Exploring the impact of irregular metabolic efficiencies and the space environment on the survivability of a regenerative life support system through agent-based modeling

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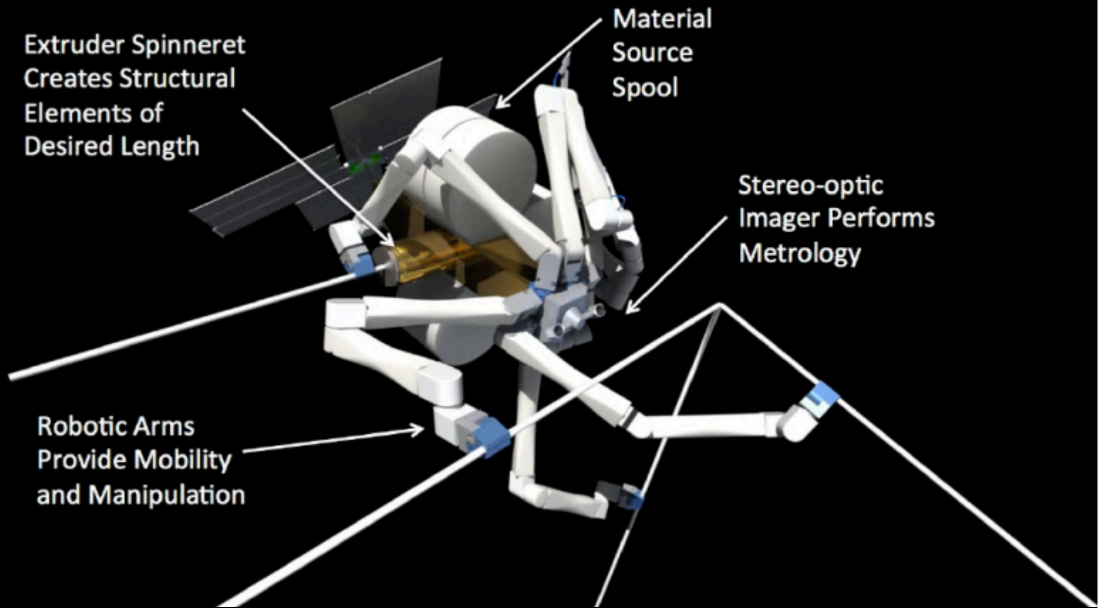
SPACE ECOLOGIES ART AND DESIGN


UNCERTAIN FUTURES

A GROWING AND EVOLVING SPACECRAFT

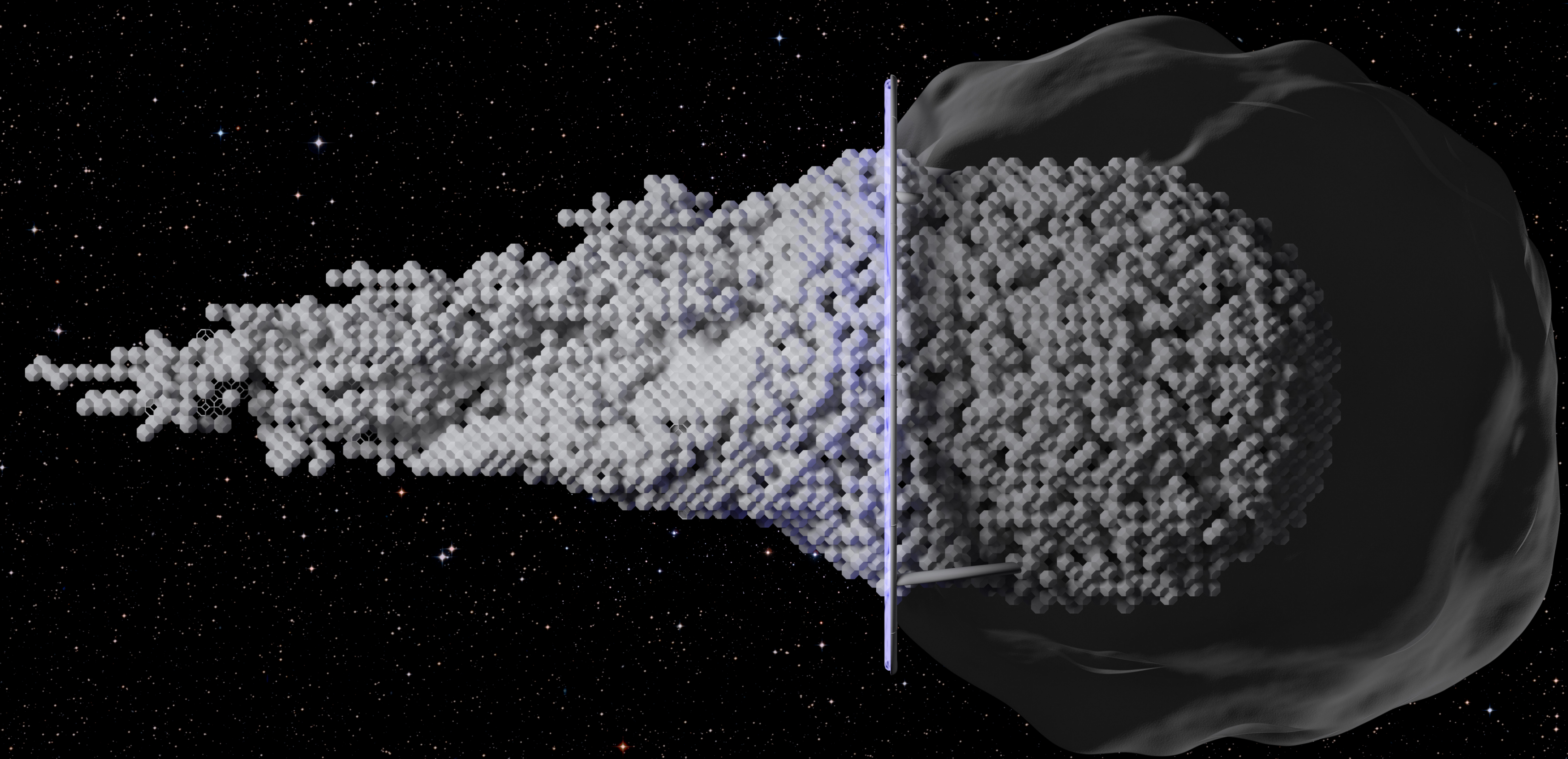
ASTEROID MINING

3D MANUFACTURING



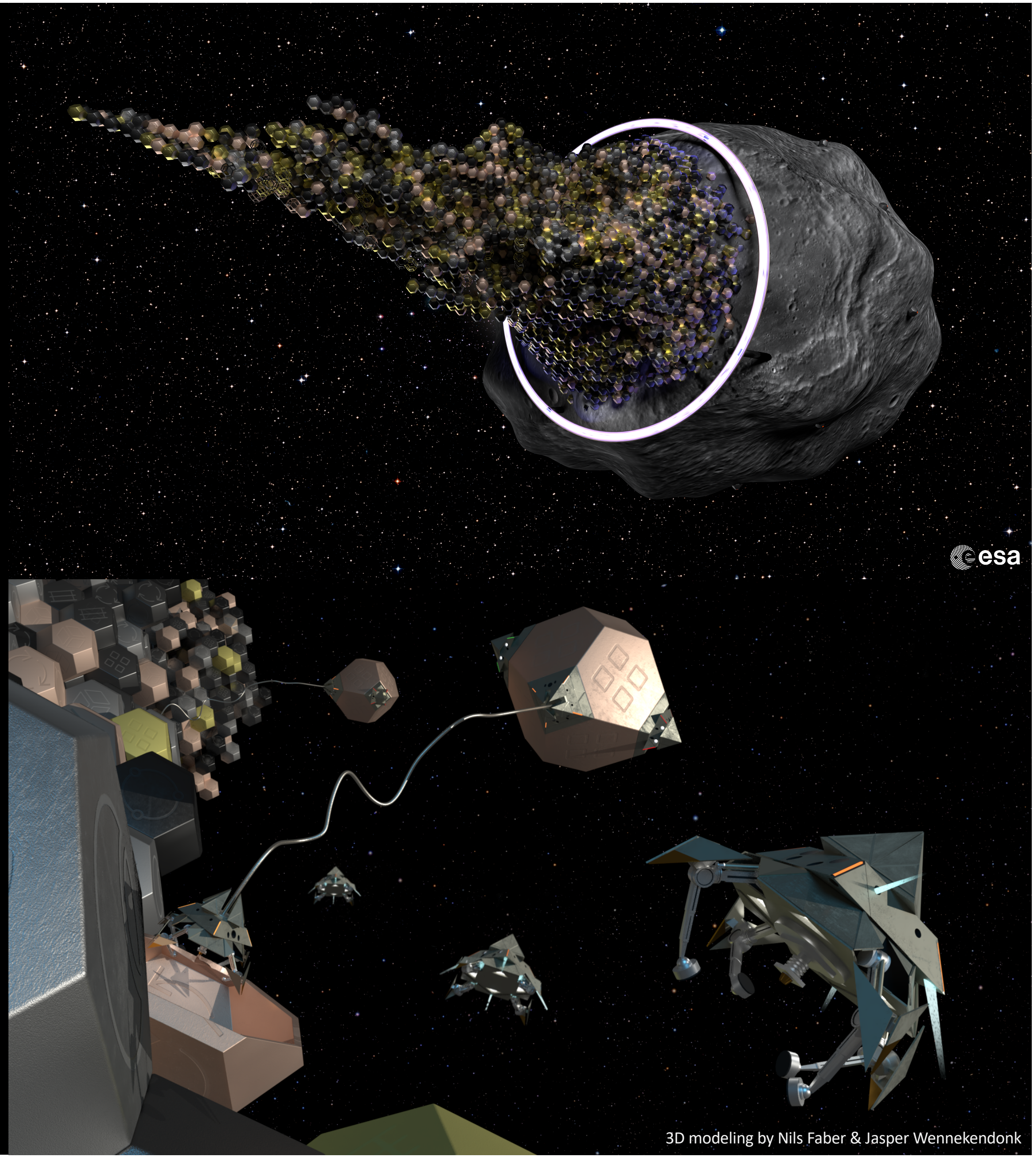
SpiderFab, Tethers Unlimited & NASA, 2013

MODULAR ARCHITECTURE

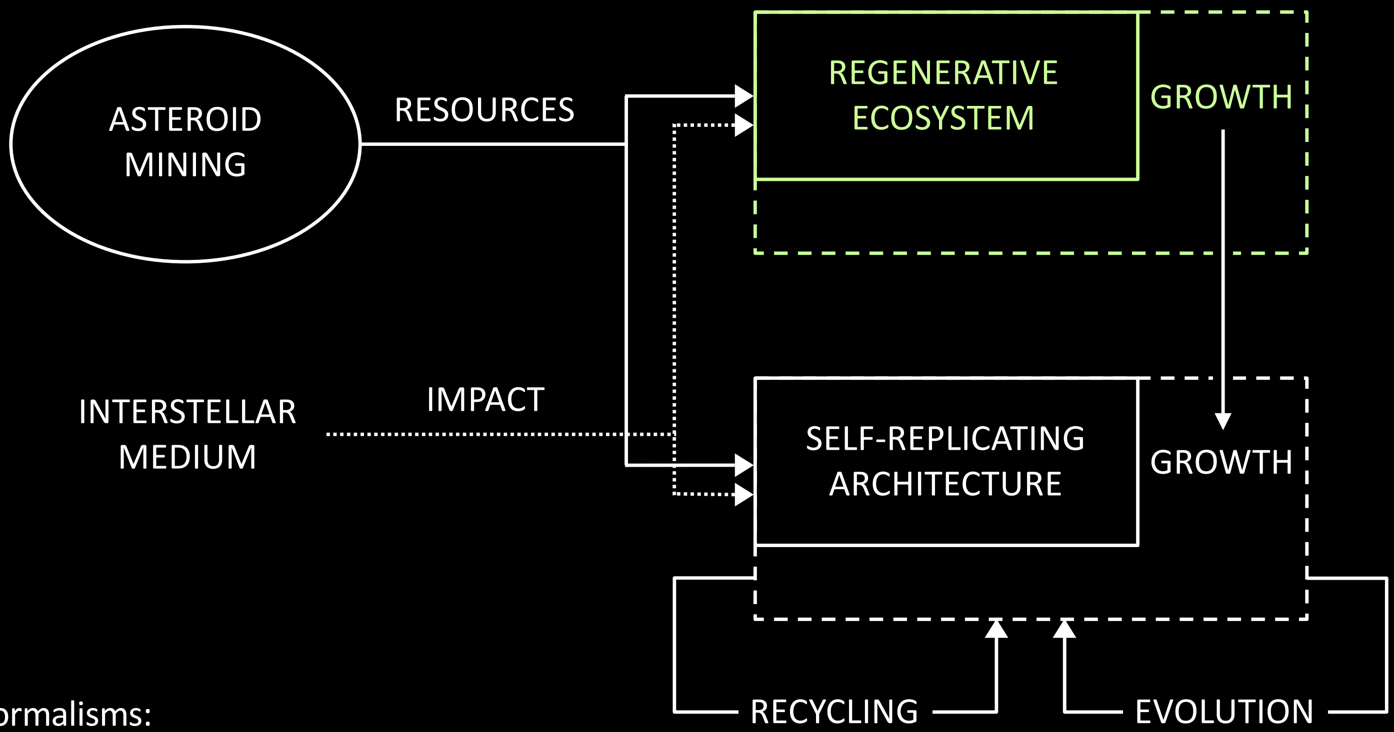


3D modeling by Nils Faber

MORPHOGENETIC ENGINEERING

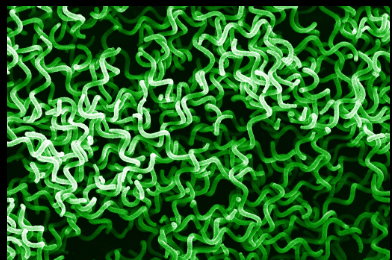


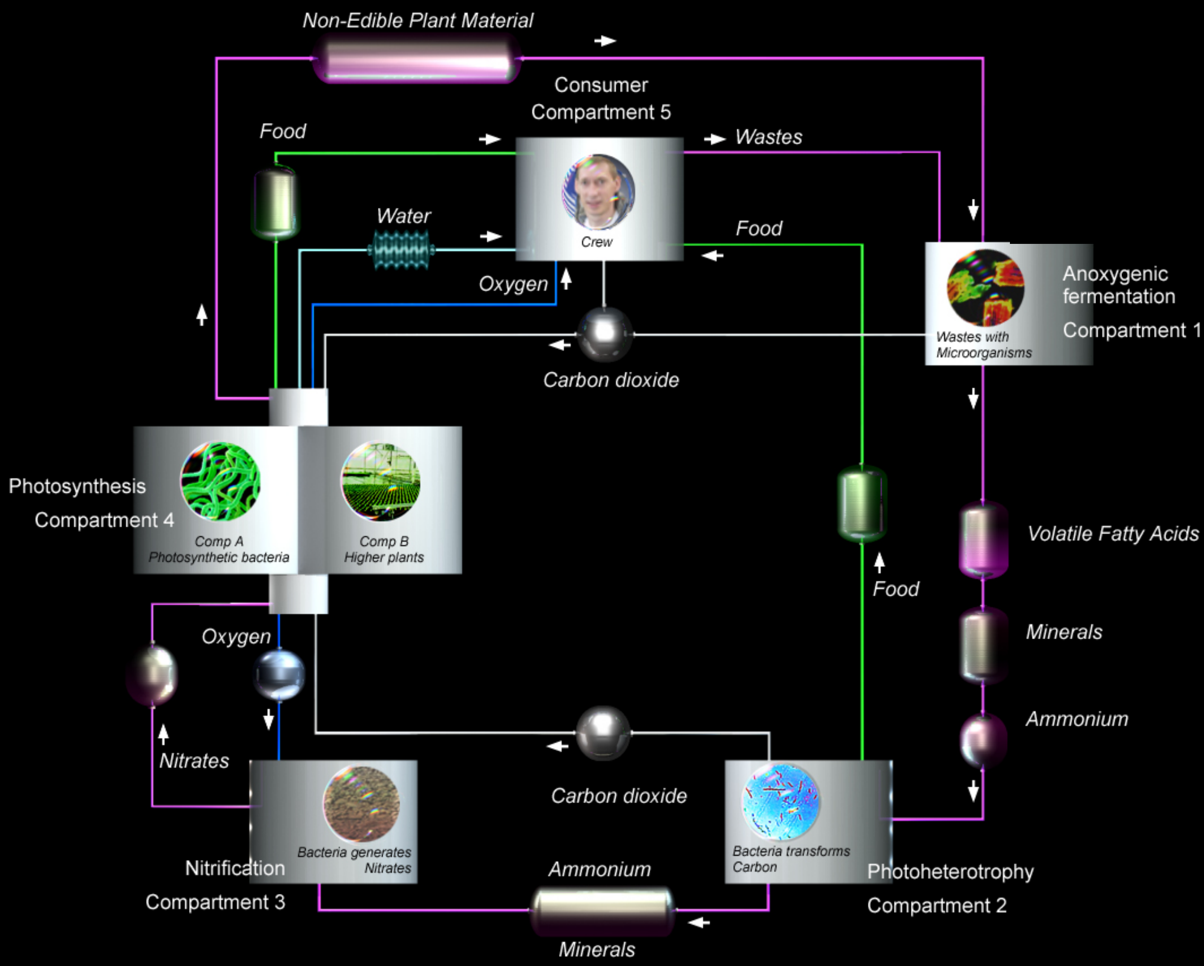
ECOSYSTEM INTEGRATION



Simulation formalisms:

- ABM (agent-based modeling)
- DEVS (discrete event system specification)
- SD (system dynamics)
- EA (evolutionary algorithms)



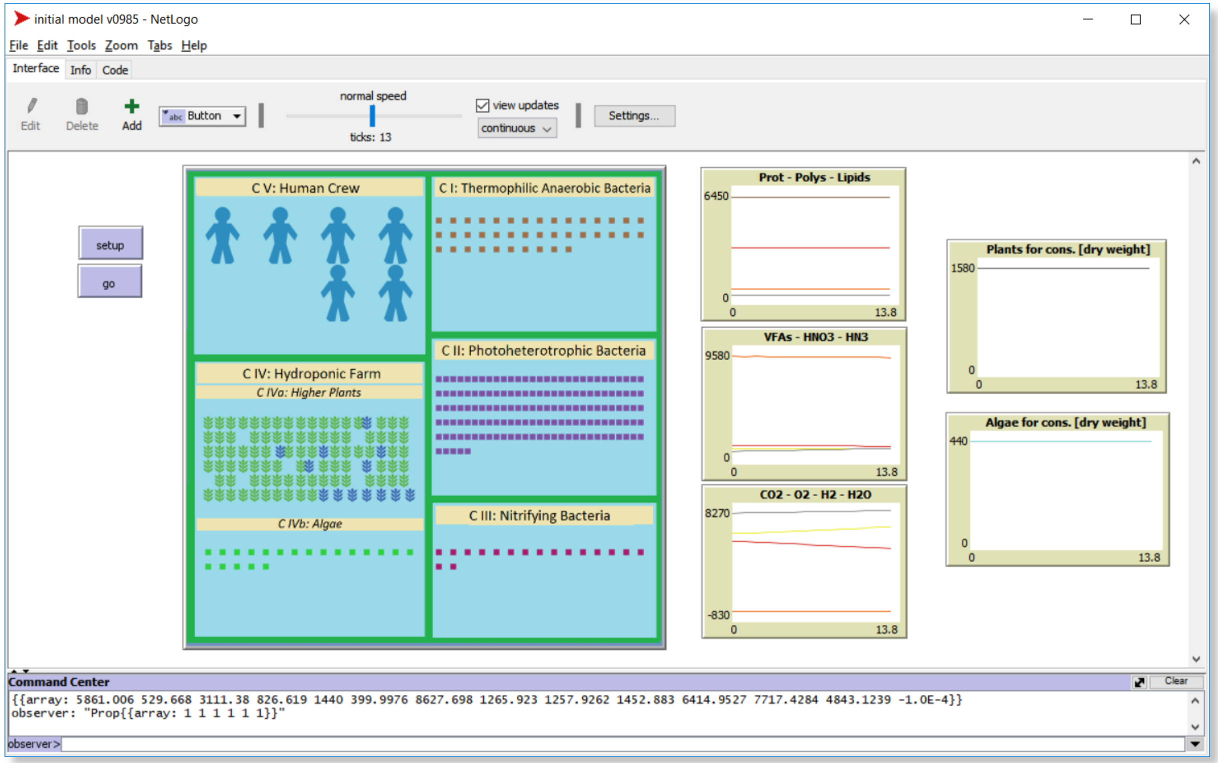


Non-Edible Plant Material
Consumer
Compartment 5
Food
Wastes
Water
Crew
Food
Oxygen
Carbon dioxide
Anoxygenic
fermentation
Compartment 1
Wastes with
Microorganisms
Photosynthesis
Compartment 4
Comp A
Photosynthetic bacteria
Comp B
Higher plants
Volatile Fatty Acids
Food
Minerals
Oxygen
Ammonium
Nitrates
Carbon dioxide
Bacteria generates
Nitrates
Bacteria transforms
Carbon
Nitrification
Compartment 3
Ammonium
Minerals
Photoheterotrophy
Compartment 2

ECOSYSTEM MODEL

AGENT-BASED MODELING

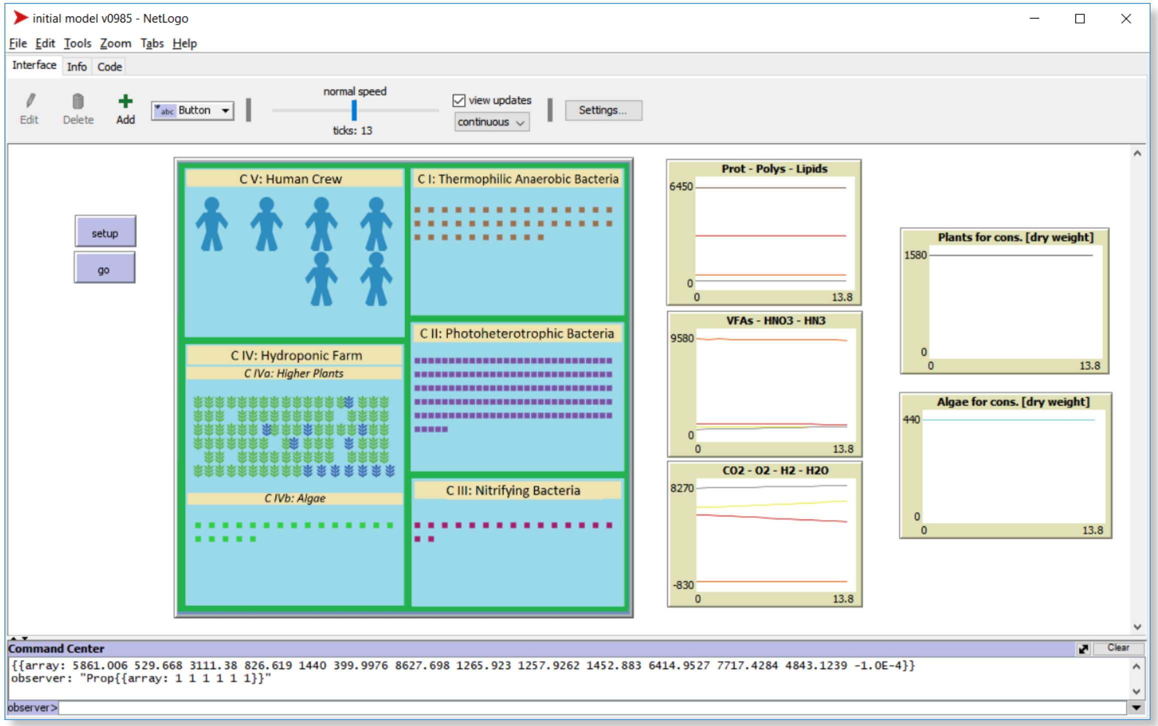
- Works with **agents**
- Focuses on **interactions** and emergent patterns
- High **granularity** and ontological correspondence



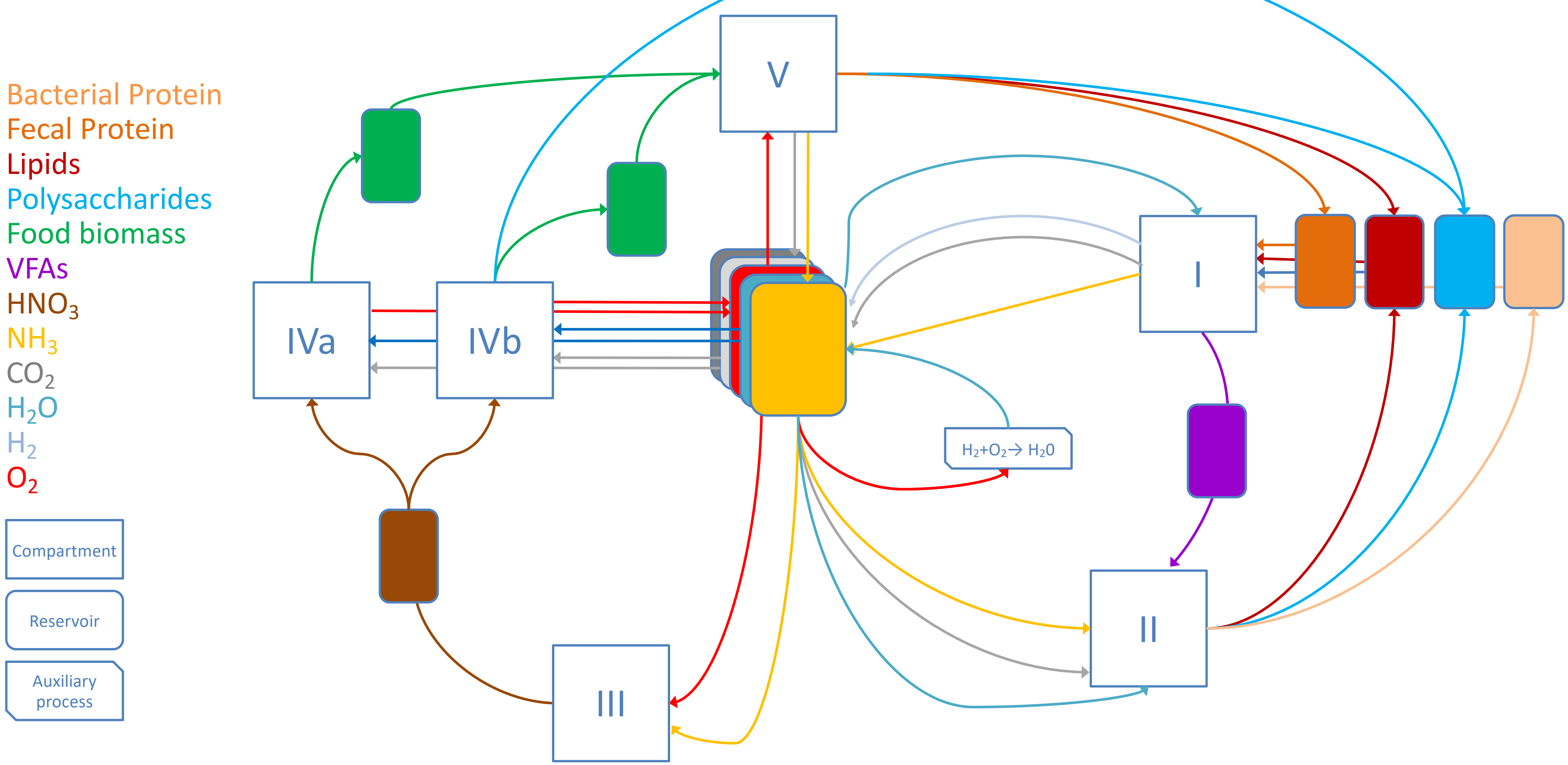
AGENT-BASED MODELING

MODEL COMPONENTS

- **Compartments**:
  MELiSSA compartments, inhabited by agents
- **Reservoirs**:
  centralized storage of all output of each compartment
- **Agents**:
  individual humans, bioreactors and plant plots

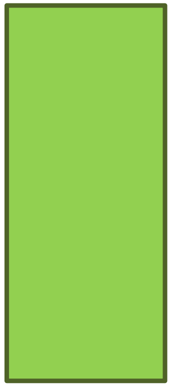


ECOSYSTEM MASS FLOWS



BIOREACTOR AGENT

1 AGENT



ATTRIBUTES

1 bioreactor = 1 agent

Compartments II and IVa create biomass (consumption)

Compartments I and III have no biomass (no consumption)

BEHAVIOR

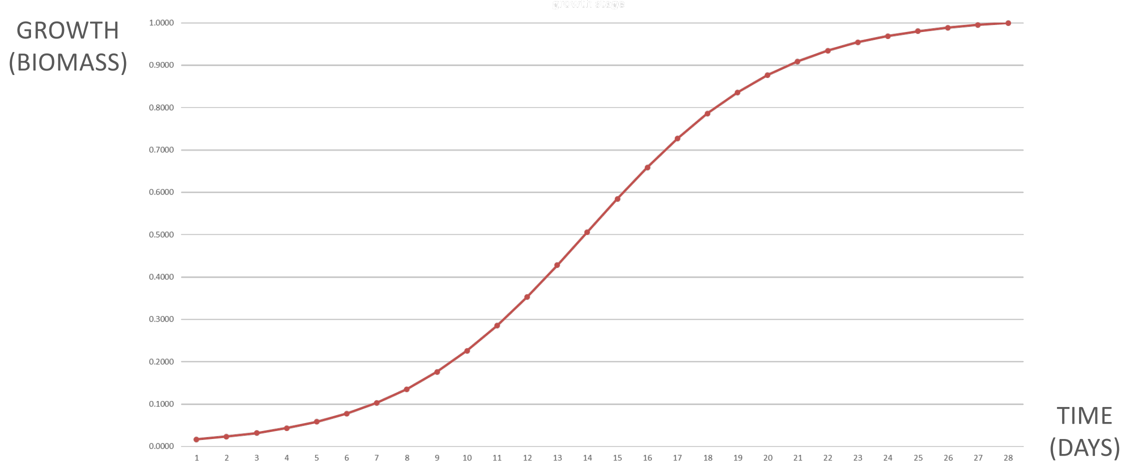
Input-output: stoichiometry

BIOREACTOR AGENT

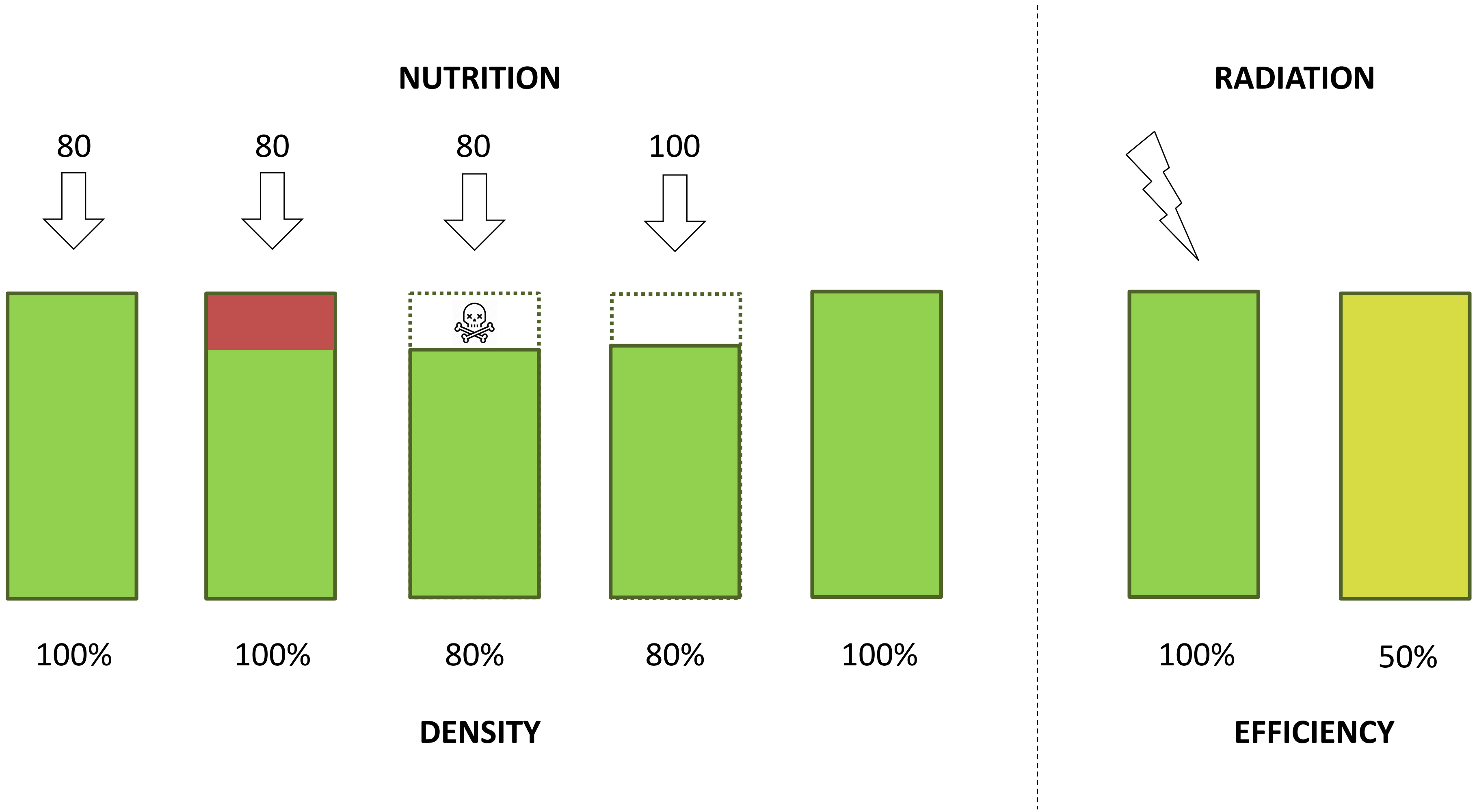
STATES

- Growth follows a sigmoid curve
- Density reaching 100% in 28 days (10% first and 10% last week)
- 100% density corresponds to maximum productivity, and a specific amount of required nutrients (according to the bioreactor's stoichiometry)*
- Each < 100% density along the curve requires a proportionally lower amount of nutrients

* At 100% efficiency.



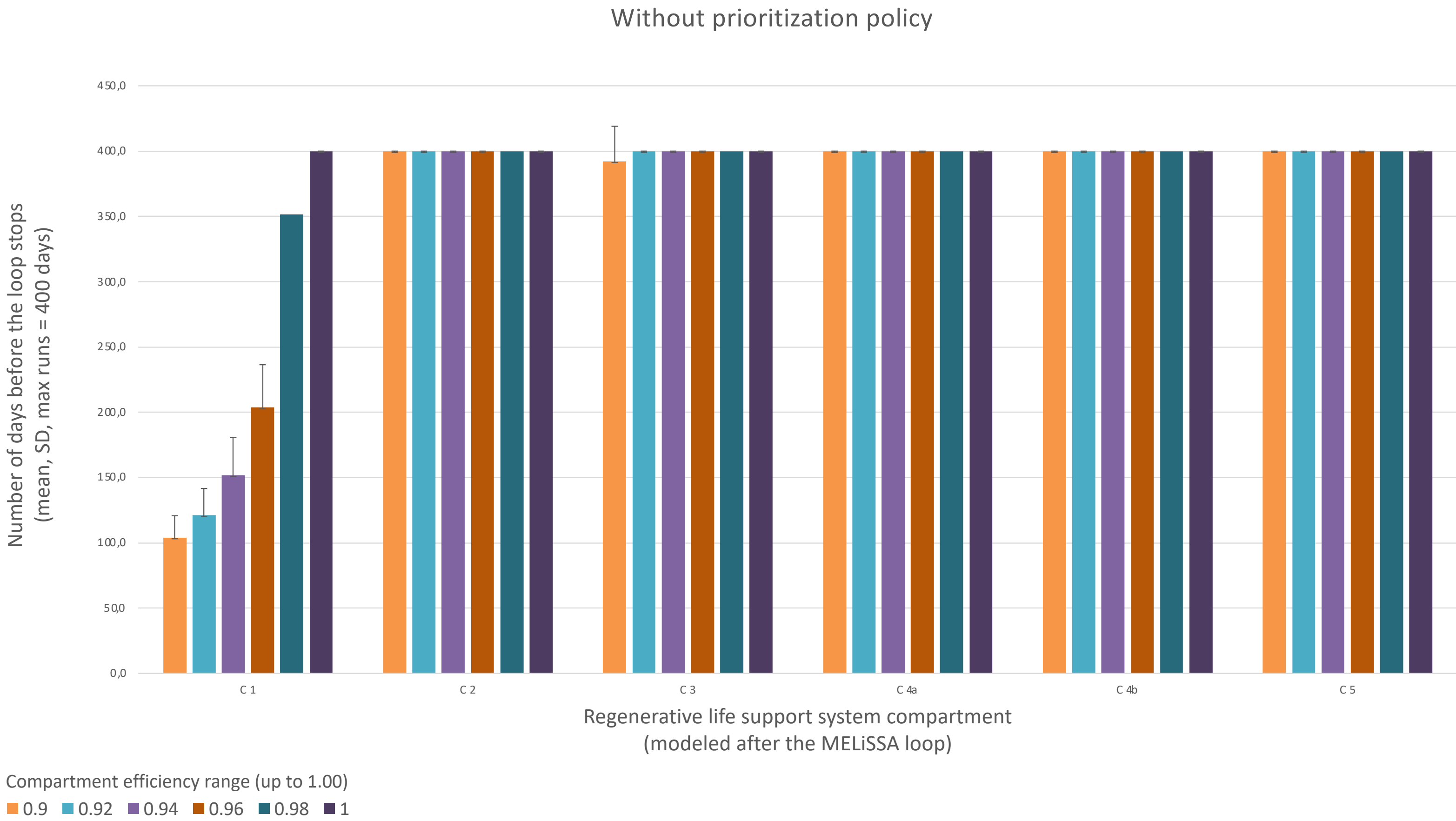
BIOREACTOR AGENT



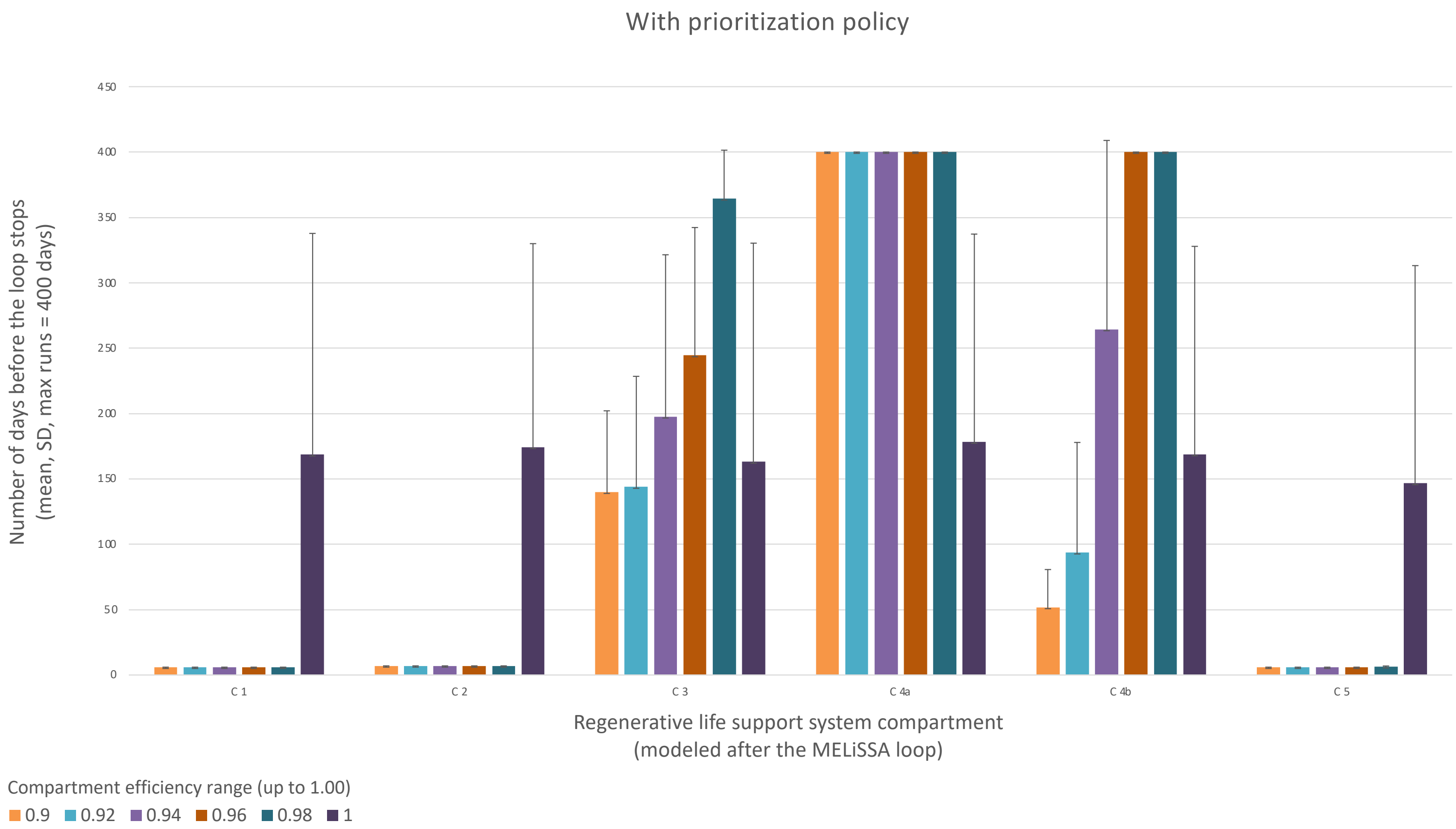
STOICHIOMETRY

Compartment	Chemical equation	Acting organism
I	Fecal protein $3,2CH_{1.76O0.239}N_{0.239} + 3,035H_2O \rightarrow C_2H_4O_2 + 0,1C_4H_8O_2 + 2.3H_2 + 0.76NH_3 + 0,8CO_2$ Bacterial protein $3,2CH_{1.4697}O_{0.34}N_{0.2807} + 2,712H_2O \rightarrow C_2H_4O_2 + 0,1C_4H_8O_2 + 1,3162H_2 + 0.8982NH_3 + 0,8CO_2$ Polysaccharides $3,199CH_{1.667}O_{0.833} + 1,134H_2O \rightarrow 1C_2H_4O_2 + 0,1C_4H_8O_2 + 1,4H_2 + 0,8CO_2$ Lipids $C_{16}H_{32}O_2 + 13,0278H_2O \rightarrow 6,5278C_2H_4O_2 + 0,6528C_4H_8O_2 + 0,3333CO_2 + 13,3611H_2$	Thermophilic anaerobic bacteria
II	Volatile fatty acids $50.39C_2H_4O_2 + 5.04C_4H_8O_2 + 25NH_3 + 0.19CO_2 \rightarrow 89.06CH_{1.4697}O_{0.34}N_{0.2807} + 18.33CH_{1.667}O_{0.833} + 0.86C_{16}H_{32}O_2 + 63.98H_2O$	Photoheterotrophic bacteria
III	Nitrification $NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$	Nitrifying bacteria
IVa	Carbon fixation $5CO_2 + 3H_2O + HNO_3 \rightarrow C_5H_7O_2N + 7O_2$	Arthrospira algae
IVb	Carbon fixation $5CO_2 + 3H_2O + HNO_3 \rightarrow C_5H_7O_2N + CH_{1.667}O_{0.833} + 7O_2$	Ideal plant
V	Consumption $2.71C_5H_7O_2N + 4.41O_2 \rightarrow 4.20CH_{1.76O0.239}N_{0.239} + 1.48CH_{1.667}O_{0.833} + 0.12C_{16}H_{32}O_2 + 5.88CO_2 + 1.70NH_3$	Crew

IMPACT OF IRREGULAR METABOLIC EFFICIENCIES



IMPACT OF IRREGULAR METABOLIC EFFICIENCIES

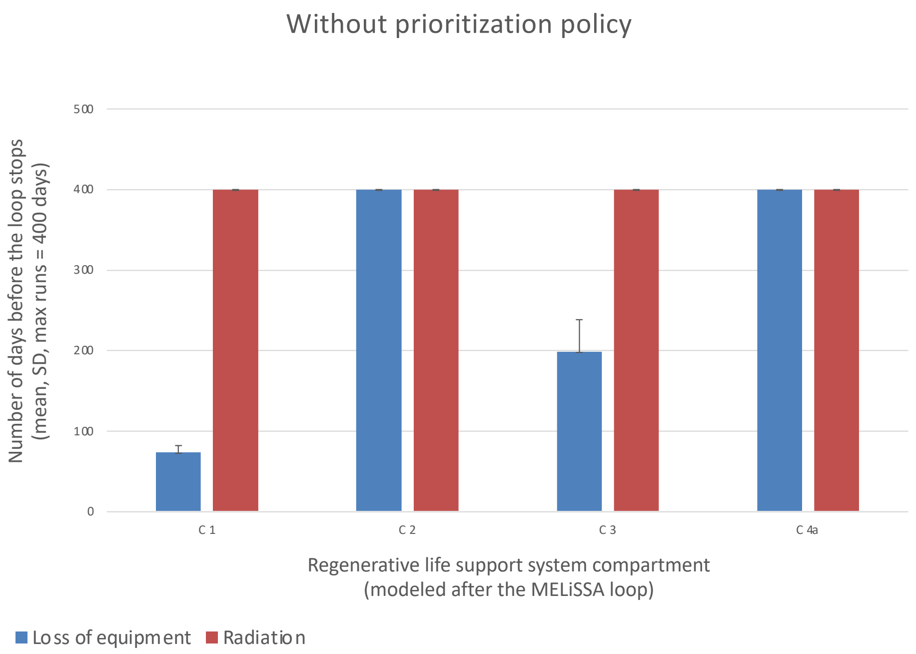


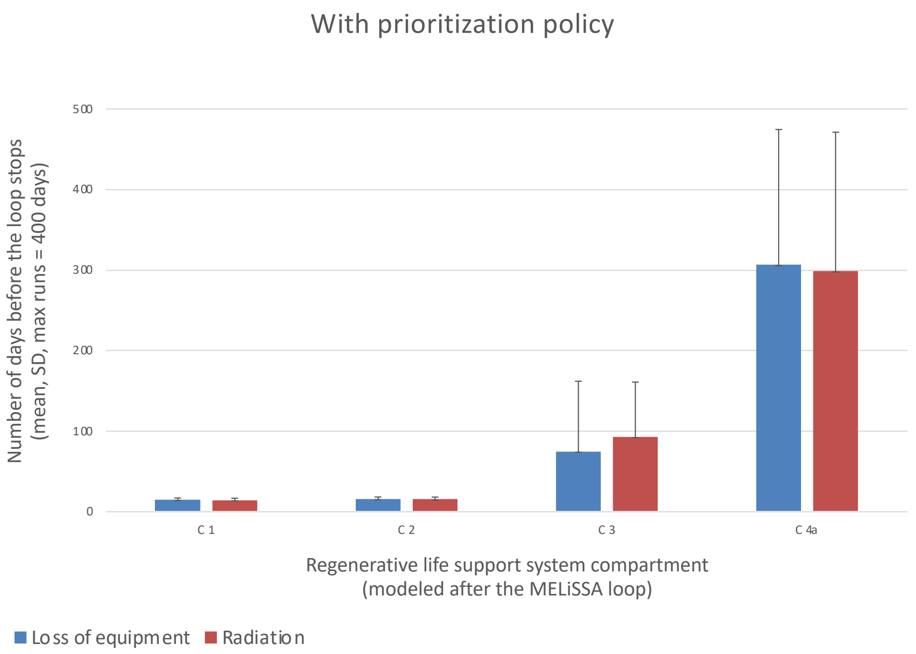
IMPACT OF THE SPACE ENVIRONMENT

EXPERIMENT DESIGN

- Loss of equipment: several bioreactors disappear from the system
- Radiation: instant decrease of bioreactor efficiencies to 50%, with slow recovery
- Impact happens on day 10
- 4-6 bioreactors are affected

IMPACT OF THE SPACE ENVIRONMENT





CONCLUSIONS

- Agent-based model of MELiSSA that can be used to:
  - explore the behavior of the system under different conditions
  - compare different policies regarding mass flow management
- Compartment 1 was the most sensitive compartment
- Using a policy that prioritizes Compartment 5 resulted in reduced system longevity
- Temporary decrease in efficiency: recovery without prioritization policy
- Loss of equipment: only limited recovery

NEXT STEPS

- Improve the stoichiometry:
  - More VFAs
  - Biomass split up in three streams (P/C/L)
  - Adjust faeces composition
- Increase levels of disruption
- Experiment with additional parameters and parameter combinations
- Use different prioritization policies (between compartments and agents)
- Vary initial conditions

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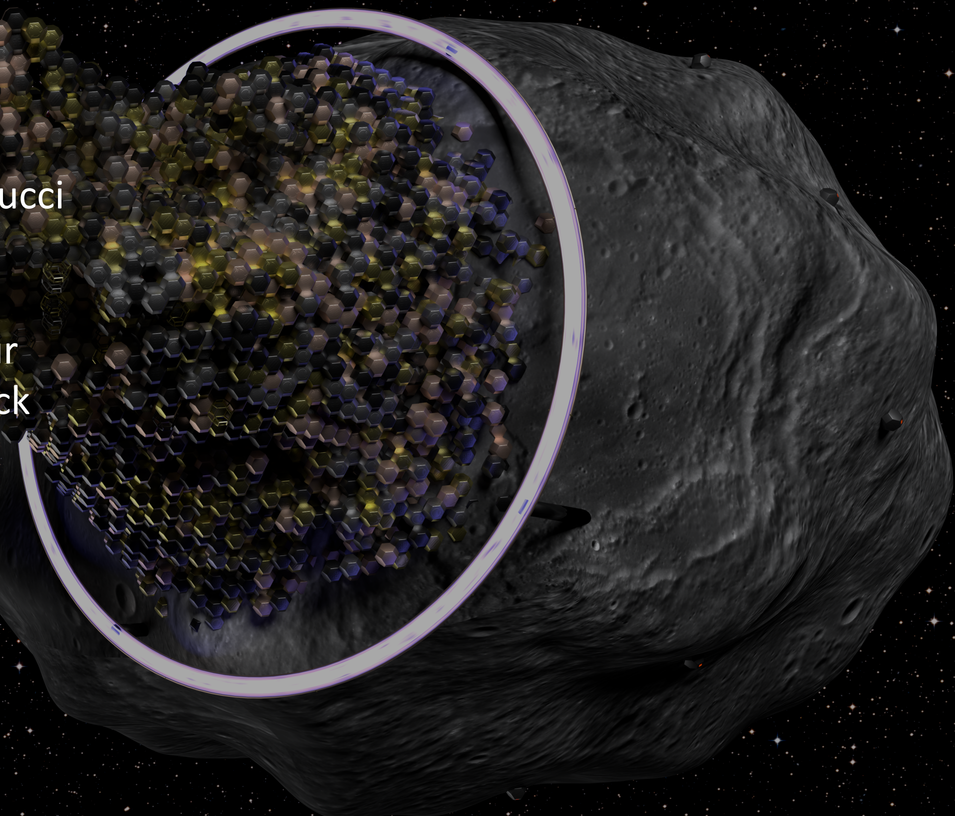

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