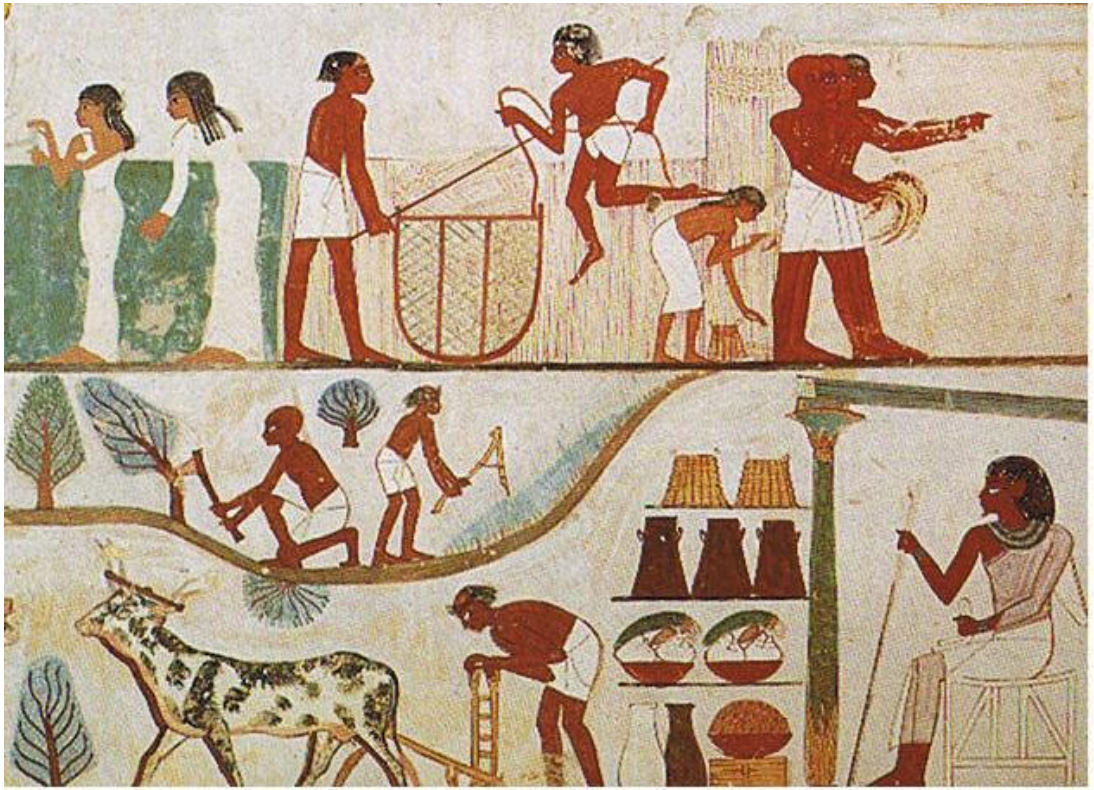
Space agriculture: from the stars to the plate

Marta Del Bianco

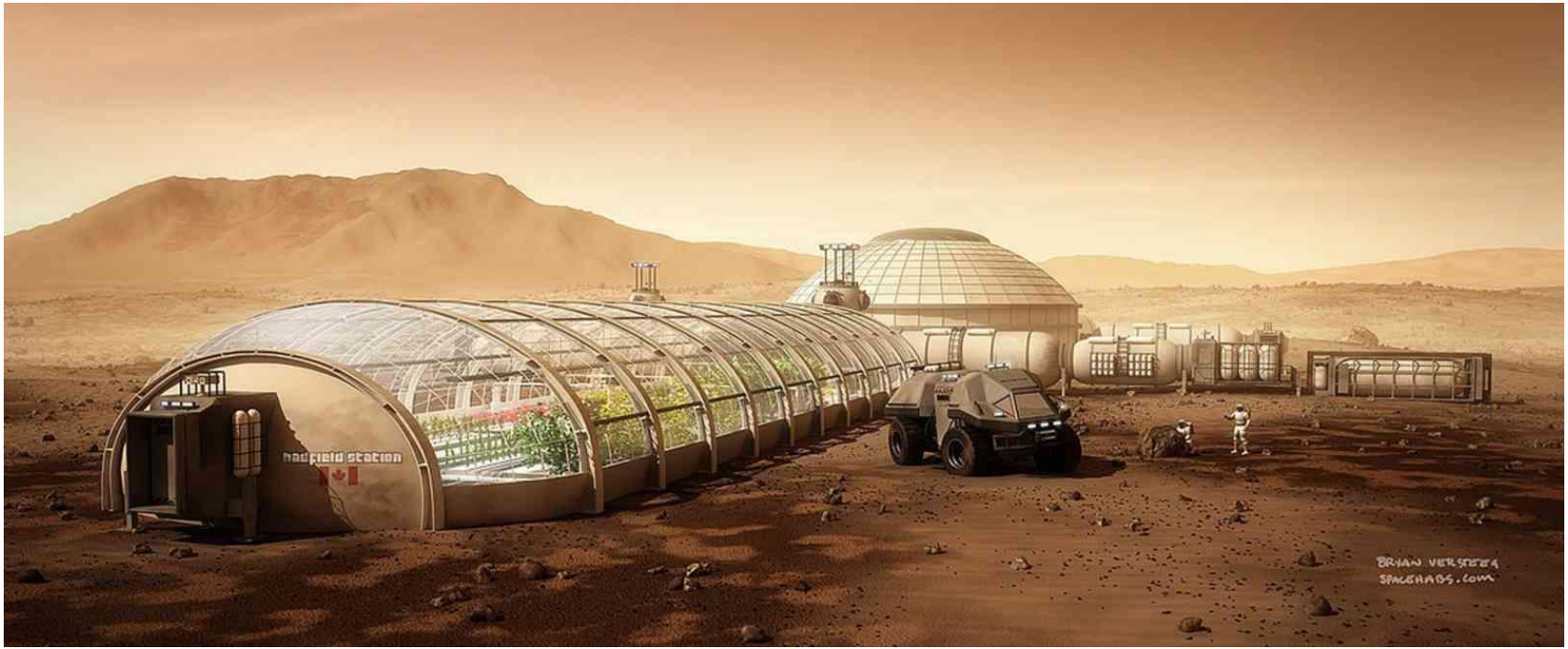
www.asi.it

08.05.2023

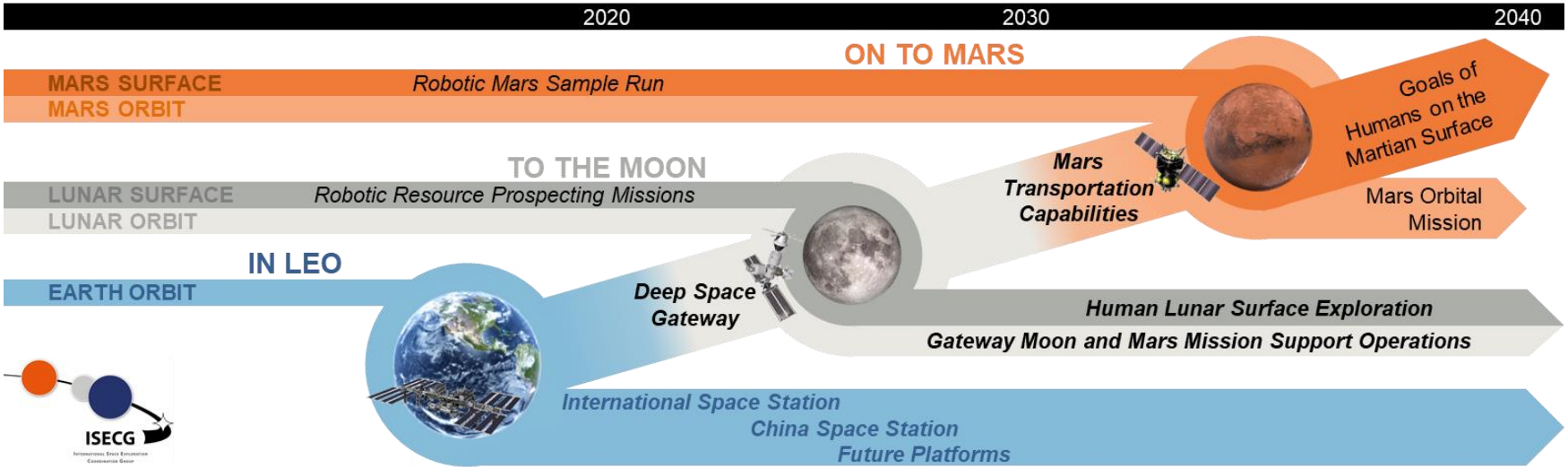
Agriculture: the start of modern society



Agriculture: a requirement for human space exploration

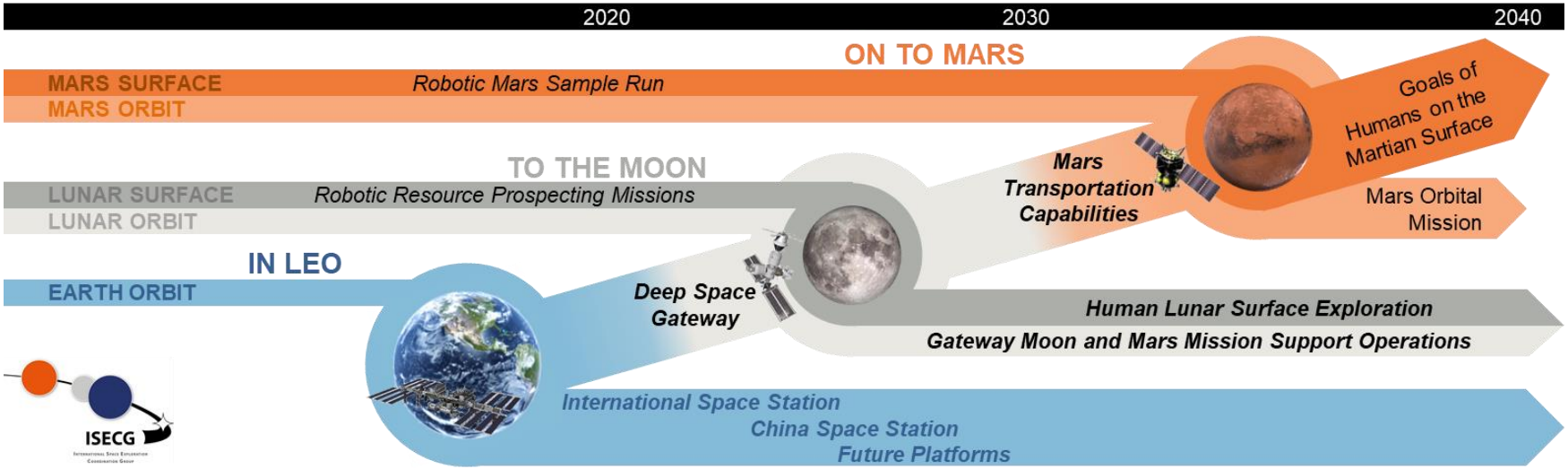


Global Exploration Roadmap



GER, ISECG = doi:10.1111/j.1750-3841.2010.01982.x

Global Exploration Roadmap



Three Year Mission to Mars: 2700 Kg of food and 2400 L of water per person

(sending 1 L of water to the ISS costs 25-50K€)

GER, ISECG = doi:10.1111/j.1750-3841.2010.01982.x

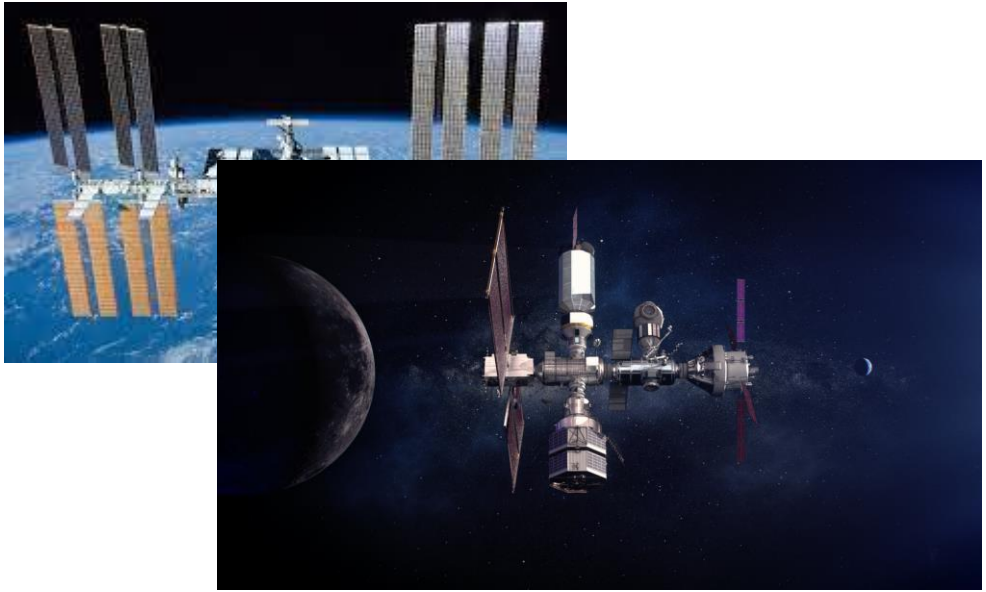
The Phases of Food Production in Space

STAGE 1: food supply is reliant on Earth

The Phases of Food Production in Space

STAGE 1: food supply is reliant on Earth

STAGE 2: fresh food as complement to the diet

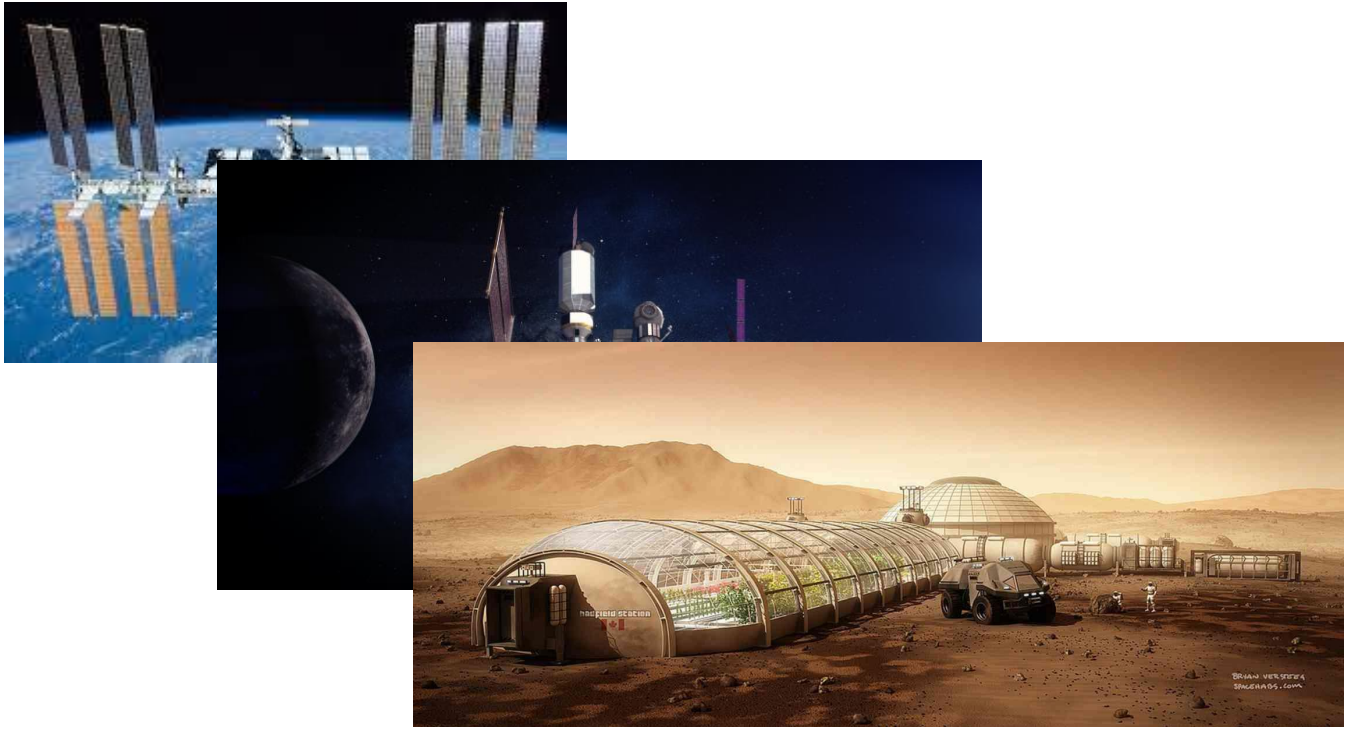


The Phases of Food Production in Space

STAGE 1: food supply is reliant on Earth

STAGE 2: fresh food as complement to the diet

STAGE 3: self-sufficient food production



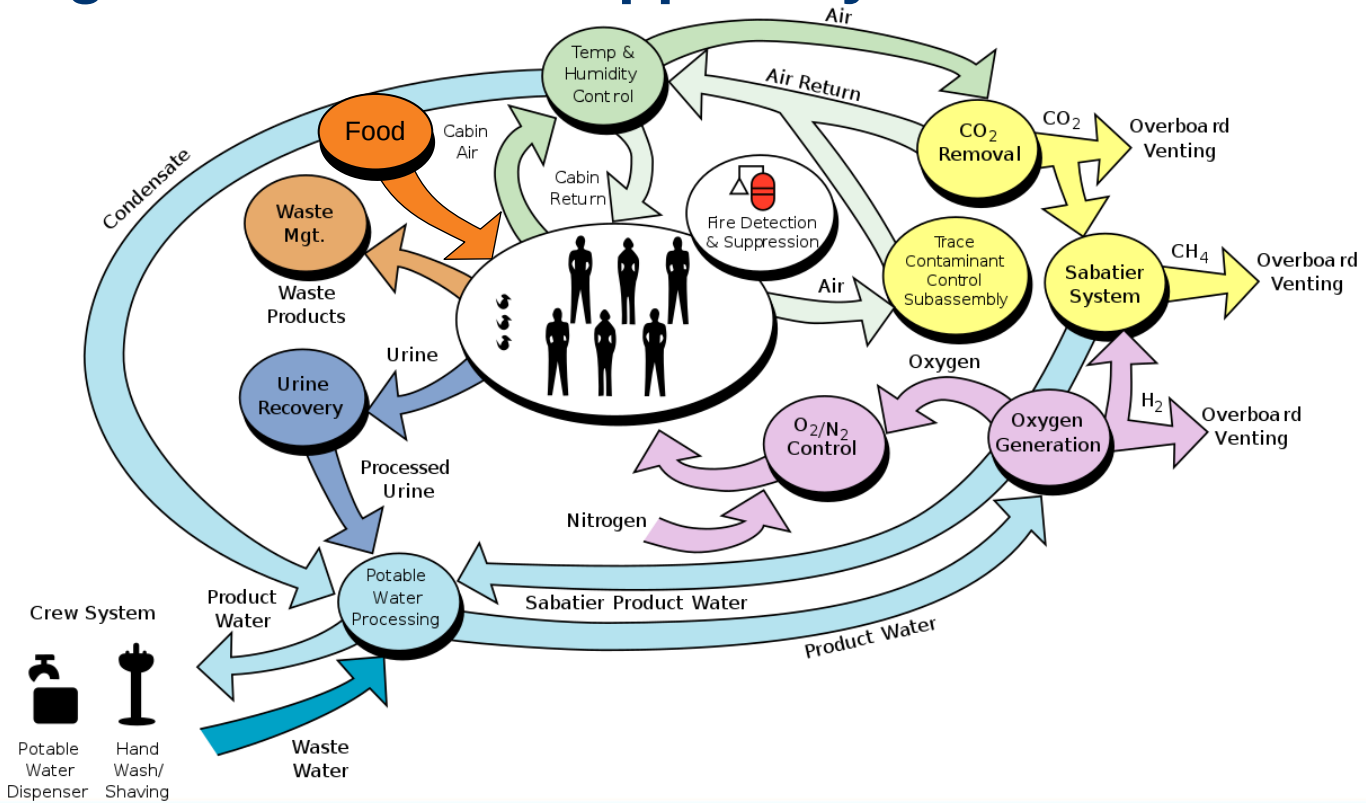
The Phases of Food Production in Space

STAGE 1: food supply is reliant on Earth

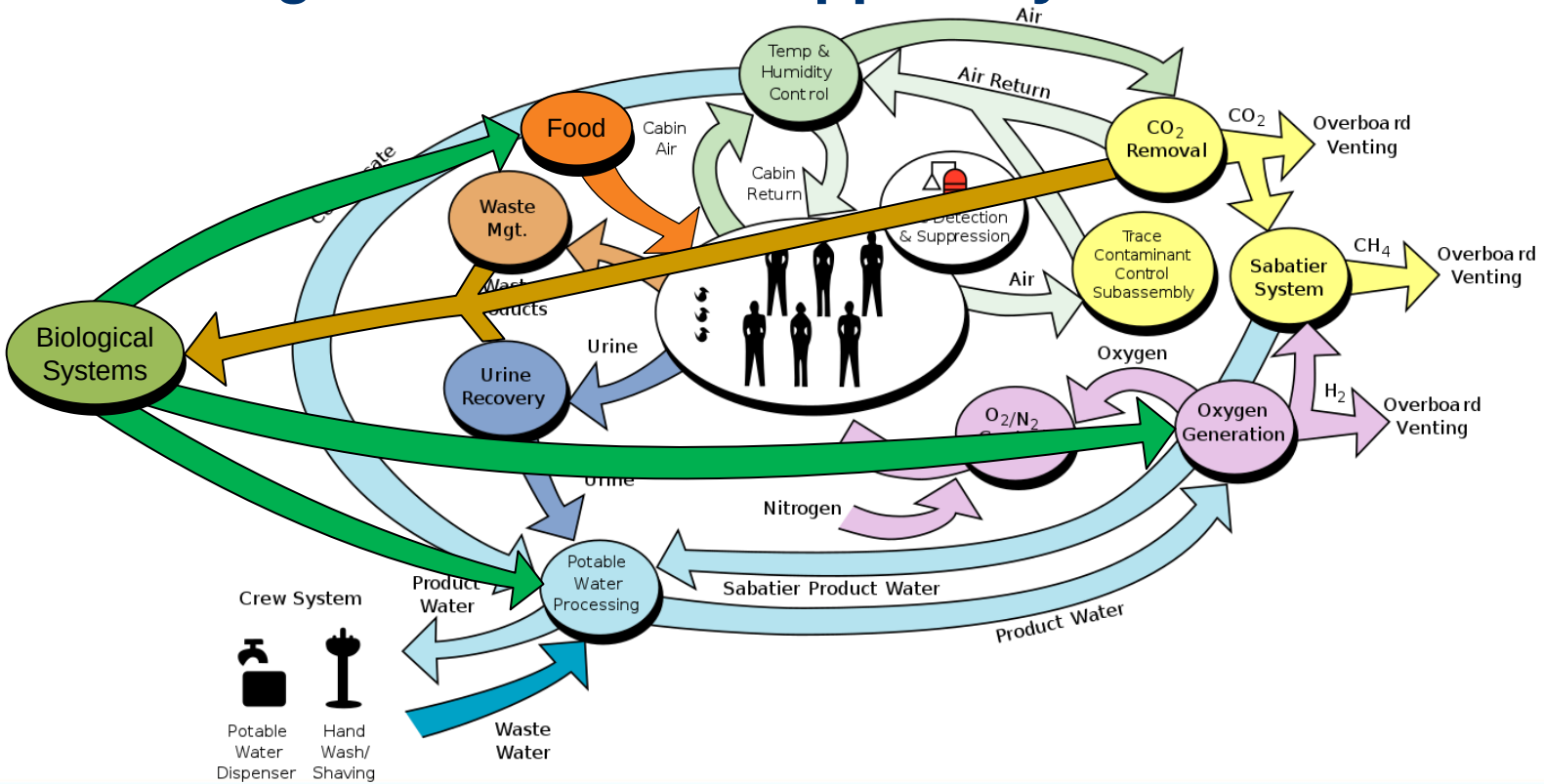
STAGE 2: fresh food as complement to the diet

STAGE 3: self-sufficient food production

BLSS – Bioregenerative Life Support Systems



BLSS – Bioregenerative Life Support Systems



The Challenges of Life in Space – A Food Perspettive

Physiological Effects

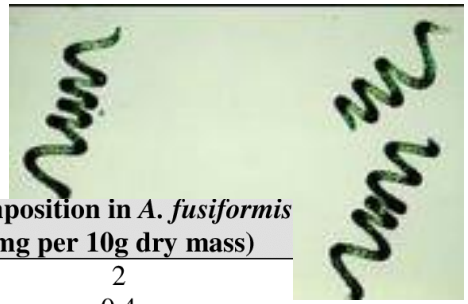
- Immune System Decreased Activity
- Higher Cancer Risk
- Muscle Loss
- Bone Loss
- Microbiome alteration -> Digestive + adsorption problems
- Fluid shift -> Loss of appetite

Psychology and Well Being

- Mood and performance -> Loss of appetite

Organisms in Bioregenerative Systems

- Microalgae and Cyanobacteria: proteins, polyunsaturated fatty acids, photoprotective and antioxidant pigments, essential minerals, and vitamins; air regeneration, water purification.

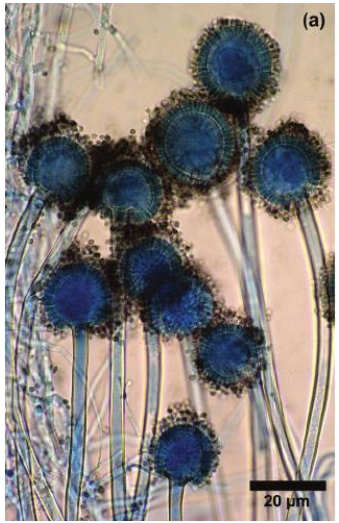


Nutrient	Composition in *A. fusiformis* (mg per 10g dry mass)
Vitamin C	2
Vitamin E	0.4
Thiamin	0.37
Riboflavin	0.46
Vitamin B6	0.07
Vitamin B12	0.02
Calcium	150
Iron	18
Zinc	N/A

Spirulina

Organisms in Bioregenerativ

- Microalgae and Cyanobacteria
- Fungi: proteins and prebiotics, waste recycling



Aspergillus niger

Fungus	Industrially relevant products	Application	References
Acremonium chrysogenum	Cephalosporin C	Pharmaceutical	Hu and Zhu (2016)
Agaricus bisporus	Edible mushroom	Food	Sonnenberg et al. (2017)
Ashbya gossypii	Riboflavin	Flavour	Aguiar et al. (2017)
Aspergillus niger	β-Galactosidase, glucoamylases, cellulases, lipases, pectinases, proteases	Food industry, laundry detergents, paper industry	Cairns et al. (2018)
	Citric acid	Preservative, acidulant, flavour enhancer, antioxidant, food, beverage, pharmaceutical, cosmetics	Show et al. (2015)
	Succinic acid	Surfactant, food, pharmaceutical	Li and Punt (2013)
	Gluconic acid	Food and pharmaceutical	Li and Punt (2013) and Hossain et al. (2016)
	Itaconic acid	Synthetic fibres and resins, plastics, rubbers, surfactants, oil additives	Hossain et al. (2016)
	Galactaric acid	Textile	Kuivanen et al. (2016)
	Enniatin, beauvericin, bassianolide	Pharmaceutical	Richter et al. (2014) and Boecker et al. (2018)
Aspergillus oryzae	Vegan mycoprotein, soy sauce, vinegar	Food	Ritala et al. (2017)
	Glucoamylases, lipases, phytases, proteases, xylanases	Food industry laundry detergents, feed	Fujita et al. (2003) and Machida et al. (2008)
Aspergillus terreus	Itaconic acid	Synthetic fibres and resins, plastics, rubbers, surfactants, oil additives	Okabe et al. (2009)
Fusarium venenatum	Vegan mycoprotein	Food	Ritala et al. (2017)
Ganoderma lucidum	Packaging material, construction material, leather cellulases, laccases, herbal medicine		Yu et al. (2012)

Organisms in Bioregenerative Systems

- Microalgae and Cyanobacteria
- Fungi
- Insects: protein rich in essential aminoacids, unsaturated fats, dietary fibres, vitamins (vitamin B12, riboflavin and vitamin A), and essential minerals; waste recycling

Hermetia illucens

Organisms in Bioregenerative Systems

- Microalgae and Cyanobacteria
- Fungi
- Insects
- Higher Plants: nutraceutical compounds (antioxidants, vitamins, micronutrient), caloric intake, fibres; regeneration of air and water, bioremediation.

Microgreen

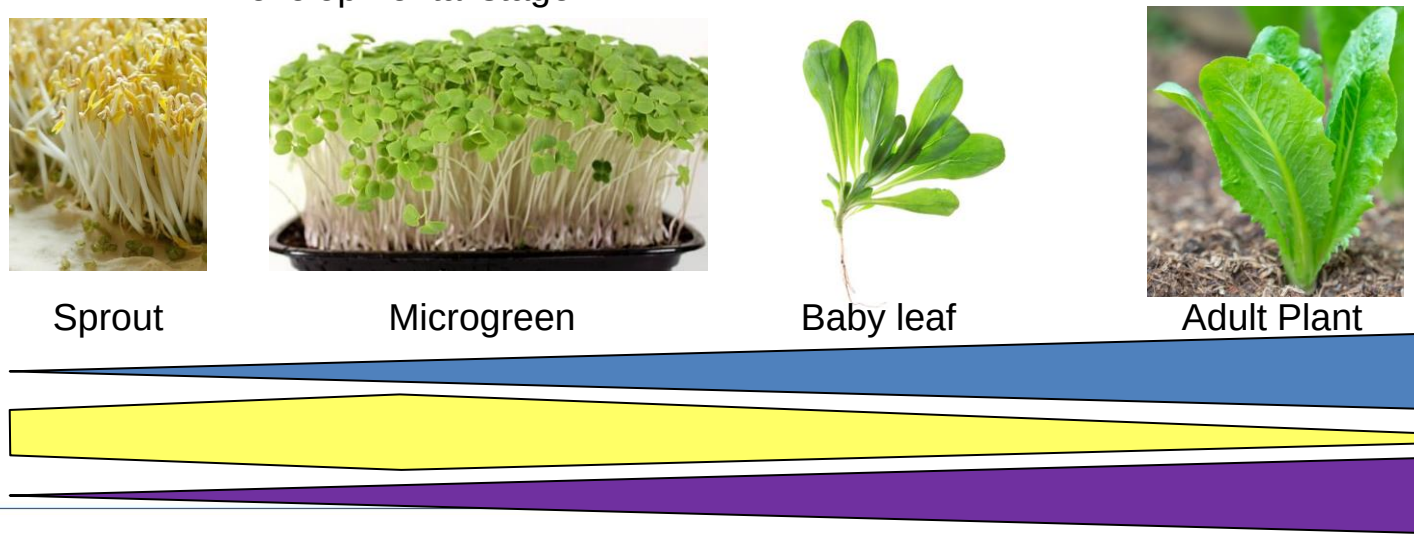
Leafy greens

Fruits

Starch rich crops

Biological Systems for Space food production

- Microalgae and Cyanobacteria
- Fungi
- Insects
- Higher plants: - Small plants with short life cycles and high yield-to-mass ratio
  - Developmental stage



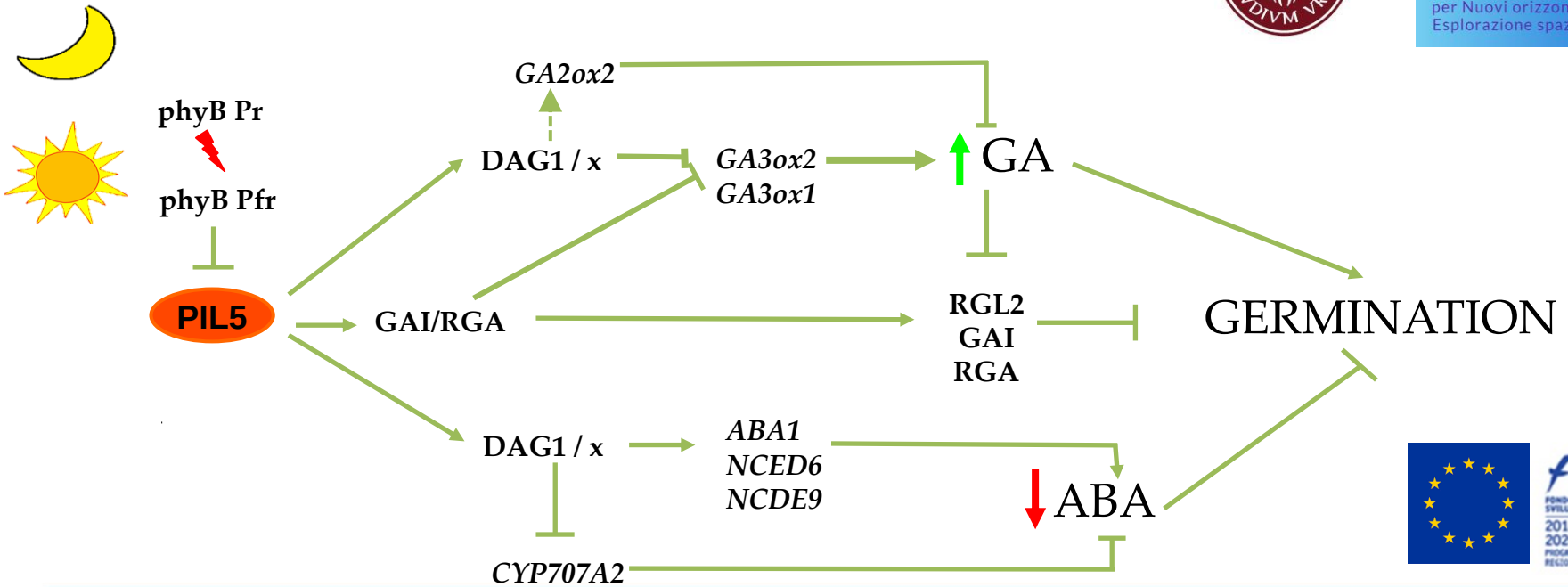
Biological Systems for Space food production

- Microalgae and Cyanobacteria
- Fungi
- Insects
- Higher plants: - Small plants with short life cycles and high yield-to-mass ratio
  - Developmental stage
  - Development of new varieties (genetic engineering, breeding)
    - Miniaturization
    - Increased nutrient level
    - Resistant to radiation
    - Resistant to microgravity
    - Increased yield in close environments

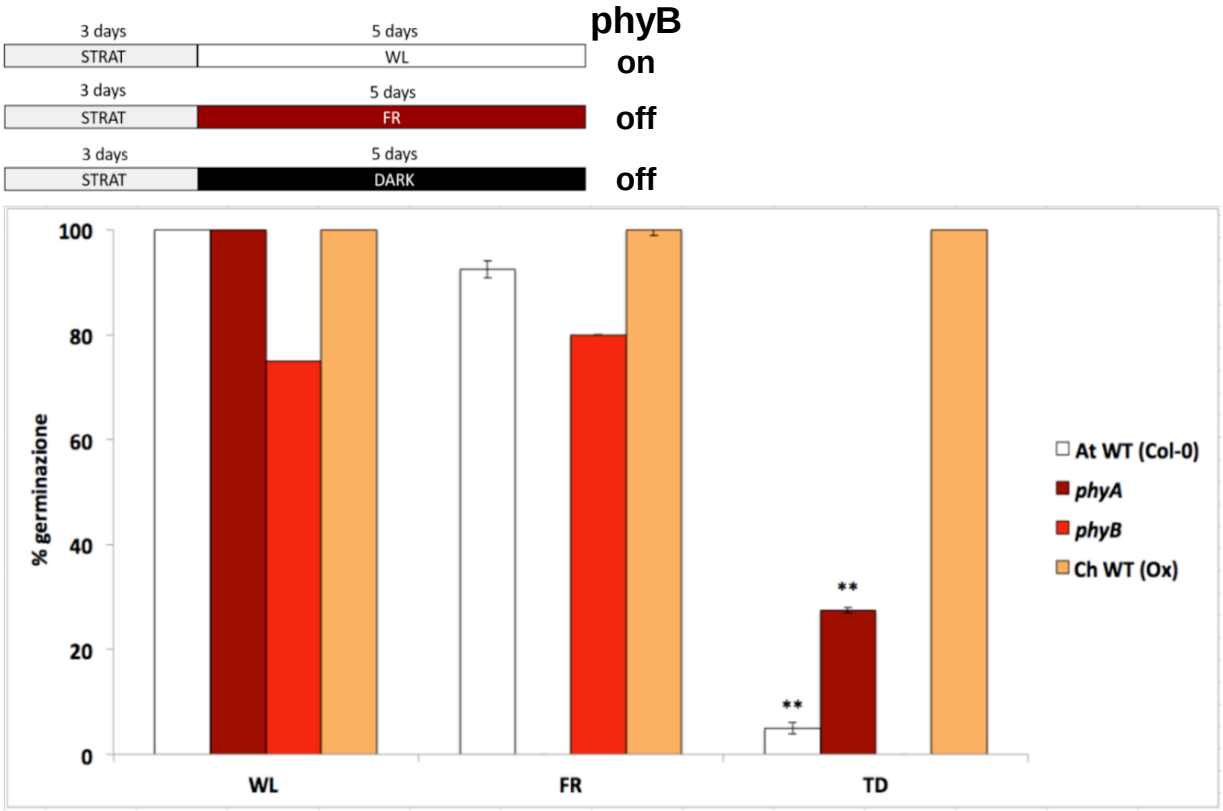
doi:10.18429/JACoW-IPAC2015-TUPWI005

SEMINE: SEeds for Microgreen production for New Exploration orizons

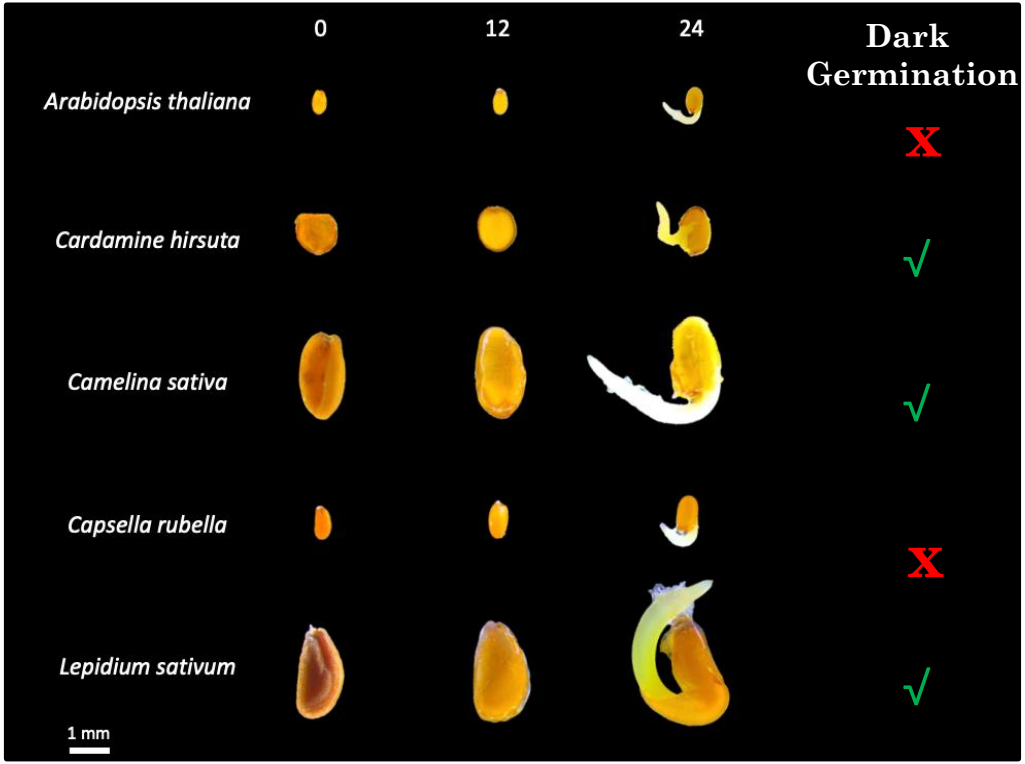
Study the mechanisms of light-independent germination



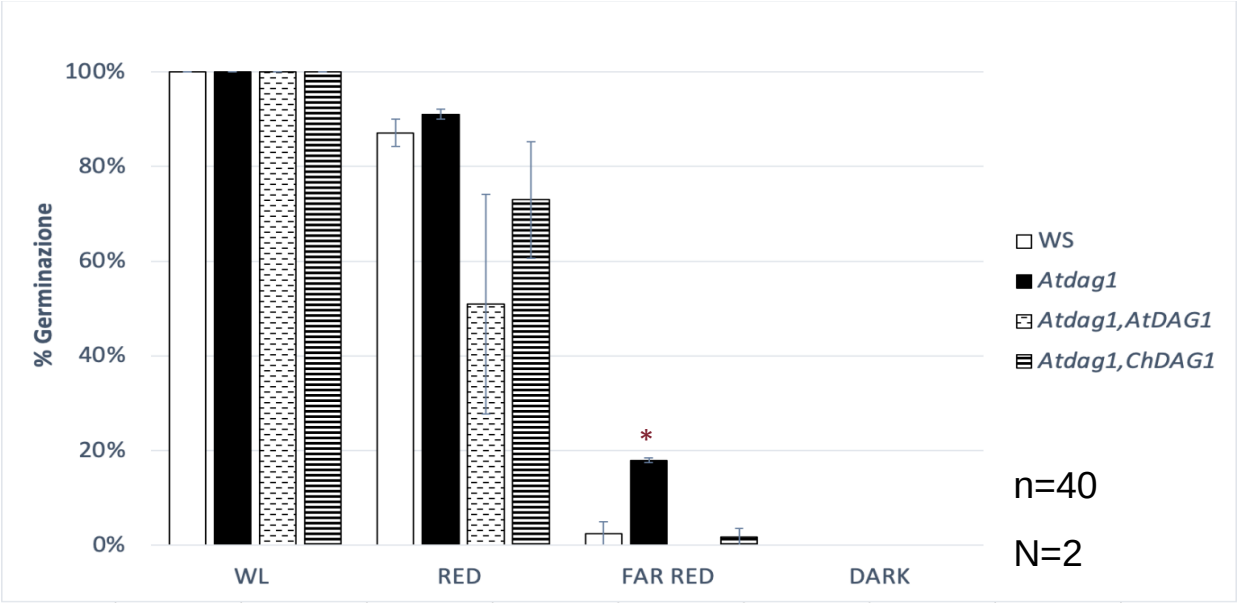
Cardamine hirsuta displays light-independent germination



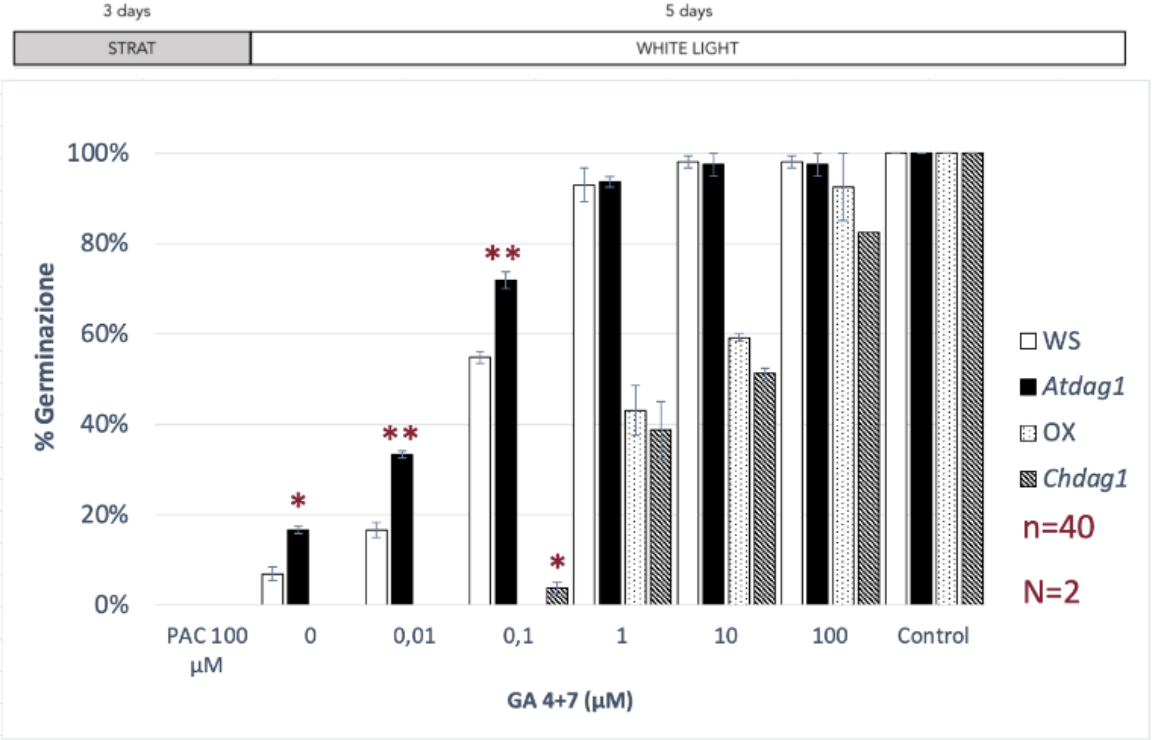
Germination behaviour in other brassicaceae species



ChDAG1 fails to confer light-independent germinability to A. thaliana



C. hirsuta displays a lower sensitivity to GA that is DAG1 independent



MicroX2: Microgreens for Microgravity

Find the better combination of:

- species
- substrate
- light recipe
- watering solution

to deliver the highest amount of VitC
for cultivation surface

Consiglio Nazionale delle Ricerche

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Agenzia Spaziale Italiana

MicroX2: Microgreens for Microgravity

Find the better combination of:

- species ➢ Raphanus raphanistrum L. subsp. Sativus
- substrate ➢ Coconut fibers
- light recipe ➢ High light
- watering solution ➢ Water

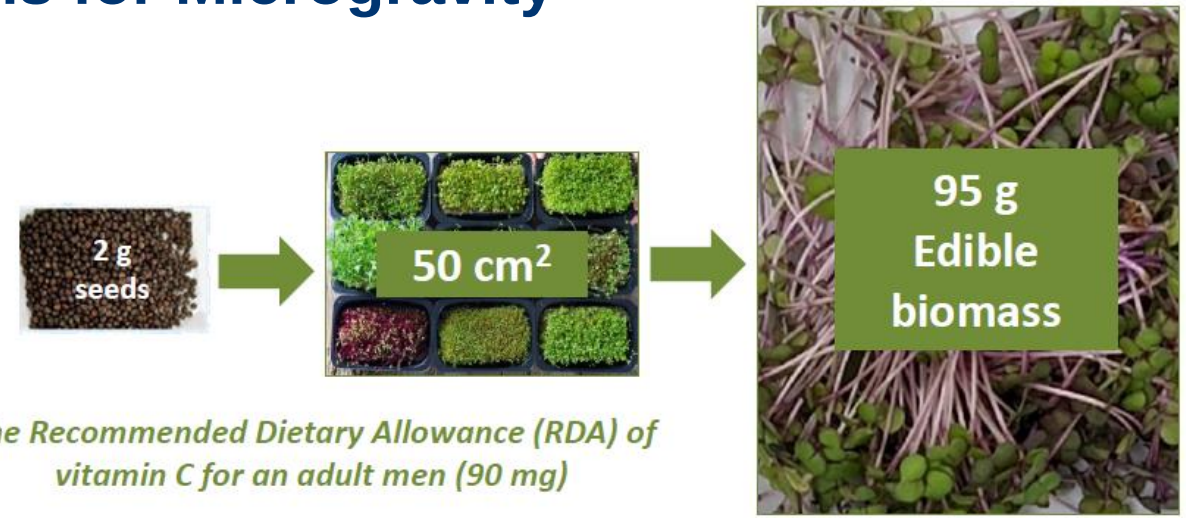
to deliver the highest amount of VitC
for cultivation surface

MicroX2: Microgreens for Microgravity

Find the better combination of:

- species
- substrate
- light recipe
- watering solution

to deliver the highest amount of VitC for cultivation surface



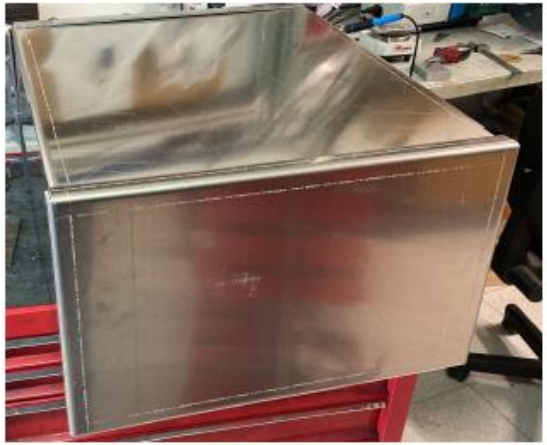
The Recommended Dietary Allowance (RDA) of vitamin C for an adult men (90 mg)

Microgreens are ideal for Space flight environments as they can be harvested directly by crew members, ensuring freshness and high quality

MicroX2: Microgreens for Microgravity

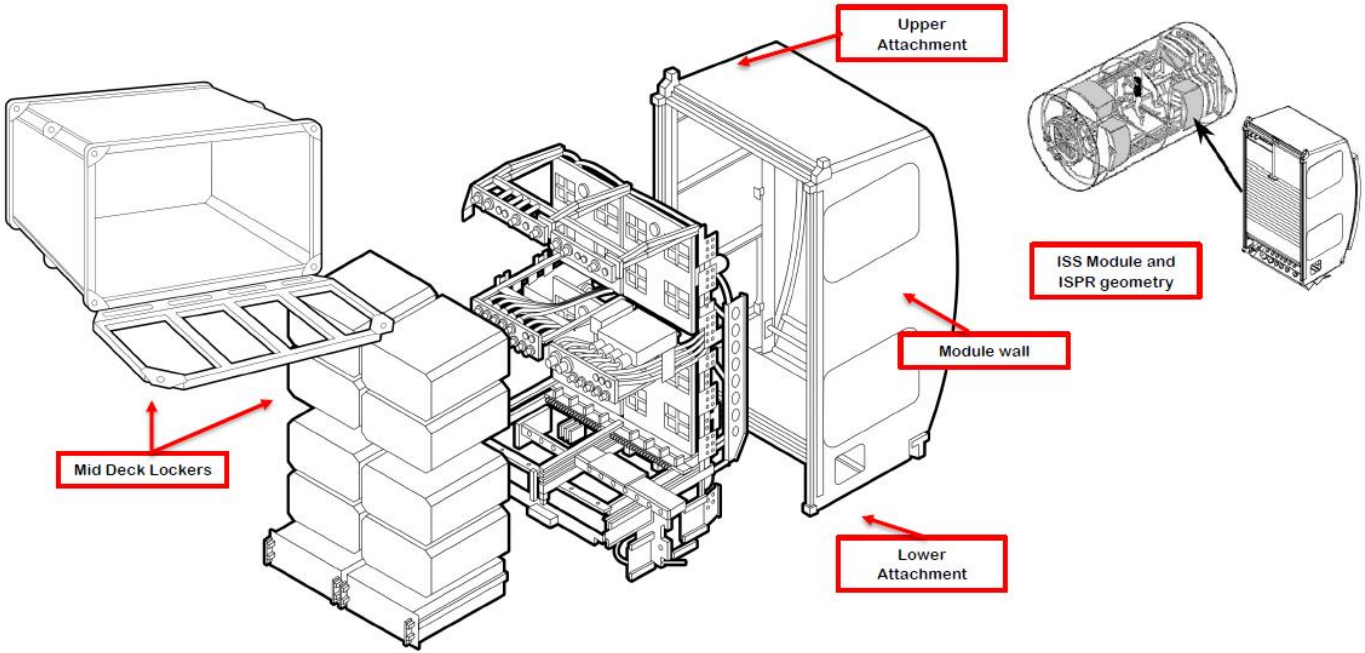
Rack

Drawer



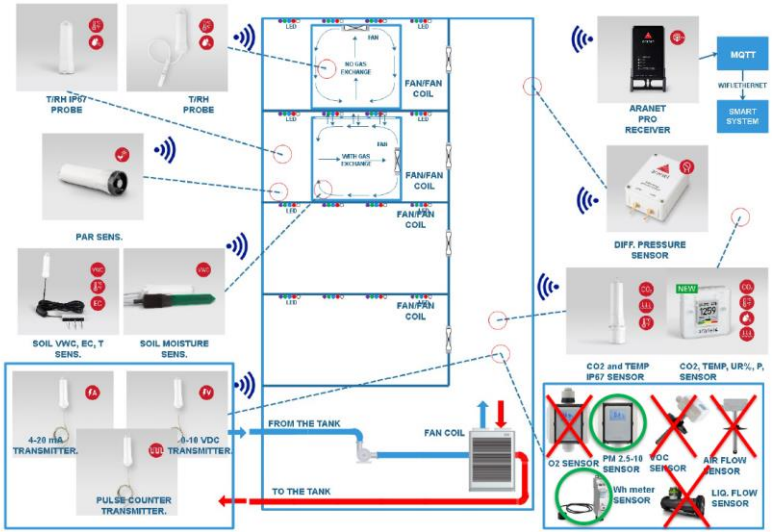
Conteiner

MicroX2: Microgreens for Microgravity



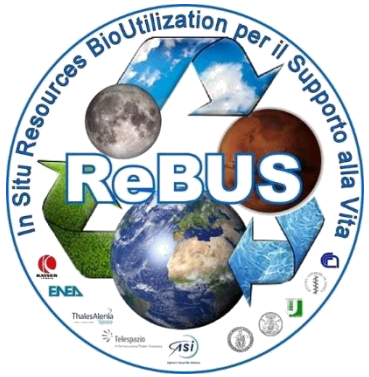
International Standard Payload Rack (ISPR)

MicroX2: Microgreens for Microgravity



Smart system for the optimization of microgreen production

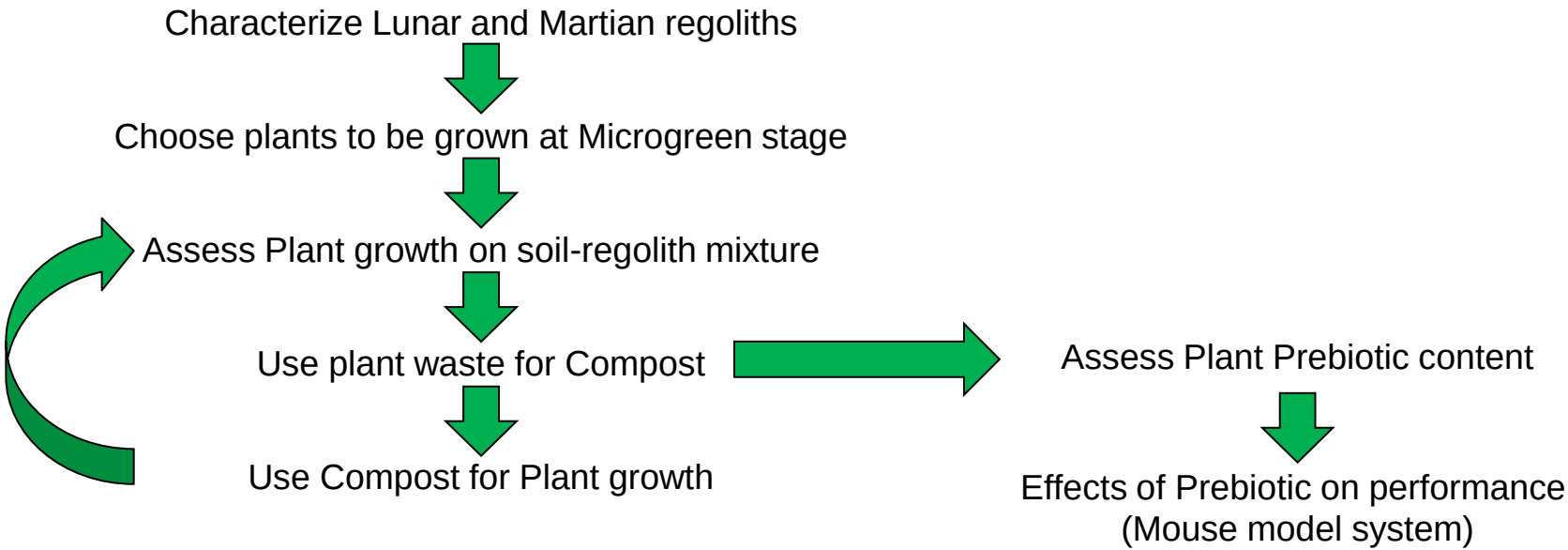
On-Going Projects – ReBUS



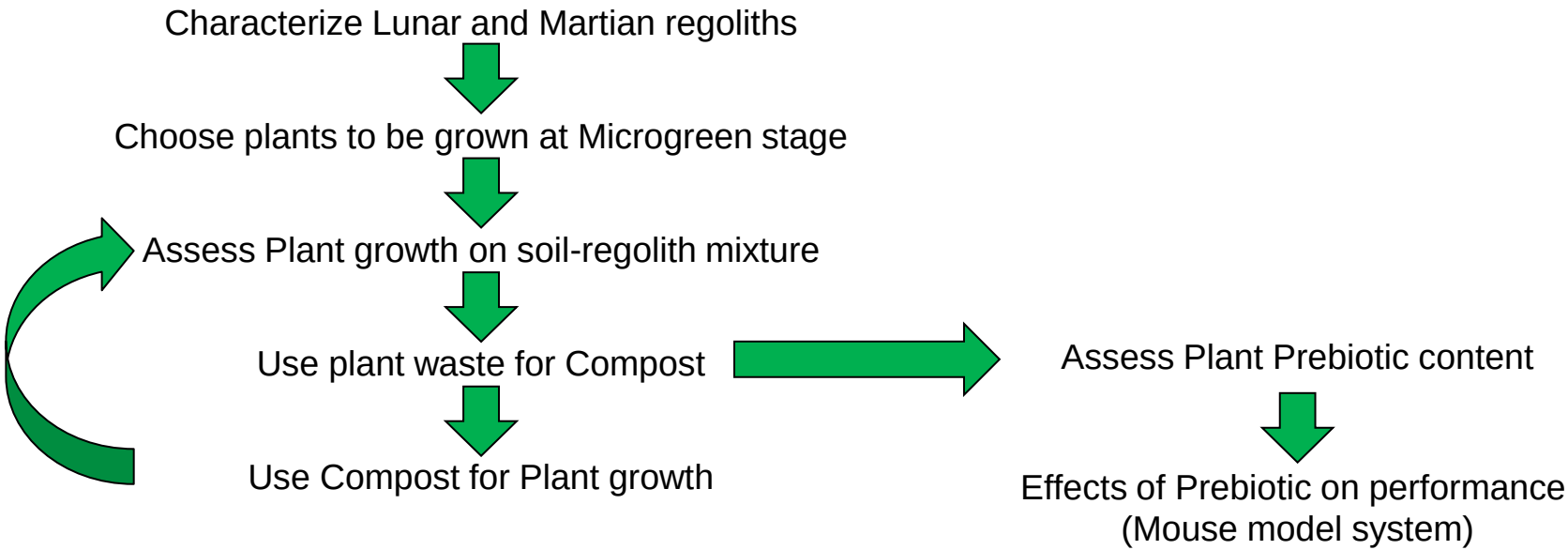
Definition of a Bioregenerative Life Support System in space with the integration of different organisms (higher plants, fungi, bacteria, cynobacteria, insects)

1. minimizing the use of exogenous resources;
2. maximizing:
   - the use of in situ resources (Lunar and Martian soils, water, gas in atmosphere);
   - the recycling of the organic matter produced in the system itself (crop residues, crew physiological waste).
3. Assess the effects of Prebiotics on psychophysiological performance (mice)

On-Going Projects – ReBUS



On-Going Projects – ReBUS



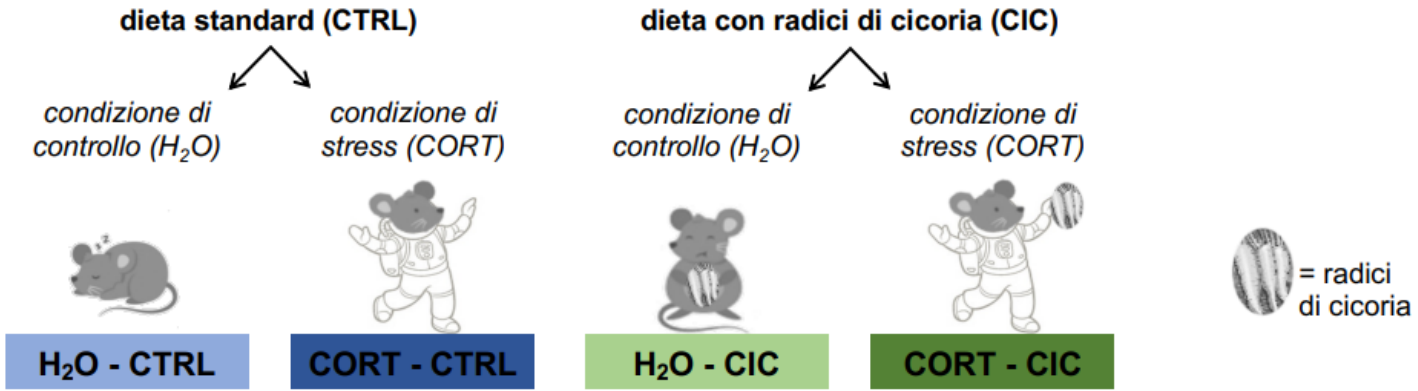
→ Verificare se il consumo di **vegetali ricchi di prebiotici**, coltivabili nei **sistemi bio-rigenerativi di supporto alla vita (BLSS)**, può avere un effetto positivo sul **benessere psicofisico** in termini di performance cognitive, funzioni esecutive, motivazione, socialità e risposte emozionali

ReBUS Project

→ studi con analogo disegno sperimentale in topi adulti maschi del ceppo C57BL/J6

STUDIO: inulina (0,4 g/die) derivante da radici di cicoria

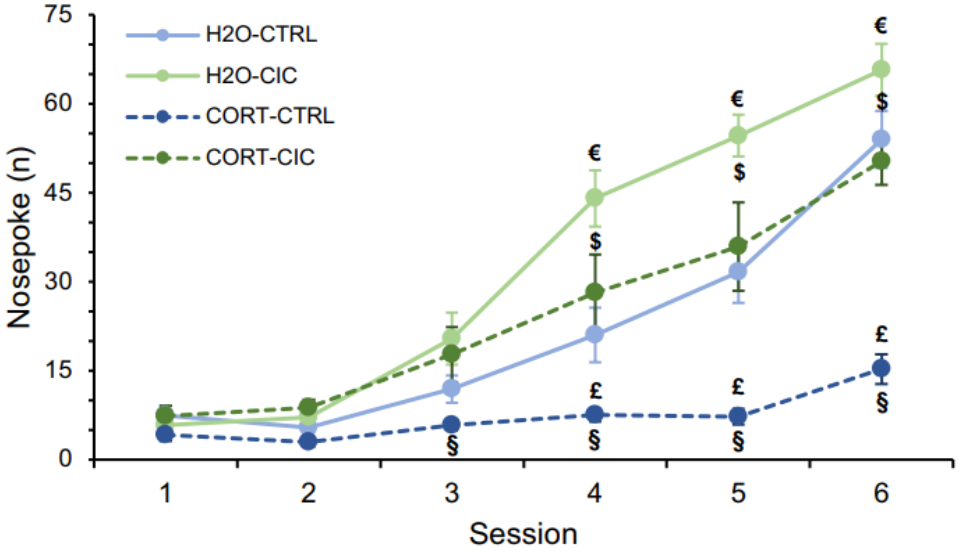
Gruppi sperimentali



Test del *fixed ratio*

Apprendimento di un compito

inserire il muso in un foro per ottenere una ricompensa



£ H_2O-CTRL vs. CORT-CTRL

€ H_2O-CTRL vs. H_2O-CIC

$ H_2O-CIC vs. CORT-CIC

§ CORT-CTRL vs. CORT-CIC

Numero di giorni necessari per raggiungere il criterio:

H_2O-CTRL: 4,43 ± 0,29

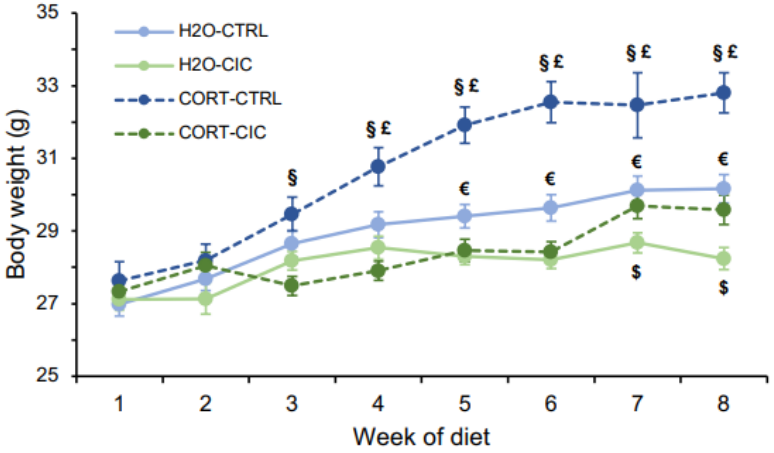
£ CORT-CTRL: 6,82 ± 0,23

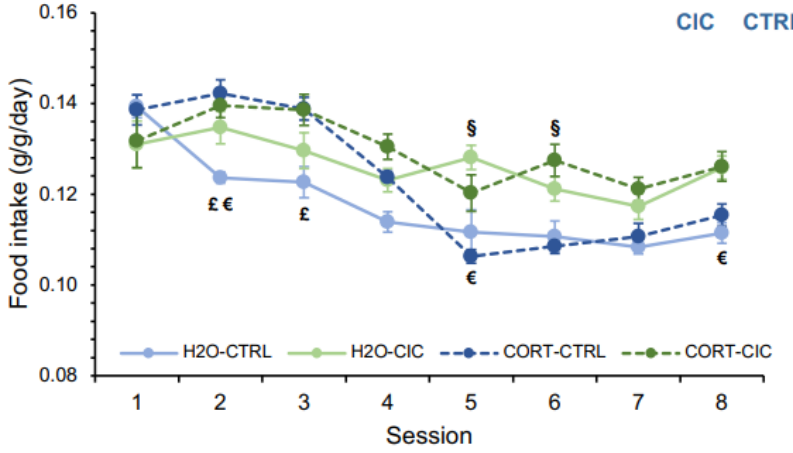
H_2O-CIC: 3,73 ± 0,21

§ CORT-CIC: 4,42 ± 0,50

Parametri fisiologici

Peso corporeo e consumo di cibo





Peso corporeo

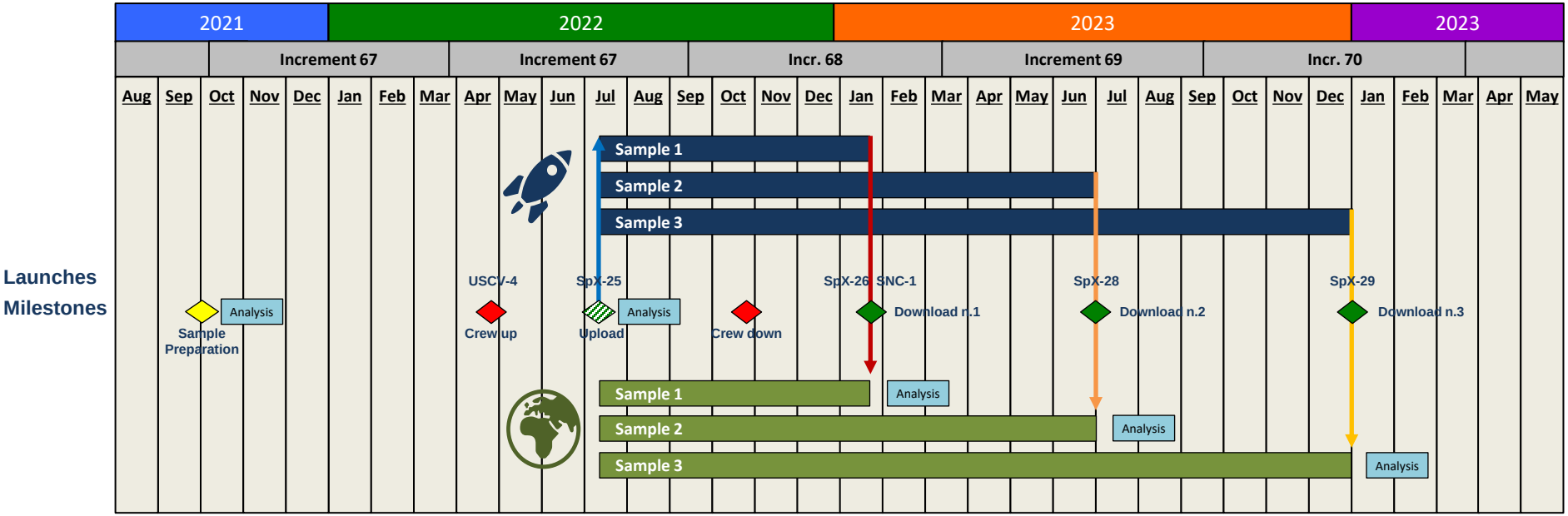
Consumo di cibo

£ H_2O-CTRL vs. CORT-CTRL € H_2O-CTRL vs. H_2O-CIC

$ H_2O-CIC vs. CORT-CIC § CORT-CTRL vs. CORT-CIC

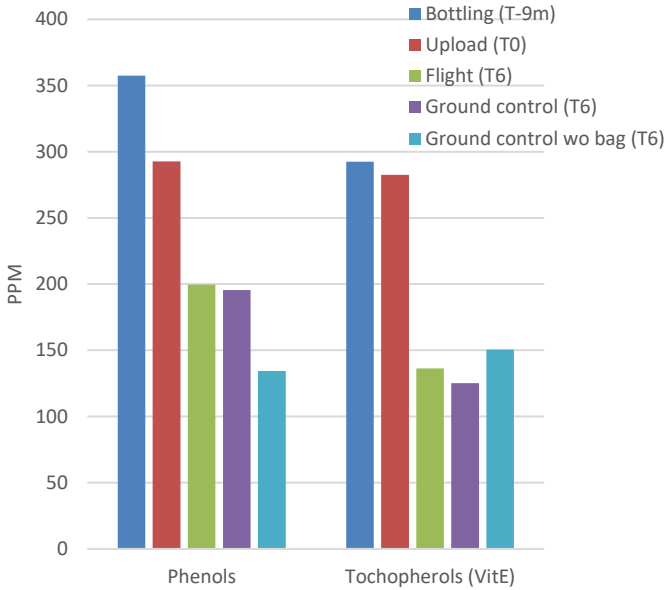
EVOOS

The objective of **EVOO in Space** is to study the impact of exposure to microgravity and radiation conditions aboard the ISS on extra-virgin olive oil physicochemical, sensorial, nutritional and microbiological characteristics.



EVOOS: First sample return

Control Glass | Control Bottle | Control Bottle + Vacuum Bag | Flight sample Bottle + Vacuum Bag



Moon-rice: COMING SOON!

Select a new variety from CRISPR/CAS library for long-term space missions:

- ultra dwarf
- high productivity
- adapted to growth in controlled environment

PaCMAN-Melissa Laboratory

Impact on Earth

SDG Target 2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture. Use of plants, fungi, cyanobacteria, and microalgae as food sources. New technoloies,. Concept of 'zero waste' agriculture.

SDG Target 6 Ensure availability and sustainable management of water and sanitation for all. Even partial adoption of BLSS concepts on water use for plant cultivation would be of great benefit for many agricultural systems on Earth.

SDG Target 11 Make cities and human settlements inclusive, safe, resilient and sustainable. Efficient environmental control, efficient food production in closed systems, resource recycling, plants as a tool to improve psychological wellbeing.

SDG Target 12 Ensure sustainable consumption and production patterns. Circularity and efficiency as BLSS concepts.

SDG Target 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Studies aiming at the stimulation of pedogenesis and induction of fertility on Mars surface could provide fundamental tools to counteract desertification.

Thank you
for your attention

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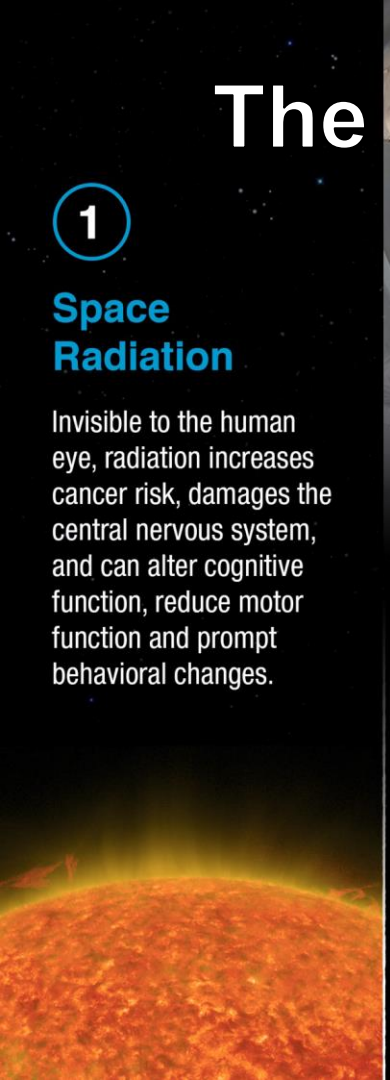
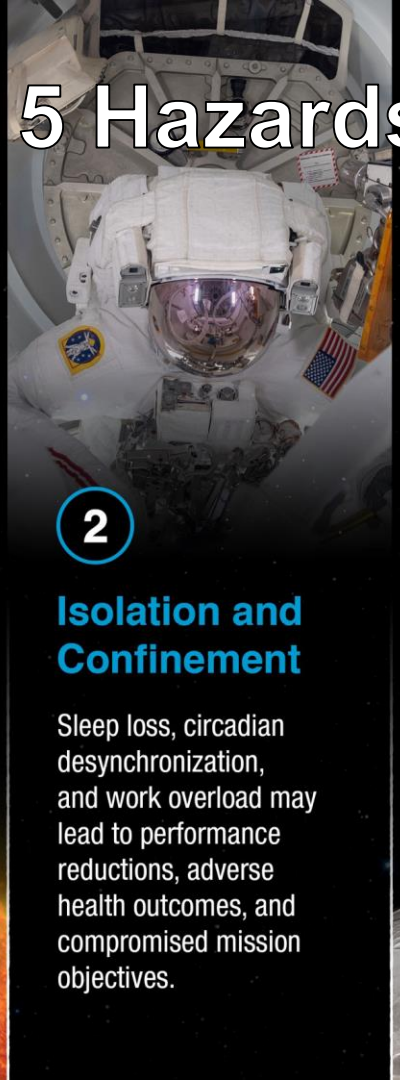
The 5 Hazards of Space Exploration



1 Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.



2 Isolation and Confinement

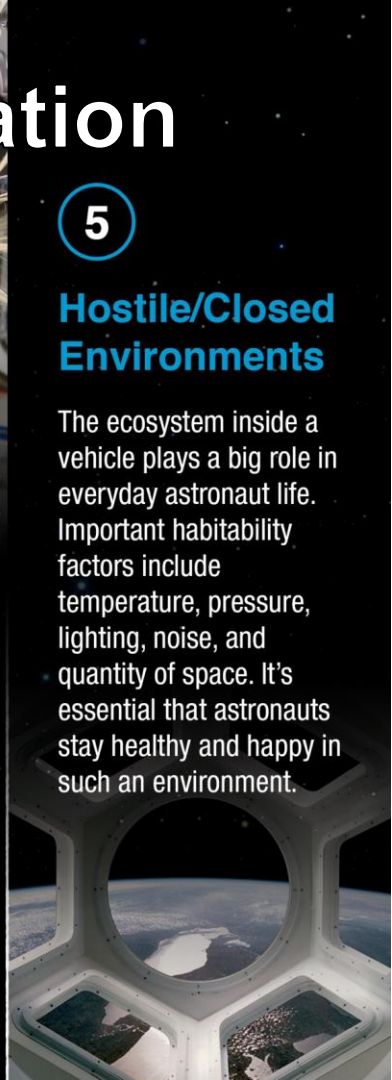
Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3 Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.

4 Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.



5 Hostile/Closed Environments

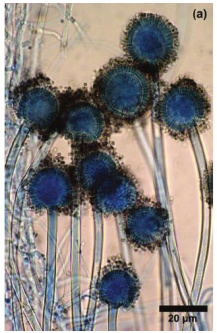
The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.

The Challenges of Life in Space – A Food Perspettive

- Nutritional countermeasure
- Effects of Space on growth -> Altered gravity + Radiations
- Space constrains (miniaturization) -> Closed Enviroment
- Safety (microbial contamination) -> Closed Enviroment
- Shelf life -> Radiation, altered gravity, distance from Earth
- Enabling Technologies
- Energy constrains (Close system/BLSS) -> Closed Enviroment

Higher plants

Microalgae



Fungi

Insects