NASA’s Interests in Bioregenerative Life Support and the Path to Mars

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Big Idea Challenge, Langley, VA April 2019

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

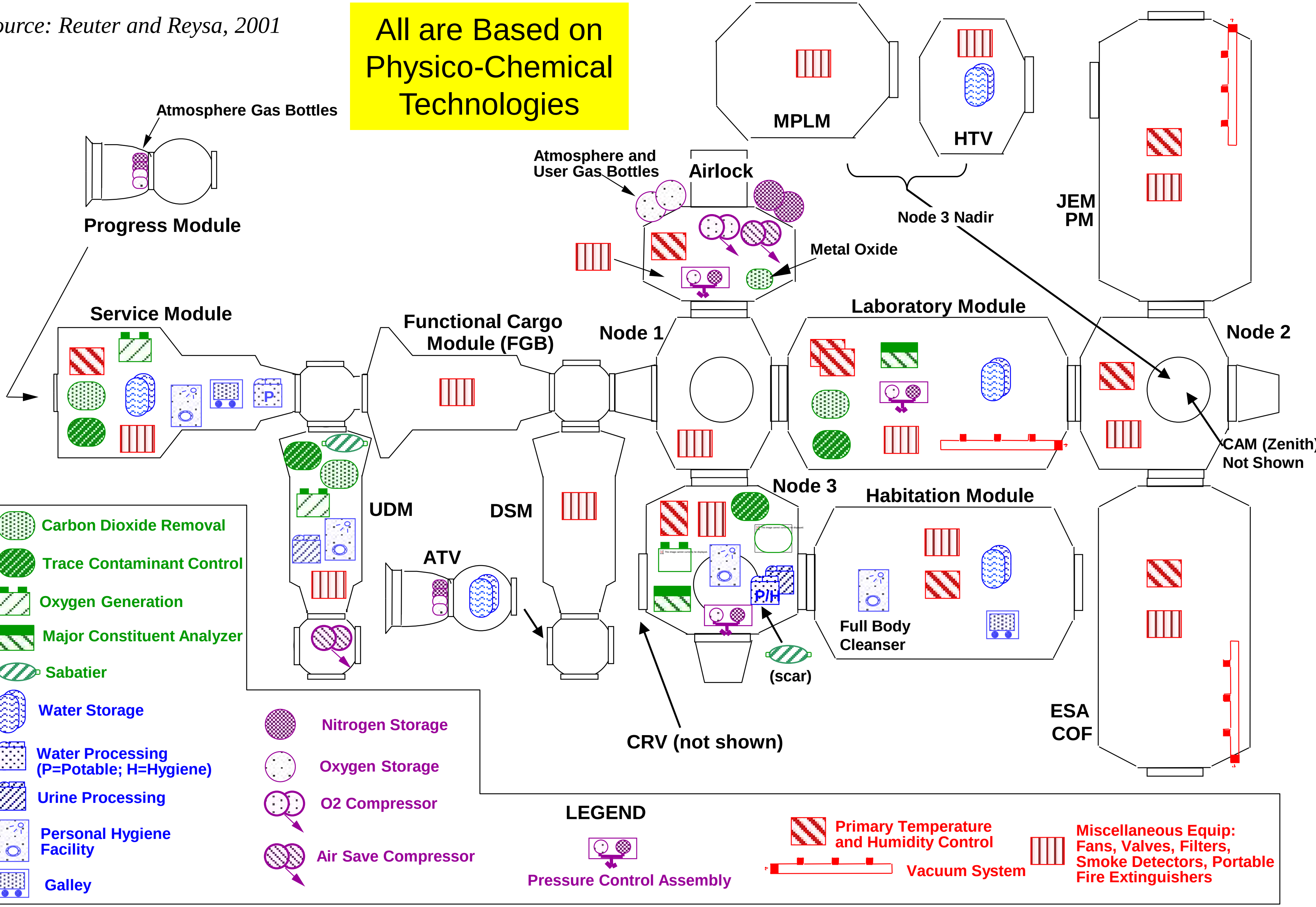
	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)
TOTAL	**31.0 kg**	

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

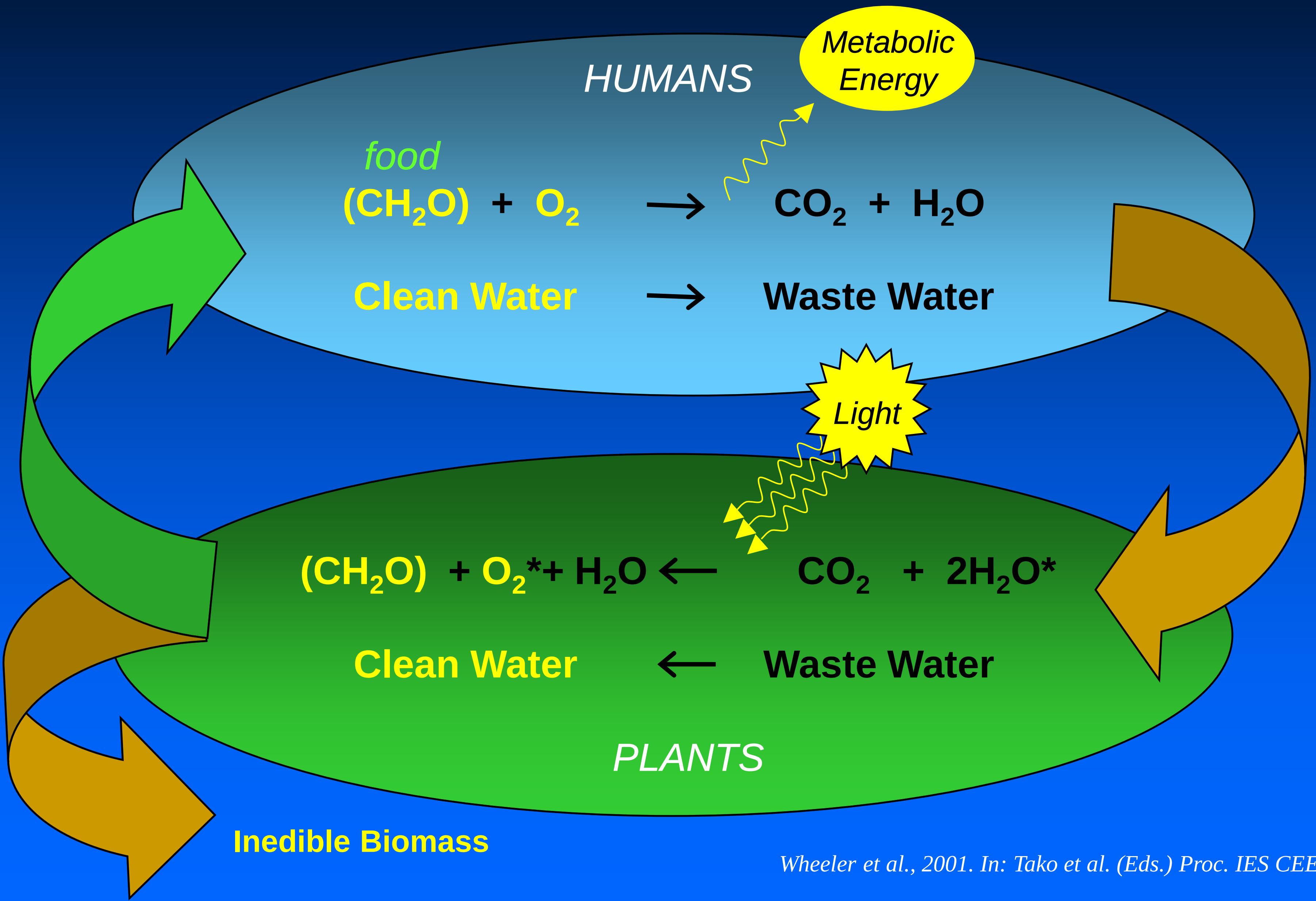
International Space Station Life Support Systems

Source: Reuter and Reysa, 2001

All are Based on Physico-Chemical Technologies

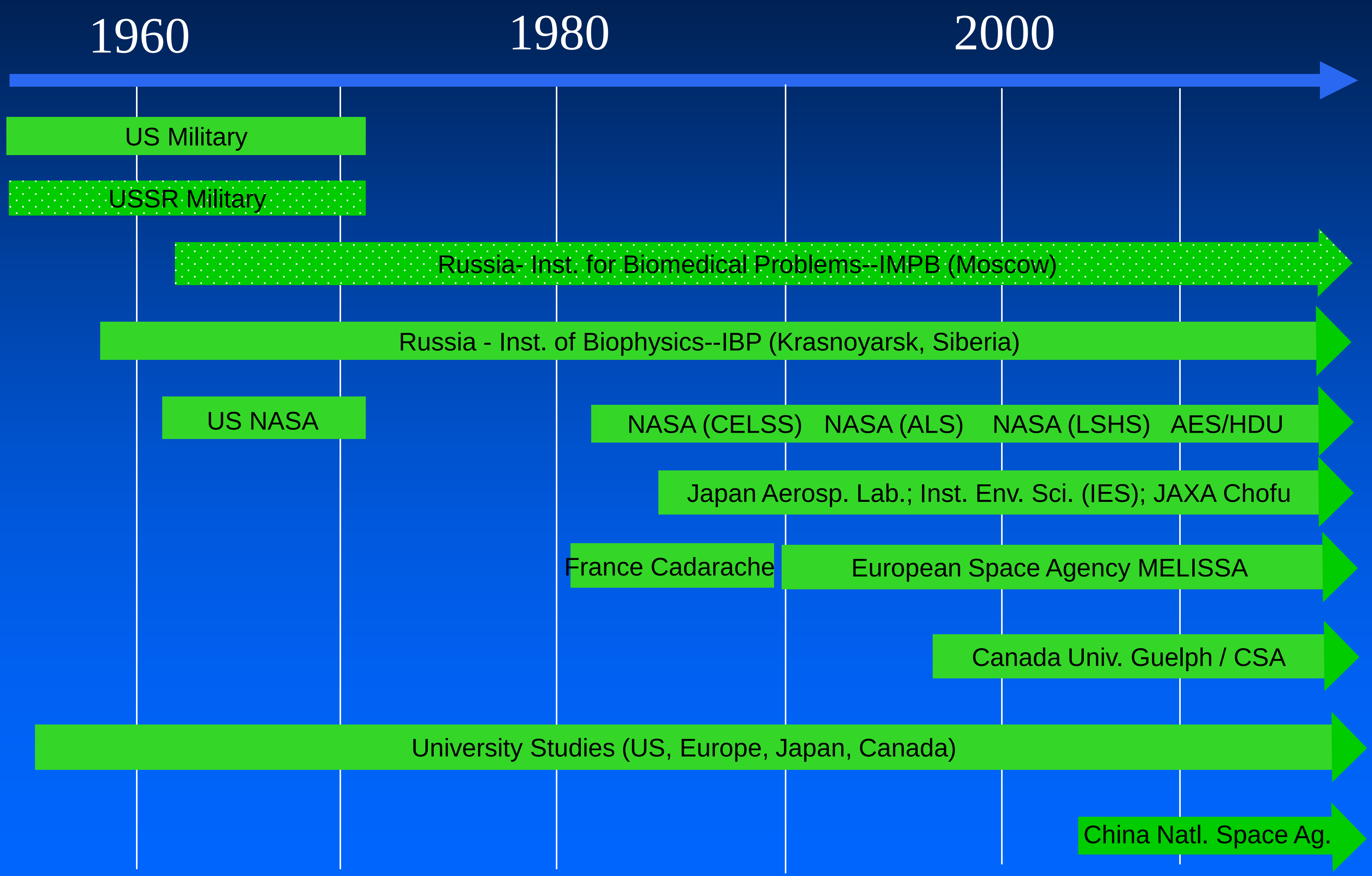


Plants for Life Support



Wheeler et al., 2001. In: Tako et al. (Eds.) Proc. IES CEEF.

Bioregenerative Life Support Testing Around the World



Crop Considerations for Space

- High yielding and nutritious
- High harvest index (edible / total biomass)
- Dwarf or low growing types
- Environmental considerations
  - light, temperature, mineral nutrition, CO_2, pressure
- Horticultural considerations
  - planting, watering, harvesting, pollination, propagation
- Processing requirements

Some Crops for Life Support

Hoff, Howe, and Mitchell (NASA)[a]	Salisbury and Clark (NASA)[b]	Crops Used in BIOS-3 (Russia)[c]	Tako et al CEEF (Japan)[d]	Waters et al. (ESA / Canada)[e]
Wheat Potato Soybean Rice Peanut Dry Bean Tomato Carrot Chard Cabbage	Wheat Rice Sweetpotato Broccoli Kale Lettuce Carrot Canola Soybean Peanut Chickpea Lentil Tomato Onion Chili Pepper	Wheat Potato Carrot Radish Beet Nut Sedge Onion Cabbage Tomato Pea Dill Cucumber Salad spp.	Rice Soybean Peanut Sweetpotato Sugar Beet Carrot Tomato Spinach Shungiku Chinese Cabbage Pea Onion/Leek Komatsuna Pepper	Lettuce Wheat Potato Sweetpotato Rice Bean Beet Cabbage Broccoli Cauliflower Carrot Kale Onion

[a] *Hoff, Howe, and Mitchell (1982);* [b] *Salisbury and Clark (1996);* [c] *Gitelson and Okladnikov (1994).*
[d] *Tako et al. (2010);* [e] *Waters et al. (2002)*

Targeted Crop Selection and Breeding for Space at Utah State University

Selection of Existing Rice Genotypes

Targeted Wheat Breeding

Photos courtesy of Bruce Bugbee, Utah State Univ.
Bugbee et al., 1997. Crop Science

'Apogee' Wheat 'Perigee' Wheat

Genetic Engineering Tools

Early Flowering and Fruit Set

No Dormancy Requirements

Overexpression of FT flowering gene in plums (ARS researchers) resulted in dwarf growth habit and early flowering

Srinivasan et al., 2012, PLOS ONE; Graham et al., 2015 Grav. Space Research

Water and Nutrients for Growing Crops

Recirculating Hydroponics

Conserve Water & Nutrients
Eliminate Water Stress
Optimize Mineral Nutrition
Facilitate Harvesting

Wheeler et al. 1999. Acta Hort.

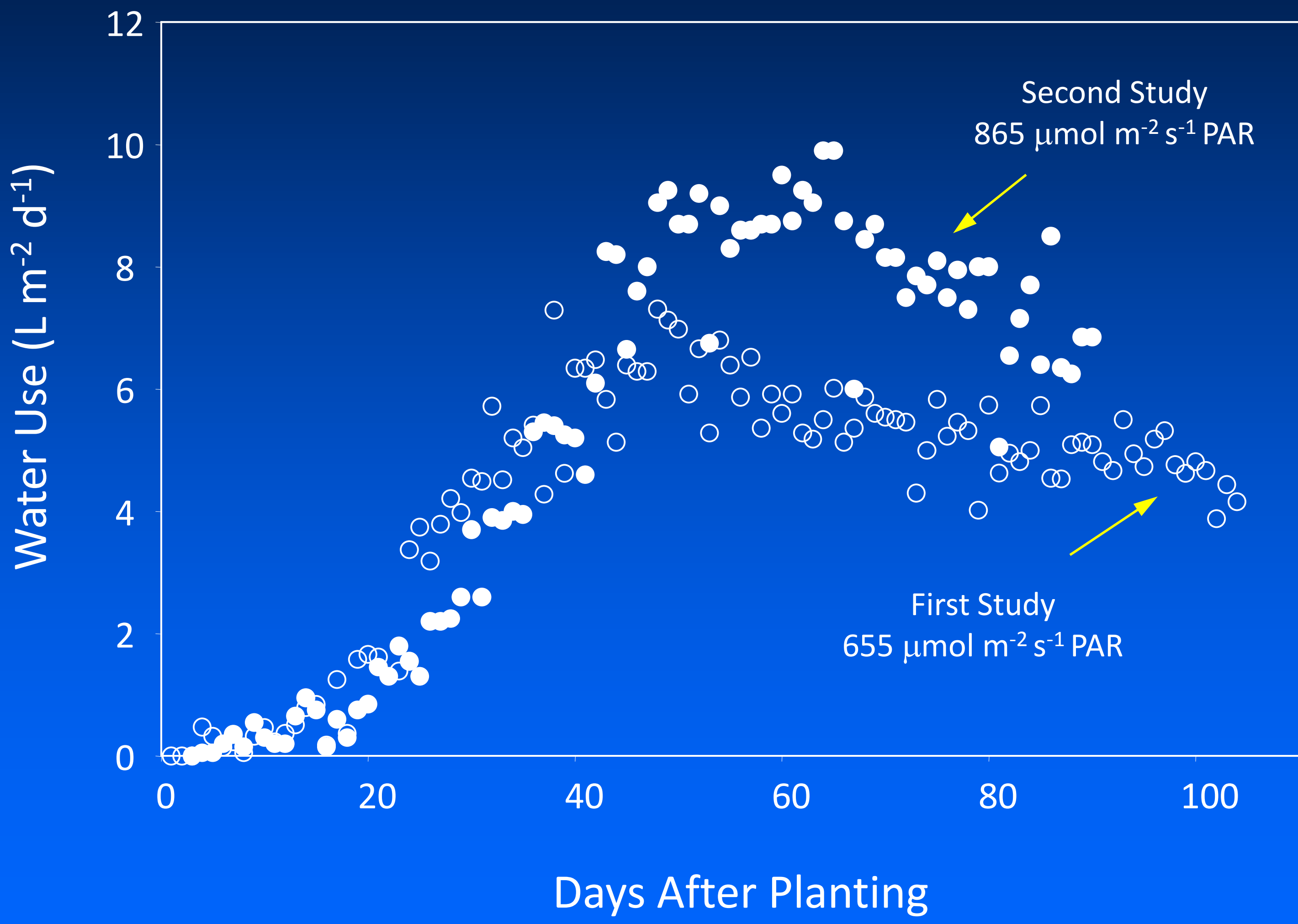
Root Zone Crops in Nutrient Film Technique (NFT)

Wheeler et al., 1990. Amer. Potato J. 67:177-187; Mackowiak et al. 1998. HortScience 33:650-651

Fig. 7

Evapotranspiration from Plant Stands (potato)

→ Dealing with the water requirements for CEA



Wheeler. 2006. Potato Research 49:67-90.

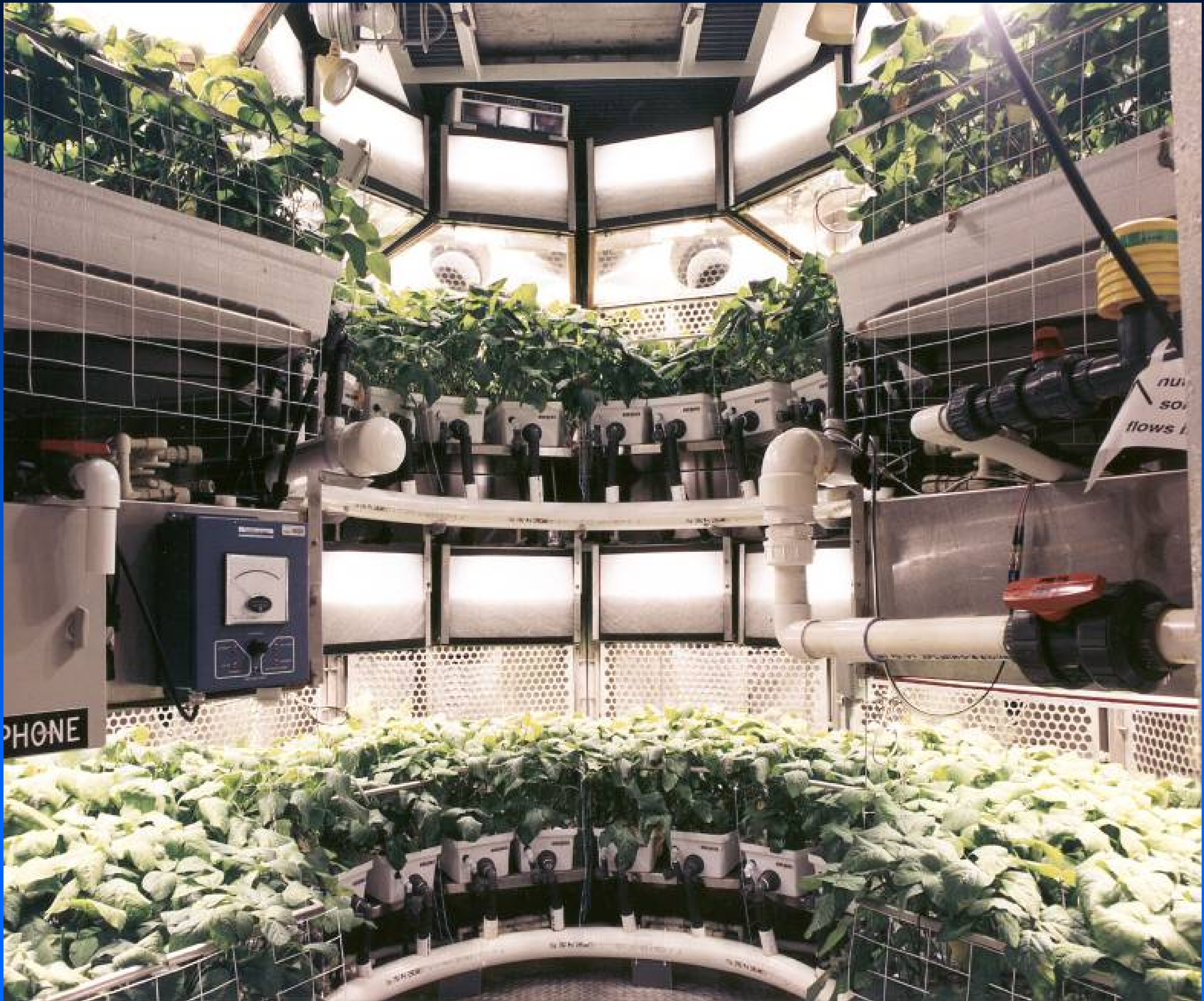
NASA's Biomass Production Chamber (BPC)

20 m^2 growing area; 113 m^3 vol.; 96 400-W HPS Lamps;
400 m^3 min^{-1} air circulation; two 52-kW chillers

Wheeler. 1992. HortScience

NASA's Biomass Production Chamber (BPC)

…an early example of a Vertical Agriculture Systems

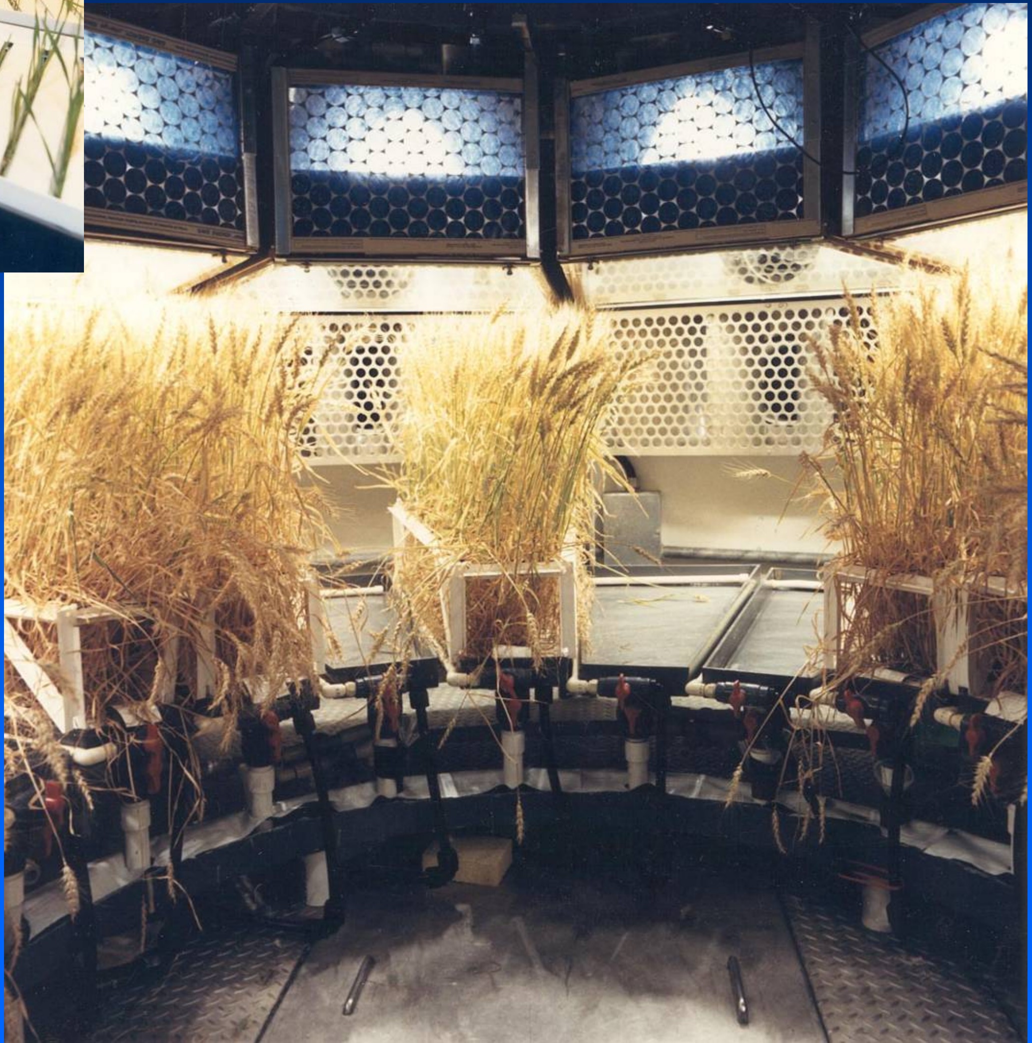


Wheat

(Triticum aestivum)

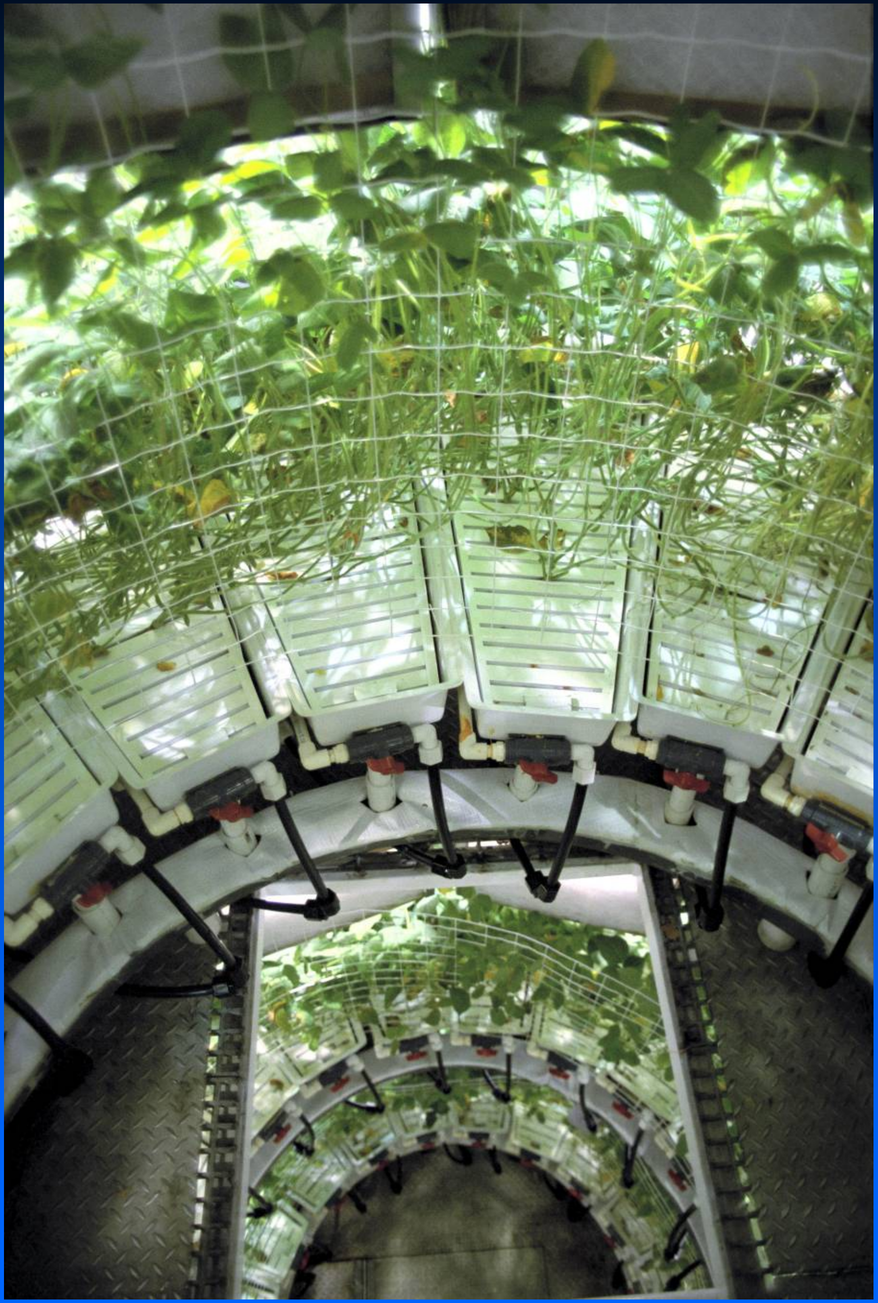
planting

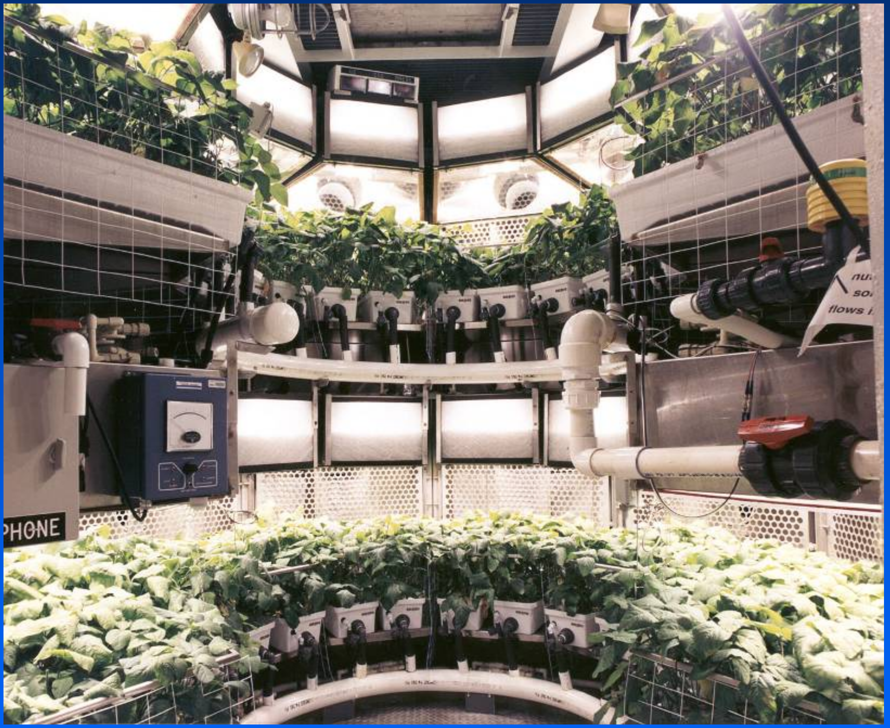
harvest



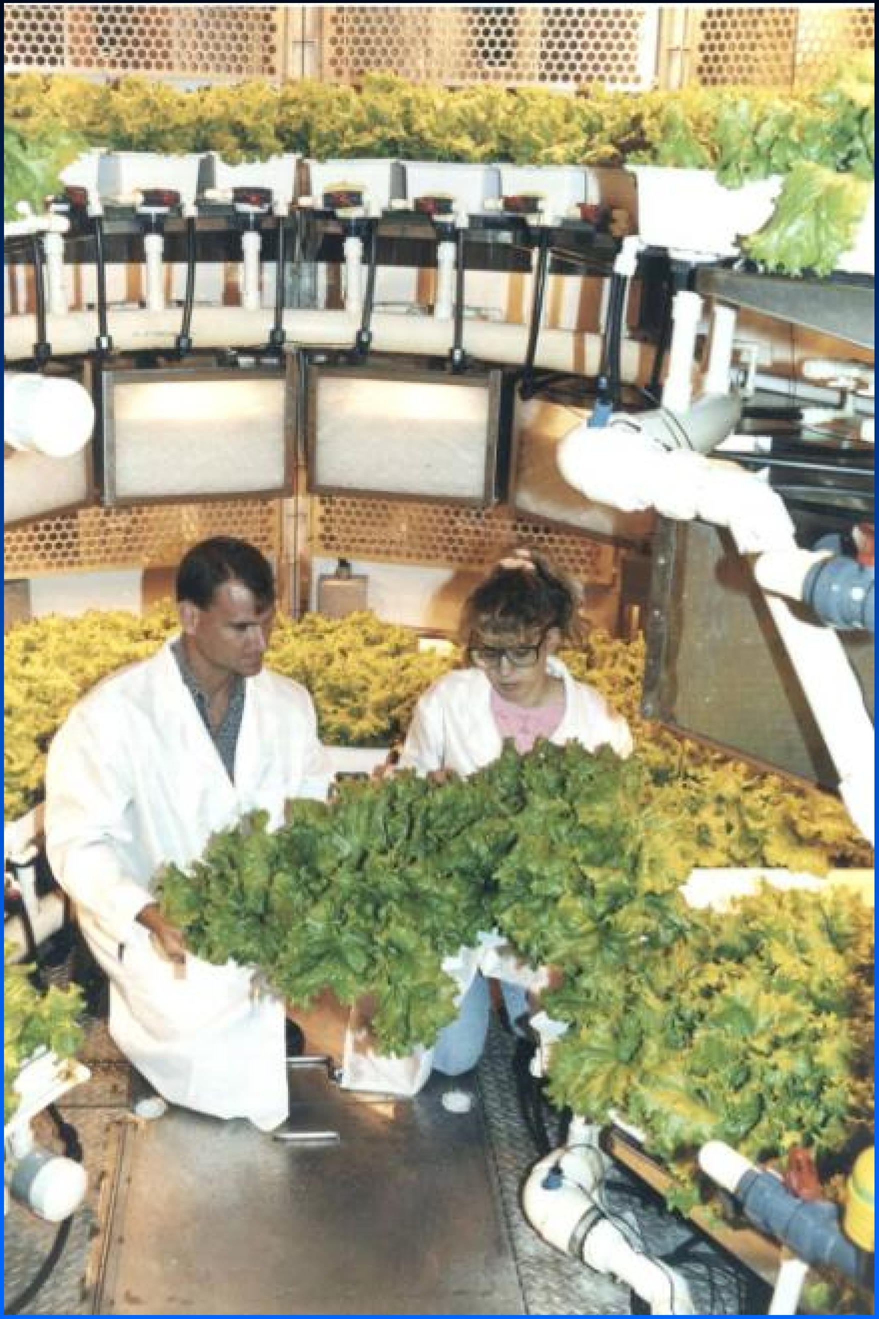
Soybean

(Glycine max)





Lettuce
(Lactuca sativa)

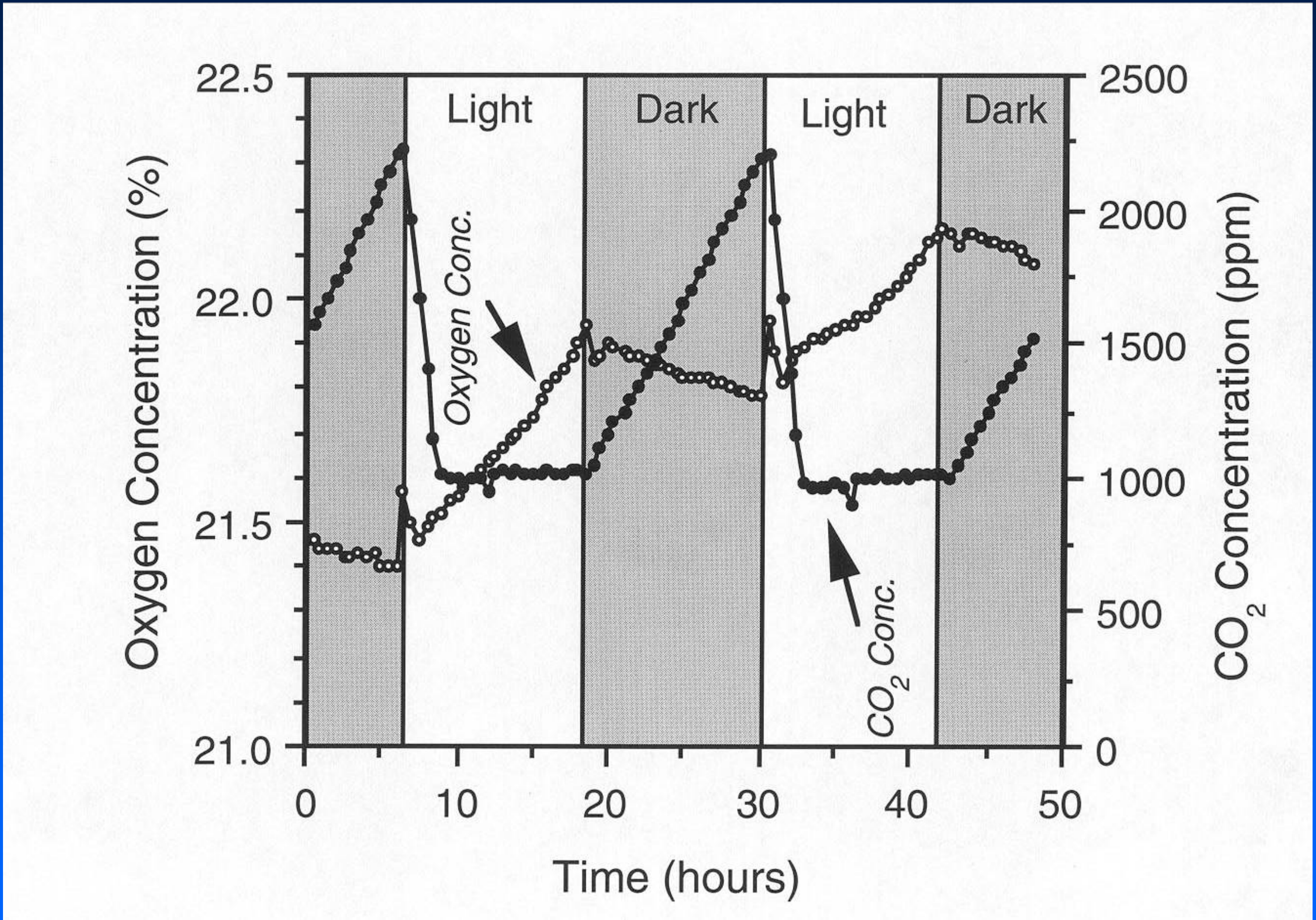


Potato

(Solanum tuberosum)

Canopy CO_2 Uptake / O_2 Production

(20 m^2 Soybean Stand)



Wheeler. 1996. In: H. Suge (ed.) Plants in Space Biology.

Human Life Support Testing with Crops

Nigel Packham, NASA JSC 1995
Photo courtesy Dan Barta, NASA JSC

Econaut, Japanese CEEF Facility 2007

Lighting for Crops on Mars

- Electric Lighting
  - Power demands ?
  - Replacement costs ?
- Solar lighting
  - Transparent or partial transparent structures ?
  - Collect and transmit light?
  - Martian diurnal cycle; dust storms?

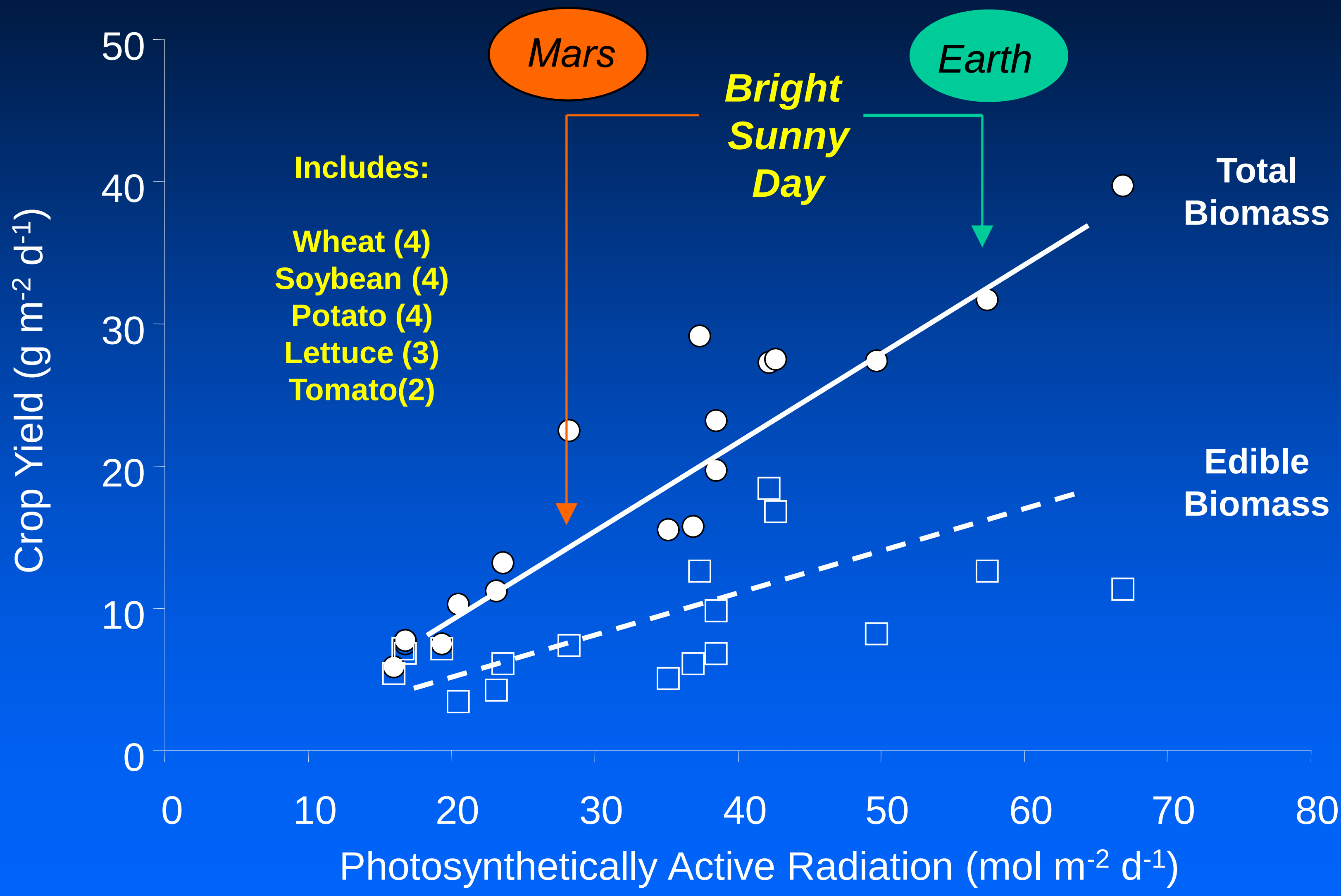
LED for Crop Production in Space

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

Goins et al. 1997. J. Ex. Bot.; Kim et al. 2004 Ann. Bot.

US Patent for using LEDs to Grow Plants Developed with NASA Funding at University of Wisconsin – WCSAR

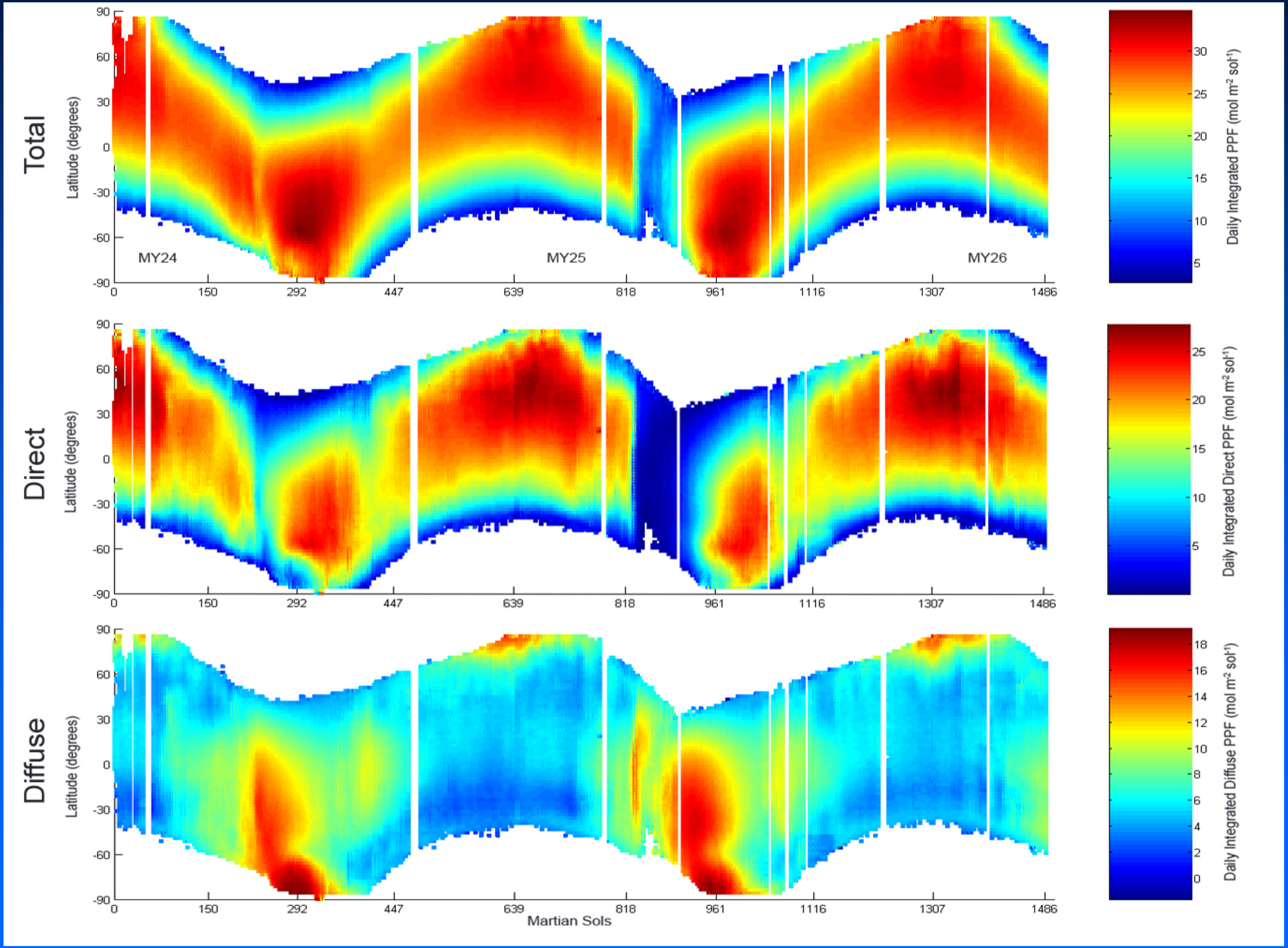
The Importance of Light for Crop Yield



Wheeler et al. 1996. Adv. Space Res.

Sunlight on Mars Surface--

Jim Clawson, Univ. Colorado, 2007



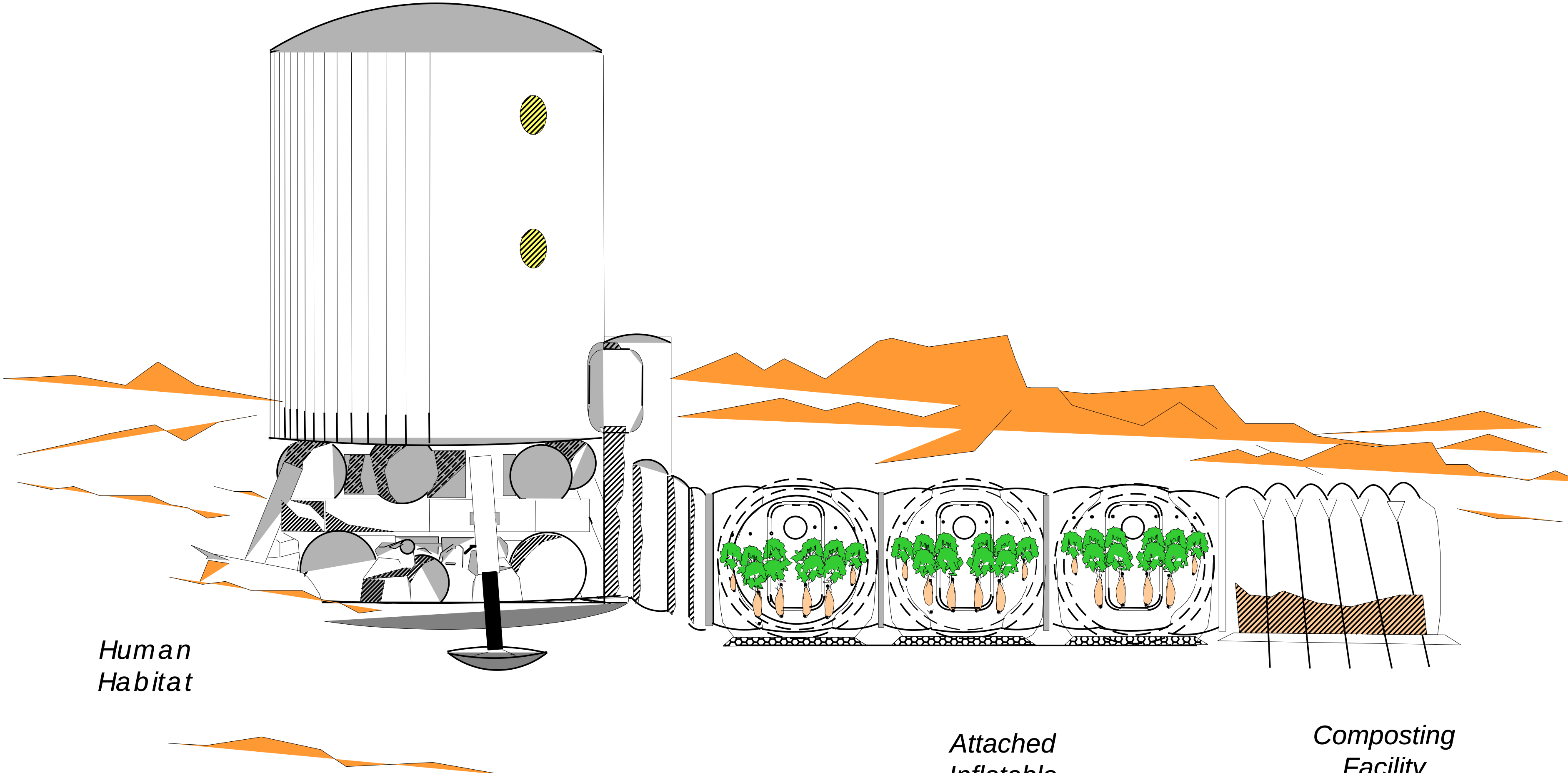
Solar Collector / Fiber Optics For Plant Lighting

2 m^2 of collectors on solar tracking drive (NASA KSC)

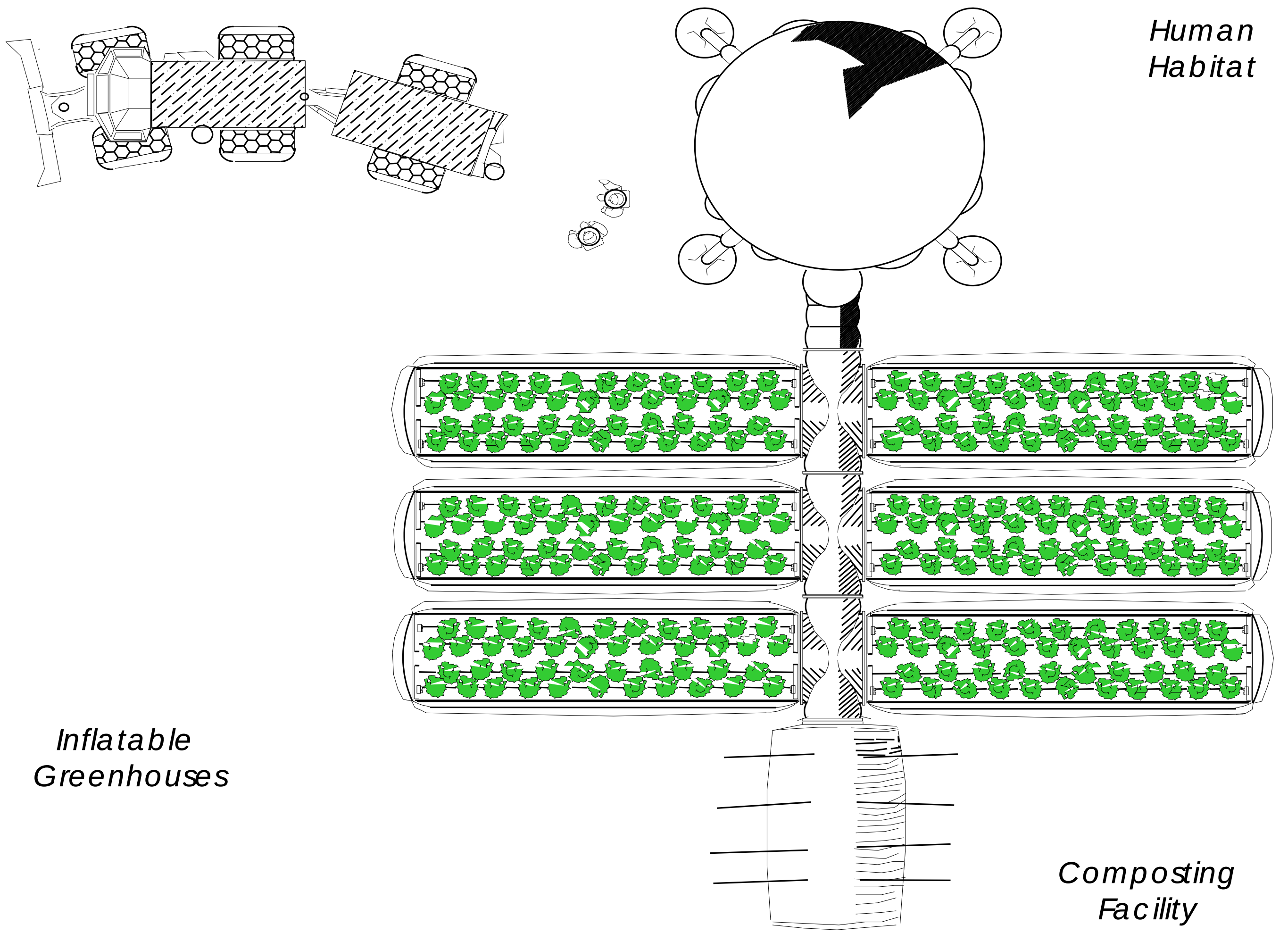
Up to 400 W light delivered to chamber (40-50% of incident light)
Takashi Nakamura, Physical Sciences Inc.

Nakamura et al. 2010. Habitation

Inflatable Greenhouses for Crop Production



Sadler, P.D. and G.A. Giacomelli. 2002. Mars inflatable greenhouse analog. Life Support Biosphere Sci. 8:115-123.



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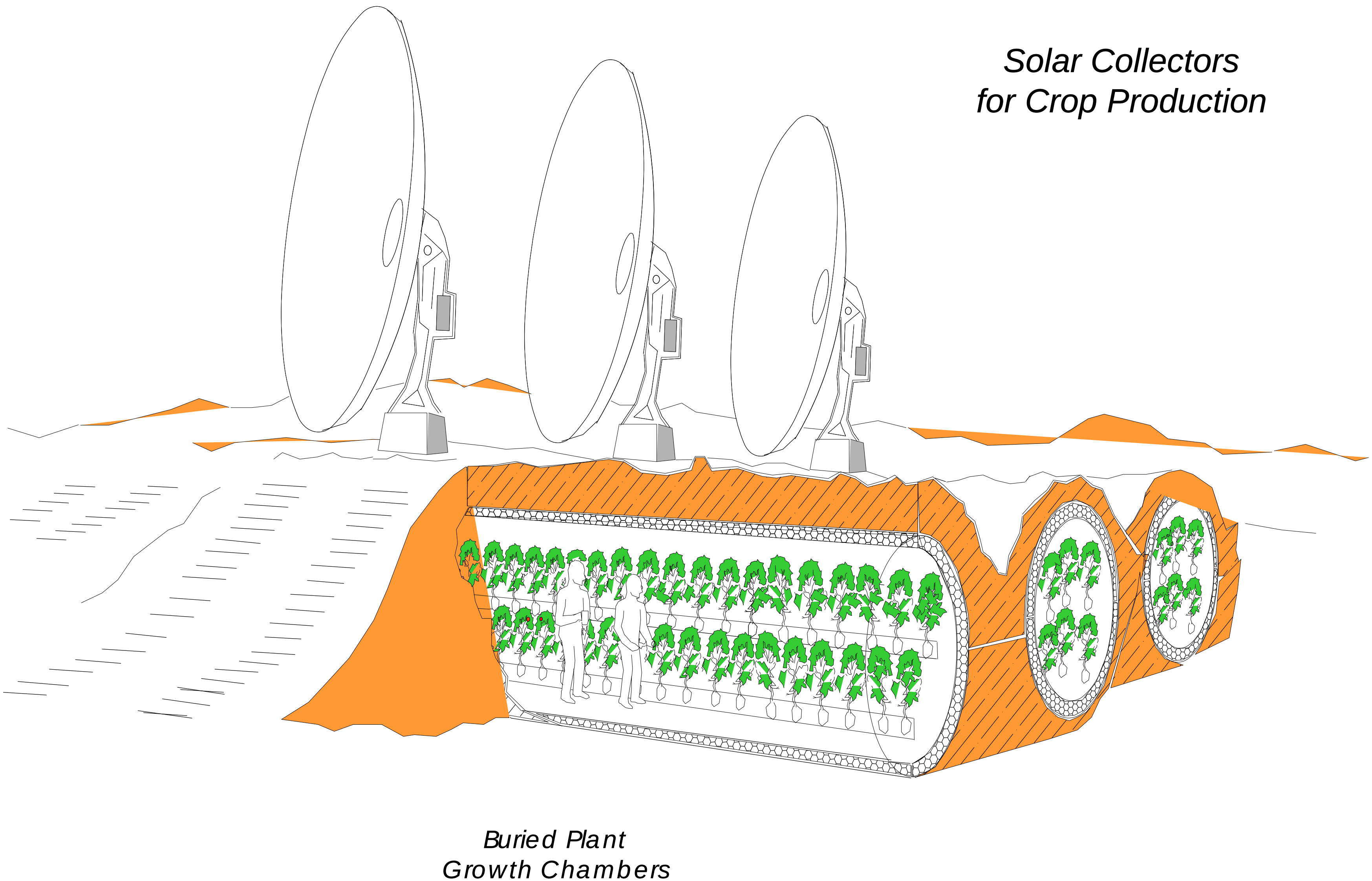
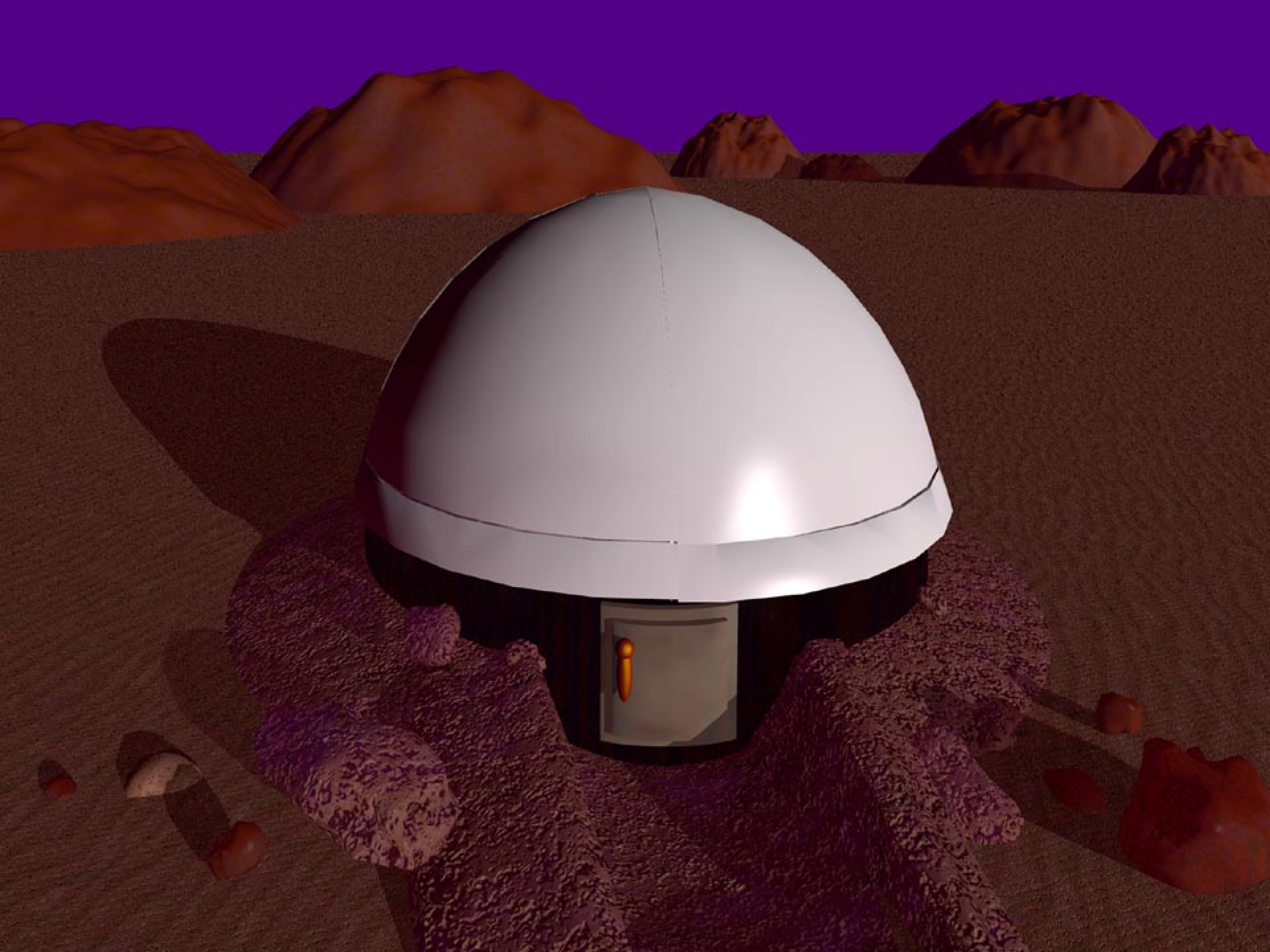
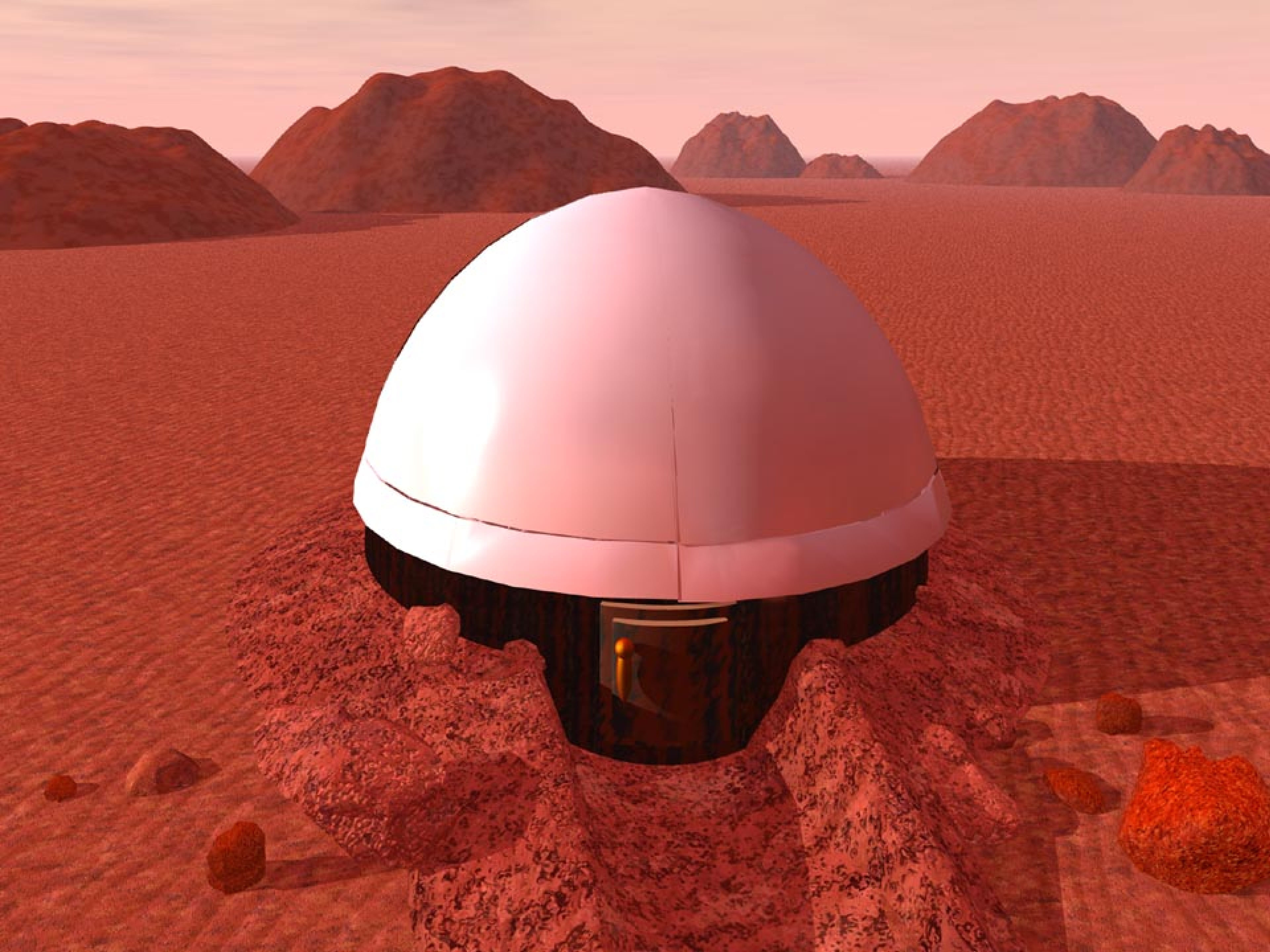


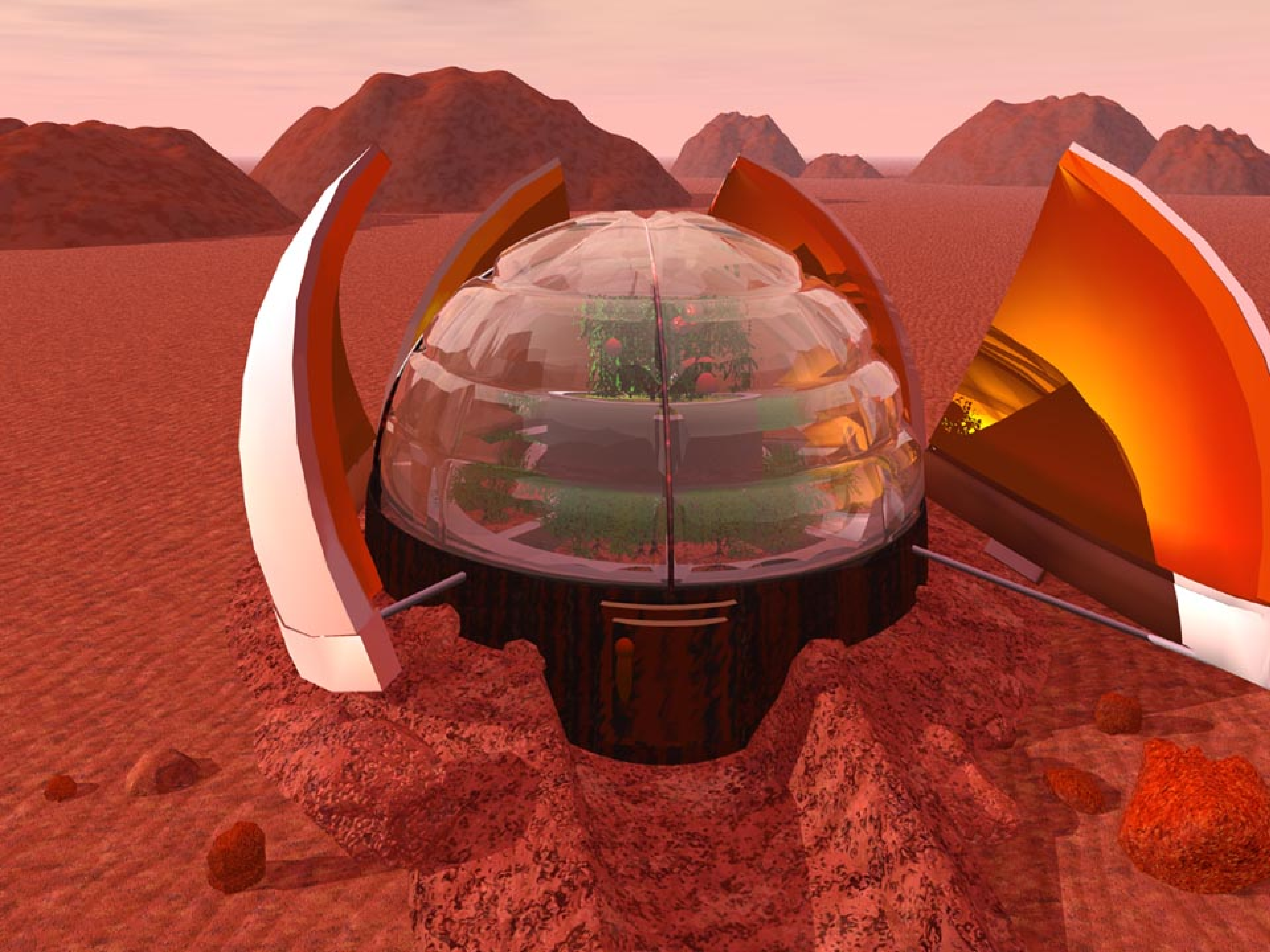
Sadler, P.D. and G.A. Giacomelli. 2002. Mars inflatable greenhouse analog. Life Support Biosphere Sci. 8:115-123.

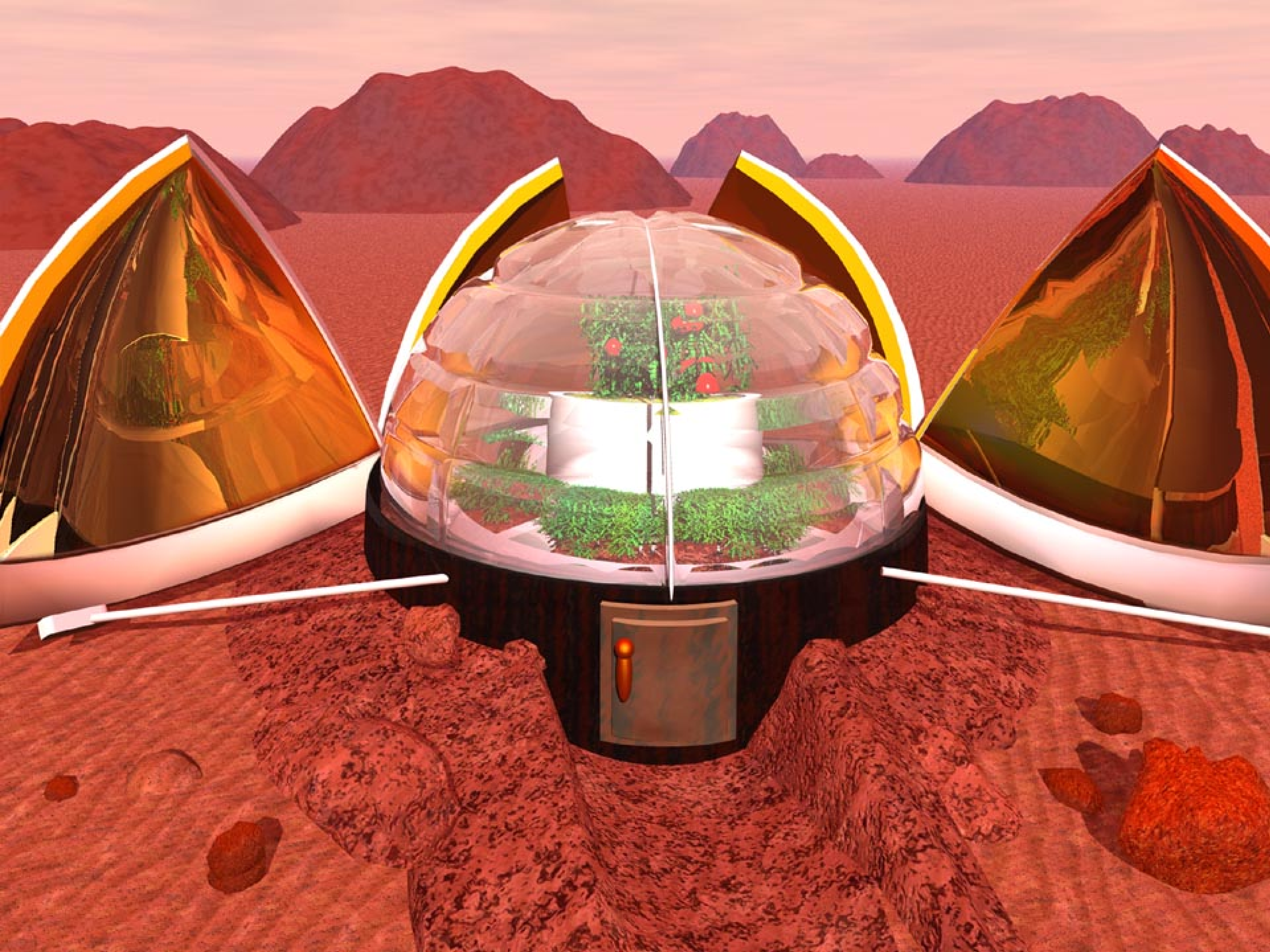
University of Arizona Deployable Greenhouse

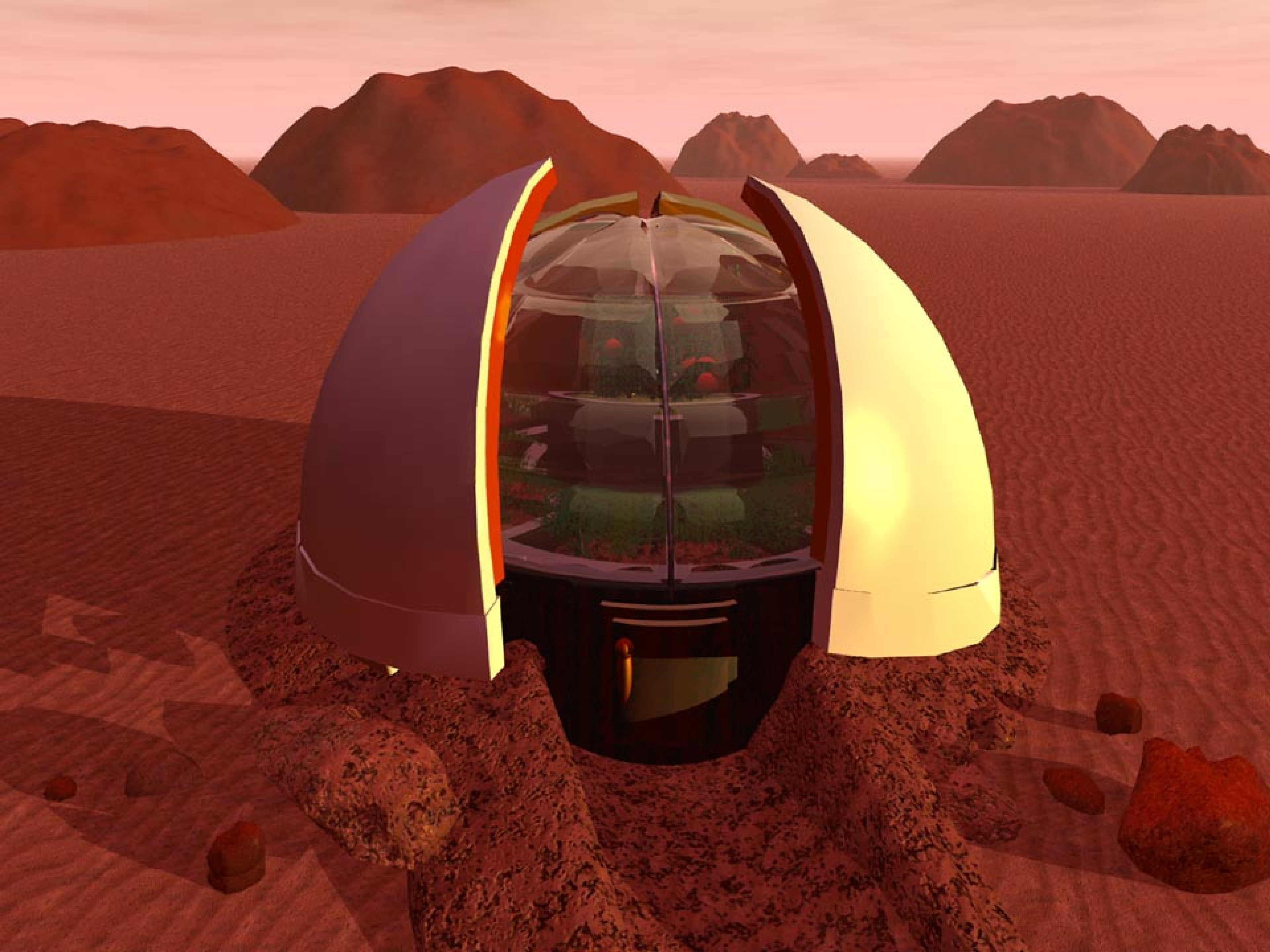
Photos Cou
Phil Sad
Univ. of Ar

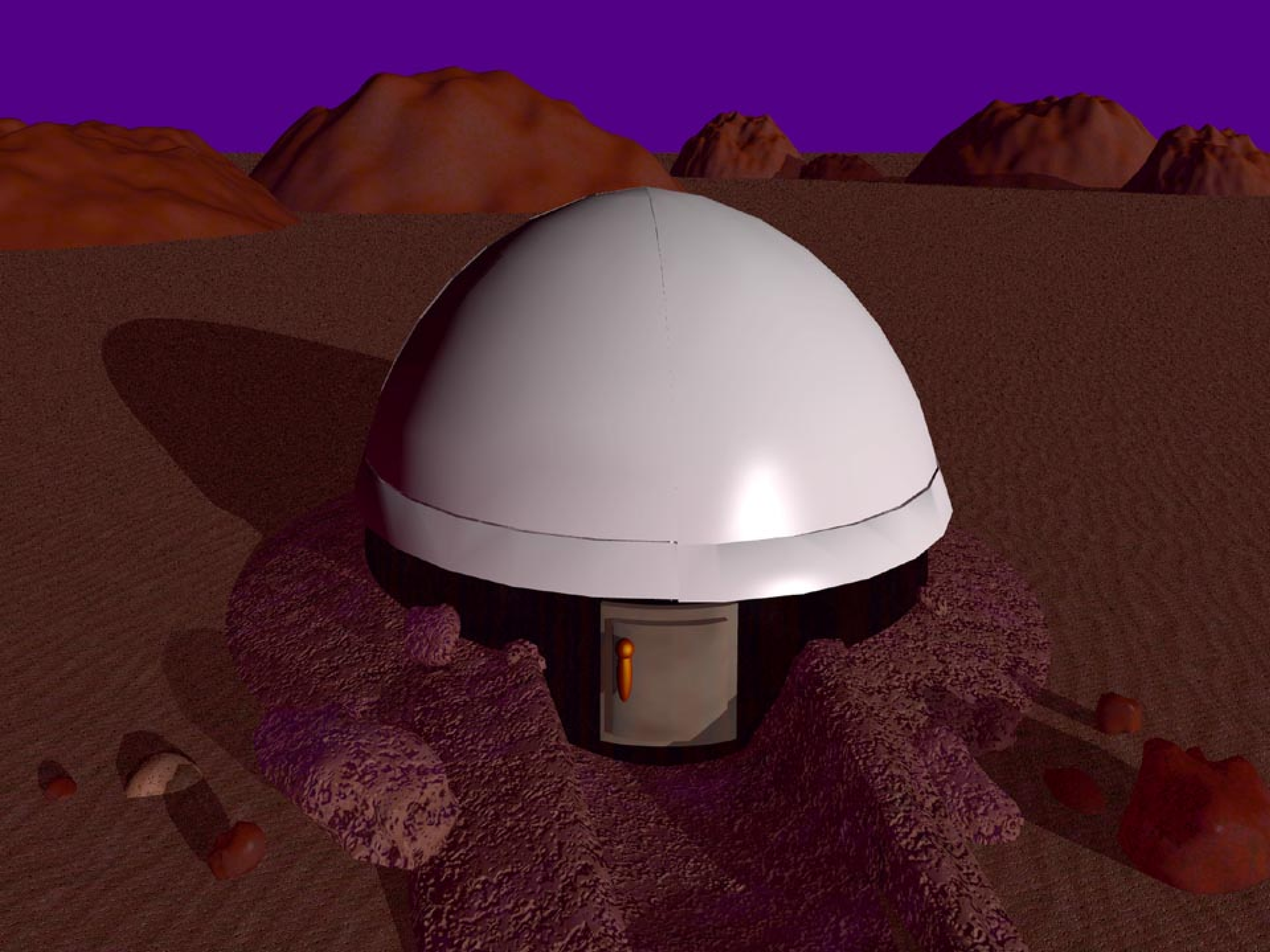












Greg Goins

Phil Fowler, Mike Dixon, Vadim Rygalov

Vadim Rygalov

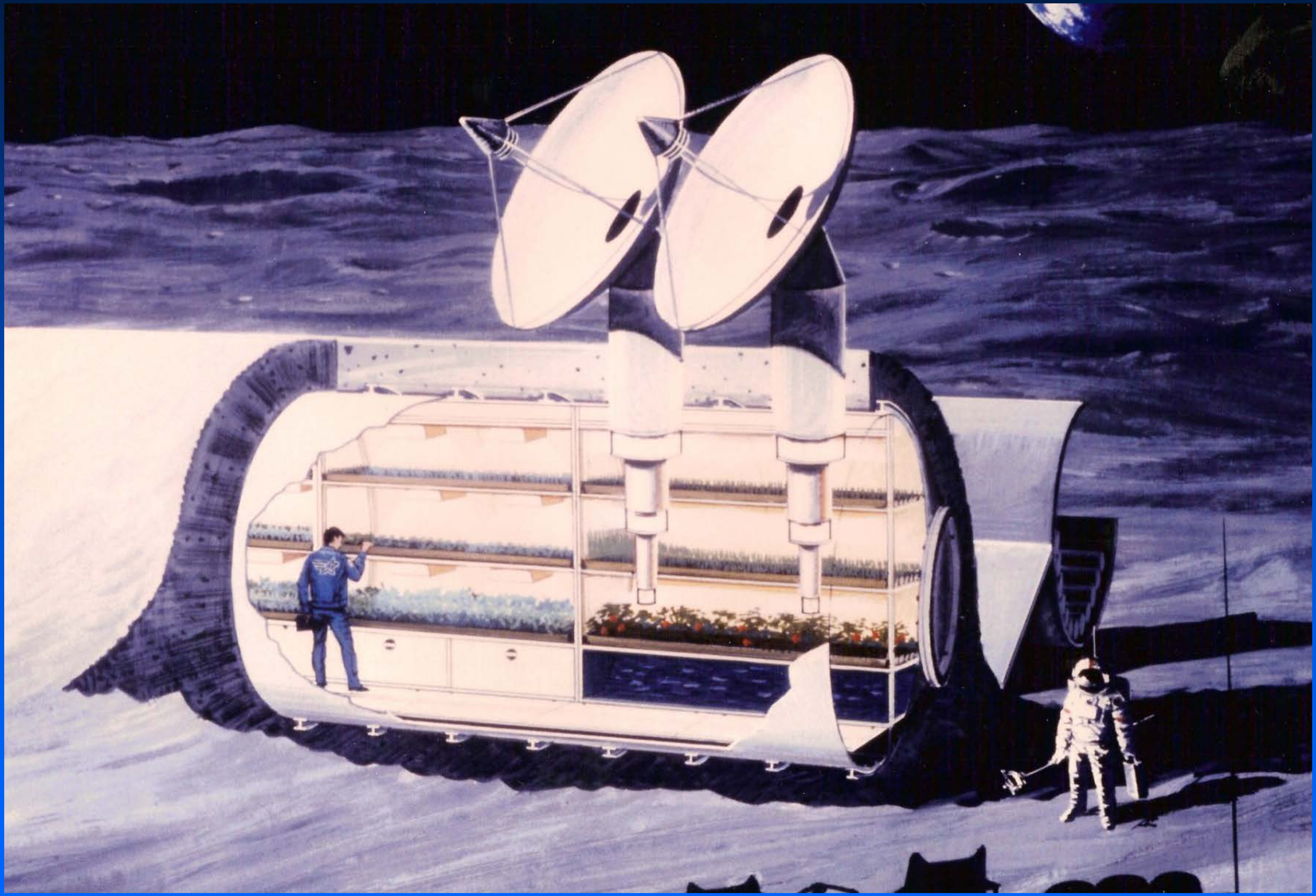
Ray Wheeler, Phil Fowler, Vadim Rygalov

Greenhouses for Mars?

Courtesy of NASA Langley Animation Office

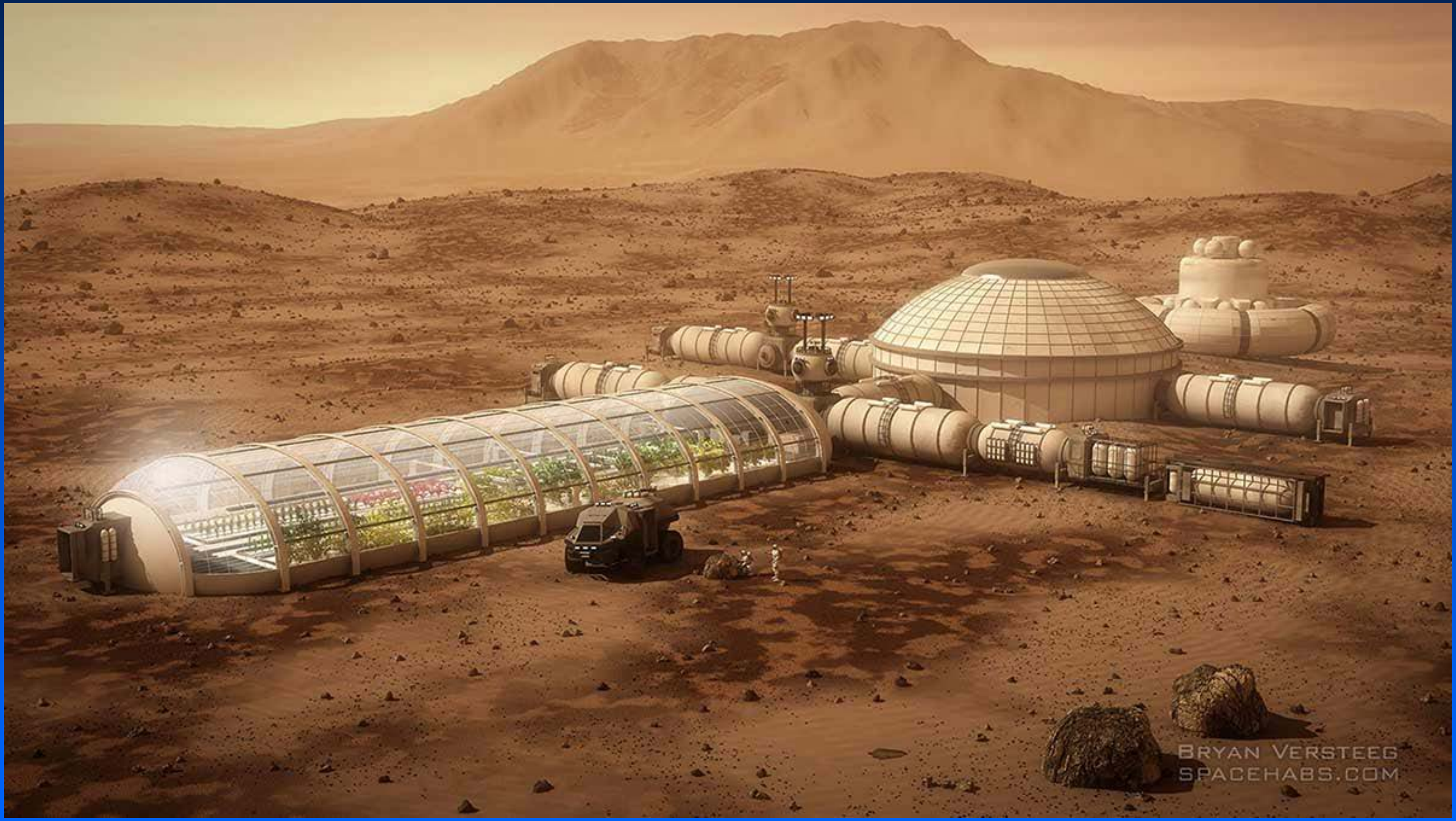
Greenhouses for Mars?

Greenhouses for Mars?



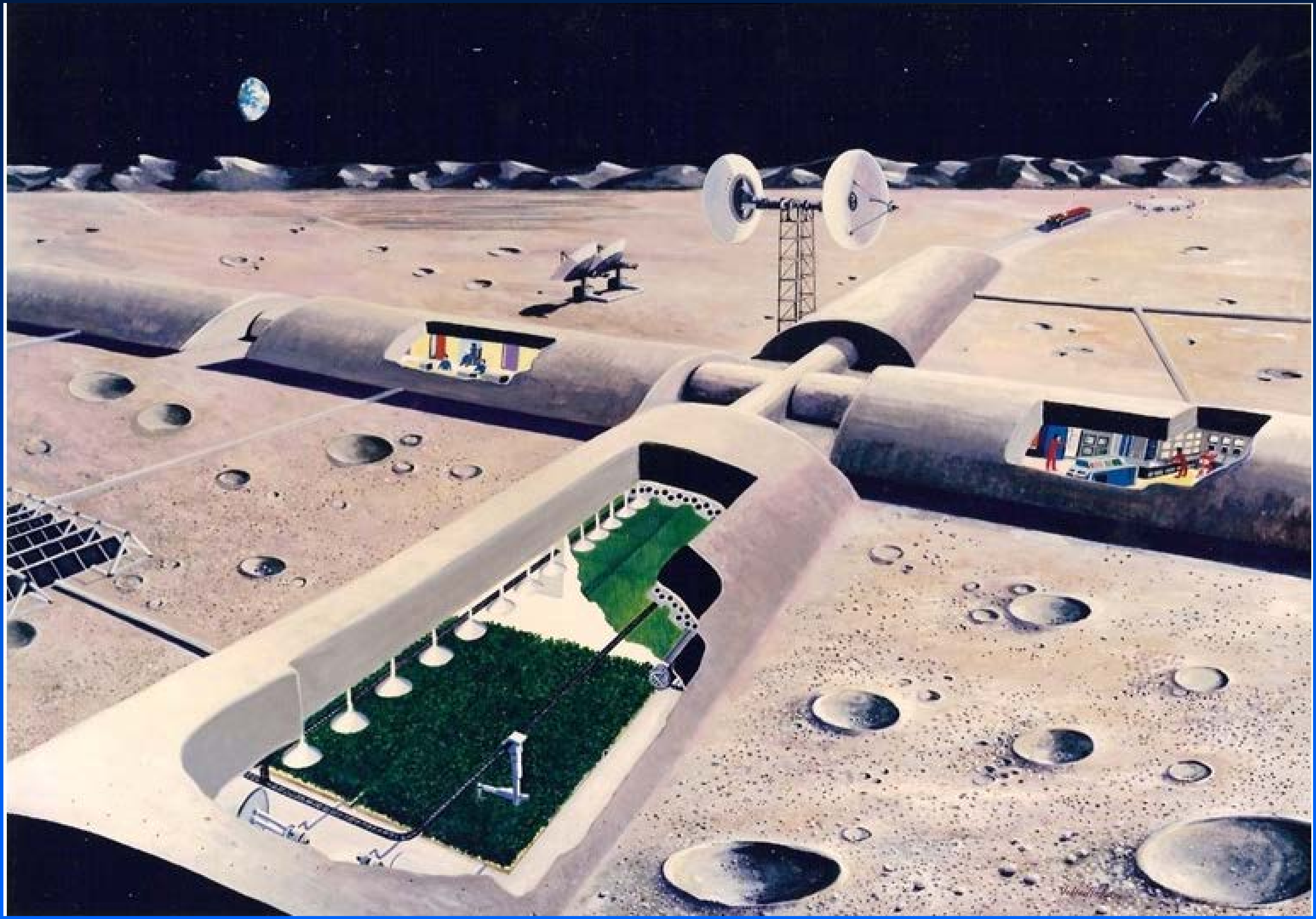
Schwartzkopf, 1992, BioScience

Greenhouses for Mars?



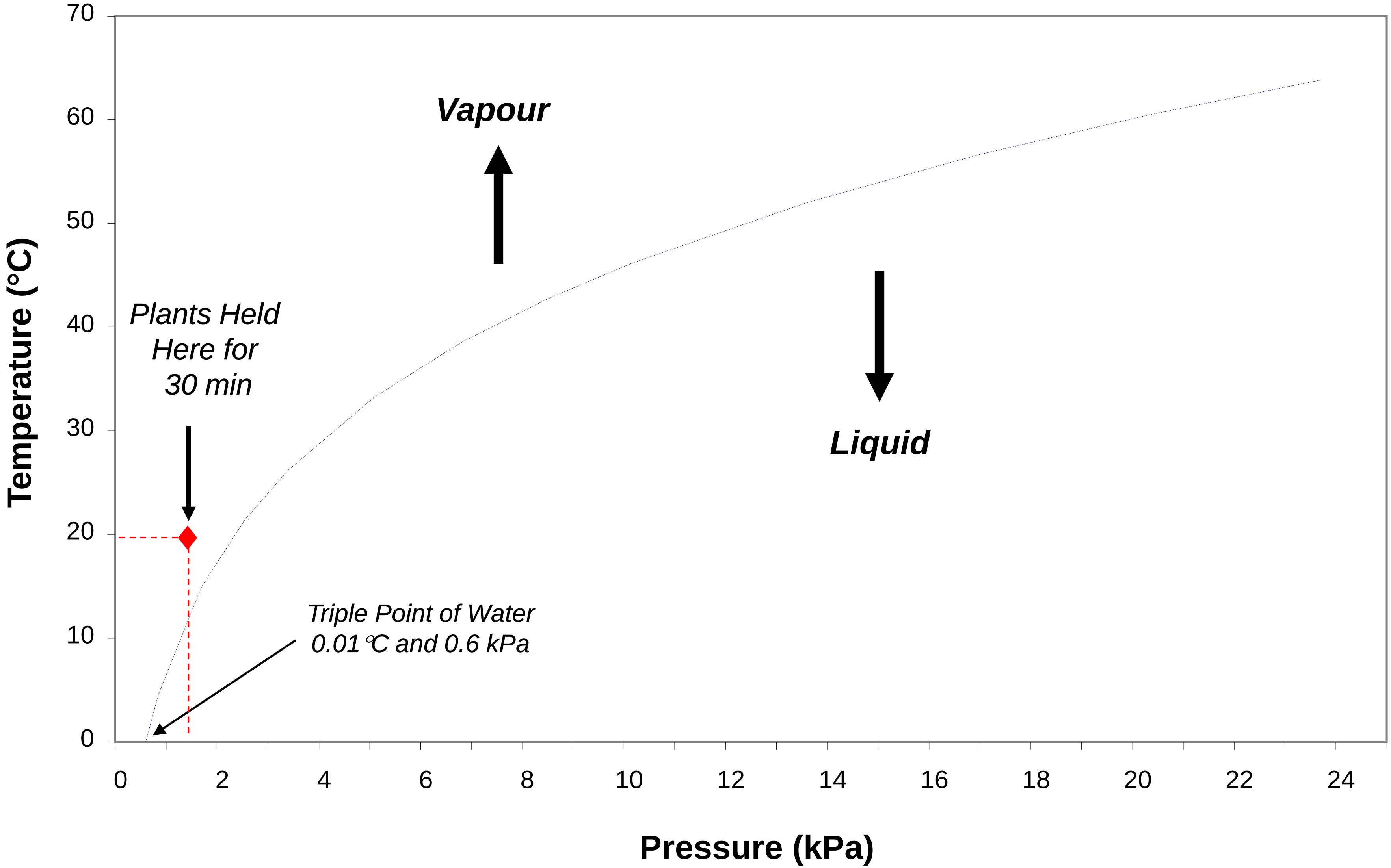
Bryan Versteeg Spacehabs.com

Greenhouses for Mars?



Source, NASA - Univ. of Wisconsin Center for Space Automation and Robotics – WCSAR 1990

Plant Can Survive Rapid Decompression for up to 30 minutes!



Wheeler et al. 2011. Adv. Space Res.

Plants and Human Well-Being—Biophilia Concept? (E.O. Wilson)

Plant Chamber at US South Pole Station

Photo courtesy of Phil Sadler, Univ. of Arizona

Some Lessons Learned from NASA CEA Research

- 20-25 m^2 of crops could provide all the O_2 for one person, and 40-50 m^2 all of the food (dietary calories)
- Better adapted crops are needed—short growth, high harvest index, improved nutrition
- Energy efficient lighting is key to sustaining high yields
- CEA systems require large quantities of water (e.g., 50 L m^{-2}) and this water must be recycled.
- Up to 90 kg of fertilizer would needed per person per year, emphasizing the need for recycling nutrients.
- Plants can provide psychological benefits to humans—this needs further study.
- The use of agriculture for space life support will likely evolve sequential, as mission infrastructures expand.

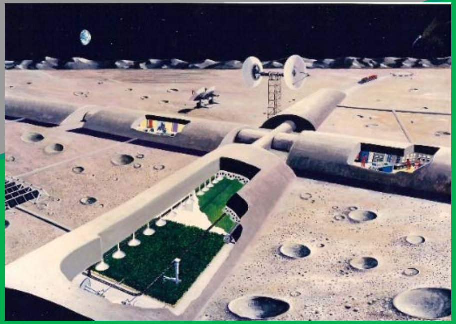
Impact of Plants on Life Support Options Depends on Mission

Short Duration Missions

Longer Durations

Autonomous Colonies

Stowage and Physico-Chemical



Bioregenerative

Supplemental Food
0.5 – 5 m^2 plant area

“More” Food, Partial O_2, CO_2 removal
5 – 25 m^2 plant area

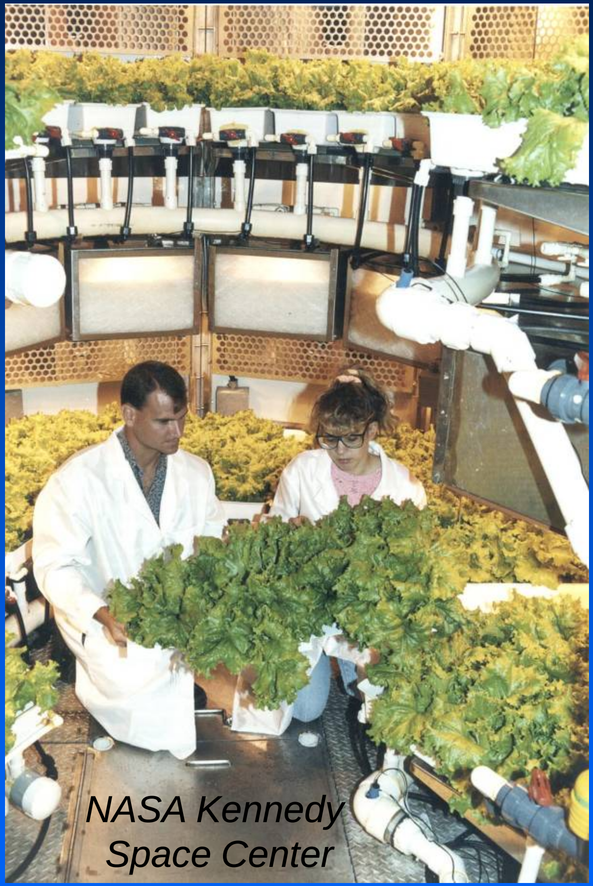
Most Food, all O_2, all CO_2 removal
25 – 50 m^2 plant area

Wheeler. 2004 Acta Hort.

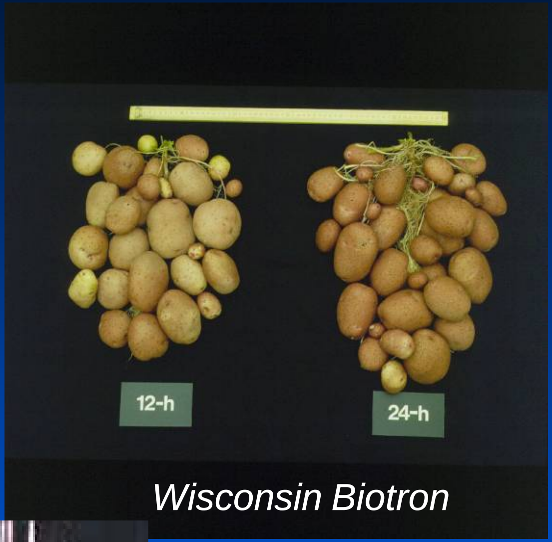
Kennedy Space Center Advanced Life Support Group 2003

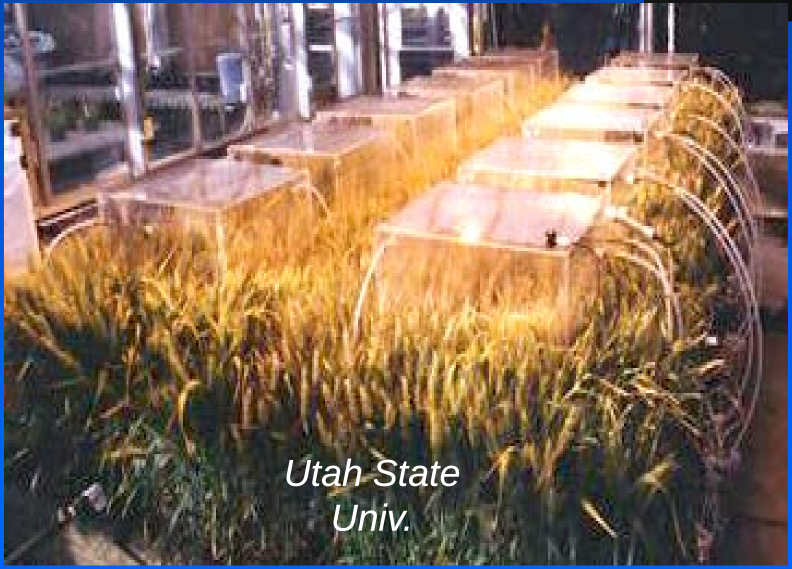
Back up Slides

High Yields from NASA Sponsored Studies



Wheat - 3-4 x World Record
Potato - 2 x World Record
Lettuce-Exceeded Commercial Yield Models





Bubgee, B.G. and F.B. Salisbury. 1988. Plant Physiol. 88:869-878.
Wheeler, R.M., T.W. Tibbitts, A.H. Fitzpatrick. 1991. Crop Sci. 31:1209-1213.

Technologies from "Space" Agriculture

*LEDs for growing plants--
patented through NASA
funded center at Univ.
of Wisconsin, ca. 1990*

*Potatoes in NFT at NASA KSC 1992, ↑
and at commercial "seed potato"
facility (Sklarczyk Farms, MI) 2016 ↓*