Space Portal at the NASA Research Park

NASA

STC Science and Technology Corporation

Industrialization of Space

Ioana Cozmuta, PhD Industry Innovative Lead, Space Portal, NASA Ames Research Center

Lynn D Harper, Integrative Studies Lead, Space Portal, NASA Ames Research Center

Daniel J Rasky, PhD Director, Space Portal, NASA Ames Research Center

Alexander MacDonald, PhD Emerging Space Office, NASA HQ

Robert Pittman, Director of Flight Projects, Space Portal, NASA Ames Research Center

Dimensions of a Space Economy

BE RESPONSIVE
BE LONG TERM RESPONSIBLE

BE CREDIBLE
BE RELIABLE
BE PROFITABLE

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

THE TECHNICAL DIMENSION

SINCE 1946

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

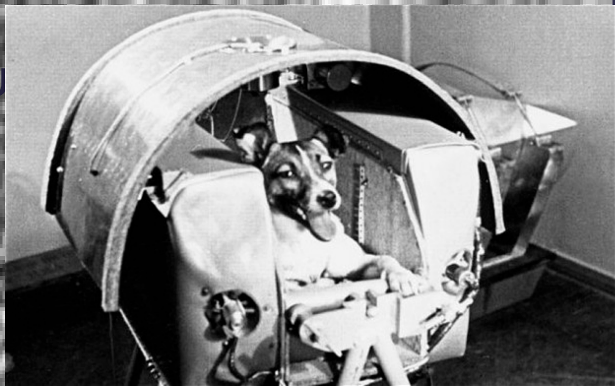
April 23, 1971 – first space station –USSR, Salyut 1

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

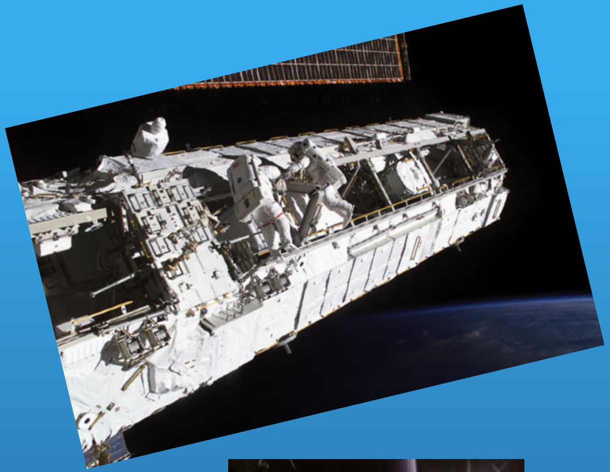
November 20, 1998 - first multinational space station (ISS)

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

Canada)



WHY SPACE?



- Challenge for survival
  - **Innovative technologies**

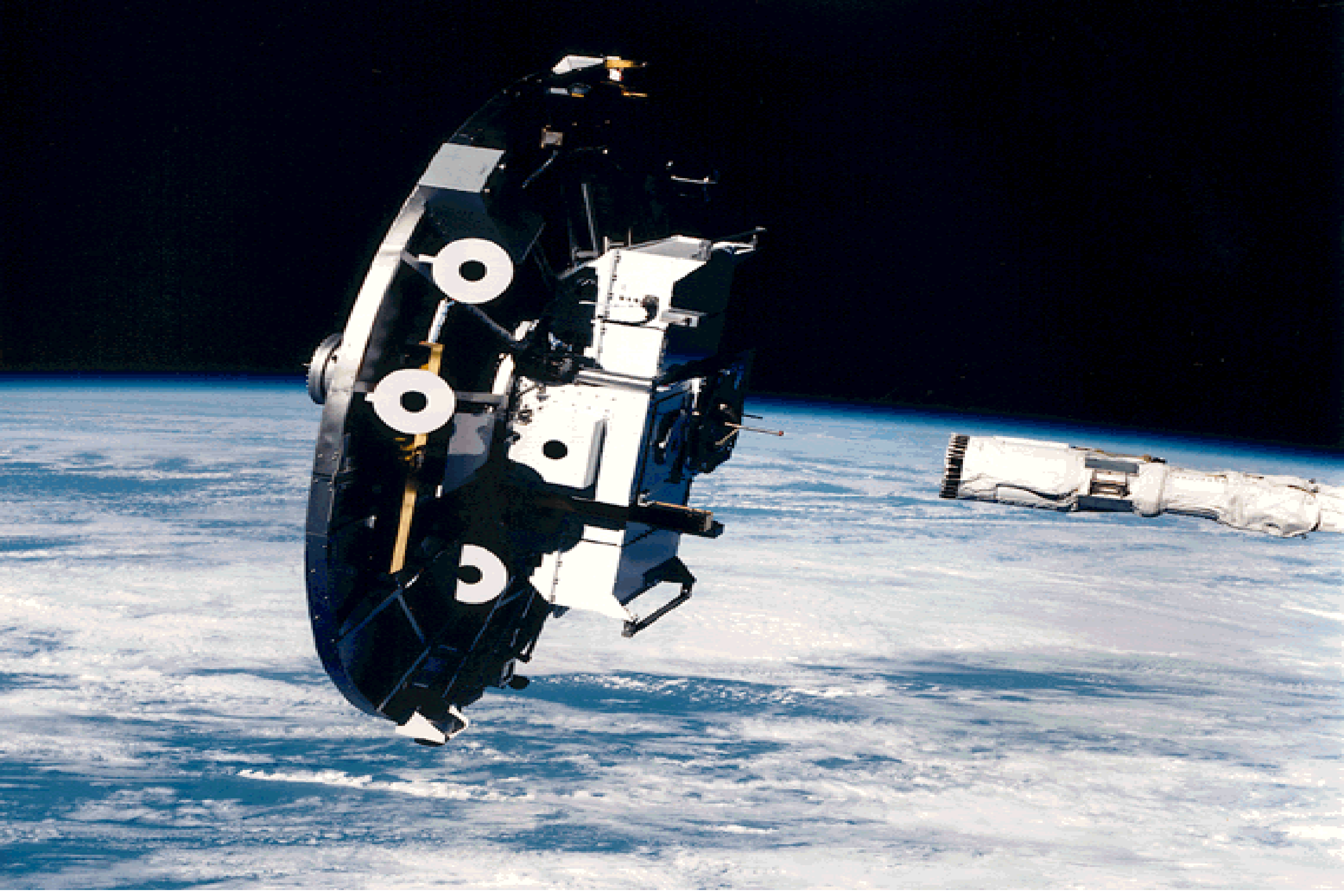
- Opportunity for **International Cooperation**

- Severe mass limitations
  - **miniaturization**

- Extreme environment:
  - **Infinite cold**
  - **Vacuum**
- **“Infinite”** solar power
- **Radiation**
- Long term exposure to reduced **microgravity**

A 3D LABORATORY AFLOAT

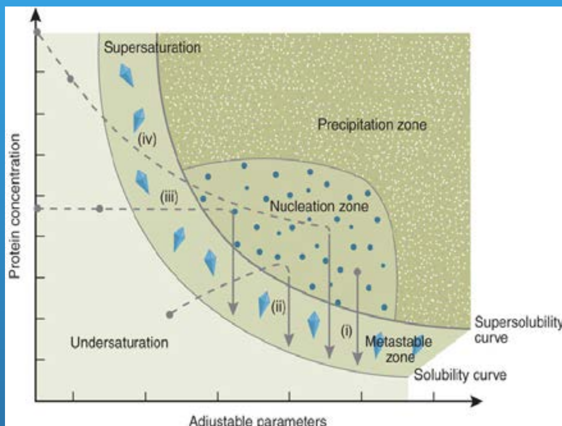
AN OPEN LABORATORY

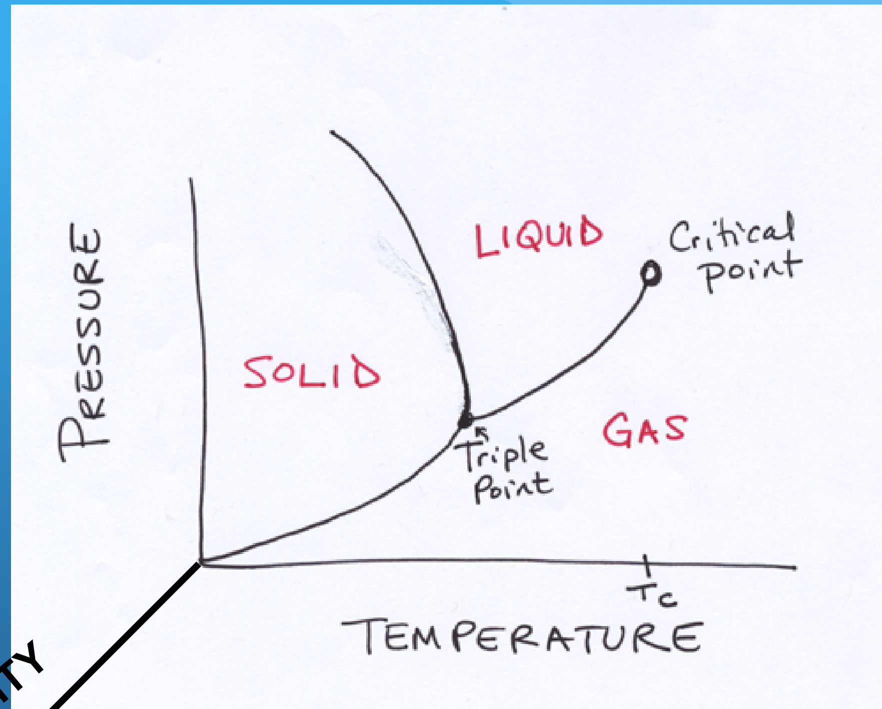


MICROGRAVITY

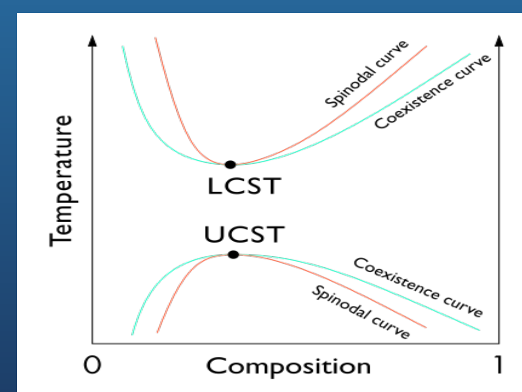
- When the force of gravity is removed other forces (**surface tension, capillary forces**) become predominant and drive a different system dynamics
- **Gravity is a physical parameter that together with pressure and temperature define the state of a system**
- Historically, major **breakthrough and 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 …

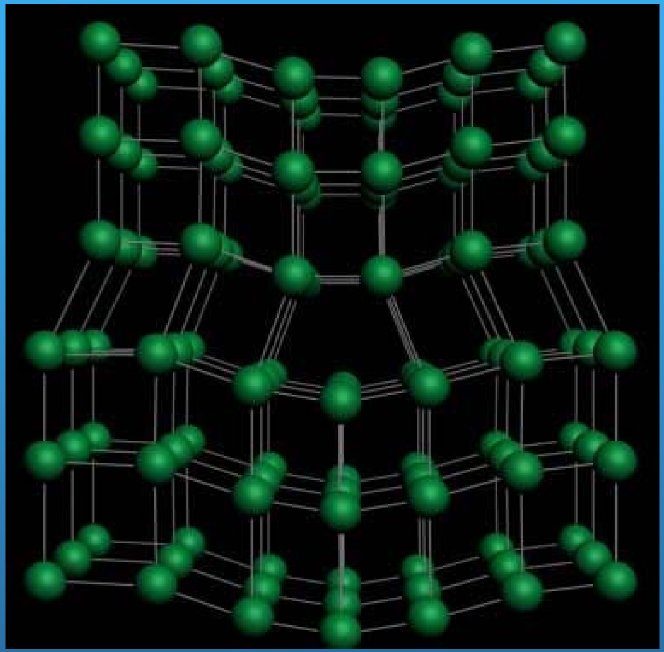




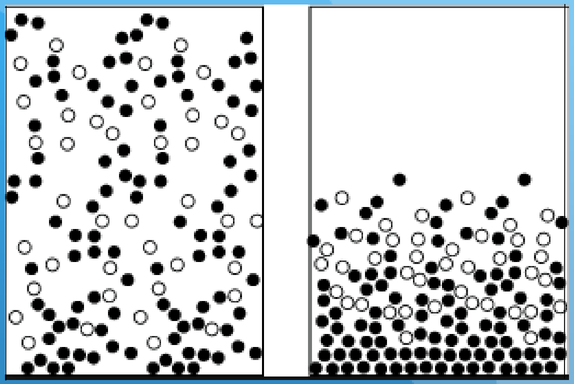
GRAVITY



BENEFITS FOR MATERIAL SYSTEMS



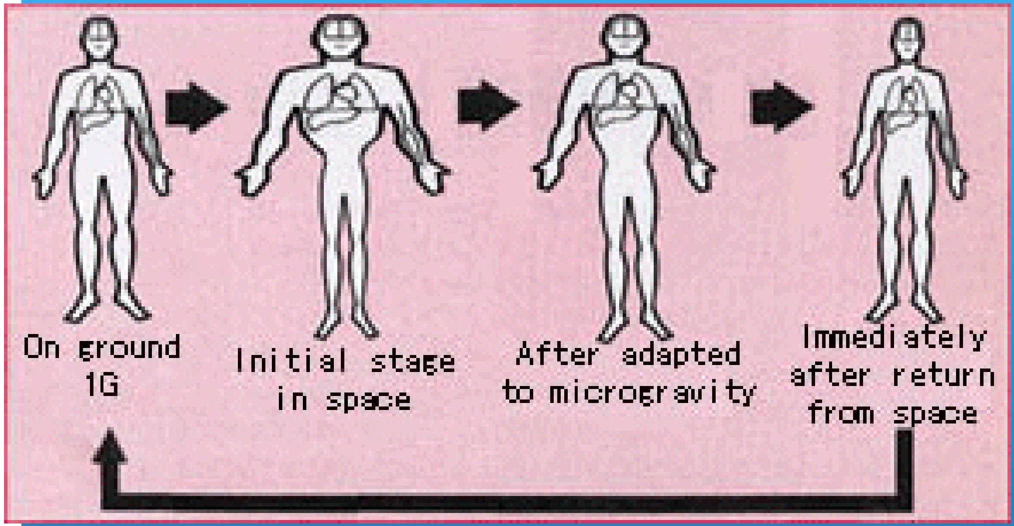
- No solute buildup
- No sedimentation
- No convection



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

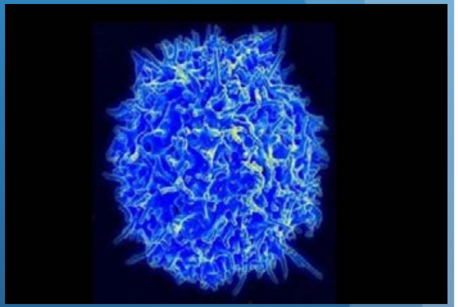
- Containerless processing
- Free suspensions
- Perfect spherical shape
- No wetting

BENEFITS FOR LIFE SCIENCE



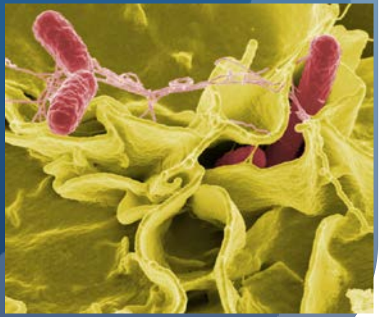
Microgravity is evolutionarily novel and enables new understanding of living systems that can be used for medicine and biotech.

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.



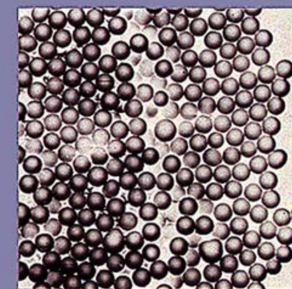
As biotech companies have found, novel environments offer novel biological responses useful for industry, medicine, and agriculture.

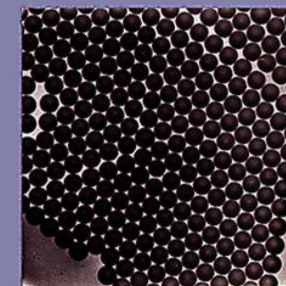
MICROGRAVITY PER DISCIPLINE

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			

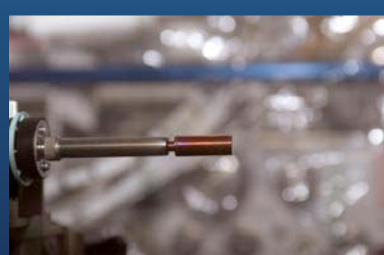
SUCCESSES: HIGH TRL EXAMPLES

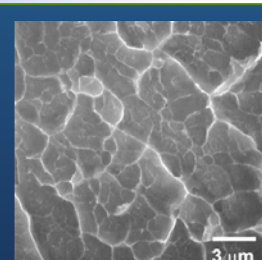
Despite relatively low funding, relatively few investigators, and great difficulties accessing space (compared with laboratory research on Earth), the success rate from microgravity R&D into applications is remarkably significant.



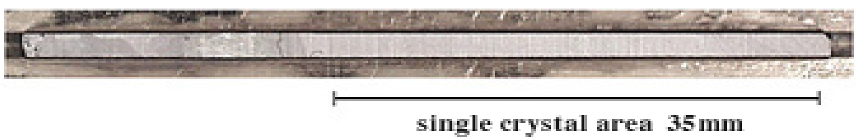


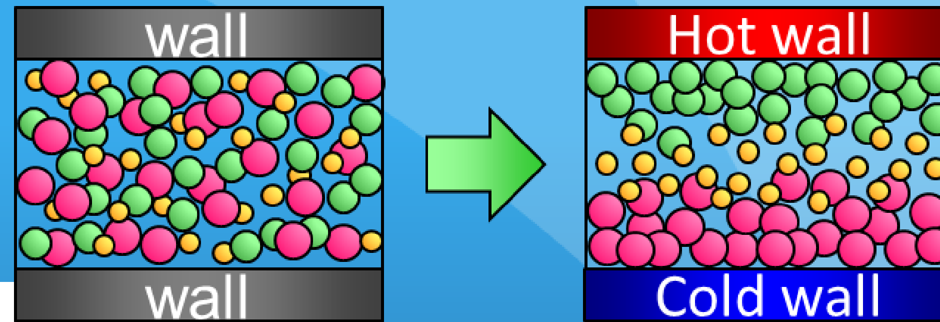
Experiment	Product	µg benefit
Space Beads	Polystyrene spheres 10 microns in diameter-calibration standard SRM 1965 for NBS	Superior product in terms of (1) sphericity (2) narrowness of size distribution (3) rigidity
Bulk Metallic Glasses	Hinges, sliders, frames, display frames, miniature camera case,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





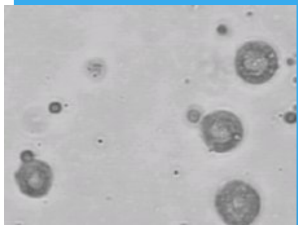
SUCCESSES: HIGH TRL EXAMPLES

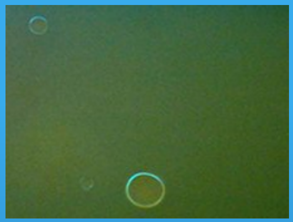


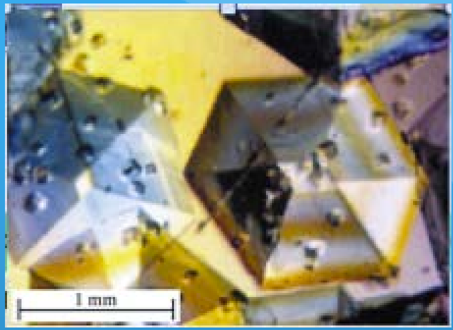


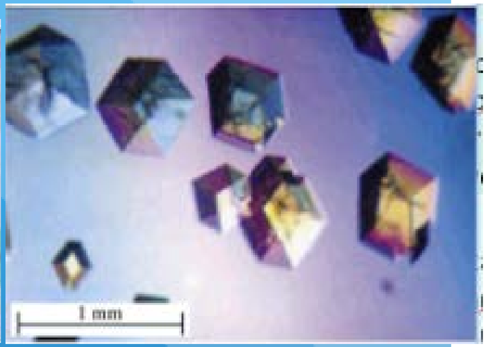
Experiment	Product	μg benefit
Semiconductor crystals	Fabrication of low noise field effect transistors (FET's), analog switch integrated circuits (LCS)	Microgravity-grown crystals have (1) increased single crystal size (2) suppressed impurities and defects (3) higher quality crystals
Thermal Diffusion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



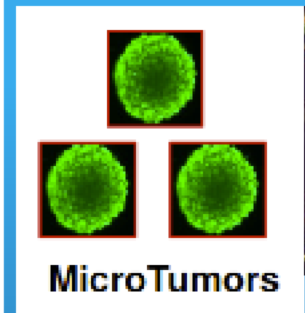


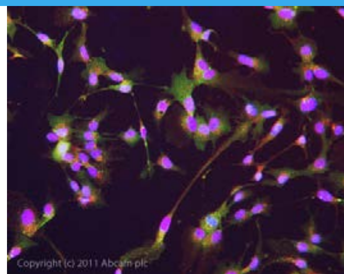


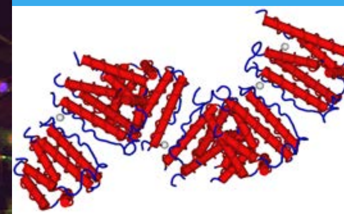


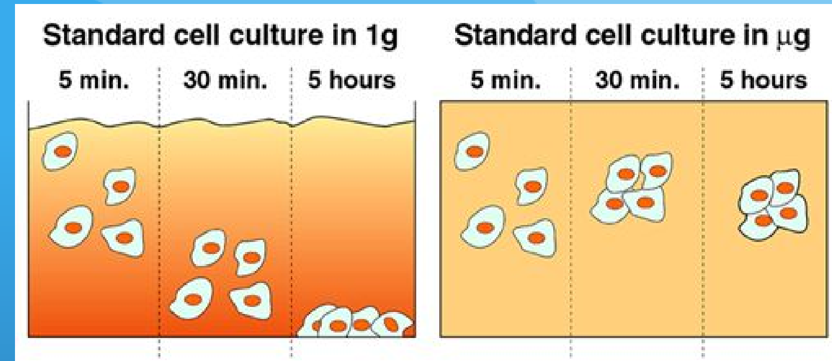
Experiment	Product(s)&Customers	μg benefit
Microencapsulation	Bright Mark line of tissue site marker for accurate tumor diagnostic devices Chemo-FDA approved drugs contained in microcapsules (clinical trials entered in 2012) for local (vs systemic) cancer chemotherapeutic treatment	Pharmaceutical drug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









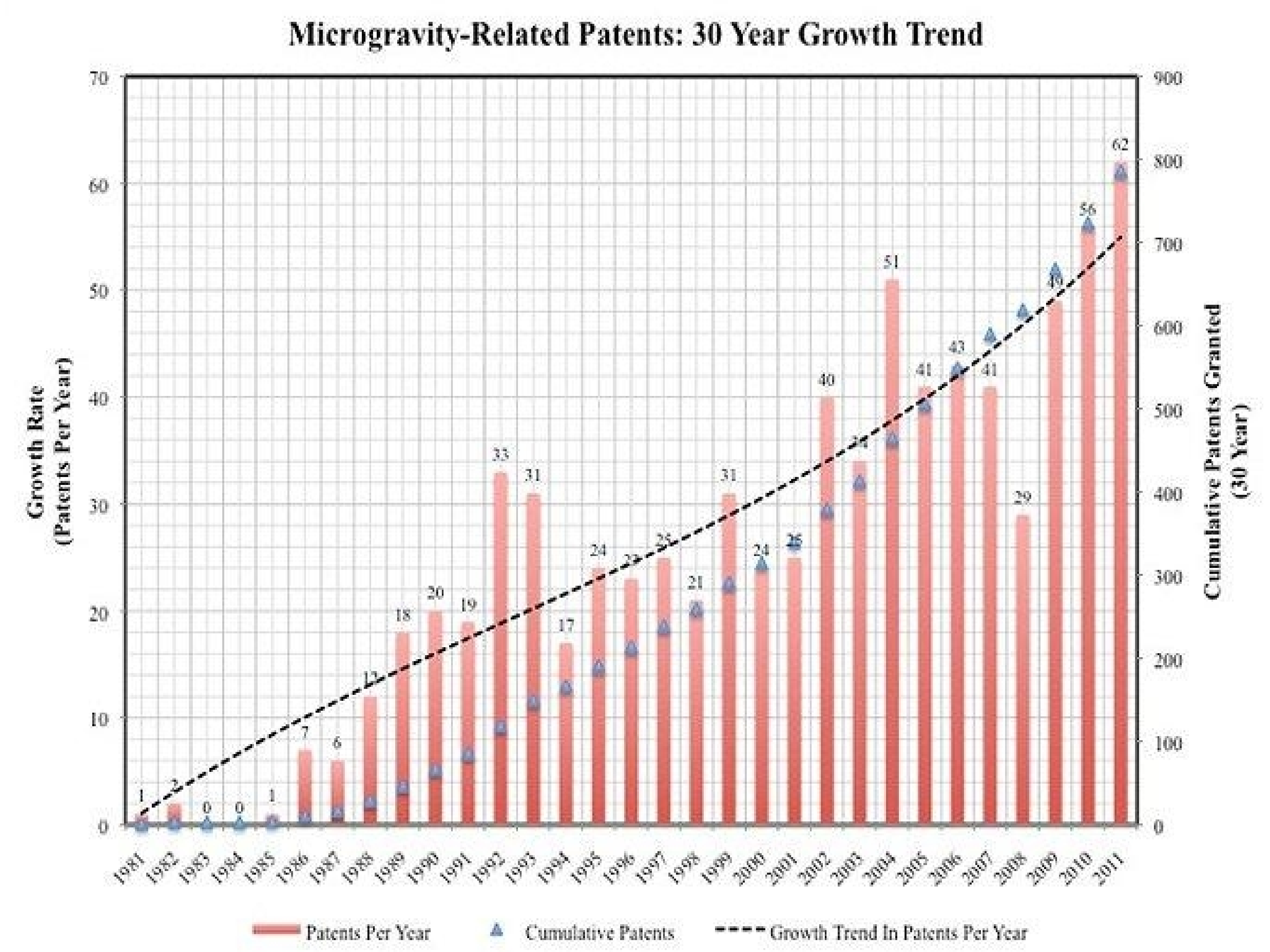
Experiment	Product(s)&Customers	μg benefit
Interferon	FDA approved Peg-Intron™, a pegylated alpha interferon formulation, for the treatment of chronic hepatitis C in January 2001.	STS-Microgravity experiments on alpha interferon, Intron A, for the first time provided Schering Plough Research Institute 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



Microgravity-Related Patents: 30 Year Growth Trend
Growth Rate (Patents Per Year)
Cumulative Patents Granted (30 Year)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
900
1981
1982
1983
1984
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0
1
7
6
18
20
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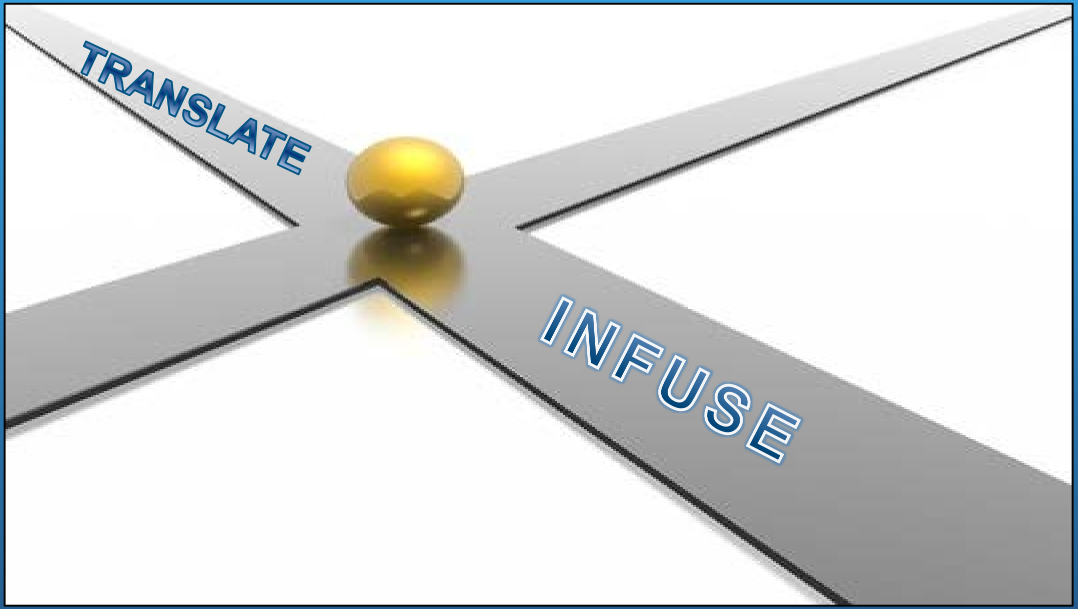
31
17
24
21
31
24
40
51
41
43
41
29
56
62
Patents Per Year
Cumulative Patents
Growth Trend In Patents Per Year

THE ECONOMIC DIMENSION

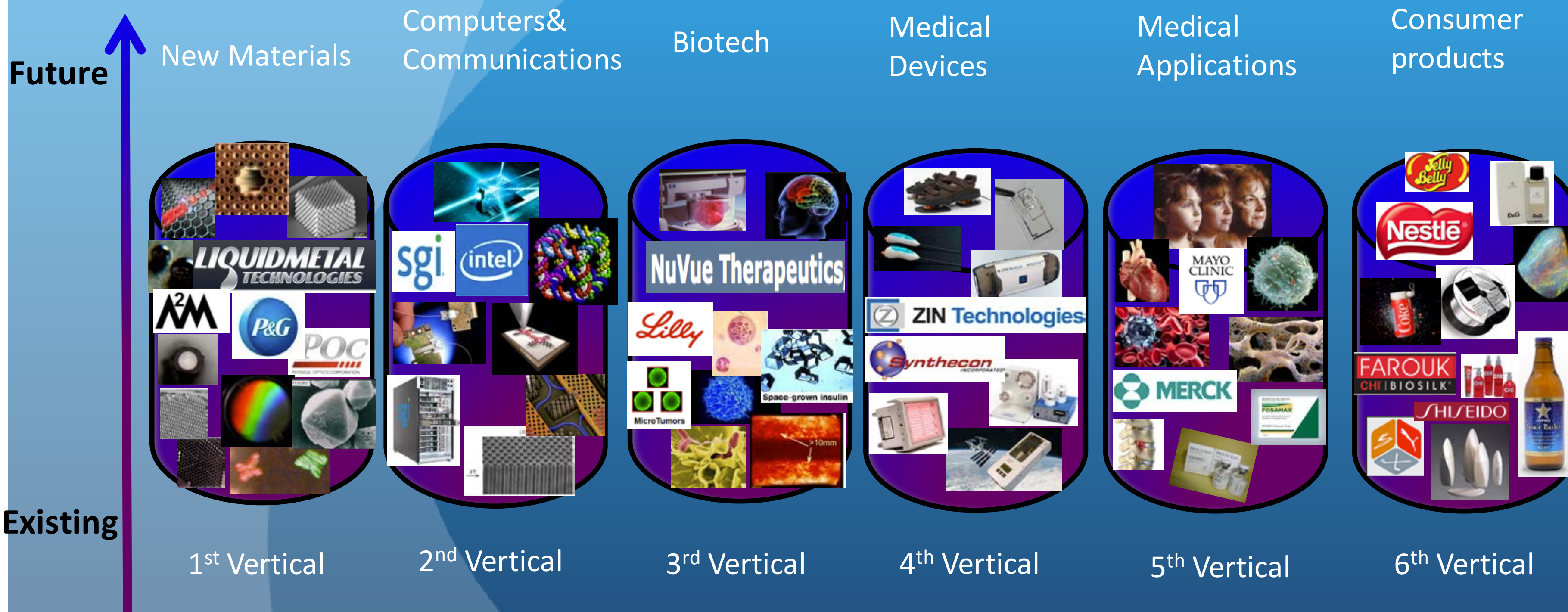
COMMERCIAL MICROGRAVITY

MICROGRAVITY FINDINGS

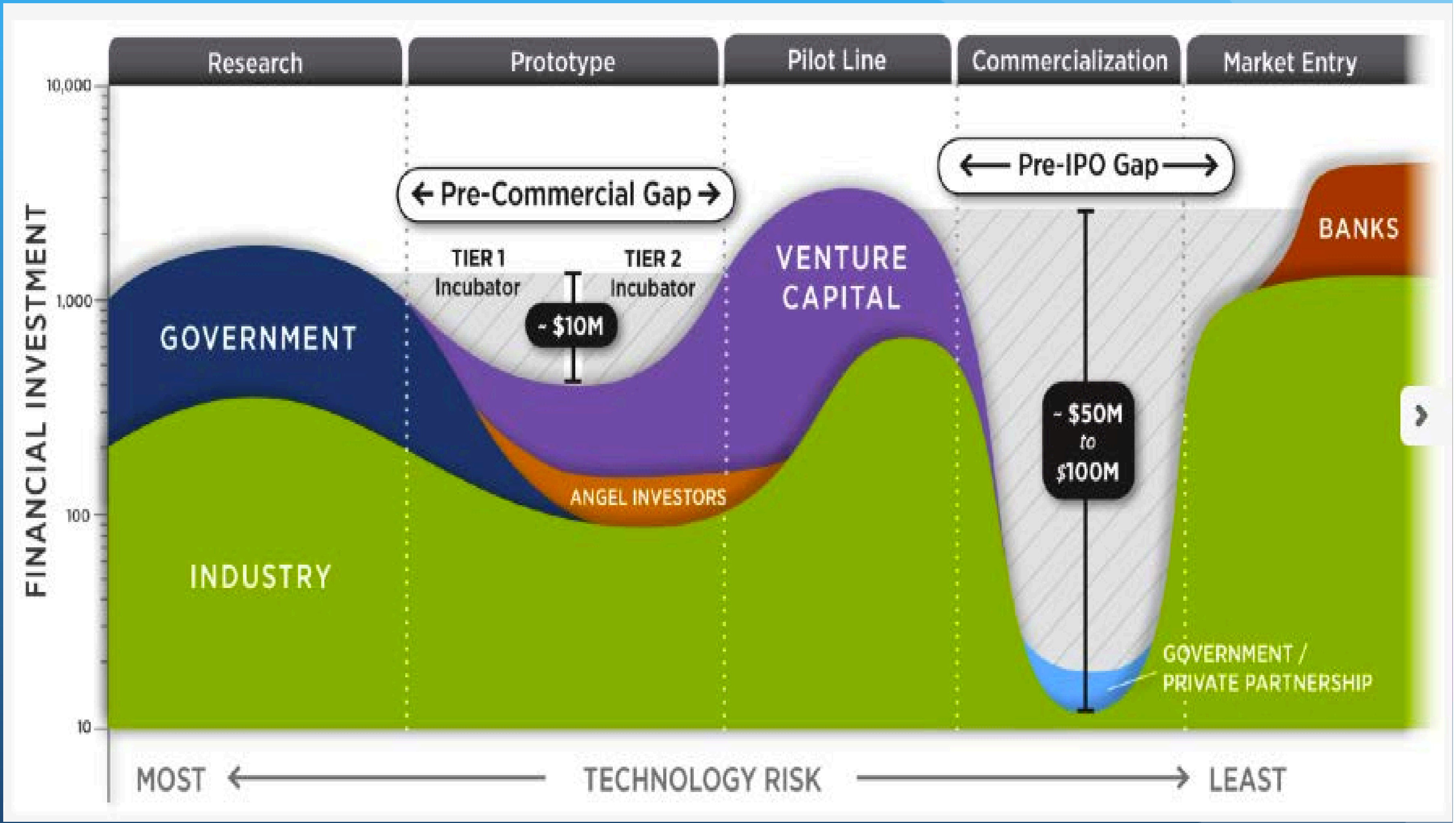


INDUSTRY SPECIFIC GRAVITY LIMITED PHENOMENA

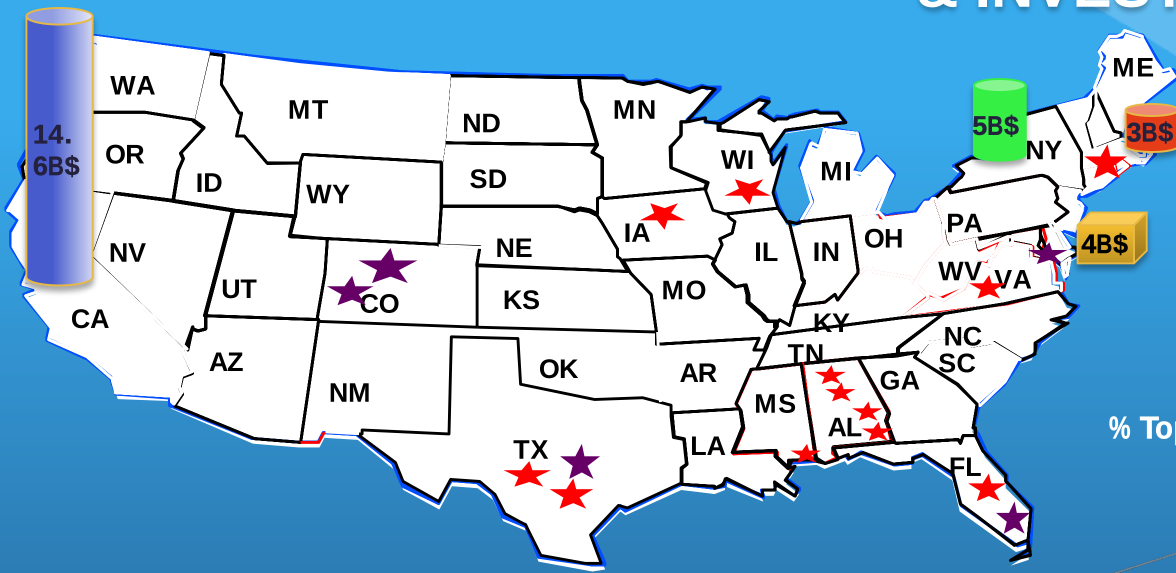
Verticals of Microgravity



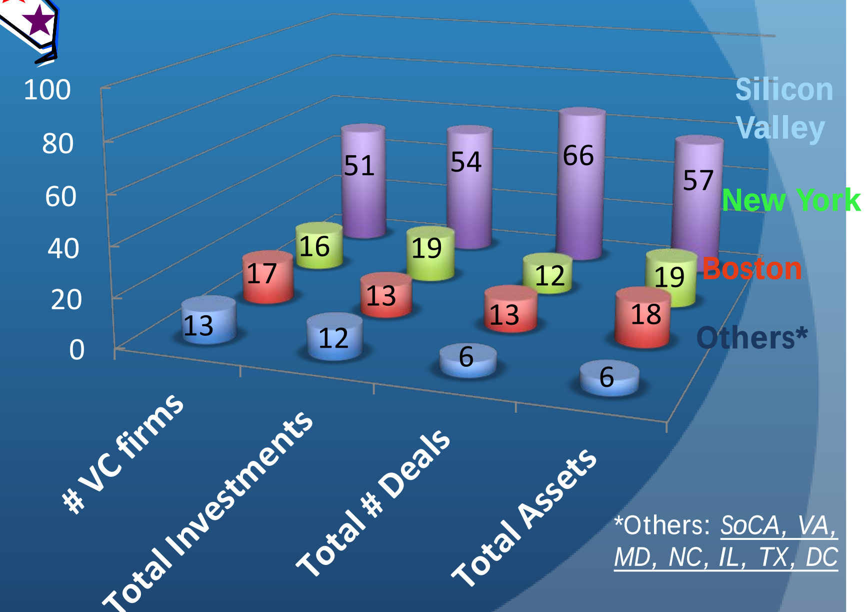
Financial Investment vs Technology Risk



COMMERCIAL MICROGRAVITY & INVESTMENT OPPORTUNITIES



% Top 100 early stage investments in 2014



*Others: SoCA, VA, MD, NC, IL, TX, DC

NASA (inactive) Commercial Space Centers (2005)

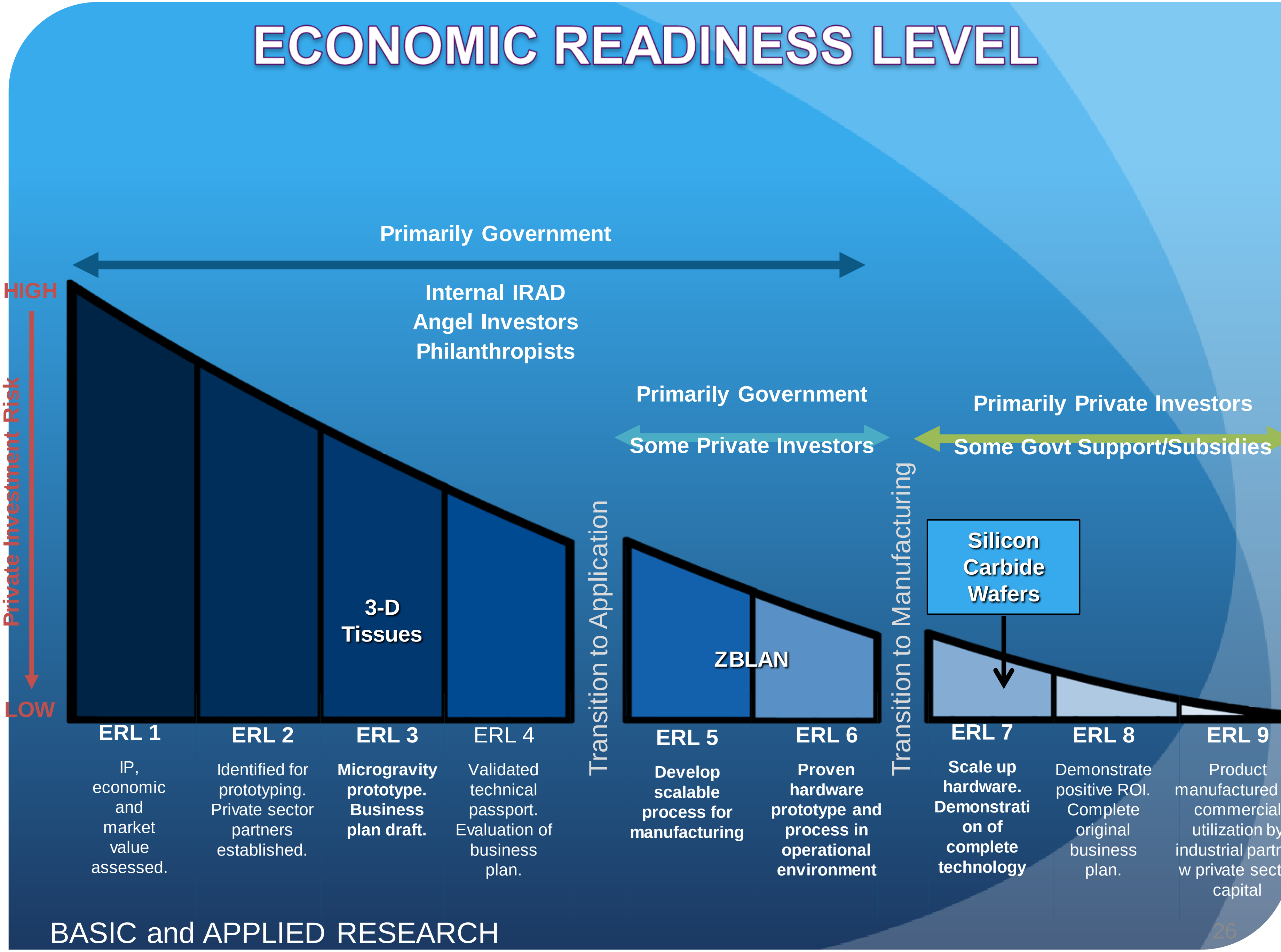
NASA active Commercial Space Centers (2014)

NASA Exploration budget (2014)

Top 100 early stage investments in the US (2014)

ECONOMIC READINESS ASSESSMENT

- *3D concept through combining: 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*


ECONOMIC READINESS LEVEL
Primarily Government
Internal IRAD
Angel Investors
Philanthropists
Primarily Government
Some Private Investors
Primarily Private Investors
Some Govt Support/Subsidies
HIGH
Private Investment Risk
LOW
3-D Tissues
ZBLAN
Silicon Carbide Wafers
Transition to Application
Transition to Manufacturing
ERL 1
IP, economic and market value assessed.
ERL 2
Identified for prototyping. Private sector partners established.
ERL 3
Microgravity prototype. Business plan draft.
ERL 4
Validated technical passport. Evaluation of business plan.
ERL 5
Develop scalable process for manufacturing
ERL 6
Proven hardware prototype and process in operational environment
ERL 7
Scale up hardware. Demonstration of complete technology
ERL 8
Demonstrate positive ROI. Complete original business plan.
ERL 9
Product manufactured for commercial utilization by industrial partner w private sector capital
BASIC and APPLIED RESEARCH

ECONOMIC READINESS LEVEL SUMMARY

ERL 1 Identify market and economic potential by constructing and scanning across current private sector verticals to identify potential demand

ERL 2 Define dependencies and risks by creating a list of requirements through engaging with potential adopters for each vertical from the private sector and the investment community

ERL 3 Define vertical specific infusion points and paths for each application

ERL 4 Review of dependencies by industry experts, investors and NASA

ERL 5 Evaluation of use case and market to prioritize investments that address dependencies

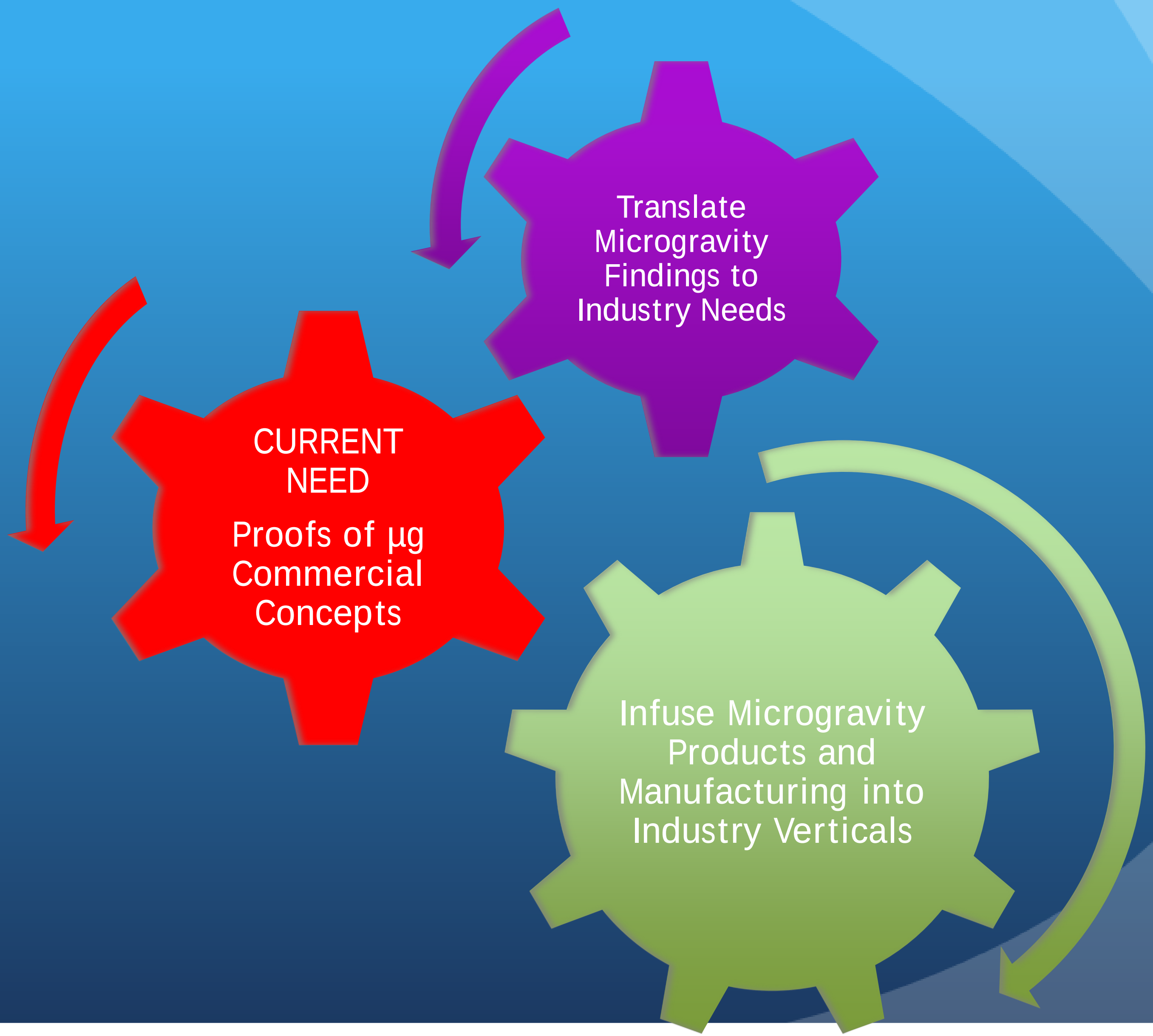
ERL 6 Demonstrate that selected dependencies have been solved

ERL 7 Product successfully licensed or spin-off to the private sector

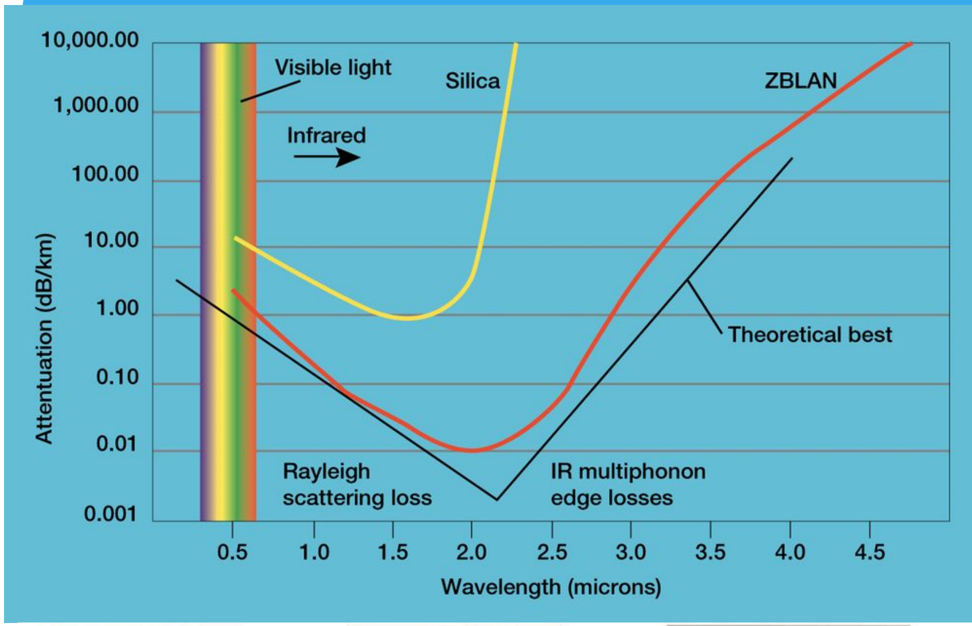
ERL 8 Product manufactured for commercial utilization by an industry partner and available in the market place

ERL 9 Technology is or contributes to a profitable product. ROI evaluation.

THE MACHINERY OF COMMERCIALIZATION



ZBLAN OPTICAL FIBER



(b)

(c)

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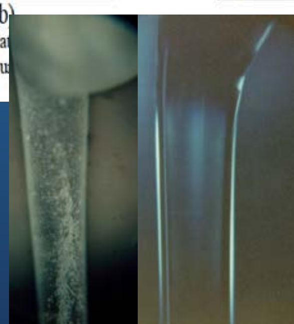
rties: (a) experimental setup,

FOMS



ZBLAN =**Z**rF_4-**B**aF_2-**L**aF_3-**A**lF_3-**N**aF

- most stable fluoride exotic glass fiber
- excellent host for doping
- large reflectivity for short distance transmission
- broad optical transmission window extending into the IR with reduced loss up to x100-1000 better than current Si fibers

ISSUE:

Different density materials with different crystallization temperatures

Gravity induced convection during pulling

Limited monolithic length (max 700m)

Microgravity suppresses nucleation and crystallization

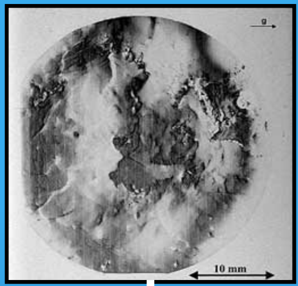
No limit of the fiber length produced in space

Estimated ROI:

1lb of preform would produce 8 km ZBLAN fiber with a nominal selling price range on Earth: $175k/km to $1,000k/km ~ROI: 90-300x

SiC wafer μg re-processing

"sermo minor, operor magis"

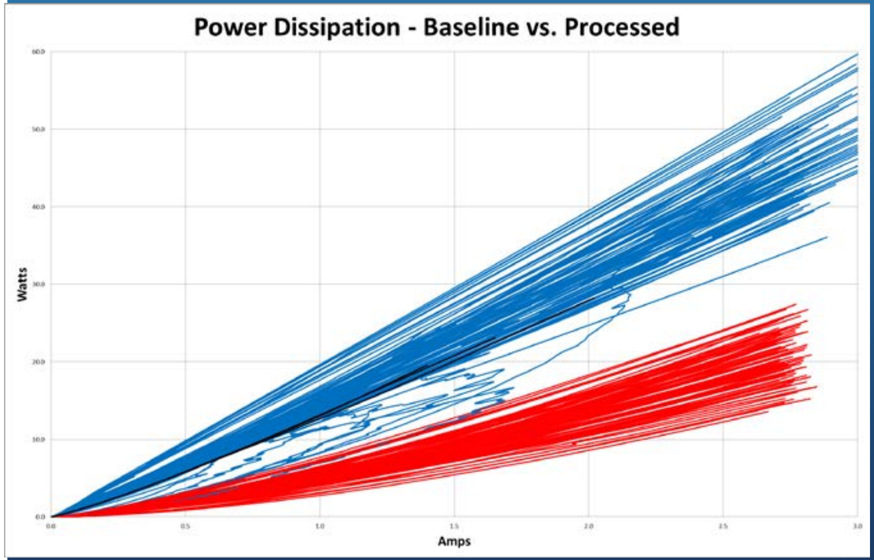


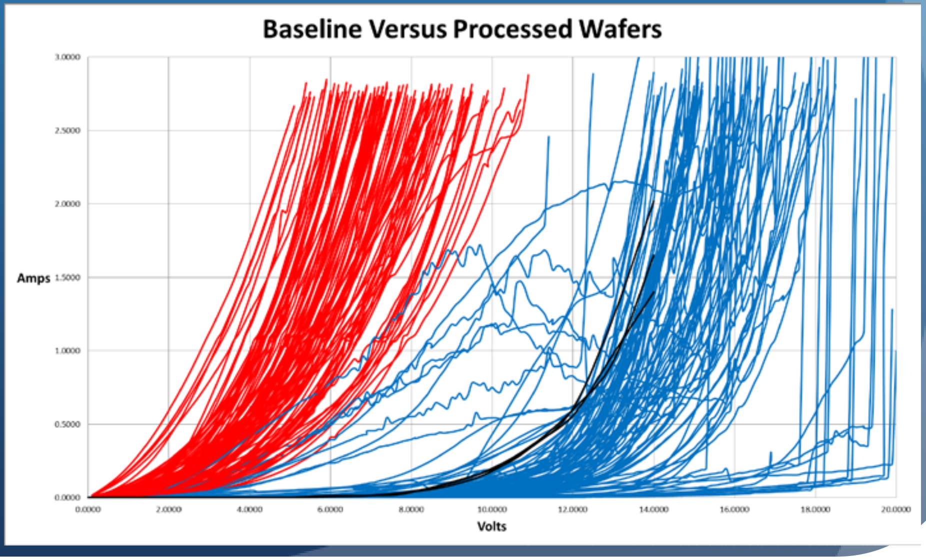
ACME μg re-processing

SiC:
- High thermal conductivity
- High electric field breakdown strength
- High maximum current density
- Very low coefficient of thermal expansion
- Inherently Rad-hard

ISSUE: defects limiting performance, reliability, fab of large scale devices

Microgravity "heals" defects important to the electrical performance of these wafers





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

Private Orbital Laboratory

ERL 1

ERL 7, 9

INNOVATION VORTEX

ERL 2-5

ERL 6

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.

VERTICALS OF MICROGRAVITY

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

Technology Ethics

"Modern technology propelled by the forces of market and politics, has enhanced human power beyond anything known or even dreamed of before. It is a power over matter, over life on earth, and over man himself…and it keeps growing at an accelerating pace.

But lately, the other side of the triumphal advance has begun to show its face with palpable threats that seem hard to counter.

The net total of these threats is the overtaxing of nature, environmental and perhaps human as well. Thresholds of processes initiated by us may be reached in one direction or another with points of no return."

–Hans Jonas, "Ethics of Technology"

Technology Impacts

Examples of human needs and wants, responsive technology and long-term impacts (T Graedel, B. R. Allenby, Industrial Ecology, Prentice Hall, 1995)

Problem / Need	Technology as Solution	Consequences
Food preservation, temperature control: nontoxic, nonflammable refrigerant	Chlorofluorocarbons	Stratospheric Ozone Depletion
Destruction of crops, illness due to "pests": agent to kill insects	Synthetic insecticides	Adverse effects on birds and mammals
Energy for consumer and industry use: cheap and readily available source	Wood, coal	Deforestation, global climate change
Increased food supply: agent to aid crop growth	Nitrogen and phosphorus fertilizers	Lake eutrophication

Great 8 macro trends through 2020

Bain Macro Trends, 201134

Space is a tapestry

People who say it can not be done should not interrupt those who are already doing it. (Unclear)

If we choose to support the explorers, the innovators, the dreamers
We might find the stars are closer than we think

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