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Dishing up the Data: the role of Australian space tracking and radio astronomy facilities in the exploration of the Solar System

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Abstract

The recent Australian film, The Dish, highlighted the role played by the Parkes Radio Telescope in tracking and communicating with the Apollo 11 mission. However the events depicted in this film represent only a single snapshot of the role played by Australian radio astronomy and space tracking facilities in the exploration of the Solar System.

In 1960, NASA established its first deep space tracking station outside the United States at Island Lagoon, near Woomera in South Australia. From 1961 until 1972, this station was an integral part of the Deep Space Network, responsible for tracking and communicating with NASA's interplanetary spacecraft. It was joined in 1965 by the Tidbinbilla tracking station, located near Canberra in eastern Australia, a major DSN facility that is still in operation today. Other NASA tracking facilities (for the STADAN and Manned Space Flight networks) were also established in Australia during the 1960s, making this country home to the largest number of NASA tracking facilities outside the United States.

At the same time as the Island Lagoon station was being established in South Australia, one of the world's major radio telescope facilities was being established at Parkes, in western New South Wales. This 64-metre diameter dish, designed and operated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), was also well-suited for deep space tracking work: its design was, in fact, adapted by NASA for the 64-metre dishes of the Deep Space Network. From Mariner II in 1962 until today, the Parkes Radio Telescope has been contracted by NASA on many occasions to support interplanetary spacecraft, as well as the Apollo lunar missions.

This paper will outline the role played by both the Parkes Radio Telescope and the NASA facilities based in Australia in the exploration of the Solar System between 1960 and 1976, when the Viking missions landed on Mars. It will outline the establishment and operation of the Deep Space Network in Australia and consider the joint US-Australian agreement under which it was managed. It will also discuss the relationship of the NASA stations to the Parkes Radio Telescope and the integration of Parkes into the NASA network to support specific space missions. The particular involvement of Australian facilities in significant space missions will be highlighted and assessed.

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Introduction

The successful exploration of our solar system, whether by robotic or manned vehicles, relies upon the ability to successfully track and communicate with the spacecraft. Tracking stations form the vital link between spacecraft and their ground controllers, enabling them to transmit instructions to the spacecraft, receive data from it and monitor its course through the heavens.

When, in the late 1950s, the United States sought to establish space tracking networks for its planned spaceflight programs, Australia was strategically placed, geographically and politically, to become a location for space tracking stations for both orbital and deep space missions: the country would eventually host the largest number of space tracking facilities outside the US[1]. Spacecraft tracking has, in fact, been Australia's longest continuous space activity, with stations operating in the country since 1957.

Australia's particular geographical suitability as the location for a deep space tracking station stems from the fact that it is approximately one third of the way around the Earth from the site of the US tracking station for planetary probes at Goldstone, California. In order to maintain continuous communications with lunar and planetary spacecraft, a minimum of three tracking stations, located around the globe at approximately 120°

apart, is required to ensure that a spacecraft remains under constant observation despite the rotation of the Earth. With its landmass covering the longitude 120^0 west of Goldstone, Australia was ideally placed to be a host location for such a station and would ultimately become the home of two Deep Space Network facilities.

Station	Location	Years of Operation
Minitrack	Woomera, SA	1957-1966
	Orroral Valley	1966-1985
Baker-Nunn	Woomera, SA	1957-1973
Muchea	*Perth, WA*	*1960-1963*
Red Lake	*Woomera, SA*	*1960-1966*
Island Lagoon	**Woomera, SA**	**1962-1972**
Carnarvon	*Carnarvon, WA*	*1964-1974*
Tidbinbilla	**Tidbinbilla, ACT**	**1965-present**
Orroral Valley	Orroral Valley ACT	1966-1985
Honeysuckle Creek	***Honeysuckle Creek, ACT***	***1967-1981***

Table 1. Major NASA Tracking Facilities in Australia

Deep space tracking facilities indicated in **bold**.
Manned spaceflight stations indicated in *italics*.
Honeysuckle Creek was both a MSFN and a DSN station across its lifetime

Similar geographic considerations also made Australia a particularly important location for tracking stations for Earth-orbiting spacecraft. The first orbit of almost all spacecraft launched from Cape Canaveral would pass within sight of Western Australia: data obtained from tracking facilities in this area would considerably facilitate the confirmation and refinement of orbits. As the country occupies such a broad swath of the Earth's surface, it was also crucially placed between Africa and Hawaii to provide the location for one or more stations that would aid in maintaining an unbroken network of contact with an orbiting spacecraft, in the days before satellite communication networks.

In addition to its geographical suitability, Australia also had the advantage of being a politically stable nation that was friendly to the United States, an important consideration in the Cold War climate of the times. All these factors, coupled with its excellent technical capabilities and its existing involvement in space-related operations at the Woomera Rocket Range, combined to make Australia a particularly attractive location for the establishment of space tracking stations in support of US space projects, including the exploration of the Solar System.

Pre-NASA Facilities

Prior to the formation of NASA, Australia gained valuable experience in space tracking operations with the establishment of two satellite tracking facilities in conjunction with the Vanguard satellite program, part of the US contribution to the International Geophysical Year 1957-58. The Minitrack (Minimum Weight Tracking) system, which used radio interferometry techniques to track satellites in low Earth orbit, was developed by the US Naval Research Laboratory. The Smithsonian Astrophysical Observatory's (SAO) optical satellite tracking facility used a Baker-Nunn camera to photograph satellites, taking advantage of the exceptional observing conditions available in the dry desert of South Australia[2].

These two facilities were established in 1957 at the Red Lake radar station on the Woomera Rocket Range in South Australia. They would remain in operation for many years (see Table 1). The Australian experience in the establishment and operation of these facilities would form the precedents under which the later NASA tracking stations would be operated[3].

The Deep Space Instrumentation Facility

Plans for the exploration of the Moon and planets, and the spacecraft necessary to undertake those missions, were already under development by the US Department of Defence and the Jet Propulsion Laboratory (JPL), prior to the formation of NASA in 1958. These projects, together with JPL itself, were transferred to NASA, which assumed responsibility for the creation of a tracking station network to monitor the proposed planetary exploration missions. Rather than construct separate tracking networks for each planetary program, NASA developed the concept of the Deep Space Instrumentation Facility (DSIF-later to be called the Deep Space Network)-a separately managed and operated world-wide communications facility that would accommodate all deep space missions[4].

While still under contract to the US Army Ordnance Corps in early 1958, the Jet Propulsion Laboratory selected the site of its first tracking facility for planetary missions, the desolate Goldstone Dry Lake area at Fort Irwin in the Mojave Desert. The location of this site dictated the approximate longitudes of the necessary two other stations required for the network and immediately pinpointed Australia as the most suitable potential location for a tracking station 120^0 west of the Goldstone site. The third station in the initial network would be established at Hartebeesthoek, near Johannesburg, South Africa.

Establishment of Island Lagoon

With Australia identified as an ideal location for a deep space tracking station, a NASA survey team visited the country in February 1959. They selected a location in the vicinity of a salt lake called Island Lagoon, about 27 kilometres south of the Woomera township, as the site of the first Deep Space Instrumentation Facility (DSIF) to be established outside the United States[5].

Designated DSIF (later DSS) 41, the Island Lagoon station (also simply referred to as Woomera) was actually located 110^0 west of Goldstone. It was equipped with a 26 metre polar-mounted antenna, of the same type as the one that had already been constructed at Goldstone. The Goldstone antenna design had itself been derived from a radio telescope design, which was at least in part the work of John Bolton, the first Director of the Parkes Radio Telescope[6].

After delays in developing the agreement under which the NASA stations in Australia were to be operated (which will be discussed below), construction of the Island Lagoon facility began in August 1960 under the supervision of a JPL engineer, Floyd W. Stoller. The station was ready for operation by November 1960 and was commissioned by receiving signals from Goldstone, bounced off the Moon, an operation that was repeated for the official opening of the facility in April 1961[7].

Initially, Island Lagoon's electronic equipment was housed in large trailers, but, as the station grew, permanent buildings were eventually constructed providing administrative offices, a library, catering and logistics facilities and a power station with a 1,000kW generating capacity[8]. Station staff lived in the Woomera township, commuting the 27km to the station for their work shifts.

When NASA was established, the Minitrack network came under its control to form the basis of its Space Tracking and Data Acquisition Network. With the selection of the Island Lagoon site for the DSIF station, the Minitrack facility at Red Lake was relocated in 1960 to the same vicinity, where it continued in operation until 1966, before being relocated again to a site at Orroral Valley, near Canberra, close to the location of Australia's second DSN station at Tidbinbilla. This move allowed the original Red Lake Minitrack site to be reused as the location for one of the two Mercury spacecraft communication stations in Australia (the other was at Muchea, near Perth, Western Australia).

In 1963, the SAO Baker-Nunn tracking camera was also transferred to the Island Lagoon site, in order to consolidate the NASA facilities in one location: the Red Lake Mercury station was closed in 1966.

DSS 41 would continue in operation until 1972, when it was closed for economic reasons. Following the closure, its electronic equipment was transferred to the Honeysuckle Creek manned spaceflight tracking station near Canberra[9]. Although the tracking antenna was offered to Australia as a potential radio astronomy facility, it was eventually deemed that it would be uneconomical to transport it to another location and the dish was sold for scrap[10].

Deep Space Missions Supported by Island Lagoon

The first operational NASA deep space tracking station outside the US, DSIF 41 Island Lagoon was commissioned in November 1960, to be available to support the Ranger Moon probes planned for 1961. Technical limitations required these early spacecraft to operate in the L-band and the Island Lagoon station was initially designed to operate at these frequencies. In 1964 it was converted to S-band operations, following NASA's decision to switch to this band for its subsequent deep space missions. However, it also retained an L-band capability, in order to be able to support the final group of Ranger Lunar missions (Rangers VI-IX)[11]

Although the early Ranger missions were unsuccessful due to launch or spacecraft systems failures, the performance of the DSIF itself was highly successful and demonstrated the importance of a world-wide tracking station network, controlled from a central location (in this case JPL), as an essential element in future space missions to the Moon and planets[12].

NASA's first successful planetary mission came in 1962, with the Mariner II Venus probe, a project in which Island Lagoon played a particularly important role. DSIF 41 was entrusted with the responsibility of commanding the Mariner spacecraft to manoeuvre so as to point its high gain antenna continuously towards the Earth. During the critical period (roughly 40 minutes) when Mariner 2 was passing Venus, Island Lagoon was the only station to maintain continuous contact with the spacecraft, managing to obtain good quality data reception from the spacecraft's 3-watt transmitters.[13]

Following this success, Island Lagoon (now identified as DSS 41, following the reorganisation and re-naming of the Deep Space Network in late 1963/64)[14] went on to provide support for the Mariner IV mission to Mars, which sent back the first detailed images of the planet's surface in July 1965. After the Martian flyby, Mariner IV went into a solar orbit that brought it back periodically into the range of the tracking stations. In October 1967 it was re-activated for the first time and sent data and television images to Woomera and other DSN stations[15].

In conjunction with the new DSN station at Tidbinbilla, Island Lagoon supported the remaining single-planet missions in the Mariner series: Mariner V to Venus and Mariners VI, VII and IX to Mars. The two stations also worked together to provide long term tracking and data acquisition support for the solar orbiting Pioneer missions, investigating the interplanetary space environment.

In the last phases of unmanned Lunar exploration, prior to the Apollo missions, Island Lagoon supported the Lunar Orbiter program, designed to take high resolution photographs of the lunar surface as an aid to the selection of suitable landing sites for the crewed Apollo spacecraft.

Tidbinbilla: Australia's Second DSN Station

As early as 1962, NASA recognised that its ambitious Lunar and planetary exploration program for the period 1965-68 would overstretch the mission support capacity of its existing deep space tracking facilities. It decided to embark upon a program to construct a 'second network' of tracking stations, one of which was to be built in Spain (lying roughly along the same longitude as the existing South African DSIF station), the other in Australia.[16]

Due to the many difficulties and higher cost of operating a remote area location like Island Lagoon (it had been particularly difficult to find and maintain adequate staffing for the site, and the rate of staff turnover was high)[17], NASA decided to seek a location for its second Australian station that was closer to a town or city that could provide adequate support for the centre, while at the same time provided a 'radio quiet' environment ot enable the reception of very weak signals from spacecraft at interplanetary distances[18].

In September 1962, a joint NASA/Department of Supply team undertook a search to identify a suitable tracking station site in south-eastern Australia. In October they announced the selection of a site in the Tidbinbilla Valley, about 40km from Canberra, the national capital. Because NASA was anxious to have the new station in operation to support the Mariner IV Mars mission, the development of Tidbinbilla was fast-tracked as much as possible, with an operations and maintenance contract for the station awarded in early 1963 and the Station Director, R.A. Leslie, appointed in May that year. [19]

A team of Australian engineers and technicians from the station spent the first half of 1964 at the Goldstone tracking station, becoming familiar with the Deep Space Network (as it had then become) and assisting in the assembly and testing of the electronic equipment designed for Tidbinbilla. This same team then carried out the installation and commissioning of the equipment at Tidbinbilla itself. This co-operative exercise worked so well that it became the model for most future development/upgrade projects of DSN facilities in Australia and elsewhere. [20]

The new space tracking facility at Tidbinbilla was designated DSIF (later DSS-Deep Space Station) 42. Like its sister facility at Island Lagoon, it was equipped with a 26 metre polar-mounted antenna, although it utilised the then-new MASER technology in its signal amplifier and operated only in the S-band21. Following the precedent set at the Goldstone station, where the various antennae were given names of the own, the original Tidbinbilla dish was named "Weemala", from an Australian aboriginal word meaning "a distant view" (although the names of both dishes at Tidbinbilla were very little used, in practice)[22].

As the spacecraft it tracked ventured further and further into the Solar System, Tidbinbilla was expanded and its antennae enlarged in order to receive the ever-fainter signals. In 1969, construction work commenced on Tidbinbilla's second antenna, a 64-metre dish whose design was based upon that of the Parkes Radio Telescope (which will be discussed further below). Designated DSS 43, and named "Ballima", meaning "very far away", this antenna became partly operational in late 1972, (supporting Apollo 17 as its first mission)[23] and was officially opened in April 1973. Intended to be in operation to support the Viking missions, which were originally scheduled to be launched in 1973, the 64-metre dish was 3.5 times more sensitive than the 26-metre antenna, but in the 1980s, to support the Voyager missions to Uranus and Neptune, both the dishes were further enlarged: "Weemala" to 34-metres and "Ballima" to 70 metres.

Unlike the fairly 'rough and ready' nature of the initial facility at Woomera, the Tidbinbilla station was equipped from the outset with an operations and engineering building, a utilities and support building (which included power-generating equipment), an antenna support building and a personnel building which provided both catering facilities and limited emergency sleeping accommodations in the event of a crisis requiring more than the usual number of staff to be on hand for long hours.[24] Under normal circumstances, station staff lived in Canberra or one of its suburbs and commuted the 40km to Tidbinbilla each day.

A Visitors' Centre was also developed at the station in the 1970s, presenting displays and audio-visual programs on the Deep Space Network and the missions it supported to the public. This small space education facility has played an important role in educating the local Canberra community and visiting tourists about the deep space exploration discoveries that have revolutionised out knowledge of the Solar System.

Although its role in deep space exploration will not be discussed in this paper beyond 1976, the Tidbinbilla Tracking Station, which later also became known as the Canberra Deep Space Communications Complex, continues in operation to this day forming a major component of the deep Space Network. It has provided support to every post-1976 NASA mission exploring the Solar System, as well as to those of other nations.

Deep Space Missions Supported by Tidnbinbilla

Tidbinbilla commenced operations in December 1964, to support the Mariner IV mission, which had been launched a few weeks previously. Its initial role was to support the spacecraft during its coast to Mars while the Woomera station was taken down to be coverted to dual L-band/S-band operation. In January 1965, Tidbinbilla supported its first space probe launch, that of the solar orbiting Pioneer 6. This spacecraft was of particular interest to Australians as it carried a cosmic ray detector designed by Australian physicist Dr. Ken McCracken[25]. Nervous about supporting their first launch, the Tidbinbilla operators asked so many questions of their counterparts at JPL and NASA's Ames Research Centre (which was managing the Pioneer program) that their concerns helped to established the standard contingency procedures for the DSN![26]

As Mariner IV approached Mars in July 1965, the Tidnbinbilla and newly-refurbished Island Lagoon stations worked together to support the flyby. Because the signal from Mariner 4 around Mars was so weak when it arrived back on Earth, it was difficult to receive. When the spacecraft was due to make its closest approach to Mars, Tidbinbilla asked the civil aviation authorities to divert all aircraft in the area that might come between the station's antenna and the signal from Mars. This provoked jokes about "little green men from Mars" and resulted in a humorous incident. Much to the surprise of the Tidbinbilla staff, just at the time when Mariner 4 passed behind Mars, they received their first ever call on their special direct line from Canberra Airport, asking if they were experiencing interference from a UFO! Later the object was identified as an errant weather balloon.[27]

As previously mentioned, Tidbinbilla went on to support the later Mariner missions to Mars and Venus and the Pioneer missions, in conjunction with the Island Lagoon station. However, while DSS 41 focussed on the Lunar Orbiter Apollo precursor missions, Tidbinbilla operated in support of the Surveyor Lunar soft-landing program, which would also pave the way for the Apollo Moon landings.

In 1966, at the time of the Surveyor 1 launch, there was no way of transmitting live television from Australia to the United States[26], so the Surveyor project required specialists at the tracking station to assist in controlling the spacecraft, based on the data received. A team of 9 engineers from the Hughes Aircraft Company were therefore assigned to Tidbinbilla for the Surveyor 1 launch in May 1966 and remained at the station until the final Surveyor mission in 1968. One of the highlights of Tidbinbilla's involvement in the Surveyor program was the 'awakening' of Surveyor 1 after its first Lunar night. Powered only by solar cells, the Surveyor spacecraft could not operate during the long Lunar night, so a successful return to operation after a 14 day 'cold soak' was vital to the ongoing operation of the mission. For his successful handling of the first Surveyor awakening, Tidbinbilla shift supervisor Paddy Johnson received the "Prince Charming Award" from the network![29]

Following its involvement in the Apollo Lunar landing missions, which will be discussed separately later in this paper, Tidbinbilla tracked the Pioneer 10 and 11 spacecraft as they sent back the first close-up images from Jupiter in 1973 and 74 respectively, with the 64-metre antenna supporting Pioneer 10 and the 26-metre dish supporting Pioneer 11. The station also provided crucial mission support to the Mariner X flyby of Venus and Mercury, the first 'two planet' mission, in 1974 and assisted in tracking the joint US-German Helios 1 and 2 solar research missions which were launched in 1974 and 75.

Perhaps the most complex support operation for the Deep Space Network up to that time, were the Viking missions to Mars, which effectively required the DSN to support up to four spacecraft at one time: the Orbiters and Landers of Viking 1 and 2. Tidbinbilla's 26-metre antenna performed the initial acquisition sequences for the launches of both Viking 1 (August 1975) and Viking 2 (Septenber 75) and DSS 43 would transmit the "Go" command that would separate the Viking 1 Lander from its Orbiter and send it on its way to providing the first striking images from the surface of Mars.[30]

Management and Operation of the Deep Space Network in Australia: The Space Co-operation Agreement

Although co-located, the pre-NASA Minitrack and SAO facilities were each operated under separate intergovernmental agreements, which were managed in Australia by the Department of Supply, the Australian Government department that was also responsible, through its agency, the Weapons Research Establishment for the Woomera Rocket Range.[31] In the case of the Minitrack station, Australia insisted that it should be managed by Australian staff and the system operated without direct interference from the United States. However, as a goodwill gesture, the Australian Government donated the land, buildings, and technical and scientific staff for the construction of the facility. These conditions set the precedent for future agreements under which space tracking operations in Australia would be managed.

When NASA assumed control of the Mintrack network, the direct transfer of responsibility created no difficulties with the existing management. However, the situation surrounding the SAO Baker-Nunn facility was more complex, as NASA, while providing some funding and assuming responsibility for the day to day operations of the station, did not have ultimate control over it: this remained with the Smithsonian Astrophysical Observatory. As a result of this complicating factor, NASA's intention to enter into a new agreement with the Australian Government, covering its growing plans for deep space, manned spaceflight and Earth-orbiting spacecraft tracking stations was somewhat bedevilled and it was not until 1960 that an agreement covering the existing or planned NASA/SAO operations in Australia was hammered out[32].

On 26 February, 1960, the Governments of Australia and the United States formally agreed to cooperate in spacecraft tracking and communications, through an "Exchange of Notes" which is generally referred to as the Space Co-operation Agreement.[33] In this treaty, NASA and Australia jointly established a management policy which has proved very successful and which has allowed the agreement to continue, virtually unchanged, until the present day.[34] Under the terms of the agreement, NASA would finance the construction and operation of the tracking stations it required, retaining responsibility for system design and policy formulation. Australia was responsible for the detailed facilities design and the installation, operation and maintenance of the stations: this included the provision of the land for the tracking station sites, the construction of access roads and connection to utilities. Australia also gained the right to use the NASA facilities for astronomical research, when they were not required for mission support.[35]

As with the earlier Minitrack/SAO agreements, Australia's commitments under the treaty were initially managed by the Australian Department of Supply, through the WRE. In 1962, when the extent of the tracking station projects and the potential benefits in technology transfer became apparent, the WRE in South Australia established a special section, the American Projects Division, to streamline its tracking station operations[36]. With the concentration of NASA facilities around Canberra in the late 1960s, this office was transferred to the Department of Supply's Canberra headquarters, where it became known as the American Projects Branch. This branch was itself transferred to the Department of Science in 1975, where it became known as the Space Projects Branch, operating under that title until transferred to the newly-created Australian Space Office in the late 1980s. Further administrative changes to the management of the DSN fall outside the timeframe of this paper.

To oversee its interests in Australia, NASA also established a liaison office in Canberra in 1962, employing a Senior Scientific Representative and a representative of the Jet Propulsion Laboratory.[37] In the late 1960s, this office also included a representative from the Goddard Space Flight Centre, overseeing the MSFN and STADAN operations in Australia.

Following the precedent established with the Minitrack station, Australian staff were employed at Island Lagoon, Tidbinbilla and the other Australian tracking stations. This accorded with the views of Eberhardt Rechtin, the chief of JPL's guidance research division, who was influential in the early development of the DSIF and believed that local staff, motivated by national pride, would ensure the best possible performance from each station outside the US.[38] At each Australian station, the Director was a senior officer of the managing agency (initially the WRE).

When opened in 1961, the Island Lagoon station was staffed by employees of the Weapons Research Establishment, who were public servants. The delays in providing adequate staffing levels at Woomera the station and a perceived "sluggishness of the WRE in responding to NASA's interests"[39] prompted NASA to insist in 1962 that the operations at Woomera and Tidbinbilla be contracted out to Australian industry. Consequently, management contracts for both facilities were let in 1963 to SpaceTrack Pty. Ltd, a consortium of Hawker deHavilland Australia Pty. Ltd., Elliots and Amalgamated Electronic Industries.[40] This company managed both DSN facilities until 1971, when it was replaced at both stations by Amalgamated Wireless (Australasia) Pty. Ltd. (AWA). Following the closure of Island Lagoon, AWA was replaced at Tidbinbilla in the mid-70s by Fairey Australasia Pty. Ltd. Despite changes in the station management companies, the staff at the facilities actually remained remarkably stable, simply switching employer with the change. At its peak, some 110 people were employed at Island Lagoon, while in 1976, during the Viking missions, Tidbinbilla employed approximately 120 staff.

The Parkes Radio Telescope [41]

At the same time that NASA's Island Lagoon tracking station was being established in South Australia, one of the world's major radio telescope facilities was being established at Parkes, in western New South Wales. This 64-metre diameter dish, designed and operated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), is one of the world's great astronomical research instruments. It was conceived in the early 1950's by Dr. Edward "Taffy" Bowen, Chief of the CSIRO's Radiophysics Division, who established that the best all-round instrument for radio astronomy would be a large, fully steerable, dish antenna.

The site chosen for the telescope was near the small town of Parkes, about 350 km west of Sydney. With grants from the Carnegie Corporation and Rockefeller Foundation, as well as equal matching funds from the Australian Government, work on the great instrument began in 1959. The telescope was completed on schedule and on budget in October 1961-a not insignificant achievement in its own right.[42]

Almost from its inception the radio telescope made many important astronomical discoveries. In 1962, the Parkes Observatory accurately located the precise position of the first known quasar; that same year, the astronomers at Parkes discovered indications that our Milky Way galaxy possessed an immense magnetic field. In the early 1970's Parkes discovered and mapped the distribution of many new molecules in space. Since the accidental discovery of Pulsars in 1967, the Parkes telescope has discovered about 3/4 of the total known number (about 1500) of these exotic remains of massive stars. Parkes also helped pioneer the technique of Very Long Baseline Interferonetry and is today still actively involved in this field.[43]

Parkes as the Prototype for the DSN 64-Metre Antennae

The unique and innovative design of the Parkes telescope, made it well-suited for deep space tracking work. Consequently, in the first decade of the exploration of the Solar System, this radio astronomy instrument had a significant influence on the design of tracking antennae for deep space missions.[44]

Early experience in tracking the first Pioneer probes in the late 1950s made it evident that spacecraft tracking at lunar and planetary distances required the largest possible dish. This prompted JPL to consider the construction of large tracking antennas to augment its existing array of 26-metre antennas. The tracking characteristics of these large antennas approximated closely with those of the Parkes Radio Telescope.

JPL required antennas that had a 6 - 12 dB improvement over its existing 26-metre diameter dishes, necessitating a dish of the 60 – 80 metre (200 - 260 ft.) diameter class. The surface accuracy of such a dish would require optimum performance around 2200 MHz (S-Band). These requirements matched the proposed Parkes telescope closely, as did the specified pointing accuracy of 1.2 minutes of arc (slightly lower than the Parkes telescope's 1 minute of arc): the required slewing rates were also not substantially different. Also important to JPL was the Parkes telescope's master equatorial precision pointing system, which was conceived by the noted British consultant engineer, Barnes Wallis, of World War II "dam busters" fame. The level of pointing accuracy that it could obtain was precisely what the DSN required in order to maintain contact with distance spacecraft.

Consequently, even while the Parkes telescope was under construction, NASA made representations to the CSIRO's Radiophysics Division about the possibility of using it for data acquisition of a short term nature where an extremely strong, reliable signal was desirable, such as the terminal phase of a spacecraft aimed to impact on the surface of another planet.

JPL's intention was to construct a Parkes-class antenna at Goldstone by 1963, with possibly two others in the DSN by 1964. However, owing to the different demands of the proposed JPL antenna, such as the need to tip the dish to the horizon and the need to utilise a Cassegrain feed system to carry the weight of instrumentation, a direct copy of the Parkes telescope was not feasible. Instead, a new design, which adapted some of the more innovative aspects of the Parkes telescope, was decided o. However, because of the design and engineering changes these modifications required, the 64-metre antenna at Goldstone, would not become operational until mid-1966.

In order to bridge the gap in its capabilities until JPL's large antennas were built, Dr. William Pickering, the JPL Director, proposed in December 1961, that the Parkes telescope be formally included in NASA's fledgling DSN. However, the demands of the observatory's astronomical research meant that the offer could not be taken up by the CSIRO. Instead, "Taffy" Bowen encouraged JPL to consider the construction a similar, large antenna near Parkes, arguing that the value of two large telescopes near to one another certainly would exceed that of the two telescopes taken individually.[45]

With budget cutbacks delaying the construction of DSN 64-metre dishes in Spain and at Tidbinbilla, NASA renewed its proposal to include Parkes permanently in its Deep Space Network, in late 1966. It was envisaged that Parkes would track NASA's deep space probes on a regular schedule of one day a week for a period that might extend up to three years. However, although the CSIRO was eager to maintain it close and friendly connections with JPL and NASA, routine nature of the tracking work did not warrant the displacement of the astronomical research being conducted at Parkes,and the proposal was, therefore, once again reluctantly declined.

In February 1962, the CSIRO was awarded a NASA Research Grant, to determine and report on the detailed characteristics of the newly commissioned Parkes telescope. As part of the grant, the CSIRO participated in feasibility studies and specification reviews of the JPL antennas. The detailed performance parameters of the Parkes telescope were determined as regards structural behaviour, characteristics of the drive system, characteristics of the master control system and radio-frequency performance. In addition, the vibration characteristics were measured as well as the dish shape in the zenith and tilted positions. This information was deemed to be of critical importance in the design and construction of the JPL antennas. During the period of the grant, a very close and warm working relationship was established between the CSIRO and JPL. This close relationship proved to be of critical worth in the Parkes support of future space missions.

Parkes Supports Mariner II[46]

In planning for the Mariner II mission to Venus, NASA considered it extremely vital that a coordinated program of ground-based bservations, both radio and optical, be carried out in conjunction with the spacecraft's planetary encounter. Parkes was invited to participate in this program and CSIRO Radiophysics chief Bowen decided that tracking the Mariner II spacecraft would be an excellent demonstration of the Parkes telescope's capabilities for communication at great distances. It would also provide the observatory personnel with valuable experience in tracking and receiving signals from spacecraft, which they might be called on to do in future cooperative experiments.

Funds from the NASA research grant being used to determine the characteristics of the Parkes telescope were also used to cover the facility's support for both Mariner II and IV.

Attempts to detect the Mariner 2 signals began on 12 December 1962. Although Parkes had a gain advantage of 8 dB (about 6 times) over the 26- metre antennas of the DSIF, and should have detected the signals easily, it experienced great difficulty in finding and locking on to the Mariner signal. There were two reasons for this : the narrow beamwidth of the 64 metre antenna made the accurate pointing of the dish absolutely crucial; and the receiver had to be tuned very precisely since its bandwidth was just 20 Hz wide, which required the Doppler shift of the signal to be known exactly. Eventually, the staff at Parkes were able to overcome these problems and were able to track Mariner II from late December 1962 until the signals ceased on 3 January 1963.

The experiment was a success and many lessons were learnt from it that contributed greatly to the success of future cooperative experiments.

Parkes Operations in Support of Mariner IV

When the Mariner IV mission was first proposed, it was envisaged that the Goldstone 64-metre antenna would be ready in time to track the spacecraft at Mars. However, by the time of the Mariner 4 fly-by of Mars in July 1965, the 64-metre dish was still about a year away from completion and Parkes was consequently approached to provide a 64-metre capability to act as a backup to the DSIF.

On June 21, Parkes began receiving the Mariner transmissions. Daily tracks were carried out during two-hour periods each afternoon centred approximately on Mariner's meridian transit. Horizon-to-horizon observations were obtained on July 3, 14, 15 and 16. Regular telemetry recordings were made from July 8 to August 27. The closest approach to Mars was scheduled to occur about 2 ¼ hours below the Parkes horizon on 15 July, but the radio telescope was able to participate, in conjunction with Tidbinbilla, in important occultation observations as the spacecraft emerged from behind the planet. These observations were intended to probe the atmosphere and ionosphere of Mars.

Parkes also received the delayed transmission data for the 22 images of the Martian surface captured by Mariner. This Parkes data was some 3 dB better than those from the existing DSIF network and was combined with the other NASA data to produce a considerable improvement in the quality of the pictures of the Martian surface, thus qualifying the Mariner IV tracks as a great success.

Apollo to the Moon

Humanity's 'in person' exploration of the Solar System began with the Apollo Lunar program of the 1960s. To handle the translunar and Lunar phases of the Apollo Moon missions, NASA established three 26-metre antennae within its Manned Spaceflight Network (MSFN), each one located near the DSN stations at Canberra, Goldstone and Madrid, so that the DSN facilities could act as back-up for the MSFN stations[47]. The DSN also contributed a great deal of technology and facility support to the Apollo program, providing the MSFN with S-band receiving, transmitting and ranging equipment and computer software for Lunar trajectory orbit determination purposes.

The Australian MSFN Apollo facility, Honeysuckle creek, was located approximately 15km south of Tidbinbilla and connected to it by a microwave link. Honeysuckle Creek was opened in 1967: it's first Apollo mission was the unmanned Apollo 4 in November that year. After the Apollo missions, Honeysuckle Creek would go on to support the Skylab space station program, before becoming a permanent part of the DSN (as DSS 44) after 1974, when control of the facility was 'transferred' to Tidbinbilla.
The Apollo program adopted the JPL phase modulated coherent S-Band system for its communications[48], which meant that similar equipment was employed at both Honeysuckle and Tidbinbilla. A second control room, the MSFN wing, was added at Tidbinbilla, and when the two stations were linked by microwave relay, Tidbinbilla became a second receiving and transmitting system for Honeysuckle Creek.

Parkes Joins the Apollo Program

In October 1968, during a visit to the United Sates, the Director of Parkes Observatory, John Bolton, was approached to consider the possibility of making the radio telescope available the for reception of signals from the Apollo 11 spacecraft, particularly during the most critical phases of the mission when the Lunar Module (LM), *Eagle*, was on the lunar surface. NASA has realised that the first Moon landing would take place towards the end of the 'view period' from Goldstone and that Parkes would be well-placed to provide backup support for Honeysuckle Creek and Tidbinbilla for most of the first Moonwalk. The historic nature of the mission, combined with the fact that human lives were at risk in space, convinced Bolton and Bowen to support the mission.[49]

The original mission plan for Apollo 11 placed Parkes in the role of backup during the moonwalk for NASA's two tracking stations, the 64-metre dish at Goldstone in California, and the 26-metre antenna at Tidbinbilla near Canberra, Australia. The flight plan had the astronauts performing the moonwalk shortly after landing, and as the Moon was not due to rise at Parkes until 1:02 pm (AEST), the EVA would have been completed by that time. The Honeysuckle Creek station Canberra, was to track the Command Module, *Columbia*, in Lunar orbit at the same time. To facilitate its role, the radio telescope would be linked by microwave relay to Tidbinbilla and Honeysuckle Creek.

All this was changed some two months before the mission, when it was decided to alter the Apollo 11 mission plan and allow a rest period before commencing the Lunar EVA, to give the astronauts an opportunity to adjust to the Moon's 1/6th gravity and start the EVA refreshed. The new plan had the EVA starting about ten hours after landing, at 4:21 pm (AEST), which was some twenty minutes after the Moon had set for the Goldstone. As the Moon would be high overhead at Parkes, the telescope's role was consequently upgraded from backup to *prime* receiving station for the television broadcast of the EVA.

One day after the launch of Apollo 11, a fire in the power supply at Tidbinbilla severely damaged the transmitter. Despite having repaired the damage in 12 hours, NASA lost confidence in the station and switched its role with Honeysuckle Creek, which would concentrate throughout the Lunar EVA on the vital telemetry data from the crews' backpack EVCS.

The Eagle has Landed

On Monday 21 July 1969, at 6:17 am (AEST), astronauts Armstrong and Aldrin landed their LM, *Eagle*, on the Sea of Tranquillity. Despite the rest period built into the flight plan, mission commander Neil Armstrong exercised his option for an immediate EVA walk - five hours before the Moon was to rise at Parkes. However, delays in the astronauts preparation for their EVA brought the time of egress loser to that of Moonrise at Honeysuckle and Parkes

At Parkes, a violent wind squall hit the telescope while the dish was at its most vulnerable, fully tipped over to its zenith axis limit, waiting for the Moon to rise and ready to receive the images and telemetry form the Moon. Two sharp gusts of wind exceeding 110 kph struck the dish, subjecting the telescope to wind forces ten times stronger that it was considered safe to stand. The control tower shuddered and swayed from this battering, creating concern in all present. The weather remained bad at Parkes, with the telescope operating well outside safety limits for the entire duration of the moonwalk, but fortunately, the winds abated as the Moon rose into the beam of the telescope, just as Aldrin activated the TV at 12:54:00 pm (AEST).

Six hundred million people, or one fifth of mankind at the time, watched Neil Armstrong's first steps on the Moon. Three tracking stations were receiving the signals simultaneously: Parkes, Honeysuckle Creek and Goldstone. Using its less sensitive 'off-axis' detector, Parkes was able to receive signals just as the Lunar Module TV camera was switched on. Eight minutes later the Moon had risen into the field of view of the Parkes telescope's main detector, and the picture quality improved.

The signals were sent to Sydney via specially installed microwave links, where a NASA officer selected between the Parkes and Honeysuckle Creek signals to be relayed to Houston for inclusion in the international telecast. In Houston a controller then selected between the Goldstone and the previously selected Australian TV signals.

During the first 9 minutes of the broadcast, NASA alternated between the signals from its two stations at Goldstone and Honeysuckle Creek, searching for the best quality images. They began with the Goldstone pictures, but the image was poor and suffered from severely high contrast. The Honeysuckle Creek pictures were very grainy because of the low signal strength received by the smaller dish, but nevertheless they were the images transmitted to the world when Neil Armstrong took that "one small step for Mankind". Finally, 8 minutes and 51 seconds into the broadcast Houston switched to the transmissions from Parkes, which were of such superior quality, that NASA stayed with the Parkes television for the remainder of the 2½-hour telecast.

Apollo 13: Emergency in Space

Following the success of Apollo 11, Tidbinbilla and Honeysuckle Creek went on to support the Apollo 12 Moon landing, in November 1969, with the Parkes Radio Telescope once again contracted to provide backup support for the Lunar landing. In recognition of the contribution of Parkes, NASA made available a grant of $90,000 to CSIRO specifically to improve the scientific research facilities at Parkes. The following year, the money was used to re-surface the antenna, allowing the telescope to operate more efficiently at higher frequencies.

Parkes was not initially required for the Apollo 13 mission. However, just two days into the mission on 14 April 1970, one of the spacecraft's oxygen tanks exploded, severely crippling the Command Module, *Odyssey*. Parkes' Director, Bolton, hearing of the emergency, anticipated that Parkes would almost certainly be called in by NASA and directed his staff to install the station's NASA equipment. Other equipment was flown to Parkes from the Radiophysics head office in Sydney and the observatory staff accomplished in just ten hours what normally took close to a week. When the request for Parkes' support finally arrived from NASA, the facility was already well on its way to being up and running for the next pass of the spacecraft. The extremely weak voice signals from the *Odyssey* were sent along landline to Sydney then onto Houston.

The micro-wave links which had been previously established for Apollo's 11 and 12, were not operational when the emergency first occurred, but a team of engineers from Honeysuckle Creek and Tidbinbilla arrived at the telescope within hours and were able to complete the set-up, while OTC and PMG technicians re-established the micro-wave links to Sydney before the next pass of the spacecraft. The critical nature of the Parkes support was evidenced by the fact that the feeble signals were a thousand times weaker than those received from Apollo 11.

The efforts of the Australian tracking stations in the rescue of Apollo 13 were co-ordinated by Mike Dinn, the Deputy Director in charge of Operations at Honeysuckle Creek, which had been tracking the spacecraft when the emergency began. At one point he had up to ten receivers tracking the spacecraft. Parkes' inclusion was critical at this stage owing to interference from the Saturn IV-B third stage, which had been placed on a trajectory that followed the spacecraft closely, so that it would impact with the Moon in order to test the seismometer left months earlier by Apollo 12.

In order to track the progress of the SIV-B, a transmitter was installed within it that operated at the same frequency as the LM transmitter. Since it been intended to switch on the LM transmitter only when it had reached the Moon (after the Saturn third stage had impacted) there should have been no problems. Now however, with the astronauts using the LM as a life-boat, the conflicting transmissions from the LM and the nearby SIV-B were interfering with each other.

The 26-metre antenna at Honeysuckle Creek did not have a sufficiently narrow beamwidth to enable it to discriminate between the two, which caused problems with tracking and signal reception. With its larger size and narrower beamwidth, Parkes was able to isolate the spacecraft. The vital signals were then passed on to Houston for analysis. The precise position of the spacecraft was determined and a new trajectory calculated to bring the crippled spacecraft home safely. Its greater sensitivity also meant that the Parkes telescope was able to acquire the low-powered signals from the LM's omni-directional antenna with less drop-out than the 26-metre antenna at Honeysuckle. The 64 metre Goldstone dish was able to do the same in the non-Parkes coverage periods and the two together were able to extract the feeble but vital telemetry and save the mission from disaster.

The Final Apollo Missions

While Tidbinbilla and Honeysuckle Creek continued to play major roles in the later Apollo missions, Parkes was not required for Apollo 14, although for Apollo 15 it again played a vital role during critical phases of the mission. For Apollo's 16 and 17 it tracked the spacecraft for very short periods to receive fast dumps of recorded data.

By the Apollo 17 mission, the 64-metre antenna at Tidbinbilla was finally completed and the need to have Parkes in the DSN waned. For the next decade and a half, Parkes was not involved in tracking duties. All this changed when it was once again called on to receive the very weak signals from the Voyager 2 spacecraft at Uranus. But, that's another story.

Conclusion

Although not generally recognised, Australia's role in both the robotic and manned exploration of the Solar System has been a vital one. In the first decade and a half of space exploration, it contributed not only 'real estate' for the location of NASA tracking stations, but also technical expertise form its radio astronomy program that enabled the growth and development of the Deep Space Network itself.

Footnotes and References

1. Dougherty, K. and James, M., Space Australia, Powerhouse Publishing, 1993, p. 32
2. These two tracking networks were effectively in competition with one another and required different local physical conditions for successful operation. Although originally conceived as being operated at the same sites, Australia was the only place in which the two facilities were co-located.
3. Baltuck, M., Cooper, D. et al., *Forty years of NASA-Australian Cooperation*, paper presented at the 49th International Astronautical Congress, Melbourne, 1998, p.2
4. http://deepspace.jpl.nasa.gov/dsn/history/index.html
5. Mudgway, D. J., *Uplink-Downlink: a History of the Deep Space Network*, NASA SP-2001-4227, 2001, p. 21; see also "Woomera on the Web" http://homepage.powerup.com.au/woomera/tracking.htm
6. Mike Dinn, quoted in Goddard, D.E. & Milne, D.K. (Eds), *Parkes: Thirty Years of Radio Astronomy,* CSIRO, 1994,p. 141; also further personal communication from M. Dinn.
7. Mudgway, op. cit., p.21
8. *Island Lagoon Tracking Station, South Australia*, Australian Department of Supply information brochure, 1971
9. Dougherty and James, op. cit., p.35
10. Mudgway, op. cit., p.21
11. Mudgway, ibid. pp.36-39, 61-63; also Leslie, R.A., *Space Tracking Stations*, [Chapter 12, excerpted from an unknown document], 1993, p. 187
12. Mudgway, ibid. p.34
13. Wills, H.A., "Co-operation Rewarded", article in the *Sydney Morning Herald*, July 15, 1963
14. The Deep Space Instrumentation Facility was originally composed of the radio tracking, telemetry, and command stations around the world. It did not include the ground-based communications network which linked them to the control centre at JPL. With the re-organisation that commenced in late 1963, all three elements, the stations, communications network, and the control centre, were combined to make up the Deep Space Network. The designations DSIF and DSS for the tracking stations continued to be used interchangeably until the latter part of the 1906s.
15. *Island Lagoon Tracking Station* brochure, op. cit.
16. Mudgway, ibid. pp. 64-65; also op. cit., p.188
17. O'Brien, J. and Tuohy, I., *Operation and Maintenance Support of the Canberra Deep Space Communication Complex*, paper presented at the 49th International Astronautical Congress, Melbourne, 1998, pp.1-2
18. Leslie, op. cit., pp.188-89
19. Leslie, ibid. p.189
20. Leslie, ibid., p.189
21. Leslie, ibid., p.189
22. The source for the Aboriginal names used for the Tidbinbilla dishes is given as "New South Wales Aboriginal Place Names and Euphonious Words, With Their Meaning", by F.D. McCarthy). Cited in *The 64-metre Deep Space Network Antenna, Dedication, 13 April, 1973* brochure.
23. Leslie, op. cit, p.192
24. DSIF: Tidbinbilla, JPL Technical Memorandum No. 33-207, JPL/CIT, 1965
25. Dougherty and James, op. cit., pp.65, 73-74
26. Leslie, op. cit, p.191. Pioneer 6 was still functioning when last contacted in December 2000, making it the oldest extant NASA spacecraft.
27. Leslie, op. cit., p.191
28. The first experimental satellite broadcast between Australia and the UK did not occur until November, 1966. It was not until the following year that the first transmissions via satellite were sent between Australia and the US.
29. Leslie, op. cit., 192

30. Mudgway, op. cit., pp.100-102
31. The Minitrack facility was managed under an agreement between the US Naval Research Laboratory (the lead agency for the Vanguard program) and the Department of Supply of the Commonwealth of Australia, that came into force on June 7, 1957. The Baker-Nunn observatory was operated under its own agreement between the Smithsonian Astrophysical Observatory and the Department of Supply, which came into effect on September 12, 1957.
32. The final agreement in relation to the SAO operations in Australia was not established until 1966, and then as a separate instrument. For further information see *A Study of NASA's Authority and Responsibilities for Establishing TD&A Stations in Australia*, NASA Office of Tracking and Data Acquisition, 1976, pp. 7-8
33. The formal title of this agreement is *Exchange of Notes constituting an Agreement between the Government of Australia and the Government of the United States of America concerning Space Vehicle Tracking and Communication Facilities*, Australian Treaty Series 1960, no. 2
34. The agreement received some minor changes in 1980 and again in 1990 to reflect changes in NASA's operations in Australia. Leslie, op. cit., p.187
35. In the period covered by this paper, the Woomera DSN station was used for Australian astronomical research, primarily on projects in association with the Universiyt of Tasmania. The Tidbinbilla tracking station would embark undertake significant VLBI radio astronomy research in conjunction with the Parkes radio telescope in the 1980s, following the installation of a permanent microwave link between the two facilities for the Voyager program.
36. Leslie, op. cit., p.188
37. Leslie, ibid. p.188
38. Waff, C. *The Road to the Deep Space Network*, IEEE Spectrum, April 1993, p.56
39. O'Brien, J. and Tuohy, I., op. cit. p.1
40. Leslie, op. cit., p.189
41. *The CSIRO 210-foot Radio Telescope*, CSIRO brochure ca. 1968
42. Despite its greater size, the 64 metre telescope was built at a substantially lower cost than the recently commissioned 26 metre antenna at Island Lagoon. This apparently also attracted the interest of JPL!
43. http://www.parkes.atnf.csiro.au/
44. The following account of the role of the Parkes Radio Telescope draws upon extensive research in the archives of the CSIRO Radiophysics Division and oral history interviews with many of the surviving participants in the programs discussed. A complete list of the references that were used in the preparation of this paper can be found at John Sarkissian's website "On Eagle's Wings" http://www.parkes.atnf.csiro.au/apollo11/
45. This was a prophetic concept, that demonstrated its viability when the Parkes and Tidbinbilla 64-metre antennas were linked together in the 1980's to support the Voyager 2 encounters of Uranus and Neptune as well as the Galileo mission to Jupiter in the mid-1990's
46. The following accounts of Parkes involvement with the Mariner II and IV missions draw heavily upon the recollections of Harry Minett, who was with the Parkes telescope throughout the 1960s and 70s and was directly involved in carrying out much of the NASA funded research discussed here.
47. Mudgway, op. cit., pp. 56-57
48. Mudgway, ibid. p.56
49. Bolton was so eager to assist the mission, that he established a simple 'one line agreement' which offered all necessary support to Apollo 11.