Binary Neutron Star Range Oscillations at LIGO Livingston Observatory: Update

Beverly K. Berger

3 June 2025

LIGO-G2401452-v4

https://dcc.ligo.org/G2401452

1

What are binary-neutron-star range oscillations?

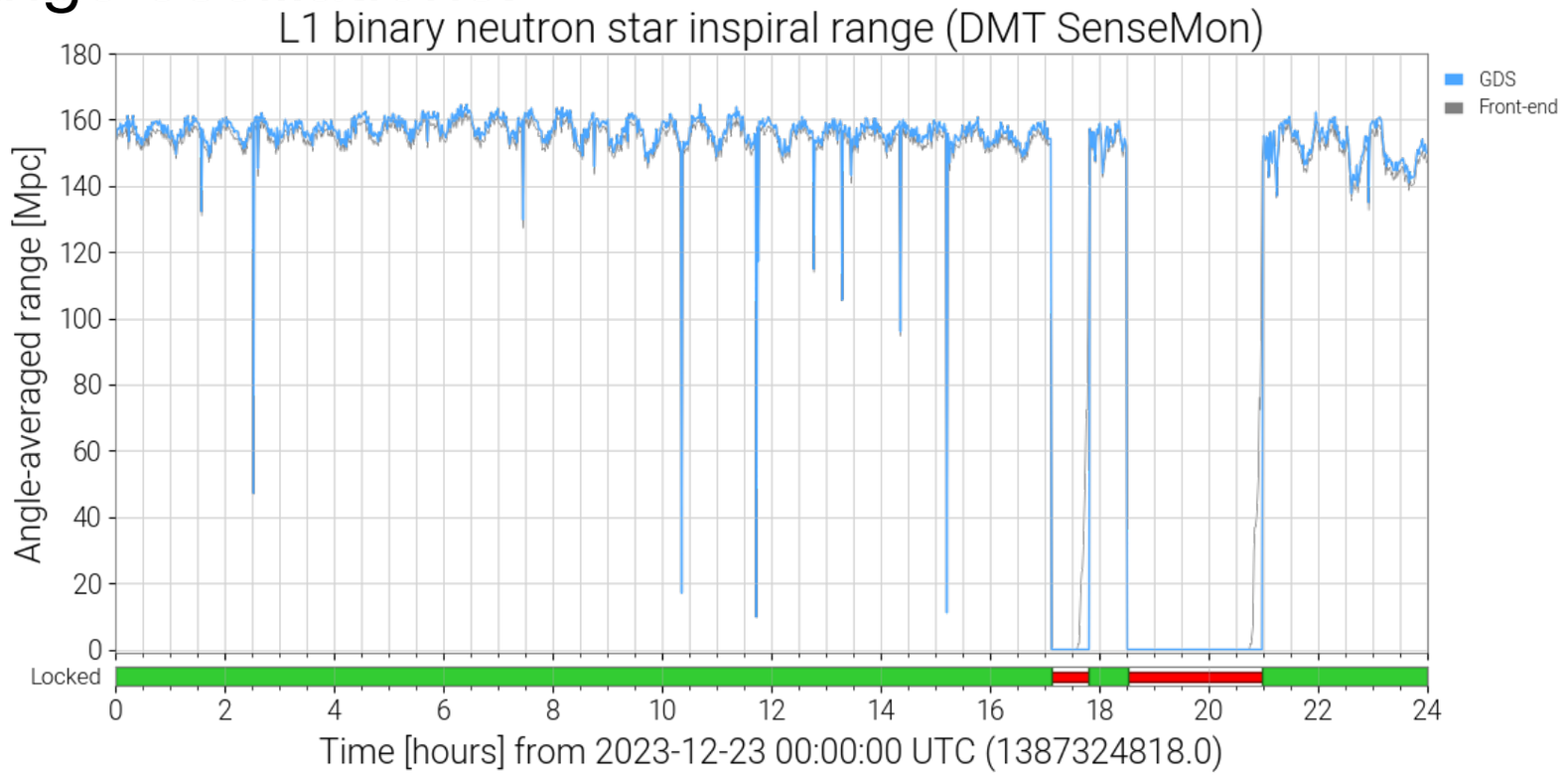
The Summary Pages allow access to LIGO data from a huge number of sensors for any collaboration member from anywhere.

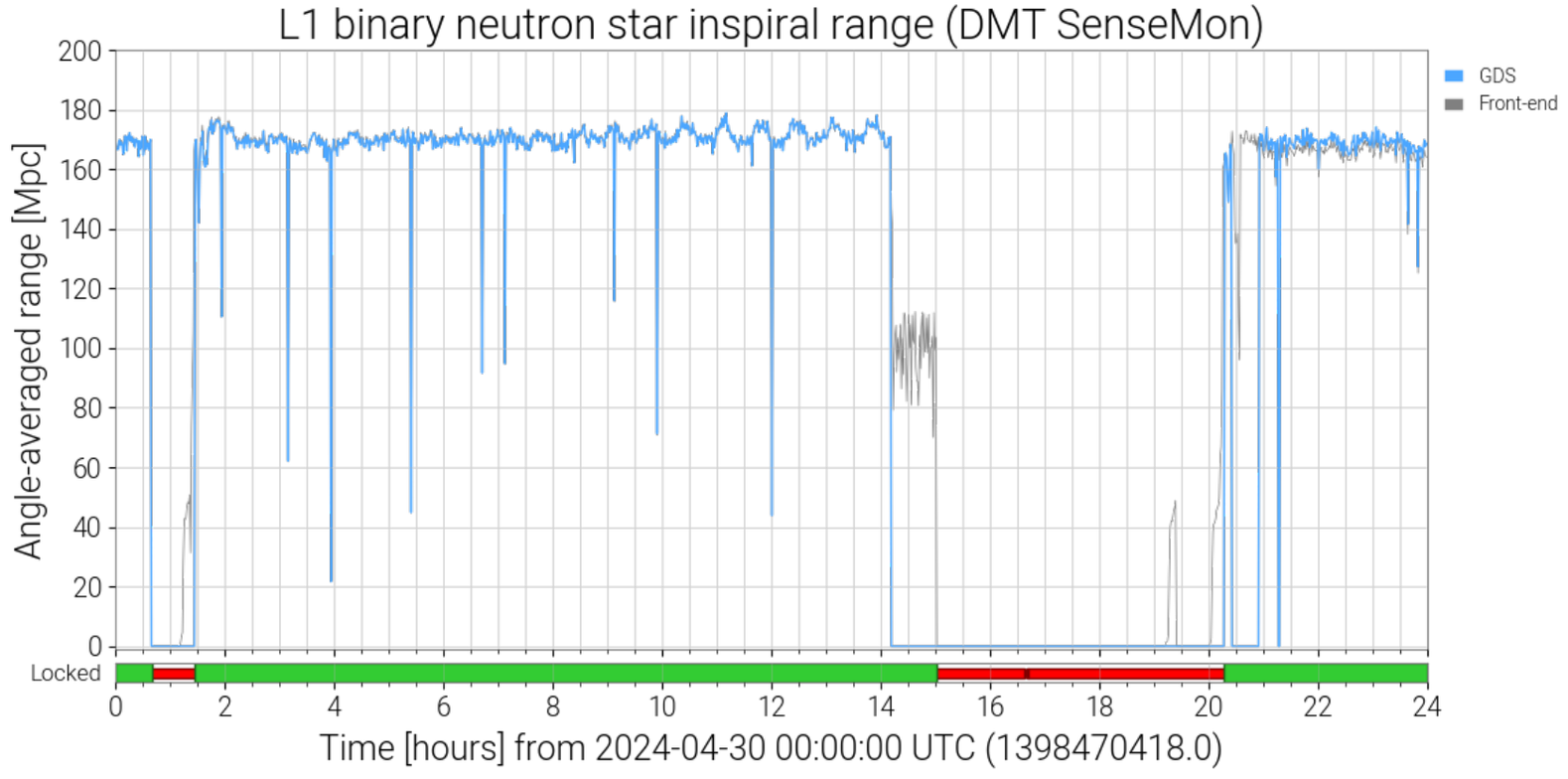
BNS range is a convenient single number — distance averaged over the sky to which GWs from a BNS merger are detectable with an SNR of 8 — to estimate the sensitivity of a LIGO instrument.

BNS range oscillations are visible on the Summary Pages.

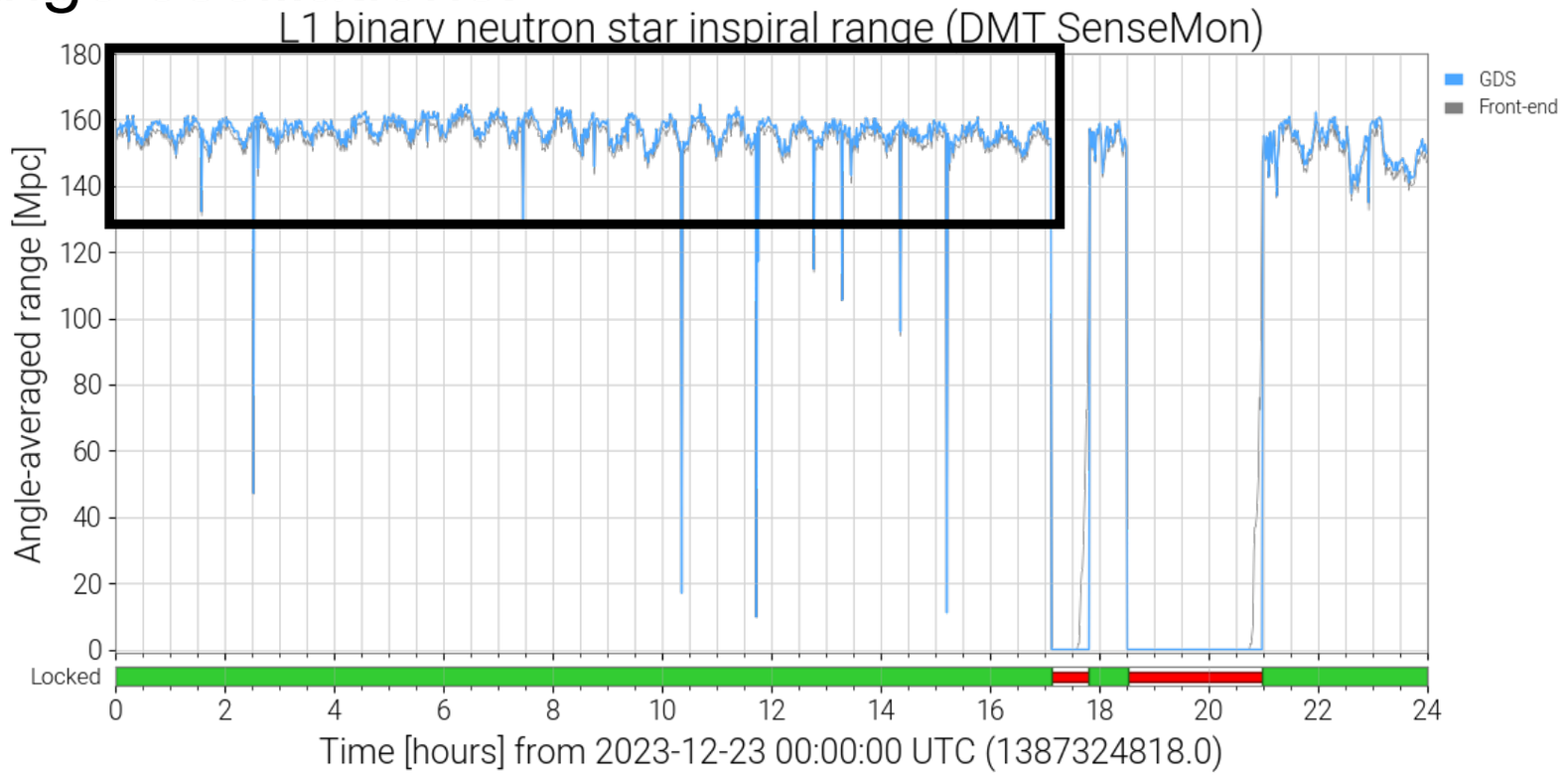
2

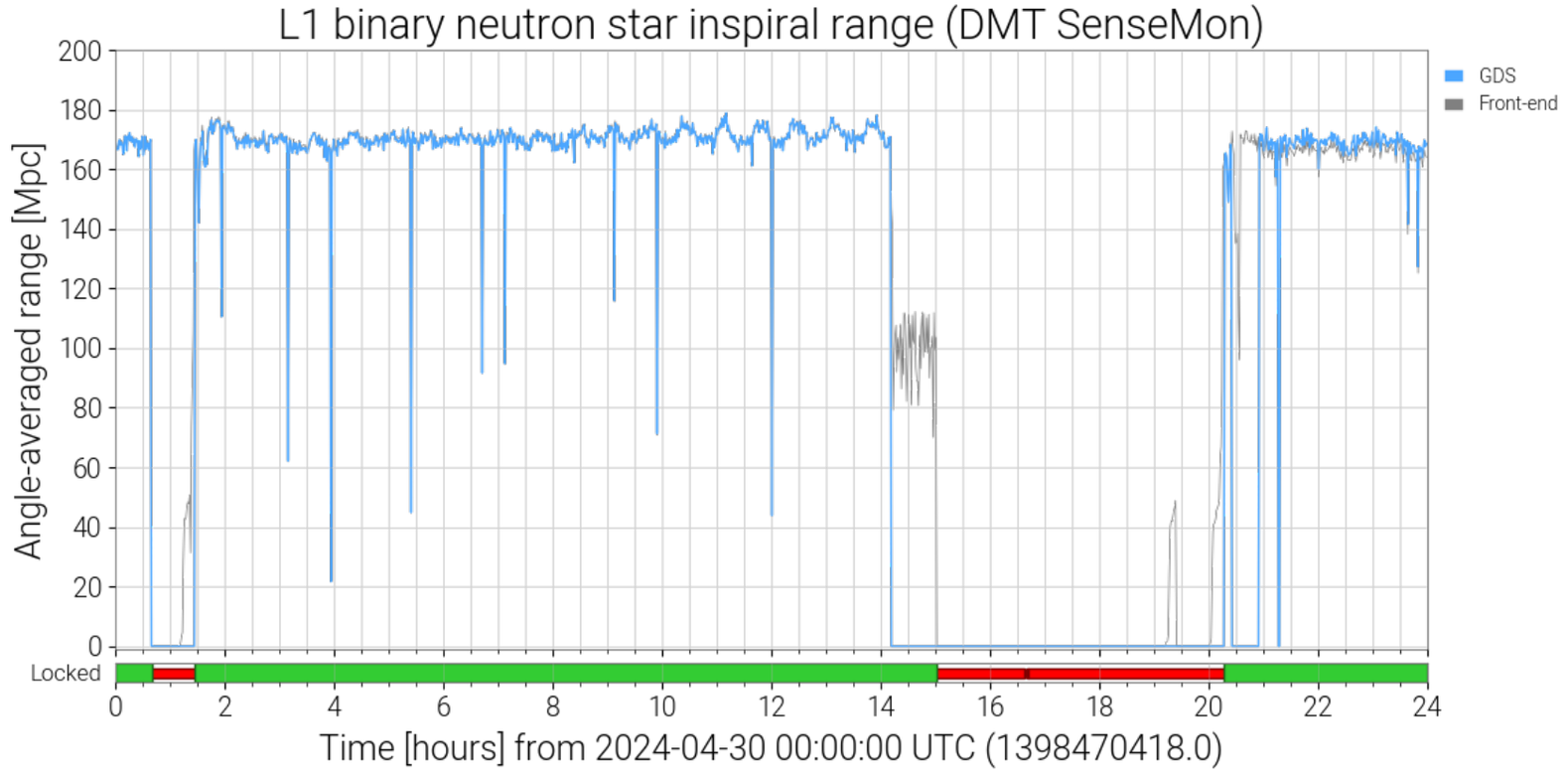
Time series of range oscillations:



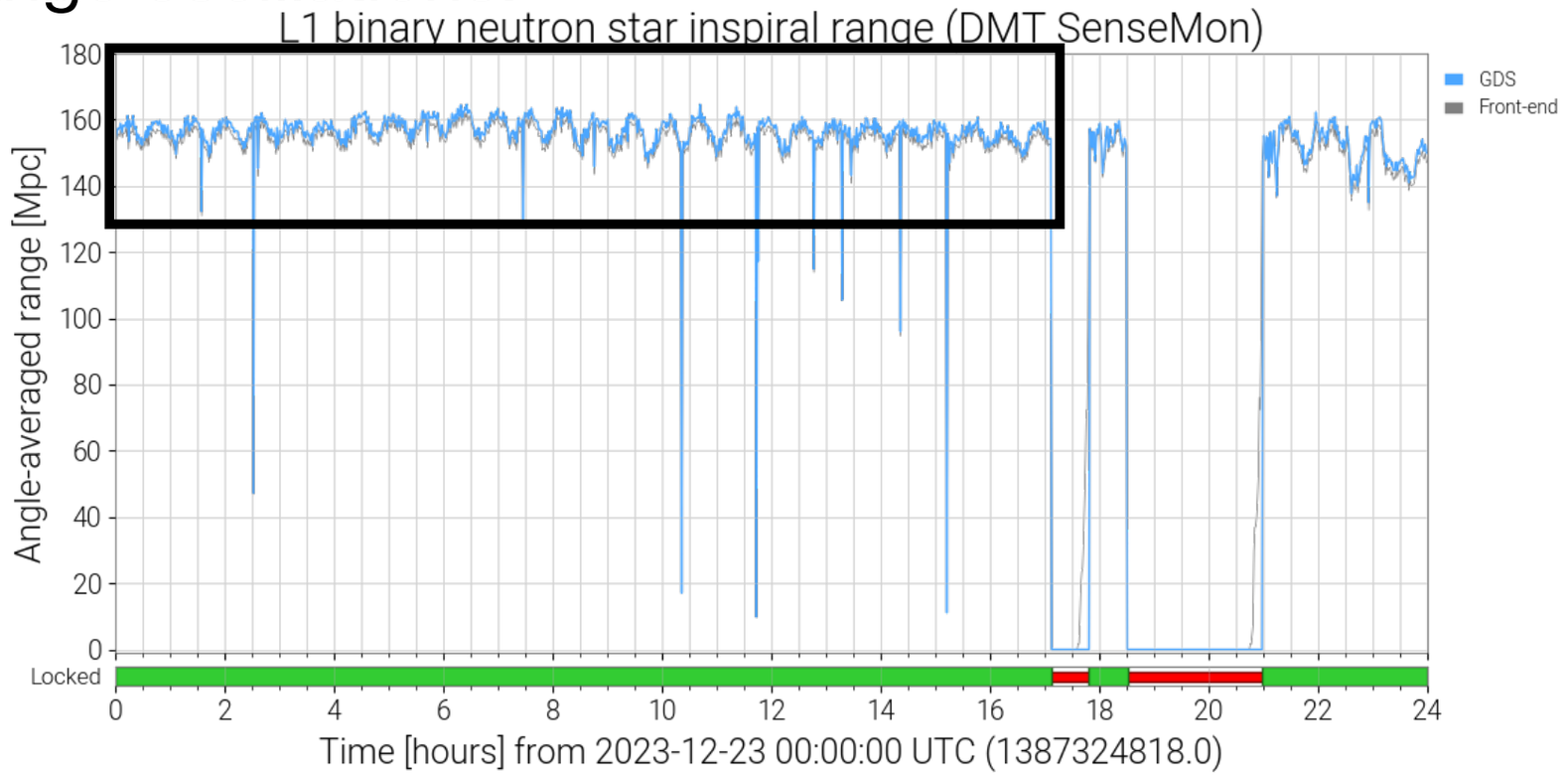


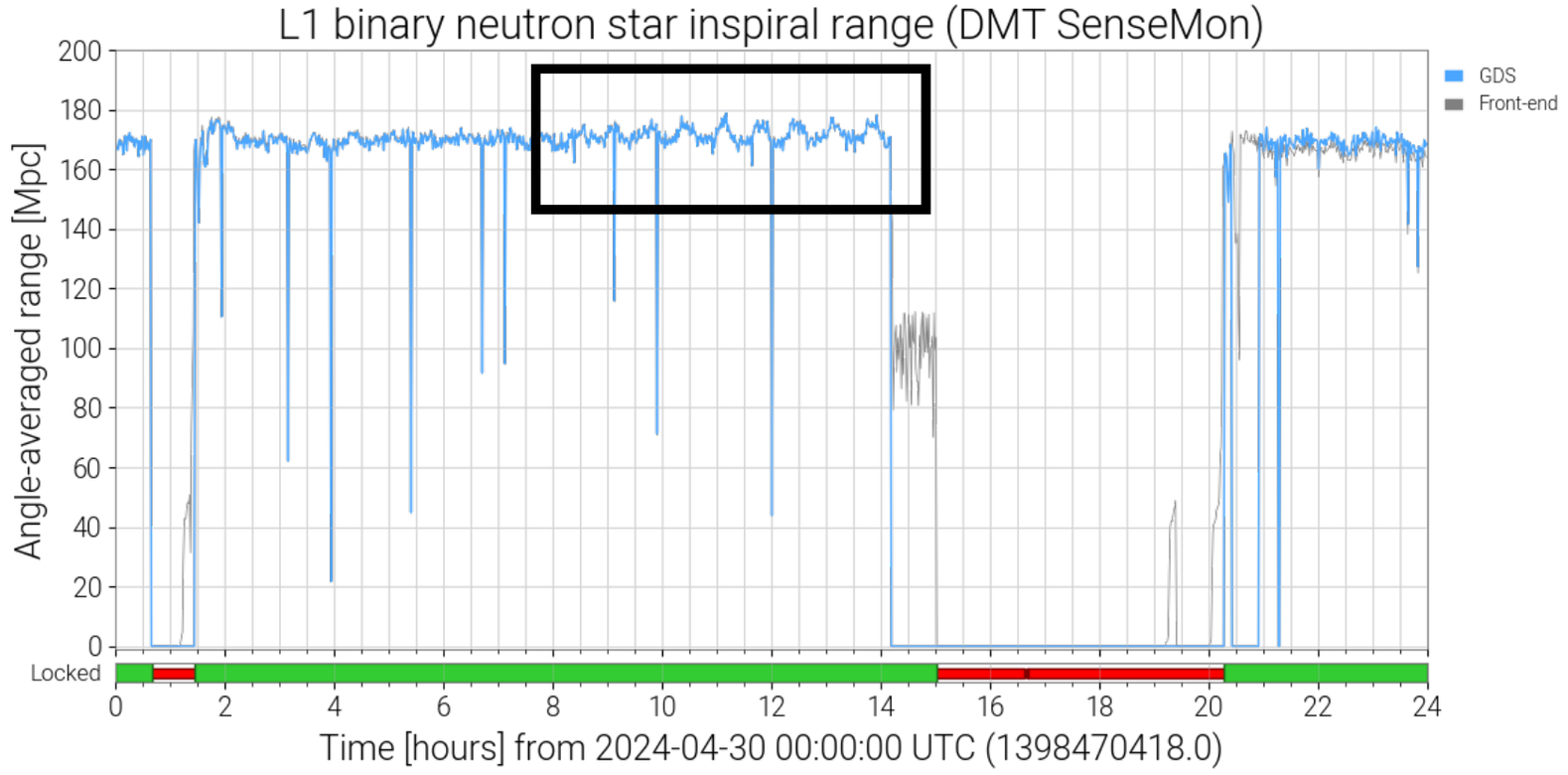
Time series of range oscillations:



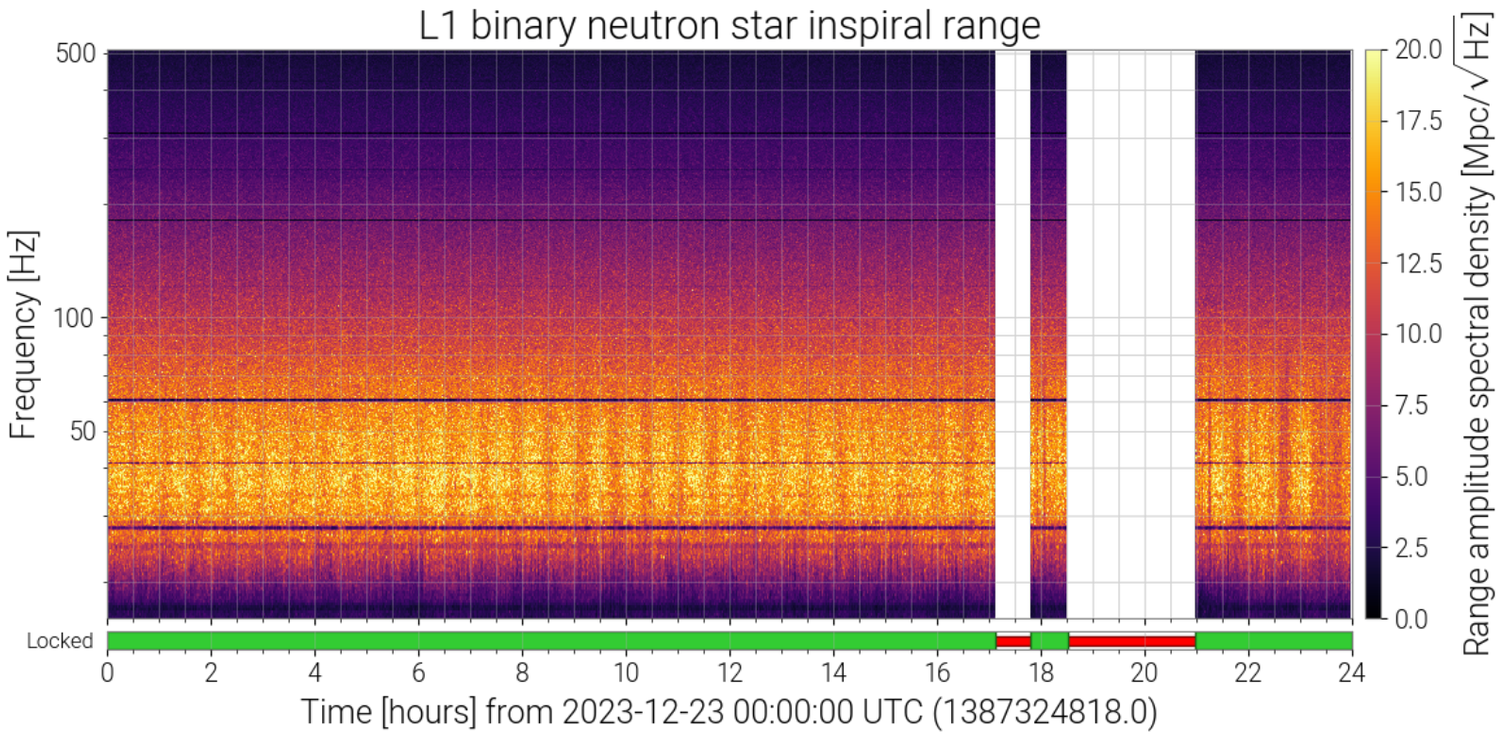


Time series of range oscillations:

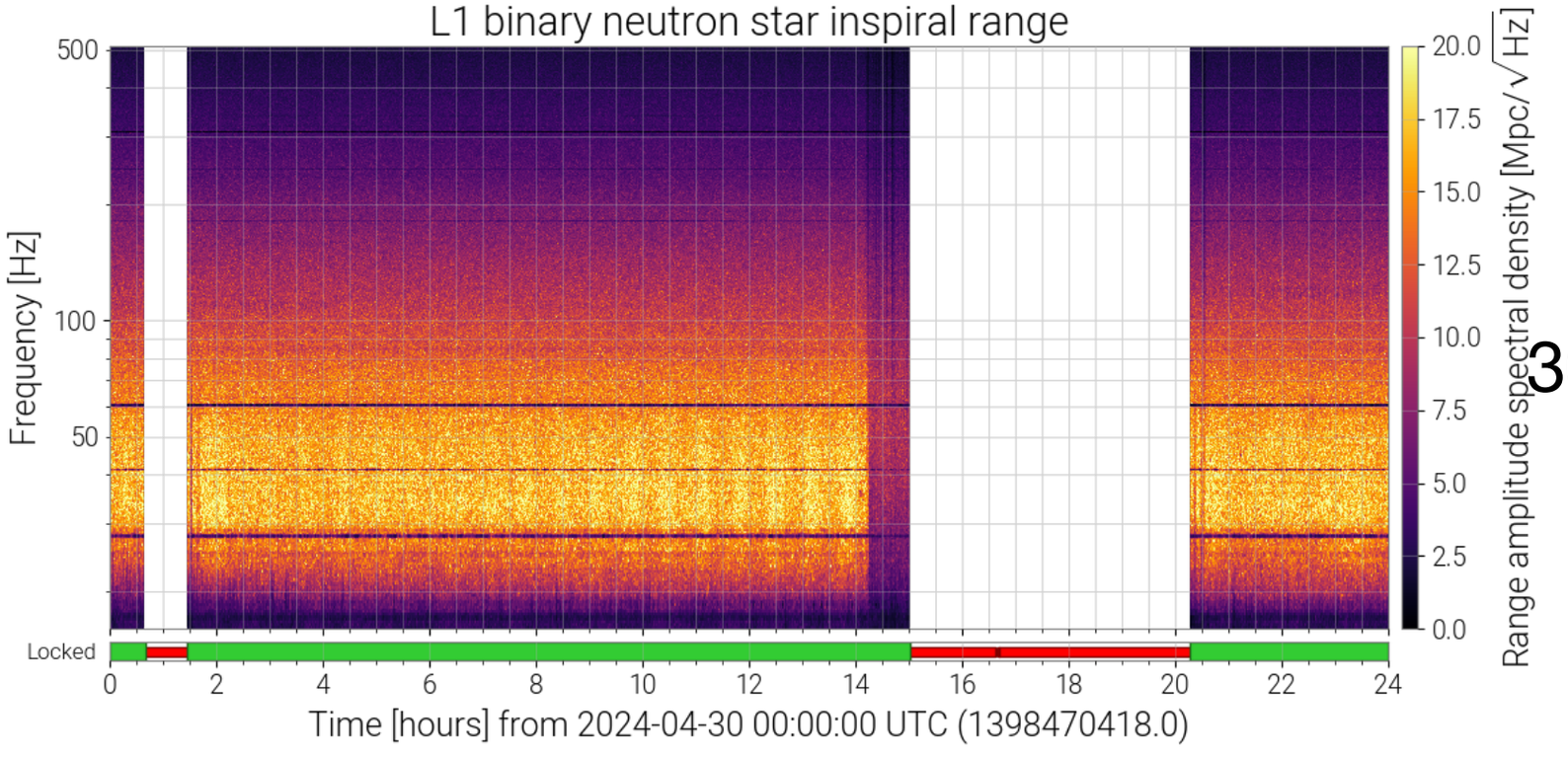




Spectrogram of range oscillations:

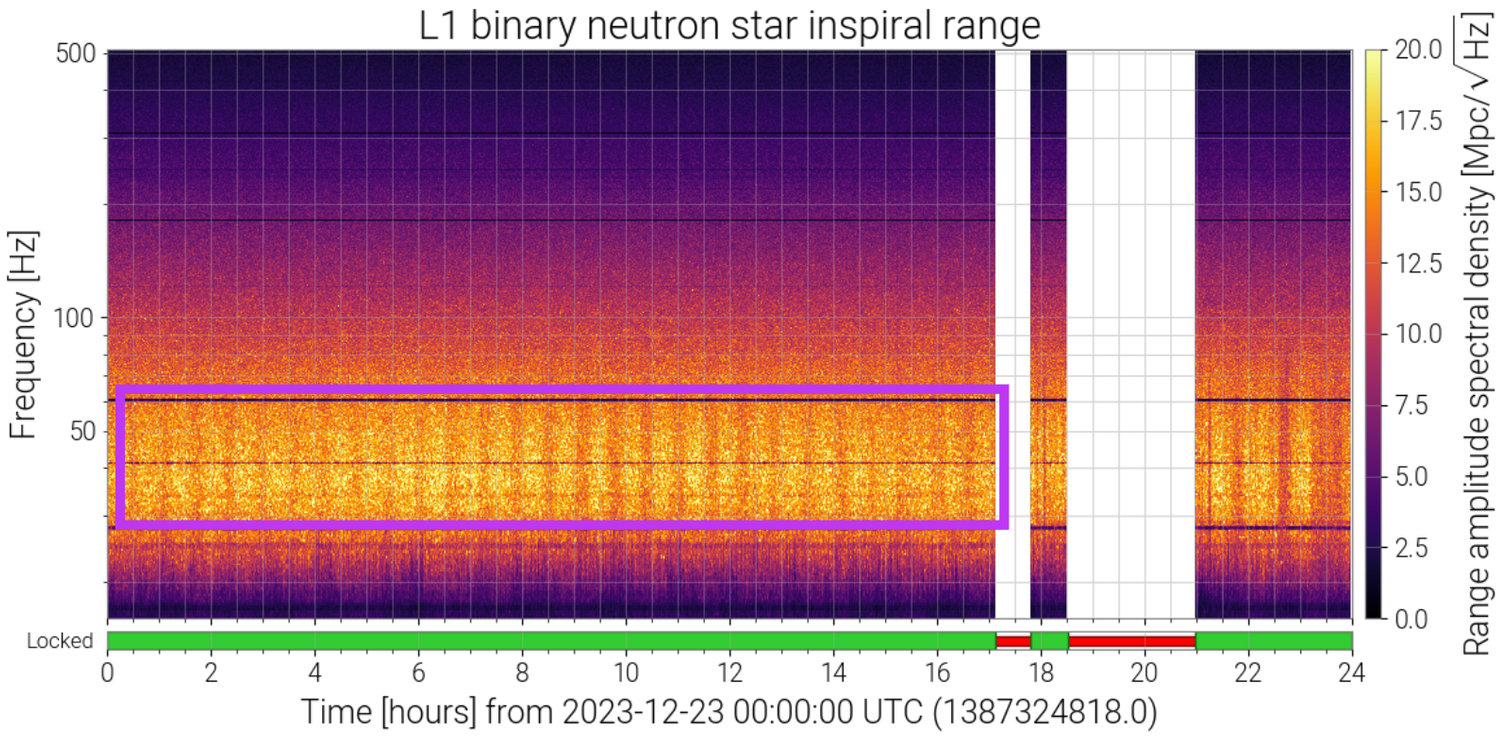


23 Dec 2023

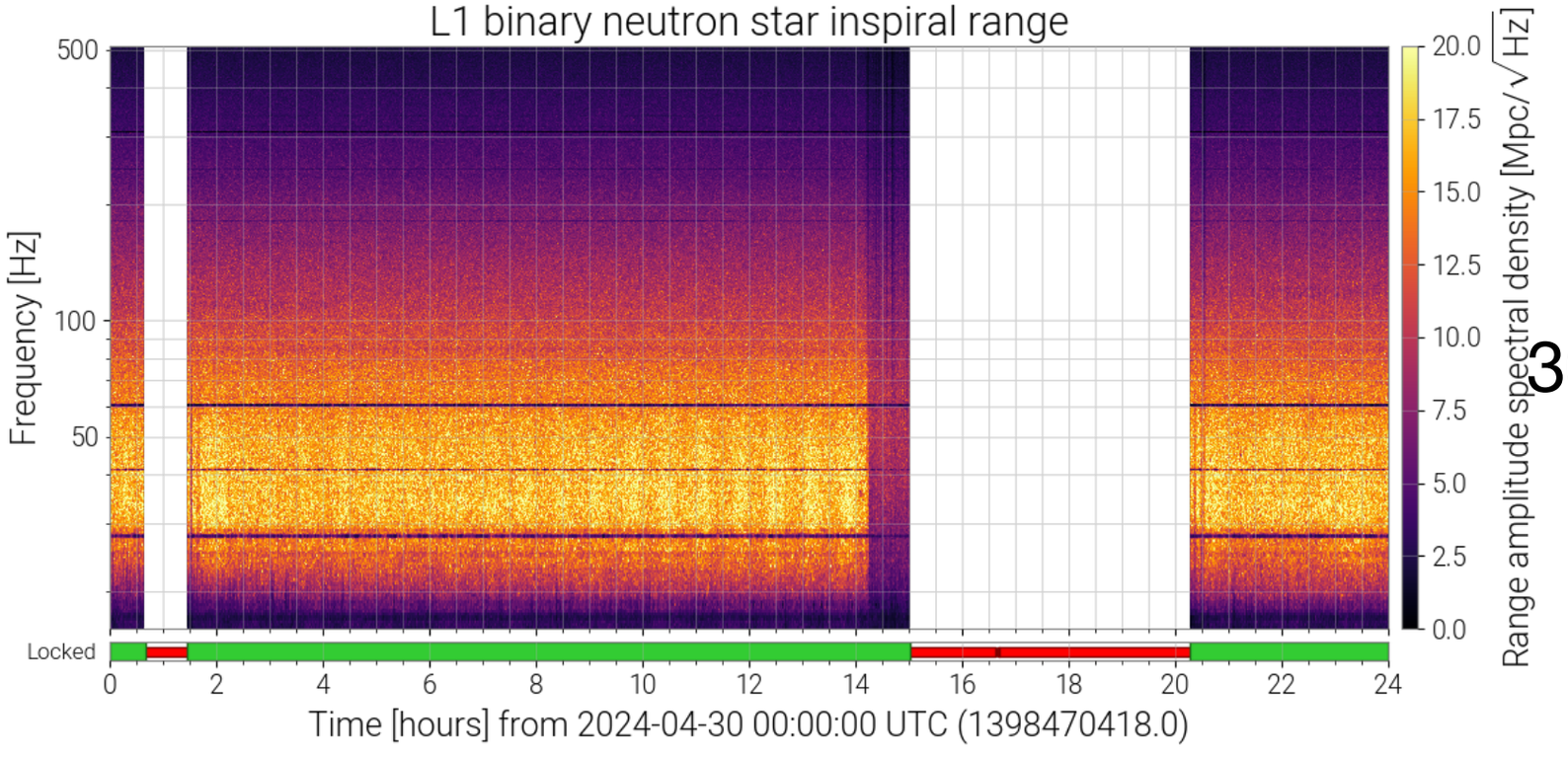


30 Apr 2024

Spectrogram of range oscillations:

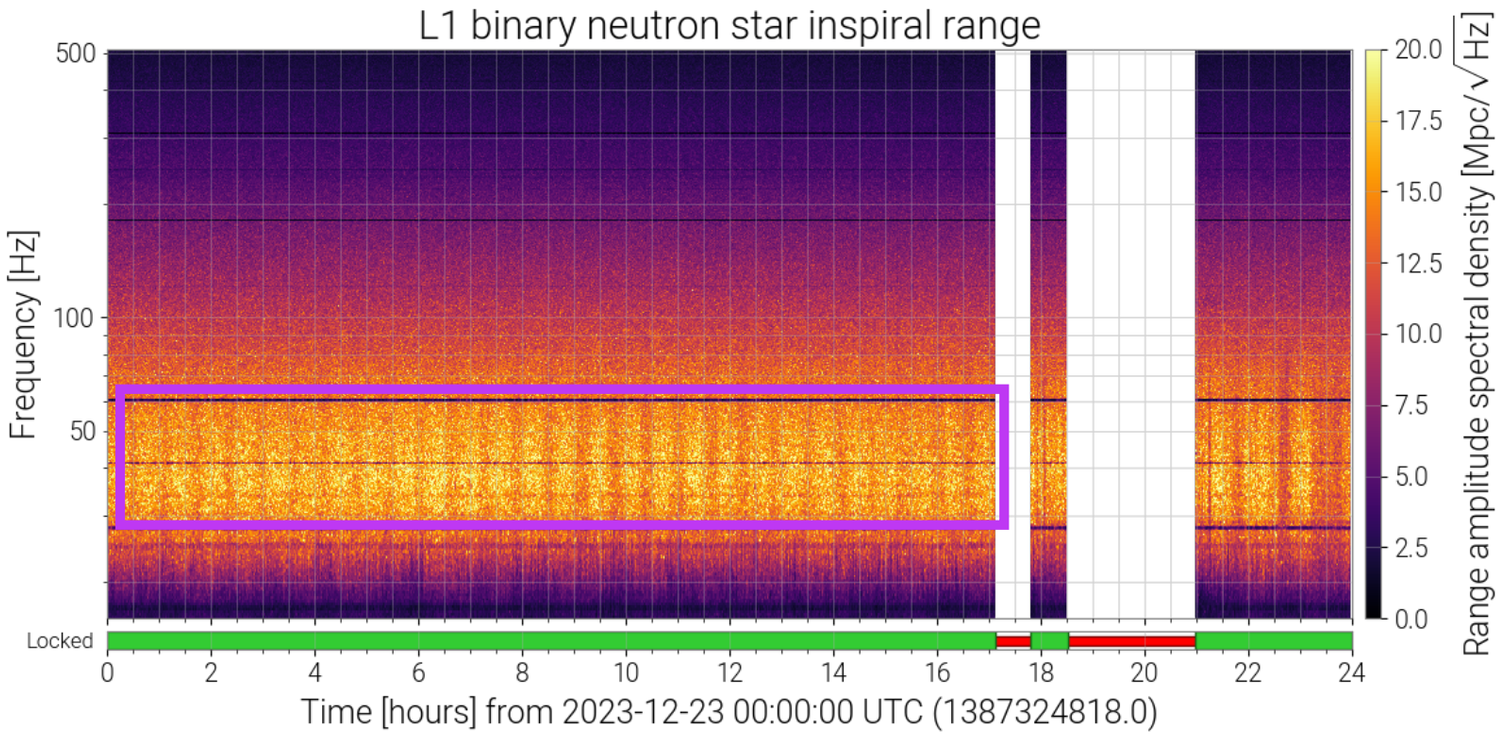


23 Dec 2023

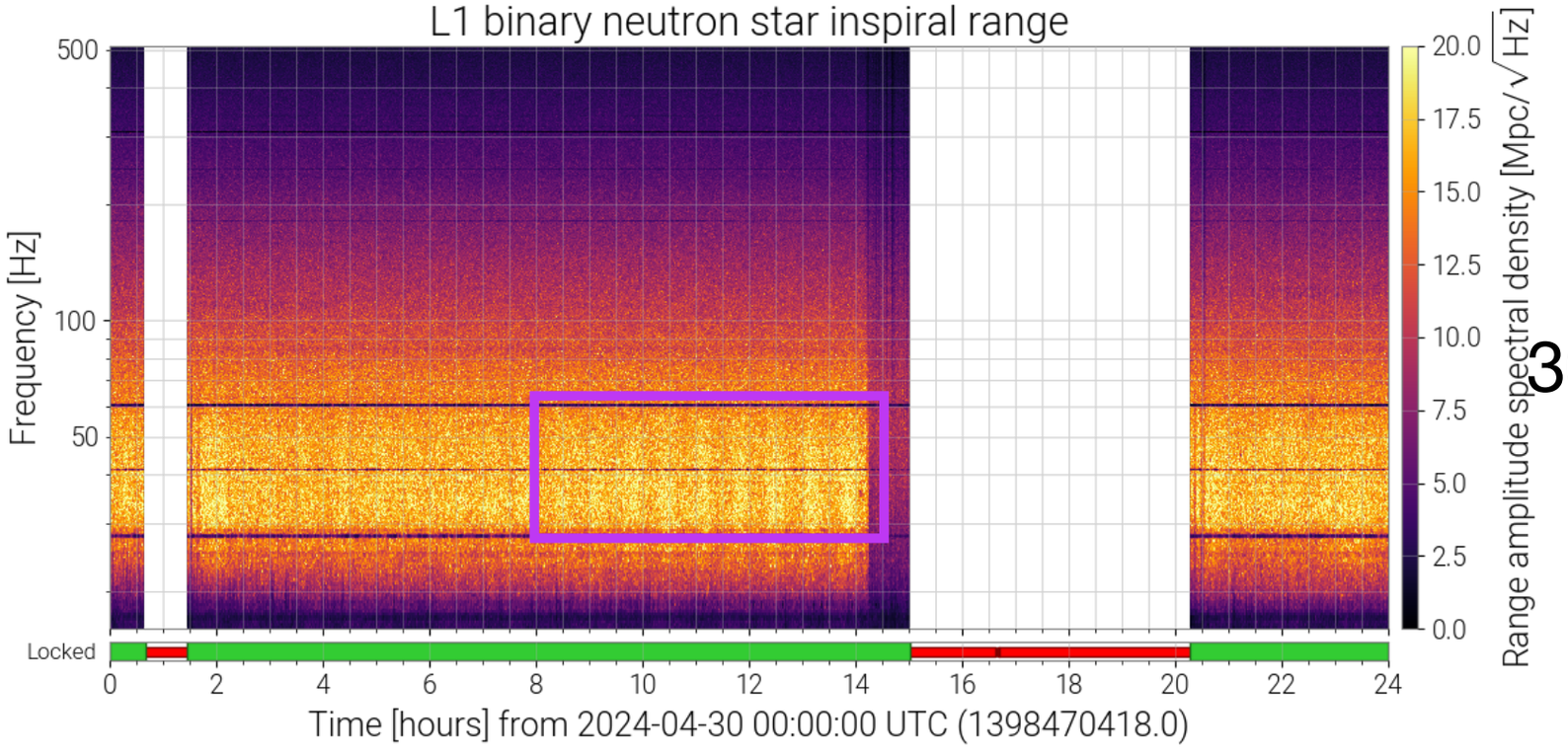


30 Apr 2024

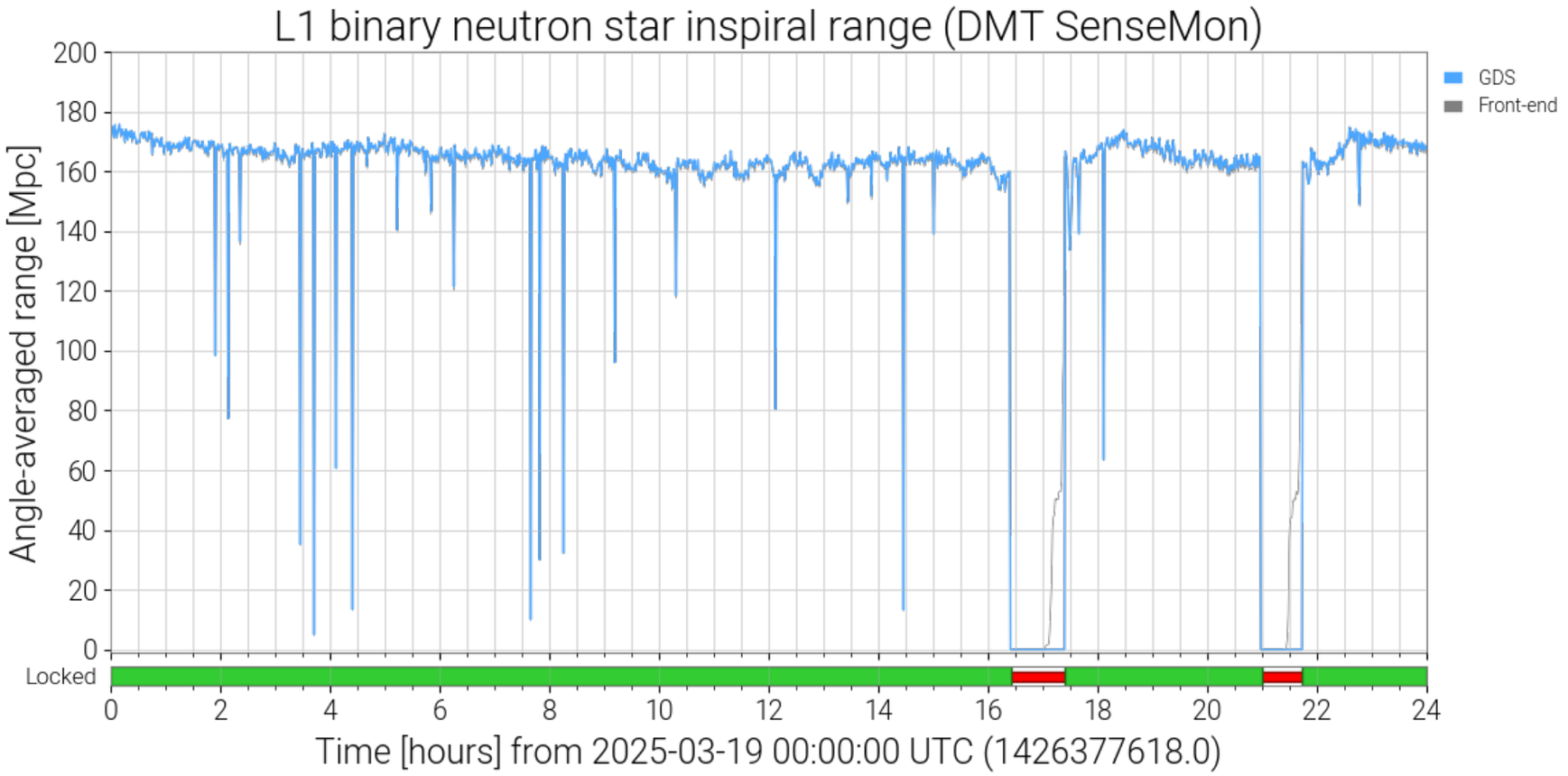
Spectrogram of range oscillations:

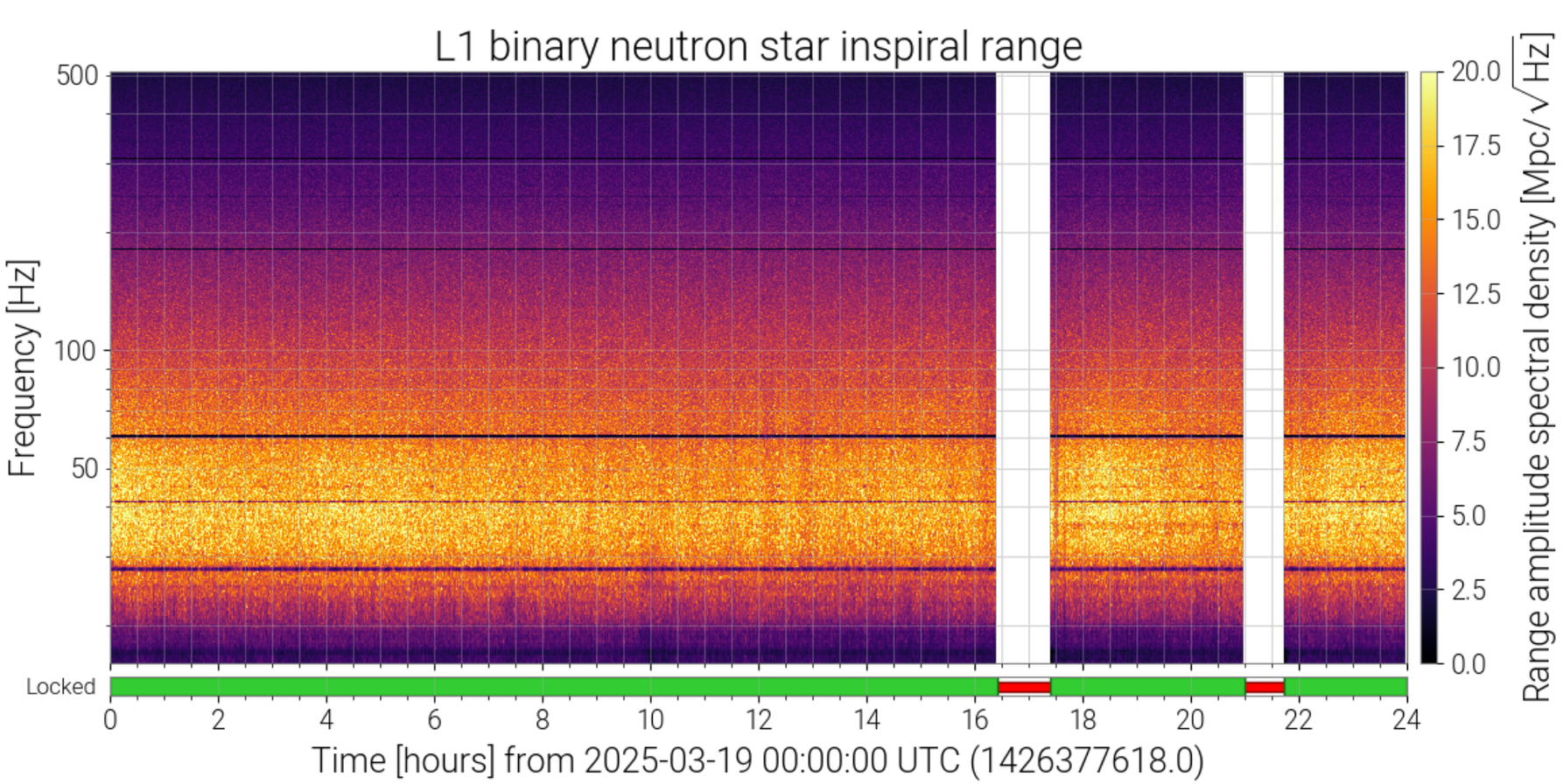


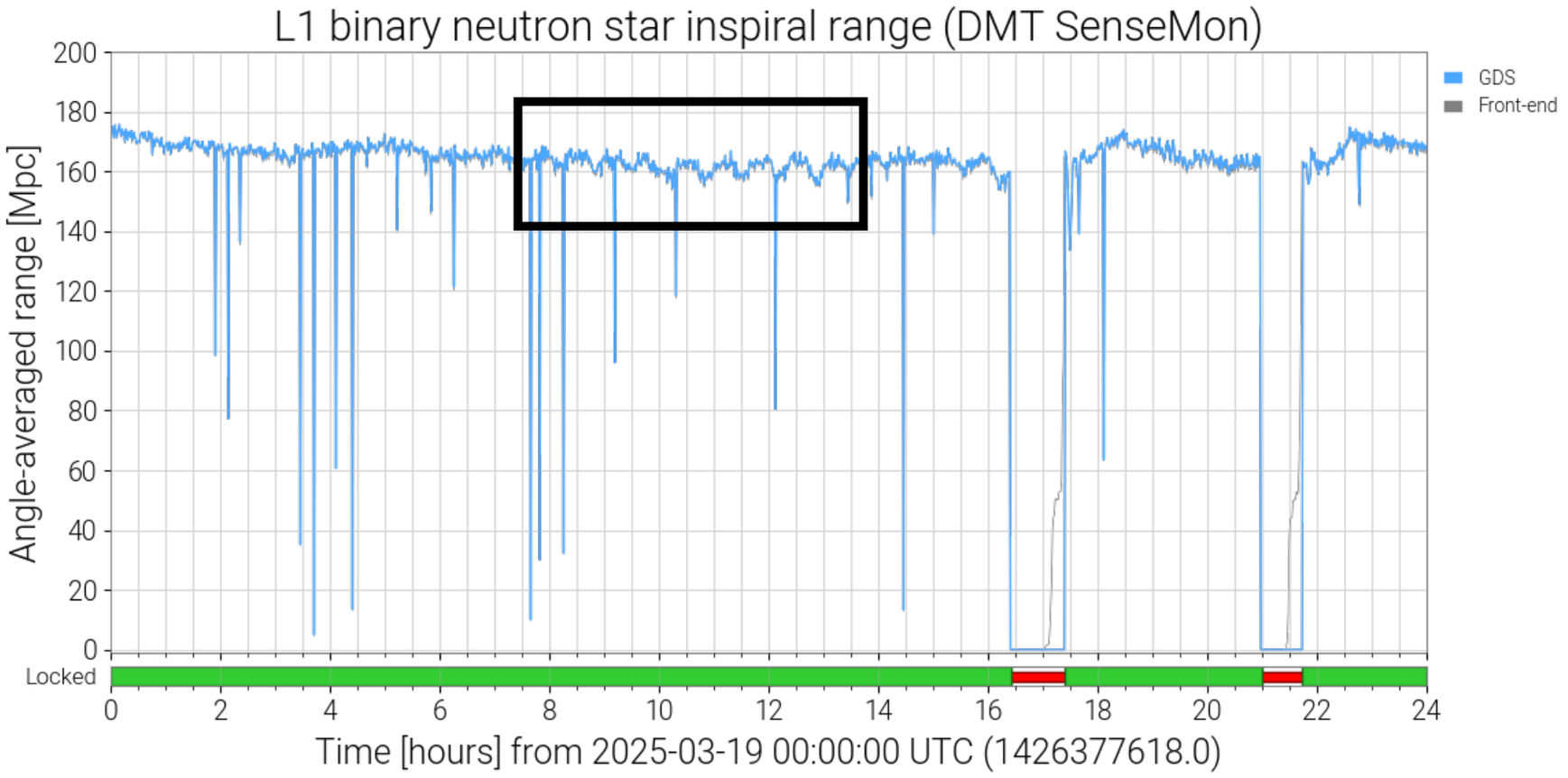
23 Dec 2023

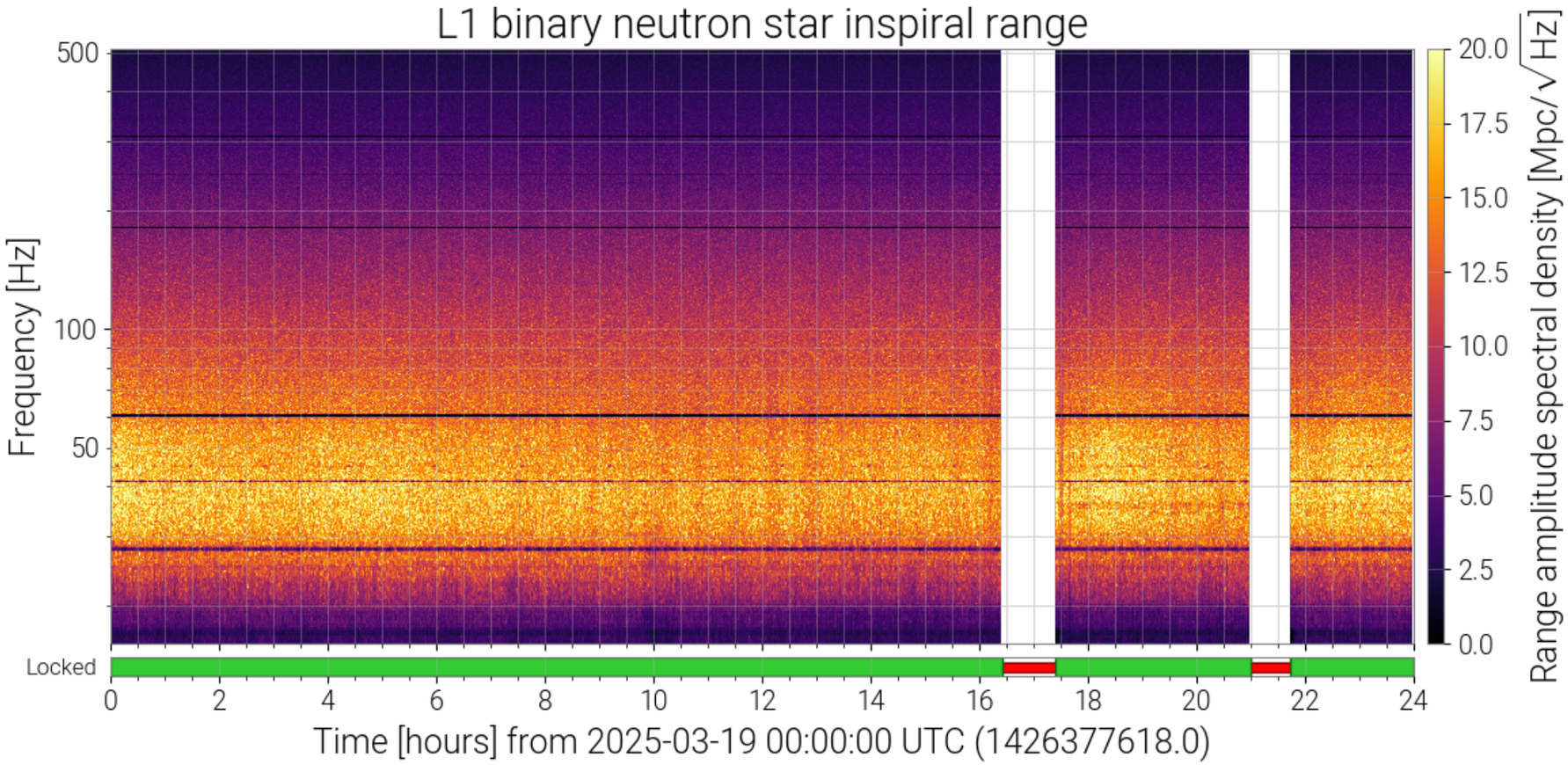


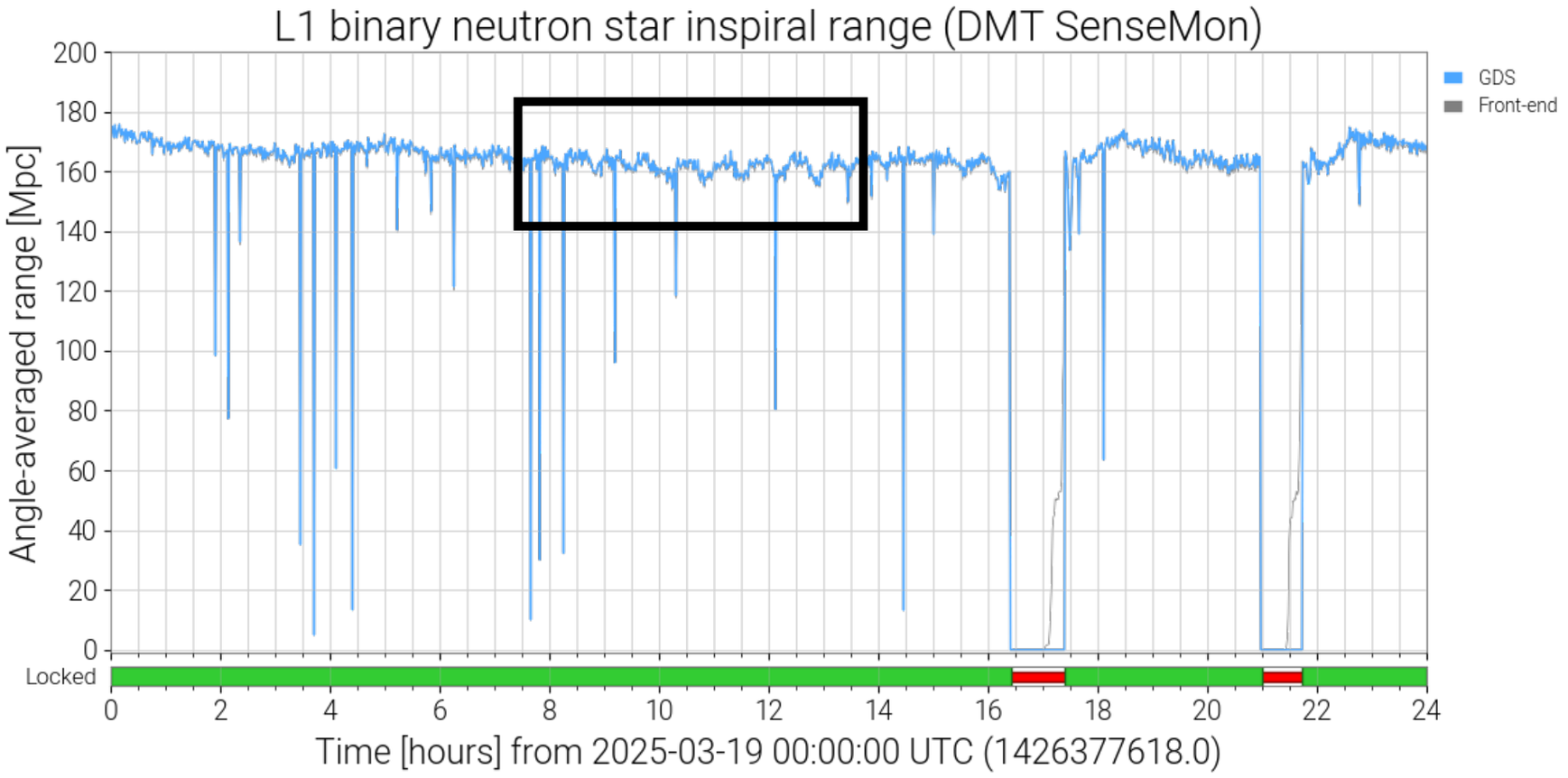
30 Apr 2024

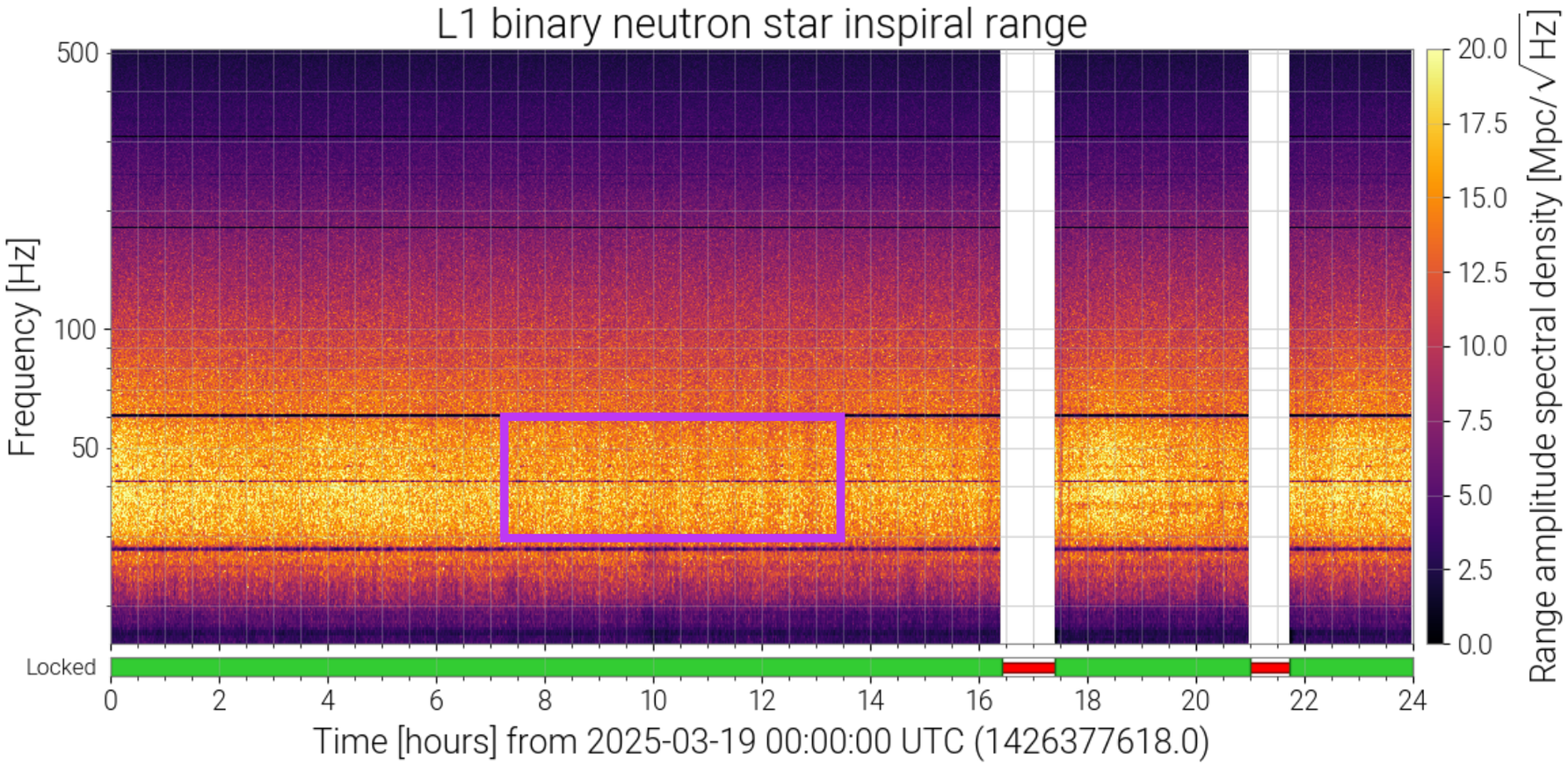

L1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
200
180
160
140
120
100
80
60
40
20
0
GDS
Front-end
Locked
0
2
4
6
8
10
12
14
16
18
20
22
24
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)


L1 binary neutron star inspiral range
Frequency [Hz]
500
100
50
Locked
0
2
4
6
8
10
12
14
16
18
20
22
24
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Range amplitude spectral density [Mpc/√Hz]


L1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
GDS
Front-end
Locked
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)


L1 binary neutron star inspiral range
Frequency [Hz]
Range amplitude spectral density [Mpc/√Hz]
Locked
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)


L1 binary neutron star inspiral range (DMT SenseMon)
Angle-averaged range [Mpc]
GDS
Front-end
Locked
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)


L1 binary neutron star inspiral range
Frequency [Hz]
Range amplitude spectral density [Mpc/√Hz]
Locked
Time [hours] from 2025-03-19 00:00:00 UTC (1426377618.0)

Why do we care?

BNS range oscillations occur sporadically, i.e., unpredictably and last typically for from several hours to a substantial fraction of a day.

One would like the range to remain steady at its maximum value. The oscillations, of up to about 10 Mpc, indicate the presence of a source of noise that worsens sensitivity.

The noise remains a mystery. It seems to be caused in the building at the end of the X-arm (EX) and is probably associated with temperature changes.

LASSO, a software package, seems in principle to be perfect for finding the noise source but in practice has not been that useful.

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LASSO

- Lasso uses a large set of auxiliary (AUX) channels to construct a best-fit model of the BNS range. Each channel used receives a score (above some threshold). The higher the score, the bigger the contribution to the range model from that channel.

- If the selected channels line up with a particular feature of the range, they may be the cause — or just a witness.

- Problems: Lasso tries to model the entire day's range separately for each longish lock. It may miss the feature of interest.

- Channels that behave like a selected channel are also given. These sometimes appear in a later round as the selected channel. This can be misleading.

- Channels are preferentially selected the better they match the details of the range. This makes, e.g., a switch difficult to find.

- LASSO is fooled by “red herrings”.

Red herrings:

(1) A channel which was essentially a copy of the range channel with a different name found its way into the Lasso channel list. Obviously, Lasso found a strong correlation.

(2) Arm Length Stabilization (ALS) system channels showed up repeatedly especially in 2024. This is mysterious because the system is active only during the locking procedure — i.e., getting the interferometer into operating mode by acquiring resonance in all the optical cavities. Apparently, the system was shuttered but not really turned off. Finally, it got turned off and mostly was not then selected by Lasso. The ALS channels were unlikely to be the cause of the oscillations which remained after turn off. However, these channels when present obscured other channels more likely to be the culprit.

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1383799886-1383825717

Below are the top 14 mean minute-trend channels, ranked by Lasso correlation with the primary.

Full results

	Channel	Lasso coefficient
1	L1:SUS-ETMY_L3_ESDAMON_UR_INMON	0.1801
2	L1:OAF-CAL_RANGE_BAND_6	0.1523
3	L1:PEM-EY_MAG_EBAY_SEIRACK_X_MON	-0.1004
4	L1:IOP-SUS_AUX_H34_MADC1_EPICS_CH17	0.0530
5	L1:HPI-PUMP_EY_PS_PRESS3_VOLTS	0.0528
6	L1:IOP-ISC_EY_MADC4_EPICS_CH0	-0.0507
7	L1:SUS-FC1_M2_VOLTMON_UR_OUT16	-0.0414
8	L1:SUS-PR3_M3_OPLEV_BLRMS_S_30M	0.0345
9	L0:ACM-DP_A_KW	-0.0320
10	L1:SUS-ETMY_L3_ESDAMON_UR_OUT16	0.0162
11	L1:IOP-SUS_AUX_EY_MADC4_EPICS_CH3	0.0080
12	L0:VAC-LX_X1_PT670A_PRESS_VOLTS	-0.0065
13	L1:SUS-ETMY_L3_ESDAMON_UR_OUTPUT	0.0016
14	L1:HPI-PUMP_EY_PS_PRESS3	0.0000

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2	L1:OAF-CAL_RANGE_BAND_6	0.1523
3	L1:PEM-EY_MAG_EBAY_SEIRACK_X_MON	-0.1004
4	L1:IOP-SUS_AUX_H34_MADC1_EPICS_CH17	0.0530
5	L1:HPI-PUMP_EY_PS_PRESS3_VOLTS	0.0528
6	L1:IOP-ISC_EY_MADC4_EPICS_CH0	-0.0507
7	L1:SUS-FC1_M2_VOLTMON_UR_OUT16	-0.0414
8	L1:SUS-PR3_M3_OPLEV_BLRMS_S_30M	0.0345
9	L0:ACM-DP_A_KW	-0.0320
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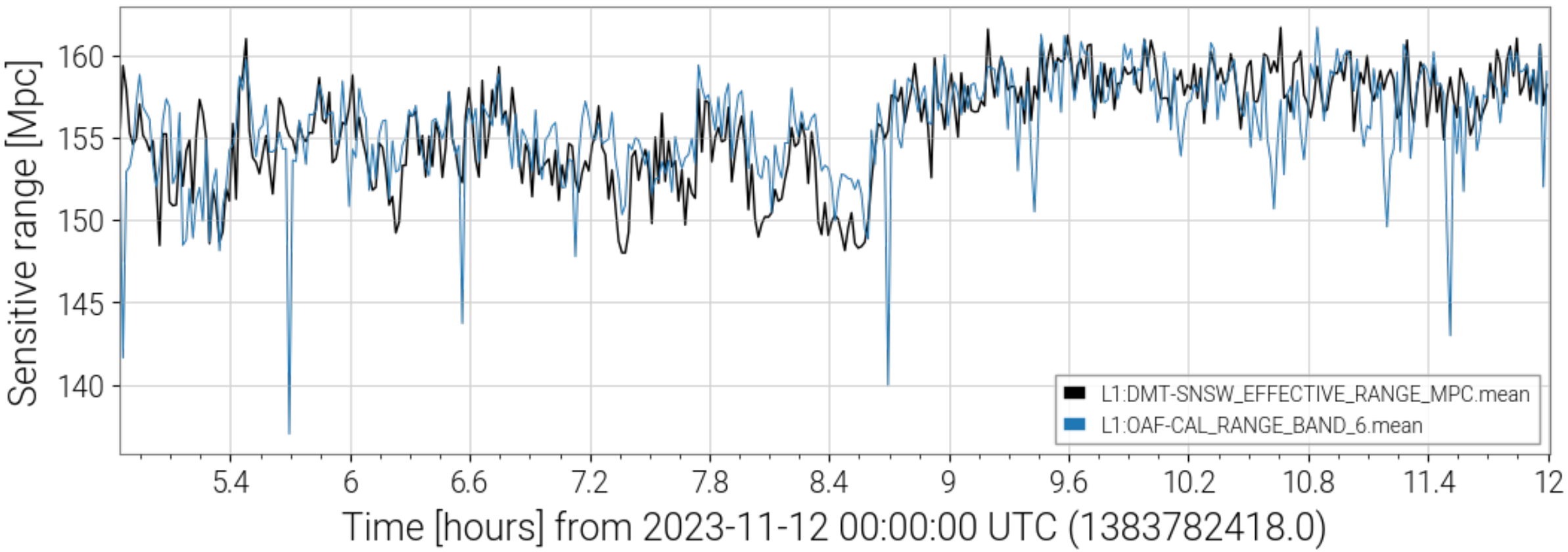
14	L1:HPI-PUMP_EY_PS_PRESS3	0.0000


Sensitive range [Mpc]
160
155
150
145
140
5.4
6
6.6
7.2
7.8
8.4
9
9.6
10.2
10.8
11.4
12
Time [hours] from 2023-11-12 00:00:00 UTC (1383782418.0)
L1:DMT-SNSW_EFFECTIVE_RANGE_MPC.mean
L1:OAF-CAL_RANGE_BAND_6.mean

10

30 April 2024

L1 « April 30 2024 » Home Summary Lock CAL DetChar IMC ISC OMC PEM PSL SEI SQZ SUS TCS

summarized and linked below. The list of channels for each segment represents the largest contributors in modeling BNS range (`L1:DMT-SNSW_EFFECTIVE_RANGE_MPC.mean`).

1398476878-1398519739

Below are the top 12 mean minute-trend channels, ranked by Lasso correlation with the primary.

Full results

	Channel	Lasso coefficient
1	L1:SUS-PRM_M1_RMSIMON_T2_MON	-0.1729
2	L1:ALS-X_REFL_SLOW_INMON	-0.1133
3	L1:SUS-RM1_LKIN_Y_DEMOD_SIG_INMON	-0.0834
4	L1:ALS-X_REFL_CTRL_OUT16	-0.0779
5	L1:ALS-X_REFL_CTRL_OUTPUT	-0.0740
6	L1:HPI-PUMP_EX_PS_PRESS1_VOLTS	-0.0636
7	L1:ASC-POP_A_MTRX_P_OUTMON	-0.0178
8	L1:SUS-RM1_M1_DAMP_Y_IN1_DQ	-0.0135
9	L1:ALS-X_REFL_CTRL_OUT_DQ	-0.0115
10	L1:ASC-AS_A_RF72_DEMOD_RFMON_3	0.0097
11	L1:ASC-AS_A_RF36_DEMOD_RFMON_1	-0.0096
12	L1:HPI-PUMP_EX_PS_PRESS1	-0.0069

30 April 2024

L1 « April 30 2024 » Home Summary Lock CAL DetChar IMC ISC OMC PEM PSL SEI SQZ SUS TCS

summarized and linked below. The list of channels for each segment represents the largest contributors in modeling BNS range (`L1:DMT-SNSW_EFFECTIVE_RANGE_MPC.mean`).

1398476878-1398519739

Below are the top 12 mean minute-trend channels, ranked by Lasso correlation with the primary.

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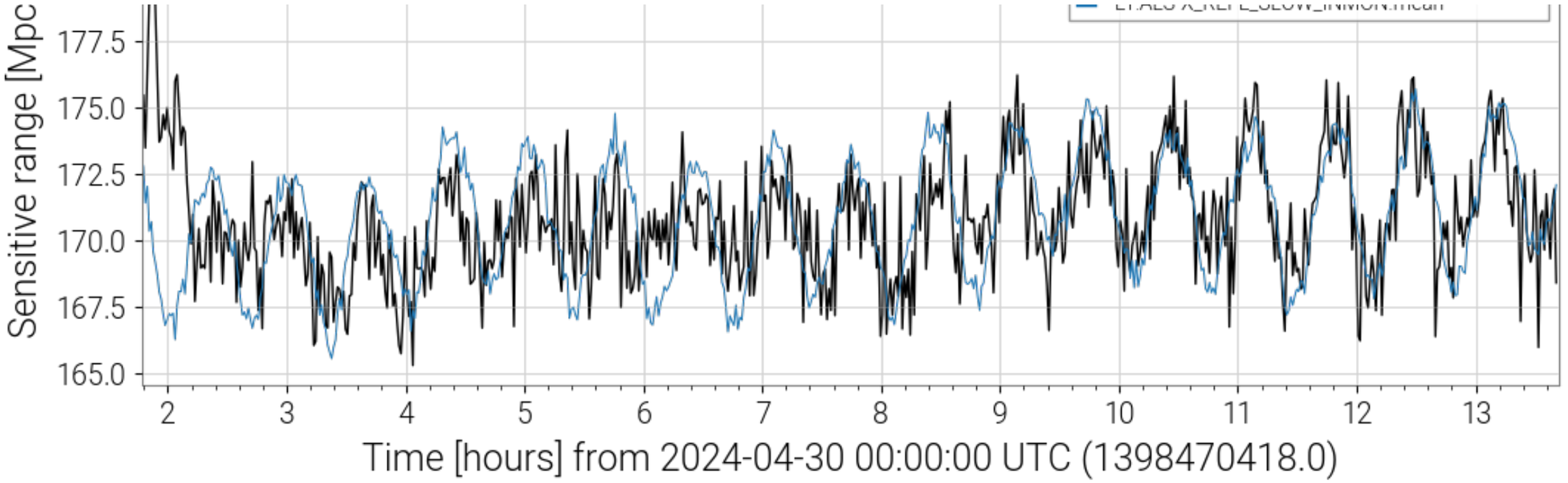
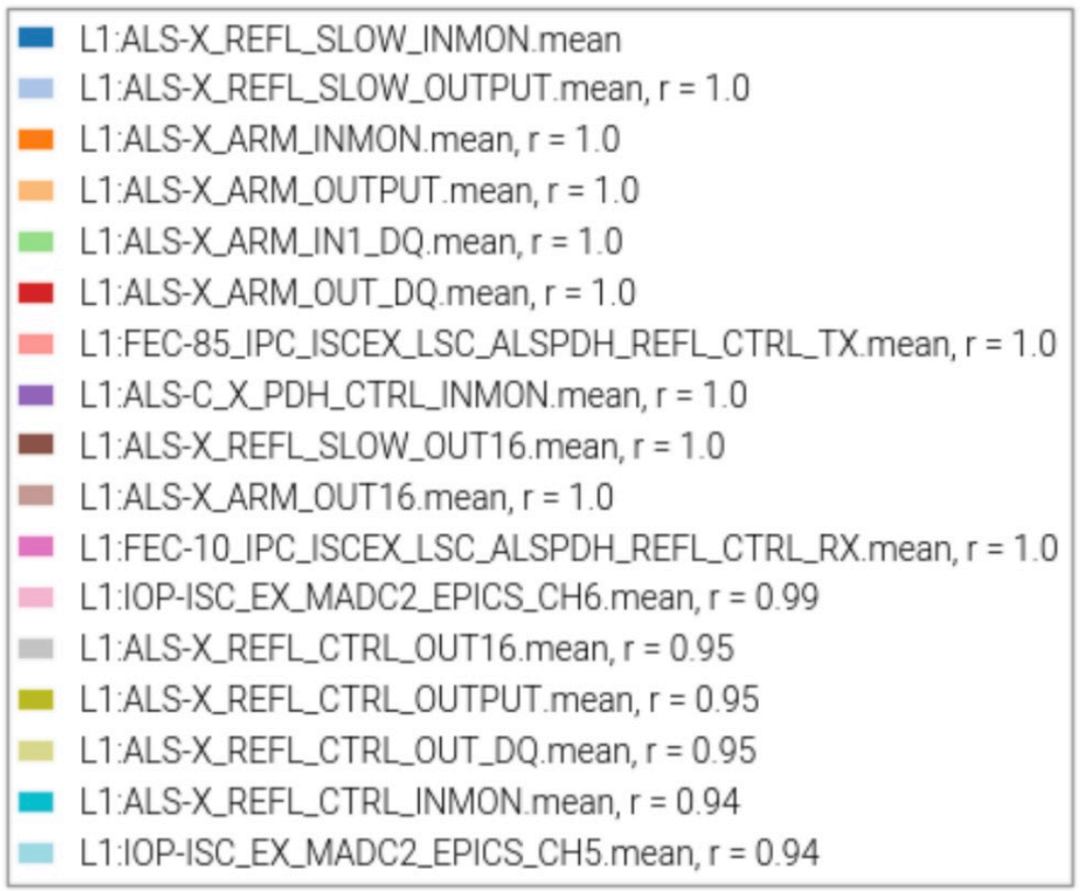
3	L1:SUS-RM1_LKIN_Y_DEMOD_SIG_INMON	-0.0834
4	L1:ALS-X_REFL_CTRL_OUT16	-0.0779
5	L1:ALS-X_REFL_CTRL_OUTPUT	-0.0740
6	L1:HPI-PUMP_EX_PS_PRESS1_VOLTS	-0.0636
7	L1:ASC-POP_A_MTRX_P_OUTMON	-0.0178
8	L1:SUS-RM1_M1_DAMP_Y_IN1_DQ	-0.0135
9	L1:ALS-X_REFL_CTRL_OUT_DQ	-0.0115
10	L1:ASC-AS_A_RF72_DEMOD_RFMON_3	0.0097
11	L1:ASC-AS_A_RF36_DEMOD_RFMON_1	-0.0096
12	L1:HPI-PUMP_EX_PS_PRESS1	-0.0069


Sensitive range [Mpc
177.5
175.0
172.5
170.0
167.5
165.0
2
3
4
5
6
7
8
9
10
11
12
13
Time [hours] from 2024-04-30 00:00:00 UTC (1398470418.0)


L1:ALS-X_REFL_SLOW_INMON.mean
L1:ALS-X_REFL_SLOW_OUTPUT.mean, r = 1.0
L1:ALS-X_ARM_INMON.mean, r = 1.0
L1:ALS-X_ARM_OUTPUT.mean, r = 1.0
L1:ALS-X_ARM_IN1_DQ.mean, r = 1.0
L1:ALS-X_ARM_OUT_DQ.mean, r = 1.0
L1:FEC-85_IPC_ISCEX_LSC_ALSPDH_REFL_CTRL_TX.mean, r = 1.0
L1:ALS-C_X_PDH_CTRL_INMON.mean, r = 1.0
L1:ALS-X_REFL_SLOW_OUT16.mean, r = 1.0
L1:ALS-X_ARM_OUT16.mean, r = 1.0
L1:FEC-10_IPC_ISCEX_LSC_ALSPDH_REFL_CTRL_RX.mean, r = 1.0
L1:IOP-ISC_EX_MADC2_EPICS_CH6.mean, r = 0.99
L1:ALS-X_REFL_CTRL_OUT16.mean, r = 0.95
L1:ALS-X_REFL_CTRL_OUTPUT.mean, r = 0.95
L1:ALS-X_REFL_CTRL_OUT_DQ.mean, r = 0.95
L1:ALS-X_REFL_CTRL_INMON.mean, r = 0.94
L1:IOP-ISC_EX_MADC2_EPICS_CH5.mean, r = 0.94

Microphones enter the puzzle.

Old results from 2024-04-30 and preliminary results from 2025-03-19.

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https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=71323

Comments related to this report

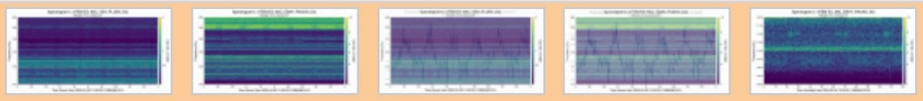
beverly.berger@LIGO.ORG - 16:35, Monday 27 May 2024 (71397)Detchar, PEM, SEI Link

Microphones at EX and BNS range oscillations:

Two EX MIC channels, L1:PEM-EX_MIC_VEA_PLUSX_DQ and L1:PEM-EX_MIC_EBAY_RACKS_DQ, exhibit the BNS range oscillations between 100 Hz and 200 Hz as described for a floor ACC in the main alog. (These appear to be the only active MIC channels in EX.) See Fig1C and Fig2C for the spectrograms and Fig3C and Fig4C for the overlays using Fig2 from the main alog.

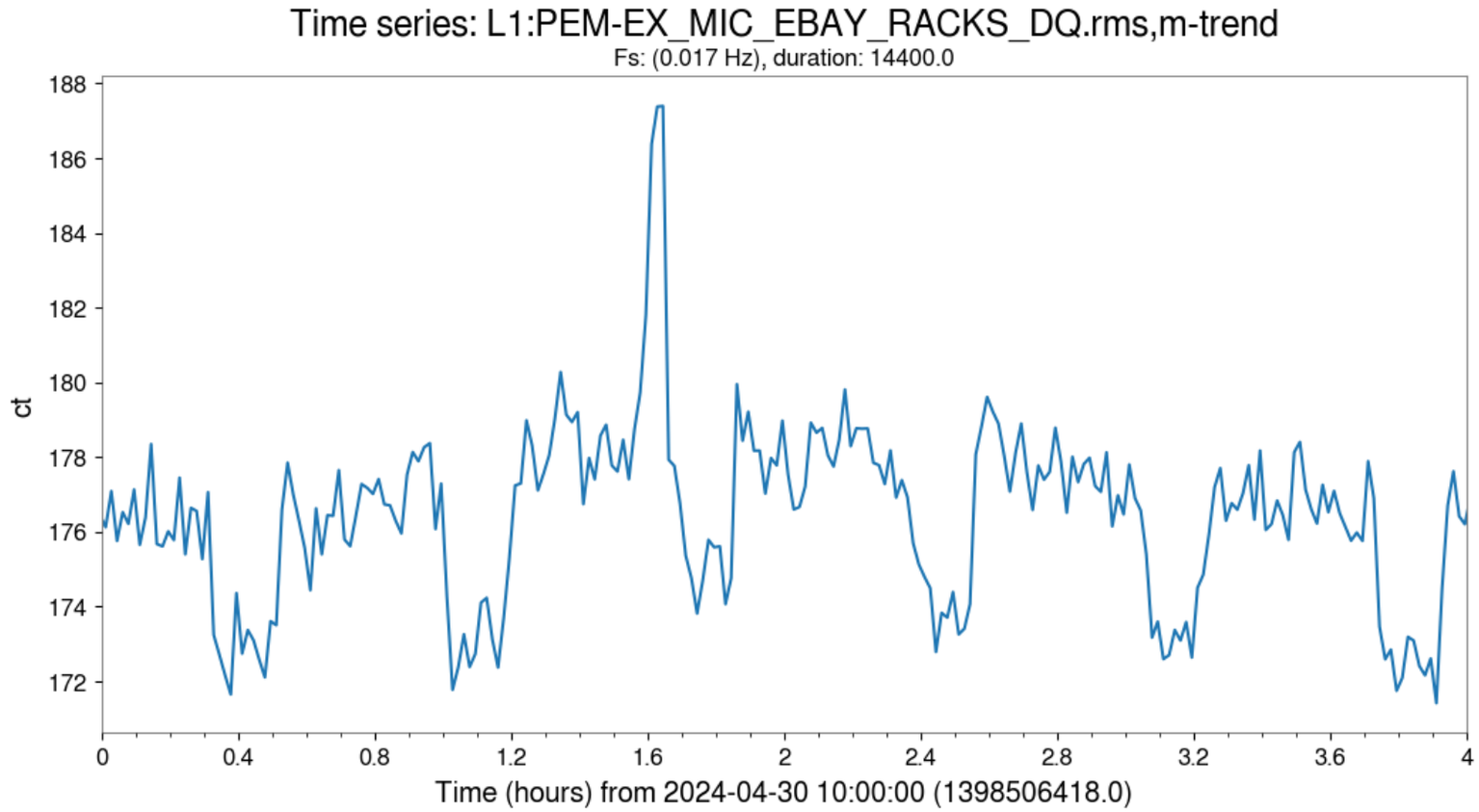
Note an unusual feature in the spectrogram for the MIC EBAY channel. There is a (not narrow) line at 115 Hz (see Fig5C for the frequency) that appears during the peaks in the BNS range. The strength of this line follows the oscillations but is apparently not coupled to the noise source. As seen in these overlays and in the main aLog, the high noise in the ground motion and the sound lines up with the low range and vice versa. However, in Fig4C, the 115 Hz line is strongest during the time of high range and weakest during the time of low range.

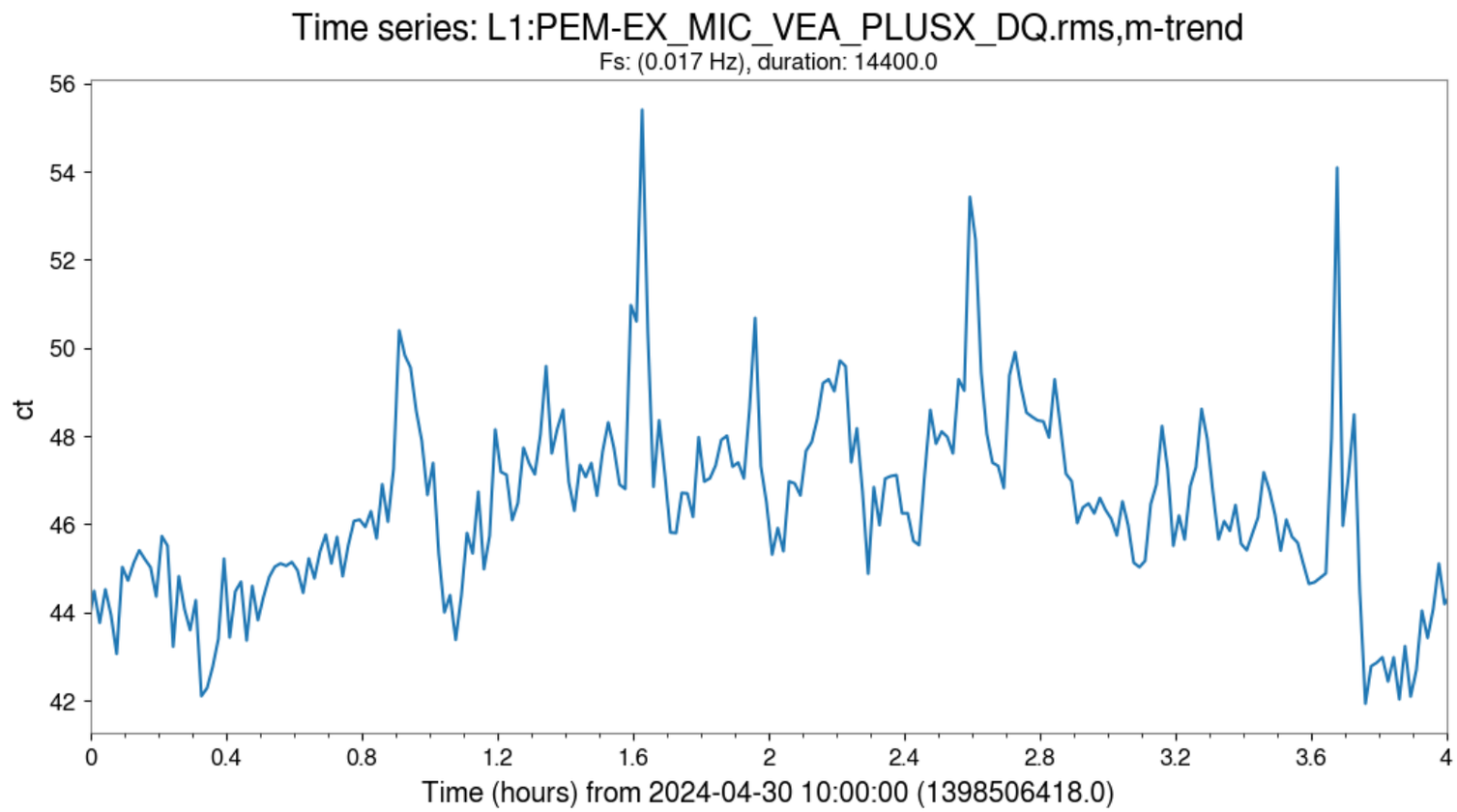
Images attached to this comment



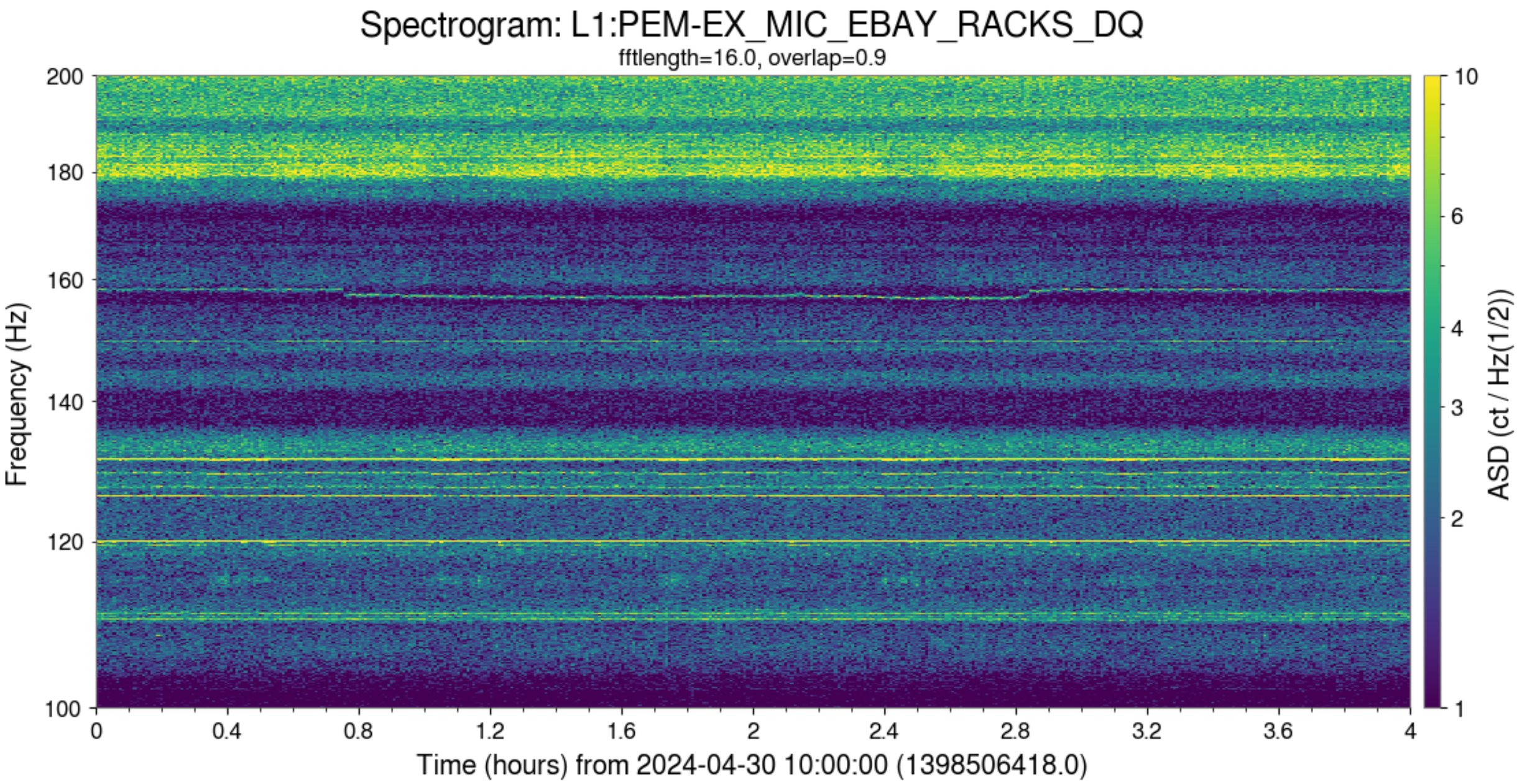
The microphone channel L1:PEM-EX_MIC_EBAY_RACKS_DQ responded strongly to the range oscillations.

14

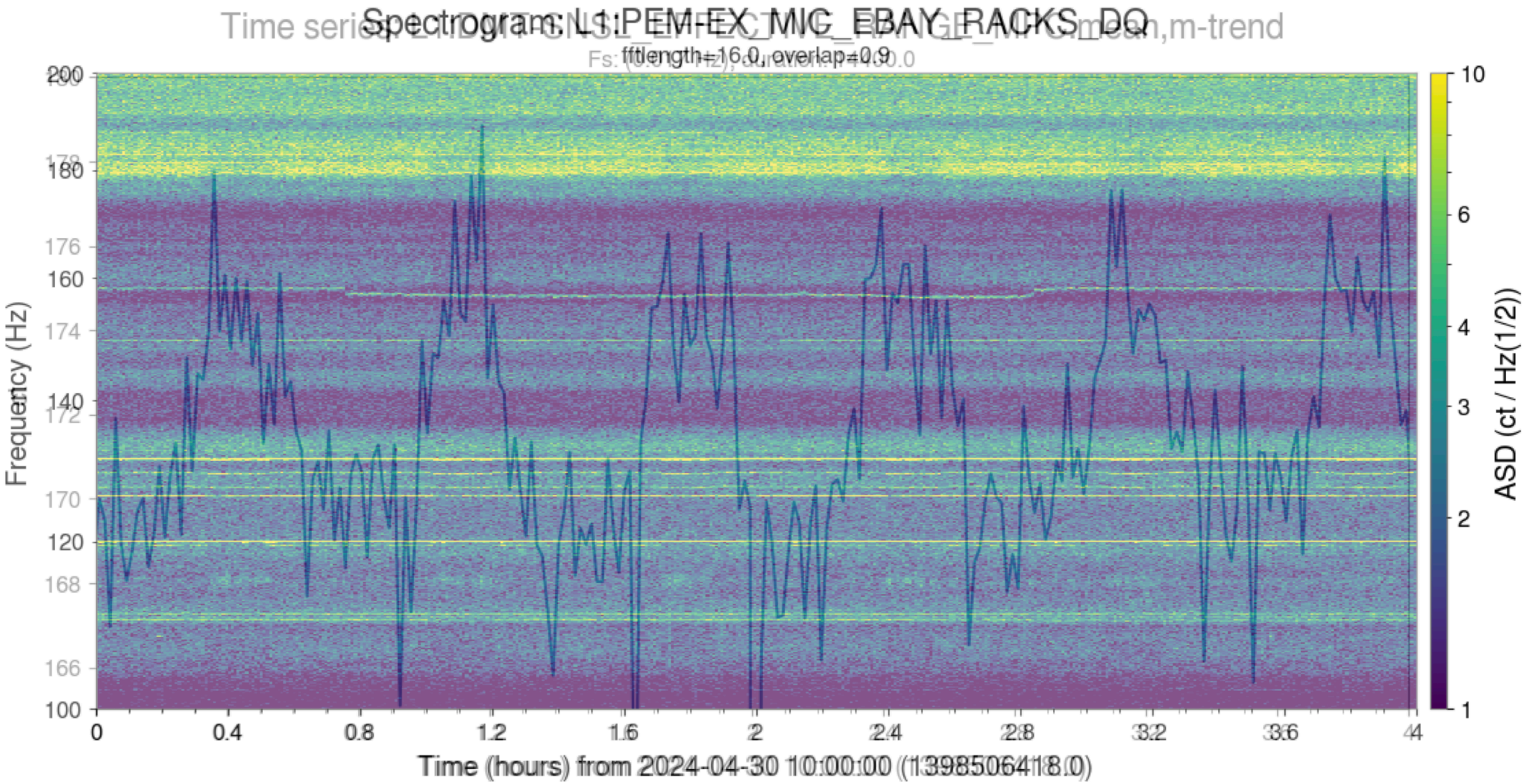

Time series: L1:PEM-EX_MIC_EBAY_RACKS_DQ.rms,m-trend
Fs: (0.017 Hz), duration: 14400.0
ct
188
186
184
182
180
178
176
174
172
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2024-04-30 10:00:00 (1398506418.0)


Time series: L1:PEM-EX_MIC_VEA_PLUSX_DQ.rms,m-trend
Fs: (0.017 Hz), duration: 14400.0
ct
56
54
52
50
48
46
44
42
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2024-04-30 10:00:00 (1398506418.0)

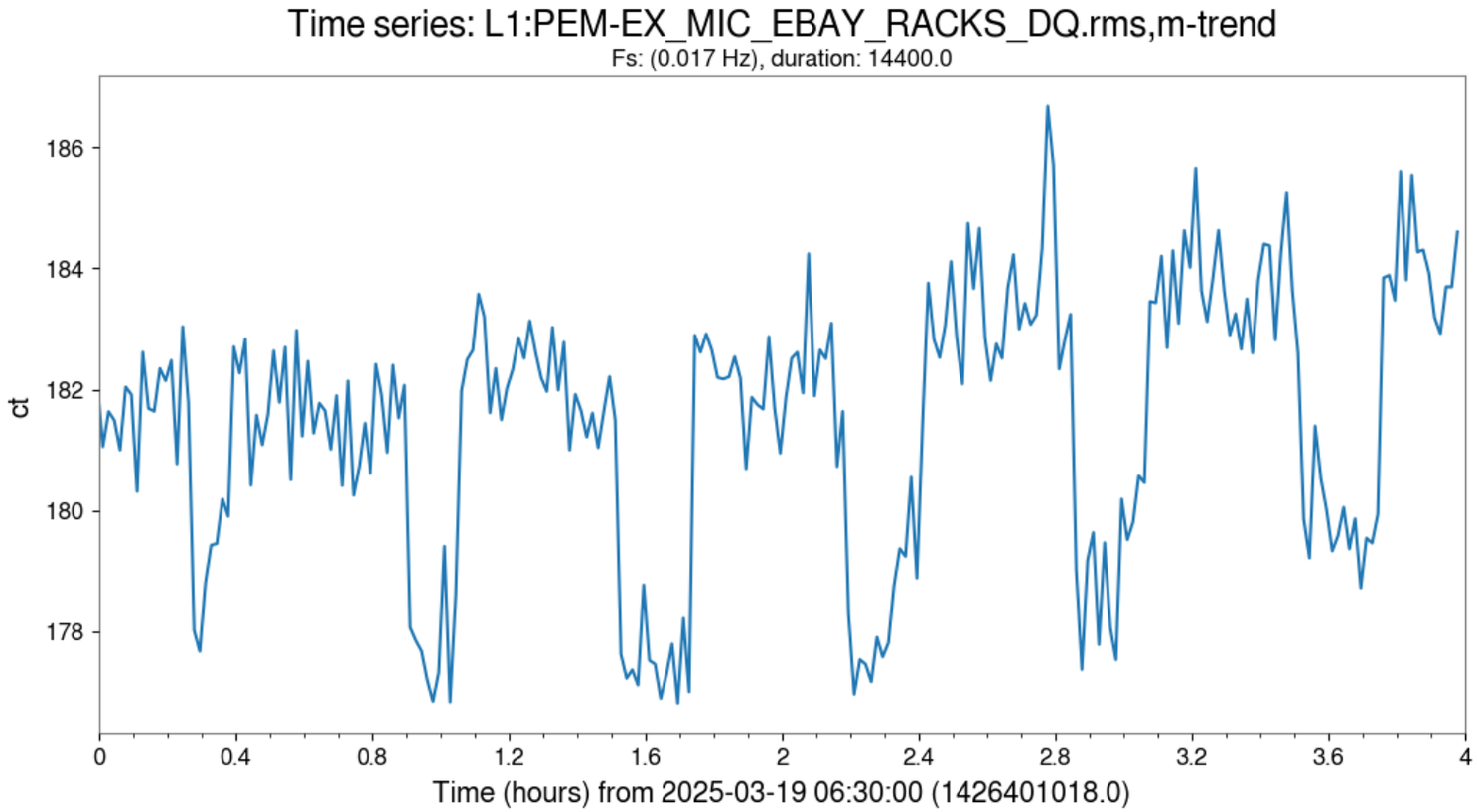
15

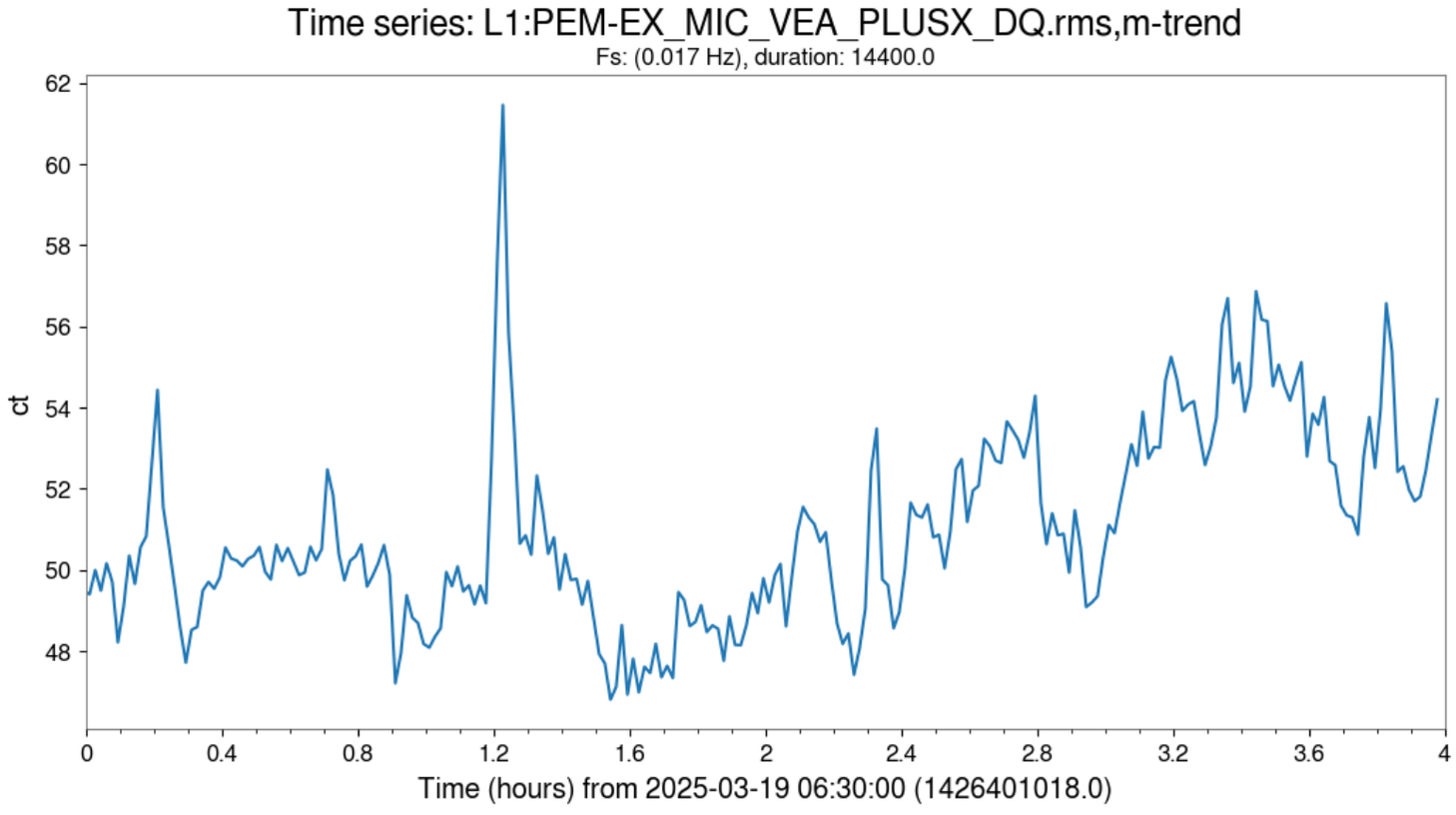

Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=16.0, overlap=0.9
Frequency (Hz)
200
180
160
140
120
100
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2024-04-30 10:00:00 (1398506418.0)
ASD (ct / Hz(1/2))
10
6
4
3
2
1

16


Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=16.0, overlap=0.9
Frequency (Hz)
200
180
176
160
174
140
172
170
120
168
166
100
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2024-04-30 10:00:00 (1398506418.0)
ASD (ct / Hz(1/2))
10
6
4
3
2
1

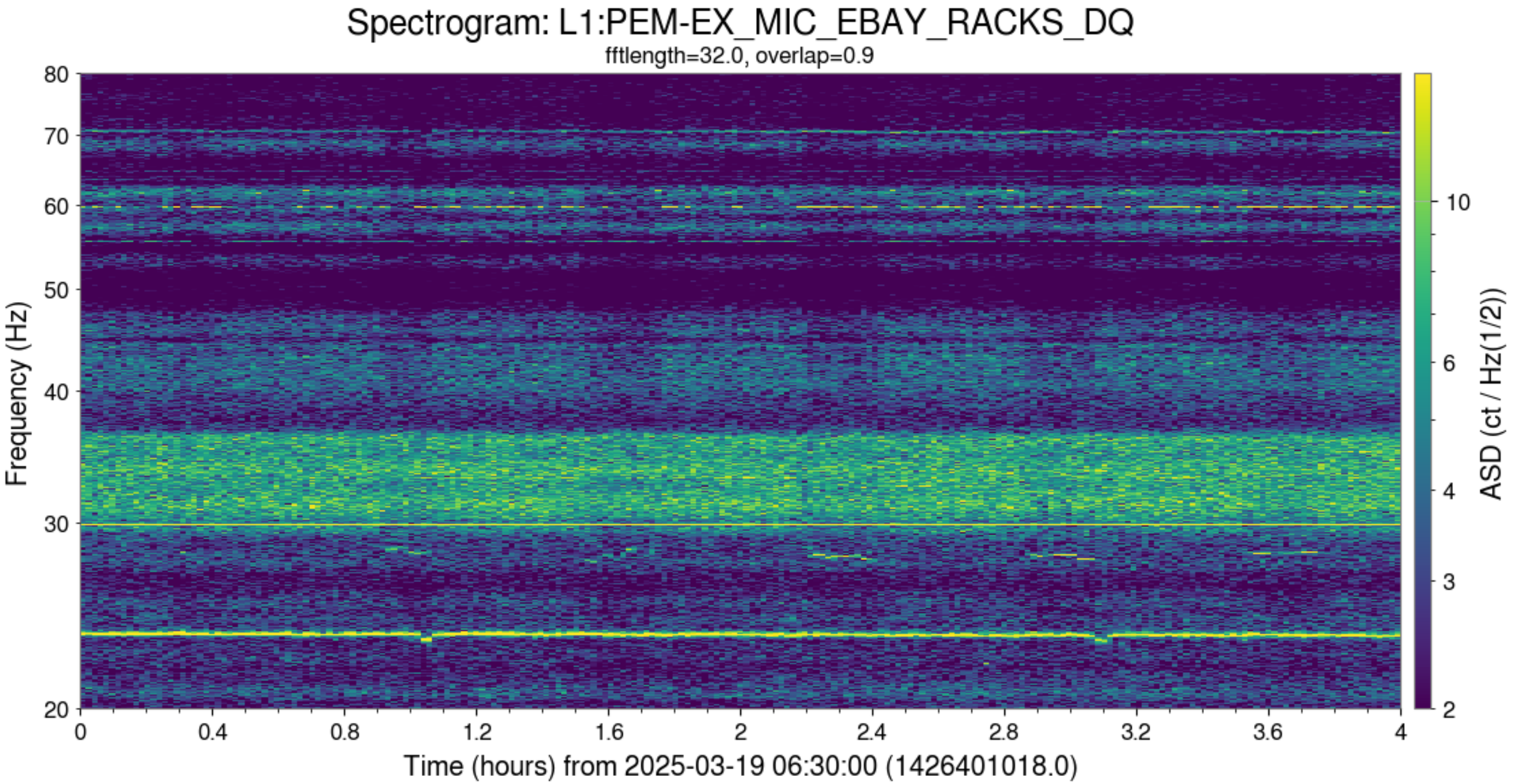
17


Time series: L1:PEM-EX_MIC_EBAY_RACKS_DQ.rms,m-trend
Fs: (0.017 Hz), duration: 14400.0
ct
186
184
182
180
178
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)


Time series: L1:PEM-EX_MIC_VEA_PLUSX_DQ.rms,m-trend
Fs: (0.017 Hz), duration: 14400.0
ct
62
60
58
56
54
52
50
48
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)

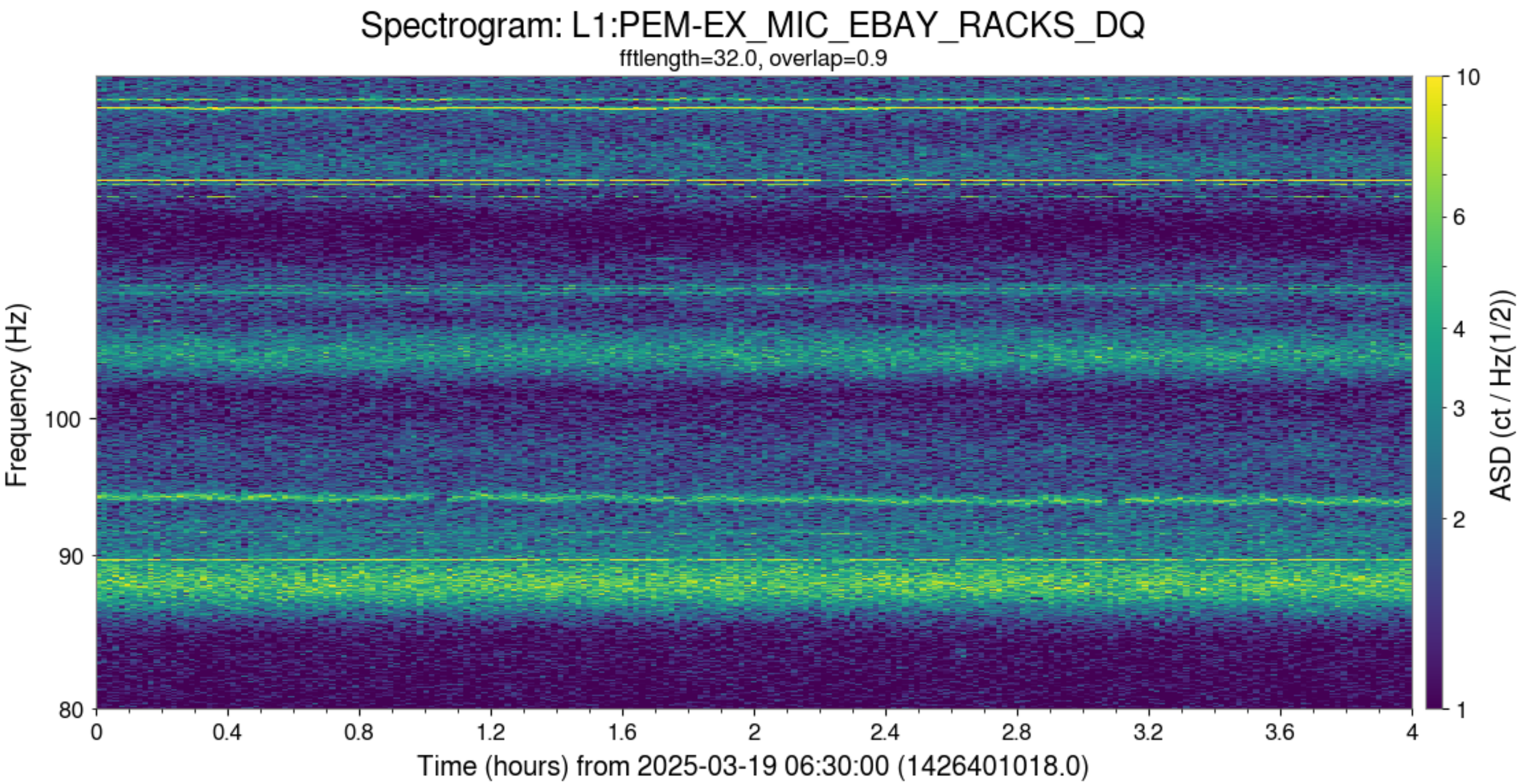
18

20-80 Hz


Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=32.0, overlap=0.9
Frequency (Hz)
80
70
60
50
40
30
20
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)
ASD (ct / Hz(1/2))
10
6
4
3
2

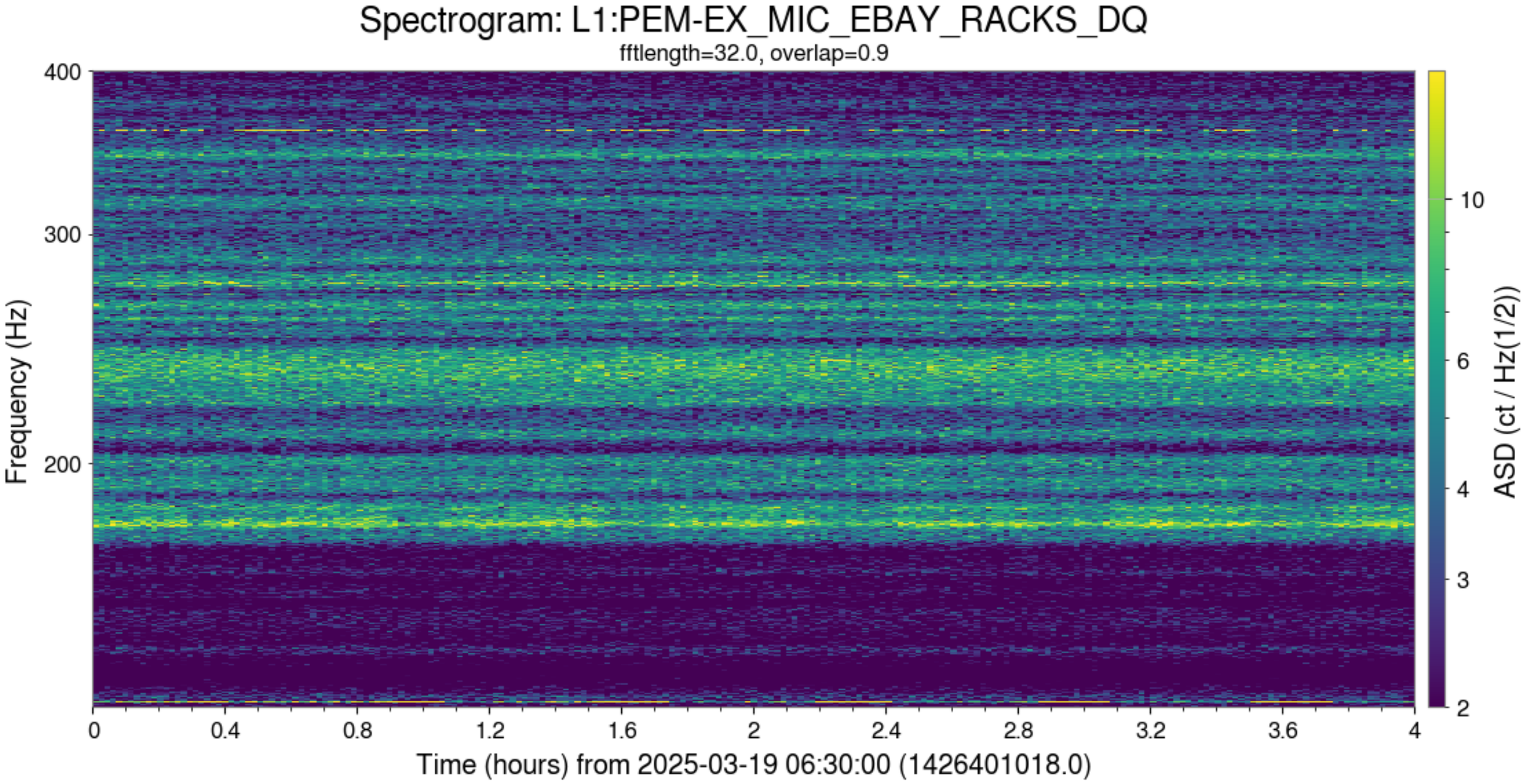
19

80-130 Hz


Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=32.0, overlap=0.9
Frequency (Hz)
100
90
80
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)
10
6
4
3
2
1
ASD (ct / Hz(1/2))

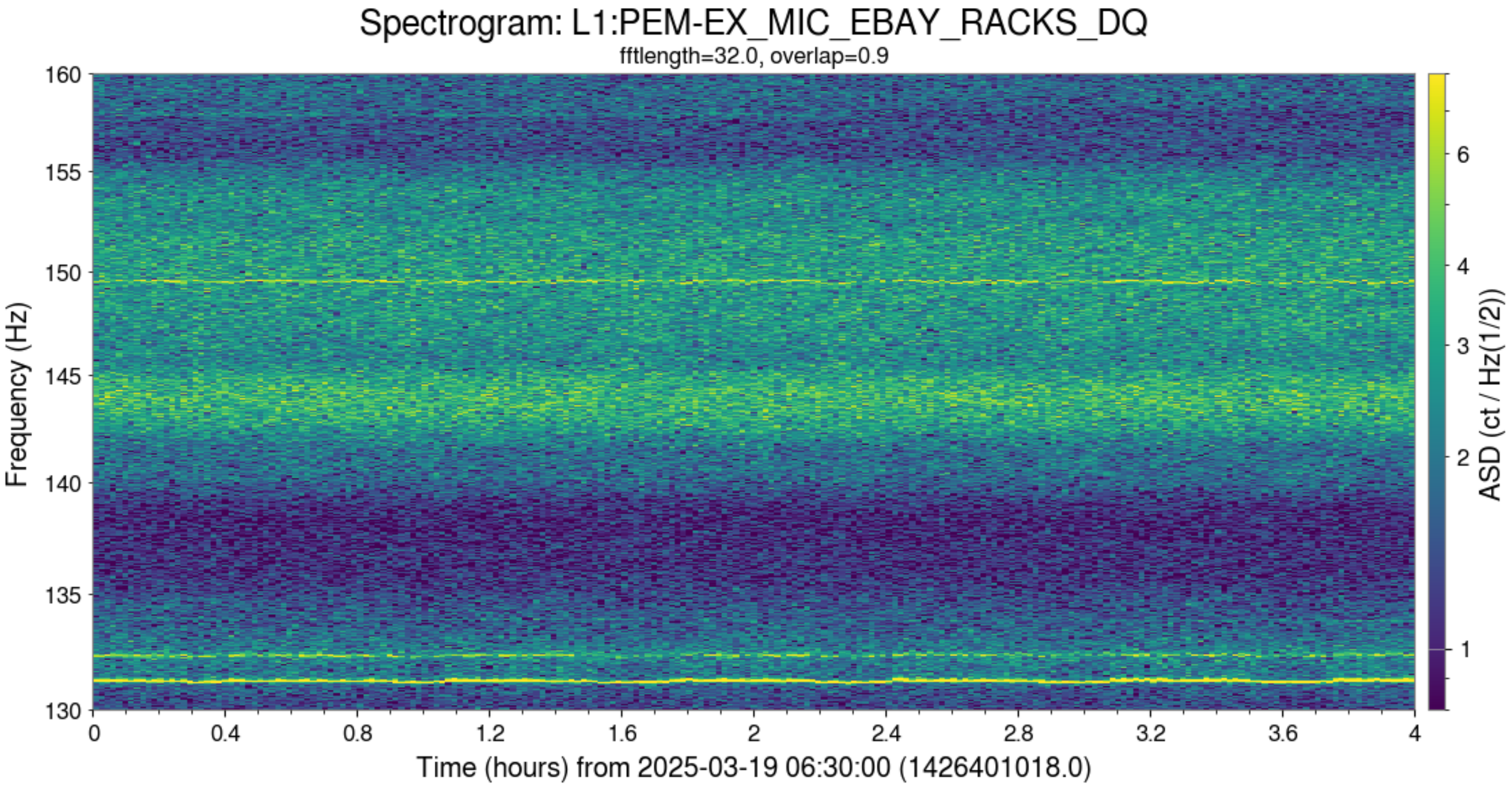
20

130-400 Hz


Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=32.0, overlap=0.9
Frequency (Hz)
400
300
200
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)
ASD (ct / Hz(1/2))
10
6
4
3
2

21

130-160 Hz


Spectrogram: L1:PEM-EX_MIC_EBAY_RACKS_DQ
fftlength=32.0, overlap=0.9
Frequency (Hz)
160
155
150
145
140
135
130
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
Time (hours) from 2025-03-19 06:30:00 (1426401018.0)
ASD (ct / Hz(1/2))
6
4
3
2
1

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Final remarks

- Will the BNS oscillations return?
- Have the properties of the oscillations evolved?
- The evidence for a relation to temperature is strong although not emphasized in this talk.
- The cause remains unknown.

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Representative aLogs

B.K. Berger, Possible correlation between LLO range oscillations and EX TEMP and ALS channels, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=68999

S. Soni, BNS range oscillations on Dec 13 and Dec 14, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=69034

J. Glanzer, March 30th BNS range oscillations - correlations with EX temp, rel humidity, and LSC-refl channels, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=70426

B.K. Berger, Odd (anti)correlations between the EX EBAY FLOOR ACC at 10 - 20 Hz and at 100 - 200 Hz and BNS range oscillations on 30 April 2024 , https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=71323

A. Mullavey, X end Pico-driver turned off, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=71412

B.K. Berger, Have the BNS range oscillations returned?, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=71786

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Representative aLogs (cont'd)

V. Frolov, Excess noise during range oscillation, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=72816

M. Strong, Range Oscillations appear to be connected to X End Air Handler , https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=73037

J. Glanzer, Low frequency half-hour oscillations present in some EX sensors on Sept 18th, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=73689

B.K. Berger, EX AHU channels when no BNS range oscillations are visible, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=73942

B.K. Berger, Data (presented as plots) for BNS range oscillations in September 2024 (version 1), https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=74482

S. Kandhasamy, half-hourly BNS range oscillations and beam movement on main optics, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=74759

B.K. Berger, Data (presented as plots) for BNS range oscillations in September 2024 (version 1), https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=74482

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