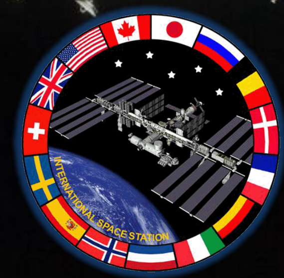
The International Space Station as an Innovation Laboratory

Materials Research And Beyond



Julie A. Robinson, Ph.D.
International Space Station Chief Scientist, NASA
TMS 2013, San Antonio
6 March 2013

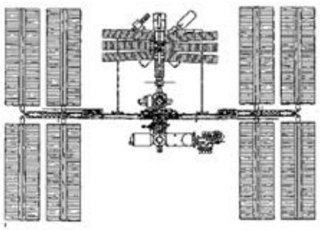
International Space Station Facts

Spacecraft Mass: ~925,000 lb (~419,000 kg)
Spacecraft Pressurized Volume: 32,333 ft3 (915 m^3)
Velocity: 17,500 mph (28,200 kph)
Altitude: ~220 miles above Earth
Power: 80 kW continuous
Science Capability: Laboratories built by US, Europe, Japan, and Russia
Extended through *at least* 2020

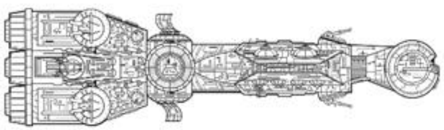
Sizemodo: How big is the International Space Station?

20 m.

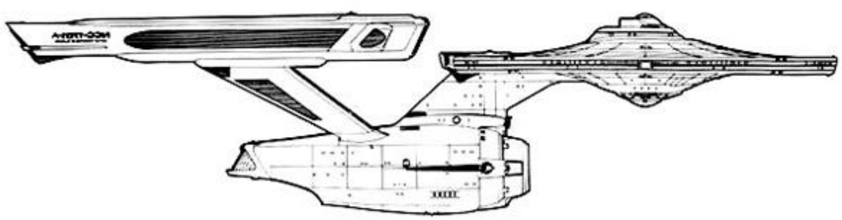
Colonial Viper Mk I: 8.7 meters



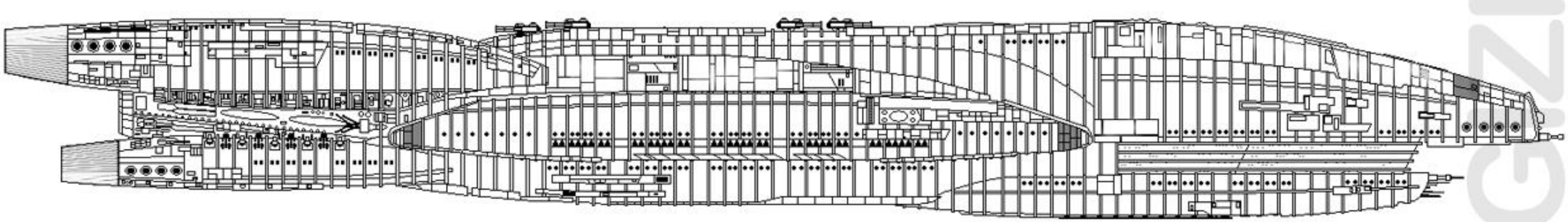
Interational Space Station: 107.4 meters



Corellian corvette: 150 meters



USS Enterprise (NCC-1701-A): 288.6 meters



Battlestar Galactica (New Series): 615 meters

Module Length	51.0 m (167.3 ft)
Truss Length	109.0 m (357.5 ft)
Solar Array Length	73.0 m (239.4 ft)
Mass	367,539 kg (810,285 lb)
Habitable Volume	343 m^3 (12,118 ft^3)
Pressurized Volume	892 m^3 (31,510 ft^3)
USOS Power Generation	8 solar arrays = 84 kW

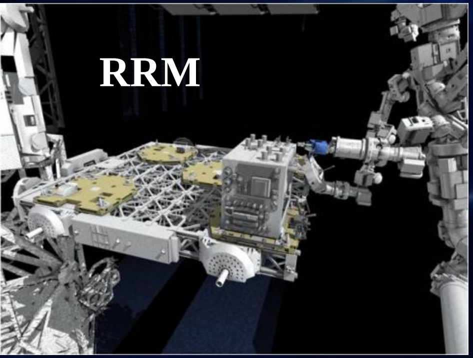
Orbital Inclination / Path	51.6 degrees, covering 90% of the world's population
Altitude	200 nautical miles (on average) above the Earth

Why do experiments in space?

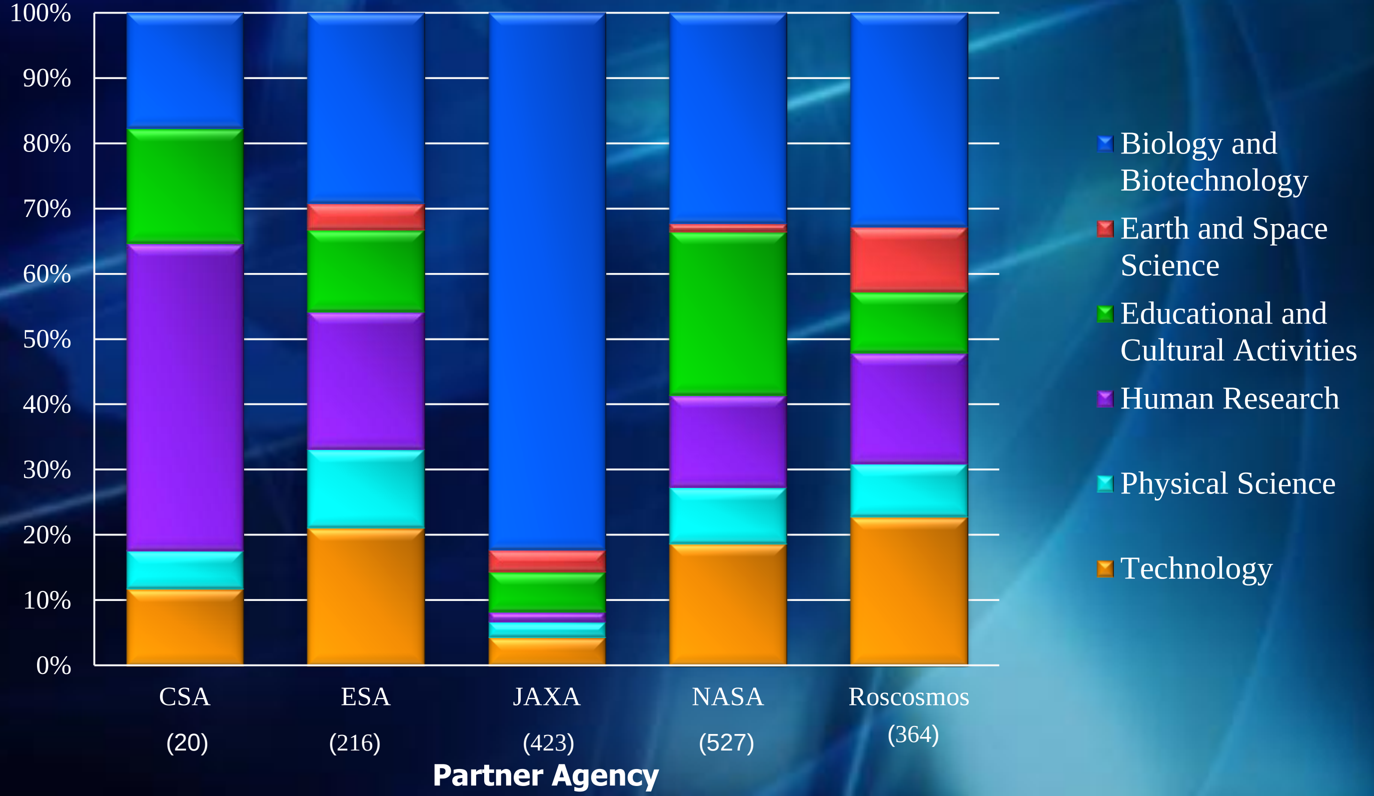
ISS Research Accomplishments

(Expeditions 0 – 28, December 1998 – October 2012, working data as of March 2013)

- Expeditions 0 – 32
  - 1550 Investigations
    - 527 NASA-led investigations
    - 1023 International-led investigations
  - > 1500 scientists served
  - >600 scientific publications
  - 65 participating countries

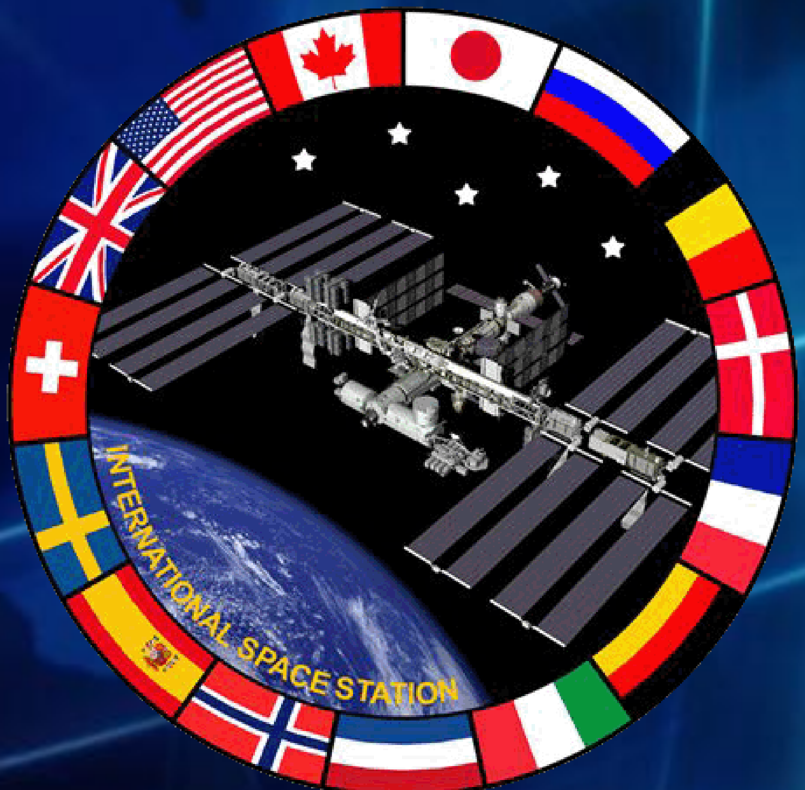


Research Disciplines of ISS Investigations By Partner Agency: Expeditions 0-32, December 1998 - October 2012



67 Countries Have Participated in ISS Utilization through 2012

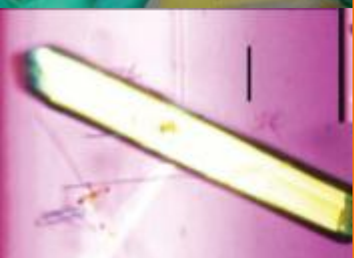
Argentina
Australia
Austria
Belarus
Belgium
Bermuda
Bolivia
Brazil
Bulgaria
Canada
Chile
China
Columbia
Croatia
Czech Republic
Denmark
Dominican Republic
Ecuador
Egypt
Fiji
Finland
France
Germany
Ghana
Greece
Guatemala
Hungary
India
Indonesia
Ireland
Israel
Italy
Japan

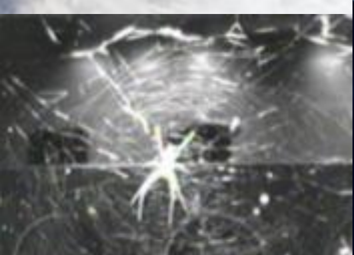


Flags= ISS Partners

Kazakhstan
Kenya
Kuwait
Lebanon
Luxembourg
Macedonia
Malaysia
Mali
Mexico
Netherlands
New Zealand
Nigeria
Norway
Peru
Poland
Portugal
Republic of Korea
Romania
Russia
Senegal
Slovenia
Spain
Sweden
Switzerland
Taiwan
Thailand
Trinidad and Tobago
Turkey
Ukraine
United Kingdom
Uruguay
USA
Venezuela
Vietnam

What are we doing on ISS today?

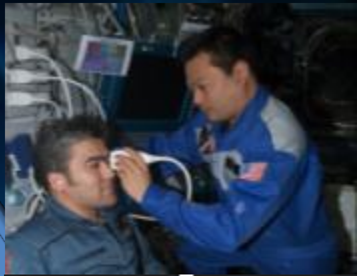



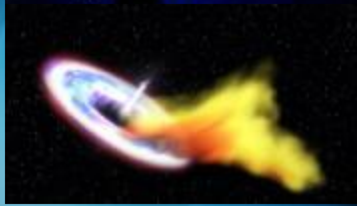


National Lab (Earth Benefits Industrial R&D)

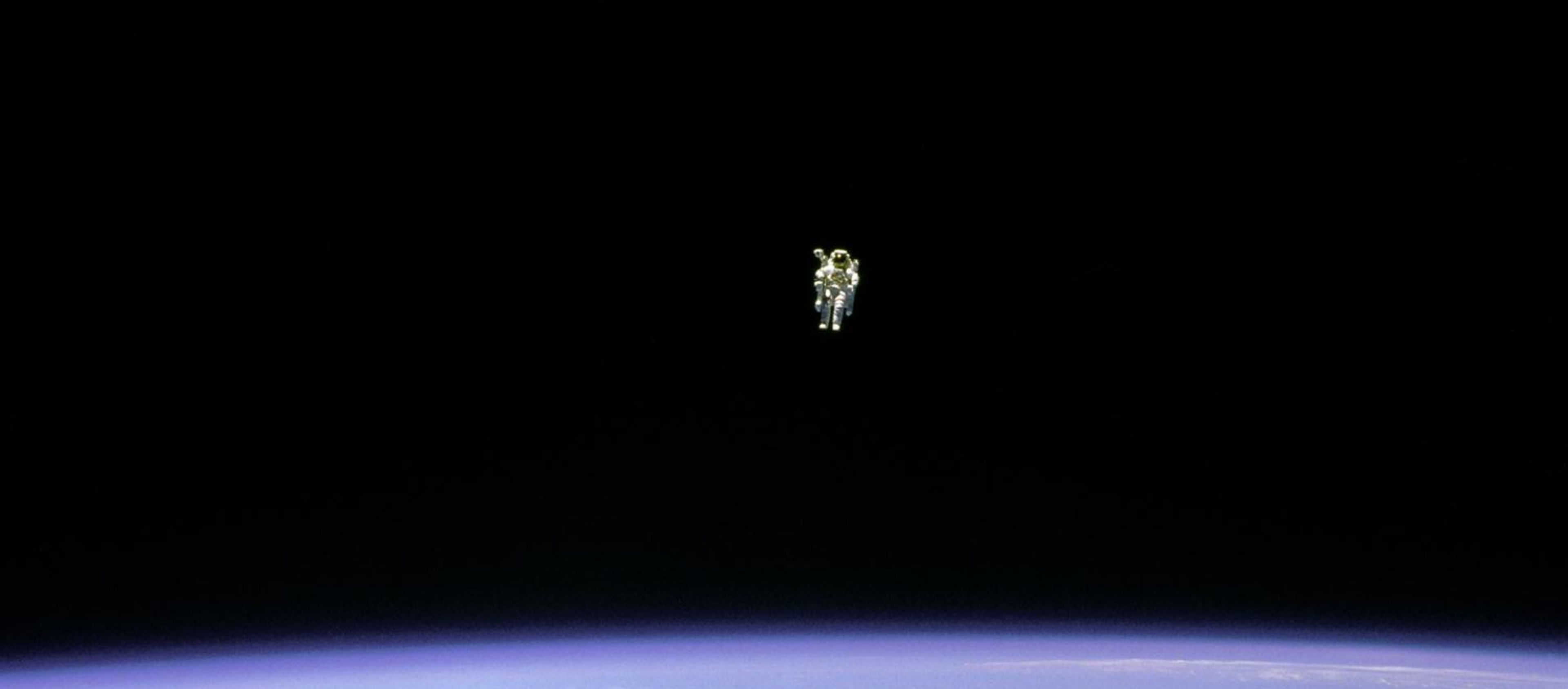
NASA (Exploration)

- Biology and Biotechnology
- Human Research
- Physical Sciences
- Tech Demos
- Astrophysics
- Earth Science
- Education



A laboratory without gravity—microgravity
A benchtop without buoyancy-driven convection or sedimentation



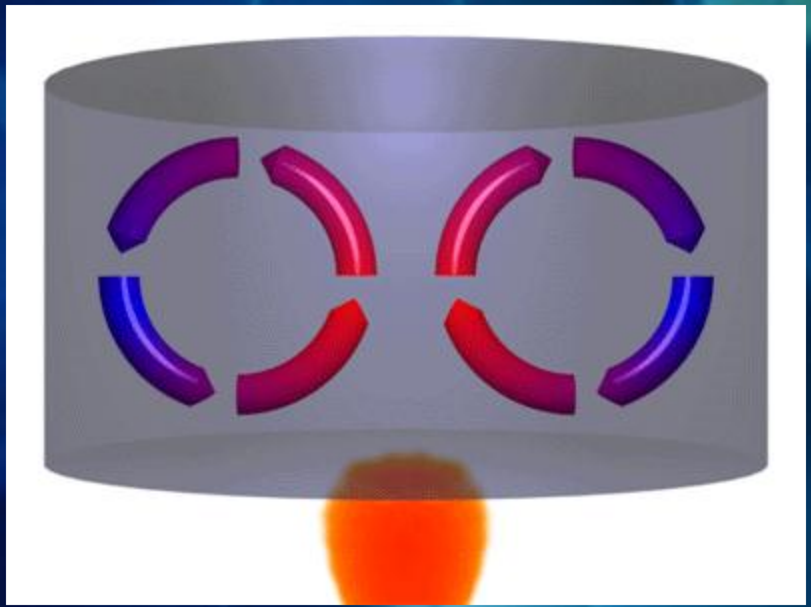
Both our mental models and our mathematical models of physical processes are compromised by gravity

- Taking gravity out of the equation provides an innovation opportunity that is completely unique

Physical Sciences: Convection

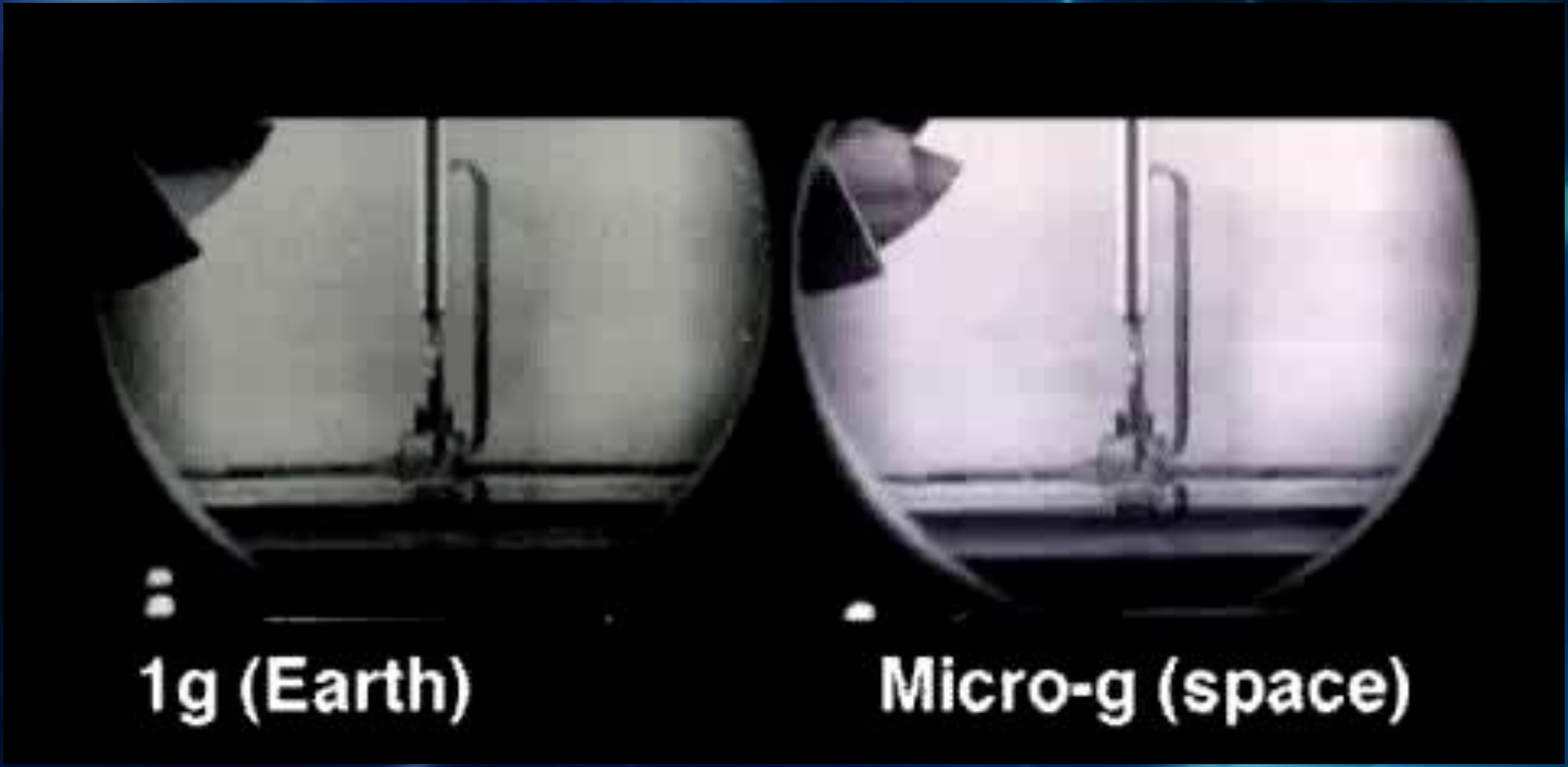
Combustion

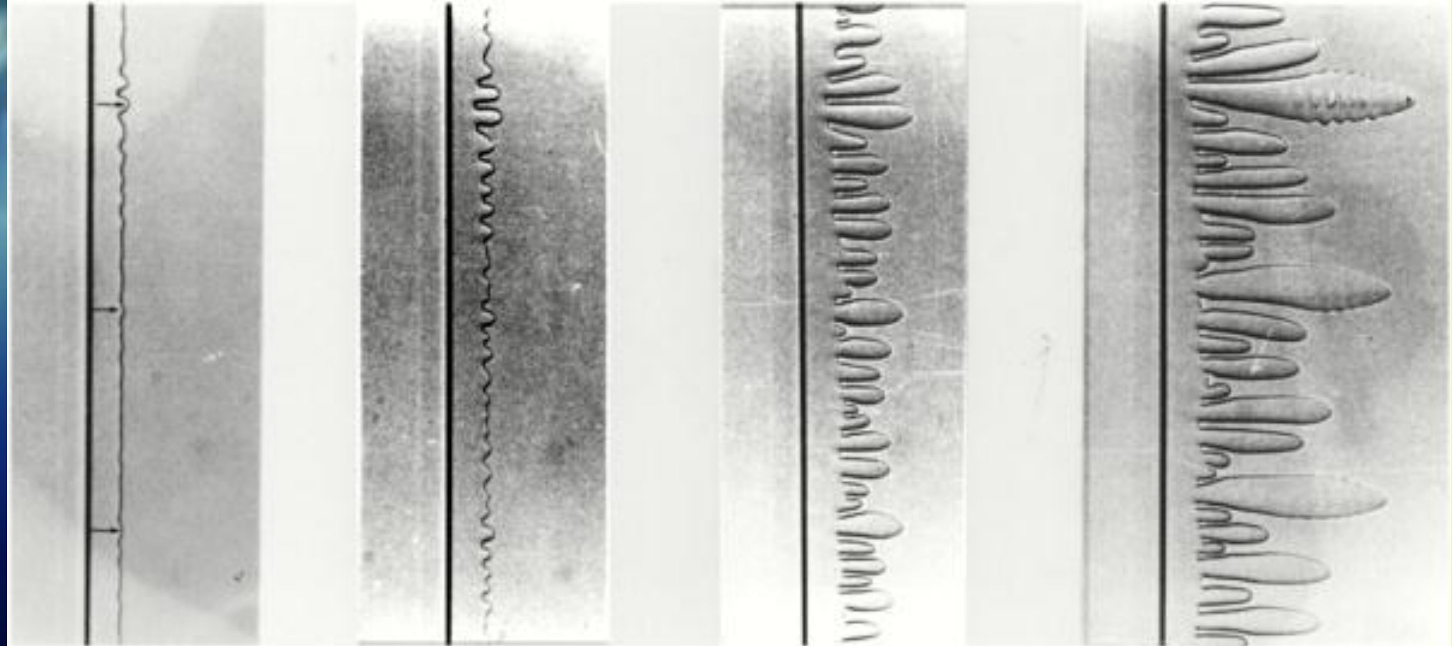
Pore formation and Coarsening



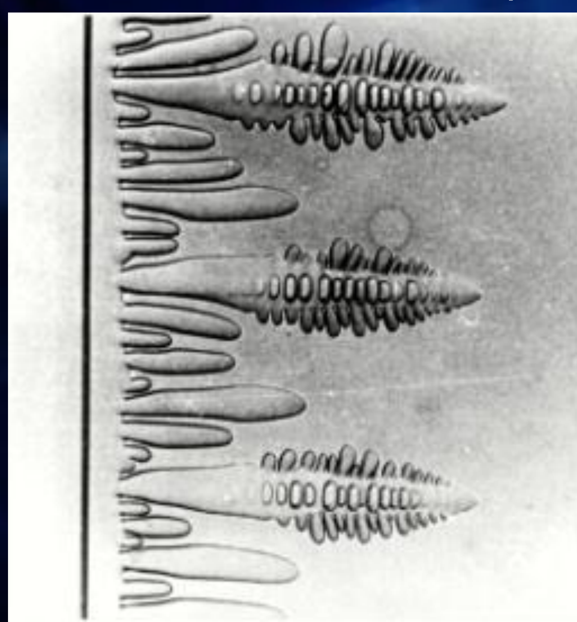
Fluids: No density or buoyancy driven Convection!

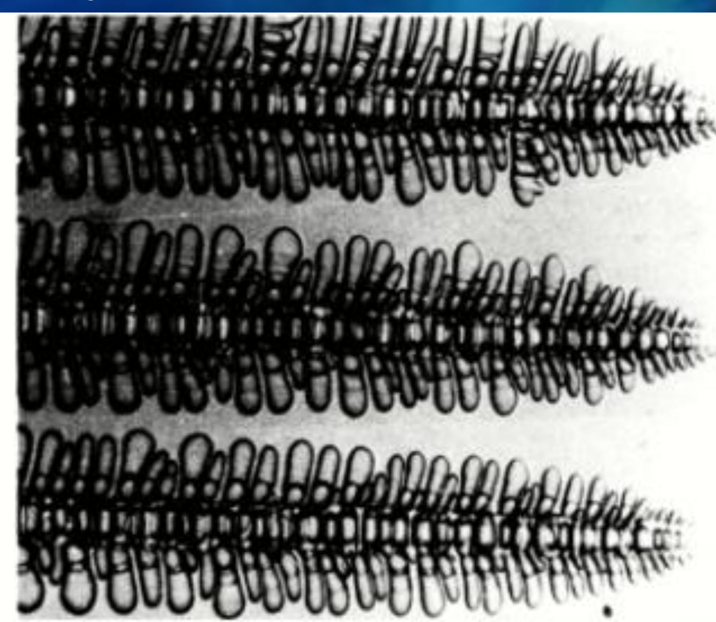
Boiling on Earth and in Microgravity

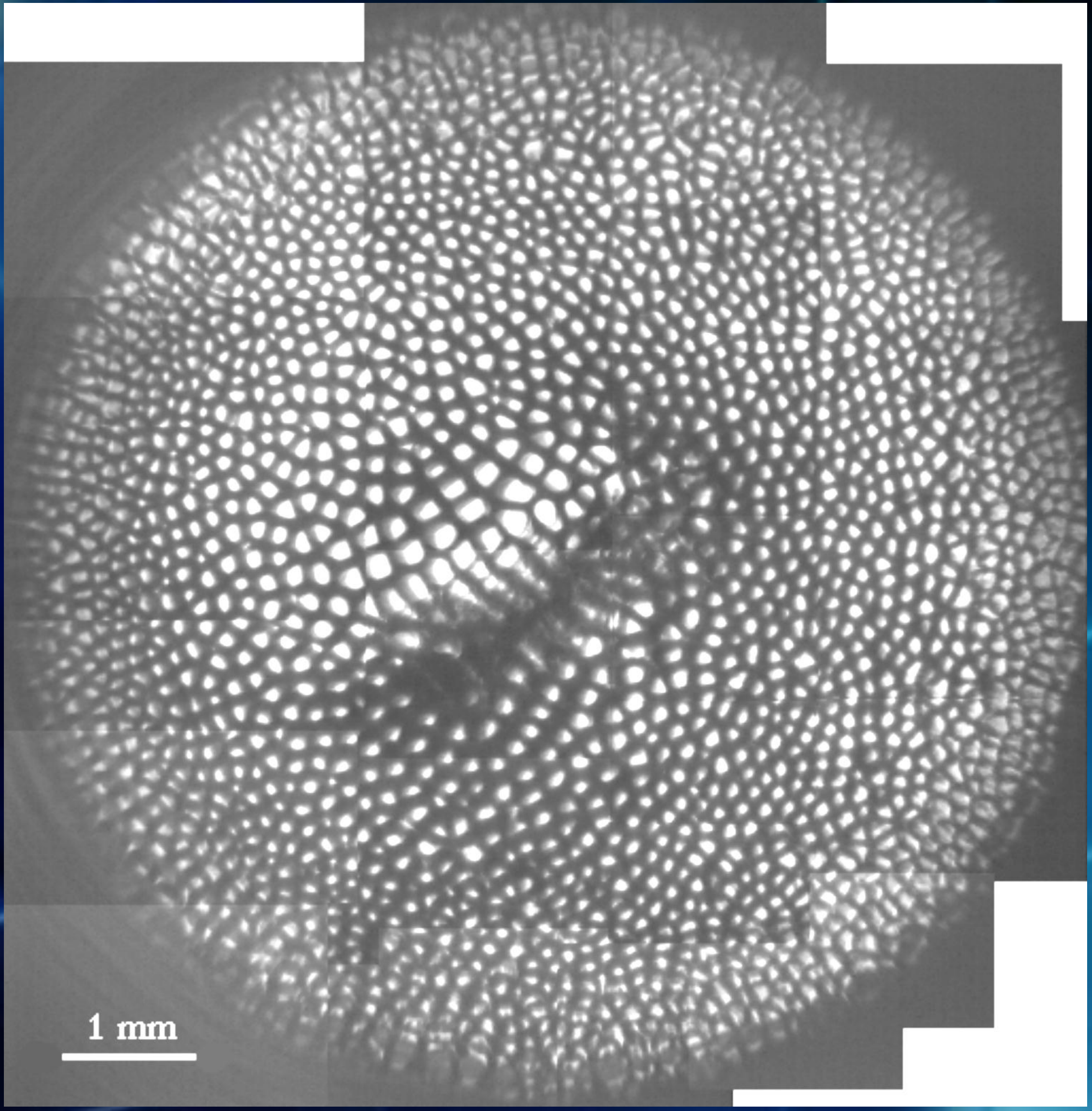




Development of cells to deep cells to dendrites with time during the directional solidification of a transparent alloy in thin samples that give two-dimensional pattern evolution under diffusive growth conditions. -- *succinonitrile-camphor,* Courtesy of Rohit K. Trivedi, Iowa State University



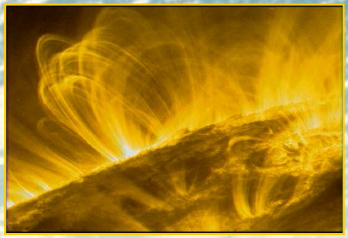




Interface pattern evolution in three-dimension, observed in bulk samples that shows a very inhomogeneous pattern evolution due to the presence of fluid flow—convection on Earth disrupts the pattern and uniformity -- succinonitrile-camphor, Courtesy of Rohit K. Trivedi, Iowa State University

Testing in the Space Environment

Materials International Space Station Experiment (MISSE)



Environmental threats include:

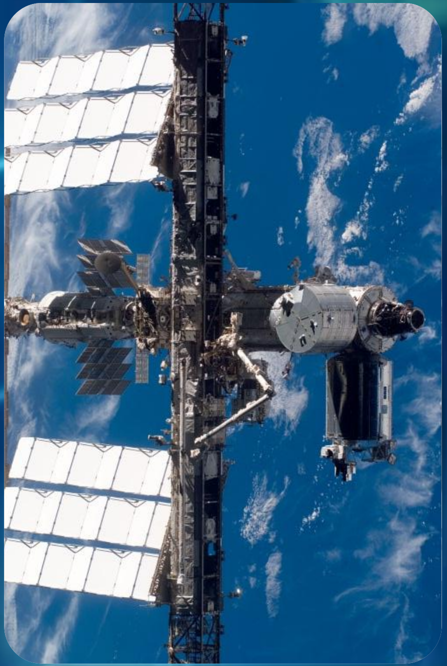
- Sun's radiation (ultraviolet (UV), x-rays)
- "Solar wind" particle radiation (electrons, protons)
- Thermal cycling (hot & cold cycles)
- Micrometeoroid & debris impacts (space particles)
- Atomic oxygen (single oxygen atom)

Three Detailed Examples

- Alloy casting
- Metallic glasses (amorphous metals)
- Semiconductor crystallization

Removing Gravity

Parabolic Flights, seconds	Sounding Rockets, minutes	ISS, hours to days



Images courtesy of ESA

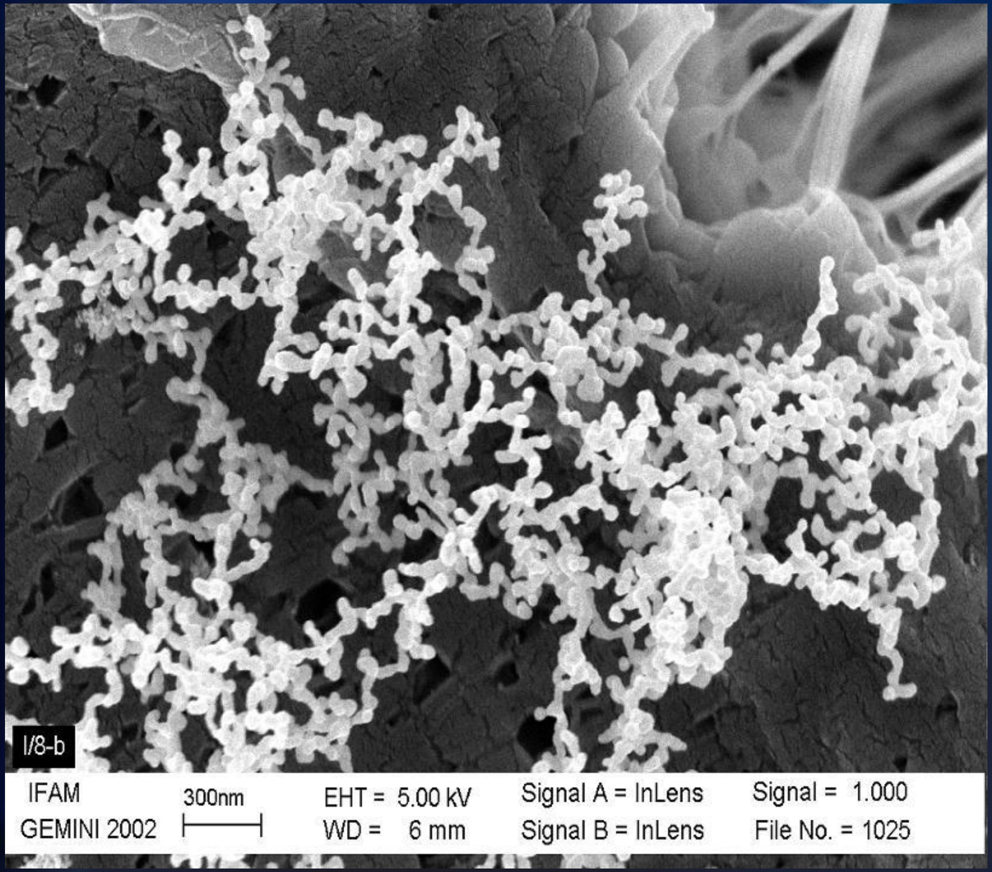
Project Objectives of IMPRESS (Intermetallic Materials Processing in Relation to Earth and Space Solidification)

Scientific: To understand critical links between the solidification processing of intermetallic alloys, the structure of the material at the micro- and nanoscale, and final mechanical, chemical and physical properties.

Technical: To develop, produce, and test novel intermetallic alloys for high quality 40cm-long investment cast and heat treated Ti-Al gas turbine blades for aero-engines and power generation turbines.

Industrial Partnership: Transvalor S.A., Alcan CRV, Arcelor Research S.A., CorusTechnology BV, Dunaferr Zrt., Femalk Rt., Honeywell International Technologies Ltd., Hydro Aluminium GmbH, MAL Magyar Aluminium Rt., Snecma - Safran S.A.

Titanium Aluminide Inter-metallics



- Remarkable mechanical and physical properties at temperatures of up to 800ºC
- Ideal combination for high performance gas turbine blades:
  - High melting point
  - High-temperature strength and creep resistance
  - Low density

Courtesy of R. Gutlin, ACCESS, Martin Zell, ESA

Top Ten IMPRESS Results for γ-TiAl Turbine Blades

1. high-yield cost-effective net-shape casting processes (both centrifugal and tilt),
2. new high-temperature capable γ-TiAl alloys (viz. Ti46Al8Nb and Ti46Al8Ta),
3. patented heat treatment process for grain refinement of cast γ-TiAl material,
4. longer lasting yttria slurries and lower cost zirconia moulds,
5. multiple VAR ingots for large-scale industrial melting up to 1 tonne,
6. novel recycling process for γ-TiAl casting scrap and out-of-service blades,
7. multi-scale modelling capabilities for all turbine blade manufacturing steps, leading to a commercial software package developed by Calcom-ESI,
8. thermodynamic and thermophysical property databases for Ti-Al-(Nb,Ta), aided by world-unique experiments in microgravity and using synchrotron X-rays,
9. first-ever mechanical property databases for both Ti46Al8Nb and Ti46Al8Ta,
10. completion of an industrial life-cycle, cost-benefit and supply-chain analysis for γ TiAl turbine blade production and in-service use.

Courtesy of R. Gutlin, ACCESS, Martin Zell, ESA

End-user aero-engine turbine application (Rolls-Royce)

Low pressure turbine blades from TiAl alloys produced by investment casting

More than 1 million LPT-blades to be manufactured over the next years

A320neo
1420 orders and options from 18 airlines by December 2011
Possible engines: LEAP-1A and GTF PW1000G PurePower
(versions A319neo, A320neo and A321neo; www.Airbus.com; January 2012)

Boeing 737 MAX
900 combined orders and options from 13 airlines by December 2011
Possible engine: LEAP-1B
(versions 737-7, 737-8 und 737-9; Flug Revue 1/2012)

COMAC C919
900 orders by December 2011
Possible engine: LEAP-1C
(Handelsblatt: „Deutsche Düsen nach China", Ausgabe 217 vom 9. November 2011, S.21)

Bombardier CSeries
110 orders and options by June 2011
Possible engine: GTF PW1100G PurePower
(http://de.wikipedia.org/wiki/Bombardier_CSeries)

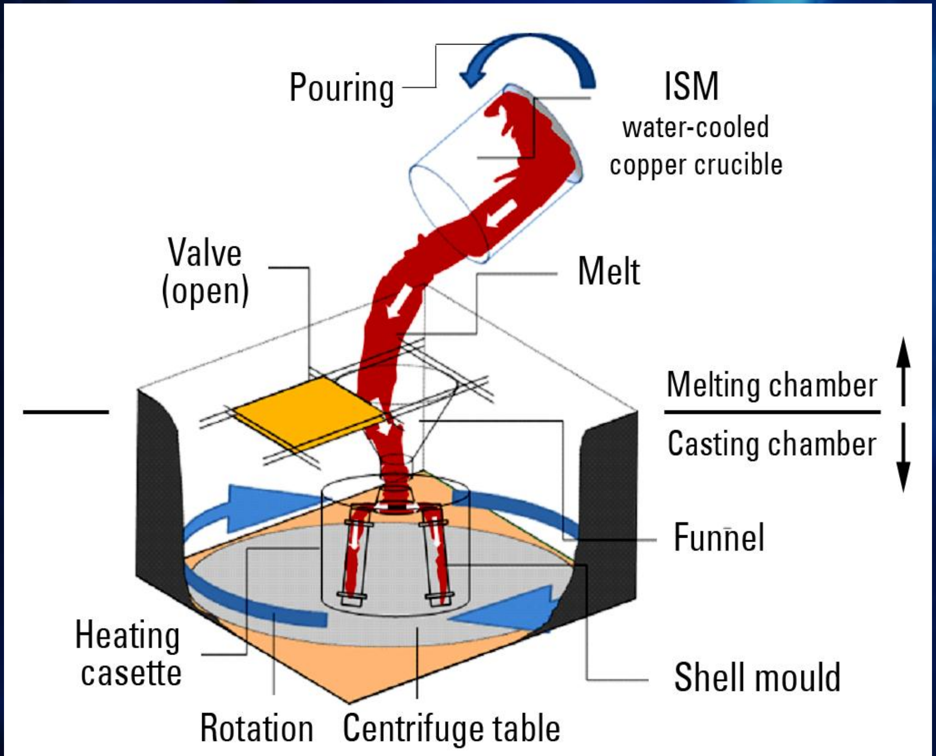
Courtesy of R. Gutlin, ACCESS, Martin Zell, ESA

Application example: casting and solidification of titanium aluminides

Courtesy of R. Gutlin, ACCESS, Martin Zell, ESA

Application example: casting and solidification of titanium aluminides

Centrifugal investment casting of aero-engine parts from titanium aluminides



Process characteristics: acceleration forces !

Materials research in micro- and hyper-gravity conditions is expected to yield :

- thermophysical properties of the liquid
- fundamental knowledge about solidification
  - → columnar-to-equiaxed transition (CET)
  - → effect of acceleration forces on CET

→ validated models for casting simulation

Courtesy of R. Gutlin, ACCESS, Martin Zell, ESA

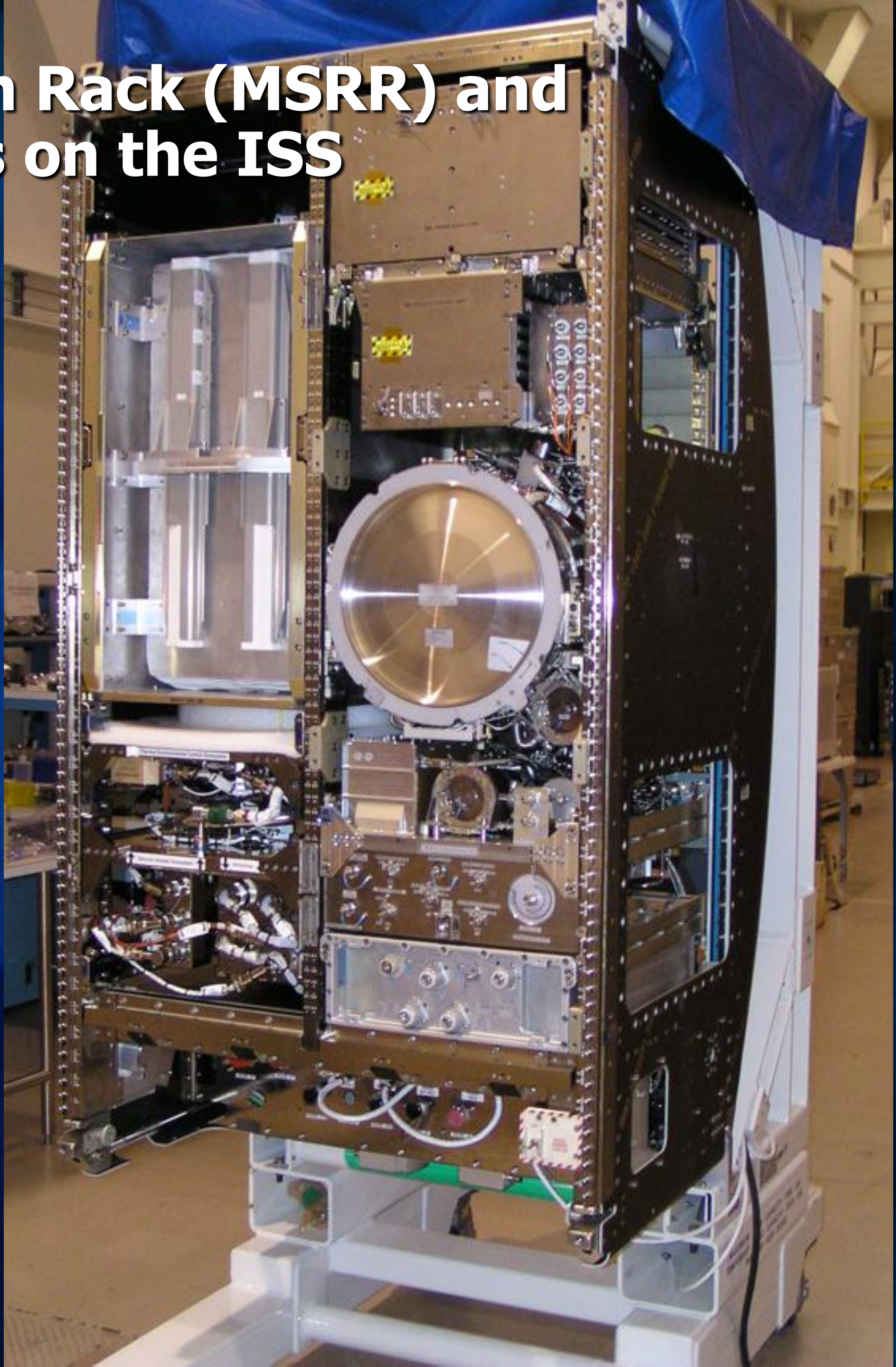
Materials Science Research Rack (MSRR) and Materials Science Facilities on the ISS

PURPOSE

- Provide a flight facility that supports research experiments to conduct material science and technology investigations in microgravity.

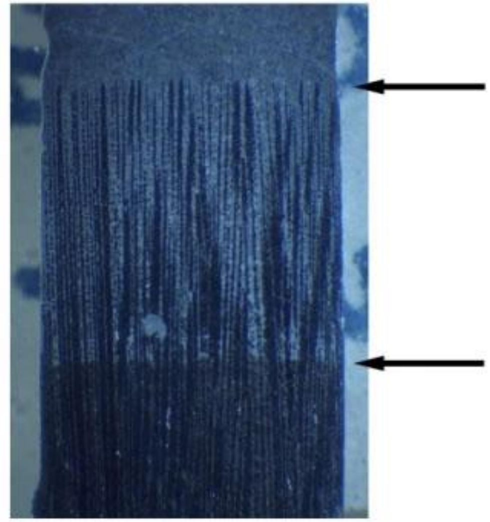
GOALS & OBJECTIVES

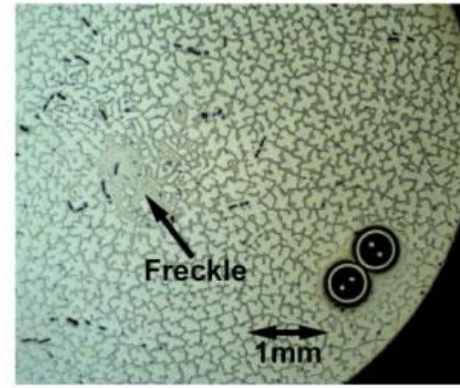
- Directional solidification of metal alloys different thermal profiles and magnetically-induced melt flow.
- Thermophysical properties of molten materials, in stable and in undercooled melts
  - surface tension, viscosity, heat capacity, enthalpy of fusion, thermal and electrical conductivity, emissivity, thermal expansion, and volume variations with melting

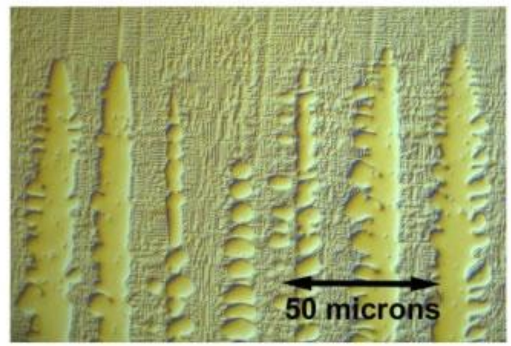


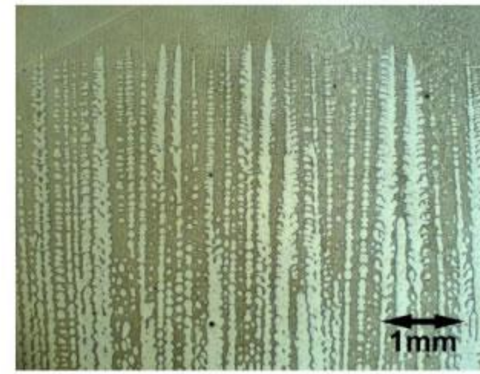
MICAST: Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically-Controlled Convective Conditions

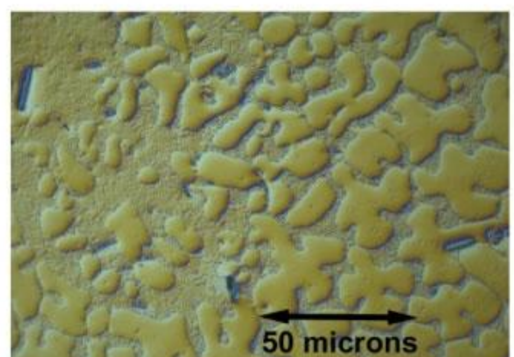
- **Defects in directionally solidified dendritic alloys result in production losses.**
  - **Misalignment of dendrite arms and macrosegregation**
  - **Uncontrolled convection.**
- **ISS research can enhance the mathematical modeling of solidification**
- **A specific objective is the simulation of solidification in castings of changing cross section.**

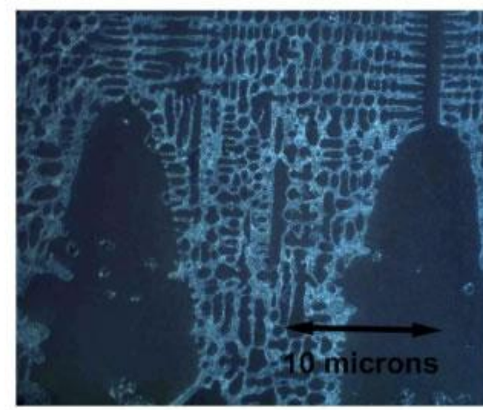








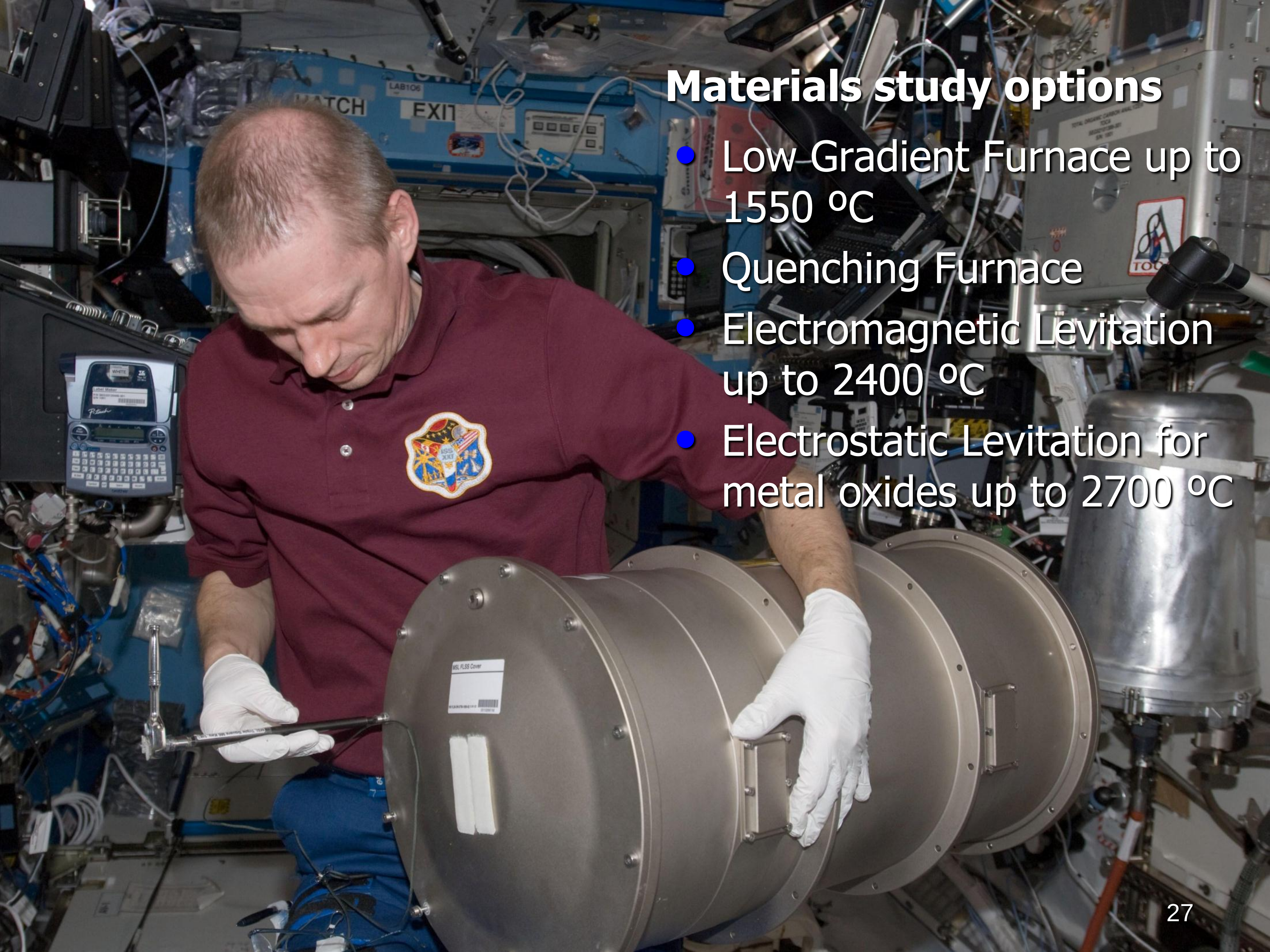




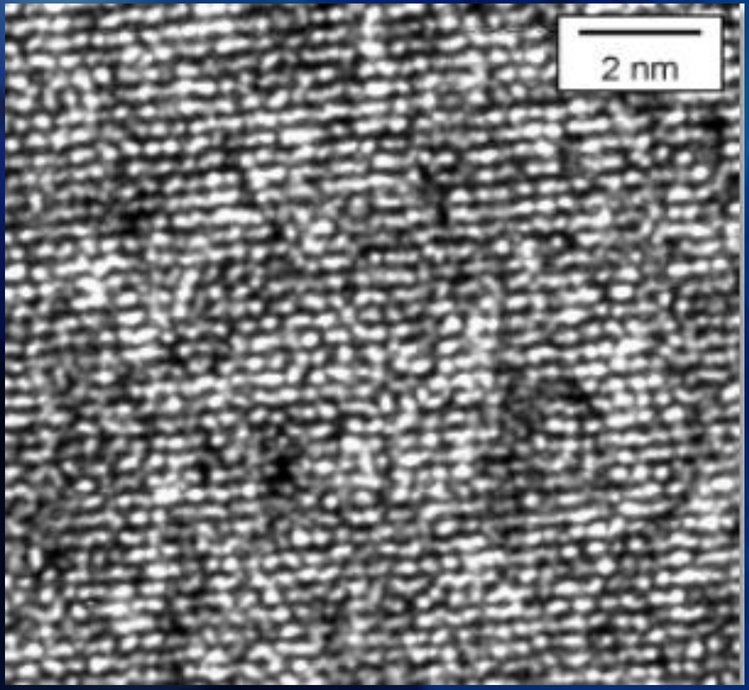
- Columnar-to-Equiaxed Transition in Solidification Processing (CETSOL)
- Growth patterns and evolution of microstructures during crystallization of metallic alloys.

Materials study options

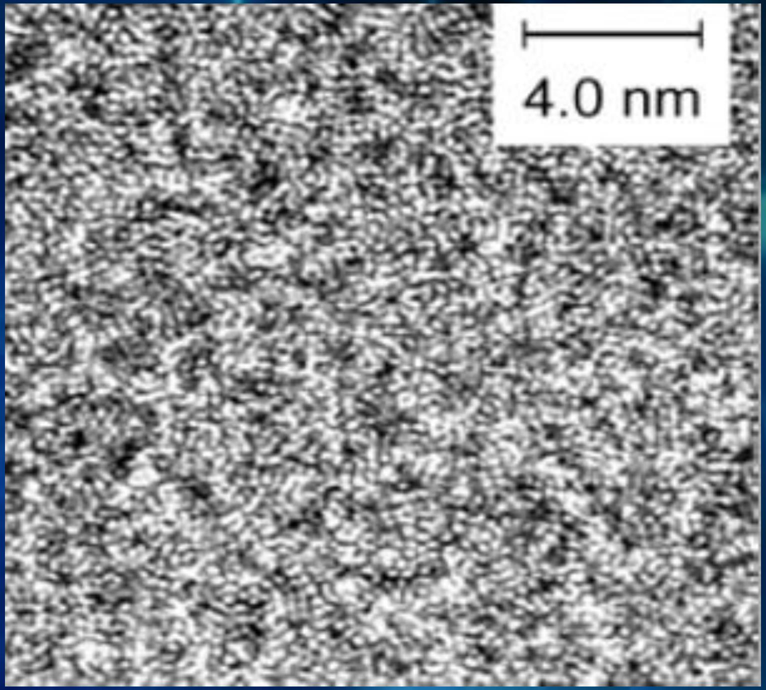
- Low Gradient Furnace up to 1550 ºC
- Quenching Furnace
- Electromagnetic Levitation up to 2400 ºC
- Electrostatic Levitation for metal oxides up to 2700 ºC



Metallic Glasses



- High resolution TEM image of a crystalline zirconium alloy

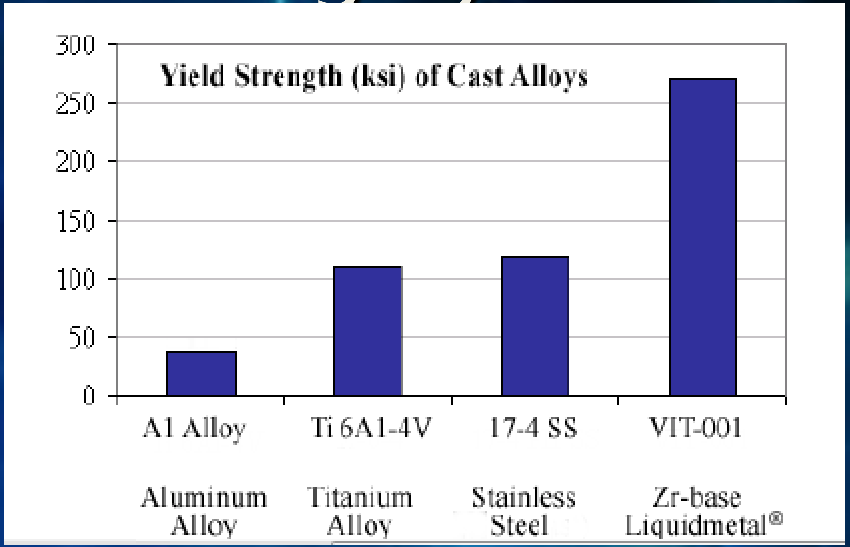


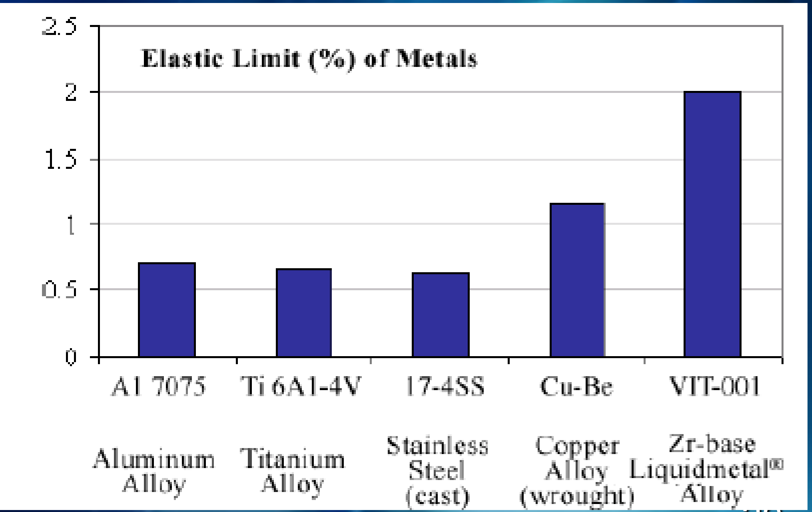
- High resolution TEM image of an amorphous zirconium alloy (metallic glass).

Glade et al. (2000) Journal of Applied Physics

TEMPUS study in space containerless processing (1997 Shuttle Flight)

- First measurements of
- specific heat and thermal expansion of glass forming metallic alloys
- Measured the specific heat capacity of the undercooled and equilibrium liquid, heats of fusion, and other thermodynamic properties
- Capability to produce bulk metallic glasses on the ground was advanced.





Glade et al. (2000) Journal of Applied Physics

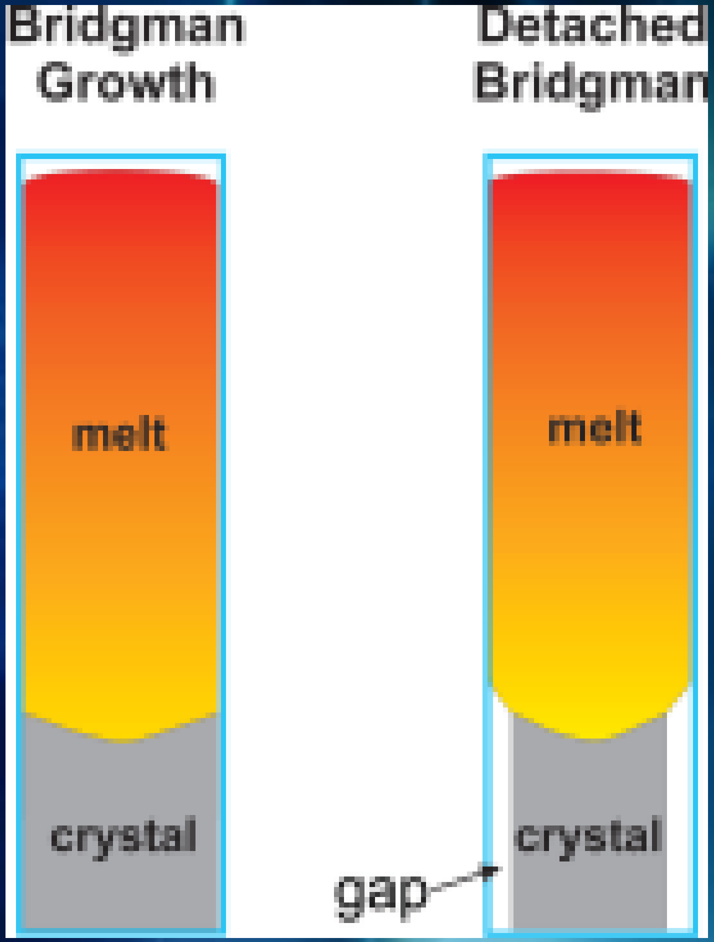
Liquidmetal® alloys

- **"Amorphous" atomic structure**, in a bulk structural metals.
- **Multi-component chemical compositions**, which can be optimized for specific properties
- **First commercially available metals** with process technologies similar to plastics.
- In 2010, Apple purchased worldwide exclusive rights to use liquidmetal in its products , renewed through 2014—but not yet used in an obvious way

Iphone SIM ejector tool

Detached Bridgeman growth technique for semiconductor crystals

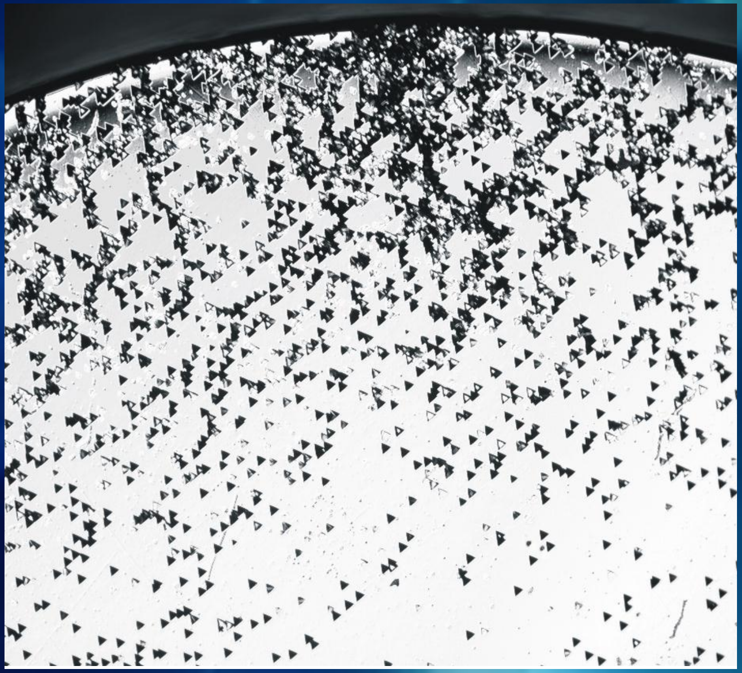
- Detached Bridgman growth--where the crystallization occurs without contacting the crucible
- First found unexpectedly in crystal growth experiments of Indium Antimonide and Germanium on Apollo-Soyuz and Skylab
- Significant reduction in crystal defects was reported for those crystals.
- Didn't always work in space, considered a curiosity



Courtesy of Martin Volz, NASA

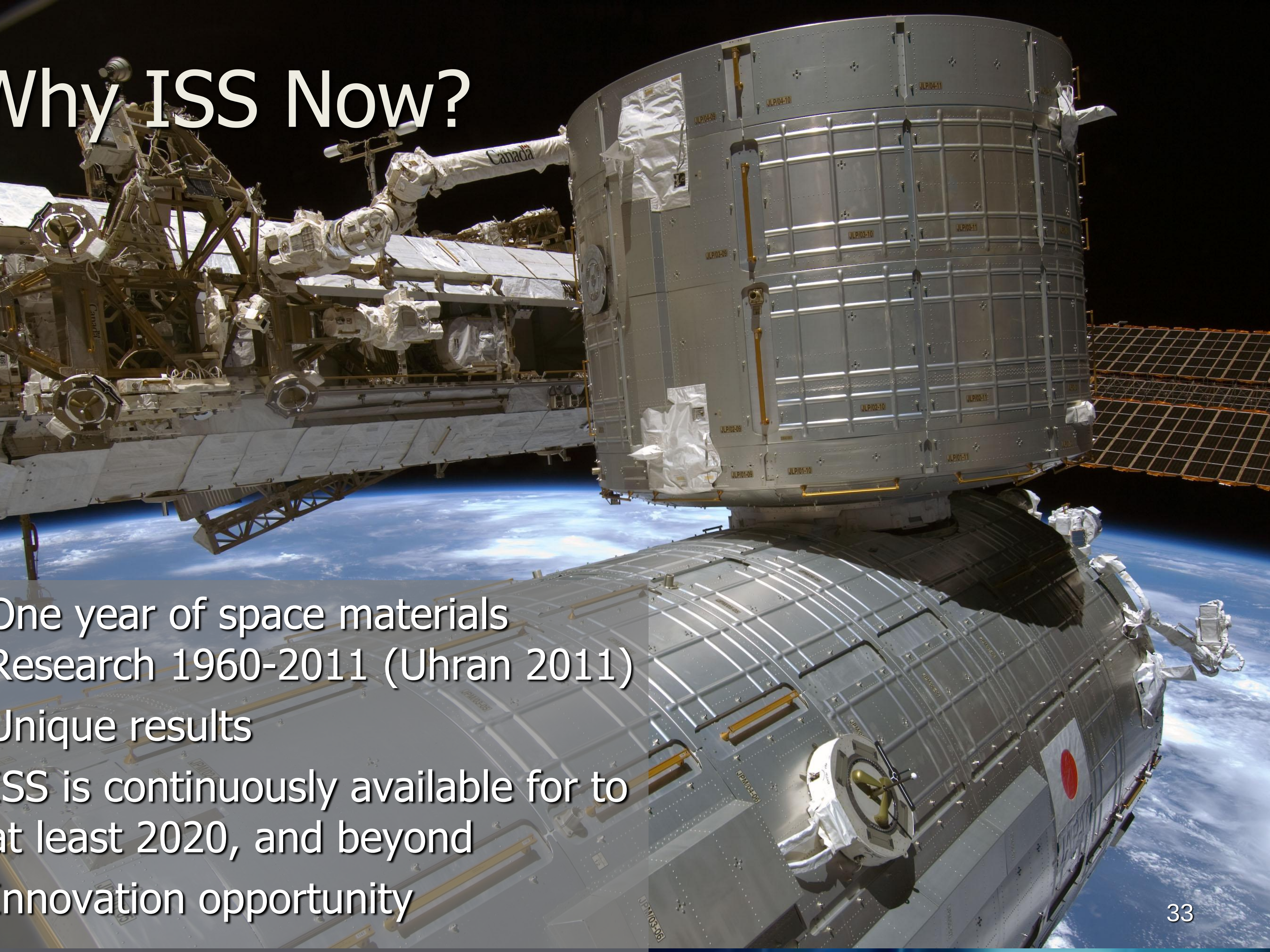
Understanding from space experiments transferred back to Earth

- Late 1990s focus on Germanium-Silicon crystals on Shuttle missions
- Detached growth made possible on Earth for Ge, Ge-Si, Gallium Antimonide, and Cadmium Telluride



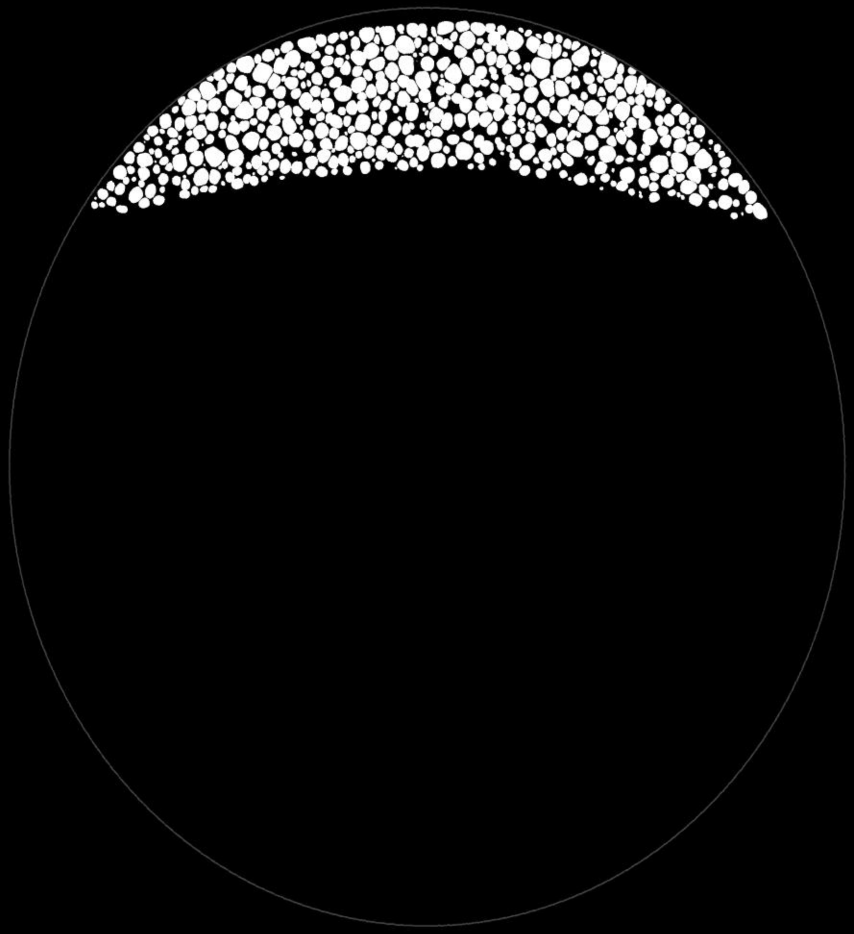
Etch pitch defects in Germanium crystals grown by detached Bridgman technique (left) and standard Bridgman (right)

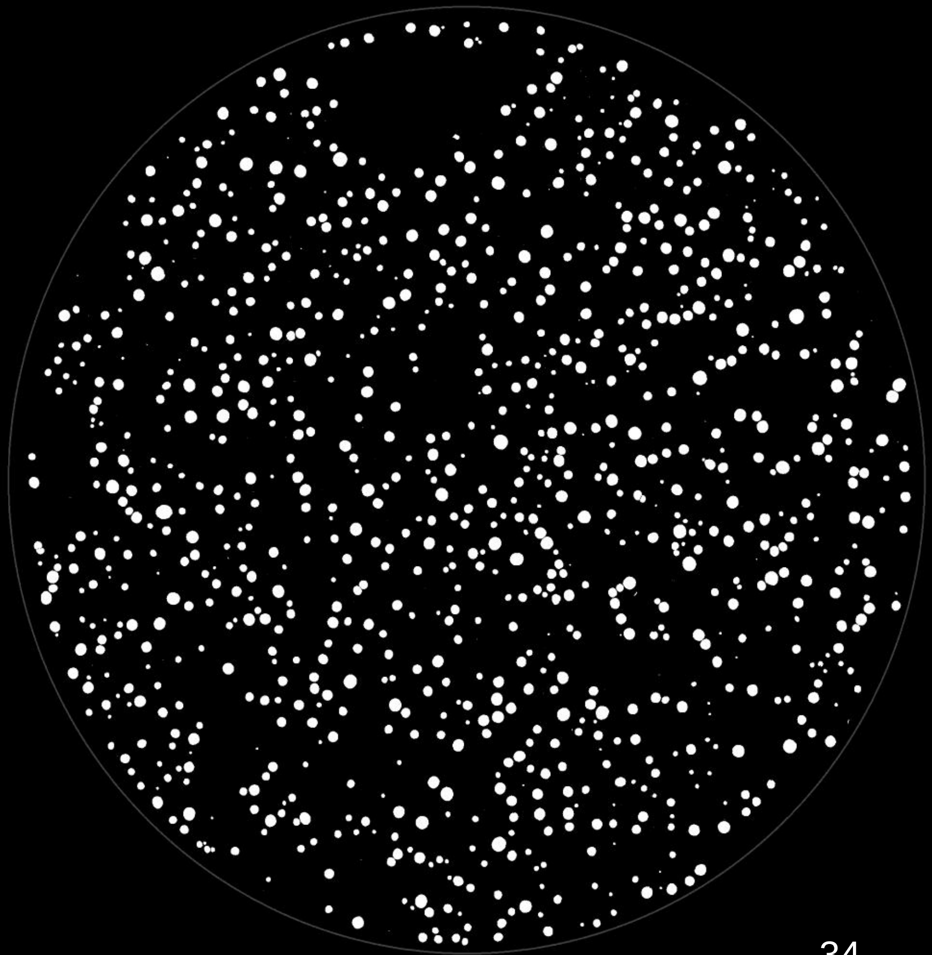
Why ISS Now?



- One year of space materials Research 1960-2011 (Uhran 2011)
- Unique results
- ISS is continuously available for to at least 2020, and beyond
- Innovation opportunity

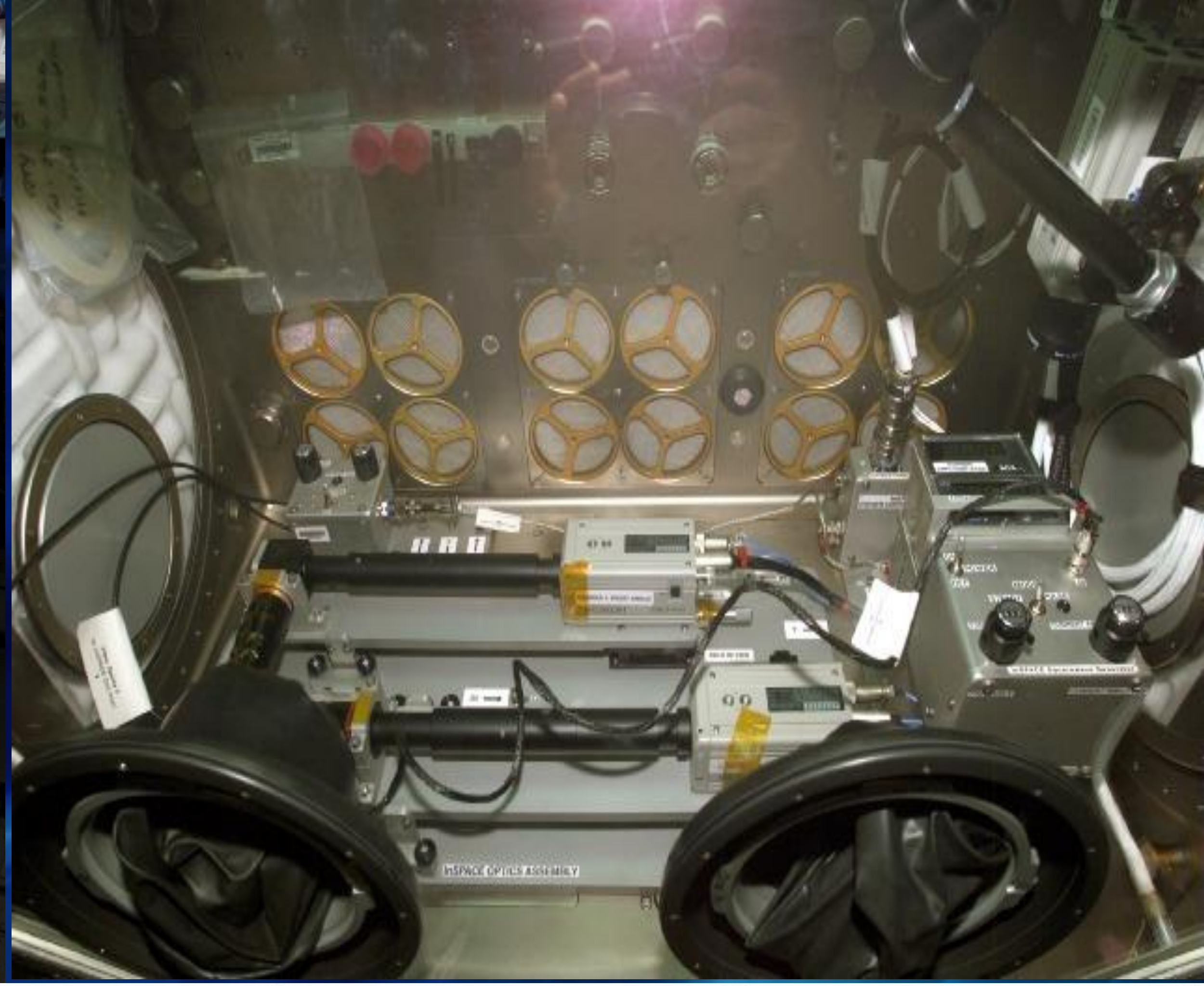
Metal Alloy processing – The reduced gravity on the ***International Space Station*** allows even distribution of particles in solid-liquid mixtures, thus providing a platform to understand the coarsening process in the development of metal alloys. Precipicalc, a code developed by a company named Questek, which is used to validate codes used in the computational design of material

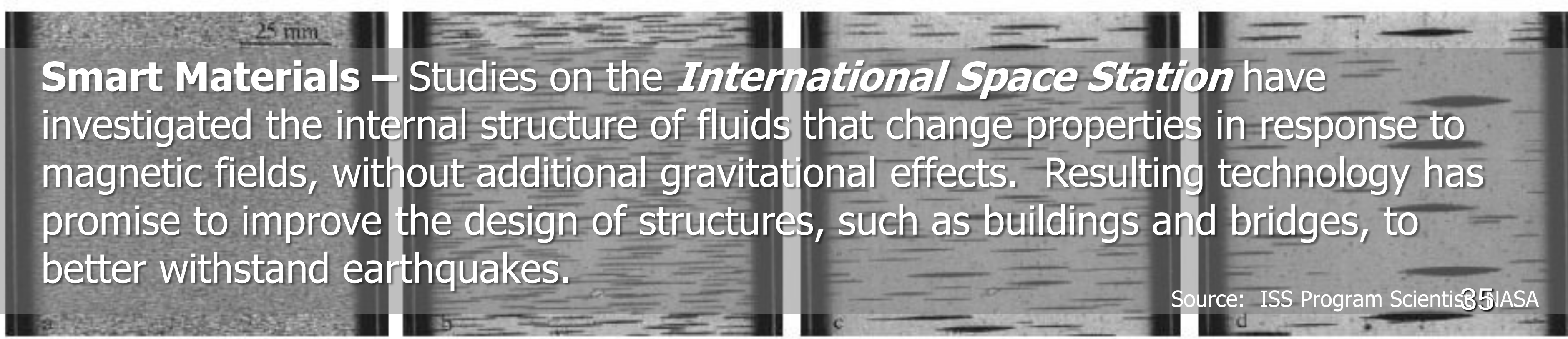




Images courtesy of Peter Voorhees, Ph.D. Northwestern University

Source: ISS Program Scientist, NASA

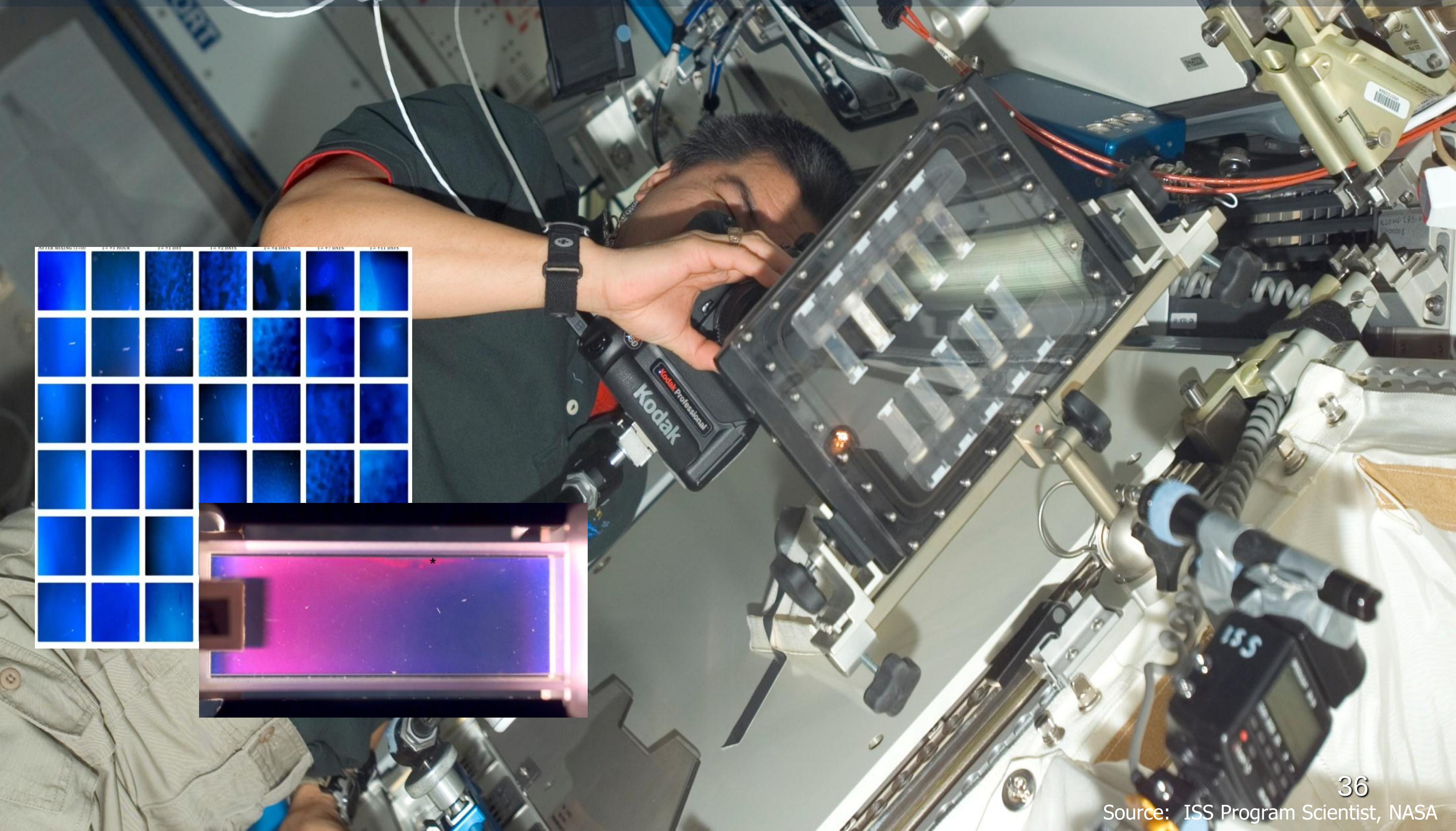




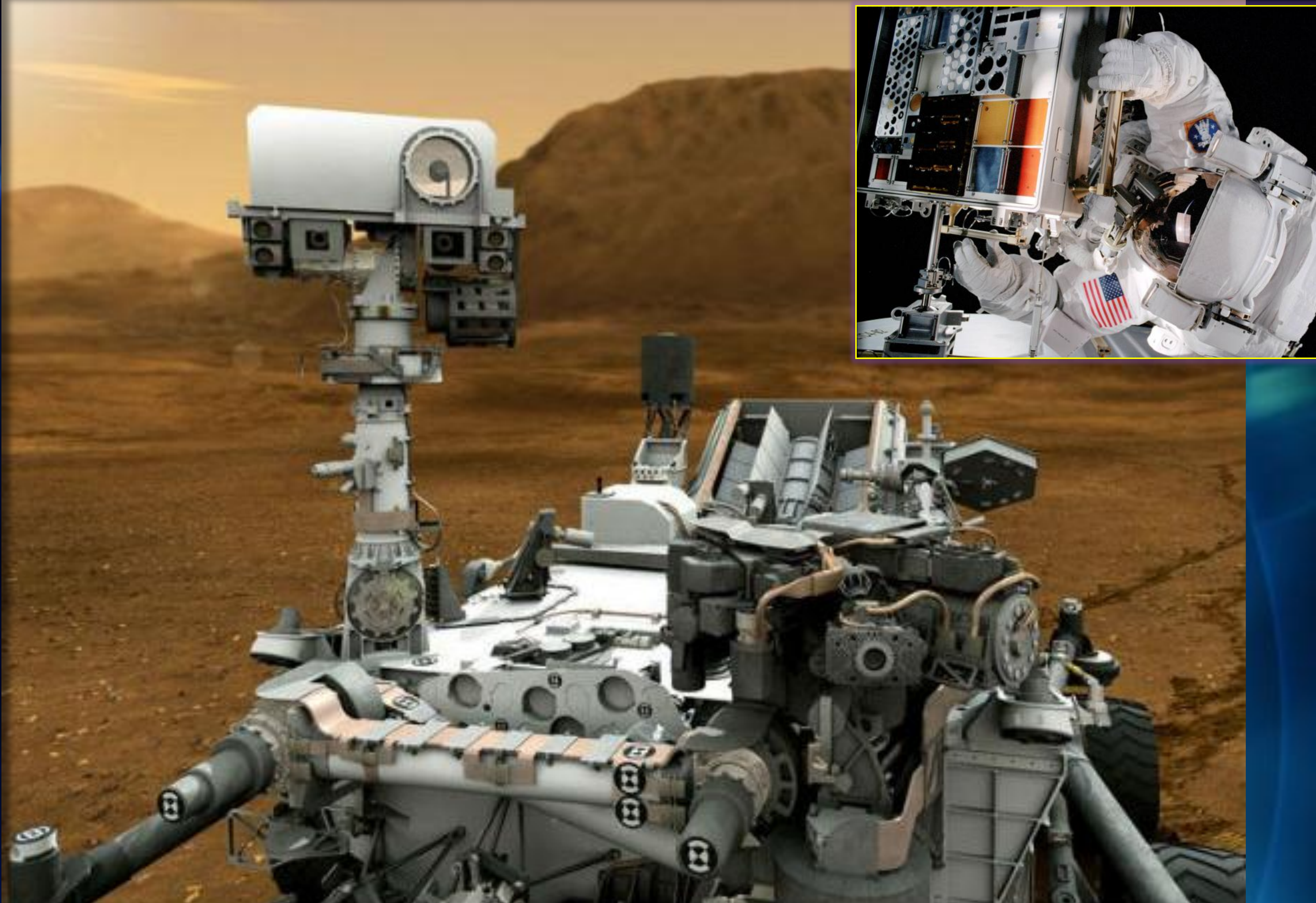
Smart Materials – Studies on the ***International Space Station*** have investigated the internal structure of fluids that change properties in response to magnetic fields, without additional gravitational effects. Resulting technology has promise to improve the design of structures, such as buildings and bridges, to better withstand earthquakes.

Source: ISS Program Scientist, NASA

Supercritical Fluids - The **Binary Colloidal Alloy Test (BCAT)** suite of studies conducted by Harvard University on the ***International Space Station*** have investigated liquid/gas phase separation changes in microgravity. Results may lead to improvements in supercritical fluids used in rocket propellants, biotechnology applications, and advancements in fiber-optics technology.



Source: ISS Program Scientist, NASA



A coating that survived long-term exposure on the ISS as part of the MISSE investigation is now protecting the Mars Curiosity Rover's critical power unit from static electricity as it collects data on Mars.

Transfer of Knowledge

Support and accelerate the transfer of knowledge generated by research in space into industrial processes or products

- Research in space - production of benchmark data - most useful if supported by a large body of ground based research
- Performing space experiments as part of industrial R&D projects is an effective way of providing industry with knowledge acquired in space

Courtesy of Martin Zell, ESA

How to Get New Research Onto ISS

◄ A 5-Phase Template ►

Summary

PHASE 1: SPONSORSHIP

- **Funding Sources**
- **Points of Contact**

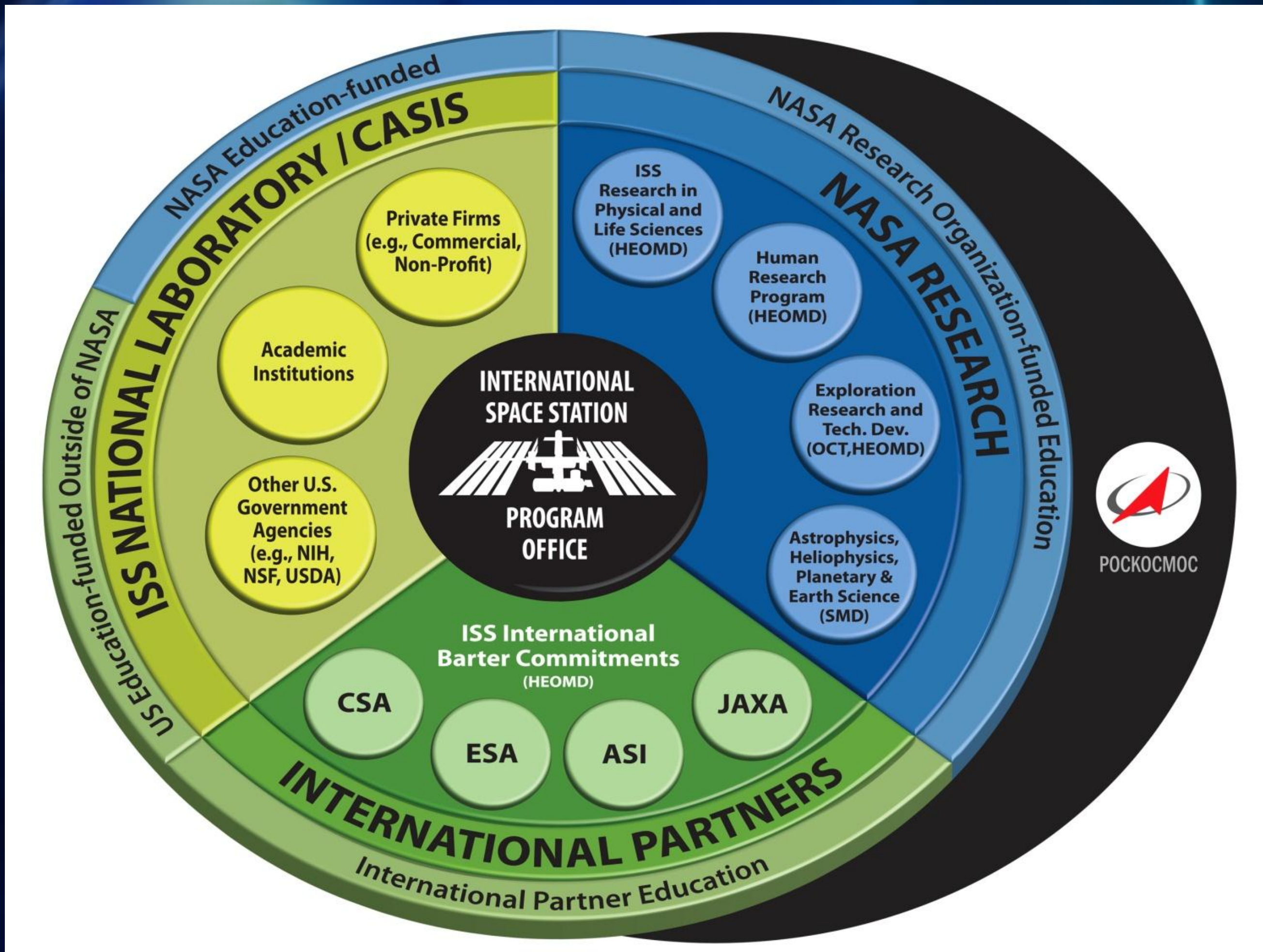
PHASE 2: STRATEGIC PLANNING

PHASE 3: TACTICAL PLANNING

PHASE 4: OPERATIONS

PHASE 5: POST-FLIGHT

PHASE 1: SPONSORSHIP
Funding Sources



(a) NASA Research

Grant opportunities and information in NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) at *http://nspires.nasaprs.com/external/*

(b) National Laboratory Research / The Center for the Advancement of Space in Science (CASIS)

The 2005 NASA Authorization Act designated the U.S segment of the space station as a national laboratory, enabling access by other Federal agencies, non-profits, and the private sector. Opportunities and information in CASIS' website at *http://www.iss-casis.org/*

(c) Educational Activities

Both NASA Education and CASIS offer education opportunities and information at NASA: *http://www.nasa.gov/mission_pages/station/research/research_teacher. html* and at CASIS: *http://www.iss-casis.org/research.php*

(d) International Partner Research

International investigators should seek sponsorship through their appropriate space agency.

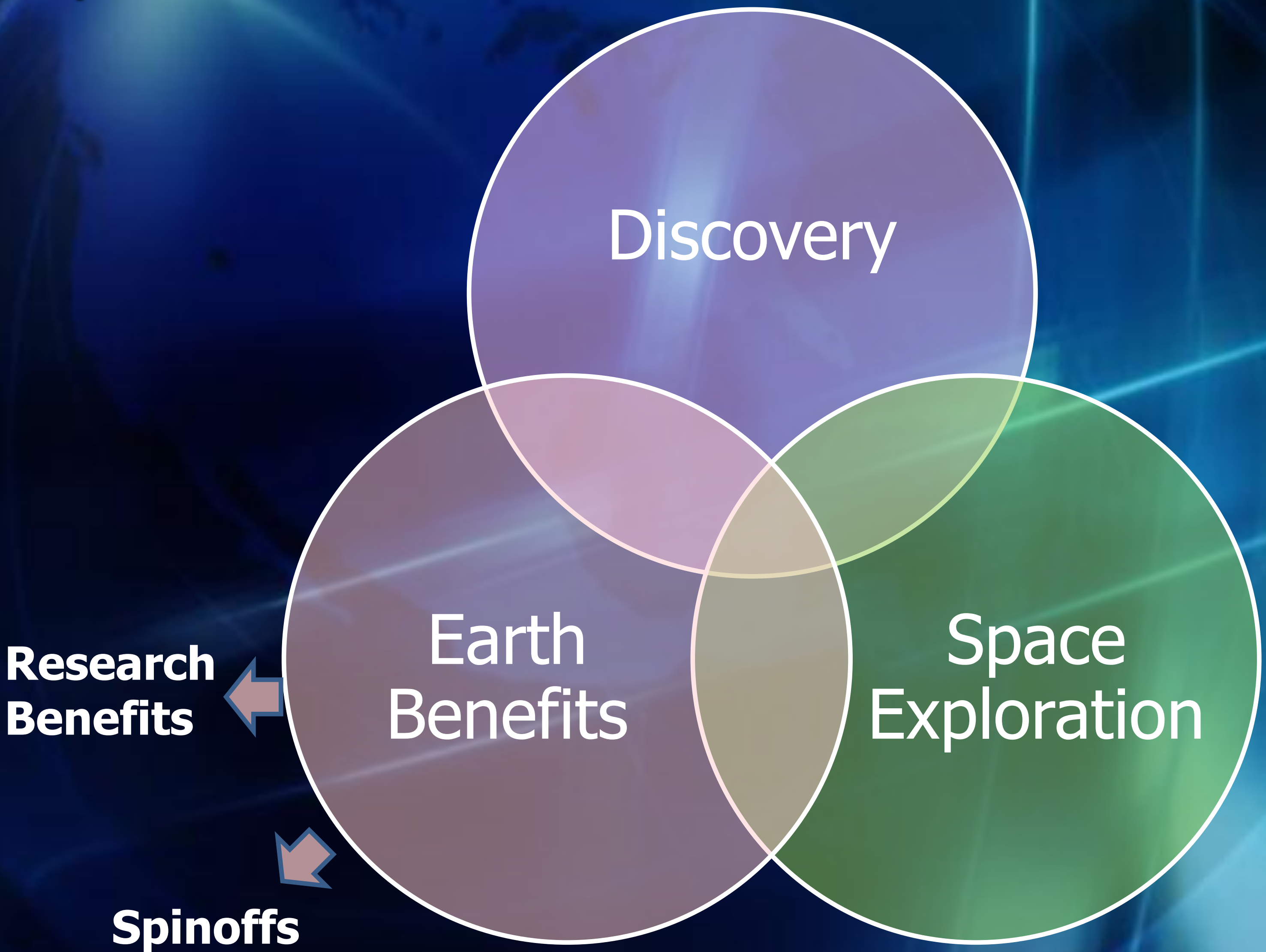
(Acronym list on last page of this presentation)

For more information on research sponsorship and funding, see:
http://www.nasa.gov/mission_pages/station/research/funding_information.html

PHASE 1: SPONSORSHIP
Points of Contact

Sponsoring Organization ***(Funding Source)***	**Selecting Organization**	**ISS Integration Contact**
NASA Life and Physical Sciences - Human Research Program *(NASA-funded)*	NASA: William Paloski	Cindy Haven, NASA/JSC
NASA Life and Physical Sciences - Physical Science *(NASA-funded)* - Space Biology *(NASA-funded)*	NASA: Marshall Porterfield	Sharon Conover, NASA/JSC
Astrophysics, Heliophysics, Space & Earth Sciences *(NASA-funded)*	NASA: Paul Hertz / Selecting Division Director	Sharon Conover, NASA/JSC
Technology Demonstration *(NASA-funded)*	- NASA Space Technology Mission Directorate: Michael Gazarik - NASA Advanced Exploration Systems: Jason Crusan	George Nelson, NASA/JSC
ISS National Laboratory *(Other government agency funded, non-profit / commercially funded)*	The Center for the Advancement of Space in Science (CASIS)	Michael Read, NASA/JSC
Education	- CASIS ISS Education: John Neubauer - NASA ISS Education: Jane Gensler	- Michael Read, NASA/JSC - Sharon Conover, NASA/JSC

What kind of benefits come from research in space?



Julie A. Robinson, ISS Program Scientist

Examples of Major ISS Benefits from the Decade of Assembly

- Discoveries
  - MAXI black hole swallowing star (*Nature*)
  - Vision impacts and intracranial pressure (*Opthalmology*)
  - Microbial virulence (*Proc. Nat. Acad. Sci.)*
- Results with potential Earth benefit
  - Candidate vaccines for Salmonella and MRSA
  - Candidate treatment for prostate cancer
  - Candidate treatment for Duschenne's muscular dystrophy
- NASA Exploration Mission
  - Life support sustaining and reliability
  - Success in bone health maintenance resistive exercise (*J. Bone Mineral Res.*)
  - Models for Atomic Oxygen erosion in orbit
- Technology Spinoffs
  - Robotic assist for brain surgery
  - TiO2 for filtering bacteria from the air in daycares
  - Remotely-guided ultrasound for maternal care in remote areas

ISS Research & Technology

http://www.nasa.gov/iss-science/

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ISS Research Blog "A Lab Aloft"

http://go.usa.gov/atI