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Electromagnetic signals from bare strange stars

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Summary. — Strange stars with a crystalline color superconducting crust can sustain large shear stresses, supporting torsional oscillations of large amplitude. We consider a simple model of strange star with a bare quark matter surface. When a torsional oscillation is excited, for example by a stellar glitch, the positive charge at the star surface oscillates, with typical kHz frequencies, for a 1 km thick crust, to hundreds of Hz, for a 9 km thick crust. Higher frequencies, of the order of few GHz, can be reached if the star crust is of the order of few centimeters thick. The estimated emitted power is of the order of 10^{45} erg/s.

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1. – Description

Quark stars (QSs) are extremely dense compact objects known to exist in the universe. There are generally two possibilities to explain the existence of QSs, one possibility is that when nuclear mater is squeezed to a sufficiently high density, there is a transition from nuclear matter to deconfined quark matter in the core of QSs, in this case we have a hybrid star in which there is a quark core and a crust of standard nuclear matter. A second possibility is that strange matter is the true ground state of the hadrons [1]. If quark matter is the ground state, it is probably necessary to assume that ordinary neutron stars are really quark stars. However, it has been claimed that the macroscopic properties of quark stars are hard to distinguish from those of neutron stars. In this paper, we consider quark star models in which there exist two region: a core of color-flavor–locked (CFL) phase [2], in which pairing between quarks of different colors and flavors is allowed and the crust of crystalline color superconducting (CCSC) phase [3]. We assume that a certain radial distance, $R_c = aR$ with $0 \leq a \leq 1$, there is a phase transition between the CFL phase and CCSC phase. The CCSC phase is extremely rigid the shear modulus is given by [4]

$$\nu = 2.47\,\mathrm{MeV/fm^3}\left(\frac{\Delta}{10\,\mathrm{MeV}}\right)^2\left(\frac{\mu}{400\,\mathrm{MeV}}\right)^2,$$

where Δ is the gap parameter and μ is the quark chemical potential. This shear modulus is extremely large and it can sustain large amplitude oscillations. When a torsional oscillations is excited, for example by a stellar glitch the positive charge at the star surface oscillates and we have an electromagnetic emission.

2. – Torsional oscillations

We are interested in torsional oscillations that are capable of generating an EM current at the star surface. Given the spherical symmetry of nonrotating stars, the displacement vector at a general point may be expressed as

$$\xi^r_{nl} = 0, \qquad \xi^\theta_{nl} = 0, \qquad \xi^\phi_{nl} = \frac{W_{nl}(r)}{r \sin\theta}\frac{\partial P_l(\cos\theta)}{\partial\theta} e^{i\omega_{nl}t}.$$

In the Newtonian limit the amplitude of the horizontal oscillation satisfies the following differential equation [5]:

$$\frac{\mathrm{d}^2 W_{nl}}{\mathrm{d}r^2} + \frac{2}{r}\frac{\mathrm{d}W_{nl}}{\mathrm{d}r} + \left(\frac{\omega^2_{nl}}{v^2_s} - \frac{l(l+1)}{r^2}\right) W_{nl} = 0,$$

where $v_s = \sqrt{\nu/\rho}$ is the shear wave velocity. The frequency of the oscillations is proportional to the shear velocity divided by the crust width. We assume that a fraction of the energy of a glitch excites the $l = 1, n = 1$ mode. We can estimate the emitted power by considering the moving electric charge as an oscillating magnetic dipole [6]. If we take $a = 0.9$ we obtain that

$$P \propto Q^2_+ \omega^6_{11} \approx 10^{45}\,\mathrm{erg/s},$$

where $Q_+ = 1.2 \times 10^5$ is the surface charge density and ω_{11} is the first excited mode.

3. – Conclusions

In our simple model, we estimate the emitted energy of the torsional oscillations using an oscillating magnetic dipole. The emitted power is extremely large, and for stars with a small CFL core it is of the order of $10^{41}\eta\,\mathrm{erg/s}$, where η is a screening factor due to the presence of the electrosphere [7]. In our treatment we have neglected the effect of the background magnetic field and the temperature.

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