Chapter 14

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 2000 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 (DSN), 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 Satellite Tracking and Data Acquisition

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§ Produced by Dish Film Ltd and released in the United States in April 2001.

Network—STADAN—and Manned Space Flight Network—MSFN) 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-m 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-m dishes of the DSN. From *Mariner 2* in 1962 until today, the Parkes Radio Telescope has been contracted by NASA on many occasions to support interplanetary spacecraft, in addition to the Apollo lunar missions.

This article 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 DSN in Australia and consider the joint U.S.–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.

Introduction

The successful exploration of the solar system, whether by robotic or manned vehicles, relies on 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 United States.[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 Earth from the site of the U.S. 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 Earth. With its landmass covering the longitude 120° west of Goldstone, Australia was ideally placed to be a host location for such a station and would ultimately become the home of two DSN facilities.

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 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 communications 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 U.S. space projects, including the exploration of the solar system.

Pre-NASA Facilities

Before 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 U.S. 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 U.S. 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 Range G 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]

Station	Location	Years of Operation
Minitrack	Woomera, South Australia (SA)	1957–1966
	Orroral Valley, Australian Capital Territory (ACT)	1966–1985
Baker-Nunn	Woomera, SA	1957–1973
Muchea	*Perth, Western Australia (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***

DSN tracking facilities indicated in **bold**.
MSFN stations indicated in *italics*.
Honeysuckle Creek was both a MSFN and a DSN station.

Table 1: Major NASA Tracking Facilities in Australia.

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 U.S. Department of Defense and the Jet Propulsion Laboratory (JPL), before the formation of NASA in 1958. These projects, together with JPL, were transferred to NASA, which assumed responsibility for the creation of a tracking station net-

* The author has indicated that in the original version of this paper, it was stated that the Minitrack and SAO facilities were originally located at the Red Lake radar station, on the Woomera Rocket Range, where NASA would later establish a Mercury tracking station. However, subsequent research revealed that these two facilities were, in fact, located at Woomera's Range G prior to their move to the Island Lagoon DSIF site. The implication in some 1960s NASA publications that they were originally at the Red Lake site was erroneous and is believed to have resulted from confusion between the Minitrack and Mercury facilities, since both Range G and Red Lake were reached via the same access road.

work 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 DSN)—a separately managed and operated worldwide communications facility that would accommodate all deep space missions.[4]

While still under contract to the U.S. Army Ordnance Corps in early 1958, JPL 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° 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 km south of the Woomera township, as the site of the first DSIF to be established outside the United States.[5]

Designated DSIF (later Deep Space Station—DSS) 41, the Island Lagoon station (also simply referred to as Woomera) was actually located 110° west of Goldstone. It was equipped with a 26-m 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 later), 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] During the same period, NASA also established one of its two Mercury spacecraft communication stations in Australia at Red Lake on the Woomera Range (the other was at Muchea, near Perth, Western Australia).

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 1,000 kW generating capacity.[8] Station staff lived in the Woomera township, commuting the 27 km to the station for their work shifts.

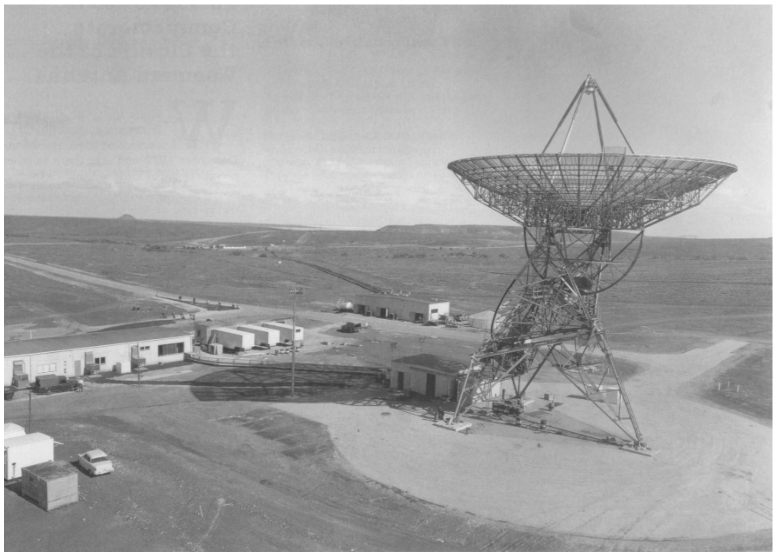

Figure 1: An early view of the DSIF 41 site showing the temporary equipment trailers. Credit: NASA.

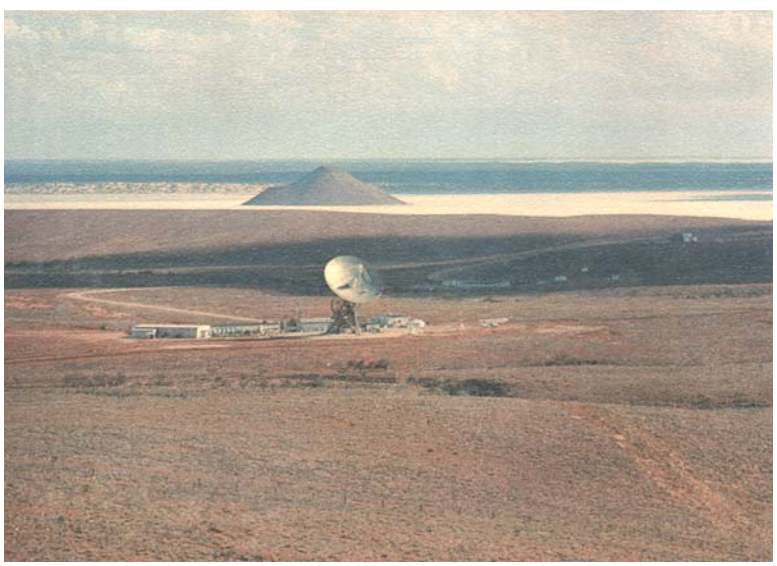

Figure 2: DSIF/DSS 41, with the Island Lagoon salt lake in the background. The Baker-Nunn camera station can be seen in the distance on the far right. The Minitrack site is out of view to the right. Credit: www.honeysucklecreek.net.

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 Range G was relocated in 1961 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.

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 United States, 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 (*Ranger 6–9*).[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 worldwide 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 2* 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 maneuver so as to point its high gain antenna continuously toward 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-W transmitters.[13]

Following this success, Island Lagoon (now identified as DSS 41, following the reorganization and renaming of DSN in late 1963–64)[14] went on to provide support for the *Mariner 4* mission to Mars, which sent back the first detailed images of the planet's surface in July 1965. After the Martian flyby, *Mariner 4* went into a solar orbit that brought it back periodically into the range of the tracking stations. In October 1967 it was reactivated 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 5* to Venus and *Mariner 6, 7,* and *9* 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, before 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 recognized 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 on 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]

Because of 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 center, while at the same time provided a "radio quiet" environment to 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 southeast Australia. In October they announced the selection of a site in the Tidbinbilla Valley, about 40 km from Canberra, the national capital. Because NASA was anxious to have the new station in operation to support the *Mariner 4* 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 DSN (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 cooperative 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) 42. Like its sister facility at Island Lagoon, it was equipped with a 26-m polar-mounted antenna, although it utilized the then-new MASER technology in its signal amplifier and operated only in the S-band.[21] Following the precedent set at the Goldstone station, where the various antennae were given names of their 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 farther and farther 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-m dish whose design was based on that of the Parkes Radio Telescope (which will be discussed later). 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-m dish was 3.5 times more sensitive than the 26-m antenna, but in the 1980s, to support the Voyager missions to Uranus and Neptune, both the dishes were further enlarged: "Weemala" to 34 m and "Ballima" to 70 m.

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 40 km to Tidbinbilla.

Figure 3: Tidbinbilla tracking station in 1965, showing the 26-m antenna “Weemala” (DSIF/DSS 42). Credit: NASA.

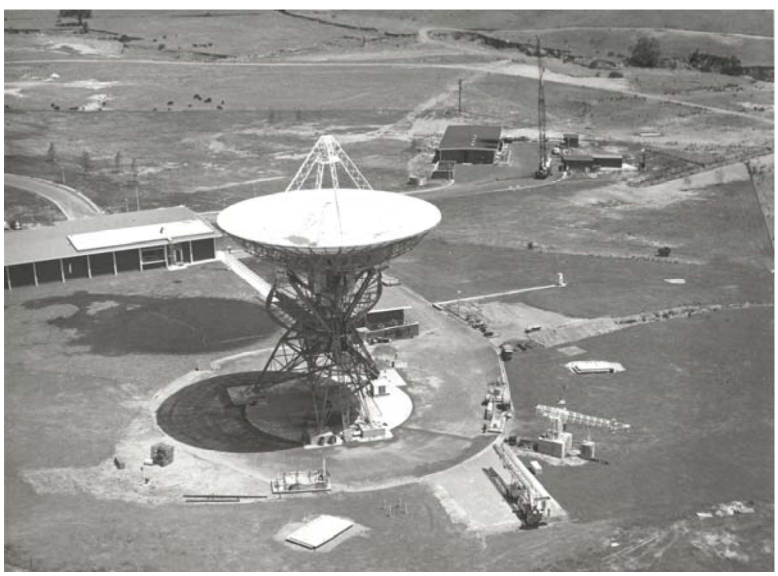

Figure 4: An aerial view of DSIF/DSS 42 and the Tidbinbilla operations building, taken during construction of the facility in 1964. Credit: www.honeysucklecreek.net.

A visitors’ center was also developed at the station in the 1970s, presenting displays and audiovisual programs on DSN 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 revolutionized knowledge of the solar system.

Figure 5: Plaque commemorating the commencement of construction of the 64-m antenna "Ballima" at Tidbinbilla in 1969. Credit: www.honeysucklecreek.net.

Figure 6: A view of Tidbinbilla tracking station in the 1970s, showing both the new 64-m antenna DSS 43 (left) and the original DSS 42. Credit: NASA

Although its role in deep space exploration will not be discussed in this article 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 DSN. It has provided support to every post-1976 NASA mission exploring the solar system, in addition to those of other nations.

Deep Space Missions Supported by Tidbinbilla

Tidbinbilla commenced operations in December 1964, to support the *Mariner 4* 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 converted 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 Center (which was managing the Pioneer program) that their concerns helped to established the standard contingency procedures for the DSN![26]

As *Mariner 4* approached Mars in July 1965, the Tidbinbilla 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 an unidentified flying object (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 focused 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 nine 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, Tidbinbilla tracked the *Pioneer 10* and *11* spacecraft as they sent back the first close-up images from Jupiter in 1973 and 1974, respectively, with the 64-m antenna supporting *Pioneer 10* and the 26-m dish supporting *Pioneer 11*. The station also provided crucial mission support to the *Mariner 10* flyby of Venus and Mercury, the first "two-planet" mission, in 1974, and assisted in tracking the joint U.S.–German *Helios 1* and *2* solar research missions, which were launched in 1974 and 1975.

Perhaps the most complex support operations for DSN, up to that time, were the Viking missions to Mars, which effectively required DSN to support up to four spacecraft at one time: the orbiters and landers of *Viking 1* and *2*. Tidbinbilla's 26-m antenna performed the initial acquisition sequences for the launches of both *Viking 1* (August 1975) and *Viking 2* (September 1975) 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 DSN in Australia: The Space Cooperation Agreement

Although collocated, 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 (WRE) 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 Minitrack 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 SAO. 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 Cooperation Agreement.[33] In this treaty, NASA and Australia jointly established a management policy that 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 DSN management fall outside the timeframe of this article.

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 JPL.[37] In the late 1960s, this office also included a representative from the Goddard Space Flight Center, overseeing the MSFN and STADAN operations in Australia.

Following the precedent established with the Minitrack station, Australian staff was 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 United States.[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 WRE, who were public servants. The delays in providing adequate staffing levels at the Woomera 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-1970s by Fairey Australasia Pty. Ltd. Despite changes in the station management companies, the staff at the facilities actually remained remarkably stable, simply switching employers 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-m 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 1950s by Dr. Edward "Taffy" Bowen, chief of 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, and 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 the Milky Way galaxy possessed an immense magnetic field. In the early 1970s 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 three-fourths of the total known number (about 1,500) of these exotic remains of massive stars. Parkes also helped pioneer the technique of Very Long Baseline Interferometry and is today still actively involved in this field.[43]

Parkes as the Prototype for the DSN 64-M 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-m 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-m diameter dishes, necessitating a dish of the 60–80 m (200–260 ft) diameter class. The surface accuracy of such a dish would require optimum performance around 2,200 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 distant spacecraft.

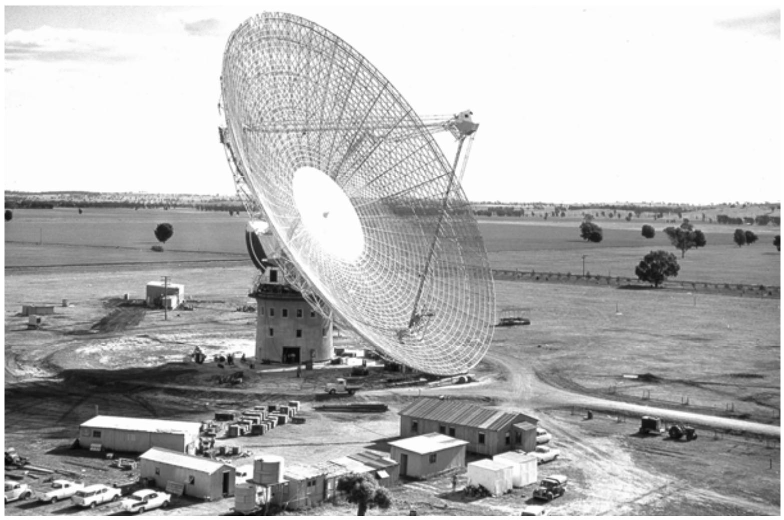

Figure 7: The Parkes Radio Telescope being tested prior to completion. Here, the dish is tipped for the first time. Credit: CSIRO/ATNF.

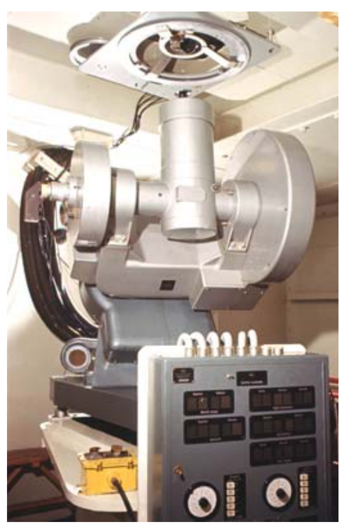

Figure 8: The master equatorial precision pointing system developed for the Parkes Radio Telescope was adapted for use in the 64-m dishes of the DSN. Credit: CSIRO/ATNF

Consequently, even while the Parkes telescope was under construction, NASA made representations to 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 utilize 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 on. However, because of the design and engineering changes these modifications required, the 64-m 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 CSIRO. Instead, "Taffy" Bowen encouraged JPL to consider the construction of a similar, large antenna near Parkes, arguing that the value of two large telescopes near to each other certainly would exceed that of the two telescopes taken individually.[45]

With budget cutbacks delaying the construction of DSN 64-m dishes in Spain and at Tidbinbilla, NASA renewed its proposal to include Parkes permanently in its DSN, 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 CSIRO was eager to maintain its close and friendly connections with JPL and NASA, the 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, 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, 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 behavior, characteristics of the drive system, characteristics of the master control system, and radio frequency performance. In addition, the vibration characteristics were measured and 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 close and warm working relationship was established between CSIRO and JPL. This close relationship proved to be of critical worth in the Parkes support of future space missions.

Parkes Supports *Mariner 2*[46]

In planning for the *Mariner 2* mission to Venus, NASA considered it extremely vital that a coordinated program of ground-based observations, 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 2* spacecraft would be an excellent demonstration of the Parkes telescope's capabilities for communications 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 2* and *4*.

Figure 9: The Parkes Radio Telescope, completed in 1961, supported the *Mariner 2* mission to Venus in 1962. Its design was the prototype for the DSN's 64-m tracking antennae. Credit: CSIRO/ATNF

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-m antennas of the DSIF, and should have detected the signals easily, it experienced great difficulty in finding and locking onto the *Mariner* signal. There were two reasons for this: the narrow beamwidth of the 64-m antenna made the accurate pointing of the dish absolutely crucial; and the receiver had to be tuned precisely, because its bandwidth was just 20 Hz wide, which required the Doppler shift of the signal to be known exactly. Eventually, the staff at Parkes was able to overcome these problems and was able to track *Mariner 2* 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 4*

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

On 21 June, Parkes began receiving the *Mariner* transmissions. Daily tracks were carried out during two-hour periods each afternoon centered approximately on *Mariner*'s meridian transit. Horizon-to-horizon observations were obtained on 3, 14, 15, and 16 July. Regular telemetry recordings were made from 8 July to 27 August. The closest approach to Mars was scheduled to occur about 2¼ 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 4* tracks as a great success.

Apollo to the Moon

Humankind'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-m antennas within its MSFN, each one located near the DSN stations at Canberra, Goldstone, and Madrid, so that the DSN facilities could act as backup 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 15 km south of Tidbinbilla and connected to it by a microwave link. Honeysuckle Creek was opened in 1967: its first Apollo mission was the unmanned *Apollo 4* in November 1967. 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.

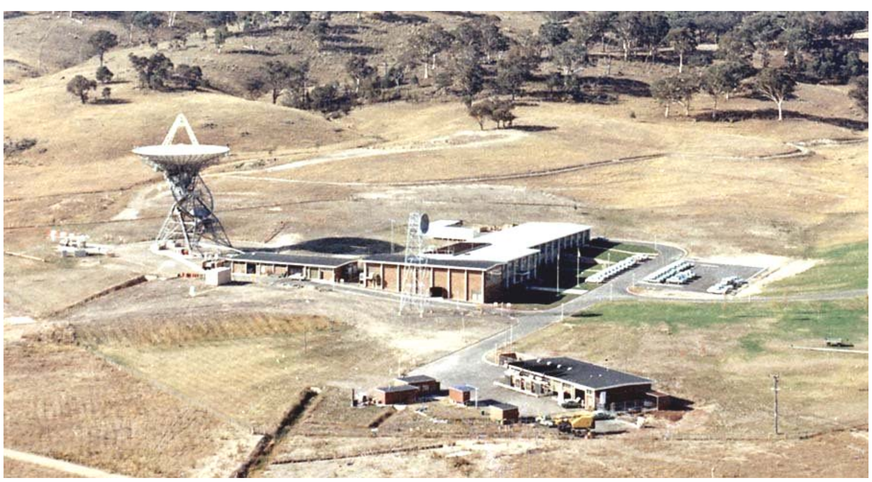

Figure 10: Tidbinbilla showing the "Apollo Wing" built in 1966 to support MSFN operations at the nearby Honeysuckle Creek station. Credit: NASA.

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 for the 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 had realized that the first Moon landing would take place toward 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-m dish at Goldstone in California, and the 26-m antenna at Tidbinbilla. 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 p.m. (AEST), the extravehicular activity (EVA) would have been completed by that time. The Honeysuckle Creek station 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.

Figure 11: Parkes Radio Telescope tracking the Moon during a test a few weeks before the *Apollo 11* mission. Credit: CSIRO/ATNF

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 10 hours after landing, at 4:21 p.m. (AEST), which was some 20 minutes after the Moon had set for 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 extravehicular communications.

The Eagle Has Landed

On Monday, 21 July 1969, at 6:17 a.m. (AEST), astronauts Armstrong and Aldrin landed their Lunar Module, *Eagle*, on the Sea of Tranquility. 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 closer 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 from the Moon. Two sharp gusts of wind exceeding 110 kph struck the dish, subjecting the telescope to wind forces 10 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 television (TV) at 12:54:00 p.m. (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 Goldstone and the previously selected Australian TV signals.

During the first nine 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 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 giant leap for mankind."* Finally, eight 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 TV for the remainder of the 2½-hour telecast.

Figure 12: Honeysuckle Creek tracking station photographed at the exact moment that it was receiving the images of Armstrong stepping onto the lunar surface. Credit: Hamish Lindsay.

* The full quote is "That's one small step for [a] man, one giant leap for mankind."

Figure 13: Robert Taylor, NASA Goddard Space Flight Center representative at Parkes, watches the control room monitor at the commencement of the lunar EVA. The upside-down image indicates that the camera was still stowed on the MESA (Modularized Equipment Stowage Assembly) at the time. Credit: CSIRO/ATNF

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 resurface 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 10 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 *Odyssey* were sent along landline to Sydney, then on to Houston.

The microwave links, which had been previously established for *Apollo 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 setup, while technicians from the Overseas Telecommunications Commission and the Postmaster General's department re-established the microwave 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 coordinated 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 10 receivers tracking the spacecraft. Parkes' inclusion was critical at this stage, owing to interference from the Saturn IV-B (SIV-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. Because it had 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 lifeboat, the conflicting transmissions from the LM and the nearby SIV-B were interfering with each other.

The 26-m 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 fewer dropouts than the 26-m antenna at Honeysuckle. The 64-m 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 16* and *17,* it tracked the spacecraft for brief periods to receive fast dumps of recorded data.

By the *Apollo 17* mission, the 64-m 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 weak signals from the *Voyager 2* spacecraft at Uranus. But, that's another story.

Conclusion

Although not generally recognized, 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 from its radio astronomy program that enabled the growth and development of DSN.

Reference Notes

[1] K. Dougherty and M. James, *Space Australia* (Powerhouse Publishing, 1993), p. 32.

[2] These two tracking networks were effectively in competition with each other 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 collocated.

[3] M. Baltuck et al., "Forty Years of NASA-Australian Cooperation," in K. Dougherty and D. Elder (eds.), *History of Rocketry and Astronautics*, AAS History series, volume 27, 2007, pp. 151-160.

[4] See http://deepspace.jpl.nasa.gov/dsn/history/index.html.

[5] D. J. Mudgway, *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 D. E. Goddard and D. K. Milne, eds., *Parkes: Thirty Years of Radio Astronomy,* CSIRO, 1994, p. 141; also further personal communication from Dinn.

[7] Mudgway, *Uplink-Downlink*, p. 21.

[8] *Island Lagoon Tracking Station, South Australia*, Australian Department of Supply information brochure, 1971.

[9] Dougherty and James, *Space Australia*, p. 35.

[10] Mudgway, *Uplink-Downlink*, p. 21.

[11] Mudgway, *Uplink-Downlink*, pp. 36–39, 61–63; also R. A. Leslie, "Space Tracking Stations," *Canberra's Engineering Heritage (2nd edition)*, Institution of Engineers, Australia, 1993, p. 187.

[12] Mudgway, *Uplink-Downlink*, p. 34.

[13] H. A. Wills, "Co-operation Rewarded," *Sydney Morning Herald* (15 July 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 that linked them to the control center at JPL. With the reorganization that commenced in late 1963, all three elements—the stations, communications network, and the control center—were combined to make up DSN. The designations DSIF and DSS for the tracking stations continued to be used interchangeably until the latter part of the 1960s.

[15] Island Lagoon Tracking Station brochure.

[16] Mudgway, *Uplink-Downlink*, pp. 64–65; also Leslie, "Space Tracking Stations," p. 188.

[17] J. O'Brien and I. Tuohy, "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, "Space Tracking Stations," pp. 188–89.

[19] Leslie, "Space Tracking Stations," p. 189.

[20] Leslie, "Space Tracking Stations," p. 189.

[21] Leslie, "Space Tracking Stations," 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, "Space Tracking Stations," p. 192.

[24] "DSIF: Tidbinbilla," JPL Technical Memorandum No. 33-207, JPL/CIT, 1965.

[25] Dougherty and James, *Space Australia*, pp. 65, 73–74.

[26] Leslie, "Space Tracking Stations," p. 191. *Pioneer 6* was still functioning when last contacted in December 2000, making it the oldest extant NASA spacecraft.

[27] Leslie, "Space Tracking Stations," p. 191.

[28] The first experimental satellite broadcast between Australia and the United Kingdom 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 United States.

[29] Leslie, “Space Tracking Stations,” p. 192.

[30] Mudgway, *Uplink-Downlink*, pp. 100–102.

[31] The Minitrack facility was managed under an agreement, between the U.S. 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 7 June 1957. The Baker-Nunn observatory was operated under its own agreement between the SAO and the Department of Supply, which came into effect on 12 September 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, “Space Tracking Stations,” 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 University of Tasmania. The Tidbinbilla tracking station would 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, “Space Tracking Stations,” p. 188.

[37] Leslie, “Space Tracking Stations,” p. 188.

[38] C. Waff, “The Road to the Deep Space Network,” *IEEE Spectrum* (April 1993): p. 56.

[39] O’Brien and Tuohy, “Operation and Maintenance Support,” p. 1.

[40] Leslie, “Space Tracking Stations,” p. 189.

[41] The CSIRO 210-foot Radio Telescope, CSIRO brochure, ca. 1968.

[42] Despite its greater size, the 64-m telescope was built at a substantially lower cost than the recently commissioned 26-m antenna at Island Lagoon. This apparently also attracted the interest of JPL!

[43] See http://www.parkes.atnf.csiro.au/.

[44] The following account of the role of the Parkes Radio Telescope draws on extensive research in the archives of 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-m antennas were linked together in the 1980s to support the *Voyager 2* encounters of Uranus and Neptune, in addition to the Galileo mission to Jupiter in the mid-1990s.

[46] The following accounts of Parkes involvement with the *Mariner 2* and *4* missions draw heavily on the recollections of Harry Minett, who was with the Parkes telescope throughout the 1960s and 1970s and was directly involved in carrying out much of the NASA-funded research discussed here.

[47] Mudgway, *Uplink-Downlink*, pp. 56–57.

[48] Mudgway, *Uplink-Downlink*, p. 56.

[49] Bolton was so eager to assist the mission, that he established a simple "one-line agreement" that offered all necessary support to *Apollo 11*.