CHAPTER 1

THE SCOPE AND THE OUTLINE OF THE THESIS

This study is devoted to a discussion of pulsars, supernova remnants, and their associations.

It is generally accepted that neutron stars are the end products of the evolution of massive stars, and as a consequence of the formation of a neutron star, there is a supernova explosion. When the blast wave from such an explosion sweeps up sufficient matter from the interstellar medium, it becomes a powerful emitter of non-thermal radio waves and thermal X-rays. Such objects are known as supernova remnants and about 150 of them are known in the Galaxy. It is also believed that the supernovae associated with the formation of neutron stars are what are called type II supernovae. According to current thinking, the other main type of supernova, namely a type I supernova, does not leave behind a neutron star.

The statistics of their occurrences suggests that the frequency of these two main types of supernovae are roughly equal. Thus one would expect to find a neutron star at the centre of at least half of the known supernova remnants. Since young neutron stars are believed to function as pulsars, one expects a physical association between pulsars and the remnants of at least the supernovae of type II. However, even though the catalogue of supernova remants is very large, in only four cases has a pulsar been detected at their centres. This raises several interesting questions. For example,

- **Is a neutron star left behind in all type II supernovae?**
- **Do all young neutron stars necessarily function as pulsars?**

If the answer to both the above questions is yes, then why is the association between pulsars and supernova remnants so poor? This is one of the main questions addressed in this study, and **Chapter** 2 is devoted to this. **Our main conclusion in this Chapter is that if there are neutron stars. in all remnants of type II supernovae, and if they function as pulsars as one expects them to, then they must** be **spinning rather slowly, contrary to what one expects.**

There has been a recent suggestion that young neutron stars may not necessarily function as pulsars because they are not endowed with a strong magnetic field at birth, which is essential for pulsar activity. The suggestion is that the observed magnetic fields of neutron stars are built up after their birth, by which time the supernova remnant would have faded away. This provides an interesting alternative way to understand the poor association between pulsars and supernova remnants. **Chapter** 3 is devoted to a critical evaluation of this suggestion. Our main conclusion in this Chapter is that even though some of the mechanisms advanced for such a post-birth build up of the magnetic field are reasonable, our present understanding of the solid state physics of the neutron star does not permit any firm conclusions regarding whether these mechanisms are likely to be efficient. Even granting that they may be so, **we argue that the main conclusion of Chapter 2, namely that the majority of the neutron stars are relatively slow rotators at birth, cannot be avoided.**

The abovementioned conclusion is contrary to the conventional wisdom. The fact that the youngest pulsar we know, namely the Crab pulsar, is spinning very rapidly led one to expect that all young neutron stars will not only function as pulsars, but will be rapid rotators. **In Chapter 4** we advance some speculations as to why young pulsars may have a rather small angular momentum at birth. One possibility is that when the core of the progenitor star collapsed, and a neutron star was formed, it was indeed spinning very rapidly, but the stored rotational energy was quickly extracted. If one grants this, it is interesting that **the amount of rotational energy extracted could in some cases be comparable to the observed energy of supernova explosions. In view of**

this we suggest that this may indeed be responsible for the supernova explosion itself.

Active pulsars are expected to produce supernova remnants like the Crab nebula. Such pulsar-produced nebulae will have a centrally filled appearance. However, the majority of supernova remnants have the morphology of shells with hollow interiors. There have been various suggestions in the literature as to why this is so. According to some, the supernova remnants of type II explosion will always have a morphology similar to that of the Crab nebula. According to others, they will initially have this morphology, but will evolve to the other kind, namely, shells with hollow interiors. In **Chapter 5** we present model calculations of expanding supernova ejecta with a **pulsar** at the centre, and examine in detail the evolution of the surface brightness and the morphology. **Our main conclusion is that whether a relatively old supernova remnant will look like a shell, or the Crab nebula, or a hybrid, will depend upon the parameters of the pulsar, the expansion velocity of the ejecta, and the interstellar medium into which it is expanding.**

In recent years, there is mounting evidence that a massive star significantly alters its immediate environment before it explodes. The result of prolonged and heavy mass loss in the form of high velocity winds is to excavate a cavity in the interstellar medium, so that when the star eventually explodes, the ejecta will be expanding not in the original interstellar medium, but into such a cavity inside which the density is expected to be very low. **This has important consequences for the morphology of the remnant, as well as its lifetime.** If we accept this, then it turns out that one will have to significantly alter the standard estimates for the birthrate of supernova remnants. We discuss this question in **Chapter** 6, and **conclude that whereas the standard estimates give a birthrate of one in $\sim$100 yr, the true birthrate could be as high as one in $\sim$30 yr.**

During the last few years Radio emission has been detected soon after a supernova explosion in some external galaxies. This was not expected in the standard models and has raised some important questions. In particular, does the mechanism responsible for this prompt radio emission continue indefinitely so that the (old) supernova remnants that have been detected are merely a continuation of this, or whether the initial mechanism ceases and the radio emission builds up much later due to very different reasons. We discuss this question in **Chapter 7**, and **conclude that if prompt radio emission occurs in most aupernovae, then this emission will fade away in a timescale $\sim$50 years and what we call supernova remnants will turn on a few centuries later.**

Having discussed the influence of pulsars on supernova remnants, as well as the possible role of a pulsar in the radio emission from supernovae, in Chapter 8 we turn to the question of the influence of pulsars on the supernova light curve itself. If the majority of pulsars are in fact born as slow rotators as argued in Chapter 2, then they will not significantly influence the light curves. However, in those rare cases when the energy loss rate of the pulsar is $\gtrsim 10^{42}$ **erg/s,** it will be an important source of energy. We **point out that in such instances the light curve may have a very extended plateau.** The light curve of the recently observed supernova in the Large Magellanic Cloud has just this property. In view of this, we suggest that this may be an example of a pulsar-powered light curve. If this is indeed true, then in a few months' time strong non thermal **W,** X-ray and γ-ray radiation should build up.

In Chapter 9 we discuss the properties of the so-called millisecond pulsars. Three such ultra rapid pulsars have been discovered in our Galaxy. **We argue in this Chapter that these pulsars must be more than 10^9 years old.** In the normal course of evolution a pulsar is expected to stop functioning in a few million years because of the decay of its magnetic field. The fact that the millisecond pulsars are functioning for so long suggests that their magnetic fields do not decay, or decay much more slowly than in normal pulsars., The millisecond pulsars have the lowest fields among all neutron stars known; but interestingly the fields of all the three millisecond pulsars are very nearly the same. **We suggest that the decay timescale of neutron star magnetic fields undergo at least a thousand-fold increase by the time its field has decayed to $\sim 5\times10^8$ gauss,** the field observed in the millisecond pulsars.

These are some of the questions we have examined in detail. Each chapter has a fairly detailed introduction to the background and also a summary of important conclusions and results obtained in that chapter.