Quantum Systems Bound by Gravity

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Bound quantum systems[1] via

<u>electromagnetic interaction</u>

- atoms
- molecules

<u>gravitational interaction</u>

?

<u>strong interaction</u>

- hadrons
- nuclei

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[1] Quantum system definition: de Broglie's wave length for a particle is about a system size.

Quantum systems bound by gravity

<u>have a horizon</u>

Graviatoms – bound quantum systems maintaining particles in orbit around mini-holes (primordial black holes).
Particles: mesons, leptons.

Graviatoms with neutrinos have macroscopic dimensions.

<u>have no horizon</u>

Macro-bodies (comet nuclei, meteorites, small asteroids) capturing neutrinos onto quantum levels.

Theoretical solution to the graviatom problem

Schrödinger's equation for the graviatom

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dR_{pl}}{dr}\right)-\frac{l(l+1)}{r^2}R_{pl}+\frac{2m}{\hbar^2}\left(E+\frac{mc^2 r_g}{2r}\right)R_{pl}=0 \qquad (1)$$

describes a radial motion of a particle with the mass m in the mini-hole potential, where $r_g = 2GM/c^2$ and M are the mini-hole gravitational radius and mass respectively.

The energy spectrum is of hydrogen-like form

$$E=-\frac{G^2M^2m^3}{2\hbar^2 n^2}. \qquad (2)$$

Graviatom existence conditions:

- the geometrical condition $L > r_g + R$, where L is the characteristic size of the graviatom and R is the characteristic size of a particle;
- the stability condition given by
  (a) $\tau_{gr} < \tau_H$, where τ_{gr} is the graviatom lifetime and τ_H is the mini-hole lifetime, and
  (b) $\tau_{gr} < \tau_p$, where τ_p is the particle lifetime (for unstable particles);
- the indestructibility condition (due to tidal forces and the Hawking effect) $E_d < E_b$, where E_d is the destructive energy and E_b is the binding energy.

The charged particles satisfying these conditions are the **electron, muon, tau lepton, wino, pion** and **kaon**.

Graviatom graphical interpretation

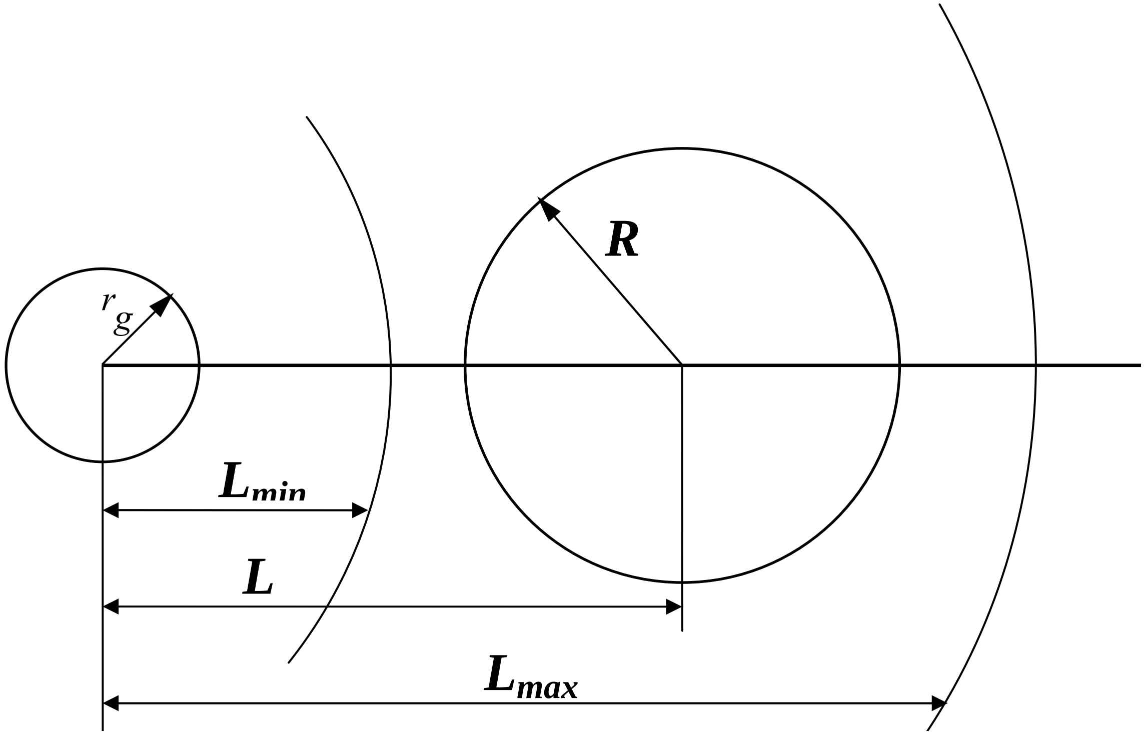

Figure 1. The geometrical condition

Dependence of mini-hole masses on charged-particle ones

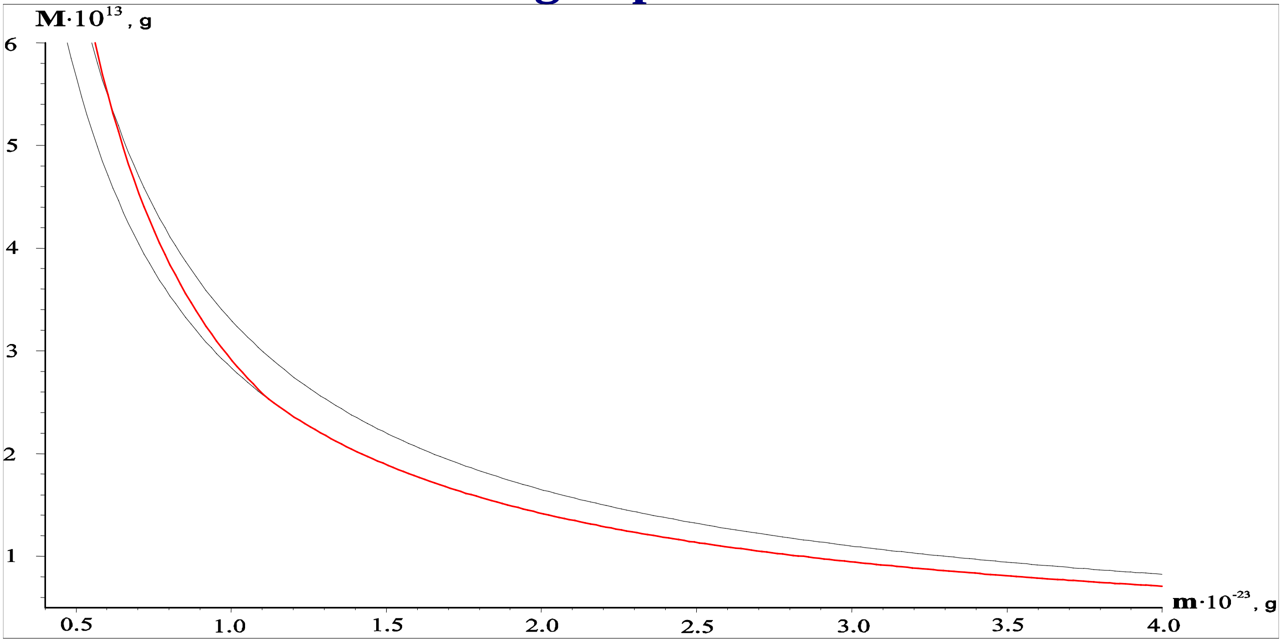

Figure 2. The black curves indicate the range of values related to the geometrical condition (the upper curve) and to Hawking's effect (the lower curve). The red curve is related to the particle stability condition ($\tau_p = 10^{-22}$ s).

Graviatom radiation

The intensity of the electric dipole radiation of a particle with mass m and charge e in the gravitational field of a mini-hole is

$$I_{fi}^{d} = \frac{2\hbar e^2 \omega_{if}^3 f_{if}}{mc^3}, \qquad (3)$$

where $\omega_{if} = (E_i - E_f)/\hbar$ is the frequency of the transition $i \to f$ and f_{if} is the oscillator strength.

The electric quadrupole radiation intensity for the transition $3d \to 1s$ is

$$I_{13}^{q} = \frac{6\hbar e^2 \omega_{31}^3}{mc^3} f_{3d\to 1s}. \qquad (4)$$

The gravitational radiation intensity for the transition $3d \to 1s$ is

$$I_{13}^{g} = \frac{24\hbar G M \omega_{31}^{3}}{c^{3}} f_{3d\to 1s}. \qquad (5)$$

The mini-hole creates particles near its horizon due to Hawking's effect, its power

$$P_{H} = \frac{\hbar c^{6}}{15360\pi G^{2} M^{2}}. \qquad (6)$$

The Hawking energy

$$E_{H} = \frac{b\hbar c^{3}}{8\pi G M}, \qquad (7)$$

where b=2.822, following Wien's displacement law.

Parameters for graviatoms with the electron and wino

	electron	**wino**
mc^2, MeV τ_p, s	0.511 ∞	$8\cdot 10^5$ $5\cdot 10^{-10}$
M, g L, cm $\hbar\omega_{12}$, MeV $I^d(2p\rightarrow 1s)$, $erg\cdot s^{-1}$	$3.5\cdot 10^{17}$ $6\cdot 10^{11}$ 0.08 $2\cdot 10^{10}$	$2.2\cdot 10^{11}$ $4\cdot 10^{17}$ $1.2\cdot 10^5$ $4\cdot 10^{22}$

Relations valid for all graviatoms

Ratios	Values	
	min	max
$I^g(3d \to 1s)/I^d(2p \to 1s)$	4.328	6.812
$I^d(2d \to 1s)/P_H$	0.390	0.715
$\hbar\omega_{12}/E_H$	0.872	1.015

The mini-hole masses for the graviatoms involving electrons, muons and pions exceed the value of $4.38 \cdot 10^{14}$ g, which means that it is possible for such graviatoms to have existed up to now. The gravitational equivalent of the fine-structure constant

$$\frac{GMm}{\hbar c} = 0.608 \div 0.707\,. \tag{8}$$

Thus, the perturbation theory remains valid.

Systems with neutrinos

De Broglie's wavelength for the neutrino

$$\lambdabar_{dB} = \frac{\hbar^2}{GMm_\nu^2}, \tag{9}$$

where m_ν is the neutrino mass.

1) Graviatom

Existence conditions: $a_B^g = \lambdabar_{dB} > 3r_g$, $\tau_{gr} < \tau_H$.

Electron neutrino rest energy: $m_\nu c^2 \sim 1 eV$.

Characteristic frequency:

$$\omega_H^g = \frac{G^2 M^2 m_\nu^3}{\hbar^2}. \tag{10}$$

Gravitational radiation:

$$I_{gr} = \frac{G^9 M^9 m_\nu^{11}}{c^5 \hbar^{10}}. \qquad (11)$$

Mini-hole masses: $10^{18}\, g < M < 10^{23}\, g$.

For example, if $M < 10^{23}\, g$, then $\hbar\omega_H^g < 0.2\, eV$, $I_{gr} < 0.2\, erg \cdot s^{-1}$.

System size is about $10^1 \div 10^6\ cm$.

2) Macroscopic system (comet nuclei, meteorites, small asteroids)

Macro-bodies capture neutrinos onto both Bohr's hydrogen-like levels (outside the body) and Thomson's oscillatory ones (inside the body).

Macro-body masses: $10^{14}\, g < M < 10^{19}\, g$.

Bohr's radius is about: $1 \div 10^5\ cm$.

The oscillation frequency $\omega = \left(4/_3 \pi\rho G\right)^{1/2}$, the gravitational radiation intensity

$$I_{mb} = \frac{\hbar^{7/3}\left(4/_3 \pi\rho G\right)^{9/4}}{c^5 m_\nu^{5/2}}, \qquad (12)$$

where ρ is the macro-body density.

Let consider the average density of a macro-body ρ equal to $4\ g\cdot cm^{-3}$. Then, we obtain the following parameters: $\hbar\omega = 9\cdot 10^{-19}\, eV$, $I_{mb} = 10^{-104}\, erg\cdot s^{-1}$.

It is of interest to note that the rotation curves of galaxies give an almost constant velocity υ on their periphery, which for $\upsilon^2 \sim GM/R$ leads to the dependence of dark matter mass $M_{dm} \sim R$, similar to the dependence of the mass of neutrinos on Bohr's radius L, since $L = a_B^g n^2$, and the total mass of all neutrinos on the nth level is equal to $M_n = 2n^2 m_\nu$. Hence, we obtain $M_n \sim L$.

Conclusion

The graviatom can contain only leptons and mesons. The observable stellar magnitude for graviatom electromagnetic radiation exceeds 23^{m}.

Stable graviatoms with baryon constituents are impossible. The internal structure of the baryons, consisting of quarks and gluons, should be taken into account. There occurs a so-called quantum accretion of baryons onto a mini-hole. The whole problem is solvable within the framework of quantum chromodynamics and quantum electrohydrodynamics.

Neutrinos can form quantum macro-systems.

Of interest is the fact that from the galaxy rotation curves it follows that the dark matter mass is proportional to the distance from the galaxy centre. Similarly, the total mass of neutrinos on the nth level is proportional to their orbit radius.

The description of gravitationally bound macro-systems with neutrinos may be helpful for solving the dark matter problem in the Universe.