50 Years of Pulsars!

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Abstract. A brief, personal, and very incomplete account of 50 years of pulsar astronomy presented at the Conference Dinner for ‘Physics of Neutron Stars – 2017 – 50 Years After”, held in Saint Petersburg, July 2017.

1. Introduction and the discovery of pulsars

First, I would like to thank George Pavlov for the invitation to attend this meeting and to present this talk at the Conference Dinner. I have to say, I was a little surprised to be asked to give the after-dinner talk as I am not well-known as a raconteur. I could only conclude that it was because I am old!

It is true that I have been involved with pulsars one way or another since their discovery, or at least the official announcement of it by Hewish et al. in the February 24, 1968, edition of Nature. I started work at the CSIRO Parkes Observatory just 12 days before the Nature paper was published and soon became involved in pulsar research.

But first back to the real beginning. In mid-1967, Jocelyn Bell was a graduate student at Cambridge University helping to build the “Four-acre array”, an array of dipoles tuned to 81.5 MHz that Antony Hewish had designed to investigate interplanetary scintillation of radio sources with the aim of identifying compact sources likely to be quasars. With the completion of the array, Jocelyn was given the job of examining the chart recordings to find the rapidly fluctuating signals from compact sources that scintillated as a result of propagation through the solar wind. She did find many of these, but also began to notice some signals that were subtly different from both the scintillating sources and radio-frequency interference. The first recorded detection of one of these “scruff” sources was on August 6, 1967, as shown in Figure 1. The break-through and the point that marks the real discovery of pulsars was when she realised that this source returned at the same sidereal time most days. This meant that it had to be outside the solar system and unrelated to terrestrial activity. A few months later, on November 28, she and Antony Hewish obtained the first high-speed recording to show that the scruff was in fact a train of pulses with a spacing of about 1.3 seconds.

Follow-up observations with the Four-acre array and other instruments at Cambridge refined the periodicity of the pulsar and showed that the signals were dispersed by their passage through the interstellar medium. A paper reporting the discovery and follow-up observations of the pulsar, then named CP 1919, and an interpretation that favoured radial pulsations of either a white dwarf or a neutron star was submitted to Nature by Hewish, Bell, et al. on February 9, 1968, and published on February 24 [2].

In 1974 Antony Hewish was awarded the Nobel Prize in Physics for the discovery of pulsars.
2. Pulsar observations at Parkes

Just two weeks after the publication of the Nature discovery paper a team from the CSIRO and the University of Sydney installed a remarkable set of five coaxial feeds with corresponding receivers at the focus of the Parkes 64-m radio telescope. On the morning of March 8, I was in the control room as the telescope slewed around to the position of CP 1919 and saw the wonderful burst of pulses come through on the chart recorder seconds later. By good fortune, this first observation at 150 MHz just caught a large scintillation maximum. The pulsar was not seen again with such high signal-to-noise for the rest of the session. This image was recorded for posterity on the first Australian $50 note (Figure 2) and also published with what are still some of the best measurements of the individual-pulse spectra of any pulsar [3].

Later on that year, having learnt something about measuring polarisation with the 18-cm receiver while working with Brian Robinson and Miller Goss on observations of OH masers, I was asked to assist Radhakrishnan investigate the polarisation of the Vela pulsar. These observations led to rotating-vector model (RVM) (or magnetic-pole model as Rad preferred to call it) for pulsar polarisation (Figure 3) [4]. In follow-up observations in mid-March, 1969, we again pointed the telescope to the Vela pulsar, recording the data with a signal-averaging system that was set up to fold the data at the expected topocentric period of the pulsar. To our surprise, rather than remaining a fixed phase on the oscilloscope display, the pulse was noticeably drifting to the left, indicating an error in the predicted period. By the evening, after a while trying to understand what was wrong, Rad said that he was going to bed and left me to sort out the problem. I again checked all the instrumentation, looked at some other pulsars and eventually concluded that it must be the pulsar that had changed. I left a note for Rad and went to bed myself.
Figure 2. The first Australian $50 note, featuring the Parkes radio telescope, a portrait of Sir Ian Clunies Ross (the first Chairman of CSIRO) and various images relating to Australian radio astronomy and biological sciences. On the left of the note is an image of the first pulsar recording made at Parkes, of CP 1919 and recorded on March 8, 1968.

Figure 3. Left: Radhakrishnan in the year 1996 (image credit: Library, Raman Research Institute). Right: plots illustrating the frequency-independence of the position-angle swing across the Vela pulsar mean pulse profile and the interpretation of that in terms of the magnetic-pole or rotating-vector model (after Radhakrishnan & Cooke [4]). In this model, the radiation is emitted tangentially to field lines and is linearly polarised in the plane of field-line curvature as indicated by the double-headed arrows in the lower plot. (Image credit: Peter Shternin)

Observations over the next few days confirmed that it was a real decrease in the pulsar period by about 3 parts in a million - the first detection of a pulsar glitch! Rad contacted Paul Reichley and George Downs who we knew were observing the pulsar using the Goldstone antenna at the Jet Propulsion Laboratory, Caltech, and found that they too had observed the glitch. Back-to-back papers reporting the discovery were published in Nature on April 19, 1969 [5, 6].
3. Searching for pulsars

Searches for pulsars are fundamentally important. Not only does the discovery of previously unknown pulsars increase the sample for all manner of statistical studies of pulsar properties and evolution, but almost every significant pulsar search has uncovered some unexpected and interesting pulsar or class of pulsars. Examples are binary pulsars [7], pulsars in globular clusters [8], RRATs [9], pulsars with planets [10], pulsars with main-sequence binary companions [11], etc., etc.

More than 2600 pulsars are now known. Figure 4 shows the rate of pulsar discovery since 1968 by observatory (or in a couple of cases, pulsar class). Small searches (including the original Cambridge search) are grouped under “Other”. This figure highlights the major contributions made by the Molonglo radio telescope in the first decade – twice in this time, more than half of the known pulsars were discovered at Molonglo – and the Parkes radio telescope. In the late 2000’s, Parkes had found more than twice as many pulsars as the rest of the world’s telescopes put together. Even now, the Parkes share is more than 55% of the total. The Parkes Multibeam Pulsar Survey [12] by itself has more than 830 pulsars to its credit, including recent discoveries from reanalyses of the dataset, e.g., [13]. In recent years, the Fermi Gamma-ray Space Telescope has been very successful in uncovering previously unknown pulsars, especially millisecond pulsars (MSPs) in so-called “redback” and “black widow” binary systems where the pulsar radio emission is often obscured or eclipsed by plasma streams from the companion star. Most of these systems have been found through radio searches of unidentified gamma-ray sources with properties known to be characteristic of pulsars, e.g., [14].

![Image of Figure 4](image_url)

**Figure 4.** Rate of pulsar discovery, sorted by observatory or class. Each bar represents the number of pulsars discovered in the corresponding 2-year interval. Data from the ATNF Pulsar Catalogue [15]

People often ask me why Parkes has been so successful in pulsar discovery. There are three main reasons:

- The centre of our Galaxy passes almost overhead at Parkes and the southern part of the Galactic plane is far richer than that in the north.
• At ATNF we have had and continue to have a very skilled group of engineers and excellent co-operation with the scientific staff. This led, for example, to the development of the Parkes 13-beam receiver system, by far the most successful pulsar-finding machine ever.

• We had very experienced teams of scientists working on the pulsar survey projects at Parkes (see, e.g., Figure 5). This led to the development of efficient signal-processing systems (both hardware and software) for pulsar detection and confirmation.

Figure 5. Andrew Lyne, Joe Taylor and Dick Manchester at IAU Colloquium 177 “Pulsar Astronomy – 2000 and beyond”, Bonn, August, 1999.

4. Key discoveries
The discovery of the first binary pulsar, PSR B1913+16, at Arecibo in 1974 by Russell Hulse and Joe Taylor [7] is the prime example of an unexpected and exciting find in pulsar searches. Observations of this system over the next few years provided the first accurate determinations of neutron-star masses, the first observational evidence for gravitational radiation and confirmation that Einstein’s general theory of relativity gives an accurate description of motions in strong gravitational fields [16, 17]. These important results led to the award of the 1993 Nobel Prize in Physics to Taylor and Hulse. As an aside, I note that I shared an office with Joe at the University of Massachusetts from 1971 to 1974, but unfortunately was not involved in the Arecibo search!

Probably the next most important pulsar discovery was that of the first MSP at Arecibo by Don Backer and his colleagues [18]. This was a little different to the other examples of important discoveries in that it was not found in a large-scale search, but rather in a directed investigation of a highly unusual radio source, 4C21.53W. This source was known to have a compact component (it scintillated) and it is steep-spectrum and polarised, all properties consistent with it being a pulsar. Yet efforts to detect a pulsar in this direction (including one at Parkes by Nichi D’Amico and RNM) had been unsuccessful. This changed dramatically when Backer et al. employed a sub-millisecond sampling system that revealed the 1.558 ms periodicity. Figure 6 shows a photograph of Don Backer, probably taken in the early 2000’s, and images from the discovery paper. Papers
suggesting that the rapid spin of the pulsar originated in an earlier phase of accretion from a companion star (since disappeared) were quickly published [19, 20]. The “recycling” idea had previously been invoked to account for the short period of PSR B1913+16 [21].

Finally, I must mention the Double Pulsar, PSR J0737−3039A/B, discovered at Parkes in 2003 [22, 23]. This system is unique in a number of ways. Firstly it is a double-neutron-star (DNS) system like PSR B1913+16, but with the very short orbital period of 2.4 h. This makes it even more “relativistic” than PSR B1913+16, with a predicted (and observed) periastron advance of 16.9° yr⁻¹, four times that of PSR B1913+16. Secondly, it was and remains the only DNS system where both stars have been observed as pulsars. The B star, although younger than the A star, has a much longer pulse period, about 2.77 s. Thirdly, the orbit is viewed almost exactly edge-on, making the Shapiro delay easy to observe [24] and allowing eclipses of the A pulsar by the magnetosphere of the B pulsar [23]. Recent observations of the system have resulted in the detection of six relativistic effects, including a measurement of the orbital decay that is an order of magnitude more precise than the PSR B1913+16 determination and fully consistent with the prediction from general relativity (Kramer et al., in preparation). It never ceases to amaze me that, despite the development of many alternative theories of relativistic gravity since general relativity, Einstein seems to have got it right the first time.

5. Future prospects
The past 50 years of pulsar astronomy have been more than interesting but there is much to look forward to. Large new radio telescope such as the recently commissioned Five hundred metre Aperture Spherical Telescope (FAST) in Guizhou province, China [25] will enable the discovery and study of many more pulsars, as well as increasing the precision of observations of currently
known pulsars. Further in the future, the Square Kilometre Array \[27\] will provide unrivalled sensitivity and resolution for essentially all radio astronomy applications. New X-ray telescopes such as eRosita, to be launched next year \[28\], and Athena, due for launch in 2028 \[29\], will provide wide-field spectroscopic imaging with unprecedented sensitivity and resolution. Existing radio telescopes will be enhanced with new wideband receivers and more sophisticated signal-processing systems. All of these and more will surely probe deeper into the secrets of pulsars, uncovering many things that are not even dreamt of yet. The future of pulsar astronomy and astrophysics is bright!

**Acknowledgments**

It has been a privilege and a pleasure to have travelled through 50 years of pulsar astronomy and astrophysics and I thank all those colleagues and friends who have helped me along the way.

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**Большое спасибо!**

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