



# Novel Tests of Gravity Below 50 Microns

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## Motivation

Although gravitational forces are well understood at large, planetary scales, where it often acts as the dominant physical force, tests to characterize its behavior at smaller scales are much harder to accomplish. At these close distances, studies into gravitational behavior may improve our understanding of physics by identifying any discrepancies between extant physical models and real physical systems. Violations of both the Inverse Square Law (ISL) and Weak Equivalence Principle (WEP) have been predicted to occur [1-3] at the scales this experiment investigates. The goal of the Cal Poly Humboldt (CPH) Gravitational Laboratory experiment is to identify and characterize the behavior of gravity at the sub-50-micron scale where such violations would occur.

## Challenges

While investigation into gravity at this scale is scientifically valuable, it poses a few key problems. In large distance regimes, gravitational action is easy to study as it is the dominant force acting on any given body. At the short scales of interest to this experiment, gravity is overpowered by the influence of the other three fundamental forces and gravitational action becomes obfuscated. This experiment is designed around reducing and, where possible, removing these overpowering influences to better analyze purely gravitational effects.

## Methods of Experimentation

The experiment is composed of an attractor mass and a parallel-plate torsion pendulum suspended from a fiber (Fig. 1,2,3). The distance between the attractor mass and pendulum is oscillated at some frequency, characterized by capacitance measurements taken from a thin copper membrane placed between the attractor mass and the pendulum (Fig. 1,3). Oscillations in the attractor mass' distance cause an oscillation in the twisting motion of the pendulum, which is quantitatively measured by optical systems. The pendulum, polished to be highly reflective, has a laser pointed at it, which reflects off of the pendulum towards a detector as shown in Fig. 1. The deflection angle of the laser changes as the pendulum twists, resulting in the laser sweeping across the detector. To measure the minute changes in the pendulum's twisting angle, an autocollimator is used, detailed in Fig. 4. The signal is recorded in real time and read out for analysis directly to the lab data analysis computers.

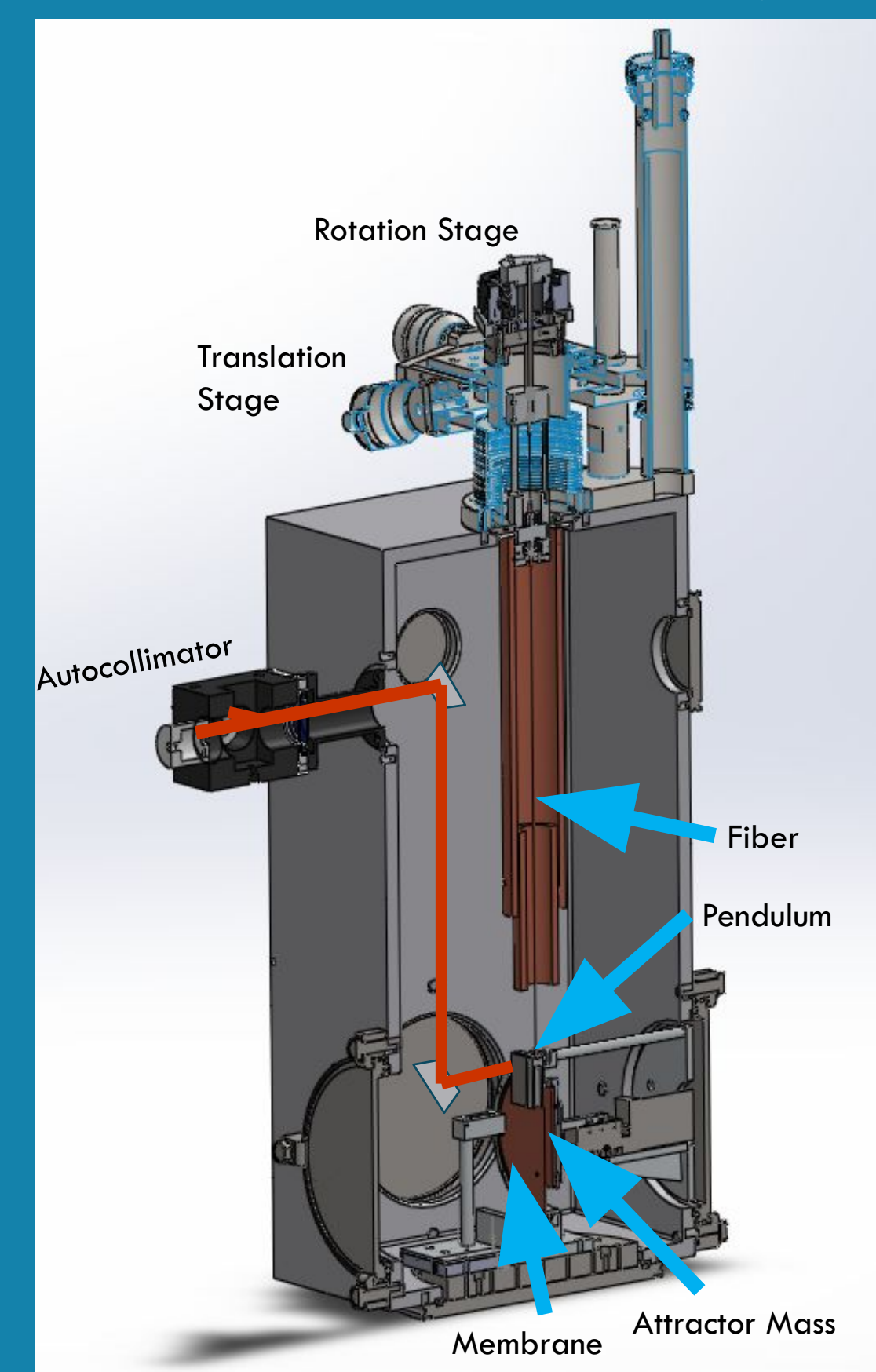


Figure 1: Model of the internal experiment

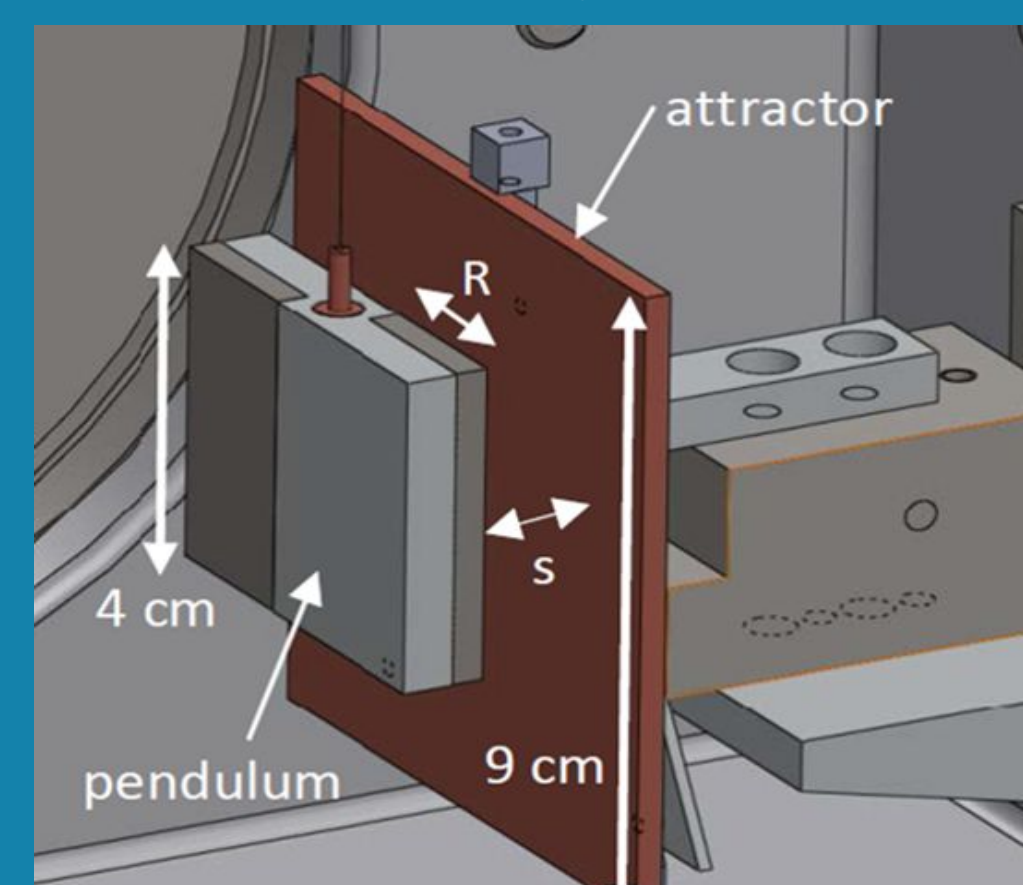


Figure 2: A close view of the pendulum and attractor. The membrane is not pictured.

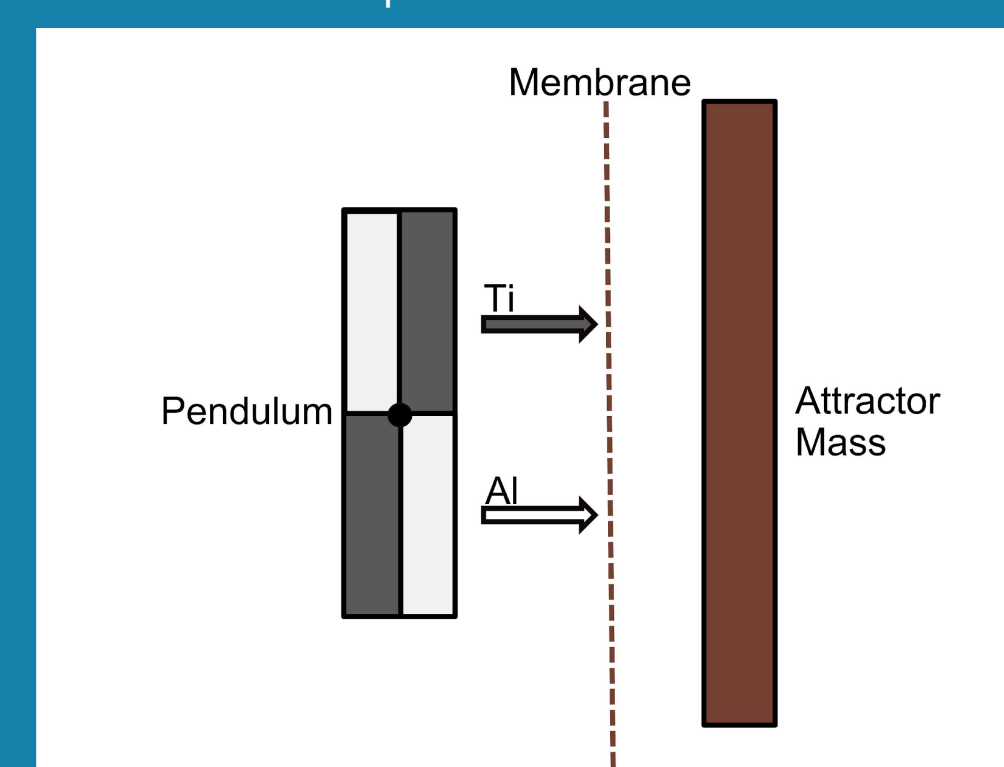


Figure 3: Top view of the composition dipole pendulum and other components.

## Controlling the Environment

To minimize the influence of aerodynamic effects and electromagnetic radiation, the torsion pendulum is suspended in a vacuum chamber, surrounded by a faraday cage, and magnetically shielded. The experimental apparatus itself is electrically grounded, tilt stabilized, and is surrounded by a temperature controlled, thermally insulated foam box.

## Tests of the WEP

As shown in Fig. 1 and 2., the pendulum is composed of two plates, titanium and aluminum. This is the basis for testing the WEP, the principle which states that two objects have the same acceleration in freefall regardless of their composition. If the WEP holds true independent of the distance, oscillating the attractor mass will not cause a composition-dependent torque as the two materials will be subject to the same gravitational force. If the pendulum experiences a composition-dependent acceleration, the WEP is violated.

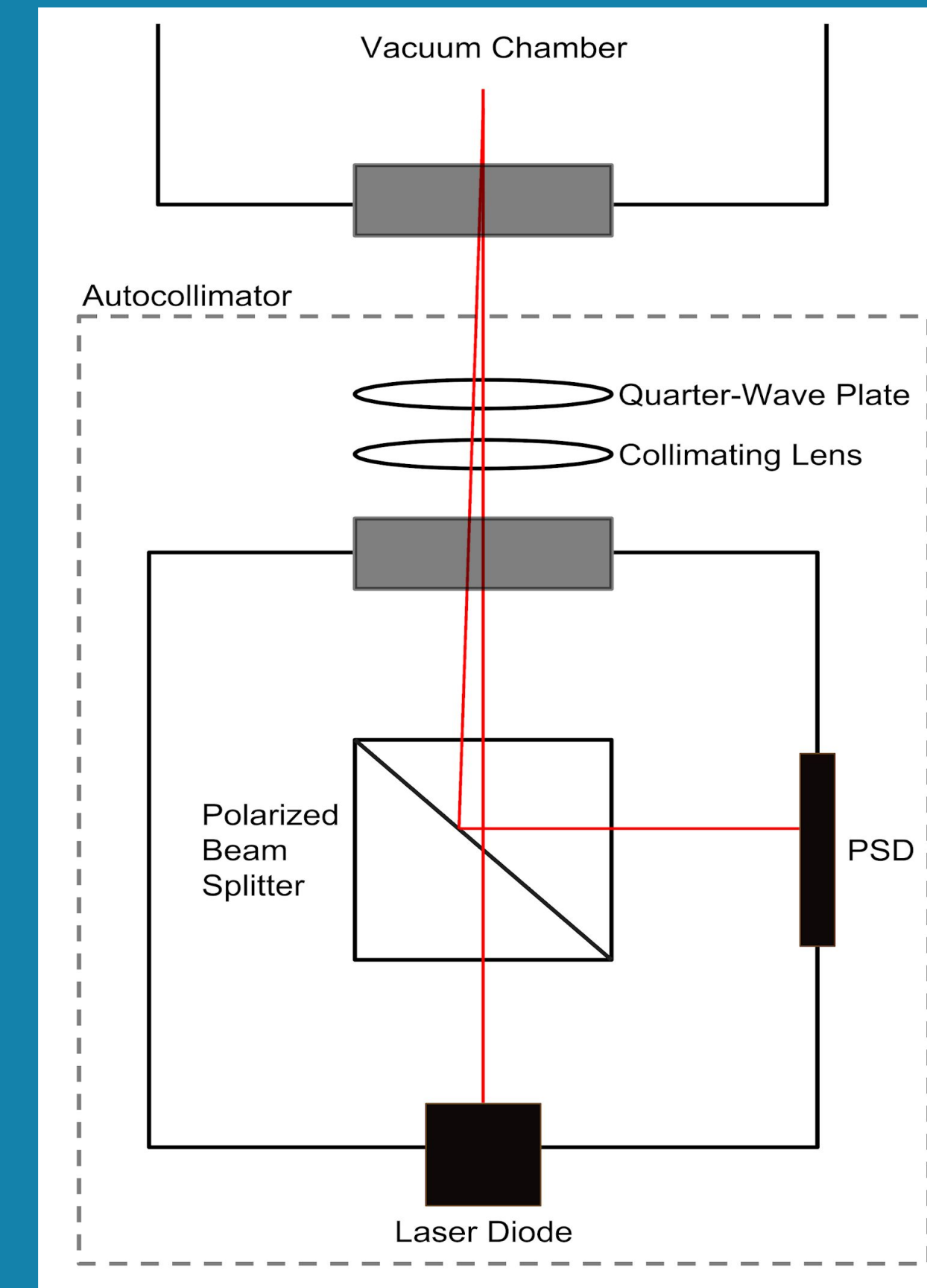


Figure 4: Shows the details of the autocollimator.

## Testing the ISL

Deviations from the ISL would be identifiable through careful analysis of our gathered data. The chosen method to quantify that deviation is to use the Yukawa potential, which adds a term to the Standard Newtonian form of the ISL which represents the deviation.

$$V(r) = -G \frac{m_1 m_2}{r} (1 + \alpha e^{\lambda/r})$$

$\lambda$  — Length scale where a deviation from ISL may occur

$\alpha$  — Strength of the potential deviation

The Yukawa potential, when used to analyze the torque response of the pendulum, allows this experiment to identify whether or not and by how much the measured motion of the pendulum differs from the predicted motion. In addition, this experiment's projected sensitivity will allow it to investigate a distance regime which has not been tested by other such projects, as shown in Fig. 5.

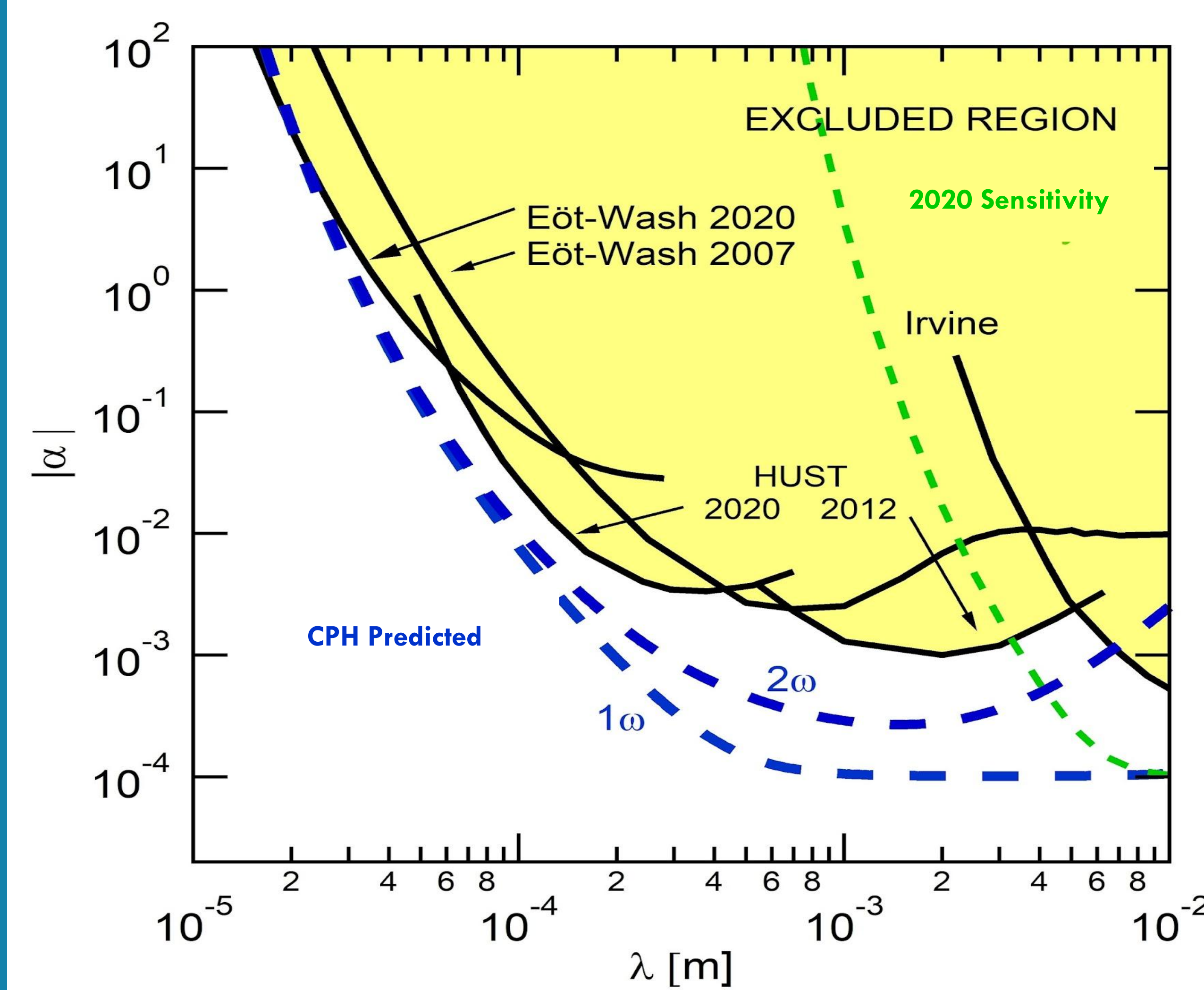


Figure 5: Results from previous experiments, shown by the curves labeled Eot-Wash [5,6], HUST [7, 8], and Irvine [9], produce the region in yellow which is excluded at the 95% confidence level. Each blue dashed line shows the predicted sensitivity of this apparatus for analyses of the first and second harmonic torque amplitudes. The green dashed line is the current expected sensitivity of the apparatus.

## Current Projects

### Python Project

Because Python 2 support ended, we needed to update all our code to Python 3. This was made easier by the python2to3 package, but several critical changes in numpy, Tkinter, and the handling of overloaded class/module variable names required some new code and manual changes. Testing has confirmed the new and old code produce the same results to a high degree of precision in many cases, but some more systematic (and single blind) testing is planned for the future to ensure there are no cases where the results meaningfully differ. The differences that do exist we believe are caused by changes in the default size of integers and related numpy changes. Current work focuses on the addition and improvement of a harmonic fit function for the main code. Previous iterations could fit data to only a single frequency after filtering out resonant motion, whereas the current iteration can accommodate the resonant frequencies of a given target.

### Magnetic Moment

In an effort to characterize the magnetic moment of the pendulum, the magnetic shield around the apparatus has been dropped and two temporary magnetic coils have been added to the insulating chamber. Voltage has been supplied to the coils, varying the amplitude of the oscillations over a given period. Multiple data runs at multiple amplitudes and periods have been taken.

### Thermal System

Because we need very precise thermal stability, we need also very precise thermal measurements. Standard commercially available thermal sensors, such as digital thermometers, are not yet good enough, so we have made our own using a thermally-dependent resistor and an op-amp. Presently we are recalibrating the sensors and redesigning the storage module for the circuitry in the hopes that the new configuration will be easier to upgrade with vacuum-compatible sensors and fit more neatly in our lab space.

### Pump Repair

Abnormalities in the vacuum chamber's pressure, manifesting as periodic jumps to a higher pressure, resulted in the partial disassembly, cleaning, and replacement of components on the roughing pump used in this experiment.



Figure 6: A photograph of a partially-disassembled roughing pump sans tip seal.

## Acknowledgements

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