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Evolution of the Magnetic Field of an Accreting Neutron Star

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The time scale for ohmic decay of any magnetic field depends upon the electrical conductivity of the medium in which the field is embedded. Therefore, in a neutron star, owing to very different physical structure and hence different electrical conductivity of the core and the crustal matter, the field evolution time scales differ significantly from one region to another. In case of a neutron star accreting matter from a companion the crustal matter is continuously pushed into the core since the mass of the crust is finite and is limited by the elastic properties of the matter. Thus, if the magnetic flux is originally confined to the neutron star crust (Yakovlev & Urpin 1980; Blandford, Applegate & Hernquist 1983; Urpin, Levshakov & Yakovlev 1986), it is evident that the field experiences a change in decay time scale as the crustal matter undergoes a phase transition in being assimilated into the core.

We explore two possibilities: a) that the state of the newly formed core material is a normal, non-superfluid one, and b) that it goes into a superfluid state.

In either case, when the accretion takes place, the crustal material is pushed into successively more dense regions (before it is finally assimilated into the core). This, because of flux freezing, causes compression of the current loops and leads to the generation of large wavenumber components of the current. These large wavenumber modes have faster decay rates since the ohmic decay time scale is inversely proportional to the square of the wavenumber (Landau & Lifshitz 1960). Hence, the magnetic flux can decay rapidly via these modes. But once the flux frozen material is completely assimilated into the core, the mode of decay will be determined by the nature of the newly formed core material.

a) *Normal, non-superfluid n–p–e matter*:

For this state of matter, the conductivity has the following features (Yakovlev & Shalybkov 1991):

1) It is highly anisotropic in presence of magnetic field.
2) It is a strong function of the field strength

$$\sigma_\perp = \sigma_0(1 + B^2/B_0^2)^{-1} \tag{1}$$

where
σ_0 is isotropic conductivity in absence of any field.
$B_0 = 10^8 - 10^9\,\mathrm{G}$ for $T_{\mathrm{core}} = 10^6 - 10^7\,\mathrm{K}$.

3) for $B \gg B_0, \sigma_\perp \ll \sigma_{\mathrm{crust}}, \sigma_0$.

Since the ohmic decay time scale is proportional to the conductivity (Landau & Lifshitz 1960), a region of lower conductivity implies a faster decay for the field.

Therefore, when the crustal material, with a larger field value of the initial field, is assimilated into the core, the field undergoes a rapid decay. But this decay rate subsequently decreases as the field approaches B_0 and $\sigma_\perp$ approaches the very large value of the isotropic conductivity.

Hence, the field decays initially with a time scale characteristic of the initial value of the field and practically stops decaying after reaching the limiting value of B_0. For reasonable values of the core temperature (Urpin & Van Riper 1993), B_0 is between 10^8 and 10^9 Gauss.

b) *Superfluid, superconducting matter in the core*:

In this state, after having undergone a superfluid-superconductor phase transition, the conductivity and hence the decay time scale lengthen to extremely large values. Therefore, one expects a phase of rapid decay of the field, during the early phase of the accretion (before the whole of the original crust is pushed into the core) followed by a stable phase for the field configuration.

References

Blandford, R., Applegate, J., Hernquist, L. 1983, *Mon. Not. R. astr. Soc.*, **204**, 1025.
Landau, Lifshitz 1960, *Electrodynamics of Continuous Media*, (Oxford: Pergamon Press).
Urpin, V. A., Levshakov, S. A., Yakovlev, D. G. 1986, *Mon. Not. R. astr. Soc.*, **219**, 703.
Urpin, V. A., Van Riper, K. A. 1993, *Astrophys. J.*, (in press).
Yakovlev, D. G., Urpin, V. A. 1980, *Soviet Astr.*, **24**, 303.
Yakovlev, D. G., Shalybkov, D. A. 1991, *Astrophys. Space Sci.*, **176**, 191.