

1. INTRODUCTION

For this analysis, we considered multiple start/end time spans (GMT) when the Combustion Integrated Rack (CIR) facility's recirculation pump(s) were operating. These time spans are shown in Table 1. The focus of our quantitative analysis will be on a narrow, 2 Hz wide frequency band centered on 50 Hz. This narrow band helps us identify the spectral signature, which we will refer to below as **RECIRC PUMP**, where this could be, in some cases, either one or two such pumps operating at a time within the same time span.

All of the Space Acceleration Measurement System (SAMS) data plots presented in this document were computed from measurements made by the Triaxial Sensor Head - Ethernet Standalone (TSH-ES, S/N 05, aka "es05") sensor mounted in the CIR facility (LAB1S3) on the International Space Station (ISS). Both the disturbance source and the measurement device housed in the same payload rack.

Row #	GMT Date	Start Time	End Time
1	2024-02-23	21:56:32	22:26:37
2	2024-02-24	00:42:26	01:12:32
3	2024-02-24	01:55:16	02:10:21
4	2024-08-01	20:49:48	21:19:18
5	2024-08-01	21:47:15	22:17:21
6	2024-08-02	02:01:46	02:39:51
7	2024-08-02	05:15:21	06:00:28

Table 1. GMT Start/End Times For Recirculation Pump(s) Ops.

2. QUALIFY

Before we undertake discussion of our quantitative analysis to characterize the vibratory impact of CIR recirculation pump operations, we qualify/identify the vibratory spectral signal attributed to the pumps via a few roadmap (overview) spectrograms. These plots help show the RECIRC PUMP operations noted in Table 1 above. In this section, we present four 8-hour roadmap spectrograms up to the full passband of the es05 sensor head, that is, up to 200 Hz. These spectrogram plots start with Figure 1 on page 3 and the four plots will cover all 7 of the time span rows in Table 1.

Roadmap Spectrogram Starting at GMT 2023-02-23/16:00: see Figure 1

This first plot covers row #1 of Table 1 and shows multiple on/off periods for the RECIRC PUMP as seen when focusing on a narrow frequency band centered on 50 Hz. The spectral signature of the pump is evident at just about 50 Hz as a red (strong) horizontal streak.

Roadmap Spectrogram Starting at GMT 2023-02-24/00:00: see Figure 2

Figure 2 on page 4 shows two on/off periods that correspond to Table 1 rows 2 and 3. The spectral signature of the pump is again strongly evident near 50 Hz.

Roadmap Spectrogram Starting at GMT 2023-08-01/16:00: see Figure 3

This figure shows two more on/off periods that correspond to Table 1 rows 4 and 5 along with another, brief on/off period (not annotated other than it is nearly encircled by the 2nd "C" in the white "RECIRC PUMP" text.

Roadmap Spectrogram Starting at GMT 2023-08-02/16:00: see Figure 4

This last roadmap spectrogram in Figure 4 on page 6 shows RECIRC PUMP on/off periods from rows 6 and 7 of Table 1. It also points out (in blue) a period of 6 successive, brief pump ON periods discussed later.

3. QUANTIFY

As a means of quantifying the impact of CIR's recirculation pump(s), we consider acceleration interval root-mean-square (RMS) levels in total and per-axis as computed via Parseval's Theorem from per-axis power spectral density (PSD) arrays derived from SAMS acceleration measurements. These results help to characterize this disturbance in nearly pinpoint fashion as we employ calculations targeted to clearly show the impact in both time and frequency in the form of RMS levels. We only consider a narrow frequency band centered on the strong spectral peak at 50 Hz.

The computations referenced above resulted in 4 interval RMS plots, starting with Figure 5 on page 7. In terms of time span, these 4 plots overlap at least partially with the previous 4 roadmap spectrograms (see bottom, horizontal-axis ticks). These RMS plots give clear indication when the pump was ON (higher RMS levels) versus OFF (baseline RMS) level).

Note that the first 2 interval RMS plots from February 2024 show slightly higher vibration levels relative to those from August 2024 – this is evident by the y-scale limits on these RMS plots. In February 2024, the RMS levels topped out near

1.5 mg_{RMS}, while in August the topouts were below 1.3 mg_{RMS}. A minor shift down in terms of RMS accelerations, and most likely due to the pump(s) vibrations themselves...however, it could be that in February, some other disturbance vibrating near 50 Hz (unaccounted for here) was contributing to the narrowband RMS levels near 50 Hz and therefore boosting the the RMS levels slightly relative to August 2024. We cannot discern the source of such a shift in vibration levels from this analysis.

Directionality Evident via Interval RMS vs. Time

The interval RMS vs. time plots of Figure 5 on page 7 and Figure 9 on page 11 show *total RMS as the top subplot* and then the 3 subplots below that are the X-axis, Y-axis, and Z-axis components, respectively. These consistently indicate that the recirculation pumps actuators are aligned primarily with the XY-plane. The Z-axis vibrations still do show indications of recirculation pump activity, but to a notably lesser degree.

Six Brief Pump ON Periods Seen via Time-Zoomed Interval RMS

The interval RMS vs. time plot of Figure 7 on page 9 shows how the RMS steps up and down for each of 6 relatively brief pump ON periods on GMT 2024-08-02 just before 03:00.

Propagation of 50 Hz CIR Recirculation Pump Disturbance

An interesting set of four "propagation plots" which show interval RMS vs. time plots analogous to that of Figure 7 on page 9 for 4 other SAMS sensors distributed throughout the US LAB:

Sensor	Location (Rack)	Figure Reference	Propagates from LAB1S3?
es20	LAB1S2	Left side of Figure 8 on page 10	Yes
es18	LAB1O4	Right side of Figure 8 on page 10	Yes
121f03	LAB1O1	Left side of Figure 9 on page 11	No
121f04	LAB1P2	Right side of Figure 9 on page 11	Yes

Table 2. Pump 50 Hz Propagation in LAB as Measured by Other SAMS Sensors.

4. CONCLUSION

SAMS measurement data from the CIR in February and August GMT 2024 were analyzed given 7 as-run ON time spans (start/end times), and the SAMS sensor (TSH ES-05) measurement data **show good SAMS timing correlation relative to the as-run recirculation pump ON times**. We were able to isolate and quantify the impact of the CIR recirculation pump operations on the vibratory environment in terms of RMS acceleration levels with a stark, clear contrast between baseline (pumps OFF) versus operations (pumps ON) for acceleration measurements made within the same rack as the CIR recirculation pump. We also showed how the 50 Hz vibrations from the pump propagate to various other SAMS sensor locations throughout the US LAB. Details in the figures throughout this document serve to qualify and quantify and thus help characterize these pump(s) operations impact on the vibratory microgravity environment in and nearby the CIR.

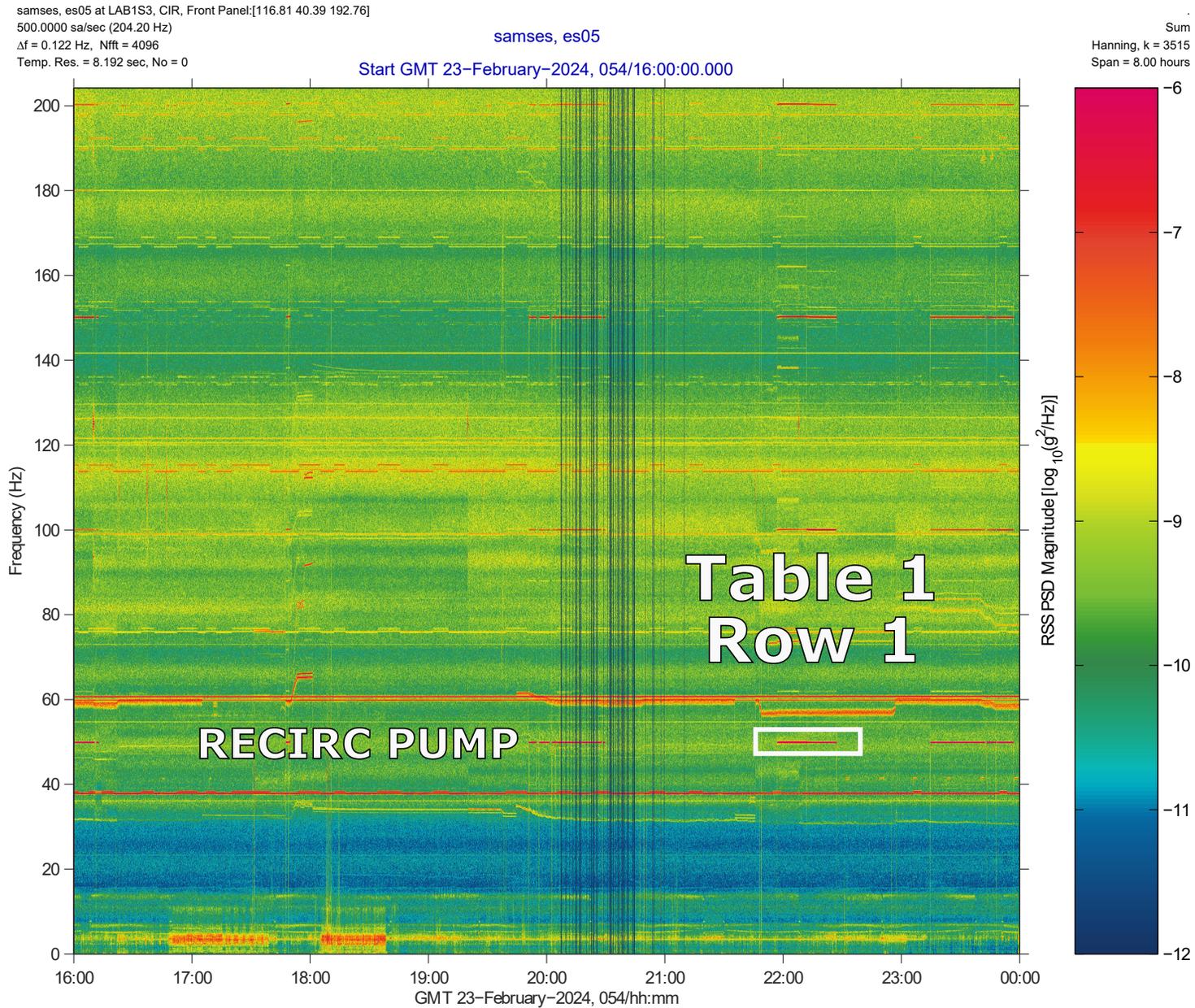


Fig. 1: SAMS es05 (CIR) Sensor 8-Hour Color Spectrogram Below 200 Hz, Starting at GMT 2024-02-23/16:00.

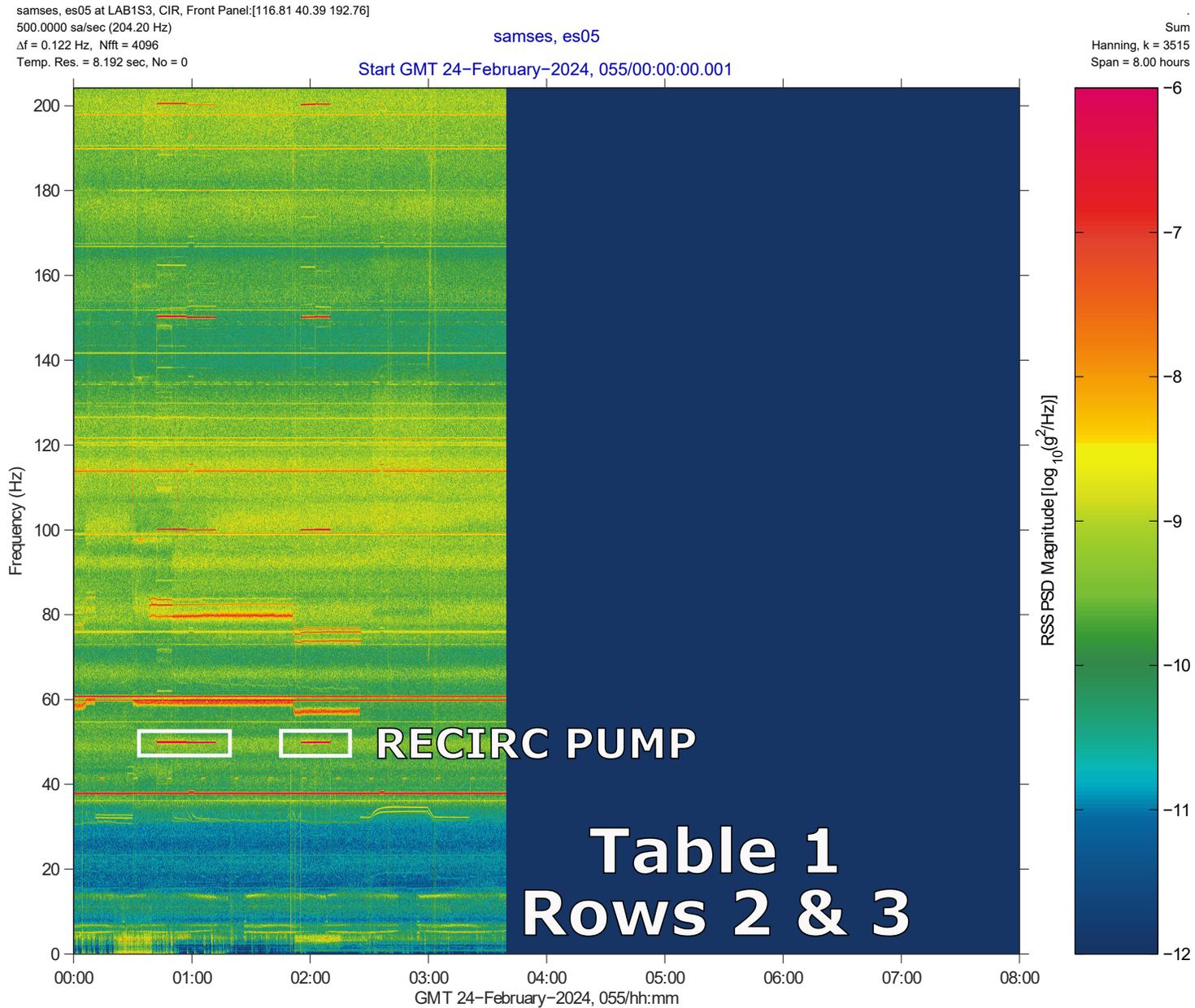


Fig. 2: SAMS es05 (CIR) Sensor 8-Hour Color Spectrogram Below 200 Hz, Starting at GMT 2024-02-24/00:00.

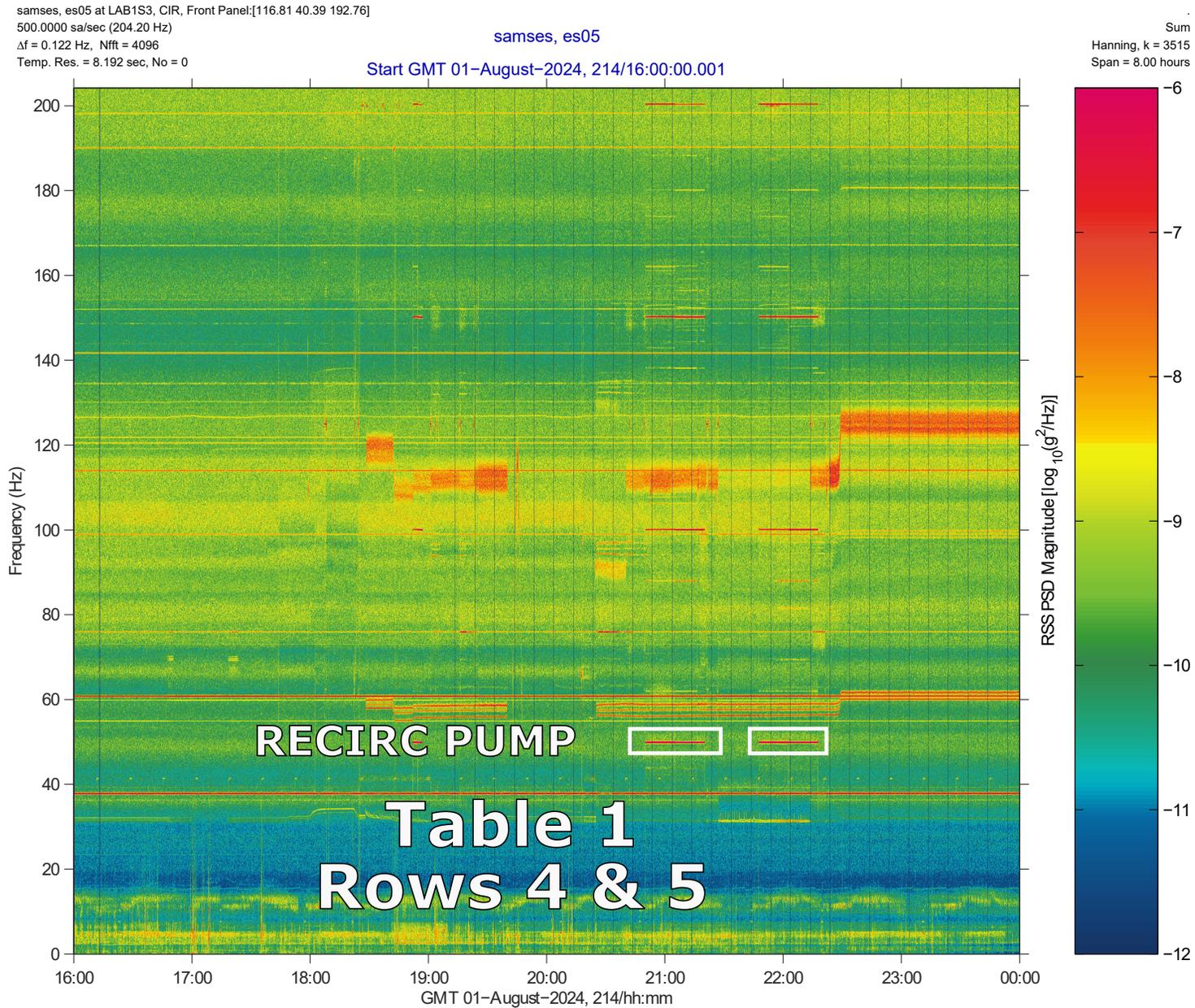


Fig. 3: SAMS es05 (CIR) Sensor 8-Hour Color Spectrogram Below 200 Hz, Starting at GMT 2024-08-01/16:00.

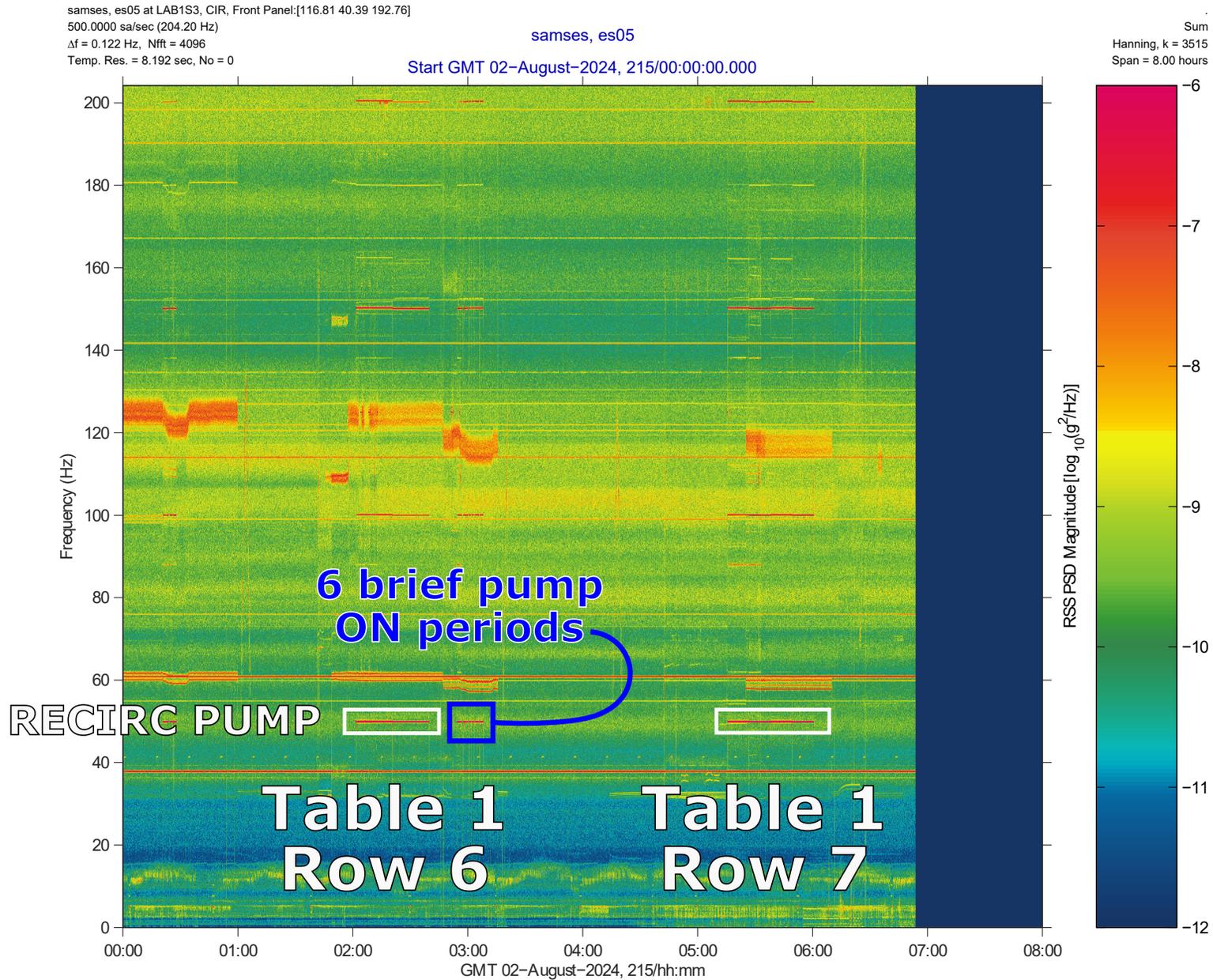


Fig. 4: SAMS es05 (CIR) Sensor 8-Hour Color Spectrogram Below 200 Hz, Starting at GMT 2024-08-02/00:00.

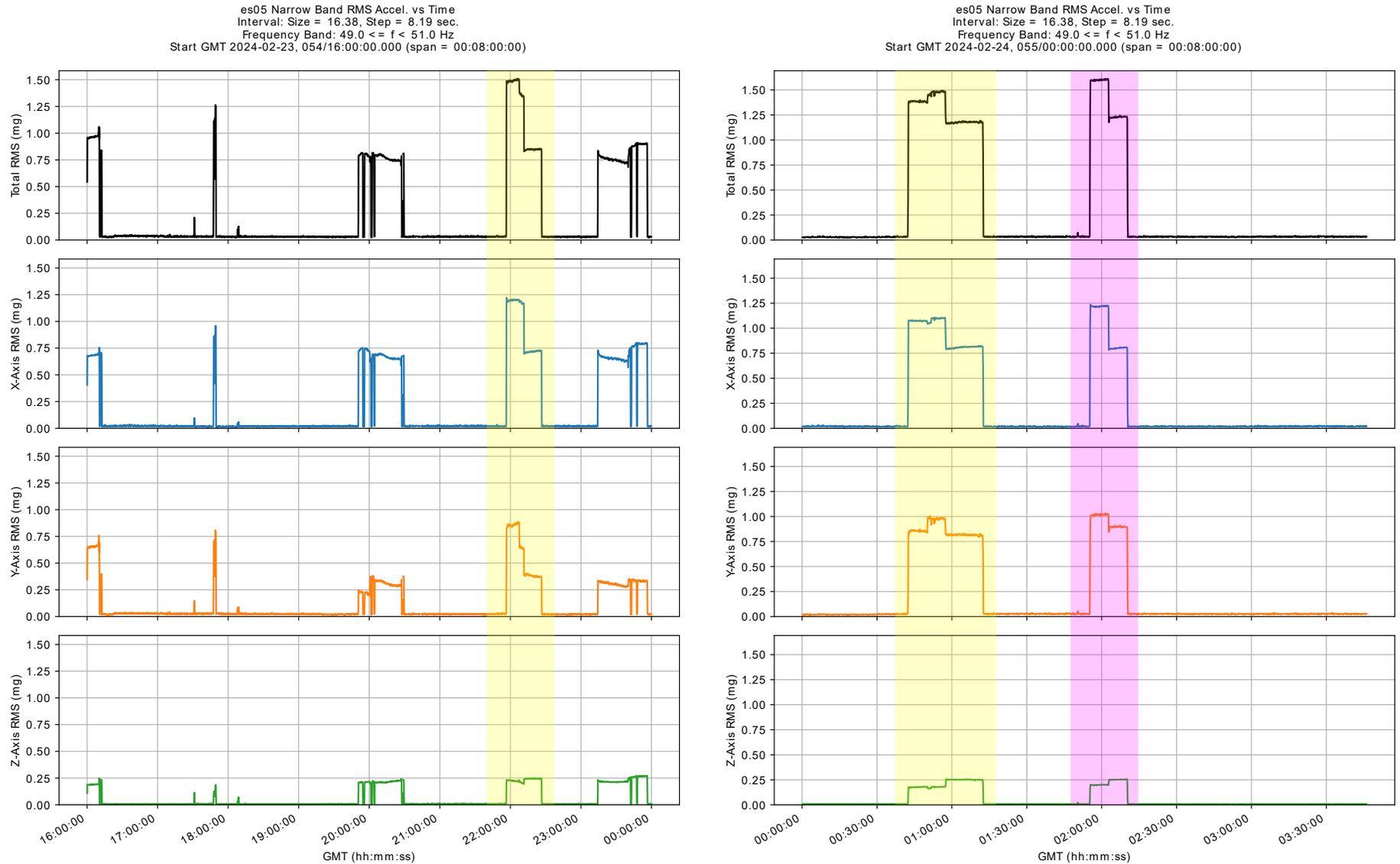


Fig. 5: SAMS es05 (CIR) Interval RMS with highlighted regions for: (left) **Table 1, Row #1** and (right) **Table 1, Rows #2 & #3**.

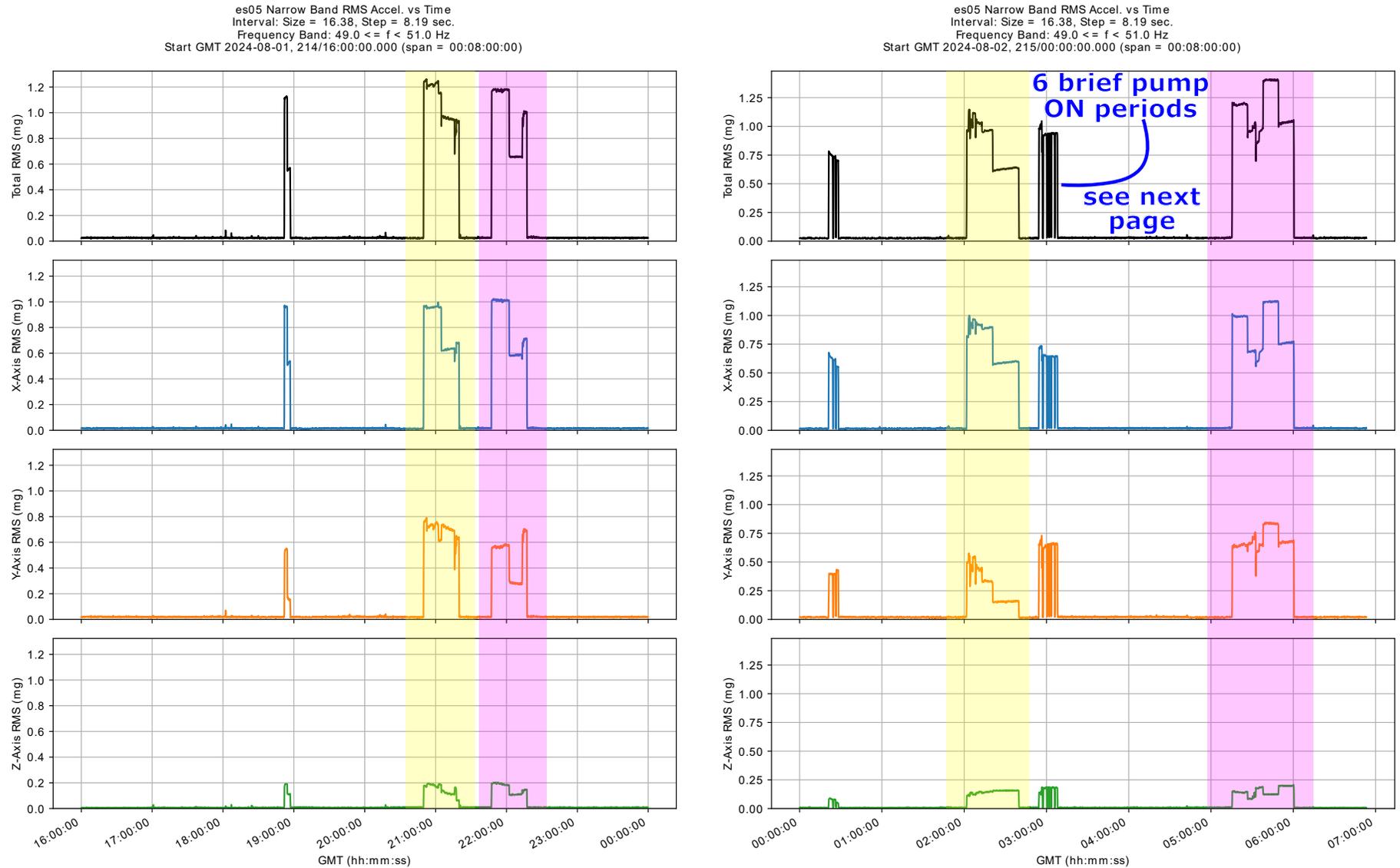


Fig. 6: SAMS es05 (LAB1S3) Interval RMS with highlighted regions for: (left) **Table 1, Rows #4 & #5** and (right) **Table 1, Rows #6 & #7**.

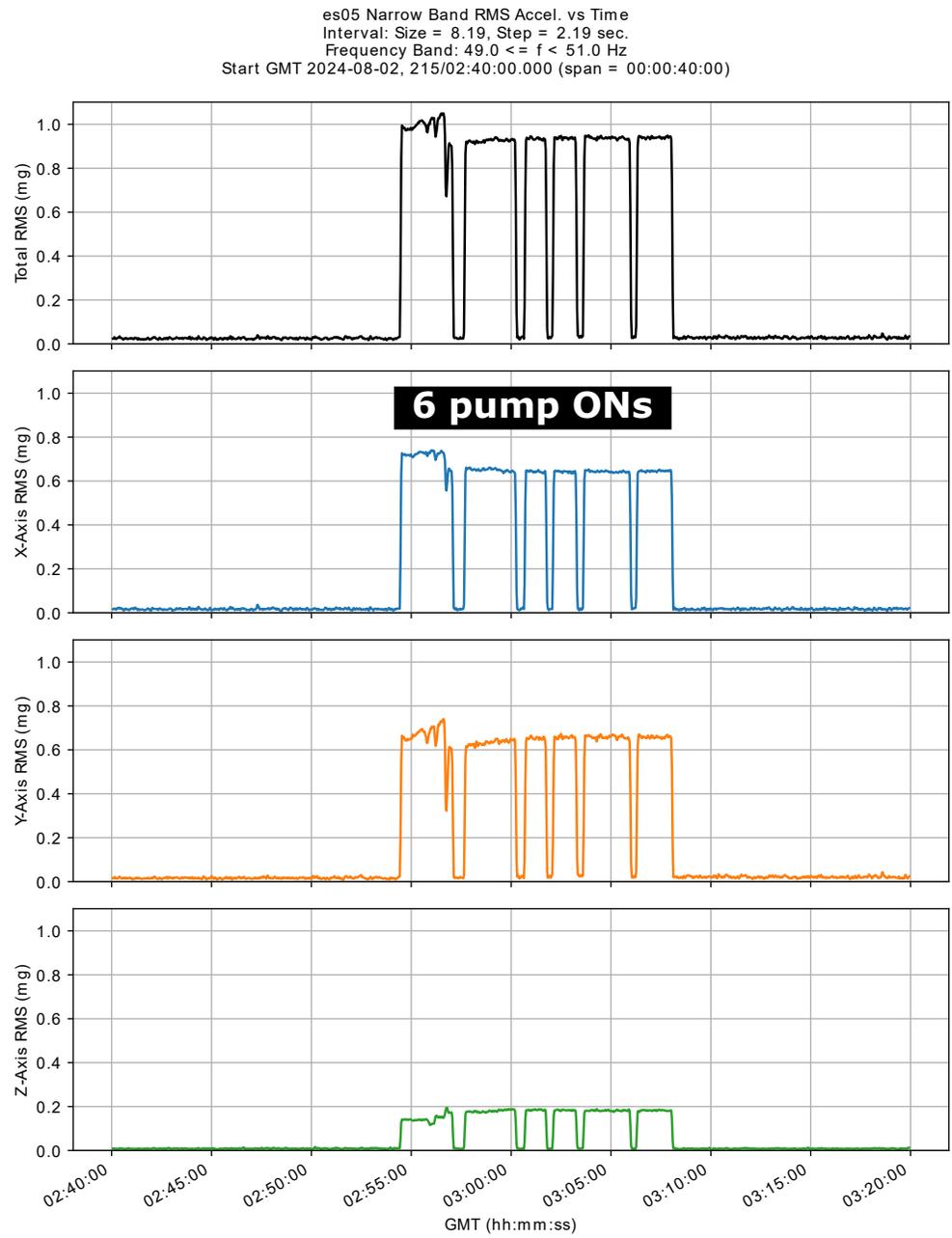


Fig. 7: SAMS es05 (LAB1S3) Interval RMS Time-Zoomed to Show **6 Brief Pump ON Periods** on GMT 2024-08-02.

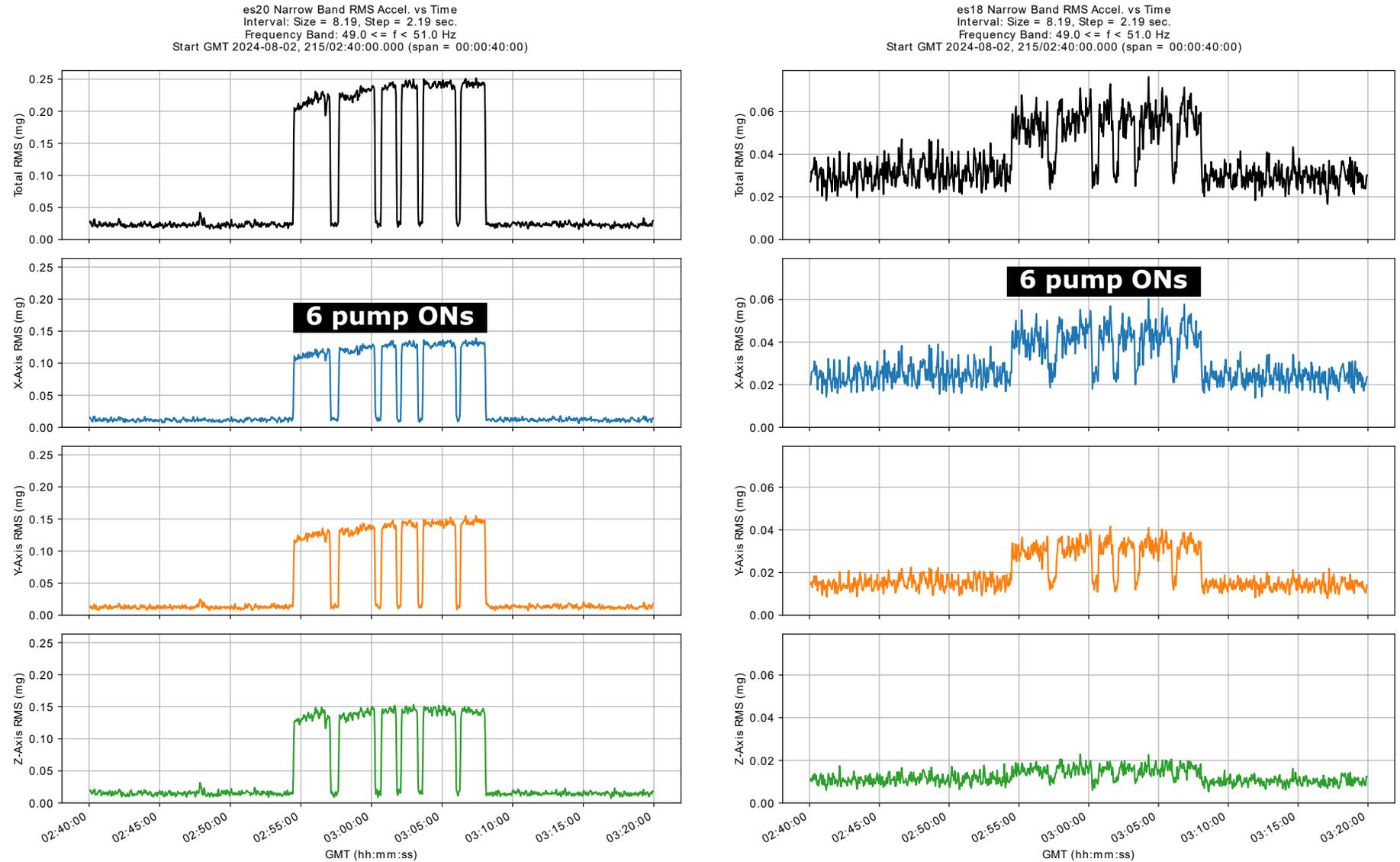


Fig. 8: Interval RMS for SAMS Sensor: (left) es20 on LAB1S2, and (right) es18 on LAB1O4

121f03 Narrow Band RMS Accel. vs Time
 Interval: Size = 8.19, Step = 2.19 sec.
 Frequency Band: 49.0 <= f < 51.0 Hz
 Start GMT 2024-08-02, 215/02:40:00.000 (span = 00:00:40:00)

121f04 Narrow Band RMS Accel. vs Time
 Interval: Size = 8.19, Step = 2.19 sec.
 Frequency Band: 49.0 <= f < 51.0 Hz
 Start GMT 2024-08-02, 215/02:40:00.000 (span = 00:00:40:00)

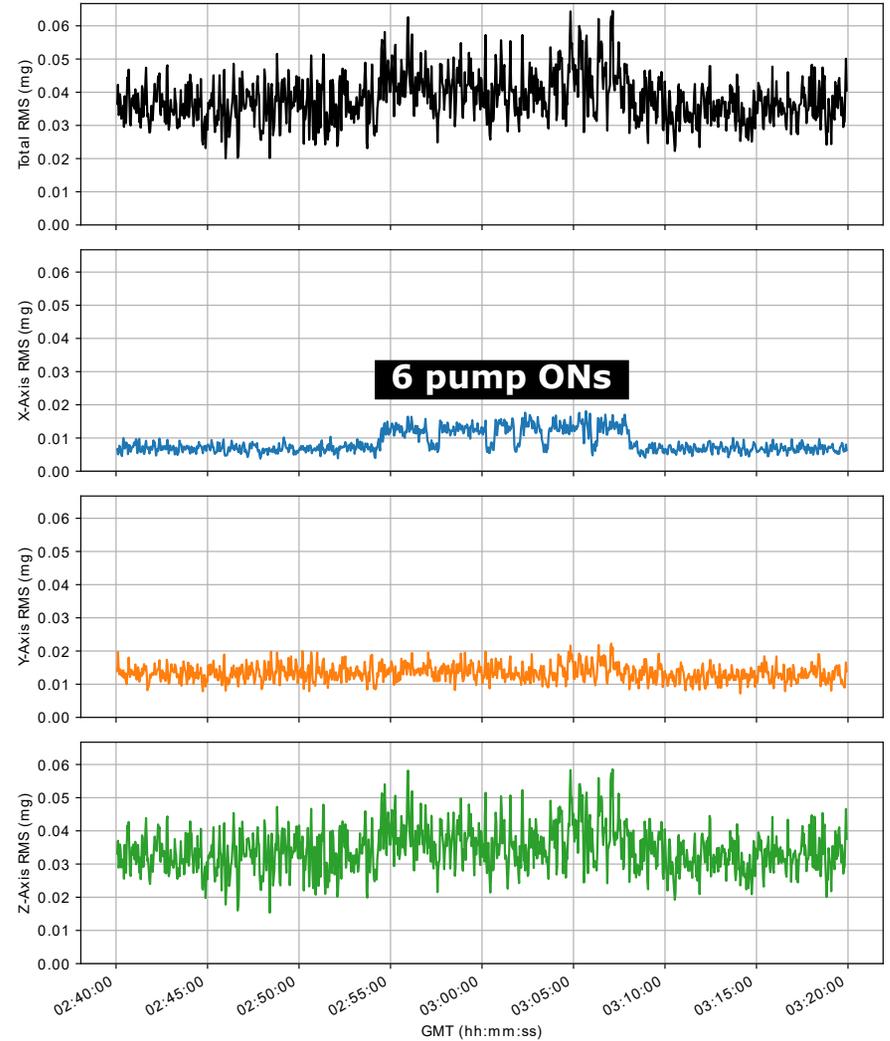
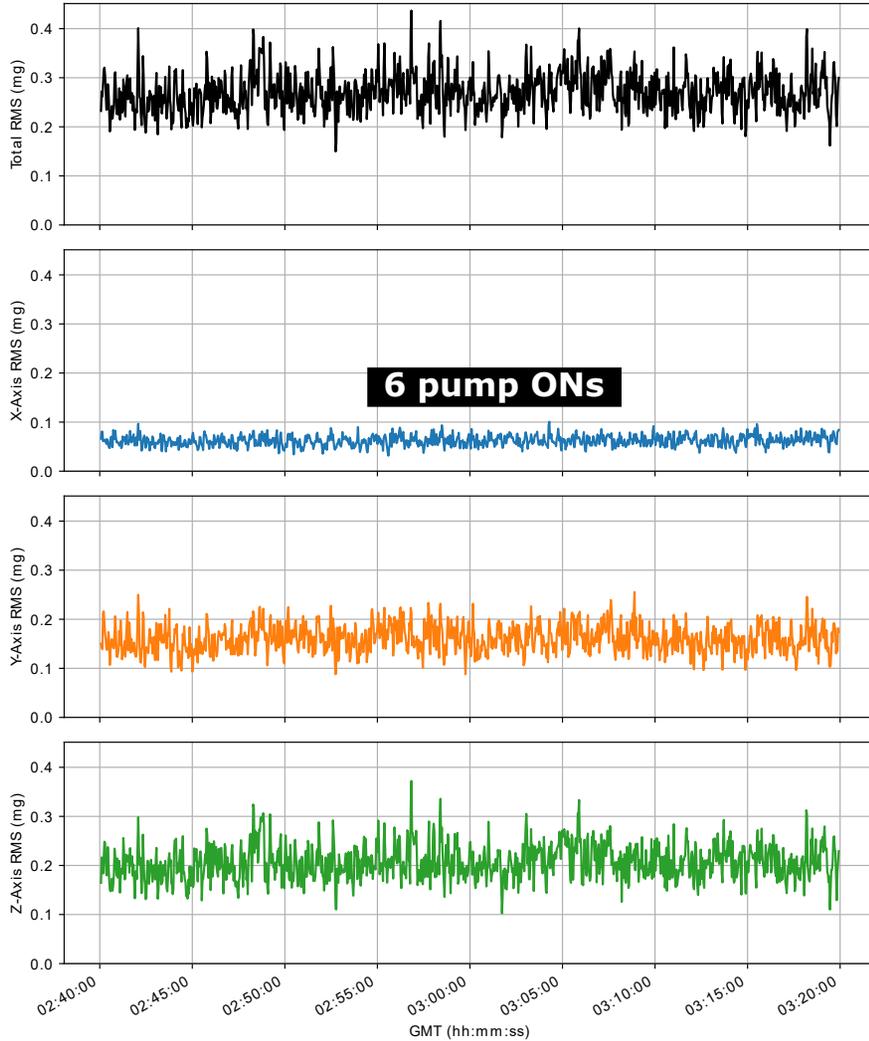


Fig. 9: Interval RMS for SAMS Sensor: (left) 121f03 on LAB101, and (right) 121f04 on LAB1P2