1. INTRODUCTION

This Wikipedia page has a section that describes how a cluster of control moment gyroscopes (CMGs) can become saturated resulting in loss of attitude control. It also states that "The only remedy for this loss of control is to desaturate the CMGs by removing the excess angular momentum from the spacecraft. The simplest way of doing this is to use Reaction Control System (RCS) thrusters."

2. QUALIFY

Information supplied by the Attitude Determination and Control Officer (ADCO) indicated thruster firings to desaturate the International Space Station's CMGs occurred on GMT 2020-04-25 at 18:33. The spectral information shown in Figure 1 was computed from SAMS sensor 121f05 measurements made in the Japanese Experiment Module (JEM) at the time.

Note the vertical yellow line in the spectrogram at that time with some structural excitation in red right at about 1 Hz and another just below 1 Hz. This is indicative of structural resonance (ringing) due to the impulsive nature of the desaturation thruster firings. Figure 2 and Figure 3 show similar characteristics from SAMS measurements made in the Columbus module and the US Laboratory, respectively.

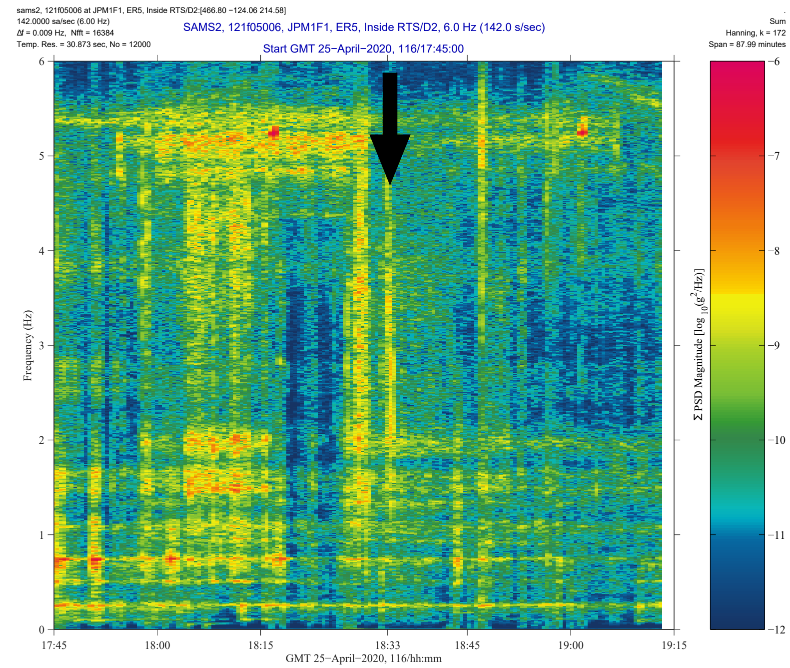

Fig. 1: Spectrogram from SAMS in JEM: CMG Desaturation at GMT 18:33.

3. QUANTIFY

The acceleration vs. time plot of Figure 4 on page 4 shows Space Acceleration Measurement System (SAMS) data recorded in the Japanes Experiment Module (JEM) during the desaturation event up to a cut-off frequency of 200 Hz. Note that these data are dominated by higher-frequency (mostly localized) vibrations near the sensor head's mounting location. For this sensor location, these higher-frequency vibrations mask the impact of the desaturation event. The desaturation thruster firing event's impulse is not clear in the as-measured (non-filtered) data, however, if you filter these data in order to focus more narrowly on vehicle structural mode regime below 6 Hz, then you see what is shown in Figure 5 on page 4. The y-scale on these two figures are not the same, things are a lot quieter in Figure 5, where we attenuated the higher-frequency components of the measured signal to now see in Figure 5 the desaturation thruster firing impulse just after about GMT 18:33, strongest on the XZ-plane. We will zoom in on this time later, after we canvas other SAMS sensor data in the other 2 laboratories of the ISS. Before we do that, we point out that the y-scale in Figure 5 was selected for direct comparison to corresponding figures for measurements in other parts of the space station, namely Figure 7 and Figure 9.

Compare Figure 6 and Figure 7 starting on page 5 and notice that the higher-frequency disturbances that were so prominent near the SAMS sensor in the JEM are not present at this location in the Columbus module. As a matter of fact, there is almost no need for low-pass filtering for the data from this location to help identify the desaturation event since the ambient is considerably quieter. We again point out that the y-scale of Figure 7 matches that from the corresponding JEM plot of Figure 5 and see here that the XZ-plane registered most of the impact from this event in the Columbus module.

Finally, let's compare Figure 8 and Figure 9 starting on page 6 and notice that what we thought were loud, higher-frequency disturbances so prominent near the

SAMS sensor in the JEM were actually miniscule by comparison to what we measured at this sensor location in the US laboratory. To observe the impact of the desaturation event from this location would be hopeless without low-pass filtering the measurements made here, where the ambient vibratory environment swamps our event of interest. We again point out that the y-scale of Figure 9 matches that from the corresponding JEM plot of Figure 5 and the corresponding COL plot of Figure 7. In the US laboratory sensor location, the Z-axis took the brunt of this particular thruster firing.

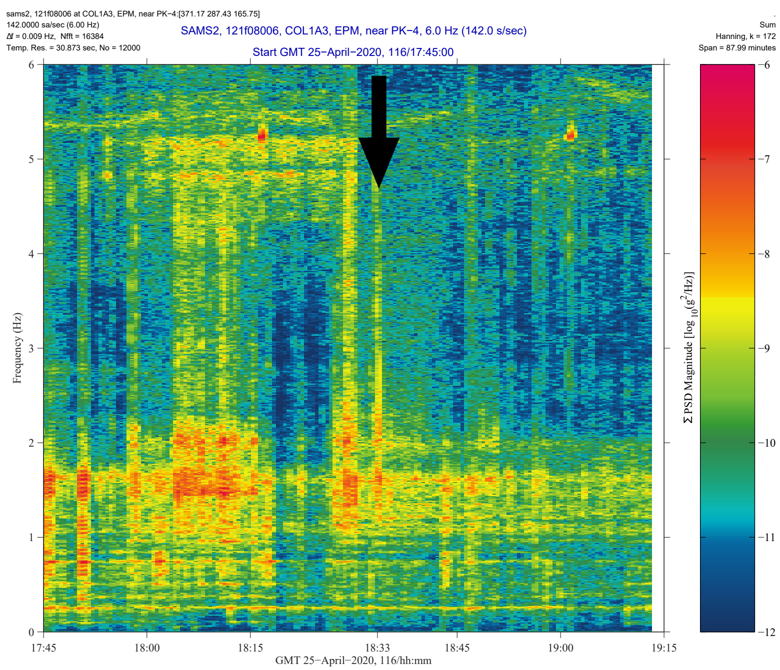

Fig. 2: Spectrogram from SAMS in COL: CMG Desaturation at GMT 19:21.

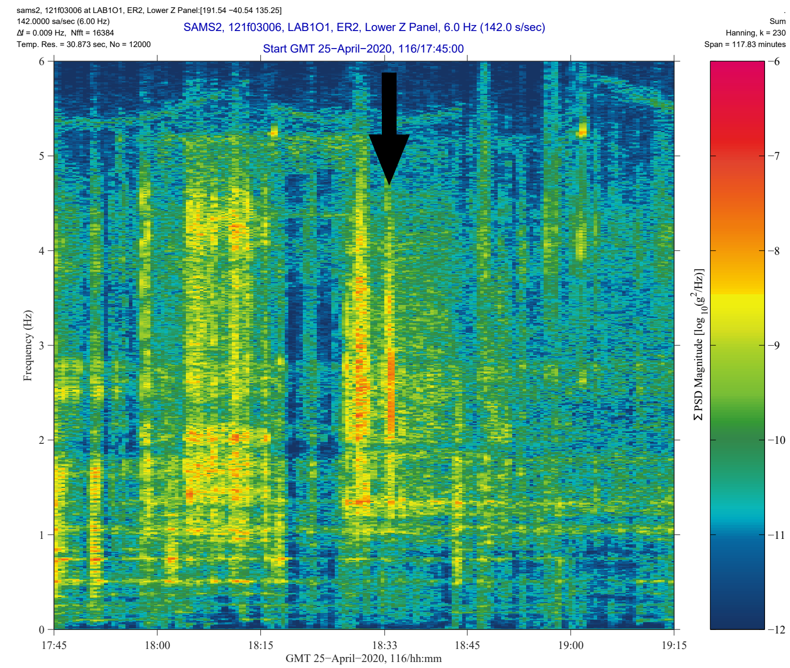

Fig. 3: Spectrogram from SAMS in LAB: CMG Desaturation at GMT 19:21.

As promised earlier, we now zoom-in temporally to get a fine accounting of the desaturation thruster firing starting with the US laboratory measurements in Figure 10 on page 7. This figure shows the ringing that begins with the desaturation thruster firing impulse at GMT 18:33:26, and has impact over several seconds as a vehicle structural mode rings-out and decays over that span. Figure 11 on page 8 shows similar (not same) characteristics in the JEM (most notably on the Y-axis), and Figure 12 on page 9 does likewise for measurements in the Columbus module. If you view this document in full-page view and flip quickly between Figure 10 (LAB), Figure 11 (JEM) and Figure 12 (COL) you gain an appreciation for the similarity and differences between what was registered at the 3 sensor mounting locations. One thing you might notice is an apparent time shift for the SAMS data collected in the Columbus module relative to what the data shows in the JEM and the LAB. Read the next section for more on this apparent time shift.

4. Timing Issue

As mentioned above, the SAMS sensor in the Columbus module appeared out-of-synchronization with other SAMS sensors. This in fact was true. A SAMS data artifact, not a causal violation or premonition. The SAMS data collected in the Columbus module was not synchronized, thus the desaturation impulse event appears to happen before GMT 18:33:26. An analysis technique involving cross-correlation of the 2 signals (the SAMS Y-axis data in the US laboratory with the SAMS Y-axis data in the Columbus module) yielded a time delay (lag) so that the event appeared to occur 13 seconds earlier in the Columbus module. That 13-second difference was strictly a time syncrhonization issue that was later resolved.

5. Conclusion

The three SAMS sensors used for analysis here all registered the CMG desaturation thruster firing event, but to differing degrees and with slightly different characteristics ostensibly due to geometry and the fact that the ISS is not a rigid body. Furthermore, it was shown the as-measured (200 Hz) data can significantly hamper detection of this event without first low-pass filtering the data (except perhaps in the Columbus module where the SAMS sensor mounting location was not dominated by higher-frequency ambient vibratory disturbances). For this desat event on GMT 2020-04-25 when considering the structural mode regime (below 6 Hz), the largest excursion appeared on the Z-axis for the SAMS sensor (121f03) in the US laboratory, with brief ringing peak-to-peak value of no more than 0.3 mg.

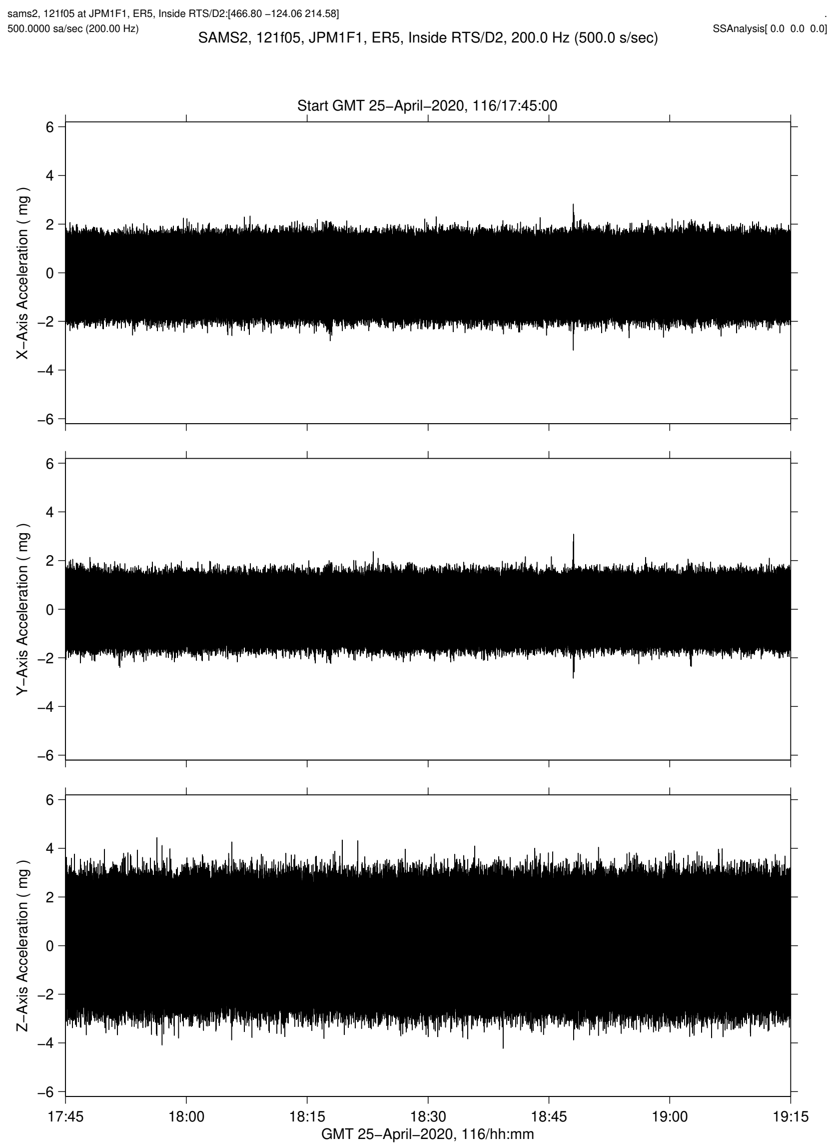

Fig. 4: SAMS JEM 121f05 acceleration data (up to 200 Hz) for desat firing.

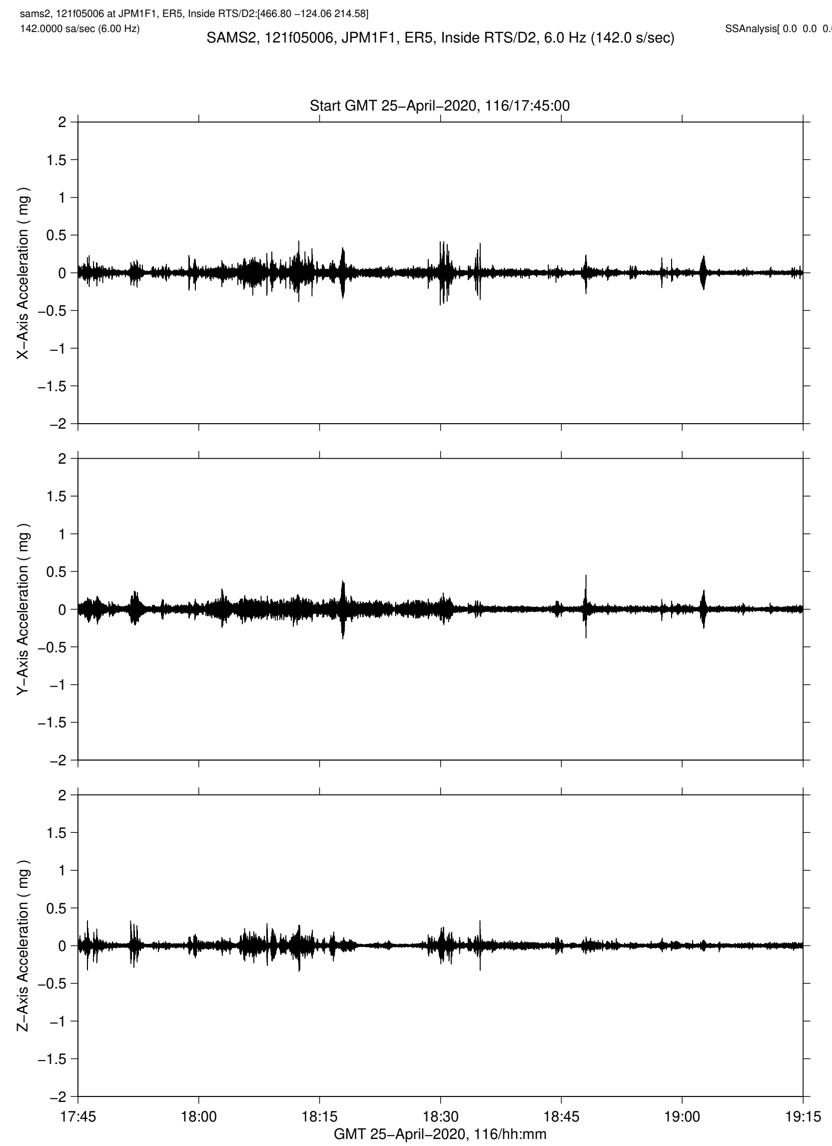

Fig. 5: SAMS JEM 121f05 acceleration data (f < 6 Hz) for desat firing.

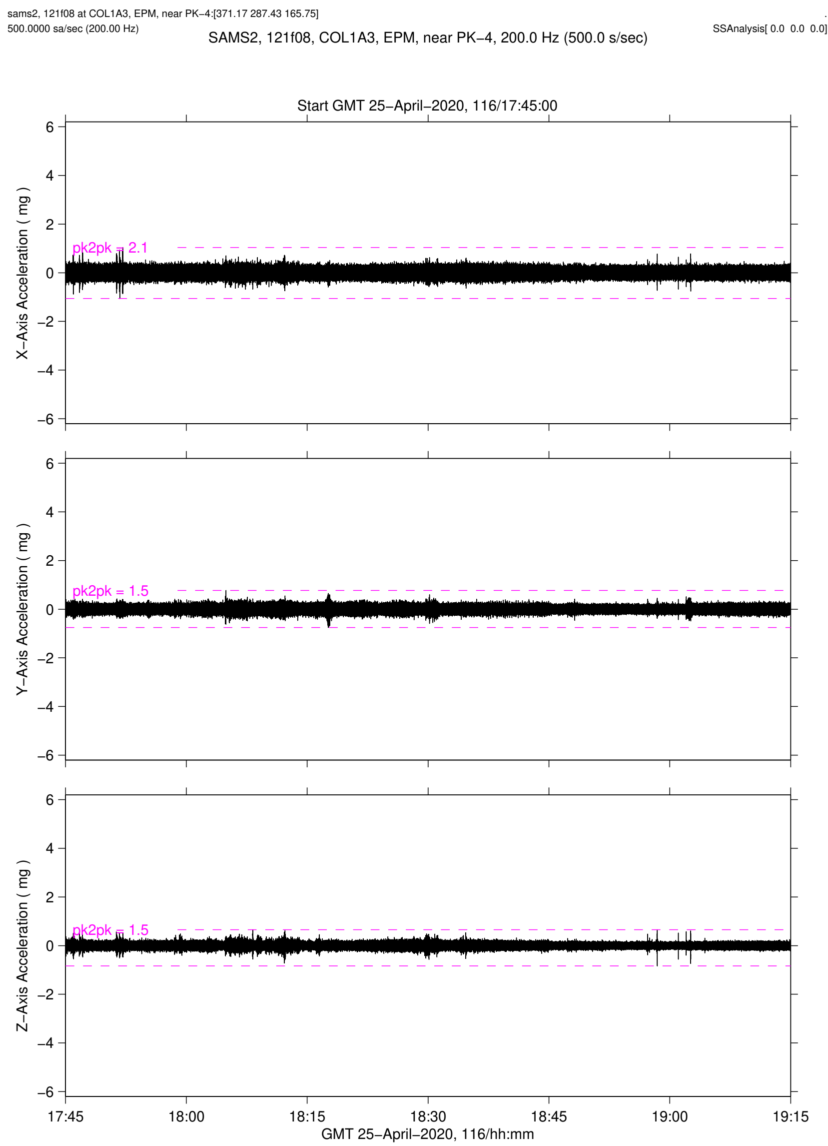

Fig. 6: SAMS COL 121f08 acceleration data (up to 200 Hz) for desat firing.

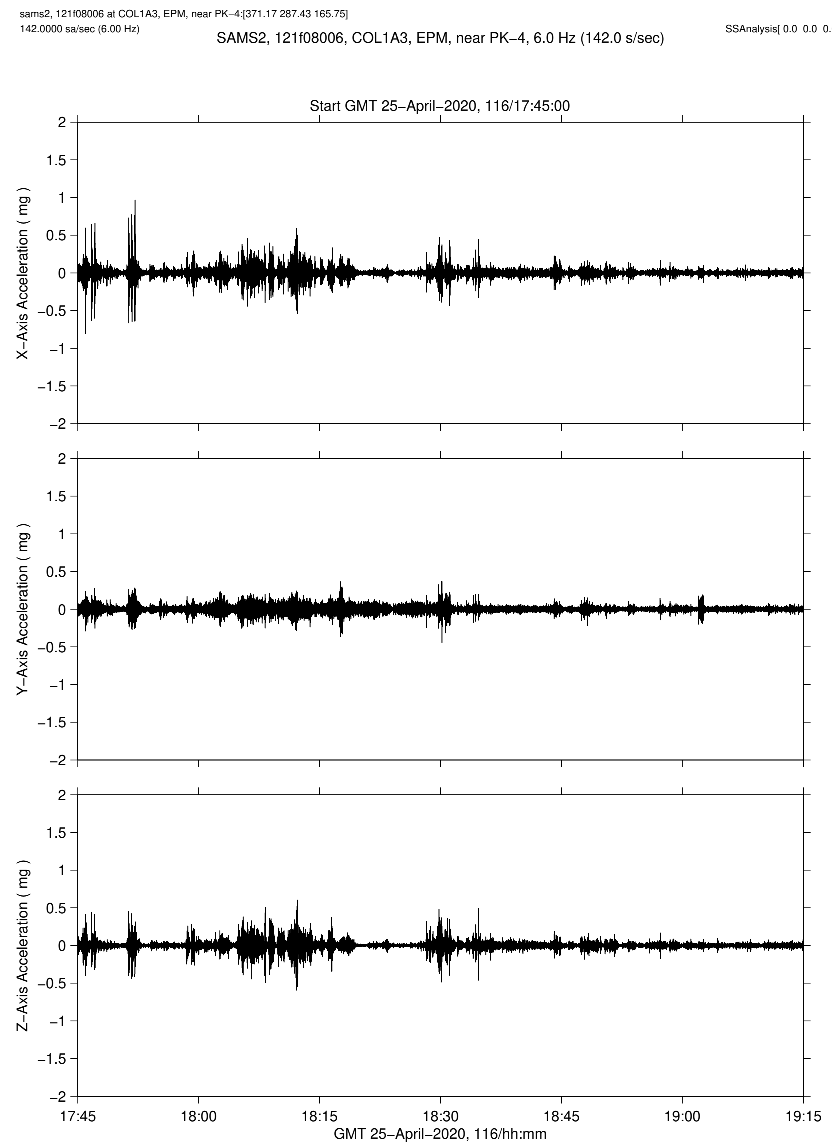

Fig. 7: SAMS COL 121f08 acceleration data (f < 6 Hz) for desat firing.

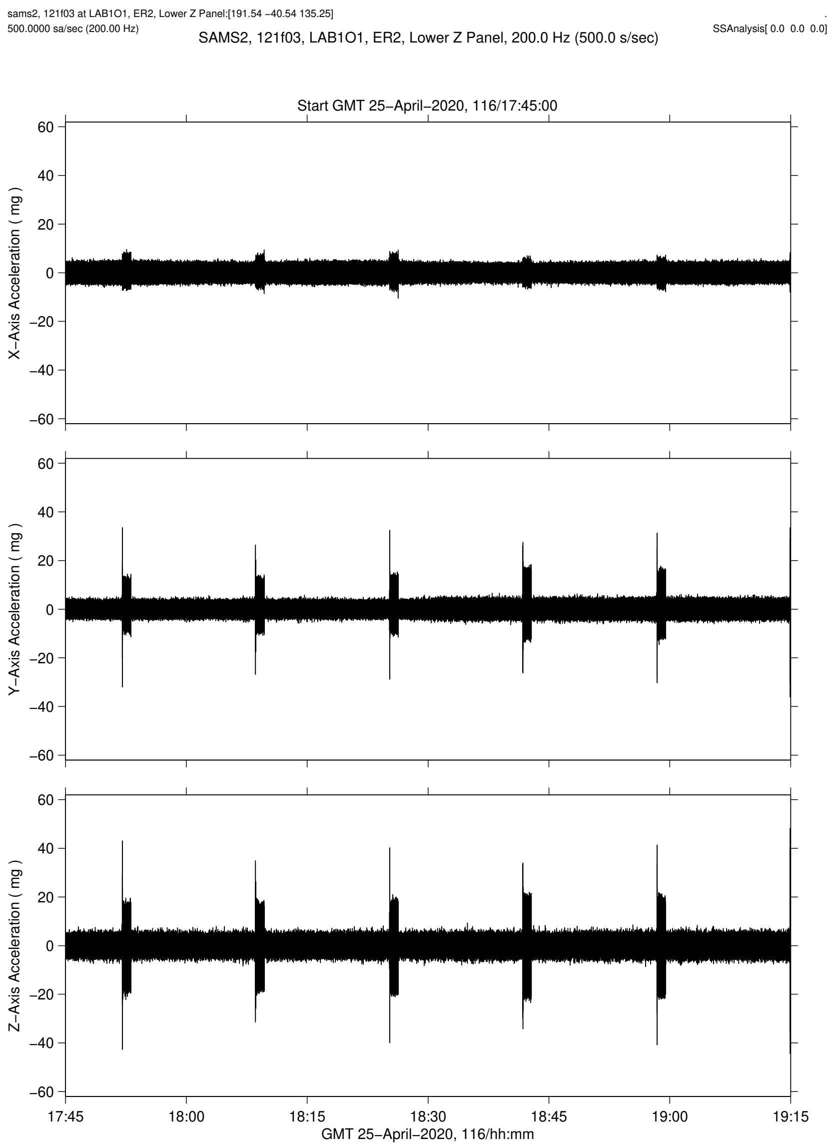

Fig. 8: SAMS LAB 121f03 acceleration data (up to 200 Hz) for desat firing.

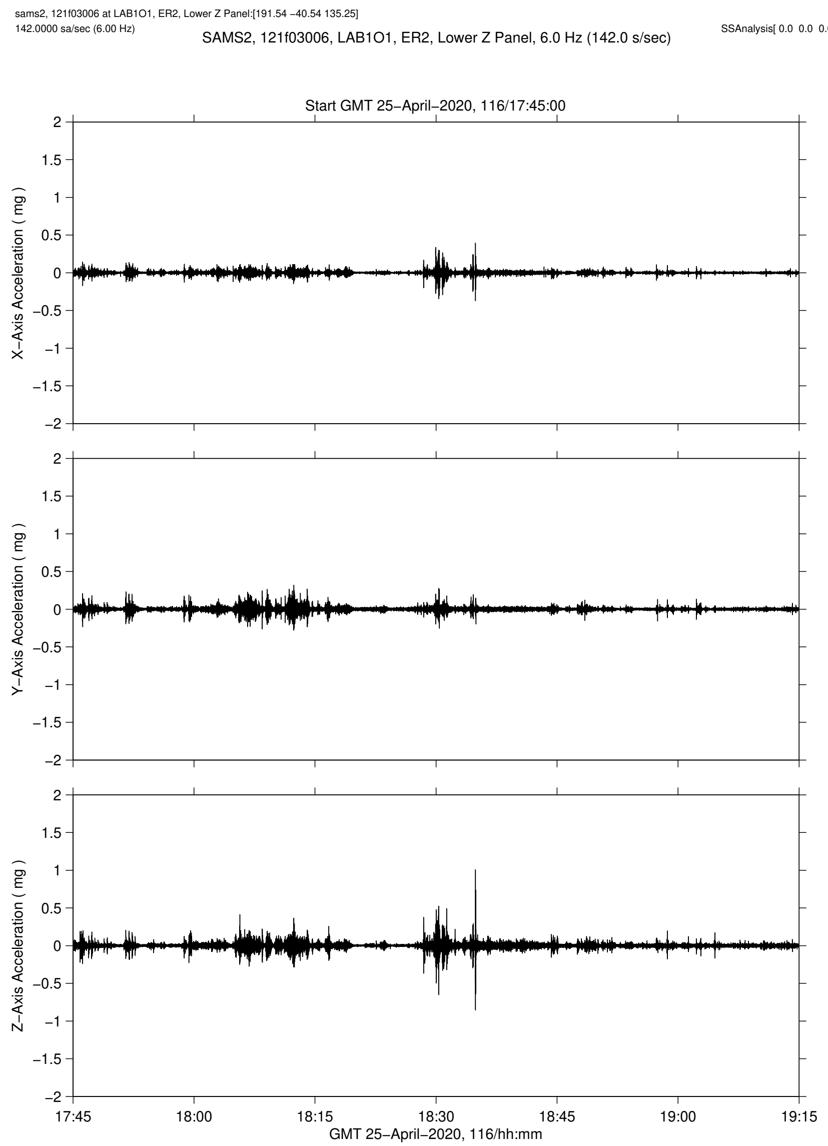

Fig. 9: SAMS LAB 121f03 acceleration data (f < 6 Hz) for desat firing.

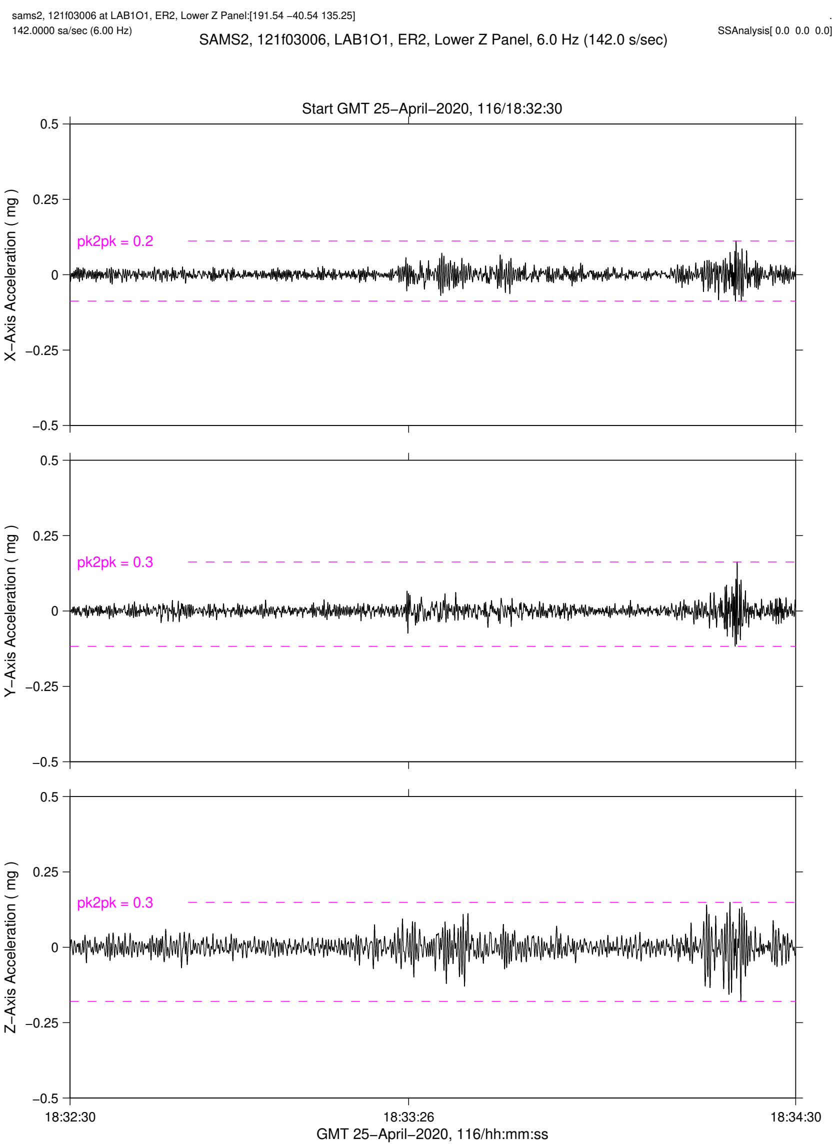

Fig. 10: SAMS LAB 121f03 acceleration data (f < 6 Hz) for desat firing zoom.

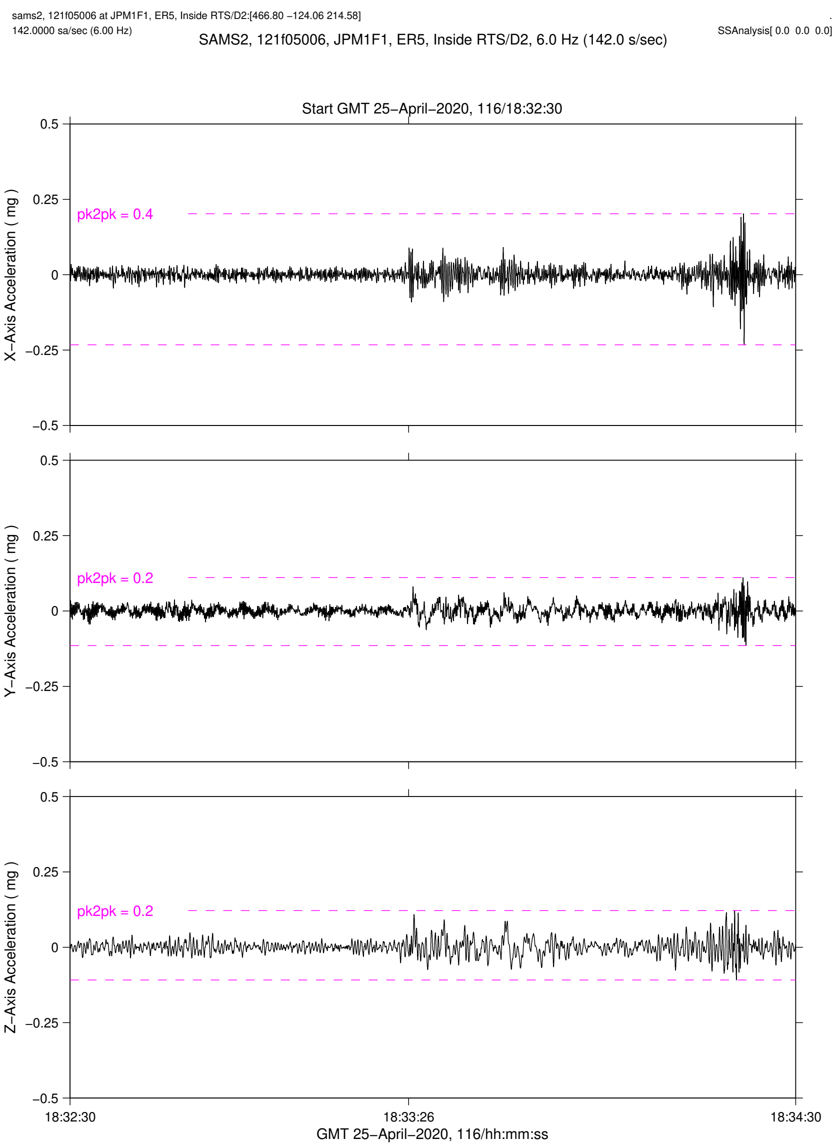

Fig. 11: SAMS JEM 121f05 acceleration data (f < 6 Hz) for desat firing zoom.

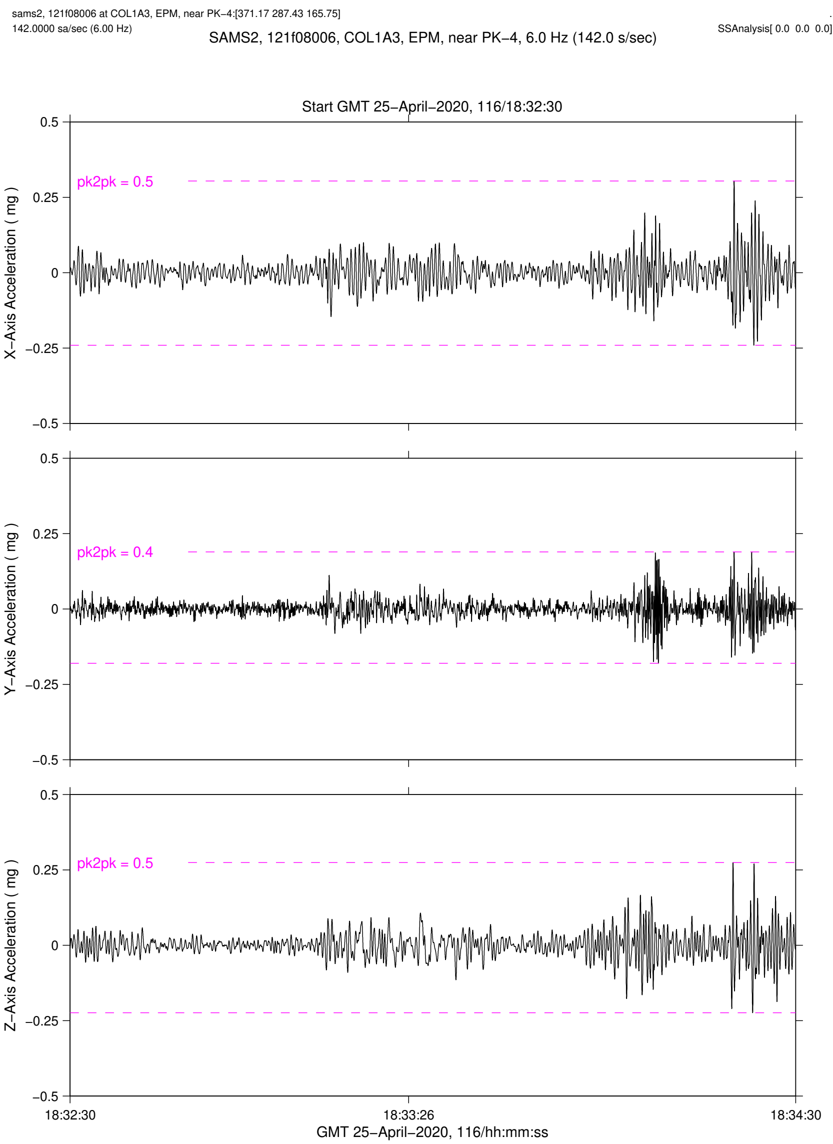

Fig. 12: SAMS COL 121f08 acceleration data (f < 6 Hz) for desat firing zoom.