Jets at all scales
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Conditions for jet formation in accreting neutron stars: the magnetic field decay

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Abstract. Accreting neutron stars can produce jets only if they are weakly magnetized ($B \sim 10^8$ G). On the other hand, neutron stars are compact objects born with strong surface magnetic fields ($B \sim 10^{12}$ G). In this work we study the conditions for jet formation in a binary system formed by a neutron star and a massive donor star once the magnetic field has decayed due to accretion. We solve the induction equation for the magnetic field diffusion in a realistic neutron star crust and discuss the possibility of jet launching in systems like the recently detected Supergiant Fast X-ray Transients.

Keywords. stars: neutron, magnetic fields, accretion, X-rays: binaries

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Magnetic field decay and jet production in SFXTs

Several Galactic bright X-ray transients presumable composed by a compact object (a neutron star (NS) or a black hole) and an OB super-giant companion have recently been discovered by *INTEGRAL*/IBIS and *Swift*. The so-called Supergiant Fast X-ray Transients (SFXTs) show short flares of typically few hours to days reaching $10^{36} - 10^{37}$ erg.s^{-1} returning to quiescent levels of $\sim 10^{32}$ erg.s^{-1} emission (Sguera *et al.* 2009). It has been stated that such systems could also emit jets only if they are weakly magnetized ($B \sim 10^8$ G) (Massi & Kaufman Bernadó 2008, Migliari & Fender 2006). We investigate here if such condition can be met for a realistic NS model born with pulsar's strength field ($B \sim 10^{12}$ G) for which the magnetic field is diffused in the NS crust in about 10^{6-7} yrs (Geppert & Urpin 1994).

Magnetic field decay in the neutron star crust

We consider that the composition of the neutron star crust is modified by the accreted material and we construct two background models as in Aguilera *et al.* 2008: a low mass NS (LM) with $M = 1.4$ $M_\odot$ and $R_{\rm NS} = 11.72$ km and a high mass NS (HM) with $M = 1.8$ $M_\odot$ and $R_{\rm NS} = 11.35$ km. For both models the crust thickness is in the range $0.5 - 1$ km, which defines a characteristic length scale for the confinement of the crustal magnetic field. The thermal evolution of the NS crust is taken from previous work Aguilera *et al.* 2008 considering different states for the $^3P_2$ neutron superfluidity in the core: strong superfluidity (SF) or no pairing at all (no SF).

We assume a dipolar magnetic field confined to the NS crust (Urpin & Konenkov 2008) described by the Stokes function $s(r, t)$ in radial coordinates which is solution of the induction equation for the magnetic field. The electrical conductivity σ is a function of the temperature T and the density ρ and includes all the relevant electron scattering processes (Potekhin 1999). The surface magnetic field at any instant can be obtained by evaluating $B(t) = B_0 s(R_{\rm NS}, t)$, where $B_0 = 10^{12}$ G is the initialfield strength.

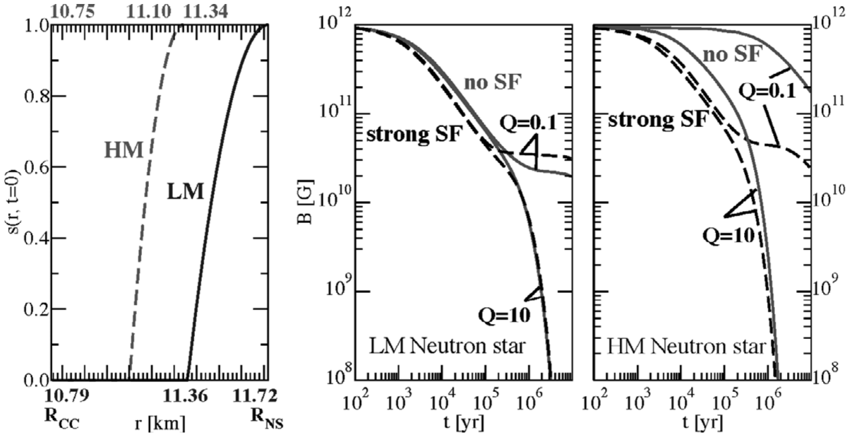

Figure 1. Initial Stokes function (left) and magnetic field evolution (middle and right).

The initial distribution we choose for the Stokes function in the NS crust is shown in Fig. 1 (left panel) and it matches with an external dipole at the NS surface imposing the condition on its derivative $ds/dr + 1/R_{\rm NS} = 0$.

Our results show that the decay of the initial field depends on the underlying NS properties like e.g. its mass and impurity content of the crust Q, as well as on the NS cooling history (SF or no SF in the core) in the relevant timescale of 10^{6-7}yr (Fig. 1, middle and right panels). As a NS cools down and $T \lesssim 10^7$ K, electron scattering on impurities becomes important and this results in a persisting magnetic field decay for the most impure crusts ($Q \sim 10$). The NS surface field could be as low as 10^8 G if the crust is very resistive (very impure) and the star is old enough ($> 10^6$ yrs). On the other hand, the magnetic field decays only about 1-2 orders of magnitude in a crust that is a nearly perfect lattice ($Q \sim 0.1$) in the same timescale. The results are less sensitive to the NS superfluidity in the core.

Conclusions

The magnetic field decay in accreting NSs depends on the NS underlying model through the cooling evolution and the crust composition. In particular, it depends strongly on the impurity content of the NS crust: NSs with high impurity content are much resistive and therefore the magnetic field can decay up to 3-4 orders of magnitude in about 10^{6-7} yrs. Thus, the magnetic field condition ($< 10^8$ G) for jet formation in SFXTs would be more likely achieved in high mass systems with high metallicity winds.

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