CHAPTER 13

THE SKY AND THE WEATHER

Harley Wood,
Government Astronomer

"This most excellent canopy, the air, look you, this brave o'erhanging firmament, this majestical roof fretted with golden fire."

—Shakespeare, *Hamlet.*

Early Period

Astronomy was closely associated with the beginning of European settlement in Australia. The idea of using a transit of Venus across the face of the Sun to determine the Sun's distance was first suggested by Kepler. This distance is the fundamental unit of distance in astronomy, called the astronomical unit, and it was so important to determine it with all practicable accuracy that the scientific world was anxious to make use of the transits of Venus in the eighteenth century, sending on each occasion expeditions to distant parts of the world. Only five transits have been observed since the invention of the telescope.

The laws of planetary motion enable the relative distances of the planets from the Sun to be found from their periods of revolution and so determination of only one distance in the solar system is needed to give the scale of the system. When Venus passes between the Earth and the Sun, its distance is only about 0·28 of that of the Sun and so to observers widely separated on the Earth the planet takes different apparent paths across the Sun. If each observer can accurately time the period taken at his location for the planet to traverse the Sun, all the angles can be found and hence, the base-line between the observers being known, the celestial distances are determined.

On the scientific expedition to observe the transit of 1769 James Cook made the exploration of the east coast of Australia which led to the foundation of the Colony in 1788. The observation made at Tahiti on 3rd June, 1769, was recorded in Cook's Journal: "We had every advantage we could desire in observing the whole Passage of the planet Venus over the Sun's Disk. We very distinctly saw an Atmosphere or Dusky shade round the body of the planet, which very much disturbed the times of Contact, particularly the two internal ones. Dr. Solander observed, as well as Mr. Green and myself, and we differed from one another in Observing the times of Contact much more than could be expected." Actually the discordances in the results referred to by Cook, which are due to the character of the observation, do not compare badly with those obtained in the transits of 1874 and 1882 when much better facilities were available, and the observations of the transit of 1769 did yield an improved value of the solar distance.

With Captain Phillip's First Fleet, too, there was an astronomer, Second Lieutenant William Dawes, one of whose duties was to establish a station from which to observe the expected return of a comet. In 1786 Maskelyne, the Astronomer Royal, had written: "The comet of 1531, 1607 and 1682 having returned in the year 1759 according to Dr. Halley's prediction in his 'Synopsis Astronomiae Cometicae', first published in Philos. Trans. in 1705 . . . there is no reason to doubt that all the other comets will return after their proper periods, according to the remark of the same author." Halley had conjectured that two comets with similar orbits, one observed in 1532 by Appian and the other in 1661 by Hevelius were identical. Maskelyne expected this comet to return in 1789 but the conjecture was probably wrong since it was not observed by Dawes nor by astronomers in the northern hemisphere where it should later have been seen to better advantage. Dawes, however, found effective employment for his talents in the preliminary exploration and survey of the young colony.

Sir Thomas Brisbane, when he was appointed Governor of New South Wales, decided to erect for himself an observatory near Government House in Parramatta. Arriving in Sydney in November, 1821, Brisbane brought with him two assistants, Charles Rümker and James Dunlop, and his instruments were set up in time to observe the solstice in December. The main instruments were an equatorial telescope of $3\frac{1}{4}$ inches aperture, two pendulum clocks and also a meridian telescope of $3\frac{3}{4}$ inches aperture and a 2-foot mural circle which were designed to observe stars at their passage across the meridian in order to determine their positions in the sky or to determine the time from stars of known position.

When Brisbane left New South Wales towards the end of 1825, first Rümker and then Dunlop had charge of the Observatory. By 1847 the wooden building "only intended as a private establishment not calculated to last beyond a few years" was in bad repair, "the floor and partitions . . . entirely destroyed by the white ant, and it was urgent to take measures to secure the instruments from further injury." Dunlop resigned and the Observatory closed.

The published work of Parramatta Observatory comprises the Parramatta Catalogue of Stars, which was prepared for publication at Greenwich Observatory, some papers on latitude and longitude and some observations of comets. Especially interesting among these was the first observation in June 1822 of Enke's Comet on its first predicted return. This was only the second case of a predicted return of a comet being verified although several other comets had periodic orbits attributed to them by this time. Dunlop published catalogues of nebulae and double stars based on private work done at his house in Parramatta. Rümker published also the results of his work on pendulums, latitude and longitude. Meteorological observations, probably the first recorded in New South Wales, and indeed in Australia, were made at Brisbane's observatory in Parramatta from October, 1822, to March, 1824.

The two decades at the middle of the nineteenth century were important in Australian history. By this time there was here a majority of people who had spent a major portion, in many cases all, of their lives in Australia. They regarded Australia as home and were anxious to see their country grow in independence with their own sons given opportunity for education and leadership. The abolition of convictism following the Order in Council by the Imperial Government in 1840 and the various movements toward self-government, from the Act for the Government of New South Wales and Van Diemen's Land in 1842 to the establishment of responsible government by the Act of 1855 were all results of this urge to establish an Australian community which could stand on its own feet. In these years were founded many of our institutions for the encouragement of learning, in particular of science. The Bill to incorporate and endow the University of Sydney was passed in 1850 and the University received its first students in 1852. The Philosophical Society of New South Wales, to become the Royal Society of New South Wales in 1866, was established in 1855. In the same period were founded the University of Melbourne, Williamstown Observatory near Melbourne and Sydney Observatory.

Sydney Observatory

The need for sufficient astronomical facilities to establish at least a time service was recognized even while the affairs of Parramatta Observatory were being wound up. Governor Sir William Denison in 1855 saw the decision to establish the Observatory through the Executive Council in a form which meant that activities would extend beyond the work connected with the running of a time ball for purposes of navigation.

"A competent person" found through the Astronomer Royal was William Scott, Mathematical Lecturer of Sydney Sussex College, Cambridge, who had been third wrangler in 1848. Scott arrived in October, 1856 on the ship *Sultana* at a cost "in the whole of £200 including beer, and wine and spirits for Mr. and Mrs. Scott". A site was selected and in 1857 commenced construction of the observatory, now recognized as one of Sydney's fine buildings. It was sufficiently advanced for Scott to move into the residence on April 11, 1858. The observatories established in the States were responsible for beginning meteorological work on a satisfactory basis, and as soon as Scott had approved of the site of the Observatory, he unpacked twelve sets of meteorological instruments which had arrived from England and made journeys into the country to establish meteorological stations. Communications were poor, and Scott writing to Airy expressed satisfaction that "of 10 (mercurial barometers) which were distributed only one was broken which was carried over mountainous country in a bullock dray that over-turned four times on the road". In 1860 Scott wrote to the Colonial Secretary asking that eight of the sets of instruments should be transferred to telegraph stations and recommended "that it be made part of the telegraph clerk's duty to take regular observations and submit a monthly return to the Observatory". This arrangement with the Superintendent of Telegraphs gave the observer a quick means of communicating results and played an important part in developing Australian meteorological services.

About this time occurred two astronomical phenomena which aroused public interest. These were the total eclipse of March 26, 1857, and the appearance of Donati's Comet in 1858. These brought to attention the necessity for providing the observatory with satisfactory equipment for observational work, and resources were granted to obtain a telescope of aperture 7¼ inches which arrived in April, 1861, and was probably first used to observe a comet discovered by an Australian, John Tebbutt, of Windsor. Scott commenced meridian observations to determine positions of stars in 1859, when the meridian telescope became available. The new equatorial telescope he decided would be devoted to "re-examination of the double stars of the southern hemisphere observed at the Cape of Good Hope by Sir J. Herschel", and the meridian instrument was used to observe the southern stars not on the programme of the Cape Observatory. Observations were made for time and in May, 1861, Scott made, with Ellery of Melbourne, a telegraphic determination of the difference in longitude between Sydney and Melbourne. Scott made observations of southern comets, including comet 1861 II (Tebbutt) which was interesting because, according to orbits calculated by Scott, Tebbutt and others, the Earth passed through the tail about June 29.

No account of Australian astronomy in this period would be complete without mention of the work of the amateur John Tebbutt. His observations extend over a period of fifty years beginning in 1854 when he was twenty. He gradually accumulated instruments until he acquired his 8-inch refractor. His record of work on comets is remarkable, for besides several discoveries, he observed more than 40 of them over as long arcs as possible for determination of orbits. He made systematic observations of double stars and a large number of miscellaneous observations of variable stars, phenomena of Jupiter's satellites and transits of Venus and Mercury. Altogether he published more than 300 contributions in scientific journals.

Scott resigned from his post in May, 1862, to go into church work successively as a master of a school, as warden of St. Paul's College within the University of Sydney and into parish work in the Goulburn Diocese. Tebbutt was offered the post but did not accept.

The next astronomer at Sydney, G. R. Smalley, also appointed at the recommendation of the Astronomer Royal, arrived in June, 1864. The Astronomer Royal prepared for the new Director of the Observatory a set of projects far beyond the resources that Smalley could command. Amongst these Smalley decided to go on with magnetic work and tidal observations and urged upon the Government that a trigonometrical survey should be started.

Smalley was responsible for the beginning of systematic recording of tides in Sydney Harbour. Fort Denison was selected for this purpose, and by 1866 the automatic records were being taken regularly (as they still are). The work on the tide gauge is mentioned from time to time in the diary kept by Russell and in letters to Smalley during his absences. Tidal work continued as a responsibility of the Observatory for many years.

Smalley continued the meteorological work and after a period when he apparently thought of curtailing the observations he decided rather to increase them and sent out a circular letter asking for volunteer observers. In this he said, "At the request of the Agricultural Society of New South Wales I am about to establish an extensive series of stations in different parts of the colony". The observers were to be issued with instruments and forms for recording rainfall, evaporation, maximum and minimum temperature and wind at an observation made at 9 a.m. on each day. Forty-three additional stations established in this way are listed in a paper laid before the Legislative Assembly in March, 1870.

A great deal of Smalley's energy in his later years was devoted to the project of establishing a base line for geodetic surveys which would "serve as a sound basis for future operations of the surveyor in carrying out a new and complete triangulation of New South Wales". He advocated also the measurement of an arc of the meridian which would afford "new and valuable data for the solution of the problem . . . of the figure of the earth". The establishment of the base line near Lake George proved full of difficulties including damage to instruments when the ship on which they arrived from England caught fire in the Harbour and had to be scuttled, trouble in getting heavy materials to the site and fluctuating level of the Lake. On one occasion one of his men who had to come from Sydney said that, if he had to pay his expenses, he would buy a horse and ride it up as it would be cheaper. At another time, Smalley, in a letter to the man he left in charge at Lake George, remarked when he was sending cheques: "I have crossed them all in consequence of the sticking up lately of the mail and do not like to send too much at a time."

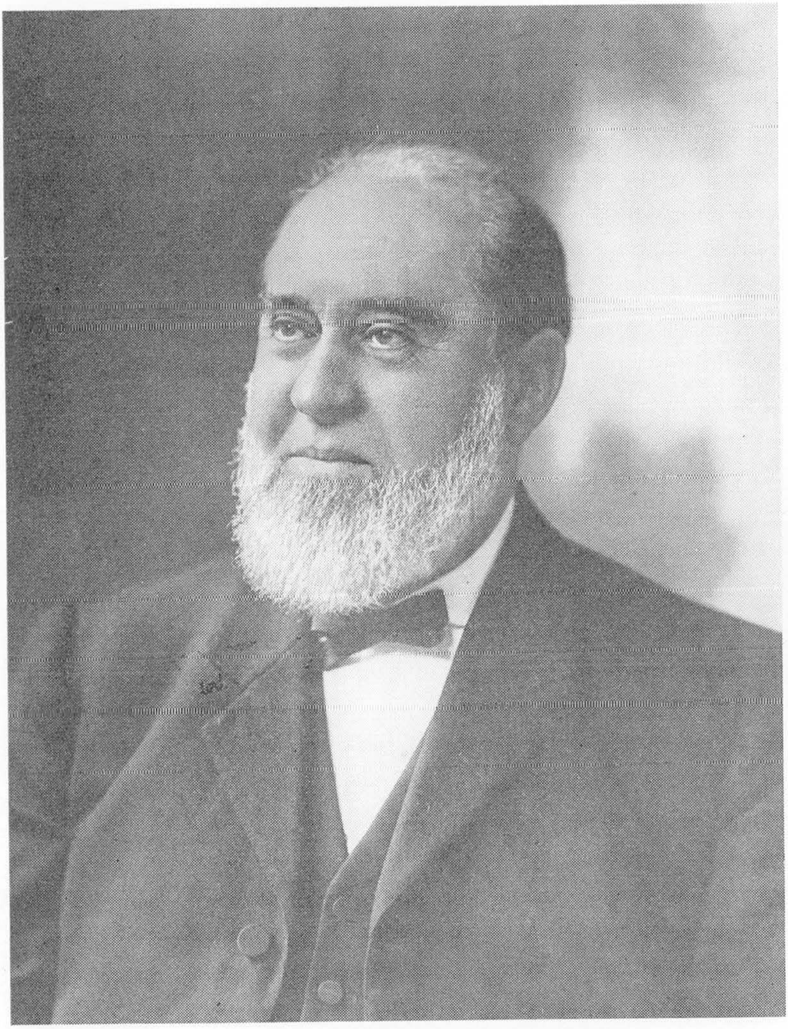
Smalley was an active member of the Philosophical Society of New South Wales. Suggestions made by him led to the change of designation to the Royal Society of New South Wales of which he became Vice-President from 1867 to 1870.

Immediately after the death of Smalley in 1870 his assistant, H. C. Russell, was appointed to succeed him. Russell was one of the early graduates (B.A.) of Sydney University. Immediately reversing Smalley's policy he decided to devote himself to astronomical work which could be carried out at the Observatory itself, handed the work on the base line over to the Surveyor-General and began energetically the work on double stars which was continued during the whole of the time he was Director of the Observatory. Measures of the orbital motion of double stars about one another afford the means of estimating the masses of the stars. With his assistants Lawrence Hargrave, J. A. Pollock and R. P. Sellors, Russell made a substantial contribution to double star work in the southern hemisphere.

At the time when Russell took office, preparations were being made to observe the transit of Venus on December 9, 1874. Having regard to the favourable situation of New South Wales for the observations, he decided to take part in the work, obtaining a grant for the purchase of an $11\frac{1}{2}$-inch refractor and other instruments to equip observing stations. Four stations were established and a very satisfactory number of observations made at three of them at Woodford, Goulburn and the Observatory itself. The results were given due weight in the resulting calculations of the solar parallax.

Among the instruments ordered by Russell during a journey to Europe in 1875 was a meridian instrument which was delivered in 1877 and was the basis of a great deal of work in future years.

Russell's important work towards the establishment of meteorology was actuated by a clear vision of the requirements of the country. As he said in a letter to the Consul for the United States in answer to an inquiry about irrigation, "after I was appointed astronomer—, knowing what important questions could only be answered by statistics about rain, rivers and evaporation, I began at once to collect them and educate the people to keep rain records". In the course of time, the effort to increase the number of places recording meteorological results by the enlistment of volunteer observers was very successful.



H. C. Russell, Sydney Observatory (1836-1907).

From the modest beginnings in the time of Scott and Smalley, the number grew to 290 in 1881 and to more than 1600 by 1898. In collaboration with Ellery (Melbourne) and Todd (Adelaide) Russell arranged in 1877 for the exchange by telegraph of meteorological observations from selected stations in each State. This was designed to be "of immediate value to our maritime community and others" and to "add largely to our knowledge of our climate generally and (. . . of . . .) movement of atmospheric disturbances". He began in February, 1877, the publication of a daily weather chart, the character of which was improved in 1888 to include more detail such as isobars. Russell wrote many papers on meteorological subjects. In his later years he did a great deal of work which he hoped would lead to recognition of periodical changes in climate and weather. He came to have a great deal of confidence in his 19-year weather cycle associated with the motion of the Moon.

Russell was interested in the application of photography to astronomical work and made some experiments on the measurement of double stars by photography and took photographs of the Moon with the 11½-inch telescope. When it was decided to hold at Paris in 1887 a conference which led to the decision to compile by photography a great Star Catalogue, Russell was invited and he undertook portions of the work on behalf of the observatories at Sydney and Melbourne. The whole sky was allotted to various observatories and eventually Sydney was assigned a zone centred on south declinations 52° to 64° and Melbourne from 65° to the South Pole. A photographic lens was ordered and a mounting designed by Russell made in Sydney by Morts Dock Engineering Company. In the early 1890's Russell took a number of photographs of Milky Way fields and some long exposure photographs of the Magellanic Clouds. The work on the Astrographic Catalogue began and, after a period during which it was hoped that measuring of the photographs might be done in Paris, measurements were started at a bureau in Melbourne with resources provided by the governments of Victoria and New South Wales. The astrographic telescope was moved in 1899 to Red Hill at the outskirts of the city.

Russell was a most energetic worker and in a list of his works there are 134 publications. He had talent as a designer of instruments among which may be mentioned an equatorial mounting with a yoke at the upper end of the polar axis similar to the one later adopted for the 200-inch telescope at Mount Palomar. He was a vigorous character and many of his letters to meteorological workers were blunt in the extreme. He was active in the organization of science, being several times President of the Royal Society of New South Wales and in 1888 was the first President of the Australasian Association for the Advancement of Science.

When Russell took sick in 1903, H. A. Lenehan was appointed Acting Government Astronomer and eventually Government Astronomer. At this time he cooperated with Otto Klotz of the Dominion

Observatory, Ottawa, in making observations of transpacific longitudes which for the first time closed the circuit of longitude around the world. In 1906 he started recording with a Milne Seismograph which continued in operation for about 40 years. His period was a difficult one because of uncertainty about the future of the Observatory at the time and he formed plans which did not bear fruit for its removal to a site either in the outer suburbs or in the country.

One of Lenehan's difficulties was his disagreement with H. A. Hunt who succeeded in separating the work of the meteorological branch and was building up his prestige as a step towards taking over the Commonwealth Meteorological services which were soon to be established. Hunt was appointed first Commonwealth Meteorologist in 1907. Lenehan died in May, 1908, and W. E. Raymond became Officer-in-Charge until 1912. He was a transit worker and with few changes continued the work with the transit instrument, magnetic observations and seismological recording. Interesting among his observations are those of Halley's Comet, which he first saw in September, 1909, and of which, with a party of local astronomers, made careful examination, including a photograph at Red Hill of the transit it made of the Sun on May 19, 1910 without any trace of it being seen on the Sun.

W. E. Cooke was appointed Government Astronomer and Professor of Astronomy of the University of Sydney in 1912. Cooke was a graduate of Adelaide University and was attached to Adelaide Observatory before he was first director of Perth Observatory when it was founded in 1896. He was very successful there, particularly in astrographic work which had been taken over from a South American Observatory, and came to Sydney with the understanding that arrangements would be made to have the Observatory moved outside the more heavily populated part of the city. A site was selected and Cooke devoted much energy to plans for the new Observatory but had to give it up in 1916. He then set about reorganizing the work of the Astrographic Catalogue, especially in the direction of obtaining the reference stars with the meridian circle. He also obtained two measuring machines and transferred the measuring work of the Catalogue to the Observatory. Among the meridian observations made during Cooke's time was a catalogue observed to supply reference stars for the zone south 30° to south 51°. This was done at the request of Professor Frank Schlesinger of Yale University Observatory in connection with his preparation of catalogues by wide angle photography.

Cooke, who was one of the early workers on receiving radio time signals over very long distances, carried out a series of experiments with the cooperation of the Astronomers Royal of England and Scotland and the Director of the French radio system.

Cooke, who retired from the Observatory in 1926, was succeeded by J. Nangle who, when he was appointed, was asked to report on "the simplest and most economical way of carrying on". He had to work with a shortened staff but nevertheless was successful in continuing the work on much the same lines as before. The financial depression in the early 1930's led to the closing of the Branch Observatory at Red Hill and the return of the astrographic telescope to Sydney. During his time, in 1940, the six dot radio time signal which still remains a feature of our broadcasting system was introduced. Nangle attached much importance to the educational work of the Observatory and arranged for public demonstrations to visitors. This activity has continued since his time and has in recent years been very much increased and contributes substantially to education in astronomy in our State through the assistance given not only to members of the public but also to teachers and university students. In any assessment of Nangle's work it must be remembered that he had three successful careers as architect, educationist and astronomer. He was for many years Director of Technical Education in New South Wales and was largely responsible for a tremendous growth of technical education there and in Western Australia and Tasmania. He died in 1941.

Under the direction of H. W. Wood it was decided to concentrate on work which would lead to the completion of the Sydney section of the Astrographic Catalogue. The lack of reference stars needed to reduce the measurements on the photographic plates to ordinary celestial coordinates was overcome by modifying the meridian programme so as to provide places of stars in those areas in which the catalogues of La Plata Observatory were deficient. At the present time the coordinates of the stars measured on plates for the whole zone have been printed in 52 volumes and only a final volume giving the history of the project and tabular matter to assist in its use remains to be published.

When Melbourne Observatory was closed, the continuation of the work on its astrographic zone was discussed and at the 1948 Assembly of the International Astronomical Union it was decided to ask Sydney Observatory to undertake its completion. At the time three volumes were published. Volumes 4, 5, 6 and 7 were prepared at Sydney Observatory and published in Paris under the direction of Dr. J. Baillaud, then President of the Carte du Ciel Commission of the Union with resources voted by the I.A.U. After Dr. Baillaud's death the last volume was printed in Sydney in 1963.

The astrographic zone allotted to Sydney includes a long arc of the Milky Way and is one of the largest in the sky. Including the Melbourne work the volumes represented measurements of nearly a million star images. The old plates are now being used to derive proper motions of variable stars in the Sydney zone and in some areas of special interest.

Interest in double stars has been revived. In 1948 a series of visual measurements was published. Later measures were made of double stars on the Sydney astrographic plates and on photographic plates taken with the astrographic telescope especially for the purpose. In this last case a number of exposures on the double star was made on each photographic plate. The accuracy is much better than can be achieved in visual measures.

In order to keep under observation the position of the Moon in its motion across the sky, occultations, disappearance of stars behind the Moon, have been observed as part of an international programme and more than 500 of these have been observed since the programme was begun. Since the times of the occultations depend on the rotation of the Earth, departure of the Moon's motion from that computed is largely due to non-uniformity in the Earth's rotation and the observation provides a means of investigating the variation of the rate of rotation of the Earth.

In 1953 the observation of the positions of minor planets which come south of the Equator was begun. The minor planets form a numerous group of bodies which have orbits around the Sun lying for the most part between the orbits of Mars and Jupiter. Over 2200 observations have been made. Many interesting dynamical problems are associated with the minor planets and there are some which are selected for purposes of fundamental astronomy including their use in defining the coordinate system in which star places are measured. Formerly observations of the Sun and the large planets were used but the observations of the minor planets are now more favoured because the observations are more precise. Sydney Observatory works on this part of the minor planet programme and in each case the selected minor planet is observed over as long an arc as possible.

In 1955 and 1956 an extensive series of plates was taken in cooperation with the Director of Yale Observatory, Dr. D. Brouwer, to provide material for the production of catalogues of southern stars. This was done with a Yale camera attached to the Sydney astrographic telescope. Yale Observatory has been prominent in this work for many years.

The Observatory is now undertaking a new catalogue of stars by photography in the Sydney zone of the astrographic catalogue. The photography is being done with a lens which gives excellent images of stars over a field of diameter 8°. The camera is attached to the old astrographic telescope mounted in a dome which replaces the old "temporary" one to which the telescope was returned in 1931. In 1966 a new measuring machine, made by Sir Howard Grubb Parsons, was delivered to the Observatory. This is designed to measure the plates taken with the Taylor, Taylor and Hobson lens. The measuring agent in each coordinate is a moire scale and the readings are digitized to one micron and recorded on punched cards for processing in a computer.

Melbourne Observatory

In 1853 R. L. J. Ellery was appointed by the Government of Victoria to establish an Observatory at Williamstown, near Melbourne, mainly for determining time for distribution to navigators. When a meridian instrument arrived, it was decided to place a geodetic survey of the Colony under the direction of the astronomer. However, a rapid growth of a railway depot near this Observatory soon rendered it unsuitable for astronomical work, and in 1863 a new building was completed in Domain Park close in to Melbourne. For some time the work was chiefly devoted to observations of the star positions required in the operation of the survey. The Observatory was responsible also for meteorological work.

In the 1850's there was a strong movement by the British Government to establish "a powerful reflecting telescope . . . in some fitting part of Her Majesty's Dominions". Melbourne Observatory had a Board of Visitors who were able to arrange for its establishment at their Observatory. The instrument was ready for work in August, 1869. This telescope was a 48-inch aperture reflector of cassegrain type, the mirror having a central opening of 8 inches in diameter to admit the passage of the cone of rays from the second mirror to the eyepiece. Since the mirror was of speculum metal, liable to surface deterioration, a second mirror was provided mounted ready for an attachment to the telescope. With one mirror in use in the telescope the other could have its surface reconditioned. This was a great disadvantage because reconditioning of the mirror meant also refiguring the optical surface. "The Great Melbourne Telescope" was for some years employed in the re-observation of nebulae and clusters which had been observed by Sir John Herschel at his period at the Cape of Good Hope from 1834 to 1838. Some photographs of the Moon were considered among the best obtained up to that time.

Several new pieces of equipment including an 8-inch refracting telescope and a photo-heliograph were obtained on the occasion of the transit of Venus in 1874. After this it became for more than 20 years a daily routine to take a photograph of the Sun on available opportunities. These were sent to Greenwich Observatory and the Solar Physics Committee in England for measurement and tabulation.

The positions of stars observed with the 5-inch meridian circle up to August, 1884, including some work done at Williamstown, were published in three general catalogues. Then a new meridian instrument of 8-inch aperture arrived from England. With this instrument the meridian observations were made during the remaining history of the Observatory. These included observations of the usual clock stars, a list of circumpolar stars and later stars needed in connection with the reduction of the photographic work of Melbourne astrographic zones.

The portion of the sky allotted to Melbourne Observatory in the astrographic programme was from 64° south to the South Pole. The astrographic telescope arrived in Melbourne in 1890. Like the one at Sydney, it consisted of a double telescope, the camera of which was 13 inches in aperture and of focal length to give a scale of one millimetre per minute of arc. The object glass of the guiding telescope was 10-inch. The work of Melbourne Observatory for the remainder of its active existence was largely centred around meridian and photographic observations required in this enterprise. Ellery retired in 1895 and was succeeded by P. Baracchi.

In 1907 the meteorological work of Victoria performed on a basis similar to that in New South Wales was also taken over by the Commonwealth Bureau of Meteorology.

After Baracchi retired in 1916 J. M. Baldwin, the last director of the Observatory, was appointed Government Astronomer. The meridian observations for the reference stars required for the Astrographic Catalogue were completed and the first three volumes of the photographic results of the Melbourne Astrographic Catalogue were published and distributed by 1930. Baldwin also operated a magnetic station at Toolangi. Although it was destroyed in the disastrous Victorian bush fires in January, 1939, it was rebuilt and has produced valuable magnetic data.

In the French annual *Connaissance des Temps* for 1914 an important list of stars for fundamental observation was published. From this list the stars accessible to observation from Melbourne were made the basis of a programme of work with the meridian circle from 1929 until they were completed about 1940.

Baldwin during the last few years at Melbourne Observatory occupied himself very seriously with the observation of variable stars and made a reputation for himself in this field.

Melbourne Observatory was closed as a State Institution in 1944 after which it was for about two years operated as a station of Mount Stromlo Observatory. The bulk of the equipment was moved to Mount Stromlo including the 48-inch Great Melbourne Reflector. The astrographic telescope came to Sydney Observatory and the 8-inch meridian instrument went to Greenwich Observatory. The valuable library was distributed mainly between the Public Library in Melbourne, Melbourne University Library and the Library of Mount Stromlo Observatory. Several valuable pieces of work were left uncompleted or unpublished, among them a large portion of the Astrographic Catalogue and the Melbourne meridian results from observations over many years. The record of the observations of the positions of the fundamental stars was transferred to Mount Stromlo for editing and publication but eventually in 1958 the offer of Pulkovo Observatory near Leningrad to reduce and publish a catalogue based on this work was accepted. At the 1964 meeting of the International Astronomical Union it was reported that the observations of the 2367 stars were being prepared for publication.

Adelaide Observatory

South Australian work in astronomy and meteorology began seriously through the appointment in 1855 of Charles Todd as Supervisor of Telegraphs and Astronomical Observer for South Australia. Like Scott of Sydney, Todd received training under Airy at the Royal Observatory at Greenwich and, like Russell, he at once saw the need, especially in an agricultural community, for reliable records of climate and rainfall throughout the whole State. He, too, organized observation by country postmasters who were supplied with rain gauges, barometers and instruments to measure wind. The work thus began formed the basis of knowledge of the climate of South Australia and the Northern Territory. The results were published in annual volumes from 1876 to 1907. For many years the weather service was the principal work of the Adelaide Observatory, and it is clear that Todd and Russell were enthusiastic in their meteorological work. In this they were both remarkably able to serve two masters, for Todd was developing the telegraph service which was carried overland to Darwin to provide the link with Europe and Russell was showing equal activity in astronomy.

At first no astronomical work was done, but in 1867 a meridian instrument originally at Williamstown Observatory was loaned to Adelaide by the Victorian Government to assist in observations to establish the position of the boundary between the two States. This instrument was also used for the purpose of determining local time. In 1880 a 6-inch transit circle similar to the one at Sydney Observatory was installed. It was used in a programme to determine positions of stars between 0° and 15° south. Observations were made for latitude using stars crossing the meridian near the zenith and a number of circumpolar stars which were observed above and below the pole throughout the year. In 1868 Todd and Smalley of Sydney worked together to determine the boundary between New South Wales and South Australia and in 1883 Todd cooperated, using his new transit instrument, in the first determination of Australian longitudes to employ the cable to transmit time signals from Greenwich to Australia. In addition to the meridian instrument there was an 8-inch equatorial telescope which was employed on observation of Jupiter's satellites and of the surface details of the planet. A large series of drawings of Jupiter was published in 1913.

When Sir Charles Todd retired in 1906, he was succeeded by R. F. Griffith who, however, soon transferred to the Bureau of Meteorology under the Commonwealth Government as chief assistant to H. A. Hunt and was followed by G. F. Dodwell as Government Astronomer in June, 1909. From that time the main observations were for time determination with the transit instrument, some observations of positions of stars for the Sydney Astrographic zones and field latitude and longitude determinations. A magnetic survey including many places in South Australia was carried on between 1929 and 1937. During this work the latitudes and longitudes of the stations were determined in connection with the survey.

Adelaide was associated with early development of wireless communication and in 1900 Todd and his son-in-law, Professor Bragg, established a station in the grounds which transmitted signals over a few miles. In 1921 radio signals were used for a series of longitude observations in the field and the first radio longitudes completely girdling the Earth were made in connection with fixing the boundary with Western Australia, the 129th meridian.

An important activity of the Observatory in the last years of its operation was the work on latitude variation. This was done as part of the activity of the Commission on Latitude Variation of the International Astronomical Union and in association with similar work at La Plata Observatory which is near the same latitude and could thus observe the same stars near the zenith. The determinations at the two observatories enabled the movement of the pole of rotation of the Earth to be followed. The zenith telescope for this work was installed in July, 1931, and continued in operation to 1940 about the time when Adelaide Observatory was closed. The last report of the Observatory to appear in the Monthly Notices of the Royal Astronomical Society was in 1939, and the Observatory was demolished in 1952.

Perth Observatory

Perth Observatory was established in 1896 under the direction of W. E. Cooke, who came from Adelaide Observatory. It was equipped with a meridian instrument of 6-inch aperture, an astrographic camera of the standard pattern used by the observatories cooperating in the astrographic programme and with two measuring machines for the measurement of photographic plates taken with the instrument. In 1900 the Observatory accepted responsibility for the astrographic work in the zone between 31° and 41° south which had been relinquished by the Observatory of Rio de Janeiro. This work, pursued with admirable efficiency, became a main activity of the Observatory for many years. The photography was completed together with the transit work necessary to find the positions of reference stars needed for the reduction of the plates. The actual publication of the photographic catalogue began in 1911 and for some years further publications were issued.

After Cooke left Perth to come to Sydney in 1912, H. B. Curlewis was acting director and later Government Astronomer. Perth Observatory went through a period of difficulty. Even in Cook's time a number of plates were measured at Edinburgh, and eventually several volumes of the Catalogue were completed there and published with funds made available by the International Astronomical Union.

After Curlewis retired in 1940 the direction of the Observatory was taken over by H. S. Spigl who worked with vigour to renew the observational activities of his Observatory. During the whole period seismographic work had been carried on and Spigl improved this and in 1956 obtained additional appointments to the staff of the Observatory. During the International Geophysical Year he cooperated in observations of the position of the Moon with a Markowitz Moon Camera attached to the astrographic telescope. A good deal of work was done on the transit telescope to bring it once more into satisfactory operation. In 1961 a programme of photography of suitable galaxies in the Perth zone was undertaken in a programme suggested by Professor A. N. Deutsch of Pulkovo Observatory to determine the proper motions of the stars of our galaxy relative to the distant galaxies. The object of this is to find a value of precession relative to a standard of non-rotation set by the system of the galaxies. In 1962 it was decided by the Government of Western Australia to take over the site of the Observatory in Perth for a large building to contain Government Offices. In the same year H. S. Spigl died and B. J. Harris was in charge for the critical period during which it was decided to build a new Observatory in the Darling Range about 20 miles east of Perth. Comparative tests of observing conditions as between Perth and the new location indicated that, although the amount of fine weather would be similar it could be expected to be better as regards transparency and seeing conditions. Here the Observatory may look forward to a new period of activity and service to astronomy. The excavation for the foundations of the instruments at their new site was done by drilling so that blasting might not produce instability. The base for the piers of the transit circle was built of old bricks to minimize any change that might arise from aging. At this time a new coordinate measuring machine by Zeiss was delivered.

In August, 1964 all observations at the old Observatory ceased and the instruments were dismantled for removal. The seismological work, stopped with the dismantling of the old Observatory, will not be recommenced at the new. Before the move to the new location a number of plates of the Deutsch programme were taken and several open clusters were photographed. In 1964 B. J. Harris was appointed Government Astronomer. The errors of the Zeiss measuring machine were measured while it was still in Perth and proved to be so small as to be almost negligible. Satisfactory progress was made, and the excellent buildings of the new Observatory were occupied in December, 1965.

A series of measurements of proper motions of open clusters is being undertaken, and it is expected that this will be a regular feature of the work of the Observatory for clusters which appear in the zone for astrographic work. Perth Observatory has made an agreement with Hamburg Observatory which has an expedition at the new site to carry on transit observations on a programme of southern reference stars. Hamburg Observatory has reconditioned and substantially modernized its meridian instrument for this work, and there is no doubt that the programme will do valuable work in this field in which observations are much needed.

The Commonwealth Bureau of Meteorology

Before federation all the meteorological work was carried on by the State Government astronomers who published annual volumes of meteorological statistics, mainly rainfall, temperature and river heights. After this it was decided, as provided in the Constitution, to establish, with headquarters in Melbourne, the Commonwealth Bureau of Meteorology to take over the weather services on a Commonwealth-wide basis. The first Director, H. A. Hunt, previously of Sydney Observatory, took office in 1907 with a nucleus of professional staff recruited from officers who had worked in the observatories.

At the beginning the Bureau was concerned, as the observatories had been, with synoptic meteorology, the taking of observations and issuing of forecasts, and climatology, the compilation of weather statistics and their practical application to man's activities.

Weather forecasting was based on surface measurements to show the movement of weather systems across Australia, with a synoptic chart compiled only once each day, combined with experience of what happened in many cyclones and anticyclones. It was realized that the knowledge should be extended and one of the subjects for study listed in a conference held near the time of the establishment of the Bureau was "Exploration of the Upper Air". The investigations in this field were begun in 1913 by Griffith Taylor who was then a member of the staff in Melbourne. Balloons were used to carry aloft small meteorographs equipped to measure pressure, temperature and humidity. This gave some useful information on the higher parts of the atmosphere and eventually was increased because of the necessity for knowing and being able to forecast conditions at levels used in aviation. The pilot balloon observations were later undertaken in Melbourne by a small Research Section set up under E. Kidson largely to observe winds. This was developed by 1937 to an Australia-wide service which makes immediately available the meteorological elements, particularly the wind, in the upper air.

The intensive study in Norway of frequent synoptic charts had led to the theory of frontal analysis which was developed in the Research Section and first used in forecasting in 1936. The method came in for special attention, under H. M. Treloar, during wartime and some differences were disclosed in the behaviour of cold fronts in the Australian region from that in Europe where the method originated. Everyone who examines the meteorological charts published in the daily newspapers is now familiar with the movements of cold fronts over the country and their influence on the weather.

The rapid growth of aviation, both civil and military, made heavy demands for increase of meteorological services and so more frequent surface observations for synoptic charts and additional data on winds at various levels, visibility and cloud ceiling were required. At a number of aerodromes stations were set up to make pilot balloon and ground observations. The Aerodrome Meteorological Office was established to make available to pilots as comprehensive as possible a picture of the conditions for their flights. The frequency of observation was increased and when war came the paramount importance of the service to aviation led to the transfer of the Bureau to the Royal Australian Air Force. Operational bases were established in islands of the South-West Pacific and later further afield, and eventually the service grew to about five times its peace-time strength.

The need for weather intelligence, both climatological for long range planning and synoptic for day-to-day military purposes led to establishment of a Climatological Intelligence Section under J. Hogan. The demands on this section grew as the area of operation was extended. The climatic studies indicated how the weather in the tropical areas north of Australia is linked closely with the prevailing monsoonal winds rather than the movement of pressure systems as in higher latitudes of which meteorologists had most experience. Forecasters were led to doubt the existence of fronts in low latitudes and they abandoned the use of frontal analysis in favour of streamline analysis and delineation of convergence zones with which clouds and unfavourable weather for flying were associated.

The amount of information available to Australian meteorologists became greater than ever before, giving them a more detailed picture of conditions in the Earth's atmosphere up to a height of ten miles. Upper air conditions were obtained by radio-sonde in which pressure, temperature and humidity were measured by instruments carried by a free balloon and the information transmitted by radio for immediate availability to meteorologists. Radar tracking of the balloons resulted in observations of winds to greater heights in all weather conditions. With this new information available meteorologists could now construct constant pressure charts for the 10,000 feet and 20,000 feet levels. Later a change was made to charts of constant pressure surfaces, the contour lines of heights of constant pressure replacing the isobars. Such charts were useful aids to forecasting winds for flying and extension to still higher levels provided data which formed the basis for development of new understanding of the circulation of the atmosphere.

When the Bureau of Meteorology was transferred back to the Department of the Interior, with loss of the majority of the war-time newcomers who returned to their civilian occupations, it was found that demand for meteorological information for primary and secondary industry and for aviation, both internal and international, had greatly expanded as compared with the pre-war era. The great strides made during the previous years in apparatus and techniques made it possible to cope with the demand. A large computer is being installed to deal with the enormous amount of data which has to be used in meteorology.

The Bureau cooperates in the activities of the World Meteorological Organisation of which the Director of the Bureau, W. J. Gibbs, is senior Vice-President. Melbourne is a "World Weather Centre", one of only three, the others being Washington and Moscow. By this arrangement the Melbourne Bureau will collect synoptic weather information from surrounding meteorological services for exchange with the other centres to construct a series of world synoptic charts for research.

The Bureau gathers data for a wide range of purposes such, for example, as the data on rainfall for the design of large dams being built by State or Commonwealth Departments or estimation of flood maxima necessary for design of bridges. A great deal of material is published in a Monthly Weather Review containing a summary of the weather over the whole of Australia only a few weeks after the end of the month to which it applies. Many Bulletins and Studies have been prepared on various aspects of meteorology, climatology or hydrometeorology. The scientific divisions of the Bureau are the Services Division, which carried on most of the public services, and the Research and Development Division. Among projects at present active are theoretical and observational work on the association of the jet stream with the movement of surface systems, a study of clear air turbulence, which is of importance in aviation and cooperation with other countries in the study of Antarctic meteorology.

As the source of information and predictions of weather which are reported by every daily newspaper and radio or television station the Bureau is the best known scientific service of Australia.

Riverview College Observatory

Riverview College Observatory was founded as a seismological station in 1908 under the direction of Father E. F. Pigot, and since then work of distinction has been carried on in this field. After Father Pigot's death in 1929 he was succeeded by Father W. J. O'Leary, who had as assistant Father D. J. K. O'Connell, who was to become Director in 1938. Under O'Leary and O'Connell variable star work began in 1935. The Observatory was equipped with three cameras, and areas of the southern sky including most of the Milky Way from Puppis to Scutum were regularly photographed. The programme included a search for variable stars brighter than 11·0 magnitude, about 100 times fainter than visible to the naked eye, at maximum, studies of cepheid variables, variables with double periods and eclipsing binaries. Riverview quickly gained a high reputation in this field.

In 1952 Father O'Connell was appointed Director of the Vatican Observatory at Castel Gandolfo near Rome. The astronomical work was carried on for a time but ceased about 1960. Seismological work of great value continues.

Mount Stromlo Observatory

At the beginning of 1910 the Government of the Commonwealth decided that tests should be made to determine whether Mount Stromlo, about seven miles west of Canberra within the Commonwealth Territory, would provide a suitable site for an astronomical observatory. The selected site is on the top of a group of hills at a height of about 600 feet above the surrounding country. A 9-inch refracting telescope donated by J. Oddie of Ballarat was mounted in a dome on the site together with a camera with a 6-inch lens, a prominence spectroscope, and a filar micrometer. P. Baracchi and J. M. Baldwin of Melbourne Observatory visited the Observatory on a number of occasions to carry out the observations at the conclusion of which it was recommended that the site was suitable.

It was not until the middle twenties that W. G. Duffield, who had been a powerful advocate for the establishment of the Observatory, was appointed its first Director. The institution was established as the Commonwealth Solar Observatory since a main object was to take a part in keeping the Sun in continuous observation by filling the gap in longitudes of observatories carrying on this type of research. Observations of solar radiation were begun in 1926 when the headquarters of the Observatory were established in the Hotel Canberra before buildings could be erected on the mountain. The main instrument in the new building was a solar type telescope which was built for the Observatory by the Ordnance Factory of the Department of Defence. Sunspot observations were made and the Observatory was equipped with a Hale spectrohelioscope with which monochromatic observations of the Sun were made. A 30-inch telescope was donated to the Observatory by J. H. Reynolds, President of the Royal Astronomical Society.

With the sun telescope research of great value on the intensity of the Fraunhofer lines was carried out by C. W. Allen who is now Professor of Astronomy at London University. Intensities and contours of the spectral lines were measured over a large part of the solar spectrum (4036-6600Å). During the same period a catalogue of the luminosities and spectroscopic parallaxes of bright blue stars was published by W. B. Rimmer who was Officer-in-Charge of the Observatory after Duffield died in 1929. Besides these activities, measurements were made of cosmic radiation, the potential gradient of the atmosphere and the brightness of the daylight sky. Later the sun telescope was used to investigate the bands of water in the atmosphere from 11,300 to 14,700Å. A 6-inch telescope was fitted to make sunspot sketches for comparison with the surveys made with the spectrohelioscope.

In 1939 R. v.d. R. Woolley was appointed as Director of the Observatory. He came from the Royal Observatory at Greenwich and the Observatories in Cambridge. For a time the work continued much as before but it was interrupted by the War of 1939-1945 when the Observatory was converted to an optical munitions factory. This service was of great importance because the Australian departments had previously been encouraged in the belief that supplies of this kind would be continuously available from sources in Europe. When it became a matter of great urgency to find a substitute source in Australia, the Observatory together with some university Departments of Physics filled the gap. The work on the Sun was continued, although at a reduced level.

After this period the Observatory resumed its more natural scientific work and enlarged its activities into general astronomy. Visual observation of double stars was undertaken with the 9-inch Oddie telescope and photo-electric observation of variable stars was commenced. To correspond with the wider sphere the name of the Observatory was changed to the Commonwealth Observatory which first appears on the annual report for 1945. The Observatory continued solar work with spectrohelioscope observations, sketching of sunspots and theoretical investigation of the solar corona. The time service was established. The 30-inch Reynolds reflector was prepared for photo-electric monochromatic photometry of stars which was commenced together with a colour gradient programme for the measurement of the surface temperature of southern stars.

After Melbourne Observatory was closed the Great Melbourne Telescope was transferred to Mount Stromlo and plans were begun to modernize it for spectroscopic and photometric research. The 48-inch speculum mirror was replaced by one of glass and most of the mounting rebuilt to form the present 50-inch telescope. After Sir Harold Spencer Jones, the Astronomer Royal, visited the Observatory in 1947 and strongly supported the recommendation that a major telescope should be made available to the Observatory the Commonwealth Government ordered from Sir Howard Grubb Parsons, Newcastle-upon-Tyne, the 74-inch telescope which is still the largest telescope of the Observatory.

In February, 1952, a serious bush fire destroyed the pine forest on the slopes of Mount Stromlo around the Observatory. Due to the energy with which the fire was fought by members of the staff, the buildings and instruments of the Observatory were saved with the exception of the workshop. This has since been rebuilt and the Observatory is now equipped with a workshop which would be the envy of most observatories. About 1950 it was decided to move the Yale-Columbia southern station from Johannesburg to Mount Stromlo, and the Observatory of the University of Uppsala in Sweden accepted an invitation to establish a 26-inch Schmidt camera on Mount Stromlo. By 1955 domes had been erected on Mount Stromlo by the Commonwealth Government for both of these Observatories and the installation of the 26-inch Yale Columbia refractor was nearing completion. At that time the 74-inch telescope and the 50-inch telescope had been erected and were at the testing stage. The 30-inch Reynolds reflector was being employed to obtain spectra for radial velocity measurements and photo-electric observations of the brighter galactic cepheids and objects in the Magellanic Clouds. After the Australian National University was established in Canberra Woolley was appointed Professor of Astronomy. It was decided to transfer the Observatory from the administration of the Department of Interior to the University. At the same time its name was once more changed to become Mount Stromlo Observatory. In 1955 Professor Woolley resigned to take up the office of Astronomer Royal at the Royal Greenwich Observatory at Herstmonceux. He was knighted at the beginning of 1963.

After Woolley's departure, A. R. Hogg was Acting Commonwealth Astronomer until B. J. Bok from Harvard University arrived in 1957 to take the position of Professor of Astronomy and Director of the Observatory, when the transfer to the administration of the School of Physical Science in the Australian National University took place. During the following years the instrumental facilities of the Observatory were continuously improved. Although tests revealed that the mirror of the 74-inch telescope was astigmatic, it was put to use for photometry until a replacement mirror could be installed while the original one was being refigured. Auxiliary equipment in the way of spectrographs and photo-electric photometers including a multi-colour photometer was provided. A coudé spectrograph capable of providing spectra with high dispersion was planned for the 74-inch telescope by T. Dunham and put into operation about 1961. A nebular spectrograph was provided for the telescope and the setting accuracy was substantially improved. The 50-inch telescope went through a similar evolution coming into observational operation with excellent new mirrors made by Grubb Parsons. It has been equipped to measure the polarization of celestial objects.

The electrical, optical and photographic workshop was erected beside the new machine shop which received further equipment. These two facilities are extremely useful for development of the instruments of the Observatory. The photographic zenith tube was erected, adjusted and was being tested by 1957. It is in continuous use for the determination of time and the measurement of variation of latitude. At this time observers arrived from Sweden to man the Uppsala telescope which has proved a valuable piece of equipment on the Mountain and the Uppsala observers exchange time on their instrument for time on the instruments of the National University. During this period the use of automatic means of data processing has been widely introduced into the work of the Observatory. Many instruments have been digitized and an automatic computer installed, to be replaced in 1964 by one of greater capacity.

Even before his arrival, Bok expressed dissatisfaction with Mount Stromlo as a site for a major observatory because of the too great frequency of cloud and because the lights of the city of Canberra were beginning to intrude in the sky. This was also felt by the Yale-Columbia administrators who were looking for a site for development in the southern hemisphere. In 1957 a site testing programme was begun by the Yale-Columbia organization shortly afterwards to be joined by Mount Stromlo. This had the objective of finding a site for the Yale-Columbia Southern Observatory and a field station for Mount Stromlo. This field station was to be within accessible distance of Mount Stromlo, but soon it was decided to include as a further aim the search for the best site to meet the possibility of having a large telescope established in Australia. Meteorological observations and observations of seeing were being made at sites in New South Wales, Victoria, South Australia and Western Australia. The decision to build the field station on Siding Spring Mountain at an altitude of 3,800 feet in the Warrumbungle Mountains was made in 1962. It had been selected as favourable at the preliminary meeting at Sydney Observatory in 1957. Site testing was still carried on simultaneously at Siding Spring Mountain and at Mount Searle in South Australia. A 40-inch reflector designed for photography and photometry already ordered for the field station came into operation in 1964. As regards the proportion of clear sky and good seeing the Siding Spring site is proving very satisfactory. A 16-inch telescope has also been installed on the mountain and, more recently, a 24-inch telescope with a rotating tube for studies of polarization. It is necessary to have a rotating tube in order to be able to eliminate any polarization which may arise within the instrument itself. In the meantime the Yale-Columbia organization who had decided to establish their southern station in South America donated the 26-inch refractor to the Australian National University.

Even before the Observatory came under the administration of the Australian National University there were people working in the Observatory for higher degrees but now the new organization favourable to advanced education in astronomy led to expansion of research facilities suitable for graduate students working for Ph.D. degrees in the Australian National University.

Because of the great importance for astronomical research of the areas of the Milky Way in the southern hemisphere and the strategic position occupied by the Magellanic Clouds as the nearest of the galaxies to us in research into the stellar populations and the contents of galaxies, it is important that advanced astronomical equipment should be situated in the southern hemisphere. The proximity of these systems allows detailed study of their contents for comparison with the Milky Way and for research into the character of galaxies throughout the universe. Bok presented this point of view with vigour and persistence, particularly towards educating the public from whom the resources would have to some. A committee of the Australian Academy of Science examined the question and made a recommendation that a telescope of 150-inch aperture should be made available in Australia, either in cooperation with a northern hemisphere country or from Australian resources alone.

Mount Stromlo astronomers have been responsible for a great deal of valuable research during these years. Important work has been done on the structure and evolution of the Milky Way and of the clouds of Magellan, on spectrographic research relating to the physics of the atmospheres of stars and their line of sight motion and on star clusters and nebulae. Only a few items can be mentioned. Much attention has been devoted to the stars of the Magellanic Clouds, inaccessible from the observatories of the northern hemisphere, particularly to their many star clusters. S. C. B. Gascoigne has been particularly active in this area. The photometric information about a group of stars can be plotted in an array which shows the relation between colour and brightness and it appears that there are globular clusters in the Clouds which are blue in colour with no counterpart in the Milky Way while others have a colour characteristic similar to the ones that occur in our Galaxy. The clusters within the Milky Way were the subject of a good deal of work by A. R. Hogg who prepared colour-magnitude arrays for several clusters. This work is of value as giving an indication of the age and distance of the cluster and contributes to our knowledge of stellar evolution. A. W. Rodgers carried out an interesting research on the coal-sack, the obvious dark patch in the Milky Way near the Southern Cross. This, situated at a distance of 500 light years, absorbs almost two magnitudes of the light of more distant stars. Measurement of brightness of the stars now takes a place of fundamental importance in astronomical research, and reliable measurements of brightness of stars depend on having good sequences of stars of carefully measured brightness available for comparison with stars which are to be investigated. Bok and his associates, including his wife, Dr. Priscilla Bok, prepared several such sequences in various areas of the sky both in the Milky Way and in the Magellanic Clouds. Valuable photographic atlases which provide a basis for research into interesting areas which are revealed on them have been prepared for the Milky Way and the Magellanic Clouds. The Observatory, particularly B. E. Westerlund and his associates, has taken part in identifying the optical counterparts of radio sources discovered in the southern hemisphere.

O. J. Eggen who arrived in July, 1966, to take the post of Professor of Astronomy and Director of the Observatories had previously spent periods as a guest astronomer on Mount Stromlo. With a wide range of fruitful astronomical activity to his credit he has had an immediate success here with the announcement at the end of April, 1967, of the agreement between the Governments of Australia and the United Kingdom to build a 150-inch telescope for Siding Spring Mountain. The Observatories continue with a wide range of astronomical research in the Milky Way and the Magellanic Clouds including photometry and spectroscopy of individual stars, the study of polarization both interstellar and intrinsic to the stars and research on galaxies identified with radio objects. To correspond with the new circumstances the name Mt. Stromlo and Siding Spring Observatories has been adopted.

Division of Radiophysics, Commonwealth Scientific and Research Organization

In 1932 it was discovered that energy reaches the Earth from space in wave-lengths which belong to the domain of radiophysics. The atmosphere transmits radio waves of length between a few millimetres and 15 metres. In the newly accessible part of the spectrum the different origin of the radiation and its interactions with matter afford new information about celestial objects and, since the radio waves penetrate better than the optical radiation the great clouds of gas and dust which lie between the stars, they can give a less obscured view of distant parts of space. In the development of radio astronomy Australia has played a crucial part. During the war of 1939-1945 the Radiophysics Laboratory in work on radar had developed substantial resources in radio science. In 1945, with E. G. Bowen as head of the Division, it was decided to give attention to the radio waves from space, and radio astronomy soon became a major activity of the Laboratory. Some members of this team have said that at first they felt that the field might soon be worked out, but as time went on the horizons have broadened and now radio asronomy is a permanent important branch of astronomical science. Vitally important information is derived about the physics of the Sun and planets, interstellar material, the structure of the Milky Way, of other galaxies and possibly of the universe.

The success of the group in the Radiophysics Laboratory, early in the field and inspired by the leadership of J. L. Pawsey, was so great as to induce other organizations to enter radio astronomy, and several members of the team are now directing radio astronomical work in laboratories in other countries as well as in Australia.

The great difficulty of working with radio waves, so very much longer than those of the optical part of the spectrum, was that of resolving fine detail and specifying the position of the body being observed. The capacity of a telescope to do these things is proportional to the number of times the wave-length is contained in the aperture, and to have a resolution equal only to that of the unaided human eye a radio telescope operating at a wave-length of one metre would need to be more than two miles across. However, radio waves are of the same kind as those of light, travelling with the same velocity and exhibiting the phenomena of interference and polarization, and soon the radio astronomers were applying with great ingenuity the knowledge gained in the science of optics to control and interpret the energy received by their aerials.

A radio aerial of ordinary size receives energy from a wide angle. An early method of improving the resolution was to combine the waves from two widely-separated aerials. The reception is then strong from the directions in which the waves received by the two aerials reinforce one another and weak from the directions in which they cancel. The interference, which parallels the phenomenon observed in optics, produces an aerial pattern with lobes of alternately strong and weak reception. An observation may be made by allowing the radio source to drift through the aerial pattern which is fixed relative to the Earth and carried around by the Earth's rotation. However, if a longer delay can be introduced between one aerial and the receiver, the lobe pattern is displaced. For example, if there is a delay from one aerial relative to the other, the pattern is displaced towards the aerial for which the delay occurs. By changing the delay the aerial pattern can be moved and made to sweep over a source. In order to decide in which lobe the source lies a second observation may be made with a different aerial pattern. Then only the true position coincides for the two systems. Beginning in 1946 an ingenious variation of this idea was used in an aerial directed across the sea from a cliff-top east of Sydney. The lobe pattern was then produced by the interference between the direct rays and the rays reflected from the sea. Identification of solar radio sources with disturbed areas of the Sun was first made with this instrument which was later applied to other celestial sources.

If additional aerials are added in the same line, the waves received from the perpendicular bisector of the set of aerials still reinforce one another but away from this tend to cancel and so the lobes can be made more narrow or separated more widely and reception from the side lobes decreased. The beam is still wide in the plane perpendicular to the line of aerials. The cross aerial designed by B. Y. Mills, now Professor of Astronomy in the University of Sydney, to survey the sky at wave-lengths of a few metres was derived by combining two long aerial arrays in the form of a cross. Each produced a fan beam. The rotation of the Earth causes each source to pass through the reception fan of the east-west array of aerials while the beam of the north-south array can be set to different distances from the equator by phase adjustments of the kind described for two aerials. When the outputs from the two aerials corresponding to each point of sky are multiplied together electrically, reception is from the narrow beam where the maxima of the two fanned aerial patterns cross. This is in a narrow "pencil beam" which has a width approximately the same as that of a parabolic aerial of a diameter equal to the length of the arms. Two crosses were constructed for use respectively at $3\frac{1}{2}$ metres and 15 metres.

An instrument, similar in principle to the Mills Cross, was designed by W. N. Christiansen, now Professor of Electrical Engineering in the University of Sydney, to give pictures of the Sun at wave-length 20 centimetres. Each arm contained 32 paraboloids of diameter 19 feet.

The most obvious way of receiving energy at radio wave-lengths is, as in the optical spectrum, to collect it in a large paraboloid which reflects it to a focus where it is picked up by a receiver to be amplified and recorded. Aerials of this pattern have been used from the beginning either singly or as elements in interferometers. The construction of a large radio telescope of this kind, with funds from the Carnegie Corporation, the Rockefeller Foundation and the Australian Government, was approved and studies for design commenced in 1955. The site selected for this now famous instrument of aperture 210 feet is near Parkes, in an area of low electrical noise. The instrument is of altitude-azimuth type but controlled by a small master equatorial which it is made to follow by a servo system. It was commissioned in 1961 as the principal instrument of the Australian National Radio Observatory at Parkes. It can receive radiation of wave-lengths between a few centimetres and several metres and of any polarization and point with high precision over a large part of the visible sky. It is used intensively for almost every type of radio radiation from almost every celestial object which provides such emission except the Sun. In order to improve the resolution of the 210-foot, to determine positions of radio objects more precisely and structures in more detail, it was provided in 1963 with a companion

60-foot telescope moved from its former site at Fleurs near Sydney. Together the two paraboloidal aerials form an interferometer. The 60-foot telescope is mounted on a carriage on a rail system to provide variable spacing and orientation.

The instrumental developments so far described are designed to measure the position and structure of the sources and their intensity, including its variation with time, but in addition to this it was desirable to have an instrument to measure the spectral distribution of the energy. This was particularly needed for observation of the Sun on which rapid change and violent events occur. So in 1949 the first solar radio spectrograph designed by J. P. Wild was erected. This consisted, after an earlier version was superseded, of four aerials each of which was connected to a receiver which could be quickly tuned across its frequency range. Thus the whole range from 25 to 210 megacycles per second was examined in half a second. The recording thus displayed continuously the changes occurring in radiation from sources whose position could be measured by one of the high resolution radio instruments and correlated with optically-observed features. A later version considerably extended the range of frequencies in a single aerial and receiver. In modernized form the radio spectrograph is being installed at the C.S.I.R.O. Solar Observatory at Culgoora near Narrabri.

Wild and his colleagues have completed for the C.S.I.R.O. Solar Observatory an instrument which will give, in radio emission at wave-length 3·75 metres, an image of the Sun and the surrounding corona each second. The pictures may later be viewed in speeded-up form as a motion picture. It is hoped to apply the instrument also to study the Milky Way and other galaxies. The aerial array for this high resolution radio instrument consists of 96 parabolic reflectors each 45 feet in diameter. They are arranged around the perimeter of a circle about two miles in diameter. The resolution is $3'{\cdot}5$, that is an angle about a tenth of the diameter of the Sun.

The distribution of the radio radiation from the Sun extends beyond the area of the Sun as seen optically. In monochromatic light in some lines of the optical spectrum there are seen bright areas called plages which are associated with active areas of the Sun, often with sunspots. The slowly varying bright areas of the radio pictures of the Sun in the decimetre wave-lengths are located over plage areas and correspond to temperatures of over 1,000,000° K. This corresponds to the temperature of the corona at the same height but the density must be greater. Monochromatic examination of the Sun, particularly in the red line of hydrogen Hα, often reveals near developing sunspots a sudden increase of intensity of light. Several types of radio disturbance may accompany these *flares* and the radio spectroscope has been a major tool in their observation. In the initial stage of the flare there are short duration bursts of radiation and these are followed by more persistent types. The wave-lengths of the emission drift during the bursts from about 1·5 metres to ten times as long. The flares are probably due to energy communicated to the ionized gases by the changing magnetic field of the sunspot, and compact groups of electrons thrown out from the disturbances produce the bursts. A supersonic shock front generated at the time of the flare explosion moves outward into the corona, and the drift in wave-length occurs as the disturbance moves into the less dense parts of the solar atmosphere. A radial speed of 1800 km/sec has been observed.

Surveys of radio sources with the Mills crosses, revealing 1300 by 1956, showed that the stronger sources are mainly concentrated near the Milky Way while the bulk of the weaker ones are more or less randomly distributed over the whole sky. This suggested that there might be two classes, the stronger ones scattered in the Galaxy and many of the weaker ones arising in the galaxies of more distant space. This picture became established.

The radiation of these sources arises almost entirely in the interstellar medium although some has been detected from one class of stars. In the continuum some is generated by thermal processes in the regions where the interstellar material, mainly hydrogen, is ionized by the optical radiation of stars embedded in it. Other sources arise in remnants of supernovae the most famous of which is the source Taurus A, the first one identified by John Bolton with the Crab Nebula which in turn arises from a supernova seen in 1054. This radiation arises when rapidly-moving electrons are accelerated in a magnetic field and is called synchrotron radiation because it was first observed in the great machines, called synchrotrons, designed for accelerating particles for experiments in atomic physics. The Parkes radio telescope has been used in an extensive survey of the accessible part of the Milky Way to provide a detailed picture of the complex distribution of the radiation.

Apart from the continuum several spectral lines are known in the radio wave-lengths. Of these, the one which has been studied longest is the 21 cm. line of hydrogen, discovered in 1951. First predicted by a Dutch astronomer and detected in the United States, it was soon the centre of an important research programme at the Radiophysics Laboratory. Besides giving information about the distribution over the surface of the sky of the interstellar material, the Doppler shifts of the line afford a measurement of the velocity in the line of sight of the hydrogen in which it arises. With a law of distribution of velocities of rotation within the Galaxy which may be derived from the radio observations, a measured velocity corresponds to and yields a distance for the hydrogen. Such observations carried out for the southern sky by the Radiophysics Laboratory and for the northern sky in Holland provide the best evidence of the large-scale spiral structure of the Galaxy. The Parkes radio telescope is equipped with a multi-channel receiver capable of receiving simultaneously 48 separate frequencies about that of the hydrogen line.

When the position of a radio source has been found a search can be made on photographs for the corresponding object as revealed by optical light. In this way a good many of the radio sources have been identified with distant galaxies. Many galaxies produce radiation to about the same extent as the Milky Way, and in the nearer ones this is observed both in the continuum and in the hydrogen line. It is not yet known what makes some of the galaxies radio emitters of an altogether greater intensity, but this is so much the case that, assuming the radio galaxies are more or less evenly distributed through space, it is clear that they can be detected at distances greater than optical observation can reach and are the most distant objects observable by mankind. Bolton and his colleagues have made catalogues of radio sources and many identifications.

A method of using the passage of the Moon in front of a radio source to find its position and structure has been developed in conjunction with the School of Physics of Sydney University. The time at which any object disappears or appears can be used to calculate the position of the limb of the Moon, and consequently, if such an observation is made two or more times, the position of the body is accurately found. Moreover, as the Moon passes over the object, successive strips are hidden or revealed and so the observation of the way in which the intensity varies gives information on the structure of the objects. This method gives positions, diameters and structures of radio sources with greater accuracy than any other. Between 1962 and 1964 a number of different radio occultations were observed by C. Hazard of the University of Sydney School of Physics using the Parkes radio telescope. In particular, the position and structure of the Cambridge radio source 3C273 were measured with sufficient accuracy for one component to be identified with a 13th magnitude star-like object. When its optical spectrum was examined this was found to have a very large red shift, and so a new class of objects was discovered, the quasi-stellar radio sources. If the red shifts of these objects of which several score are now known correspond to velocities and distances which would ordinarily be accepted for galaxies, they are at extreme distances and emit energy in enormous amounts. One interesting case is the identification through radio occultation of the source which is the remnant of the supernova observed by Kepler in 1604. The radio position is in good agreement with the positions found by Kepler and with the nebular optical filaments observed in the vicinity.

The Radiophysics Laboratory has now joined the optical astronomers in detailed study of the Magellanic Clouds, the nearest of the external galaxies. Observations are made both in the continuum and in the hydrogen line. The more intense areas of the radio-emitting regions of both kinds are comparable in distribution with that of the optical emission. The hydrogen emission extends over a much larger area. Velocity measures from the Doppler shifts of the hydrogen line give valuable information on the dynamical structure of the Clouds. The velocity distribution is consistent with that of the stars. The Large Cloud is a rotating system, the total mass of which can be derived from the pattern of the rotation. The study of the radiation also gives the mass of the neutral hydrogen. The mass of the Large Cloud is uncertain because of doubt as to the inclination to the line of sight which is needed to convert radial velocities to orbital velocities and because an inaccuracy in the distance would lead to uncertainty in the scale of the system, but it appears to be about a tenth of that of the Milky Way. The Small Magellanic Cloud consists of two separate masses of gas and stars which are moving apart.

The Parkes radio telescope with a sensitive receiver enables similar work, although not in the same detail, to be done on others of the larger southern galaxies. For several of them valuable information has been obtained on the red shift, hydrogen content, dynamics and distribution of mass.

Synchrotron radiation is substantially polarized with the electric vibration perpendicular to the magnetic field from which the radiation comes. Hence observation of the polarization yields information on the magnetic fields present in the sources and adds to knowledge of the physical processes involved in the emission. The radio source Centaurus A is identified with a comparatively near peculiar galaxy with a dark band cutting across its centre. The radio emission extends over an area far beyond the optically observable object. The magnetic fields are of enormous extent that would not have been suspected a few years ago.

When the radiation on its way to us passes through an ionized material in a magnetic field, the plane of polarization is rotated. Observations of this effect with the Parkes radio telescope are used to provide information on the field in our Galaxy. The magnetic fields of the galaxies in which ionized interstellar material exists may have an important influence on evolution and structure of the galaxies.

Work on radar during the War gave the Radiophysics Laboratory familiarity with techniques which have been applied to study of rain physics by E. G. Bowen and his colleagues. The radio waves penetrate into the clouds and allow some of the processes going on in the formation of rain to be observed. In this way the Division was led to a study of cloud physics and rain formation. Laboratory experiments were devised and eventually aeroplanes were used to make examination of the clouds and work was done on the artificial stimulation of rain from suitable cloud formations.

Aircraft and radar provide the tools for measuring in the clouds many of the quantities needed to study them. Samples taken from aircraft to find the distribution in size of the droplets in the clouds showed that the character of the clouds changes quickly from place to place. The drop size appears to be a maximum near the tops of cumulus clouds. Continental clouds have smaller drops than those over the sea.

Rain may develop in cloud if the water becomes super-cooled at the top until ice crystals form. As the crystals fall, they grow at the expense of the surrounding water droplets, become larger, and when they descend far enough melt and fall as rain. Radar observations show that there are also non-freezing clouds which give rain in which large drops in falling collect enough smaller ones to grow to raindrop size. The development of the rain in either case can be followed by the radar observations. At centimetre wave-lengths radar can be used to observe the formation and growth of the precipitation elements in the clouds. The ice particles and droplets are detected when they have grown to a size of about a tenth of a millimetre. The precipitation depending on ice causes a different radar pattern from that which arises from water drop coalescence. The former shows a flat top or "melting band" at the level where the melting occurs and the radar reflection improves. In rain taking place through coalescence there is often a rather bunched pattern of the cells of the cloud in which the process is occurring most vigorously.

If nuclei on which the ice can form are present the freezing occurs at a higher temperature, and the Laboratory has made a close study of nuclei for condensation and their role in droplet formation. Techniques have been developed for counting ice nuclei and it has been shown that low counts of nuclei occur in Australia in the area below the jet stream which flows high in the atmosphere. Experiments with a fine powder of zinc sulphide released from aircraft at 45,000 feet showed rapid mixing of the air since the zinc sulphide was soon found at all levels. Zinc sulphide is used because it can be easily detected by its fluorescence when illuminated by ultra-violet light. This technique is a powerful one for tracing circulation in the atmosphere and suggests that the particles may spread in a downward direction.

The number of freezing nuclei in the atmosphere was shown to vary over a very large range and exhibit a tendency to repeat at the same time each year. The rainfall tends also to correspond to the regular periods of high concentration of nuclei. This effect is world wide and widespread increase in nuclei and rain indicates possible extra-terrestrial influence and E. G. Bowen has suggested that there is a connection with meteor showers which could provide the nuclei on which ice could form. Careful inspection showed that there appears to be approximately a 30-day lag between the arrival of a shower of meteors in the top of the atmosphere and the period with a strong tendency for heavy rain to occur.

Attempts to associate the movement of the Moon with the weather have a long history and Russell of Sydney Observatory has been mentioned in this connection. In the Radiophysics Laboratory the relation between precipitation and phase of the Moon has been studied using a large number of stations in New Zealand and the United States. There is a tendency for large precipitation to occur in the first and third weeks of the lunar months, that is, about three to five days after new Moon and full Moon. Rainfall tends to be low near new Moon. Measurements of the number of ice nuclei also show the concentrations near first and third quarters of the Moon to be about three or four times as great as at new Moon and full Moon. It may be that the rate of arrival of meteors, if Bowen's theory of the meteoric origin of the ice nuclei is correct, is affected by the position of the Moon and radar observation of meteor rates does appear to verify this.

Rain-making experiments by seeding the tops of suitable clouds began in 1947. A cumulus cloud with a temperature of $-10°$ C. at the top was found suitable for the purpose and after dry ice, frozen carbon dioxide, is fed from a plane into the top of such a cloud rain may appear in about 25 minutes. This process depends on the stimulation of ice crystal formation by use of the dry ice. Another process has been tried in which the stimulation is achieved by providing freezing nuclei at the top of the cloud. Silver iodide, the best known substance for this latter purpose, is provided in the form of a smoke of very fine particles produced by burning a solution of silver iodide in acetone. The silver iodide crystals have properties similar to those of ice and so are particularly suitable as nuclei. It is not effective if released at ground level because movement to a sufficient height is too slow but when released from aircraft at the top of a suitable cloud behaves just as dry ice does and much smaller amounts are needed. Trials, in carefully controlled experiments with the help of the Bureau of

Meteorology to measure the rain, have been made to see if average rainfall can be influenced over a wider area. It appears so far that the attempt to increase rainfall may be successful in some areas but not in others.

The attempts to stimulate rain have been applied to clouds already assembled by nature and apparently near the point of producing rain. The results show without doubt that the seeding for ice crystal formation can stimulate suitable clouds to give rain. Experiments have also shown that warm clouds can be stimulated to rain by spraying with water, but the process is not economical because of the large volumes of water which would need to be used. Experiments of this kind may have an extremely valuable future for a country like Australia where one of the great problems is scarcity of water over such large areas.

The Division of Physics, C.S.I.R.O.

Situated in Sydney, the Division of Physics works on a wide range of physical problems important among which are those presented by the Sun. The present Chief of the Division, R. G. Giovanelli, began his professional career in the Commonwealth Solar Observatory where he made observations of the Sun by direct photography and by the use of a spectroheliosope. He joined the Division when it was formed in 1941. About 1946 he renewed his interest in the Sun with a theory of solar flares, sudden brightening of areas of the Sun, particularly as seen in monochromatic light of a line of hydrogen in which the movements of charged particles were associated with changes in electromagnetic fields in the vicinity of sunspots. This acted as a stimulant to others to investigate the possibilities of explaining phenomena in the atmosphere of the Sun in terms of the action of magnetic and electric forces.

Through a visit to the High Altitude Observatory in Colorado about 1958, Giovanelli became interested in the explanation of the non-uniform appearance of the solar atmosphere, particularly the granulation of the photosphere and the formations in the chromosphere which can be observed only in monochromatic light. Work in this direction is still going on. It turns out that regions of higher density are automatically darker as seen in the continuous spectrum because of absorption of radiation from lower layers and, where the density is less, it is possible to see deeper into the Sun. So the interpretation of the granulation becomes complex because variation in temperature, density and convective heat transfer must all be taken into account.

This work naturally led to an observational programme in order that the objects of theoretical study could be observed. In 1950 a filter was set up to study the Sun in monochromatic light. During the International Geophysical Year (1957-1958) a patrol to observe flares was begun and carried on for about three years. For high resolution observation a filter passing only one eighth angstrom and tunable over the vicinity of the red Hα line of hydrogen was prepared. It was fitted to a 5-inch telescope on an equatorial mounting of design similar to the one used at the High Altitude Observatory. With this photoheliograph, R. J. Bray and R. E. Loughhead studied the granulation and sunspots, paying particular attention to fine detail and time changes. The work is fully described in their two books, one on *Sunspots* and the other on *Solar Granulation*. About 1960 the filter was first used to make observations in opposite wings of the Hα line in order to study the vertical velocities in the chromosphere.

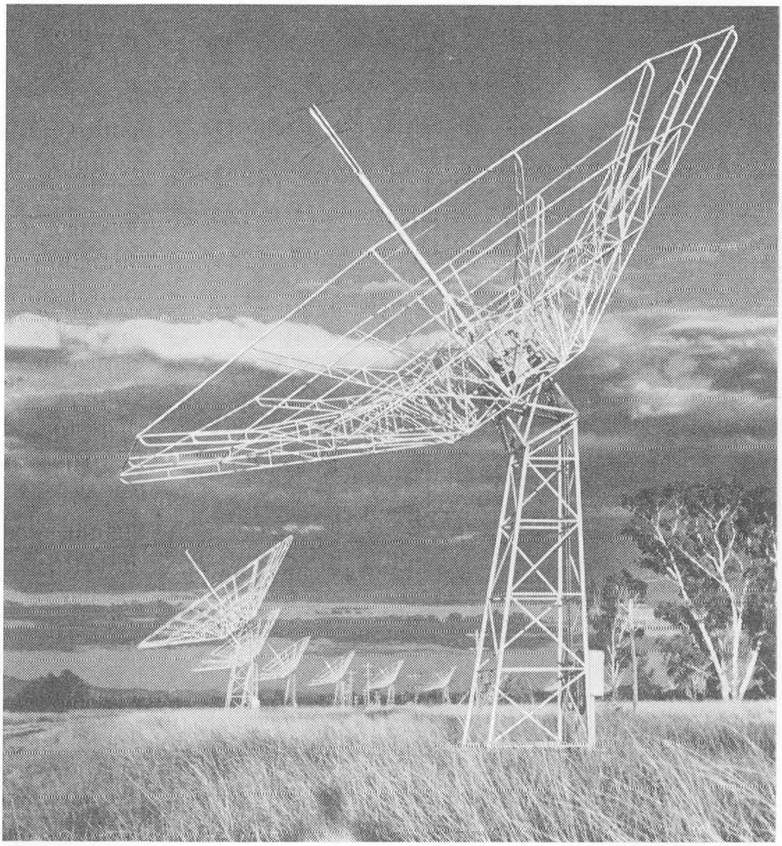
The strategic position in longitude occupied by Australia for keeping the Sun under continuous observation led to the idea that the patrol for flares should be recommenced. At the same time it was realized that this would be better done with a larger telescope and at a site which would give better seeing conditions, and a greater proportion of clear sky. In this way more frequent observations and much to be desired improved resolution could be obtained.

It was natural to look for a site west of the Blue Mountains where better meteorological conditions could be expected and so intensive studies of seeing were made. A seeing monitor was developed which enabled photographs to be made during instants of good seeing. The work by C. Coulman, working in conjunction with the Division of Meteorological Physics, led to the recognition that these instants were associated with gaps between rising convective cells of air. The relation between seeing and the structure of the lower part of the Earth's atmosphere was studied and it was shown that solar seeing improves rapidly with height of the telescope above the ground where moments of good seeing are both longer and more frequent.

A comparison showed that better seeing conditions for solar observation would be more likely on the plain near Siding Spring Mountain than on the Mountain itself. This led to the decision to establish the optical observation of the Sun planned by the Division of Physics at the same place at Culgoora near Narrabri as the Radiophysics Laboratory's radioheliograph which required a large flat area for the establishment of its aerials.

The first installation at this site was for a flare patrol financed by the United States Bureau of Standards. A mounting equipped with the 5-inch lens and the filter is being used to obtain routine rapid observations at the centre and wings of the hydrogen line giving line of sight velocities in the case of these fast-moving events on the Sun.

A larger 12-inch photoheliograph has since been installed. This is mounted at a height of about 60 feet above the ground with elaborate precautions to prevent reduction in image quality being caused by solar heating of the telescope, its mounting or building. This was brought into operation in 1967. The one-eighth angstrom filter is being fitted and the telescope will be used for studies of the chromosphere. Since



The radioheliograph of the C.S.I.R.O. Solar Observatory.

such rapid events occur on the Sun, it is necessary to have a continuous record in both visual radiation and in the radio wave-lengths and, since magnetic fields are so important, it was realized that rapid observations are also required of the magnetic field of the Sun, especially in active regions. A new type of instrument has been developed under the sponsorship of the National Aeronautical and Space Administration of the United States to give continuous measurement of the magnetic field distribution. Spectrum lines which originate from atoms in a magnetic field are split and the component lines are polarized. From the separation and the nature of the polarization it is possible to find the strength of the magnetic field and an indication of its direction. The cine-magnetograph which has been designed to take photographs showing the distribution of the magnetic field of the Sun makes use of this principle. It consists of a high resolution filter with which can be observed the different types of polarization in the wings of spectrum lines with suitable television-type equipment for recording the magnetic fields over extended areas of the Sun. These pieces of equipment have worked separately and they are being put together for installation at the C.S.I.R.O. Solar Observatory at Culgoora.

Thus in this Observatory there is a magnificent opportunity to record continuously the appearance of the Sun in the visual part of the spectrum and in the radio and to keep at the same time a record of magnetic fields. This very large amount of information can be handled only with data processing equipment which has become available in recent years, and it is expected that correlation between the separate records will reveal a great deal about the structure and the events in the Sun's atmosphere.

Division of Meteorological Physics, C.S.I.R.O.

In 1946 C. H. B. Priestley, a scientist from the British Meteorological Office, was invited to establish a Meteorological Physics Section which has become the Division of Meteorological Physics situated at Aspendale, some 17 miles south of Melbourne. From the outset the Division was fortunate in that it was established purely as a research unit free from the obligation of providing weather forecasts.

The major fields of research selected were the general circulation, which is the statistical description of atmospheric motions, and micrometeorology, the study of the physical processes occurring within the lowermost few metres of the Earth's atmosphere. Dynamic meteorology, which deals with large-scale weather processes and provides the backing for analysis and forecasting of day-to-day weather, also received early attention.

A proper understanding of the physical processes which occur in the first few metres of the earth's atmosphere is fundamental to the study of most branches of meteorology. All weather phenomena are a result of energy transformations which take place at the Earth's surface. Plants and animals live close to the ground in a microenvironment which is usually very different from that obtaining even a metre above in the free atmosphere. Much of the Division's effort was directed first to the theory of turbulence, the mechanism by which energy is distributed through the atmosphere, and second to elaborate field experiments which measure the transfer coefficients of heat, water vapour and momentum. A unique piece of equipment known as the Evapotron has been developed which, for the first time permits direct measurement of evaporation from any natural surface, such as meadowland, forest or swamp.

The prospect of world food shortages on an unprecedented scale coupled with Australia's natural shortage of water suggests the great importance of agricultural meteorology. Within the canopy of a growing plant there exists a delicately-balanced microclimate—temperature, water vapour pressure, wind speed, radiation, carbon dioxide concentration, and so on, all having values which are different from those just above the canopy. The agricultural meteorologist examines the inter-relationship between these quantities as well as their relationship with plant growth, water consumption and the macro-climate outside the canopy. Evaporation from growing vegetation is measured by specially-developed instruments known as lysimeters, whilst the artificial control of evaporative processes is studied through the application of foliar sprays.

Study of solar radiation which is the ultimate source of life on the Earth is of fundamental importance to theoretical studies of global heat balance, aerosol distribution and atmospheric dynamics. At Aspendale work has centred on radiative flux divergence in fog conditions with the measurement from a ship of the upward and downward components of long- and short-wave radiation over the sea and from an aircraft over varying types of terrain. Specialized equipment has been developed to measure the heat balance of a single biological specimen such as a sheep, and a net radiometer able to explore the energy balance of a single leaf. Automatic recording equipment which scans the solar spectrum between 0·381 micron and 0·781 micron in steps of 0·001 micron every seven minutes throughout the day has recently been installed.

Measurements at high altitudes in the atmosphere are made primarily to provide information on atmospheric motions, both horizontal and vertical. Until recently the stratosphere—that region lying above approximately 50,000 feet and, unlike the troposphere beneath, possessing an almost zero vertical temperature gradient—was thought to be largely inert. This is now known to be untrue. Radioactive fallout originating in atomic bomb explosions and washed out of the atmosphere by rainfall is an excellent tracer which reveals circulation at these levels. Knowing the half lives of the radioactive materials involved and using measurements of radiation intensities, the speed of travel of the material can be computed. Measurements are made both on the ground and on balloon-borne equipment.

A section of the Division's work deals with large-scale atmospheric processes. These range from phenomena of squall line size (50-100 miles) up to those of global dimensions as, for example, in energy transfer across latitude circles, the heat balance of the Antarctic Plateau and the nature of the Southern Oscillation—basically a mass flow of air between the Indian and Pacific Oceans. On a smaller scale, examples are the effect of sea surface temperature on rainfall, cool changes, sea breezes and katabatic winds.

The Division is a national calibrating authority for radiometers and anemometers and has developed over the years for special purposes a number of meteorological instruments, some of which have been patented, made commercially under licence, and sold widely overseas.

Meteorology, which is necessarily a truly international science with growing application to human needs, must be on the eve of spectacular advances. Satellites are providing us with observations from vast previously inaccessible ocean areas, especially in the southern hemisphere, where lack of observations has impeded progress towards an understanding of general circulation, and high-speed computers are reaching the stage where accurate machine-made global weather forecasts will be possible. Not only do weather and climate touch on every phase of human activity, but in Australia, a primary-producing country lacking adequate water supplies over most of its area, certain aspects, such as the economic use of water in agriculture, are of extreme importance. In terms of economics alone, it has been estimated that the saving to the nation as a result of a thorough application of meteorology could well be of the order of several hundred million dollars a year.

The University of Melbourne

Because of the ever increasing demand for meteorological services the Bureau of Meteorology in Melbourne has established courses of training but there was no organized instruction in any Australian University until the Meteorology Department was established in 1937 in the University of Melbourne. The first head was F. Loewe, a German pioneer in weather flying and polar meteorology. This Department in which most of Australia's present leading meteorologists have been trained remains the only one teaching meteorology in an Australian University. Besides offering undergraduate courses there is provision for graduate research and study to the Ph.D. level. Since 1961 the head of the Department has been U. Radok.

The early research of the Department was concerned with the climatology of the Australian and southern hemisphere free atmosphere and with special phenomena such as dust storms and fogs and with periodicities in rainfall. In the 1950's research in the Department clarified some of the difficulties of long range weather prediction. Success in this field still eludes the meteorologist but it is of great importance since progress might provide some alleviation of the disastrous effects of flood and drought. Another field of great promise, in which the Department made the first Australian experiments, is that of weather prediction by computer. Work on numerical weather prediction, aided by access to the University's computer, as a form of experimentation with large atmospheric systems, and antarctic glaciological studies in collaboration with the Antarctic Division of the External Affairs Department for which many experiments have been designed have grown in the sixties. In recent years aeronautical meteorology, concerned with low-level and high-level turbulence affecting aircraft, and agricultural meteorology, dealing with energy budgets of crops and of the underlying soil, have been added to the research programme. The Mount Derrimut Meteorology centre provides an undisturbed agricultural environment twelve miles from the University.

The University of Adelaide

A very important and encouraging aspect of the growth of astronomy in Australia since 1945 has been its development in the universities. It is possible to mention only a selection of these activities. Perhaps the first to enter the field, at least observationally, was the Department of Physics in the University of Adelaide, which inherited some of the responsibilities of the old Observatory.

The programme in astronomy commenced in 1949 with radio studies of meteor trails. Since that time studies of meteor astronomy by radio techniques have provided a substantial amount of information about meteor showers as well as providing information about atmospheric winds at high altitudes. Adelaide, under the direction of Professor S. R. Carver, is one of the world centres of radio meteor astronomy. More recently, astronomy in Adelaide has been concerned with observations made from rockets and balloons, with particular emphasis on the facilities which are available at Woomera rocket range operated by the Weapons Research Establishment. These facilities open up new avenues of research in ultraviolet and X-ray astronomy at wave-lengths which do not penetrate the atmosphere and thus are inaccessible to ground-based observatories. The Department is looking forward to extension in the near future of efforts in the avenues of astronomical research which can be pursued only by using vehicles which escape from the Earth's atmosphere.

The University of Tasmania

The Department of Physics in the University of Tasmania, under the direction of Professor G. R. A. Ellis, is engaged in a range of activities in radio astronomy. A survey of the sky has been made in wave-lengths longer than usually used by other radio astronomers. In these wave-lengths the Milky Way appears dark compared with the area around the galactic pole, and the observations are explained if the radiation comes from a corona surrounding the Milky Way and is absorbed by the ionized gas in its plane. The way in which the intensity of the radiation varies with wave-length also accords with this explanation. Observations of the radio emissions of Jupiter have been carried on at decametric wave-lengths. This University has plans for the development of an optical observatory and has acquired a site on which it is intended to place a 36-inch reflector.

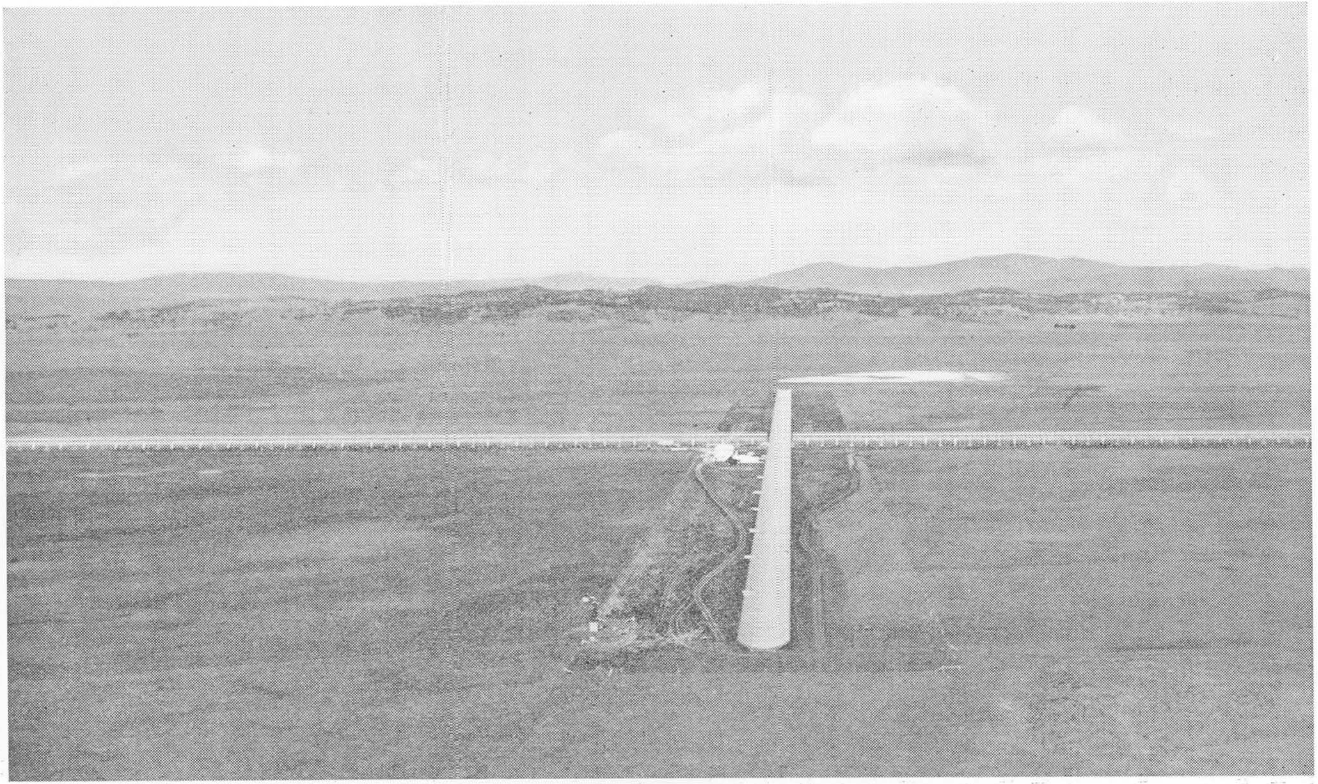
In the University of Tasmania cosmic ray observations have been made. Evidence has been found of a maximum in intensity outside the Earth's field in both directions along an axis which is taken to correspond to the direction of the local galactic magnetic field. The direction is reasonably in accord with determinations made by radio and optical astronomy.

The Department of Physics is cooperating with colleagues in the University of Adelaide in the use of the facilities offered by the Weapons Research Establishment in South Australia for observation from vehicles travelling beyond the atmosphere. In 1967 apparatus carried for the universities on a Skylark rocket led to the discovery of the second brightest X-ray source so far found in the Galaxy.

The University of Sydney

Research in astronomy is actively carried on in the Schools of Physics and Electrical Engineering and in the Department of Applied Mathematics of the University of Sydney. In the School of Physics the Chatterton Astronomy Department was formed in 1959. Later, a second department was formed and it was decided to join forces with the astronomers of Cornell University so that the resources of both Universities would be best used by a wider group of scientists. The two Departments are now run as part of the Cornell-Sydney University Astronomy Centre. The Departments of the University are making valuable contributions to astronomy and have established opportunities for graduate study which can take students to the level of Ph.D.

The School of Physics, which plans to install a large optical telescope, has at present two spectacular instruments, the stellar intensity interferometer and the Molonglo radio telescope.



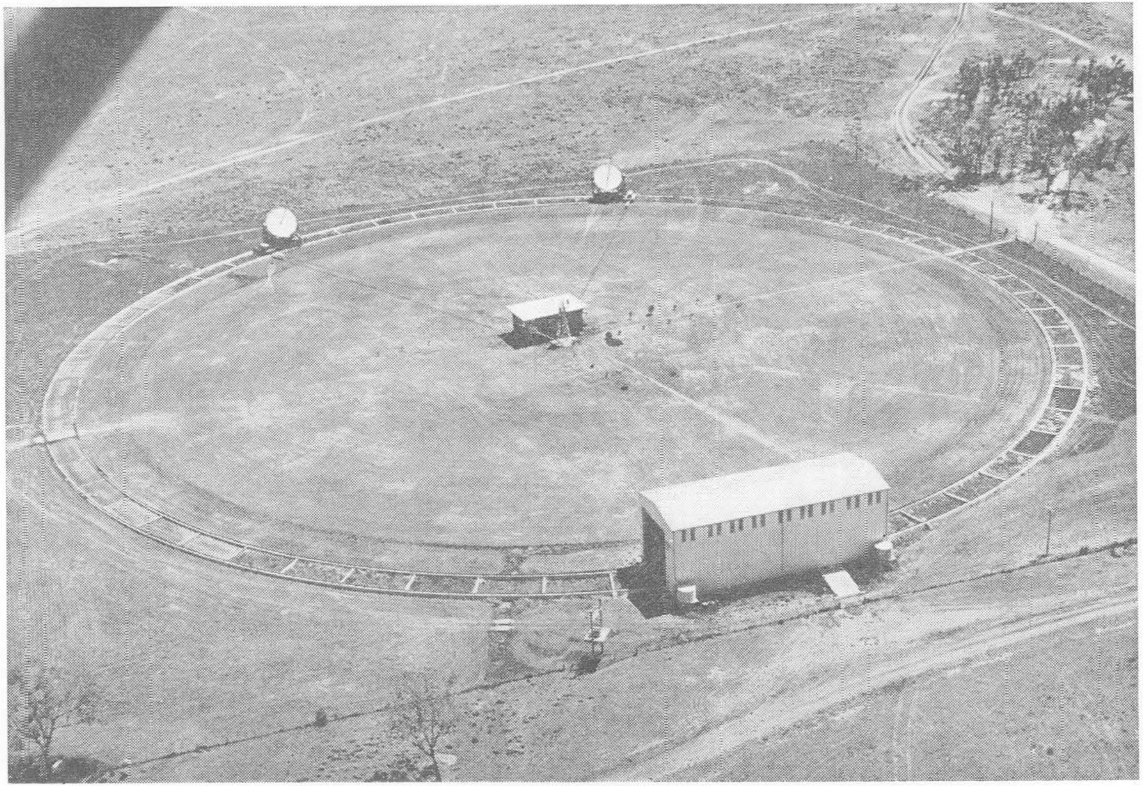
The Molonglo radio telescope of the University of Sydney.

When light from a point source is brought together from two places some feet apart, the interference pattern consists of a series of bright and dark bands. Only a very few giant stars have an angular diameter large enough to make the interference pattern disappear by separating the mirrors in the biggest interferometer so far constructed, the Michelson interferometer attached to the 100-inch telescope on Mount Wilson.

The limitations of the Michelson interferometer are overcome in the intensity interferometer designed by R. Hanbury Brown, now Professor of Physics (Astronomy) at Sydney, and R. Q. Twiss, and erected near Narrabri in New South Wales. The starlight from two mirrors is focused on photo-electric detectors. In each case the light has a varying component, which is followed by the variations in output of the corresponding photo-electric detector. The fluctuating outputs from the two mirrors are correlated if the light falling on the two detectors could be made to interfere upon combination in a suitable optical system as in a Michelson interferometer. The correlation is measured by amplifying the outputs of the two detectors and evaluating their product in an electric circuit over a suitable period. The correlation measured for different separation of the mirrors is proportional to the square of the fringe visibility in a Michelson interferometer with the same spacing, decreasing with increasing separation of the mirrors, and the decrease may be matched to a theoretical curve which corresponds to the angular diameter of the star.

The interferometer built in this way can be very much larger than possible for the Michelson type and the large mirrors do not need to be of optical quality. In the Narrabri instrument each of the mirrors is made of 252 hexagons put together to form a 22-foot diameter mirror from which all of the light falls in a circle about one inch across. The two large mirrors are on a circular track 600 feet in diameter which provides for the possibility of separations from 30 to 618 feet. Delivery of parts of the instrument began in 1962 and the first stellar diameter, that of Vega, was measured in 1963 as $0''\cdot0037 \pm 0\cdot''0002$. If the angular diameter of a star is measured and its distance is known, its actual size can be determined and, from the amount of light which it gives out, its effective temperature, and so it is hoped to improve the temperature scale for hot stars as well as to evaluate sizes which are important in the study of stellar structure. This instrument renders accessible to measurement many more stellar diameters than was thought possible in the past.

Many of the strong radio sources correspond to very faint optical objects and so accurate radio positions are needed to make satisfactory identifications. B. Y. Mills, now Professor of Physics (Astrophysics)



The stellar intensity interferometer of the University of Sydney at Narrabri.

obtained resources for the construction of a magnificent version of the Mills cross which was begun in 1962 on a level site among the hills about twenty miles east of Canberra. One of the main tasks of this instrument, the Molonglo radio telescope, will be to measure positions, intensities and, where possible, angular sizes of up to 100,000 radio objects and obtain statistical information on the distribution of a much larger number. The identification of only a small fraction of these with optically-observed galaxies would give data which might prove of great importance in studying the nature and evolution of the universe. Besides the observation of the radio galaxies, a wealth of detail should be resolved in the Milky Way and the Magellanic Clouds to provide new information on their structure, possibly, in the case of the Milky Way, hidden from optical view by interstellar material.

Each arm of the radio telescope, which operates at a frequency of 408 Mc/s, is almost a mile long. The east-west arm is a 38-foot wide cylindrical paraboloid which can be tilted about an east-west axis, to observe objects from north of the Equator down to the South Pole. By itself this arm collects radiation from a fan beam of width 1.′5 and length, along the meridian of 4°. The north-south arm is 42 feet wide. It is fixed but the beam is moved to different distances from the zenith by electrical phasing of the kind used in the original Mills cross, and the intersection of the two aerial patterns will produce a narrow area of reception enabling radio objects to be positioned with accuracy or examined in detail. Much of the electronics of the instrument was designed and built in the School of Electrical Engineering under Professor W. N. Christiansen.

The east-west arm was first completed and used to measure one coordinate of a number of radio objects, some of them known and used for calibration. It appeared clearly that the predicted accuracy of position measurement was being reached. In April, 1967, a party was held in the Department to celebrate the beginning of the operation of the Molonglo radio telescope as a "T". This established the improved resolution in the other coordinate, and now fully accurate positions will be determined. Later, the other half of the north-south arm will be completed and the instrument will really be a cross.

In 1963 the C.S.I.R.O. transferred the lease of its "Fleurs" radio astronomy field station to the University of Sydney, and presented to the School of Electrical Engineering the antennas and equipment, including the crossed-grating interferometer designed by the head of the School, Professor W. N. Christiansen, when he was a member of the C.S.I.R.O. radio astronomy group. This equipment has made daily observations of the brightness distribution over the Sun at wave-lengths of 21 cm. and 42 cm. since 1964. At the same time, the construction of two new radio telescopes was commenced. One of these is a cross-type telescope, with a 1 Km. long east-west arm and a synthesized north-south arm, operating at a wave-length of 10 metres. The other is a compound-grating interferometer using the Earth's rotation to make it equivalent to an aperture nearly one square kilometre in area. The telescope synthesizes an image one square degree in angular extent with a resolution of 40 seconds of arc. In addition to this work the spectrum of the background galactic radiation has been determined by means of scaled antennas.

The School of Electrical Engineering, having outstanding design experience, has also been involved in work on several other radio telescopes including design development work on the electronic equipment for the Cross antenna of the School of Physics and on a large radio telescope in the Netherlands, where members of the school have worked for periods of a year or more. The school has also been occupied in the design work on a two-mile rotational radio telescope near Peking and on the feed antenna for the Arecibo (Puerto Rico) 1,000-foot spherical reflector.

In the Department of Applied Mathematics, under Professor K. E. Bullen, work is being done on the internal constitution of the planets. The relations between the pressure and density which are needed for these theories are derived from studies of internal zones of the Earth. The observed waves from distant earthquakes have penetrated deeply into the Earth and so the travel times for different distances enable the speeds of the waves at different depths to be found, hence giving information on the elastic properties and densities of the material through which they have come. Professor Bullen has long been in the forefront of these investigations. The observational data for the other planets are mainly the masses and radii and moments of inertia. The model of the internal density distribution must fit these data. The radius of a planet is not easy to observe with the accuracy required, but the observations from the space probe Mariner IV give a radius of Mars which fits theories put forward about 1950. In the case of the Earth the moment of inertia from the orbital motions of artificial satellites is found to be less than formerly accepted and has recently led to a reduction in the estimate of density in the Earth's mantle.

About 1960, P. R. Wilson, of the same Department, stimulated by contact with the C.S.I.R.O. Division of Physics, became interested in problems of the solar atmosphere. He has studied radiative transfer of energy in inhomogeneous atmospheres and applied the results to inhomogeneities of density and field in the Sun's atmosphere. The granulation of the photosphere, sunspot structure and the formation of spectral lines have been investigated.

University of Queensland

Research on the problems associated with the determination of the abundances of the elements in the solar atmosphere from the strength of the absorption lines in its spectrum, commenced about 1958 in the Department of Physics under the leadership of Professor D. Mugglestone. The work began using weak-line theories and later extended to the use of lines of medium strength. These studies must be made in conjunction with a detailed model of the physical conditions in the outer layers of the Sun. The influences which broaden or change the shape of the spectrum lines, such as electric fields or turbulence, which operates through the Doppler effect, need to be taken into account, and the way in which the line grows with increasing abundance under a given set of physical conditions must be determined. The abundance results from the medium-strength lines using the theory which was developed were consistent with those from the weak lines. Results have been given for oxygen, nitrogen and carbon.

More recently, the influence of the broadening effects on the strong solar lines has been considered, particularly as applied to theoretical reproduction of the shape of the sodium D lines. Interest centres on the influence of non-equilibrium thermodynamic conditions near the centres of the lines. This focuses attention on the upper part of the photosphere and the lower chromosphere which have influences on this part of the line. This work may well find application to other stars. Abundance studies have important bearing on evolutionary theories of stars since the relative proportions of the elements give clues on their formation which may, for example, involve the gathering together of material derived from stars of a previous generation.

Monash University

Work on astronomy at Monash University began with the appointment of Professor K. C. Westfold in 1961 since when Professor R. Van der Borght arrived from the Australian National University. Both are continuing astronomical activities on which they were already engaged and are collaborating with able students.

In 1949, when he was in the Radiophysics Laboratory, Westfold published, with S. F. Smerd, a theory of the thermal radio-frequency radiation in an ionized gas with applications to the transfer of radiation in the solar atmosphere. Some of his work related to the theory of the shock waves mentioned in connection with the bursts of radio waves from the Sun. Other work included study of radiation in ionized media situated in magnetic fields and the emission of radiation from extremely fast-moving electrons in a magnetic field giving the first determination of polarization characteristics. This is the synchrotron radiation which is a main type in astronomical contexts.

Van der Borght is interested in the theory of stellar structure and stability. His research is largely concerned with massive stars, including their pulsations and the evolution of those initially composed of hydrogen. Work on non-radial oscillations of such massive stars has been published in 1966 and 1967. With students, this work is being continued and extended to include the effects of magnetic fields and rotation on stellar structure.

The University of Newcastle

The astronomical work in the Physics Department of the University of Newcastle, initiated when Professor C. Ellyett took up his position as head of the Department late in 1964, is non-optical in nature.

The absorption of radio waves in the atmosphere in excess of quiet day conditions is produced mainly by increased X-radiation from the Sun which produces increased ionization in the lower ionosphere. The monitoring of the galactic noise levels is being used to measure, on the surface of the Earth, variations in X-ray and ultra-violet solar emission around times of solar flares.

Analysis of radar meteor films previously obtained at Christchurch, New Zealand, has been carried on and the work is shortly to be published. A new project is under way to establish two fully automatic radar meteor recording systems, one by a Canadian group for the Northern Hemisphere and another by Newcastle to monitor continuously the flux of meteoritic material encountered by the Earth. By pooling the experience and resources of the two groups and by the use of automated analysis, full meteor rate data will be on a continuous basis and available without the delays which occurred before the appearance of processed records. The hydromagnetic waves generated in the Earth's magnetosphere by the influx of particles from the Sun are being investigated both theoretically and observationally. The speed and direction of the hydromagnetic wave in the ionosphere is found by measurement of the same wave passage at spaced stations on the Earth's surface. The extent of the wave fronts will be measured when a third observing unit is installed at Woomera.

Participation in the Space Programme

Since October, 1957, many satellites and space probes have been launched in the U.S.S.R. and in the United States. Space science is of much astronomical interest for radiations which could previously not be observed because they do not penetrate to the Earth's surface are rendered accessible to observations from vehicles which pass beyond the atmosphere. The ultra-violet including that arising from hydrogen, the most abundant of all elements, X rays and particle radiation, such as comes from the Sun, may be investigated. Space probes have made landings on and photographed the Moon and have flown to Venus and Mars to gather scientific information and take close-up photographs. Men have orbited the Earth in space vehicles and may shortly be expected to land on the Moon to make detailed scientific examination of its surface.

To maintain the programme with the space probes and space vehicles it is desirable to keep them under continual observation and at all times to be able to receive the data they send back or to issue by radio commands to set the probe to work in some desirable way or to control its manœuvres or change its path.

Australia's geographic position so far away from North America and Europe gives it a great advantage as a location for stations to maintain contact with space vehicles when they would otherwise be out of sight or radio contact. Consequently, Australia has, from the beginning, had a part in the space programme with cooperation during the International Geophysical Year (1957). A radio tracking system, called minitrack, and one of the elaborate type of camera devised for photographic determination of positions of satellites were established in the Weapons Research Establishment at Woomera. Agreement was reached in 1960 between the Australian and United States Governments for the establishment of space-tracking stations in Australia.

Stations for space tracking and data acquisition for scientific, communication and meteorological satellites are at Carnarvon in Western Australia, Cooby Creek in Queensland and Orroral Valley in the A.C.T. The deep space probes are catered for at Woomera in South Australia and Tidbinbilla in the A.C.T. Many of us remember the sense of excitement when the transmission of the photographs taken by Mariner IV during its passage near Mars was being received at Tidbinbilla in 1965. The preparation for manned space flights, especially the planned expedition to the Moon, known as the Apollo project, has led to establishment of elaborate stations at Carnarvon, Tidbinbilla and Honeysuckle Creek, also in the A.C.T. Each of these stations is equipped with large parabolic radio antennas.

The project to land a man on the Moon will require reliable and continuous tracking and communication during the whole duration of the expedition. For this reason, stations sufficiently spread in longitude are being established in California, Spain and Australia. The Australian centre is at Honeysuckle Creek. Each installation is provided with an

85-foot aerial and to ensure complete reliability the Honeysuckle Creek Station is connected to the existing 85-foot antenna at the deep space network station at Tidbinbilla.

In May, 1967, plans were announced for the launching of the first Australian satellite later in the year. This satellite, which will be lifted by an American rocket, is designed and built by the Weapons Research Establishment in South Australia. It will study solar physical phenomena, particularly X-ray and ultra-violet radiation, which have a long-term effect on climate. The United Kingdom shares in the project for which the United States National Aeronautics and Space Administration will make available its world-wide network of stations.

Epilogue

The material in this chapter is necessarily sketchy and has for some institutions been reduced from a good deal larger amount. The amount included for any institution is an increasing function of the age of the institution, my knowledge and the work done. Some of my colleagues will no doubt disagree on the emphasis, but I shall be pleased if most of them are satisfied with the account of institutions other than their own. I have had a good deal of help, both in conversation and by correspondence, and it would be too complicated a business to make individual acknowledgement. Even so mention should be made of Mr. J. Hogan and Mr. P. D. Berwick who helped me with the meteorology. It was a pleasure to share in the preparation of a volume to celebrate the centenary of the Royal Society of New South Wales of which every astronomer of Sydney Observatory has been an active member.

There is no doubt that the outlook for astronomy and meteorology in Australia is good. There are far more workers in these fields than ever before (with peace time stipulated for meteorology) and, if the amount of work done had been the only criterion, the account of the period since 1945 would have been much expanded. Australia has special responsibilities in both of these sciences. The southern sky, which contains the Magellanic Clouds, the centre of the Milky Way and many individual objects of unique interest, is of immense importance to astronomy and inaccessible from the great centres of the world's wealth and population which are in the northern hemisphere. Similarly, the strategic position of Australia on the Earth's surface gives us a unique responsibility and opportunity in the study of world meteorology. Who should make the observations and interpretation of the weather and climate of our part of the world unless we do it ourselves?

It is striking how intimately the progress in these sciences and, I suppose, in others, is bound to development of new techniques. There are clear examples in the chapter of cases in which an advance in technique has led to new knowledge, and of at least one in which theoretical study led to the requirement for and development of new instrument resources. Science is now on a larger scale than in previous times, and more care is taken to provide installations well adapted to their purpose. With the establishment of the National Radio Observatory at Parkes and the field station of the Australian National University on Siding Spring Mountain we have, for the first time in Australia, observatories placed in sites selected because of suitability for their intended scientific work rather than for nearness to the capital from which they are administered. This principle is followed in the Molonglo radio telescope, the C.S.I.R.O. Solar Observatory and the intensity interferometer.

Astronomy and meteorology began together in Australia and with growth have now drifted apart. They have had in common that they are concerned with the upper half of our environment and that they have been observational sciences in which man observes as well as he is able what occurs in nature without himself being able to intervene. In meteorology now experiments in the laboratory attempt to imitate on a small scale conditions which occur in the atmosphere and experiments in the field attempt to alter natural conditions so as to induce rain. In astronomy space science is responsible for the beginning of intervention further afield. It is not possible to see where and how far these trends will lead.

The Astronomical Society of Australia was founded in 1966 and, with restriction to professional workers, the membership quickly grew to more than 170. Early in the period reviewed, say about 1880, the number would have been about six. The increase of education in astronomy and meteorology is a most encouraging feature. At one end of the scale most Australian states have, in recent years, included astronomy as part of the science courses in secondary schools, and at the other most of the universities can now offer postgraduate students encouragement to study some branch of astronomy or astrophysics. This together with the very great expansion in instrumental facilities enables us to look forward to a very bright future.