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SHEVE '82, Tasso, and the coming of age of Southern Hemisphere VLBI

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Abstract

After a short description of the earliest days of southern hemisphere VLBI, I concentrate on the period 1982 through March 1987, from SHEVE'82 and the start of Tasso's PhD to the time he left Australia to take up a research position at Jodrell Bank. These five years marked the coming of age of southern hemisphere VLBI.

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Introduction

The engineer, educator, broadcaster and author John Lienhard opens his book 'The Engines of our Ingenuity' (Oxford University Press, 2000) with the insightful and thought-provoking message "that our technologies are mirrors of ourselves". He emphasises the point that while we shape our technologies, we are in turn, shaped by our technologies. It is this human ingenuity that we share with those whose minds conceived and built the Antikythera device two thousand years ago. In appreciation of Lienhard's ideas, I have chosen here to concentrate on the people, rather than the technology and the science. This is with the wish to emphasise the importance of the players in SHEVE'82 and the early days of southern hemisphere VLBI. They saw the available technology, seized the opportunity, shaped, and were in turn shaped by southern hemisphere VLBI.

After a short description of the earliest days of southern hemisphere VLBI, I concentrate on the period 1982 through March 1987, from SHEVE'82 and the start of Tasso's PhD to the time he left Australia to take up a research position at Jodrell Bank. These five years marked the coming of age of southern hemisphere VLBI.

Gubbay and Robertson and the earliest days of southern hemisphere VLBI

Southern hemisphere VLBI started soon after the northern hemisphere first fringes had been found in mid-1967. In June that year, Jack Gubbay and Dave Robertson at the Weapons Research Establishment in Adelaide, successfully detected 3C273 at 2.295 GHz using an intensity interferometer between the two Deep Space Network stations, DSS42 at Tidbinbilla, near Canberra, and DSS41, Island Lagoon near Woomera (Gubbay and Robertson, Nature, **215**, 1157, 1967). However, because of the low sensitivity of the intensity interferometer, the potential number of accessible sources was seriously limited. They then extended their observations to independent local oscillator interferometry, i.e. VLBI, by making use of the excellent frequency, timing and data recording capabilities of NASA's Deep Space Network facilities in both Australia and California.

Such a move afforded significant improvements and in June 1969 they ran a series of observations from DSS13 at Goldstone to DSS42 at Tidbinbilla, in parallel with our first successful trans-Pacific experiments (Cohen et al., ApJ.,

158, L83, 1969, Kellermann et al., ApJ., **161**, 803, 1970). Both groups were highly successful. Based on the apparent decrease in the VLBI flux density of the compact component in 3C273 compared to the unchanged total flux density, Gubbay et al. concluded that the radio outburst in 3C273 was expanding with a Lorentz factor > 3, i.e. that the source was undergoing super-luminal expansion (Gubbay et al., Nature, **224**, 1094, 1969). This thus pre-dated the US trans-continental observational results that were coming in about the same time. One source that they spent considerable effort on in 1969–70, was PKS1934-638, which was also a prime target for SHEVE'82, as we shall see.

The situation for Gubbay and Robertson, however, soon changed dramatically. December 1972 saw the South Australian DSN Island Lagoon tracking station, DSS41, closed by NASA and the antenna dismantled and sold for scrap at 10c a pound! Sadly, the loss of DSS 41 also resulted in the closure of their group, which had made such judicious use of the technology available to them through NASA's Deep Space Network tracking station facilities in Australia and in California.

Bob Preston and the Tidbinbilla long baseline survey era

1974 saw the rise of the role and importance of NASA's Tidbinbilla tracking station, and the beginning of a very long and productive collaboration with Bob Preston and his group at JPL. After my visits to Tidbinbilla for the 1969 and 1973 VLBI observations, and after discussions with the Director, Tom Reid, I approached Paul Wild, then Chief of CSIRO Radiophysics, about the possibility of taking up a position in Canberra specifically to use Tidbinbilla's facilities for radio astronomy. Under the Host Country Agreement between Australia and the US, Australian astronomers were given access to NASA's Tidbinbilla facilities for up to 5% of the telescope time on a 'non-interference' basis. As nobody was making use of this, it seemed to me to be an incredible opportunity and I was keen to take it up. Paul was enthusiastic about the possibilities, and agreed to my suggestion.

I joined CSIRO Radiophysics from Cornell University in 1974 with two objectives, to set up a VLBI program in Australia, given the demise of the Adelaide group, and to work with Sam Gulkis at JPL to build the Tidbinbilla Interferometer to measure arc-second precision radio positions for unbiased optical identifications. I moved to Canberra, with an office with the CSIRO Division of Soils, where I was made most welcome, and I consolidated links with Tom Reid and Tidbinbilla. Tom's approach was that we astronomers would make use of, and so push his facilities, in ways beyond those encountered in their everyday activities. He claimed that our presence would be of benefit to both, a claim that proved to be correct.

Soon afterwards, together with Bob Preston and his group at JPL, Dave Morabito, Roger Linfield, Art Niell, an ex-student of mine from Cornell, the remarkable Lyle Skjerve, Don Spitzmesser and Ann Wehrle, we started a series of VLBI trans- and inter-continental 2.29 GHz survey observations. We used the DSN facilities world-wide to catalogue the incidence and intensity of compact, milliarcsecond components in the many radio quasars and galaxies over the whole sky. The 2.29 GHz survey program proved most productive, giving full-sky coverage through observations over the Tidbinbilla and Parkes to HartRAO, Tidbinbilla to Goldstone, and Goldstone to Madrid baselines, with baseline lengths of 64 to 81 x 10^6 wavelengths.

The survey observations ran from July 1974 through June 1983. They covered 1398 flat-spectrum sources, with 917 sources detected, including 93% of the BL Lacs, 86% of the quasars and 36% of the radio galaxies. The resulting catalogue of compact radio sources (Preston et al., A.J., **90**, 1599, 1985 and references therein) proved most valuable for a variety of astrophysical studies, for the preparations for Space VLBI with VSOP, and in the construction of VLBI celestial and terrestrial reference frames.

An important product of these surveys was the determination of arcsecond radio source positions (see Morabito et al., 1986, A.J., **92**, 546). Tidbinbilla's DSS43 64-metre (as it was then) served as the main Australian antenna, in collaboration with Bob Preston at JPL, while across the Indian ocean the 26-metre antenna of the Hartebeesthoek Radio Observatory (HartRAO) in South Africa provided the other end of the 10,000km baseline, through collaboration with George Nicolson. The accurate VLBI radio positions were a valuable part of the program of optical identification of compact, flat-spectrum sources from the Parkes 2.7 GHz catalogue.

As the survey observations progressed, it became clear that there was an increasing need for an Australian VLBI imaging capability, especially given the increasing number of interesting VLBI sources that we uncovered in the survey. Amongst these were the nearby radio galaxy Centaurus A, the compact dust-lane galaxy PKS1934-638 at a redshift of 0.138, PKS0438-436, at a redshift of 2.863, the most radio-luminous quasar known at that time, and the flaring X-Ray binary Circinus-X-1.

Tasso and SHEVE 1982

We named the first arraying experiment the Southern Hemisphere VLBI Array, SHEVE. It was a cooperative effort of both astronomers and geodesists, and was conceived and organised jointly by Bob Preston at JPL and by me at CSIRO, over a two-year period starting in 1980. Other Australian observatories and universities were also active participants, as was the Hartebeesthoek Radio Astronomy Observatory in South Africa. Some 29 people from 14 institutions made up the author list on the first major publication. Observations were performed over a two-week period from the 20th April through the 3rd May 1982. We had extensive use of DSS 43 at Tidbinbilla. The geographic location of the SHEVE 1982 antennas is shown in Figure 1.

Figure 1: The geographic location of the SHEVE 1982 antennas.

The arraying experiment was an amazing exercise in personal and institutional collaboration, as much as it was an exercise in technological innovation. We used six southern antennas in Australia, Tidbinbilla, Parkes, Fleurs, Hobart and Alice Springs, plus Hartebeesthoek in South Africa. Of these, one, at Alice Springs had never been used for radio astronomy before, three, at Fleurs, Alice Springs and Hobart had not been involved in VLBI before, and all but Tidbinbilla and Hartebeesthoek had no permanent VLBI equipment.

Time synchronisation consisted of taking the portable Rubidium clock of the Division of National Mapping (now Geoscience Australia) to each Australian site before the experiment. Mk II recording equipment from JPL was installed at each site, and all observations were made in right circular polarisation. The JPL team consisted of Bob Preston, Dave Morabito, Dave Meier, Art Niell, Lyle Skjerve and Ann Wehrle. At Parkes the observing team included Bob Batchelor, John Gates and Graham Moorey, as well as a number of the extra-galactic astronomers, Raymond Haynes, Bruce Slee and Alan Wright.

Tasso played a pivotal role in the SHEVE '82 observations. He was introduced to VLBI by his then supervisor, Bob Frater at Sydney University Electrical Engineering. Tasso was given the responsibility for installing the 2.29 GHz receiver on one of the 45 ft/13.7 m Fleurs dishes, and getting it operational in time for the observing. Soon afterwards Bob moved to CSIRO as the new Chief of Radiophysics, where he continued to support VLBI, and I became Tasso's joint thesis supervisor. Tasso had strong support from his Sydney University Physics thesis supervisor, Bruce McAdam, and from the other Fleurs engineering staff, especially Arthur Watkinson. Getting an antenna operational that has never participated in a VLBI experiment before is no easy task.

Tasso presented his experiences at the 20th International Electronics Convention and Exhibition of the Institution of Radio and Electronics Engineers Australia, in Melbourne September 1985. His presentation described the hardware and software he had developed specifically for SHEVE '82 and it was written up as 'A VLBI observing system for the FLEURS radiotelescope' in Proceedings of IREE Aust., 607-610, 1985. That their preparations were so successful is a tribute to the 'can-do' attitude of all involved. The Fleurs antenna is shown in Figure 2.

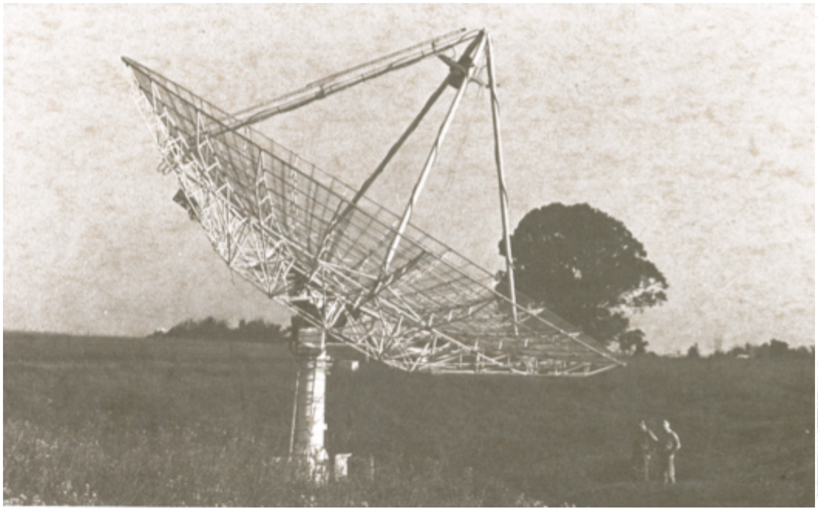

Figure 2: The 45 ft/13.7 m antenna that was used by Tasso, Bruce McAdam and Arthur Watkinson for SHEVE'82, was part of the Fleurs Array. Inset is a photo of Tasso and Arthur VLBI observing at Fleurs in 1982.

VLBI was a new experience for the University of Tasmania. Peter McCulloch, Pip Hamilton and Greg Royle were prepared for the challenge. Site preparation commenced with the felling of trees to clear the antenna horizon, and the 2.29 GHz receiver was installed on their 45 ft/13.7 m dish. As with the Fleurs and Alice Springs antennas, Hobart needed also to determine accurate pointing models, as 2.3 GHz was a significantly higher frequency than had been previously used.

The 9 m Australian Landsat antenna at Alice made its debut as an astronomy antenna with the SHEVE'82 observations. The Landsat Director, Don Gray, was the Director at Tidbinbilla when I visited in 1969 for the NRAO-Cornell group's first successful trans-Pacific VLBI observations. Don was receptive to my request for access to the Alice Springs antenna and made it available on a 'non-interference' basis, with the SHEVE'82 observations spread around the station's Landsat commitments; usually 20 – 22 hours per day were available for VLBI. Normal operation is at 2.3 GHz so we used the existing feed and receiver system. The ability to drive in celestial coordinates was achieved by means of an external microprocessor to calculate the necessary azimuth and elevation angles, which were then transferred to the station's control unit. An RF co-axial switch in the antenna pedestal accomplished the transfer to VLBI operations.

The three antennas, Parkes, Fleurs and Tidbinbilla formed an equilateral triangle of about 250 km on a side. Hobart was a further 1,000 km to the south and the 9 m Landsat antenna at Alice Springs about 2,000 km west. The longest baselines by far were those to George Nicolson at Hartebeesthoek in South Africa, a further 8,000 km to the west. George was an old-hand at VLBI, and a long-time friend and colleague of mine, so was well prepared for the SHEVE'82 exercise.

In addition to the imaging and astrometry objectives of SHEVE'82, there were also significant geodetic goals. While geodetic VLBI was already well established in the northern hemisphere, SHEVE'82 was the first attempt to build up a similar community in the south. Art Stolz and Bruce Harvey from the School of Surveying at the University of New South Wales, together with Ben Greene from the Division of National Mapping, and Kurt Lambeck from the ANU Research School of Earth Science made up the geodesy team.

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Only the Australian antennas took part in the geodesy component. As part of our geodesy program an S/X-Band receiver was installed at Parkes, along with a Hydrogen Maser as the station time and frequency standard. Bandwidth Synthesis, BWS, measurements were made at 2.3 and 8.4 GHz between Tidbinbilla and Parkes and yielded a three-dimensional baseline with 7–15 cm accuracy. On the Fleurs to Tidbinbilla and Parkes baselines, BWS measurements were made only at 2.3 GHz with an accuracy of 15–30 cm. The single 1.8 MHz bandwidth on the Hobart and Alice Springs baselines yielded 1–2 m accuracy. The first Australian VLBI geodesy results were presented by Art Stolz and Bruce Harvey, then Art's PhD student at UNSW (Stolz et. Al., The Australian Surveyor, **31**, 5, 1983, Harvey et al., Aust. J.Geod. Photo. Surv., **38**, 39, 1983).

The geodesy VLBI collaboration was also a first for the most of the institutions involved, and demonstrated the value of such collaborative efforts. This is a hallmark of VLBI where the scientific return for such observations increases dramatically as the number of participating antennas, and hence participating institutions, increases. In order to build a new VLBI community, bringing in new graduate students proved to be an effective tactic. At this time the VLBI technology was well understood and well demonstrated. Most importantly, it was also available to us through Tidbinbilla, JPL and NASA's Deep Space Network.

May 1982 came and as our SHEVE'82 observations got underway, the press came around in force; ABC TV even sent a helicopter to cover the event at Parkes. Canberra newspapers and TV came out to the tracking station, and the much heralded 'event' was seen across the country. Such extensive press coverage proved to be of considerable value, as we shall see. It also demonstrated the public's desire to know what is happening in science, Australian science in particular, and wants to hear it from the scientists themselves.

Our VLBI need at that time was for new people, not new technology. In the 1980s John Bolton was one of the few staff members at CSIRO Radiophysics who had PhD students, with Jas Wall and Ann Savage (for an entertaining insight into John and his students I refer the interested reader to "Wild, Wooley and Savage – or how John Bolton and I went hunting Quasars and QSOs" by Ann Savage, Aust. J. Phys., **47**, 589, 1994). So Tasso was the first of a new Australian and southern hemisphere astronomy graduate student VLBI community.

We correlated the SHEVE'82 VLBI data tapes at the Cal Tech-JPL correlator in Pasadena, California, and there followed a long period of data reduction, calibration, data editing, model fitting, hybrid mapping where appropriate, and then at last interpretation and understanding. Much of this took place with the SHEVE'82 Team gathering at a variety of institutions, JPL in Pasadena, and Canberra and Hobart in Australia. However, one notable data analysis visit was to the Arcetri Astrophysical Observatory in Florence in 1985, which was an important part of Tasso's introduction to the international astronomy community.

Figure 3: A SHEVE team meeting at Tidbinbilla; left to right, Dayton Jones, Bob Preston, Dave Murphy, Dave Jauncey, Dave Meier and Don Hoard, photo courtesy of Bob Preston.

An unexpected outcome from SHEVE'82.

The extensive press coverage that surrounded SHEVE'82 also had another profound yet unexpected effect. Since 1974-75, in order to keep their research capabilities at the cutting edge, Australian radio astronomers had been pushing for a major new instrument. This was originally planned as an interferometer to be built at Parkes utilising the 64 m telescope plus a number of other, smaller dishes. It was to be called the Australian Synthesis Telescope (c.f. Wellington, K.J., Proc. ASA, **3**, 1, 1976). As the 1970s became the 1980s, a proposal for funding the Australian Synthesis Telescope was submitted to government, but approval was not forthcoming and the proposal was turned down. Thus the future of Australian radio astronomy hung in the balance, for without a major new investment, the future looked bleak indeed.

August 1982 and Australian astronomy was at a crossroads; the situation leading up to this time is well presented in Brian Lee's New Scientist article of 19 August 1982 (New Scientist, **95**, 471, 1982). Fortunately, as Brian Lee points out, in the early 1980s Australian astronomy was also riding a wave of major discoveries. March 1982 saw the discovery of the redshift 3.78 quasar PKS 2000-330, which set a new record for the most distant object in the Universe (Peterson et al., ApJ. **260**, L27, 1982). This discovery was made on the basis of the precise radio position Sam Gulkis and I had measured with the now completed Tidbinbilla Interferometer (Jauncey, et al., AJ., **87**, 763, 1982), and with the optical spectrum from the Anglo Australian Telescope. The discovery ended a ten-year drought in finding ever more distant objects. It also overcame the feeling that was prevalent among many astronomers at the time, that the edge of the Universe had already been reached. And it received front-page press coverage across Australia and world-wide (Jauncey, D., in 'Celebrating the AAO – Past, Present and Future', 2011, Eds. Cannon & Malin, pp 137). The extensive press coverage of SHEVE'82 just a few months later added significantly to public understanding, and gave an appreciation of the capability and quality of Australian astronomical research. The impact of the SHEVE'82 discoveries extended well beyond the news. They had demonstrated the value and power of an Australian VLBI array.

SHEVE'82 was instrumental in expanding the earlier AST proposal to move the smaller dishes from Parkes to Narrabri to provide a much improved VLBI capability. SHEVE'82 also played a significant role in the addition of another radio telescope at Mopra, 100 km south of Narrabri, again, to improve VLBI capabilities. As Bob Frater said "You can't design what you can't conceive". This revised proposal, now re-badged as the **Australia Telescope** rather than the AST, was before the government awaiting a decision. The new name followed easily from the character of SHEVE'82 with its radio telescope encompassing much of the Australian continent. Moreover, SHEVE'82s influence extended to the idea of posing the newly named Australia Telescope as a Bi-Centennial Project. Fortunately, the result for both was positive, and the Australia Telescope was funded. As the Chief of CSIRO Radiophysics, Bob

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Frater's Australia Telescope Proposal was to go ahead, an excellent reward for all his effort. And southern hemisphere VLBI was to get two additional new telescopes.

What came next for Australian VLBI?

As noted above, immediately after the SHEVE observations, considerable time and effort continued to go into the data analysis. In parallel, events moved quickly to realise the opportunities that came available through the successful operation and technical advances flowing from the technical and scientific success of SHEVE'82. These next 5 years were to provide an amazing southern hemisphere VLBI adventure for all of us involved, and represented the coming of age of southern hemisphere VLBI.

The Parkes-Tidbinbilla Interferometer

The SHEVE'82 access to the Tidbinbilla DSN telescope produced a significant technological step forward in the form of Ray Norris's 1984 proposal for a Parkes-Tidbinbilla Interferometer, the PTI (Norris, R., Technical Notes and Reports, AT/20.1.1/002, 1984). Ray proposed to use the radio link between the two telescopes, the link that was in use when Parkes was being used as an adjunct to Tidbinbilla for tracking NASA's spacecraft. The link, which gave Tidbinbilla real-time access to spacecraft data from Parkes, was to be used to pass real-time radio astronomy data back to Parkes.

With a 275 km baseline the PTI was to become the world's longest baseline real-time interferometer. By making judicious use of existing electronics, plus developing the necessary software, the ingenuity of Ray and Mike Kesteven was responsible for the development of a remarkable and unique instrument. Its real-time operation gave it an edge when studying rapidly varying and transient radio sources, as was well demonstrated in their publication for the Parkes 50th Birthday Celebrations (Norris and Kesteven, in 'Science with Parkes @ 50 Years Young', 2012, Editor Robert Braun). Its scientific and technical successes are a tribute to its designers and builders and, as noted by Norris and Kesteven, to the staff at both the Parkes and Tidbinbilla telescopes.

Tasso and PKS1934-638

PKS1934-638 was a prime target of SHEVE'82, and the imaging was a major part of Tasso's thesis. Importantly, as already noted, PKS1934-638 had also been observed at 2.29 GHz in 1969 – 70 by (Gubbay et al., A.J., **76**, 965, 1971), on the Tidbinbilla to Woomera baseline. Tasso carefully investigated both hybrid mapping and model fitting to determine the milli-arc-second structure of PKS1934-638, and then compared it with the Gubbay et al., data from 12 years earlier, to see if there was any evidence for structural change. The underlying structure of PKS1934-638 is a compact double for which Tasso determined a separation of 42.0 +/- 0.2 mas and orientation 90.5^{o} +/- 1^{o}. This compared with the Gubbay et al., model fitting values of 41.9 +/- 0.2 mas and 90^{o} +/- 2^{o}. In his PhD thesis, Tasso concluded 'there is no evidence for any significant change in the structure of PKS1934-638 over the 12 year period 1970-1982'.

The imaging, hybrid mapping and model fitting strategies that Tasso developed played a critical role in the overall analysis of the SHEVE'82 results. Independently, the JPL group had also developed separate strategies; the final results were determined only through agreement between the two analysis strategies.

A new/old 26 m telescope for Hobart

While the development of the PTI was underway, NASA made the decision to close the Orroral Valley tracking station. This came about as the tracking and data relay satellite system, TDRSS, was coming into operation in 1983, and it was designed to take over Orroral Valley's satellite tracking operations. As opposed to the situation a decade earlier with the closure of Woomera, this time NASA was prepared to negotiate its closure. I was a little surprised when asked one day at Tidbinbilla, "Dave, do you want a 26 m antenna, or do you know someone who does?"

When Peter McCulloch and Pip Hamilton were approached, they and the University of Tasmania embraced the idea of moving the Orroral Valley 26 m antenna to Hobart, especially as it came with substantial funds from NASA for the move. After all, the success of SHEVE'82 had demonstrated to Peter and Pip the great advantages of having their own large radio telescope. Orroral Valley was closed in 1985. McCulloch and Hamilton and the University of Tasmania were very pleased to take on the job of moving and resurrecting the antenna at their Mount Pleasant Observatory outside Hobart. And importantly, Lee Hopson, the senior technician of the hydraulics section at Orroral, also moved to Hobart to supervise the relocation.

The new Mount Pleasant Observatory telescope was opened on the 13th of May 1986 by the then Governor of Tasmania, His Excellency Sir James Plimsoll. Since then it has proven to be an amazingly successful instrument, especially in the capable hands of the Physics Department of the University of Tasmania. Remarkably, it has now been a radio telescope longer than it was a NASA tracking station. Its story as a tracking station has been documented in Phillip Clark's book 'Acquisition! The Story of Orroral Valley Space Tracking Station', which is a moving tribute to the people who worked at Orroral Valley. The University of Tasmania soon moved seriously into many new fields, including VLBI, with their 'new' telescope.

Figure 4: Jim Lovell's beautiful image of the Hobart 26 m telescope at Mount Pleasant.

TDRSS and the first successful venture into Space VLBI

One of the reasons for NASA's closure of the Orroral Valley tracking station was bringing on-line the Tracking and Data Relay Satellite System, TDRSS. It is ironic that just as TDRSS was responsible for Orroral Valley being closed, TDRSS itself should become the next major player in Australian VLBI. The TDRSS VLBI program led at JPL by Gerry Levy, Roger Linfield and Bob Preston, proposed to make use of the 4.9 m TDRSS-E as a space VLBI element.

The objective was to demonstrate the successful operation of VLBI on baselines in excess of the diameter of the Earth in order to directly probe brightness temperatures in excess of the 10^{12} K inverse-Compton limit. This was to be done without launching a new space radio telescope.

TDRSS-E normally communicated with the Earth, and thus pointed towards it. But to view a set of radio quasars it was necessary for it to look past the Earth. Because of this geometry, with the satellite directly over the US, the ground antennas were necessarily on the opposite side of the Earth from the US. The two largest antennas available were the 64 m NASA tracking station at Tidbinbilla in Australia, and the 64 m tracking station at Usuda in Japan. Support for the TDRSS VLBI observations came from Prof Hirabayashi on site at Usuda, and from Bill Peters and me at Tidbinbilla.

VLBI observations using the 4.9 m TDRSS antenna were first made in July and August 1986 at 2.29 GHz. The results of these first successful space VLBI observations were published the same year (Levy et al., Science, **234**, 187, 1986) with the magazine giving its cover image to the experiment. Following this first success, additional observations were made in January 1987, again using the 64 m antennas at Tidbinbilla and Usuda (Linfield et al., IAU Symposium 129, M.J. Reid & J.M. Moran Eds., Kluwer, pp 457, 1988). The data were correlated at Haystack and, of the 25 sources observed, 23 were detected. The maximum baseline for each source depended primarily on declination and ranged from 0.94 to 2.15 Earth diameters. The most compact source was PKS1519-273 with 1.1 Jy correlated flux on a 2.02 D_E baseline, giving a size of 0.33 mas and brightness temperature of ~9 x 10^{12} K at its redshift of 1.294. In 1988 successful observations were made with TDRSS-A at 15GHz simultaneously with 2.29GHz, greatly increasing the angular resolution and demonstrating the feasibility of space VLBI and phase-transfer techniques at high frequencies.

The outstanding success of the TDRSS SVLBI demonstration revealed measured brightness temperatures well in excess of 10^{12} K. Thus, the TDRSS program paved the way for the successful launch of the Japanese VSOP mission a decade later, with Prof Hirabayashi as its Project Scientist. Importantly, it also demonstrated yet again the value of international collaboration, with cooperation across 11 institutions in the US, Japan and Australia. And it introduced the Japanese SVLBI team led by Profs Hirabayashi, Morimoto, and Inoue.

SN1987A and Tasso's departure for Jodrell Bank

As 1987 approached and Tasso was finishing writing up his PhD thesis, several important events happened which had a significant effect on southern hemisphere VLBI. The first was the arrival of John Reynolds at Tidbinbilla and the second was the arrival of SN1987A in the Large Magellanic Cloud. John had been OIC at Sydney University's Molonglo Radio Observatory some 40 km east of Tidbinbilla, and had moved from there to Mount Stromlo to take up the 'Friend of the Telescope' position at Tidbinbilla. The new Molonglo OIC was Duncan Campbell-Wilson. Both Duncan and John were about to become engulfed with the discovery of a naked-eye supernova, SN1987A.

The explosion of SN1987A was first detected on Earth on the 24th of February 1987 and because of its proximity it became the first naked-eye supernova in almost 400 years. Immediately after the discovery was announced, virtually every telescope in the southern hemisphere was pointed at it. Duncan Campbell-Wilson at Molonglo was the first to detect radio emission from the supernova, at 843 MHz, two days after its discovery, and he alerted the rest of the radio community. Because of its location in the Large Magellanic Cloud, high angular resolution radio observations were essential to separate the supernova radio emission from the crowded radio background, hence the success of Molonglo in the radio discovery. This was just the right situation too, for the recently operational Parkes-Tidbinbilla interferometer, which was able to follow the rise and fall of the radio emission at both 2.29 and 8.41 GHz. PTI observations were underway almost immediately and four days later the radio emission had peaked at around 150 mJy near 1 GHz. But a few days later it had faded to become undetectable (Turtle et al., 1987, Nature, **327**, 38, 1987).

Past supernova had demonstrated that supernova explosions frequently lead to the formation of a powerful radio remnant in the months and years afterwards. If such an event were to happen with SN1987A, it would offer the unique opportunity of following the birth and expansion of such a radio remnant in greater detail than had ever been achieved. A well-equipped permanent Australian VLBI array was needed; however, following SHEVE'82, much of the borrowed recording equipment and Rubidium frequency standards had been returned.

The timing of SN1987A was fortunate, as many northern hemisphere observatories were in the process of upgrading their VLBI recording equipment, and also many were upgrading their frequency standards to

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Hydrogen masers. The scientific case was strong, so my request to the global VLBI community for their old MkII recorders and Rubidium frequency standards was remarkably successful. Within weeks the Australian VLBI stations, including the new/old 26 m antenna at Mount Pleasant in Tasmania, were equipped and ready. SHEVE'82 and Tasso's PhD had proven successful, and soon after Tasso's departure for Jodrell Bank, the SHEVE VLBI array was ready and waiting if the radio remnant of SN1987A should reappear.

Figure 5: Tasso saying goodbye at Sydney Airport March 1987, photo courtesy of Bruce McAdam.

May 1987 heralded the celebration of 20 years of VLBI with IAU Symposium 129 'The Impact of VLBI on Astrophysics and Geophysics'. Only five years after SHEVE'82, IAU 129 saw a significant contribution, 10 presentations with southern hemisphere VLBI authors. The topics covered included SHEVE'82 results, the PTI as well as some of the first radio results SN1987A. But it was the TDRSS Demonstration observations that were chosen as the cover illustration for the Symposium volume.

Tasso's return

Skipping ahead to 1990, Tasso's return to Australia saw the Australia Telescope Compact Array at Narrabri completed and operational after the 1988 Bi-Centennial opening. Bob Frater and John Brooks and the AT Team had done a magnificent job and Australia had a superb new radio telescope. The SHEVE'88 VLBI session was the first science observations with it. The Radiophysics Division was no more, now it was called the Australia Telescope National Facility, ATNF.

Meanwhile, I was co-supervising two fresh VLBI students who were embarking on new projects for their PhDs, Edward King from the University of Tasmania and Steven Tingay from the Mount Stromlo and Siding Springs Observatories. Both would shape and be shaped by their southern hemisphere VLBI experiences, and would continue to make significant contributions to Australian science. And Matthew Bailes, also from Mount Stromlo had finished his PTI pulsar proper motion PhD with John Reynolds, and was off to Jodrell Bank.

All the SHEVE'82 astronomy papers were published in the July 1989 Astronomical Journal. In all, we observed 29 sources, the more interesting of which were presented as six consecutive papers; Preston et al., **98**, 1, 1989, Centaurus A, Meier et al., et al., **98**, 27, 1989, PKS1934-638, Tzioumis et al., **98**, 36, 1989, Sagittarius A, Jauncey et al., **98**, 44, 1989, Radio-Optical Position Comparison, Jauncey et al., **98**, 49, 1989, and Optical Identifications, Jauncey et al., **98**, 54, 1989. Moreover, we were fortunate to have the journal display as its cover, the geographic location of the SHEVE 1982 antennas, as is shown in Figure 1 above.

In recognition of the achievements of the decade of southern hemisphere VLBI observations that began with SHEVE'82, and had continued through the Australia Telescope opening, the SHEVE Team was awarded a NASA Group Achievement Award in July 1992. Figure 6 shows some of the Australian members of the Team receiving the Award from the NASA Representative in Australia, Ted Ankrum, at the Radiophysics laboratory in Sydney.

Tasso had returned to ATNF, as had John Reynolds, the SHEVE series of VLBI observations had continued successfully, and with SHEVE '88, we made the first science observations with the newly completed Australia Telescope National Facility Compact Array at Narrabri. The TDRSS series had run through 1986, 1987 and 1988, and had also received a NASA Group Achievement Award, as had the Tidbinbilla Interferometer.

The years starting with SHEVE'82 had indeed seen southern hemisphere VLBI come of age. Without Australian astronomy's access to NASA's Tidbinbilla tracking station facilities, without the collaboration formed with JPL astronomers, without the support of Bob Preston and Bob Frater, and especially without the 'can-do' support of Tasso and the whole SHEVE Team, VLBI in Australia and the southern hemisphere would have followed a very different path. The outcome of my discussions with Paul Wild back in 1973 had proven more successful and productive than either of us could have anticipated.

Figure 6: July 1992: Ted Ankrum, the NASA Representative in Australia, presents us with the NASA Group Achievement Award as members of the Southern Hemisphere VLBI Experiment Team. Left to right: Paul Jones, Tasso Tzioumis, Bruce McAdam, Ray Norris, Ted Ankrum, John Reynolds, Dave Jauncey, Bob Duncan, Dick Ferris and Mal Sinclair, photo courtesy of CSIRO.