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Nichi in Australia – the Early Years

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Abstract. My scientific association with Nichi D'Amico began in the late 1970s with collaborative work on the connections between radio and gamma-ray emission from pulsars, primarily using data from the recently launched COS-B Gamma-Ray Telescope. To pursue these connections, I visited the group in Palermo in 1978 and Nichi first visited Australia in 1981. There followed many subsequent visits by Nichi to Australia, including several with his family, and several by me, sometimes with family, to Italy. The collaboration broadened into searches for pulsars, first for young pulsars which might have gamma-ray or supernova-remnant associations, then for pulsars associated with globular clusters and finally into wide-area searches for pulsars, mostly with the Parkes radio telescope. These culminated in the very successful Parkes Multibeam surveys, from which among many important results, the most significant was the discovery of the first and still only-known "Double Pulsar", PSR J0737−3039A/B. Along with some personal reminiscences, this article reviews these scientific projects with an emphasis on Nichi's contributions.

Key words. obituaries, biographies – pulsars: general – surveys

1. Background

My association with Nichi D'Amico dates back to the late 1970s. The University of Palermo gamma-ray astrophysics group led by Rosolino Buccheri was analysing data from the European Space Agency COS-B Gamma-Ray Telescope, which had been launched in 1975. Nichi was a graduate student at the University and was working with Buccheri and his group on the COS-B data, specifically on the emission of gamma-rays by pulsars. I was contacted in connection with establishing the phase relationship of the radio and gamma-ray pulses from the Vela pulsar, work that resulted in the first collaborative paper (Buccheri et al., 1978) between the groups. Around the time of publication of that paper I visited Palermo and met Nichi for the first time. The idea of his visiting Australia to follow up on pulsar – gamma-ray associations was discussed during my visit.

I believe that Nichi first visited Australia in late 1981 – early 1982 (although it's possible that he made an earlier visit in 1980 as well) when we had Parkes observing to search for young pulsars associated with some COS-B unidentified sources, as well as with supernova remnants (SNR) and some other possible associations. The results of this work, which resulted in the discovery of three possibly associated pulsars and the detection of radio emission from the previously known X-ray pulsar, PSR B1509-58, were described in the 1985 paper by Manchester, D'Amico and Tuohy. This work is discussed in more detail in Section 2 below.

Over the next two+ decades, Nichi made numerous visits to Australia, including three extended visits with his family, in 1984, 1991 and 1993. During this time Nichi was a key member of several collaborative pulsar search projects. Broadly, these can be divided into two main areas: searches for pulsars associated with globular clusters and wide-area pulsar searches as described in Sections 3 and 4 below. The globular-cluster searches were very successful, notably the discovery of ten millisecond pulsars (MSPs) in 47 Tucanae (ultimately with 22 associated MSPs) and ten other cluster-associated pulsars. The wide-area pulsar searches have been even more successful, especially the Parkes Multibeam Pulsar Survey which has (so far – pulsars are still being discovered in archival data using more and more sophisticated signal-processing algorithms) resulted in the discovery of 832 pulsars, more than any other survey by a large factor. Key members of the Parkes pulsar search team in 1991 are shown in the photograph reproduced in Fig. 1.

In this article I will describe the main Australian pulsar projects to which Nichi made a significant contribution, emphasising his important role in them. As outlined above, these extended over more than two decades from the late 1970s. In the later years of our collaboration, especially from 2002 when Nichi was appointed Director of the Astronomical Observatory of Cagliari, he became more involved with important roles in the Italian astronomical community and his participation in Parkes projects tapered off. However, there is no doubt that his contributions have had and continue to have a lasting impact that will be remembered far into the future.

2. Pulsar – Gamma-ray Associations

The first Australian collaborative project that Nichi was involved with concerned the relative phases of the gamma-ray and radio pulses as emitted from the Vela pulsar (PSR B0833−45). As reported in the paper by Buccheri et al. (1978), it was found that, on emission, the radio pulse leads the first of the two gamma-ray pulse components by 11.5 ± 0.5 ms. It had been known for a year or so that the gamma-ray pulsed emission from the Vela pulsar had two components separated by about 31 ms and that there was pulsed optical emission with two components separated by about 21 ms. In Manchester & Taylor (1977), it was shown that the two optical pulse components lie symmetrically between the two gamma-ray pulse components, with the centroid of both trailing the radio pulse by about 27 ms or 30% of the pulse period.

Nichi's main project on his first visits to Australia in the early 1980s was the search for short-period pulsars in a variety of possible associations (Manchester et al., 1985). These included several previously unidentified COS-B gamma-ray sources, SNRs, both in our Galaxy and in the Magellanic Clouds, evolved stellar binary systems that might harbour a relative young pulsar, X-ray sources, some of which had known X-ray pulsations, and finally the steep-spectrum radio source 4C21.53W, which was later shown to be the first-known millisecond pulsar (Backer et al., 1982).[1] The search was carried using the Parkes radio telescope at 1.4 GHz with a total bandwidth of 20 MHz and, for the time, a relatively short sampling interval of 2 ms. The data were processed on the best available computing systems accessible to us in Australia and at the University of Palermo. Because of the large error circle for the gamma-ray sources and the large extent of many of the SNRs, most of these searches required multiple pointings of the telescope.

The search discovered three pulsars: PSRs B1338−62, B1758−23 and B1757−24, and detected radio pulsations from the previously known X-ray pulsar PSR B1509−58. All four of these pulsars are associated with a SNR. They also all have relatively high dispersion measures (DMs), with one (PSR B1758−23) more than doubling the previously largest known DM. PSR B1338−62, which has a pulse period of 193 ms, was tentatively associated with the SNR G308.8−0.1, an association later confirmed by Caswell et al. (1992). PSRs B1758−23 and B1757−24 were found in the search of the error circle for the COS-B source

[1] Unfortunately, our careful anti-alias filtering of the data prevented us from recognising this as an ultra-short period pulsar!

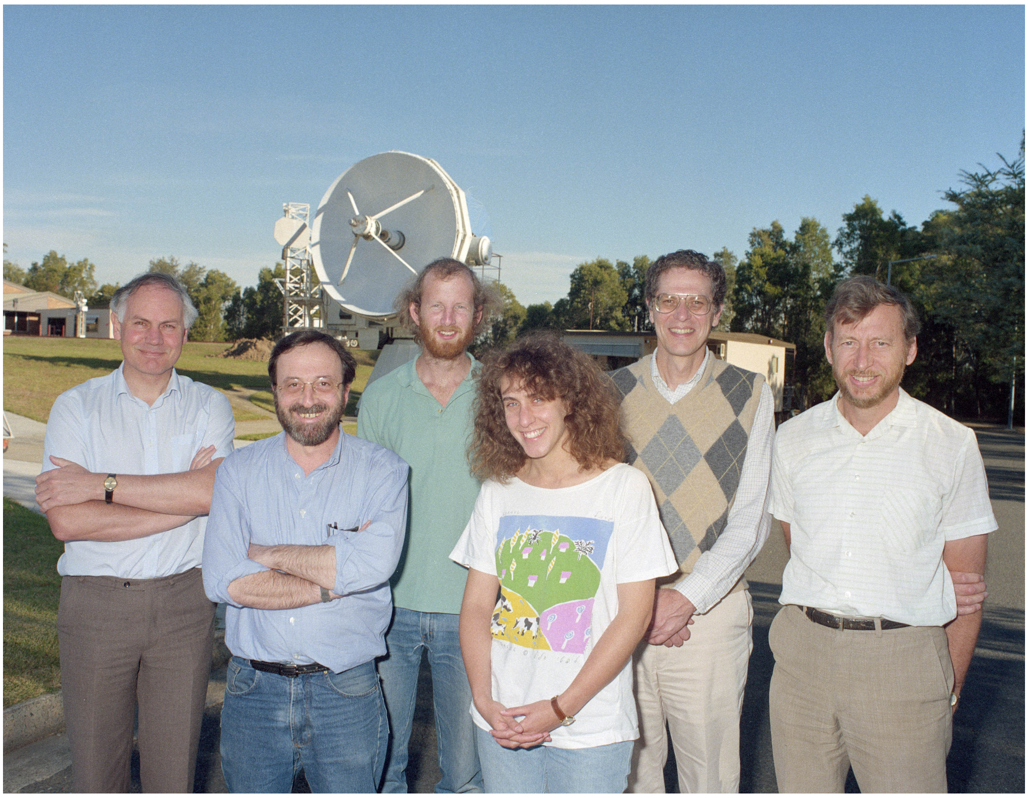

Fig. 1. The key members of the Parkes pulsar search team in 1991. From left, Andrew Lyne, Nichi, Simon Johnston, Vicky Kaspi, Joe Taylor, and the author. Image Credit: John Masterton, CSIRO, ATNF Image Archive.

2CG006-00 (see Fig. 2 - note that the name B1758−24 given in the figure was changed to B1757−24 following a more precise measurement of the position).

The association of PSR B1758−23 with the SNR W28 remains to be confirmed, but that of PSR B1757−24 with SNR G5.3−1.0 (also since renamed to G5.4−1.2) has been confirmed. A high-resolution radio image from the Very Large Array (VLA) (Frail & Kulkarni, 1991) shows that this object has a peculiar fan-shaped morphology with the pulsar located outside the main body of the SNR and joined to it by a "handle" of emission. The obvious interpretation of this structure is that the pulsar has a high space velocity and has overtaken the shell of the expanding SNR. However, this interpretation was disproved by Gaensler & Frail (2000) who used VLA observations to show that the pulsar proper motion is up to an order of magnitude less than implied by the "obvious" interpretation (see also Blazek et al., 2006). This implies that the pulsar is an order of magnitude older that its characteristic age of 16,000 yr, evidently implying a pulsar "braking index" of about 1.3, much less than the magnetic-dipole value of 3.0 (which the characteristic age assumes).

The SNR G320.4−1.2 (also known as MSH 15−52) was a search candidate. Initially the search concentrated on the brighter northern portion of the remnant, but, early in 1982 we were advised by Fred Seward that a very young X-ray pulsar, B1509−58, had been discovered further south, near the geometric centre of the SNR (Seward & Harnden Jr., 1982).

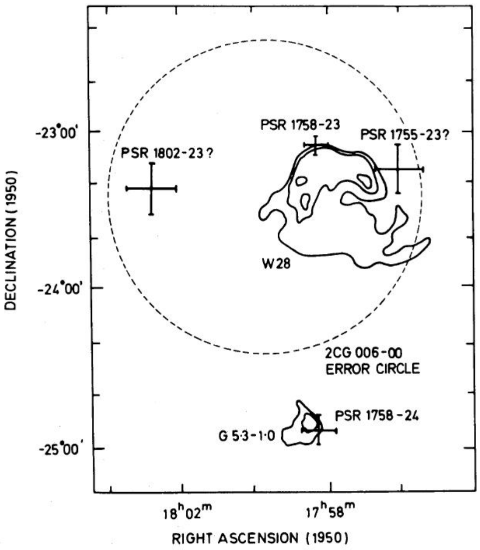

Fig. 2. The search area centred on the unidentified gamma-ray source 2CG006-00 from the second COS-B catalogue. Two confirmed pulsars and two good but unconfirmed candidates were found (Manchester et al., 1985).

Longer Parkes observations at this position revealed radio pulsations which confirmed the low characteristic age (1570 yr) and, from the DM and estimated pulsar distance, the association with G320.4−1.2 (Manchester et al., 1982). The unusual morphology of this pulsar – SNR system was attributed by Manchester (1987) to a biconical outflow from the pulsar, an interpretation supported by Gaensler et al. (2002) based on X-ray observations of the SNR.

3. Globular Cluster searches

Searching for MSPs in globular clusters was a major focus of Nichi's Australia-related activities from the late-1980s through to the mid-2000s. A major result from this work was the discovery of PSR B0021−72C (also known as 47 Tuc C) in the southern globular cluster 47 Tucanae (Manchester et al., 1990). This pulsar was discovered using a 50-cm-band receiver on the Parkes telescope and confirmed with 20-cm-band observations in 1988 and 1989. It has a pulse period of 5.75 ms and a DM of 25.6 cm^{-3} pc. 47 Tucanae lies about 3.2 kpc below the Galactic plane, well outside the Galactic electron layer, and this DM is consistent with the pulsar lying in the cluster. Despite its "C" designation, this was the first confirmed pulsar to be found in 47 Tucanae. A few months before our discovery, Ables et al. (1989) had announced the discovery of two pulsars in the cluster, designated PSR B0021−72A and PSR B0021−72B. These pulsars had DMs of about 67 cm^{-3} pc, which Manchester et al. (1990) argued was inconsistent with location in the cluster, and their existence was never confirmed.

Another major find of the Parkes globular cluster search was that of PSR B1744−24A, the second-known eclipsing binary pulsar (after PSR B1957+20) and the first pulsar to be associated with Terzan 5, a massive cluster located near the Galactic Centre (Lyne et al., 1990). Subsequent searches have shown that Terzan 5 contains more pulsars, 34 at last count, than any other cluster. PSR B1744−24A has a pulse period of 11.56 ms and is in a circular orbit, with period of just 1.8 hr, about a low-mass companion, believed to be a degenerate dwarf star. The radio pulses are eclipsed every orbit by an ionised wind emanating from the companion. The eclipse durations are typically about 30% of the orbital period, but are very variable in duration and are sometimes total. Along with the prototype, PSR B1957+20, PSR B1744−24A is a member of the so-called "Black Widow" group of binary pulsars.

Another significant paper, led by Nichi, from the globular-cluster search, (D'Amico et al., 2001), announced the discovery of an MSP in each of four clusters: NGC 6266, NGC 6397, NGC 6544 and NGC 6752. In all cases, the new pulsar was the first to be associated with its cluster. The pulsars are all in binary systems with circular orbits and low-mass companions. The pulsar in NGC 6544 (now called PSR J1807−2459A) is an extreme example with an orbital period of just 1.7 hr and a companion of planetary mass.

There followed a series of four papers, the first two led by Nichi, (D'Amico et al., 2001, 2002; Possenti et al., 2003; Corongiu et al., 2006), reporting on timing results for the Parkes discoveries, including the two discoveries announced in the third paper.

D'Amico et al. (2001) reported on one year of timing observations of PSR J1740−5340A in NGC 6397 and showed it to have strong and variable dispersive delays and associated eclipses despite its wider orbit (orbital period 1.35 d) than the Black Widow pulsars such as PSR B1957+20 and PSR B1744−24A. The companion is a star with mass greater than 1.9 $M_\odot$, most likely an evolved main-sequence star which frequently overflows its Roche Lobe, causing eclipses of the pulsar. This established PSR J1740−5340A as the first of a class of eclipsing binary pulsars later dubbed "Redbacks" by Mallory Roberts (Roberts, 2011).

The discovery of PSR J1910−5959A in NGC 6752 and the measurement of its DM (D'Amico et al., 2001), facilitated a deeper search of the cluster which resulted in the discovery of a further four MSPs. The discovery of these four pulsars and timing observations of all five pulsars were presented in the second paper in the series, (D'Amico et al., 2002). Together, they provided evidence for a cluster mass-to-light ratio > 10, a much higher ratio than estimated for any other globular cluster, and perhaps indicating the presence of a black hole in the cluster core. Two of the pulsars, A and C, are located well outside the cluster core, suggesting unusual non-thermal dynamics in the cluster core that resulted in the ejection of these two pulsars. It is curious that they somehow managed to avoid total ejection from the cluster.

Possenti et al. (2003) reported the discovery of two more MSPs in NGC 6266 and the timing of the three Parkes discoveries (PSRs J1701-3006A – C) in this cluster. Three more associated pulsars (D – F) were separately discovered by Chandler (2003). PSR J1701-3006B is in a 3.5-hr binary orbit and has a moderate-mass companion which is now thought to be a helium white dwarf. The pulsar is partially or fully eclipsed for about 20% of the orbit, clearly by a wind emanating from the companion, although the mechanism driving the wind is still uncertain.

The remaining paper of the series, (Corongiu et al., 2006), reports on timing observations from a 5-yr Parkes data span for the five known MSPs in NGC 6752, which improved on the results given by D'Amico et al. (2002). The paper concentrates on the measured proper motions for the five pulsars and speculates on whether or not two of them which are well outside the core of the cluster (coincidentally, also PSRs A and C!) are indeed associated with the cluster. The measured proper motions of these two pulsars are similar, but are somewhat discrepant with the optical determination of the cluster proper motion. Subsequent X-ray observations of the pulsars in NGC 6752 have confirmed their cluster membership (Forestell et al., 2014).

4. Wide-Area Pulsar Searches

The Parkes radio telescope has an enviable record in discovering pulsars in wide-area, unbiassed searches. From 1997 until recently, these searches were dominated by the Parkes 20cm 13-beam receiver which greatly increased the efficiency of wide-area searches. However, prior to that, there were several wide-area searches using other receiver systems. It was natural for Nichi, with his frequent visits to Sydney and his pulsar search interests, to become involved in these projects, especially those managed by the CSIRO Australia Telescope National Facility (ATNF) pulsar group.

The first survey that Nichi participated in was in fact not with Parkes at all, but was a follow-up to the very successful Second Molonglo pulsar survey (Manchester et al., 1978), using the 1.6-km cylindrical Molonglo Observatory Synthesis Telescope (MOST) which operated at 843 MHz. A 2°-wide strip along part of the southern Galactic plane was searched using 0.5 ms sampling. The survey was designed to find MSPs that would have been missed by the Second Molonglo survey because of the much slower sampling used there. In fact, no MSPs were discovered, showing that strong MSPs like PSR B1937+21 are relatively rare in the Galaxy, but one interesting young pulsar with a period of 107 ms and a strong interpulse, PSR B0906-49, was discovered.

The next wide-area survey that Nichi participated in was the Parkes Southern Pulsar Survey (Manchester et al., 1996). This survey was at a frequency of 436 MHz, and used a dual-polarisation circular disk feed and cryogenically-cooled FET amplifiers with an overall bandwidth of 32 MHz and a filterbank system with 256×0.125 MHz channels one-bit sampled at 300 μs intervals. Data were analysed using networks of work-stations at ATNF, Jodrell Bank and at the Istituto di Radioastronomia del CNR, Bologna, to which Nichi had recently moved. The survey covered the entire Southern Hemisphere and was very successful, ultimately discovering 101 pulsars (Lyne et al., 1998), including the very strong MSP PSR J0437−4715 (Johnston et al., 1993). Nichi led a third paper on the timing of 84 longer-period pulsars discovered in the survey (D'Amico et al., 1998), including an analysis of the timing noise-properties of the pulsars. They also showed that the best model (at the time) for the Galactic electron-density distribution (Taylor & Cordes, 1993) had a Galactic layer that was evidently too thin, a conclusion confirmed by later analyses of the Galactic electron density distribution.

The advent of the Parkes Multibeam system in 1996 (Staveley-Smith et al., 1996) revolutionised the field of wide-area un-biassed pulsar surveys. Several surveys of different parts of the sky and with somewhat different scientific objectives were undertaken with this receiver system. However, there is no doubt that the Parkes Multibeam Pulsar Survey (PMPS, Manchester et al., 2001) is by far the most successful pulsar survey ever, with 832 pulsars discovered so far, nearly 30% of the 2872 pulsars currently known.[2] Nichi played a significant role in both the observations and data analysis for this survey and for a number of other associated surveys, for example, the "Parkes High-Latitude" survey (Burgay et al., 2006) the "Perseus Arm" survey (Burgay et al., 2013). The former is especially famous for the discovery of the first- and still the only-known "Double Pulsar" PSR J0737−3039A/B (Burgay et al., 2003; Lyne et al., 2004), sometimes called the *"Jewel in the Crown"* of the Parkes pulsar surveys. This system has many claims to fame, but the most significant is the demonstration that Einstein's general theory of relativity (GR) is the most accurate known theory of gravitation in the strong-field regime occupied by the Double Pulsar system (Kramer et al., 2006).

[2] ATNF Pulsar Catalogue, V1.64, (Manchester et al., 2005)

5. Conclusions

The association with Australia and, in particular with the ATNF pulsar group, had a major influence on Nichi's scientific career. He made significant contributions to many important pulsar projects in Australia, including the discovery of the famous Double Pulsar system. These contributions were recognised, not only by the many scientific papers produced, but also by several important awards, including the CSIRO Medal in 1993 and the 2005 Descartes Prize, awarded by the European Union for outstanding collaborative research. It has been a privilege to work with Nichi and to get to know him and his family. Like everyone who knew him, I was greatly saddened to learn of his untimely death. I hope that this article does justice to his legacy and I thank the organisers of this Memorial volume for the invitation to contribute.

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