1. INTRODUCTION

This document aims to characterize two dynamic events, each associated with the Russian Soyuz 66S crew vehicle: (1) docking on GMT 2021-12-08, and (2) undocking on GMT 2021-12-19. Particular interest will be the vibratory impact registered by a Space Acceleration Measurement System (SAMS) sensor head mounted in support of the Material Science Research Rack (MSRR) in the US Lab of the International Space Station (ISS).

The image in Figure 1 shows the zenith-pointing port location on the MRM-2 where the Soyuz docked on GMT 2021-12-08, and then undocked later on GMT 2021-12-19, but the Soyuz vehicle is not shown in this image. Intuition suggests that with the center-of-mass somewhere forward in the US Lab, then an abrupt downward push toward the aft of the ISS would result in acceleratory reaction mostly in the XZ-plane. SAMS plots shown below will bear this out.

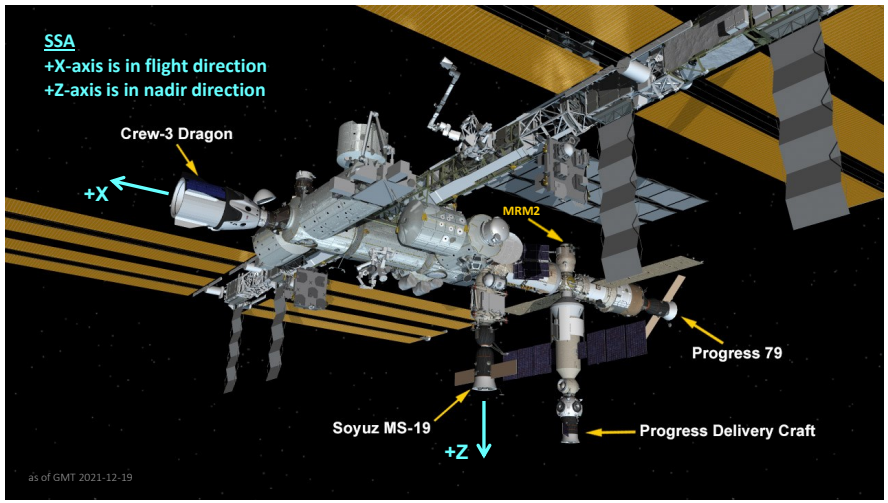

Fig. 1: Soyuz 66S's Docking Location at MRM-2's Zenith Port.

2. SOYUZ 66S DOCKING ON GMT 2021-12-08

The vibratory acceleration spectral information shown in Figure 2 on page 3 was computed from measurements near the MSRR by SAMS Triaxial Sensor Head (TSH) S/N 18. This plot only crudely shows SAMS timing, yet it agrees with the as-flown timeline accounting that the docking event occurred at GMT 13:41. This spectrogram helps to qualify and emphasize the 2 main impacts observed for the docking event: (1) the impulsive "bang" at the time of impact as indicated at the time of the down arrow, and (2) the structural response "ringout" that persists for several seconds (about 35s as will be shown in a later plot) – this structural excitation is indicated by the 2 right arrows at about 0.2 Hz and 0.4 Hz starting at the time of Soyuz vehicle impact.

The as-measured 200 Hz acceleration data in Figure 3 on page 4 shows roughly the same time span as the previous spectrogram plot. The red rectangle was put in place to surround the docking event time and demonstrate that docking is hard to discern with 200 Hz data. However, that same red rectangle for the same time frame is used to annotate Figure 4 on page 4. Here we clearly see and can quantify the vibratory impact of the Soyuz vehicle's impact. To better see and quantify, we zoom in on the y-scale to yield Figure 5 on page 5. This zoom-in plot shows **docking peak-to-peak values of about 3 mg, 1 mg, and 2 mg on the X-, Y-, and Z-axis, respectively (below 6 Hz)**. Keep in mind that this disturbance only becomes clear with 6 Hz low-pass filtering; otherwise, we would have a difficult time discerning this disturbance were it not for spectral decomposition showing structural response "ringout" below 1 Hz or so. Figure 6 on page 5 gives a good zoom-in on the time scale to show the various space station structural responses on the X-, Y-, and Z-axis. The longest "ringout" span appeared to be on the Z-axis as annotated in magenta on the bottom subplot lasting about 35 seconds.

3. SOYUZ 66S UNOCKING ON GMT 2021-12-19

The vibratory acceleration spectral information shown in Figure 7 on page 6 was computed from measurements near the MSRR by SAMS Triaxial Sensor Head (TSH) S/N 18. This plot crudely indicates SAMS timing as nearly matching the as-flown timeline accounting, and we will later see that the undocking event occurred at GMT 23:50:45 by SAMS timing – just about 15 seconds later than the as-flown timeline. This spectrogram again helps to qualify and emphasize the 2 main impacts observed for the undocking event: (1) the impulsive "boing" at the onset time of physical separation as indicated at the time of the down arrow, and (2) the structural

response "ringout" that persists for several seconds (about 30s as will be shown in a later plot) – this structural excitation "ringout" is not annotated in the figure, but can be seen as brief horizontal orange streaks that start just after the undocking event and lasting only several seconds at about 0.2 Hz and 0.4 Hz starting at the time of Soyuz vehicle push-off. The 6 Hz low-pass filtered data in Figure 8 on page 7 shows the distinctive signature of the Soyuz undocking at GMT 23:50:45.

Finally, the zoomed-in 6 Hz time plot of Figure 9 on page 7 shows **undocking peak-to-peak values of about 1 mg, <0.5 mg, and 2 mg on the X-, Y-, and Z-axis, respectively (below 6 Hz)**. This figure also gives a good zoom-in on the time scale to show the various space station structural responses on the X-, Y-, and Z-axis. The most pronounced "ringout" span appeared to be on the XZ-plane and lasting about 30 seconds.

4. CONCLUSION

The SAMS sensor mounted near the MSRR showed that for both the Soyuz 66S docking on GMT 2021-12-08 and its undocking on GMT 2021-12-19, acceleration peak-to-peak values below 6 Hz were at or below 3 mg but to varying degrees on the 3 independent measurement axes. These data also showed that space station structural response "ringout" persisted for up to about 35 seconds or so on the Z-axis for the docking event. This signal feature notable in 6 Hz low-pass filtered data was closer to 30 seconds for the undocking event.

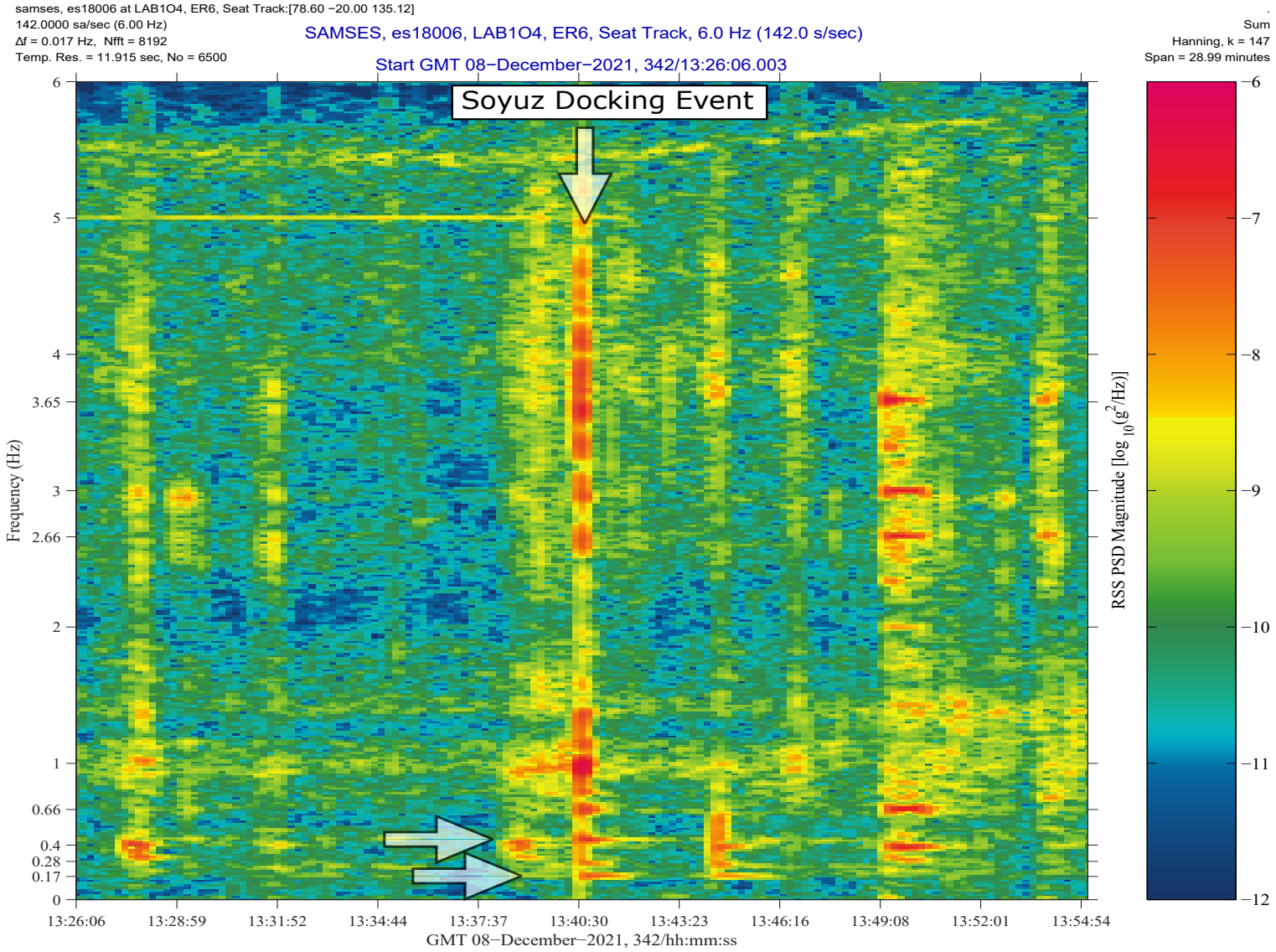

Fig. 2: Spectrogram of Soyuz 66S Docking Event on GMT 2021-12-08.

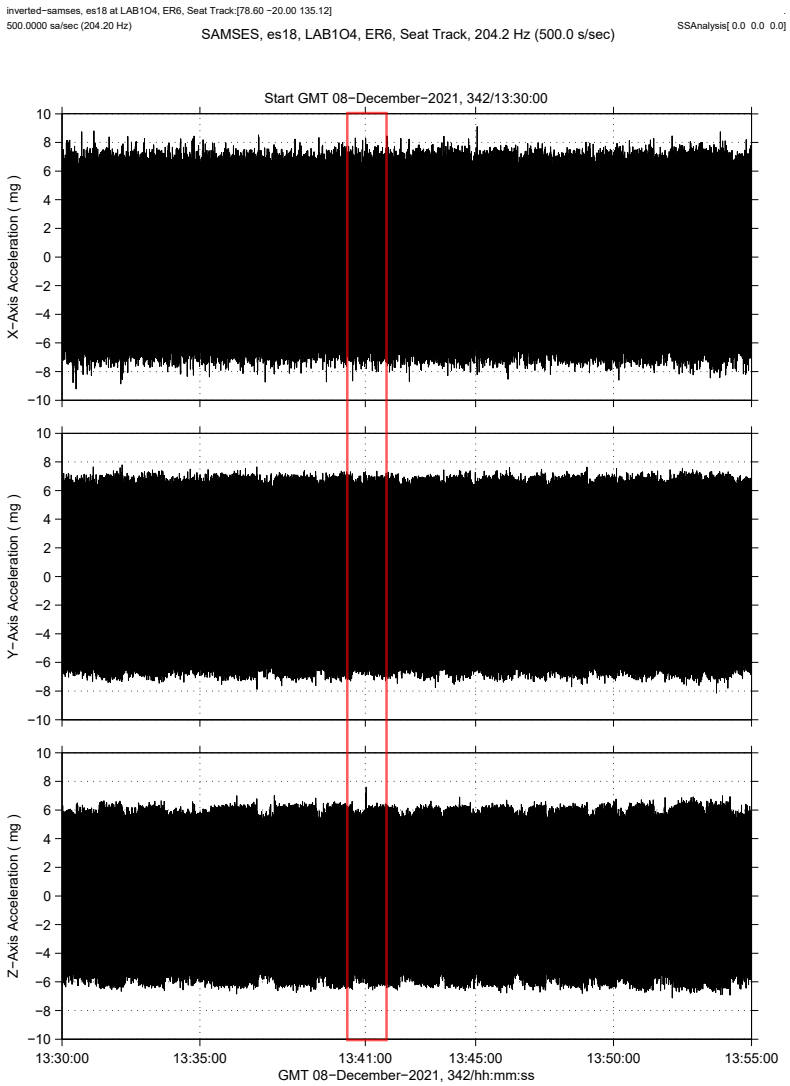

Fig. 3: SAMS es18 Acceleration vs. Time (f < 200 Hz) for Docking Event.

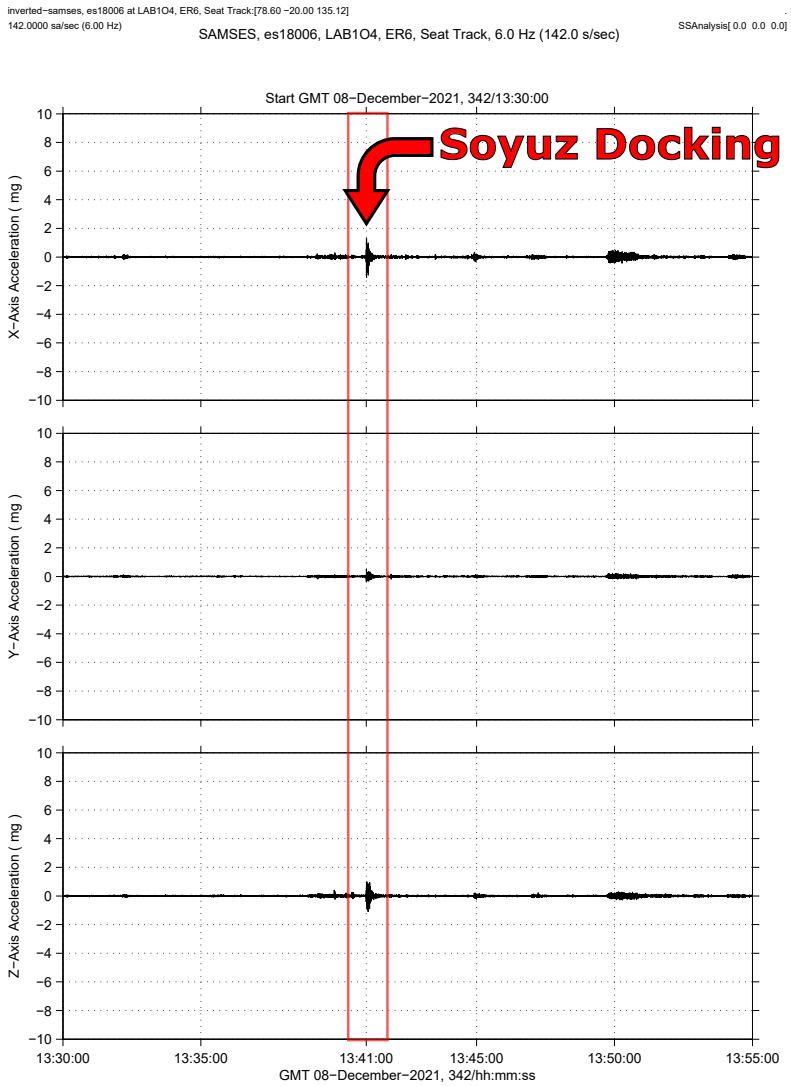

Fig. 4: SAMS es18 Acceleration vs. Time (f < 6 Hz) for Docking Event.

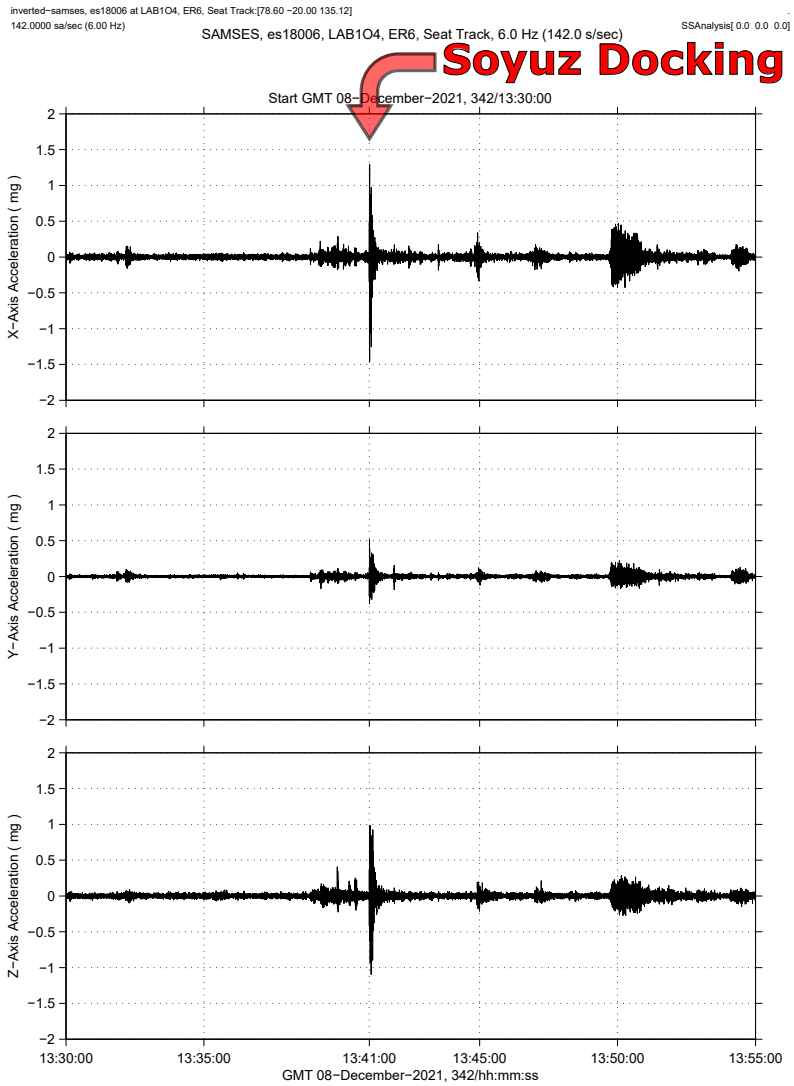

Fig. 5: SAMS es18 **Acceleration Zoom-In** vs. Time (f<6 Hz) for Docking.

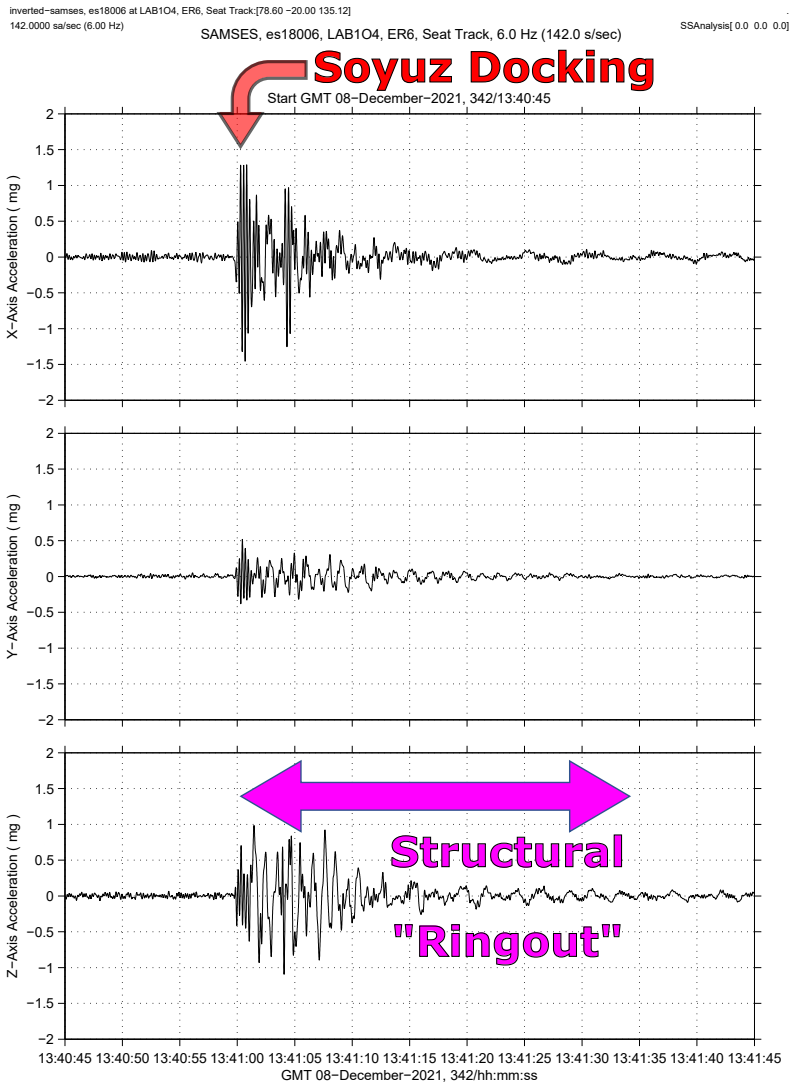

Fig. 6: SAMS es18 Acceleration vs. **Time Zoom-In** (f<6 Hz) for Docking.

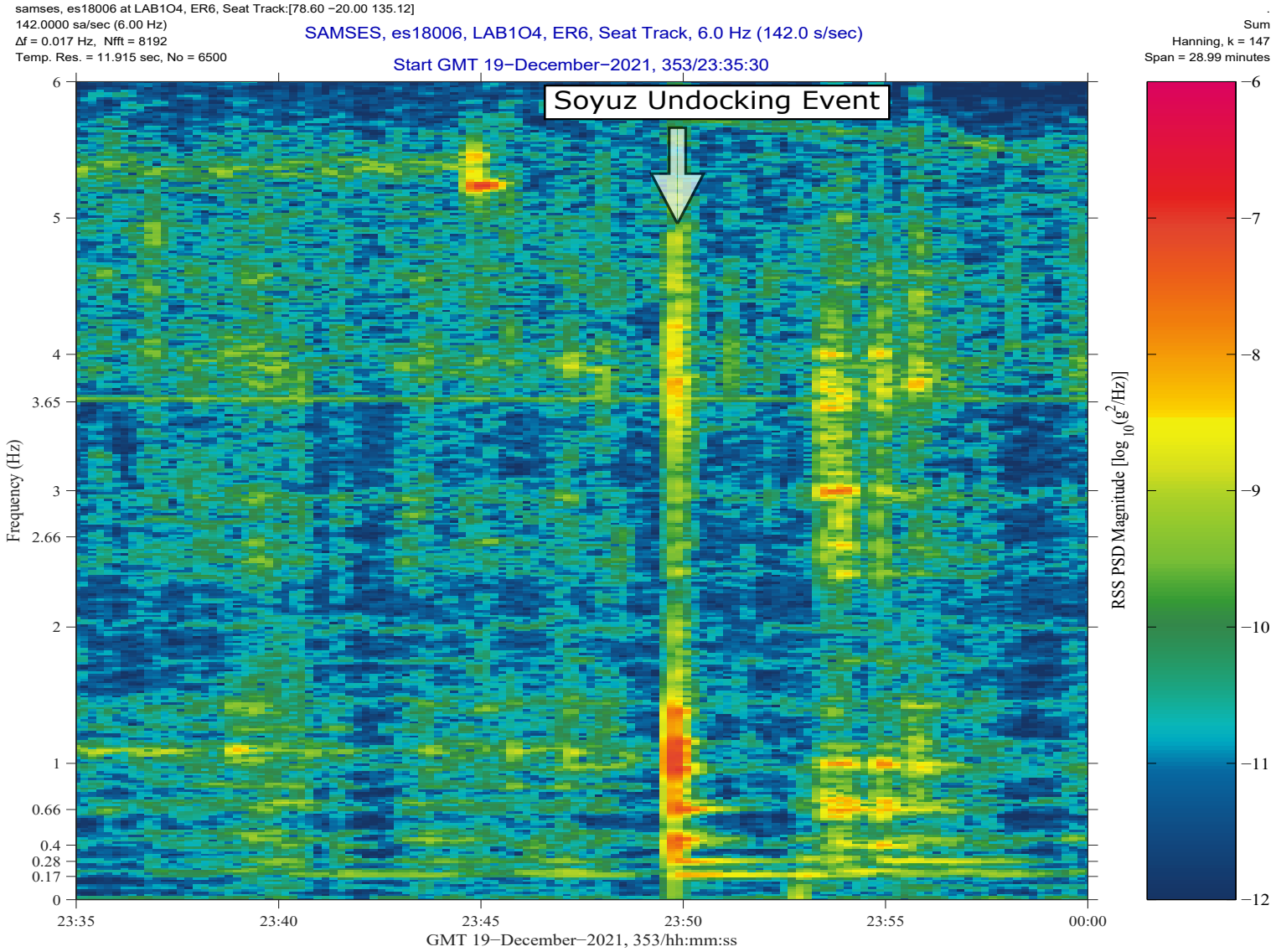

Fig. 7: Spectrogram of Soyuz 66S Unocking Event on GMT 2021-12-19.

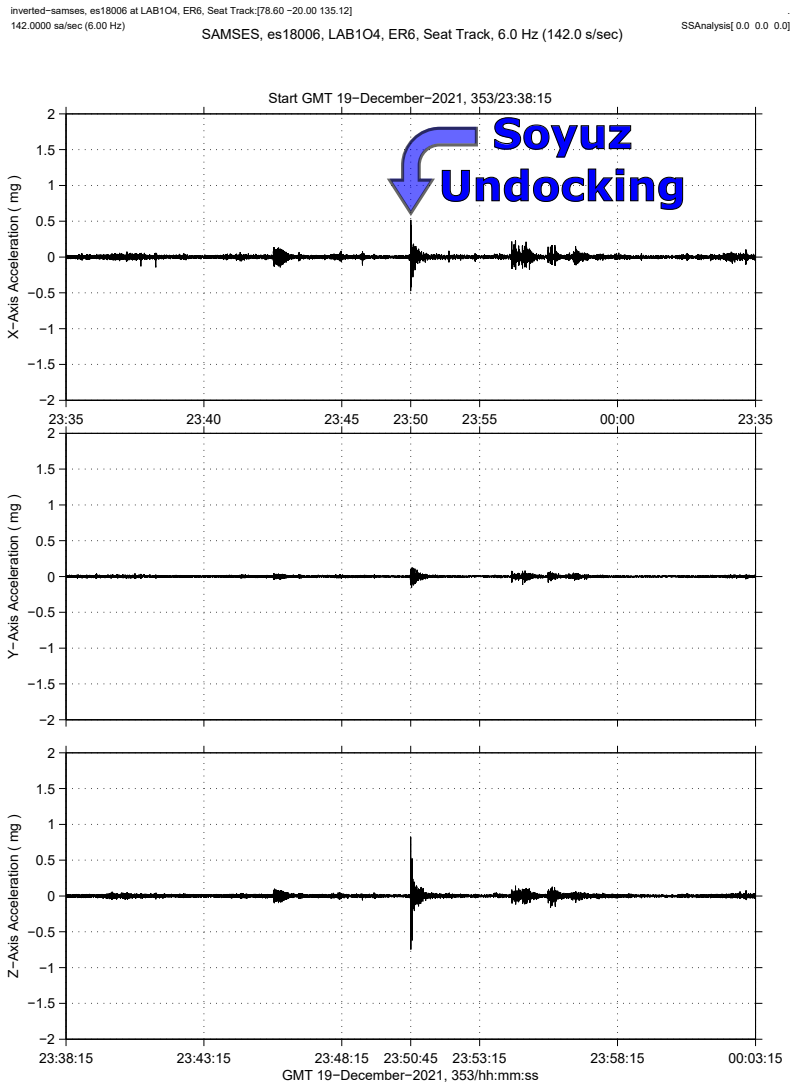

Fig. 8: SAMS es18 Acceleration vs. Time (f<6 Hz) for Undock.

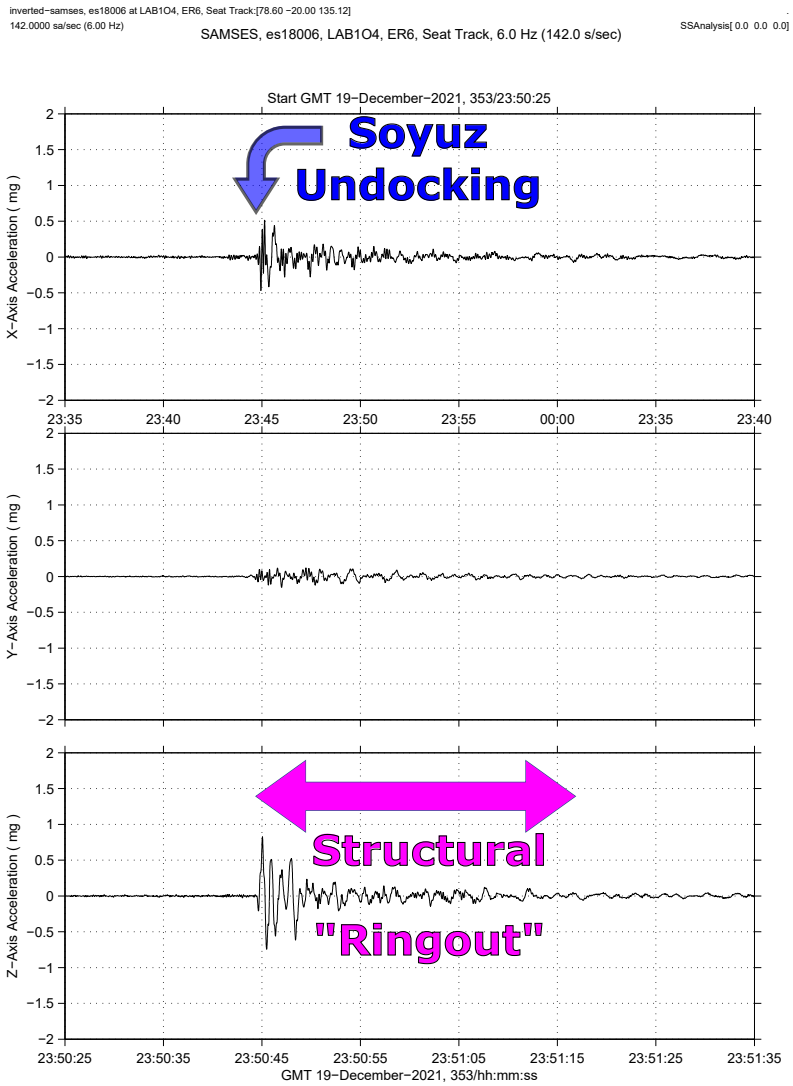

Fig. 9: SAMS es18 Acceleration vs. **Time Zoom-In** (f<6 Hz) for Undock.