World Ships – Feasibility and Rationale

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ESA Advanced Concepts Team Interstellar Workshop
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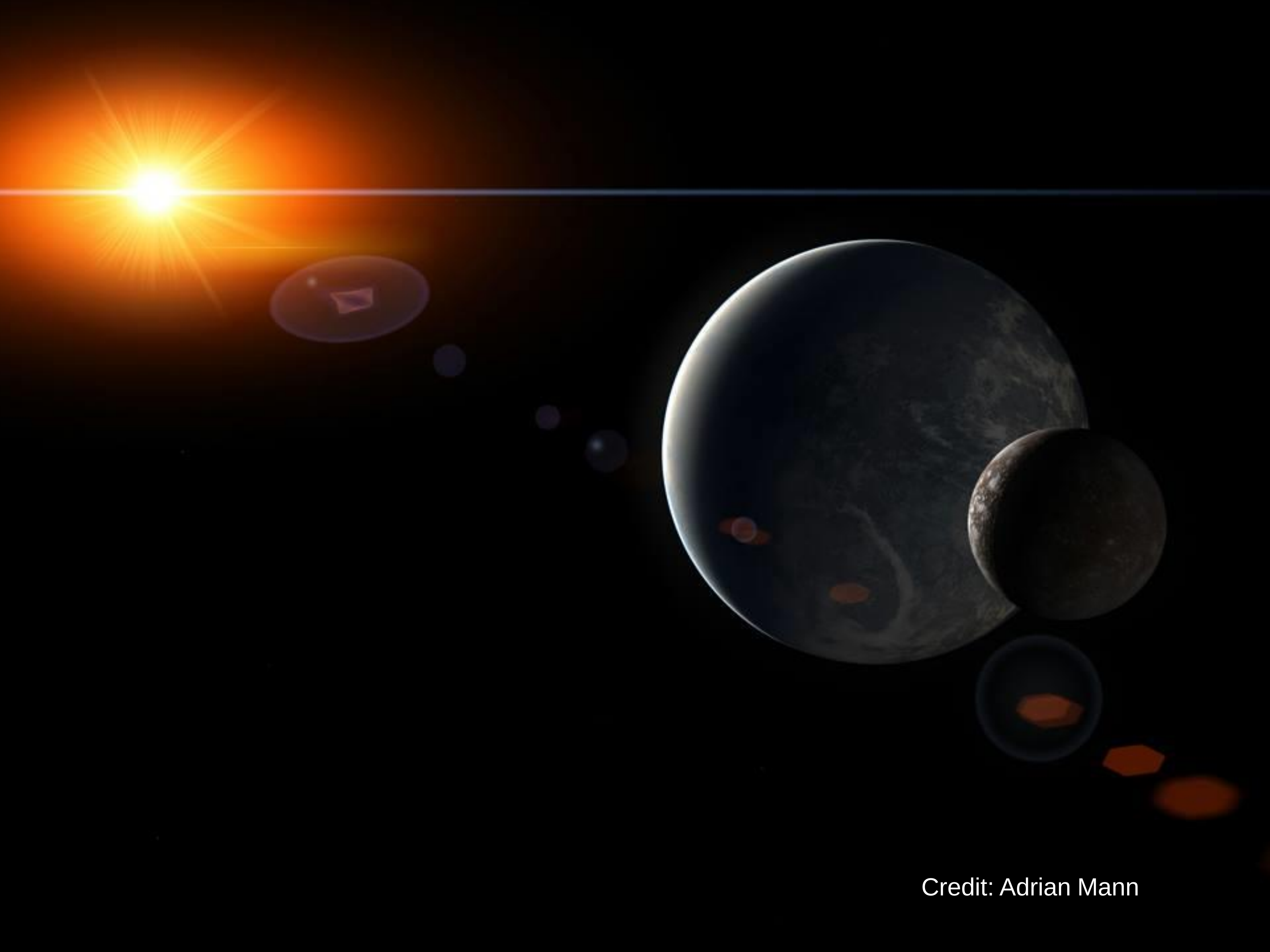
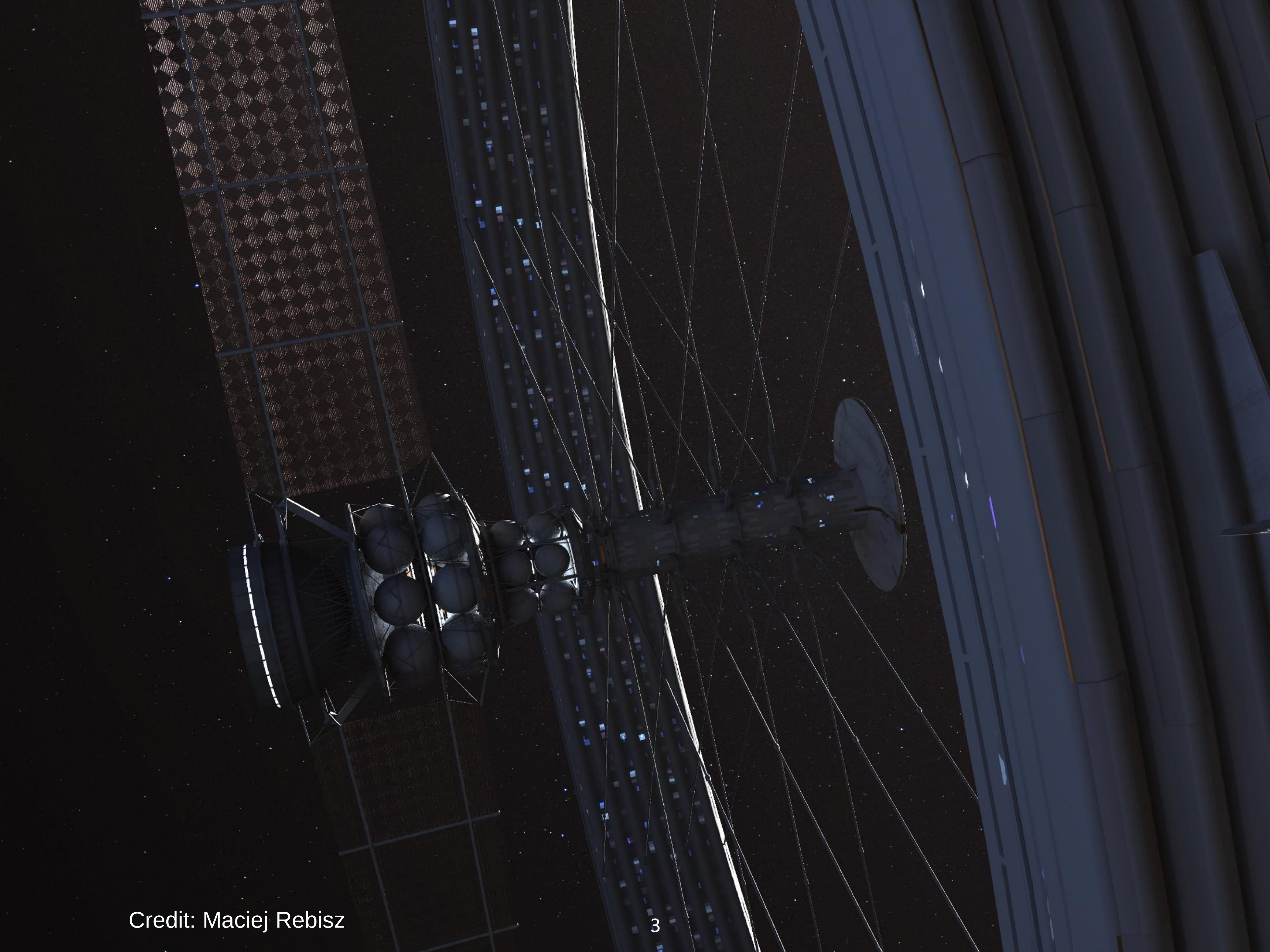


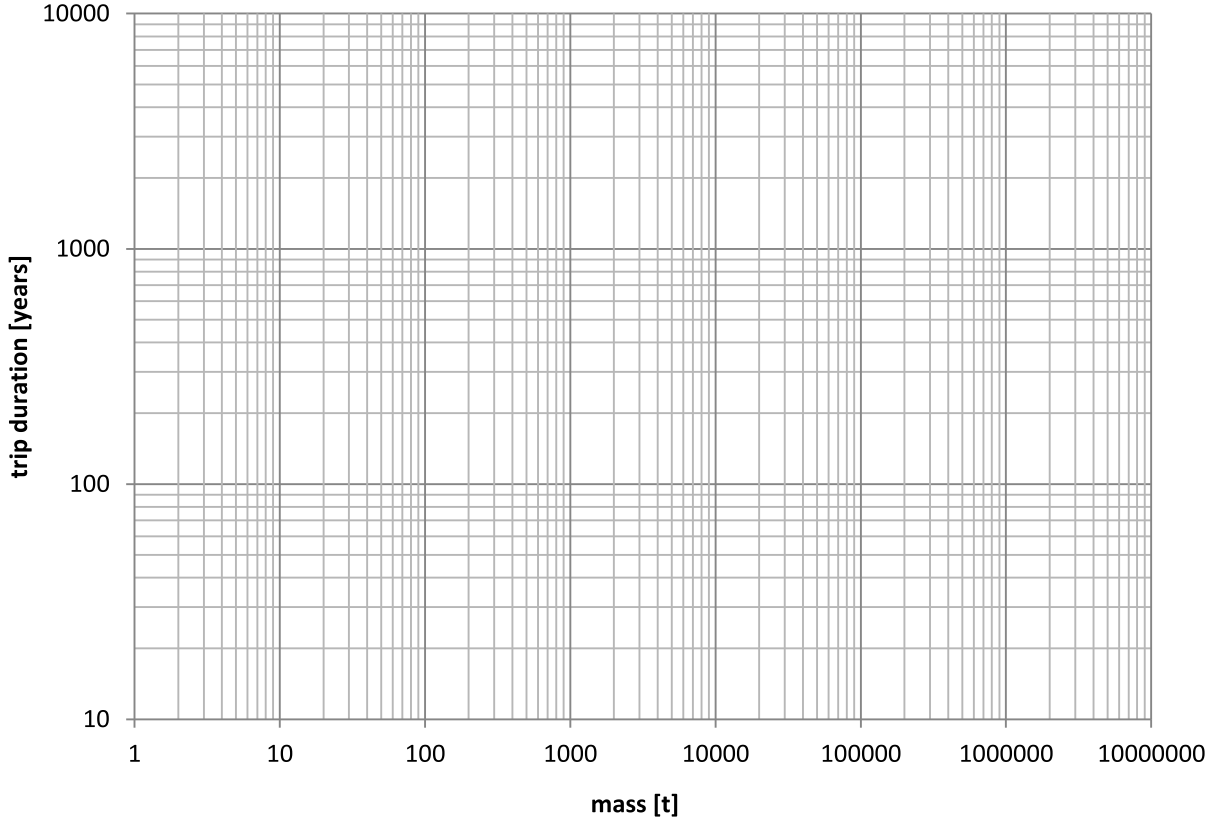
Credit: Adrian Mann



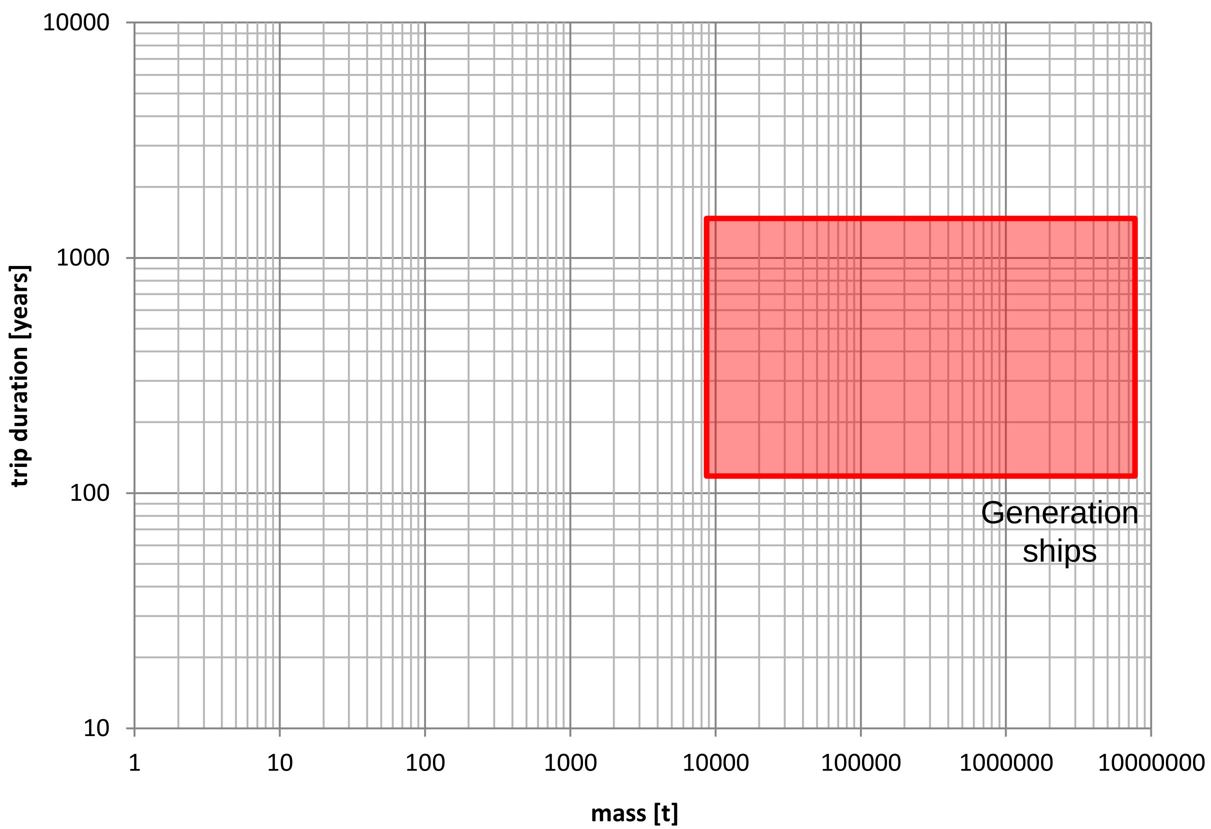
Credit: Maciej Rebisz

Time-mass problem

Time-mass map: Crewed interstellar travel concepts can be located in this map:

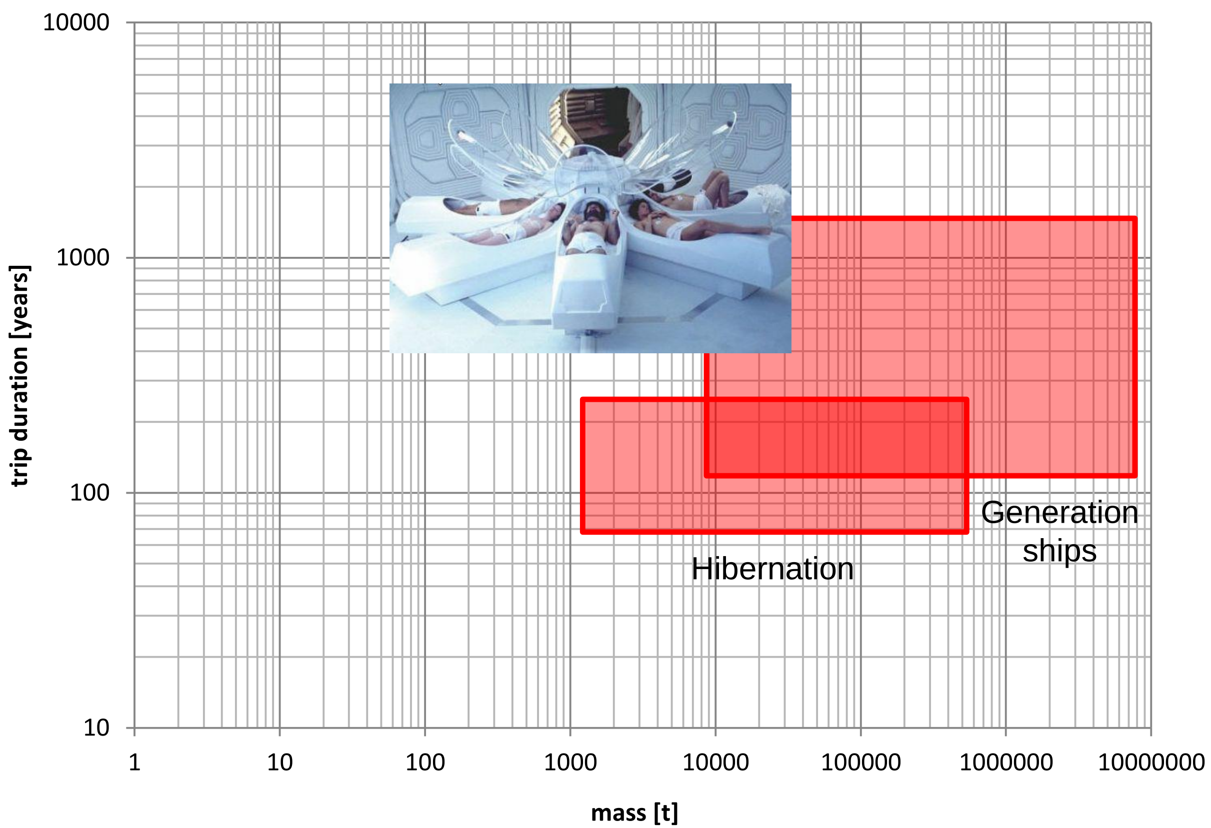


Generation ships



Challenge: Sustain human life over generations

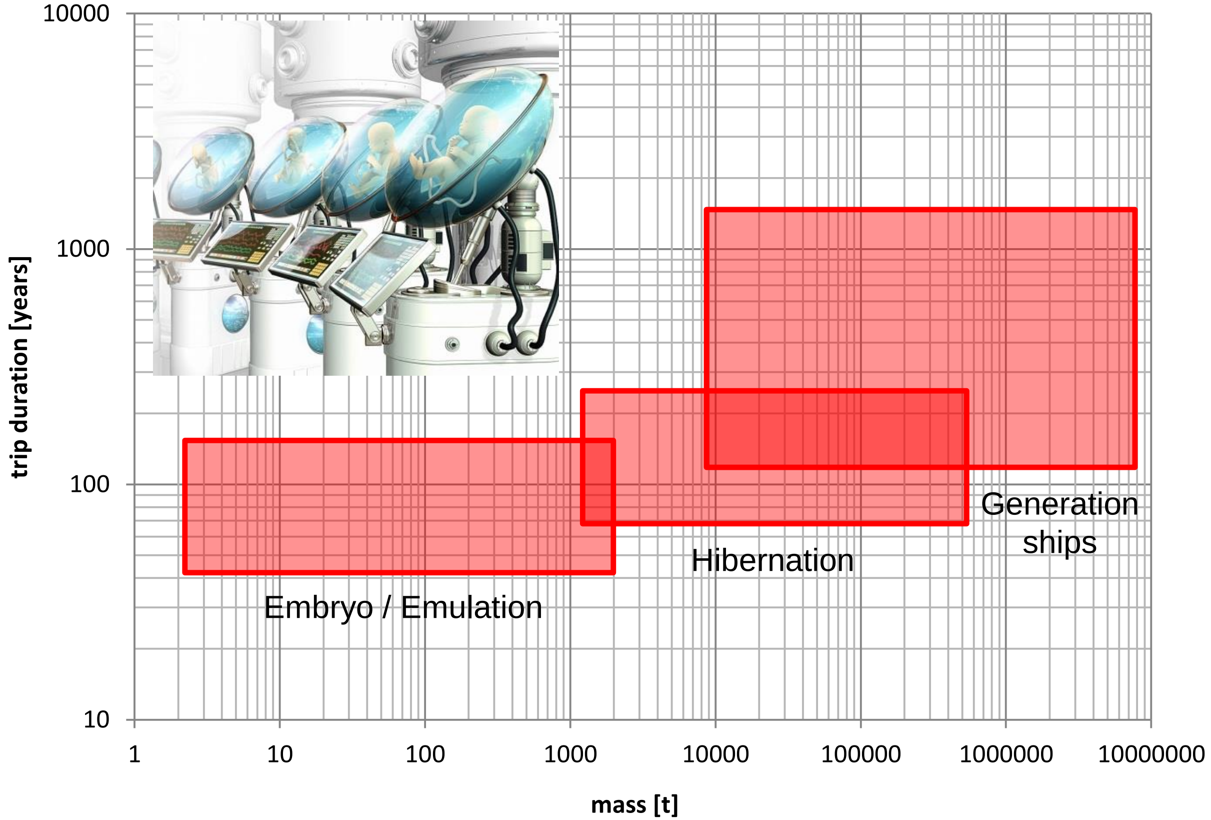
Sleeper ships



Looks good in theory but signficant biological issues

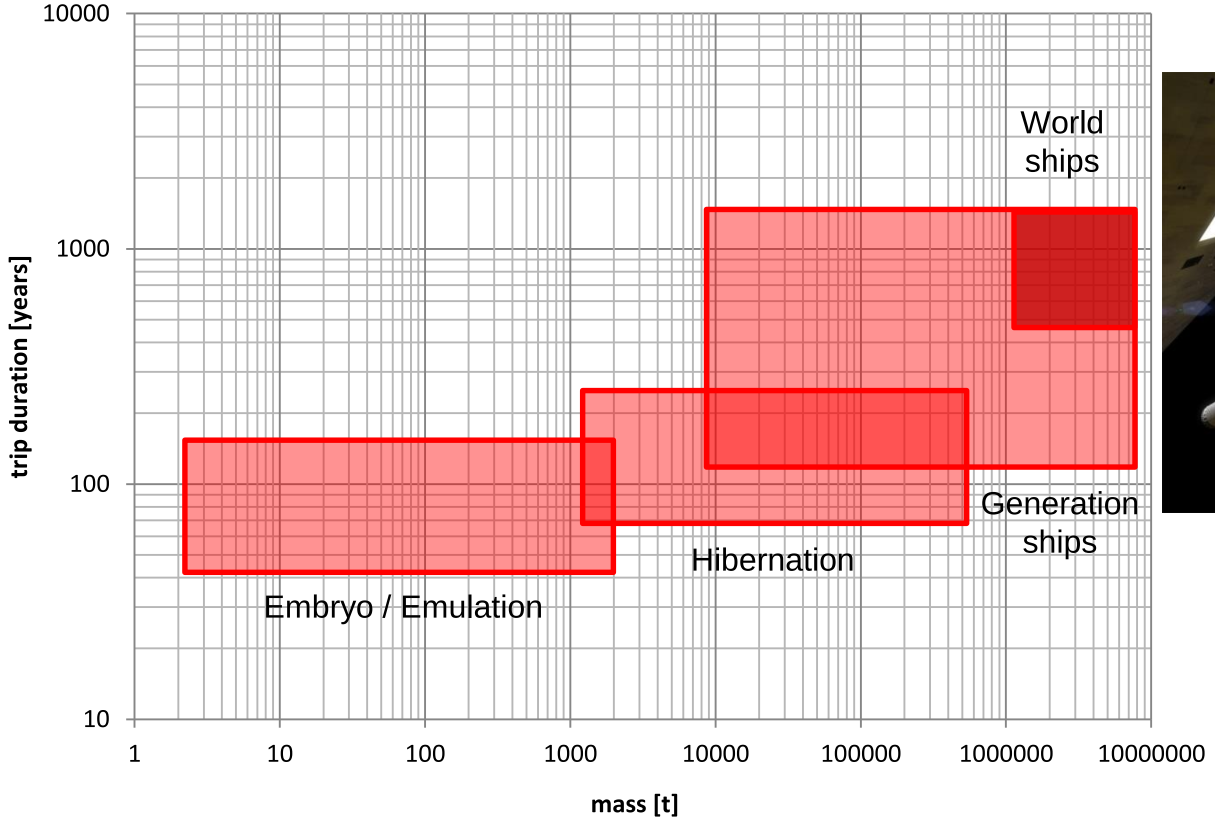
Embryo / Emulation ships

(Hein & Baxter, 2019)
(Crowl et al., 2012)



Light, fast, but significant technical feasibility issues

World ships



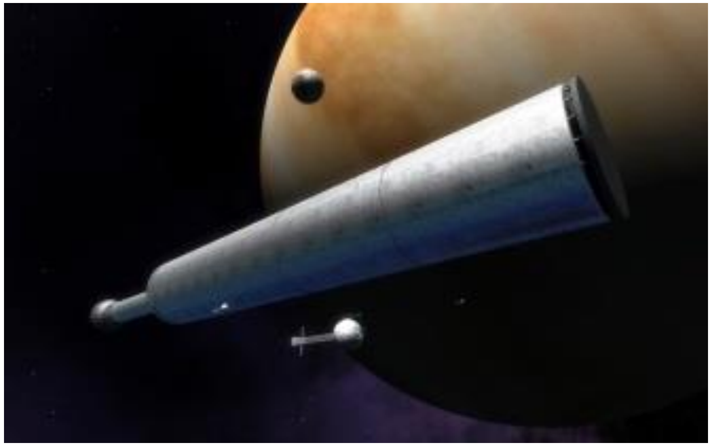
Credit: Adrian Mann

Heavy, slow, but **no principle feasibility issue**

World ship characteristics

World ship characteristics (Martin, 1984; Bond & Martin, 1984; Hein et al., 2012):

- Self-sufficiency: thousands of years
- Population size: > 100,000
- Cruise velocity: < 1%c



Credit: Adrian Mann

	Population size		
Cruise velocity [%c]	< 1000	$< 100,000$	$> 100,000$
> 10	Sprinter	Colony ship	-
< 10	Slow boat	Colony ship	World ship
< 1	-	Colony ship	World ship

(Hein et al., 2019) – Acta Futura paper

World ship designs

Existing world ship designs from the literature:

Design	Population size	Dry mass [tons]	Propellant mass [tons]	Cruise velocity [%c]
Enzman world ship [17]	20,000 - 200,000	300,000	$3 \cdot 10^6$	0.9
Torus world ship [32]	100,000	10^7	$5 \cdot 10^7$	1
Dry world ship - Mark 2A [12]	250,000	$2.0 \cdot 10^{11}$	$8.2 \cdot 10^{11}$	0.5
Dry world ship - Mark 2B [12]	250,000	$5.7 \cdot 10^{11}$	$2.3 \cdot 10^{12}$	0.5
Wet world ship [12]	250,000	$2.2 \cdot 10^{12}$	$9.0 \cdot 10^{12}$	0.5

(Hein et al., 2019) – Acta Futura paper

[12] (Bond & Martin, 1984)
[17] (Crowl et al., 2012)
[32] (Hein et al., 2012)

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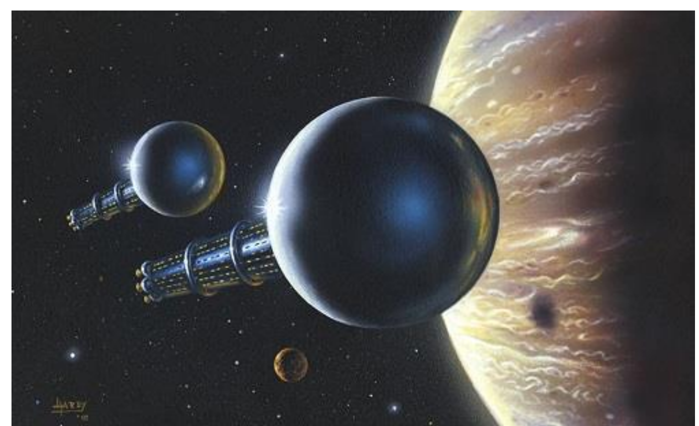
Credit: Syd Mead



Credit: Adrian Mann

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(Hein et al., 2012)

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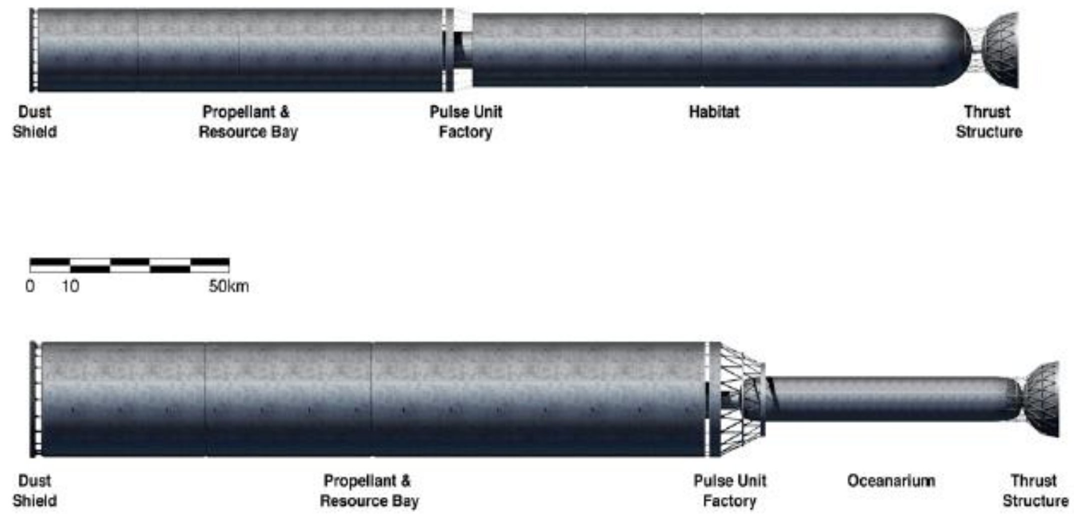
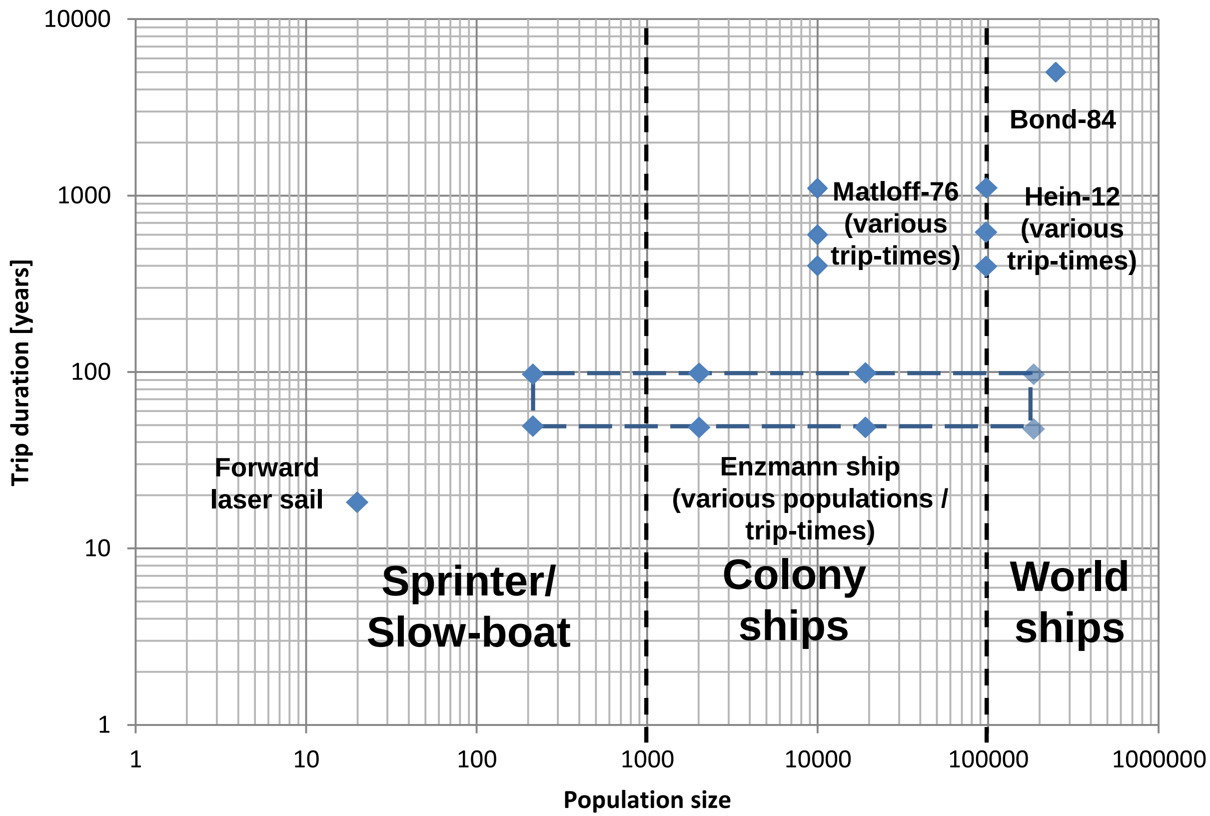


Credit: Adrian Mann

World ships and population size

Replacing spacecraft mass by population size:



(Hein et al., 2019) – Acta Futura paper

Genetics – population size

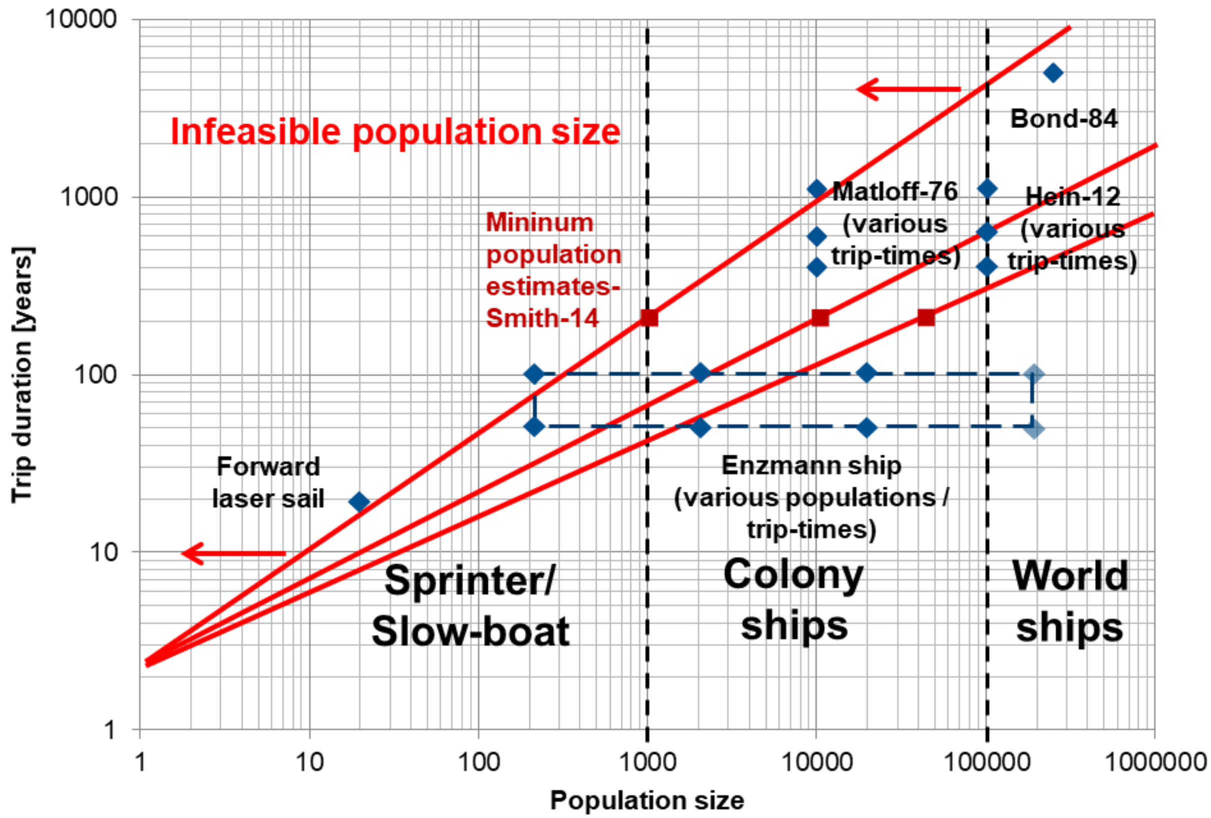
Model	Model type	Spacefaring simulations?	D1	Current regard
ETHNOPOP	Demographic	Few	<300	likely low
SMITH	Statistical	Several	>7,500, ideally larger (14,000 – 44,000)	lower & middle figures reasonable, higher figures too high
GARDNER-O'KEARNY	Statistical Agent-Based	Several	>2,000	possibly reasonable
HERITAGE (paper 1)	Monte Carlo Agent-Based	Many, ongoing	>5,000	possibly reasonable
HERITAGE (paper 2)	Monte Carlo Agent-Based	Many, ongoing	mathematical minimum 98, ideally larger	possibly reasonable
HERITAGE (paper 3)	Monte Carlo Agent-Based	Many, ongoing	circa 500	possibly reasonable
HERITAGE + SMITH	Monte Carlo Agent-Based + Anthropological	Yes, ongoing	Some multiples of 500 – 1,000 person village modules	biologically and culturally realistic and reasonable
SIMOC	Monte Carlo Agent-Based	Many (parallel computing)	Unknown	Unknown

(Hein et al., 2019) – Acta Futura paper

Population sizes on the order of 1000 – 10,000 needed

Which world ship designs are feasible?

Suitable **population size estimates** and feasibility of world ship concepts:



(Hein et al., 2019) – Acta Futura paper

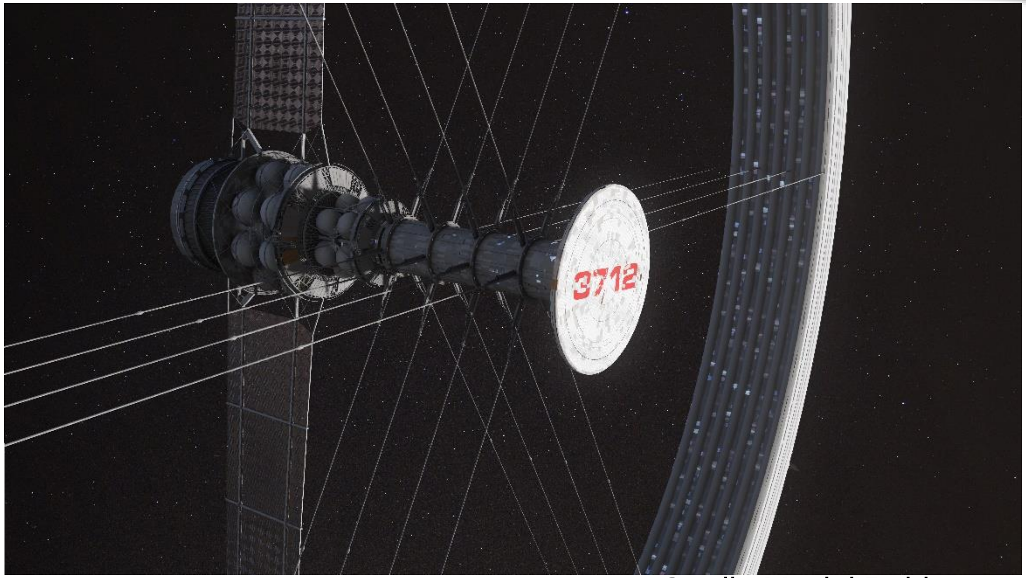
Reliability and maintenance

World ships will comprise billions of components (hardware, software, biological…) → **Reliability**

Reliability	Replacement rate [1/s]
99.99%	3
85%	0.05

(Hein et al., 2012)

Very sophisticated, AI-driven maintenance system needed!



Credit: Maciej Rebisz

Credit: Adrian Mann

Economics

Estimates when Earth economy could sustain a world ship:

Reference	Year of breakeven
Martin (1984) [46]	2500-3000
Hein (2011) [29]	2300-3000

(Hein et al., 2019) – Acta Futura paper

Estimates based on GDP extrapolations

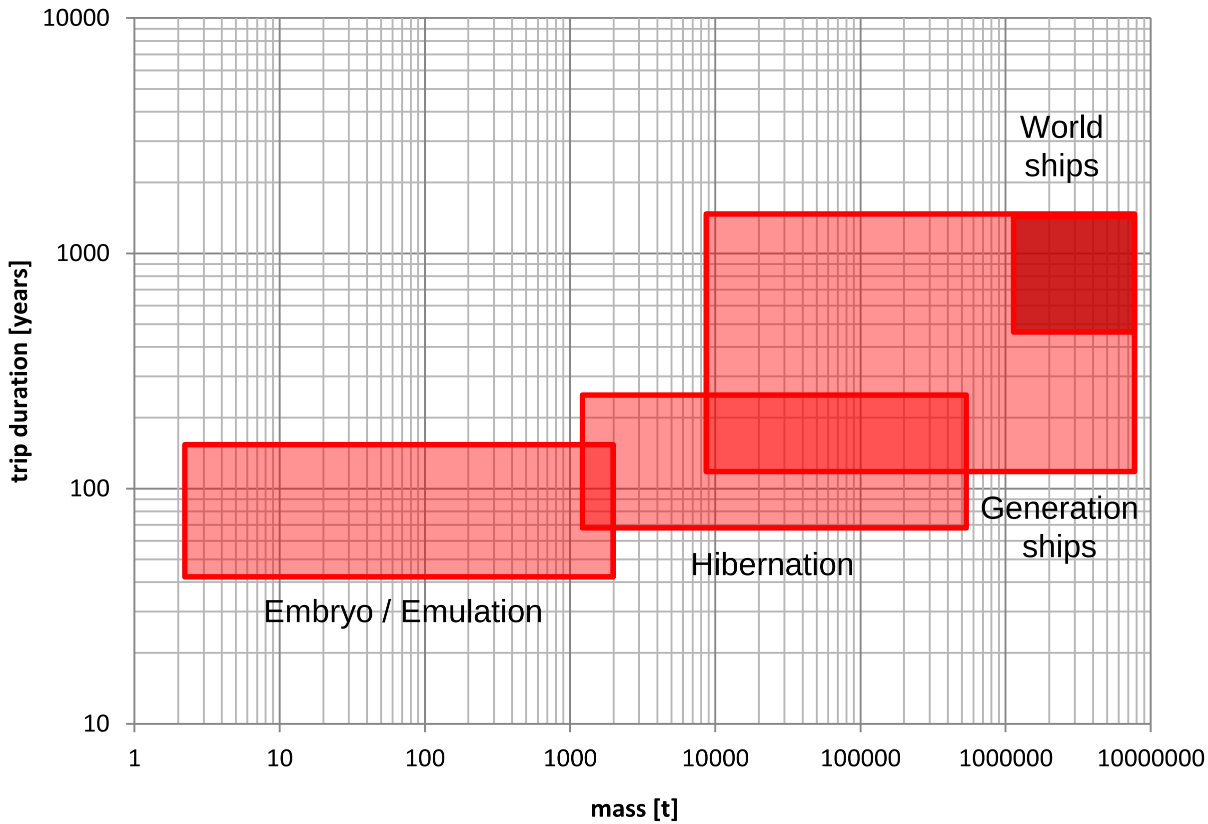
Credit: Samsung

[29] (Hein, 2011)
[46] (Martin, 1984)

Pure economic feasibility in hundreds of years – Does not tell if we want to invest

What about alternatives?

World ships: one of many concepts



Heavy, slow, but no principle feasibility issue

Overview of results

Results for some of the feasibility criteria:

Feasibility category	Criteria	Preconditions
Biological	Genetics	Population size from 10^3 - 10^4
Cultural	Knowledge transmission	Unknown
Social	Societal structure	Modular habitat (10^3 per section)
Technical	Technological performance	Velocities higher than $> 1\%c$ required
	Technological maturity	Solar system precursors required
	Technological reliability	Order of 1-0.01 parts replaced per second, AI-based maintenance system
Economic	Scope of economic activities	Solar System-wide economy
	Wealth	GNP breakeven in year 2300-3000
Alternatives	Emergence of other modes of crewed interstellar travel	Likely to exist in year 2300 and beyond

(Hein et al., 2019) – Acta Futura paper

Several key issues recently addressed; several open issues

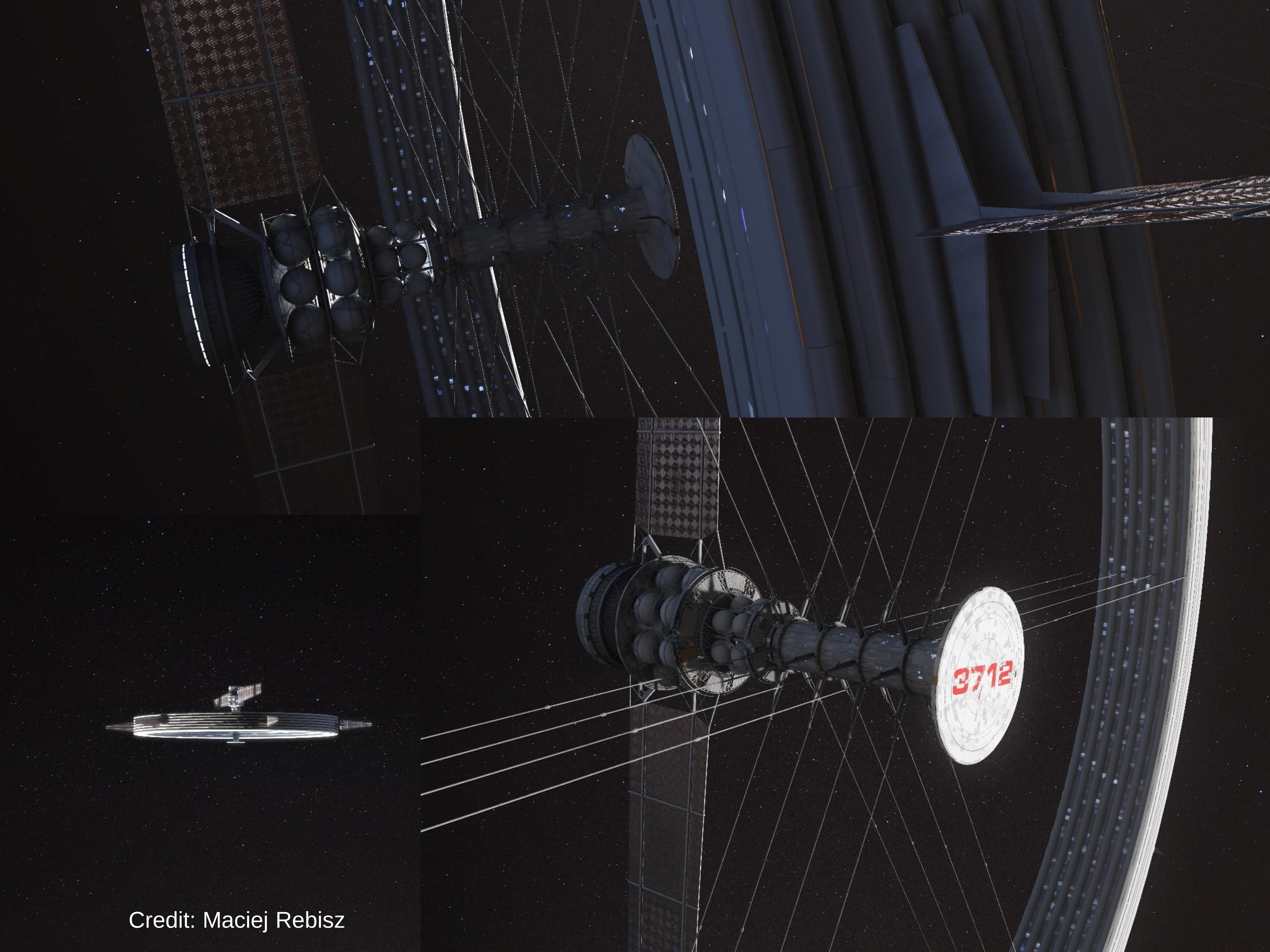
Conclusions

Conclusions:

- World ships remain an interesting concept to study
- How to sustain human life in space over extended time frames
- Key feasibility issues:
  - Maintenance
  - Obsolescence due to other transportaiton modes → world ships as mobile solar system habitats?

Future work:

- Cultural and social aspects → shed light on resource-constrained societies in general



Credit: Maciej Rebisz

References

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Introduction

Andreas Hein, PhD

- Systems engineering researcher
- Aerospace engineer

Currently:

- Assistant professor in systems engineering at CentraleSupélec, Univers Paris-Saclay
- Executive Director Initiative for Interstellar Studies (i4is)

Previously: Dr.-Ing. Technical University of Munich, visiting researcher MIT, Diploma Technical University of Munich; Stanford Ignite Program fellowship, ISAE

Professional experience: ESA-ESTEC Architecture & Strategy Office, Paris-Saclay Efficacité Énergétique (PS2E), Knowledge Inside systems engineering consultant

Publications: 60 papers in peer-reviewed journals and conference proceedings

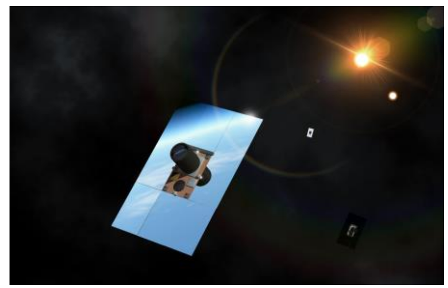
Awards (selection): Exemplary PhD Thesis Award, Systems Engineering Honor Society, Willy Messerschmitt Award (Faculty of Mechanical Engineering, TUM)

Initiative for Interstellar Studies (i4is)

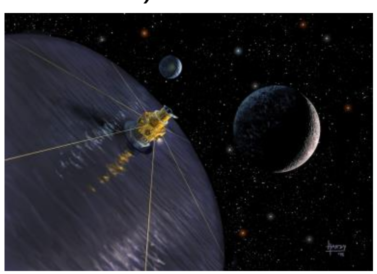
UK **not-for-profit company** founded in 2014
Objectives: Conduct R&D, education, and public outreach on interstellar travel

Achievements

Project Lyra: mission to interstellar asteroid / comet (2017/2018)



Andromeda Probe: Concept study for Breakthrough Starshot (2016)



Project Dragonfly: International interstellar laser sail mission design competition (2015)

INTERNATIONAL® SPACE UNIVERSITY ISU

Collaboration with ISU: 2-week interstellar & ChipSat module, student projects (since 2015)

Collaborations

INTERNATIONAL® SPACE UNIVERSITY ISU

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

Drexel UNIVERSITY

CentraleSupélec

Initiative for Interstellar Studies (i4is)

Some recent press coverage:

MIT Technology Review

Business Impact

Femto-Spacecraft Could Travel to Alpha Centauri

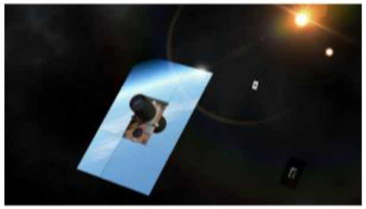
Earth's nearest exoplanet twin orbits a star about four light years from here. Now scientists say it's possible to visit this system in our lifetimes by propelling a tiny spacecraft on the tip of a laser beam.

by Emerging Technology from the arXiv August 31, 2017

Last year, a small team of astronomers announced the discovery of an Earth-like planet orbiting the red dwarf star Proxima Centauri, one of our nearest neighbors in the Alpha Centauri system. This exoplanet, called Proxima Centauri b, sits in the habitable zone around its host. Any water there should exist in liquid form, making this planet an important candidate in the search for extraterrestrial life.

Consequently, Proxima Centauri b has generated intense interest. It is about 40 trillion kilometers from Earth, a distance light travels in just over four years. A spacecraft traveling at about a tenth of light speed could make the trip in about 50 years.

And that raises an interesting question. Is it possible to build a spacecraft that we could send to Proxima Centauri within the lifetimes of people living today?



IEEE SPECTRUM

29 Nov 2017 | 16:00 GMT

How We Could Explore That Interstellar Asteroid

Sending a spacecraft to 'Oumuamua would be a challenge, but we might be able to do it if we move fast

By Evan Ackerman

Illustration: M. Kornmesser/European Southern Observatory

2007

SCIENTIFIC AMERICAN

SpaceX's Planned Giant Rocket Could Chase Down Interstellar Asteroid

A new study charts potential courses for missions to 'Oumuamua, an oddly-shaped space rock from another star

By Mike Wall, SPACE.com on November 29, 2017