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John Paul Wild 1923–2008[1]

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Paul Wild stands tall among the founding fathers of modern radio astronomy. His early work became the foundation for all future research on solar radio bursts. He established the theory and identified the different types of radio bursts. He developed new types of instrument including the dynamic spectrograph and a radioheliograph to make two-dimensional movie images. His early interest in the radio spectrum of hydrogen led to analysis of the hyperfine structure of hydrogen emission and a publication that became a classic paper in the field. Recognition that the 21 cm hydrogen line could be used to measure the Zeeman effect and through that magnetic fields in astronomical sources was another key contribution to modern astronomy. He became Chief of the CSIRO Division of Radiophysics and developed and demonstrated an outstanding microwave landing system for aviation. As Chairman of CSIRO he led the organization through a major restructuring and adapted CSIRO to bring it closer to industry while maintaining a high standard of excellence and originality. Throughout his career, Paul Wild provided great leadership at all levels of science in Australia.

Introduction

The period after the Second World War was a period of rapid advance in the field of radio astronomy. Hey and others had made the first observation of a radio source other than the Sun and research groups were forming to develop the field. Two key groups in this early phase were led by Martin Ryle in Cambridge and Joe Pawsey in Sydney. There were exceptional opportunities for exceptional people. Two people from Sheffield who came to Sydney were to play a major role in establishing the foundations of modern radio astronomy; they were John Bolton (99) and Paul Wild. Bolton tackled the early cosmic work while Wild studied the Sun.

John Paul Wild was born on 17 May 1923 in Sheffield, England, the son of cutlery manufacturer Alwyn Wild and Bessie Wild (née Arnold). He was one of four brothers. Arnold was the eldest, followed by Mark, Ted and then Paul as the youngest. In an interview late in life he recorded (Moyal 1994):

> My father was a cutlery manufacturer living in a rather grand house with, I think, three cars including a Rolls and a Daimler and something else. However, just about the time I was born,

[1]A similar memoir will appear in *Biographical Memoirs of Fellows of the Royal Society of London*, vol. 58, 2012.

> which was 1923, there was a depression and he went bust. And when I was three months old he left the country to go to America in an attempt to sell his patents and so on for cutlery manufacture, and in the event he never returned. I met him eventually when I was thirty-three years old.

The family moved to Croydon, south of London and, as Paul described it, went from riches to rags. The family was really struggling until some financial dealings had come through for his father. At the age of six, Paul got off a train and was run over by a lorry. He spent six months in hospital with a fractured skull but recovered completely. After an unhappy spell in boarding school, Paul and Ted attended a local preparatory school and then the Whitgift School in Croydon. Mark and Arnold went to Whitfield Grammar School. A gift of a Hornby train from his mother when Paul was seven years old started his lifelong love of trains. The locomotive had 'Great Western' written on it and it started Paul on a study of the history of the Great Western Railway. He also read about the railways and extraordinary ships that the famous British engineer Isambard Kingdom Brunel built and claimed Brunel as his first source of inspiration. When he was young, Paul visited Southampton many times to see and take photographs of the ships he loved. He was particularly interested in the big ocean liners such as *Queen Mary*. Sometimes his brother Ted would row him out in a small dingy so that Paul could take better, closer photographs. Paul described three ambitions when he was seven years old: to be a train driver on a King Class locomotive, to be an opening batsman for Yorkshire and to become a Fellow of the Royal Society. As he said 'I was happy I achieved one of these'. Paul had an early love of mathematics and attributed much to his school mathematics teachers, separate teachers for analysis, calculus and modern geometry. With this came a 'little bit of physics and current affairs' and leisure times devoted to bridge. Paul went to Cambridge in 1942:

> And the first year I did Mathematics Part 1, Mathematical Tripos Part 1, but I could only stay on at the time without going into war service if I did something more useful to the national war effort. So that's how I became a physicist. I went straight into Part 2 Physics, which is fairly tricky because the great majority of people had already done two years of it before, so it was a real challenge. But I enjoyed it very much, and I was very inspired by the sort of grandeur of the approach, the wonders of quantum mechanics and relativity and that kind of thing. It was hard work, it was six days a week. In the event, I left after the second year and had the choice of joining one or other of the three services or going to research, radar research, or industry. And I joined the navy, because I'd always had a great interest in ships and the sea in general. It turned out, since I went up one term late when I went to Cambridge, that I only spent five terms at a university, and I've only spent five terms in my life at a university. After a year away, they gave you a wartime degree, which was a Bachelor of Arts. But a few years later, one paid £5 and it became a Master of Arts. That's the way things happen at Cambridge. And after ten years of research, I collected a whole lot of papers up and sent them to Cambridge and, after a two-year deliberation, they gave me a Doctor of Science at Cambridge. And that's my very limited university career.

Wartime

Paul joined the navy in July 1943 as a 'Probationary Temporary Acting Sub-lieutenant (Special Branch RNVR)'. He did a six-month training course at Portsmouth as a radar officer, drawing on a special radio course he had done at Cambridge. Paul became Assistant, then Senior Radar Officer on the Flagship, HMS *King George V*. The ship was part of Taskforce 57 that served in the Pacific. Paul spent the next two and a half years in that role, being promoted to Lieutenant. Before setting sail for the Pacific, the *King George V* was in Scotland where it was visited by King George VI, Queen Elizabeth and Princesses Elizabeth and Margaret. Paul spoke of making his name by responding to a question from the Admiral at a critical moment that 'normal' meant 'at right angles to' and then watching the radar in amazement as the whole fleet turned through ninety degrees. Sydney was the rear base for Britain's Pacific fleet and it was during his many visits to Sydney that Paul met Elaine Hull—giving him a good reason to come to Australia. There was frequent correspondence after Paul returned to England at the end of the war, and he proposed to Elaine and sent a ring by mail. Back in England he taught radar to naval officers until, in 1947, he obtained a job at the Radiophysics Laboratory of CSIR in Sydney, to maintain and develop test equipment. After a year in this role, he was able to get into radio astronomy research with Joe Pawsey's group. Paul was a great admirer of Pawsey: 'He just provided ideal conditions, an ideal environment to allow everyone to use their own initiative'. Pawsey gave him the option of joining a colleague, John Bolton, to do work on radio sources or else joining another colleague, Lindsay McCready, on building a solar spectrograph (3). Paul saw that with John Bolton he would be very much a second-incommand, and if he joined McCready he would be able to do his own thing. As he said: 'And that's why I became a solar man' (97).

Solar Spectral Work at Penrith and Dapto

In his then role as an Assistant Research Officer, Paul was able to start his work in solar radio astronomy working with McCready to build a spectrograph to study solar bursts. They set up a very crude field station with just a couple of trailers and the antenna not far from the railway line at Penrith Station at the foot of the Blue Mountains outside Sydney, a very sparsely populated area in those days so there was a reasonably low radio noise level. As Paul described it: 'Then one just waited until something happened. Every now and then a great burst would come from the Sun and we were very excited and we photographed everything that went on with a movie camera. After four months we got so much data that we just closed everything down and came back and I analysed the data at very great length; the results were spectacular'. With this instrument, which allowed for the first time a display of frequency versus time (that is, dynamic spectra) covering a swept frequency range from 40 to 70 MHz, they identified and named three types of bursts—Types I, II and III, distinguished by the way the frequency drifted with time—and published a series of papers in 1950 (4, 5, 6) that became the foundations for all future work on solar bursts. They deduced that the Type II bursts were associated with shock waves coming out through the solar atmosphere at 1000 km s^{-1} and were associated, thirty hours later, with aurorae in the earth night sky. They associated Type III bursts with streams of electrons being ejected at a third the speed of light and taking only an hour to reach the earth (10, 11). The mechanisms proved to be correct and their nomenclature for the phenomena became the international standard. In 1954 a more sophisticated dynamic spectrograph was built on a dairy farm at Dapto, 100 km south of Sydney, where Paul was joined by the electrical engineer John Murray and technician William Rowe (11). The site was chosen to be free of man-made radio frequency interference. Three rhombic antennas covered a frequency range from 40 to 240 MHz. The first results were presented at the 1952 URSI General Assembly in Sydney (Sullivan 2009). The earlier results were confirmed and extended over the next decade. The dynamic spectra showed the way the complex frequency structure in the solar radio emission varied with time (frequency sweep). A slanting board in these two-dimensional displays indicated a continuous variation in the burst frequency with time (Figure 1).

Paul described the work as follows (Bhathal 1996):

> Through a long series of observations, involving high-precision directional observations, as well as frequency-sweep, plus a lot of theory, we were able to prove the meaning of these slanting bands. Around the Sun is a huge atmosphere (the 'corona', seen only at total eclipses) of ionised gas. This is where the radio waves originate: different frequencies originate at different levels, high frequencies closer to the Sun's visible surface, lower frequencies further away. This meant that the slanting bands were due to the source of radiation *moving outwards through the solar atmosphere.* With the aid of models based on eclipse data, we were able to work out the height in the solar atmosphere corresponding to each frequency; and so from the slant of the bands we could work out the speed at which the source was ascending. It turned out that the speeds fell into two very distinct categories. One was around 1000 kilometres per second (km s^{-1}); the other at least a hundred times faster, or about one-third the speed of light.

Nothing had ever been seen to move on the Sun at such high speed and this interpretation was inevitably met with considerable scepticism (Sullivan 2009). Paul likened this research to the study of taxonomy that preceded Darwin's 'Origin of Species'. His analysis of the anatomy of the solar flares and his development of the physical interpretation culminated in a unified model that integrated the apparently complex radio flare phenomena in the solar chromosphere, the

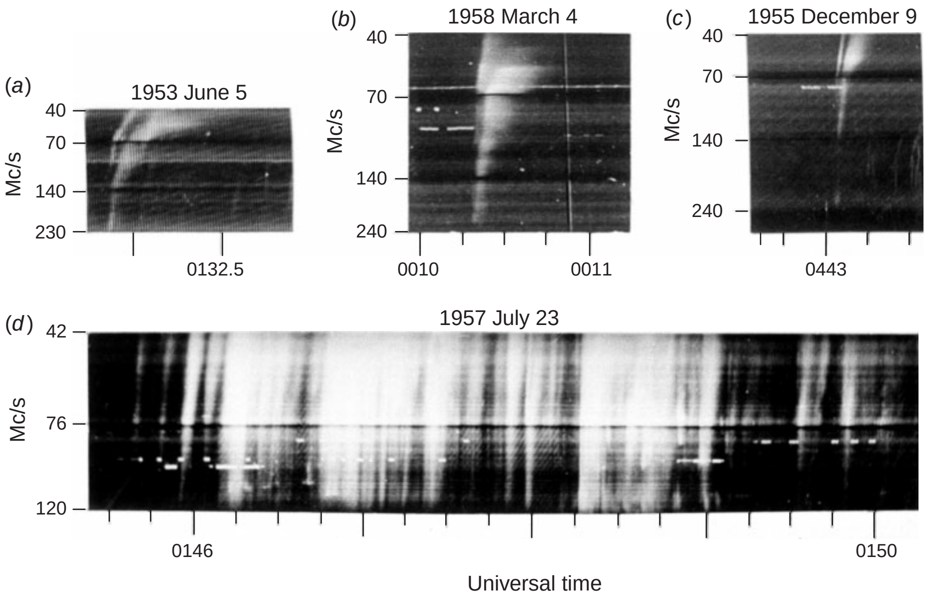

Figure 1. Examples of type III bursts observed with the Dapto dynamic spectrograph in 1959. In (*a*)–(*c*) are individual bursts where first and second harmonics can be seen, while (*d*) shows a typical large group of Type III bursts.

solar corona, and the interplanetary space (see for example (38)). The phenomena of Type II and Type III bursts, especially the latter because of their simple structure, stimulated a great deal of interest among theoretical physicists and, in particular, plasma physicists. After ten years of research, Paul's collected papers (1–22) gained him a Doctor of Science degree from Cambridge. The Sydney group was the pre-eminent group in the world for solar radio astronomy and would continue their work for three decades.

Ionospheric Scintillation

A sunspot minimum occurred in 1955 not many years after the Dapto solar radio spectrograph commenced operation and in this period solar observations were only recorded occasionally when sunspots were visible. Paul used the resulting availability of equipment and manpower to study the ionospheric intensity scintillations. He was joined by Jim Roberts and they confirmed previous findings that the scintillations resulted from relatively stable spatial patterns of intensity with scale sizes of the order of 10 km drifting across the ground at speeds of the order of 100 m s^{-1} (15). Two new results were that the patterns on the ground were elongated, and that the ionospheric irregularities causing the day-time scintillations were located in the E-layer, while those causing the night-time scintillations were in the F-layer—this latter result being the subject of a paper in *Nature* (17). Paul was able to measure the dynamic spectra for the first time and he realized that the observed scintillations must be produced by the focusing effect of large refracting elements in the ionosphere. If contributions were received from many small refracting elements then the features would be narrow-band and dispersed randomly in the time-frequency plane and this was only occasionally observed. This interpretation was counter to the prevailing theory, based on the diffractive scattering caused by small scale irregularities, that had been developed in the Cambridge group. Because of this disagreement in interpretation, Paul's work received very little recognition at the time. Not until 1975 was the full theory of scattering by a power-law spectrum worked out by Gochelashvily and Shishov (Prokhorov *et al.* 1975). This made it clear that the diffractive scintillations described by the Cambridge model were modulated by the refractive scintillations that had already been seen so clearly in the dynamic spectra of Wild and Roberts taken twenty years earlier (15). This power-law model has now been successful in describing scintillations in the ionosphere, the solar wind, and the interstellar plasma. Had Paul's demonstration of the importance of refractive effects been accepted at the time, scintillation theory would have advanced much more rapidly.

The Hydrogen Line and the Zeeman Effect

In the course of this solar work, Paul began to suspect that there were spectral lines in the solar burst they were observing and became interested in the radio spectrum of hydrogen. He wrote up an internal report related to the potential for spectral lines in the solar bursts (1, 2). When 'Doc' Ewen and Ed Purcell at Harvard in the USA first detected the 1420 MHz (21 cm) hydrogen line transition in the interstellar medium in 1951, Paul went back to his report, generalized it to include the hyperfine structure of hydrogen, and six months later published the first detailed theoretical paper on the hydrogen lines (7)—a classic in the field. The Assistant Research Officer had come a long way in the brief period since 1947! One of the powerful tools in modern astronomy is the use of the Zeeman effect to make a direct measurement of the strength of the magnetic field in astronomical sources by measuring the slight shift in the frequency of spectral lines. Paul played a key role in the recognition that the 21 cm hydrogen line could be used to measure this Zeeman effect as he describes in his biographical memoir of John Bolton (99):

> On a visit to Caltech in 1957 I spent a day at Mount Wilson Observatory and watched Babcock measure solar magnetic fields by observing the split of spectral lines by the Zeeman effect. Next day I made the long drive to the Owens Valley radio Observatory with John Bolton. I said 'I wonder if it would be possible to measure galactic magnetic fields by observing the Zeeman splitting of the hydrogen line'. We talked about it exchanging ideas in an exhilarating conversation throughout the drive. Next day I wrote the Bolton and Wild paper (23) that incorporated the ideas of both of us. This paper started a prolonged search in a number of observatories and was eventually successful.

Zeeman-splitting observations of the 21 cm line and other radio lines have become the key to our understanding of magnetic fields in our galaxy with some 400 papers now published on this topic.

The Radioheliograph

All the results from Paul's group had been inferred from the spectral observations and there was a growing desire to be able to image the Sun at the same range of frequencies with angular resolution comparable to the human eye. In other words, they now wanted to get a moving picture of the phenomena on the Sun. This was a formidable challenge that dictated the need for an instrument more than a million times the size of the aperture of the human eye—that is, 3 km across. The first formal proposal for such an imaging instrument was put forward by Paul in June 1959 (32). At this stage he envisaged a crossed-grating instrument of the type used by his Radiophysics colleague W. N. Christiansen. He envisaged two modes, one where pictures would be formed in seconds and another where perhaps one picture per hour would be made. As the proposal evolved, it became the only project, other than the construction of the Parkes 64 m telescope, that would be carried out in CSIRO's Division of Radiophysics. Proposals from two other senior members of the Division, Bernie Mills and 'Chris' Christiansen, were not supported and they left the Division to take up roles at the University of Sydney where Mills, as Professor of Physics, built the Mills Cross at Molongolo and Christiansen became Professor of Electrical Engineering. With Paul's influence and Pawsey's support, the old Fleurs Field Station was transferred to Christiansen's group, who went on to build the Fleurs Synthesis Telescope. As Paul developed his proposal, he rejected the cross structure because of potential side lobe problems. He devised, instead, a unique beam-forming method using an annular structure with 96 antennas on a circle 3 km in diameter. This would behave like a filled dish 3 km in diameter (32, 34). The fast image generation needed to make a moving two-dimensional image of the Sun exceeded the computational capability of contemporary computers and Paul invented a new image processing technique called J^2 synthesis (46) which used the real-time electronic summation of Bessel functions to solve this problem.

Figure 2. Artist's impression for the Radio Heliograph built at Culgoora near Narrabri in north-west NSW in 1967. The 96 13.7 m dishes evenly placed in a circle 3 km in diameter. © CSIRO Australia.

With Pawsey's help, $630,000 was raised from the Ford Foundation in the USA to build a Radioheliograph. Originally the plan was to locate it at Parkes. However, the area required (3 km by 3 km) was too large to be accommodated at Parkes, so a more suitable site was found on the north-west plains of New South Wales at Culgoora, near the town of Narrabri, some 600 km from Sydney (Haynes *et al*. 1996) (Figure 2). Paul's friend Kevin Sheridan, Chief Electronics Engineer at CSIRO, was the key figure in the development of the Radioheliograph. The instrument was completed and commenced operation in 1967. It could produce dual-polarization radio pictures of the Sun at a rate of one two-dimensional image per second and normally cycled through four observing frequencies: 327, 160, 80 and 43 MHz (Figure 3). Paul's own description captures the performance of the instrument:

> It was a hell of a business getting it right, getting all the phasing and so on and it took quite a team of us, after building it, a couple of months or more getting it to work. When it did work it worked beautifully and we photographed these solar phenomena in two senses of circular polarisation and ultimately displayed this as a colour picture, red being right- handed and blue being left-handed polarisation. The pictures were very spectacular and showed all manner of phenomena. It showed what the different types of bursts looked like. Type III were little spikes, little concentrations of light, whereas for the Type II you could actually see the great shock waves propagating across the Sun.

The two-dimensional moving images from the Radioheliograph provided very important details on the evolution of the Type II and Type III bursts but for the Type IV bursts it gave a completely new picture. One could also see for the first time that they were not all the same but included a lot of different phenomena with great loop structures associated with giant magnetic fields and sometimes polarized blobs that moved out to a great distance (Sullivan 1978). They would take perhaps half an hour to travel out to distances up to six or more solar radii. So what this did in a way was to increase the size of the observable Sun by a factor of six in radius. Another early exciting discovery was that there were bursts that were not all coming from the same centre, as had previously been assumed. Two active centres, separated on the Sun's surface by as much as a million kilometres, appeared nearly simultaneously as if they could move faster than the speed of light. In reality an event deeper in the Sun was triggering both bursts. The Heliograph stayed in operation for seventeen years from 1967, providing a wealth of new information and new insights into phenomena of the solar corona and the relationship between

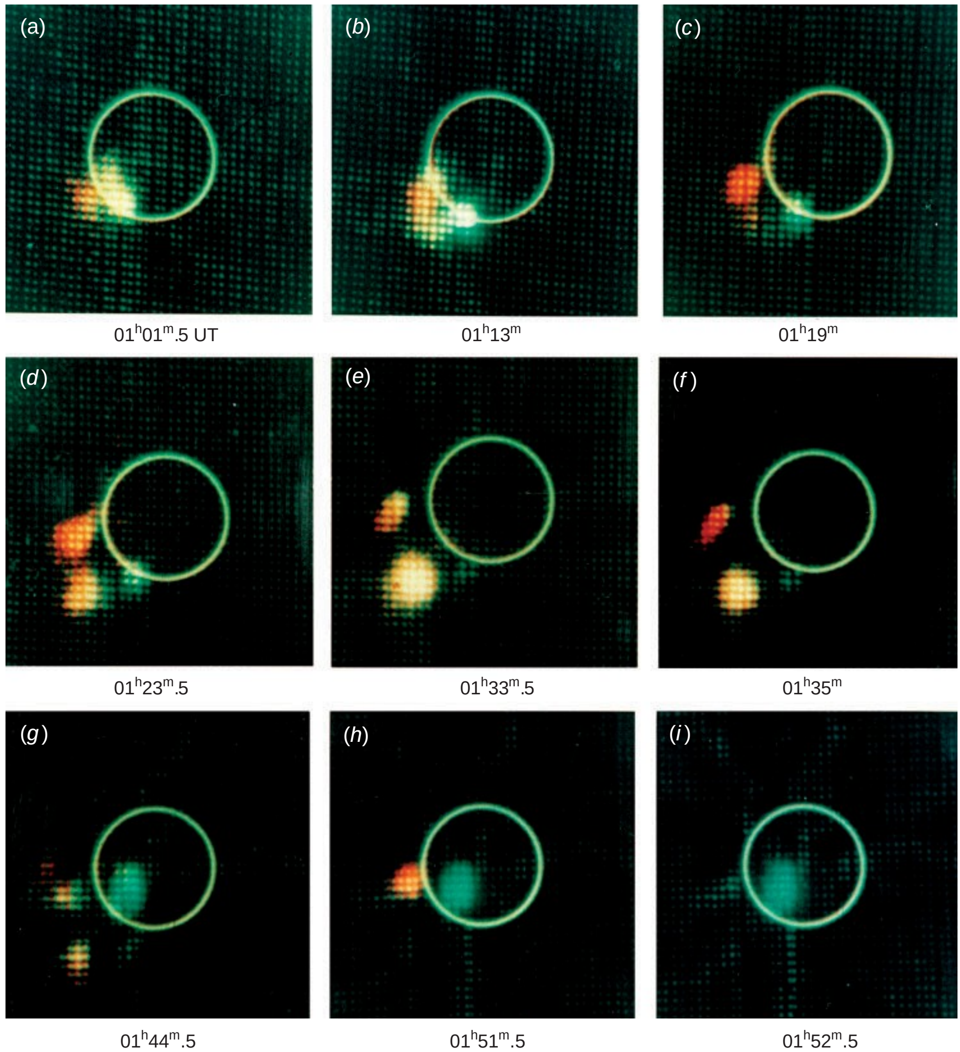

Figure 3. Selected 1-s frames of the 80 MHz radioheliograph record of the event of November 22, 1968. The photographs have been made by superposition of left and right-handed circularly polarized heliograms through red and blue filters respectively. The circle represents the size of the Sun. © CSIRO Australia.

solar and terrestrial phenomena. Paul published 30 papers (51–81) on the design and research with the instrument. The remarkable contribution of the Radioheliograph was summarized in a book edited by his colleagues Don Mclean and Norm Labrum (1985) to which Paul contributed the introductory chapter: 'The beginnings [of solar radiophysics].' We conclude this discussion of solar radio astronomy with these insightful remarks made by Paul in an address to the IAU General Assembly in Sydney in 1973 (78):

> I have the feeling that to most astronomers the Sun is rather a nuisance. The reasons are quite complex. In the first place the Sun at once halves the astronomer's observing time from 24 to 12 hours, and then during most of the rest of the time it continues its perversity by illuminating the Moon. Furthermore I have met numerous astronomers who regard solar astronomy to be

now, as always before, in a permanent state of decline—rather like Viennese music or English cricket. Nevertheless those who study the Sun and its planetary system occasionally make significant contributions. There were, for instance, Galileo and Newton who gave us mechanics and gravitation; Fraunhofer who gave us atomic spectra; Eddington and Bethe who pointed the way to nuclear energy; and Alfvén who gave us magneto-hydrodynamics. Perhaps the point to be recognized is that the Sun has more immediately to offer to physics than to astronomy.

Astronomical Society of Australia (ASA)

In 1966 Paul was one of the driving forces behind the foundation of the Astronomical Society of Australia. He chaired the inaugural meeting in November 1966. In his opening address Dr R. G. Giovanelli likened the emergence of the Society to the build-up of a signal amidst noise, and he linked the names of Buscombe, Gascoigne, Giovanelli and Wild to the generation of the first signal (PASA 1967). Paul was one of the first Vice-Presidents of ASA and was also the editor of the Society's new Australian astronomy journal, *Proceedings of the Astronomical Society of Australia*, for its first two years.

Chief of Radiophysics

Edward 'Taffy' Bowen had been Chief of CSIRO's Division of Radiophysics since the end of the Second World War. Paul, who succeeded Bowen as Chief in 1971, had this interesting analysis of his predecessor (Hanbury Brown, Minnett & White 1992):

> I was one of several young research scientists who joined the CSIR Radiophysics Laboratory in the early post-war years. The Chief, Taffy Bowen, was firmly in command: young, confident, cheerful and breezy, always optimistic and giving the impression that he knew exactly where he was going. He had supervised the transition of the laboratory from its wartime programme of military radar to its new peacetime policy. By the mid 1950s the laboratory's activities had narrowed down to two large programmes: cloud physics under Taffy's direction, and radio astronomy under Joe Pawsey's. Both programmes stood high in international repute.

When Bowen left, the Division was split into two, Radiophysics and Cloud Physics, and Paul took over as Chief of the Division of Radiophysics. While continuing his interest in the solar area, he now looked for opportunities to use the skills gained from the radio astronomy work so as to provide a balance of pure and applied work in the Division.

> I found myself being chief of a division that was doing nothing but pure research and I felt very exposed. And I thought it was very important, as an insurance policy really, to protect radio astronomy, to get involved in some applied project which was easily seen to be useful to the community, yet using the techniques of radio astronomy.

Discussions with Egon Stern from Australia's Department of Civil Aviation identified a Microwave Landing System as a replacement for the then internationally standard ILS (Instrument Landing System) as a key opportunity. This was taken up with great enthusiasm by Paul. These discussions coincided with the call by the International Civil Aviation Organisation (ICAO) for member states to propose new systems. Four countries—the USA, Britain, France and Germany—had put in submissions, and Paul (with Stern's support) decided to put in an Australian submission. Paul had devised a very simple and attractive approach—the Interscan System (82, 83). In this system, a beam is swept from left to right and then from right to left in a few milliseconds. The aircraft picks up two pips, and can tell its angular position by the time spacing of these. The idea was to allow aircraft to used curved approaches, in contrast to the then current approach of having a straight approach with aircraft queued for ten to fifteen miles, and to have a system that was robust against reflections and climatic environmental conditions. The implementation of this system was a major system development project for the Division that drew on the extensive experience from radio astronomy. In 1974, an evaluation where an American scanning-beam system failed against a Doppler system provided an opening for the Interscan system. After the subsequent evaluation where the simplicity and superb test results shone through, the Americans adopted the Interscan system. Subsequently, the Soviet Union adopted it and in a full ICAO meeting in 1978, Interscan was selected as the international standard. At this stage, the Americans called it the 'time reference scanning beam' system. The take-up of the system slowed through the 1980s and 1990s with the development of GPS based systems so that it never reached its full potential.

Chairman of CSIRO

In 1976 the Government appointed a three-person committee chaired by Professor Arthur Birch to carry out a comprehensive review of CSIRO. The committee recommended that the principal type of research performed by CSIRO should be strategic long-term, directed in support of primary, secondary and tertiary industry or in areas of community interest such as the environment or in relation to national obligations such as astronomy or oceanography. The committee recommended that the 37 Divisions of CSIRO be grouped into five Institutes each headed by a Director and that the Executive be reduced in size to three full-time members including the Chairman and five part-time members. The Government accepted most of the recommendations of the Birch committee and sought the committee's advice on the appointment of the Chairman. Paul Wild was appointed Chairman in July 1978 for a term of seven years. He led the Organisation through the restructure. Paul realised that the Organisation must adapt to bring it closer to the industries and the community that it serves and to provide scientific and technological leadership in a changing world. Accompanied by Keith Boardman, who had been reappointed a full-time member of the Executive, Paul travelled to all the Australian states to address the staff of CSIRO and to outline his vision for the Organisation. Paul emphasised the need to maintain an appropriate balance between fundamental research and the strategic mission-orientated research recommended by the Birch committee as CSIRO's principal type of research. He stressed that the Organisation must continue to recruit research scientists of the highest calibre and to provide a stimulating environment and the necessary resources for research. Priorities would be determined by scientific opportunities and the potential of the research to contribute to Australia's primary, secondary and tertiary industries and other national needs and obligations. An important initial role for Paul as Chairman was the establishment of the Institutes and the appointment of their Directors. In the interviews to select the Directors, Paul sought among other things the views of the candidates on the appropriate balance in types of research, ways to improve the interaction with the users of the research and the application of the successful research. During this period he was instrumental in securing funding for major national research facilities including an oceanographic research vessel, the Australian Animal Health Laboratory and the Australia Telescope, and he established a new Division of Information Technology. The Australia Telescope consisted of a compact array of six antennas at Narrabri that could be linked to one at Coonabarabran and the Parkes radio telescope. The Australia Telescope was built on the site of Paul's Radioheliograph and the Observatory was named the 'Paul Wild Observatory' (Frater, Brooks and Whiteoak, 1992). An Australian bicentennial project, the Australia Telescope was officially opened by the Prime Minister, Bob Hawke, in September 1988. Paul Wild was a strong proponent for the construction of the Australian Animal Health Laboratory, a sophisticated facility for handling animal disease agents under very secure containment conditions. There was heated opposition to the proposal due to the danger of importing dangerous animal disease agents and to the high cost of construction and operation. Over the years since its construction, the Australian Animal Health Laboratory, staffed and operated by CSIRO, has more than justified its existence with its research on disease agents such as Hendra virus, H1N1 swine influenza and avian influenza. During Paul's chairmanship the then Prime Minister, Malcolm Fraser, telephoned and requested that CSIRO transfer a significant research activity to Tasmania. Paul saw an opportunity to provide a major stimulus to CSIRO research on marine science, including fisheries and physical oceanography. The Tasmanian Government donated a magnificent site for a laboratory and wharf facilities on the Derwent River at Hobart and the Australian Government provided the funding for the laboratory and the research vessel. Paul was very proud of the result.

Two notable outcomes from CSIRO research during Paul's chairmanship were the high-security polymer bank note developed in collaboration with the Reserve Bank of Australia and the anti-influenza drug Relenza, developed in collaboration with the Victorian College of Pharmacy. Sirotech was established as a subsidiary of CSIRO to assist the Institutes and Divisions in the commercialization or utilization of research results. Sirotech had an independent Board and was given the responsibility of negotiating licence agreements for the Organisation and assisting in patent applications. Paul provided great and stabilizing leadership of CSIRO during a period of change in the Australian economy and a reducing Government appropriation for CSIRO. He identified with the research staff and received strong support and loyalty from them. The allocation of resources between the areas of CSIRO research was influenced by the decreased contribution of the rural sector to Australia's gross domestic product, the increased importance of high-technology products and services to world trade, and the recognition of significant Australian environmental problems. The Government proposed to reduce its appropriation to CSIRO by thirty per cent and that the Organisation obtain the equivalent amount from industry or government contracts. Paul persuaded the Government to allow CSIRO time to increase its funding from industry before a reduction in the appropriation from Government. As Chairman of CSIRO from 1978 to 1985, Paul Wild was a national science leader. He led the Organisation through the restructure designed in 1978 to modernize it and to bring it closer to the industries and community that it serves, but without ever losing sight of key principles: 'whatever the changes, one characteristic must remain inviolate: a high standard of excellence and originality. Without excellence and originality, research achieves nothing' (Moyal, 1994).

The Very Fast Train Project

Another project that started in this era (1984) was Paul's Very Fast Train (VFT) project that he conceived following a train trip from Sydney to Canberra. He envisaged a fast train based on the French TGV (Train à Grande Vitesse) technology linking Sydney, Canberra and Melbourne. In 1986, he became Chairman of the VFT consortium, which comprised the companies TNT, Elders IXL, BHP and Kumagai Gumi. Studies, environmental arguments and enquiries by state and Federal government agencies continued until 1991 when the project collapsed after the Government rejected proposals for suitable tax benefits for such infrastructure projects (VFT 1997–8).

Gravitational Theory

A longstanding interest of Paul's was gravitational theory. In his later years he published a modified Newtonian theory of gravity that satisfies the demands of special relativity (100). The resulting theory is simpler than the general theory of relativity but still yields the Schwarzchild metric and makes equivalent predictions. Although this is acknowledged as a valid and complementary approach to the theory of general relativity it has had limited impact. Paul's deep physical understanding of gravity theory led him to an insight that provided a link between inertial and gravitational mass and a prediction of the mass density of the universe. This would have been a significant extension of his gravity theory beyond a complementary approach but the work was still incomplete when he died.

Other Contributions

Paul played several broader roles in the astronomy and wider scientific communities. He became a member of the Anglo-Australian Telescope Board in 1973 (88, 89) and was there through the difficult times of deciding on the location of a Sydney Headquarters and Laboratory on the Radiophysics site at Marsfield. Paul was greatly relieved when Sir Harrie Massey worked with the staff and the communities to arrive at that conclusion. This provided a broader interaction base for the astronomers of the Anglo-Australian Observatory and the Radiophysics Division. Paul played a crucial role in presenting the case for increased funding to the Australian Government in 1979. When he retired from the Board in 1982, Sir Harrie Massey described him as 'having that special ability to temper the cold light of reason with a warm outlook for people and for science'. 'In addition', Massey continued, 'he had played an important part in negotiating the arrangements with the Australian National University which produced the present fruitful cooperation with the Board'. (Gascoigne, Proust and Robbins, 1990) Paul served as Foreign Secretary of the

Australian Academy of Science, 1973–7, and was President of the International Astronomical Union's Commission on Radio Astronomy, 1967–0.

Paul Wild—The Man

Throughout his life, Paul was highly respected by his superiors, his peers and those who worked for him, but he was a generally reserved, private person. Jim Roberts, one of Paul's colleagues in the early days at Dapto, describes what it was like working with him and particularly, 'the humanity of the man'. Jim recalls:

> Personally, I benefited greatly from Paul's nurturing and kindness. He taught me a great deal about radio astronomy and fostered my career in many ways—I imagine he was disappointed at my failure to capitalise on some of the opportunities he offered. He treated this new boy as an equal colleague, inviting me to tennis with his friends, etc. He even taught me to drive—initially round the paddocks at Dapto and then as a learner driver of his car on our weekly trips to Dapto.

Bob Frater recalls when he commenced as Chief of Radiophysics going to meet Paul to tell him that he thought the Radioheliograph should be closed down. Bob explained his position and to his surprise, Paul immediately put him at ease and agreed that it was the right decision. He was supporting the person he had appointed as Chief in a very difficult decision. Paul was an enthusiastic supporter of the Australia Telescope from proposal to completion. Ray Haynes captured the general view: 'His relaxed manner and infectious enthusiasm inspired great loyalty and devotion from his staff, and many a productive scientific discussion occurred at the hotel opposite the Laboratory or at the local rugby club on the way home at night.' (Haynes *et al.* 1996).

Summary

Paul Wild stands as one of the founding fathers of Australian radio astronomy, a towering figure in the solar arena and a great scientific leader on the broader scene. He spent his entire professional career in CSIRO, despite some very attractive offers from elsewhere, including Cornell. The 'big-picture' people in science, the 'system thinkers' who can see their way through the complexity to set the path are the ones who take the world forward. In this arena, Paul was in the absolute top drawer. On any technical issue, 'he got it!' This shows through from Paul's earliest work. He clearly had an exceptional intellect, wide knowledge and a continuing and unstoppable interest in 'the new'. During his career he published around 100 research papers. Paul gained many honours. These include the Hale Prize in 1980. He was a Fellow of the Australian Academy of Science and of the Australian Academy of Technological Sciences and Engineering, a Fellow of the Royal Society of London, a Foreign Member of the American Philosophical Society and of the American Academy of Arts and Sciences. He was made a Commander of the Order of the British Empire (CBE) in 1978 and a Companion of the Order of Australia (AC) in 1986. Paul's wife Elaine died in 1991. Paul subsequently married Margaret Haddock and spent his last years between Margaret's home in Ann Arbor, Michigan in the USA and his home in Canberra. Paul is survived by his son Peter, daughter Penny and son Tim and Tim's children Arnold and Victor.

Honours and Awards

1944 BA (Cambridge)
1950 MA (Cambridge)
1962 ScD (Cambridge)
1957 Edgeworth David Medal, Royal Society of New South Wales
1961 Foreign Honorary Member, American Academy of Arts and Sciences
1962 Foreign Member, American Philosophical Society
1964 Fellow, Australian Academy of Science
1969 Balthasar van der Pol Gold Medal, International Union of Radio Science, for 'Radio astronomy, including completion of a notable high-resolution radio-heliograph'
1969 Hendryk Arctowski Gold Medal, US National Academy of Sciences, 'In recognition of his many and comprehensive contributions to solar radio astronomy'
1969 Corresponding member, Royal Society of Liège
1970 Fellow, Royal Society of London
1971 Lady Masson Lecture, Melbourne University Chemical Society, Australia

1973 Jansky Lecture, National Radio Astronomy Observatory, USA
1974 Herschel Medal, Royal Astronomical Society
1974 Matthew Flinders Medal & Lecture, Australian Academy of Science
1975 Thomas Rankin Lyle Medal, Australian Academy of Science
1977 Fellow, Australian Academy of Technological Sciences and Engineering
1978 Commander of the Order of the British Empire (CBE)
1978 Pawsey Medal & Lecture, Australian Academy of Science
1979 Honorary DSc, Australian National University
1980 Hale Prize for Solar Astronomy, American Astronomical Society
1980 Royal Medal of the Royal Society of London, 'In recognition of his conception of the basic principles of the Interscan aircraft instrument landing system and the guidance of its development to a successful conclusion'.
1981 Advance Australia Award
1982 Honorary Fellow, Peterhouse College, Cambridge
1982 Guild of Air Pilots and Navigators Grand Master's Australian Medal
1982 Honorary DSc, University of Newcastle, New South Wales
1984 ANZAAS Medal, Australian and New Zealand Association for the Advancement of Science
1986 Companion of the Order of Australia
1988 Hartnett Medal, Royal Society of Arts, London

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