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## Gamma Ray Bursts, Neutron Star Quakes, and the Casimir Effect.

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### Abstract

We propose that the dynamic Casimir effect is a mechanism that converts the energy of neutron starquakes into  $\gamma$ -rays. This mechanism efficiently produces photons from electromagnetic Casimir energy released by the rapid motion of a dielectric medium into a vacuum. Estimates based on the cutoff energy of the gamma ray bursts and the volume involved in a starquake indicate that the total gamma ray energy emission is consonant with observational requirements.

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Observationally, Gamma Ray Bursts (GRBs) are characterized by the following generic parameters: (i) observed peak energy fluxes are of the order  $10^{-4}$  to  $10^{-7}$  erg cm $^{-2}$  s $^{-1}$  [1, 2], (ii) burst durations are distributed according to a bimodal distribution with peaks at  $\approx 0.3$  sec and  $\approx 25$  sec and median at  $\approx 10$  sec, and (iii) observed photon energies run from a few times 10 keV out to 10 MeV [1] and sometimes beyond [3]. (The larger figures can be taken as an effective momentum cutoff on the Physics of the GRBs.) In addition, GRBs are characterized by a highly non-thermal spectrum and show fluctuations over times on the order of milliseconds [4].

For these GRBs to come from neutron stars and still fit within the observed pattern of isotropy, the stars must be located in an extended galactic halo with a radius of the order of a few times  $10^5$  ly. (The extended halo may be tied to the recent finding that supernova explosions give rise to high velocity neutron stars, with the neutron stars retained by Milky Way being distributed in a large isotropic halo [5].) Since BATSE sees down to fluences of about  $10^{-7}$  erg/cm $^2$ , this translates into an emitted energy *at the source* of [6]

$$E_{\text{Source}} \approx 10^{41} \text{ erg} \times \left( \frac{D}{3 \times 10^5 \text{ ly}} \right)^2 \left( \frac{F}{10^{-7} \text{ erg/cm}^2} \right). \quad (1)$$

Any effect or theory that professes to explain GRBs must face and explain this figure together with (i), (ii) and (iii) above. Furthermore, since the energies are almost exclusively in the gamma ray range, one needs to identify a process that efficiently produces this type of radiation.

One efficient process that could produce this kind of radiation is the Casimir effect. This well known effect [8] consists on the force appearing on a system of “parallel interfaces in dielectric media” due to the quantum nature of the electromagnetic force and its associated quantum fluctuations. The Casimir force varies as the fourth power of the interface separation (unlike its classical antecedent, the electromagnetic force, which varies like  $r^{-2}$ ), and therefore a large amount of energy can be involved when the separation is very small. A system with conducting plates, where the plates are accelerated to separate over a very small distance and then contract (or viceversa) can be a source of “Casimir light” emitted as the system relaxes [9]. It is not difficult to imagine that essentially this situation could occur at the surface of a neutron star when a starquake afflicts the star. It may also happen in

quark stars, where there is a thin neutron *shell* enveloping a quark matter core.

In this letter, we will explore this scenario: a neutron star undergoing a quake (we do not enter here into a discussion of the mechanism giving rise to the starquake) and then relaxing. This gives rise to a “global” Casimir effect and we estimate the total energy released, the time scale for the phenomenon, and some general aspects of the physics involucrated.

Previous applications of the Casimir effect to study little understood physical phenomena, include the series of papers (some of them appearing at about the time of his death) written by the late J. Schwinger to understand the phenomenon of sonoluminescence [10]. Here we extend some of his ideas to the case of a quaking spherical neutron star. In the end, by analogy, we infer that sonoluminescence in bubbles of liquid material, such as water, may very well provide us with a terrestrial, laboratory scale model for GRBs in a neutron star.

Typically, a neutron star quake deforms the surface of the star by a  $\Delta R$  of anywhere between  $O(1 \text{ cm})$  in PSR 0540 – 69 to  $O(1 \mu\text{m})$  in a small Crab glitch [7]. (The scale of the deformation can be inferred from the change in angular momentum produced by the quake and then *assuming* that the glitches observed in the periods of the pulsar are due to the starquake.) Here  $R$  is the radius of the star, typically of the order of 10 km. Assuming this change is uniform, a vacuum shell may be formed by a separation between the stellar (neutron) core and the surrounding (Iron) surface; the corresponding Casimir energy, given by

$$E_{Casimir} = \frac{\hbar c}{12\pi} \frac{3}{4\pi} \cdot V \cdot K^4 \cdot (1 - \epsilon^{-1/2}) \quad , \quad (2)$$

undergoes a change proportional to  $\Delta R$ . In Eq.(2),  $V$  denotes the volume of the star,  $K$  is the momentum cutoff for the radiation emitted on relaxation, and  $\epsilon$  is the dielectric constant for the medium. Since a neutron star is close to a metal in its electrical properties, we will take  $\epsilon_{Neutron \text{ Star}} \rightarrow \infty$  for frequencies corresponding to photon momenta below the cutoff. At 100% efficiency for the conversion of Casimir energy into light, for a spherical neutron star undergoing a  $\Delta R(\text{cm})$  starquake, the released Casimir energy is

$$\Delta E_{Cas.} = 15 \times \left[ \frac{K(\text{MeV}/c)}{10 \text{ MeV}/c} \right]^4 \times \left[ \frac{\Delta R(\text{cm})}{1 \text{ cm}} \right] \times 10^{40} \text{erg} \quad (3)$$

We see explicitly from this expression that (1) the Casimir energy scales as the fourth power of the momentum cutoff and the first power of the change in radius; thus, a very small change in the cutoff scale has a large effect. And (2) that the larger portion of the energy is radiated in wavenumbers close to the cutoff. Therefore it does not have the same properties as a blackbody radiation, a point which can be used to test the validity of the present model when enough data are accumulated. Of course, the flat spectrum produced (up to the cutoff) may well be attenuated at the higher energies by scattering on star material or material in the surrounding system.

In the model we are describing here, the physics of the cutoff is related to the physics of the collapse of the shell formed between core and surrounding surface, and is cognate to the effective, differential collapse velocity  $\Omega$ , by

$$\Omega^2 = \frac{\hbar c}{12\pi^2} \frac{K^4}{\rho_0} (1 - \epsilon^{-1/2}) \quad (4)$$

where  $\rho_0$  is the density of the material. This is the speed that a shell of collapsing material would reach if *all* its Casimir energy were transformed into kinetic energy.

We consider two extreme values for  $\Omega$ : a lower limit obtained by assuming that the shell is free falling in the gravitational field of the neutron star, and an upper limit obtained by assuming that the shell falls with the speed of light. The two limiting values are easily computed from Eq.(4), which gives  $K_{lower} = 14$  MeV and  $K_{upper} = 400$  MeV.

Using these values and Eq. (3), we see that the total energy released in each case (assuming 100% energy conversion efficiency) is

$$\Delta E_{Casimir}^{lower} = 57.6 \times \left[ \frac{\Delta R(\text{cm})}{1\text{cm}} \right] \times 10^{40}\text{erg} \quad (5)$$

and for the upper limit we get

$$\Delta E_{Casimir}^{upper} = 38.4 \times 10^6 \times \left[ \frac{\Delta R(\text{cm})}{1\text{ cm}} \right] \times 10^{40}\text{erg} \quad (6)$$

These two results clearly demonstrate that the two observational values for the total energy quoted above can be amply met by the release of Casimir energy in the process of a starquake in a neutron star. The Casimir “limiting speed”  $\Omega$  given by Eq. (4) that results for a cutoff of 100 MeV can be readily

calculated to be  $4.9 \times 10^8$  cm/s, a little less than two percent the speed of light.

The burst time observed on Earth is the time that the signal at this speed takes to propagate around (*half*) the surface of the neutron star, and this is

$$T_{Total} = 6.5 \times 10^{-3} \left[ \frac{100 \text{ MeV}/c}{K(\text{MeV}/c)} \right]^2 \text{ sec} \quad (7)$$

in excellent agreement with the observational data for the shorter bursts. Of course, there is no reason, in principle, why the quake should not reverse its course across the star surface and so extend the burst time.

Let us address the question of overall mechanism efficiency. This can be estimated by comparing the change in the gravitational energy of the quaking star to the energy converted into gamma rays by the Casimir effect as described here. Using Eq.(3) and with Newtonian gravity and mechanics (justified because of the low  $\Omega$ ) we have that the efficiency,  $\eta$ , required by the Casimir mechanism is given by

$$\eta = \frac{E_{Casimir}}{E_{Starquake}} \approx 2.5 \times 10^{-7} \left[ \frac{K(\text{MeV}/c)}{10 \text{ MeV}/c} \right]^4 \quad (8)$$

that is, for a 100 MeV/c cutoff the efficiency need not be any higher than about 0.25%.

We close with a number of remarks.

The starquake-Casimir mechanism we have presented is not cataclysmic. The neutron star survives and there could be repetitions of GRBs from the same source on a time scale of years. Our discussion uses spherically symmetric starquakes for the sake of simplicity. This is unlikely to be the case in practice, and so repetition—or coincidence with a pulsar glitch [11]—would require also that the starquake be in a region of the star facing Earth.

A cataclysmic version of a collapse-Casimir mechanism may be possible, and may be relevant if evidence that GRBs emanate from cosmological distances becomes compelling. For example, if a neutron star accretes mass from a nearby star and passes over the Chandrasekhar limit, it will collapse into a black hole. vacuum does not give Casimir If there is any bounce, or sudden outflow of dense material as a result of collapse, energetic Casimir radiation can ensue.

Details of the burster length and time structure depend on details of the infall, reverberation, and lateral spread of a starquake. Further work on this as well as on equation of state effects, effects of finite permittivity, and *ab initio* calculation of the cutoff wave number is under study. The reason for the existence of two classes of GRBs, if indeed the two classes are really distinct, is also open, although we expect it is related to the preceding list.

In summary, we have presented the dynamic Casimir effect as a mechanism that could efficiently explain the conversion of starquake energy into gamma rays. The total energy converted into gammas depends on the gamma ray cutoff energy and the volume of material involved in the starquake. Furthermore, our estimates are in encouraging agreement with observation.

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