Null Test of Newton's Law at 1 m

New weakly interacting particles have been proposed to solve remaining puzzles in gravity and particle physics. Many of these theories predict a departure of the gravitational $1/r^2$ law in the form:

$$\phi(r) = -\frac{GM}{r}\left[1 + \alpha \exp\left(-\frac{r}{\lambda}\right)\right], \tag{1}$$

where α and λ are the dimensionless strength and the range of the Yukawa potential. The Poisson equation for the potential is now replaced by

$$\nabla^2\phi = 4\pi G\rho - \frac{GM}{r}\frac{\alpha}{\lambda^2}\exp\left(-\frac{r}{\lambda}\right). \tag{2}$$

This suggests a *null* test of the $1/r^2$ law: If the $1/r^2$ law is valid, $\nabla^2\phi$ must vanish outside the source (ρ = 0). The Laplacian of the potential is the trace of the gravity gradient tensor Γ_{ij}. Therefore, by summing the outputs of a three-axis in-line-component gradiometer in response to a locally generated time-varying gravity field, one can perform a null test of Newton's $1/r^2$ law [Paik, 1979].

We have carried out a series of laboratory tests of the $1/r^2$ law using our SGG as a null detector [Chan *et al*, 1982; Moody *et al*., 1993]. Figure 1 shows the source-detector configuration. The source was a 1500 kg lead (Pb) pendulum suspended from the laboratory ceiling. The three-axis Model II SGG was used as the detector in the latest experiment. The gradiometer was in the "umbrella orientation," in which all three sensitive axes make the same angle, 54.7°, with respect to the vertical.

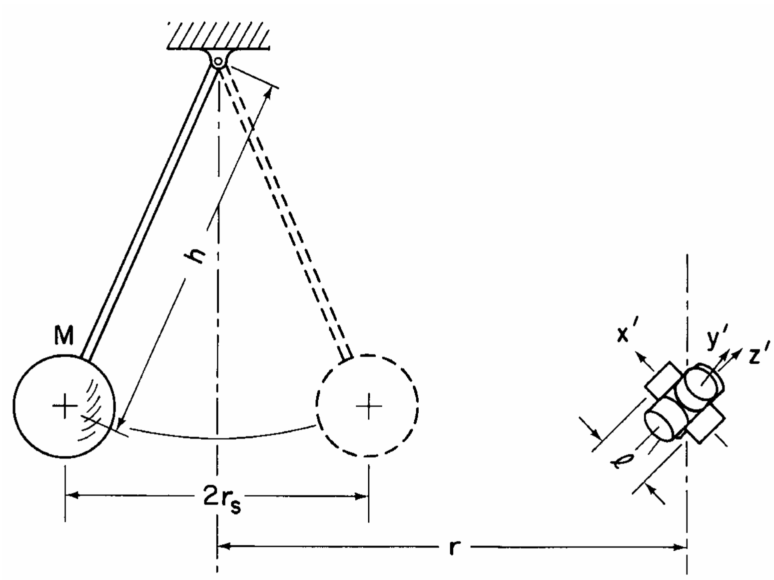

Figure 1. Source-detector configuration for the test.

In order to match the scale factors for the three orthogonal gradients, the SGG was rotated about the vertical into three azimuthal positions separated by 120 degrees, and each gradiometer output was summed over the three positions. This method has the additional advantage of averaging out the horizontal components of all acceleration errors by symmetry [Park, 1990].

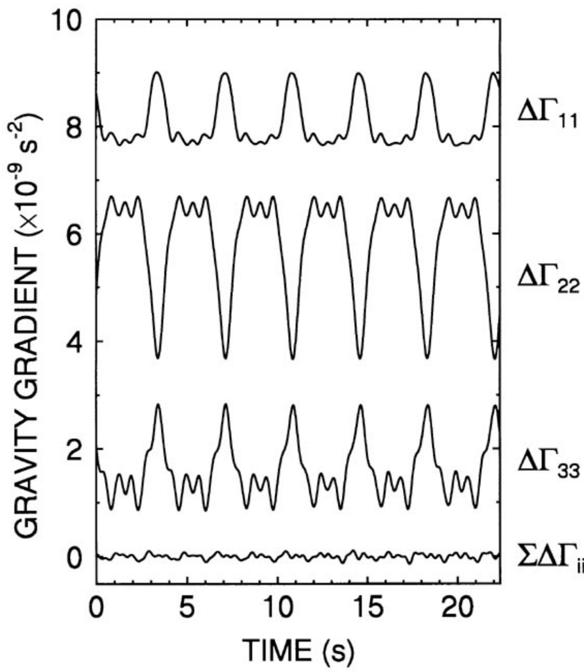

Figure 2. Inverse-square law data.

Figure 2 shows the outputs of one of the SGG axes in three orientations over six pendulum cycles and their sum. Data were collected and analyzed over 33 nights to obtain the final result of $(0.58 \pm 3.10) \times 10^{-13}$ m s^{-2}. This null result has been used to obtain upper limits of α as a function of λ.

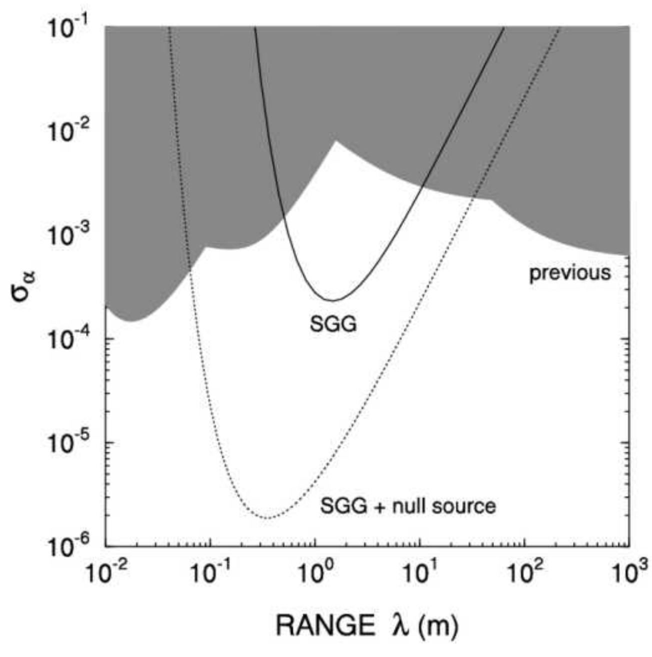

Figure 3. Resolution of our null experiment.

Figure 3 shows the 1σ error in α plotted as a function of λ. The shaded region is the excluded parameter space set by previous experiments. Our experiment has improved the limit of the $1/r^2$ law by more than an order of magnitude at a 1.5 m distance. The dotted line represents the potential resolution of a future experiment where a cylindrical shell is used as a null source.

Chan, H. A., Moody, M. V., and Paik, H. J. (1982), *Phys. Rev. Lett.* **49**, 1745-1748.
Moody, M. V. and Paik, H. J. (1993), *Phys. Rev. Lett.* **70**, 1195-1198.
Parke, J. W. (1990), Ph. D. thesis, University of Maryland, College Park, Maryland.