Space Acceleration Measurement System (SAMS) on Mir

Investigation 8.8.1 / SAMS
Summary Report

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1. Introduction

1.1 Hypothesis

The characterization of the microgravity (acceleration) environment of the Russian Mir Space Station will aid Principal Investigators (PIs) of Mir-manifested experiments to help identify those experiment results which were related to acceleration events. The Space Acceleration Measurement System (SAMS) provides the capacity for simultaneous measurements of up to three remotely located Triaxial Sensor Heads (TSHs), with a nominal 1 µg resolution for each axis. Both raw data and analyzed results are made freely available to PIs, so they may make use of these microgravity measurements as they analyze their experimental data.

1.2 Objectives of Investigation

There are two main objectives of the SAMS investigation. The first objective is to record the acceleration environment to support microgravity science PIs. The second objective is to characterize the Mir microgravity environment as it pertains to unavoidable disturbance sources (life support systems, structural modes, etc.), regular activities (equipment operations, crew exercise, etc.), and less frequent activities (extravehicular activities (EVAs), module reorientation, and Progress/Soyuz/Shuttle docking events, etc.).

Analysis of previous acceleration data may help an investigator to plan experiment run times, request a specific experiment location, or provide other insight into the acceleration environment which would not be possible without previous acceleration knowledge.

1.3 Background/History of Project

The SAMS was designed by a team at NASA NASA Glenn Research Center (GRC). The seven flight units of SAMS were flown on twenty Shuttle missions between June 1991 and January1998. The SAMS flight unit “E” was first flown on STS-43 in the middeck and on STS-47 (Spacelab J) in the Spacelab module. Shannon Lucid and John Blaha flew with SAMS flight unit “E” on STS-43 and were later re-united with it on Mir.

In late August 1994, the SAMS flight unit “E” was flown on-board the Progress 224 (M-24) flight and transferred to Mir by the Russian cosmonauts. Since that time, data have been recorded to support a number of U.S. and Russian science experiments by providing acceleration measurements during periods of microgravity science experiment operations, other experiment operations, and various mission events.

The Principal Investigator Microgravity Services (PIMS) project at NASA Glenn Research Center (GRC) analyzes the SAMS data recorded aboard Mir and publishes summary reports which describe the acceleration environment. The data are made available to interested parties via anonymous file transfer protocol (ftp) over the internet. Additionally, requests for specific data analysis by interested PIs are handled by the PIMS project.

1.4 List of Acronyms and Abbreviations

ALB	Angular Liquid Bridge experiment
BCAT	Binary Colloidal Alloy Test
BKV-	Russian acronym for life support compressor
BTS	Biotechnology System Facility
CAPE	Canadian Protein Crystallization Experiment
CFM	Candle Flames in Microgravity
CGEL	Colloidal Gelation
DCAM	Diffusion Controlled Apparatus Module
DMT	Decreed Moscow Time (day/hour:minute:second)
EVA	extravehicular activity
f	frequency (Hz)
f_c	cutoff frequency (Hz)
f_s	sampling rate (samples per second)

FFFT	Forced Flow Flame Spreading Test
ftp	file transfer protocol
g_0	nominal acceleration due to gravity (9.81 m/s^2)
GRC	NASA John H. Glenn Research Center (Cleveland, Ohio) (previously Lewis Research Center or LeRC)
Hz	Hertz
IPCG	Interferometric Study of Protein Crystal Growth
JSC	NASA Lyndon B. Johnson Space Center
LMD	Liquid Metal Diffusion experiment
MB	megabyte (~10^6 bytes)
mg	milli-g (1/1,000 of g_0)
MGBX	Microgravity Glovebox
MIM	Microgravity Isolation Mount
MiPS	Mir Payload Support
MiSDE	Mir Structural Dynamics Experiment
NASM	National Air & Space Museum
OFFS	Opposed Flame Flow Spread on Cylindrical Surfaces experiment
PCG	Protein Crystal Growth
PI	Principal Investigator
PIMS	Principal Investigator Microgravity Services
POSA	Payload Operation Support Area
PSD	power spectral density
QUELD	Queen's University Experiments in Liquid Diffusion
RSS	root sum of squares
RSC	Rocket Space Corporation
SAMS	Space Acceleration Measurement System
STS	Space Transportation System
TEM	Technical Evaluation of MIM
TEPC	Tissue Equivalent Proportional Counter
TSH	triaxial sensor head

2. Methods/Research Operations

2.1 Functional Objectives

During the NASA-Mir program, the SAMS unit supported experiments conducted in the Kvant module, the Kristall module, and the Priroda module from October 1994 to January 1998. The experiments supported included:

Angular Liquid Bridge (ALB) experiment
Biotechnology System facility operations (BTS)
Canadian Protein Crystallization Experiment (CAPE)
Candle Flames in Microgravity (CFM)
Colloidal Gelation (CGEL)
Diffusion Controlled Apparatus Module (DCAM) experiments,
Forced Flow Flame Spreading Test (FFFT)
Interferometric Study of Protein Crystal Growth (IPCG)
Liquid Metal Diffusion (LMD) experiment
Microgravity Glovebox operations (MGBX)
Microgravity Isolation Mount (MIM)
Mir Structural Dynamics Experiment (MiSDE)
Opposed Flame Flow Spread (OFFS) on Cylindrical Surfaces experiment
Protein Crystal Growth (PCG) experiments
Ambient Diffusion Controlled PCG
PCG in Dewar

Queen's University Experiments in Liquid Diffusion (QUELD)
Technical Evaluation of MIM (TEM)
Tissue Equivalent Proportional Counter (TEPC)

Data was recorded to support and characterize a number of significant events on Mir, such as:

- firing of the Progress vehicle's engine to reboost Mir
- docking operations of Soyuz and Progress vehicles
- docking and undocking of Shuttle vehicles
- Mir structural modes
- Mir vehicle system and subsystem equipment
  - life-support fans
  - gyrodynes
- crew exercise
- EVA
- cyclic broadband behavior around 90-100 Hz
- unknown disturbances

2.2 Hardware Items

The SAMS experiment consists of the SAMS main unit (signal conditioning and data sampling devices, and two optical disk drives), two TSHs (100 Hz lowpass frequency cutoff and 10 Hz lowpass frequency cutoff), a calibration mounting plate, and a supply of optical disks.

Each optical disk is double-sided, and can hold approximately 200 megabytes (MB) of data per side. Approximately 12 hours of SAMS data can be recorded on each disk side. The SAMS unit has two optical drives and can therefore record about 24 hours of data before both disks' sides become full which then requires crew intervention to change the disks.

2.3 Sessions/FO Table

The SAMS data were recorded at various times the NASA-Mir program and were scheduled to support the experiments' operation times and/or to capture specific mission events.

The various increment reports for SAMS contain listings of the SAMS sensor head locations and orientations for the SAMS data sets and the date and time recording was initiated and terminated.

2.4 Data Analysis Methods

SAMS data for the increment reports were analyzed using a variety of techniques, including acceleration versus time, interval average acceleration versus time, power spectral density (PSD) versus frequency, and spectrograms (PSD versus frequency versus time). Each of these techniques is used to highlight a different aspect of information contained in the data. SAMS data analysis also included discussions with some astronauts and cosmonauts, examination of the SAMS crew logbooks, and operations centers' notes.

2.5 Discussion of Methods

Spectrograms are used to display long periods of data, on the order of tens of minutes to multiple hours. Spectrograms provide a road map to the data, showing how the microgravity environment varied as a function of time and frequency content. These are useful for showing signals which turn-on, turn-off, or change with respect to time.

The logbook and operations centers' notes provided information as to the actual activities which occurred on Mir. This information provided clues to the identity of disturbances to the microgravity environment and also supplies leads to investigate the characteristics of a specific disturbance. Past analysis results were also used for characterizing these data.

3. Results

3.1 Pre-, In-, and Post-Flight Anomalies

The lowest frequency cutoff sensor head (SAMS TSH C, f_c=2.5 Hz) did not function since the installation of the SAMS unit on Mir in 1994. Due to this, sensor head C is typically not connected to the main unit. Aside from the possible data from a third location, this missing sensor head data has no impact on the experiment's objectives. Since both SAMS TSH A (f_c=100 Hz), and SAMS TSH B (f_c=10 Hz) record the microgravity environment below 2.5 Hz, the information which this head would have gathered is available from the two remaining sensor heads.

3.2 Completeness/Quality of Data

3.21 Mir-16 (Prior to NASA-Mir Increment 1)

The channel in the SAMS Main Control Unit used in conjunction with the TSH that measures microgravity accelerations in the 0.05-2.5 Hz range was inoperable since the SAMS was first installed on Mir. The other two channels were functional; the heads associated with these channels measure accelerations in the 0.05-10 Hz and the 0.05-100 Hz ranges, so data in the 0.05-2.5 Hz range are available.

3.22 Increment 1

The data during days 84 and 85 of 1996 were not valid for TSH A due to an unknown problem. It appears from the data recorded on the flight disks as if the sensor head was not connected properly during these two days.

3.23 Increment 2

According to the Payload Operation Support Area (POSA) daily status reports, the SAMS unit was activated to capture the acceleration environment of the Mir/Atlantis (STS-76) docking event. This data was not present in any of the optical discs which were returned to Earth. Therefore, one of two possibilities was assumed: 1) The POSA reports were incorrect, or 2) the disk(s) containing this data were never returned to Earth.

3.24 Increment 3

No known anomalies.

3.25 Increment 4

During the de-brief with the SAMS and PIMS team, Jerry Linenger mentioned that he felt that the SAMS unit should be turned on to record data. It should not be turned on and off to capture data for small portions of time.

3.26 Increment 5

There was a large discrepancy (approx. 20 hours) between the time stamps in SAMS data for the STS-86 docking and the time for this event as reported by NASA Johnson Space Center (JSC).

3.27 Increment 6

No known anomalies.

3.28 Increment 7

There was a small discrepancy (1.25 hours) between the time stamps in SAMS data for the STS-89 undocking and the time for this event as reported by NASA JSC.

3.29 Overall

There were times (noted in the various SAMS Acceleration Measurements on Mir NASA Technical Memorandum reports listed in the SAMS/Mir Publications section) when the time synchronization was not possible between SAMS and the Mir Payload Support (MiPS) computer. PIMS endeavored to establish a time synchronization with other sources, such as crew logbooks, POSA notes, mission events, etc. Therefore, the timestamps in the SAMS data may be off from actual Decreed Moscow Time (DMT) by up to two days (typically, times gaps of a few minutes to an hour or two are seen). This time synchronization was complicated by a lack of information about when mission events actually occurred.

4. Discussion

4.1 Status of Data Analysis

Once returned to Earth, the optical disks were processed by the SAMS project to convert from the internal storage format into engineering units of g's (where 1 $g_0 = 9.81\ m/s^2$). These data were placed on an internet file server, beech.lerc.nasa.gov, and are available to users. All the data obtained from SAMS operations on Mir have been processed.

Three sets of CD-ROM disks were prepared which contain the data. One copy was put into the GRC Microgravity Science Division archives, one will be used by PIMS, and one was given to the Russian co-investigator for SAMS, Stanislav Ryaboukha, RSC Energia.

When the data were available from the SAMS project, the PIMS project processed the data to produce the PSD versus frequency versus time (spectrogram) plots, which serve as a road map to the data. These plots show times which may be of interest for PI experiments or for Mir microgravity characterization

4.2 Preliminary Research Findings

NASA Technical Memorandum reports, published for each increment, contain the PIMS data analysis and the spectrogram plots for the entire data set. Users who are interested in an in-depth discussion of the data are encouraged to request a report from the PIMS project at NASA GRC (contact the PIMS Project manager by e-mail at PIMS@GRC.NASA.GOV). Additional in-depth analyses may be found by consulting the SAMS Acceleration Measurements on Mir reports listed in the SAMS/Mir Publications section. Two examples of analyses are included here.

4.21 Progress vehicle engine burn for MiSDE

As part of the MiSDE tests, the Progress engine was fired while the Progress was docked to the Mir. Figure 1 is a plot of 1 second interval averages of acceleration vs. time for the engine firing recorded by the SAMS TSH B with f_c =10Hz. The largest response to the engine firing recorded by the SAMS is shown on the $Z_{h,B}$ axis plot. The acceleration level in the $Z_{h,B}$ axis is about 0.4 mg for the approximately 6.5 minutes of the engine burn.

4.22 Spectrogram Analysis of SAMS Data for a 24-Hour Period

Because of the periodic nature of equipment operation, crew activity, etc., no single day can provide a comprehensive overview of the microgravity environment on Mir. However, an assessment of SAMS data for a 24-hour period can provide useful observations and insights about the microgravity environment. Figure 2 is a SAMS color spectrogram of a 24-hour period, DMT 1996 277/00-278/00, for TSH A, with a cutoff frequency of 100 Hz (f_c =100 Hz). The color spectrogram shows the operation of the dehumidifier system compressor, BKV-3 (Russian acronym). The 24 Hz fundamental frequency of the compressor can be seen as a red horizontal line, from about 10:00 am - 7:00 pm (DMT). The harmonics of the 24 Hz disturbance can be seen at 48 Hz, 72 Hz, and 96 Hz. The 40-45 Hz fundamental frequency of the life support system fans and the 80-90 Hz harmonics can also be seen as horizontal lines for the total time covered by the spectrogram. The broadband response that can be seen in the 90-100 Hz region of the spectrogram is of unknown origin. It is also interesting to note, and of potential interest to PIs, that the period from about 12:00 Midnight to about 8:00 am appears more free of disturbances below about 10 Hz than other time periods covered by this spectrogram. This time period coincides with the crew sleep period.

4.3 Recommendations

Many of the PIMS analyses and conclusions are based upon somewhat sketchy timeline information and/or crew notes. More accurate and detailed timeline information would help to characterize disturbances caused by machinery operation. More detailed crew notes would help to characterize those microgravity disturbances which are crew-induced. An increase in crew and ground controller awareness and training is probably the best way to achieve a better data product.

4.4 Conclusions

The microgravity environment of the Mir space station is a complex phenomenon, which is a combination of (among other things) structural modes, equipment operation, life support system operation, and crew activity.

The SAMS and PIMS projects processed the SAMS data from Mir and made them available via an internet file server. NASA Technical Memorandum reports were also prepared for each NASA-Mir increment which summarize the microgravity acceleration environment. With the exception of the lowest-frequency sensor head channel, the SAMS unit continued to function nominally throughout its nearly four years of operation on Mir.

4.5 End Result

The SAMS unit was returned to Earth from Mir on STS-91. A physical and functional examination was performed with the unit functioning properly except for the TSH C channel. The malfunction of this channel was found to be a broken wire in the cable that connects the TSH to the SAMS main unit. The condition of the unit was excellent considering that it originally was designed for operation in one to two week flights of the Shuttle. This particular unit, after being aboard two Shuttle flights, spent three years and ten months on-board Mir.

Since the SAMS unit was the U.S. equipment on Mir for the longest time during the NASA-Mir program, it was accepted to be in the collection of the National Air & Space Museum (NASM), Washington, DC. The SAMS main unit, the sensor heads, cables, crew logbooks, data disks (both flight originals and processed data), photographs, a drawing package, sensor head calibration fixture (training unit), and PIMS analysis reports were all submitted to the NASM in early 2000.

5. SAMS/Mir Publications

DeLombard, Richard, and Melissa J. B. Rogers. Quick Look Report of Acceleration Measurements on Mir Space Station During Mir-16. Cleveland: NASA LeRC, January 1995. NASA TM 106835.

DeLombard, Richard, Stanislav Ryaboukha, Ken Hrovat, and Milton Moskowitz. Further Analysis of the Microgravity Environment on Mir Space Station During Mir-16. Cleveland: NASA LeRC, June 1996. NASA TM 107239.

DeLombard, Richard, Ken Hrovat, Milton Moskowitz, and Kevin McPherson. SAMS Acceleration Measurements on Mir from June to November 1995. Cleveland: NASA LeRC, September 1996. NASA TM 107312.

DeLombard, Richard. SAMS Acceleration Measurements on Mir from November 1995 to March 1996. Cleveland: NASA LeRC, April 1997. NASA TM 107435.

DeLombard, Richard, Kevin McPherson, Kenneth Hrovat, Milton Moskowitz, Melissa J. B. Rogers, and Timothy Reckart. Microgravity Environment Description Handbook. Cleveland: NASA LeRC, July 1997. NASA TM 107486.

Moskowitz, Milton E., Ken Hrovat, Duc Truong, and Timothy Reckart. SAMS Acceleration Measurements on Mir from March to September 1996. Cleveland: NASA LeRC, August 1997. NASA TM 107524.

Moskowitz, Milton E., Ken Hrovat, Robert Finkelstein, and Timothy Reckart. SAMS Acceleration Measurements on Mir from September 1996 to January 1997. Cleveland: NASA LeRC, December 1997. NASA/TM-97-206320.

Rogers, M.J.B., K. Hrovat, M. Moskowitz, Low-gravity Environment of the Mir Space Station, Adv. Space Res. Vol. 22, No. 8, pp. 1257-1260, 1998.

DeLombard, Richard, SAMS Acceleration Measurements on on Mir from January to May 1997 (NASA Increment 4). Cleveland: NASA LeRC, October 1998. NASA/TM-1998-208646.

DeLombard, Richard, SAMS Acceleration Measurements on on Mir from May 1997 to June 1998 (NASA Increments 5, 6, and 7). Cleveland: NASA GRC, August 1999. NASA/TM-1999-209282.

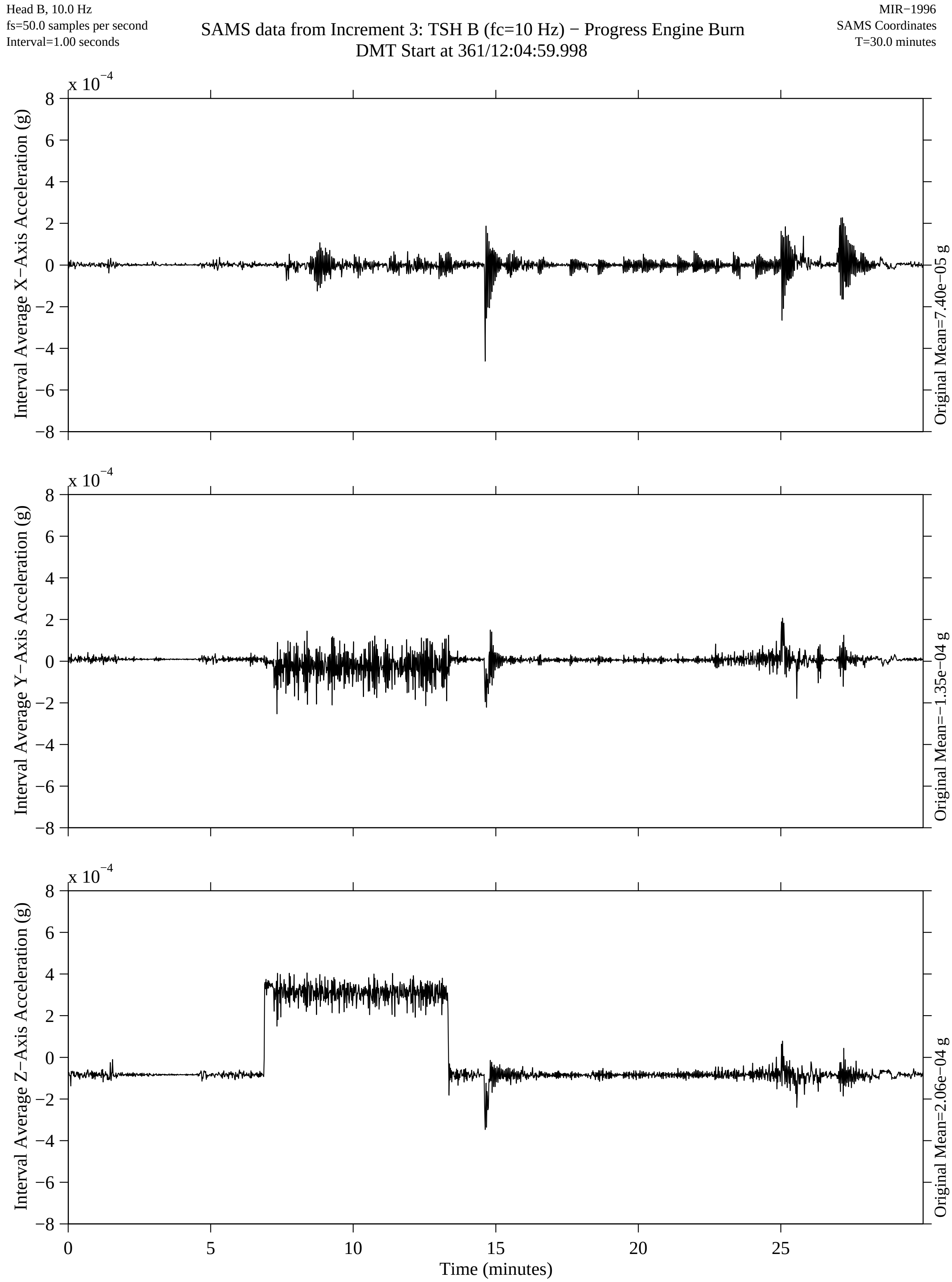

Figure 1. SAMS TSH B Acceleration vs. Time for MiSDE Progress Engine Burn Test.

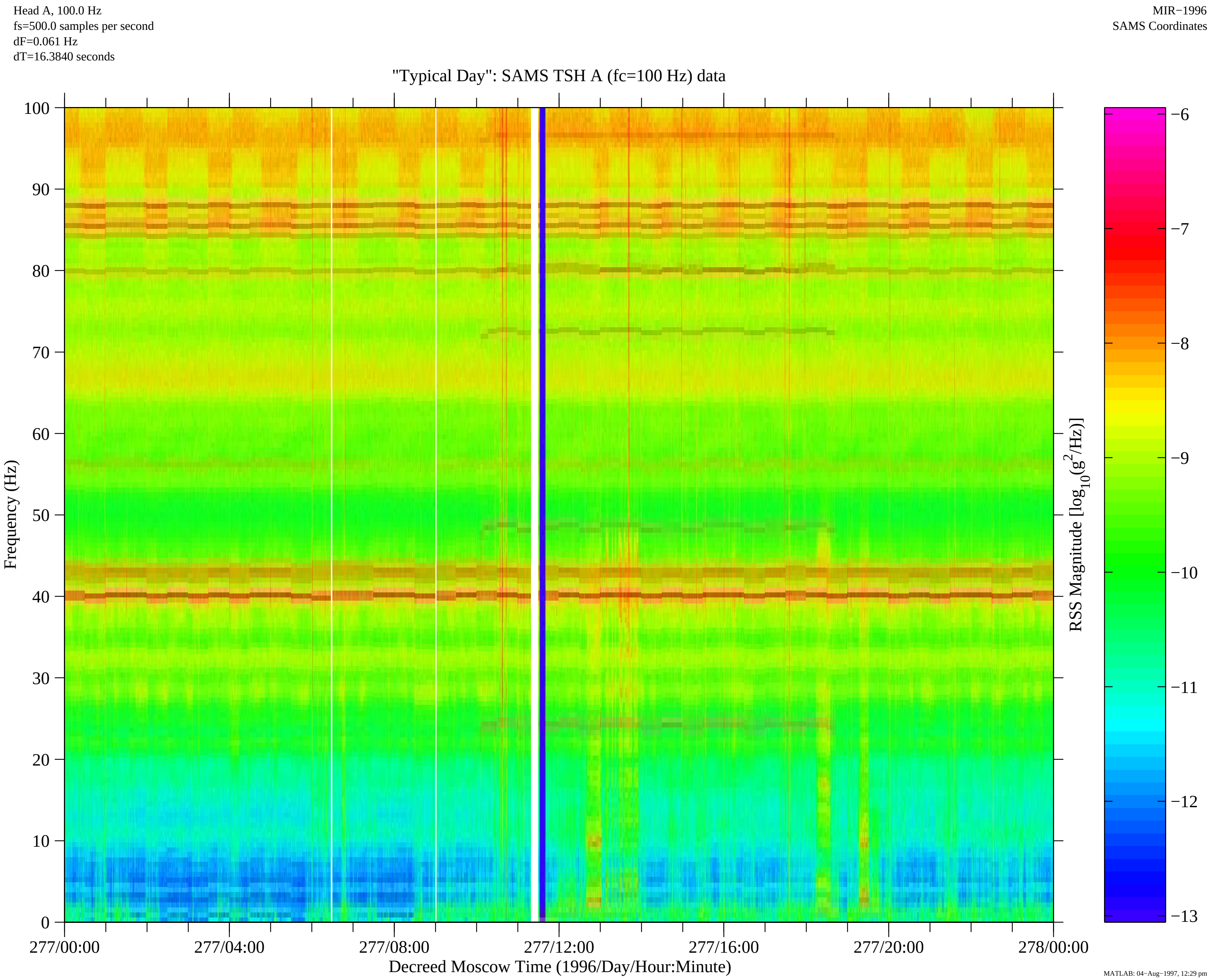

Figure 2. SAMS TSH A Color Spectrogram of 24 Hour Period (277/00:00 - 278/00:00).