1. INTRODUCTION

The HRF Centrifuge is a swing-bucket, unrefrigerated centrifuge used to separate substances of different densities via relative centrifugal force that would normally separate slowly under the influence of gravity or not at all in microgravity. This unit, launched on SpX-14 during Expedition 55, is based on a modified Drucker Model 755VES centrifuge, and is mounted to the internal sliding tray of an HRF Payload Drawer (a sub-rack support platform occupying an 8PU drawer shell that provides power and data interfaces for either internal or external payloads). The HRF Centrifuge supports the use of up to 6 HRF Centrifuge Tube Carriers, suspended from the rotor using magnets and each containing 4 wells – 2 for 15-mm to 16-mm outer diameter (OD) centrifuge tubes and 2 for 12-mm to 13-mm OD centrifuge tubes. **Spin times range from 1 to 99 minutes in duration (in one-minute increments) at a rotor speed of 1,000 to 4,300 RPM (in increments of 100 RPM)**. Braking force is selectable (ranges from 0, for no additional braking force, to 9, which provides maximum active braking force), and the imbalance detection threshold, based on tri-axial accelerometers, can be specified between 1 (no alarm) and 10 (hair-trigger sensitivity) for each axis. The HRF Centrifuge enables ground controllers to customize spin protocols, start runs and query various telemetry parameters in real-time via RDP on the HRF PC.

2. QUALIFY

"A piece of cake"...that is, we should be able to use the yellow-highlighted information on spin times and rates, cited in the section above, to identify the centrifuge vibration signature using Space Acceleration Measurement System (SAMS) measurements made in the Columbus module on this day of centrifuge operations. First though, let's see the layout in the Columbus module with respect to the locations of 2 SAMS sensor heads and the centrifuge. Figure 1 shows the layout in the Columbus module with:

- centrifuge located in the rack designated COL1A4
- SAMS sensor head (SE-F08) in the rack designated COL1A3
- SAMS sensor head (SE-F02) in the rack designated COL1A1

SAMS Measurement Correlation with Reported Operations Notes

Note that the SAMS SE-F08 sensor head in the EPM rack was mounted directly adjacent to the HRF-2 rack, which houses the centrifuge. Furthermore, a color spectrogram computed from Space Acceleration Measurement System (SAMS) sensor 121f08 measurements in Figure 2 on page 3 shows two spin cycles starting at the times annotated with arrows at the **fundamental frequency of 44.9 Hz (2,694 RPM) and a duration of 15 minutes for each spin cycle – both of these parameters fall within the expected range for the HRF-2 centrifuge**.

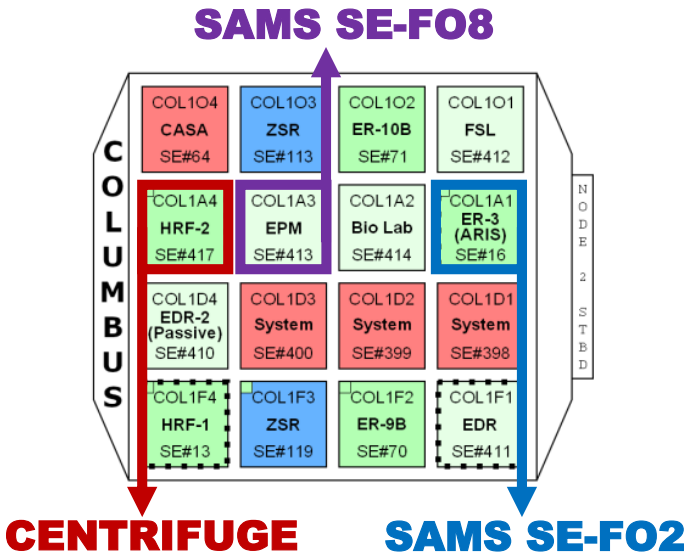

Fig. 1: Topology in Columbus Module.

As we see on page 4 in Figure 3 the ER-3 (COL1A1) rack, where the SAMS SE-F02 sensor head is mounted, is a noisier ambient, local vibratory environment. This makes the centrifuge vibrations signature less distinctive by comparison. Also, this sensor is 3 racks away from the centrifuge, so the centrifuge signal reaching here is attenuated along its transmission path. We show a zoom-in of the first spin cycle on the subsequent page (Figure 4), where the centrigure's narrowband signature is more distinctive and spin-up and spin-down are seen as red vertical streaks on either end of the red, horizontal (constant frequency) plateau at the fundamental frequency of 44.9 Hz.

3. QUANTIFY

Taking a first crack at quantifying the centrifuge vibratory impact, we show Figure 5 on page 6 with several power spectral density (PSD) plots computed from:

- SAMS sensor head (SE-F02) in the rack designated COL1A1 on the left
- SAMS sensor head (SE-F08) in the rack designated COL1A3 on the right

The 3 subplots for each sensor head show:

- X-axis on the top subplot
- Y-axis on the middle subplot
- Z-axis on the bottom subplot

and each subplot shows 2 PSDs from 14-minutes of data starting at:

- GMT 09:00:00 when the centrifuge was OFF in black
- GMT 07:48:00 when the centrifuge was ON in red

These PSD plots serve to only crudely quantify the impact and propagation of the centrifuge vibrations at two SAMS sensor head locations. The main impact and signal feature is shown just to the right of the vertical dashed line at 40 Hz in Figure 5. That is the narrowband spectral peak at the fundamental frequency of the centrifuge at 44.9 Hz on the red traces, all axes, both sensor heads when it was ON (spinning). There are harmonics present at integer multiples of the fundamental frequency, but those are lower in magnitude and thus less of an impact. Also, the centrifuge impact is quite a bit more at the SAMS sensor head (SE-F08) location that is closer to this disturbance source.

Parseval's Theorem to Better Quantify the Centrifuge's Impact

When we focus on a narrow band of frequencies ($44.6 < f < 45.2$ Hz) around the fundamental frequency of the centrifuge (44.9 Hz), we now can isolate this band to quantify in terms of acceleration root-mean-square (RMS) magnitude via Parseval's theorem. Figure 6 on page 7 shows a 16-second interval acceleration RMS versus time plot for each of 3 XYZ axes plus the overall RMS value as a black trace. Notice that the SE-F02 sensor head registers the centrifuge mainly aligned with the XZ-plane and less so on the Y-axis. The next page with Figure 7 shows the same time of plot, but this time for the SE-F08 sensor head. Again, we see XZ-plane alignment (mostly), and much less so on the Y-axis. Also, note that at this closer sensor head location, we see **over ten times the RMS value at the SE-F08 location compared to the SE-F02 location.**

4. CONCLUSION

We have shown that SAMS vibratory sensor measurements in the Columbus module correlated closely with the operational parameters for the HRF centrifuge on GMT 2022-10-06. For calculations based on SAMS measurements, we see that a strong disturbance aligned mainly with the XZ-plane propagates through the Columbus module with primary impact near 45 Hz and RMS acceleration levels approaching 5 mg at the closer of two SAMS sensor head locations.

FOLLOW-UP

It was noted after an initial draft of this document that the centrifuge signature appeared again starting at about GMT 2022-10-14/11:07 – perhaps a follow-up/comparison analysis will be coming on this!

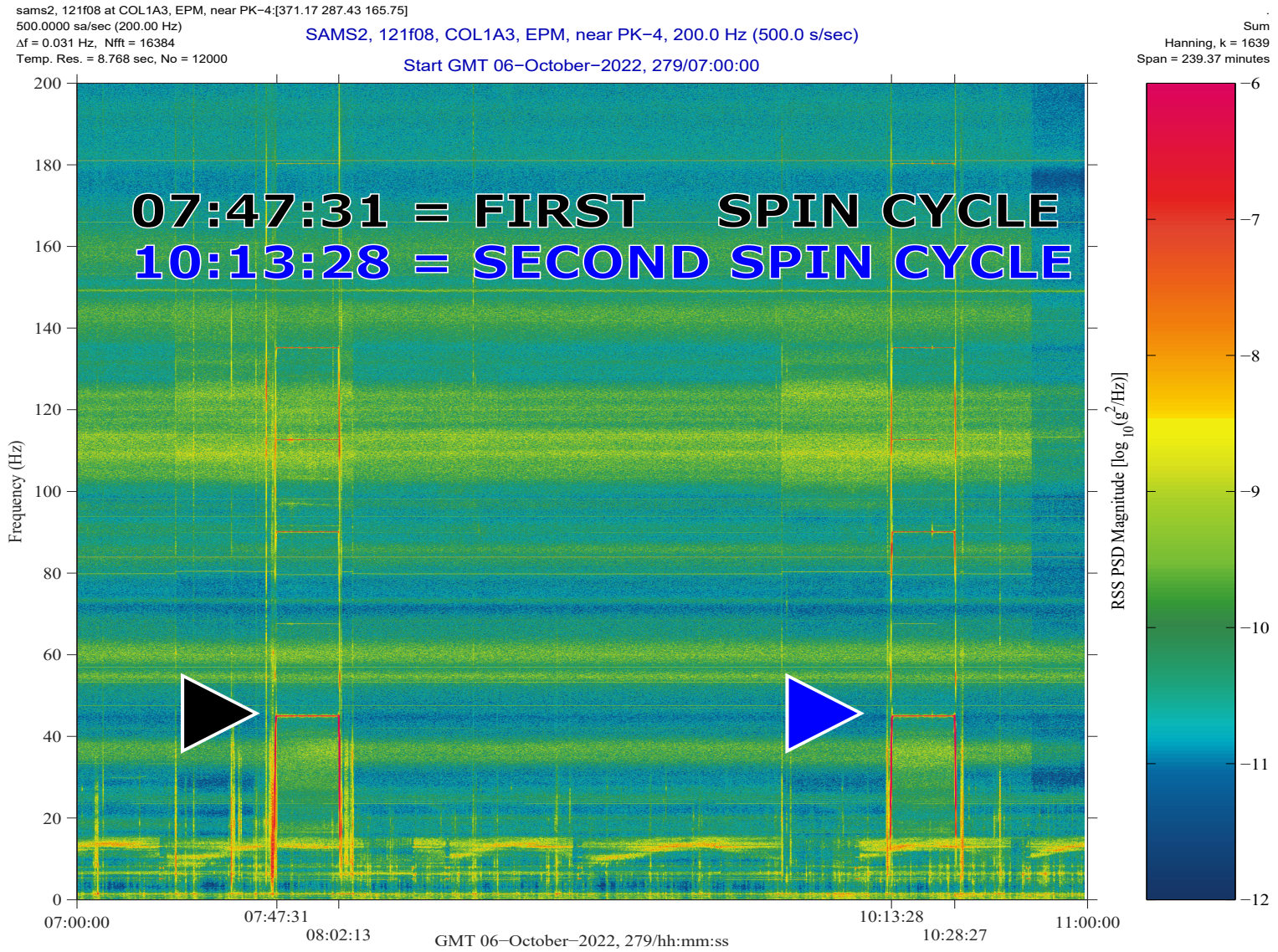

Fig. 2: 4-Hour Spectrogram (Nearby SAMS Sensor) Showing Two Centrigure Spins on GMT 2022-10-06.

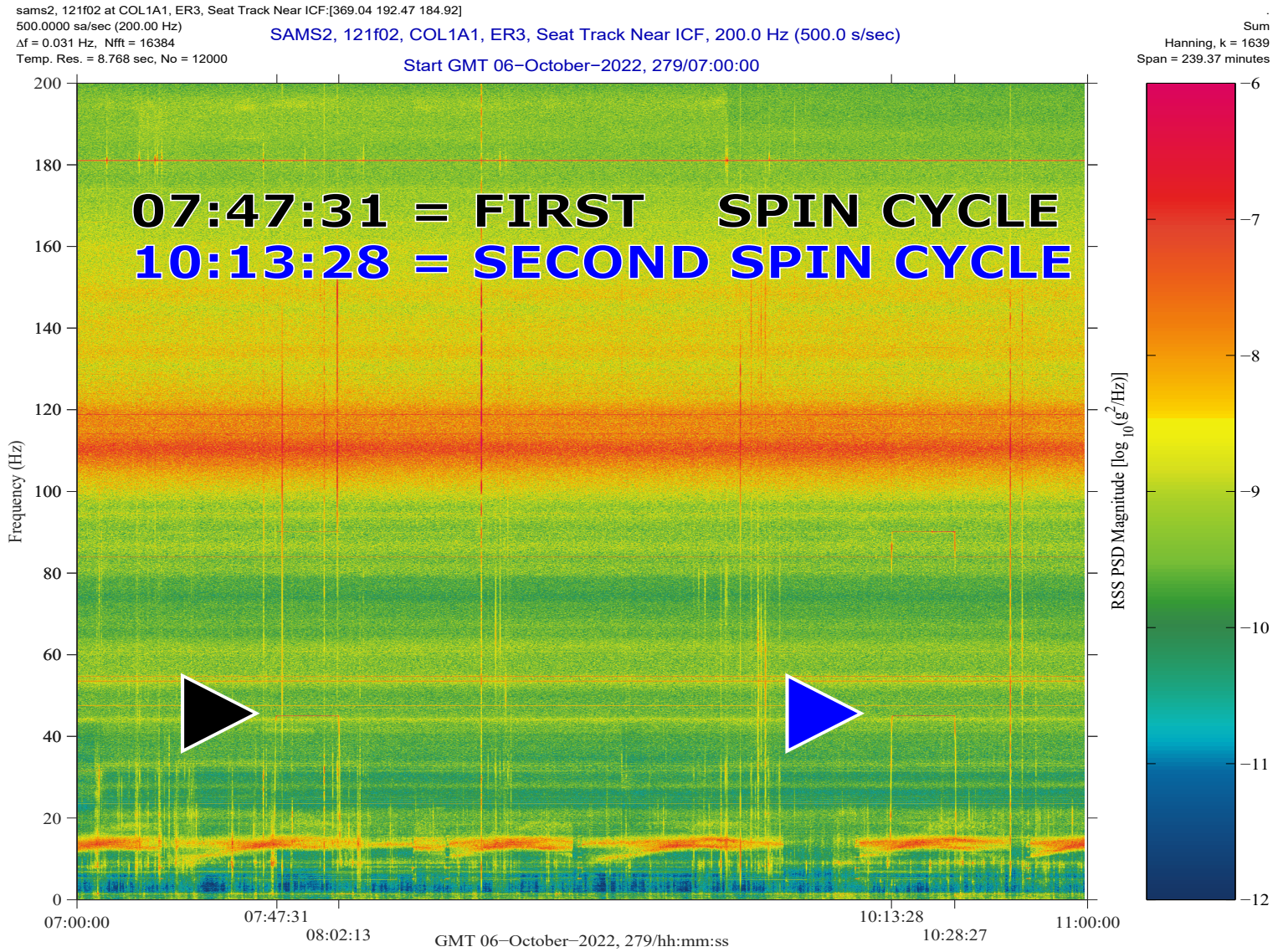

Fig. 3: 4-Hour Spectrogram (Farther Away SAMS Sensor) Showing Two Centrigure Spins on GMT 2022-10-06.

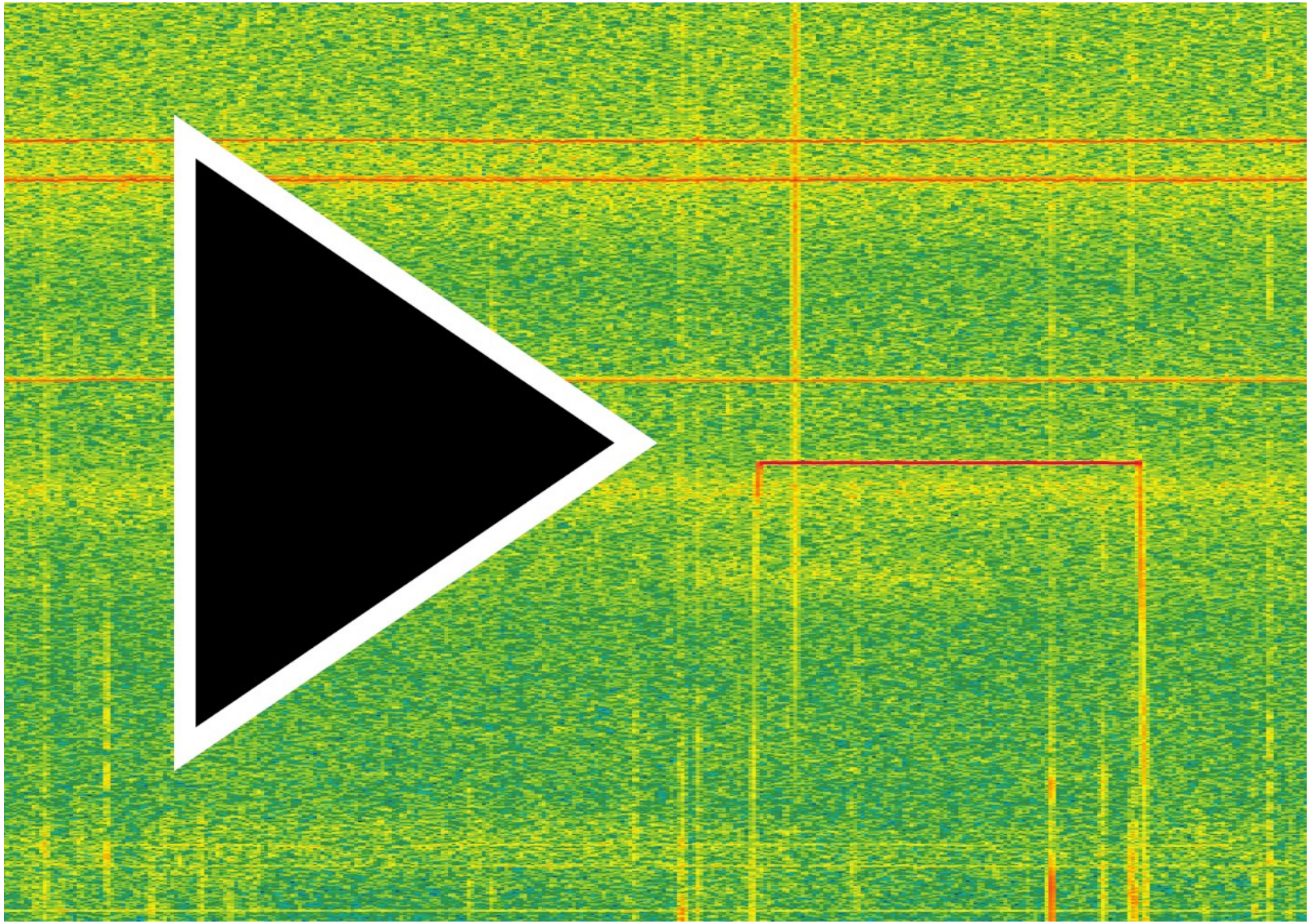

Fig. 4: SAMS SE-F02 Spectrogram Zoom-In on 1st Centrigure Spin Cycle.

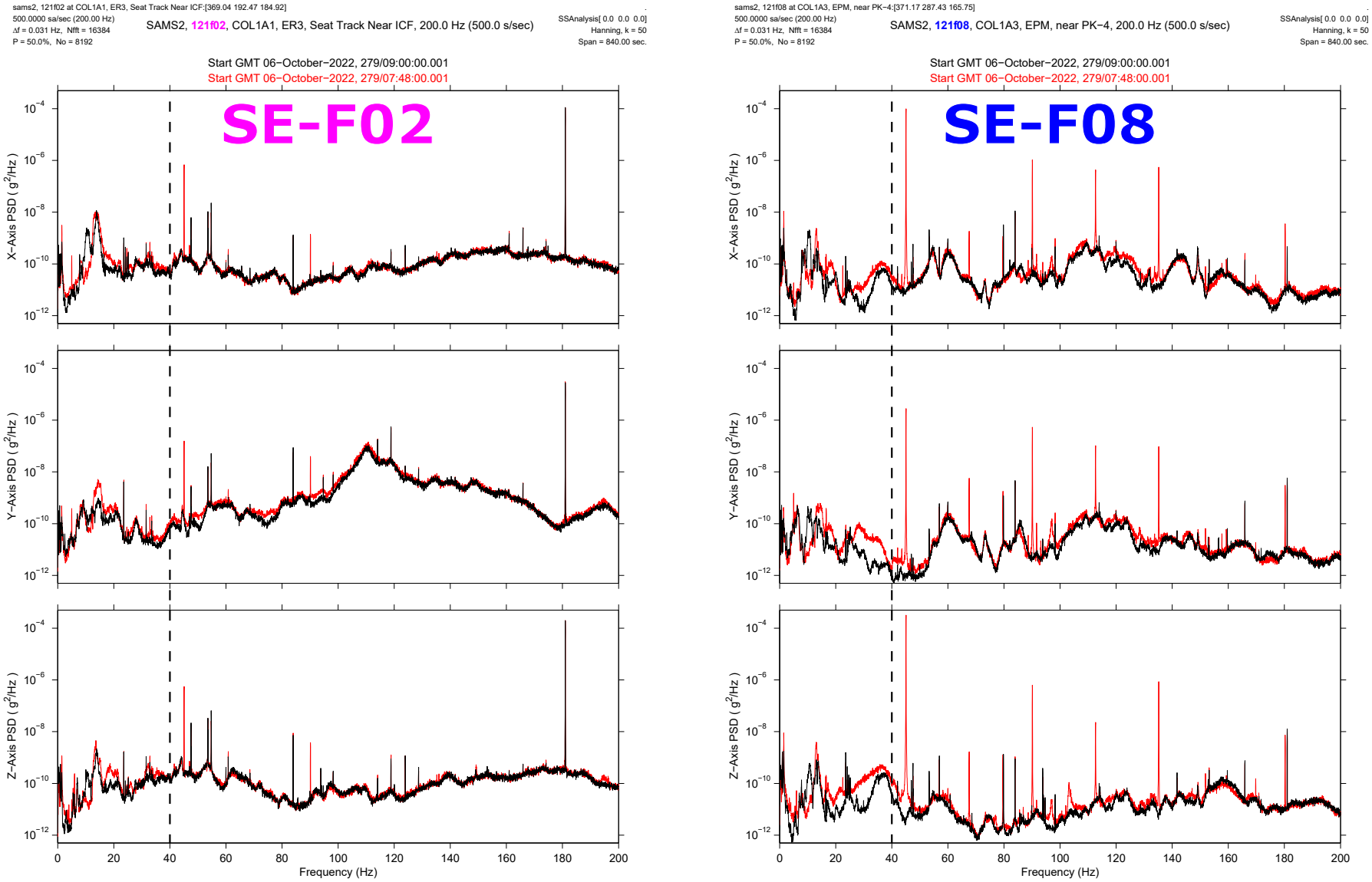

Fig. 5: SAMS XYZ PSDs for (left) SE-F02, ER-3 & (right) SE-F08, EPM, Comparing Centrifuge **ON (in red)** versus **OFF (in black)**.

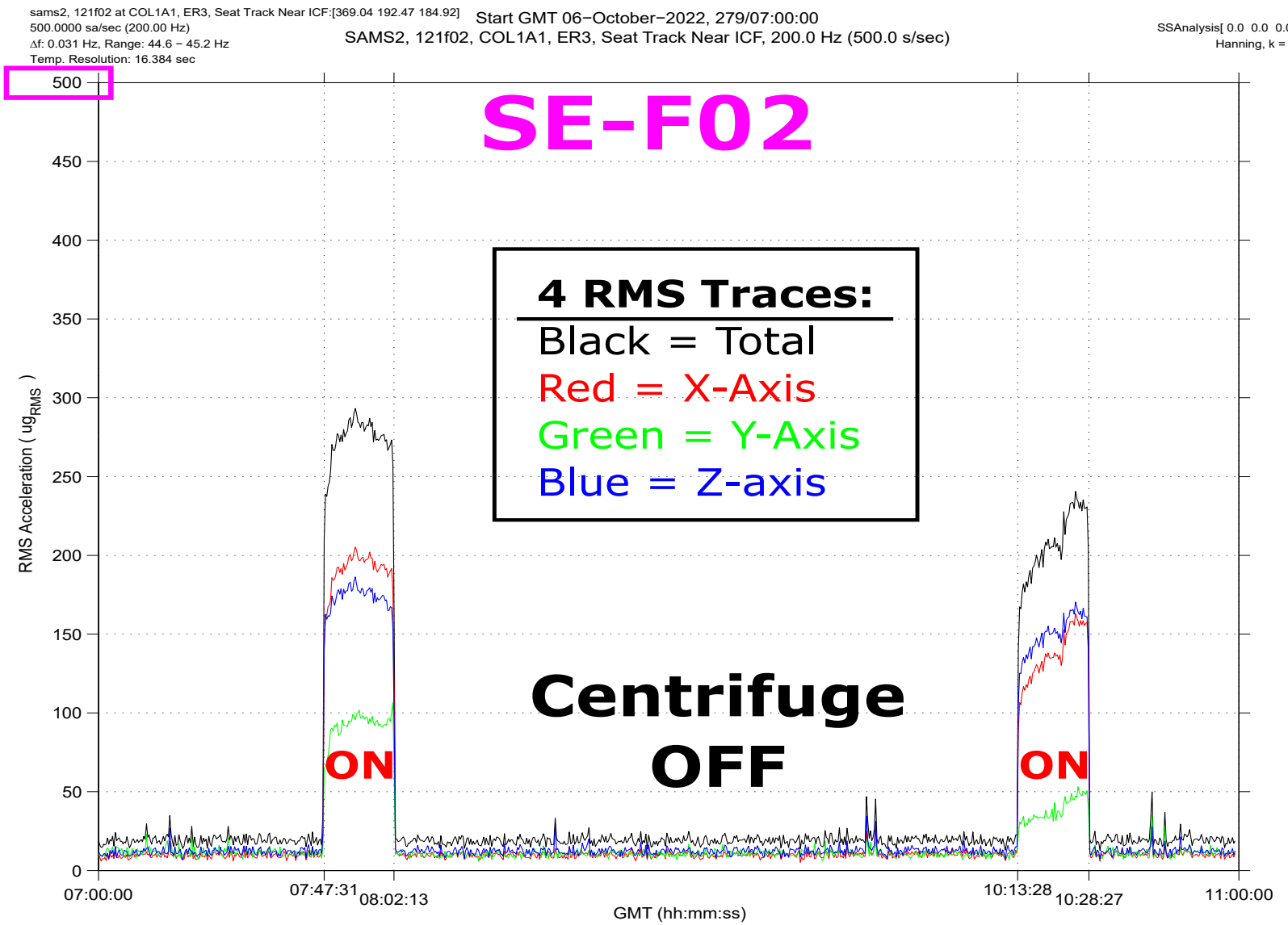

Fig. 6: SE-F02 16-Second Interval RMS (44.6 < f < 45.2 Hz) Shows 2 Centrigure Spins on GMT 2022-10-06.

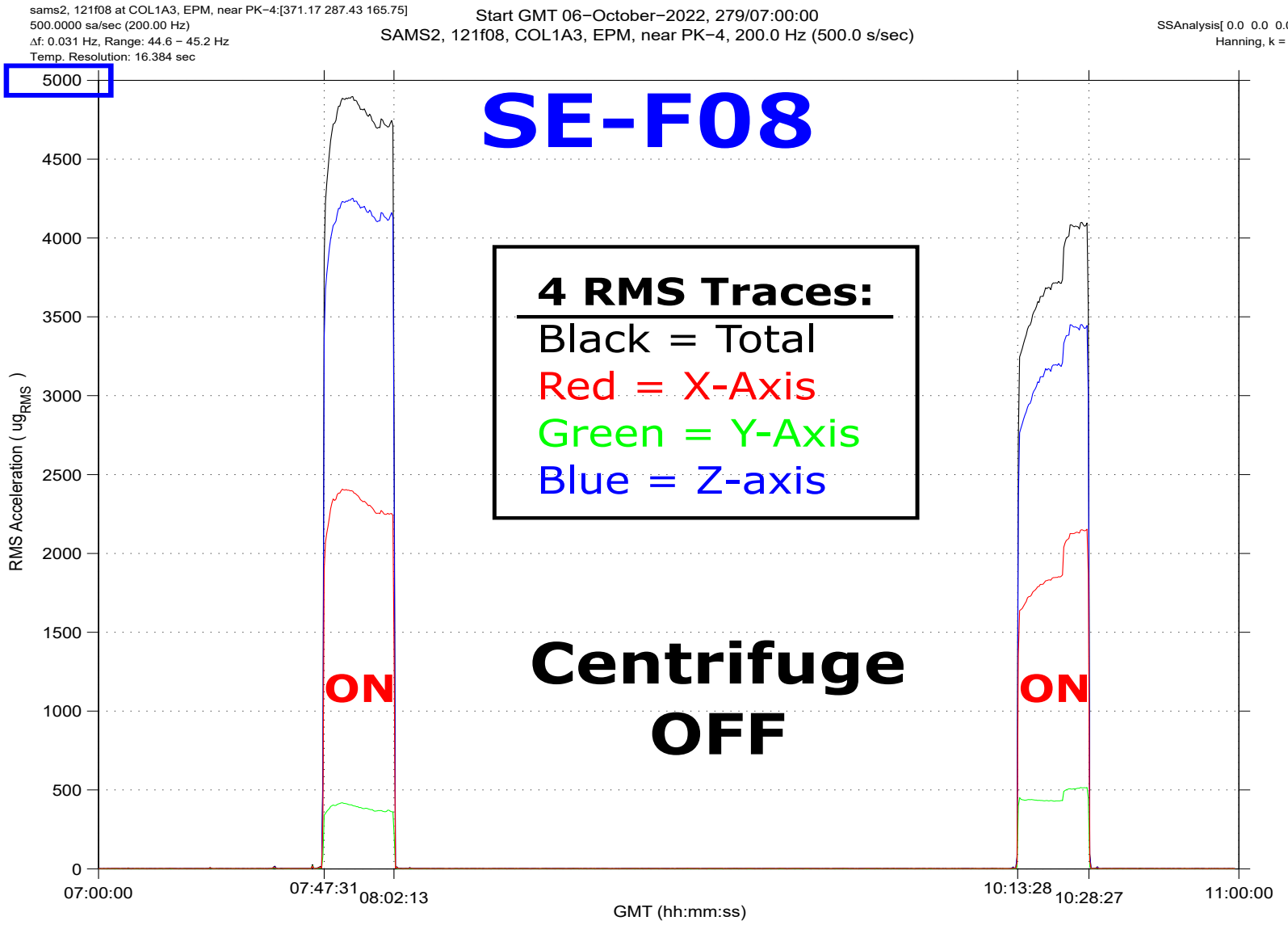

Fig. 7: SE-F08 16-Second Interval RMS (44.6 < f < 45.2 Hz) Shows 2 Centrigure Spins on GMT 2022-10-06.

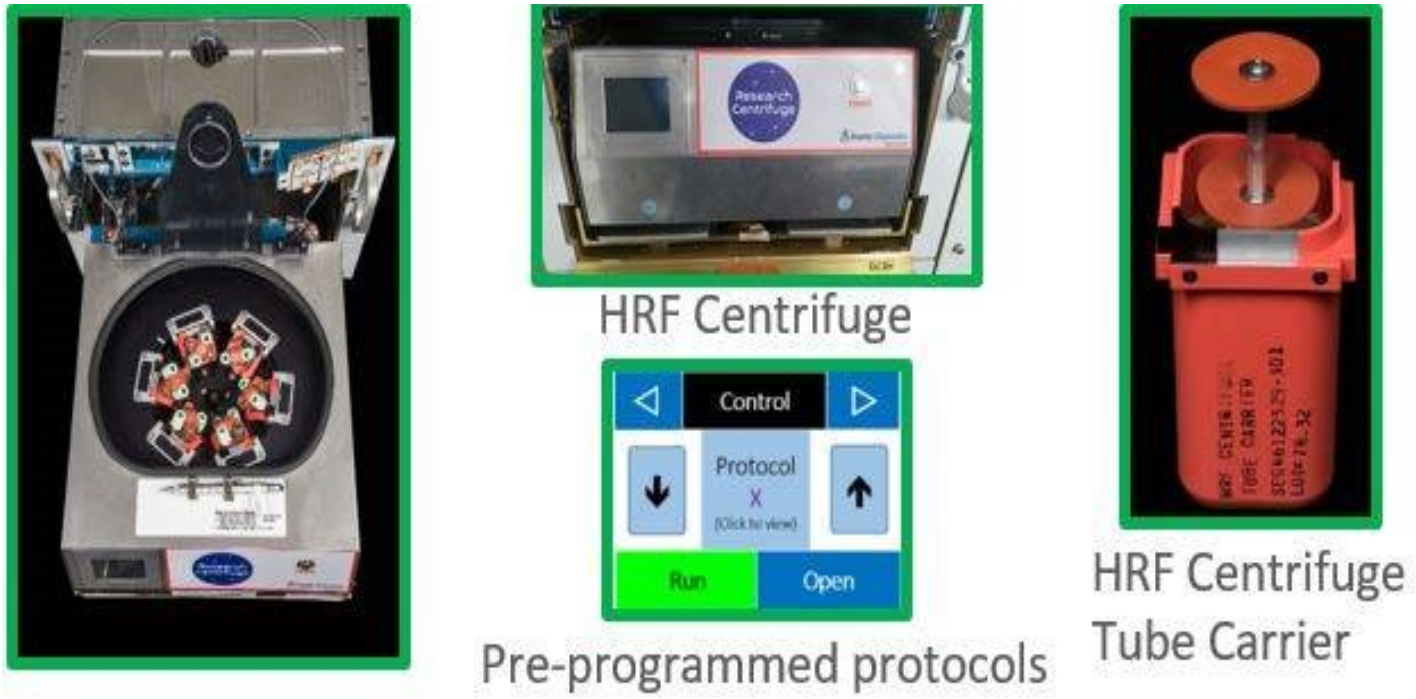

Fig. 8: Depiction of Centrifuge Equipment in HRF-2.