IoE Research Centre on Extra-Terrestrial Manufacturing (ExTeM)

Webinar – Exploring the Opportunitis and Utilizing Space for Scientific Research
Organized by Vellon Space

23 May 2024

https://www.visualcapitalist.com

We have transformed earth to this

Can we transform the Moon’s surface? Mars’?

Images from various web sources

Think about what India can do in Space today …

Today we make satellites in earth facilities…

… and launch them

We are trying to get loser to Sun!

Images from various web sources

We have done this

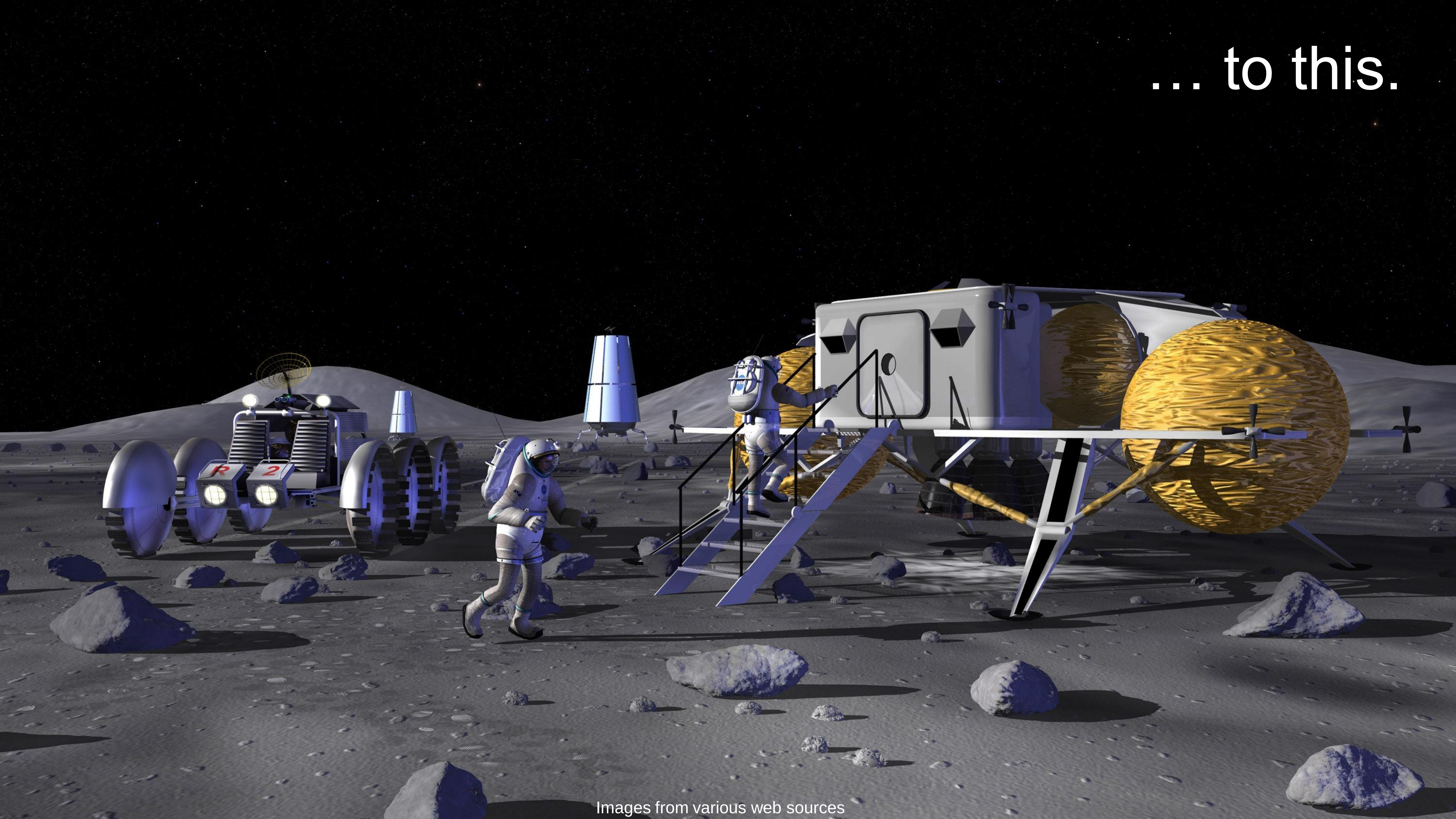
Images from various web sources

What India can do in Space further … in the future?

So that we can go from this …

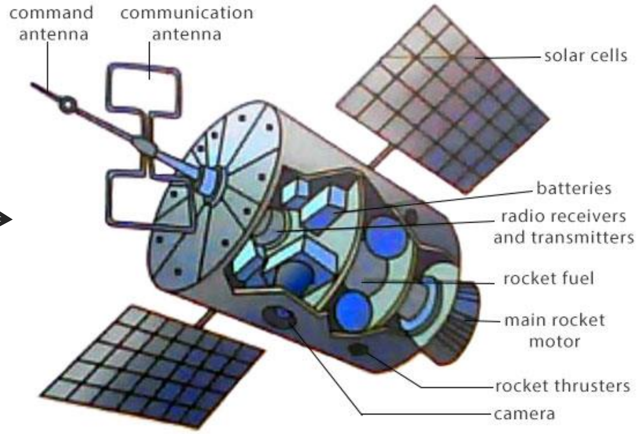
Images from various web sources

… to this.



Images from various web sources

Tomorrow, we could launch only raw materials



Use these to manufacture & assemble parts, in **on-orbit factories**, into functional satellites

Or, we use raw materials already available there !!

Images from various web sources

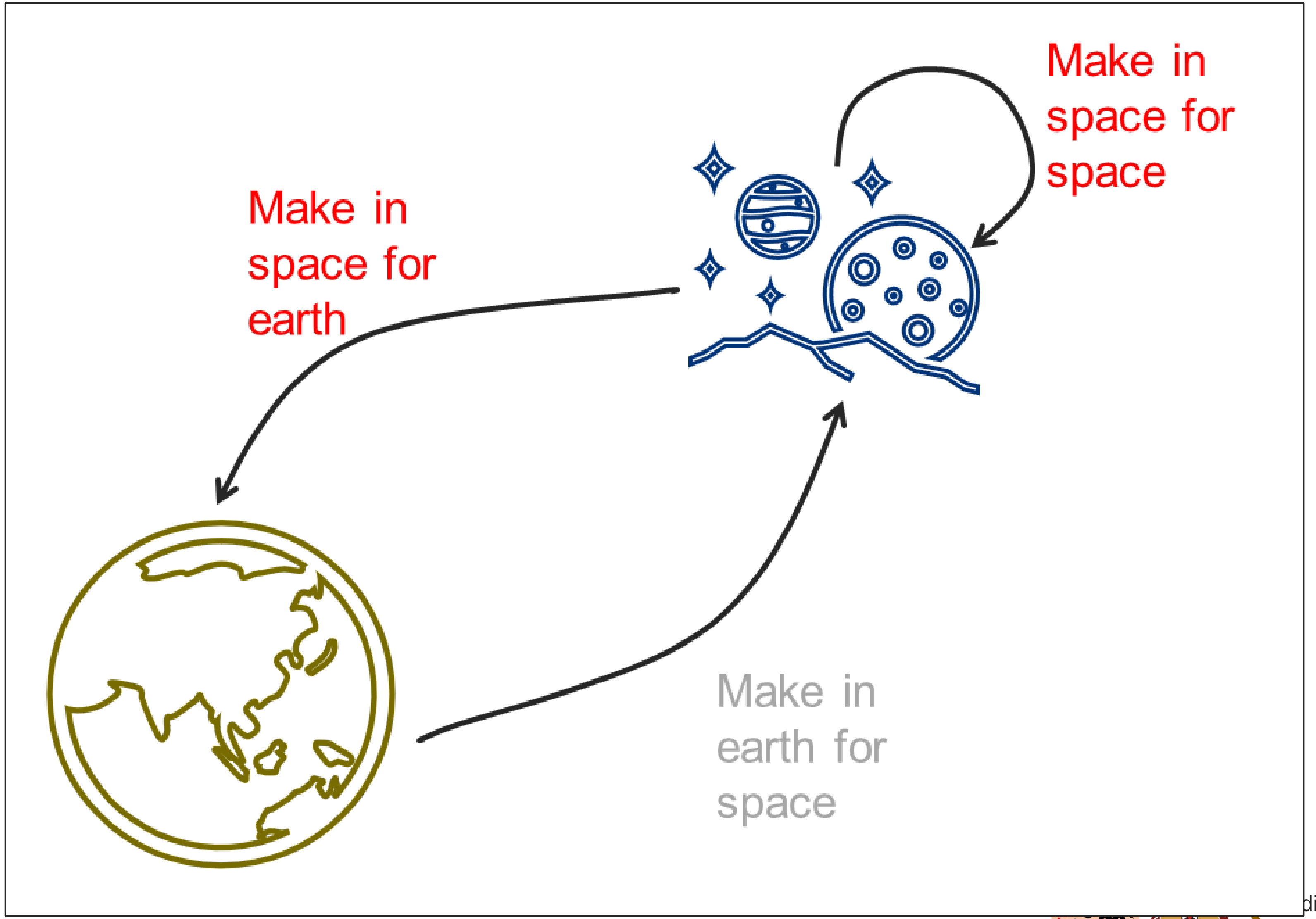
Space 2.0 and Manufacturing (in-space)

- Space 1.0: launching rockets, satellites, unmanned missions to sun, venus etc.
- Era of Space 2.0: exploring outer space involves long human missions, creating settlements in faraway locations (Moon, Mars), and exploiting partial gravity, commercializing space
- These require extra-terrestrial manufacturing capability
- The center will develop ability to safely manufacture components, assemblies, and biologicals in outer space for use in space and back on Earth.
- The manufacturing technologies needed in space differ from the earth-based ones due to limited resources (space, energy, water, materials), micro/partial gravity, and recycling.

New acronyms

- In-Space Manufacturing (ISM)
- In-Space Assembly and Manufacturing (ISAM)
- In-Space Service, Assembly and Manufacturing (ISSAM)
- On-orbit Service and Manufacturing (OSM)
- Extra Terrestrial manufacturing (ExTeM)

Space related manufacturing



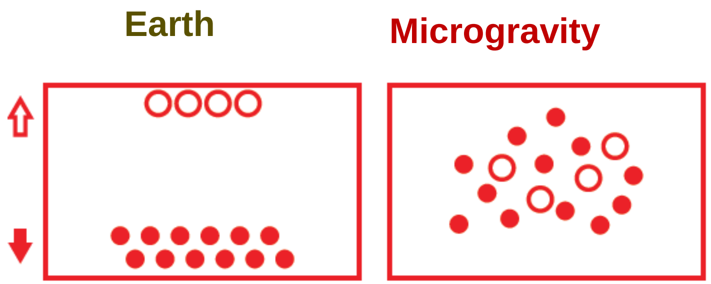
Space Vs. Earth - Boundary conditions

1. Microgravity

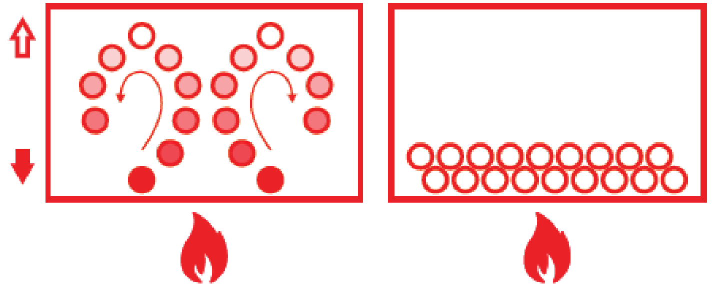
Effects

i. Absence of sedimentation
ii. Absence of natural convection
iii. Absence of hydrostatic pressure
iv. Absence of buoyancy forces
v. Domination of surface tension effects

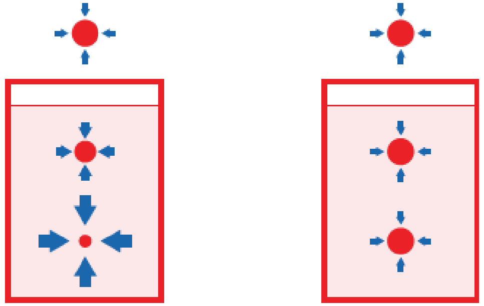
Source: Stanford University Workshop on Semiconductor Manufacturing in the Space Domain, 2023 [2]



Sedimentation



Natural convection



Hydrostatic pressure

2. Temperature extremes

Effects

- Fluctuations due to the position of spacecraft facing towards and away from the sun
- Fluctuations due to the surface topography of Moon

3. Vacuum environment

Effects

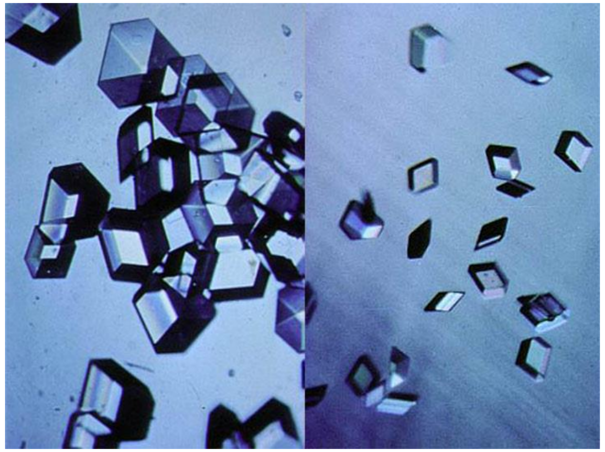
- Lower sublimation temperature of metals
- Outgassing of polymeric materials, paints and solvents

Positive impact of microgravity

Absence of crystal growth

Bulk metallic glasses like ZBLAN

Source: Factories in space



Manufacturing of semiconductors in space

Source: ISS National Laboratory

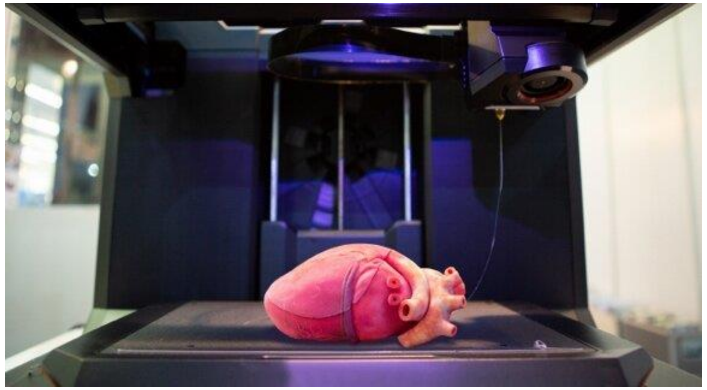
Growth of protein crystals for pharmaceuticals

Source: ISS National Laboratory

Manufacturing of novel superalloys in space

Source: Axiom space

Absence of hydrostatic pressure



Printing of Biological organs

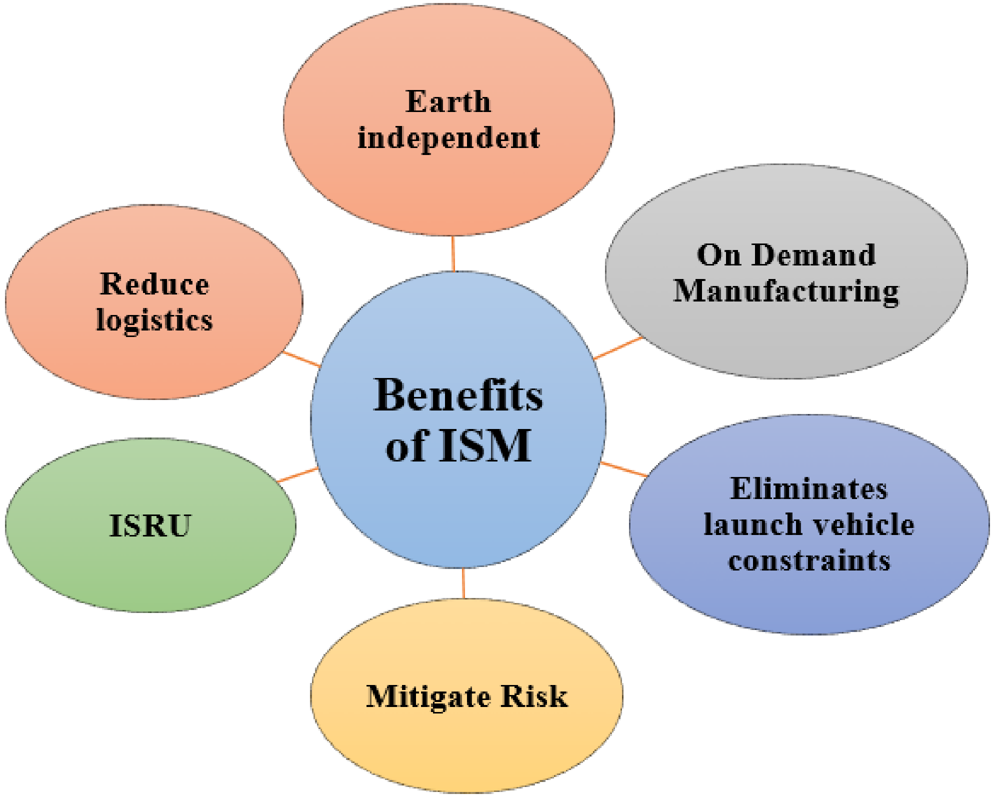
Source: Axiom space

Containerless processing

- Shape control using electric, magnetic and acoustic fields
- Better microstructure because of absence of container walls
- Precise measurements of thermophysical properties of liquid melts

In-space manufacturing (ISM)

Definition of ISM: According to Skomorohov et.al, 2016, ISM encompasses any endeavor which takes place outside of the Earth's atmosphere and which performs any of these three activities: fabrication, assembly, and integration.



Various benefits of ISM

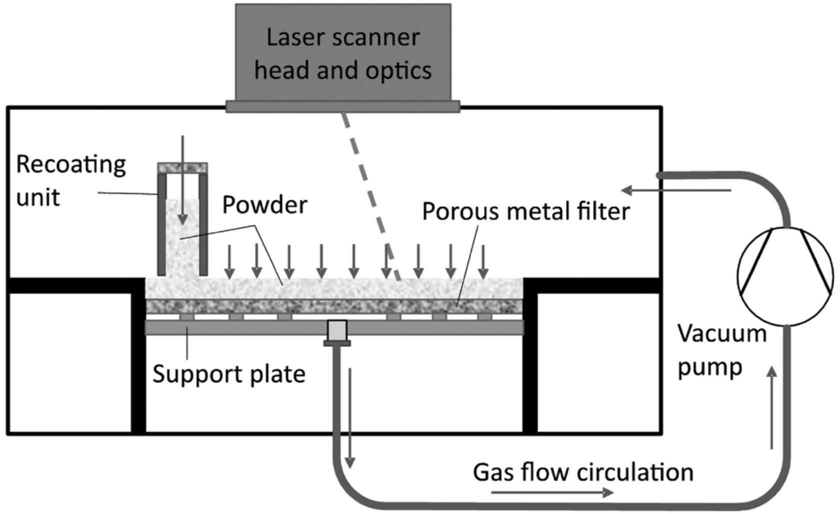
A framework for ISAM *Source: Malshe et al., 2023 [1]*

Constraints on In-Space Manufacturing processes and machines

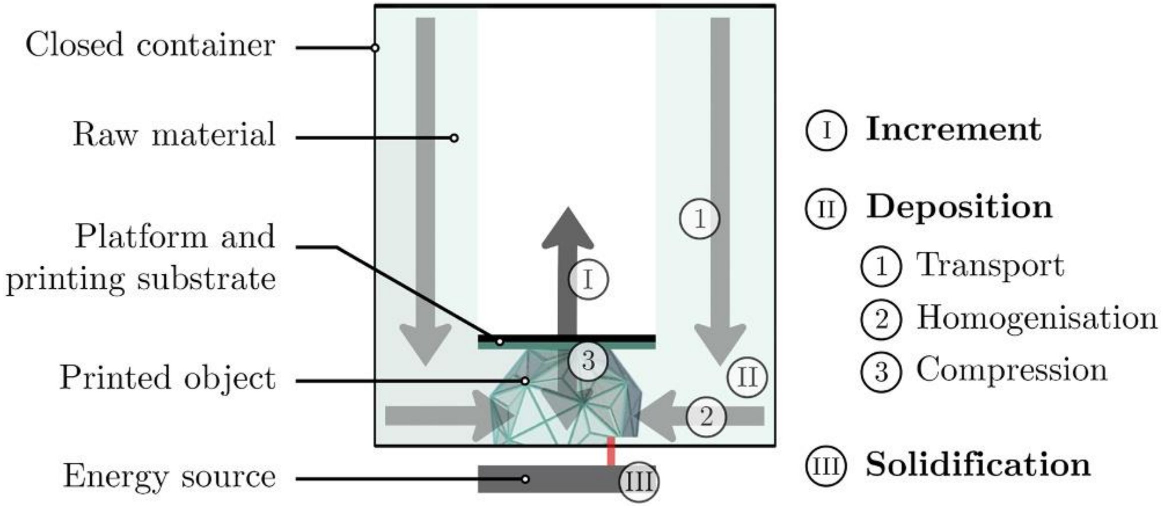
Constraints

- Material scarcity – recycling, repurposing, refurbishment, direct use of feedstock
- Multi-manufacturing processes
- Wide variety of materials
- Multi-manufacturing processes
- Low mechanical force
- Size, Weight and Power (SWaP) allocation
- Greater autonomy and teleoperation constraints
- Debris free machining, devoid of sparks/fumes and highly reliable/safe

Special machines and processes for microgravity

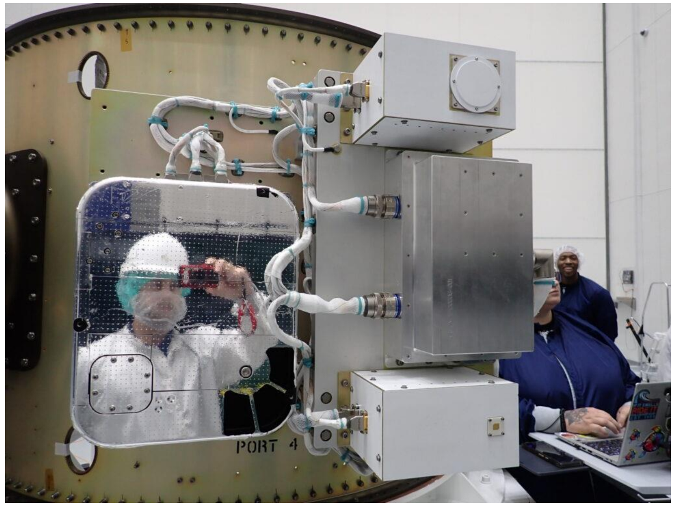


Source: Zocca et al., [3]



Source: D' Angelo et al., [4]

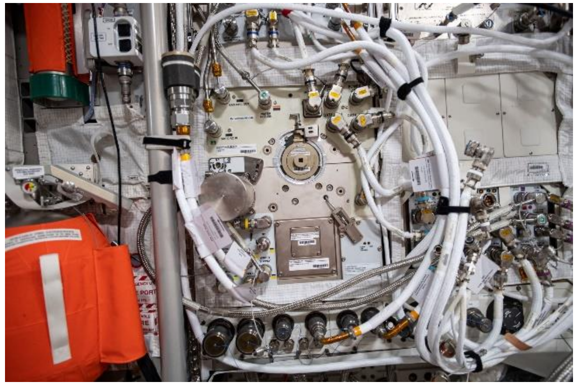
Setup for Powder Bed Fusion technique in microgravity



Debris free machining in microgravity

Source: Voyager space

Containerless processing – for precise measurements of thermophysical properties of liquid metallic alloys

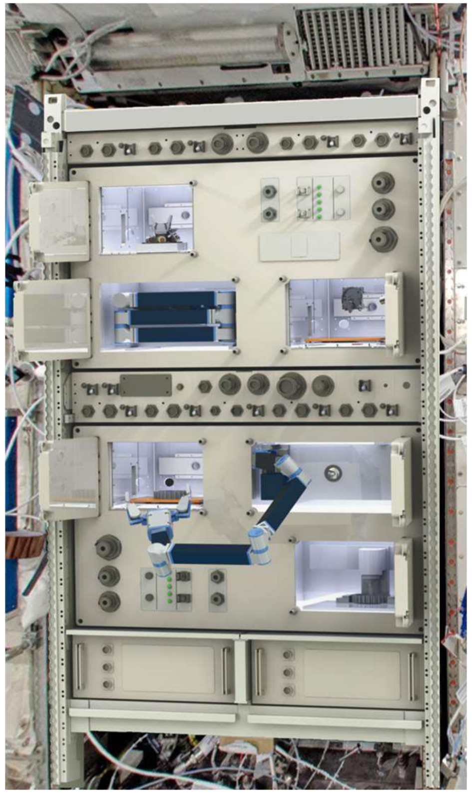


Electromagnetic levitator inside ISS

Source: European space agency

Size, Weight & Power constraints - ISM equipment design

Multi-material processing technique – Fabrication of metals, plastics, ceramics and electronics within a single manufacturing equipment



Tethers Unlimited Inc- FabLab.

Source: Prater et al., (2018)

Hybrid manufacturing processes – Multiple manufacturing processes included within an ISM machine

Made in space "Vulcan" – integrates Additive manufacturing and CNC machining

Source: Prater et al., (2018)

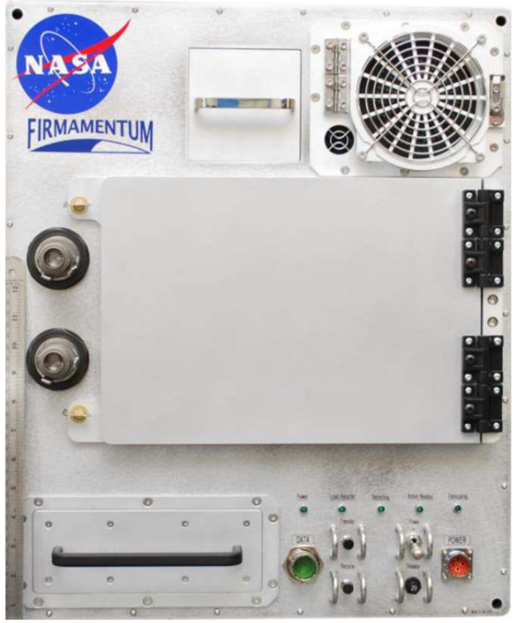
Highly energy-efficient manufacturing processes like Blue laser based Additive manufacturing

Key metals	Blue to IR Absorption Ratio
Gold	66 X
Silver	17 X
Copper	13 X
Aluminium 1100	3 X
Nickel	1.5 X
Steel	1.5 X

Source: Aerospace Manufacturing and Design

ISM - Material recycling and in-situ resources

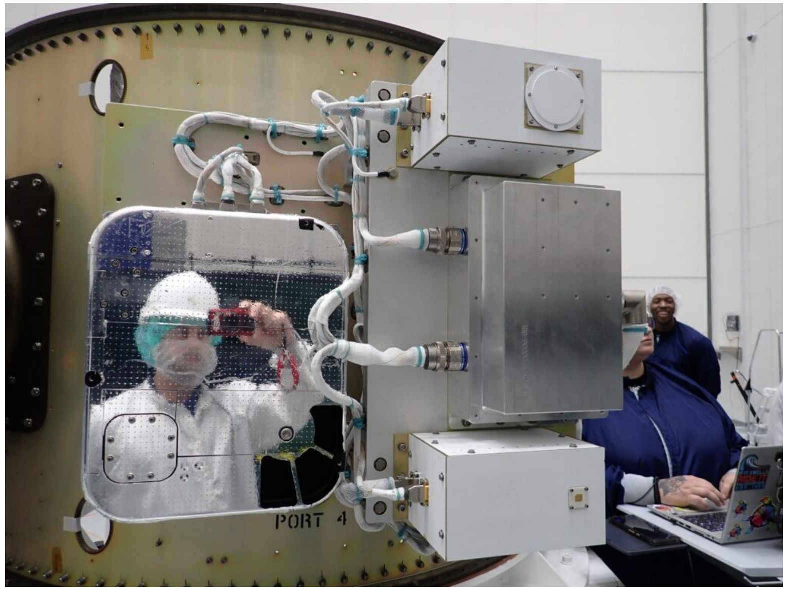
Material recycling



Refabricator for recycling of plastics

Source: Prater et al., (2018)

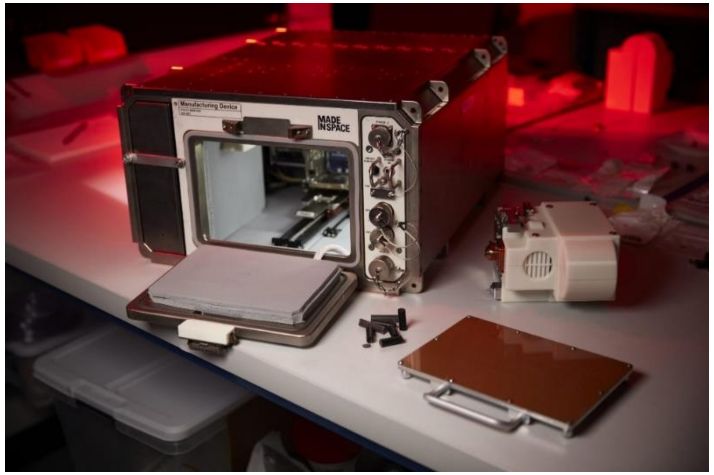
Recycling of upper stages of rocket into outposts for habitat



Nanoracks OMD-1 mission using friction milling tool

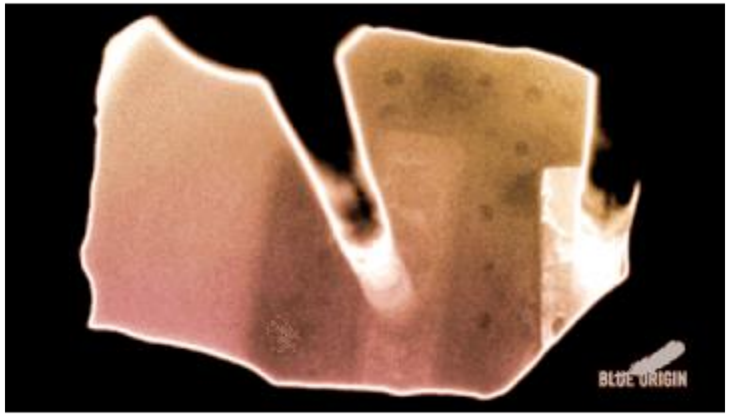
Source: Voyager space

In-situ resources on Extra-terrestrial bodies



Redwire Regolith Print

Source: Redwire space



Solar cell prototype

Source: Blue Origin

AM technologies for Lunar base - Assessment

The following information has been collected for each of the AM processes:

- Processed materials
- Core elements
- Feedstock form
- Build environment
- Means to consolidate the part
- Post processing
- Mandatory post-processing infrastructure
- Recycling
- Unbound material recycling
- Printed parts recycling
- Recycling infrastructure
- Power
- Part dimensional accuracy
- Max build volume
- Parts features
- Pre-production infrastructure
- ISRU infrastructure
- Lunar environmental impact
- TRL (Technology Readiness Level)

AM Process ranking:

1. Fused Filament Fabrication (FFF)
2. Continuous Filament Fabrication (CFF)
3. Contour Crafting (CC)
4. Big Area Additive Manufacturing (BAAM)
5. Atomic Diffusion Additive Manufacturing
6. Laser Metal Deposition
7. Fiberoptic Solar Concentrator/Solar Sintering
8. Wide and High Additive Manufacturing
9. Selective Separation Sintering
10. Binder Jetting
11. Material Jetting
12. Direct Ink Writing
13. Laser Engineering Net Shaping
14. Supersonic 3D Deposition
15. Ultrasonic Consolidation
16. Electron Beam Freeform Fabrication
17. Selective Laser Sintering
18. Magnetojet
19. Electron Beam Additive Manufacturing
20. Electron Beam Melting

AM Technology	Lunar Gravity
Material extrusion	Printed part will be strengthened by microgravity effects on material sedimentation and crystallization
VAT Photopolymerization	Requires additional control measures to maintain a flat liquid photopolymer bed
Powder bed fusion	Requires additional control measures to maintain a flat powder bed
Material jetting	Precise droplet deposition requires additional calibrations and controls
Binder jetting	Requires high degree of control to prevent powder clouding and liquid blobbing
Sheet lamination	Not affected by Lunar gravity
Direct Energy Deposition	Printed part will be strengthened by microgravity effects on material sedimentation and crystallization

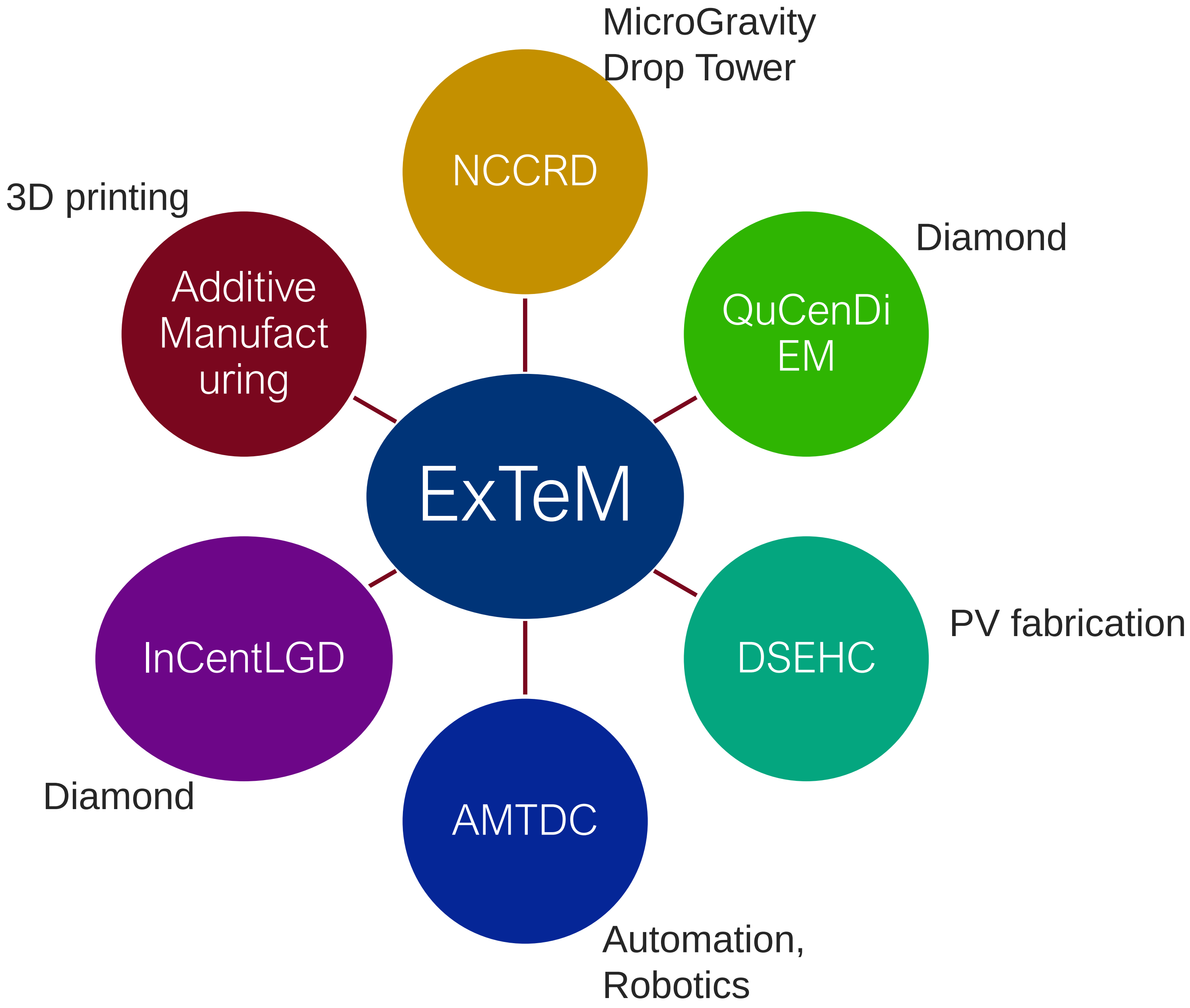
Source: Sgambati et al., [6]

IoE Research Centre ExTeM & IITM

- Via IoE scheme, ExTeM centre has been established via some seed funds
  - 2021-23: Phase 01
  - 2023-26: Phase 02
- Several activities and sub-projects are on-going

- Sustained funding needed to test a plethora of manufacturing processes and automations under various micro-gravity platforms

Working in collaboration with other centres @ IITM



ExTeM – structure

Manufacturing in earth for space

- Manufacturing challenges in making components in launch vehicles, satellites, etc..
- Already on going in IITM –ISRO cell
- **This centre will *not* focus on this**

A: Manufacturing in Space for Space

- A1: Human settlement in planets
  - Mining raw materials
  - Making use of Martian/Lunar soils
- A2: Long term space flight onboard a space-ship
  - Making in-situ things onboard
  - Recycling material onboard
  - Space factories

B: Manufacturing in Space for Earth

- Materials/parts that can be manufactured in space better than in earth (micro-g)
- Take raw materials to space; make things there, bring back to earth and sell it (commercial angle)
- E.g. Foams, crystals, Optical fibres, biologicals, body part printing etc.

Robotics & Automation

C: Micro-gravity platforms

- IITM 2.5 s drop tower
- Rotary Cell Culture System (RCCS) and Random Positioning Machine
- Parabolic test flights (e.g. Diamond Air, Zero-G)
- Orbital platforms (e.g. Axiom Space, ISS)

ExTeM Core Team and Collaborators

Vertical A1	Vertical A2	Vertical B	Vertical C
Project A1-1: Martian concrete Piyush Chaunsali (CE)	Project A2-1: 3D printing polymer-based shape memory structures R Velmurugan (AE), R Sarathi (EE)	Project B1: BMG and BMG composite foams S Sankaran (MME)	Micro-gravity tests for various projects in verticals A and B Amit Kumar (AE)
Project A1-2: Unmanned robotic drilling Prabhu Rajagopal (ME) Team Abhiyaan **Project A1-3: Robotics for Space Exploration** (with L&T collaboration) – requires funds	Project A2-2: Hybrid 3D printing + machining for metals Sivasrinivasu (ME), Murugaiyan (MME)	Project B2: Diamond crystal growth Ramachandra Rao M S (PH)	**Project C1-1:** Human safety in space
	Project A2-3: CVD coatings and PV cells fabrication Ramachandra Rao M S (PH) Project A2-4: In-situ optics fabrication Arunachalam (ME)	Project B3: Manufacturing of Biologicals and Bio-parts in Space: Stress-based Improvements: Suraishkumar GK (BT)	Vellon Space
	Project A2-5: Recycling chips & Al-foils into feedstock Sushanta K Panigrahi		
	Project A2-8: Recycling used electronics: elements reclaim Kothandaraman R (CY)		
	Project A2-9: Heavy Metal Glass Preform and Optical Fibres in Microgravity Sathyan Subbiah (ME)	(Highlighted projects were added in Phase II)	
	Project A2-10: Space Factory for Regiloth Processing Sathyan Subbiah (ME)		

Micro-gravity platform access needed for ExTeM R&D

01
Identification

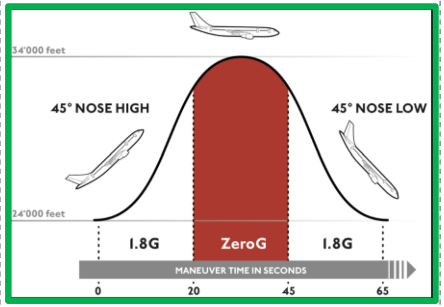
- **Identifying** the potential In-space manufacturing processes and the parameters of interest under µg.
- **Segregating** sub-projects according to test duration in Drop tower test or Parabolic flight or Orbital platform.

02
Drop Tower test

- Capsule modification to accommodate the manufacturing unit
- Choosing sensors and DAQ to withstand high impact g forces during deceleration.
- Analyze if microgravity has considerable effect in the 2.5s

03
Parabolic flight

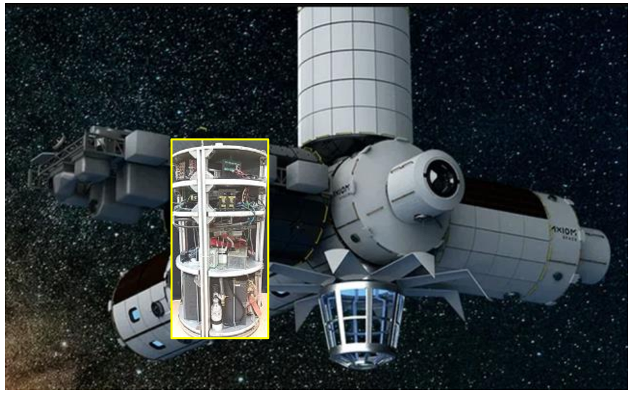
Conducting microgravity test in parabolic flight with each cycle of approx. 20s microgravity



04
Orbital platform

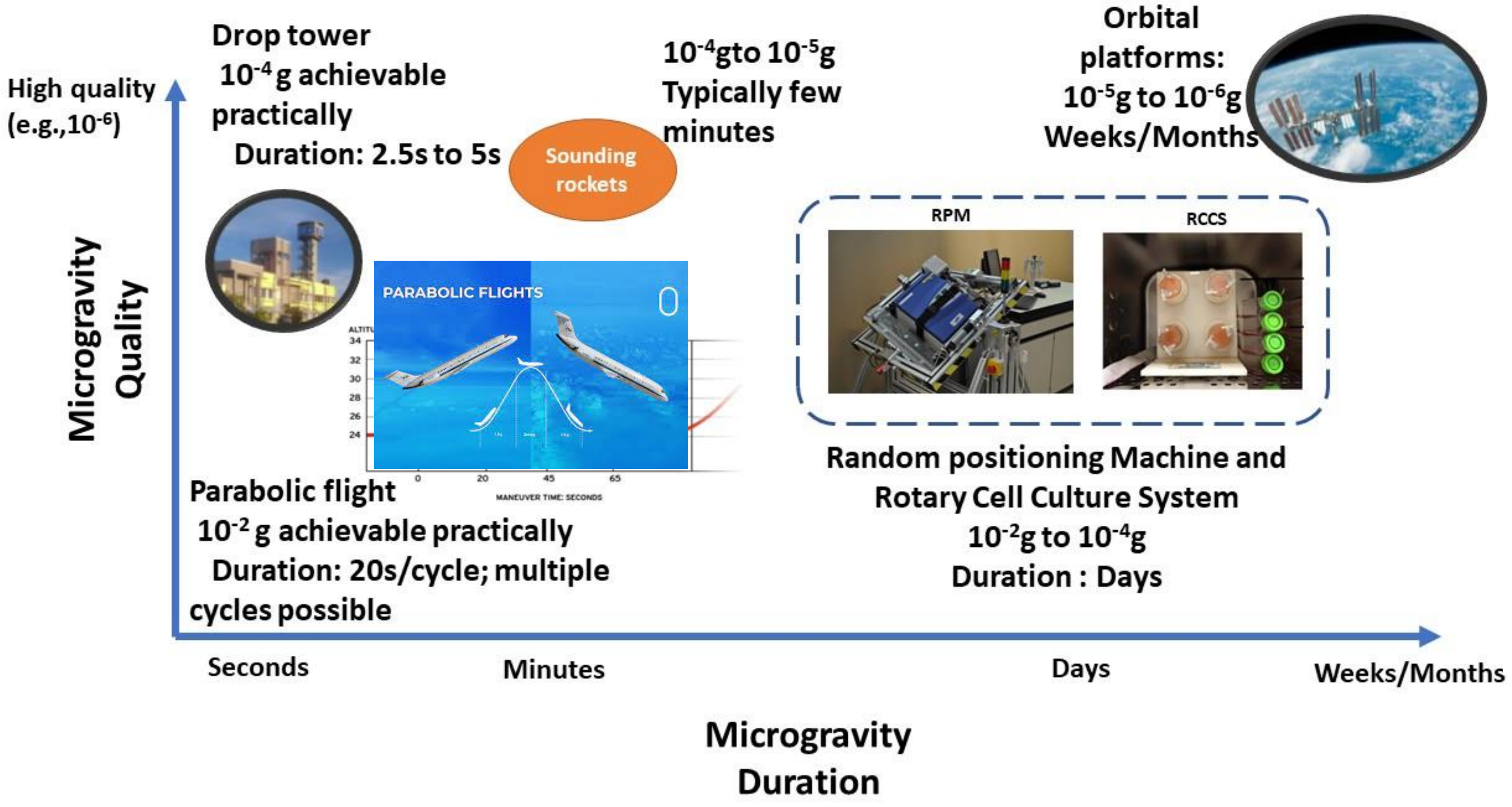
Placing India's first manufacturing setup in orbit

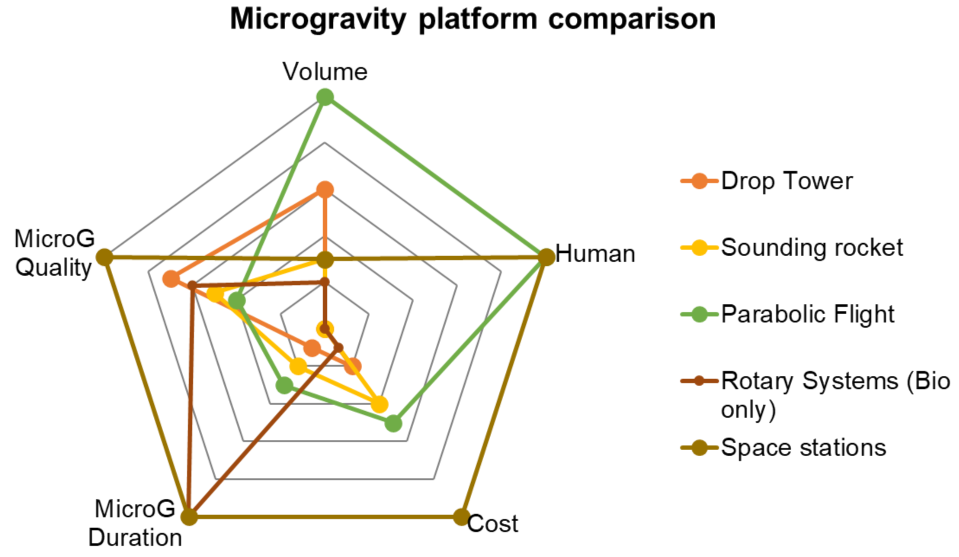
Analyzing the gravity's effect on the quality of the product fabricated.



Images from various web sources

Micro-gravity platforms compared





Images from various web sources

Micro-gravity platforms in India

- Drop-tower: we have one in IIT Madras campus (2.5 seconds micro-gravity)
- Parabolic flight services: discussions on-going to see if commercial services can be launched in India; is feasible with support
- Sound rockets: available with limited capability
- RCCS/Rotary systems (for bio): small lab systems are available in India; larger systems are not available.
- Orbital platforms: some startups are coming up (e.g. Vellon Space); ISRO has plans for Indian space station; foreign commercial space stations at a cost to friendly nations (e.g. Blue Origin, Axiom Space)

Images from various web sources