2023-02-03

Tiverton and Devon Astronomical Society - Lecture on On Orbit Manufacturing and Quantized Inertia

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Introduction To On Orbit Manufacture (OOM)

Introduction:
On Orbit Manufacture (OOM)

What is On Orbit Manufacture?

What Could Humanity Achieve By Having OOM Capability?

Top Level OOM Process

Example Mission & Product Walkthrough

Summary / Recap

What Is On Orbit Manufacture?

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“Spacecraft building Spacecraft…In Space”

The aim of On Orbit Manufacture (OOM) is to manufacture space-qualified structural components; the current focus of work is on the capability to manufacture a strut.

Structural components (such as a strut) that are produced in space could then form part of a larger assembly (like a truss) and be attached to customer satellites which would also be in orbit.

OOM has many similarities to On Orbit Servicing (OOS), which considers functions such as repair, salvage, upgrade, refuelling and resupply.

What Is On Orbit Manufacture?

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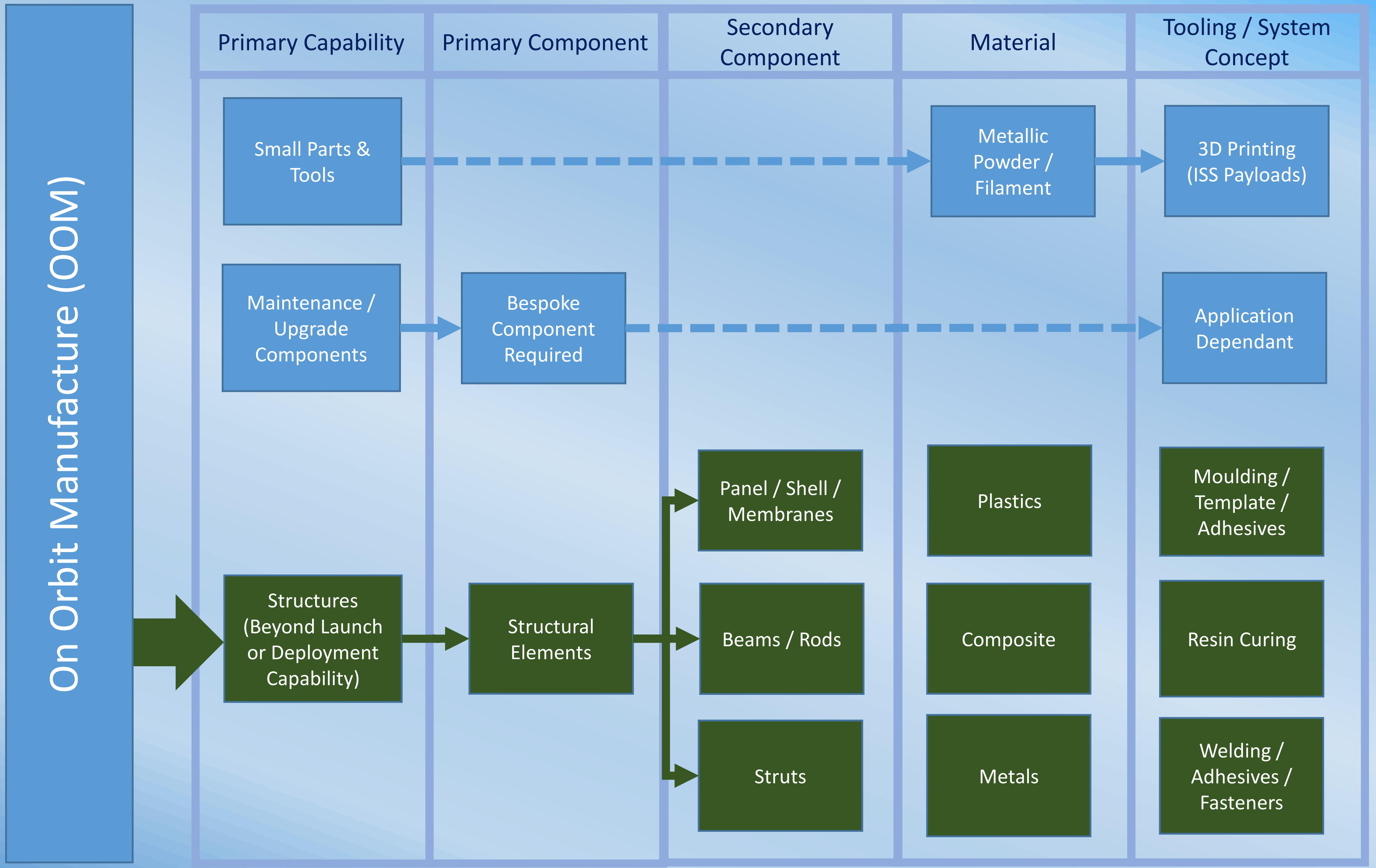


What Could Humanity Achieve By Having OOM Capability?

Infrastructure for Colonisation / Resource Acquisition

Support Capability (telescopes / antenna reflectors)

Interstellar Exploration

Infrastructure for Colonisation and/or Resource Acquisition

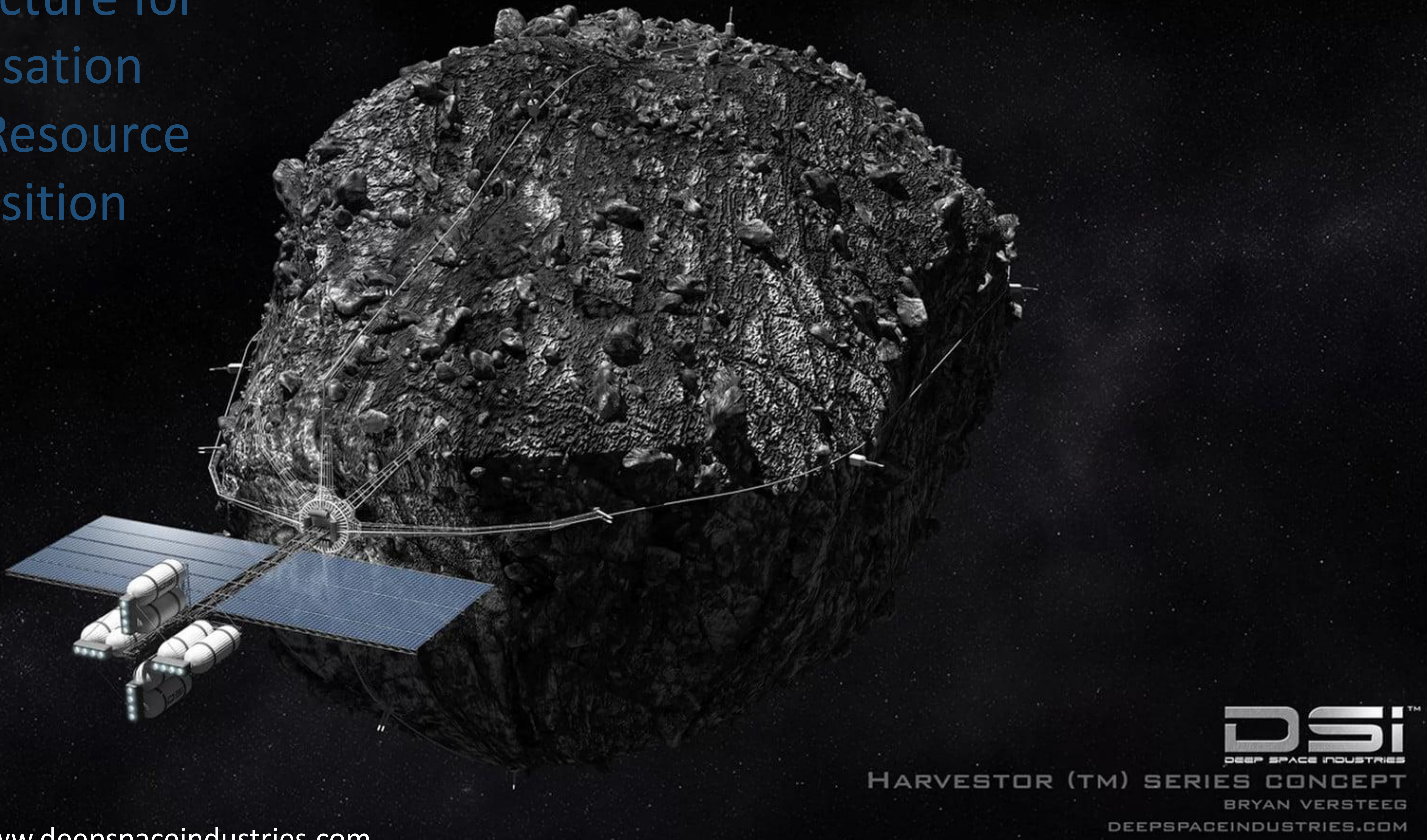


Image Source: www.deepspaceindustries.com

Recycling

Plastic recycling is an opportunity to repurpose some of the waste on Earth to create useful structures in space.

Different structural components can be created using plastics but would need to withstand the space environment (where the product will be used).

Image Source: Inhabitat

Image Source: Plastic Expert

Spacecraft Debris & Salvage

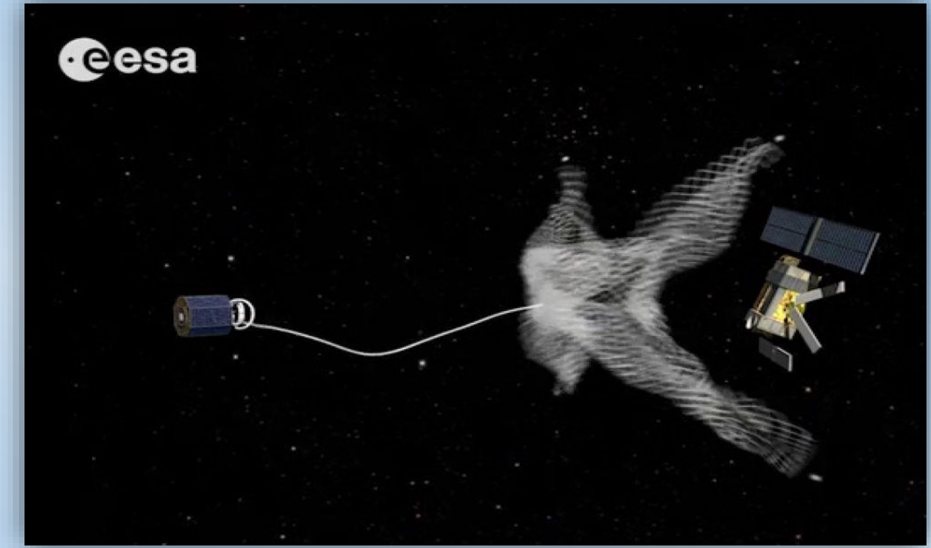
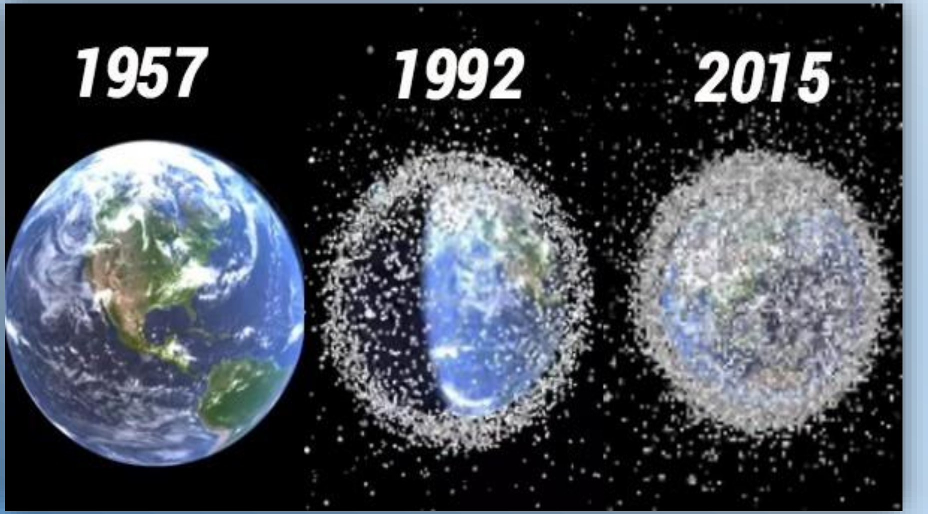


Image Source: European Space Agency

Image Source: Pinterest



Spacecraft salvage has the potential to help with the growing space debris problem in Low Earth Orbit.

Collecting this “space junk” has had attention in recent years with concepts that include space harpoons and nets to retrieve objects and derelict spacecraft.

If space debris could be retrieved and then have useful components salvaged, this would be a good source of material for an OOM Facility.

Image Source: European Space Agency

Image Source: Phys.org

Space Mining

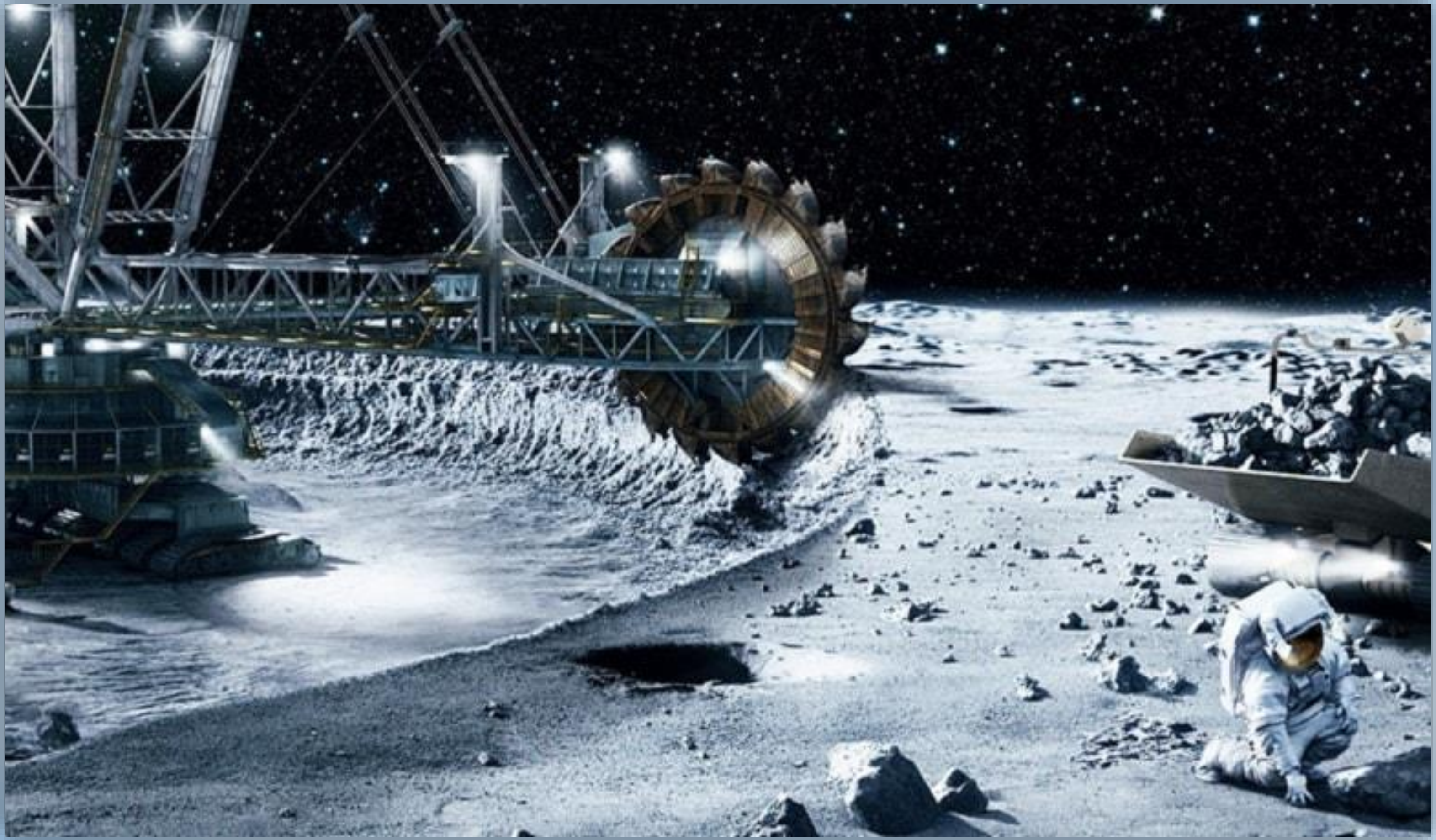


Image Source: The Space Journal

Space mining has the potential to provide resources for OOM, but would require further processing facilities to make use of it such as a Moon base – Artemis mission.

Recent missions such as Osiris-Rex to Bennu have looked at exploring asteroids and there are concepts that are considering asteroid mining in order to acquire raw materials.

Lunar Aluminium from Regolith

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XRF Analysis done by Washington State University's Peter Hooper Geoanalytical Laboratory

Mineral component ratios can be changed and additives used to approximate specific Apollo samples.

General Mare Simulant

90% Basaltic Cinder, 10% Anorthosite

Chemical Components (% Mass)			
	Lunar Soil 14163*	OPRL2N	% Difference
SiO_2	47.30	47.35	0.05
TiO_2	16.00	1.47	-14.53**
Al_2O_3	17.80	17.40	-0.40
Fe_2O_3	0.00	0.00	-0.00
FeO*	10.50	9.67	-0.83
MnO	0.10	0.16	0.06
Cr_2O_3	0.20	0.00	-0.20
MgO	9.60	8.10	-1.50
CaO	11.40	11.08	-0.32
Na_2O	0.70	2.83	2.13
K_2O	0.60	0.69	0.09
P_2O_5	0.00	0.58	0.58
Sum	99.80	99.32	
LOI %	0.00	0.07	

*Papike J.J., Simon S.B., and Laul J.C., (1982) The Lunar Regolith: chemistry, minerology and petrology, Rev. Geophys. Space Phys., 20 pp. 761-826

**We can increase the titanium component with an ilmenite additive if desired

General Nearside Highland Simulant

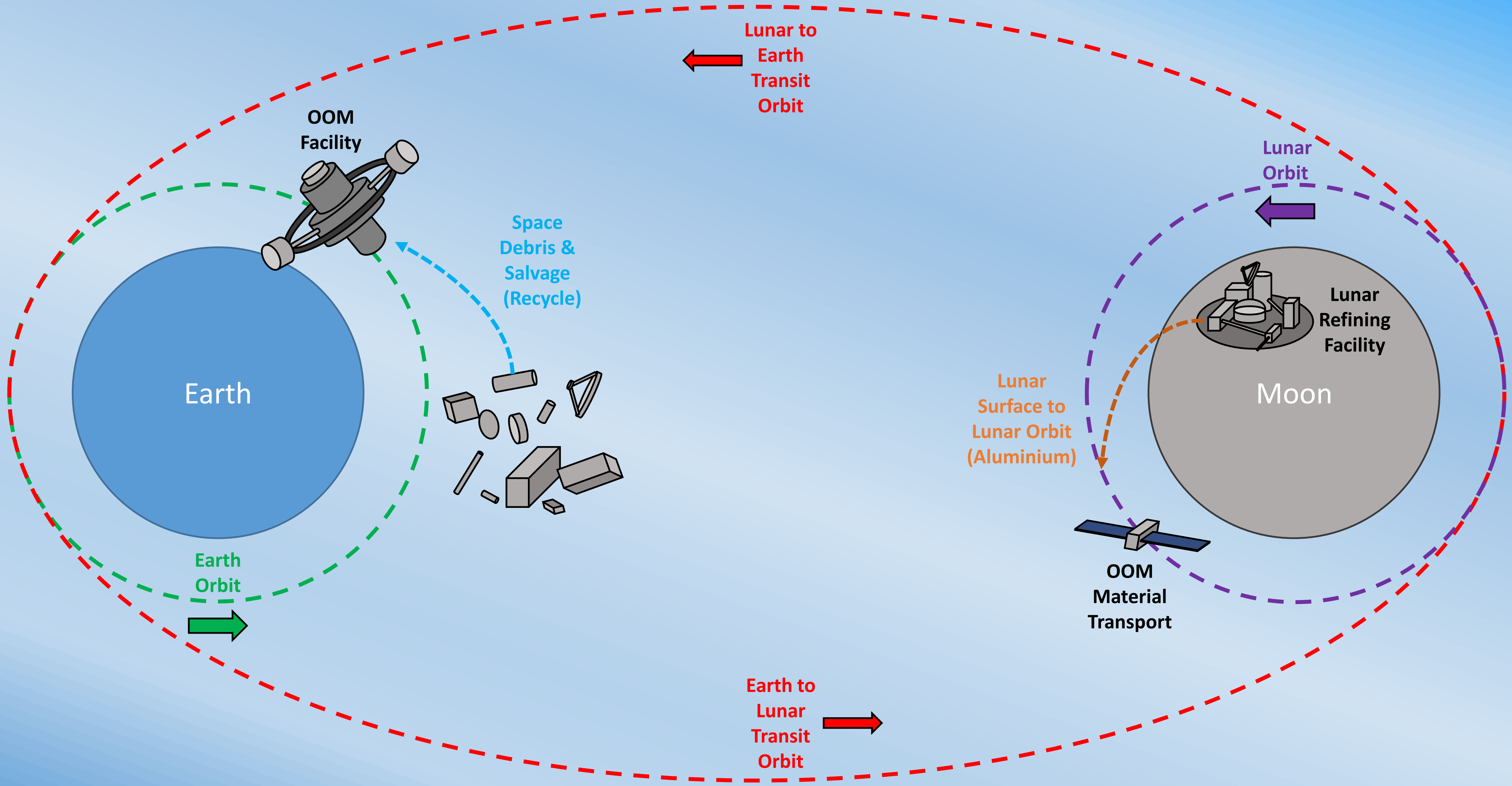
70% Anorthosite, 30% Basaltic Cinder

Chemical Components (% Mass)			
	Apollo 16*** Highland Samples	OPRH2N	% Difference
SiO_2	45.10	47.89	2.79
TiO_2	0.60	0.52	-0.08
Al_2O_3	26.80	27.06	0.26
FeO*	5.40	3.68	-1.72
MnO	0.22	0.06	-0.16
MgO	5.70	2.84	-2.86
CaO	15.60	14.19	-1.41
Na_2O	0.43	2.43	2.00
K_2O	0.14	0.25	0.11
P_2O_5	0.10	0.20	0.10
Sum	100.09	99.12	
LOI %		0.88	

***Information from Table 7.15, Lunar Sourcebook. 16c Average composition of selected Stone Mountain and South Ray soils (64420, 64500, 64800, 65500, 65700, 66040, 66080) from the Apollo 16 site.

Source: Off Planet Research LLC 2021

Moon/Earth: Material Acquisition



OOM Example Product: Antenna Reflector Frame

Imagine a core module of electronics and other systems for an antenna system. The outer case of the module also functions as a structural hardpoint and is the base of manufacture for the antenna reflector to form around.

A base module could be relatively small (especially compared to an OOM antenna reflector) and could be stored within the OOM facility (perhaps as part of a supply mission or a customers payload that has been collected.)

Support Capability

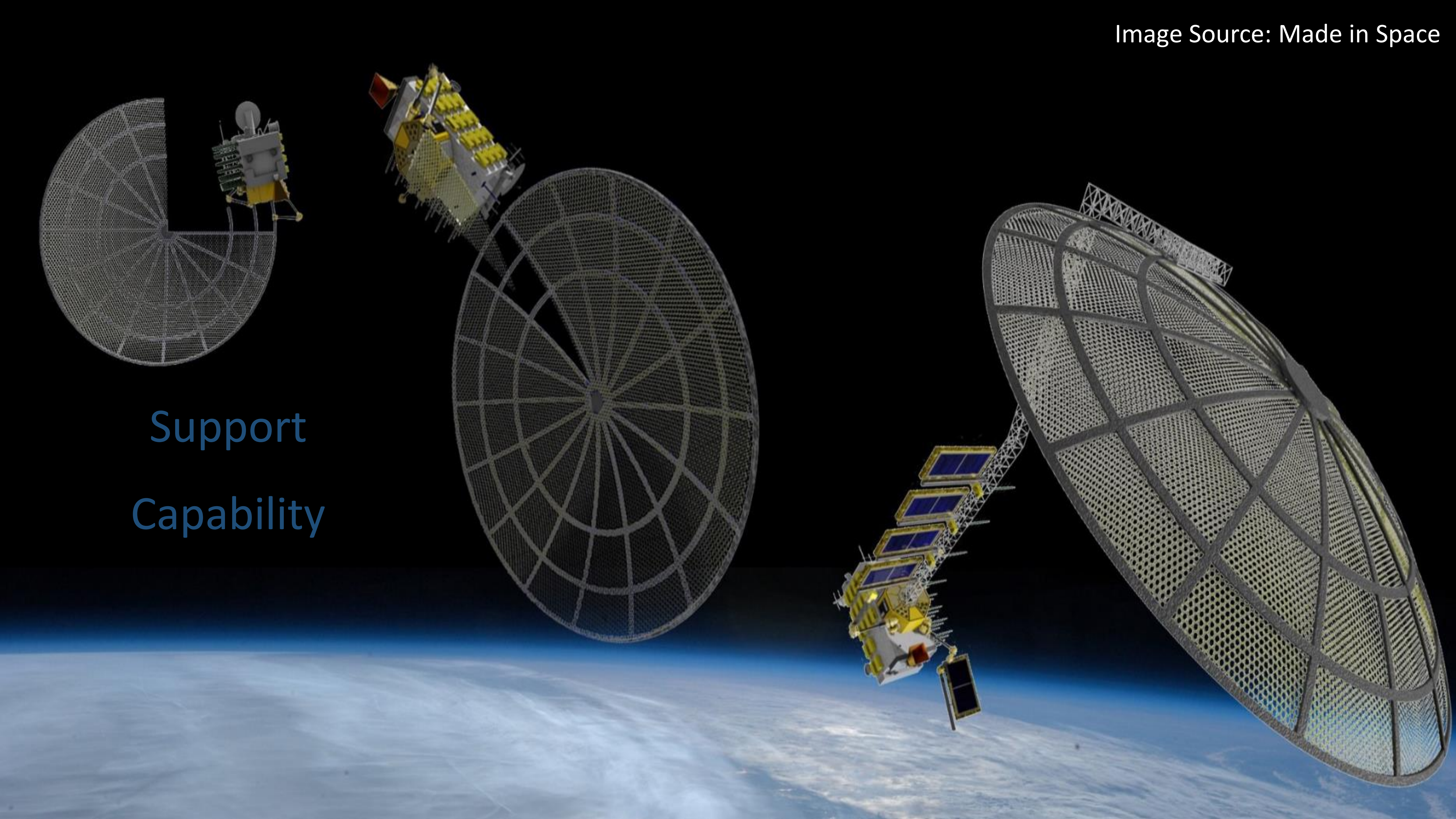


Image Source: Made in Space

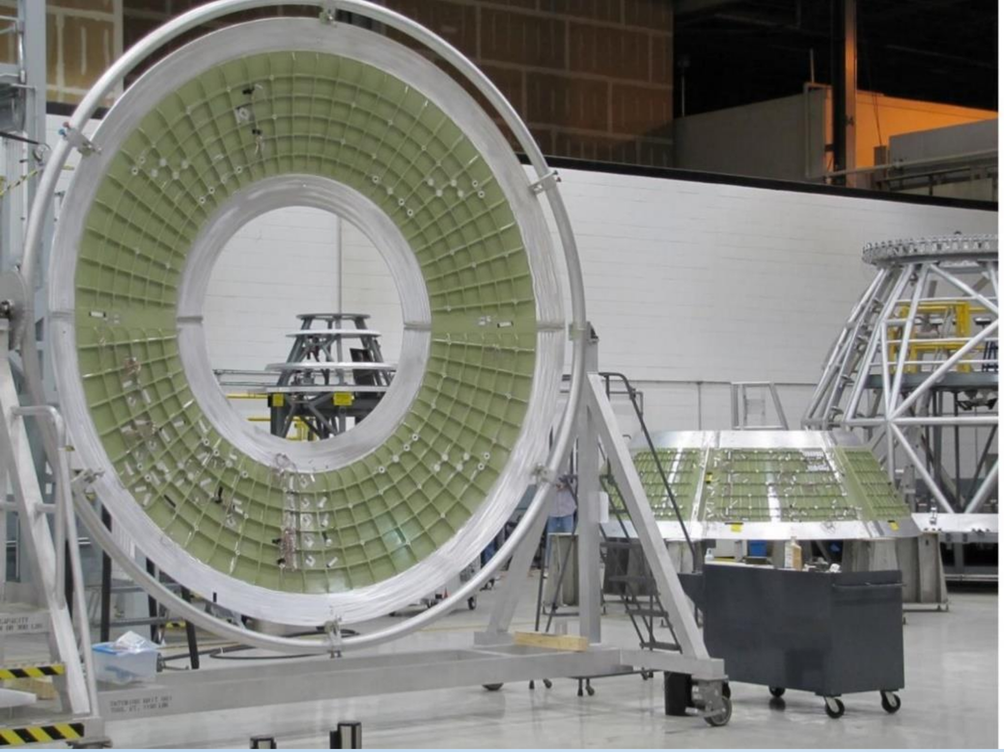
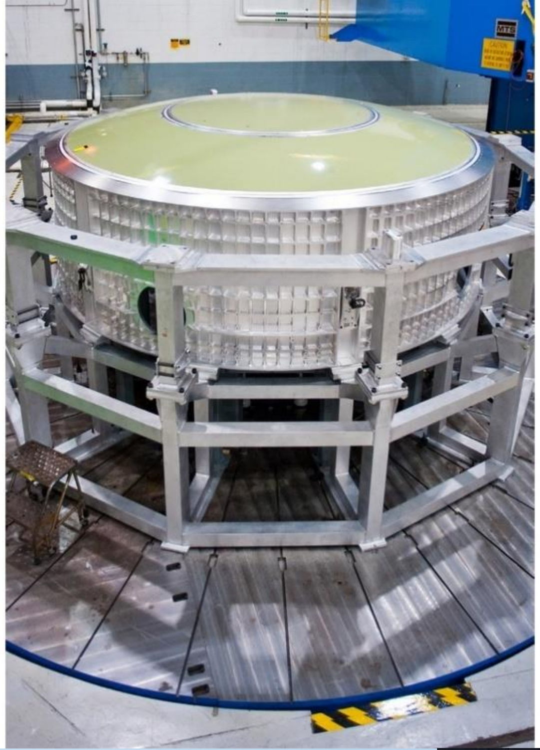




Image Source: Orion @ NASA

Greater Payload Capability

(Telescopes / Antenna Reflectors)

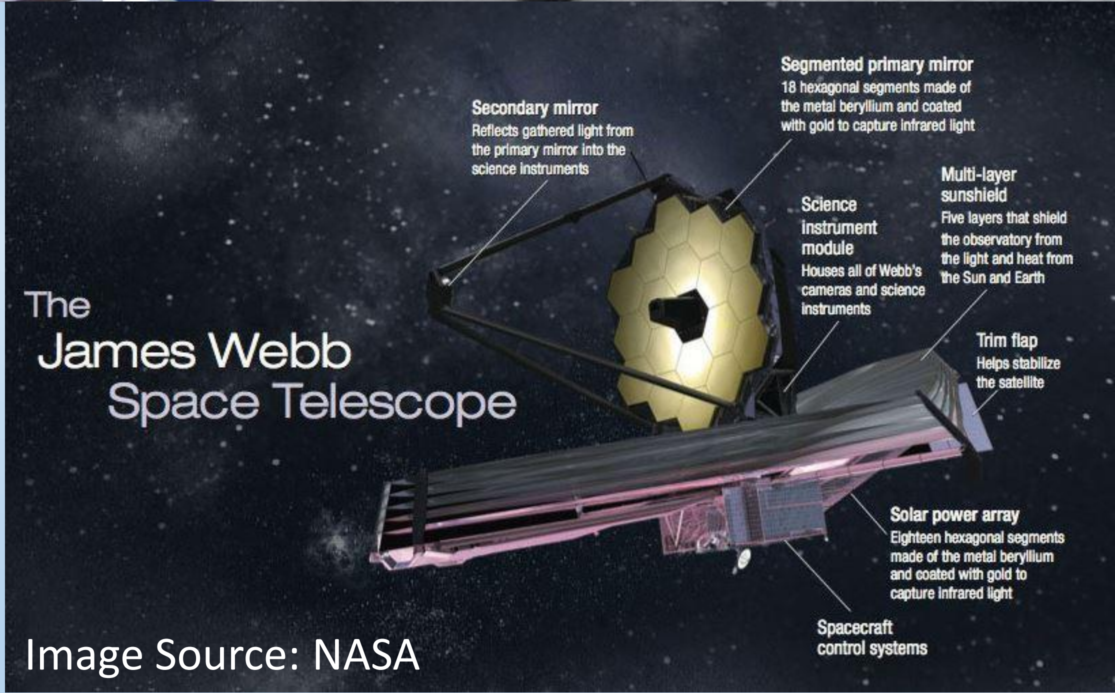
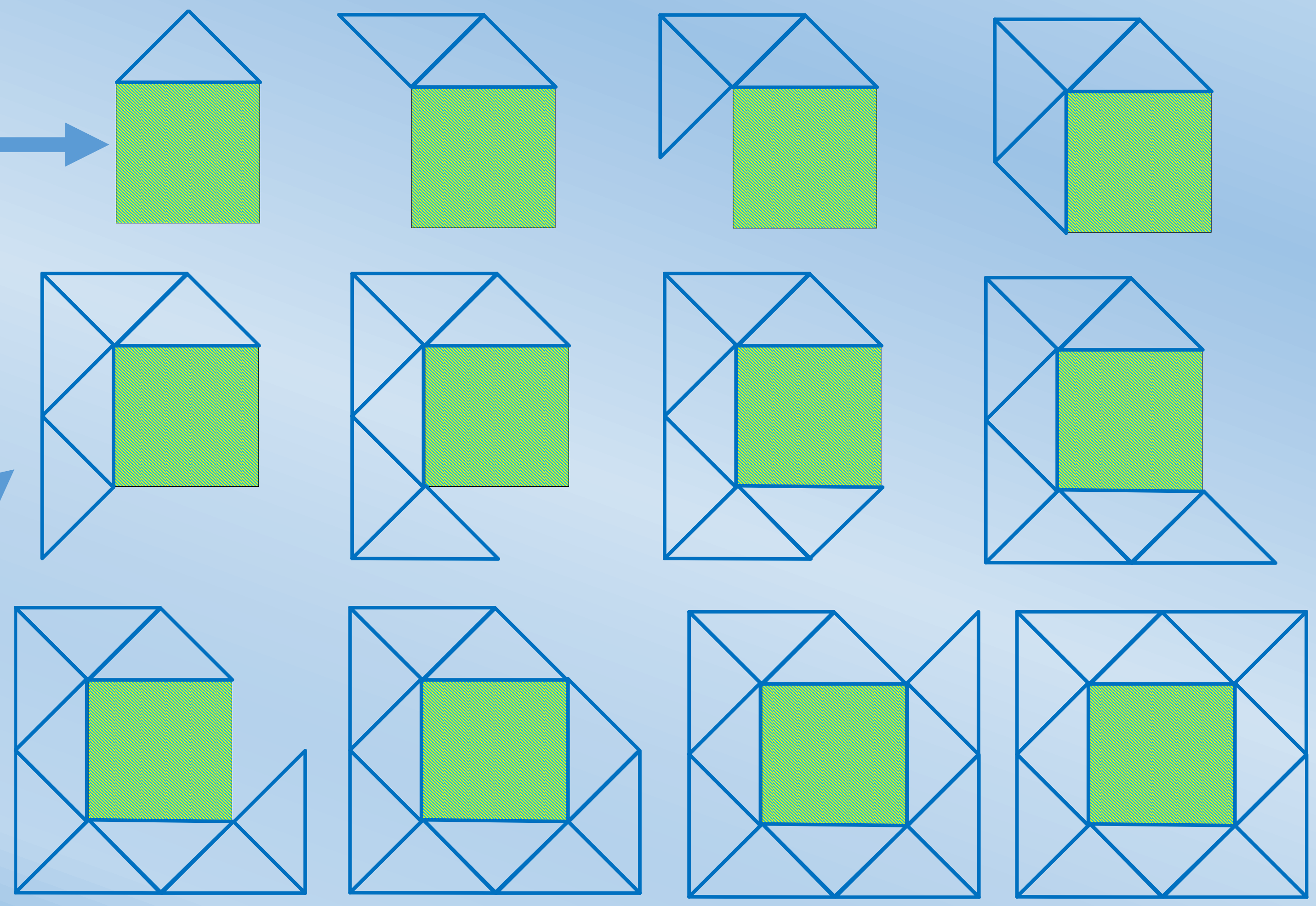


Image Source: NASA

OOM Example Product: Antenna Reflector Frame

Antenna Interface Module (I.e. electronics, etc)



Framework assembled gradually as each strut is manufactured

This process could theoretically be continued until the desired shape and size has been reached (within structural limitations)

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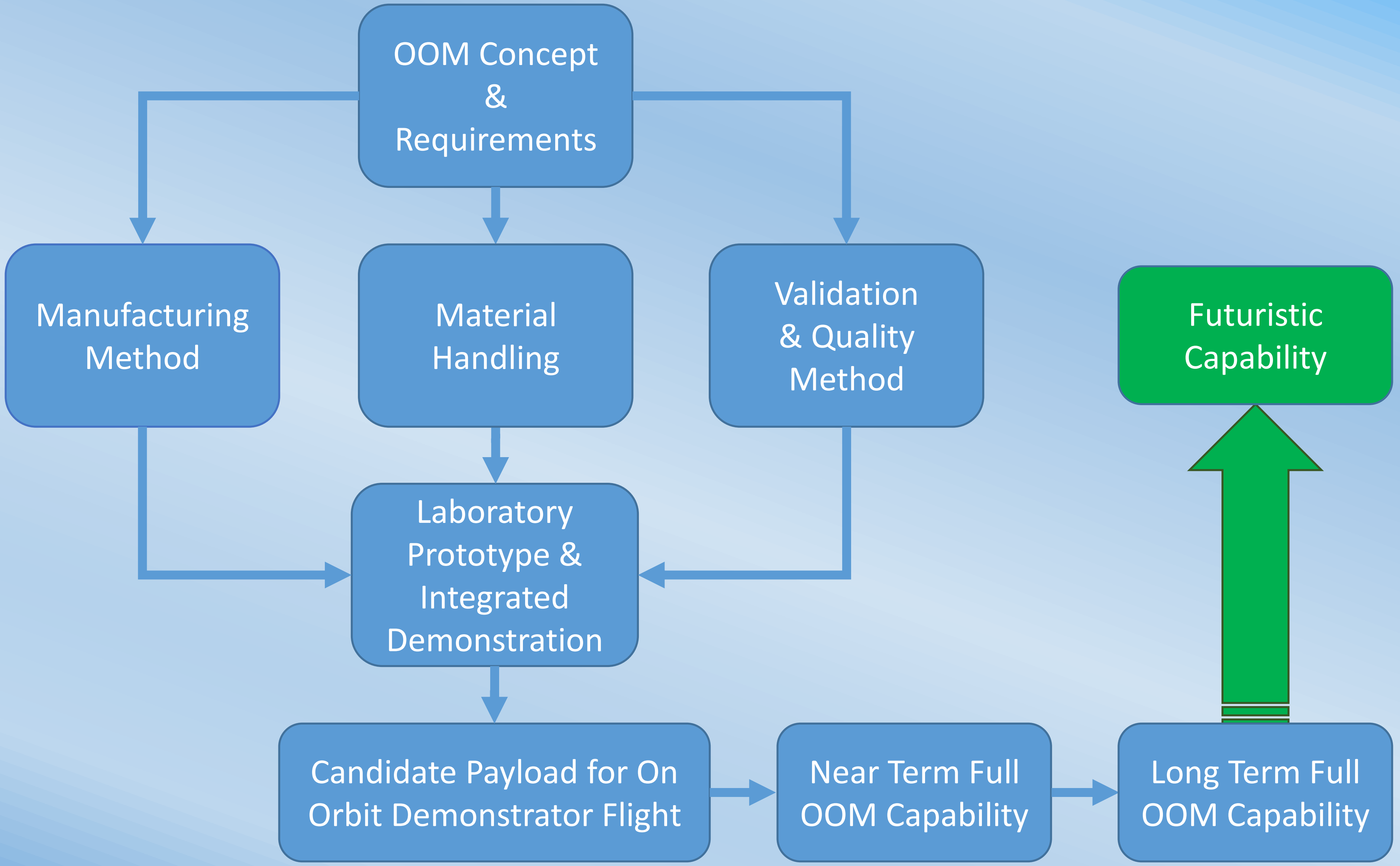
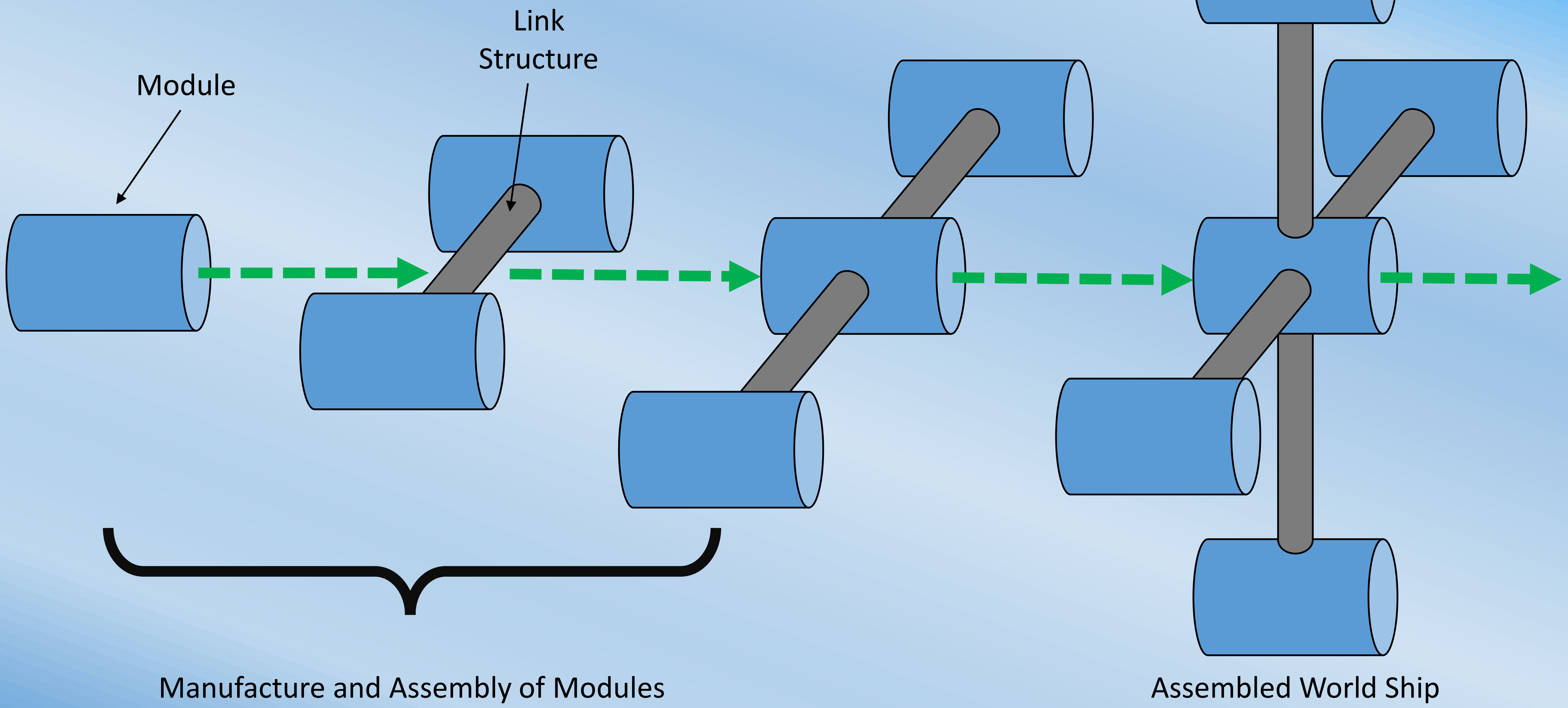
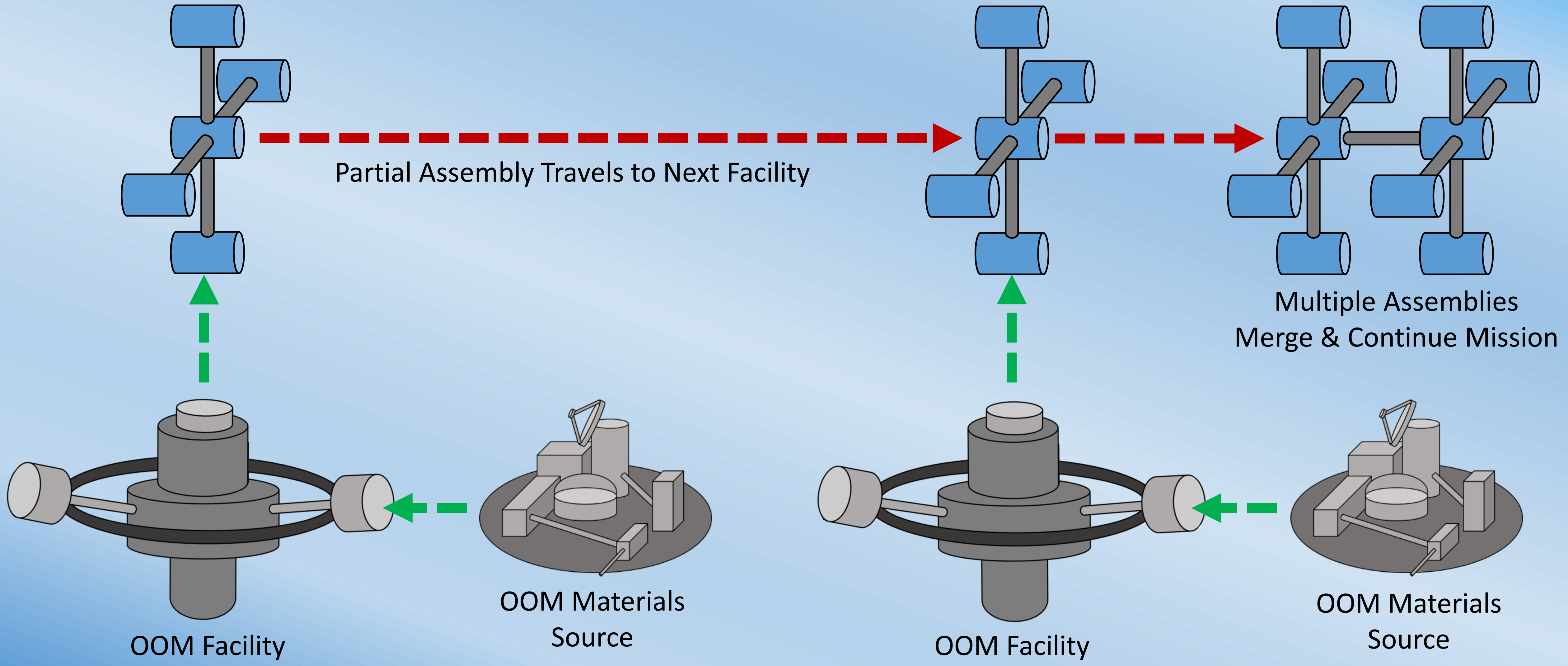
Top Level Technology Roadmap



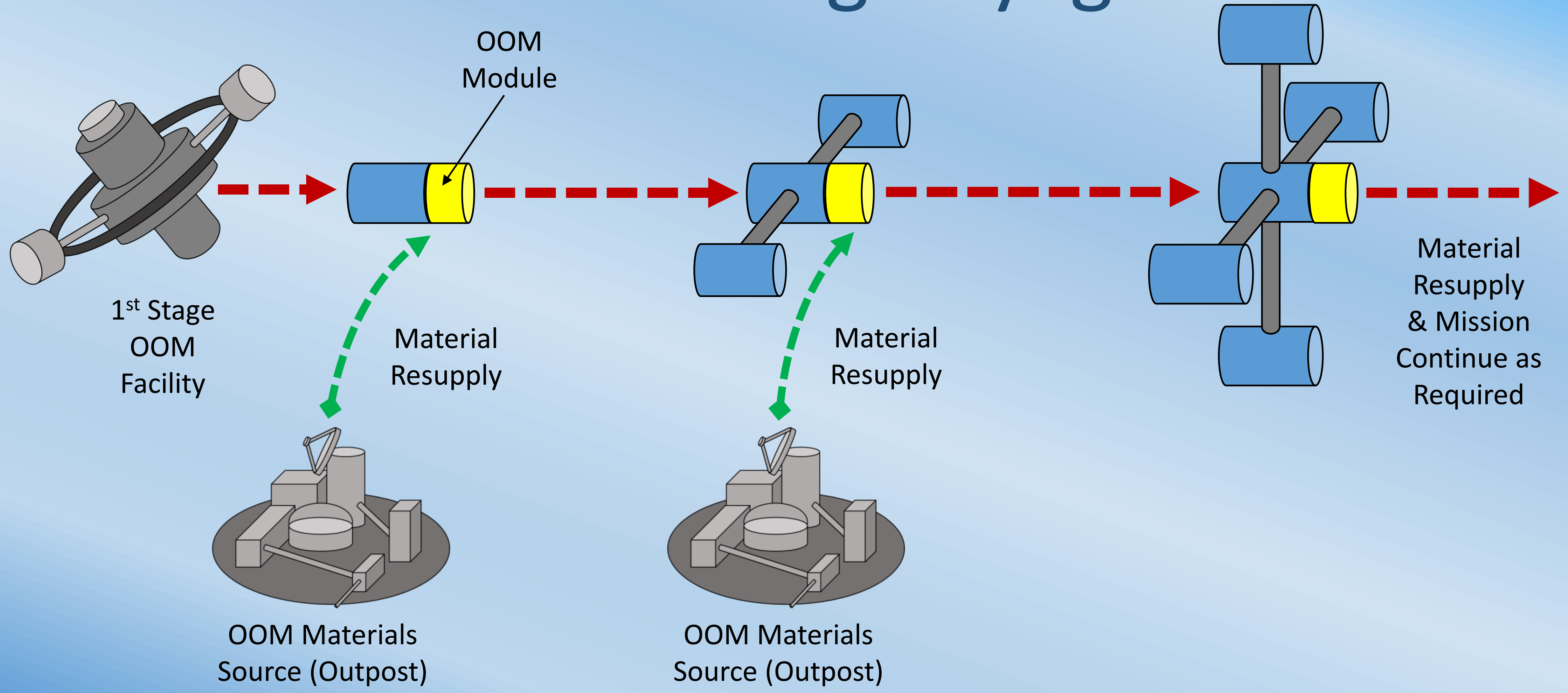
OOM of World Ships



Mission Concept: OOM Stage Builds and Rendezvous



Mission Concept: OOM During Voyage



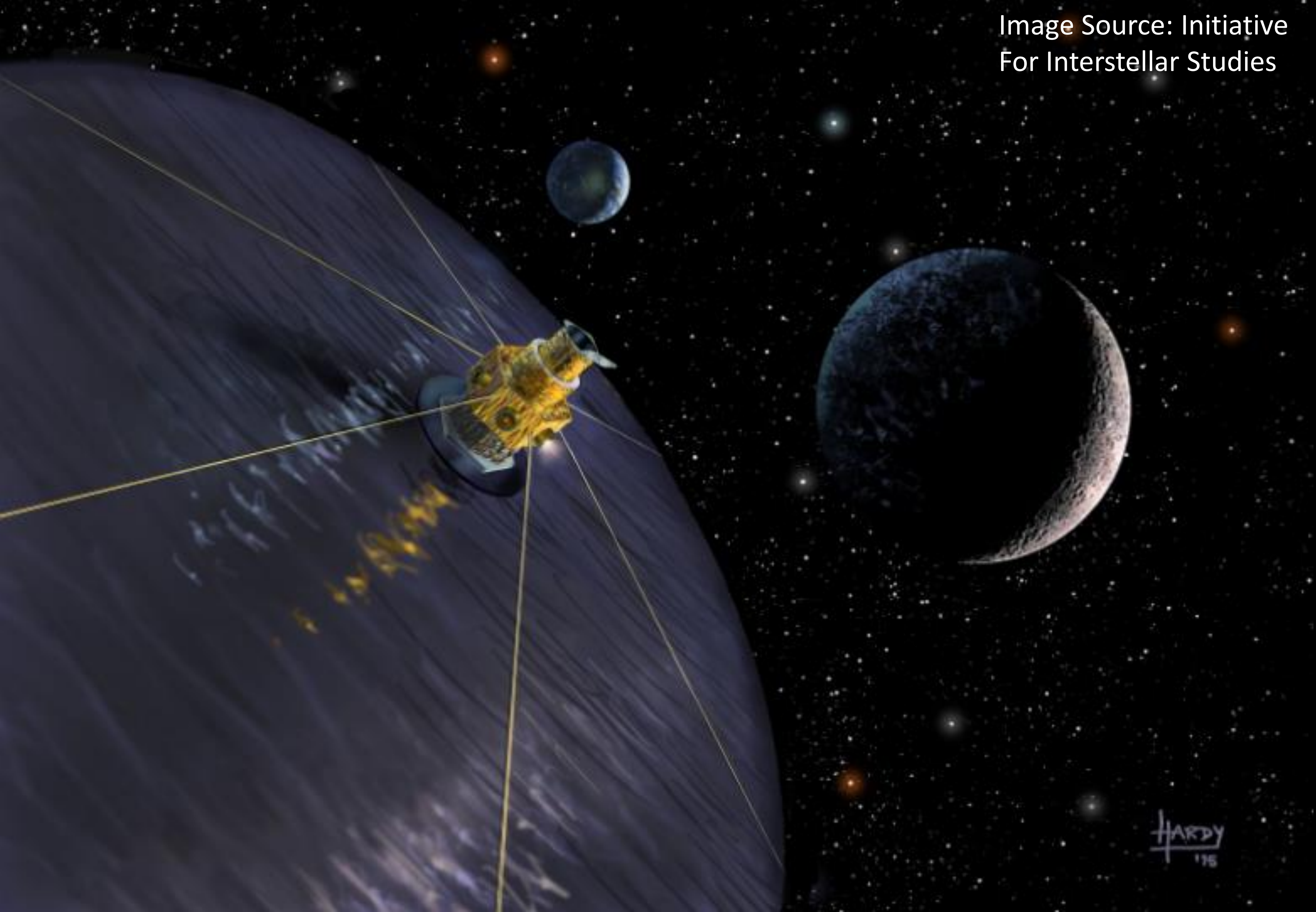
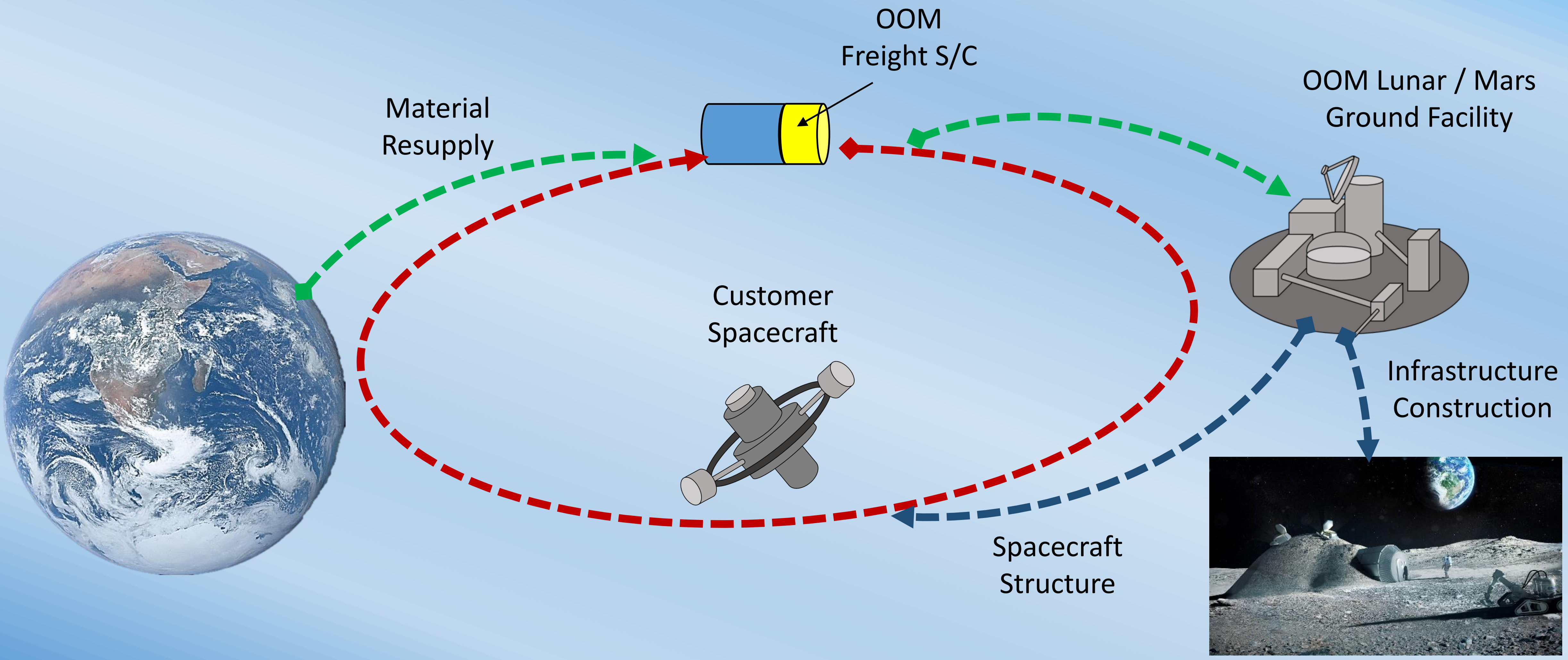


Image Source: Initiative For Interstellar Studies

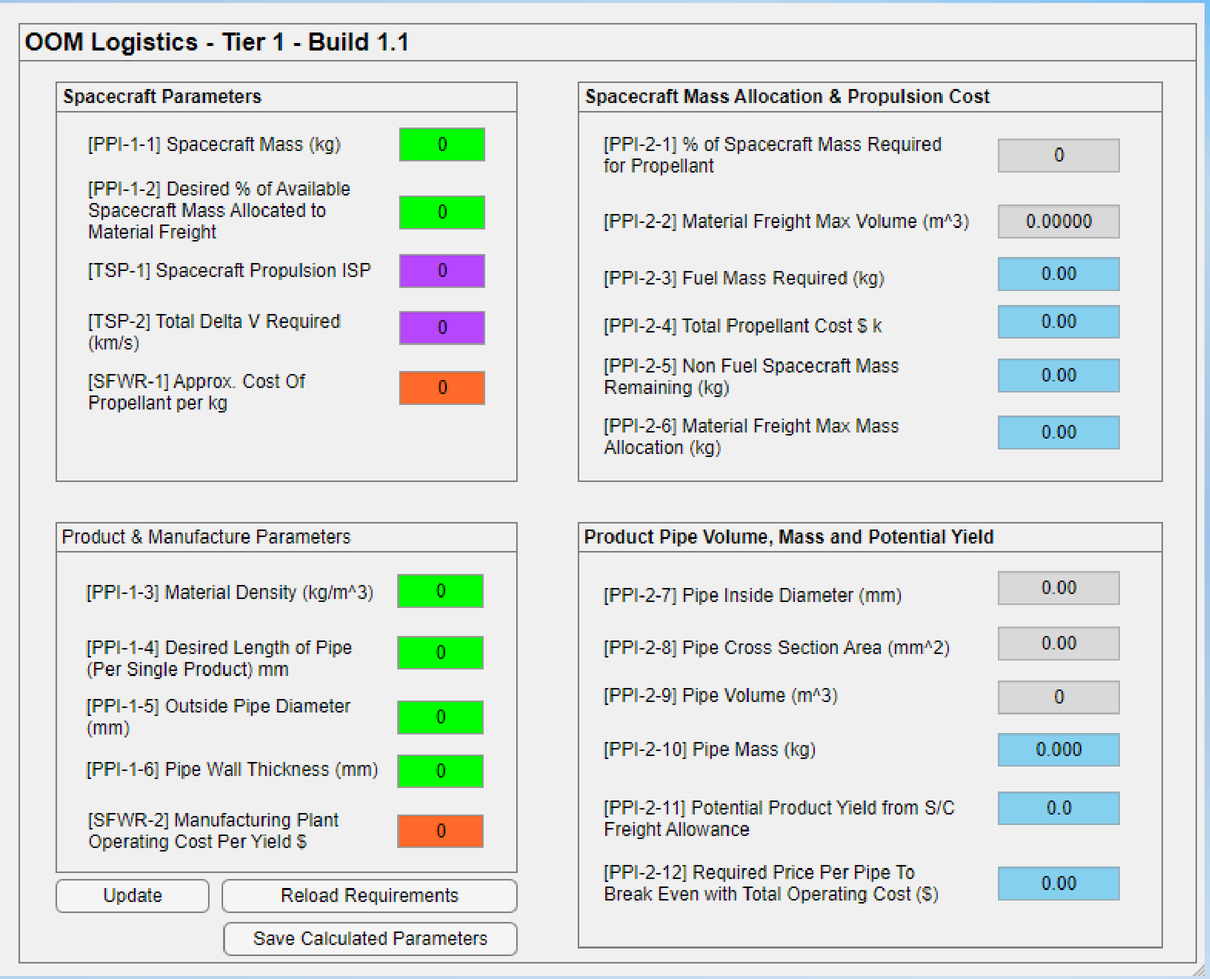
Interstellar Exploration

Mission Concept:
Lunar / Mars Ground Facility

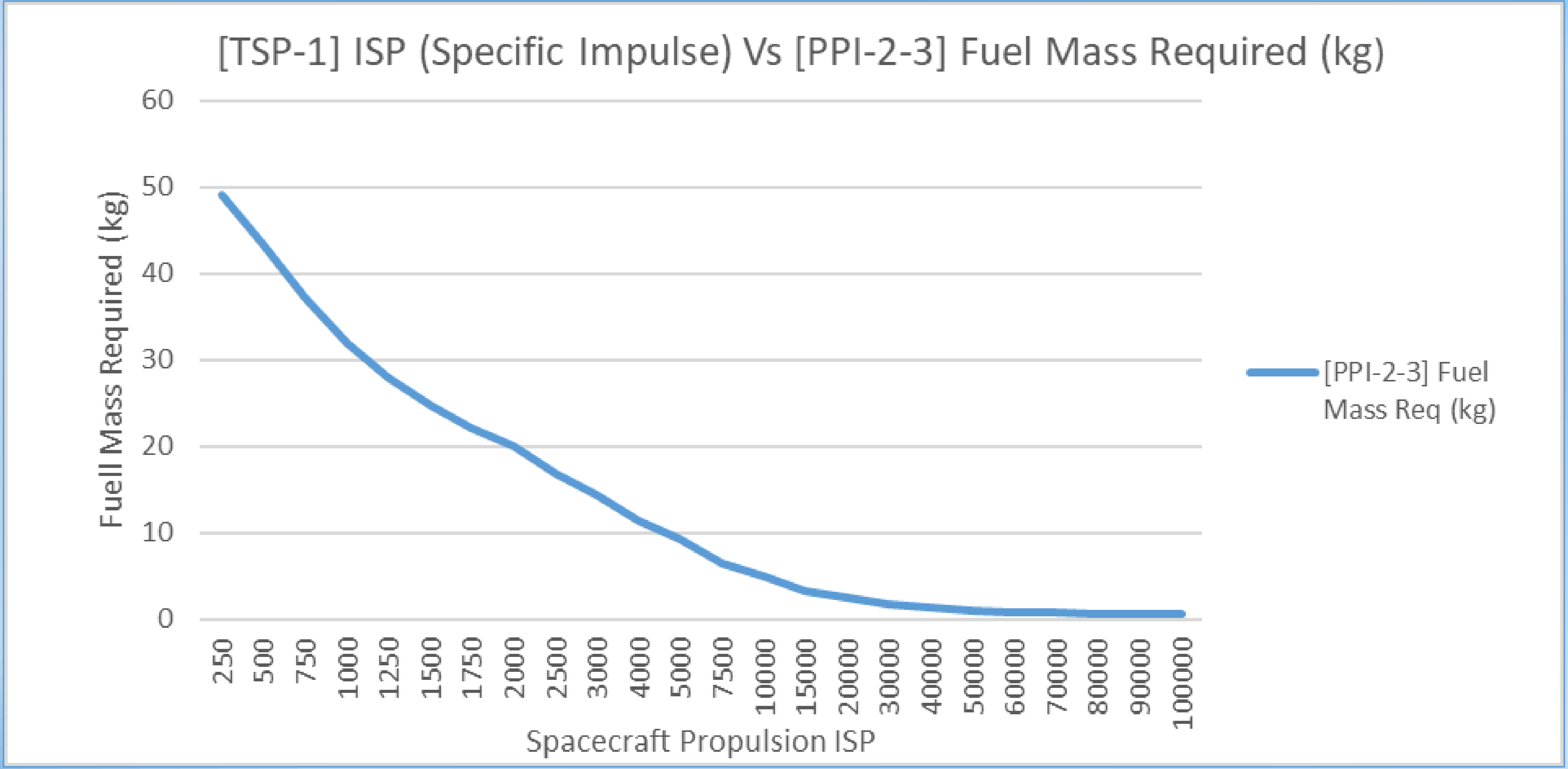


OOMSAT (OOM System Architecture Tool)

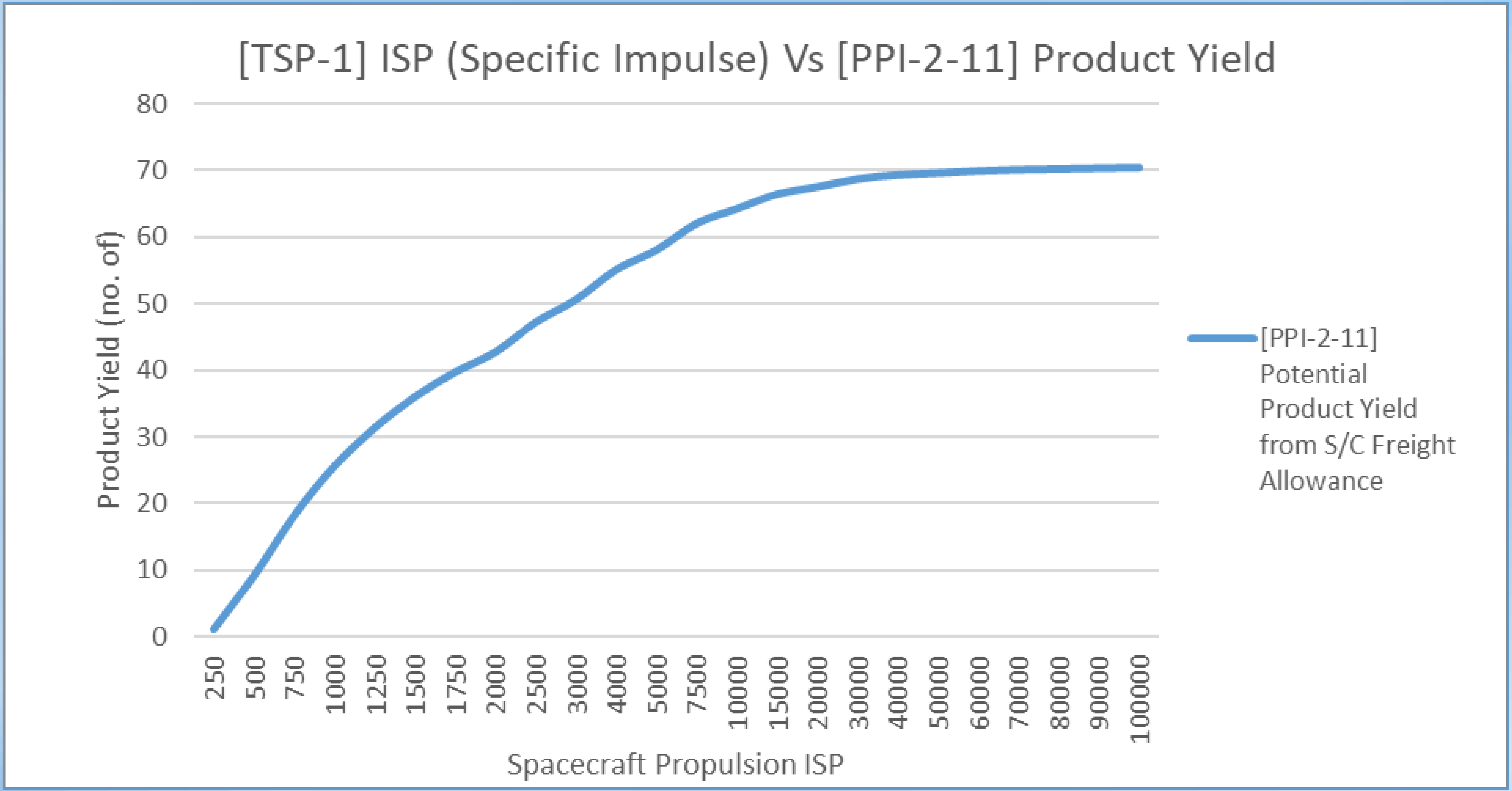
Scenario No.	1	Small Spacecraft (I.e. Micro-Satellite)
PPI. ID	**Parameter Title**	**Default Value**
[PPI-1-1]	S/C Wet Mass (kg)	50
[PPI-1-2]	S/C Freight % Allocation	80
[PPI-1-3]	Material Density (kg/m^3)	2710
[PPI-1-4]	Desired Pipe Length (mm)	1000
[PPI-1-5]	Outside Pipe Diameter (mm)	25
[PPI-1-6]	Pipe Wall Thickness (mm)	3
[TSP-1]	Spacecraft Propulsion ISP	1000
[TSP-2]	Total Delta V Required (km/s)	10
[SFWR-1]	Approx Cost of Propellant per kg	125
[SFWR-2]	Manuf. Plant Operating Cost Per Yield ($)	2750



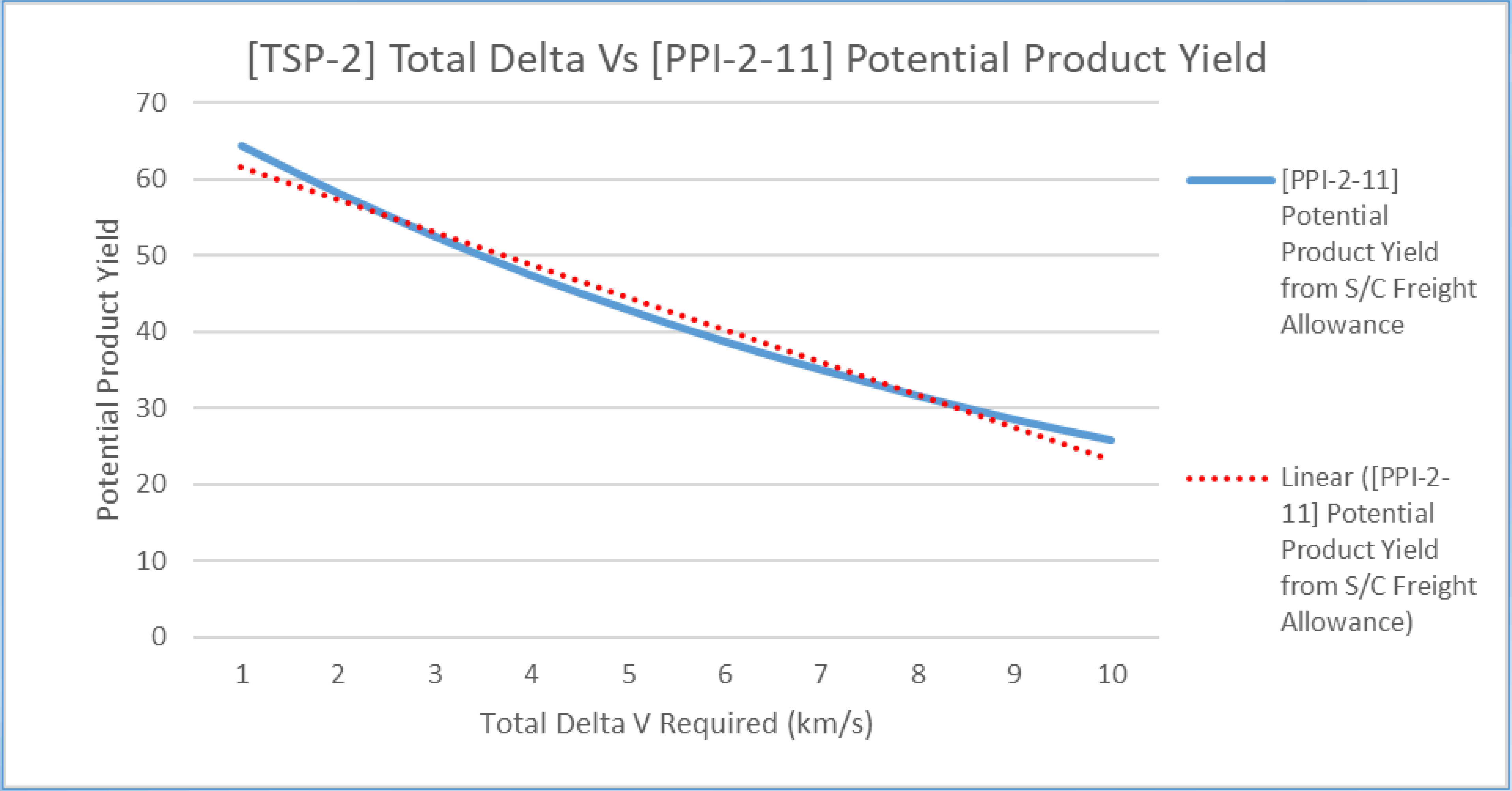
Logistics Parameter Results & Analysis (1/3)



Logistics Parameter Results & Analysis (2/3)



Logistics Parameter Results & Analysis (2/3)



Propulsion and OOM Freight Logistics

- The challenge of moving around OOM Freight in space is significant
- Refuelling and Engine Efficiency (Specific) Impulse
- Spacecraft Volume % dedicated to propulsion takes up valuable freight cargo
- A potential opportunity of propulsion…Quantised Inertia (QI)

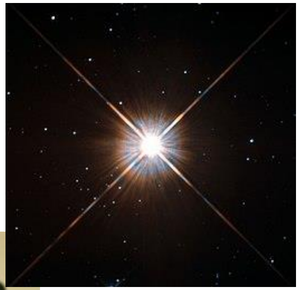
Dr Mike McCulloch will now present the theory behind QI

Talk for TivAS, Devon

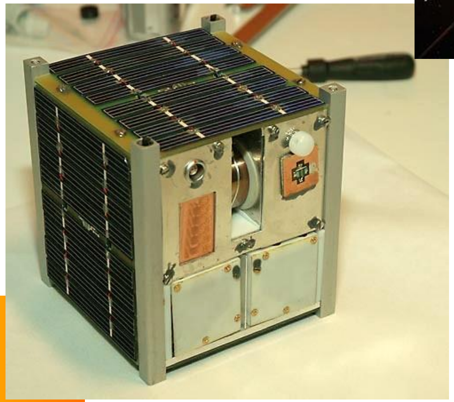
Dr Mike McCulloch, University of Plymouth, UK.

February 2023

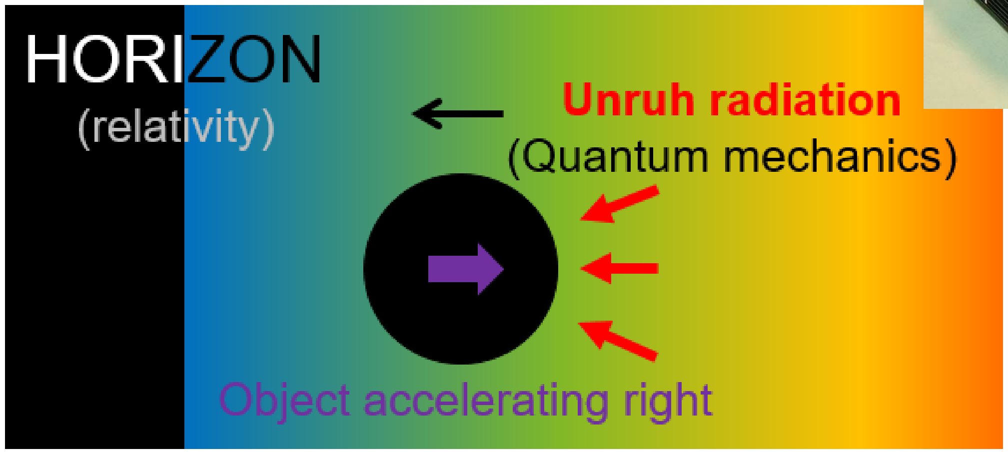
Destination



Application



QI Theory



Inertia?

Quantised inertia

Evidence for QI

Propellant-less Thrust

Conclusions

My Background

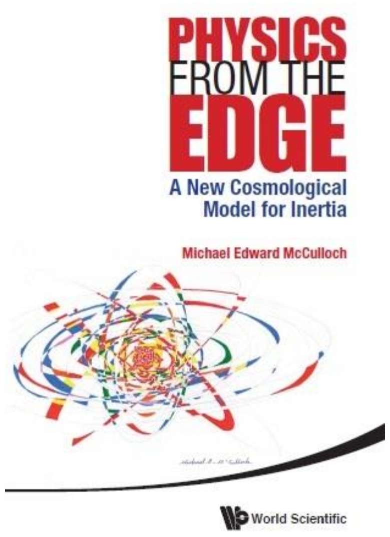
1991.
BSc in physics at the University of York, UK.

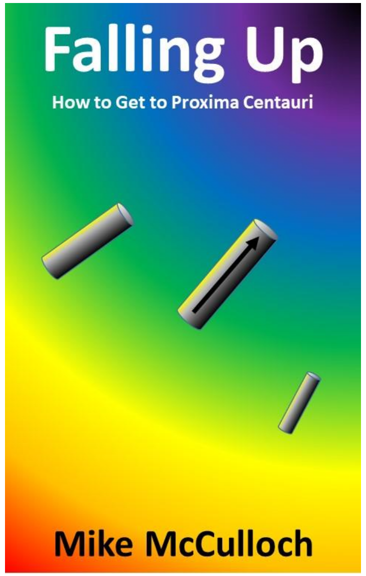
1995.
PhD in Ocean Physics at Liverpool University.

1998-2008.
Scientist at the UK Met Office, Bracknell & Exeter.

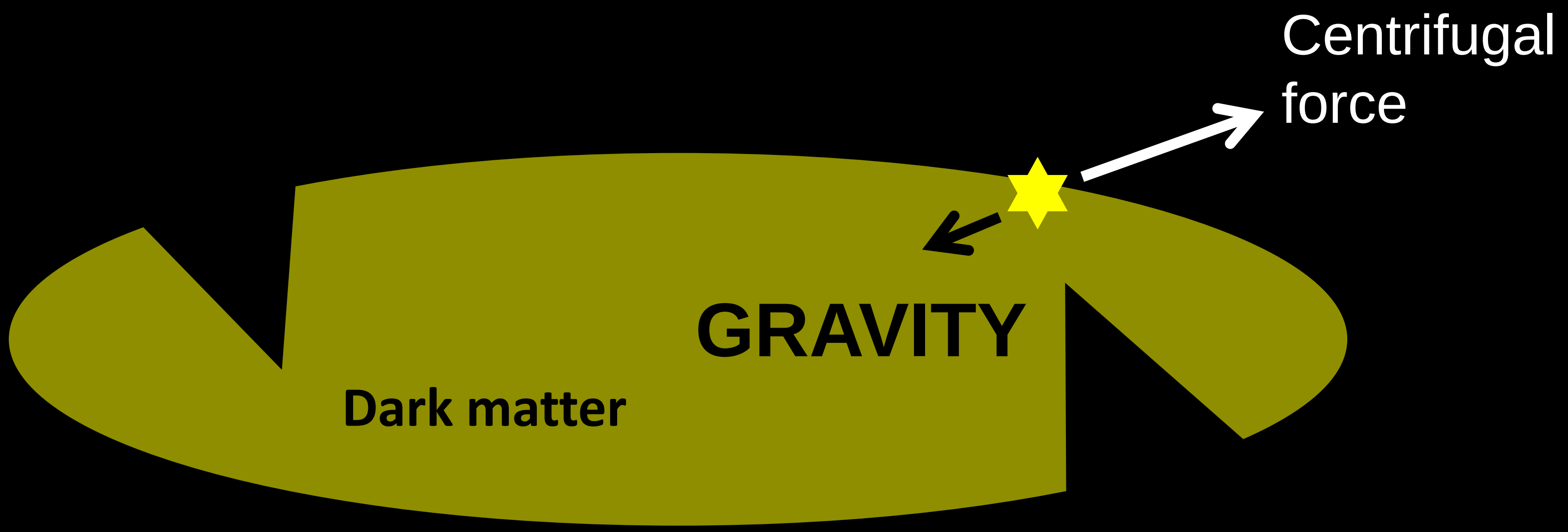
2008-now.
Lecturer in Geomatics (the maths of positioning in space) at Plymouth University.

I have published 26 papers proposing quantised inertia & two books →





The problem: Galaxies Spin Faster than Physics Predicts



So they should fly apart inertially, but don’t!
(Zwicky, 1933, Rubin, 1980)

Counter Evidence for Dark Matter

1. Renzo’s rule, speed follows the light, see Lelli et al. (2016).
2. **Milgrom’s ‘break’** implies new dynamics not matter (Milgrom, 1999).
3. Globular clusters cannot contain DM, yet show similar anomalies.
4. Wide binaries cannot contain DM, yet show similar anomalies.
5. The cusp-core problem. CDM predicts galactic centres wrongly
6. No direct evidence, after 40 years of searching.
7. Not falsifiable, you can look forever for more exotic versions.

I Focused on Inertia

Inertia has never been understood, just assumed: “Things keep going in a line…”

Surely we need a **reason** why speed is constant.

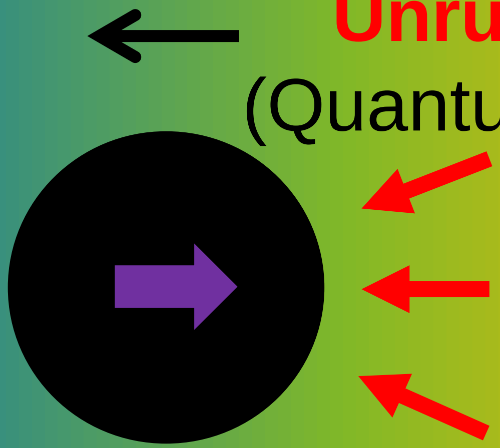
Inertial mass is not due to a Higgs field: only explains the mass of quarks (0.1%).

I’ve proposed a new model for inertia combining relativity & quantum mechanics →

A New Model for Inertia
Quantised Inertia

HORIZON
(relativity)

Unruh radiation
(Quantum mechanics)



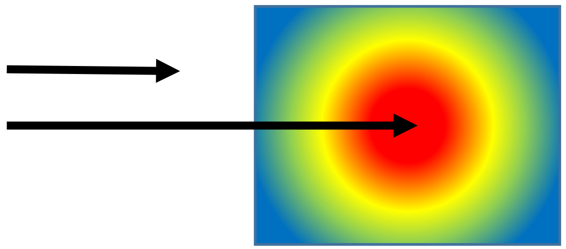
Object accelerating right

McCulloch, M.E., 2013. Inertia from an asymmetric Casimir effect. *EPL*, 101, 59001.

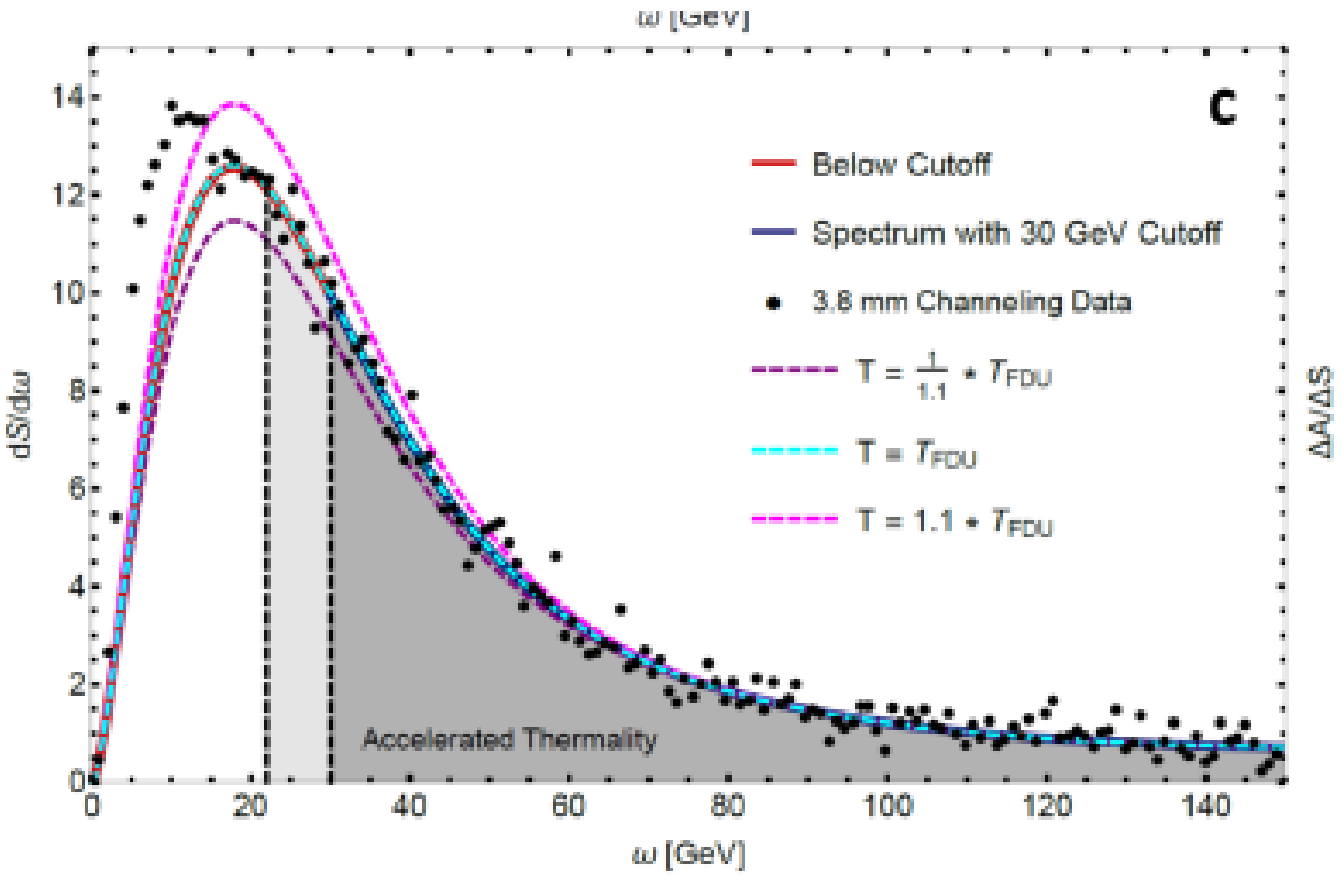
Horizon damps energised Unruh field to the left
Object pushed back against its acceleration

Unruh Radiation was Confirmed Last Year

Lynch et al., 2021 looked at radiation emitted by high energy positrons decelerating in a silicon crystal:



They showed the spectrum of heat radiation emitted was identical to that predicted by Unruh radiation →



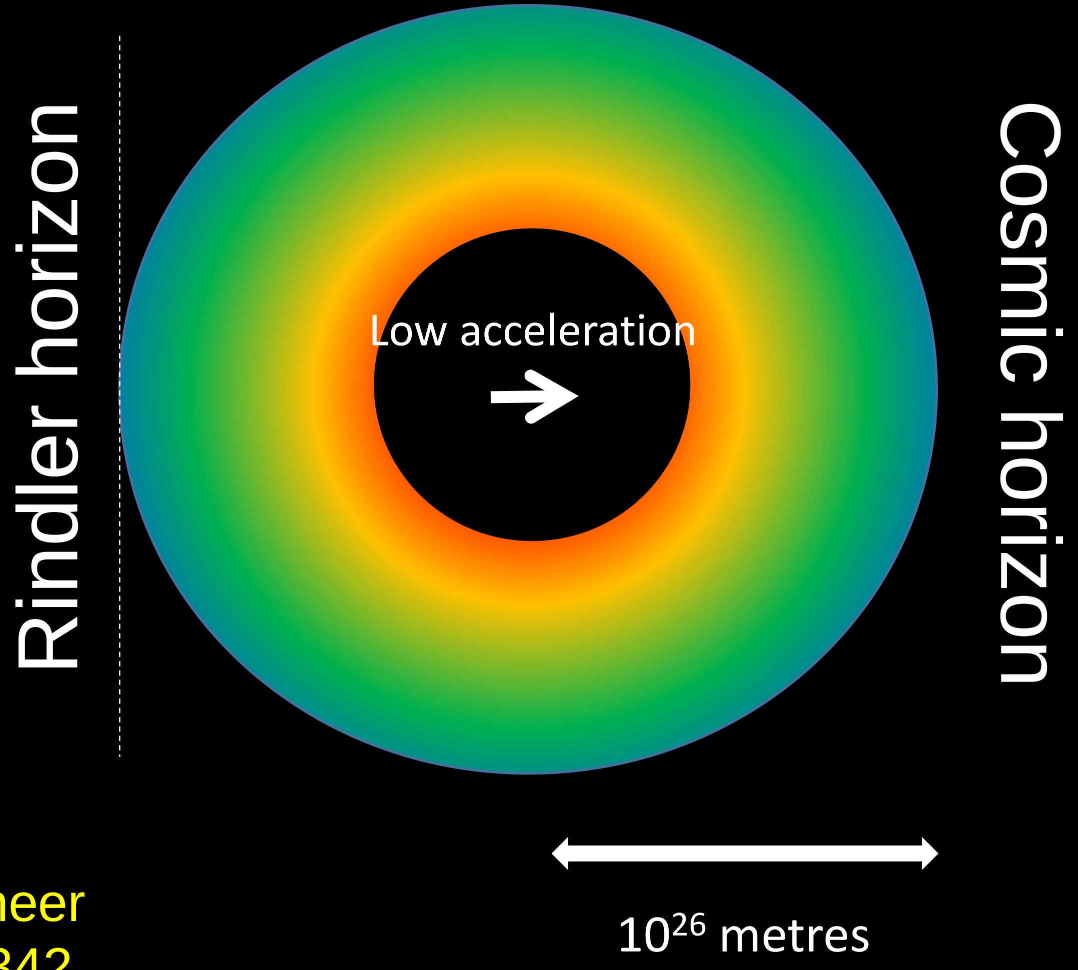
Experimental Observation of Acceleration Induced Thermality (Unruh Radiation)
Lynch et al., 2021 Phys Rev. D., 104, 025015.

Quantised Inertia At Low Acceleration

For objects with very low acceleration the Rindler horizon goes behind the cosmic horizon.

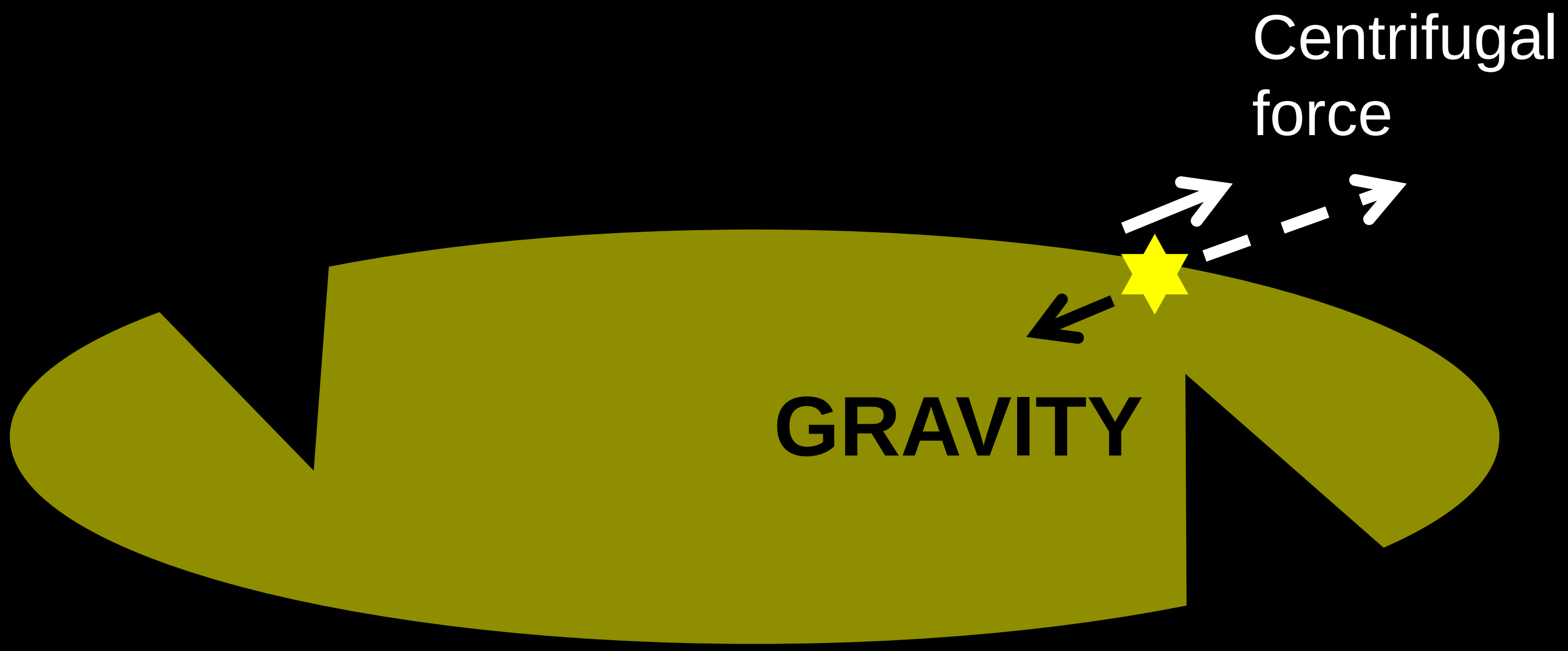
No horizon asymmetry – no inertia!

$$m' = m\left(1 - \frac{2c^2}{a\Theta}\right)$$



McCulloch, M.E., 2007. Modelling the Pioneer anomaly as modified inertia. *MNRAS,* 376(1), 338-342

Just What We Need For Galaxies!



So they should fly apart inertially, but don't!
(Zwicky, 1933, Rubin, 1980)

Derivation of QI from Uncertainty.

Start by considering one Planck mass accelerating to the right. Δp is inversely proportional to Δx.

$$\Delta p \Delta x \geq \frac{\hbar}{2} \qquad \Delta p \geq \frac{\hbar}{2\Delta x}$$

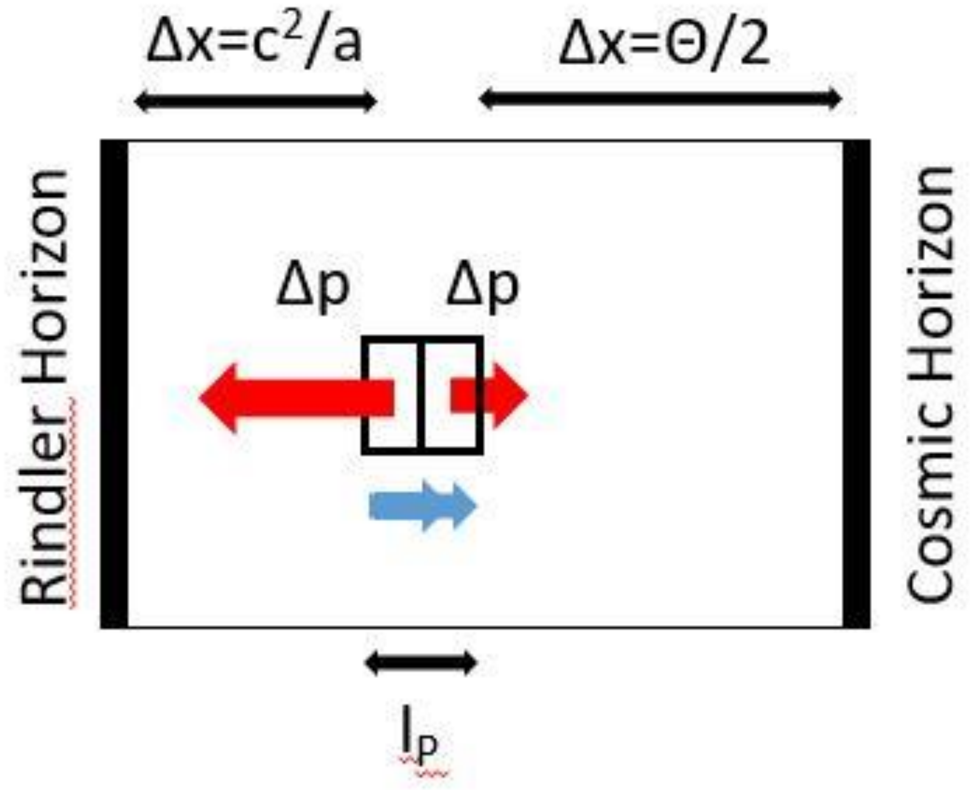
$$F = \frac{dp}{dt} = \frac{dp}{dx}\frac{dx}{dt} = c\frac{dp}{dx}$$

Assume Δx = distance to a horizon (QI)

$$F = \frac{c\left(\frac{2\hbar}{\Theta/2} - \frac{\hbar}{c^2/a}\right)}{l_P/2}$$

$$F = -\frac{\hbar}{c l_P}\left(1 - \frac{2c^2}{a\Theta}\right)a = ma$$

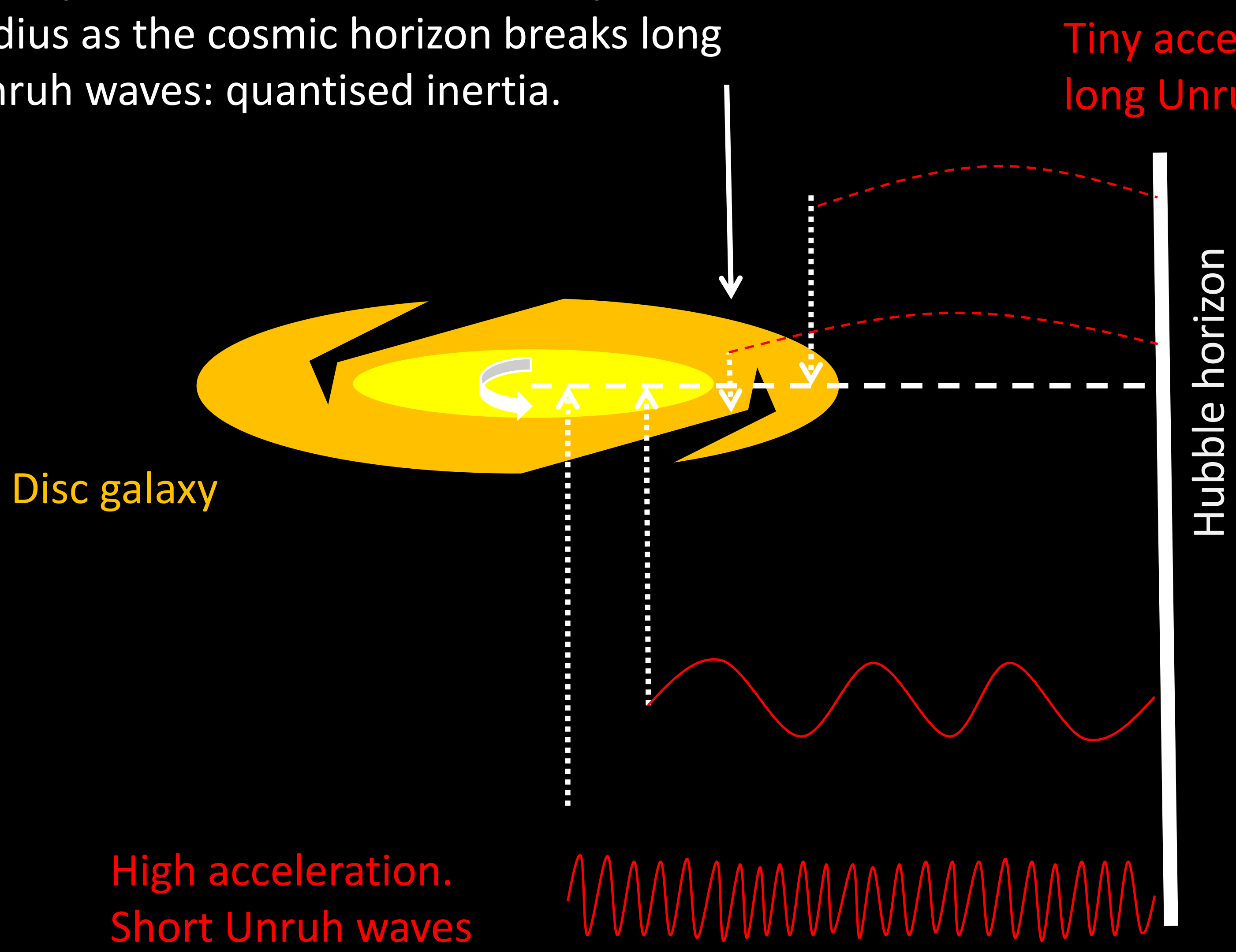
Planck mass



McCulloch, M.E., 2016. Quantised inertia from relativity and the uncertainty principle. EPL, 115, 69001 (updated)

It's Quantised Inertia, not Dark Matter. The Smoking Gun:

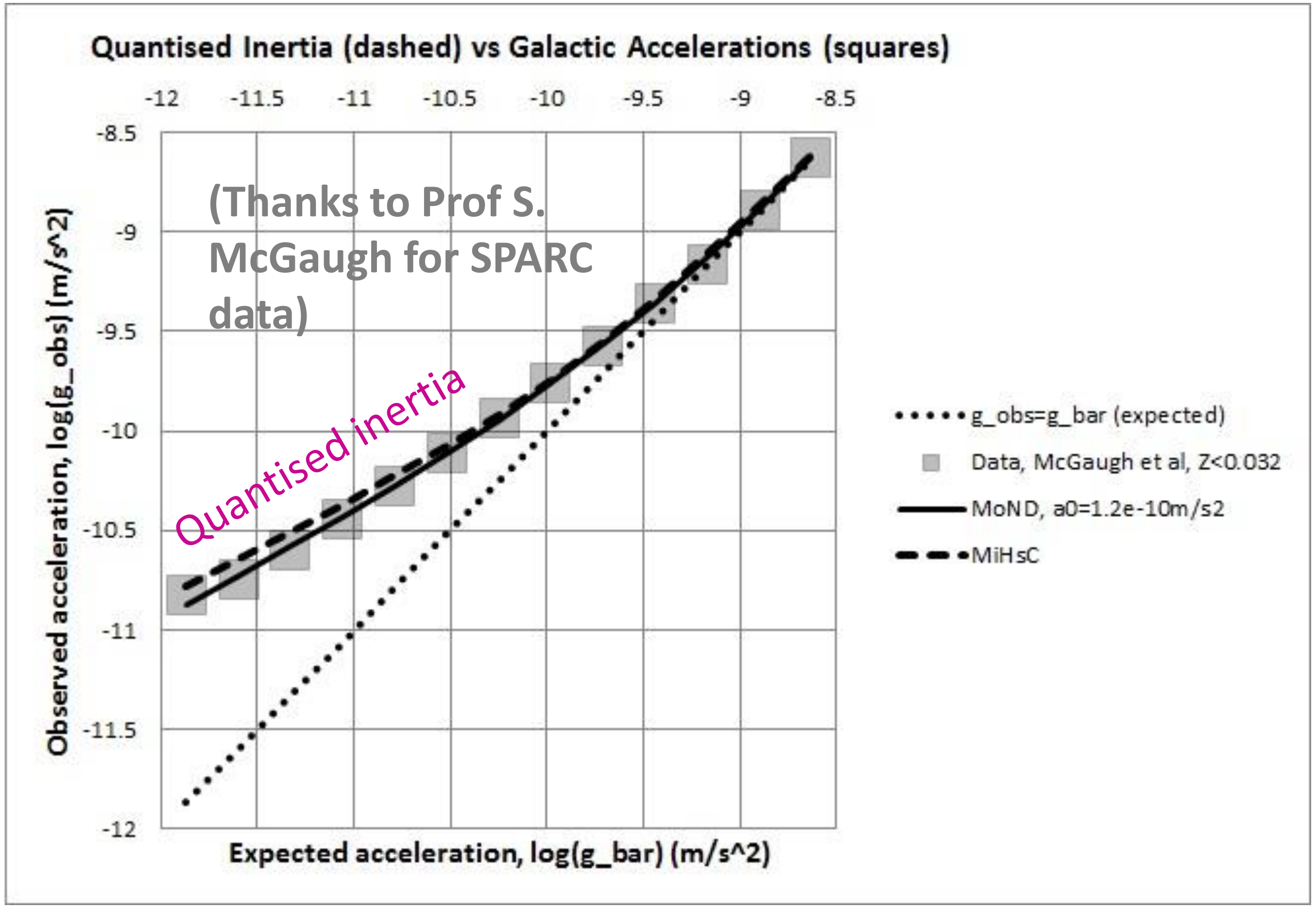
Galaxy rotations becomes odd beyond this radius as the cosmic horizon breaks long Unruh waves: quantised inertia.



$$m' = m\left(1 - \frac{2c^2}{a\theta}\right)$$

$$\lambda \sim \frac{8c^2}{a}$$

Testing Quantised Inertia with 153 Galaxy Rotations



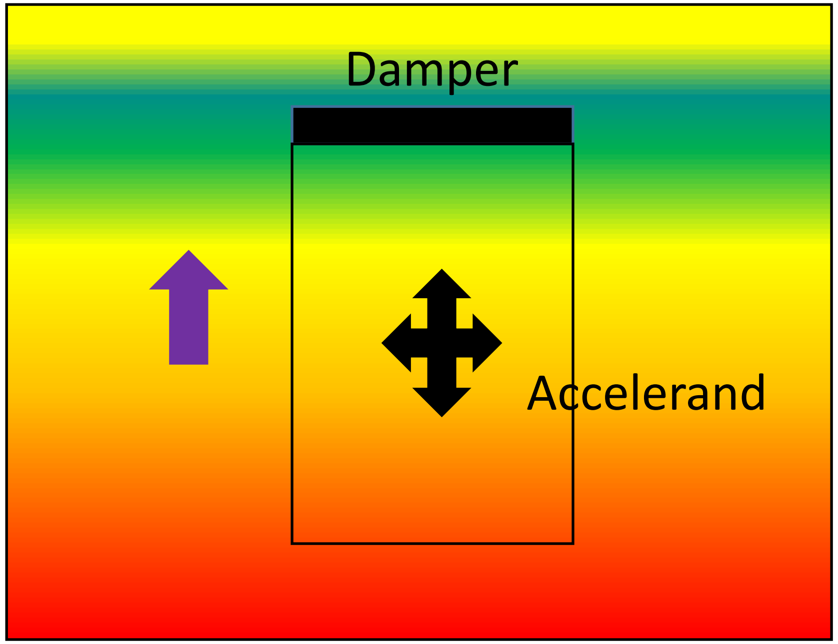
QI predicts galaxy rotation without dark matter & <u>without adjustable parameters</u>

$$v^4 = \frac{2GMc^2}{\Theta}$$

McCulloch, 2017. Galaxy rotations from quantised inertia & visible matter only. Astrophys. & Space Sci, 362, 149. https://arxiv.org/abs/1709.04918

If We Understand Inertia Then We Can Control It

McCulloch, M.E., 2013. Inertia from an asymmetric Casimir effect. EPL, 101, 59001.



McCulloch, M.E., 2018. Propellant-less propulsion from quantised inertia. Sp. Explor, 7, 3.

Horizon drives: a propellant-less alternative to rocket launches

Applied Cosmology. DARPA Project, 2018-Now.

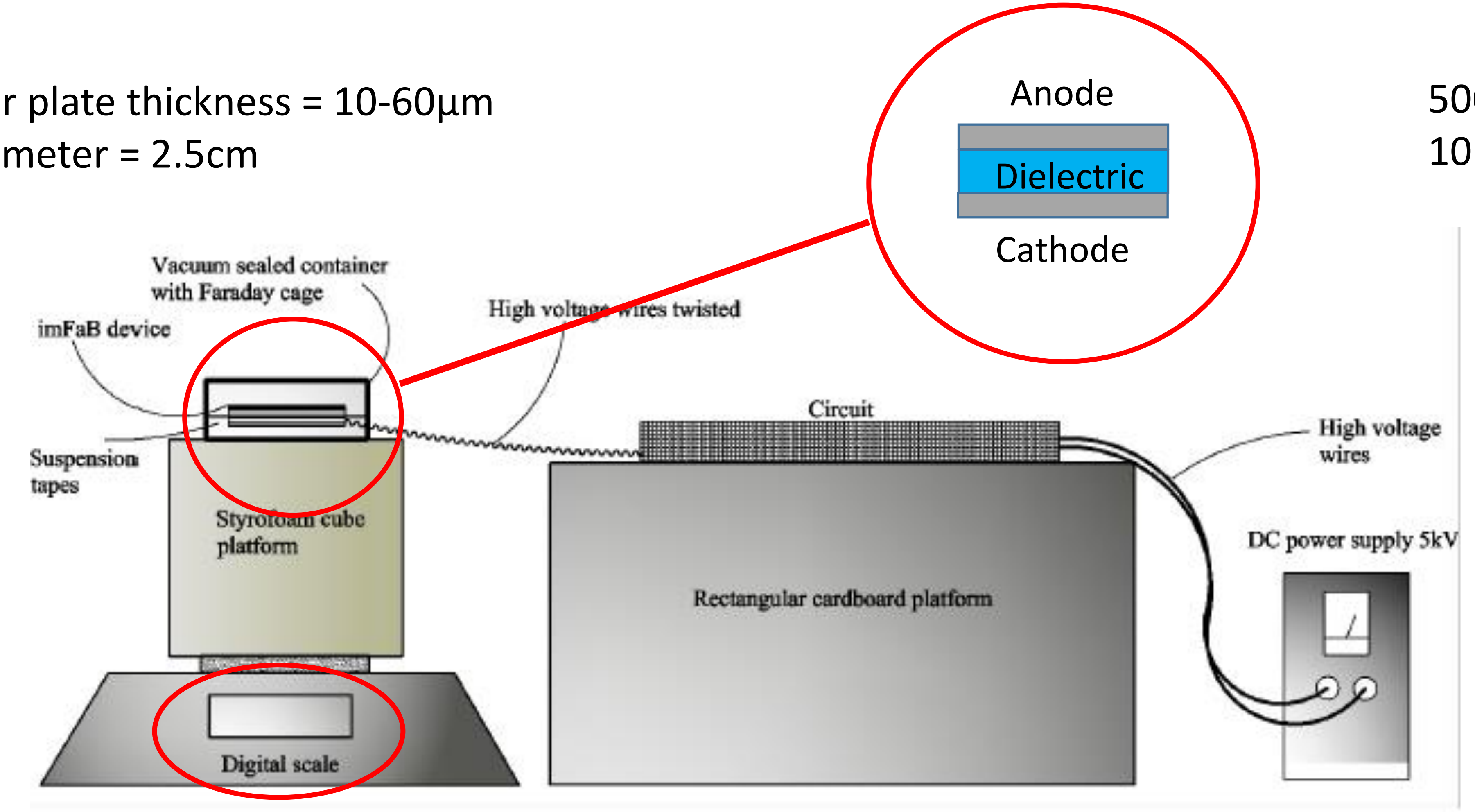
I was contacted by DARPA. I applied for funding & was awarded $1.3M

Project aims to demonstrate scalable thrust from QI in the lab.

F. Becker & A. Bhatt Read My Papers. Tried a Capacitor Setup, 2018

Capacitor plate thickness = 10-60µm
Plate diameter = 2.5cm

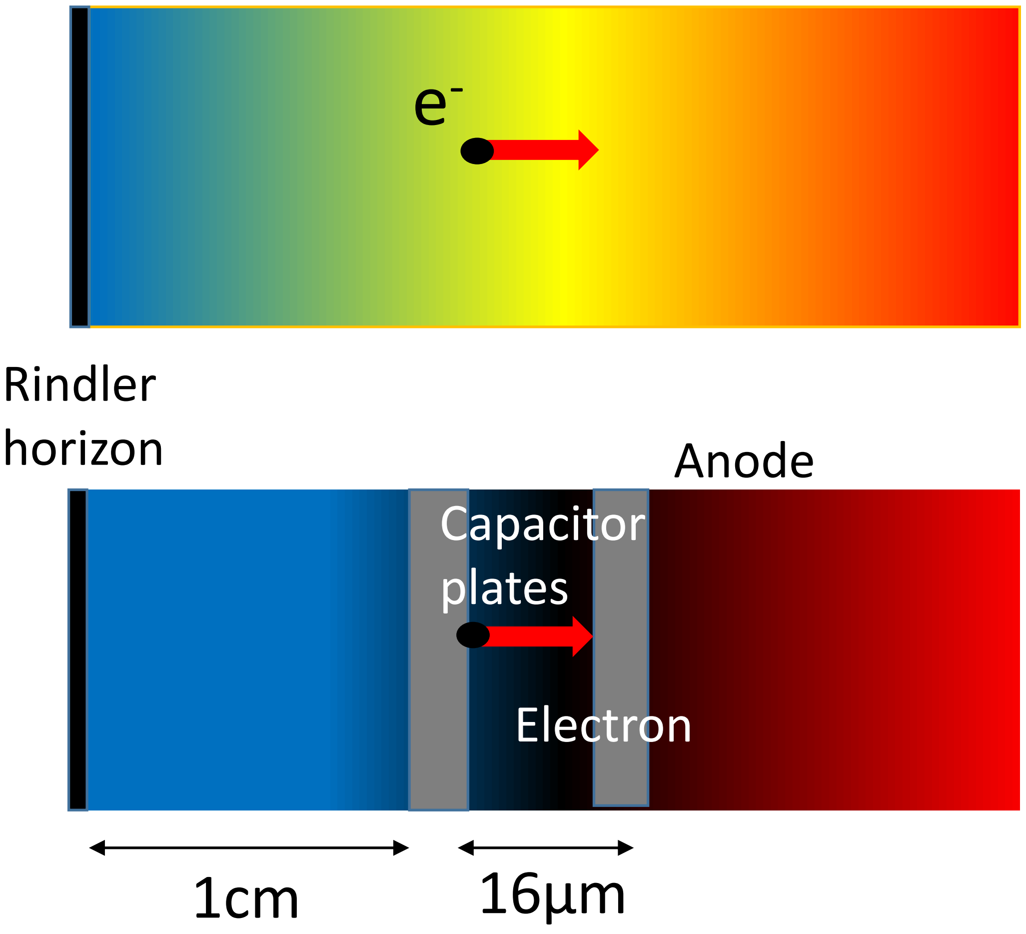
5000 V
10µA



Susceptibility to electronic artefacts or tension of cables?

Figure 2: Experiment setup

Explanation of QI Capacitor Horizon Drive



Normally, in QI, an accelerated **electron** would see more Unruh radiation in front (red, no horizon damping) and less behind (yellow, Rindler horizon damping), so it would have inertia, ie: be pushed back.

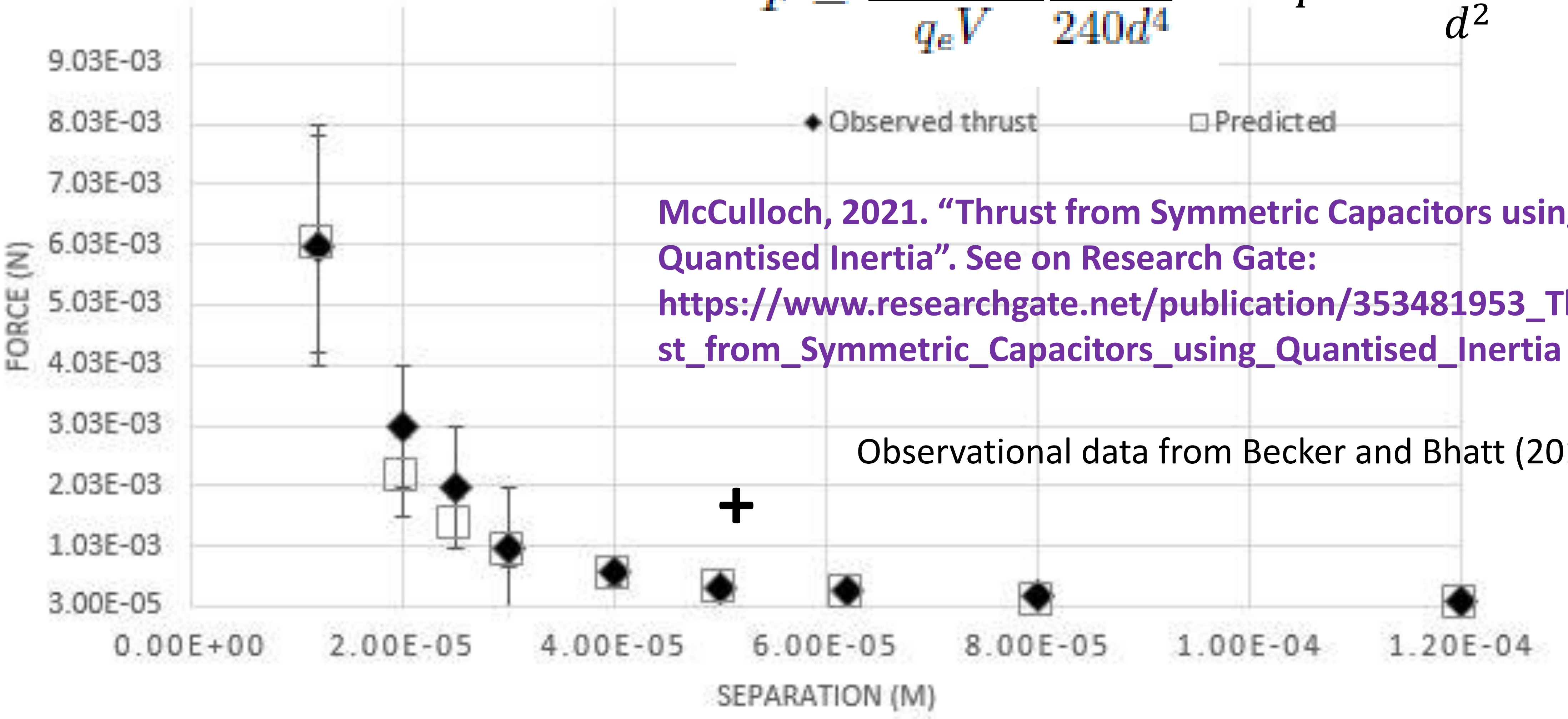
Because of the damping of the capacitor plates (grey) the normal gradient is reversed and now there are more Unruh waves behind the electron (blue area) so the electron gets an extra kick forward which is translated to the anode.

McCulloch, 2021. Thrust from Symmetric Capacitors using Quantised Inertia. Research Gate

OBSERVED THRUST & THAT PREDICTED BY QI

$$F = \frac{2Pd^2 m_e}{q_e V} \frac{c\pi^2 A}{240 d^4}$$

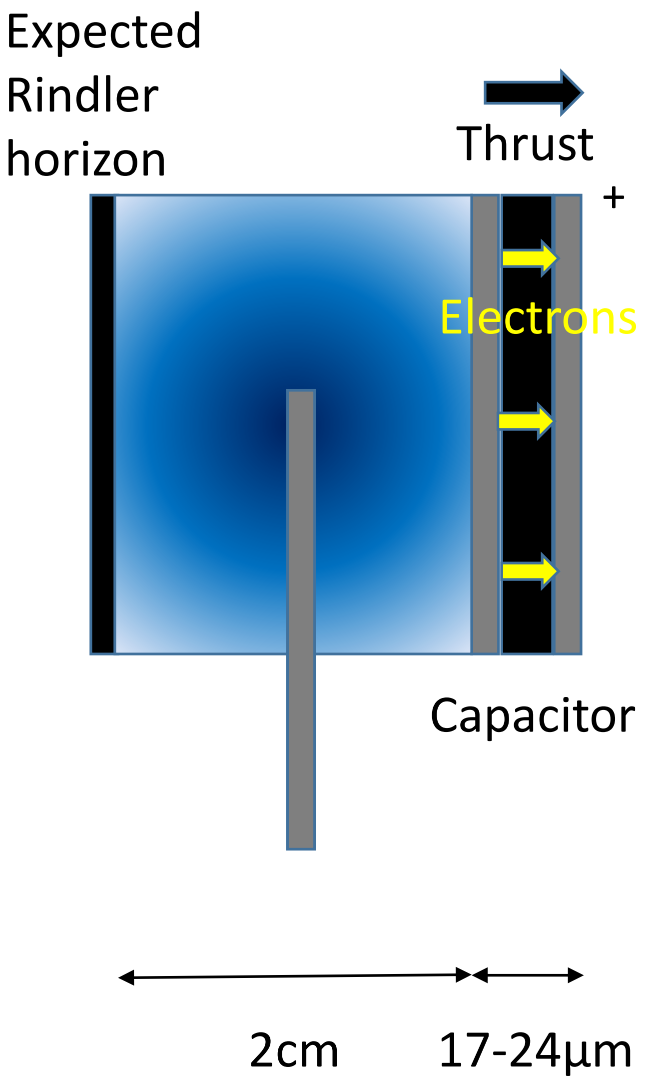
$$F \sim \frac{0.00014 IA}{d^2}$$



McCulloch, 2021. "Thrust from Symmetric Capacitors using Quantised Inertia". See on Research Gate: https://www.researchgate.net/publication/353481953_Thrust_from_Symmetric_Capacitors_using_Quantised_Inertia

Observational data from Becker and Bhatt (2018)

Experimentum Crucis – Rindler Horizons are Real!



The thrust is towards the anode (+).

When a metal baffle (grey) is inserted into the blue area, the thrust is equal and opposite.

If the baffle is moved beyond the calculated point of the Rindler horizon (the vertical black line) the force is again towards the anode.

This is direct proof the cause is quantised inertia.

Applied Cosmology!

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Quantized Inertia
Horizon Engine Development & Laboratory Setup
May-Feb 2023

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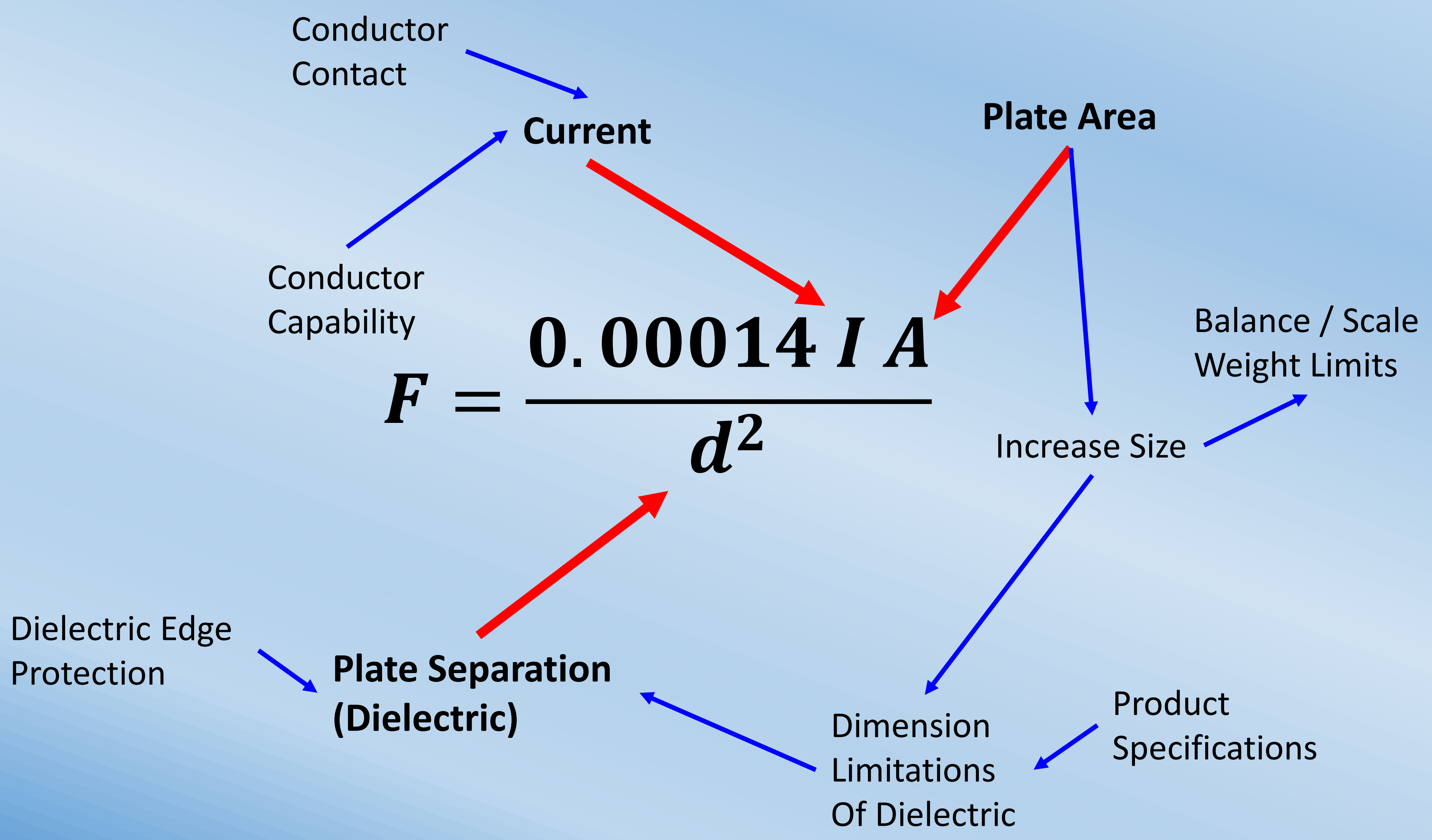
QI Capacitor Force Equation & Relationships



$$F = \frac{0.00014\, I\, A}{d^2}$$

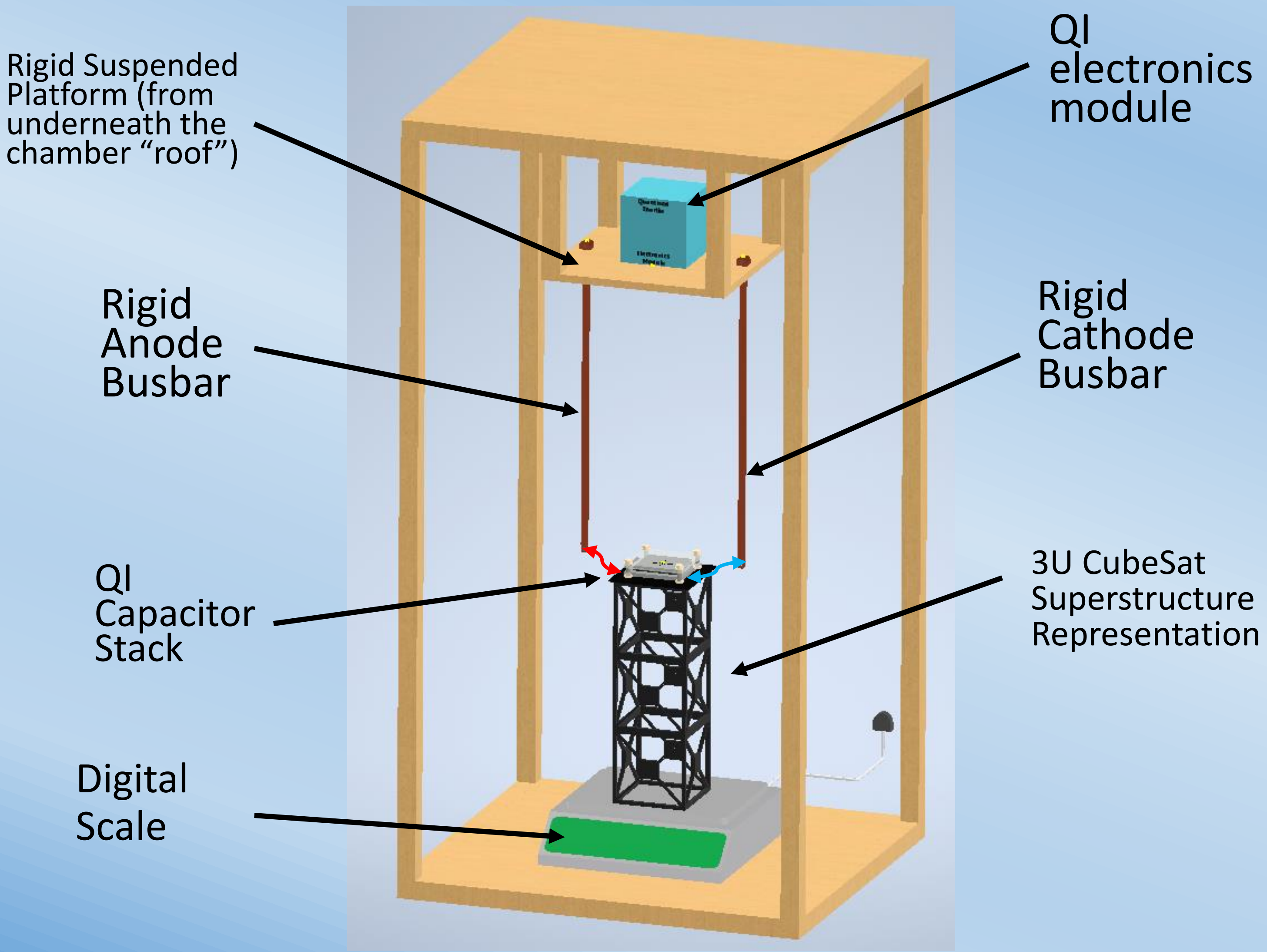
Notes:

- Larger capacitor build
- Improved Kapton dimensions allowing for larger dielectric and hence larger capacitor area

Next Area to Improve:

- Dielectric Edge Protection
- Balance / Scale Consistency

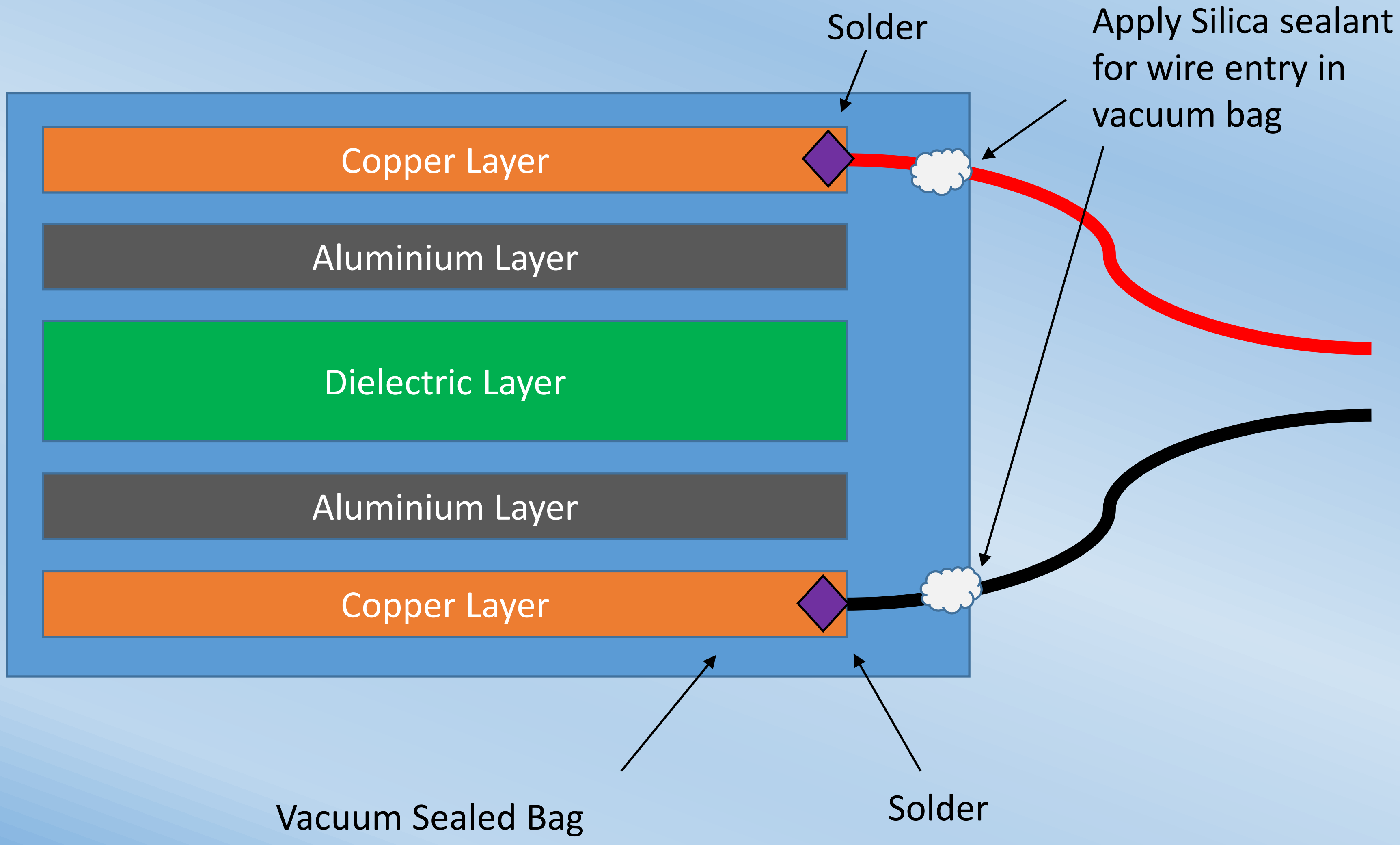
QI Test Chamber V1 (Non Vacuum)



Revised Quantised Inertia Test Chamber

- Wooden frame to avoid any undesired conduction
- Adjustable height Rigid bus bars suspended for anode / cathode conductors linked to the QI electronics module
  - End stage connectors using typical wires to link with the QI capacitor
- QI Capacitor rests upon 3U CubeSAT superstructure (and also to add distance from digital scale in case of electromagnetic interference)

Initial Capacitor Stack Design – Jun 2022



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QI Capacitor "Toastie"

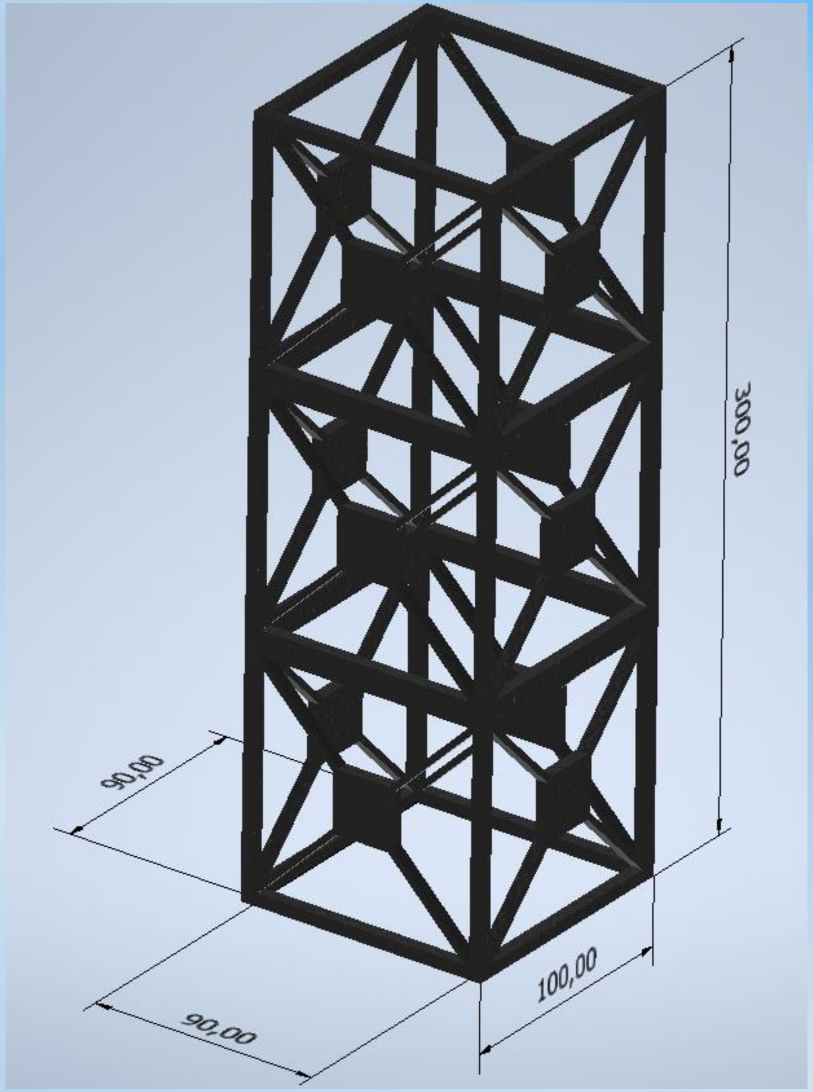
Conductor wires to "Galinstan Whiskers"

21^{st} Sep 2022:

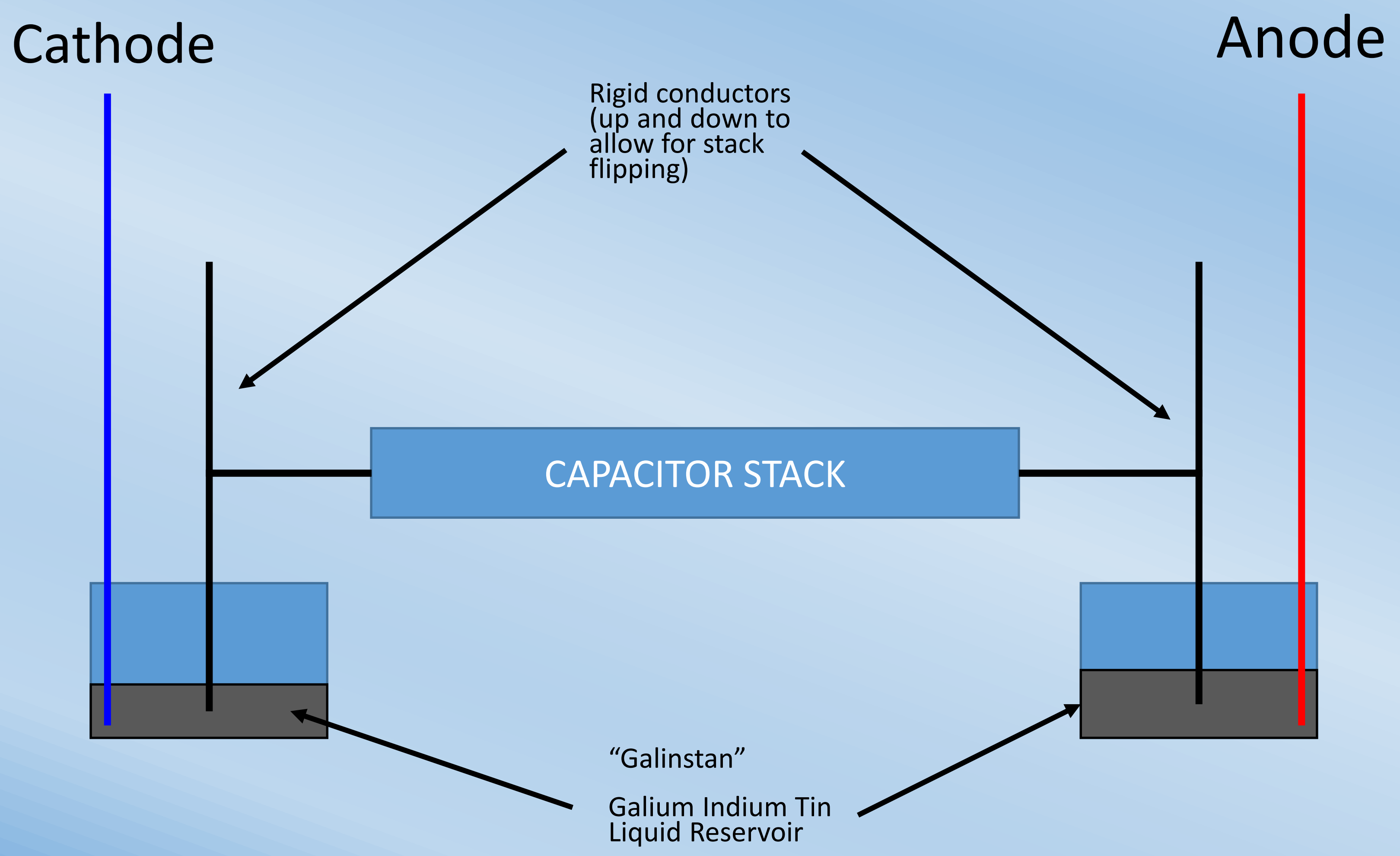
"Toastie V3" is composed of 2 x (160 x 160 mm) pieces of Perspex Acrylic (4 mm thick). Masking tape is used on one side to form a temporary "hinge" and 3 mm holes drilled in the centre of each piece to allow access for conductor wires.

Phase 1 –"CubeSAT" Superstructure Stand Concept

- To get into a positive future thinking mindset, the proposed "stand" should resemble a future 3 Unit CubeSat mission (i.e. 3U)
- Each unit is 100 x 100 x 100 mm, therefore a 3U is 300 x 100 x 100 mm
- As this is a concept superstructure model, actual CubeSat dimensions may vary, but I have made assumptions that with a 5 mm frame thickness, a working volume within each unit is 90 x 90 x 90 mm
- Mike has calculated that a minimum of 150 mm is ideal to minimise / eliminate electrostatic effects, but increasing this to 200 mm gives a factor of safety margin.
- This therefore implies that the QI electronics should ideally fit within a 90 x 90 x 90 mm volume envelope. Utilising 1U of volume therefore also provides the desired >200 mm clearance from the bottom of the stack to the top



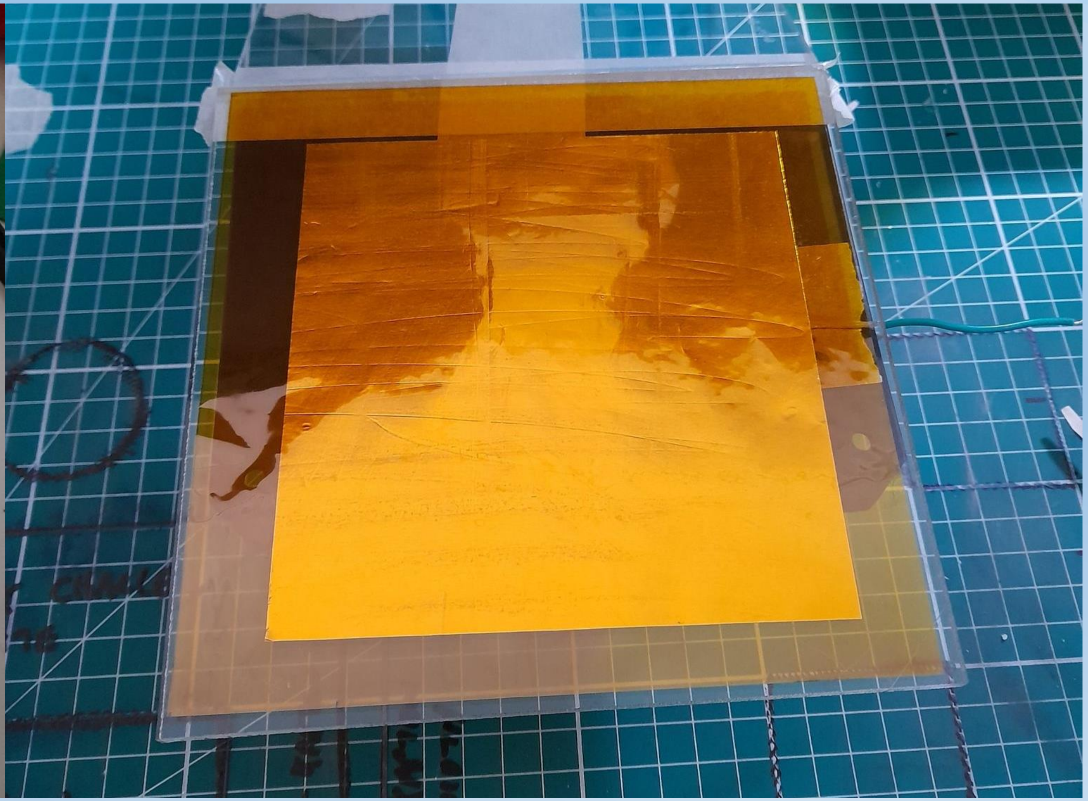
Connector Revision for QI Test Chamber



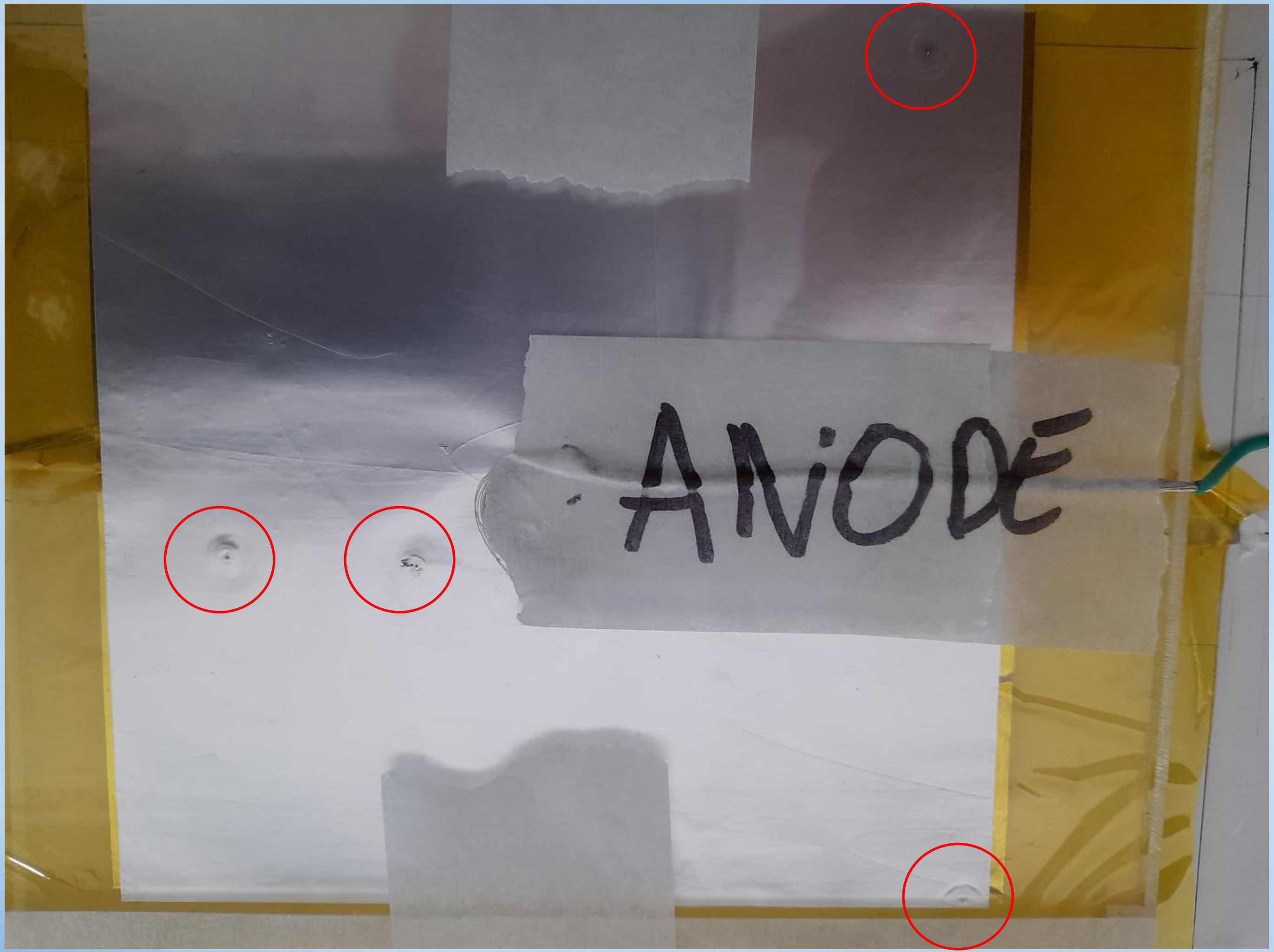
Invertible capacitor stack with T shaped rigid conductors that "stand" in the Ga-In-Sn reservoirs.

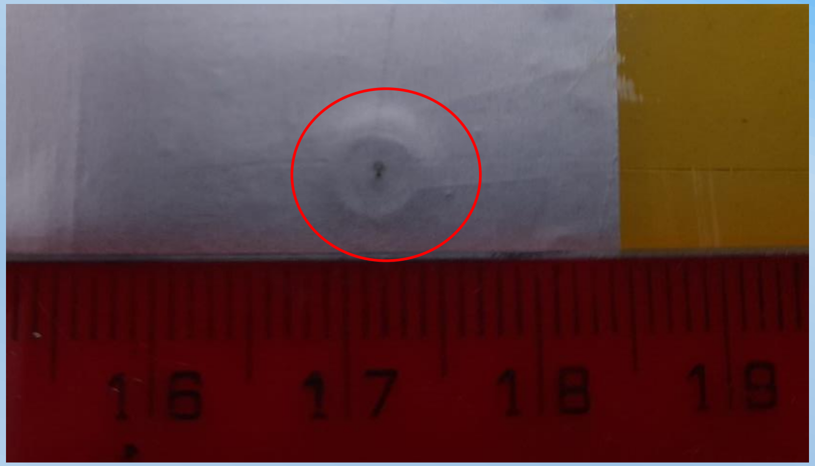
These reservoirs then have anodic / cathodic conductors that are routed away (so that the QI electronics module can be connector accordingly to them)

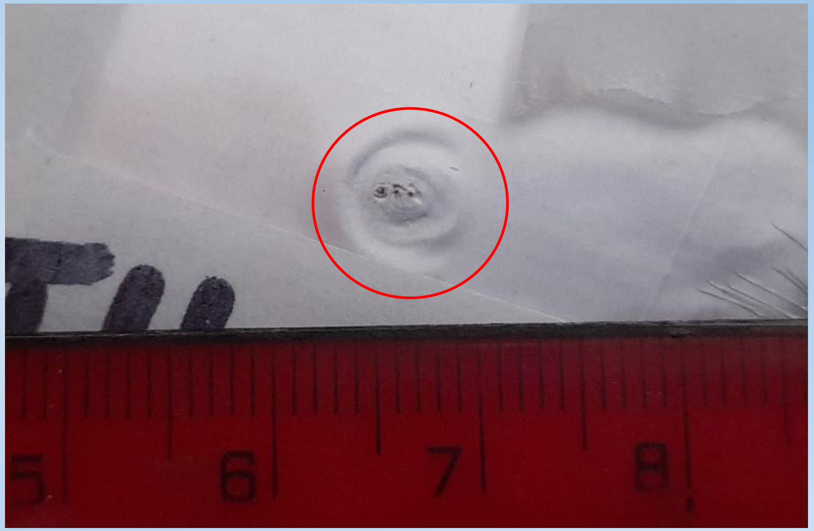
25th September 2022 – New 25um Kapton Sheet for Dielectric



Capacitor Damage P1-X103 (25 Sep 2022)







Capacitor damage of bullet holes observed during P1-X103. Likely suspect cause is due to heated pockets of air creating bubbles in the air gap between capacitor layers which then eventually rupture.

2nd Oct 2022 Engineering Improvements

Current Setup (as of Feb 2023)

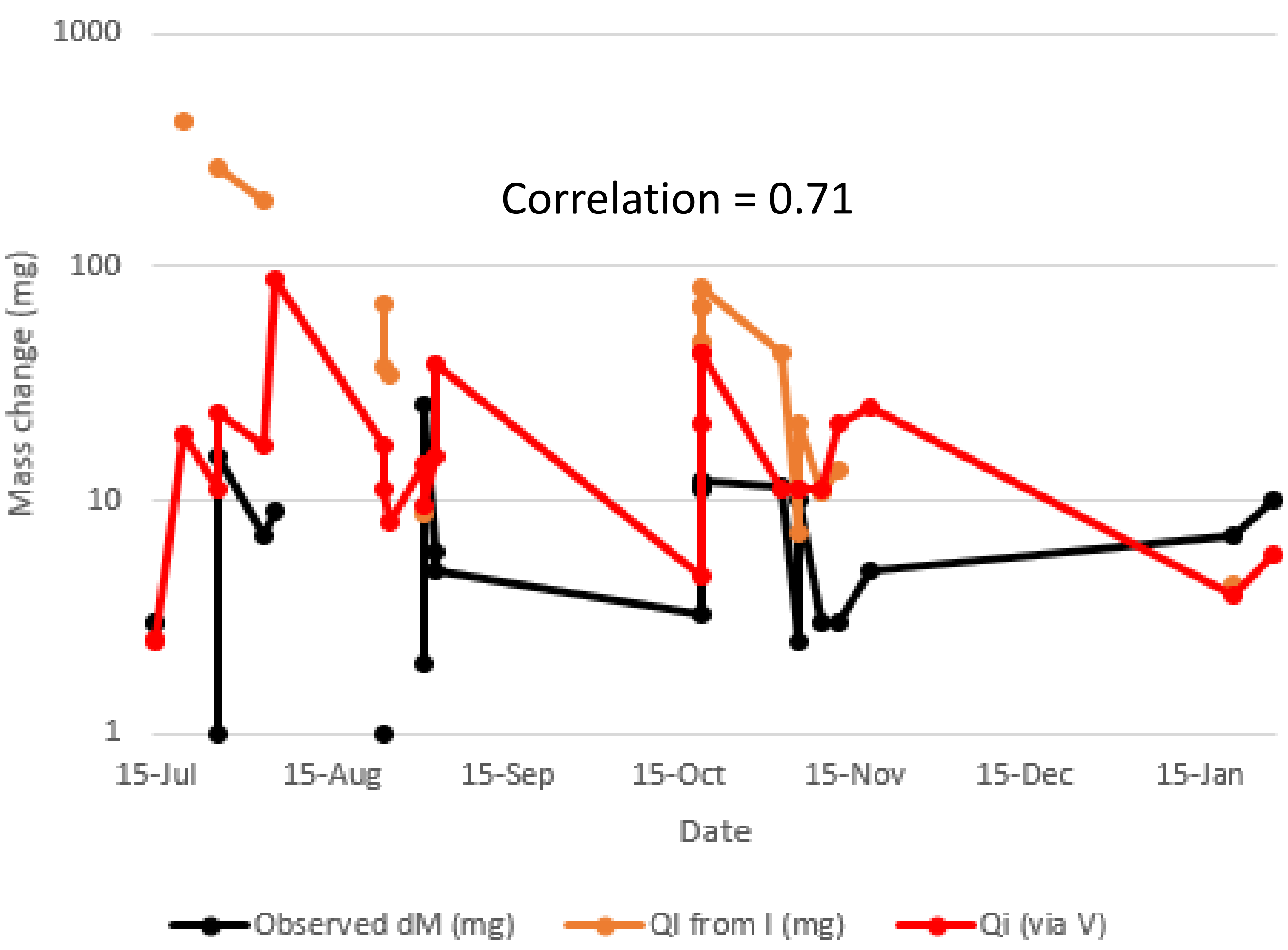
The lightbulb suspended from above is used to illuminate and preheat the capacitor stack (we aim for approx. 50 degrees). The lightbulb SHOULD BE REMOVED prior to testing to avoid electromagnetic interference / attraction from the capacitor stack (and therefore give spurious scale readings).

Note however that this is the SURFACE temperature we observe (using a thermal laser gun reader) so at this stage the internal temperature is unknown.

We have also noted that "overheating" can lead to premature capacitor breaking.

Quantised Inertia Test Results (Up to 2023)

Thrust Timeline



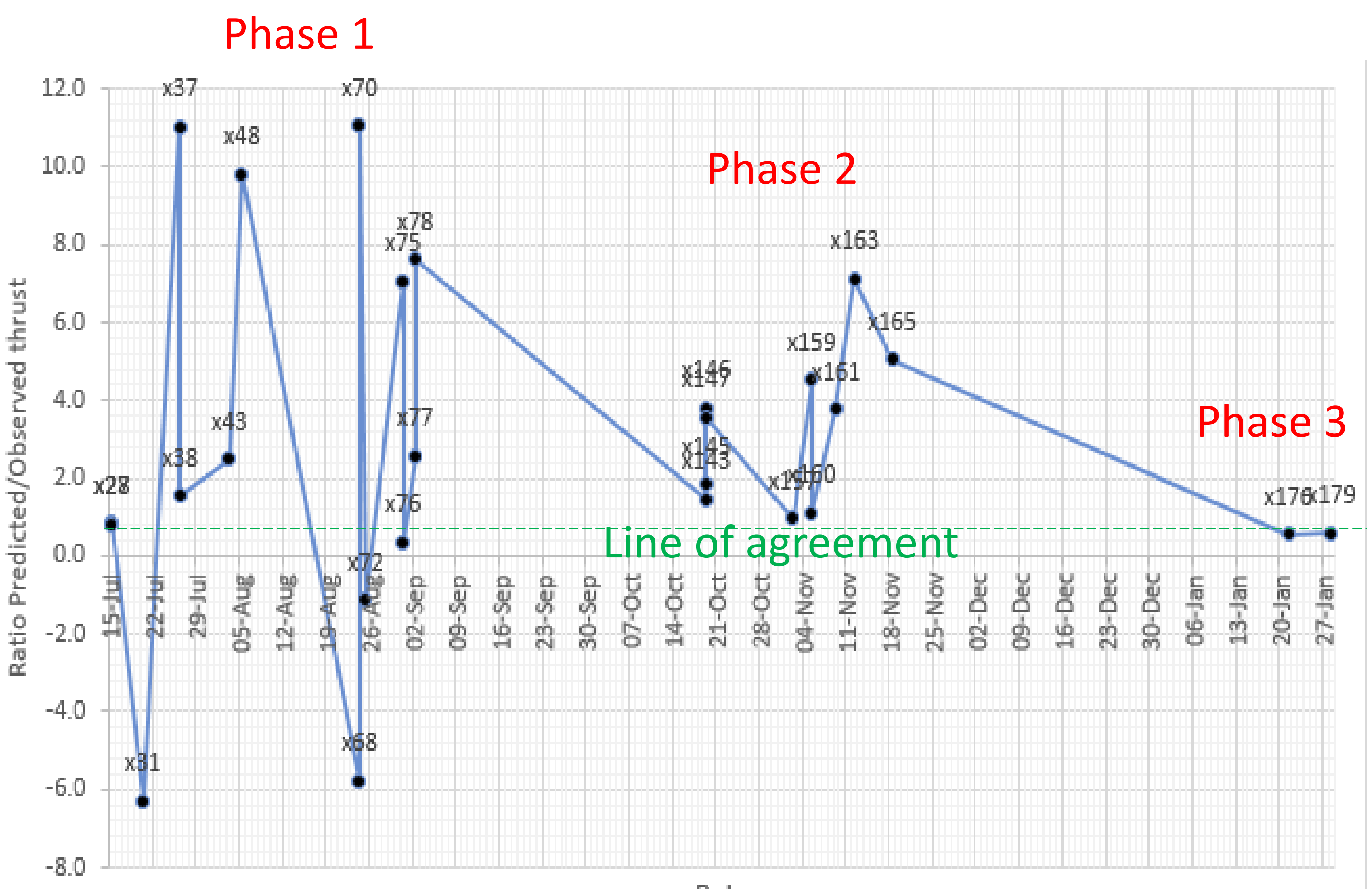
Thrusts of up to 10mg are being regularly seen and reverse on flipping the capacitor.

10mg is 0.1mN.

We heat the capacitor with 1W so we have a thrust to power ratio of 0.3 N/kW.

This is 15 times better than ion drives, without fuel!

Comparison with QI Theory

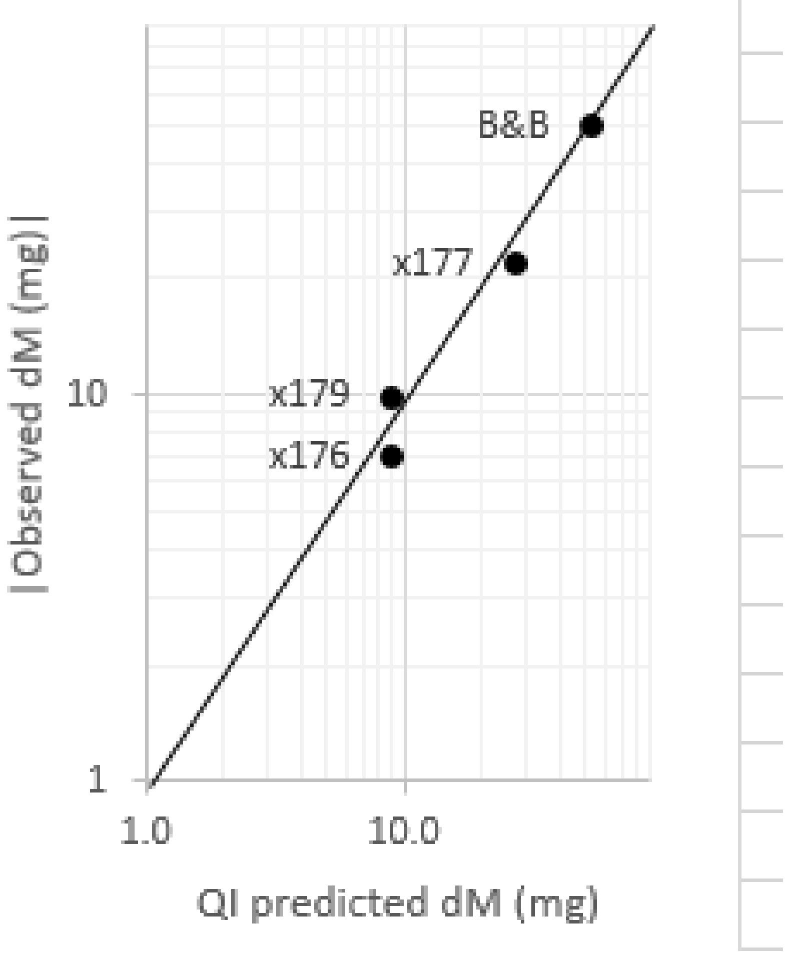


Initially comparison with QI was erratic (Jul-Sep, phase 1).

With the implementation of shielding, galinstan, Vitrek the results improved (phase 2).

With the addition of heating to >50degC results are now close to QI predictions (phase 3).

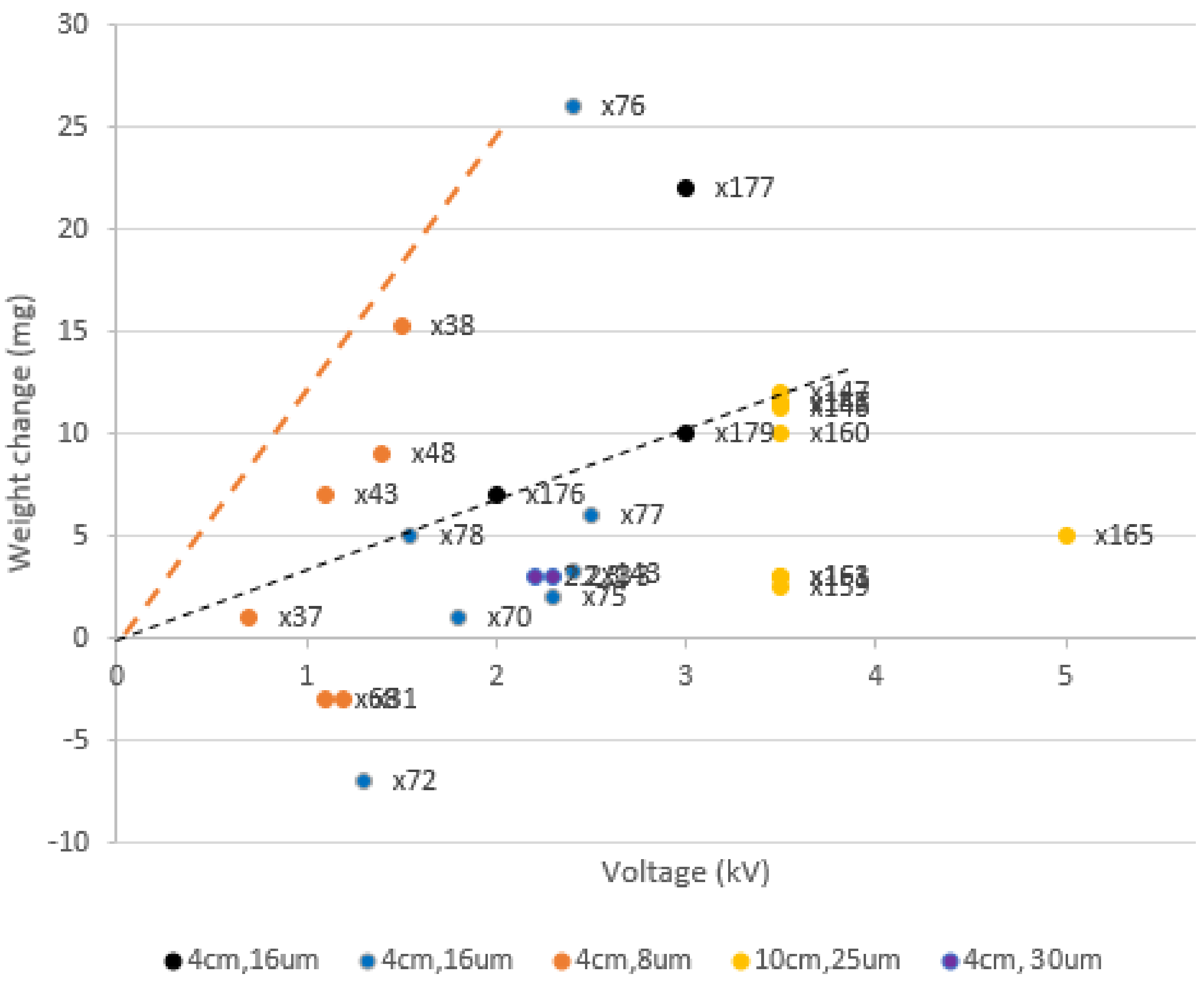
Comparison with QI & Other Tests



For the last few tests, which have included a better heating systems (as good as B&B's) we have results that are consistent with QI (see the line).

They also agree with the earlier test of B&B.

Testing the Result of Changing Separation



Given the predicted formula we should have more thrust with less separation, d, and more with more plate area (A).

$$F = \frac{0.00014IA}{d^2}$$

The black line shows the prediction for the heated 4x4 cm, 16 um capacitor. The data (black/blue dots) are close. The orange line shows the higher prediction for the 4x4 cm, 8 um plates. There is also reasonable agreement.

However, the larger plates (10cm, yellow) should produce more thrust…

Artifacts?

Buoyancy forces due to heating of air pockets have been excluded by flipping the capacitor.

Body forces were mostly excluded by the galinstan.

The **radiation pressure** (force) from a 42 W bulb is F=P/c = 0.014 mg. Observed = 10 mg

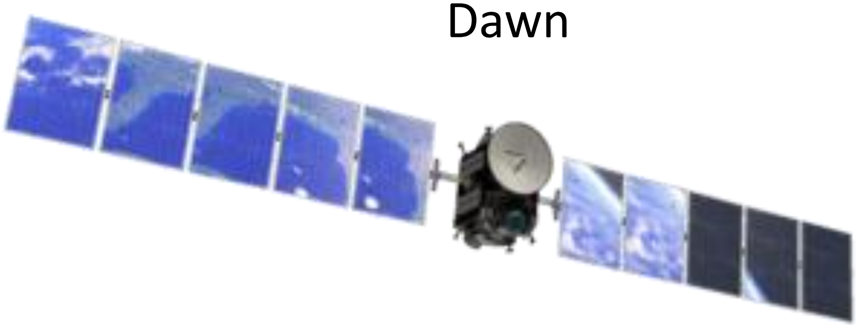
The force due to the **Earth's magnetic field** is F=Current x length x Mag field strength
$F{\sim}10^{-6} \times 0.15 \times 1{\sim}1.5 \times 10^{-7}N$. Observed = 0.0001 N

An **electrostatic force** was identified and subtracted from runs 106-150.
The other results were not affected.

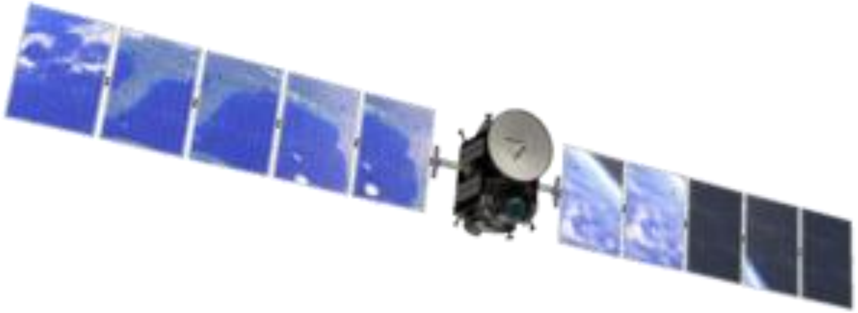
Magnetic interactions between wires have been calculated to be way too small.

Comparison with Dawn Ion-Drive Spacecraft

Dawn



Horizon 1



Its ion drive produced **90 mN**

Weight = 9 kg + 425 kg propellant = **434 kg**

Needed **2100 W** of power.

0-60 mph (27 m/s) in 1-2 days

We have seen ~**0.1 mN** (10mg) at Plymouth

Weight ~ **3 kg**, no propellant just a 3U cubesat.

Needs 1W.

0-60 mph (27 m/s) in 10 days

Applications of QI

Satellite station keeping and OOM

Lighter satellites to launch (no fuel)

Flying cars, all-electric aircraft.

Structures that hover.

Easier, cheaper, safer, silent launch.

Inertial damping – no whiplash

Energy from the vacuum.

Interplanetary trips become easier/cheaper (100 AU = 2 years)

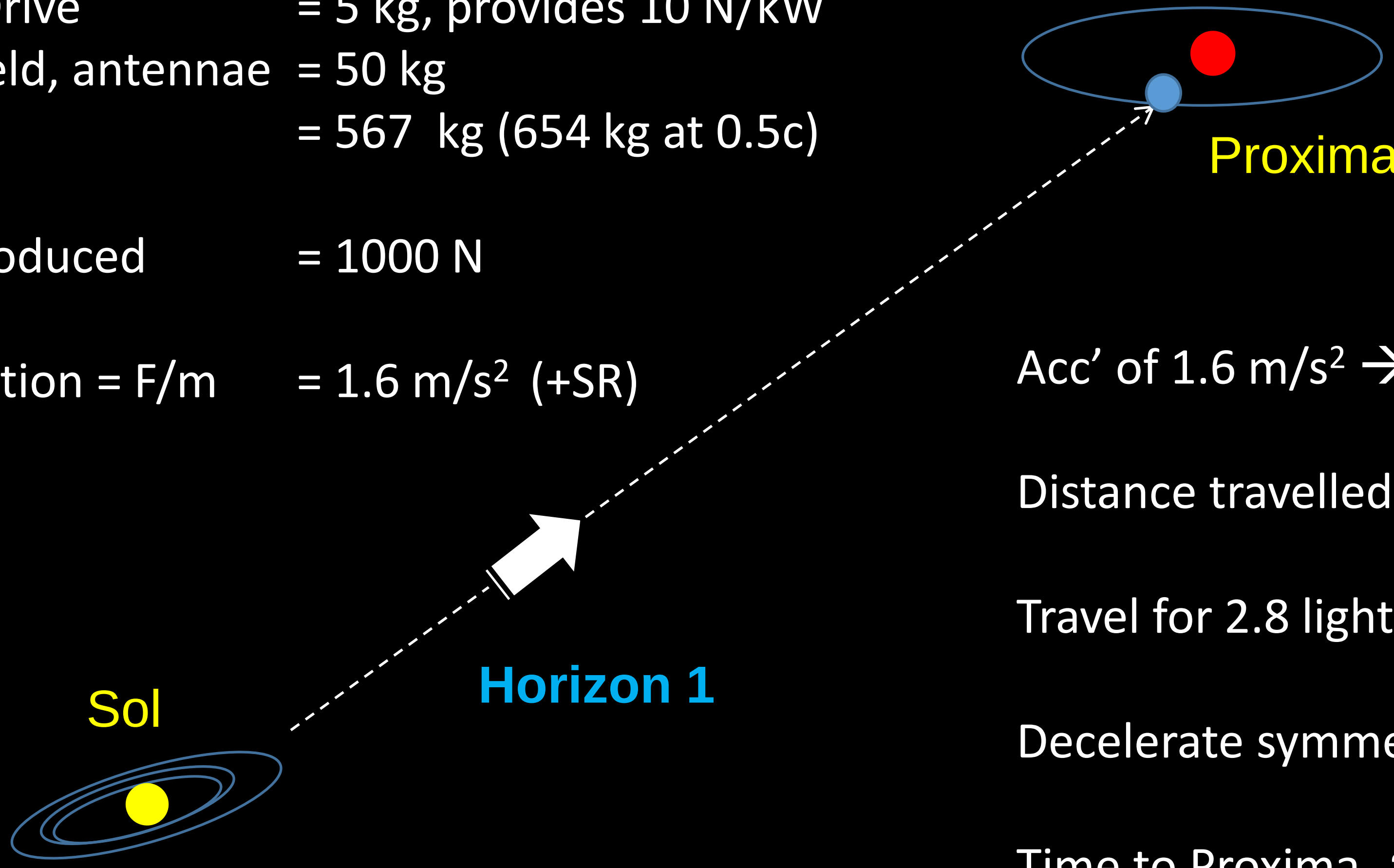
Interstellar trips possible in a human lifetime (propellant-less thrust)

QI Enables a Trip to Proxima Centauri in ~10 Years

SAFE-400 fission reactor = 512 kg, provides 100 kW (T. Taylor)
QI Horizon Drive = 5 kg, provides 10 N/kW
Camera, shield, antennae = 50 kg
Total = 567 kg (654 kg at 0.5c)

The force produced = 1000 N

The acceleration = F/m = 1.6 m/s^2 (+SR)



Acc' of 1.6 m/s^2 → 0.5c in 3 years

Distance travelled is 0.7 light years

Travel for 2.8 light years at 0.5c, 5.6 years

Decelerate symmetrically

Time to Proxima ~ 11.6 years (Earth time)
~ 10.6 years (ship time)

Conclusions

Quantised inertia is the first mechanistic model for inertial mass.

It predicts galaxy rotation without dark matter.

It is the first lab-testable cosmology.

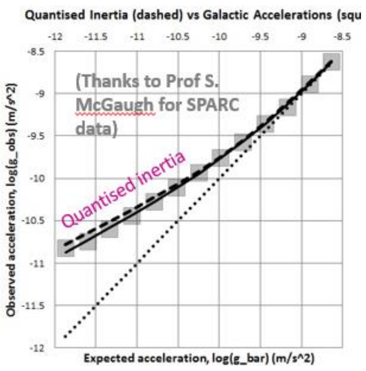
Offers a thrust application, good for OOM.

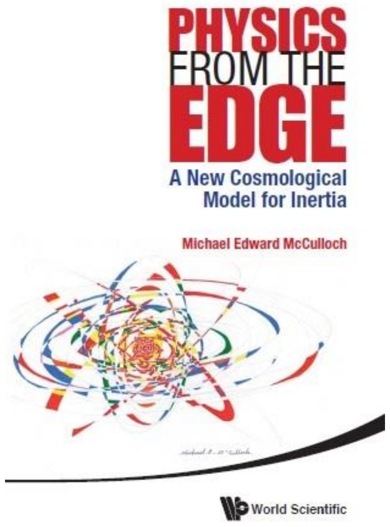
Enables interstellar travel in a human lifetime.

Lab tests have shown thrust (probably!).

The next stage is as yet unclear…

Any questions? My email is mike.mcculloch@plymouth.ac.uk
My blog and book are called 'Physics from the Edge'.





Summary

- Opportunities for Manufacturing Infrastructure In Space
- Significant Engineering Challenges Remain
- Opportunity for efficient propulsion via Quantised Inertia (QI)
- Testing at University of Plymouth for QI effects
- Ongoing developments!

Thankyou for listening – Happy to take questions!

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Questions & Discussion

APPENDIX ADDITIONAL OOM & QI SLIDES

OOMSAT Algorithm

OOMSAT Build V.1

OOMSAT – Basic Spacecraft Scenario

Scenario No.	**1**	**Small Spacecraft (I.e. Micro-Satellite)**
PPI. ID	**Parameter Title**	**Default Value**
[PPI-1-1]	S/C Wet Mass (kg)	50
[PPI-1-2]	S/C Freight % Allocation	80
[PPI-1-3]	Material Density (kg/m^3)	2710
[PPI-1-4]	Desired Pipe Length (mm)	1000
[PPI-1-5]	Outside Pipe Diameter (mm)	25
[PPI-1-6]	Pipe Wall Thickness (mm)	3
[TSP-1]	Spacecraft Propulsion ISP	1000
[TSP-2]	Total Delta V Required (km/s)	10
[SFWR-1]	Approx Cost of Propellant per kg	125
[SFWR-2]	Manuf. Plant Operating Cost Per Yield ($)	2750

Current Research Outputs

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OOMSAT:

On Orbit Manufacture

System Architecture Tool

OOM Capability

Manufacturing Techniques &

Processes For Space

1st Iteration OOM Concept

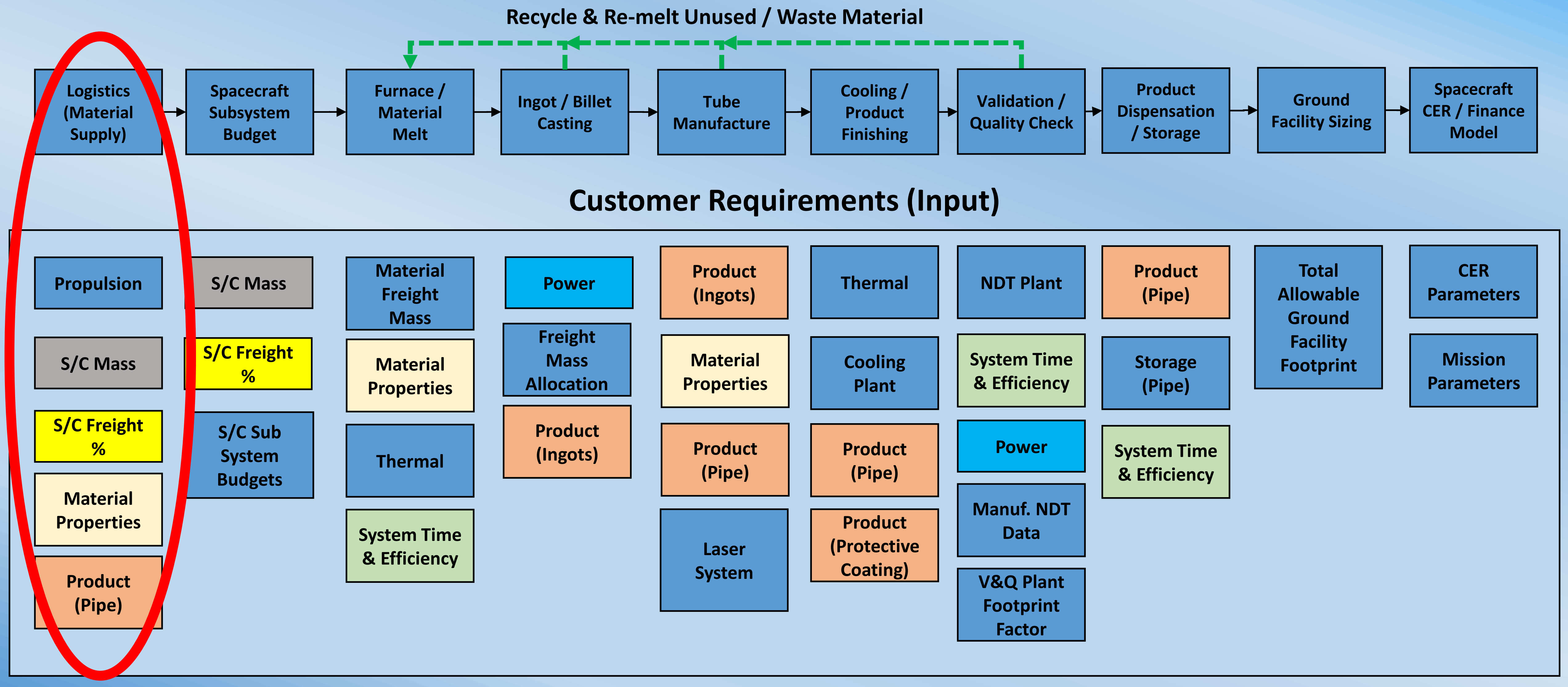
System Level Design for a

Potential OOM Facility

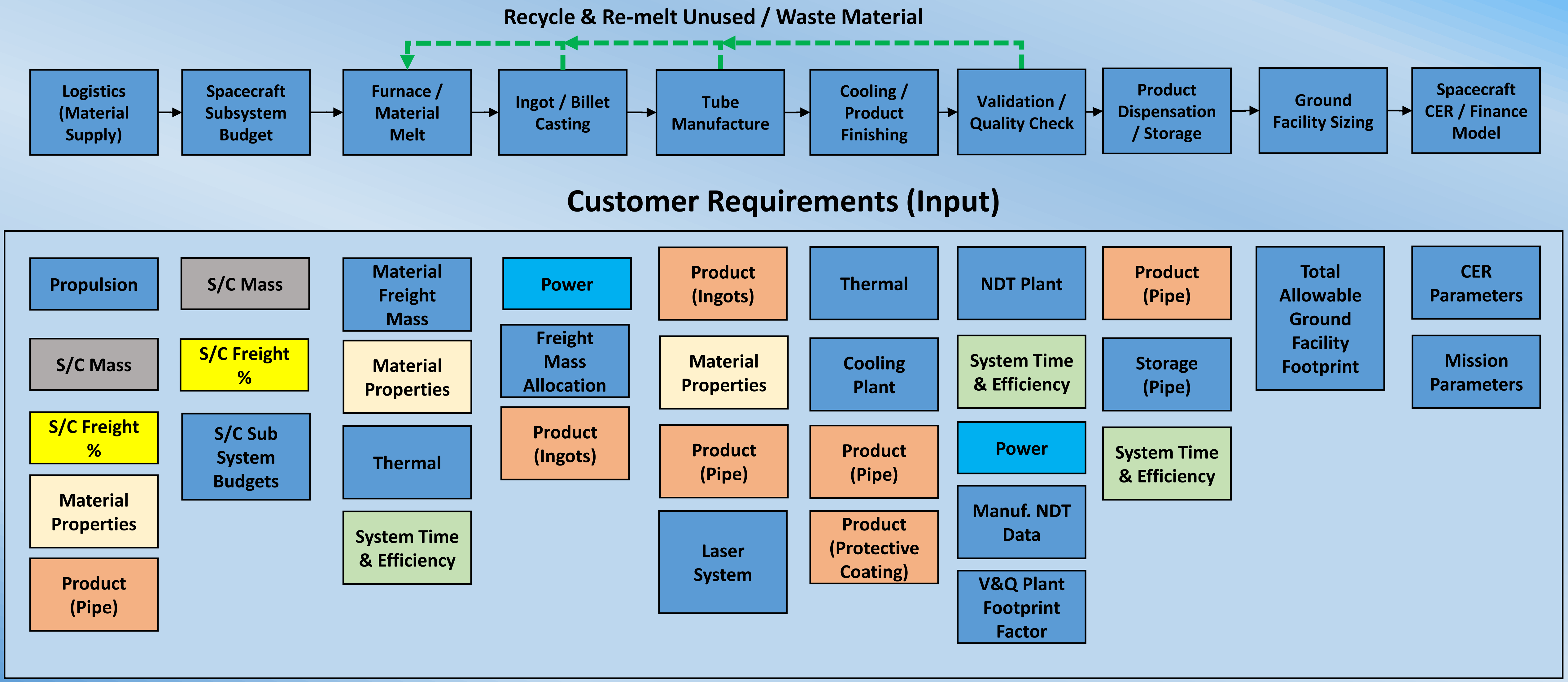
Opportunities

What Future Work Is There

OOMSAT: Tier 1 Calculation Algorithm (Build V.1)



OOMSAT: Tier 1 Calculation Algorithm (Build V.1)



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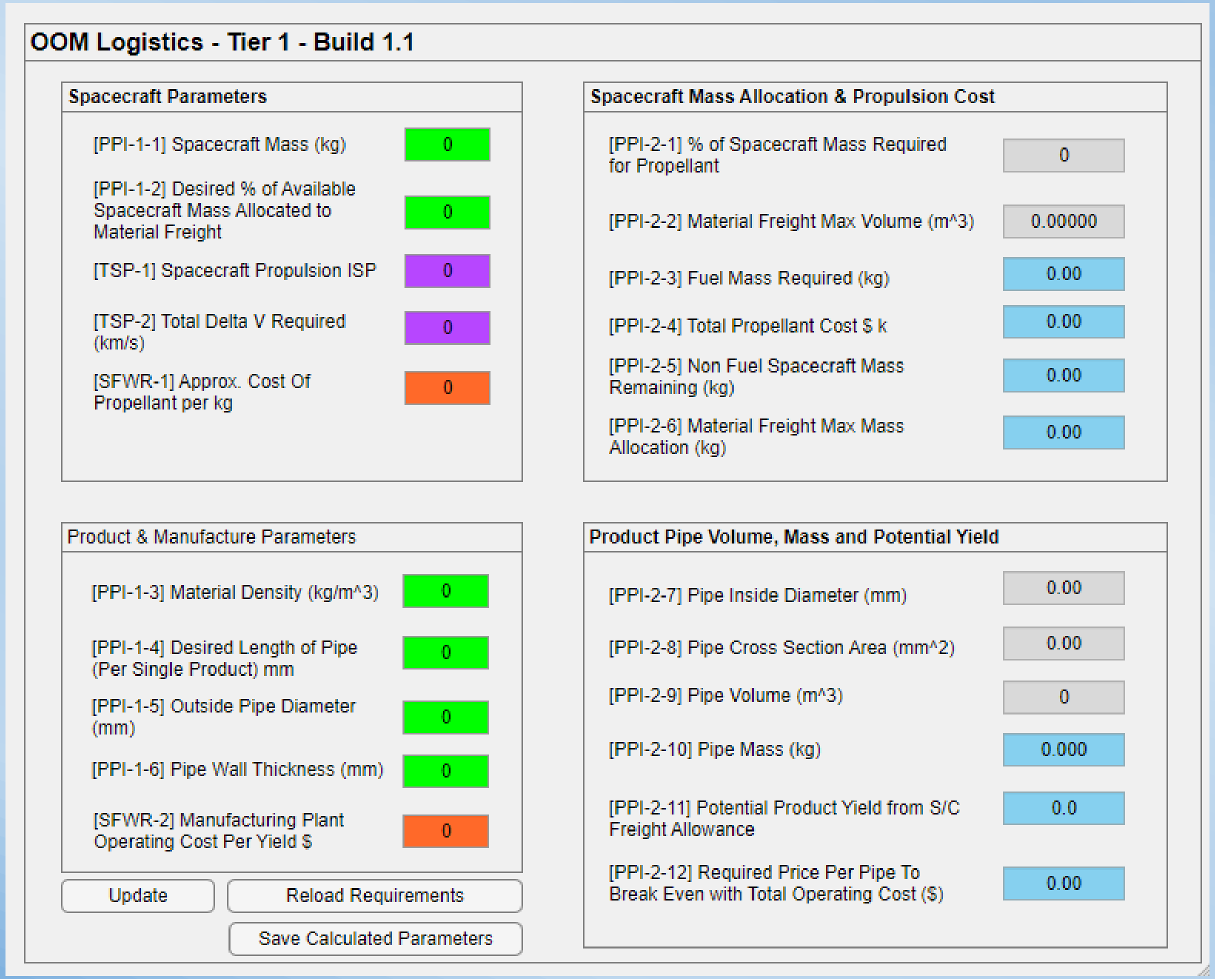
OOMSAT: Tier 1: Parameter Impact - Increases

Mission Cost Increase	
Freight Spacecraft Mass	Expected increase in mission cost due to freight S/C mass increases. This systemically applies as a larger spacecraft has a higher volume of spacecraft subsystem associated costs and being larger, can also transport more freight material for manufacture. This larger material volume then impacts on the manufacture process timings and cost, hence the expected increases.
ISP (Specific Impulse)	A significant jump in yield potential is mostly seen in the lower ISP ranges (200 to 600). After this, the yield potential still increases but the ratio is reduced, suggesting that there are diminishing returns after 600 ISP. Therefore, it could be considered that the greatest ratio for ISP / Yield is between 600 to 1200 ISP, where the yield is at least 10 products higher than the previous ISP band. Associated increase in mission cost was expected, due to the reduced fuel mass required (and therefore spacecraft subsystem budgets increase, therefore increasing the CER model cost calculations.) The total manufacture time increased in line with product yield, as expected (more products = more process time).

OOMSAT: Tier 1: Parameter Impact - Decreases

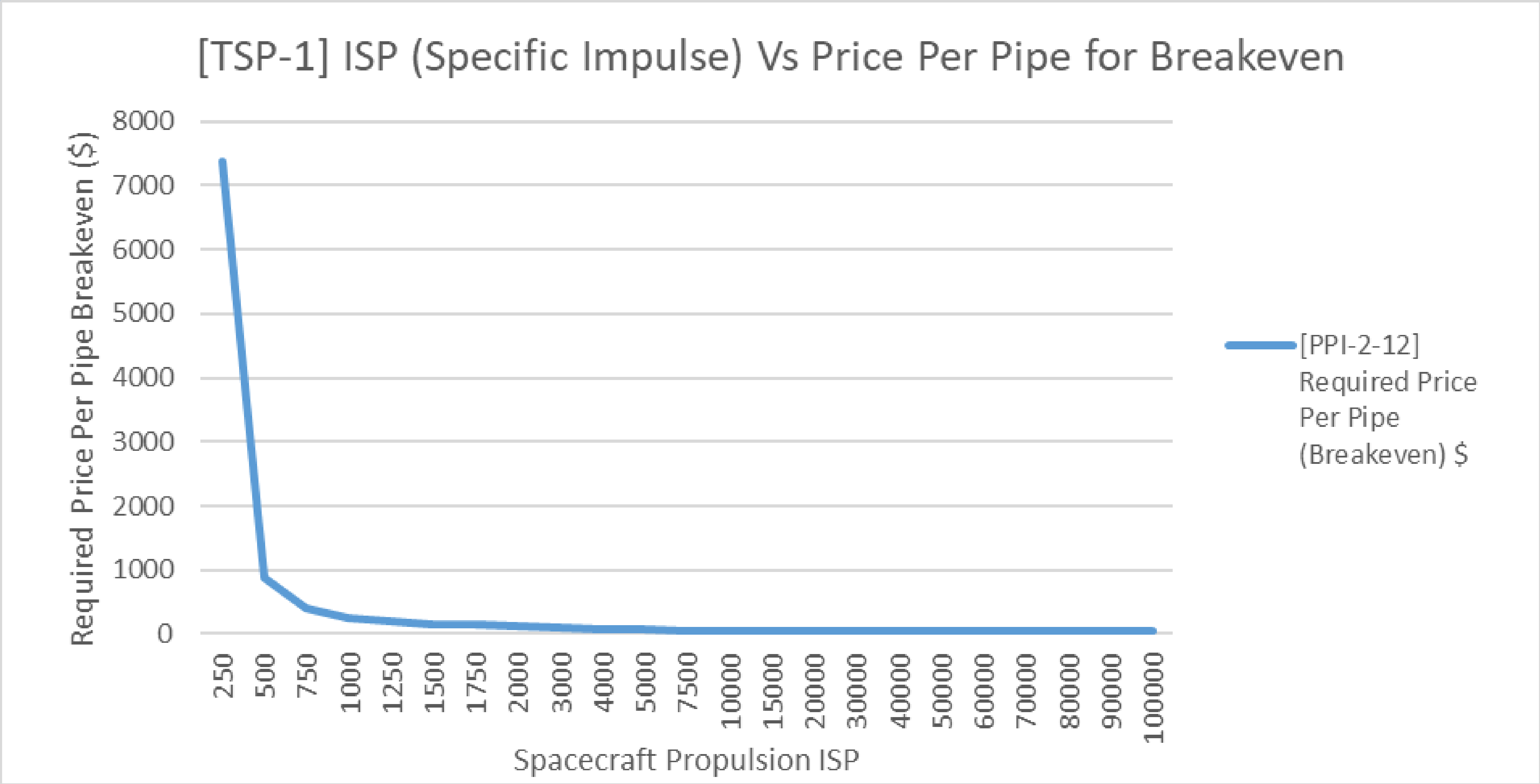
Mission Cost Decrease	
Increase in Delta V	As the S/C system payload % budgets remain fixed and as the Delta V increases, more fuel is required and therefore reduces the mass (and volume) of the other subsystems, which therefore drives down costs. With the current OOMSAT build (V1 Mar 2022), it can therefore be considered that the cost of propellant offsets the cost of having more permanent, expensive subsystems.
Increase in Product: Pipe / Tube Length	Increases in product length has an expected overall reduction in cost, product yield and manufacture time. Significant time savings can be achieved in manufacture processes such as validation and quality checking. The yield reduction is expected because the products are "larger" and therefore each item uses more of the available material. The operational cost also sees expected decreases because of the reduced number of products that requires manufacture. In this iteration of the OOMSAT, timing per product is calculated.
Increase in Spacecraft Freight Payload Mass %	Expected decrease in mission cost as payload mass % increases due to the structure of the OOMSAT calculation for spacecraft subsystems. At this iteration of the OOMSAT, the freight payload system is not explicitly modelled and is considered as a simpler entity compared to other, more expensive S/C subsystems. Therefore, by virtue of increase freight mass %, this reduces available mass for the S/C subsystems and therefore cost. A linear increase in yield and therefore manufacture time was also expected - more freight payload = more product manufacture opportunity and therefore longer total manufacture time.

OOMSAT – Logistics App Build V.1.1

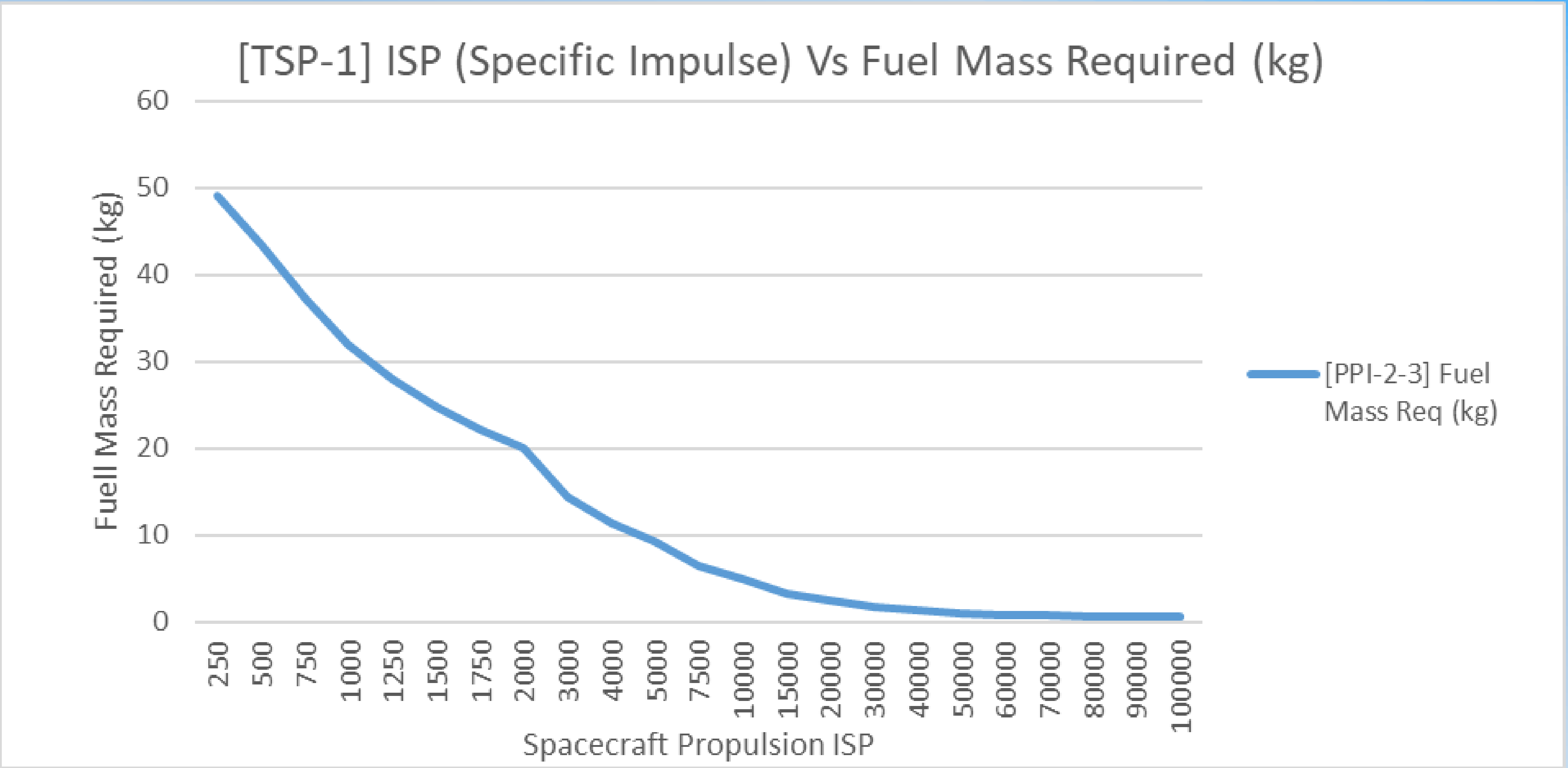


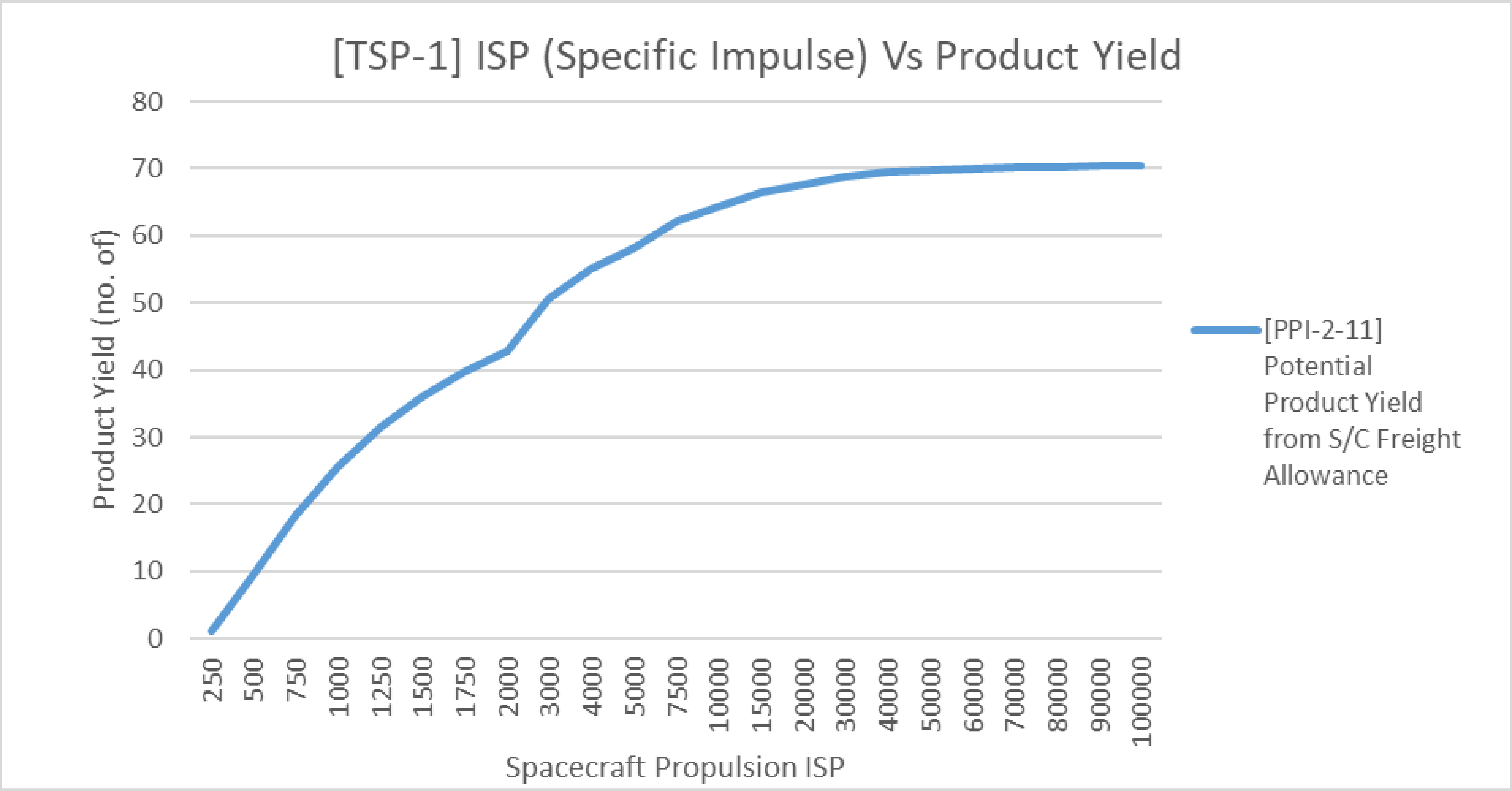
The OOM Logistics (OOMLOG) is the first application that is run during the Tier 1 OOMSYNC algorithm. Its purpose is to calculate the potential mass allocation of an OOM Freight spacecraft in terms of propellant, subsystems and OOM material freight. It also provides an approximate price / value of the product vs the freight characteristics. It achieves this as a combined function of:

- required Delta V for the spacecraft journey
- associated propulsion requirements for the freight spacecraft
- OOM product specifications
- The operating cost of the manufacturing plant



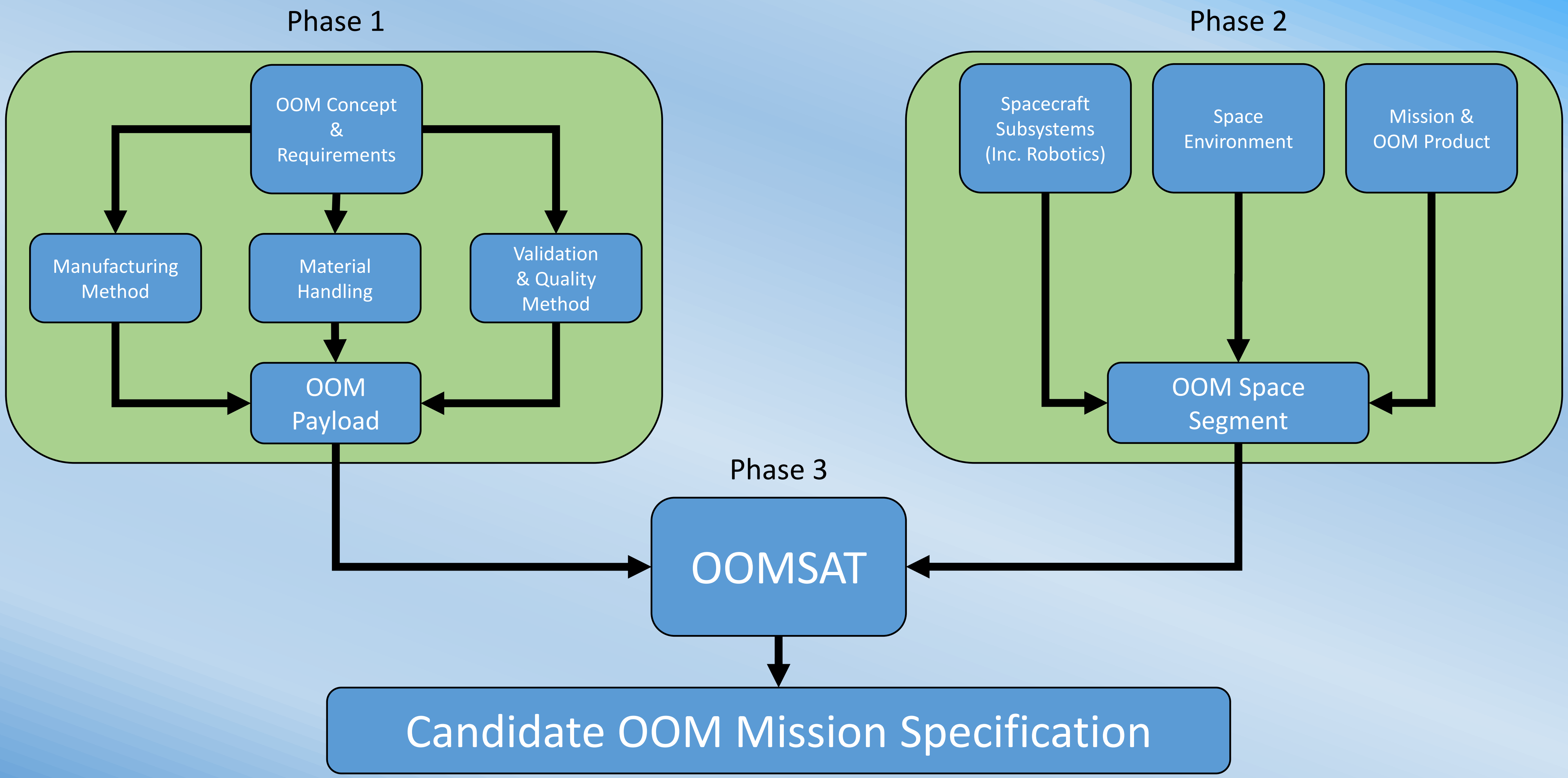
[TSP-1] ISP (Specific Impulse) Vs Price Per Pipe for Breakeven
Required Price Per Pipe Breakeven ($)
8000
7000
6000
5000
4000
3000
2000
1000
0
250
500
750
1000
1250
1500
1750
2000
3000
4000
5000
7500
10000
15000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Spacecraft Propulsion ISP
[PPI-2-12] Required Price Per Pipe (Breakeven) $


[TSP-1] ISP (Specific Impulse) Vs Fuel Mass Required (kg)
60
50
40
30
20
10
0
Fuell Mass Required (kg)
250
500
750
1000
1250
1500
1750
2000
3000
4000
5000
7500
10000
15000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Spacecraft Propulsion ISP
[PPI-2-3] Fuel Mass Req (kg)

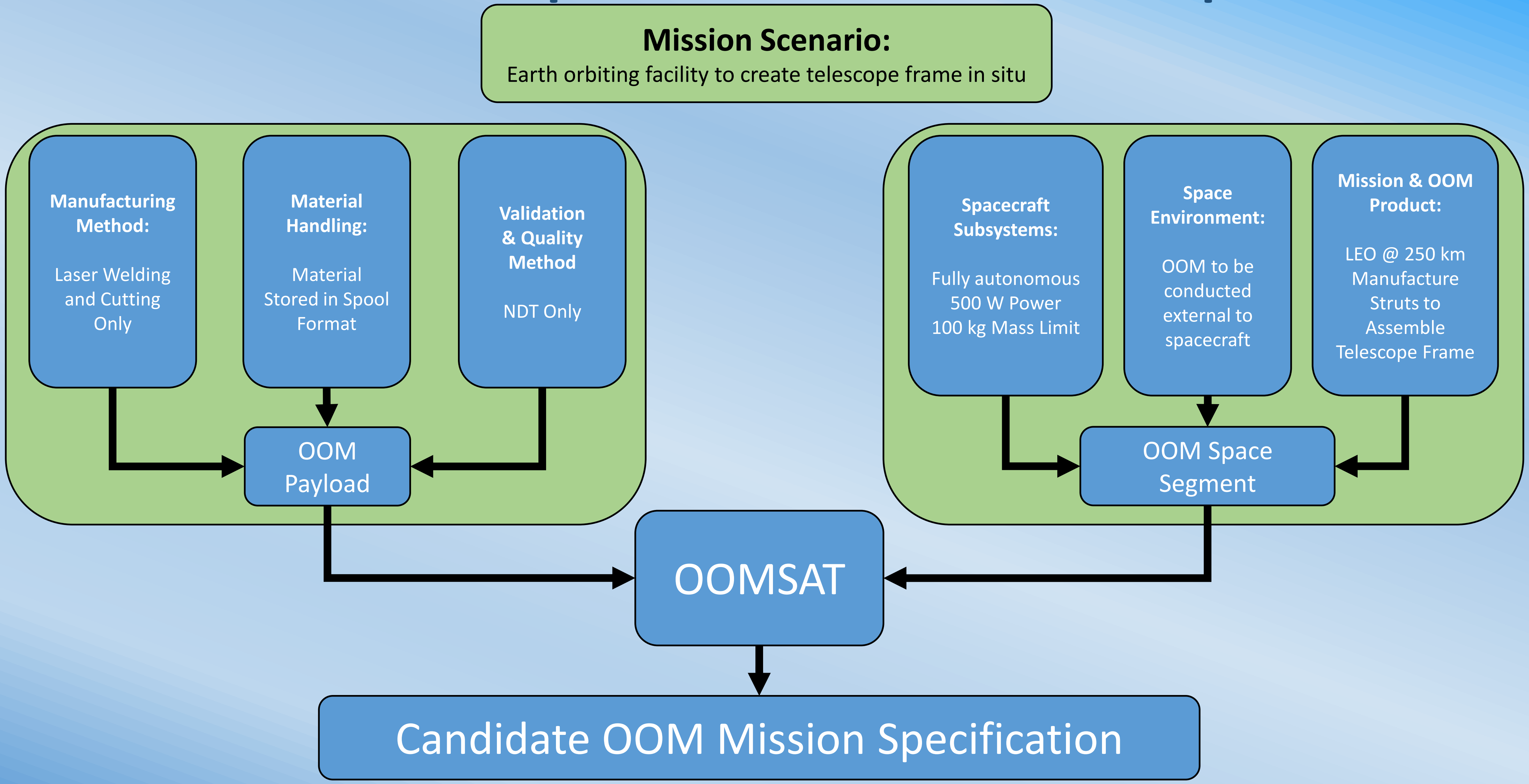


[TSP-1] ISP (Specific Impulse) Vs Product Yield
Product Yield (no. of)
0
10
20
30
40
50
60
70
80
250
500
750
1000
1250
1500
1750
2000
3000
4000
5000
7500
10000
15000
20000
30000
40000
50000
60000
70000
80000
90000
100000
Spacecraft Propulsion ISP
[PPI-2-11] Potential Product Yield from S/C Freight Allowance

Research Roadmap



Mission Specification Example 1



Mission Specification Example 2

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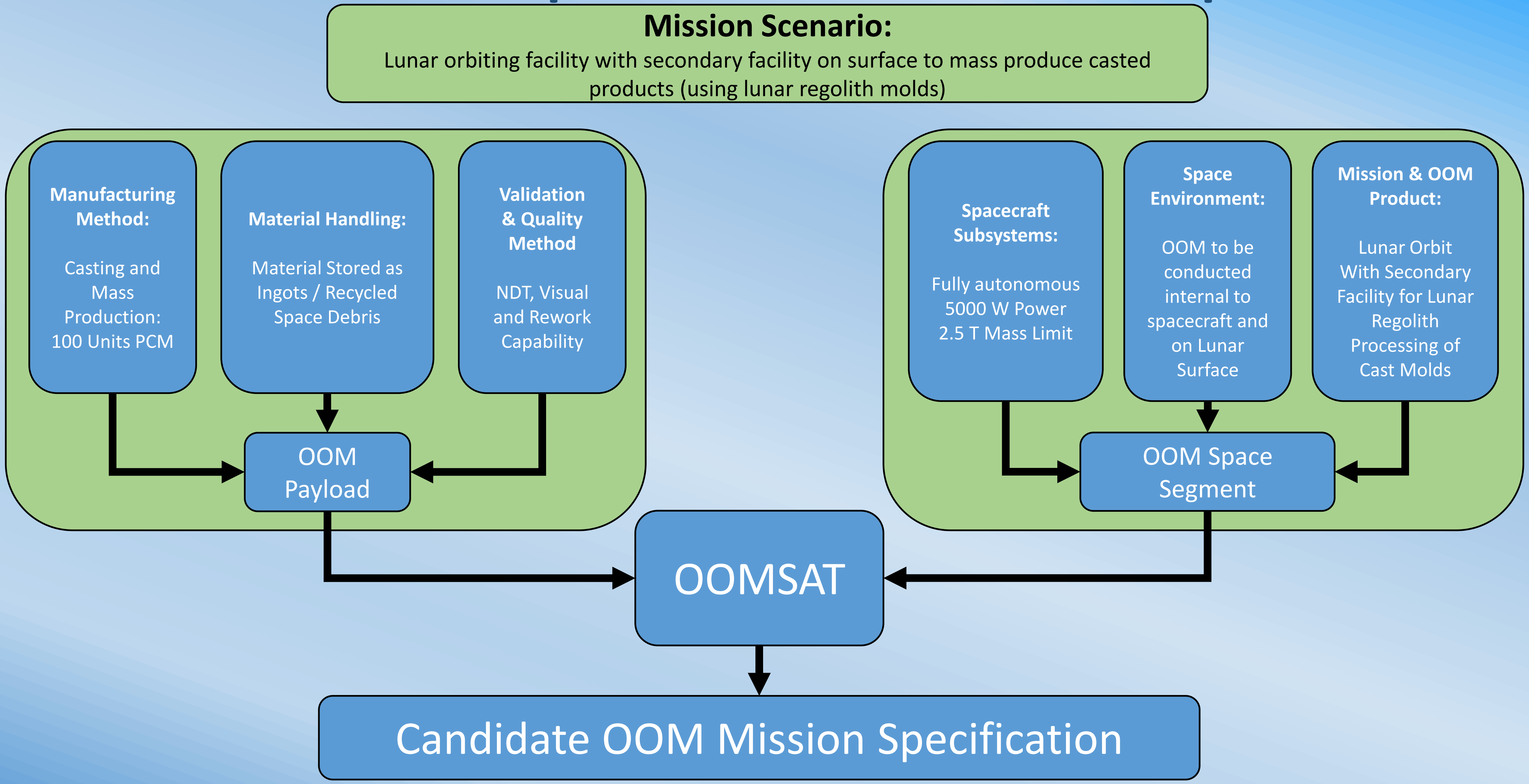

OOMSAT Development Example

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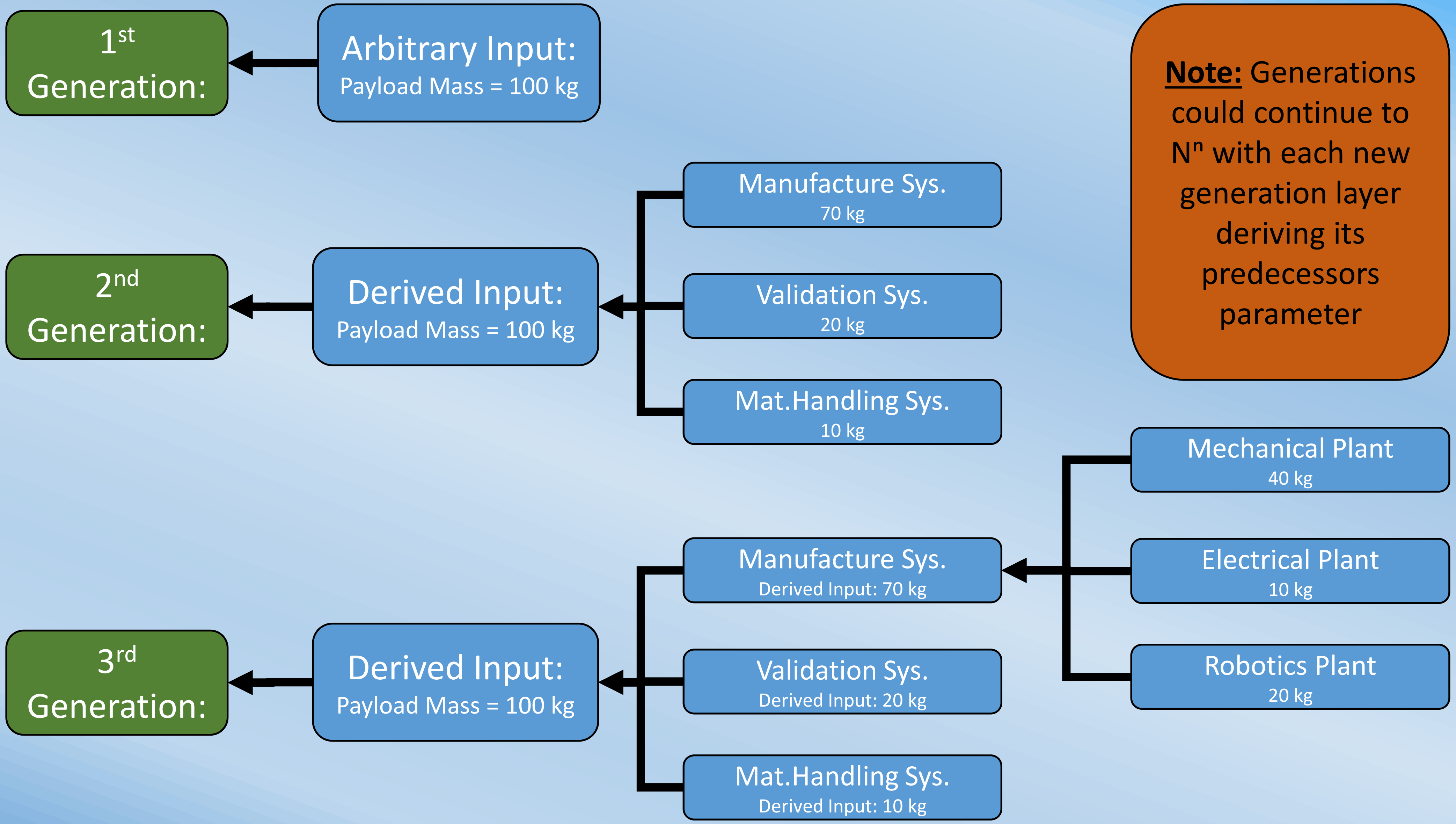
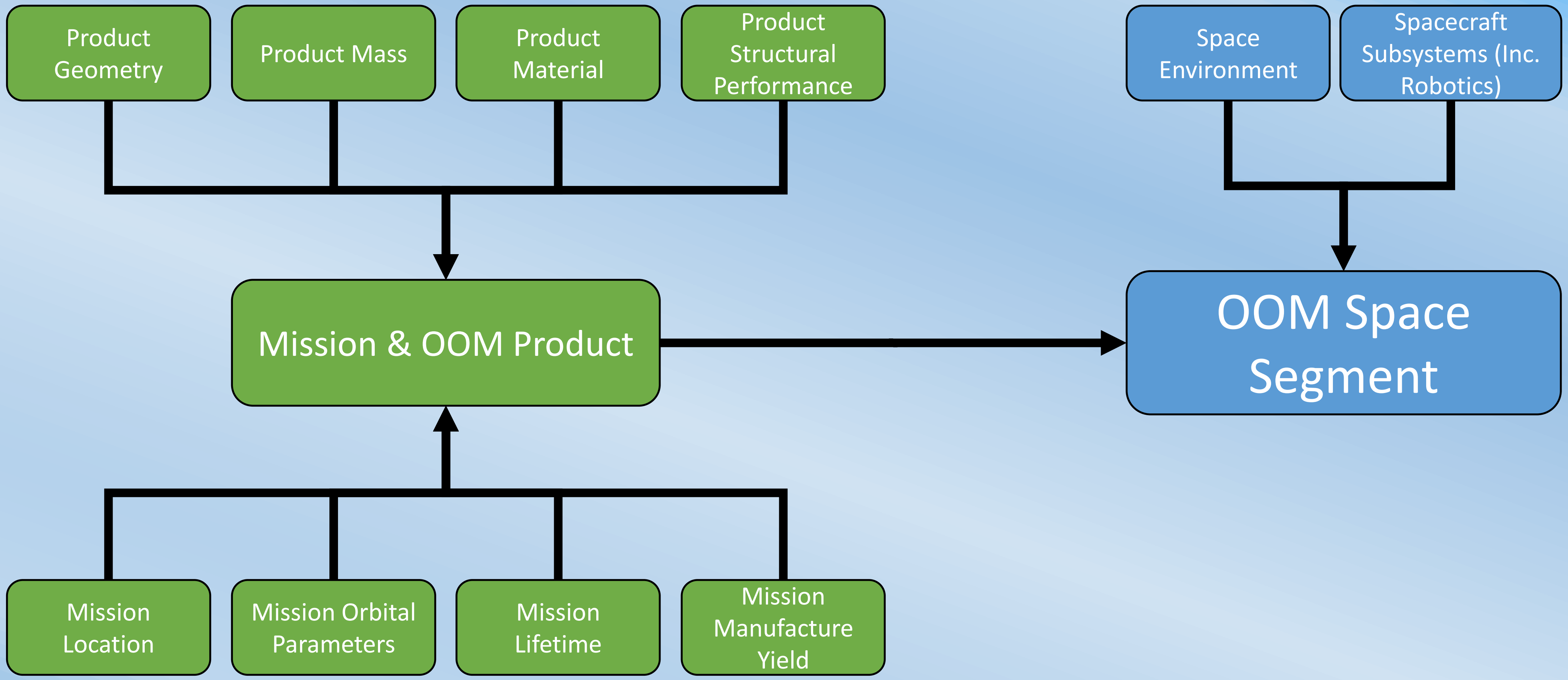


Product Requirements / Definition



Manuf. Method Efficiency Drivers