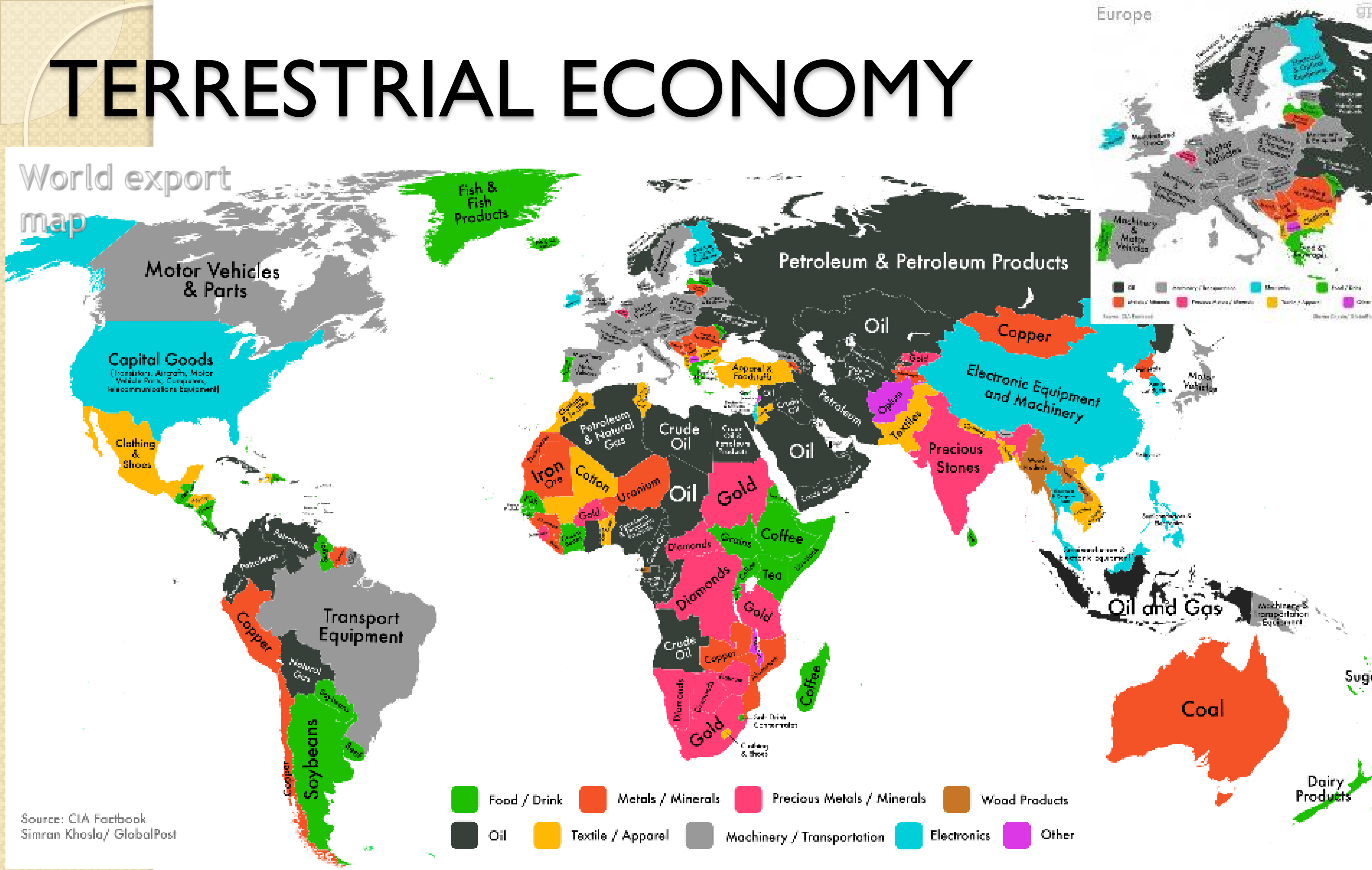
SPACE PORTAL
for enterprise and commerce

Economic Readiness Level Considerations for a Robust LEO Economy

Dr. Ioana Cozmuta
Industry Innovation and Microgravity Lead

Science and Technology Corporation
Space Portal, NASA Ames Research Center

TERRESTRIAL ECONOMY



ECONOMY

A country's <u>RESOURCE</u> management through production & consumption

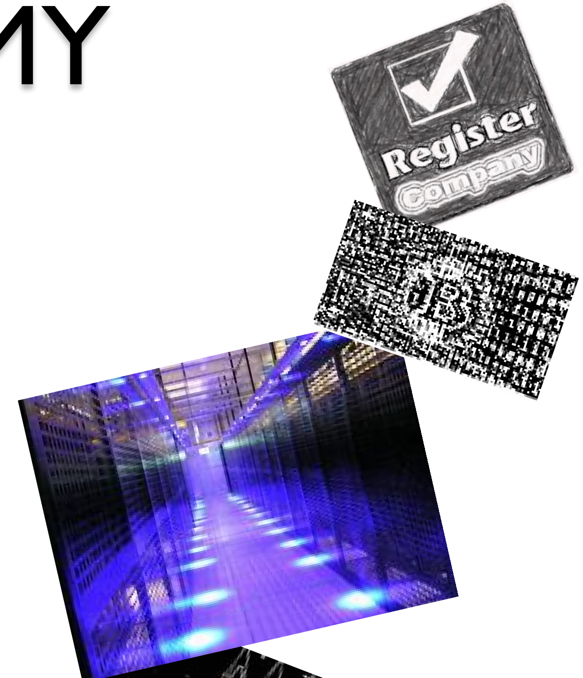
I. Cozmuta, Techsylvania 2016 Keynote, https://www.youtube.com/watch?v=wdz6V1cr8KY

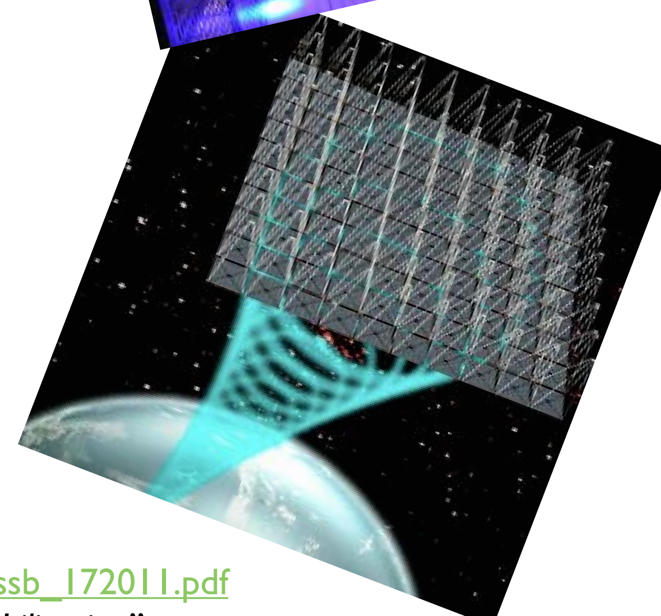
WHAT HAPPENS AT THE EDGE OF SPACE?

ORBITAL ECONOMY

ORBITAL ECONOMY

- GLOBALIZATION
- INTERNET OF SPACE
- LAW & REGULATIONS
- ORBITAL CURRENCY
- SPACE RESOURCES





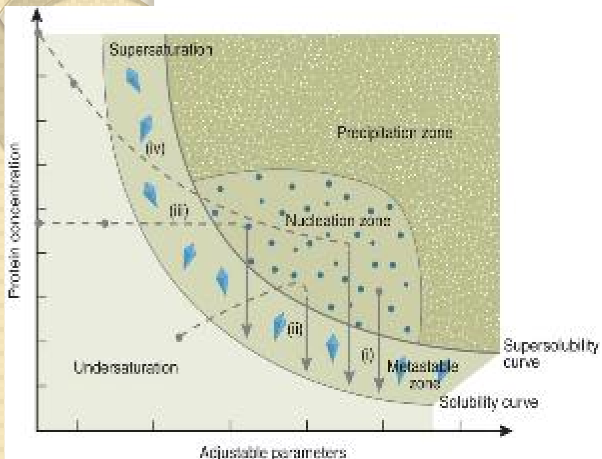
I. Cozmuta, National Academy of Sciences, Leo commercialization day: http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_172011.pdf

Webinar "On-Orbit Manufacturing: From Orbital Factories to In Situ Resource Utilization" https://attendee.gotowebinar.com/register/5666583135043371522

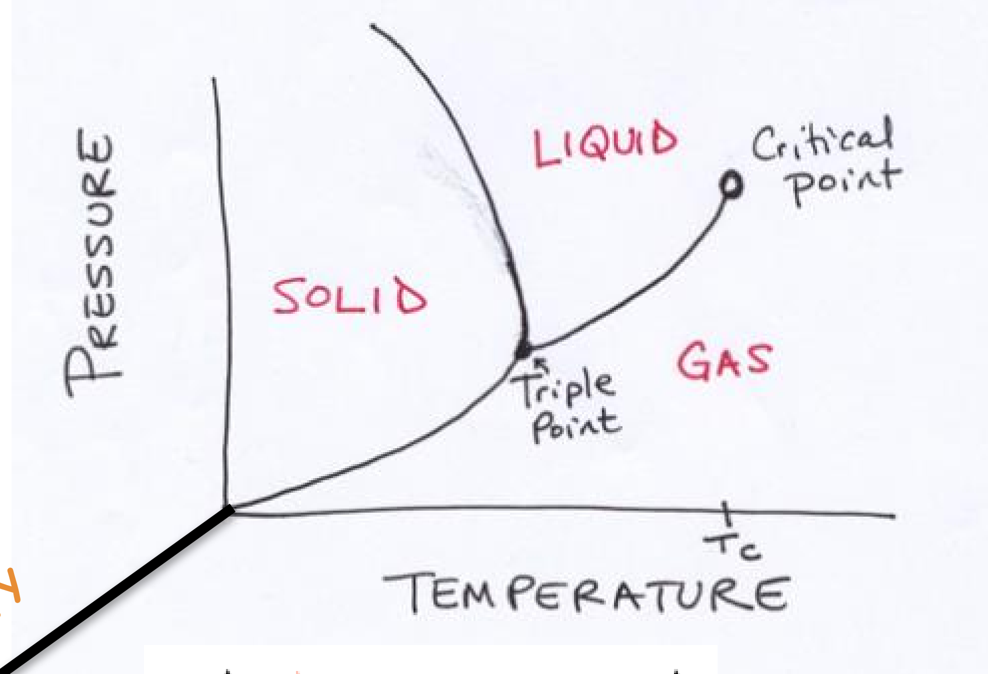
WHAT IS MICROGRAVITY?

- **Microgravity** or **reduced gravity** represents ~6 orders of magnitude reduction in one of the fundamental forces (gravity)
- **Gravity is a physical parameter that together with pressure and temperature define the state of a system**
- When the force of gravity is removed other forces (**surface tension, capillary forces**) become predominant and drive a different system dynamics
- Historically, major **breakthrough and innovations** were achieved when systems were studied, for example, at low temperatures.
- Many of our intuitive expectations do not hold up in microgravity!

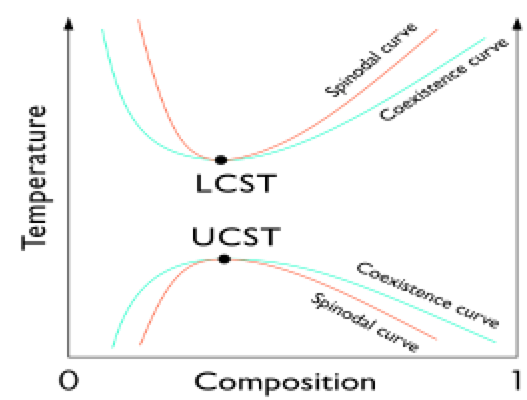
GRAVITY AND PHASE DIAGRAMS



CRYSTALLIZATION
PHASE DIAGRAM

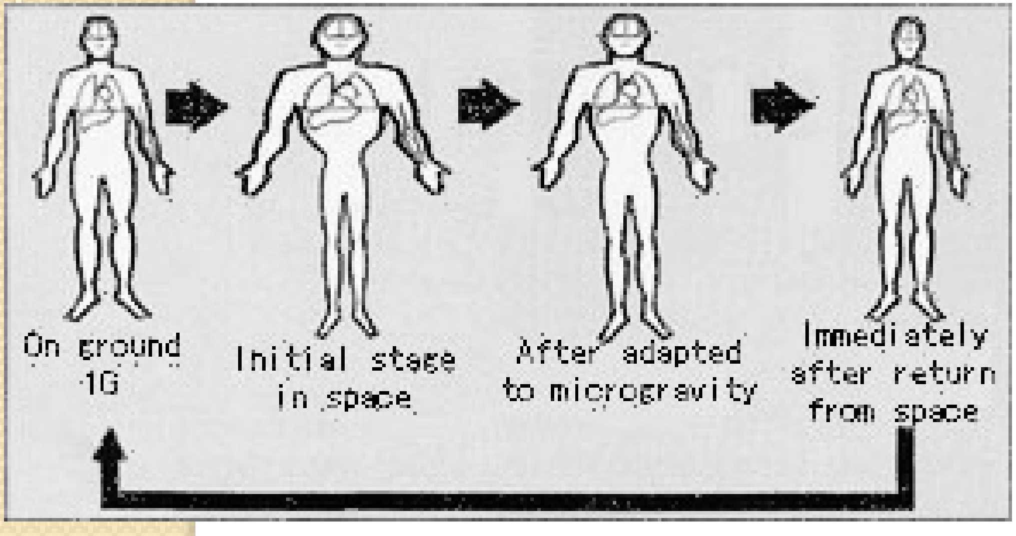


GRAVITY



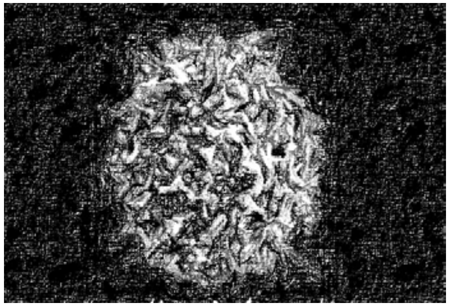
BINARY COLLOIDS
PHASE DIAGRAM

BENEFITS FOR LIFE SCIENCE



Microgravity is evolutionarily novel and enables new understanding of living systems that can be used for medicine and biotech.

Commercial biosciences and pharmaceutical companies have flown experiments in space since the 1980s.

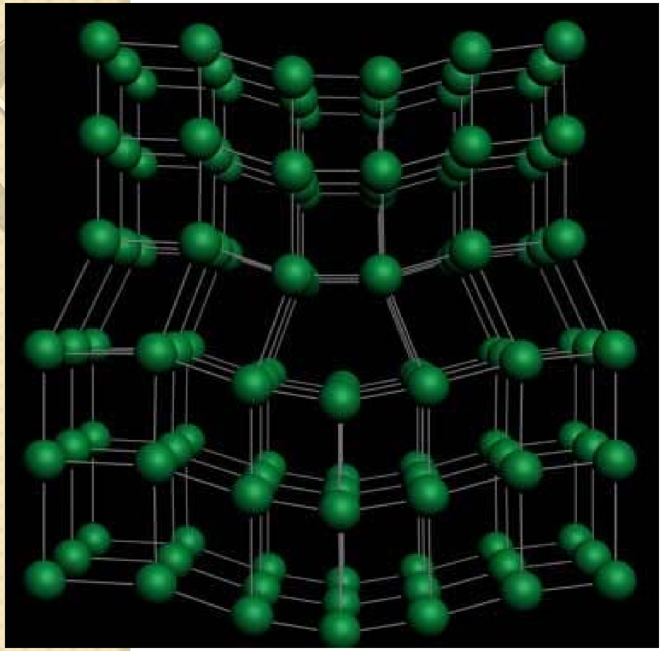


Response to gravity is complex.

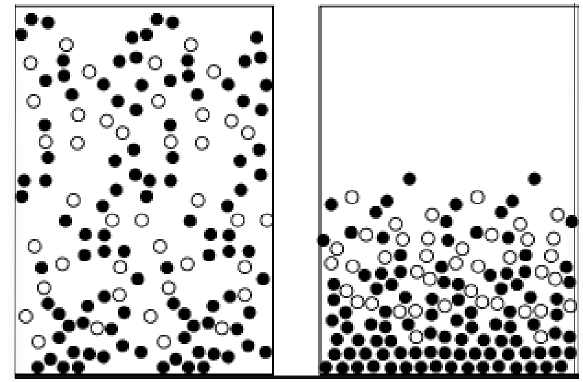
All levels of biological organization, cells, tissues, organs, organisms, are affected by gravity/microgravity, often in novel and useful ways, sometimes in ways that allow medical problems on Earth to be better studied.

As biotech companies have found, novel environments offer novel biological responses useful for industry, medicine, and agriculture.

BENEFITS FOR MATERIAL SYSTEMS

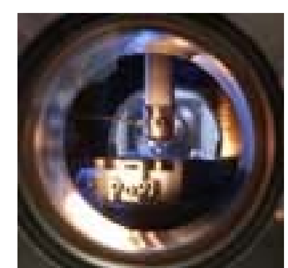


- No solute buildup
- No sedimentation
- No convection



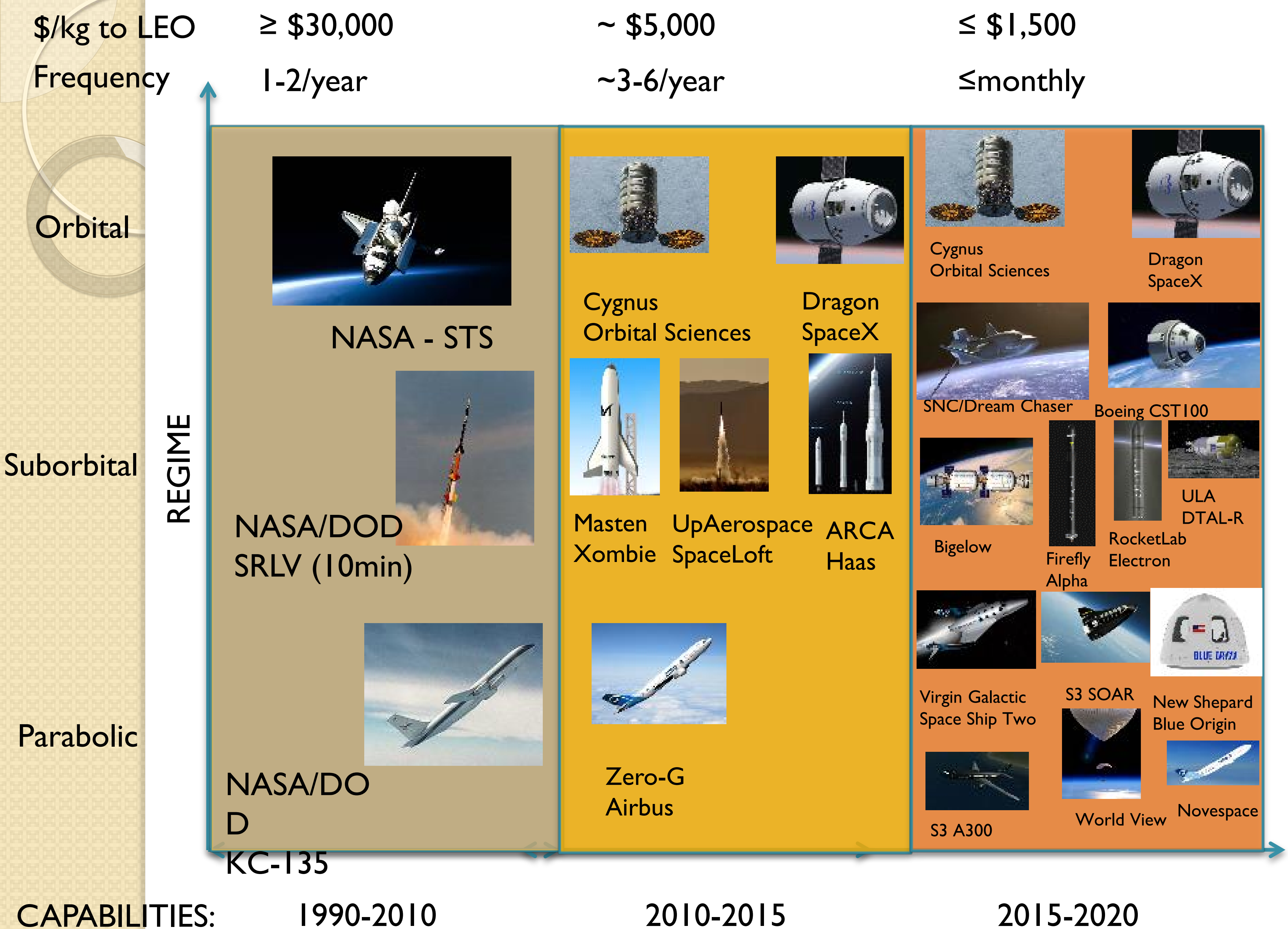
- Defect free
- Homogeneous
- Controlled, symmetric growth
- Avoidance of nucleation or single nucleation
- High resolution

- Containerless processing
- Free suspensions
- Perfect spherical shape
- No wetting



SINCE 1946

May 10, 1946 – first space research flight (cosmic radiation experiments) –US, V2 rocket
February 20, 1947 –first animals into space (fruit flies)–US, V2
November 3, 1957 –first animal in orbit (the dog Laika) -USSR, Sputnik 2
August 19, 1960 –first plants and animals to return alive from Earth orbit –USSR, Sputnik
April 12, 1961 –first human spaceflight -Yuri Gagarin –USSR, Vostok 1
1969 –first Welding experiment in space –Soyuz 6
1971 – composite casting – Apollo 14
1973-1979 – Skylab Materials Processing Facility, Multipurpose Furnace System, Skylab
1980-2000 – Spacelab, etc – Shuttle Era (STS-3 through 87)
April 23, 1971 – first space station – USSR, Salyut 1
February 19, 1986 –first inhabited long-term research space station -USSR, MIR
November 20, 1998 - first multinational space station (ISS)
Largest man-made object built in space to date (Russia, USA, Europe, Japan, Canada)



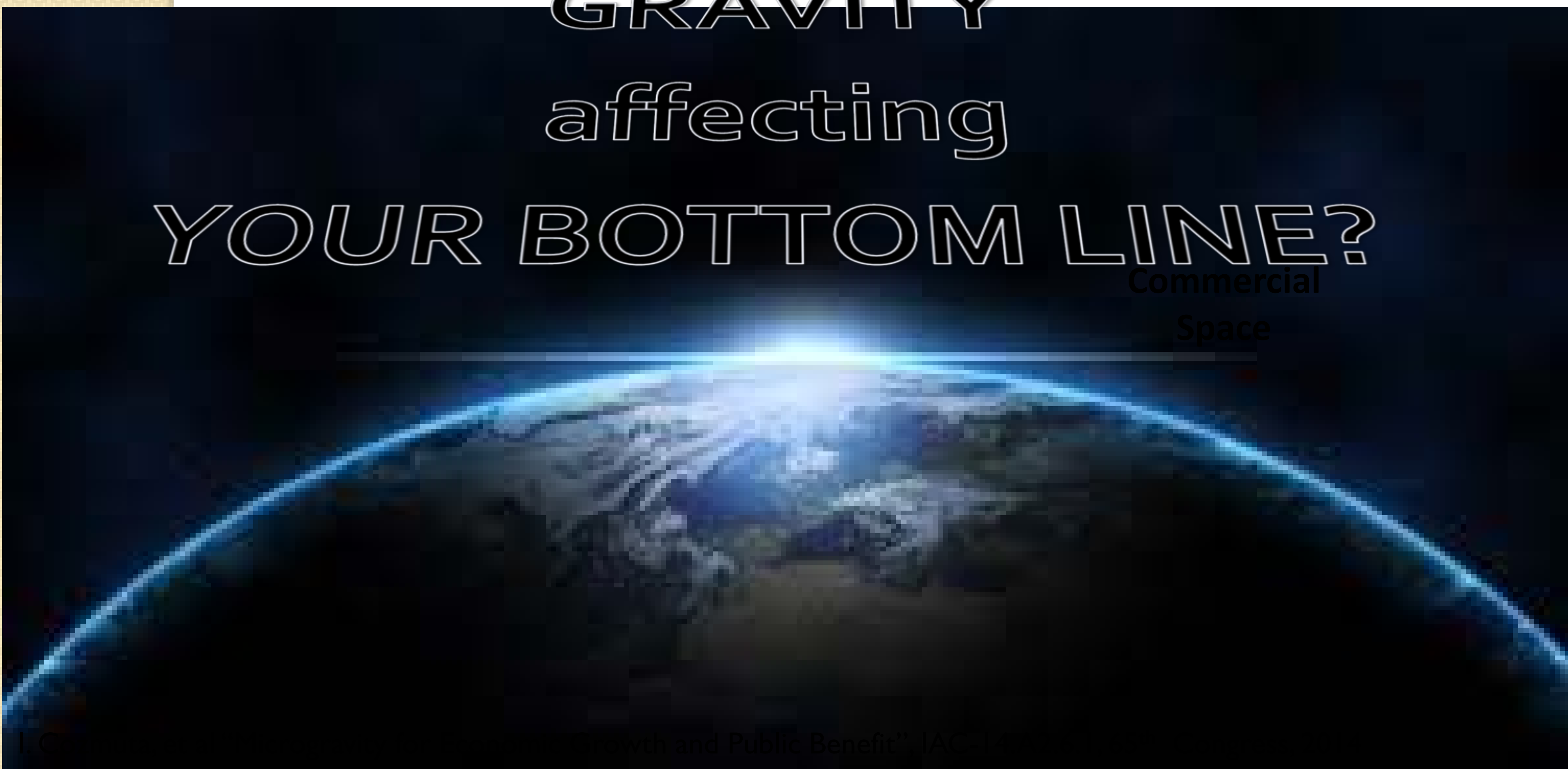
$/kg to LEO
≥ $30,000
~ $5,000
≤ $1,500
Frequency
1-2/year
~3-6/year
≤monthly
Orbital
Suborbital
Parabolic
REGIME
NASA - STS
NASA/DOD SRLV (10min)
NASA/DOD KC-135
Cygnus Orbital Sciences
Dragon SpaceX
Masten Xombie
UpAerospace SpaceLoft
ARCA Haas
Zero-G Airbus
Cygnus Orbital Sciences
Dragon SpaceX
SNC/Dream Chaser
Boeing CST100
Bigelow
Firefly Alpha
RocketLab Electron
ULA DTAL-R
Virgin Galactic Space Ship Two
S3 SOAR
New Shepard Blue Origin
S3 A300
World View
Novespace
CAPABILITIES:
1990-2010
2010-2015
2015-2020

BACKGROUND

- Reviewed microgravity findings **since 1985**: materials, life science, (limited) human medical research
- Reviewed **1000+ papers** and reports in **30+ topic areas** TO assess potential terrestrial applications
- Reviewed NASA and OGA **spinoffs database** as appropriate
- Reviewed **153 pool of technologies under Flight Opportunities**
- Interviewed **150+ microgravity PI's** TO understand implications of their findings and potential success enablers
- Discussed with **400+ industrial lead scientists and technologists** TO understand their technical problems caused by gravity
- Discussed with **100+ venture capitalists and financiers** (primarily from Silicon Valley) TO understand the risks they perceive for microgravity related applications
- Identified **30+ potential candidates for commercial microgravity** feasibility to implement, and company interest.
- Completed **4 in-depth Case Studies (Exotic optical fibers and glasses, Semiconductor materials, Biotech, Solar Power Data Centers)**

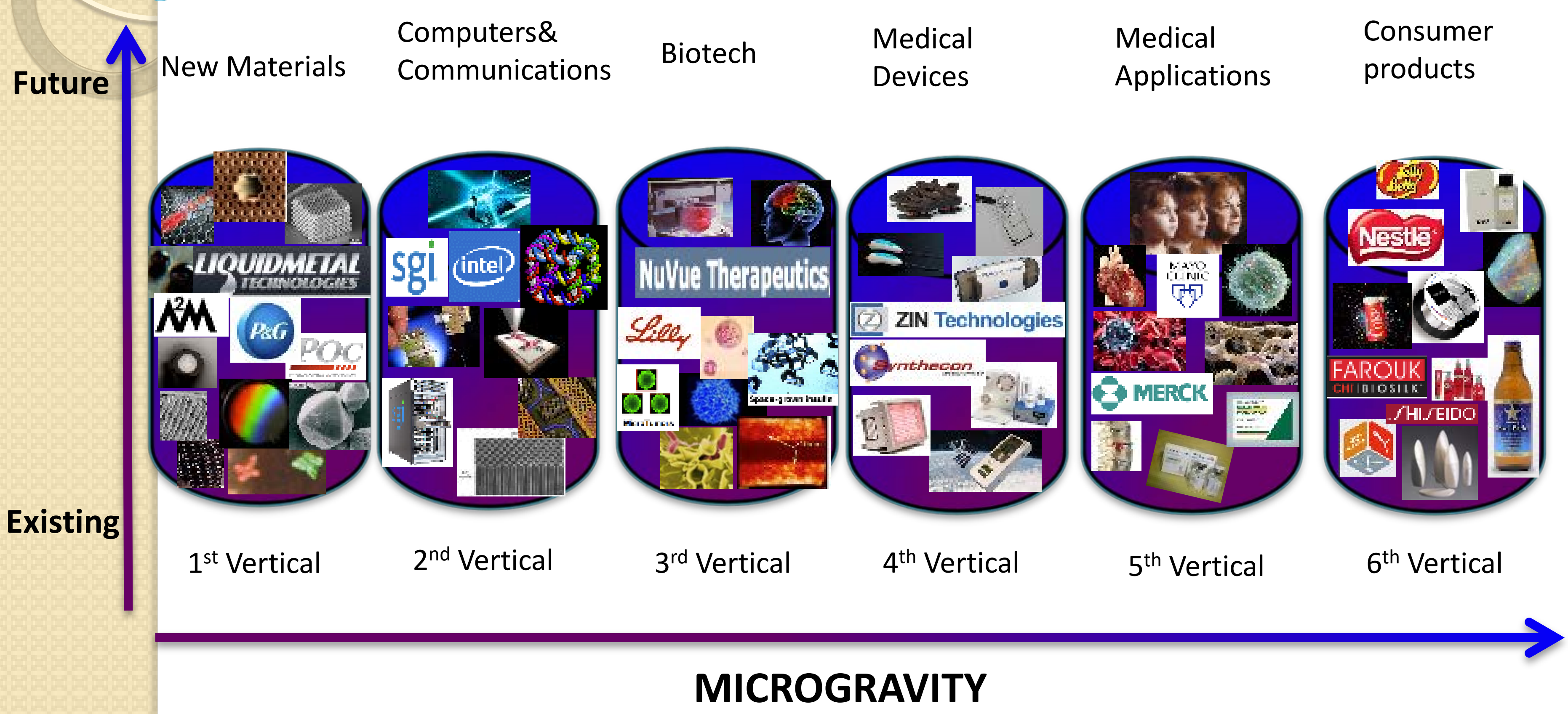
How is GRAVITY affecting YOUR BOTTOM LINE?

Commercial Space



Growth and Public Benefit", IAC-14

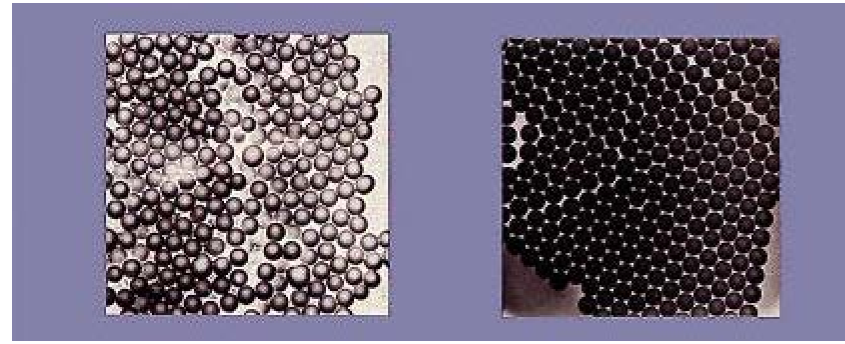
VERTICALS OF MICROGRAVITY



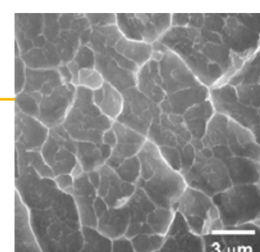
Developed to capture in a compressed manner a mix of very diverse values (knowledge, processing) of the microgravity environment. Emerging from a common background, that of microgravity, the verticals extend from existing companies and their microgravity products, to new players & future partners that could potentially benefit of the microgravity environment.

SUCCESS STORIES

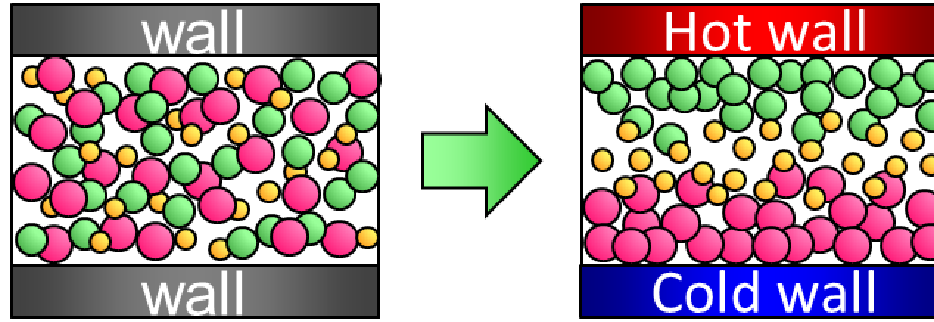
Despite relatively low funding, relatively few investigators, and great difficulties accessing space (compared with laboratory research on Earth), the success rate from microgravity R&D into applications is remarkably significant.



Space Beads	Polystyrene spheres 10 microns in diameter-calibration standard SRM 1965 for NBS	Superior product in terms of (1) sphericity (2) narrowness of size distribution (3) rigidity
Bulk Metallic Glasses	Hinges, sliders, frames, display frames, miniature camera case, phone cases, golf clubs, surgical tools, SIM eject tool for iPhone	Helped develop BULK (vs thin) metallic glasses by acquiring understanding in microgravity underlying viscosity of

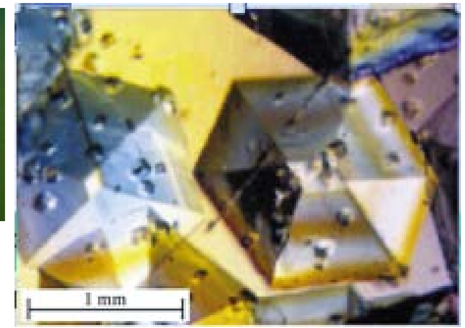


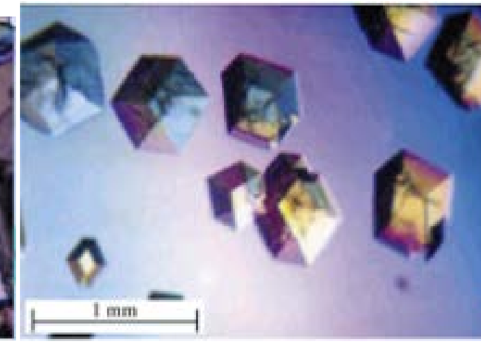
SUCCESSE STORIES



Exp		
Semiconductor crystals	Fabrication of low noise field effect transistors (FET's), analog switch integrated circuits (LCS)	Microgravity-grown crystals have (1) increased single crystal size (2) suppressed impurities and defects (3) higher quality crystals
Thermal Diffusion Coefficients	Database of Soret coefficients for various mixtures	Capturing the diffusive aspect of thermodiffusion (no convection)
Capillary Flow Experiments	Software for modeling of complex interface configurations. New rapid diagnostic for infant HIV for the developing world,	Capturing fluid and bubbles system dynamics as driven by capillary and surface tension forces in microgravity (in the absence of buoyancy driven convection) has resulted in high performance,

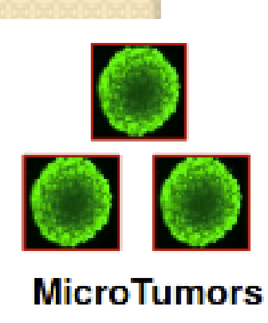
SUCCESSE STORIES

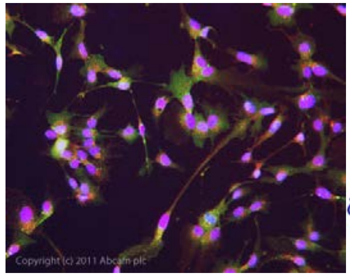


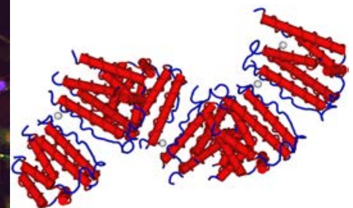


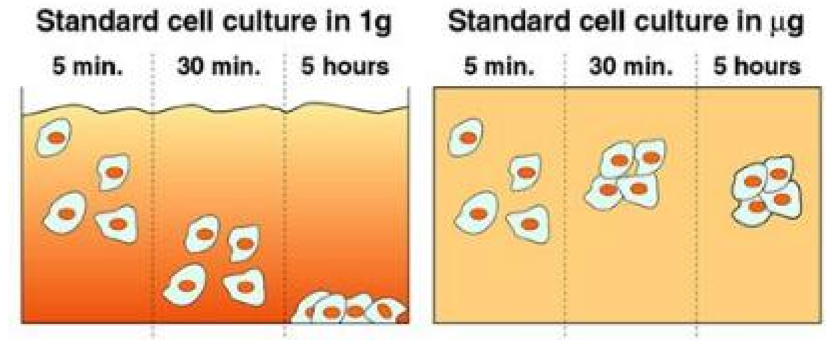
Experi		
Microencapsulation	Bright Mark line of tissue site marker for accurate tumor diagnostic devices Chemo-FDA approved drugs contained in microcapsules (clinical trials entered in 2012) for local (vs systemic) cancer chemotherapeutic treatment	Pharmaceutical drug and its outer membrane form spontaneously improving ease of drug manufacturing and direct injection into tumoral tissue; controlled layering enables timed delivery of drug.
Insulin crystals	Slow absorption diabetic drug	Well ordered, high resolution crystals of the T3R3 insulin hexamer variant were produced in microgravity resulting in designing a stable form that dissolves at the right rate inside the body[6].

SUCCESSE STORIES









Experi		
Interferon	FDA approved Peg-Intron™, a pegylated alpha interferon formulation, for the treatment of chronic hepatitis C in January 2001.	STS-Microgravity experiments on alpha interferon, Intron A, for the first time provided Schering Plough Research Institute with large quantities of large, high quality crystals. This was a critical stimulus that enabled the company to demonstrate the crystals' suitability as a long lasting formulation, one of its goals.
3D cell cultures	39000 Rotating Wall Vessel/Bioreactor units. Synthecon is the manufacturer and distributer. Industry standard for 3D	Inspired by characteristics of microgravity, the design minimizes shear and turbulence in the mixing process and produces superior 3-D cell and tissue cultures

NEAR TERM POTENTIAL

Topic		
ZBLAN optical fibers	Mid-IR lasers, Photonics, Thermal imaging, Sensing, Spectroscopy, Biomedical devices, telecom	Fibers made in microgravity would result in very low broadband attenuation (~100x better than currently used Si fibers)
3D tissue and tumor growth	Growth of patient derived tumor cultures for selection of chemotherapy drugs	Size of tumors grown in microgravity ~10x larger[1] than on ground and of higher tissue fidelity
Freeze cast foams	Bottom-up processing/manufacturing	Solid oxide fuel cells; ISRU; fast dissolving pharmaceutical tablets;
Zeolite crystals	Catalysts, ion exchangers; absorbents/separation; hydrogen storage; "green" household products; Photocatalysts	Growth of large, uniform, high-quality/zeotypes ETS titanosilicate crystals; reduced defect concentrations and types; attunement of chemical formulation, growth&composition
Field-Directed colloidal and nanoparticle self assemblies	Magneto-rheological (MR) dampers for energy absorption (earthquake, automobiles, trucks) Electro-rheological (ER) fluids for haptic controllers and	Knowledge: formation and dissolution of structures for rapid and reversible change of rheological properties. Microgravity offers a unique opportunity to interrogate the structural evolution, pattern formation and aggregation dynamic of dipolar suspensions.

NEXT GENERATION

Topic		
Amyloid fibrils	Neurodegenerative diseases (Alzheimer, Parkinson)	Understanding disease mechanism
3D DNA	DNA nanotechnology, DNA based computing	DNA self-assembly crystals to control inter-molecular contacts
Nanoclays	Flammability inhibitors, rheological modifiers, gas absorbents, liquid crystal displays, drug carriers	More uniform clay-polymer mixtures generated in the microgravity environment with reduced mixing time.
Plant Cells	Essential oils, scents, flavors, biodiesel (Jatropha Curcas)	Breeding and genetic improvement by comparing cell differentiation and regeneration through gene-wide expression profiling in space and on Earth
Ultra thin coatings	Biocompatible coatings for implanted batteries&devices; photovoltaic coatings; semiconductor components manufacturing; storage systems; photoresist microelectronics	Gravitational forces create shear stresses in the flow introducing 3D instabilities (waves, ribs, streaks) in the film, directly altering device performance. In microgravity the surface tension&viscous forces in the meniscus region lead to smooth&uniform thin films.
Hollow bearings	Load-bearing machines with moving parts, tribology	High sphericity, narrow size distribution, hollow; multimaterials, multilayered

SELECTED PUBLICATIONS


IAC-14-A2.6.1

MICROGRAVITY FOR ECONOMIC GROWTH AND PUBLIC BENEFIT

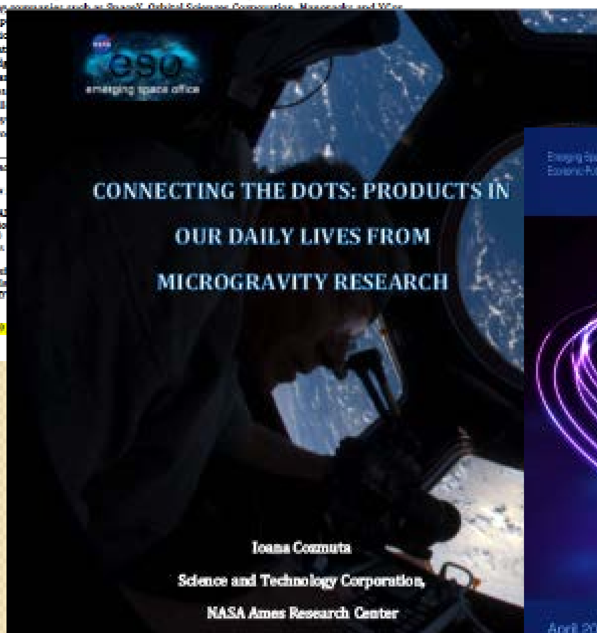
Ioana Cozmuta, Ph. D.
Science and Technology Corporation, Space Portal, Moffett Field, USA

Lynn D Harper
NASA Ames Research Center, USA

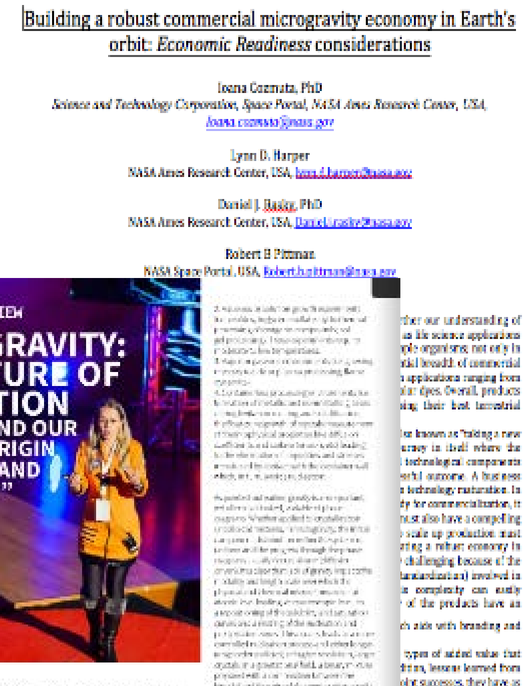
Daniel J Rasky, Ph. D.
NASA Ames Research Center, USA

Robert B Pittman
NASA Space Portal, USA

Alexander C MacDonald
NASA HQ, USA



Microgravity session to support Degenerative Diseases – SBMT World Congress


Building a robust commercial microgravity economy in Earth's orbit: *Economic Readiness* considerations

Ioana Cozmuta, PhD
Science and Technology Corporation, Space Portal, NASA Ames Research Center, USA

Lynn D. Harper
NASA Ames Research Center, USA

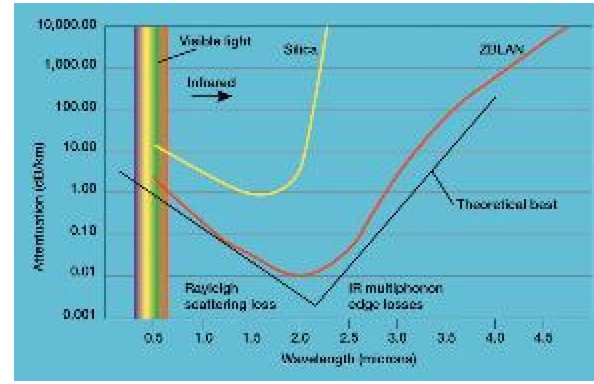
Daniel J. Rasky, PhD
NASA Ames Research Center, USA

Robert B Pittman
NASA Space Portal, USA

Nanoscientific, Fall 2015

*I Cozmuta, et al; "Innovation at the Edge of Space: Commercial Microgravity Science" webinar:*https://attendee.gotowebinar.com/register/8328957085888480516

ZBLAN OPTICAL FIBERS



ZBLAN optical fiber	• Heavy metal fluoride glasses have been studied for ~35 years • ZrF_4-BaF_2-LaF_3-AlF_3-NaF (ZBLAN) showed the most promise as optical fiber
ZBLAN Properties	• Most stable fluoride exotic glass and excellent host for doping • Broad optical transmission window extending from ~0.3 microns UV out to ~5 microns IR • Theoretical loss coefficient is 0.001 dB/km at 2 microns (~100x better than Si fibers)

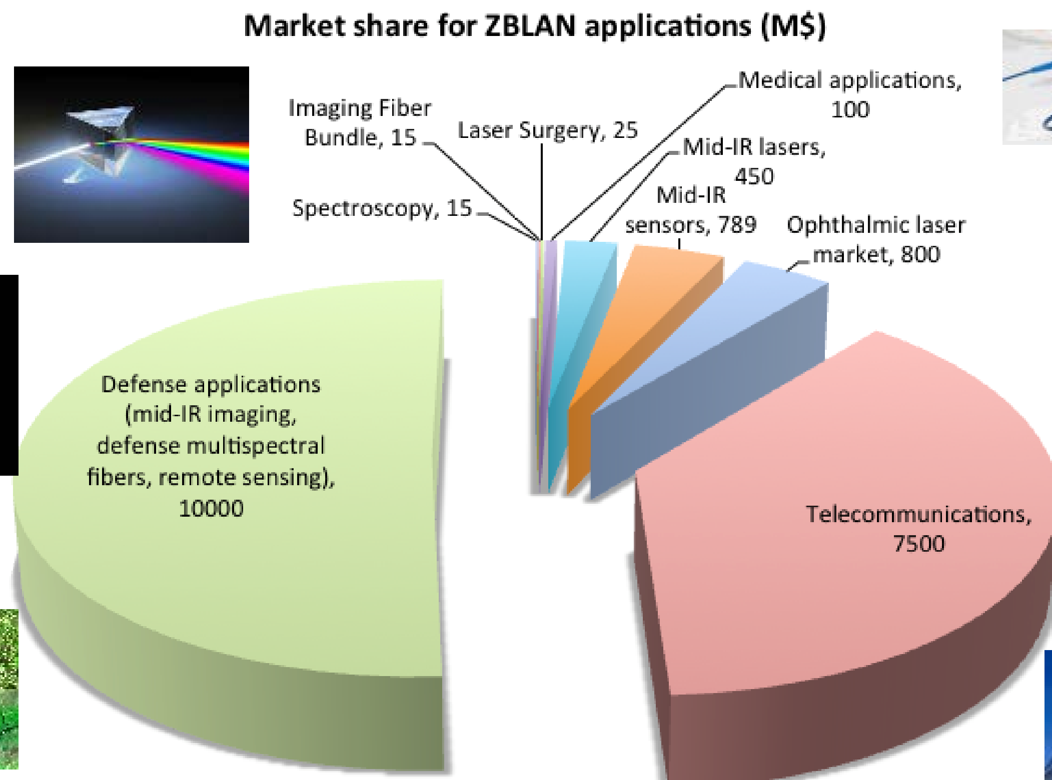
ZBLAN limitations and applications	• Theoretical loss has not been achieved to date due to intrinsic and extrinsic processes
	• Intrinsic and Extrinsic processes limit light propagation
	    • Intrinsic: band gap absorption, Rayleigh scatter, multiphonon absorption
	    • Extrinsic: impurities such as rare-earth ions and crystallite formation
	• Applications: fiber amplifiers, fiber lasers, nuclear radiation resistant links

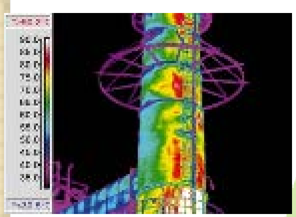
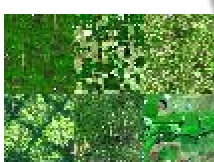
MICROGRAVITY EXPERIMENTS

Hardware and Procedure	• ZBLAN fibers obtained from Infrared Focal Systems, Inc. and Bell Laboratories • Fibers were stripped of coating and placed in evacuated quartz ampoules
Parabolic Flights	• Fibers first flown on NASA's KC135 Reduced Gravity Aircraft • KC135 produces ~25 sec. of reduced gravity per parabola • One week of flights led to ~200 total parabolas • Fibers were heated to the crystallization temperature during reduced gravity and compared to unit gravity for the same amount of time
Sub-orbital Flights	• Fibers were flown on board Conquest sub-orbital rocket • This flight gave 6.5 minutes of reduced gravity

MICROGRAVITY FABRICATION

- Microgravity suppresses the effect of nucleation and crystallization – directly underlying attenuation-broadband properties
- No limit to the length that can be produced in space without need to adjust payload size (no need for drop towers)
- 1lb of preform would produce ~8 km ZBLAN fiber
- Nominal selling price range on Earth for space manufactured fibers: $175k/km to $1,000k/km ~ROI: 90-300x (w/o amortization costs)





HISTORY & FUTURE STEPS TOWARDS ZBLAN COMMERCIALIZATION

ZBLAN investigation
Dr. Dennis Tucker
20 sec of μg (total 6.5 ......)
20+ samples

SPACE PORTAL
Assessment of technical and commercial value
CASIS engaged

Ground: Develop technology to make ZBLAN preform

ISS: Validate technology to make ZBLAN preform

ISS: Develop and validate technology to make other exotic fiber preform

2015 | 2017 | 2020

1998 | 2012 | 2014

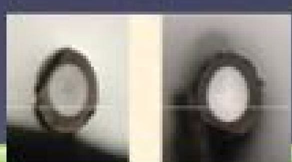
Space made ZBLAN spools

BURST OF PHOTONICS INDUSTRY

PAYLOAD DEVELOPMENT: Automated manufacturing

2015 | 2017 | 2020

PAYLOAD TESTED AT AF KIRKLAND
Dr. D. Starodubov/Physical Optics Corp
Preform reprocessing &fiber drawing in μg
Few cm of fiber D-100μm



ISS: One time operation
15m of μg ZBLAN fiber
100μm diameter

ISS: Multiple automated ops
100m μg ZBLAN fiber
100μm diameter
MID-IR lasers

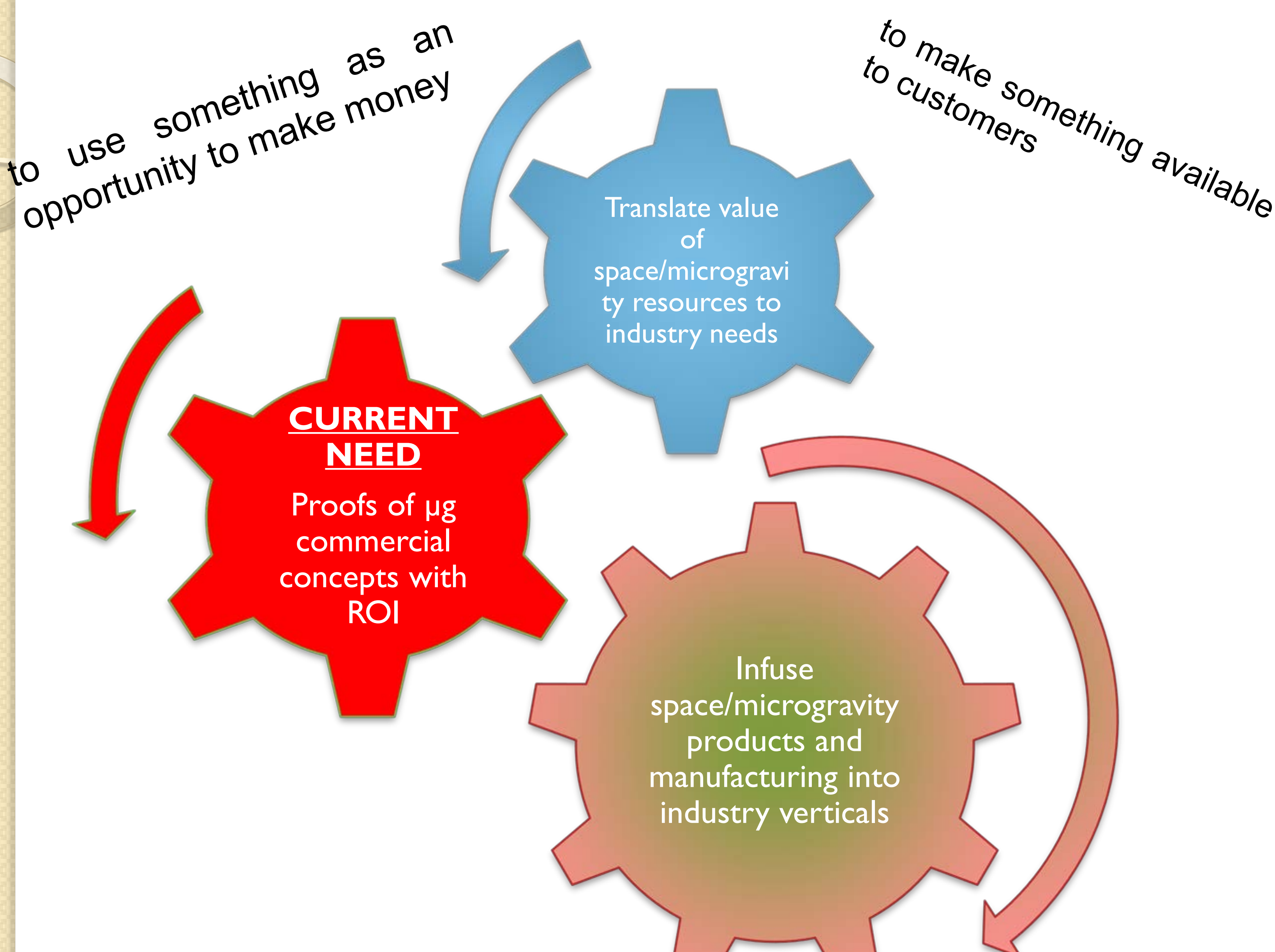
ISS: Multiple
100m μg ZBLAN fiber
20 cm diameter
Telecomunications

2024: BROADEN MANUFACTURING TO OTHER EXOTIC FIBERS

ECONOMIC READINESS ASSESSMENT

- *Combines technology readiness, market need and investment risk*
- *Bridges between supply, demand and capital in a systematic, standardized manner.*
- *To advance on a Economic Readiness Level the technology itself may not necessarily need to mature but the understanding of its economic potential does.*
- *The ultimate goal of the TRL is to mature a technology from a fundamentally new idea (research) to incorporation and efficient use into a system* by optimizing a program's performance, schedule and budget at key points of its life cycle.
- *Commercializing a technology or "taking a technology to market" builds upon the alignment of the technological push with the business development and the market and economic pull*

THE MACHINERY OF COMMERCIALIZATION

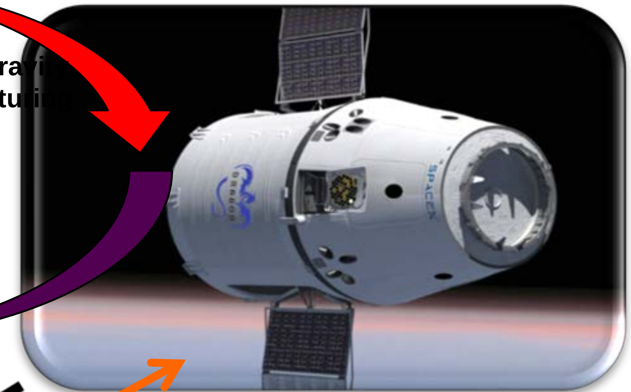


COMMERCIAL MICROGRAVITY LEO BASED PRODUCT CYCLE

ISS

Transfer and scale advanced microgravi
based technologies to LEO manufactu

Identify and start new lines of R&D investigations



ERL 1

ERL 7, 9

Private Orbital Laboratory

Identify and invest in new commercially relevant discoveries-topics that address industry needs where microgravity provides a better solution than Earth-based options.

Create new lines of investigations.

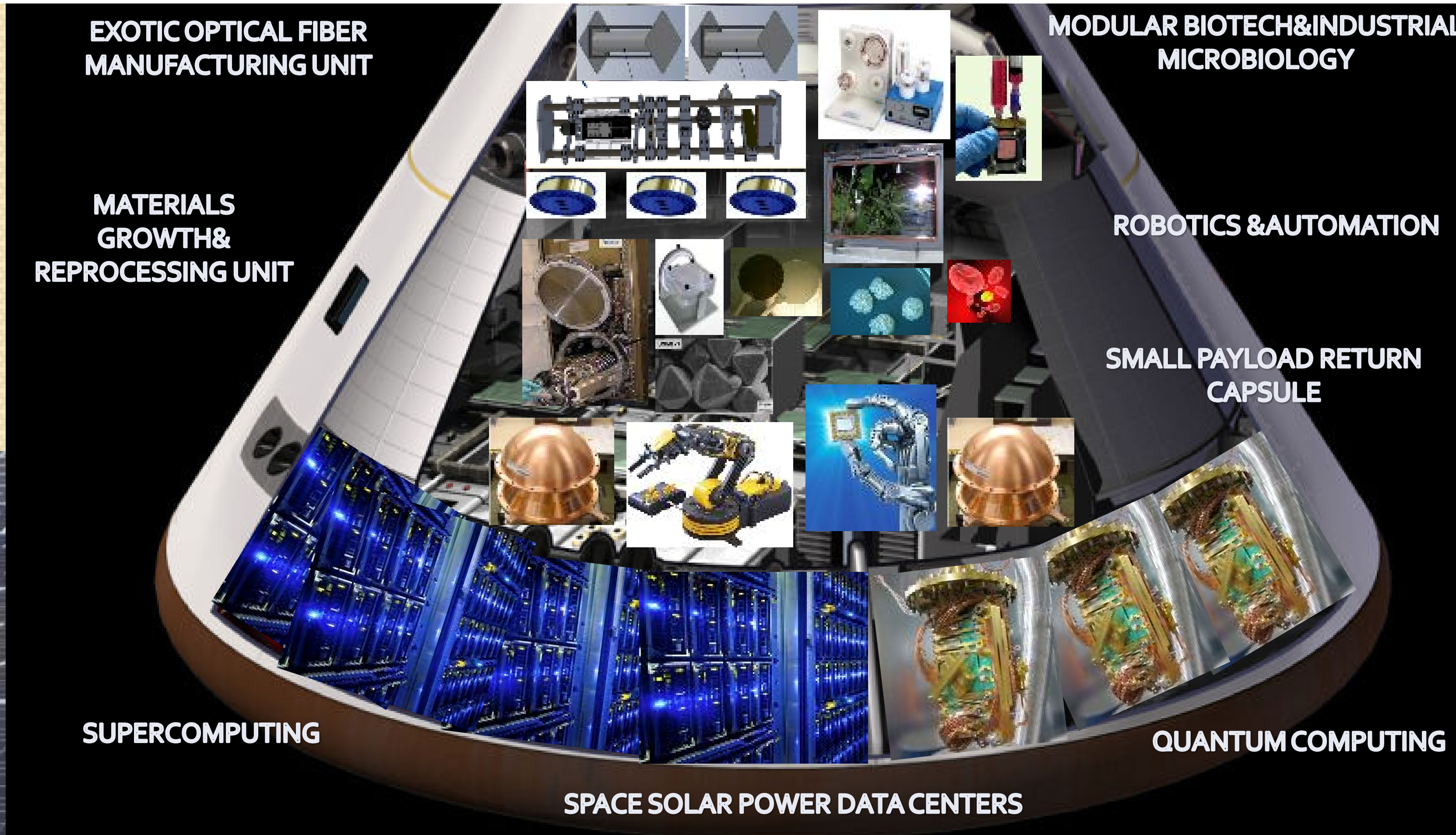
ERL 2-5

Attract, build trust, sell, develop microgravity brand loyalty, and build a rich relation so that customers will rally for the new brand

PROTOTYPE LABORATORY FOR COMMERCIAL MICROGRAVITY

BUILD A COALITION TO:

1. **DESIGN AND INTEGRATE THE COMPONENTS OF A MODULAR FREE FLYING COMMERCIAL INCUBATOR**
2. **DEVELOP AN ATTRACTIVE BUSINESS VALUE PROPOSITION FOR PRIVATE SECTOR UTILIZATION OF COMMERCIAL MICROGRAVITY**



PATENT PROVISION

Thank you!

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Dr. Dan Rasky
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Bruce Pittman
Chief Systems Engineer

Mark Newfield
Technical Operations Manager

Lynn Harper
Lead for Integrative Studies

Dr. Ioana Cozmuta
Lead for Microgravity Studies

OBJECTIVE

Assess the potential of microgravity for <u>public benefit</u> and <u>economic growth</u> over the next decade.

1. Potential	What are the benefits of microgravity for material and life sciences? How deep is the understanding of the microgravity phenomenon? How can microgravity products or insights affect the state-of-the-art on Earth? What is their value/relevance in the current landscape of applications?
2. Credibility	How credible are the microgravity based results? What is the current appreciation and value of the microgravity based applications that have previously returned value to the tax payers? Are there revenue generating companies from a microgravity based product?
3. Accessibility & Awareness	Who is aware of microgravity and to what extent? How structured/accessible is the scientific and commercial value of microgravity? When challenged by a technical problem caused by gravity, do scientists in either the academic or the private sectors think of using microgravity to solve it?
4. Interest	To what extent is there interest in pursuing microgravity based investigations for new knowledge and product innovation? What are the target areas that would benefit most from R&D in microgravity? What is the industry specific infusion point for microgravity driven discoveries?
5. Commercialization	What are generic challenges for commercialization? What are challenges specific to microgravity/space commercialization? What are commercialization challenges specific to a certain sector of the industry? What are driving incentives across the various sectors of the industry?

STRATEGY

Commercial Microgravity Products	• Online research reviewing the entire ISS database (including the one behind the firewall), selected scientific literature, and spinoff databases to identify microgravity products for specific application areas. • One-on-one interviews with PI's of microgravity investigations • Discussions with industry scientists, chief technology and executive officers and venture capitalists from the private sector (mostly Silicon Valley) • Summarized scientific publications, patents and spinoffs per application
Potential Microgravity Benefits and Solutions	• Microgravity seminars at major universities across the US • One-on-one discussions with faculty and students of various disciplines relevant to microgravity R&D. • In-depth examination of promising topic areas, especially comparison and validation against current SOA on ground • Technical exchanges among experts in microgravity research, PIs, microgravity commercial service providers, recognized scientists at the cutting edge of terrestrial SOA and potential commercial users of microgravity R&D .

APPROACH

1. Identify products originating from microgravity research, describe their known technological advantages over Earth-manufactured counterparts, and provide clear traceability from microgravity R&D through product development.
2. Organize results with relevance to a specific application (across disciplines); results from most microgravity investigations branch out in a wide (sometimes unexpected) variety of areas
3. Identify potential microgravity-based technical solutions for commercial applications and their possible infusion points into the product development cycle, using results from step (1) and survey of existing market values to provide realism.
4. Evaluate potential commercial benefits from microgravity R&D over the next decade through the lens of the current state-of-the-art of analogous processes on the ground and anticipated industrial high-tech trends.
5. Select topics for in-depth case studies and obtain independent review and validation of findings by both technical and business experts for selected case studies and selected potential products.

MICROGRAVITY PER DISCIPLINE

Fundamental Physics	**Fluid Physics**	**Material Science**	**Combustion science**
Test basic scientific theories	Perfect shape (surface tension)	Relationship: structure, properties, processing	Ignition
Thermodynamics	Surface tension driven flow	Production of alloys and composites	Flame spreading
Atomic physics	Welding	Dendrites	Flame extinction
Relativistic physics	Dynamics of liquid drops	Ceramics and glass experiments	Role of soot formation
Low-temperature physics	Microfluidics	Optical engineering	Air flow, heat transfer
Heat energy	Dynamics of gases	Containerless processing	
New forms of matter			