NASA and ISS National Lab
InSpace Production Applications (InSPA)

Microgravity Manufacturing for Terrestrial Applications

What's Different Now?
November 2024

Microgravity Effects on Materials/Biomaterials Important to Pharmaceuticals, Semiconductors, Industries and Government Agencies

Lynn D. Harper NASA/ARC/Space Portal/InSPA/ISSNL
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Strategic Integration Advisor to ISS National Lab and NASA InSPA
Technical Monitor of 10+ Space Manufacturing for Earth Applications Implemented on ISS since 2019

To Download Public Domain Slides and Notes:
https://docs.google.com/presentation/d/1-UVkEdGLv5jGvGSMBh-BSKUcloXkV8lhpjdAj0Eu9XU/edit#slide=id.g2ecba9a6f5c_3_81

Reporting on the Pioneering Work of Many. All Mistakes Are Mine.

NASA Space Act of 1958 as Amended

PUBLIC LAW 111–314—DEC. 18, 2010

Foundations of this Report

(c) COMMERCIAL USE OF SPACE.—Congress declares that the general welfare of the United States requires that the Administration ***seek and encourage, to the maximum extent possible, the fullest commercial use of space.***

(f) BIOENGINEERING RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAMS.—Congress declares that the general welfare of the United States requires that the unique competence of the Administration in science and engineering systems be directed to assisting in bioengineering research, development, and demonstration programs designed to ***alleviate and minimize the effects of disability.***

This Presentation is Based on Input from the Following With Deep Thanks
(Not even close to a Complete List)

Organizations

Apsidal

Arizona State University

Aspera

Auxilium

Axiom

Bioserve Space Systems

BryceTech

Butler University Microgravity Crystal Database Team

Cedars-Sinai

Flawless Photonics

FOMS, Inc.

GeneLab/NASA ARC

International Space Station National Lab

LambdaVision

Mayo Clinic

Mercury Systems

NASA JSC Cell Science Program

NASA Human Research

NASA SBIR

NASA Space Biology and Physical Sciences

NASA Space Portal

NASA Vascular Tissue Centennial Challenge

National Stem Cell Foundation

New Organ Alliance

NIH

NSF

Palo Alto Veterans Research

Redwire

Sachi Bioworks

Sanford Institute

Space Tango

SpaceX

Stanford University

STPI

Tulane University

University of California San Diego

University of Connecticut

Veterans Administration

Wake Forest Institute for Regenerative Medicine

Individuals

Dr. Greg Autry, Arizona State University
Dr. Mel Averner, NASA Space Biosciences
Dr. Baruch Blumberg, Nobel Laureate
Dr. Anna Brady-Estevez, NSF
Dr. Victor Buchli, Univ College London
Dr. Lawrence DeLucas, Astronaut Crystallographer
Dr. Lisa Carnell, NASA BPS
Dr. Lynn Clary, NASA BPS
Dr. Ioana Cozmuta, STC
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Mr. Kevin Engelbert, NASA InSPA
Dr. Jessica Frick, Astral Materials
Dr. Jeffrey Ganley, US Space Force
Dr. Randy Giles, ISS National Lab
Mr. Richard Glover, ACME Adv. Materials
Dr. Marc Guilianotti, ISS National Lab
Dr. Timothy Hammond, Tulane
Dr. Rose Hernandez, ISS National Lab
Mr. Curtis Hill, NASA
Dr. Emily Holton, NASA ARC
Dr. Antony Jeevarajan, NASA JSC
Mr. Kris Kimmel, KentuckySpace
Dr. John Love, NASA JSC
Dr. Alexander MacDonald
Dr Davide Marotta, ISS National Lab
Mr. Alan Marty, JP Morgan
Mr. Joshua Neubert, Competition Sciences
Mr. Mark Newfield, NASA ARC
Dr. Cheryl Nickerson, Arizona State University
Dr. Neil Pellis, JSC Cell Biology
Dr. Donald Pettit, Astronaut
Mr. Bruce Pittman, Space Portal
Dr. Daniel Rasky, NASA Space Portal
Mr. Michael Reed, NASA/ISS/OZ
Dr. Richard Roberts, Nobel Laureate
Dr. Michael Roberts, ISS National Lab
Mr. Gary Rodrigue, ISS National Lab
Dr. Kenneth Savin, Redwire
Dr. Debbie Senesky, Stanford
Ms. Jana Stoudemire, Axiom
Dr. Dennis Tucker, NASA MSFC
Dr. William Wagner, McGowan Institute
Dr. Anne Wilson, Butler University

All Projects have Problems.

Successful Ones Solve Them.

Experienced Ones Avoid Them.

Smart Ones Test.

SPACE.com

Space Exploration | The Universe | Stargazing | Launches & Spacecraft

Space Exploration > Missions > International Space Station

International Space Station Gets Life Extension Through 2024

News By Tariq Malik published January 8, 2014

10 YEARS AGO

A Very Wise Decision was made.

Here are some of the things that happened as a result

• Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

• **First National Laboratory Beyond Earth**

First Sustained Commercial Deliveries Of People And Cargo Between Orbit And Earth

First Orbital Commercial Scale Manufacturing

First Sustained Orbital Power Station

First Orbital International Space Port

24 Years and Counting of Continuous Human Habitation Beyond Earth

- **Catalyst, Inspiration, and Accelerator of Commercial Space Enterprises**
- **Existence Proof that Permanent Human Occupation of Other Worlds is Feasible**

• Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

● **First National Laboratory Beyond Earth**

First Sustained Commercial Deliveries Of People And Cargo Between Orbit And Earth

First Orbital Commercial Scale Manufacturing

For the rest of the century …We should never have fewer capabilities in LEO than we do now.

In fact, LEO and microgravity research and applications for Earth and space should grow now for near term benefits, long term prosperity, and competitive skill development for industries of the future.

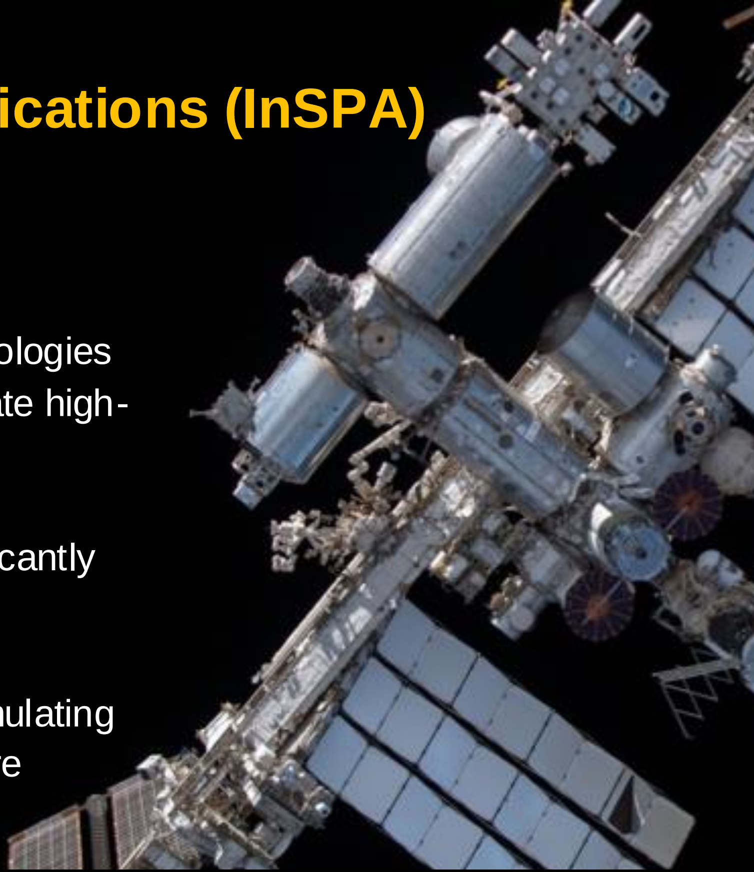
First Sustained Orbital Power Station

First Orbital International Space Port

24 Years and Counting of Continuous Human Habitation Beyond Earth

- **Catalyst, Inspiration, and Accelerator of Commercial Space Enterprises**
- **Existence Proof that Permanent Human Occupation of Other Worlds is Feasible**

NASA InSpace Production Applications (InSPA)
In Space for Earth



Serve U.S. national interests by developing materials and technologies that strengthen industry leadership and national security, and create high-quality jobs.

Provide benefits to humanity by developing products that significantly improve the quality of life for people on Earth.

Accelerate development of the space economy in LEO by stimulating demand for scalable and sustainable non-NASA utilization of future commercial LEO destinations.

Approach: Increase proficiency in orbital manufacturing through utilization of ISS National Lab. **Independent validation** of superior product manufacturing in LEO compared to ground control.

ISS NATIONAL LABORATORY®

CENTER FOR THE ADVANCEMENT OF SCIENCE IN SPACE

The ISS National Lab (ISSNL) was chartered by Congress in 2005 to manage 50% of the R&D resources of the International Space Station (ISS).

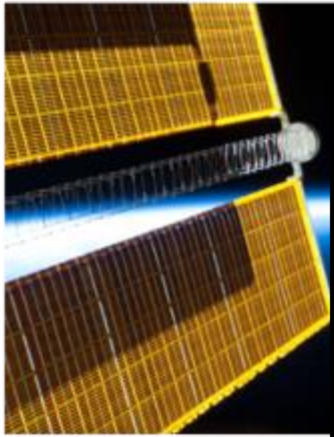
The ISSNL is managed by the Center for the Advancement of Science in Space (CASIS) and began operations in 2010.

Since then, on an annual operating budget of $15M,

ISSNL has enabled:

- **200+** Payloads flown with the ISS National Lab supported by 10 Implementation Partners
- **5+** patents as a result of ISS National Lab R&D
- **$285M** in committed sponsored program funding

CASIS funding for newly selected projects in FY23 was matched 5:1 by committed funding from non-NASA, third-party entities and the selected institutions themselves—an increase over last year's ratio of 4:1.



The ISS National Lab's first flight was in 2013. They reached a healthy growing cadence of pioneering R&D on iSS by 2015 and got steadily better.

Many of the advances shown in this report resulted from their early investments.

Enabling Pioneering Payloads on 55 launches since 2013

2014: Where is Gravity Impeding US Industry?

NASA ESO Findings 2014

Demand Trends

in High Tech

These demands push materials and processes to the point where ***defects at the atomic and molecular level matter*** ...

this is where microgravity can help.

- more bandwidth
- faster processors
- greater energy efficiency
- specific wavelength applications (lasers)
- more processing power in smaller volumes
- better performance in more extreme environments
- more effective pharmaceuticals and treatments
- atomic and molecular level precision

No end to that demand in sight

2014: Where is Gravity Impeding US Industry?

Even more true in 2024

NASA ESO Findings 2014

Demand Trends

in High Tech

These demands push materials and processes to the point where ***defects at the atomic and molecular level matter*** ...

this is where microgravity can help.

- more bandwidth
- faster processors
- greater energy efficiency
- specific wavelength applications (lasers)
- more processing power in smaller volumes
- better performance in more extreme environments
- more effective pharmaceuticals and treatments
- semiconductors
- atomic and molecular level precision

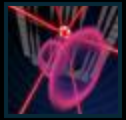
No end to that demand in sight

- regenerative medicine
- medical devices

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Quantum
Subatomic



Cold
Atom
Lab

Manufacturing Bose-Einstein Condensates in Space near absolute zero since 2019 on ISS

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Quantum
Subatomic

Cold
Atom
Lab

Molecular

Crystals
Pharma
Industrial
Semiconductors

80+% of 500+ Crystals Manufactured in Space since 1973 Improved in Structure, Uniformity, Size or Reduction of Defects.

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Translating 50 years of microgravity R&D into high-value applications from subatomic through human

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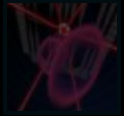

Cold
Atom
Lab

Molecular

Crystals
Pharma
Industrial
Semiconducto
r

Thin Films

Medical
Devices
Artificial Retina
Nerve Regen

Semiconductors

Space Manufactured Artificial Retinas Ready for Animal Trials, Semiconductors in parabolic testing

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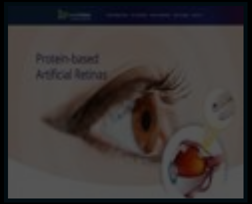


Medical Devices
Artificial Retina
Nerve Regen

Semiconductors

Alloys and Photonics

ZBLAN Optical Fibers
Semiconductors

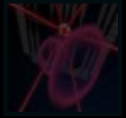
High Throughput 11.9 km optical fiber manufactured on ISS to commercial lengths

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Medical Advances from Space
for 50+ years

Quantum
Subatomic



Cold
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Molecular

Crystals
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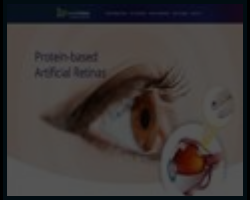


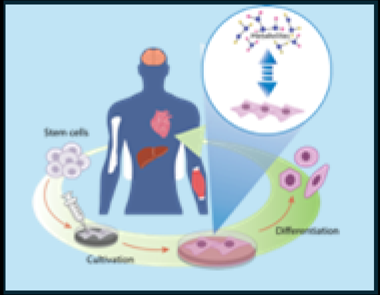
Medical
Devices
Artificial Retina
Nerve Regen

Semiconductors

Alloys and
Photonics

ZBLAN Optical
Fibers
Semiconductors

Cells and Tissues



Cancer
Neurodegenerative
Stem Cells
3D Tissues
Artificial Organs

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Medical Advances from Space
for 50+ years

Quantum
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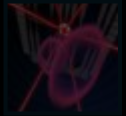

Cold
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r

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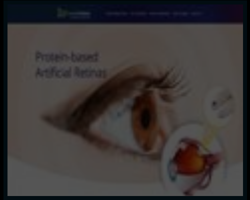

Medical
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Alloys and
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ZBLAN Optical
Fibers
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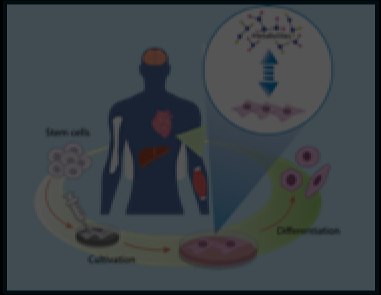
Cells and Tissues



Cancer
Neurodegenerative
Stem Cells
3D Tissues
Artificial Organs

Whole Organisms

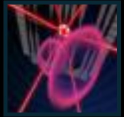
Plants
Animals
Humans

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Medical Advances from Space for 50+ years

Quantum Subatomic



Cold Atom Lab

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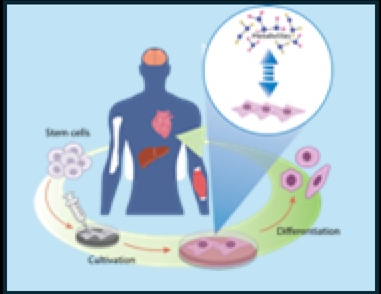

Cancer
Neurodegenerative
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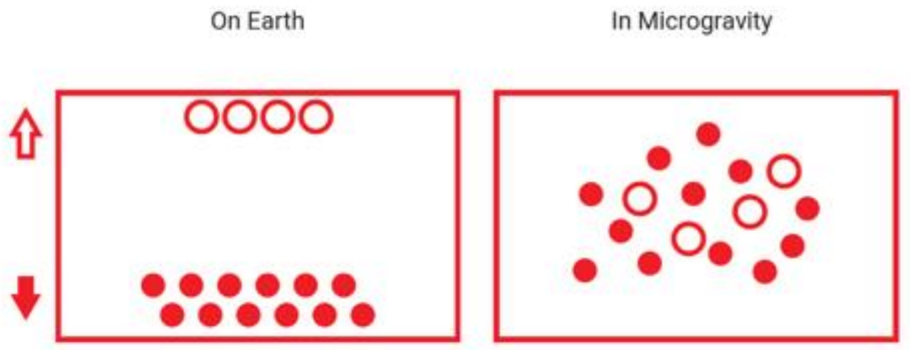
Whole Organisms

Plants
Animals
Humans

- High Throughput 11.9 km optical fiber manufactured on ISS to commercial lengths
- Space Manufactured Artificial Retinas Ready for Animal Trials, Semiconductors in parabolic testing
- 80% of 500+ Crystals Manufactured in Space since 1973 Improved in Structure, Uniformity, Size or Reduction of Defects
- Manufacturing Bose-Einstein Condensates in Space near absolute zero since 2019

18

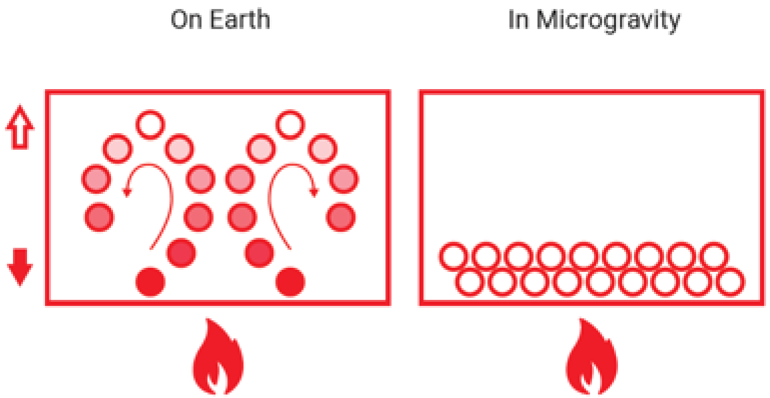


Why Microgravity Works

Helps with alloys and biomanufacturing

1. **Absence of Buoyancy & Sedimentation.** On Earth, a material's density (mass per unit volume) determines whether it will float (buoyancy) or sink (sedimentation). For example, when adding honey and olive oil to a glass of water, the honey will sink to the bottom of the glass while the olive oil will float on top. In microgravity, the relative density of substances does not matter—meaning that the mixture of honey, olive oil, and water will disperse much more evenly. This enables greater precision, improved materials structure, and increased uniformity in microgravity.

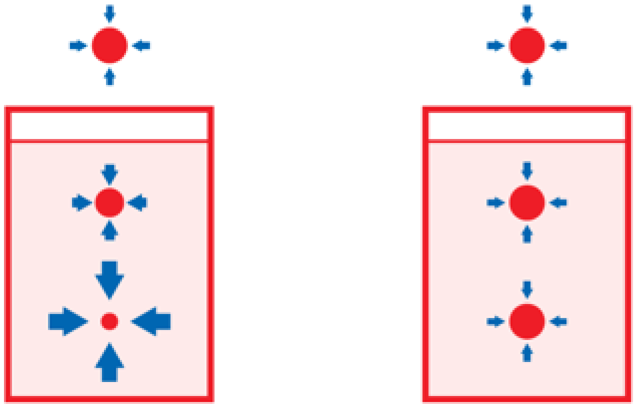
Source: Frick, J., Rodrigue, G., Senesky, D., Hill, C. Semiconductor Manufacturing in Low Earth Orbit for Terrestrial Use. 2023 Workshop Report. https://osf.io/preprints/osf/d6ar4



Why Microgravity Works

2. Absence of Convection. This is the most complicated and technical consideration. The best way to understand this phenomenon is to consider thermal convection, which relies on understanding the relative densities of a substance. On Earth, when heating a pot of water, for example, the water closer to the heat source gains energy (i.e., becomes warmer), and therefore becomes less dense and rises to the top. This cycle of warm liquid rising and cool liquid falling creates the cycle called convection. This phenomenon is alleviated in microgravity because of the absence of buoyancy and sedimentation. For a more thorough discussion, review "Convection Phenomena of Importance for Materials Processing in Space" by Prof. Simon Ostrach.[2]

Source: Frick, J., Rodrigue, G., Senesky, D., Hill, C. Semiconductor Manufacturing in Low Earth Orbit for Terrestrial Use. 2023 Workshop Report. https://osf.io/preprints/osf/d6ar4



Why Microgravity Works

3. Absence of Hydrostatic Pressure. This is the pressure exerted by a fluid in a confined space due to the weight of the fluid itself. Atmospheric pressure is mostly approximated by the hydrostatic force due to the weight of the air on the surface of the Earth. The closer an object is to Earth's surface, the more air that is above it, resulting in higher atmospheric pressure. This phenomenon is completely dependent on gravity and is therefore weakened in microgravity, helping with precision placement of materials.

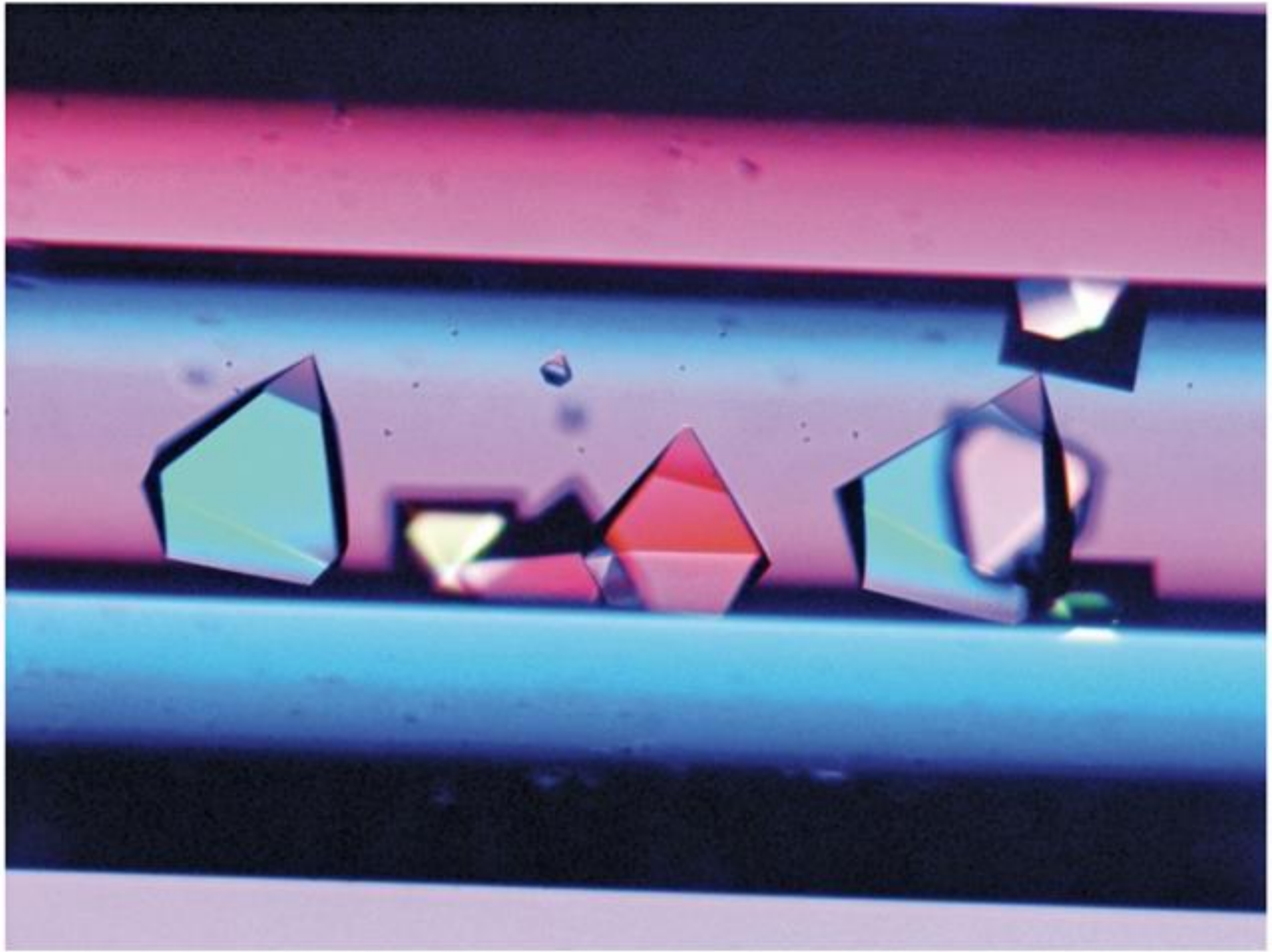
Source: Frick, J., Rodrigue, G., Senesky, D., Hill, C. Semiconductor Manufacturing in Low Earth Orbit for Terrestrial Use. 2023 Workshop Report. https://osf.io/preprints/osf/d6ar4

Why Microgravity Works

4. Absence of Container Requirements. Without costly and intricate methods of intervention, liquids cannot be confined on Earth without the use of containers, with which they must be in direct contact. Microgravity alleviates the need for containers, which on Earth can create disadvantages in semiconductor processing such as size limitations and sample contamination.

Also important for biomanufacturing

Source: Frick, J., Rodrigue, G., Senesky, D., Hill, C. Semiconductor Manufacturing in Low Earth Orbit for Terrestrial Use. 2023 Workshop Report. https://osf.io/preprints/osf/d6ar4



Credit: JAXA

Proteins' crystals are grown in microgravity in the Japan Aerospace Exploration Agency's Kibo module on the International Space Station.

InSPA Butler University Microgravity Crystal Summary
Updated March 2024

Improvement in One Metric: Structure, Uniformity, Size, Resolution, Reduction in Defects, Performance in Application

	Better	Same	Worse	Total (n)
Macromolecules/Organics	288	17	13	**318**
	91%	**5%**	**4%**	
Inorganic (all)	164	7	17	**188**
	87%	**4%**	**9%**	
• **Semiconductors (subset of Inorganic)**	120	3	17	**140**
	86%	**2%**	**12%**	
• **Inorganic (other remaining Inorganic)**	44	4	0	**48**
	92%	**8%**	**0%**	
TOTAL µg Crystals	452	24	30	**506**
	90%	**4%**	**6%**	

Contact Dr. Anne Wilson at amwilson@butler.edu or 317-940-9408

Summary: Crystals grown in microgravity show improvement

	Macromolecules/ Organics	Inorganics	Semiconductors
Improved in at least one metric*	288 (n = 318); 91%	164 (n = 188); 87%	120 (n = 140); 86%
Improved in two or more metrics	229 (n = 318); 72%	99 (n = 188); 53%	69 (n = 140); 49%
Improved in three or more metrics	155 (n = 318); 49%	38 (n = 188); 20%	22 (n = 140); 16%

***Metrics:** Size, structure, uniformity, resolution limit, mosaicity and/or performance. Most reports do not include data on more than one or two metrics.

DETAILS OF MICROGRAVITY CRYSTAL GROWTH 1973-2016

Table 3. Overall evaluation of crystals based on individual metrics; complications removed.

	Macromolecules/ Organics	Inorganics	Total
Larger	82% (n = 239)	64% (n = 89)	77% (n = 328)
Structurally better	75% (n = 162)	83% (n = 121)	78% (n = 283)
More uniform	89% (n = 226)	88% (n = 115)	89% (n = 341)
Improved resolution limit	82% (n = 163)	n/a	82% (n = 163)
Improved mosaicity	77% (n = 131)	n/a	77% (n = 131)

Table 3 provides data only from microgravity investigations where the hardware worked properly

Table 1. Overall evaluation of crystals based on individual metrics; all data, n = 507.

	Macromolecules/ Organics	Inorganics	Total
Larger	81% (n = 250)	64% (n = 90)	77% (n = 340)
Structurally better	73% (n = 170)	80% (n = 125)	76% (n = 295)
More uniform	88% (n = 237)	85% (n = 125)	87% (n = 362)
Improved resolution limit	81% (n = 177)	n/a	81% (n = 177)
Improved mosaicity	77% (n = 136)	n/a	77% (n = 136)

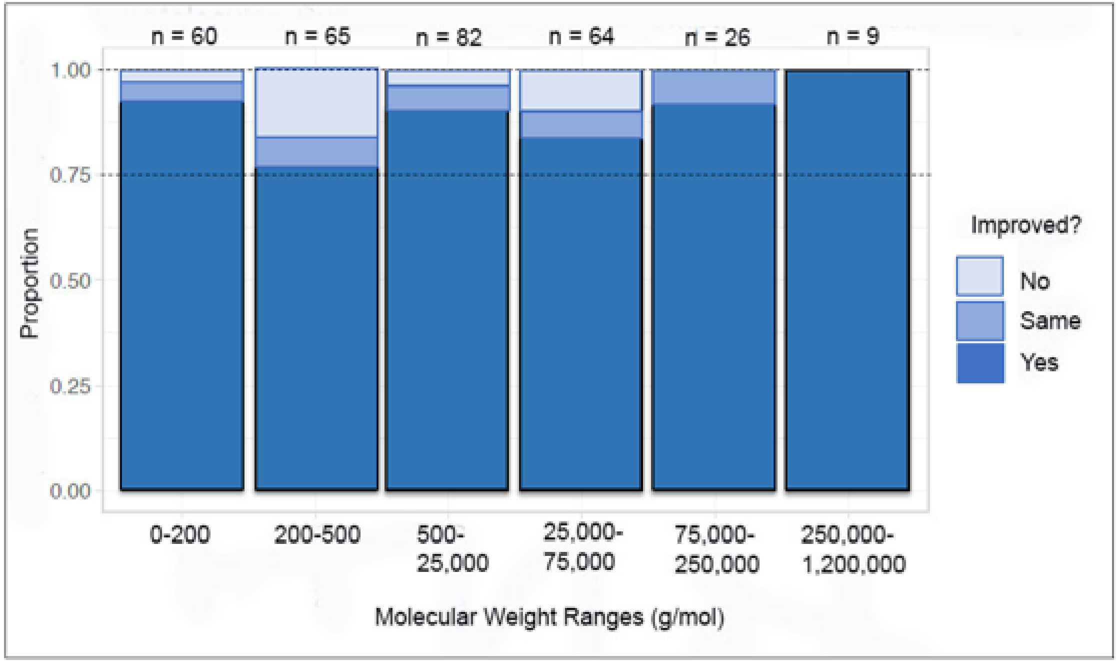
Table 2. Overall improvement in one, two, three, or more metrics (n = 507); all data.

	Macromolecules/ Organics	Inorganics	Total
No improvement or the same in all metrics	30	25	55 (11%)
Improved in one metric	288	164	452 (89%)
Improved in two metrics	229	99	328 (65%)
Improved in three or more metrics	155	38	193 (38%)

Tables 1 and 2 include data from microgravity investigations that failed because of spacecraft or hardware rather than microgravity.

Complexity does not seem to significantly impact crystallization

Comparisons of Space Flight vs Ground grown crystals on the basis of **Molecular Weight /Complexity** with molecular weight used as a surrogate for complexity.

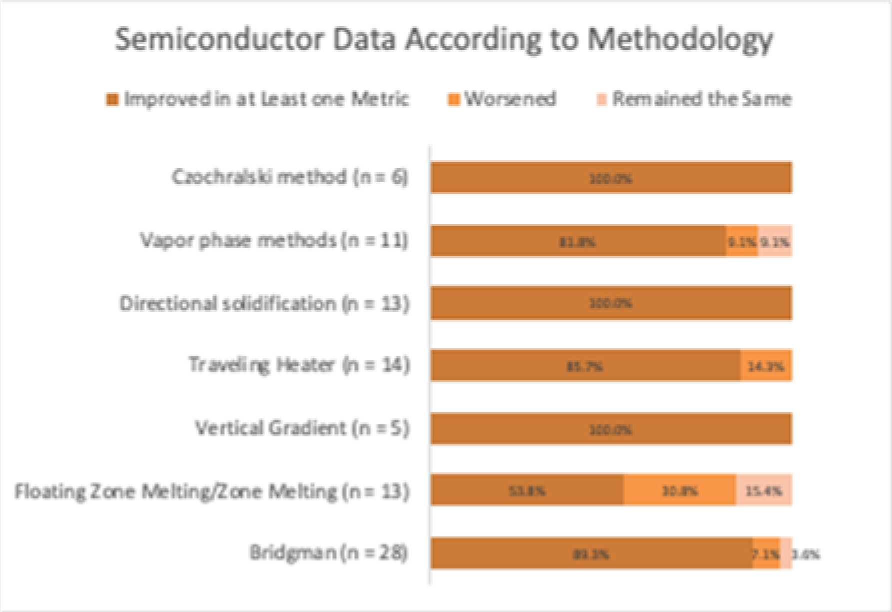


Crystalization methods do not seem to significantly impact success

Example, Semiconductors:

140
Space Semiconductor Crystals

>85%
Improve in Space

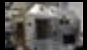


Comparisons of Space Flight vs Ground grown crystals on the basis of **Different Crystallization Methods** focusing on Semiconductors. Similar results were seen for other crystal types as well.

Flawless Space Fibers

Commercial Scale Manufacturing of ZBLAN Fiber on the ISS

Shrink functions of 30ft Earth production system to 30 inches to fit in MSG



1141m

100µ diameter ZBLAN Fiber

- Longest Single Inspace Draw

27 Feb 2024

Held Steady in the Manufacturing Sweet Spot in Space for 3+ Hours

14 of 16 fiber draws each produced >100 meters

9 of 16 fiber draws each produced >700 meters of fiber

3 of 16 fiber draws each produced >1000 meters of fiber

11.9km

100-125µ ZBLAN Fiber

Cumulative Fiber Produced Inspace

9 Feb - 14 Mar2024

In 16 manufacturing runs

OVERVIEW

Using the Microgravity Science Glovebox on the ISS, Flawless Photonics µg optical fiber manufacturing system “Excalibur” is first to produce commercial lengths of ZBLAN fiber in space. FP, the 5th U.S. company to attempt high-quality ZBLAN fiber production on ISS, was funded by the Luxembourg Space Agency and the Univ. of Adelaide, with sponsorship from ISS National Lab.

RESULTS

Excalibur produced 11.9 km of ZBLAN fiber over 3 weeks on ISS. Longest continuous run of 1.1km exceeded known record for commercial production on Earth (700 meters), where gravity impedes length and quality. Most FP draws, including record breakers, were witnessed by NASA and ISS National Lab

IMPACT

Flawless Photonics demonstrated control of high-throughput inspace manufacturing processes that meet upper end of single runs ZBLAN lengths manufactured commercially on Earth. Depending on space fiber quality, the LEO business case could close. FP demonstrated exceptional microgravity manufacturing skill to achieve commercial class scaleup in space. This achievement increases confidence in space manufacturing.

SPACE TANGO LambdaVision

Space Assisted Products: Artificial Retinas

LambdaVision InSPA Phase I Exit Interview

- **8 flights; achieved 200 layers 6 times and 50 layers 4 times (Metric was 50 layers for Proof of Concept but 200 layers are needed for the finished product**)

- **Layering protocol developed – the “Secret Sauce” for optimization of layering on orbit**

Acta Pharm Sin B. 2022 Jul; 12(7): 3049–3062. PMCID: PMC9293739
Published online 2022 Feb 11. doi: 10.1016/j.apsb.2022.02.002 PMID: 35865092

Why 90% of clinical drug development fails and how to improve it?

Duxin Sun,[a,*] Wei Gao,[a] Hongxiang Hu,[a] and Simon Zhou[b]

"Drug discovery and development is a long, costly, and high-risk process that takes over 10–15 years with an average cost of over $1–2 billion for each new drug to be approved for clinical use[1].

For any pharmaceutical company or academic institution, it is a big achievement to advance a drug candidate to phase I clinical trial after drug candidates are rigorously optimized at preclinical stage.

However, nine out of ten drug candidates after they have entered clinical studies would fail during phase I, II, III clinical trials and drug approval[2,3].

It is also worth noting that the 90% failure rate is for the drug candidates that are already advanced to phase I clinical trial, which does not include the drug candidates in the preclinical stages.

If drug candidates in the preclinical stage are also counted, the failure rate of drug discovery/development is even higher than 90%."

Part of the reason that candidate drugs fail in patient clinical trials is because existing Earth based cell/tissue culture models, animal models, and computer models informed by them are **still not good enough to predict the performance of a drug in a human patient.**

When it works, a cell/tissue culture can **accelerate** the identification of the cause of a disease as well as the **development and testing of therapeutics to cure the disease**.

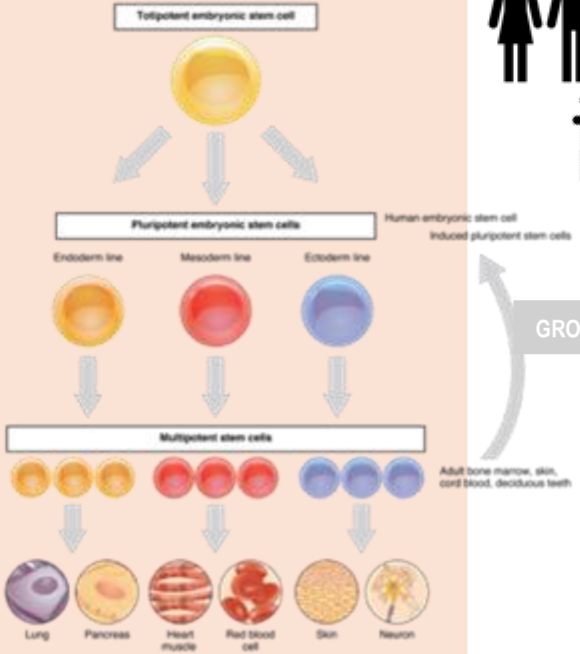
The value of a cell or tissue culture depends entirely on how well the culture model mimics what is really happening biochemically in the patient's body.

This is where microgravity can help.

Stripped of all glamour, we can keep 3D cell and tissue cultures suspended without touching the sides or bottoms of the tissue growth containers a lot longer in space than we can on Earth.

The cells all respond to unconstrained growth in 3 dimensions. But in an increasing number of cases, some grow better, faster, and more akin to how they would react in a patient's body. Not in all cases, but in enough cases now to pursue it further as a priority.

Harvest Cells from Healthy and/or Sick People



Cells and Tissues in the body grow in 3D

Faster, Safer, Better Therapeutics for Cancer and Neurodegenerative Diseases, Organ Diseases, and Personalized Medicine

Grow cells to tissues outside the body as close as possible to how they grow inside the body

GROW OUTSIDE BODY

MICROGRAVITY

InSPA Awards

Blood Cancer	Alzheimer's
Brain Cancer	Lou Gehrig Disease
Breast Cancer	Parkinsons
Ovarian Cancer	Multiple Sclerosis

Artificial Retina
IPSCs/Stem Cells
3D Nerve Regeneration
3D Tissue Engineering
Pharmaceuticals

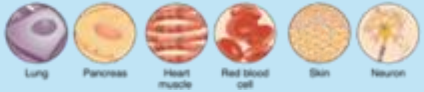
GRAVITY

Gravity causes the 3D cells and tissues in cultures to sink and flatten into 2D structures, which provides the wrong biological signals to the cells and leads to medically misleading information

90% of new drugs fail in patient trials because terrestrial models are not good enough

- Accelerate knowledge
- Accelerate identification of therapeutic targets
- Accelerate drug testing
- Organ bandages
- Artificial Organs

ISS National Lab



Space cells and tissues grow in 3D – not perfectly -- but much closer to how they grow in the body.

Faster iPSC expansion, increased iPSC stability, larger tissues and organoids. Pre-Cancer cells respond rapidly to ug like stress-induced aging on Earth.

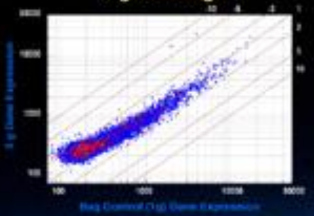
THE VALUE OF A CELL OR TISSUE CULTURE DEPENDS ON HOW WELL IT MIMICS WHAT ACTUALLY HAPPENS IN THE BODY

Gravity and Biology

Changes in Gravity

Renal Cells

3 g Centrifuge



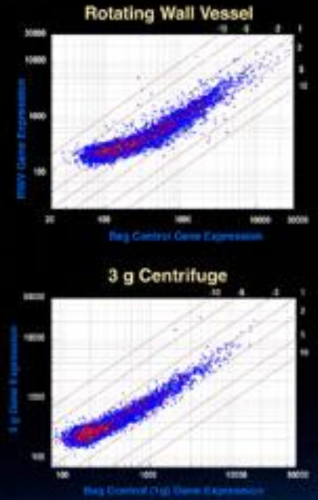
Microvilli

3G

Hammond, T.G., F.C. Lewis, T.J. Goodwin, et. al. Gene expression in space. Nature Medicine 5:359 1999

Changes in Gravity

Renal Cells



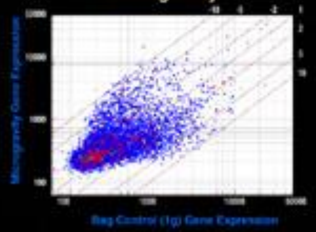
Hammond, T.G., F.C. Lewis, T.J. Goodwin, et. al. Gene expression in space. Nature Medicine 5:359 1999

Gravity and Biology

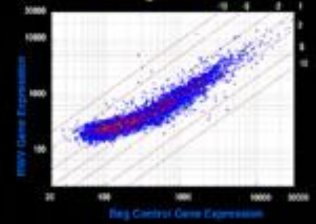
Changes in Gravity

Renal Cells

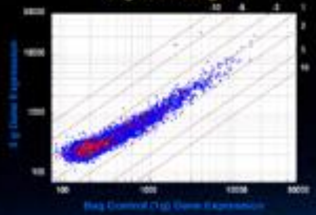
Microgravity



Rotating Wall Vessel



3 g Centrifuge



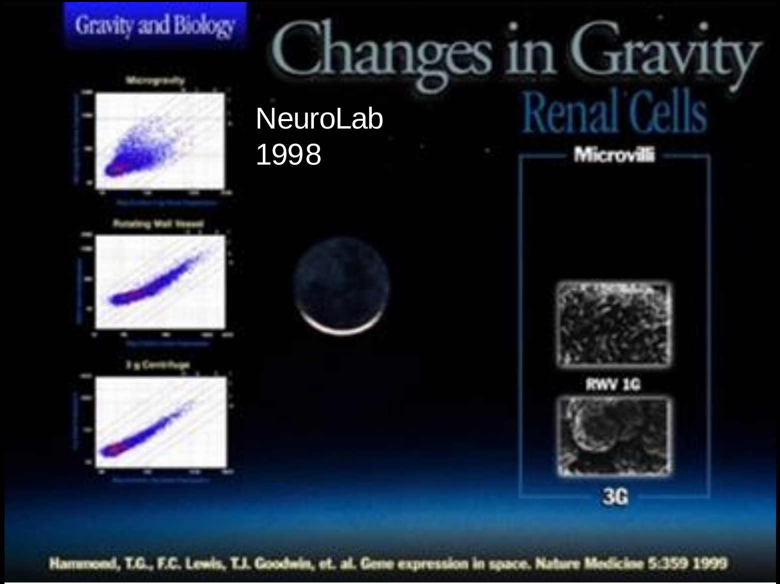
Microvilli

RWV 1G

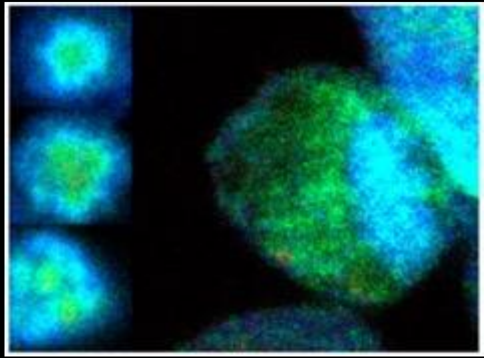
3G

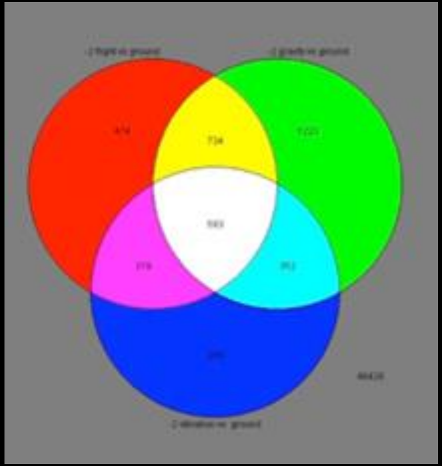
Hammond, T.G., F.C. Lewis, T.J. Goodwin, et. al. Gene expression in space. Nature Medicine 5:359 1999

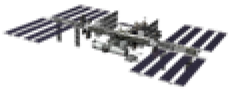
2001 STS106 Follow-Up Flight



Genomics data (left) versus structural changes (right)
Bottom = 3-g centrifuge
Middle = Rotating Wall Vessel
Top = Microgravity





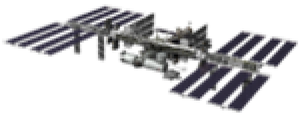


Developing and Testing 3D Organoids in Microgravity:

Improved Cancer Models > New Drug Targets > Accelerated Drug Testing

NASA InSPA and ISS National Lab Portfolios 2020-2024

InSPA Targets	Relevant US Cancer Statistics
Brain Cancer (Glioblastoma)	**95% fatal** in 5 years. 15,000 new cases per year. Most common brain cancer in adults.
Blood Cancer (AML)	**65% fatal** in 5 years. 20,000 new cases per year.
Breast Cancer	**300,000 new cases per year**. Breast cancer results in **40,000 deaths per year**, but 5-year prognosis is good if caught before metastasis.
Colon Cancer	**35% to 90% fatal** in 5 years, depending how early it is caught. 125,000 new cases per year.
Liver Cancer	**80% fatal** in 5 years. 36,000 new cases per year.
Ovarian Cancer	**50% fatal** in 5 years. 20,000 new cases per year.
Metastasis	**93% fatal** in 5 years for metastatic lung cancer. **84% fatal** for metastic colon cancer. **70% fatal** for metastatic breast cancer.
Cancer Overall	**One in 3 people will be diagnosed with cancer in their lifetimes.** 18 million new cases per year worldwide. 9.8 million deaths per year worldwide.



NASA InSPA and ISS National Lab Portfolios 2020-2024

Developing and Testing 3D Organoids in Microgravity: Improved Neurodegenerative Disease Models > New Drug Targets > Accelerated Drug Testing

InSPA Targets	Relevant US Neurodegenerative Disease Statistics
Amyotrophic Lateral Sclerosis (ALS) "Lou Gehrig and Steven Hawking Disease"	**75% fatal in 5 years. 90% fatal in 10 years.** Patients decline rapidly to full paralysis. 5000 new cases per year in US.
Alzheimer's Disease	**Life span after diagnosis 6-10 years.** 500,000 new cases per year in US and 6,000,000 active cases in US now. Cost to the US for care and treatment estimated at $300B. Expected to increase as Baby Boomers age. **1 in 10 people over age 65 will get Alzheimers.**
Multiple Sclerosis	While MS patients can live a normal life span, they do so in progressive decline, requiring more and more care and special treatment. **900,000 people have MS in the US. Cost to US estimated at $85B.**
Parkinsons' Disease "Michael J. Fox Disease"	**50% survive for 10 years under continual decline,** with survival determined largely by age at time of diagnosis. Today, 1,000,000 live with Parkinson's Disease in the US and 90,000 new cases are diagnosed each year. Cost to US is $50B per year.

NASA InSPA March 2024 Biomanfacturing and Pharmaceutical Applications Portfolio

Biomanufacturing:

•Protein-Based Artificial Retina for Blindness. LambdaVision

•Cancer Stem Cell Therapies. UCSD/Sanford Stem Cell Inst.

•Stem Cell Therapies for Blood Disorders. Univ. Colorado Boulder and Mayo Clinic

•Stem Cells (iPSC) for Heart, Brain, Blood Therapies. Cedars Sinai

•RNA Therapeutics and Cartilage. UConn & Eascra Biotech

•NanoligomerTM based Drug Discovery. Sachi Bio

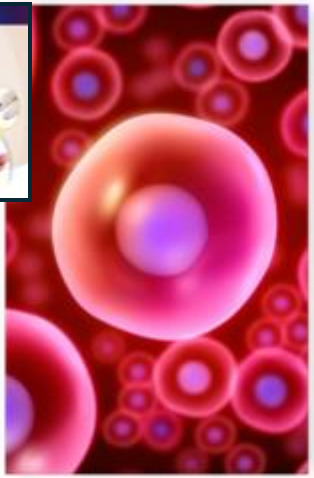
•3D Printed Nerve Regeneration. Auxilium Biotechnologies

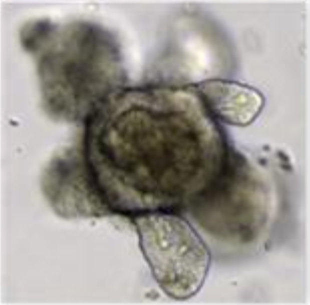
•3D Printed Cartilage. Lawrence Livermore National Labs

•3D Engineered Liver Tissue. Wake Forest Institute of Regenerative Medicine

Pharmaceuticals:

•Protein Crystal Growth for Pharmaceuticals. Redwire Space

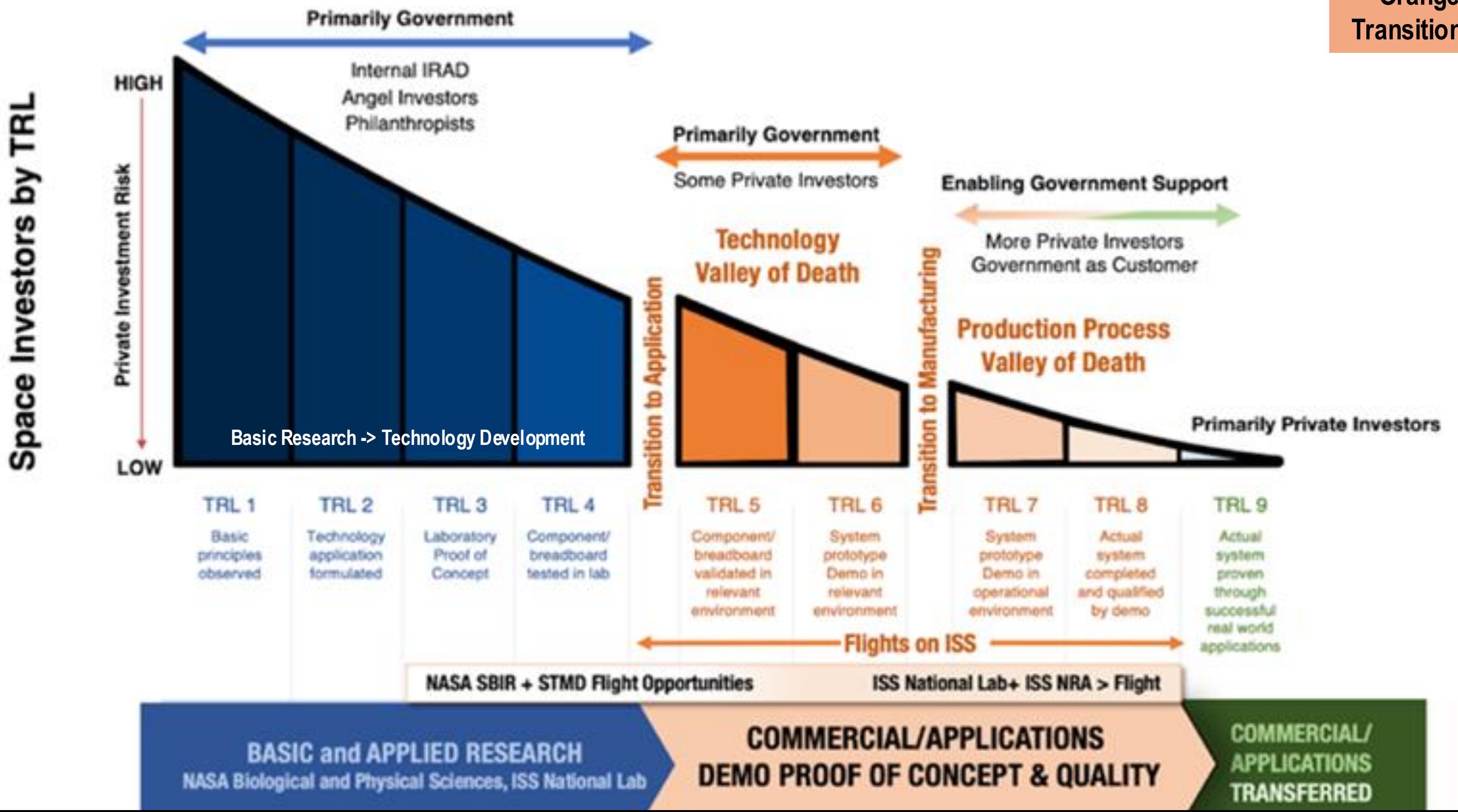




APPLICATIONS STAND ON THE SHOULDERS OF BASIC RESEARCH

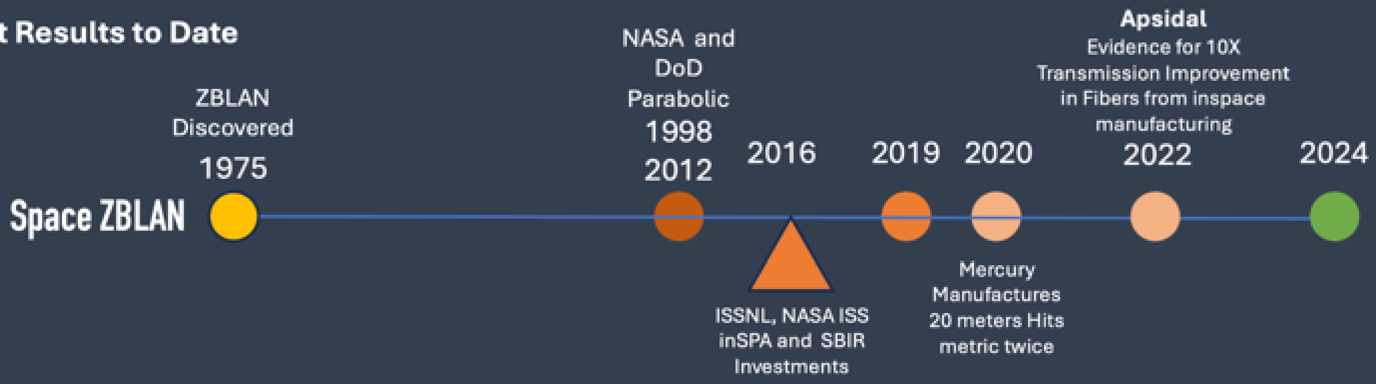
Approach: Build. Fly. Learn. Fix. Improve. Iterate. Repeat. Succeed. Through the Valleys of Death to Applications via Practice

Orange shows Transition to InSPA

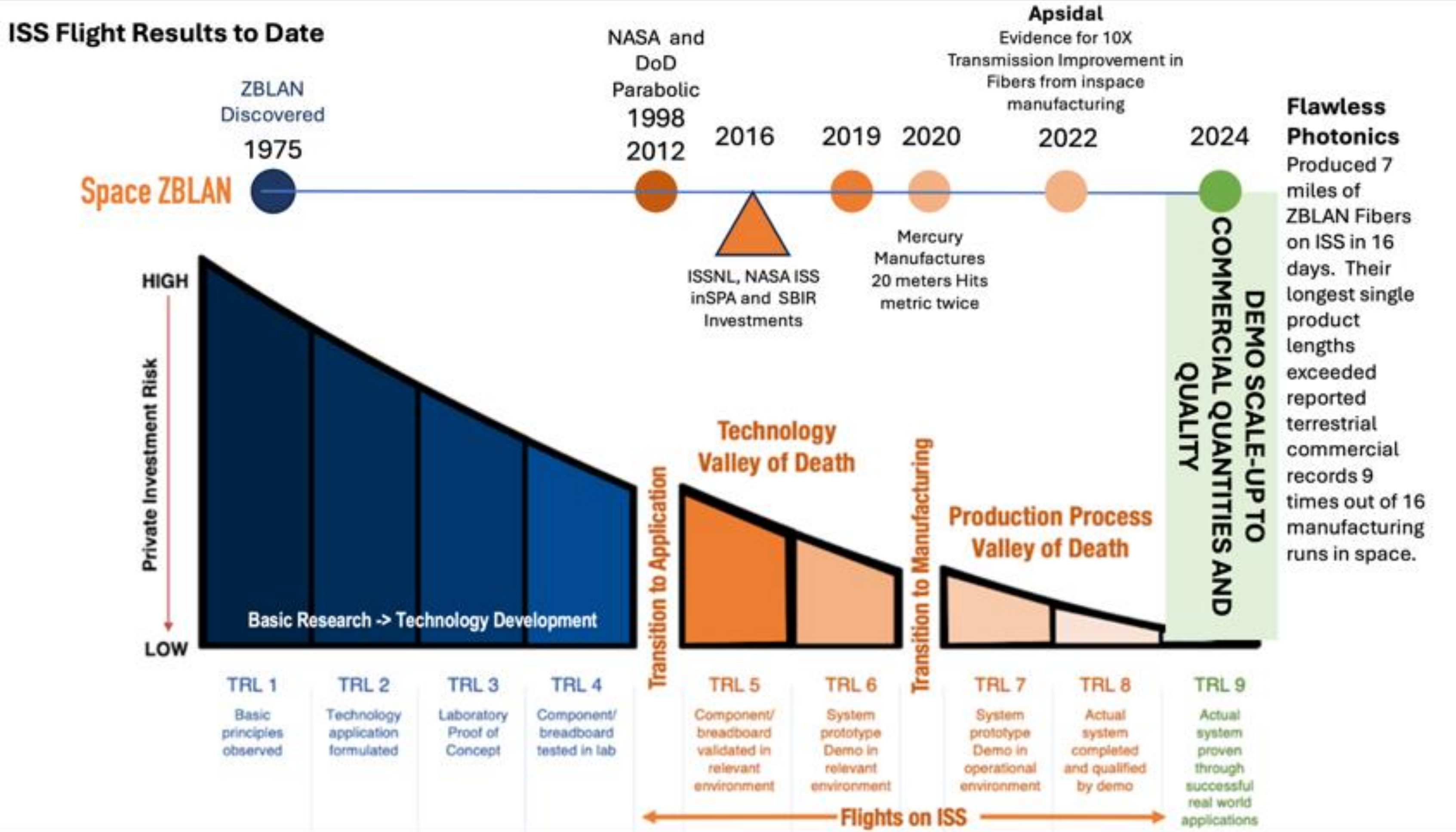


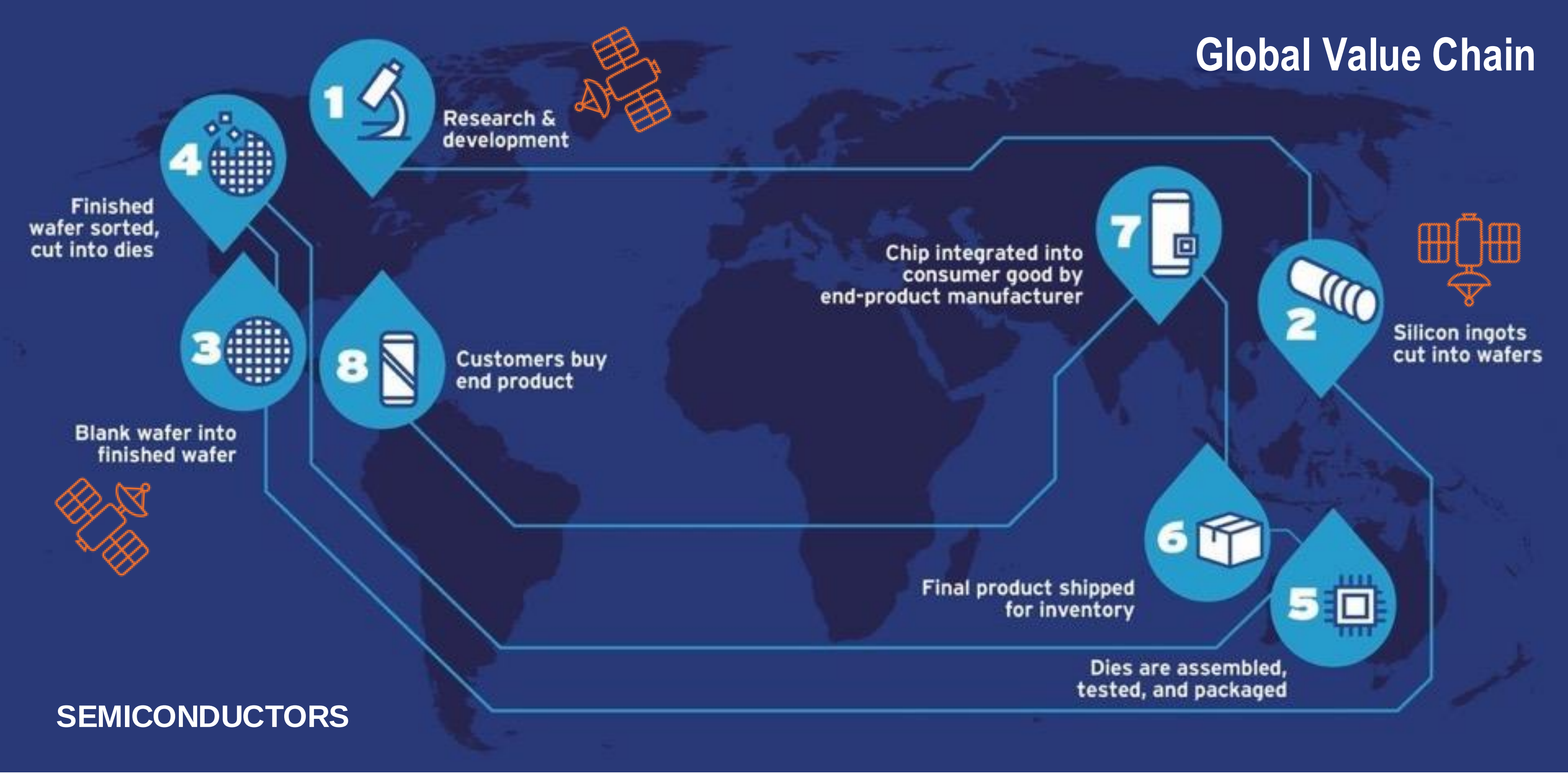
GOVERNMENT NECESSARY TO ENABLE BREAKTHROUGHS BEFORE PROFITABILITY IS OBVIOUS

Flight Results to Date

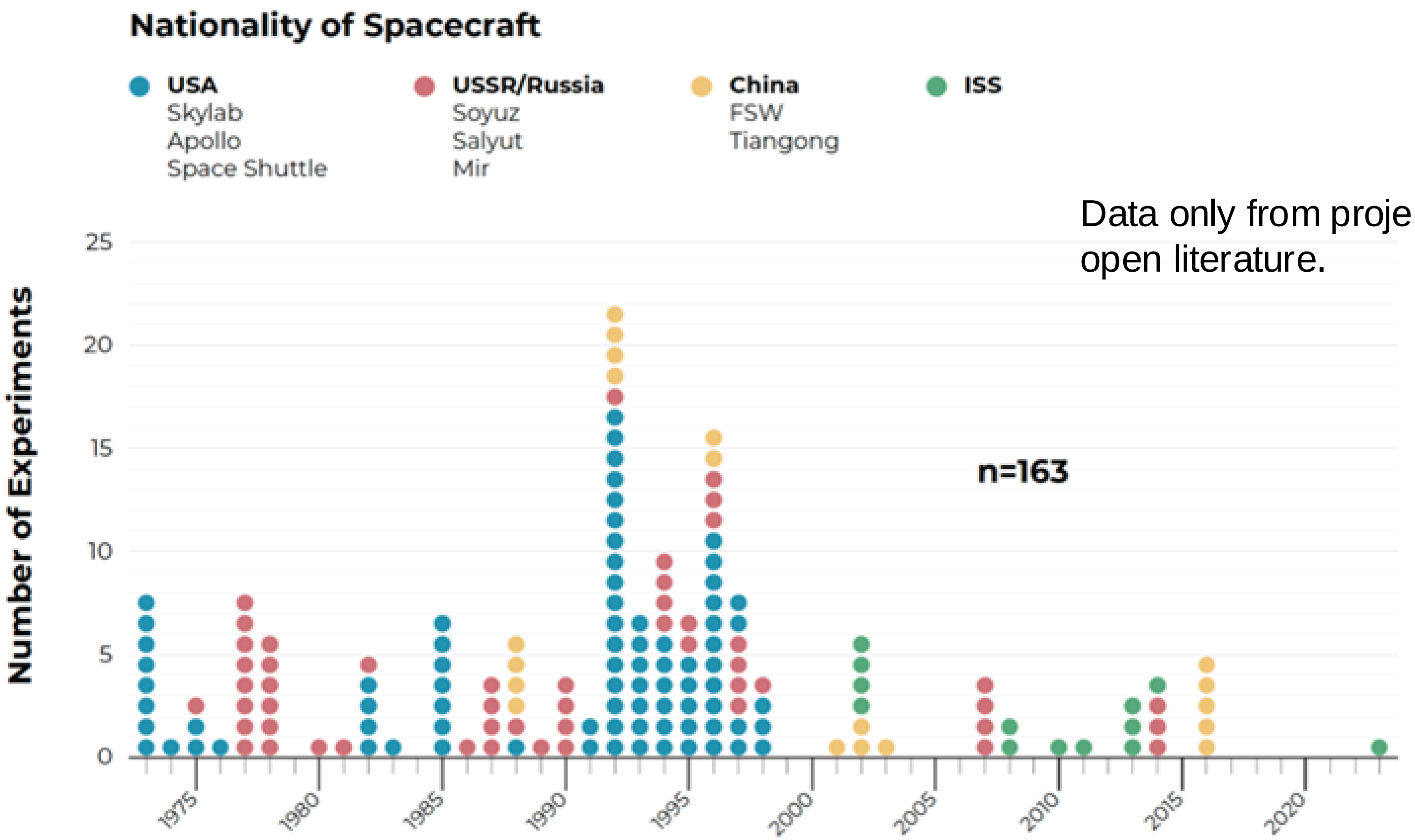


Flawless Photonics
Produced 7 miles of ZBLAN Fibers on ISS in 16 days. Their longest single product lengths exceeded reported terrestrial commercial records 9 times out of 16 manufacturing runs in space.


ISS Flight Results to Date
Space ZBLAN
ZBLAN Discovered
1975
NASA and DoD Parabolic
1998
2012
2016
ISSNL, NASA ISS inSPA and SBIR Investments
2019
2020
Mercury Manufactures 20 meters Hits metric twice
Apsidal
Evidence for 10X Transmission Improvement in Fibers from inspace manufacturing
2022
2024
Flawless Photonics
Produced 7 miles of ZBLAN Fibers on ISS in 16 days. Their longest single product lengths exceeded reported terrestrial commercial records 9 times out of 16 manufacturing runs in space.
HIGH
Private Investment Risk
LOW
Basic Research -> Technology Development
Transition to Application
Technology Valley of Death
Transition to Manufacturing
Production Process Valley of Death
DEMO SCALE-UP TO COMMERCIAL QUANTITIES AND QUALITY
TRL 1
Basic principles observed
TRL 2
Technology application formulated
TRL 3
Laboratory Proof of Concept
TRL 4
Component/ breadboard tested in lab
TRL 5
Component/ breadboard validated in relevant environment
TRL 6
System prototype Demo in relevant environment
TRL 7
System prototype Demo in operational environment
TRL 8
Actual system completed and qualified by demo
TRL 9
Actual system proven through successful real world applications
Flights on ISS



Where Space Can Help



Data only from projects reported in open literature.

Figure 5. *In-Space Semiconductor Crystal Growth Experiments*

Space-Assisted Applications from InSpace Manufacturing Projects:

NRC Criteria for Enabling Technology

"...characteristics of a general-purpose technology ...

a technology in which advances foster innovations across a broad spectrum of applications in a diverse array of economic sectors.

Improvements in those sectors in turn increase the demand for the technology itself, which makes it worthwhile to invest further in improving the technology, thus sustaining growth for the economy as a whole. . ."

National Research Council. *Optics and Photonics: Essential Technologies for Our Nation*. Washington, DC: The National Academies Press, 2013.

Most inspace production, manufacturing, and applications projects will inform and open new classes of materials, applications, and products that are variations in formulas and end item uses. They are not 'one-offs' specific to a single composition or manufacturer.

Opportunities and WorkForce Development for Industries of the Future

Space industries, and the opportunities and revenues from them, have grown steadily for the past 60 years. The rate of development is accelerating as more technically sophisticated countries successfully implement projects in LEO.

Space offers a new way of manufacturing that supports industries of the future.

Opportunities and Work Force Development for Industries of the Future

Space offers a new way of manufacturing that supports industries of the future.

We recommend that hands-on training and education programs be put in place focused on the development of microgravity manufacturing skills starting with worthy terrestrial applications.

Further that these training programs be conducted online through professional University and other expert oversight to allow participation from anywhere in the country with access to the internet.

Opportunities and Work Force Development for Industries of the Future

Remote Manufacturing.

One unique aspect of manufacturing in space is the need to develop world class skills in how to manufacture remotely.

Remote manufacturing is not just valuable for space, it could revitalize America’s skills in different kinds of manufacturing applications and provide more opportunities for innovation and growth.

Space technologies apply to many Earth applications.

Industries of the Future

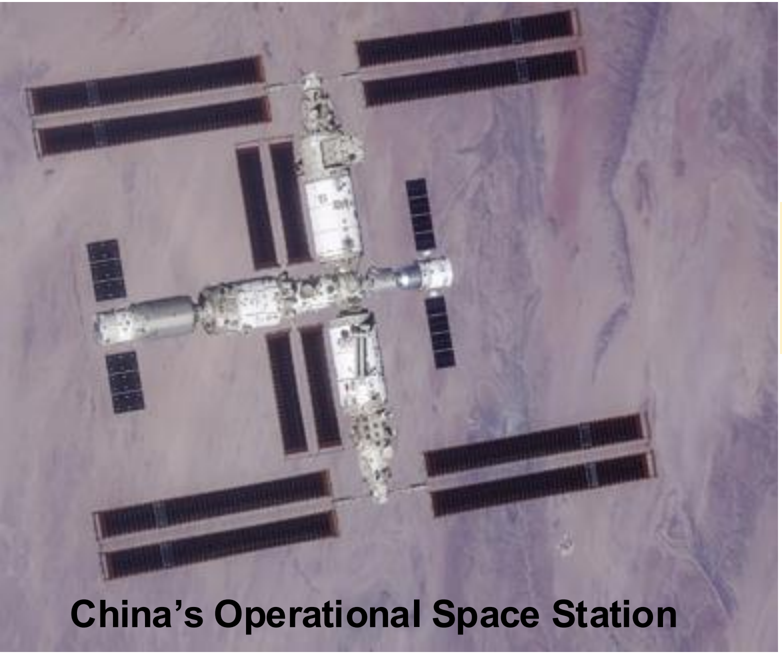
Remote Manufacturing on Earth and in Space

If we can manufacture remotely in space, we can manufacture remotely anywhere on Earth with internet access and power.

Skilled technical practitioners could live wherever they wanted and work from the most convenient and affordable locations. That should have a stimulating effect on the housing markets around the country.

Space could play an important role for hands-on training starting now with the ISS and CLDs to ensure that America’s manufacturing skills can successfully compete in the world marketplace.

Remote Manufacturing opens many opportunities, on Earth as well as in space.



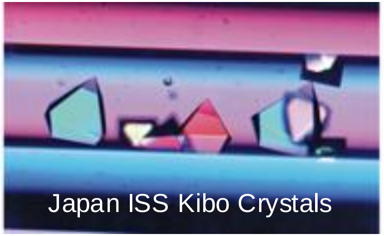
China's Operational Space Station

Significant Additional Investment is Needed in InSpace Manufacturing to Maintain US Leadership

High-tech global competition is increasing and those who are best at using space will obtain a competitive edge in high tech materials and devices, including semiconductors, biomaterials and medical devices.

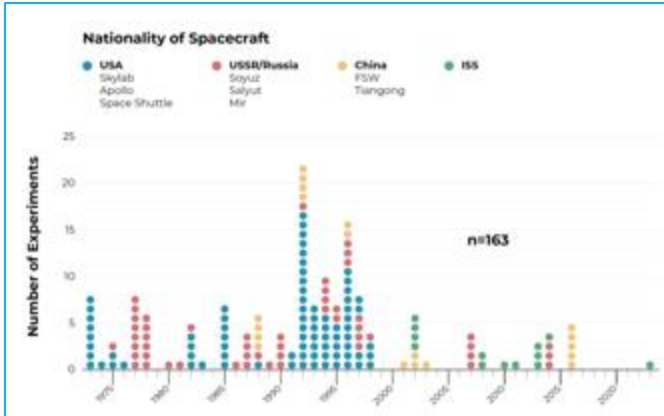
Most new enterprises in space need a minimum of 10 tries in space before mastering microgravity processes well enough to produce products in commercial quantities that are significantly better than what can be achieved on Earth. Currently InSPA can only fund 2-3 flights.

Microgravity is a strange environment and the stresses of launch and landing add additional complications to delicate instruments and biologicals.



Japan ISS Kibo Crystals

The International Space Station provided us with the home court advantage and US innovators have gotten skilled.



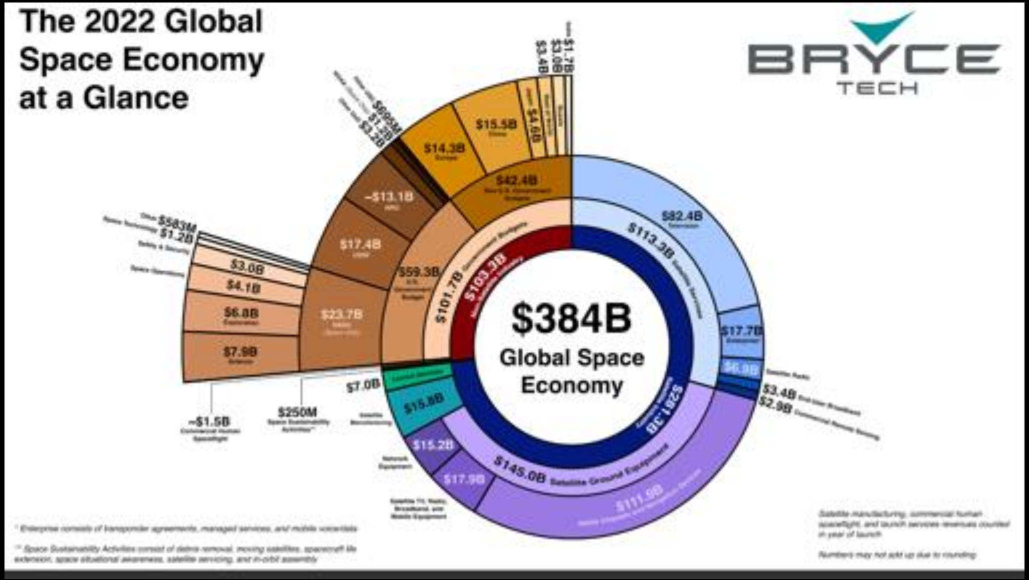
But with technologically sophisticated entrants into the space arena like China, Japan, Russia, India and others, ***the US needs to step up our game***

Excellent Investment. Space enterprises have proven to be excellent investments for America that touch and improve our daily lives in many ways. The ISS has shown that increasing the use of space to benefit Earth has matured enough to be a cutting-edge option for US technology development and many technical disciplines leading to wealth generation.

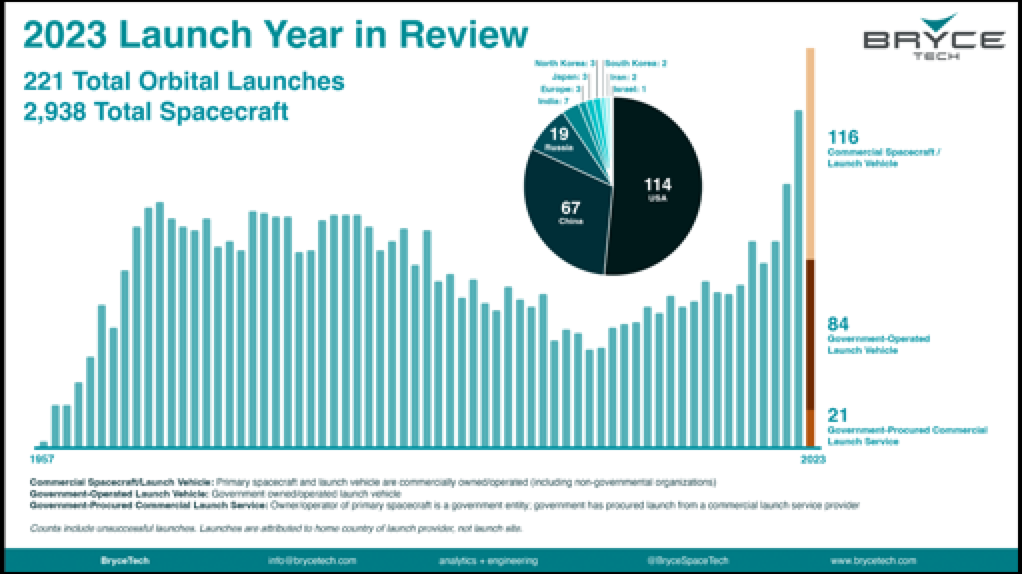
Benefit America. Benefit Earth. The development of space to benefit Earth as well as space is a good investment for America that offers real opportunities and real training for people everywhere in America to develop the space industries of the future.

Start Now. The International Space Station is available now to develop national skills and capabilities beyond Earth.

Growth Opportunities. As new Commercial LEO destinations and transport services increase, the options for customization of space projects and industries increase exponentially.



Compete To Win. Developing best in class capabilities in an increasingly competitive high-tech world will require significantly more funds than we are now investing in developing valuable new applications from space.



Invest in American Innovators.
Increase Investments in Inventors Nationwide and Increase Flight Opportunities for implementation at least 10X.

We need to increase investments in space assisted technologies by funding the inventors and their teams, contemporary inspace manufacturing capabilities, the new equipment needed to implement space research and manufacturing projects. And the transportation and inspace services they need.

These need iteration to achieve the quality needed to succeed, enabled by the flight frequency necessary for learning, success, and steady state commercial manufacturing operations.

1973

GE Congressional testimony –
INSPACE MANUFACTURING
could have an annual value of over
$2 billion in the 1980s.

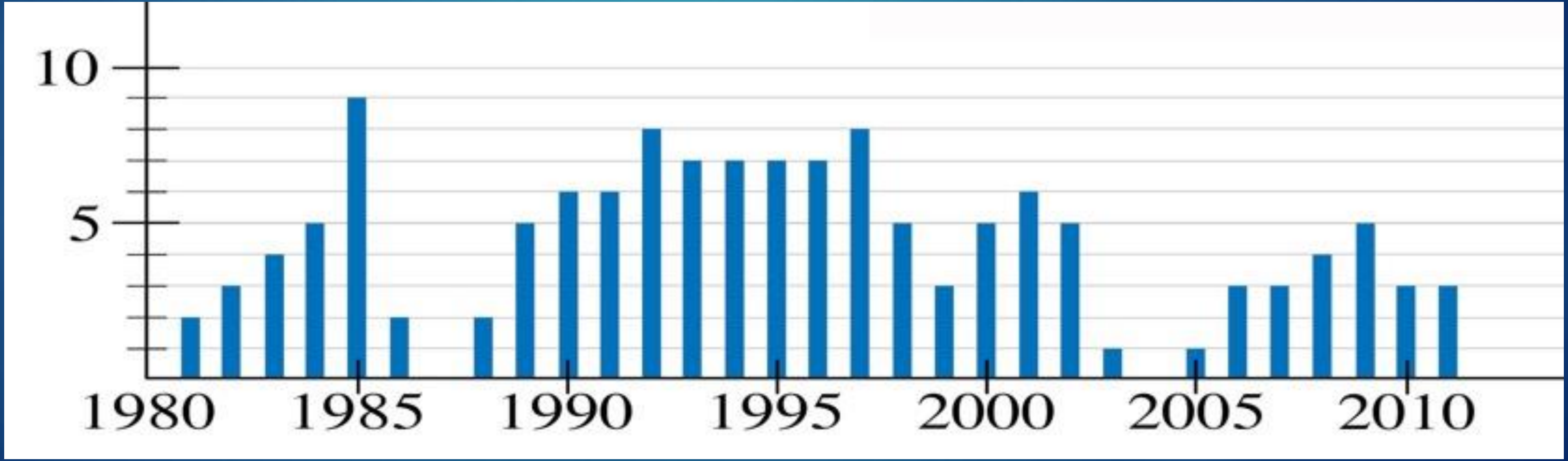
That didn’t happen.

Why? FLIGHT FREQUENCY AND LAUNCH COSTS

Space Shuttle Flights

- Total time in space over 28 years = 3.6 years
- Average flights per year = 4.5
- Costs between $ .5B to $1.5B per flight
- Estimated $27K/kg for payloads

Flights per



2024

What’s Different *Now*?


In Space From Earth
• 24 • 7 • 365 •
25 years and counting
270+ People
The ISS Changed Everything

International Space Station Gets Life Extension Through 2024

News By Tariq Malik published January 8, 2014

10 YEARS AGO –

A Very Wise Decision was made.

Here are some of the things that happened as a result

• Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

• **First National Laboratory Beyond Earth**

First Sustained Commercial Deliveries Of People And Cargo Between Orbit And Earth

First Orbital Commercial Scale Manufacturing

First Sustained Orbital Power Station

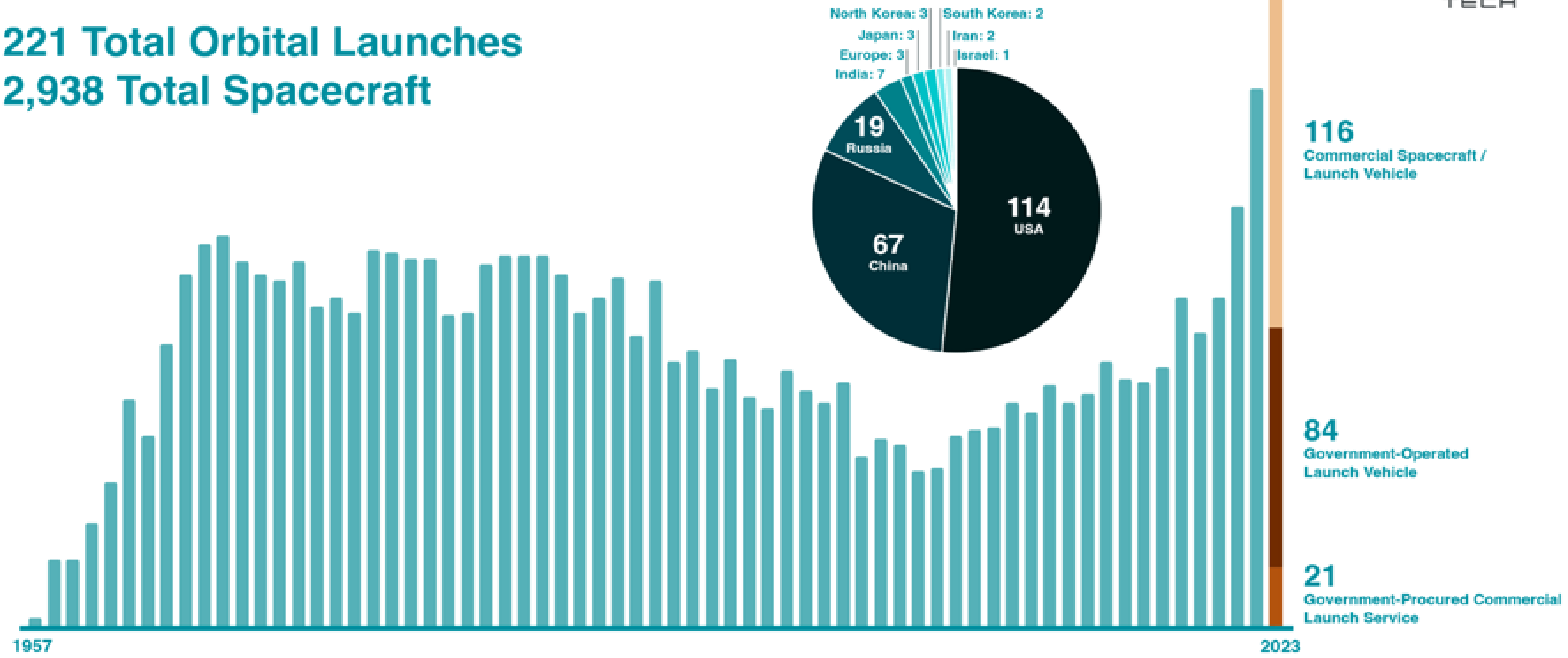
First Orbital International Space Port

24 Years and Counting of Continuous Human Habitation Beyond Earth

- **Catalyst, Inspiration, and Accelerator of Commercial Space Enterprises**
- **Existence Proof that Permanent Human Occupation of Other Worlds is Feasible**

2023 Launch Year in Review

221 Total Orbital Launches
2,938 Total Spacecraft



Commercial Spacecraft/Launch Vehicle: Primary spacecraft and launch vehicle are commercially owned/operated (including non-governmental organizations)
Government-Operated Launch Vehicle: Government owned/operated launch vehicle
Government-Procured Commercial Launch Service: Owner/operator of primary spacecraft is a government entity; government has procured launch from a commercial launch service provider

Counts include unsuccessful launches. Launches are attributed to home country of launch provider, not launch site.

Enabling Discoveries and Applications for Earth

24 • 7 • 365

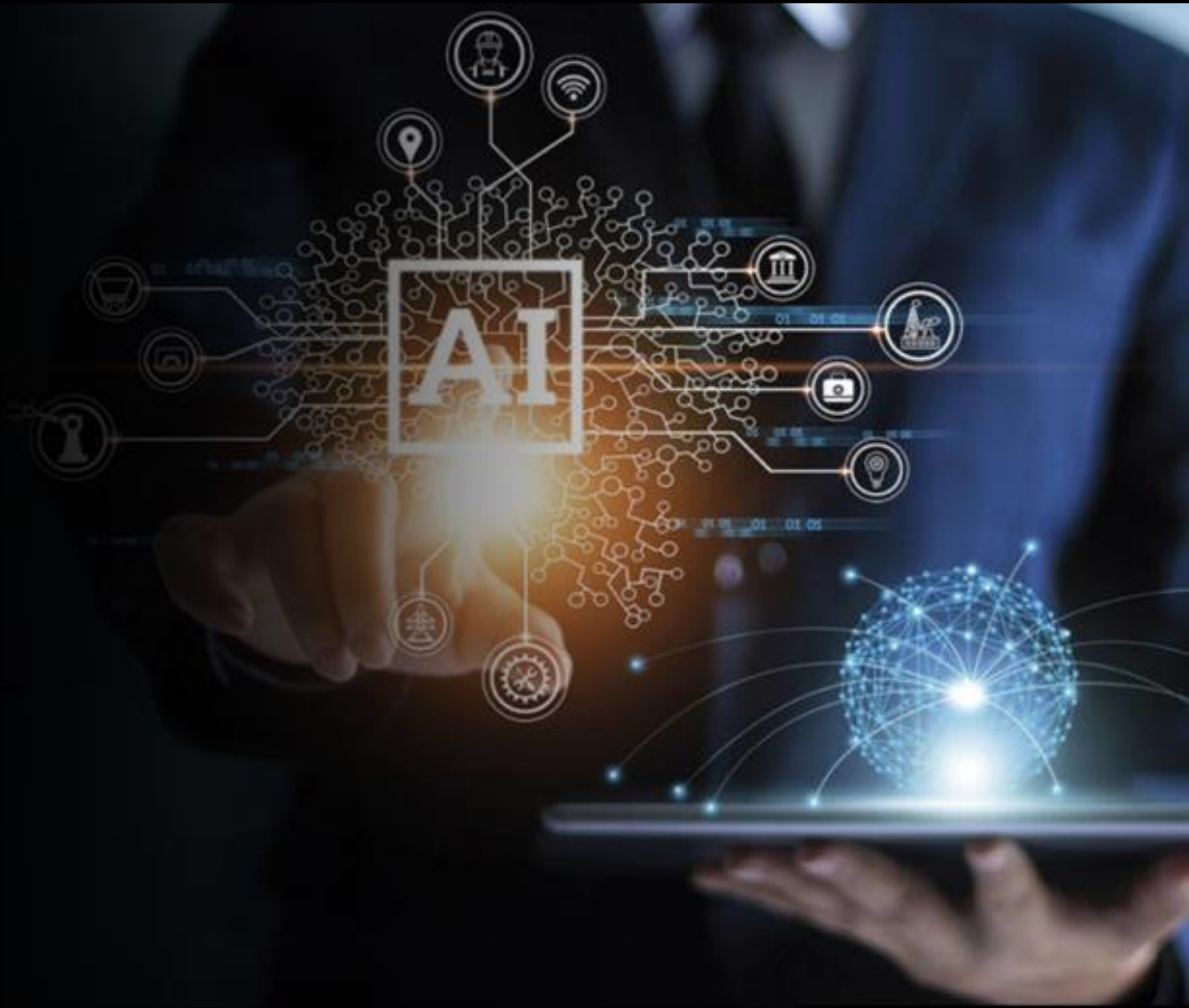
This is the foundation for the next decade in space applications for Earth markets and medicines

Commercial LEO – The Next Decade

AI • Space • Materials •
Biologicals • Medicine

Accelerating Understanding
Controlling Manufacturing

Combining the best from Earth
with the best from space.

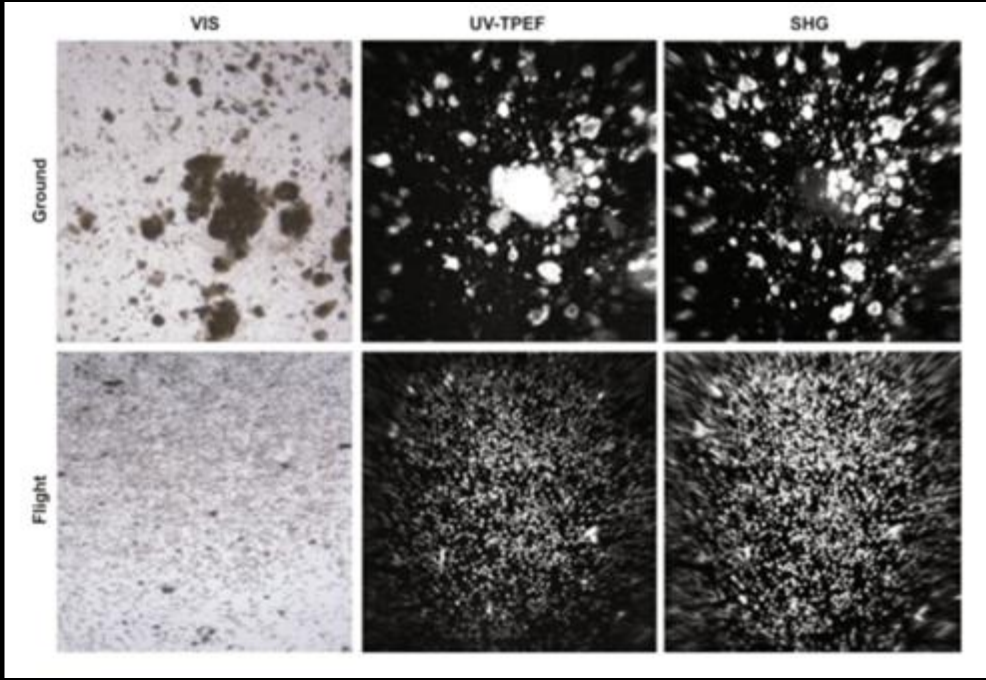


2024 DEMAND

Led by the rise of small inventive space businesses pioneering microgravity manufacturing for valuable terrestrial applications.
Most of these space manufacturing innovations started through SBIRs.

Demands for space services that enable microgravity manufacturing are increasing in multiple areas simultaneously.

Downmass is as important as upmass when inspace manufacturing serves terrestrial markets.



The first solid evidence from ISS of the value of inspace manufacturing for Earth

2019 Sagan Test 0: ISS National Lab: Historic First - Demonstration that Merck's leading cancer drug Keytruda formed significantly more uniform crystals without gravity. Merck and (Implementation Partner/Space HW Alabama)

This knowledge product from ISS led to the ability to improve the quality of the drug on Earth by controlling the size of the individual crystals in a way not previously considered. This project showed how microgravity crystal growth can benefit high-value contemporary products. Published in Nature Microgravity Dec. 2019.

Merck's goal was to produce many crystals of uniform size in space in order to develop a safer and more effective product to treat cancer. **It worked extraordinarily well.**

2022

NASA InSPA and the ISS National Lab identified 2 more projects that required extraordinary evidence and third party review before entering the next phase of funding and flight opportunities.

Both passed.

They were not from traditional space states.

ISS National Lab and NASA InSPA

µG Confirmed

Needs Clinical Trials

Sagan Test 1: LambdaVision (CT) using Space Tango (KY) hardware repeatedly manufactured the 50 layers of precisely deposited proteins and conductive polymers needed to make artificial retinas on Earth to help cure blindness**.** ***The <u>50 layer deposition</u> in space to the quality sought is confirmed.*** *Final Product value will be determined after clinical trials by the FDA.*

Blindness

2022

ISS National Lab and NASA InSPA

Confirme
d

Sagan Test 2: Butler University (IN) collected, curated, and analyzed results reported on 500 crystals grown in microgravity since 1973 and discovered that *more than 80% of the crystals, from the simplest to the most complex, from the lightest to the heaviest, improved in an important feature from being grown in space. Confirmed and published.*

Pharmaceutical, Industrial and Semiconductor Crystals

2022

In 2024, NASA InSPA and the ISS National Lab identified an unprecedented 8 exceptional projects that require extraordinary evidence and third party review to enter the next phase of funding and flight opportunities.

Some have passed, the rest are still in testing.

All are examples of US ingenuity and skill in space manufacturing.

µG Confirmed

Needs Clinical Trials

ISS National Lab and NASA InSPA

February
Sagan Test 3: UCSD Sanford – Aspera - Axiom – Space Tango Provided Compelling Evidence of Accelerated Cancer Cell Growth in Space That Could Accelerate Therapeutic Development for Personalized Medicine – Published. *Final Product value will be determined after clinical trials by the FDA.*

Cancer

2024

ISS National Lab and NASA InSPA

µG Confirmed

In Testing for Quality

March

Sagan Test 4 : Historic First – Flawless Photonics – Luxumbourg – Australia – Visioneering Team – Demonstrated Commercial Manufacturing Scale-up in Space That Exceeds Reported Terrestrial Commercial Manufacturing Quantities of ZBLAN Fiber. Manufactured 7.4 miles of ZBLAN fiber in 16 draws in space. Inflight Manufacturing Control witnessed and confirmed by independent 3rd parties. Quality currently being independently validated by 5 labs around the world.

Industrial Materials: Glass Alloys: Commercial-Scale Manufacturing In Space

2024

ISS National Lab and NASA InSPA

Testing

March

Sagan Test 5: Sachi Bioworks and Space Tango. Historic First. In-Space Treatment of Space-Induced Neuropathology for accelerated screening of therapeutics for neurodegenerative diseases like Alzheimers, ALS, Parkinsons - Published. *Final Product value will be determined after clinical trials by the FDA.*

Neurodegenerative Diseases: Alzheimers, ALS, Parkinsons

2024

ISS National Lab and NASA InSPA

Confirmed

Spring
Sagan Test 6: LambdaVision. Space Tango. Spring 2024 Historic First - Space-Assisted Artificial Retinas Manufacturing Method Validated in Space to 200 layers needed for artificial retinas. 200 layers manufactured in space is **confirmed.** *Final Product value will be determined after clinical trials by the FDA.*

Blindness

2024

ISS National Lab and NASA InSPA

Confirmed

Spring
Sagan Test 7: Redwire - Eli Lilly - Butler University. World class pharmaceutical and industrial crystals on test flight of PILBOX Hardware. Confirmed by independent 3rd party experts with additional strong evidence provided by Butler University Microgravity Crystal Database

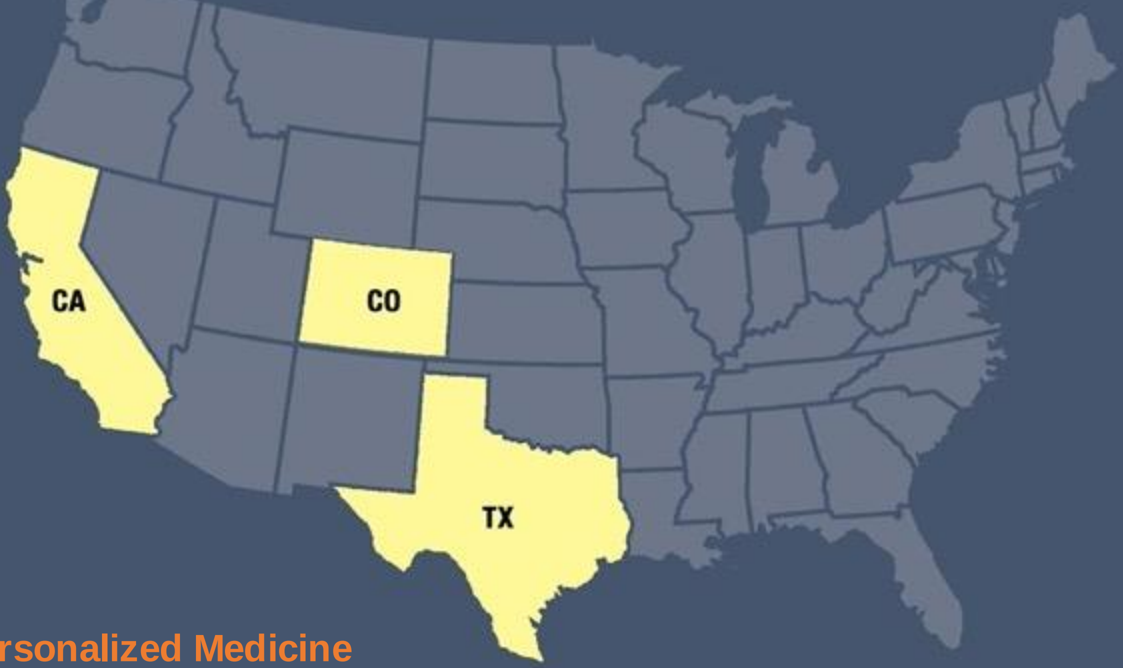
Superior Pharmaceutical and Industrial Crystals

2024

µG Confirmed **Tests begin when Samples return Nov 2024**

ISS National Lab and NASA InSPA

July
Sagan Test 8: Cedars-Sinai – Axiom - Bioserve. Historic First – Human Adult Skin Cells Reprogrammed in space to embryonic type stem cells called induced Pluripotent Stem Cells (iPSCs).. In-space reprogramming **Confirmed** by visual observations from multiple independent witnesses**.** Quality of the results will be determined after the samples are returned from ISS in Nov 2024.



Stem Cells for Personalized Medicine
Applicable to Many Diseases

2024

In Testing

ISS National Lab and NASA InSPA

August
Sagan Test 7: Historic First - 5 to 10X Quality Improvement in Transmission from Space Manufactured ZBLAN reported by both Apsidal/Axiom (10X) and Flawless Photonics/Visioneering (5+X)

Industrial Materials: Superior Glass Alloys

2024

ISS National Lab and NASA InSPA

µG Confirmed

Needs many more µG statistics and other medical confirmation tests

August
Sagan Test 9: Encapsulate/Space Tango. Historic First - InSpace Detection of Metastasis reveals important features of cancer cells that cannot be seen on Earth because gravity masks them. Once proven by statistics and clinical trials, this can be used to accelerate and improve diagnoses.

Cancer: Metastasis

2024

ISS National Lab and NASA InSPA

2024. These states triggered a remarkable 8 Sagan tests in a single year because American teams have gotten that good at working in space. And they get better with each flight.

Cancer • Neurodegenerative Diseases • Better Pharmaceuticals and Industrial Crystals • Better Quality Induzstrial Materials (Glass Alloys) to Commercial Scale Manufacturing Beyond

2024

ISS National Lab and NASA InSPA

2024. **The following states are in the pipeline waiting for near term flight opportunities to implement projects as remarkable as the ones reported previously.**

Add
Semiconductors
Nerve Regeneration
Nanomedical Devices
Novel Industrial Materials
Advanced Materials

Cancer • Neurodegenerative Diseases • Better Pharmaceuticals and Industrial Crystals •
Better Quality Industrial Materials (Glass Alloys) to Commercial Scale Manufacturing Beyond Earth

ISS National Lab and NASA InSPA

2024 **This shows how previous expertise carries into important new projects while participation by non-traditional aerospace states in the pipeline almost doubles. There is genius to invest in all over the US.**

Add
Semiconductors
Nerve Regeneration
Nanomedical Devices
Novel Industrial Materials

Cancer • Neurodegenerative Diseases • Better Pharmaceuticals and Industrial Crystals • Better Quality Industrial Materials (Glass Alloys) to Commercial Scale Manufacturing Beyond

Now is not the time to clip America's wings. Now is the time to enable more of the country to use their innovative genius to deliver products from space to improve life on Earth.

There is a way to do that now.

When you combine the best you can do on Earth

And enable the best you can do in space

With sufficient statistics and controls

And the brightest minds to interpret

and inform the results …

When Microgravity Works:

Translating 50 years of microgravity R&D into high-value applications from subatomic through human

Just the beginning …

Medical Advances from Space
for 50+ years

Quantum
Subatomic

Cold
Atom
Lab

Molecular

Crystals
Pharma
Industrial
Semiconductors

Thin Films

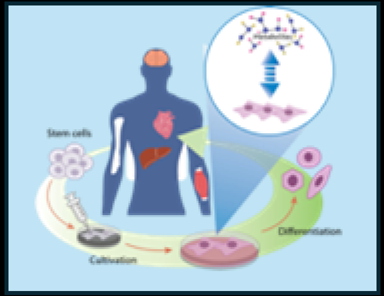
Medical
Devices
Artificial Retina
Nerve Regen

Semiconductors

Alloys and
Photonics

ZBLAN Optical
Fibers
Semiconductors

Cells and Tissues



Cancer
Neurodegenerative
Stem Cells
3D Tissues
Artificial Organs

Whole Organisms

Plants
Animals
Humans

High Throughput 11.9 km optical fiber manufactured on ISS to commercial lengths

Space Manufactured Artificial Retinas Ready for Animal Trials, Semiconductors in parabolic testing

80% of 500+ Crystals Manufactured in Space since 1973 Improved in Structure, Uniformity, Size or Reduction of Defects

Manufacturing Bose-Einstein Condensates in Space near absolute zero since 2019

85

2024 INVESTMENTS
and
OPPORTUNITIES

“In order for an enterprise to succeed,

supply, demand, and capital

all need to be appropriately supported.

You can’t just fund 2 out of 3 and expect to get 66% ROI.

Odds are, you will get little or nothing.”

Alan Marty, Legacy Ventures. Venture Capital Advisor to NASA Commercial Orbital Transportation Services Program. First ISS National Lab Workshop. October 2007. NASA Ames Research Center.

Building & supporting the space economy together; (along with hundreds of companies and researchers!)

NASA

NSF

ISS
U.S. NATIONAL LABORATORY

NIH National Institutes of Health

U.S. Department of
Health and Human Services
Enhancing the health and well-being of all Americans

Department of Energy
United States of America

Department of Transportation
United States of America

Executive Office of the President of the United States
Office of Science and Technology Policy

SBA U.S. Small Business Administration

ARPA H

U.S. Department of Defense

National Oceanic and Atmospheric Administration
NOAA
U.S. Department of Commerce

Department of Commerce
United States of America

The Department of the Treasury
1789

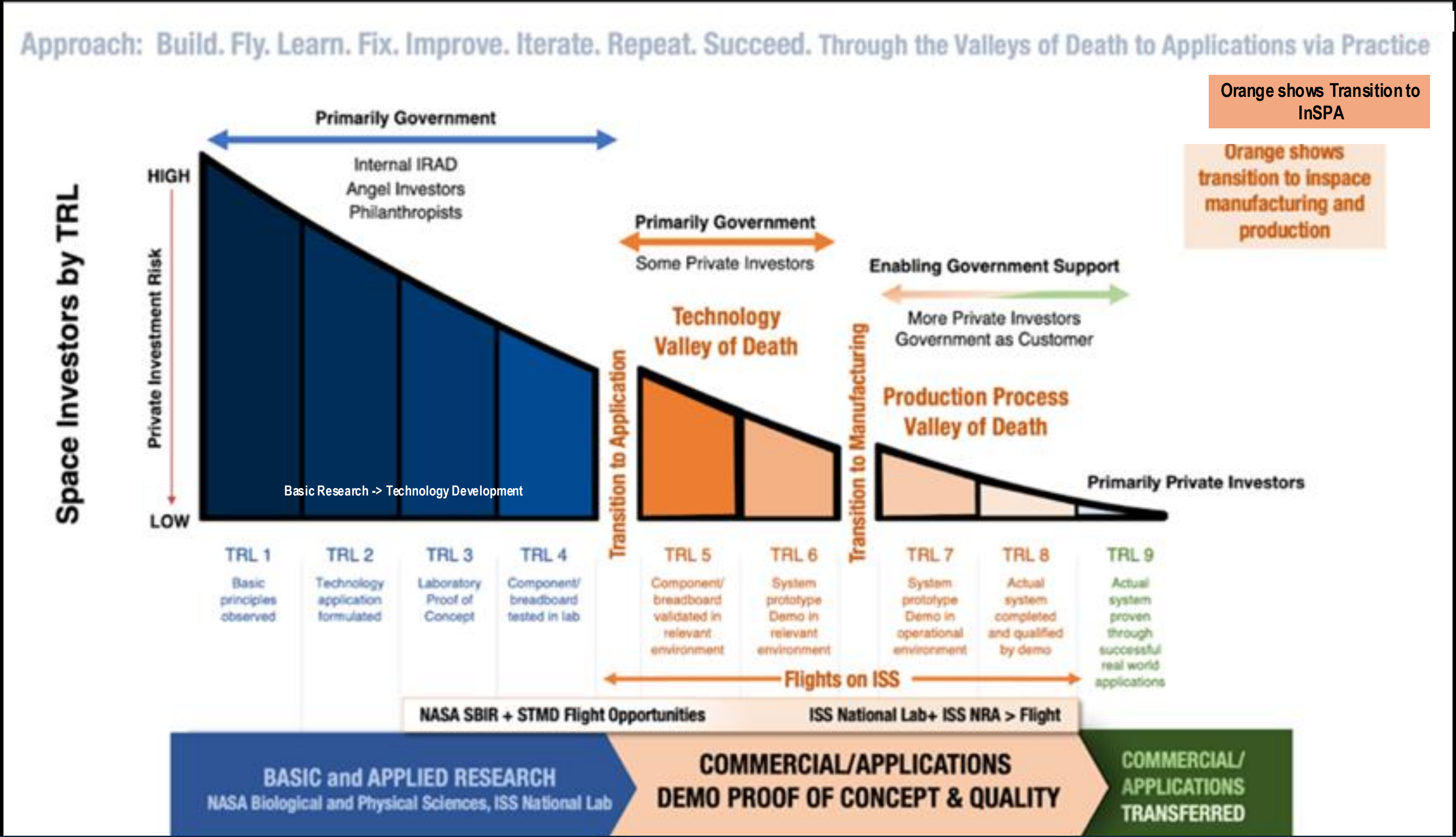
United States Space Force

U.S. AIR FORCE

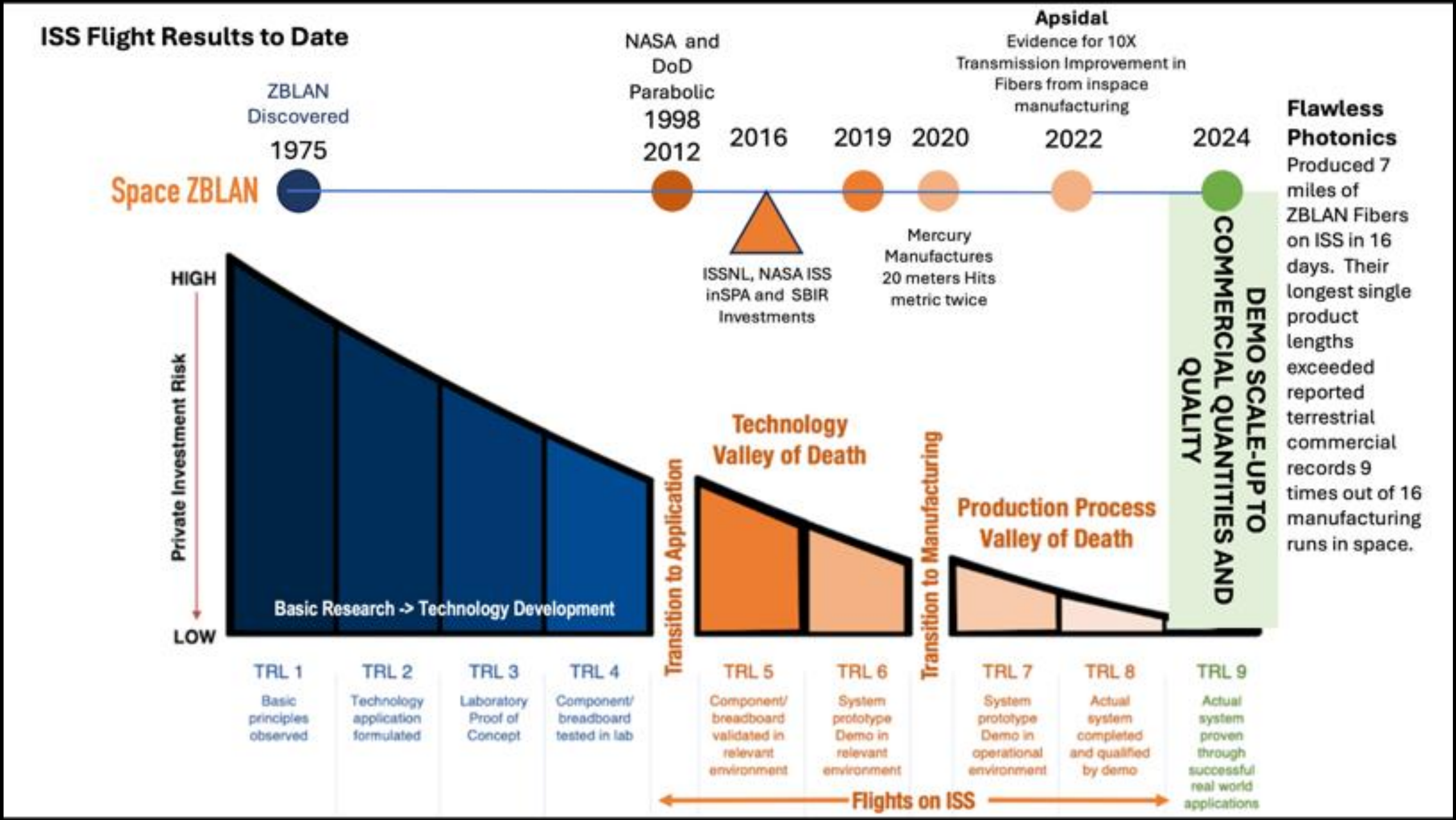
United States Navy

DARPA

FEED THE PIPELINE FOR US LEADERSHIP AND SUCCESS



GOVERNMENT FUNDING IS NEEDED WHEN THE SOLUTION IS IMPORTANT AND PROFITABILITY IS NOT OBVIOUS


ISS Flight Results to Date
Space ZBLAN
ZBLAN Discovered
1975
NASA and DoD Parabolic
1998
2012
2016
ISSNL, NASA ISS inSPA and SBIR Investments
2019
2020
Mercury Manufactures 20 meters Hits metric twice
Apsidal
Evidence for 10X Transmission Improvement in Fibers from inspace manufacturing
2022
2024
Flawless Photonics
Produced 7 miles of ZBLAN Fibers on ISS in 16 days. Their longest single product lengths exceeded reported terrestrial commercial records 9 times out of 16 manufacturing runs in space.
HIGH
Private Investment Risk
LOW
Basic Research -> Technology Development
Transition to Application
Technology Valley of Death
Transition to Manufacturing
Production Process Valley of Death
DEMO SCALE-UP TO COMMERCIAL QUANTITIES AND QUALITY
TRL 1
Basic principles observed
TRL 2
Technology application formulated
TRL 3
Laboratory Proof of Concept
TRL 4
Component/ breadboard tested in lab
TRL 5
Component/ breadboard validated in relevant environment
TRL 6
System prototype Demo in relevant environment
TRL 7
System prototype Demo in operational environment
TRL 8
Actual system completed and qualified by demo
TRL 9
Actual system proven through successful real world applications
Flights on ISS

The results presented describe the floor we stand on for the next decade of discoveries and applications from LEO and from deep space.

We will get better from here through practice in space to unlock microgravity’s potential for the benefit of Earth.

Thank you to all who step up and try. We learn from you.

Thank you to all who succeed, you float all our boats and inspire our best efforts.

Thank you to those who helped, we couldn’t make it to space and back without you.

It takes a village to craft successful enterprises in space.

It takes a village

• Crew • CLDs • Commercial Space • Inventors • Investors • Integration Partners • International Partners • ISS • ISSNL/CASIS • Launch and Transportation Services • MO&I • MSG • NASA BPS • NASA Centers • NASA LEO Comm • NASA OZ • NASA Procurement • NIH • NIST • NSF • OGAs • Payload Services • Pharma • PIM Team • • Safety • SBIR • Scientists • SHERPAs • SMEs • STMD Flight Opportunities • Students • Technologists • Technologies • Universities • US Industries • • •

• *Thank You All! It takes a village to enable successful enterprises in space*

Very different futures are available to those who can thrive beyond their planet of origin versus those whose resources and destinities are constrained to a single world.

Selected Microgravity Materials Manufacturing References

Subatomic:

Cold Atom Lab: https://coldatomlab.jpl.nasa.gov/

Crystals:

Microgravity effects on Merck cancer drug Keytruda: Reichert, P., Prosise, W., Fischmann, T.O. *et al.* Pembrolizumab microgravity crystallization experimentation. *npj Microgravity* 5, 28 (2019). https://doi.org/10.1038/s41526-019-0090-3

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Butler University Microgravity Crystal Database Links

Macromolecules:
https://docs.google.com/spreadsheets/d/1JrXe4Dme7JKcU4EKG7ObQDfrm6EzrZkneTCrPyYZos/edit#gid=1461894258

Inorganics:
https://docs.google.com/spreadsheets/d/1PZ8AAZlXYAln4d2UNR4x_zu-rpkWK8ByG04KiprAAXM/edit#gid=1518976417

Semiconductors:
https://docs.google.com/spreadsheets/d/1Zl_B_IbC_UFx4VfFamhCQcGgUdtk64r6wOdQ_wO3lHU/edit#gid=218298295

ZBLAN and related glasses:
https://docs.google.com/spreadsheets/d/1a00HP8Hmb_jj3YVZKrDl3zPuKnae1YZZxWG22EaOJhA/edit#gid=1607766944

Protein deep dive:
https://docs.google.com/spreadsheets/d/1mRCn0m1vNynou8Yl26Sw7__l5Jf4Ta_UXYgHPkG6mw8/edit#gid=0

Selected Microgravity Materials Manufacturing References

Thin Films:

LambdaVision: Thin Film Applications - https://www.issnationallab.org/release-ng20-lambdavision-retinal-implant/

Microgravity Thin Film Deposition Advantages: https://www.issnationallab.org/ispa-thin-layer-deposition/

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https://link.springer.com/article/10.1140/epje/i2016-16132-4

Alloys and Photonics

Space News 2024. Flawless Photonics Kicking Glass: https://spacenews.com/flawless-photonics-kicking-glass/

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Studying Stem Cells in Space for the Benefit of Humankind on Earth and Beyond - ISS National Lab – https://www.issnationallab.org/stem-cell-research-results-published-zubair/

Stem Cell-Derived Brain Organoids on Ax-3 Mission Seek to Improve Modeling for Neurodegenerative Diseases: https://www.issnationallab.org/release-ax3-stem-cells-nscf/

NASA 3D Bioprinting in Space: https://www.nasa.gov/missions/station/iss-research/3d-bioprinting/

NIH Tissue Chips in Space. https://ncats.nih.gov/research/research-activities/tissue-chip/projects/space

Biomanufacturing in Low Earth Orbit: https://www.sciencedirect.com/science/article/pii/S2213671121005981?via%3Dihub Sharma et al 2021 (being updated)

https://pubs.acs.org/doi/full/10.1021/acschemneuro.4c00160 Inflammasome-Inhibiting Nanoligomers are Neuroprotective Against Space-Induced Pathology in Healthy and Diseased 3D Human Motor and Pre-Frontal Cortex Brain Organoids. Sadhana Sharma, Vincenzo S. Gilberto, Jon Rask, Anushree Chatterjee, Prashant Nagpal. ACS Chemical Neuroscience. August 2024.

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Artificial tissue creation under microgravity conditions: Considerations and future applications
Vishal Swaminathan, Grace Bechtel, Vakhtang Tchantchaleishvili
https://onlinelibrary.wiley.com/doi/abs/10.1111/aor.14017

Tissue Engineering Under Microgravity Conditions–Use of Stem Cells and Specialized Cells. Authors: Daniela Grimm, Marcel Egli, Marcus Krüger, Stefan Riwaldt, Thomas J. Corydon, Sascha Kopp, Markus Wehland, Petra Wise, Manfred Infanger, Vivek Mann, and Alamelu SundaresanAUTHORS INFO & AFFILIATIONS
Publication: Stem Cells and Development
https://doi.org/10.1089/scd.2017.0242

The effects of microgravity on differentiation and cell growth in stem cells and cancer stem cells. Daniela Grimm, Markus Wehland, Thomas J. Corydon, Peter Richter, Binod Prasad, Johann Bauer, Marcel Egli, Sascha Kopp, Michael Lebert, Marcus Krüger. Stem Cells Journals. 30 April 2020
https://doi.org/10.1002/sctm.20-008

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From lift off to splash down: An update on Mayo Clinic stem cells in space
https://newsnetwork.mayoclinic.org/discussion/from-lift-off-to-splash-down-an-update-on-mayo-clinic-stem-cells-in-space/

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Selected Microgravity Whole Organism References

Cells and Tissues Continued

Inflammasome-Inhibiting Nanoligomers Are Neuroprotective against Space-Induced Pathology in Healthy and Diseased Three-Dimensional Human Motor and Prefrontal Cortex Brain Organoids
Sadhana Sharma, Vincenzo S. Gilberto, Jon Rask, Anushree Chatterjee, and Prashant Nagpal
ACS Chemical Neuroscience 2024 *15* (16), 3009-3021
DOI: 10.1021/acschemneuro.4c00160

Whole Organisms

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NASA Astronaut Twin Study (Human) – https://www.nasa.gov/humans-in-space/twins-study/

Corydon TJ, Schulz H, Richter P, Strauch SM, Böhmer M, Ricciardi DA, Wehland M, Krüger M, Erzinger GS, Lebert M, Infanger M, Wise PM, Grimm D. Current Knowledge about the Impact of Microgravity on Gene Regulation. Cells. 2023 Mar 29;12(7):1043. doi: 10.3390/cells12071043. PMID: 37048115; PMCID: PMC10093652.

GeneLab (non-human) – https://genelab.nasa.gov/

Mighty Mice in Space May Help Patients With Bone and Muscle Loss on Earth. 2023 https://www.issnationallab.org/upward-uconn-jaxlab-mighty-mice/ . and https://www.jax.org/news-and-insights/2020/september/mighty-mice-in-space

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De Micco, V., Aronne, G., Caplin, N. *et al.* Perspectives for plant biology in space and analogue environments. *npj Microgravity* 9, 67 (2023). https://doi.org/10.1038/s41526-023-00315-x

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Semiconductor Manufacturing in Low Earth Orbit for Terrestrial Use. 2023 Workshop Report. https://osf.io/preprints/osf/d6ar4

Wilkinson, A.R., Brewer, F., Wright, H. *et al.* A meta-analysis of semiconductor materials fabricated in microgravity. *npj Microgravity* 10, 73 (2024). https://doi.org/10.1038/s41526-024-00410-7

Butler Microgravity Crystal Database: Semiconductors: Semiconductors (160 entries of semiconductor crystals grown in space since 1973 with references):

https://docs.google.com/spreadsheets/d/1Zl_B_IbC_UFx4VfFamhCQcGgUdtk64r6wOdQ_wO3lHU/edit#gid=218298295

NASA astronaut and Expedition 65 Flight Engineer Megan McArthur works in the Microgravity Science Glovebox swapping samples for an experiment called Solidification Using a Baffle in Sealed Ampoules, or SUBSA. The physics investigation explores experimental methods of crystallizing melts in microgravity and is expected to result in reduced fluid motion in the melt, leading to better distribution of subcomponents and the potential for improved technology used in producing semiconductor crystals.
NASA

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From Axiom

Ax1 (all peer-reviewed)

CRISPR-based genetic diagnostics in microgravity - ScienceDirect

Leveraging Space-Flown Technologies to Deliver Healthcare with Ho...: Ingenta Connect

Observing lightning and transient luminous events from the international space station during ILAN-ES: An astronaut's perspective - ScienceDirect

Space-based optical imaging of blue corona discharges on a cumulonimbus cloud top - ScienceDirect
JPR_A_440630 4253..4266 (nih.gov)

Ocular rigidity and choroidal thickness changes in response to microgravity: A case study (nih.gov)

Amorphous calcium carbonate enhances osteogenic differentiation and myotube formation of human bone marrow derived mesenchymal stem cells and primary skeletal muscle cells under microgravity conditions - ScienceDirect

Ax2 (BioRxiv)
Studies on the International Space Station to assess the effects of microgravity on iPSC-derived neural organoids | bioRxiv

Accelerated Hematopoietic Stem Cell Aging in Space | bioRxiv

In-Space Fabrication of Janus Base Nano-Matrix for Improved Assembly and Bioactivities | bioRxiv

From Space Tango

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8. Coelho, L., & Muotri, A. R. (2022). Cortical brain organoid as a model to study microgravity exposure. *Artificial Organs*, *47*(1), 5–7. https://doi.org/10.1111/aor.14460
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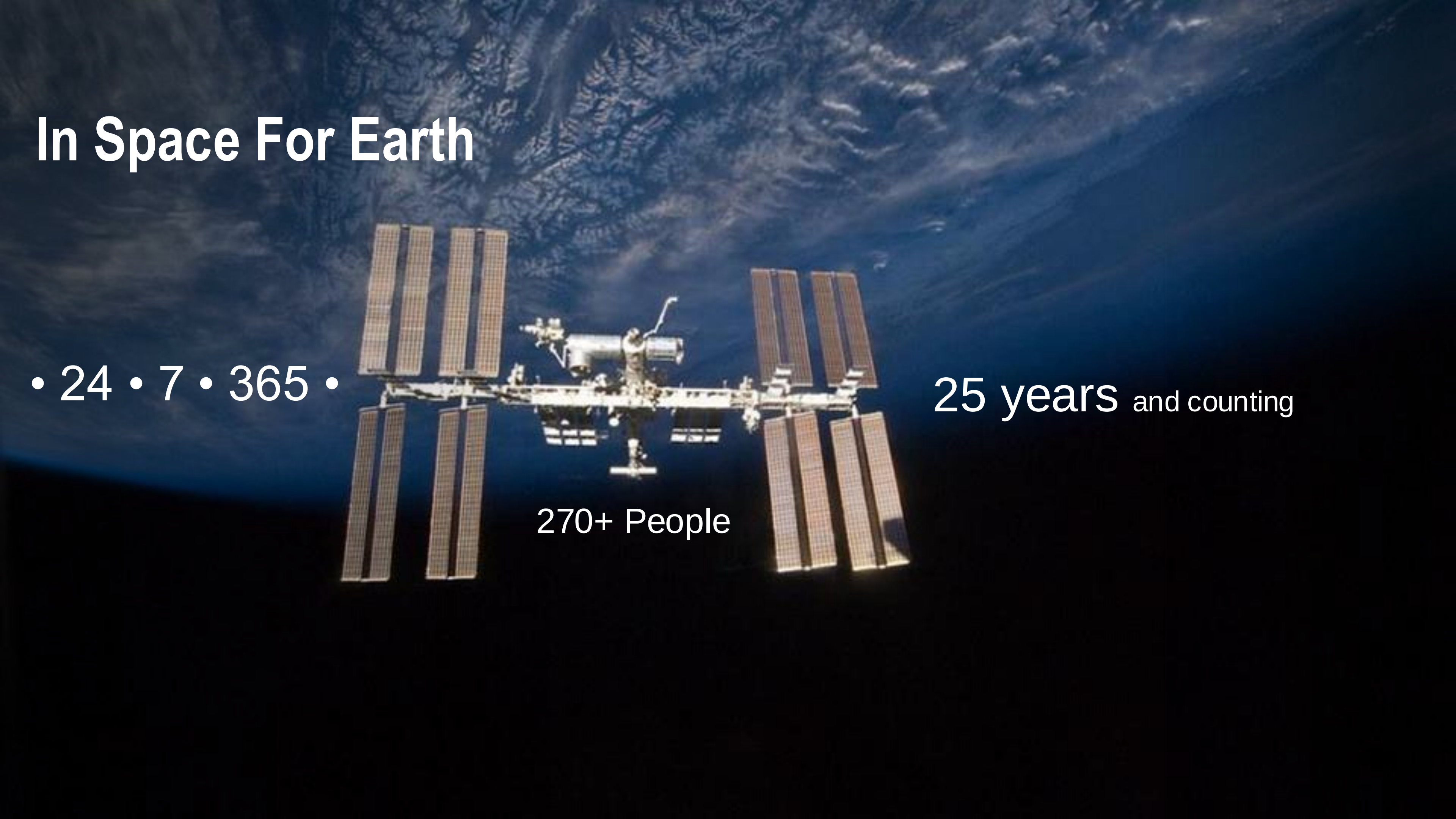
Backup Charts


In Space For Earth
• 24 • 7 • 365 •
25 years and counting
270+ People

Rule of Thumb 1

For commercial enterprises where profit is the key metric …

If you can produce the product well enough on Earth, don’t go to space.

But if it is important enough to improve and gravity is impeding progress,

Micrgravity and inspace production can offer some real advantages.

Rule of Thumb 2

The product you produce in space for terrestrial markets not only must be better than anything you can produce on Earth, but so much better that it makes good business sense to go to space to manufacture it. Quality matters.

Rule of Thumb 3

Trust but verify. The Carl Sagan rule applies to space enterprises:

“Extraordinary claims require extraordinary evidence”

NASA InSPA requires independent 3rd party validation of exceptional space findings before confirming quality.

Rule of Thumb 4

Practice, Practice, Practice in microgravity.

Microgravity is a strange and versatile tool. Like all tools, it takes practice to gain the necessary skills

Hone your microgravity skills the fastest cheapest ways you can.

Practice in microgravity, on parabolic aircraft, on suborbital vehicles, and especially in orbit if your projects need more time.

Let the Data Talk to You

Get enough data to establish causal relationships and statistical confidence.

Don’t let your hypotheses strangle your observations.

BIOSTATISTICS and SPACEFLIGHT OPPORTUNITIES

33.3% of the rats were
CURED by the treatment

BIOSTATISTICS and SPACEFLIGHT OPPORTUNITIES

33.3% of the rats were
CURED by the treatment

33.3% of the rats
DIED from the treatment

BIOSTATISTICS and SPACEFLIGHT OPPORTUNITIES

33.3% of the rats were
CURED by the treatment

33.3% of the rats
DIED from the treatment

The third rat got away

SPACE.com

Space Exploration | The Universe | Stargazing | Launches & Spacecraft

Space Exploration > Missions > International Space Station

International Space Station Gets Life Extension Through 2024

News By Tariq Malik published January 8, 2014

10 YEARS AGO

A Very Wise Decision was made.

Here are some of the things that happened as a result

● Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft •

● Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

● Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

● **First National Laboratory Beyond Earth**

● Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

● **First National Laboratory Beyond Earth**

First Orbital International Space Port

● Assembly of Large Structures in Space via Multiple Flights and Multiple Spacecraft • Versatile Human Supported Space Laboratories • Technology Testbed • Observatories for Earth and Space • STEM • Commercial R&D • 15 Nations Collaborating for Decades •

● **First National Laboratory Beyond Earth**

First Orbital International Space Port

First Sustained Orbital Power Station

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First Sustained Commercial Deliveries Of People And Cargo Between Orbit And Earth

EXISTENCE PROOFS

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24 Years and Counting of Continuous Human Habitation Beyond Earth

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And Cargo Between Orbit And Earth

First Sustained Orbital Power Station

First Orbital International Space Port

24 Years and Counting of Continuous Human Habitation Beyond Earth

- **Catalyst, Inspiration, and Accelerator of Commercial Space Enterprises**

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- **Existence Proof that Permanent Human Occupation of Other Worlds is Feasible**

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For the rest of the century …We should never have fewer capabilities in LEO than we do now.

In fact, LEO and microgravity research and applications for Earth and space should grow now for near term benefits, long term prosperity, and competitive skill development for industries of the future.

First Sustained Orbital Power Station

First Orbital International Space Port

24 Years and Counting of Continuous Human Habitation Beyond Earth

- **Catalyst, Inspiration, and Accelerator of Commercial Space Enterprises**
- **Existence Proof that Permanent Human Occupation of Other Worlds is Feasible**

Other Challenges for the 21st Century in Space

We need to be able to detect killer NEOs 50 meters or larger at least 1 year before they arrive in Earth's vicinity..

A NEO monitoring strategy that is blind to hazardous objects coming directly at Earth is incomplete and unacceptably flawed.

Hazards

As of this writing, we cannot see asteroids of any size coming directly at Earth from any direction until they are too close to respond safely and effectively.

- Asteroids coming directly at us do not appear to be moving in the sky.
- We are at the wrong angle to see these dark cold objects against a dark cold sky because almost all of our killer Near Earth Object (NEO) detection assets are here on Earth.
- In order to see the asteroids coming at Earth, we need to monitor the sky from different angles.
- This requires NEO detection systems infrastructure deployed throughout the solar system.

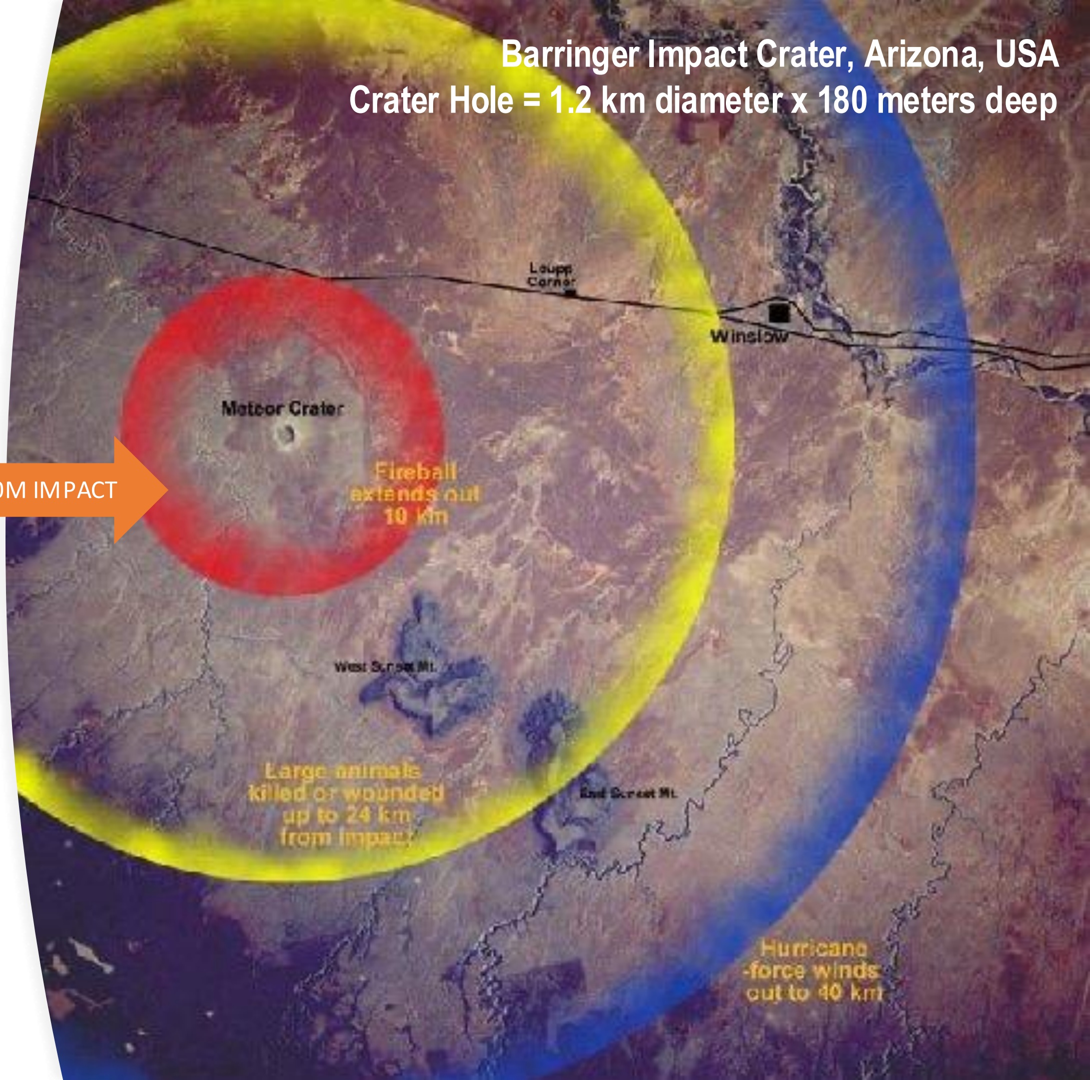
Why Before How
Impact Hazards

- Impact of a 50-meter asteroid would cause local *damage equivalent to the largest nuclear weapon on Earth*. ***Currently we have detected ~ 5% of an estimated 230,000 of these near-Earth objects.***

- 150-meter asteroid would cause *destruction on a regional to national scale*. Energy released: ~50 nuclear bombs. ***Currently we have detected ~45% of an estimated 24,000 of these near-Earth objects.***

- 300-500-meter asteroid would cause *destruction on a continental scale*. Energy released: ~1000 nuclear bombs. ***Currently we have detected ~68% of an estimated 3500-7200 of these near-Earth objects.*** *(note the size of the error bar).*

- 1000-meter asteroid would cause global effects with *many millions dead*. Energy released: ~8000 nuclear bombs. ***Currently we have detected ~95% of an estimated 940 of these near-Earth objects, leaving ~50 undetected.***



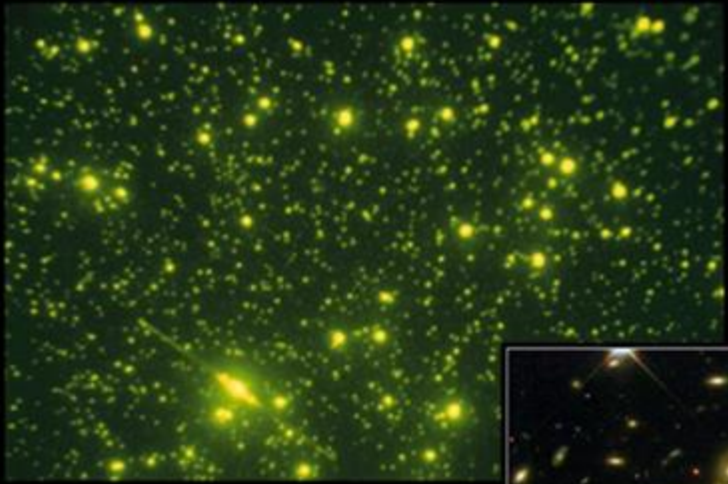
Killer Asteroids – **Status Today**

·Analysis of data obtained by NASA's DART investigation team shows the spacecraft's kinetic impact with its target asteroid, Dimorphos, successfully altered the asteroid's orbit.

We can redirect asteroids away from Earth …

IF we can find them early enough.

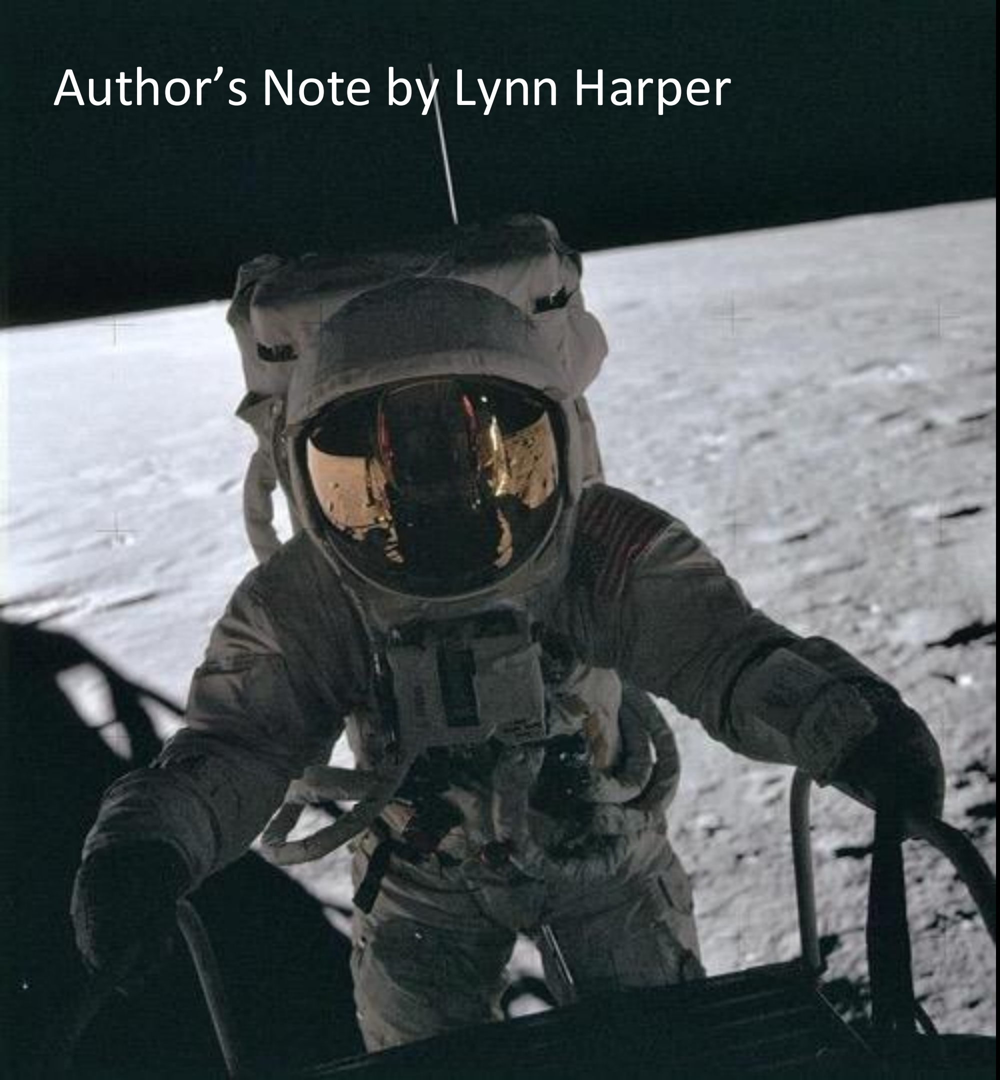
That's where solar system infrastructure comes into play.

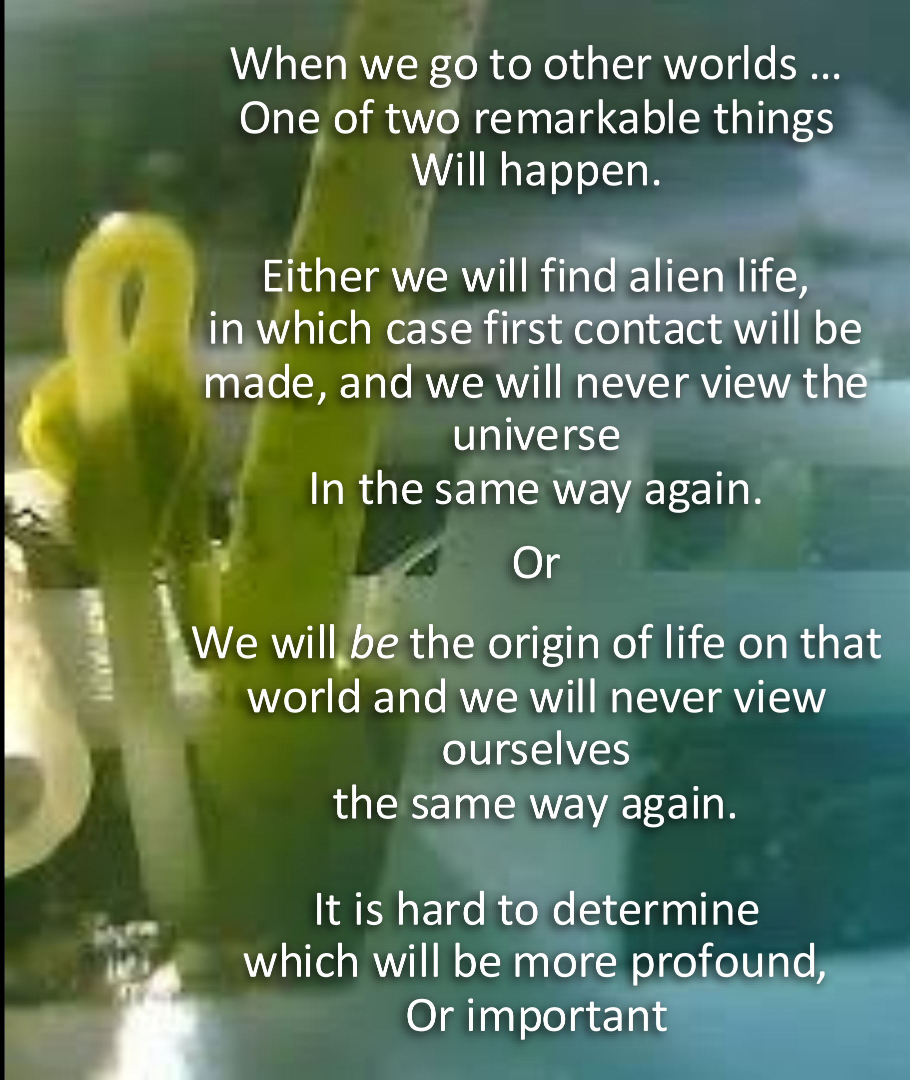


Whether on Earth or Beyond …
What does it mean to be human?

This is the story
of the only life in the universe we know,
in our first generations
beyond the planet of our origin.

You ain't seen nothing yet.


Author’s Note by Lynn Harper


When we go to other worlds …
One of two remarkable things
Will happen.
Either we will find alien life,
in which case first contact will be made, and we will never view the universe
In the same way again.
Or
We will *be* the origin of life on that world and we will never view ourselves
the same way again.
It is hard to determine
which will be more profound,
Or important