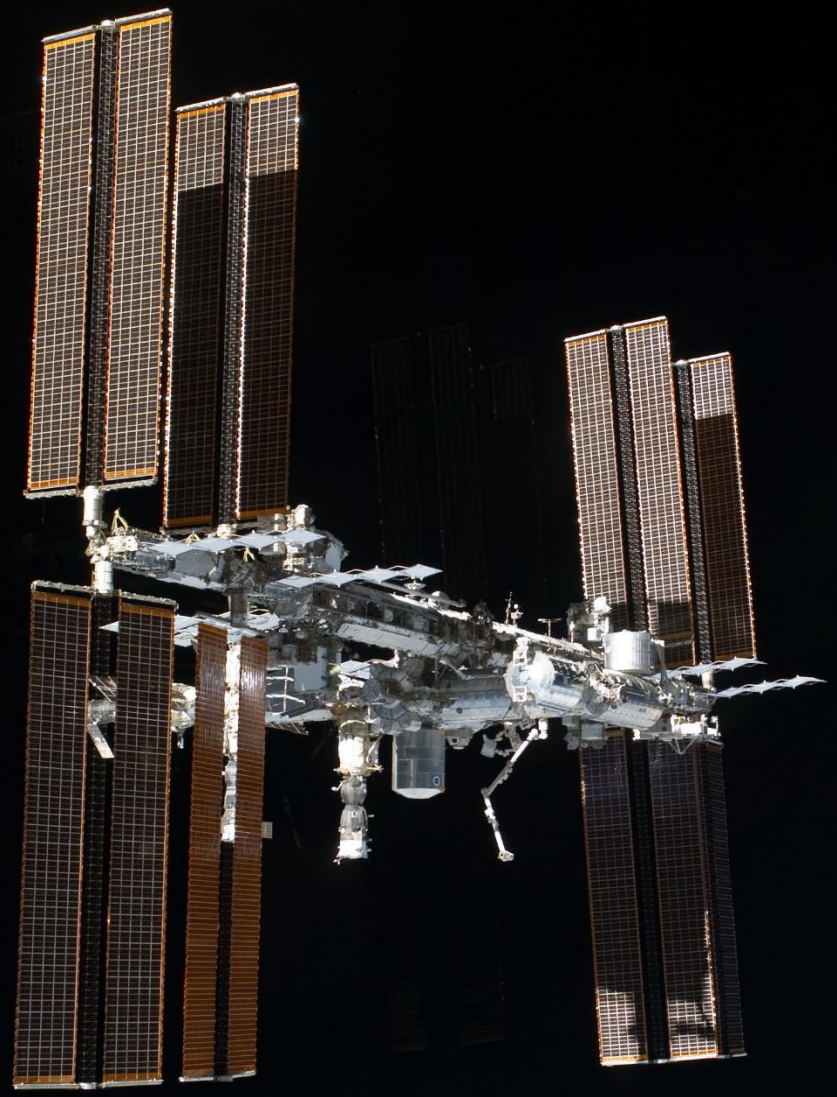

ISS National Laboratory
CENTER FOR THE ADVANCEMENT OF SCIENCE IN SPACE

IN-SPACE PRODUCTION APPLICATIONS WITH A FOCUS ON CRYSTALS

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CENTER FOR THE ADVANCEMENT OF SCIENCE IN SPACE (CASIS)

Designated by Congress to work in partnership with the National Aeronautics and Space Administration (NASA) to manage the U.S. National Laboratory on the International Space Station (ISS).

MANAGING THE ISS NATIONAL LAB

Pursue groundbreaking science, technology, and innovation

Advance the nation's leadership in commercial space

Inspire the next generation with ISS STEM opportunities

ADVANCED MANUFACTURING & MATERIALS FOR IN-SPACE PRODUCTION APPLICATIONS

Advanced Manufacturing and Materials
Projects that develop next-generation production methods, improve understanding of mechanisms involved in material transformations, advance fundamental materials discovery, or test processes or manufacturing methods of novel design and synthesis pathways.

In-Space Production Applications
LEO-based applied R&D microgravity applications seeking to demonstrate space-based manufacturing and production activities that enable new business growth and capital investment, represent scalable and sustainable market opportunities, and produce reoccurring value with the potential to generate demand for and revenue from access to space.

Microgravity

Extreme conditions

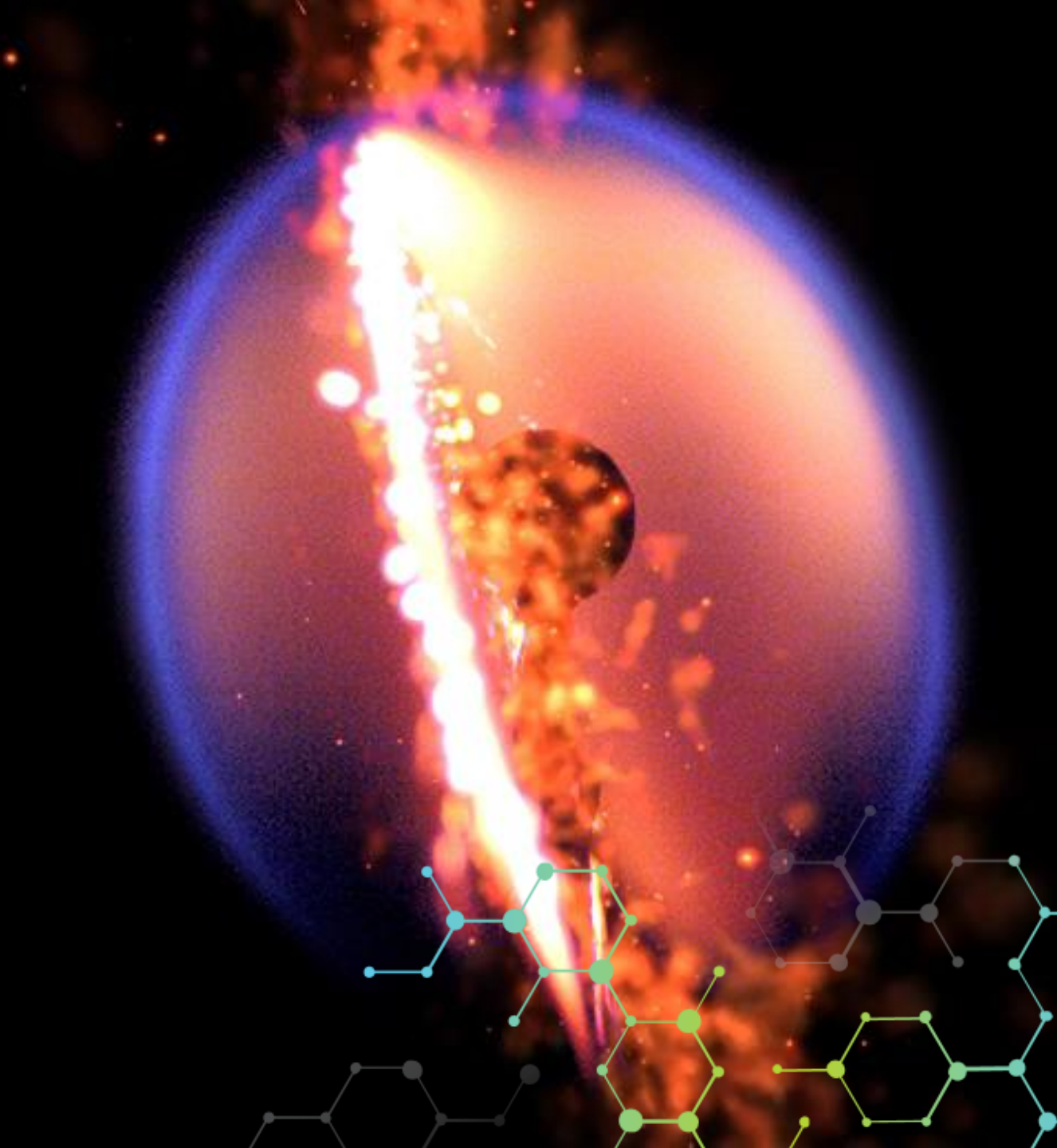
Vantage point

WHY SPACE?

Paradigm shift: Access to space reveals features of terrestrial life and physical processes that cannot be seen or manipulated on Earth.

MICROGRAVITY

Microgravity affects the fundamental physics of molecules in solids, fluids, and gases (convection, buoyancy, sedimentation).

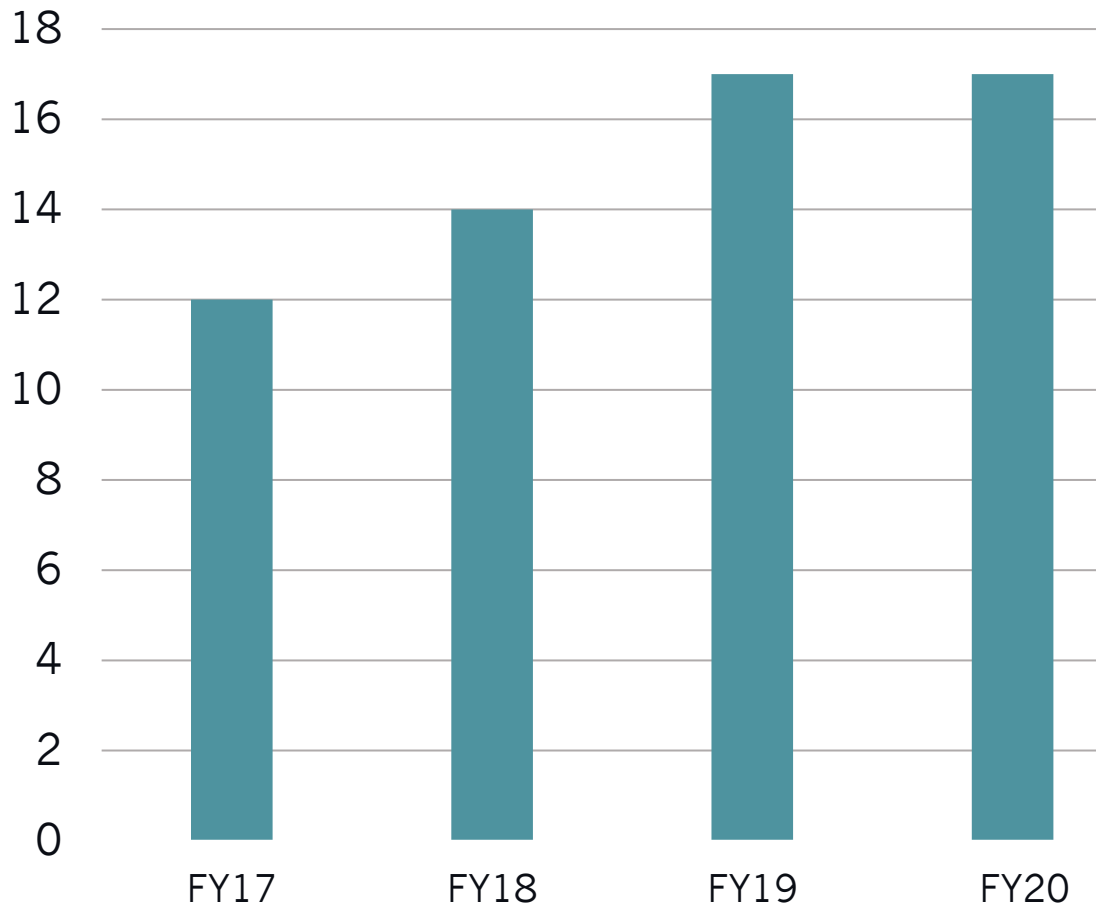


IN-SPACE PRODUCTION APPLICATIONS PROJECTS ENABLED BY THE ISS NATIONAL LAB

Through December 2020:

- 57 payloads flown with the ISS National Lab
- 58 projects supported by 10 Implementation Partners
- Several patents as a result of ISS National Lab R&D in this focus area
- The 2020 Materials Workshop Report
- $13.3M in committed Sponsored Program funding
- Several commercial efforts have benefitted as a result of ISS National Lab R&D in this focus area

COMMERCIAL FACILITIES ON STATION



Multipurpose facilities/platforms

External exposure platforms

Furnaces

Combustion reactors

Confocal microscopes

3D printers

3D biofabrication

CubeSat deployers

Remote sensing platforms

MATERIALS SCIENCE

POTENTIAL APPLICATIONS

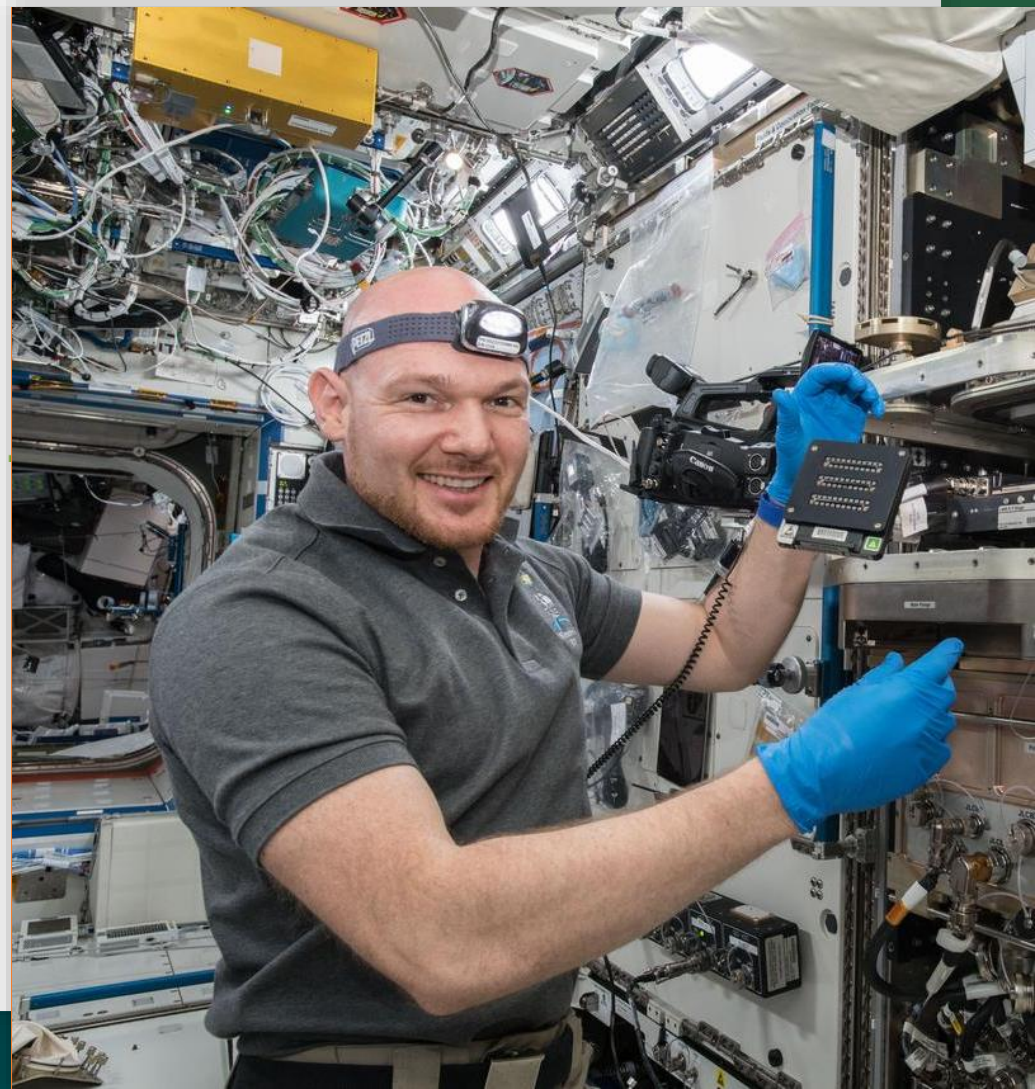
Knowledge gained from past and current efforts enable the development of novel materials and better manufacturing processes on Earth for commercial products, building materials, and electronics.

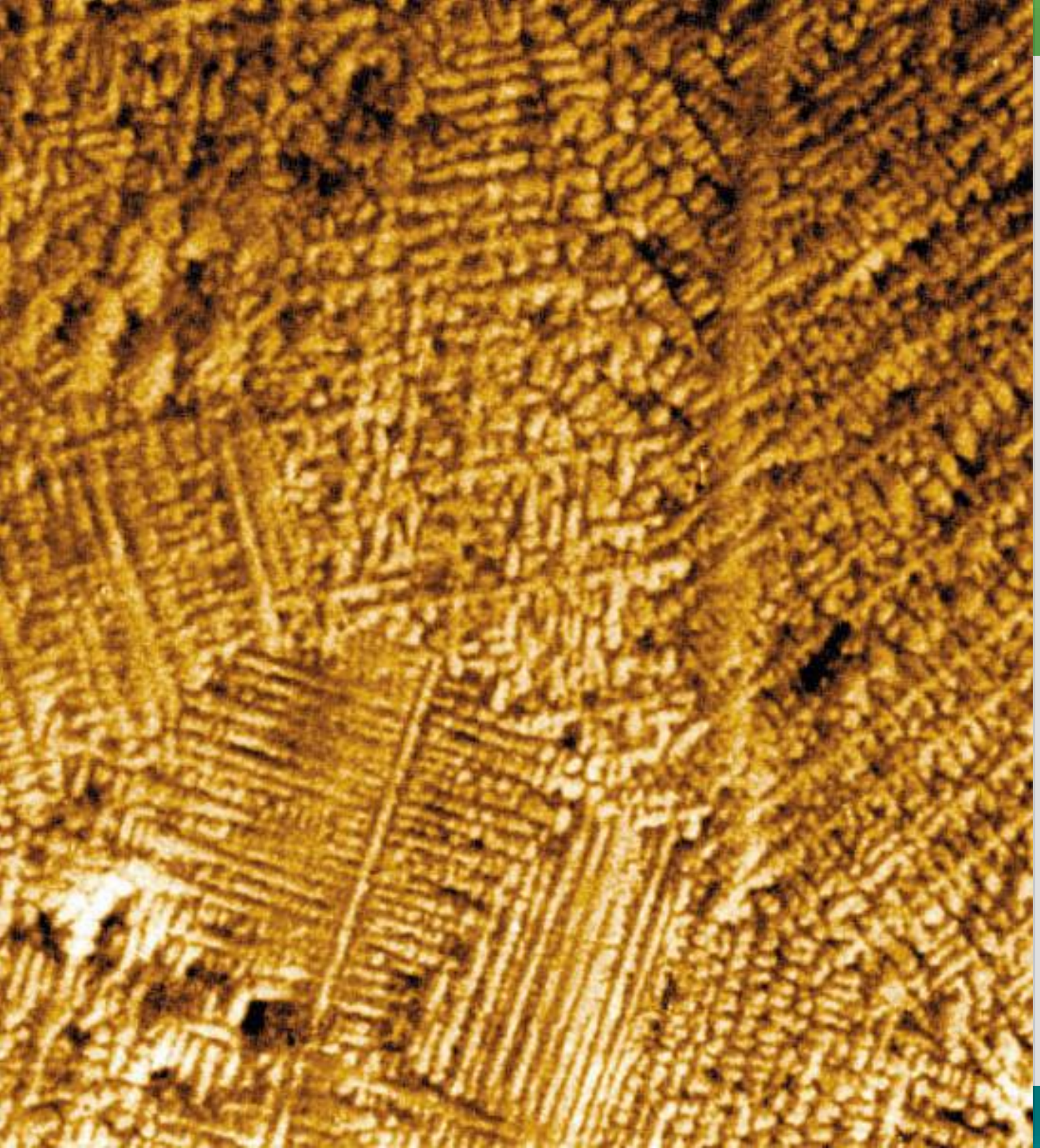
FLUID DYNAMICS

Buoyancy, a major cause of convection (the bulk movement of molecules within a fluid) and **hydrostatic pressure** (the force exerted by a fluid at equilibrium at a given point within the fluid) are both dependent on gravity. They are functionally absent in the microgravity environment of the ISS.

INTERFACIAL PHENOMENA

Effects on fluid movement also influence how substances interact—for example, at the boundary (or interface) between a liquid and a solid or a liquid and a gas. Many aspects of the interaction at these boundaries are easier to study in microgravity.





INTERFACIAL PHENOMENA

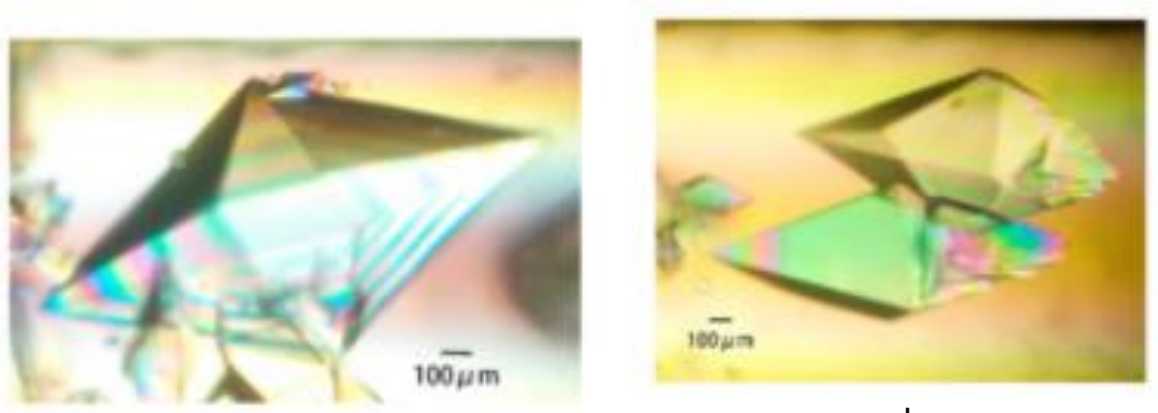
POTENTIAL APPLICATIONS

Studies focused on fluid-gas boundaries in foams and gels impact consumer care products, drug formulation and delivery, and advanced manufacturing processes.

WHY DOES IT MATTER?

Gravity's impact on material production can be seen in several ways:

- During solidification, materials may form voids (gas-filled pockets), cracks, and phase distortions (glasses, amorphous, or misaligned crystals) that affect material durability, strength, and performance.
- Density differences can cause heavy atoms to sink, leading to nonuniform alloys, ceramics, and glasses.
- Crystals tend to be smaller and less uniform because crystallization is an exothermic reaction.
  - Heat and concentration gradients lead to currents.



a b

Thaumatin crystals grown in space (**a**) and terrestrially (**b**) by the dialysis (DL) method.

Takahashi, S.; Koga, M.; Yan, B.; Furubayashi, N.; Kamo, M.; Inaka, K.; Tanaka, H. JCB-SGT crystallization devices applicable to PCG experiments and their crystallization conditions. *Int. J. Microgravity Sci. Appl.* **2019**, *36*, 360107.

PRIORITY AREAS

Focus areas of special interest for the ISS National Lab in materials R&D in space include **advanced or exotic materials, their production or use in microgravity, and technologies related to their production in microgravity that improve their application.**

Areas of interest include:

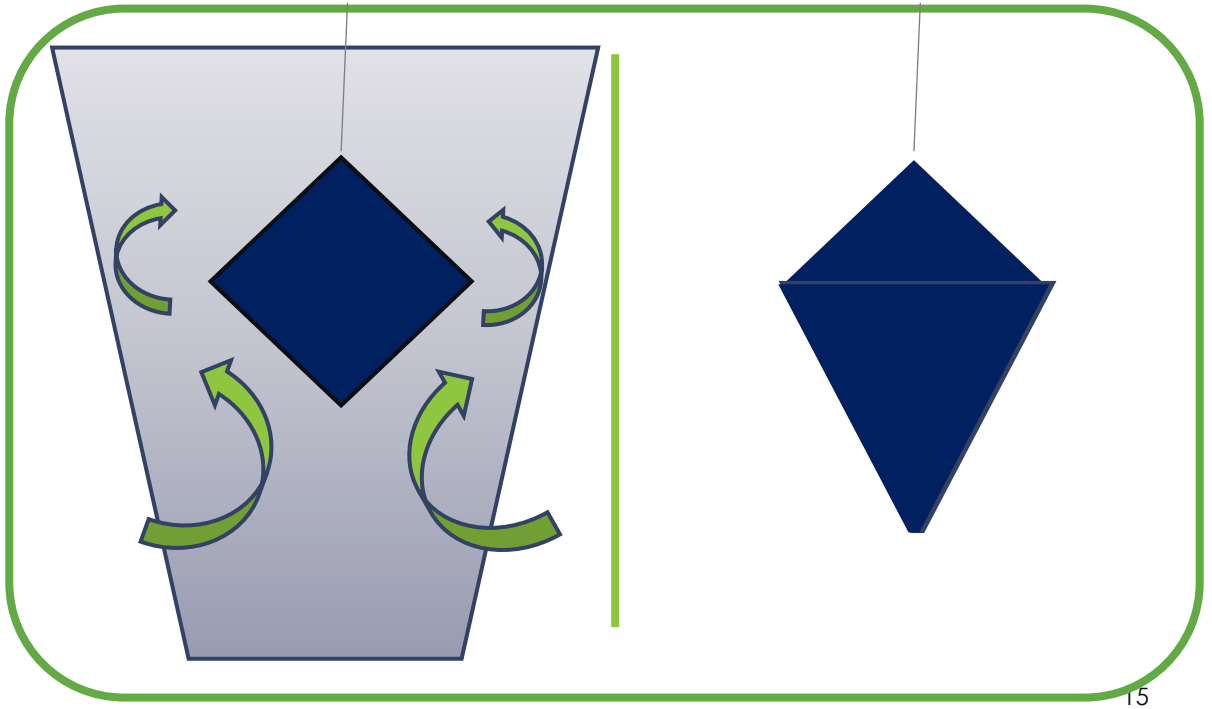
- Exotic glasses
- Thin-layer deposition
- Metallurgy
- Crystal growth

ADDING UP THE FACTORS

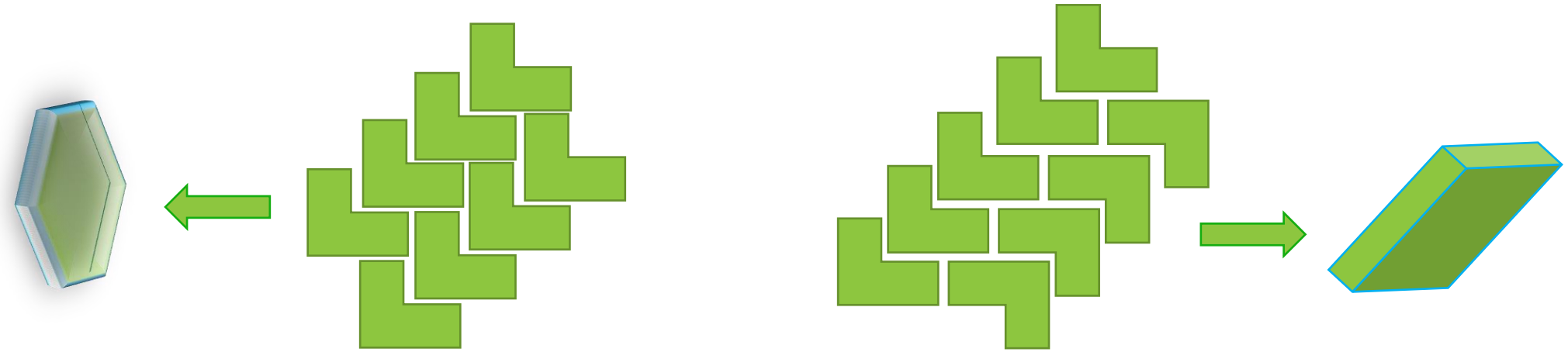
One effect of gravity is that terrestrially grown crystals expand or grow downward.

Although it appears that the force of gravity is pulling on the crystal and thus distorting crystal formation, that is not the case.

Reinforcing effects resulting from sedimentation and convection lead to crystals growing down terrestrially, **but neither effect occurs in microgravity.**



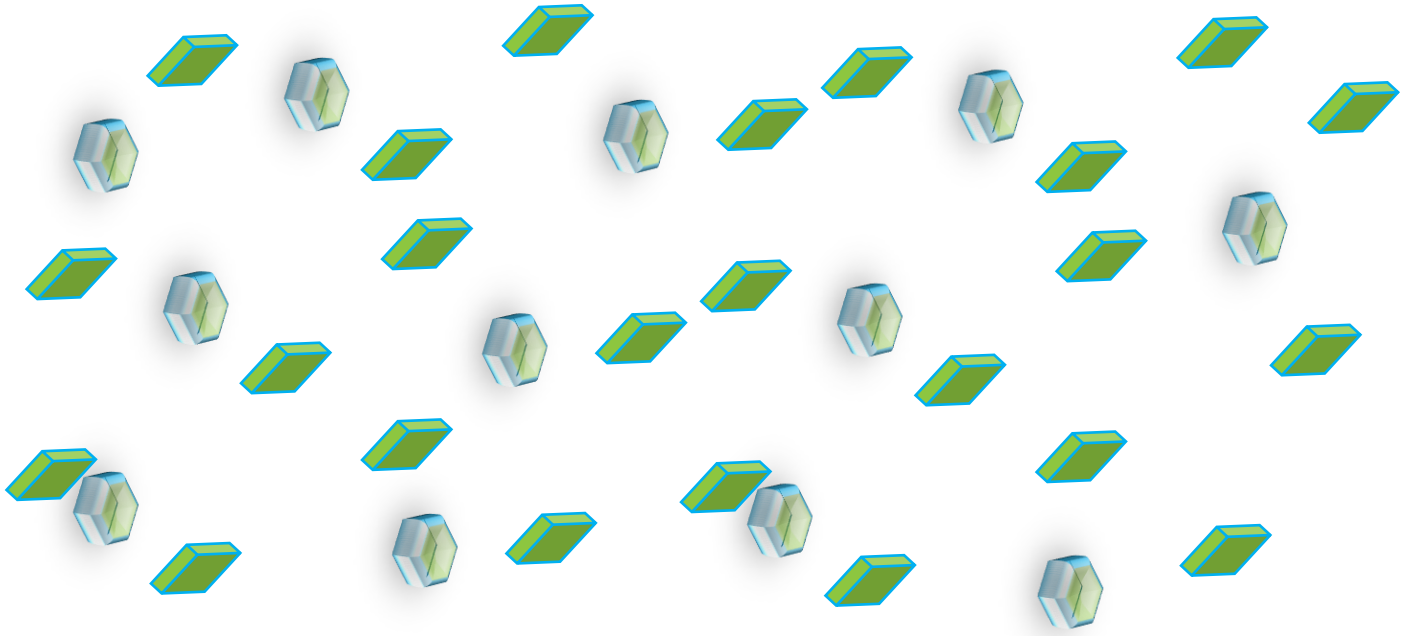
DIFFERENT CRYSTAL FORMS



The same molecule can potentially crystalize (layer upon itself in a regular pattern) in different ways to create different macromolecular structures.

We call these different structures ***forms.***

A 2:1 MIXTURE OF CRYSTALS



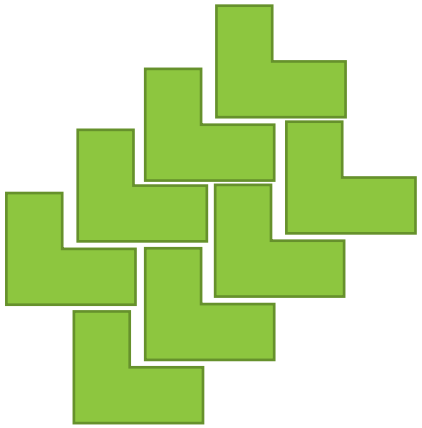
If two crystal forms are possible and can develop under the same conditions, it could result in a mixture of crystals that are made up of the same molecules but caught in different forms and potentially having different properties.

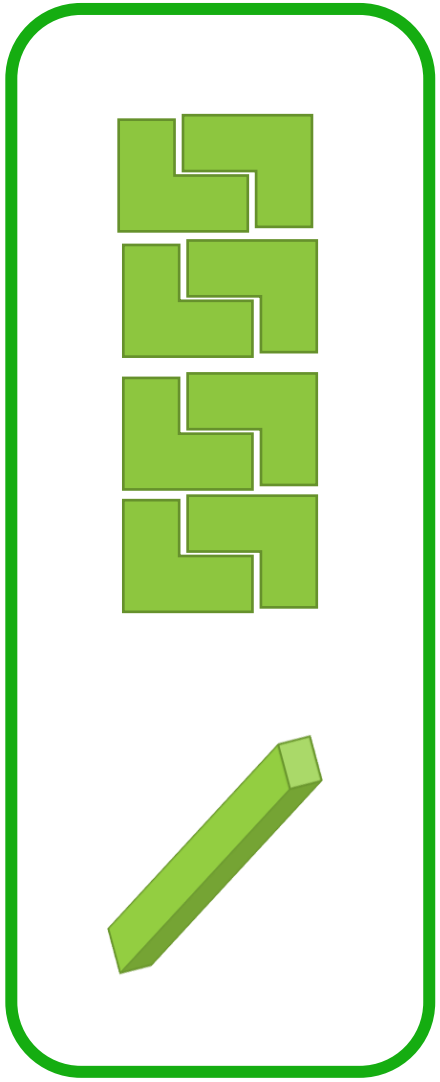
WHAT DON'T WE KNOW?

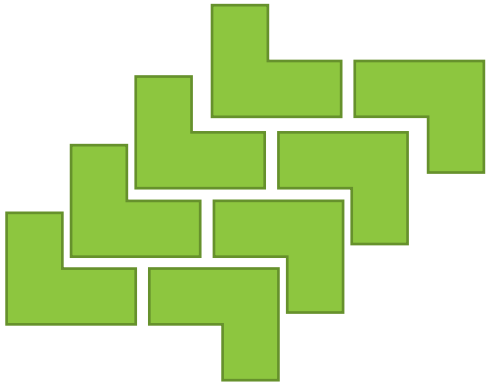
Are there other possible crystal forms that have different properties but are not made under the same conditions as the known forms?

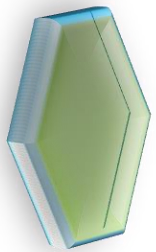
NEW FORMS WITH NEW POTENTIAL

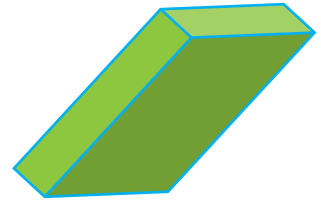
Yes …





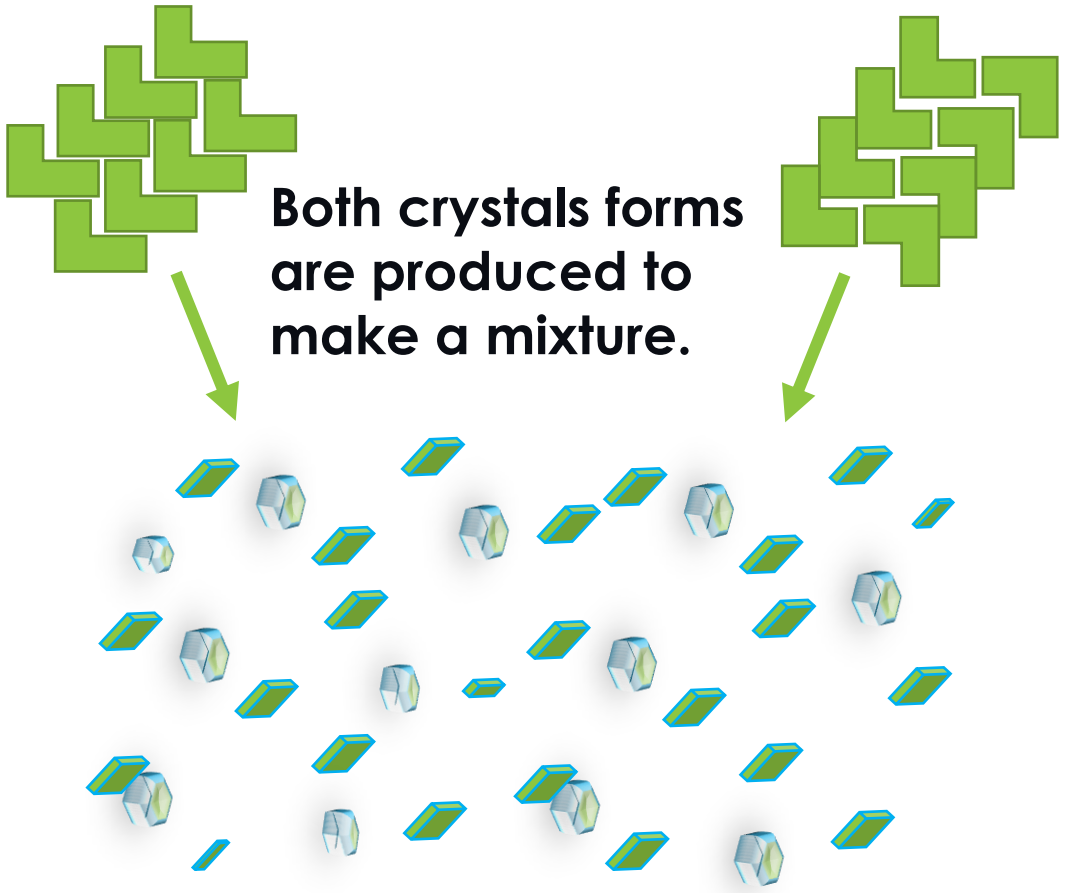




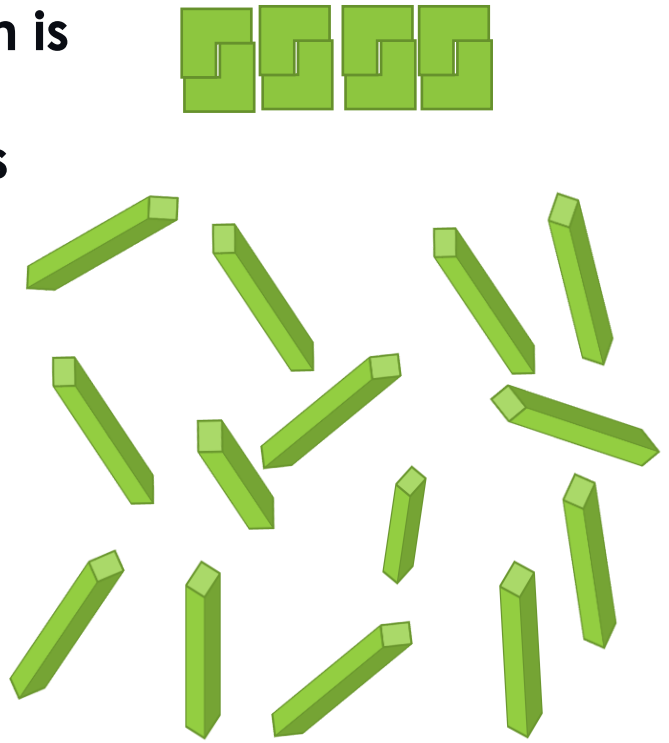


A SIGNIFICANT BENEFIT

Not only is there a new crystal form but, under the right conditions, the only structure that develops is made up of just that one crystal form.



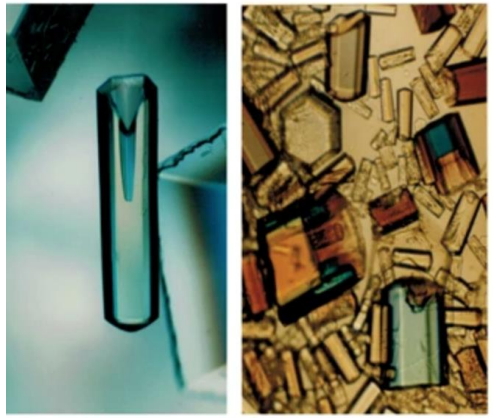
Here only one crystal form is produced. We call this *uniformity*.

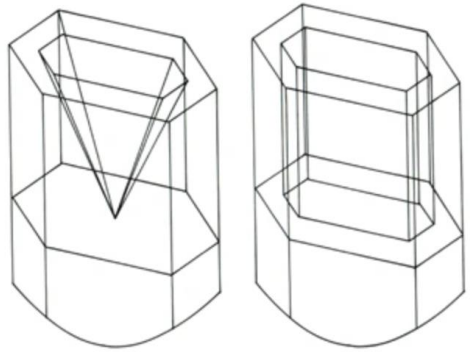


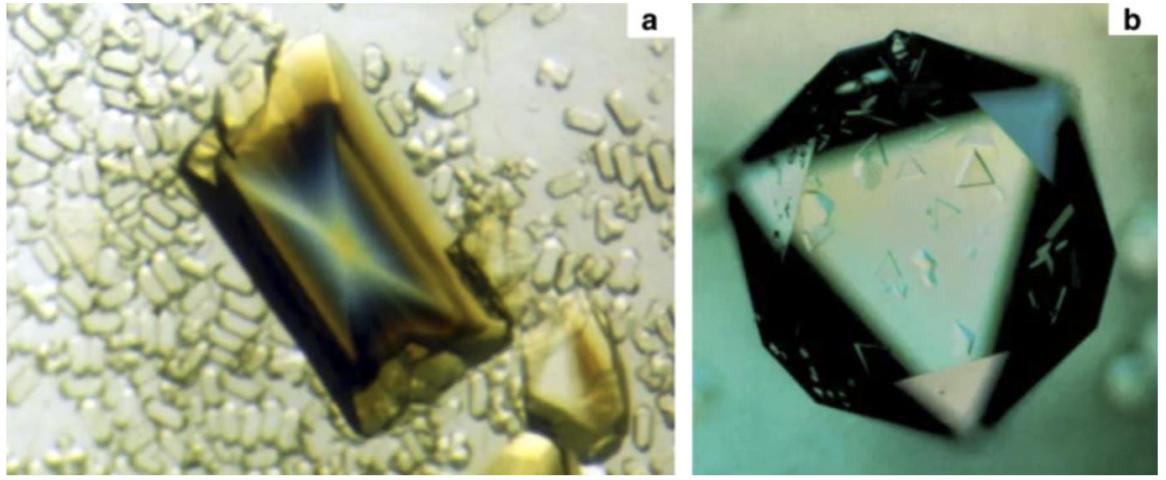
NEW CRYSTAL FORMS

There are past examples of new crystal forms being created, but the application of uniform crystals was not a focus, so it was not explored.

Canavalin



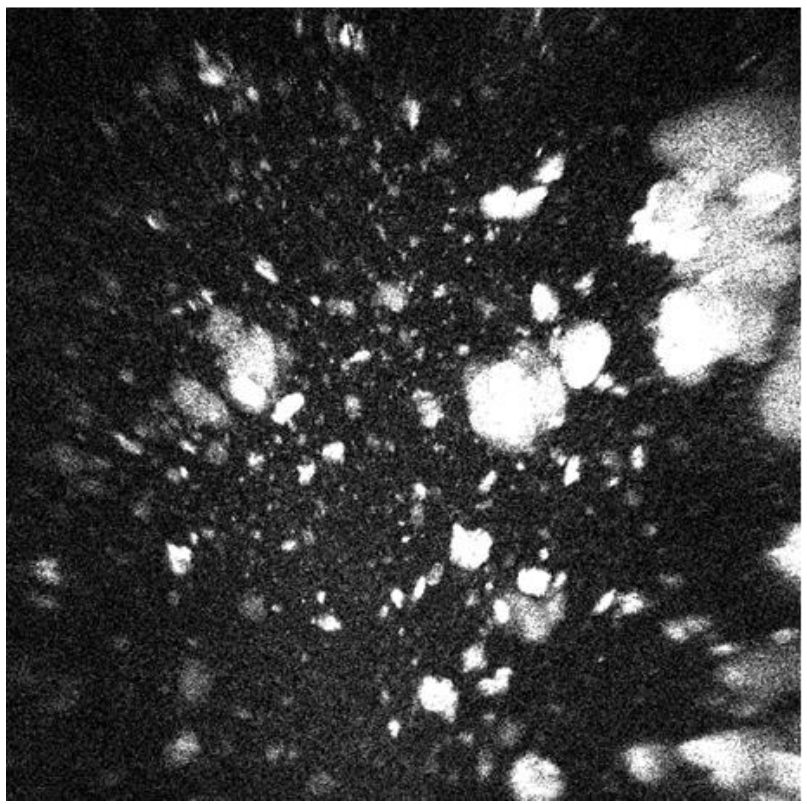


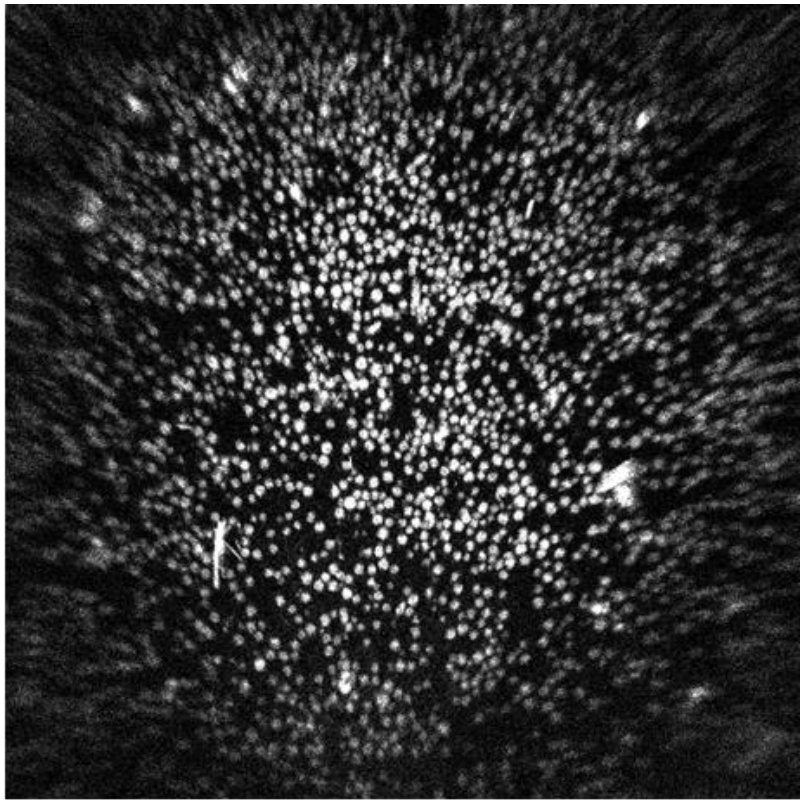


In (**a**) is an orthorhombic crystal of satellite tobacco mosaic virus (STMV) that is more than 1.5 mm in length and was about 30 times the volume of any STMV crystal ever grown on Earth. It was grown in the Cryostat instrument on IML -1. The small STMV crystals in the background formed after return to Earth when the retrograde solubility of the virus remaining in the mother liquor was induced to crystallize by the heat of the microscope lights used for observation. In (**b**) is an equivalent sized cubic crystal of the same virus, again, far exceeding in dimensions any grown in an Earth laboratory.

Microgravity Protein Crystallization, Alexander McPherson and Lawrence James DeLucas, Nature Microgravity, 2015.

AN INDUSTRIALLY APPLIED EXAMPLE





UV imaging of a ground control sample (left) and spaceflight sample (right)

This is from Merck's Keytruda® crystal investigation, clearly showing the much more uniform size and distribution of crystals grown in microgravity.
Image courtesy of Merck

https://www.nature.com/articles/s41526-019-0090-3.pdf

KEY POINT FOR CONSIDERATION

The four types of pharmaceutical patents (ways to protect your intellectual property through a patent):

- Formulation (this includes the molecular structure as well as how a drug is mixed to make the dose formula)
- Manufacturing process
- Mixtures of drug combinations
- **Crystal forms**

Mak Wen Yao , 03 Oct 2016

THE COMMERCIALIZATION OF SPACE

What will it look like?

- Tourism?
- Real estate?
- Do we make a bunch of something?

A mix of new capabilities, intellectual property creation, and unique products, with a focus on the value-to-mass ratio of retuned product.

Wikipedia

RESEARCH ANNOUNCEMENT OVERVIEW

ISS National Lab Research Announcement (NLRA) 2021-5: In-Space Production Applications: Advanced Manufacturing and Materials: LEO-based applied R&D microgravity applications seeking to demonstrate space-based materials manufacturing and production activities that:

- Enable new business growth and capital investment
- Represent scalable and sustainable market opportunities
- Produce reoccurring value with the potential to generate demand for and revenue from access to space

Learn more about the research announcement at:

www.issnationallab.org/research-on-the-iss/solicitations/nlra2021-5/

THANK YOU

Discover the unique advantages of conducting research in microgravity onboard the ISS National Lab.

ISS NATIONAL LABORATORY

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Uluru, or Ayers Rock, a massive sandstone monolith in the heart of Australia's Northern Territory's arid "Red Centre" as seen from the ISS.

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