Chapter 1

The outline of the thesis

This thesis is devoted to a study of some of the statistical properties of radio pulsars in the Galaxy.

Many of the statistical properties of radio pulsars have been understood by studying the distribution and evolution of some of the observable parameters like rotation period, its time derivative (or magnetic field strength, which can be derived from period and its time derivative) *etc.* Similarly, the kinematic properties can be studied by their spatial distribution and the measured proper motion. This thesis deals with some of the important properties of pulsar population like the *distribution of their initial periods, their formation rate, their spatial distributicn in the Galaxy, and the kinematic properties of millisecond pulsars in the Galaxy.*

Many authors have studied the statistical properties of pulsars like birth rate, distribution of initial periods, *etc.* However, in the recent times there have been a lot of changes in our understanding of distances to the observed pulsars, and the radio luminosity model. Since pulsars suffer from severe observational selection effects, it is important to have a good distance model and the radio luminosity model to estimate the *true* distribution of pulsars in the Galaxy. Now, with our revised understanding on the distance model and the luminosity model, it is important to have a fresh look at the pulsar statistics. Moreover, there is yet another important reason for this.

Pulsars have their rotation periods ranging from about a few milliseconds to a few seconds. They are born with relatively short periods, and during their evolution, period lengthens to about a few seconds before they cease to act as pulsars. Though the distribution of initial periods of pulsars was debated for a long time, some of the earlier works on this subject have indicated that a significant fraction of pulsars are born rotating with relatively long periods (say, a few hundred milliseconds). While this idea has been there in the literature for fifteen years or so, one has not understood the reason for why a good fraction of pulsars are born rotating relatively slowly. The exercise described in Chapter **2** explores the ideas given above.

The main results of Chapter **2** can be summarised as follows:

- The birth rate of pulsars in the Galaxy is one in about 75 years or so. The new distance model has reduced the birth rate by about a factor of two.

- The phenomenon of *injection* has been interpreted as due to the recycled pulsars from massive binaries and intermediate mass binaries in the Galaxy. This naturally helps one to explain the distribution of birth rate of pulsars as a function of characteristic age and the height from the Galactic plane.

- With the assumption that the injected pulsars are the recycled pulsars from massive and intermediate mass binaries, the upper limit to the fraction of recycled pulsars in the main population of pulsars is computed to be about 10–15%.

The estimation of the fraction of recycled pulsars in the main population of pulsars is quite important. Another simulation was done, to estimate this number through a completely different method. Chapter 3 describes a Monte Carlo simulation of massive stellar systems which was done to estimate this fraction. Since this simulation dealt with stellar systems of all kinds which finally lead to the formation of neutron stars, it was used to derive some other parameters like the formation rate of double neutron star binaries, the number of *observable* (at least one neutron star is alive as pulsar) double neutron star binaries, and the merger rate of these binaries due to the emission of gravitational radiation.

Quite a few earlier works have tried Monte Carlo techniques to understand the properties of binary systems in the Galaxy. The procedure followed in Chapter 3 is essentially derived from all those earlier works. However, we have incorporated a number of important improvements. Pulsars produced in this simulation are evolved in a more complete fashion than any other previous work. The observational selection effects were taken into account to find out the distribution of various parameters (like rotation period, magnetic field strength) of *observable* pulsars in the Galaxy, so that they can be compared with the known pulsars. Since one knows quite clearly how to compensate for the observational selection effects of pulsars, a satisfactory job can be done in comparing the simulated pulsar population with the observed.

The results of Chapter 3 can be summarised as follows:

- The fraction of recycled pulsars in the main population of pulsars is about 5–8% of the total number. The fractional birth rate of these recycled pulsars is $<3\%$ of the total birth rate.

- the number of *observable* double neutron star binaries in the Galaxy is about a few thousands. The formation rate of these binaries is about $10^{-4}\mathrm{yr}^{-1}$. If one assumes that all galaxies are similar to ours. the merger rate of double neutron star binaries up to a distance of 200 Mpc turns out to be about a few events per year.

Chapters 4 & 5 deal with a different problem — the kinematic properties of pulsars. The former deals with the spatial distribution of pulsars in the Galaxy, and the latter deals with the kinematic properties of millisecond pulsars in the Galaxy.

Massive stars in the Galaxy are restricted to the spiral arms of the Galaxy. This is because, they do not live for long enough time to move sufficiently away from the spiral arms, after their birth. However, this is not the case with low mass stars ($M \sim 1M_{\odot}$). Since they live for hundreds of million years they lose their memory of their birth place completely. **A** seminal work done by Blaauw in 1985 indicated that the massive OB associations contribute only about 15% of the pulsar population, and the vast majority of pulsars are produced by relatively low mass stars, whose masses are in the range 6–$10M_{\odot}$. This led him to come to a very important conclusion that pulsars, on the Galactic scale, are tracers of past locations of the spiral arms, and not the present locations. *i.e.,* there must be a correlation between the distribution of pulsars in the Galaxy and the Iodation of spiral arms at some epoch in the past. The aim of the exercise described in chapter 4 is to see if there exists such a correlation. It has been found from this exercise, that this correlation exists. This implies many interesting conclusions. One important conclusion is that the vast majority of pulsars are produced by the progenitor stars whose masses are roughly $7M_{\odot}$. The second result is regarding the average spatial velocities of pulsars. The fact that the correlation exists shows that the spatial velocities of pulsars are not high enough to smear out the correlation. Because. if the velocities are high pulsars will move far away from their birth places and they will lose the memory of their birth places. As described in Chapter 4, within the statistical errors, we can conclude that the average velocities of pulsars is about 200 km/sec. However, this may be treated as only a lower limit.

Chapter 5 deals with a different question viz., the kinematic properties of millisecond pulsars and Low Mass X-Ray Binaries (LMXBs). The motivation behind this exercise is the following. The initial space velocity of LMXBs is the centre of mass velocity which they acquire during the supernova explosion of the primary star. If LMXBs are the progenitors of millisecond pulsars, then the velocity distribution, and hence the spatial distribution of millisecond pulsars in the Galaxy must be identical to that of LMXBs. The exercise basically tries to compare the kinematic properties of LMXBs and millisecond pulsars. A Monte Carlo simulation was done to simulate the LMXB population in the Galaxy, and the kinematic properties of LMXBs and millisecond pulsars were matched with the simulated results. Since one does not have a clear idea about the birth rate distribution of LMXBs in the Galaxy that was kept as one of the free parameters. Various asymmetric supernova kick speed distributions were tried out to find out the kind of distributions the known LMXB and millisecond pulsar samples suggest.

The results of this exercise are summarised below.

- The kinematic properties of LMXBs and millisecond pulsars are consistent with each other, supporting the idea that LMXBs are the progenitors of millisecond pulsars.

- The known samples of LMXBs and millisecond pulsars prefer kick speed distributions with considerable number of low speed objects.

- The average speeds of millisecond pulsars may be quite less from that of normal pulsars.

Chapter 6 gathers together the main conclusions of the thesis in detail. Each chapter has a fairly detailed introduction to the background and the summary of the important conclusions obtained in that chapter.