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Updating the Theoretical Analysis of the Weak Gravitational Shielding Experiment.

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Abstract

The most recent data about the weak gravitational shielding produced recently through a levitating and rotating HTC superconducting disk show a very weak dependence of the shielding value ($\sim 1\%$) on the height above the disk. We show that whilst this behaviour is incompatible with an intuitive vectorial picture of the shielding, it is consistently explained by our theoretical model. The expulsive force observed at the border of the shielded zone is due to energy conservation.

74.72.-h High-T_c cuprates.

04.60.-m Quantum gravity.

The measurements of Podkletnov et al. of a possible weak gravitational shielding effect [1, 2] have been repeated several times and under different conditions by that group, with good

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reproducibility, including results in the vacuum. In the forthcoming months other groups will hopefully be able to confirm the effect independently. While the Tampere group was mainly concerned with obtaining larger values for the shielding, studying its dependence on numerous experimental parameters and testing new materials for the disk, in the future measurements it will be important to obtain more exact data, including detailed spatial field maps. The theoretical model suggested by us [3] is still evolving, although at a fundamental level; a more detailed account appears elsewhere [4].

Let us recall in short the main features of the experiment. A HTC superconducting disk or toroid with diameter between 15 and 30 cm, made of $YBa_2Cu_3O_{7-x}$, is refrigerated by liquid helium in a stainless steel cryostat at a temperature below 70 K. The microscopic structure of the material, which plays an important role in determining the levitation properties and the amount of the effect, is described in details in the cited works.

The disk levitates above an electromagnet and rotates by the action of lateral alternating e.m. fields. Samples of different weight and composition are placed over the disk, at a distance which can vary from a few cm to 1 m or more (see below). A weight reduction of about 0.05% is observed when the disk is levitating but not rotating; the weight loss reaches values about 0.5% when the disk rotates at a frequency of ca. 5000 rpm. If at this point the rotating fields are switched off, the sample weight remains decreased till the rotation frequency of the disk decreases. On the other hand, if the rotation frequency is decreased from 5000 to 3500 rpm using the solenoids as breaking tools, the shielding effect reaches maximum values from 1.9 to 2.1%, depending on the position of the sample with respect to the outer edge of the disk.

This effect, if confirmed, would represent a very new and spectacular phenomenon in gravity; namely, as well known, there has never been observed any conventional gravitational shielding up till now, up to an accuracy of one part in 10^{10}, and General Relativity and perturbative Quantum Gravity exclude any measurable shielding [3]. Our temptative theoretical explanation is based on some properties of non-perturbative quantum gravity. We have shown that the density field $|\phi_0|^2$ of the Cooper pairs inside the superconductor or, more likely, the squared gradient $(\partial_\mu \phi_0)^*(\partial^\mu \phi_0)$ may act as localized positive contributions to the small negative effective gravitational cosmological constant Λ; if the sum turns out to be positive in a certain four-dimensional region, a local gravitational singularity arises there, affecting the gravitational propagators and thus the interaction potential (between the Earth and the samples, in this case).

To sketch our model – although not rigorously – we could say that there is an "anomalous coupling" between the mentioned density $|\phi_0|^2$ or the squared gradient $(\partial_\mu \phi_0)^*(\partial^\mu \phi_0)$ and the gravitational field, and that the net result is to partly "absorb" the field. We expect that only in some regions of the superconductor the density $|\phi_0|^2$ or the squared gradient will be strong enough and that the inhomogeneities of the material and the pinning centers will be crucial in determining such regions. Since the gravitational field is attractive, its "absorption" requires energy from the outside. This means that there must be some mechanism external to the disk which *forces* $|\phi_0|^2$ or $(\partial_\mu \phi_0)^*(\partial^\mu \phi_0)$ to take high values. This is caused in the experiment by the action of the external electromagnetic field and by the disk rotation.

The dependence of the shielding effect on the height, at which the samples are placed above the superconducting disk, has been recently measured up to a height of ca. 3 m [5]. No difference in the shielding value has been noted, with a precision of one part in 10^3. It is also remarkable that during the measurement at 3 m height the sample was placed in the room which lies above the main laboratory, on the next floor; in this way the effect of air flows on the measurements was greatly reduced. For the used 500 g sample the weight loss was ca. 2.5 g.

Such an extremely weak height dependence of the shielding is in sharp contrast with the intuitive picture, according to which the gravitational field of the Earth is the vectorial sum of the fields produced by each single "portion" of Earth. In the absence of any shielding, the sum results in a field which is equivalent to the field of a pointlike mass placed in the center of the Earth; this can be checked elementarily by direct integration or invoking Gauss' theorem and the spherical symmetry. But if we admit that the superconducting disk produces a weak shielding, the part of the Earth which is shielded lies behind the projection of the disk as seen from the sample, i.e., within an angle θ about the vertical direction, such that $\tan \theta = h$, where h is the sample height over the disk measured in units of the disk radius. (For simplicity we suppose now the sample to be centered above the disk.)

In order to obtain the shielding effect as a function of h, taking into account this geometrical factor, one must integrate the Newtonian contribution $\cos \phi / R^2$ over the intersection between the Earth and the cone defined by $\phi < \theta$. We have done this for the values $h = 1, 2, 3, 4, 6, 8, 10$, through a Montecarlo algorithm. We took into account the higher density of the Earth's core ($\rho_{core} \sim 2\rho_{mantle}$; $r_{core} \sim (1/2) r_{Earth}$; it is straightforward to insert more accurate values, but the final results change very little); we also computed analytically the contribution of the tip of the cone, from the Earth's surface to the Earth's core, in order to reduce the fluctuations in the Montecarlo samplings for small R. [2] The resulting values were the following:

h	shielding/maximum-shielding
1	0.62 +/- 0.02
2	0.34 +/- 0.01
3	0.18 +/- 0.01
4	0.102 +/- 0.003
6	0.050 +/- 0.002
8	0.029 +/- 0.001
10	0.018 +/- 0.001

This strong height dependence is clearly incompatible with the mentioned experimental data, which instead seem to indicate that in the shielding process all the mass of the Earth behaves effectively as if it would be concentrated in one point.

In our theoretical model this property arises in a natural way. We employ a quantum formula which expresses the static gravitational interaction energy of two masses m_1 and m_2 in terms of an invariant vacuum expectation value, namely [6]

$$E = \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{\int d[g] \exp\left\{-\hbar^{-1}\left[S[g] + \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} dt \sqrt{g_{\mu\nu}[x_i(t)]\dot{x}_i^\mu(t)\dot{x}_i^\nu(t)}\right]\right\}}{\int d[g] \exp\left\{-\hbar^{-1} S[g]\right\}} \quad (1)$$

$$\equiv \lim_{T\to\infty} -\frac{\hbar}{T} \log \left\langle \exp\left\{-\hbar^{-1} \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} ds_i\right\}\right\rangle_S \quad (2)$$

where g has Euclidean signature and S is the gravitational action of general form

$$S[g] = \int d^4x \sqrt{g} \left(\lambda - kR + \frac{1}{4} a R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma}\right). \quad (3)$$

[2] For the detailed algorithm and figures please ask the author at the e-mail address above.

The constants k and λ are related – in general as "bare quantities" – to the Newton constant G and to the cosmological constant Λ: k corresponds to $1/8\pi G$ and λ to $\Lambda/8\pi G$. The trajectories $x_i(t)$ of m_1 and m_2 are parallel with respect to the metric g; let R be their distance.

In the weak-field approximation, eq. (1) reproduces to lowest order the Newton potential and can be used to find its higher order quantum corrections [7], or implemented on a Regge lattice to investigate the non-perturbative behaviour of the potential at small distances [9]. The addition to the gravitational action (3) of a term which represents a localized *external* Bose condensate [3] mimics a shielding effect which is absent from the classical theory and which we take as our candidate model for the observed shielding.

The feature of eq. (1) which is of interest here is that if the two masses m_1 and m_2 are not pointlike, the trajectories $x_1(t)$ and $x_2(t)$ must be those of their centers of mass. (This also makes irrelevant the question – actually ill-defined in general relativity – whether they are pointlike or not.) Thus, when applying eq. (1) to the Earth and the sample, we only need to consider the centers of mass of those bodies. In this way we reproduce the observed behaviour for the shielding as well as for the regular interaction. The ensuing apparent failure in the "local transmission" of the gravitational interaction does not contrast with any known property of gravity (compare [6, 8], and references about the problem of the local energy density in General Relativity and [6] about the non-localization of virtual gravitons. One should also keep in mind that (1) holds only in the static case.)

Finally, if we describe the shielding effect as a slight diminution of the effective value of the gravitational acceleration g, and remember that the gravitational potential energy $U = -\frac{Gm_{Earth}}{r_{Earth}} = -gr_{Earth}$ is negative, it follows that the energy of a sample inside the shielded zone is larger than its energy outside. This means in turn that the sample must feel an expulsive force at the border of the shielded region. Such a force has been indeed observed [5], although precise data are not available yet. From the theoretical point of view it is however not trivial to do any prevision about the intensity of the force. In fact, the shielding process absorbs energy from the experimental apparatus and thus any transient stage is expected to be highly non-linear, especially for heavy samples.

[3] This means that the density of the condensate is not included into the functional integration variables.

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