CONSIDERATIONS FOR A ROBUST ECONOMY IN EARTH'S ORBIT

Commercial Space

Ioana Cozmuta, PhD

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Space Portal, NASA Ames Research Center

Space Portal at the NASA Research Park

NASA

My values…

Born in Communist Romania…

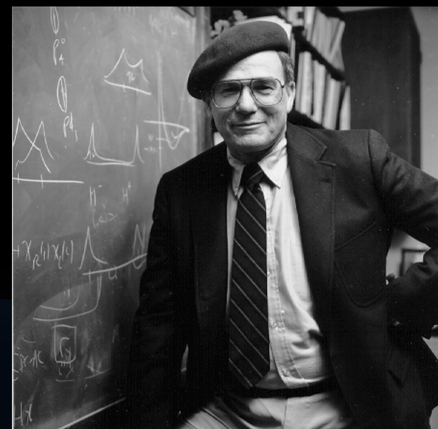

In CONGRESS, July 4, 1776.

The unanimous Declaration of the thirteen united States of America.

…On the 4th of July

The Golden Giants

Dr. Emiel van der Graaf,
University of Groningen, NL
Adj Director, Nuclear Physics Institute

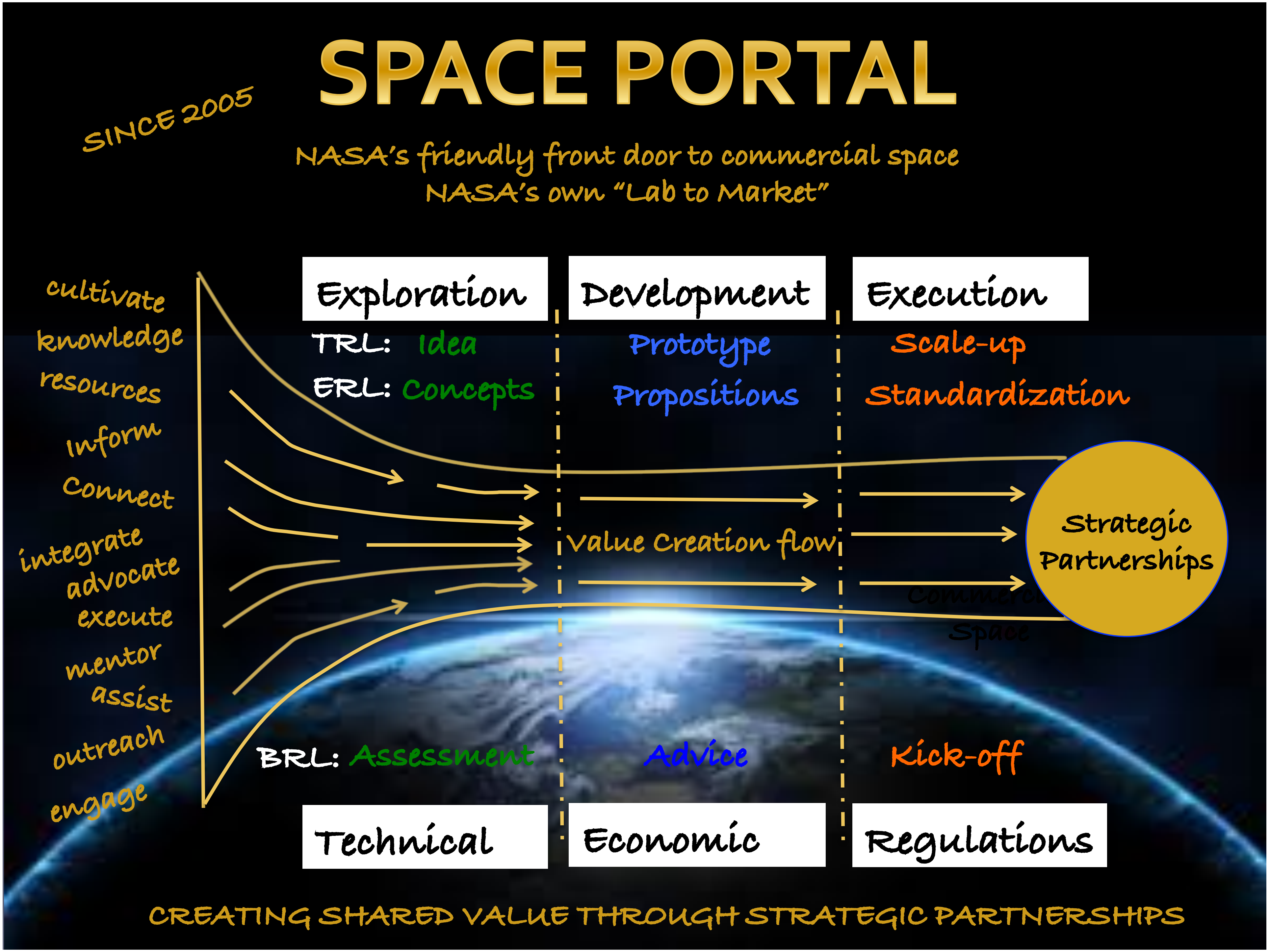


Prof. William Goddard
Caltech
Professor of Chemistry, Material Science and Applied Physics
Director Material and Process Simulation Center

Prof. Ronald W Davis
Stanford
Professor of Biochemistry and Genetics
Director Genome Technology Center

Dr. Elaine Baskin
Executive Director
Institute for Personal Change

Dr. Dan Rasky
NASA Ames Research Center
Director, Space Portal



SPACE PORTAL
SINCE 2005
NASA's friendly front door to commercial space
NASA's own "Lab to Market"
cultivate
knowledge
resources
inform
connect
integrate
advocate
execute
mentor
assist
outreach
engage
Exploration
Development
Execution
TRL: Idea
Prototype
Scale-up
ERL: Concepts
Propositions
Standardization
Value Creation flow
Strategic Partnerships
BRL: Assessment
Advice
Kick-off
Technical
Economic
Regulations
CREATING SHARED VALUE THROUGH STRATEGIC PARTNERSHIPS

OBJECTIVE

Assess the potential of microgravity for public benefit and economic growth 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?

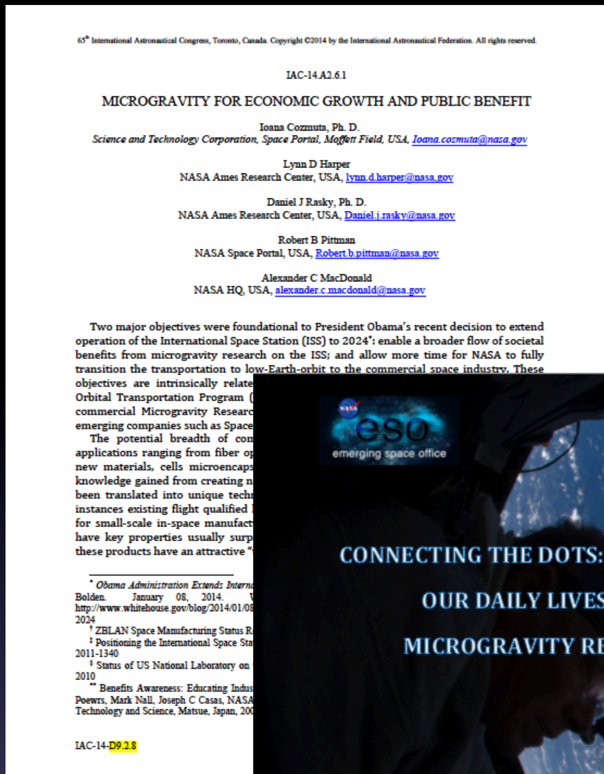
STRATEGY

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.

SELECTED PUBLICATIONS



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MICROGRAVITY FOR ECONOMIC GROWTH AND PUBLIC BENEFIT

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Two major objectives were foundational to President Obama's recent decision to extend operation of the International Space Station (ISS) to 2024*: enable a broader flow of societal benefits from microgravity research on the ISS; and allow more time for NASA to fully transition the transportation to low-Earth-orbit to the commercial space industry. These

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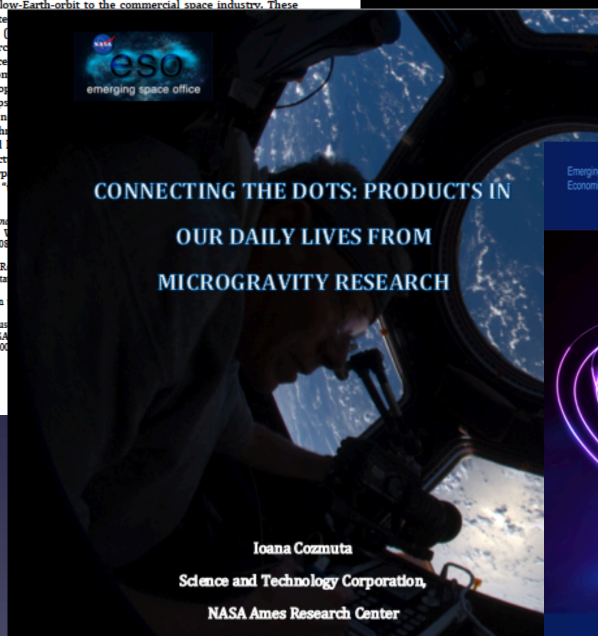
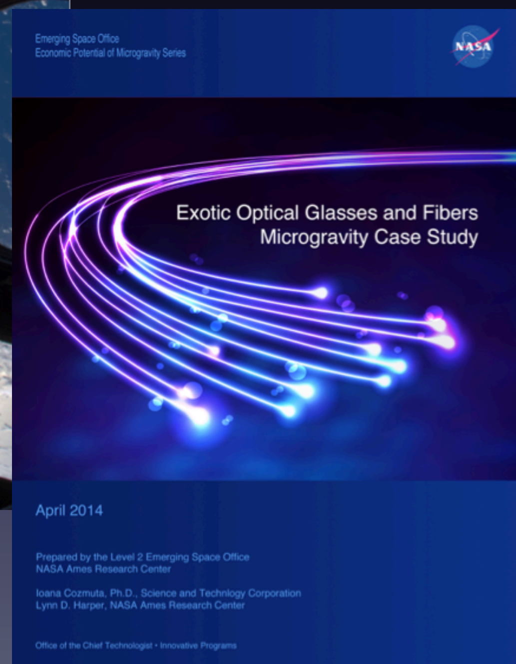


Microgravity session to support Degenerative Diseases – SBMT World Congress



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

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The reduced gravity environment of space provides a unique opportunity to further our understanding of various materials phenomena involving the molten, fluidic and gaseous states as well as life science applications where, contrary to earlier beliefs, microgravity induces changes in single cells and simple organisms; not only in large organisms with a complex overall response to gravity (or lack thereof). The potential breadth of commercial opportunities in microgravity thus spans over many verticals of the private sector with applications ranging from fiber optics, high-resolution crystals, microencapsulation, 3D organs to perfume and color dyes. Overall, products manufactured in microgravity hold the promise to have key properties surpassing their best terrestrial counterparts.

Commercialization, also known as "taking a new technology to market", is a journey in itself where the business, economic, market and technological components must align to generate a successful outcome. A business perspective is very different than technology maturation. In order for a technology to be ready for commercialization, it must not only be mature, but it must also have a compelling business case, and the means to scale up production must be identified and practical. Creating a robust economy in Earth's orbit (Fig 1) is especially challenging because of the complexity (high risks, lack of standardization) involved in predicting future growth. This complexity can easily overwhelm the fact that many of the products have an attractive "touch of space" which aids with branding and marketing.

Figure 1 Concept of a robust Earth's orbit economy building upon Microgravity Verticals and Economic Readiness Level

This paper reviews the types of added value that can be extracted from space, with an emphasis on the microgravity environment. In addition, lessons learned from past commercialization efforts will be reviewed. While past efforts have yielded some point successes, they have as a whole failed to precipitate a sustainable LEO based market (Fig 2).

Currently supporting Flight Opportunities and CPP under STMD for economic analysis of the FO technology pool

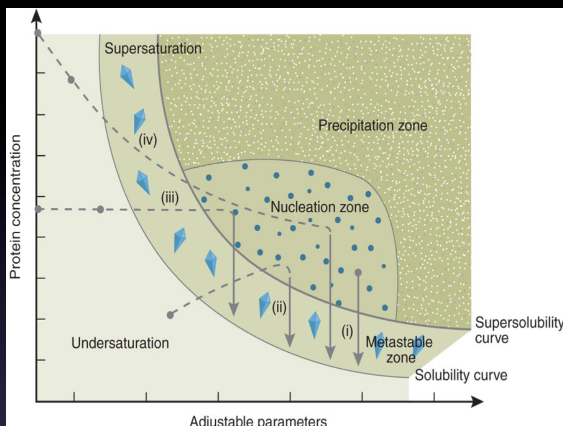
Microgravity sessions at various workshops across SV
-Institute of Competition Sciences& Methuselah foundation – currently Vascularization Challenge

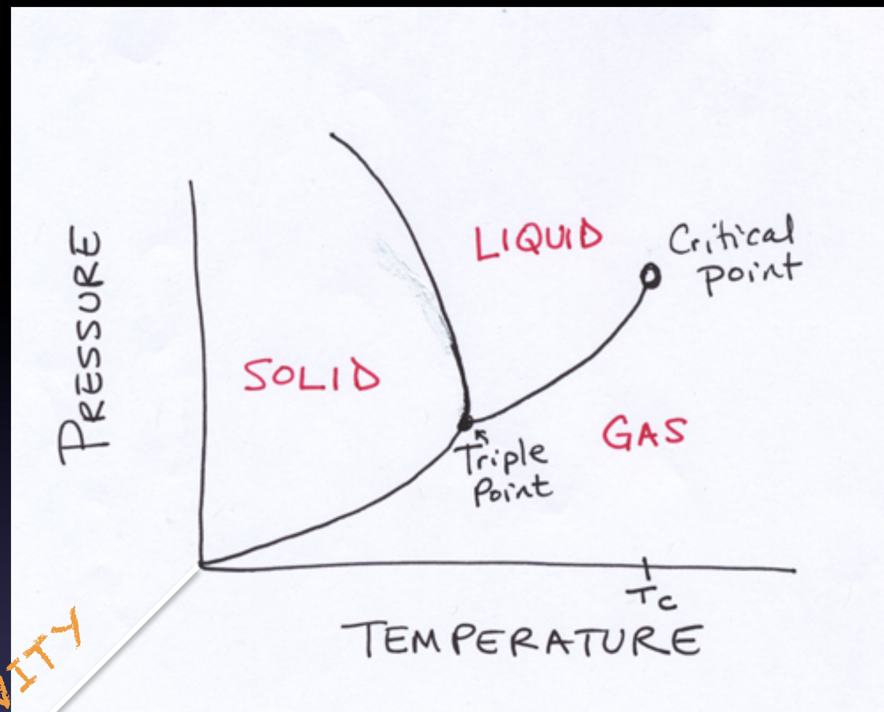
THE TECHNICAL DIMENSION

MICROGRAVITY

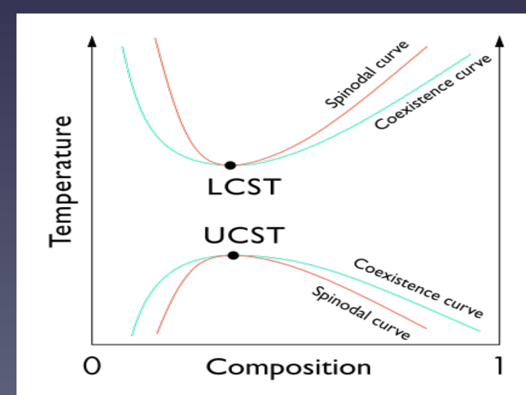
- When the force of gravity is removed other forces (**surface tension, capillary forces**) become predominant and drive a different system dynamics
- **Gravity is a physical parameter that together with pressure and temperature define the state of a system**
- Historically, major **breakthrough and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

A PHYSICIST'S VIEW ...

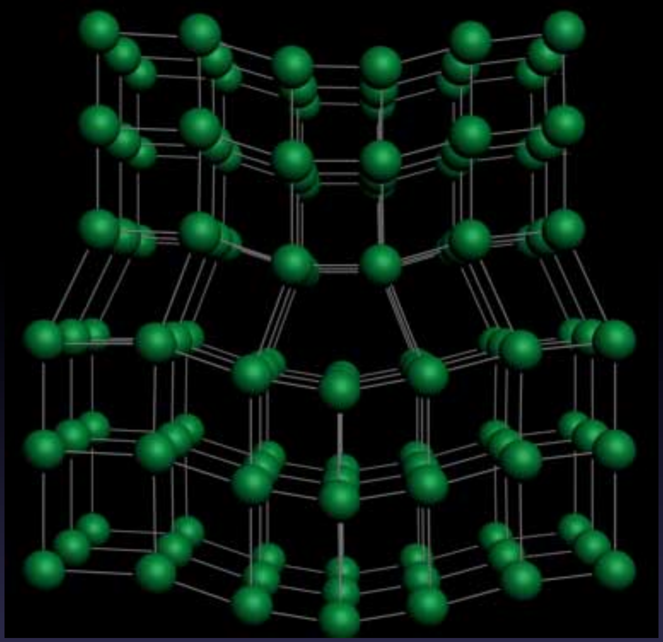




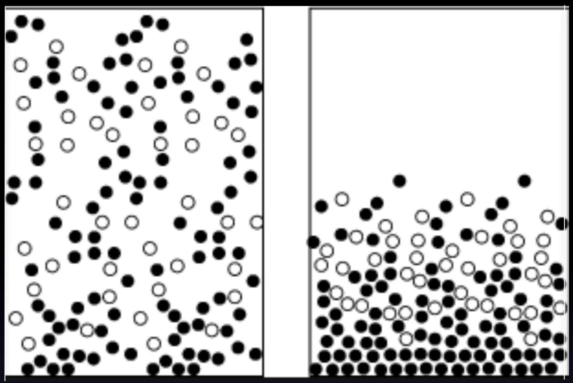
GRAVITY

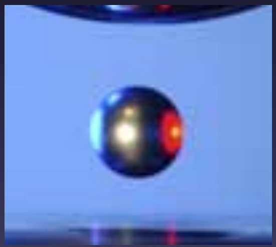


BENEFITS FOR MATERIAL SYSTEMS



- No solute buildup
- No sedimentation
- No convection

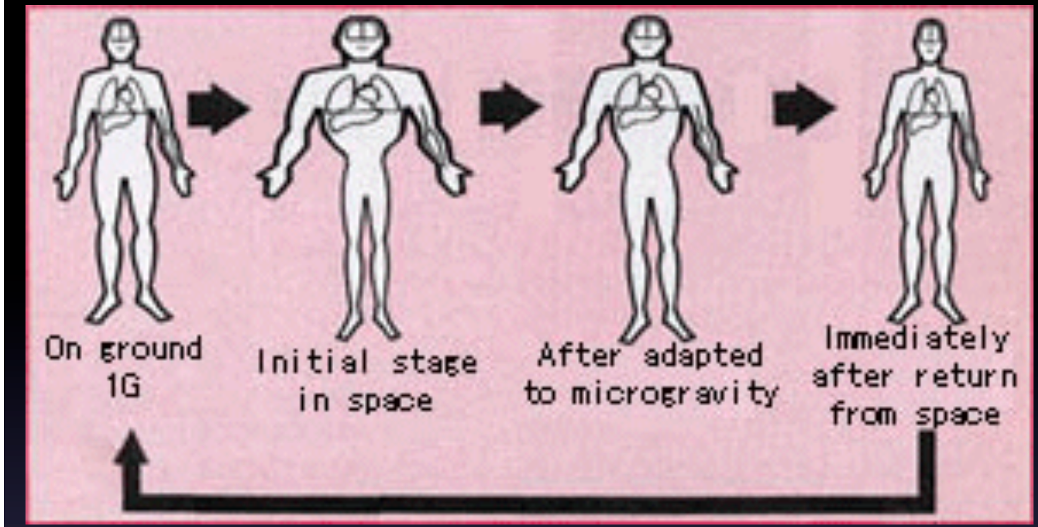




- Defect free
- Homogeneous
- Controlled, symmetric growth
- Avoidance of nucleation or single nucleation
- Higher resolution

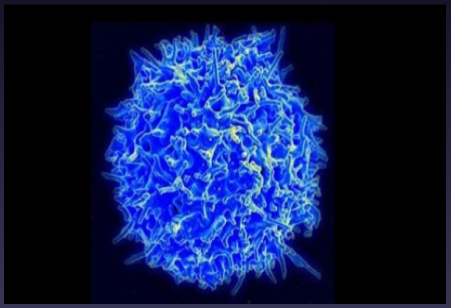
- Containerless processing
- Free suspensions
- Perfect spherical shape
- No wetting

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.

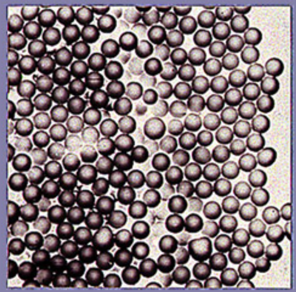
As biotech companies have found, novel environments offer novel biological responses useful for industry, medicine, and agriculture.

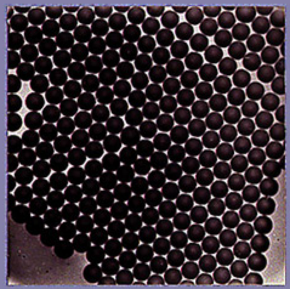
Microgravity Per Discipline

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			

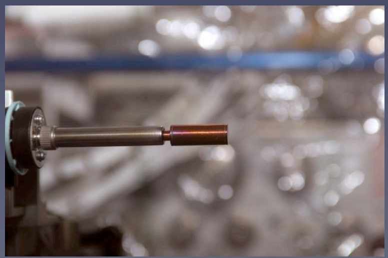
SUCCESSES: HIGH TRL EXAMPLES

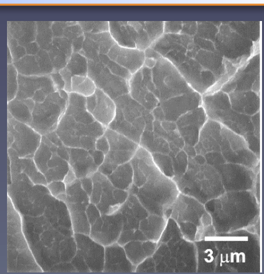
Despite relatively low funding, relatively few investigators, and great difficulties accessing space (compared with laboratory research on Earth), the success rate from microgravity R&D into applications is remarkably significant.



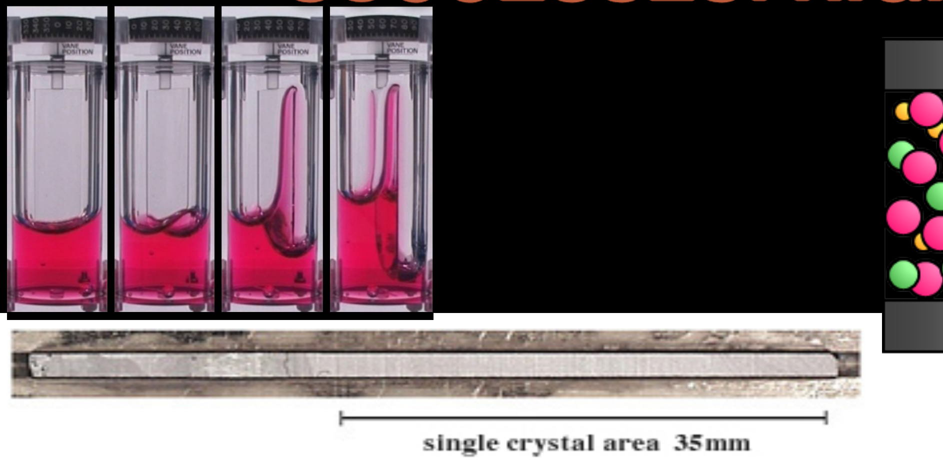


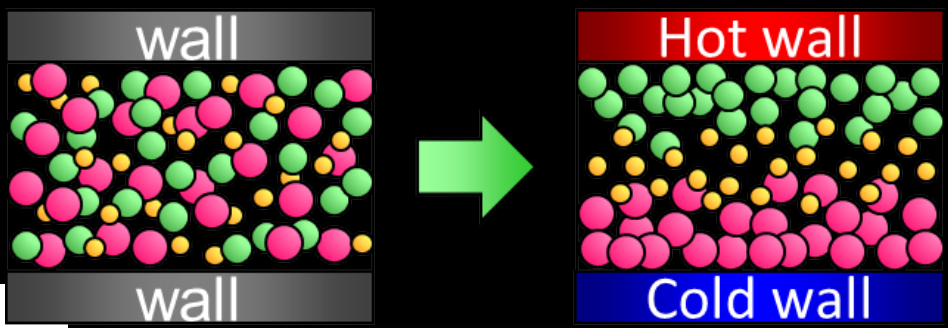
Experiment	Product	μg benefit
Space Beads	Polystyrene spheres 10 microns in diameter-calibration standard SRM 1965 for NBS	Superior product in terms of (1) sphericity (2) narrowness of size distribution (3) rigidity
Bulk Metallic Glasses	Hinges, sliders, frames, display frames, miniature camera case, 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 this material.





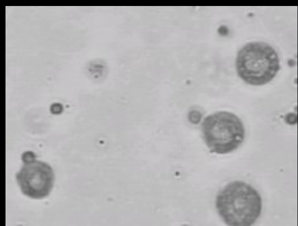
SUCCESSES: HIGH TRL EXAMPLES

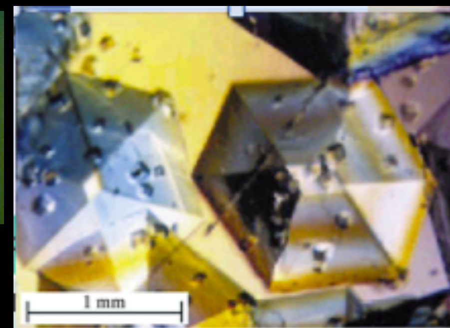


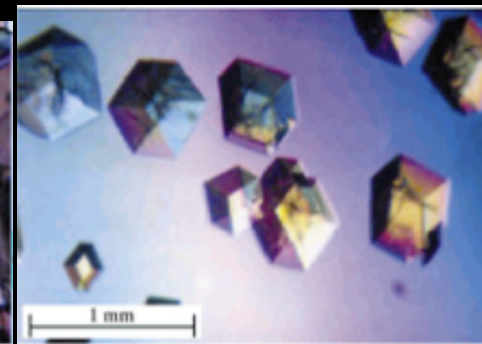


Experiment	Product	μg benefit
Semiconductor crystals	Fabrication of low noise field effect transistors (FET's), analog switch integrated circuits (LCS)	Microgravity-grown crystals have (1) increased single crystal size (2) suppressed impurities and defects (3) higher quality crystals
Thermal Diffusion 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, unique theoretical models.

SUCCESSES: HIGH TRL EXAMPLES

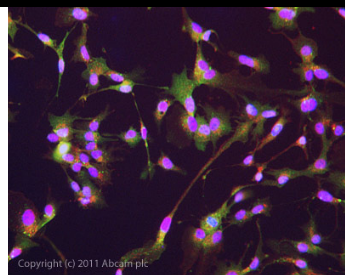


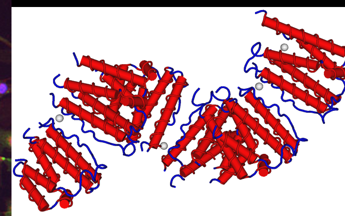


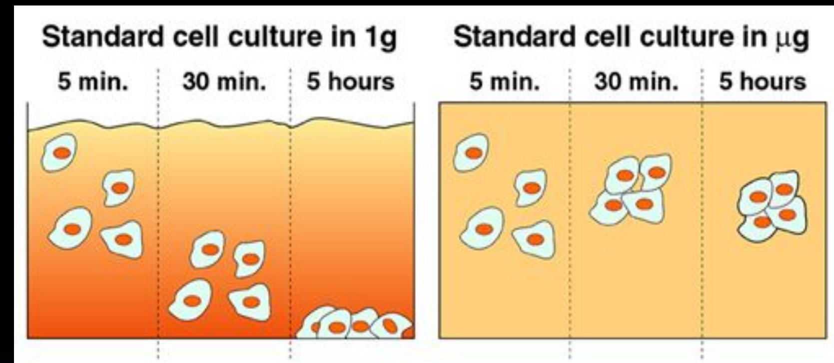


Experiment	Product(s)&Customers	μg benefit
Microencapsulation	Bright Mark line of tissue site marker for accurate tumor diagnostic devices Chemo-FDA approved drugs contained in microcapsules (clinical trials entered in 2012) for local (vs systemic) cancer chemotherapeutic treatment	Pharmaceutical drug 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].

SUCCESSES: HIGH TRL EXAMPLES







Experiment	Product(s)&Customers	µg benefit
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 tissue cultures (cancer, organ disease, diabetes, aging)	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: INTERMEDIATE TRL

Topic	Potential Application	μg Benefit
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
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 and chemical control
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 tactile displays in microelectronic devices	Understanding of mechanisms of formation and dissolution of structures for rapid and reversible change of rheological properties. Studies in microgravity offer a unique opportunity to interrogate the structural evolution, pattern formation and aggregation dynamic of dipolar suspensions.

NEXT GENERATION TECHNOLOGIES: LOW TRL

Topic	Potential Application	Hypothesized μg benefit
Hollow bearings	Load-bearing machines with moving parts, tribology	High sphericity, narrow size distribution, hollow; multimaterials, multilayered bearings; monolithic
3D DNA	DNA nanotechnology, DNA based computing	DNA self-assembly crystals to control inter-molecular contacts
Nanoclays	Polymer nanocomposites, 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.
Membrane proteins	Study of neural systems and diseases (Parkinson, Huntington, etc)	Crystallization of membrane proteins with high resolution and clarity for engineering better ground counterparts. Current crystals on ground do not diffract
Ultra thin coatings	Biocompatible coatings for implanted batteries, devices; Photovoltaic coatings; Manufacture of semiconductor components; Magnetic information storage systems; Photoresist microelectronics	In a gravitational field the gravitational force acts parallel to the flow thereby creating shear stresses in the film and introducing 3D instabilities (Waves, ribs, streaks) that interfere with the manufactured device performance. In microgravity the surface tension forces and viscous forces in the meniscus region would lead to smooth, uniform and highly accurate thin

THE MARKET AND BUSINESS DIMENSION

SINCE 1946

May 10, 1946 – first space research flight (cosmic radiation experim –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)

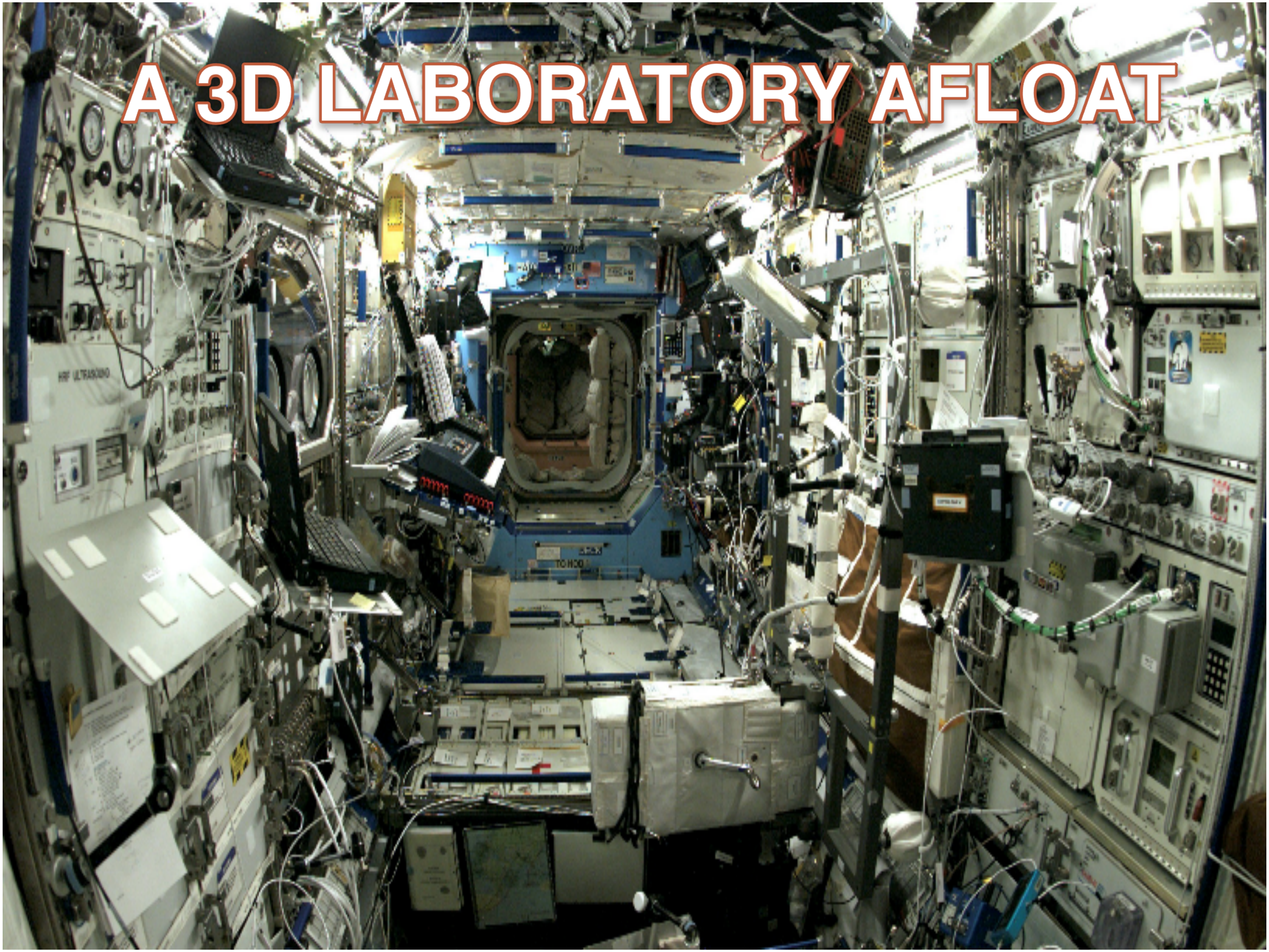
April 23, 1971 – first space station –USSR, Salyut 1

February 19, 1986 –first inhabited long-term research space station -U

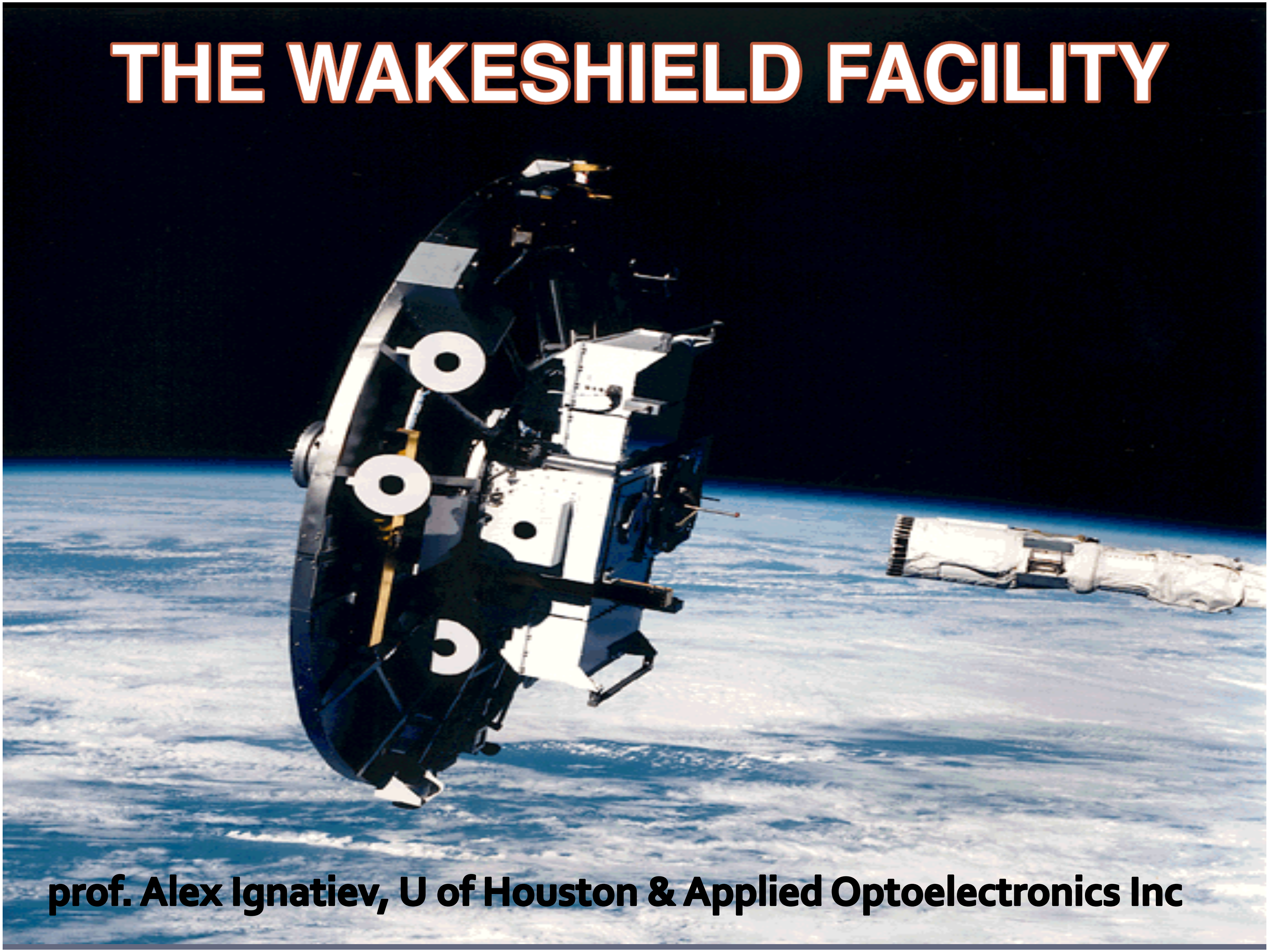
November 20, 1998 - first multinational space station (ISS)

Largest man-made object built in space to date (Russia, USA, Europe,

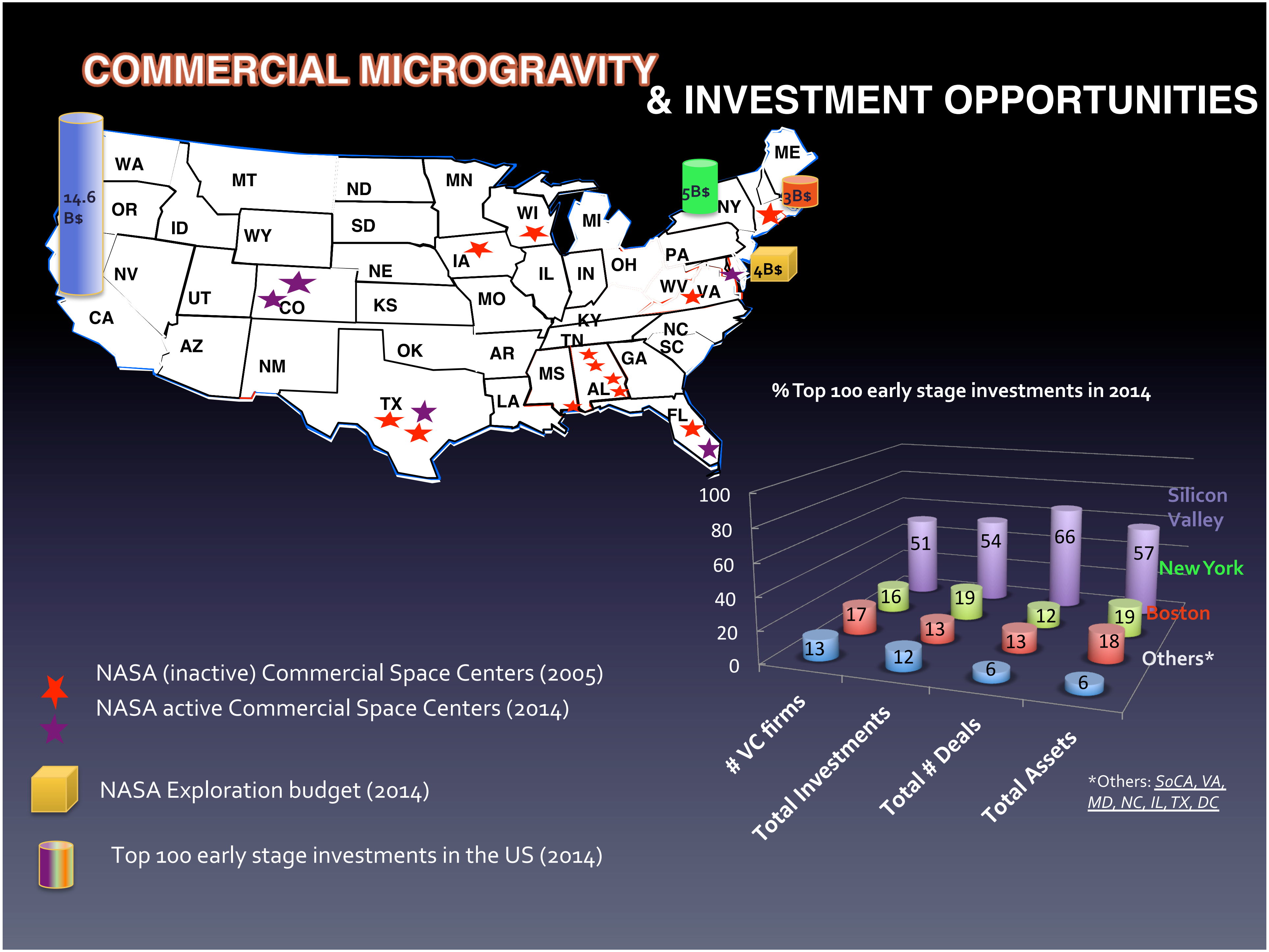
Canada)


A 3D LABORATORY AFLOAT

THE WAKESHIELD FACILITY



prof. Alex Ignatiev, U of Houston & Applied Optoelectronics Inc


COMMERCIAL MICROGRAVITY
& INVESTMENT OPPORTUNITIES
WA
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OH
KY
TN
MS
AL
GA
FL
NC
SC
WV
VA
PA
NY
ME
14.6 B$
5B$
3B$
4B$
% Top 100 early stage investments in 2014
100
80
60
40
20
0
Silicon Valley
New York
Boston
Others*
51
54
66
57
16
19
12
19
17
13
13
18
13
12
6
6
VC firms
Total Investments
Total # Deals
Total Assets
*Others: SoCA, VA, MD, NC, IL, TX, DC
NASA (inactive) Commercial Space Centers (2005)
NASA active Commercial Space Centers (2014)
NASA Exploration budget (2014)
Top 100 early stage investments in the US (2014)


$/kg to LEO
≥ $30,000
~ $5,000
≤ $1,500
Frequency
1-2/year
~3-6/year
≤monthly
Orbital
Suborbital
Parabolic
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
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1990-2010
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2015-2020
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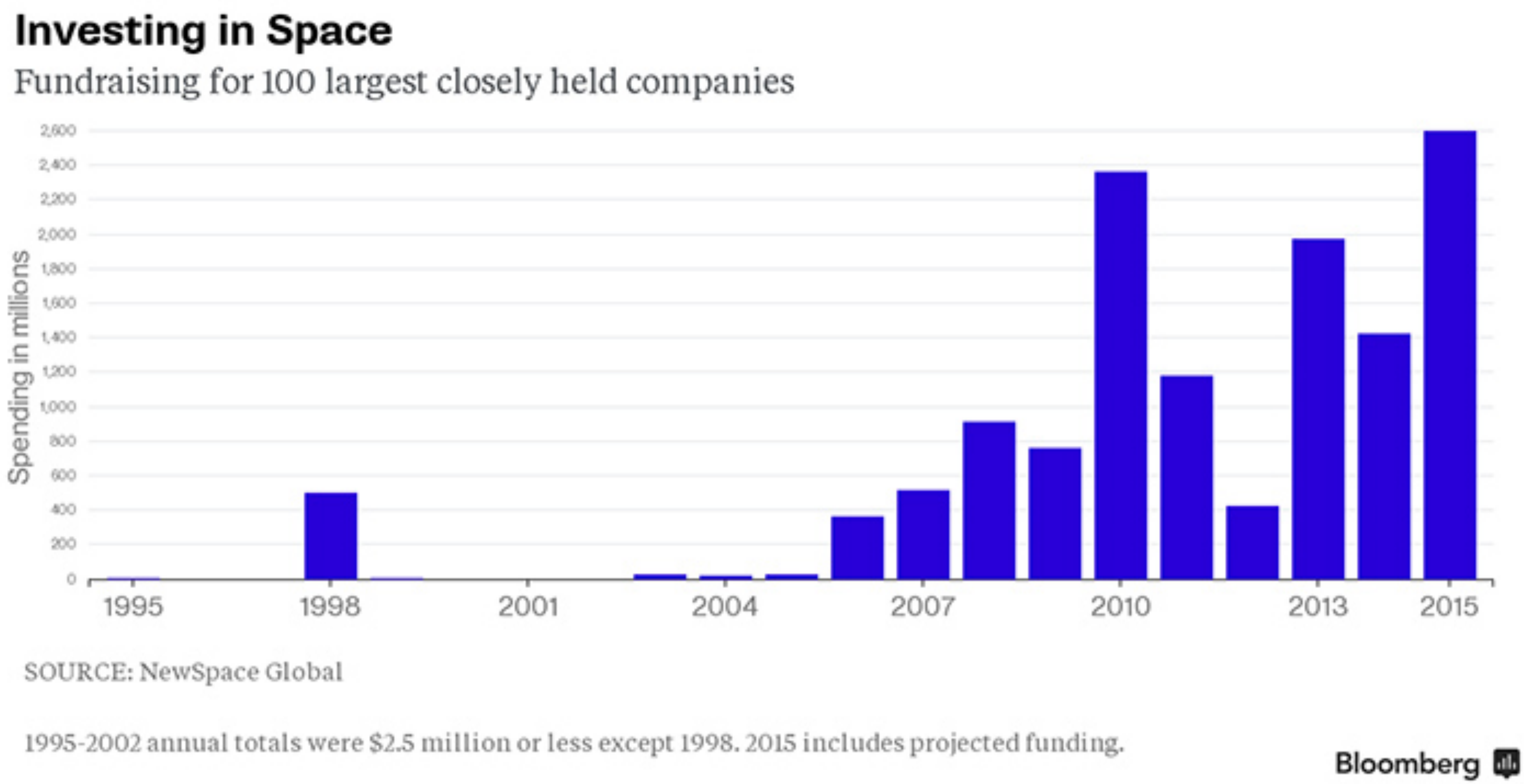
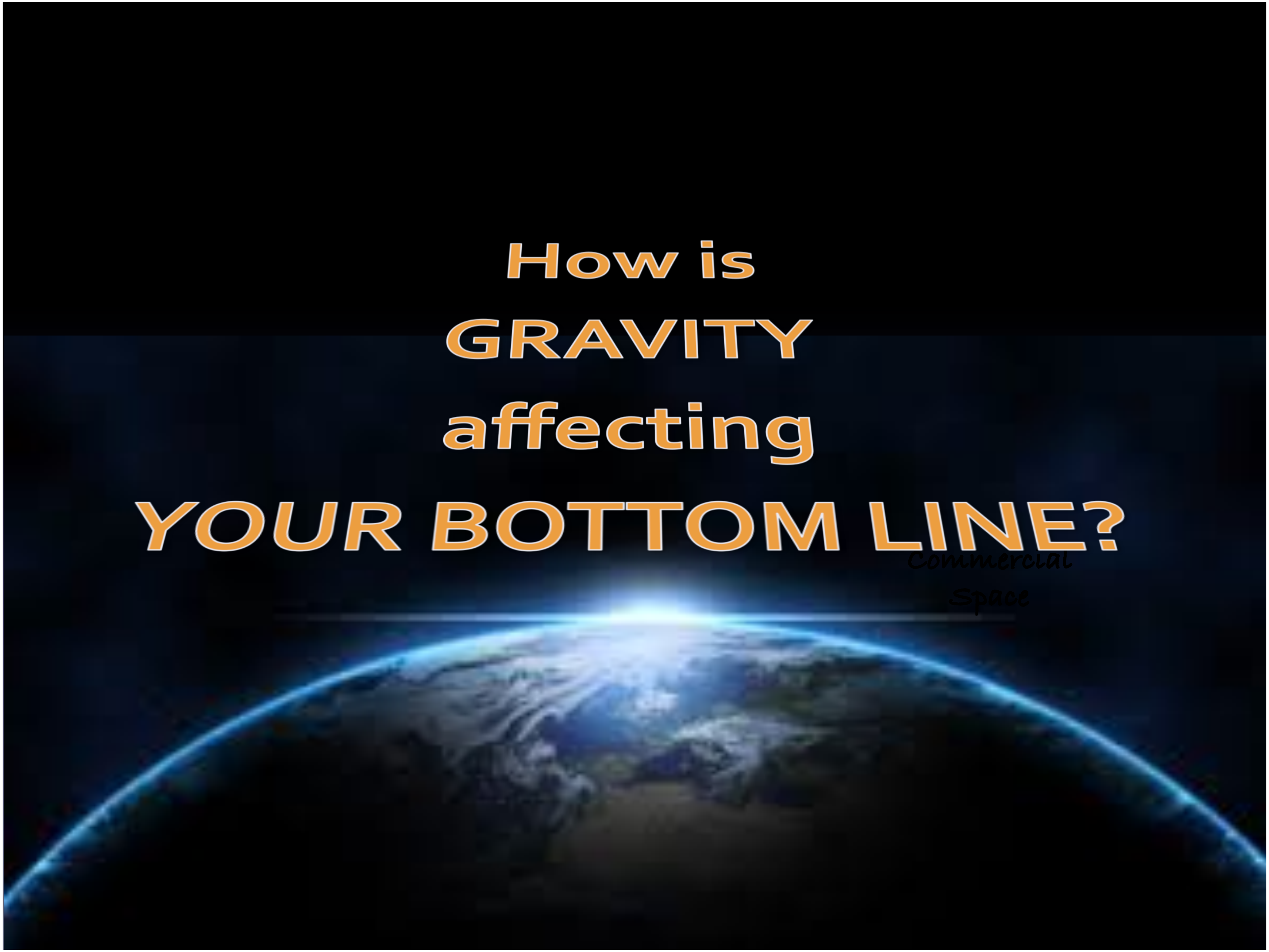
26



Investing in Space
Fundraising for 100 largest closely held companies
Spending in millions
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1995
1998
2001
2004
2007
2010
2013
2015
SOURCE: NewSpace Global
1995-2002 annual totals were $2.5 million or less except 1998. 2015 includes projected funding.
Bloomberg


How is
GRAVITY
affecting
YOUR BOTTOM LINE?
Commercial
Space

Verticals of Microgravity

Future

New Materials | Computers& Communications | Biotech | Medical Devices | Medical Applications | Consumer products

Existing

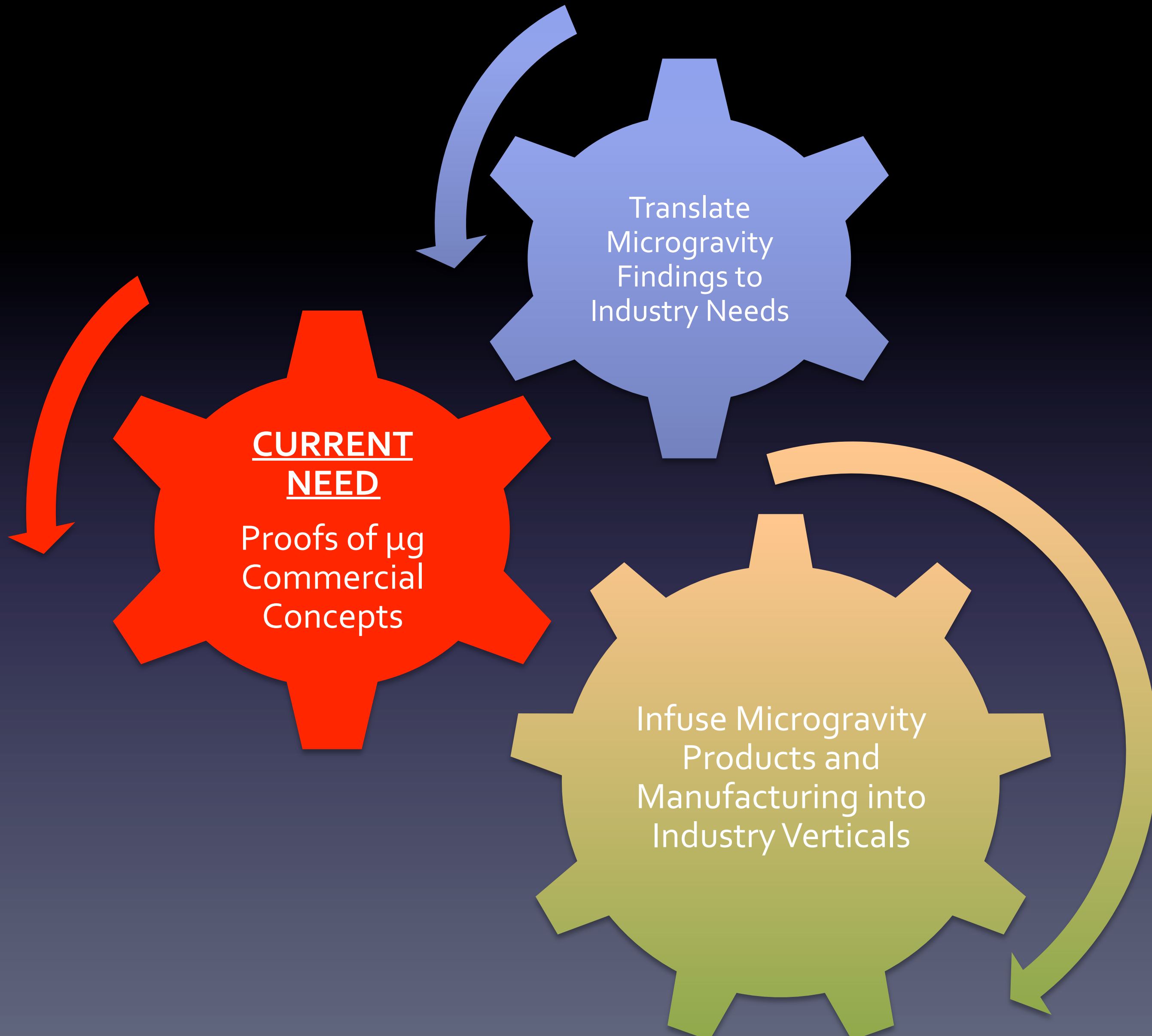
1st Vertical | 2nd Vertical | 3rd Vertical | 4th Vertical | 5th Vertical | 6th Vertical

Developed to capture in a compressed manner a mix of very diverse values (knowledge, processing) of the microgravity environment and companies who self identified to mature those technologies for commercial applications

ECONOMIC READINESS ASSESSMENT

- *Combines technology readiness, market need and investment risk*
- *Bridges between supply, demand and capital in a systematic, standardized manner.*
- *<u>To advance on a Economic Readiness Level the technology itself may not necessarily need to mature but the understanding of its economic potential does.</u>*
- *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

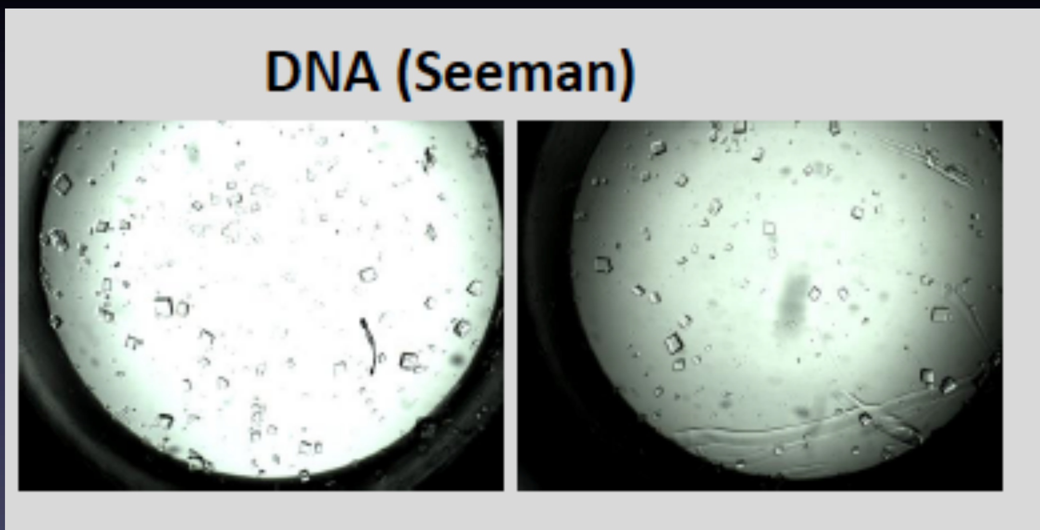


RETURNING THE VALUE OF MICROGRAVITY TO EARTH

- NEW INSIGHTS into systems behavior and response to variations in their environment to identify new final states. Knowledge captured in Earth Orbit. Technology developed on ground able to mimic the new system state.
- PROCESSING/REPROCESSING IN SPACE of products manufactured on Earth for improvements in properties and performance through a processing cycle in space
- MANUFACTURING AND ASSEMBLY IN SPACE of a product built in the reduced gravity usually from its component elements.

NEW INSIGHTS: STRUCTURAL DNA NANOTECHNOLOGY

More than 30 years ago Prof. Ned Seeman, NYU founded the field of Structural DNA Nanotechnology. This area of chemistry uses the information inherent in DNA for structural purposes. Central to this effort are branched DNA molecules.



Cohesive ends allow DNA to assemble to produce polyhedra and nanotubes.

3D lattices – studied by x-ray crystallography

It is important to have high resolution crystals to understand and confirm where the branched DNA molecules connect.

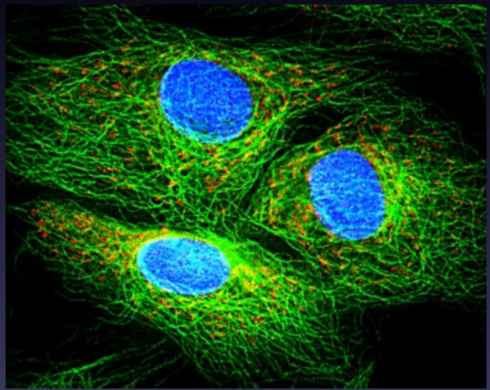
Vapor diffusion method, 4 degC
Original Load: April 12, 2014
Reload on April 16 for a launch on April 18, 2014
(samples undergoneundezired freeze –thaw cycle)
Experiment activation: April 21

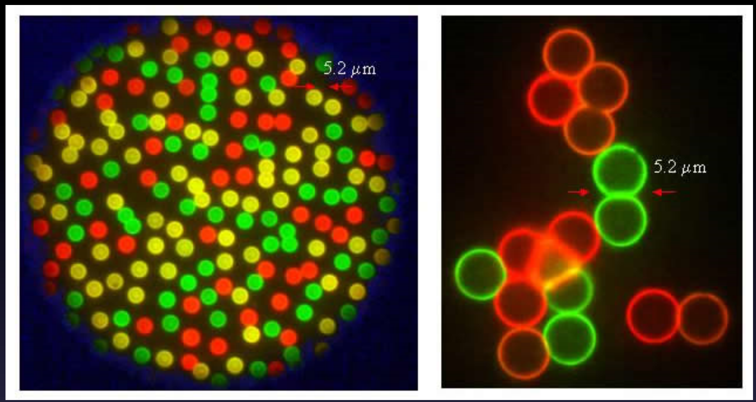
Applications: DNA- based computation, self-replicating systems, nanomechanical devices, etc

NEW INSIGHTS: Assembly of quantum dots

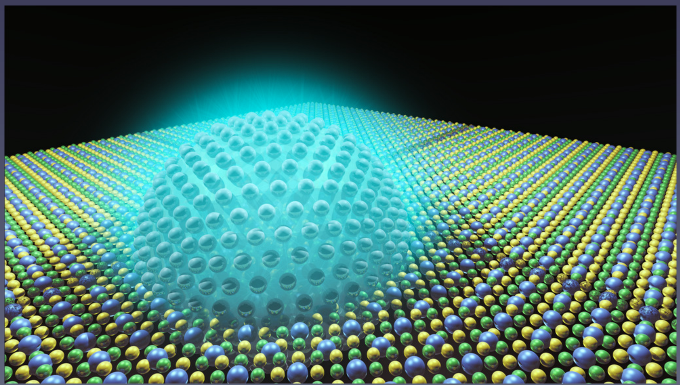
Quantum dots = nanoscale semiconductor devices that tightly confine electrons or electron holes in all three spatial dimensions

APPLICATIONS:
Quantum computers
Breast cancer detection (replacement of traditional dyes)





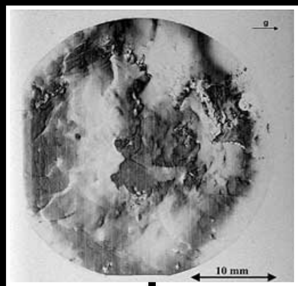
CHALLENGE: coupling quantum dots to optical structures is difficult because they have random positions and sizes/shapes which results in inhomogeneous broadening (each QD has different transitions). Highest quality solid state quantum emitters are InAs QD in GaAs



MICROGRAVITY could help by growing QDs with smaller inhomogeneous broadening (more regular shapes&sizes)

SiC wafer μg re-processing

sermo minor, operor magis”



SiC (class of compound semiconductors) ISSUE:
defects limiting performance, reliability, fab of large scale devices

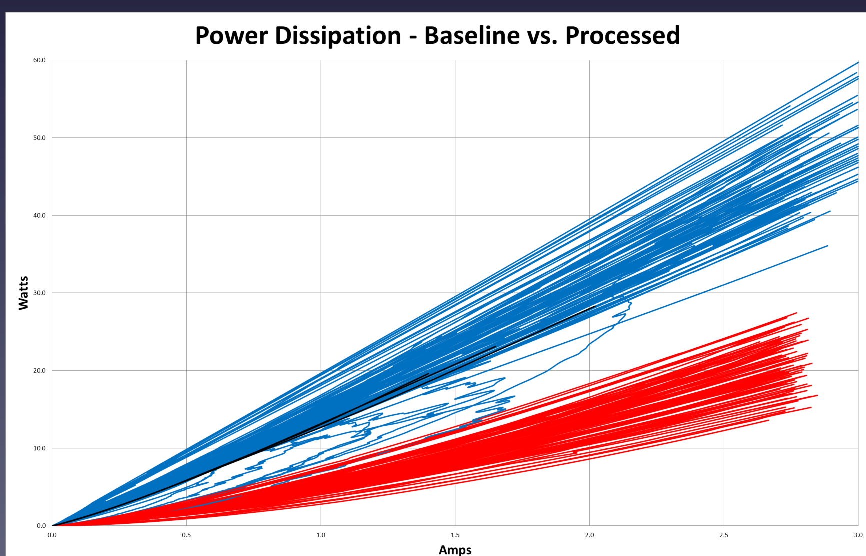
ACME μg re-processing

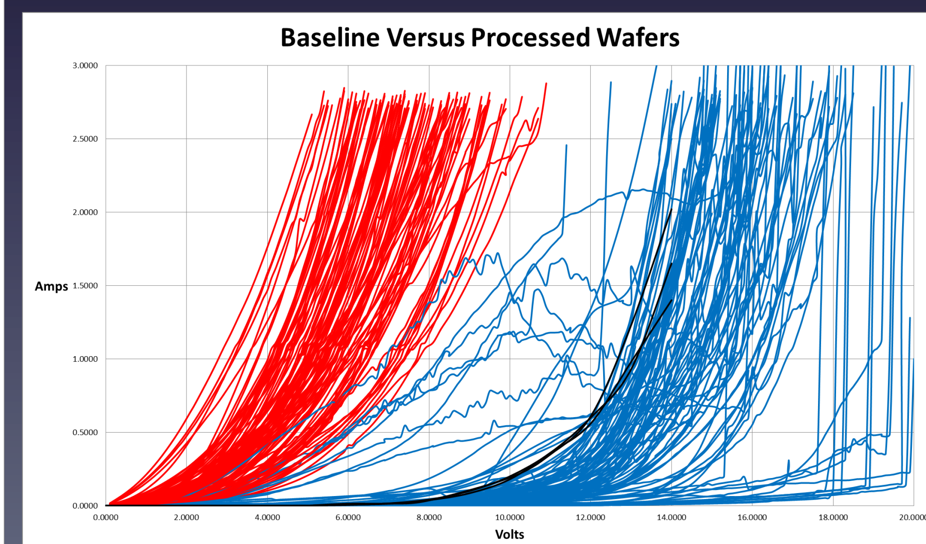
Microgravity “heals” defects important to the electrical performance of these wafers – HOW?

Hypothesis: Grains rearrangement leading to “cleaner” XRD spectra

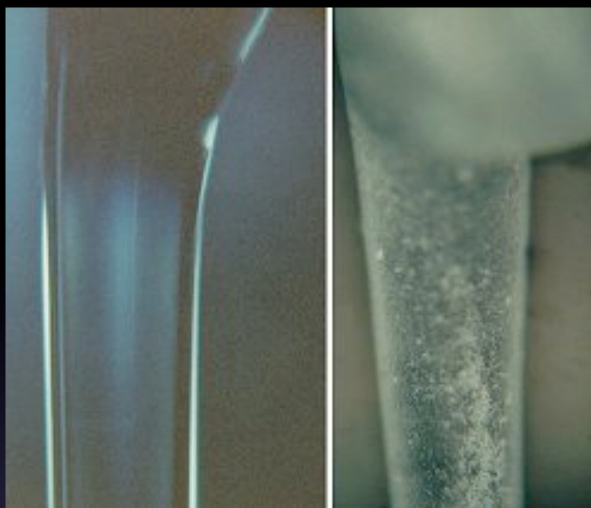
Independent validation- working with Stanford Xlab

Recommended a Shake and Bake at Ames





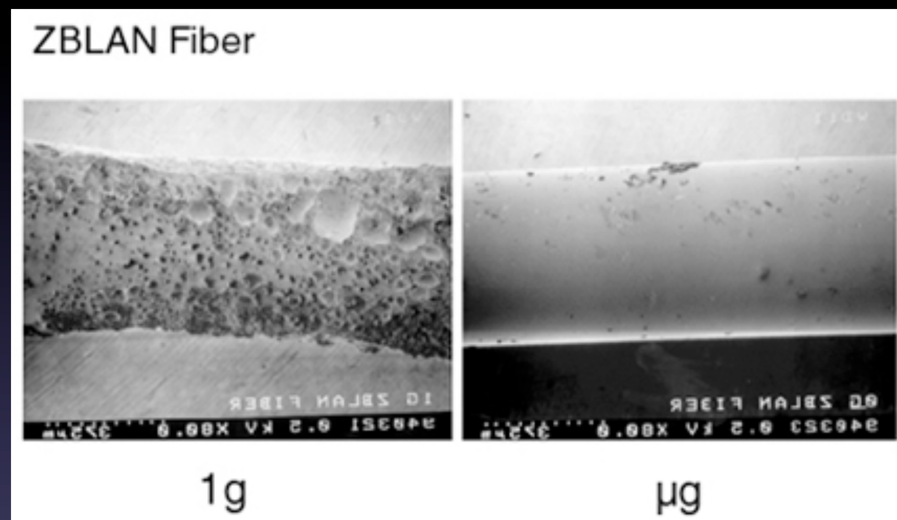
REPROCESSING IN SPACE : EXOTIC OPTICAL FIBERS



µg 1 g

(left) Defect free ZBLAN fiber pulled during a low-g arc aboard the KC-135 (right) a crystallized fiber pulled from the same apparatus under 1-g

EARTH pulled fibers: gravity causes convection and mixing in a melt leading to reduced viscosity which then increases crystallization before glass can form



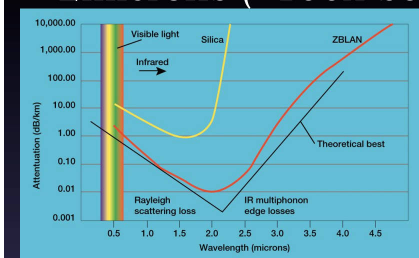
MICROGRAVITY REPROCESSING benefit:

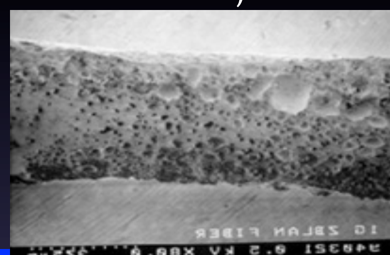
- improved clarity
- reduced signal attenuation (a factor of x200-2000 better than current Si-based fibers)
- wide spectral band optical transmission
- expansion of detection range from UV to IR
- enables manufacturing of hollow fibers; doping

EXOTIC OPTICAL FIBERS

WHY ZBLAN-ZrF_4-BaF_2-LaF_3-AlF_3-NaF

- Most stable fluoride exotic glass and excellent host for doping
- Broad optical transmission window extending from 0.3 microns UV to 7 microns IR
- Theoretical loss for ZBLAN is 0.001dB/km at 2microns (~100x better than Si fibers)





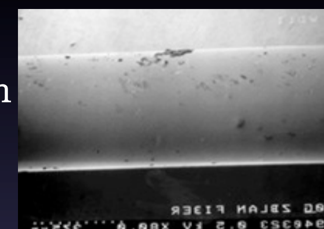
MICROGRAVITY BENEFIT

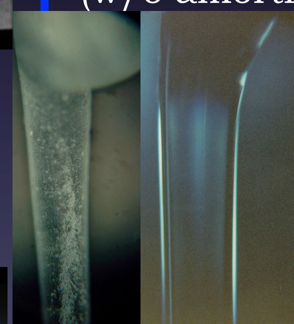
- Microgravity suppresses the effect of nucleation and crystallization –directly underlying attenuation-broadband properties
- No limit to the length that can be produced in space without need to adjust payload size
- 1lb of preform would produce 8 km ZBLAN fiber
- Nominal selling price range on

Earth: $175k/km to $1,000k/km

~ROI: 90-300x

(w/o amortization costs)



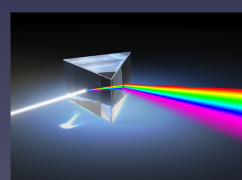


APPLICATIONS

Image fiber bundle

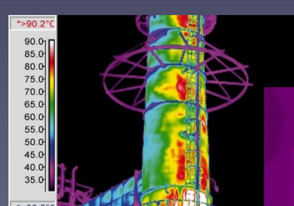
Medical applications

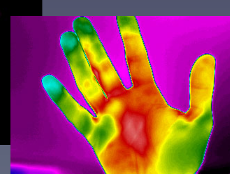
mote sensing



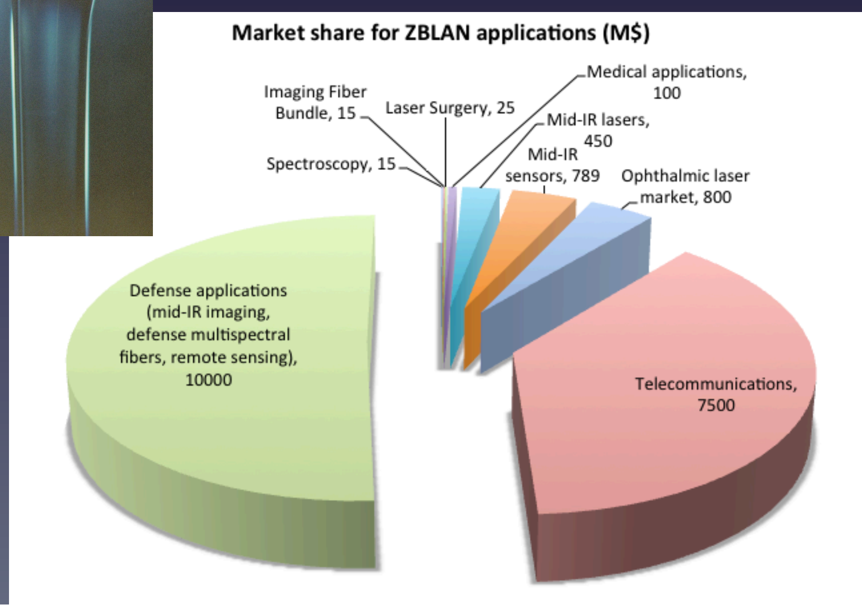
Laser spectroscopy

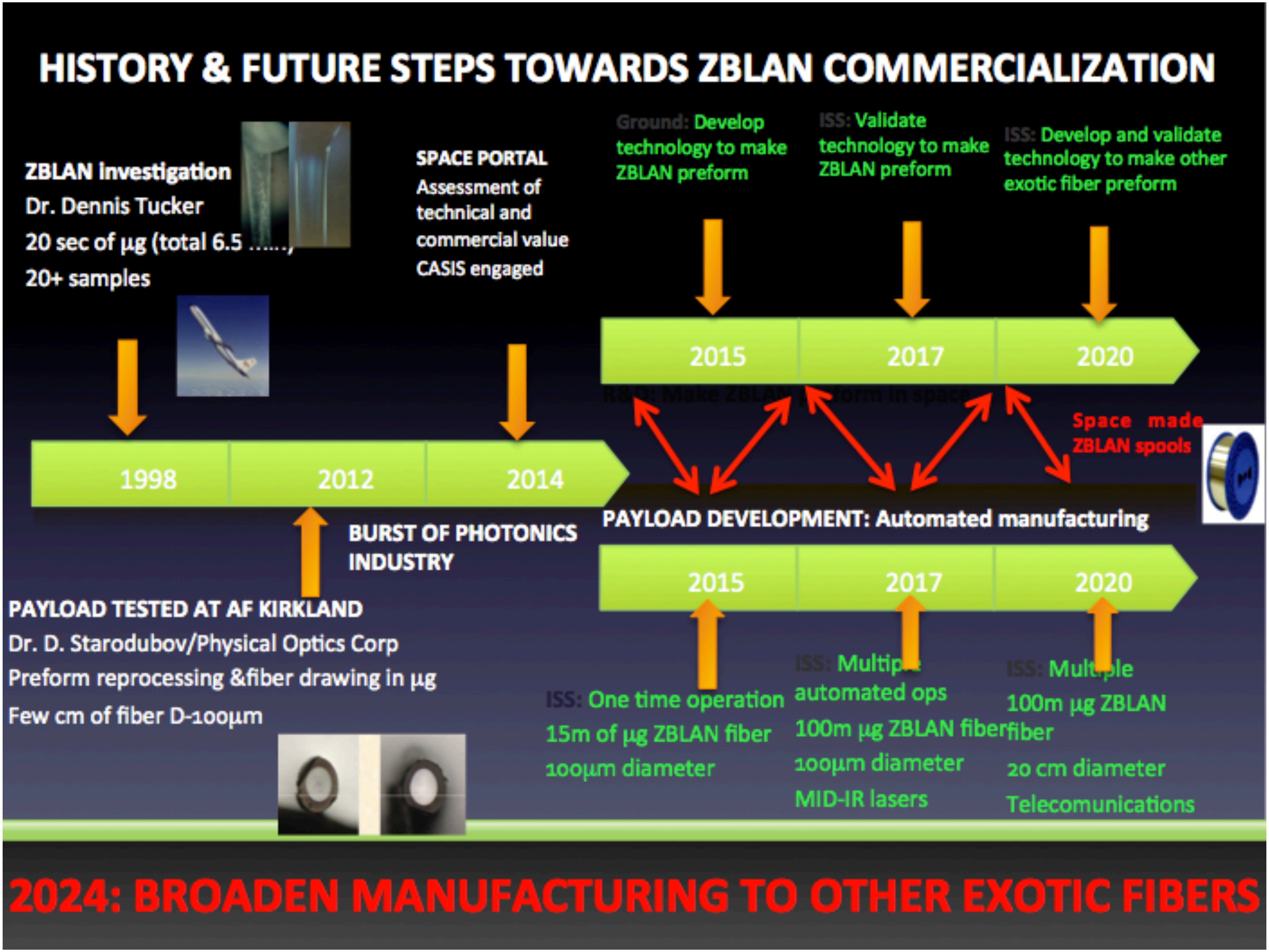
Mid-IR lasers



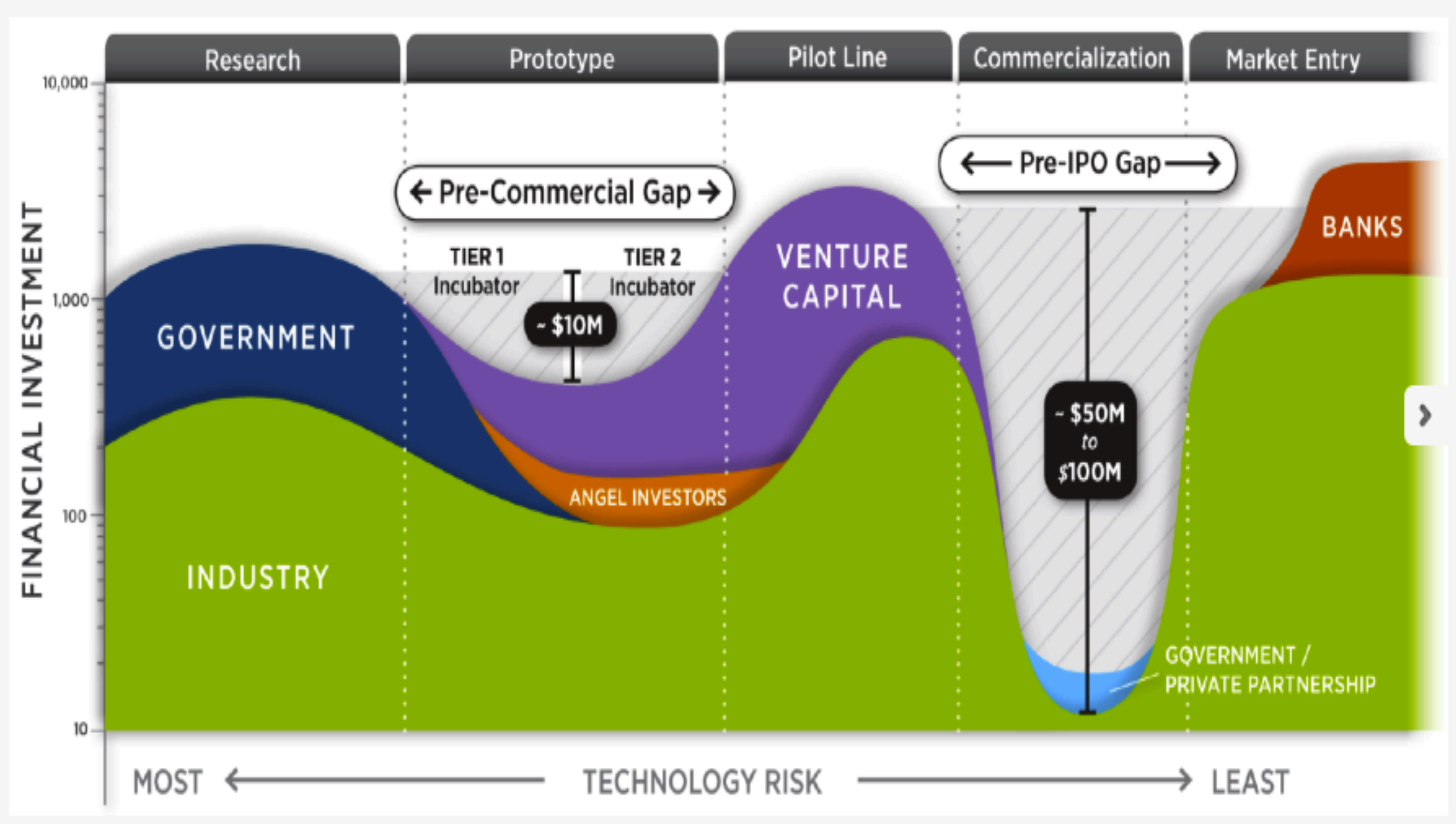


Thermal imaging




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
R&D: Make ZBLAN preform in space
Space made ZBLAN spools
1998
2012
2014
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

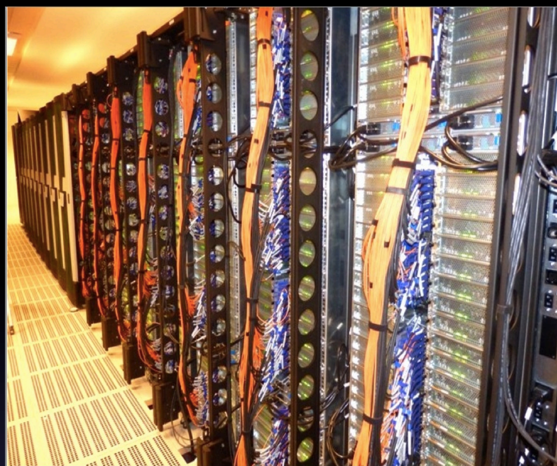
Financial Investment vs Technology Risk

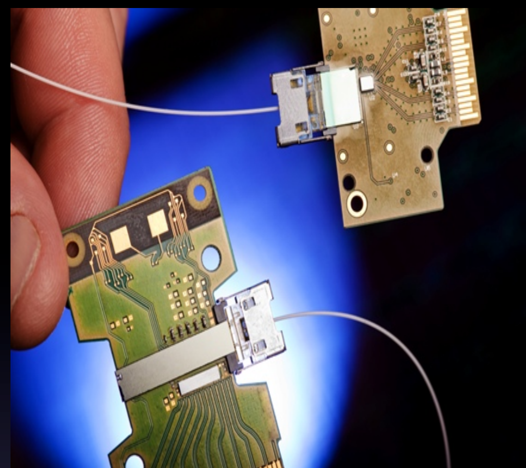


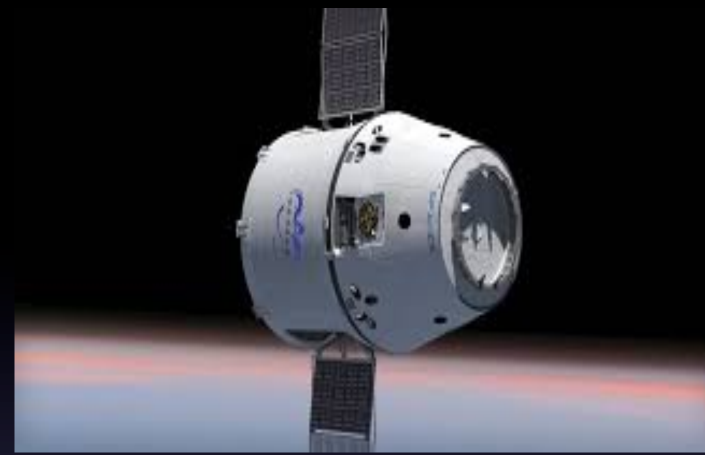
DOE – Sunshot Initiative- Technology to market program

To involve VC's and the private sector to get involved in the space sector one needs to understand the financial landscape. They usually do not take high risk R&D

SOLAR POWER DATA CENTERS







CREATING A CONSTANT PULL FOR MICROGRAVITY DRIVEN DISCOVERIES BY INITIATING PROJECTS OF CURRENT RELEVANCE

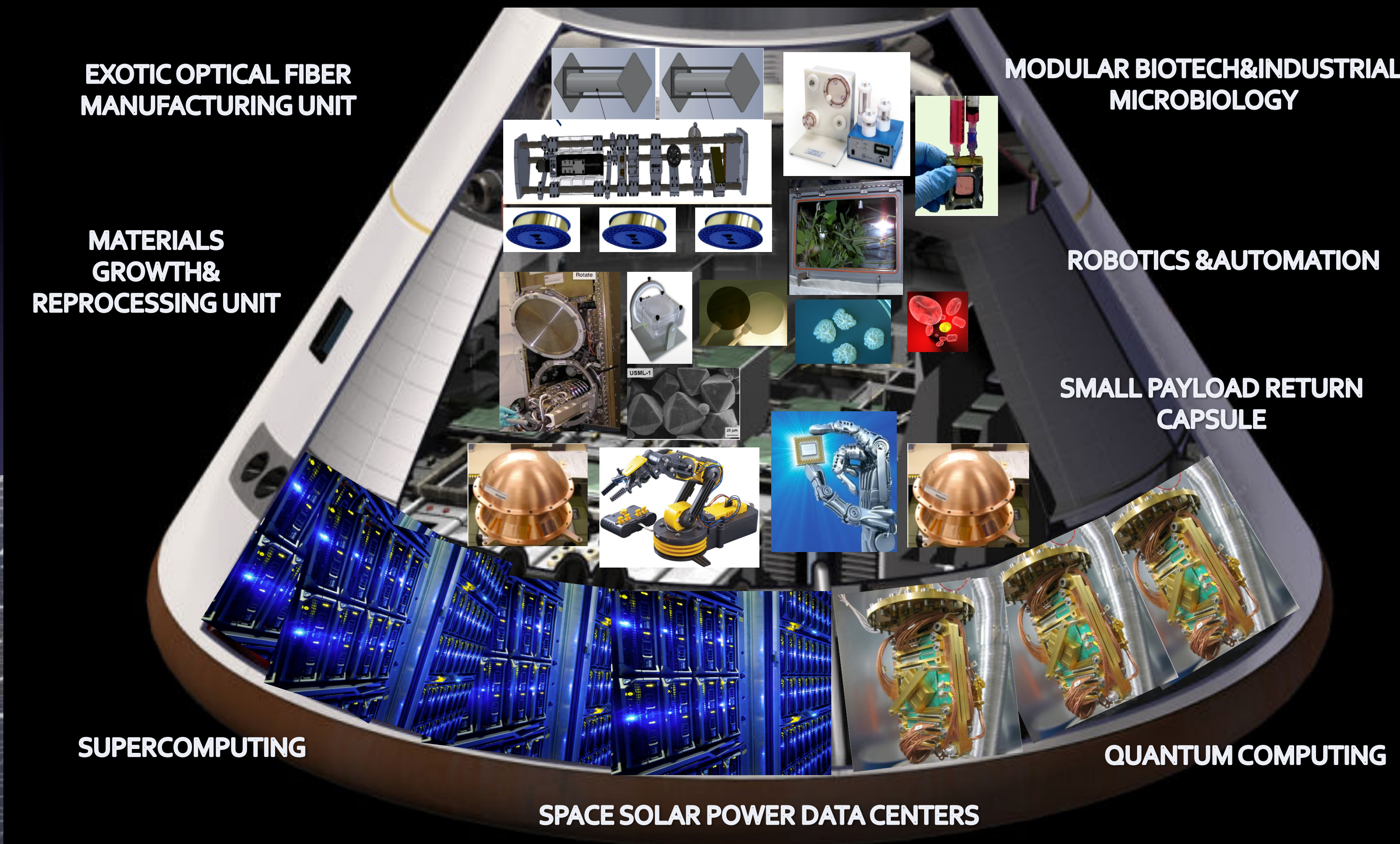
April 2014

- The biggest challenge for supercomputers is cooling and SGI is exploring benefits of immersion in "unusual" environments
- Space offers two advantage: infinite energy and infinite cooling
- SGI is interested in flying a supercomputer in space and assessing its operational performance in an unshielded environment to demonstrate ability to support high processing demands of current and future needs in LEO.
- SGI is the provider of the supercomputing hardware using Intel Silicon Photonics next generation technology to link the CPU's.
- **Concept currently in the works through ISS Technology Demonstrations through Mr. Sam Scimemi**
- **CASIS has also selected (October 2015) "Business Integra" for technology development showcase**

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



POC: IOANA.COZMUTA@NASA.GOV

Space Portal at the NASA Research Park

A LOOK INTO A POSSIBLE PRODUCTION DAY IN ORBIT…

SLAVA OSIPOV, PhD & MICHAEL KHASIN, PhD

Applied Physics Group

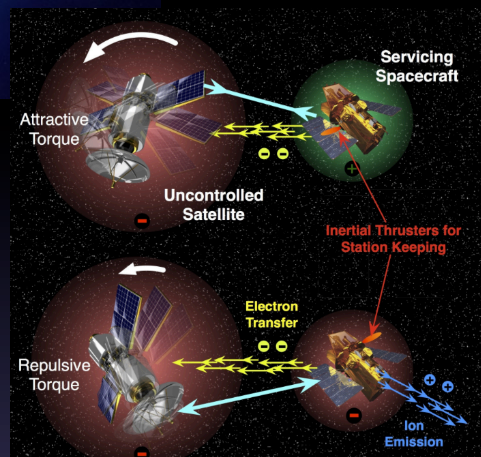
NASA Ames Research Center

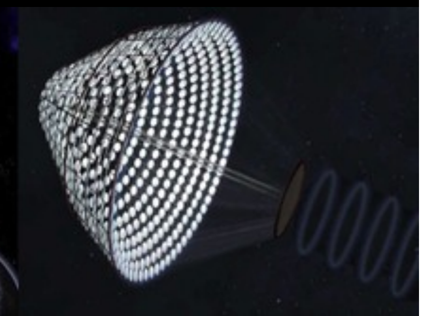
IOANA COZMUTA, PhD

Space Portal

NASA Ames Research Center

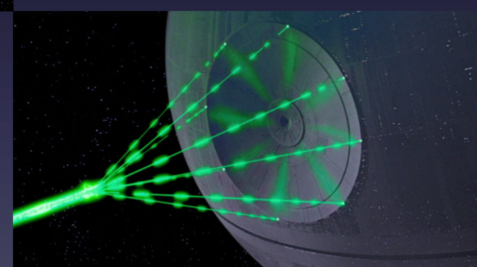
Space Portal at the NASA Research Park





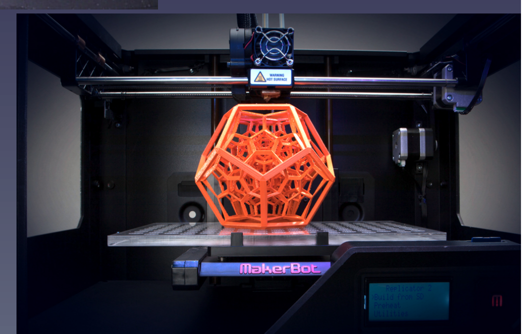
Orbital Debris as
In Situ resource

De-spinning and storage*

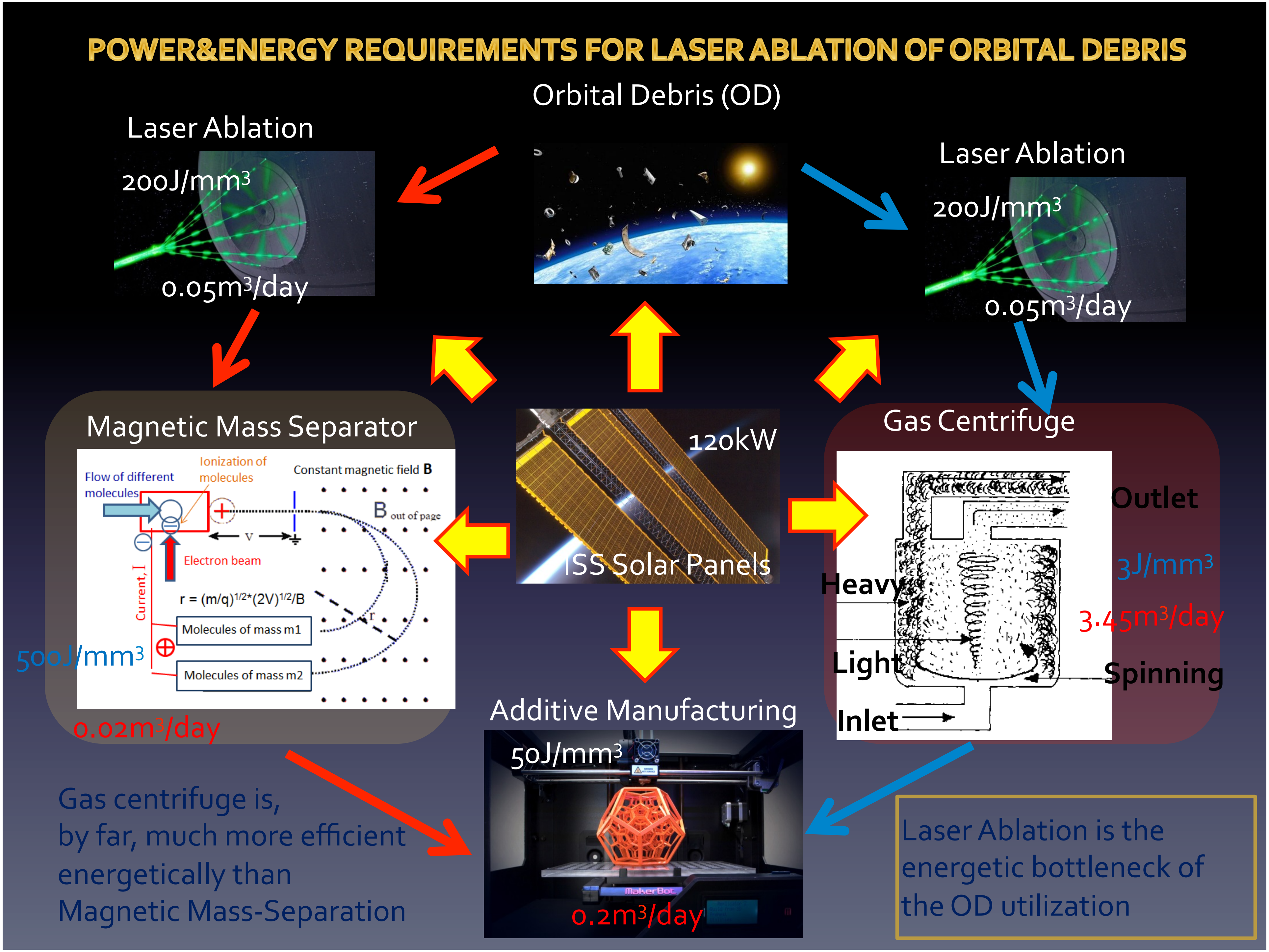


Laser Ablation&
Elemental Separation

3D printing/Additive
Manufacturing**



*U of Colorado
**Made in Space



POWER&ENERGY REQUIREMENTS FOR LASER ABLATION OF ORBITAL DEBRIS
Orbital Debris (OD)
Laser Ablation
200J/mm3
0.05m3/day
Laser Ablation
200J/mm3
0.05m3/day
Magnetic Mass Separator
Flow of different molecules
Ionization of molecules
Constant magnetic field B
B out of page
Electron beam
Current, I
r = (m/q)1/2*(2V)1/2/B
Molecules of mass m1
Molecules of mass m2
500J/mm3
0.02m3/day
120kW
ISS Solar Panels
Gas Centrifuge
Outlet
Heavy
Light
Inlet
Spinning
3J/mm3
3.45m3/day
Additive Manufacturing
50J/mm3
0.2m3/day
Gas centrifuge is, by far, much more efficient energetically than Magnetic Mass-Separation
Laser Ablation is the energetic bottleneck of the OD utilization

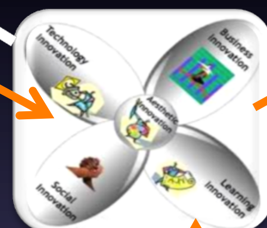
COMMERCIAL MICROGRAVITY LEO BASED PRODUCT CYCLE

ISS

Transfer and scale advanced microgravity based technologies to LEO manufacturing

Identify and start new lines of R&D investigations

ERL 1



INNOVATION VORTEX

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

ERL 6

Attract, build trust, sell, develop icrogravity brand loyalty, and uild a rich relation so that ustomers will rally for the new rand

VERTICALS OF MICROGRAVITY

Space Portal at the NASA Research Park

On Orbit manufacturing-

from orbital factories to in-situ resource utilization

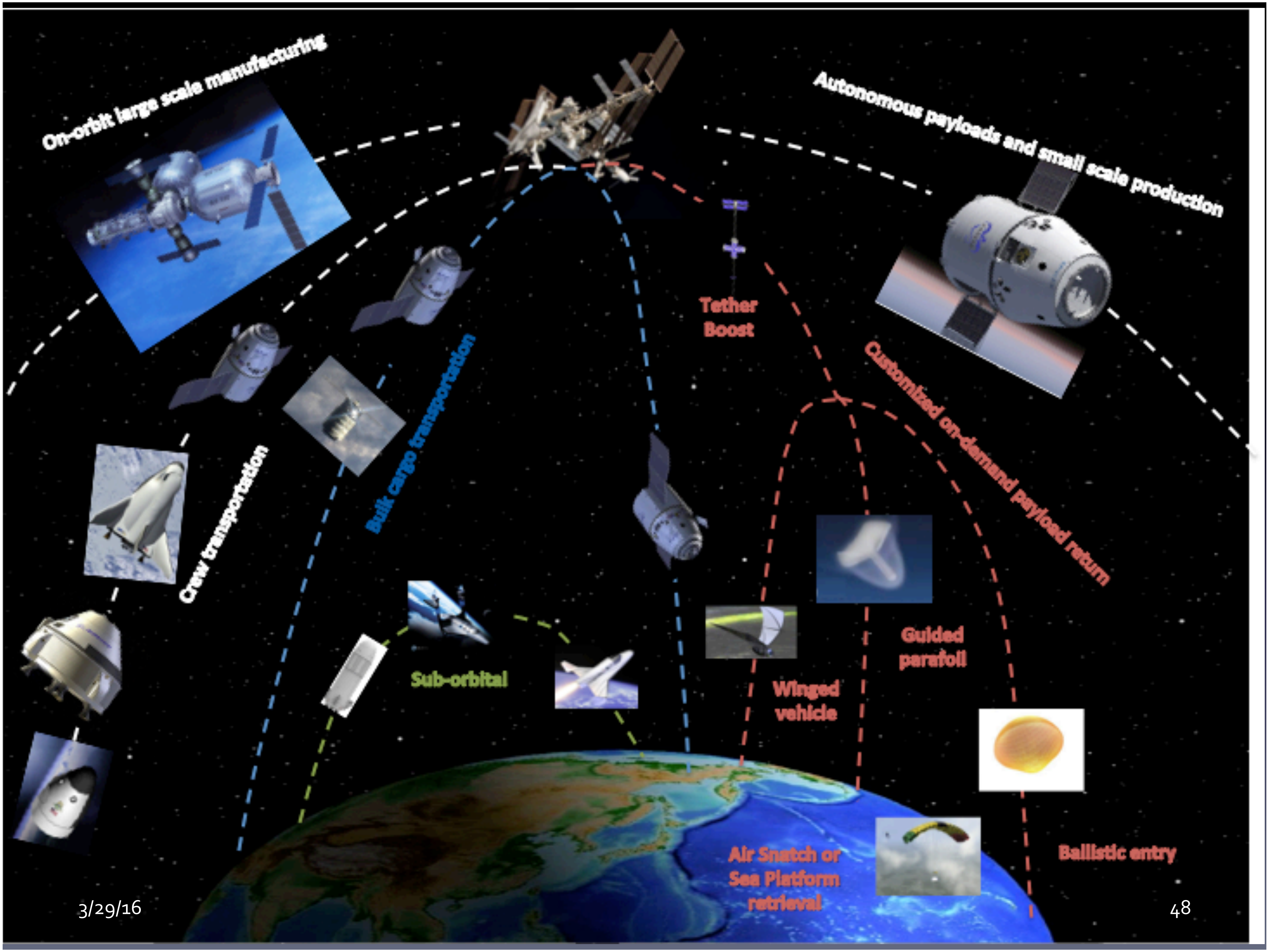
Recording at:
https://attendee.gotowebinar.com/register/5666583135043371522

ON-ORBIT MANUFACTURING

Position your company to be a frontrunner in on-orbit manufacturing with this complimentary webinar

Tuesday, March 1, 2016 | 1:00 - 2:30pm Eastern | Free

THE ECONOMIC AND POLICY DIMENSION


On-orbit large scale manufacturing
Autonomous payloads and small scale production
Crew transportation
Bulk cargo transportation
Tether Boost
Customized on-demand payload return
Sub-orbital
Guided parafoil
Winged vehicle
Ballistic entry
Air Snatch or Sea Platform retrieval

THE PILLARS OF A ROBUST ECONOMY

- *Economy:* term referring to the set of interrelated production and consumption activities relying on a careful management of available resources (usually ties to a territory ownership)

- *Sustainability* ties to the ability of an economy to be long term profitable, i.e. contributing to a steady growth of GDP per capita

- *LEO economy*
  - Need of a top-down approach to set in place building blocks
  - Decentralized concept? Currency/transactions options? (solarcoins?)
  - Mechanisms for LEO economy to add value to current GDP

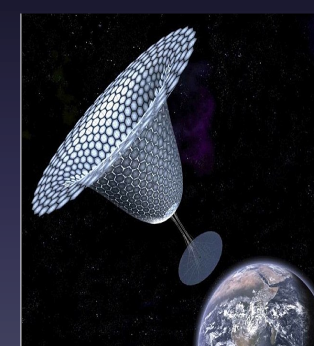
DEVELOPMENT&IMPLEMENTATION OF AN ECONOMIC CRITERIA FOR SELECTION OF MATURING TECHNOLOGIGIES

WHY SPACE?

- Challenge for survival
  - **Innovative technologies**

- Opportunity for **International Cooperation**

- Severe mass limitations
  - **miniaturization**



- Extreme environment:
  - **Infinite cold**
  - **Vacuum**
- **High performance materials**
- **“Infinite”** solar power
- **Radiation**
- **Sustainable, green manufacturing**

Dimensions of a Space Economy

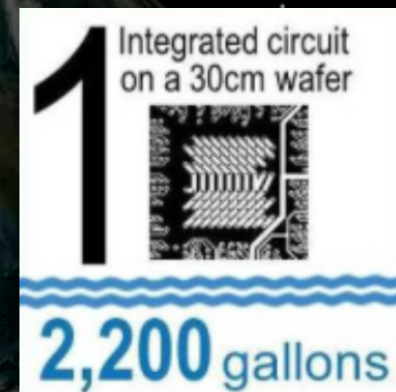
BE RESPONSIVE
BE LONG TERM RESPONSIBLE

Technology often begins with a near-term, and often shortsighted response to a human need or want, and while it addresses the immediate need, often causes long-term consequences that are deleterious.

BE CREDIBLE
BE RELIABLE
BE PROFITABLE

OBEY THE LAW
BE ETHICAL: DO WHAT IS RIGHT, JUST AND FAIR
IMPROVE THE QUALITY OF LIFE

On Orbit Manufacturing for a Green Planet

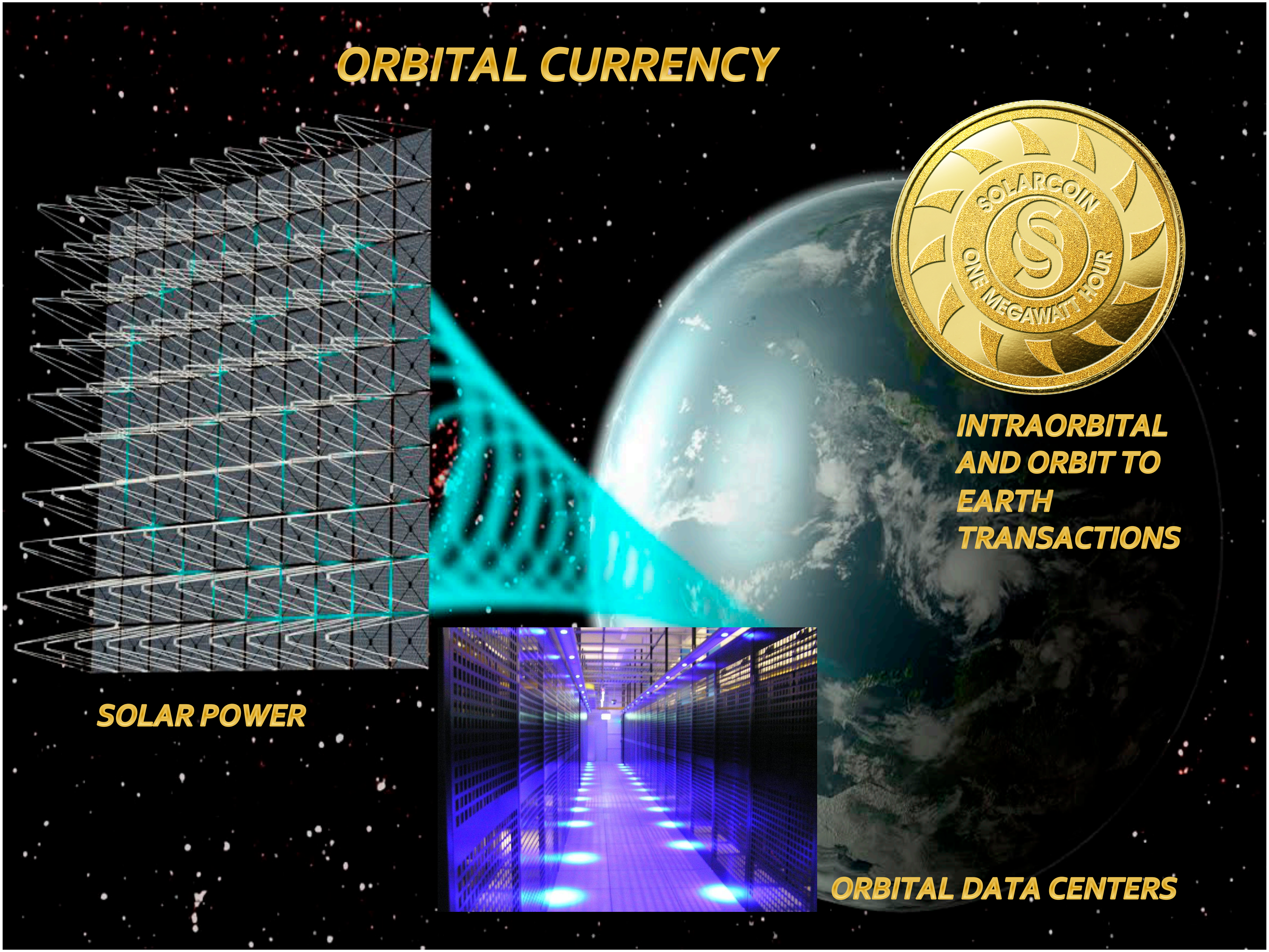


SPACE

Use vacuum and cold from space
Atomic oxygen for Molecular Beam Epitaxy
No water
Environmentally neutral
Zero carbon footprint

EARTH

900 B units in 2015
Energy of a fab lab could power a small city
150 fabs representing 41 companies
$1B spent by semicon industry on water and wastewater


ORBITAL CURRENCY
SOLARCOIN
ONE MEGAWATT HOUR
INTRAORBITAL
AND ORBIT TO
EARTH
TRANSACTIONS
SOLAR POWER
ORBITAL DATA CENTERS

POSSIBLE TAX INCENTIVES

- Develop equivalent concept to incorporation in low earth orbit (LEO vs INC)

- Offer companies a tax break - a ten-year tax holiday revenue from the sales of products made in LEO would be a $-neutral cost

- Incentivize companies to explore the value of space in their product development cycle by investing $$’s parked outside of the US, i.e. for every dollar invested in the space aspect, a company could bring back to the US a dollar parked outside, tax free

COST OF A SEMICONDUCTOR FAB

2000-2015	**2016**	**Renovate/ Retrofit** (*C neutrality)
~$3B-$4B Global Foundry: $3B-$5B TSMC: $9.3B (fab 15 300nm)	New Fab: $8B-$10B DRAM: $.35B- $4.5B NAND flash: $7B Leading Edge fab: $15B-$20B (Gartner R)	$37M-$55M

Historically, semiconductor companies in the US have been subject to litigation linked to groundwater. 2003-2013: over 10,000 environmental violations for key semiconductor companies

OTHER FACTORIES COSTS

Market	New facility	Renovate/ Retrofit (*C neutrality)
Biological Pharma	\$500M-\$2B Genentech Vacaville \$150M (1994) + \$600M (2004 expansion) Amgen: \$3B (2003-2006) \$200M (antibody site in Singapore) Eli Lilly Plant: \$1B (Insulin Lispro, Puerto Rico)	\$150M-\$200M
DATA CENTER	\$600M to build Google (2007) Building alone:\$25M Power costs ~70-80% of total costs	

VALUE PROPOSITIONS FROM SPACE AS POSSIBLE ACTIONABLE IDEAS

Reference to create more centered standards for sustainable living

Leverage of space assets (solar power, vacuum, cold, etc)

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Increase transfer and utilization of sustainable technologies from space

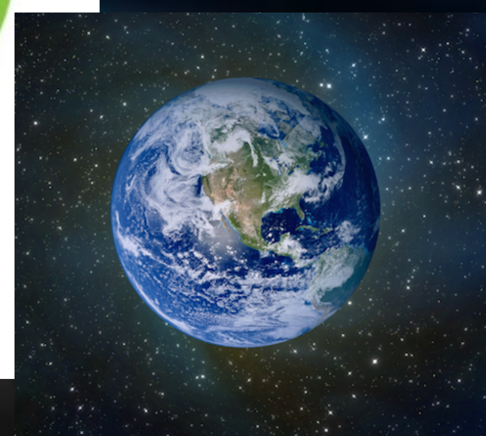
Move polluting manufacturing (part or whole) for appropriate industries in space

Remote sensing and observation

Create superior products (technical performance, energy usage, reusable, sustainable)

CREATE A HEALTHY ECOSYSTEM OF COMMERCIAL SPACE COMPANIES WITH TRIPLE BOTTOM

Commercial



Thank you

Gravity Free Regards!

SPACE PORTAL TEAM:
Lynn Harper
Dan Rasky, Ph. D.
Bruce Pittman