The 8gr8 Cygnus Survey for New Pulsars and RRATs

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Abstract. We are currently undertaking a survey to search for new pulsars and the recently found Rotating Radio Transients (RRATs) in the Cygnus OB complex. The survey uses the Westerbork Synthesis Radio Telescope (WSRT) in a unique way called the 8gr8 mode, which gives it the best efficiency of any low-frequency wide-area survey. So far we have found a few new pulsars and the routines for the detection of RRATs are already implemented in the standard reduction. We expect to find a few tens of new pulsars and a similar number of RRATs. This will help us to improve our knowledge about the population and properties of the latter poorly known objects as well as provide an improved knowledge of the number of young pulsars associated with the OB complexes in the Cygnus region.

1. The 8gr8 survey of pulsars and RRATs

The 8gr8 Cygnus Survey will cover the region of the Galactic plane located between 100 < \( \ell \) < 40 and 0.25 < \( b \) < 7.25 respectively, covering around 420 sq deg. in Cygnus. This region is known as the Cygnus superbubble [Uyanke re et al. 2001], contains a lot of OB associations and hot gas that might be generated by SN explosions, producing a large amount of compact objects [Perna & Gaensler 2004].

In these regions we expect to find significant numbers of young pulsars [Dewey et al. 1985] made a previous survey in this area finding a few tens of new pulsars. In the 8gr8 survey, we expect to have about 5 times better sensitivity than the previous surveys, for pulsars with \( P < 1 \) s, and more than an order of magnitude for those with \( P = 1 \) s. The 8gr8 survey will cover an area of the sky which has not been revisited in the latest big surveys for pulsars and according to our simulations we expect to find a few tens of pulsars.

1.1. Current pulsar surveys

Recent pulsar surveys have not been able to cover all of this region of Galactic plane and this survey provides an excellent way to do this with high sensitivity. To date the most successful survey is the Parkes Multibeam Survey [Manchester et al. 2001] which has discovered approximately half of the known pulsars.

This survey covered a region of the sky located along the Galactic plane at low latitude (\( \ell < 5 \)) and with a Galactic longitude of 32 < \( \ell < 77 \). This survey applied a multibeam technique using a receiver with 13 beams.

Another remarkable survey is the Arecibo P A survey [CorDES et al. 2006]. This survey expects to find a few hundred new pulsars and is concentrated at very low Galactic latitudes (\( \ell < 5 \)) and along the region of the Galactic plane visible from Arecibo, 32 < \( \ell < 77 \) and from 168 < \( \ell < 214 \). This survey uses 7 beam receivers and to date has found a few tens of new pulsars.
12. RRATs a new type of sources

These recently discovered RRATs are a new type of radio sources, and are one of the most extreme and powerful radio emitters. They were found by McLaughlin et al. (2006) in the Parkes Multibeam Survey. The 11 known RRATs are located at low Galactic latitudes (b< 2°), they show bursts of radio emission that last between 2 and 30 ms. They can not be detected using the standard Fourier techniques used for pulsars making their detection very difficult. These sources have periods within the range 0.4–7 s, measured by analysing the arrival times of the individual pulses. For three of them, there are period derivatives now known, with values that vary from 7.87 to 12.6 × 10^{-15} s^{-1}. These values imply the presence of a very strong magnetic field (B ~ 10^{13} G). The true nature of the RRATs is still unknown. There is no consensus about the origin of their powerful bursts and also about their evolutionary stage. They have been related to different types of neutron stars: (a) radio quiet X-ray NS population associated with AXPs and SGRs, possible magnetar candidates (McLaughlin et al. 2006), see also Habel et al. (2004) and Woods & Thompson (2004); (b) isolated neutron stars (Reynolds et al. 2006); (c) re-activated radio pulsars (Zhang & Dyks 2006), and, (d) bright pulses of distant pulsars like PSR B0656+14 (Ekelove et al. 2006).

Finding new pulsars and new RRAT (like sources will allow us to better understand the life-cycle of massive stars, their population, and to test, with better statistics, the theoretical models that predict the evolution and behaviour of these systems. Finally, pulsars can provide a unique opportunity to study extreme gravitational fields and are excellent systems for testing General Relativity.

2. A low frequency survey

Most of the recent pulsar surveys have been carried out at frequencies near 400 MHz, or at 1.4 GHz for the Parkes Multibeam Survey (Manchester et al. 2003) and PALLAS surveys (Ordas et al. 2006). Our survey is performed at 328 MHz to maximise the sky coverage per sensitivity threshold. The W RST in the 8gr8 mode allows us to explore this frequency range with better sensitivity than other radio telescopes. The observations are made using 12 W SRT telescopes which are arranged as a square array (i.e., they are equally spaced). The data is then combined in such a way that we have 8 separate beams pointing at different locations in the primary beam. Thus we get the sensitivity of all 12 dishes but at a gain of just one! To reach our sensitivity goals and to optimise the data reduction, our observations have 2^{22} samples with a sampling time of 8192 s and a total dwell time of 6872 s. In total we have 72 observation points and between 900 and 2200 beam samples per pointing. For each pointing we have a minimum of two observations, the original observation and a comparison observation.

Fig. 2. Plot showing the contour and shape of the beam. The grayscale shows the beam with the largest S/N response for the candidate shown in Fig. 3.

3. Reducing the data

The observations were made between 2004 and 2005. Each observation consists of 8 sets of data of 10 MHz wide, per main beam. The data goes from the receivers located in the focal plane of each antenna to a tied array beam former that combines samples for delays in arrival times due to the separation of the antennas. The data is then digitised using a digital back-end known as the Pulsar Machine (Pulm) and converts the analogue data into spectra of 512 frequency channels. These sets of data are stored locally for later offline analysis.

The first step in our analysis is to form dispersions time series for a number of trial DM values. This is done using a cluster of computers with 31 nodes. In the same cluster, once the data is dispersed, we combine the 8 beam sets into a single set of DM, sub-beam per beam (beam 0, the num ber depends on the position of the main beam on the sky, see Fig. 2). Each of the DM sub-beam s is searched for periodicities and for single pulses. A typical search run takes between one and two days of computing time. For our reduction and also for the pulsar search described below, we are using the same software developed by Russell Edwards with the single pulse search extensions discussed below.

3.1. Pulsar search

For the pulsar search, we use the so-called standard search, calculating an FFT for each time series per DM value. For the 8gr8 survey our DM range goes from 0 to 1200 pc cm^{-3}. Once a candidate is identified a refined analysis is performed to get the best period and DM value.
Fig. 3. Example of the output from a pulsar search of data, a new pulsar candidate from the 8gr8 Cygnus Survey. The plots clearly show a pulsating signal and its properties. The upper left plot shows a grey-scale plot of frequency vs. pulse phase and shows clearly vertical features that reveal the presence of a pulsating source. In the second box on the left side we plot the time series vs. pulse phase, and again we can see the same vertical features. Finally the pulsating nature of the source appears clearly in the third box on the left side, where we plot the intensity vs. pulse phase. The boxes on the right side show the best DM value for that signal and the distribution of acceleration trials vs period (third box, right) and period trials vs DM (lower right box).

for it. This analysis includes trying values for linear acceleration steps. The correction for acceleration should lead to a sharper pulse profile for real binaries.

A possible candidate for a new pulsar should have a plot like that shown in Fig. 3, and also it must appear at the same position in both of the beam plots for the rest and for the comparison observations. In Fig 2 we show one of the beams for the pulsar candidate shown in Fig 3.

3.2. Single pulse search

For the detection of RRATs, we have implemented an approach similar to the one used by McLaughlin et al. (2006), this consists of a search in the data for high S/N events with the same DM value as shown in Fig. 4. We have also implemented a collection of scripts to search for high S-N events (above the 5 threshold detection limit), and also for events at the same DM values. This will allow us to detect RRAT-like sources and potentially dim pulsars, without having to manually view many thousands of plots.

4. Work in progress & future plans

The aim of the survey is to locate as many candidates for pulsars and RRATs within the Cygnus region. We have already found a few candidates for new pulsars and we are already implementing and performing the analysis to search for RRATs. Besides this, we expect to make a comprehensive analysis of the data we have so far:

We expect to make an individual analysis of sources in order to establish their properties.
We have completed the search for new pulsars in a large fraction of the 72 observation points in the DM range 0-700 pc cm$^{-3}$. We expect to have all the observations reduced in the near future.
We are currently undertaking the analysis of the 72 observations to search for RRAT sources.
A long term goal is to perform a multiwavelength follow up analysis of the objects to search for possible optical and high energy counterparts.

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Fig. 4. Sample search code for RRATs type objects. The plots correspond to the pulsar PSR B2334+61 and are an example of how a signal (as for RRATs), should appear. The upper plot shows the detected signals above a 5σ threshold plotted as circles with a radius proportional to the SN. The abscissa of both upper boxes shows the arrival time of the signals while the ordinate shows the value of the DM and the value for the intensity for the upper and lower box respectively. The later one clearly reveals the presence of bright pulses. The two lower boxes on the left side show the DM value on the abscissas while the relative SN on the ordinates and the number of detections. They clearly shows a bright source with a high number of counts at DM = 58 pc cm$^{-3}$. Finally the right box below shows the number of detections with the same SN. Due to the finite width of the bursts coming from the pulsar, many of them are detected at multiple DM values resulting in a vertical broadening of the features. Bursts which are strongest at zero DM are due to terrestrial interference and are not shown here.

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