Integrating Microbial Radioresistance into MELiSSA

Pathways Towards Opportunistic Radiation Shielding for Deep Space Exploration

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07/10/2025

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How do you imagine the space-rated Spirulina Food Production Unit of MELiSSA ?

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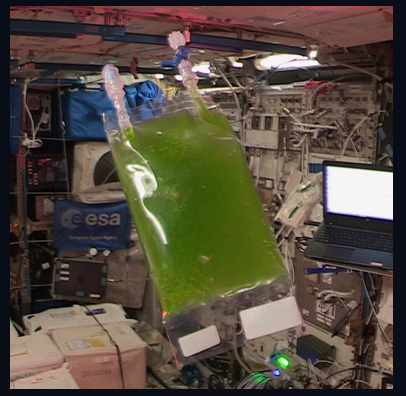
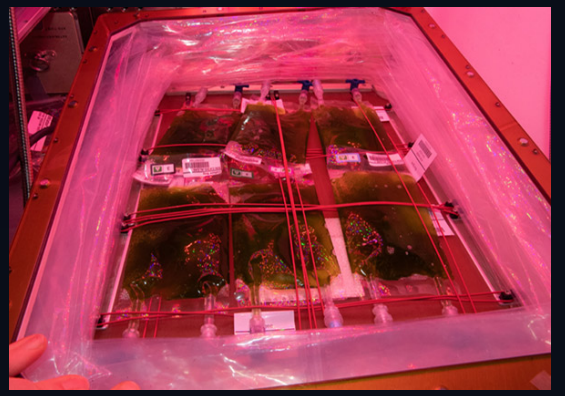
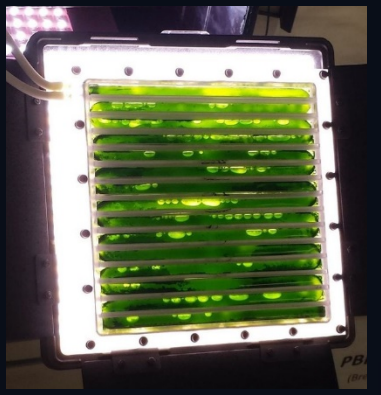


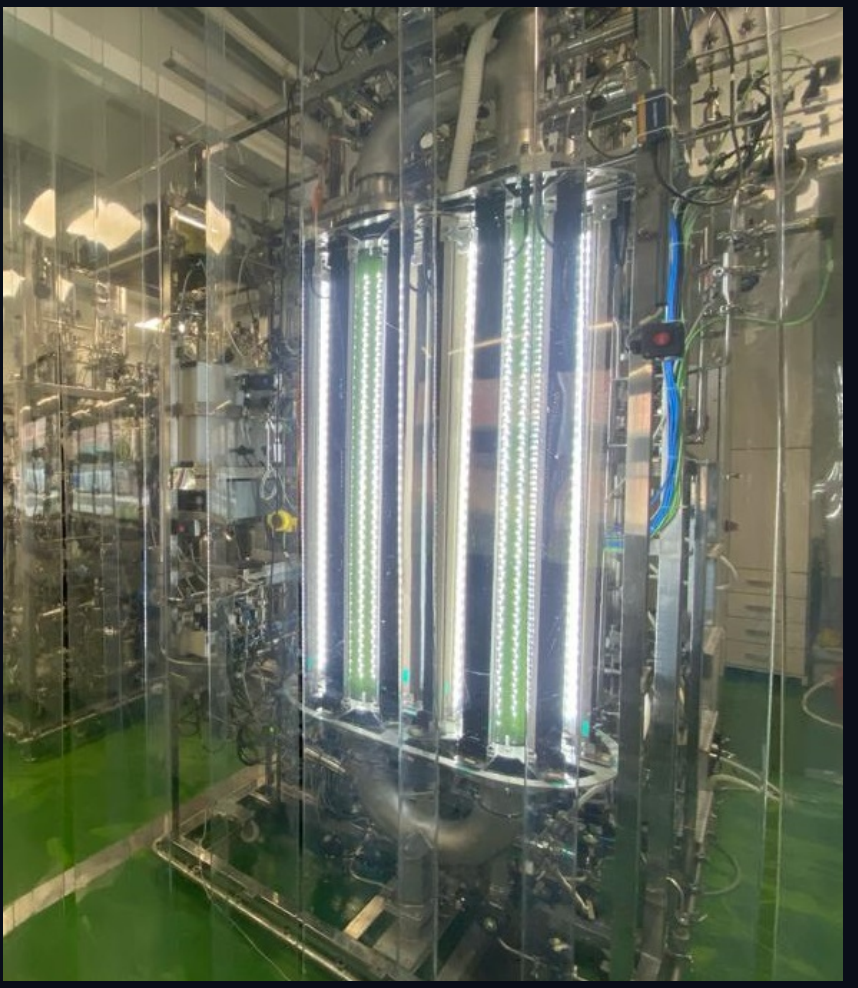
Plastic bag (NASA)



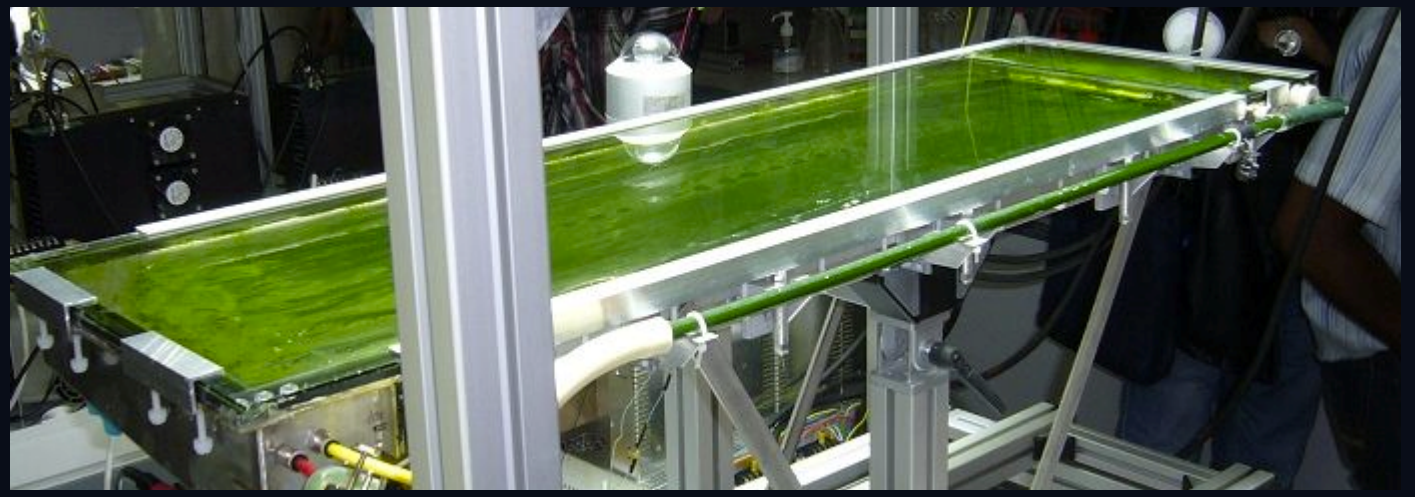
Adapted VEGGIE (NASA)



Panel (IRS Stuttgart)

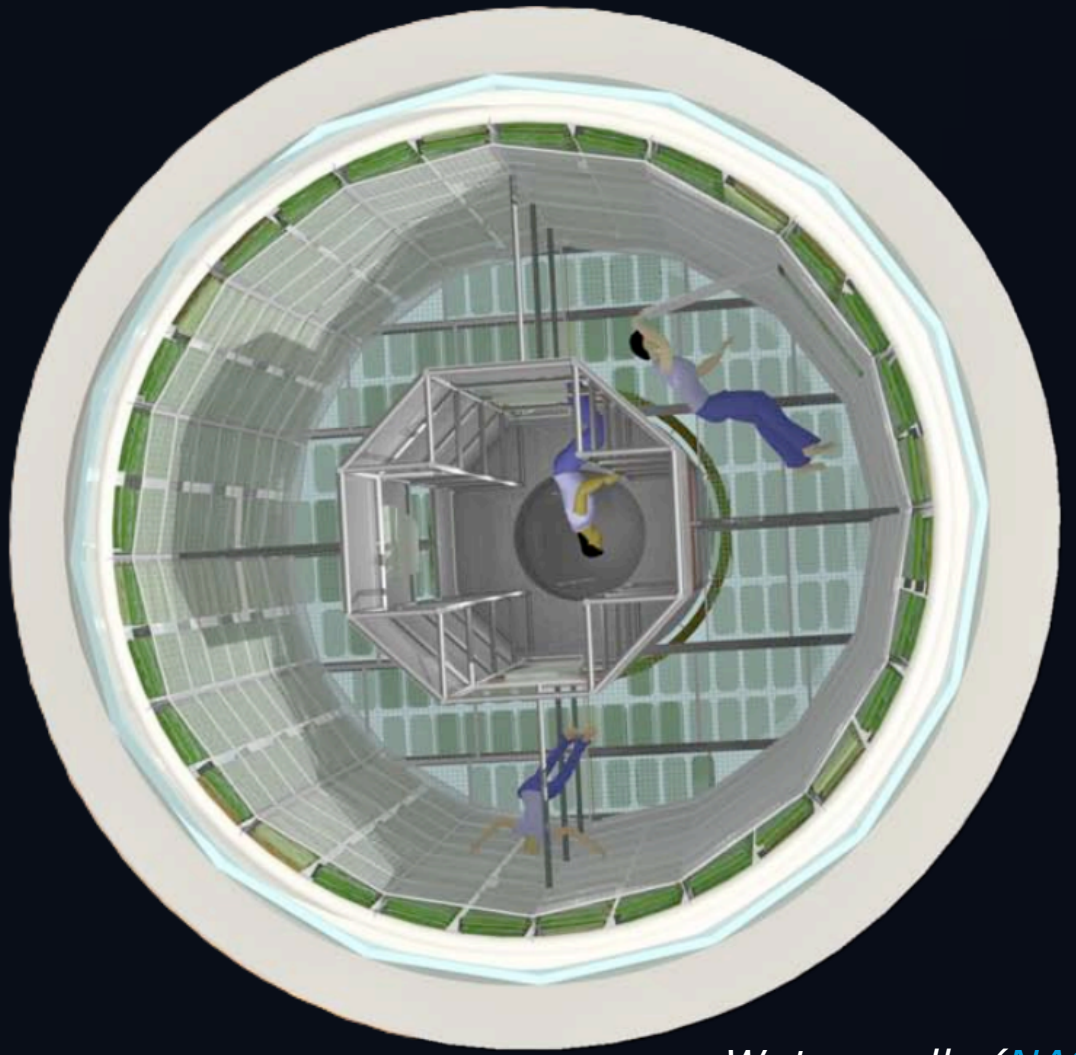


C4a 83L airlift bioreactor (MPP)



Intensified panel photobioreactors (Algosolis)

What if it looked like this?



Water walls (NASA)

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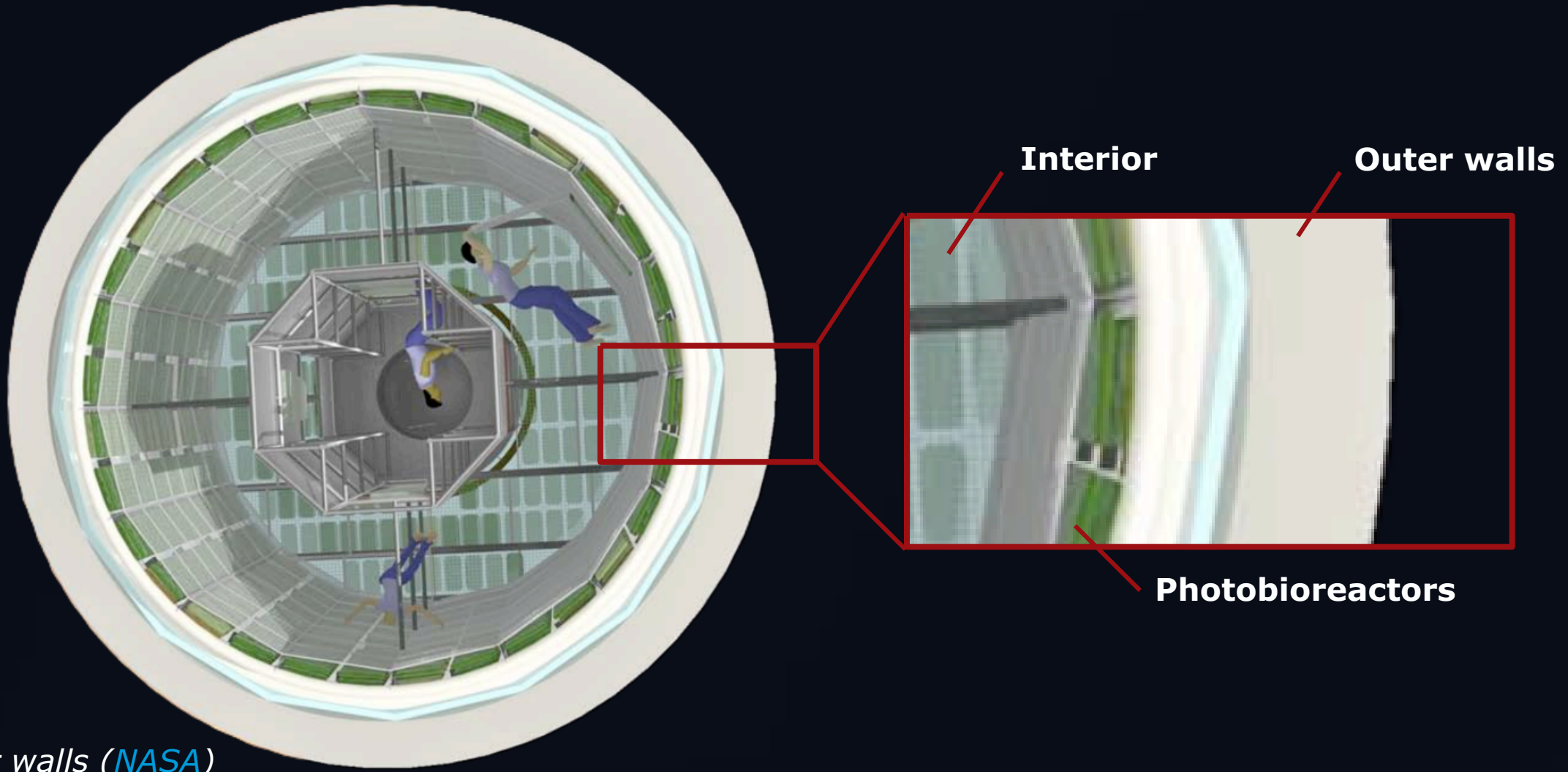

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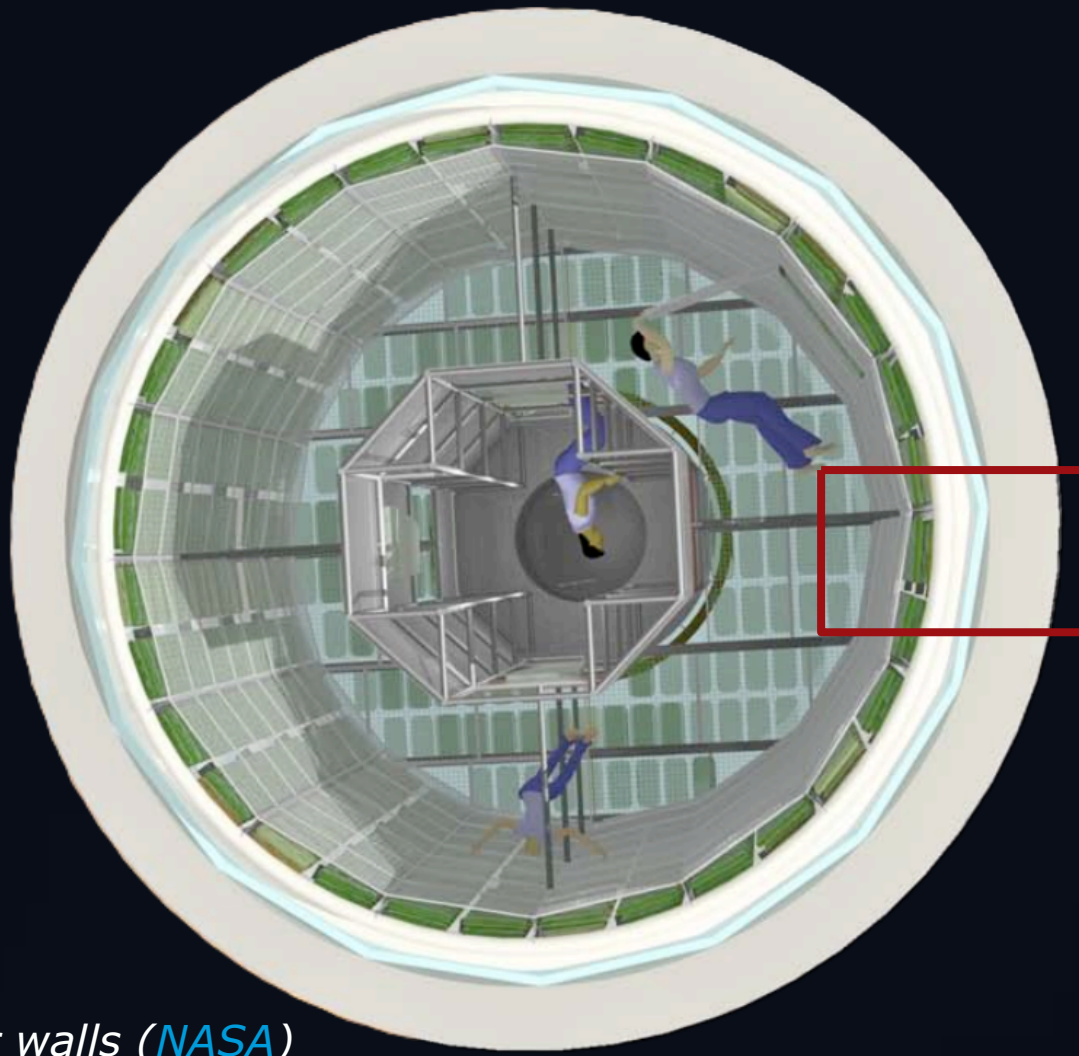

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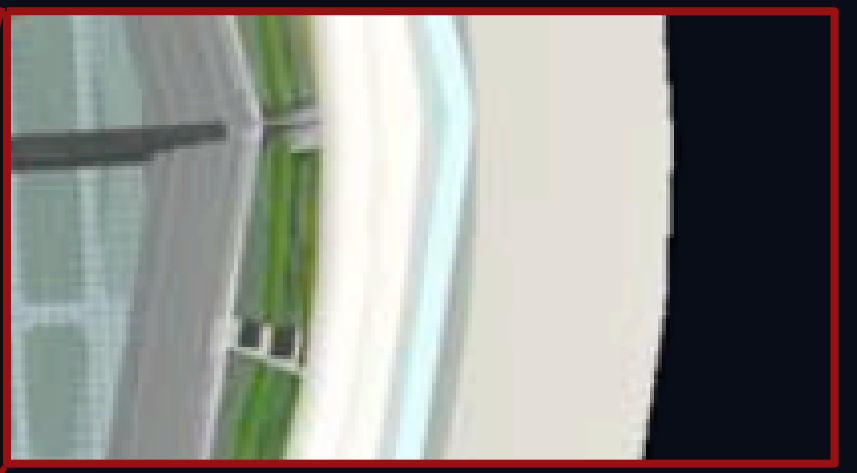
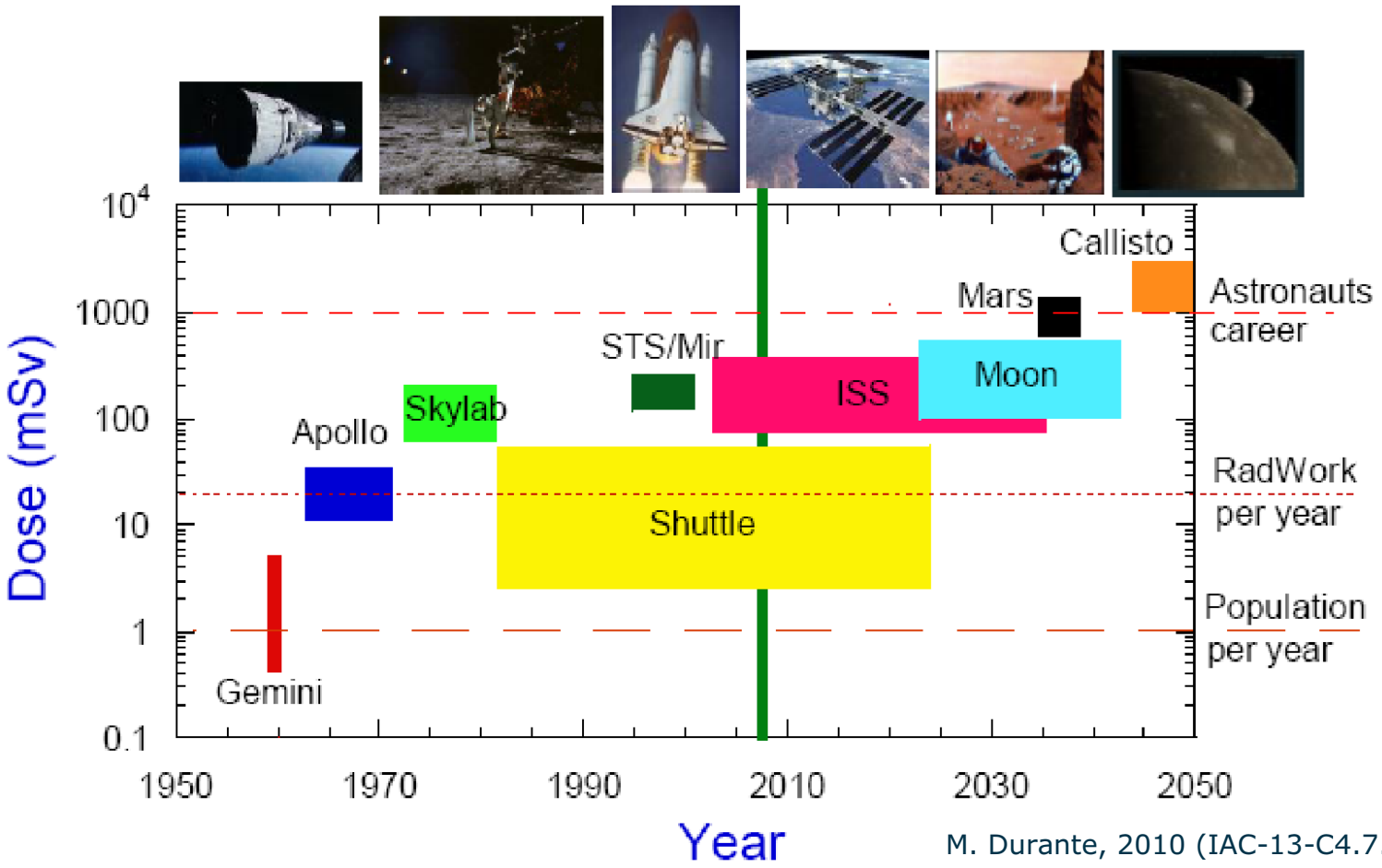


Issues:
- Radiation shielding ?
- Illumination ?
- Harvesting & maintenance?
- Centralisation?
- Sizing ?
- etc…

} Derisking MELiSSA?

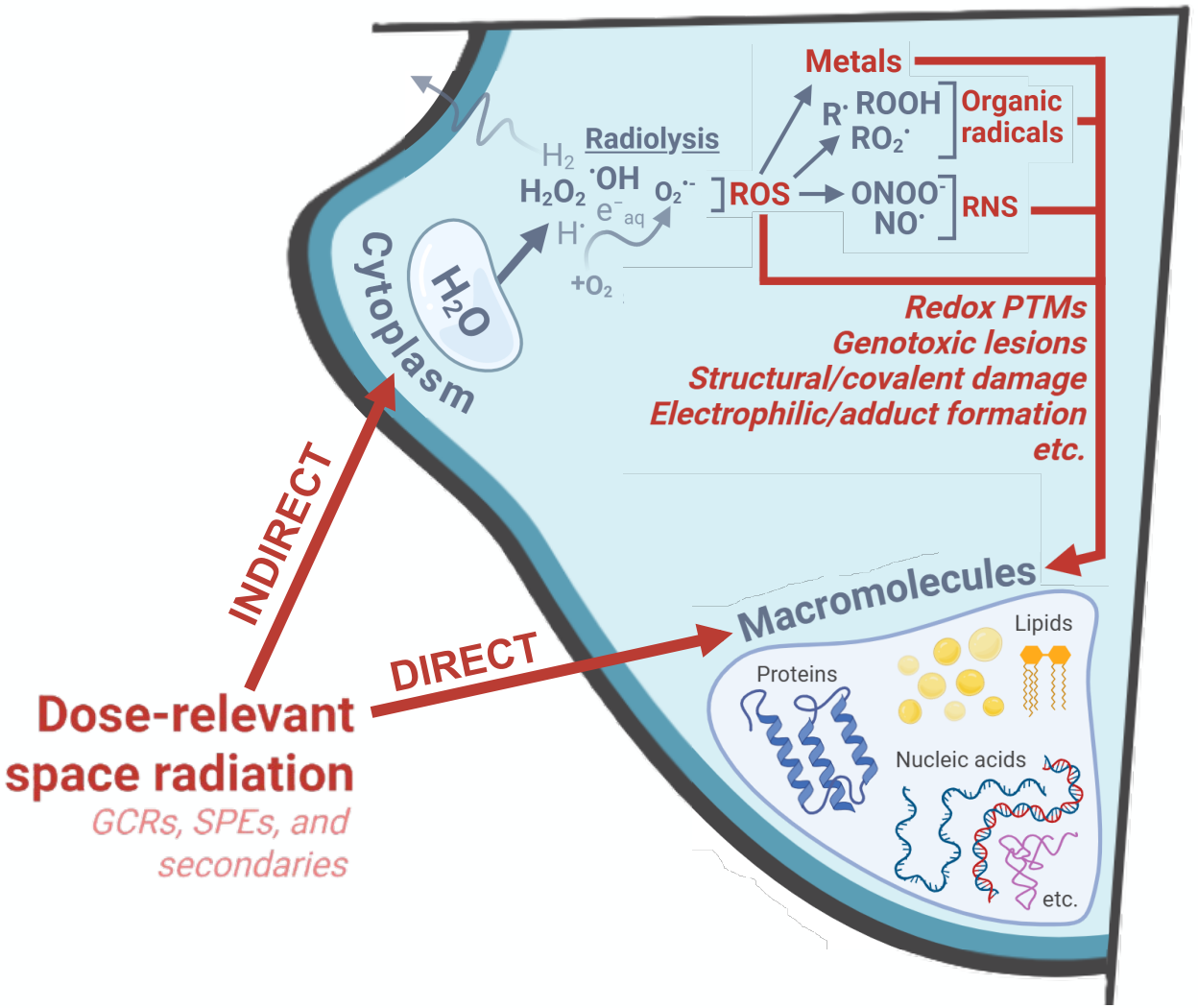
Radiation in deep space – *A hazard for all beings*



M. Durante, 2010 (IAC-13-C4.7.8)

→ Microorganisms of the MELiSSA loop, much like astronauts, will suffer from the increased radiation dose.

Radiation in deep space – *Sensitivity of microorganisms*



Resistance pathways:

- DNA repair, nucleoid compaction, redundancy
- Spores, dessication, endolithic dormancy
- Pigments, antioxidants, metallic ion shields
- Community protection (*e.g.* biofilms)
- Membrane adaptations
- etc.

Innate resistance of selected MELiSSA strains is already high. However, is it **high enough** to:

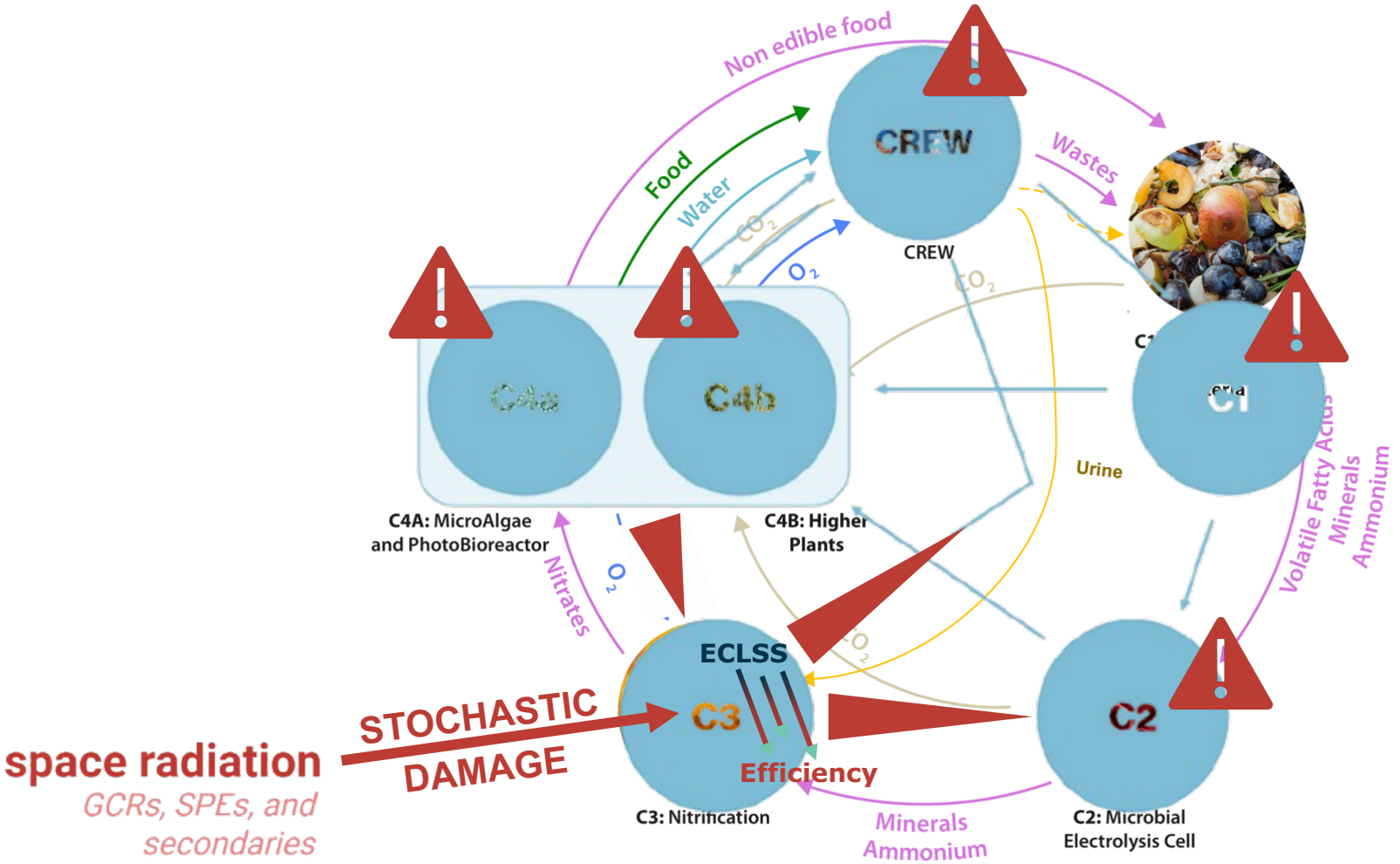
- Tackle unforeseen **stochastic damage** in cells?
- **Derisk** MELiSSA >< Physiochemical ECLSS?

GCRs = Galactic Cosmic Rays / SPE = Solar Particle Events

ECLSS = Environmental Control and Life Support Systems

Radiation in deep space – *Danger for interconnected BLSS*

BLSS = Biological Life Support Systems



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Radiation in deep space – *Danger for interconnected BLSS*

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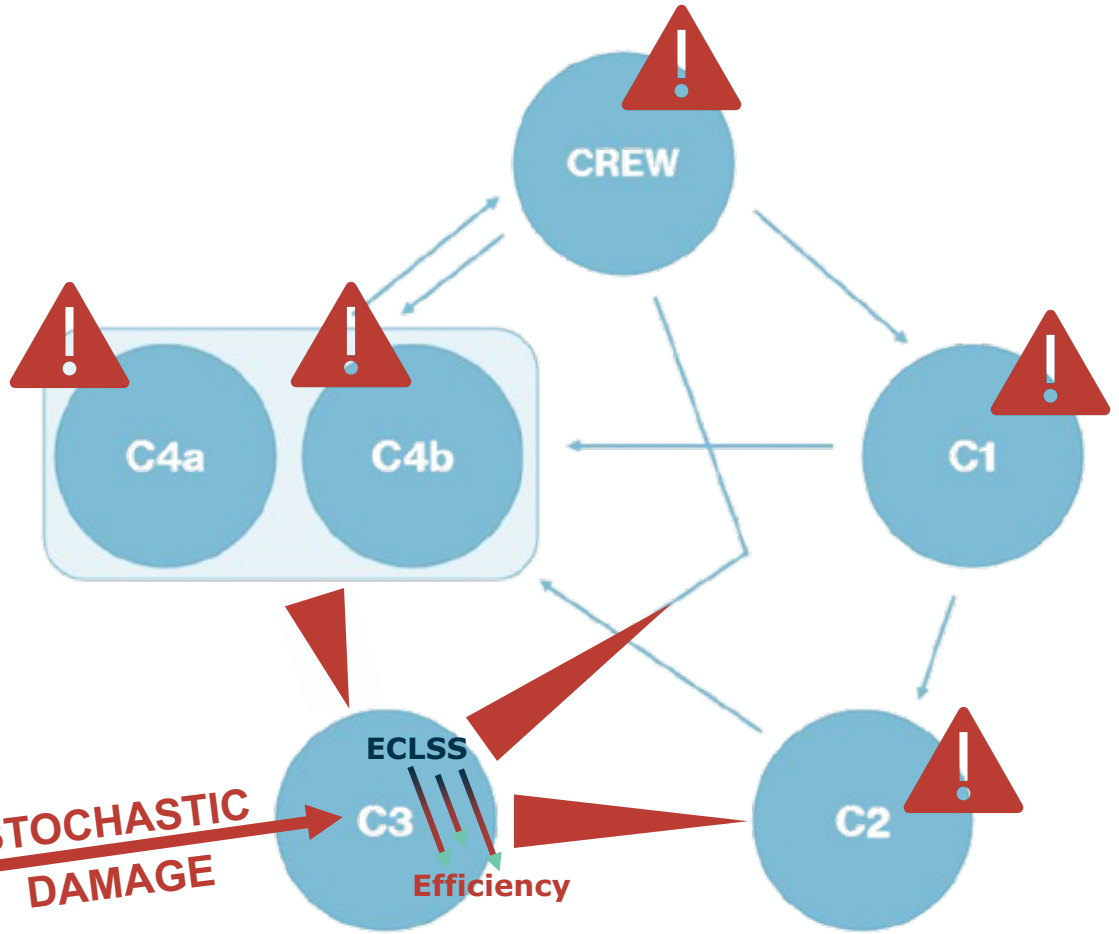
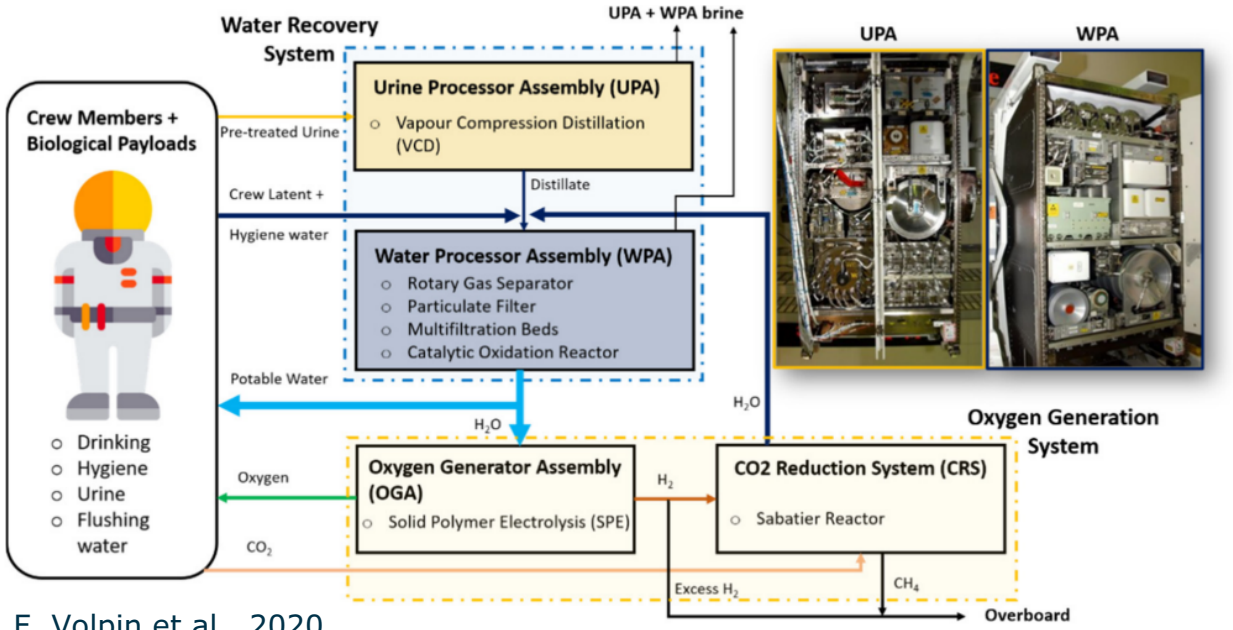




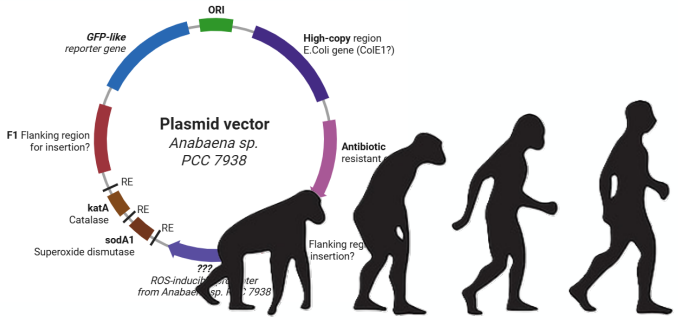
F. Volpin et al., 2020

Goal: Derisking MELiSSA by **increasing space radiation tolerance** to avoid loop destabilisation by compartment failure.

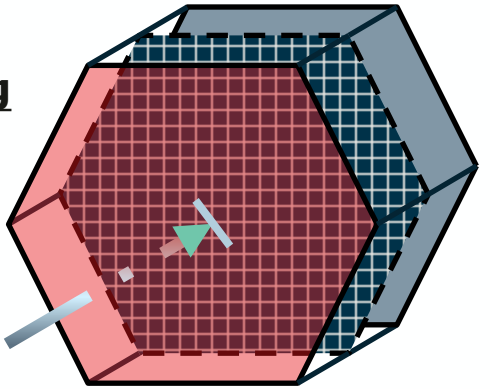
ECLSS = Environmental Control and Life Support Systems

Three pathways – *Radio-resistance/shielding/mitigation*

Enhancing **radioresistance** of the chosen microorganisms



Integrating **radioshielding** design in bioreactors

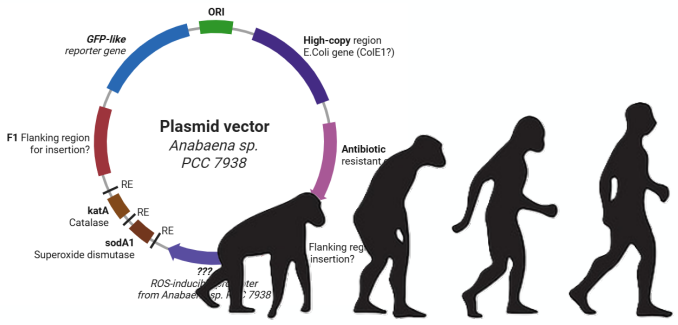


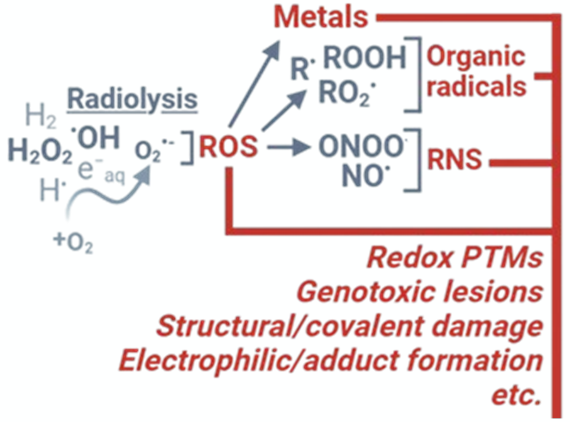
space radiation
GCRs, SPEs, and secondaries

Exploiting the **radiomitigation** capacity of the biomass

Three pathways – *Radio-resistance/shielding/mitigation*

Enhancing **radioresistance** of the chosen microorganisms





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- Membrane adaptations
- etc.

Which pathways?
Most likely **ROS**
→ Review 2026

Without genetic modifications:

- Directed laboratory evolution
- Natural/artificial selection

With genetic modifications:

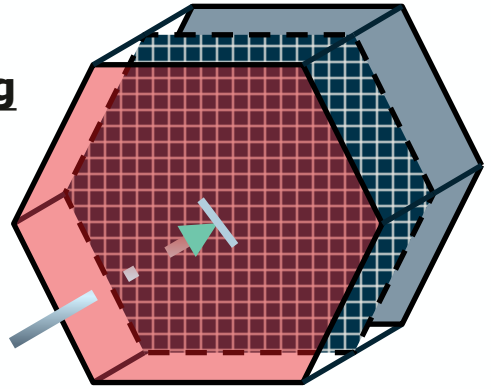
- Enhancement of the innate radioresistance pathways
- Transfection of new traits

ROS = Reactive Oxygen Species

Three pathways – *Radio-resistance/shielding/mitigation*

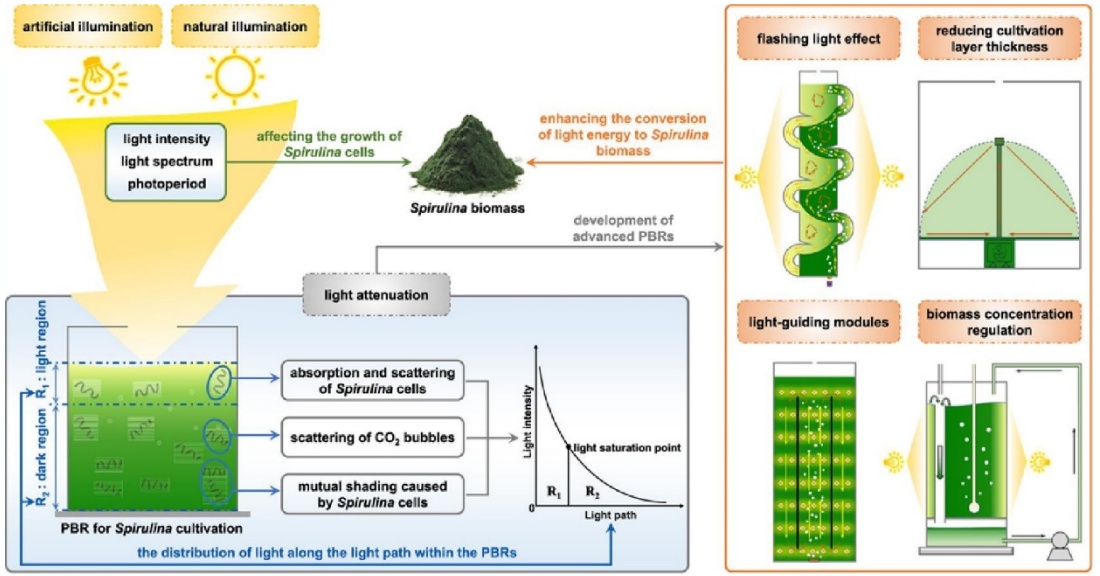
BLSS = Biological Life Support Systems

Integrating **radioshielding** design in bioreactors



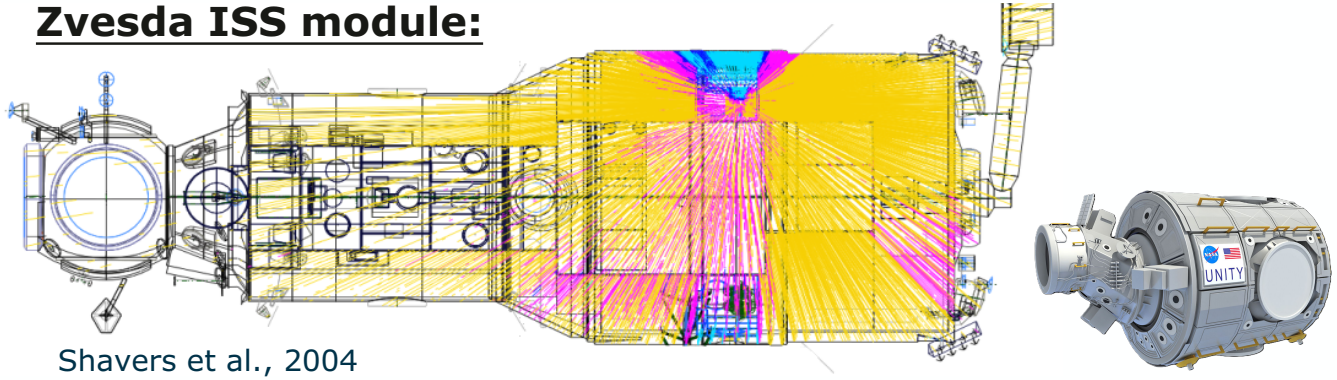
(1) Determining the **optimal bioreactor configuration** while supporting efficient BLSS.

(2) Identifying **bioreactor materials** that support bacterial growth and radiation attenuation.



Guoyu et al., 2025

Zvesda ISS module:



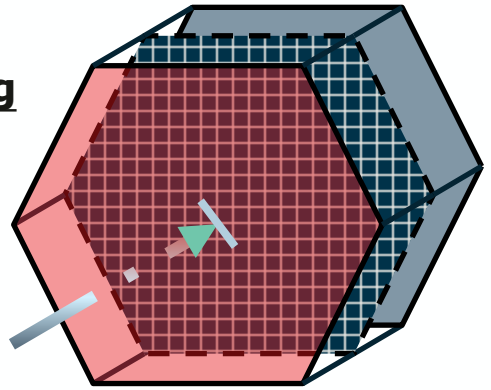
Shavers et al., 2004

☑ **Polyethylene** (Retro-fit) + ISS **water** walls (Node 1)
→ **Low-Z** = ↓↓ secondaries + ↓↓ particle speed

Three pathways – *Radio-resistance/shielding/mitigation*

BLSS = Biological Life Support Systems
ESM = Equivalent System Mass

Integrating **radioshielding** design in bioreactors

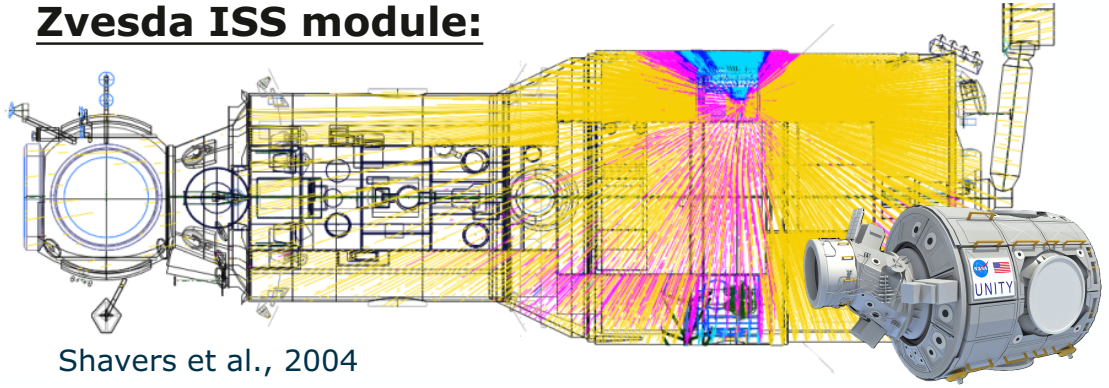


(1) Determining the **optimal bioreactor configuration** while supporting efficient BLSS.

(2) Identifying **bioreactor materials** that support bacterial growth and radiation attenuation.

(3) **Evaluating** the resulting shielding efficiency relative to standard shielding materials (ESM).

Zvesda ISS module:



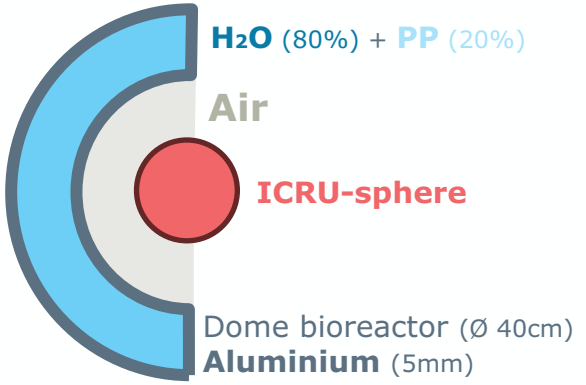
Shavers et al., 2004

☑ **Polyethylene** (Retro-fit) + ISS **water** walls (Node 1)
→ **Low-Z** = ↓↓ secondaries + ↓↓ particle speed
→ **PP bioreactors + Water?**

Scenario 1:

38M p_+

10 MeV - 10 GeV
(GCR 2020, BON2020)



Scenario 2:

Mass equivalent of S1 with aluminium.

Results: **S1**: **124** mSv (σ < 0.9 %), **7%** from neutrons
S2: 134 mSv (σ < 0.6 %), 11% from neutrons

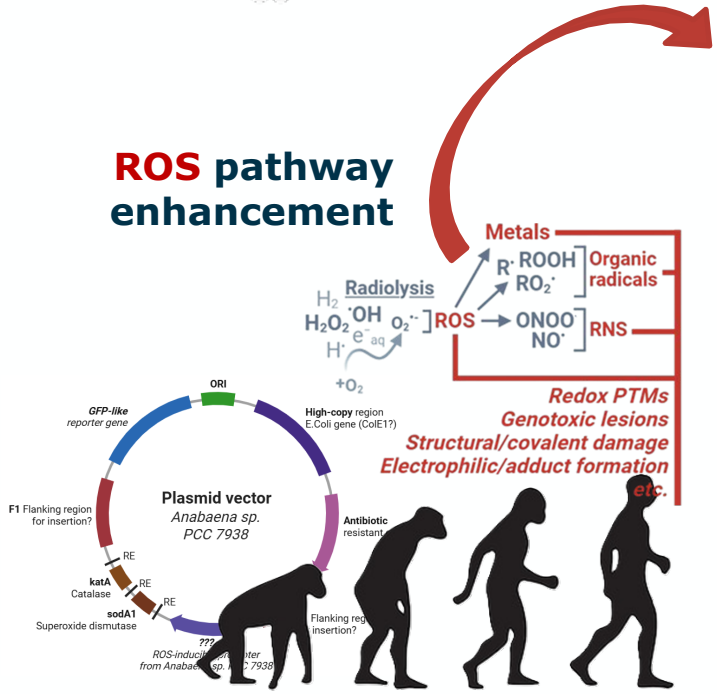
PP = Polypropylene / p_+ = proton

Three pathways – *Radio-resistance/shielding/mitigation*

Exploiting the **radiomitigation** capacity of the biomass → Use the produced biomass as **antioxidant agent** for the other MELiSSA compartments (incl. C5!)

ROS & radiation

ROS pathway enhancement



$O_2^- + O_2^- + 2\,H^+ \rightarrow H_2O_2 + O_2$

Superoxide dismutase

$H_2O_2 + H_2O_2 \rightarrow 2\,H_2O + O_2$

Catalase

Antioxidants (Basel). 2023 Feb 24;12(3):572. doi: 10.3390/antiox12030572

***Limnospira indica* PCC 8005 Supplementation Prevents Pelvic Irradiation-Induced Dysbiosis but Not Acute Inflammation in Mice**

Charlotte Segers [1,2,†], Mohamed Mysara [1,†], Amelie Coolkens [1,†], Shari Wouters [1,§], Sarah Baatout [1], Natalie Leys [1], Sarah Lebeer [2], Mieke Verslegers [1,‖], Felice Mastroleo [1,*]

Editors: Elena Obrador Pla, Alegria Montoro

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PMCID: PMC10045453 PMID: 36978820

Benefits:

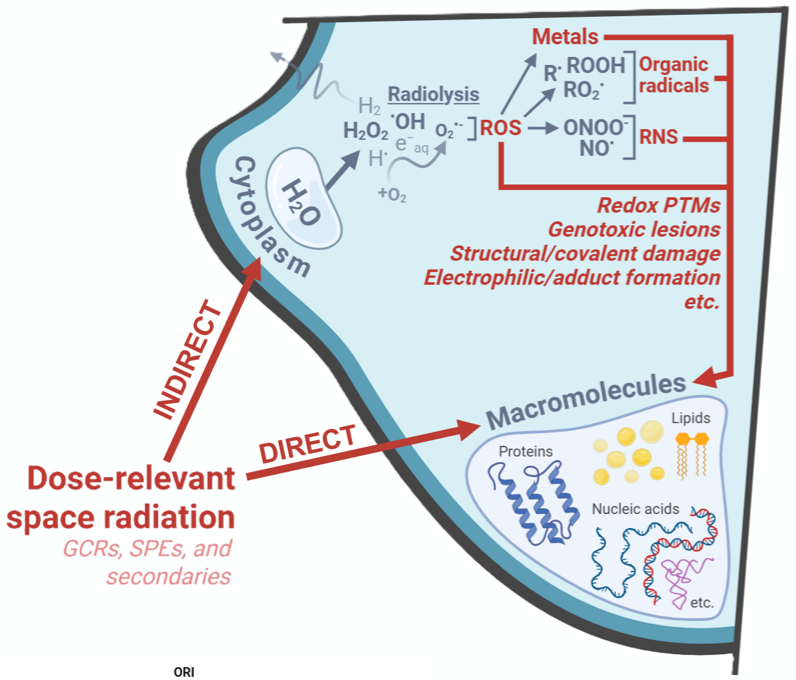
- ↑ **Safety** (↓ single-fault failure risks).
- ↑ **Reliability** for mission requirements.
- ↓ **Shielding** ESM needed.
- Opportunistic radio**shielding** and **mitigation** for astronauts.

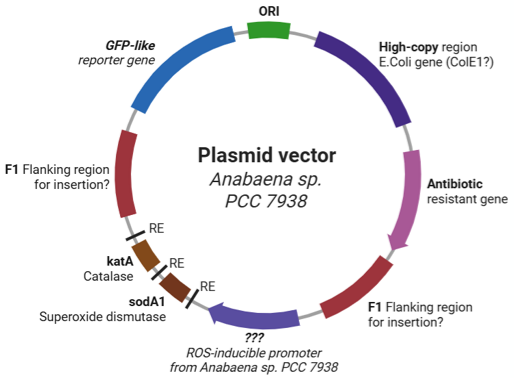
→ **De-risks MELiSSA + ↑*attractiveness***

ROS = Reactive Oxygen Species

Integration example – *Mars ISRU Bioreactors PhD*

Enhancing radioresistance in *Anabaena*





ZARM

UF UNIVERSITY of FLORIDA

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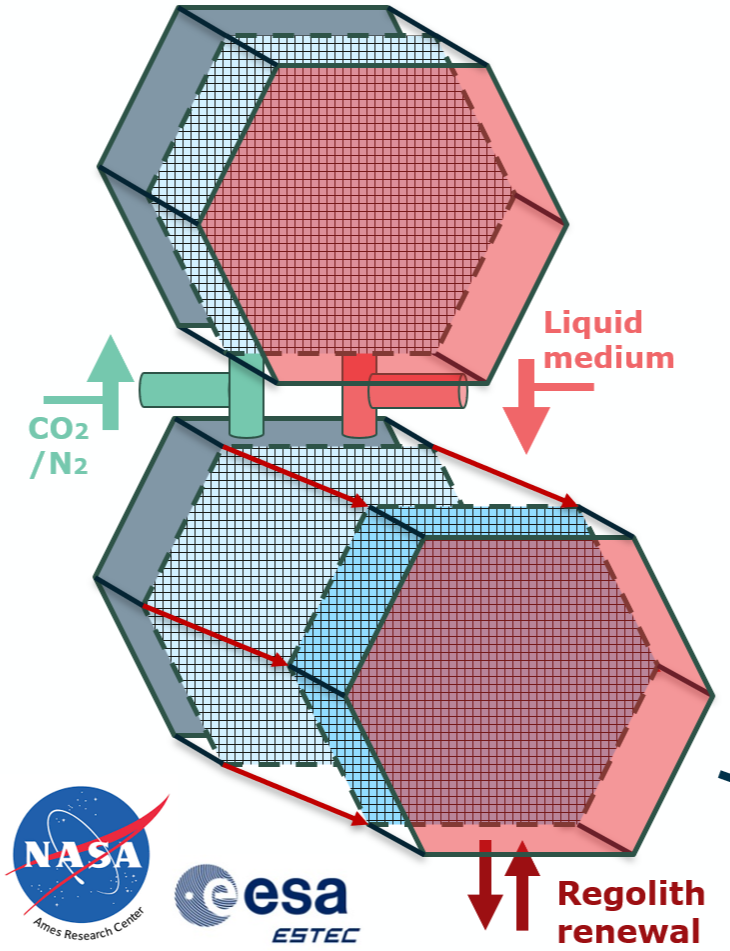
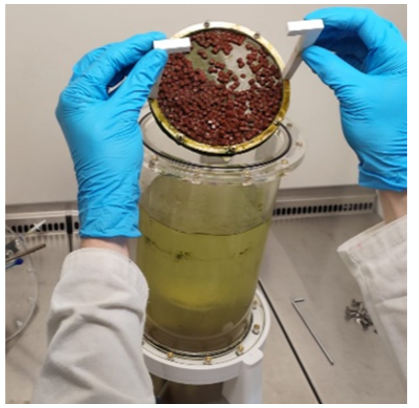
Integrating ISRU radioshielding bioreactors in Mars habitats



Evaluating the radiomitigation capacity of the biomass

sckcen



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esa ESTEC

MELISSA

Thank you!

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