

1. PREAMBLE FOR GROWTH OF TERNARY COMPOUND SEMICONDUCTORS (GTCS) TEAM

This document was originally drafted for a look at a debris avoidance maneuver on GMT 2021-11-10, however, it also contains information regarding thruster firings from a perspective near the Material Science Research Rack (MSRR) location.

The section below with the heading “Russian Segment Thruster Firings” presents observations from 3 thruster firings that took place during a span when the Russian Segment (RS) was in control of space station attitude leading up to what was effectively a reboost event. We considered only up to 6 Hz in the vibratory regime as this is where the thruster firing impact is most distinct (and not swamped or overwhelmed by higher-frequency vibrations). We see that below 6 Hz, the peak-to-peak impact (per-axis) was just about 0.2 mg.

2. INTRODUCTION

At GMT 2021-11-10, 314/20:15, the International Space Station (ISS) began a ~six-minute Pre-determined Debris Avoidance Maneuver (PDAM) using Progress 79P aft-pointing thrusters. The purpose of the PDAM was two-fold: (1) to avoid debris, and (2) for setting up phasing requirements for downstream events, previously established by a scheduled reboost on November 16th. The graphic of Figure 1 shows the location and alignment of the Progress 79P, and the cyan-colored annotations show nominal flight attitude. To prepare for this event, the space station was maneuvered to a reboost attitude from GMT 19:54 to 19:59, and then back to nominal Local Vertical Local Horizontal (LVLH) again from GMT 20:21 to 20:26. Predictions were for a desired ΔV of about 0.7 meters/second with a goal to boost the space station’s altitude by about 1.2 km – *as the gigantic space station sidesteps a tiny, fast-moving, destructive chunk of space debris.*

3. QUALIFY

The information shown in Figure 2 on page 4 was calculated from SAMS sensor 121f04 measurements made in the US Laboratory on the Cold Atom Lab facility. This plot shows structural vibration excitation between about GMT 19:15 and 20:40, which roughly lines up with what we know from the as-flown timeline as the Russian Segment (RS) controlling attitude using thrusters between GMT 19:05 and 20:50 – see white, double-arrow annotation, so we can attribute some of this structural excitation/vibration to RS attitude control. These increased structural

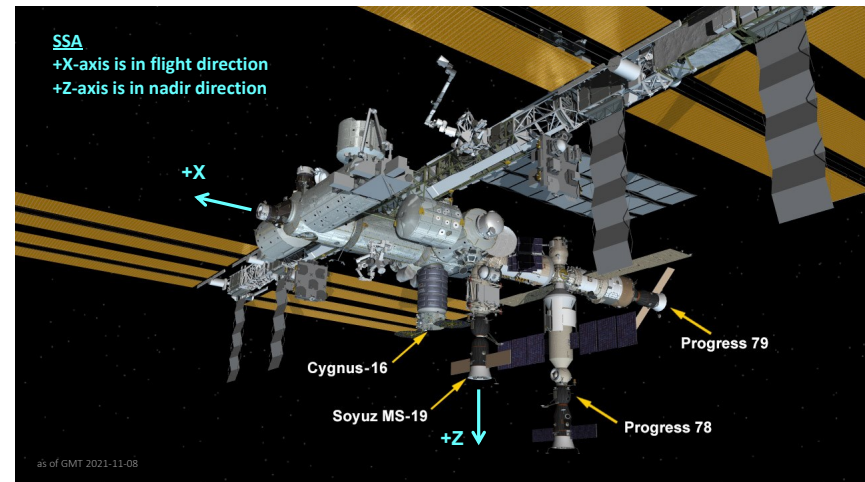


Fig. 1: Progress 79P’s location and alignment during PDAM.

vibrations are evident as more noticeable horizontal streaks (structural/spectral peaks) that change from quieter (green/yellow) to more energetic (orange/red) during this period of RS attitude control lasting more than 1.5 hours (and marked with red arrow and text at 0.4 Hz) while the actual reboost segment of the activity lasted only about 6 minutes, and is shown within the span indicated by the REBOOST text annotation on Figure 2. For science operations and general situational awareness, it is prudent to be aware that the transient and vibratory environment (primarily below about 10 Hz or so) is impacted not only during the relatively brief reboost part of this PDAM, but also during the span of Russian Segment attitude control.

Crew Exercise on BD-2 Treadmill

As pointed out by Kristin Fitzpatrick from the Loads and Dynamics team in Houston, TX, another notable disturbance seen in Figure 2 is that associated with crew exercise on the Russian *Begushaya Dorozhka* (BD-2) treadmill located in Zvezda Service Module. The Russian term *Begushaya Dorozhka* would literally be translated as the "Running Path", but here it is a term for the treadmill. The BD-2 has its own vibration isolation system and a built-in control system along with a

fixation system to counteract reaction forces, which might otherwise push on the crew member, causing them to "fly away". Vibrations from the BD-2 exercise from about GMT 18:52 to roughly 19:15 proved to be relatively strong, and a profoundly broadband disturbance below about 5 Hz as indicated by the black double-arrow and black text in the figure.

4. QUANTIFY

The as-flown timeline for this event indicated the reboost would start at GMT 20:15 and have a duration of just over 6 minutes. Analysis of Space Acceleration Measurement System (SAMS) data recordings shows the tell-tale X-axis step that nearly matches the start time and the duration as seen in Figure 4. Calculations show a ΔV of about 0.73 meters/second, which was intended.

Table 1. X-axis step (mg) during reboost event for 6 SAMS sensors.

Sensor	X-Axis	Location
121f03	0.206	LAB1O1 (ER2)
es18	0.207	LAB1O4 (ER6)
121f04	0.205	LAB1P2 (ER7)
121f05	0.205	JPM1F1 (ER5)
121f02	0.207	COL1A1 (ER3)
121f08	0.206	COL1A3 (EPM)

Five more plots of 20-second interval average acceleration versus time for SAMS sensors distributed throughout the ISS are shown at the end of this document, starting with Figure 5 on page 6. The interval average processing effectively low-pass filtered the data so as to help emphasize the acceleration step that occurs on the X-axis during the reboost (step) event. It should also be noted that we flipped the polarity (inverted) of each axis in the SAMS plots owing to a polarity inversion issue inherent in SAMS transducers. A somewhat crude quantification of the reboost as measured by the 6 distributed SAMS sensors is given in Table 1.

Root-Mean-Square Comparison: Crew Exercise on BD-2 Treadmill vs. Reboost

The time frame around the PDAM's reboost presented a good opportunity to compare the impact of a reboost to that of crew exercise on the BD-2 treadmill.

Figure 10 on page 9 gives us that comparison in the form of a 20-second interval root-mean-square acceleration (RMS) versus time for the SAMS sensor (121f04) mounted on the Cold Atom Lab. The pinkish shading is a backdrop for the span of time a crew member was on the BD-2 treadmill exercising and we see the RMS levels raised well above baseline and approaching that of the reboost, where the start of reboost is marked by the vertical, blue dashed line. Just how much those compare and stack up is shown in Table 2, which breaks out the per-axis and total RMS values for comparing BD-2 Exercise period to the Reboost period in terms of root-mean-square acceleration levels below 6 Hz.

micro-g RMS (below 6 Hz)				
During	X	Y	Z	RSS
BD-2 Exercise	114.8	78.0	42.5	146.2
Reboost	234.3	53.5	50.2	249.5

Table 2. Sensor SE-F04 RMS Acceleration Levels Below 6 Hz.

Russian Segment Thruster Firings

The time frame around the PDAM's reboost also presented a good opportunity to take a close look at the impact of Russian Segment (RS) thruster firings as those were registered near the Material Science Research Rack (MSRR) as measured by the SAMS sensor located nearby. It was imperative to low-pass filter the data below 6 Hz, otherwise higher-frequency vibrations (up to the sensor cut-off of 200 Hz) would overwhelm and obscure the distinction of those impulsive, thruster-firing-induced vibrations. Figure 14 on page 11 shows the low-pass filtered, per-axis acceleration data for the same 4-hour time span as the spectrogram of Figure 3 on page 5. Note the thin blue band from GMT 19:41 to 19:43. There were 3 thruster firings in this span that we zoom into in Figure 15 on page 11. The largest magnitude and structural response came on the Z-axis with 3 blue arrows pointing out the times of the 3 firings. Note that different frequencies ring out on each of the 3 axes as the structural dynamics of the space stations dictate. In all 3 axes' cases, we observed peak-to-peak acceleration values below 6 Hz of around 0.2 mg.

5. CONCLUSION

While SAMS sensors were designed to characterize the vibratory environment of the ISS, and not so much the quasi-steady environment, they perform well for capturing the relatively large X-axis step induced by a reboost used for this debris avoidance maneuver. Despite the underlying low-frequency & low-magnitude baseline being obscured by transducer bias/offset, SAMS sensors easily detect the gross acceleration step of reboost as demonstrated here. The SAMS sensor data analyzed showed an X-axis step during the Service Module reboost of about 0.2 mg. Furthermore, calculations based on SAMS sensor (121f03) mounted on EXPRESS Rack 2 in the US LAB indicate a ΔV of about 0.73 meters/second was achieved. This value matched the planned value of $\Delta V = 0.7$ meters/second. Not a calculation based on SAMS measurements, but flight controllers in Houston reported an increase in altitude of about 1.2 km of the space station.

Furthermore, we had a good opportunity to compare crew member exercise on the BD-2 treadmill to the reboost in the form of RMS acceleration levels measured by SAMS on the Cold Atom Lab and we saw that exercise vibrations (primarily in the XY-plane) approach that of a reboost, which is concentrated mainly on the X-axis.

Finally, we also zoomed in on 3 thruster firings from the Russian segment that were used for attitude control around the time of the PDAM and looking at measurements filtered below 6 Hz from the SAMS sensor on the MSRR. Those showed peak-to-peak values (all 3 axes) of about 0.2 mg.

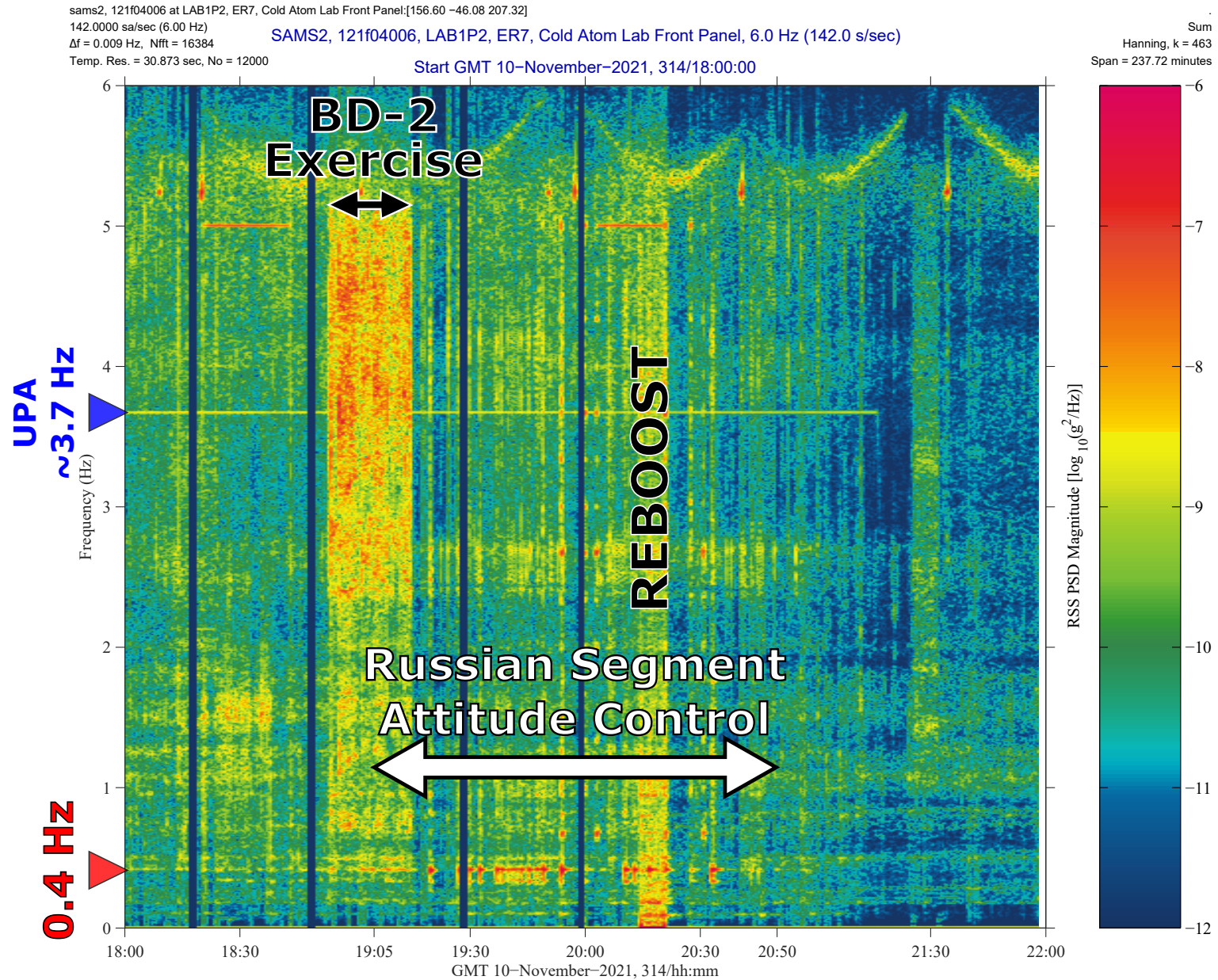


Fig. 2: Spectrogram showing PDAM/Reboost on GMT 2021-11-10 for Cold Atom Lab sensor.

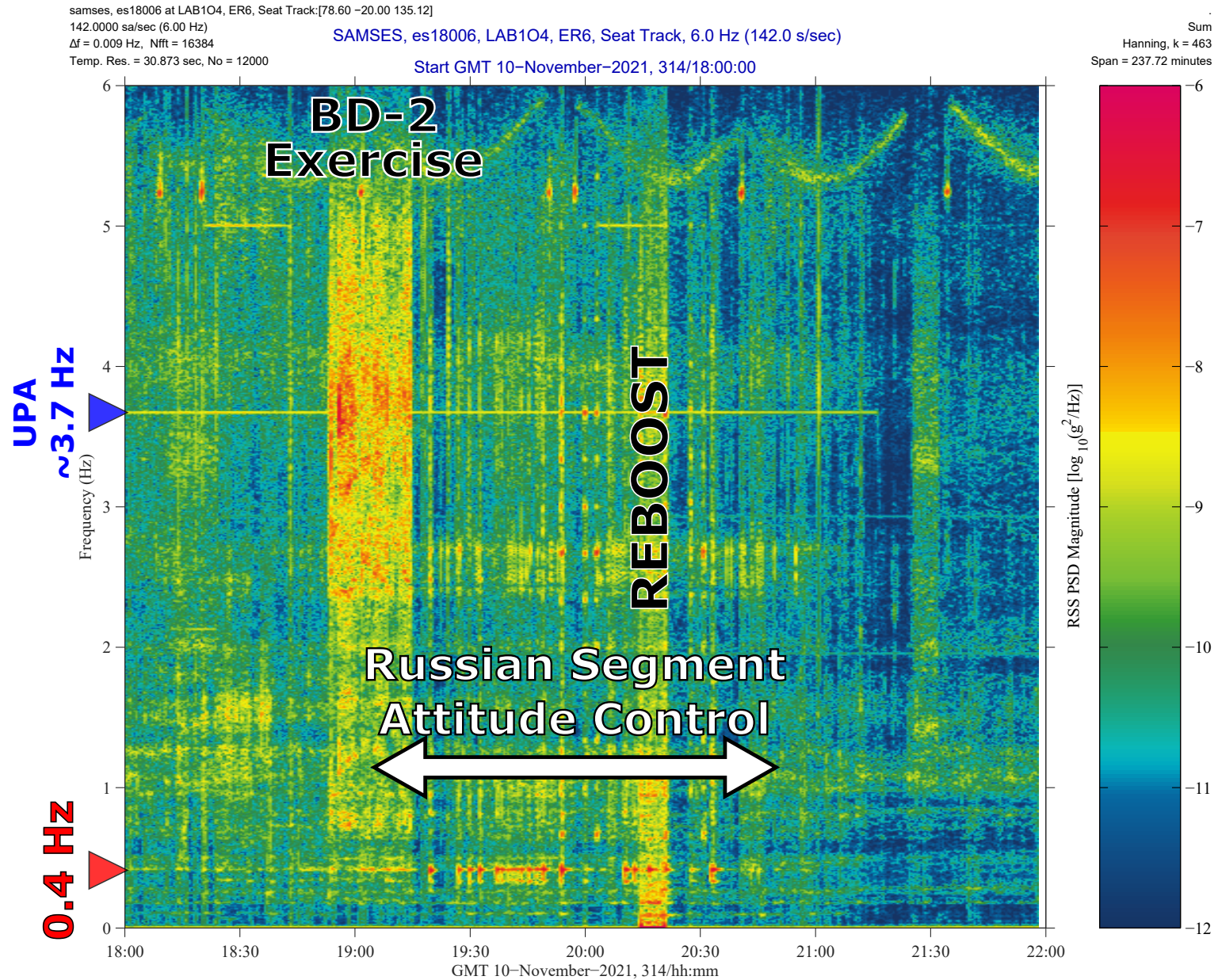


Fig. 3: Spectrogram showing PDAM/Reboost on GMT 2021-11-10 for Material Science sensor.

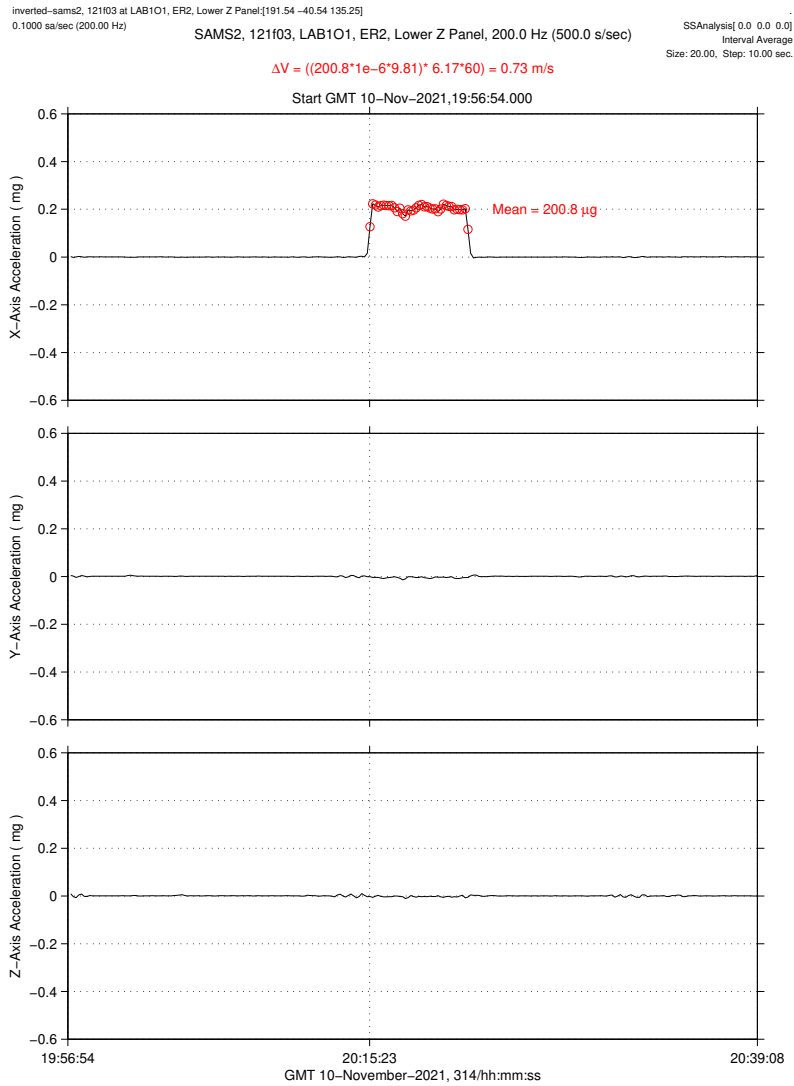


Fig. 4: 20-sec interval average for SAMS 121f03 sensor in the LAB.

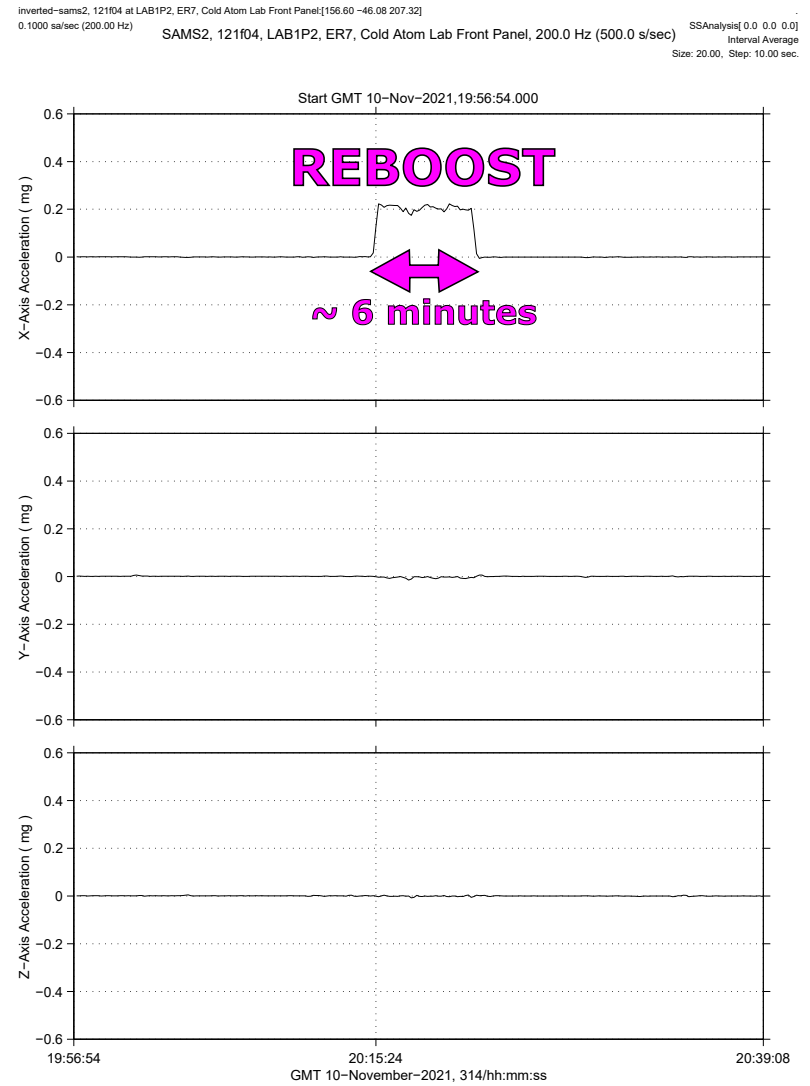


Fig. 5: 20-sec interval average for SAMS 121f04 sensor in the LAB.

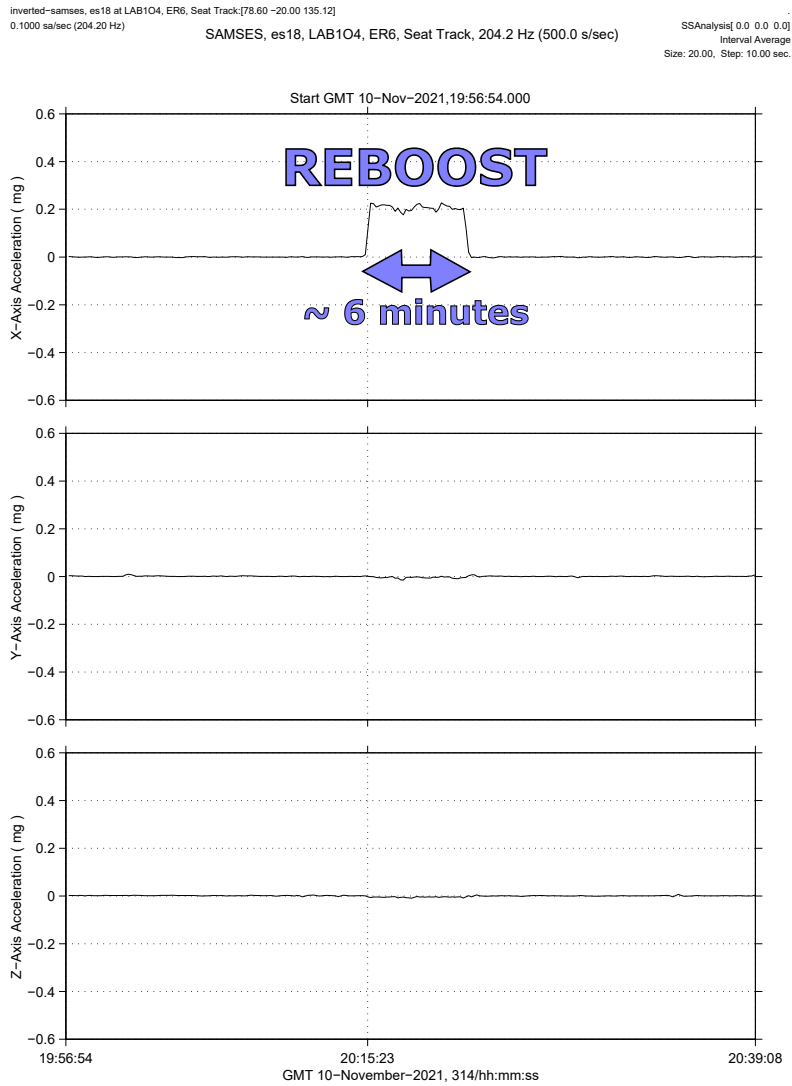


Fig. 6: 20-sec interval average for SAMS es18 sensor in the LAB.

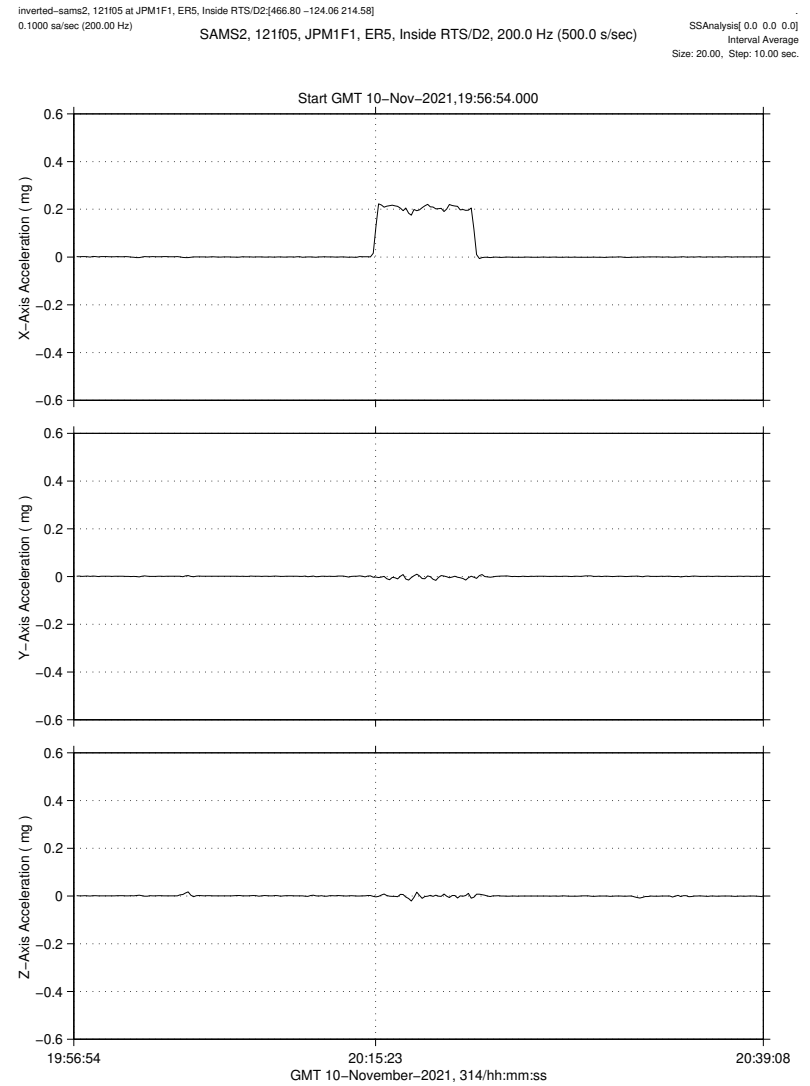


Fig. 7: 20-sec interval average for SAMS 121f05 sensor in the JEM.

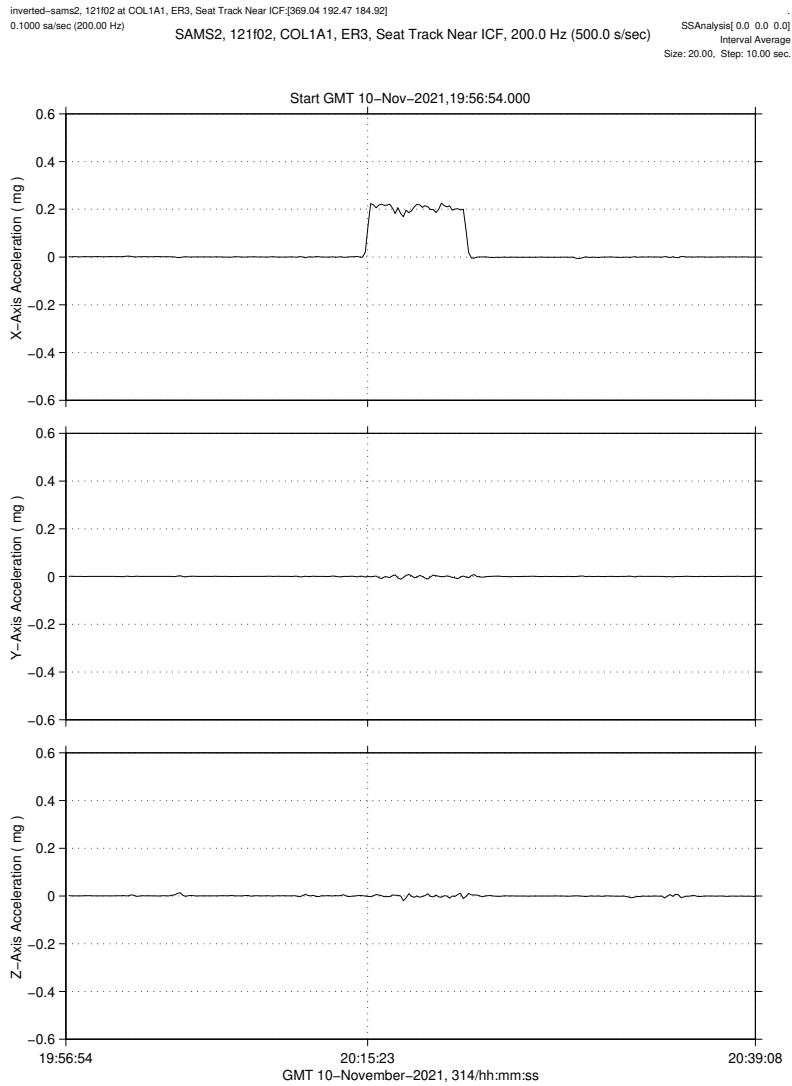


Fig. 8: 20-sec interval average for SAMS 121f02 sensor in the COL.

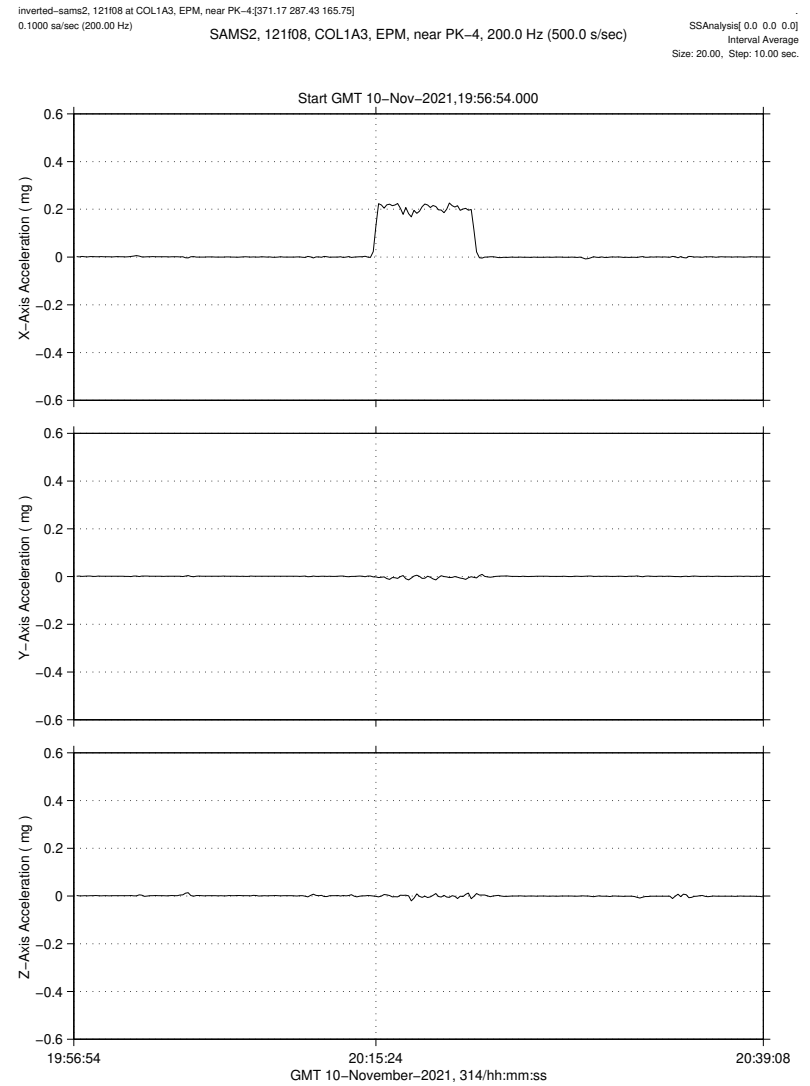


Fig. 9: 20-sec interval average for SAMS 121f08 sensor in the COL.

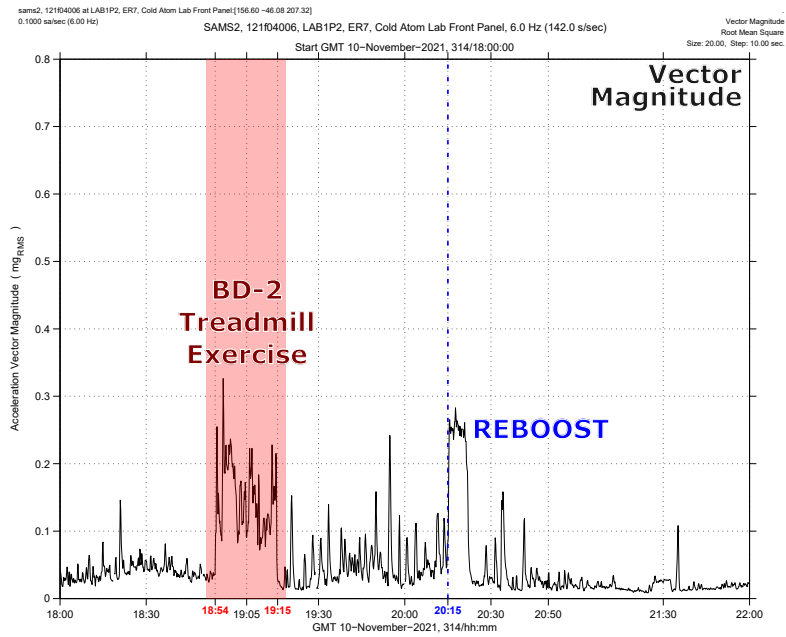


Fig. 10: 20-sec Interval RMS Accel., SAMS 121f04, Cold Atom Lab

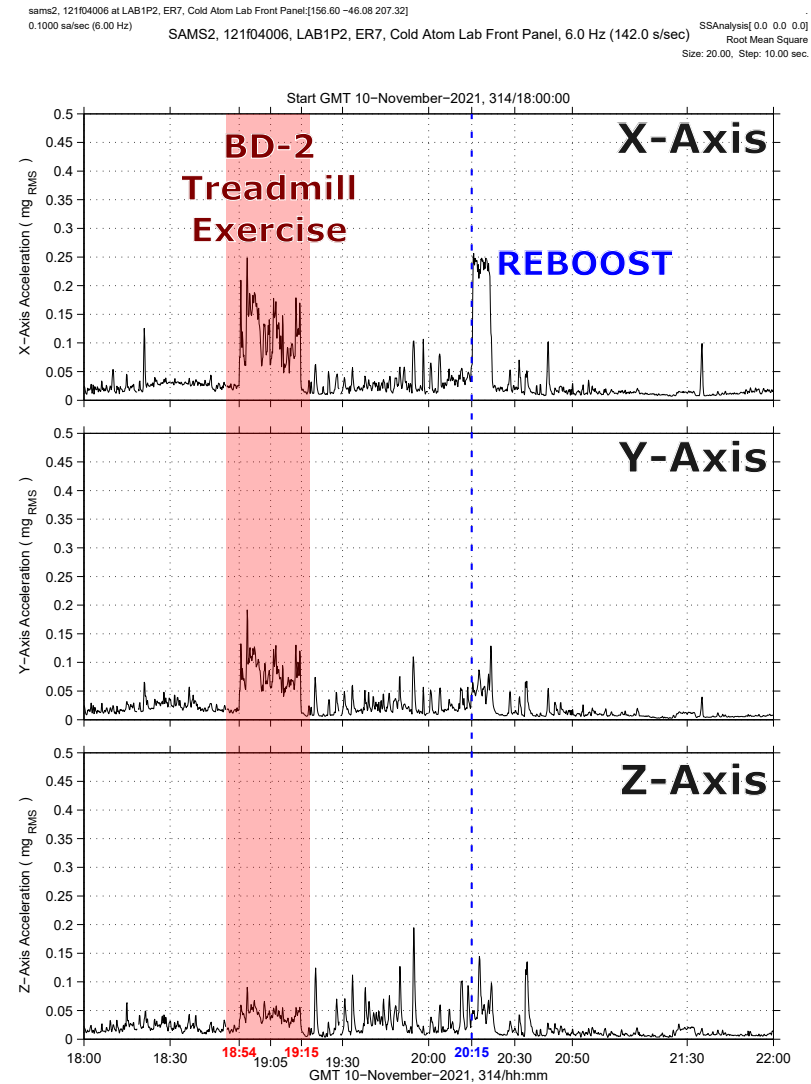


Fig. 11: Per-Axis 20-sec Interval RMS Accel., SAMS 121f04, Cold Atom Lab

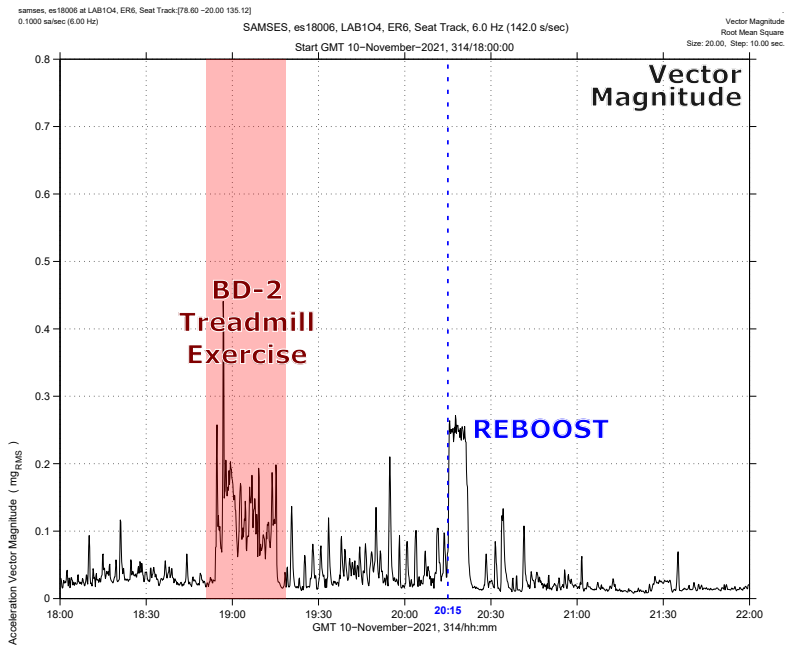


Fig. 12: 20-sec Interval RMS Accel., SAMS es18, Material Science

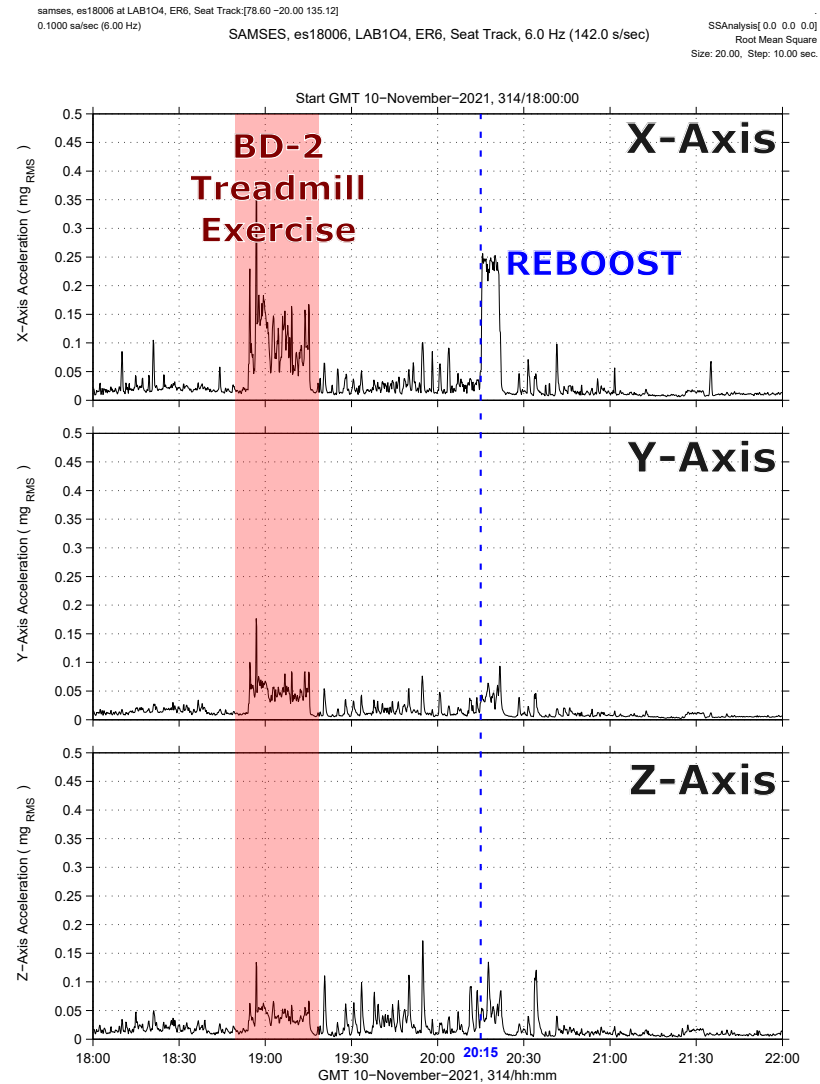


Fig. 13: Per-Axis 20-sec Interval RMS Accel., SAMS es18, Material Science

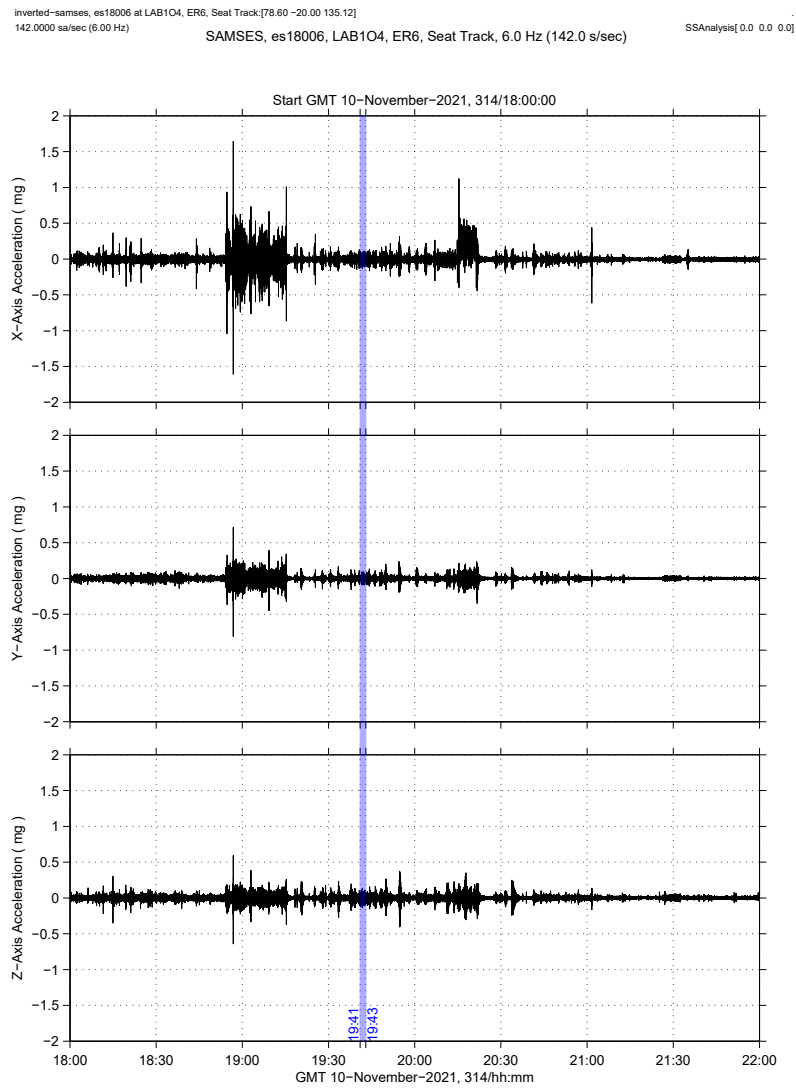


Fig. 14: Acceleration Below 6 Hz for SAMS es18 sensor on MSRR.

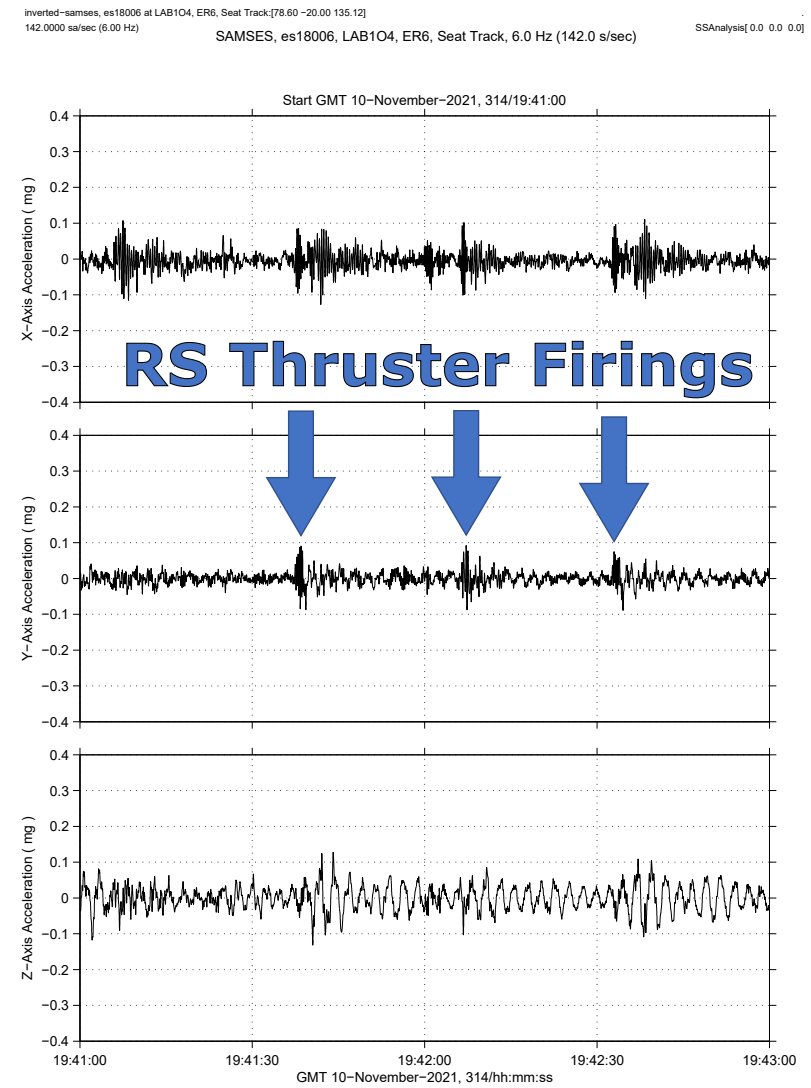


Fig. 15: Acceleration Below 6 Hz (Zoom-In) for SAMS es18 sensor on MSRR.