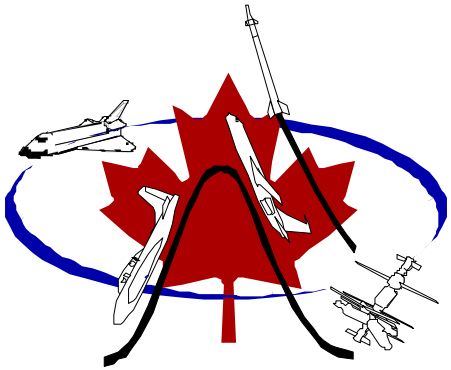


Bjarni Tryggvason

Canadian Space Agency

Glenn Research Center

March 6-8, 2001

The Microgravity Vibration Isolation Mount (MIM-2)

Isolates experiments from spacecraft vibrations

6 DOF magnetically levitation system

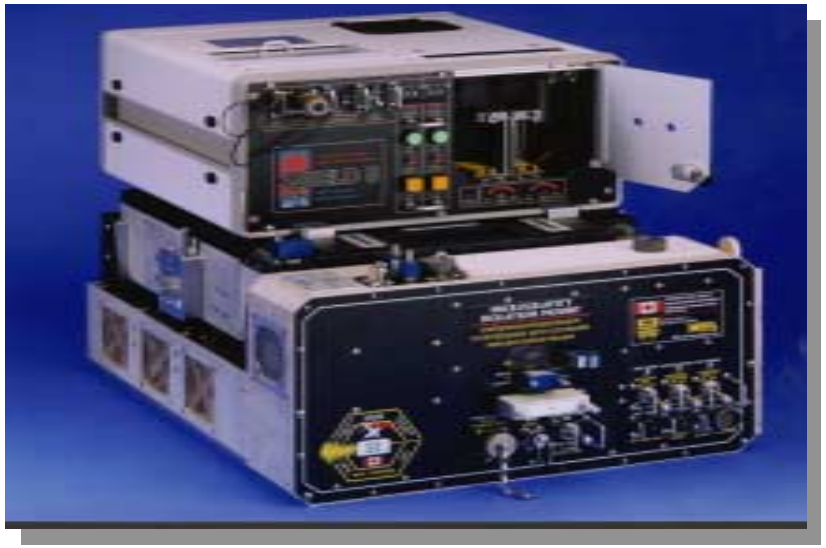
Optical tracking system and accelerometers for monitoring and control

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.

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


MiM

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**

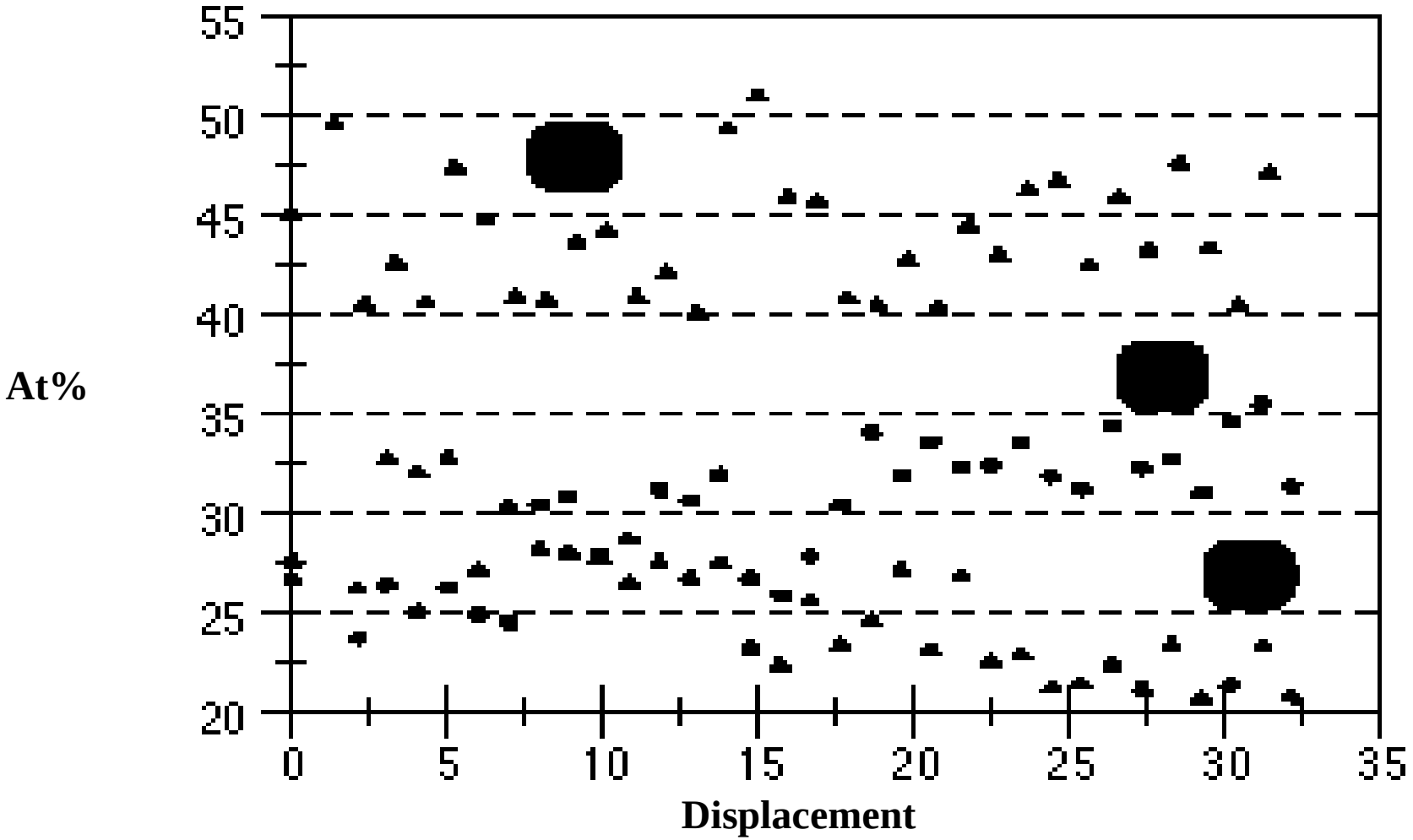
The contributions to the measured diffusion coefficient can be attributed to:

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

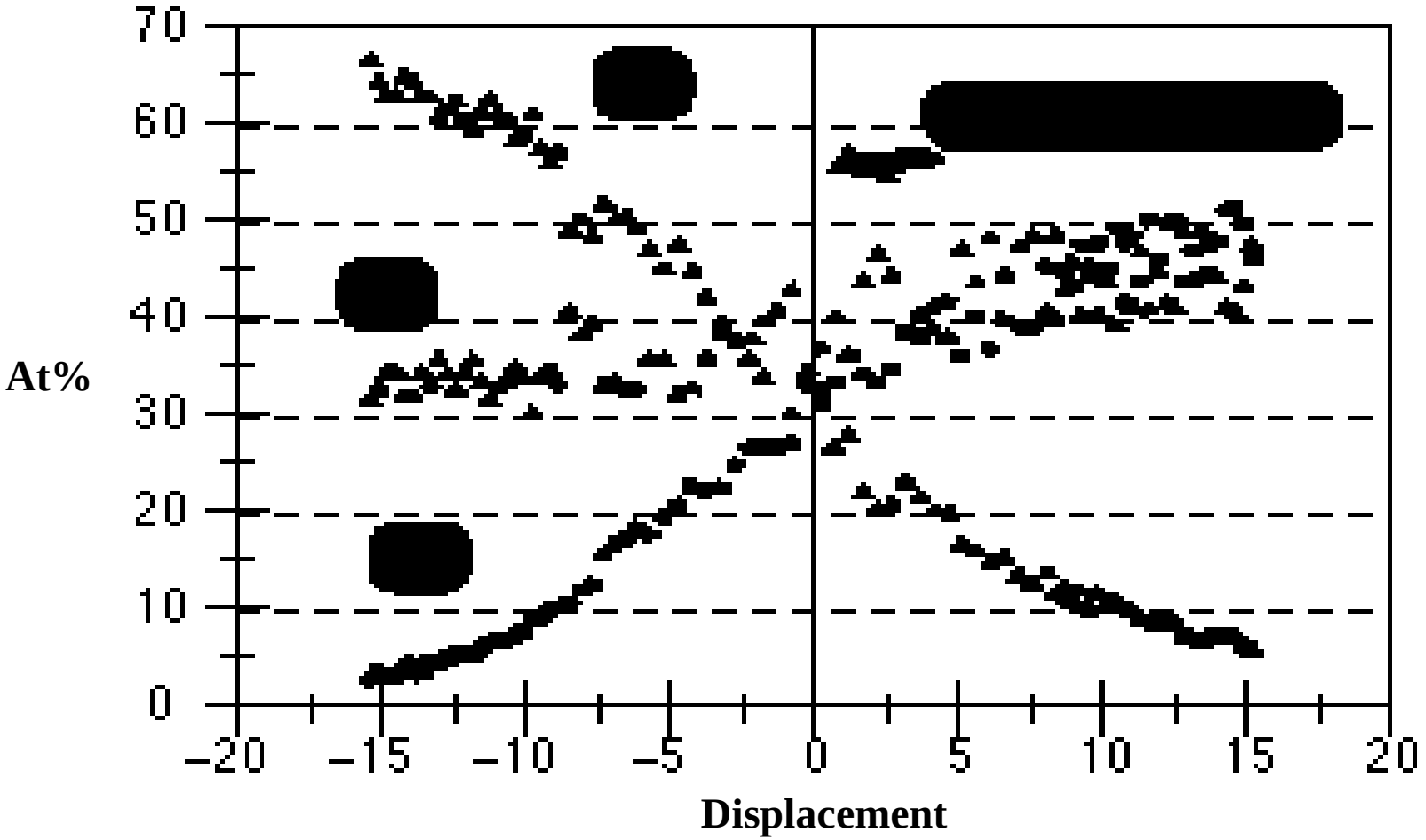
Estimating the Intrinsic Diffusion Coefficient

- 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.

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

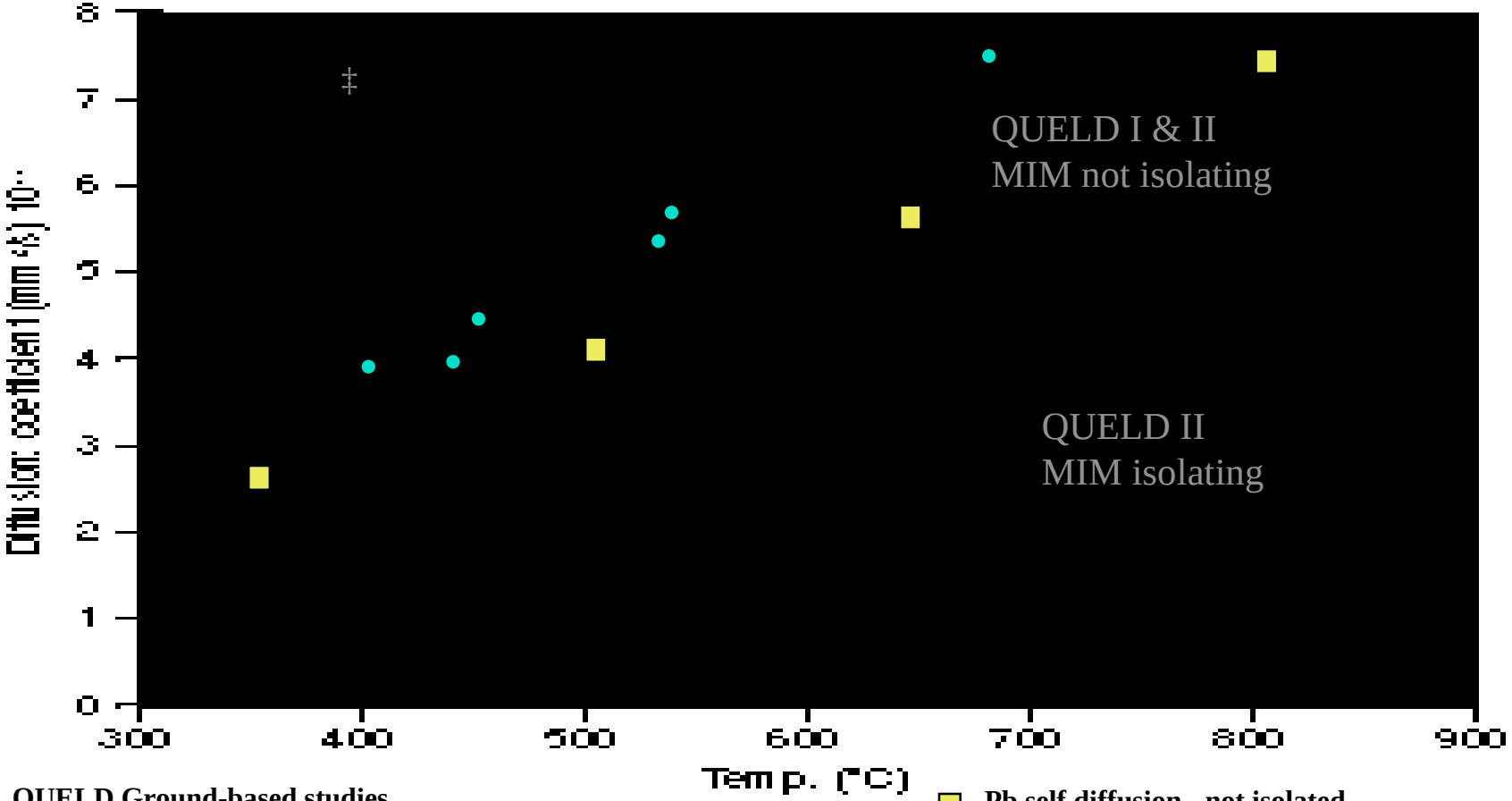
- There are many competing models for the temperature dependence of diffusion.
- The fluctuation model, supported by previous microgravity experiments, proposes that the diffusion coefficient should be proportional to the temperature squared, i.e.,

$$D = AT^{2}$$

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

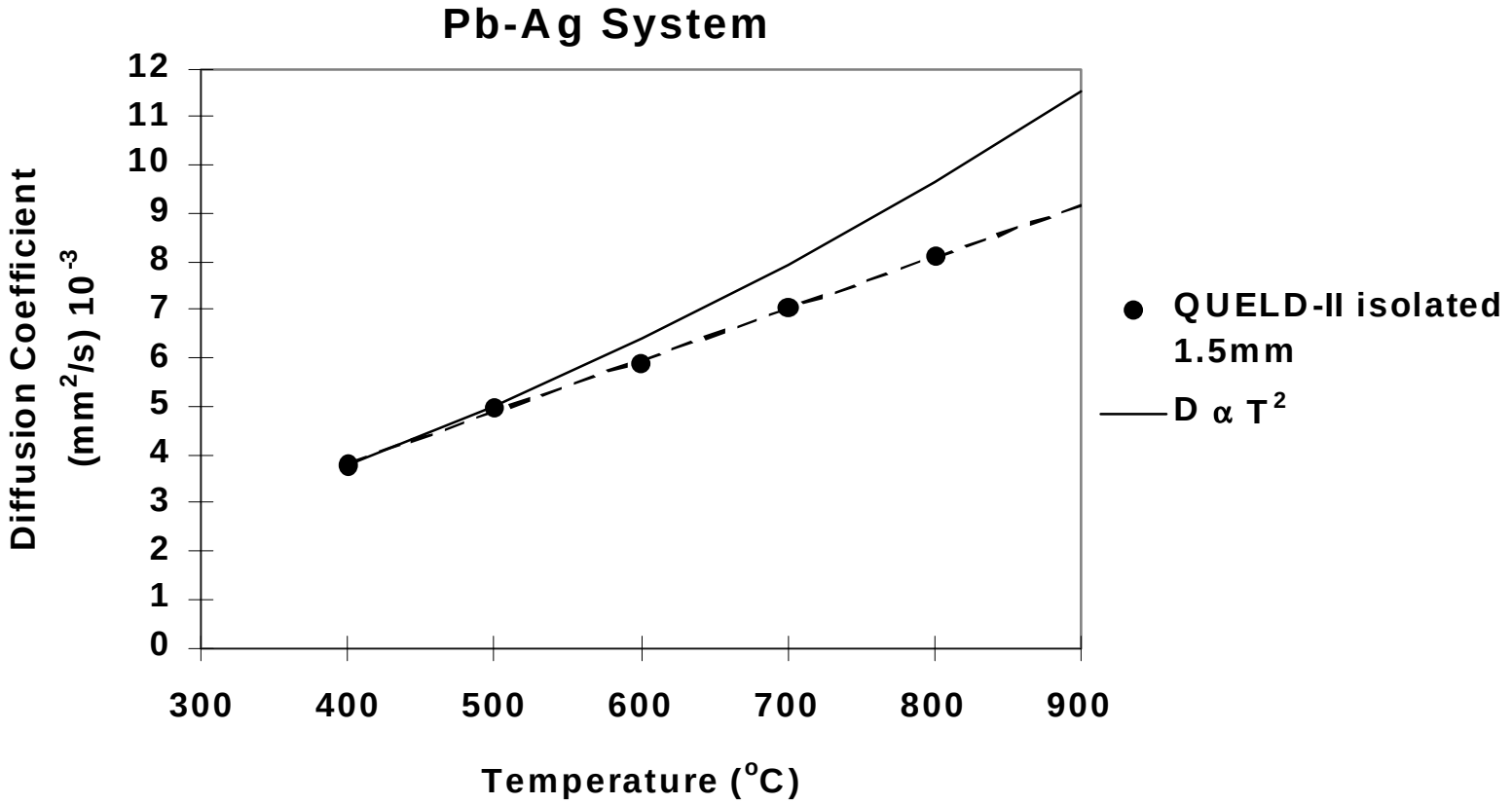
$$D = -a + bT$$

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

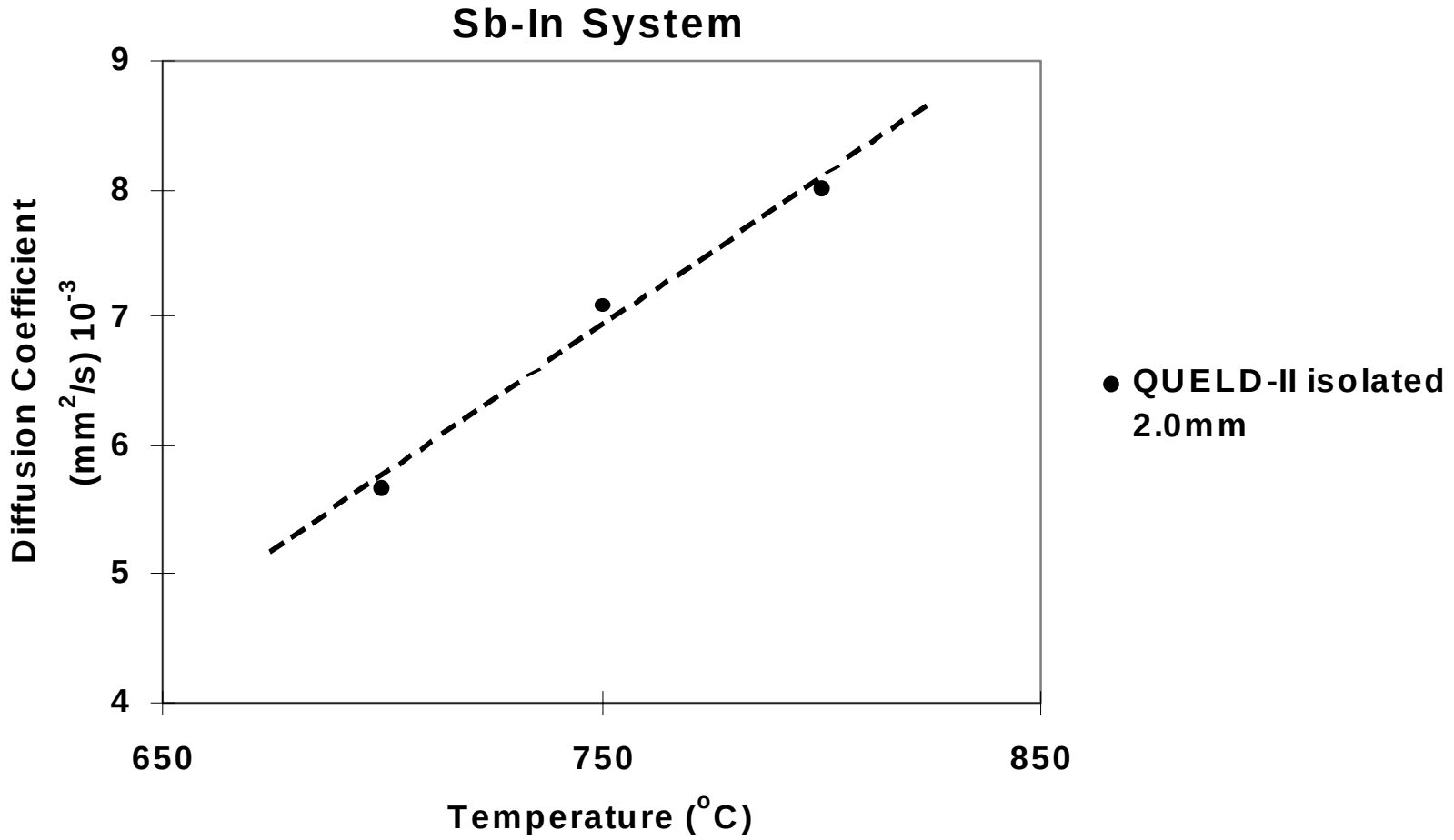


QUELD Ground-based studies
(1 mm dia. specimens)

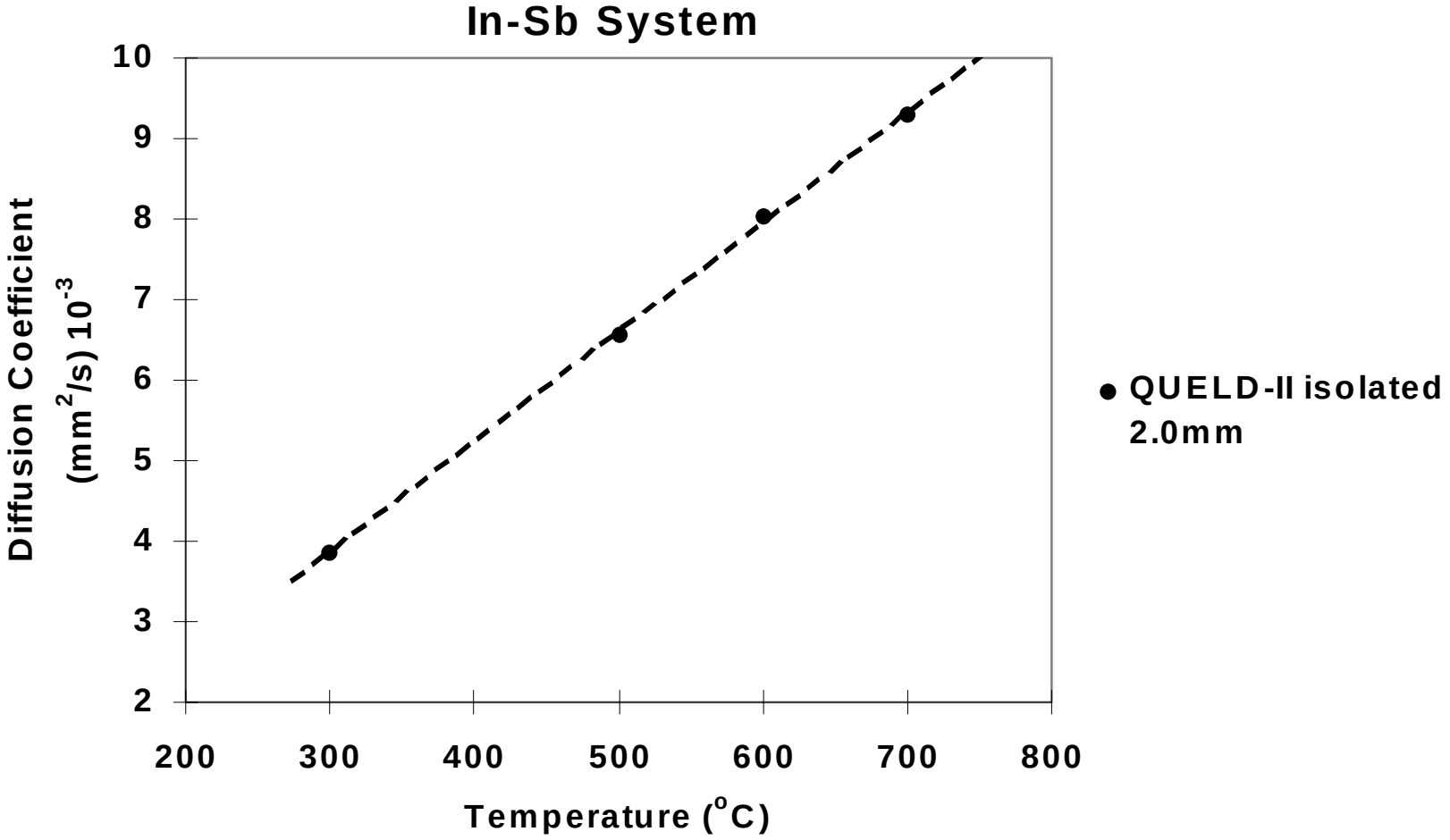
- **QUELD I & QUESTS (MIM not isolating)**
- **QUELD II (MIM not isolating)**
- **Pb self diffusion - not isolated (Frohberg et. al.)**
- **QUELD II forced 0.1 Hz, 0.004g**
- **QUELD II isolated by MIM (1.5 mm and 3 mm dia. specimens for µg)**



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



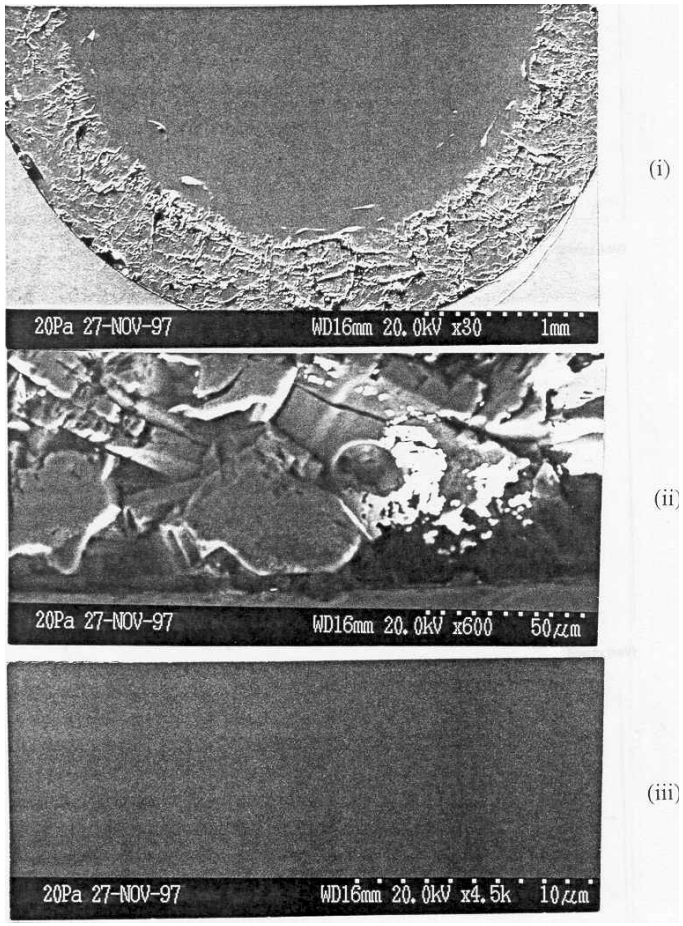
Diffusion Coefficients of Indium in Antimony (Smith et. Al.).



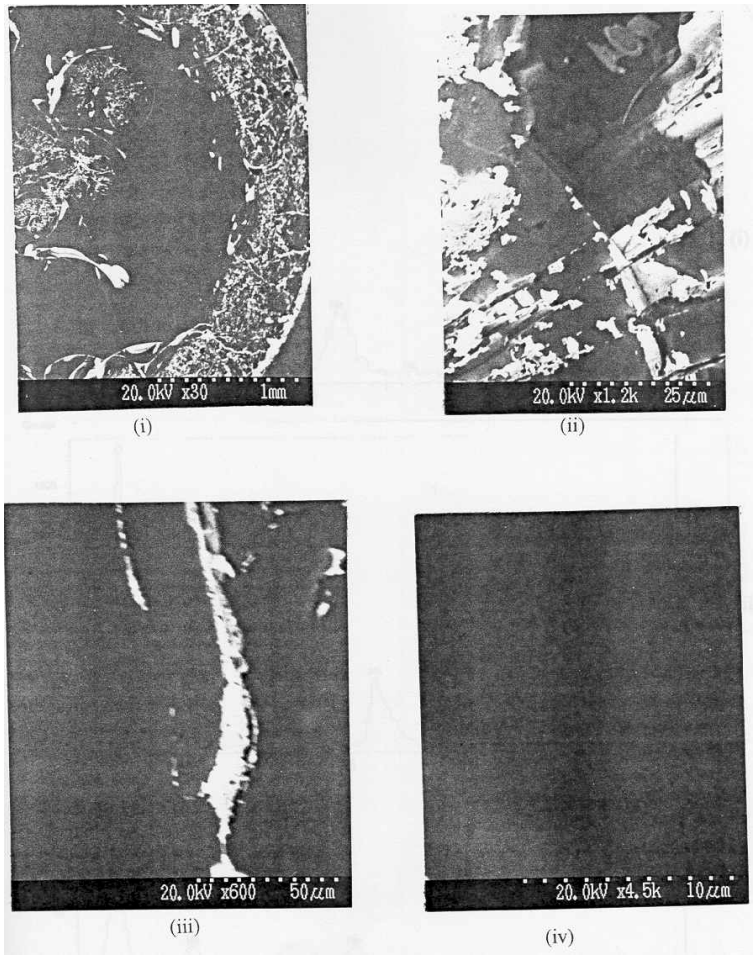
Diffusion Coefficients of Indium in Antimony (Smith et. Al.).

Material $Nb_2Na_2B_2O_9$ (NNB)

- Experimental processing conditions
  - Temperature 575 ^{o}C
  - Time 1 hour
  - container SiO_2
  - g-jitter varied from isolation to g-pulses
    - g-pulses at 1000 μg at 0.1 Hz



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).



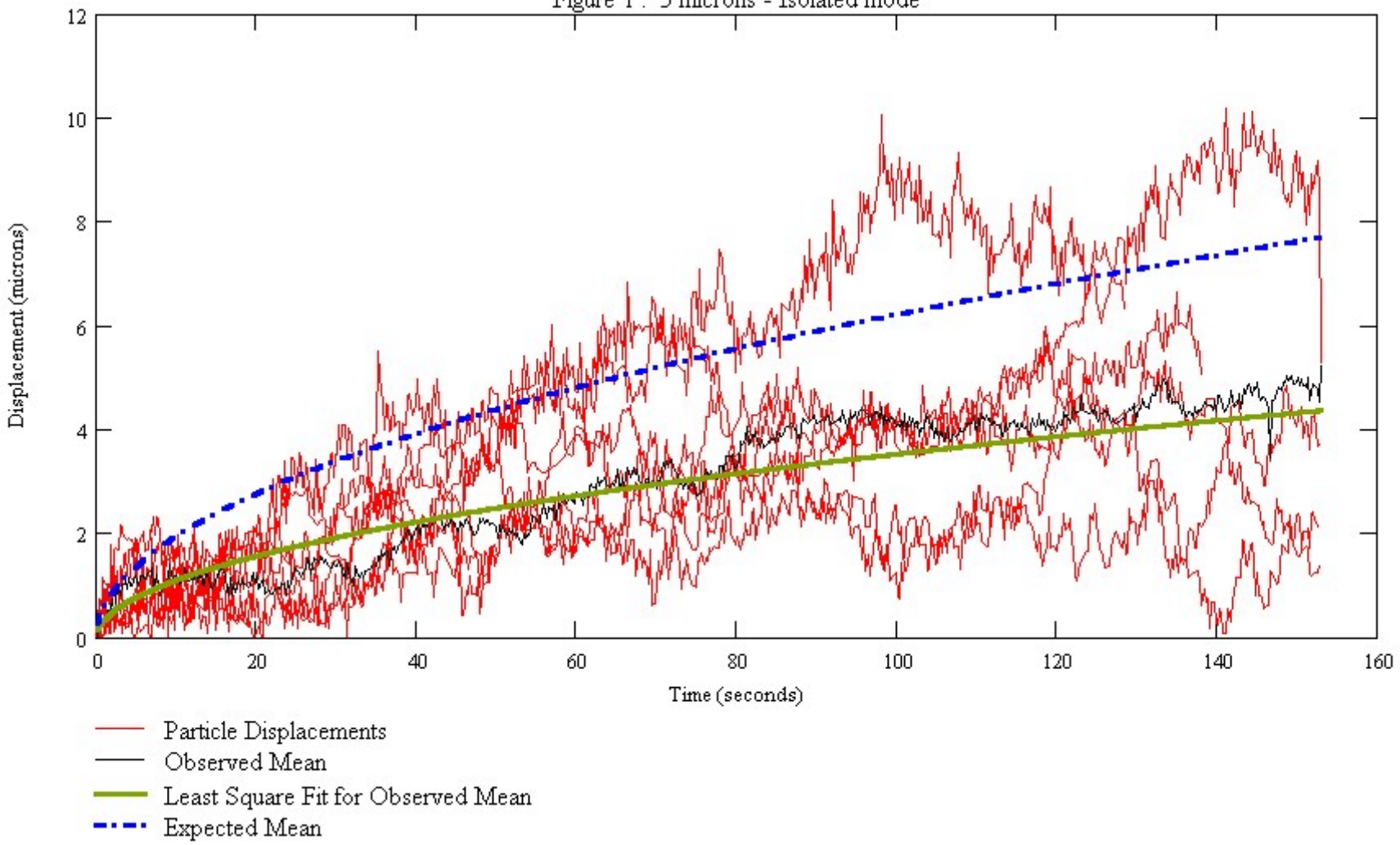
NNB glass processed in microgravity having force g-pulses at 1 mg at 0.1 Hz, showing mixing or streaming of crystal phase from edge to center of specimen.

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



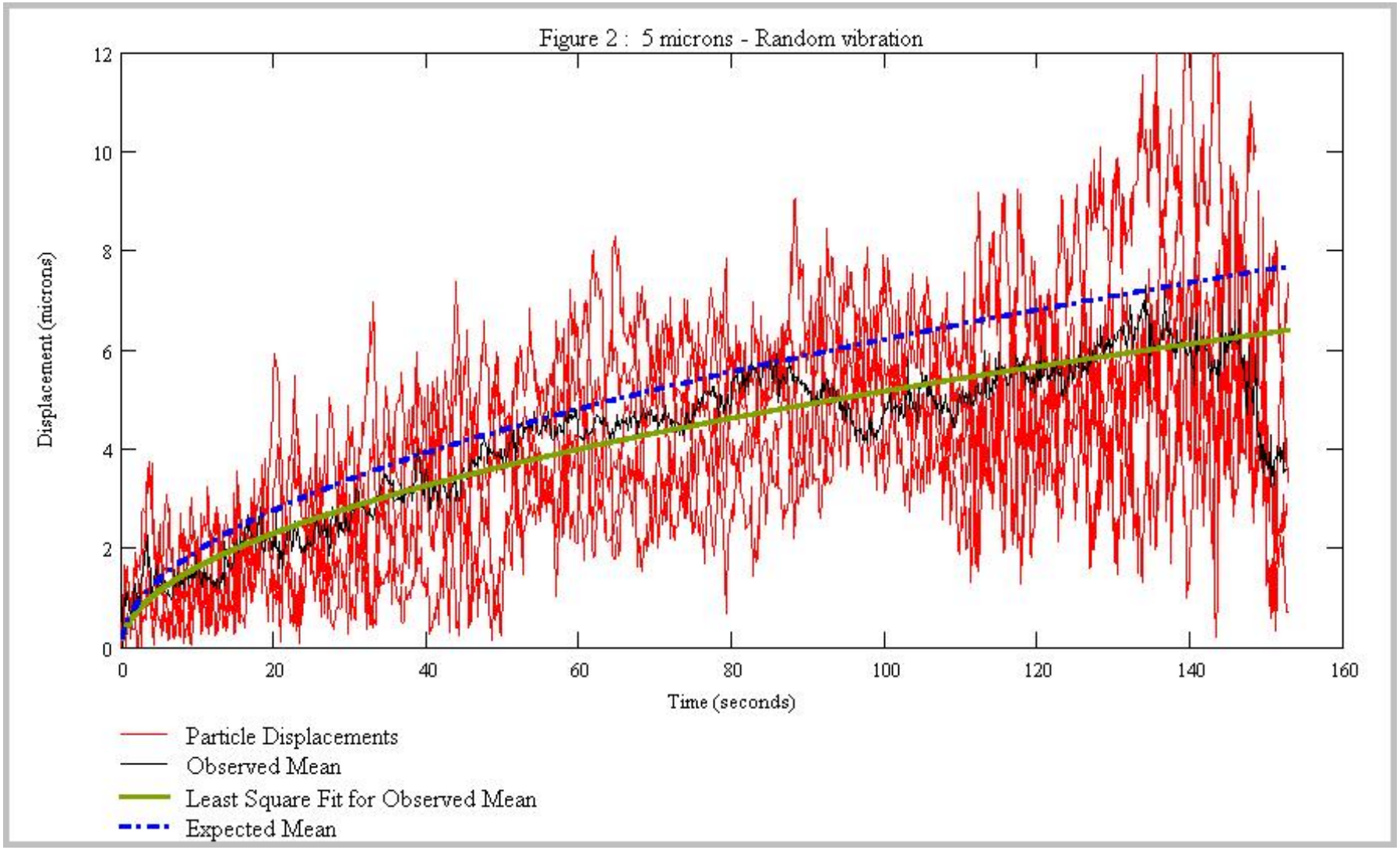


Figure 2 : 5 microns - Random vibration
Displacement (microns)
Time (seconds)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
Particle Displacements
Observed Mean
Least Square Fit for Observed Mean
Expected Mean

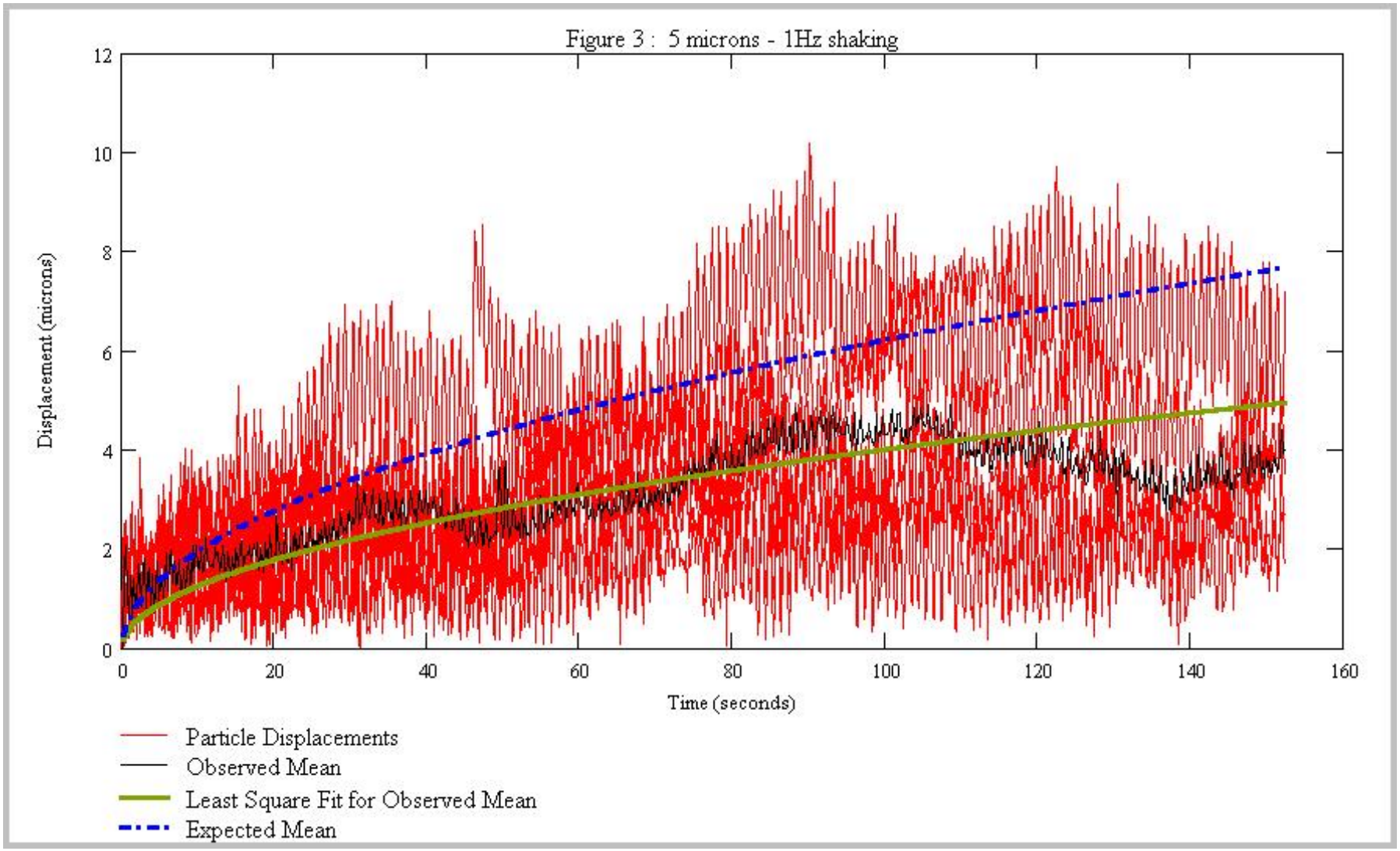


Figure 3 : 5 microns - 1Hz shaking
Displacement (microns)
Time (seconds)
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
Particle Displacements
Observed Mean
Least Square Fit for Observed Mean
Expected Mean

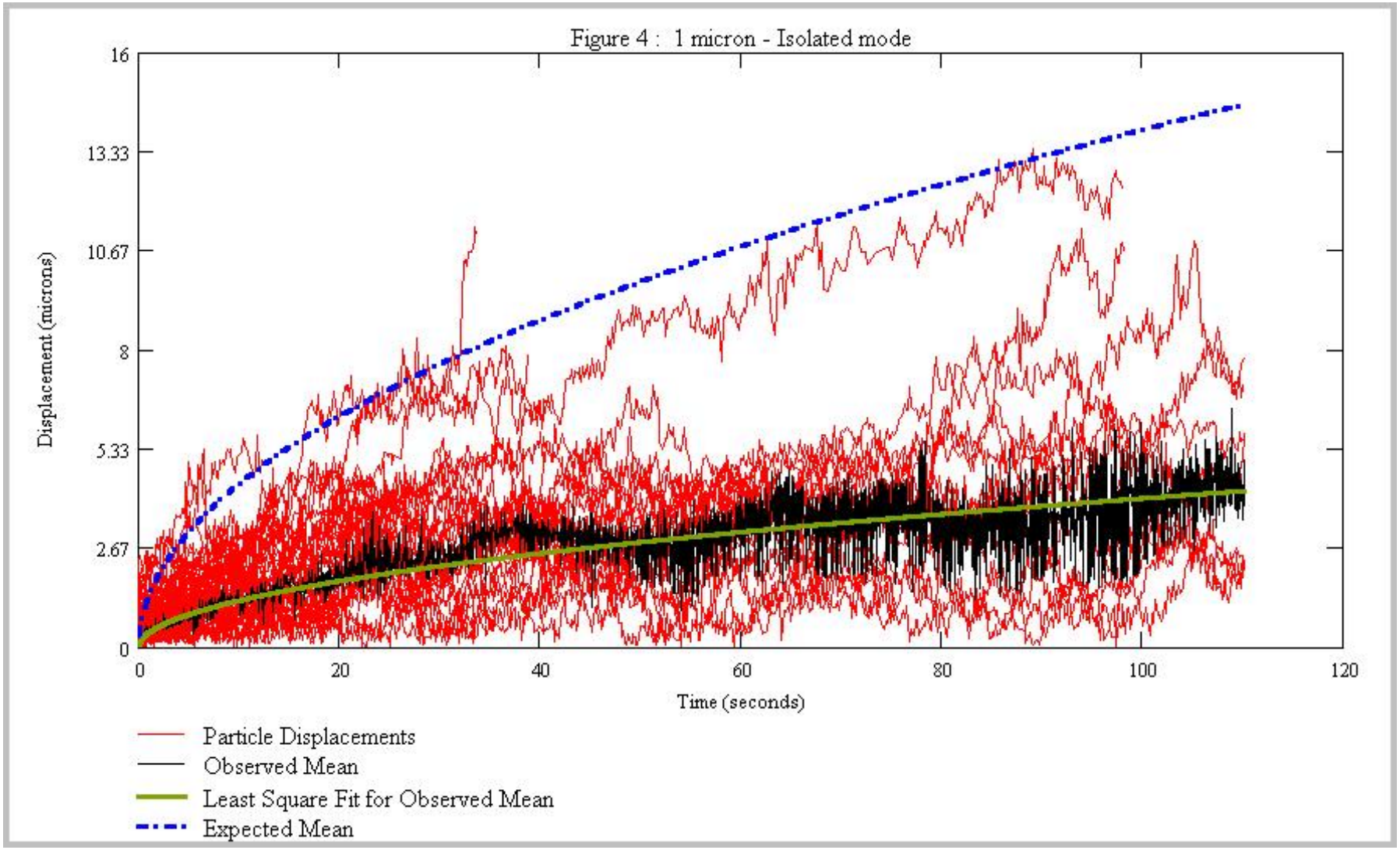


Figure 4 : 1 micron - Isolated mode
Displacement (microns)
16
13.33
10.67
8
5.33
2.67
0
0
20
40
60
80
100
120
Time (seconds)
Particle Displacements
Observed Mean
Least Square Fit for Observed Mean
Expected Mean

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.

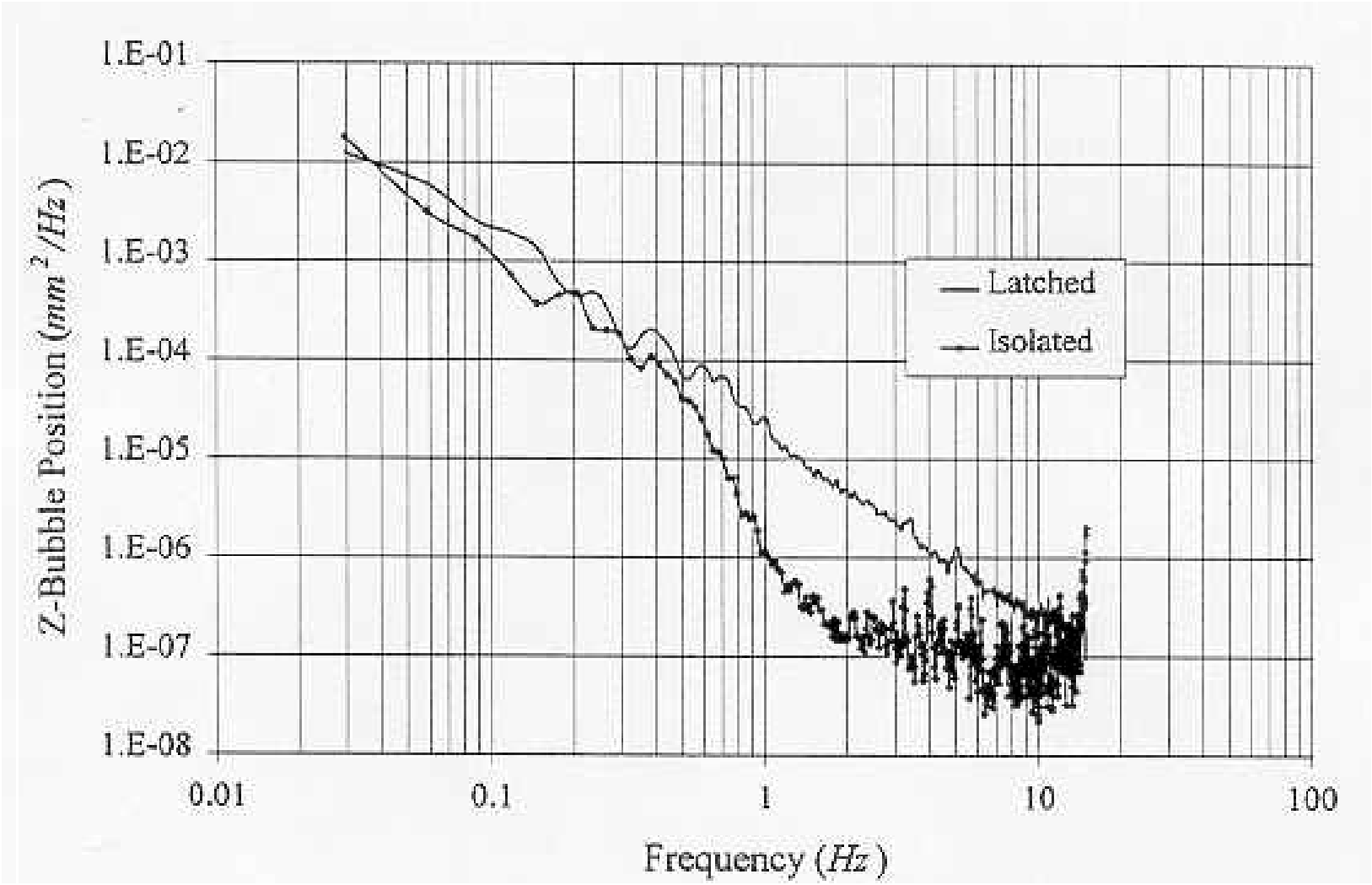
The sensitivity is in the frequency range 2 Hz to 100 Hz.

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

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


1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
Z-Bubble Position (mm^2/Hz)
Latched
Isolated
0.01
0.1
1
10
100
Frequency (Hz)

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.

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

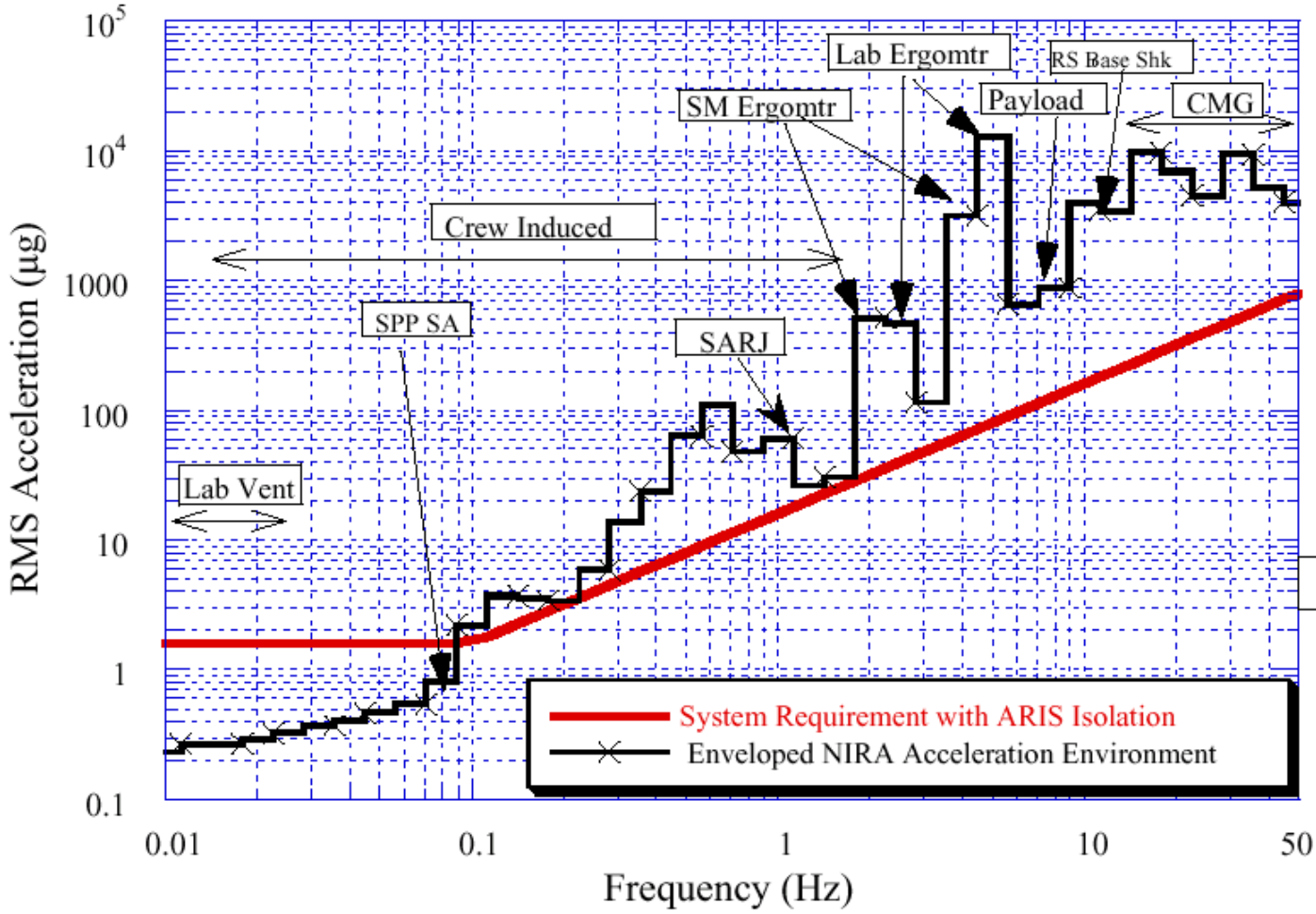
About 100 hours of data was obtained during the shuttle experiments

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

The following figure summarizes:

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

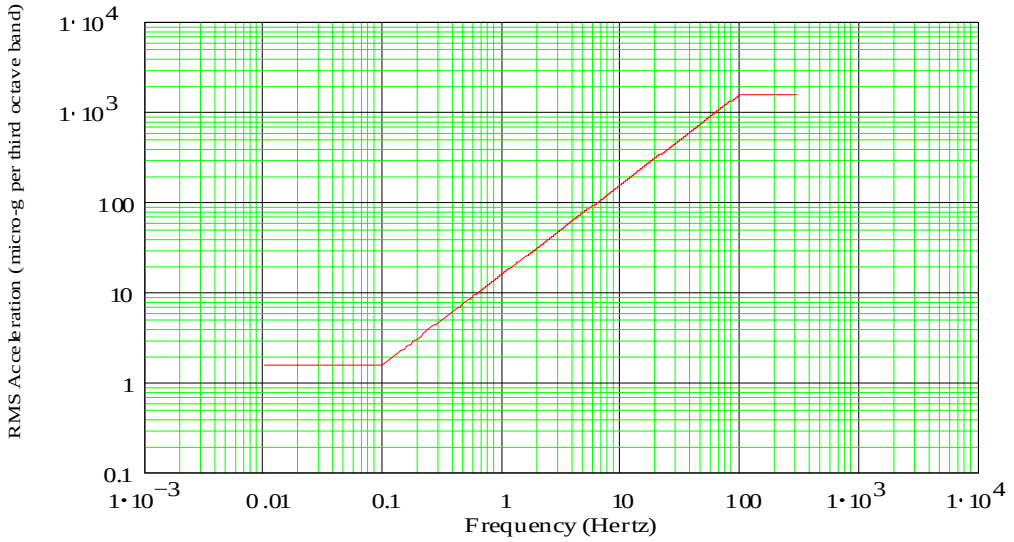
Non-Isolated Rack Assessment - Low Frequency



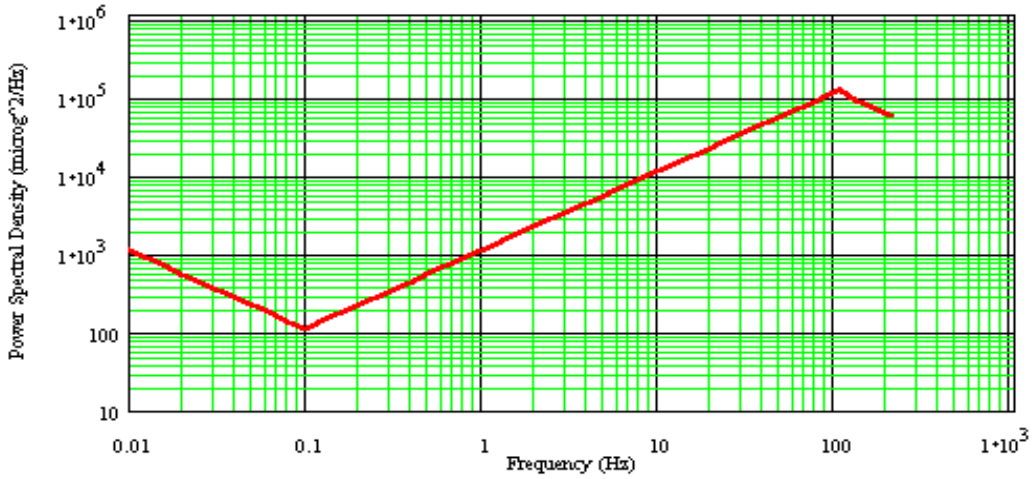
DAC #6
6/98

Data from Boeing

Graph obtained from NASA web site http://www.lerc.nasa.govWWW/MMAP/PIMS/MEIT/meit99pdfs.html

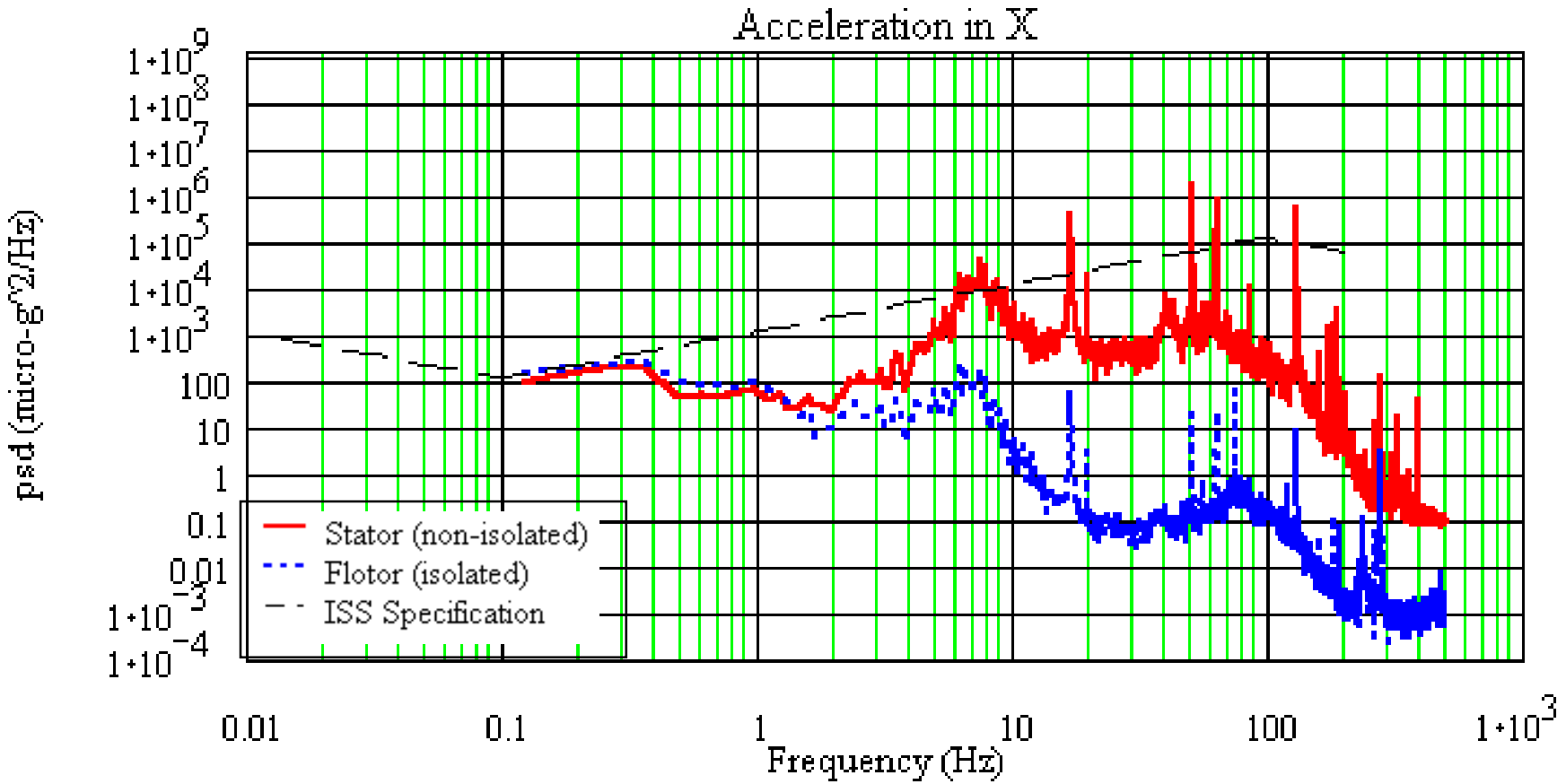


Data obtained from Microgravity Control Plan:
International Space Station Program,
NASA document SSP50036, Revision A

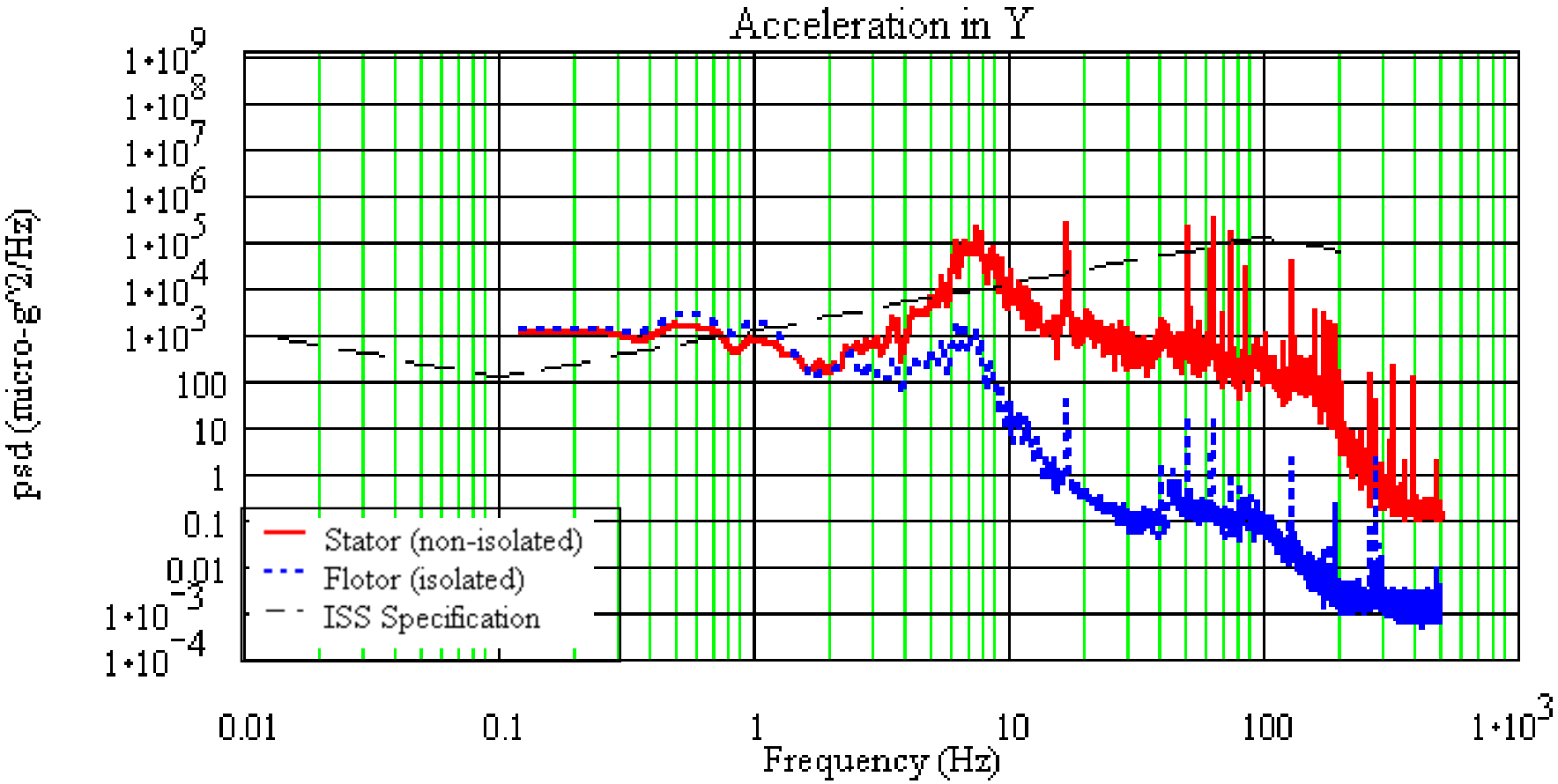


Typical Acceleration Levels on the Shuttle

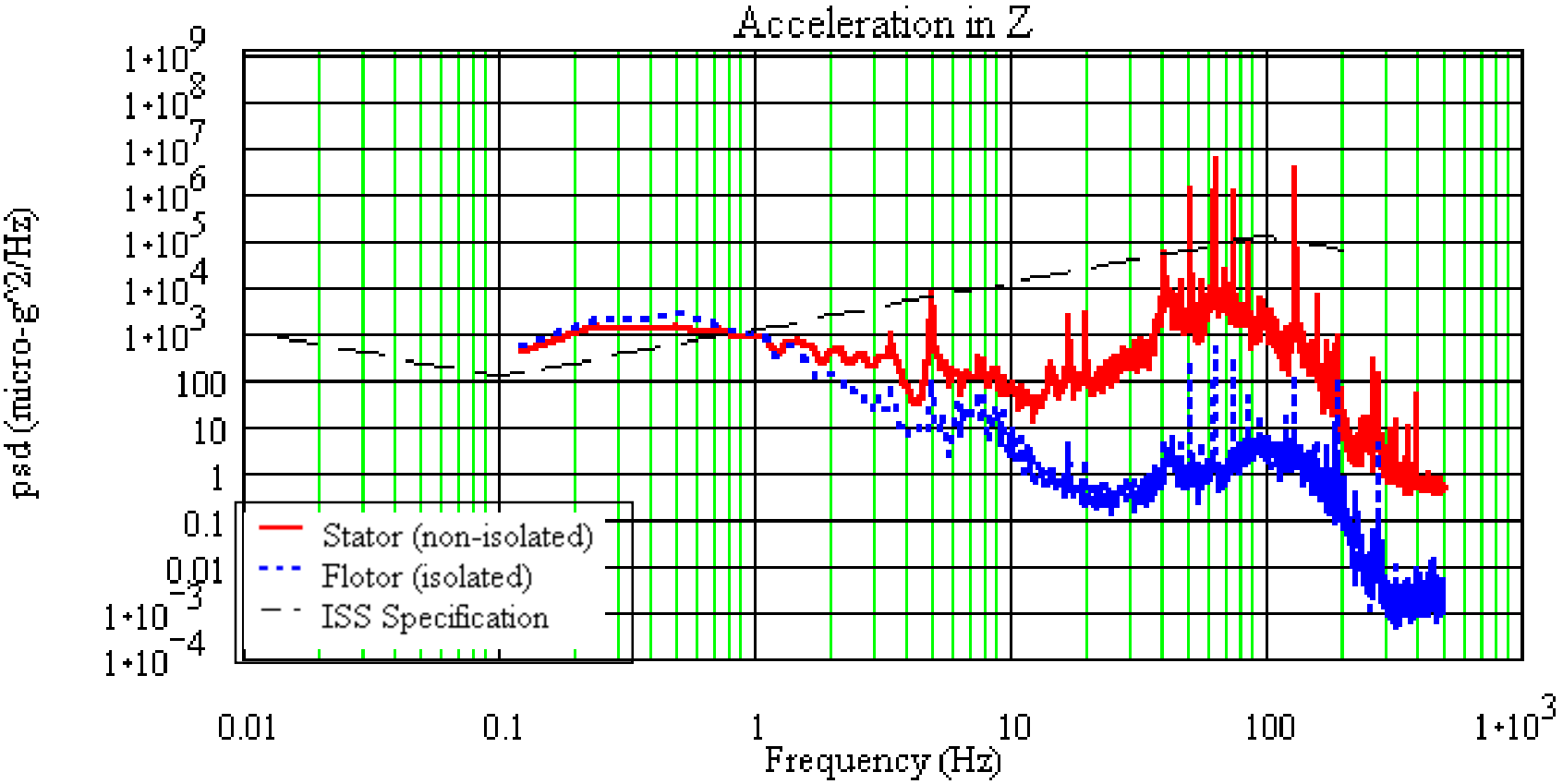
Acceleration levels on the Space Shuttle



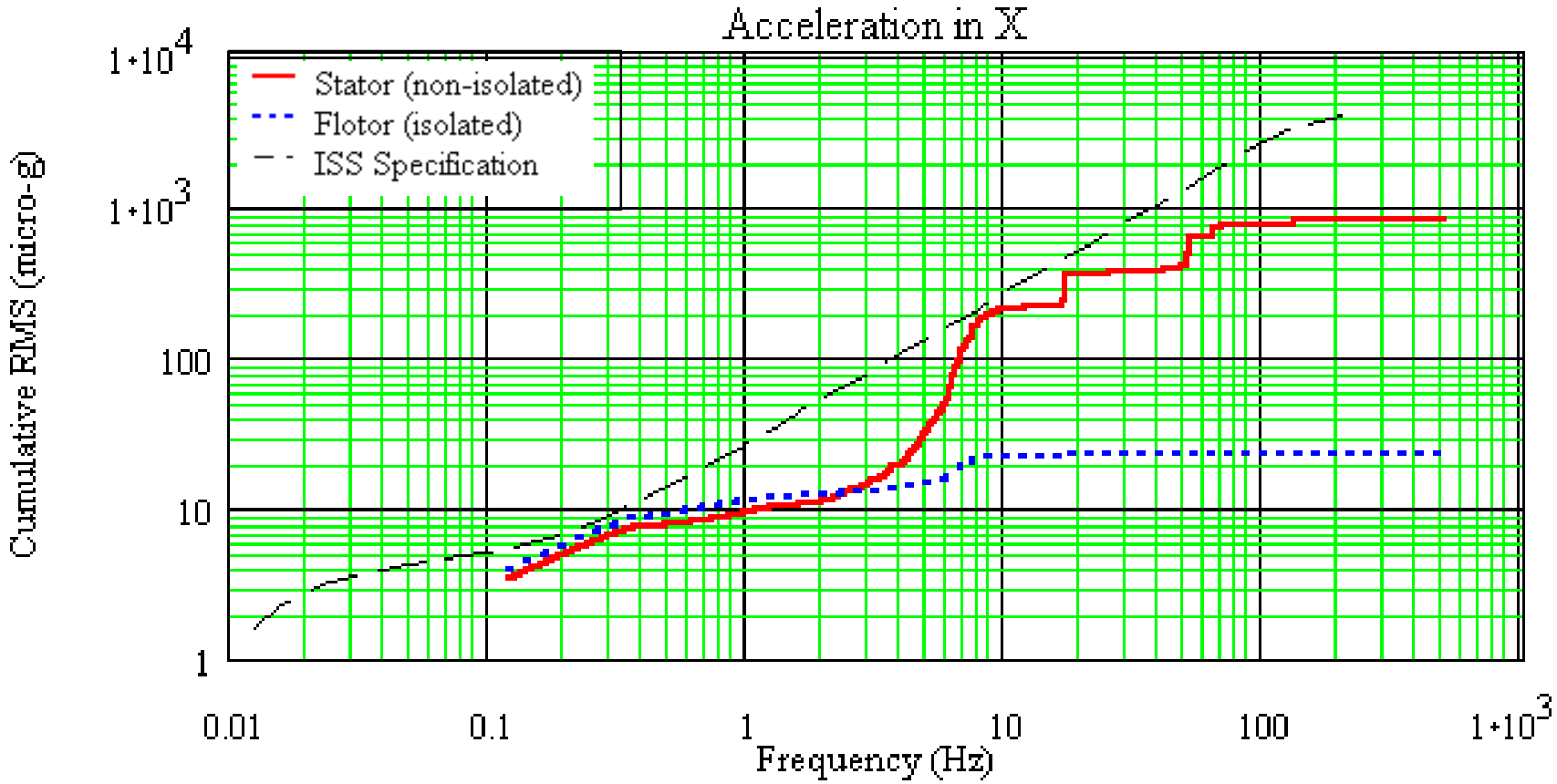
Acceleration levels on the Space Shuttle



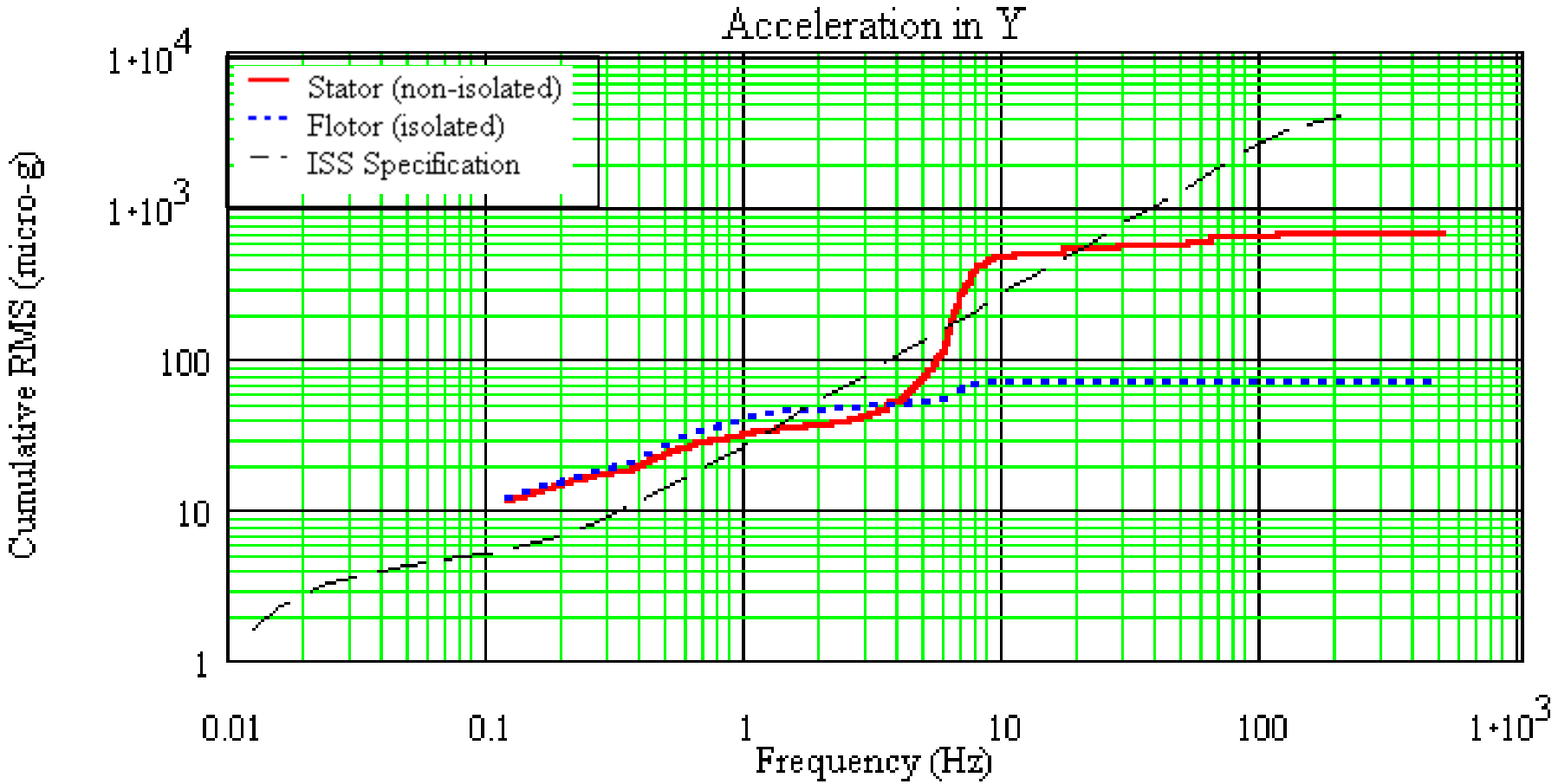
Acceleration levels on the Space Shuttle



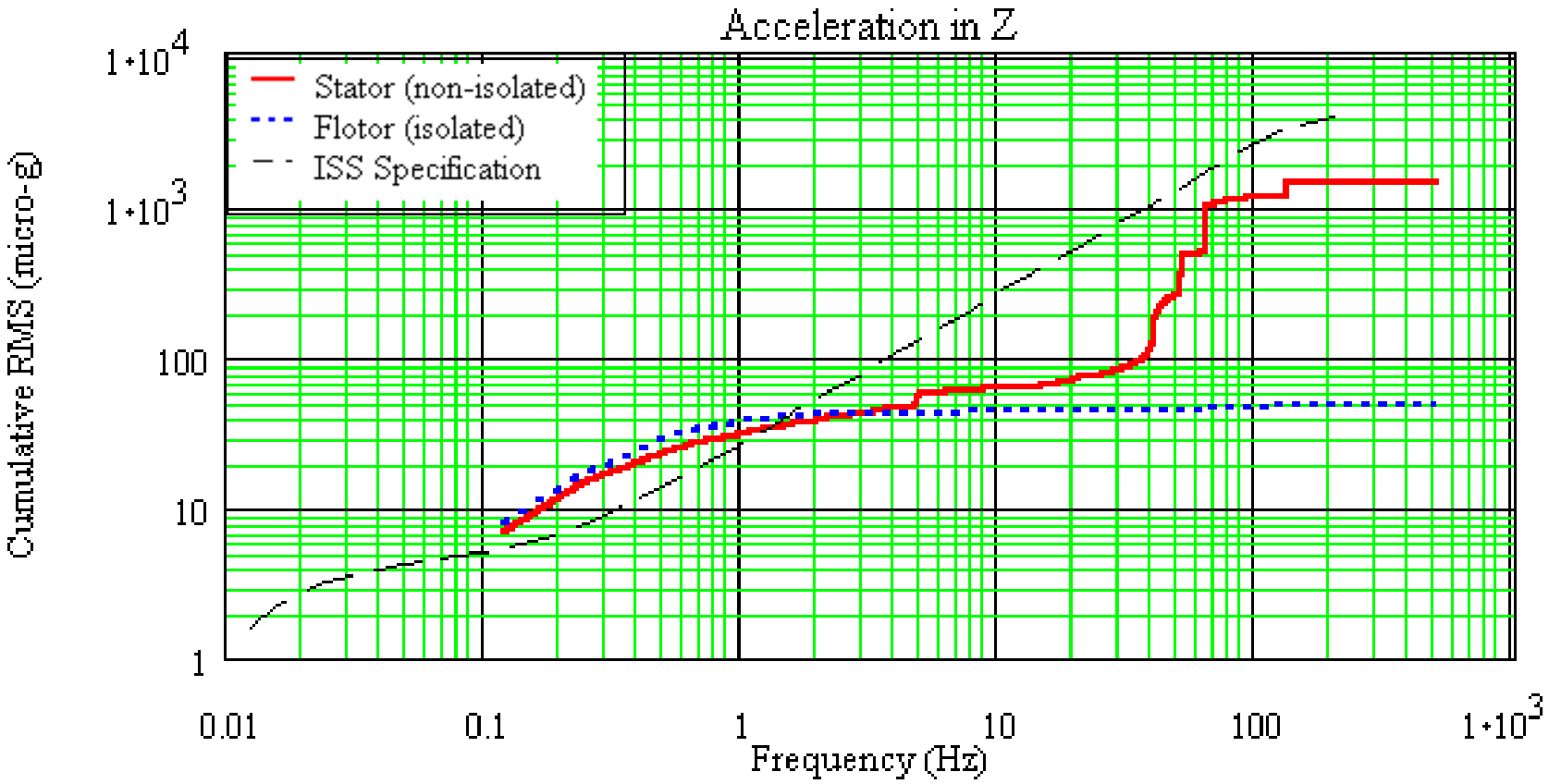
Cumulative Acceleration Levels on the Space Shuttle



Cumulative Acceleration Levels on the Space Shuttle



Cumulative Acceleration Levels on the Space Shuttle

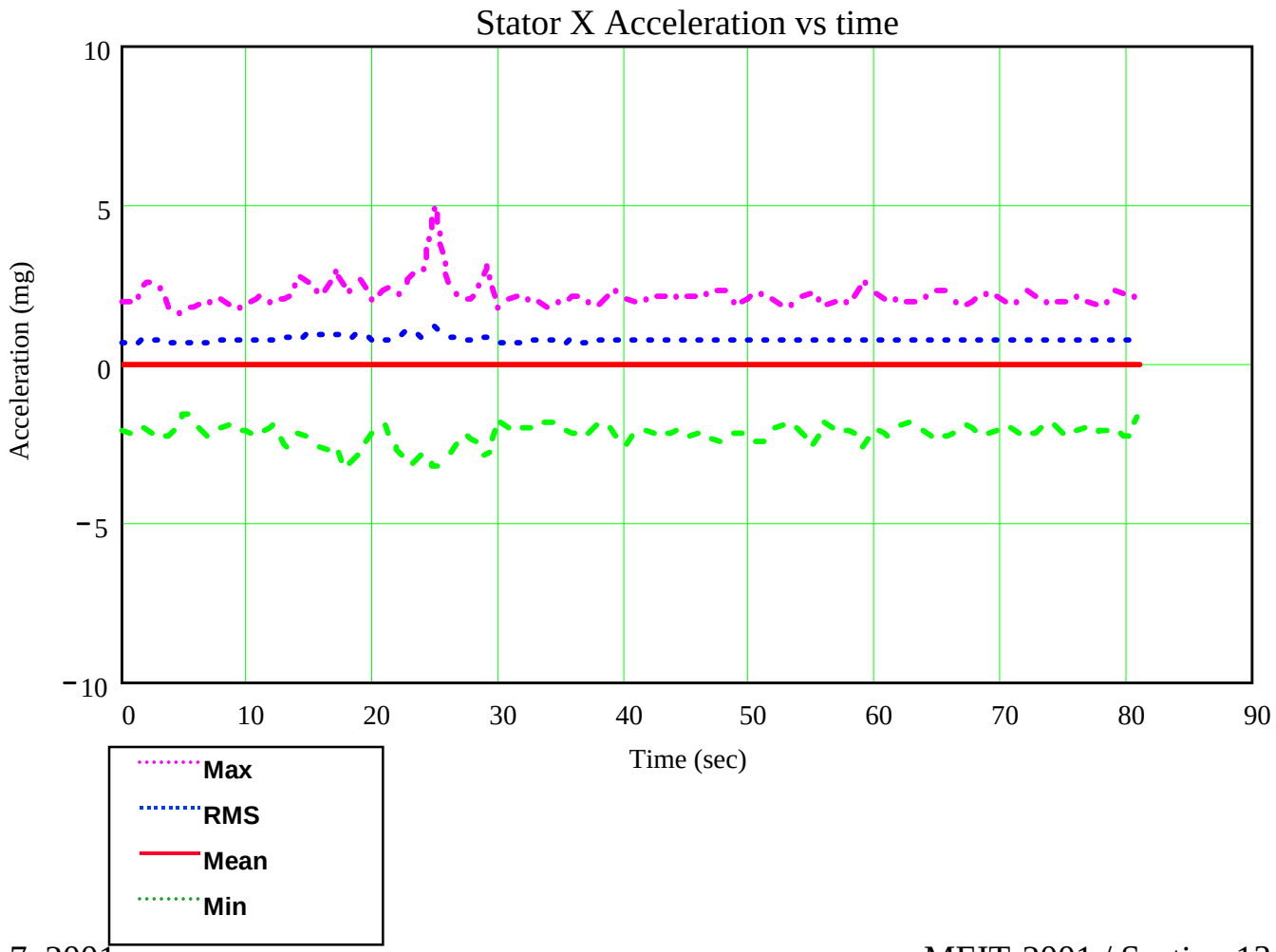


Format for Presentation of Time Histories for Accelerations

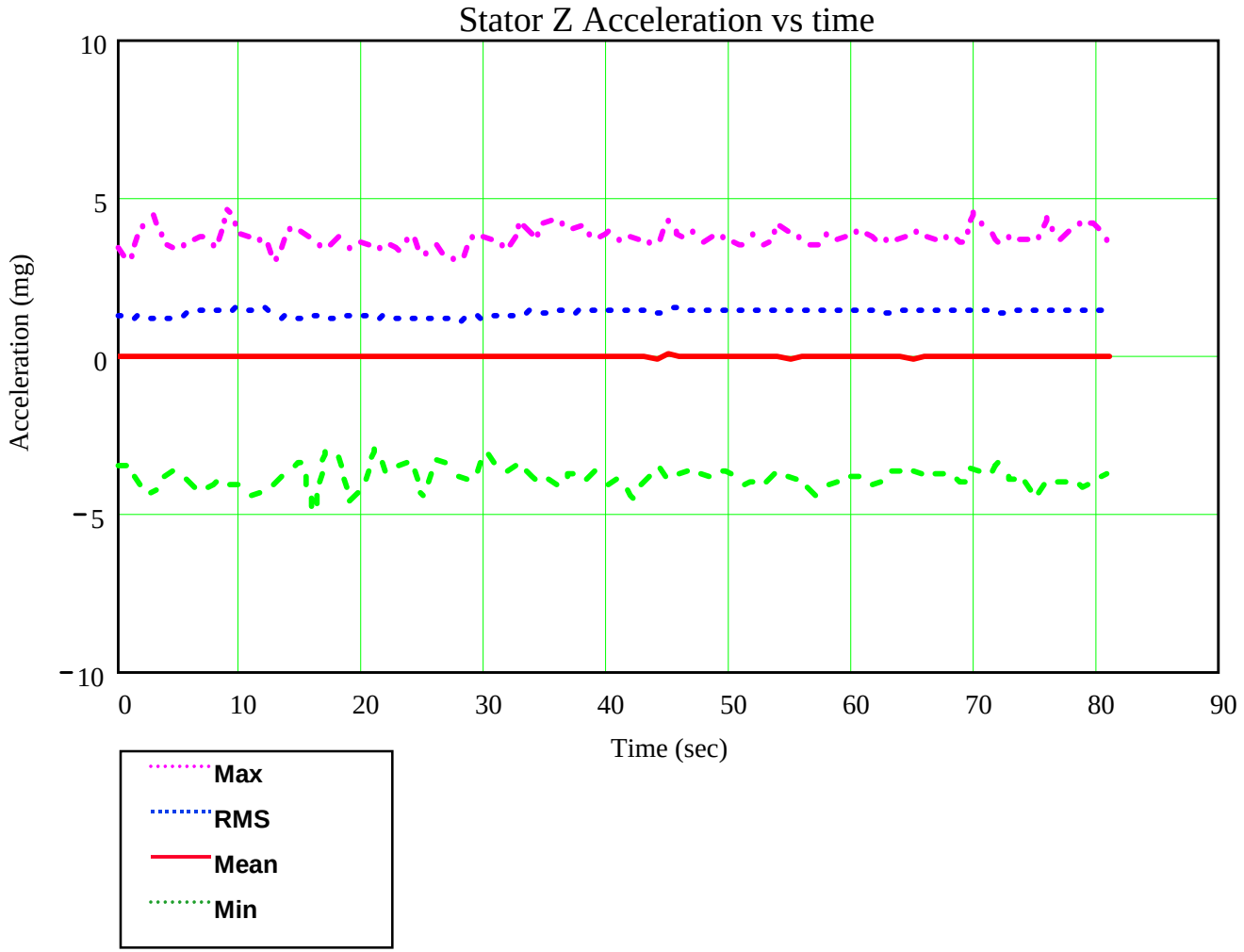
On the time traces four lines are plotted on each figure. These are the following statistics:

- **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**

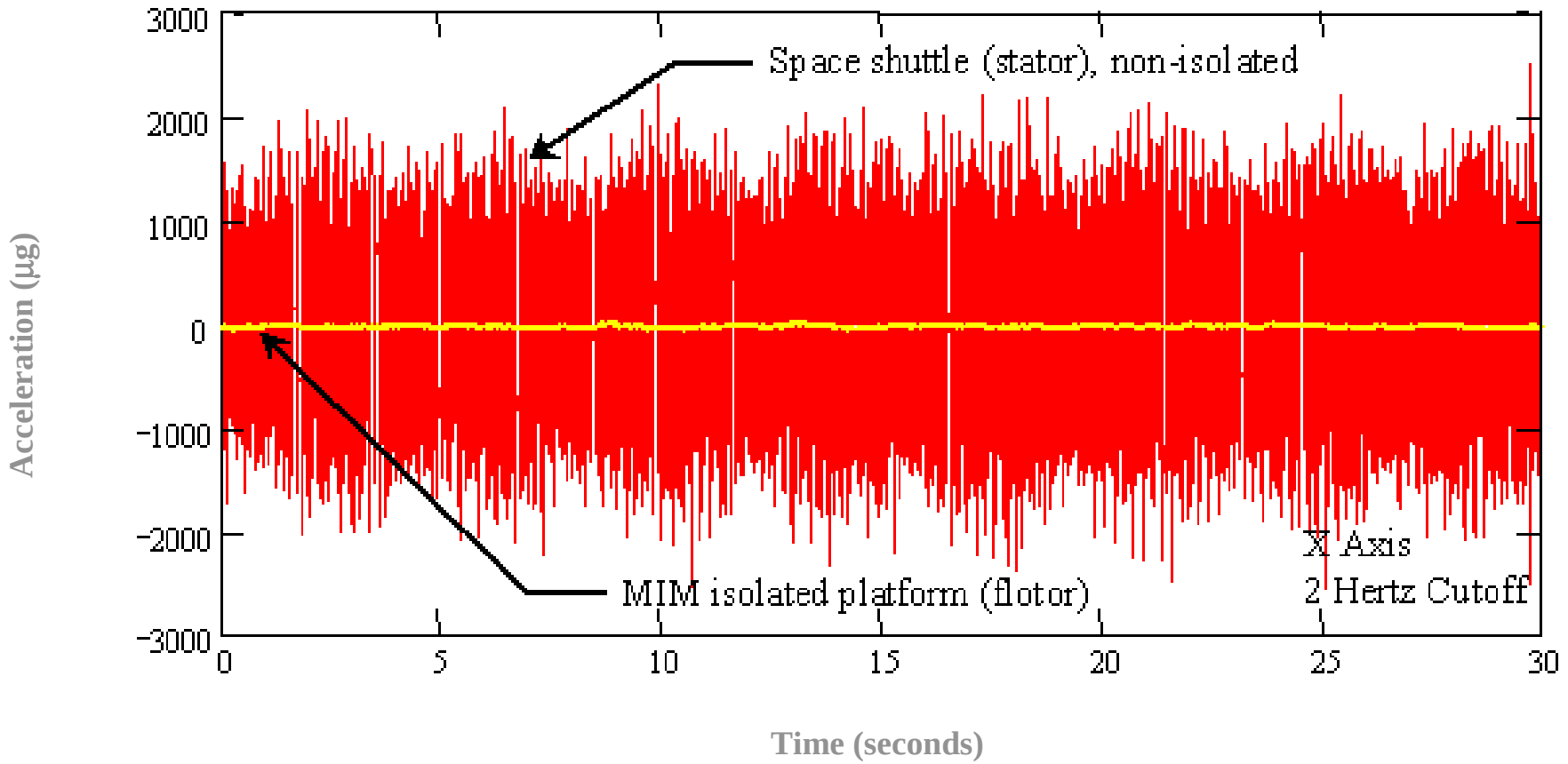
Acceleration on the Space Shuttle



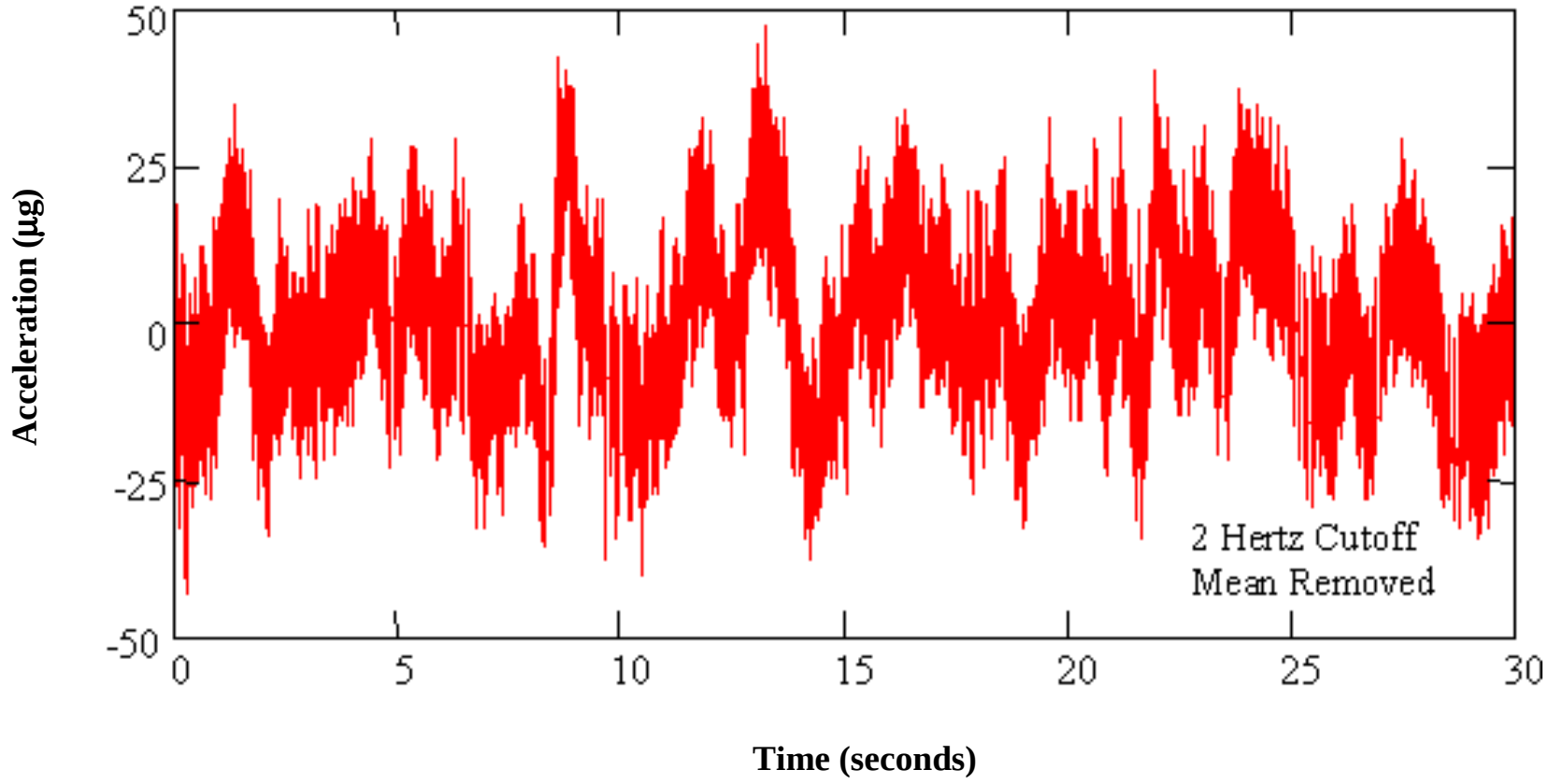
Acceleration on the Space Shuttle



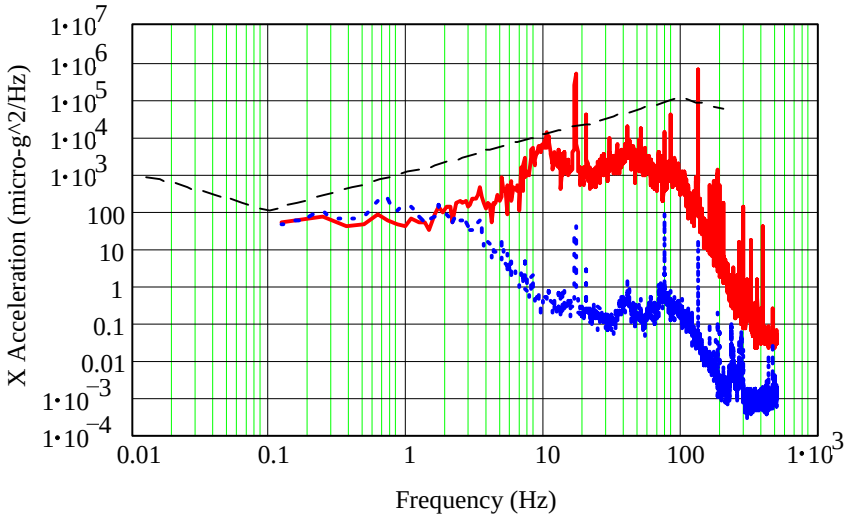
Acceleration Levels of the Space Shuttle and the MIM Flotor

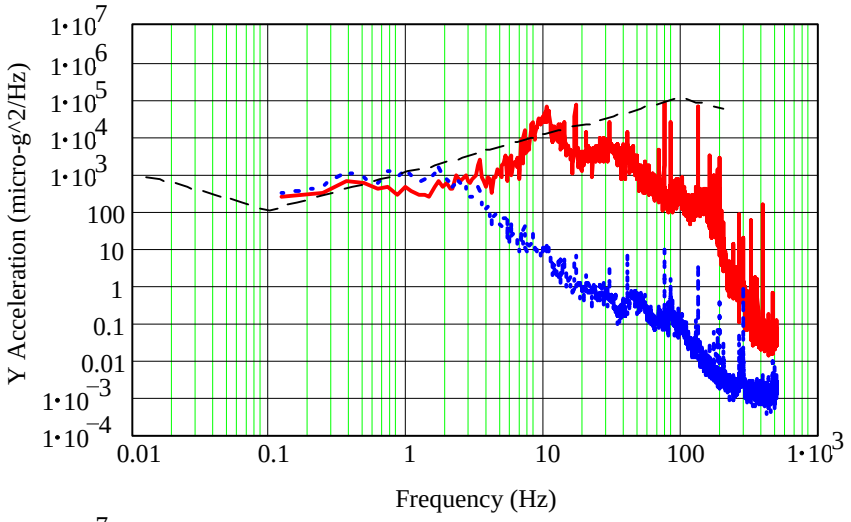


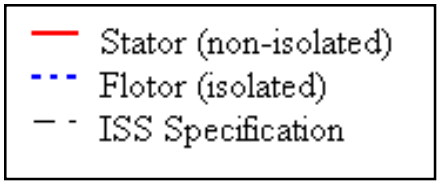
Flotor X Acceleration

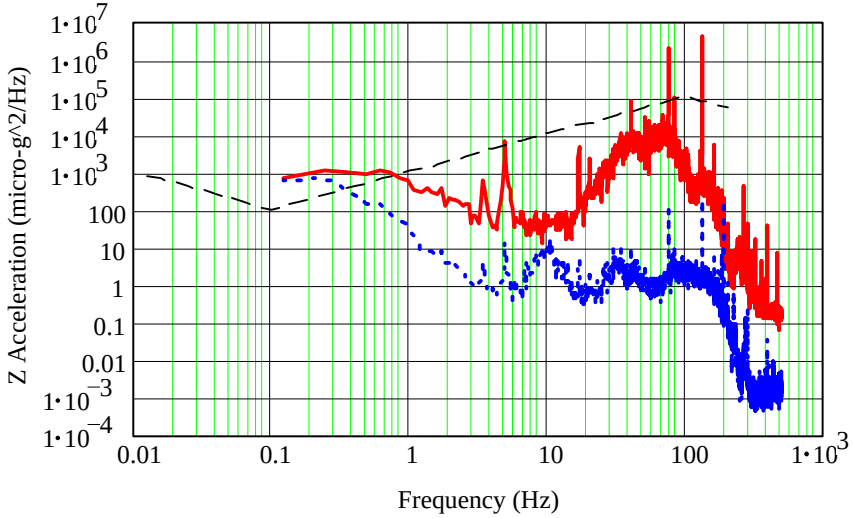


Power Spectral Densities for the Shuttle and MIM Flotor Accelerations



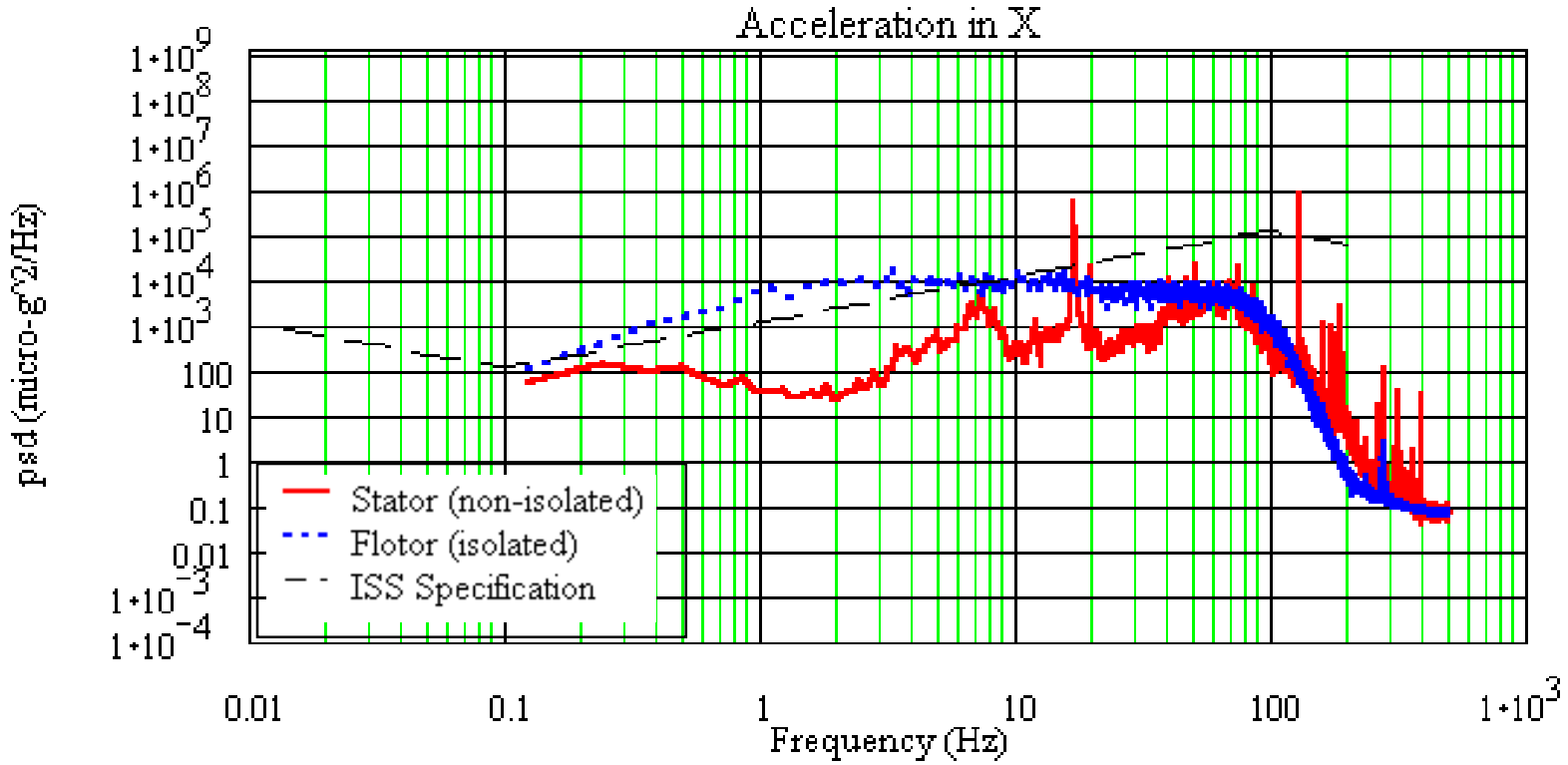




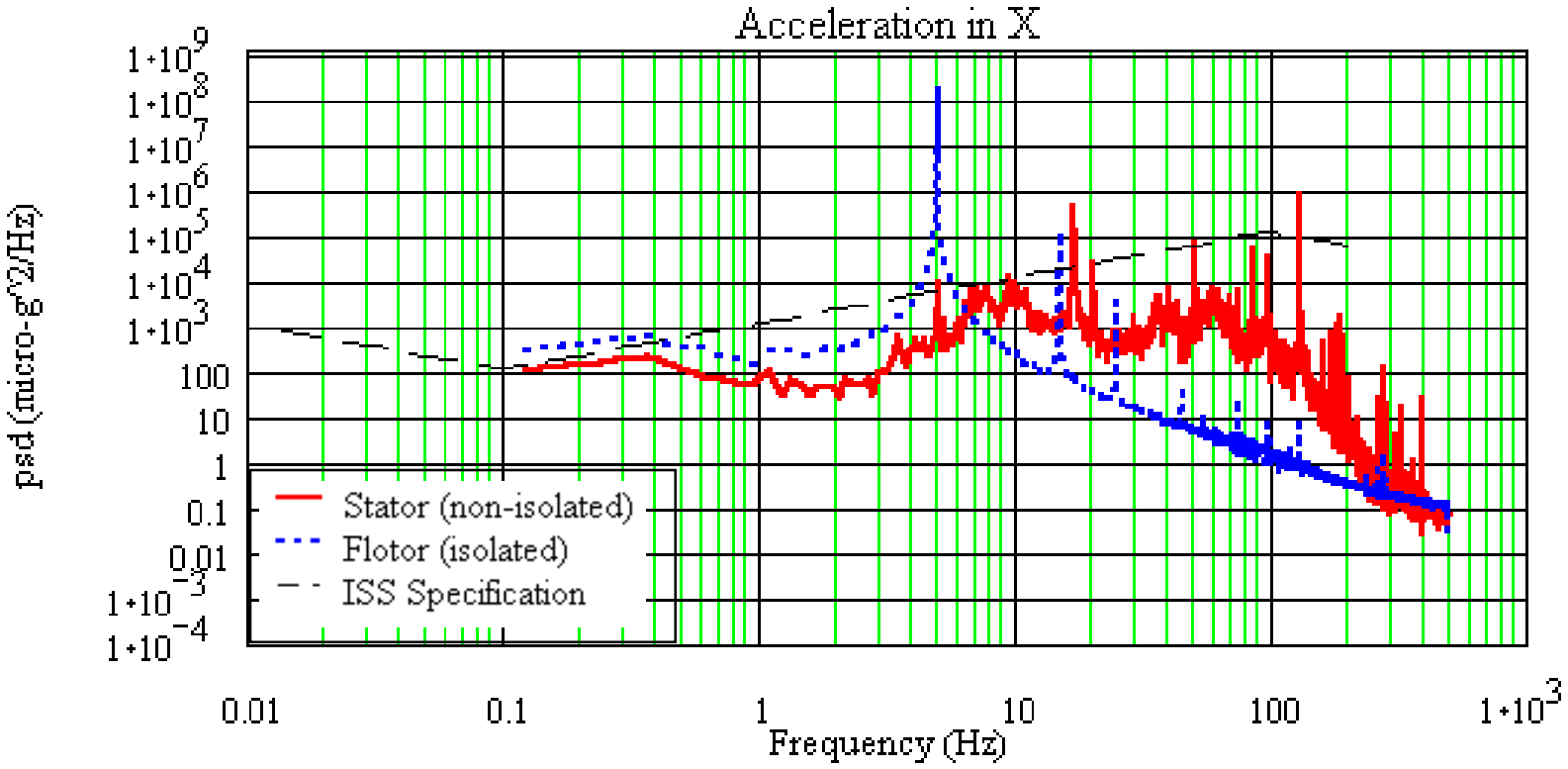


DPID, XY: 2 Hertz, Z: 0.1 Hertz
File: D7081621

MIM Driven Mode - Random



MIM Driven Mode - 5 Hz



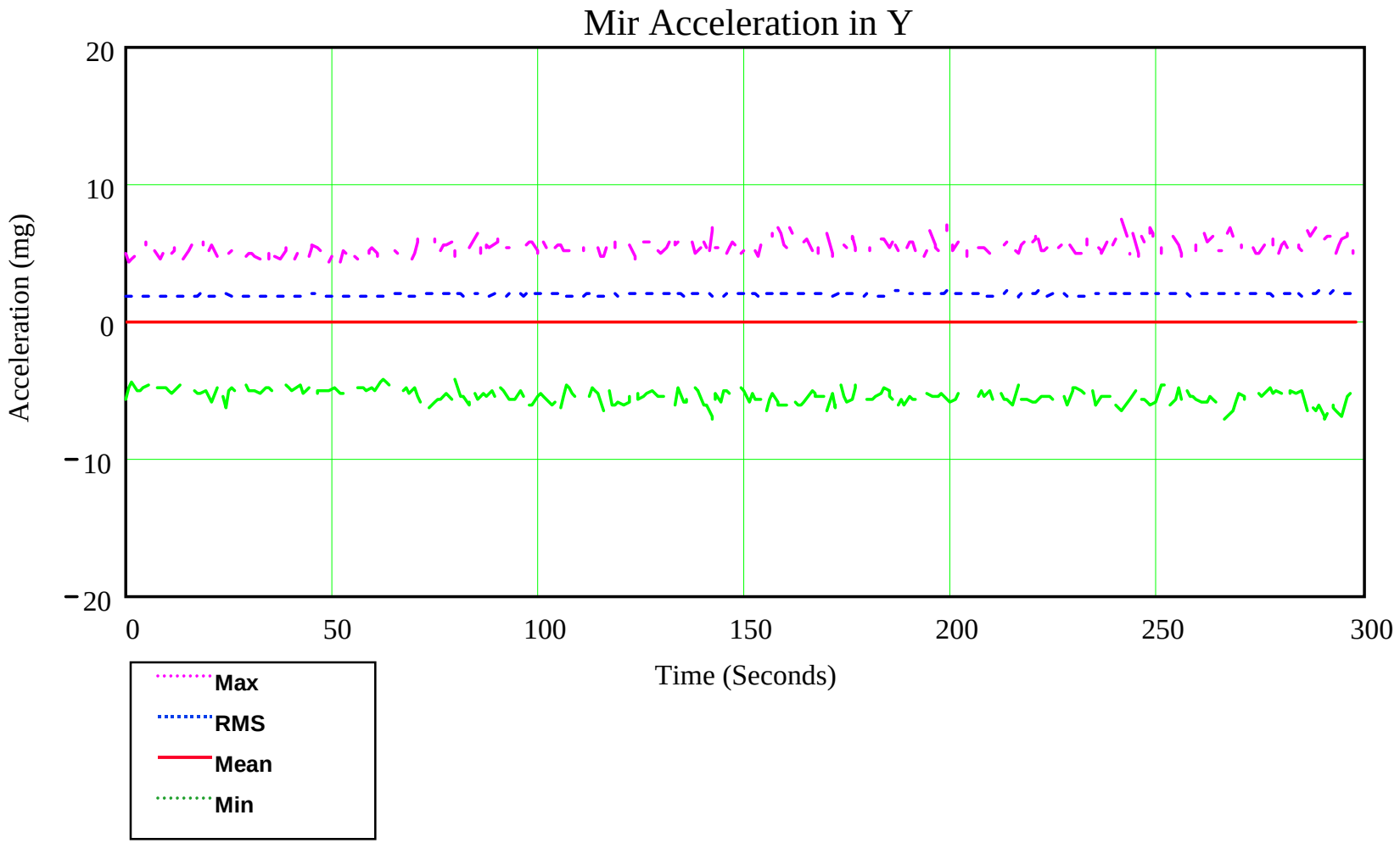
Operational from May 1996 to January 1998

3000 hours of operations supporting material science experiments:

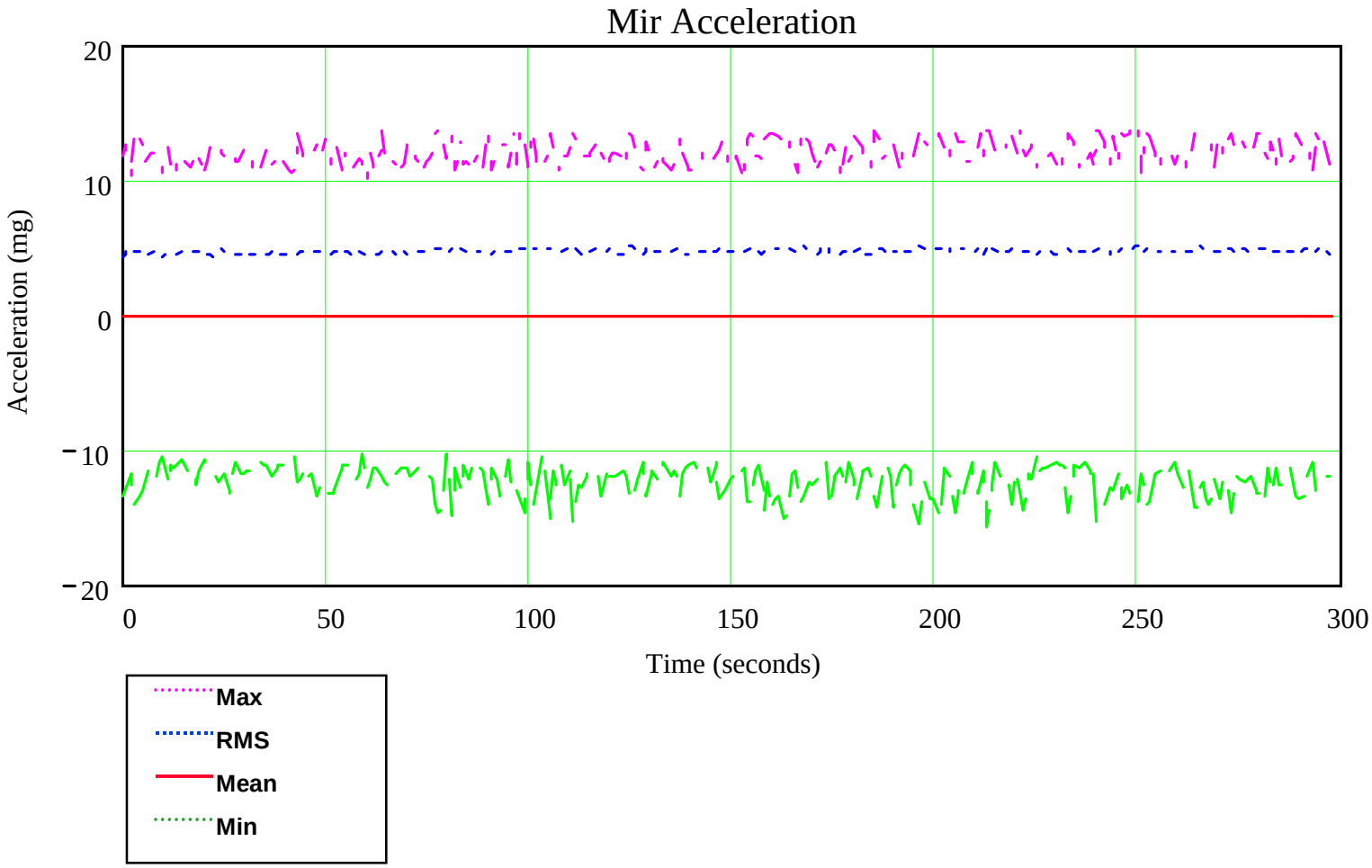
- **Diffusion in liquid metals, Nucleation in glasses, Particle pushing, Semiconductor crystal growth, Protein crystal growth, Liquid-vapor interface dynamics**

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

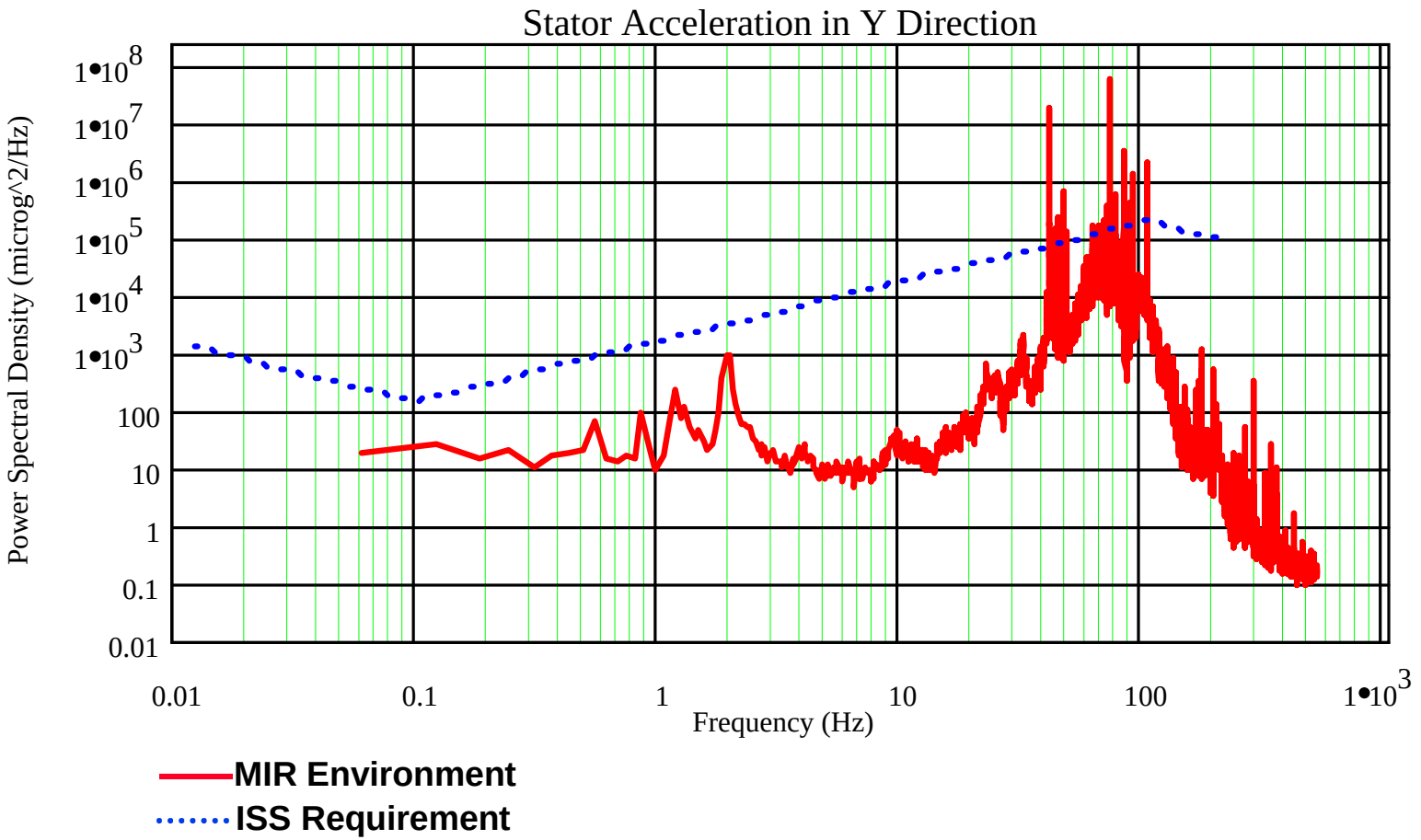
Accelerations on Mir as Measured with the MIM



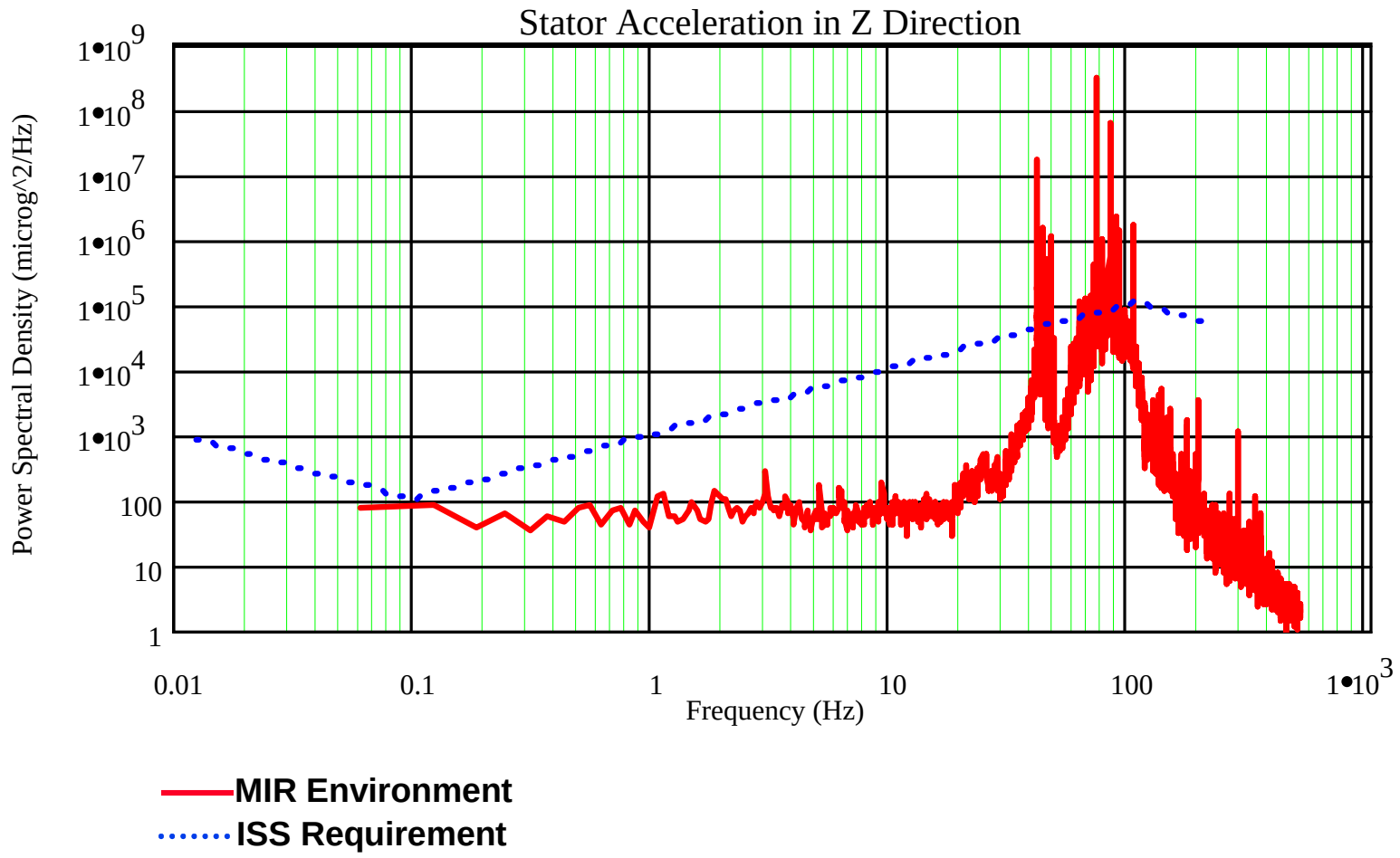
Accelerations on Mir as Measured with the MIM



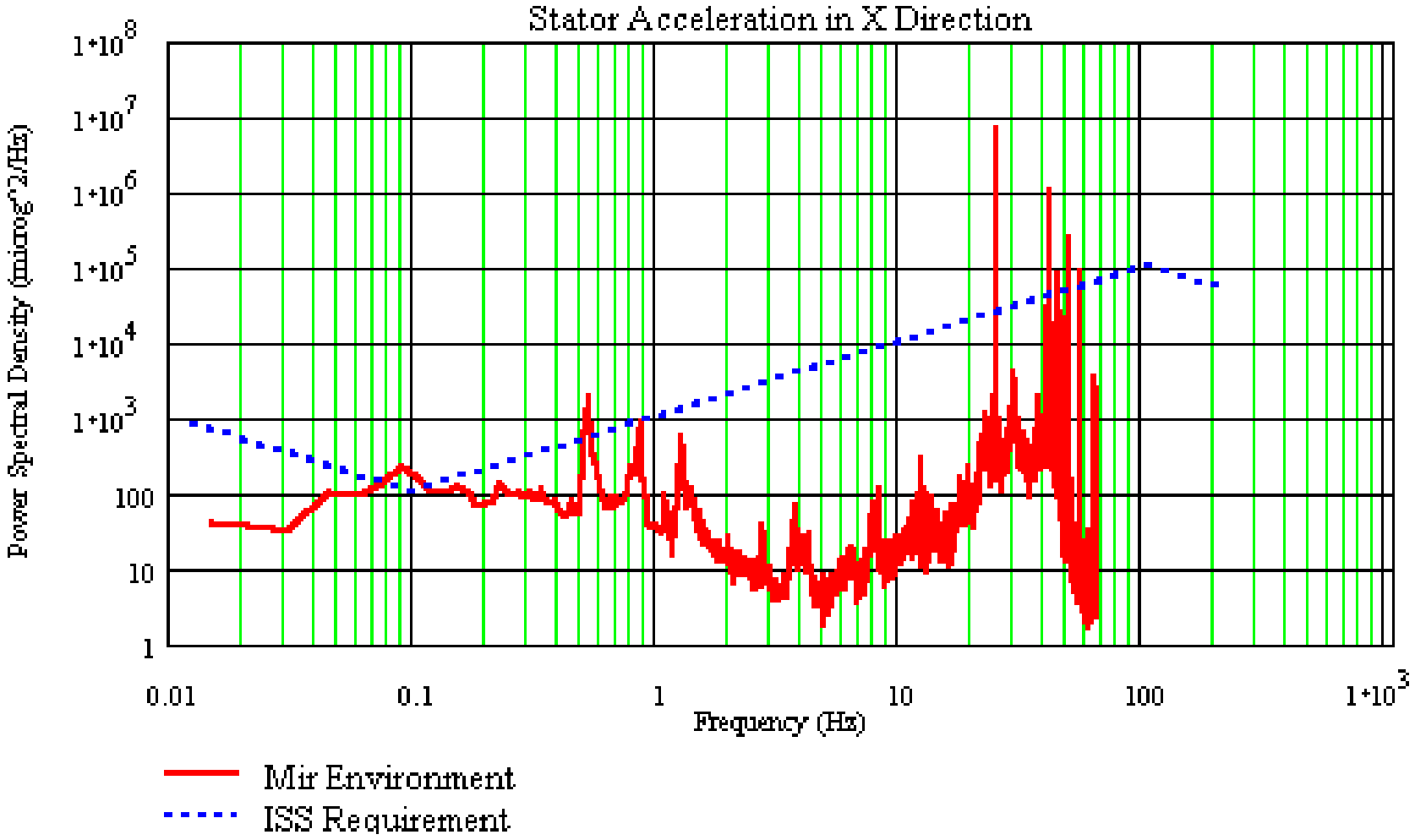
Accelerations on Mir as Measured with the MIM



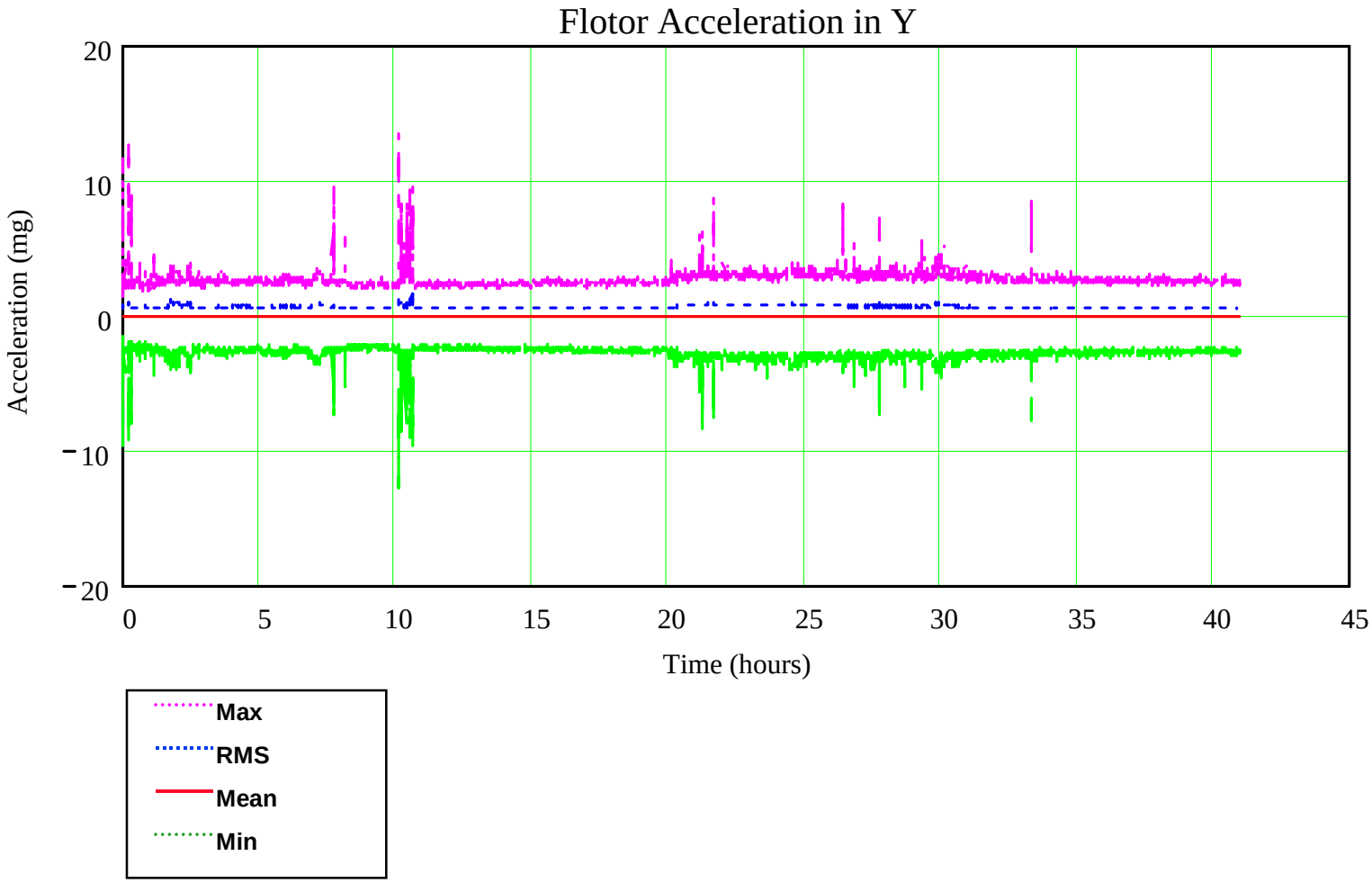
Accelerations on Mir as Measured with the MIM



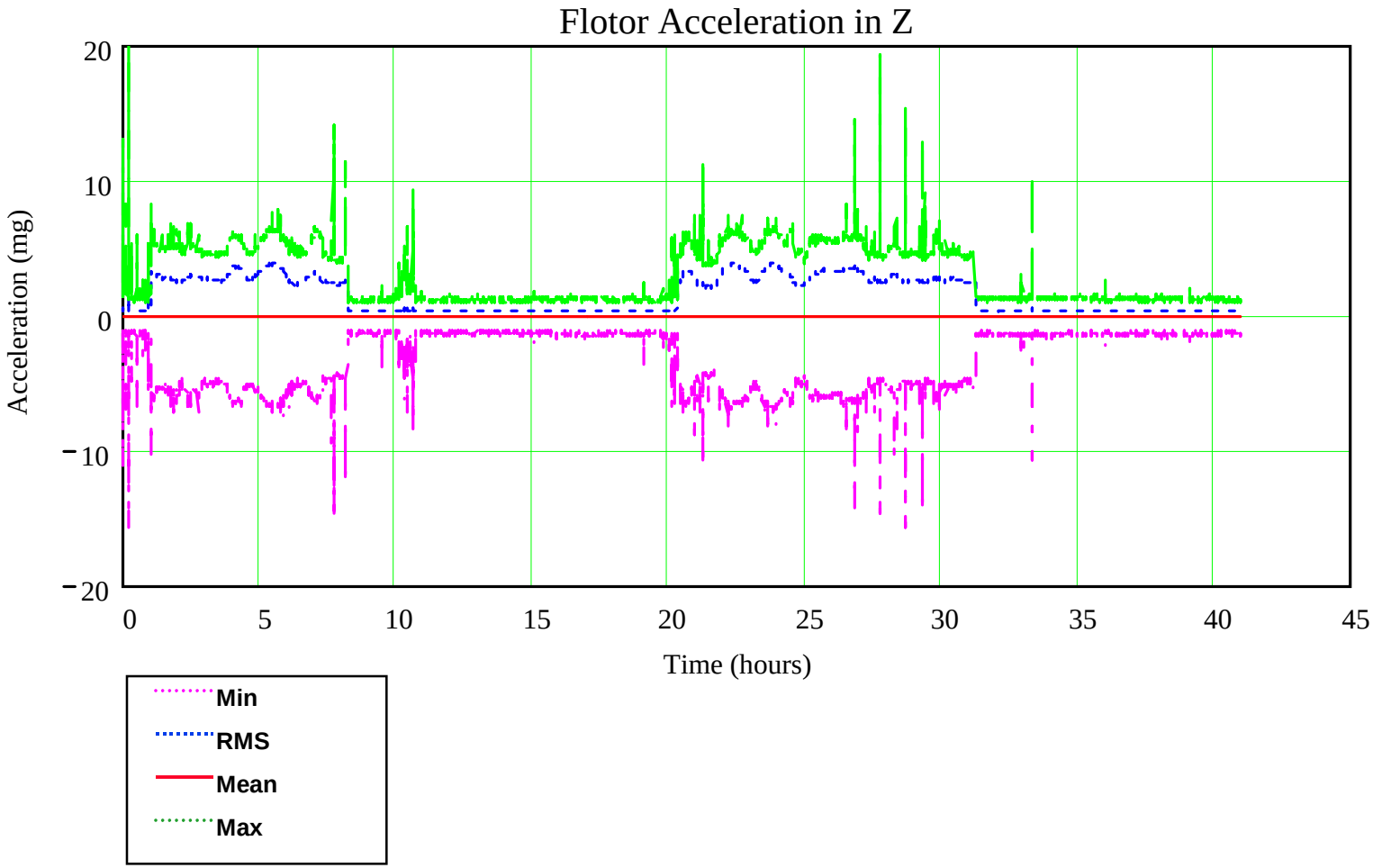
Accelerations on Mir as Measured with the MIM



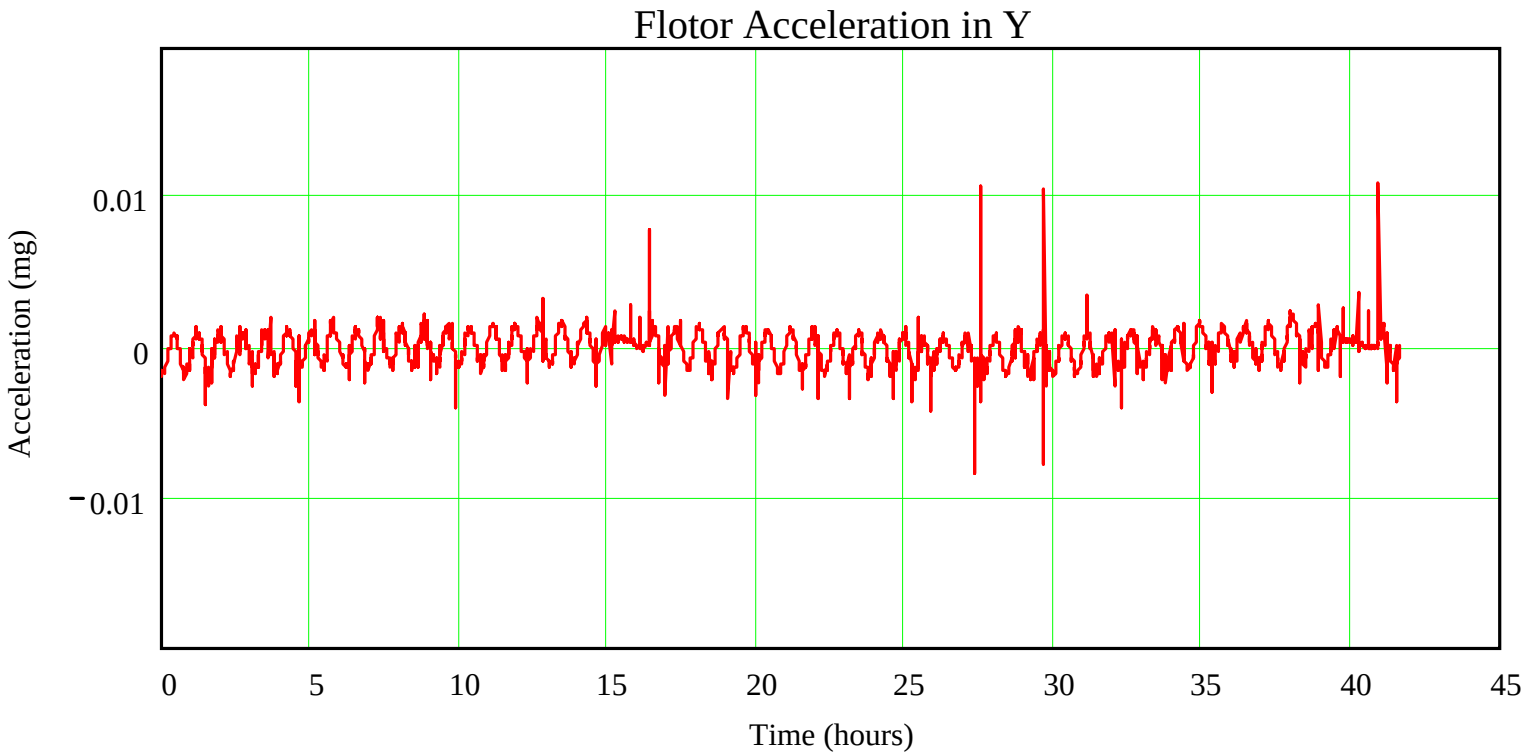
Accelerations on Mir as Measured with the MIM



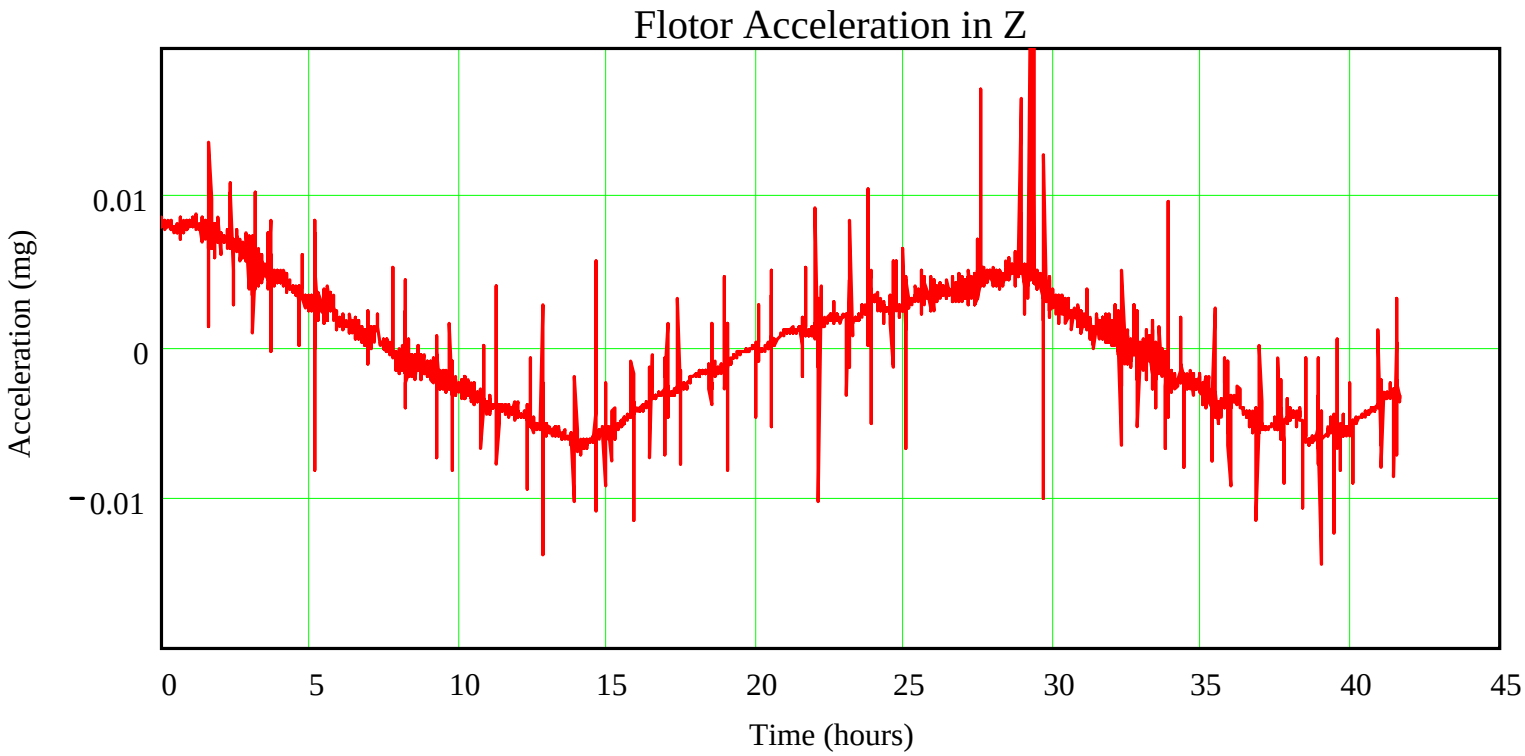
Accelerations on Mir as Measured with the MIM



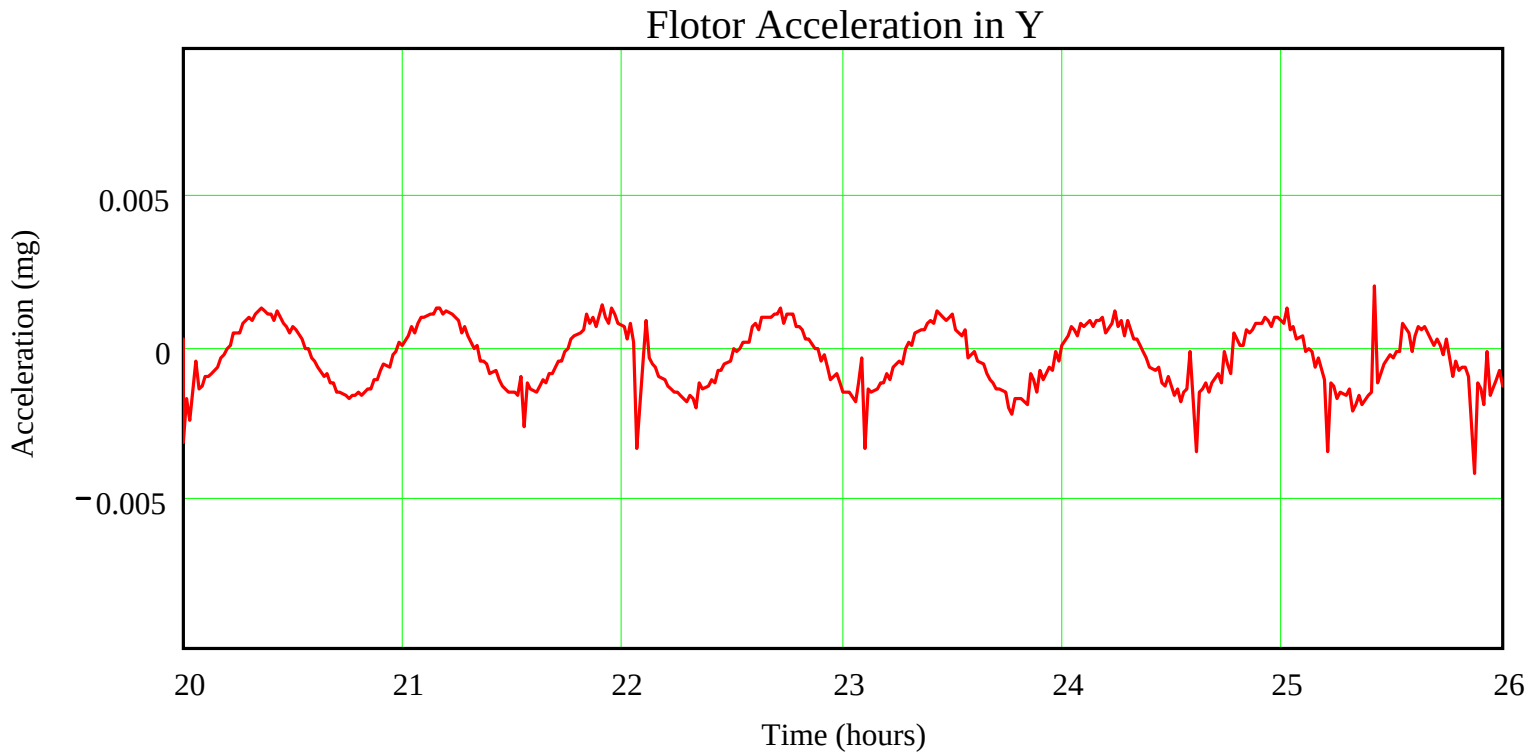
Mean Acceleration on an Expanded Scale



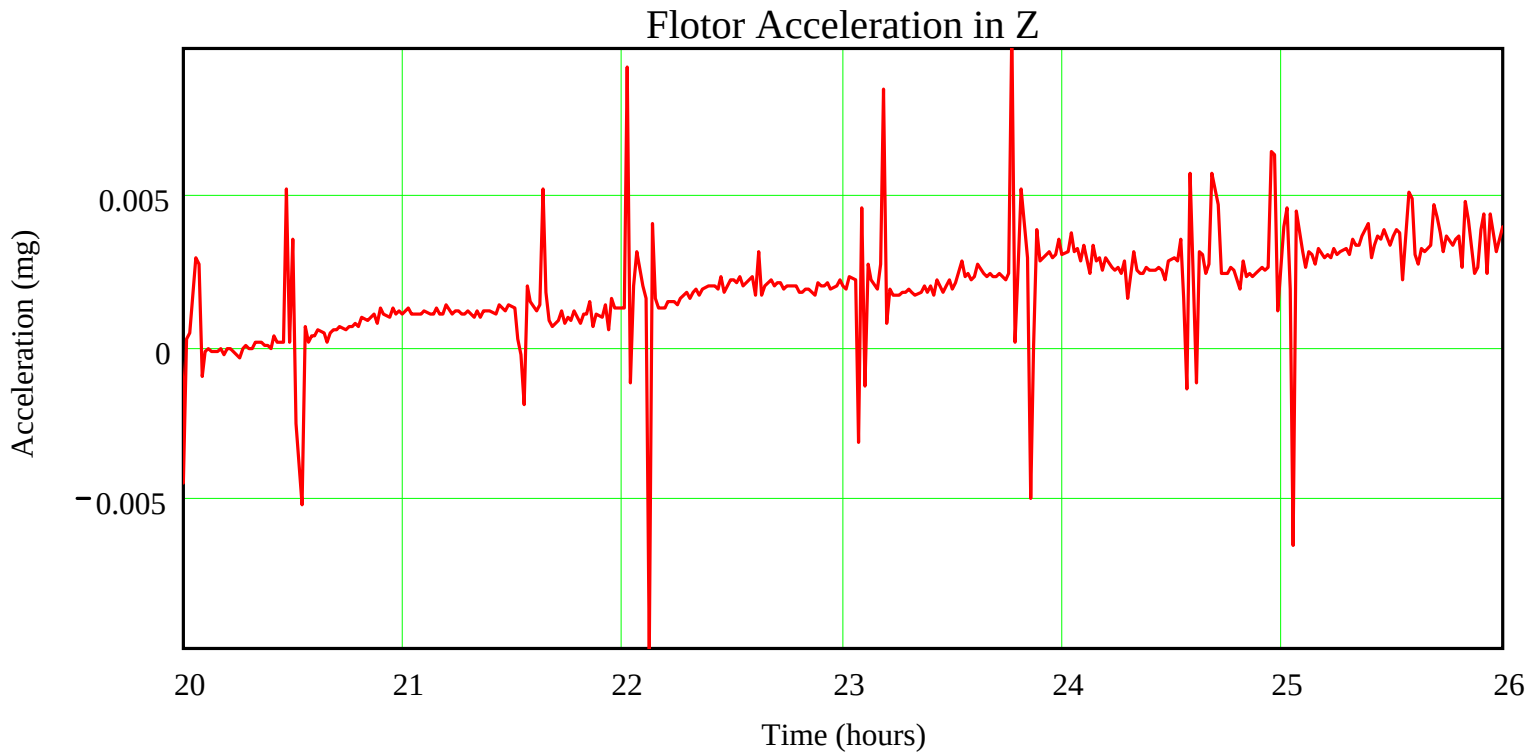
Mean Acceleration on an Expanded Scale



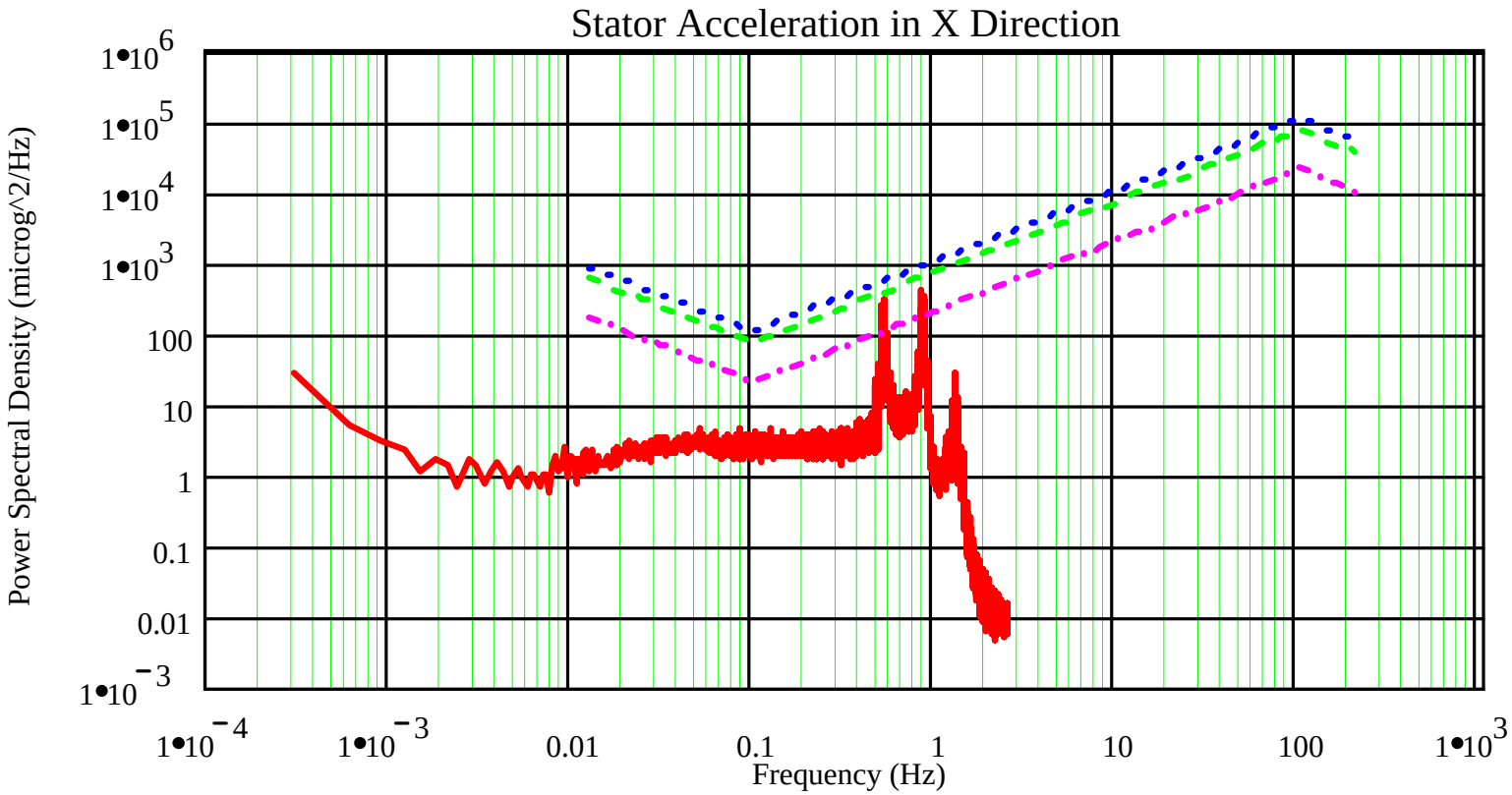
Mean Acceleration on an Expanded Scale



Mean Acceleration on an Expanded Scale



Spectrum for Intermediate Frequency Acceleration on Mir



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

Experimenters should be aware of the vibration levels on the ISS