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NEW ZEALAND'S CONTRIBUTION TO INTERNATIONAL SCIENCE: THE ROLE OF THE UNIVERSITY OF CANTERBURY'S ROLLESTON RESEARCH STATION

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Abstract: This paper details the research work carried out over some 35 years at the University of Canterbury's research station near Rolleston in mid-Canterbury New Zealand on radar meteors and their radiants; on the ionic processes that control the duration of both radar and visual long enduring trains; radar work on the aurora; and an extensive programme of radar work mapping the details of the dynamics of the Earth's mesosphere.

Keywords: meteors; radar astronomy; New Zealand; Rolleston research station; C.D. Ellyett; K.W. Roth; R.G. Bennett; G.J. Fraser; meteor radiants; meteor plasma processes; radar aurorae; mesosphere dynamics.

1 INTRODUCTION

New Zealand astronomers made important contributions to international meteor astronomy during the 1920s through 1940s (Luciuk, 2007; McIntosh, 1946; Orchiston, 2016: 523–561; Orchiston et al., 2021; Taibi, 2017), but this visual research was curtailed in the immediate years following World War II (WWII) with the international emergence of radar meteor astronomy (Lovell, 1954; Pawsey and Bracewell, 1955: 306–338). Two former staff members from the Department of Physics at the University of Canterbury, Clifton Darfield (Clif) Ellyett (1915–2006; Figure 1)[1] and John Banwell (1908–1982; Fraser, 2016), were involved in this early research while at the University Manchester in the mid- to late 1940s. When they returned to New Zealand Ellyett decided to continue this line of research (Keay, 1965), and also to investigate the dynamics of the mesosphere.[2] This paper is about the work he, his collaborators and his successors carried out at the Rolleston research station near Christchurch (for New Zealand and Pacific Ocean localities mentioned in the text see Figures 2 and 3).

2 ESTABLISHMENT OF ROLLESTON RESEARCH STATION

The University of Canterbury's Rolleston Research Station was located at 43° 37′ South, 172° 24′ East, just south of the (then) small community of Rolleston south-west of Christchurch (Figure 2) and operated from 1951 to 1985. The station was established by the University (then Canterbury College) through the initiative of Clif Ellyett on his return from his research period at Jodrell Bank, UK. The approximately 20-hectare site was leased from a farmer and was located in a (then) electrically quiet area with power available from an installed 11 kV power line. The chosen site was very rural, with a pig farm bordering its eastern fence-line.

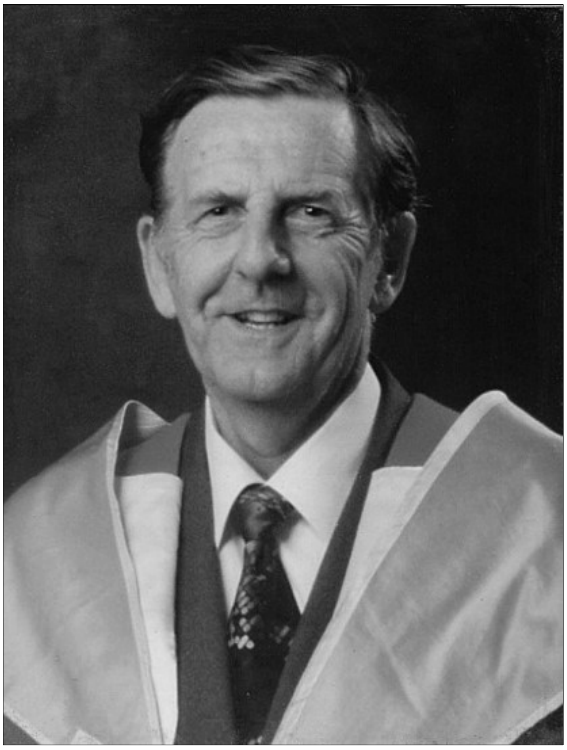


Figure 1: Clifton Darfield Ellyett (courtesy: University of Canterbury).

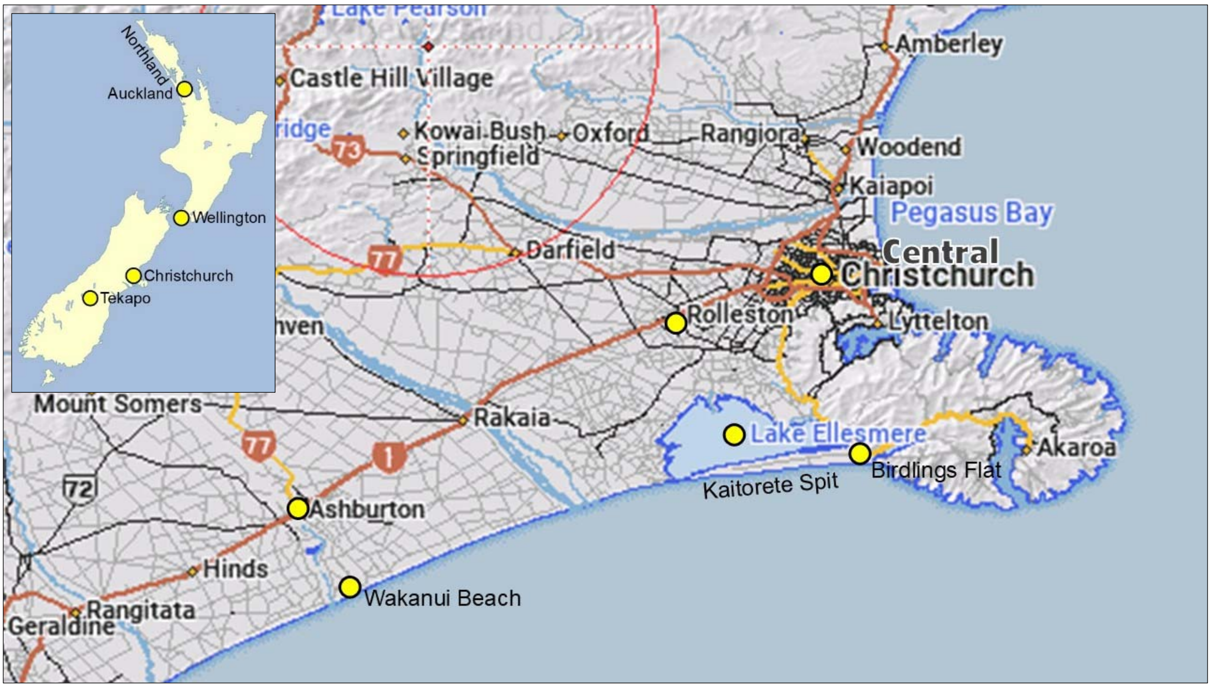


Figure 2: New Zealand (insert) and mid-Canterbury localities (yellow circles) mentioned in the text. For scale, on the mid-Canterbury map the distance from Ashburton to Wakanui Beach is 18 km (the mid-Canterbury map is adapted from ch-canterbury-region-map-14959.png; map modifications: Wayne Orchiston).

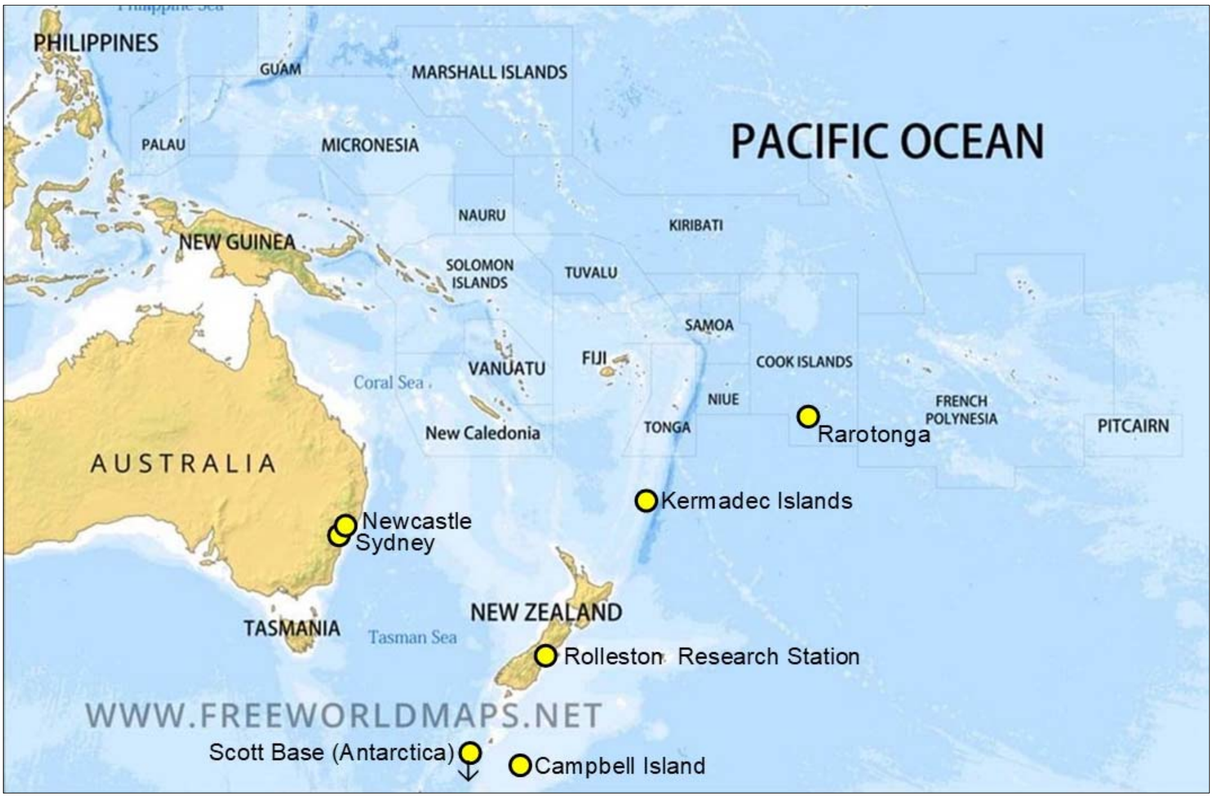


Figure 3: New Zealand, Australian and Pacific Ocean localities mentioned in the text (base map adapted from www.freeworldmaps.net; map modifications: Wayne Orchiston),

During 1940–1943 Ellyett was an Assistant Lecturer at Canterbury University College, where he lectured on radio and radar and location techniques during WWII. He worked on ionospheric ionosondes in Christchurch and Rarotonga, and on Campbell Island and the Kermadec Islands (see Figure 3) for radio communication in the South Pacific, liaising in 1943 between Australia and New Zealand to co-ordinate ionospheric work and in 1944 attended a forward-looking meeting in the US on radio propagation and communication.

To support research at the Rolleston station, in the late 1950s Ellyett secured contract funding from the U.S. Air Force, Office of Naval Research and the National Aeronautics and Space Administration (NASA). The financial interest of NASA was because of the need to secure reliable measures of the flux of meteoroids both near the Earth and in the inner Solar System because of the implications for space vehicle impacts by such material.

The major research effort at Rolleston was principally divided into (a) radar meteors and ionic processes in meteoric plasma and (b) ionospheric sounding using pulsed radars to map lower mesospheric winds.

2.1 Two Significant Developments: Radar Meteor Speeds and the T/R Switch

Working for his PhD at the University of Manchester, Ellyett developed the technique of meteor speed measurement from the Fresnel diffraction characteristics of radar reflections from meteor plasma trains (Figures 4 and 5). As an ablating meteoroid travels past the point on its track orthogonal to the line-of-site to the radar, the developing column of ionisation reflects radio waves that can be described in terms of successive Fresnel zones. The diffraction pattern so produced yields the zone creation speed and hence meteoroid speed. For good signal conditions the speed can be derived for a majority of meteoroids. In Figure 4 the horizontal plot is time measured in radar pulses while in Figure 5 an exponential time is employed to present an easier interpretation (the work was performed many years before the advent of electronic data analyses). The theoretical behaviour of the meteor echo amplitude-time profile as a function of time was governed by the atmospheric diffusion coefficient (Figure 6) after Bennett (1958). Figure 6 can be used to reveal the meteor speed: the derived speed for Figure 5 was 34.7 km s^{-1} with an uncertainty of 2.2 km s^{-1}. This development (Davies and Ellyett, 1949; Ellyett and Davies, 1948), and Bennett (1958), were of fundamental importance in efforts to determine meteoroid orbits in the Solar System and became a vital tool for speed (not vector velocities) measurements in subsequent determinations involving meteoroid dynamics.

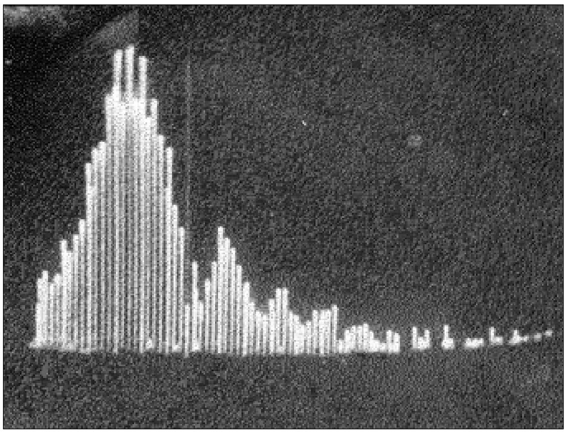


Figure 4: Diffraction pattern echo amplitude vs time produced from a pulse radar reflections from a radio meteor (courtesy: University of Canterbury).

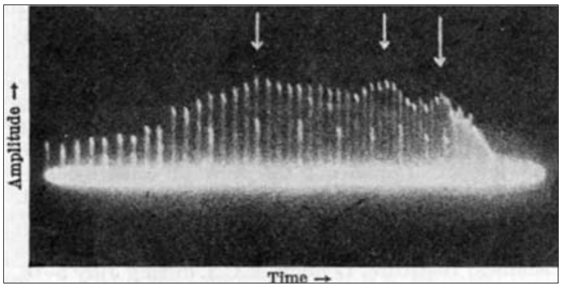


Figure 5: Diffraction pattern as recorded by Ellyett and Davies 1948 (courtesy: University of Manchester).

Although not active himself at Rolleston, mention should be made of another UC graduate, the aforementioned John Banwell. He arrived in wartime UK to undertake a PhD at Cambridge University, but soon transferred to the Telecommunications Research Establishment (TRE) where he developed an electronic transmit/receive (T/R) switch, a valuable electronic device that saw much use during WWII,

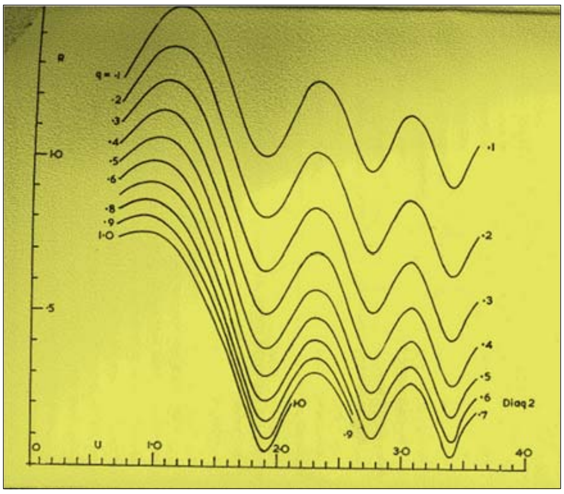


Figure 6: Modelling plots of diffraction pattern behaviour echo amplitude vs time. Various plots under different conditions of atmospheric diffusion as modelled by RGT Bennett (courtesy: University of Canterbury).

Figure 7: Rolleston research station aerial view ~1960. Features are as indicated: 1. Crossed dipoles for all-sky meteor surveys; 2. Array for radiant determination; 3. Broadside rotating (360°) array (the first array on the site); 4. Broadside array of eight Yagis each of 7 elements for radiant determination; 5. Receiver and recording hut (black walls); 6. Hut with 200 MHz radar and behind is the CHL rotating antenna; 7. The hut, behind the 200 MHz radar, housing the 69 MHz GL2 transmitter; 8. More Yagis for radiant determination; 9. Additional broadside array for radiants. 10. Broadside transmitting array for the partial reflection atmospheric radar operating on 1.75 MHz. 11. 1.75 MHz circular polarisation receiving array (courtesy: University of Canterbury).

and later at Rolleston: The operation of this switch utilized sections of ¼-wave transmission lines to permit isolation of transmitter and receiver when using a common antenna.

2.2 Layout of the Rolleston Field Station

The layout of the various radar antenna systems employed at Rolleston is shown in Figure 7 where the individual items indicated are shown in the key. This aerial view shows the equipment layout in the early 1960s.

Figure 8: The tracking antenna used for solar noise monitoring (courtesy: University of Canterbury).

2.3 Solar Noise

Solar radio emission was an early research area in the post-WWII period and Richard N. (Dick) Manchester, a graduate of UC, carried out work at Rolleston with the Sun-tracking antenna shown in Figure 8. He later moved to Australia (when Ellyett transferred his research group *en masse* to the University of Newcastle, north of Sydney) and worked on micro-pulsations.[3] He then went on to establish an international reputation using the Parkes Radio Telescope to research pulsars.[4]

3 ATMOSPHERIC DYNAMICS

An extensive programme of research was initiated at Rolleston by John Gregory (Figure 9)[5] and Grahame J. Fraser (Figure 10). Those two UC academics and later colleagues were responsible for a long-term important body of work which was later (post-1980) extended at the UC Birdlings Flat research station on Kaitorete Spit (see Figure 2). This survey was maintained over a total of some sixty years. This long-term project was to determine the principal driving forces that control the dynamics of the Earth's atmospheric regions in the height range ~70–100 km (the mesosphere). The technique used was to monitor the atmospheric dynamics by mapping, using ground antennas operating at a radar frequency of 1.75

MHz at Rolleston and 2.4 MHz at Birdlings Flat (and also at Scott Base in the Antarctic).

These radar frequencies are above the critical frequency of the lower E-region so that total radio wave reflection does not occur: instead, detection of partial reflection takes place so the motion of electron density fluctuations can be recorded: mapping such fluctuations by spaced antennas on the ground is a direct measure of the neutral wind at the reflection point: this is true since the electron collision frequency is sufficiently high—a condition existing for heights below about 110 km.

Multiple antennas spaced on the ground mapped the two-dimensional pattern of radar returns from partially reflected radio waves from ionization irregularities produced by winds. For efficient operation the transmitter and receiver antennas (centre-fed half wave dipoles) were required to be at substantial heights (~25 m). The various antenna arrays can be seen in Figure 7. The complex dynamics of the Earth's middle atmosphere were analyzed from small-scale to large: of small-scale turbulence, diurnal meridional and zonal components and long period (days) planetary waves for example (Craig et al., 1980; Gregory, 1956; 1961; Fraser, 1965; 1968; Fraser and Vincent, 1970).

4 RADAR METEORS

The earliest work devoted to radar meteors recorded at Rolleston were those on observations of meteor showers by Ellyett and Roth (1955), while Ellyett and Fraser (1956) investigated the effects of receiver noise and concluded that the minimum detectable radar meteor sampled by the 69 MHz transmitter and Yagi antenna array used was equivalent to +9 magnitude. At that time, K. Walter Roth (Figure 11),[6] an escapee from WWII Europe, and Grahame Fraser were both Lecturers in Physics.

The modelling work of Robert G. (Bob) Bennett (Figure 12) was supported by observational work to measure meteor diffraction behaviour (Bennett, 1958). This experimental work was performed at a lower frequency than had been used for the previous meteor work: modifying the previous 69.5 MHz system to operate at 39.2 MHz. Meteor radar echoes endure a factor of ~3 longer at the lower frequency in addition to having a larger scattering cross section. The antennas used for transmission and receiving were collinear arrays each of ten halfwave dipoles placed one eighth of a wavelength from a wire mesh reflection screen (see Figure 7).

4.1 Radiant Surveys

The meteor work initiated by Ellyett led to the mapping of meteor shower radiants, little radio work on which had been carried out previously in the Southern Hemisphere. The radar equipment for the work was the military Gun-laying GL Mk 2 radar transmitter (Figure 13) that had been in use during WWII in the Auckland area and after the war was used for the 'Canterbury Project' (Figure 14), based initially at Wakanui Beach and subsequently at nearby Ashburton Aerodrome to investigate anomalous radio wave propagation in the troposphere at a frequency of 97.5 MHz (Milnes and Unwin, 1950; Orchiston, 2017: 682–683).

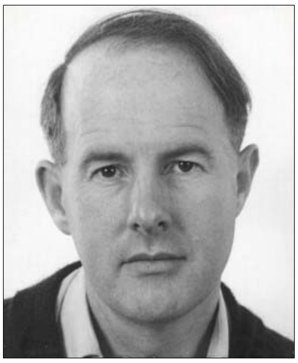


Figure 9 (left): John Gregory (courtesy: University of Canterbury).
Figure 10 (right): Grahame Fraser (courtesy: University of Canterbury).

The modified equipment employed for meteor work at Rolleston used a 69 MHz 80 kW pulsed transmitter using arrays of Yagi antennas and later (after ~1968) a rotating antenna that had been used in the Chain-Home Low (CHL) defence radars in the UK.

The transmitter used four VT98 triode power valves (Figure 15)—two as oscillators and two as power amplifiers—and required skilled work to get it operational, skills that were provided by our ever ingenious colleague Bob Bennett.

Extensive surveys of radar meteor radiants were carried out during the 1960s by Ellyett (Figure 1) and Colin Stuart Keay (1929–2015;

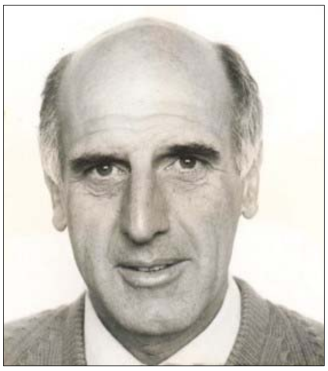


Figure 11 (left): Walter Roth (courtesy: University of Canterbury).
Figure 12 (right): Bob Bennett (courtesy: University of Canterbury).

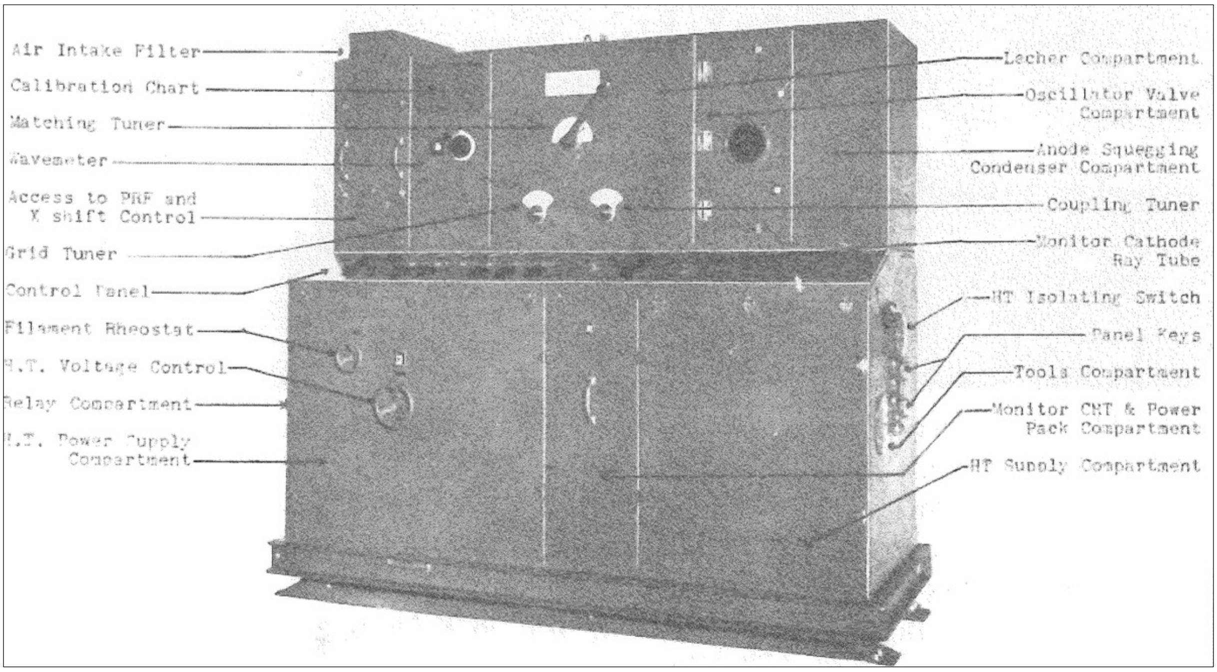


Figure 13: Transmitter as used for WW2 CHL radar (after Lathan and Stobbs, 1999).

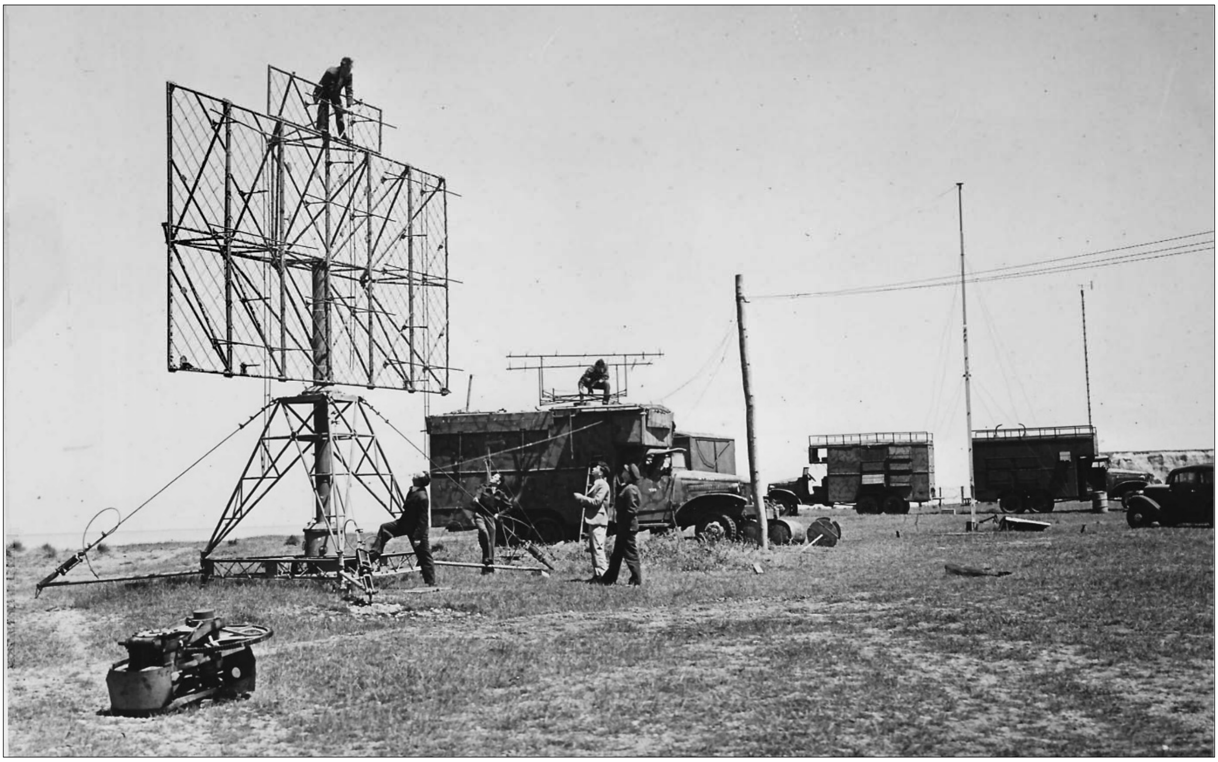


Figure 14: Construction of equipment for the Canterbury Project based, initially, at Wakanui Beach near Ashburton (Orchiston Collection).

Figure 16)[4] and Bennett making use of: (a) narrow beam radars employing common transmit/receive stacked Yagis: horizontal stacks of eight 7-element Yagis (Figure 17) and using TR switches and (b) omnidirectional crossed folded halfwave dipoles at height 0.325 wavelength above raised wire mesh ground-planes (Figures 18 and 19), the antenna radiation pattern being measured by a balloon-borne transmitter, as well as an echo elevation measurement (Figure 20) (that together with radar echo range permits a value of the meteor echo height to be determined).

Separate transmit and receive antennas with ~400 m separation were employed. This ar-

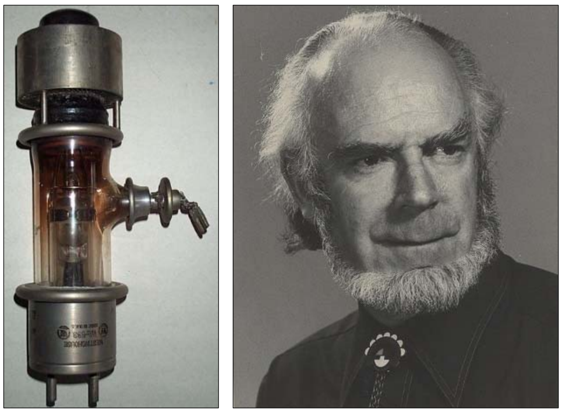


Figure 15 (left): Radar transmitting valve as used in the GL2 radar transmitters (courtesy: The Valve Museum).
Figure 16 (right): Colin Keay (courtesy: University of Canterbury).

rangement enabled sampling of the entire celestial hemisphere to be achieved. The surveys were carried out employing very close monitoring of equipment sensitivity: cosmic noise monitoring (employing a noise source automatically replacing the antenna briefly every hour), TX output and ensuring near continuous operation by employing two transmitters to deal with equipment faults. Parameters such as TX power output, cosmic noise were measured and displayed along with the film-recorded time-range of each radar echo (Figure 21). An overall up-time of 95% was maintained.

The limiting sensitivity was maintained at equivalent to a radar magnitude of +8.5. The time-range data were secured on 35 mm film and subsequent reading of the large amount of film records was a large task, on which technical staff Errol McLauchlan (Mac) and Peter McNab provided dedicated work in radar maintenance and film reading and Lorrie Hunter's skilled equipment maintenance.

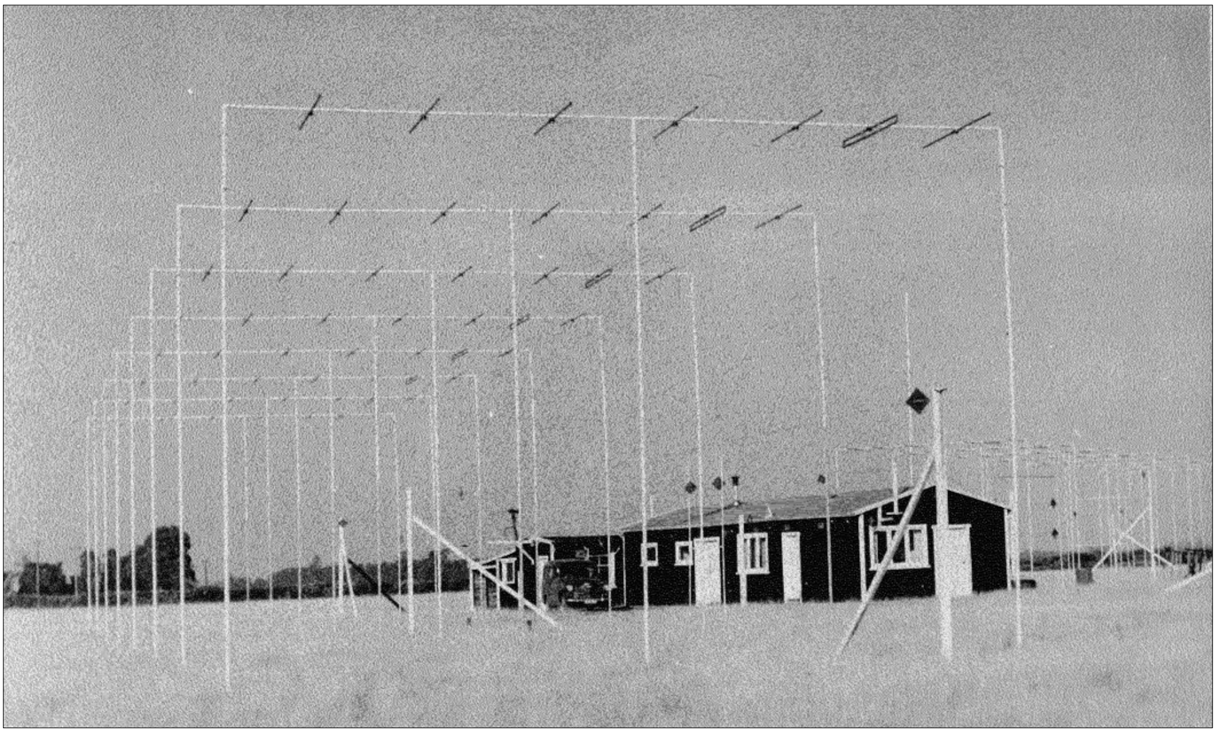


Figure 17: Yagi array for meteor radiant work; eight 7-element Yagis (courtesy: University of Canterbury).

Subsequent to1970 the meteor radiant work was carried out using a common TX/RX configuration with a modified Chain-Home Low (CHL) rotating antenna (Figure 22): the original vertical metallic sheet (that had acted as a reflector for the multi-Yagi CHL antennas) being replaced by a horizontal stack of Yagis and a newly constructed transmitter and receiver operating at 26.36 MHz employed. To facilitate the rotating arrangement an inductive coupler (Figure 23) with a Faraday screen was employed.

4.2 Meteor Plasma Column Radii

Multi-frequency observations were carried out by Baggaley (Figure 24) and Fisher to measure the radii of ionization columns produced by radar meteors. The term 'overdense' is used to describe a situation where the meteor train plasma produced by meteor ablation is of sufficiently high density to yield total reflection of the incident radio wave. Probing of each meteor plasma train to measure its effective diameter was achieved by employing a triple frequency

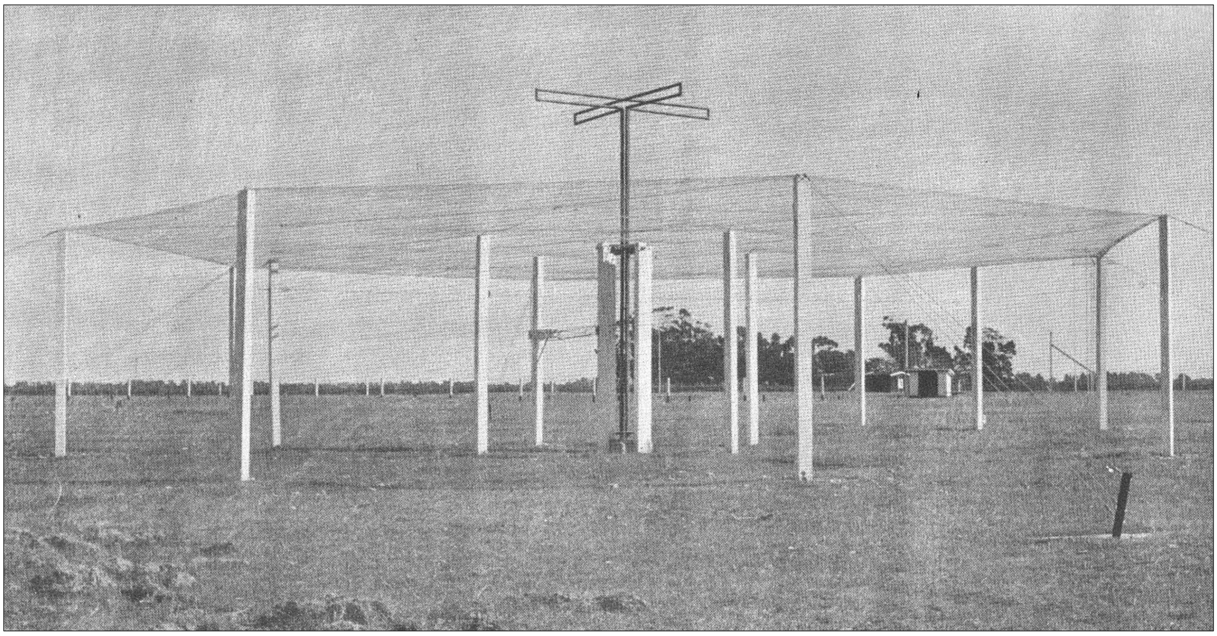


Figure 18: Meteor radiant survey employing omnidirectional crossed dipoles and ground planes (courtesy: University of Canterbury).

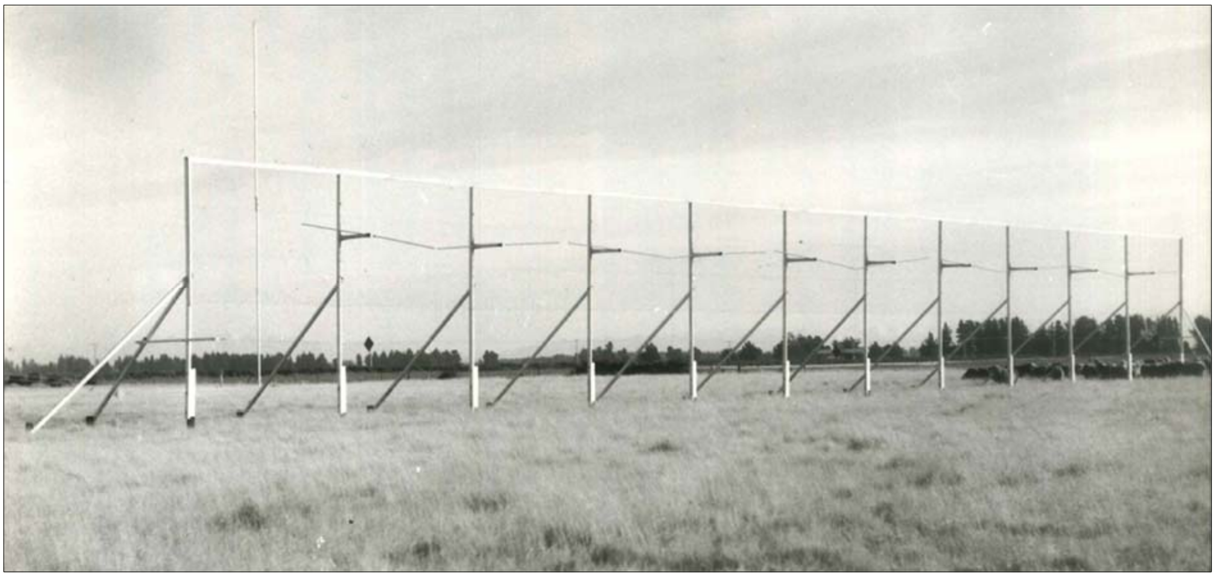


Figure 19: Broadside array used for the meteor radiant survey (courtesy: University of Canterbury).

system (Baggaley and Fisher, 1980) using radars operating at 26.36 MHz, 69.5 MHz and 148.5 MHz. The condition of over-dense plasma depends not only on the meteoroid physical size and speed and ablation height but on the operating radar wavelength. This multi-wavelength arrangement enabled the variation of plasma train diameter with meteor ablation heights to be measured. The reason for the study was two-fold: the need to understand the processes governing the expansion rate of a diffusing plasma—a process that is dictated by ionic processes (ambipolar diffusion) and by dynamics as governed by eddy diffusion. Knowledge of what processes are acting is important because they influence the inferred radar echo scattering cross section and hence the derived meteoroid mass.

The 26.36 MHz transmitter (Figure 25) and receiver were constructed in the Physics Department; the 69.5 MHz system (Figure 26) was the GL2 transmitter as used for meteor radiant studies, and the 148.5 MHz transmitter was a model that had been used for radio auroral work by the Government's Department of Scientific and Industrial Research (DSIR) with the receiver constructed in the UC Physics Department. The 148 MHz TX and RX antennas were horizontally staggered to reduced mutual coupling (Figure 27).

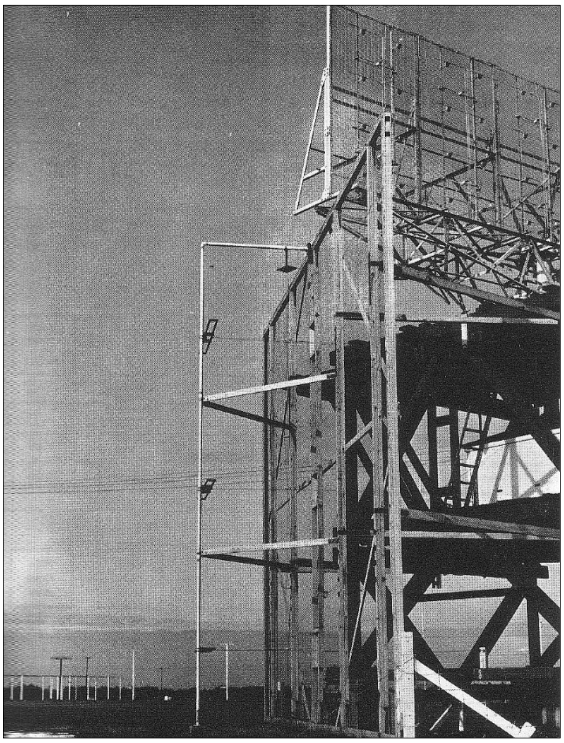


Figure 20: Echo elevation finding dipoles (courtesy: University of Canterbury).

The elevation of each meteor was measured using the 69.5 MHz system (Figure 28) achieved by employing two receiving antennas (each consisting of a horizontal folded dipole with reflector) which were placed at heights of 0.3 and 0.6 wavelengths above a conducting wire mesh as a ground-screen. The radar echoes from the two antennas were displayed on an oscilloscope together with the echoes from similar folded dipoles and reflecting dipole antennas received at 26.36 and 148.5 MHz (see Figures 29 and 30).

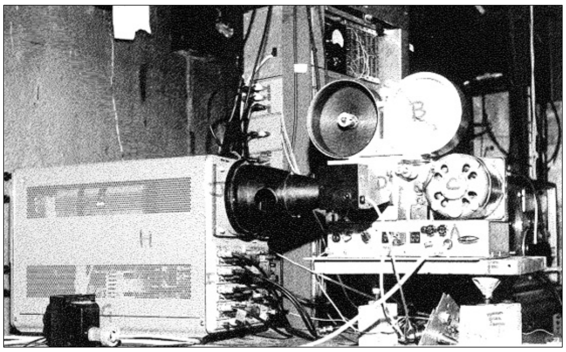


Figure 21: Radar meteor film recording via oscilloscope (courtesy: University of Canterbury).

4.3 Auroral Studies

At the time of the solar maximum around 1956, Tom Seed (Figure 31) carried out radar work employing the rotating 69.5 MHz system to track the azimuthal changes in the position of the auroral scattering centres (see Seed, 1958; Seed and Ellyett, 1958).

4.4 Atmospheric Winds Sampled from Meteor Plasma Drift

Atmospheric winds in the height regime 70–110 km can be measured by monitoring the dynam-

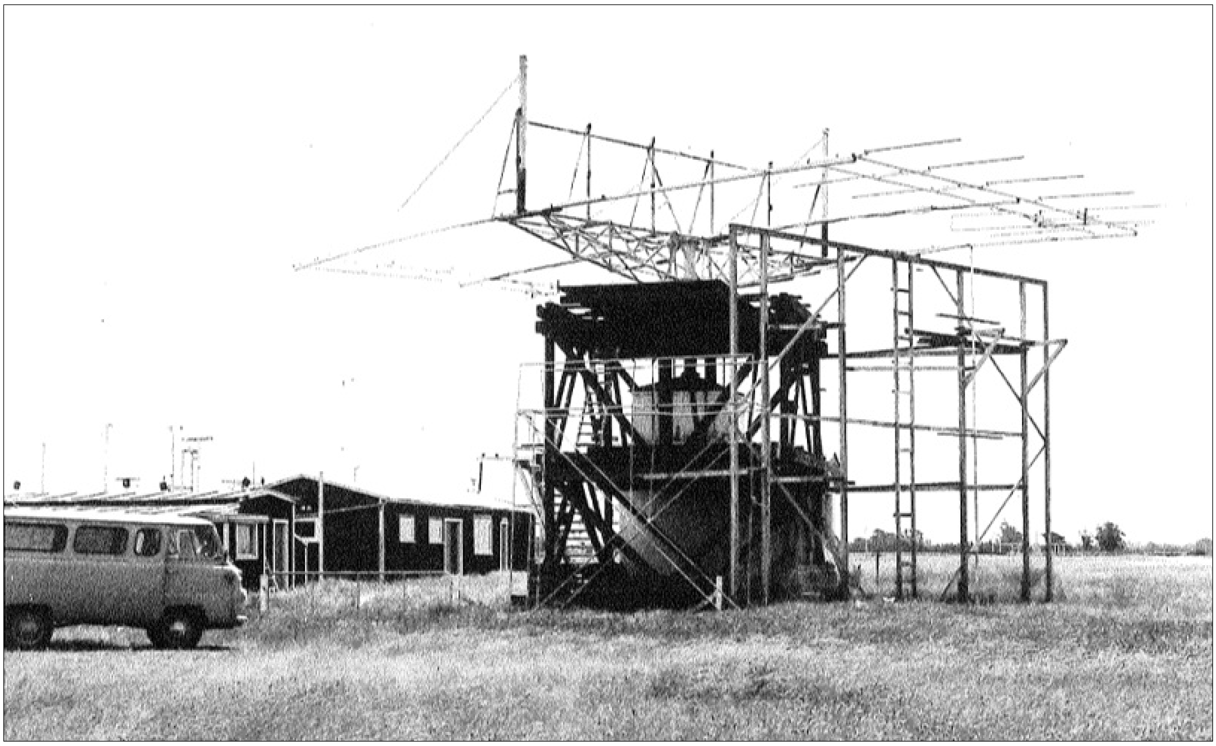
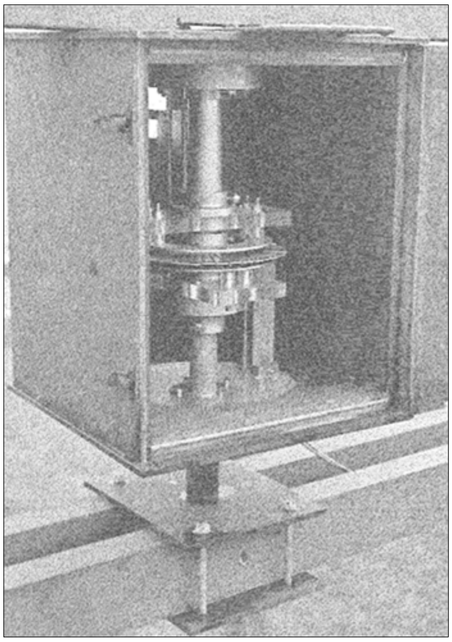


Figure 22: Rotating antenna operating at 26.36 MHz (courtesy: University of Canterbury).



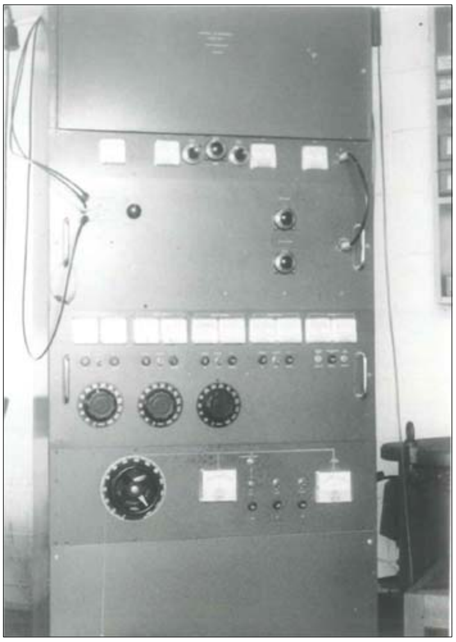


Figure 23 (left): Inductive coupler (after Lathan and Stobbs, 1999).

Figure 24 (above): Jack Baggaley (courtesy: University of Canterbury).

Figure 25 (right): 26.36 MHz transmitter (courtesy: University of Canterbury).

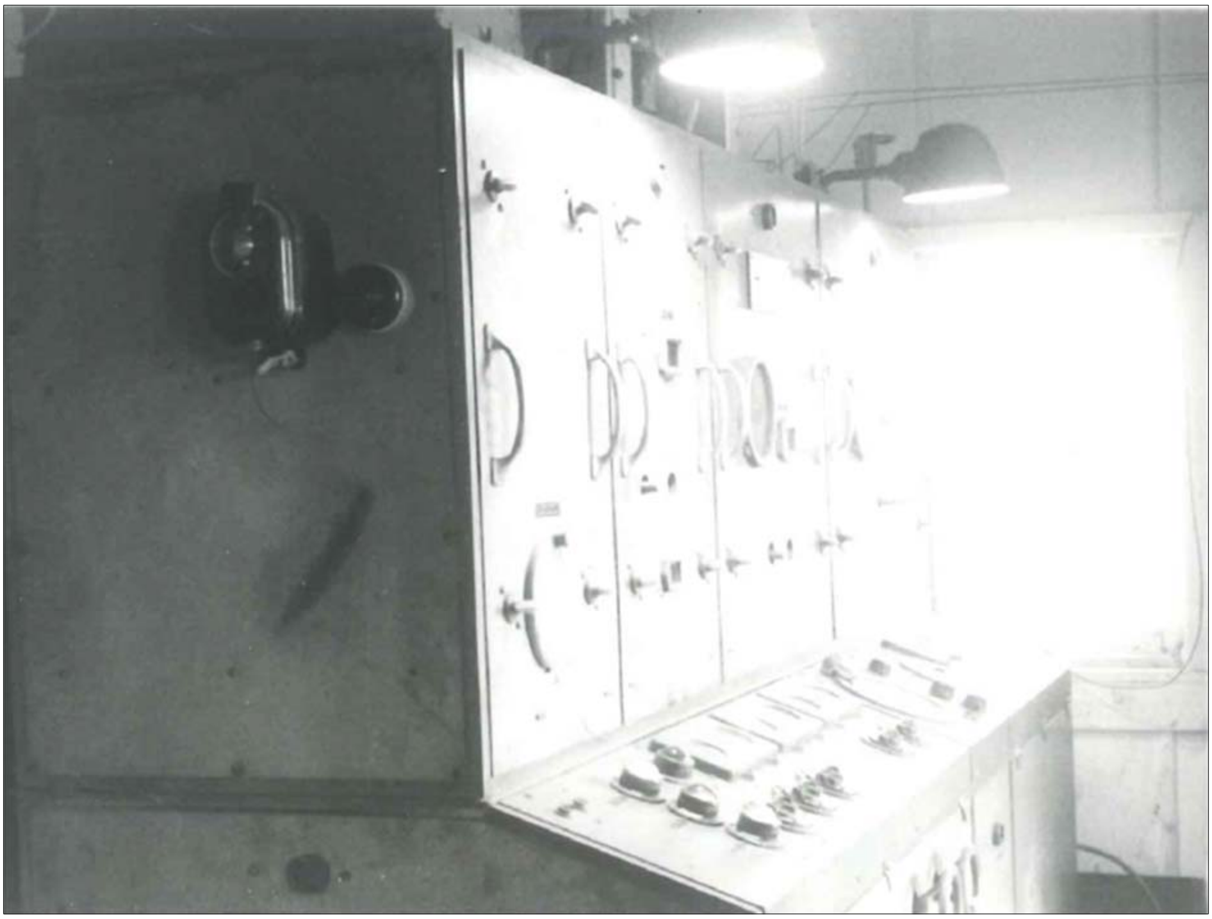


Figure 26: 69.5 MHz GL2 transmitter (courtesy: University of Canterbury).

ics of meteor plasma that drifts under the influence of the mesosphere neutral winds.

The 26.36 MHz radar with rotating antenna was used by Baggaley and Wilkinson in a series of campaigns to resolve these atmospheric motions (Baggaley and Wilkinson, 1974; Wilkinson and Baggaley, 1975).

4.5 Meteor Streams

A programme of studies of comet-related meteor streams was accomplished, with Baggaley (1973) monitoring the time changes in meteor

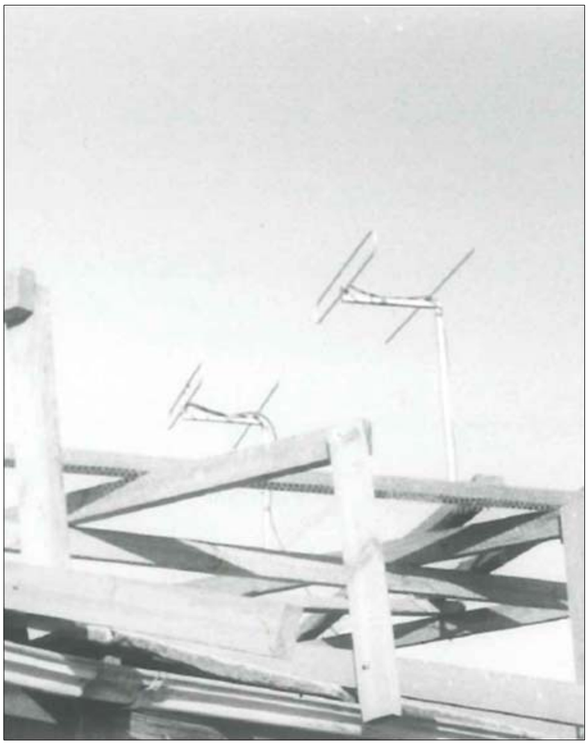


Figure 27 (above): 148.5 MHz TX and RX antennas, staggered horizontally to restrict mutual coupling (courtesy: University of Canterbury).

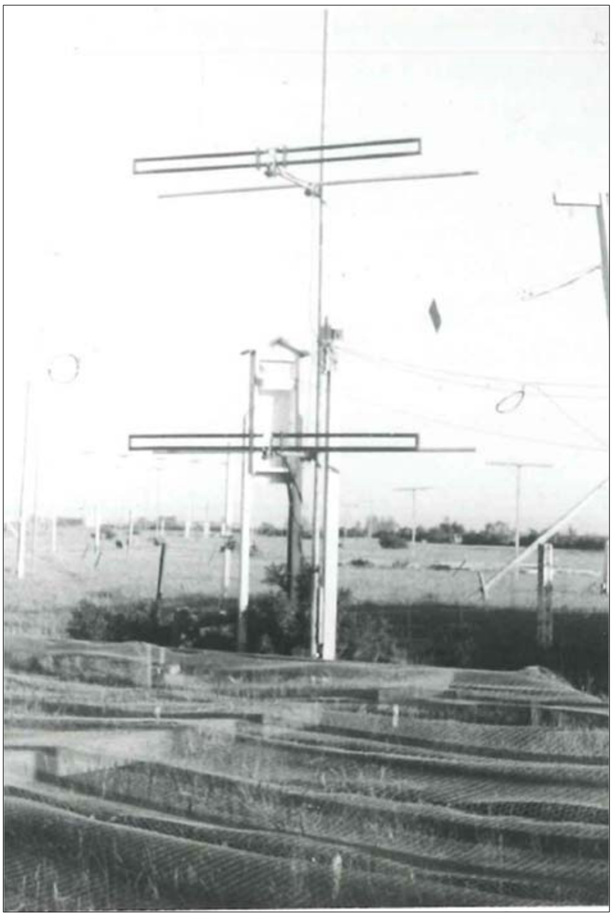


Figure 28 (right): 69.5 MHz height-finding antennas (courtesy: University of Canterbury).

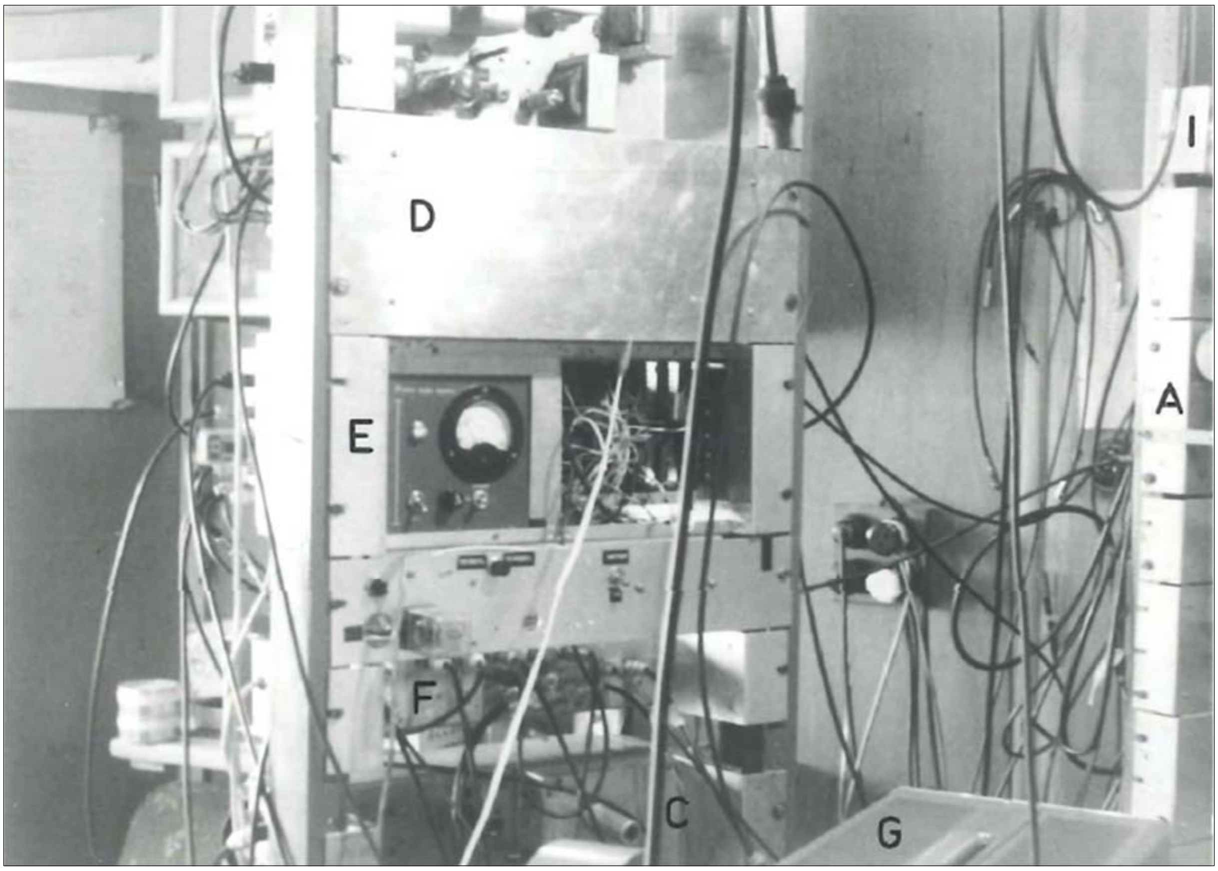


Figure 29: Triple frequency radars, receivers and control (courtesy: University of Canterbury).

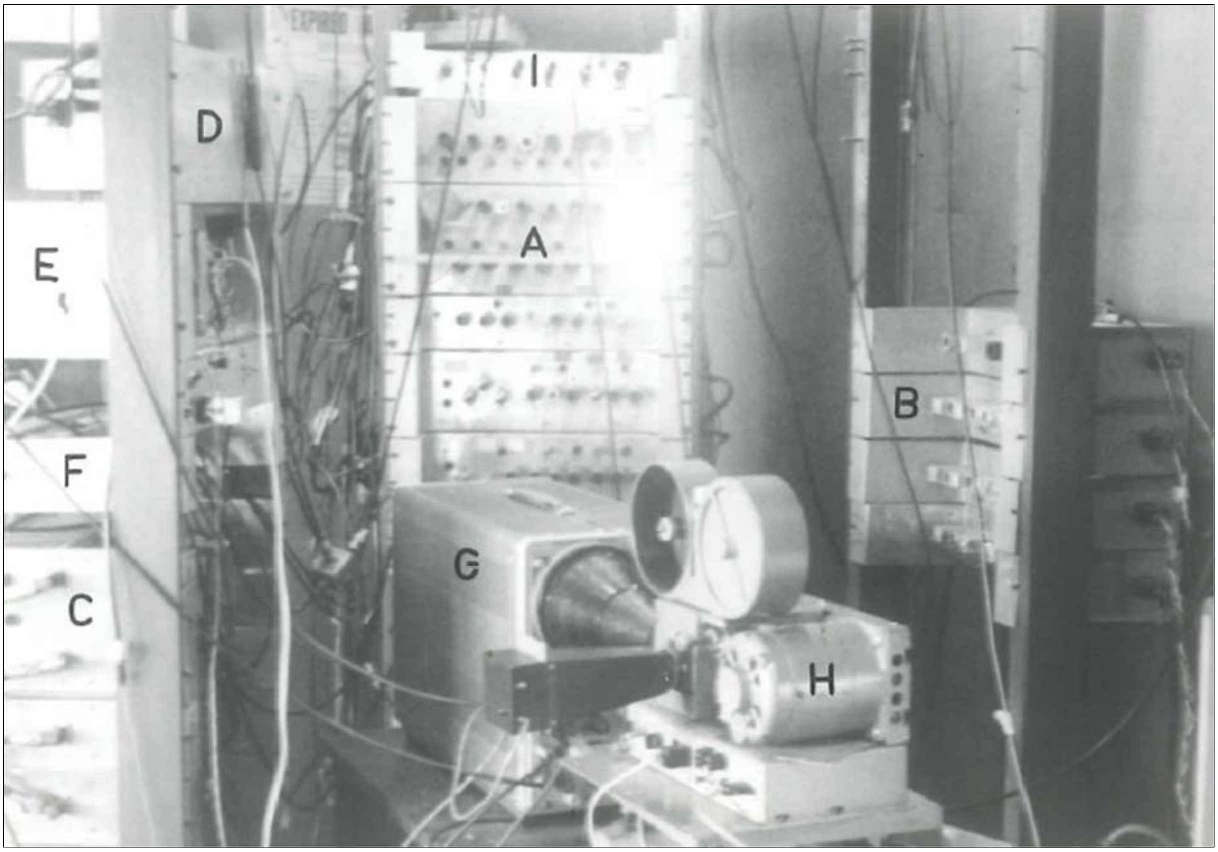


Figure 30: Triple frequency radar cameras and oscilloscope system. The letters A, C, D, E, F, G and I indicate identical components shown on this photograph and in Figure 29 (courtesy: University of Canterbury).

stream radiants.

4.6 Ionic Processes in Meteor Trains

Records of long-enduring radar echoes from meteoric plasma recorded at Rolleston led to the study of the ionic processes occurring in meteor trains: both the influence on long-lived radar echoes and also enduring light emission where the mechanism that produced visible trains lasting ≥40 minutes was investigated. The inter-atomic and molecular reactions that take place in a meteor plasma can be complex (Baggaley, 1972; 1976a; Baggaley and Cummack, 1974).

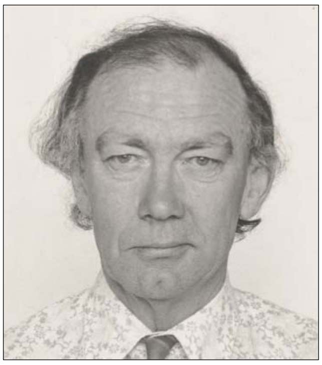


Figure 31: Tom Seed (courtesy:University of Canterbury).

For example, the radar meteor records obtained at Rolleston showed that a significant proportion of meteor radar echoes lasted several minutes (as obtained on film or, in later work, on emerging data tapes and electronic files). Modelling studies demonstrated that such unexpected enduring echoes could be explained by complex ion reactions occurring in the meteor train plasma.

An interesting feature of visual observations is that visible meteor trains have been historically observed to endure for up to an hour (the first author, WJB, had the fortune to observe one such event one evening that lasted 40 minutes). Indeed, the feature was used in early (~1960) atmospheric studies to delineate the wind structure in the upper atmosphere. This phenomenon had posed a problem for researchers because an adequate mechanism that could yield such prolonged emissions had been difficult to identify. Baggaley (1975a; 1975c) examined the interactions of the complex of ions diffusing in a plasma train, and found a process involving a catalytic mechanism involving ozone, O_3, explained the phenomenon. Further work was proposed to explain other long-enduring meteor train emissions (Baggaley, 1975b; 1976c; 1978).

Short-lived green emission from meteors that lasted for about 1 second has been often historically observed. A proposal (Baggaley, 1975b; 1976b) involving the excitation of oxygen atoms in the meta-stable state OI(^{1}S) following the dissociative recombination of ground state molecular oxygen was proposed as a viable mechanism.

In a separate study, Baggaley (1977) considered how historical records of daytime fireballs could be used to infer the size distribution of large meteoroid bodies.

5 THE CLOSE DOWN OF THE RESEARCH STATION

In the late 1970s the population of the town of Rolleston was expanding with a resulting increase in electrical interference at the research station. In addition, there were proposals to develop a satellite town in the area, which would introduce more facilities and increased interference at the research site.[7] As a result, the Physics Department (which changed its name to 'Physics and Astronomy' in 1991) at UC decided to close the research station and move operations to an electrical quieter location on Kaitorete Spit, Lake Ellesmere (Figure 2). The final move of all equipment occurred in the mid-1980s.

When the Rolleston facility was closed the historical GL2 radar transmitter was donated to the Ferrymead 'museum' in Christchurch.

6 CONCLUDING REMARKS

Following strong interest in ionospheric research and radio propagation (Fraser, 2005), during the short period 1945–1948 (inclusive) New Zealand was very actively involved in what from 1948 would be known as 'radio astronomy', with various research projects carried out in Northland, Auckland, Wellington, and Ashburton (Orchiston, 2016: 629–671; 2017: 675–702; Skinner et al., 2023). However, 1948 marked the disappearance of this discipline from New Zealand until its re-emergence at Auckland University of Technology in the present century through the initiative of Professor Sergei Gulyaev (Hearnshaw and Orchiston, 2017). During the 60-year hiatus between the demise of New Zealand radio astronomy and its re-emergence it was only through the work carried out at the Rolleston research station that New Zealand was able to maintain any international level of visibility in radio/radar astronomy.

However, the closure of the Rolleston research station led to a further enhancement of this reputation with radar monitoring of atmospheric dynamics continuing at Kaitorete Spit until ~2015, while the radar meteor work was augmented by the construction of multiple broadside arrays of Yagi antennas to determine each meteor's azimuth and elevation complimented by antennas at remote (8 km) distance in order to measure each meteors velocity components. This programme was to study the orbital distribution of Solar System (and extra-Solar System) meteoroids, providing

> … surveillance of the Earth's dust environment with >10^6 orbits in the data base. Targeted sources were cometary streams, asteroidal collisional debris material, Earth-orbit space debris and interstellar grains. (Hearnshaw and Orchiston, 2017: 613).

For further details of the AMOR (Advanced Meteor Orbit Radar) project see, for example, Baggaley et al. (1994) and Baggaley (2001).

Meanwhile, optical observations of meteors from New Zealand have experienced a recent re-awakening with the rapid spread of 'meteor cameras' throughout the nation (Scott et al., 2023), culminating in the discovery on 13 March 2024 of a stony meteorite near Tekapo. The passage through the atmosphere of the associated meteoroid was recorded on a number of cameras (Wynne-Harris, 2024).

7 NOTES

1. Ellyett played a key role in New Zealand science that went well beyond meteor astronomy, upper atmospheric physics and the Rolleston research station. He was instrumental in initiating the interest of Frank Bateson from the Royal Astronomical Society of New Zealand and The University of Pennsylvania (through Professor Brad Wood) that led to the formal agreement between the two universities for a joint program of research and teaching in astronomy—which eventually led to the establishment of Mt John Observatory at Tekapo (see Hearnshaw and Gilmore, 2015). But Ellyett's commitment to research and education also went far beyond academia: he was the driving force behind the founding of the planetarium at Canterbury Museum (see Ellyett, 1960). He also was involved in the Canterbury Branch of the Royal Society of New Zealand.
2. After a stint at the TRE and withdrawing from his Cambridge University PhD Banwell joined Lovell at the University of Manchester, and in addition to radar observations of meteors (Lovell et al., 1947; Prentice et al., 1947) he observed solar radio emission from Jodrell Bank (Lovell and Banwell, 1946). When he went back to New Zealand, in-

stead of returning to the University of Canterbury and radio or radar astronomy he decided to take advantage of New Zealand's key position on 'The Ring of Fire' and focus on geothermal research and power generation. Eventually he became an international authority in this field (Dawson, 1989).

3. 'Micro-pulsations' are tiny fluctuations in the Earth's magnetic field at frequencies of about 1 Hz.
4. See: https://csiropedia.csiro.au/manchester-richard-norman/
5. Around the same time when the political upheavals in the Department of Physics at UC led to the mass exodus of the radar astronomers to the University of Newcastle in Australia, John Gregory transferred his ionospheric research to the University of Saskatchewan in Canada.
6. Clif Ellyett, Walter Roth and Colin Keay all believed in fostering amateur astronomy, and during the 1950s and 1960s they played a key role in developing the Canterbury Astronomical Society. Their lectures and reports at monthly meetings were particularly enjoyed by the second author of this paper (WO), who sometimes assisted Walter Roth in running Friday evening 'public nights' at the University's Townsend Observatory.
7. This is precisely what happened, and the farm paddocks that once hosted the research station are now part of a large housing development (see Google maps). Sadly, none of the street names in the development reflect the major research role that this site played in international science from 1951 through into the 1980s.

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William Jack Baggaley is a Professor Emeritus at the University of Canterbury in Christchurch, New Zealand. He obtained a PhD from the University of Sheffield UK in 1966, and was elected a Fellow of the Royal Astronomical Society while still an undergraduate.

Jack has been on the academic staff of the Department of Physics & Astronomy at the University of Canterbury since February 1967, where he enjoyed lecturing and student interaction at all stages and particularly final year Physics Electromagnetism as well as Astronomy. He also enjoyed supervising Masters and PhD students.

His special interests are radar meteors, plasma processes in meteor trains, orbital dynamics of meteoroids, sources of interstellar dust impacting the Solar System. His current interest is the radar detection of objects making up the Earth's dust cloud—dust that has been captured into an orbit dynamically related to the Earth's orbit. He has produced some 160 publications.

Jack is a member of the International Astronomical Union and Past President of Commission F1 (Meteors, Meteorites and Interplanetary Dust). He was awarded a DSc by the University of Canterbury in 1983 and made a Fellow Royal Society of New Zealand in1993. Asteroid Baggaley 5136 has been named after him.

Professor Wayne Orchiston was born in Auckland (New Zealand) in 1943, and has BA First Class Honours and PhD degrees from the University of Sydney. He is employed by the University of Science and Technology of China in Hefei as the Co-editor of the *Journal of Astronomical History and Heritage*. He is also an Adjunct Professor of Astronomy in the Centre for Astrophysics at the University of Southern Queensland (USQ) in Toowoomba, Australia. Formerly, Wayne worked at observatories, research institutes and universities in Australia, New Zealand and Thailand. Over the past two decades he has supervised more than 35 Master of Astronomy and PhD history of astronomy research projects through three different Australian universities.

Wayne has wide-ranging research interests and more than 500 publications, mainly about historic transits of Venus; historic solar eclipses; historic telescopes and observatories; the emergence of astrophysics; the history of cometary and meteor astronomy; the astronomy of James Cook's three voyages to the Pacific; amateur astronomy and the amateur–professional interface; the history of meteoritics; Indian, Southeast Asian and Māori ethnoastronomy; and the history of radio astronomy. Around 100 of these publications deal with the history of astronomy in Australia, France, India, Japan, New Zealand and the USA.

Recent books by Wayne include *Exploring the History of New Zealand Astronomy …* (2016, Springer); *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy* (2017, Springer); *The Emergence of Astrophysics in Asia …* (2017, Springer, co-edited by Tsuko Nakamura); *Exploring the History of Southeast Asian Astronomy …* (2021, Springer, co-edited by Mayank Vahia) and *Golden Years of Australian Radio Astronomy: An Illustrated History* (2021, Springer, co-authored by Peter Robertson and Woody Sullivan). In addition, Wayne has edited or co-edited a succession of conference proceedings.

Since 1985 Wayne has been a member of the IAU, and he is a Past President of Commission C3 (History of Astronomy). In 2003 he founded the IAU's Historical Radio Astronomy Working Group, and is the current Radio Astronomy Subject Editor for the Third Edition of Springer's *Biographical Encyclopedia of Astronomers*. He also founded the IAU Working Group on Historic Transits of Venus, is the Founding Chair of the History & Heritage Working Group of the SE Asian Astronomy Network, and is the founding Director of the Historical Section of the Royal Astronomical Society of New Zealand.

In 1998 Wayne co-founded the *Journal of Astronomical History and Heritage,* and was the Managing Editor until 31 July 2022 when he passed ownership of the journal to the University of Science and Technology of China. In 2013 the IAU named minor planet 48471 'Orchiston', and in 2019 he and Dr Stella Cottam were co-recipients of the American Astronomical Society's Donald E. Osterbrock Book Prize for their 2015 Springer book, *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perception of the Skies Changed*. In 2023 Wayne was elected an Honorary Member of the Royal Astronomical Society of New Zealand, and Springer published the following Festschrift: Gullberg, S., and Robertson, P. (eds), *Essays in Astronomical History and Heritage: A Tribute to Wayne Orchiston on His 80th Birthday*. In January 2024 Wayne and Darunee Lingling Orchiston attended the Winter Meeting of the American Astronomical Society in New Orleans, where he was presented with the 2024 Le Roy E. Doggett Prize for History of Astronomy.