Pointing Stability of Hinode and Requirements for SOLAR-C (Option-B)

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Purpose:

Toward next Solar-C satellite with higher pointing-stability,

- Report "on-orbit" performance of image stabilizing system on-board Hinode satellite
  - Identify major sources for disturbances
  - Asses the achievement of Hinode Satellite
  - Raise Issues in realizing Solar-C (Option-B)

Contents:

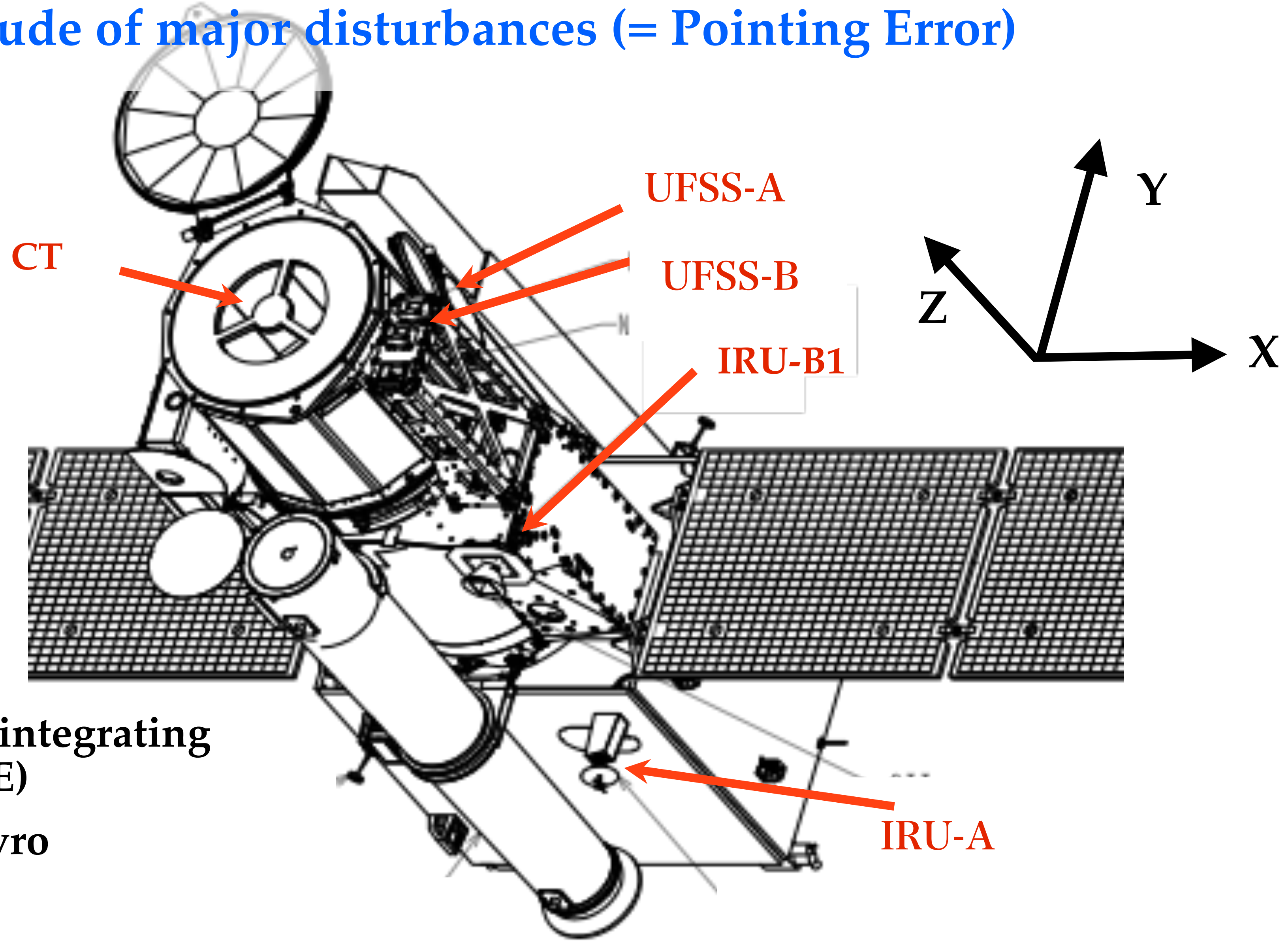
1. Analysis on jitter ambient in the telemetry data of UFSS and IRU [low frequency regime (10^{-4} Hz $< f <$ 10^{-1} Hz)]
2. Analysis on the jitter ambient from SOT with CT servo on/off [high frequency regime (10^{-2} Hz $< f <$ *200* Hz)]
3. Requirements for Solar-C V.S. Performance of Hinode on-orbit

Image Stabilizing System on-board Hinode

Position Control Sensors and Correlation Tracker on board Hinode

- Ultra Fine Sun Sensor [UFSS (-A,-B)], (10^{-5} Hz < f < 10^{-1} Hz)
- Inertia Reference Unit [IRU (-A, -B1)], (10^{-2} Hz < f < 10^{-1} Hz)
- Correlation Tracker [SOT/CT], (10^{-2} Hz < f < 290 Hz)

- Specify the dominant disturbances in the jitter by Fourier Analysis
- Evaluate the amplitude of major disturbances (= Pointing Error)

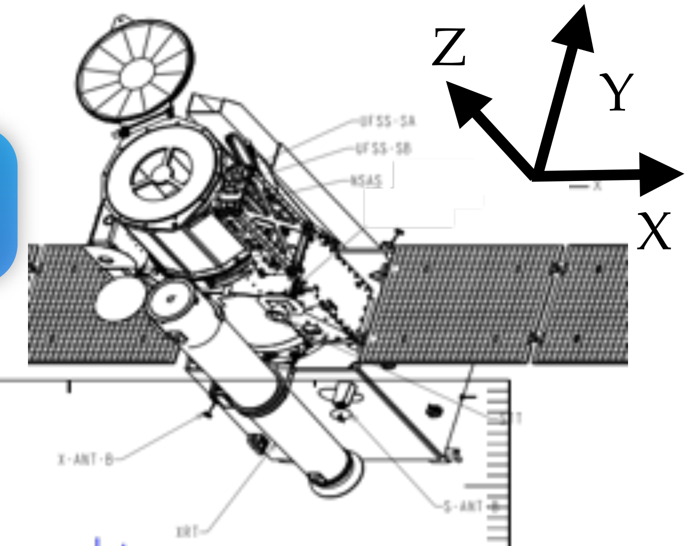


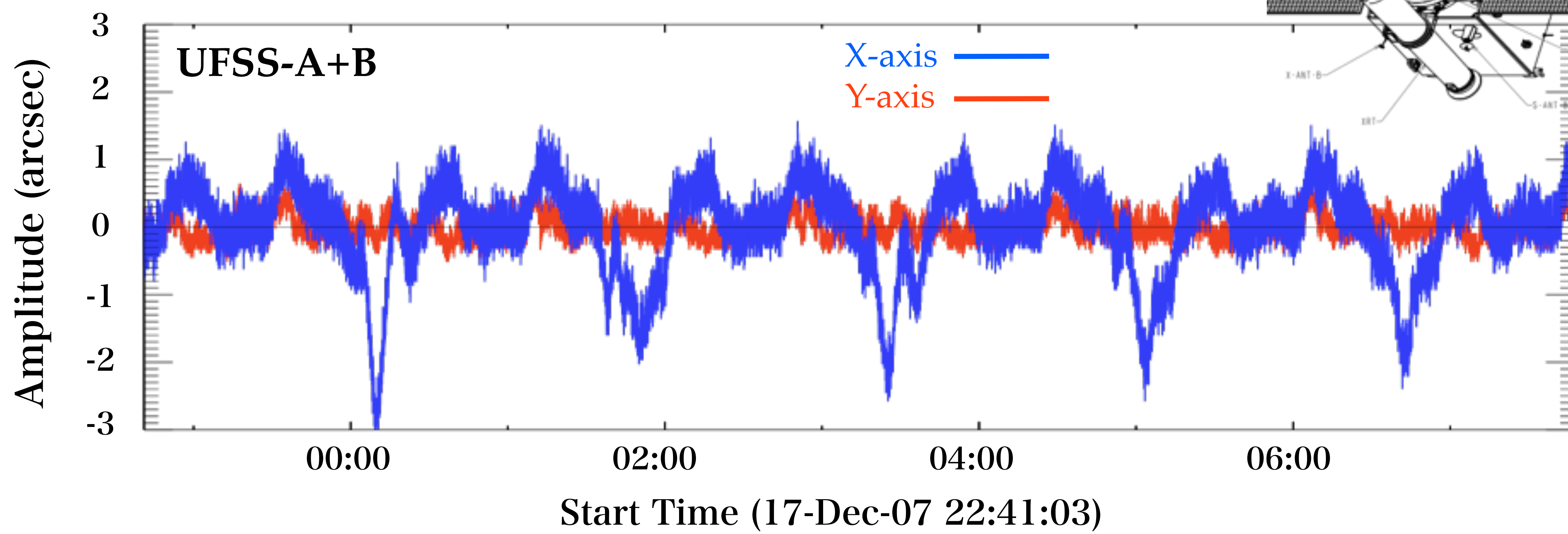
※) IRU-A : FRIG floated rate integrating gyro (made by JAE)

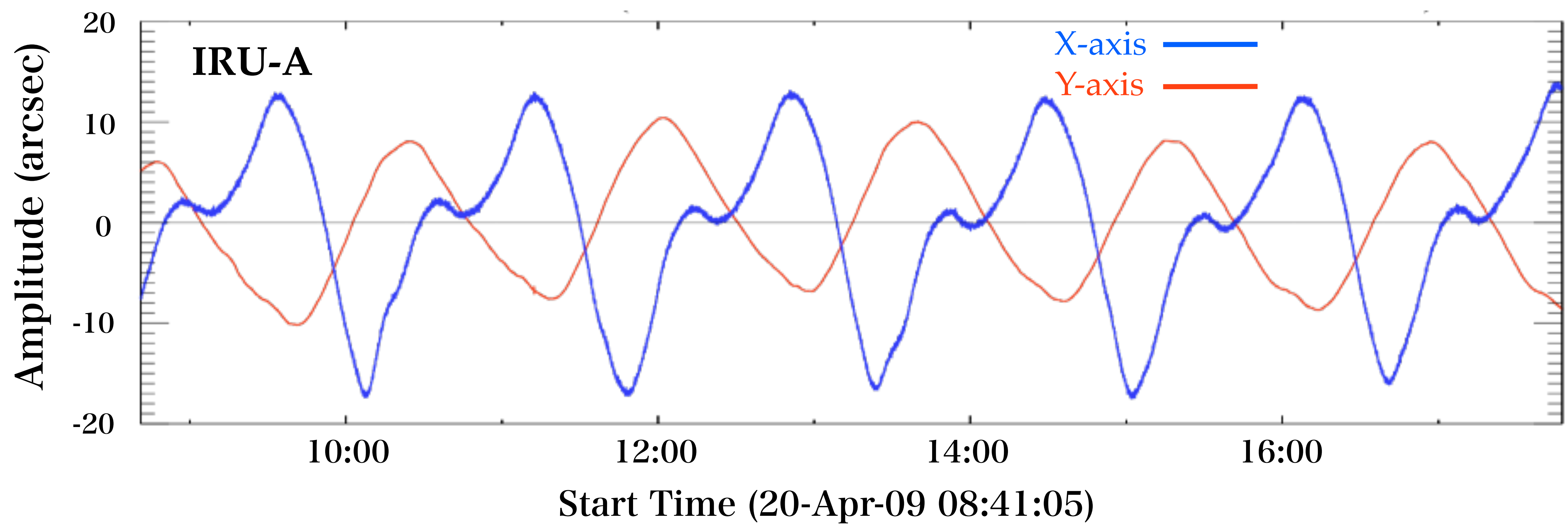
IRU-B1: TDG tuned dry gyro (made by MPC)

1. Diagnostic data of UFSS / IRU

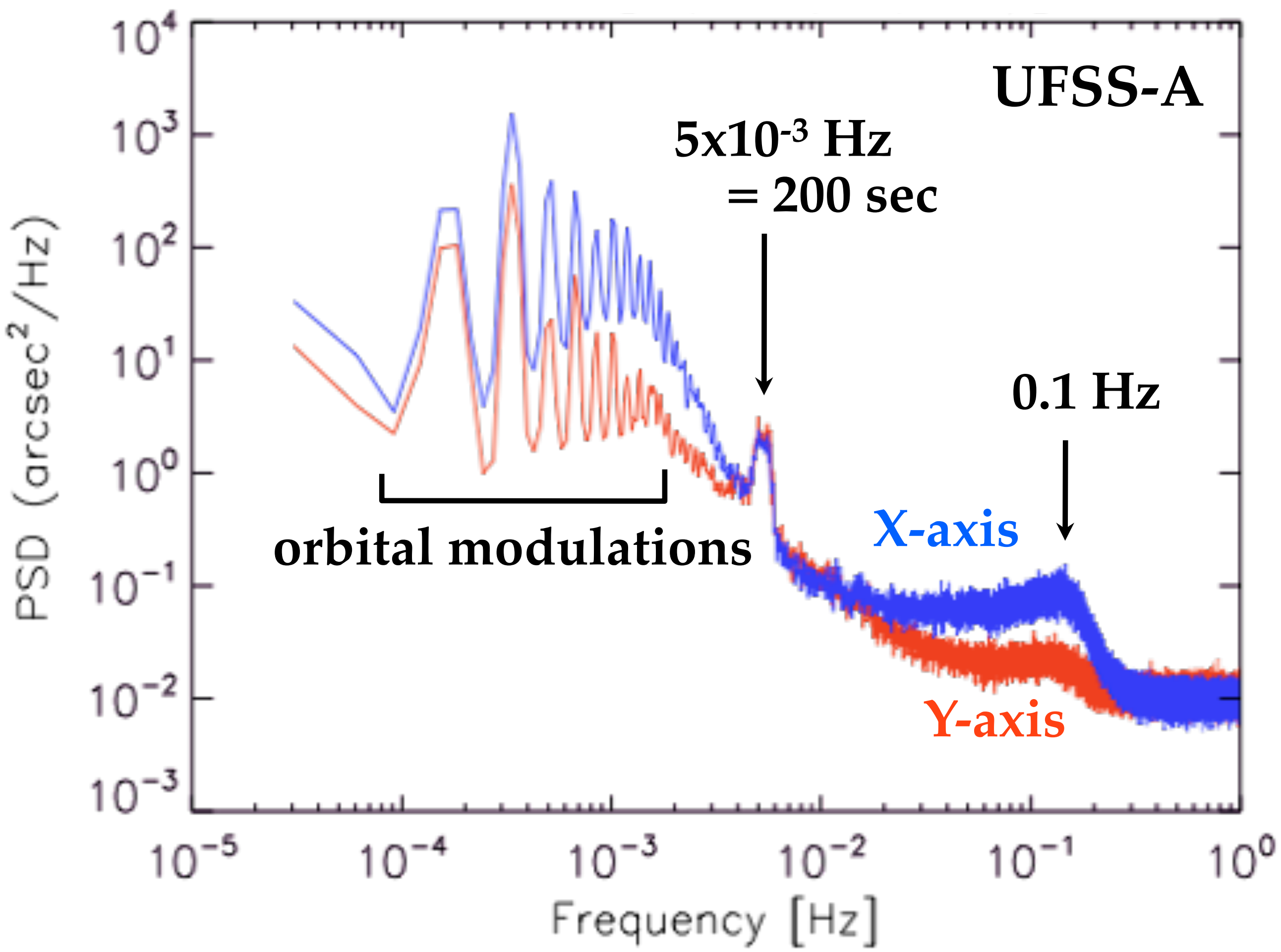
Time Profile: Telemetry data of UFSS and IRU

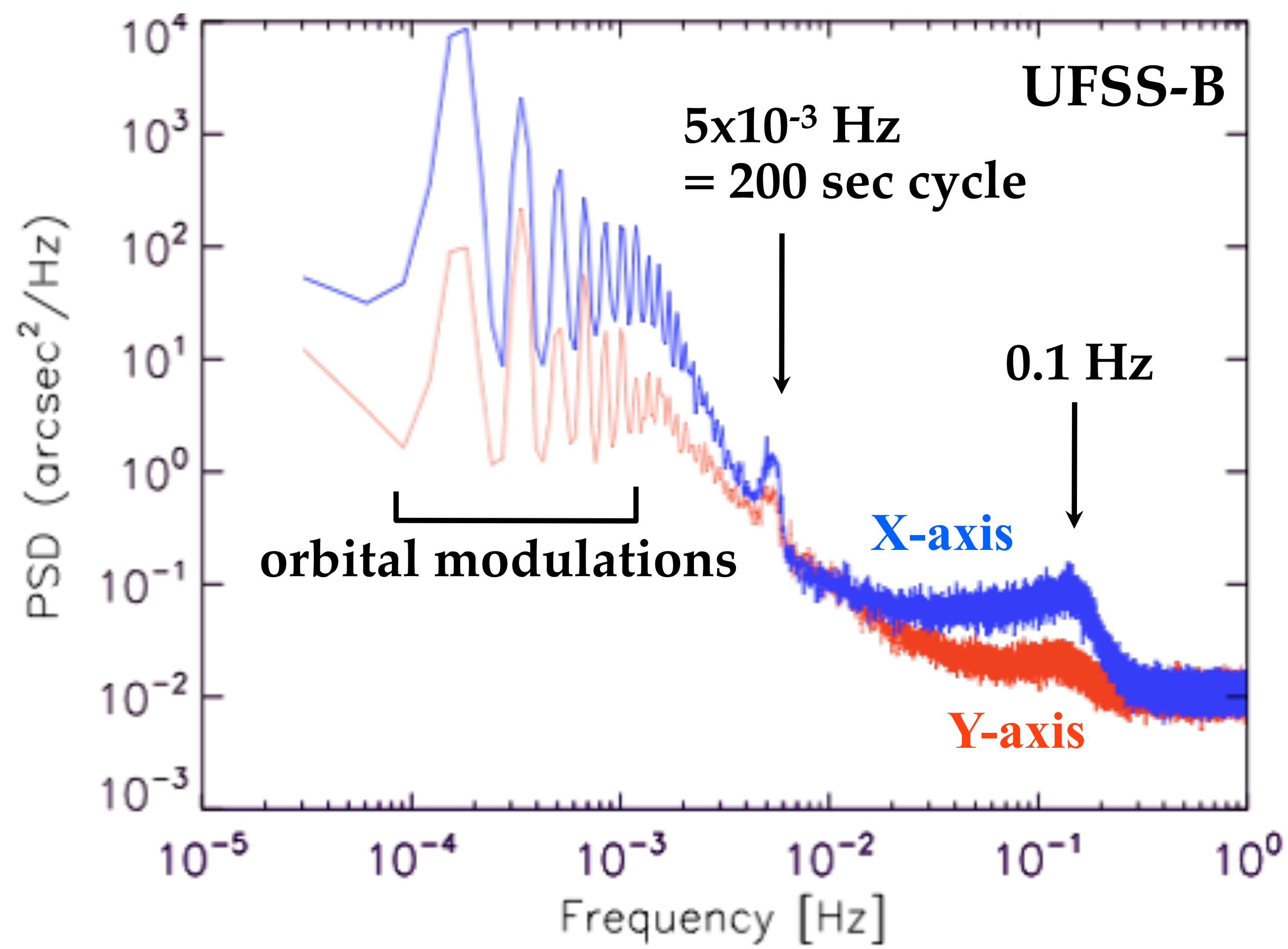






Power Spectrum Density for Jitter Disturbances (UFSS)





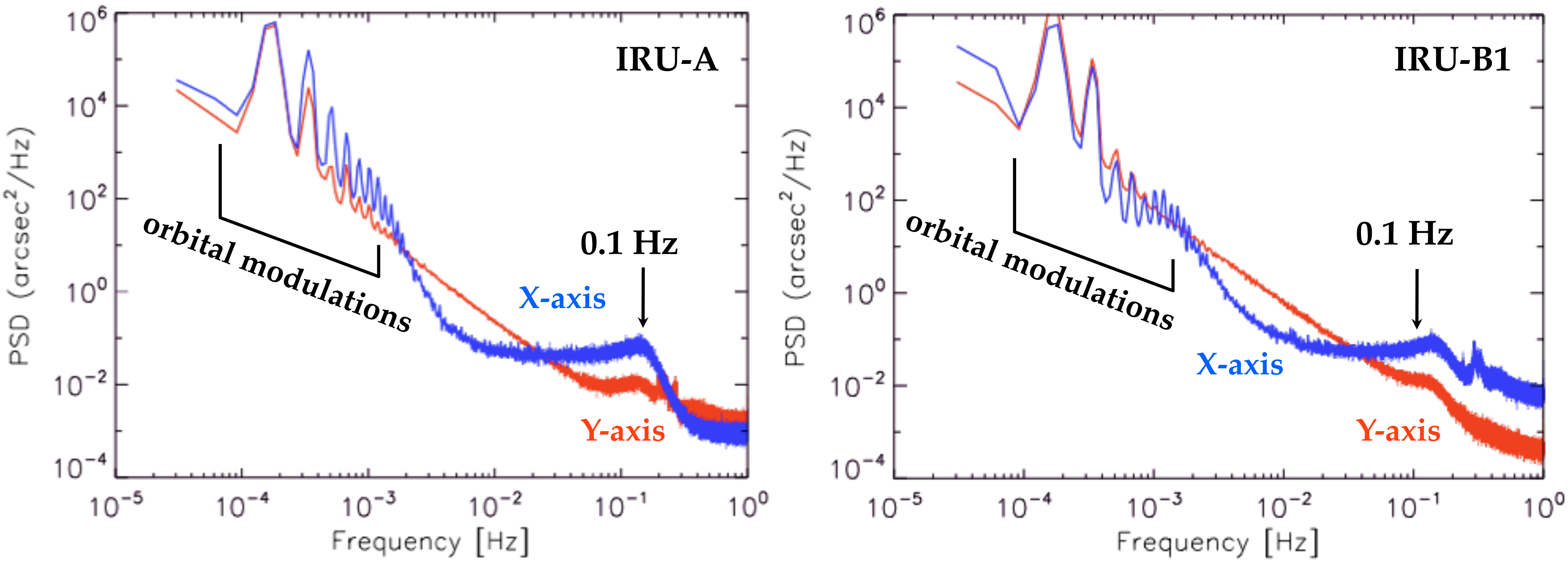
- **Features and Major Sources for Disturbances in the jitter of UFSS:**

- f ~ 0.1 Hz : position sensor can control the disturbances with f < 0.1 Hz

- f < 10^{-3} Hz: orbital modulation + its higher frequency (2f,4f,6f …)

[f ~ 5×10^{-3} Hz: unidentified (but, the contribution to the jitter is small)]

Power Spectrum Density for Jitter Disturbances (IRU)



- <u>**Features and Major Sources for Disturbances in the jitter of IRU:**</u>

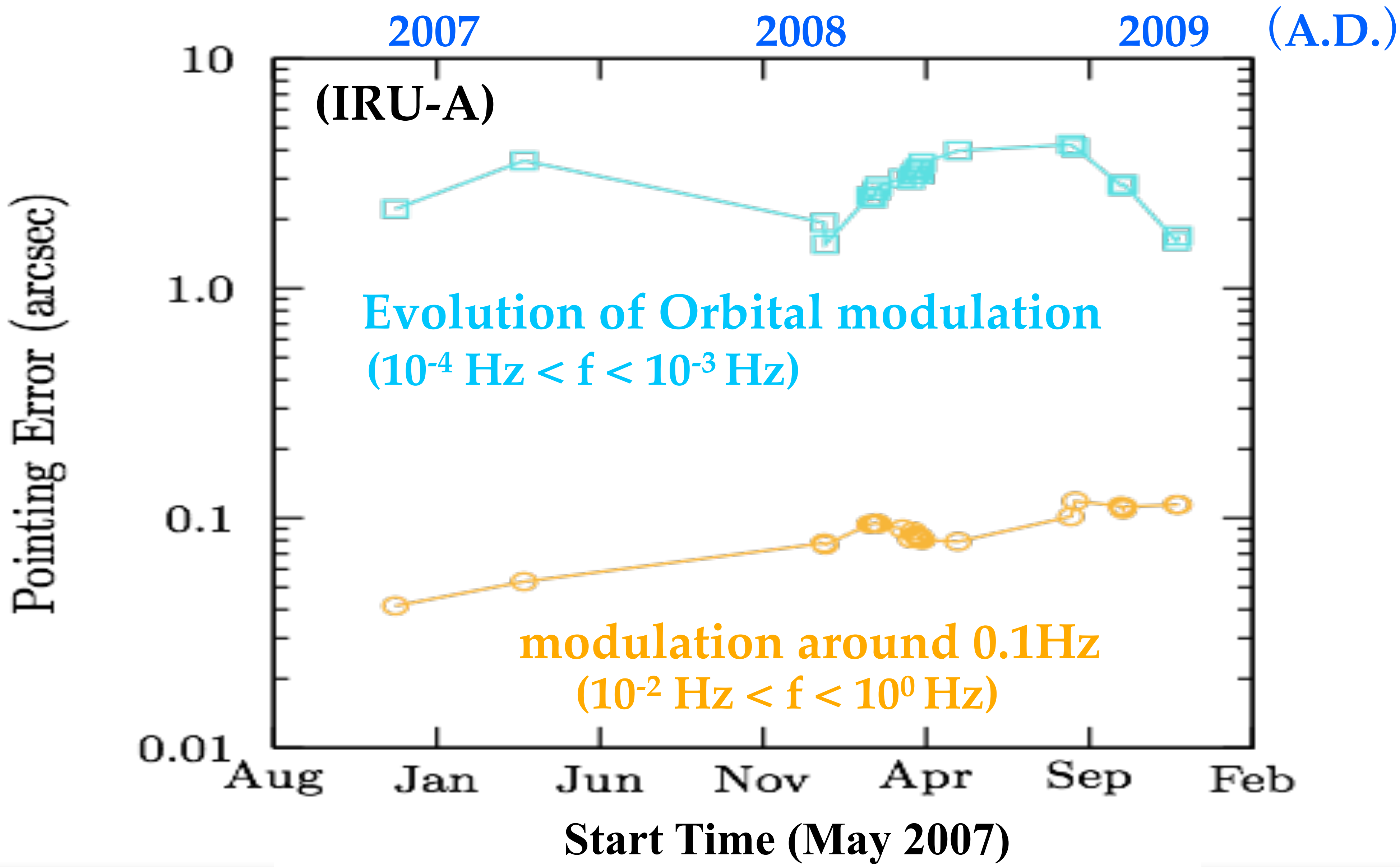
- f ~ 0.1 Hz : position sensor can control the disturbances with f < 0.1 Hz

- f < 10^{-3} Hz: orbital modulation + its higher frequency (2f,4f,6f …)

[no peak around f ~ 5×10^{-3} Hz which can be seen in UFSS data]

The characters of PSD in the case IRU are almost same as that in UFSS

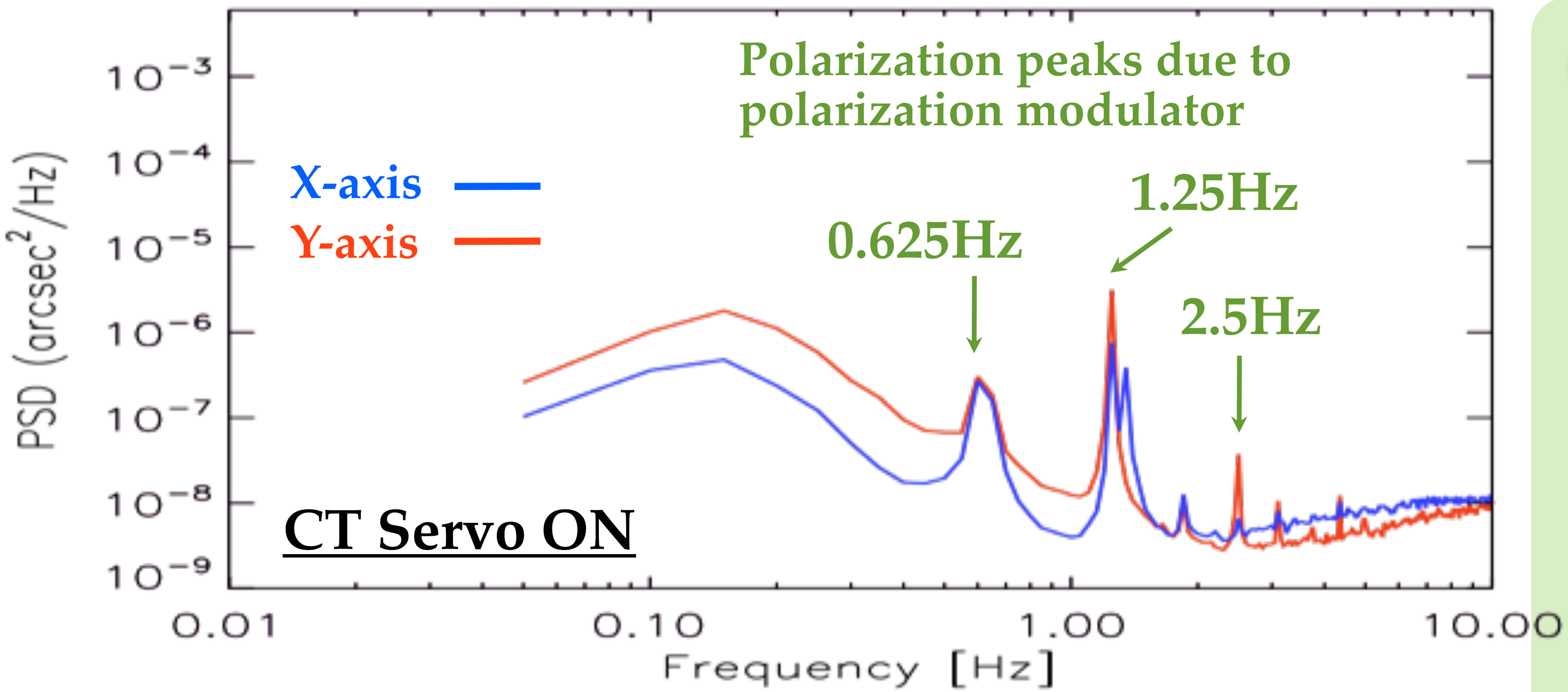
Secular variation of the pointing error

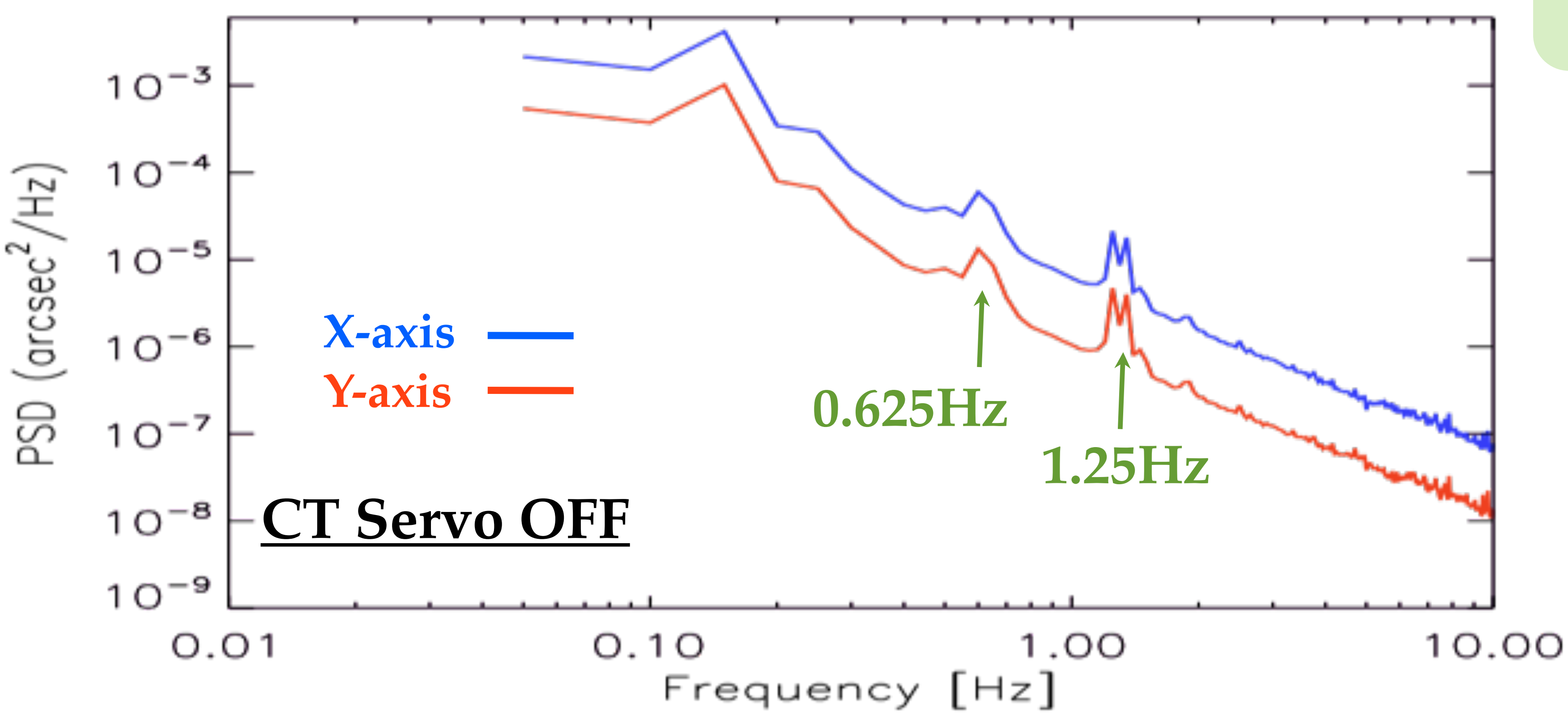


- Characteristics in the long term variation:
  - There is a seasonal variation in the orbital modulation as expected.
    : shade term (Apr. to Aug.) → large error, but it become smaller during Oct.-Jan.
  - The modulation around 0.1 Hz increases secularly (we don't know why...).

SOT Diagnostic data

Fourier Power Spectrum: SOT/CT - lower frequency band





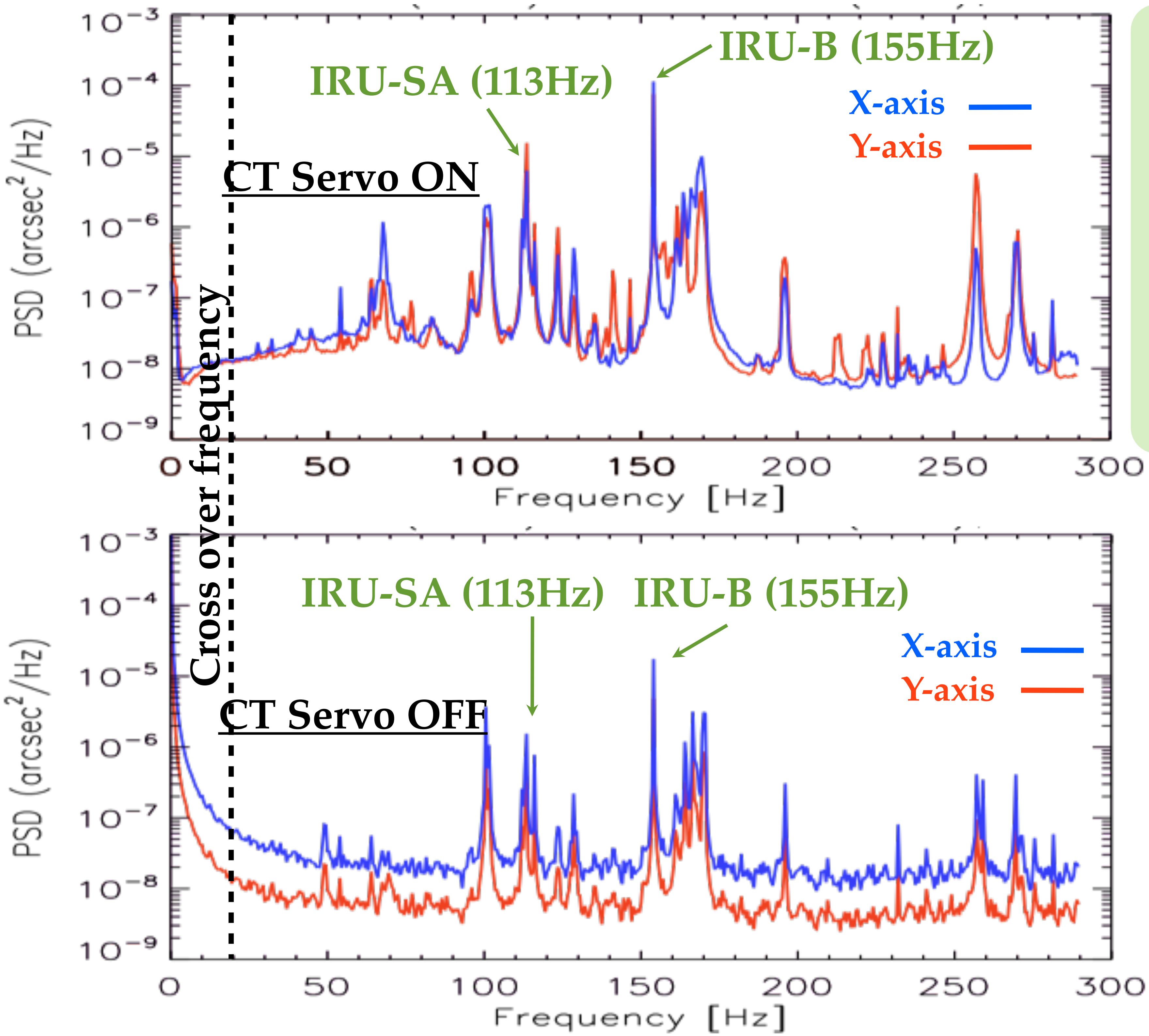
- **Features:**

- the disturbances are reduced clearly by CT in f < 10 Hz

- Peaks around *1.0* Hz are due to the polarization modulator rotating with *period 1.6* sec
  - **0.625 Hz**
  - **1.25 Hz (Stokes V)**
  - **2.5 Hz (Stokes Q and U)**

※ Polarization modulator which is located in the optical path generates the modulations of the circular and linear polarization signals

Fourier Power Spectrum: SOT/CT - higher frequency band



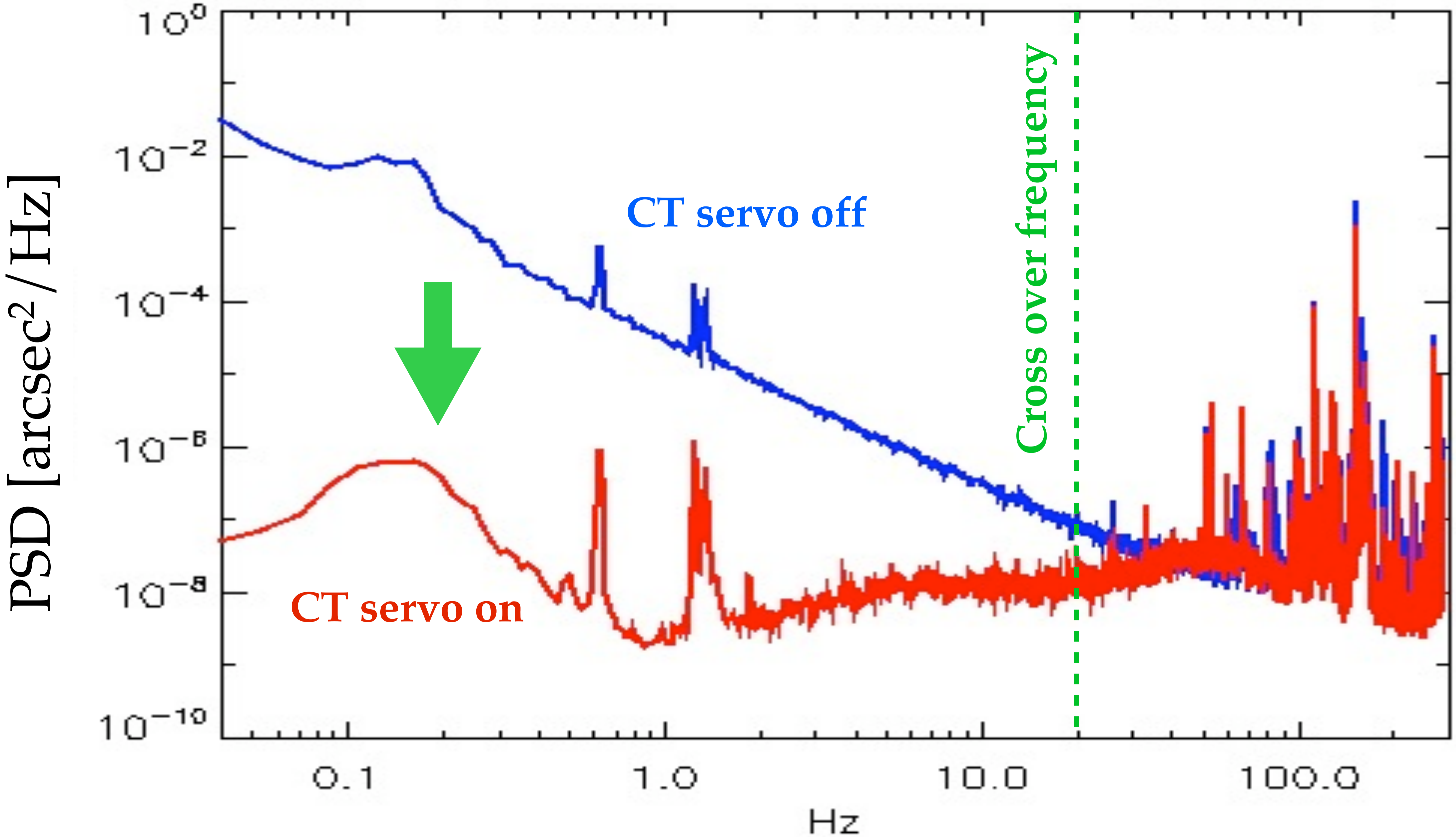
- **Features:**

- 40-290Hz → a lot of peaks are generated due to the external disturbances (momentum wheel)

- The peak value of the error is typically 10^{-2} [arcsec]

20Hz (= cross over frequency)

SOT/CT performance on-orbit: Excellent !



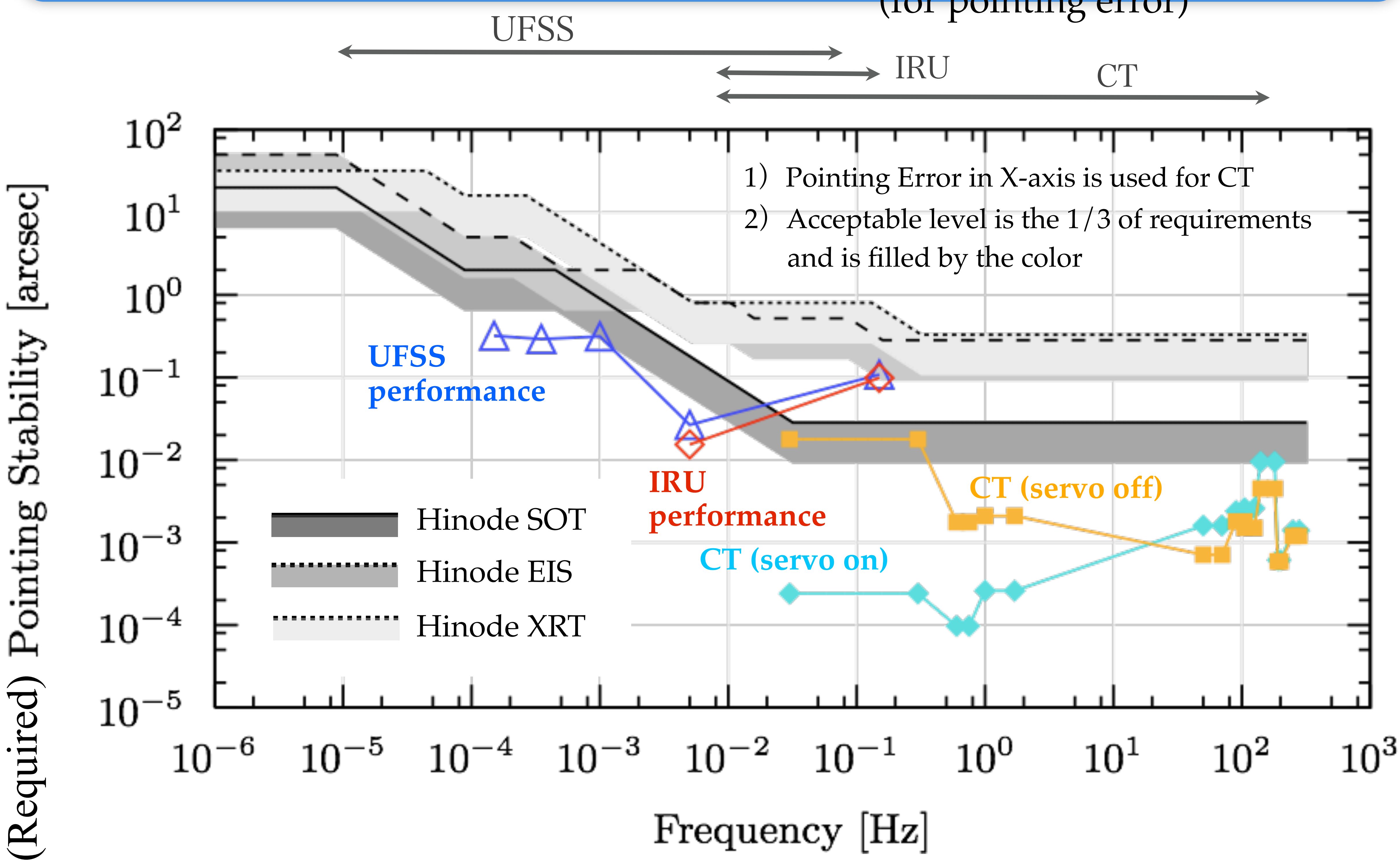
- The disturbances are reduced drastically at the lower frequency band than 20Hz (= cross over frequency).
- SOT/CT show, even on-orbit, the performance expected before launching.

Requirements for Solar-C
V.S.
Performance of Hinode on-orbit

- Asses the achievement of Hinode Satellite
- Raise Issues in realizing Solar-C (Option-B)

Required Ability for Hinode and its Performance on-orbit

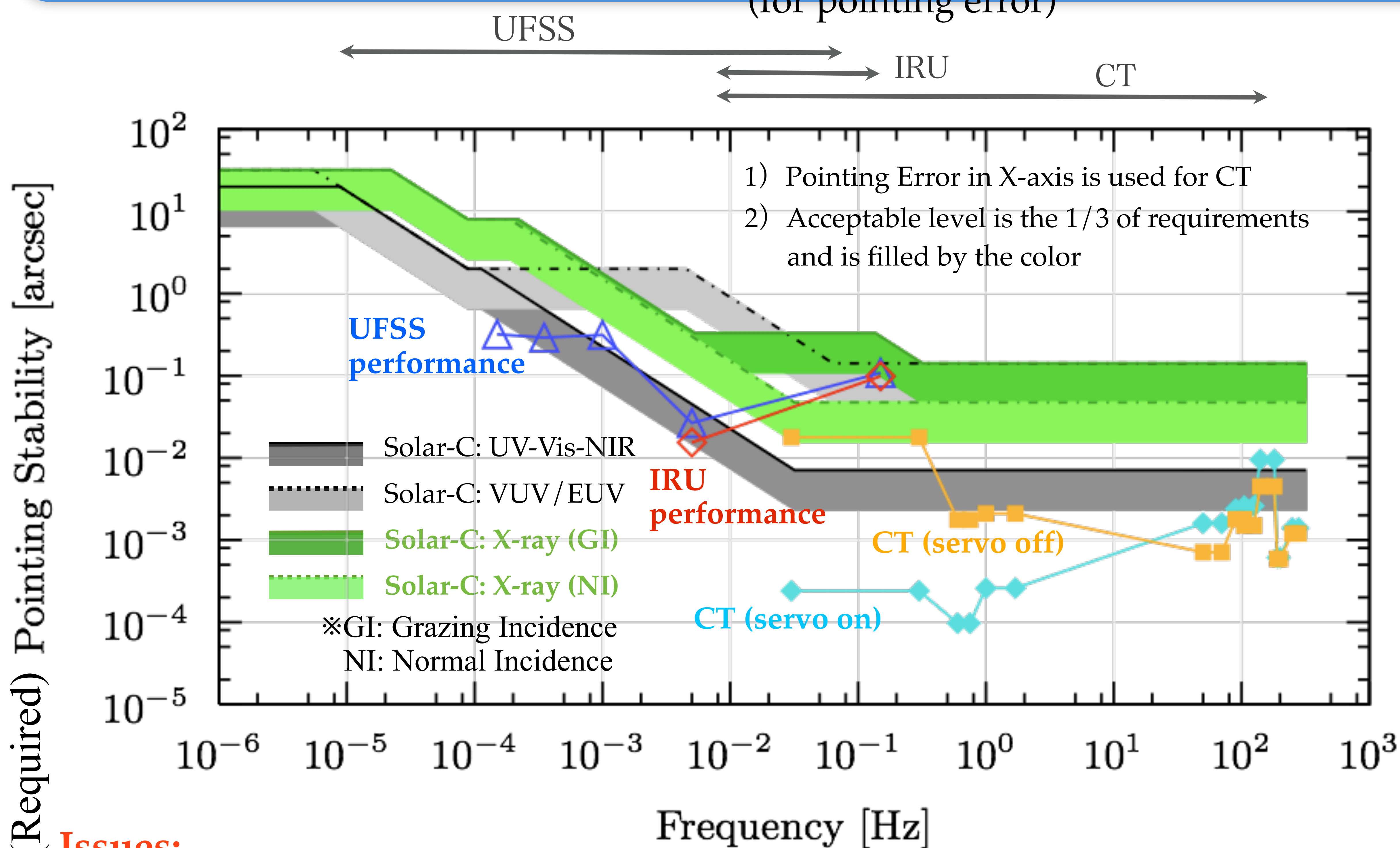
(for pointing error)



- The performance of image stabilization system on-board Hinode is excellent and meets the required ability even on-orbit.

Requirements for Solar-C and Performance of Hinode on-orbit

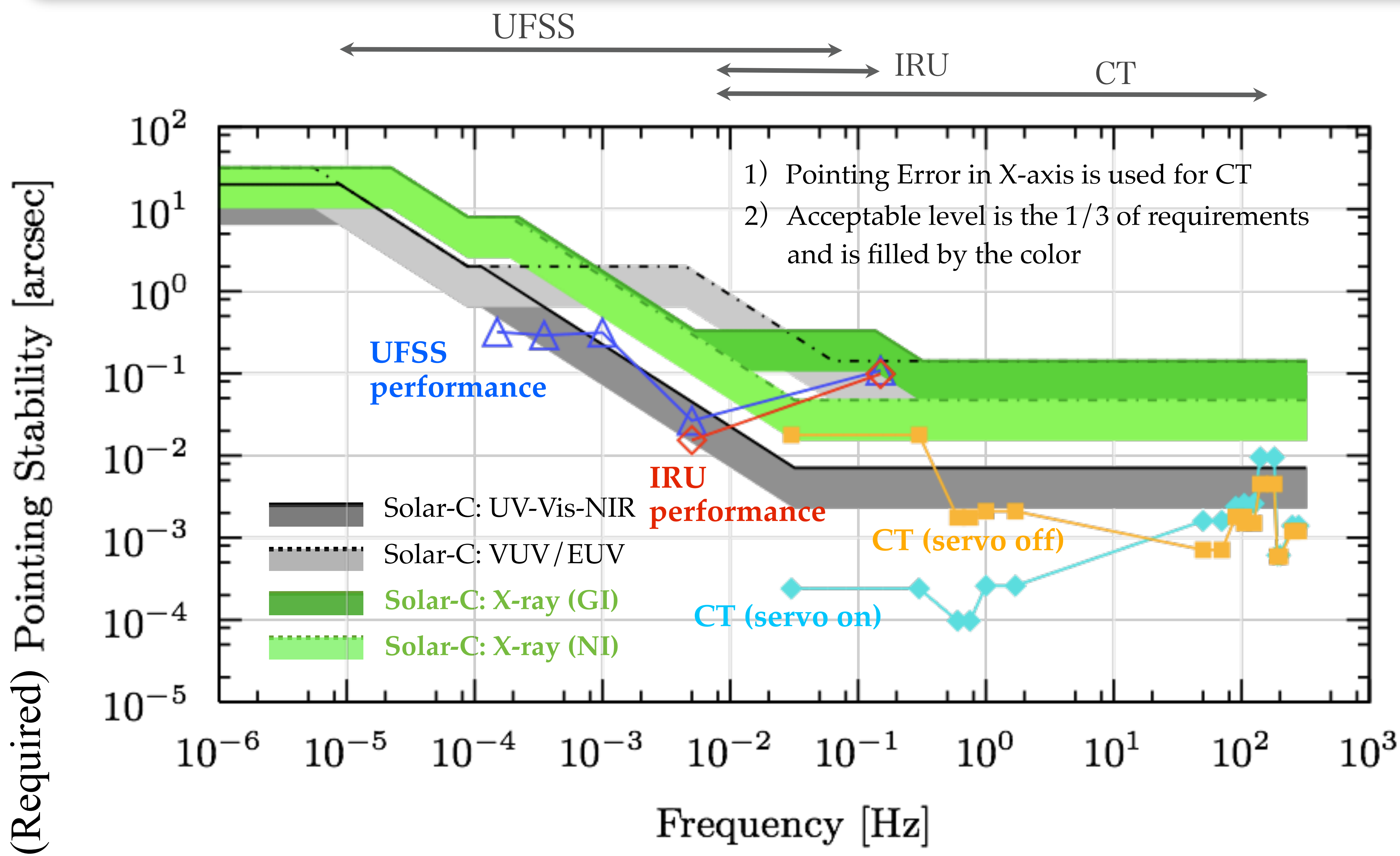
(for pointing error)



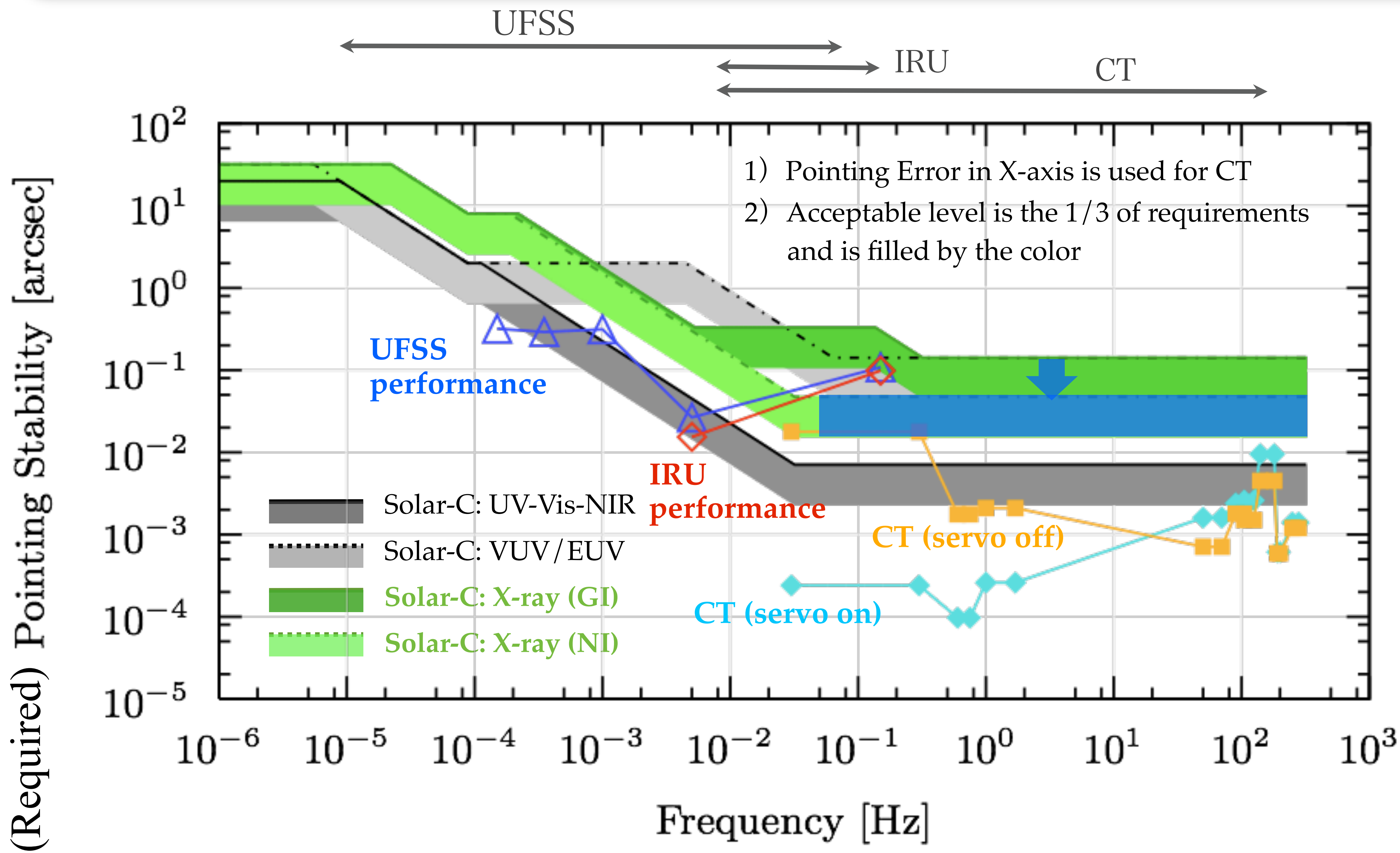
Issues:

- The performance of Hinode around 0.1 Hz does not meet the requirement for X-ray (NI)
- The performance of Hinode around 100 Hz does not meet the ability for UV-Vis-NIR

Requirements for Solar-C and Performance of Hinode on-orbit



Requirements for Solar-C and Performance of Hinode on-orbit



- If UV spectrograph with 0.2″ spatial resolution is assumed, the required ability for VUV/EUV become more severe (0.3 arcsec → 0.05 arcsec).

Summary: Toward Solar-C with required ability for Option-B

- In the band f > 20Hz, we should reduce the disturbances generated by MW or extend the cross over frequency up to 300 Hz in order to meets the requirement.

- The major disturbance source in UFSS/IRU is the orbital modulations in the band f < 10^{-3}Hz. They are generated due to the change of thermal environment, not due to the characteristics of the position control sensors.

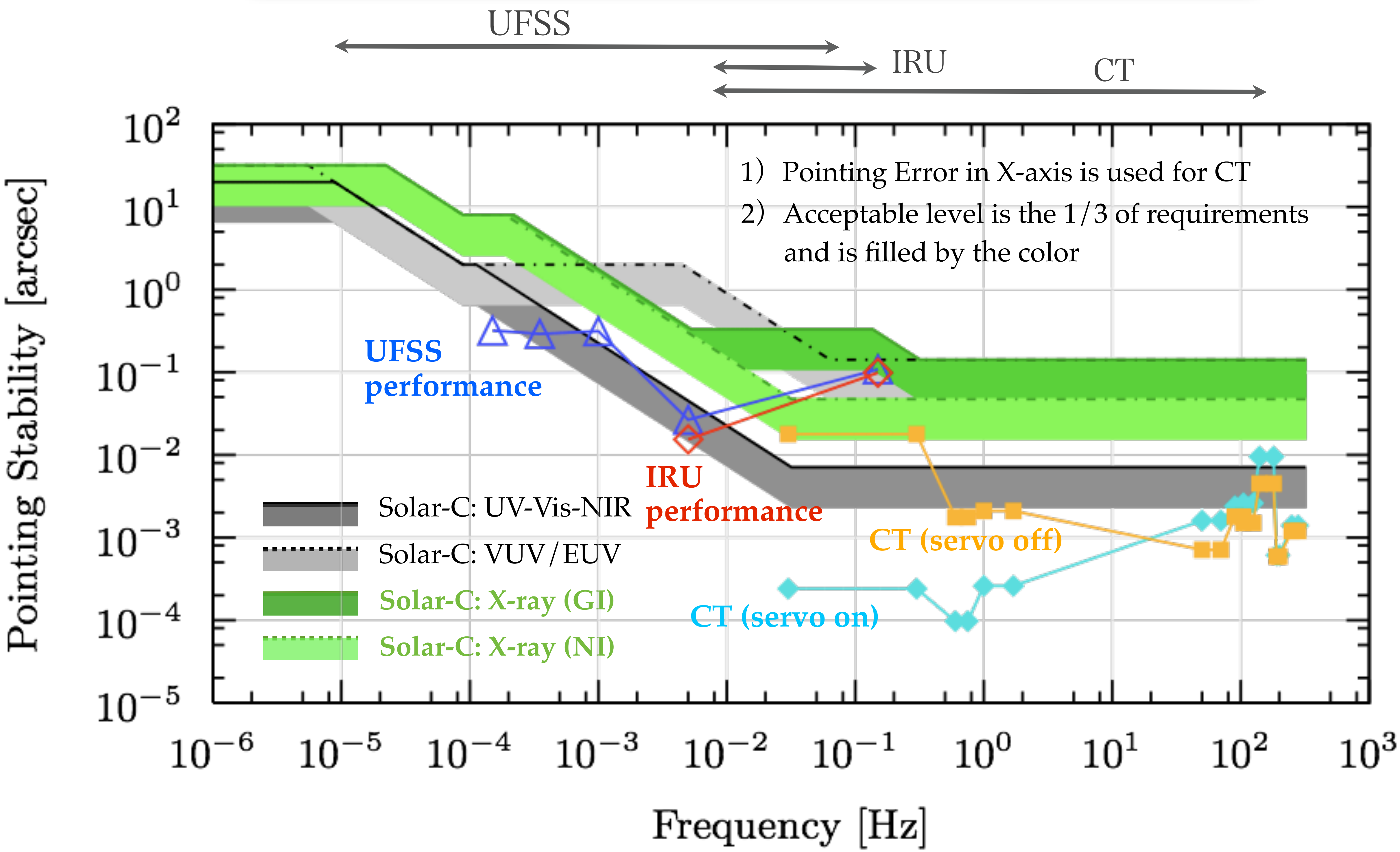
  ➡ **We should consider seriously the thermal structure of Solar-C**

- In the band 0.01Hz < f < 1Hz, the performance meets the required abilities for UV-Vis-NIR, VUV/EUV and X-ray (GI) at least, but not for X-ray (NI).

  ➡ **CT would be needed for X-ray (NI) with required ability**
  CT would be needed for UV spectrograph with 0.2″ spatial resolution

- The disturbances in ~ 0.1 Hz seems to have serious impacts on Solar-C. It must be reduced in designing the position control sensor for Solar-C.

Please keep this viewgraph in your mind !



when you explore the science target for Solar-C

Appendix

Instruments on board Hinode and Data Sets

Position Control Sensors and Correlation Tracker on board Hinode

- **Ultra Fine Sun Sensor [UFSS (-A,-B)], (10^{-5} Hz < f < 10^{-1} Hz)**
- **Inertia Reference Unit [IRU (-A, -B1)], (10^{-2} Hz < f < 10^{-1} Hz)**
- **Correlation Tracker [SOT/CT], (10^{-2} Hz < f < 290 Hz)**

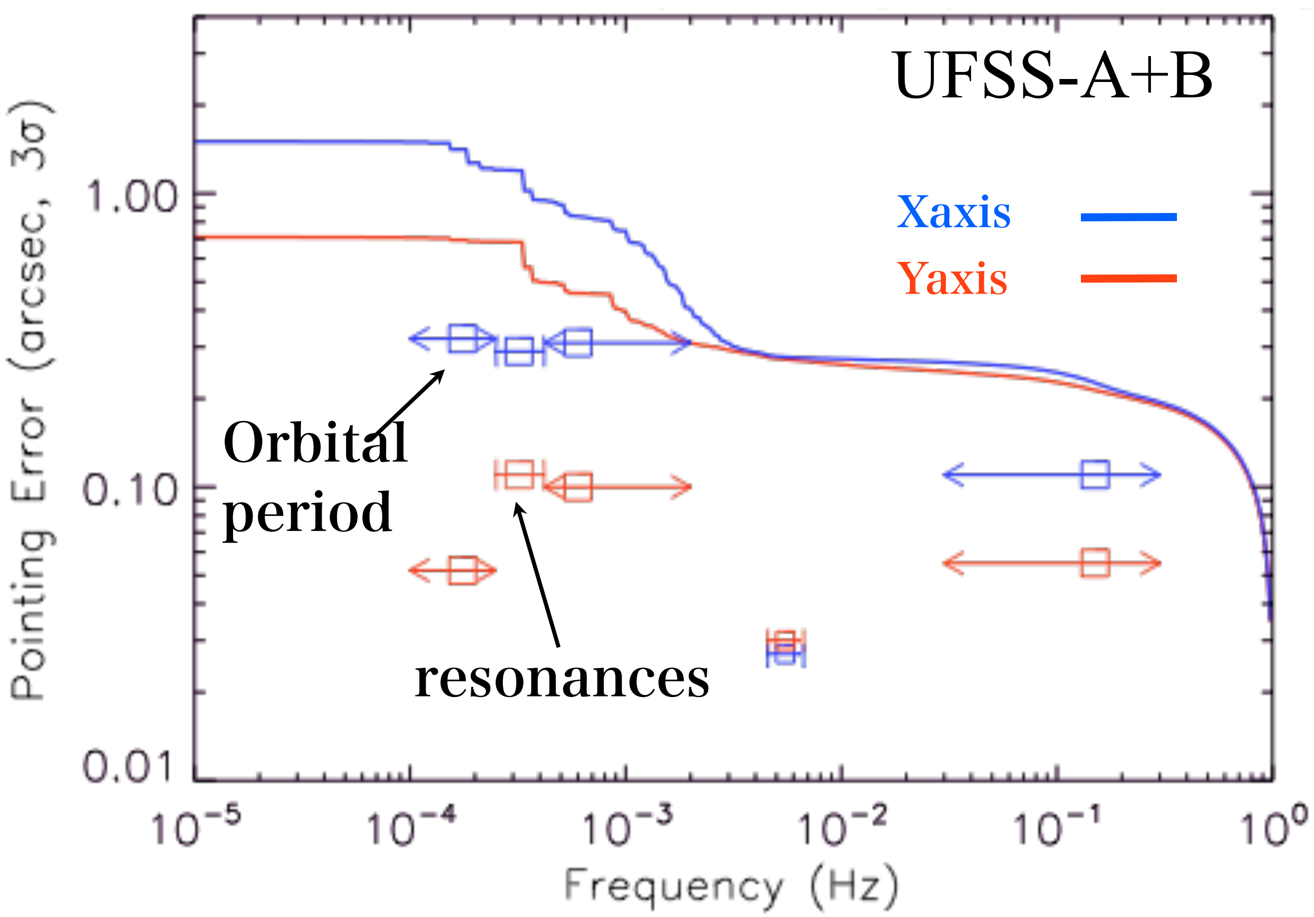
We analyze the jitter in telemetry date of UFSS, IRU and diagnostic data of SOT/CT

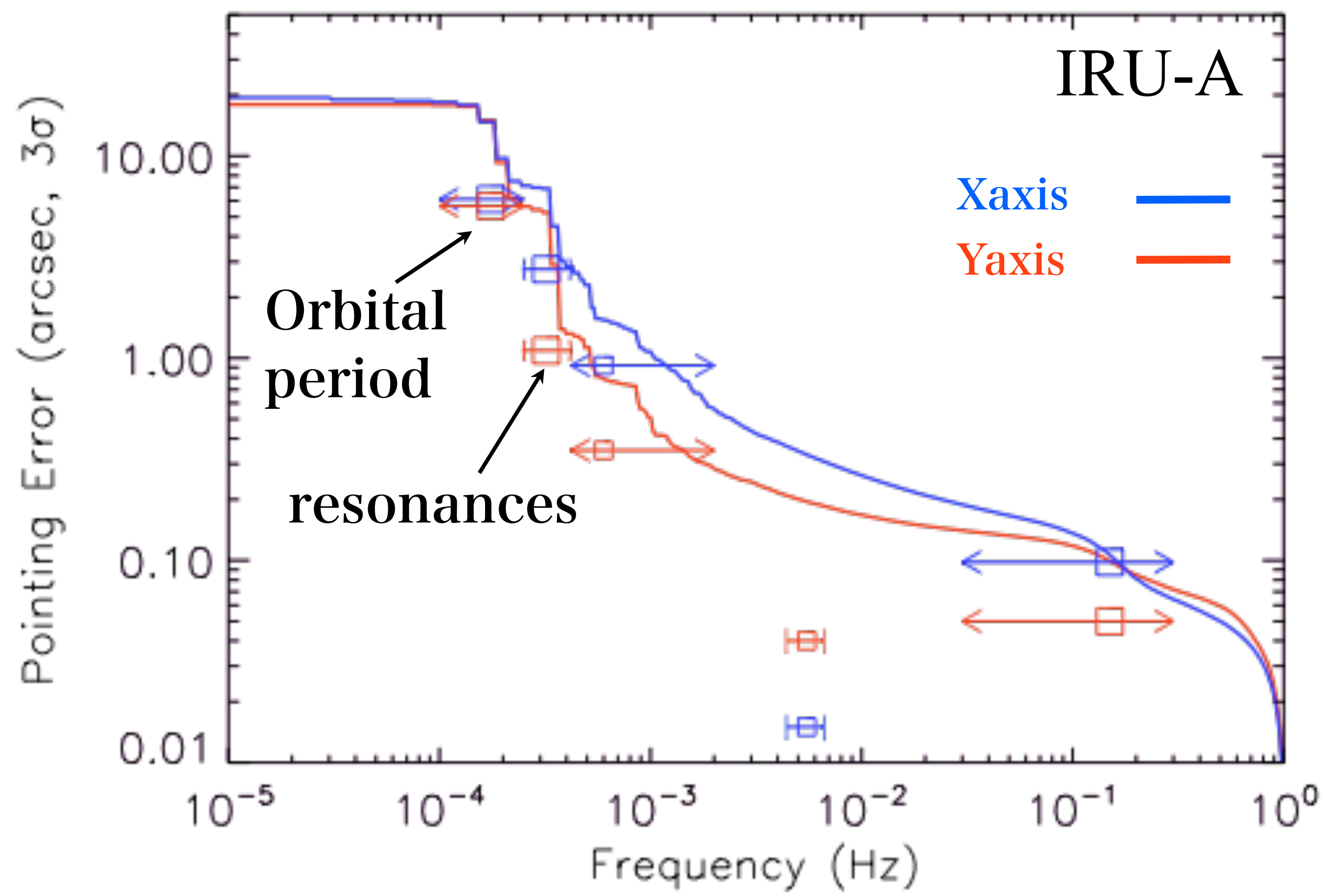
- UFSS, IRU:
  - 40 data sets [from November 2006 to April 2009 (full disk only)]
  - Sampling: 0.5 sec (successive data more than 9 hours)
  - drift component is removed (by using the linear fitting)
- SOT/CT:
  - diagnostic data of CT servo on/off [focus on Dec. 2007]
  - Sampling: 580 Hz (df = 0.5 Hz for averaging)

- **Specify the distinguished peak from Fourier Power Spectrum (PSD)**
- **Evaluate the amplitude of the major disturbances (= Pointing Error)**

※) IRU-A : FRIG floated rate integrating gyro (made by JAE),
IRU-B1: TDG tuned dry gyro (made by MPC)

Pointing Error (UFSS, IRU)





- **Evaluation Methods for Disturbances**

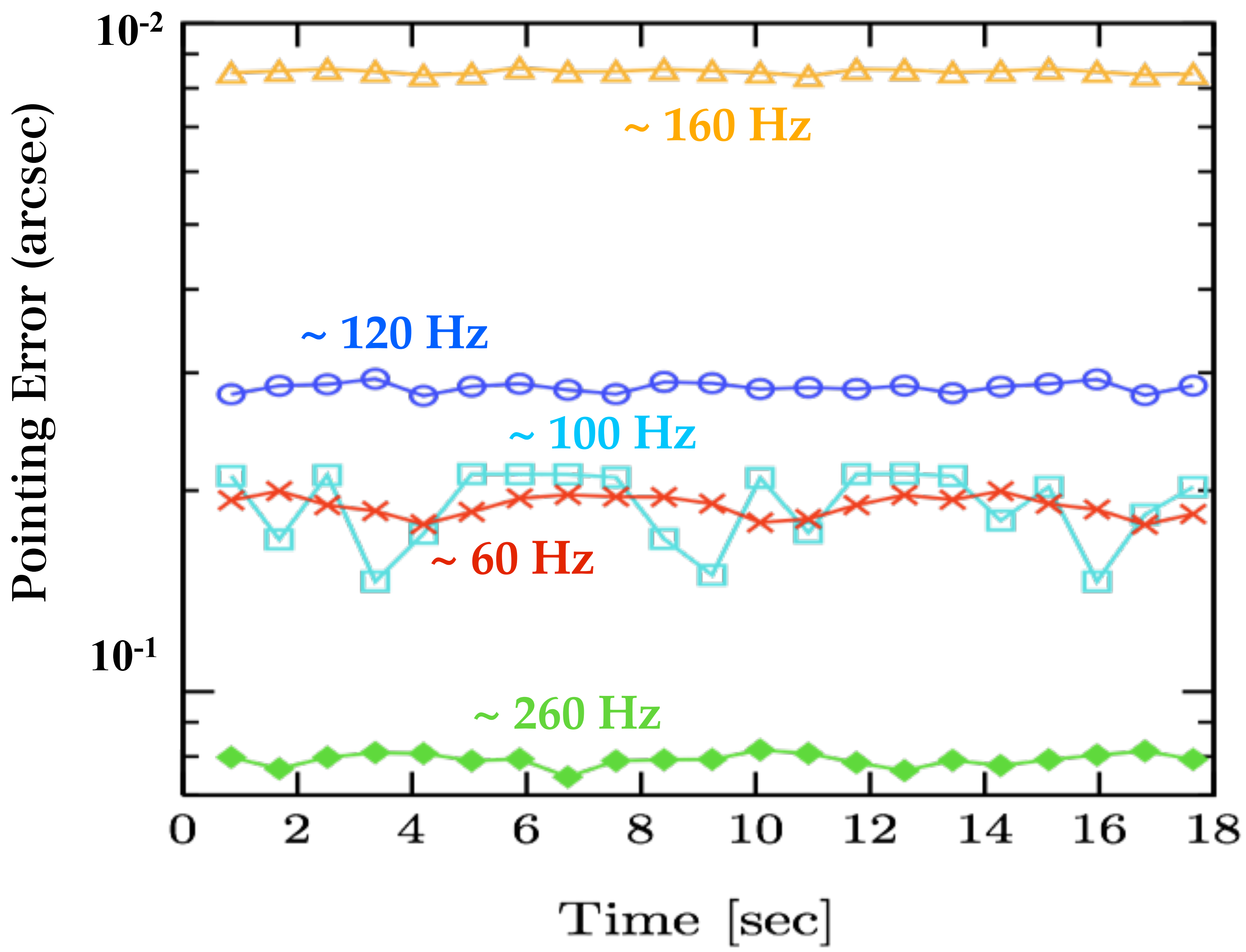
  - Thick line：By using high pass filter, we integrate PSD in the lower frequency regime

  - Symbol：By picking the distinguished peak from PSD up, we integrate the peak value around peak frequency

Pointing error with high pass filter gives the upper limit of the error

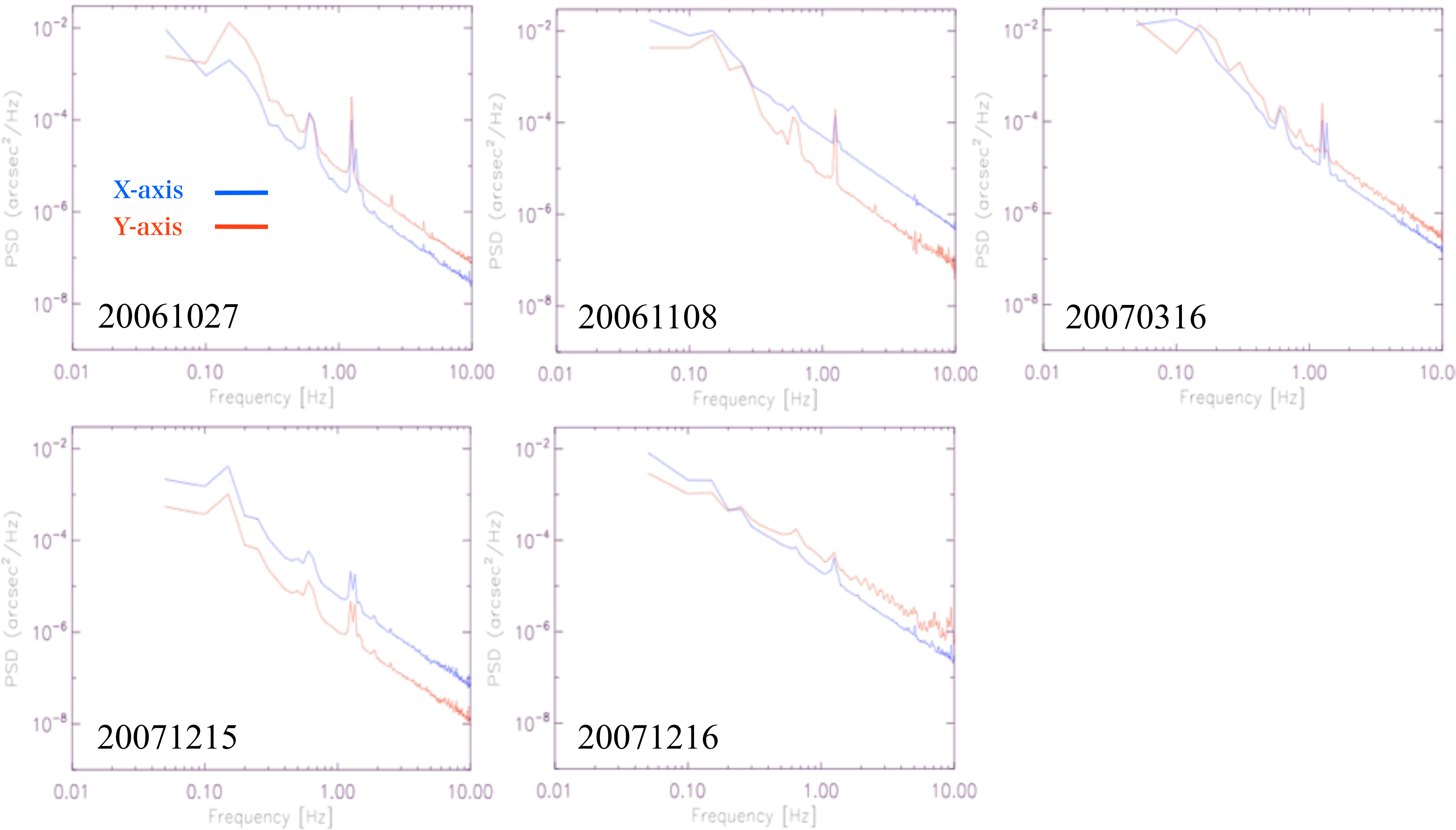
Short term variation of higher frequency peaks

Short term variation of higher frequency peaks around 100Hz (t < 20sec)

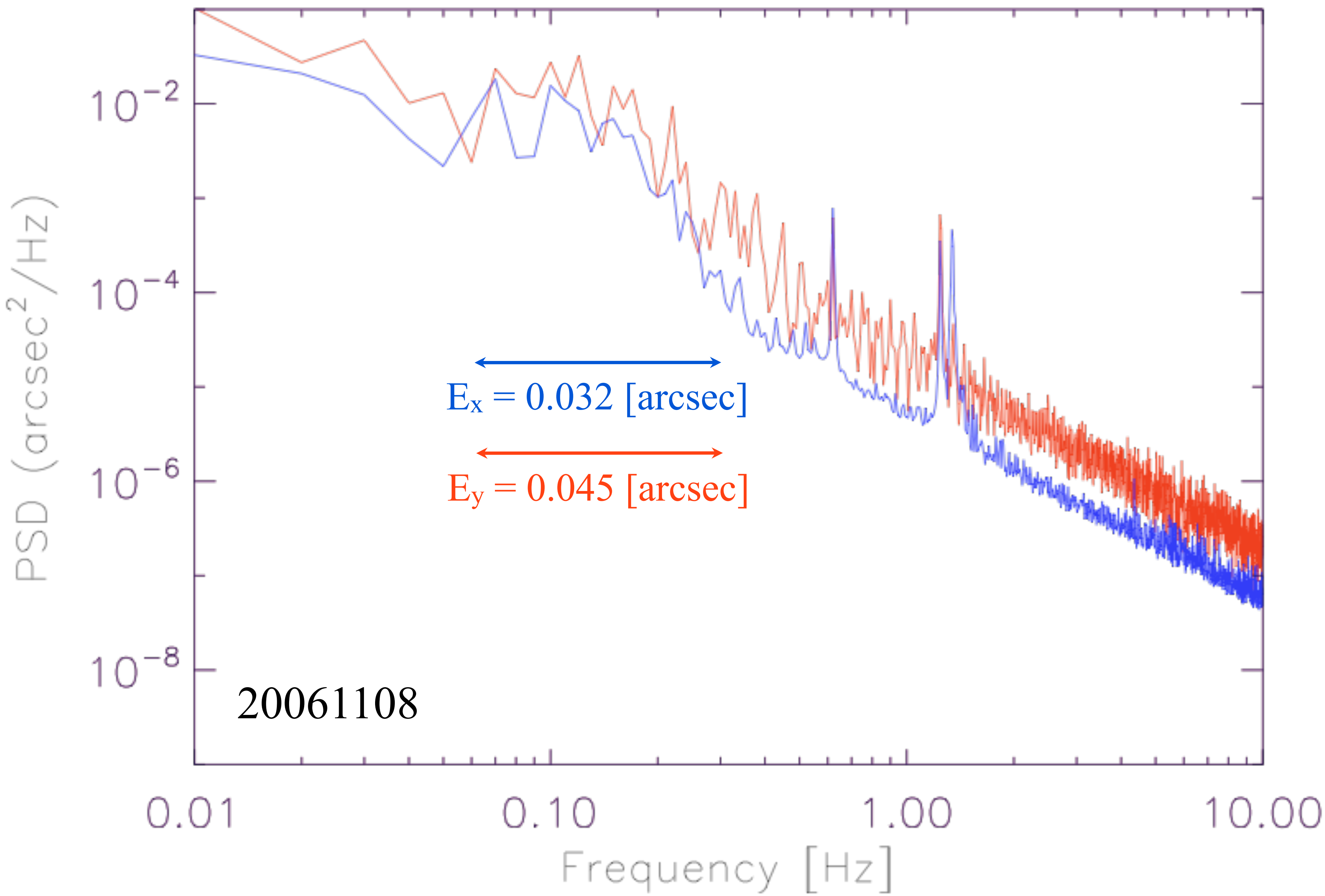


- no remarkable variation in short term

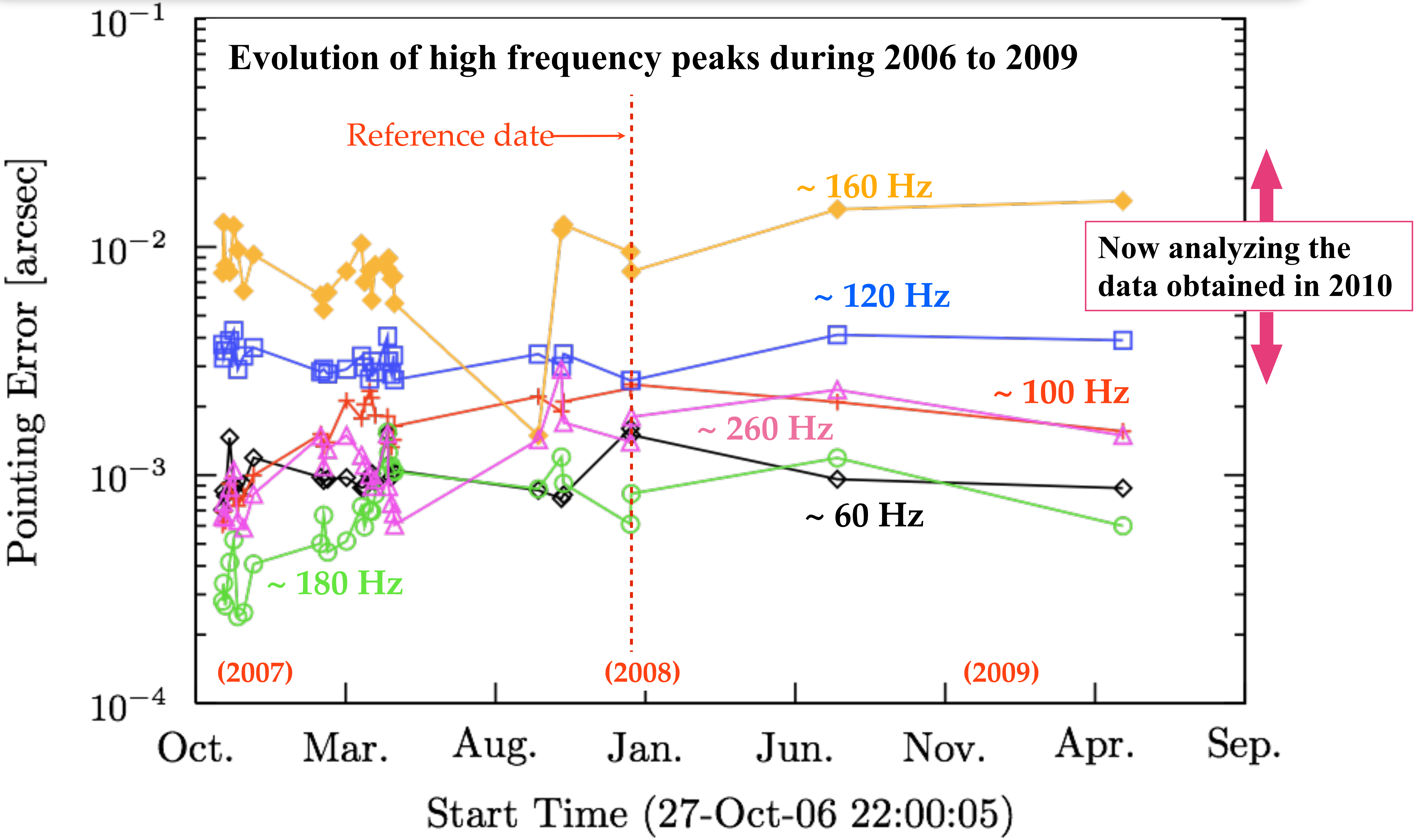
Long term variation for pointing error in CT Servo off



PSD from diagnostic data in CT servo off (100sec data)

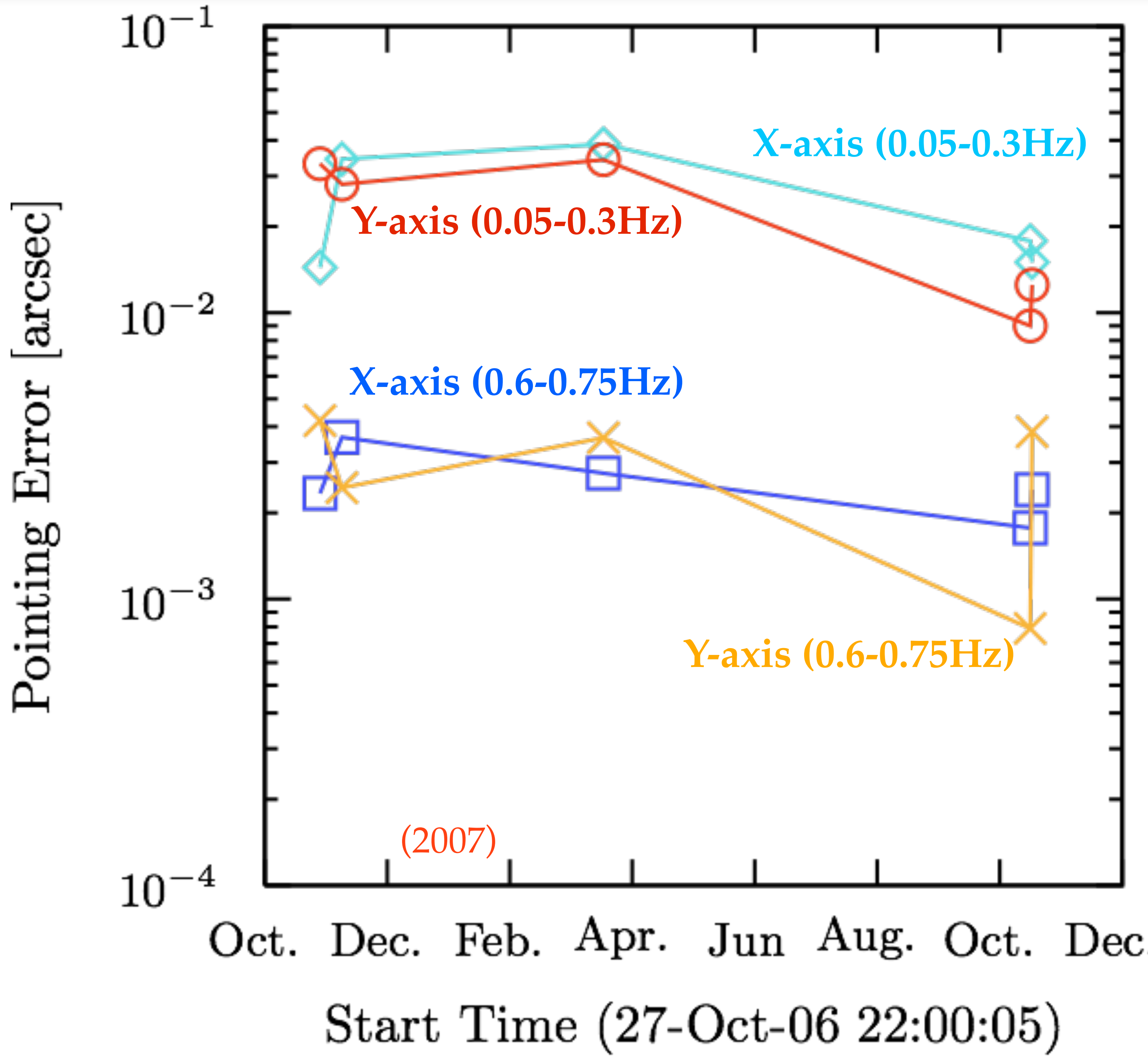


Secular swing for the disturbances in the higher frequency



- Higher frequency disturbances tend to increase secularly.
- The peaks around 150Hz (due to IRU) and 180Hz swing remarkably.

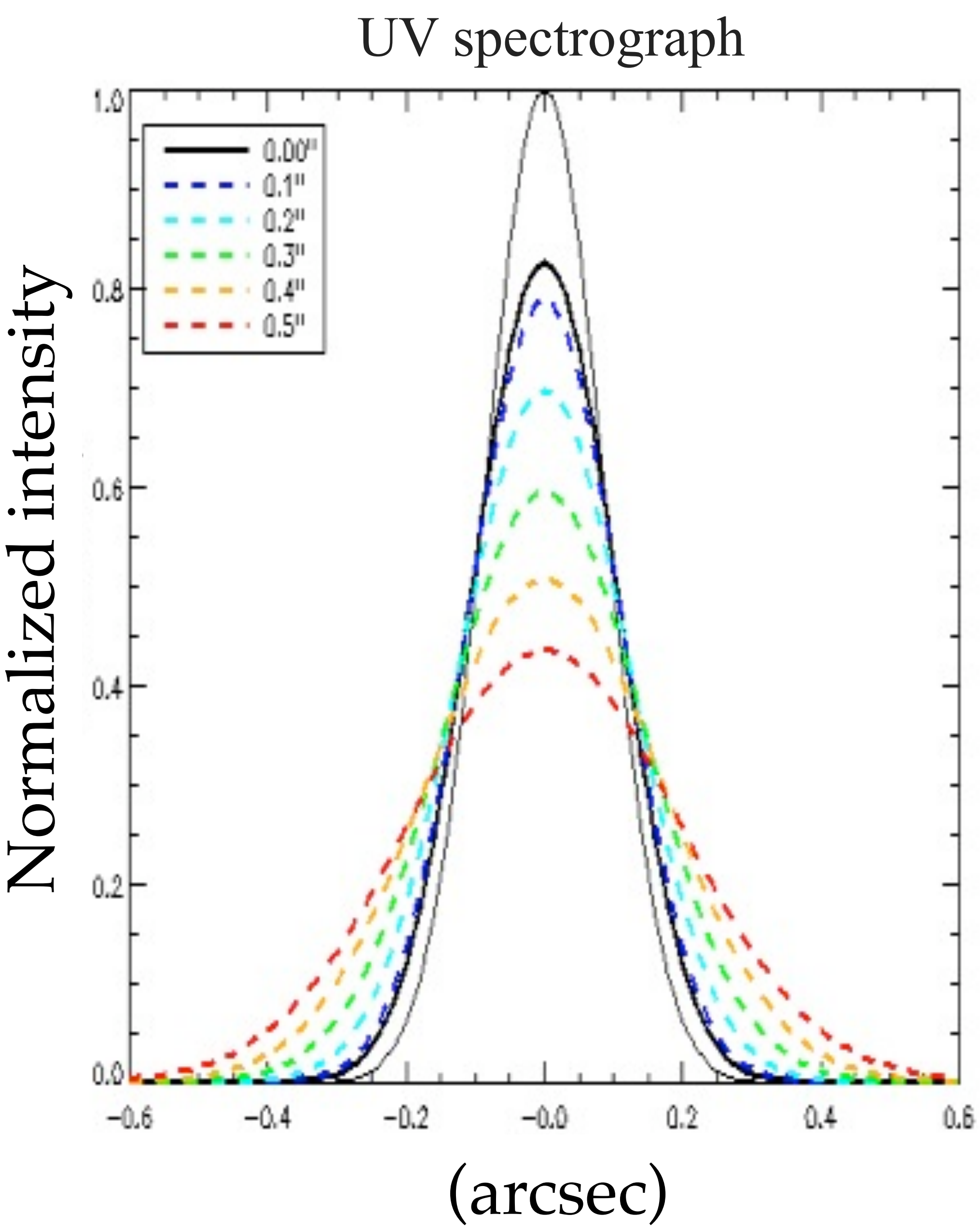
Secular swing for the disturbances in the lower frequency

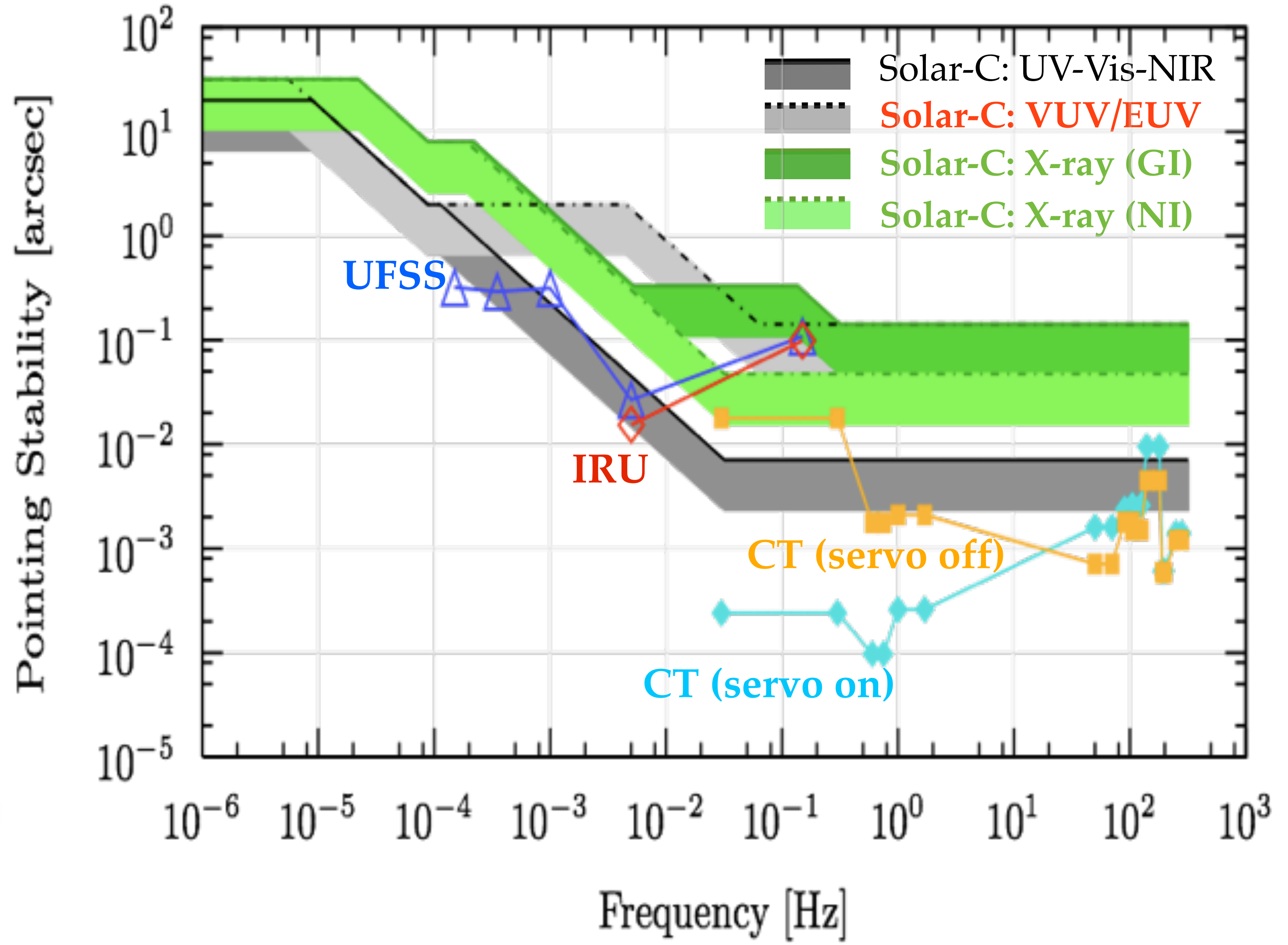


- There is no significant secular variation in lower frequency band.

Comment on Solar-C VUV/EUV

UV spectrograph in Solar-C can really achieve 0.2” resolution ?



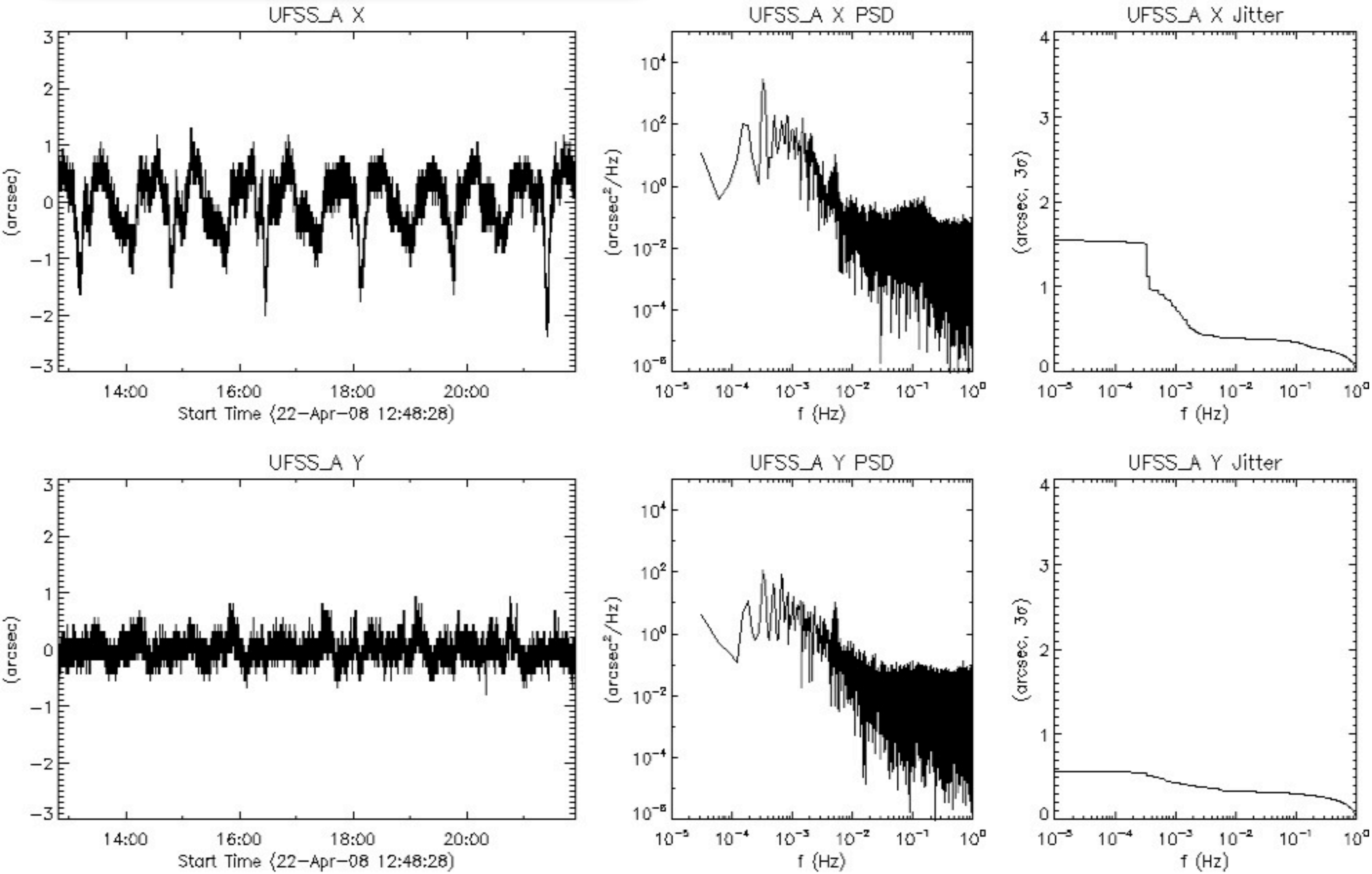


We need CT in UV spectrograph for realizing 0.2” pointing resolution

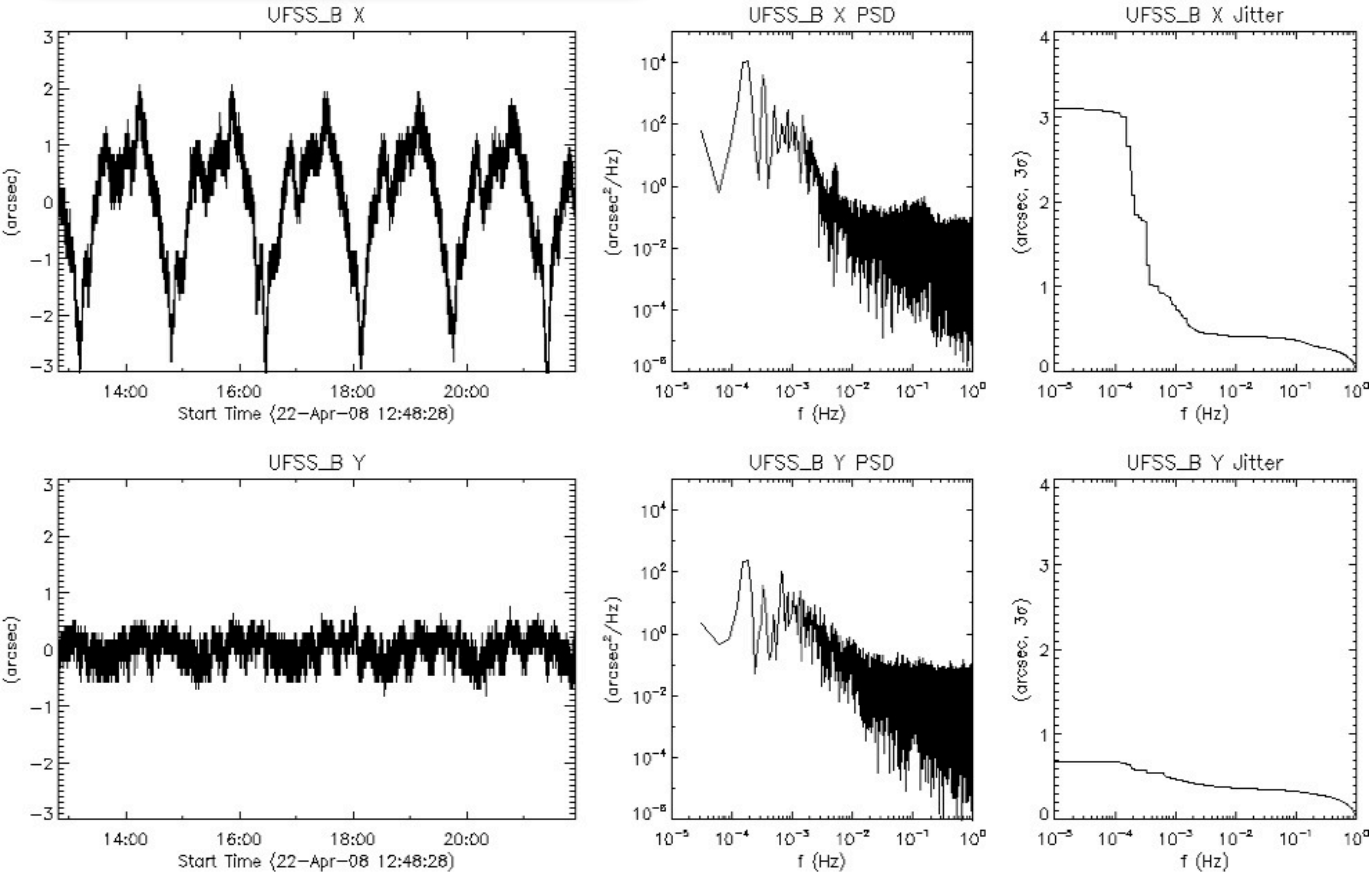
Appendix 2：Data Sets (UFSS/IRU)

2008-4-22

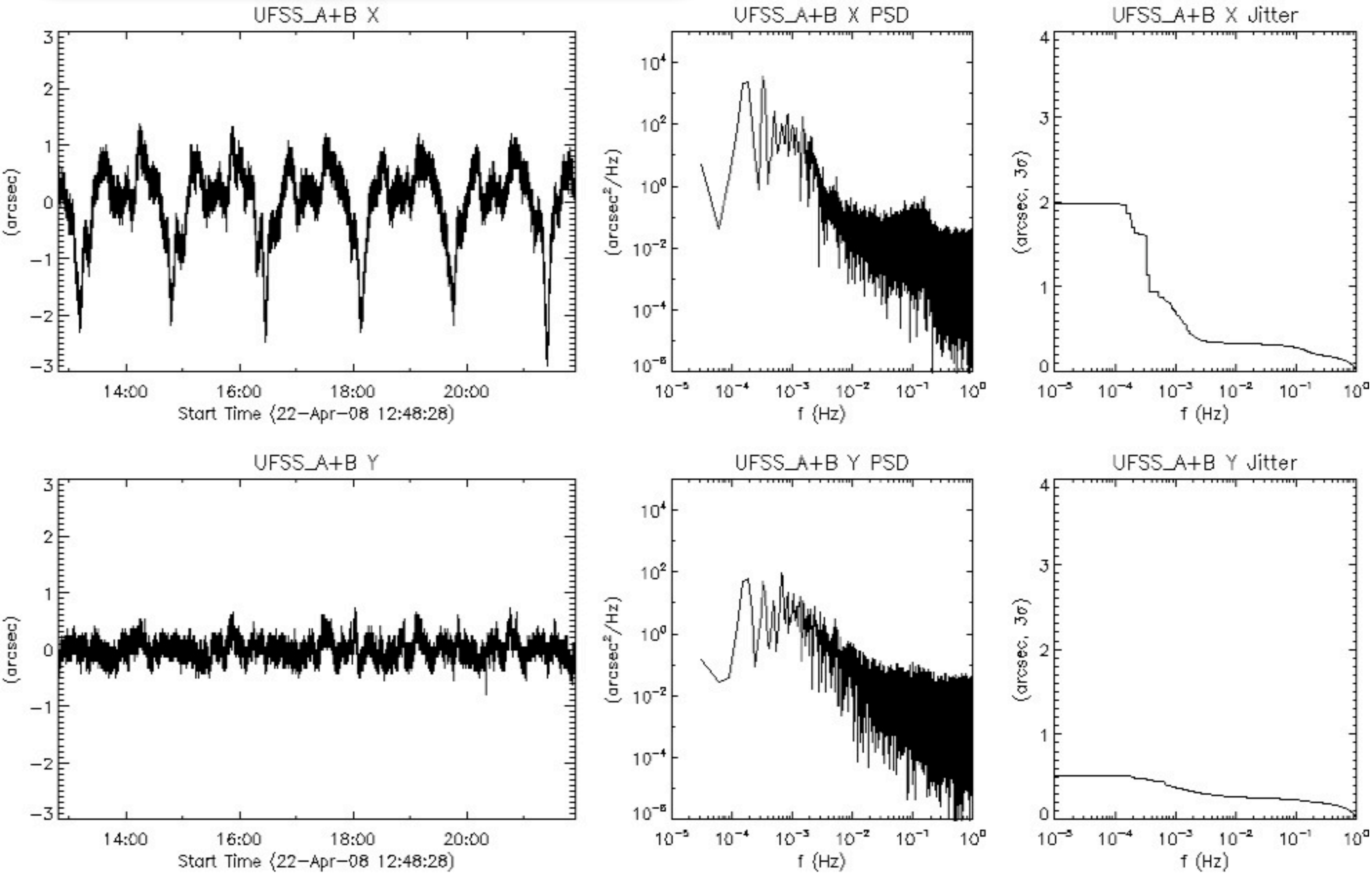
UFSS-A: (2008-4-22)



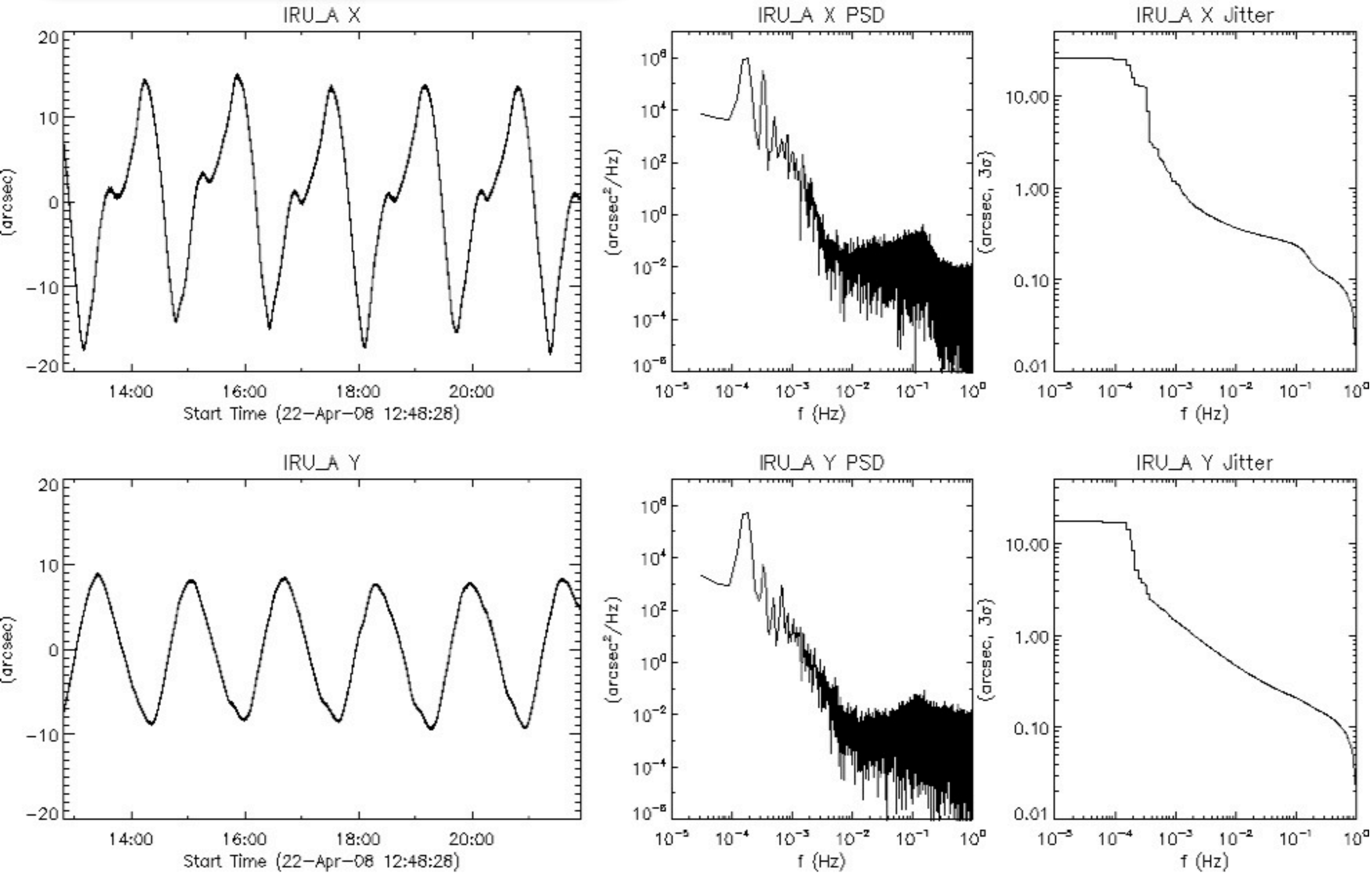
UFSS-B: (2008-4-22)



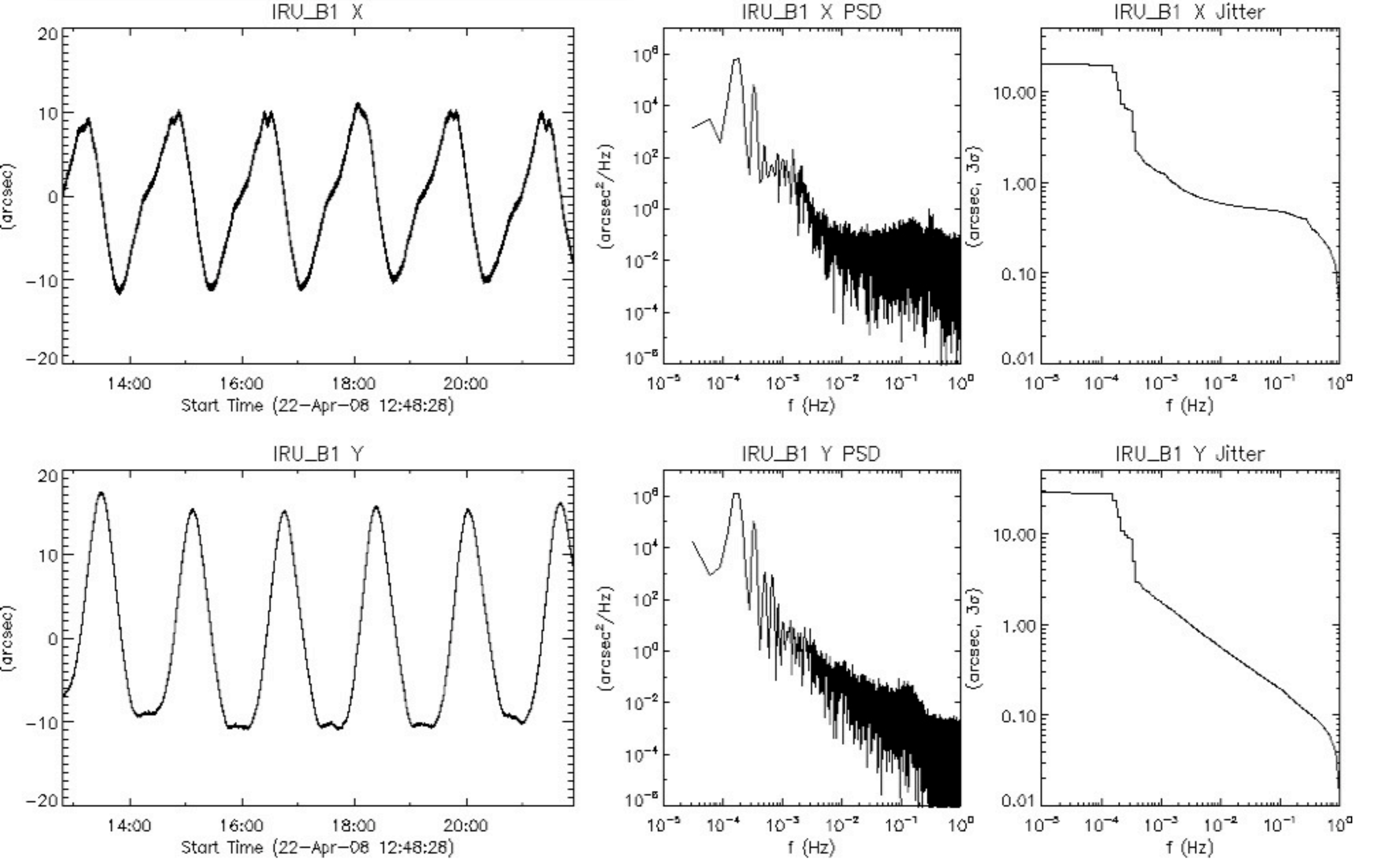
UFSS-A+B: (2008-4-22)



IRU-A: (2008-4-22)

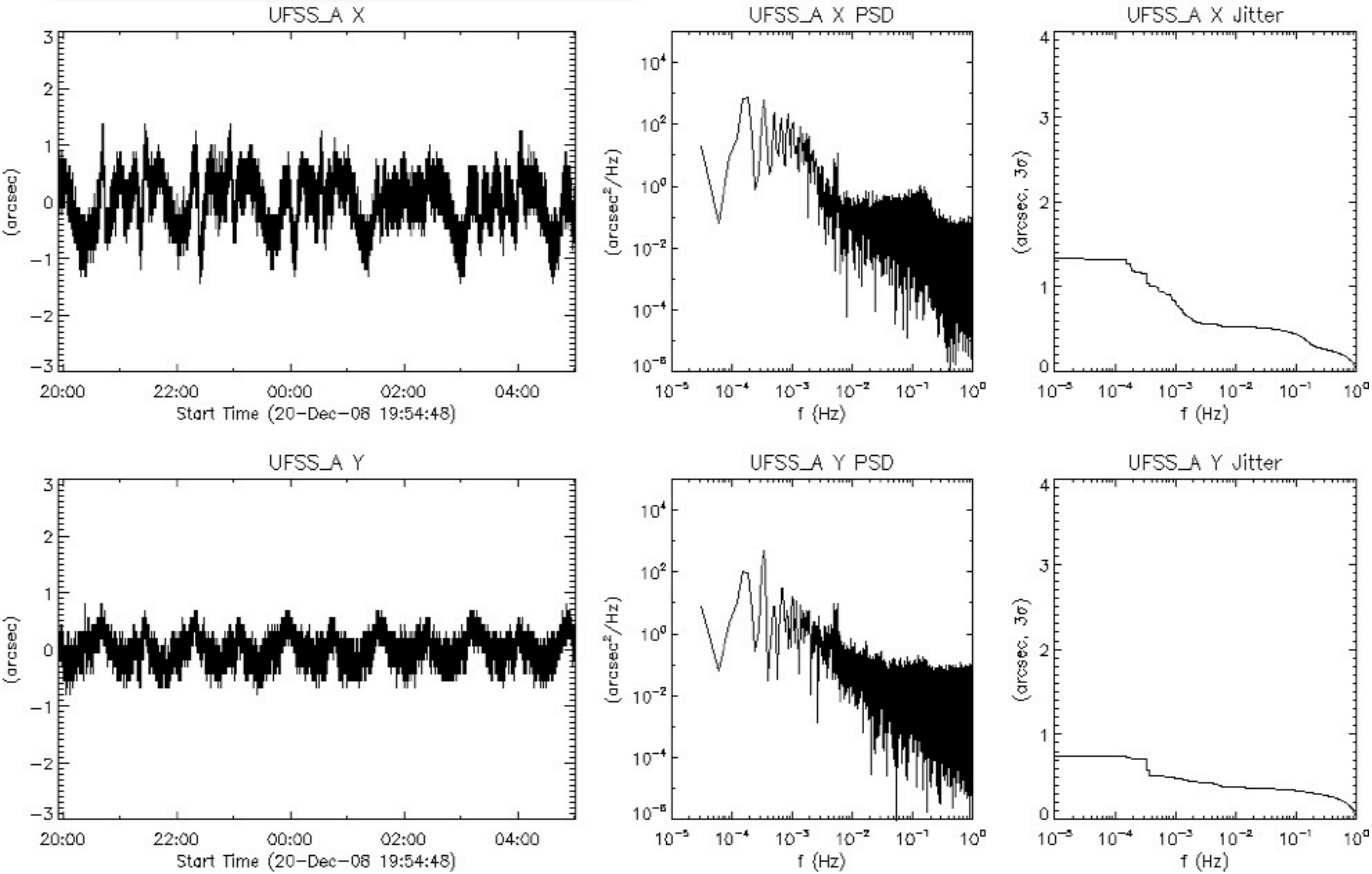


IRU-B1: (2008-4-22)

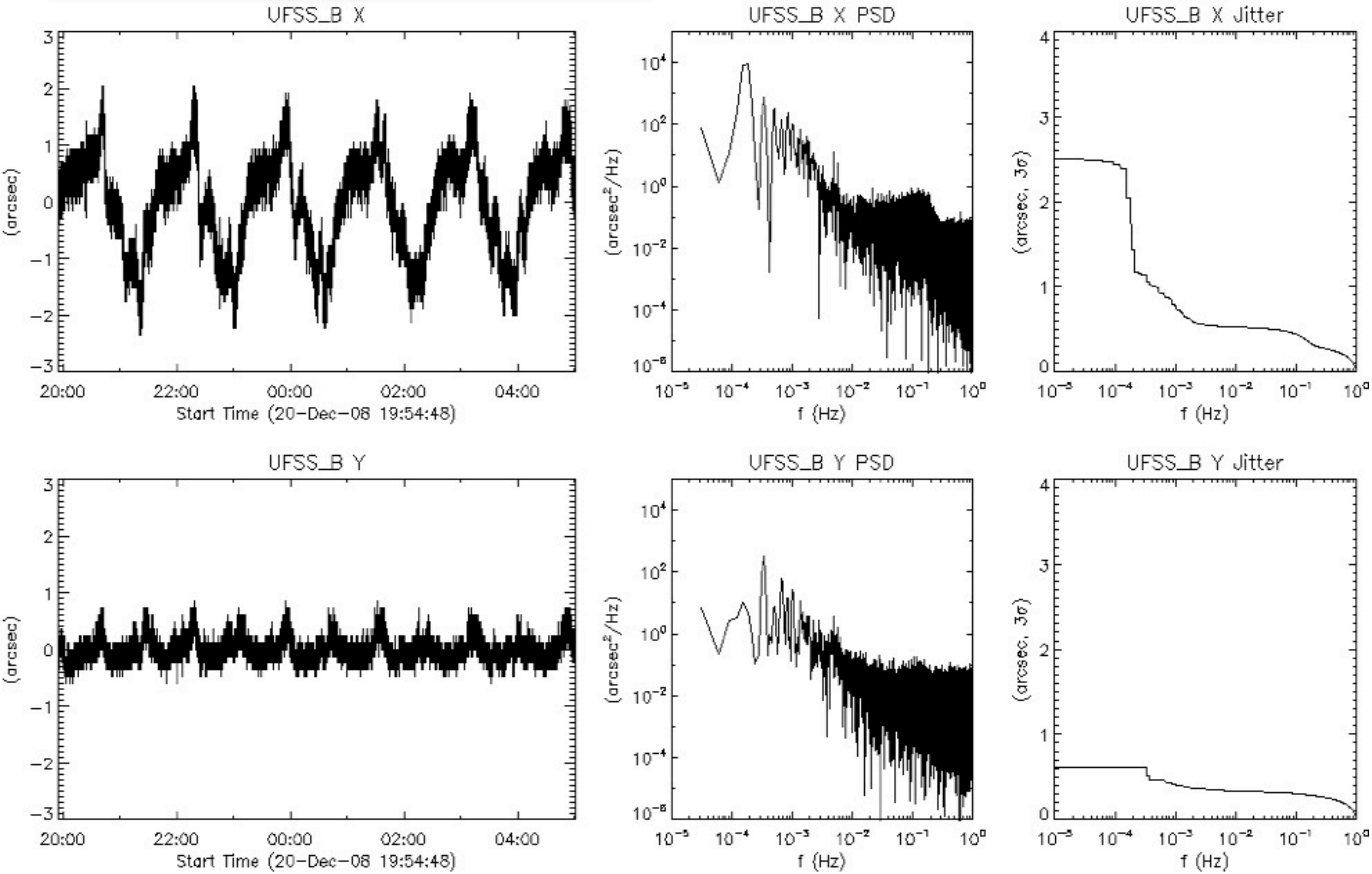


2008-12-20

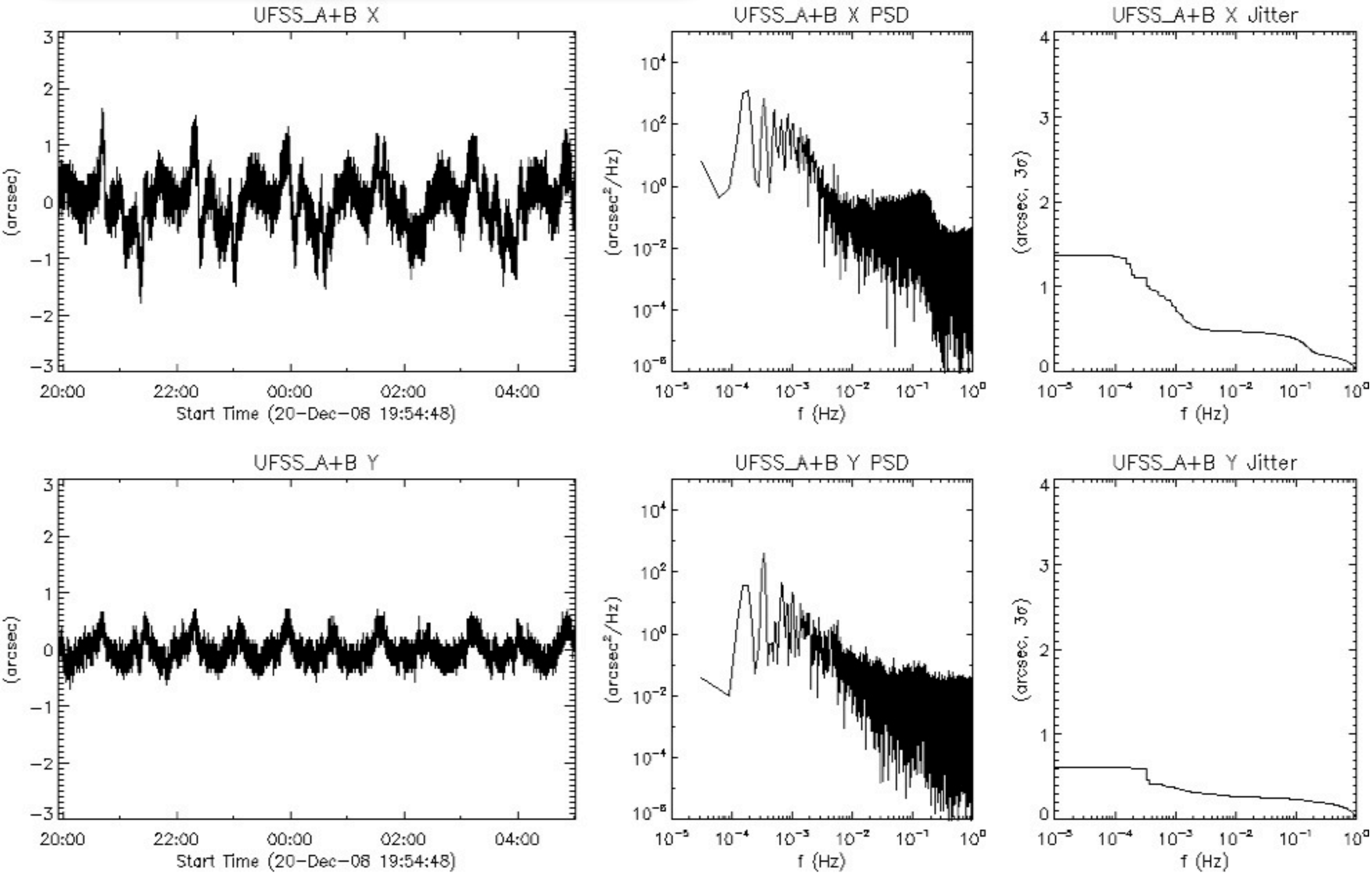
UFSS-A: (2008-12-20)



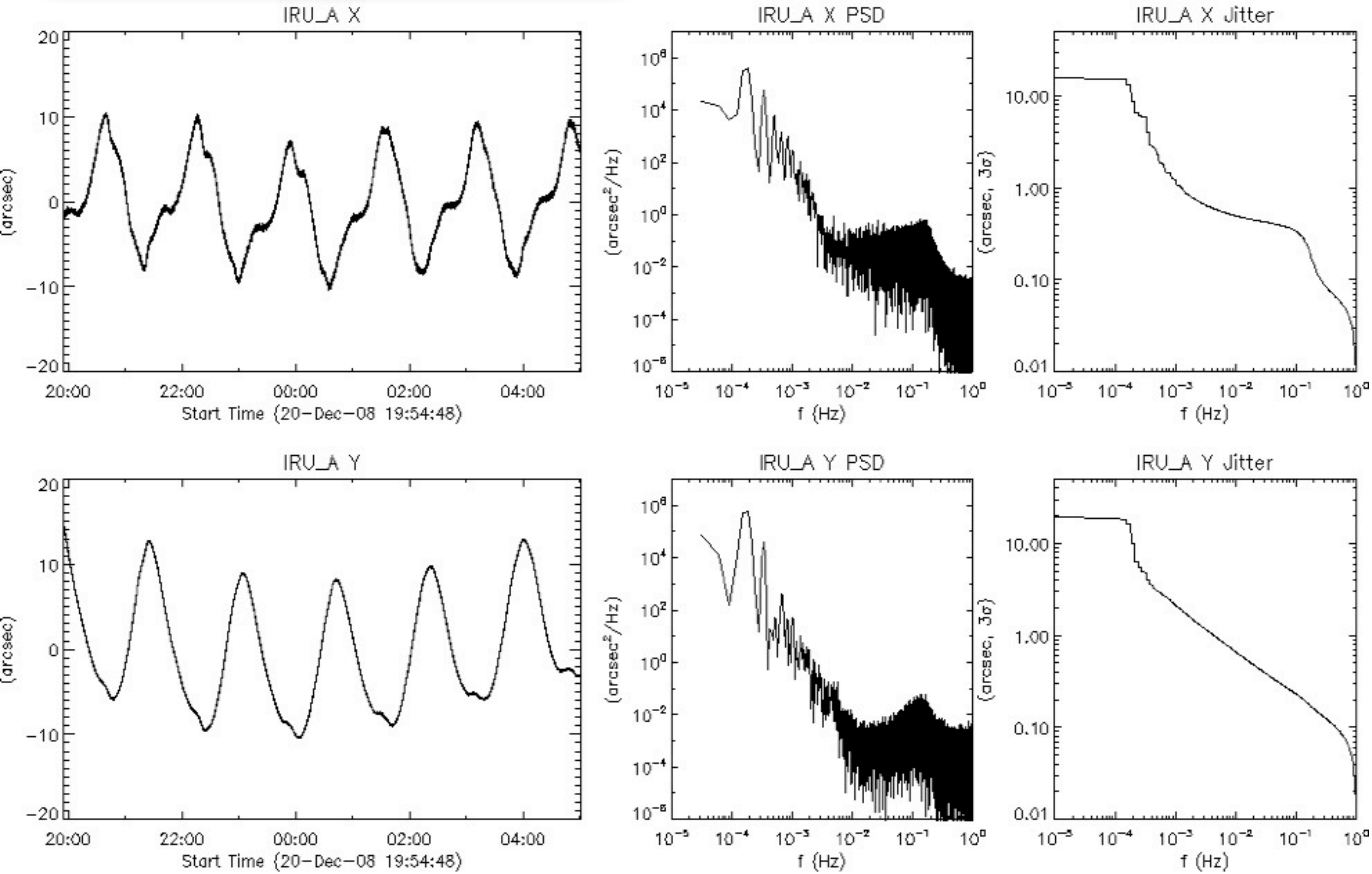
UFSS-B: (2008-12-20)



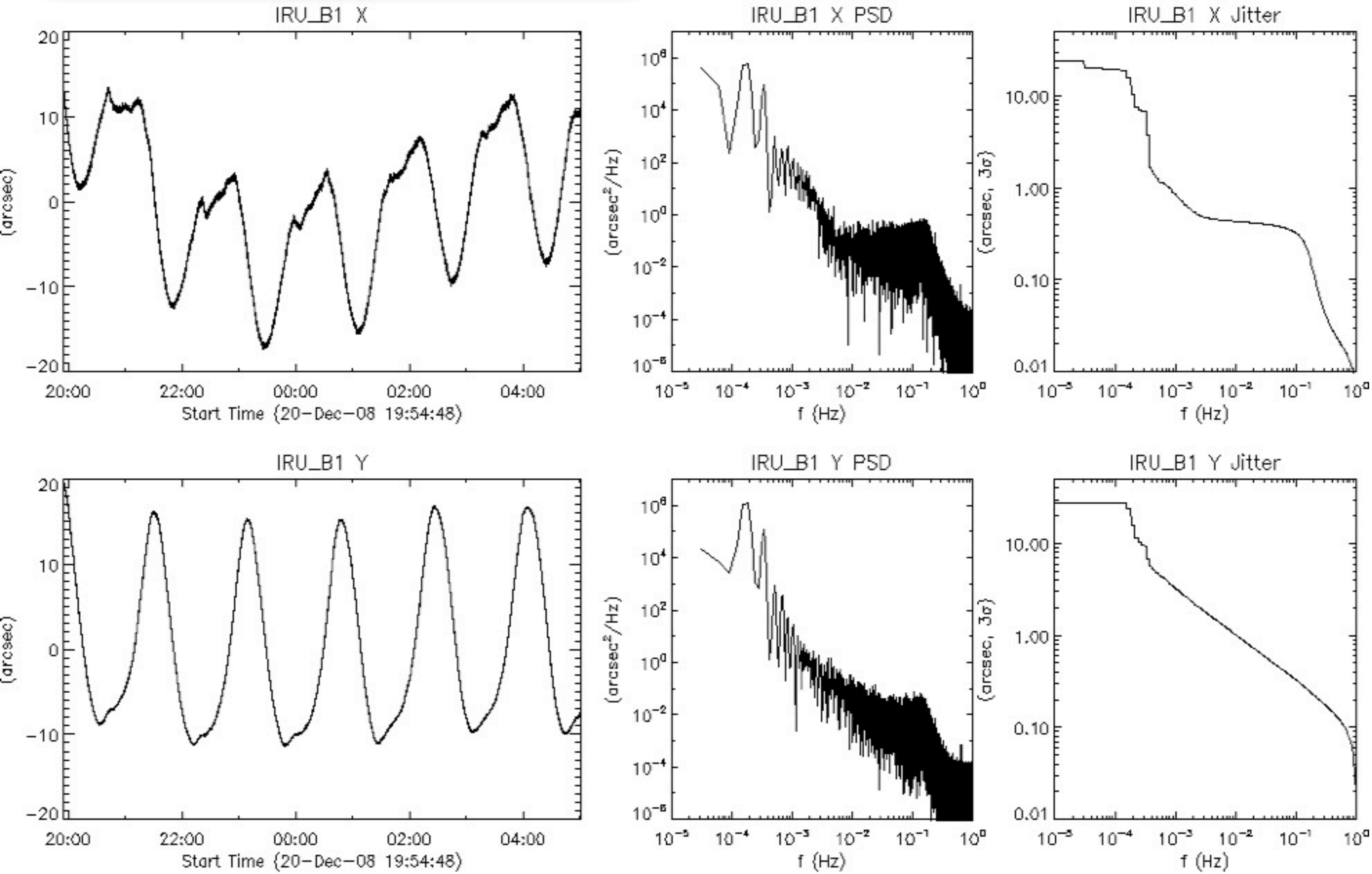
UFSS-A+B: (2008-12-20)



IRU-A: (2008-12-20)



IRU-B1: (2008-12-20)



Appendix 3：data sets (SOT/CT)

Summary of data analyzed

	Data Set 1		Data Set 2		Data Set 3	
on/off	servo on	servo off	servo on	servo off	servo on	servo off
Date	2006/10/31	2006/10/27	2007/12/15	2007/12/15	2007/12/16	2007/12/16
T_d [sec]	1687	256	1965	30.0	1724	24.1
Δf_1 [Hz]	0.5	0.5	0.5	0.5	0.5	0.5
Δf_2 [Hz]	0.025	0.025	0.025		0.025	

T_d ・・・duration of data

Δf_1 ・・・frequency resolution for analyzing higher frequency band

Δf_2 ・・・frequency resolution for analyzing lower frequency band

Data Set 1

Figure 1: normal plot

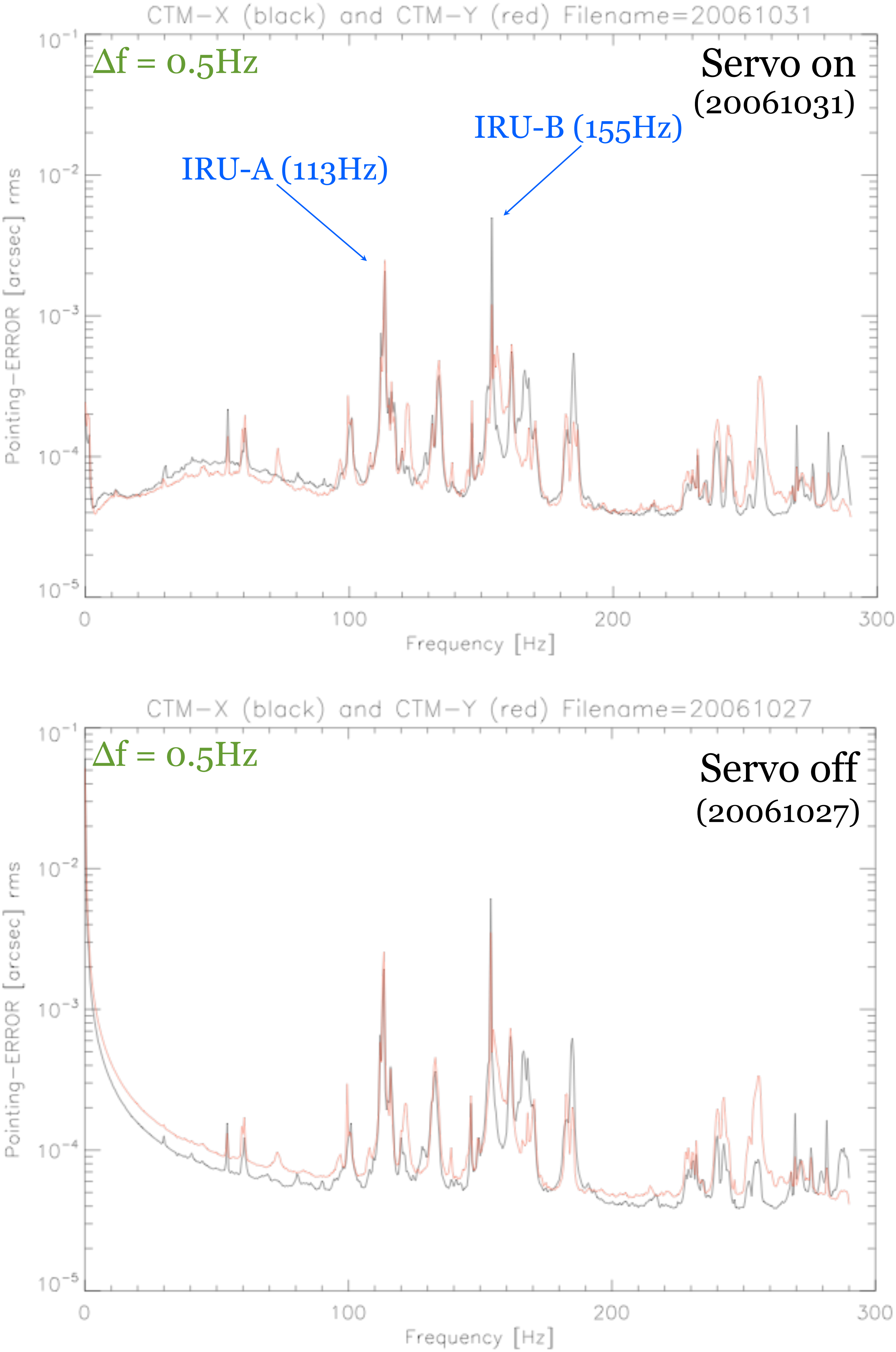
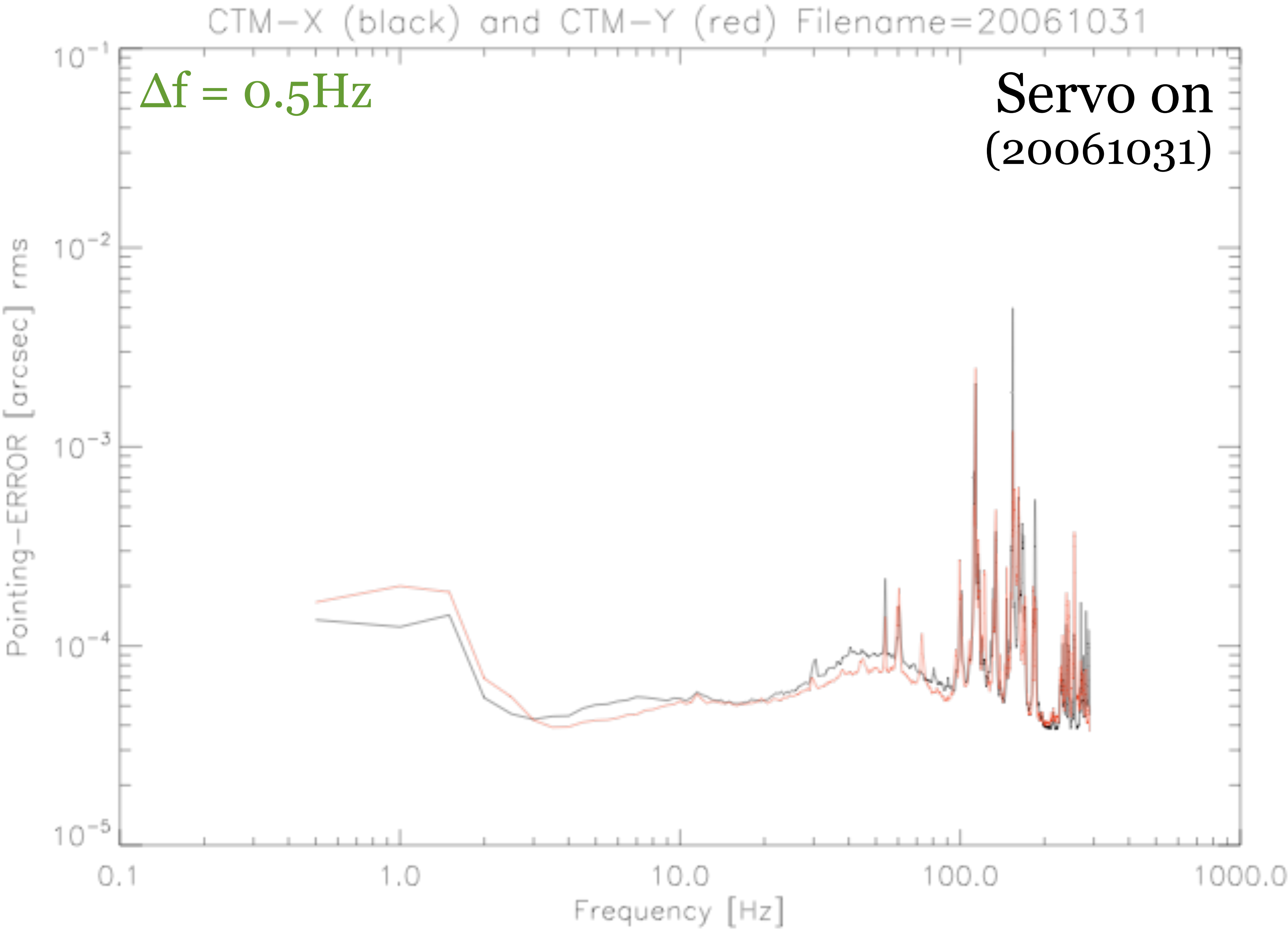


Figure 2: logarithm plot of Fig.1



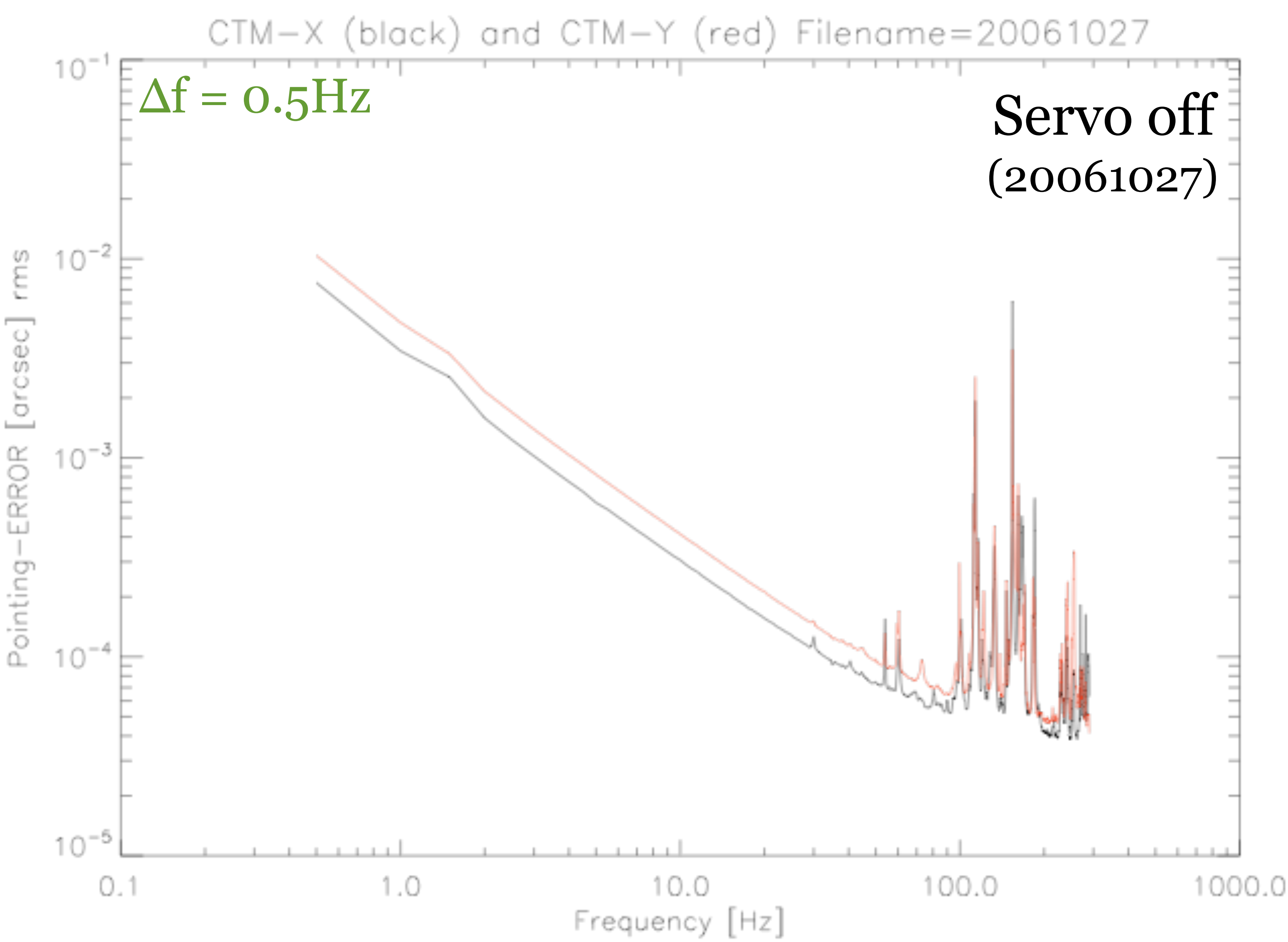


Figure 3: low frequency regime of Fig.1

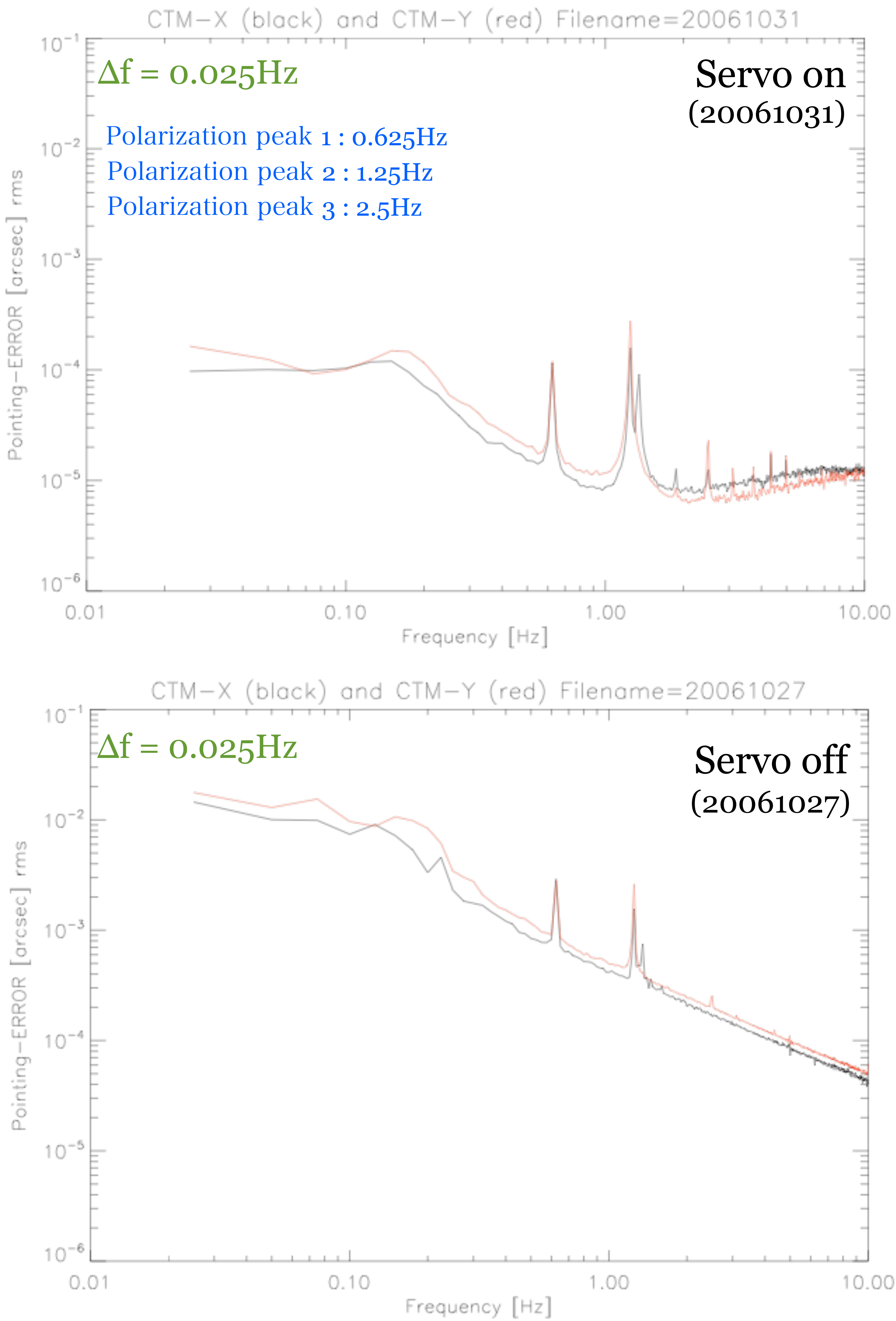
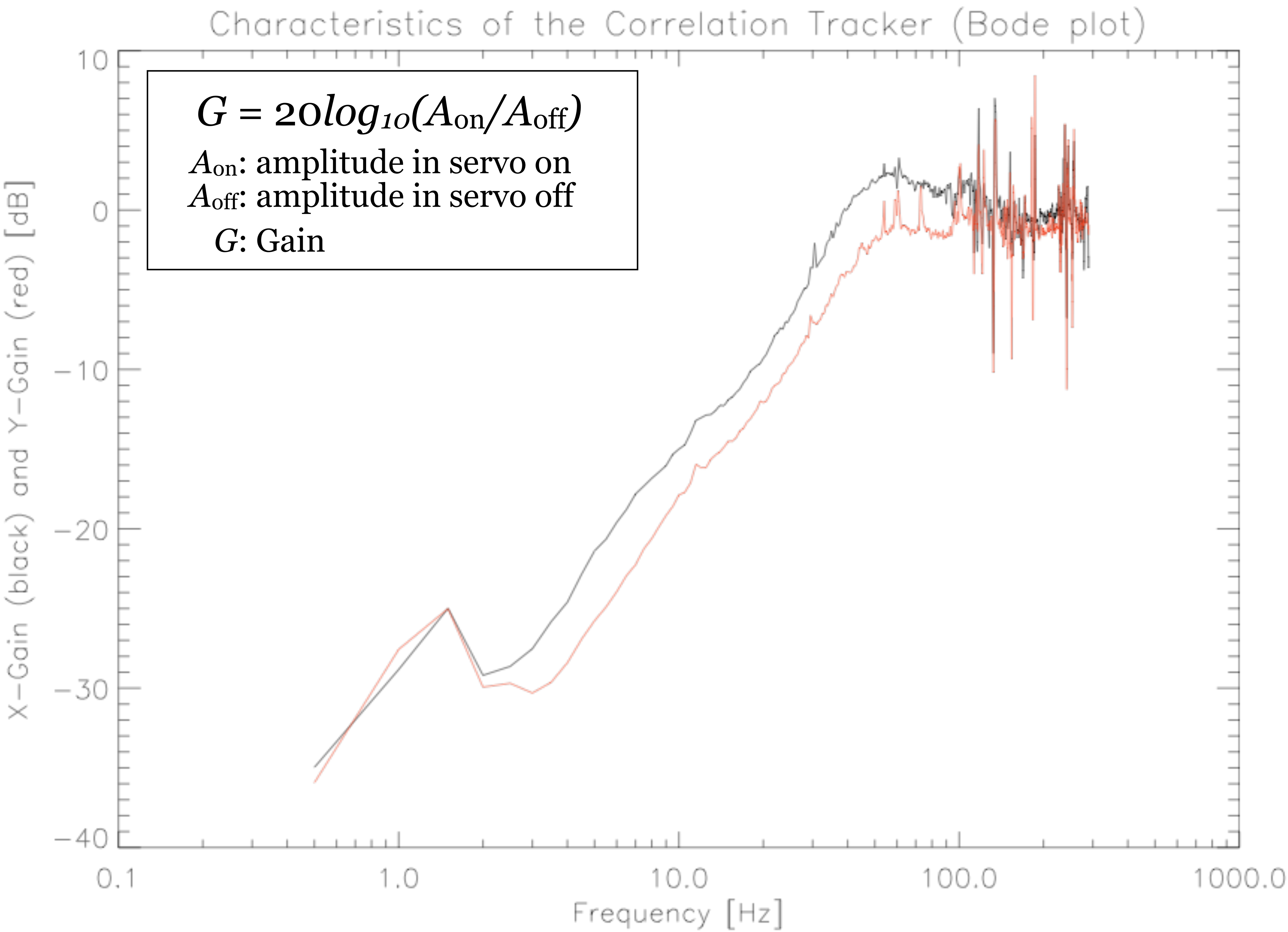
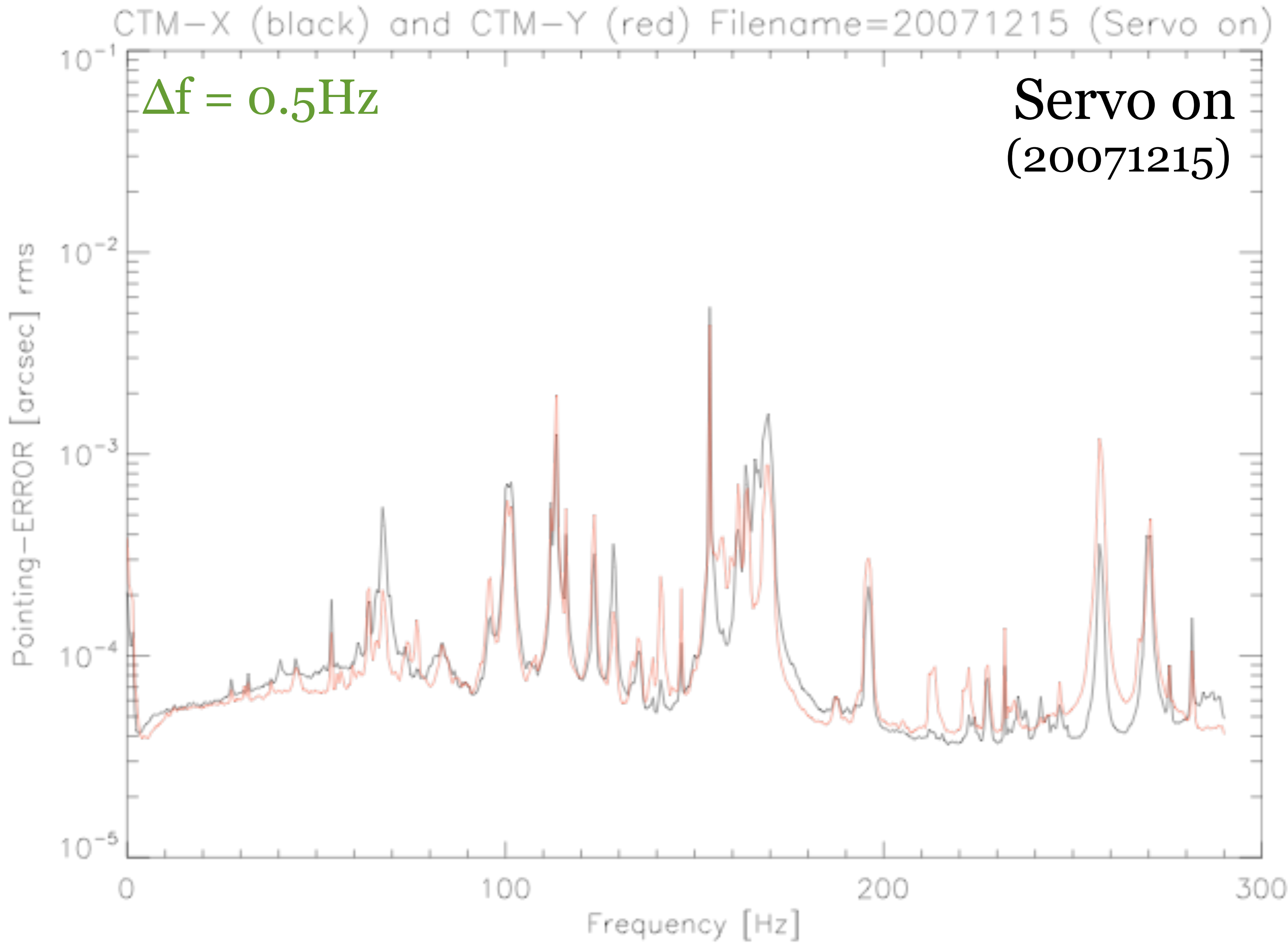


Figure 4: Bode plot



Data Set 2

Figure 5: Other date (meanings are same as Fig.1)



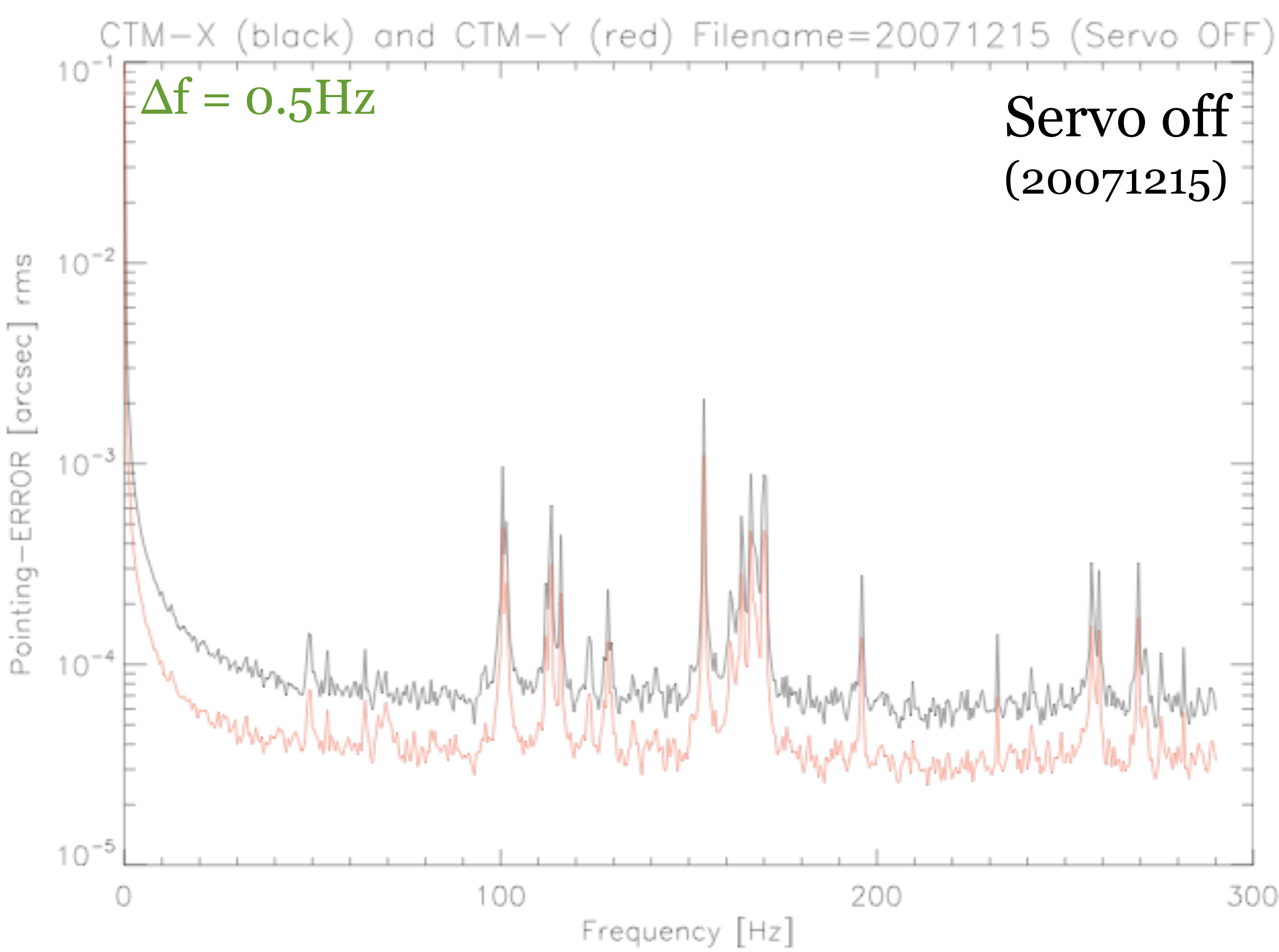
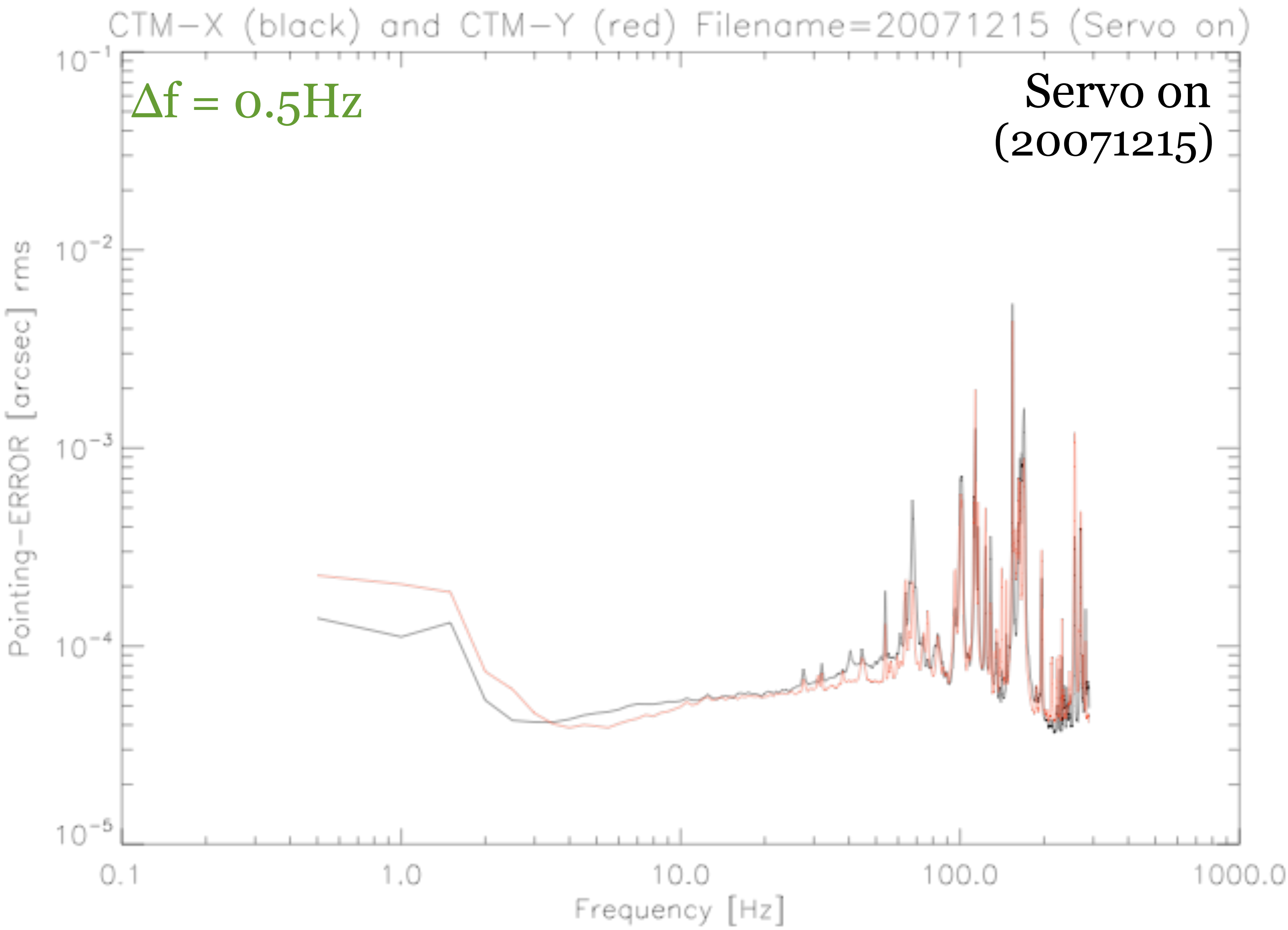


Figure 6: Other date (meanings are same as Fig.2)



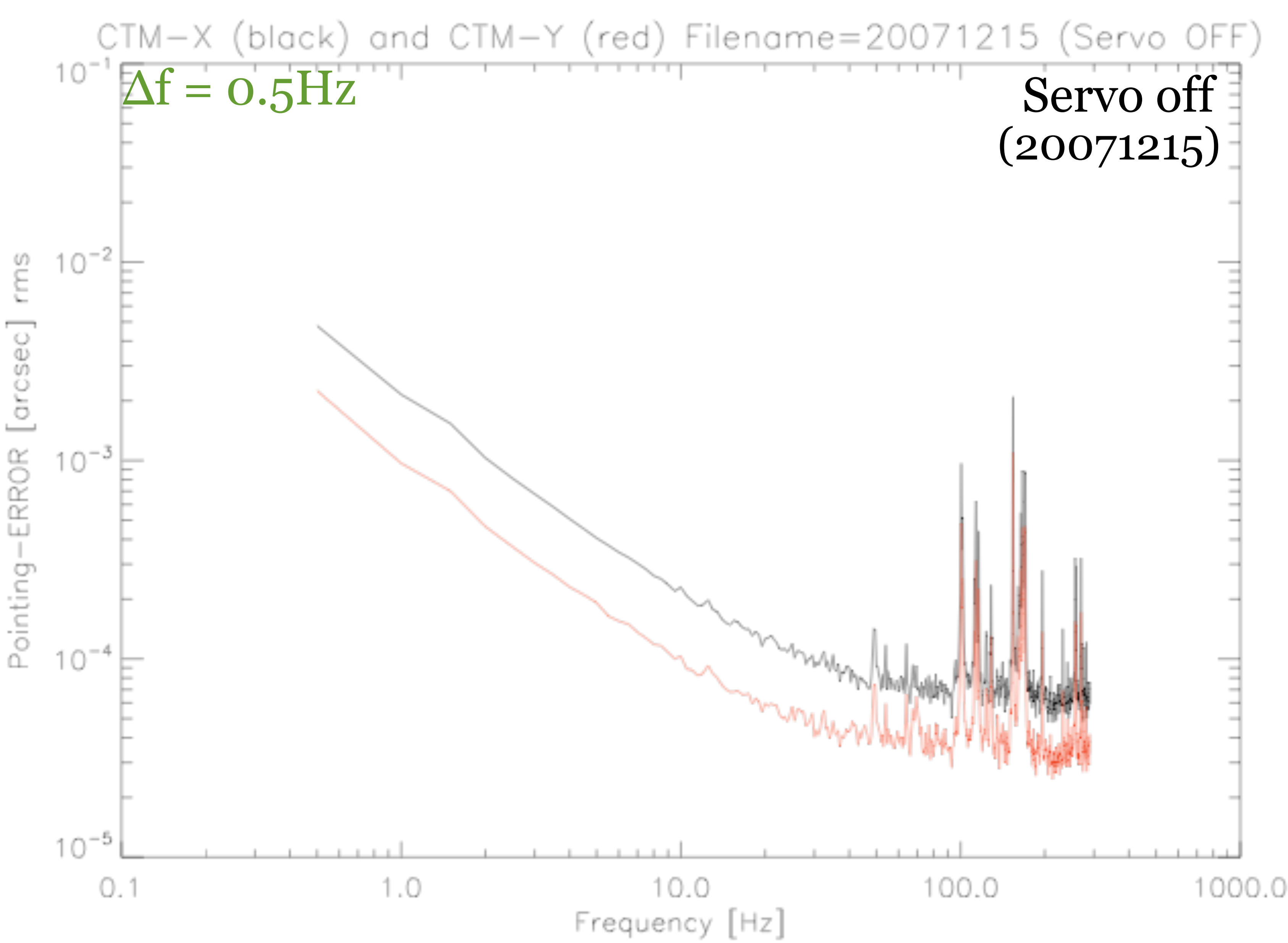
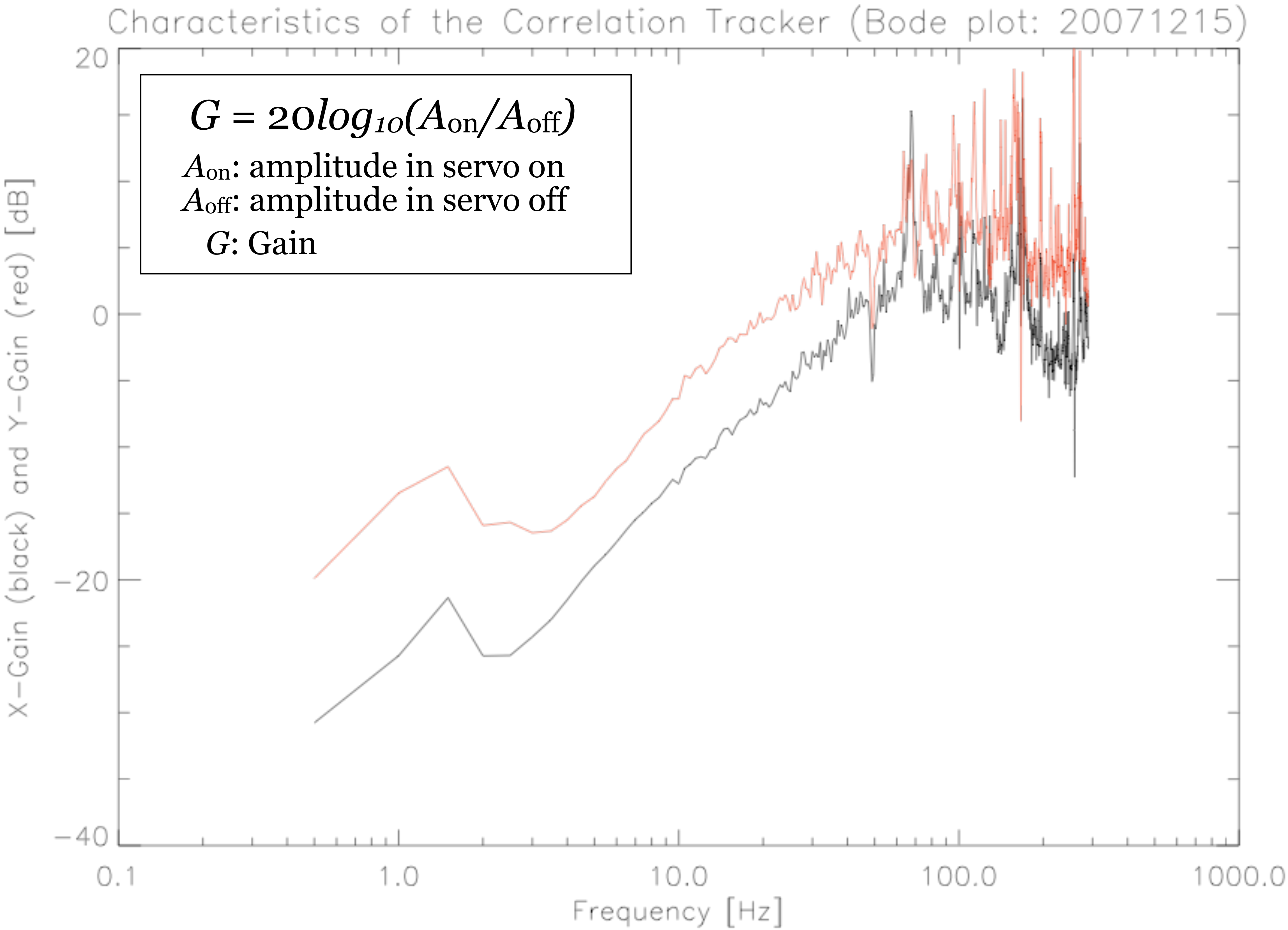
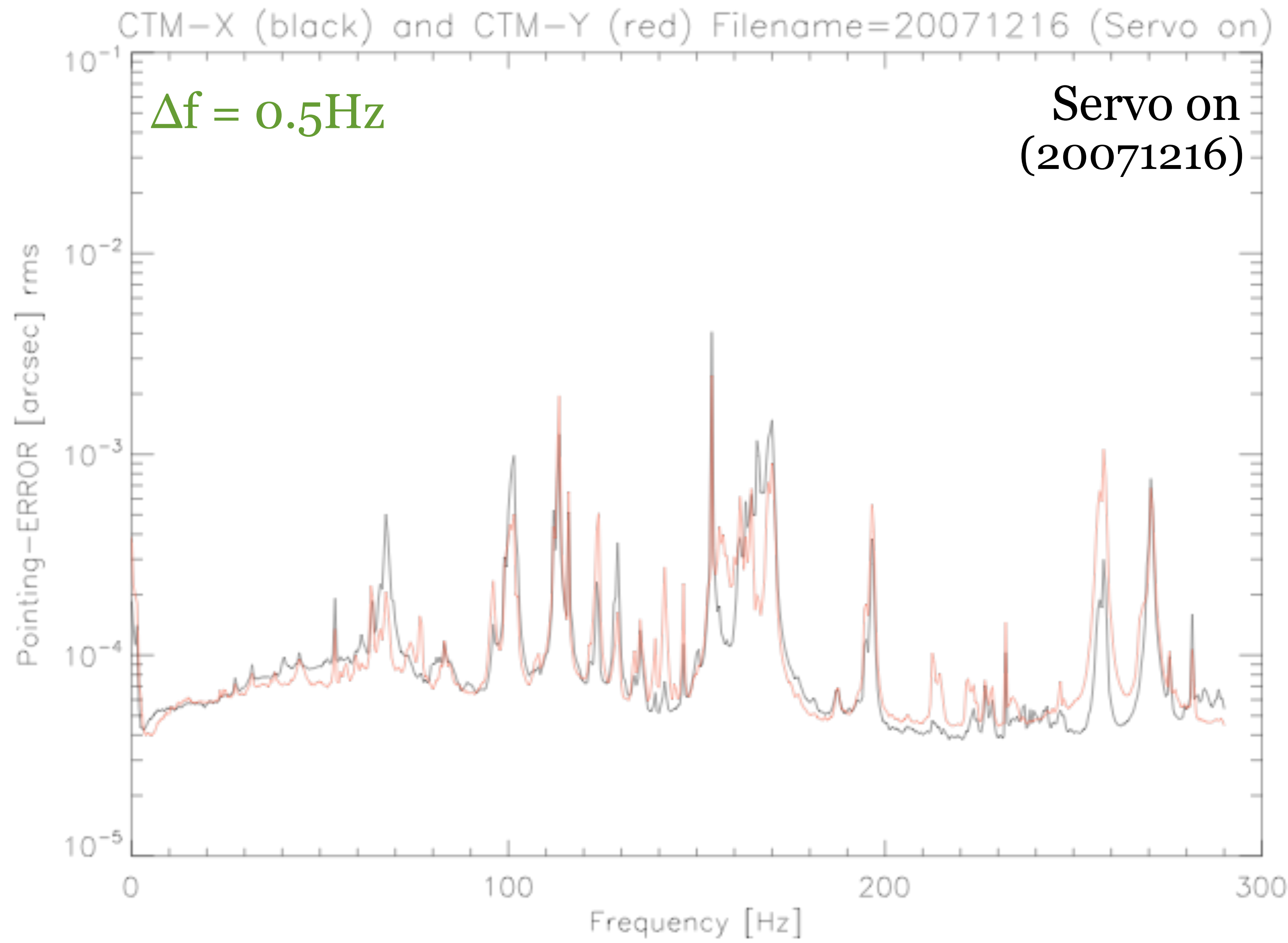


Figure 7: Bode plot



Data Set 3

Figure 8: Other date (meanings are same as Fig.1)



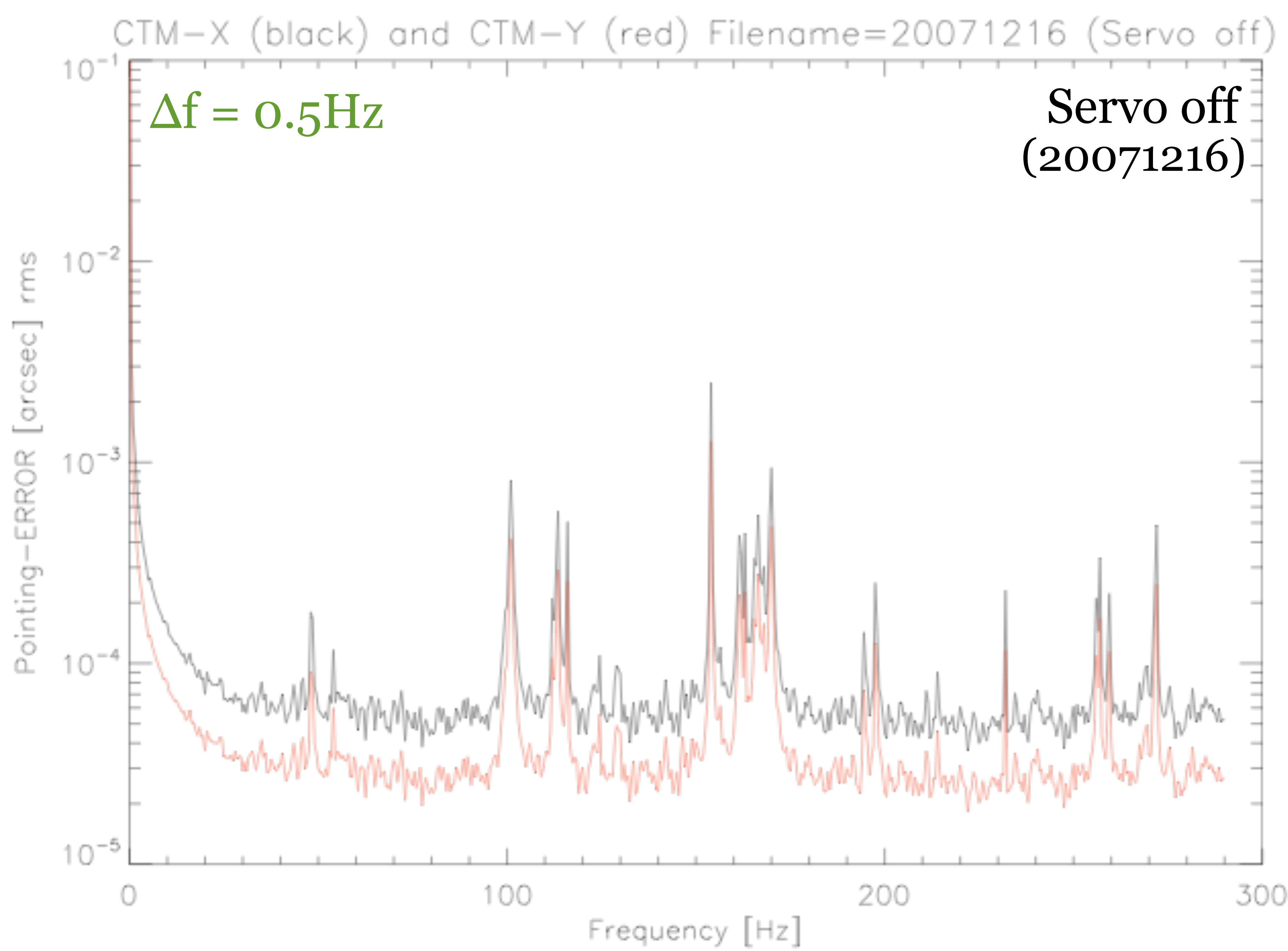
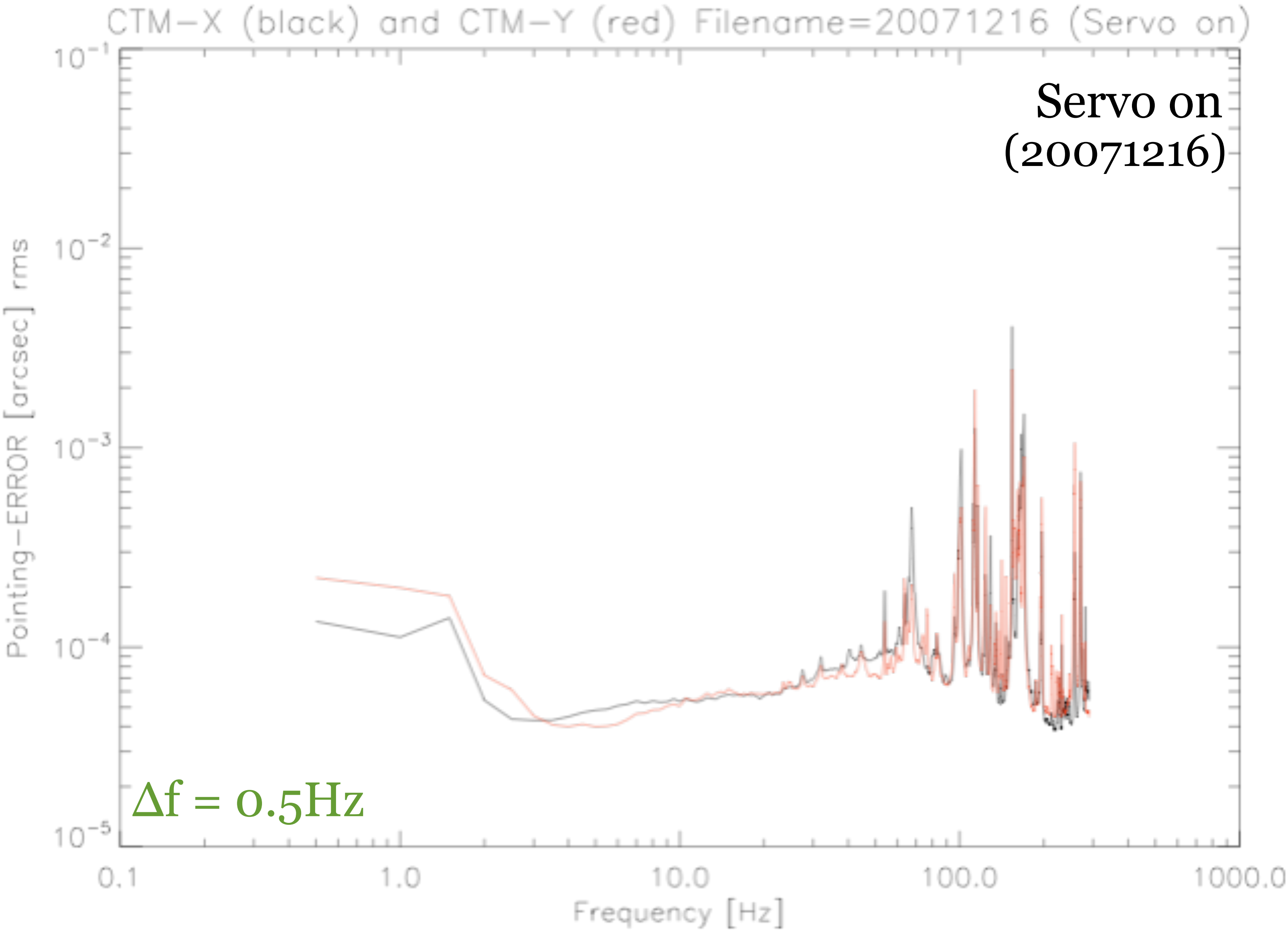


Figure 9: Other date (meanings are same as Fig.1)



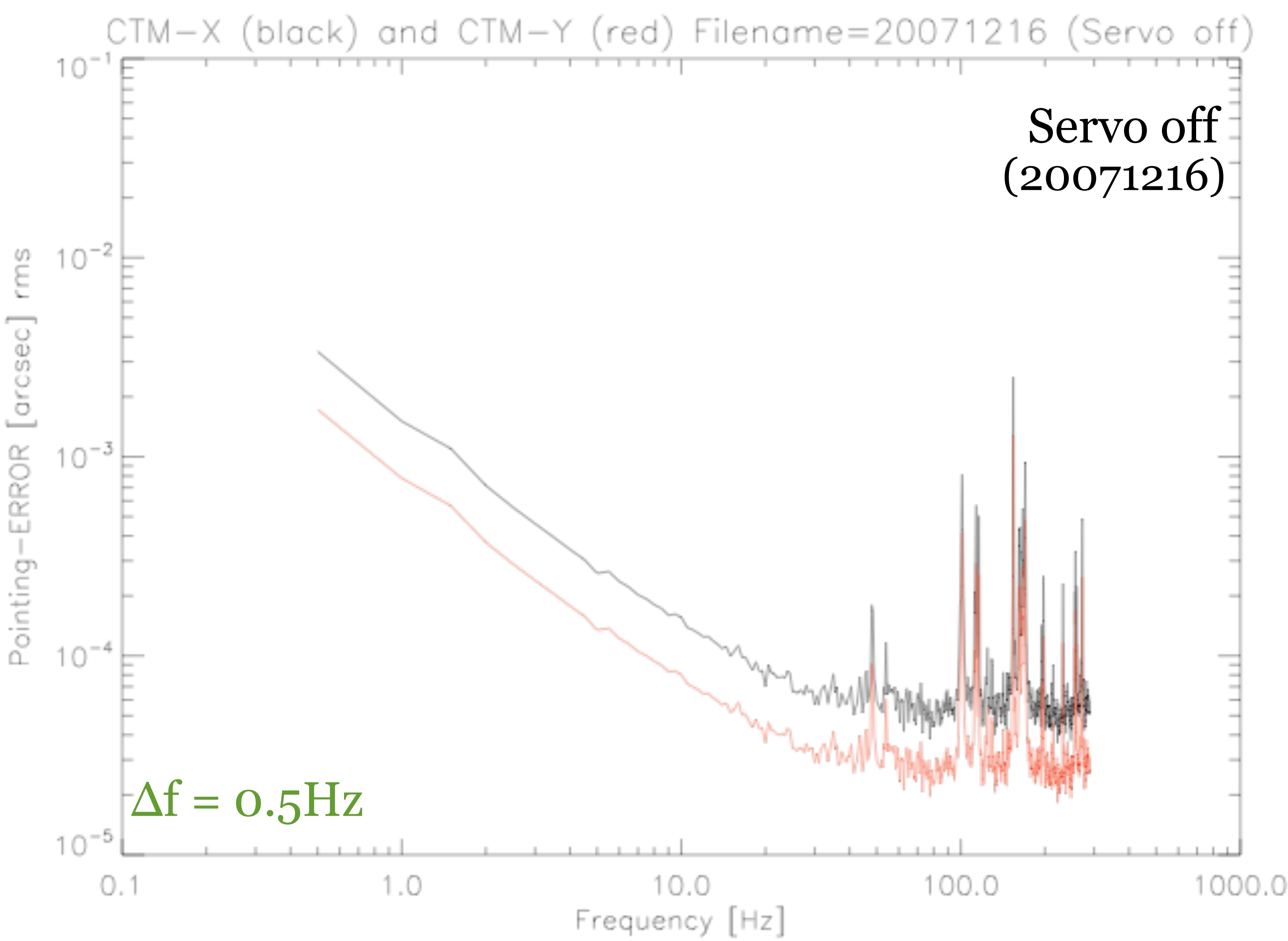


Figure10: (Bode plot)