Magnetars versus Radio Pulsars: MHD stability in newborn highly magnetized neutron stars

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ABSTRACT: We study the stability/establishment of poloidal MHD equilibrium configurations in newborn neutron stars (NSs) in dependence on the rotation velocity $\vec{\Omega}$ and on the initial angle α between rotation and magnetic axis. The NS is modeled as a sphere of a highly magnetized ($B \sim 10^{15}$G) incompressible fluid of uniform density which rotates rigidly. For the initial dipolar background magnetic field, which defines the magnetic axis, two different configurations are assumed. We solve the 3D non-linear MHD equations by use of a spectral code. The problem in dimensionless form is completely defined by the initial field strength (for a fixed field geometry), the magnetic Prandtl number, and the normalized rotation rate. The evolution of the magnetic and velocity fields is considered for $t_{Ohm}/t_{Alfven} \approx 1000$, for magnetic Prandtl numbers 0.1, 1, 10, and the ratio of rotational period and Alfven travel time,$P/t_{Alfven} = 0.012, 0.12, 1.2, 12$. We find hints for the existence of a unique stable dipolar magnetostatic configuration for any specific α, independent of the initial field geometry. Comparing NSs possessing the same field structure at the end of their proto-NS phase, it turns out that sufficiently fast rotating NSs ($P \leq 6\,\mathrm{ms}$) with $\alpha \leq 45^0$ retain their magnetar field, while the others lose almost all of their initial magnetic energy by transferring it intomagnetic and kinetic energy of relatively small-scaled fields and continue their life as radio pulsars with a dipolar surface field of $10^{12...13}$G.