University of Washington, Seattle

Eöt-Wash Group Overview

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GWANW June 2025

UNIVERSITY *of* WASHINGTON

CENPA
Center for Experimental Nuclear Physics and Astrophysics
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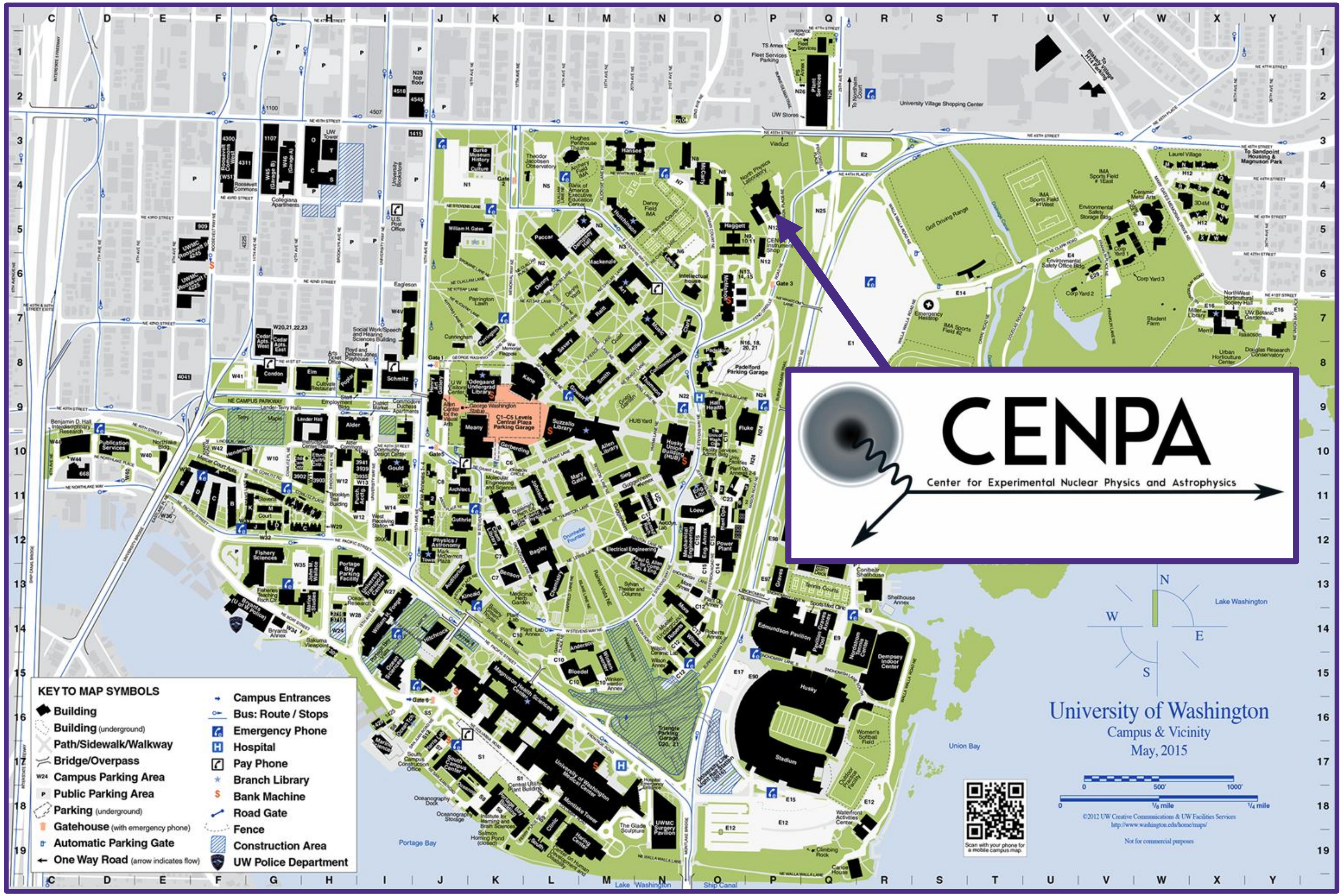
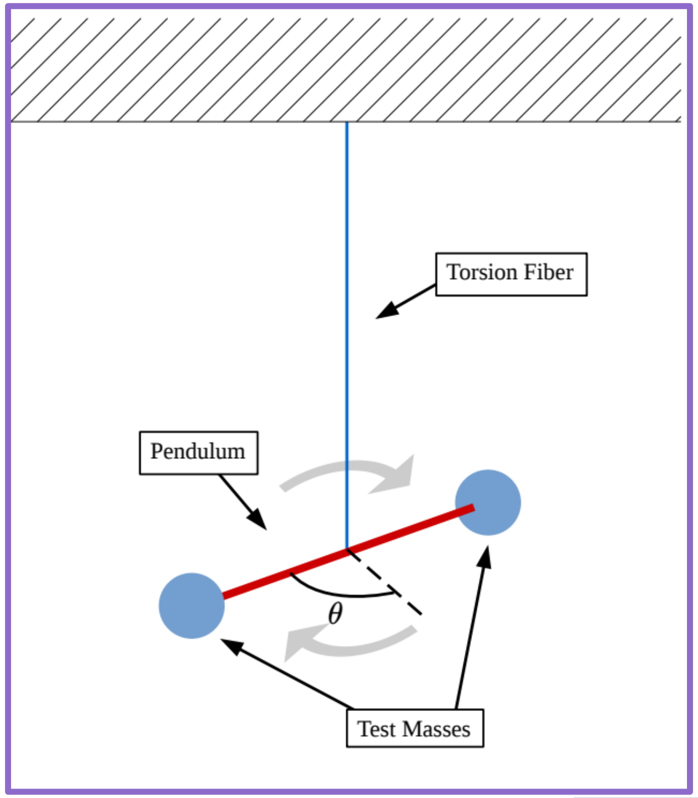
Eöt-Wash Group Background

- **CENPA:** Center for Experimental Nuclear Physics and Astrophysics
- **What we do:**
  - Fundamental Gravity Experiments
  - LIGO Instrumentation

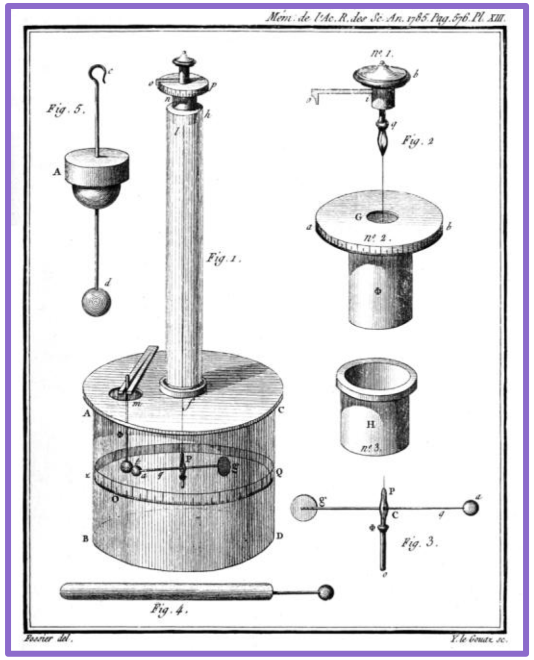


Fundamental Gravity Experiments:
Torsion Balances

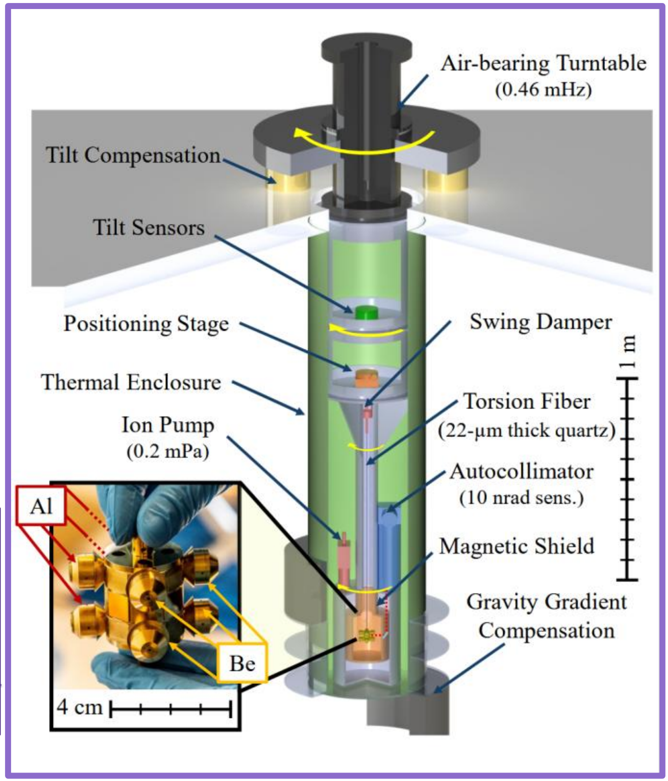
- Pendulum with two masses suspended from a fiber → Spring mass system
  - Fiber has a very weak spring constant to allow for very precise measurements
- Measures torque produced by a field interacting with a dipole*
- Invented by Coulomb
  - Used in the Cavendish experiment to measure the force of gravity
  - Used in Eötvös Experiment in late 1800s to ‘prove’ equivalence principle
- Usually measure changing angle with an autocollimator



A diagram of Coulomb’s torsion balance from ~1780



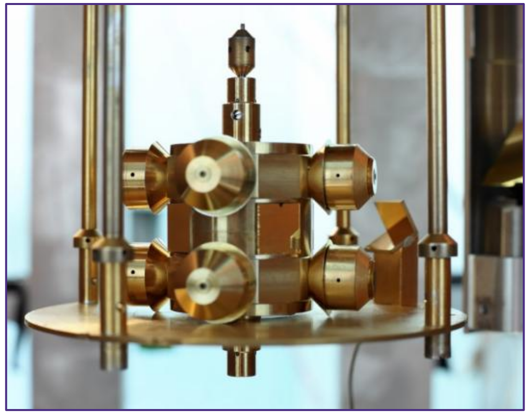
A modern torsion balance from our lab!



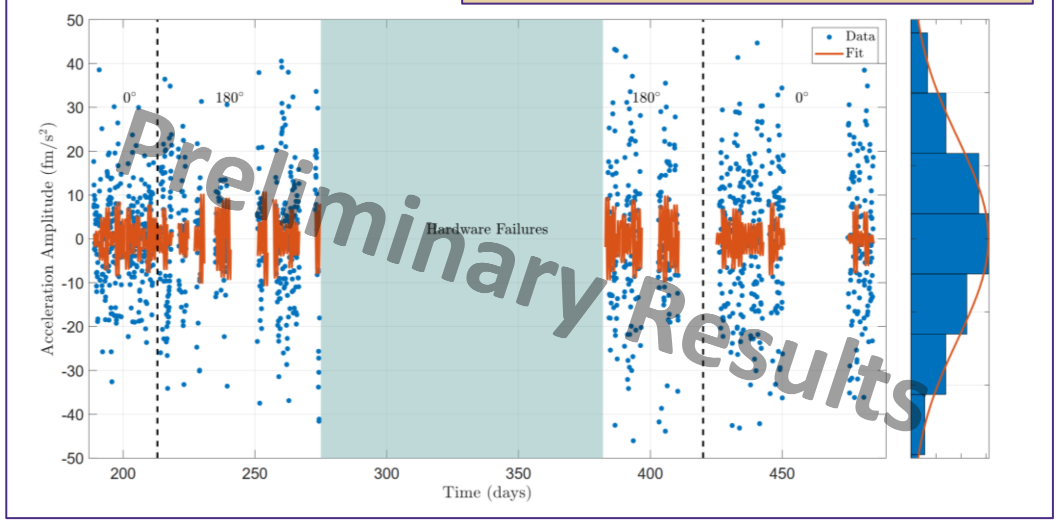
Fundamental Gravity Experiments:

Torsion Balances

- Very difficult to measure gravitational force precisely
  - Mu-metal shielding
  - Gold coat pendulums
  - Silica fiber (for some experiments)
  - Lots of environmental sensors
- What we measure:
  - Equivalence Principle Test (Paper coming soon!)
  - Ultra-light Dark Matter search (Paper also coming soon!)
  - Short-Range gravity
  - 5th force tests

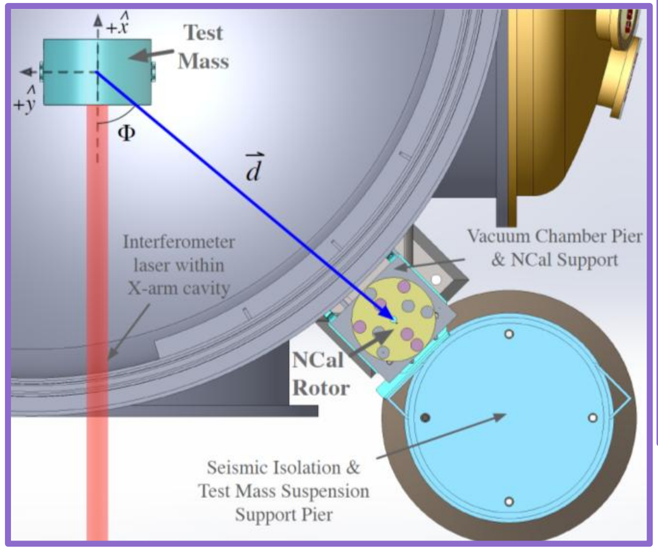


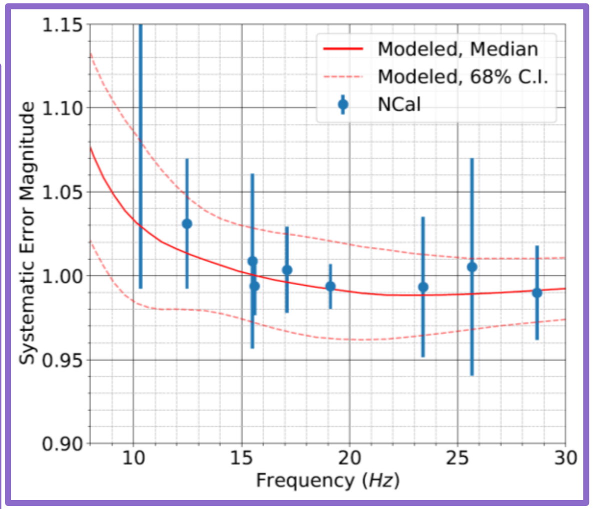
Torsion balance experiments can take a long time!



LIGO:
Newtonian Calibrator

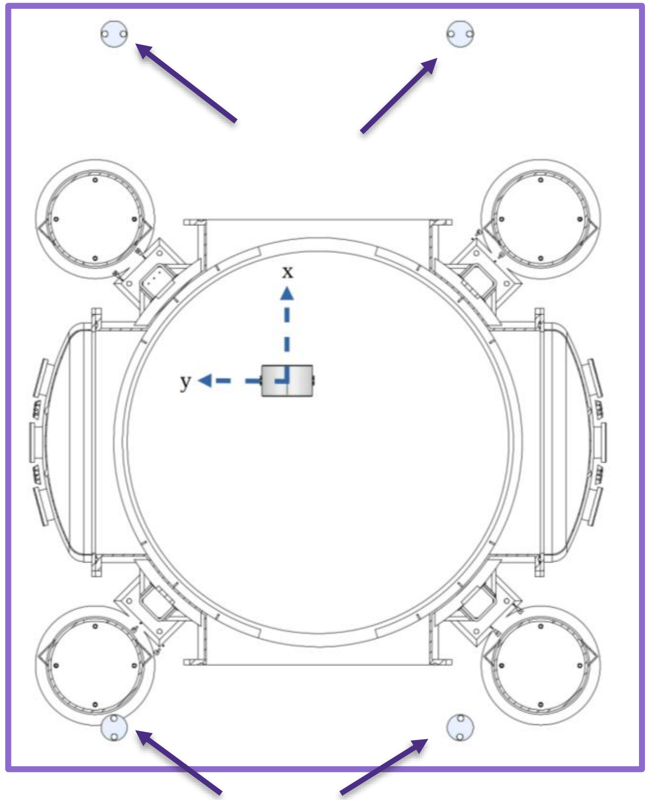
Current NCal design





- Calibrating LIGO via gravity
- Rotor with rotating tungsten masses cause gravitational force on LIGO test masses
- Currently have one rotor installed at LHO (EndX) and successfully injected force during O3
  - Initial Results yielded ~1% absolute calibration: https://arxiv.org/abs/2107.00141
- New design has four rotors placed around the test Mass
  - Expected to reach ~0.1% uncertainty: P2200021
  - Skylar Kemper (Masters student) working on new design

Planned new NCal design



LIGO:
Rotation Sensors

- LIGO uses a lot of seismometers for active seismic isolation
- Issue: (horizontal) seismometers don't work when they experience tilt → Detects tilt as horizontal motion
- High winds → lots of ground rotation → seismometers not working → interferometer can't lock → can't observe
- Solution: Build dedicated rotation sensor

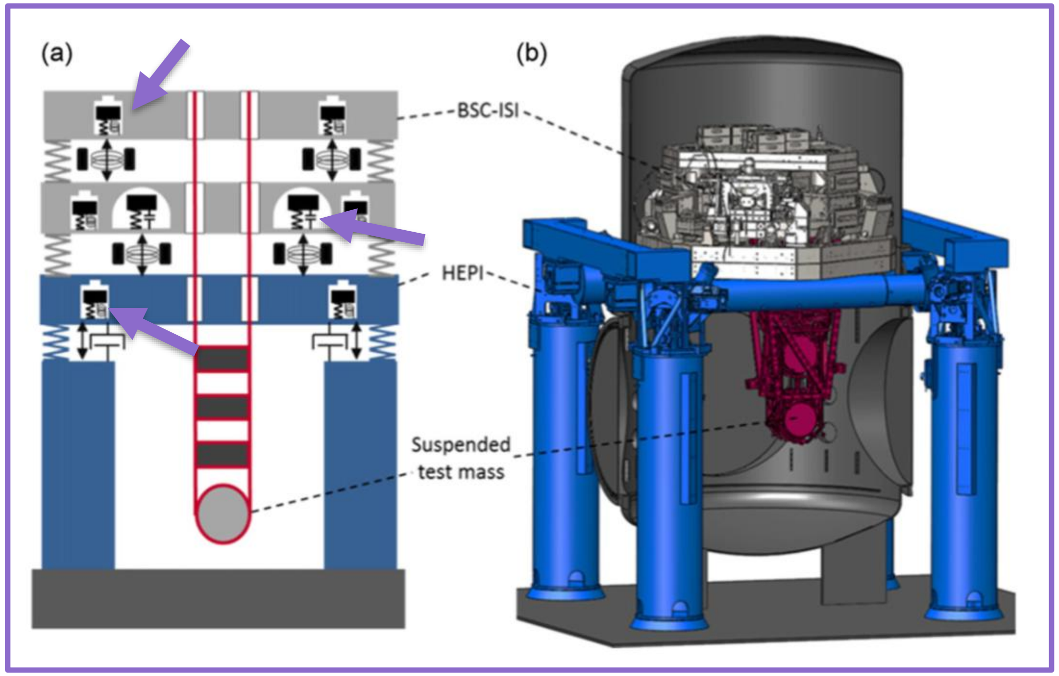
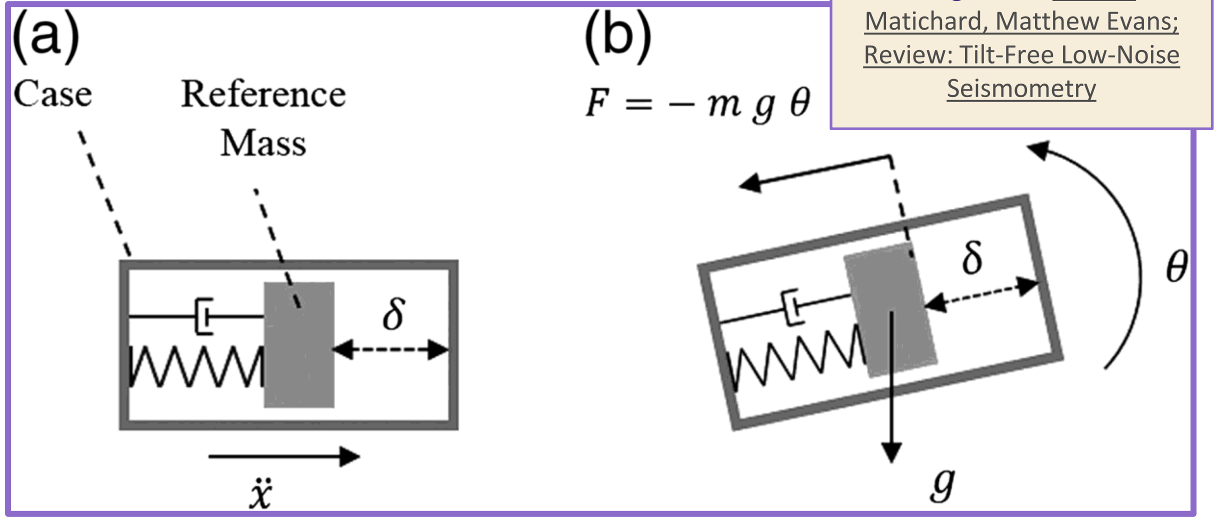
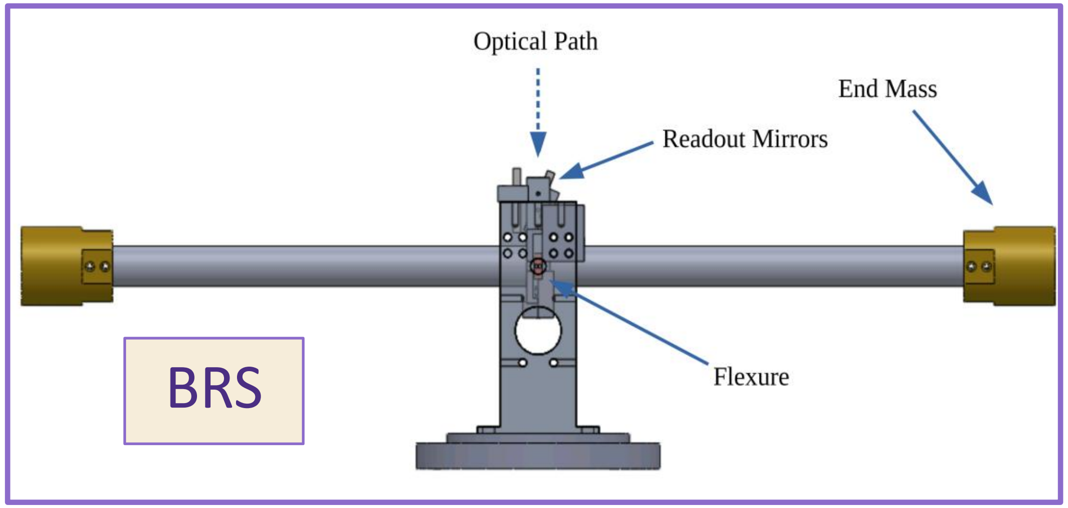


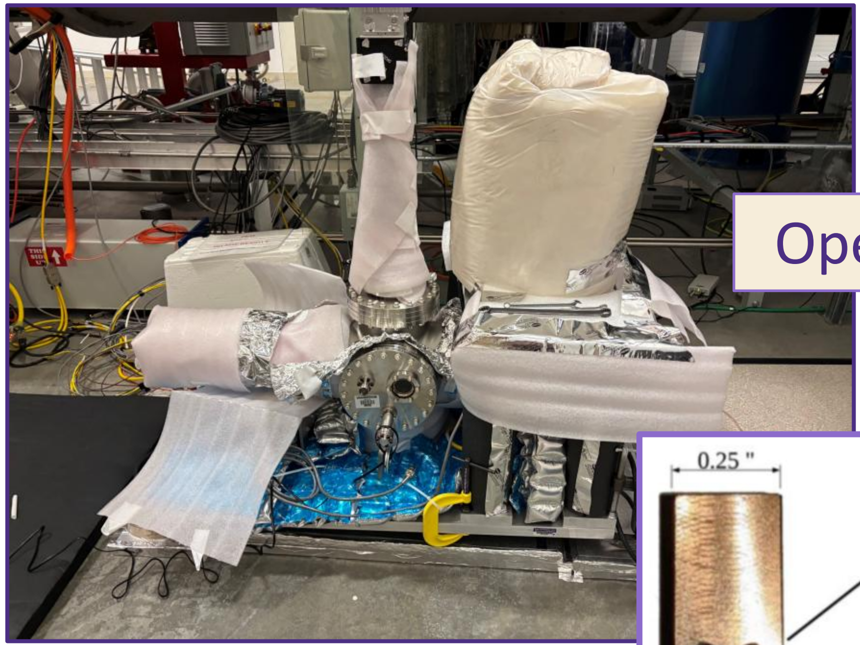
Image from: Fabrice Matichard, Matthew Evans; Review: Tilt-Free Low-Noise Seismometry

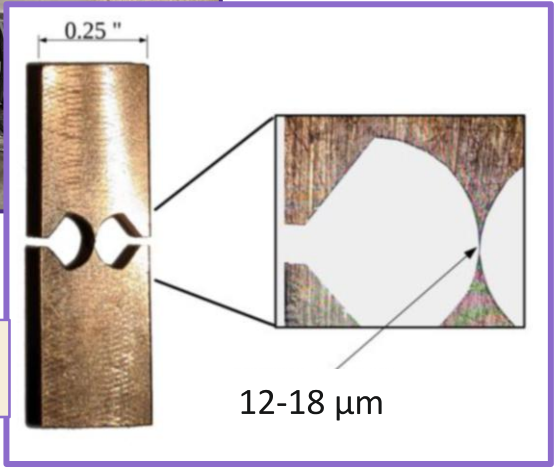


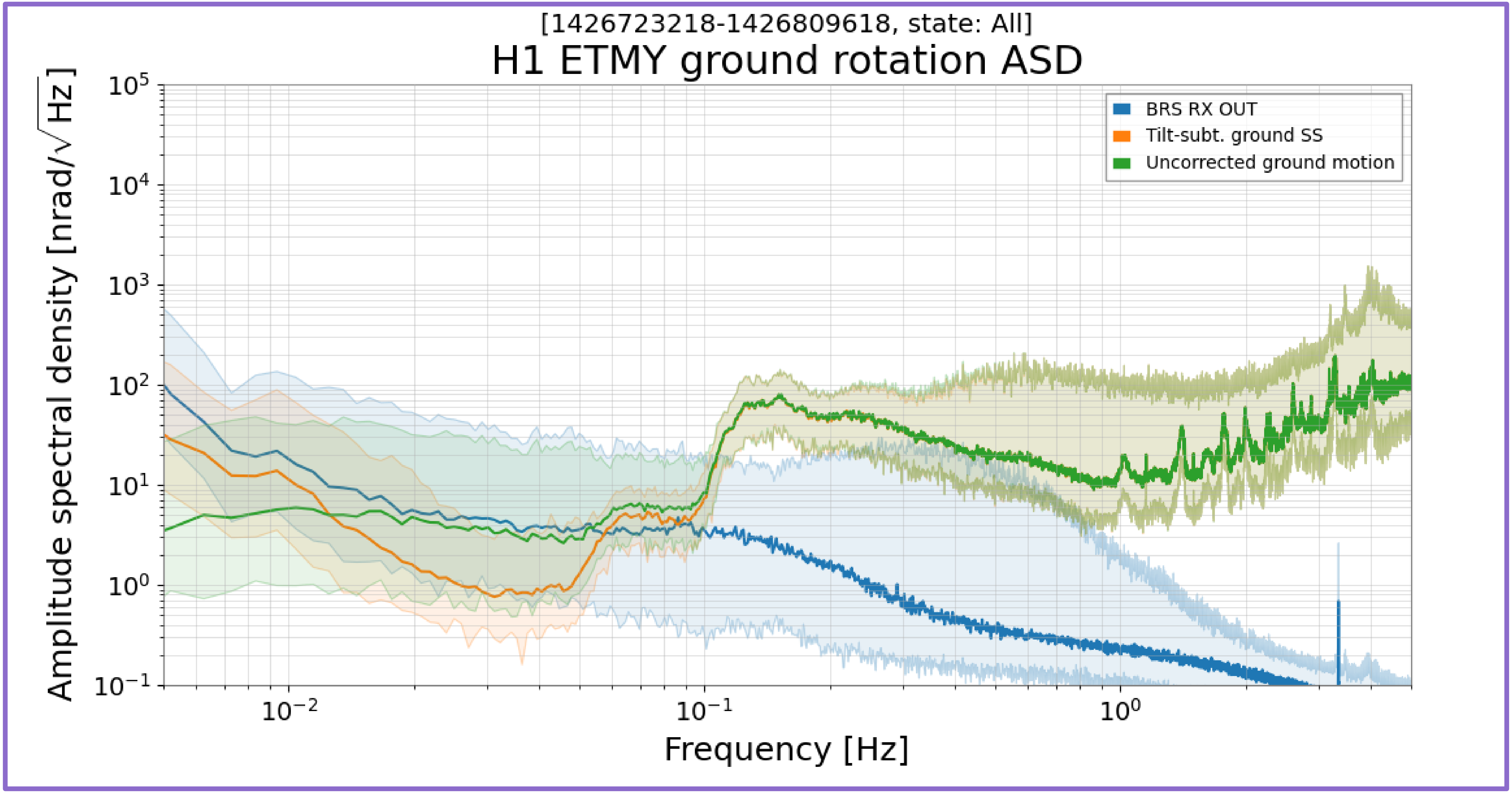
LIGO:
Rotation Sensors

- **BRS—Beam Rotation Sensor**
  - **1-m long beam with autocollimator readout**
  - **~7mHz resonance frequency**
  - **Measures ground tilt to nrad level**
  - **Proof Mass (beam) Suspended via two Be-Cu flexures (~12-18 μm)**
  - **6 total installed in LIGO (4 in Livingston, 2 in Hanford)**



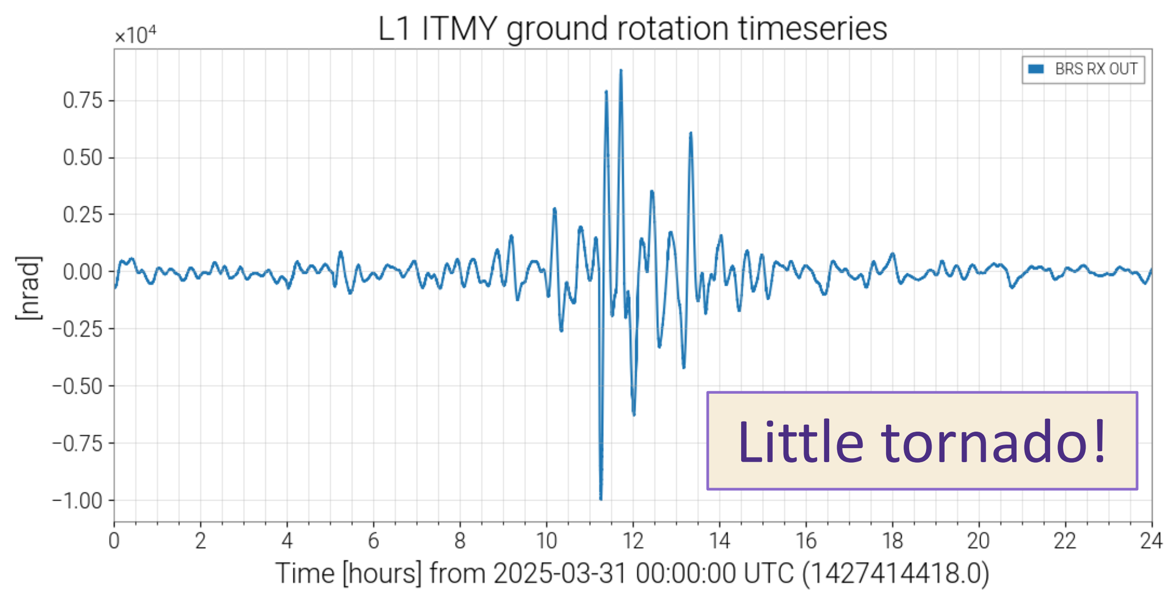




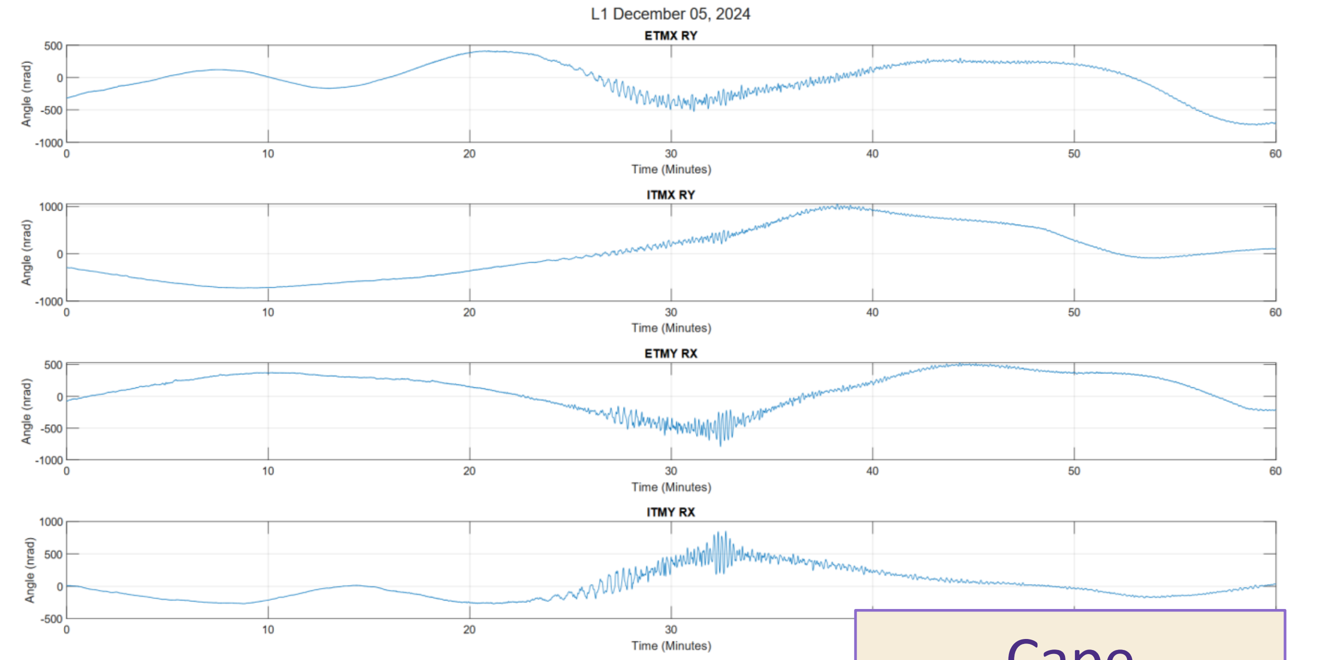

[1426723218-1426809618, state: All]
H1 ETMY ground rotation ASD
Amplitude spectral density [nrad/√Hz]
Frequency [Hz]
BRS RX OUT
Tilt-subt. ground SS
Uncorrected ground motion
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-1}
10^0

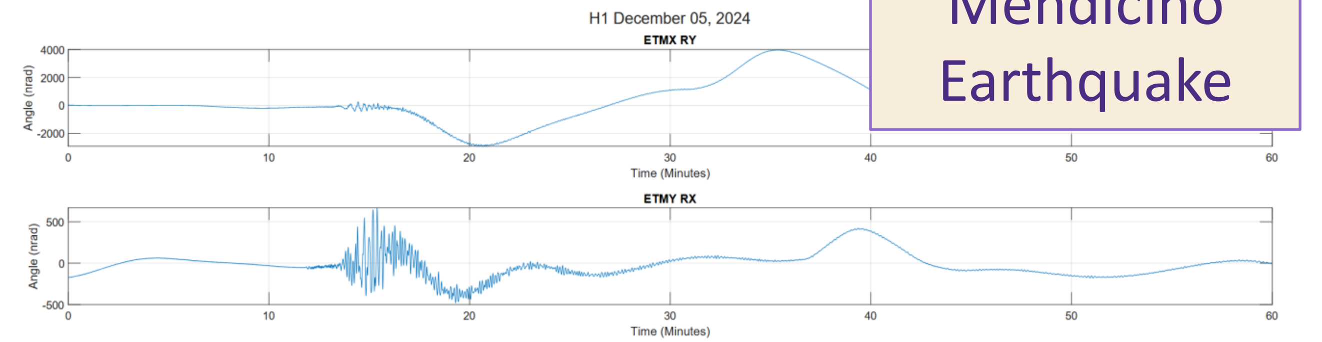
BRS:
Seismology Sidebar

- **Working with seismologists to use the BRS data to look at various events**
  - **Local motion**
  - **Earthquakes**
  - **Tornados**
  - **Storms**
  - **Etc.**
- **Might turn into a larger project**



Little tornado!

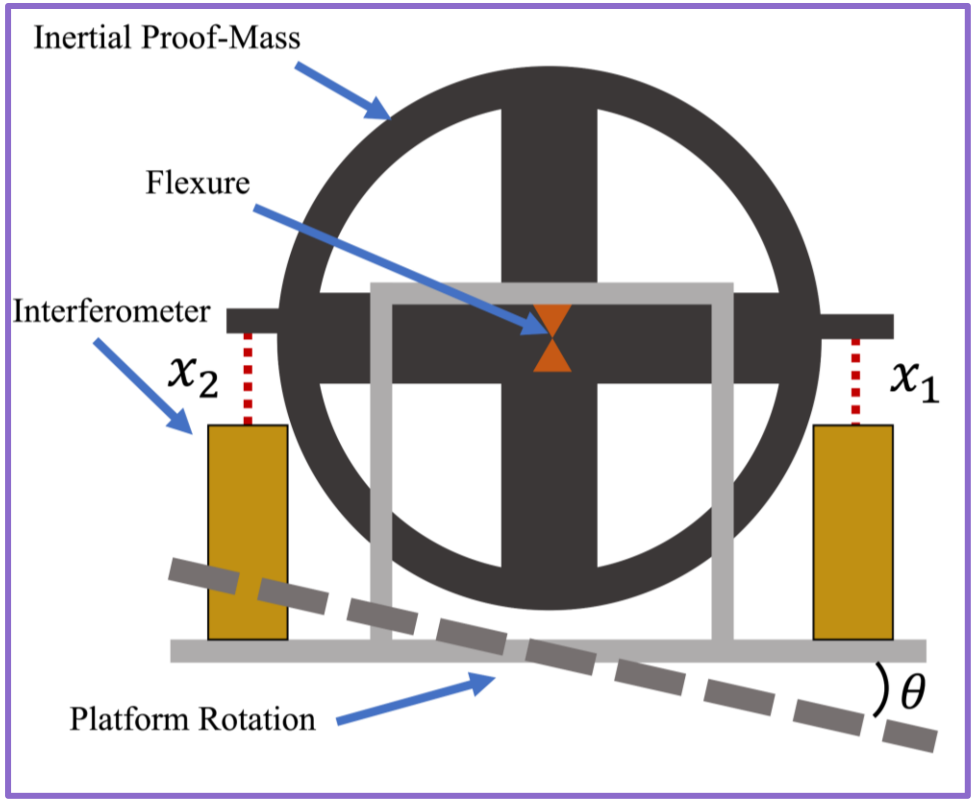




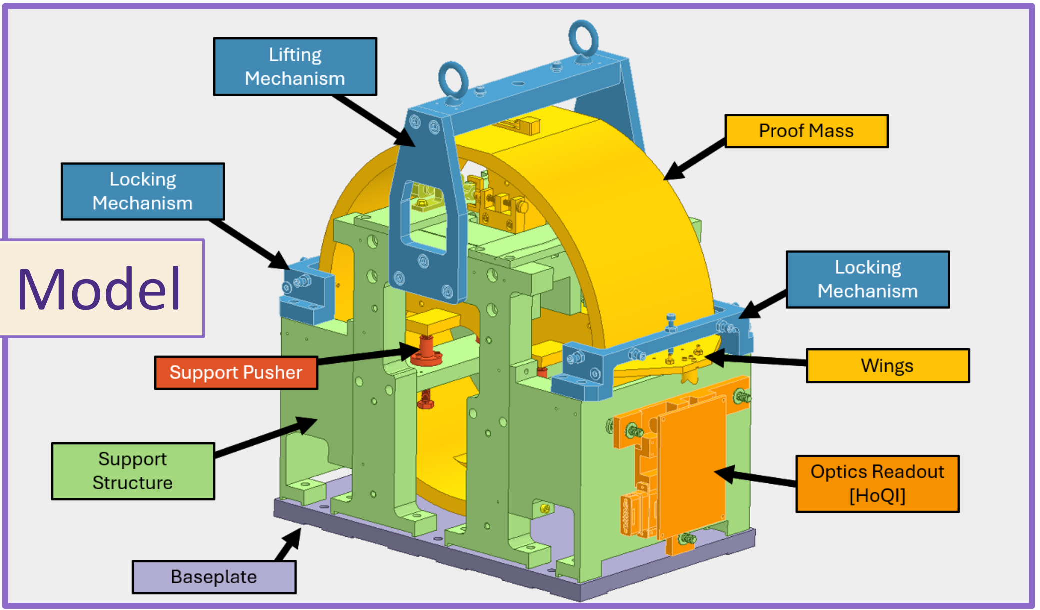
Cape Mendicino Earthquake

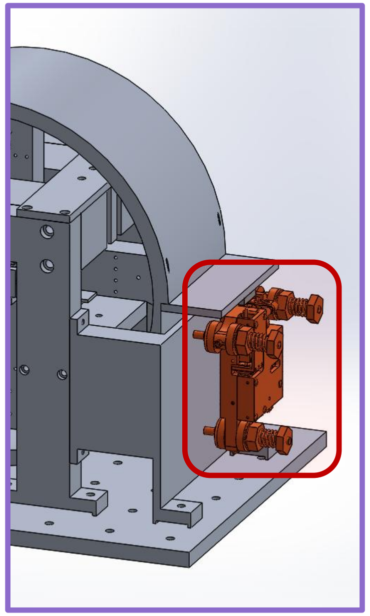
LIGO:
Rotation Sensors

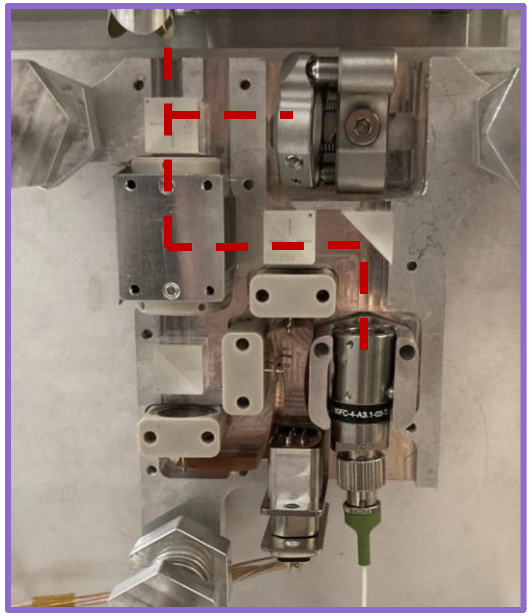
- CRS—Cylindrical Rotation Sensor
  - Compact version (30cm cylinder) to go on ISI
  - Transportable!
  - ~18mHz resonance frequency
  - Currently being machined
  - Testing at MIT in September
  - Planned install before O5
  - To be built for Virgo



CAD Model



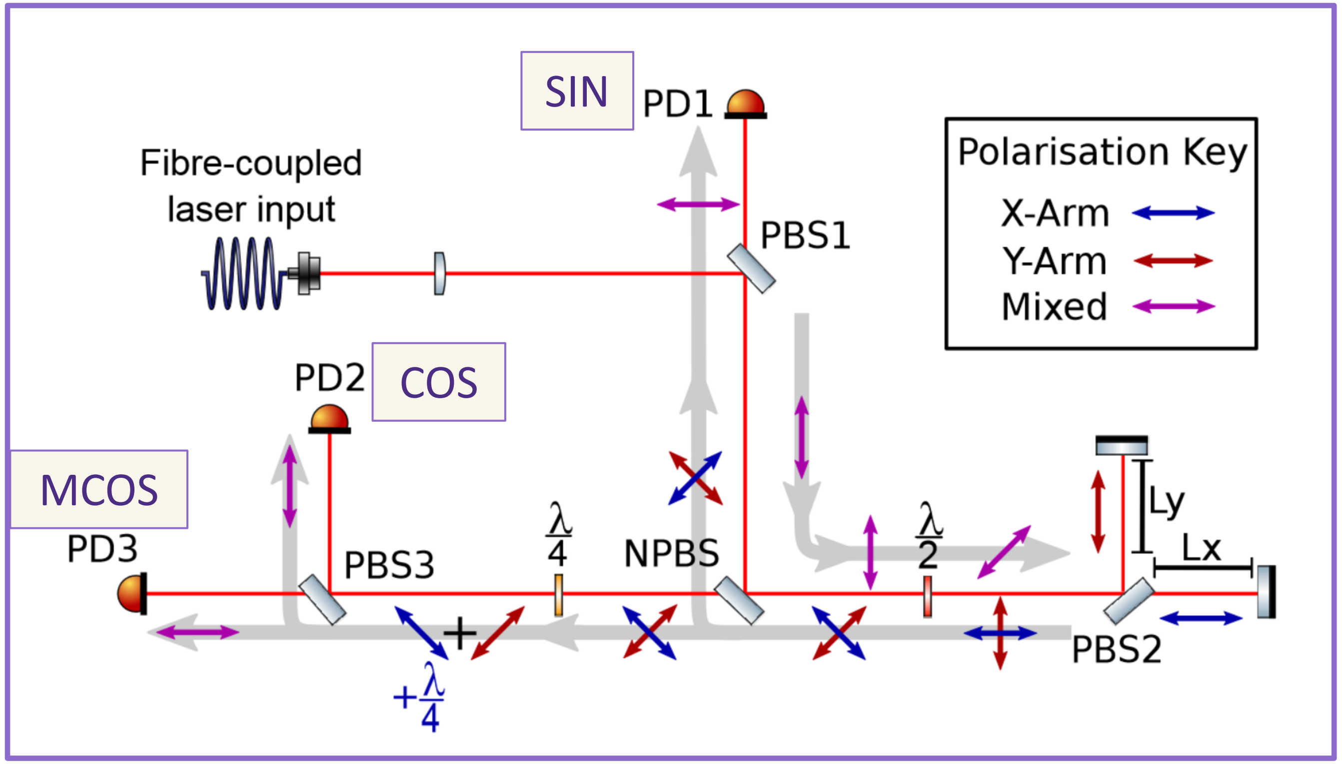




Optical Readout (HoQIs)

- **Homodyne Quadrature Interferometer (HoQI)** **[arXiv: 1710.0593]**
- **Developed at Vrije Universiteit Amsterdam & University of Birmingham**

$$\frac{P_{PD1} - P_{PD2}}{P_{PD1} - P_{PD3}} = \tan(\Delta\phi)$$



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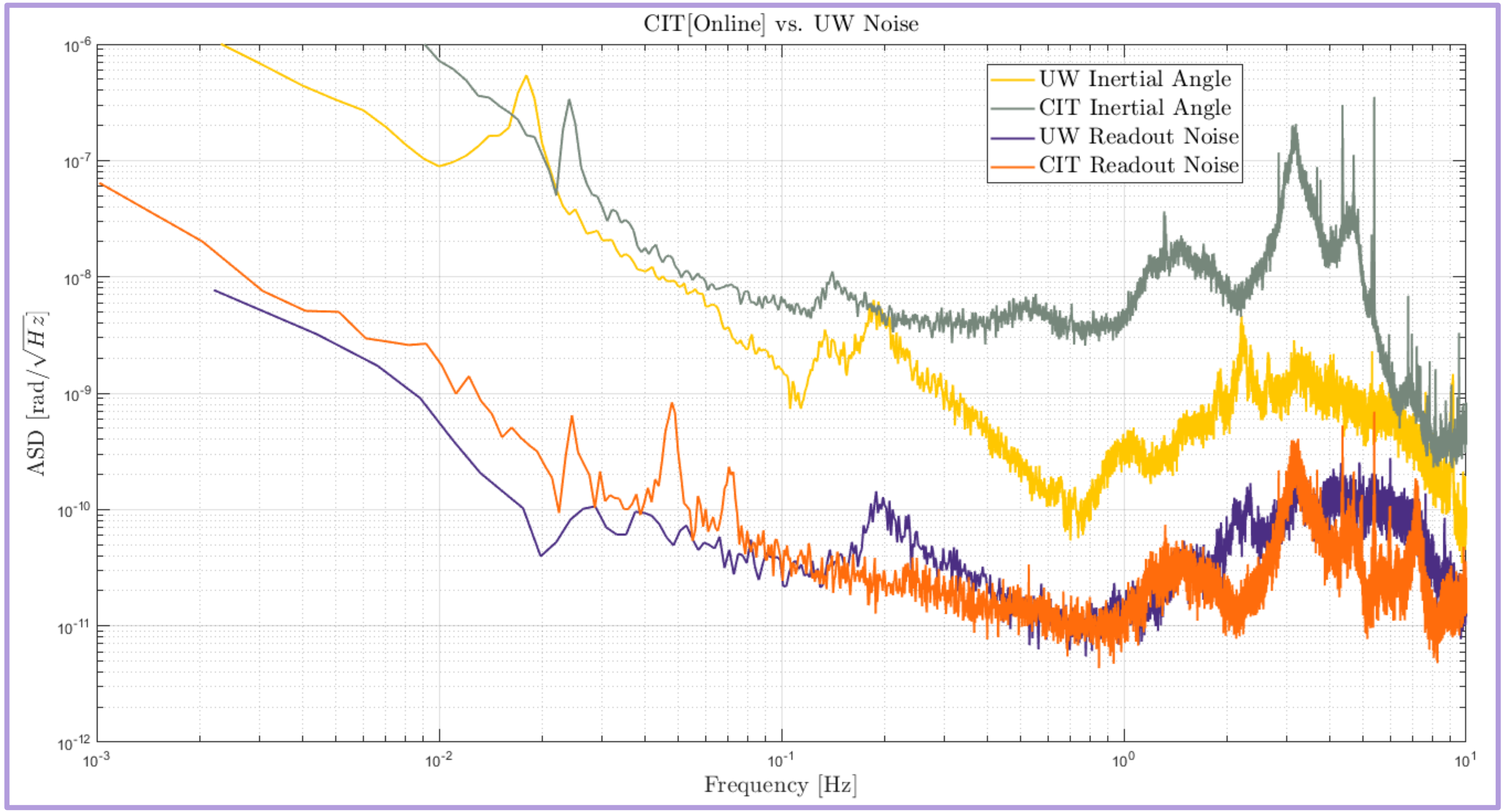
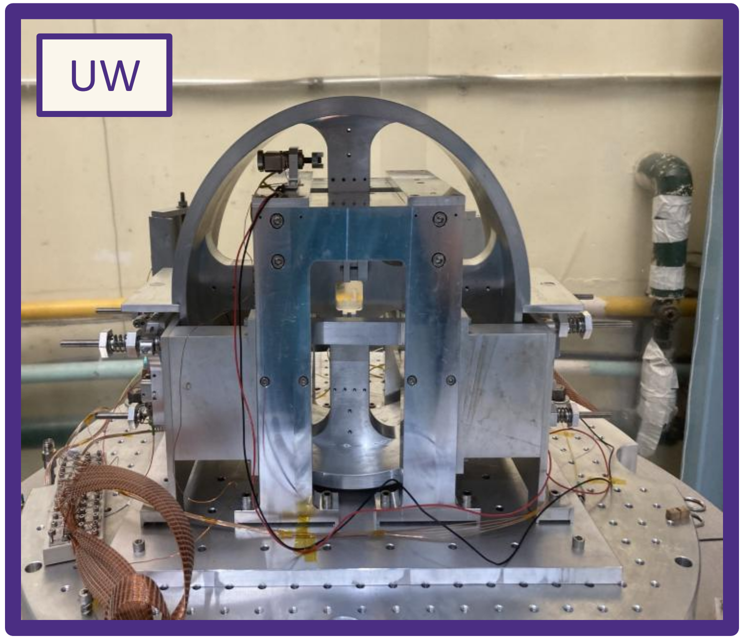
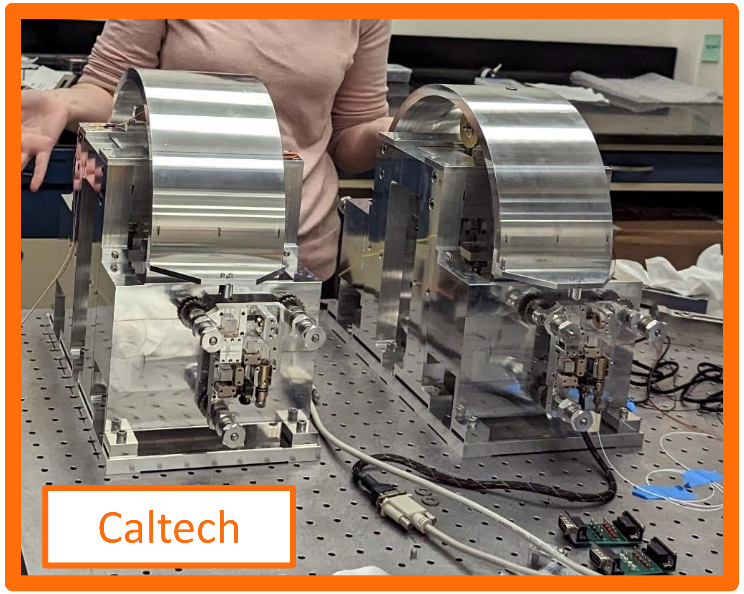
Noise Results

- V1 @ UW, V2 @ CIT (x2)
- Reaches peak sensitivity of ~5 prad
- Caltech CRS matches UW

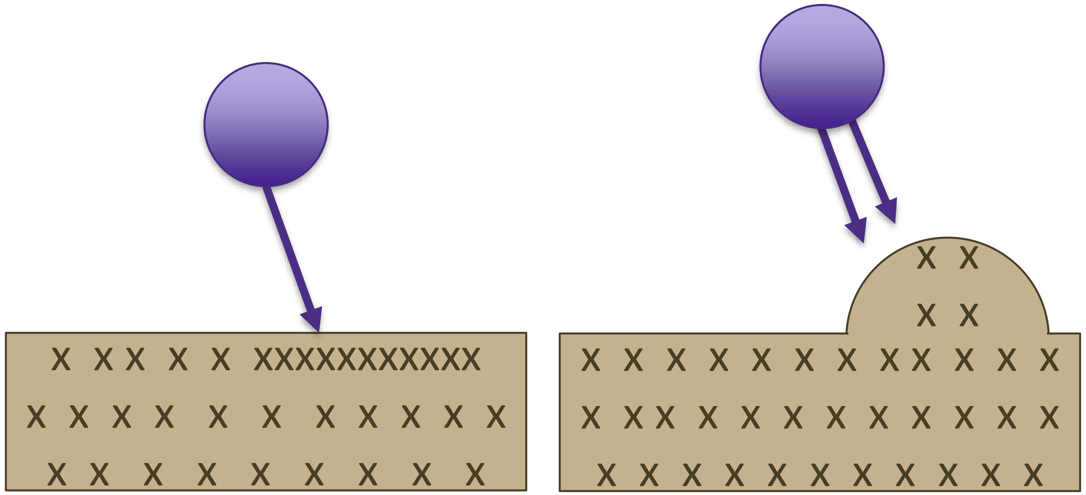






LIGO:
Rotation Sensors

- **NRS—Newtonian Rotation Sensor**
  - **Rotation sensor built to measure Newtonian Noise**
  - **Newtonian Noise is caused by acceleration on the Test Masses due to a fluctuating gravitational field**
  - **For above ground detectors (LIGO, CE, etc.), main source of NN is seismic (Rayleigh) waves**
  - **Newtonian Noise from Rayleigh waves can be derived from their tilt!**
  - **Proposed in 2016 with previous rotation sensor**



Acceleration on Test Mass Due to NN:

$$\delta\vec{\boldsymbol{a}}(\vec{r}_0,t)= 2\pi G\rho_0\,\gamma e^{-hk}\xi_z e^{i(\vec{k}\cdot\vec{\varrho}_0-\omega t)}\begin{pmatrix} i\cos(\phi)\\ i\sin(\phi)\\ -1\end{pmatrix}$$

Tilt due to Rayleigh Wave:

$$\vec{\tau}(\vec{\varrho},t) = i\,k\,\xi_z e^{i(\vec{k}\cdot\vec{\varrho}-\omega t)}\cos(\phi)$$

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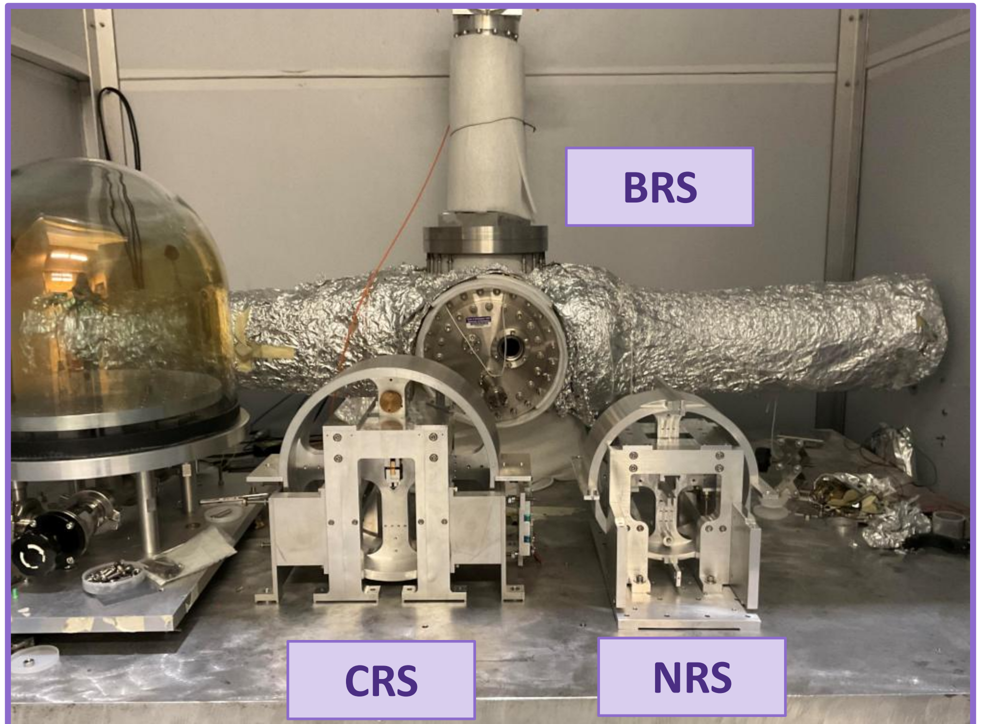
LIGO:
Rotation Sensors

- NRS—Newtonian Rotation Sensor
  - Small enough to fit below the Test Mass chambers (~3/4 of CRS)
  - Higher relevant resonance frequency (10-30Hz)→allows for smaller Proof Mass and thicker flexures (12-18 μm → 18-30 μm)
  - Prototype currently being tested/developed at UW
  - Plan: Test at Hanford next year!

Me realizing that the CRS won't fit under the BSC



Thank You

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