The Project - What are we doing?

This project is a test of the Gravitational Inverse Square Law. The law, written down by Isaac Newton in the seventeenth century, states that the gravitational force between any two point-particles or spherical masses is, and so varies as the product of the masses and in inverse proportion to the square of distance between the center of the masses:

\[ F(r) = -\frac{G m_1 m_2}{r^2} \]

The potential energy associated with this interaction is:

\[ V(r) = -\frac{G m_1 m_2}{r} \]

In these expressions, the negative sign indicates attraction and \( G \) is the Newtonian gravitational constant.

The value of this constant implies that the gravitational force is extremely weak compared to the other known fundamental forces in nature (the electromagnetic and nuclear forces). For example, the gravitational force between a proton and an electron is about \( 10^{-40} \) Newtons. This is the question tested by the Indiana short-range experiment.

How do we describe deviations from 1/r²?

In the quantum picture, forces between particles arise from the exchange of other particles between them. The exchange of a single massless particle results in a 1/r² force. The exchange of multiple massless particles results in different power-law forces, and the exchange of a massive particle results in an exponential "Yukawa" force (which reduces to a 1/r² force in the limit that the mass of the exchange particle vanishes).

The IU Experiment – How do we do it?

• Test masses mounted on 100 micron range, which are mounted to vibration isolation stacks.
• Vibration isolation stacks: Bragg disks, Koch symmetry, or "Yukawa" force (which reduces to a 1/r² force in the limit that the mass of the exchange particle vanishes).

The Challenge – Scaling and Backgrounds

• In order to test gravity at a given range \( r \), the size of the experimental test masses must in general be scaled to that range. Otherwise, the experimental signal will be overwhelmed by the Newtonian gravitational signal arising from all the extra mass at ranges greater than \( r \).

The plot above is the Yukawa parameter space, showing experimental limits on the strength \( \alpha \) of the Yukawa force as a function of the range \( r \). In the 1790s, the best limits were obtained using torsion pendula (which measured gravity using a balance between the force due to gravity and the restoring force of a torsion pendulum). With new, thinner test masses, currently under development, we will yield an experiment sensitive to gravity at 20 microns (lower dashed curve).

In the literature, the most common way to parameterize deviations from the inverse square law is with a Yukawa-power-law, experiments usually report their results in terms of limits on the strength of the Yukawa force relative to gravity.

Central apparatus

• In addition to Newton’s claim that the inverse square law is universal:

1. Current experimental limits allow for new forces in some millicorns of force stronger than gravity over the distances involved in the experiment.
2. Specific predictions of new forces arise in many models that attempt to describe gravity and the other fundamental forces in the same theoretical framework, including:
   - modified gravity and dilaton theories, which are predicted by string theory (1)
   - signatures of extra spacetime dimensions, in which gravity alone "leaves" and appears weaker than the other forces (2)

The plot above is the Yukawa parameter space, showing experimental limits on the strength of a hypothetical new interaction as a function of the range \( \lambda \) and the "short" range \( \lambda_s \) for gravity (1 cm = 1.0 m). This experimentally excluded region is above and to the right of the solid blue curve. In the range above 100 m, the limits are defined by "Classical" gravity measurements using torsion pendula to the original Cavendish experiment (which first measured the Newtonian constant \( G \) in 1798). Below a few microns, the best limits derive from atomic force microscopy experiments, and experiments used to measure the Casimir force, a force which arises between conductors due to zero-point fluctuations of the electromagnetic field. The initial limits from the Indiana short-range experiment (originally at the University of Colorado) are also indicated(3).

References


Current and Projected Limits – Where are we going?

• Current preliminary limits (20 cm) on order of best published limits to date, gap uncertainties remain.
• With new, thinner shield, one day of running will result in limits more sensitive than the current best limit by 1-2 orders of magnitude at the 10 micron range (upper dashed curve).
• A cryogenic experiment (operated at T = 0 K) with thinner test masses, currently under development, will yield an experiment sensitive to gravity at 20 microns (lower dashed curve).
• Both projections assume the thermal noise limit can be attained, with all other backgrounds controlled.