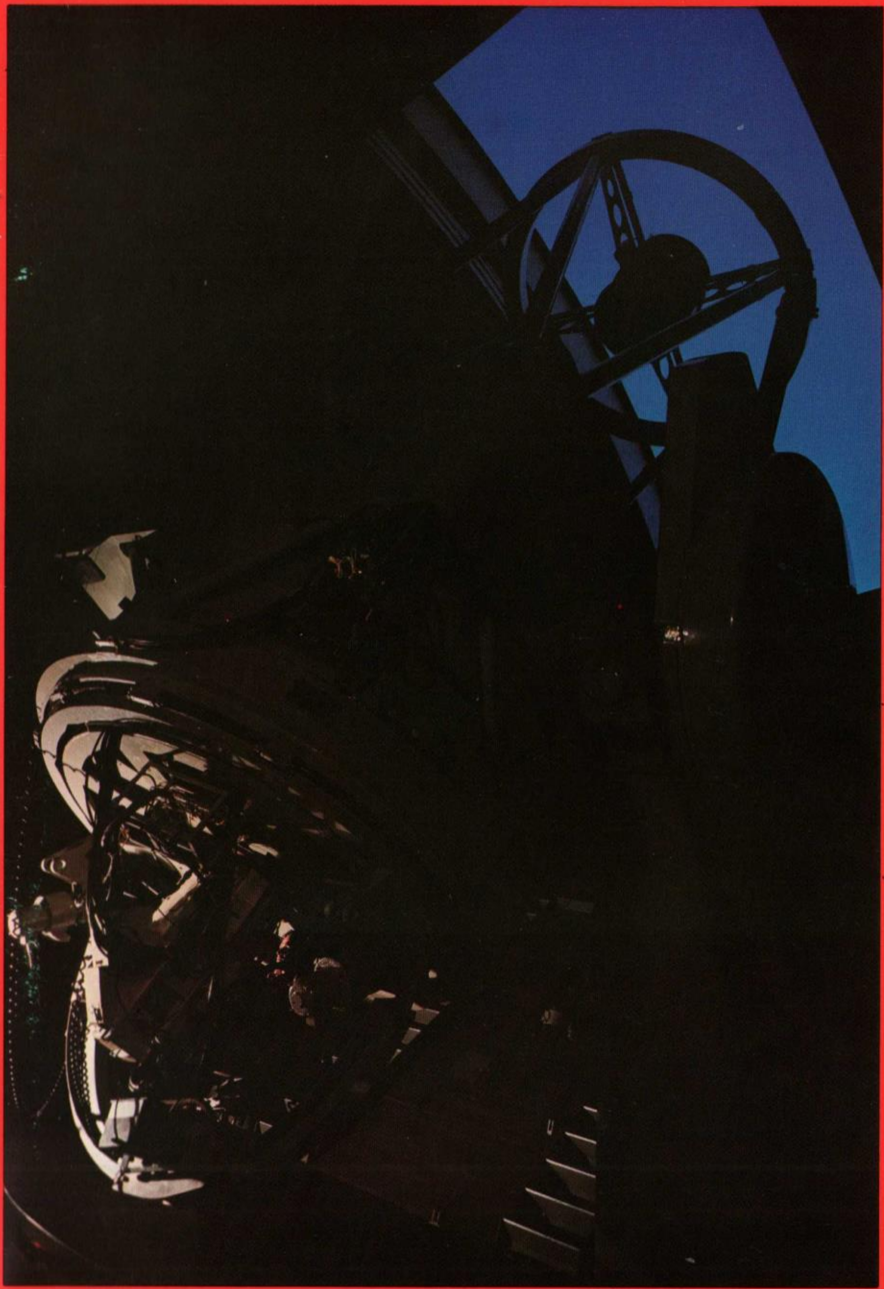


Royal Greenwich Observatory

Illustrated

Science
Research
Council

Most people remember Isaac Newton for his discovery of the law of gravity but his abilities were practical as well as theoretical and he succeeded in making one of the world's first reflecting telescopes. A replica of his telescope can be seen next to the visitors' gallery. The modern Isaac Newton Telescope looks very different from Newton's original, but in fact they work in exactly the same way with light being reflected and focused by a dish-shaped mirror. The front cover shows the appearance of the Isaac Newton Telescope when observing at night.

A photograph taken shortly after the announcement that Prof F. Graham Smith FRS was to be the new Director of the Royal Greenwich Observatory. On the right is Dr A. Hunter the present Director who is a specialist in the accurate measurement of star distances. Dr Hunter joined the Observatory from Imperial College in 1937 and became Director in 1973. He will be succeeded by Prof Graham Smith on 1 January 1976. Prof Graham Smith, a distinguished radio astronomer and authority on pulsars, joined the Observatory from the Nuffield Radio Astronomy Laboratories at Jodrell Bank in October 1974. They head a staff of 250 people.
Sussex Express and County Herald

Royal Greenwich Observatory *Illustrated*

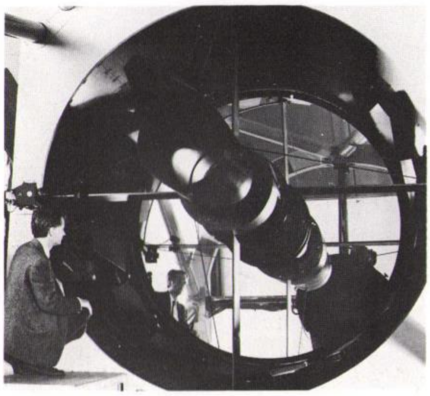
The Royal Observatory was founded at Greenwich by Charles II in 1675, and is Britain's oldest scientific institution. The site at that time seemed well chosen but over the years the lights of London became more and more obtrusive and industrial pollution made the sky less and less transparent. A decision was therefore taken in 1939 to move the Observatory to a new site with clearer skies. This was prevented by the outbreak of war, but discussion continued and by 1948 Herstmonceux had been selected and the move started. Observing conditions at Herstmonceux were indeed found to be much better than at Greenwich, and research activities expanded rapidly. No new large telescopes were provided until 1967 when the 98-inch Isaac Newton Telescope was commissioned. Its sensitivity, as measured by the collecting area of its mirror, is ten times more than any other telescope on the site and it has opened up a whole new field of exciting research.

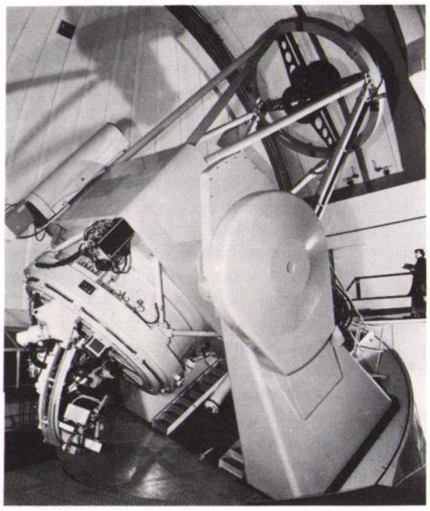
Herstmonceux Castle viewed from the south-west.

The money to run the Observatory comes from the British tax-payer. In 1965 the responsibility for allocating this money was transferred from the Admiralty to the newly created Science Research Council. The first duty of the Science Research Council is to support scientific research in British universities and so the prime function of the Observatory is to provide telescopes and related instruments for the use of astronomers from the universities and the Observatory itself. In addition the Royal Greenwich Observatory is the national observatory and has a national responsibility for providing accurate time-keeping and navigational almanacs as well as measuring the positions of the Sun, Moon and planets.

Astronomy in Great Britain is a rapidly expanding science and many astronomers are already looking for a new telescope even more powerful than the Isaac Newton. An application has been made to the government for a telescope nearly twice the size to be built either in Hawaii or in the Canary Islands. As part of the same plan the Isaac Newton Telescope would be moved to the same site where its power could be used to greater advantage. Such a Northern Hemisphere Observatory would be administered from Herstmonceux where all the day-time work would continue to be done. The overseas site would be purely an observing station.

This booklet describes only the present work of the Royal Greenwich Observatory. The original buildings at Greenwich are open to the public as part of the National Maritime Museum. Most of the rooms, and many of the instruments have been restored to their original state.



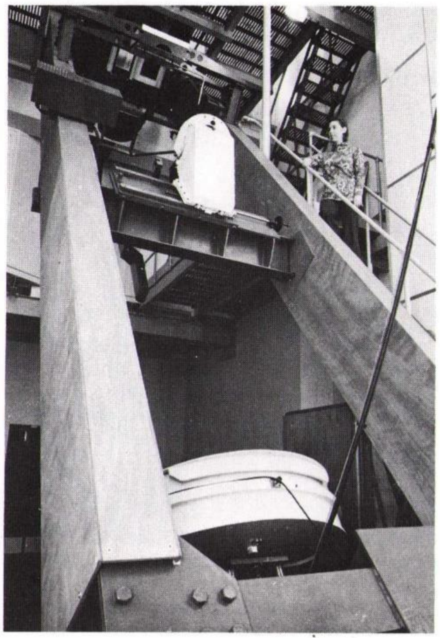


The heart of the Isaac Newton Telescope is the 98-inch mirror. The mirror was made by Cornings (USA) of a pyrex material as an experimental casting for the 200-inch mirror of the Mount Palomar telescope. The optical surface was ground and polished to the required optical figure by the manufacturers of the telescope, Sir Howard Grubb Parsons Ltd of Newcastle. Light is reflected from the front surface of the 16-inch thick disc which is coated with a thin film of aluminium. As this film is exposed to the damp night air it begins to deteriorate after a few months. When this happens the 4½ ton mirror is lowered 60 ft to the ground floor. The old film is washed off and a new one deposited in a specially designed vacuum tank.

While the astronomer is observing he is forced to remain in the observing chair, so the telescope must be controlled by the second member of the observing team, the night assistant. The night assistant sits at the console (*middle photograph above*) and moves the telescope from star to star as requested by the astronomer over the intercom. He keeps the log and watches the weather. Astronomers are always at great pains to make their equipment sensitive so that they can detect the light of the faintest stars possible. Such feeble signals might easily be swamped if stray light from the console were to fall on the equipment. The night assistant must therefore work in a carefully shuttered enclosure. He cannot see the telescope and must "fly blind" on instruments alone. His only view of the sky is by closed circuit television looking through a smaller telescope attached to the big one.

The Isaac Newton Telescope (*above, right*) is mounted on a massive polar disc whose axis is parallel to the Earth's axis. This is because the rotation of the Earth makes every star appear to follow a circle with its centre on the Earth's axis, close to the direction of the Pole Star. A rotation about this axis can counteract the rotation of the Earth, so that the telescope can follow the movement of a star as it moves across the sky from east to west. Without this rotation, the stars would move across the field of view in a few seconds; but with it the stars appear in the telescope to stand still in the sky. To keep the stars fixed in the field of view, the telescope must move very smoothly. The main bearing of the telescope is therefore a very important component; it is an oil pad bearing which carries a total weight of 72 tons.

The telescope is equipped with three different foci which are adapted for different tasks. Most simply, the light reflected from the primary mirror is focused on to a photographic plate in the middle of the telescope tube. This is called the prime focus and the plateholder and seat for the observer are encased in the prime focus cage. This is also in the middle of the tube and obstructs about a fifth of the incoming light. The most complex focus is the coudé focus which is reserved for stationary instruments. However the focus most frequently used is the Cassegrain focus shown in the picture. The prime focus cage is replaced by a convex mirror which redirects the light through the centre-hole of the 98-inch mirror to the focus behind. This is the most convenient position for photometers and other intermediate-size instruments.



Engineers replacing the Cassegrain secondary mirror after the completion of a run with the coudé spectrograph.

The largest spectrograph for the Isaac Newton Telescope is much too heavy for the telescope to carry. It occupies a large room filling the whole height of the tower on the south side of the building. The star light reaches it by a five-mirror system wherever the telescope is pointing. The shape of the light path gives the spectrograph its name "coudé" from the French word for elbow.

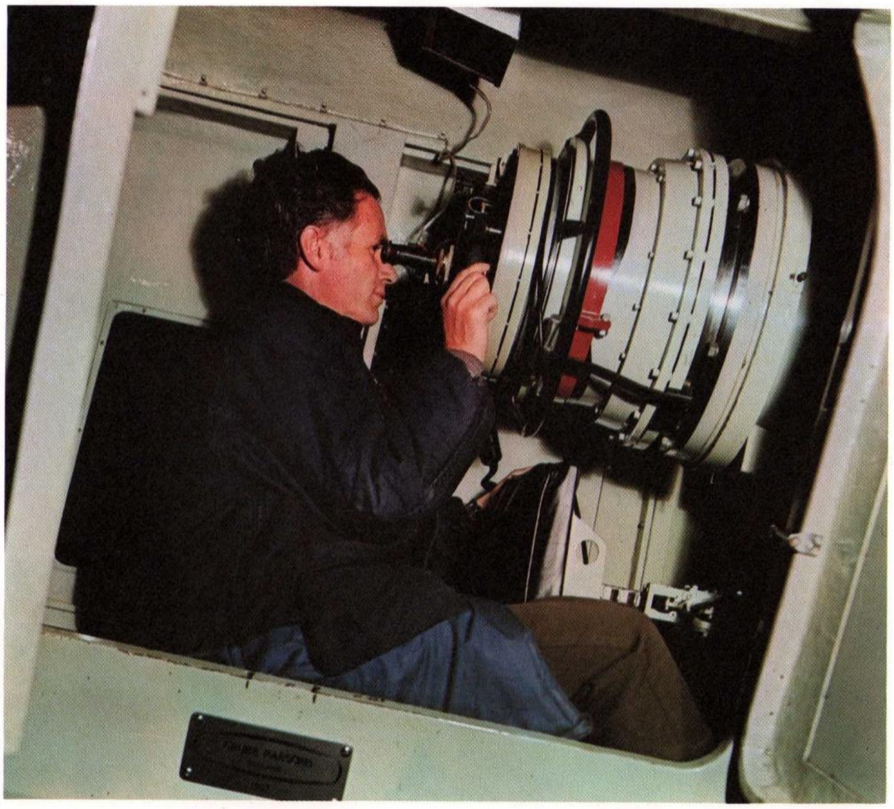
(*Above right*) A new Michelson interferometer developed by an astronomer from Imperial College. The Isaac Newton Telescope is provided for the use of the whole British scientific community, and because of its great power there are more scientists wanting to use it than can be catered for. The Science Research Council has set up a panel of experts to allocate time on the telescope according to the scientific merits of the different projects. The maintenance of the telescope is the direct responsibility of the Royal Greenwich Observatory but new instruments to be used with it are built either at universities or the Observatory as needs dictate.

Her Majesty the Queen at the official opening of the telescope in 1967. Demonstrating the instrument is Sir Richard Woolley FRS, then Astronomer Royal. *Evening Argus*

The Isaac Newton Telescope Building from the north-east. The total height of the building is 90 ft. The two shutters open by moving sideways on rails to leave an open gap for the telescope to look through. To bring this gap into the position required, the whole dome weighing 140 tons and occupying the top third of the building can be rotated. If the telescope is tracking one star from east to west then the dome is rotated at the required speed to keep a clear gap always in front of the telescope. However, should the need arise, the dome can be turned through a complete circle in four minutes.

There is always a limit to the fineness of the detail which can be seen through a big telescope, because small air currents in the Earth's atmosphere make a star's image shimmer and tremble like a pebble seen at the bottom of a pond. Astronomers go to great lengths to cut down this shimmering, which they call "bad seeing"; otherwise the high performance of the telescope would be wasted. For this reason the telescope is mounted 60 ft. above the ground where the air is not so turbulent. The ground around the telescope has been thickly planted with quick-growing trees. They prevent the Sun over-heating the ground, and so reduce the hot air currents. They also serve as a wind break.

The Orion nebula photographed with the 30-inch reflector. This nebula is in our own galaxy and comparatively near by astronomical standards. Its distance is 1500 light years so that the light we are now receiving left the nebula during the dark ages. Stars are being formed in the nebula out of gas and dust. The picture shows mostly gas but dust and young stars are more obvious in the infra-red (light beyond the red end of the spectrum where the eye cannot see). Infra-red studies of stars in the process of formation have been made in several nebulae by astronomers at the Observatory.



Exposing a photograph in the prime focus cage of the Isaac Newton Telescope. Most of the objects photographed are too faint to be seen by the observer. He has an eyepiece beside the plate-holder to watch a comparatively bright star. If this star indicates any error in the tracking of the telescope he corrects with the telescope controls.

Nowadays optical astronomers are much more involved with other sciences than they were a few years ago. Radio astronomy has flourished in Britain since World War II and British scientists are making increased use of rockets and satellites to observe X-rays and ultra-violet light from space. However these observations do not supersede optical astronomy, they complement it. Frequently the sources which are brightest to radio astronomers are extremely inconspicuous at optical wavelengths. The prime focus of the Isaac Newton Telescope is regularly used to photograph such sources in order to measure their positions.

a

b

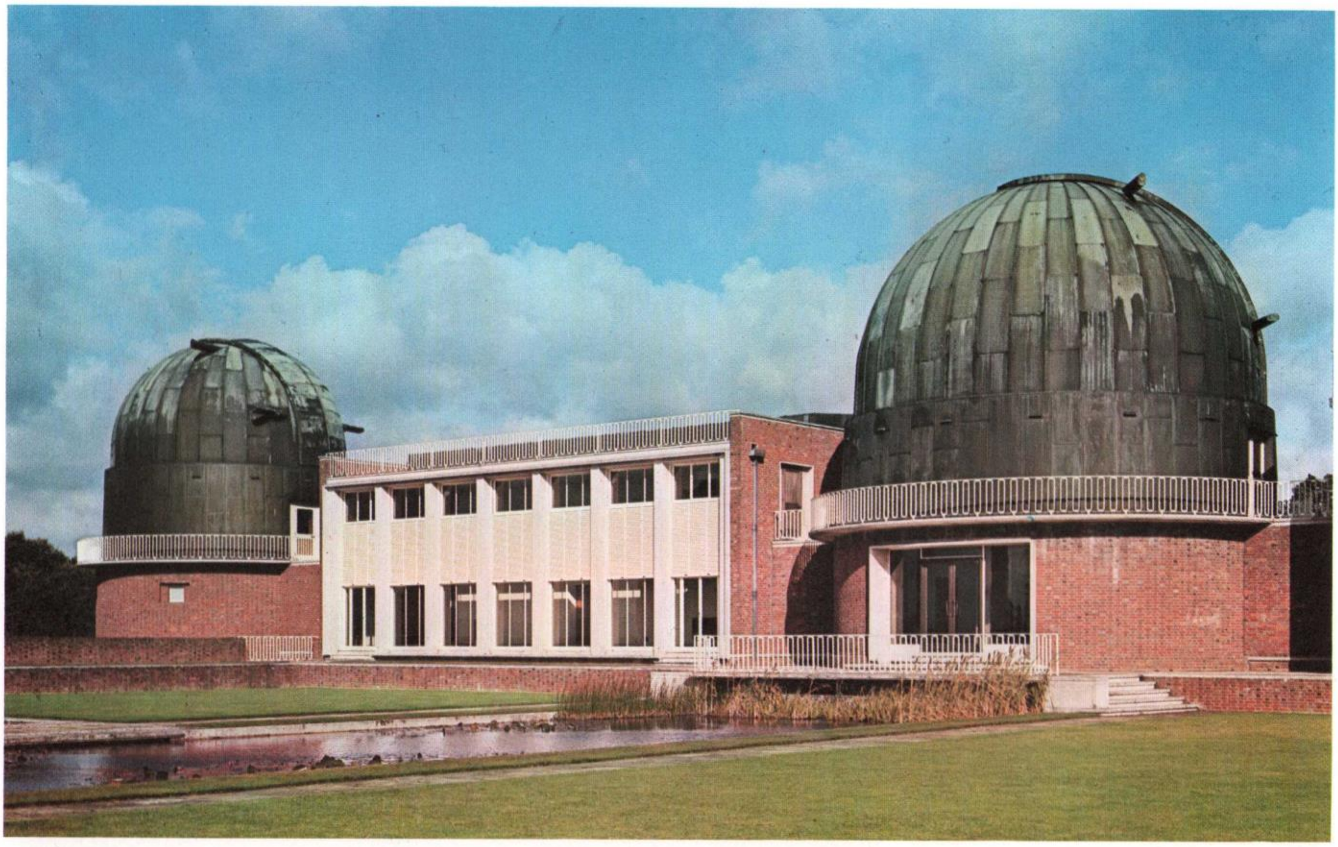
The Observatory's research on distant objects has centred on the rapid light variations of quasars. These are star-like objects which are very condensed and energetic galaxies, so bright that they can be seen at greater distances than any other galaxy or star. The observer in the picture (*below, right*), is using a photometer to monitor their changes in light intensity. The quasar under observation, 3C48, is believed to be five thousand million light-years away and is probably the most distant object observed with the telescope. (A light-year is the distance that light travels in a year, travelling at 186,000 miles a second. The Sun is eight light-*minutes* away). It is difficult to define the range of a telescope with any precision. One difficulty is that the range is greater for a straightforward task like photography than it is for a complex one like spectrography. Another is that measured distances are not necessarily the real ones because of the curvature of space. A rough practical limit to the range of the Isaac Newton Telescope is ten thousand million light-years.

c

Isaac Newton Telescope photographs of three spiral nebulae similar to our own Milky Way. Their distances are believed to be (*a*) M33, two and a half million light-years. This galaxy belongs to the same group as our own and has been the subject of particular study by a group from the University of Oxford. (*b*) M51, sometimes known as the whirlpool nebula, with its companion, 12 million light-years. (*c*) M81, eleven million light years.

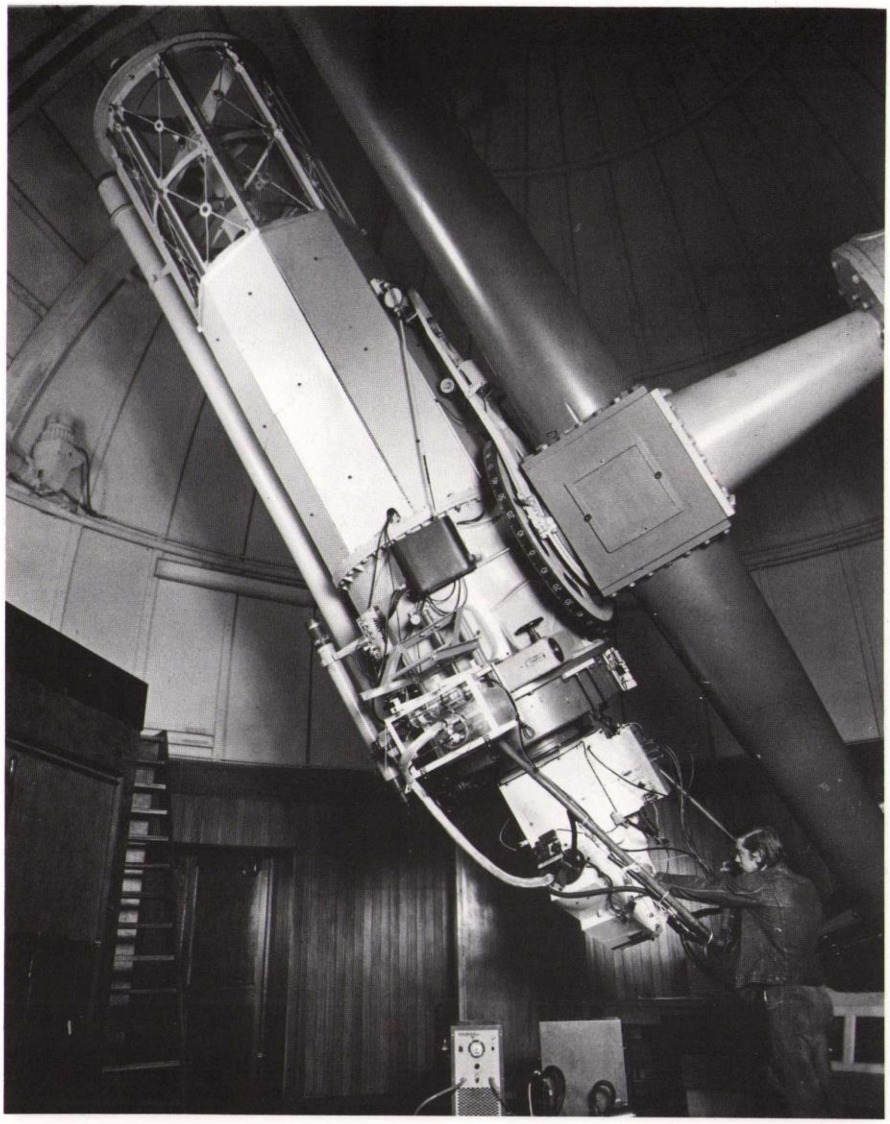
Above: M3 photographed with the Isaac Newton Telescope. M3 is a globular cluster, 42 thousand light years away, within our own galaxy. There are about a hundred globular clusters in our galaxy and several have been intensively studied at the Observatory. One of their most interesting characteristics is the large number of variable stars which they contain.

The popular picture of a scientist is a man wearing a white laboratory coat, but an astronomer is far less elegant. When working at night the astronomer's chief enemy is cold, because any attempt to warm the inside of the dome would cause hot air currents which would destroy the sharpness of the images. The only escape is to muffle in warm clothing. A single observer works from dusk till dawn in summer; in winter the night is divided between two. They often carry on longer – especially when they expect the answer to an interesting question. Many observers are women; they work under the same conditions as men.



The domes housing the 30-inch and 36-inch reflectors. In the building between them there is a laboratory where their mirrors are re-coated with aluminium, usually about once a year.

Facing: Six telescopes, like the Isaac Newton Telescope equatorially mounted, are positioned in the "Equatorial Group", a quarter of a mile north of the Isaac Newton Telescope. Every care was lavished on the appearance of this group of buildings so that it should not detract from one of the most beautiful parts of rural Sussex. The knapped flint walls are a special feature.



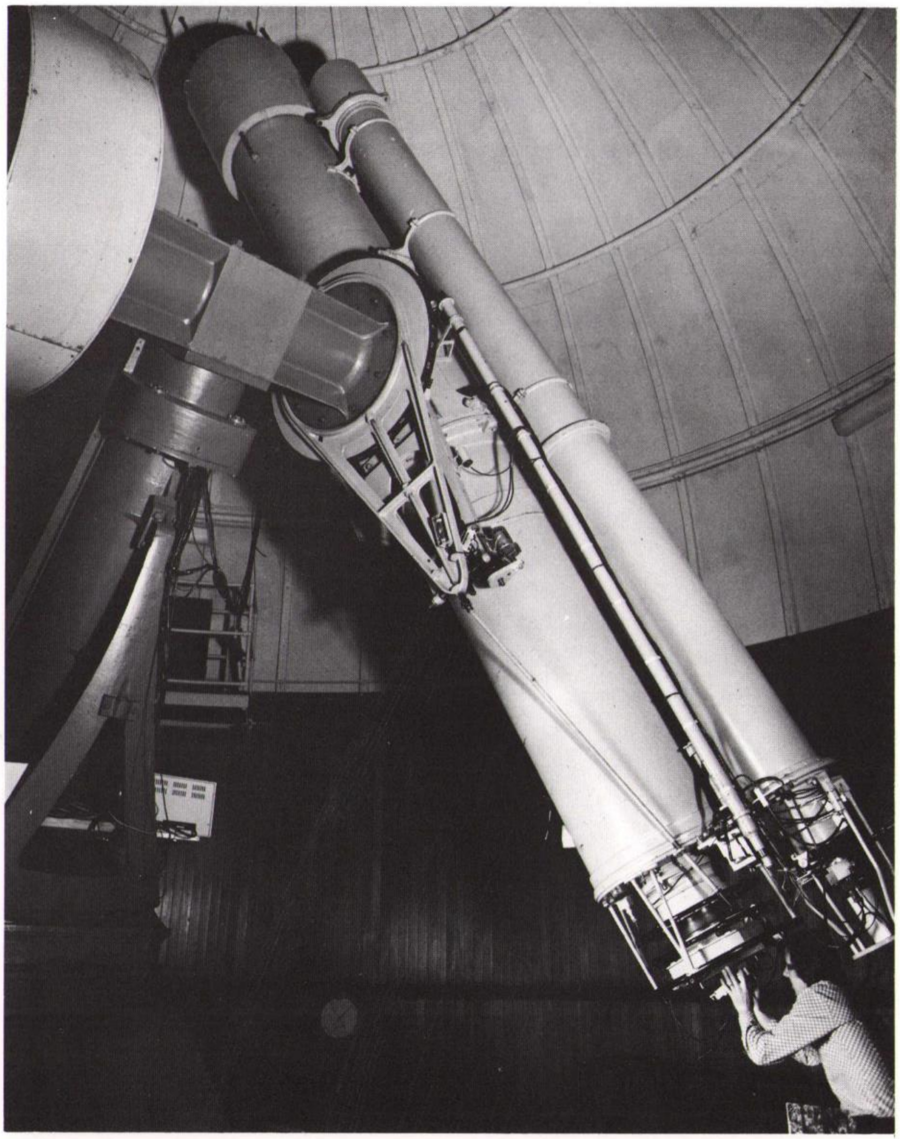
The 36-inch Yapp reflector. The light gathering power of a telescope depends on the diameter of its largest mirror or lens and is the usual way of describing it. Thus the Isaac Newton is a 98-inch telescope and the Yapp reflector is a 36-inch. The 36-inch was given to the Observatory by a private benefactor, Mr William Johnston Yapp, in 1932, and remained the Observatory's largest telescope until the commissioning of the Isaac Newton Telescope in 1967.

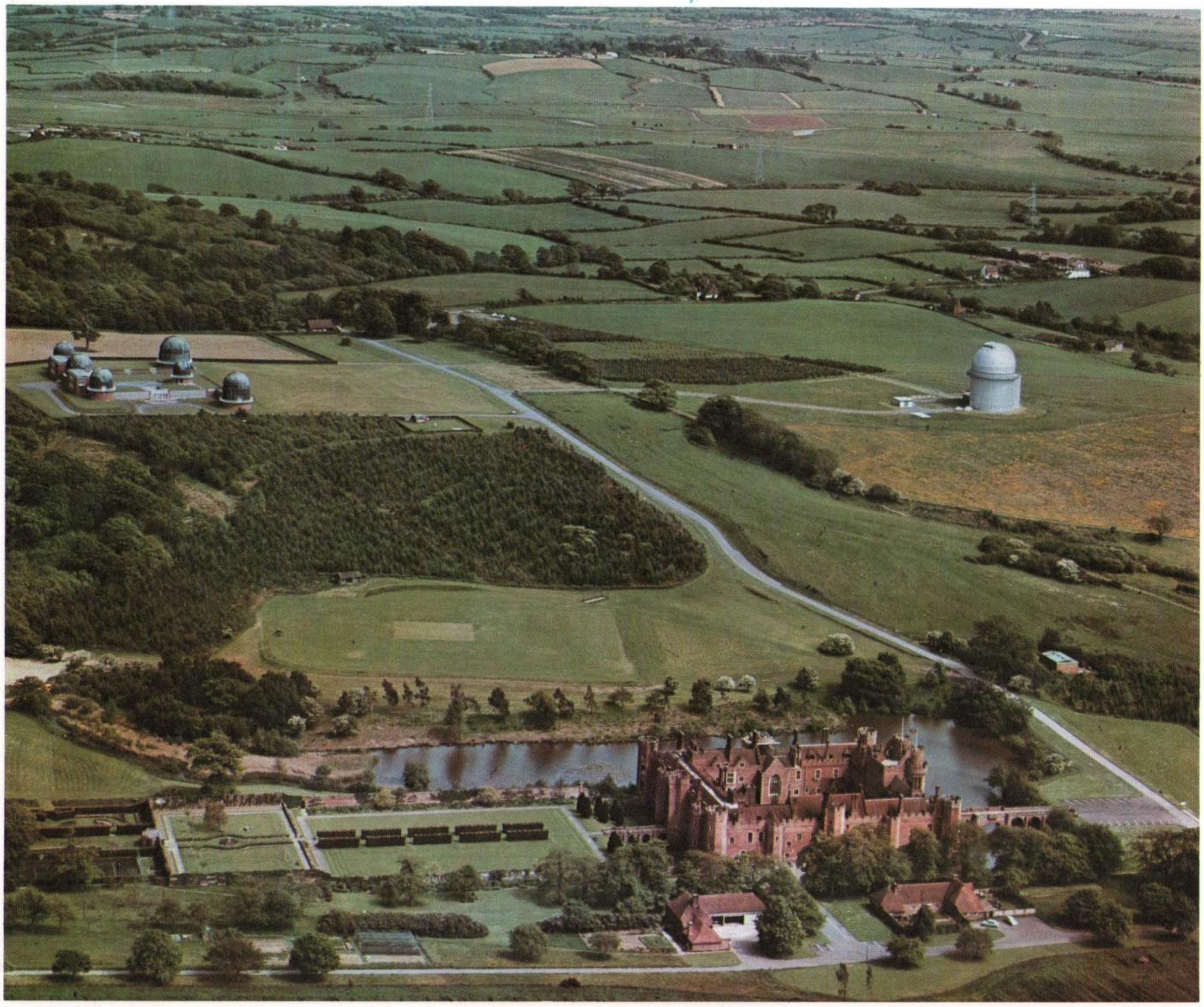
Mounted below the 36-inch is an image tube spectrograph built in the Observatory workshop. The spectrograph is one of the astronomer's most powerful tools; it analyses light into its constituent colours and can be used to measure how hot a star is, what chemical substances are in its atmosphere and how fast it is moving towards or away from us.

The 36-inch was not made obsolete by the Isaac Newton Telescope. In fact the larger telescope can be used more effectively when supported by a group of smaller, more specialized telescopes. The 36-inch now does much the same work as the Isaac Newton Telescope but on brighter stars where its smaller light grasp is no hindrance. It has been found so successful in this rôle that it is now being modernized so that it can be used as a regular reserve and test-bed for new auxiliary instruments.

The 26-inch telescope. The 26-inch differs from the 36-inch because it gathers light with a lens – like a sailor's spy-glass – not with a mirror. It is used solely for photographing the sky and is thus nothing but a camera, albeit a very large and precisely constructed one. It is mounted equatorially, like the Isaac Newton Telescope, although the actual mechanism is rather different. In practice it is impossible to make the mounting to the exacting standards required so a second 13-inch telescope is rigidly attached to the 26-inch. Before the exposure starts, the observer aims the telescope carefully in the required direction, and sets the cross-wires in the focus of the 13-inch telescope to coincide with a suitable star in the field. Until very recently it was necessary for him to hold the star exactly on the cross-wires throughout the exposure by eye, using the telescope controls manually. This ensured that the resulting photograph was as sharp as possible. This process has now been completely automated by the provision of the "auto-guider", shown behind the observer's head in the picture, which does a very difficult job much better than any human being.

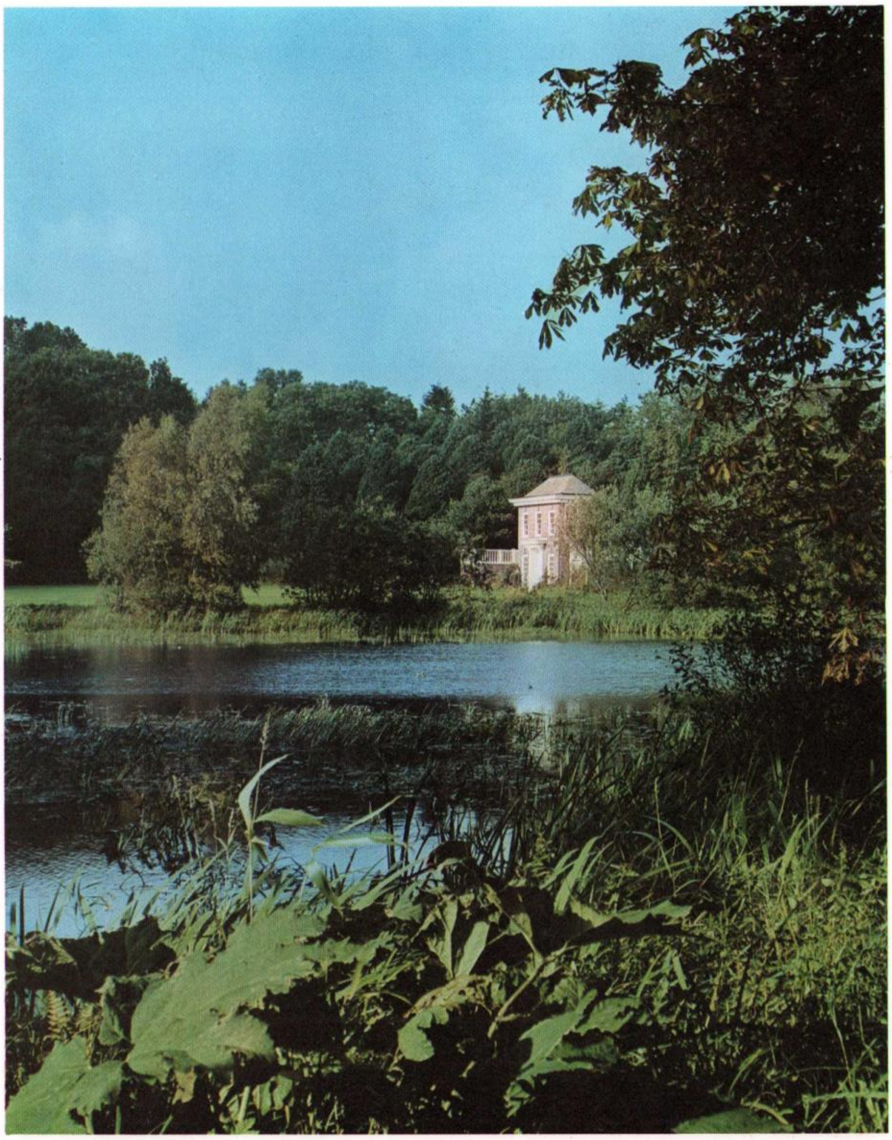
The chief work of this telescope is to measure the distances of stars, using the conventional surveyor's method of finding distances. In a few selected areas and the fields of star clusters it has also been used to measure the motions of faint stars across the face of the sky. These displacements are so small that they can only be detected by a careful comparison of two photographs, well separated in time. For this reason all the photographic negatives taken over the eighty years of the telescope's life are carefully indexed and stored.



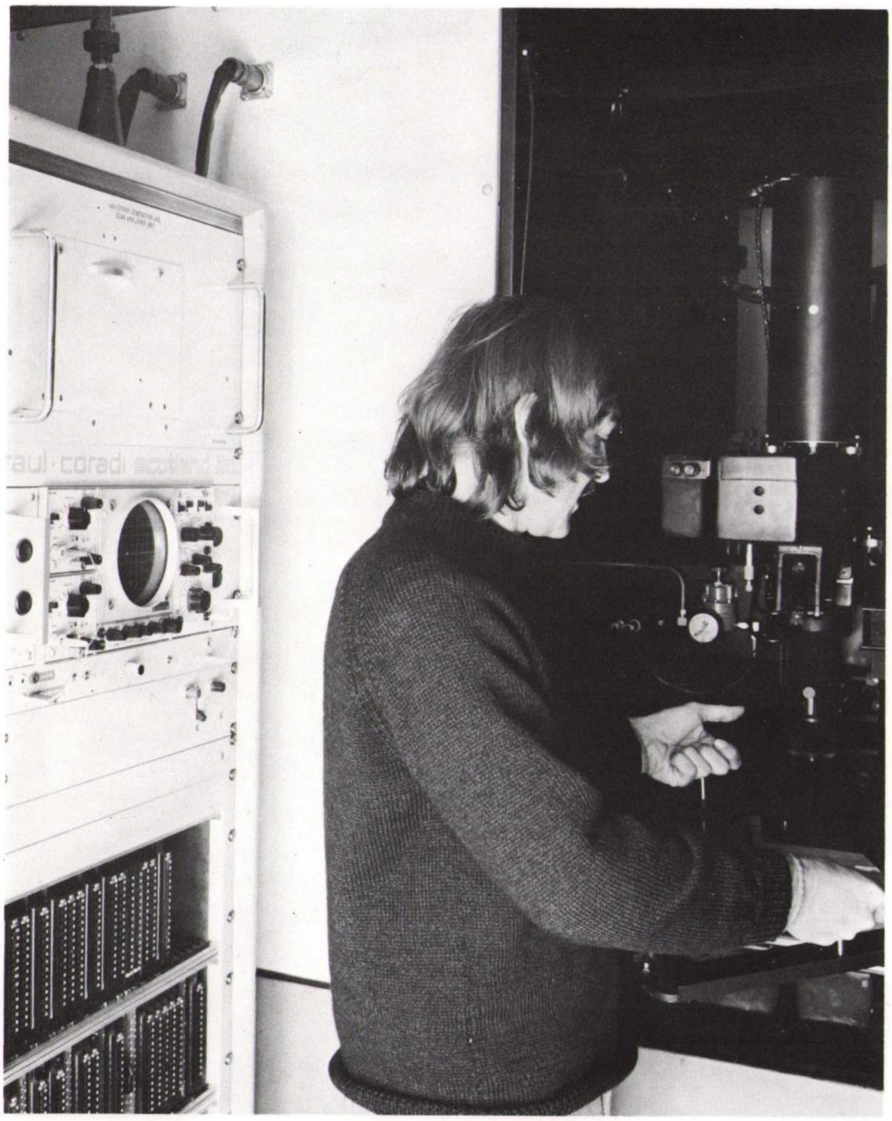


Facing: An aerial view of the Observatory. The castle is in the foreground, the Equatorial Group in the left distance and the Isaac Newton Telescope in the right distance.

The buildings of the Observatory are dotted over a 380-acre estate. The formal garden is north of the castle (*left in the picture*), with an expanse of grass and parkland beyond. Some parts of the site are solely devoted to forestry, both because it is the best commercial use of poor agricultural land and because the trees enhance the astronomical value of the site by keeping the ground cool and providing windbreaks. Waterfowl are encouraged on the castle moat by daily feeding and there are native wildfowl in abundance throughout the grounds. Badgers are plentiful although rarely seen except at night. One of the pleasures of observing on a summer night is to hear the song of the nightingale.

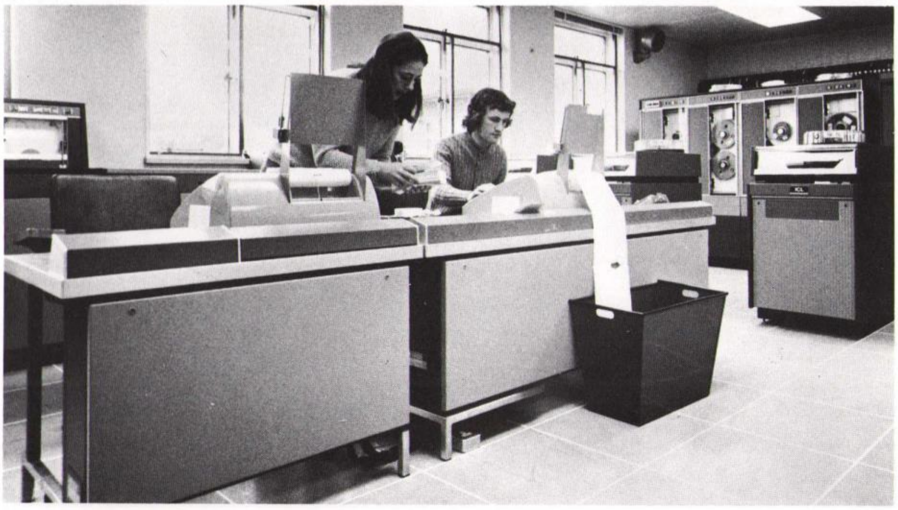


Right: The upper lake and Folly. The Folly was built by a previous owner to complete the view from the north windows of the castle.

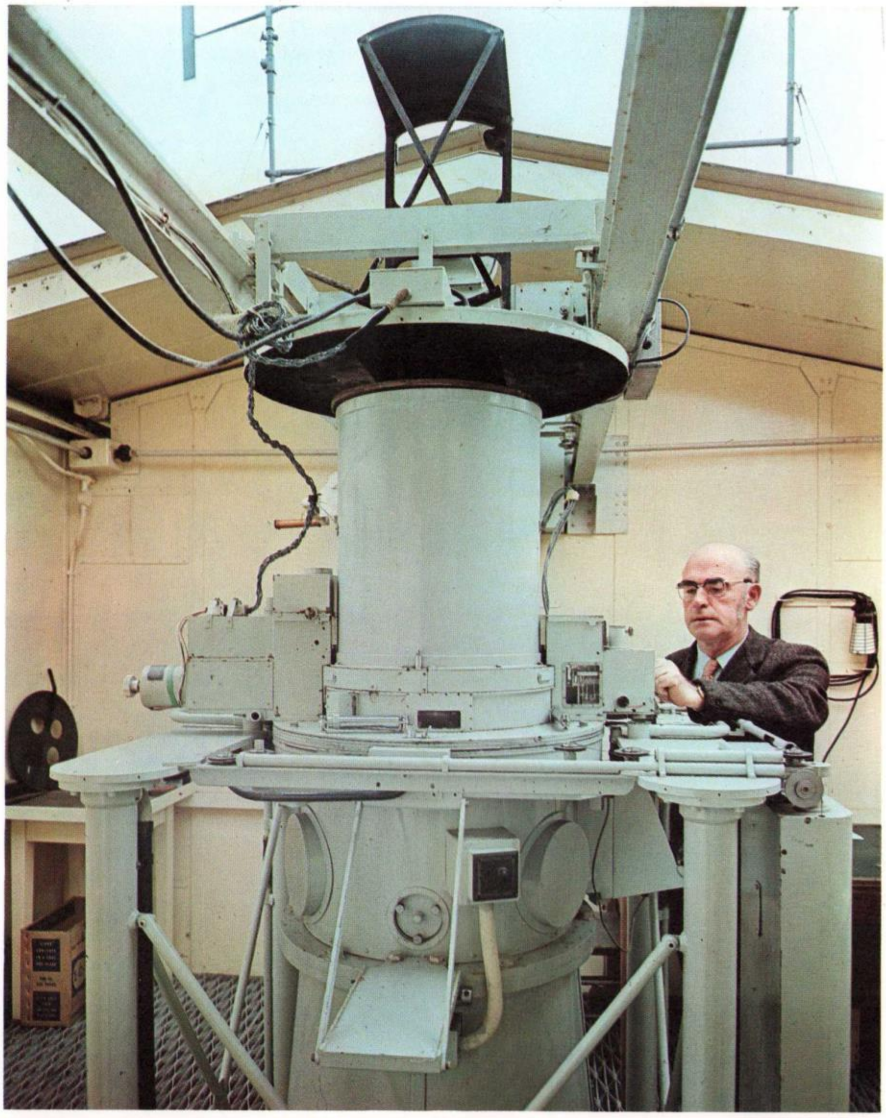


Once a photograph has been exposed at night the astronomer's work has only just begun. Measuring just one six-inch square photographic plate may involve many hours of work. On some plates the stars must be measured to an accuracy of 1/25,000 of an inch (about a fiftieth of a human hair). On others the image sizes must be measured to find the brightness of the different stars. Others require an even more elaborate analysis. To do all these different jobs calls for many different measuring machines. Most of them are in the lower basement of the West Building where their temperature can be easily controlled. To speed up the measuring these machines are being made increasingly automatic. Shown in the picture is G A L A X Y, a large fully-automatic measuring machine, developed at the Royal Observatory, Edinburgh and made by the Scottish firm of Faul-Coradi. This machine searches a photograph for star images and records their rough positions. It then makes a second run, measuring the size and position of each star image accurately, and delivers this information on a paper tape which is later read by the central computer. Not only is such a machine faster than a human being, it can work up to 24 hours a day without getting tired.

An older measuring machine built by the German firm of Zeiss. The operator measures by positioning the image on the cross-wires: the measurement is recorded automatically on paper tape, which can be fed into a computer.

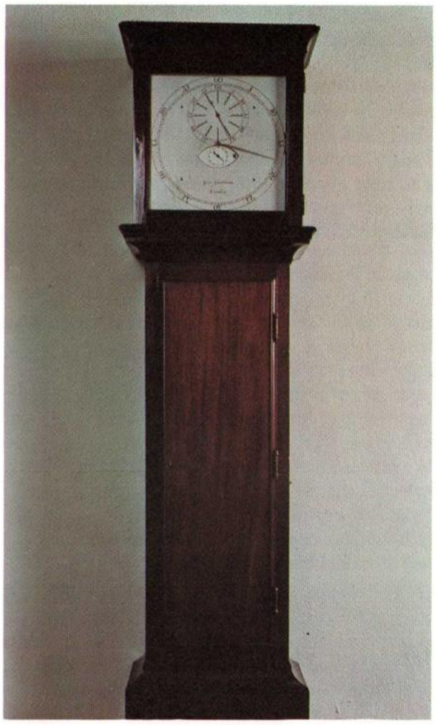


The Observatory is equipped with an ICL 1903 T computer. Such a powerful machine is required to prepare the *Nautical Almanac* and to handle the large amounts of data produced by the measuring machines.



Left: Preparing the photographic zenith tube for a night's work.

The Greenwich Meridian was adopted in 1884 as the reference for the measurement of time and longitude throughout the world. Herstmonceux is now the home of Greenwich Mean Time, familiar to most people from the six pips on the radio. The time required for day-to-day use is measured by the rotation of the earth. In the Spencer Jones group there is a specially designed telescope, a photographic zenith tube, which measures the rotation of the Earth relative to the stars. Since the Observatory at Herstmonceux is 15 miles east of the Greenwich Meridian, the observed time is corrected by 81 seconds and expressed as Greenwich Mean Time. For navigation, time determined from the Earth's rotation is needed to find the longitude. However, for many other scientific purposes, involving a uniform scale of time or frequency, the Earth is not a sufficiently accurate clock. The half-dozen atomic clocks in the basement of the West Building run much more uniformly than the Earth. There is no real independent check on the constancy of an atomic clock but there are now about 70 working continuously throughout the world and they are regularly intercompared by means of special radio navigational signals, to an accuracy of a few tenths of a millionth of a second. The Observatory not only maintains independent scales of Greenwich Mean Time and atomic time but has taken a leading part in the establishment of International Reference time scales and in the co-ordination of radio time signals.



This long case clock by G. Graham was bought by Halley in 1725 for £12. With some modification it was regularly used for maintaining Greenwich time until 1874. Pendulum clocks are now obsolete for accurate time-keeping but the Observatory takes a pride in keeping them in full working order.

An atomic clock being tuned up prior to installation. Once the clock is running in the air-conditioned basement it will not be touched except for the most pressing reasons.

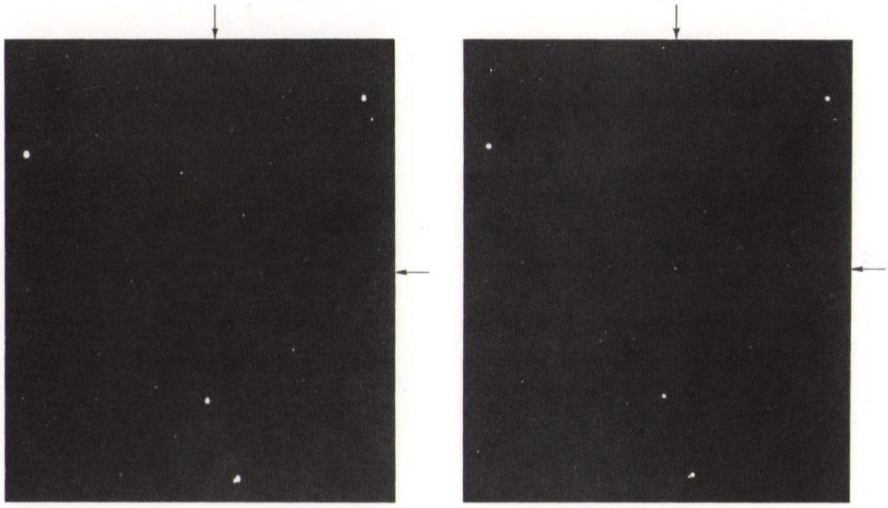
Above: Time: 09 00 00. Monitoring the transmission of the Greenwich Time Signal. There is a small lag in the line to the BBC transmitter and the pips are regularly checked to make sure that the lag has been correctly compensated.

Because the Observatory is equipped with atomic clocks and a photographic zenith tube there are ample data to study the rotation of the Earth. A good night's work with the photographic zenith tube yields the time difference between the Earth's rotation and the atomic clocks accurate to a thousandth of a second (a millisecond). The observations show that the length of the day fluctuates by about a millisecond during a year, mostly because of the seasonal effect of the Sun on the Earth's atmosphere. Smaller changes arise from the deformation of the body of the Earth. The study of the Earth's rotation has been carried back in time to the foundation of the Observatory at Greenwich, even though neither atomic clocks nor photographic zenith tubes were available then. The long series of observations made at Greenwich of the position of the Moon relative to the stars provide most of the necessary data because the motion of the Moon is so well understood that it can be used as a clock. The old observations not only show that the length of the day varied in the past but also that the day is getting progressively longer, year by year. This slowing down of the Earth's rotation is not small – if an atomic clock had been set running in 1675 it would now be three minutes fast! It is believed that the Earth slows down because of the action of the tides raised by the Moon and Sun.

Canadian astronomers have built another photographic zenith tube at Calgary, at the same latitude as Herstmonceux, which observes the same stars but eight hours later. Comparison between the two stations shows that the North Pole is not fixed relative to the Earth's surface but wanders by as much as fifty feet from its mean position. The pole is responding partly to movements of large air masses and partly to movements deep in the Earth's interior.

HISTORY OF THE GALAXY

Our own galaxy is probably typical of millions of other galaxies in the universe. It is believed that the galaxy was originally much larger than it is now and composed mostly of hydrogen. It then began to collapse and stars began to form. Eventually it arrived at its present cartwheel shape. During this time, elements heavier than hydrogen – iron for instance – were being formed deep inside stars. When, as often happens, stars exploded, the heavy elements were returned to the gas and became mixed into stars formed later. Thus stars born early in the galaxy's history have high speeds which they gained during the galaxy's collapse and a low iron content; while those formed recently share the cartwheel rotation of the galaxy and have a high iron content. Research work at Herstmonceux is aimed at both these aspects. The abundances of iron and many other heavy elements in stars are studied with one of the several spectrographs; as a by-product the speed in the line of sight is measured. By comparing direct photographs taken twenty years apart or more, it is possible to measure the speed across the line of sight.



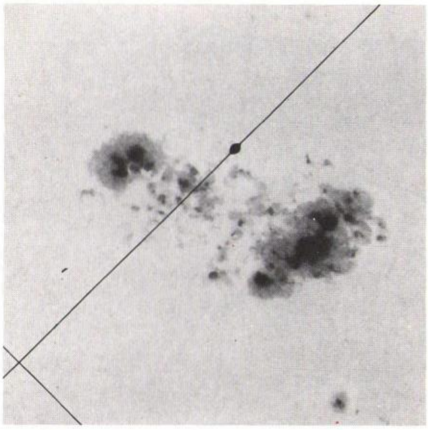
The optically violently variable quasar 3C48. In the second photograph it is more than twice the brightness in the first, although the photographs are separated by only three weeks.

HIGH ENERGY ASTROPHYSICS

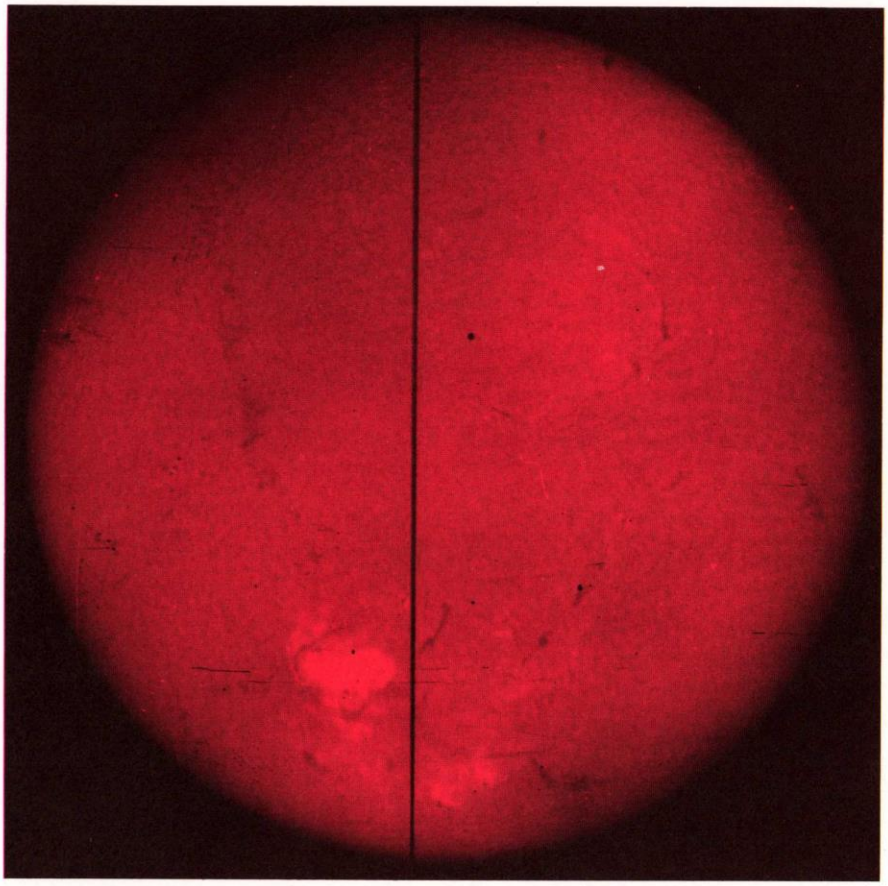
Modern astronomy is strongly involved with several different kinds of object which have little in common except that a great deal of energy is enclosed in a comparatively small space. The Observatory has made important contributions in high energy astrophysics, mostly in two unrelated fields.

Shortly after launch in 1971, the *Uhuru* satellite found that the strong source of X-rays in the constellation Cygnus was highly variable. The Isaac Newton Telescope was promptly turned in the same direction and the brightest star close to the X-ray position was observed with the spectrograph. A few nights' work with the spectrograph revealed that the star's speed was not constant; sometimes it was approaching and at others retreating and the pattern repeated itself every five days. This is just what happens when one star rotates about another, in a double system held together by gravity. The speed changes indicated that both stars had masses ten to twenty times that of the Sun. Only the biggest star could be seen. But why was the second star invisible, especially when it was such a strong source of X-rays? Some astronomers believe that here we have a "black hole", an object whose gravitational field is so intense that light cannot escape. The X-rays are explained by the heating of matter falling into the "hole". This explanation is not accepted by all astronomers but it is a frequent source of discussion!

Radio astronomers discovered in the 1950's that some peculiar galaxies were strong emitters of radio waves. However in the directions of some strong radio sources nothing but ordinary-looking stars could be seen. In 1963 came the discovery that – if the redshifts of their spectra were a reliable method of measuring distance – some of these star-like objects were powerful sources of both light and radio waves, located at the outer fringes of the known universe. They were quickly given the nick-names "quasars"; short for quasi-stellar radio sources. For the last decade they have been the subject of intense theoretical and observational research. The Observatory's chief contribution has been to monitor the brightnesses of quasars. Work here shows that there is a special OVV class of quasar: – "Optically violently variable". Such quasars frequently double their light output in a matter of months. This suggests that quasars are less than a light-year across whereas our own Galaxy – the Milky Way – is 75,000. (A light-year is the distance light travels in a year, travelling at 186,000 miles a second. The Sun is eight light *minutes* away). When allowance is made for their great distance, it is found that quasars are much brighter than our own Galaxy, especially at radio wavelengths. It is difficult to understand how so much energy can be confined in so small a volume.



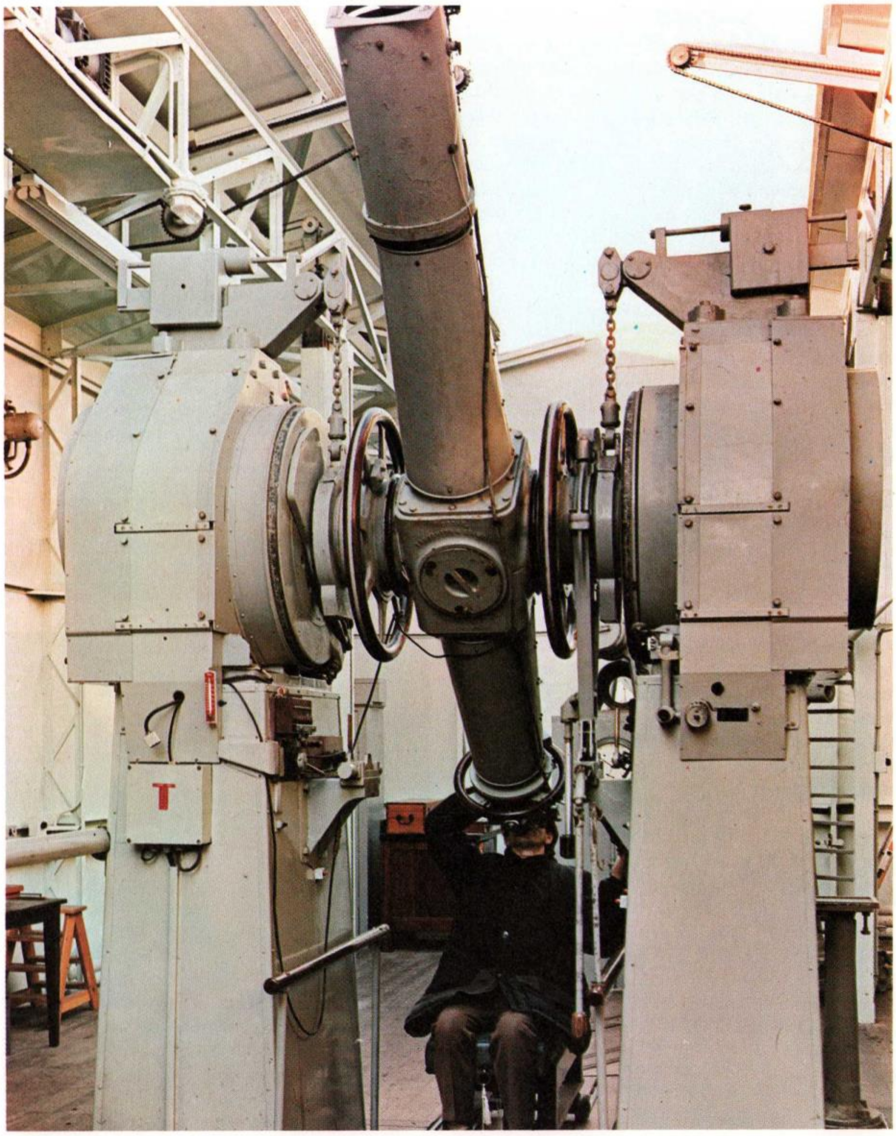
A large group of sunspots.



The Sun is kept under daily observation at Herstmonceux and, when possible, it is photographed in both white and hydrogen light. If it should be cloudy at Herstmonceux the series is completed with photographs from the South African Astronomical Observatory, Cape Town, or the Indian Institute of Astrophysics, Kodaikanal. This provides a record of the ever-changing number of sunspots that appear on the Sun's surface. The life of a sunspot can vary between a few hours and several months. As the Sun rotates sunspots appear to move across the Sun's disc. They tend to occur in groups and the picture shows the largest spot group ever photographed at Greenwich or Herstmonceux, photographed in white light, 1947 April. The straight lines are for reference purposes when the photograph is measured. The little circle on one line is roughly the size of the Earth to the same scale.

The Sun photographed in the light of glowing hydrogen gas, which is most prominent in the red. The vertical line is a reference mark made in the camera. Sunspot groups are frequently the sites of great storms on the surface of the Sun, called solar flares. One such flare appears as a bright area on the picture above. Radiation and particles from these flares interact with the Earth's upper atmosphere and can lead to sudden enhancements of atmospherics or complete breakdowns in short wave radio reception. Because radio communications are so sensitive to the Sun's activity it is important to keep the Sun under continuous watch.

Observing by daylight with the transit circle. Most observations are made by night but the Sun, Moon, planets and a few bright stars are observed by daylight when appropriate.



The transit circle is supported between trunnions lying due east-west. As the telescope is turned on these trunnions it is rigidly confined to the north-south line called the meridian. The observer sets the telescope so that the star he wants will travel through the middle of the field of view. As he follows the star across, bisecting its image with a moving vertical wire, an electronic clock registers the time of crossing the meridian. This gives the star's "right ascension" which is the astronomical equivalent of longitude on a map. This instrument is capable of attaining a very high accuracy. The typical error corresponds to a fifth of a second of arc which is the diameter of a two-penny piece as seen at a distance of fifteen miles.

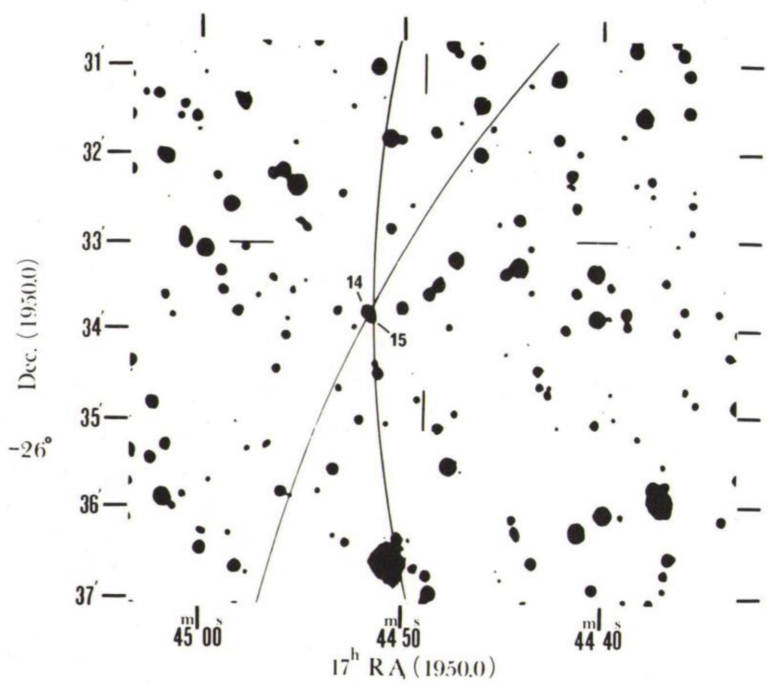
The transit circle has a longer history than any other type of important astronomical instrument; it has been used for measuring star positions for the last two hundred years. Although it is one of the few remaining instruments in which the observer still looks through the telescope, it is nevertheless in the forefront of astronomical research. For many years radio astronomers were not able to observe positions as accurately as optical astronomers but the situation has been revolutionized by radio interferometers like the new 5-km radio telescope at Cambridge. Despite their great accuracy radio interferometers are still unable to determine the zero-point from which right ascensions are measured. The Herstmonceux transit circle has co-operated in fixing the zero-point of right ascensions measured with the Cambridge 5-km radio telescope.

H.M. NAUTICAL ALMANAC OFFICE

The Nautical Almanac and Astronomical Ephemeris containing tables of the positions of Sun, Moon, planets and stars, was first published by the fifth Astronomer Royal, Nevil Maskelyne, for the year 1767. Its principal purpose was to provide seamen with reliable data so that they could find their position from sextant observations of the Sun, Moon and stars. Even with to-day's artificial satellites and other electronic aids, the use of the *Nautical Almanac* and a good chronometer remains the most widely used method of ocean navigation. *The Nautical Almanac* has appeared annually since 1767, although nowadays there are different almanacs to cater for the needs of seamen, air navigators, land surveyors and astronomers. The most precise predictions are given in the *Astronomical Ephemeris*. Not the least responsibility of the Nautical Almanac Office is to calculate the times of sunrise, sunset, lighting-up time and other things which affect the ordinary citizen.

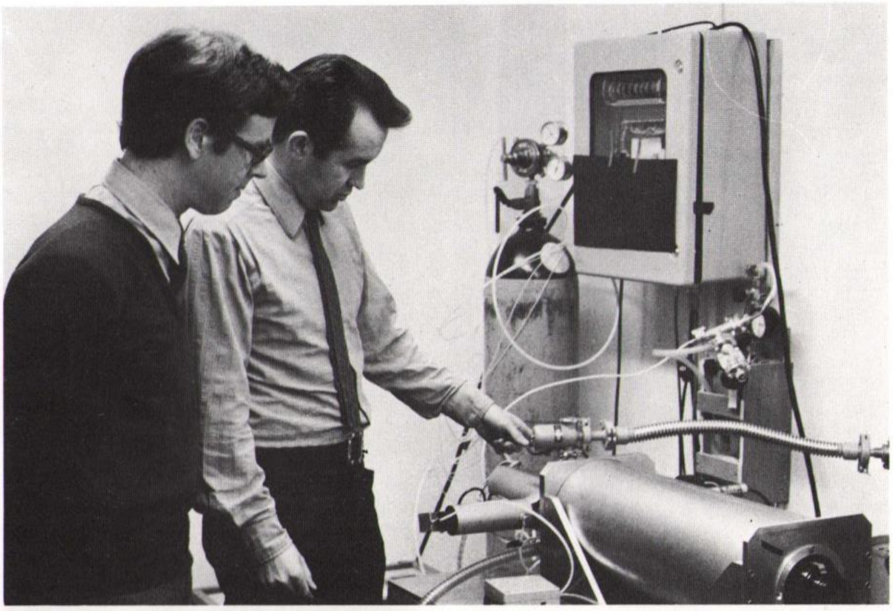
By international agreement the calculations and printing are shared between a number of countries, including France, Germany, USA and USSR. The British responsibilities are for the fundamental positions of the Sun, Moon and planets, calculated from the theories of their motions, which are based on Newton's law of gravitation. The actual calculations are made on a powerful ICL 1903 T computer, and many of the printed pages are composed automatically from magnetic tapes prepared on the computer.

Just as the Earth has the Moon revolving around it, several of the other major planets have one or more moons revolving about them. The moons of Mars, Jupiter and Saturn have been the objects of special attention here. In principle their motions are governed solely by gravitation but it is very difficult to calculate their paths in practice. Any one moon is not only affected by the gravitational pull of its parent planet but also by the other moons in the system and by the Sun. Tides are an additional complication.



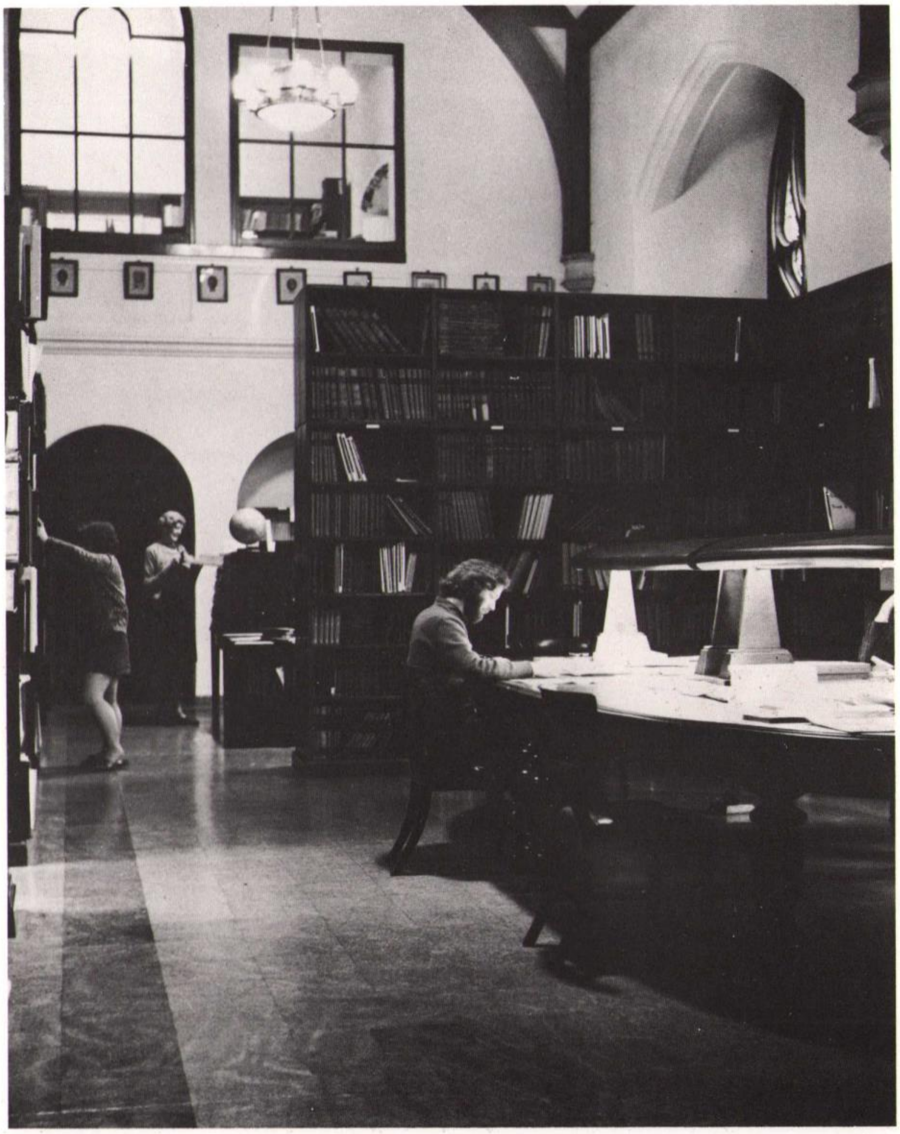
If an X-ray source lies in the path of the Moon as it makes its monthly circuit of the heavens, its signals will be suddenly extinguished when the Moon passes in front. This is called an occultation. The Moon's position is calculated from the *Astronomical Ephemeris* for the instant of occultation and the source must lie somewhere along the Moon's edge. To find the exact position two occultations are needed. The picture shows a negative picture of the sky so that stars appear as black dots on a white background. Satellite observations showed that there was a strong X-ray source somewhere between the four short lines but existing X-ray detectors could not distinguish any more closely. There were about thirty stars in the field to choose from; moreover it was possible that the X-rays were not coming from a star at all. The two long curved lines show the edge of the Moon at different times when the X-rays were observed to cut out suddenly. This work was done by the Nautical Almanac Office in co-operation with the Universities of Leicester and London. (By courtesy of *Nature*).

There is little to be gained by building bigger and bigger telescopes if no attention is paid to improving the ways in which star light can be recorded. The rapid advance in the performance of image intensifier tubes is one of the most exciting developments in modern astronomy. Many stars are so faint that enormously long exposures are required to photograph them, even with a large telescope. It is impossible to amplify the light but it is possible to convert light into an electric current and then to amplify the current – rather like a television set working in reverse. This part of the problem is straightforward; the real difficulty is in keeping the image sharp and undistorted while it is being amplified. An image intensifier tube giving good pictures up to one and a half inches across, designed and built at the Observatory, is shown in the picture. Further tubes twice this size are under development.



Spectrographs, photometers or other instruments are often mounted at the focus of a telescope as auxiliary instruments. A large part of the Observatory's effort goes into maintaining the auxiliary instruments and into developing and building new ones. To do this job effectively embraces a wide variety of expertise in design, engineering, electronics and optics; quite apart from the skilled men who do the actual construction. The picture shows the finishing touches being put to a large spectrograph intended for the 150-inch Anglo-Australian telescope on Siding Spring Mountain.

Facing: Herstmonceux Castle was built in 1441 but fell into decay after the interior was deliberately gutted in 1777 to build the nearby Herstmonceux Place. Apart from the outer shell the existing building dates from 1911 or later. The interior was gradually rebuilt, first by Col Lowther and later by Sir Paul Latham. For this reason, only the outer shell is scheduled as an ancient monument. It remains the separate responsibility of the Department of the Environment. The castle courtyard shown opposite all dates from the twentieth century – difficult to believe though this is. The castle now houses the administrative offices of the observatory, the main library, staff canteen, conference rooms and bedrooms for the night observers. Nearly all the daytime work which requires special equipment such as computers, clocks and measuring machines takes place in the West Building. The telescopes are all in their own domes or special buildings.



Right: The Observatory Library. Like other sciences, astronomy has its own specialist journals and a modern observatory needs adequate facilities to house them. The Observatory's own publications are the Royal Observatory Annals, Bulletins, Circulars and the Greenwich Time Reports. In addition many specialized research papers by astronomers at the Observatory are published by the Royal Astronomical Society. Major observatories throughout the world have a similar output, so a library grows rapidly even though specializing in astronomy alone.

This booklet was prepared by Dr D. H. P. Jones assisted by Miss A. R. Hewerdine and Mr C. M. Lowne; the photography was done by Mr D. A. Calvert. They all wish to thank their colleagues who helped in various ways.

Herstmonceux Castle illuminated by night at the time of the Queen's visit to open the Isaac Newton Telescope.

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