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Major advances in astronomy since 1890

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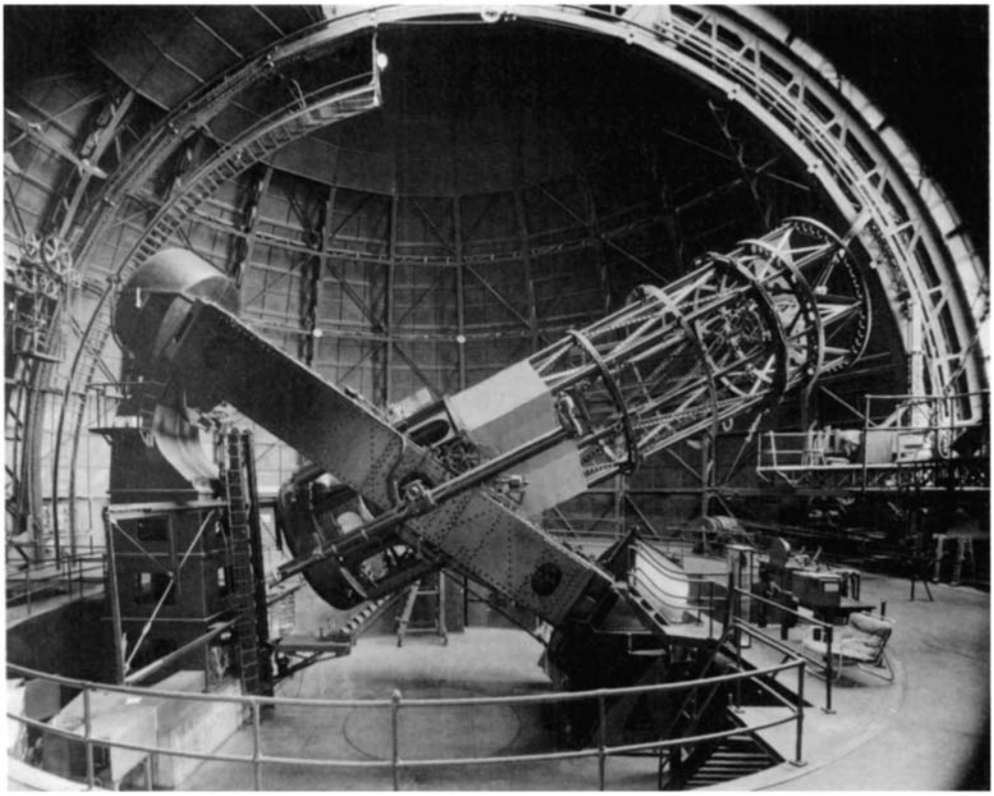
Over the last one hundred years, astronomy has seen an advance unprecedented during any previous century. This has been due primarily to two factors. In the first place there has been a vast growth in ways of observing the universe. Not only have telescope apertures increased in size, allowing ever dimmer objects to be discerned and so enabling astronomers to penetrate much deeper into space, but also totally new techniques have made it possible to examine hitherto unavailable evidence. For the first time in history, astronomers are now able to study all radiation emanating from the universe, no longer restricting themselves to one narrow range of the spectrum – visible light. Space-craft and electronic techniques have also made it practicable to probe the planets of the solar system in ways still thought impossible even thirty-five years ago.

The second significant change which has come about in astronomy is due to the increasingly effective interplay between astronomy and physics – particularly particle physics. Admittedly this last began more than a century ago, but only within the last hundred years has it been possible for these results to yield their true significance. In consequence, astronomers now understand the basic processes by which stars form, generate their energy, and age or evolve. They are able not only to show that some of what they once called nebulae are in fact external galactic systems of which ours is only one of millions, but also that all are moving away from each other – in brief that we live in an expanding universe. They have discovered exotic new objects such as pulsars and



1. Reflecting telescopes could be built with larger apertures than refractors. The 100-inch reflector at the Mount Wilson Observatory completed in 1917 was the largest in the world for some decades.

quasars, and are even able to apply the theory of relativity and the quantum theory of matter to discuss scientifically the origin of the universe and its ultimate fate.

Yet even as early as 1897 the fundamental importance of this marriage between astronomy and physics was appreciated by George Ellery Hale, that indefatigable progenitor of large aperture telescopes, when he remarked that the new Yerkes Observatory with its vast 40-inch (1-metre) aperture refractor, was 'in reality a large physical laboratory as well as an astronomical establishment . . .'

Although the Yerkes telescope was a refractor, Hale was the central figure during the past century to promote the move to reflecting telescopes because these could be made with apertures far larger than any refractor. Mounted with all the aplomb of twentieth-century mechanical engineering, such telescopes have revolutionised observations from Earth-based observatories.

This takeover by the reflector began in earnest in 1908. Ever since then apertures have kept increasing, so that now a 10-metre aperture reflector, the Keck Telescope, is to be established on Mauna Kea in Hawaii. This instrument will be another of a new generation of optical telescopes which will make use of computer-control of the optics in a novel way, devised originally in the late 1970s for the United Kingdom Infra-Red Telescope (UKIRT) in Hawaii. In the UKIRT instrument the mirror is much thinner than usual – a factor which reduced the cost both of the mirror itself and its mounting – and is supported all over its rear surface by pads, each hydraulically controlled so that the shape of the

2. The Mauna Kea Observatory in Hawaii, home to some of the world's largest telescopes. The Keck telescope, a 10-metre aperture reflector, is the most recent addition.

mirror does not alter as the telescope moves to observe different celestial objects. This method allows a precision of control which the old mechanical linkage supports of the past could never attain. The New Technology Telescope (NTT) of the European Southern Observatory in Chile finished in 1989 has adopted this by computer control techniques with notable success at optical wavelengths which, being much shorter than infra-red, impose more stringent requirements. Because a solid 10-metre diameter mirror would be impossible to construct, the technique is being taken a stage further in the Keck telescope, where the 10-metre mirror is in fact a collection of thirty-six small hexagonal mirrors, all of which the computer-controlled supports will retain in perfect optical alignment.

Another radical change to telescopes since the establishment of the reflector came in 1932 when the Estonian Bernhard Schmidt announced a totally new design. Schmidt's aim was to devise an instrument with a wide field of view of the order of seven degrees across, compared with the maximum of about one-fifteenth of a degree of the then largest astronomical telescopes. He succeeded by inventing a catadioptric system – a cross between a refractor and a reflector – though his telescope could not be used visually as its image was accessible only to a photographic plate placed inside the instrument. Photographic surveys of large areas of the sky are now commonplace, making possible observations which otherwise would have been totally impracticable.

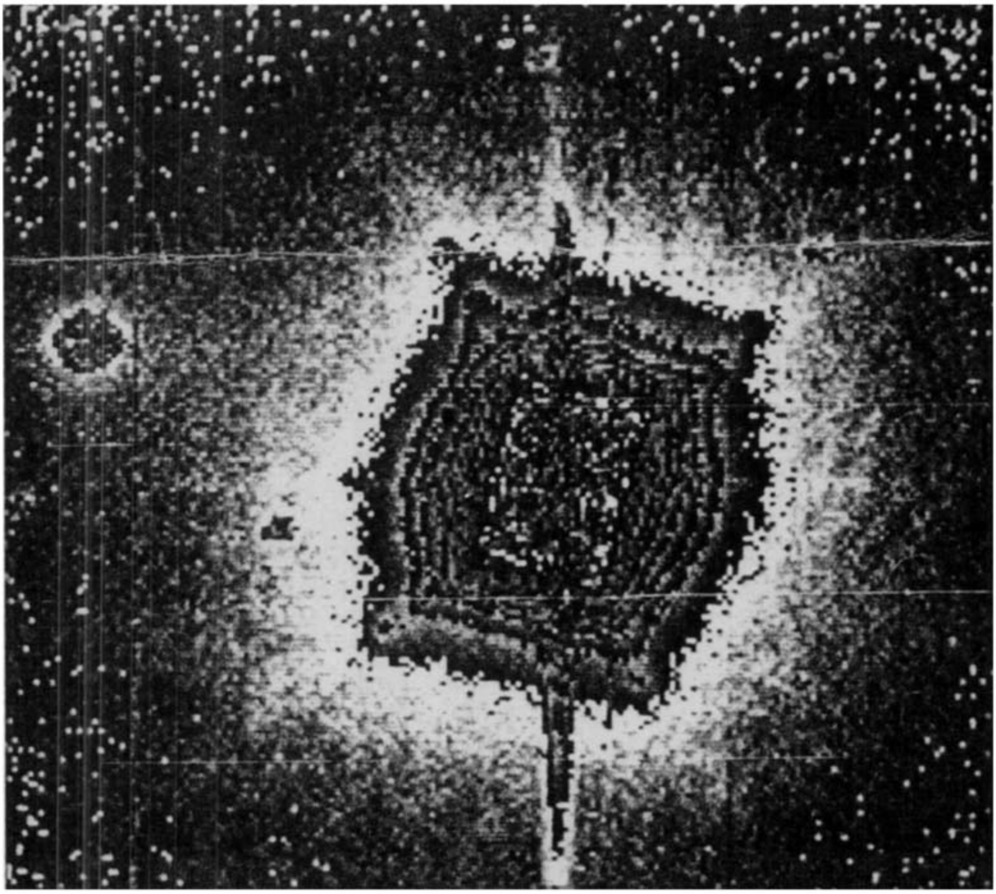
Optical observing has also been much affected by the use of electronics and computers.

Light-sensitive devices are now in wide use. Among them are electronic cameras with photo-cathodes which multiply the electrons emitted by their light-sensitive surfaces and record them on photographic plates, all essentially developments of a design originated by the French astrophysicist André Lallemand and used first in 1947–8. Yet even higher sensitivity is attained by the Image-Photon-Counting System. Invented in the 1980s by the British astronomer Alec Boksenberg, this uses an image-tube to intensify the light received by a telescope some 700 000 times, and then processes the output with a computer, building up an image which can be studied visually. Another product of the same decade is the development within the electronics industry of the charge-coupled-device (CCD), a silicon chip divided into some 640 000 separate sensitive areas which feed their results directly to a computer, Such developments as these have meant an increased sensitivity for earthbound telescopes, whatever their size. All the same, photographic techniques still play a significant part; they continue to be an important way of recording information, while increased sensitivity of emulsions and, in the last decade, the use of 'unsharp masking techniques' have made it possible to detect material previously inaccessible to the photographic plate, as the recent discovery (1989) of a giant galaxy Malin 1 (named after the photographer David Malin) bears witness.

There has also been considerable development of that basic attachment to the telescope, the spectroscope. So that the lines in a spectrum may be analysed and measured more precisely to give greater understanding about the physical processes within stars, and to measure 'line-of-sight' or radial velocities with increased accuracy, new designs of spectroscope have been developed. Multi-slit instruments, spectroscopes using interference of the incoming light to form a spectrum, and either novel 'objective prisms' for fitting at the front end of a telescope, or special direct-viewing instruments such as that designed by Patrick Treanor whereby the spectra of a host of stars may be photographed at a time, have been developed. These allow spectral surveys to be made and also great numbers of radial velocities, particularly of high velocity objects such as distant galaxies and quasars, to be measured. Image dissectors using fibre optics have even been introduced to increase precision measurement, and both photon counters and CCDs are used so that spectra of much dimmer objects can now be measured.

In the last twenty-five years, other applications of electronics and computer assistance in the optical field have been in the processing of observations and in the increasing automation of telescopes themselves.

As far as the processing of observations is concerned, there are two aspects. One is the examination of photographic plates. Even twenty years ago astronomers had the labourious task of measuring with a special microscope each separate celestial object recorded on the plate. This could be, and was, extremely time-consuming; with plates taken using Schmidt telescopes the vast amount of information available became virtually impossible to handle. At last, in 1969, a great measure of automation came with the invention of a machine which measured the brightness of each separate image and its position on the plate. A commercial development, made in conjunction with Vincent Reddish of the Royal Observatory at Edinburgh, it has made possible the measurement of at least 900 images per hour. Similar devices have been built elsewhere, notably an automatic instrument, developed by Edward Kibblewhite at Cambridge University in the



3. This CCD (charge-coupled-device) image was obtained using the Anglo-Australian Telescope. The rectangle is a region of very faint nebulosity surrounding a bright star.

1970s, which will not only measure images but also select those given by objects of different kinds – galaxies, stars, etc. – and chart the results. However, measurements using computer programs alone are now possible if the output from CCDs is recorded on magnetic tape.

The second technique which has been developed by many astronomers is the computer-processing of observations. Here specialised computer programs provide images with the various aspects under investigation being emphasised by display in different colours. Images of this kind are now produced not only for optical observations but also for those made at other, non-visible, wavelengths. They can be seen throughout the rest of this book.

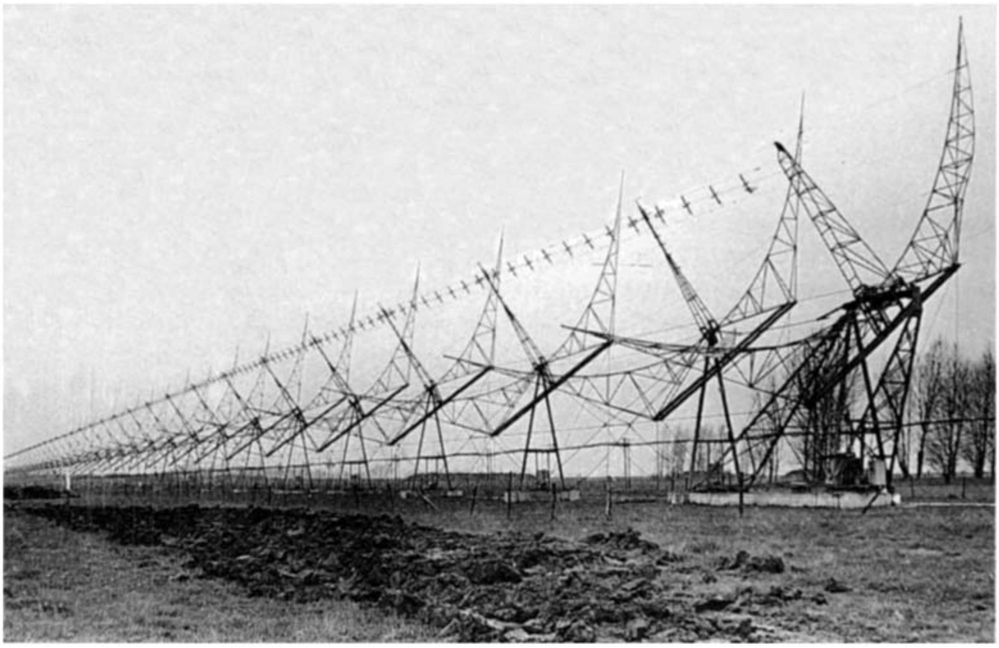
As far as telescope automation is concerned, in 1948 the 200-inch reflector had a computer to correct the setting of the instrument on any selected celestial object for apparent distortions of position due to effects of the Earth's atmosphere. But since the 1960s complete automation has been achieved, telescopes being designed so that they automatically follow selected celestial objects on which they can set themselves once the coordinates are programmed into their computers. This not only relieves astronomers of tedious sessions at the telescope, but also speeds up the amount of work which can be done each night with a particular instrument and, at the same time, allows telescopes to be operated by remote control over intercontinental distances. But of course the most sophisticated of all remote control applications is that applied to orbiting space-craft such as planetary and lunar probes, X-ray satellites such as the American Einstein probe of 1978 and the European Space Agency's Exosat launched in 1983, and the infra-red astronomical satellite IRAS, also placed in orbit in 1983.

Mention of the European Space Agency underlines another new factor in astronomy of the twentieth century, namely the growth of international cooperation, which is coupled with the fact that astronomers now tend to work in teams rather than as isolated individuals. International cooperation has also been a feature of this century's astronomical scene. In 1922 the International Astronomical Union was formed to encourage cooperative planning of observational programmes and the adoption of internationally agreed constants, constellation boundaries, and so on. It also promotes specialist symposia in various countries.

The use of computerised control has also meant that, since the late 1950s, telescopes could be mounted on the simpler altazimuth mounting instead of the expensively engineered equatorial with its axis tilted over at an angle depending on the latitude of the observatory. The computer does the necessary calculations for following a celestial object as it appears to move across the sky. Although this has only come into general use for optical telescopes within the last decade, it now means that costs of construction can be reduced and that very large telescopes, like the Keck 10-metre, become a practical possibility.

However, the computer-controlled altazimuth mounting was first designed for use with radio telescopes, the first of the non-visual wavelength instruments with which astronomers have begun to observe the universe since the Second World War. Admittedly, attempts to observe radio signals from the Sun were made between 1894 and 1902, but all proved unsuccessful since the equipment used was unsuitable, and the true beginnings of radio astronomy began serendipitously in the United States in 1930 when Karl Jansky was making studies of radio 'static and interference'. He noted that some of the static appeared to come from the region of the Milky Way. However, astronomers appear to have taken but slight interest in his observations, which were followed up only by Gert Reber, an amateur radio enthusiast, who in 1937 built the first specially designed radio telescope, a dish 9.4 metres (31 feet) in diameter. Between 1940 and 1942 Reber published more detailed observations than Jansky had been able to obtain, and in 1946, after wartime hostilities had ceased, his results stimulated others to take up the work.

In the United States emission from the Sun was detected by Reber and George Southworth, and research was pursued at the Naval Research Laboratory at Georgetown University, but it was in Britain that James Hey, making use of wartime radar equipment, discovered in 1942 radio emission from the Sun, and in 1945 used radar itself to detect meteors. His efforts stimulated a number of radio physicists in Britain and Australia to pursue radio astronomical research; in particular they led Martin Ryle to begin establishing



4. In the early 1940s radio physicists turned to radio astronomical research. A radio astronomy observatory was established at Cambridge in 1945 and telescopes were built to survey the sky for radio sources.

a radio astronomy observatory at the University of Cambridge in 1945, at almost the same time as Bernard Lovell at the University of Manchester. In Australia, Edward Bowen and Joseph Pawsey of the Commonwealth Scientific and Research Organization set up a radio astronomy group, also in 1945, while in 1946 groups formed in both Canada and in The Netherlands.

Since radio wavelengths are at least some 100 000 times longer than those of light, to begin with radio astronomers were unable to pinpoint celestial radio sources precisely enough to incorporate their results fully into the main body of astronomical knowledge. To overcome this serious disadvantage, therefore, interferometers for radio observation were developed very early on in both Australia and Cambridge. However, interferometers in astronomy were nothing new. In 1919 Albert Michelson had fitted such an instrument of his own design to the 100-inch reflector in order to measure stellar diameters by causing the light waves from two beams of light from a star to interfere, and successful measures of Betelgeuse were made the following year. Bowen and Pawsey's group used different designs for radio astronomy, but Ryle developed Michelson's method, which, in the late 1950s, was to yield the powerful technique of aperture synthesis using a collection of electronically linked radio telescopes, the interfering signals from which were analysed by computer. From 1967 onwards techniques for electronically coupling radio telescopes in different countries to give giant interferometers have become possible, so that radio astronomy has been able to compete and even surpass optical astronomy in discerning detail in celestial objects observed by both techniques.

The success of radio astronomy in discovering neutral hydrogen gas, which radiates no visible light (1951), objects like quasars (1963) and pulsars (1967), and even complex molecules in space (1968 onwards), alerted astronomers to the advantages of probing space in non-optical wavelengths. Although heat or 'infra-red' rays were discovered in 1800, their significance in astronomy remained generally unappreciated until the 1960s. Only then did sensitive detectors for such radiation became available and astronomers begin to appreciate that this radiation band could help give insight into regions both within and outside our own Galaxy, which were blacked out optically by clouds of dust. Since then, infra-red detectors from Earth-based equipment such as the United Kingdom Infrared Telescope (UKIRT) of 1979 and from space-craft like the 1983 Infra-red Astronomical Satellite (IRAS) have made notable contributions to astronomy, such as the detection of dust rings round stars, the discovery of very low mass stars – 'brown dwarfs' – and have shed much light on the nature of clouds of gas molecules in those regions where stars are formed and, indeed, on the nature of star formation itself.

The short end of the wavelength range – ultra-violet emissions, X-rays and gamma rays – have also produced new evidence for astronomy. Again, although ultra-violet radiation was discovered in 1801, and X-rays were detected first in 1895, little astronomical use was made of the former and none of the latter until it became practicable to make observations from high up or even outside the Earth's atmosphere. High-flying aircraft and then high-altitude balloons were used first for such observations in the late 1940s, but it was when rockets were sent up in the 1950s that studies in X-ray and the far ultra-violet wavelengths began to gather momentum.

After the launch by the Russians of the Sputnik space-craft in 1957, the practicability of using artificial orbiting satellites became realised, and in 1962 an exploratory study led by Riccardo Giacconi in the United States brought about the discovery of an intense X-ray source, later to be called Scorpius X-1; this appears to be a binary system in which one star is drawing away material from the other, which seems to be a black hole. Since then X-ray probes like Uhuru (1970), Einstein (1979) and Exosat (1983) have shown up the existence of slowly rotating neutron stars and even intense X-ray sources within some galaxies such as Centaurus A. They have also shown the presence of otherwise invisible material around some galaxies, and even of gas at the very high temperature of 100 million degrees lying right within clusters of galaxies.

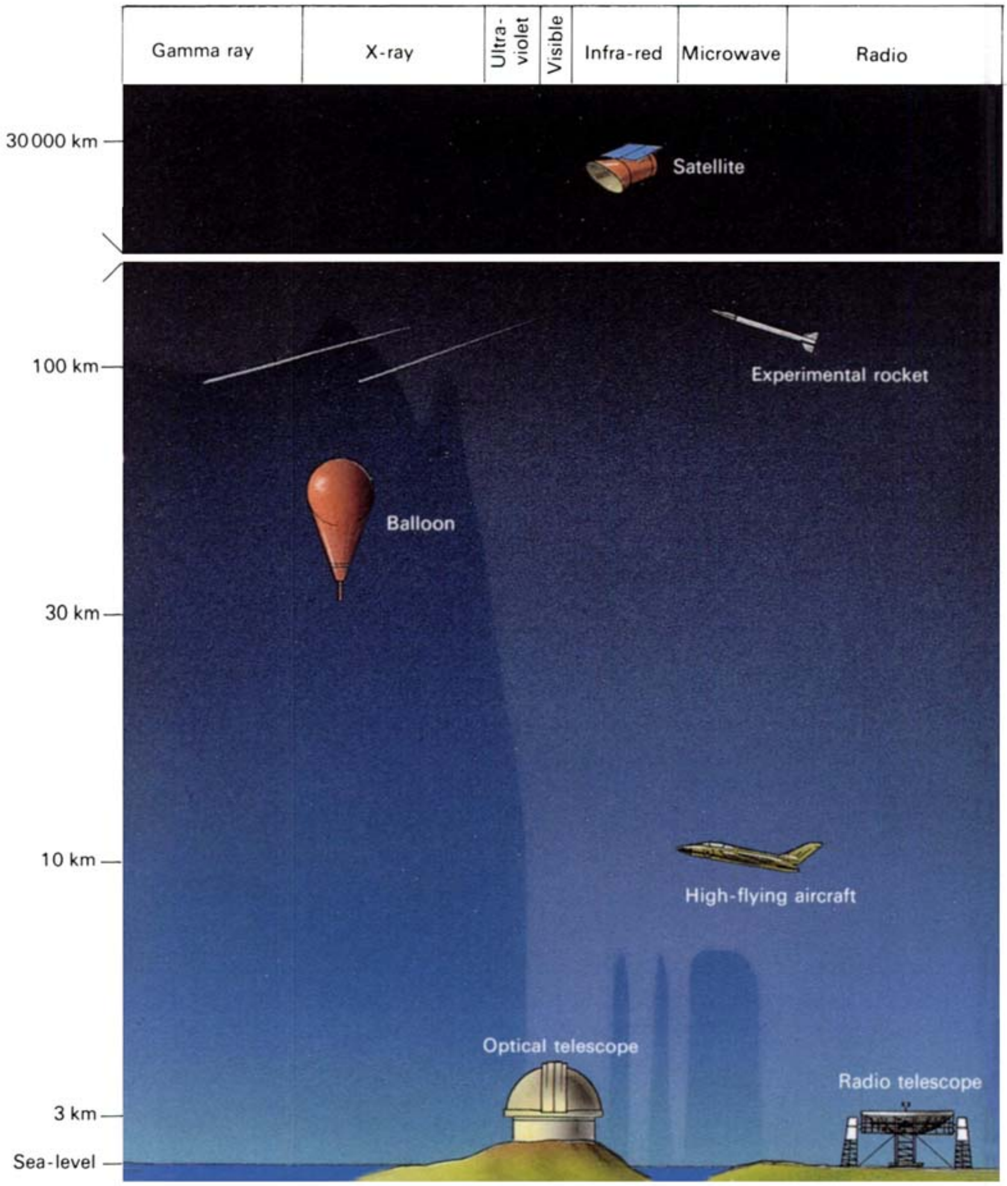
The full ultra-violet range of wavelengths became available for study from the early 1970s onwards, and most notably with the International Ultraviolet Explorer (IUE) of 1978. Used primarily to examine sources using spectroscopes, ultra-violet probes have already provided much detailed information on the gas lying between stars – the interstellar medium – and the nature of very hot stars which radiate very strongly at ultra-violet wavelengths, showing up the existence of stellar winds from such stars and the transfer of material from one star to another in some binary star systems. Moreover, spectroscopic studies of the ultra-violet radiation from some nearby galaxies have shown certain interesting similarities between them and quasars.

As far as cosmic rays are concerned, their study has a long history which goes back at least to 1910 when Theodor Wulf took instruments to the top of the Eiffel Tower in Paris to determine how discharges of electrical equipment, first discovered in the laboratory, varied as one rose above the Earth's surface. He found that the discharges increased at a height of 300 metres (984 feet), and this suggested an extraterrestrial source for the radiation causing them. Confirmed on balloon flights taken the next year by Victor Hess, and in 1913 by Werner Kohlhörster, they were named 'cosmic rays' by Robert Millikan in 1925. Subsequent investigations during the 1930s by Patrick Blackett at Manchester and Cecil Powell at Bristol showed that very short wavelength gamma rays were the discharging agency, but that these were produced by atomic particles arriving from space. From the late 1940s onwards studies have increased, and by the 1980s it had become evident that not only is the Sun a source of such radiation, but so also is the Galaxy, and that such radiation is emitted from other galaxies as well. The atomic particles are primarily protons; they possess immense energies and, at least for the most part, come from the remnants of supernova explosions.

For the greater part of the last century, observation of the Moon and the planets of the solar system has been primarily the province of the amateur observer, though the first satisfactory photographic atlas of the Moon was made by the professionals Maurice Loewy and P. H. Puiseux between 1896 and 1910. Nevertheless, amateurs made far more detailed studies of the lunar surface and of the planets than photography could achieve; indeed it was Percival Lowell, a business-man turned astronomer, who was the central figure in the great controversy about the martian surface, which began in 1895 with Giovanni Schiaparelli's description of *canali*. Schiaparelli was adamant that these should not be regarded as watercourses, but Lowell in particular believed they were and charted them with care during the succeeding decades. Only now, with the advent of space probes, has the matter been settled and the canals found to be a very persuasive optical illusion.

However, in the last thirty years, observation of the solar system has been revolutionised by the use of space-craft. The far side of the Moon, invisible to Earth-based observers, was photographed in 1959 and again in 1965 by Russian space-craft, and American probes took close-up photographs of the lunar surface from 1964 onwards. In 1970 and 1973 the Russians landed remote-controlled unmanned vehicles on the lunar surface, but already by 1969 the Americans had achieved manned landings and had managed to place experimental equipment on the Moon for later use; they also brought back to Earth samples of lunar rock, the first pieces of the surface of another celestial body to be artificially recovered for later study.

As far as the major planets are concerned, Venus seems by and large to have become the province of Russian probes, which started exploration in the 1970s, though American craft mapped the surface by radar at the end of 1978. For the rest, American space vehicles have taken very good close-up photographs of Mercury (1974), Mars (1964 to 1975), Jupiter (1972 to 1979), Saturn (1980 and 1981), as well as Uranus (1986) and Neptune (1989), including some detailed images of their satellites, and have achieved two soft landings on Mars in 1976. These last have analysed martian soil and led to the conclusion that, whatever might have been the case in the distant past, Mars harbours no living



5. Astronomers now study all the different forms of electromagnetic radiation given off by astronomical objects. But not all wavelengths reach Earth, as indicated by the shading. Specialised instrumentation and techniques have been developed to collect and investigate the different wavelengths.