RPW ANOMALY REVIEW BOARD

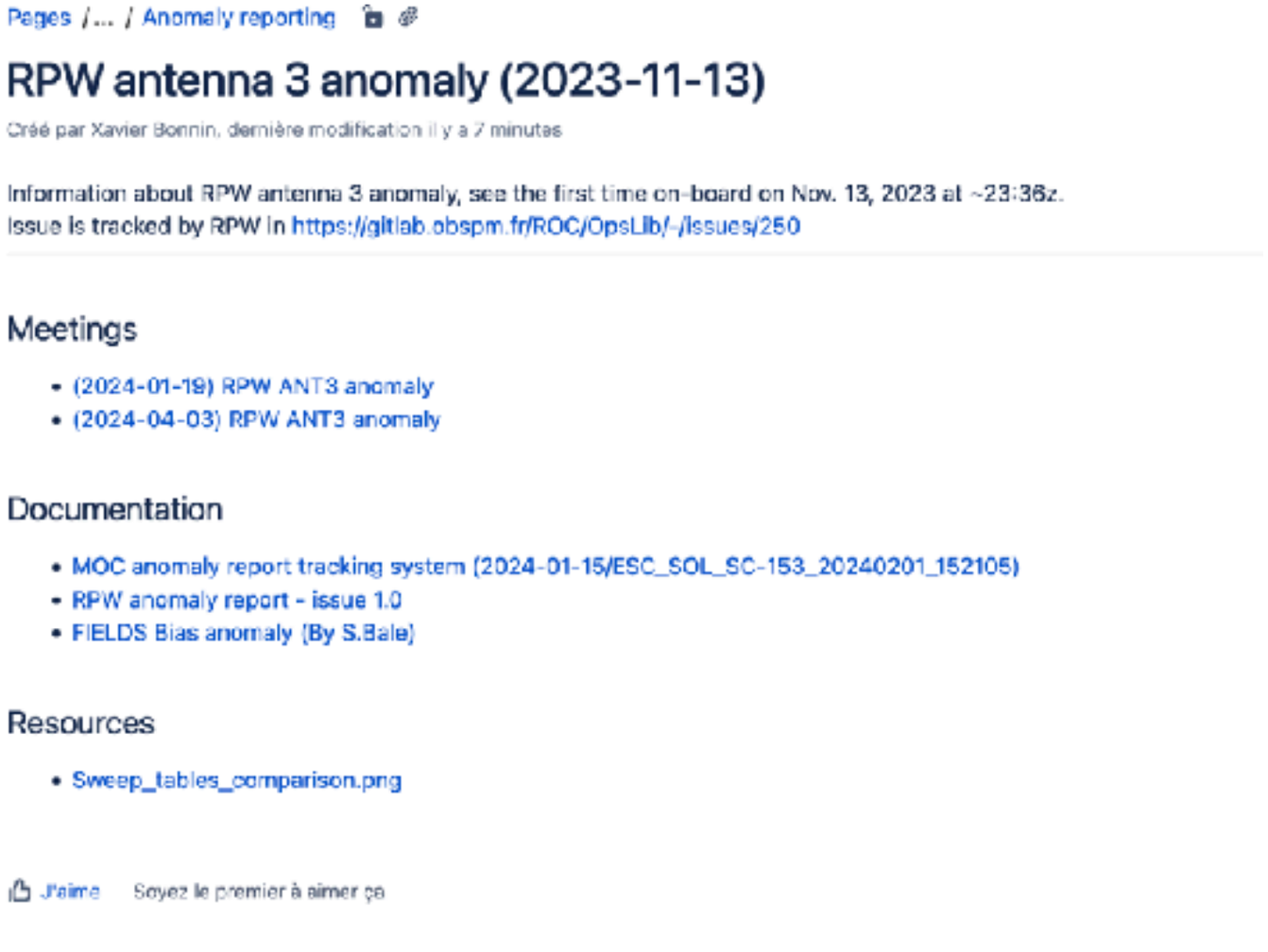
April 26, 2024

Agenda

1. Round table introduction. Proposed minutes writer José Luis Pellón Bailón (+ somebody from RPW?)
2. Introduction to the anomaly and the current status of RPW (RPW)
3. Tests run so far (RPW)
4. Mitigation measures taken up to now (RPW, MOC)
5. Results of the data analysis & potential root cause (RPW)
6. Any remaining open points, any additional tests that can be run (RPW)
7. Way forward (All)

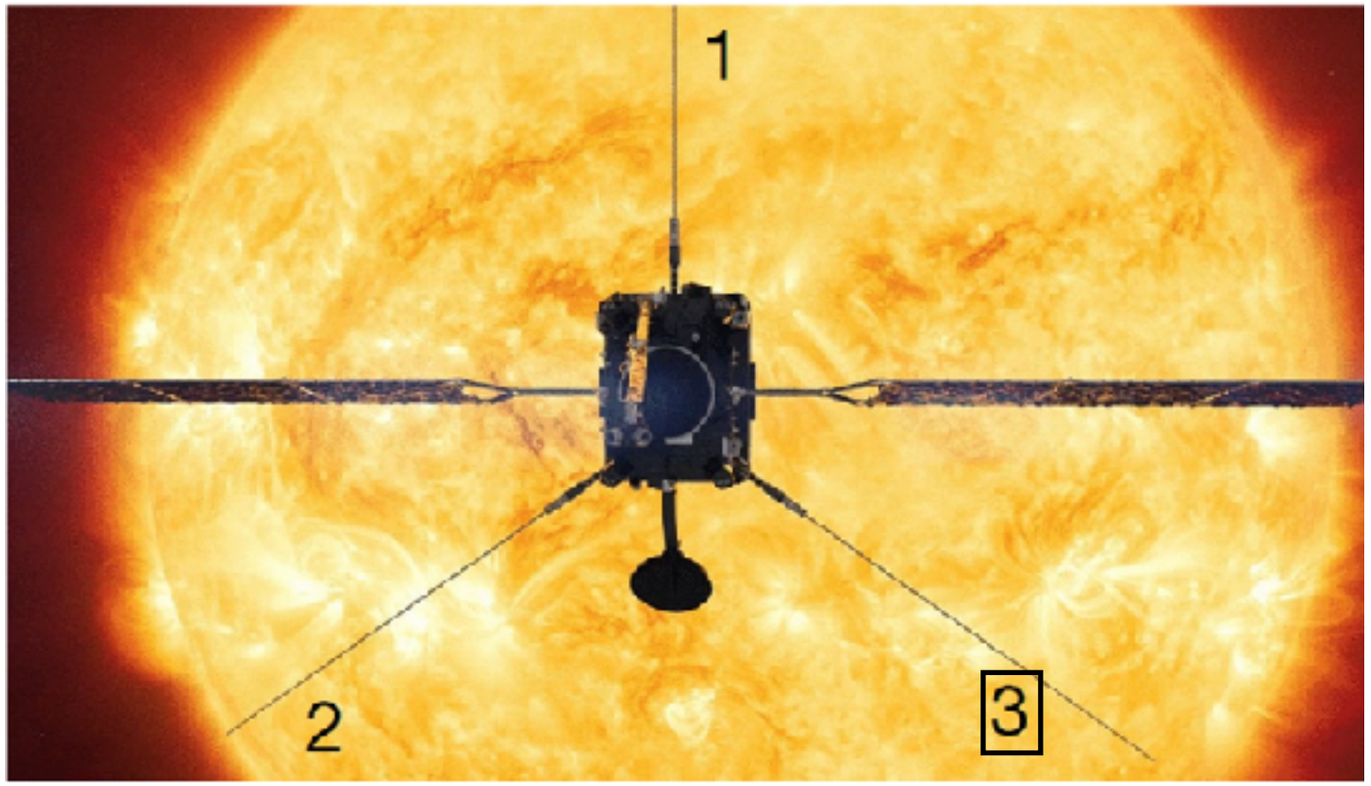
Before we start

- Minutes, documentation and resources related to the anomaly are available in the RPW ground segment Wiki
  - https://confluence-lesia.obspm.fr/pages/viewpage.action?pageId=142639190



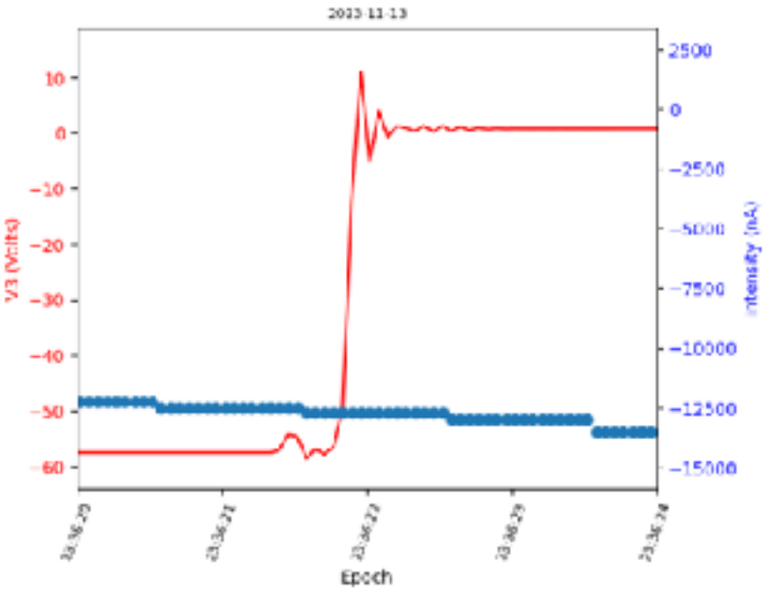
Introduction to the anomaly

- On Nov. 13, 2023 (STP283) at ~23:36z, RPW electrical antenna 3 [MY] (ANT3) signal was suddenly and unexpectedly changed to constant voltage (~0.7V) during a daily Bias sweep
- No special activity scheduled at this time for RPW or payload in general
- Occurred during a S/C attitude disturbance ("SLEW")



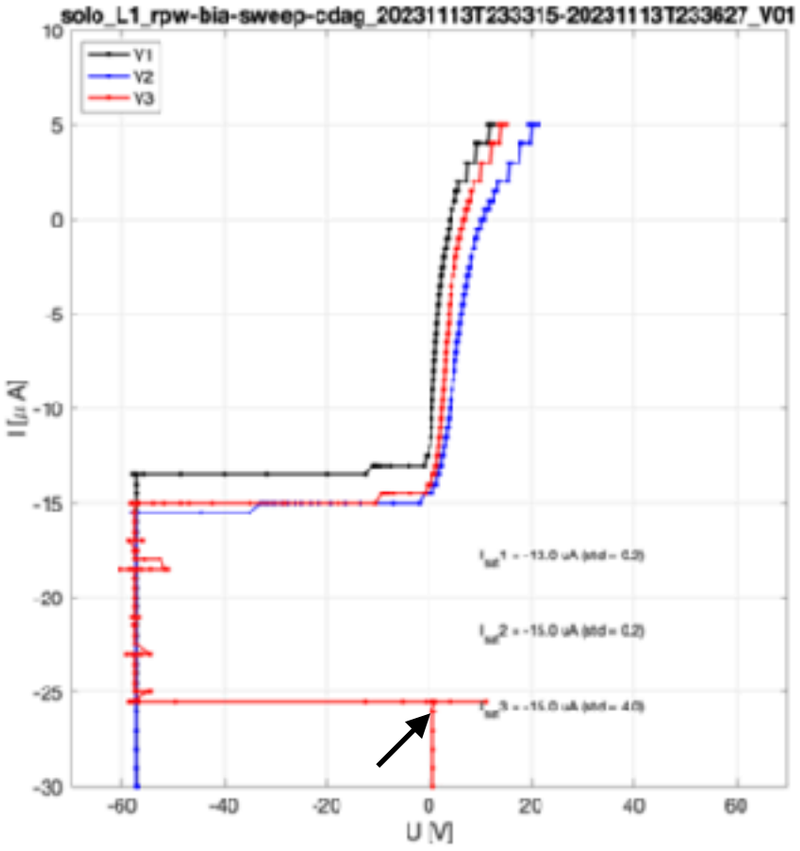
Introduction to the anomaly

- RPW Low Frequency (LF) measurements around anomaly time

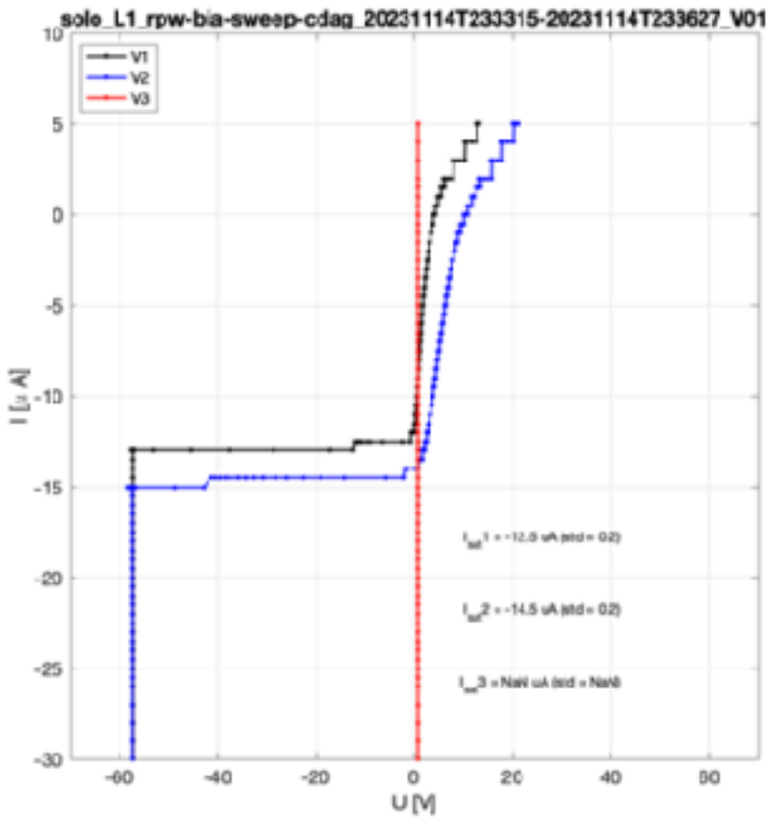


LFR CWF data on
Nov. 13 around 23:36z

Bias sweep on Nov. 13

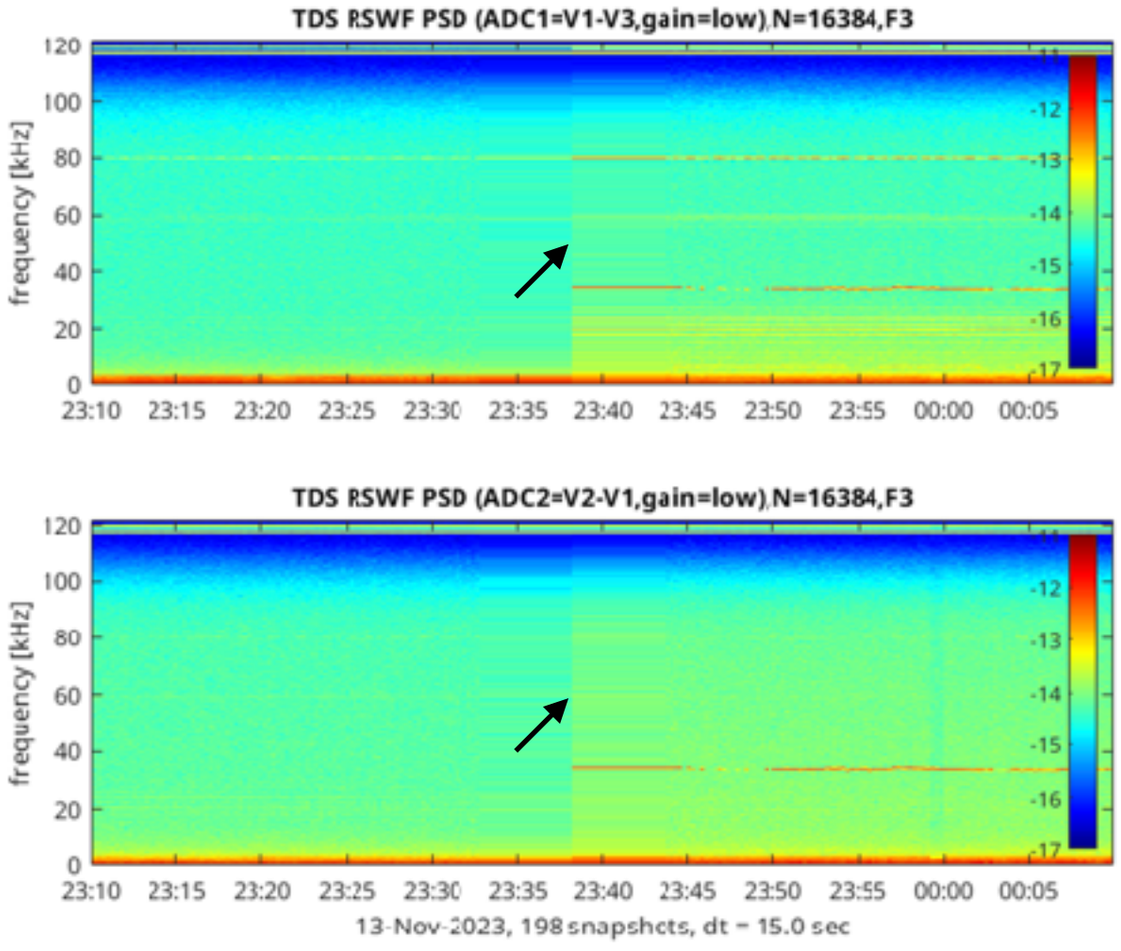


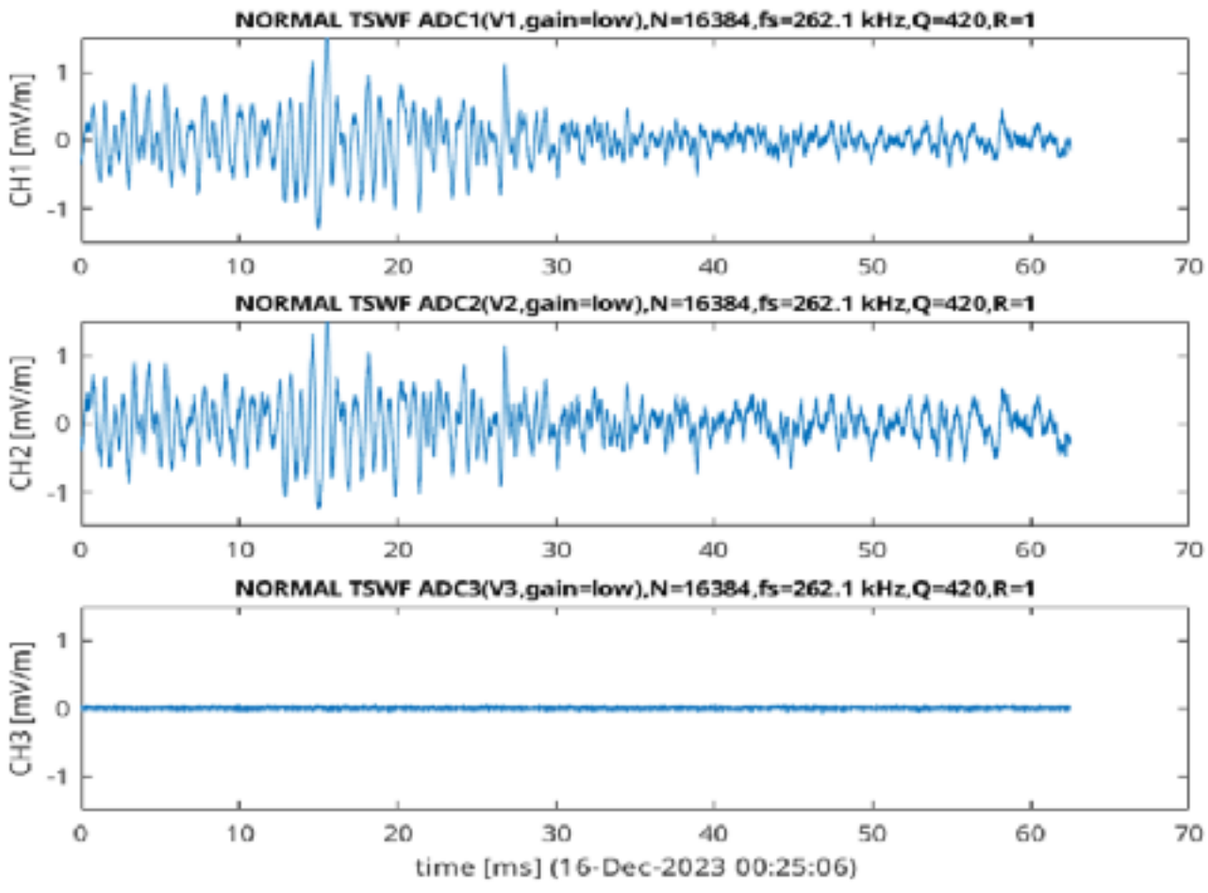
Next Bias sweep on Nov. 14



Introduction to the anomaly

- Also observed in High Frequency (HF) measurement (here on TDS data)…

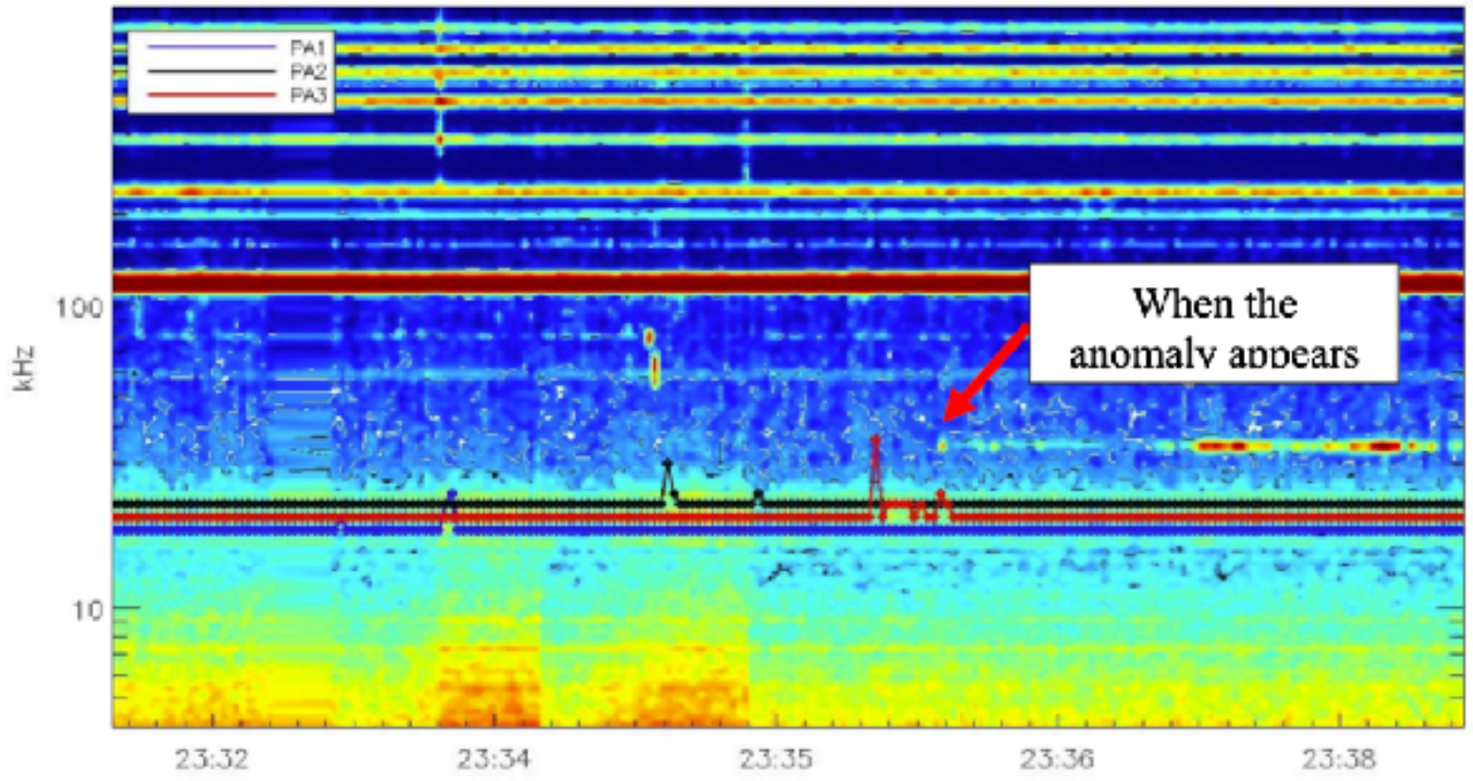




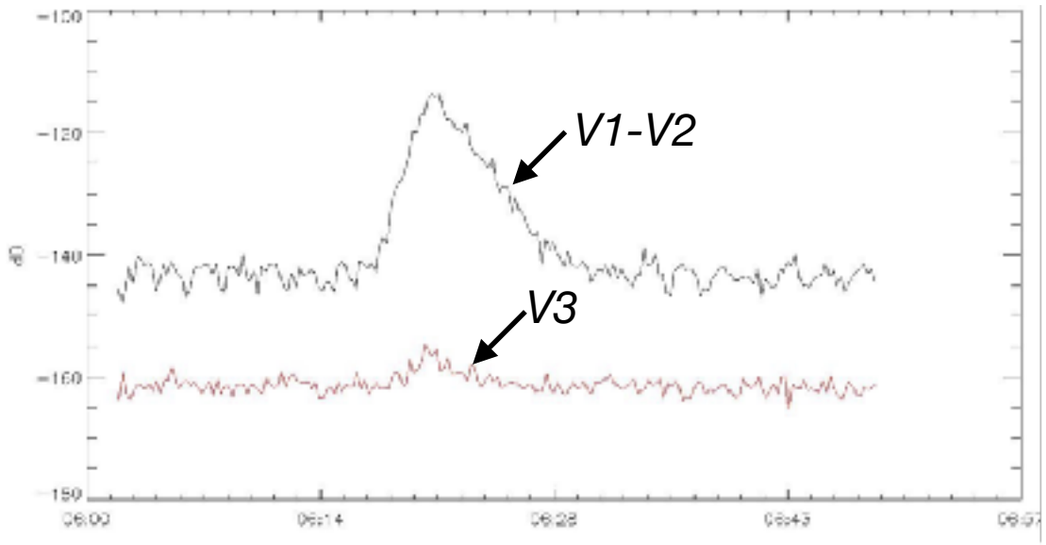
TDS Triggered Snapshot Waveforms (TSWF) acquired during TDS diagnostic test on Dec. 16, 2023

Introduction to the anomaly

- Here on THR data



Type III burst seen on Jan 22, 2024 by TNR at ~634 kHz



Introduction to the anomaly

- Science impact on Bias
  - 2D DC/LF electric field is no longer measured
  - Only one component of DC/LF electric field is available
  - Otherwise, computing spacecraft potential and plasma density is fine using V1 only.
- Science impact on TDS
  - The overall impact of the anomaly on TDS science performance is thus relatively limited.
  - TDS has been switched to a monopole configuration (sampling the antennas individually), which is robust with respect to issues on one antenne. The basline dipole configuration used since the beginning of the mission is not very suitable, because, V3-V1 dipole measurement is more difficult to interpret when V3 signal is lost.
  - This configuration still allows to reconstruct two components of the electric field as before, but the noise and various interferences are more prominent in this mode, comparing to the dipole mode.

Introduction to the anomaly

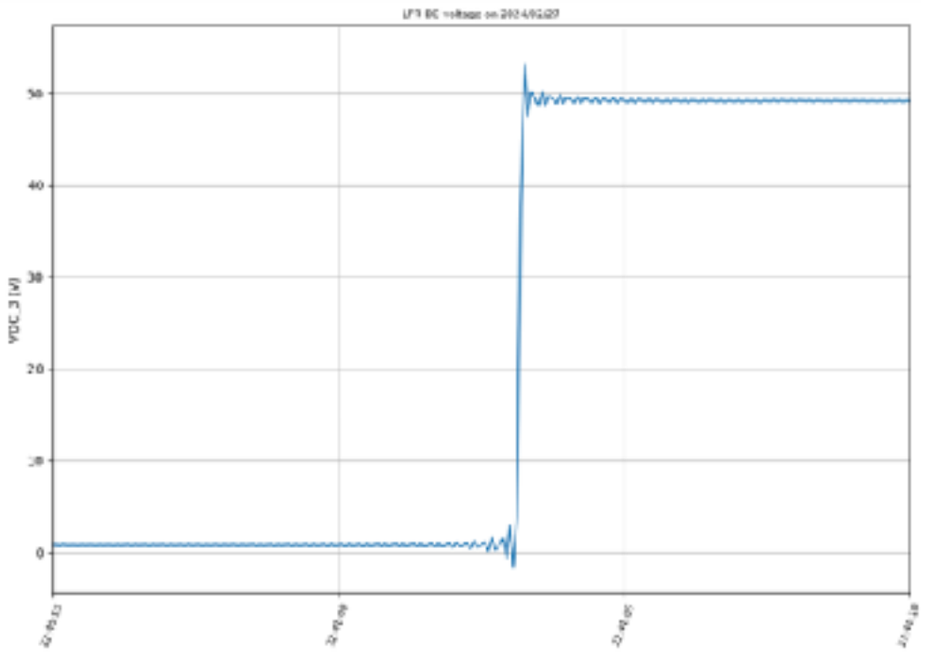
- Science impact on LFR
  - The BP1 spectral products combining two electric field components are no longer possible (radial component of the Poynting flux, phase velocity).
  - The onboard calibrated 5x5 spectral matrices BP2 and ASM have presently wrong electromagnetic crosscorrelations, as well as wrong electric autocorrelations, because the two electric field components used, V23_AC and V13_AC, are wrong.
  - For the same reason, the BP1 spectral product PE (trace power spectrum of the electric field) is presently wrong
  - By using back the V12_AC electric field component one may recover correct measurements of corresponding electromagnetic crosscorrelations and electric autocorrelations, so with just one electric field component instead of two. However, this will also require updating the kcoefficients used for the onboard calibration of spectral matrices, which has been implemented since LFR FSW update 3.3.0.16 (03/14/2023).

Introduction to the anomaly

- Science impact on THR
  - In HFR, measurements in dipole mode involing V3 is not possible anymore. Can be replaced by V1-V2 dipole.
  - In TNR, measurements in monopole mode involing V3 is not possible anymore. Can be replaced by other antennas V1, V2.
  - In TNR, the capability to perform goniopolarimetry measurements may be affected

Introduction to the anomaly

- ANT3 signal went back on Feb. 27, 2024 at ~22:40z,
  - Recovery was confirmed by all RPW subsystem teams
  - No special activity scheduled by RPW or in "E-FECS" at that time
  - ANT3 was lost again several times after Feb. 27, 2024 (see table below)



V3 DC voltage measured by LFR (CWF) suddenly changed from 0.7V to 49V on Feb. 27, 2024 around 22:40z

Period of ANT3 unavailability	Comments
March 3 between ~04:20z and ~20:00z	Nothing to report
Between March 8 at ~23:38z and March 9 ~04:22z	Bias sweep on ANT3 at start
Between March 9 at ~23:38z and March 10 ~05:59z	Bias sweep on ANT3 at start
Between March 10 at ~23:38z and March 11 ~05:49z	Bias sweep on ANT3 at start
Between March 11 at ~23:38z and March 12 ~01:55z (TBC)	Bias sweep on ANT3 at start
Between March 13 at ~23:38z and March 14 ~04:24z	Bias sweep on ANT3 at start

Current status of RPW

- ANT3 behavior is nominal
- No new failure observed since March 14, 2024
- Actions taken to mitigate the risk (see next slides)
- Investigations are still on-going (see latest results in next slides)

Tests run

Date	Test Run	Purpose(s)
12/12/2023	- Bias unit and LF PA power cycle	- First test to re-initialize Bias unit + LF PA
16/12/2023	- Bias diagnostic test - TDS in monopole mode	– Test set of BIAS output signals (MUX) – Acquire TDS measurements in V3 channel
25/12/2023	- Bias switched to MUX_4 instead of MUX_0	- Use Bias calibration mode 0 with V3_DC acquired in Bias_3 output
22/01/2024	- Set iBias3 current value to +10 uA - THR diagnostic test	- Acquire TNR-HFR measurement using V3 (only dipole for HFR)

Mitigations taken up to now (on-board)

Action taken	Justification(s)	Date of application
Avoid Bias sweep during S/C attitude maneuvers (checked on both RPW and SOC sides)	To prevent risk, since anomaly occurred during a Bias sweep and a S/C attitude maneuver.	19/01/2024
Perform Bias sweep on ANT3 every 3 months only	To prevent risk (see above)	03/04/2024*
Reduce the rate of Bias sweeps on ANT1 and ANT2 (using new sequence AIWF033T), depending of the S/C distance to Sun	To prevent risk (see above)	21/04/2024
Apply tables with "smoother" current values for Bias sweep (using new sequences AIWF033U, 33V, 33W and 33Y)	To prevent any risk of premature aging of PA electronics	STP310

** Bias ANT1/2/3 sweeps on April, 3, 8 and 16 2024 were manually disabled by MOC*

Mitigations taken up to now (on-ground)

Action taken	Justification(s)	Date of application
Update RPW operation instructions guide	to take account of restrictions of activities permitted on-board (see previous slide)	21/04/2024 (last update)
Update IOR generation tool	To prevent about possible errors by operator	02/04/2024
Suspend temporary the delivery of RPW science data (generated after Nov. 13, 2023) to SOAR to let time to update CDF content	Data users shall be informed when ANT3 failure occurs (degraded science data)	08/02/2024
Write and publish an RPW anomaly report		23/04/2024
Plan with ESA, CNES and other RPW sub-system teams an anomaly review board (ARB)		26/04/2024

Results of data analysis

- **Bias unit + LF PA data analysis report (by Bias team)**
- THR + HF PA data analysis report by (THR team)
- TDS data analysis report (by TDS team)

SolO RPW Antenna 3 Issue

The BIAS team @ IRF Uppsala
25 April 2024

Summary

During a bias sweep at 23:35 UT, Nov 13, 2023, the voltage from antenna 3 suddenly jumped from -60V to an anomalous state close to 0V. The behaviour persisted for three months. Between Feb 27 and March 14, ANT3 toggled a few times between nominal and anomalous status. Since then its behaviour has been nominal.

During anomalous periods, ANT3 sweeps show a small (~0.5V) stable (±10mV) positive voltage irrespective of applied bias current.

Bias sweeps over the calibration resistor in the preamp are still nominal during anomalies. The calibration resistor relay is the first component the signal encounters in the BIAS preamp, so all electronics behind it are intact. The relay switches as it should and a relay problem resulting in a short at one of its positions is extremely unlikely. So the issue is a short outside the BIAS preamp: on the antenna, or between preamp and antenna. From the bias point of view, a failure in the HF preamp could be a possibility; however, this is ruled out by its continued function

A short of ANT3 to ground is supported by the signals on the other antennas during sweeps. Before the anomaly, a change in potential (due to the varying bias current driving the s/c potential) is observed on the other two antennas when any one of them is swept. This is still so for 1 and 2, but nothing is seen on them when 3 is sweeping. Therefore, the current must be taking another route to ground, along a (comparatively) low-resistance path.

Possible failure modes include some piece of MLI, perhaps a fringe torn by a micrometeoroid impact with one end still attached and the other close to some ANT3 element (which can be close to the preamp). This would explain that several instances of the anomaly started during sweeps, when electrostatic fields between ANT3 and s/c surfaces are strongest and thus can exert a (weak) force on a nearby fringe-like grounded object. To decrease the likelihood of this happening, operational measures have been taken as outlined in the RPW presentation. This failure mode requires quite particular “bad luck”, meaning there is no reason to believe the other two antennas are at particular risk.

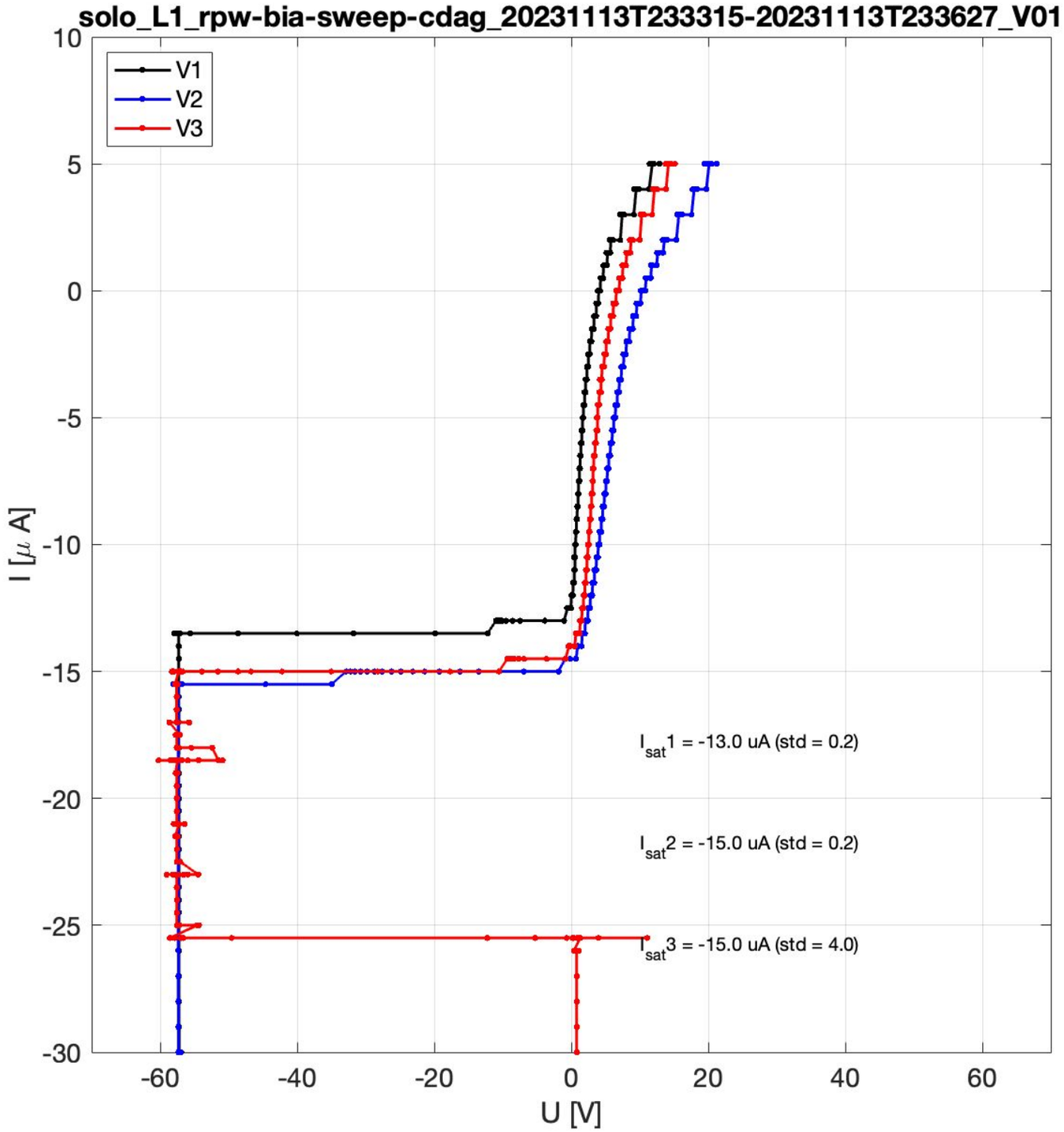
First identified appearance

Found by Niklas when evaluating photosaturation current.

First suspicion was some electronics problem so initial efforts concentrated on finding where.

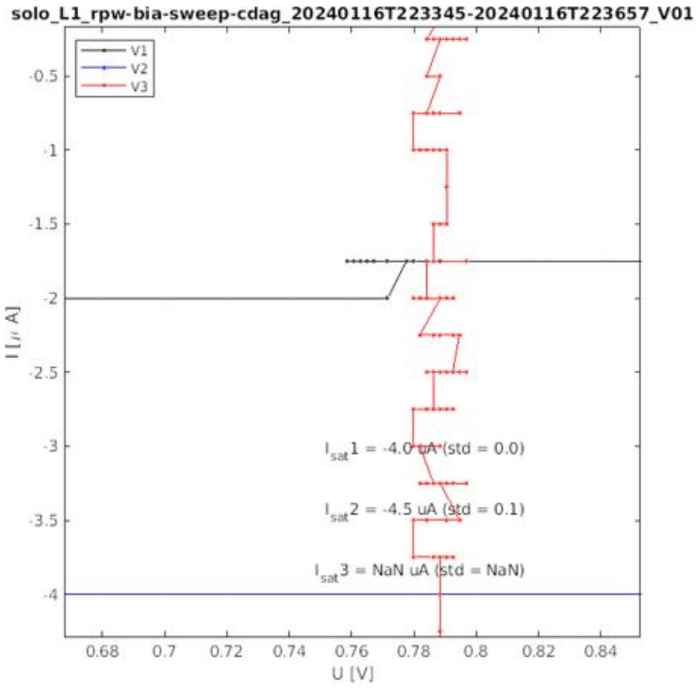
Calibration sweeps (later slides) showed the issue is a short outside the BIAS preamp.

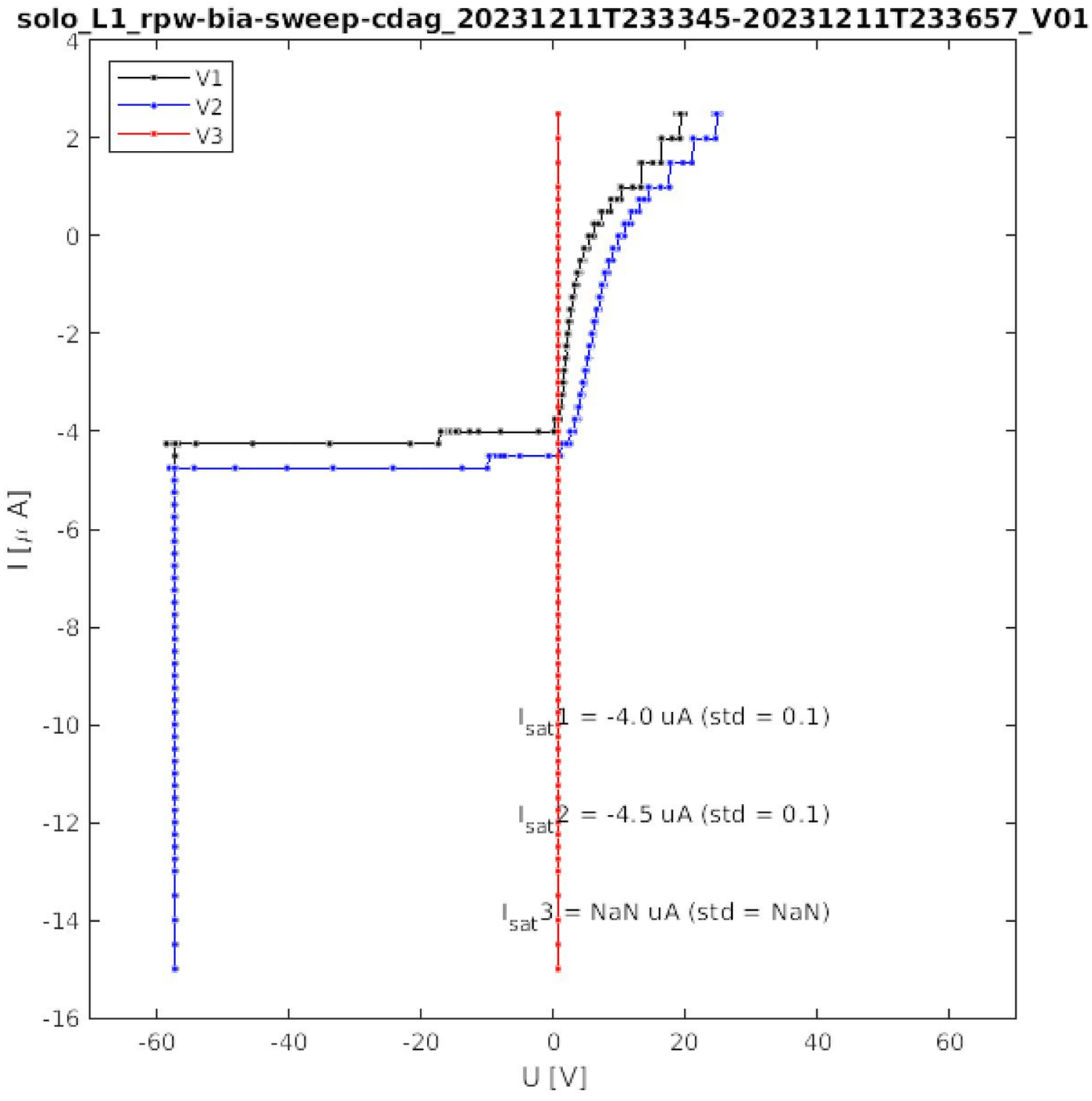
A short due to conductive debris settling might be intermittent and partial at first, as observed.



Subsequent sweeps

Stable (±10mV) and slightly positive (~0.8V) output voltage on antenna 3 for all input bias currents

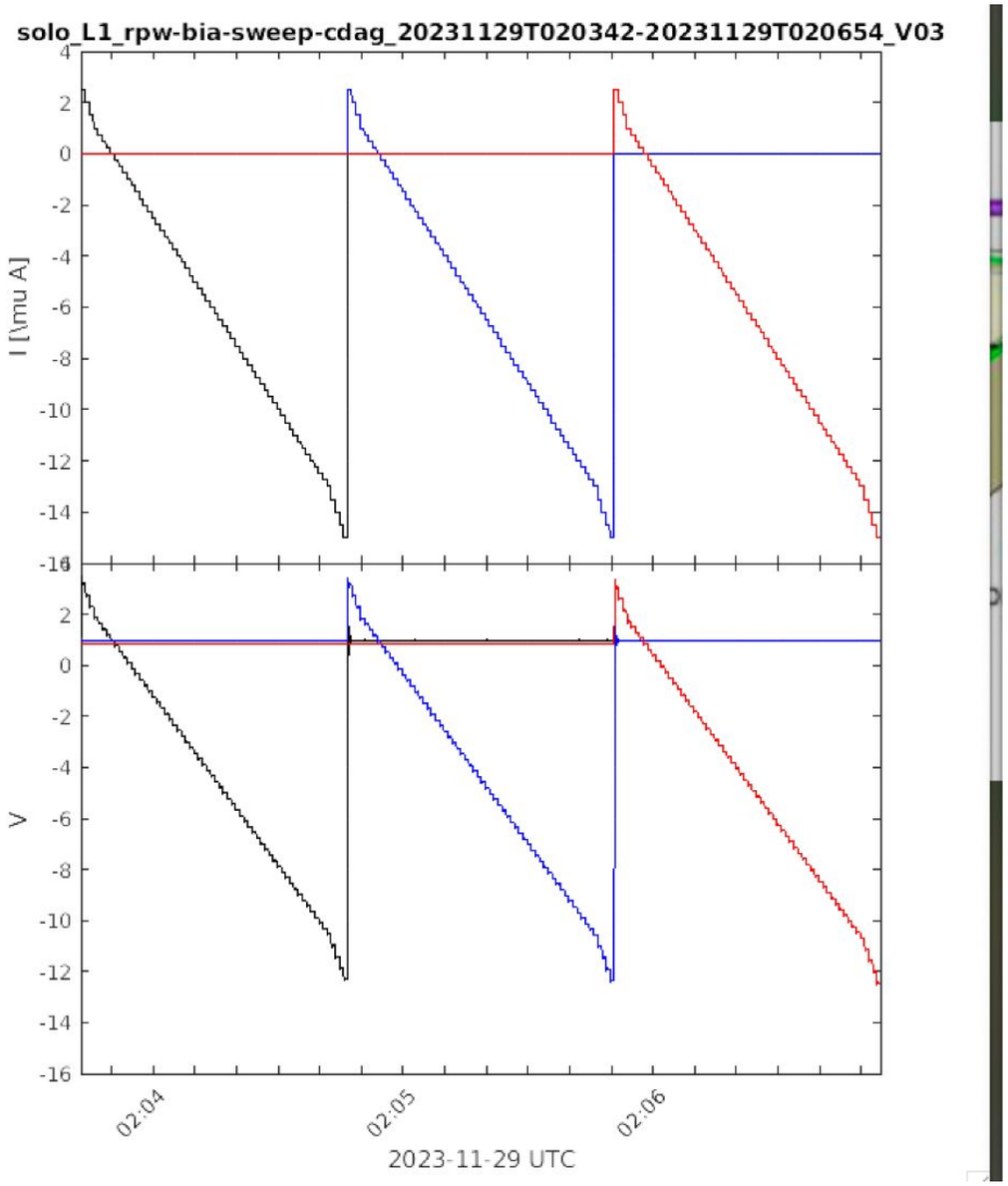


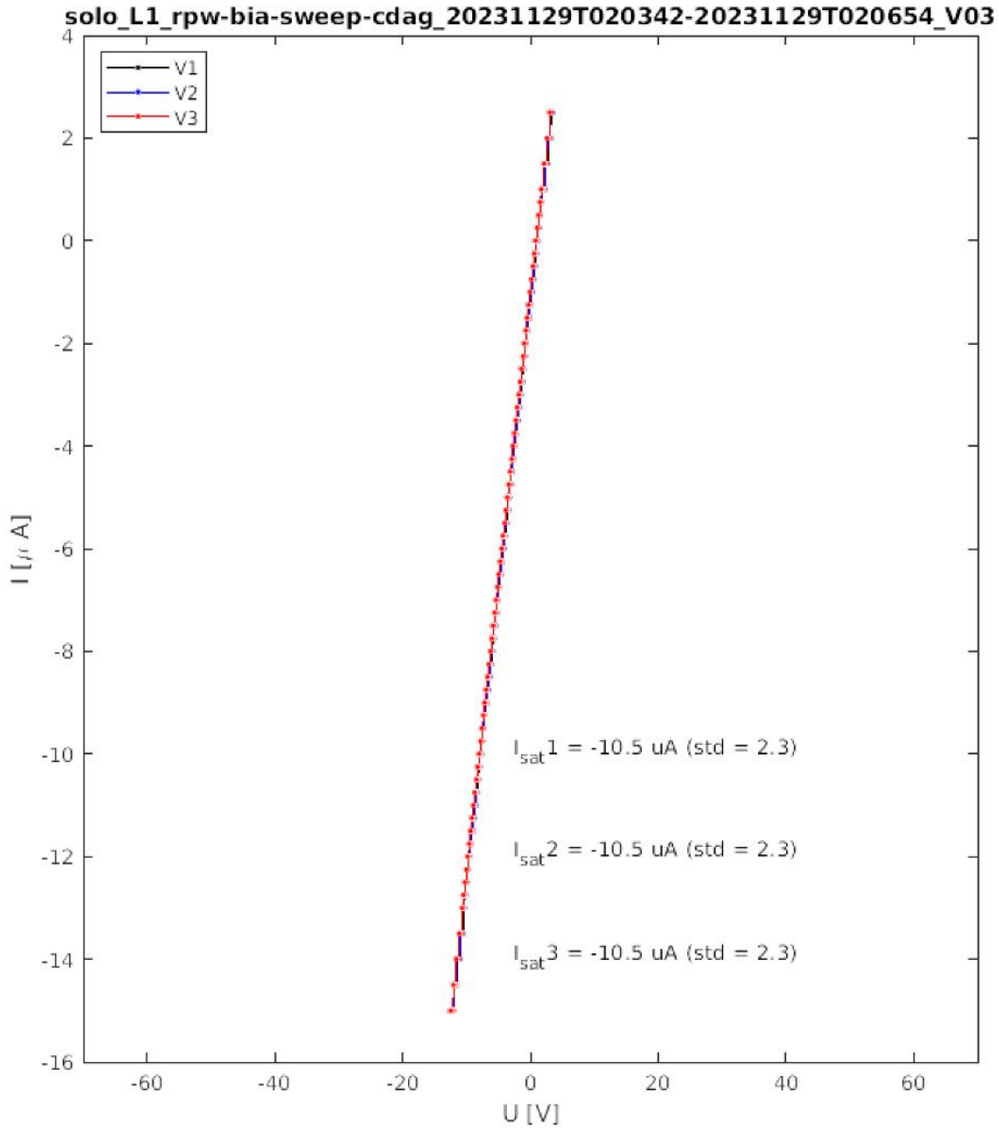


Sweeps over cal resistor

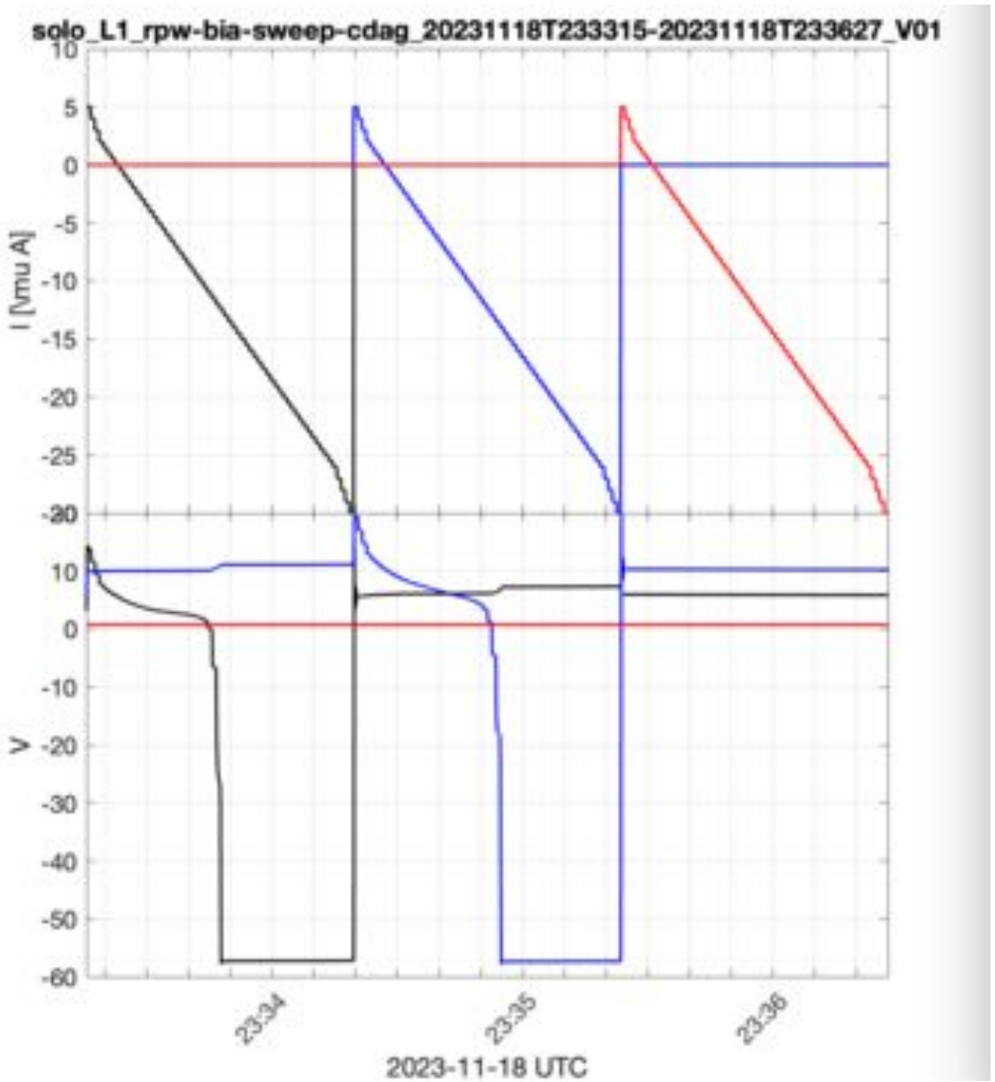
Perfectly nominal on all antennas

=> BIAS electronics nominal





Sweep impact on Vsc



Until the anomaly, the voltage on two antennas could be seen to vary when the third is swept. This is expected as the s/c potential adjusts to the varying current.

Since the anomaly, antennas 1 and 2 still show this effect when the other is sweeping, but nothing is seen when we sweep on 3.

This is consistent with antenna 3 being shorted to ground.

Failure modes

The short must be outside of the bias cal relay.

The route between preamps and antenna appears to include exposed conductors possibly in the vicinity of MLI, therefore possibly prone to fringes of (the upper layer of) MLI torn by a micrometeoroid impact. Small MLI fringes likely have lower mechanical resistance to bending and would be more easily attracted by weak electrostatic forces than intact MLI sheets loosened by e.g. a glue failure.

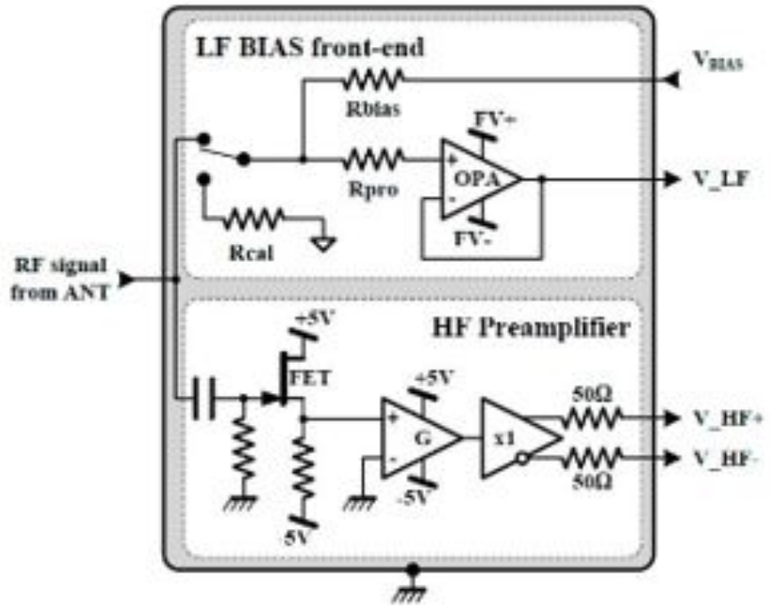
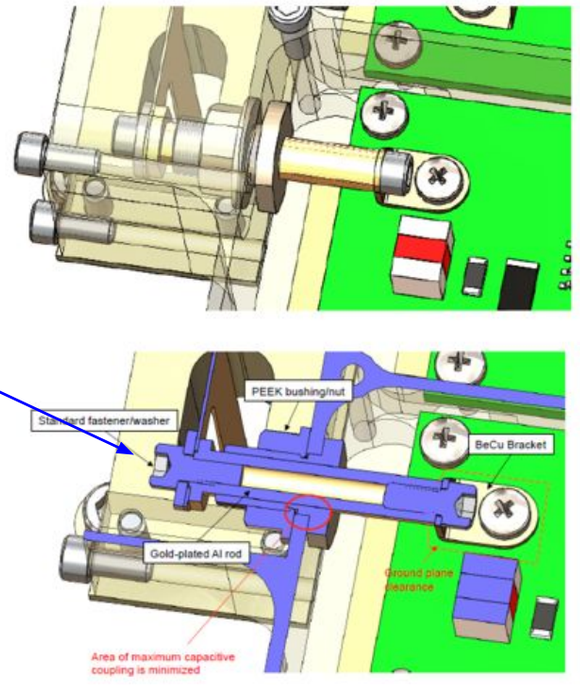


Fig. 8. Antenna preamplifiers electrical design. See text for more details.



Equivalent short resistance

Based on Antonios plot on the solar burst signal difference between V3 vs V1-V2 (~45dB @ 634kHz) the equivalent ohmic resistance can be calculated.
Given is that the antenna capacitance to infinity is ~63pF and the antenna base capacitance is ~77pF and the JFET preamps adds another ~33pF (The Solar Orbiter Radio and Plasma Waves (RPW) instrument) the damping of the signal would be a similar result as if there was a shot to S/C GND from the antenna element of about 61 ohms.
It should be noted that this short is intermittent and has also in some occasions shown much higher resistance (hundreds of mega ohms)

Science impact BIAS during anomaly

- Spacecraft potential and plasma density are OK – using V1 only.
- 2D DC/LF electric field is no longer measured. L3 E-FILED data product likely to be discontinued.
- One component of DC/LF electric field is available.

Summary

During a bias sweep at 23:35 UT, Nov 13, 2023, the voltage from antenna 3 suddenly jumped from -60V to an anomalous state close to 0V. The behaviour persisted for three months. Between Feb 27 and March 14, ANT3 toggled a few times between nominal and anomalous status. Since then its behaviour has been nominal.

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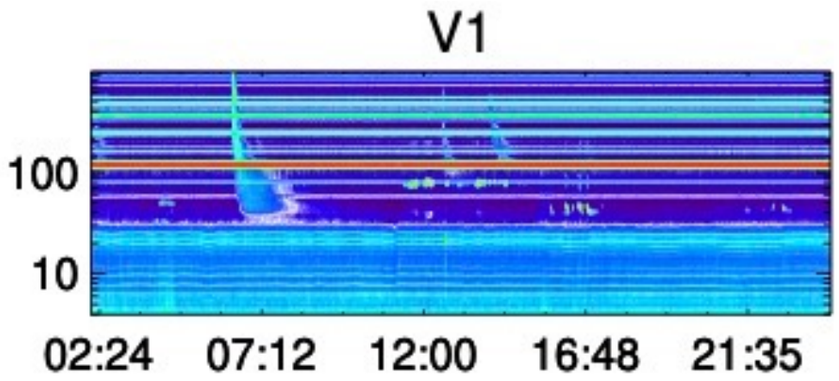
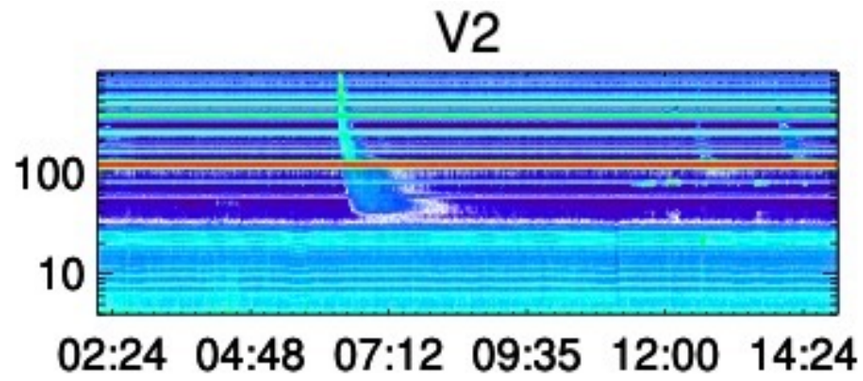
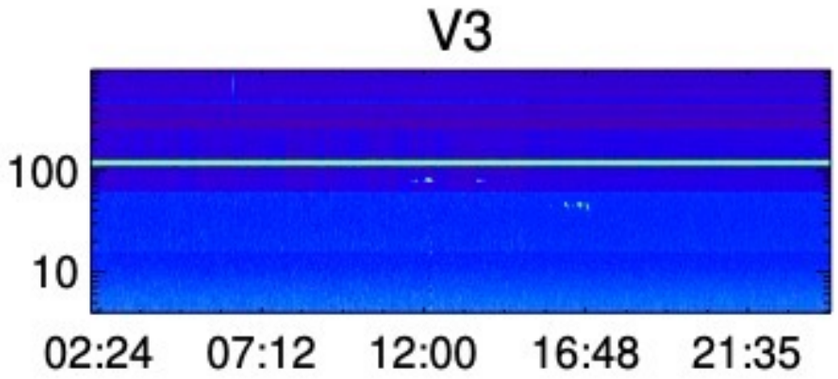
Results of data analysis

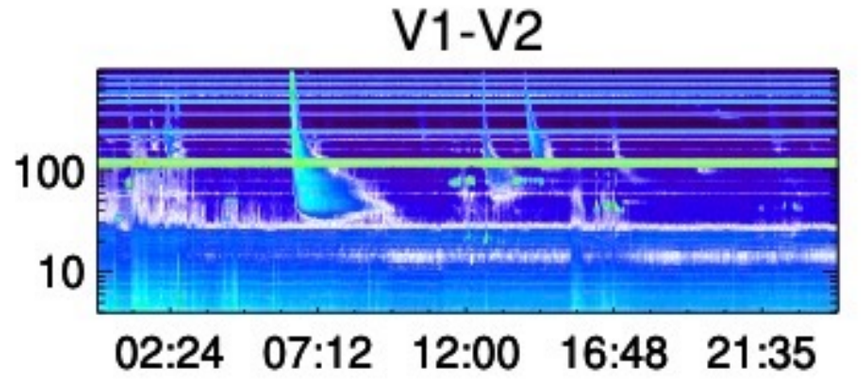
- Bias unit + LF PA data analysis report (by Bias team)
- **THR + HF PA data analysis report by (THR team)**
- TDS data analysis report (by TDS team)

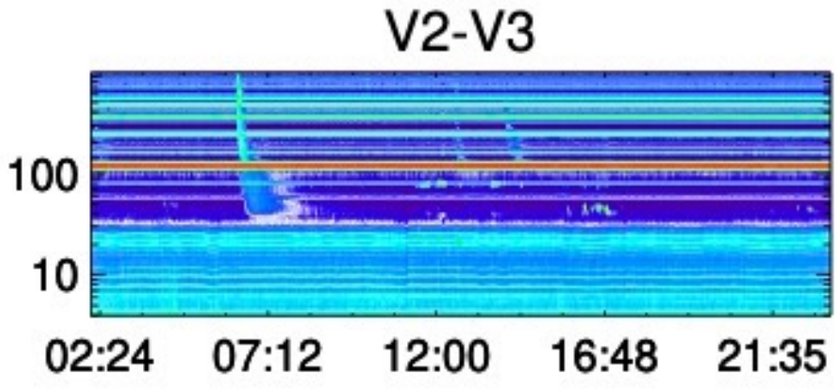
22/01/2024

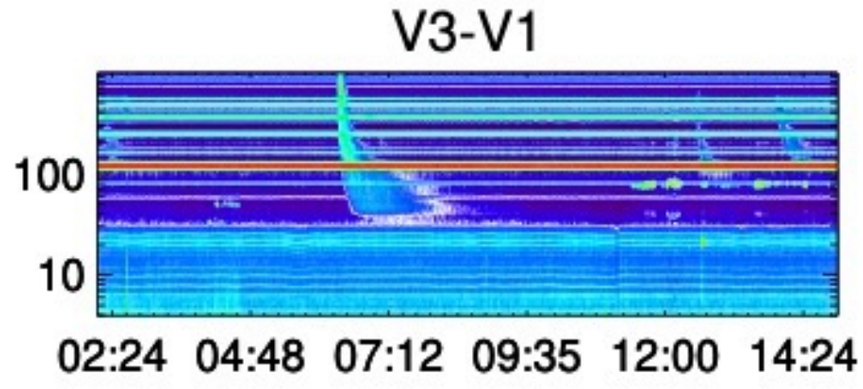

V1
100
10
02:24
07:12
12:00
16:48
21:35


V2
100
10
02:24
04:48
07:12
09:35
12:00
14:24

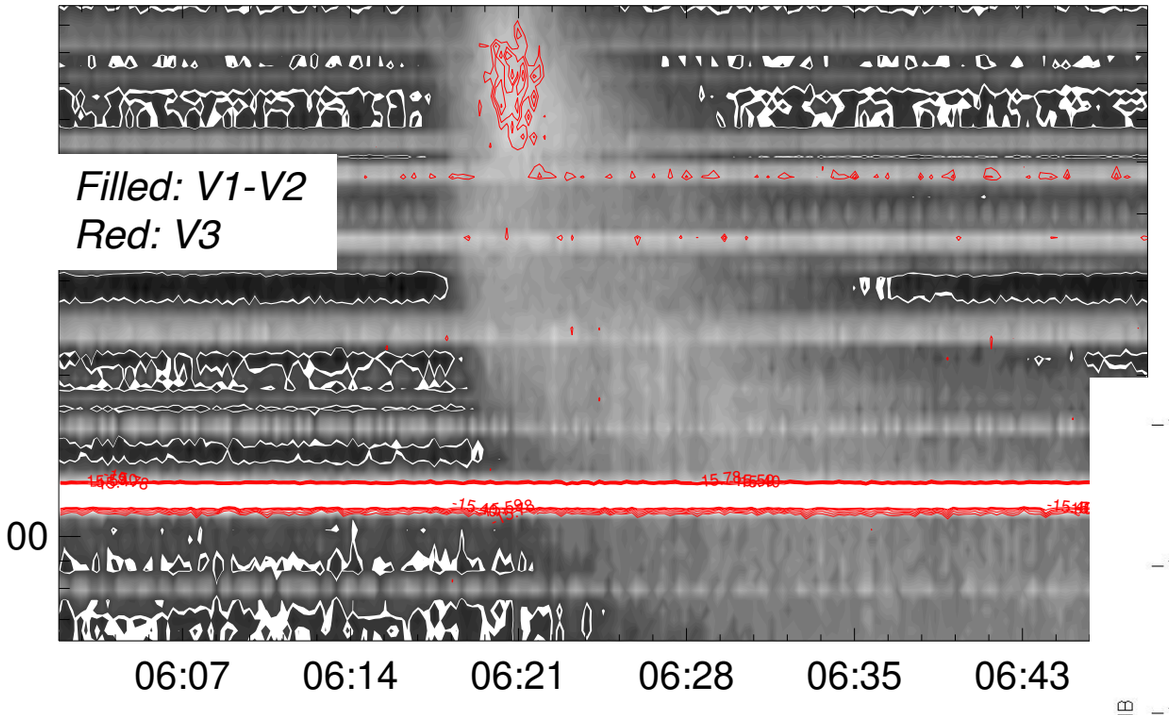

V3
100
10
02:24
07:12
12:00
16:48
21:35

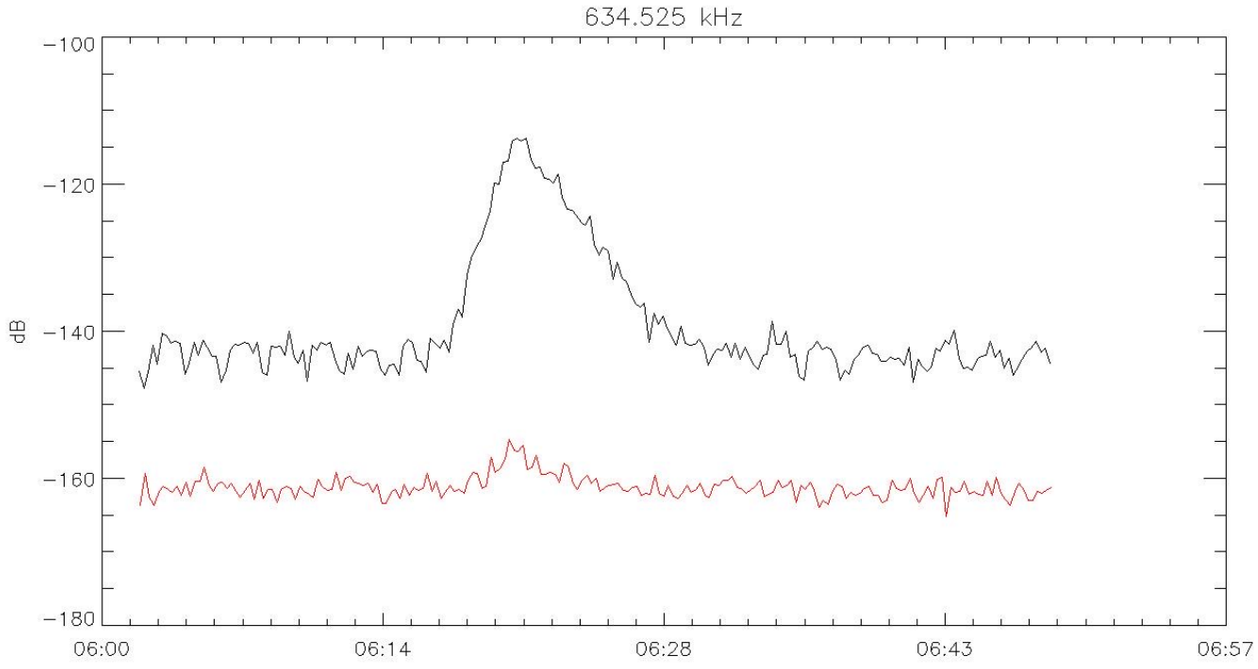

V1-V2
100
10
02:24
07:12
12:00
16:48
21:35


V2-V3
100
10
02:24
07:12
12:00
16:48
21:35

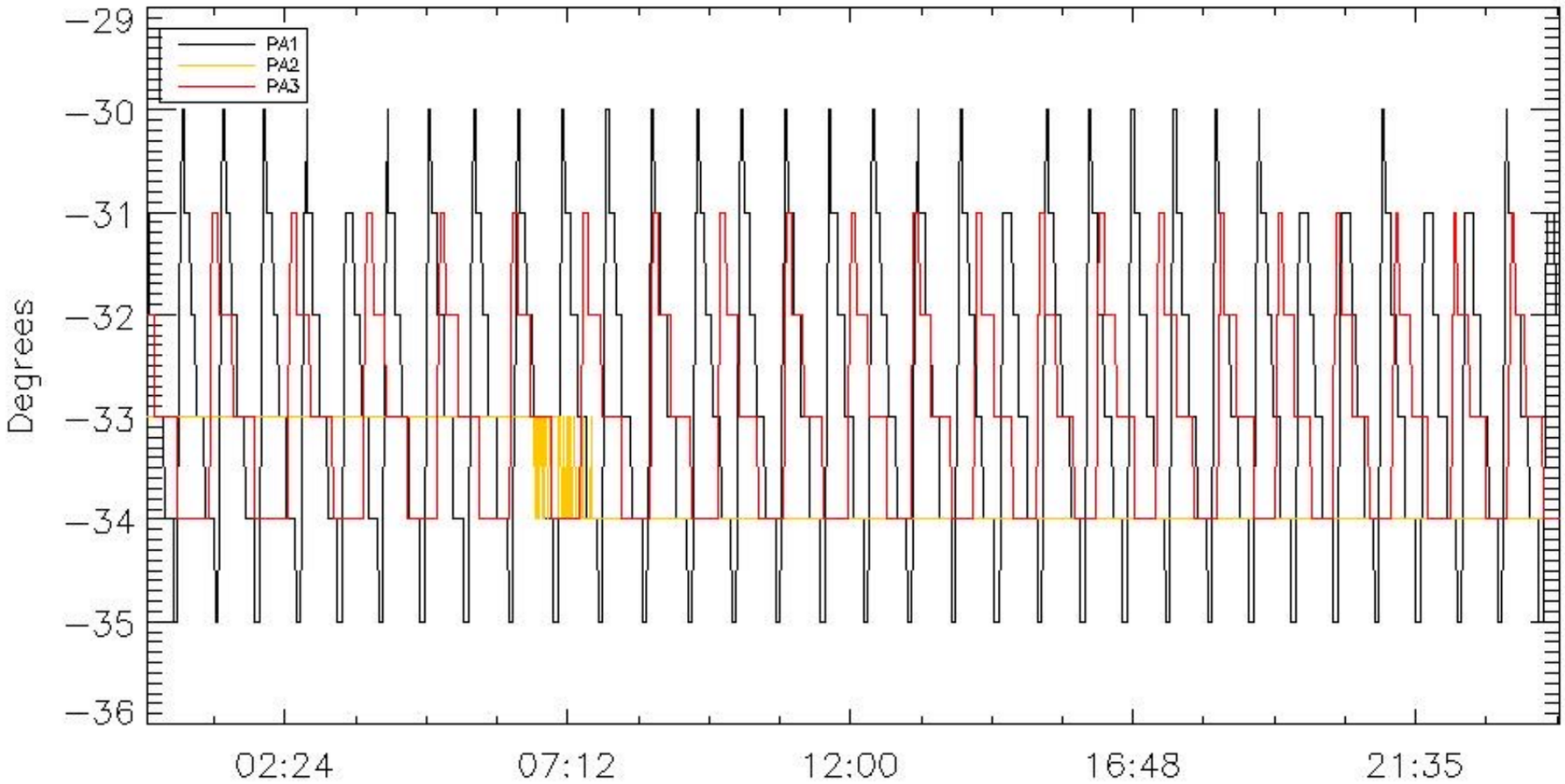

V3-V1
100
10
02:24
04:48
07:12
09:35
12:00
14:24

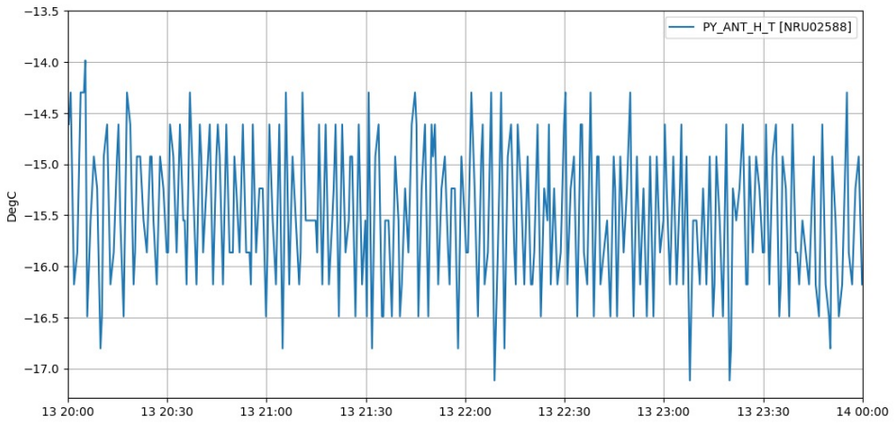
22/01/2024

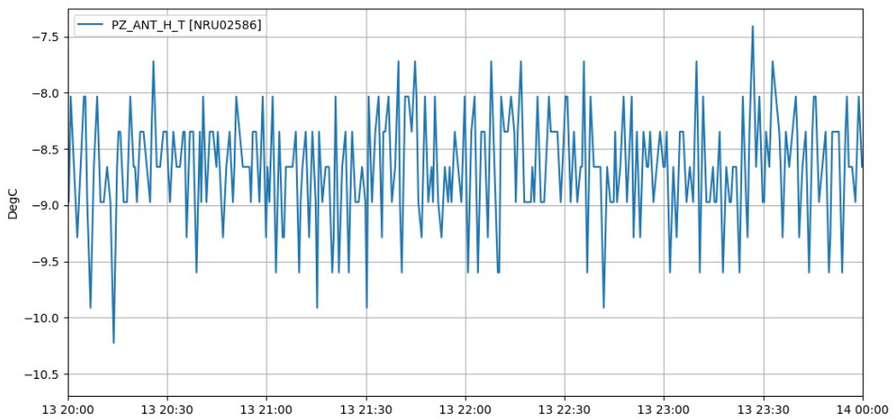

Filled: V1-V2
Red: V3
00
06:07
06:14
06:21
06:28
06:35
06:43

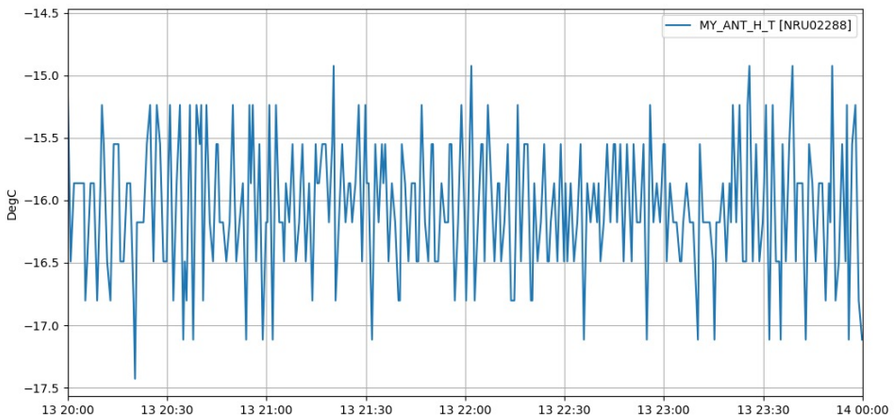

634.525 kHz
−100
−120
−140
−160
−180
dB
06:00
06:14
06:28
06:43
06:57

Temperature for ANT PA

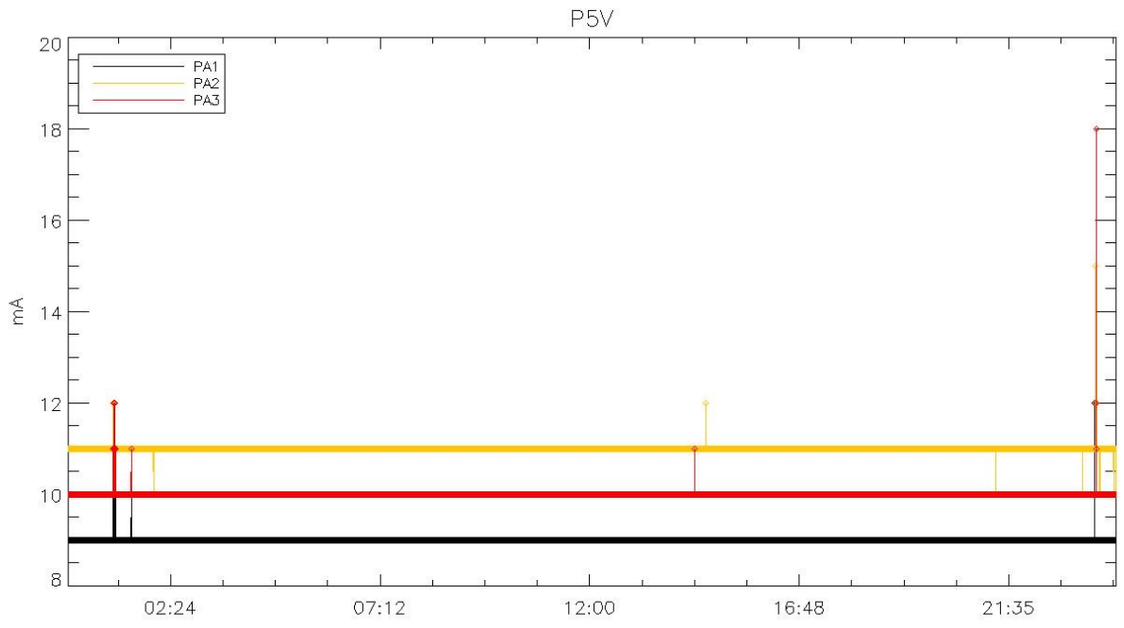


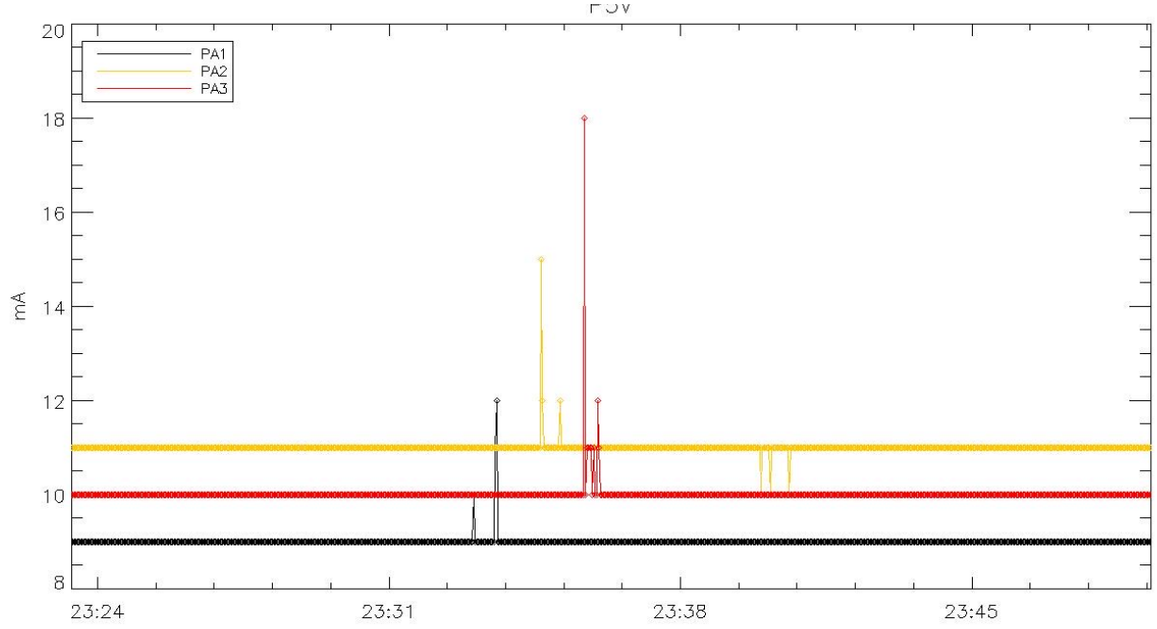




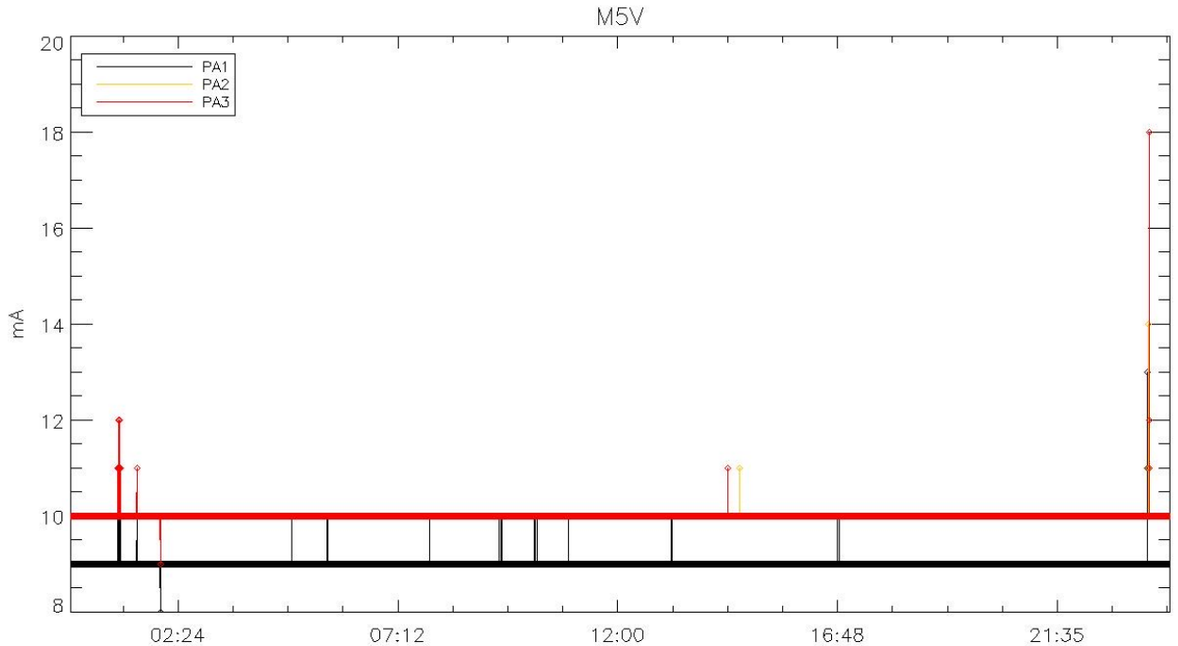


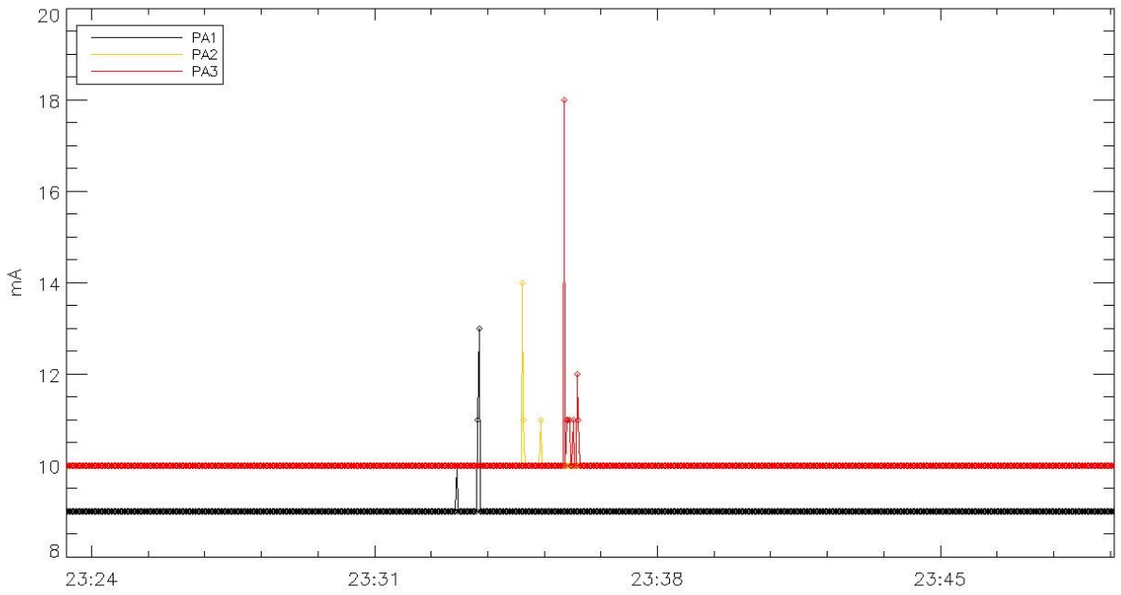
Temperature of Hinges



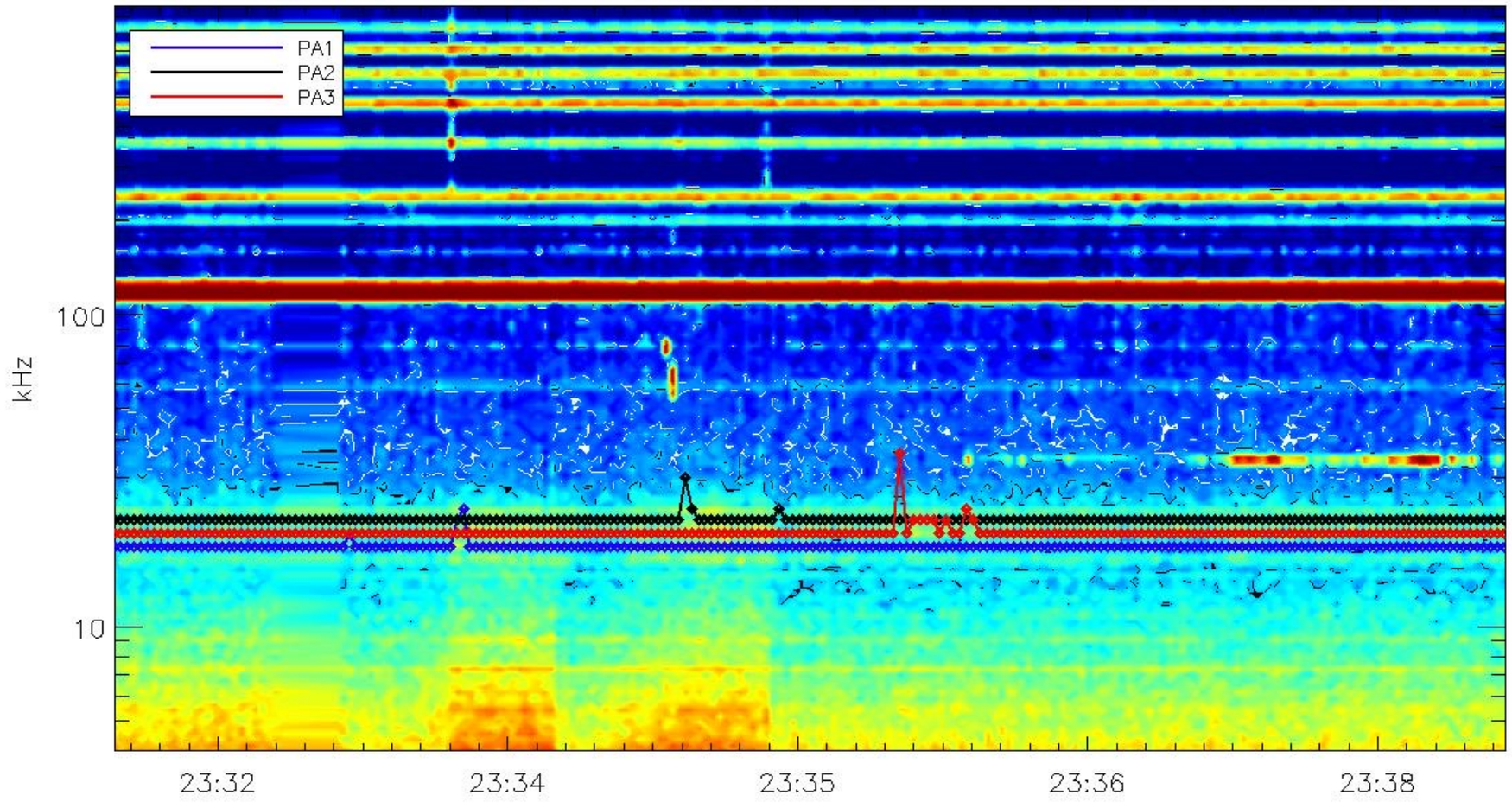


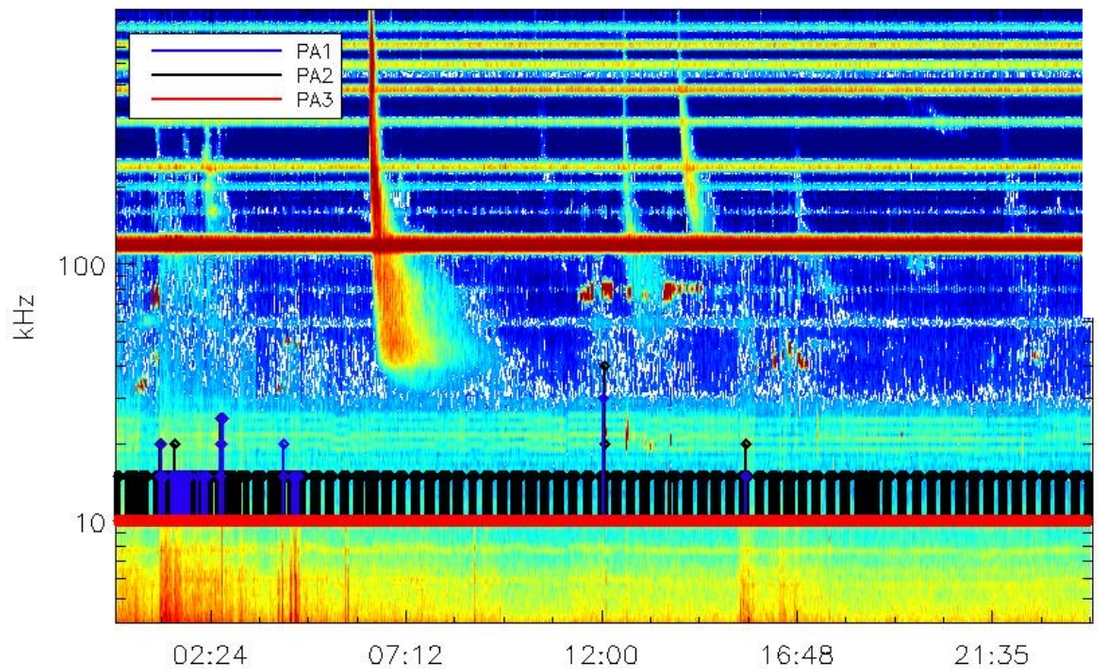
currents for ANT PA, analogue devices: +5V.

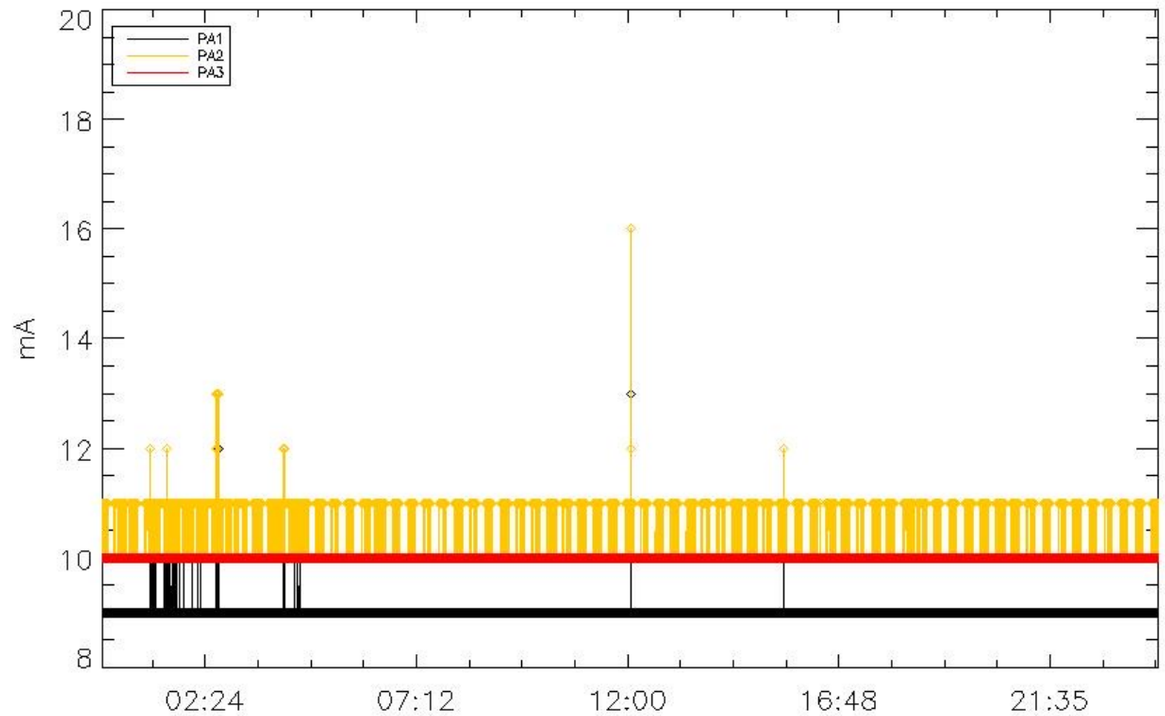


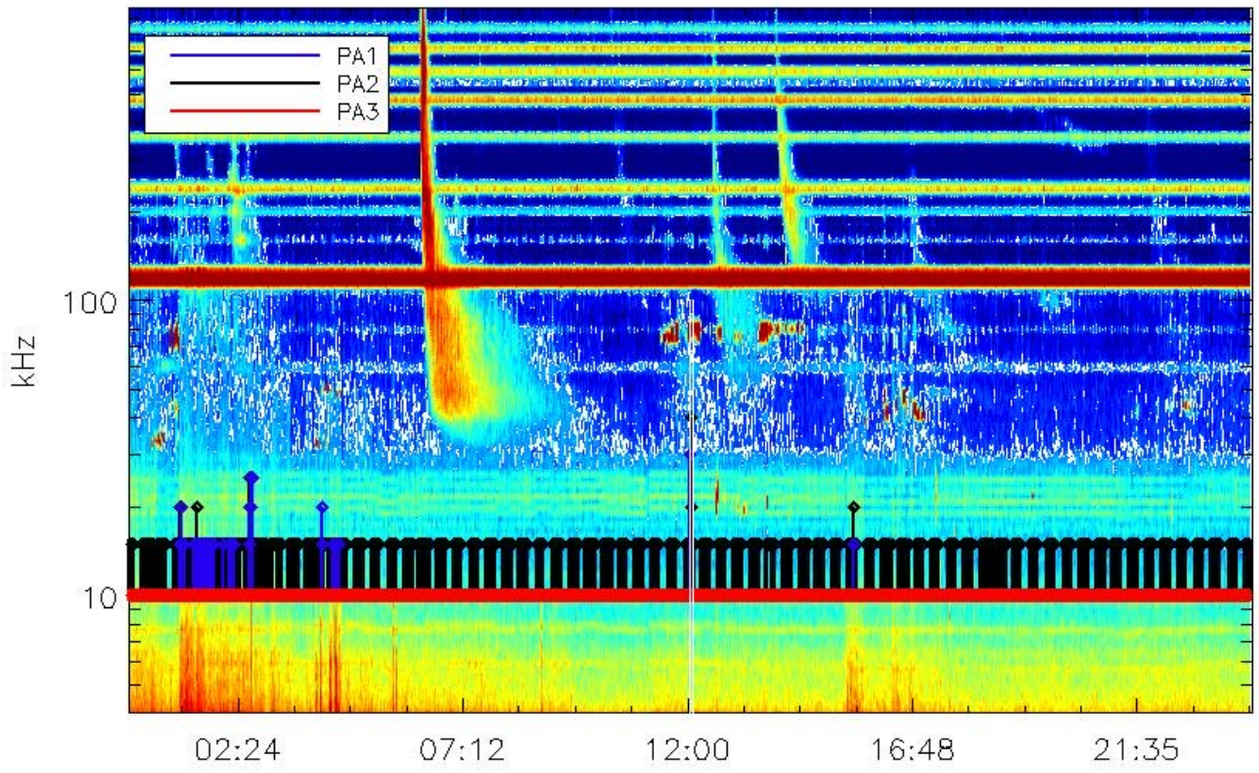


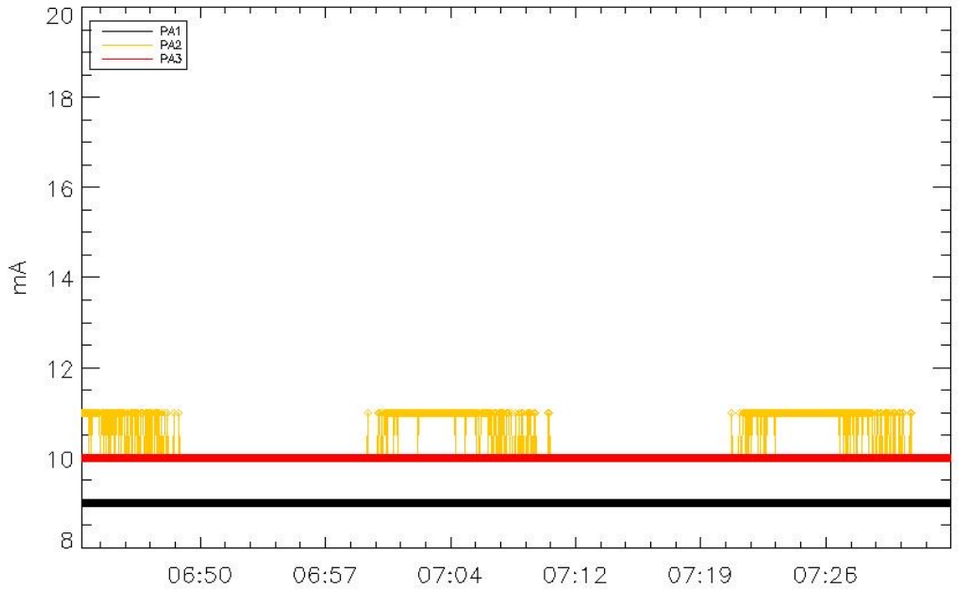
currents for ANT PA, analogue devices: -5V.


PA1
PA2
PA3
100
kHz
10
23:32
23:34
23:35
23:36
23:38

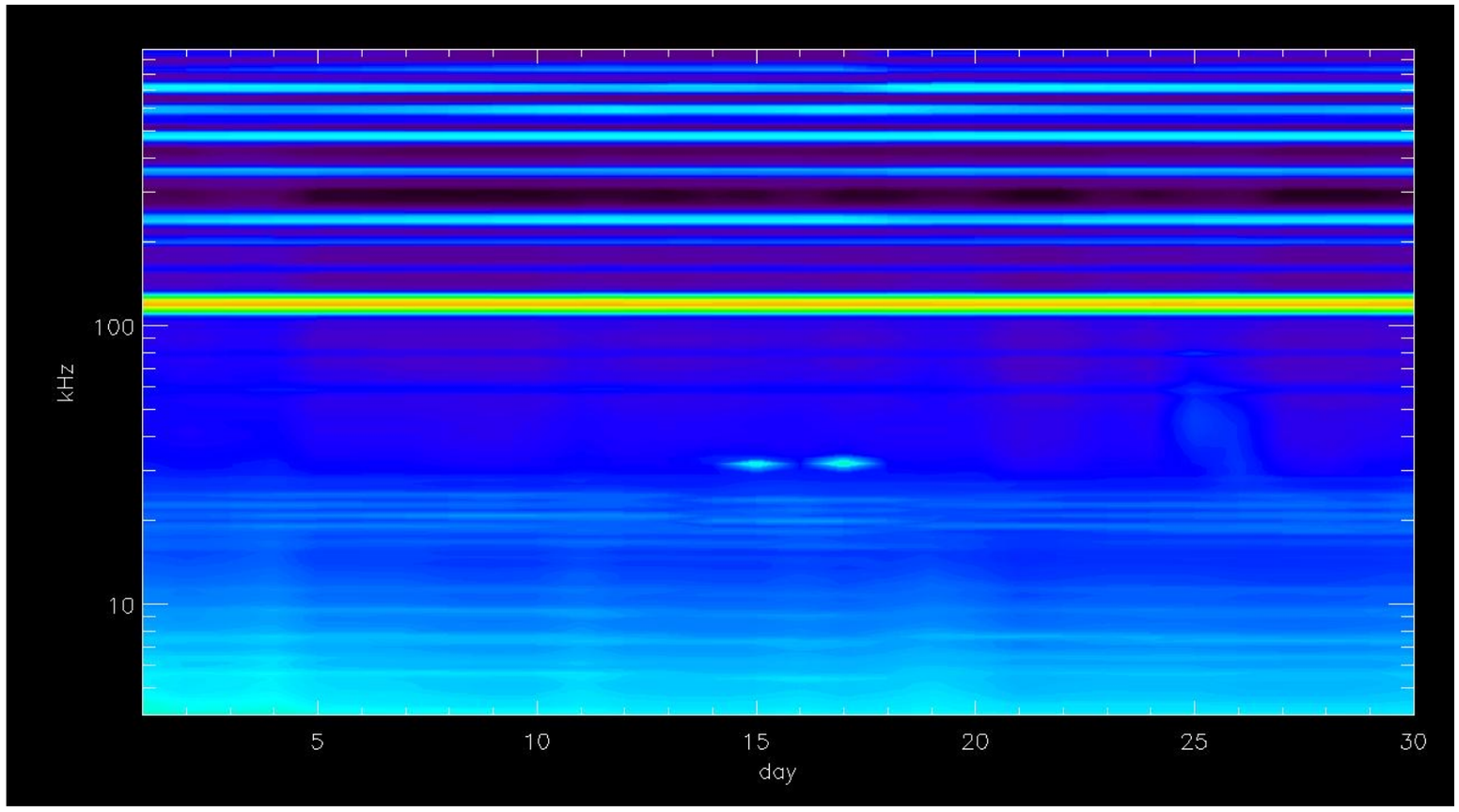

PA1
PA2
PA3
kHz
100
10
02:24
07:12
12:00
16:48
21:35


PA1
PA2
PA3
mA
20
18
16
14
12
10
8
02:24
07:12
12:00
16:48
21:35


PA1
PA2
PA3
kHz
100
10
02:24
07:12
12:00
16:48
21:35


PA1
PA2
PA3
mA
20
18
16
14
12
10
8
06:50
06:57
07:04
07:12
07:19
07:26

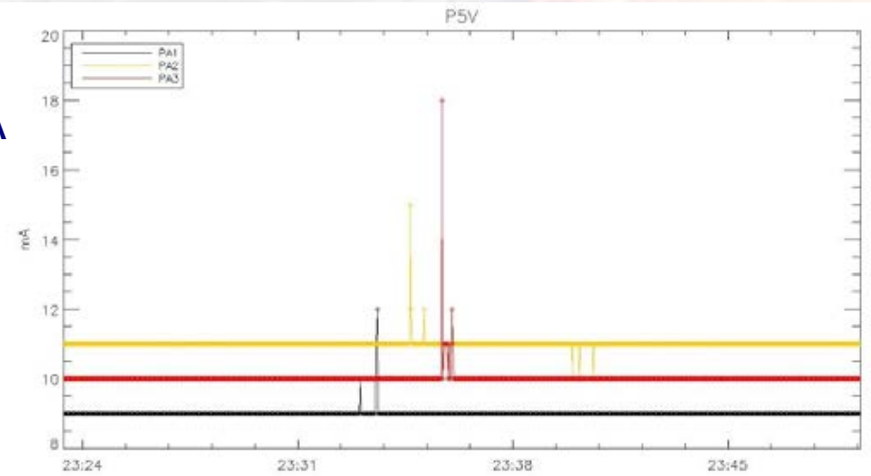
November 2023 TNR Background (median over a day)



HF preamps analysis

Context

- Overconsumption peaks occurred at the time of the failure on the HF PA
- It was then found that these current peaks systematically appear during BIAS sweeps

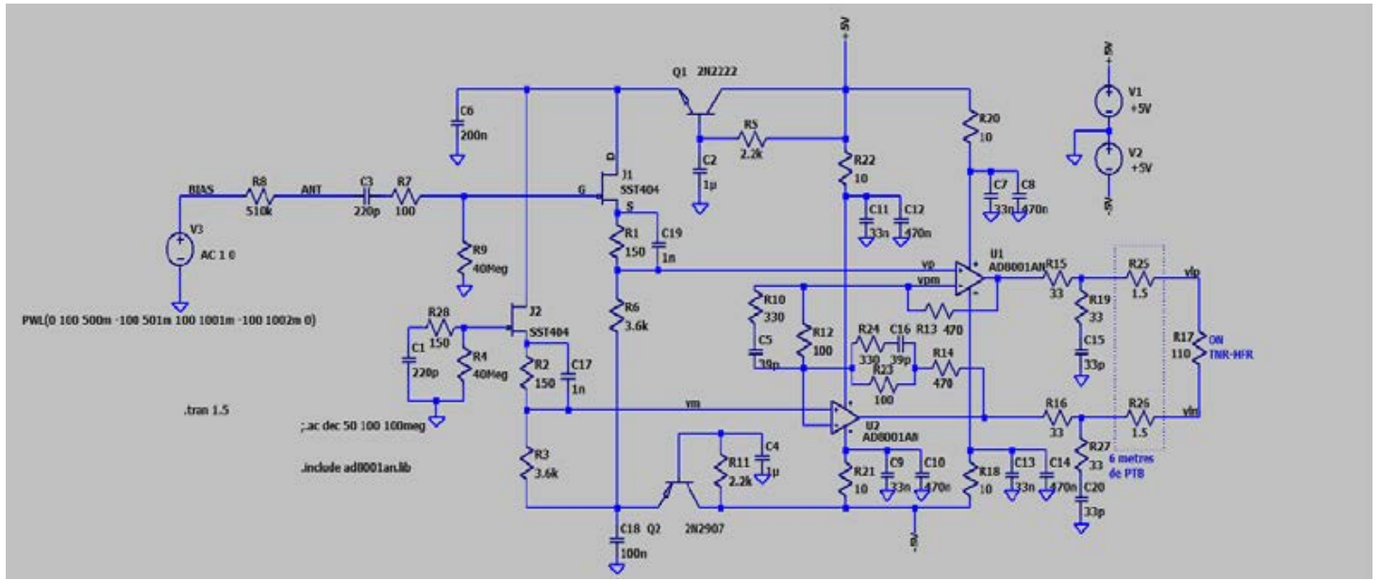


Simulation analysis

- To understand the reason of these overconsumption peaks and their relation with BIAS sweeps
- To estimate the possible stress caused by these peaks on the preamps

Modeling setup

- Model taking into account all the stages of the preamp **and** the output impedance of the BIAS current source
- Realistic configuration is for normal operation … but not necessarily for the anomaly
- Large ramp of +/-100V to simulate the BIAS sweeps → **Extreme worse case conditions**



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HF preamps analysis

Simulation results

1/ Checking the derating parameters

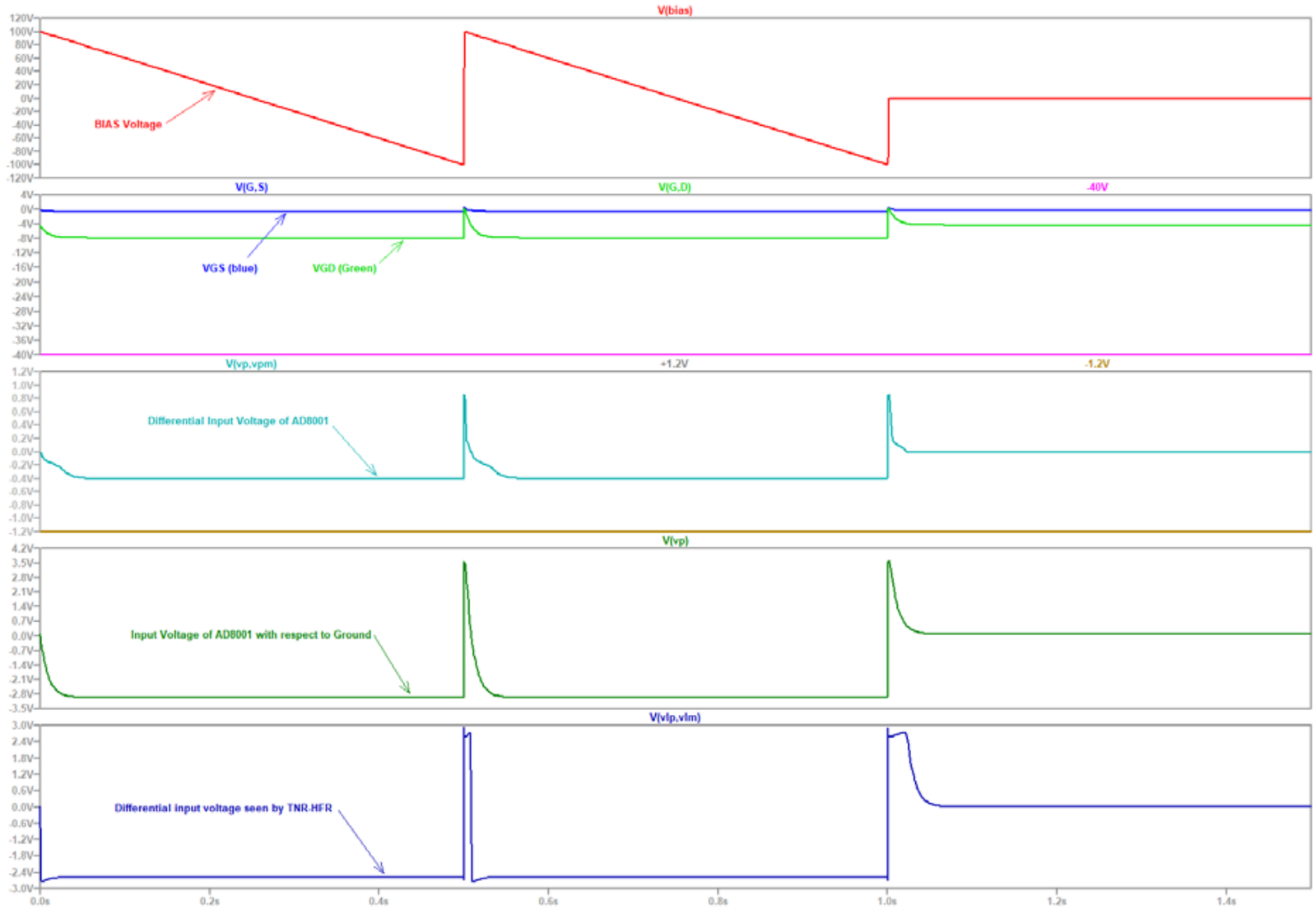
- VGS,VGD at the JFET stage
- AD8001 differential input
- AD8001 single end input

Derating satisfied with comfortable margins despite the large ramp → **no stress**

2/ Explaining current peaks

- Differential output of the preamp

Output voltage pulses occur on the rising edge of the BIAS sweeps → this explains the consumption peaks due to the 110 ohm load



HF preamps analysis

About possible latch-up

- Undesirable state that leads to temporary (eventually permanent) loss of the function
- Persistent state that does not go away on its own → OFF/ON cycle to release it
- It causes overconsumption that is observable on the power rails
  - The HF preamps **systematically and instantly** return to normal consumption after the pulses transients (those caused by the BIAS sweeps)
  - In addition, preamps have been carefully designed to be latch-up free and verified by applying +/-100V short transients to their input

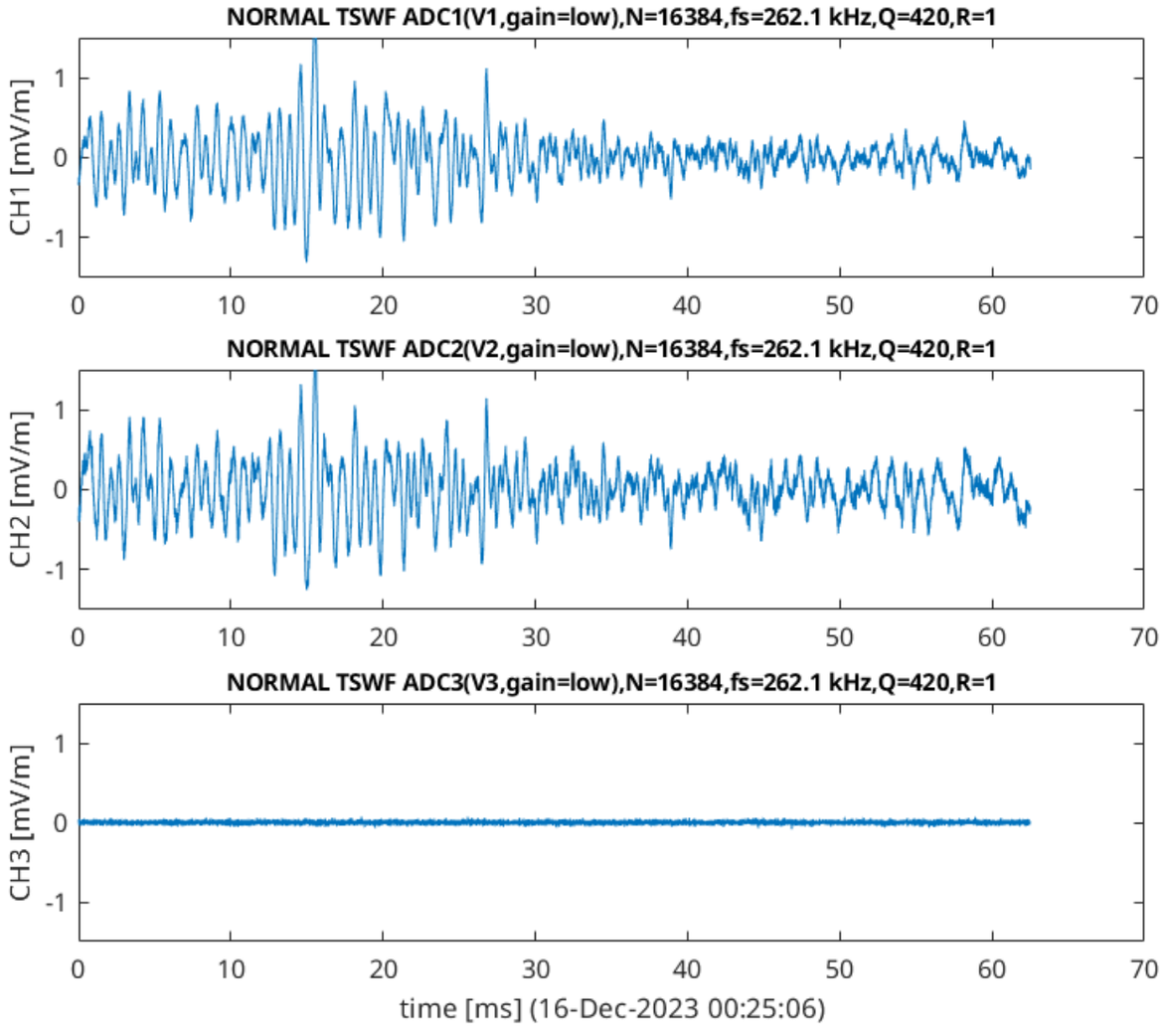
About possible damages

- A single fault in the HF PA does not propagate to the LF section and would not affect the LF operations
- But this would be visible on the data from the HF section
- A double fault can propagate to the LF section, but this is very unlikely
- And, it would have been very clearly visible in the scientific and monitoring data
- When ANT#3 recovers function, the observables did not reveal any obvious difference

Results of data analysis

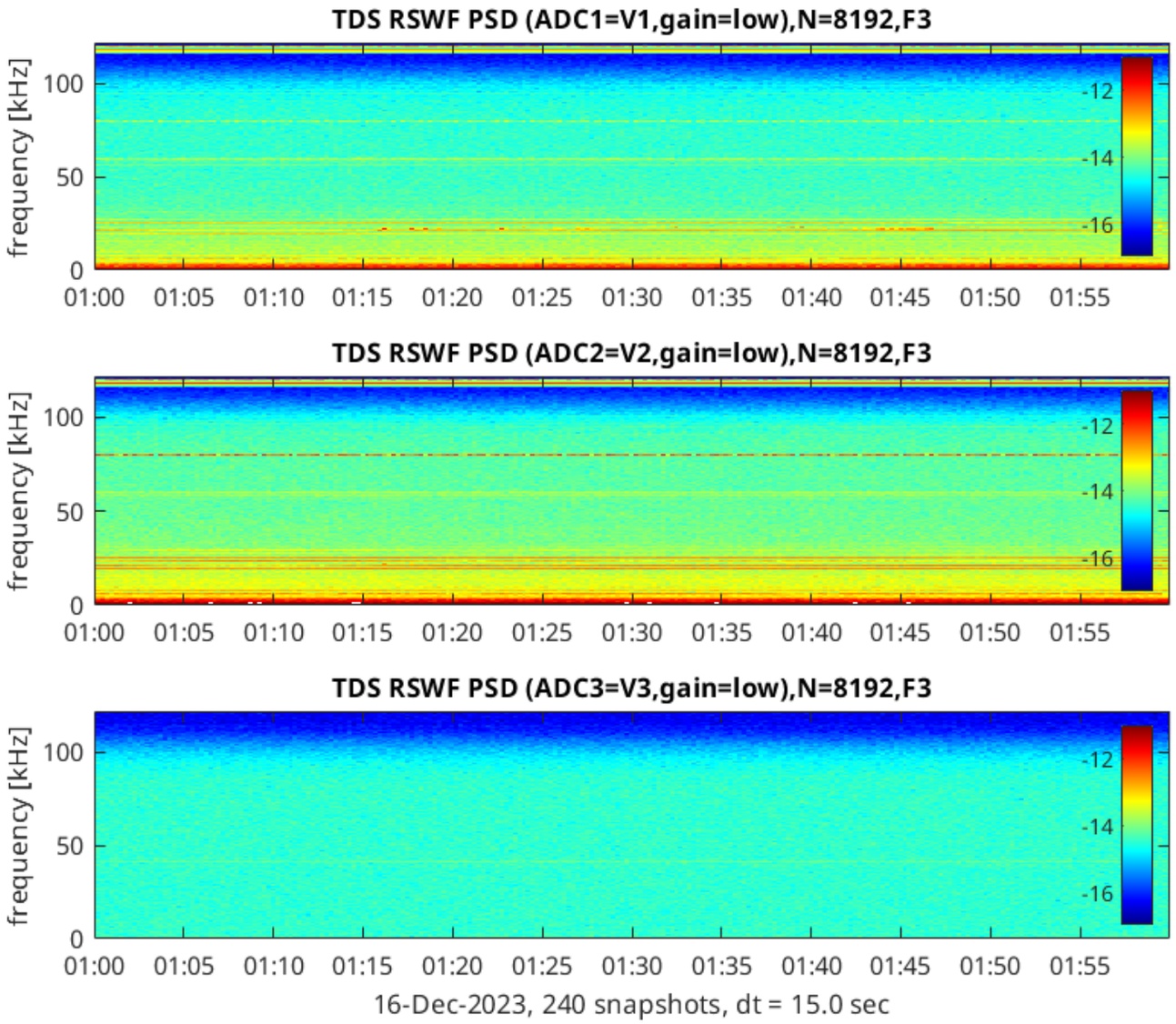
- Bias unit + LF PA data analysis report (by Bias team)
- THR + HF PA data analysis report by (THR team)
- **TDS data analysis report (by TDS team)**

TDS data after the anomaly



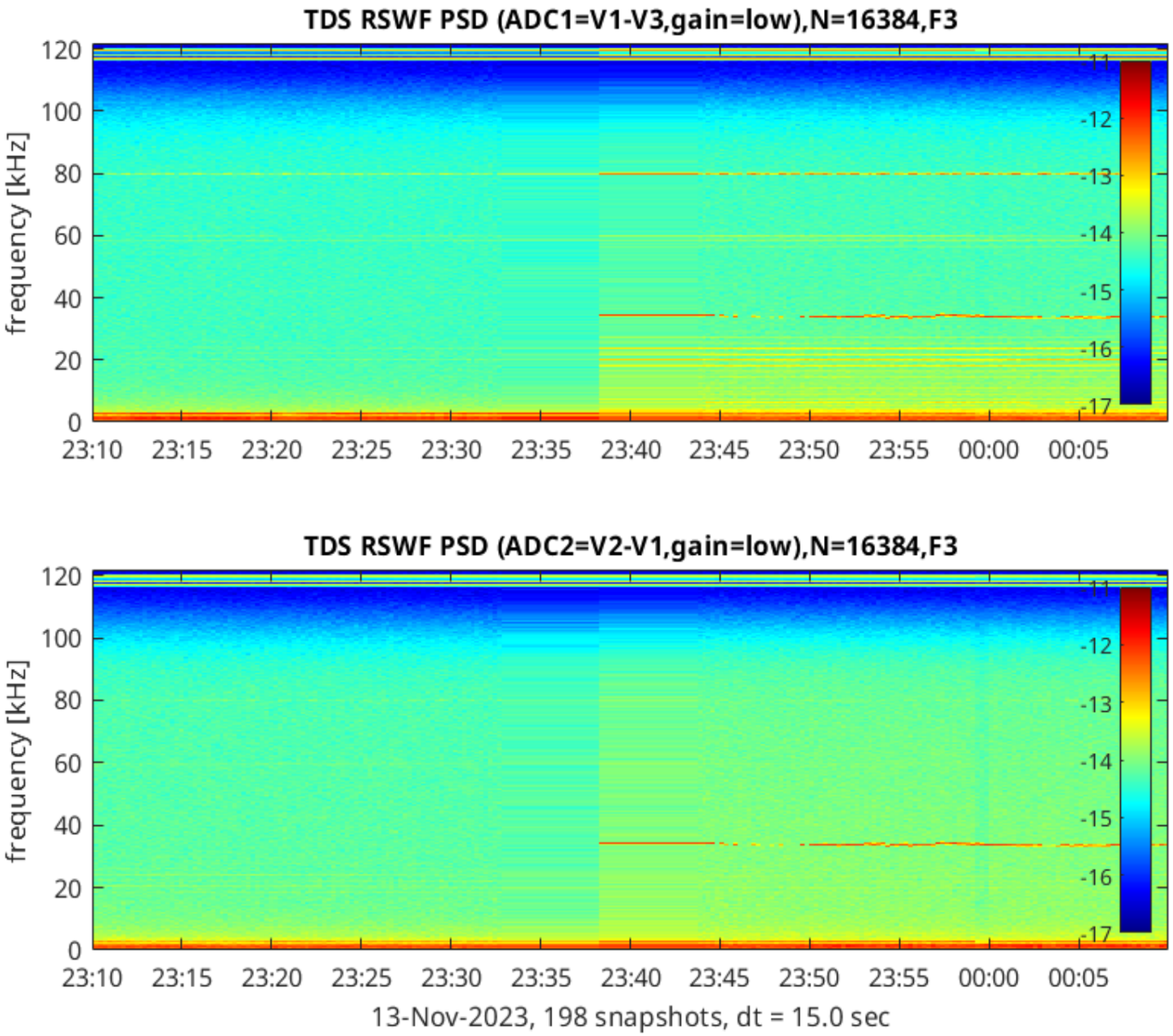
- On December 16, TDS was configured to a monopole mode, where each channel samples a single antenna.
- Clearly, Antenna 3 sees no signal at all
- TDS uses a high frequency preamplifier (different from the one used by the RPW bias), but sharing the same antenna connection “pigtail”

TDS data after the anomaly (spectrum)



- Channel3 only sees (analog) noise, comparable to a situation when the preamplifier would be grounded at its input.
- Even the 120 kHz interference from the PCDU is gone.

TDS data during anomaly on Nov 13



- V3 anomaly occurred on Nov 13, 23:38.
- TDS was in a dipole configuration
- Channel 1 (V1-V3) observes an increase in background interferences due to changing from a dipole to effective monopole
- Increase of the 40 kHz interference observed on both channels, this is common after a BIAS current change.
- A slight increase of background noise on V2-V1 channel observed too. Origin unknown, may or may be related to the anomaly or a bias current change.

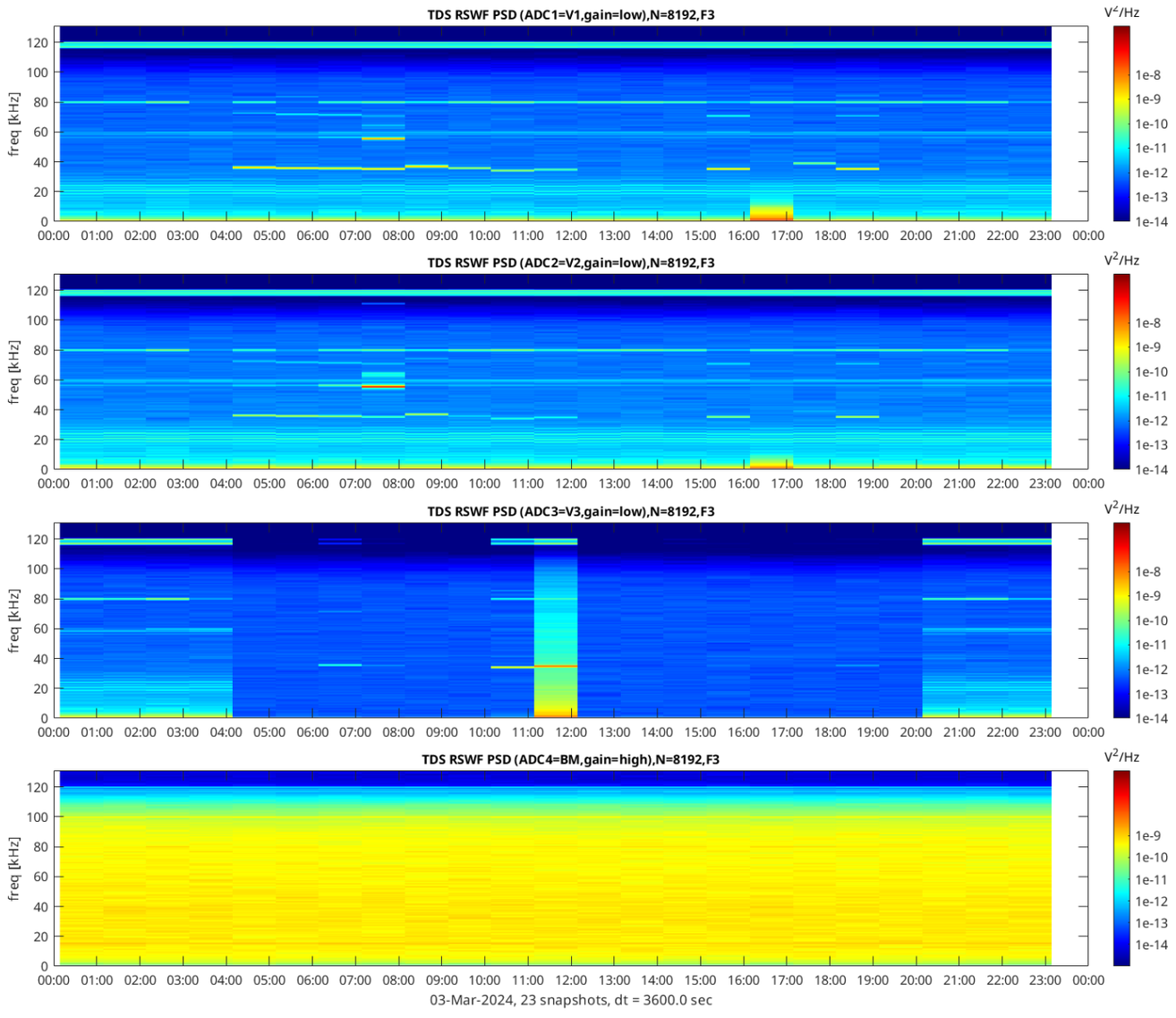
Data loss and possible mitigations on TDS

- On TDS we usually run in a dipole config, sampling
  - CH1 = V3-V1
  - CH2 = V1-V2
  - CH3 = V2

This configuration is not suitable anymore, because the V3-V1 dipole is degraded

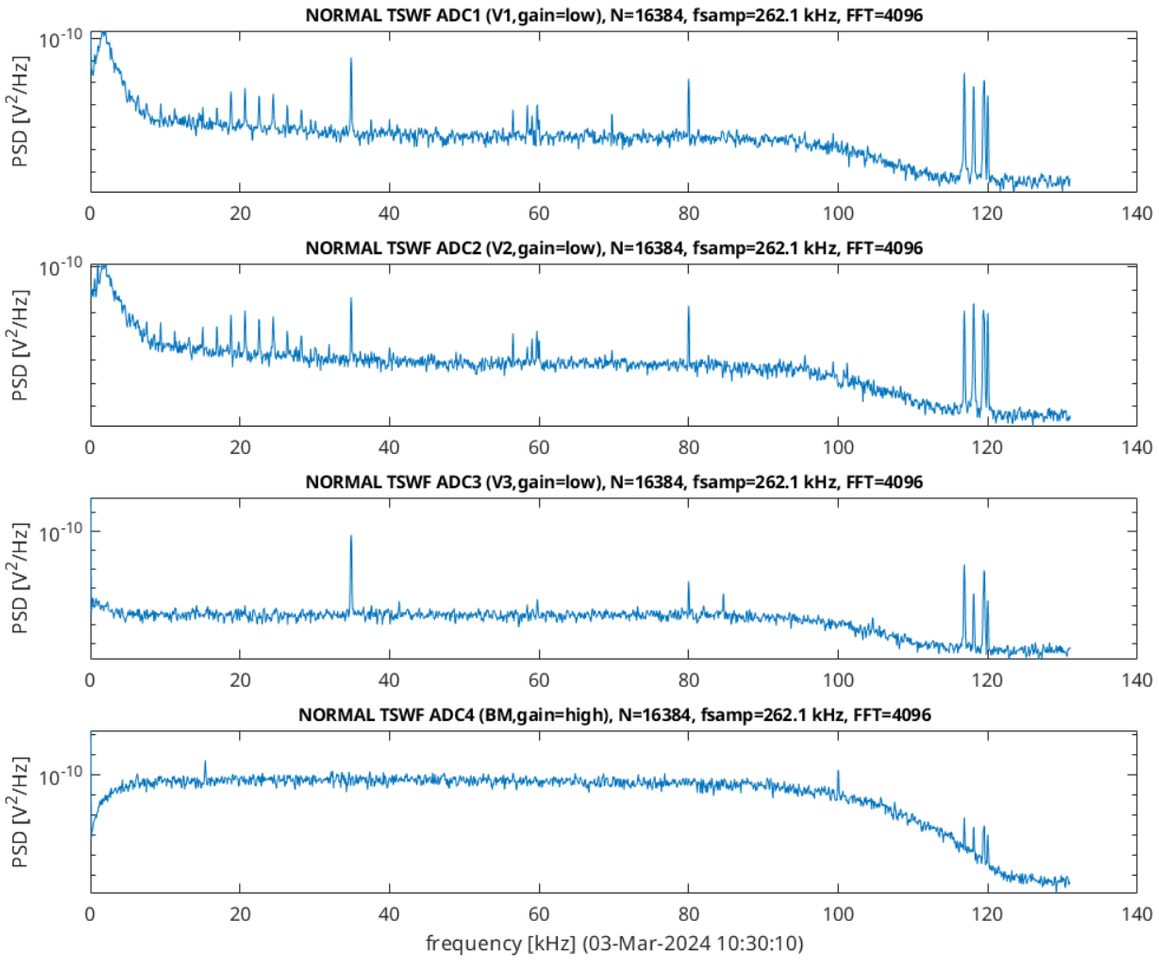
- Short term configuration (since January 22)
  - A full monopole config CH1 = V1, CH2 = V2, CH3 = V3
- Short term configuration (since January 22)
  - CH1 = V1
  - CH2 = V1-V2
  - CH3 = V2
- After this configuration change, the data degradation on TDS will not be too bad
  - We will still be able to recover two components of E-field
  - Triggering of the automatic detection can be done on the V1-V2 dipole as until now, which provides the cleanest spectrum.
  - Slightly increased noise on the V1 and V2 monopoles, compared to dipole measurements
  - On the other hand, this configuration is (somehow) better for dust detection.

TDS data – March 3, intermittent V3 loss



- After recovery of V3, the sginal has been lost again temporarily on the 3rd of March.
- Regular snapshots, only 1 hour resolution available
- Intermittent loss of signal with a short recovery around mid-day.
- There are snapshots where some high frequency signal is still observed, but attenuated (looks like a capacitive short).

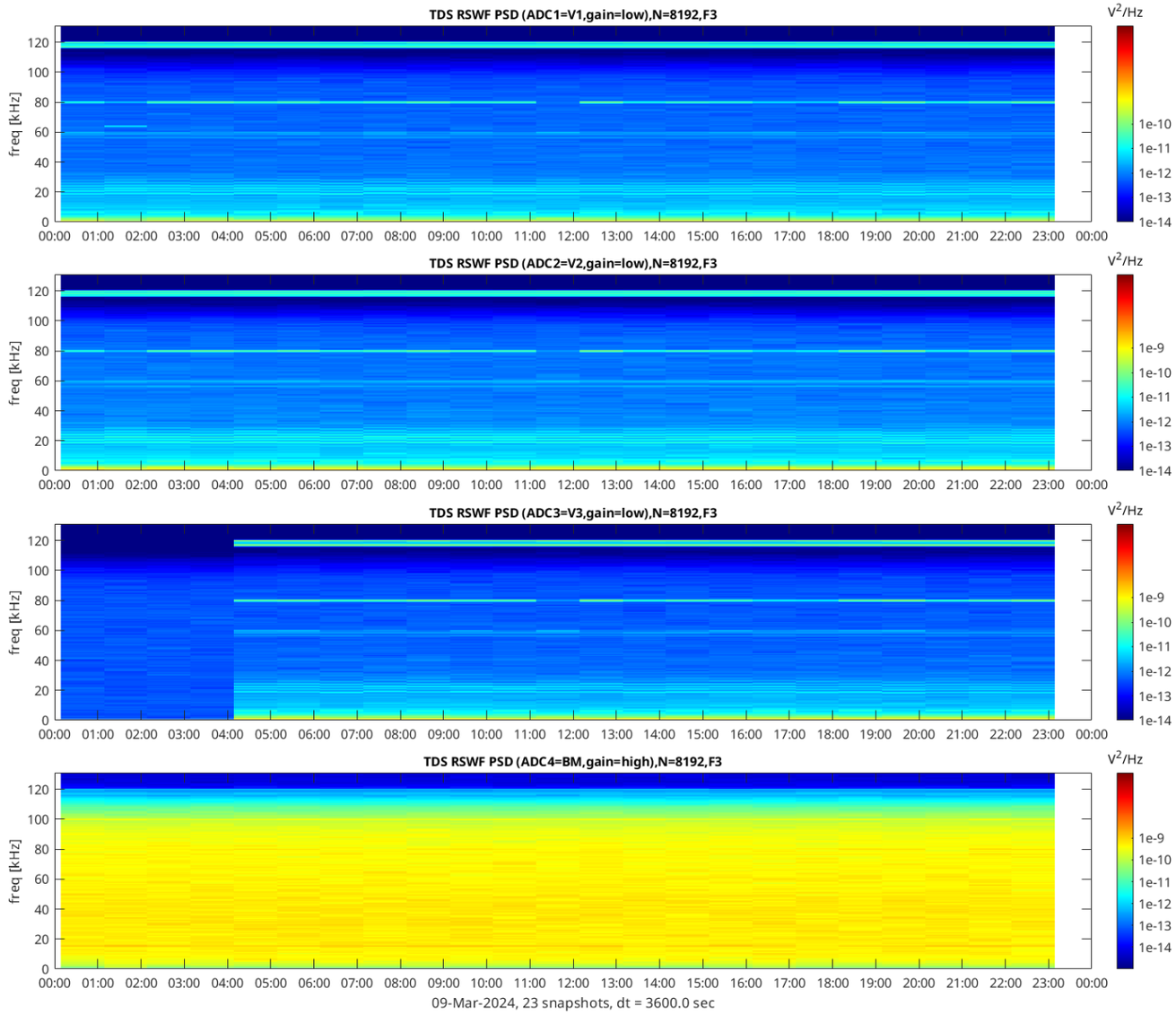
Example of the “partial” anomaly on March 3



- ❑ No low frequency signal
- ❑ Attenuated 120 kHz and other interferences
- ❑ Some (real science) signal at 35 kHz observed, probably with attenuation.

TDS data: Example of loss of signal after a BIAS sweep (March 9)

- Regular snapshots, only 1 hour resolution available
- Signal lost again for a few hours on March 9 after the BIAS sweep.
- This pattern has repeated several times in March until the sweeps have been stopped.



Possible root causes

CAUSE	INITIAL JUSTIFICATION(S)	PROS	CONS
“Ground” element in contact with the antenna	An “ground” element in contact with the antenna can create a short Element could be floating MLI/SLI (glue problem?), PA box mechanical part (small top doors used to free the stacer during antenna deployment?) or condensed material (provoking discharges?)	All the observations reported can be compatible with a short caused by an element in contact, or close to, with the ANT3	
Direct impact by dust or micrometeorit	Dust impacts were reported on November 13, 2023. It is known from previous space missions that micrometeorits can damage antennas (cf. Wind/Waves X dipole was broken twice during the mission on 2000 and 2002).		After verification, the dust impact occurred earlier on November 13. No dust impact observed in the data during anomaly Direct impact should cause irreversible damage Direct impact may not impact both LF and HF signals RPW antenna diameter (3.8 cm) is large (compared to the diameter of Wind/Waves antennas: 0.04 cm). The risk of break by micrometeorits is very low here.

Possible root causes

CAUSE	INITIAL JUSTIFICATION(S)	PROS	CONS
Spacecraft 'debris' caused by dust impacts	Stuart Bale (PSP/FIELDS PI) reported a Bias anomaly on FIELDS due Spacecraft heatshield 'debris' being catched by antennas 1 and 2. SoloHI images let think the Solar Orbiter heatshield also released 'debris' (see image in appendix 7.7) Do accumulated debris could cause a short with ANT3?		No direct observation of such `debris` has been reported on RPW. Analysis of SoloHi images may help to confirm it. Anomaly occurred suddently Setting Bias current for ANT3 to +10 uA did not permit to recover the nominal signal for ANT3
Energetic particle event		The peaks seen on the HF PA -+ 5V currents at the time of anomaly (Figures 10 and 11) could be caused by an energetic particle event. High enough energetic particle event could deteriorate the electronics	Energetic particle event should also be seen by other instruments, which was not the case. HF PA -+5V current peaks were already observed during bias sweeps in the past (see for instance in [RD2])
Electronics failure	Short may cause by electronics failure	A failure at PCB level is still possible Risk of HF PA latch-up? (See CNES analysis, April 3 meeting)	Anomaly is observed by all the analyzers TDS, LFR and HFR with acquisitions from both HF and LF channels According to THR and Bias teams, latch-up in HF PA is not the root cause of the failure

Possible root causes

- By elimination, the most likely root cause is an element (from PA box, S/C body or accumulated material) in contact with the antenna
- Scenarios can be reasonably rejected (direct impact, solar event, HF PA latch up, Bias unit electronics failure)
- Other scenarios are less probable, but still possible (PCB failure)

Any remaining open points & tests

- If a mechanical element in contact with antenna is the root cause, the origin of this element is still not clearly established (MLI/SLI? Elements from PA box?)
- Accumulated `Debris` or PCB electronics possible failures have not been definitively rejected

Way forward

- Discussions (All)

Extra slides

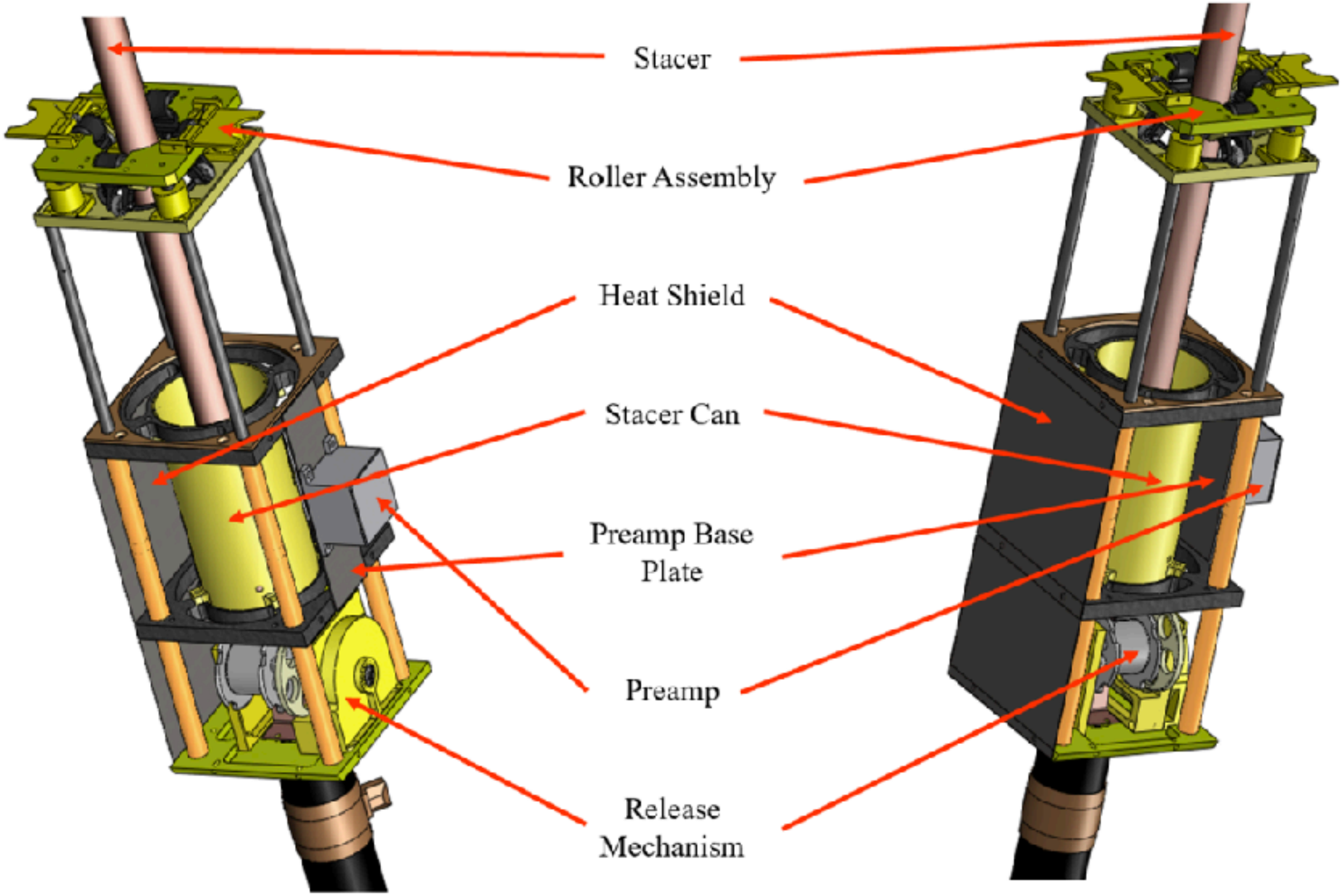
Extra slides

	BIAS output signals					
MODE	**BIAS_1**	**BIAS_2**	**BIAS_3**	**BIAS_4**	**BIAS_5**	**Operation**
0	V1_DC	V12_DC*	V23_DC	V12_AC*	V23_AC	Standard operation
1	V2_DC	V3_DC	V23_DC	~~V12_AC*~~	V23_AC	probe 1 fails
2	V1_DC	V3_DC	V13_DC*	V13_AC*	~~V23_AC~~	probe 2 fails
3	V1_DC	V2_DC	V12_DC*	V12_AC*	~~V23_AC~~	probe 3 fails
4	V1_DC	V2_DC	V3_DC	V12_AC*	V23_AC	Calibration mode 0
5	2.5V Ref	2.5V Ref	2.5V Ref	V12_AC*	V23_AC	Calibration mode 1
6	GND	GND	GND	V12_AC*	V23_AC	Calibration mode 2
7	GND	GND	GND	V12_AC*	V23_AC	Calibration mode 2

where * denotes the ability to switch from V12_AC and V12_DC, to V13_AC and V13_DC, using the latching relay, in the case of failure of probe 2. It is not possible to have a combination of V12 and V13 signals in the same mode.

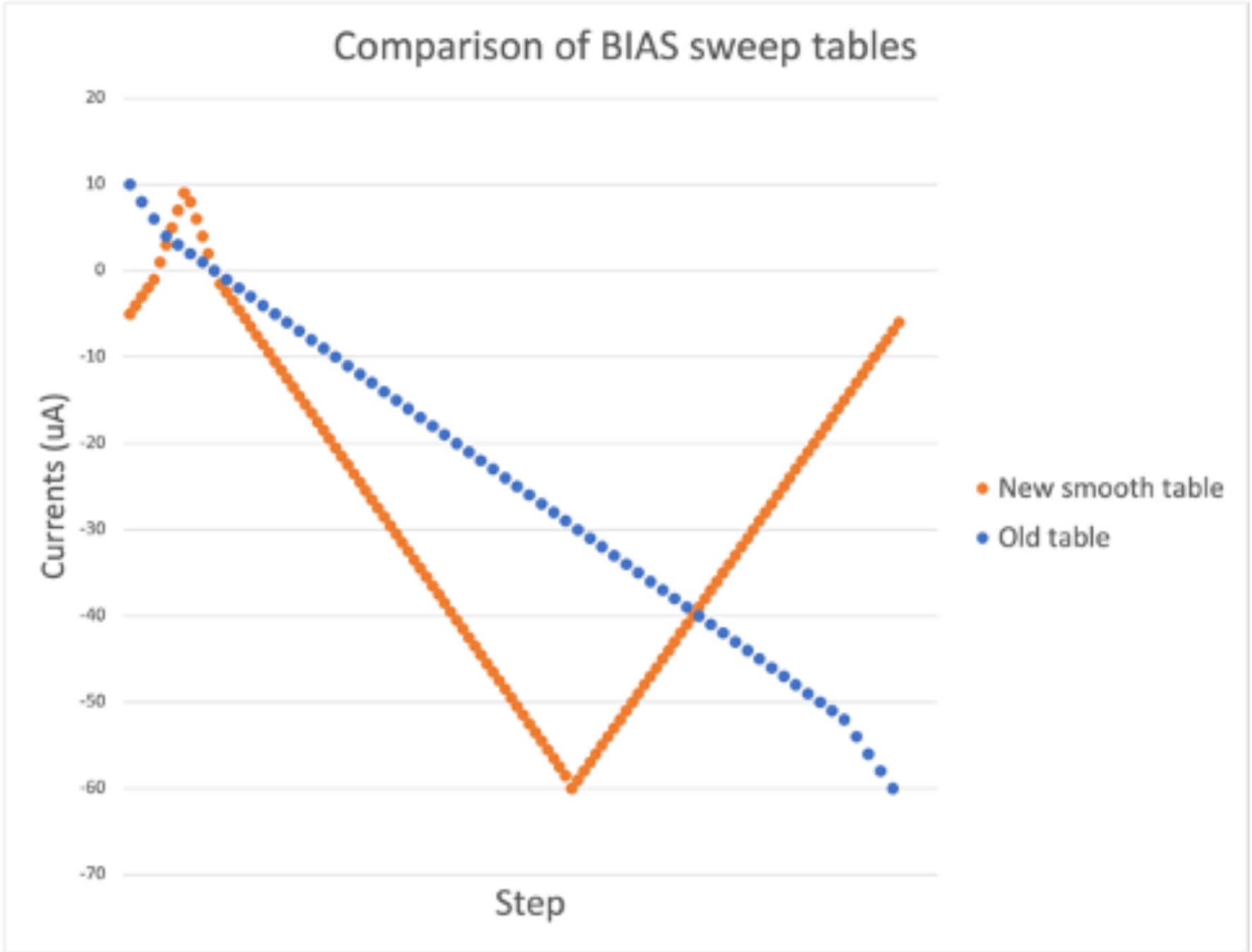
Table 4 LFR/TDS BIAS unit output signals.

Extra slides



Current SolidWorks Model

Extra slides



Extra slides

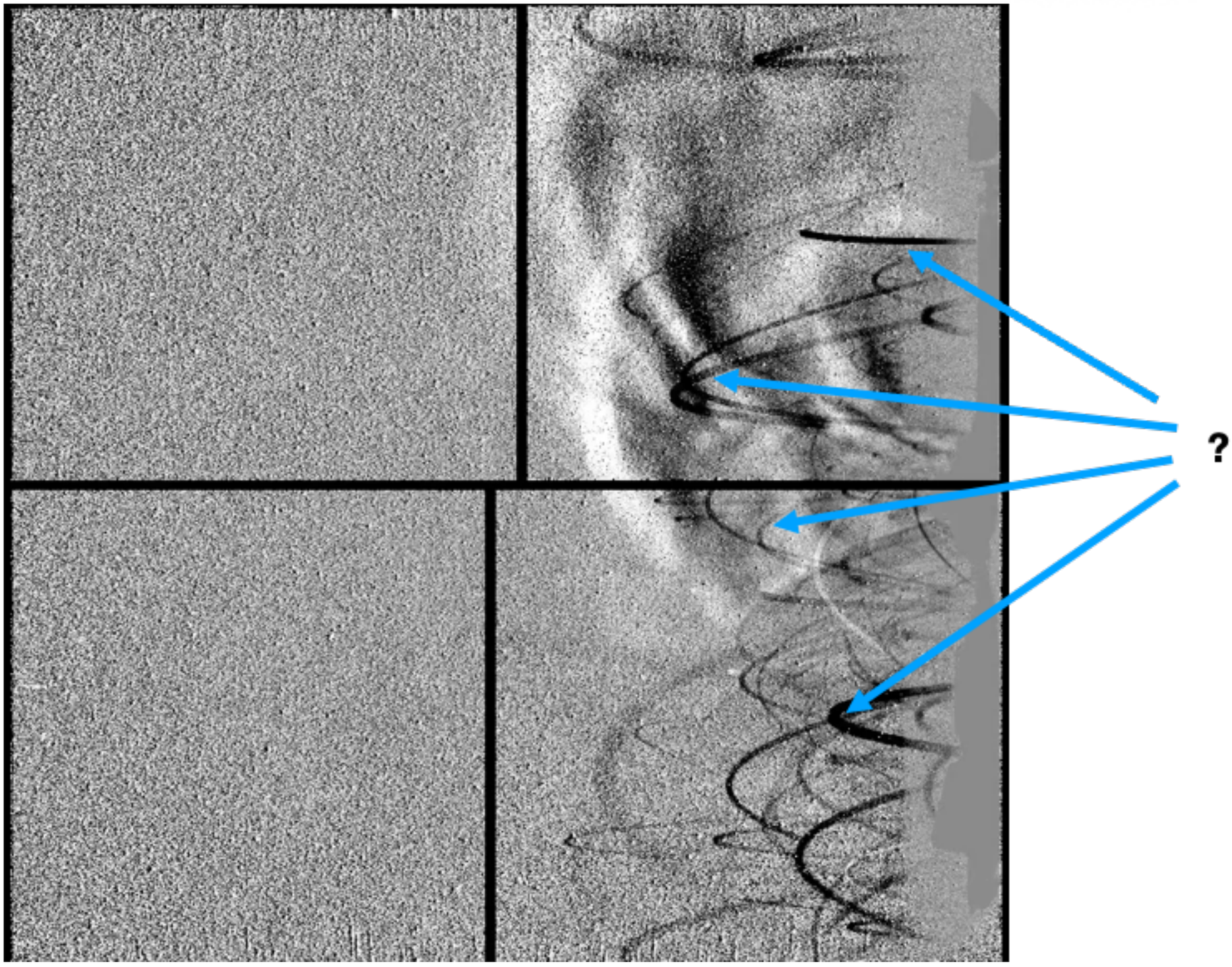


Image from SoloHI