I see my journey rolling out in front of me
It reaches on ahead far as the eye can see
"I See My Journey" by Eileen McGann

Chapter 7

Conclusions

The observations in this thesis were undertaken to investigate the current and magnetic field structure in the magnetospheres of millisecond pulsars, and to shed light on the processes responsible for radio emission in pulsars.

Part I

Normal pulsars, with spin periods near 1 second and surface magnetic fields near 10^{12} Gauss, have been successfully classified based on multi-frequency observations of their intensity profiles and polarization properties. The pulse profile morphology, coupled with the available polarization position angle information, suggests that the emission is produced in a hollow cone filling the open field line region around the magnetic axis. Shorter-period pulsars, with periods between 1 and 50 milliseconds and magnetic fields of $\sim 10^9$ Gauss, have remarkably similar emission properties. This is due to the fact that the accelerating voltage, believed to play an important role in the emission process, is proportional to B/P^2 and is therefore similar for the two classes of objects. Millisecond pulsars do not, however, fit into the classification scheme developed for canonical pulsars.

The magnetospheric configurations of millisecond and normal pulsars can be quite different. The open field line region above the polar cap scales with $P^{-1/2}$, and is therefore much larger in the short-period objects. An emission beam filling this region should therefore be much broader. In addition, the distance to the light cylinder (which scales with P) is much less in these objects. The radio emission is more likely to originate at an altitude which is significant fraction of the light cylinder radius. Rotational sweep-back of the magnetic field and relativistic effects are also likely to be more important.

Careful polarimetric observations have been presented for nine millisecond pulsars at 575 MHz, 820 MHz, and 1410 MHz. This high resolution multi-frequency data set is the first of its kind. A few additional objects have been studied at a single frequency. As has been noted in other studies, the component widths for these objects are typically narrower than expected based on the observed distribution for slower pulsars. The relationship between core component width and pulse period that is true for long-period pulsars does not explain the observations for these objects. To further complicate matters, the dependence of conal component widths on pulse period is poorly understood for all pulsars. The classification of pulse components into core and cone components remains uncertain, as several components which might otherwise be considered core components have flat spectra. As a result, millisecond pulsar pulse intensity profiles do not develop with frequency in the same way as do those for normal pulsars. Component separations and pulse widths change very little with radio frequency, indicating that the emission region is very compact. For radiation which fills the open field lines, only a very narrow range in altitude is consistent with the observations.

The polarization profiles of millisecond pulsars exhibit many of the features that are seen for normal pulsars: significant linear and circular polarization under some pulse components, well-defined polarization position angle curves, and orthogonal mode transitions accompanied by a decrease in the linearly polarized radiation. The radiation does not depolarize at high frequencies, however, contrary to the canonical behaviour. In addition, the distribution of slopes of the polarization position angle curves in normal pulsars has a wider range than the distribution for millisecond pulsars. Although this effect has been attributed to magnetic field distortions, a simple geometric $P^{-1/2}$ scaling of the open field line region explains the observations.

Intensity profile variations have been discovered in several millisecond pulsars. These occur on longer time scales than the traditional 'moding' behaviour exhibited by slow pulsars. The fraction of objects exhibiting profile variations may, however, be similar. In contrast, temporal variations of the fractional polarization appear to be much more common in millisecond pulsars.

The classification of millisecond pulsars is still uncertain, within the canonical models. A larger multi-frequency data set of polarization profiles for low-period objects would be useful. In particular, detailed observations of pulsars with intermediate periods of about 100 milliseconds might help to define the transition between the emission properties of the two classes of objects. Polarization data at both higher and lower frequencies could prove useful. The steep spectra of these objects makes high-frequency polarimetry difficult, and scattering effects at low radio frequencies may limit their usefulness. Observations taken with a larger telescope would assist the investigation of short-term temporal variations in the intensity and polarization profiles of these pulsars. The long-term temporal variations could be studied in more detail through intensive monitoring with a telescope of modest size.

Part II

Single pulse measurements of normal pulsars have revealed the presence of microstructure, on times scales of $\sim 10 - 100\mu$s. If this phenomenon is due to an angular effect, it should scale with pulsar period. High time-resolution observations of the single pulses of millisecond pulsars would then show a characteristic time scale of at most a few μs in these objects. If microstructure is due to a temporal variation in the emission beam, then it should be visible on the same time scales in millisecond pulsars.

The giant pulses of the Crab pulsar are unusual, since at some radio frequencies these rare pulses dominate the emission. Simultaneous observations of this object at 610 MHz and 1400 MHz revealed that the emission mechanism is broadband on this time scale. The arrival times of the giant pulses are tightly correlated between the two radio frequencies, limiting the effects of frequency dependent propagation in the magnetosphere. An emission bandwidth of at least 0.8 GHz at 1 GHz constrains models of the emission process to those which can explain its broadband nature. Both angular and temporal origins for the energy modulation are possible: we cannot distinguish between the effects of a randomly wobbling intense beam and an intrinsic change in the intensity of the emission. The pulse shapes at 1400 MHz are complex, and suggest the possibility that a single giant pulse is multiply imaged in the surrounding nebular material. These observations occurred during an epoch of extreme scattering in the nebula. A study of these pulse shapes at epochs with reduced scattering will reveal whether their characteristics are constant, or vary with the nebular scattering.

The fastest millisecond pulsar, PSR B1937+21, also exhibits the phenomenon of giant pulses, although they do not contribute as large a fraction of the radio pulse energy as is true for the Crab giant pulses. These giant pulses occur on extremely short time scales, and are unexpectedly delayed relative to the peaks in the average pulse profile. They probably coincide with the sharp trailing features seen in the 1410-MHz pulse profile. Their properties are difficult to explain with a randomly wobbling beam. A separate emission component with temporal modulation may be the origin of these pulses. Simultaneous dual-frequency observations of these giant pulses could help constrain the emission process, but will be difficult. No other pulsar is known to emit pulses which can be classified as giant. Single pulse measurements of the millisecond pulsar PSR B1534+12 show no evidence for microstructure which scales with pulse period. Characteristic time scales less than about 2μs would not, however, be seen in our data. Broadband data recorders are now being used to investigate single pulses with higher time resolution.

Many aspects of millisecond pulsar emission remain puzzling. Nonetheless, average polarization profiles and single-pulse investigations of these objects provide valuable constraints on pulsar emission geometries and processes.

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