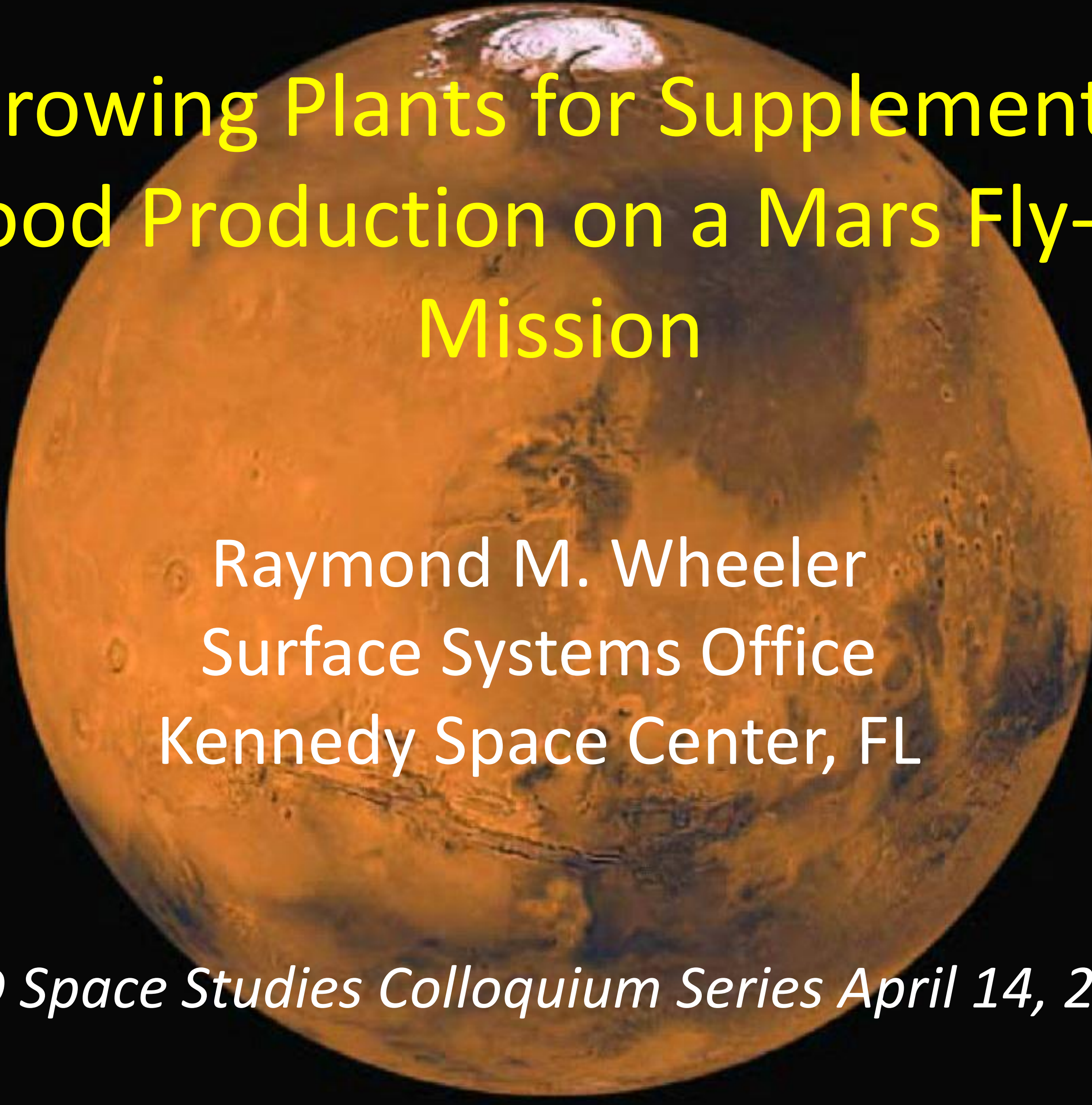
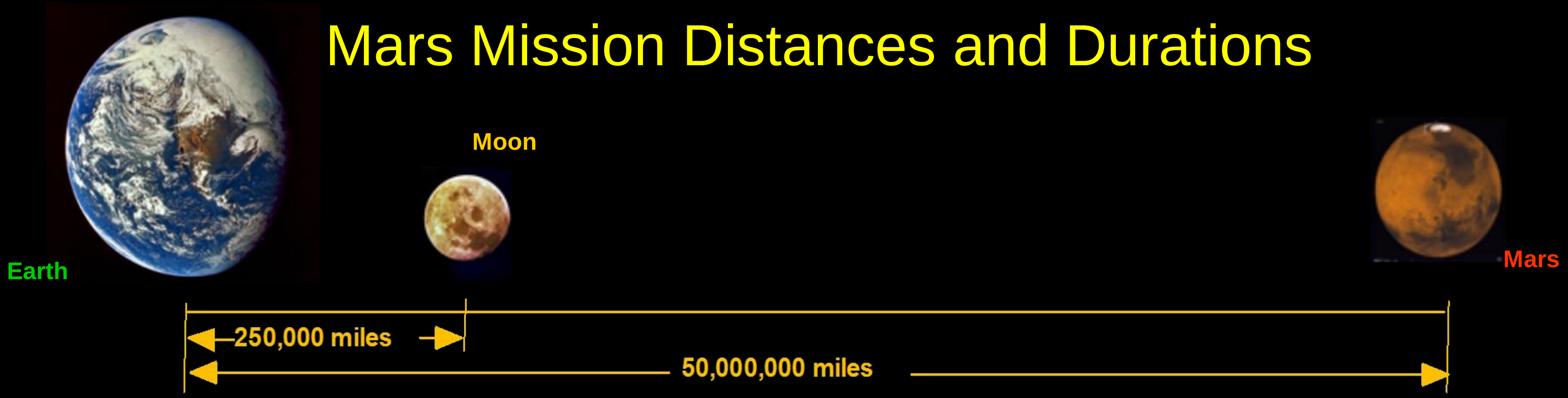
Growing Plants for Supplemental Food Production on a Mars Fly-By Mission

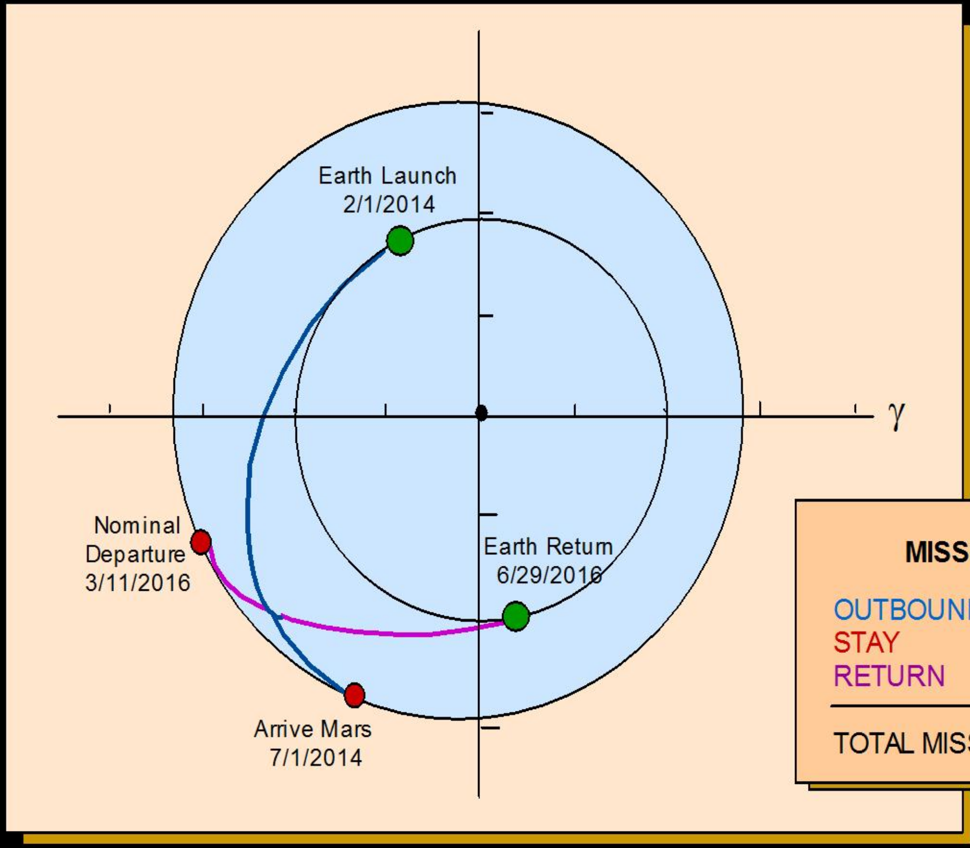


Raymond M. Wheeler
Surface Systems Office
Kennedy Space Center, FL

UND Space Studies Colloquium Series April 14, 2014

Mars Mission Distances and Durations





MISSION TIMES

OUTBOUND	150 days
STAY	619 days
RETURN	110 days
TOTAL MISSION	879 days

Human Life Support Requirements:

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%

TOTAL 31.0 kg

Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)

TOTAL 31.0 kg

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

Why Plants for a Mars Mission?

- Currently, food consumed by astronauts is all preserved or thermo-stabilized, package food
- Plants could supply of fresh foods to supplement the packaged food diet
  - Improve nutrition for the crew through bio-available nutrients and antioxidants as radiation countermeasure
  - Improve the acceptability of the meals
    - Add textures, flavors, and colors of fresh vegetables
  - Improve crew morale through the presence of plants
  - Depending on size of the plant growth system, help supply O_2 production and remove CO_2

Fresh Foods for Long Space Missions

Colors
Textures
Aromas

Cherry
Tomato

Strawberry

Red and Green
Leaf Lettuce

Dwarf
Pepper

Antioxidants and Supplemental Nutrients

Anthocyanin induced by blue and UV light in red-leaf lettuce;
Others might include lycopene, lutein, Vit. K, Ca and phenolics.

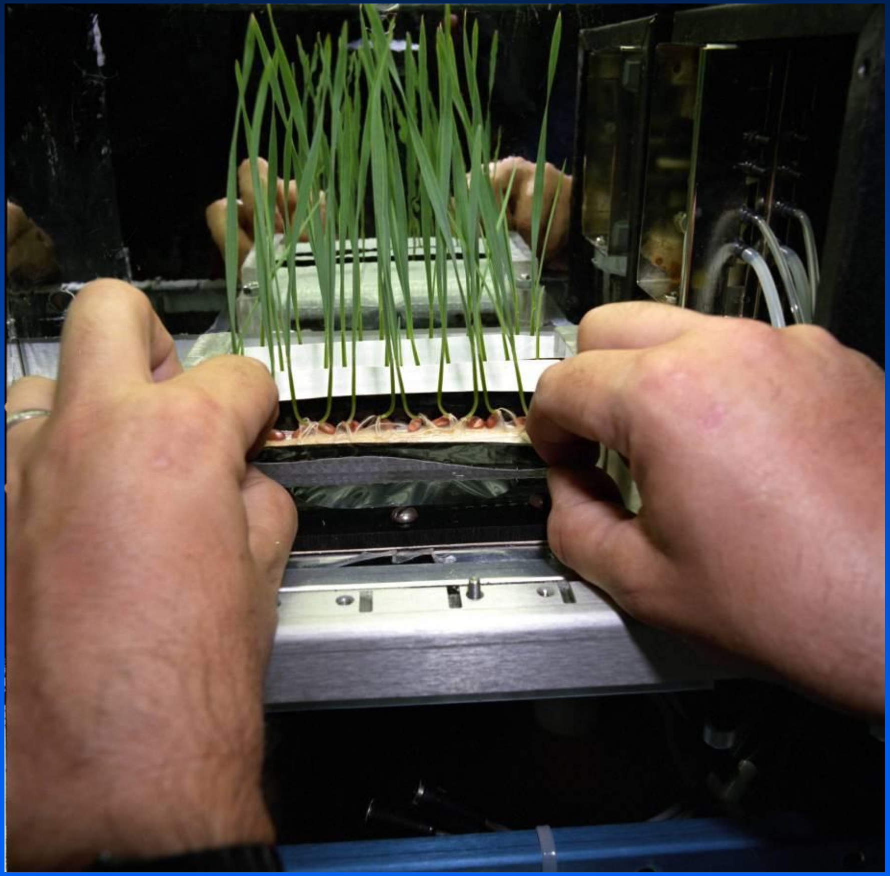
Crew Morale: Plants could provide comfort to crew

(Photo from US South Pole Plant Chamber)

Challenges for Growing Plants for a Mars Mission?

- Microgravity
  - Watering, thermal mixing, plant physiological responses
- Lighting
  - Power for electric lighting; interference with crew ops
- Atmospheric Closure
  - Trace contaminants, e.g., ethylene
  - Super-elevated CO_2 (e.g., > 5000 ppm)
- Radiation Exposure
- Food Safety Issues

Watering Systems for Weightlessness



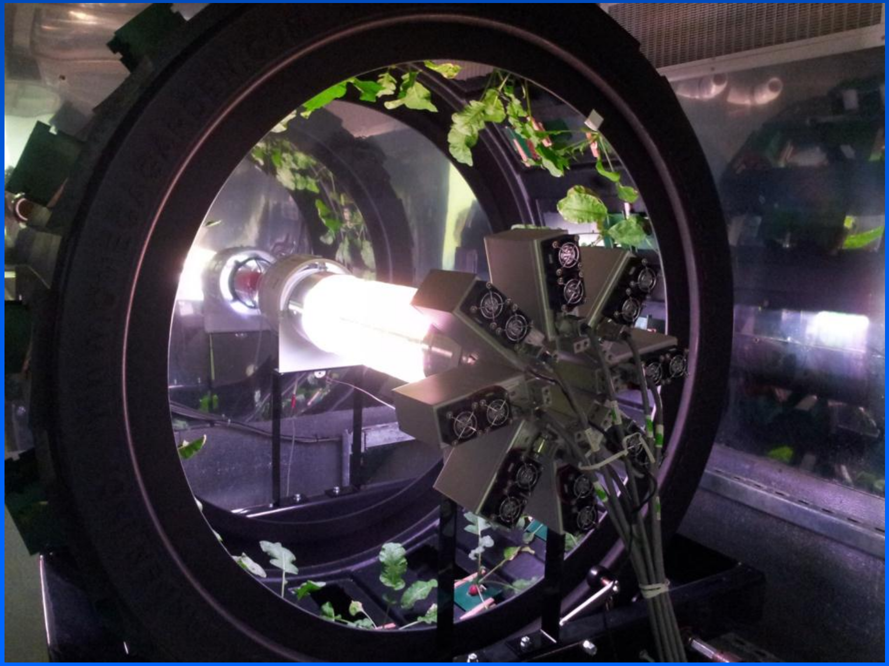
Porous ceramic or steel tubes to contain the water which then moves by capillary forces to the roots

Wright et al. 1988. Trans. ASAE 31:440-446; Dreschel and Sager. 1989. HortScience 24:944-947.

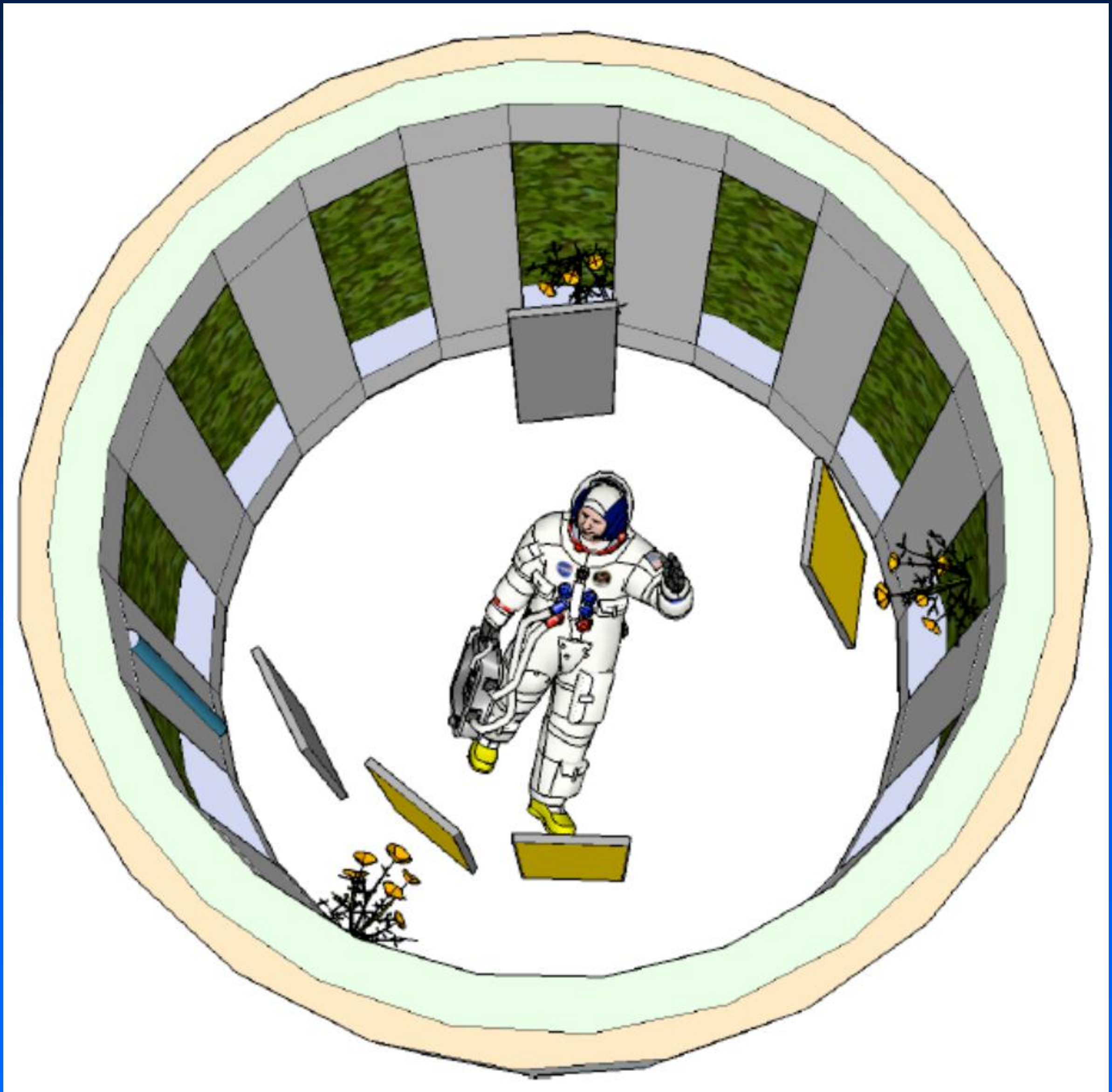
Biomass Production System (BPS)

Porous steel tubes surrounded
by arcillite rooting media
with time-release fertilizer

Rotating Plant Growth System for Artificial Gravity ?



Perhaps even and a larger rotating system within a space module?



Concept drawing
By Morgan Simpson
NASA Kennedy Space Center

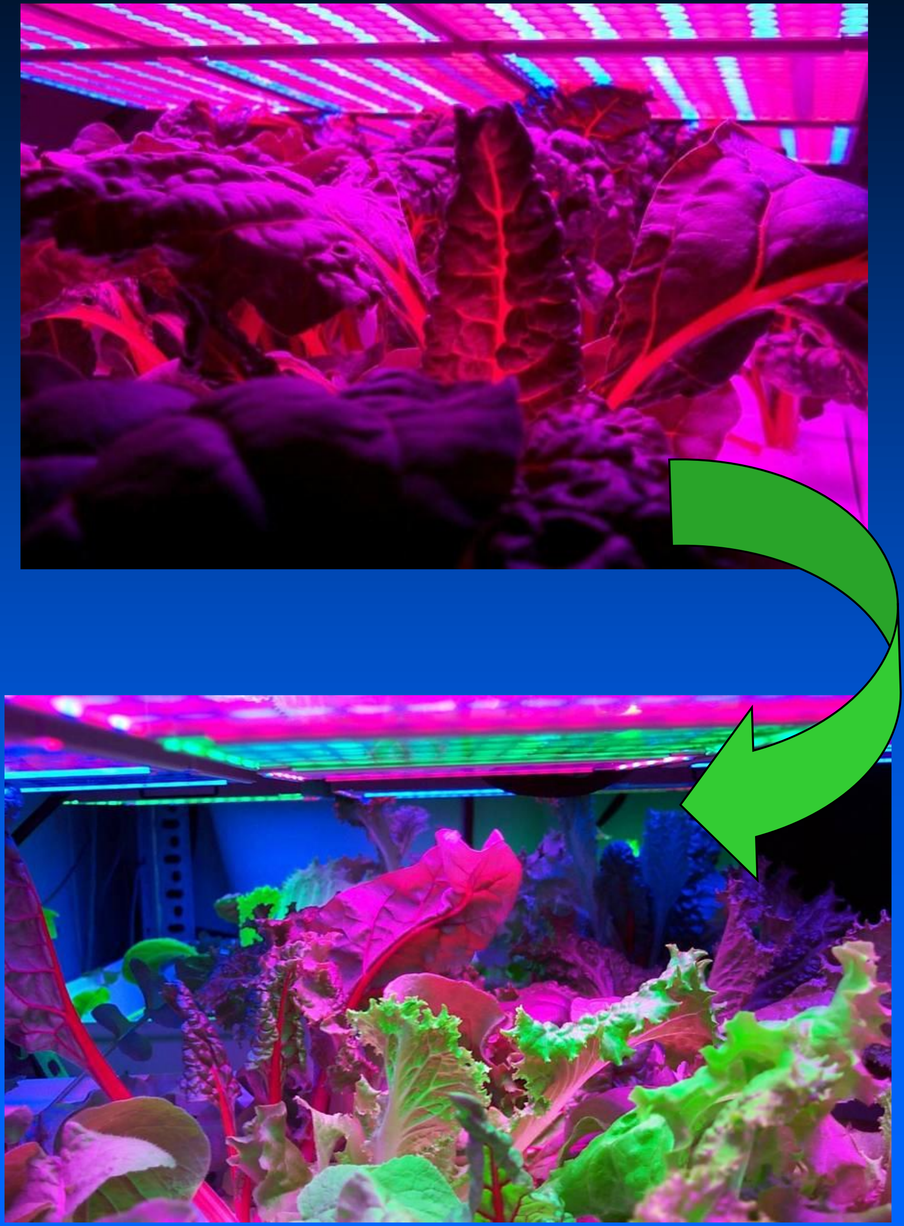
The Importance of Lighting
--Electric Lamp Options

Lamp Type	*Conversion* Efficiency*	*Lamp Life* (hrs)*	*Spectrum*
• Incandescent/Tungsten**	5-10%	2000	Intermd.
• Xenon	5-10%	2000	Broad
• Fluorescent***	20%	5,000-20,000	Broad
• Metal Halide	25%	20,000	Broad
• High Pressure Sodium	30%	25,000	Intermd.
• Low Pressure Sodium	35%	25,000	Narrow
• Microwave Sulfur	35-40%+	?	Broad
• LEDs (red and blue)****	>40%	100,000 ?	Narrow

** Approximate values.*
*** Tungsten halogen lamps have broader spectrum.*
**** For VHO lamps; lower power lamps with electronic ballasts last up to ~20,000 hrs.*
***** State-of-Art Blue and Red LEDs most efficient.*

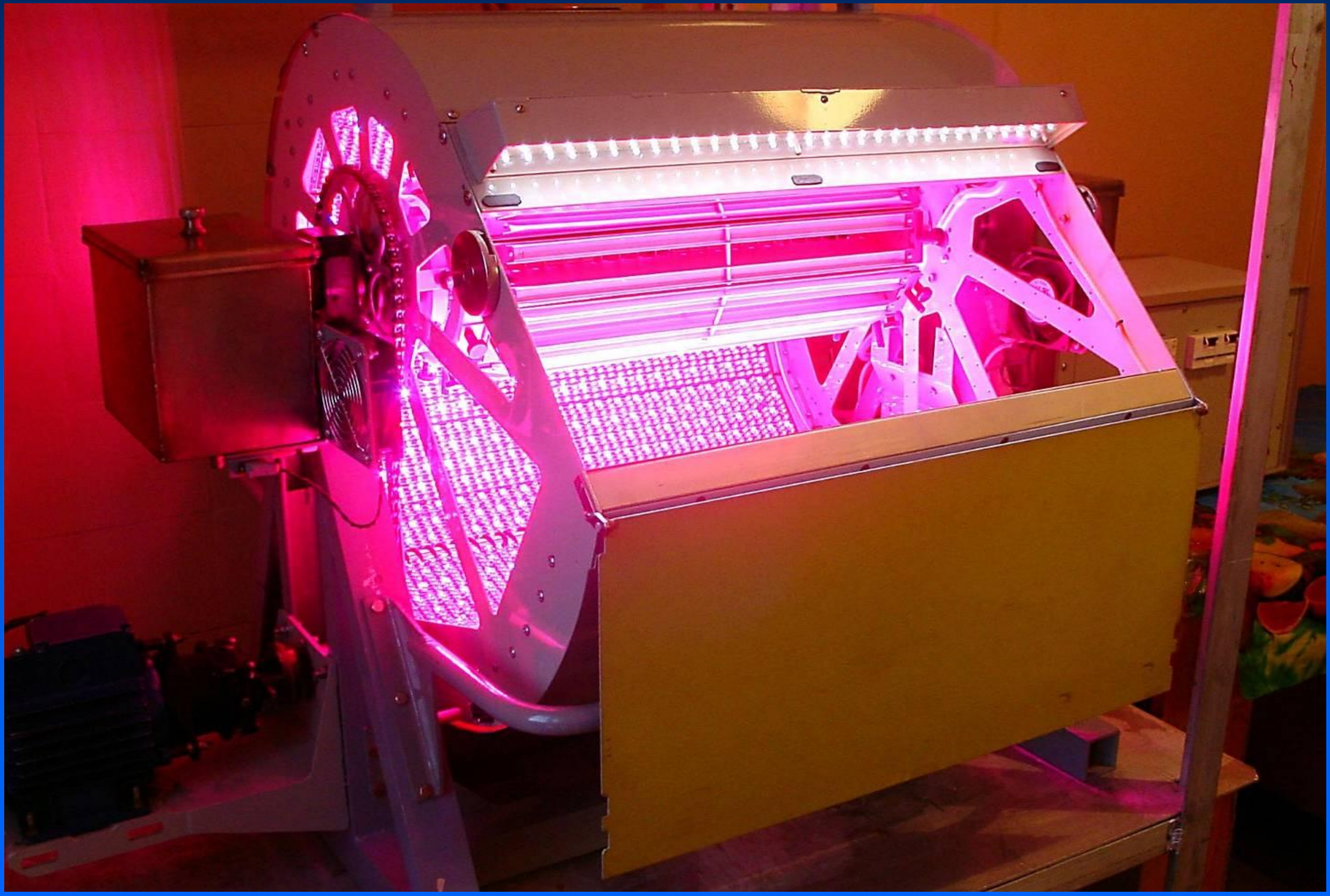
LED for Plants in Spaceflight Chambers

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision



John Sager, KSC, Testing Prototype Flight Plant Chambers with LEDs

Russian Phytoconveyor (IMBP)—Proposed for Vegetable Production for the ISS and Mars Transit



Chief Engineer: Yuliy Berkovich, IMBP, Moscow

Can Direct Solar Lighting Be Used for Mars Missions?

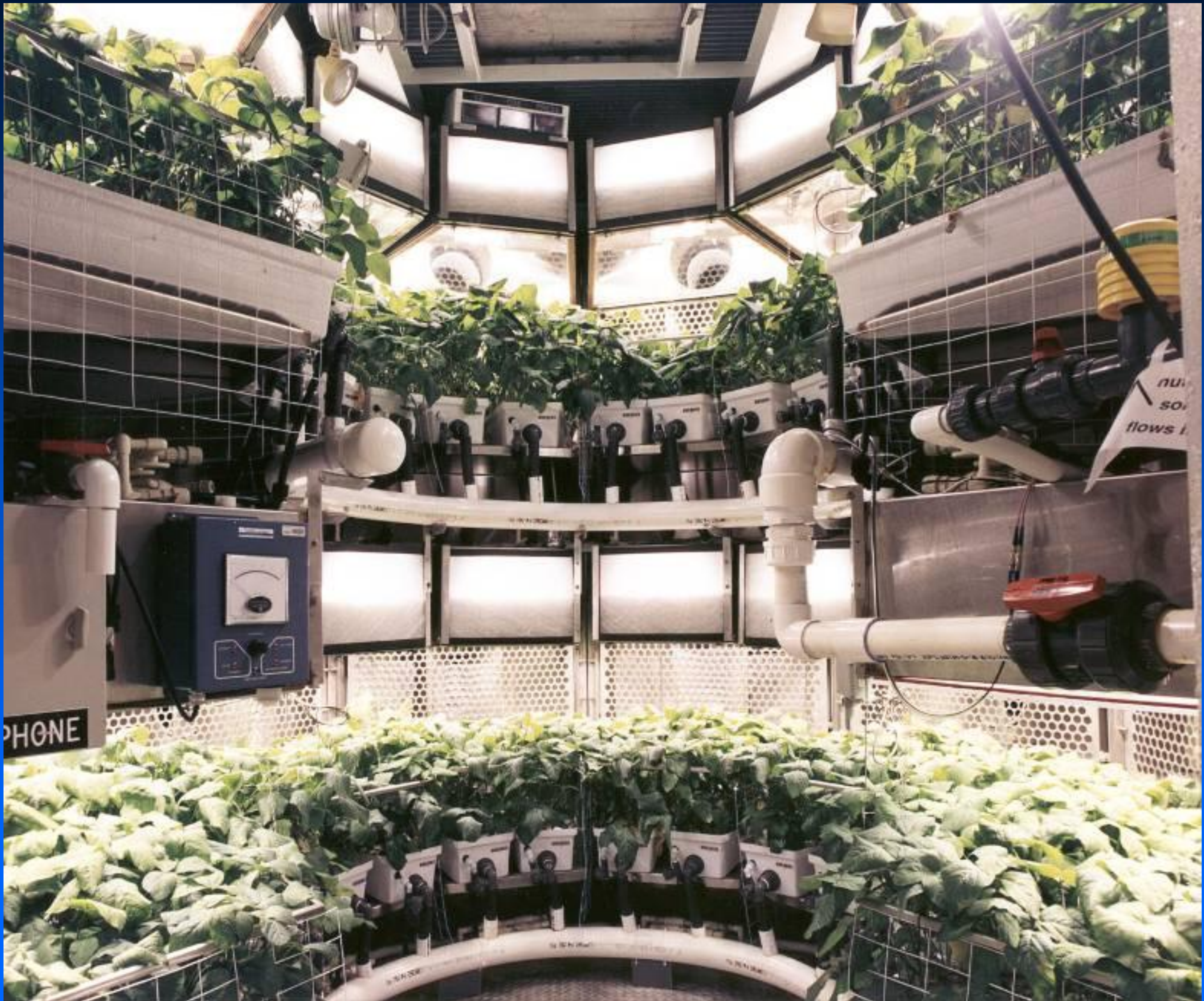
2 m^2 of collectors on solar tracking drive -- roof of Space Life Sciences Lab, KSC

Up to 400 W of solar light delivered to a plant chamber (40-50% of incident light)

Cuello et al. 1998. Life Sup Biosphere Sci.
Drysdale et al., 2008 . Adv. Space Res.

How would plant growth systems fit within human habitats or spacecraft ?

NASA's Biomass Production Chamber (BPC)



Smaller Scale Lab Testing

Testing of Plants in NASA’s Habitat Demonstration Unit

Habitat Demonstration Unit, Near Flagstaff Arizona

Plant Atrium In HDU 2011 with Red/Blue LED lighting

Plant Atrium In HDU 2012 With White LED lighting

Plant Growth Testing in Space

(mostly with seedlings or small plants)

- Early Russian and US Testing (60s through 80s)
  - Wheat, peppers, duckweed, carrot
- NASA Sky Lab
  - Rice
- Shuttle
  - Sunflower, potato, brassica, mung bean, oat, soybean, others
- Russian Mir Space Station
  - Wheat, mizuna, Chinese cabbage, brassica, others
- International Space Station
  - Wheat, mizuna, pea, barley, soybean, others

Plant Chambers for Space Shuttle and ISS

SVET
on Mir

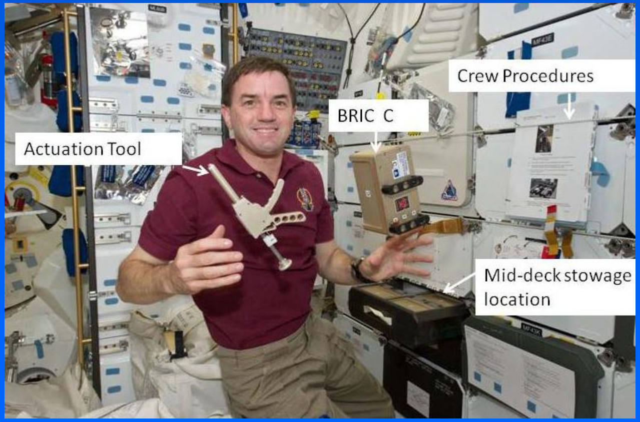
BPS
on ISS

PGBA on
Shuttle

Life Science Space Flight Experiments

Potato Tubers in Space (STS 73)

Photosynthesis in µ-gravity
(STS 110 / 8A)



Plant / Bacterial
Nitrogen Fixation
In Space (STS 135)

Croxdale et al. 1997. J. Exp Bot.
Monje et al. 2005. Planta

Russian "Lada" Plant Chamber on ISS

Mizuna Plants
(Japanese Mustard)

Plants in Tightly Closed Atmospheres:
Ethylene Effects

Epinastic (rolled)
Wheat Leaves
Ethylene at ~120 ppb

Epinastic
Potato Leaves
Ethylene at ~40 ppb

Food Safety Considerations

- Plants have to meet microbiological safety (e.g., coliform bacteria)
- Levels of biocides from water might be a concern (e.g., iodine and silver)

Top, Cosmonaut harvesting Mizuna on the ISS

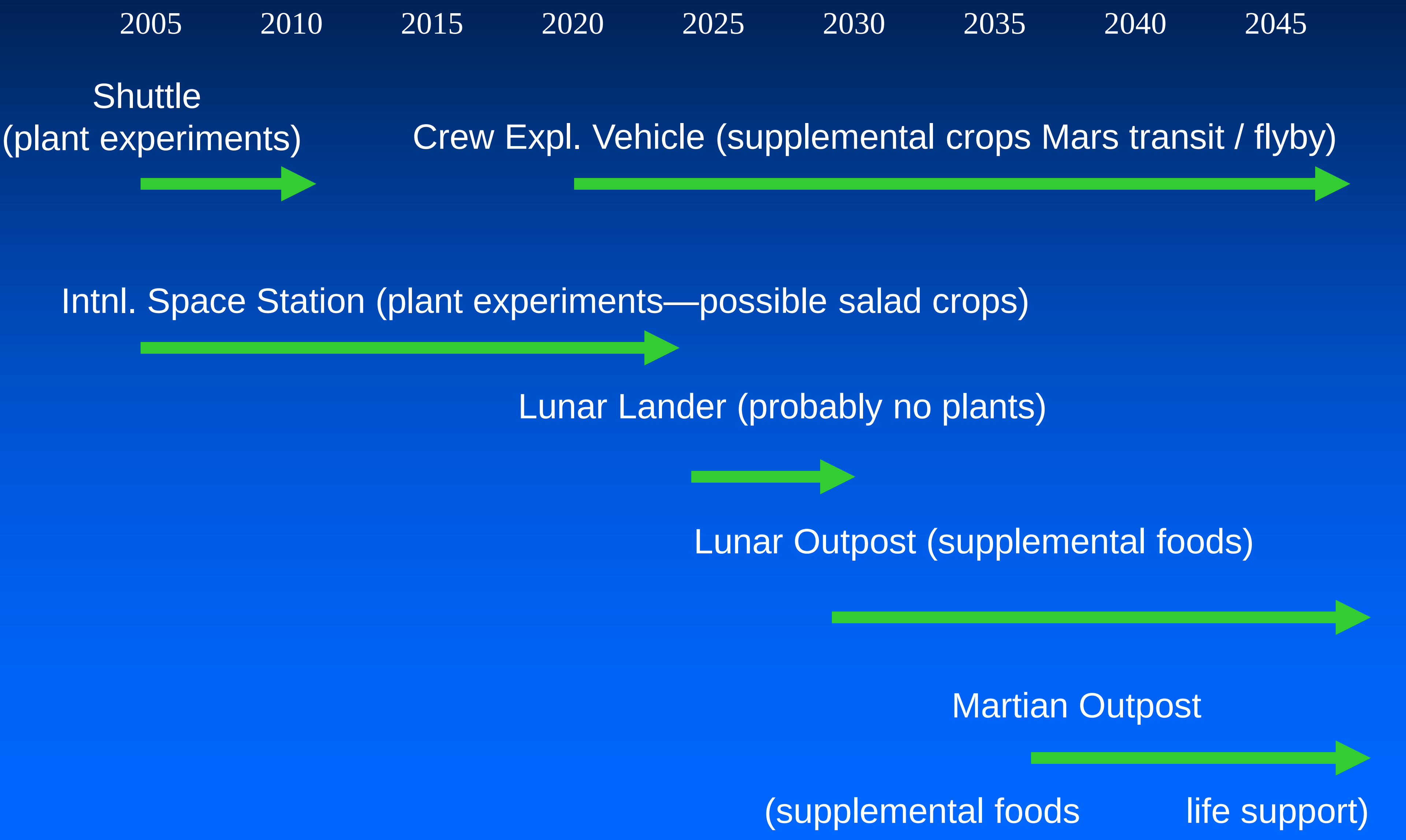
Bottom, sanitizing lettuce leaves In NASA HDU study in 2010

Constraints for Crop Production for Mars Flyby or any Space Mission:

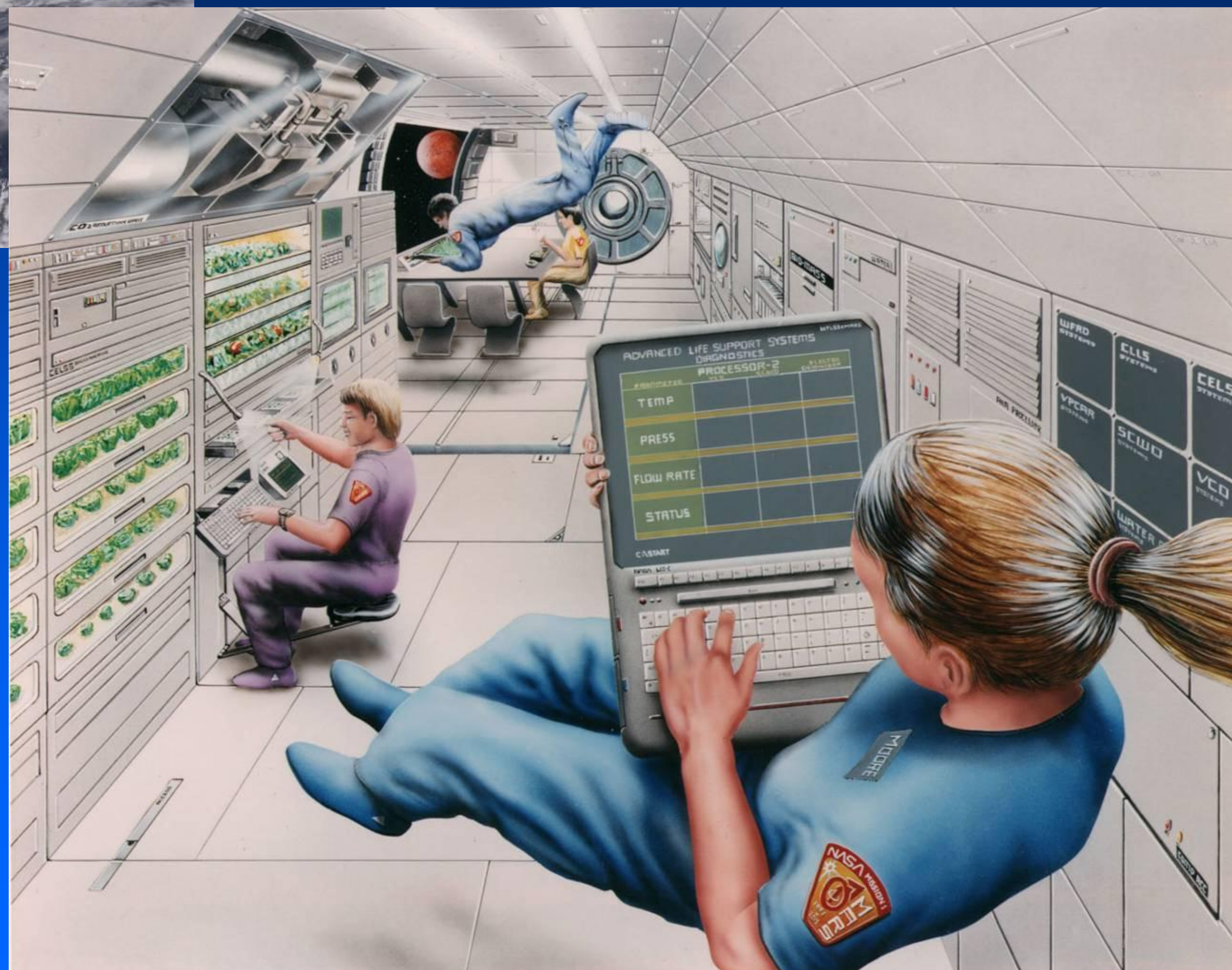
- Energy Requirements
- System Mass
- System Volume
- Crew Time
- System Reliability

These apply for all life support technologies, including the use of plants

Plants for Future Space Missions



Hopefully plants will accompany humans on their missions to Mars!



Thanks to my colleagues at NASA’s Kennedy Space Center