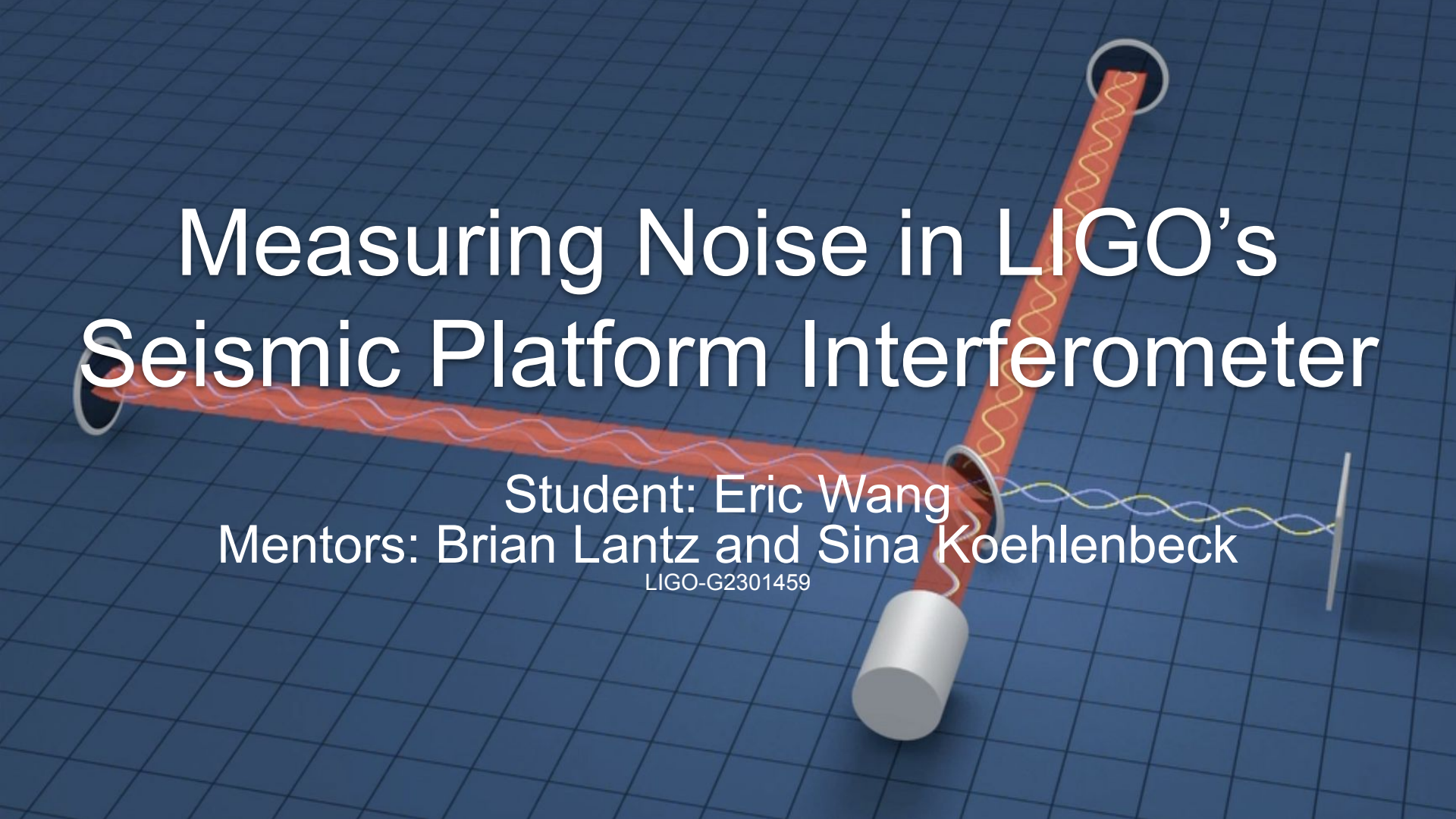


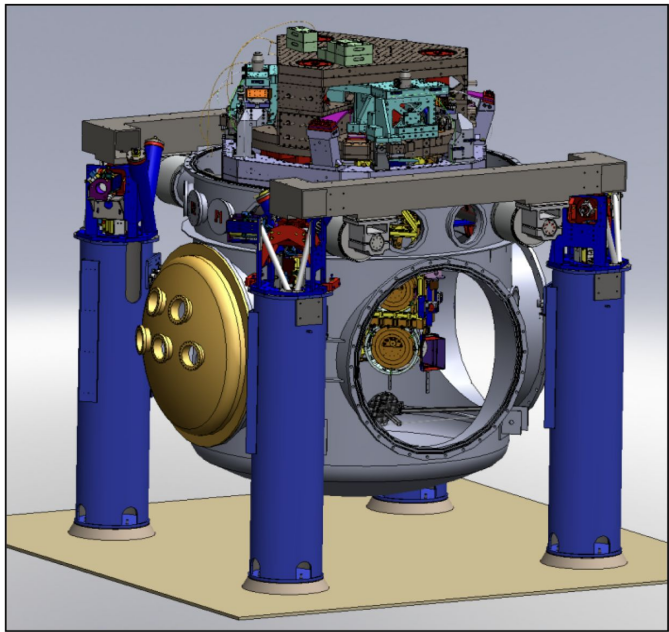
Measuring Noise in LIGO's Seismic Platform Interferometer

Student: Eric Wang
Mentors: Brian Lantz and Sina Koehlenbeck

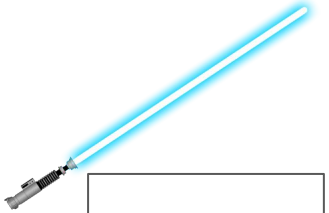
LIGO-G2301459

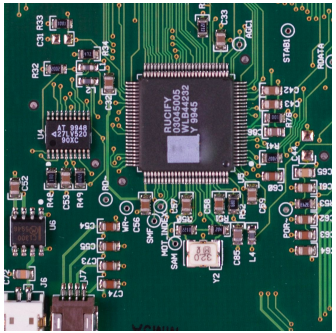
Background: LIGO and the SPI

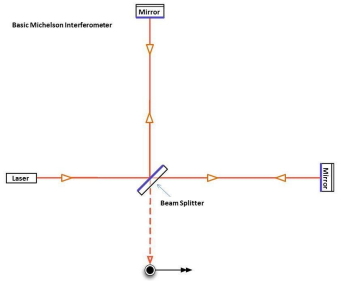
- LIGO: the Laser Interferometer Gravitational-Wave Observatory
  - Look for collisions of black holes, neutron stars
- Need high level precision for detection
- **Seismic Platform Interferometer** to stabilize LIGO from earthquakes
  - New system trying to upgrade LIGO
  - Certain amount of noise in SPI
  - Want to **quantify the limit to our measurement**



Slide 2







Laser → Electronics → Computer → Optical Lever (Sensor)

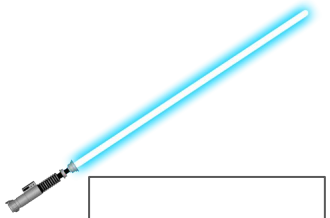
Laser Stability

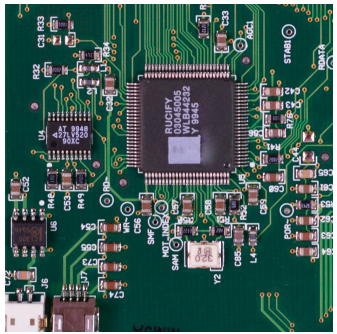
Electronic Noise

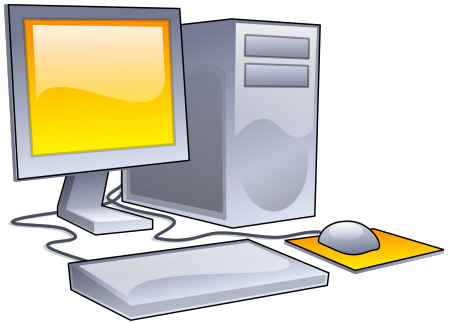
Digitization Noise

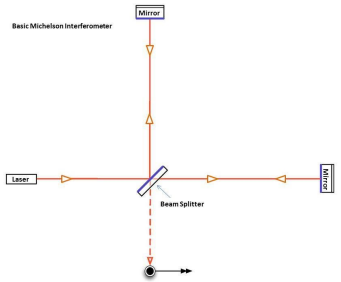
Measurement (Signal)

Slide 3









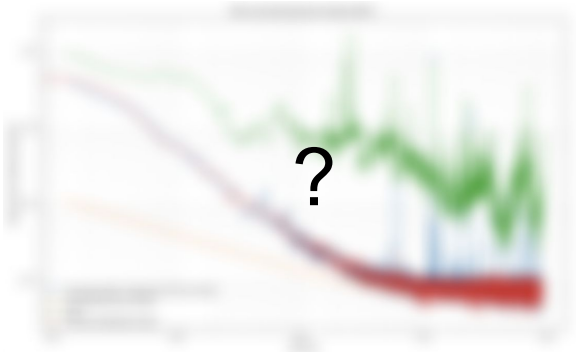
Laser → Electronics → Computer → Optical Lever (Sensor)

Laser Stability

Electronic Noise

Digitization Noise

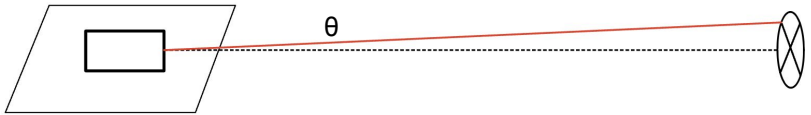
Measurement (Signal)



Laser Pointing Noise Measurement: Optical Lever

Laser w/o disturbance

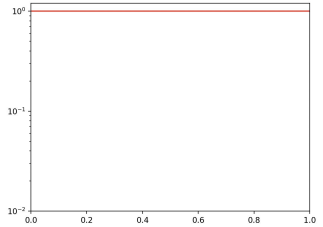
Functioning Optical Lever:
Using beam to measure angular motion



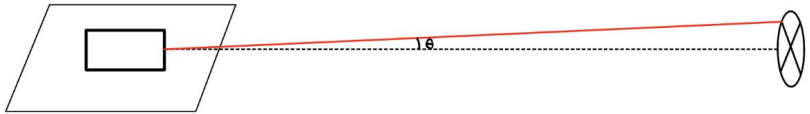
Laser Pointing Noise

Laser Pointing Measurement: Optical Lever

QPD setup in optics system

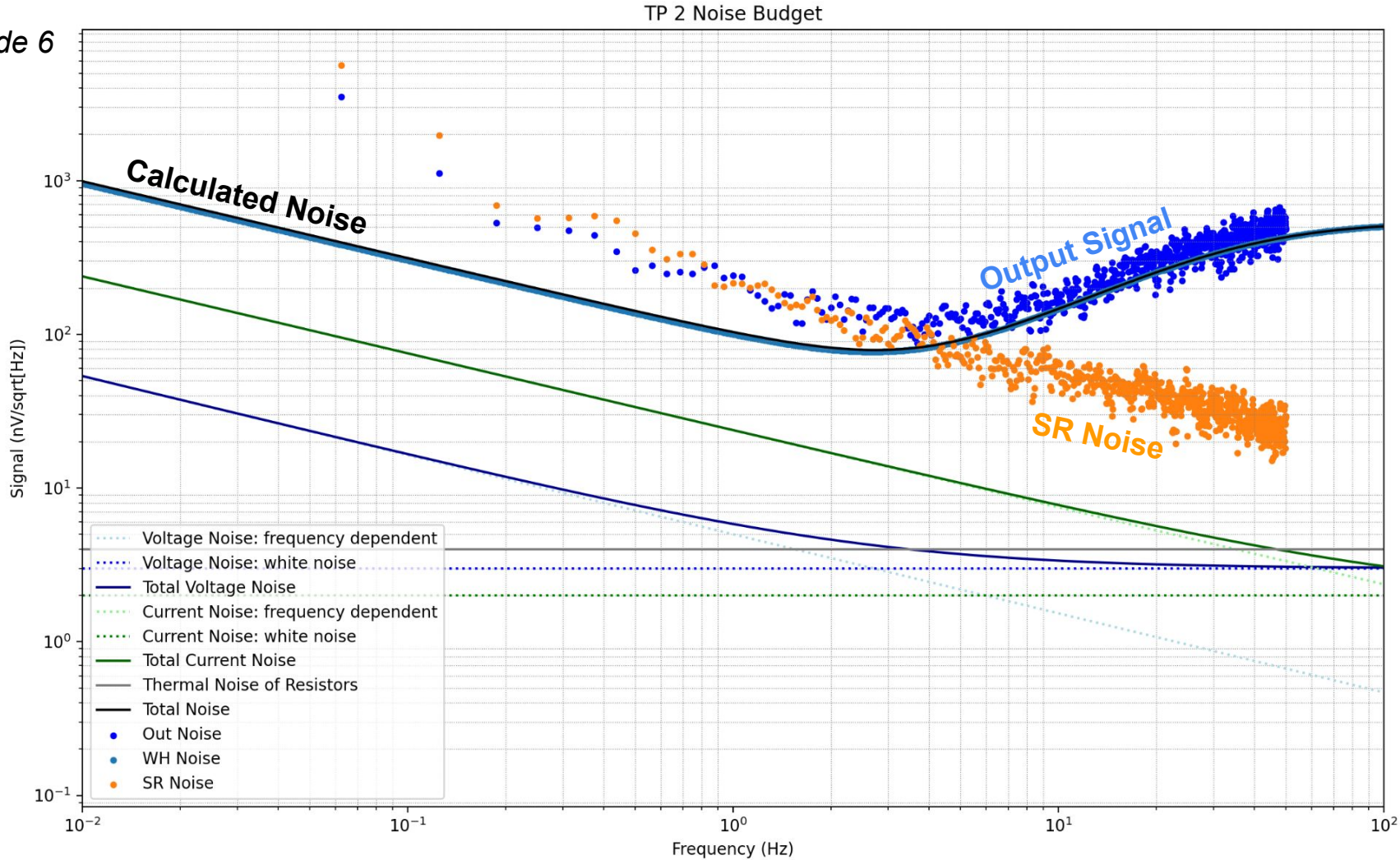


Amplitude/Pitch/ Yaw between QPDs: coheres? Scales?



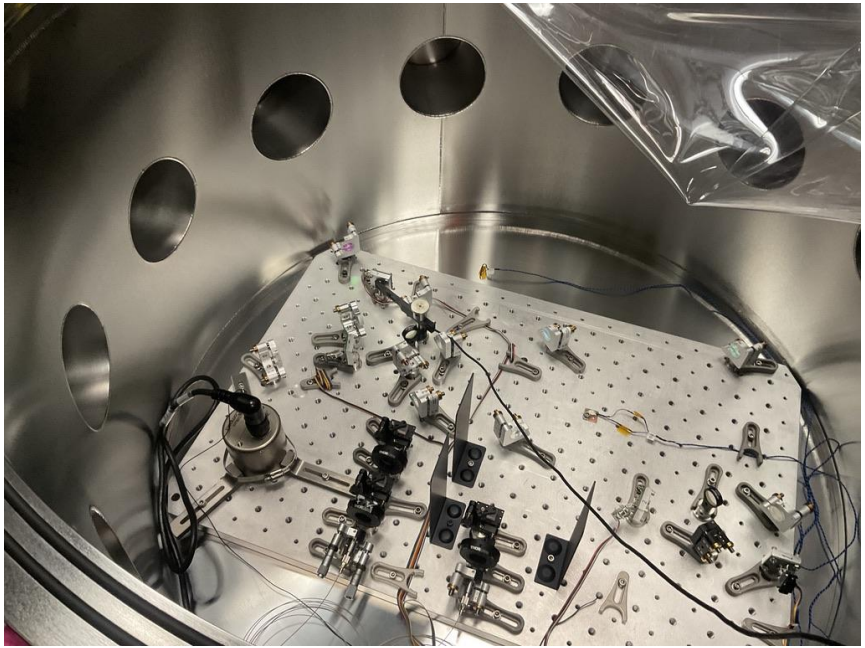
Laser Pointing Noise

Slide 6


TP 2 Noise Budget
Calculated Noise
Output Signal
SR Noise
Signal (nV/sqrt[Hz])
Frequency (Hz)
Voltage Noise: frequency dependent
Voltage Noise: white noise
Total Voltage Noise
Current Noise: frequency dependent
Current Noise: white noise
Total Current Noise
Thermal Noise of Resistors
Total Noise
Out Noise
WH Noise
SR Noise

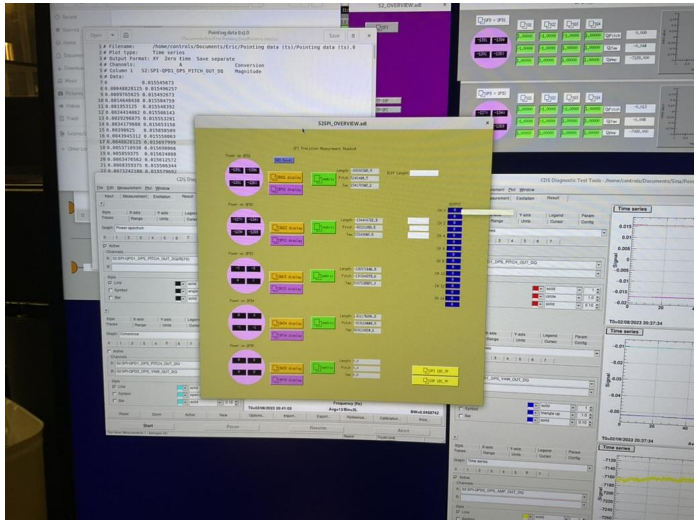
Creating a Noise Budget: Digitization on CDS

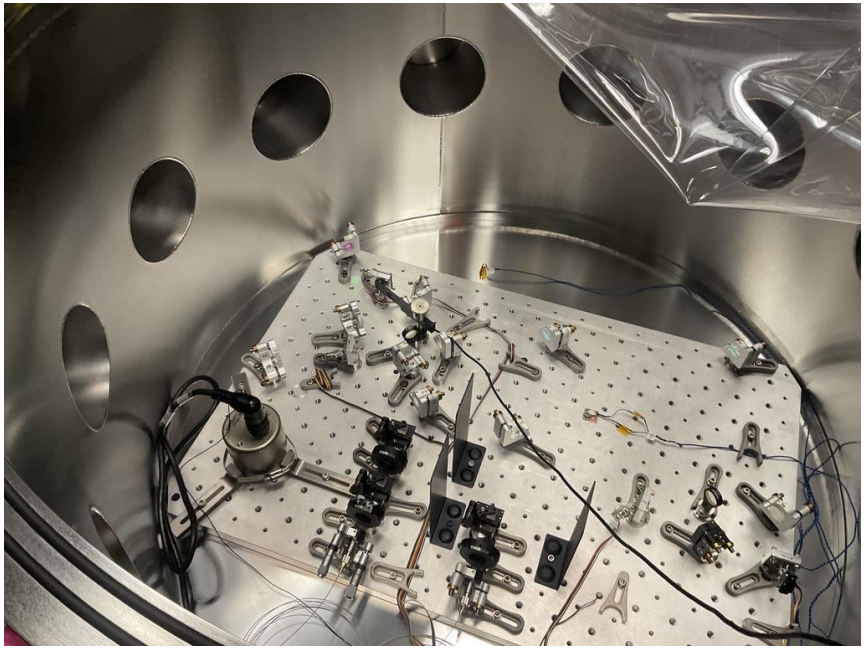
1. Use optical setup with QPD connected - “computer” part of noise (Dark Noise)



Creating a Noise Budget: Digitization on CDS

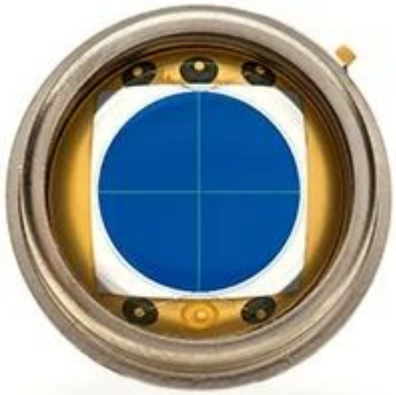
1. Use optical setup with QPD connected - “computer” part of noise (Dark Noise)
    a. Instead of SR Noise, now have **Digitization** Noise
        i. Conversion V to counts



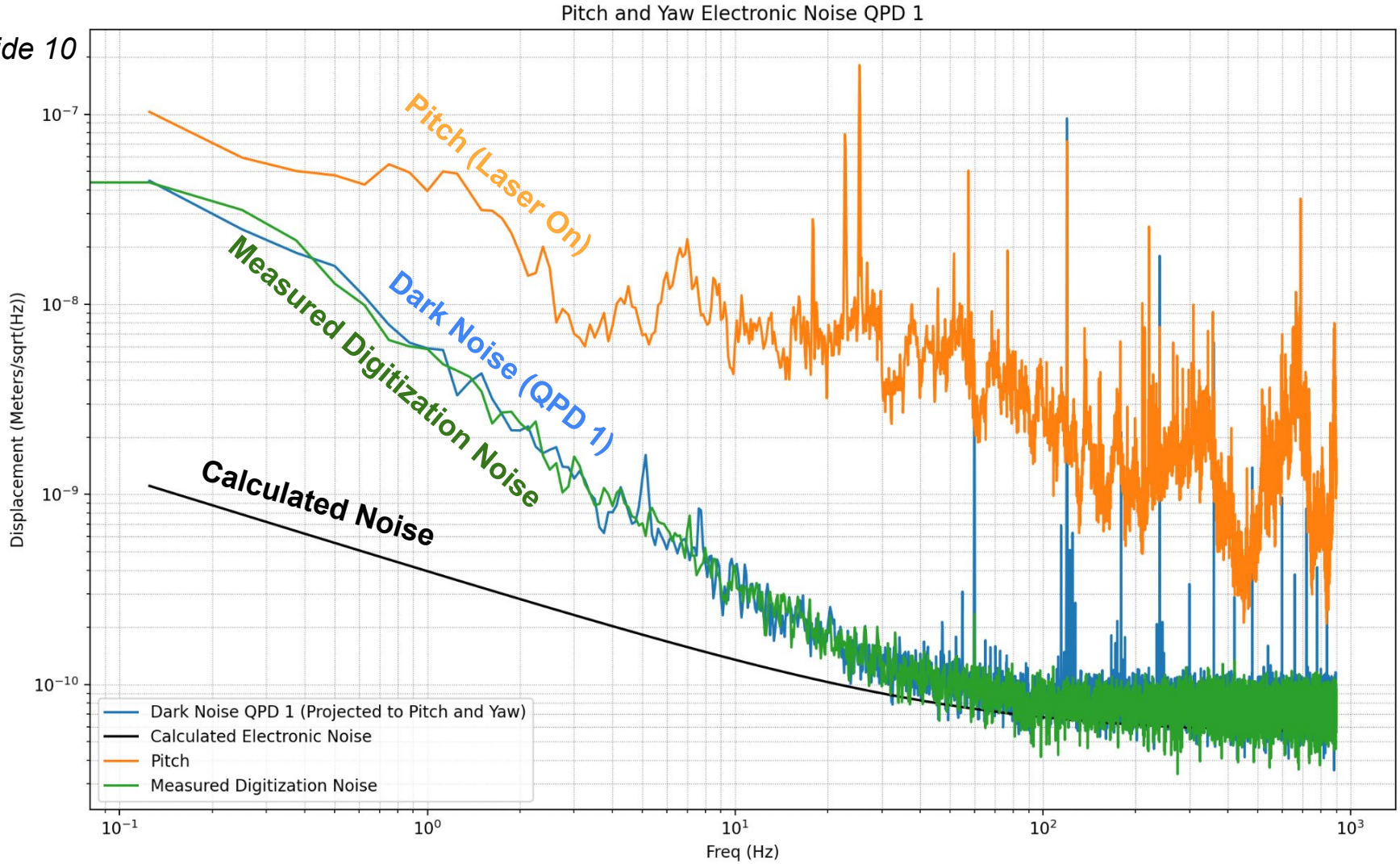


Creating a Noise Budget: Laser Pointing Noise

1. Use optical setup with QPD connected - “computer” part of noise (Dark Noise)
    a. Instead of SR Noise, now have **Digitization** Noise
        i. Conversion V to counts
2. Laser noise: caused by fiber collimator
    a. Pitch and Yaw – amount of offset



Slide 10


Pitch and Yaw Electronic Noise QPD 1
Pitch (Laser On)
Dark Noise (QPD 1)
Measured Digitization Noise
Calculated Noise
Displacement (Meters/sqrt(Hz))
Freq (Hz)
Dark Noise QPD 1 (Projected to Pitch and Yaw)
Calculated Electronic Noise
Pitch
Measured Digitization Noise

Concluding Thoughts: Laser Pointing Noise

- Pitch and Yaw don’t appear to scale/cohere between QPDs
  - Doubtful from Laser: instead, other noise source disrupting (air currents)
  - Additionally, pointing noise is too high for SPI
- However, well defined low noise calibrated system
- **Next Step:** pump air out, repeat experiment with system at vacuum

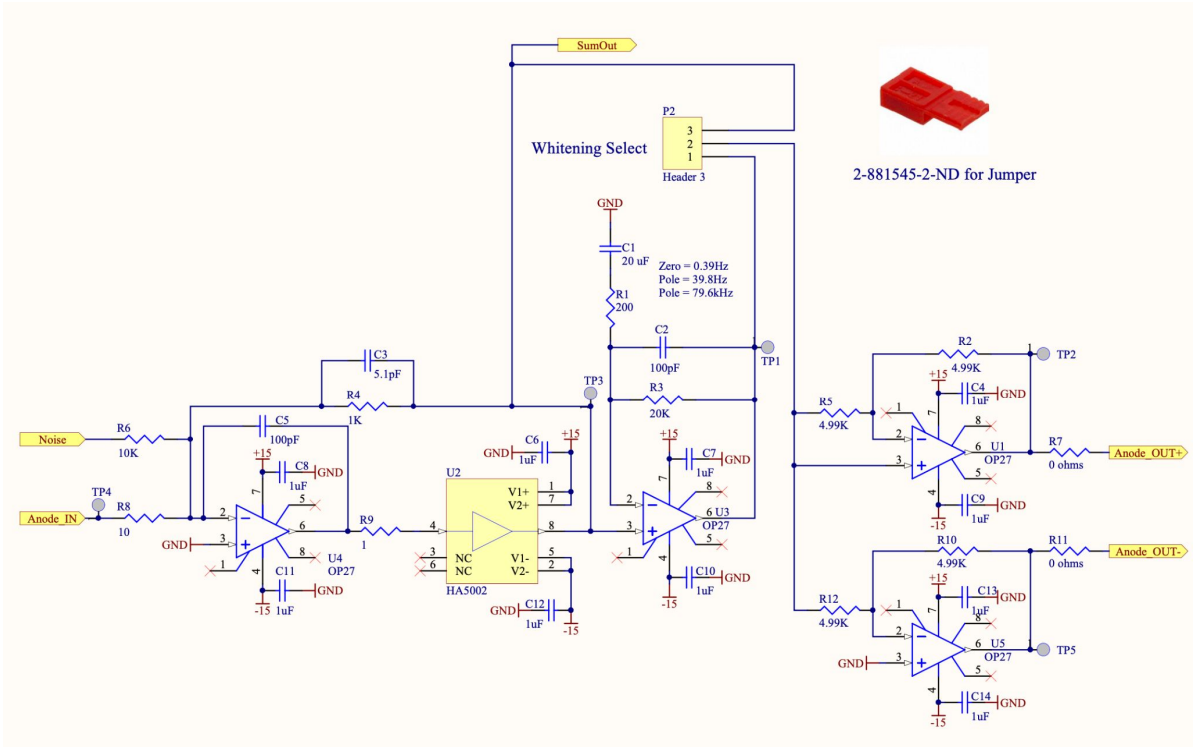
Extra Slides:

My Project – Motivation and About

- Motivation: making measurements for future experiments
  - All plots are log-log, frequency vs. signal
  - 1. **Noise Budget** of Circuit, Digitization Noise, Laser Noise, etc.
  - 2. **Angular Noise of Laser**
    - Pitch and Yaw of laser on QPD (Quadrant Photodiode)
    - Look at characteristics of noise: angular, translational?
- Two measures of noise: **Spectrum Analyzer** and **Optical Setup**, CDS (Control and Data System)

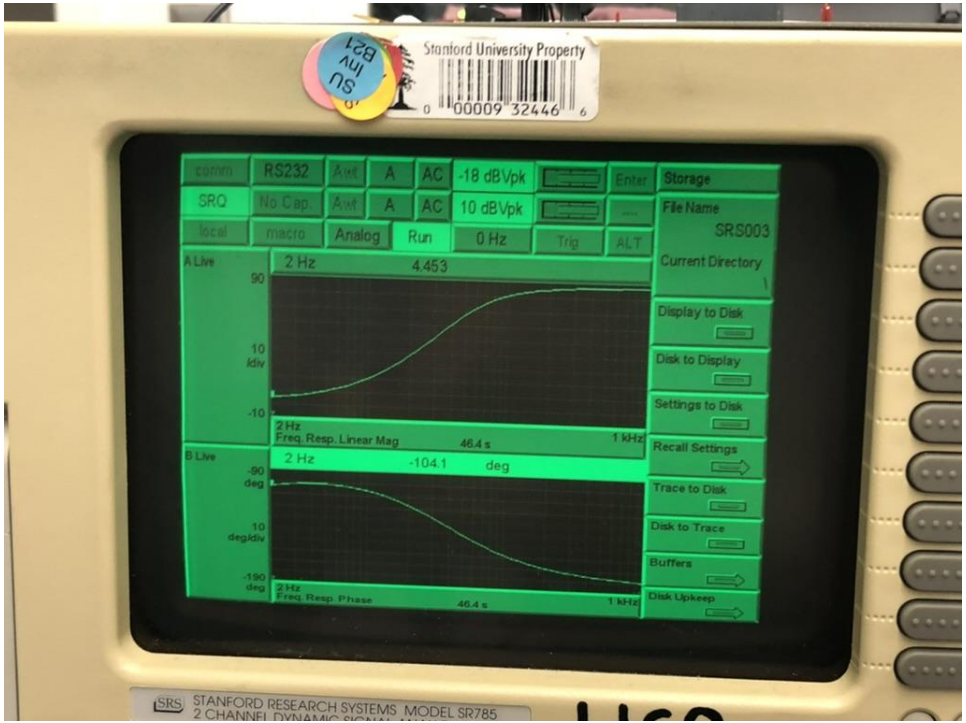
Creating a Noise Budget: Electronic Noise

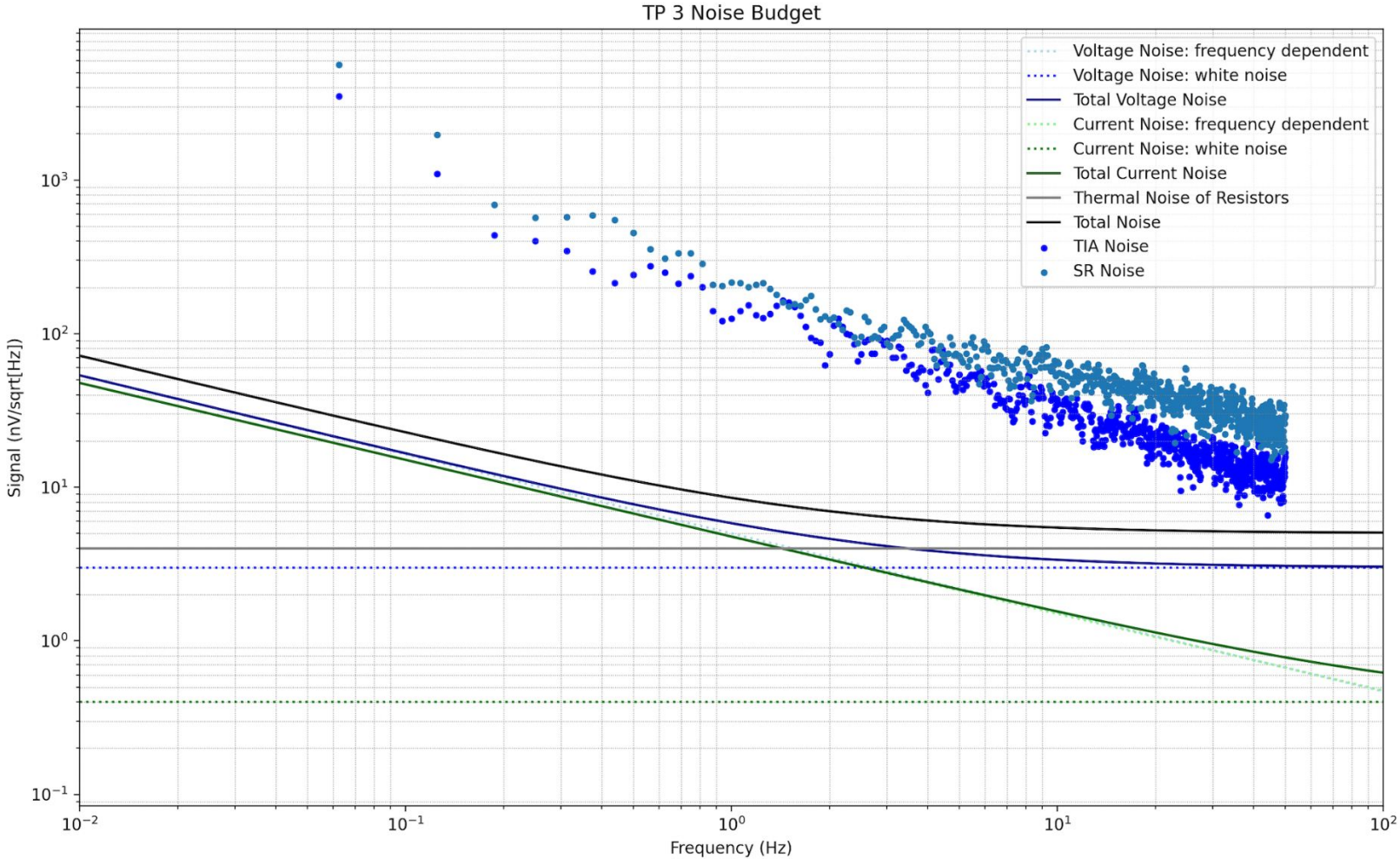
1. Calculate Electronic Noise from QPD Circuit - “Electronics” part of noise

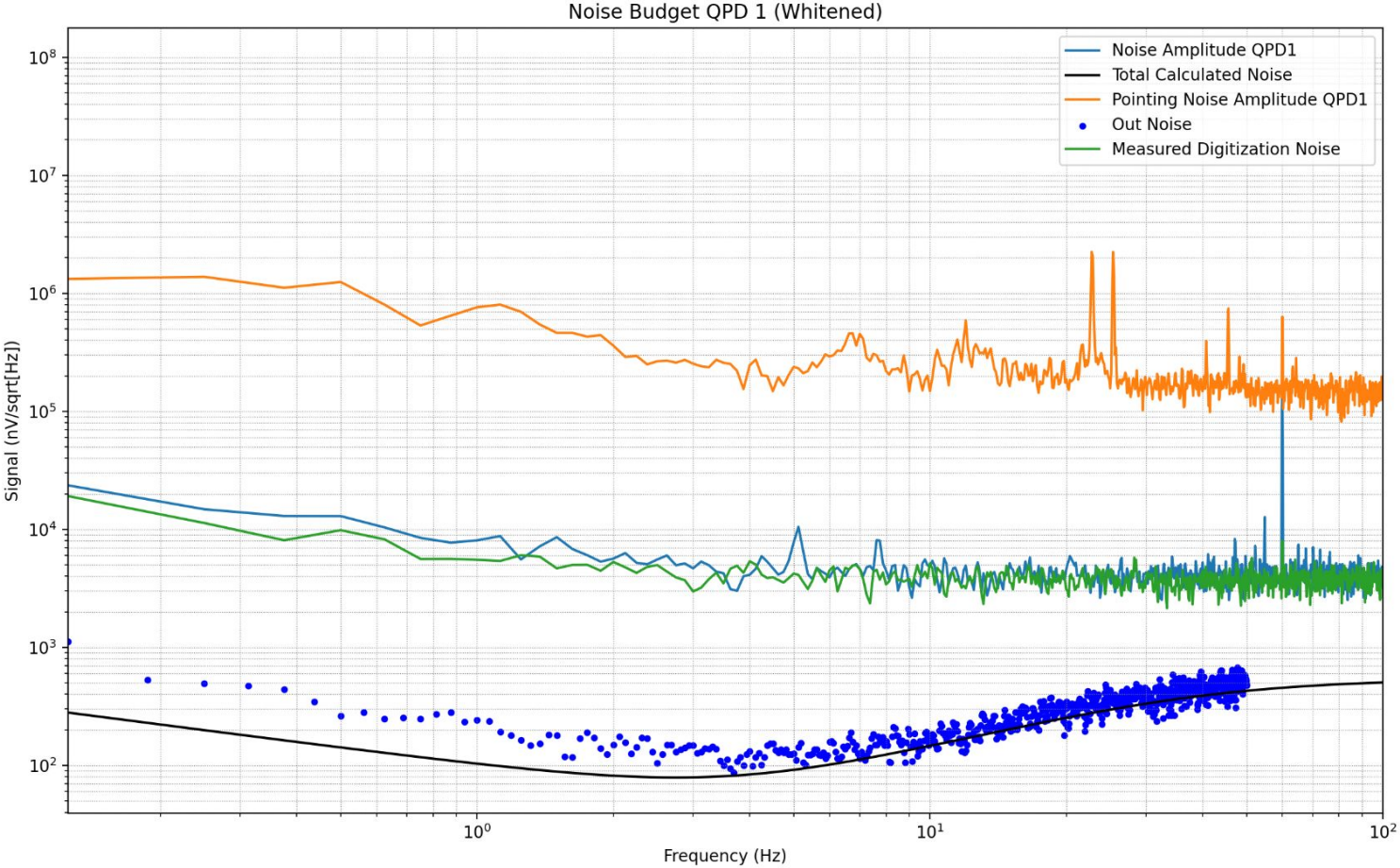


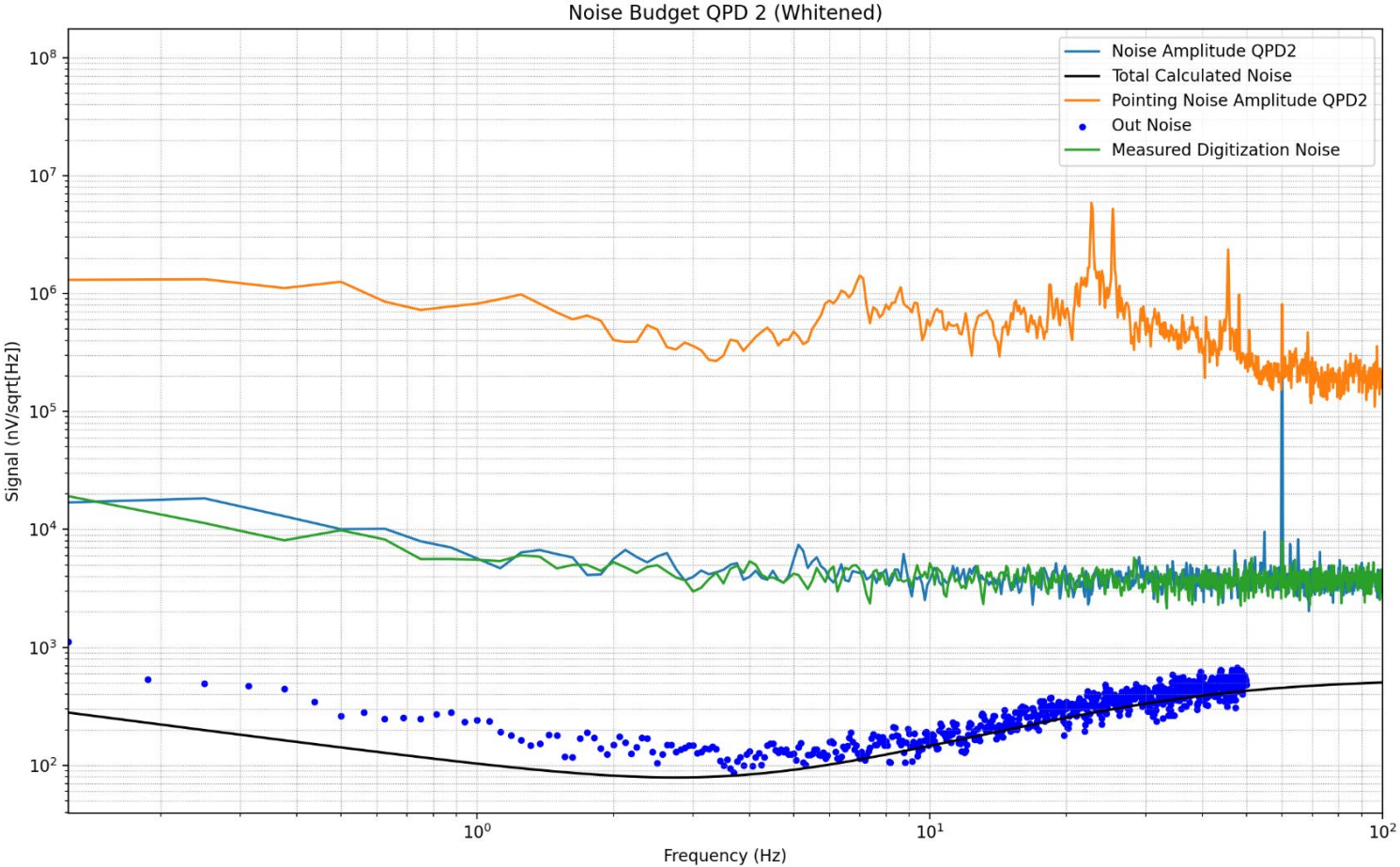
Creating a Noise Budget: Electronic Noise (SR)

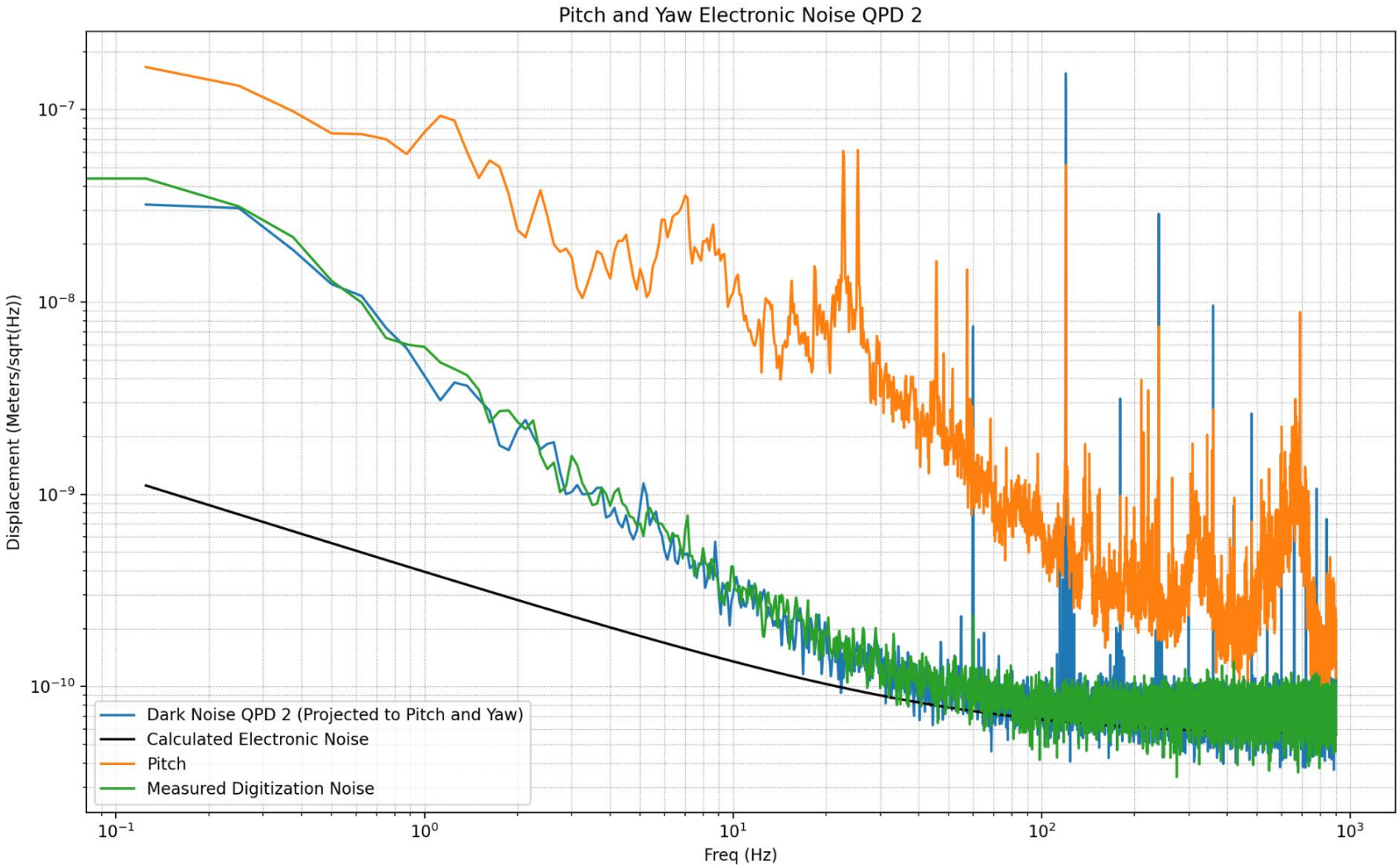
2. Measure Electronic Noise from 2 Channel Dynamic Signal Analyzer

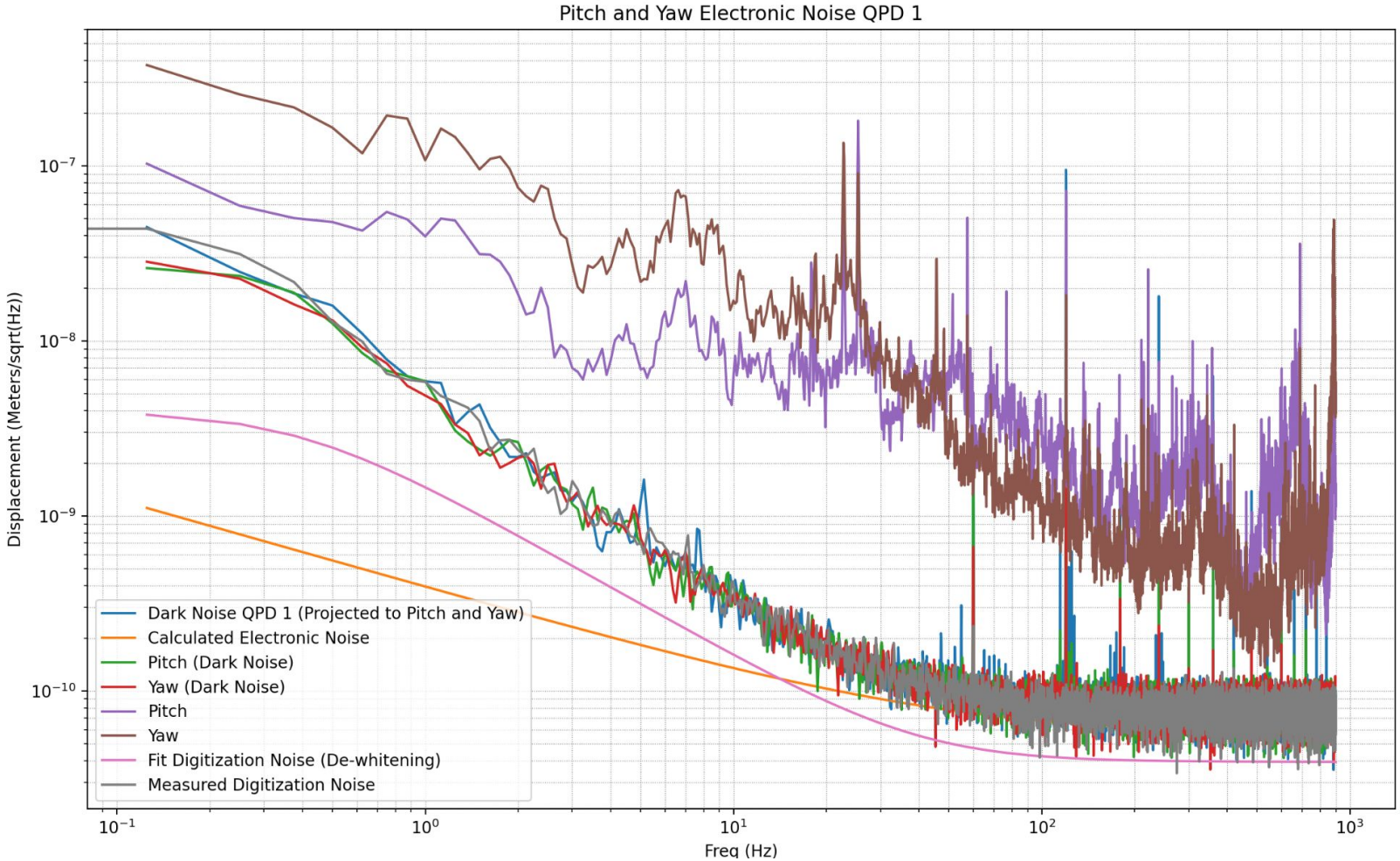



TP 3 Noise Budget
Voltage Noise: frequency dependent
Voltage Noise: white noise
Total Voltage Noise
Current Noise: frequency dependent
Current Noise: white noise
Total Current Noise
Thermal Noise of Resistors
Total Noise
TIA Noise
SR Noise
Signal (nV/sqrt[Hz])
Frequency (Hz)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}


Noise Budget QPD 1 (Whitened)
Noise Amplitude QPD1
Total Calculated Noise
Pointing Noise Amplitude QPD1
Out Noise
Measured Digitization Noise
Signal (nV/sqrt[Hz])
Frequency (Hz)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^0
10^1
10^2

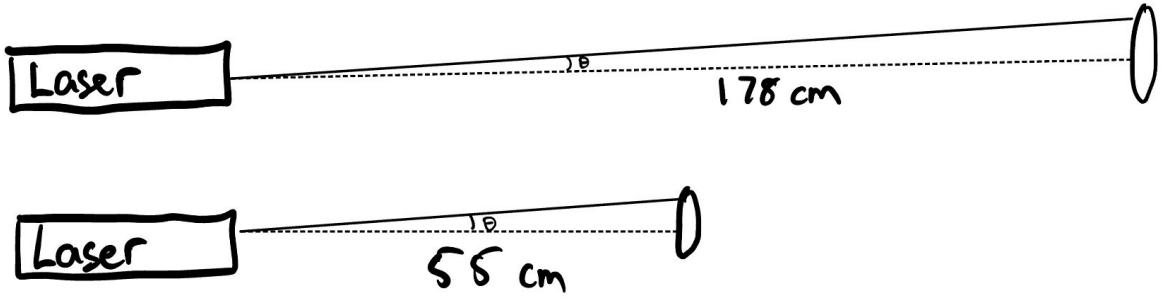

Noise Budget QPD 2 (Whitened)
Noise Amplitude QPD2
Total Calculated Noise
Pointing Noise Amplitude QPD2
Out Noise
Measured Digitization Noise
Signal (nV/sqrt[Hz])
Frequency (Hz)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^0
10^1
10^2


Pitch and Yaw Electronic Noise QPD 2
Displacement (Meters/sqrt(Hz))
Freq (Hz)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Dark Noise QPD 2 (Projected to Pitch and Yaw)
Calculated Electronic Noise
Pitch
Measured Digitization Noise

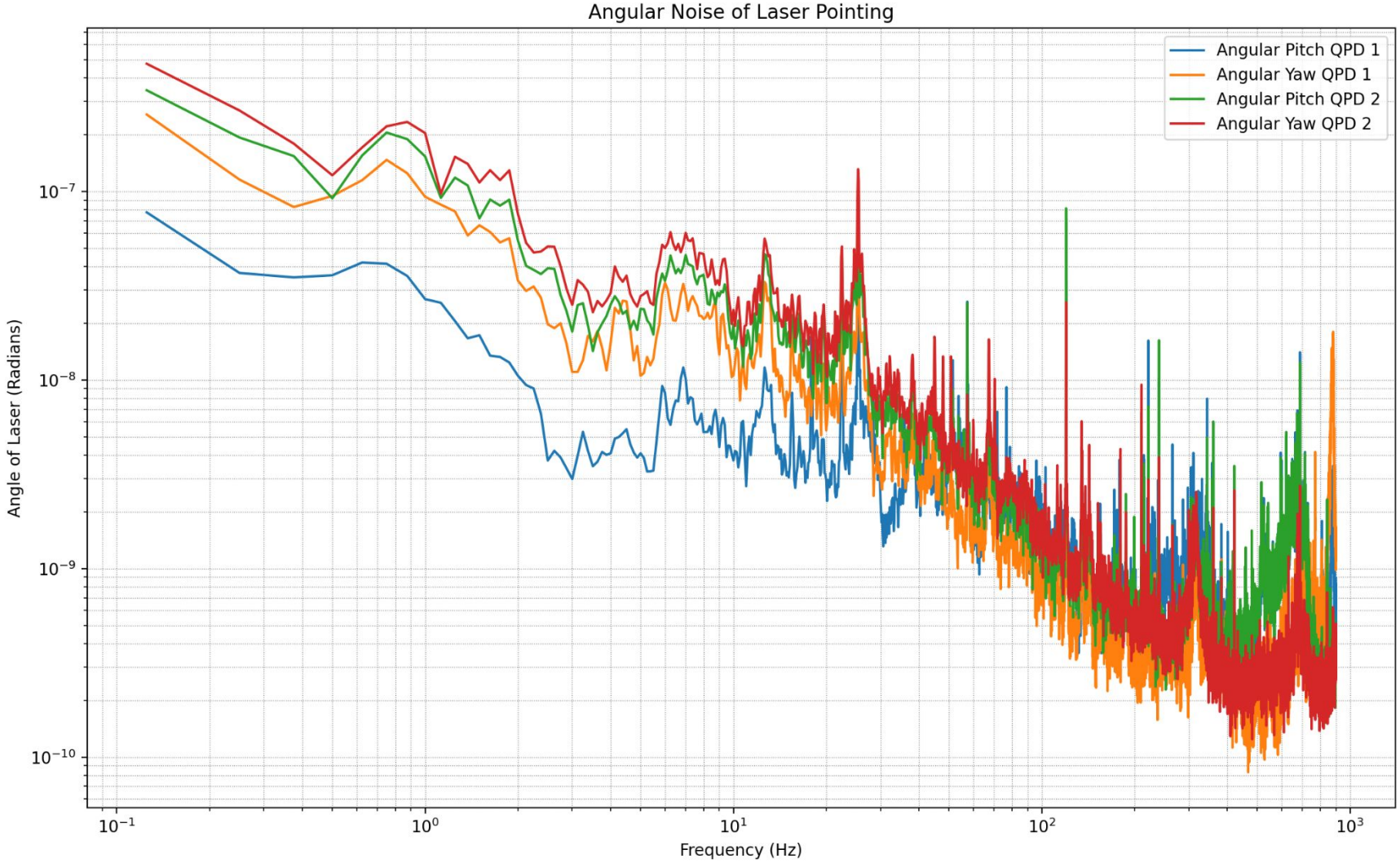

Pitch and Yaw Electronic Noise QPD 1
Displacement (Meters/sqrt(Hz))
Freq (Hz)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Dark Noise QPD 1 (Projected to Pitch and Yaw)
Calculated Electronic Noise
Pitch (Dark Noise)
Yaw (Dark Noise)
Pitch
Yaw
Fit Digitization Noise (De-whitening)
Measured Digitization Noise

Looking at Laser Noise Characteristics: Coherence

- Nature of laser noise: possibly angular
  - At different distances, would mean different displacement on QPD

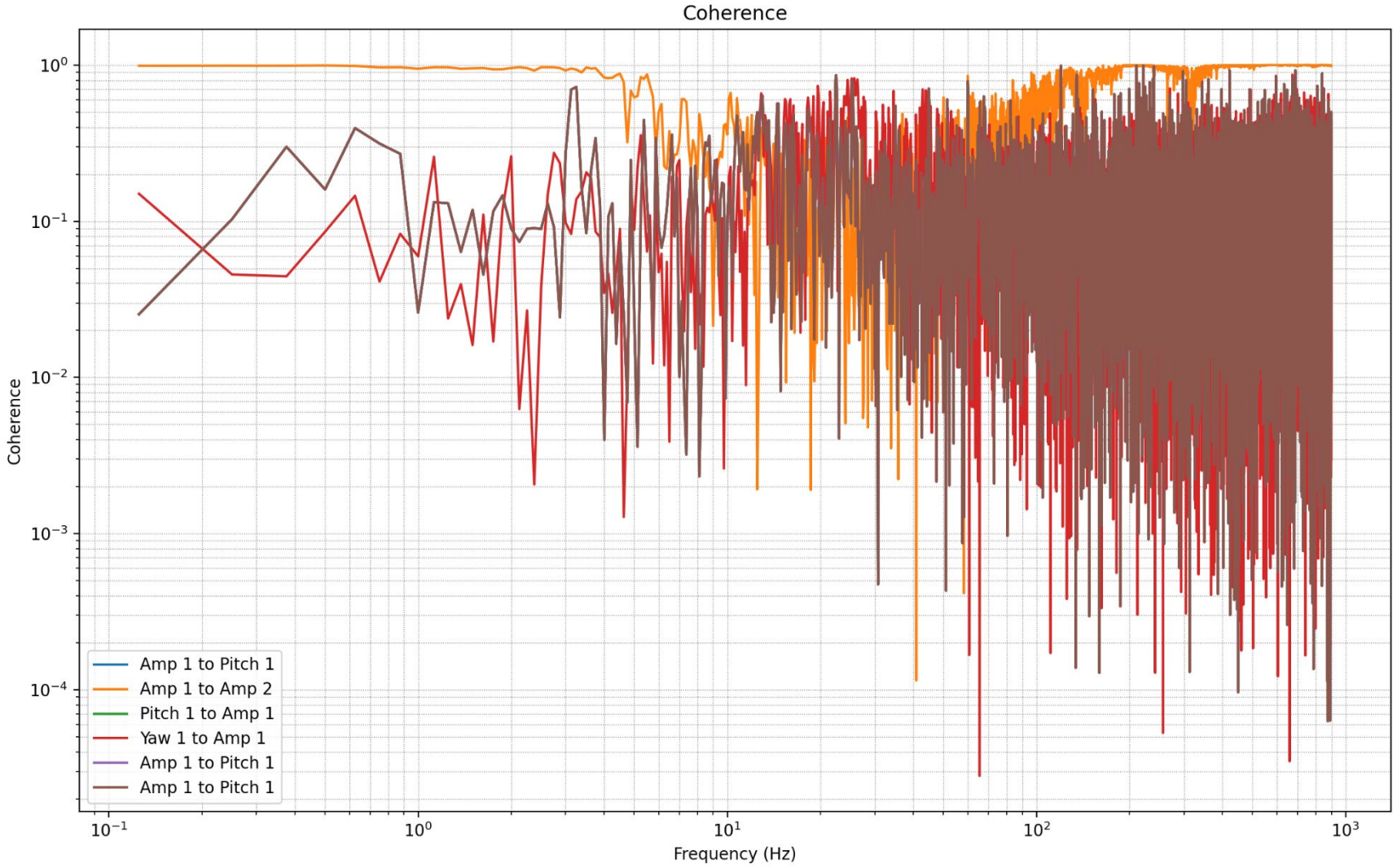


- How well does pitch/yaw cohere between two QPDs?


Angular Noise of Laser Pointing
Angular Pitch QPD 1
Angular Yaw QPD 1
Angular Pitch QPD 2
Angular Yaw QPD 2
Angle of Laser (Radians)
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Frequency (Hz)

Future Directions

- Project much more of a setup for future experiments
  - Knowledge of Noise sources, etc.
- Find noise source contributing to lack of coherence at middle frequencies
- Improvement: for transfer function, laser that modulates amplitude instead of Voltage and resistor in place


Coherence
Coherence
Frequency (Hz)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Amp 1 to Pitch 1
Amp 1 to Amp 2
Pitch 1 to Amp 1
Yaw 1 to Amp 1
Amp 1 to Pitch 1
Amp 1 to Pitch 1