Timing Radio Pulsars

Thesis submitted to Jawaharlal Nehru University
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Doctor of Philosophy

by

C. Indrani

Raman Research Institute
Bangalore 560 080

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DECLARATION

I hereby declare that this thesis is composed independently by me at the Raman Research Institute, Bangalore, under the supervision of Prof. G. Srinivasan. The subject matter presented in this thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title in any other University.

(Prof. G. Srinivasan)
Raman Research Institute
Bangalore

(C. Indrani)

CERTIFICATE

This is to certify that thesis entitled **Timing Radio Pulsars** submitted by C. **Indrani** for the award of the degree of DOCTOR OF PHILOSOPHY of Jawaharlal **Nehru University** is her original work. This **has** not been published or submitted to any other University for any other Degree or Diploma.

Prof. N. Kumar
(Centre Chairperson)
Director
Raman Research Institute

Prof. G. **Srinivasan**
(Thesis Supervisor)
Raman Research Institute

Contents

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Preface

Pulsars are rapidly rotating magnetized neutron stars with rotation period ranging from 1.5 ms to $\sim$ 2 secs. As the pulsar ages, it slows down due to the loss of rotational energy predominantly through dipole radiation. Although 700 pulsars are known so far, period derivative measurements (required for the estimation of age and the magnetic field strength of pulsars) are not available for a significant fraction of the sample. Rotational parameters of pulsars can be determined by carrying out ***timing observations*** systematically over a suitably long time span. In addition to the secular slow-down, sudden jumps in the period (Glitches) as well as slow variations known as 'Timing Noise' are observed in some relatively young pulsars. Study of these phenomena provides valuable clues to our understanding of the interior structure of the neutron stars. With a long term goal of extending studies on such phenomena, we developed an observational and analysis set-up using the Ooty Radio Telescope for pulsar timing. Using this set-up, we have made timing measurements on 16 newly discovered pulsars with an immediate goal of obtaining their rotational and positional parameters to an useful accuracy. In this thesis, we describe the work on timing and other observational studies on pulsars using the Ooty Radio Telescope at 327 MHz. A brief introduction about pulsars, the timing observations made using Ooty Radio Telescope, timing analysis and the results are presented in five chapters. In the last chapter of this thesis, we have discussed our attempts towards refining the model for the large scale magnetic field in our galaxy using rotation measures of pulsars.

Chapter 1 gives an overview of the some of the topics relevant to the present work. First, we present a brief discussion on basic pulsar properties, the various mechanisms proposed to explain their emission, the observed polarisation characteristics, the variety in the observed pulse shapes and the classification schemes based on these. This is followed by a discussion of the propagation effects on the pulsar signal in the interstellar medium such as absorption, dispersion, faraday rotation and scattering. The subject of pulsar ***timing*** is also introduced.

Chapter 2 deals with timing observations made on 30 recently discovered southern pulsars using the Ooty Radio Telescope at 327 MHz, with a preliminary aim of obtaining their period derivatives, improved positions and average pulse profiles. Details of the telescope used are described followed by a description of the back-end receiver which was used for these observations. We then describe the time-stamping set-up that was built and used to note the starting time of the observation to an accuracy of $0.1\mu s$. We conclude this chapter with a discussion on our source selection procedure and mention some of the problems faced during the observations,

Pulsar Timing Analysis consists of a series of stages, such as determining the arrival time of the **pulse** at the observatory, converting these local arrival times to the arrival times with respect to Solar System Barycentre by removing the effects of the Earth's motion, dispersive delays and other relativistic effects. Rotational and positional parameters of a pulsar are obtained by comparing the barycentric arrival times of the pulses with the expected arrival times based on timing models of pulsar rotation. Our timing analysis were performed off-line in such series of stages. Details of these analyses are described in Chapter 3.

Chapter 4 lists a number of results obtained from our observations. First we present and discuss the average profiles obtained for all pulsars in our sample. Also, we have attempted when possible, to classify the pulse profiles based on the pulse widths and the number of components seen. The best-fit rotational parameters obtained **from** the arrival-time analysis and other important derived parameters such as surface magnetic field (B) and characteristic age (τ_{ch}) are presented. In all cases the period uncertainties are improved to one part in 10^{11} (compared to one part in 10^5 of the previous available values). The period derivatives for all the pulsars in our list are obtained for the first time. Also, more accurate positions of the pulsars have been obtained. Next we discuss the procedure for estimating pulse broadening due to the interstellar medium and present our estimates of scatter braodening for **10** pulsars.

One of the main motivation for increasing the sample set of pulsars with known $\dot{P}$ is to improve the sample useful for many statistical studies of **pulsars** such as estimation of the pulsar current and the pulsar birth rate in our galaxy. In the third section, we present a re-analysis of pulsar current and birth rate after **including the** contributions **from** our sample and the latest Parkes Survey. We end this chapter with a discussion of some new result we have obtained on an interesting pulsar **PSR B1952+29.** This pulsar **has** a normal period of **~0.426 secs** but has a period **derivative**($\dot{P}$) which is about three orders of magnitude lower than those of normal pulsars. Also, we see that over the time its $\dot{P}$ is systematically reducing. Based on our data and earlier measurements, we have estimated its proper motion which is quite different than the earlier estimates in the literature. We also discuss the possibility of the pulsar having the binary companion based on the available data.

Timing Noise can be characterised by random walk in phase, rotational frequency or frequency derivative of the pulsar, which might arise due to random changes in the emission region or beam direction, moment of inertia of the star and the process of rotational energy loss respectively. Mostly young pulsars show high timing activity. Chapter **5** begins with a brief review of our present understanding of this phenomena. The data on **16** pulsars over a **1.5** year baseline is then examined for the presence of detectable timing noise. This analysis and results are discussed in the end.

Chapter 6. The work presented in this last chapter is **unrelated** to the previous chapters, **and attempts** to get a handle on the large **scale magnetic** field of our Galaxy from pulsar observations. Pulsars act as excellent probes of the galactic magnetic field as their radiation is often highly linearly polarised. The plane of polarisation rotates due to the presence of the electron plasma and the magnetic field in the intervening medium; an effect known as 'Faraday Rotation'. Using a model for the electron density distribution in our galaxy and the data on Faraday rotation in directions to the pulsars we have tried to re-examine the various models for the large scale galactic magnetic field. The details and results of this investigation are presented.