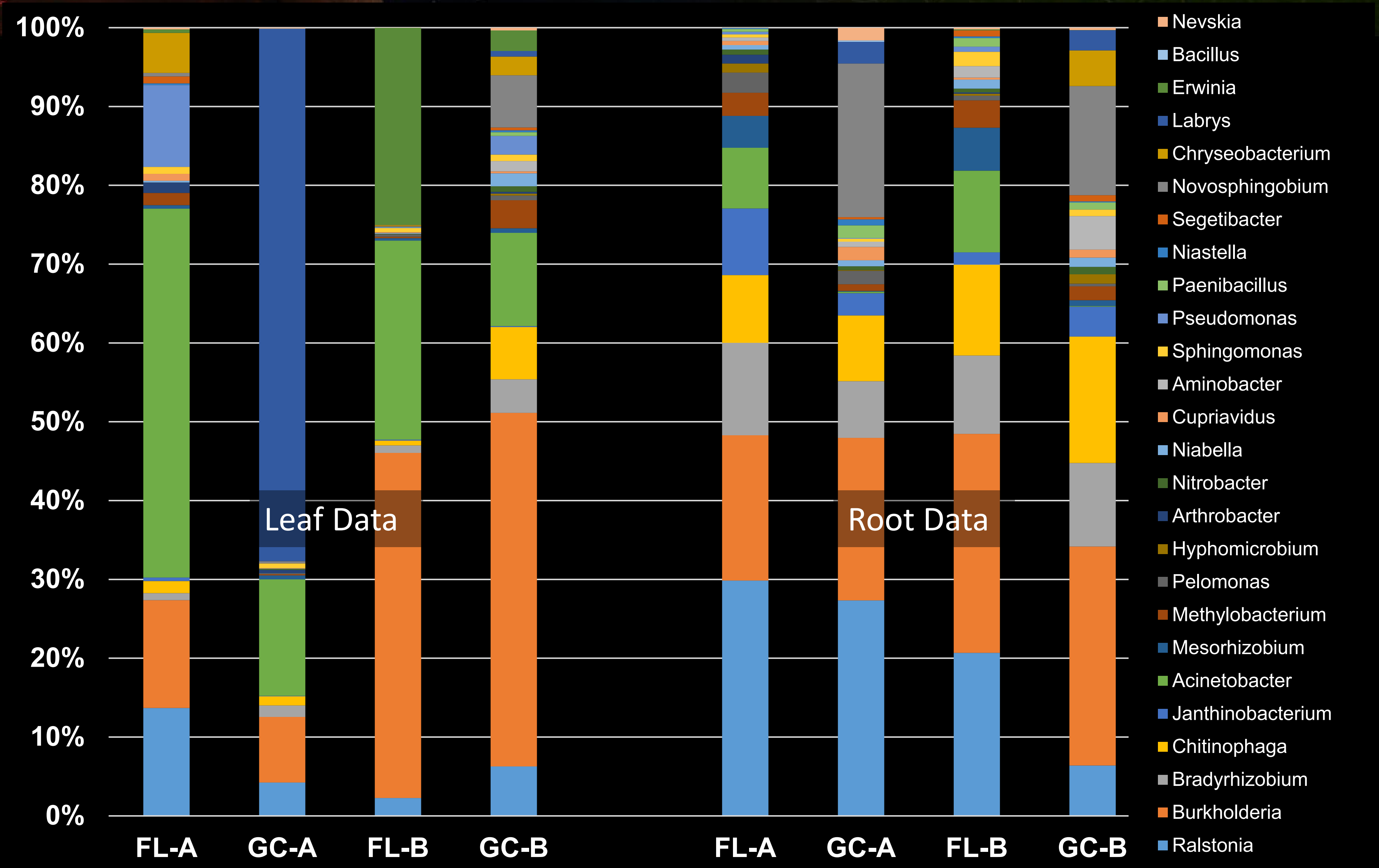


Lettuce



Data distribution Box and whiskers plots for aerobic bacteria (APC) and yeast and mold counts on cleaned (water rinse) and not cleaned lettuce from various sources. CACA=cut and come again harvest. + indicates mean, whiskers are max and min values. Market lettuce n=18, Chamber, n=6, VEG-03A n=5, VEG-03D n=4.

VEG-01A & B 'Outredgeous' Lettuce Leaf and Root Bacterial Community - Flight and Ground



Ventilation and Water Issues & Consequences in Zinnia

Guttation and Leaf Curling

Fungal Development & Abnormal Growth

VEG-03 Crop Testing

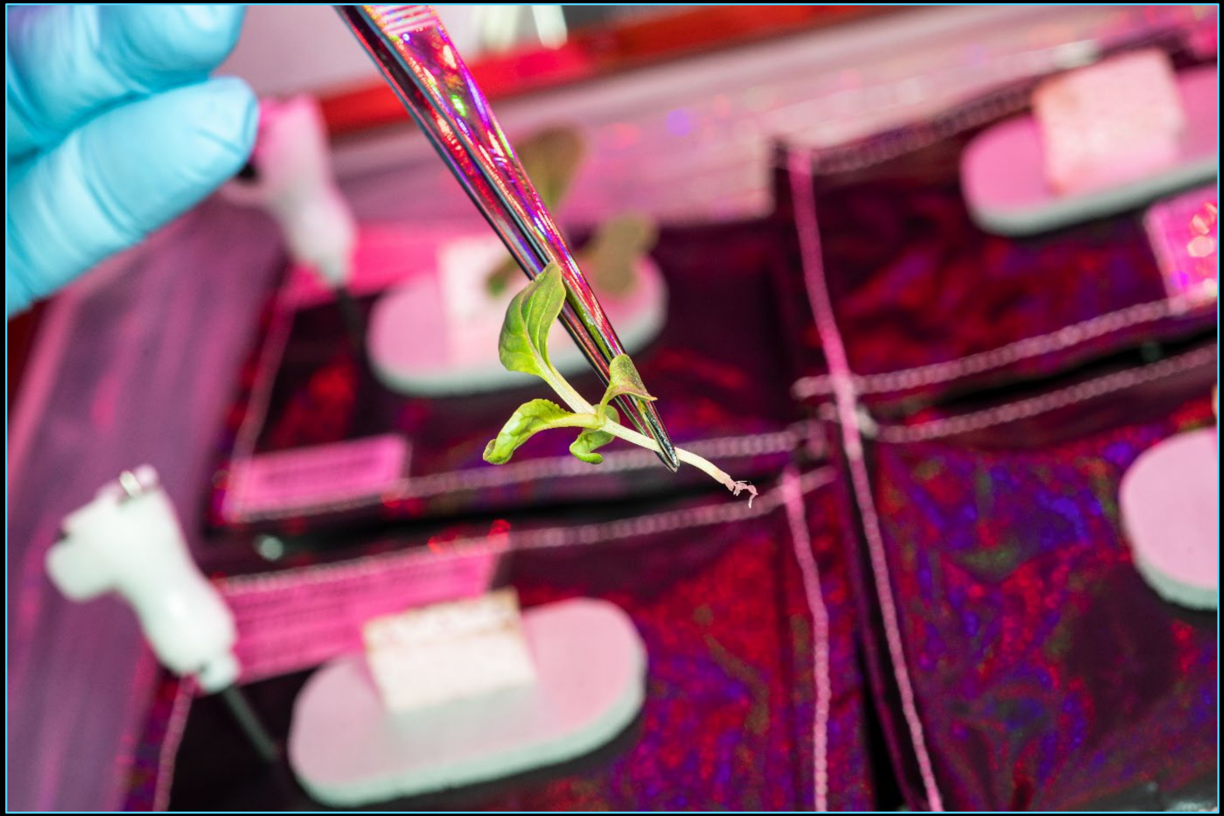
- Red Russian Kale
- *Dragoon Lettuce
- Wasabi Mustard
- *Extra Dwarf Pak Choy
- Amara Mustard

*= Student Selected Crops!





ISS Crop Research



Transplanting 10 Days after initiation

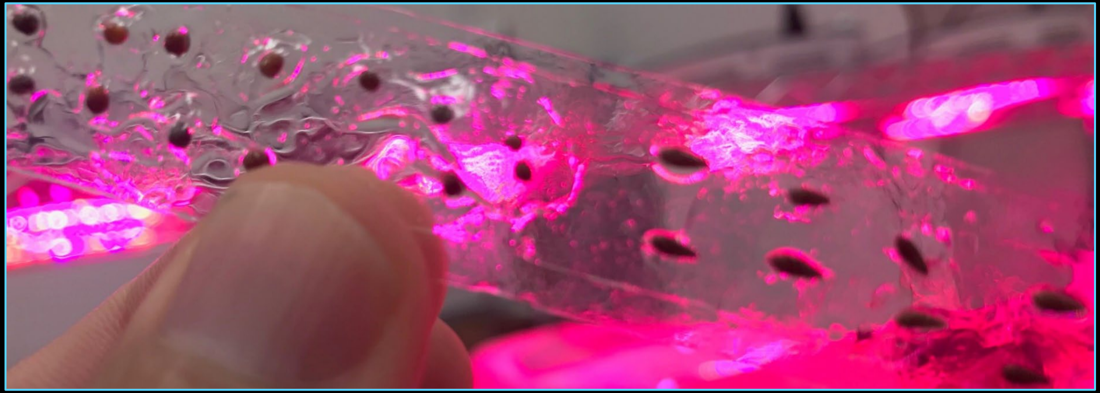
Original

Transplant

Harvest at 29 days

Successful transplanting of 'Extra Dwarf' Pak Choi in VEG-03 I

ISS Crop Research



Seed Film technology tested successfully in VEG-03 J

VEG-04

Research to study the impacts of Red: Blue: Green light ratios on Mizuna crop growth, nutrient composition, organoleptic appeal and microbial food safety with additional assessments of crew behavioral health.

Collaboration between KSC, JSC, Purdue University, and Sierra Space with Florikan consulting.

Space Chile!

- Española Improved Hatch Chile Peppers in APH
- PH-04 mission July – Nov. 2021
- Red or Green?

Space Chile!

Recently grown - dwarf tomato in VEG-05!

Preflight Ground Testing

Recently grown - dwarf tomato in VEG-05!

Selection Factors for Space Plants

Targeted breeding areas could fall into several categories:

- Plant Growth and Development
- Plant Physiology
- Produce Nutrition
- Produce Organoleptic Acceptability
- Postharvest

Plant Growth and Development

- Compact size (low height and volume)
- High yield
- High edible/inedible biomass ratio (harvest index)
- Reliable germination
- Rapid growth to first yield
- Uniform growth and development between individuals
- Propagules with long shelf stability (seeds, cuttings)
- Sustained production capability over long duration (e.g. repetitive fruiting, or cut-and-recut leafy production)
- Low debris formation (leaves, flowers, pollen, seeds, etc., remain attached)
- Custom microbiome of plant protective and growth promoting microorganisms

Plant Physiology

- Stress tolerance (esp. water stress)
- Ability to grow well under conditions of:
  - Elevated CO_2
  - Low relative humidity
  - Uniform temperature of 20-23°C
  - Narrow spectrum electric lights
  - Short photoperiods (to save lighting energy) or long/continuous photoperiods (to speed growth)
  - Tolerance of broad environment range
  - Tolerance of reduce pressure
- No dormancy requirements
- Low or pleasing aroma
- Low release of volatile organics
- High sodium tolerance (e.g. urine recycling)
- Preference for ammonia nitrogen sources (e.g. urine recycling)

Produce Nutrition

- High normal levels of antioxidants
- High normal levels of beneficial phytonutrients (e.g. lutein, zeaxanthin, lycopene, phenolics, anthocyanins)
- For fresh produce to supplement a packaged diet:
  - High normal levels of Potassium and Magnesium
  - Low normal levels of Iron
  - High normal levels of Vitamins, especially C, B_1, and K
- Low levels of antinutrients

Produce Organoleptic Acceptability

- Excellent flavor
- Intense flavors
- Good texture
- Good appearance, color, aroma

Postharvest

- Good produce shelf life or storage on the plant
- Reduced processing (e.g. seeds easy to remove from seed coats)
- Easy composting/digestion of inedible plant material for nutrient reclamation (and possibly less structure in micro/partial g)
- Use of waste as resources for other food system components (e.g. fish, edible fungus, cellular ag feedstocks)
- Other useful materials produced from waste (e.g. life support, shielding, building, fuel, medicinal compounds & molecular pharming)


SPACE PLANT BIOLOGY
APH
ADVANCED PLANT HABITAT
Large Plant Reacarch Facility
SPACE PLANT BIOLOGY
Veggie
Food Production and Astronaut Nutrition
AVOID
NEGATIVITY

Thank you!

- Veggie, APH, and Space Crop Production teams
- NASA's astronauts
- NASA's Space Biology Program, ISS Program, Human Research Program, Mars Campaign Office