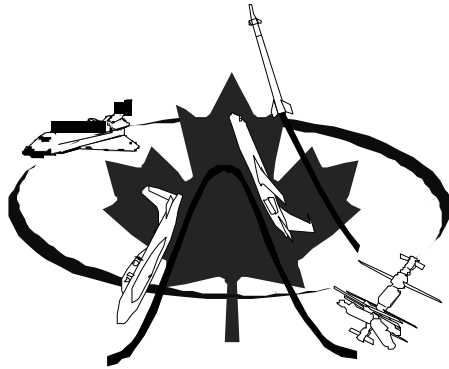


Impact of the Microgravity Environment on Experiments

The Effect of G-Jitter on Fluid Science Experiments



Bjarni Tryggvason

Canadian Space Agency

Glenn Research Center

March 5-7, 2002



The Microgravity Vibration Isolation Mount (MIM-2)



Isolates experiments from spacecraft vibrations

6 DOF magnetically levitation system

Optical tracking system and accelerometers for monitoring and control

Provides data acquisition services and control functions to an experiment mounted on the flotor

Capable of “shaking” an experiment with acceleration levels from several micro-g to 25 milli-g over range 0.01 Hz to 50 Hz.

MIM-1 Fluid Physics Experiment on the Mir Space Station



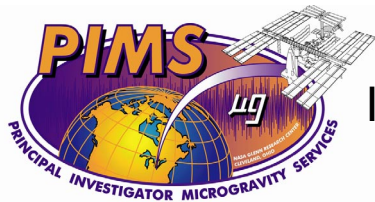
Supported numerous experiments that examined effects of g-jitter on fluids

- ✦ QUELD-II
- ✦ Liquid Metal Diffusion (LMD)
- ✦ TEM, TEM-2
- ✦ Canadian Protein Crystallization Experiment (CAPE)



Queen's University Experiment in Liquid Diffusion

- ✦ Operational on Mir Space Station from May 1996 to January 1998
- ✦ Operating temperature up to 900 °C
- ✦ Two independent furnaces
- ✦ Automatic sample processing



Impact of the Microgravity Environment on Experiments

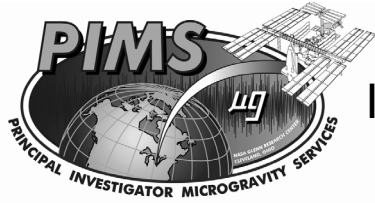


MIM- 2 on Shuttle Mission STS-85



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Impact of the Microgravity Environment on Experiments

Summary of the Experiments

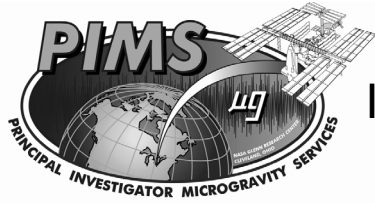


ISS Phase-I on Mir:

- **measurement of diffusion in liquid metal systems**
- **observations of nucleation in glasses**
- **particle pushing**

STS-85:

- **effect of g-jitter on Brownian motion**
- **effect of g-jitter on the motion of encapsulated bubbles**
- **effect of g-jitter on interface dynamics in a liquid-liquid system**
- **effects of g-jitter on interface dynamics in liquid-vapour systems**



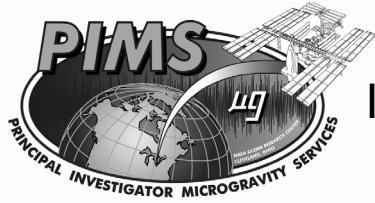
Liquid Diffusion Coefficient

The contributions to the measured diffusion coefficient can be attributed to:

$$D_{Measured} = \left[\begin{array}{l} D_{intrinsic} + D_{buoyancy} + D_{container} \\ + D_{thermal} + D_{Marangoni} \end{array} \right] \quad (1)$$

Estimating the Intrinsic Diffusion Coefficient

- Microgravity eliminates buoyancy effects.
- The effect of the container is estimated by varying the sample diameter.
- A well designed sample eliminates surface tension induced Marangoni convection by the use of a spring to adjust for specimen contraction and expansion.
- An isothermal furnace eliminates thermal gradient induced motion.

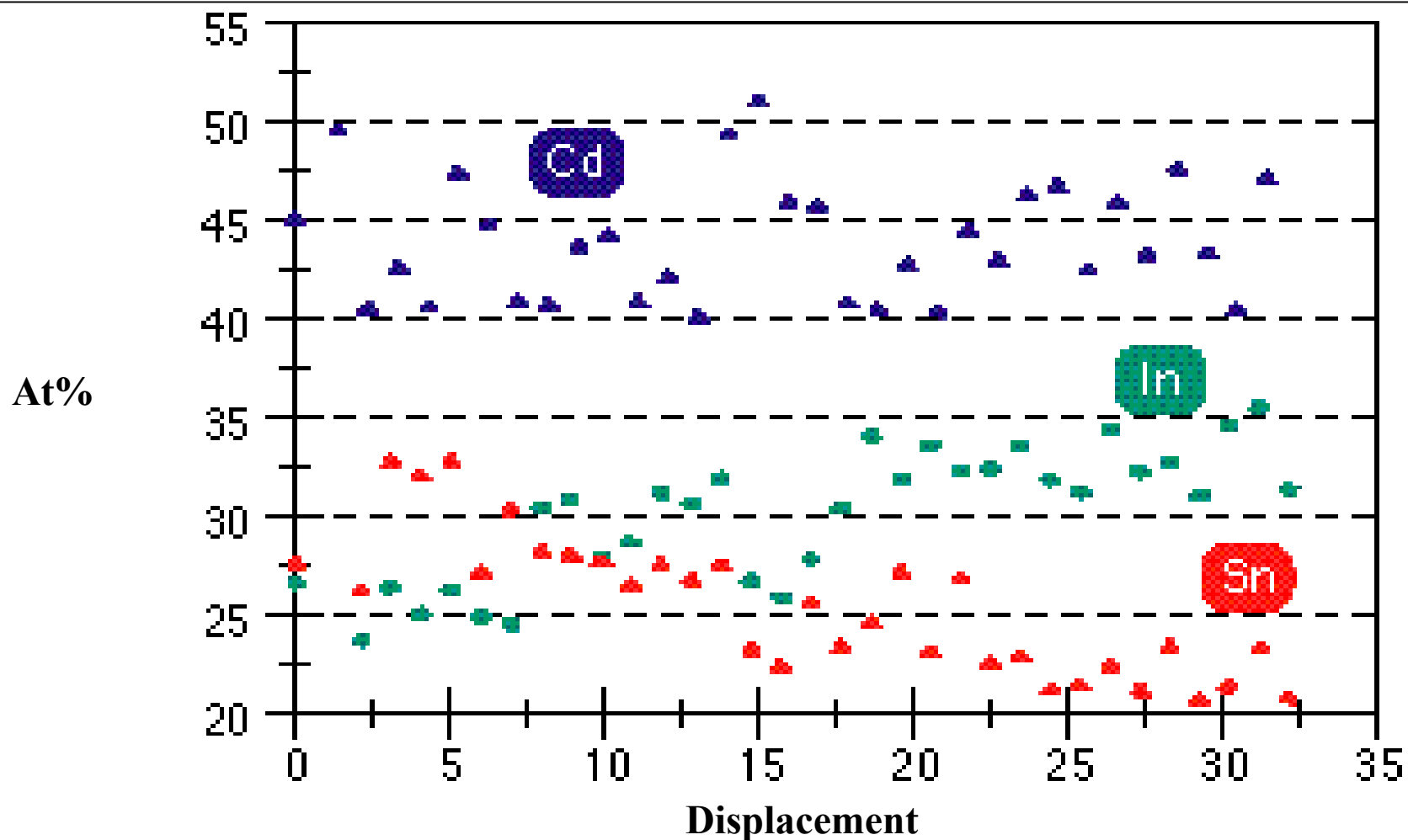


Impact of the Microgravity Environment on Experiments

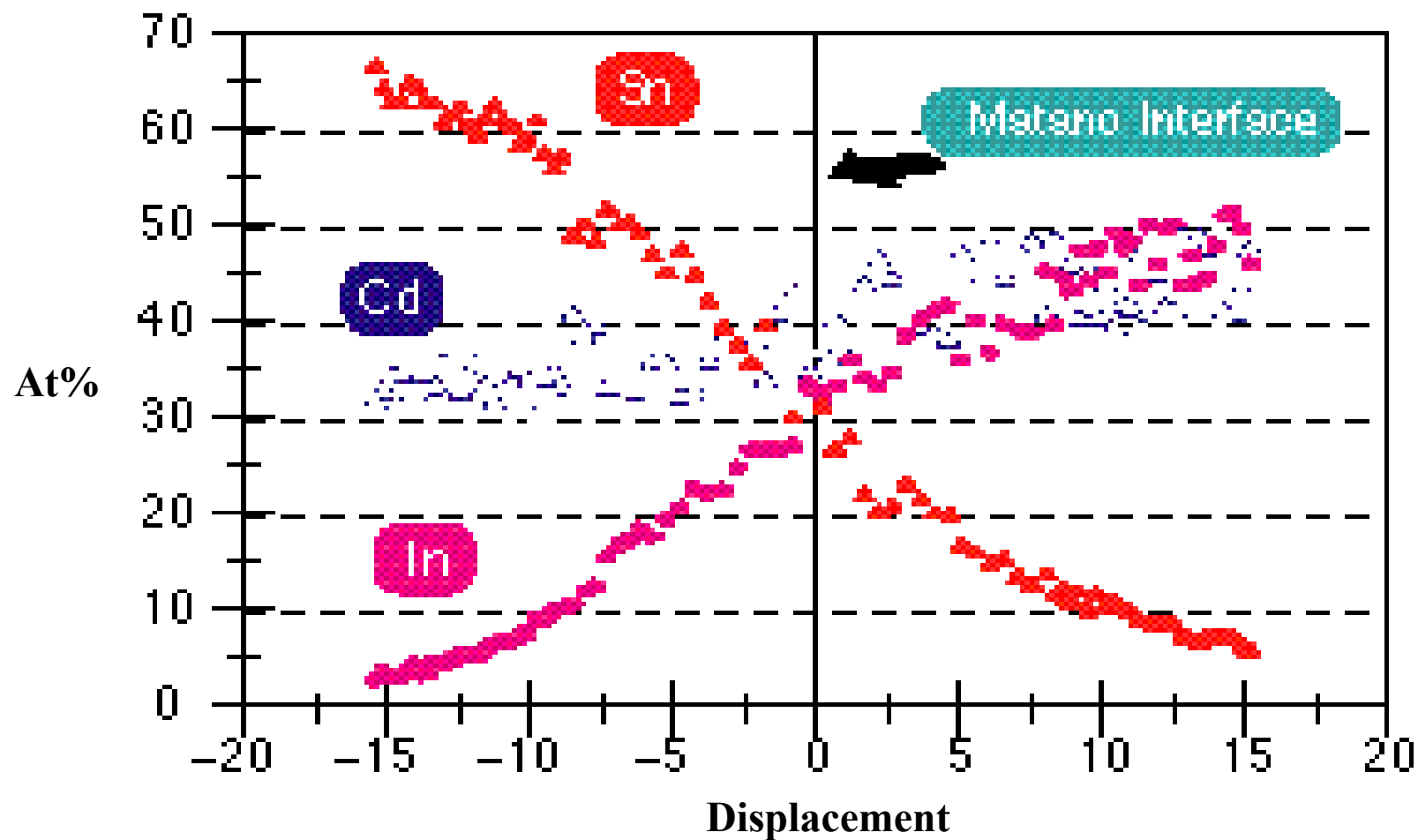
Comparison of Terrestrial and On-Orbit Data



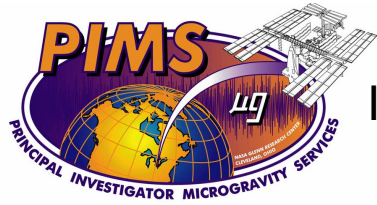
CdIn / CdSn diffusion couple specimens processed terrestrially and in microgravity at 690 C for 90 minutes [Tandon, Cahoon and Chaturvedi. CSA Interim Report] .



Terrestrial liquid-metal diffusion measurements of a CdIn/CdSn diffusion couple specimen at 690 C for 90 minutes [Tandon, Cahoon and Chaturvedi. CSA Interim Report] .



Microgravity liquid-metal diffusion measurements of a CdIn/CdSn diffusion couple specimen at 690 C for 90 minutes [Tandon, Cahoon and Chaturvedi. CSA Interim Report].



Temperature Dependence of Diffusion

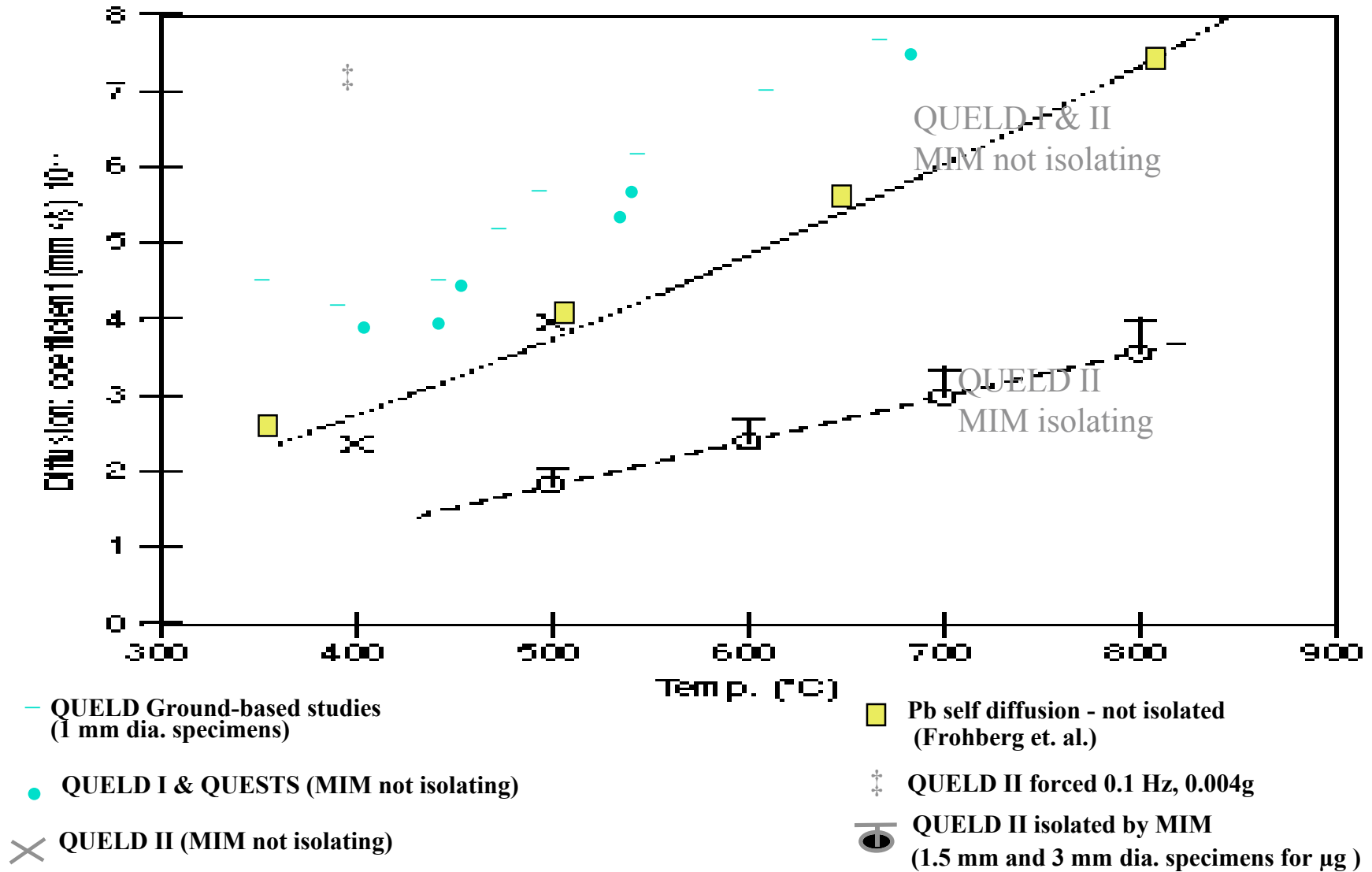
- There are many competing models for the temperature dependence of diffusion.
- The fluctuation model, supported by previous microgravity experiments, proposes that the diffusion coefficient should be proportional to the temperature squared, i.e.,

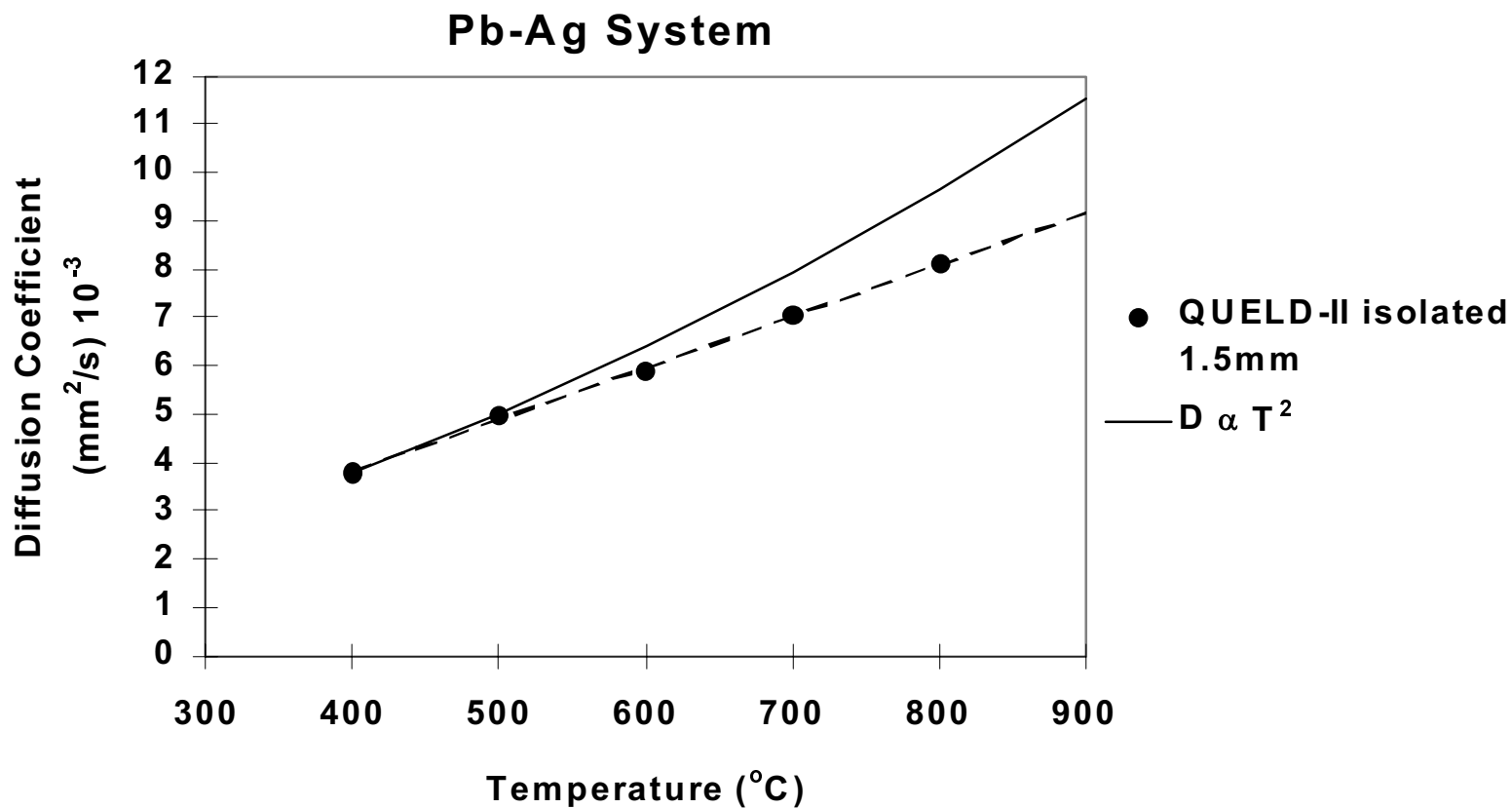
$$D = AT^2$$

- Another model predicts a linear relationship between the diffusion coefficients and temperature, given simply as,

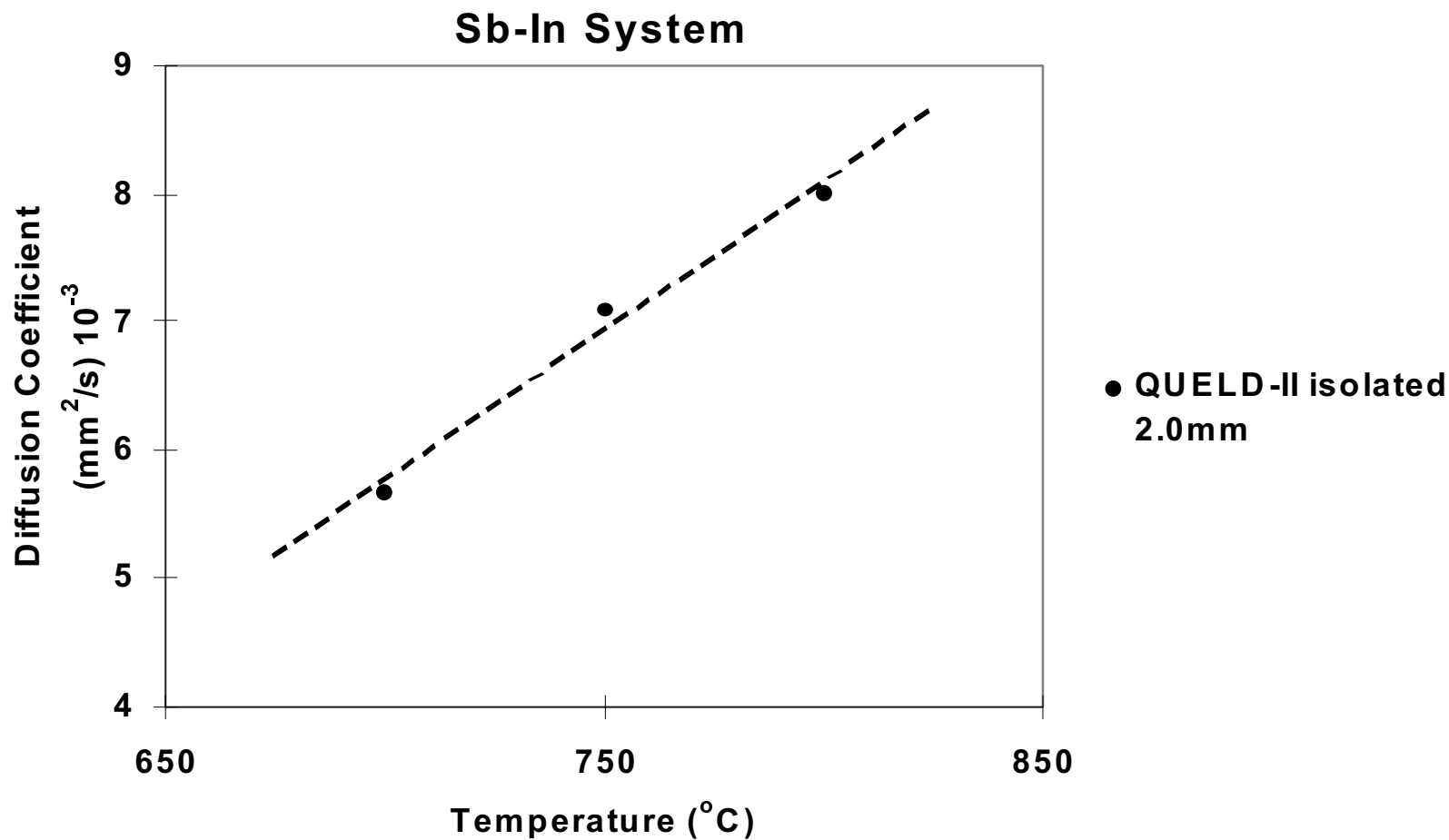
$$D = -a + bT$$

- The difference between the two models is quite severe, especially at the higher temperatures.

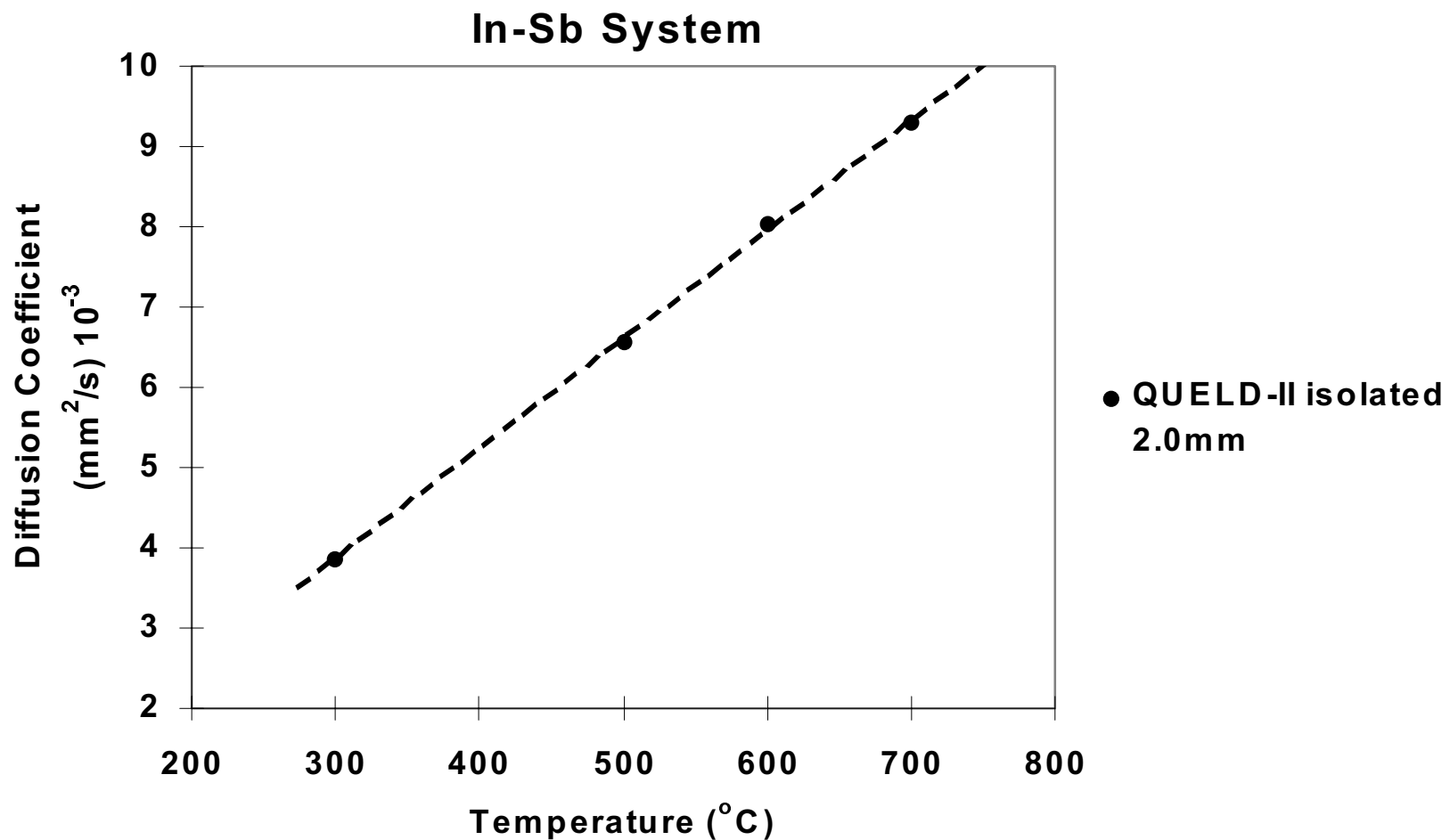




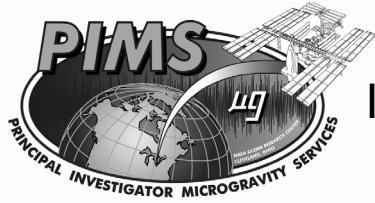
Microgravity Diffusion Coefficients of Silver in Lead showing the difference between a linear and a parabolic fit to the data (Smith et. Al.).



Diffusion Coefficients of Indium in Antimony (Smith et. Al.).



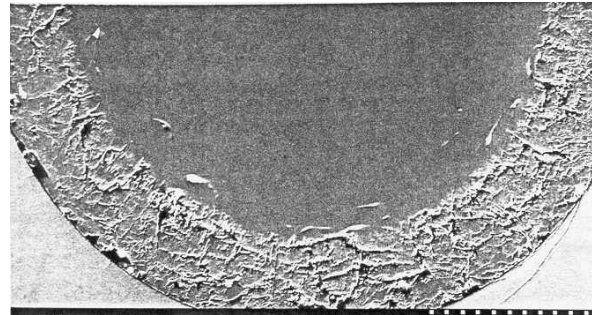
Diffusion Coefficients of Indium in Antimony (Smith et. Al.).



Processing of Infra-Red Glass in Microgravity

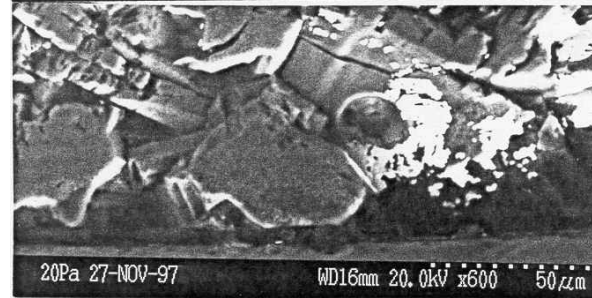
Material $\text{Nb}_2\text{Na}_2\text{B}_2\text{O}_9$ (NNB)

- ✦ Experimental processing conditions
 - ✦ Temperature 575°C
 - ✦ Time 1 hour
 - ✦ container SiO_2
 - ✦ g-jitter varied from isolation to g-pulses
 - ✦ g-pulses at $1000\ \mu\text{g}$ at $0.1\ \text{Hz}$



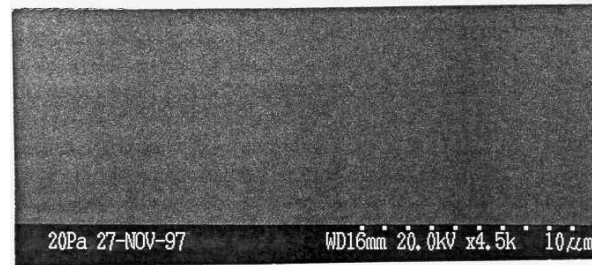
20Pa 27-NOV-97 WD16mm 20.0kV x30 1mm

(i)



20Pa 27-NOV-97 WD16mm 20.0kV x600 50μm

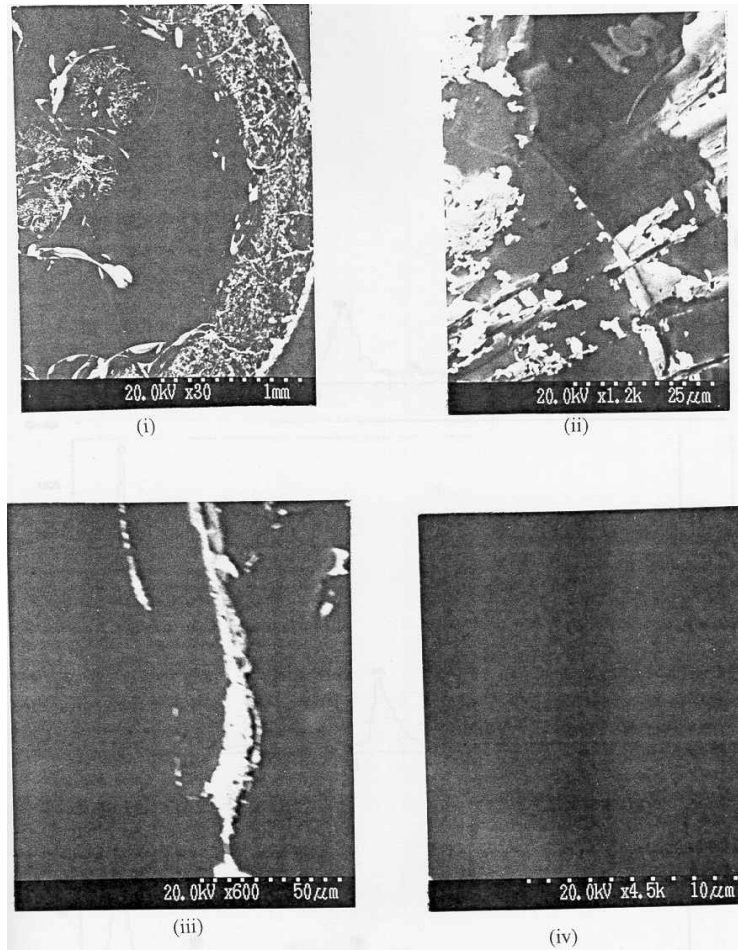
(ii)



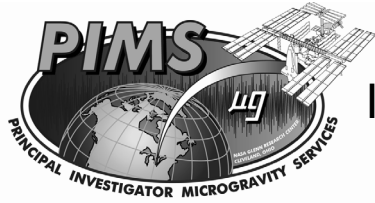
20Pa 27-NOV-97 WD16mm 20.0kV x4.5k 10μm

(iii)

NNB Glass processed in microgravity at 575 K with isolation, showing (upper) a crystal phase only around the edge of specimen (enlarged center) but not in the specimen center (lower image).



NNB glass processed in microgravity having force g-pulses at 1 mg at 0.1 Hz, showing mixing or streaming of crystal phase from edge to center of specimen.



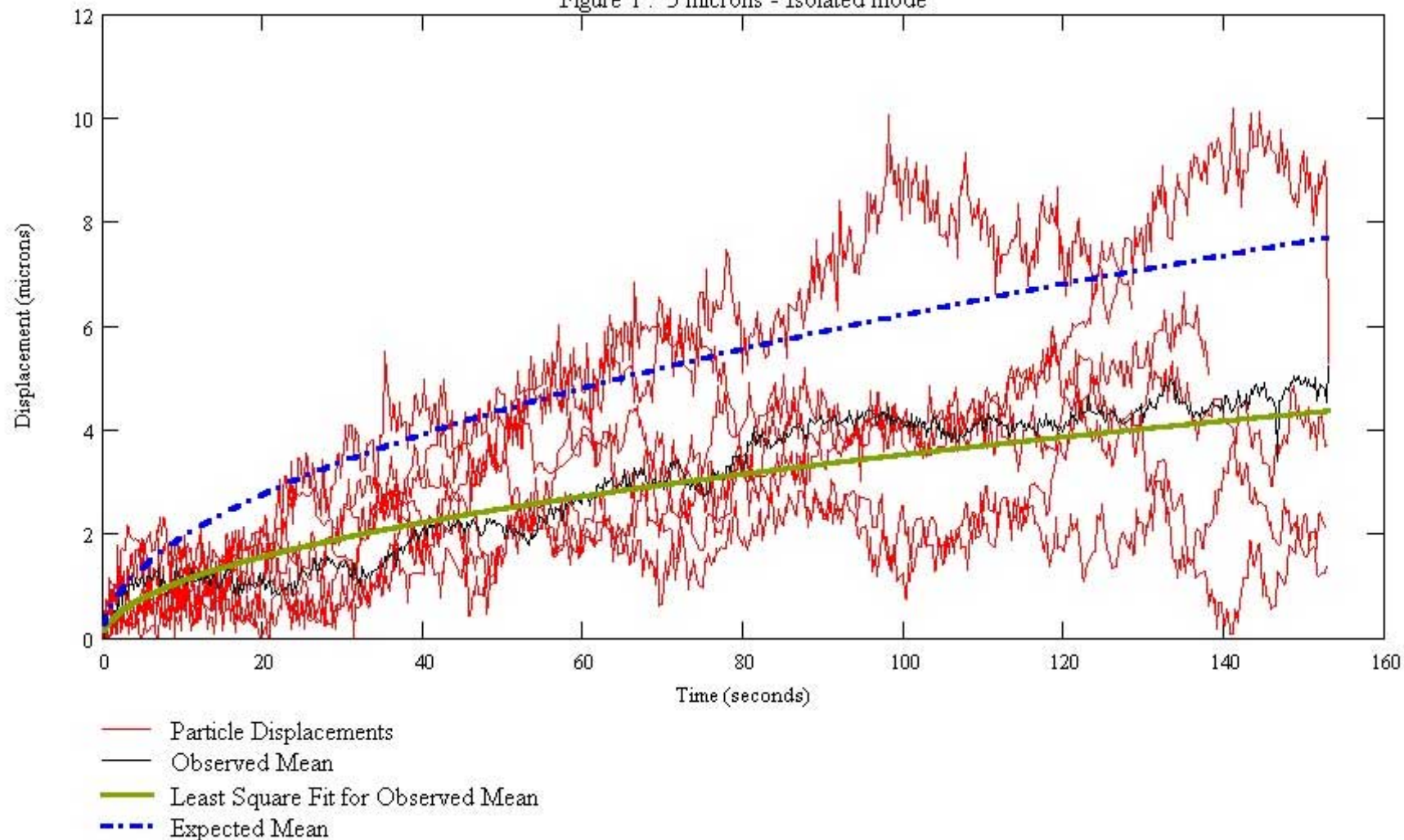
Brownian Motion

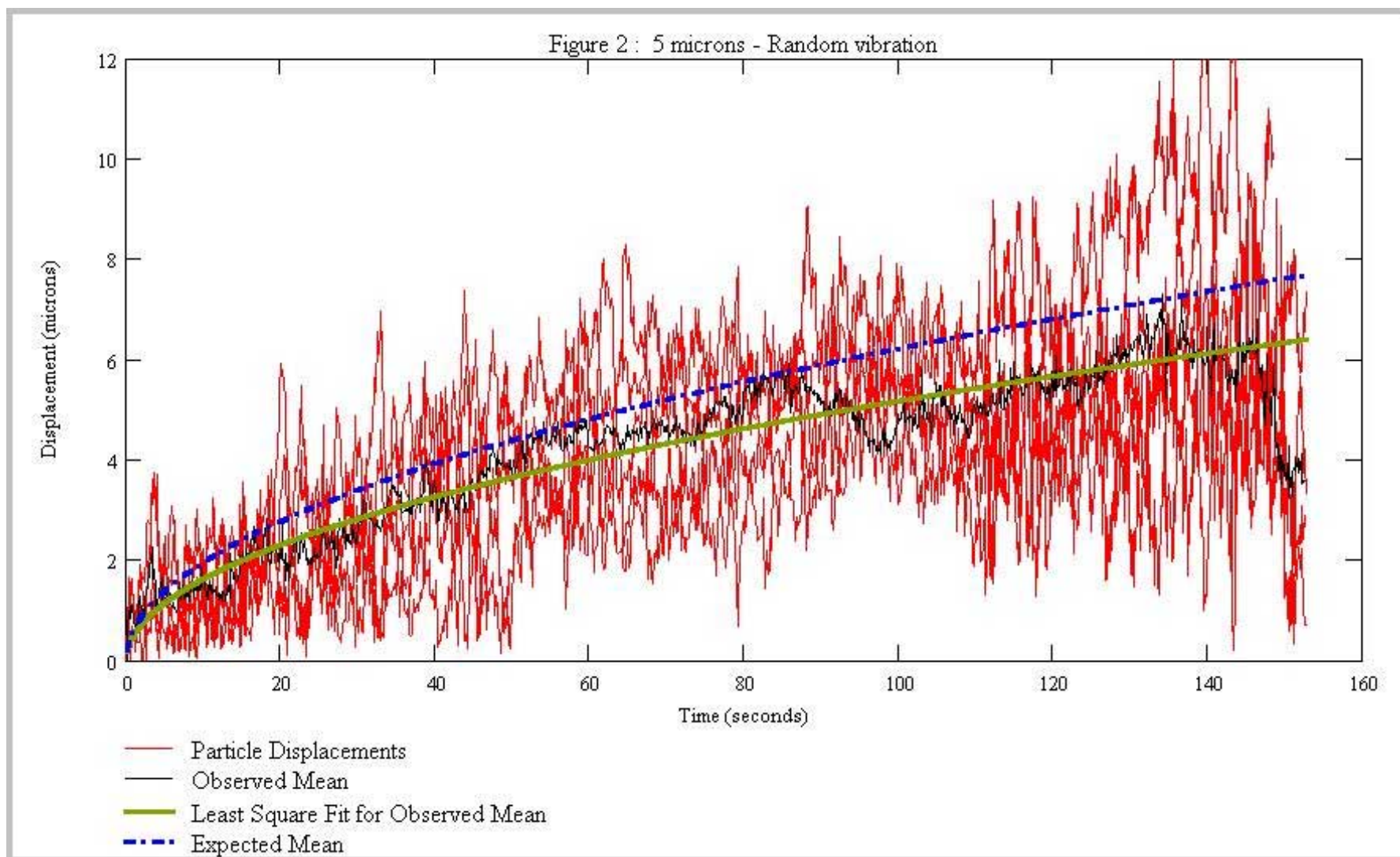
Experiment Objectives

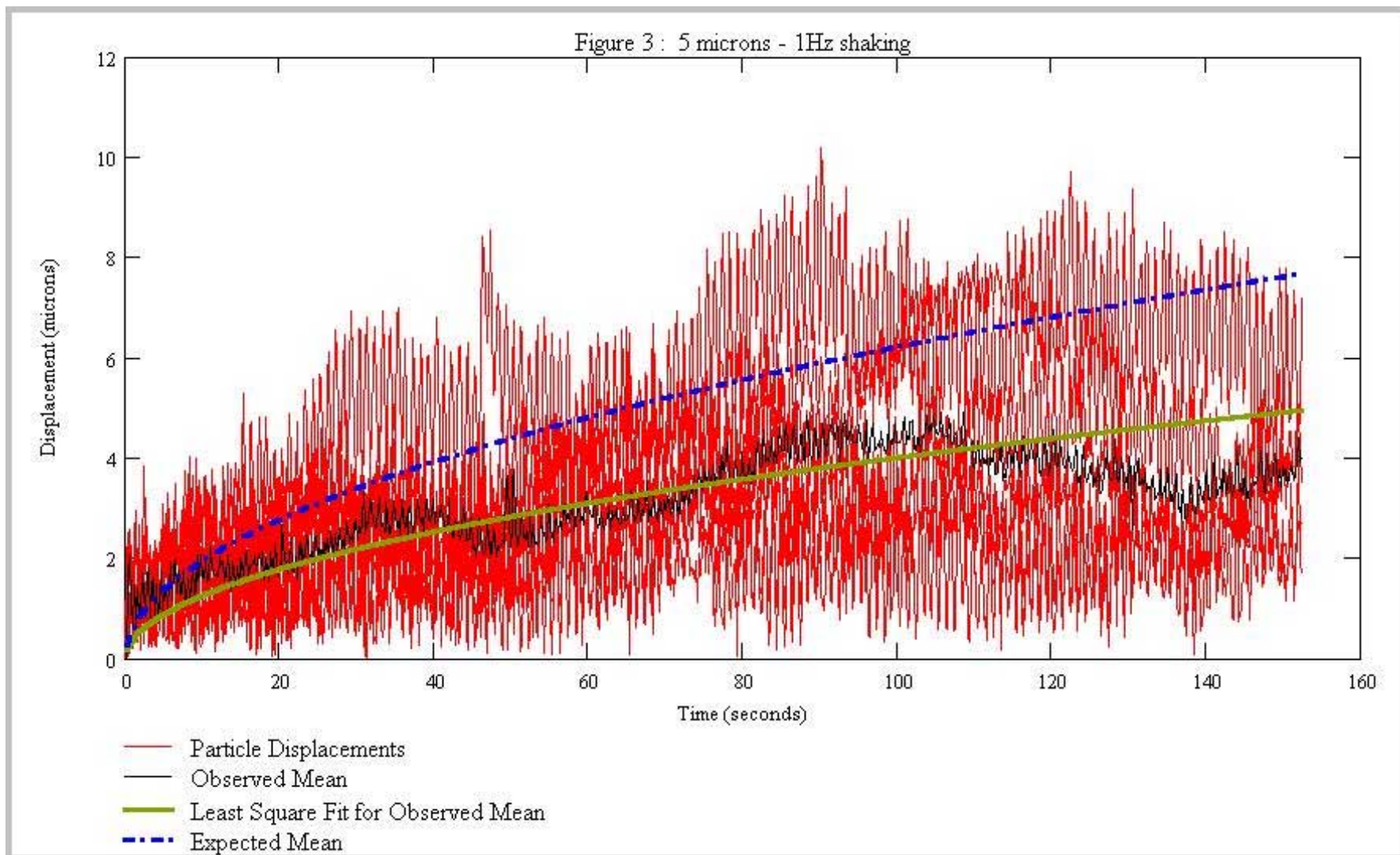
Examine the effect of g-jitter on the motion of small particles in fluids, under condition of:

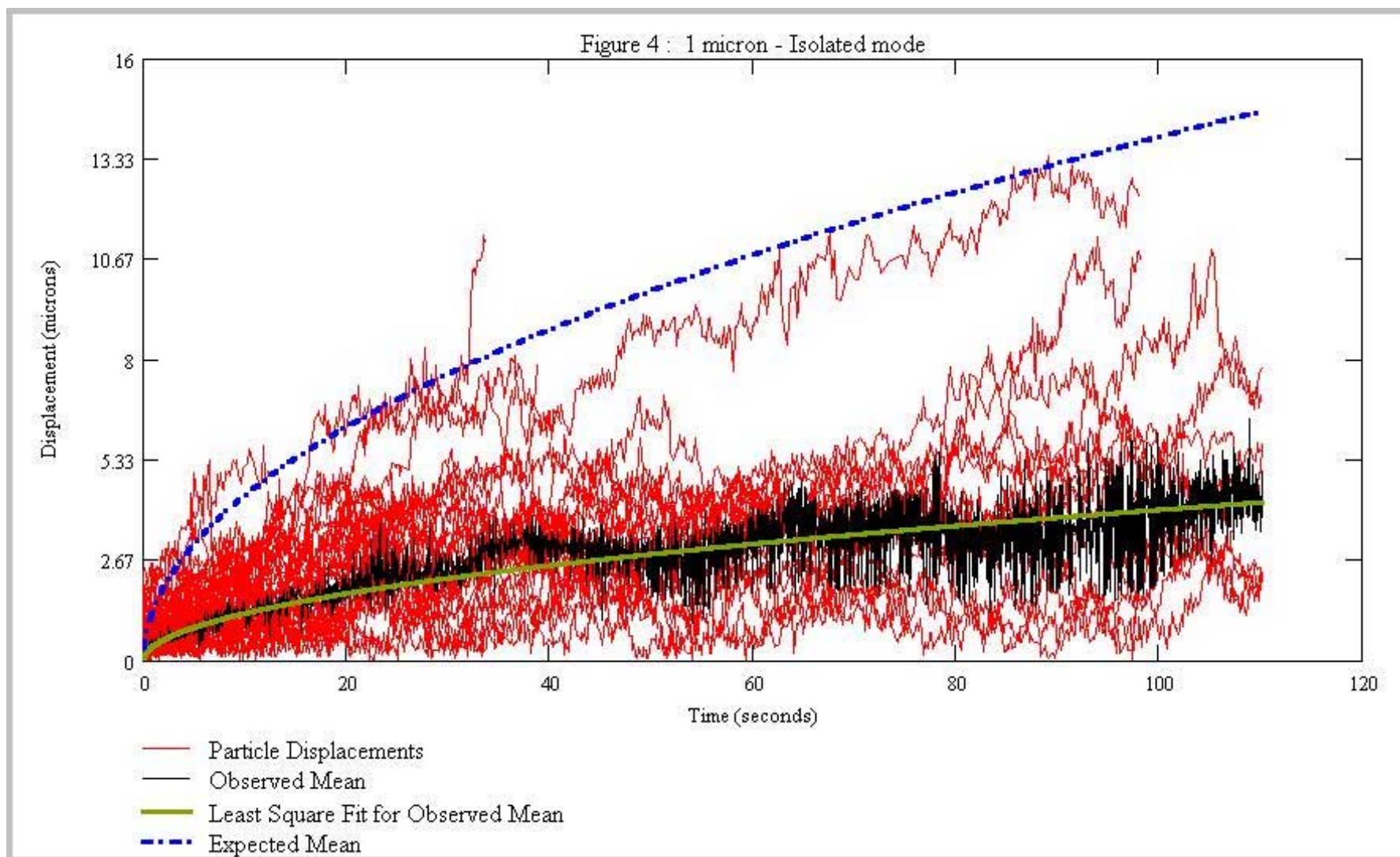
- **Non-isolating mode, i.e., g-jitter present**
- **Isolated mode**
- **Driven mode**
 - **Sinusoidal**
 - **Random broad band**

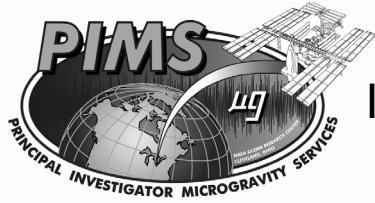
Figure 1 : 5 microns - Isolated mode









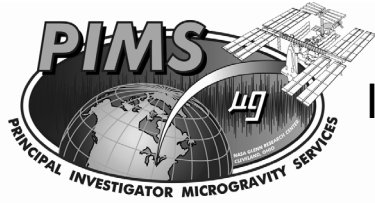


Brownian Motion Discussion

The results of diffusion work carried out on the shuttle and the Mir, the Brownian Motion experiments conducted on the shuttle show a consistent sensitivity to g-jitter.

The sensitivity is in the frequency range 2 Hz to 100 Hz.

The vibration levels that effect the diffusion are generally below the current ISS vibratory specification



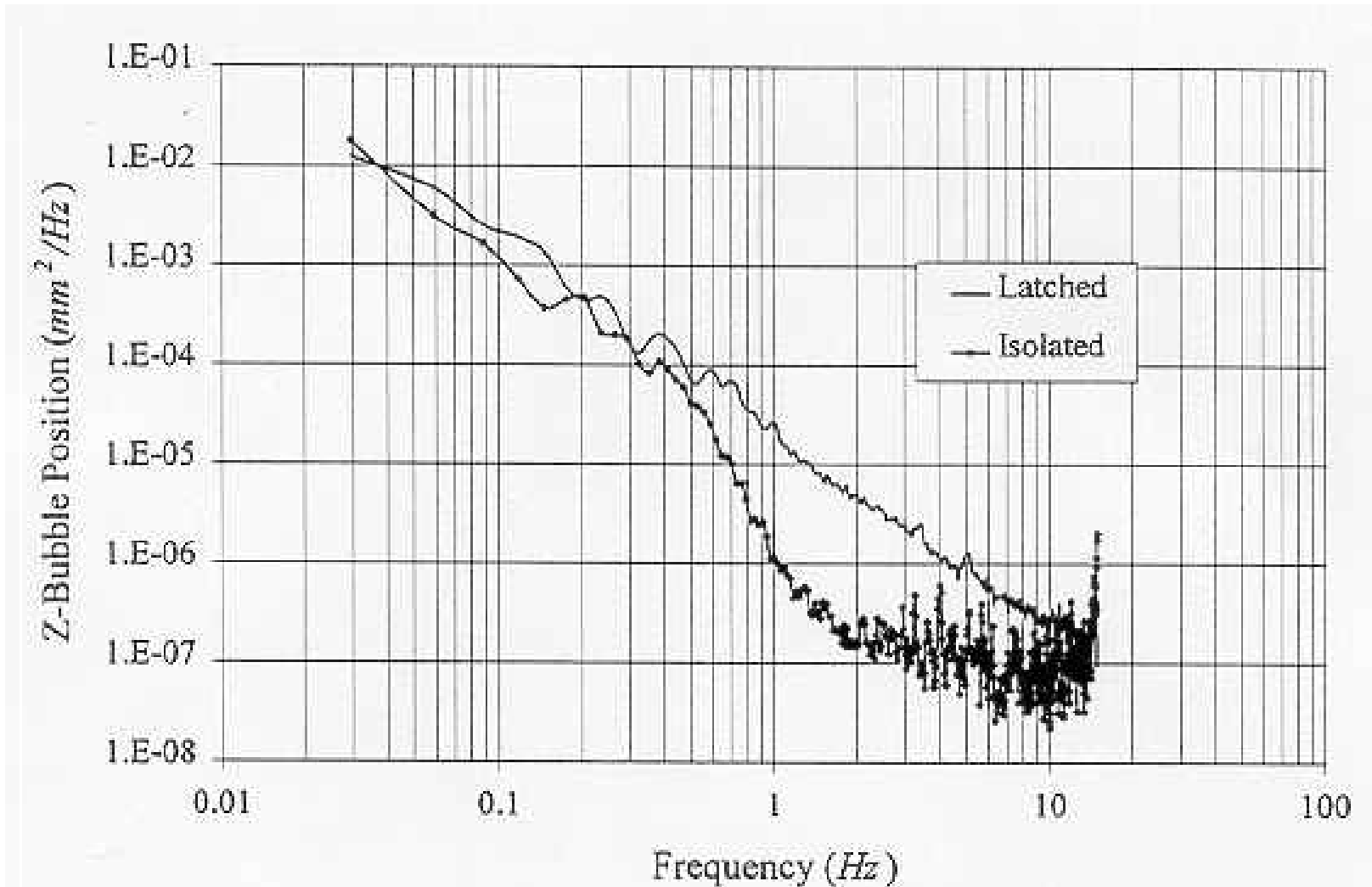
Impact of the Microgravity Environment on Experiments

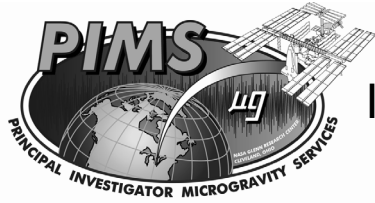
Effect of G-Jitter on the Motion of an Encapsulated Bubble



The motion of a bubble several mm in diameter was recorded on video

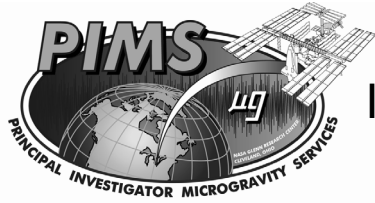
The motion was compared for cases with and without isolation





In summary

- ✦ Use of the MIM enabled examining the sensitivity to g-jitter
- ✦ The diffusion experiments show sensitivity to g-jitters:
 - ✦ intrinsic diffusion coefficient by 2-3 times lower for isolated case vs. non-isolated case
 - ✦ clear indication that diffusion is linear with temperature for the isolated case
- ✦ The fluid science results from STS-85 show significant fluid motion due to g-jitters.



Impact of the Microgravity Environment on Experiments

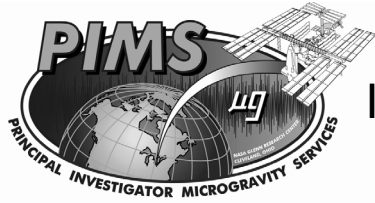
The Vibration Environment of the Mir and the Shuttle



Over 3000 hours of acceleration data was obtained during the Mir based experiments

About 100 hours of data was obtained during the shuttle experiments

The characteristics of the vibration levels are summarized in the following figures



Impact of the Microgravity Environment on Experiments

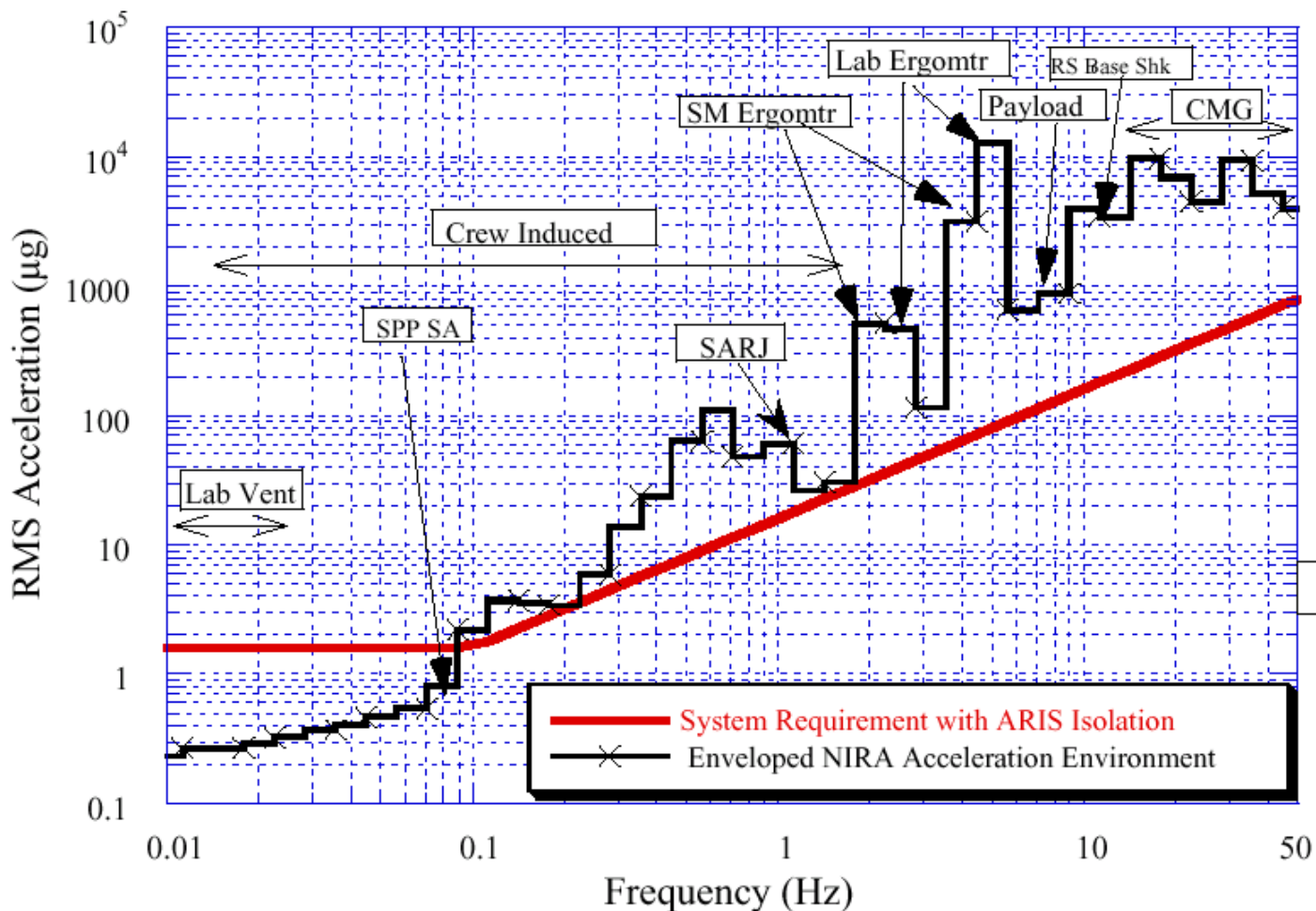
Space Station Vibratory Requirement for Isolated Payloads



The following figure summarizes:

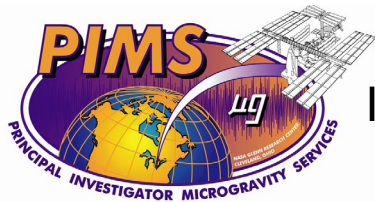
- **the vibration limits for an isolated rack on ISS**
- **the predicted vibration levels for the ISS**

Non-Isolated Rack Assessment - Low Frequency

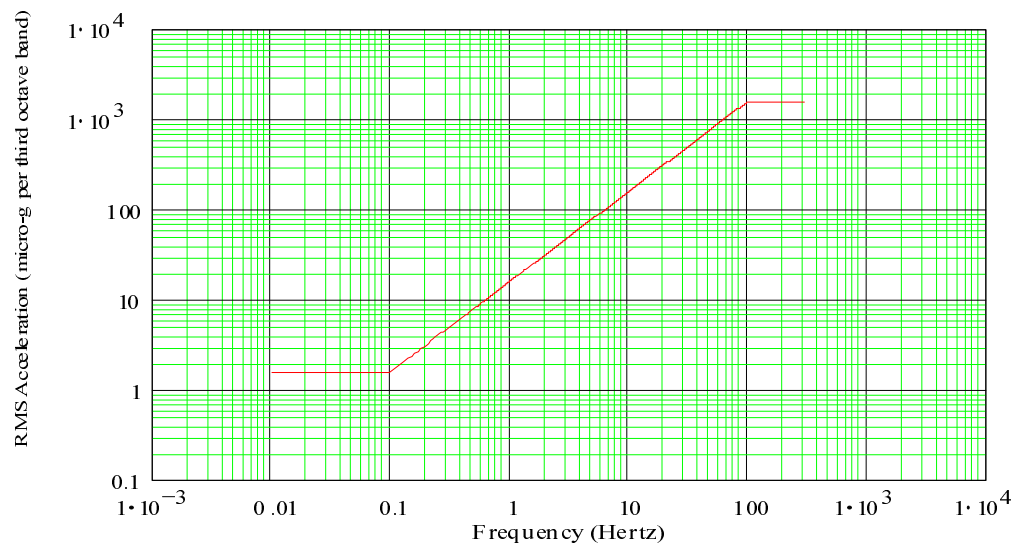


DAC #6
6/98
Data from Boeing

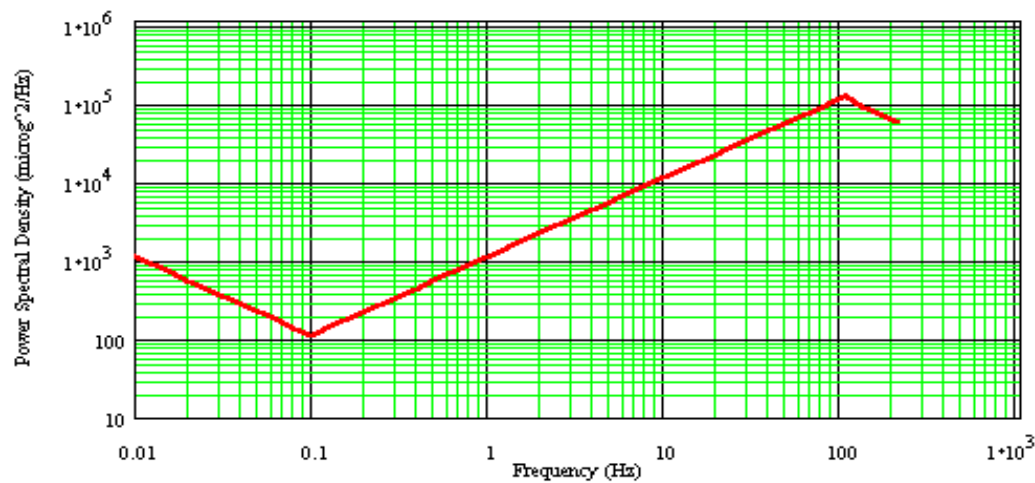
Graph obtained from
NASA web site
<http://www.lerc.nasa.gov/WWW/MMAP/PIMS/MEIT/meit99pdfs.html>

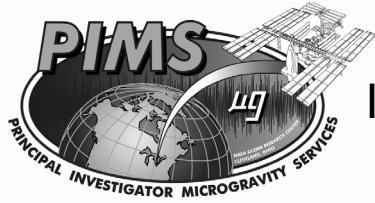


Impact of the Microgravity Environment on Experiments



Data obtained from Microgravity Control Plan:
International Space Station Program,
NASA document SSP50036, Revision A





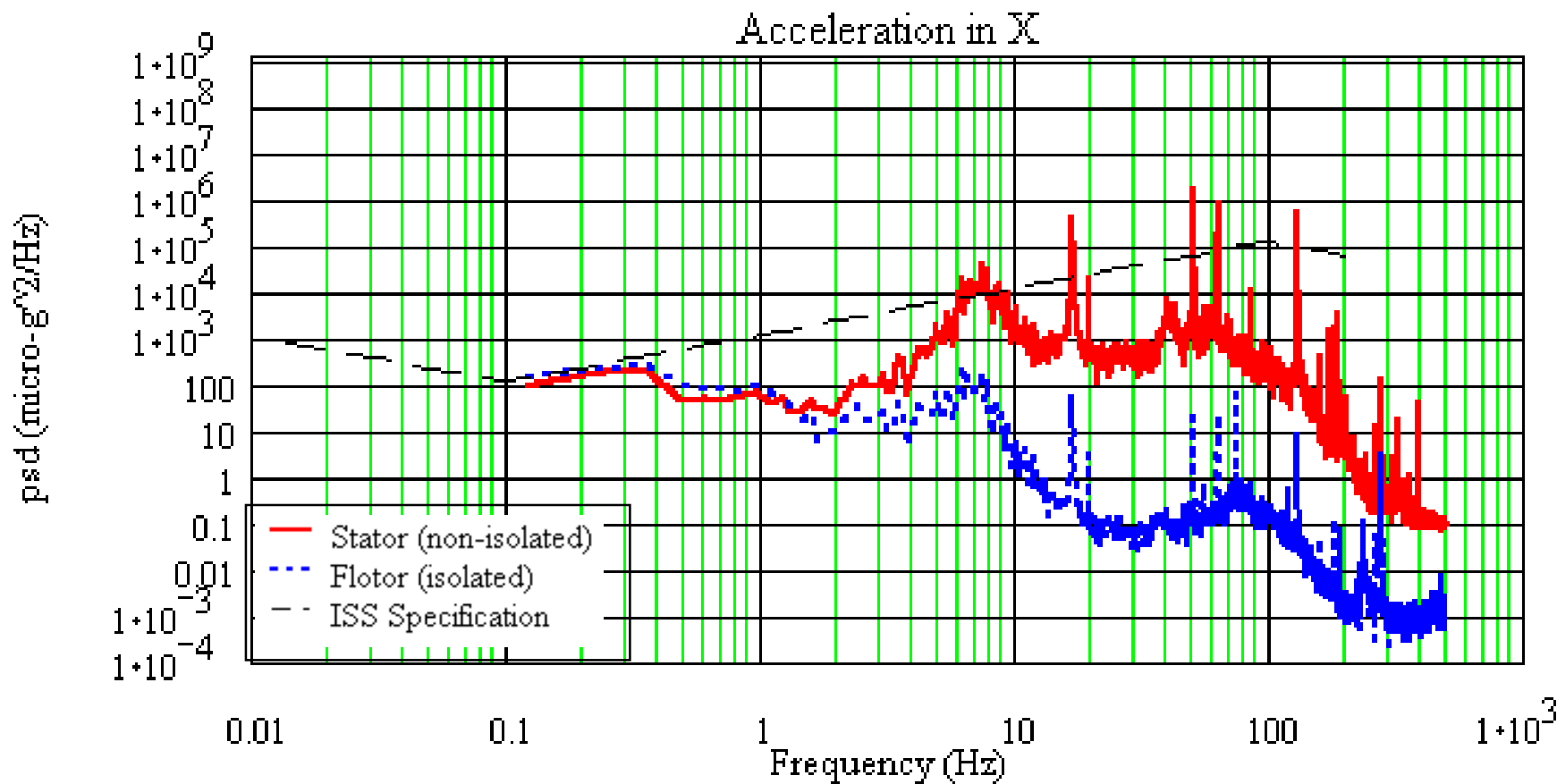
Impact of the Microgravity Environment on Experiments

Acceleration levels on the Space Shuttle

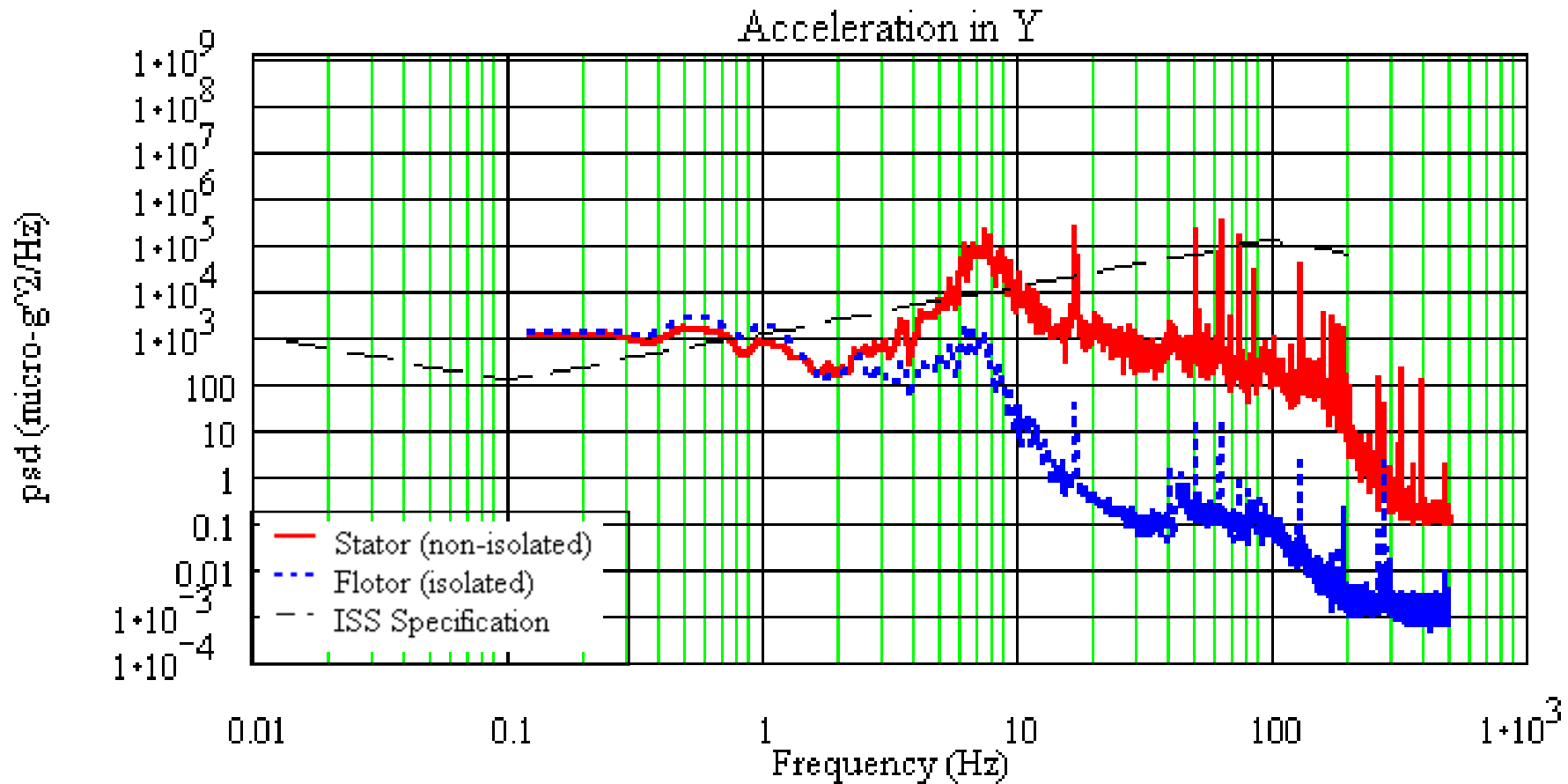


Typical Acceleration Levels on the Shuttle

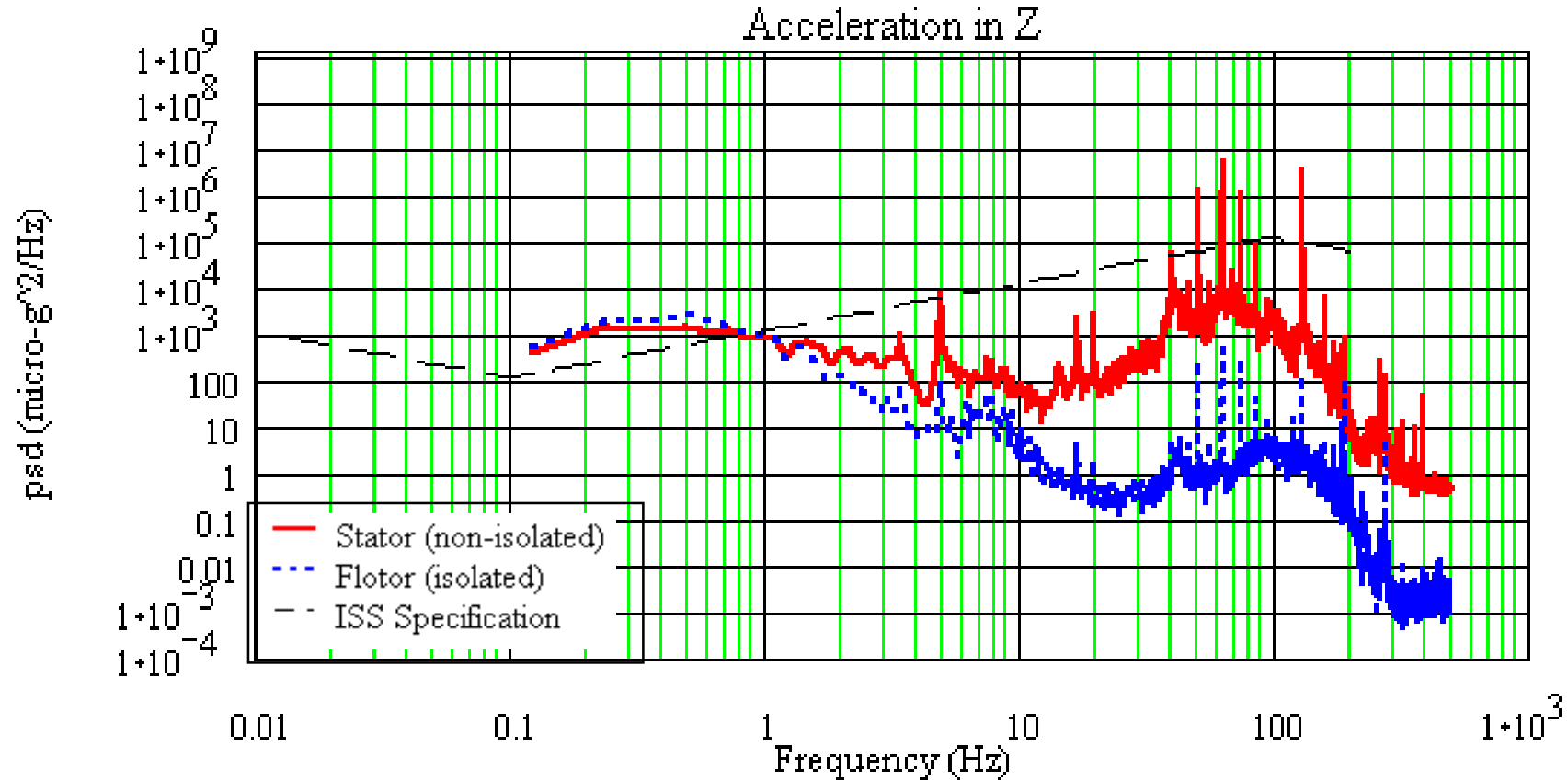
Acceleration levels on the Space Shuttle

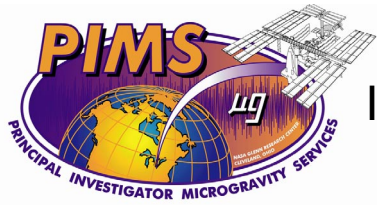


Acceleration levels on the Space Shuttle



Acceleration levels on the Space Shuttle

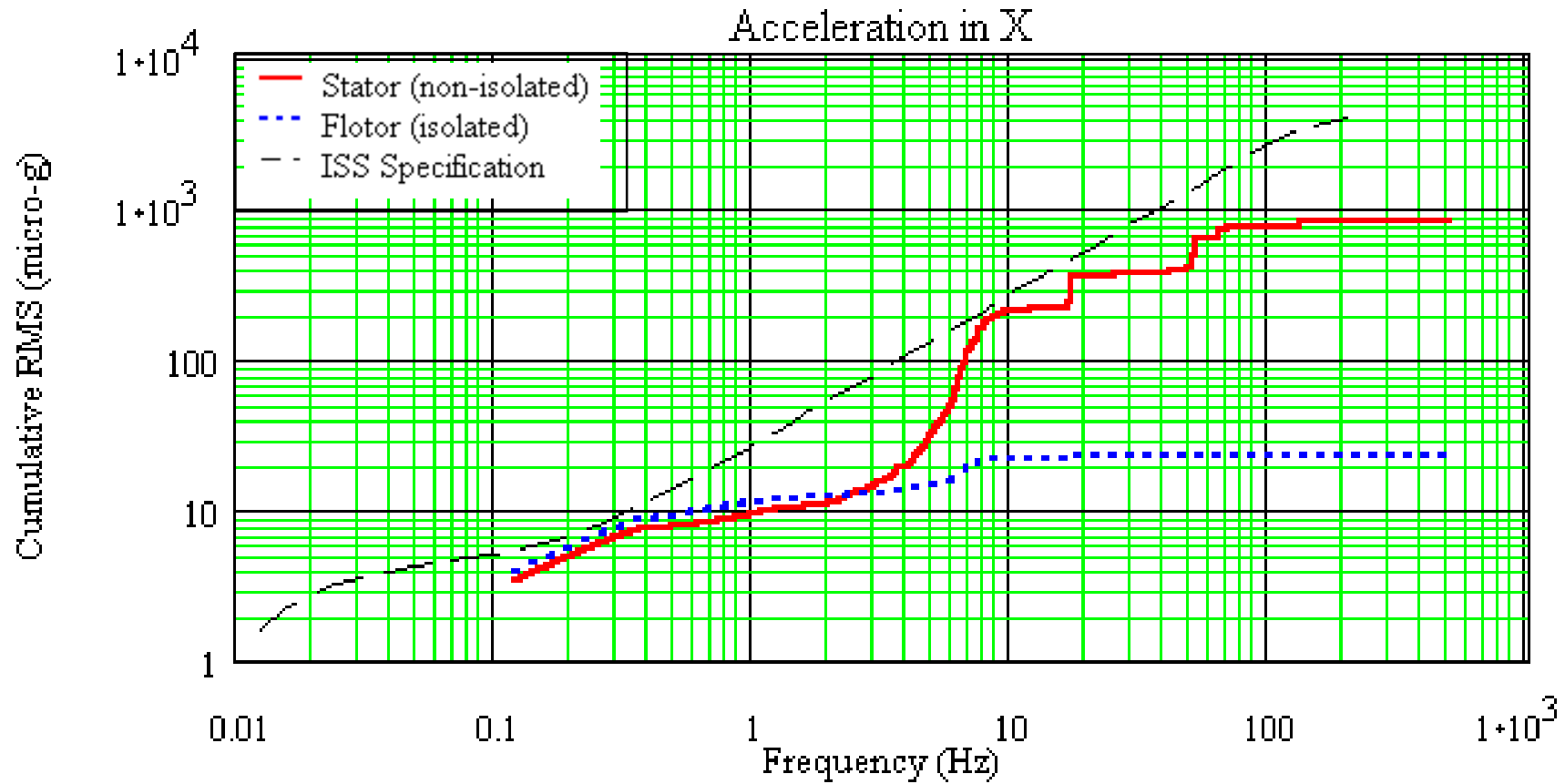


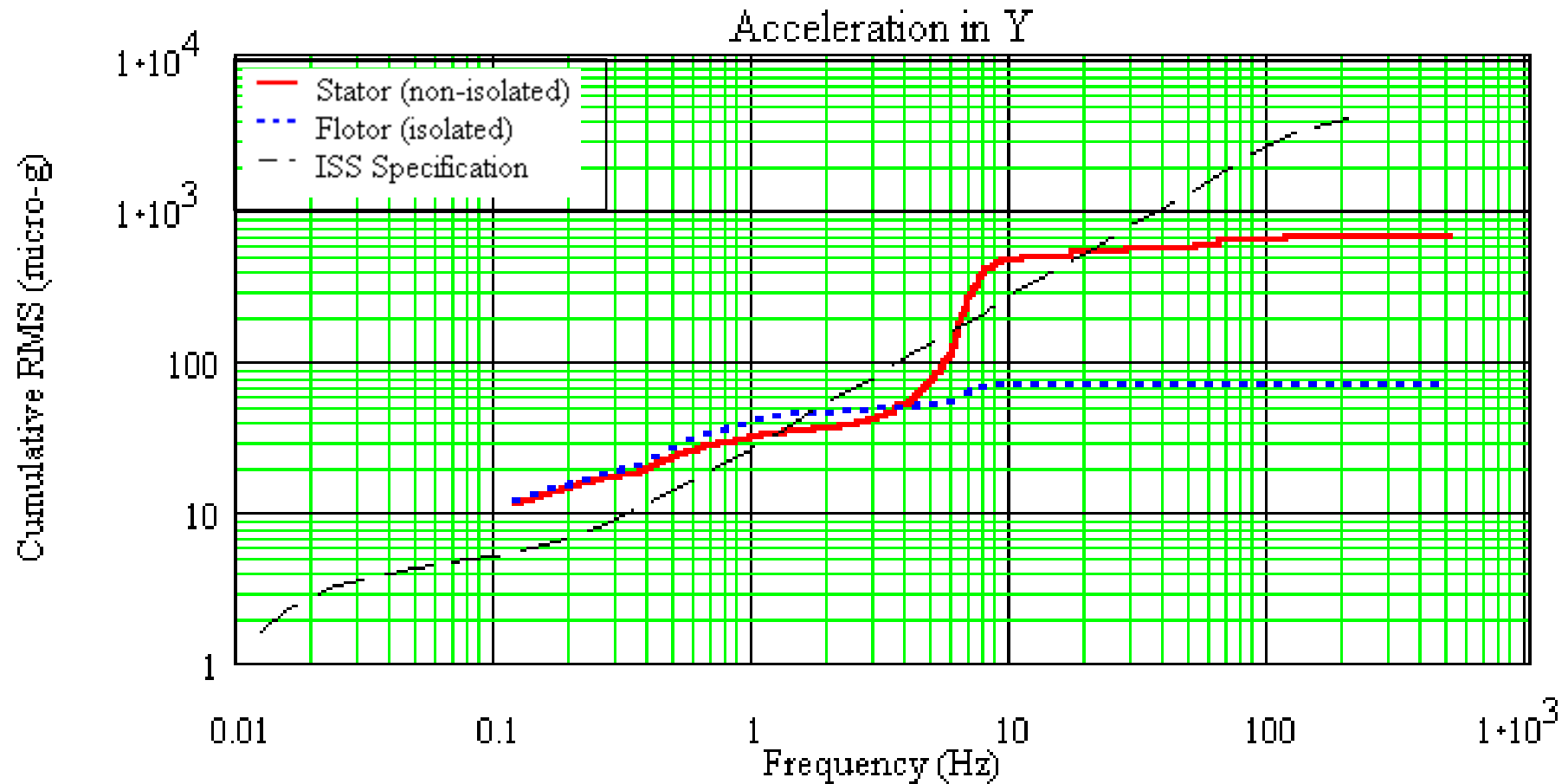


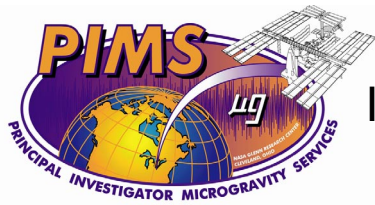
Impact of the Microgravity Environment on Experiments



Cumulative Acceleration Levels on the Space Shuttle



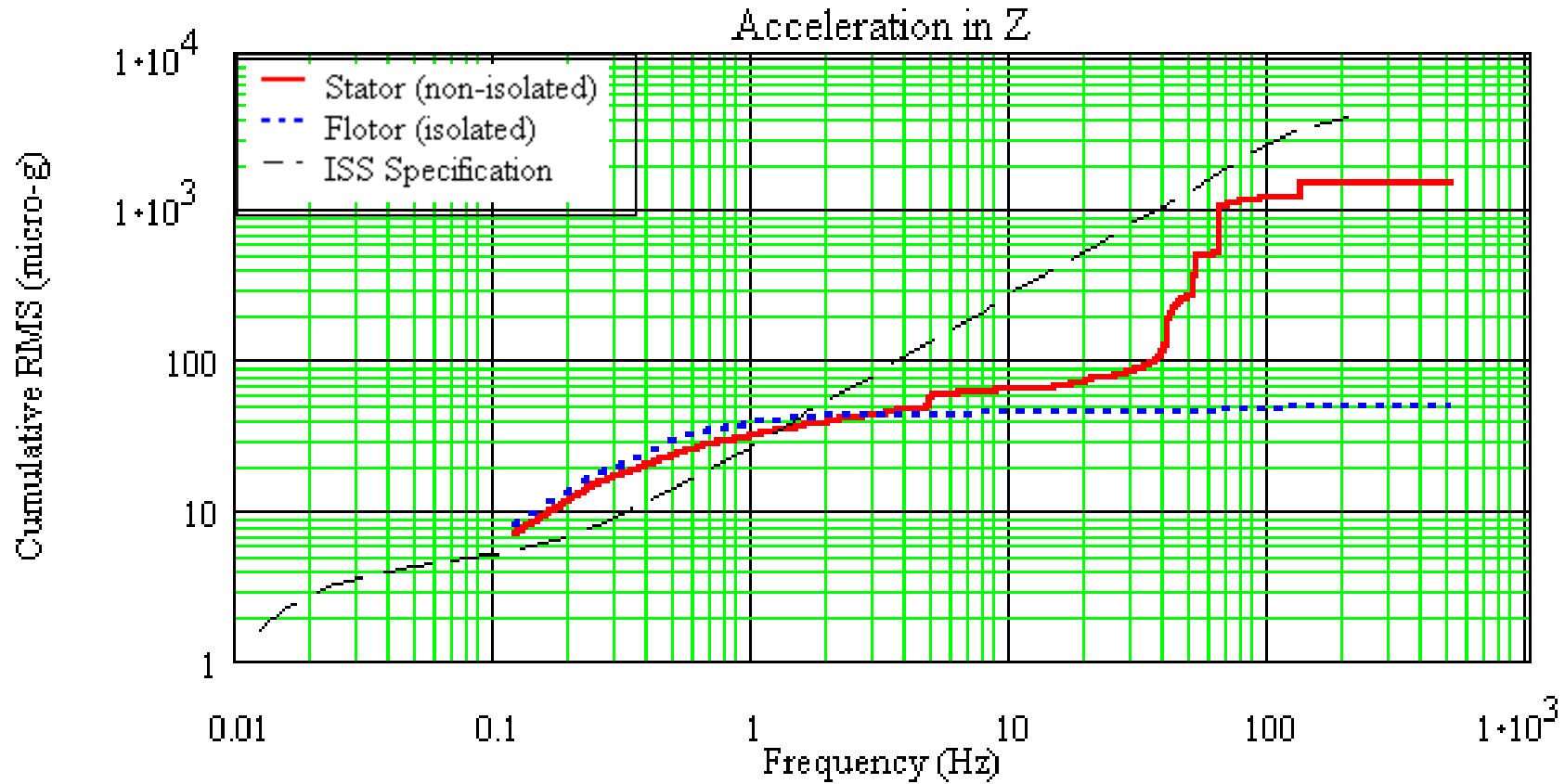


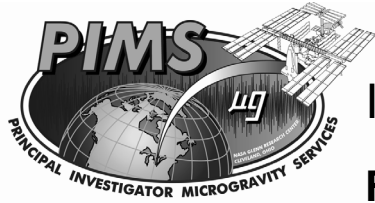


Impact of the Microgravity Environment on Experiments



Cumulative Acceleration Levels on the Space Shuttle



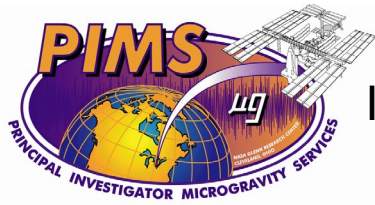


Impact of the Microgravity Environment on Experiments
Format for Presentation of Time Histories for Accelerations



On the time traces four lines are plotted on each figure. These are the following statistics:

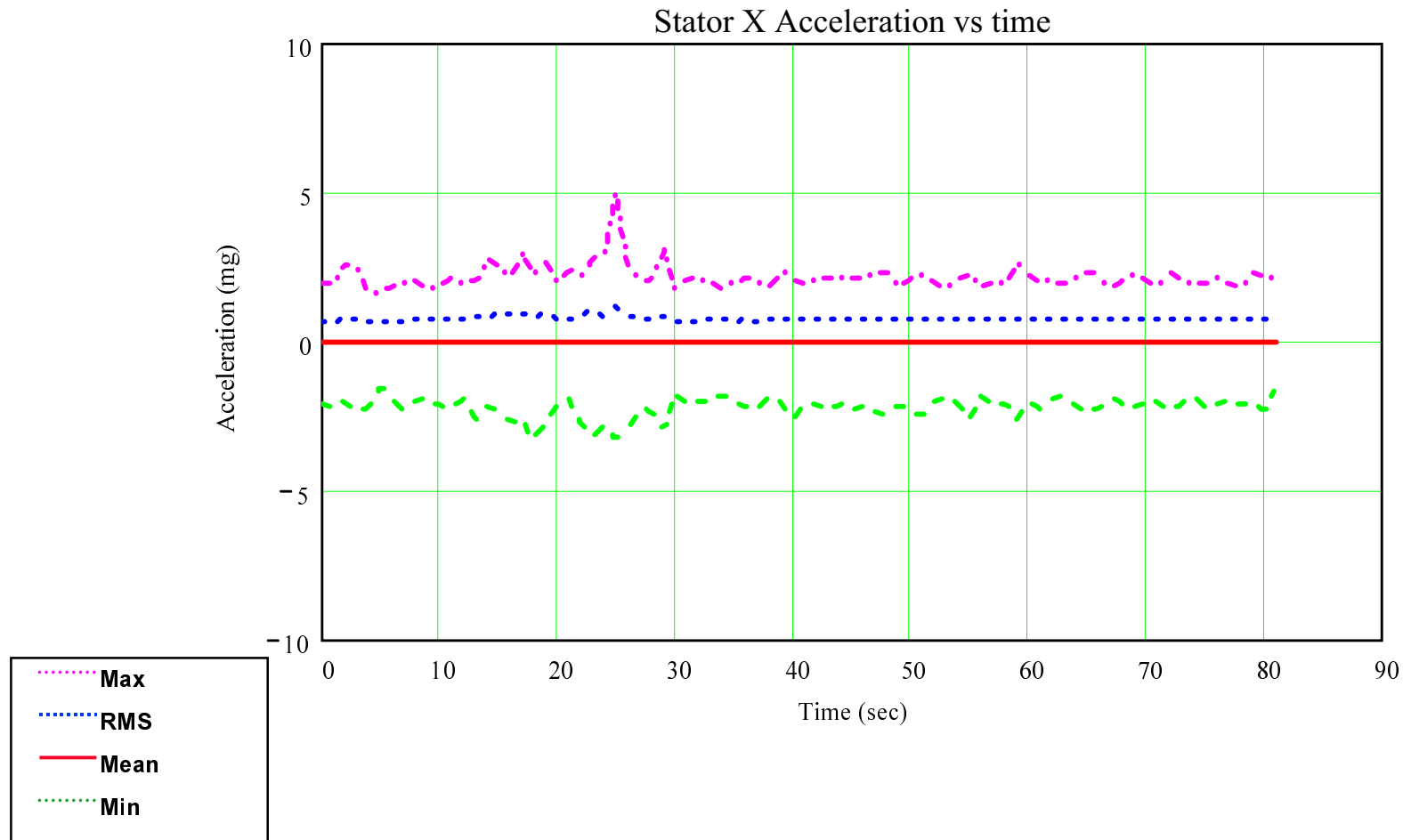
- **Maximum acceleration sampled over a one second interval**
- **Minimum acceleration sampled over a one second interval**
- **Standard deviation of the acceleration over the one second interval**
- **The mean acceleration over the one second interval, with the mean for the whole record removed**



Impact of the Microgravity Environment on Experiments

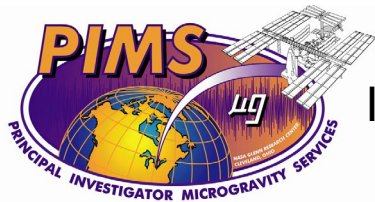


Acceleration on the Space Shuttle

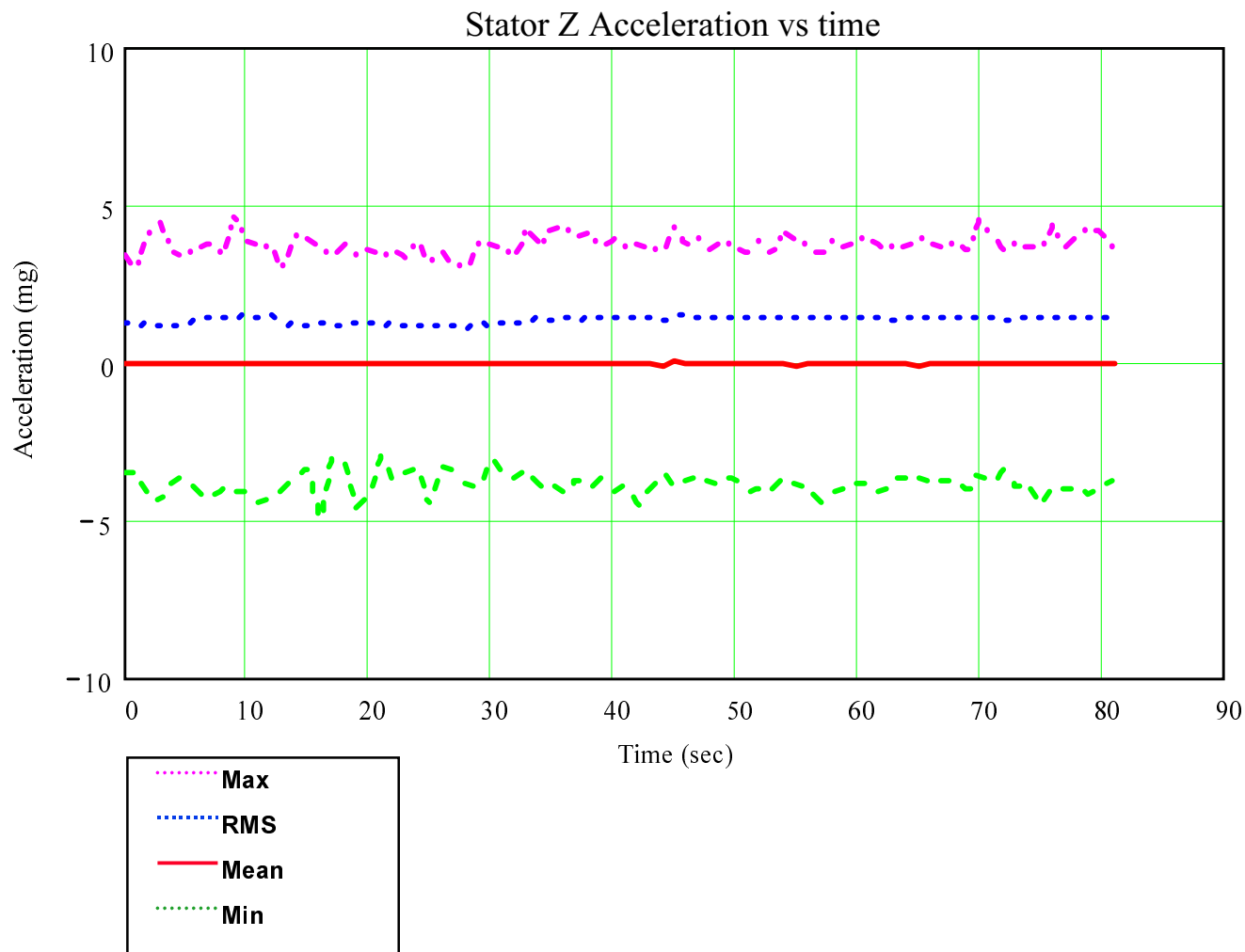


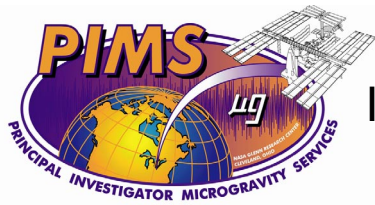
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Acceleration on the Space Shuttle

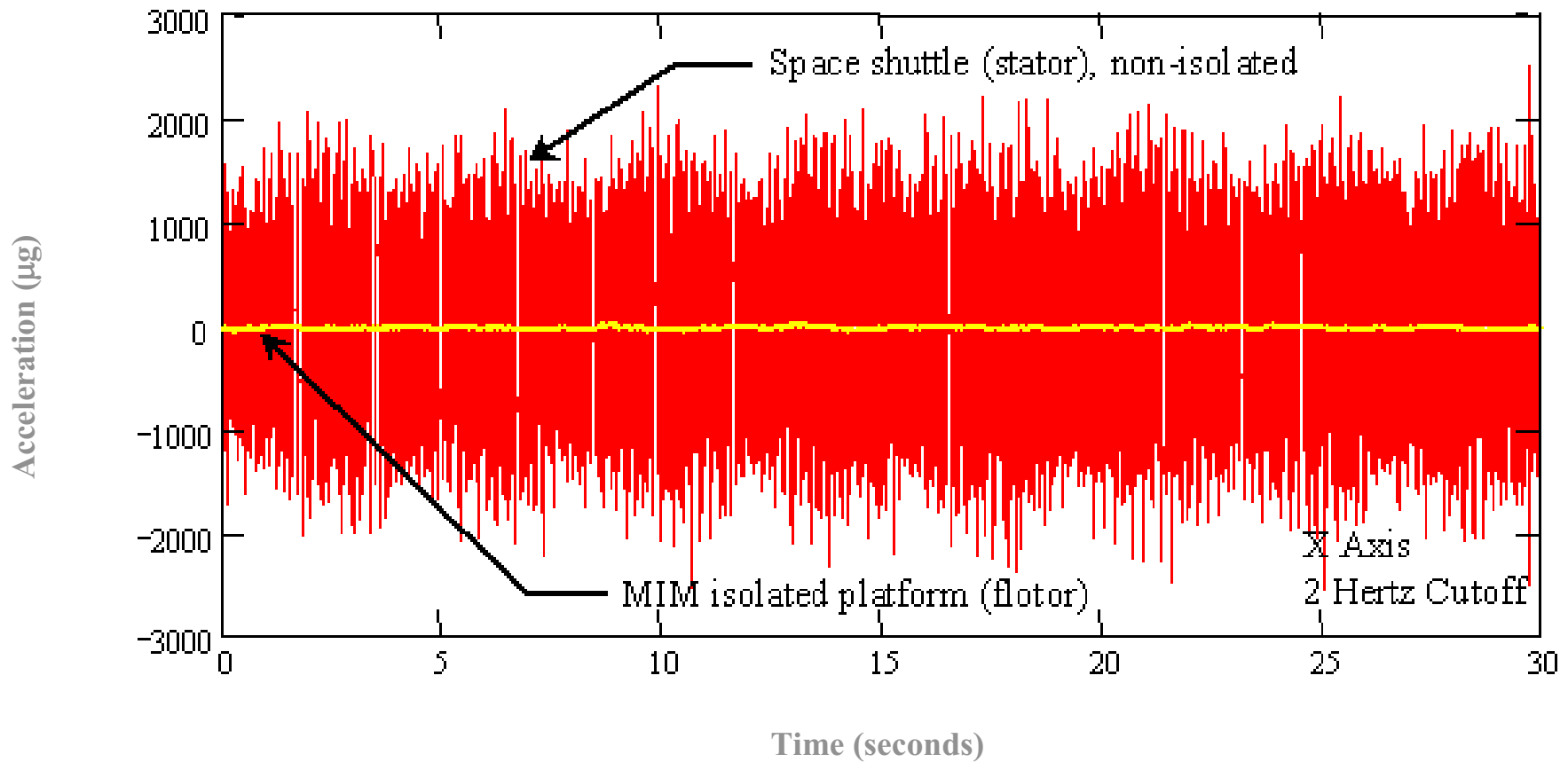




Impact of the Microgravity Environment on Experiments

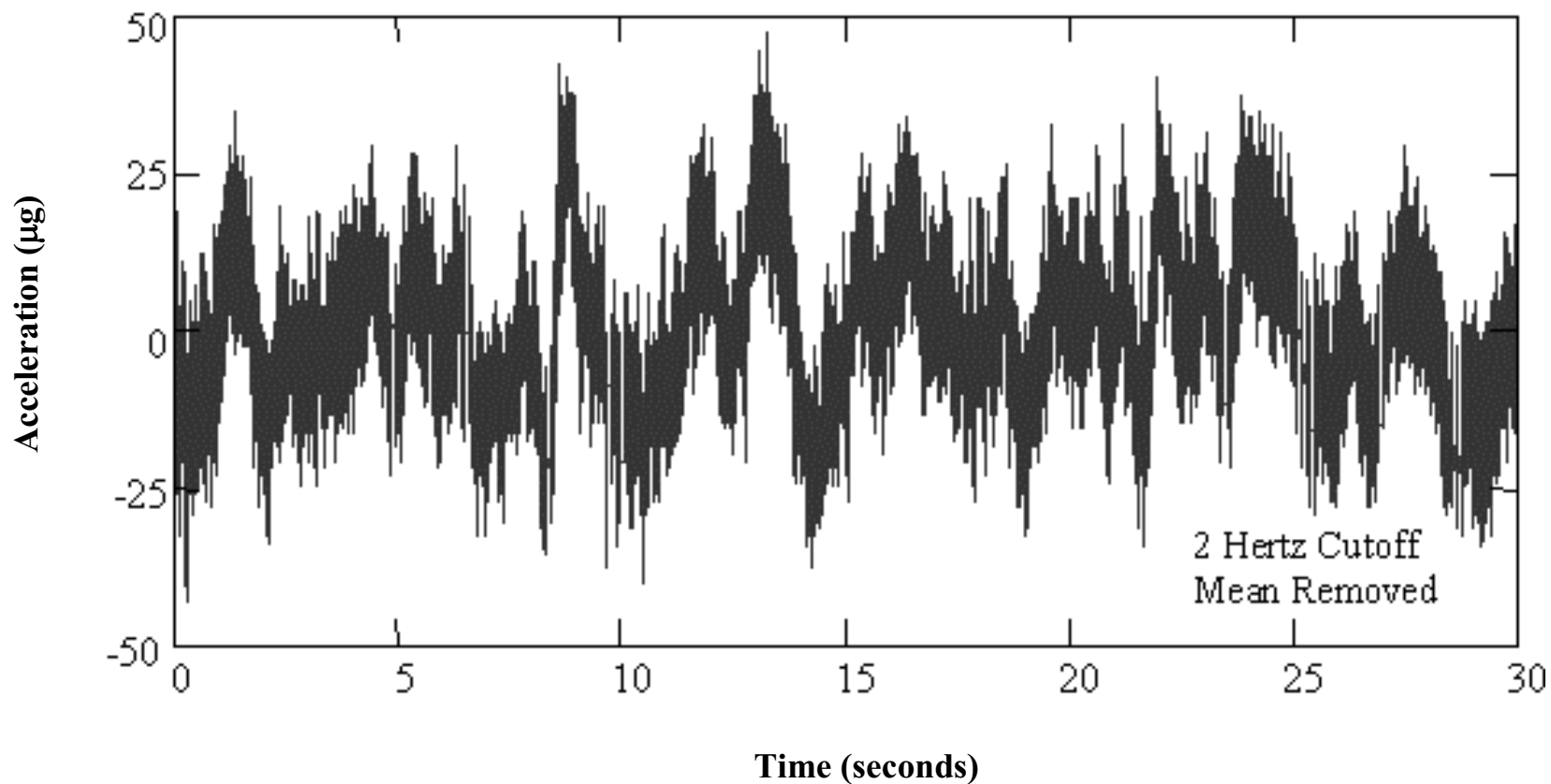


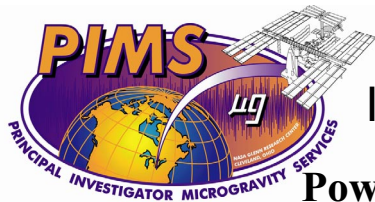
Acceleration Levels of the Space Shuttle and the MIM Flotor



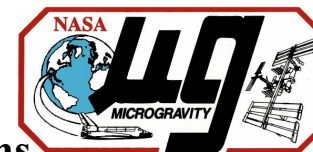


Flotor X Acceleration

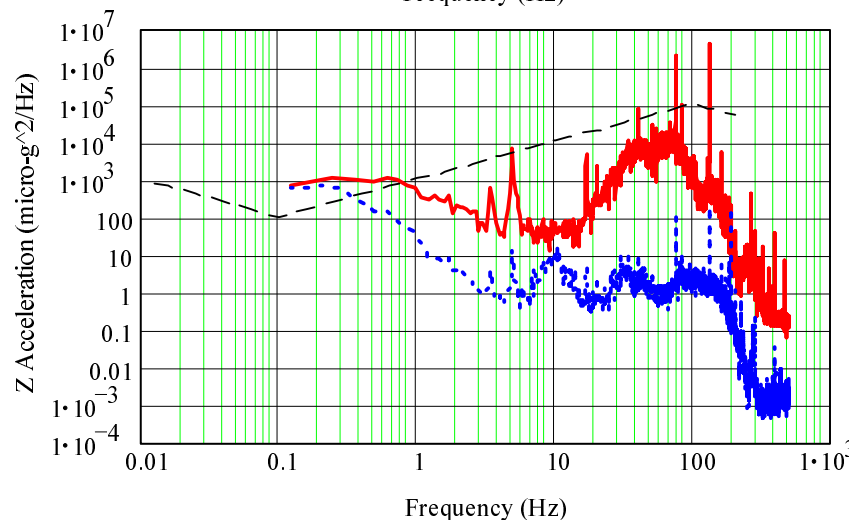
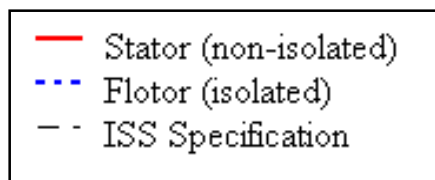
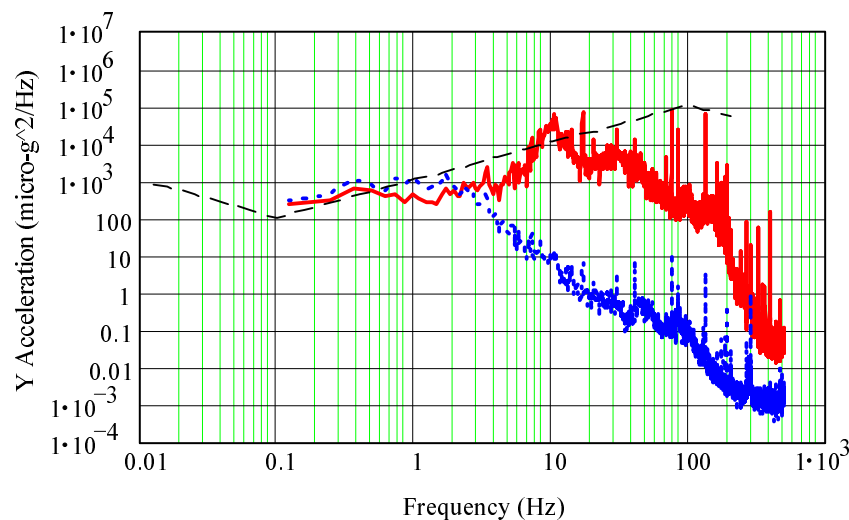
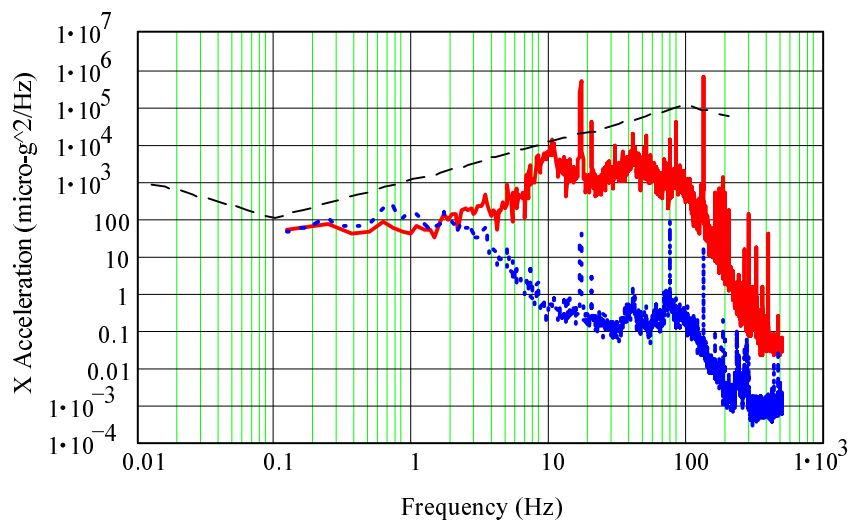




Impact of the Microgravity Environment on Experiments

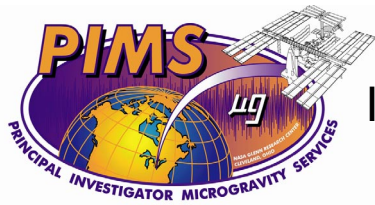


Power Spectral Densities for the Shuttle and MIM Flotor Accelerations

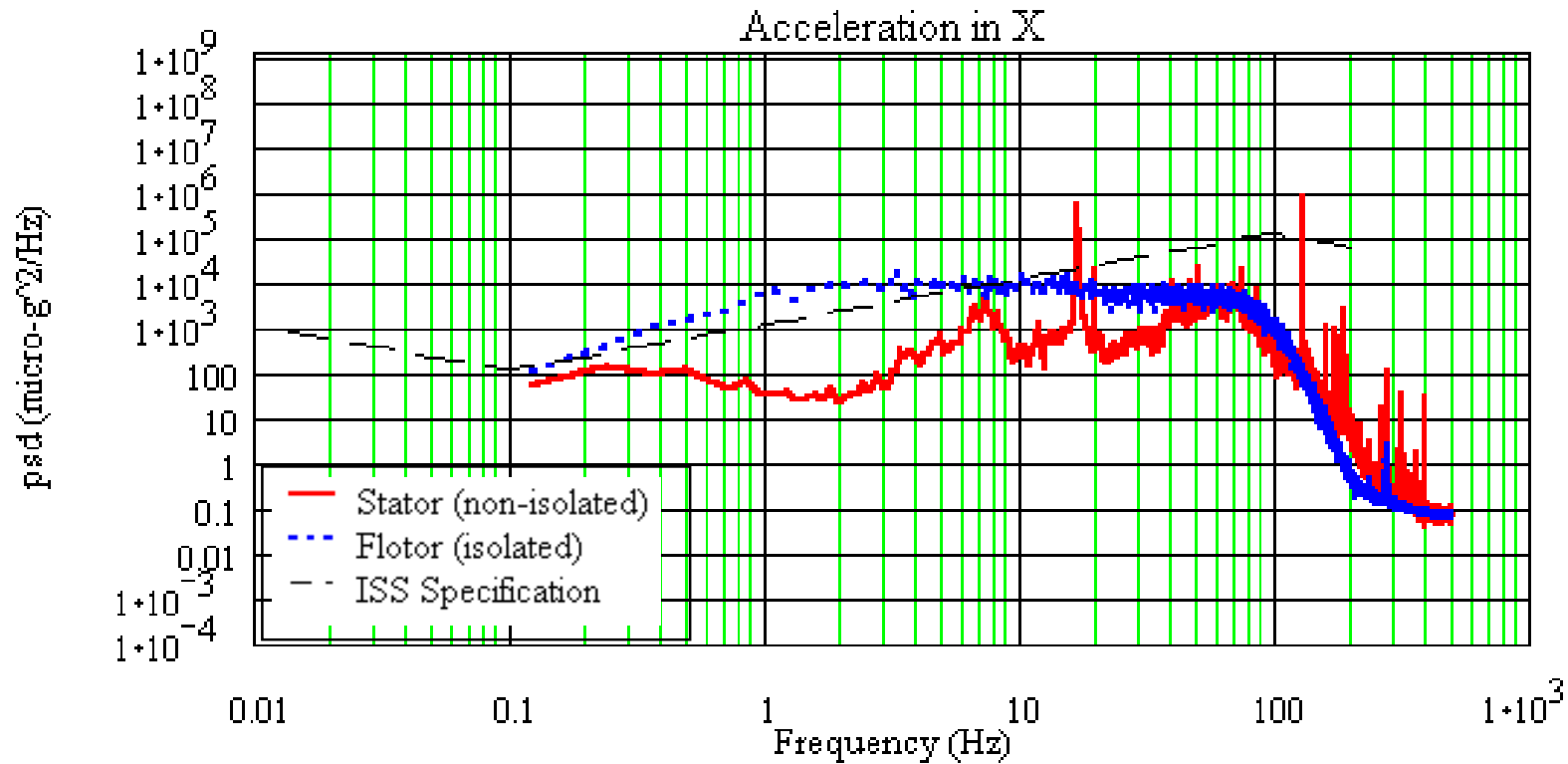


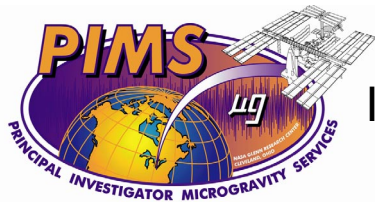
DPID, XY: 2 Hertz, Z: 0.1 Hertz
File: D7081621

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MIM Driven Mode - Random

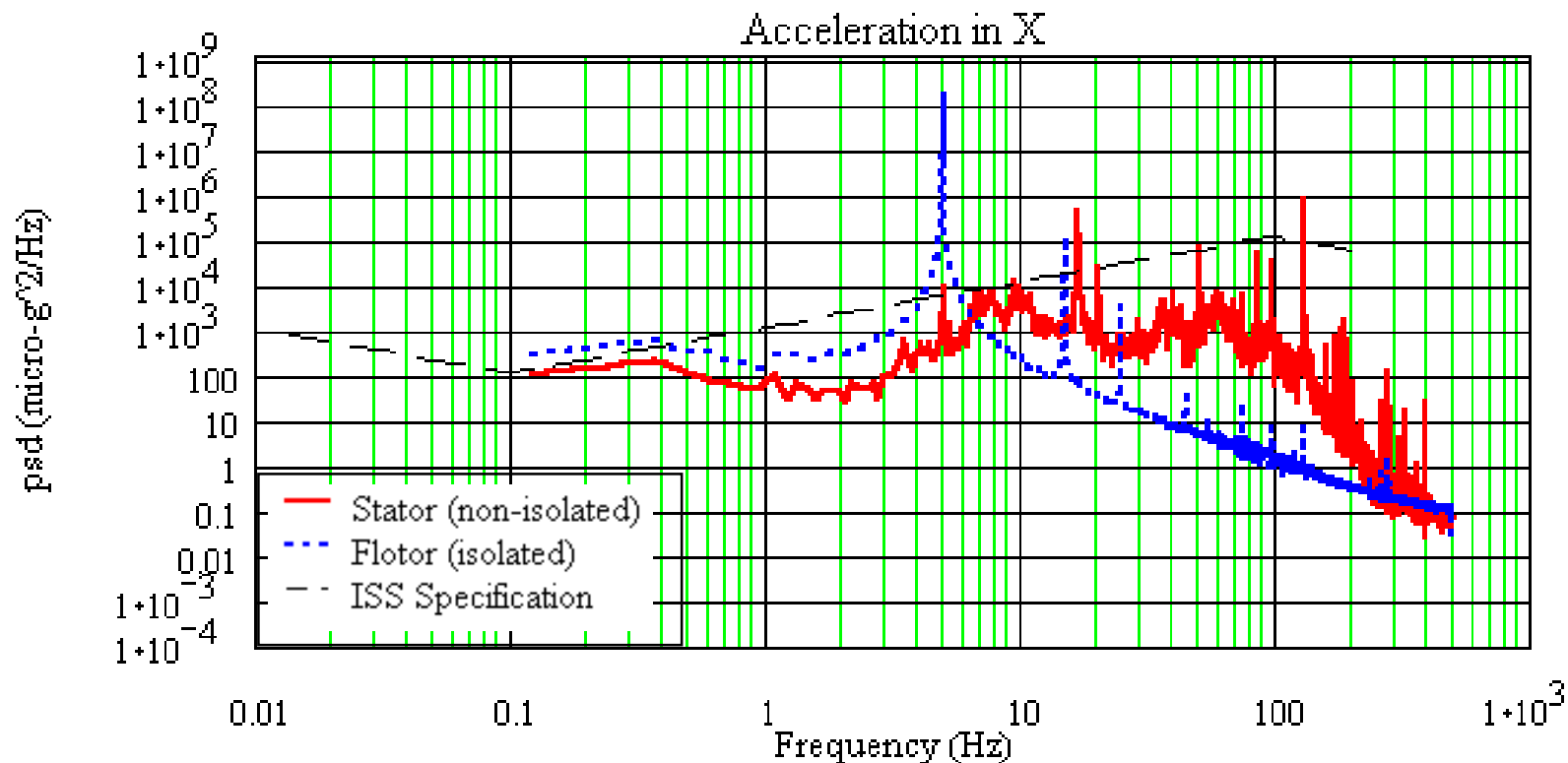


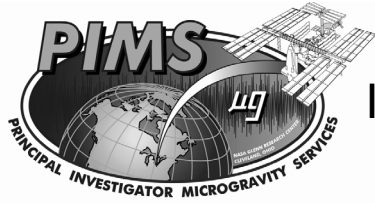


Impact of the Microgravity Environment on Experiments



MIM Driven Mode - 5 Hz





Impact of the Microgravity Environment on Experiments

MIM-1 Operations on Mir

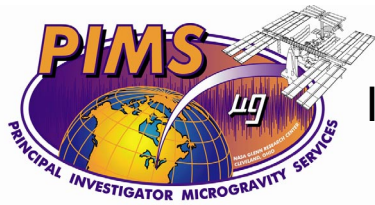


Operational from May 1996 to January 1998

3000 hours of operations supporting material science experiments:

- Diffusion in liquid metals, Nucleation in glasses, Particle pushing, Semiconductor crystal growth, Protein crystal growth, Liquid-vapor interface dynamics

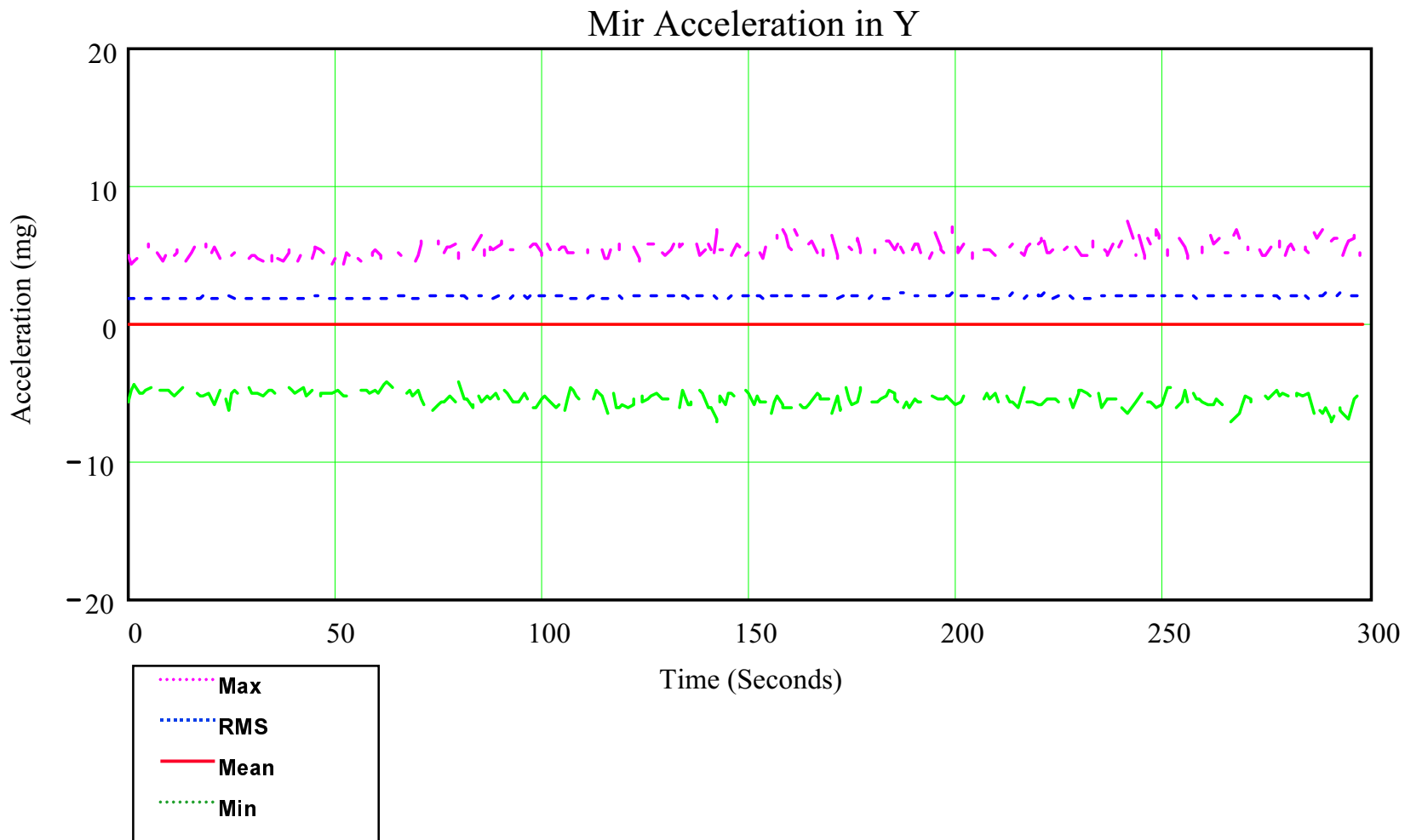
Acceleration data collected for most of this time with sampling rate up to 1000 s/s for several minutes and continuous time recordings up to seven days at lower sampling rates

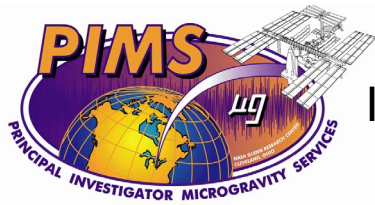


Impact of the Microgravity Environment on Experiments



Accelerations on Mir as Measured with the MIM

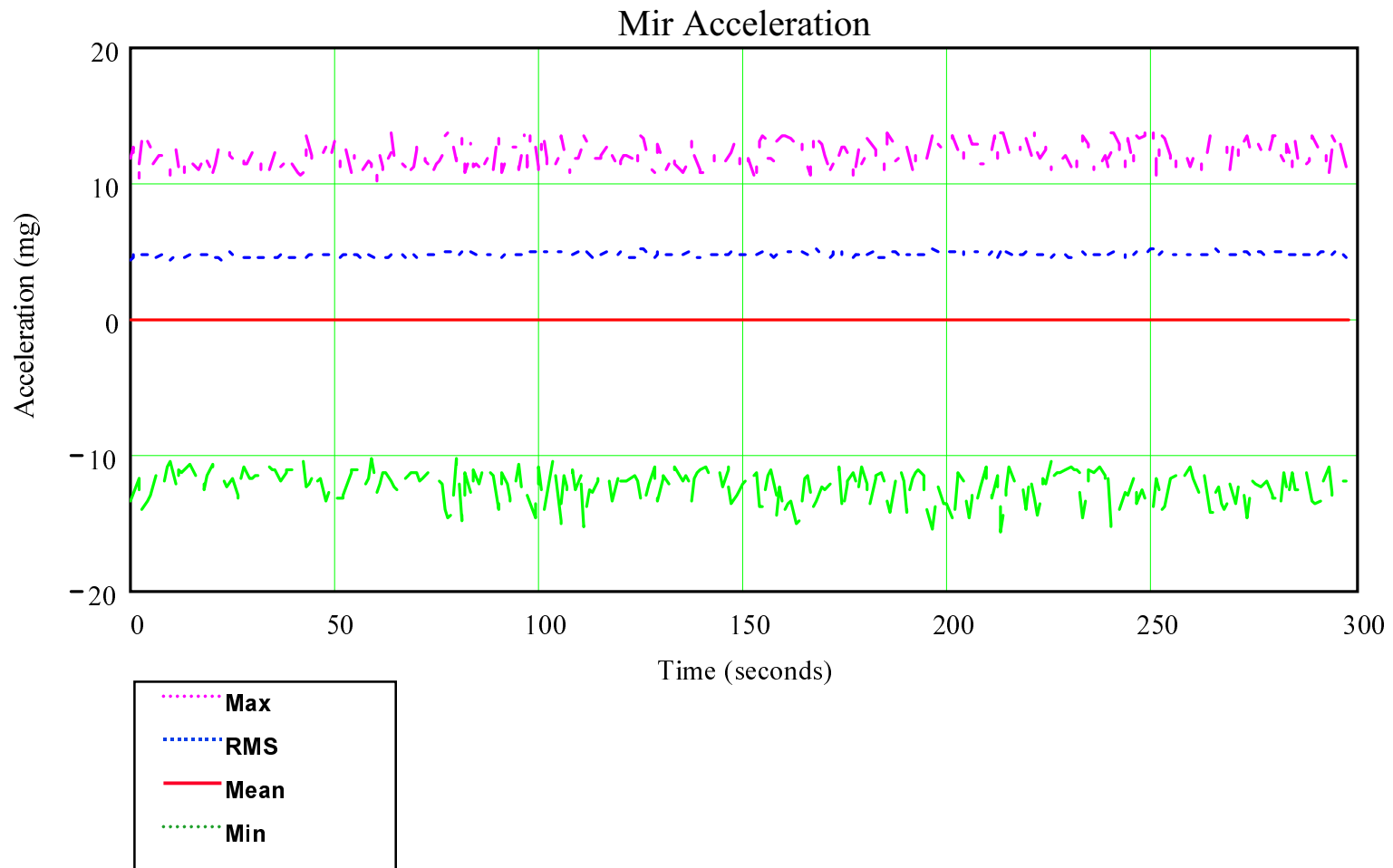


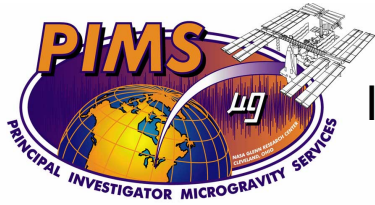


Impact of the Microgravity Environment on Experiments

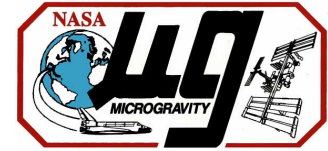


Accelerations on Mir as Measured with the MIM

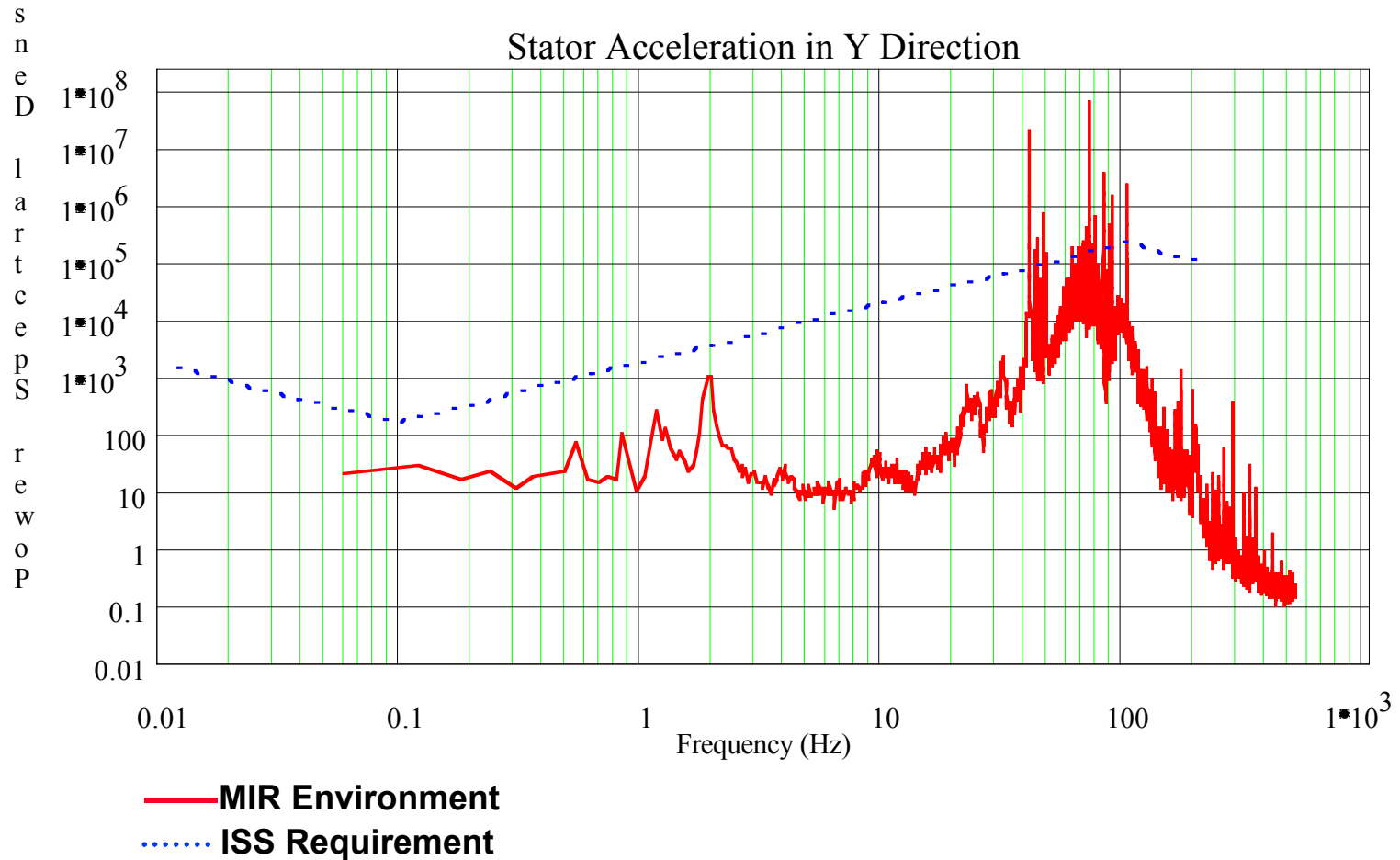


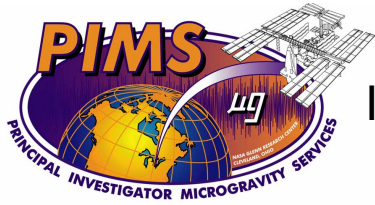


Impact of the Microgravity Environment on Experiments



Accelerations on Mir as Measured with the MIM

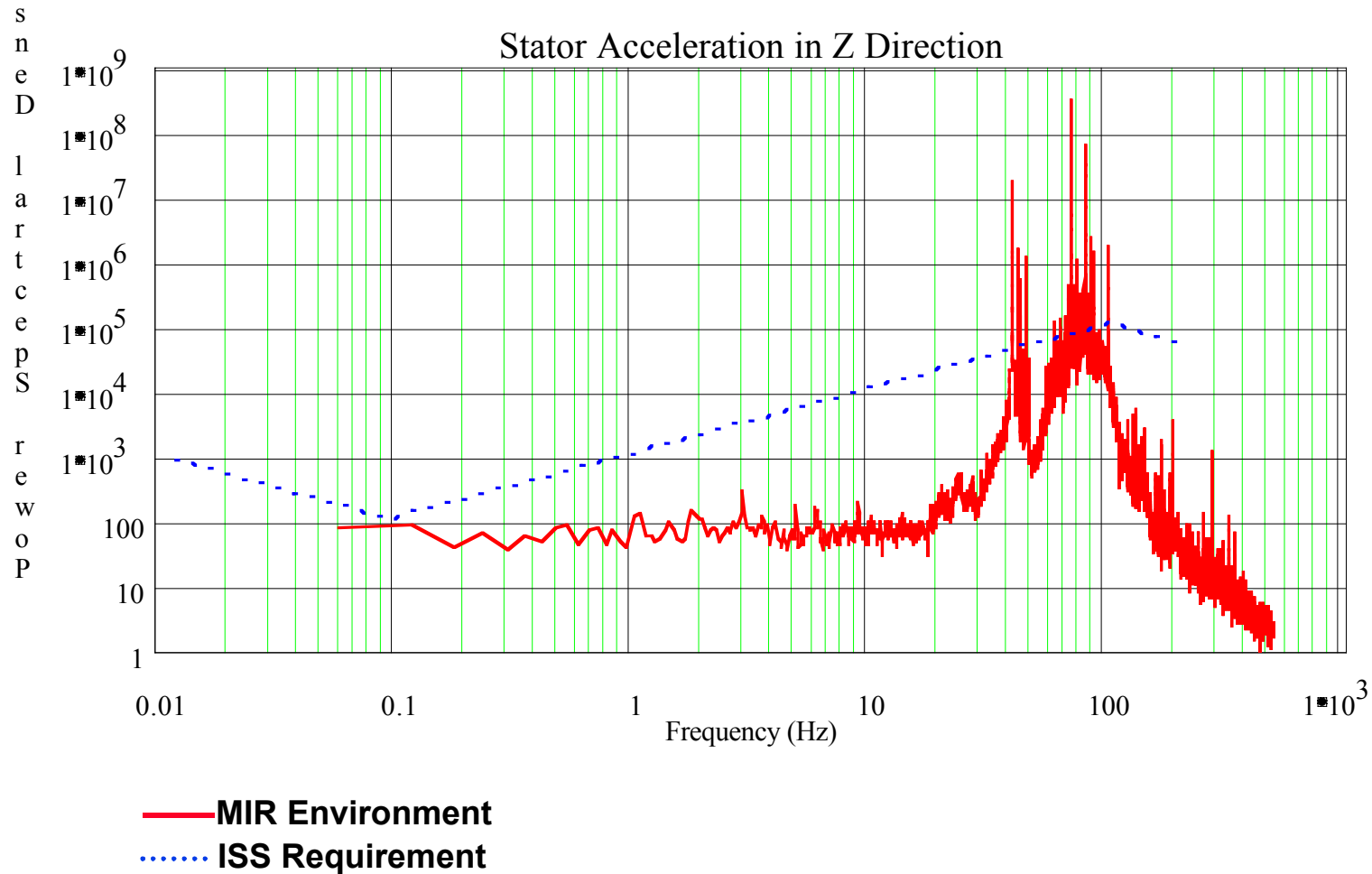




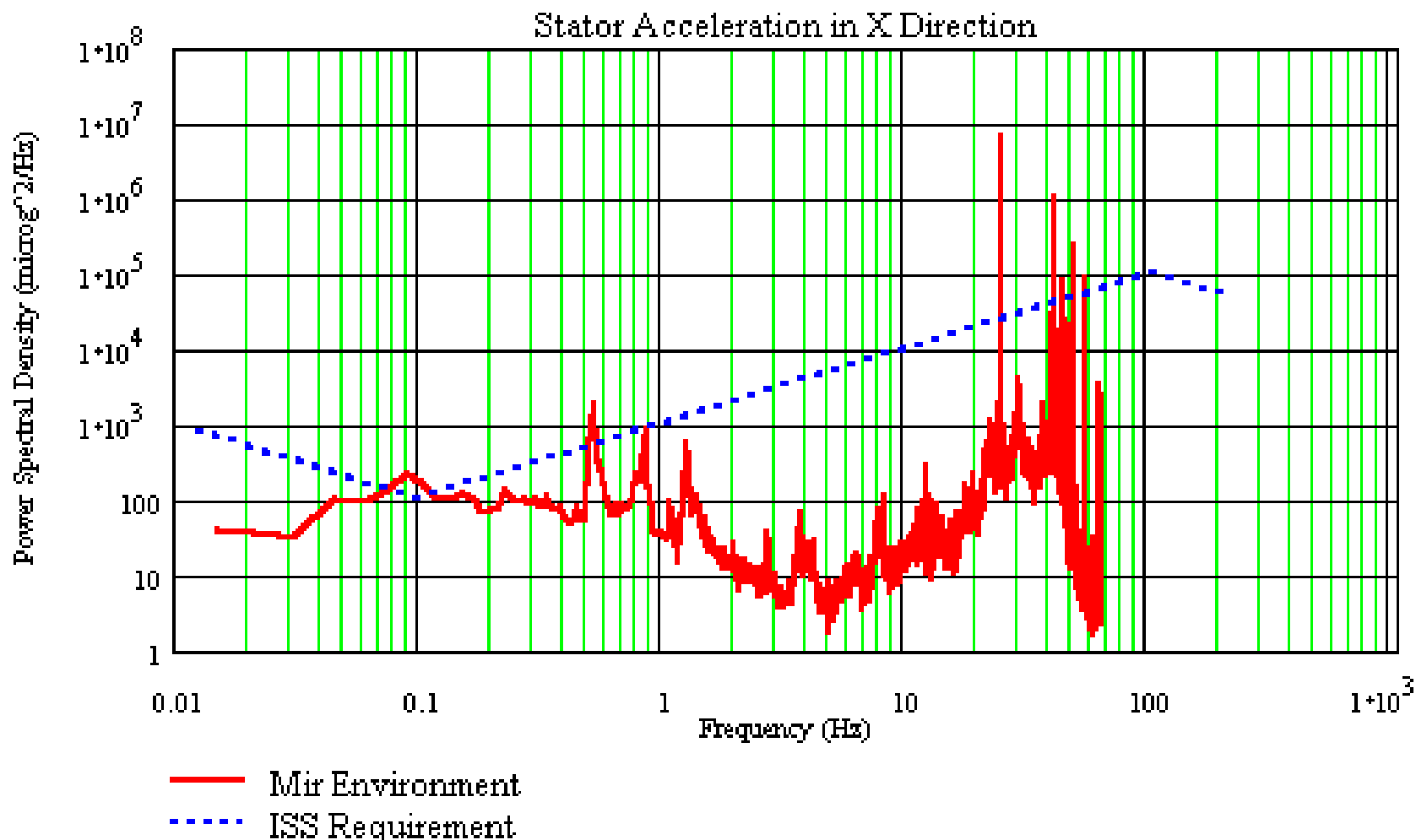
Impact of the Microgravity Environment on Experiments

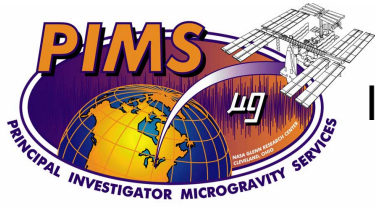


Accelerations on Mir as Measured with the MIM



Accelerations on Mir as Measured with the MIM

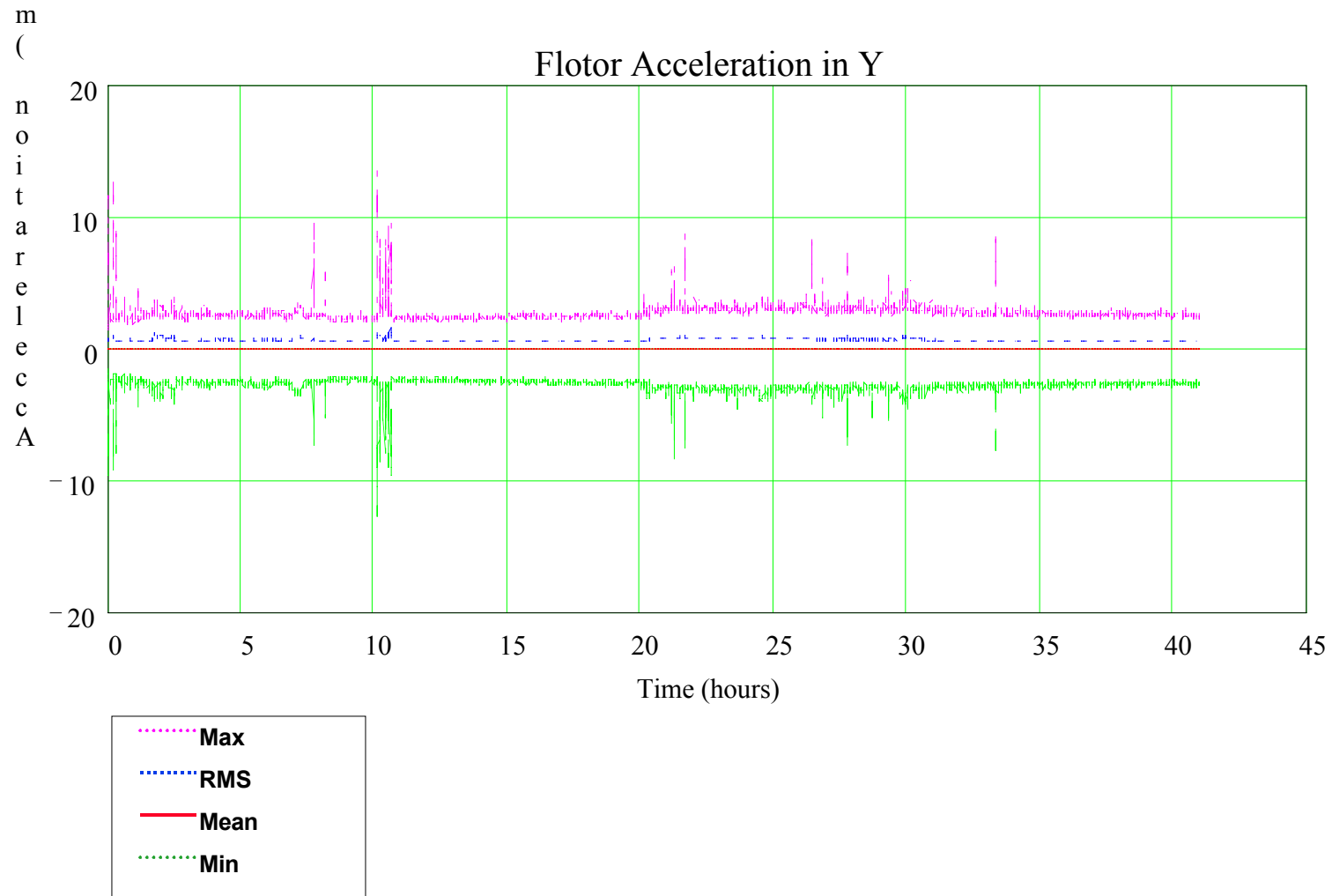




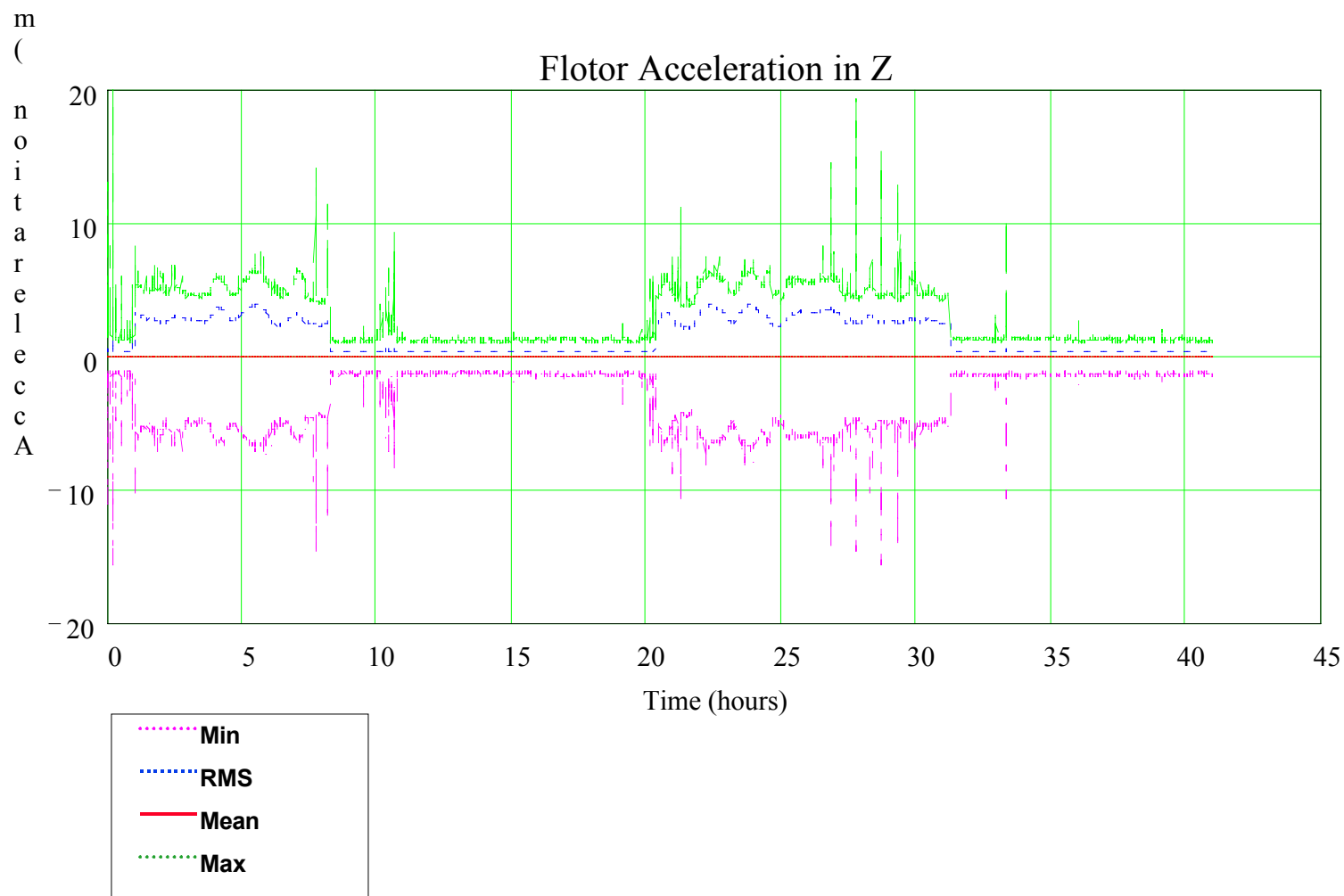
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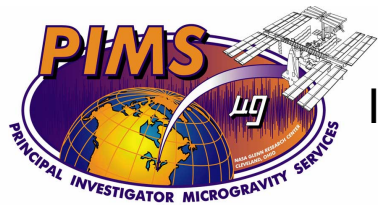


Accelerations on Mir as Measured with the MIM



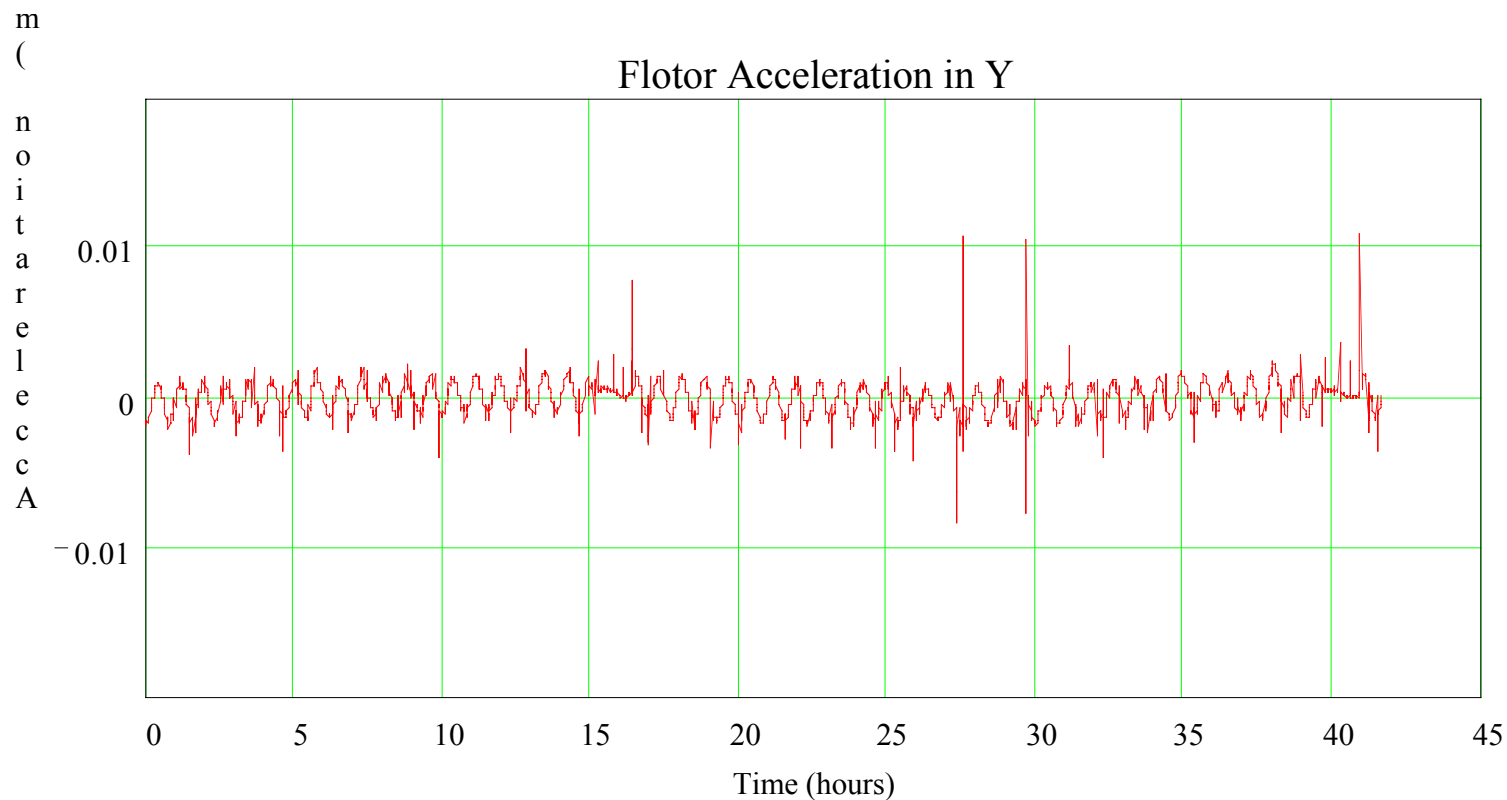
Accelerations on Mir as Measured with the MIM

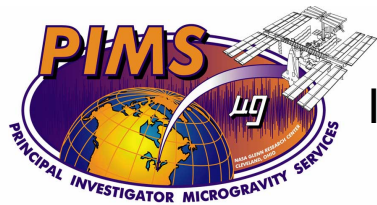




Impact of the Microgravity Environment on Experiments

Mean Acceleration on an Expanded Scale

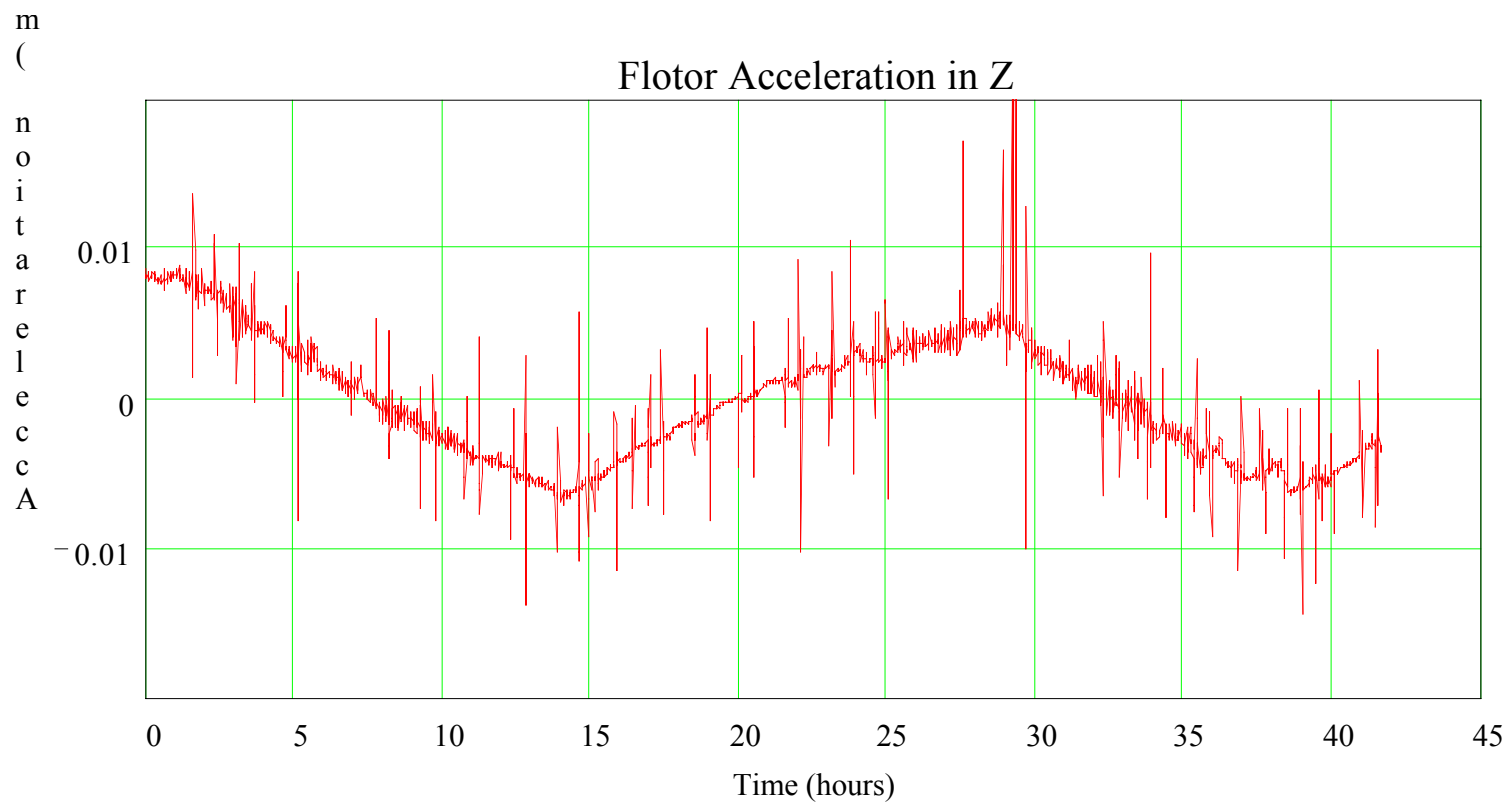


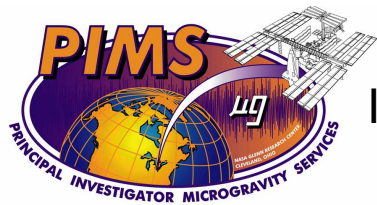


Impact of the Microgravity Environment on Experiments



Mean Acceleration on an Expanded Scale

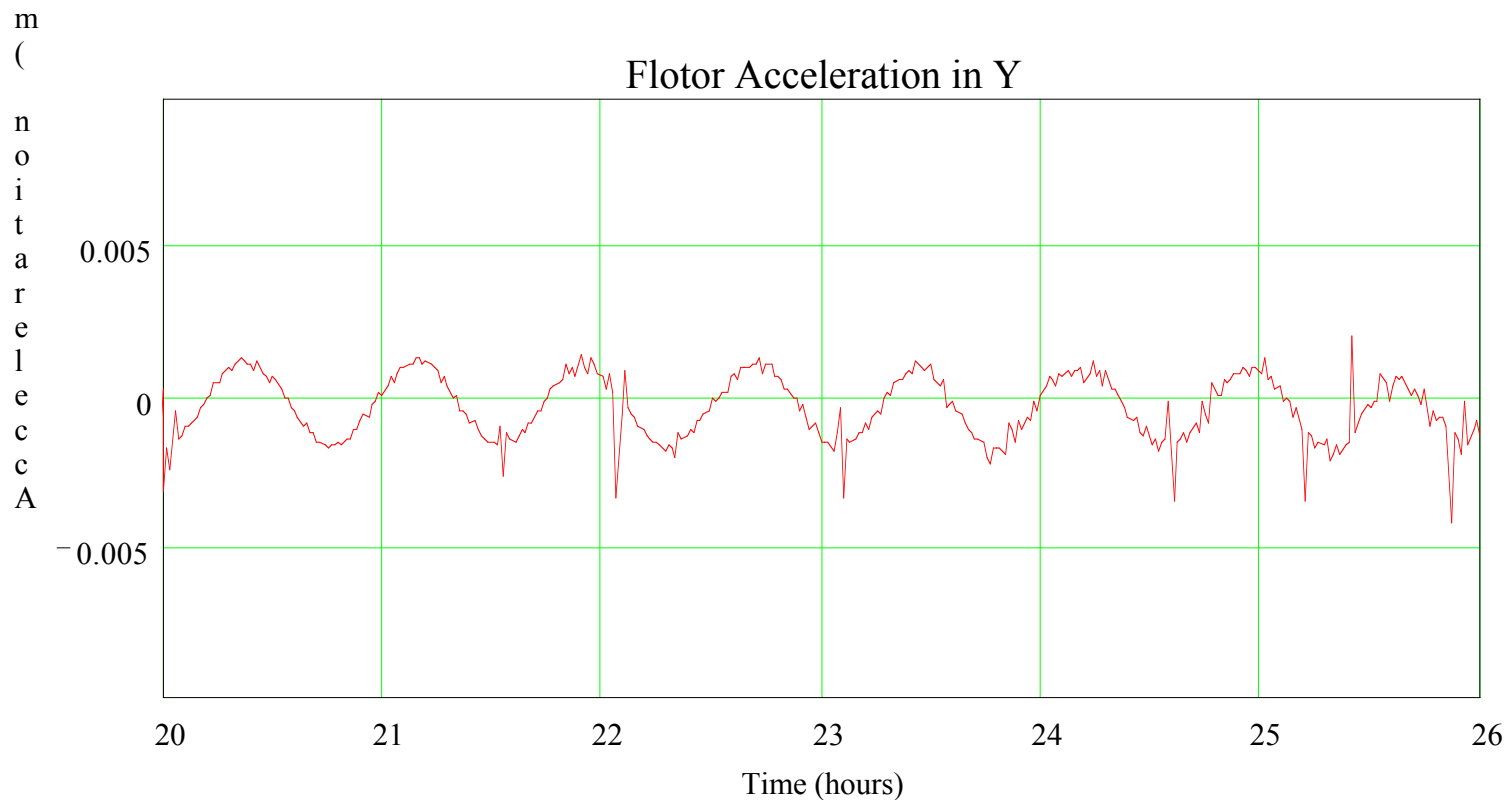


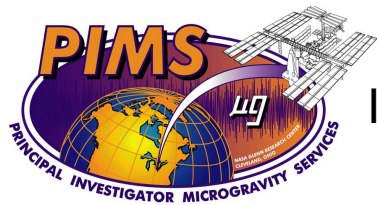


Impact of the Microgravity Environment on Experiments



Mean Acceleration on an Expanded Scale

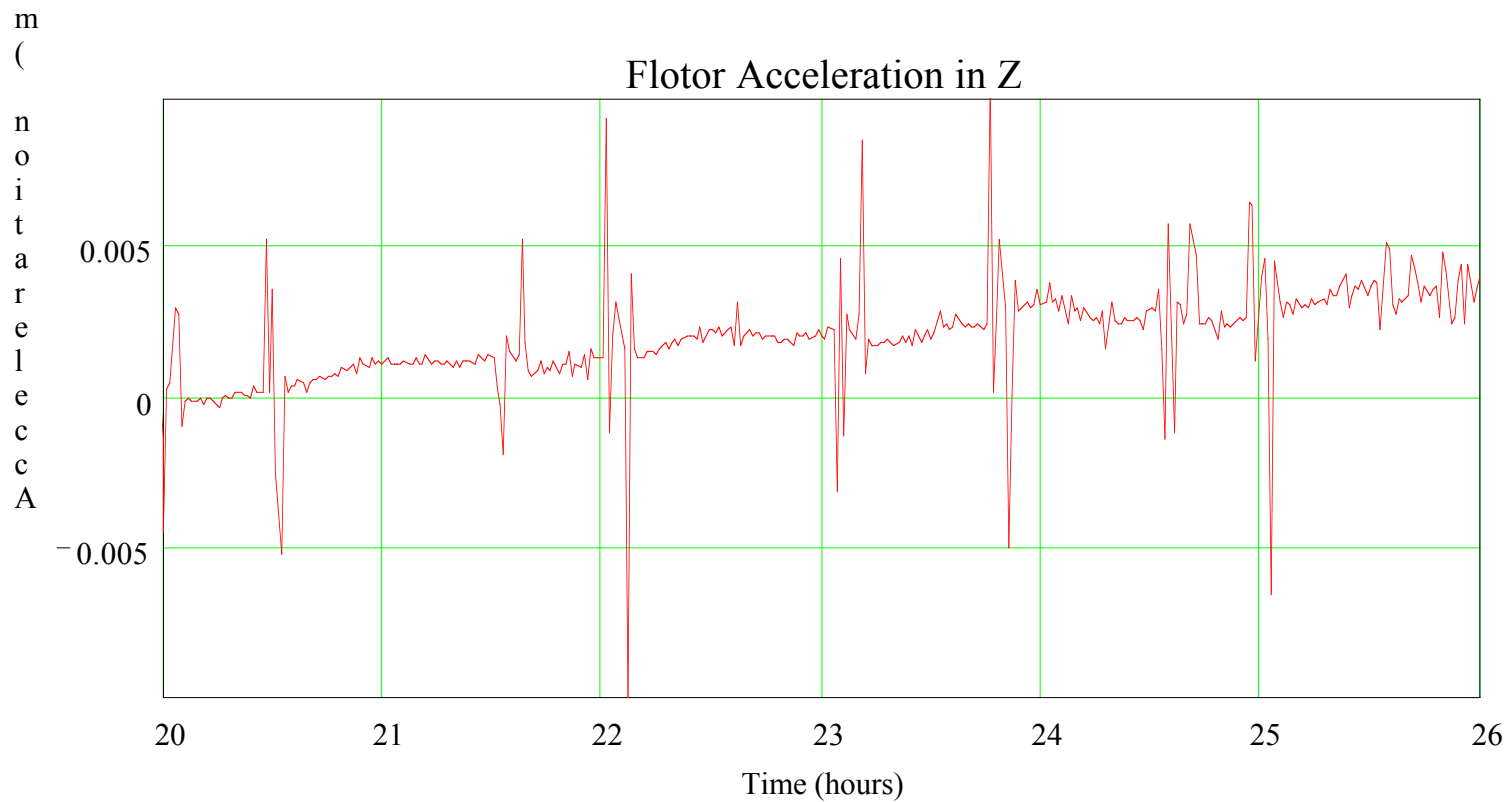


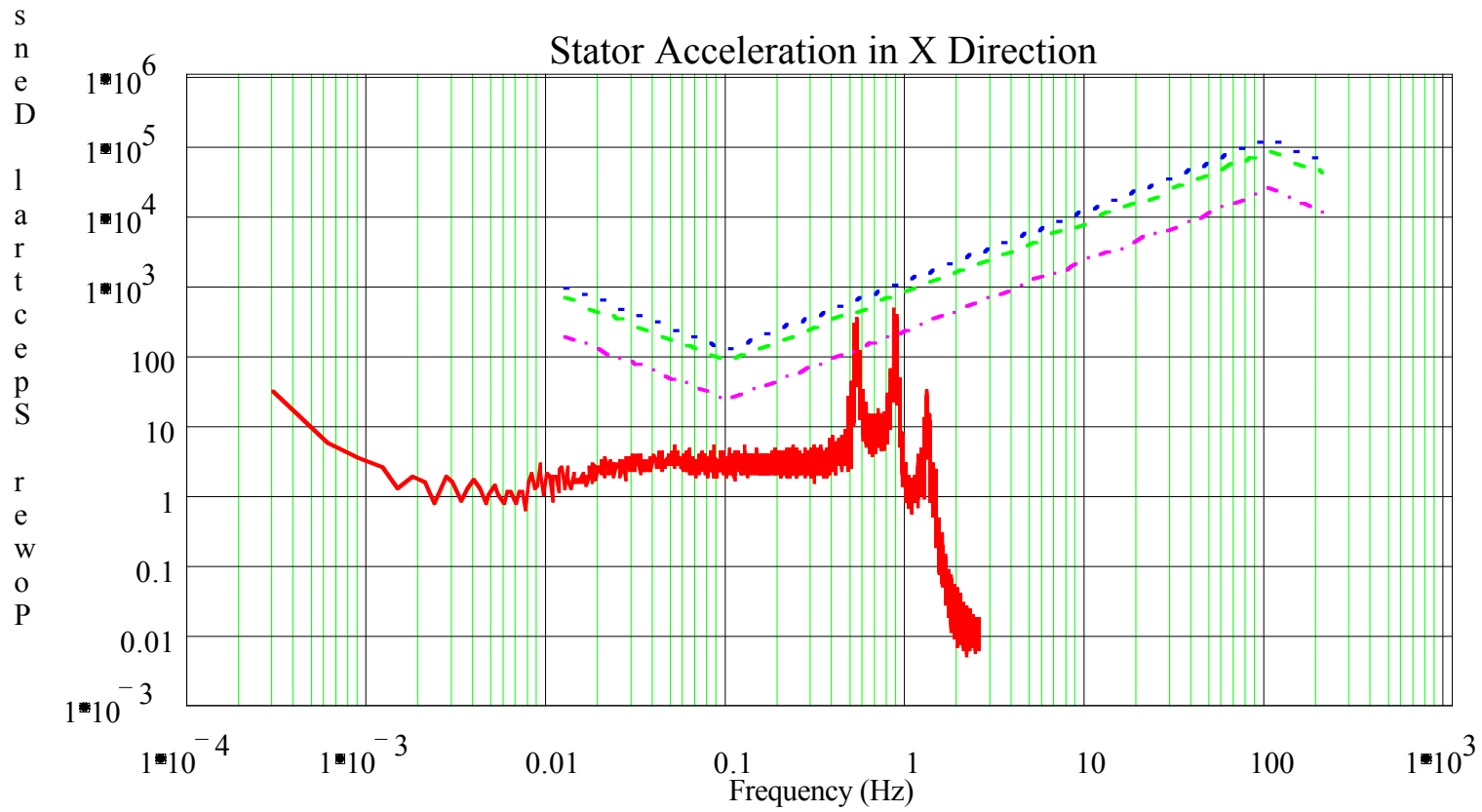


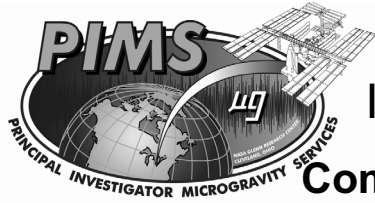
Impact of the Microgravity Environment on Experiments



Mean Acceleration on an Expanded Scale







Impact of the Microgravity Environment on Experiments

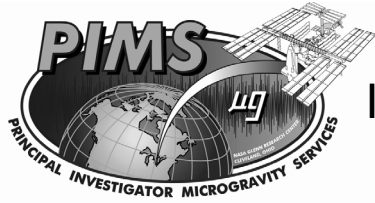
Comments on Acceleration Environment on Mir and the Shuttle



Over most of the frequency band covered by the ISS specification the acceleration levels on the Mir are well below the specification for isolated racks

The same holds true for the acceleration levels on the shuttle

Coupled with the observed sensitivity of diffusion and internal fluid flow to g-jitter at these levels this indicates that the current specification for isolated racks on the ISS is not conservative for fluid based experiments



Closing Remark

Experimenters should be aware of the vibration levels on the ISS