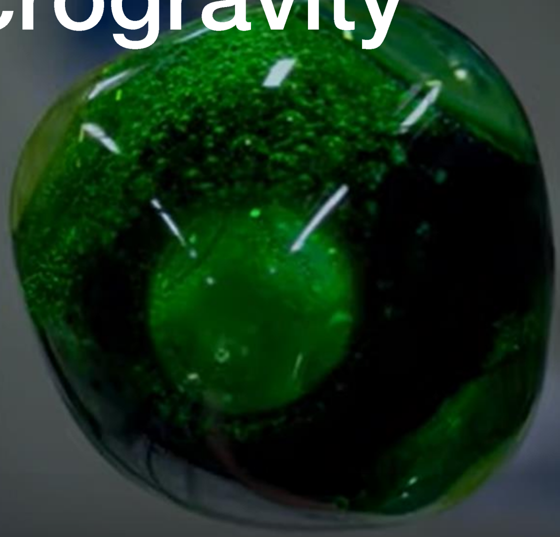
UNOOSA Microgravity/ Hypergravity Webinar Series

Fluid Dynamics in Microgravity

May 26, 2021



Divya Panchanathan
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Axiom Space
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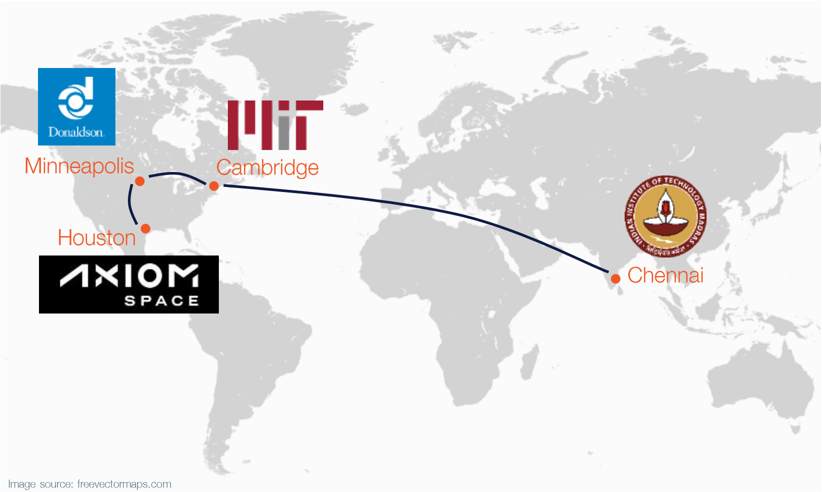
About me



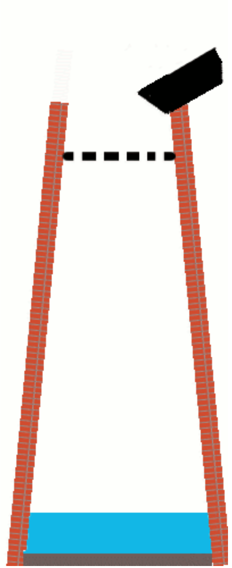
My journey through fluid and material sciences

- Pool boiling of nanofluids
- Photocatalytic membranes
- Superhydrophobic surfaces
- Drag reduction
- Room-temperature Leidenfrost effect
- Oily particulate aerosol filtration
- Particle-fiber interaction
- Physical and material science in space

Early forms of low-gravity manufacturing

Shot towers were used to manufacture nearly-perfect spheres of lead shots for firearms.

In 1782, William Watts obtained a patent on this process after building the first shot tower at Redcliff (Bristol, England). The tower had a total drop height of 27 m.



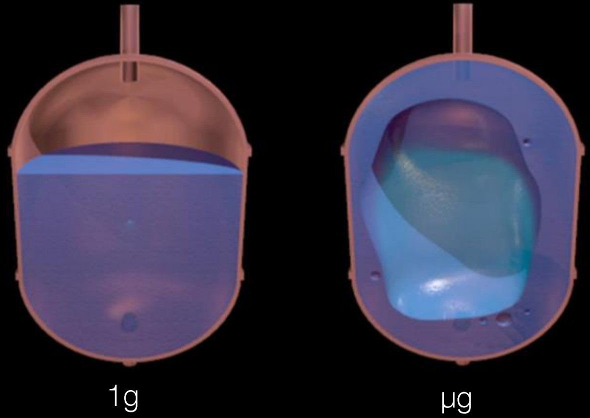
Martin Tester 1966

AXIOM SPACE

Early studies of fluid dynamics in microgravity

Fluid behavior in a propellent tank

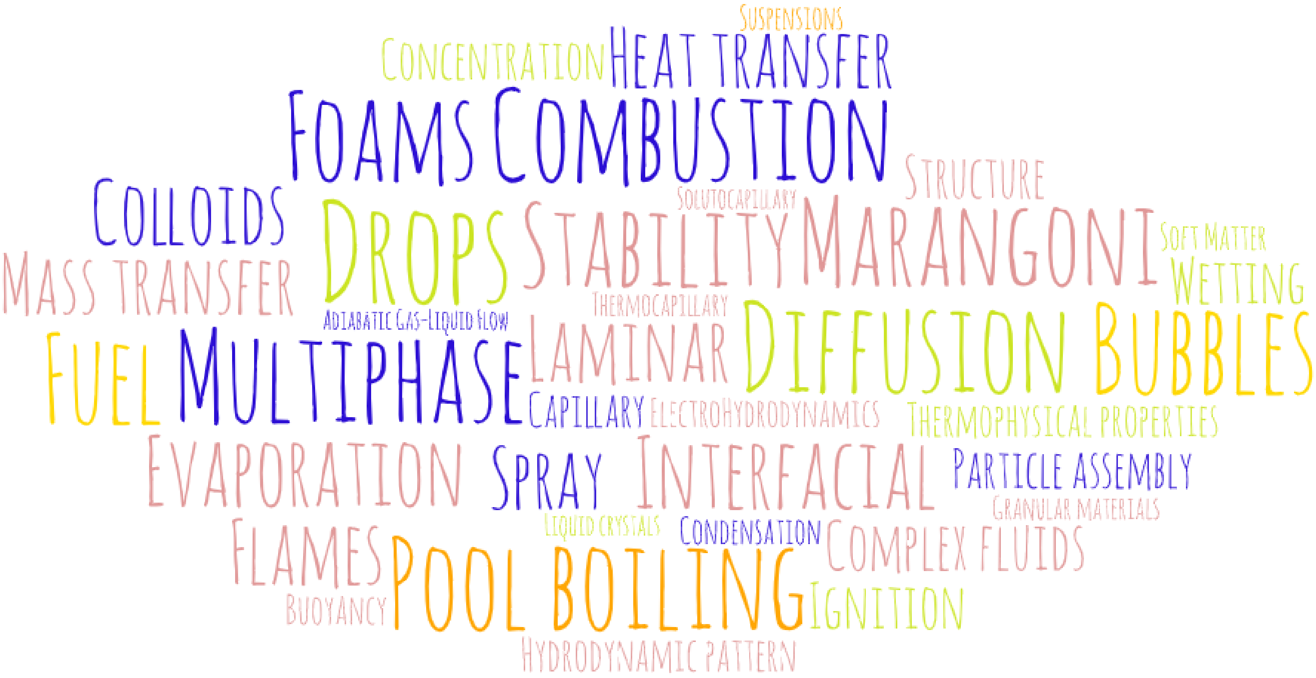
- The space race in the 1950s spurred interest in understanding fluid behavior under microgravity and hypergravity environments.
- Challenges included liquid expulsion, liquid positioning, liquid draining, and vapor venting.



NASA/Glenn Research Center

DiFrancesco JM & Olson JM, npj Microgravity 2015
Antar BN & Nuotio-Antar VS, CRC Press 2019

Fluid dynamics in microgravity



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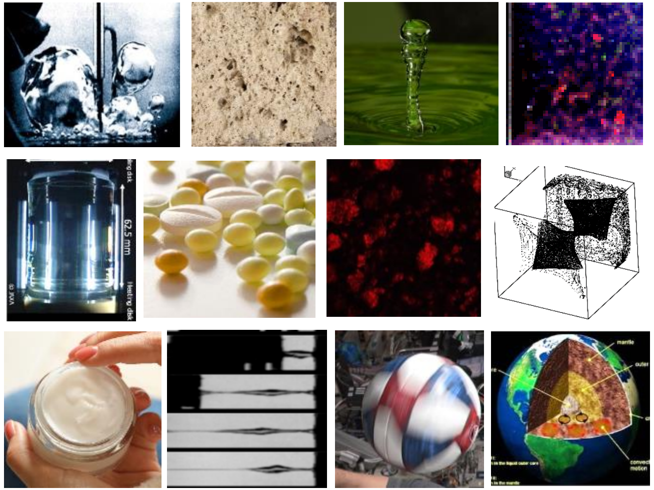
Experimental advantages of microgravity

Slowing down of inertio-capillary phenomena

Using larger quantities of fluid or dimensions

Domination of diffusion, surface tension, Marangoni flows etc.

Isolation of gravitational effects to understand particle agglomeration and coalescence



Use large particles to simulate atomic scale phenomena

No need to density match particles and fluids, or increase fluid viscosity

No directional constraints

No sagging effects

No need to constrain fluid using container or needles

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Marangoni convection

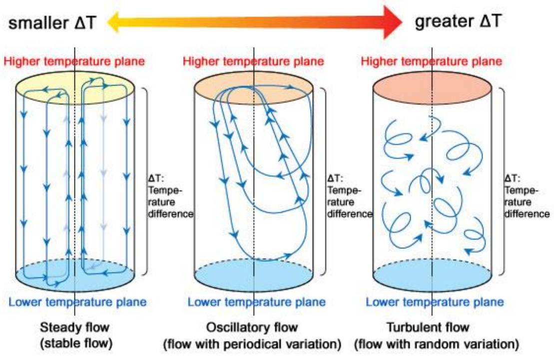
- Study the onset of unsteady (or oscillatory) convection and the corresponding
- Microgravity allows the formation of **large liquid bridges** and **isolates Marangoni effects** from buoyancy convection.
- Applications in production of high-quality crystal growth (semiconductors) and micro-fluid handling techniques (DNA examination, clinical diagnostics).

Capillary length

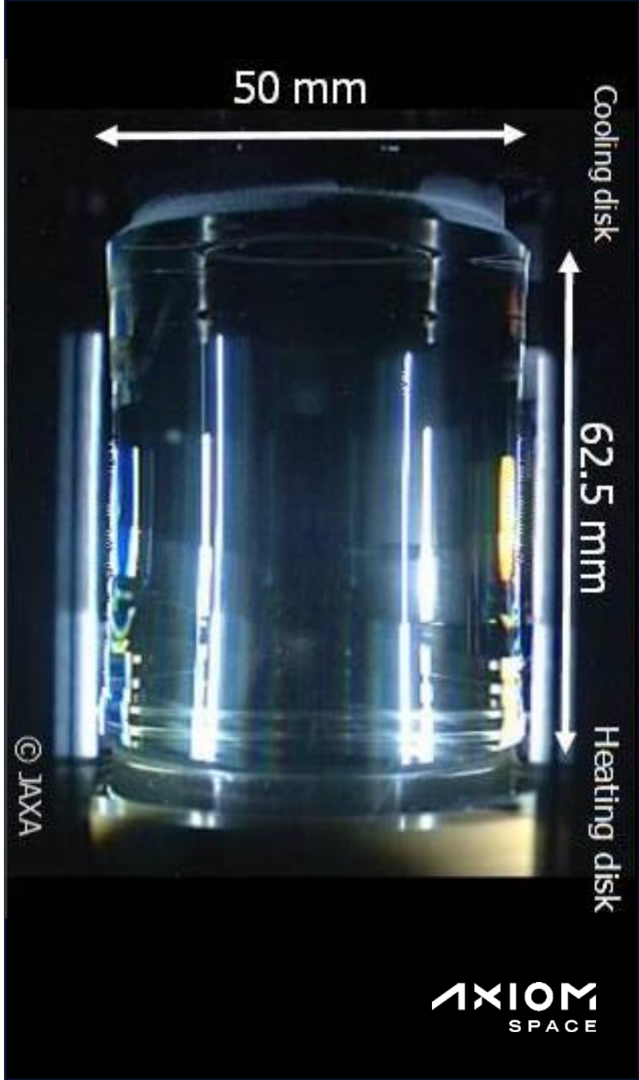
$$l_{cap} = \sqrt{\frac{\sigma}{\Delta\rho g}}$$

2.7 mm in 1g

1 m in µg



Yoda S., JAXA



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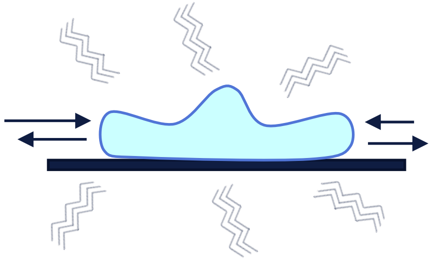
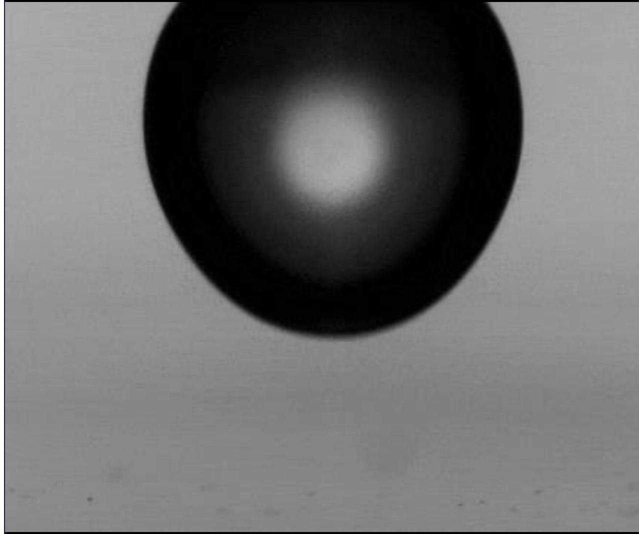
Droplet motion

- Study the behavior of big liquid drops whose contact line moves rapidly as the drops change shape forced by vibration.
- The **length and time scale** of the motion **is larger** in microgravity.
- Applications in self-cleaning surfaces, water harvesting devices, anti-frost coatings and the fabrication of semiconductors.

Inertiocapillary timescale (t_{IC})

$$t_{IC} = \sqrt{\frac{\rho R^3}{\sigma}}$$

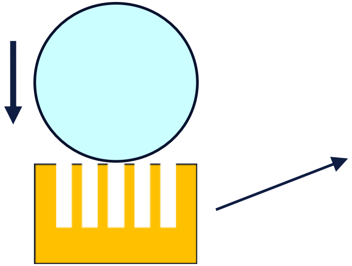




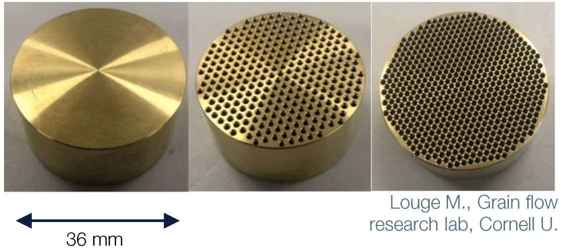
Steen Research Group, Cornell Engineering

Wetting in a porous media

- Study of the inertial phase of imbibition of water through capillary pores
- The **length and time scale** of the motion **is larger** in microgravity.
- Applications in flood control, irrigation, fuel cells, oil and gas exploration, and pharmaceutical production on Earth.



*Not to scale



Louge M., Grain flow research lab, Cornell U.

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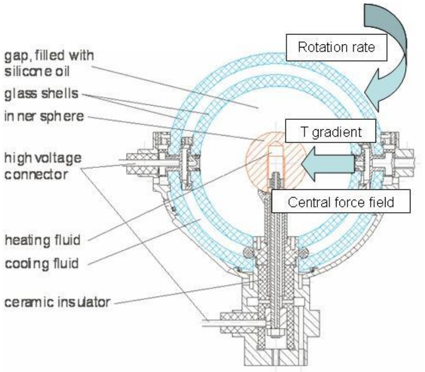
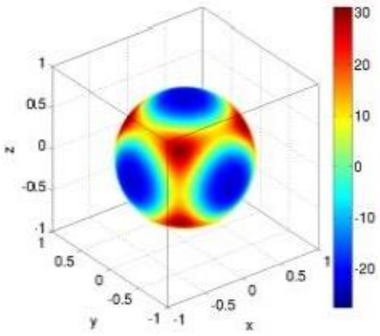
Geophysical flows

- Study the convective cells set up in the earth's mantle due to centrifugal and temperature gradients
- The **radial symmetry** can be achieved only using microgravity
- Applications: Prediction of earthquakes and volcanic eruptions



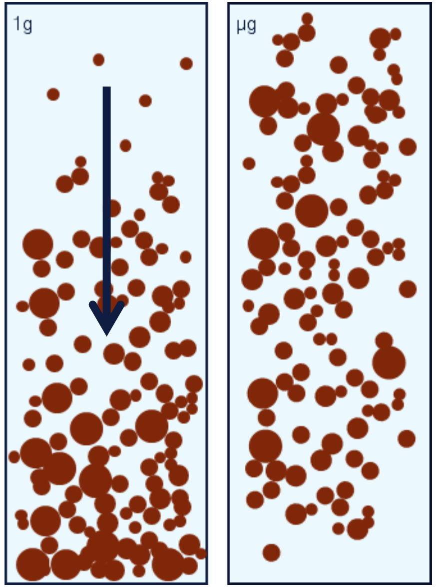


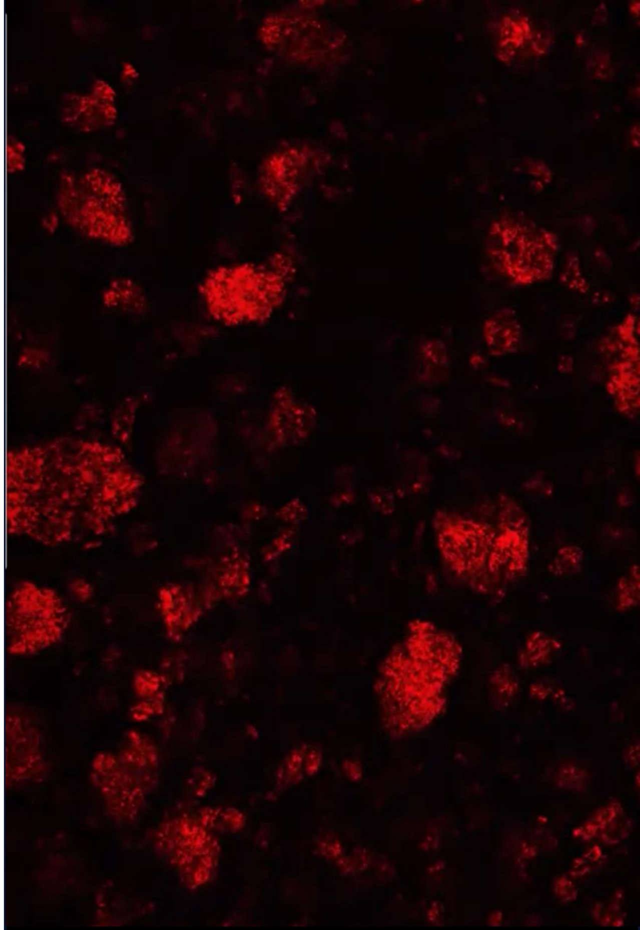
Egbers C., Brandenburg University of Technology

Egbers C., Brandenburg University of Technology

Sediment dynamics

- Measure cohesion and adhesion induced dynamics in sedimentation by imaging the agglomeration behavior of clay particles without sedimentation.
- Microgravity **isolates sedimentation** effects from agglomeration.
- Applications in predicting and mitigating erosion, deep water hydrocarbon exploration etc.





Luzzatto-Fegiz P., UC Santa Barbara
https://www.youtube.com/watch?v=76w8ly56z6l&t=11s

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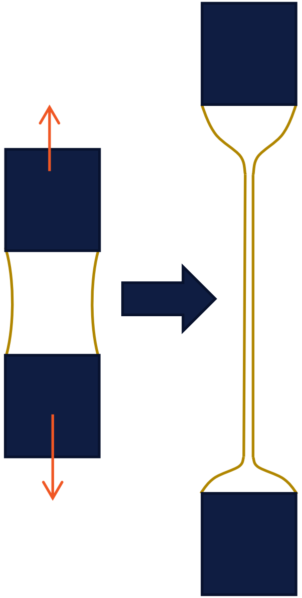
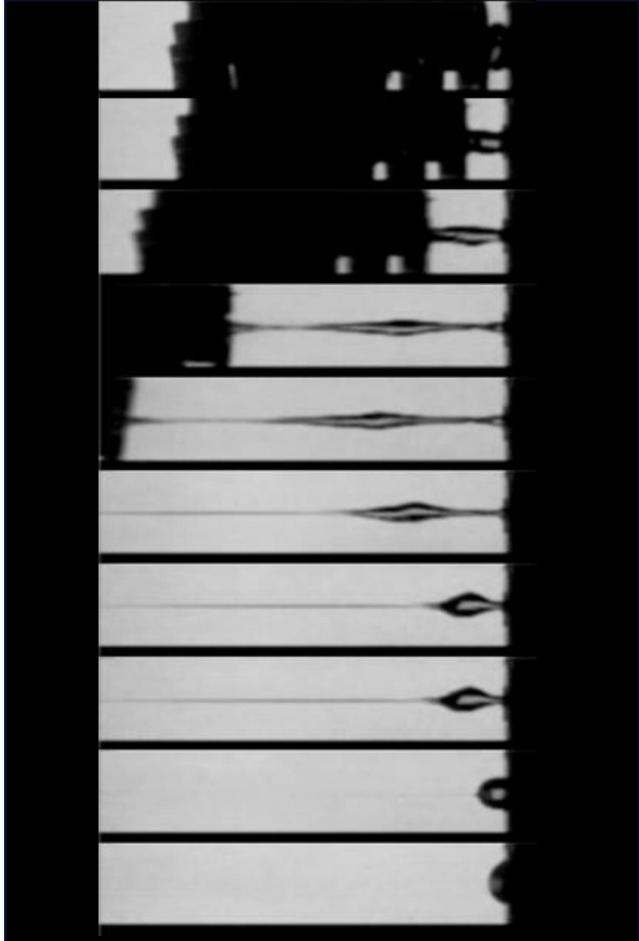
Extensional rheology

- Measure extensional viscosity of a polymer or any viscoelastic material without sagging effects.
- **Sagging is prevented** and makes it easier to measure extensional viscosity accurately in microgravity.
- Applications in manufacturing like extrusion, blow-molding and fiber spinning.

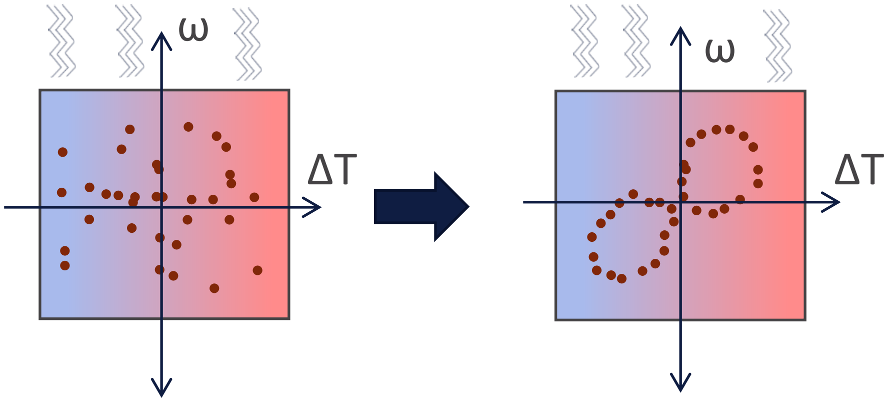


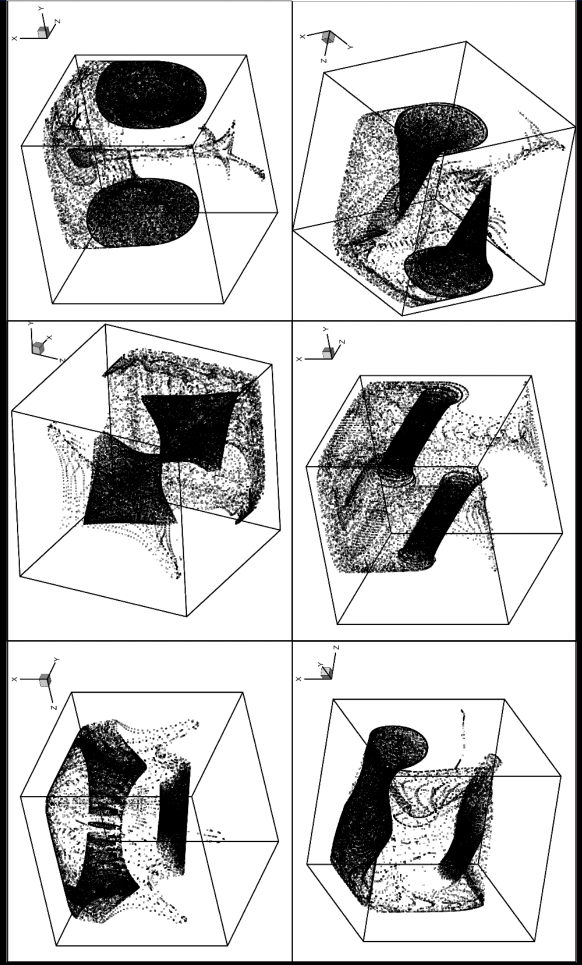


Hall, Nancy, McKinley G.H., et al. *47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition*, 2009.

Particle self-assembly

- Highly ordered structures formed from uniformly distributed particles when subject to vibration in a non-isothermal liquid.
- Particle must have different density from the liquid for this to work. **No density-matching** is need in microgravity.
- Applications in self-assembly of particles to form useful material structures.





Particle Vibrations Experiment (UK Space Agency), PI: Marcello Lappa, University of Strathclyde

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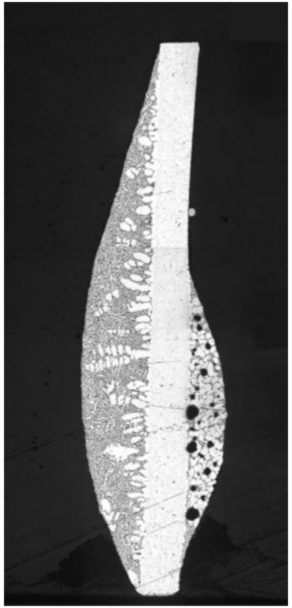
Brazing of aluminum alloys

- Study of capillary flow, interface reactions and bubble formation during solidification of brazing alloys in microgravity.
- **Surface tension dominates** the brazing process.
- Applications: in-situ repair of spacecraft structures.



Sekulic D., University of Kentucky

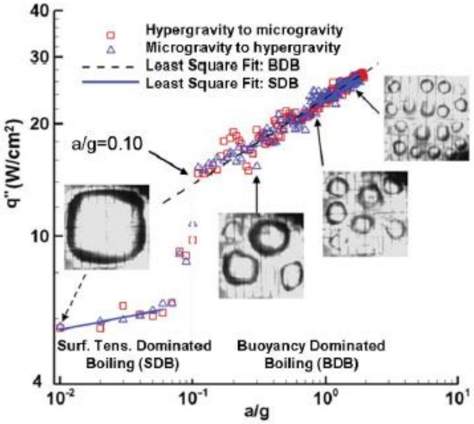
Image credit: Official U.S. Navy Imagery

Pool Boiling

- Study to the effect of heater size on the pool boiling heat transfer.
- Possible to study **surface tension dominated** boiling regime at larger length scales.
- Applications in power and cooling systems for microelectronics, fusion reactors and space vehicles.

For surface tension dominated boiling

$$l_{heater} < 2.1\sqrt{\frac{\sigma}{\Delta\rho g}}$$



Kim & Raj, NASA/CR-2014-216672

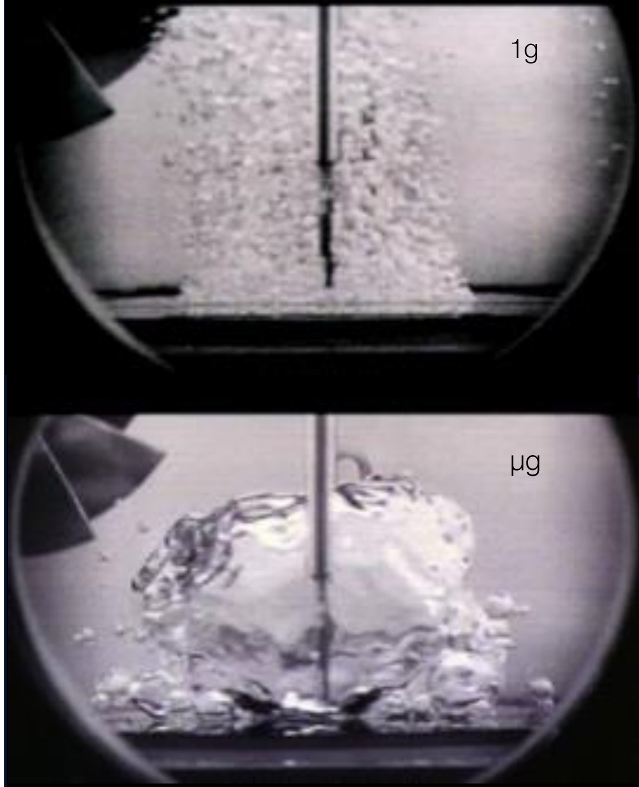


Image: NASA

Commercial applications

Droplet formation

Delta Faucet

- Study to determine the maximum droplet size that they can obtained with a jet nozzle and fluidic nozzle.
- Microgravity allows the **growth of large size droplets**
- Objective is to reduce water consumption and energy by making the user feel more pressure using fewer and larger droplets.

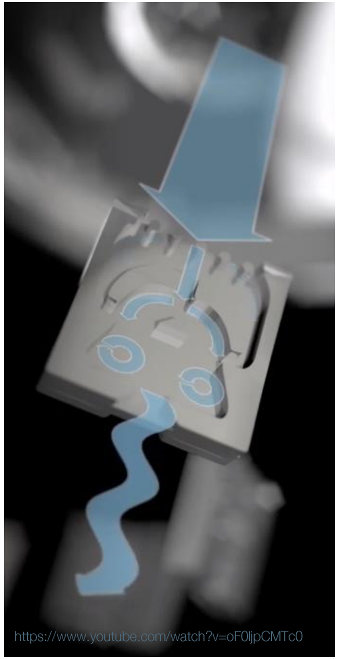
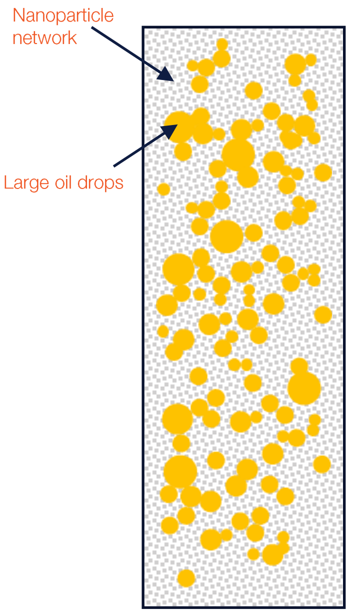


Image credit: ISS NL/Delta

Sedimentation behavior of gels

Procter & Gamble

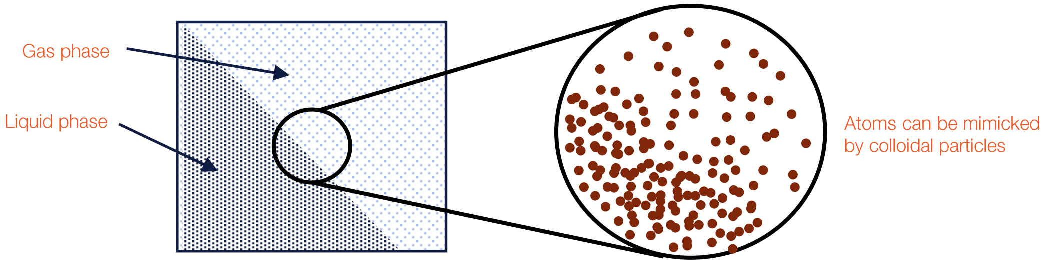
- Study the kinetics of coarsening in polydisperse colloidal systems
- Microgravity **isolates effects of phase separation** from coarsening
- Applications in extending shelf life of food, medicines, cosmetics, cleaning solutions etc.

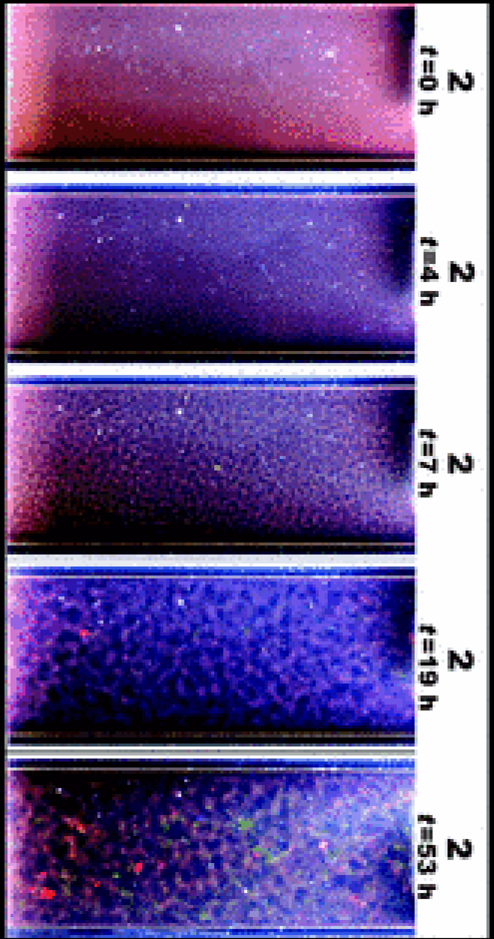


Phase separation in critical fluids

Procter & Gamble

- Study the interplay between phase separation and crystallization in a colloid-polymer mixture in samples which exhibit three-phase equilibrium coexistence.
- A colloidal system can be used to study phenomena taking place at the atomic scale
- Application: increase shelf life of household products like foods, medicines, fabric softeners etc. with minimal additives.





Peter J. Lu and David A. Weitz, Harvard University

Fluid dynamics of soccer ball

Adidas

- Study free-flight behavior of a soccer ball
- Microgravity allows to study **without restrictive mechanical supports**
- Understanding the spherical aerodynamics leads to the improved design and aerodynamic properties of sports balls.

Image credit: Adidas

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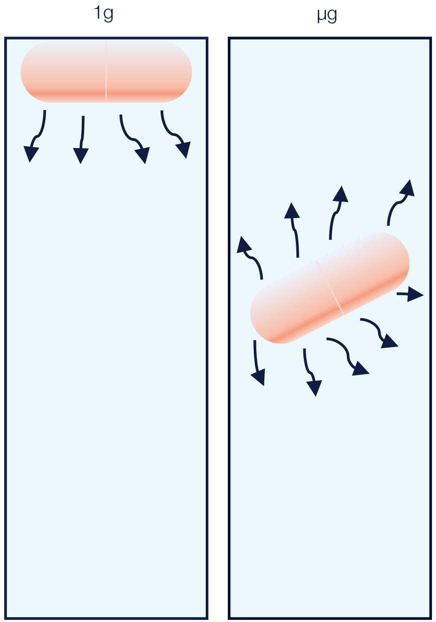
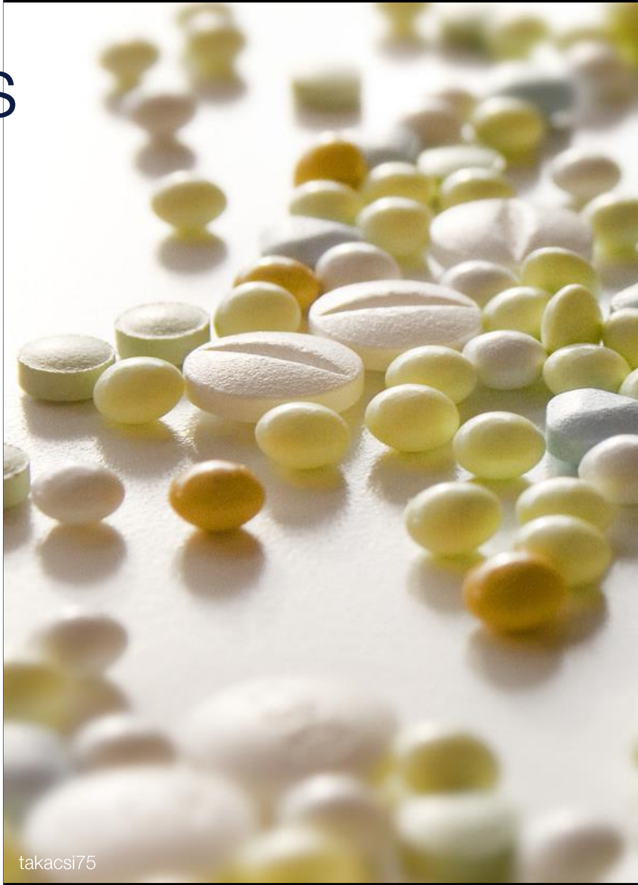
Dissolution of hydrophobic drugs





Eli Lilly and Company

- Study to determine the effect of hydrophobicity on dissolution of tablets without buoyancy effects.
- Learning applied to improve drug formulations for use in space and on earth.

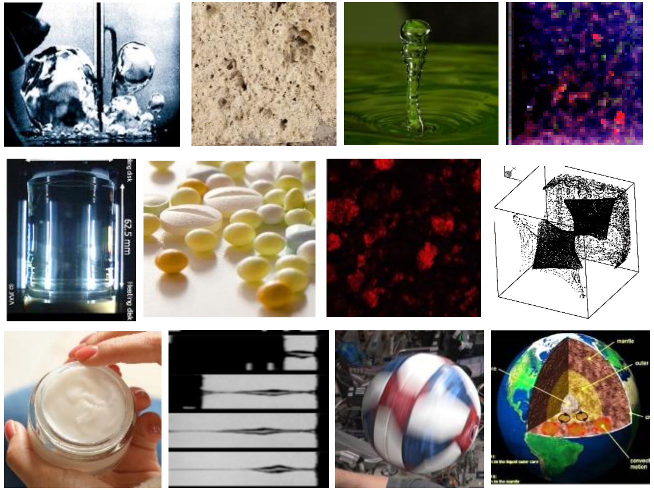
How can you take advantage of microgravity?

Slowing down of inertio-capillary phenomena

Using larger quantities of fluid or dimensions

Domination of diffusion, surface tension, Marangoni flows etc.

Isolation of gravitational effects to understand particle agglomeration and coalescence



Use large particles to simulate atomic scale phenomena

No need to density match particles and fluids, or increase fluid viscosity

No directional constraints

No sagging effects

No need to constrain fluid using container or needles

Microgravity facilities

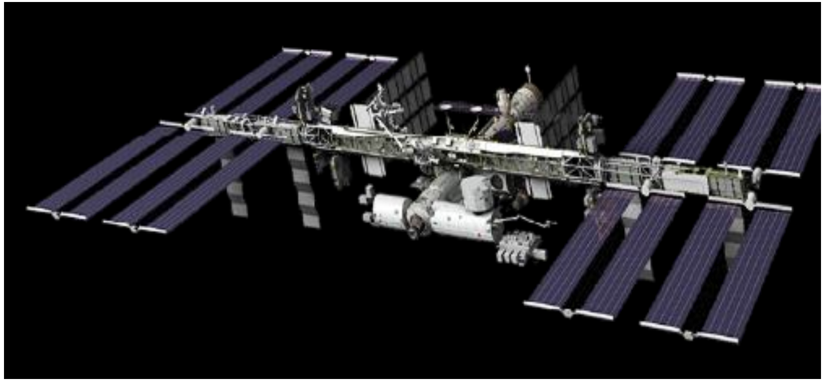
Which μg platform should you use?

Location	Platform	Duration (uninterrupted μg)	Gravity force (g)	Crew-tended?
Space	ISS, Axiom Station	Unlimited	10^{-5} - 10^{-6}	✓
Space	Nano-satellites	2-3 years	10^{-5} - 10^{-6}	✗
Flight	Sub-orbital flights	10 mins	10^{-3} - 10^{-5}	✓
Flight	Sounding rockets	5 - 20 min	10^{-3} - 10^{-4}	✗
Flight	Parabolic flights	20 - 30 s	10^{-2} - 10^{-3}	✓
Ground	Drop towers	2 - 10 s	10^{-2} - 10^{-5}	✗
Ground	Random Positioning Machine	Hours	10^{-2} - 10^{-3}	✓

Space Stations

Skylab
1973

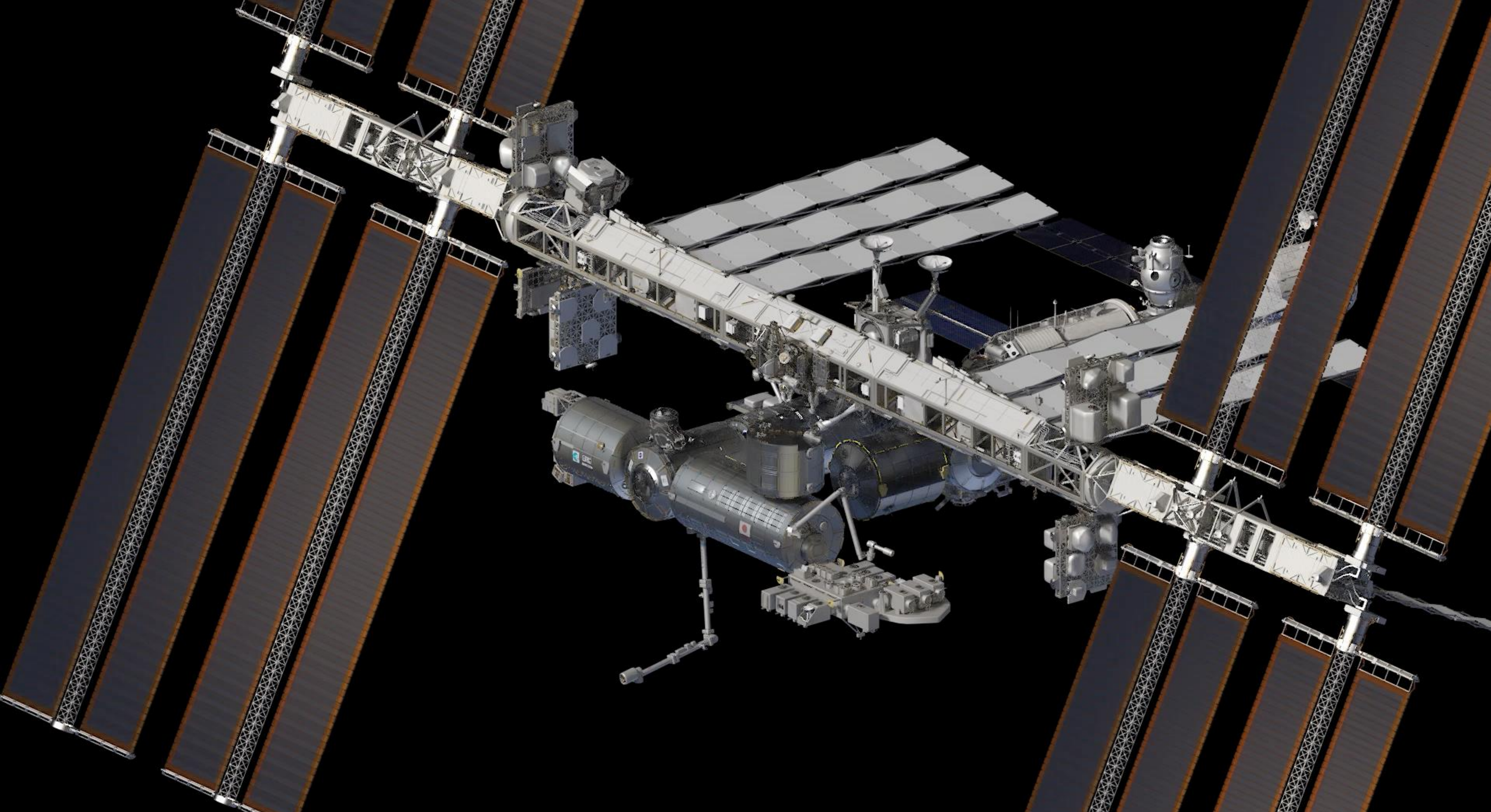
Mir
1986-2001



International Space Station
2000 ~ 2030
Retiring “soon”

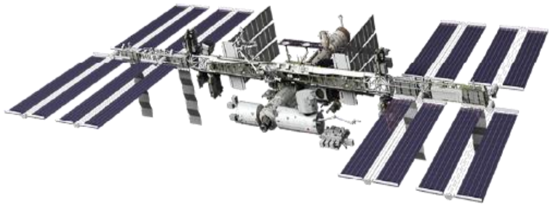
Axiom Station

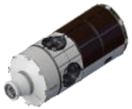
The world's 1^{st} commercial space station

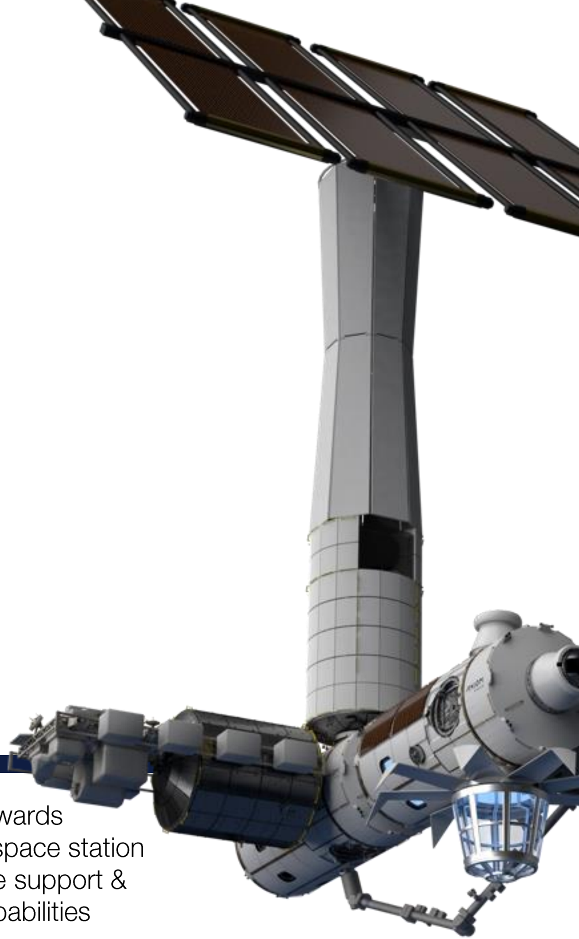


Axiom Station’s Timeline

Today Axiom Space provides immediate access to low Earth orbit (LEO) via the ISS and will provide expansive new opportunities to scale commercial applications on the Axiom Station starting in 2024.







2021-2024
Axiom provides access to space through missions to the ISS

2024-2027
Axiom modules with modern architecture available on the ISS for research and manufacturing

2028 onwards
Fully operating space station with power, life support & storage capabilities

AXIOM SPACE

Orbital Lab for Research & Manufacturing

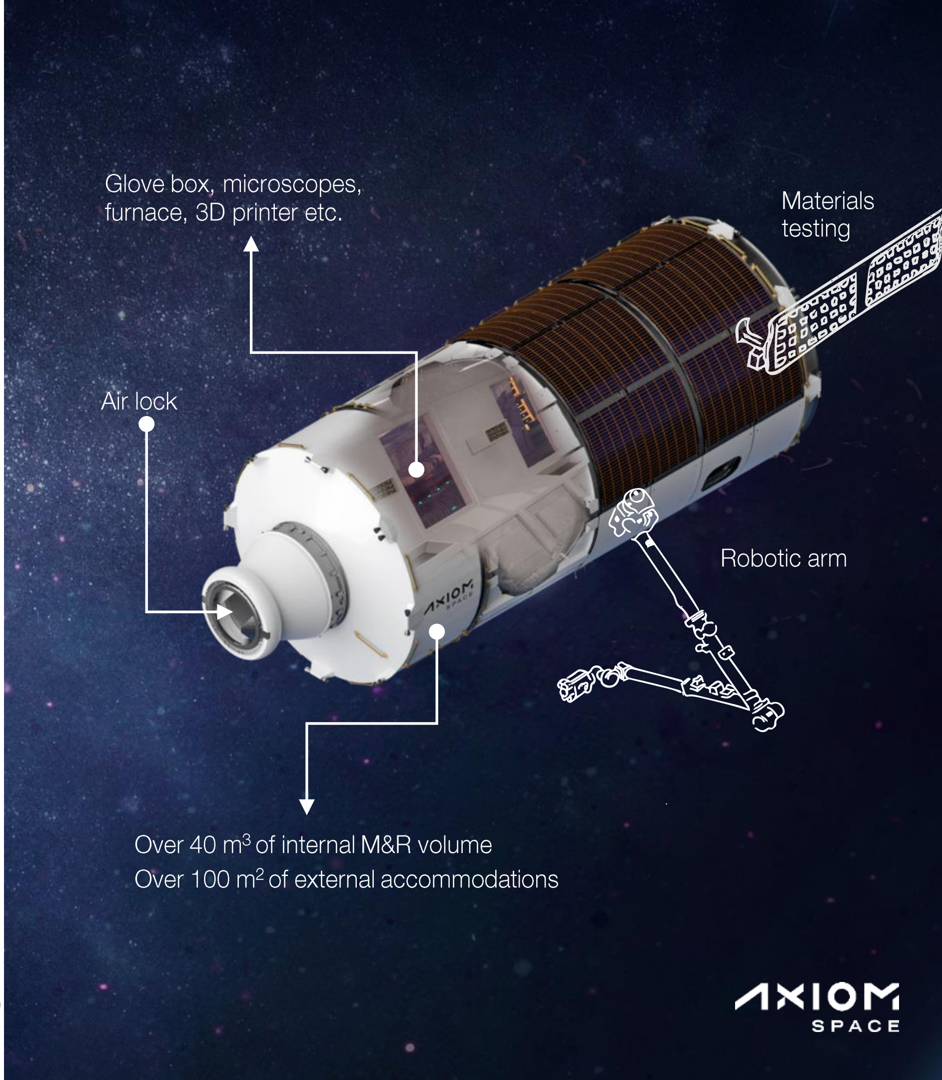
Axiom station provides state-of-the-art facilities for in-space production and scientific research.

Pre-launch services

- Flight hardware design and build
- Payload integration
- Safety inspection
- Frequent launch and return

On-orbit services & utilities

- Modular “plug n play” interfaces
- Up to 8 crew for complex integration
- State-of-the-art characterization facilities
- Utilities including gases, fluids, power, data transmission, data processing



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How can you get involved?

Opportunities in space

DISCOVER

- Apply microgravity to your research or production process

INNOVATE

- Entrepreneurship
- Applied research for growing the commercial benefits of space

INFLUENCE

- Funding (2022 NASA Decadal survey)
- Define in-space facility needs
- Train the next-gen scientists for space
- Network at ASGSR, SEDS, SELGRA, UNOOSA

AXIOM SPACE

STARS Scholarship

Science Technology Art and Research in Space Scholarship

How would you use the space environment to change the world?

Three $1,000 scholarships will be awarded.
Open to undergrad or grad students in a degree program.

axiomspace.com/stars

Applications due June 30, 2021

Imagine the possibilities… without *g*

$$\mathrm{Ar} = \frac{gL^3\rho_l(\rho - \rho_l)}{\mu^2}$$

Archimedes number

Navier Stokes Equation

$$\frac{\partial u}{\partial t} + (u.\nabla u) = -\frac{1}{\rho}\nabla P + \frac{\mu}{\rho}\nabla^2 u + g$$

$$\mathrm{Bo} = \frac{gL^2\,(\rho - \rho_l)}{\sigma}$$

Bond number

$$\mathrm{Ra} = \frac{gL^3\beta(T_s - T_o)}{\alpha\nu}$$

Raleigh number

$$\mathrm{Fr} = \frac{u}{\sqrt{gh}}$$

Froude number

$$\mathrm{Ri} = \frac{gh}{u^2}$$

Richardson number

$$\mathrm{Gr} = \frac{gL^3\beta(T_s - T_o)}{\nu^2}$$

Grashof number

$$\mathrm{Coh} = \frac{1}{\rho g}\left(\frac{\sigma^5}{E^{*2}R^{*8}}\right)^{\frac{1}{3}}$$

Cohesion number

$$\mathrm{Mo} = \frac{g\mu^4\Delta\rho}{\rho^2\sigma^3}$$

Morton number

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26 MAY 2021