Singie–pulse Studies of Pulsars
at
Decameter Wavelengths

A Thesis
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by

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Declaration

I hereby declare that the work presented in this thesis is entirely original, and has been carried out by me at the **Raman Research Institute** under the auspices of the **Joint Astronomy Programme** of the **Department** of **Physics, Indian Institute of Science.** I hereby declare that this has not formed the basis for the award of any degree, diploma, membership, associateship or similar title of any University or Institution.

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This thesis is dedicated to my grandmother, whose blind faith that I was a scientist in the making, has been a motivation!

to earlier attempts at decameter wavelengths. We describe this data acquisition system and processing procedures in Chapter **2.**

In Chapter **3** we present average properties of pulsars observed at 34.5 MHz. For a possible study of a large sample of pulsars at low frequency, we carefully selected pulsars from the catalog of known pulsars. Their flux densities at 34.5 MHz were estimated by a suitable extrapolation from available measurements at higher frequencies and allowing for the possibility of a spectral turnover. The detectability was assessed after taking into account the background sky temperature, dispersion, and scattering in the direction of the pulsar. About 40 pulsars qualified as detectable (signal at a 5a level or higher) with our telescope assuming a reasonable duration of observations and a bandwidth of 1-MHz. This sample of pulsars was monitored over a period of 4 months during March-June, 1997. Each pulsar was observed for an effective duration of typically 2000 seconds. The data were analysed for possible pulsar detections. The results were consistent with our improved sensitivity and a total of 10 pulsars were detected from these observations. We present average pulse profiles for all the detections, together with the modulation indices of fluctuations and the behavior of linear polarization in a few cases.

We studied pulse-to-pulse fluctuation properties of a few 'bright pulsars in our sample. In order to achieve a reasonable signal-to-noise ratio in such an analysis, a large number of continuous sequences of single pulses (typically 500-1000) were required. We observed a few bright pulsars several times, with each observation of duration $\sim$ 20 minutes, during Feb-Apr 1999. The fluctuation spectra of 8 pulsars in the decameter wave band, presented in Chapter 4, are believed to be first such reliable spectra reported in the literature at these low radio-frequencies. Apart from fluctuation spectra, a number of other tools were used to study the fluctuation phenomena in these pulsars. We describe these tools in detail and present the results of our analysis for a total of 8 pulsars. We find that, in keeping with the trend from higher frequencies, all pulsars exhibit an enhanced modulation at 34.5 MHz. In the case of pulsar B0943+10, the spectral modulation features have a high-Q ($\sim$ 250), which compares well with the steady drift behavior seen at meter wavelengths. The frequencies of the modulation features seen in the spectra are consistent with those seen at higher frequencies.

Our prime target for a detailed analysis of single pulse sequences was pulsar B0943+10 (Chapter 5). A recent detailed study of drifting-subpulse emission from this pulsar, using 430 MHz and 111 MHz data, identified the origin of the stable and steady drift with a system of 20 distinct subbeams of emission rotating steadily around the magnetic axis of the star. We describe the technique of 'Cartographic Transformation', where every sample from each single pulse is uniquely mapped onto the polar region of the pulsar, which provides new means of probing emission processes using single-pulse sequences. We have used this technique to map the regions of observed decameter emission on the pulsar polar cap. We have shown, that:

- The fluctuation spectra at decameter wavelengths also display a narrow feature, close to $0.5\,c/P_1$ (P_1 is the pulsar spin period) and with a high Q, which is related to the 'drifting' character of its subpulses.

- This fluctuation feature in the longitude-resolved spectra is aliased and the true frequency of the primary phase modulation is somewhat higher than $0.5\,c/P_1$.

- A system of 20 subbeams, rotating around the magnetic axis of the star with a circulation time $\hat{P}_3$ of about 37 P_1, is responsible for the observed stable subpulse-modulation behavior.

- Compared with the higher frequency maps, the 35-MHz maps sample the subbeams much more completely. However, the 35-MHz subbeams, on the whole, show much less uniformity in their positions and intensities.

- Both at 35 MHz and at higher frequencies, the intensities of individual subbeams fluctuate, with the subbeams maintaining a stable brightness only for a few circulation times. The stability time-scale of the entire pattern at 35 MHz and 430 MHz appears roughly comparable.

This similarity between our (34.5 MHz) maps and those at 430 MHz, combined with the 'radius-to-frequency mapping', implies that the regions of radio emission correspond to a well-organized system of plasma columns in *apparent* circulation around the magnetic axis of star, and a common 'seed' activity is likely to be responsible for both the generation and motion of this relativistic plasma. We expect this basic picture of subbeams and their apparent circulation to be valid in other pulsars as well, although the viewing geometry and other quantitative details may differ. The apparent nature of the modulation/fluctuation would depend largely on the viewing geometry.

We followed our previous work with a similar analysis on the pulsar B0834+06. We have unambiguously determined the circulation time of the polar emission pattern and its drift direction and studied the polar emission maps. Here too, a system of discrete subbeams in steady rotation around the magnetic axis was found responsible for the observed single-pulse fluctuations. The emission beams in the case of B0834+06 are discrete, but they are **not** uniformly spaced along the hollow cone of emission and they all differ from each othkr in their appearance. The subbeams appear broader in radial cross-section, with $\Delta\rho/\rho \gtrsim 25\%$, and seem to fluctuate around their average position and intensity more than what was observed in the case of B0943+10. The increased jitters in the subbeam position could result in the low Q-value of the observed fluctuation features.

We also made maps from successive subsections of the pulse sequence and viewed them in a 'movie'-like fashion. For all the data sets of B0943+10 and B0834+06 discussed, it was noticed that only a few subbeams (different ones at different times) usually dominated in intensity over a few circulation times. Overall, the brightness of a given subbeam was observed to fluctuate by up to about a factor of 4 over the length of the sequence. Given the above, it is tempting to suggest that (a) an inhibition of emission (or the underlying sparks) occurs over the rest of the polar cap due to the active subbeams, or (b) A critical combination of parameters required for stable, uniform subbeams.

B0834+06 happens to be the only other case where such a treatment has been possible based on our decameter-wavelength observations alone. The single-pulse fluctuations in this case are general modulation of component amplitudes, unlike the stable 'drift' patterns observed in the case of B0943+10. Even such a general amplitude modulation appears to be related to a well-defined rotating pattern of discrete entities in the polar cap region. Various other issues related to the fluctuation phenomena of this pulsar are discussed in the thesis and are compared with the high-frequency behavior.

The next part of this thesis concerns our attempts to search for radio pulsation in the directions of two high-energy pulsars. The gamma-ray pulsar Geminga attracted attention of the astronomers recently, with the reported detection of its pulsed radio emission by three Russian groups at 102 MHz. Since Geminga, one of the brightest Gamma-ray sources in the sky, is the only known gamma-ray pulsar that has not been detected at radio wavelengths, confirming its pulsed radio emission and determining the reasons for its radio weakness are essential to understand the relationship between pulsar gamma-ray and radio emission. Geminga is also important as it may be a prototype for a growing class of radio-weak or radio-quiet high-energy pulsars and isolated neutron stars. Searches for a pulsed radio emission from Geminga have been carried out earlier by other groups with none of them confirming the Russian claim of detection (this also included a search at 35 MHz using the GEETEE). These negative results meant that the pulsar was either weak and undetectable at the other frequencies of observation (detectable only at 102 MHz), or is a transient source and highly variable. Refractive scintillation could also make its detection difficult. Hence, we attempted near-simultaneous observations of this pulsar at 35 MHz and 102 MHz using the GEETEE and the Puschino Observatory, Russia. Since both the telescopes are transit instruments, there was a difference of about $\sim$ 3 hours in between two recorded data sets. In such a scheme if a pulsed signal was detected at Puschino, then we could confirm the same in our 35-MHz data. If the pulsar is an intermittent source of a few intense pulses similar to the Crab pulsar, we may detect such a signature in our data set. Though the initial analysis of Puschino data indicated some pulsed emission, there was no detection of a pulse in the 35-MHz data on the corresponding days. Our tentative upper limit on the average flux of Geminga at 35 MHz is $350\,\mathrm{mJy}$ (3σ) using data obtained on 3 days. Shorter intervals of data were searched for a possible intermittent emission, again providing a null result. Our observations, analysis procedure, the final results, and their interpretation are described in Chapter 6.

Typical radio pulsars are magnetized neutron stars that are born rapidly rotating and slow down on time scales of 10 to 100 million years. However, millisecond radio pulsars (MSPs) spin very rapidly even though many are billions of years old. The most compelling explanation is that they have been 'spun up' by the transfer of angular momentum during accretion of material from a companion star in so-called low-mass X-ray binary systems, LMXBs. The recent detection of coherent X-ray pulsations with a millisecond period from a suspected LMXB system SAX J1808.4-3658 appears to confirm this link. An exciting possibility is that this object will, at some point, turn on as a radio pulsar, producing pulsed radio emission characteristic of MSPs. We observed in the direction of this system in the X-ray quiescent state to look for a possible pulsed radio signal at 327 MHz using the Ooty Radio Telescope. The pulsar was observed for 10 minutes in each run to minimize the effect of period variation due to the pulsar's orbital motion, a total of 10 such successive scans were analysed. This search was tuned for the known parameters of the binary system, where the effects of binary acceleration on pulsar periodicity, and some possible extra dispersion due to the passage of the radio pulse through the extended wind from the companion, were allowed for. Our search was optimized for about 50% duty cycle (that is, a roughly sinusoidal signal), and we searched up to a maximum DM of $250\mathrm{pc/cm}^3$. No radio pulsations were detected at 327 MHz, which translates into a flux density upper limit of $0.8\,\mathrm{mJy}$ $(3\,\sigma)$ if all the data sets are combined. We discuss our upper limit and its implications in Chapter 6.

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