Chapter 5

Epilogue

Magnetic field evoution

The main objective of this thesis was to investigate the decay of magnetic fields of neutron stars. The observational evidence from radio and X-ray pulsars suggests that magnetic fields of solitary neutron stars do not decay substantially during their lifetime as radio pulsars. The reported observations of cyclotron line like features in the X-ray spectrum of some gamma-ray bursters suggests that the magnetic fields of solitary neutron stars may not decay significantly even over timescales comparable to the age of the Galaxy. On the other hand, the measured magnetic fields of binary and millisecond pulsars definitely point to a decay of their magnetic fields subsequent to their birth. Further, given the fact that the overwhelming majority of millisecond pulsars have magnetic fields $\sim 5 \times 10^8$ G, one has been led to conclude that their magnetic field does not decay indefinitely but reaches an asymptotic value. These then are the phenomenological features that any theoretical attempt to account for field decay must explain.

In our opinion the only reasonable hypothesis that has been advanced so far attributes field decay to the secular spinning down of the neutron star. The particular suggestion that has been made is that as the neutron star slows down the vortices in the neutron superfluid drag the fluxoids in the proton superconductor with them, thereby depositing the core field at the bottom of the crust where it subsequently decays. This is the so called spindown-induced flux expulsion scenario (the SIF model). The major part of the investigation presented in this thesis is devoted to a very detailed investigation of this suggestion. We have already summarized the main conclusions at the end of Chapters 2 and **3.** Here we shall be even more selective and single out only a few of our conclusions.

Solitary pulsars

- Our calculations vindicate the earlier conjectures that the population of solitary pulsars could be an admixture of neutron stars born from singlar stars and those that were born, processed and released from mass transfer binary systems. More specifically, our detailed investigations agree with the suggestion that recycled pulsar from massive binaries would not yet have experienced significant field decay. Although during the course of their evolution in the binary a fraction of the flux trapped in the core would most likely have been expelled to the crust, there would not have been enough time for the field to decay before the neutron star was resurrected from its graveyard and starts functioning again as a recycled pulsar. Their fields will decay eventually.

- Very old neutron stars born from solitary pulsars are expected to have surface field strength $\sim 10^{11}$ G.

Binary and recycled pulsars

(a) Massive binaries

- The evolutionary tracks of puslars processed in massive binary systems would be along nearly vertical tracks in the magnetic field-period plane.

- Recycled pulsars might populate the region between the "Hubble line" and the "death line" in the magnetic field-period plane, although their rapid downwards evolution mentioned above will make the chance of observing them rather small. The magnetic field of such recycled pulsars could eventually decay to very low values $\sim 10^6$ G. They will obviously not function as pulsars unless they acquire another binary companion – and a low mass companion at that(!) – and get spun up to submillisecond periods. For only then can they function as radio pulsars.

(b) **Low-mass binaries**

- In neutron stars with low mass companions spin periods as large as $\sim 10^3$ s can be reached in the SIF scenario. This is to be contrasted with a maximum period of only ~ 10 s if the magnetic field of the neutron star were to decay spontaneously and exponentially.

- In the models we have investigated, the observed magnetic fields $\sim 10^8 - 10^9$ G in millisecond pulsars can be obtained under a variety of circumstancs. We believe that this is the first time this has been demonstrated through detailed calculations.

- The lowest value of field strength achieved for pulsars recycled in low mass binary systems are $\sim 10^8$ G in our models. This is a direct consequence of the fact that the maximum spin periods acquired by neutron stars in such systems never exceed a value $\sim 10^4$ s *irrespective of the initial conditions we have explored.*

- We find that there is a broad agreement between the predicted and observed trends in magnetic field strength as a function of the initial orbital period of the binary.

- Recycled pulsars in globular clusters will have higher residual fields than their counterparts in the disk population. This is a result of their lower magnetic fields when they are captured into a binary orbit by a passing companion!

Rotational dynamics

In Chapter 4 we have explored some consequences of the interpinning between fluxoids and vortices for the rotational dynamics of the star. We believe that this is the first time this question has been addressed. The occurrence of superfluidity and superconductivity in the core of neutron stars was predicted even prior to their discovery. Although superfluidity of the crustal neutron fluid was invoked quite early on to explain the phenomenon of glitches, the core superfluid was assumed to be a passive companion. In our opinion such an attitude is untenable if the vortices in the core neutron superfluid are strongly pinned to the fluxoids in the core superconductor. Although such an interpinning was overlooked for nearly twenty-five years after the discovery of pulsars, the arguments for it are quite compelling. At the end of the previous chapter we have pointed out several possible interesting implications of such an interpinning for the rotational history of a neutron star. We do not wish to repeat them here. Although the specific suggestions we have made should be viewed as tentative, we would like to forcefully argue that any reasonable theory for the origins of glitches and post-glitch relaxation cannot and should not ignore the role of the pinned core superfluid.

Chapter 6

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