On weak field gravity-Maxwell symmetries in SC fluctuations regime

Gravity vs. condensed matter physics

Antonio Gallerati

Politecnico di Torino - Dipartimento di Scienza Applicata e Tecnologia

Istituto Nazionale di Fisica Nucleare - Sez. TO

Outline

Outline

1. Introduction

Outline

Outline

Outline

Introduction

Introduction

It is since 1966, with the paper of DeWitt [*Phys. Rev. Lett. 16 (1966)*], that there is great interest in the interplay between the theory of gravitation and superconductivity

POLITECNICO DI TORINO DISAT

It is since 1966, with the paper of DeWitt [*Phys. Rev. Lett. 16 (1966)*], that there is great interest in the interplay between the theory of gravitation and superconductivity

- Podkletnov and Nieminem declared to have observed a gravitational shielding in a rotating disk of YBaCuO (YBCO) [*Physica C: Superconductivity 203 (1992)*].

POLITECNICO DI TORINO
DISAT

It is since 1966, with the paper of DeWitt [*Phys. Rev. Lett. 16 (1966)*], that there is great interest in the interplay between the theory of gravitation and superconductivity

- Podkletnov and Nieminem declared to have observed a gravitational shielding in a rotating disk of YBaCuO (YBCO) [*Physica C: Superconductivity 203 (1992)*].

- In 1996 Modanese proposed a theoretical explanation [*EPL 35 (1996)*] in the frame of a quantum field formulation.

Introduction

It is since 1966, with the paper of DeWitt [*Phys. Rev. Lett. 16 (1966)*], that there is great interest in the interplay between the theory of gravitation and superconductivity

- Podkletnov and Nieminem declared to have observed a gravitational shielding in a rotating disk of YBaCuO (YBCO) [*Physica C: Superconductivity 203 (1992)*].
- In 1996 Modanese proposed a theoretical explanation [*EPL 35 (1996)*] in the frame of a quantum field formulation.
- It is instructive to explore a weak field expansion for nearly flat spacetime configurations (generalization of Maxwell equations).

POLITECNICO DI TORINO DISAT

1. **Classical framework**: impossible to extract experimental evidences.

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

   - the probability of a graviton excitation of a medium particle is suppressed;

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

   - the probability of a graviton excitation of a medium particle is suppressed;

   - possible interaction of the gravitational field with some particular state of matter, like a Bose condensate or a more general superfluid:

POLITECNICO DI TORINO DISAT

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

   - the probability of a graviton excitation of a medium particle is suppressed;

   - possible interaction of the gravitational field with some particular state of matter, like a Bose condensate or a more general superfluid:

$$\mathscr{L}_{\text{int}} \propto h^{\mu\nu}\, \partial_\mu \phi_0^*\, \partial_\nu \phi_0\,,$$

POLITECNICO DI TORINO

DISAT

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

   - the probability of a graviton excitation of a medium particle is suppressed;

   - possible interaction of the gravitational field with some particular state of matter, like a Bose condensate or a more general superfluid:

$$\mathscr{L}_{\text{int}} \propto h^{\mu\nu}\, \partial_\mu \phi_0^*\, \partial_\nu \phi_0\,, \qquad \mathscr{L}_0 = -\frac{1}{2}\, \partial_\mu \phi_0^*\, \partial^\mu \phi_0 + \frac{1}{2}\, m^2\, |\phi_0^2|\,,$$

1. **Classical framework**: impossible to extract experimental evidences.

2. **Quantum picture**: observable effects are possible

   - the probability of a graviton excitation of a medium particle is suppressed;

   - possible interaction of the gravitational field with some particular state of matter, like a Bose condensate or a more general superfluid:

$$\mathscr{L}_{\text{int}} \propto h^{\mu\nu}\,\partial_\mu \phi_0^*\,\partial_\nu \phi_0\,, \qquad \mathscr{L}_0 = -\frac{1}{2}\,\partial_\mu \phi_0^*\,\partial^\mu \phi_0 + \frac{1}{2}\,m^2\,|\phi_0^2|\,,$$

where $g_{\mu\nu} \simeq \eta_{\mu\nu} + h_{\mu\nu}\,, \quad \phi_0 = \langle 0|\phi|0\rangle\,.$

The general Einstein equations are written as

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G_N T_{\mu\nu} \ .$$

The general Einstein equations are written as

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}\, g_{\mu\nu}\, R = 8\pi G_N\, T_{\mu\nu}\ .$$

- Let us now consider a nearly flat spacetime configuration where the metric can be expanded as $g_{\mu\nu} \simeq \eta_{\mu\nu} + h_{\mu\nu}$ and introduce then the tensors

$$\bar{h}_{\mu\nu} = h_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}\, h\,, \qquad \mathscr{G}_{\mu\nu\rho} \simeq \partial_{[\nu}\bar{h}_{\rho]\mu}\,,$$

having imposed the gauge condition $\partial^{\mu}\bar{h}_{\mu\nu} \simeq 0$;

The general Einstein equations are written as

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}\, g_{\mu\nu}\, R = 8\pi G_N\, T_{\mu\nu}\ .$$

- Let us now consider a nearly flat spacetime configuration where the metric can be expanded as $g_{\mu\nu} \simeq \eta_{\mu\nu} + h_{\mu\nu}$ and introduce then the tensors

$$\bar{h}_{\mu\nu} = h_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}\, h\,, \qquad \mathscr{G}_{\mu\nu\rho} \simeq \partial_{[\nu}\bar{h}_{\rho]\mu}\,,$$

  having imposed the gauge condition $\partial^{\mu}\bar{h}_{\mu\nu} \simeq 0$;

- in first-order approximation, the Einstein equations can be then rewritten as

$$G_{\mu\nu} = \partial^{\rho}\mathscr{G}_{\mu\nu\rho} = 8\pi G_N\, T_{\mu\nu}\ .$$

- Now, let us introduce the new fields

$$\mathbf{E}_g \equiv E_i = -\frac{1}{2}\,\mathscr{G}_{00i} = -\frac{1}{2}\,\partial_{[0}\bar{h}_{i]0}\ ,$$

$$\mathbf{A}_g \equiv A_i = \frac{1}{4}\,\bar{h}_{0i}\ , \qquad \mathbf{B}_g \equiv B_i = \frac{1}{4}\,\varepsilon_i{}^{jk}\,\mathscr{G}_{0jk}\ ,$$

POLITECNICO DI TORINO DISAT

- Now, let us introduce the new fields

$$\mathbf{E}_g \equiv E_i = -\frac{1}{2}\,\mathcal{G}_{00i} = -\frac{1}{2}\,\partial_{[0}\bar{h}_{i]0}\,,$$

$$\mathbf{A}_g \equiv A_i = \frac{1}{4}\,\bar{h}_{0i}\,, \qquad \mathbf{B}_g \equiv B_i = \frac{1}{4}\,\varepsilon_i{}^{jk}\,\mathcal{G}_{0jk}\,,$$

- it is then possible to write the set of equations:

$$\nabla\cdot\mathbf{E}_g = \frac{\rho_g}{\varepsilon_g}\,; \qquad \nabla\cdot\mathbf{B}_g = 0\,;$$

$$\nabla\times\mathbf{E}_g = -\frac{\partial\mathbf{B}_g}{\partial t}\,; \qquad \nabla\times\mathbf{B}_g = \mu_g\,\mathbf{j}_g + \frac{1}{c^2}\,\frac{\partial\mathbf{E}_g}{\partial t}\,,$$

- Now, let us introduce the new fields

$$\mathbf{E}_g \equiv E_i = -\frac{1}{2}\,\mathscr{G}_{00i} = -\frac{1}{2}\,\partial_{[0}\bar{h}_{i]0}\,,$$

$$\mathbf{A}_g \equiv A_i = \frac{1}{4}\,\bar{h}_{0i}\,, \qquad \mathbf{B}_g \equiv B_i = \frac{1}{4}\,\varepsilon_i{}^{jk}\,\mathscr{G}_{0jk}\,,$$

- it is then possible to write the set of equations:

$$\nabla \cdot \mathbf{E}_g = \frac{\rho_g}{\varepsilon_g}\,; \qquad \nabla \cdot \mathbf{B}_g = 0\,;$$

$$\nabla \times \mathbf{E}_g = -\frac{\partial \mathbf{B}_g}{\partial t}\,; \qquad \nabla \times \mathbf{B}_g = \mu_g\,\mathbf{j}_g + \frac{1}{c^2}\,\frac{\partial \mathbf{E}_g}{\partial t}\,,$$

having defined $\rho_g \equiv -T_{00}\,, \quad \mathbf{j}_g \equiv T_{0i}\,.$

Then, we introduce the generalized fields and potentials

$$\mathbf{E} = \mathbf{E}_\mathrm{e} + \frac{\mathfrak{m}}{e}\,\mathbf{E}_\mathrm{g}\,; \qquad \mathbf{B} = \mathbf{B}_\mathrm{e} + \frac{\mathfrak{m}}{e}\,\mathbf{B}_\mathrm{g}\,;$$

$$\phi = \phi_\mathrm{e} + \frac{\mathfrak{m}}{e}\,\phi_\mathrm{g}\,; \qquad \mathbf{A} = \mathbf{A}_\mathrm{e} + \frac{\mathfrak{m}}{e}\,\mathbf{A}_\mathrm{g}\,.$$

Then, we introduce the generalized fields and potentials

$$\mathbf{E} = \mathbf{E}_e + \frac{m}{e}\,\mathbf{E}_g\,; \qquad \mathbf{B} = \mathbf{B}_e + \frac{m}{e}\,\mathbf{B}_g\,;$$

$$\phi = \phi_e + \frac{m}{e}\,\phi_g\,; \qquad \mathbf{A} = \mathbf{A}_e + \frac{m}{e}\,\mathbf{A}_g\,.$$

The *generalized Maxwell equations* for the above fields become:

$$\nabla\cdot\mathbf{E} = \left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_0}\right)\,\rho\,; \qquad \nabla\cdot\mathbf{B} = 0\,;$$

$$\nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}\,; \qquad \nabla\times\mathbf{B} = (\mu_g + \mu_0)\,\mathbf{j} + \frac{1}{c^2}\,\frac{\partial\mathbf{E}}{\partial t}\,.$$

Then, we introduce the generalized fields and potentials

$$\mathbf{E} = \mathbf{E}_\mathrm{e} + \frac{m}{e}\,\mathbf{E}_\mathrm{g}\,; \qquad \mathbf{B} = \mathbf{B}_\mathrm{e} + \frac{m}{e}\,\mathbf{B}_\mathrm{g}\,;$$

$$\phi = \phi_\mathrm{e} + \frac{m}{e}\,\phi_\mathrm{g}\,; \qquad \mathbf{A} = \mathbf{A}_\mathrm{e} + \frac{m}{e}\,\mathbf{A}_\mathrm{g}\,.$$

The *generalized Maxwell equations* for the above fields become:

$$\nabla \cdot \mathbf{E} = \left(\frac{1}{\varepsilon_\mathrm{g}} + \frac{1}{\varepsilon_0}\right)\rho\,; \qquad \nabla \cdot \mathbf{B} = 0\,;$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}\,; \qquad \nabla \times \mathbf{B} = (\mu_\mathrm{g} + \mu_0)\,\mathbf{j} + \frac{1}{c^2}\,\frac{\partial \mathbf{E}}{\partial t}\,.$$

[AG, *Eur.Phys.J. C77 (2017), Symmetry 11 (2019)*]

The fluctuation regime can be described using the time-dependent Ginzburg-Landau equations that, for $T > T_c$, read

$$\Gamma\left(\hbar\frac{\partial}{\partial t} - 2\,i\,e\,\phi\right)\psi = \frac{1}{2m}\left(\hbar\nabla - 2\,i\,e\,\mathbf{A}\right)^2\psi + \alpha\,\psi\,.$$

The fluctuation regime can be described using the time-dependent Ginzburg-Landau equations that, for $T > T_c$, read

$$\Gamma \left(\hbar \frac{\partial}{\partial t} - 2\, i\, e\, \phi \right) \psi = \frac{1}{2m} \left(\hbar \nabla - 2\, i\, e\, \mathbf{A} \right)^2 \psi + \alpha\, \psi\,.$$

- First, we look for a solution of the form

$$\psi(\mathbf{x}, t) = f(\mathbf{x}, t)\, \exp\left(i\, g(\mathbf{x}, t) \right);$$

The fluctuation regime can be described using the time-dependent Ginzburg-Landau equations that, for $T > T_c$, read

$$\Gamma\left(\hbar\frac{\partial}{\partial t} - 2\,i\,e\,\phi\right)\psi = \frac{1}{2m}\left(\hbar\nabla - 2\,i\,e\,\mathbf{A}\right)^2\psi + \alpha\,\psi\,.$$

- First, we look for a solution of the form

$$\psi(\mathbf{x},t) = f(\mathbf{x},t)\,\exp\left(i\,g(\mathbf{x},t)\right);$$

- one then finds for the superfluid speed

$$\mathbf{v}_s = \frac{1}{m}\left(\hbar\,\nabla g + 2\,\frac{e}{c}\,\mathbf{A}\right),$$

The fluctuation regime can be described using the time-dependent Ginzburg-Landau equations that, for $T > T_c$, read

$$\Gamma\left(\hbar\frac{\partial}{\partial t} - 2\,i\,e\,\phi\right)\psi = \frac{1}{2m}\left(\hbar\nabla - 2\,i\,e\,\mathbf{A}\right)^2\psi + \alpha\,\psi\,.$$

- First, we look for a solution of the form

$$\psi(\mathbf{x},t) = f(\mathbf{x},t)\,\exp\left(i\,g(\mathbf{x},t)\right);$$

- one then finds for the superfluid speed

$$\mathbf{v}_s = \frac{1}{m}\left(\hbar\nabla g + 2\,\frac{e}{c}\,\mathbf{A}\right),$$

while the associated current density has the form

$$\mathbf{j}_s = -2\,\frac{e}{m}\,|\psi|^2\left(\hbar\nabla g + 2\,\frac{e}{c}\,\mathbf{A}\right) = -2\,e\,f^2\,\mathbf{v}_s\,.$$

Microscopic model

POLITECNICO DI TORINO DISAT

Using fluctuations theory, we can calculate the supercurrent $\mathbf{j}_s(t)$ for three-dimensional samples with dimensions greater than the correlation length.

Microscopic model

Using fluctuations theory, we can calculate the supercurrent $\mathbf{j}_s(t)$ for three-dimensional samples with dimensions greater than the correlation length.

- The potential vector $\mathbf{A}(x, y, z, t)$ can be then extracted from:

$$\mathbf{A}(x, y, z, t) = \frac{1}{4\pi} \int \frac{\mathbf{j}_s(t) \; dx' \, dy' \, dz'}{\sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2}} \;,$$

when the time variations of external fields are small.

Using fluctuations theory, we can calculate the supercurrent $\mathbf{j}_s(t)$ for three-dimensional samples with dimensions greater than the correlation length.

- The potential vector $\mathbf{A}(x, y, z, t)$ can be then extracted from:

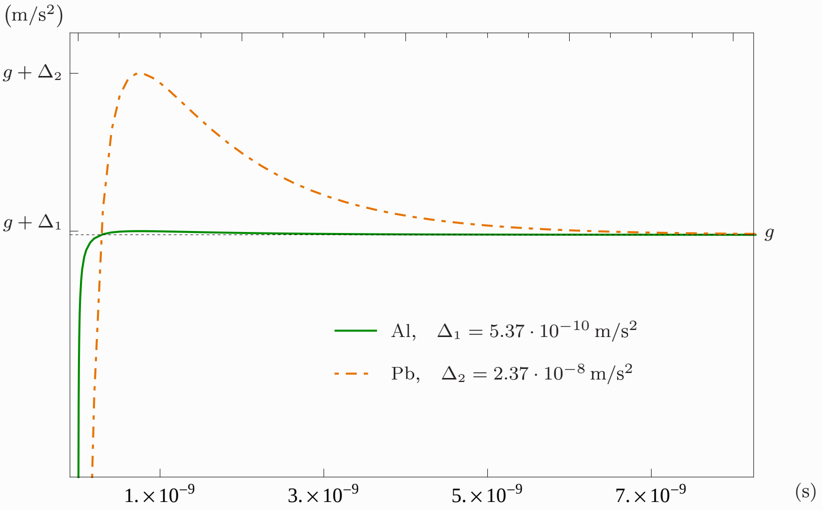
$$\mathbf{A}(x,y,z,t) = \frac{1}{4\pi} \int \frac{\mathbf{j}_s(t)\ dx'\, dy'\, dz'}{\sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}} \ ,$$

when the time variations of external fields are small.

- The generalized electric field $\mathbf{E}(x, y, z, t)$ can be then written as

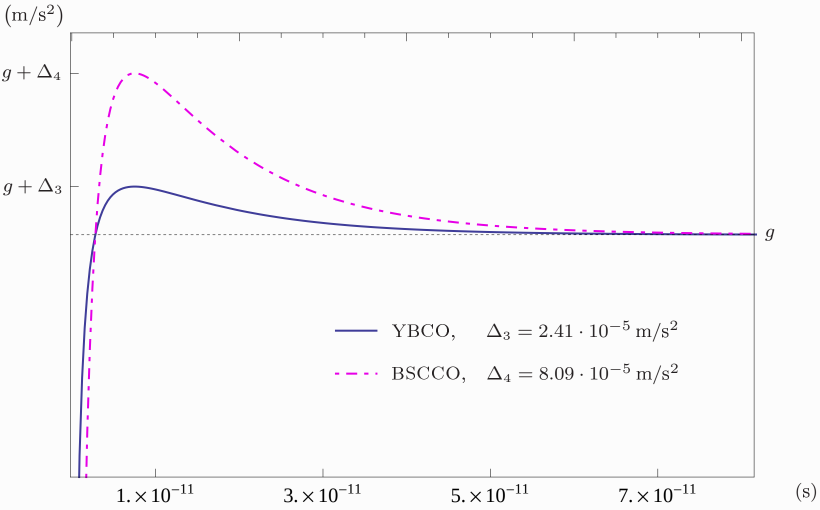
$$\mathbf{E}(x,y,z,t) = -\frac{1}{c}\frac{\partial \mathbf{A}}{\partial t} + \frac{m}{e}\mathbf{g} = -\frac{1}{c}\frac{\partial \mathbf{j}_s(t)}{\partial t}\ \mathcal{C}(x,y,z) + \frac{m}{e}\mathbf{g} \ ,$$

where we have considered the static weak (Earth-surface) gravitational field contribution, and where $\mathcal{C}(x, y, z)$ is a geometrical factor.



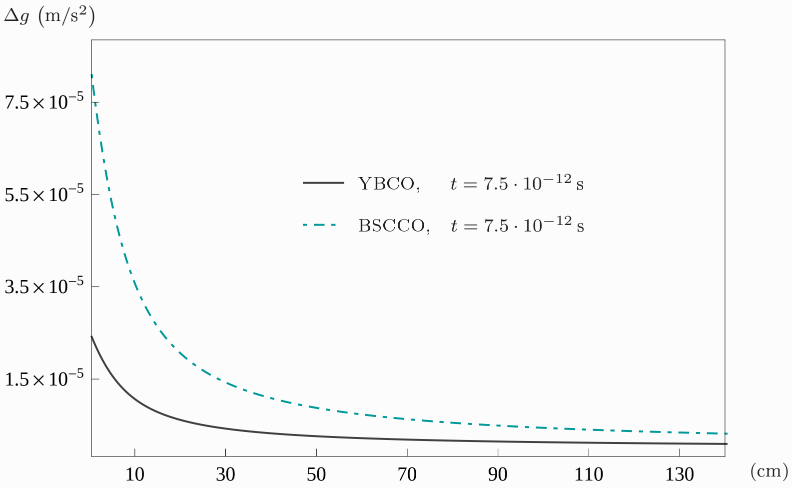
Disk with $R = 10\,\text{cm}$, $h = 1\,\text{cm}$, bases parallel to the ground; the corrections are calculated at a fixed distance $d = 0.5\,\text{cm}$ from the base surface [AG, *Symmetry 11 (2019)*].

Results YBCO vs. BSCCO



Disk with $R = 10\,\text{cm}$, $h = 1\,\text{cm}$, bases parallel to the ground; the corrections are calculated at a fixed distance $d = 0.5\,\text{cm}$ from the base surface [AG, *Symmetry 11 (2019)*].

Results YBCO vs. BSCCO



Field variation measured along the axis of the disk, at fixed time $t = \tau_0$ that maximizes the effect [AG, *Symmetry 11 (2019)*].

Conclusions

Conclusions

1. In a very short initial time interval, the gravitational field is reduced w.r.t. its unperturbed value; after that, it increases up to a maximum value and then decreases to the standard external value.

Conclusions

1. In a very short initial time interval, the gravitational field is reduced w.r.t. its unperturbed value; after that, it increases up to a maximum value and then decreases to the standard external value.

2. The value of the maximum variation Δ is in principle measurable (especially in high-T_c superconductors), while the problem lies in the short time intervals in which the perturbation manifests itself.

Conclusions

POLITECNICO DI TORINO
DISAT

1. In a very short initial time interval, the gravitational field is reduced w.r.t. its unperturbed value; after that, it increases up to a maximum value and then decreases to the standard external value.

2. The value of the maximum variation Δ is in principle measurable (especially in high-T_c superconductors), while the problem lies in the short time intervals in which the perturbation manifests itself.

3. It is possible to show that $\tau_0 \propto (T - T_c)^{-1}$, so it is fundamental to be very close to the critical temperature in order to increase the time range in which the effect takes place.

Conclusions

1. In a very short initial time interval, the gravitational field is reduced w.r.t. its unperturbed value; after that, it increases up to a maximum value and then decreases to the standard external value.

2. The value of the maximum variation Δ is in principle measurable (especially in high-T_c superconductors), while the problem lies in the short time intervals in which the perturbation manifests itself.

3. It is possible to show that $\tau_0 \propto (T - T_c)^{-1}$, so it is fundamental to be very close to the critical temperature in order to increase the time range in which the effect takes place.

4. The maximum value of the correction is obtained for $t = \tau_0$ and is proportional to $\xi(T)^{-1}$: this means that the effect is larger in high-$T_c$superconductors, having the latter small coherence length.

Thank you for listening!