EVOLVING ASTEROID STARSHIPS: A BIO-INSPIRED APPROACH FOR INTERSTELLAR SPACE SYSTEMS

Angelo Vermeulen[1,2], Mikhail Sirenko[1], Farshad Goldoust[1], Daniela Hallak[1], Brennan Lutkewitte[3], Alvaro Papic[1], Jason Kiem[1,4], Frances Brazier[1]

[1] Delft University of Technology, Delft, the Netherlands
[2] SEAD (Space Ecologies Art and Design)
[3] Technical University of Berlin, Berlin, Germany
[4] SmartCrops BV, The Hague, the Netherlands

Interstellar Exploration Workshop
ESA/ESTEC, Noordwijk
20 June 2019

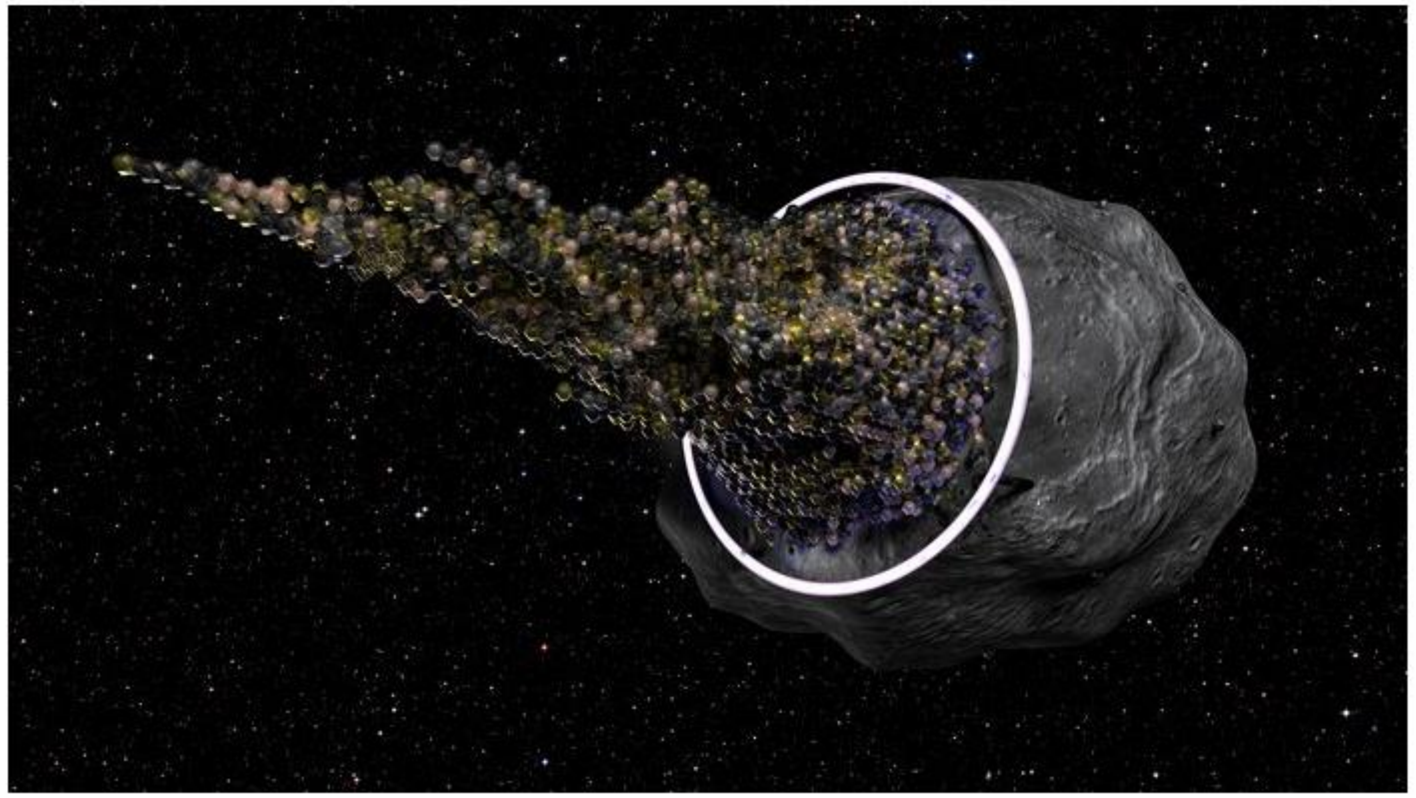
TU Delft

SPACE ECOLOGIES ART AND DESIGN

FREE SEARCH (24451 IMAGES)

Search for images... Go

TU DELFT E|A|S (EVOLVING ASTEROID STARSHIPS) PROJECT



DOWNLOAD HI-RES JPG (3.31 MB)

DETAILS ▼

Title TU Delft E|A|S (Evolving Asteroid Starships) project

Released 25/04/2018 11:24 am

Copyright Design by Nils Faber & Angelo Vermeulen

Description

A group of students and researchers at Delft University of Technology are designing a starship capable of keeping generations of crew alive as they cross the gulf between stars – and they've turned to ESA for the starship's life support.

DSTART, the TU Delft Starship Team, is bringing together a wide variety of disciplines to perform advanced

RELATED IMAGES

05 June 2009

Inauguration MELiSSA pilot pla...

376

Votes: 3

05 June 2009

Inauguration of the MELiSSA pi...

665

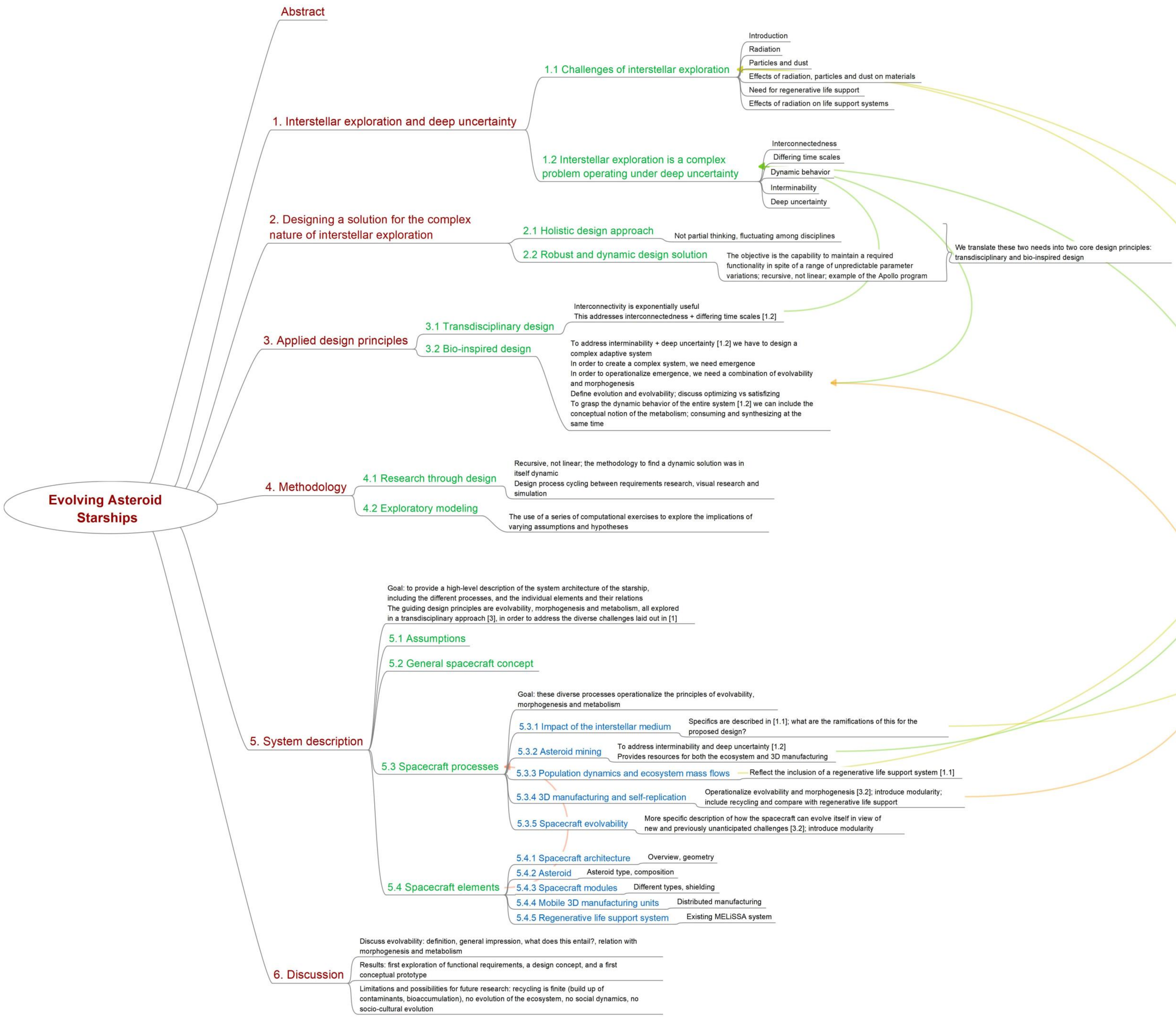
Votes: 2

USING OUR IMAGES

Terms and conditions

Contact us

Commenting guidelines



Evolving Asteroid Starships
Abstract
1. Interstellar exploration and deep uncertainty
1.1 Challenges of interstellar exploration
Introduction
Radiation
Particles and dust
Effects of radiation, particles and dust on materials
Need for regenerative life support
Effects of radiation on life support systems
1.2 Interstellar exploration is a complex problem operating under deep uncertainty
Interconnectedness
Differing time scales
Dynamic behavior
Interminability
Deep uncertainty
2. Designing a solution for the complex nature of interstellar exploration
2.1 Holistic design approach
Not partial thinking, fluctuating among disciplines
2.2 Robust and dynamic design solution
The objective is the capability to maintain a required functionality in spite of a range of unpredictable parameter variations; recursive, not linear; example of the Apollo program
We translate these two needs into two core design principles: transdisciplinary and bio-inspired design
3. Applied design principles
3.1 Transdisciplinary design
Interconnectivity is exponentially useful
This addresses interconnectedness + differing time scales [1.2]
3.2 Bio-inspired design
To address interminability + deep uncertainty [1.2] we have to design a complex adaptive system
In order to create a complex system, we need emergence
In order to operationalize emergence, we need a combination of evolvability and morphogenesis
Define evolution and evolvability; discuss optimizing vs satisficing
To grasp the dynamic behavior of the entire system [1.2] we can include the conceptual notion of the metabolism; consuming and synthesizing at the same time
4. Methodology
4.1 Research through design
Recursive, not linear; the methodology to find a dynamic solution was in itself dynamic
Design process cycling between requirements research, visual research and simulation
4.2 Exploratory modeling
The use of a series of computational exercises to explore the implications of varying assumptions and hypotheses
5. System description
Goal: to provide a high-level description of the system architecture of the starship, including the different processes, and the individual elements and their relations
The guiding design principles are evolvability, morphogenesis and metabolism, all explored in a transdisciplinary approach [3], in order to address the diverse challenges laid out in [1]
5.1 Assumptions
5.2 General spacecraft concept
5.3 Spacecraft processes
Goal: these diverse processes operationalize the principles of evolvability, morphogenesis and metabolism
5.3.1 Impact of the interstellar medium
Specifics are described in [1.1]; what are the ramifications of this for the proposed design?
5.3.2 Asteroid mining
To address interminability and deep uncertainty [1.2]
Provides resources for both the ecosystem and 3D manufacturing
5.3.3 Population dynamics and ecosystem mass flows
Reflect the inclusion of a regenerative life support system [1.1]
5.3.4 3D manufacturing and self-replication
Operationalize evolvability and morphogenesis [3.2]; introduce modularity; include recycling and compare with regenerative life support
5.3.5 Spacecraft evolvability
More specific description of how the spacecraft can evolve itself in view of new and previously unanticipated challenges [3.2]; introduce modularity
5.4 Spacecraft elements
5.4.1 Spacecraft architecture
Overview, geometry
5.4.2 Asteroid
Asteroid type, composition
5.4.3 Spacecraft modules
Different types, shielding
5.4.4 Mobile 3D manufacturing units
Distributed manufacturing
5.4.5 Regenerative life support system
Existing MELiSSA system
6. Discussion
Discuss evolvability: definition, general impression, what does this entail?, relation with morphogenesis and metabolism
Results: first exploration of functional requirements, a design concept, and a first conceptual prototype
Limitations and possibilities for future research: recycling is finite (build up of contaminants, bioaccumulation), no evolution of the ecosystem, no social dynamics, no socio-cultural evolution

CHALLENGES OF HUMAN INTERSTELLAR EXPLORATION

Radiation
Particles and dust
Regenerative life support
Not part of this study:
- propulsion & power supply
- social & cultural aspects

HUMAN INTERSTELLAR EXPLORATION IS A COMPLEX PROBLEM OPERATING UNDER DEEP UNCERTAINTY

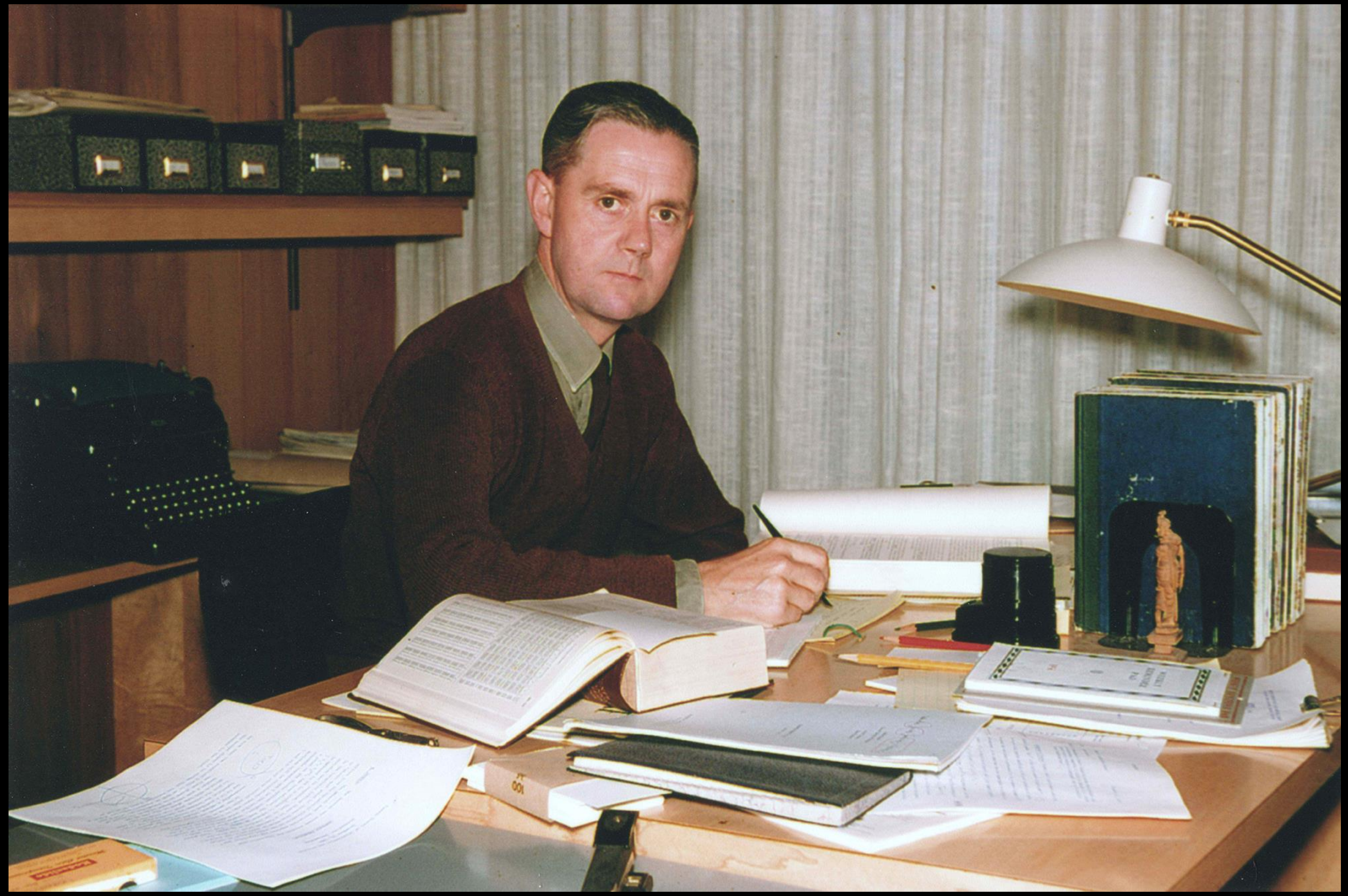
Interconnectedness
Differing time scales
Dynamic behavior
Interminability
Deep uncertainty

BIO-INSPIRED DESIGN FOR HUMAN INTERSTELLAR EXPLORATION

- To address interminability and deep uncertainty we have to design a complex adaptive system (CAS)
- To create a complex system, emergence is needed
- Emergence can be operationalized through a combination of evolution and morphogenesis

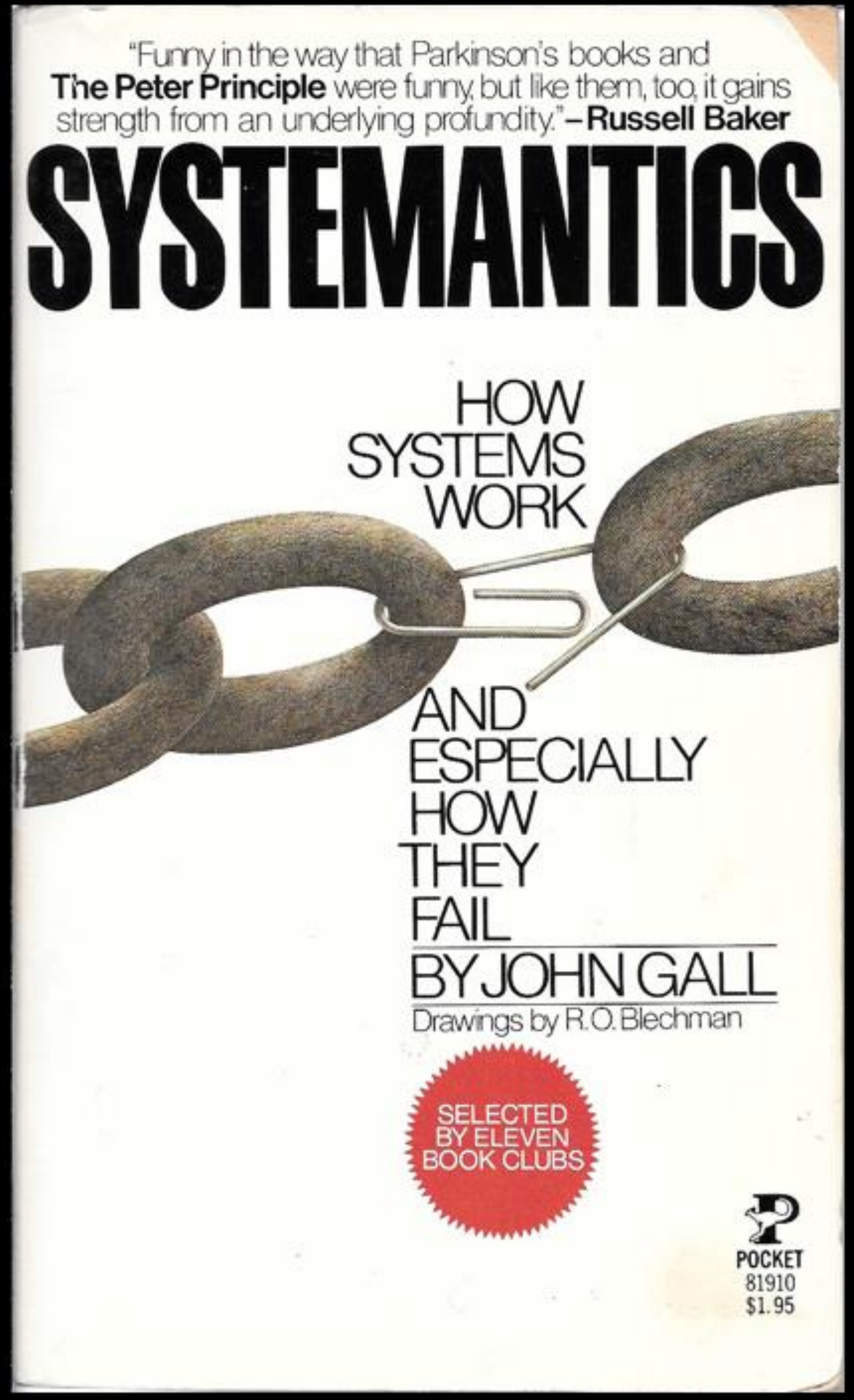
ASHBY'S LAW OF REQUISITE VARIETY

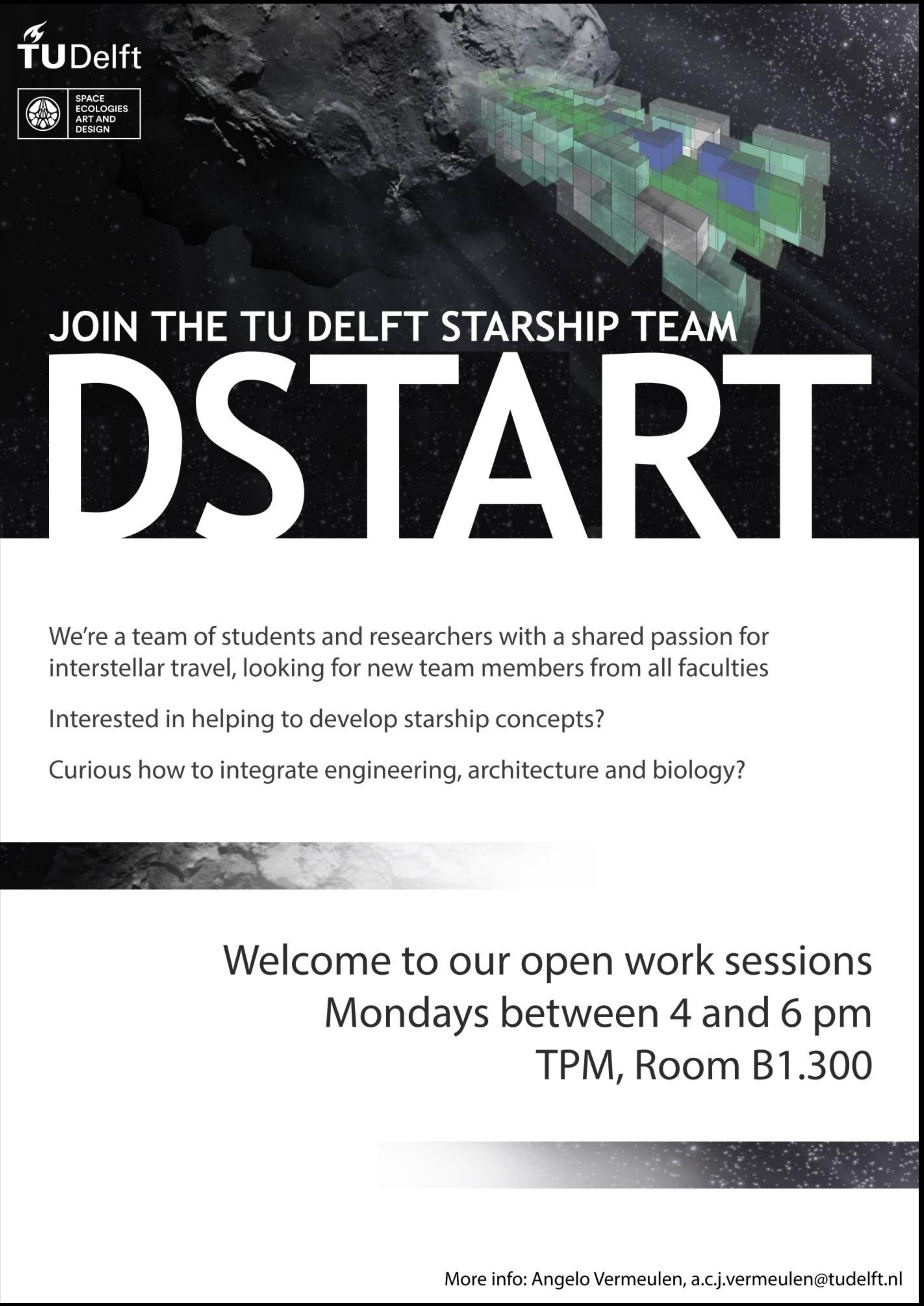
The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate.



GALL'S LAW

A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over with a working simple system.



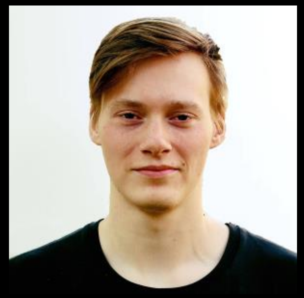


Mikhail Sirenko
Statistics
Modeling

Arise Wan
Architecture
Biomimicry

Anton Dobrevski
Architecture
Web design

Alvaro Papic
Biological life support
Agent-based modeling



Joris Putteneers
Architecture
Animation

Jimmy Verkooijen
Background research
Outreach

Farshad Goldoust
Astrophysics
Modeling

Nils Faber
3D modeling
Visualization

Sharon van Rijthoven
Aerospace engineering
Community management

Daniela Hallak
Astrophysics
Requirements analysis

Jasper Wennekendonk
3D modeling
Visualization

Angelo Vermeulen
Model development
Biological life support

Brennan Lutkewitte
Asteroid mining
Requirements analysis

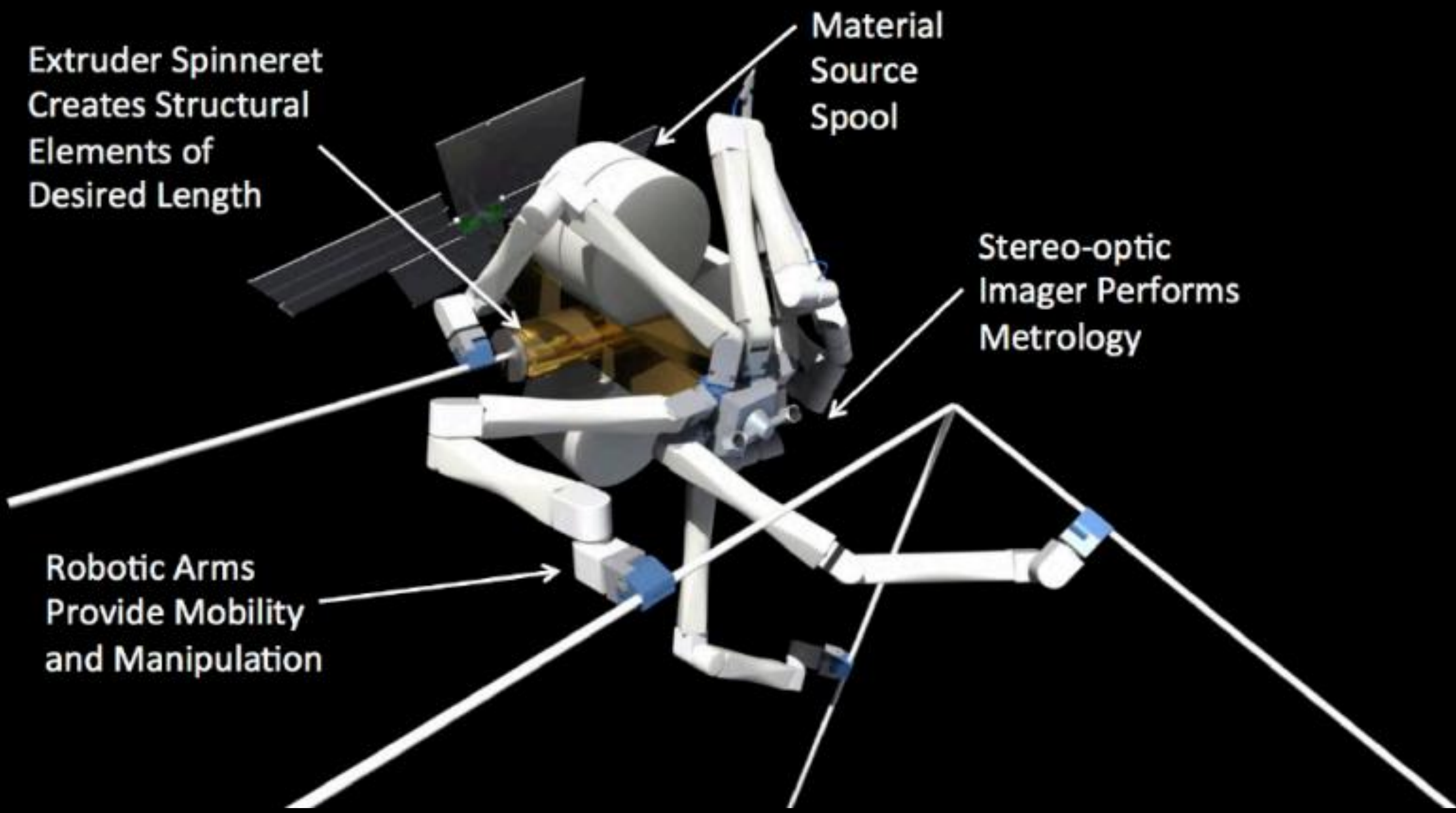
Amelie Kim
3D modeling
Architecture

Jason Kiem
Mass flow analysis
Requirements analysis

Andreas Theys
Aerospace engineering
Programming

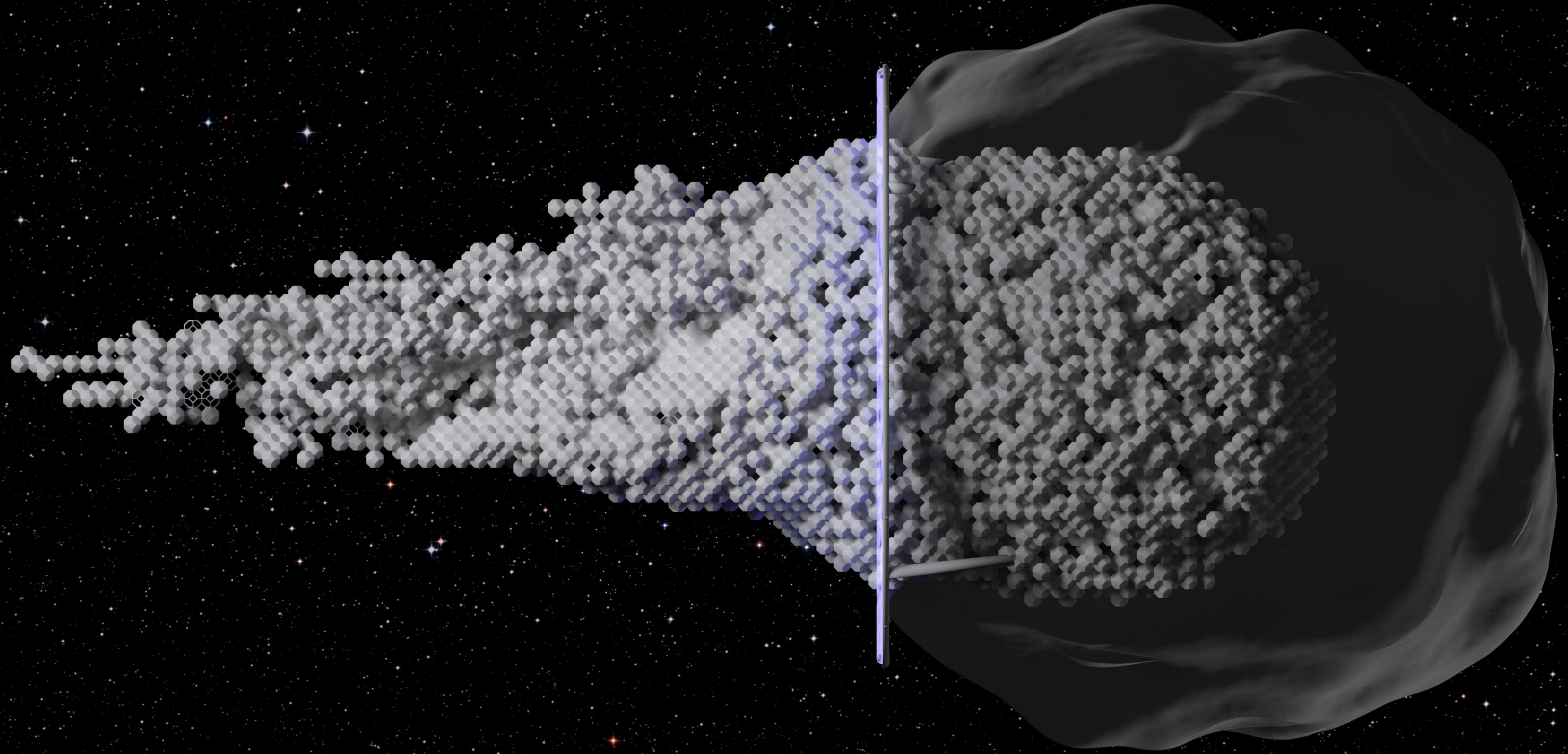
ASTEROID MINING

3D MANUFACTURING

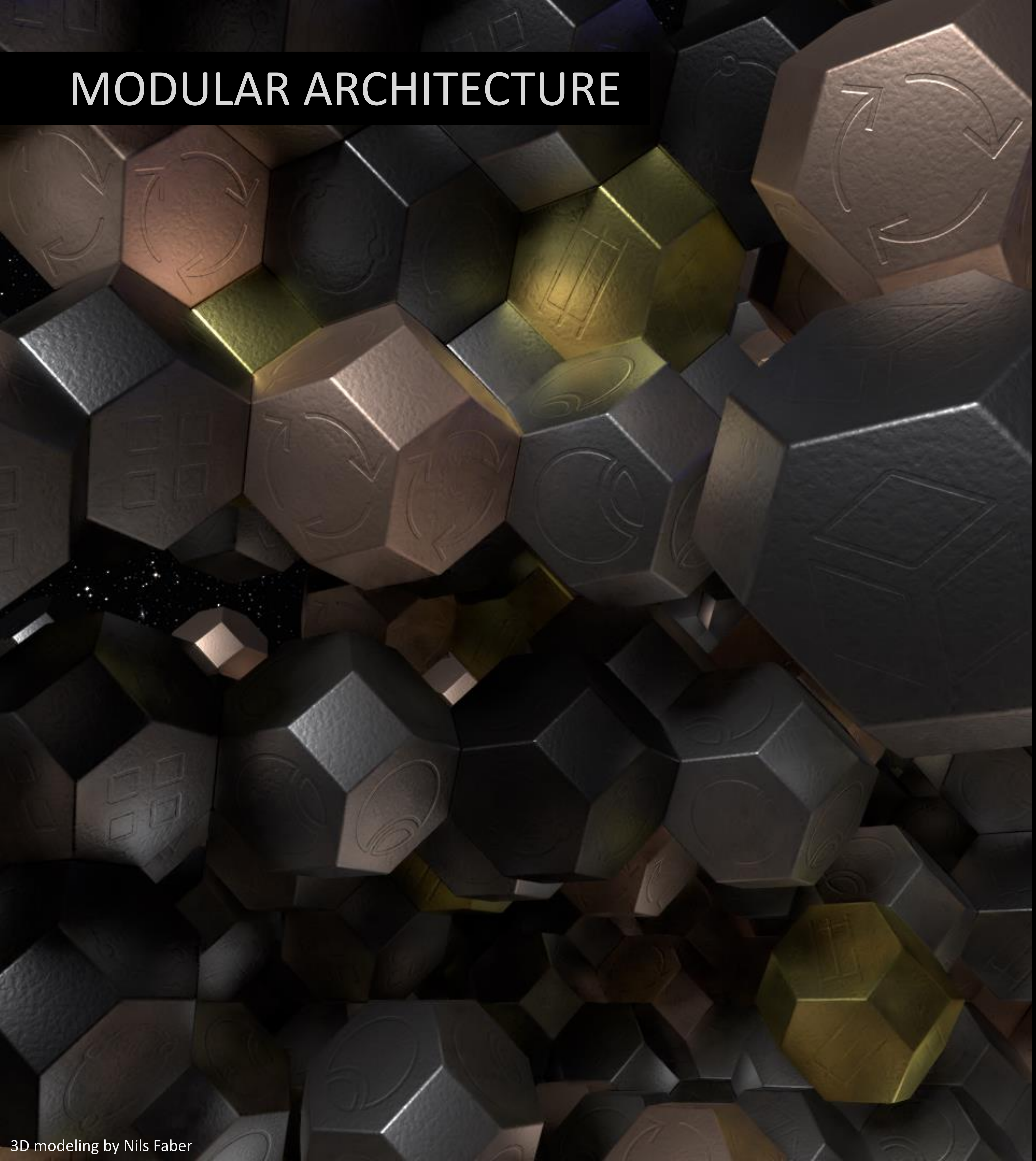


SpiderFab, Tethers Unlimited & NASA, 2013

MODULAR ARCHITECTURE



3D modeling by Nils Faber

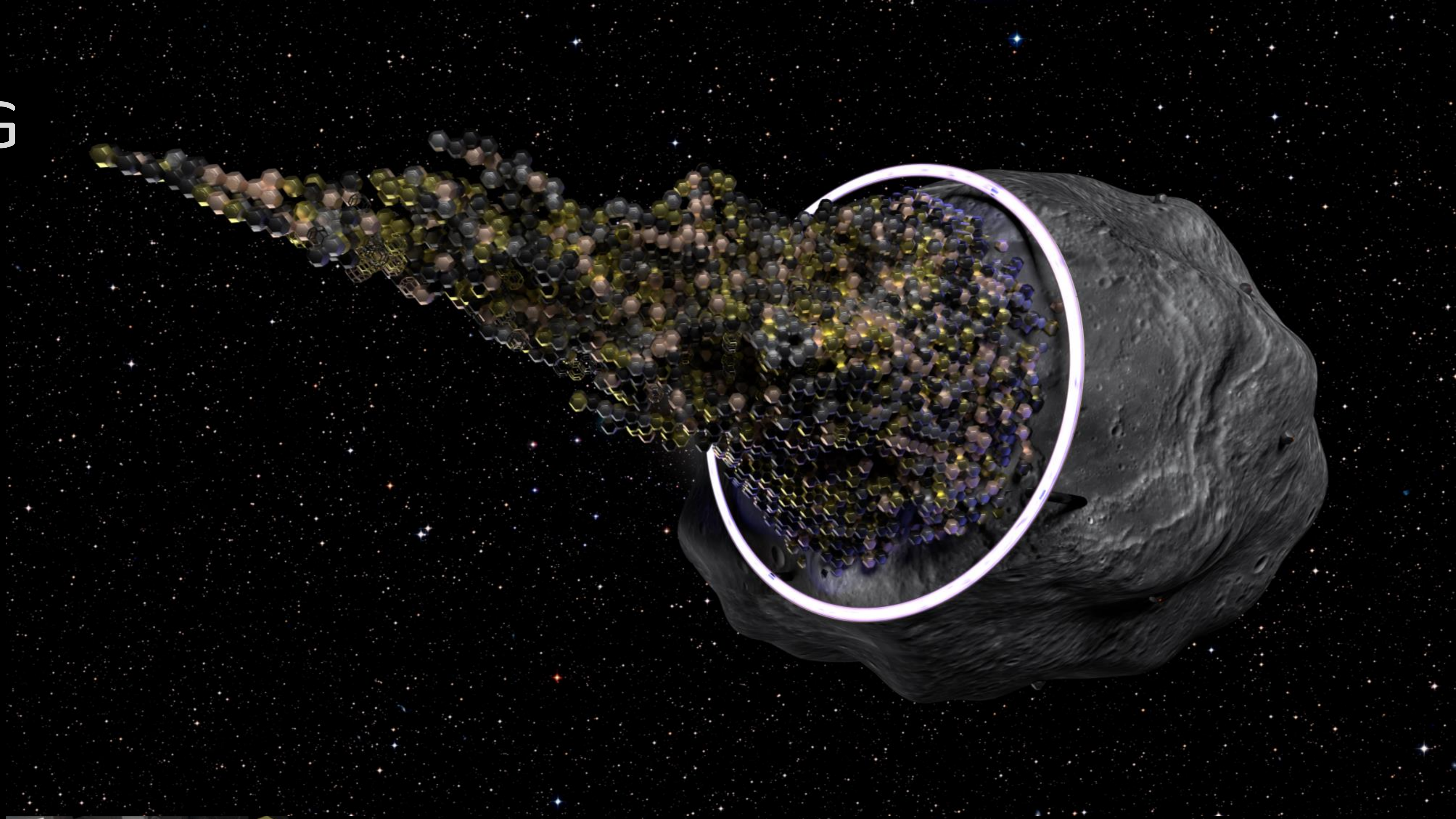


3D modeling by Nils Faber

MODULE TYPES

1. Regenerative life support
2. Habitation
3. Radiation shielding
4. Collision shielding
5. Mining
6. Processing
7. Manufacturing
8. Ore storage
9. Refined materials storage

MORPHOGENETIC/EMERGENCE ENGINEERING

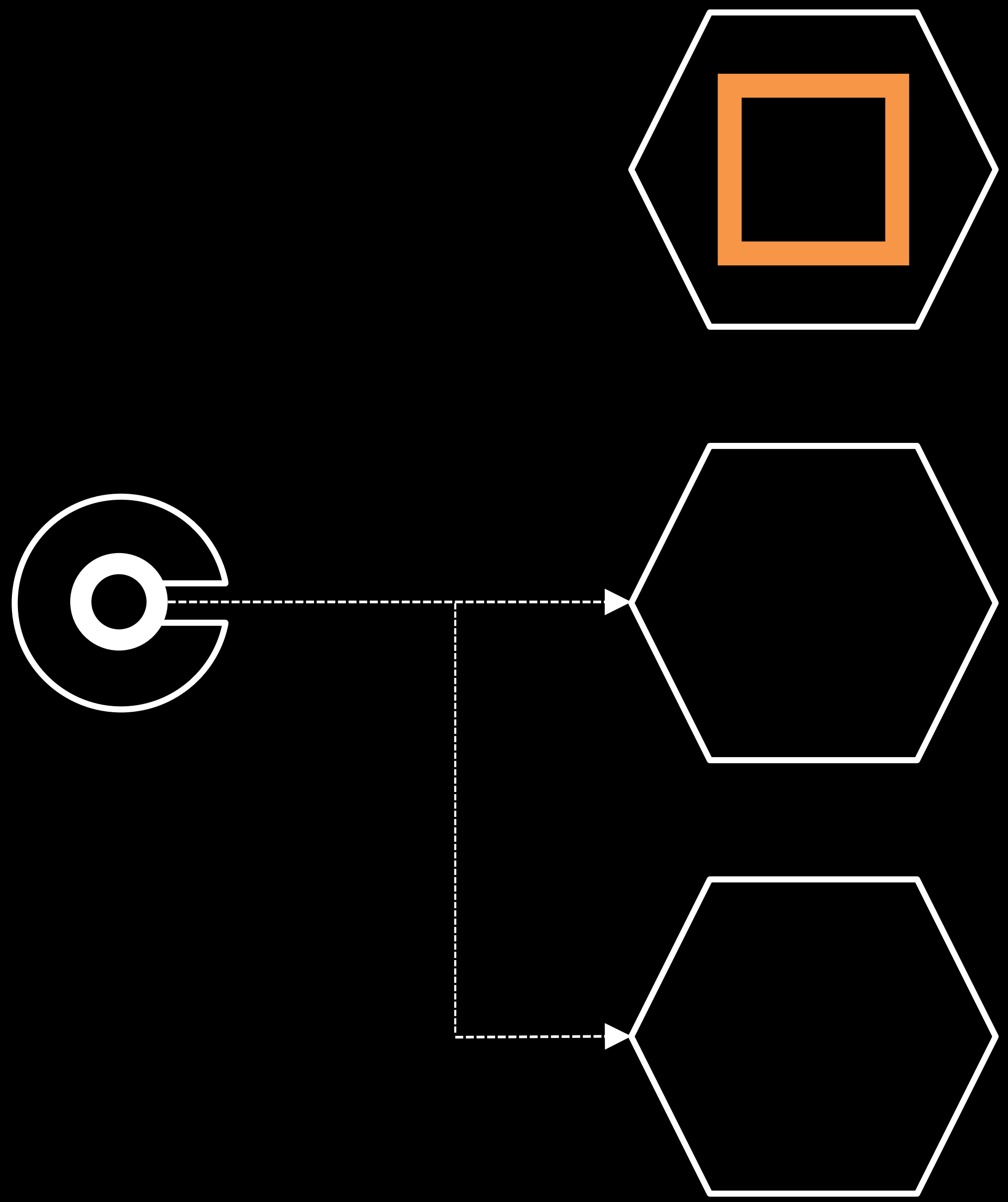


3D modeling by Nils Faber & Jasper Wennekendonk

VON NEUMANN SELF-REPLICATION

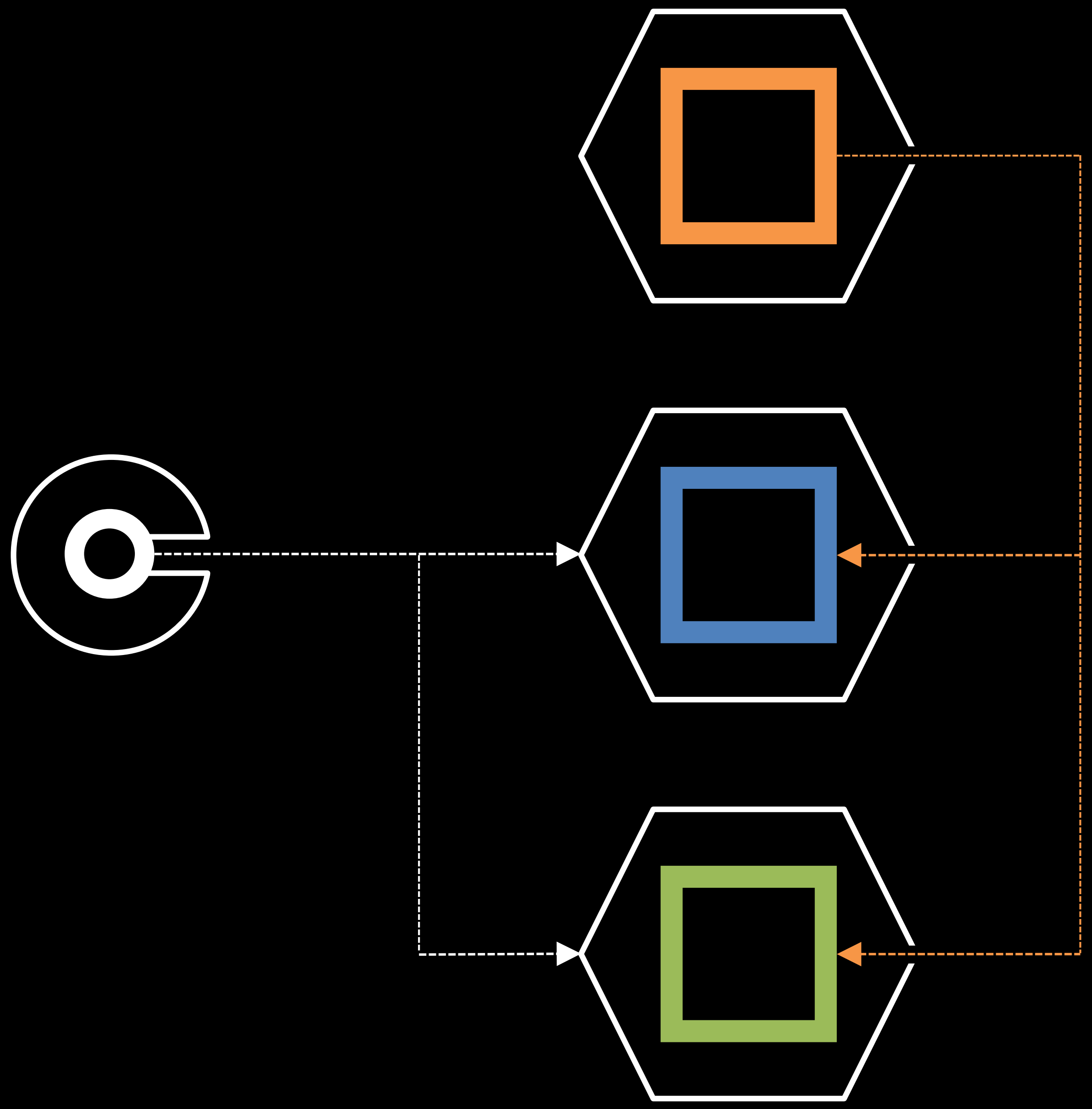
3D manufacturing robot
Manufacturing module

VON NEUMANN SELF-REPLICATION



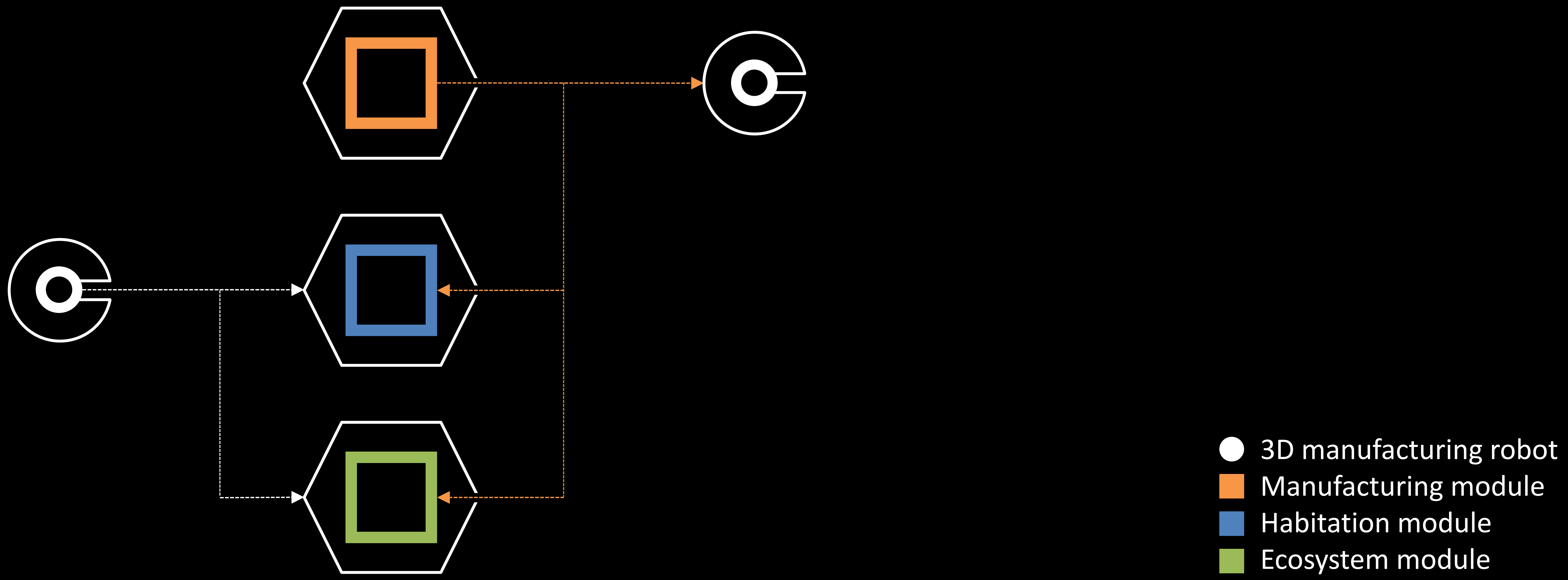
3D manufacturing robot
Manufacturing module

VON NEUMANN SELF-REPLICATION

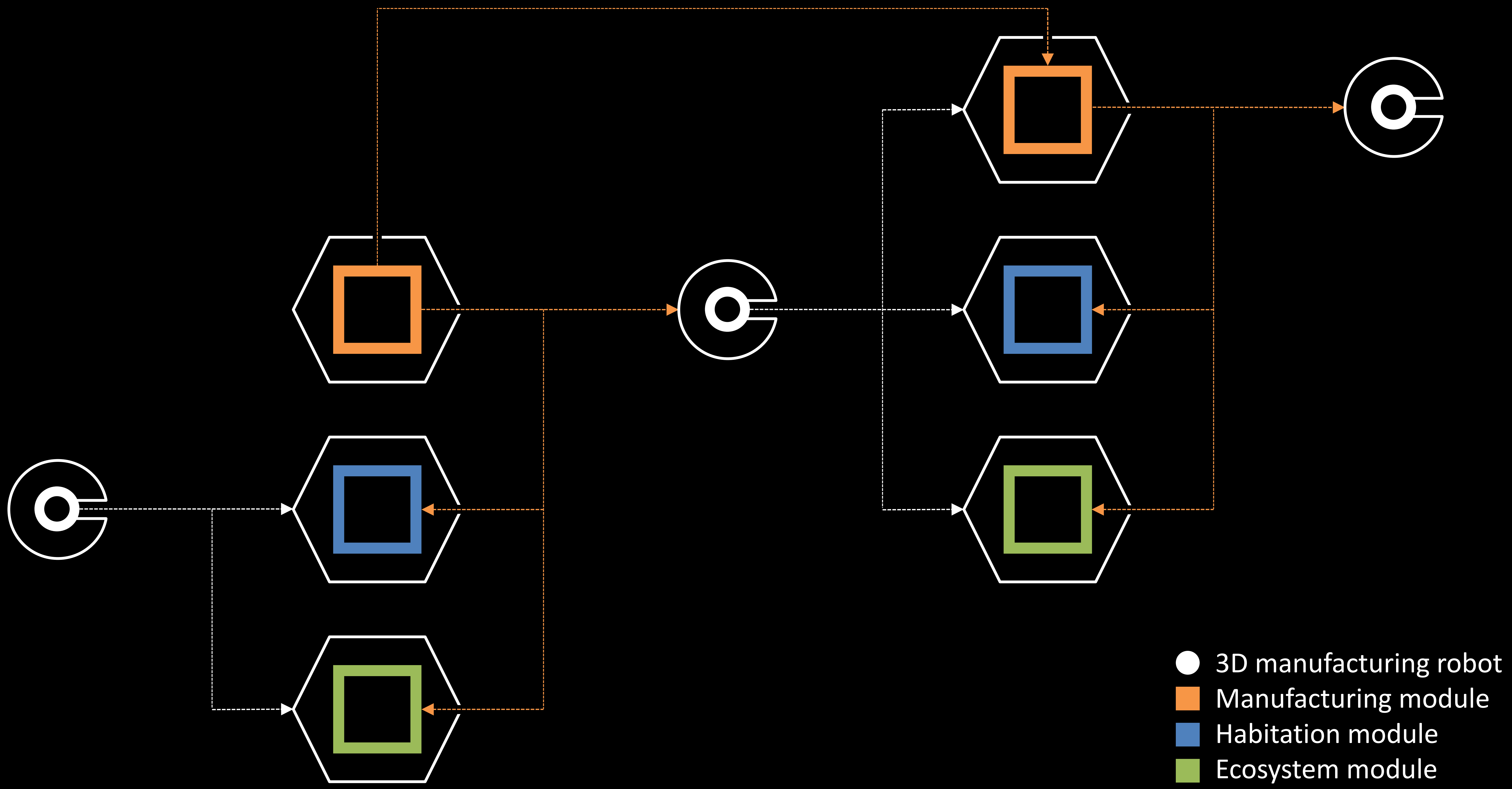


3D manufacturing robot
Manufacturing module
Habitation module
Ecosystem module

VON NEUMANN SELF-REPLICATION



VON NEUMANN SELF-REPLICATION



DISCRETE EVENT SYSTEM SPECIFICATION

main.ipynb

Markdown

Python 3

Corresponding classes are defined in the following way.

[2]:
```python
import numpy as np
class Spacecraft:
    """The overarching class for an evolving asteroid starship (EAS)


    Attibutes
    ---------
    structure : array
        A list of important spatial characteristics

    total_population : int
        Total population of a EAS

    n_modules : int
        Total number of modules of a spacecraft
    """

    def __init__(self, total_population=np.random.randint(50, 100), structure=[], n_modules=5):
        self.total_population = total_population # draw a sample from discrete random unifrom distribution
        self.structure = structure
        self.modules = []
        self.asteroid = Asteroid()
        for modules in range(n_modules):
            module = Module()
            self.modules.append(module)
```

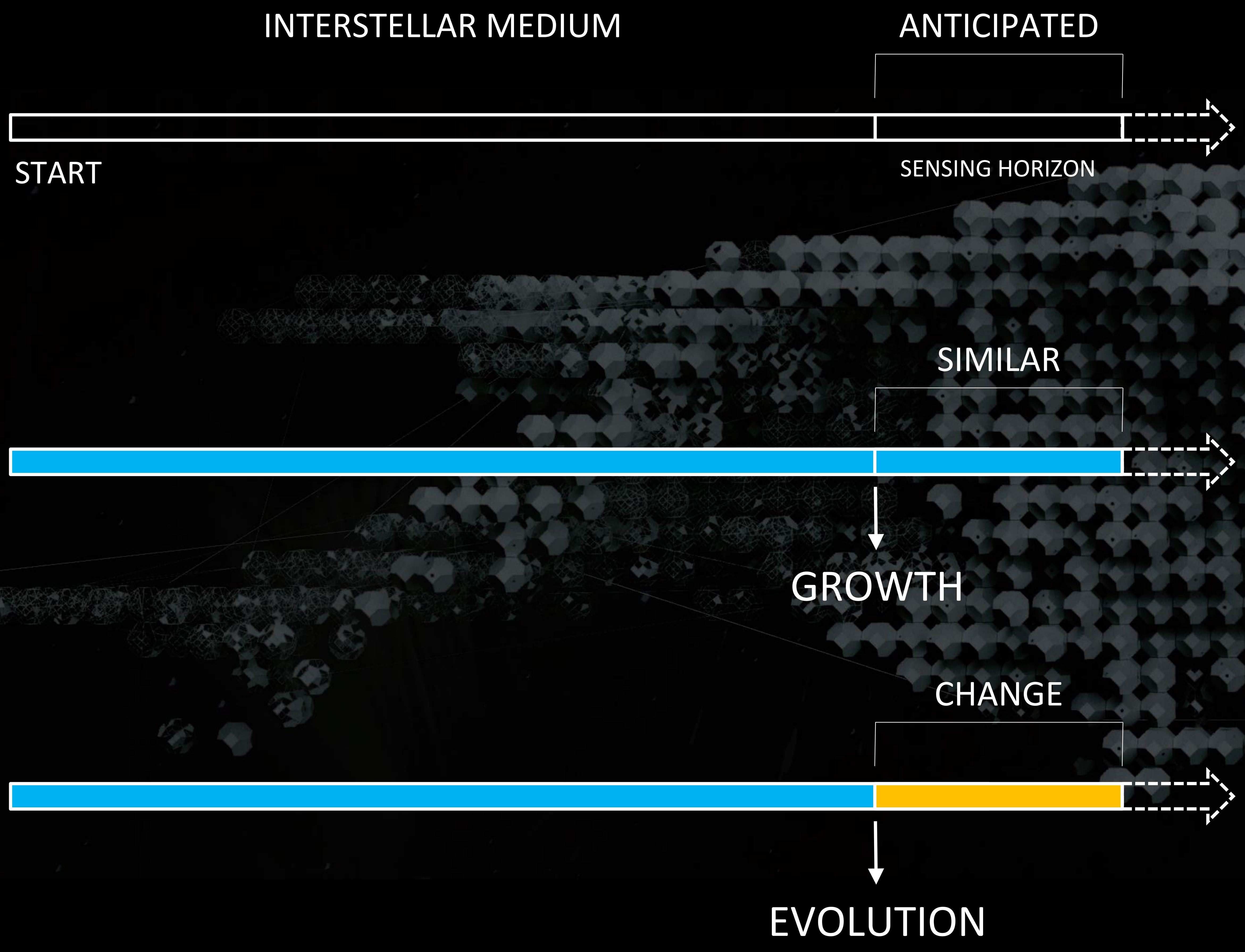
[3]:
```python
class Asteroid:
    """A class representing an asteroid object


    Attributes
    ----------
    chemical_composition : array
        Chemical composition of a given asteroid

    """
    def __init__(self, chemical_compostition = [0, 0, 0]):
        self.chemical_compostition = chemical_compostition
```

[4]:
```python
class Module:
```

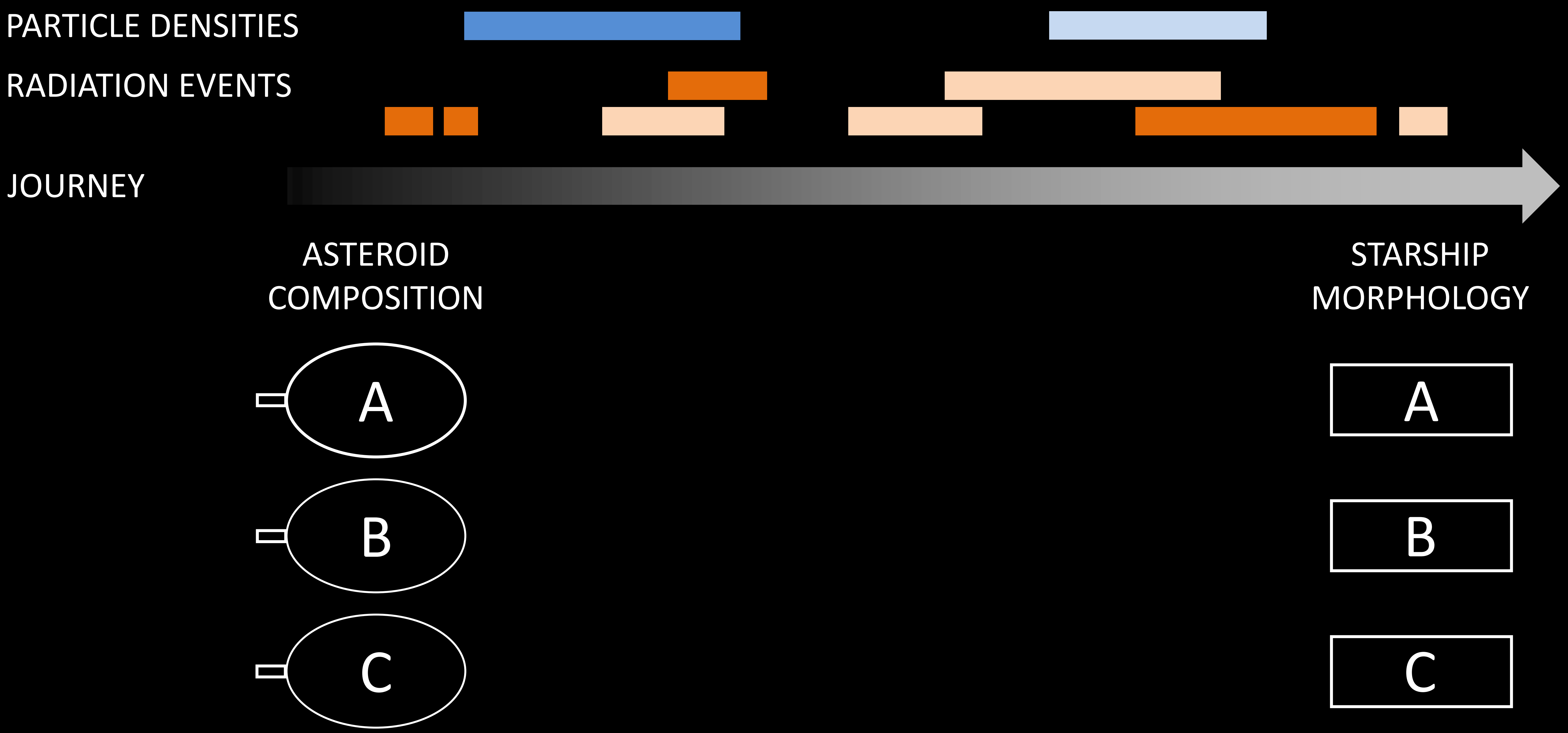
UNPREDICTABLE CHALLENGES

COSMIC RADIATION
PARTICLES AND DUST

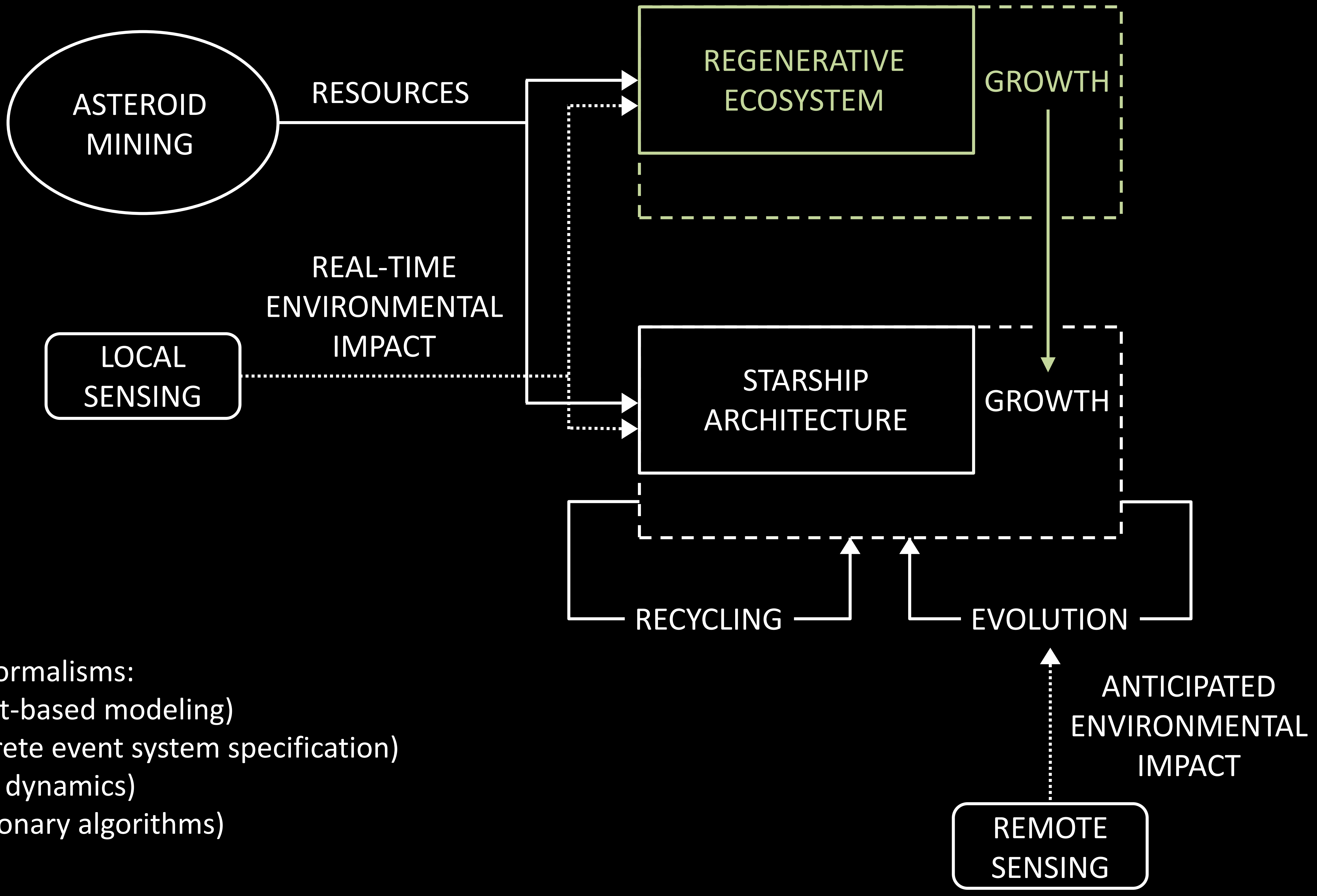
EVOLVABILITY



SIMULATION EXPERIMENTS

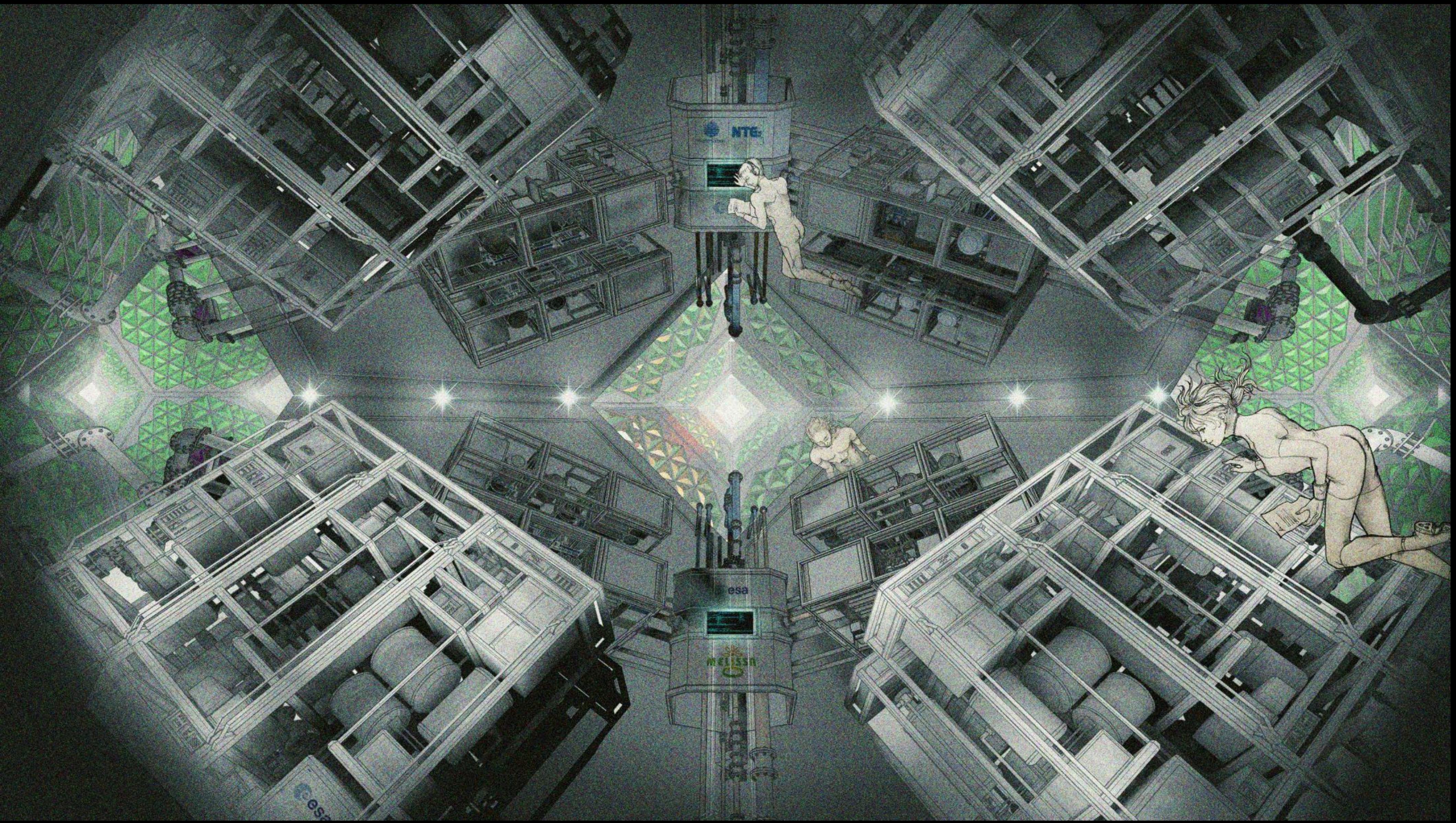


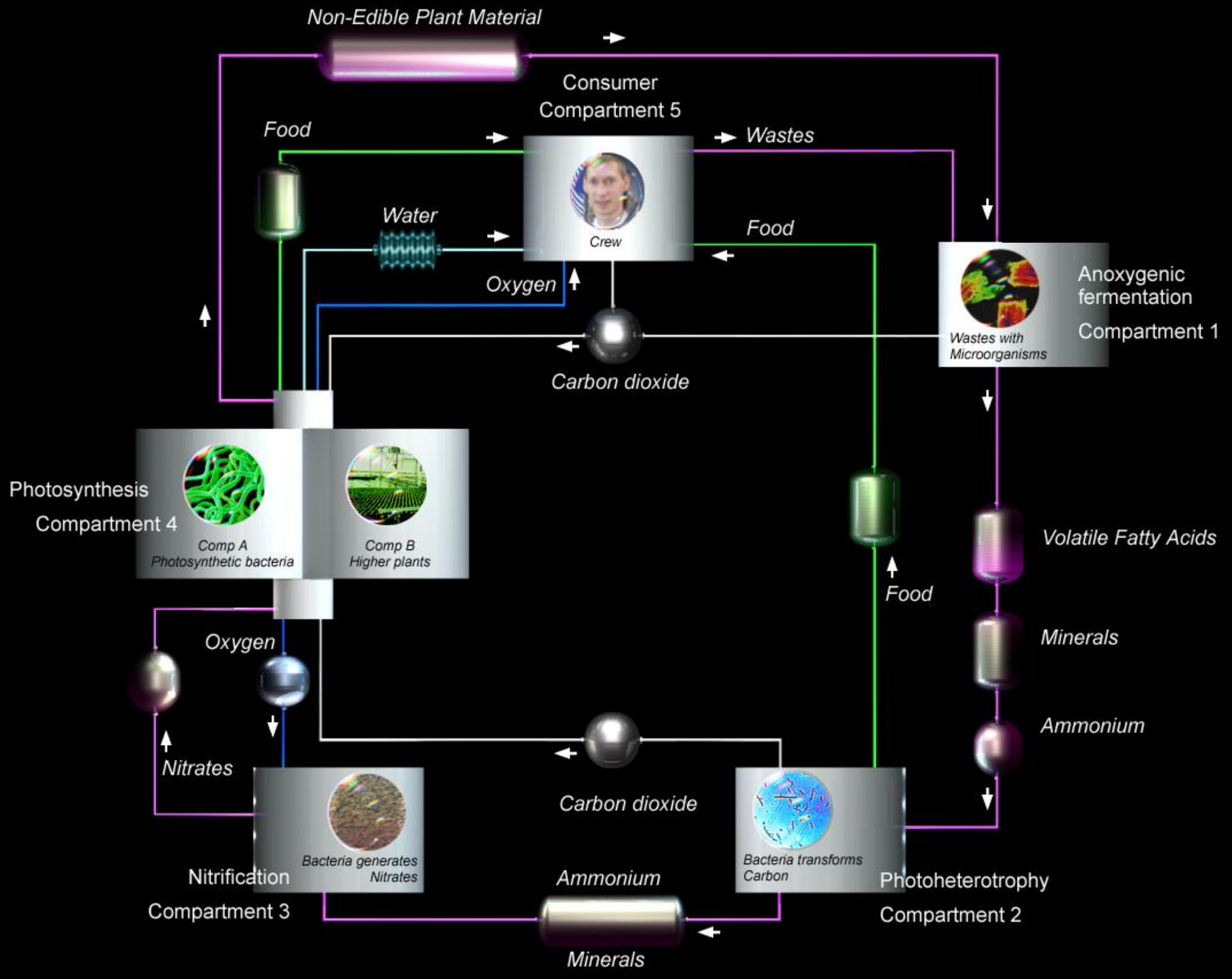
ECOSYSTEM INTEGRATION



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

ECOSYSTEM INTEGRATION

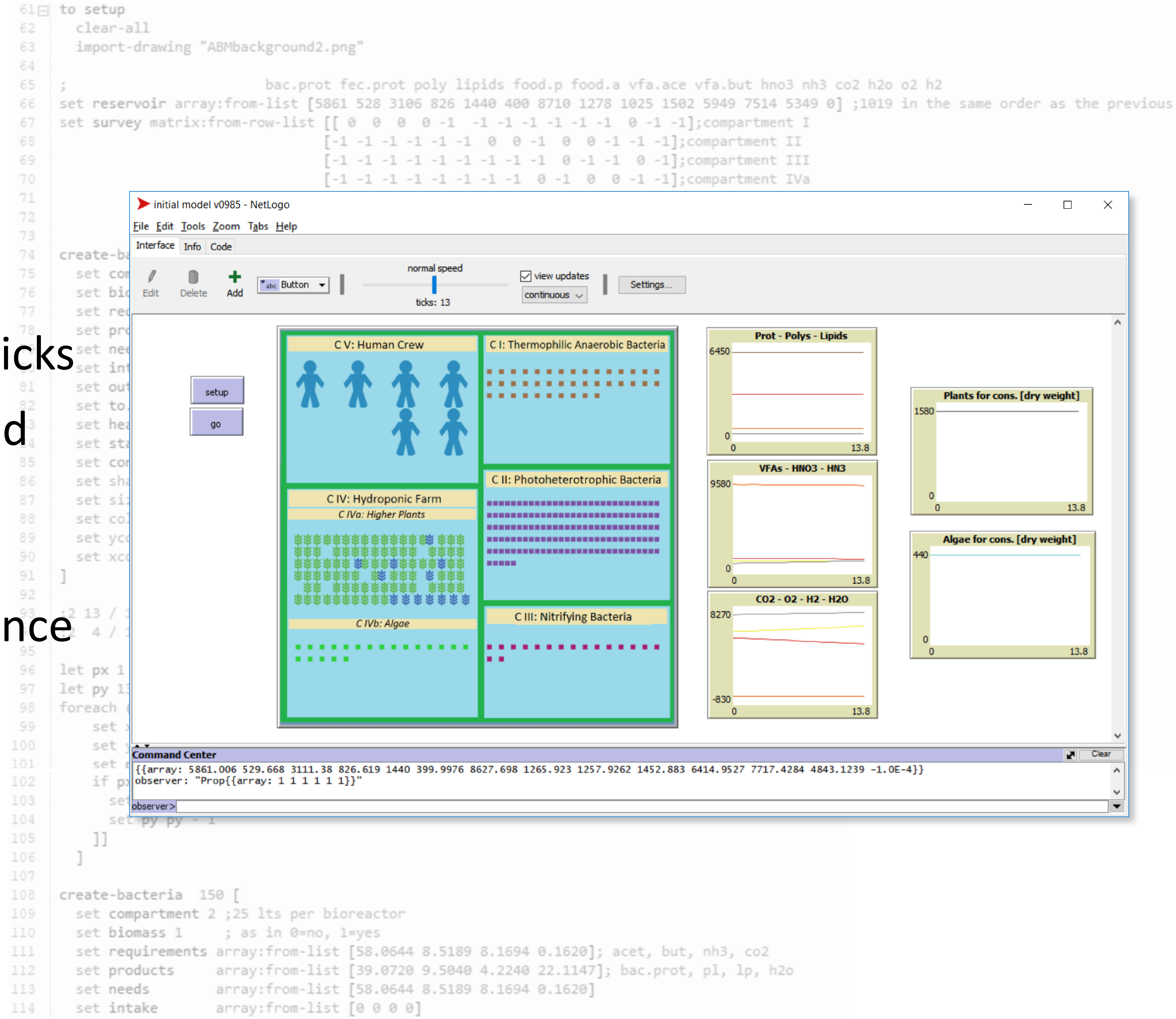




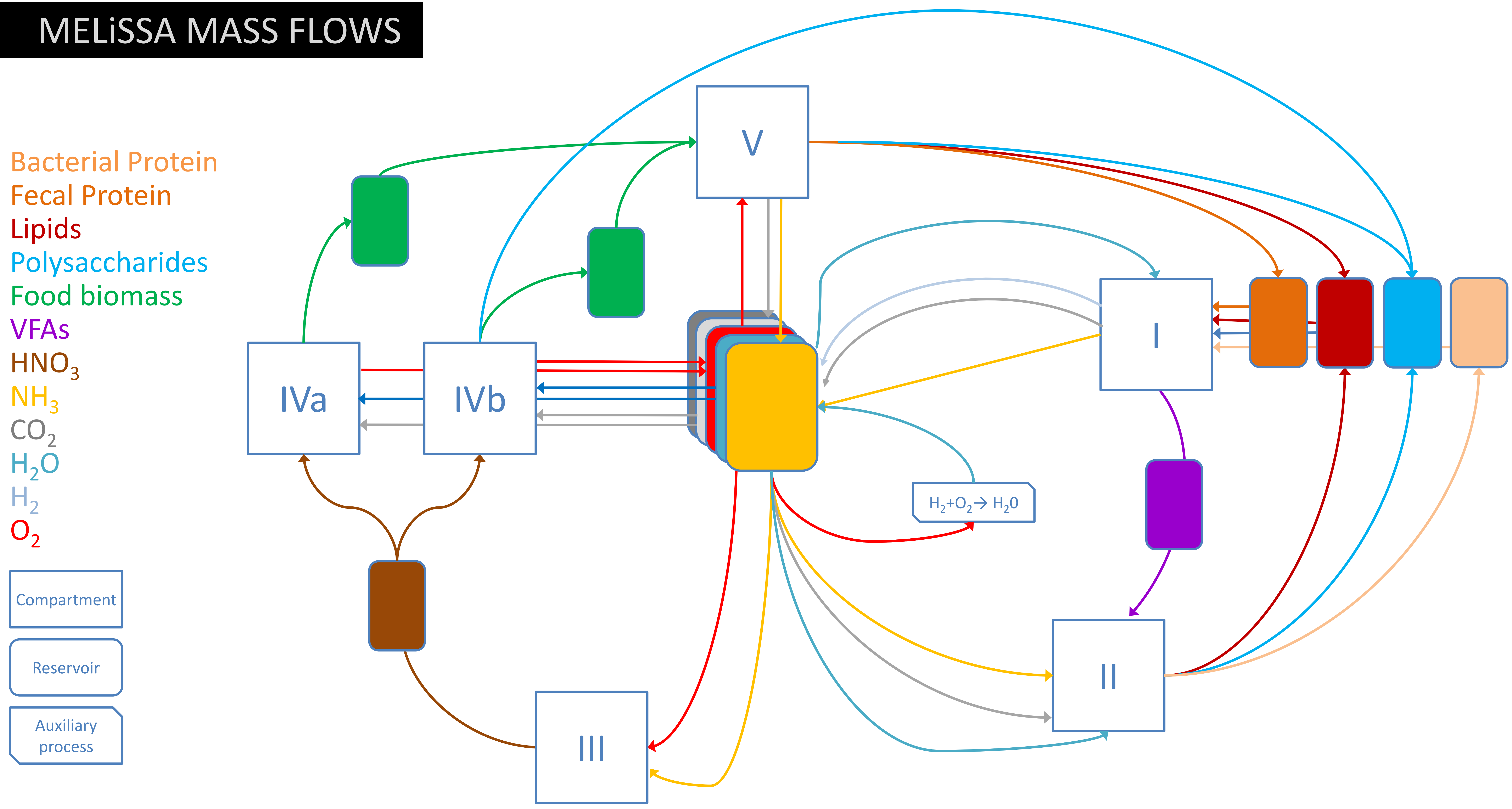
AGENT-BASED MODELING

DEFINITION

- Works with agents and ticks
- Focus on interactions and emergent patterns
- High granularity and ontological correspondence



MELiSSA MASS FLOWS



COMPARTMENT I

Fecal protein

$3,2CH_{1.76}O_{0.239}N_{0.239} + 3,035H_2O = C_2H_4O_2 + 0,1C_4H_8O_2 + 2.3H_2 + 0.76NH_3 + 0,8CO_2$

Bacterial protein

$3,2CH_{1.4697}O_{0.34}N_{0.2807} + 2,712H_2O = C_2H_4O_2 + 0,1C_4H_8O_2 + 1,3162H_2 + 0.8982NH_3 + 0,8CO_2$

Polysaccharides

$3,199CH_{1.667}O_{0.833} + 1,134H_2O = 1C_2H_4O_2 + 0,1C_4H_8O_2 + 1,4H_2 + 0,8CO_2$

Lipids

$C_{16}H_{32}O_2 + 13,0278H_2O = 6,5278C_2H_4O_2 + 0,6528C_4H_8O_2 + 0,3333CO_2 + 13,3611H_2$

COMPARTMENT I

Fecal protein

$3{,}2CH_{1.76}O_{0.239}N_{0.239} + 3{,}035H_2O = C_2H_4O_2 + 0{,}1C_4H_8O_2 + 2.3H_2 + 0.76NH_3 + 0{,}8CO_2$

Bacterial protein

$3{,}2CH_{1.4697}O_{0.34}N_{0.2807} + 2{,}712H_2O = C_2H_4O_2 + 0{,}1C_4H_8O_2 + 1{,}3162H_2 + 0.8982NH_3 + 0{,}8CO_2$

Polysaccharides

$3{,}199CH_{1.667}O_{0.833} + 1{,}134H_2O = 1C_2H_4O_2 + 0{,}1C_4H_8O_2 + 1{,}4H_2 + 0{,}8CO_2$

Lipids

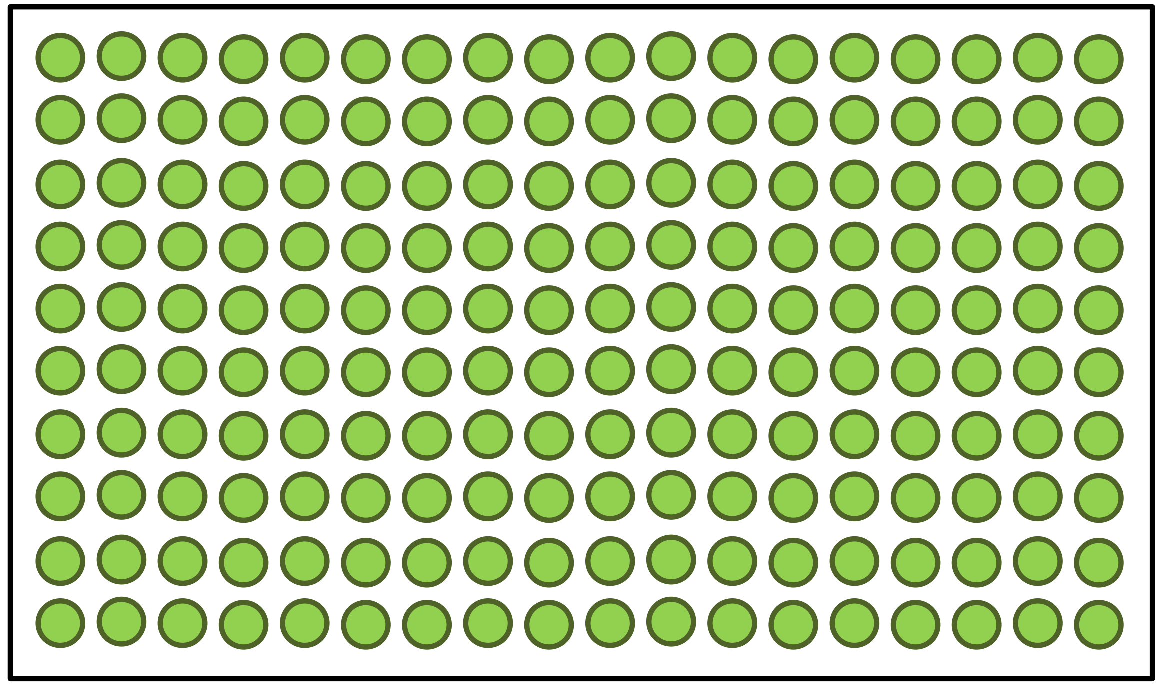
$C_{16}H_{32}O_2 + 13{,}0278H_2O = 6{,}5278C_2H_4O_2 + 0{,}6528C_4H_8O_2 + 0{,}3333CO_2 + 13{,}3611H_2$

MELiSSA MASS BALANCE

Compound	Consumed (g)	Produced (g)	Flow conservation	Delta
Bacterial Protein	13828	13828	**100.0%**	0.00
Fecal Protein	1148	1148	**100.0%**	0.00
Polysaccharides	7486	7486	**100.0%**	0.00
Lipids	1912	1912	**100.0%**	0.00
Food - higher plants	3600	3600	**100.0%**	0.00
Food - algae	400	400	**100.0%**	0.00
Acetate	20501	20501	**100.0%**	-0.01
Butyrate	3008	3008	**100.0%**	-0.01
HNO_3	2228	2228	**100.0%**	-0.07
NH_3	3487	3494	**99.8%**	6.90
CO_2	13703	13788	**99.4%**	85.92
H_2O	17602	17564	**100.2%**	-37.95
O_2	12186	12186	**100.0%**	0.00
H_2	1018	1027	**99.2%**	8.18
Total	102107	102170	**99.9%**	62.95

PLANT PLOT AGENT

1 AGENT



ATTRIBUTES

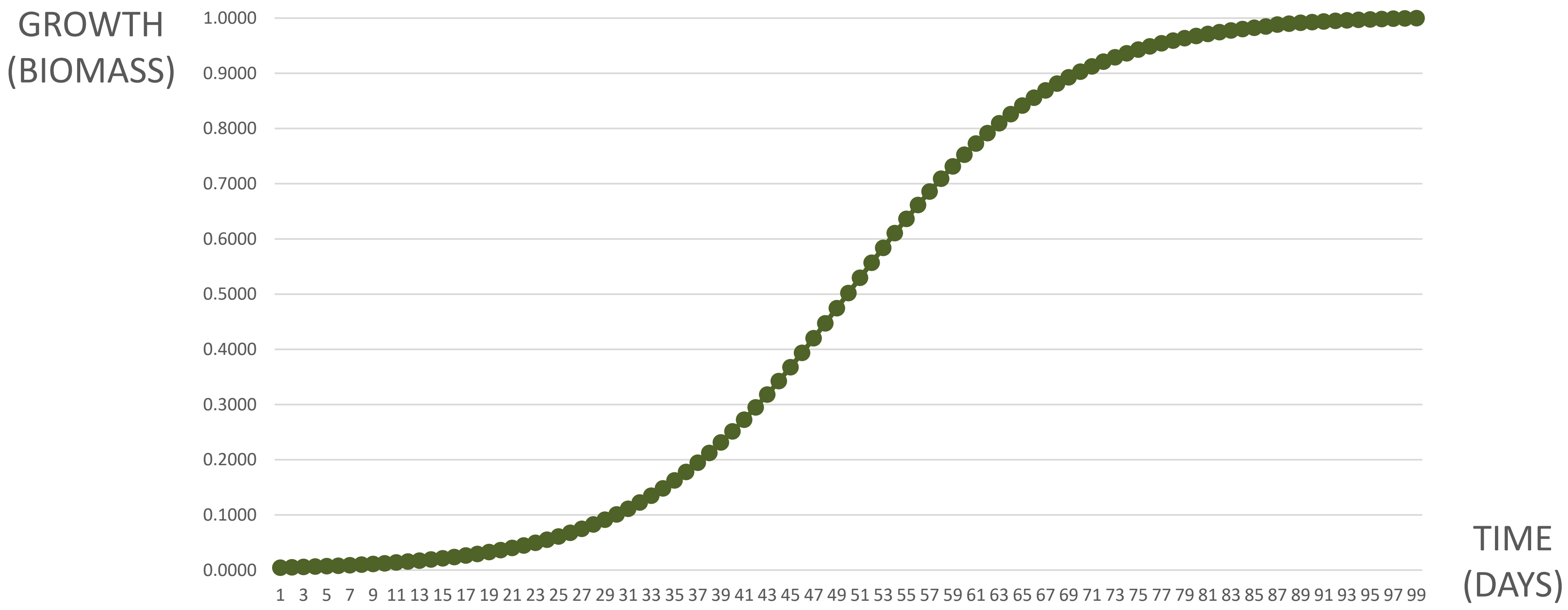
- Ideal plant: 100 day growth cycle, 40g dry weight, 60kcal, 0.5 harvest index
- Plant plot agent: 180 plants, 1 plant plot provides enough nutrients for a crew of 6 for 1 day
- 100 day production line: 100 plant plots

BEHAVIOR

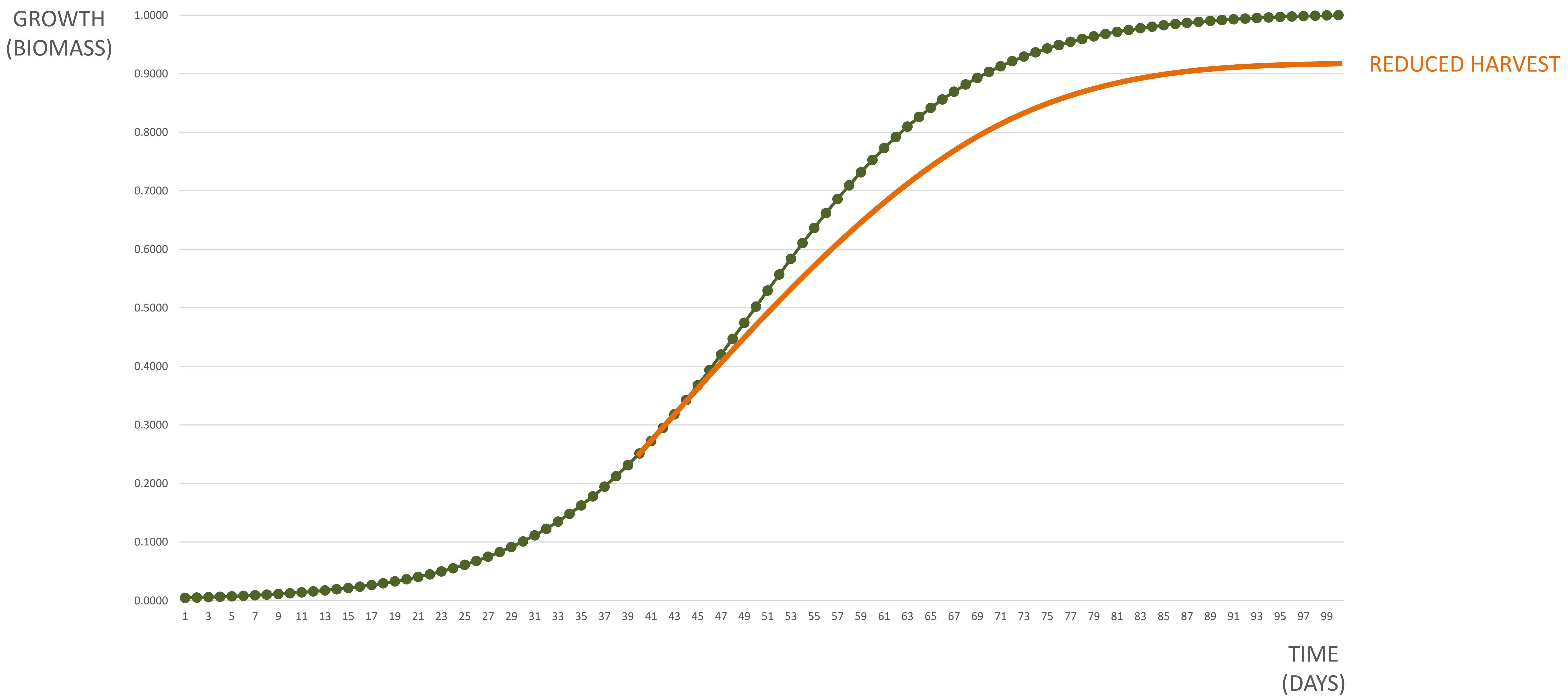
Input-output: stoichiometry

STATES

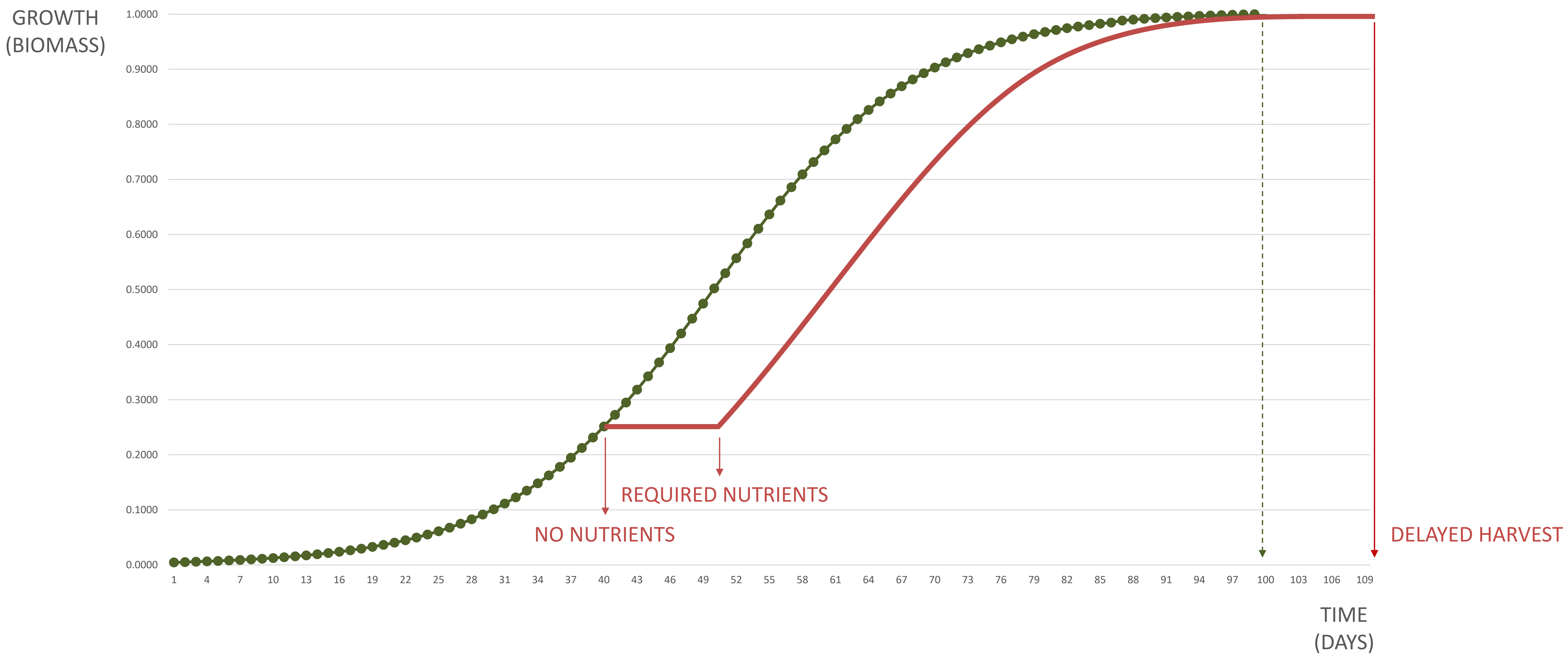
- Growth follows a sigmoid curve
- Reaching 40g in 100 days (10% first and 10% last week)
- For each day there's a specific biomass increase, and hence, the corresponding necessary input can be deduced according to the plant plot's stoichiometry



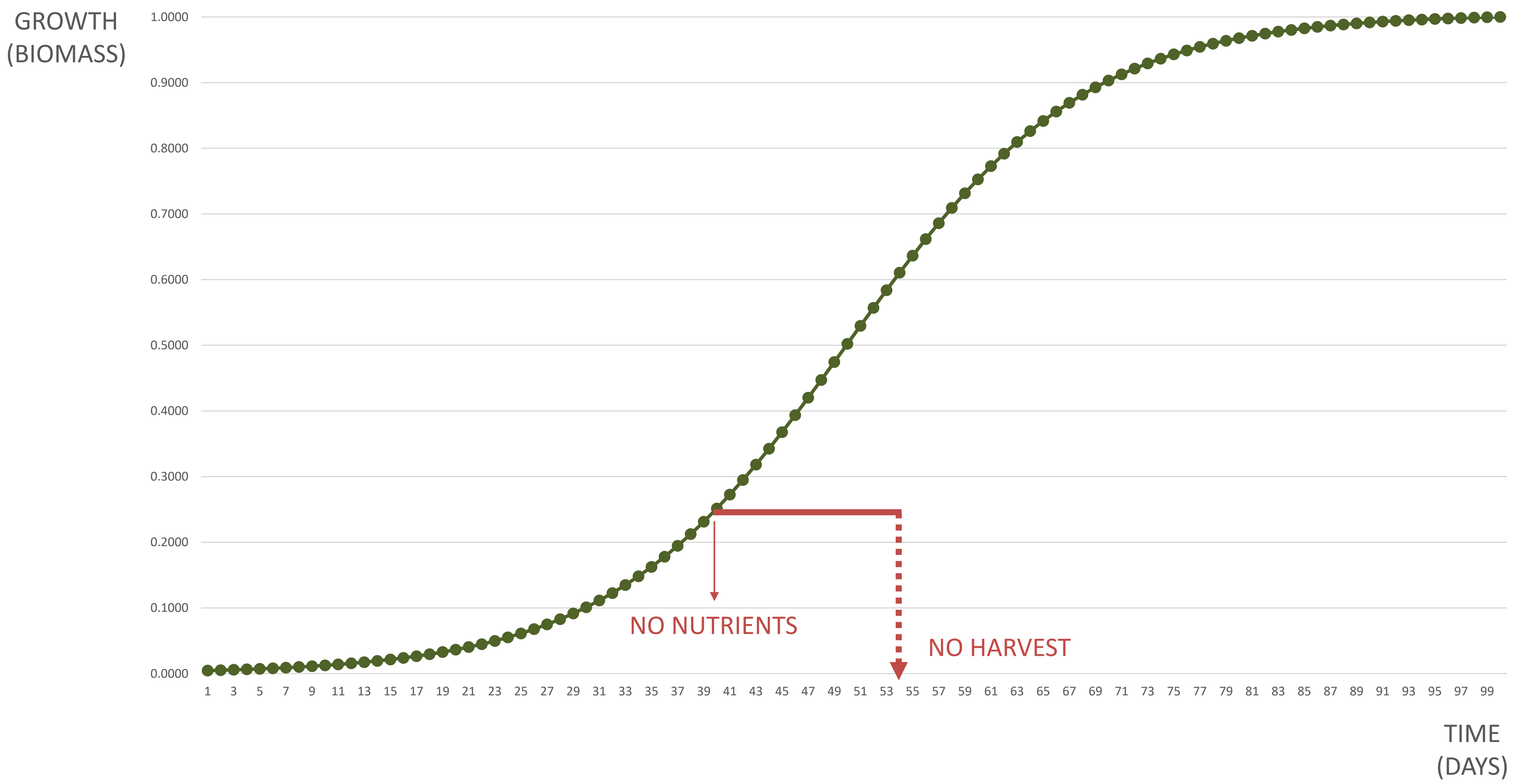
PLANT PLOT AGENT



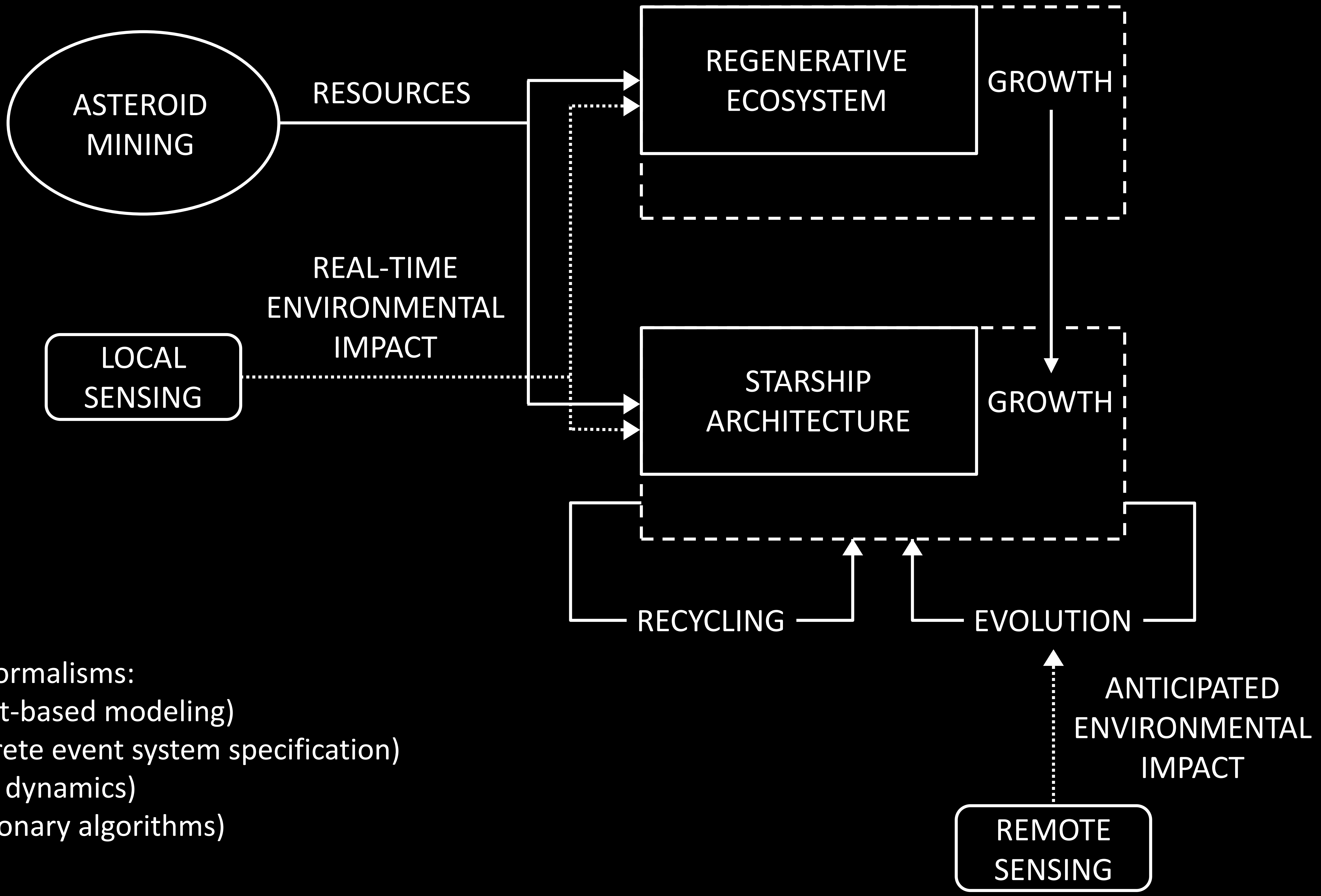
PLANT PLOT AGENT



PLANT PLOT AGENT



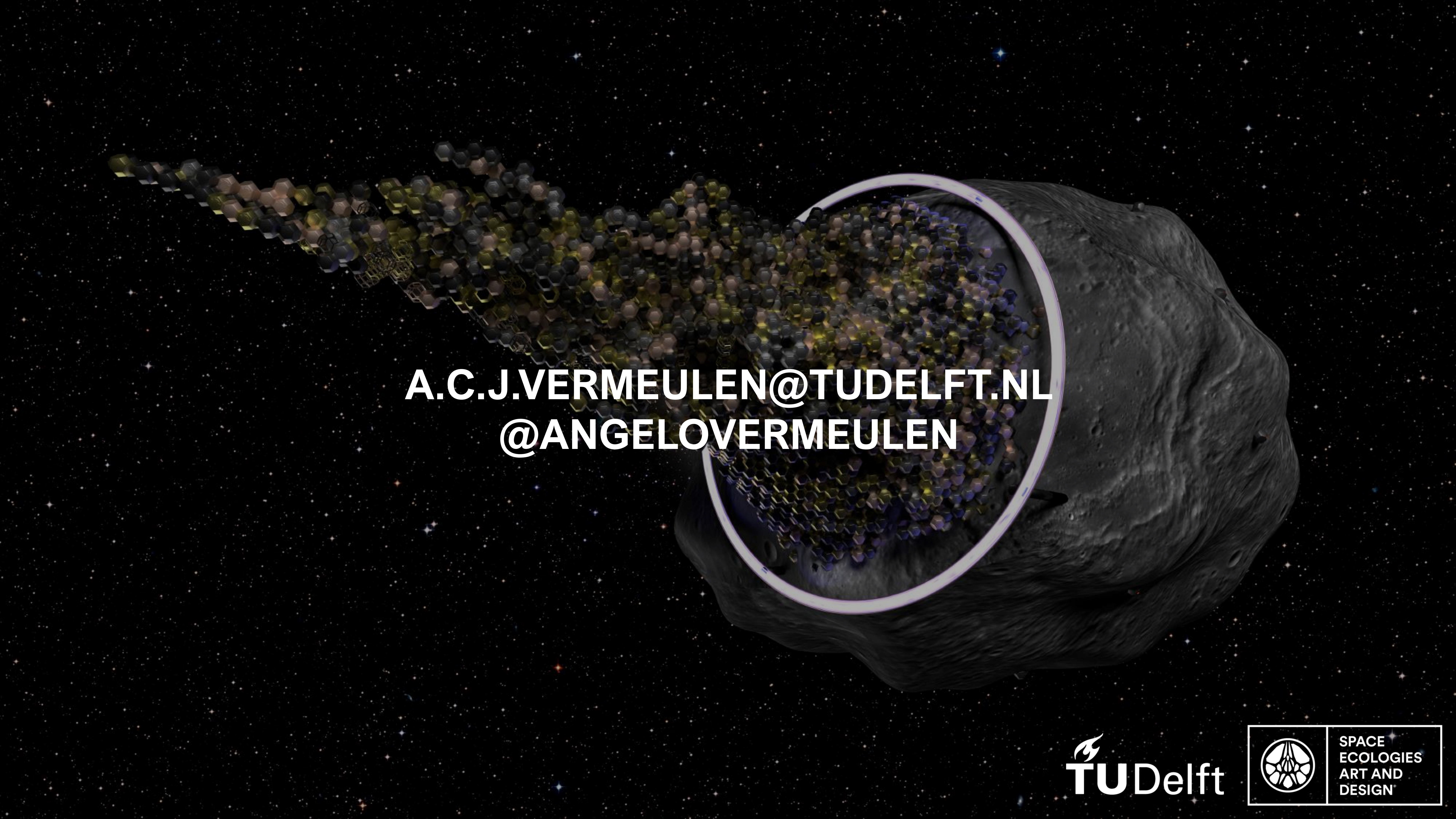
SIMULATION OVERVIEW



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

CONCLUSIONS

- CAS approach to create a robust system
- Exploratory modeling, not predictive modeling
- Consequences: co-evolution, intractability



A.C.J.VERMEULEN@TUDELFT.NL
@ANGELOVERMEULEN

TUDelft

SPACE ECOLOGIES ART AND DESIGN