Materials Science in Microgravity

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Early Microgravity Applications

NASA was not the first to understand and utilize the benefits of processing materials in a microgravity environment.

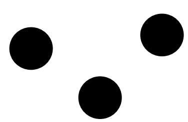
William Watts of Bristol, England built a “drop tower” in 1753 to process molten lead into uniformly spherical shot for firearms

Boughton Shot Tower
Chester, England
1799, 168’ tall

Molten lead is poured

Through a sieve

Uniform drops freefall (microgravity), buoyancy effects are minimized



Surface tension dominates forming uniform spheres

Solidified shot lands in a cushion of cooling water

Phoenix Shot Tower
Baltimore, MD, 1828
234’ - tallest structure in US
2.5 million pounds shot/year

Long Duration Microgravity Materials Science Research

Foundational Era 1950's to 1980	Shuttle Era 1980 to 2000
Mercury / Gemini / Apollo / Soyuz Spacecraft / Skylab	STS and MIR

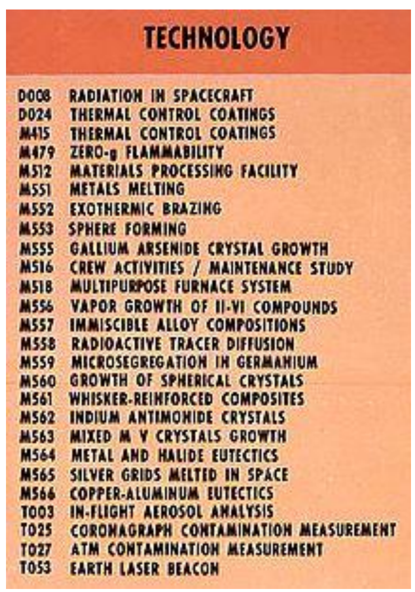
Soyuz 6 1969 1st Welding Experiment
Apollo 14 1971 Composite Casting
Skylab 1973-1979

Apollo Furnace

Skylab

Skylab: "such tests proved that the processing of metals without using containers is feasible in space".

Skylab Materials Processing Facility
Multipurpose Furnace System

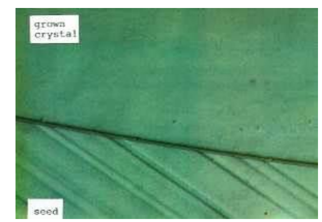


TECHNOLOGY

D008	RADIATION IN SPACECRAFT
D024	THERMAL CONTROL COATINGS
M415	THERMAL CONTROL COATINGS
M479	ZERO-g FLAMMABILITY
M512	MATERIALS PROCESSING FACILITY
M551	METALS MELTING
M552	EXOTHERMIC BRAZING
M553	SPHERE FORMING
M555	GALLIUM ARSENIDE CRYSTAL GROWTH
M516	CREW ACTIVITIES / MAINTENANCE STUDY
M518	MULTIPURPOSE FURNACE SYSTEM
M556	VAPOR GROWTH OF II-VI COMPOUNDS
M557	IMMISCIBLE ALLOY COMPOSITIONS
M558	RADIOACTIVE TRACER DIFFUSION
M559	MICROSEGREGATION IN GERMANIUM
M560	GROWTH OF SPHERICAL CRYSTALS
M561	WHISKER-REINFORCED COMPOSITES
M562	INDIUM ANTIMONIDE CRYSTALS
M563	MIXED III-V CRYSTALS GROWTH
M564	METAL AND HALIDE EUTECTICS
M565	SILVER GRIDS MELTED IN SPACE
M566	COPPER-ALUMINUM EUTECTICS
T003	IN-FLIGHT AEROSOL ANALYSIS
T025	CORONAGRAPH CONTAMINATION MEASUREMENT
T027	ATM CONTAMINATION MEASUREMENT
T053	EARTH LASER BEACON

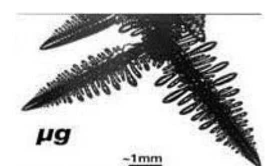
STS3 1982 Latex Spheres
STS9 1983 Spacelab 1
STS17 1985 Spacelab 3
STS51B 1985 Spacelab 2
STS61A 1985 Spacelab D1
STS40 1991 Spacelab LS1
STS42 1992 IML1
STS50 1992 USML
STS46 1992 EUREKA
STS47 1992 Spacelab-J
STS55 1993 Spacelab D2
STS57 1993 LEMZ
STS60 1994 CLPS
STS62 1994 USMP2
STS65 1994 IML2
STS73 1995 USML2
STS76 1996 QUELD LPS
STS77 1996 CFZF SEF
STS78 1996 LM2
STS94 1997 MSL
STS87 1997 USMP4

STS3 Latex Spheres



STS9 InP THM

IML1 HgI VCG



USMP2 IDGE

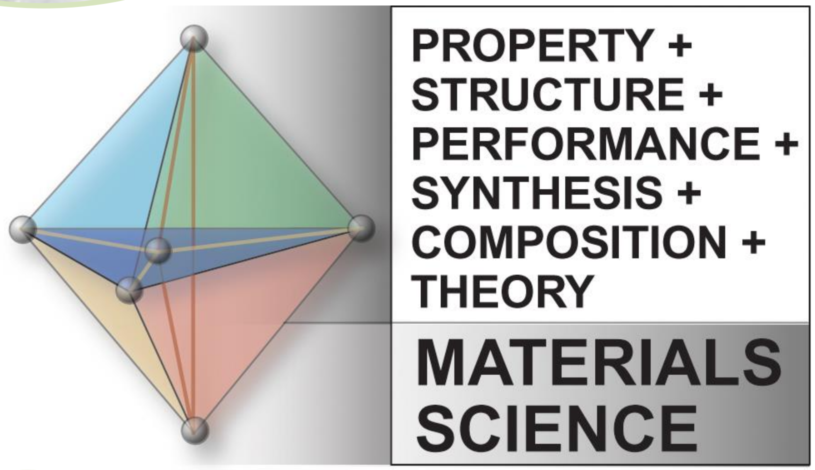
Materials Science Performance Goal

Establish and improve quantitative and predictive relationships between the structure, processing, and properties of materials.

Polymers & Organics

Metals

Glasses & Ceramics



Semiconductors

Granular Materials

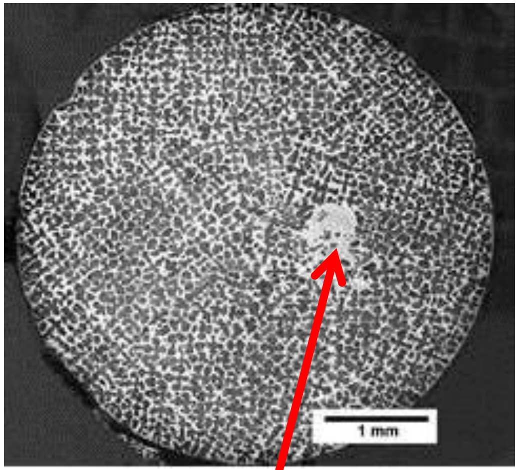
Biomaterials

Microgravity Reduces Thermal and Solutal Convection

- Microgravity promotes diffusion controlled growth and the uniform solidification of microstructures

Earth-grown

Al 7% Si
Anisotropic dendrite formation



Segregation channel
Al 7% Si

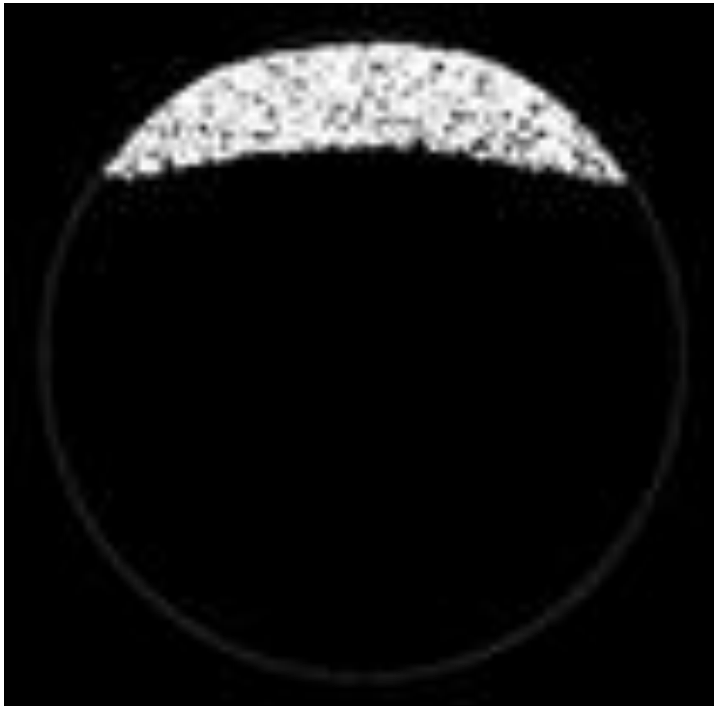
Space-grown

Pb-Sn alloy
uniform microstructure

Microgravity Minimizes Sedimentation and Buoyancy

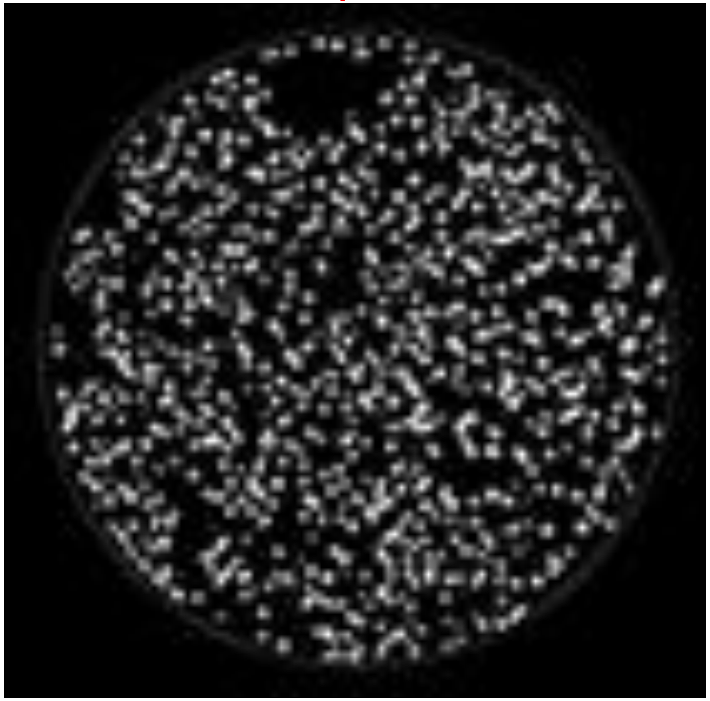
- Promotes uniform particle distributions
- Advances our understanding of coarsening and sintering

Earth



Pb-Sn alloy (*Sn in white*)
Particles rise to top

Space

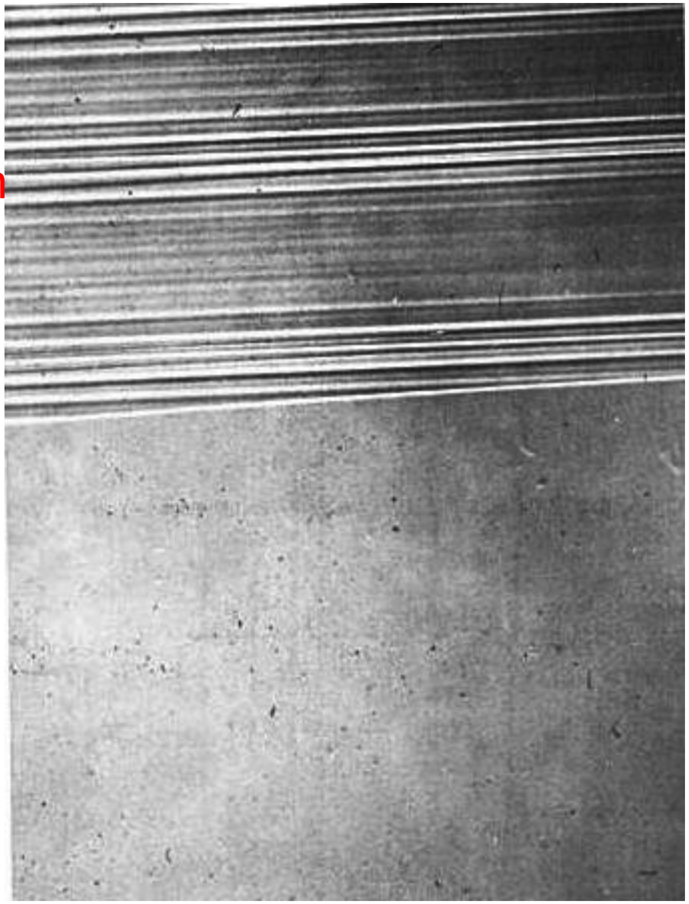


Pb-Sn alloy
uniform particle distribution

Microgravity Increases Dopant Homogeneity in Semiconductors

Objective

- Semiconductors are often doped to establish specific electronic properties (i.e. n-type or p-type).
- Convection on Earth can cause the distribution of these dopants to be inhomogeneous, degrading the suitability of crystals for their intended application.
- Absence of convection in microgravity enables an uniform distribution of the dopants.

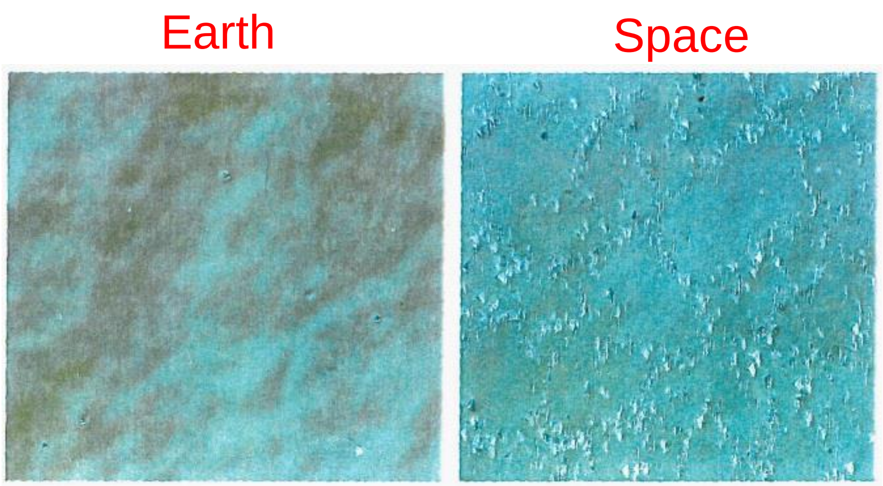


Right: Te segregation behavior revealed by etching InSb. Top portion is the seed crystal grown on Earth. Bottom section is regrowth in microgravity. Sample grown during the Skylab mission.

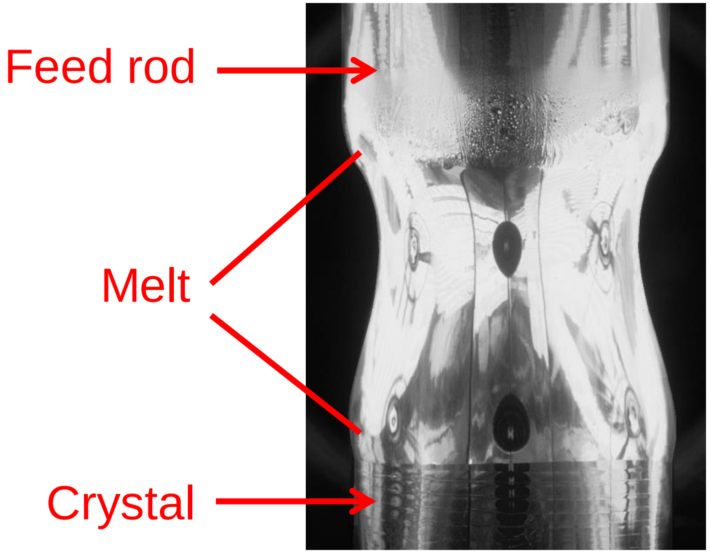
A. F. Witt, H. C. Gatos, M. Lichtensteiger, M. C. Lavine, and C. J. Herman, *Journal of the Electrochemical Society* **122**, 276-283 (1975)

Microgravity Expands the Possibilities for Containerless Processing

- Enables accurate measurements of material properties such as viscosity and surface tension
- Facilitates nucleation studies
- Increases the size of crystals that can be grown containerless
- Reduces defect densities from contact with container wall



Above: Magnification of defect structures from CdZnTe samples grown on Space and on Earth. The microgravity sample was grown during the USML-1 SpaceLab mission in 1992. Growth in microgravity resulted in a 100-fold decrease in defect density as compared to Earth.



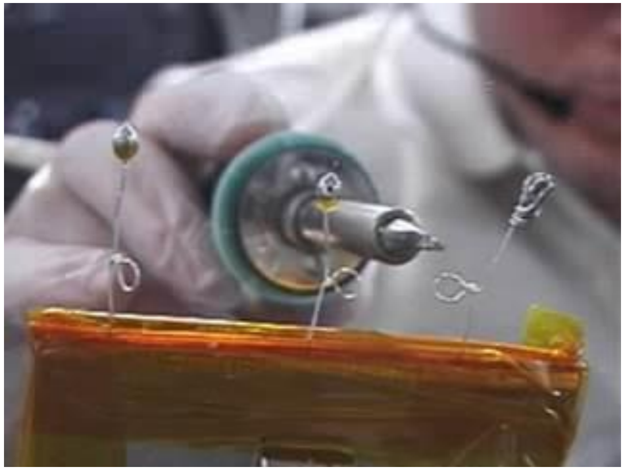
Si Float-Zone sample. The weight from gravity collapses the melt zone. The size and types of materials that can be processed are increased in microgravity

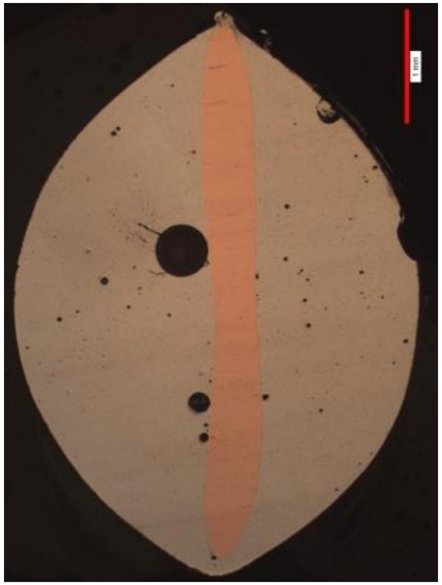
Microgravity Enables Study of Physical Phenomena Normally Masked by Gravity

- Thermocapillary effects and surface tension effects become paramount

Soldering drop in microgravity from the ISSI investigation.

Thermocapillarity causes flux and resultant bubbles to coalesce at the junction, weakening the joint.





- Removal of pressure head effects allows the study of granular materials
- Absence of buoyancy convection enables the study of thermocapillary and solutocapillary effects in systems with free surfaces

ISS US Materials Experiments to Date

Solidification Using a Baffle in Sealed Ampoules (SUBSA): MSG; Dr. Aleksander Ostrogorsky

- A series of InSb semiconductors were grown doped with Te and Zn under diffusion controlled conditions.

Pore Formation and Mobility Investigation (PFMI): MSG; Dr. Richard Grugel:

- Vapor bubble transport due to thermocapillary forces and the resultant microstructural disruption during melting

In Space Soldering Investigation (ISSI): Microgravity Workbench; Dr. Richard Grugel

Coarsening in Solid-Liquid Mixtures (CSLM): MSG; Dr. Peter Voorhees

- Observed coarsening in Pb-Sn mixtures

Dynamic Selection of Three-Dimensional Interface Patterns in Directional Solidification: DECLIC DSI; Dr. Rohit Trivedi

- Observed time dependent behavior showed cyclical patterns of expanding then contracting cellular tip radii

Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments: MSRR LGF, SQF; Dr. David Poirier

- Examine the effects of growth speed and speed-changes (step increase in growth speed and step decrease in growth speed) on the primary dendrite distribution and morphology during steady-state directional solidification of single crystal dendritic arrays (Al 7%Si alloys).

ISS Materials Program Current Status

- The microgravity materials program investigators are developing experiments to be performed on ISS in the following facilities
  - Glovebox (1 investigator)
  - DECLIC (1 investigator)
  - Electro-Magnetic Levitator (3 investigators)
  - Materials Science Research Rack (8 investigators)

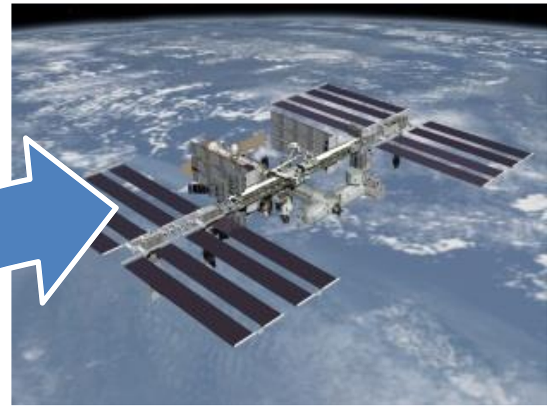
- Three other investigators are performing calculations or modeling in support of flight investigations

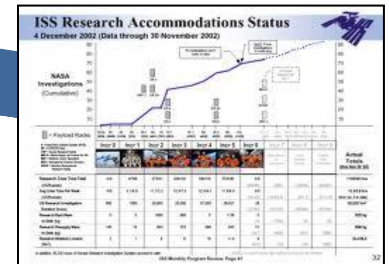
Current Areas of Investigation

- Thermo-Physical Properties of Undercooled Melts
- Metals and Alloys (Solidification)
- Semiconductors – Electronic and Photonic Materials

"materialsLAB"

A New Generation of Materials Science Experiments





Purpose: Engineers & scientists identify most promising engineering-driven ISS materials science experiments

Goal: Seek needed higher-performing materials by understanding materials behavior in microgravity

Open Source and Informatics: Inspire new areas of research, enhance discovery and multiply innovation

Linkage: Materials Genome Initiative

Engineering-Driven Science

Partners:

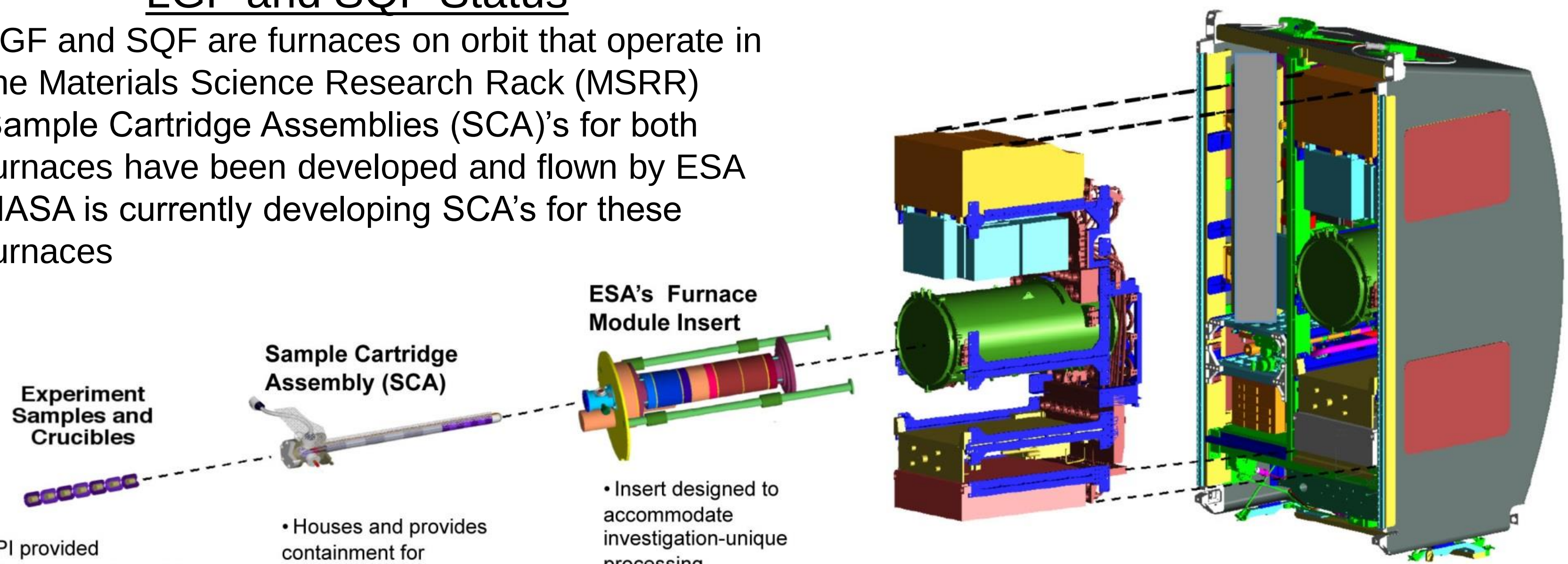
- Industry
- Academic institutions
- DOD
- NIST
- Other Government agencies
- International partners
- NASA
- CASIS

Materials Science Facilities on the ISS:

Low Gradient Furnace (LGF) & Solidification Quench Furnace (SQF)

LGF and SQF Status

- LGF and SQF are furnaces on orbit that operate in the Materials Science Research Rack (MSRR)
- Sample Cartridge Assemblies (SCA)'s for both furnaces have been developed and flown by ESA
- NASA is currently developing SCA's for these furnaces



Experiment Samples and Crucibles

- PI provided
- Samples and crucible for processing

Sample Cartridge Assembly (SCA)

- Houses and provides containment for sample and crucible set
- Instrumentation sensors for monitoring temperature and cartridge integrity
- Loaded into the insert by flight crew
- Sealed to provide one level of containment

ESA's Furnace Module Insert

- Insert designed to accommodate investigation-unique processing requirements
- Replaceable on-orbit
- Provides for "Automatic" processing
- Vacuum operations

Materials Science Laboratory Experiment Module Accommodates ESA Module Insert

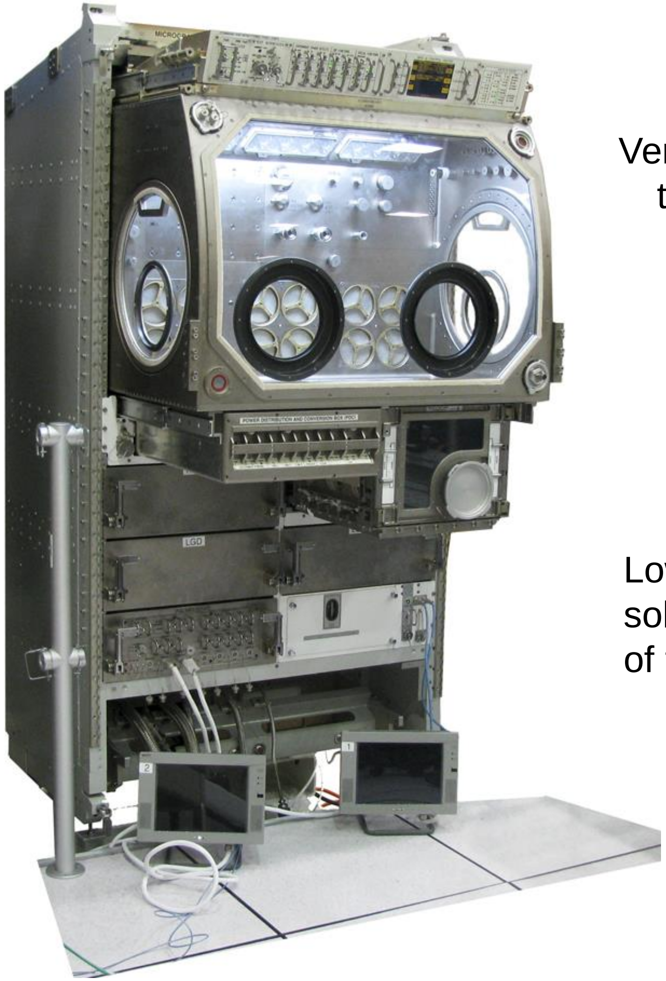
ESA Provides:

- Core Facility
- Power Supply
- Avionics/Control System
- Gas/Vacuum Distribution
- Sub-system
- Data Electronics
- Water Pump Package
- Gas Supply

MSRR-1

- NASA provides Rack and Subsystems
- NASA integrates the Rack with Payload Experiment Hardware

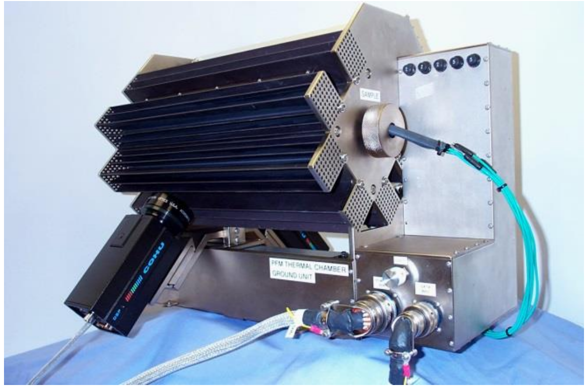
Materials Science Facilities on the ISS:
Materials Science Glovebox (MSG) Facilities



Materials Science Glovebox

SUBSA
Vertical gradient furnace with transparent growth zone

PFMI
Low temperature furnace for solidification and remelting of transparent materials



CSLM
Quench furnace used for coarsening experiments