Graviton detection

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Abstract. The article discusses the possibility of detecting of gravitons using recently created devices with cold atoms at picokelvin temperatures.

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1 Introduction

The detection of gravitational waves [1] poses a new task - the detection of gravitons. The ability to perform this task does not yet fit into the capabilities of modern technology. Not limited to technical boundaries, we can build a theoretical experiment, possible in the future, and evaluate a possible signal with some assumptions that do not contradict existing ideas.

The work is organized as follows. In the second section, I discuss the use of ultracentrifuges to study the redshift of spectral lines from discharge tubes located on these centrifuges. This part is based on the proven results for the redshift of spectral lines in accelerated systems [2]. In the third section, the coalescence of binary neutron stars is used to estimate the graviton flux and the possibility of its detection. The last section contains conclusions.

2 Experimental simulation of gravitational redshift

Modern ultracentrifuges used in biomedical research provide centrifugal accelerations up to $803000 g_\oplus$[3], where $g_\oplus = 9.8\, m/s^2$. Replacing tubes with a biochemical liquid with discharge tubes with a rarefied gas allows you to create a gravitational redshift of spectral lines from a gas discharge (Fig. 1). The discharge tubes should be parallel to the axis of rotation, and their diameters should be much less than the distance from the tube to the axis of rotation.

Taking an ultracentrifuge at a speed of 10^5 revolutions per minute (rpm) [3], we artificially create a system located in a gravitational field with an intensity $g \simeq 8030000\, m/s^2 = 803000\, g_\oplus$ if R $= 7.18\, cm$ (Angle Rotor P100AT2 in [3]).

The relative frequency shift under the action of the centrifugal forces [4], confirmed experimentally in [2], is

$$\frac{\nu_0 - \nu}{\nu_0} = 1 - \sqrt{1 - \frac{\omega^2 R^2}{c^2}} \approx \frac{\omega^2 R^2}{2c^2}. \quad (1)$$

Substituting the used parameters $\frac{\nu_0 - \nu}{\nu_0} = \frac{4\pi^2 \cdot 10^{10} \cdot 0.0718 \cdot 0.0718}{3600 \cdot 2 \cdot 9 \cdot 10^{16}} = 3.14 \cdot 10^{-12}$, which is three orders of magnitude more than in the classical experiment [5] confirming the gravitational redshift of the radiation frequency.

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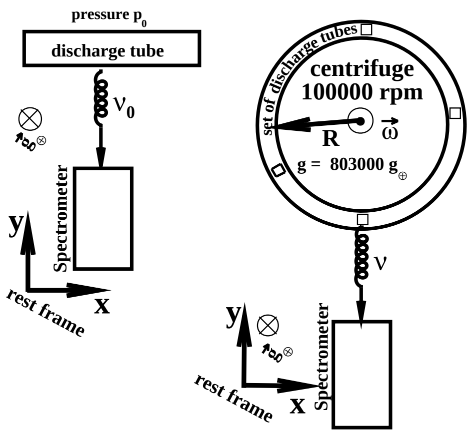

Figure 1: Sketch of an experiment to demonstrate gravitational redshift using an ultracentrifuge. The upper part of the discharge tubes on the rim of the centrifuge is shown inside the torus with a large radius R in the form of squares.

We can increase the relative frequency shift by an order of magnitude if we use a faster centrifuge, as in race cars with $3 \cdot 10^5$ rpm (centrifugal compressor) [6] and with the same radius R. Then we get: $\frac{\omega^2 R^2}{2c^2} = \frac{4\pi^2 \cdot 9 \cdot 10^{10} \cdot 0.0718 \cdot 0.0718}{3600 \cdot 2 \cdot 9 \cdot 10^{16}} = 2.8 \cdot 10^{-11}$.

3 Detection of gravitons

Consider the binary system of canonical neutron stars orbiting around their center of mass at the final stage of their evolution before merging. The mass of each neutron star $m_1 = m_2 = 1.4 M_\odot$, semi-major axis of the orbit $R = 4 \cdot 10^3\, km$ (let it be circular), orbit period of neutron stars $T = 2.6\, sec$ [7] (I used Kepler's third law to get the necessary values from those given in[7]: $R' = 2 \cdot 10^6\, km$ and $T' = 8$ hours). The reduced mass of such a system is $\mu = \frac{m_1 m_2}{m_1 + m_2} = 0.7 M_\odot$. Then the intensity of the gravitational radiation of this system (two rotating masses around their center of mass) in the direction perpendicular to the plane of the orbit, we take from [8]:

$$I = \frac{8G \cdot \mu^2 \omega^6 R^4}{2\pi c^5} / (\pi R^2) = 7.35 \cdot 10^{22}\, J/(m^2 \cdot s) = 4.6 \cdot 10^{41}\, eV/(m^2 \cdot s), \tag{2}$$

where $\omega = 2\pi/T$, G is the gravitational constant. The energy of the created gravitons is $\epsilon_g = h \cdot 2\nu = h \cdot 2/T = 3.2 \cdot 10^{-15}\, eV$. That is, the system emits almost $F = \frac{4.6 \cdot 10^{41}\, eV/(m^2 \cdot s)}{3.2 \cdot 10^{-15}\, eV} \approx 1.4 \cdot 10^{56}$ gravitons$/(m^2 \cdot s)$. We will evaluate the opportunity to detect this stream of gravitons, taking into account that the cross section for the absorption of graviton by matter is around $7 \cdot 10^{-50}\, m^2$ [9].

The graviton absorption rate is

$$R_N = A \cdot l \cdot F \cdot n \cdot \sigma, \tag{3}$$

where A is the absorber area transverse to the gravitons' flux, l is the absorber depth, F is the flux of gravitons, n is the density of atoms of the absorber, and σ is the graviton interaction cross section with substance. The absorption of graviton by a substance causes a change in the temperature of this substance in the range of tenth pico-Kelvin: $\Delta T = h \cdot 2\nu = 3.2 \cdot 10^{-15}\, eV \simeq 10^{-11}\, K$. Take into account the possibility of detecting temperature changes in the pico-Kelvin range [10]. Let assume that the gravitational radiation passes through the substance at a low temperature. Let this substance is a gas of ^{87}Rb in the tube under pico-Kelvin tempriture [10]. Let this tube is constructed as an array of experimental devices like in [10] in which such temperature is reachable. The density of atoms of rubidium is $n = 6 \cdot 10^{17}\, atoms/m^3$ [10]. The transverse size of detector let be $r = 1cm$, and transverse area $A = \pi r^2 = 3.14 \cdot 10^{-4}\, m^2$. Assume that the longitudinal size of detector (a tube filled with rubidium gas) is around 10 m. The flux of gravitons is $F = 1.4 \cdot 10^{56}$ gravitons$/(s \cdot m^2)$ (from above). Taking the absorption cross section of the graviton by the substance $\sigma = 7 \cdot 10^{-50}\, m^2$ [9] (this cross section corresponds to interaction of graviton with the nuclear matter of neutron star), we get from (3) the rate of graviton detection by means of counting the temperature changes inside of each element of array: $R_N = 1.8 \cdot 10^{22}\, s^{-1}$ which is unbelievable, therefore σ has been taken greatly increased. Let us take into account that cross section of neutrino with matter is around $10^{-48}\, m^2$ [11] and that weak interaction is stronger than gravitational on 25 orders, then let take for gravitation $\sigma = 10^{-73}\, m^2$. In result we have the rate of graviton detection $R_N \approx 0.026\, s^{-1}$ or 9 events per hour.

Though we used here the flux of gravitons F as the flux of gravitons near the neutron stars. But the flux near the Earth will be small, and the same is for the rate of graviton detection R_N near the Earth. Let suppose the neutron stars are at the distance of about $D = 100\, pc = 3 \cdot 10^{18}\, m$. Then D/R is about 10^{12}, and the flux near the Earth is about $F/10^{24}$. It means the rate of graviton detection with first value of the absorption cross section $\sigma = 7 \cdot 10^{-50}\, m^2$ [9] is $R_N/10^{24} = 1,8 \cdot 10^{22}\, s^{-1}/10^{24} \approx 10^{-2}\, s^{-1} \approx 2000$ per twenty-four hours what is also very good.

4 Conclusion

We have shown that the technical improvement of the characteristics of ultracentrifuges (increasing rotational speed and radius) can make it possible to verify the general theory of relativity in ground-based laboratories with good accuracy.

Recent discoveries of the merging of binary neutron stars/black holes and the recent achievement of the temperature range in the pico-Kelvin region may make it possible to design graviton detectors. In principle, this is possible even at the modern level of technological advances.

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