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RESEARCH EXPERIENCES ON MATERIALS SCIENCE IN SPACE ABOARD SALYUT AND MIR

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ABSTRACT

From 1980 through 1991 approximately 500 materials processing experiments were performed aboard the space stations Salyut 6, Salyut 7 and Mir. This includes work on catalysts, polymers, metals and alloys, optical materials, superconductors, electronic crystals, thin film semiconductors, superionic crystals, ceramics, and protein crystals. Often the resulting materials were surprisingly superior to those prepared on earth. The Soviets were the first to fabricate a laser (CdS) from a crystal grown in space, the first to grow a heterostructure in space, the first superionic crystal in space, the first crystals of CdTe and its alloys, the first zeolite crystals, the first protein crystals, the first chromium disilicide glass, etc. The results were used to optimize terrestrial materials processing operations in Soviet industry.

The characteristics of these three space stations are reviewed, along with the advantages of a space station for materials research, and the problems encountered by the materials scientists who used them. For example, the stations and the materials processing equipment were designed without significant input from the scientific community that would be using them.

It is pointed out that successful results have been achieved also by materials processing at high gravity in large centrifuges. This research is also continuing around the world, including at Clarkson University. It is recommended that experiments be conducted in centrifuges in space, in order to investigate the acceleration regime between earth's gravity and the microgravity achieved in orbiting space stations. One cannot expect to understand the influence of gravity on materials processing from only two data points, earth's gravity and microgravity. One must also understand the influence of fluctuations in acceleration on board space stations, the so-called "g-jitter."

International workshops on high gravity materials processing and jitter are being held at Clarkson in June 1993.

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Research Experiences on Materials Science in Space aboard Salyut and Mir

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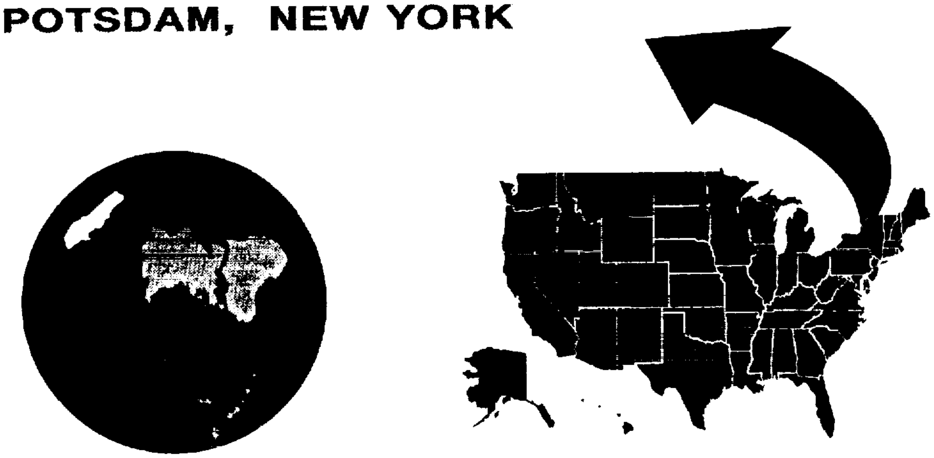

"We have labelled civilizations by the main materials which they have used:

The Stone Age,
The Bronze Age,
The Iron Age...

a civilization is both developed and limited by the materials at its disposal. Today, man lives on the boundary between

the **Iron Age** and the **New Material Age.**"

- Dr. George P. Thomson,
Nobel Laureate in Physics

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Materials Processing Areas

- Catalysts
- Polymers
- Metals and Alloys
- Non-Linear Optical Materials
- Superconductors
- Electronic Crystals
- Thin Film Semiconductors
- Ceramics
- Protein crystals

Some Consequences of "Microgravity" Environment

- Greatly reduced buoyancy-driven convection.
- Greatly reduced sedimentation of second phase.
- Greatly reduced hydrostatic pressure.
- Easier containerless processing.
- Surface phenomena more important.

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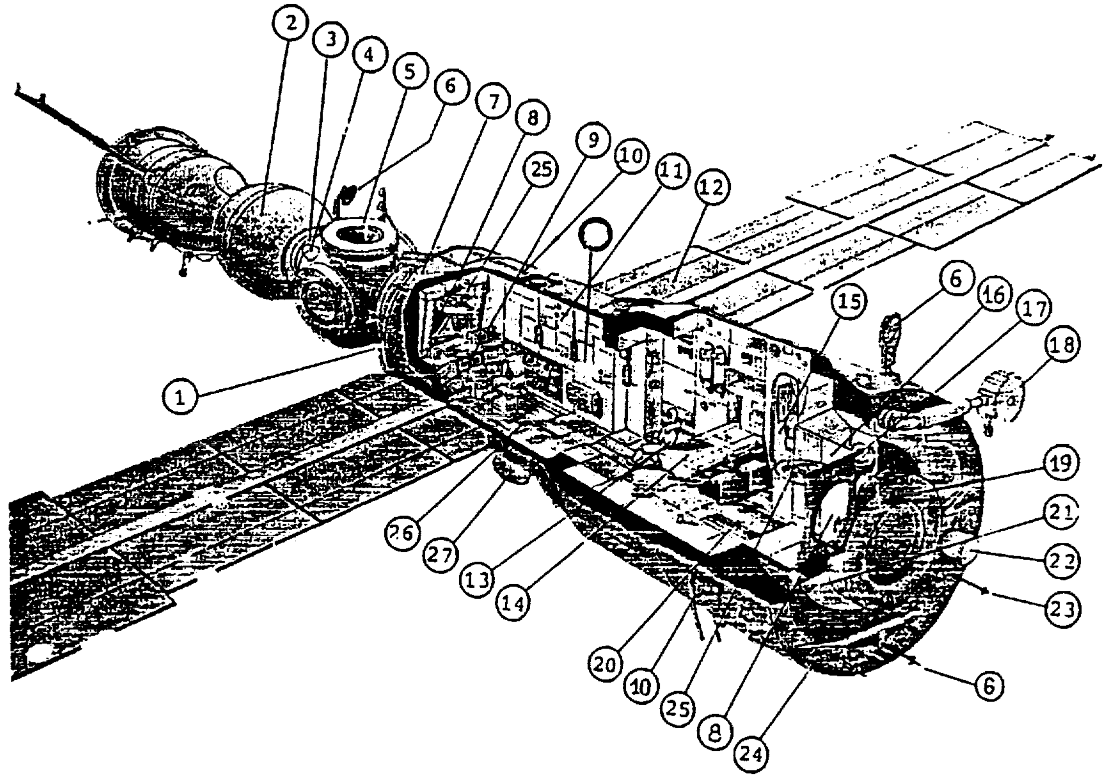
Why Research on Materials Processing in Space?

- Learn more about influence of these phenomena.
- Improve processing on earth.
- Perhaps learn consequence of improved materials.
- Helpful in assembling space stations.
- Maybe manufacturing in space, someday.



CHARACTERISTICS OF MIR

Inclination of orbit : 51.6°

Height of orbit : 300-400 km

Accuracy of orientation:
Usual - < 1.5
Precise - < 15 minutes

Total mass of complex : >130,000 kg

Volume pressurized : 400 m

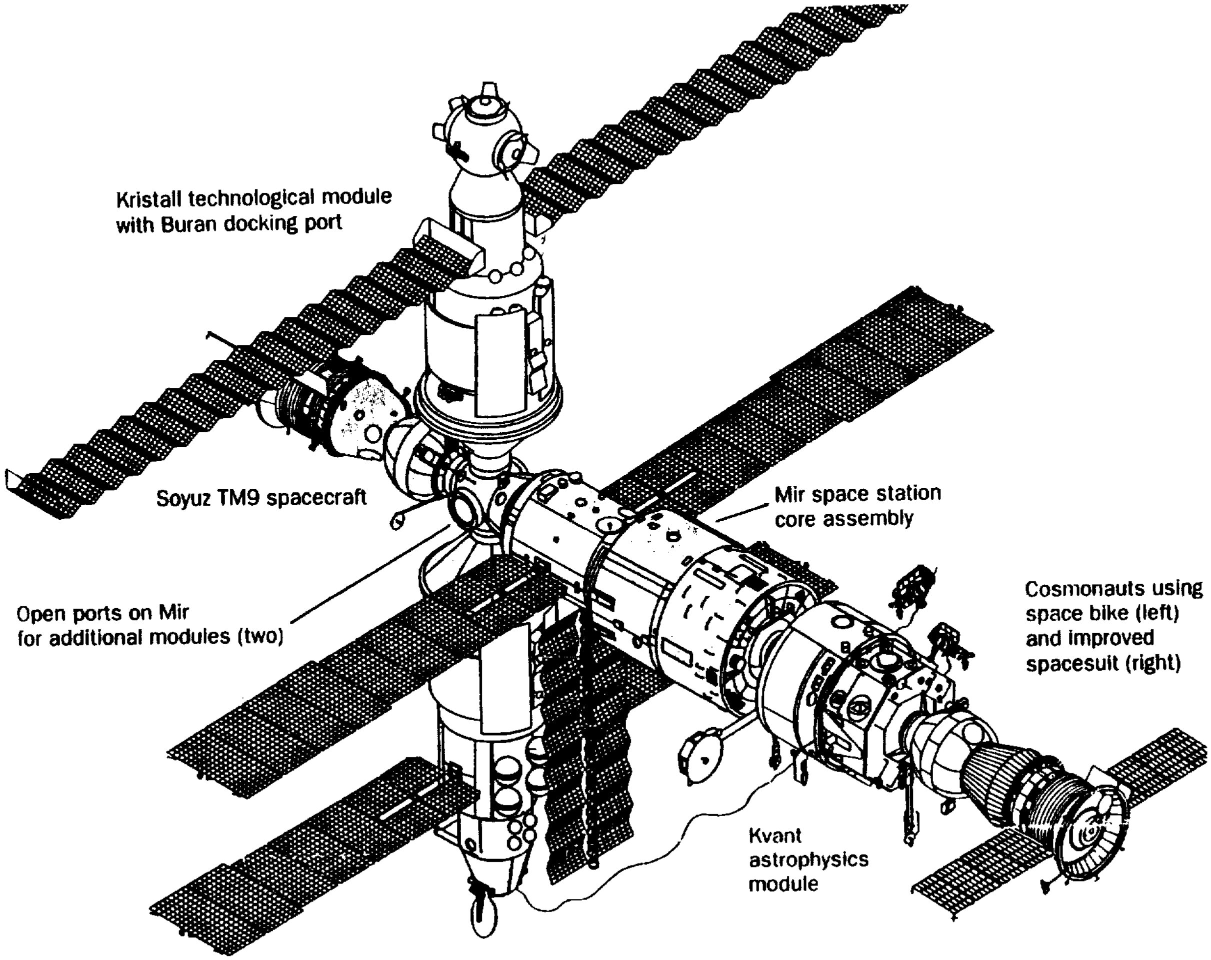
Length of basic block :
Kvant + 2 spacecraft : 32.9 m

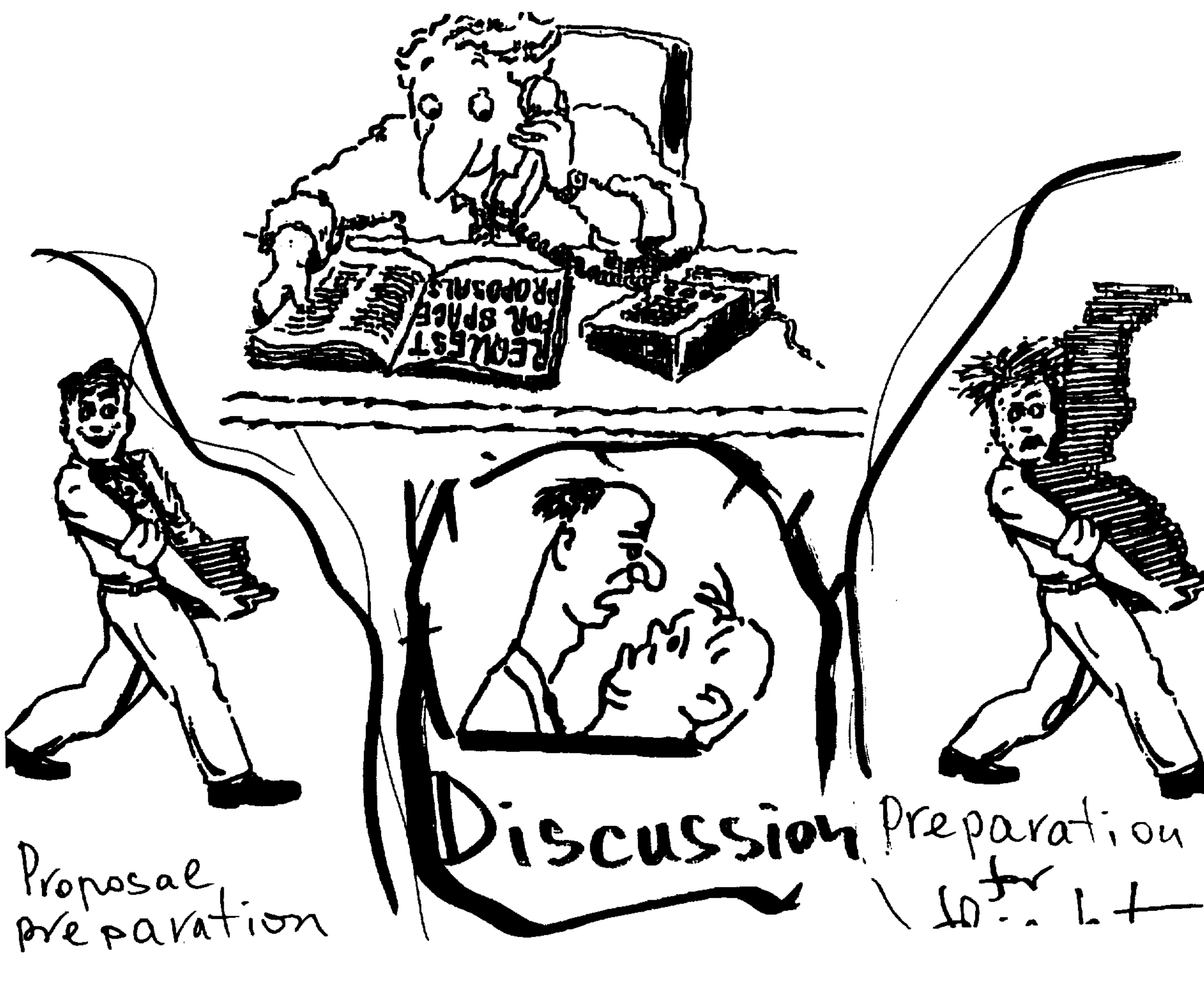
Maximum number of modules : 5

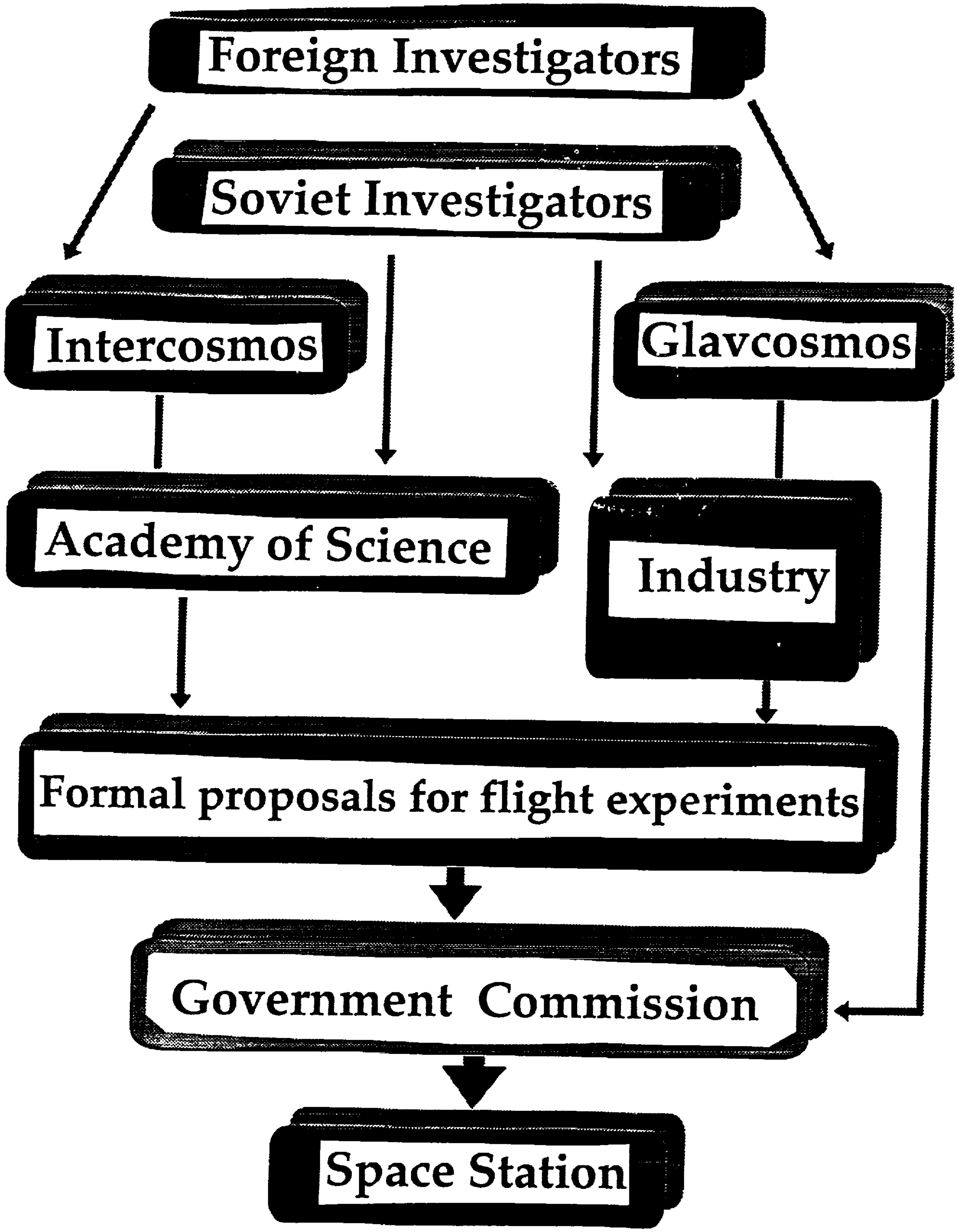
Number of Soyuz that can dock : 0,1,2

Number of Progress that can dock : 0,1

Number of occupants:
Long term - 2,3
Short term - 2,3


Kristall technological module
with Buran docking port
Soyuz TM9 spacecraft
Mir space station
core assembly
Open ports on Mir
for additional modules (two)
Cosmonauts using
space bike (left)
and improved
spacesuit (right)
Kvant
astrophysics
module


REQUEST FOR SPACE PROPOSALS
Proposal preparation
Discussion
Preparation for


Foreign Investigators
Soviet Investigators
Intercosmos
Glavcosmos
Academy of Science
Industry
Formal proposals for flight experiments
Government Commission
Space Station

Examples of Hardware in Krystal Module

- **Gallar** Tube furnace for 33 mm diameter ampoules, maximum temperature 1300 °C, 1 kw.
- **Crater** Tube furnace for 56 mm diameter ampoules, maximum temperature 1250 °C, 2 kw.
- **Splav** Gradient furnace 20 mm diameter ampoules, 500 to 1050°C, maximum gradient 130K/cm.
- **Optizone** Mirror furnace for floating zone melting of 10 mm diameter silicon up to 150 mm long, 300 to 2100 °C, up to 1.6 kw.

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Characteristics of Typical Scientific Module: Kristall

- **Mass of Module** **20,600 kg**
- **Length of module** **12.5 m**
- **Mass of payload** **5,000 kg**
- **Transport vehicle** **Proton or Energy**

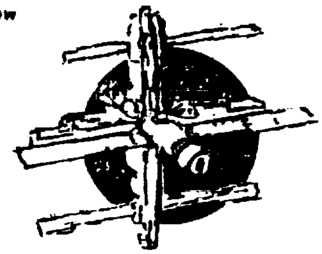
Apparatus and samples delivered to Moscow

2

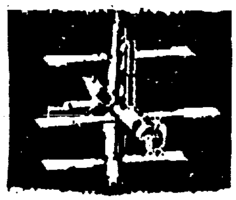
Baikonur

2* 7* 25*

Soyuz Modul Progress



MIR



Experiments performed in MIR

Results of experiments returned

2*

Baikonur

2*

Schedule for transportation of experimenta apparatus from Moscow to MIR and return.

Advantages of Crystal Growth in Mir and Salyut

- Could perform long duration experiments.
- Cosmonauts available to repair equipment and modify experiments.
- A lot of space for equipment, including materials characterization equipment and general purpose apparatus.

Some Crystal Growth Results from Mir and Salyut

- First to fabricate laser from crystal (CdS) grown in space.
- First semiconductor heterostructure grown in space.
- First crystals of CdTe, HgCdTe, ZnCdTe, and MnCdTe.
- First superionic crystal grown in space.
- Large monodispersed polymer latex spheres.
- First zeolite crystals, several times larger than on earth.

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- First protein crystals; insulin, pro-insulin, glucogen, tymozine, antitrypsinn, interferon.
- First chromium disilicide glass.
- First crystallization by rapid mixing of two solutions, to grow hydroxyapatite and calcium sulfate (gypsum).
- Results helped to optimize terrestrial crystal growth...
- ...
- ...

Problems Encountered in Mir and Salyut

- **Designed without input from user community, resulting in:**
  - Limited power for experimental equipment.
  - Limited periods when power available for experiments.
  - Mass restrictions for equipment.
  - Limited time for experiments.
  - Equipment located far from center of mass of station.
  - Limited air-to-ground communications and data transmission.
- **No accelerometer data to investigators.**
- **Lengthy delays in return of samples and data to investigators**

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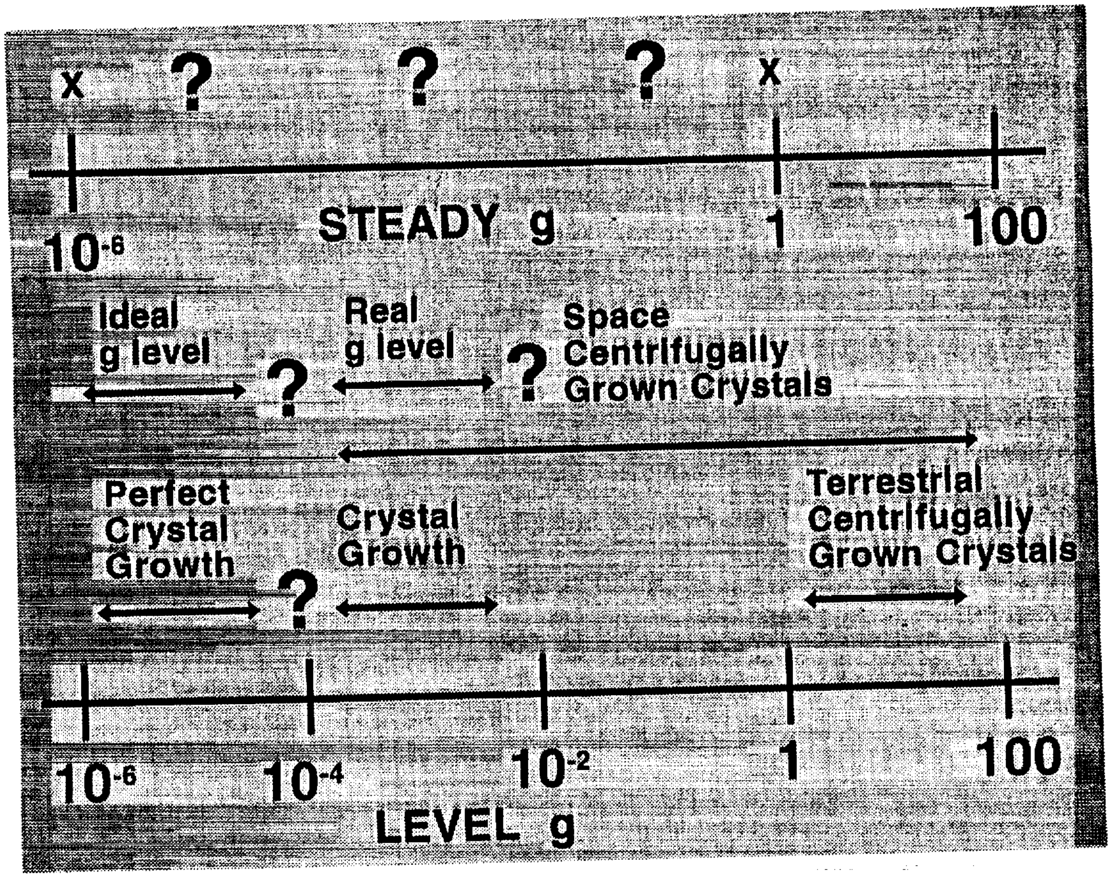
- **Too many scientific disciplines for cosmonauts to master.**
- **Insufficient training on flight apparatus before launch.**
- **Excessive paperwork for investigators.**
- **Replication of experiments rarely possible.**
- **No support for thorough analysis of flight samples and results.**
- **Criteria for selection of flight experiments never revealed.**



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Phenomena in a centrifuge

- Sedimentation
- Increased pressure
- Increased buoyancy convection
- Coriolis forces
- Acceleration gradients

Materials Processing Results

- **Very high g:**
  - **Solution growth**
  - **Eutectic solidification**
  - **Movement of solvent inclusions**
- **Moderate g with unstable gradient**
- **Moderate g with "stable" gradient**
  - **Single phase solidification**
  - **Eutectic solidification**
- **Vapor transport at moderate g**

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Implications of Fluid Flow Experiment to Crystal Growth

- Space Centrifuge Fluid Flow Experiment will increase the understanding of the controlling forces influencing crystal growth of any material in a wide range of g levels.
- Crystal growth in a centrifuge offers a unique environment in which the fluid flow magnitude and flow pattern are controllable, which in turn effects the concentration field.

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Why Materials Processing Experiments in a Centrifuge in Space Station Freedom?

- **To obtain data points between 10^{-6} g and 1 g; necessary to understand influence of g.**
- **To explain ground based results from centrifuge without complications of earth's gravity.**

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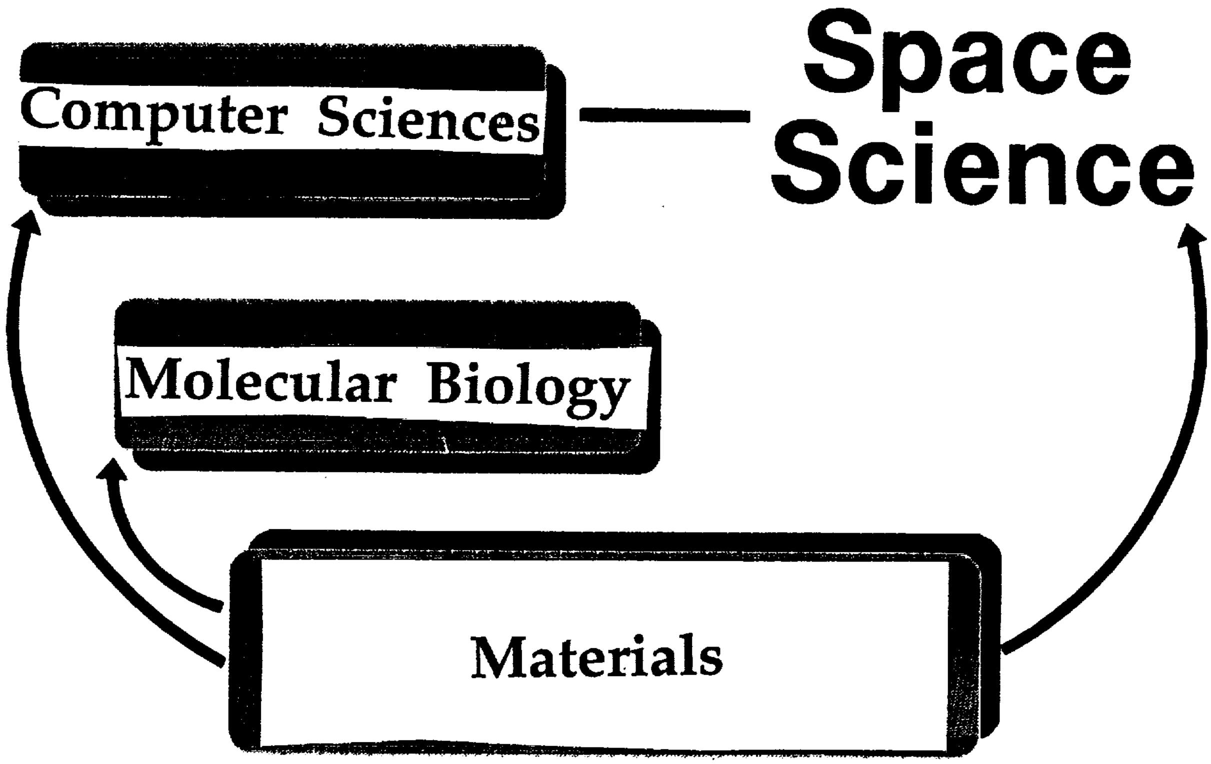
First International Workshop on g-jitter

Clarkson University, June 13-18, 1993

- What is g-jitter and how does it arise?
- How can it be predicted?
- How can it be measured?
- How can it be reduced and controlled?
- What does it do to fluids?
- How does it influence materials processing?
- How does it influence combustion?
- How does it influence biological processes?
- What R&D needs to be done?



"IT'S A MATERIAL WORLD"

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One of the most pervasive myths of space materials science is that "nothing is known for sure." This adage projects a disarming modesty. Even scientists have been known to fall into the arms of this myth in order to avoid the appearance of dogmatism and arrogance.

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Space, Space, Space Science . . . what a wonderful, powerful sounding word! It instantly induces an atmosphere of pure rationality. It rings loudly a symphony of universal knowledge and understanding. It forcefully projects an aura of all encompassing order and of control.

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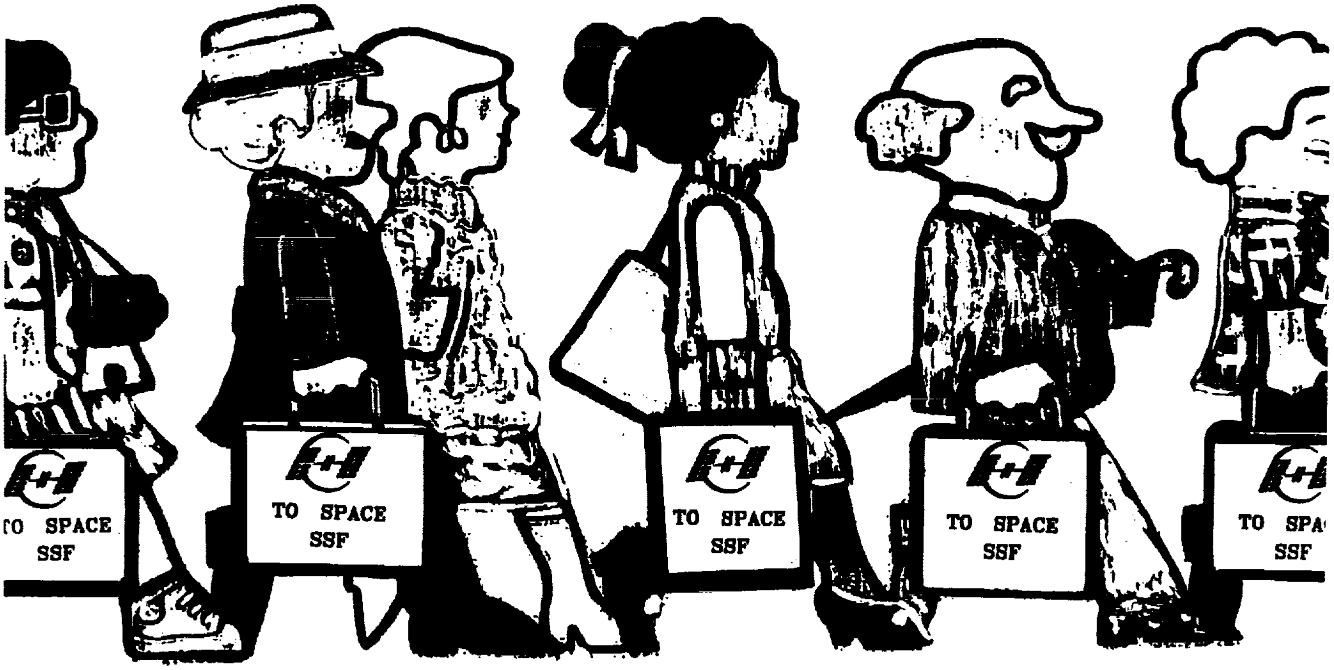
In terms of quantity and in terms of analytic inference, it seems to me that space science and sports are very much parallel at the level of public concern. A lot of complexity, a lot of tactics, a lot of numbers, and a lot of perhaps poorly understood probabilistic judgements are present.



ALL ABOARD !