



U.S. Materials Science on the International Space Station: Status and Plans

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Status

- Current NASA plans for materials science on the ISS include seven current and two planned investigations
- All except one are or will be collaborations with European investigation teams—seven with ESA and one with CNES
- Two investigations have experiments that were launched to the ISS in 2009
- The sole US-only investigation will be launched in 2010 to be carried out in the Microgravity Science Glove Box
- Two levitator investigators have collaborated with ESA teams on proposals that have passed the science review and been recommended for funding—EML launch scheduled on ATV3 in October 2011
- Experiments for two crystal growth investigations will be launched later, dates TBD
- ESA has invited two additional US investigators to join ongoing investigations



Current Plans

- Continue to participate in six ongoing collaborative investigations with ESA and CNES
- Carry out the MSG investigation
- Select and fund the two investigators recently invited by ESA
- Plan for a possible Materials Science NASA Research Announcement (NRA) in spring 2010



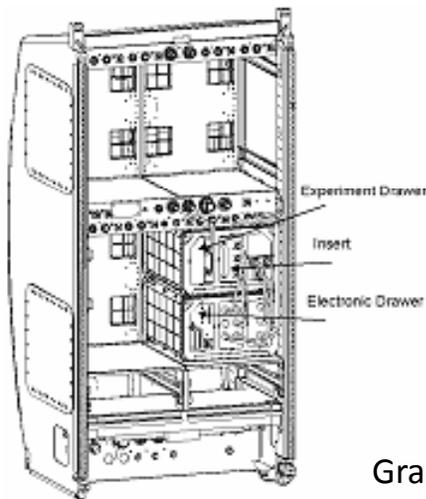
Investigations launched in 2009

- Dynamic Selection of Three-Dimensional Interface Patterns in Directional Solidification (DSIP)
 - This investigation will use the CNES-built DECLIC with the Directional Solidification Insert
- Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (MICAST/CETSOL)
 - This investigation will use the ESA-built Materials Science Laboratory and Low-Gradient Furnace which are contained in the Materials Science Research Rack built by NASA
- Both the DECLIC and the MSRR/MSL/LGF were launched on August 28 and both have completed commissioning of the hardware

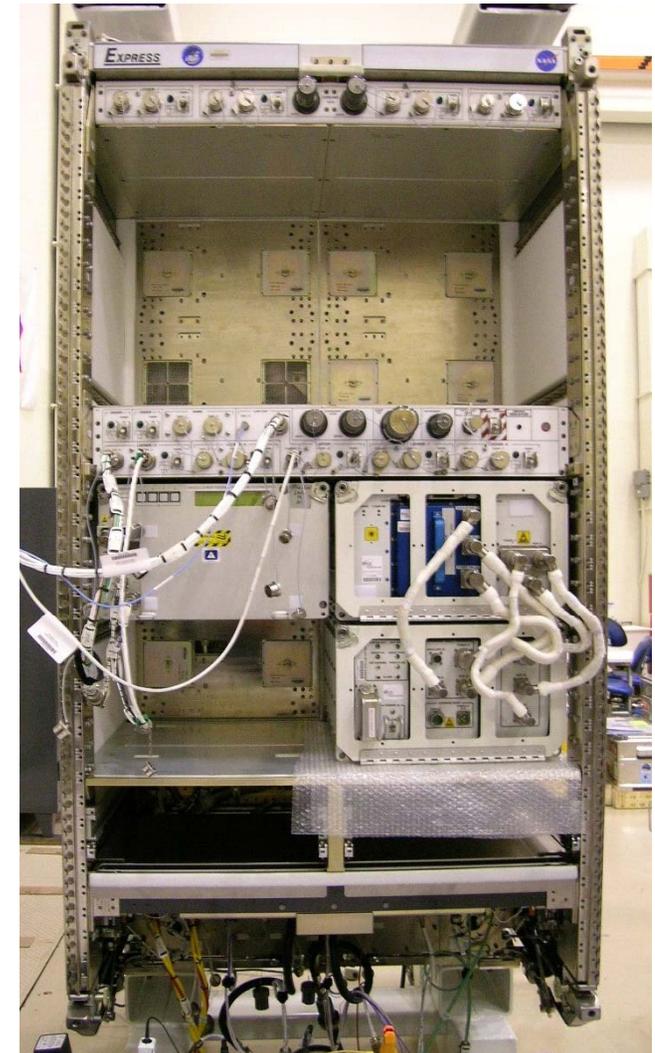


DECLIC in an EXPRESS Rack

DECLIC is a multi-user facility to investigate low and high temperature critical fluids behavior, chemical reactivity in supercritical water, directional solidification of transparent alloys, and more generally transparent media under micro-gravity environment on board the International Space Station (ISS).



DECLIC - Dispositif pour l'Etude de la Croissance et des Liquide Critiques (DEvice for the study of Critical Liquids and Crystallization).



Graphics and description taken from CNES web sites



Dynamical Selection of Three-Dimensional Interface Patterns in Directional Solidification (DSIP)



U.S. PI: Prof. Rohit Trivedi, Iowa State University

CNES Team Coordinator: Dr. B. Billia, Université Paul Cézanne, Marseille, France

Objective:

- Understanding of dendrite evolution
- Understand the dynamics that lead to uniform and reproducible three-dimensional pattern formation
- Obtain benchmark data establishing detailed dynamics of interface pattern selection during the solidification of alloys

Relevance/Impact:

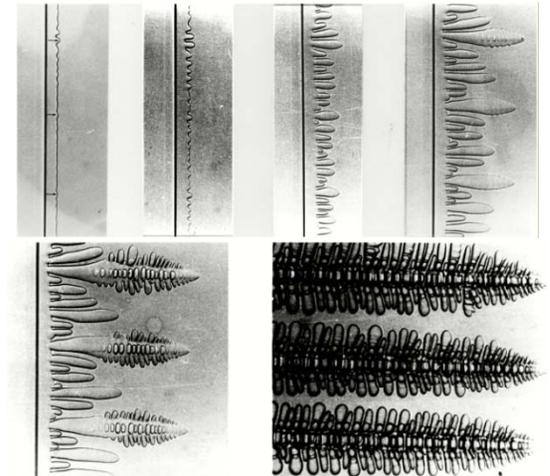
- Many industrial applications involve directional solidification
- Pattern formation is vital for controlling microstructure in high temperature, high strength alloys

Development Approach:

- Transparent alloy of succinonitrile will be used as an analog of metallic alloys
- Sample will be observed by microscopy, interferometry with a resolution of 5 microns with a sampling rate – up to 25Hz
- Samples can be re-run with different experimental conditions.

Ground-based Research:

Pertinent data are overwhelmed by gravitational effects in bulk samples.



ISS Accommodation	DECLIC
Launch	Shuttle flight 17A, August 28, 2009
Experiments	January 2010

DECLIC - Dispositif pour l'Etude de la Croissance et des Liquide Critiques.

•Accommodation will be CNES's DECLIC equipment housed within an EXPRESS rack.

•DSI, Directional Solidification Inert will be used.



Materials Science Research Rack (MSRR)



Project Manager: Jimmie Johnson/MSFC

Marshall Space Flight Center

Status:

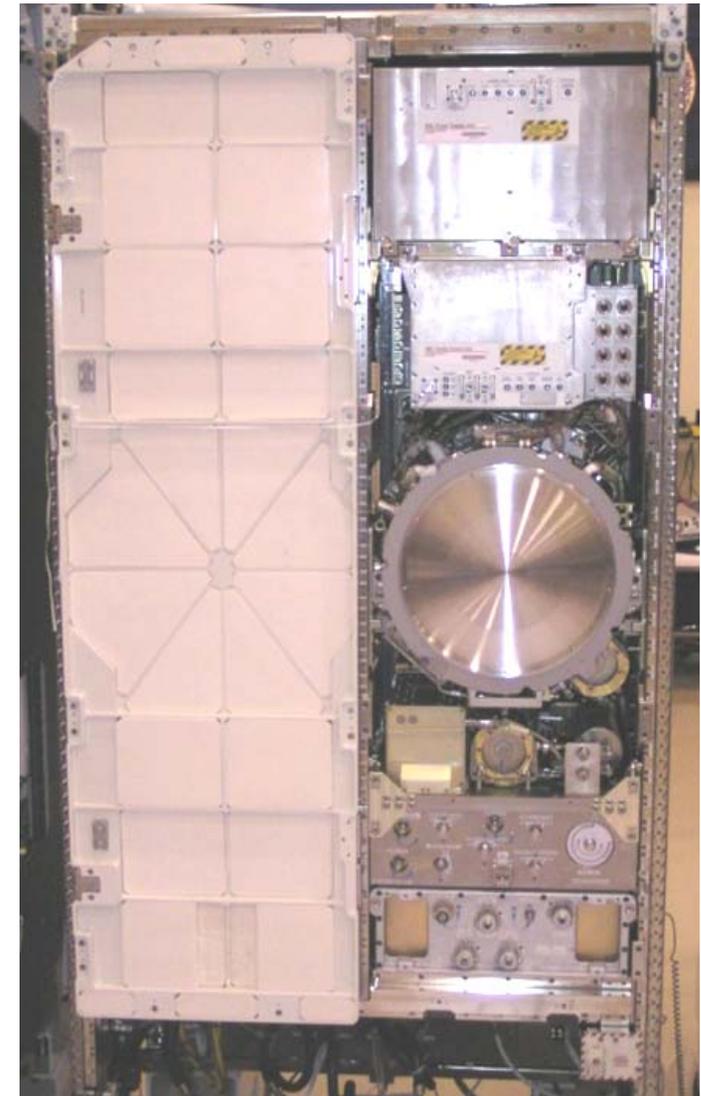
- Operational aboard the ISS

Purpose:

- To provide a facility onboard the ISS to conduct materials science research/technology experiments

Relevance/Impact:

- The MSRR can be utilized for multi-Program tasks
- The MSRR will accommodate the operation of the European Space Agency Materials Science Laboratory (MSL)





Materials Science Laboratory

Built by EADS Astrium for ESA

Status:

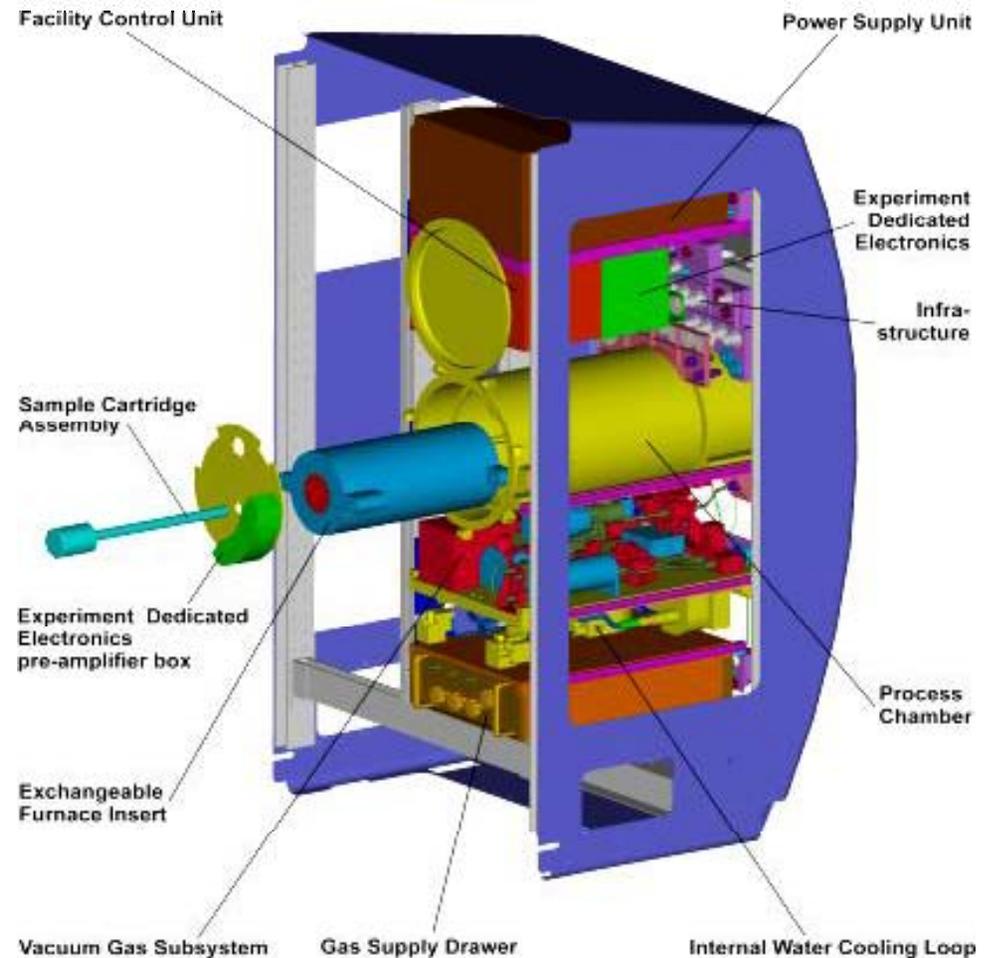
- Operational aboard the ISS with the LGF

Purpose:

- Provide operational support for furnaces including
 - Low Gradient Furnace
 - Solidification and Quenching Furnace

Relevance/Impact:

- The MSL can be utilized for multi-Program tasks



<http://www.spaceflight.esa.int/users/materials/facilities/facilities/msl.html>



Comparison of Structure and Segregation in Alloys Directionally Solidified in Terrestrial and Microgravity Environments (MICAST/CETSOL)

U.S. CSS PI: Prof. David Poirier, The University of Arizona

ESA MICAST Team Coordinator: Dr. L. Ratke, Inst. of Materials Physics in Space, DLR, Germany

ESA CETSOL Team Coordinator: Prof. Charles-André Gandin, ARMINES-ENSMP-CEMEF, France

NASA Objectives and Contributions:

- Defects in directionally solidified dendritic alloys result in production losses. Misalignment of dendrite arms and macrosegregation are produced by uncontrolled convection.
- NASA's interest is in enhancing the mathematical modeling of solidification with global objectives.

Relevance/Impact:

- Many industrial applications involve directional solidification. Convective effects are significant, particularly in today's more complex alloys.

Development Approach:

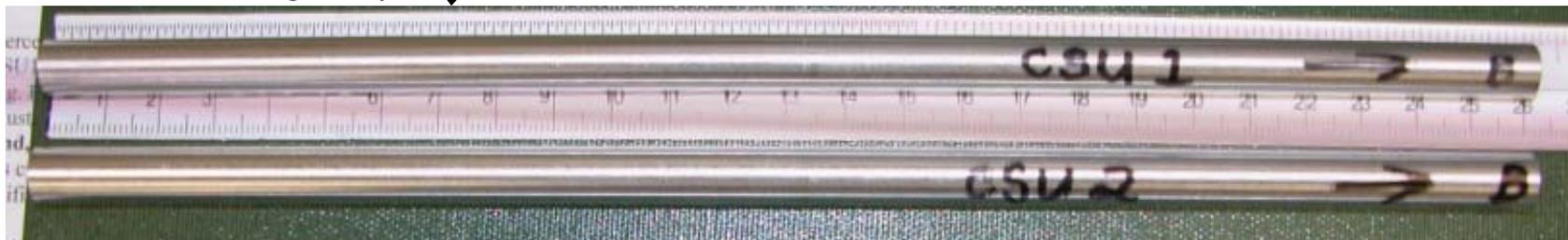
- The MICAST team will focus on microstructure control during directional solidification, particularly in Al-Si alloys.
- CETSOL will investigate pattern formation in castings, particularly the transition from columnar to equiaxed.

ISS Accommodation	LGF & MSL within MSRR
Launch	Shuttle flight 17A, August 2009
Experiments	February and June 2010

LGF – Low Gradient Furnace, MSL – Materials Science Laboratory

MSRR – Materials Science Research Rack

Flight Samples ▼



04 January 2010

AIAA ASM-48, Orlando, Florida

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Coarsening in Solid-Liquid Mixtures-2 Reflight (CSLM-2R)



MSG has been performing research on ISS since 2002



CSLM-2 in the Microgravity Science Glovebox on board the ISS

ISS Accommodation	Microgravity Science Glovebox (MSG)
Launch	Shuttle Flight 19A, March 2010
Return	May 2010



CSLM-2R



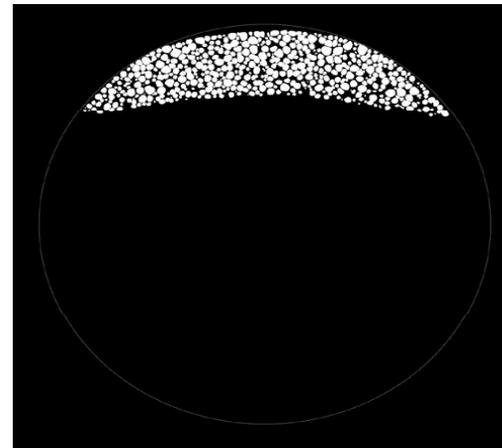
PI: Peter W. Voorhees, Northwestern University

Objective:

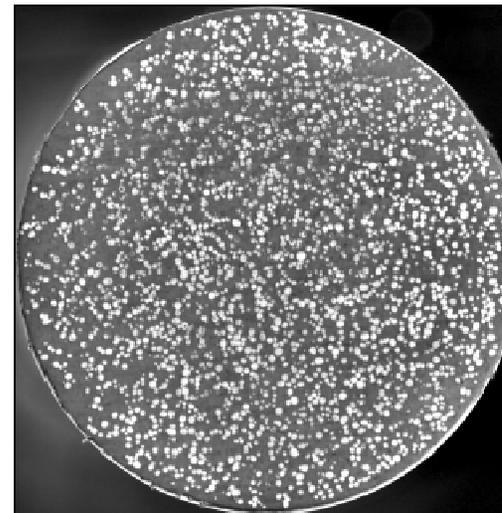
- Support the development and improve the accuracy of theoretical models of the Ostwald Ripening (coarsening) process.
- Determine the factors controlling the morphology of solid-liquid mixtures during coarsening.
- Determine the kinetics of the coarsening process, the spatial distribution of the particles, and the particle size distribution as function of the volume fraction of solid.

Relevance/Impact:

- CSLM-2 R results will provide input that will improve design codes that are based on incomplete models and databases.
- CSLM-2 R will thus aid in the development of new high-temperature materials, such as those used in nuclear propulsion and waste heat coolant loops.



Ground-Based Sample



CSLM-2 30% high volume sample from ISS Increment 16



Crystal Growth Investigations

- The experiments planned for the two crystal growth investigations will also use the MSRR/MSL/LGF
 - Crystal Growth of Ternary Compound Semiconductors (GTS/CdTe)
 - Reduction of Defects in Germanium Silicon (RDGS)



Crystal Growth of Ternary Compound Semiconductors (GTS/CdTe)

Crystallization of Cadmium-Telluride and Related Compounds

US CGT/CdTe PI: Dr. Ching-Hua Su, NASA MSFC

ESA Team Coordinator: Dr. Michael Fiederle, Freiburg, Germany

NASA Objectives and Contributions:

- In crystal growth there is a need to understand the relation between processes in the fluid phase, both liquid and vapor, such as buoyancy driven convection, the incorporation of impurities, and defects in the resulting crystal
- Relation between fluid phase processes and the generation of defects in a grown crystal is an outstanding problem in materials growth
- Studies in microgravity will be compared with modeling and will be used to optimize ground-based experiments

Relevance/Impact:

- Ternary compound semiconductors are of vital national interest as sensors in x-ray telescopes and for homeland security, and as substrate materials for infrared sensors.

Development Approach:

- Vapor transport and directional solidification will be investigated in CdZnTe.
- Phase equilibria and other thermodynamic properties are being studied on the ground.

Ground-based Research

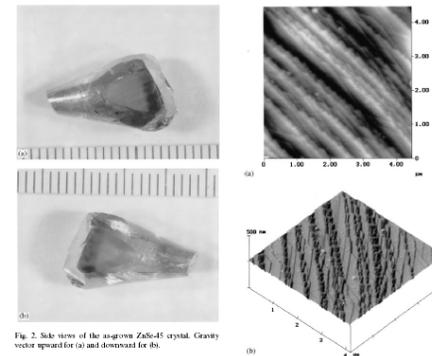


Fig. 2. Side views of the anaglyph ZnSe/CdTe crystal. Gravity vector upward for (a) and downward for (b).

Crystal terraces on this ZnSe (110) facet are separated by ~0.5 mm on the freshly grown surface and were measured between 20 and 60 nm height. Facets tend to align parallel to gravity vector.

ISS Accommodation	LGF & MSL within MSRR
Launch	TBD

LGF – Low Gradient Furnace, MSL – Materials Science Laboratory,
MSRR – Materials Science Research Rack



Reduction of Defects in Germanium Silicon (RDGS)



U.S. RDGS PI : Dr. Martin P. Volz, NASA MSFC

ESA Team Coordinator : Dr. Arne Cröll, University of Freiburg, Germany

NASA Objectives and Contributions:

- Partially detached crystals can be grown on Earth
- Test the theory that solidification free of wall contact reduces defect density.
- Evaluate competing theories for the production of critical materials by testing different growth configurations and using the space environment

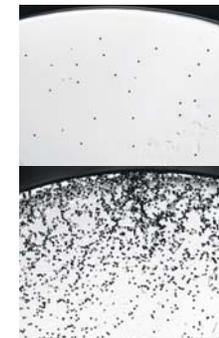
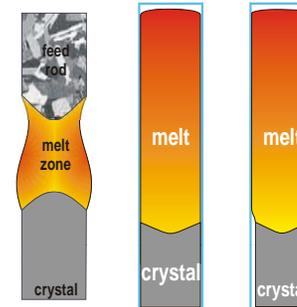
Relevance/Impact:

- Defects in semiconductor substrates propagate into the final electronic devices thereby reducing their performance
- Ideal is a breakthrough in understanding and control of detached terrestrial growth in many materials of technological and commercial interest.

Development Approach:

- NASA will concentrate on Bridgman growth, with the German team working on float zone.
- German teams will make use of free flyers (FOTON)
- Flight experiments will be done in LGF/MSL/MSRR

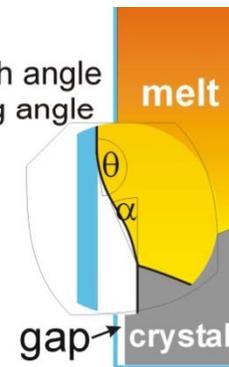
Float Zone Solidification Attached Solidification Detached Solidification



Detached

Attached

α : growth angle
 θ : wetting angle



Two order of magnitude reduction in etch pits when grown detached.

ISS Accommodation	LGF & MSL within MSRR
Launch	TBD

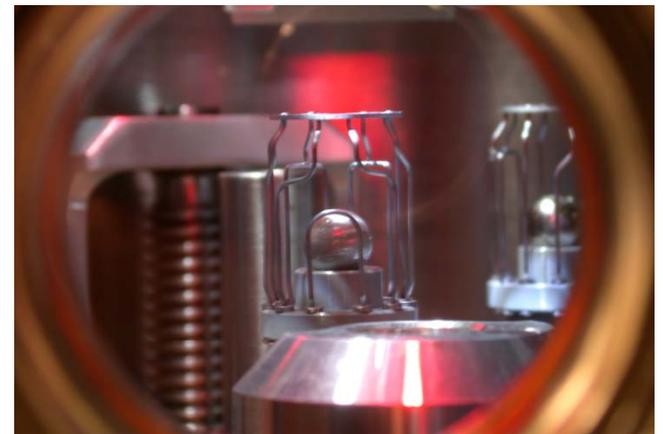
LGF – Low Gradient Furnace, MSL – Materials Science Laboratory

MSRR – Materials Science Research Rack



Levitator Investigations

- Two US investigators have written joint proposals with European investigators to use the DLR-ESA Electromagnetic Levitator planned for the Columbus Orbiting Laboratory.
- Proposals were submitted to the ESA 2009 AO and have passed the science review.





Quasi-Crystalline Undercooled Alloys for Space Investigation (QUASI)

U.S. PI: Dr. Kenneth Kelton, Washington University in St. Louis

ESA Team Coordinator:

Objectives:

- Tests of Nucleation Theories
- Determine influence of liquid solid short-range order on thermophysical properties
- Determine dependence of growth mechanism on the complexity of the crystallizing phase
- Study the influence of fluid flow on the growth kinetics and microstructure formation during solidification of structurally complex solid phases

Fundamental Scientific Questions:

- What are the local structures of undercooled metallic liquids?
- Does the evolving liquid structure underlie novel behavior such as mode-coupling and fragile-to-strong transitions, and the glass transition?
- Does the liquid local structure couple with the nucleation barrier as predicted by Frank?
- Do predictions from the Classical and Coupled-Flux Theories agree with data for undercooled liquid alloys?
- What influence does fluid flow have on the crystal growth velocity during solidification of undercooled liquids and on the microstructure formation?

Practical Importance:

- Provide data for numerical modeling of thermophysical materials properties in the stable and undercooled liquid
- Provide insight for development of new advanced products to reduce energy consumption and environmental pollution and guarantee sustainable growth.

ISS Accommodation	Electromagnetic Levitator (EML) in Columbus Orbiting Facility
Launch	ATV3 in October 2011



The Role of Convection and Growth Competition in Phase Selection in Microgravity (LODESTARS)

U.S. PI: Dr. Douglas Matson, Tufts University

ESA Team Coordinator:

Objectives:

- Obtain a comprehensive understanding of the processes involved in phase selection and the transformation kinetics for developing models to control properties in commercially important structural materials solidifying from the undercooled melt.
- Propose a new transformation theory to explain the influence of convection on phase selection

Relevance/Impact:

- Applicable to alloys including ternary austenitic Fe-Cr-Ni steel alloys, soft magnetic FeCo peritectic alloys, and titanium aluminide compositions used in turbine blade applications.

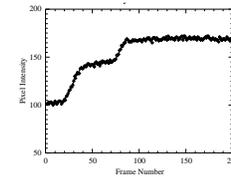
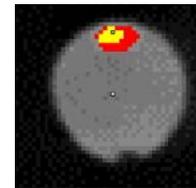
Development Approach:

- Using containerless techniques establish a data base to test dendritic growth models over a wide range of undercoolings
- Determine the mechanism for stable phase nucleation by defining how convection influences the delay time over a broad range of fluid flow conditions
- Determine the relationship between alloy composition and kinetics of the transformation from metastable phase formation to final stable phase microstructure to define the solidification path for these important alloy systems

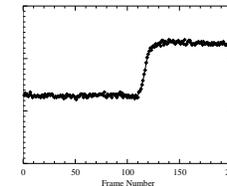
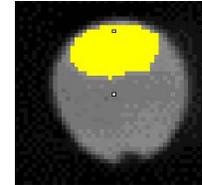
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Ground-based Research (Electrostatic Levitator)



Austenite (yellow) growth from primary ferrite (red)



Austenite growth directly from supercooled liquid (grey)

ISS Accommodation	Electromagnetic Levitator (EML) in Columbus Orbiting Facility
Launch	ATV3 in October 2011



Planned Additional Investigations

- ESA has invited NASA to provide US investigators for two additional ongoing investigations
 - SETA (Solidification along an Eutectic path in Ternary Alloys, Dr. Stephan Rex, team coordinator)
 - METCOMP (Metastable solidification of Composites: Novel peritectic structures and in-situ composites, Prof. Michel Rappaz, team coordinator)
- NASA is working to identify and fund investigators for SETA and METCOMP



SETA

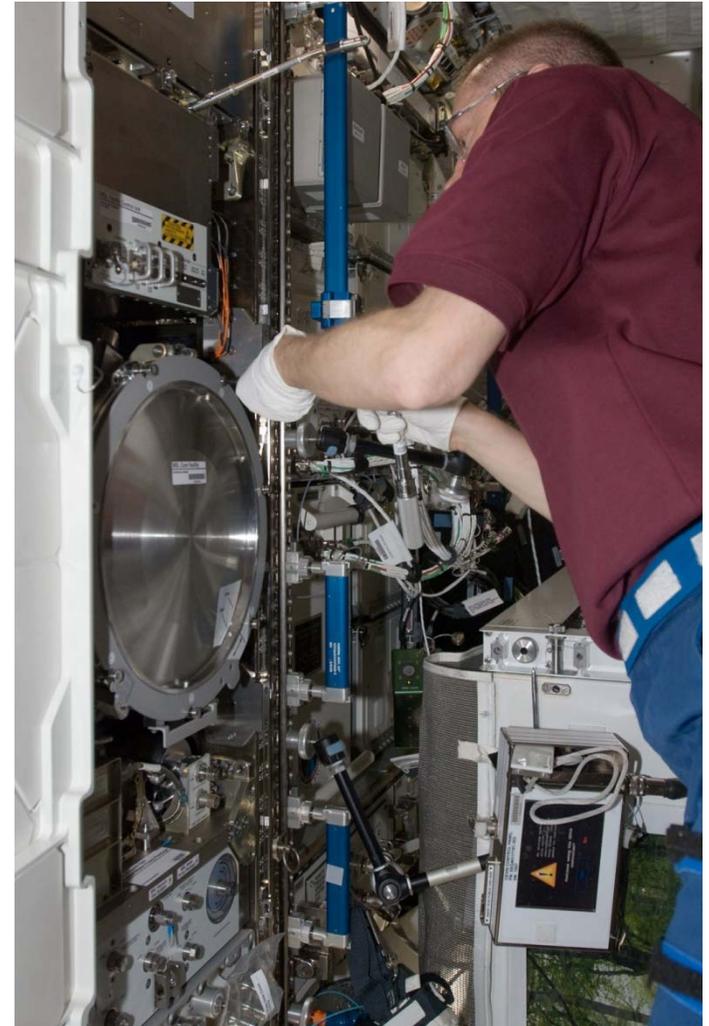
- The work of SETA is the investigation of morphological transitions and coupled growth configuration in two-phase (univariant) and three-phase (nonvariant) eutectics growing from a ternary liquid. The investigation includes:
 - Solidification of ternary aluminum alloys
 - Solidification of transparent model materials
 - Modeling calculations





METCOMP

- The aim of METCOMP is to improve the processing of commercial peritectic alloys through microstructure control, e.g. through the development of a phase selection model, and of a model predicting the pushing/ engulfment of particles by a growing dendritic front.



▲ Astronaut Frank De Winne works with MSRR on-orbit



Materials Science NRA

A NASA Research Announcement (NRA) for materials science is possible in the spring of 2010. This will be for ground-based work with the possibility of transitioning to a flight investigation.

- Therefore, investigations based on experiments compatible with the Low Gradient Furnace (LGF) or the Solidification and Quenching Furnace (SQF) will be solicited. Depending on the ingenuity of the proposer, subject areas might include, among others:
 - Metals and alloys
 - Electronic Materials
 - Ceramics
 - Glasses
- Use of other International Partner hardware may also be offered
- Among proposals rated excellent for science, preference will be given to those judged more likely to support the advancement of NASA and other nationally needed technologies