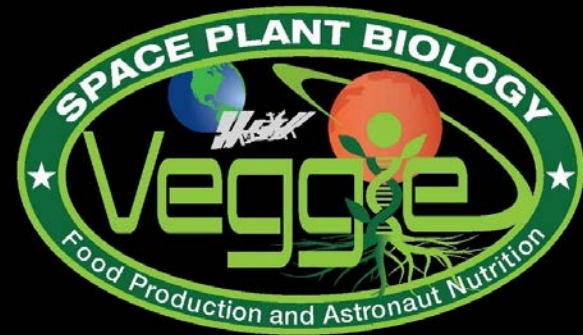


Food Production for Space Exploration



**Exploration Research and
Technology Programs**



Gioia Massa
Project Scientist
NASA, Kennedy Space Center

Space Food Production

- Goal: To produce safe, nutritious, appealing food to supplement a stored diet
 - As mission duration increases, a greater percentage of the diet might be produced
- Key Factors:
 - Production in controlled environments
 - Any solar light reduced and indirect
 - High CO₂ levels likely (ISS ≥3000 ppm)
 - Common environments for multiple crops
 - Crop scheduling is critical
 - Power, mass, volume, and crew time must be minimized
 - Sustainability - minimizing waste, nutrient recycling
 - Biotic stresses - carried from Earth, mutation
 - Abiotic stresses - related to micro or fractional gravity
 - Opportunities:
 - Designer plants for space growth and nutrition
 - Automation
 - In Situ Resource Utilization (Regolith, CO₂, water)



61

FARMING ON THE MOON

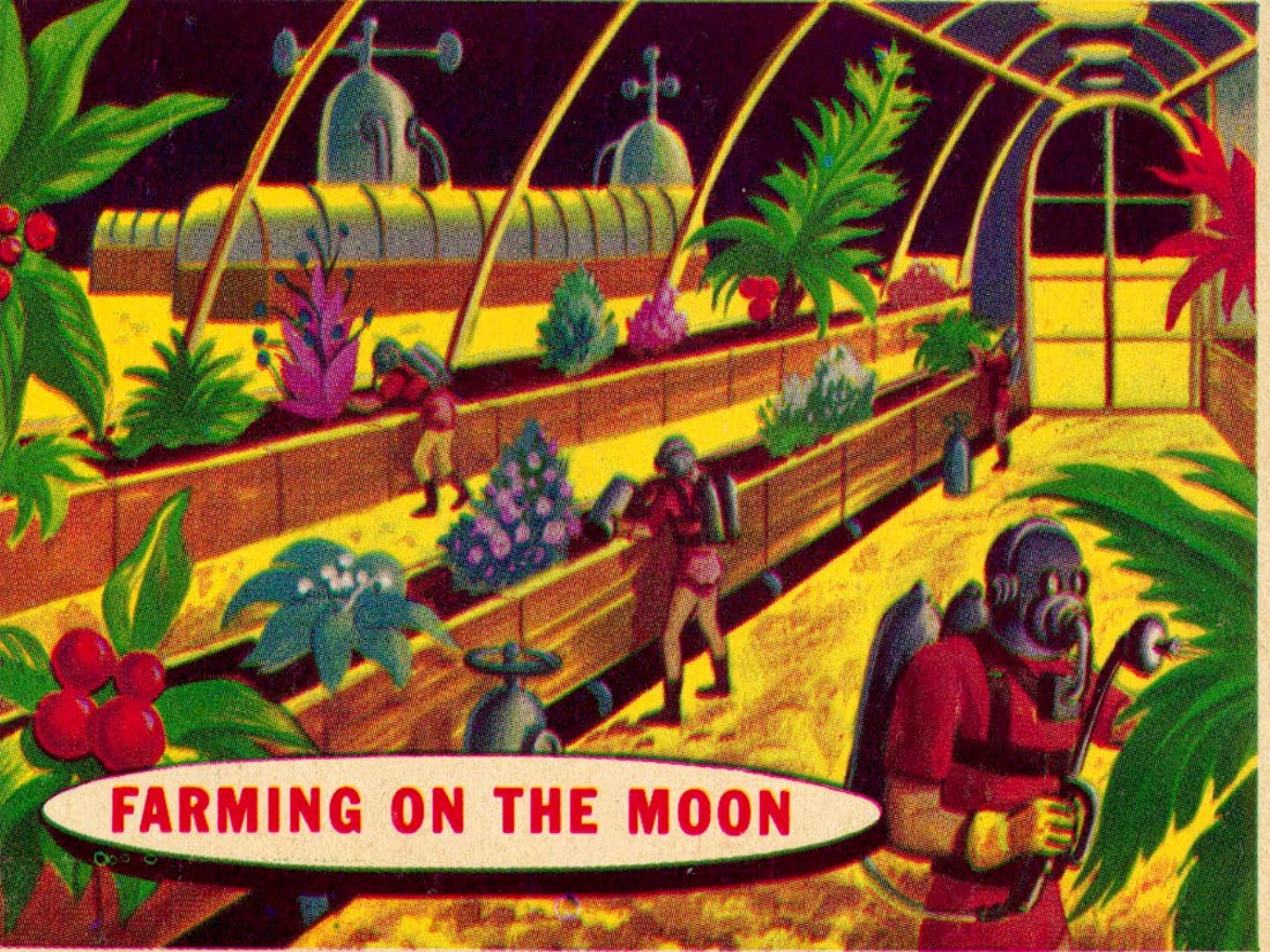
Farming on the moon will be mostly done 'indoors,' under a large plastic dome. Carbon Dioxide will be pumped in and sunlight will pour down on the plants. Special types of plants will be developed to give high energy foods to compensate for the pioneers' lack of meat. Certain plants like strong cactus that can withstand the blistering rays of the sun, will be able to grow 'outdoors' on the moon.

See Card No. 62—MOON TRAINS

TARGET: MOON

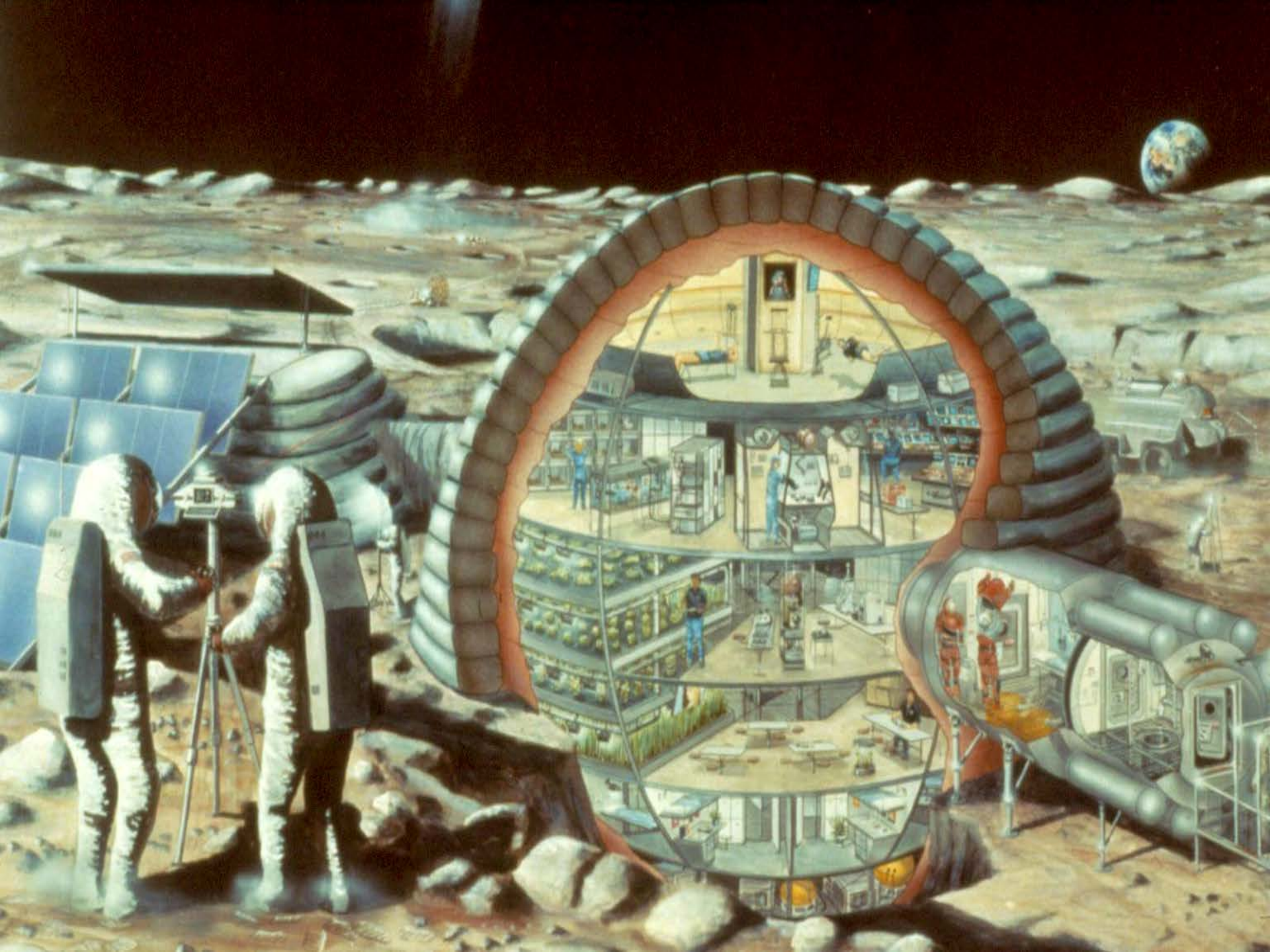
©T.C.G.

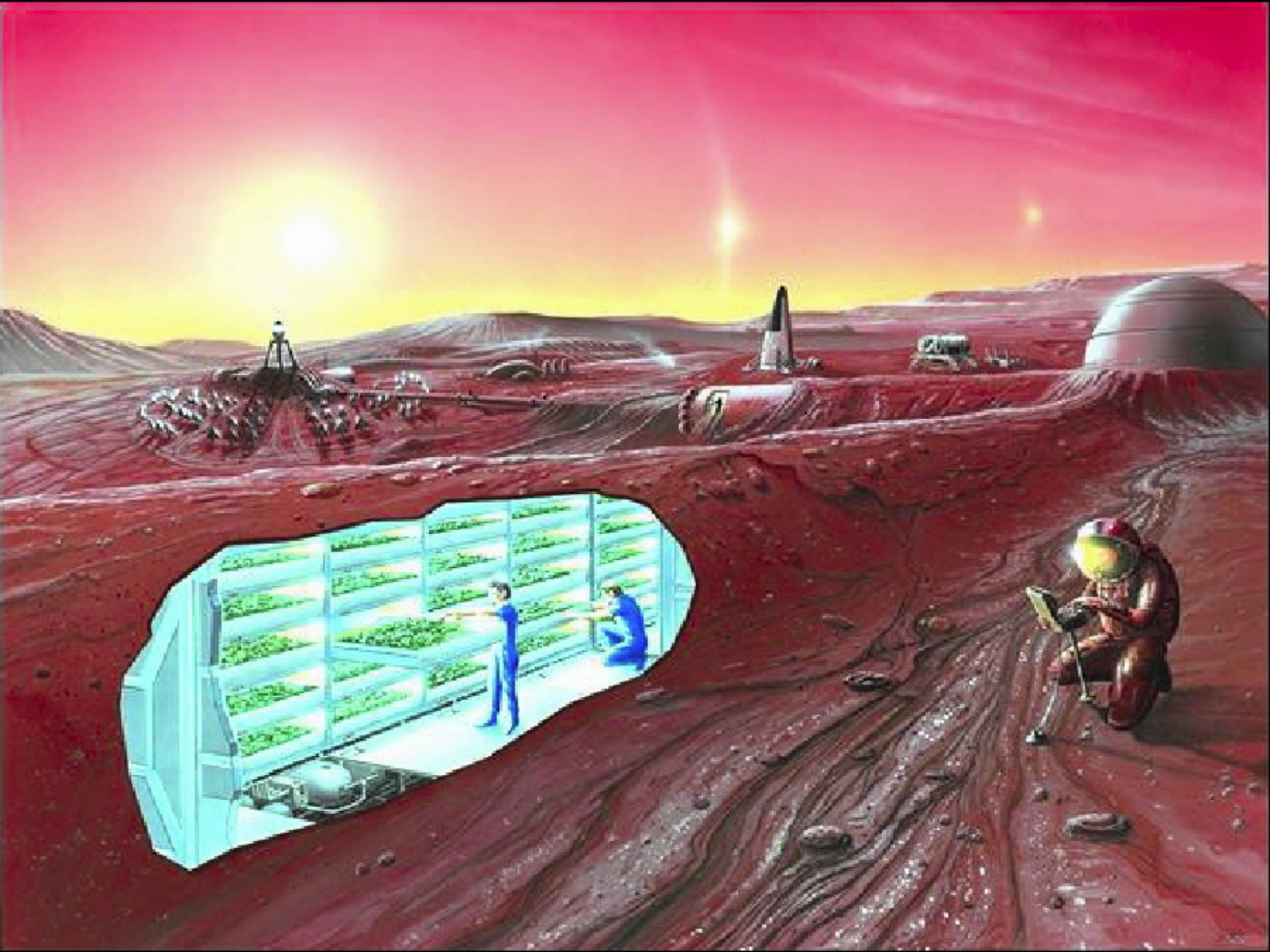
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FARMING ON THE MOON







Plant Factories



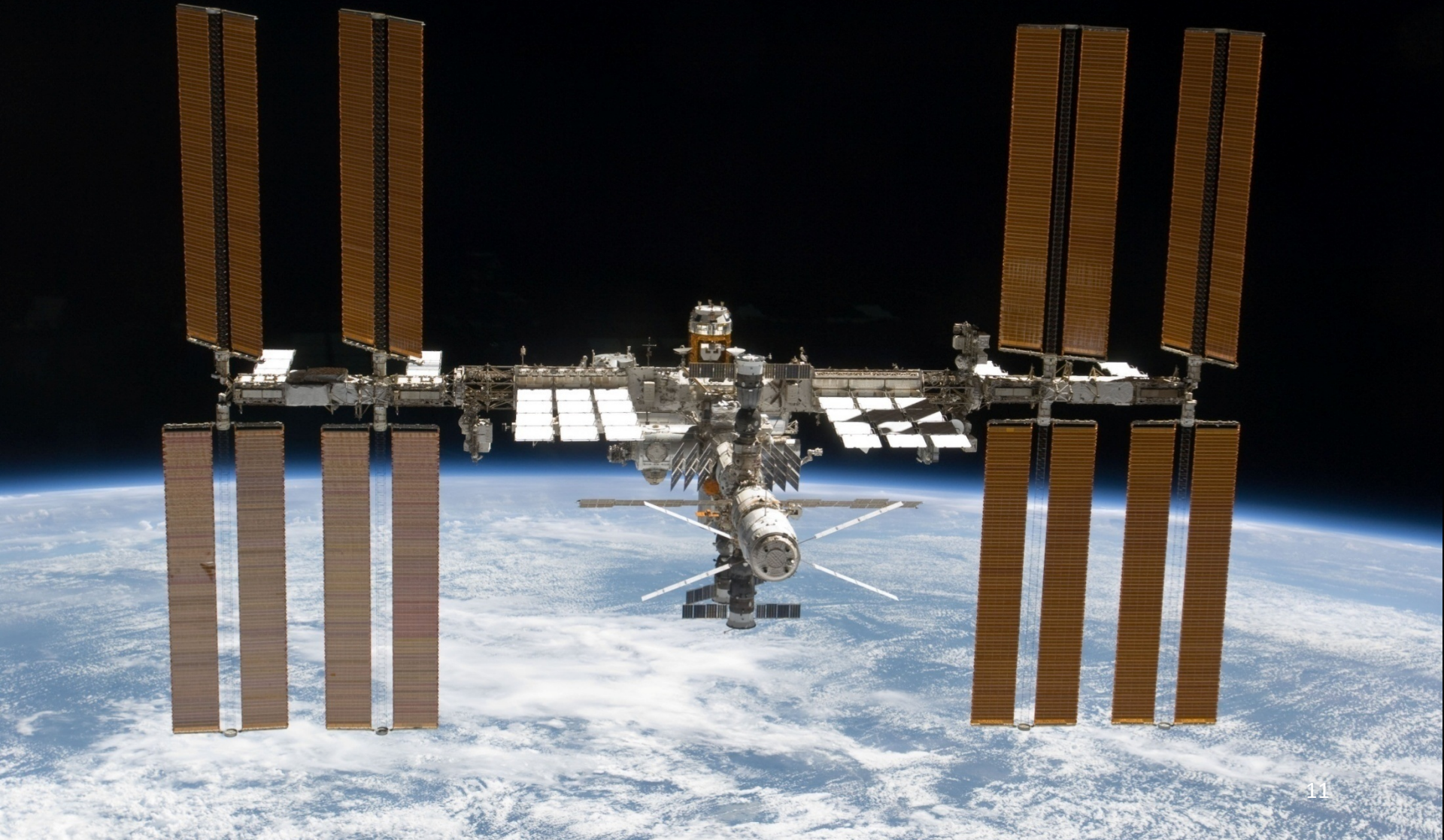


South Pole Greenhouse

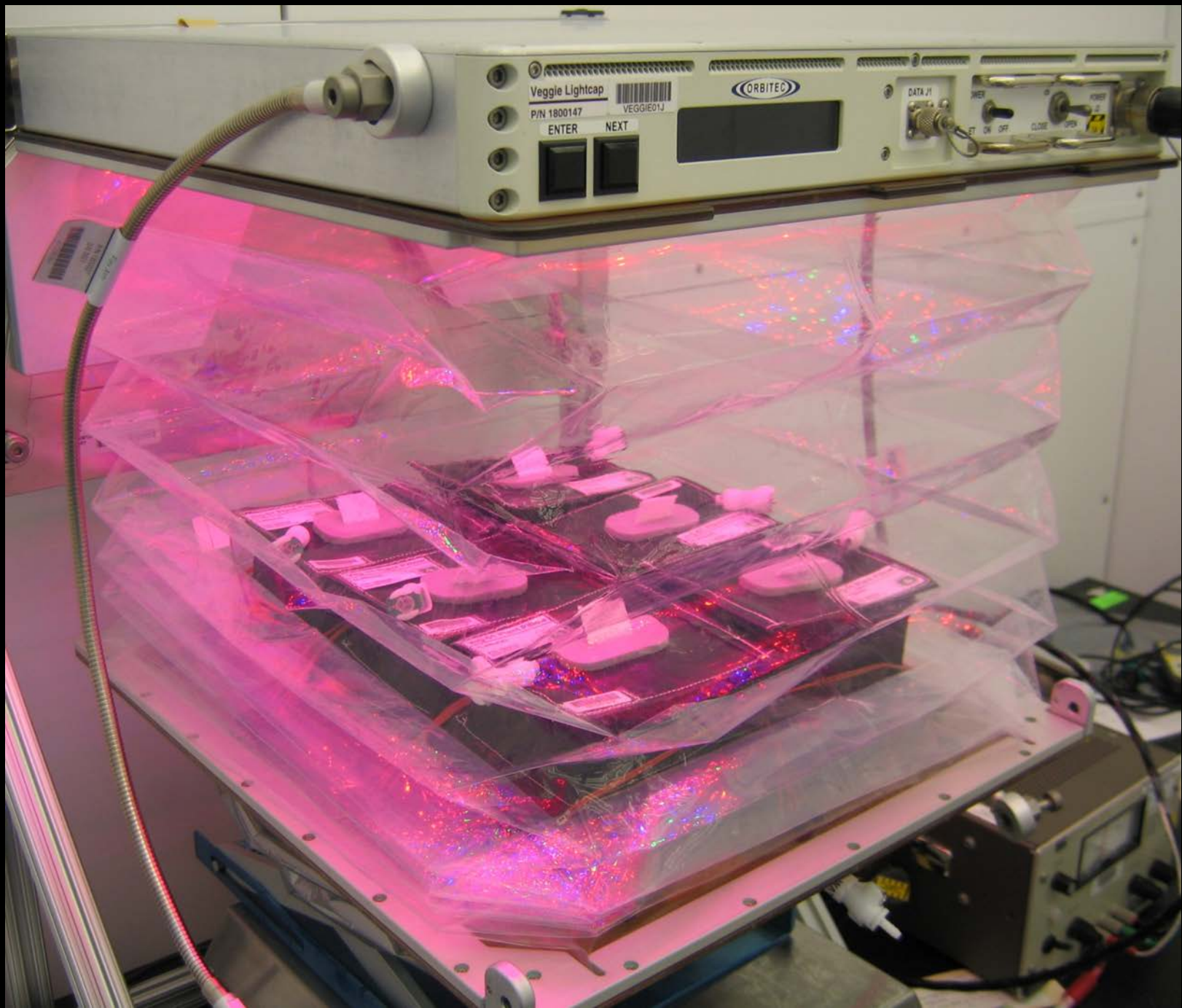


Photo from "On the Ice" Blog of Russ Durkee

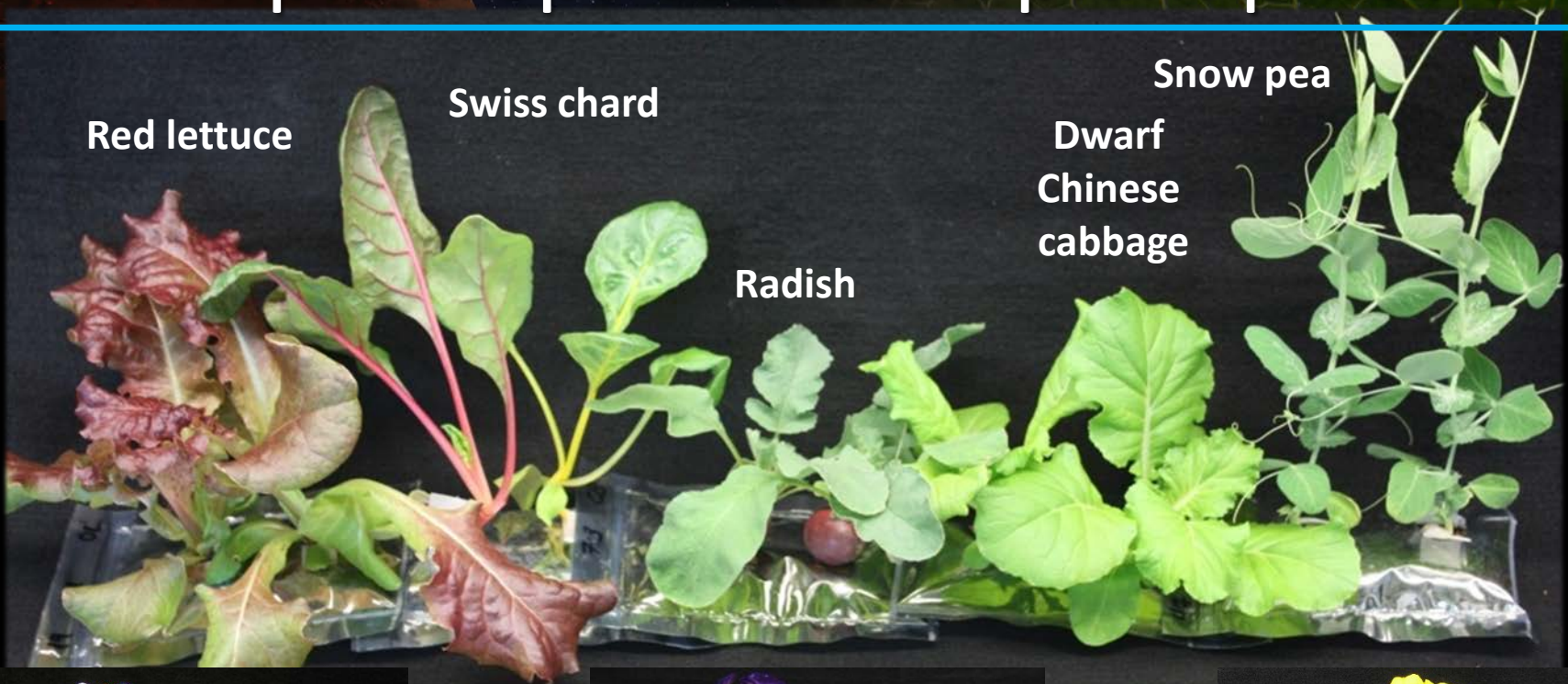
The International Space Station



Designed
and built by
ORBITEC



Example crops tested in plant pillows





Crop Selection for VEG-01

- Reliable germination
- Rapid growth
- Attractiveness
- Low native microbial levels
- Palatability / acceptability
- Antioxidants

VEG-01 consisted of two sets of 'Outredgeous' lettuce and one set of 'Profusion' zinnia pillows

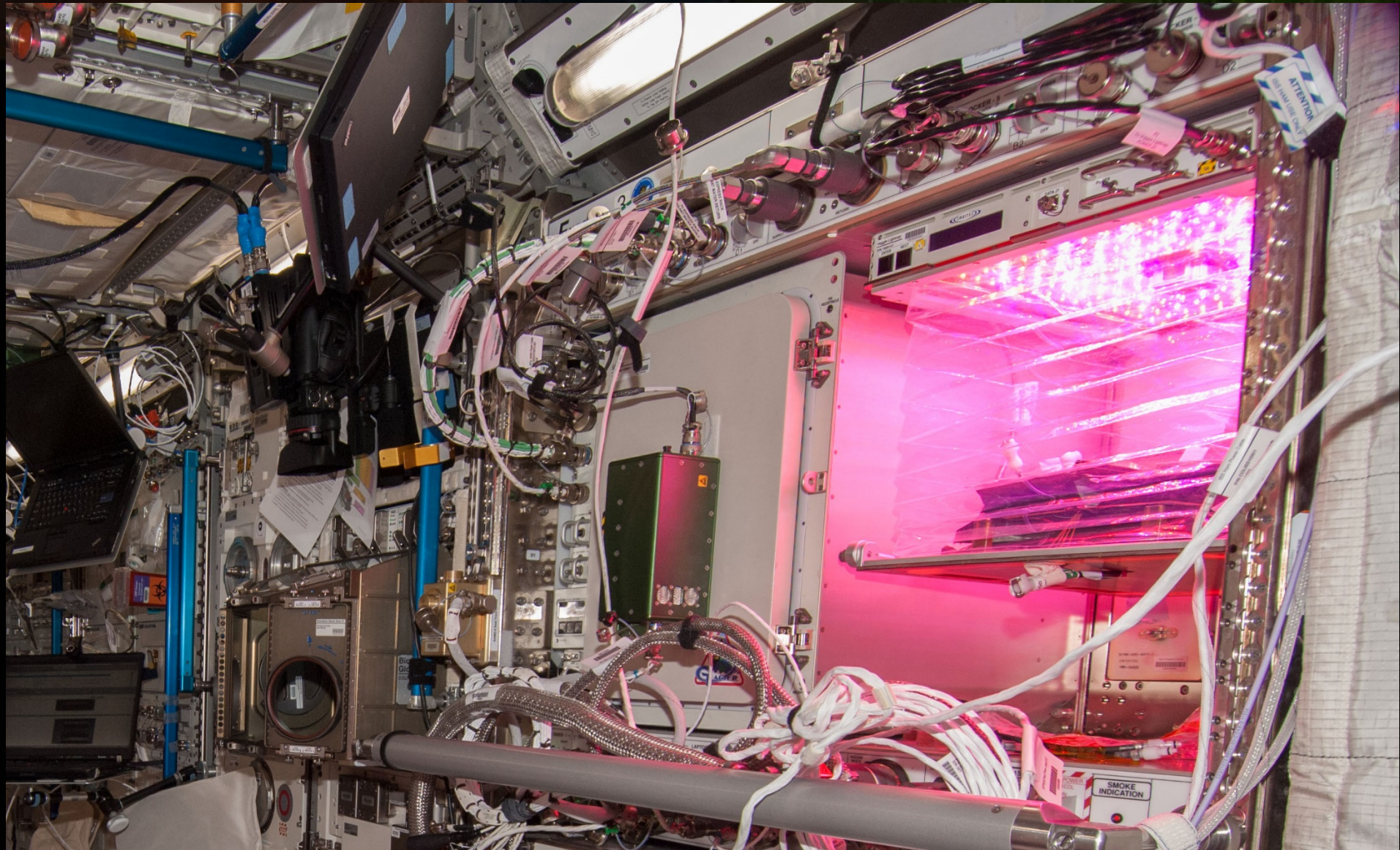


'Outredgeous'
red romaine lettuce



'Profusion'
Zinnia

Veg-01 initiation



Veg-01 wick opening (3 DAI)

Veg-01 on-orbit wick opening assisted seedling growth (3 days after initiation)



Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources



Veg-01 plant thinning (7 DAI)

Veg-01 on-orbit plant thinning operation eliminated competition for resources

- Pillow B did not germinate
- 5 pillows contained seedlings



Veg-01 water stress

Veg-01 on-orbit plants exhibited low water response characteristics. Water was added directly to pillows to ensure water availability for the seedlings.



Veg-01 water stress

Plants in pillows A and C grew well

Plants in pillows D, E, and F exhibited stunting and water stress

D ultimately recovered and E and F died



Veg-01 Harvest (33 DAI)

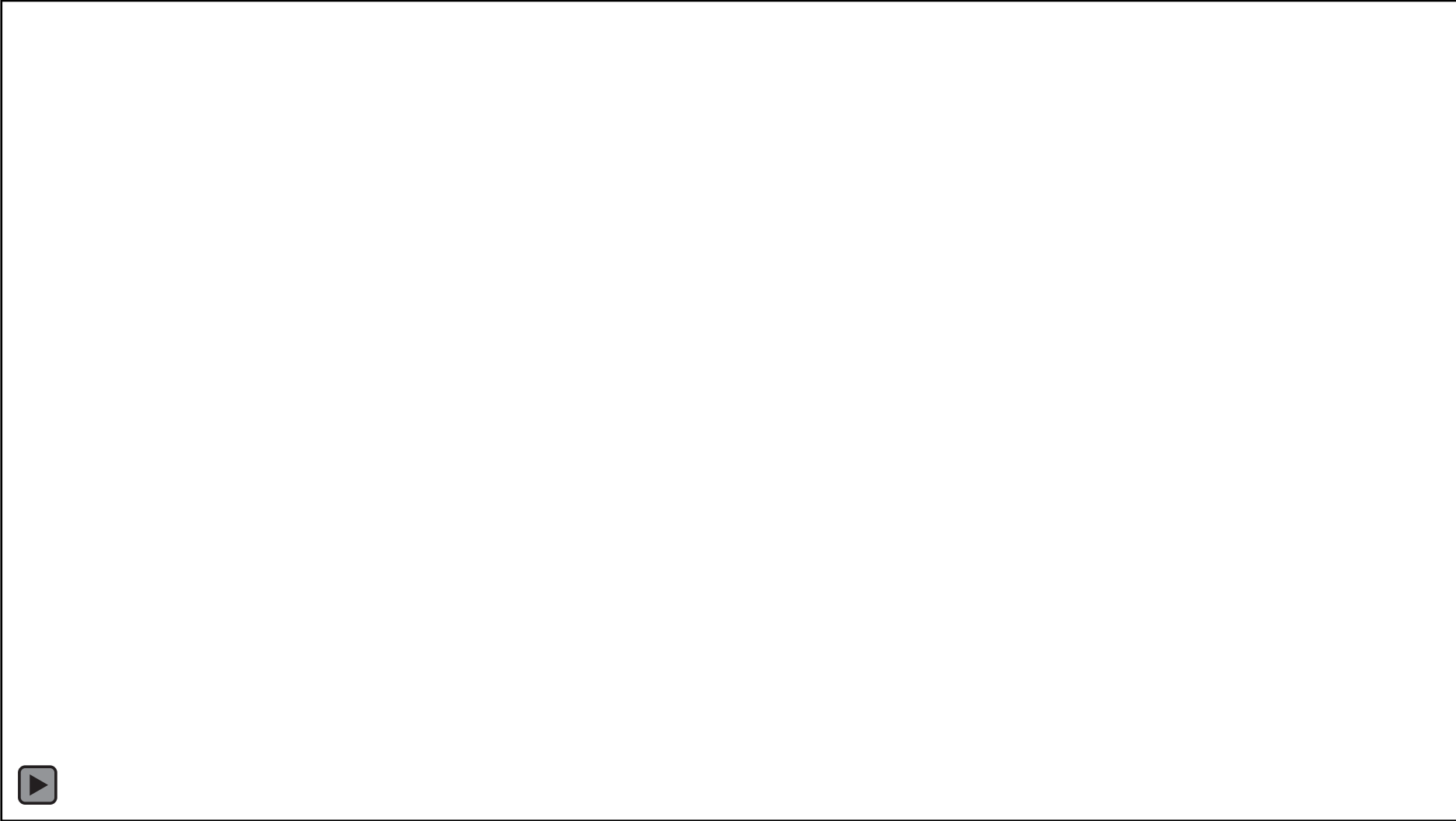


Veg-01 Harvest

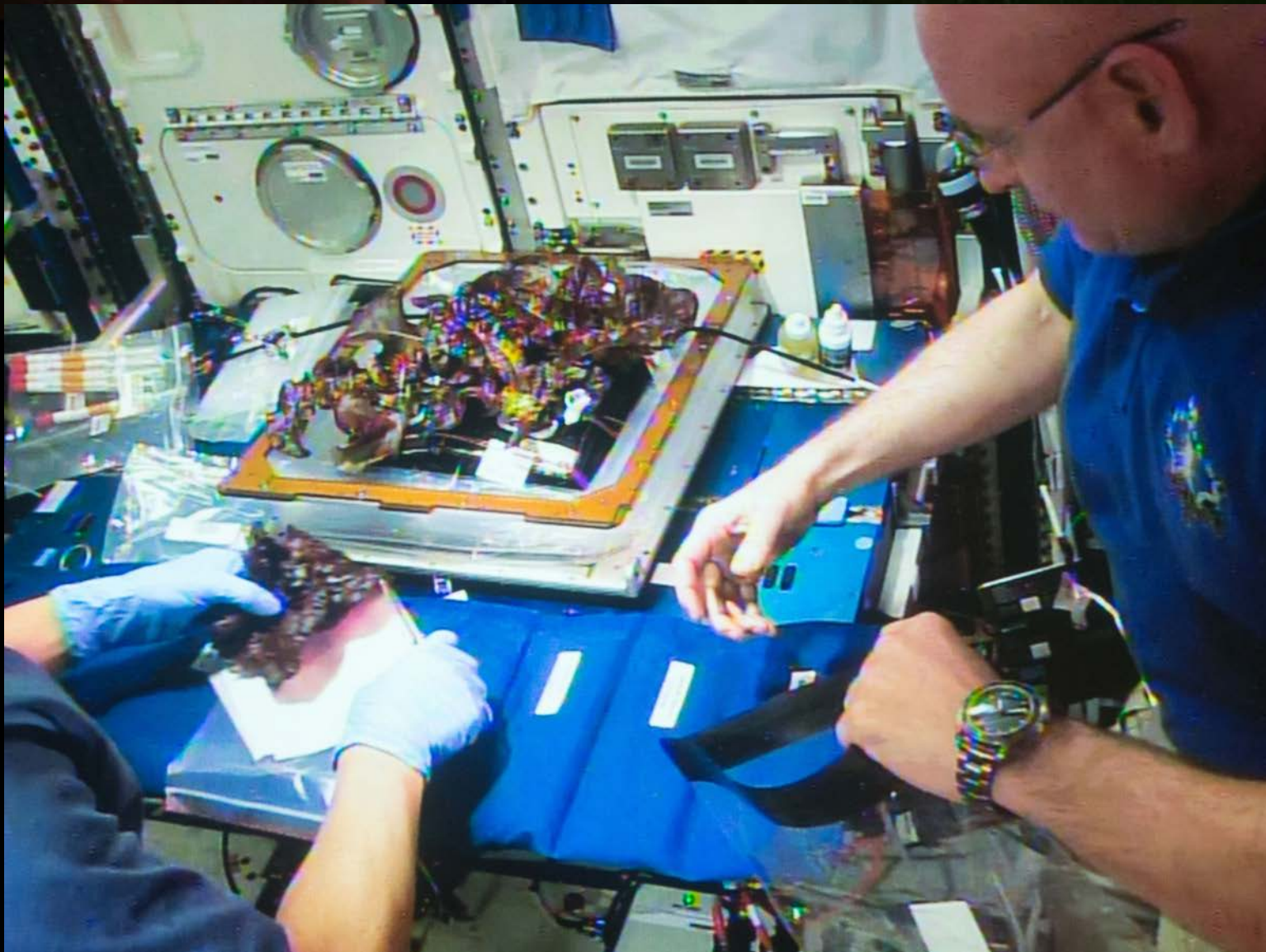


Veg-01 Second Crop

- Modified watering procedures, increased photo frequency
- Initiated by Scott Kelly on July 8, 2015 from seeds previously sent
- Grown by Scott Kelly and Kjell Lindgren
- Water stress observed but astronauts intervened and grew 5 plants
- ½ the produce for consumption, ½ for science
- Plants harvested Aug. 10, 2015, live on NASA TV
- Science samples frozen and returned May, 2016.



Sanitizing Produce



Astronaut Comments

- Scott Kelly

- the logistical complexity of having people live and work in space for long periods
- the supply chain that is required
- For Mars, need a space craft that is more self-sustainable with regards to its food supply

- Kjell Lindgren

- benefit of eating the fresh food
- contribution that plants have to the ISS ecosystem
- psychological benefit - it's really fun to see green growing things in the sterile environment of the ISS



Veg-01 Third Crop - Zinnia

- Directly watered plants after initiation, decreased photos to reduce crew time demands
- Initiated on Nov. 16, 2015 from seeds previously sent
- Grown by Kjell Lindgren and Scott Kelly
- Plants received too much water; fungus developed
- Mitigation attempted but several plants were lost before flowering
- Autonomous gardening started in Dec.
- Plants harvested Feb. 14, 2016
- Samples frozen and returned May, 2016

Water Issues / Consequences



Guttation and Leaf Curling



Fungal Development
& Abnormal Growth

And they bloomed, and bloomed...



87 DAI

Zinnia (Zinnia)
Veg-01 Plant
P/N 180005
S/N VEG-01

Bungee
P/N 54366
S/N 0020
001816914

Bungee
P/N 54366
S/N 0020
001816914

Zinnia Action Shots



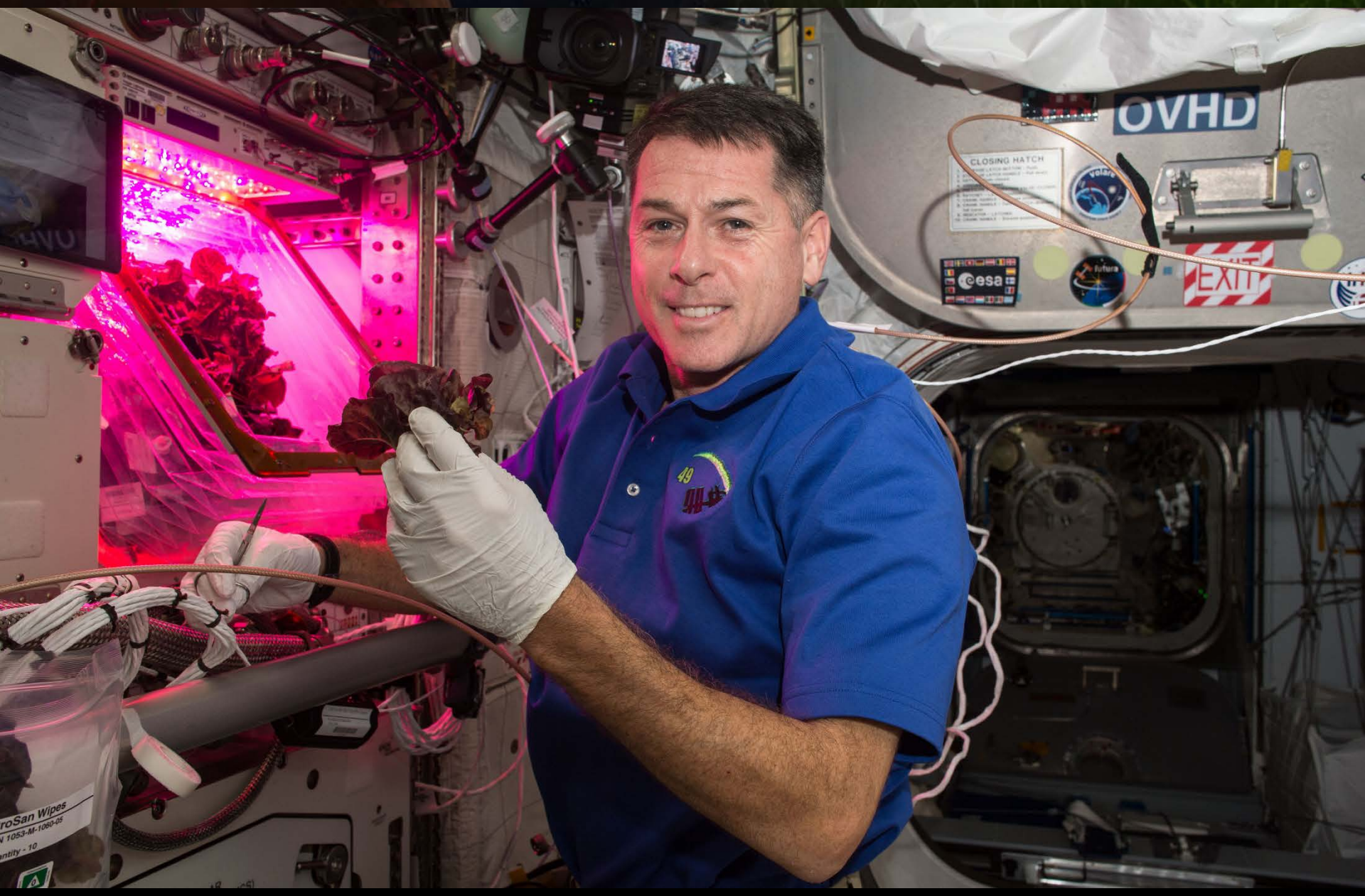
90 DAI: Harvest on February 14, 2016



Valentine's Day Bouquet on the ISS



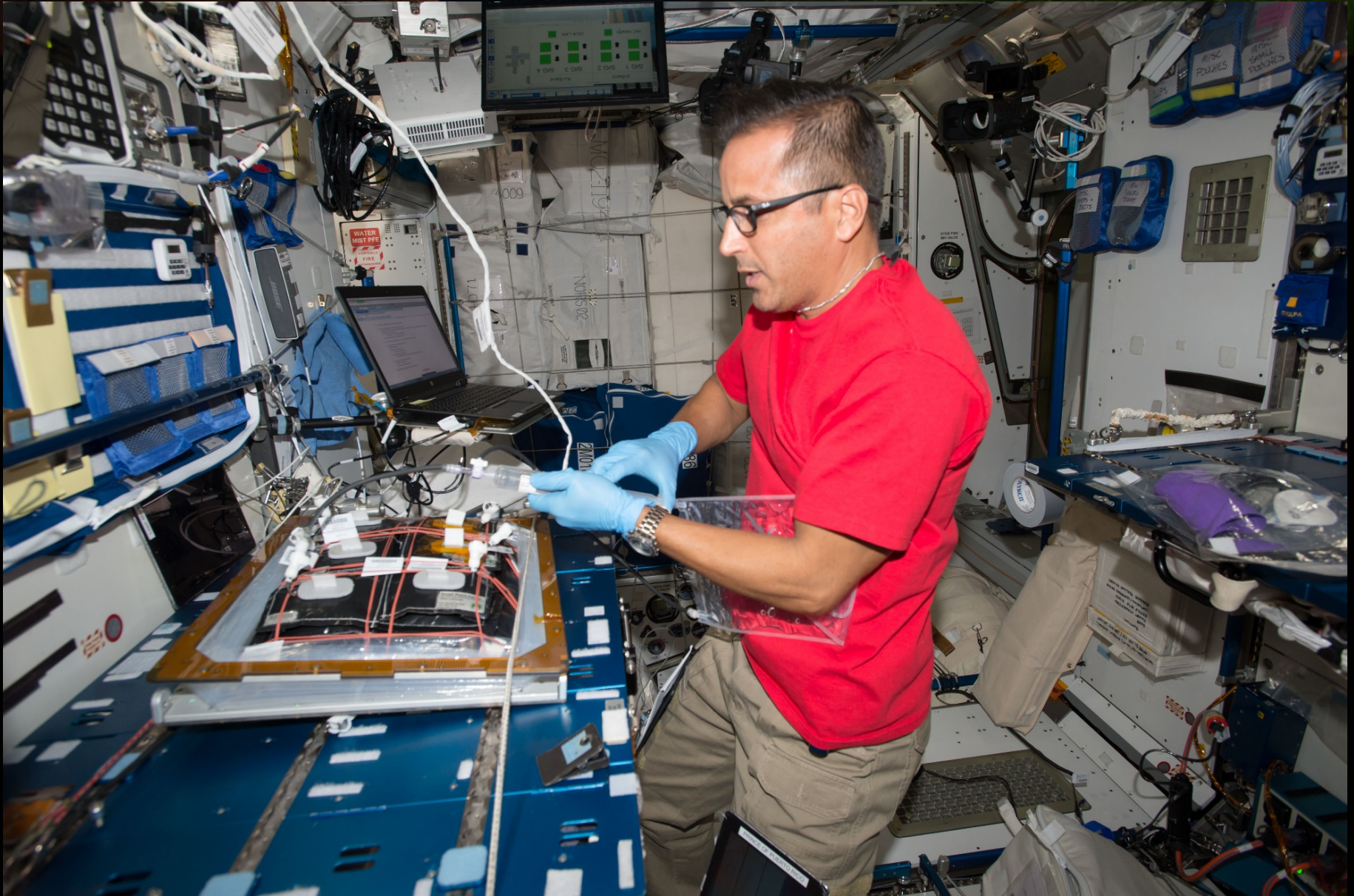
VEG-03A Cut-and-Come-Again



VEG-03 Cut-and-Come-Again



VEG-03 D – Mixed Crop Tests



Veg-03D - Mixed Crop Tests



Next Up - A Tale of Two Veggies



Thank you!

- Veggie and VEG-01 teams at KSC and ORBITEC
- Astronauts Steve Swanson, Rick Mastracchio, Scott Kelly, Kjell Lindgren, Shane Kimbrough, Peggy Whitson, Jack Fischer, Joe Acaba
- Payload Operations and Integration Center
- NASA's Space Life and Physical Sciences, ISS Program, Human Research Program



Just Installed!
NASA's Advanced Plant Habitat