

# EXPERIMENTAL EVIDENCE AGAINST REPULSION IN HOLLOW SPHERICAL SHELLS\*

Tom Martin  
Gravity Research Institute  
Boulder, Colorado 80306-1258  
martin@gravityresearch.org

## *Abstract*

*We have performed a simple version of the hollow shell Cavendish experiment. We were unable to detect the characteristic repulsive force which is logically implied when one assumes the boundary condition of continuity of flow across material interfaces in spatial flow theories of gravity. We conclude that this boundary condition is not in agreement with physical reality (rather than taking the much stronger position that spatial flow theories are necessarily wrong).*

## 1. Introduction

Some of our recent theoretical work [1,2,3] has been exploring the possibility that gravitation might be related to the flow of space into or out of gravitational attractors such as planets and laboratory-sized objects. We have compared this possibility to the more familiar General Relativistic explanation which envisions space as being essentially static and curved in the vicinity of such attractors and also to the approximate Newtonian action-at-a-distance model of attraction. In our most recent article on this subject [4], we uncovered the implication that, if one makes the fundamental assumption that the flow of space is necessarily continuous across material boundaries, spatial flow theories predict an unexpected and yet characteristic *repulsive* gravitational force in the interior of any homogeneously dense hollow spherical shell of ordinary matter. This result is in rather striking contrast to the Newtonian or General Relativistic theories which predict a diminishing attraction all the way to the cavity of the shell. The predicted repulsive force appears to be rather independent of the particular mathematical equations one might use to model the flow, because its relative strength and spatial distribution seem to be

---

\* <http://www.gravityresearch.org/pdf/GRI-011011.pdf>

logically necessary just on the basis of the spherical symmetry of the flow and the assumption that the flow speed must decrease to zero at the surface of the cavity if there is continuity of flow at such interfaces. In the type of spatial flow theories we have considered, the gravitational force (the force per unit of test mass) is caused by the spatial acceleration of the flow (the inhomogeneity of the flow). As a consequence, the repulsive force one expects to measure as one approaches the shell's cavity is larger in magnitude than the attractive force at the outer surface of the shell. This is because the speed of the flow must diminish rapidly to zero *entirely within the shell*, whereas in contrast, the speed increases rather slowly from zero at infinitely distant points to moderate values at points near the shell's outer surface in the case of the familiar exterior attraction.

Since the repulsive force is expected to be relatively strong (and hence easily measurable), and since it might be a surprising and distinguishing feature of spatial flow theories when compared to the continually diminishing *attractive* force within the interior of a hollow spherical shell which is predicted by Newtonian gravitational theory and General Relativity, we have designed and constructed a simple experiment to attempt to measure it. Our experiment is a static version of the hollow shell Cavendish experiment which was extensively discussed in reference [4]. It observes the forces on a constrained test mass rather than observing the overall motion of a freely moving test mass. We will describe the components of the experiment in Section 2. The details of a typical measurement sequence will be given in Section 3.

The results of the experiment appear to be decisive. We were unable to detect any repulsive forces anywhere within the hollow spherical shell even though the apparatus had about five or ten times the sensitivity needed to observe them. As will be discussed in Section 4, we are inclined to conclude that *the assumption that the flow of space is continuous across material boundaries is not in agreement with physical reality*. This conclusion leaves the possibility of spatial flow theories intact, but it also increases the challenge of explaining why space should "flow" in the rather odd way that it does.

## 2. The Hollow Shell Apparatus

Photograph (2-1) shows the overall setup of our hollow shell experiment. We see the base pedestal, the shot cylinder box, the Tel-Atomic torsion balance<sup>1</sup> (which is mounted on top of the shot cylinder box), and some of the electronics associated with the experiment.



(2-1)

The base pedestal is capable of containing up to 10 cubic feet of sandstone rock and is used for the purpose of mechanical stabilization. It rests on a concrete floor.

The shot box is our method of fabricating a simple hybrid cylindrical/spherical hollow shell source for the experiment. It consists of a raised wooden cube inside of which a 10 foot roll of aluminum sheet is allowed to expand to a diameter of about 9 inches. The aluminum sheet is 10 inches wide, and the resulting inscribed cylinder is

---

<sup>1</sup>The Tel-Atomic torsion balance is manufactured primarily as a pedagogical device, but our experience with it has demonstrated that it is also a very good research tool. For detailed information about the balance, see <http://www.telatomic.com/sdct1.html> .

filled to a height of 9 inches with 133.5 pounds of #9 gauge lead shot. This is shown clearly in photograph (2-2).



(2-2)

One can see the symmetric differential capacitive bridge circuit boards in the lower central part of the Tel-Atomic torsion balance. These provide a stable and sensitive readout of the horizontal angular deflection of the balance. Their associated output voltage is read by a digital multimeter PC interface which allows one to comfortably observe and record the various phases of the experiment on a personal computer which is located about 40 feet from the base pedestal. In this balance, an aluminum beam is suspended from a 25 micron tungsten wire, and the beam is free to rotate in a horizontal plane between the circuit boards. It has a typical period of oscillation of about 3.5 minutes. At the extremities of this beam, one can see two small spherical lead calibration test masses which we use in conjunction with the much larger 1 kg lead balls for the purpose of calibrating the torsion balance. The larger 1 kg lead balls are located on a beam of their own which can be rotated into clockwise and counter-clockwise calibration positions. In (2-2), they are shown in their null or neutral calibration position. Our simple calibration procedure allows us to bypass the determination of the actual physical parameters of the torsion wire and the balance beam oscillator (this procedure is described in Section 3).

One can also see that the torsion balance has been modified on its right-hand side with a 1/2 inch diameter thin wall vertical brass tube. This tube reaches a little more than half way down into the interior of the lead shot source and allows a 2.93 gm spherical lead test mass to be suspended by a thin woven nylon cord from the upper right-hand

calibration test mass so that the interior gravitational forces within the central horizontal plane bisecting the cylinder of shot can be measured. The nylon cord is a very rigid connection to the torsion beam for the small forces involved in turning the beam. The restoring force of the beam at the radius of the test masses due to the angular torquing of the torsion wire is typically on the order of  $10^{-10}$  newtons (a small fraction of a microgram weight-equivalent). The sum of the masses of the right-hand calibration test mass, the mass of the nylon cord, and the 2.93 gm test mass is made equal to the mass of the left-hand calibration test mass so that the torsion beam remains balanced on the tungsten suspension wire and properly positioned within the angular readout circuit boards.

At the (vertical as well as the horizontal) center of the cylinder of shot is a 2 inch diameter #24 gauge thin wall copper spherical float which is used to create the cavity of the shell. This is shown in photograph (2-3). It has a 3/8 inch diameter thin wall brass filler tube on its top which allows the cavity to be filled with #9 lead shot. It also has a similar tube on its bottom which is used to empty the cavity of shot when a small rubber stopper is removed. The shot flows in and out of the cavity as a well-behaved fluid.

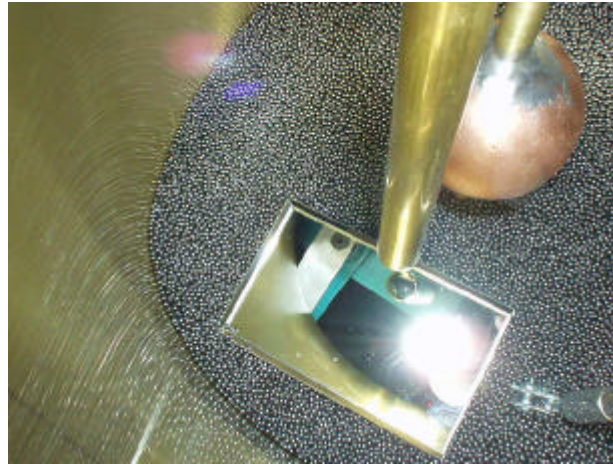


(2-3)

In (2-3), one can see the vertical brass tube extending down from the torsion balance in a typical position on the left of the copper cavity. The tube has a simple nylon bottom cap to protect it from the shot. The center of the 2.93 gm test mass inside this tube is located in the central horizontal plane which bisects the cavity. The essential concept here is that the horizontal plane through the center of the cavity is the same as a plane through the center of a hollow spherical shell. To a high degree of approximation, a small test mass in this horizontal plane (i.e., the 2.93 gm test mass) will experience the

same forces as it would in a plane through a hollow spherical shell of the same dimensions. We are able to measure the forces inside a spherical shell by using a slice of a spherical shell which is inscribed in a cylinder. Hence, we have progressed from cube to cylinder to spherical shell. (The lead shot in this photograph has not been leveled, and there is distortion of the appearance of the circular shape of the aluminum cylinder caused by the rather wide angle of the camera lens.)

There are brass leveling screws and nuts on the bottom legs of the shot box, and ultimately, these are used in conjunction with a mirror to center the 2.93 gm test mass as a plumb bob inside the 1/2 inch vertical tube. Photograph (2-4) shows the test mass being centered in the tube.



(2-4)

### 3. A Typical Measurement

This experiment was designed to determine whether or not the hollow shell shows evidence of interior repulsive gravitational forces of the type and magnitude as those which were discussed extensively in reference [4]. It is a qualitative experiment rather than a precision quantitative experiment. Hence, we will not concern ourselves with the errors associated with the numerical values of the various physical parameters.

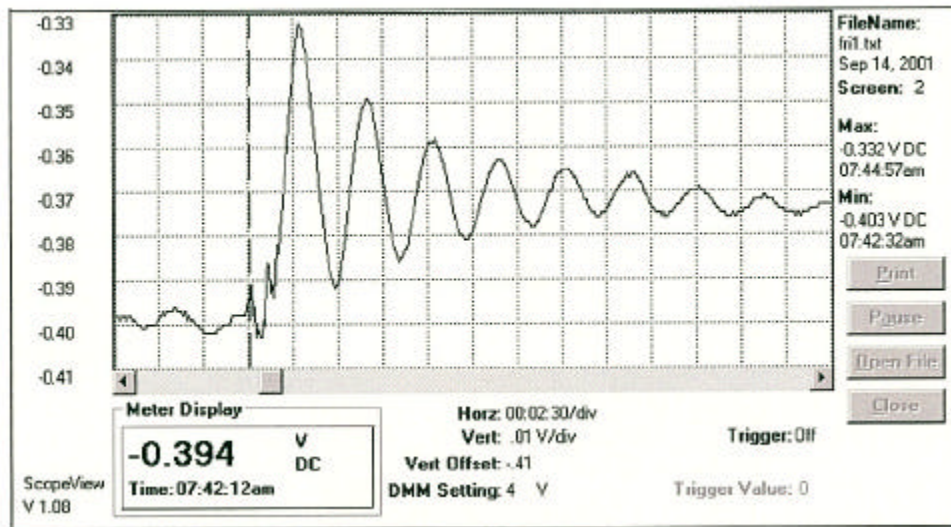
We looked for repulsive forces on the 2.93 gm test mass at several radial distances from the copper cavity starting from a position where the vertical test mass tube was just touching the cavity and proceeding on outward. In this Section, we report the results of a typical set of measurements when the center of the tube (and therefore the center of the

test mass) was located 4.8 cm from the center of the cavity. This corresponds to a relative radius of 0.43 for the position of the test mass in a shell whose relative cavity radius is 0.23 times the size of the overall shell.

The basic measurement procedure is straightforward. According to the spatial flow theory, there will be no repulsive forces anywhere in the region beyond the cavity when the cavity is *filled* with shot. In this case, we have an approximately homogeneous sphere (which is actually inscribed in our cylinder of shot), and the internal gravitational behavior of such a sphere coincides with the predictions of ordinary Newtonian theory (diminishing attraction all the way to the center). Thus, we have merely to 1) have our 2.93 gm test mass positioned at a given distance (4.8 cm) from the *filled* cavity, 2) calibrate the torsion balance to establish how much force causes how much angular deflection (and corresponding voltage output), and then 3) *empty* the cavity and measure the supposed resulting repulsive force acting on the 2.93 gm test mass.

The calibration of the torsion balance is in all cases carried out by means of the two 1 kg lead balls (actually equal to 1.04 kg each) acting on the two internal calibration test masses inside the torsion balance. When the 1 kg balls are rotated on their beam to their maximum clockwise or counter-clockwise positions, the centers of the balls are approximately 4.6 cm from the centers of the calibration test masses. The angular deflection of the torsion balance which is caused by moving the balls between their maximum clockwise and counter-clockwise positions is read out by the symmetric differential capacitive bridge and appears as a recorded voltage by means of the computer interface. (The actual angular deflection visually appears to be not more than a degree or two.) The calibration deflection voltage for the measurement we are considering in this Section is shown in figure (3-1). It shows the effect of having rotated the beam with the 1 kg balls from its maximum counter-clockwise position to its maximum clockwise position at 7:42 A.M. on the day of the measurement sequence. This sudden step-function type change in the forces on the calibration test masses causes the balance beam to oscillate. The oscillations decay exponentially over time. One can see that the final voltage increment corresponding to the change in calibration positions is about +0.03 volts (there was a thermal drift of about -0.01 volts in 40 minutes in this particular measurement sequence due to early morning environmental changes). Note the initial mechanical disturbance after the calibration beam was turned.

Let us determine the total force increment acting on the calibration test masses which corresponds to the calibration voltage deflection of +0.03 volts in figure (3-1). The mass of the left-hand calibration test mass was determined to be 14.54 gm, and the right-hand one was 11.59 gm. Thus, the force acting on the left-hand test mass



(3-1)

due to the 1.04 kg ball at the separation distance of 4.6 cm is

$$F_{left} = \frac{GMm}{r^2} = \frac{(6.67 \times 10^{-11})(1.04)(14.54 \times 10^{-3})}{(4.6 \times 10^{-2})^2} = 4.77 \times 10^{-10} \text{ newtons.}$$

The force acting on the right-hand test mass is

$$F_{right} = \frac{GMm}{r^2} = \frac{(6.67 \times 10^{-11})(1.04)(11.59 \times 10^{-3})}{(4.6 \times 10^{-2})^2} = 3.80 \times 10^{-10} \text{ newtons.}$$

Neglecting the forces of the 1 kg balls on the more distant opposite test masses, the final deflection of approximately +0.03 volts in figure (3-1) corresponds to twice the sum of the forces  $F_{left}$  and  $F_{right}$ , and this equals  $1.71 \times 10^{-9}$  newtons. This result gives us a rough calibration of the torsion balance for this particular measurement sequence.

Next, we determine the magnitude of the repulsive force we expect to observe acting on the 2.93 gm test mass when the rubber stopper is pulled and the cavity is allowed to empty. We use equation (4-7b) of reference [4] to determine the force per unit mass  $g$  at the distance  $r$ :

$$g(a \leq r \leq b) = 2p Gm \left( \frac{2a^3}{3r^2} - \frac{2}{3}r + \frac{ab(a+b)}{r^2} \right)$$

where

$a \equiv 2.54 \times 10^{-2}$  meters (the radius of the cavity)

$b \equiv 11.11 \times 10^{-2}$  meters (the radius of the shot cylinder)

$r \equiv 4.8 \times 10^{-2}$  meters (the radial position of the test mass)

$m \equiv 5.60 \times 10^3$  kg/meter<sup>3</sup> (the measured density of the lead shot)

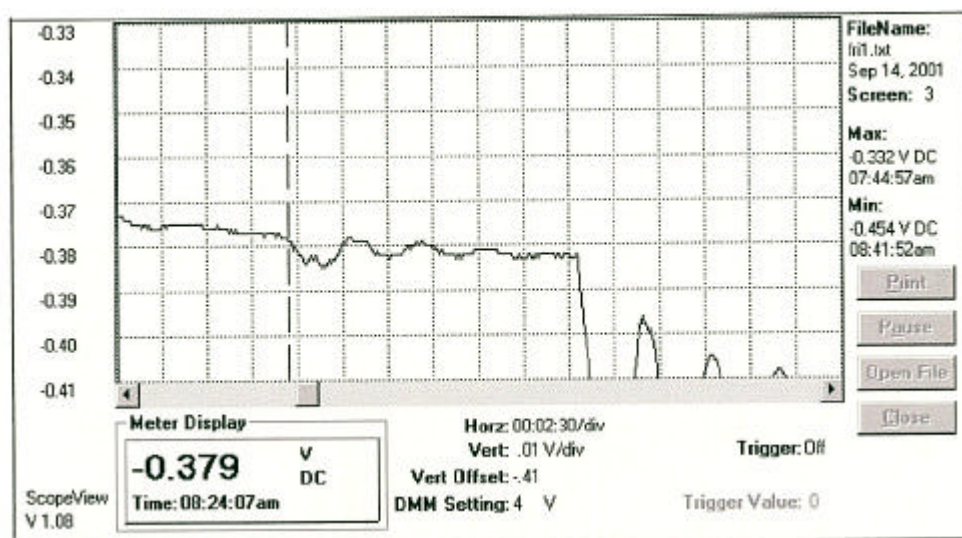
$G \equiv 6.67 \times 10^{-11}$  newton meter<sup>2</sup> / kg<sup>2</sup> (the gravitational constant) .

We find that

$$g = 3.26 \times 10^{-7} \text{ newton/kg ,}$$

and this results in a force of  $9.55 \times 10^{-10}$  newtons on the 2.93 gm test mass. Since the calibration deflection in figure (3-1) corresponds to a force of  $1.71 \times 10^{-9}$  newtons, we can expect the repulsion predicted by the spatial flow theory to cause about half of this deflection when the cavity is emptied.

In fact, we observed no such deflection. Figure (3-2) shows the record of the event of emptying the cavity at 8:24 A.M. One observes an initial mechanical disturbance

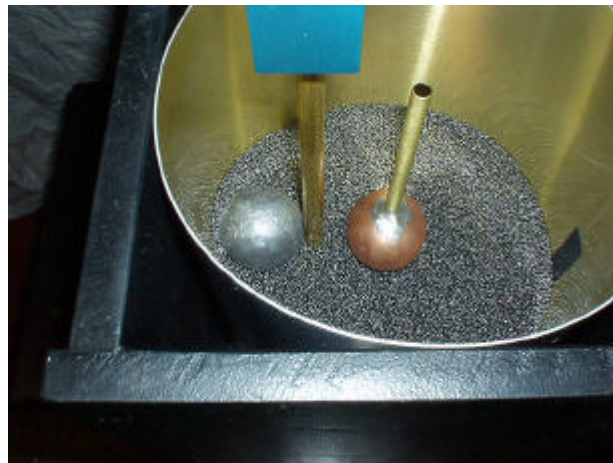


(3-2)

caused by the emptying procedure and a little resulting oscillation of the torsion beam, but there is no detectable deflection at all (the thermal drift mentioned earlier is still present). Just after 8:31 A.M., the calibration beam with the 1 kg balls was rotated back to its maximum counter-clockwise position. Emptying the cavity should have produced approximately half this deflection (roughly -0.015 volts).

From the Newtonian perspective, one might expect to see the reduction in the Newtonian attraction due to the evacuation of the cavity. This would be observed as a "repulsion". But the effect turns out to be too small to observe at the level of sensitivity of the experiment. The center of the 2.93 gm test mass is 4.8 cm from the center of the cavity, and the mass of the lead shot in the cavity is  $3.84 \times 10^2$  gm. The resulting Newtonian attraction is only  $3.26 \times 10^{-12}$  newtons, and this is equivalent to only about two thousandths of the calibration deflection.

In this measurement sequence, as in some others, we ran a control experiment to make sure the 2.93 gm test mass was working in the expected manner. The lead shot was removed from the shot cylinder down to a level where it could be conveniently used to support one of the 1 kg lead balls when it was placed next to the 2.93 test mass in its tube. This configuration is shown in photograph (3-3). The distance between the centers of the 1 kg ball and the 2.93 gm test mass was 3.38 cm. This produced a force of



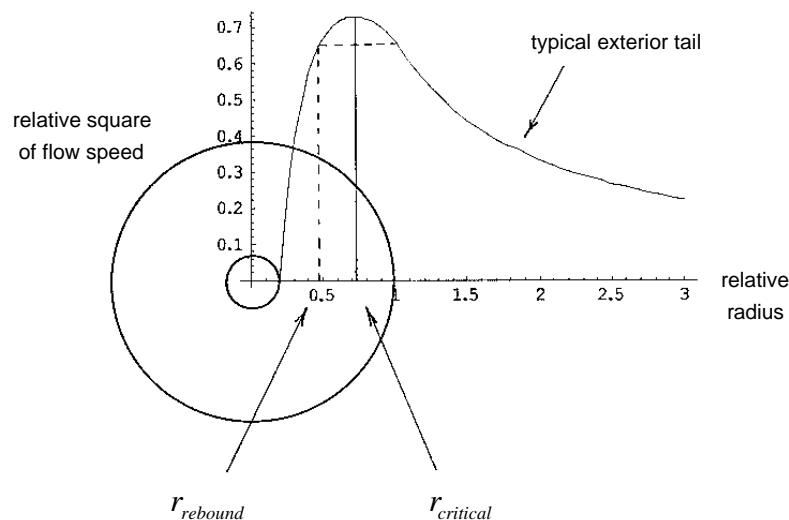
(3-3)

$1.71 \times 10^{-10}$  newtons acting on the test mass, and this force could be removed by simply removing the 1 kg ball. The resulting voltage deflection was observed to correspond

correctly to the predicted deflection. Since the deflection in this easily observable control experiment was about one tenth the strength of the calibration deflection and about one fifth the strength of the deflection expected from the repulsion predicted by the spatial flow theory, we were able to use it to estimate the sensitivity level of the overall experiment. As mentioned in Section 1, we had five to ten times the sensitivity needed to observe the repulsion if it had been present.

#### 4. Discussion and Conclusion

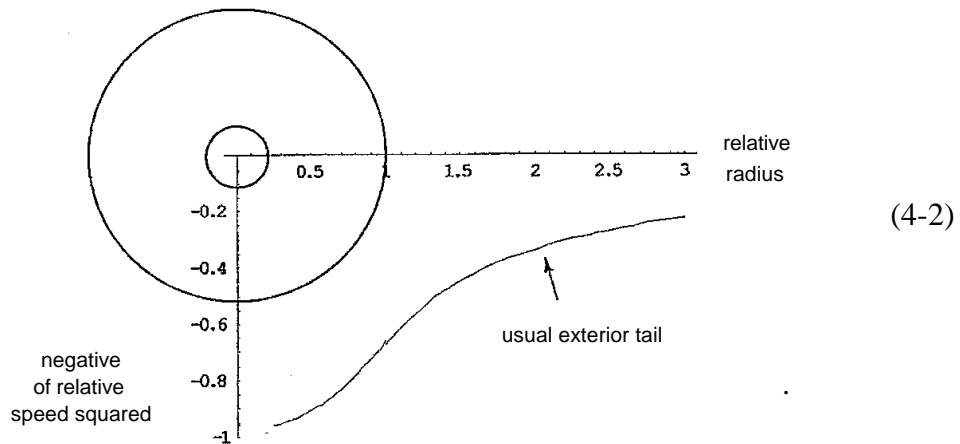
The sum total of our measurements leaves us with no doubt that repulsive forces (as large as those expected) do not exist in the interiors of hollow spherical shells. In view of the claims made in reference [4], we should be forced to conclude that spatial flow theories of gravity are wrong and that the Newtonian and General Relativistic theories prevail. However, there is a hitch which allows us to backpedal a little bit. On page 13 of reference [4], we mentioned the fact that we were making the fundamental assumption that the flow of space is everywhere continuous. Since the speed of the flow inside the cavity of the shell must be zero (by spherical symmetry), this continuity requirement implied that the flow inside the shell itself had to rapidly diminish to zero as one approached the cavity. This implication led to the conclusion that the graph of the square of the speed of the flow throughout the shell and beyond must always look something like that of figure (4-6) on page 14 of reference [4] (which we reproduce here):



(4-1)

However, is it correct to assume that the flow of space is continuous at material boundaries? Perhaps not. In spatial flow theories in which matter obviously acts as a source or sink of space, it would only seem natural to consider the possibility of having discontinuities at such interfaces.

We could drop the continuity assumption at material boundaries and assert the validity of a spatial flow theory of gravity where the speed of the flow associated with a hollow spherical shell gives rise to the usual diminishing attraction predicted by Newton's action-at-a-distance formulation. In this case, the graph of the (negative) of the square of the speed of the flow would have to be roughly the same as that of the Newtonian potential of the shell which appeared in figure (3-9) on page 10 of reference [4] (except that the speed would be zero inside the cavity):



We should explicitly mention that this flow could not simultaneously be a spatial flow solution of Einstein's field equations for a spherical shell of *ordinary* matter (for the very reasons we carefully laid out in Section 2 of reference [4]). In other words, we might have a spatial flow theory of the shell of ordinary matter which correctly mimics the predicted Newtonian behavior, but it would not lead to a spatial flow metric which is consistent with General Relativity.

If we take this dubious position, we are left with the daunting challenge of explaining why space must "flow" in this rather peculiar manner. We would have to sarcastically add that finding such an explanation would be no greater challenge than finding an answer to the question of why the exterior flow speed diminishes with the inverse *square*

*root* of the radial distance. This deep and unresolved mystery has been with us from the start.

It is not our desire to defend the viability of spatial flow theories by concluding that the continuity boundary condition is not in agreement with the experimental facts. However, unless someone can come up with an explanation of why it is indubitably necessary for the flow of space to be continuous at material interfaces, we have simply taken the implications of the results of the experiment as far as they can honestly be taken.

### Acknowledgement

Thanks again to Harold and Helen McMaster whose generosity helped make this work possible.

### References

- [1] Tom Martin, *Testing the Boundary Conditions of General Relativity Near the Earth-Sun Saddle Point*, <http://xxx.lanl.gov/abs/gr-qc/9806033>
- [2] Tom Martin, *On the Motion of Free Material Test Particles in Arbitrary Spatial Flows*, <http://xxx.lanl.gov/abs/gr-qc/9807006>
- [3] Tom Martin, *General Relativity and Spatial Flows: I. Absolute Relativistic Dynamics*, <http://xxx.lanl.gov/abs/gr-qc/0006029>
- [4] Tom Martin, *General Relativity and Spatial Flows: II. The Hollow Shell Cavendish Experiment*, <http://www.gravityresearch.org/pdf/GRI-010515.pdf>