Modeling and simulating the MELiSSA loop to understand the effects of system interaction on survivability during long-duration interstellar missions: an agent-based approach

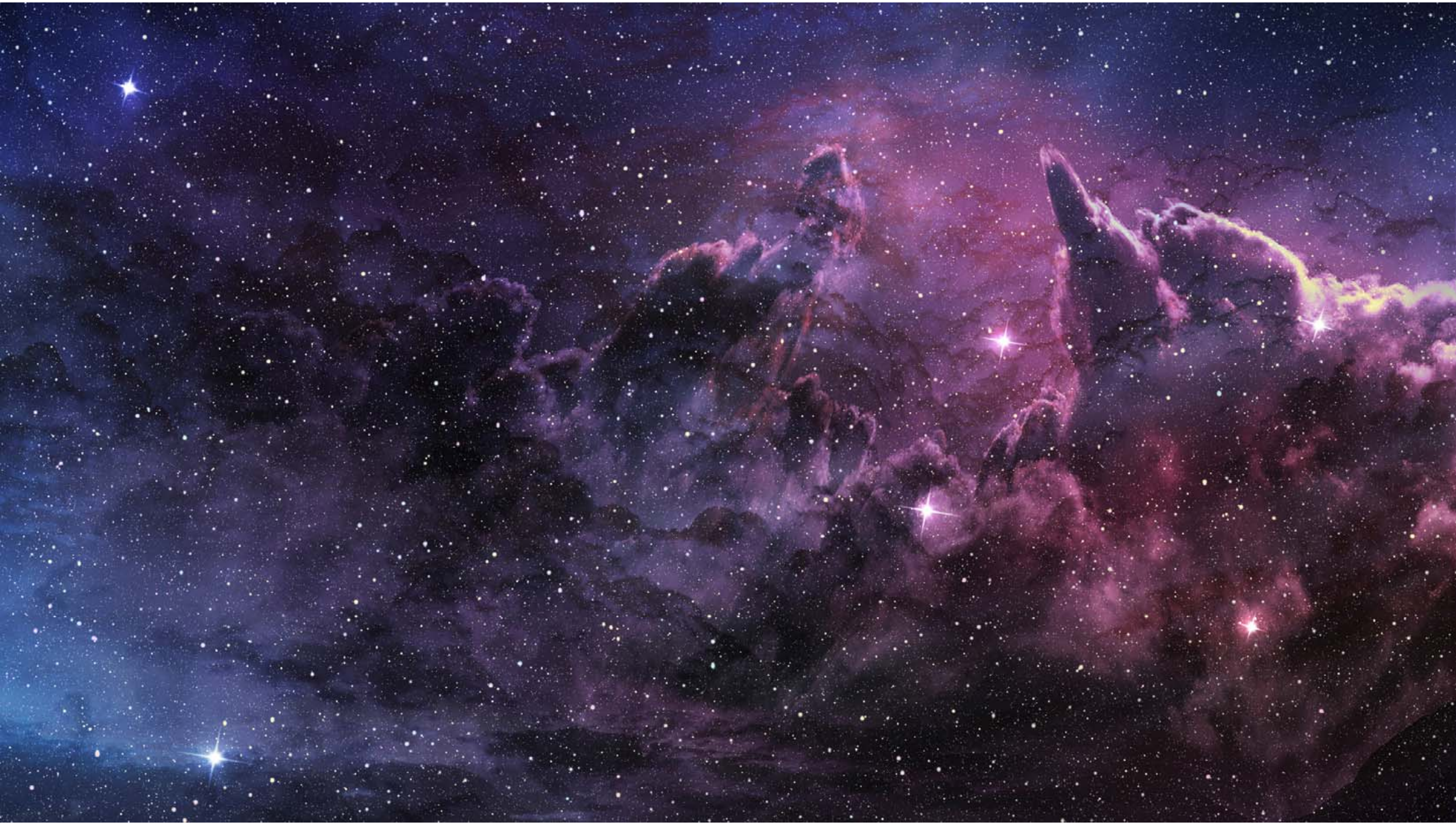
ANGELO C.J. VERMEULEN, ALVARO PAPIC, JASON KIEM & FRANCES BRAZIER

Systems Engineering and Simulation Section, Faculty of Technology, Policy and Management, TU Delft | DSTART, TU Delft

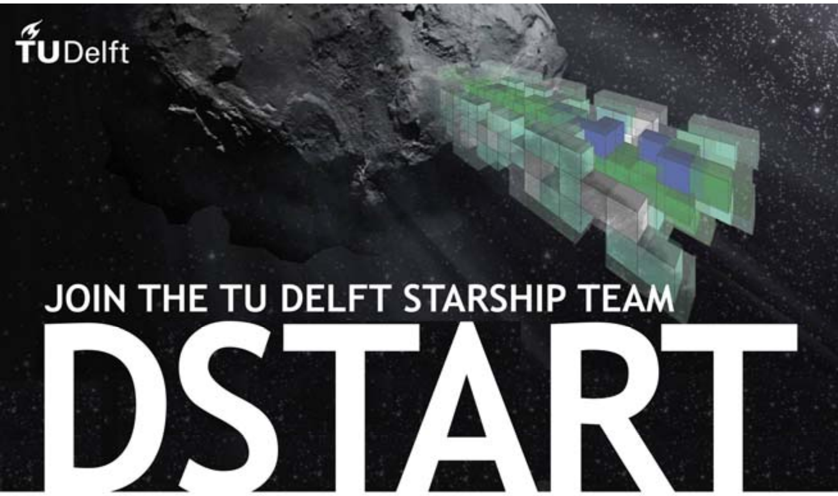
Agrospace-MELiSSA Workshop
Headquarters of the Italian Research Council, Rome
17 May 2018

TU Delft

SPACE ECOLOGIES ART AND DESIGN



UNCERTAIN FUTURES



We're a team of students and researchers with a shared passion for interstellar travel, looking for new team members from all faculties

Interested in helping to develop starship concepts?

Curious how to integrate engineering, architecture and biology?

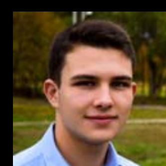
Welcome to our open work sessions
Mondays between 4 and 6 pm
TPM, Room B1.300

Period: from Q3 till Q4 2017
More info: Angelo Vermeulen, a.c.j.vermeulen@tudelft.nl

Alvaro Papic
Agent-based modeling
Biological life support

Jason Kiem
Systems engineering
Mass flow analysis

Andreas Theys
Equation-based modeling
Morphogenetic engineering



Anton Dobrevski
Architecture
Webdesign

Jimmy Verkooijen
Background research
Outreach

Sharon van Rijthoven
Aerospace engineering
Community management

Nils Faber
3D modeling
Visualization

Arise Wan
Architecture
Biomimicry

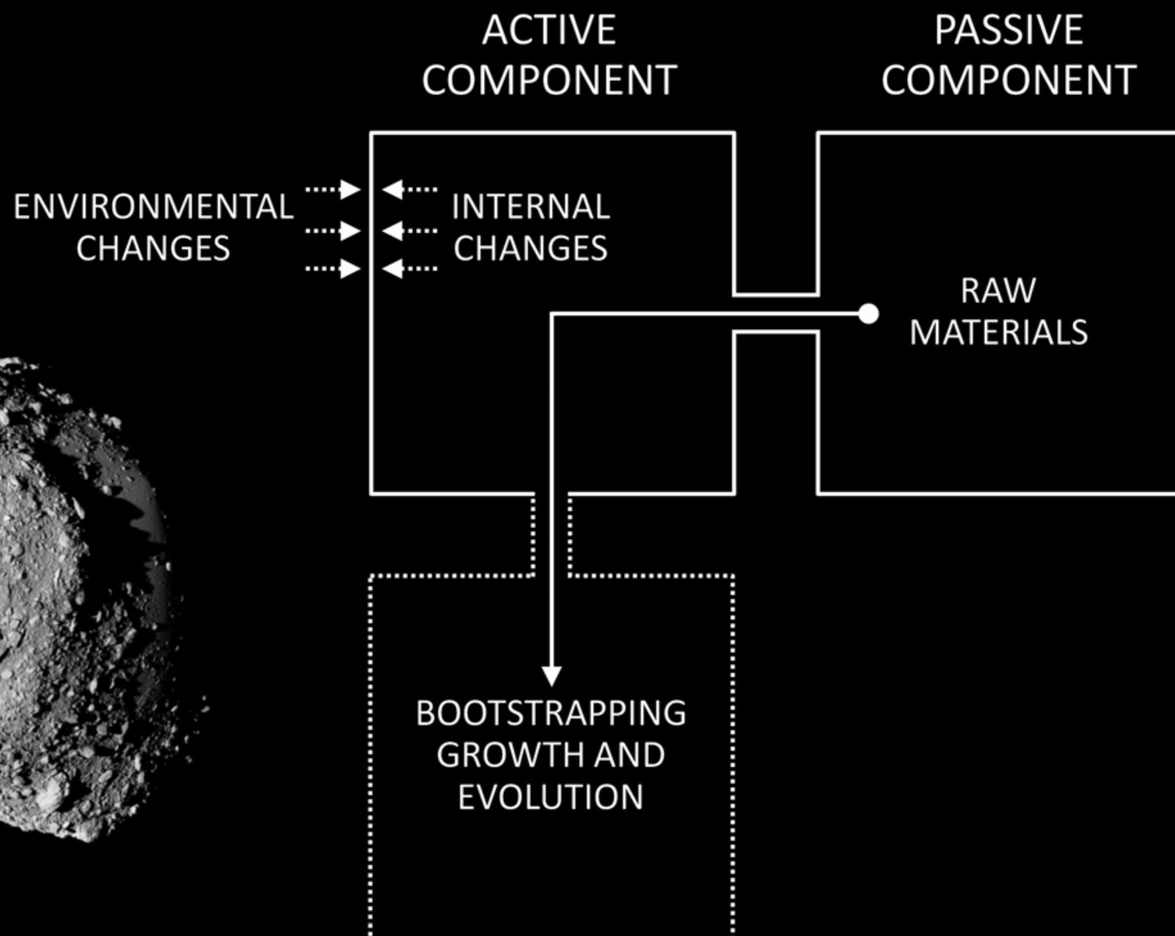
Amelie Kim
Architecture
3D modeling

Jasper Wennekendonk
Concept design
Visualization

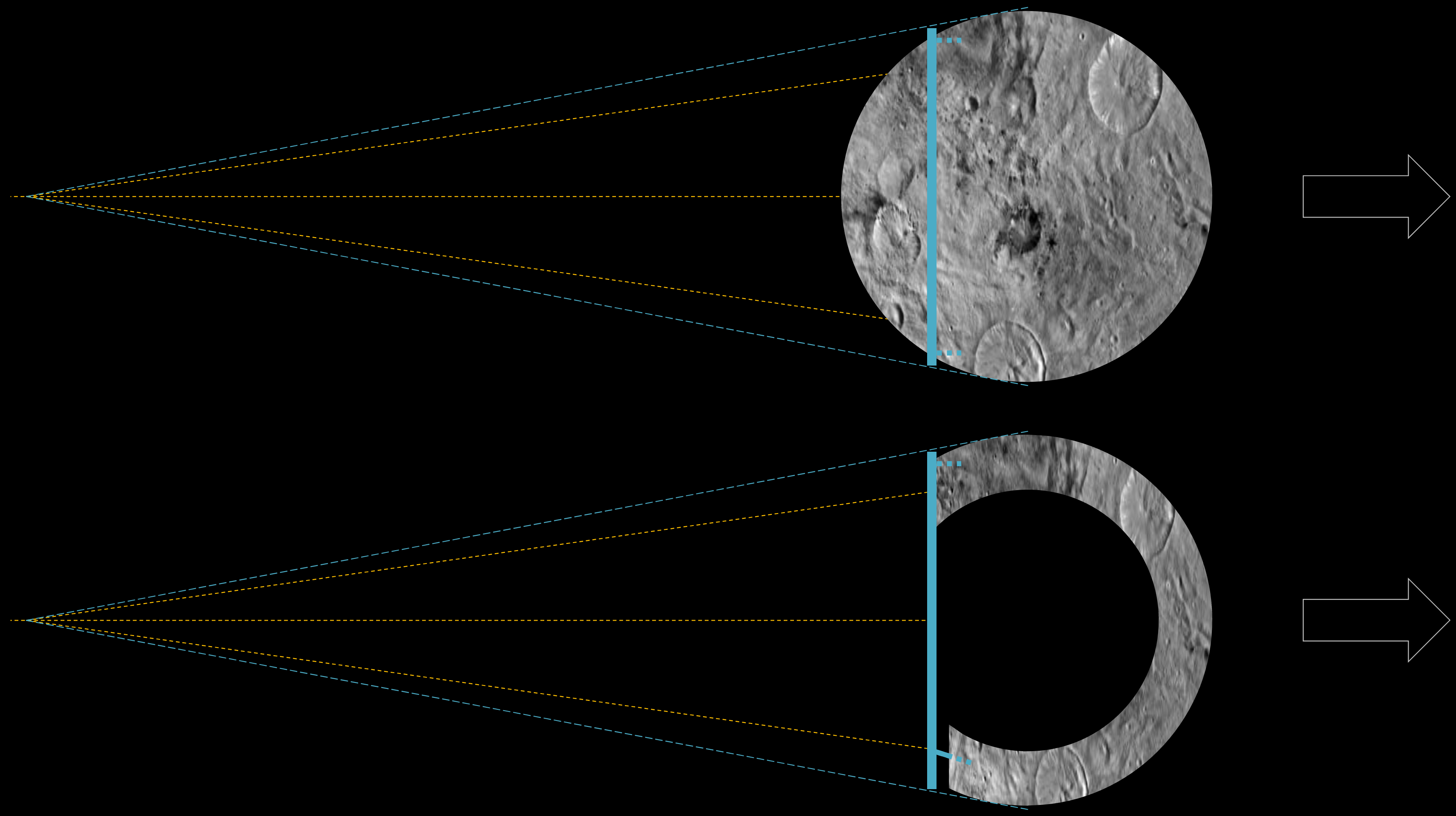
Bhavna Thyagarajan
Landscape architecture
Interior design

Angelo Vermeulen
Model development
Biological life support

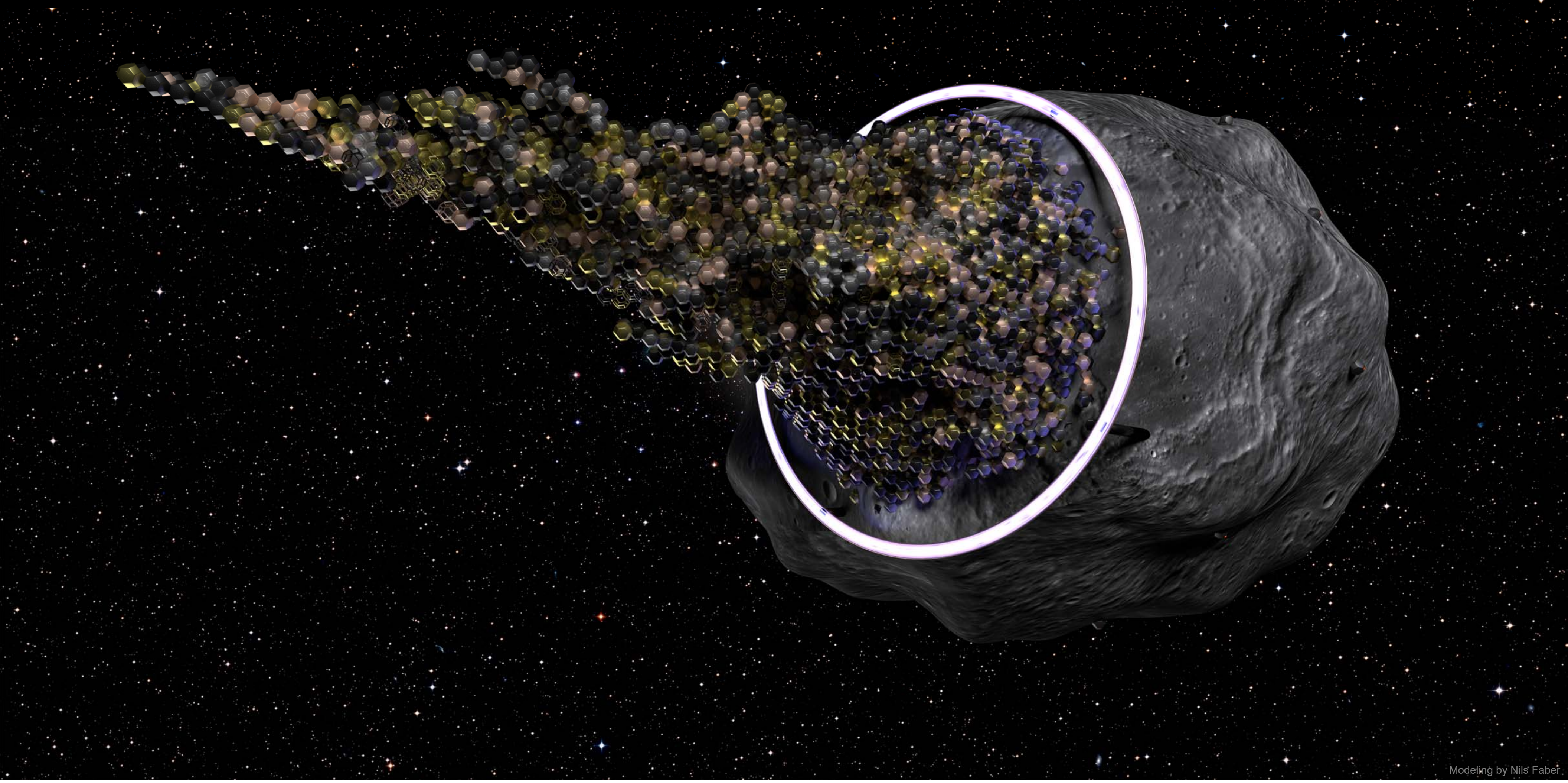
EVOLVABLE SPACECRAFT



ASTEROID MINING



3D PRINTED MODULAR ARCHITECTURE



EUROPEAN SPACE AGENCY | ABOUT US | OUR ACTIVITIES | CAREERS AT ESA | FOR MEDIA | FOR EDUCATORS | FOR KIDS

space in images

esa

ESA | SPACE IN IMAGES

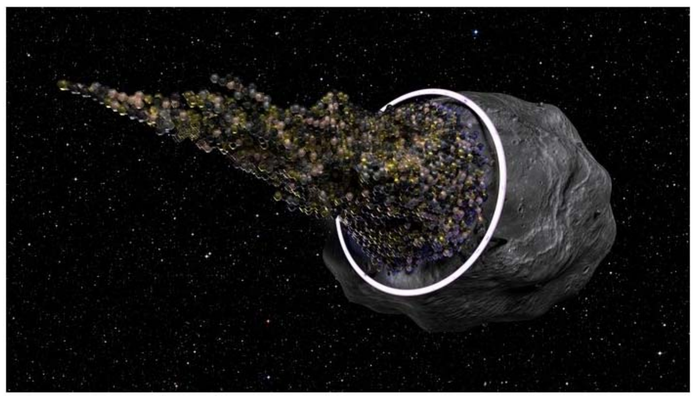
ESA > Space in Images > 2018 > 04 > TU Delft E|A|S (Evolving Asteroid Starships) project

Login | Register

FREE SEARCH (22275 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

RELATED IMAGES

05 June 2009
A view inside the MELiSSA pilot...
1345
Votes: 12

05 June 2009
Inauguration of the MELiSSA pi...
537
Votes: 2

Technology Image of the Week Archive

USING OUR IMAGES

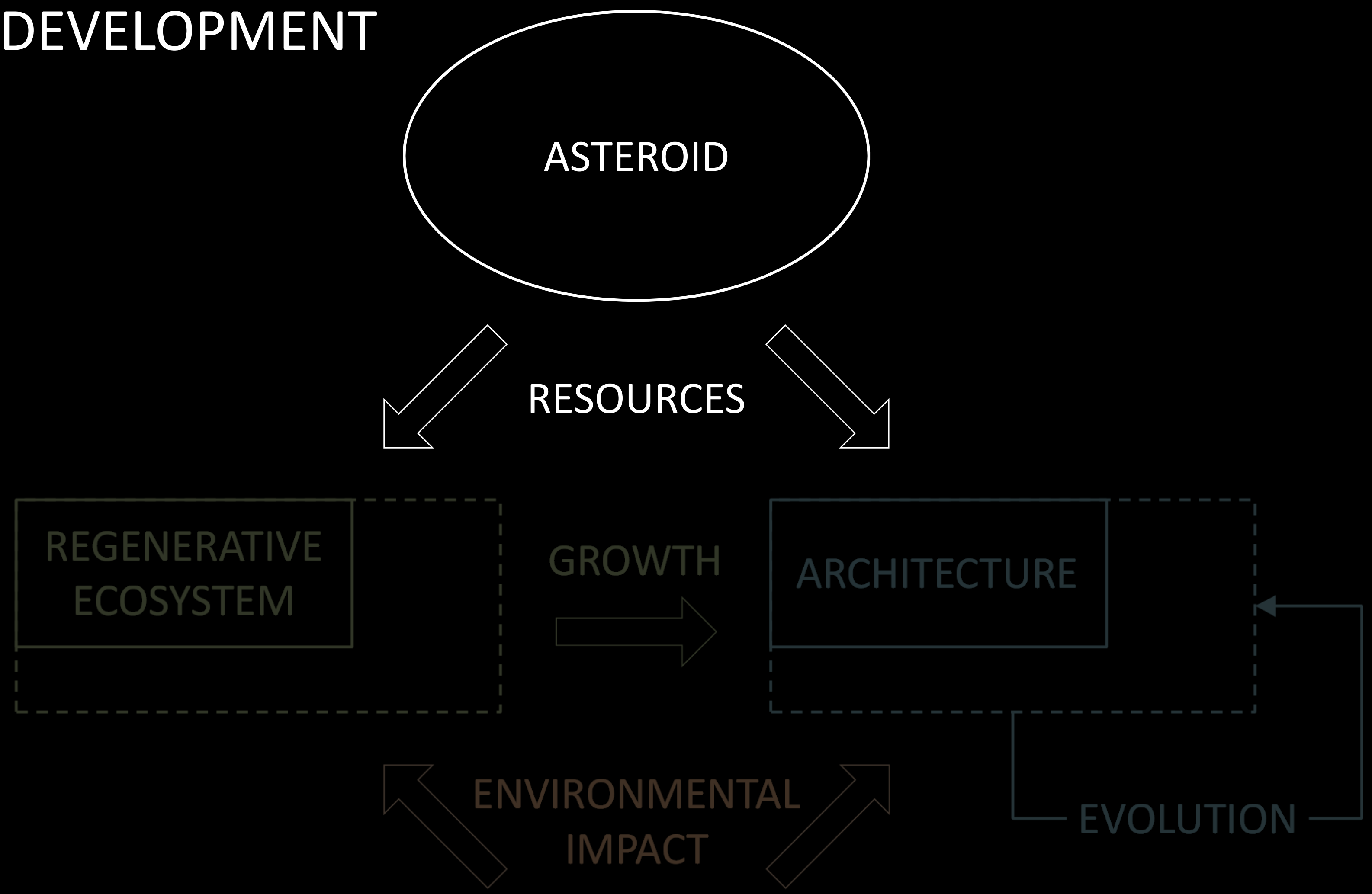
Terms and conditions

Contact us

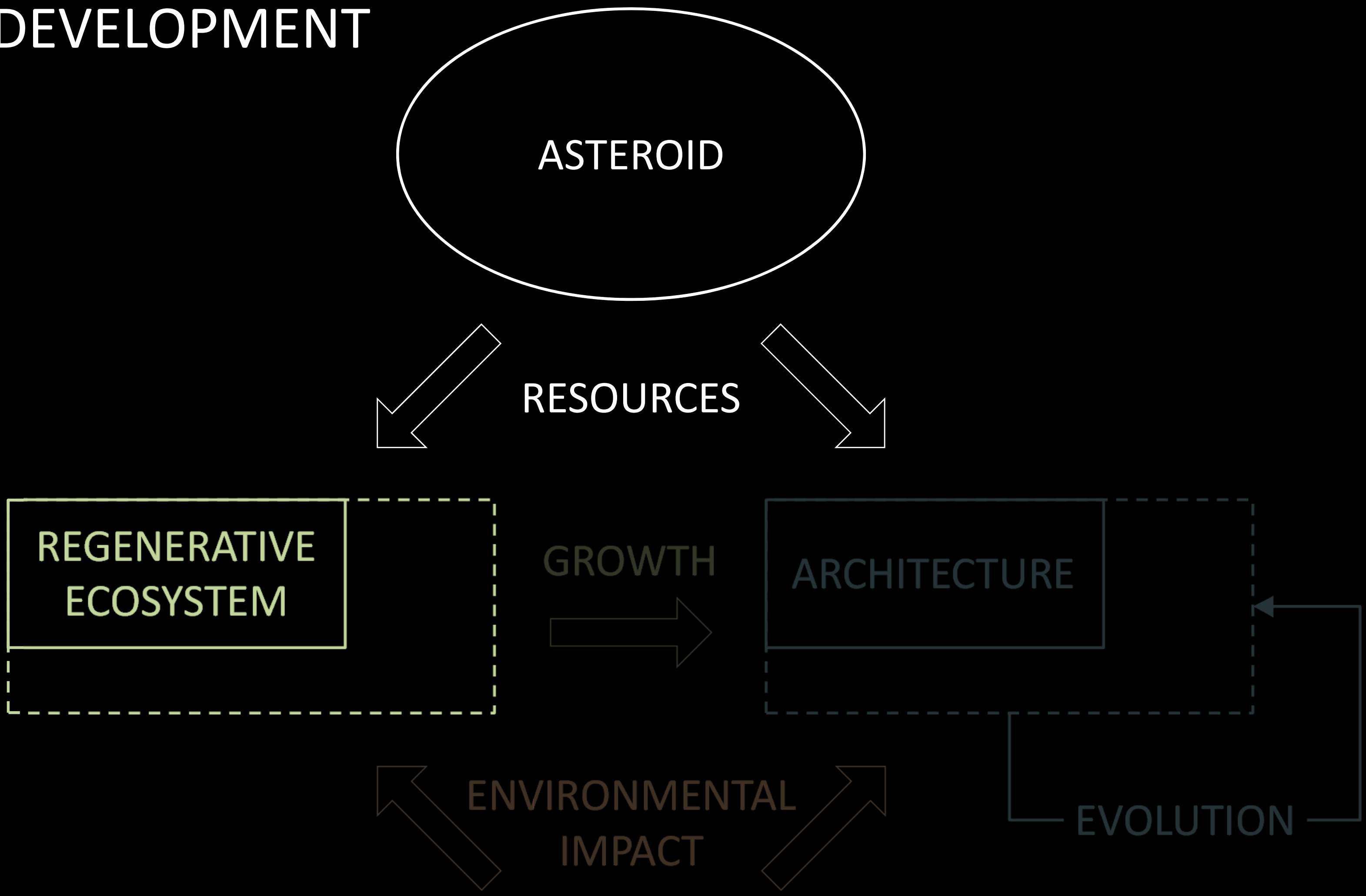
Commenting guidelines

Modeling by Nils Faber

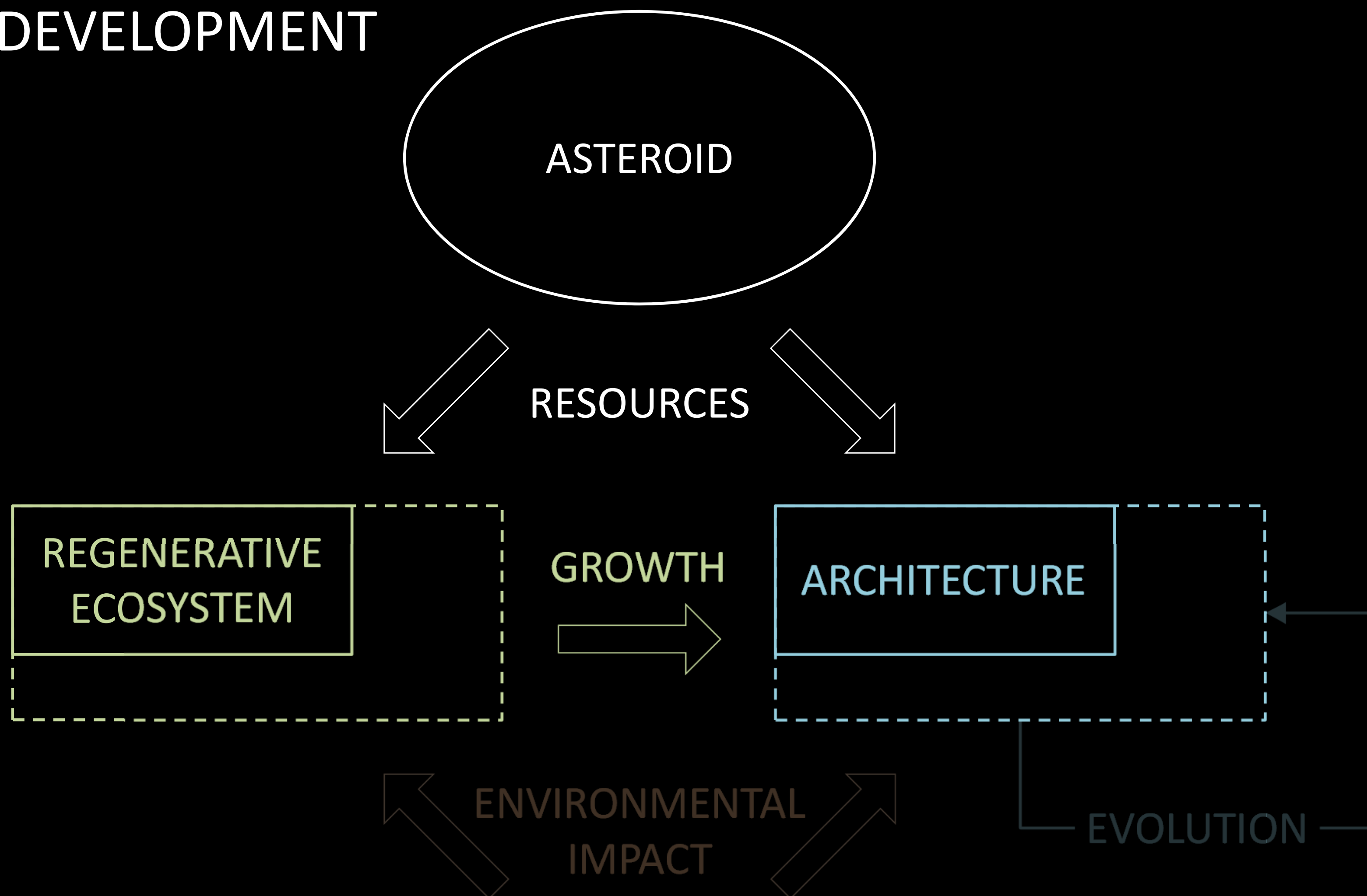
MODEL DEVELOPMENT



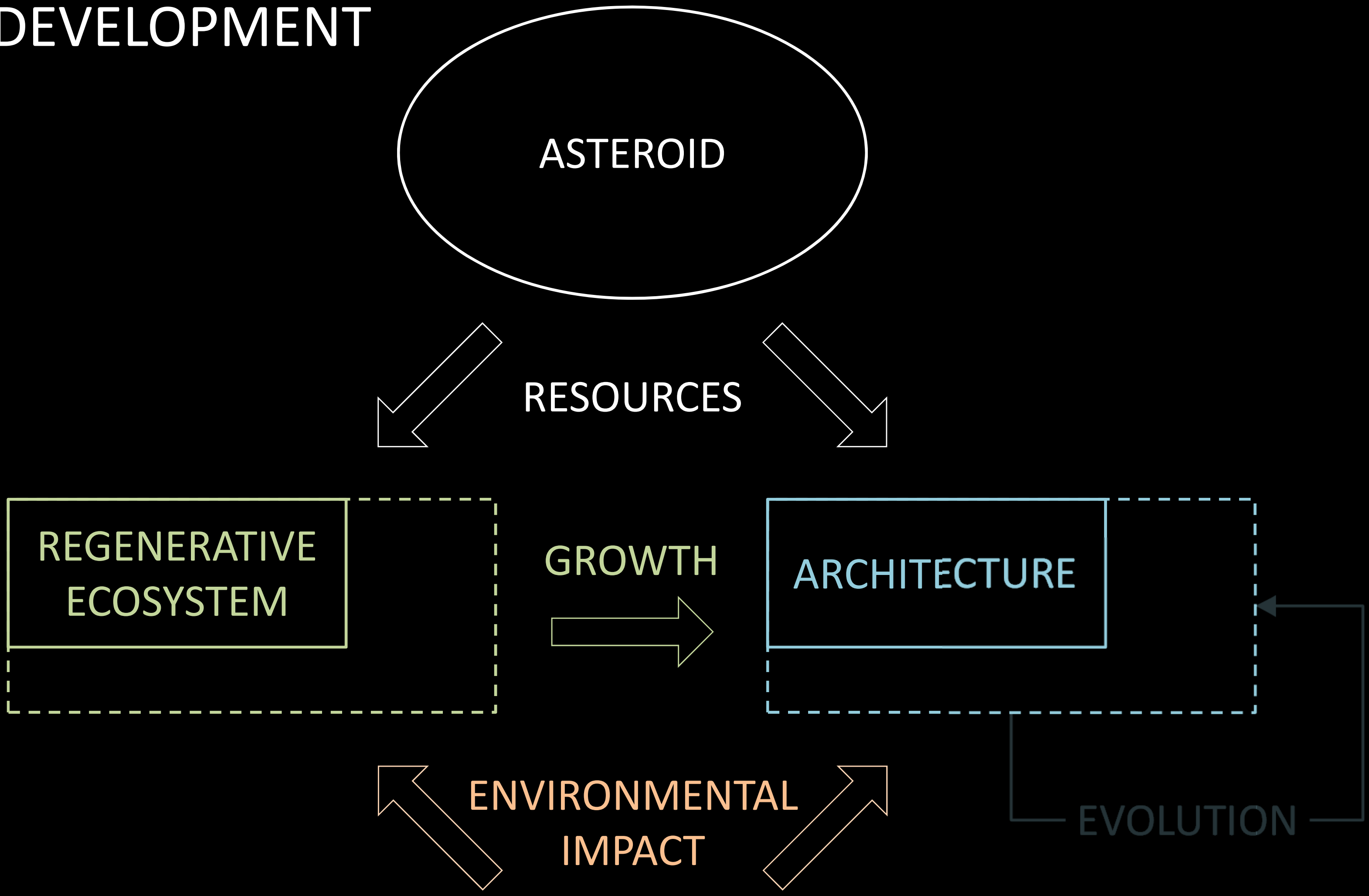
MODEL DEVELOPMENT



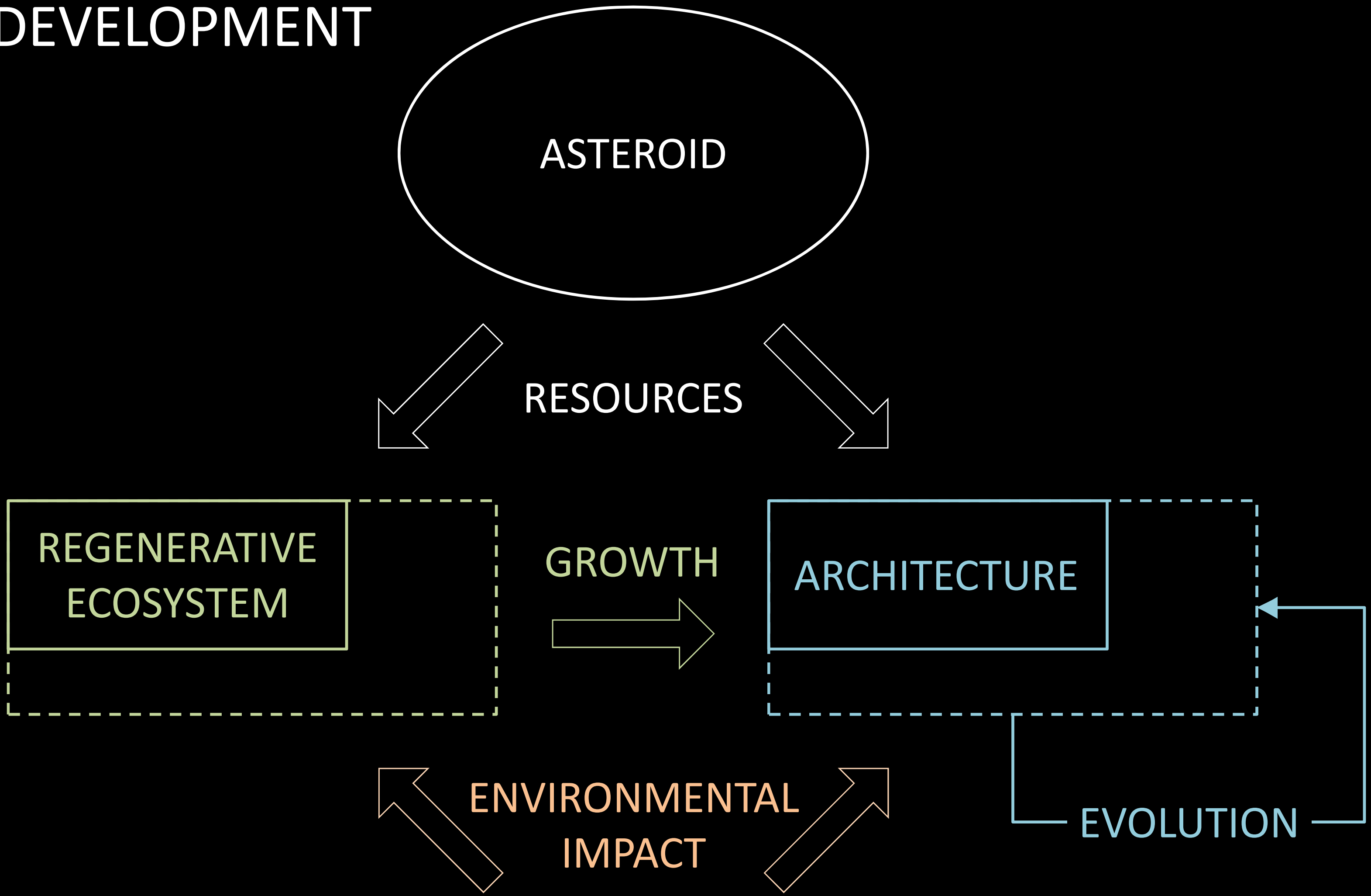
MODEL DEVELOPMENT



MODEL DEVELOPMENT

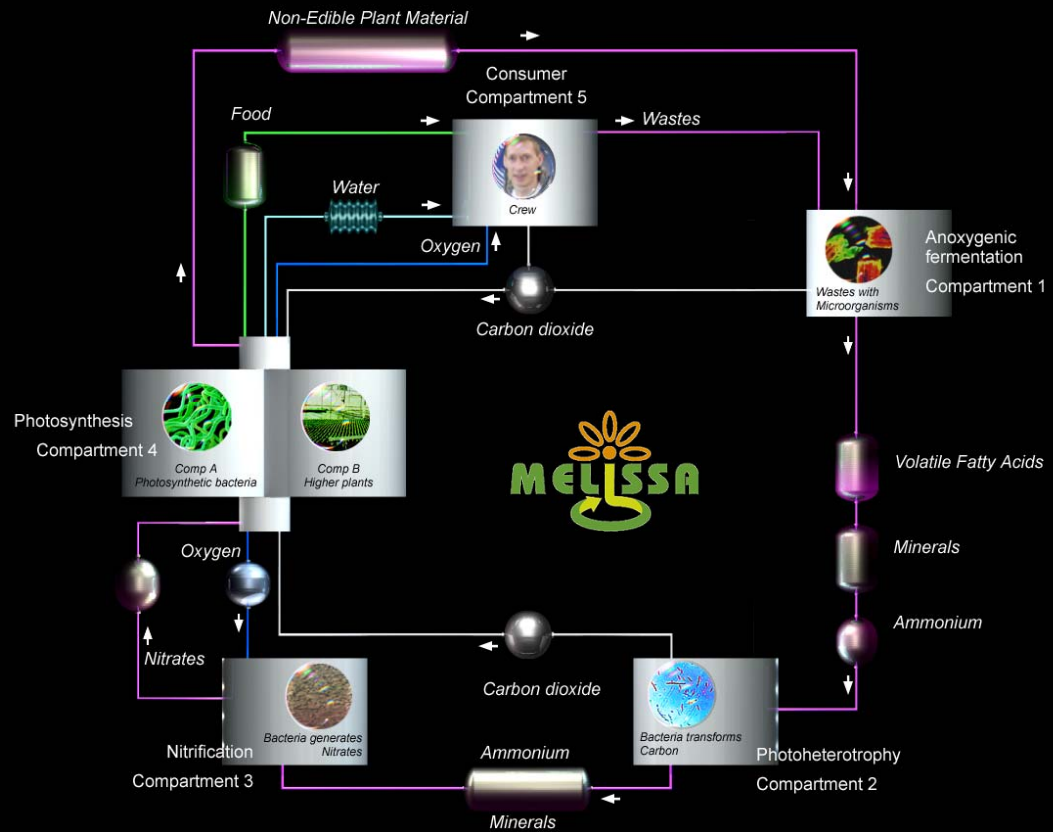


MODEL DEVELOPMENT



MODEL DEVELOPMENT

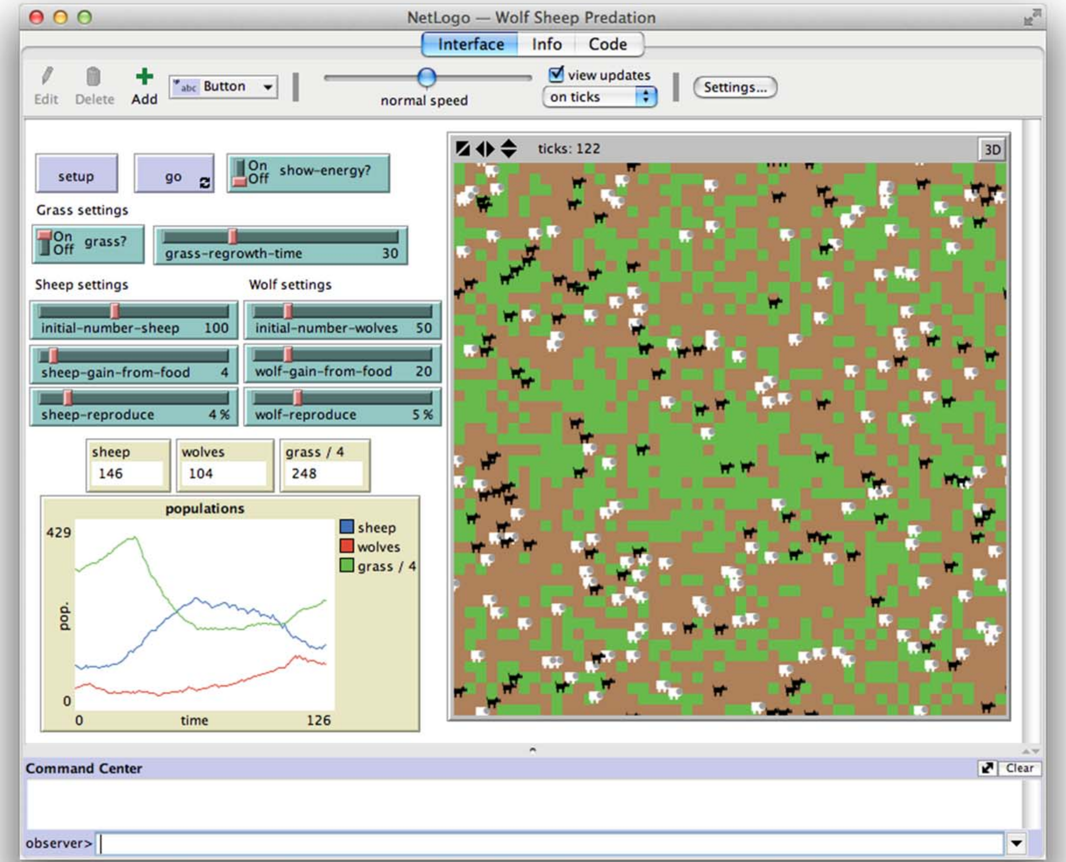
REGENERATIVE ECOSYSTEM



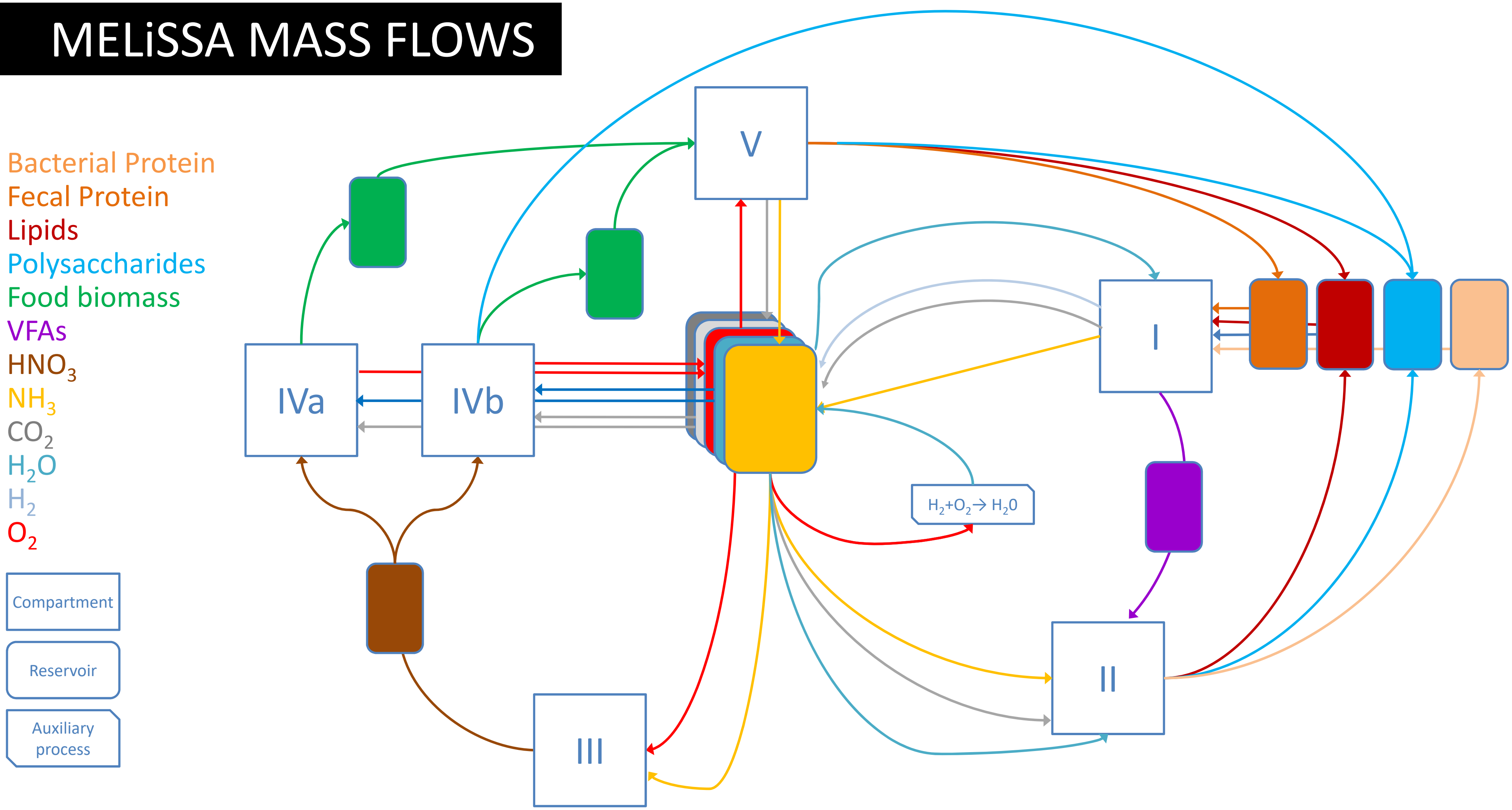
AGENT-BASED MODELING

DEFINITION

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



MELiSSA MASS FLOWS



MELiSSA MASS FLOWS

ASSUMPTIONS & ADDITIONS

- 12 reservoirs
- 1 auxiliary process: hydrogen oxidization
- Surplus biomass of Compartment II goes to Compartment I
- 3 biomass formulas: edible + non-edible + Rhodospirillum
- 2 protein formulas: plant/algae/feces + Rhodospirillum

MELiSSA STOICHIOMETRY

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 STOICHIOMETRY

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 STOICHIOMETRY

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 STOICHIOMETRY

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

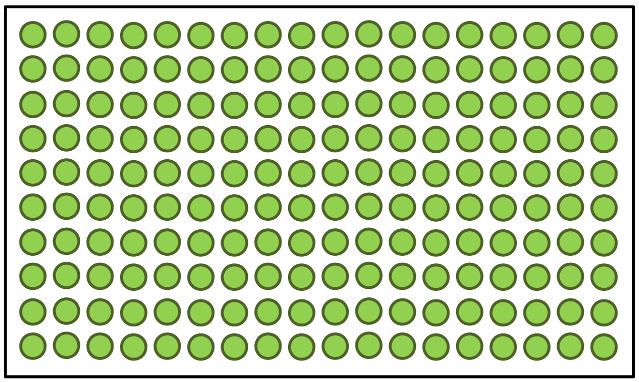
$C_{16}H_{32}O_2 + 13,0278H_2O = 6,5278C_2H_4O_2 + 0,6528C_4H_8O_2 + 0,3333CO_2 + 13,3611H_2$

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

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

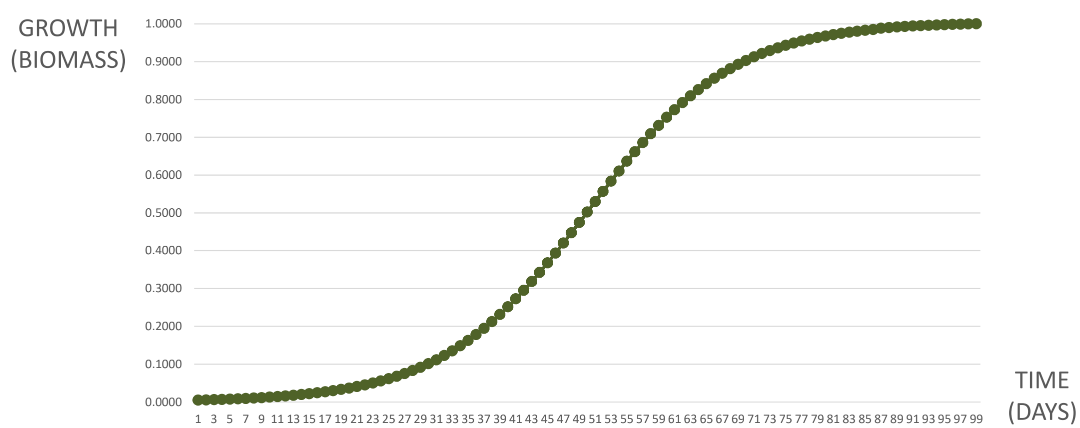
BEHAVIOR

Input-output: stoichiometry

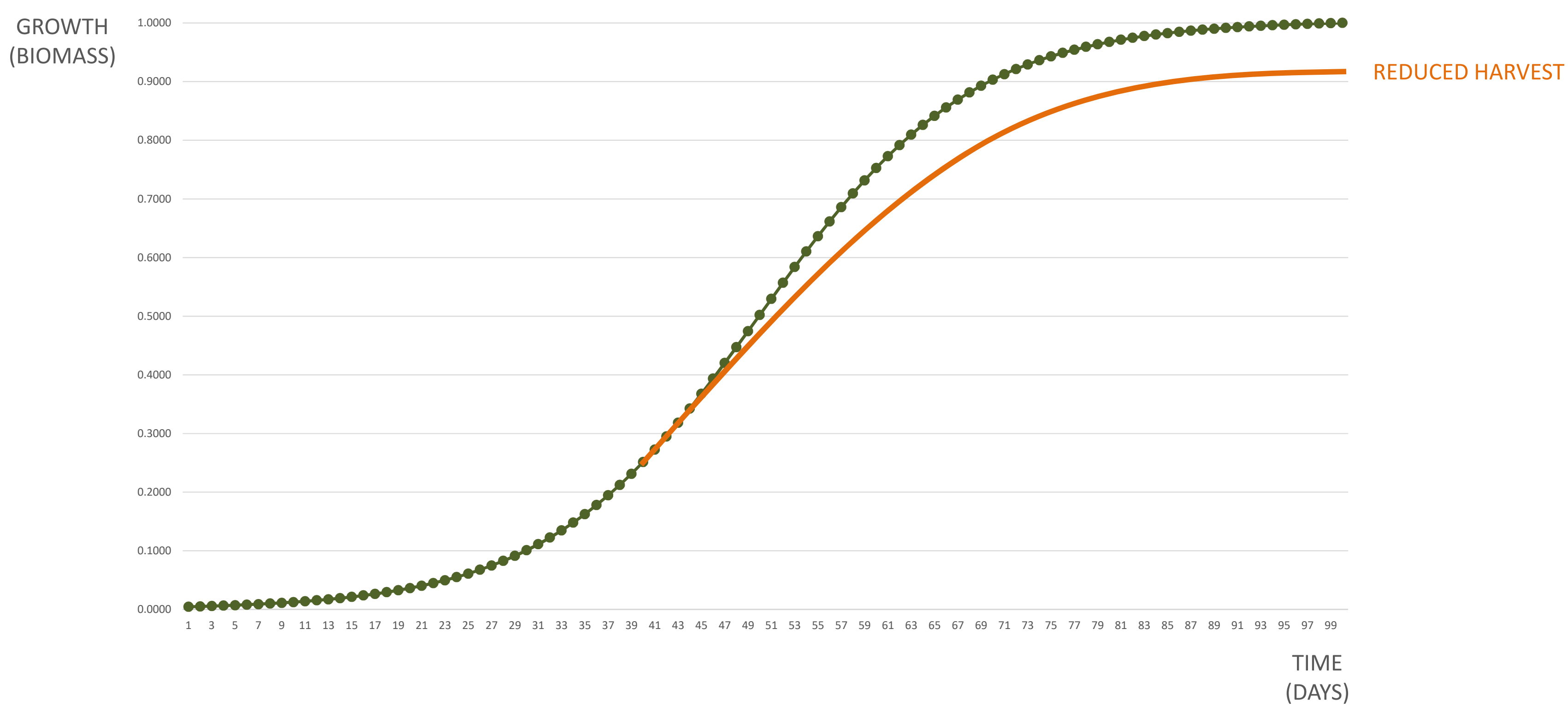
PLANT PLOT AGENT

STATES

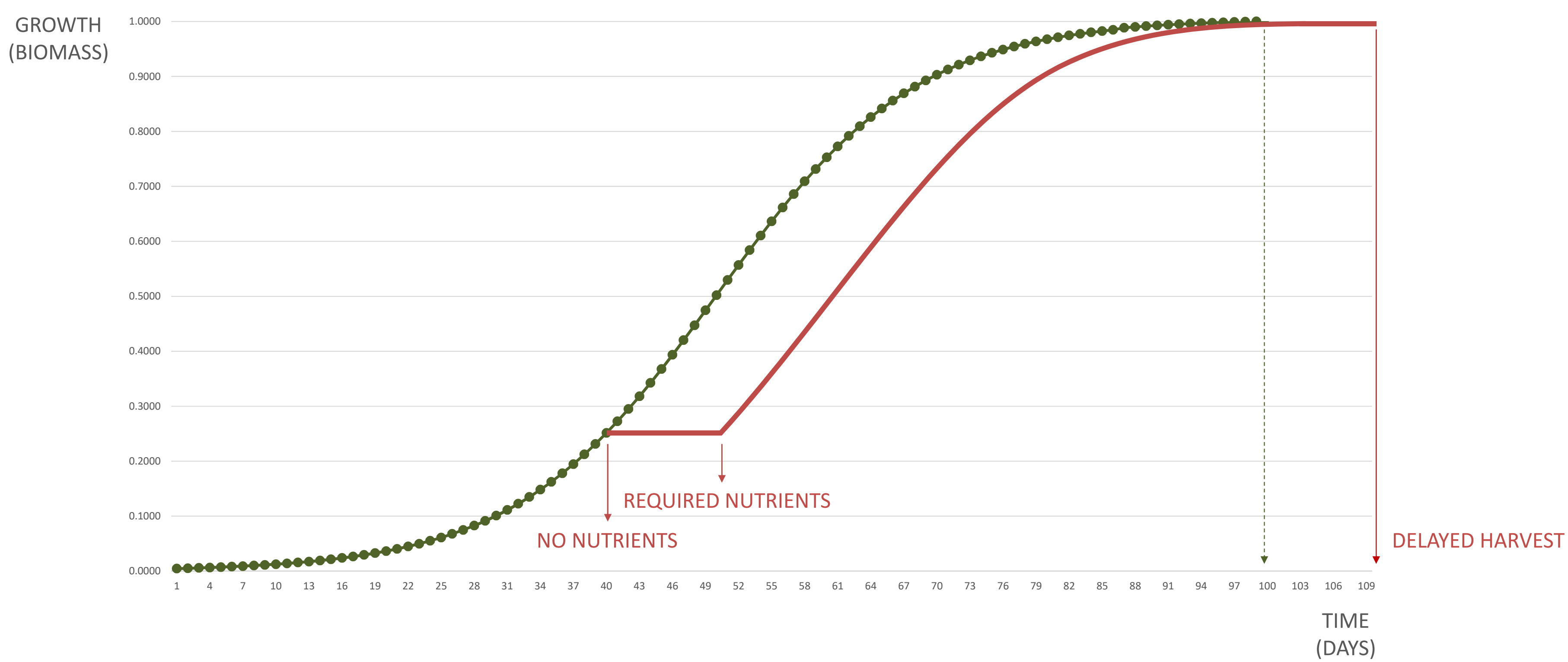
- Growth follows a sigmoid curve
- Reaching 40g in 100 days (10% first and 10% last week)
- For each day there's a specific biomass increase, and hence, the corresponding necessary input can be deduced according to the plant plot's stoichiometry



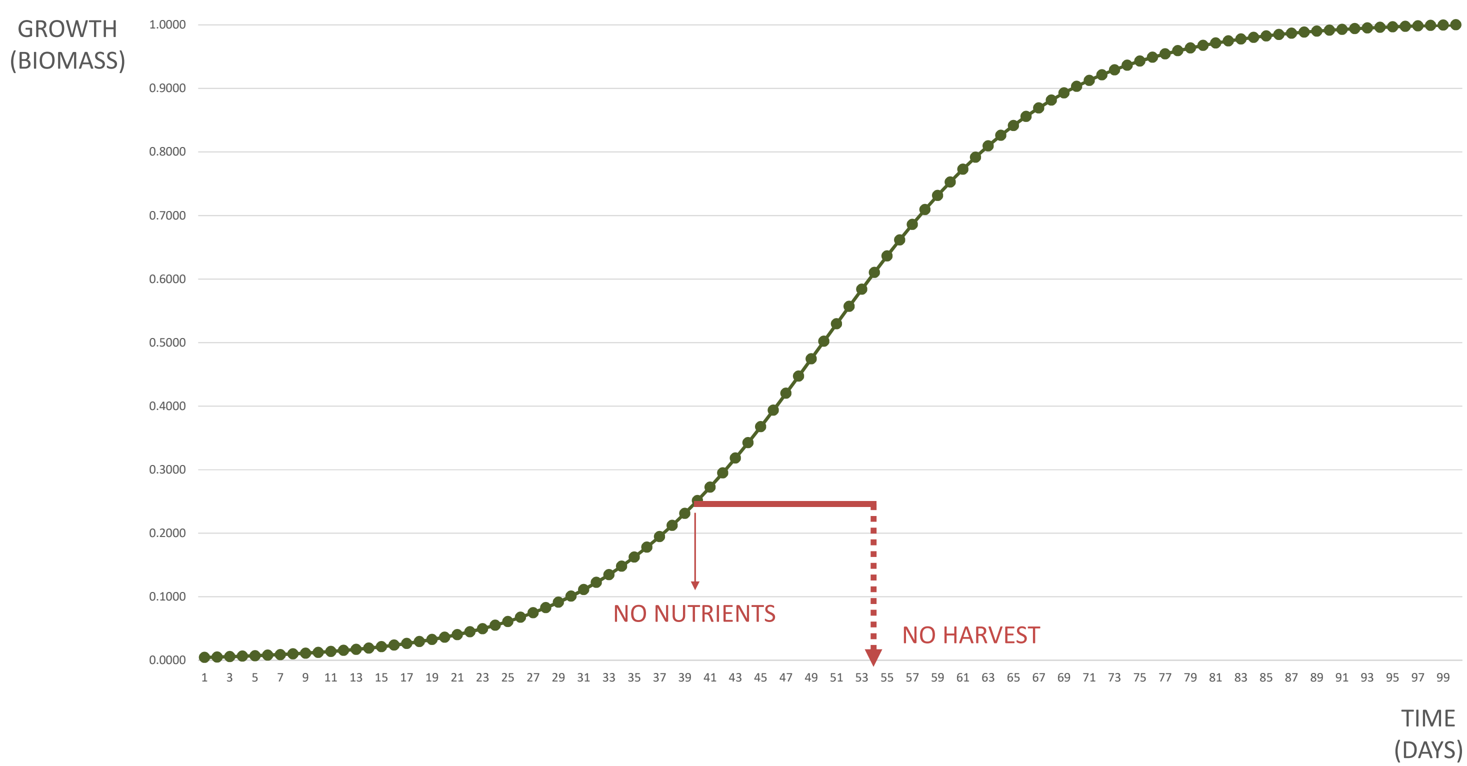
PLANT PLOT AGENT



PLANT PLOT AGENT

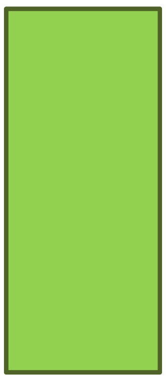


PLANT PLOT AGENT



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

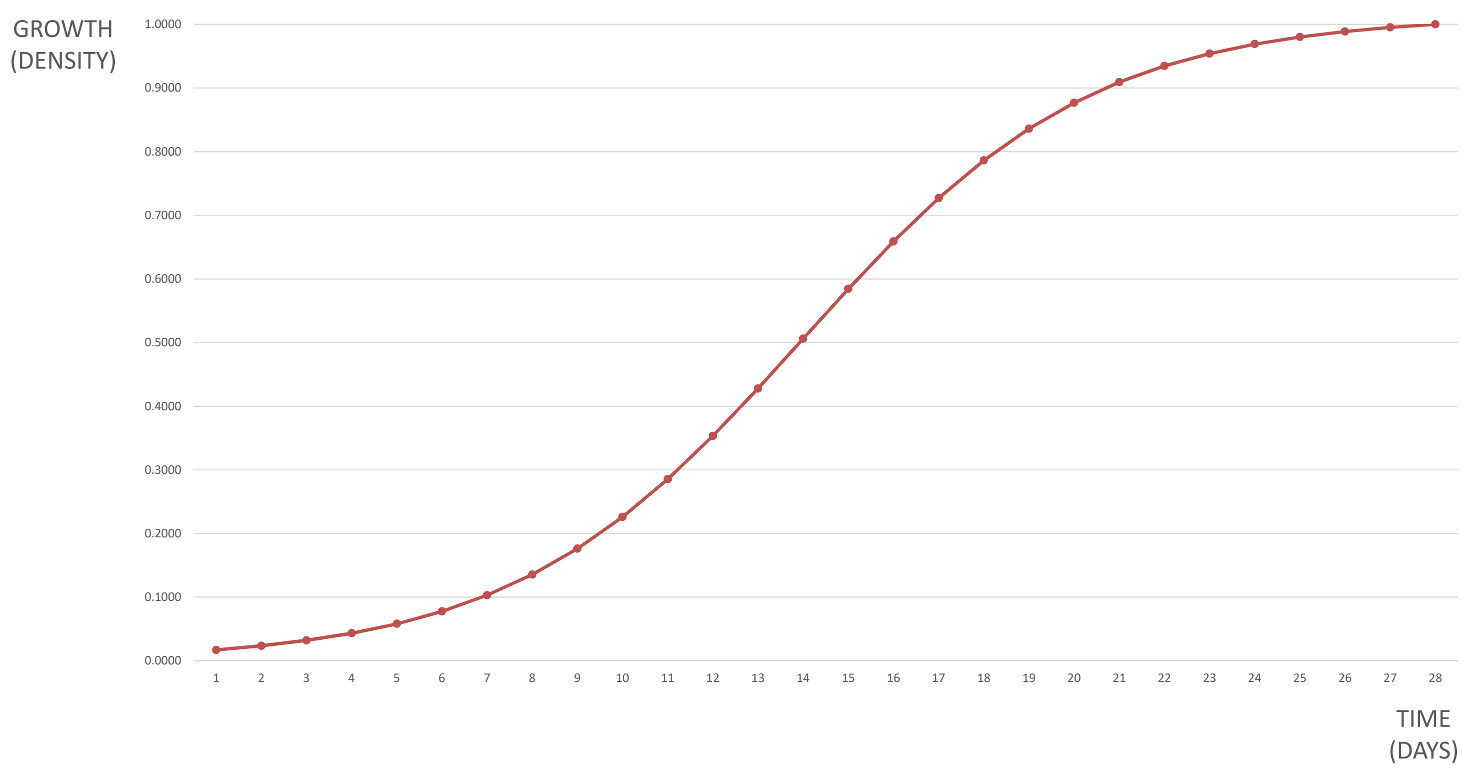
Input-output: stoichiometry

BIOREACTOR AGENT

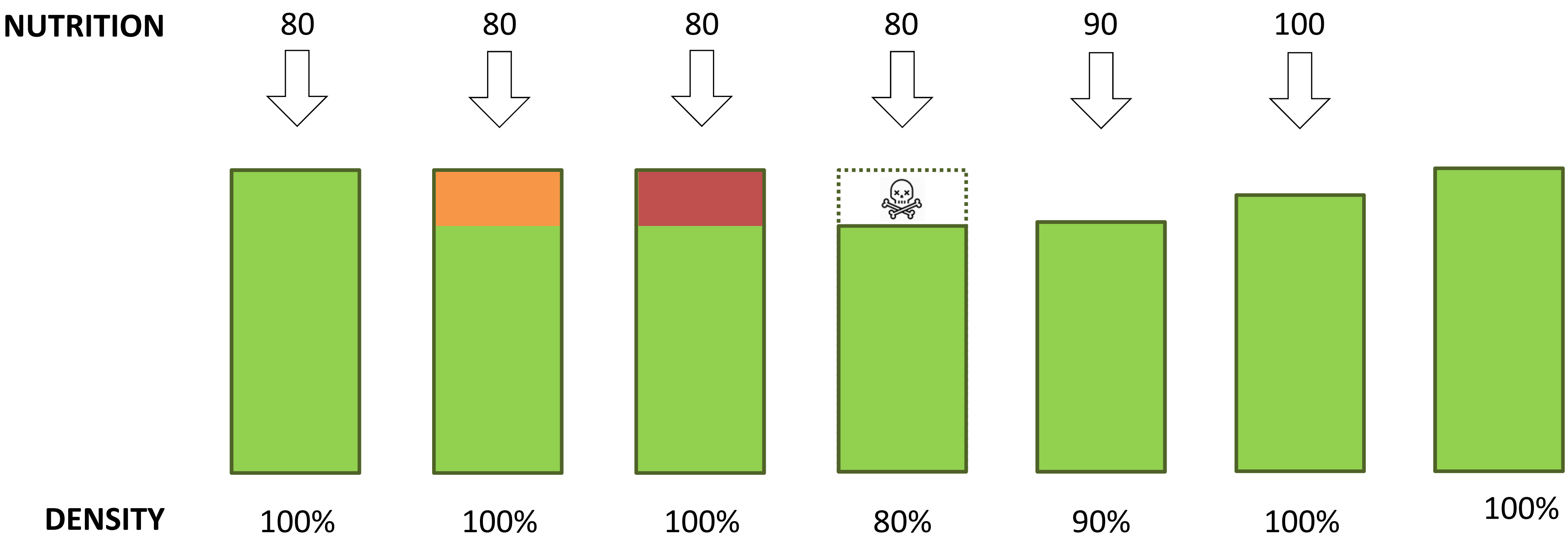
STATES

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

BIOREACTOR AGENT



BIOREACTOR AGENT

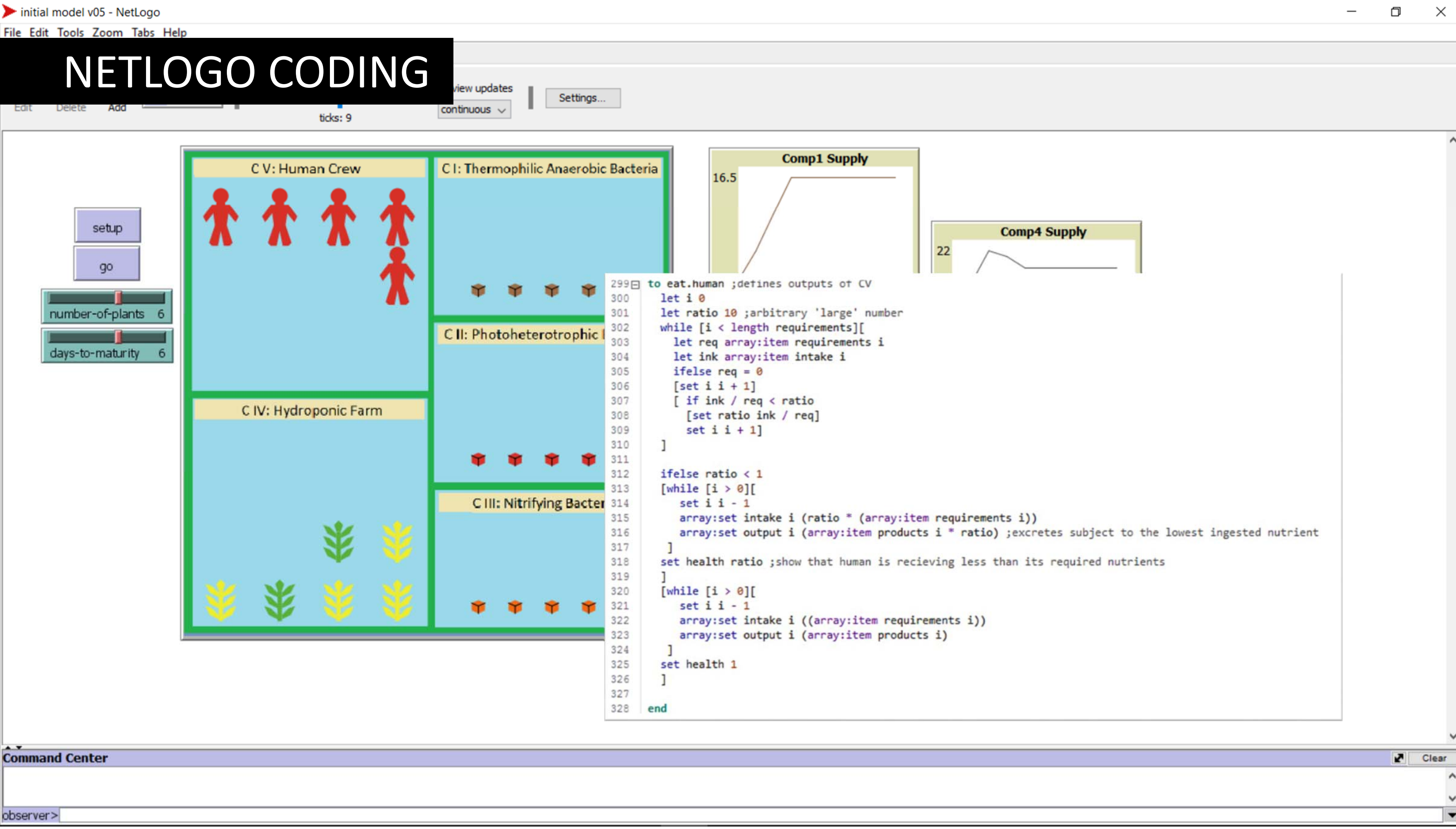


PRODUCTIVITIES

Compartment	Type	Organism	Productivity	Nutritional value
I	Bioreactor	Fermenting bact.	6000mg VFAs/L/day*	
II	Bioreactor	Rhodospirillum	2112mg biomass/L/day*	
III	Bioreactor	Nitrifying bact.	8740mg nitrates/L/day*	
IVa	Bioreactor	Arthrospira	7990mg biomass/L/day*	6 x 200 kcal
IVb	Plant plot	Ideal plant	7200g biomass/day†	6 x 1800 kcal
V	Cap	Crew	350g feces/day†	

* Peer-reviewed literature
† Calculated

NETLOGO CODING



CONCLUSIONS

- Abstraction of the MELiSSA system with a stoichiometrically balanced representation of all key mass flows
- This was translated into a working agent-based model (proof of concept stage)
- Agent-based modeling seems a proper tool to perform design research of a complex system such as MELiSSA:
  - individual interactions and network effects
  - ontological correspondence

NEXT STEPS

- Increase the fidelity of the model (e.g. crop differentiation, organism-specific growth curves, environmental effects)
- Set up experiments exploring system design principles for maximizing survivability in adverse deep space conditions
- Make the model decision making processes evolvable
- Connect this model to the mining-architecture model of the starship

CONTRIBUTORS & COLLABORATORS

DSTART
Anton Dobrevski
Nils Faber
Jason Kiem
Amelie Kim
Alvaro Papic
Andreas Theys
Bhavna Thyagarajan
Sharon van Rijthoven
Jimmy Verkooijen
Arise Wan
Jasper Wennekendonk

TU DELFT
Frances Brazier
Martijn Warnier
Angelo Cervone
Alessandra Menicucci

MELiSSA/IPStar
Christophe Lasseur
Claude-Gilles Dussap
Rob Suters

EMAIL: A.C.J.VERMEULEN@TUDELFT.NL
SOCIAL: @ANGELOVERMEULEN

TUDelft

SPACE ECOLOGIES ART AND DESIGN