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**A study on giant radio pulses**

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## CHAPTER 7

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# Conclusions and future work

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**Abstract** In this chapter conclusions and the scope for the future work are presented.

## 7.1 Conclusions

In Chapter 2 of this thesis, the design and development of a modern pulsar machine, PuMa-II was presented based on a distributed recording and computing technique. PuMa-II offers superior flexibility as a pulsar processing backend system at the Westerbork Synthesis Radio Telescope (WSRT) and it was specifically designed to take advantage of the upgraded WSRT. The instrument is based on a computer cluster running the Linux operating system, with minimal custom hardware. A maximum of 160 MHz analogue bandwidth sampled as  $8 \times 20$  MHz can be recorded on disks attached to separate acquisition nodes. The data can be processed in the additional 32-nodes allowing near real time coherent dedispersion for most pulsars observed at the WSRT. PuMa-II doubled the bandwidth and time-resolution (50ns) for pulsar observations in general, and has enabled the use of coherent dedispersion over a bandwidth eight times larger than was previously possible at the WSRT. The system is now routinely used for high precision pulsar timing studies, polarization studies, single pulse work and a variety of other observational work.

A flavour of the flexibility and power of the instrument was given in the following four chapters, where the single pulse aspect of a few pulsars was discussed, with a focus on the giant pulse emission. The pulsar embedded in the bright, young Crab supernova remnant is known for its narrow giant pulses at higher frequencies. Past studies have concentrated only on the very bright pulses or were not sensitive to the faint end of the giant pulse luminosity distribution. With the possibility of a large bandwidth and high time resolution in PuMa-II, combined with the narrow radio beam of the Westerbork Synthesis Radio Telescope, the weak giant pulse emission was probed by characterizing a large population of the Crab pulsar giant pulses. The study revealed the existence of double giant pulses and the spectral index for a large number of giant pulses is derived.

The flexible processing in PuMa-II and the availability of Low Frequency Front Ends allowed a sensitive study of Crab giant pulses at very low sky frequencies. A large number of Crab giant pulses in the 115–180 MHz range were analysed using full coherent dedispersion in PuMa-II. From the dispersion-free giant pulses, the scatter timescales and the pulsar spectrum in this frequency range was derived. The sensitive observations and better processing method showed that there is a precursor to the interpulse and that it comprises no giant pulses. Therefore, this can be attributed to a similar emission source as the precursor to the main pulse. Together these precursors might be the normal emission seen from the majority of radio pulsars. More than 1000 giant pulses were detected at each band and from this the giant pulse emission rates, scattering time scales were found and in each observed band.

The LFFEs at the WSRT and PuMa-II were used to characterize a large collection of single pulses from four low magnetic field pulsars by means of pulse energy and intensity distributions, microstructure and drifting subpulse analysis. The study examines the presence of giant pulse emission in these pulsars by coherently dedispersing the signals from the pulsars. Classical giant pulses are reported from PSR B1112+50 and very bright pulses in PSRs B1133+16 and B0031–07. All three pulsars show a large modulation that points to rapid changes in the single pulse intensity. Evidence for global magnetospheric effects are provided by our detection of bright double pulses. From the multi frequency observations

radio emission heights in PSR B1133+16 were derived. The non-detection of giant pulse radio emission from PSR J1752+2359 is reported. An accurate estimation of the dispersion measure of two pulsars and the subpulse drift modes in these pulsars are reported.

Utilising the flexibility and high time resolution of PuMa-II, the high precision pulsar timing data were examined for giant pulse emission from a selection of millisecond pulsars. Giant pulses were detected from PSR B1937+21 but none were detected in PSRs B1821–24, J0218+4232 and B1957+20. In all three cases the lack of detection was consistent with previous determinations of giant pulse strengths and emission rates. An improved technique for searching the PuMa–II data for giant pulses resulted in many more detections from PSR B1937+21 and it is planned that this method will be used to make GP searches part of the standard processing pipeline for all MSP observations in the future.

## 7.2 Future work and outlook

PuMa–II is in operation for nearly four years, and a few comments on future pulsar instrumentation follow.

In the short term, PuMa-II can be expanded and improved in the following ways:

- The 14-telescope array produces only 6-bit data, which is read in as 8-bits. Changing acquisition software to write 6-bit data to disk will immediately allow one to save 25% disk space. The processing software needs to be adapted to read 6-bit data.
- The distributed recording aspect of PuMa-II can be expanded to include the compute nodes, which has the potential of achieving true realtime coherent dedispersion.

In order to reduce computational time and quick turn-over of scientific results, a PuMaII-like machine needs to be augmented with additional hardware. For example in certain applications like the timing of long period pulsars for which a computer cluster is an overkill and a full-coherent dedispersion may not be required. Therefore, a configurable digital filterbank for comparatively low DM, long period pulsars is adequate. Moreover, for applications like pulsar surveys, a search in the DM space is much more productive with the filterbank data. The semiconductor industry led by Xilinx and Altera, have introduced newer reconfigurable silicon chips packed with a few million logical elements in a single Silicon die. These reconfigurable hardware are given an umbrella term “Flexible Programmable Gate Arrays” (FPGAs) and are excellent candidates for digital filterbanks. The large number of configurable elements and deterministic compute times in these devices allows real-time processing capability.

Coherent dedispersion is a necessity for large DM millisecond pulsars and despite faster computers, the process is still computationally intensive and time consuming in nature. Therefore, for very large bandwidths, e.g larger than  $\sim 100$  MHz, the signal needs to be split into subbands to allow efficient processing. Complementary to the FPGA advances, developments in the computer graphics industry has packed tremendous computing power in graphics processors, as in nVidia graphics processors. nVidia introduced the Compute Unified Device Architecture (CUDA) method of programming their graphics processing units

(GPUs) and claim up to 2 TFlops of computational power in one of their multi-processor GPUs. These products can be extended with more physical memory and the pulsar signal can be coherently dedispersed. However, the GPUs do suffer from a somewhat lower data throughput, making them useful only as an off-line coherent dedisperser or to process smaller chunks of data in real-time.

The computer gaming industry has also pushed the limits of computing power as in hardware like Sony Playstation 3, and Microsoft XBox 360 Elite. These products can be a cost-effective solution for computational needs, but they may involve considerable programming efforts. Secondly, these are proprietary products - hence large scale deployment, as in the Square Kilometer Array (SKA) might prove expensive when intellectual property costs are included.

Future Pulsar Machines will probably consist of at least a few elements discussed above - a large bandwidth baseband recorder, additional computing power with graphics processors and a FPGA based module for filterbank like applications. What is perhaps needed is a fresh look at the algorithms used to process pulsar signals. The main idea behind coherent dedispersion is to deconvolve the pulsar signal with a function that represents the transfer characteristics of the interstellar medium. This is most easily done in the Fourier domain involving large FFT operations. This algorithm was introduced in the 70's and to this day there are no alternative means to dedisperse. Coherent dedispersion is a "phase shift" filter, that introduces a frequency dependent phase-shift. Development in this direction can be done if this technique is applied in time-domain, instead of the FFT-based convolution methods. Such algorithms allows efficient implementation in FPGAs. Therefore, research in improving or finding an alternative fast coherent dedispersion method will be a big step forward.

The pulsar science indeed stands to benefit from the advances in observing facility. In the technique employed to study Crab giant pulses in Chapter 3, the synthesis nature of the telescope was used to resolve out the Crab Nebula, and to improve sensitivity to weak giant pulses. Similar technique can be used when the forthcoming projects like the Large European Array for Pulsars (LEAP) become operational. The LEAP will digitally combine telescopes across Europe to simulate a Arecibo-like telescope. In observations of the Crab pulsar, the narrow beam of the LEAP will greatly reduce the effect of Crab Nebula on the system temperature. Therefore, this will allow an even deeper look at the Crab pulsar giant pulse emission phenomena. The sensitivity of such a fully steerable array will also aid uncover many more weak giant pulses from the millisecond pulsars and we may finally be able to perform single pulse studies on the MSPs. The sensitivity if LEAP also holds promise in the possible detection of extragalactic young Crab-like pulsars by detecting giant pulses.

With the forthcoming telescopes like the Low Frequency Array (LOFAR), the low frequency pulsar studies will receive a fresh look. With the most modern methods, and relatively large computational power a whole range of physics can be done, as seen in chapter 4. LOFAR will offer a wide-band coverage. The narrow subbands can be placed at suitable RFI free sections of the radio-band in the 120–240 MHz range. Single pulse studies which include drifting, giant pulse, nulling and microstructure phenomena can be effectively addressed for a wide variety of pulsars using LOFAR. Similarly, fluxes of several pulsars could be measured at low frequencies, allowing one to study pulsar spectra at these frequencies.

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The method described in Chapter 6, where piggy-back observing of millisecond pulsars shows the effectiveness and advantages of flexible computing. The presence of bright pulses in apparently normal pulsars, discussed in Chapter 4 shows that a blind search for giant pulses can potentially uncover many more giant pulse sources. Apart from new giant pulse sources, the piggy-back method can be used to collect many more giant pulses from known sources, improving the statistics and allowing better characterisation of the giant pulse emission. The polarization of giant pulses has received somewhat less attention in the literature. This can be done in a relatively straight forward manner in a instrument like PuMa-II. Detailed polarimetry of the giant pulses can point to their physical locations in the pulsar magnetosphere.