PHYSICAL DERIVATION OF THE COHERENT GRAVIDYNAMIC QUANTUM 1/F EFFECT

P.H. HANDEL

Department of Physics and Astronomy, Univ. of Missouri, St. Louis, MO 63121

G.L. WITT

Air Force Office of Scientific Research, Arlington, VA 22203-1977

Quantum 1/f noise is a fundamental fluctuation of currents, physical cross sections or process rates, caused by infrared coupling of the current carriers to very low frequency (soft) quanta, also known as infraquanta. The latter are soft gravitons in the gravidynamic case with coupling constant g considered here, soft photons in the electrodynamic case, and soft transversal piezo-phonons in the lattice-dynamical case. Quantum 1/f noise is a new aspect of quantum mechanics expressed mainly through the coherent quantum 1/f effect $2g/\pi f$ derived in this paper in large systems, and mainly through the conventional quantum 1/f effect in small systems or individual particles. Both effects are present in general, and their effects are superposed in first approximation with the help of a weight parameter that will be derived elsewhere for the gravitational case.

1. Introduction

This effect arises in a beam of neutrons, atoms molecules (or other neutral or charged particles of any kind propagating freely in vacuum) from the definition of the physical particle as a bare particle plus a coherent state of its own gravitational field. It is caused by the energy spread characterizing any coherent state of the gravitational field oscillators, an energy spread which spells non-stationarity, i.e., fluctuations. To find the spectral density of these inescapable fluctuations which are known to characterize any quantum state which is not an energy eigenstate, we use an elementary physical derivation based on Schrödinger's definition of coherent states.

The coherent quantum 1/f effect will be derived in three steps: first we consider a hypothetical world with just a single mode of the gravitational field coupled to a beam of material particles. Considering the mode to be in a coherent state, we calculate the autocorrelation function of the quantum fluctuations in the particle-density (or concentration) which arise from the nonstationarity of the coherent state. Then we calculate the amplitude with which this one mode is represented in the field of an electron, according to electrodynamics. Finally, we take the product of the autocorrelation functions calculated for all modes with the amplitudes found in the previous step.

2. Coherent Quantum 1/f Effect from a Single Field Mode

Let a mode of the gravitational field be characterized by the wave vector q, the angular frequency $\omega = cq$ and the polarization λ. Denoting the variables q and λ simply by q in the labels of the states, we write the coherent state [1] of amplitude $|z_q|$ and phase arg z_q in the form

$$|z_q\rangle = \exp[-(1/2)|z_q|^2] \exp[z_q a_q^+] |0\rangle = \exp[-(1/2)|z_q|^2] \sum_{n=0}^{\infty} (z_q^n) /n! |n\rangle. \qquad (1)$$

Here a_q^+ is the creation operator which adds one energy quantum to the energy of the mode. Let us use a representation of the energy eigenstates in terms of Hermite polynomials $H_n(x)$

$$|n\rangle = (2^n n!\, \sqrt{\pi})^{-1/2} \exp[-x^2/2]\, H_n(x)\, e^{in\omega t}. \tag{2}$$

This yields for the coherent state $|z_q\rangle$ the representation

$$\Psi_q(x) = \exp[-(1/2)|z_q|^2]\exp[-x^2/2]\sum_{n=0}^{\infty} \{[z_q e^{i\omega t}]^n/[n!(2^n\sqrt{\omega})]^{1/2}\}H_n(x)$$
$$= \exp[-(1/2)|z_q|^2]\exp[-x^2/2]\exp[-z_q^2 e^{-2i\omega t} + 2xz_q e^{i\omega t}]. \tag{3}$$

In the last form the generating function of the Hermite polynomials was used. The corresponding autocorrelation function of the probability density function, obtained by averaging over the time t or the phase of z_q, is, for $|z_q|<<1$,

$$P_q(\tau,x) = \langle|\Psi_q|_t^2\ |\ \Psi_q|_{t+\tau}^2\ \rangle = \{1 + 8x^2|z_q|^2[1 + \cos\omega\tau] - 2|z_q|^2\}\exp[-x^2/2]. \tag{4}$$

Integrating over x from $-\infty$ to ∞, we find the autocorrelation function

$$A^1(\tau) = (2)^{-1/2}\{1 + 2|z_q|^2\cos\omega\tau\}. \tag{5}$$

This result shows that the probability distribution contains a constant background with small superposed oscillations of frequency ω. Physically, the small oscillations in the total probability describe self-organization or bunching of the particles in the beam. They are thus more likely to be found in a measurement at a certain time and place than at other times and places relative to each other along the beam. Note that for $z_q = 0$ the coherent state becomes the ground state of the oscillator which is also an energy eigenstate, and therefore stationary and free of oscillations.

We now determine the amplitude z_q with which the gravitational field mode q is represented in the correct definition of the physical particle. The simple way to do this, is to let a bare particle of mass M dress itself through its interaction with the gravitational field, i.e. by performing first order perturbation theory with the non-relativistic interaction Hamiltonian

$$H' = M\varphi\ , \tag{6}$$

where φ is the scalar gravitational potential. This corresponds to a Fourier expansion $-4\pi GM/q^2$ of the gravitational potential $-GM/r$ of a material particle in a box of volume V, and multiplication with a squared gravitonic "wave function" $(\hbar cqV)^{-1}$. This way we obtain

$$|z_q|^2 = \pi G(M/q)^2(\hbar cqV)^{-1}. \tag{7}$$

3. Coherent Quantum 1/f Effect from All Modes of the Field

Considering now all modes of the gravitational field, we obtain from the single - mode result of Eq. (5)

$$B(\tau) = C\, \Pi_q\{1 + 2|z_q|^2\cos\omega_q\tau\} = C\{1 + \Sigma_q\, 2|z_q|^2\cos\omega_q\tau\}$$

$$= C\{1 + 4(V/2^3\pi^3) \int d^3q\, |z_q|^2 \cos \omega_q\tau\} \quad (8)$$

Here we have again used the smallness of z_q and we have introduced a constant C proportional to the squared velocity of the particles in the beam. Using Eq. (7) we obtain

$$B(\tau) = C\{1 + 4\pi(V/2^3\pi^3)(4\pi/V)G(m^2/\hbar c) \int(dq/q)\cos \omega_q\tau\}$$

$$= C\{1 + 2(\beta_{coh}/\pi) \int\cos(\omega\tau)d\omega/\omega. \quad (9)$$

Here

$$\beta_{coh} = GM^2/c\hbar = 10^9 M^2/\mathrm{gram}^2 \quad (10)$$

where M is the mass of the particles and G is the constant of universal gravitation, replaces in our case the fine structure constant $\alpha=e^2/c\hbar$ present in the electromagnetic CQ1/fE The first term in curly brackets is unity and represents the constant background, or the d.c. part of the mass current density defined by the motion of the beam of particles through vacuum. The autocorrelation function for the relative (fractional) density fluctuations, or for the fractional mass-current density fluctuations in the beam of material particles is obtained therefore by dividing the second term in curly brackets by the first term. The constant C drops out when the fractional fluctuations are considered. According to the Wiener-Khintchine theorem, the coefficient of $\cos\omega\tau$ is the spectral density of the fluctuations, $S_{|\psi|^2}$ for the particle concentration, or S_j for the current density $j=e(k/m)|\psi|^2$

$$S_{|\psi|^2}\langle|\psi|^{-2}\rangle = S_j\langle j\rangle^{-2} = 2(\beta_{coh}/\pi fN)= 2GM^2/\pi fNc\hbar \approx 4.4\cdot 10^9 M^2/(\pi fN\mathrm{gram}^2). \quad (11)$$

Here we have included the total number N of material particles of mass m that are observed simultaneously in the denominator, because the noise contributions from each particle are independent. This result is related to the conventional gravidynamic quantum 1/f effect [2] first submitted to PRL in 1975. For example, for $m = 10^{-6}$g =1μg, we get about $10^{-3}/fN$ from Eq. (11).

4. Discussion

The results obtained in the last section show that the new coherent gravidynamic Quantum !/f Effect (Q 1/fE) can not be observed on atomic particles, but is easy to observe as a new form of 1/f noise in beams of mesoscopic aggregates. The new effect differs from the well known earlier form, because it is present in any current of matter, and not only as a result of scattering, as we know [2], was the case for the Conventional Gravidynamic Q 1/fE. The latter was a property of the physical quantum mechanical cross sections that we had introduced as part of a new aspect of quantum mechanics. Instead of Eq. (10), it had a different β in Eq. (11),

$$\beta_{conv} = (8G/5c^5\hbar)\,\mu^2 v^4 \sin^2\theta, \quad (12)$$

where θ is scattering angle of the particles in the center-of-mass reference system, with relative velocity v of the particles that scatter on each other, and their reduced mass is μ. We now understand that in the gravidynamical case, just as in the electrodynamical or lattice-dynamical cases discussed elsewhere, the observed quantum 1/f noise represents genuine macroscopic or mesoscopic quantum fluctuations (1/f), including both coherent and conventional contributions

$$\beta = \beta_{conv} + s''\beta_{coh}, \tag{13}$$

and

$$s'' = 2N'M/c^2 = N'r_s. \tag{14}$$

Here N' is the number of particles per unit length, r_s is their Schwarzschild radius, and s'' is a coherence parameter introduced by Handel like the parameter s for electromagnetic Q1/fE and s' for the piezoelectric Q1/fE. The derivation will be shown in a future paper, because of the space limitations here. Simple formulas allow for calculating both effects.

The gravidynamic Q1/fE should be detectable both in cosmos, e.g., in cosmic jets, and in terrestrial jets of matter, e.g., in hydroelectric power plants. The classical character of macroscopic and mesoscopic particles or parcels of matter causes the corresponding wave packets to be extremely narrow. As was proven in the early paper on “Survival of the long-time correlations”, the Q1/fE is not affected by this, being independent of any overlap between the wave packets. Saturn’s rings should exhibit this 1/f spectrum over the longest wavelength region along the circular trajectory of the material particles. Over shorter wavelengths one obtains a regular array of “spokes” and electrostatic discharges. These are caused by the well-known polarization catastrophe present both inside and between the ice particles of the ring [3], particularly strongly while in Saturn’s shadow, across the whole C-ring.

Practical applications of this effect could include the detection of graviton sources without any noticeable transfer of energy or momentum. The gravitons would just change the distribution of matter in time and space in stationary flows or jets, that would have no other reason for any non-uniform distribution in time and space. Military applications would include for instance the passive detection of large rotating or pulsating machinery in cosmos, where there is no medium transmitting sound or other mechanical vibrations. Also, jets used by space-craft for steering purposes could be observed this way. (Fig. 1)

Additional applications are of active nature, e.g., for secure communication channels that can not be shielded or impeded in any way. This would be based on detection of gravitonic radiation on the 1/f noise background as seen in Fig. 2.

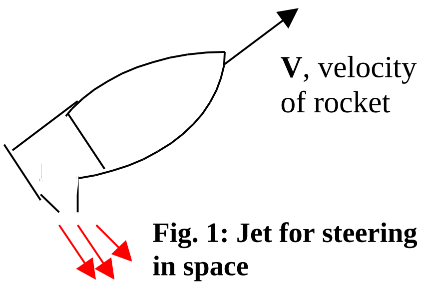

Fig. 1: Jet for steering in space

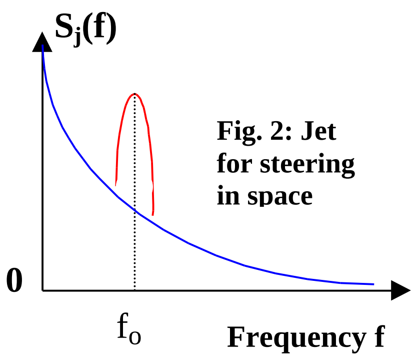

Fig. 2: Jet for steering in space

References

[1] J.M. Jauch, and F. Rohrlich, *The Theory of Photons and Electrons* (Springer, 1976)

[2] P.H. Handel, "Gravidynamic Quantum 1/f Noise", in the book *"Noise in Physical Systems and 1/f Noise"*, North Holland Publishing Co. 1985, pp. 477-480.