1. INTRODUCTION

The International Space Station (ISS) is a large, distributed structure as shown in Figure 1 (docked visiting vehicles not shown), where the main truss is nearly the length of an American football field. Flight Controllers monitor the structure for unusual rates, which are defined as vehicle rotational rates exceeding 5 mdeg/s for five or more oscillations with a period between 2 and 10 seconds. If these criteria are met, then a log entry is created, and the crew is polled with questions regarding activities at the time. In this case, the crew replied that crew exercise activity was occurring at the time, however, it was deemed not likely a factor in the unusual rates. There was a concurrent crew translation maneuver in the Russian Functional Cargo Block (FGB) and the crew had high confidence this was the stimulus for the unusual rates that they will avoid in the future. Referring back to Figure 1 on page 3, with the center-of-mass below the main truss and the stimulus (crew translation) aftward in the FGB, it's natural that the "see-saw" response would primarily be aligned with this translation maneuver by the crew and in the forward portion of the ISS, e.g. the Columbus module and the Japanese Experiment module (JEM).

2. QUALIFY

Figure 2 on page 4 shows spectral calculation results from measurements made by the Space Acceleration Measurement System (SAMS) sensor head (S/N 121f08) in the Columbus module (in rack COL1A3) for an 8-hour span centered on the time of the unusual rate signature detected at about GMT 2024-09-03/19:16:38. Note the excitation (red, horizontal streak) at just under 0.2 Hz and lasting a few minutes. On a plot of this type, it may not be obvious that this is an event of concern. We leave quantifying this for later in this document.

Similar to the event noted in the previous figure, we see other perspectives from three other SAMS sensor heads:

1) Figure 3 on page 5 from a SAMS sensor head in the LAB (LAB1P2).
2) Figure 4 on page 6 from a SAMS sensor head in the LAB (LAB1O1).
3) Figure 5 on page 7 from a SAMS sensor head in the JEM (JPM1F1).

In Figure 5 for the JEM sensor head, the curved brackets show that the structural mode near 0.2 Hz was excited in this location longer and more notably than the other sensor heads. In these long-duration (context) spectrograms, we can clearly see this frequency corresponds to a global structural mode that tends to be excited with crew activity, when there is enough vigor and at such a rate as to excite a large structure's natural frequency.

3. QUANTIFY

The 4 acceleration power spectral density (PSD) figures on the plots of Figure 6 and Figure 7 serve to compare the impact of this unusual rate signature event, but only crudely quantified as PSD units are generally not intuitive.

Per-Axis Comparison of Unusual Rate Signatures

These figures show per-axis acceleration PSD plots for 4 SAMS sensor heads during the unusual rate. From these 4 figures, we note that the 2 sensor heads outside of the US LAB registered the higher PSD magnitudes at 0.19 Hz, while the 2 sensor heads in the LAB showed notably weaker response. **These clearly suggest Z-axis direction for primary alignment of the crew translation maneuver and to a lesser extent on the X-axis resulting in the unusual rate signature event on GMT 2024-09-03.**

Parseval's Theorem and RMS Acceleration

The power spectral density (PSD) plots showed us how vibrational energy is distributed across a key portion of the acceleration spectrum relevant to vehicle structural modes, specifically for large structures with vibrational frequencies below 3 Hz. We looked at those on a per-axis (XYZ) basis. By computing the root-sum-of-squares (RSS) of the per-axis PSDs, we can determine the total acceleration PSD, independent of direction. Now, to better quantify the impact of the crew translation maneuver that caused the unusual rate event, we convert these results into more intuitive units — *RMS acceleration (mg)* — instead of PSD units (g^2/Hz). To achieve these results, we apply *Parseval's Theorem*, which enables us to convert the spectral energy distribution (PSD) into RMS acceleration.

Think of the PSD as a representation of how vibrational energy is distributed across different frequencies within the acceleration spectrum. By applying Parseval's Theorem, we can sum the energy across all frequencies and express it as total acceleration — much like combining the intensities of different spatial frequencies (wavelengths) of light to determine the overall brightness.

In our case here, we are focused on the frequency band between 0.14 Hz and 0.5 Hz in order to bound and include the main structural resonance at 0.19 Hz and its second harmonic at 0.38 Hz. By integrating the area under the PSD curve over this frequency range, we can quantify the root-mean-square (RMS) acceleration — *a measure of the intensity of the vibrations* — due primarily to those 2 notable spectral components. Figure 8 on page 10 depicts this concept.

Our results, expressed as RMS acceleration, provide a clear metric that quantifies the intensity of the vibrations during the event. The gray-shaded area in Figure 8 highlights the portion of the PSD curve contributing to the unusual rate signature, allowing us to isolate the crew's activity in a straightforward and measurable way. By repeating this analysis across multiple time segments, we gain insight into how RMS acceleration varies over time within a narrow frequency band, as illustrated in the subsequent figures.

Figure 9 on page 11 and Figure 10 on page 12 present the results of our total RMS acceleration calculations, focused on a narrow frequency band between 0.14 Hz and 0.5 Hz. These four figures correspond to data from four SAMS sensor heads at various locations (see figure captions), covering an 8-hour period centered on the unusual rate event detected on GMT 2024-09-03. From these figures, we observe that the two sensor heads in the US LAB detected structural resonance just above the ambient background excitation in this frequency range, while the sensors in the JEM and Columbus module recorded these structural vibrations with more excitation on the XZ-plane, and significantly more so along the Z-axis.

Uncovering Important Vibrations via Time Series Filtering

Although the spectrograms presented earlier clearly highlight the low-frequency excitation caused by this vibratory event, someone examining a plot of the raw data (up to 200 Hz) would not detect visually that such an event had occurred. For instance, the 200 Hz raw data (from the SAMS sensor, S/N 121f05, in the JEM), plotted on the left side of Figure 11 on page 13, shows no clear evidence of the event. However, when we apply a 6 Hz low-pass filter to the same data, as displayed on the right side of that page, we bring forth the evidence. Be sure to note the large difference in y-scales when comparing the two figures, the two 3-panel (XYZ) plots on this page – there is a difference of 100 fold.

Figure 12 on page 14 and Figure 13 on page 15 are corresponding plots as those on page 13, but now for a SAMS sensors, S/N 121f08 in COL and 121f03 in the US LAB. The y-scales have the same correspondence and we can see the structural response to the vibratory crew input excitation is nearly the same in COL and notably weaker when we compare the Z-axis of the 6 Hz low-pass filtered data in the US LAB.

Consider now the 6 Hz low-pass filtered and zoomed-in SAMS 121f05 (JEM) data shown in Figure 14 on page 16. The 2 vertical cursors were placed such that 30 cycles were counted between them and the time difference was 155.443 seconds.

This gives a better approximation of the resonant frequency response in the JEM to the crew stimulus in the FGB. The frequency was in fact closer to 0.193 Hz and the large structural vibrations lasted just about 7-minutes in the JEM. To be clear, we are not asserting that this total duration was the "structural ring-out" or purely response. In fact, a good portion of this time may have been taken by input stimulus at or about this oscillation frequency. The fact that the stimulus frequency hit near a structural resonance was a concern and probably led to sustaining the flexing and bending of large space station structure for longer than desirable.

4. CONCLUSION

This document presents a comprehensive analysis of an unusual rate event detected on the International Space Station (ISS) on GMT 2024-09-03. It is intended to present clear sections that guide the reader through the identification, qualification, and quantification of the event. We utilize mathematical and signal processing techniques — including detailed examination of power spectral densities (PSDs), root mean square (RMS) acceleration, and time series data — to provide the reader razor-sharp insight and quantitative assessment of the vibrational impact of this crew activity.

The analysis of the unusual rate event caused by the crew translation maneuver provided feedback into the vibrational dynamics of the aging space station. By quantifying the impact — specifically the 0.19 Hz fundamental frequency and its second harmonic at 0.38 Hz — and correlating these with the crew activity, we isolated and identified the structural resonance frequency components and their contributions to the overall vibratory response. The most pronounced directional response was observed along the Z-axis, with varying degrees of intensity at the four sensor locations across the ISS. Worst-case in our narrowband RMS acceleration analysis was registered in the JEM with RMS levels peaking at just under 0.2 mg during the event, nearly an order of magnitude above baseline levels around 0.02 mg.

This analysis highlights the importance of monitoring and evaluating crew activities with the intent of assessing the mechanical response and behavior of large ISS structures. The triggering of special monitoring and analysis related to this event demonstrates the need for continuous assessment of crew-related activities to ensure the operational stability and safety of the ISS as some crew activities can significantly amplify vibrations in the space station's structures, especially when the stimulus occurs at or near their natural frequencies, resulting in undesirable resonant structural vibrations. See also this document for more unusual rate signature events.
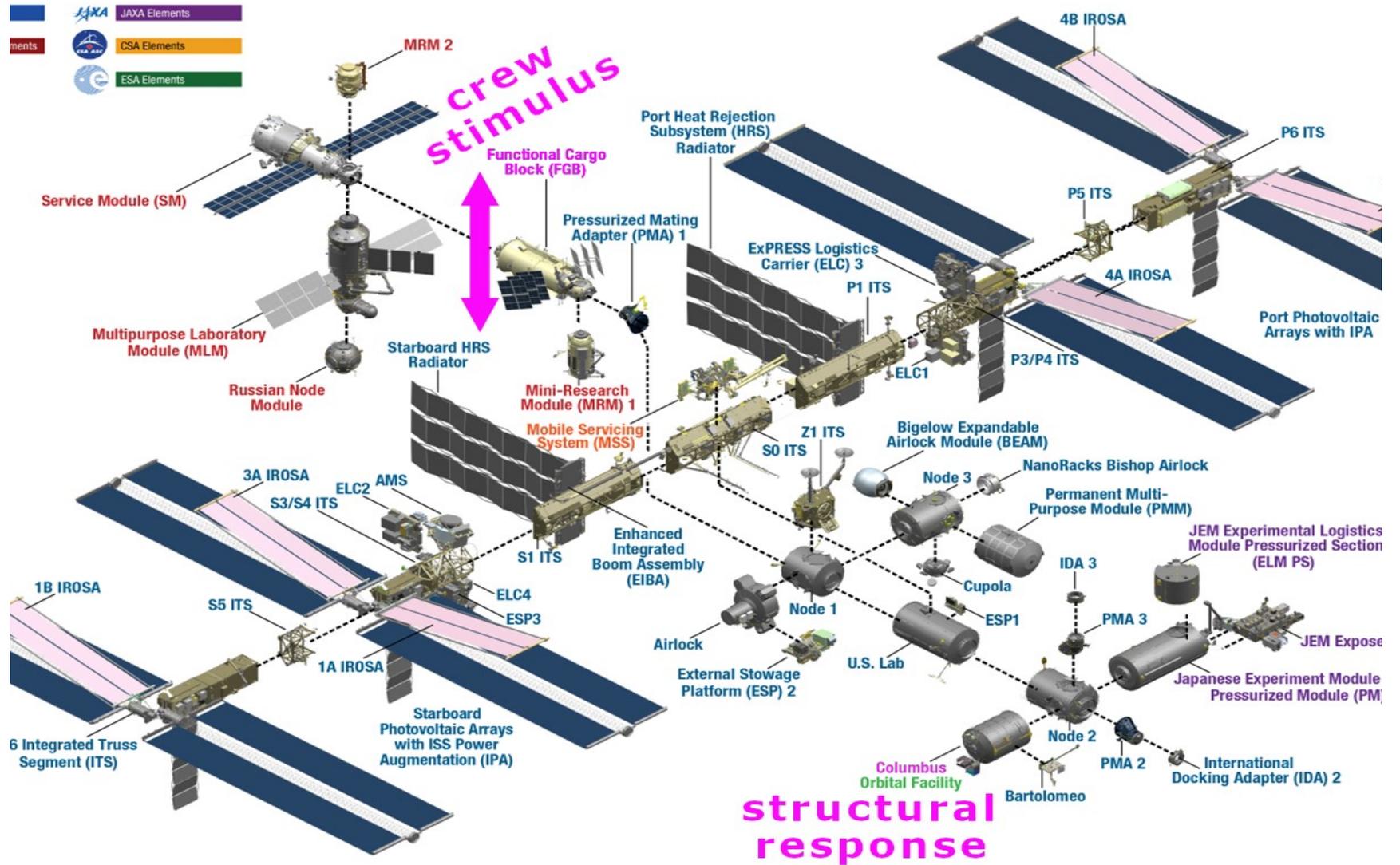
Fig. 1: Crude Depiction of Crew Stimulus Toward Aft of ISS and Structural Response at Forward End.
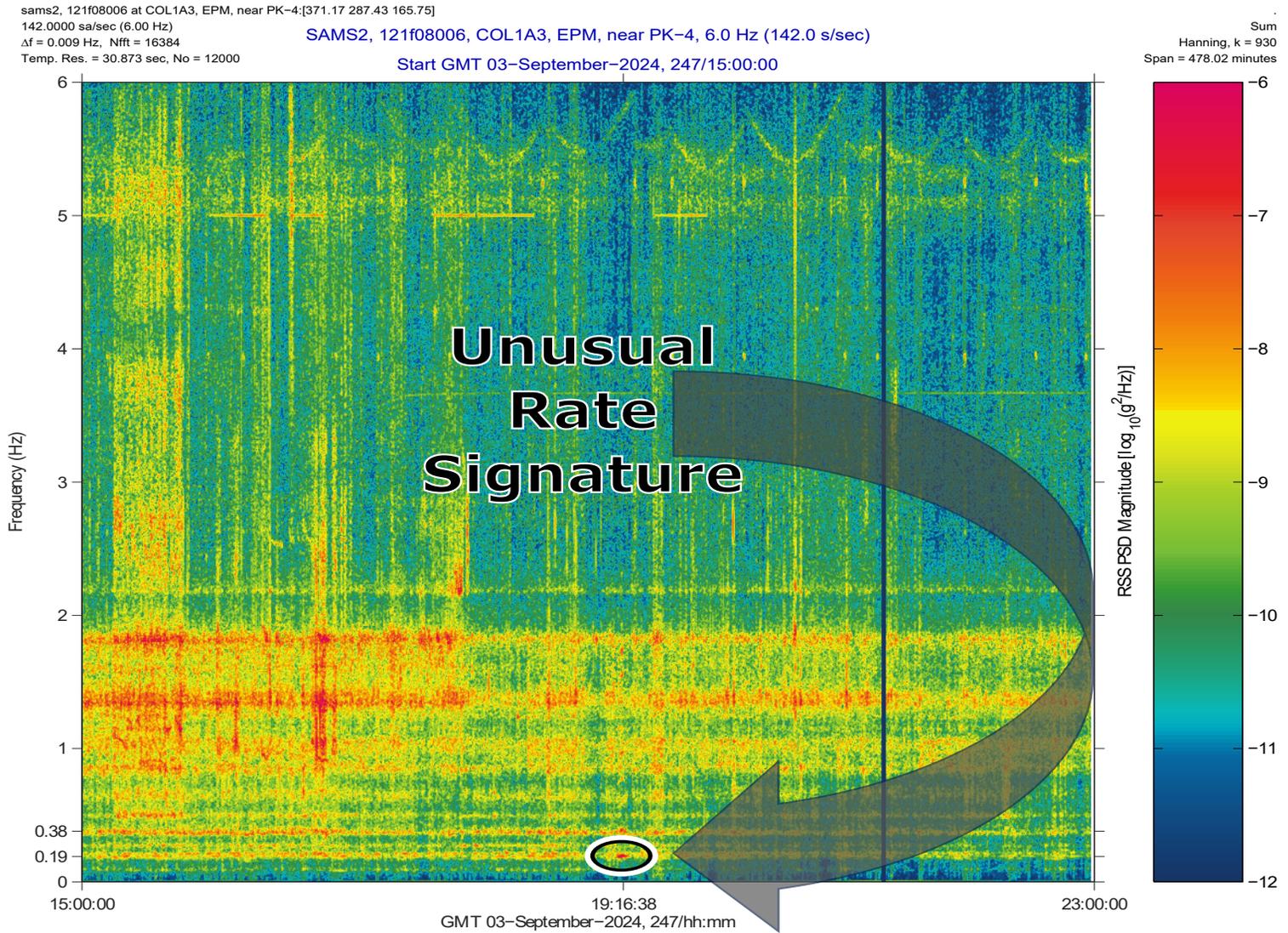
Fig. 2: 8-Hour Spectrogram, SAMS Sensor 121f08 (COL), Shows ~5-Minute Excitation Starts at ~GMT 2024-09-03/19:16:38.
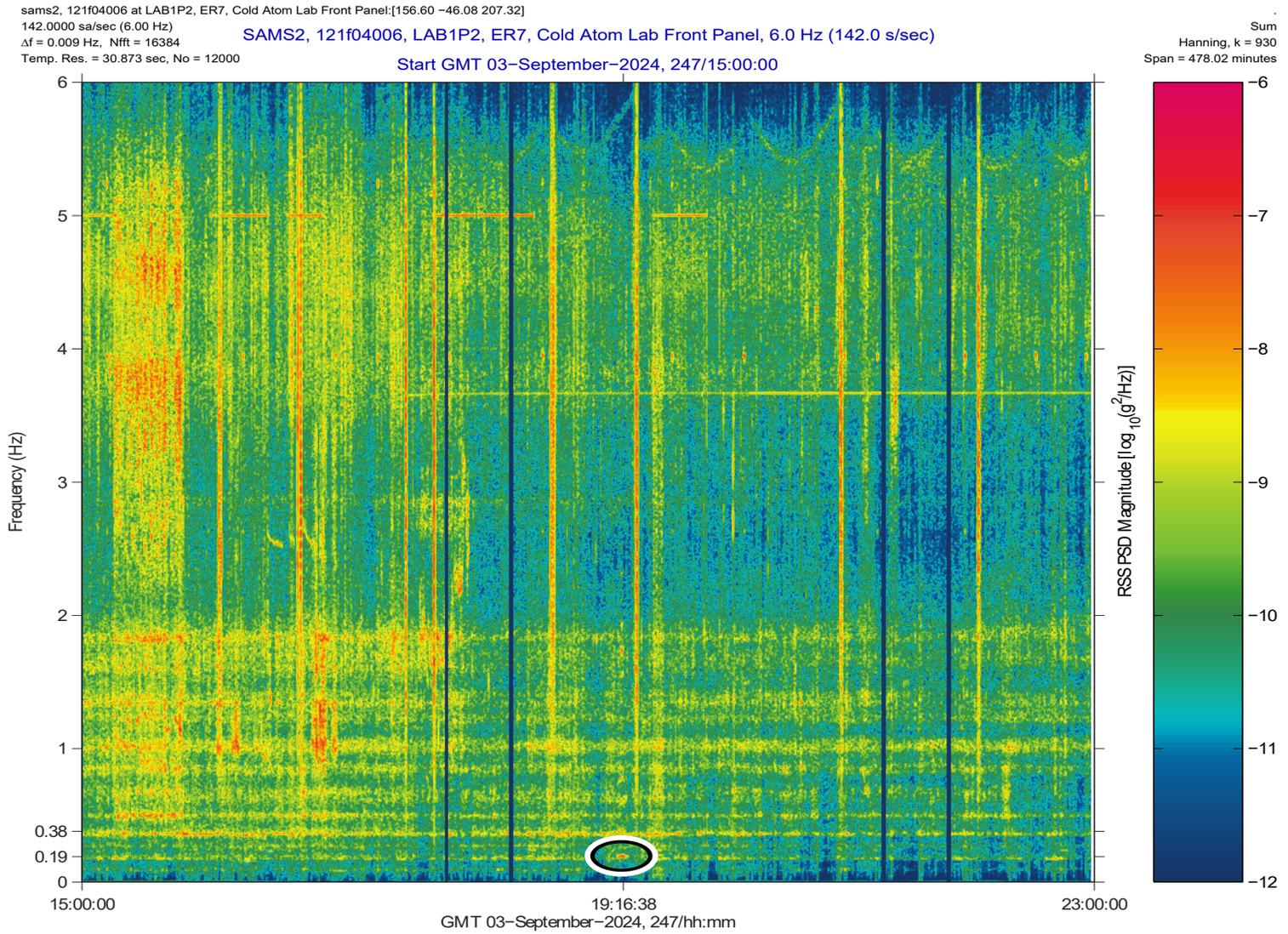
Fig. 3: 8-Hour Spectrogram, SAMS Sensor 121f04 (LAB), Shows ~5-Minute Excitation Starts at ~GMT 2024-09-03/19:16:38.
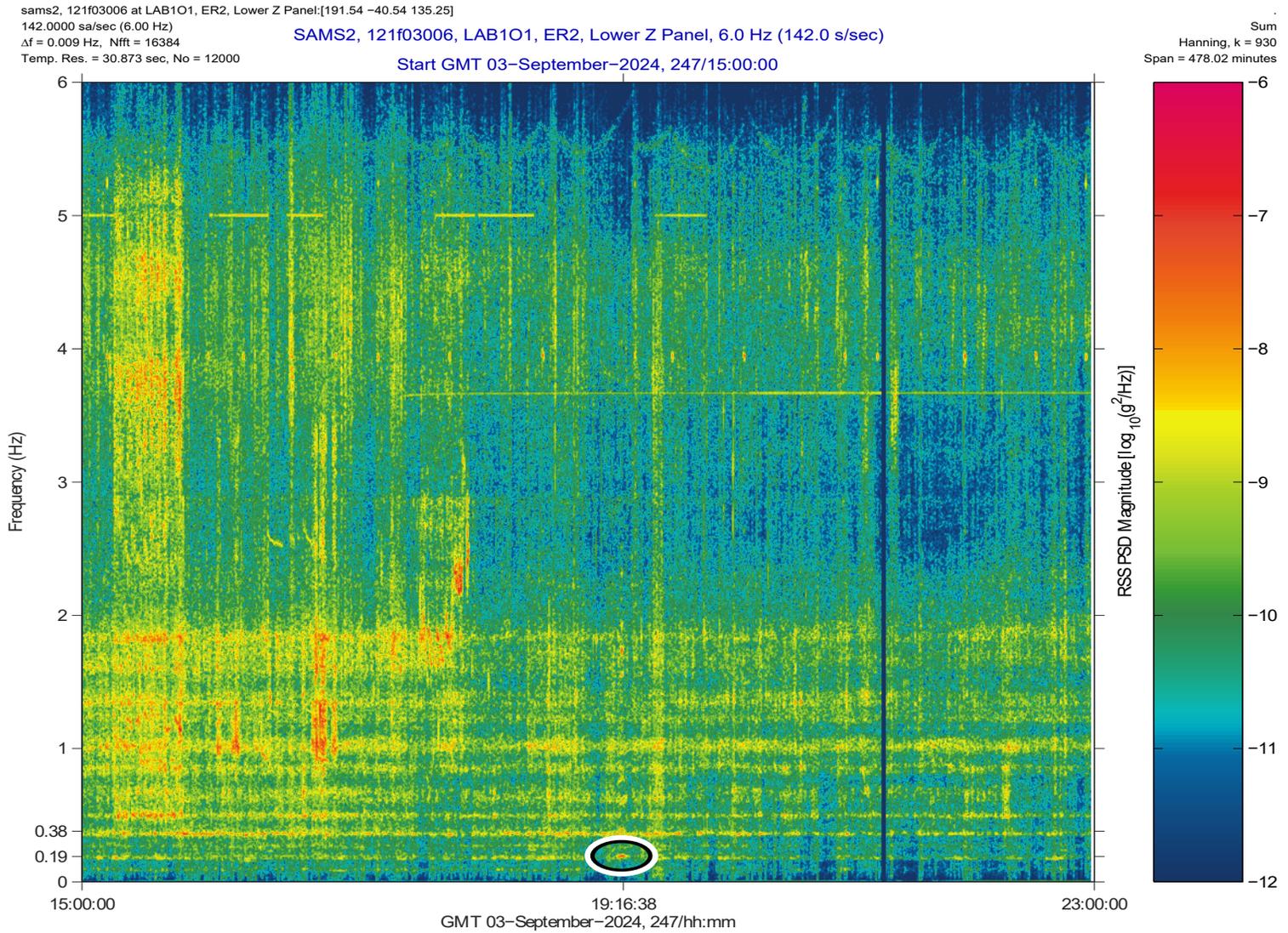
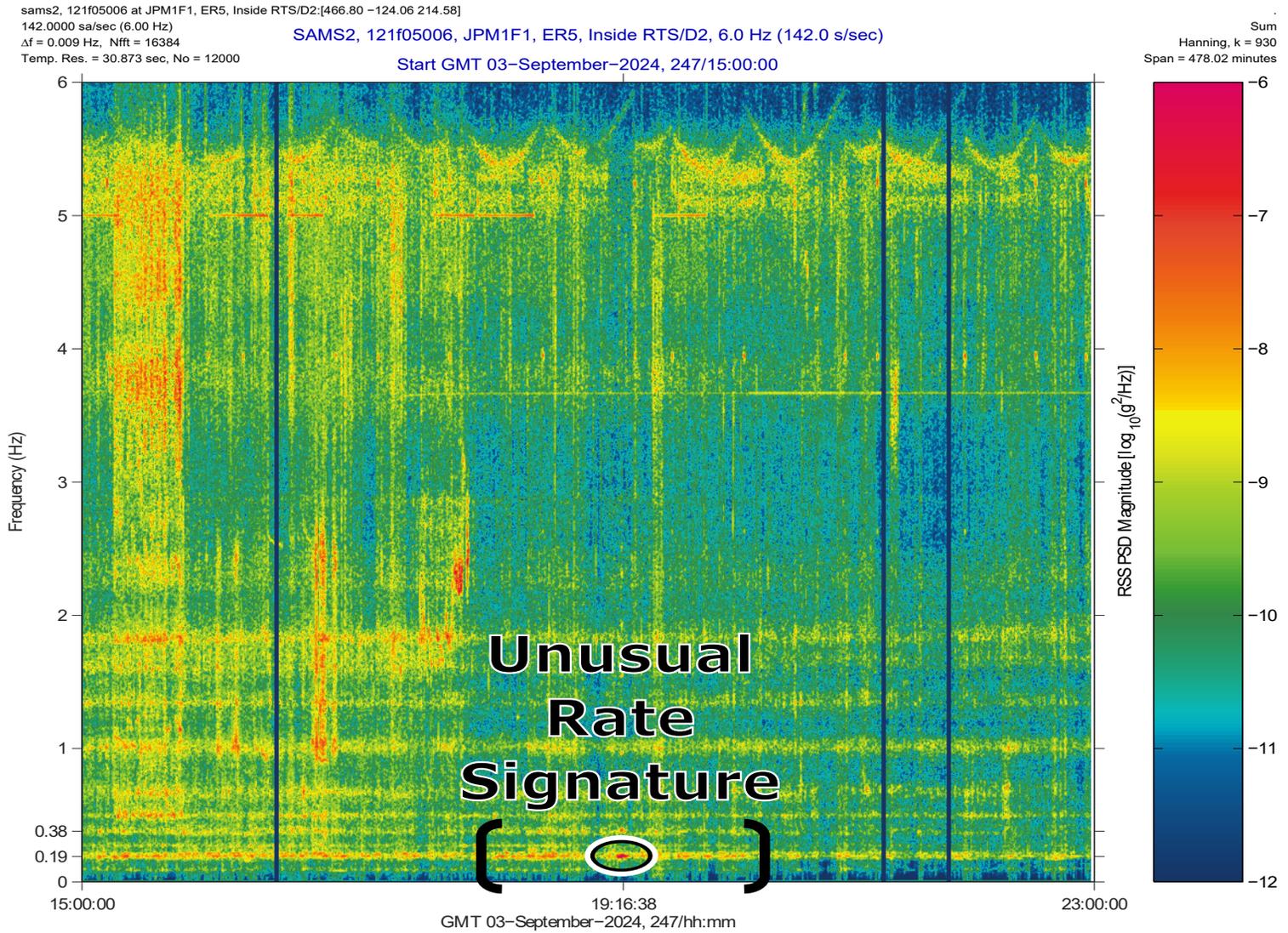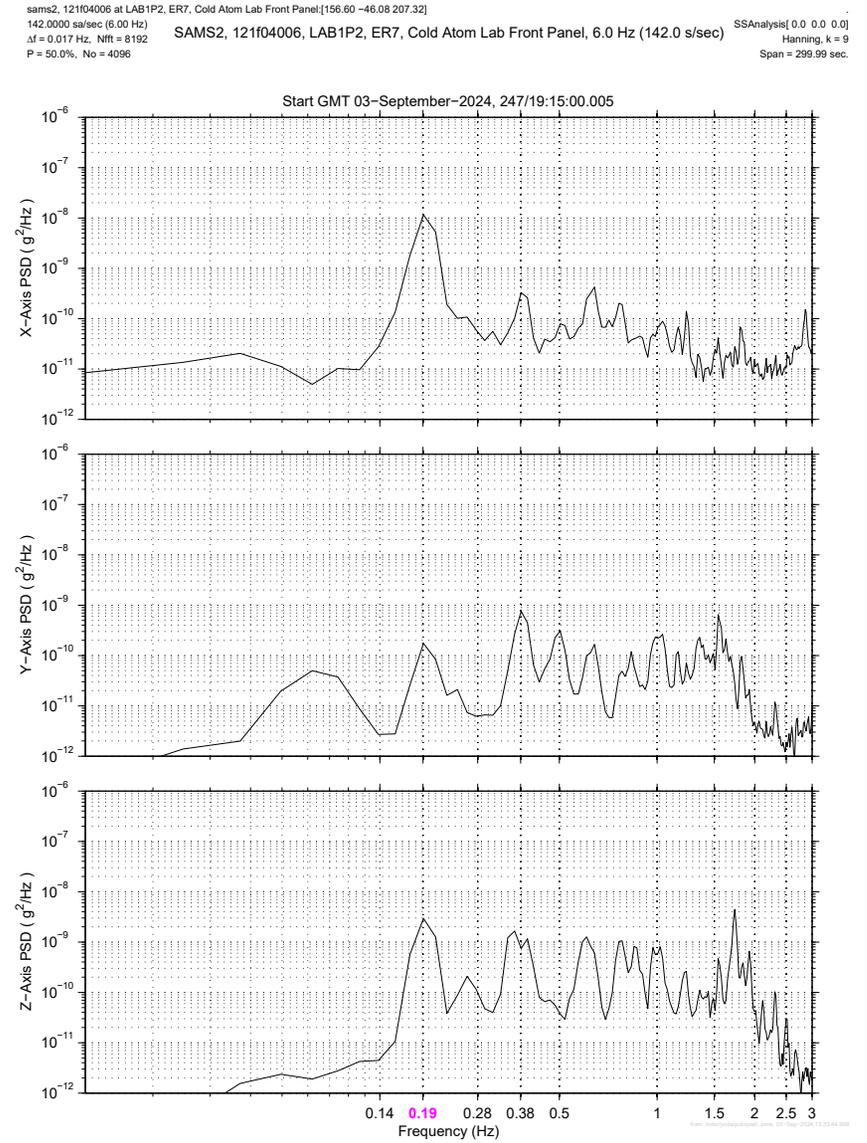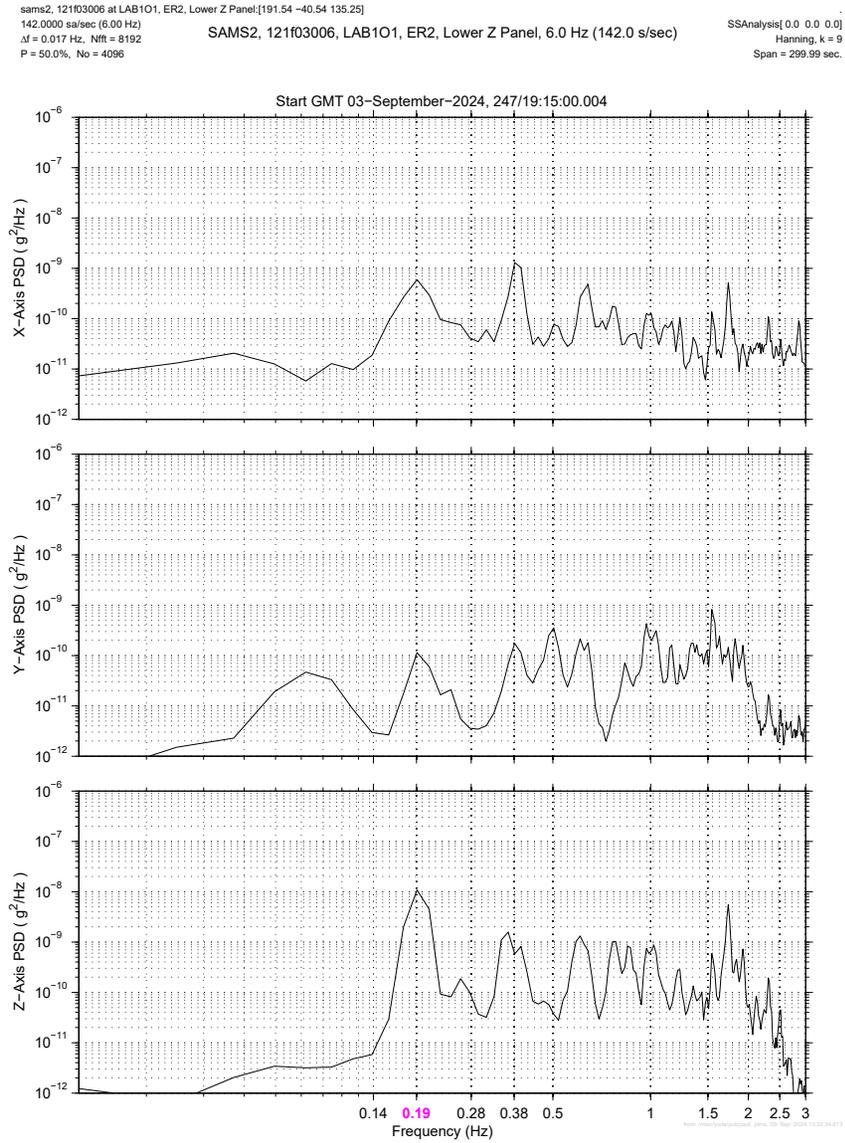Fig. 4: 8-Hour Spectrogram, SAMS Sensor 121f03 (LAB), Shows ~5-Minute Excitation Starts at ~GMT 2024-09-03/19:16:38.

Fig. 5: 8-Hour Spectrogram, SAMS Sensor 121f05 (JEM), Shows ~5-Minute Excitation Starts at ~GMT 2024-09-03/19:16:38.

Fig. 6: SAMS in LAB, Shows 5-Minute, Per-Axis PSDs Starting at GMT 2024-09-03/19:15: (left) **121f03 at LAB1O1**, (right) **121f04 at LAB1P2**.
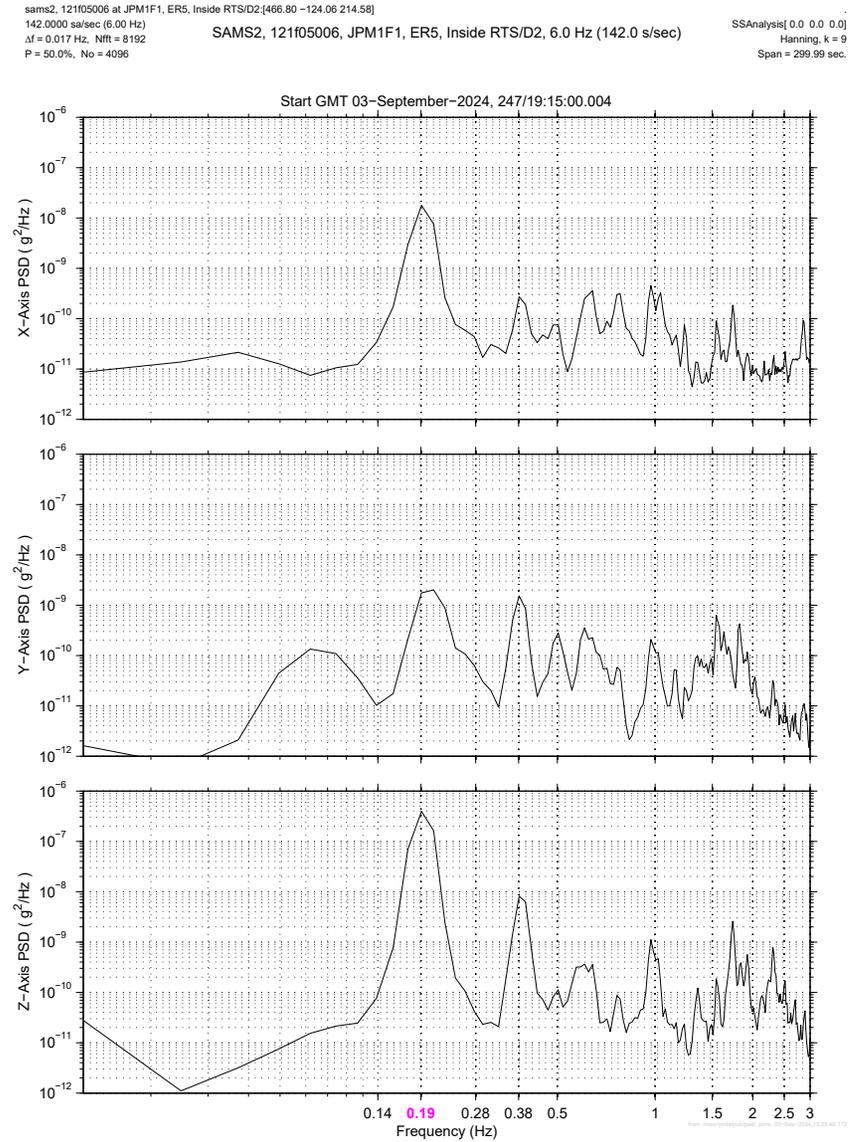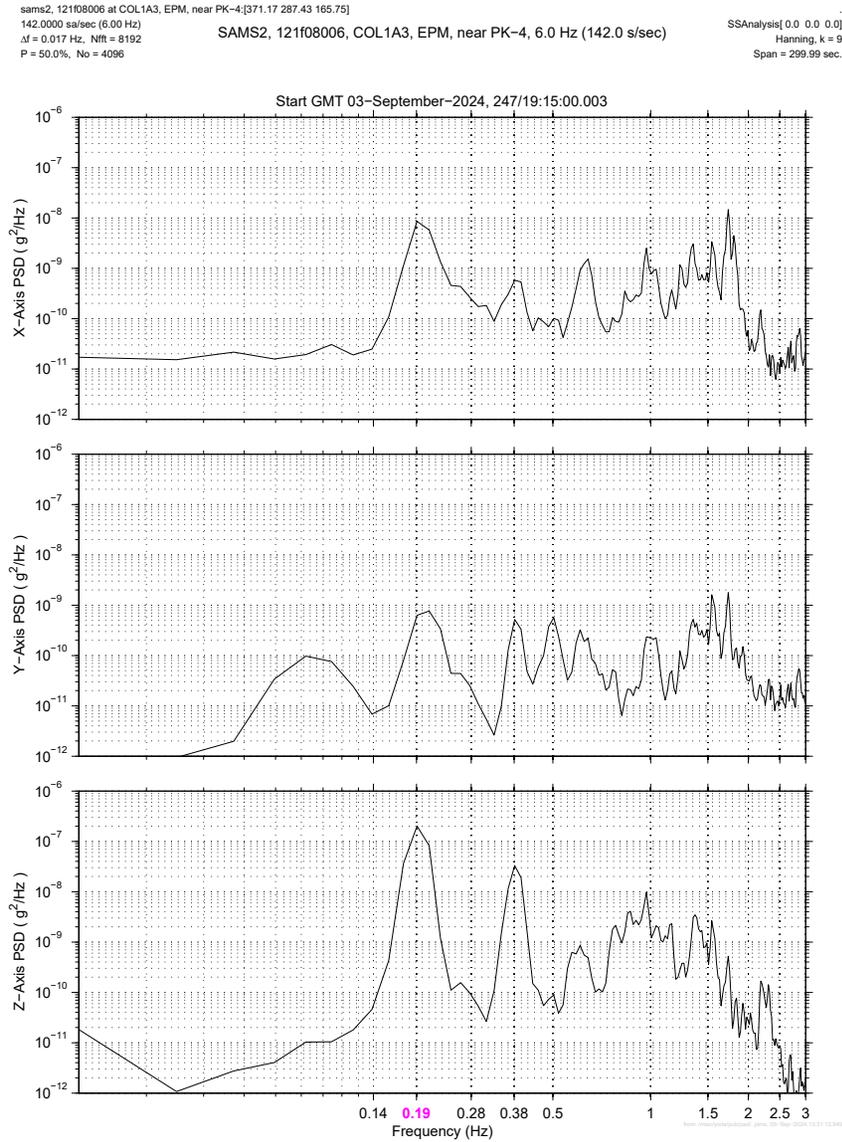
Fig. 7: SAMS in COL and JEM, Shows 5-Minute, Per-Axis PSDs Starting at GMT 2024-09-03/19:15: (left) **121f08 at COL1A3**, (right) **121f05 at JPM1F1**.
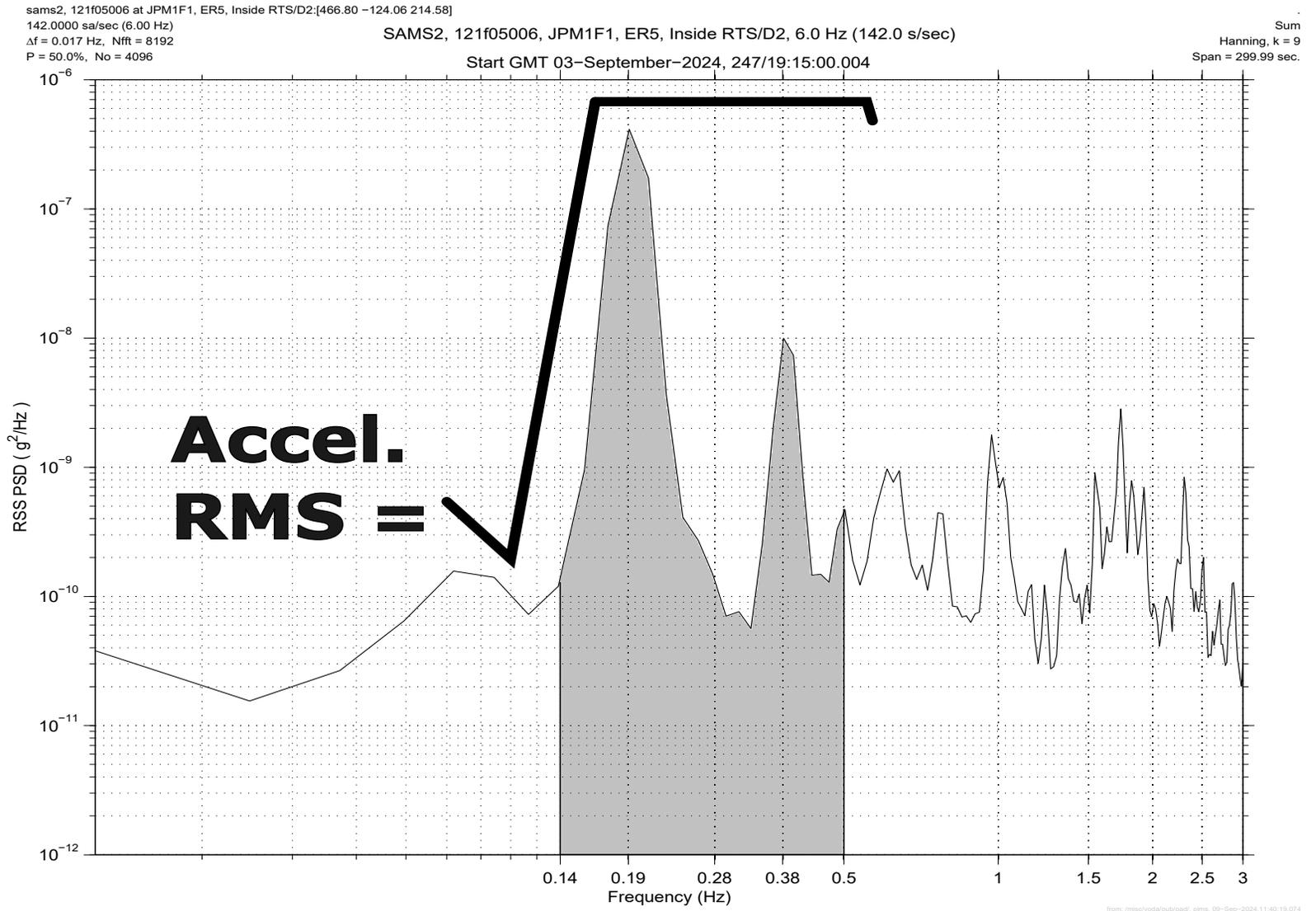
Fig. 8: Comparison of Accel. PSDs via SAMS Sensor 121f05 (JEM) for Two Distinct Unususal Rate Periods in 2024.
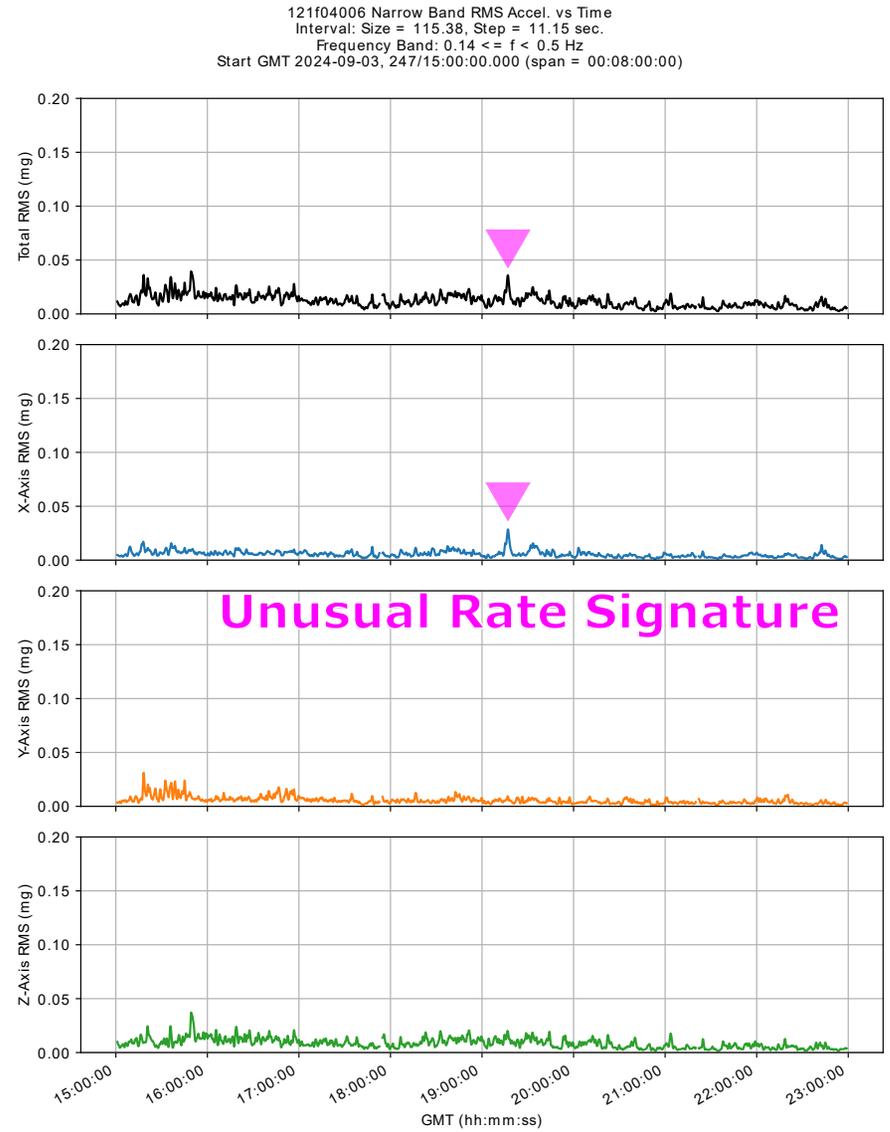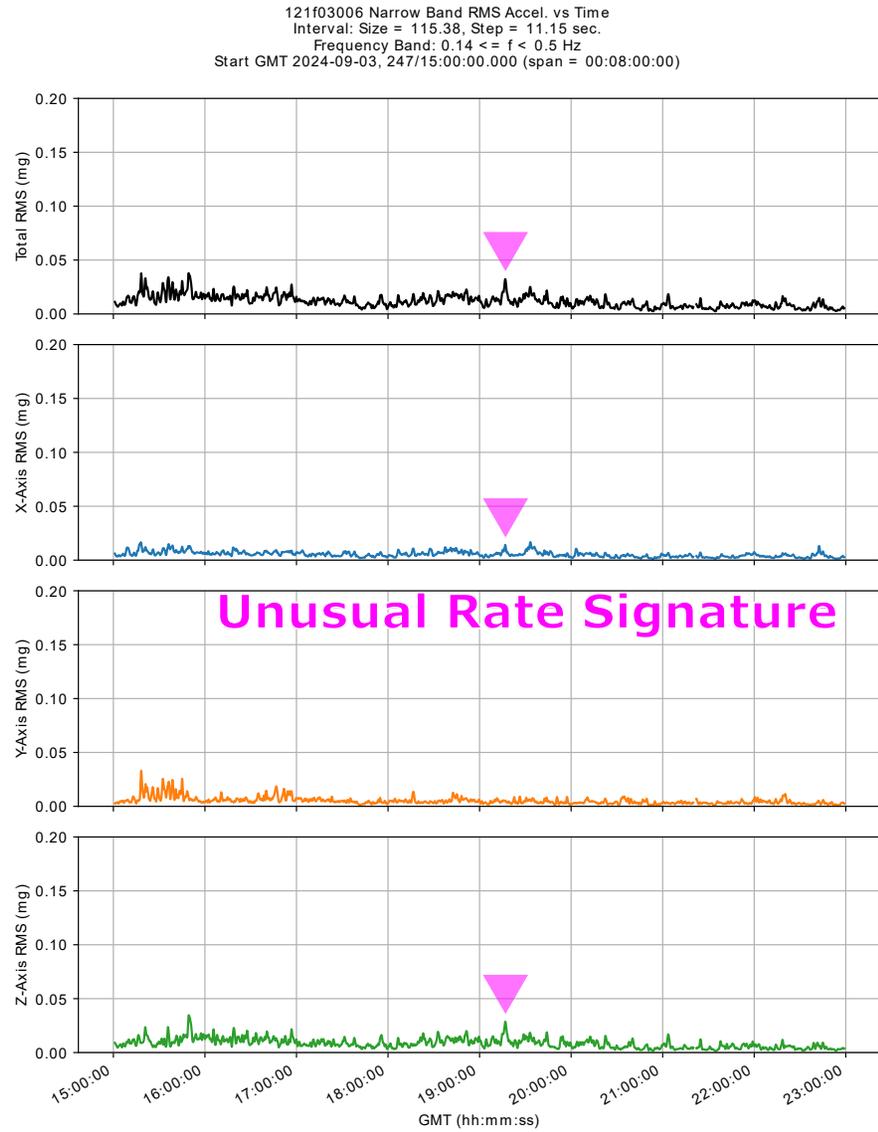
Fig. 9: 8-Hour, Total and Per-Axis Accel. Narrowband RMS vs. Time Starting at GMT 2024-09-03/15:00: (left) **121f03 at LAB1O1**, (right) **121f04 at LAB1P2**.
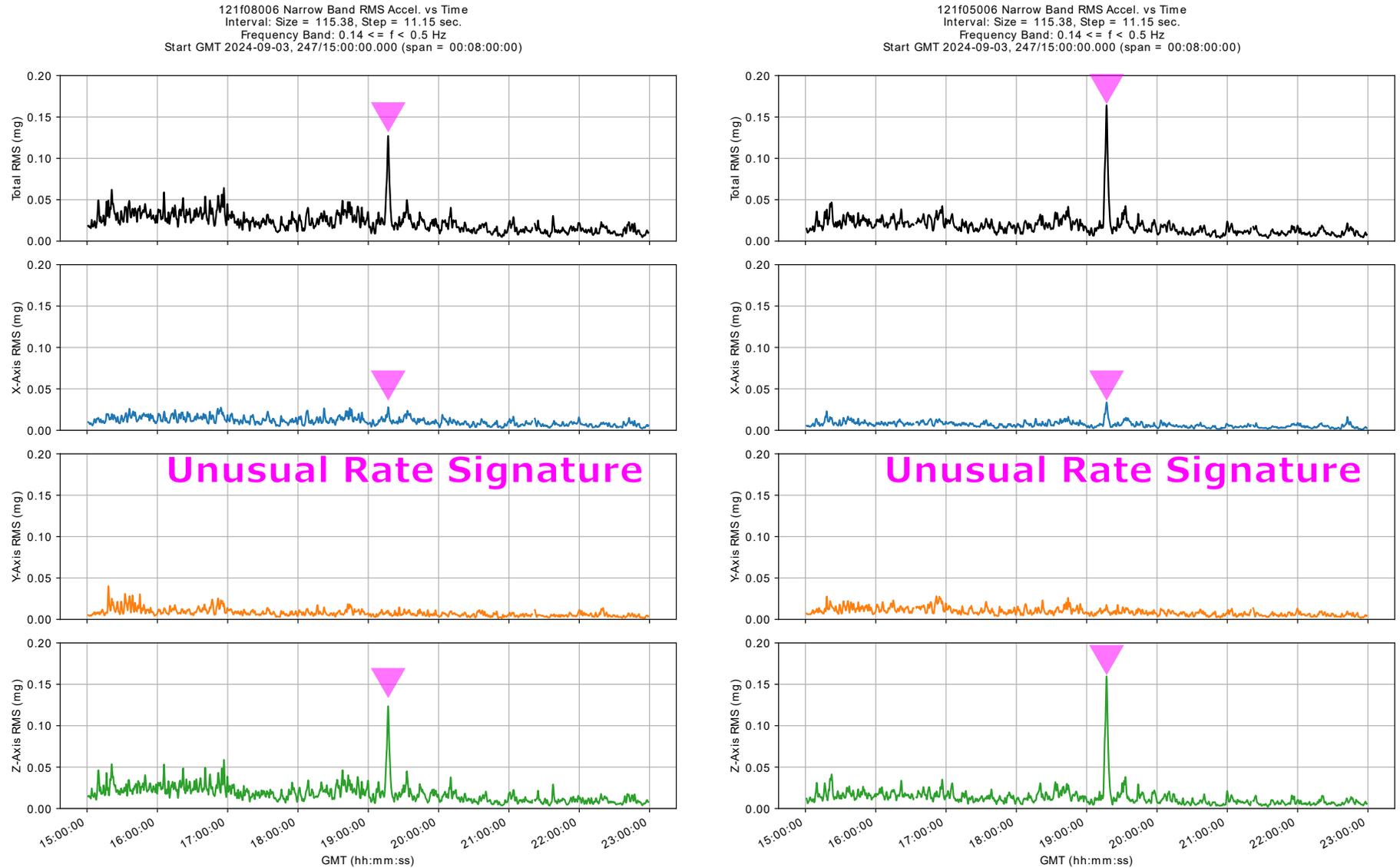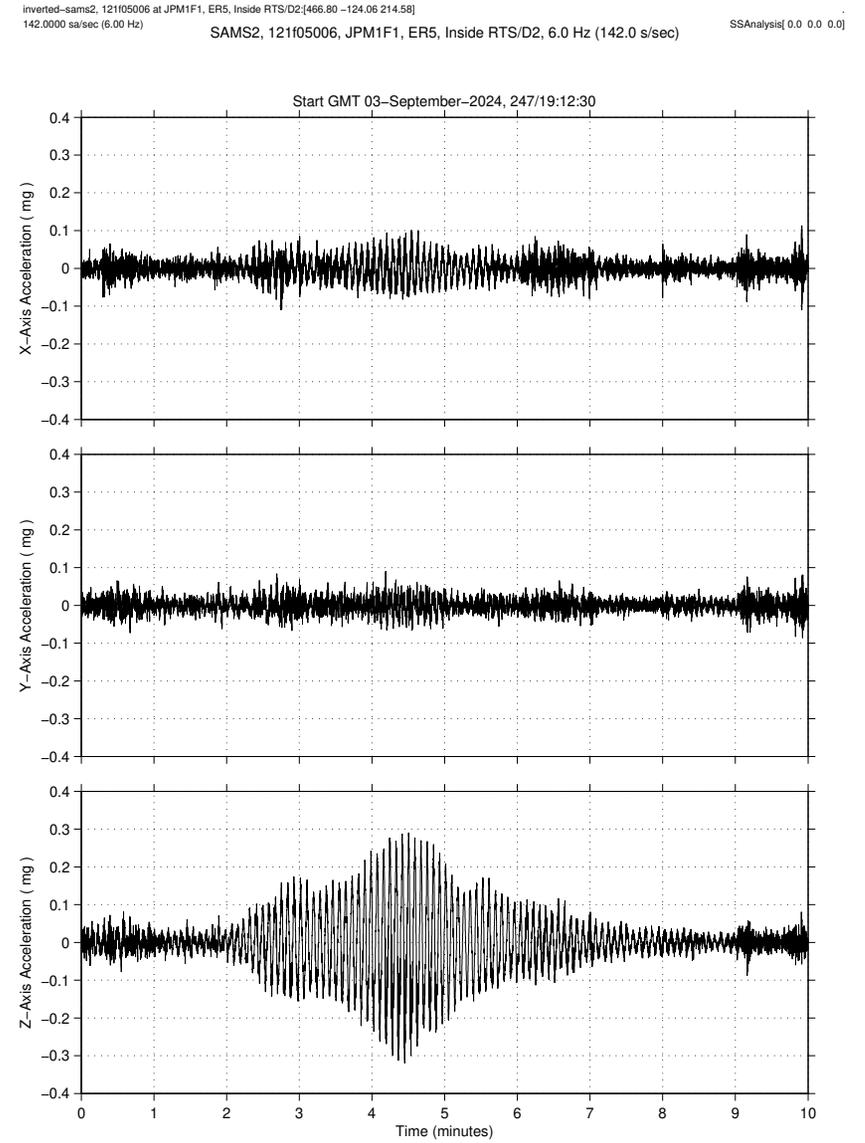
Fig. 10: 8-Hour, Total and Per-Axis Accel. Narrowband RMS vs. Time Starting at GMT 2024-09-03/15:00: (left) **121f08 at COL1A3**, (right) **121f05 at JPM1F1**.
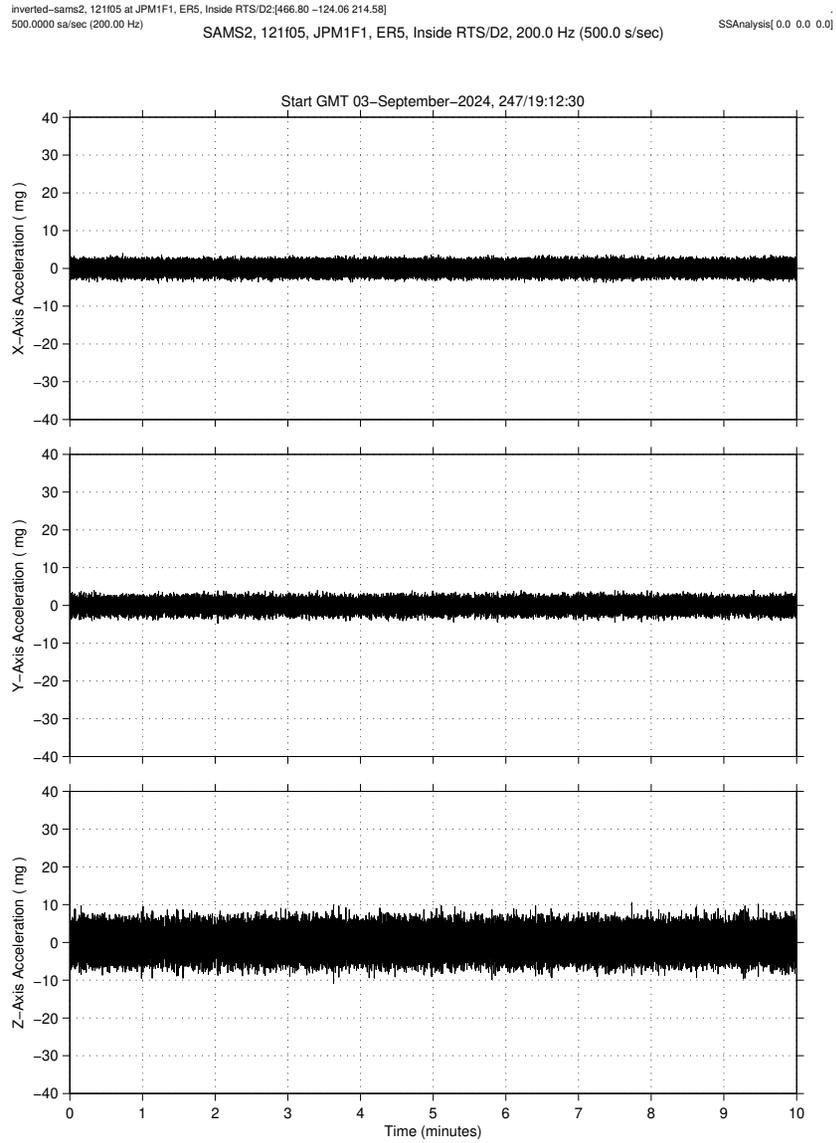
inverted−sams2, 121f05 at JPM1F1, ER5, Inside RTS/D2:[466.80 −124.06 214.58]
500.0000 sa/sec (200.00 Hz)   SAMS2, 121f05, JPM1F1, ER5, Inside RTS/D2, 200.0 Hz (500.0 s/sec)   SSAnalysis[0.0 0.0 0.0]

inverted−sams2, 121f05006 at JPM1F1, ER5, Inside RTS/D2:[466.80 −124.06 214.58]
142.0000 sa/sec (6.00 Hz)   SAMS2, 121f05006, JPM1F1, ER5, Inside RTS/D2, 6.0 Hz (142.0 s/sec)   SSAnalysis[0.0 0.0 0.0]

Fig. 11: 10-Minutes, Accel. vs. Time Starting at GMT 2024-09-03/12:30, 121f05 at JPM1F1: (left) **full pass-band up to 200 Hz**, (right) **low-pass filtered at 6 Hz**.
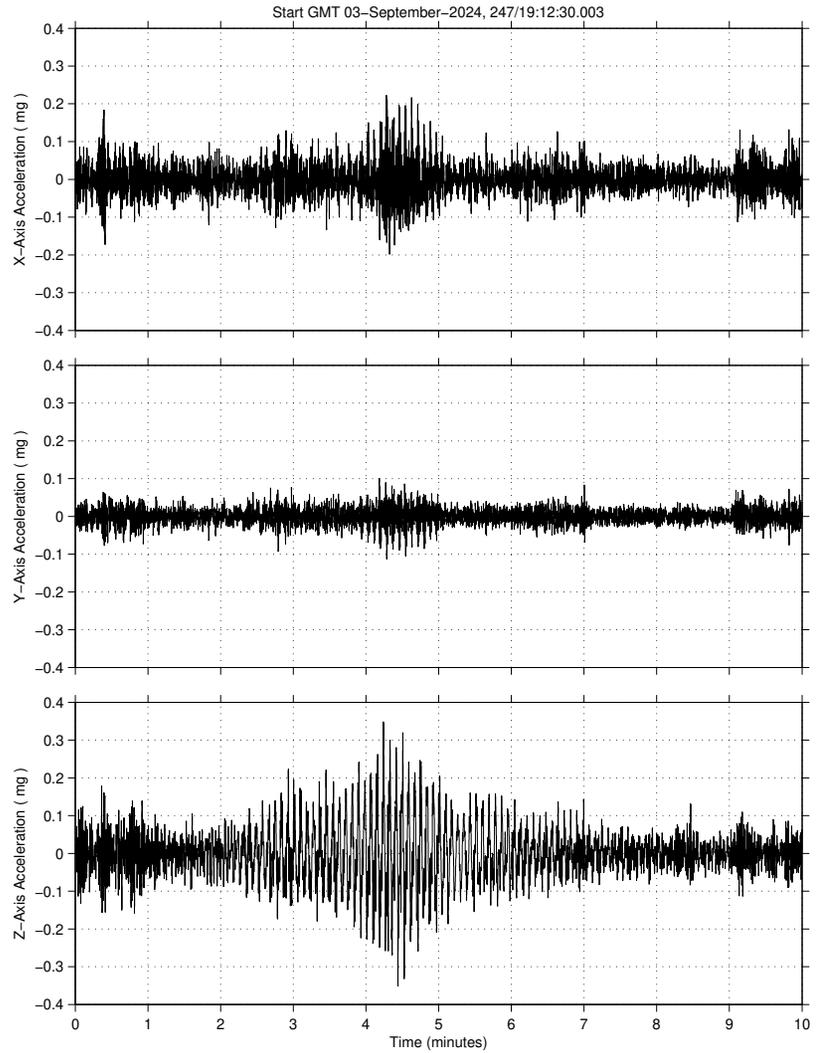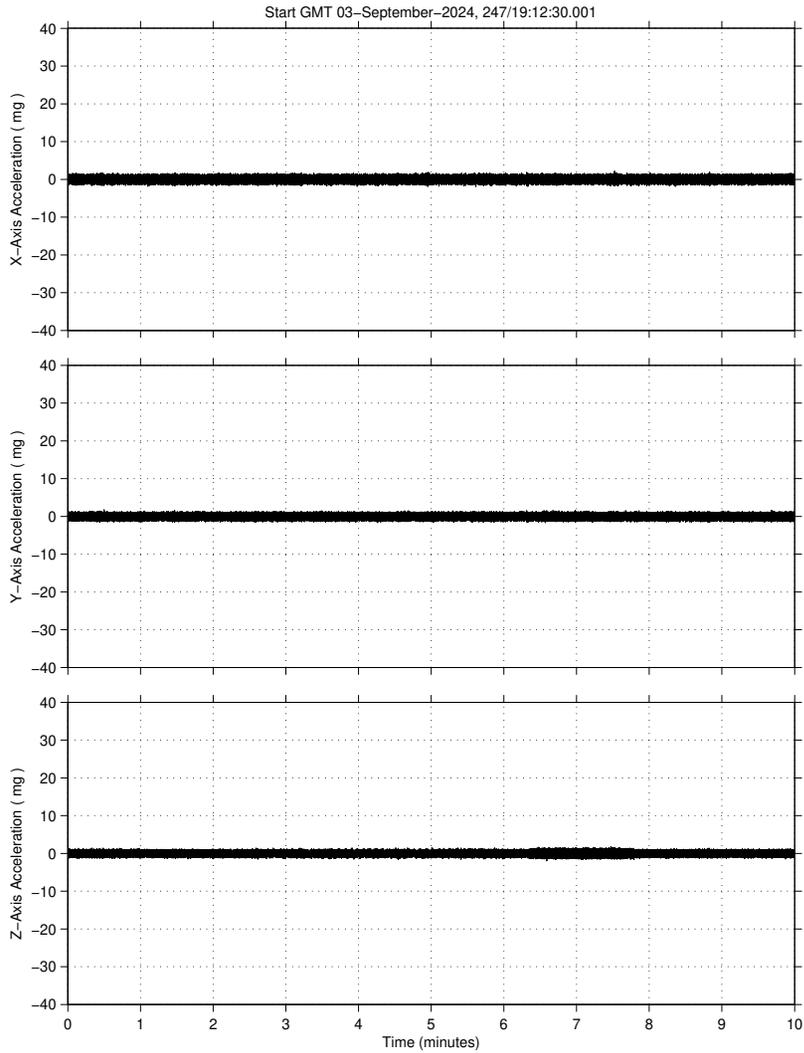
Fig. 12: 10-Minutes, Accel. vs. Time Starting at GMT 2024-09-03/12:30, 121f08 at COL1A3: (left) **full pass-band up to 200 Hz**, (right) **low-pass filtered at 6 Hz**.

inverted–sams2, 121f03 at LAB1O1, ER2, Lower Z Panel:[191.54 –40.54 135.25]
500.0000 sa/sec (200.00 Hz)   SAMS2, 121f03, LAB1O1, ER2, Lower Z Panel, 200.0 Hz (500.0 s/sec)   SSAnalysis[0.0 0.0 0.0]

inverted–sams2, 121f03006 at LAB1O1, ER2, Lower Z Panel:[191.54 –40.54 135.25]
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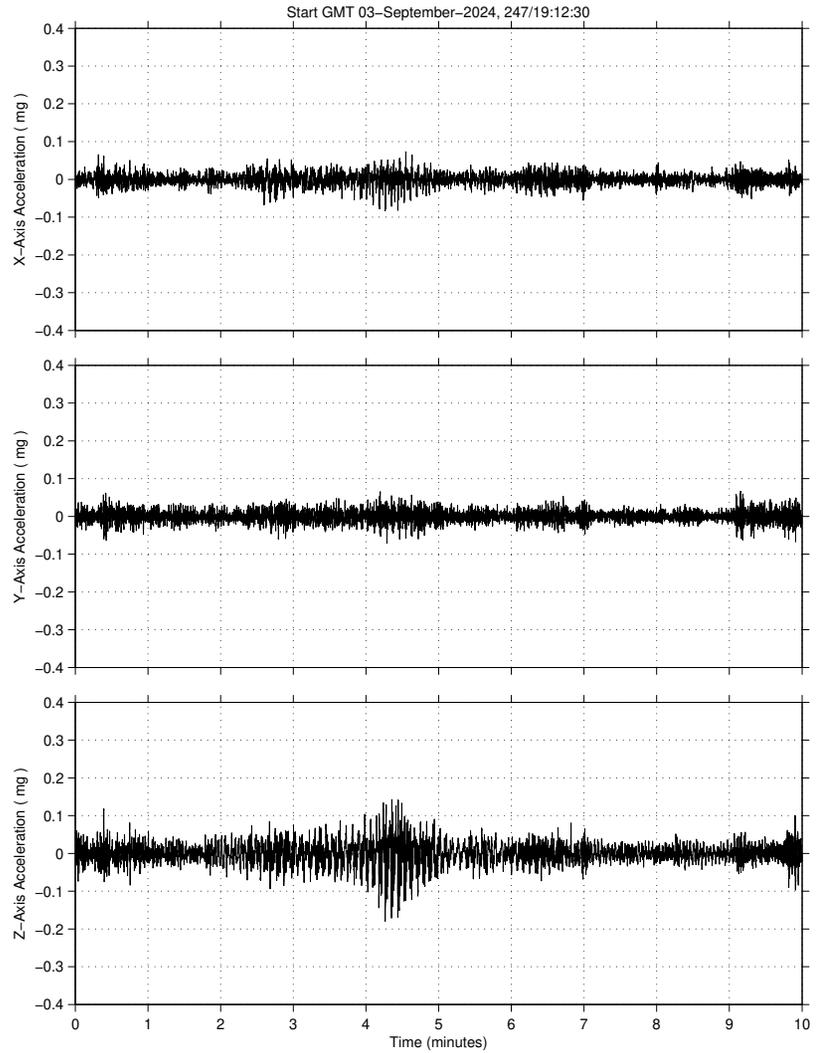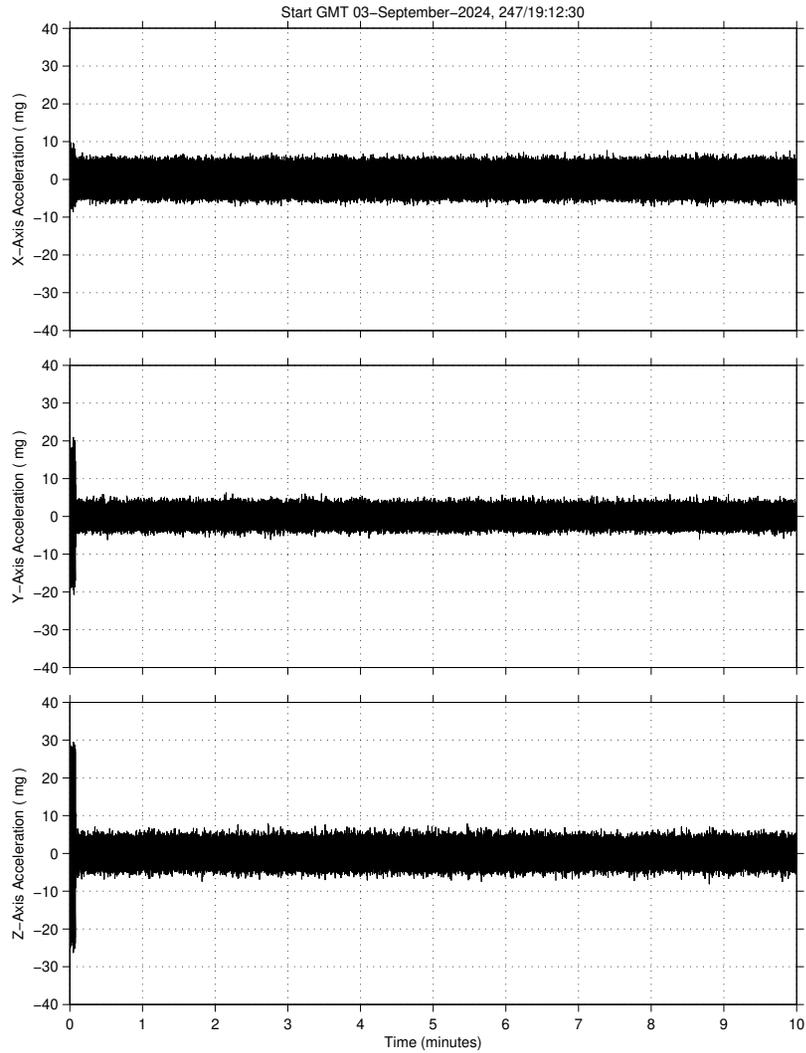

Fig. 13: 10-Minutes, Accel. vs. Time Starting at GMT 2024-09-03/12:30, 121f03 at LAB1O1: (left) **full pass-band up to 200 Hz**, (right) **low-pass filtered at 6 Hz**.
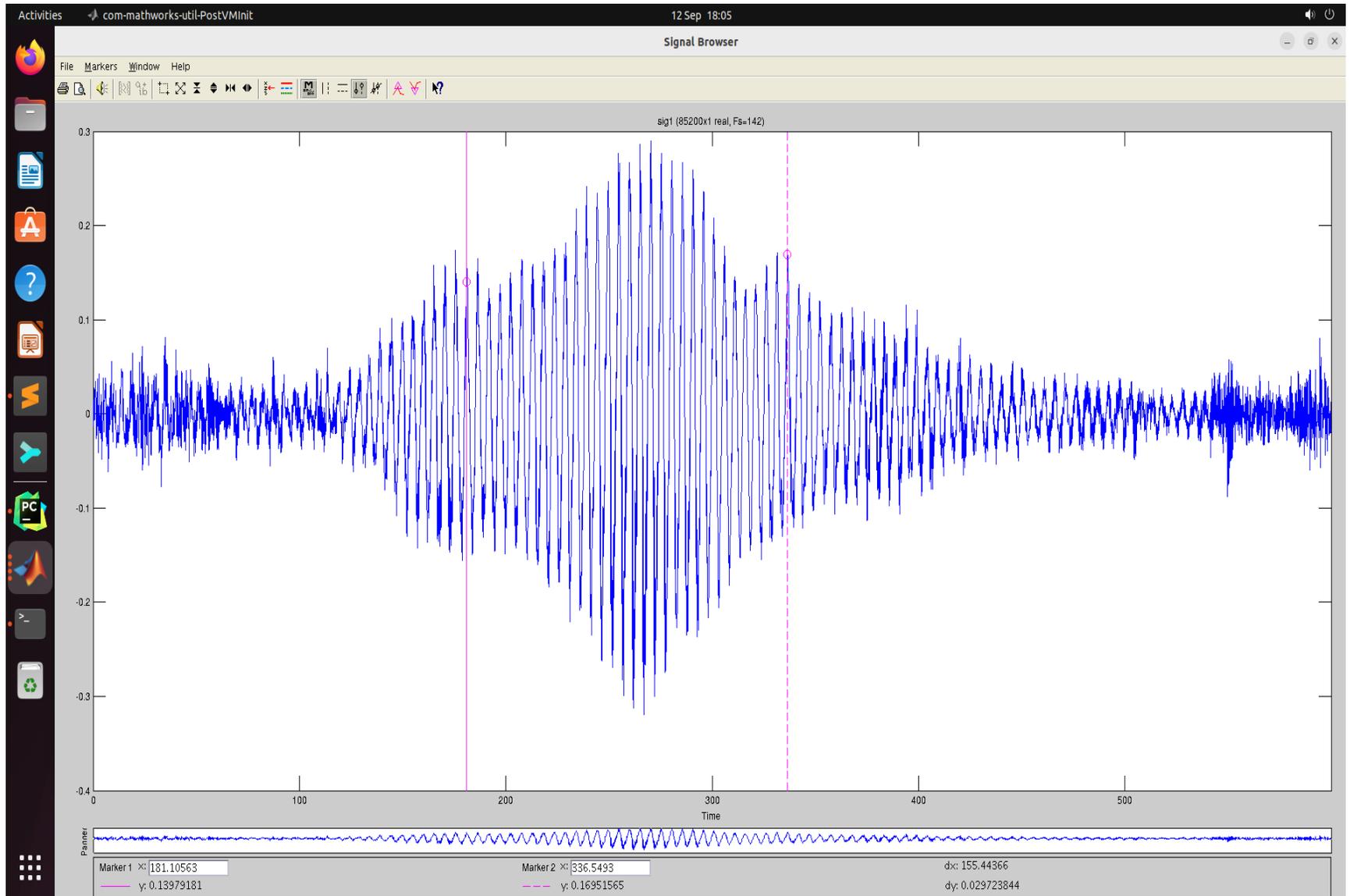
Fig. 14: SAMS Sensor 121f05 Z-Axis vs. Time Shows **7-Minute Excitation/Response** Started at GMT 2024-09-03/**19:14:30** & 30 cycles in 155.443 sec = **0.193 Hz**.