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Influence of stellar oscillations on pulsar and magnetar magnetospheres

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Abstract. We investigated influence of stellar oscillations on the electrodynamics of pulsars as well as magnetars magnetosphere. Besides finding noticeable modification of electromagnetic field and charge density in the polar cap vicinity of oscillating neutron stars we proposed qualitative hypotheses explaining phenomena of part time pulsars as well as sporadic radio emission from generally radio-quiet magnetars with the help of stellar oscillations.

Keywords. Stars: neutron, stars: oscillations, (stars:) pulsars: general.

Investigations of oscillating neutron stars are motivated by the detection of quasi-periodic oscillations (QPOs) in the spectra of soft gamma-ray repeaters (SGRs), which are thought to be neutron stars with very strong magnetic fields (Duncan & Thompson (1992)). The idea that stellar oscillations may induce high energy emission in neutron star magnetospheres was developed in a series of papers by Timokhin and collaborators (see Timokhin *et al.* (2000), Timokhin *et al.* (2008)), after the first pioneering investigations in McDermott *et al.* (1984), Muslimov & Tsygan (1986) and Rezzolla & Ahmedov (2004), where the case of an oscillating neutron star in a vacuum was considered. Starting from Abdikamalov *et al.* (2009), where the theoretical basis of our approach was developed, in a series of papers (Morozova *et al.* (2010), Morozova *et al.* (2012), Zanotti *et al.* (2012)) we have explored the influence of neutron star oscillations on such characteristics of pulsar and magnetar magnetosphere as charge density and electromagnetic field in the polar cap region of the magnetosphere, electromagnetic energy losses as well as conditions for the charged particles acceleration in the magnetosphere. In our research we used toroidal model of stellar oscillations described in Unno *et al.* (1989).

In Morozova *et al.* (2010) we explored the magnetosphere of a slowly rotating magnetized neutron star subject to toroidal oscillations in the relativistic regime. Under the assumption of a zero inclination angle between the magnetic moment and the angular momentum of the star, we analysed the Goldreich-Julian charge density and derived a second-order differential equation for the electrostatic potential. The analytical solution of this equation in the polar cap region of the magnetosphere revealed noticeable modification induced by oscillations on the accelerating electric field and on the charge density. We found that, after decomposing the oscillation velocity in terms of spherical harmonics, the first few modes with $m = 0, 1$ are responsible for energy losses that are almost linearly dependent on the amplitude of the oscillations and that, for the mode $(l, m) = (2, 1)$, can be a factor ~ 8 larger than the rotational energy losses, even for a velocity oscillation amplitude small in comparison with the linear velocity of stellar rotation. Based on these results we proposed a qualitative model for the explanation of the phenomenology of intermittent pulsars (Lyne (2009)). The idea is that stellar oscillations, periodically excited by star glitches, can create relativistic winds of charged particles because of the additional electric field. When the oscillations damp, the pulsar shifts below the death line in the $P - B$ diagram, thus entering the OFF invisible state of intermittent pulsars.

In Morozova *et al.* (2012) we investigated the conditions for radio emission in magnetospheres of rotating and oscillating magnetars. The activity of magnetars is observed in the form of bursts in X-ray and γ-ray bands, while there is no periodic radio emission from the majority of magnetars. We found that as soon as magnetar oscillations are taken into account, their death lines in the $P - B$ diagram shift downward and the conditions necessary for the generation of radio emission in the magnetosphere are met. Present observations (Malofeev *et al.* (2007), Malofeev *et al.* (2010)) showing a close connection between the burst activity of magnetars and sporadic detection of the radio emission from some magnetars are naturally accounted for within our interpretation.

In Zanotti *et al.* (2012) we explored he conditions for charged particle acceleration in the vicinity of the polar cap of pulsar magnetosphere in presence of stellar oscillations. We solved numerically the relativistic electrodynamics equations in the stationary regime, focusing on the computation of the Lorentz factor of a space-charge-limited electron flow accelerated in the polar cap region of a rotating and oscillating pulsar. We found that star oscillations may be responsible for a significant asymmetry in the pulse profile that depends on the orientation of the oscillations with respect to the pulsar magnetic field. In particular, significant enhancements of the Lorentz factor are produced by stellar oscillations in the super-GJ current density regime.

Some recent investigations have tried to connect the models of stellar oscillations with the observational data available for pulsars (see Rosen & Demorest (2011), Rosen *et al.* (2011)). The scenario that is emerging from these studies is that the presence of stellar oscillations creates different kinds of "noise" in the clock-like picture of pulses, i.e. changes in the pulse shape, changes in the spin-down rate, and the switching between different regimes of pulsar emission. As the next step in our future research we plan to thoroughly check the analytical results described above and the proposed hypotheses with the help of observational data on pulsar and magnetar radio emission.

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