A Rutherford Appleton Laboratory Monograph

The Universe and Man

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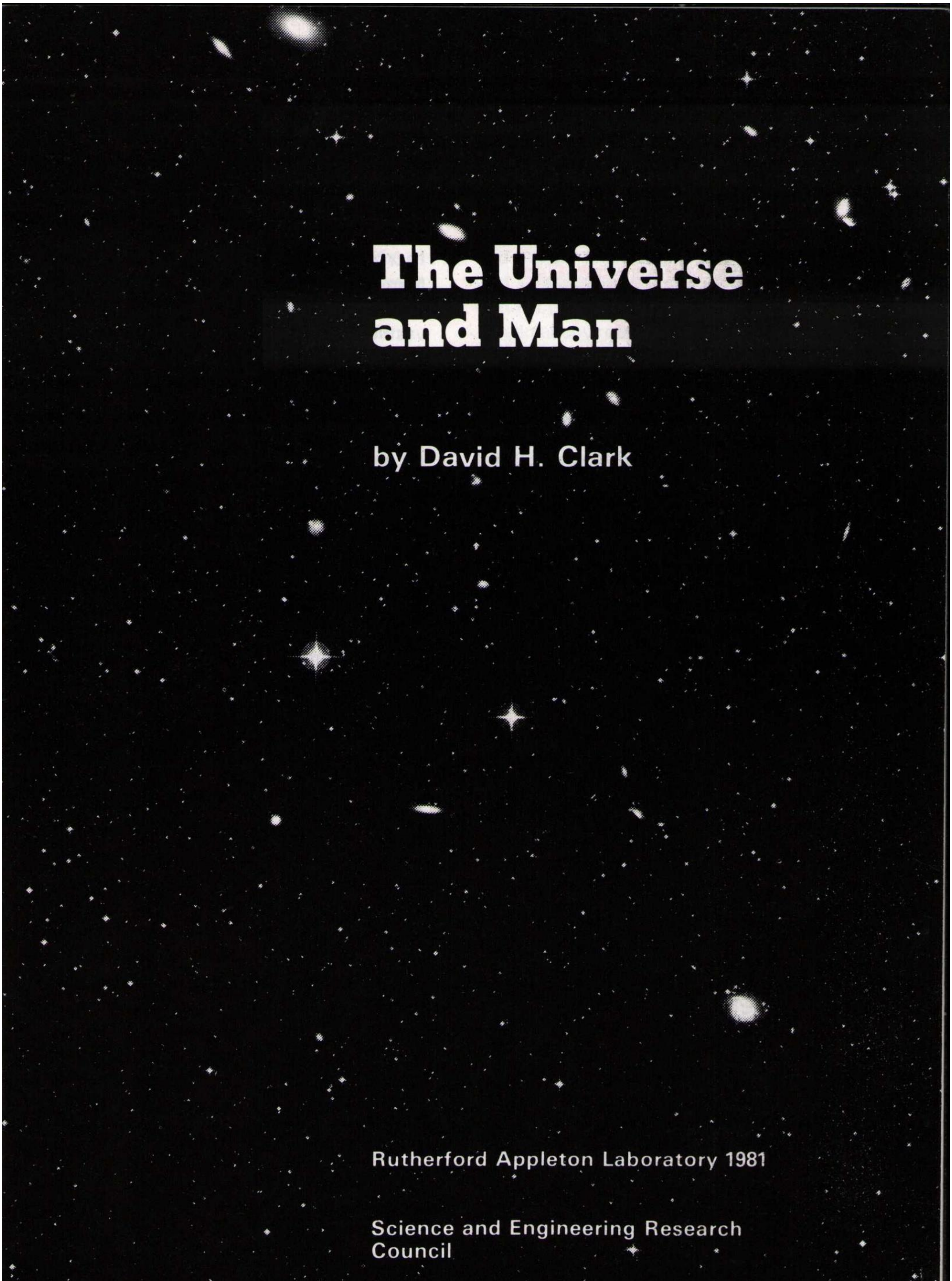

The Universe and Man

by David H. Clark

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Science and Engineering Research Council

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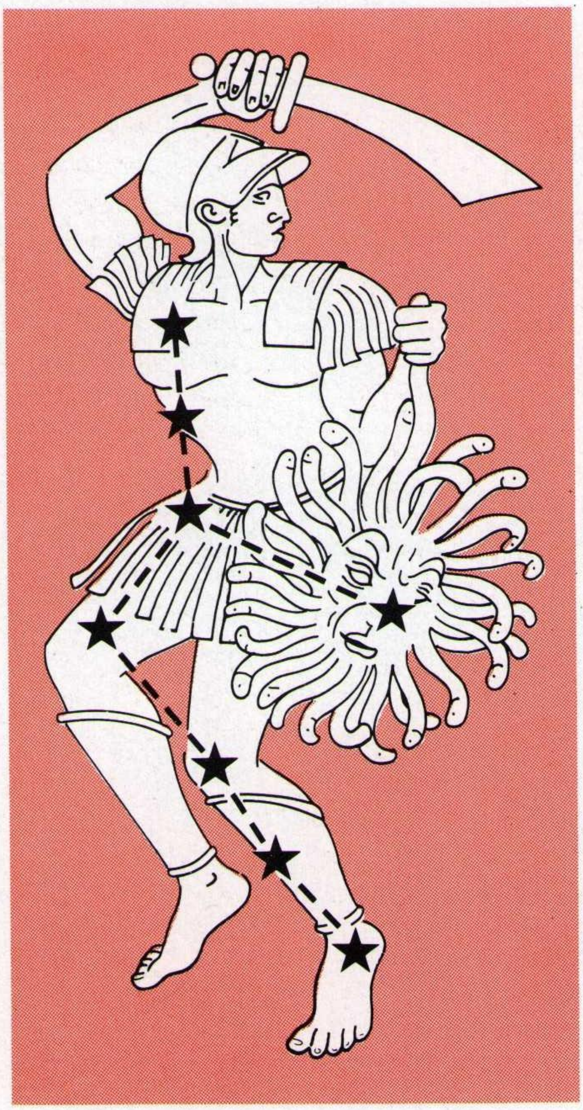
Fig. 1. **The legend of Perseus and Andromeda. From earliest times man has worshipped the celestial bodies and assigned them mystical powers.**



Introduction

Man has always viewed the heavens with wonder and awe, sensing the vastness of space, the power of the creation, and perhaps even something of his own origins as he looked out into a clear night sky. Until the past few decades, however, he could have had no real appreciation of the true enormity of the Universe, the cataclysmic nature of its origin, or his own close relationship to the stars. Yet scientists now put forward theories describing the evolution of the Universe from a time just a fraction of one second after the "Creation"—the *Big Bang*. They claim that all the material of common experience, including the constituents of the organic compounds of which life-forms are made, were forged in the interiors of stars from the simple atomic components of the early Universe. Indeed, it is suggested that life itself had its origins in outer space. Thus the quest for an understanding of our origins must be made on the celestial scale. The vision of modern scientists extends therefore beyond their present terrestrial domain, out to the limits of the observable Universe and back to the beginning of time.

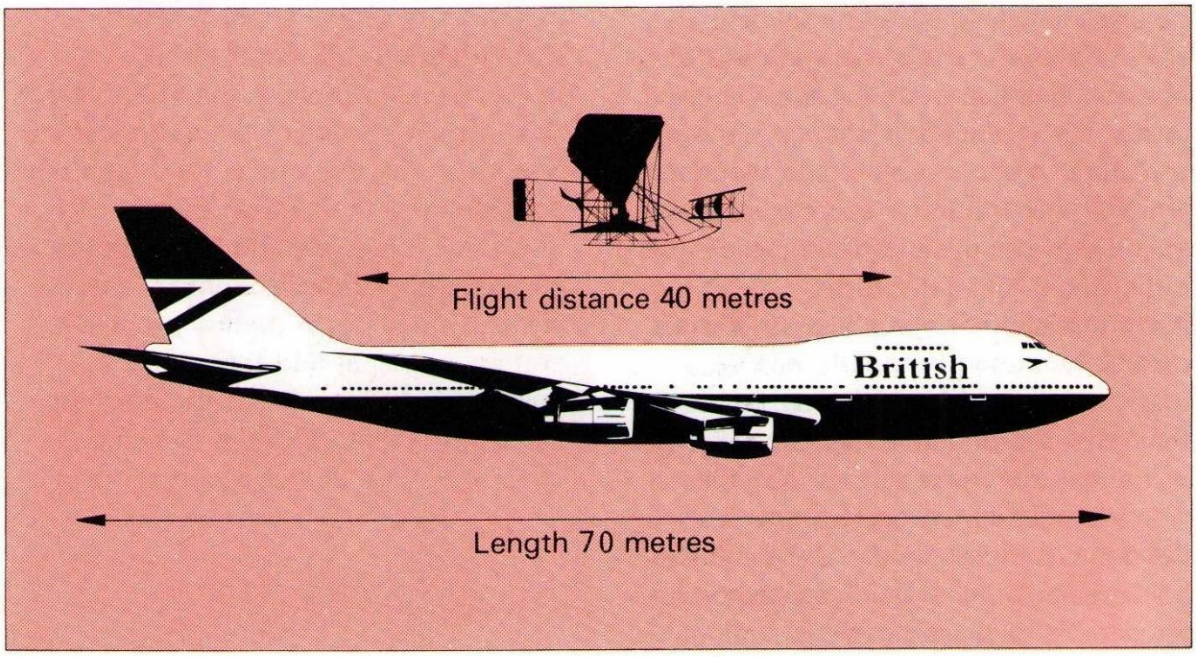
Astronomy is one of the most ancient of sciences. Primitive man worshipped the celestial bodies and assigned them mystical powers, this worship eventually evolving to rational and systematic investigation. Despite the many centuries over which astronomers have been pursuing disciplined study of the planets and stars, the astronomical picture of the Universe cannot yet be considered complete or final. (If it were so, astronomers could terminate their research now. The fact that a growing world community of astronomers pursue their investigations with undiminished enthusiasm, demanding still bigger and better telescopes, testifies to their belief that the Universe still has many important secrets to reveal.) The astronomer's picture of the Universe differs from that put forward by, for example, poets, artists, theologians or philosophers. None of these differing views of the Universe is necessarily less valid than any other. They must be considered to be complementary. We will be concerned in this monograph only with the picture of the Universe revealed by modern astronomical research, a picture no less beautiful than that presented by any poet or artist, nor less pleasing than that proposed by any philosopher or theologian. What we will be discussing will be currently held scientific beliefs based on centuries of observations and evolving astronomical ideas. The scientific "facts" presented, therefore, must be seen to be the ideas which are found to be acceptable to the majority of scientists at the present time, rather than "ultimate truths". Astronomical monographs and journals record the state of modern man's understanding of his Universe, just as in their time did primitive man's cave paintings. Just as surely as the latter was superseded, so our current astronomical ideas of the Universe can be expected to change. They are no less remarkable because of this limitation, and remain testimony to the imagination and investigative powers of Mankind and his desire to understand his universal environment.

The scope of present-day astronomical research extends from the origin of the Universe, beyond its present turbulent state, to predictions about its ultimate fate—it extends from the Earth's nearest, and comparatively well understood, planetary and stellar neighbours to bizarre and enigmatic objects at the very limits of the observable Universe, accessible only with the most powerful instruments technology has been able to devise to extend the limited scope of the human senses. It calls on the skills of a host of research disciplines: for example, those of the engineers who design and build enormous telescopes, extending engineering techniques to new bounds of precision; those of the designers and operators of highly sophisticated computers used to control the telescopes and process the information they acquire; those of the astronomers who push the telescopes (and their night assistants) to their limits; those of the physicists, chemists and mathematicians who interpret the astronomical data in terms of the known natural processes and phenomena; and those of the cosmologists who merge the resulting ideas into a picture of the Universe consistent with all the observations.

The Size of the Cosmos

Where does planet Earth fit on the "cosmic scale"? Our understanding of physical dimensions, such as distance, mass and time, is limited by our everyday experiences, although this understanding has changed dramatically during the present century. Medieval astronomers voyaged the thousands of kilometres around the globe on time-scales of years—modern adventurers have completed the ¾ million kilometre return journey to the Moon within days. Almost eighty years ago the first motor-driven flight carried one man a mere 40 metres. This first flight at Kittyhawk could have been completed within the economy-class section of a modern Boeing 747 Jumbo Jet, which now wings over 450 passengers at a time across the continents in just a few hours. Yet this newly acquired global freedom and appreciation of terrestrial distances ill-prepares us for accepting the enormous scale of cosmic distances. Thus, if we were to imagine that we could set out on a journey to Pluto, the outer planet, in a supersonic Concorde jet aircraft, it would take 300 years to get there. A Concorde trip to reach the nearest star beyond the solar system, Proxima Centauri, would take over two million years! On such a scale, it makes little sense to measure distances in kilometres. Rather, astronomers define a unit which uses the distance light travels through free space in a year – the so called *light year*. Light travels at the incredible speed of 300 thousand kilometres each second. Thus a pulse of

Fig. 2. The first powered aeroplane flight by the Wright brothers (1903) could have been completed within the economy-class section of a modern jumbo jet.



light could circumnavigate the globe eight times in a second, or complete the journey to the Moon in just a little longer. The light which reaches us from the Sun takes 8 minutes to transit the 150 million kilometres. The nearest star is four light years distant. Thus if we were able to travel at close to the speed of light – that is to say, at almost half a million times faster than Concorde's "snail pace", it would still take us almost a decade to complete the return journey to Proxima Centauri. One light year is equivalent to 9.46 million million kilometres.

Fig. 3. A face-on spiral galaxy (M83). Our Sun is just one of a 100,000 million stars contained in a similar spiral structure (Photo: ROE).

In establishing the distance of the nearest star to the solar system, we still have no real appreciation of the enormity of the Universe. Stars are not uniformly scattered throughout space, but accumulate in conglomerates called *galaxies,* containing many thousand millions of stars. Galaxies themselves accumulate into *clusters.* Our Sun is just one of an estimated one hundred thousand million stars within our galaxy, called the Milky Way. The Milky Way is discus shaped, a full 100 thousand light years across at its widest, with our Sun occupying a rather insignificant location closer to its periphery than its centre. Looking down from "above", the bright stars of the Milky Way would appear to be concentrated within intertwined *spiral arms.*

THE GALAXY
The Galaxy, seen edge-on. The Sun is 30,000 light-years from the centre of the system.

If our place within the Milky Way seems insignificant, then the place of our galaxy within the Universe is equally so. The observable Universe is now believed to contain at least 10 thousand million galaxies, clustering together in their hundreds or thousands but still spaced from one another by many

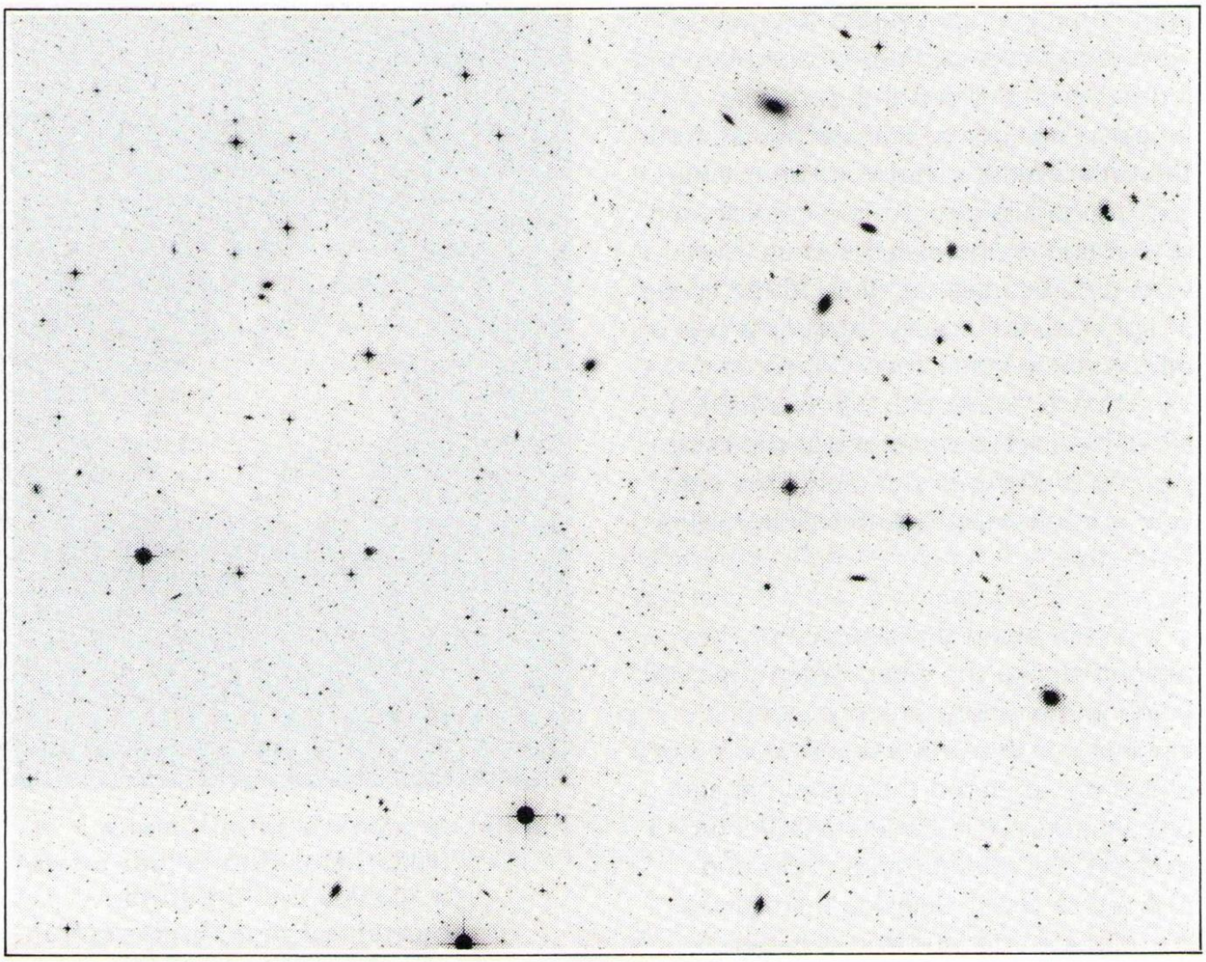


Fig. 4. A loose, moderately rich cluster of galaxies (IC4329), about 250 million light years away in the constellation of Centaurus (Photo: ROE).

millions of light years. The most distant galaxies observable with giant telescopes are of the order of 10 thousand million light years distant! On this scale, planet Earth shrinks into insignificance as a mere speck of cosmic dust. The determination of the cosmic distance scale has been one of the major achievements of twentieth century astronomy.

The Telescope as a Time Machine

It is important to stress that in looking out into the Cosmos through a large telescope, one is looking not only deep into space but also back in time. Thus, because of the finite speed of light, the telescope acts as a "time machine", observing the nearby stars as they were just a few years or tens of years ago, and the more distant stars within the Milky Way as they were hundreds or thousands of years ago when the light now reaching the Earth commenced its cosmic journey. The nearby galaxies appear as they were millions of years ago, and the more distant galaxies as they were hundreds to thousands of million years ago. Few of the objects observed would exist at this instant, at least in the form we presently see them! Thus the history of the Universe is laid out, like a cosmic kaleidoscope for Earth-bound astronomers to view. The telescope represents a "magic carpet" from which astronomers can study stars and galaxies at various stages of their evolution—nascent stars procreated from giant clouds of interstellar gas, young stars, middle-aged stars, old stars, dying stars and dead stars—young galaxies, interacting galaxies, galaxies in formation, and galaxies being torn apart! The Universe reveals itself as a spectacle of unfolding drama, as stars and star-systems are born and die, often violently.

Further adjustment to our terrestrial way of thinking is required if we are to appreciate the mass and time scales involved in understanding the nature of the Universe. We choose to measure the mass of objects of common experience in terms of a convenient standard mass, the kilogram. Thus for example an adult human may have a mass typically up to about 80 kilograms. The mass of planet Earth, however, is 6 million million million million kilograms, with the Sun being some 300,000 times more massive. On the astronomical scale, we tend to use the mass of our Sun as an appropriate mass standard. Hence the mass of a star could be described as being so-many *solar masses.* The mass of the Milky Way is believed to be of the order of one hundred thousand million solar masses—and the mass of the Universe is certainly greater (perhaps very much greater) than 300 million million million solar masses! No less of a challenge to the human imagination are the time scales involved in describing astronomical phenomena. Earth-bound events are conveniently defined by the *siderial day,* the time for the Earth to revolve once about its axis measured with respect to the fixed stars, and the *siderial year,* the time for the Earth to complete one orbit about the Sun, again measured relative to the fixed stars. The Sun and other stars orbit around the centre of the Milky Way, like a gigantic cosmic katherine wheel. At the Sun's distance, the stars take over 200 million years to complete a single revolution of the galactic centre—an interval known as the *galactic year.* Just as a human life time typically spans several tens of terrestrial years, so stars of similar mass to the Sun have life times which span a few tens of galactic years. Strangely, the more massive a star, the shorter its life expectancy! The Sun has survived for about 20 galactic years since its birth, and is expected to survive in its present state for at least a similar interval. But what of the age of the Universe itself? This remains somewhat uncertain, but cosmologists now believe the most recent "epoch of creation" to have been between 10,000 to 20,000 million years ago!

The Expanding Universe

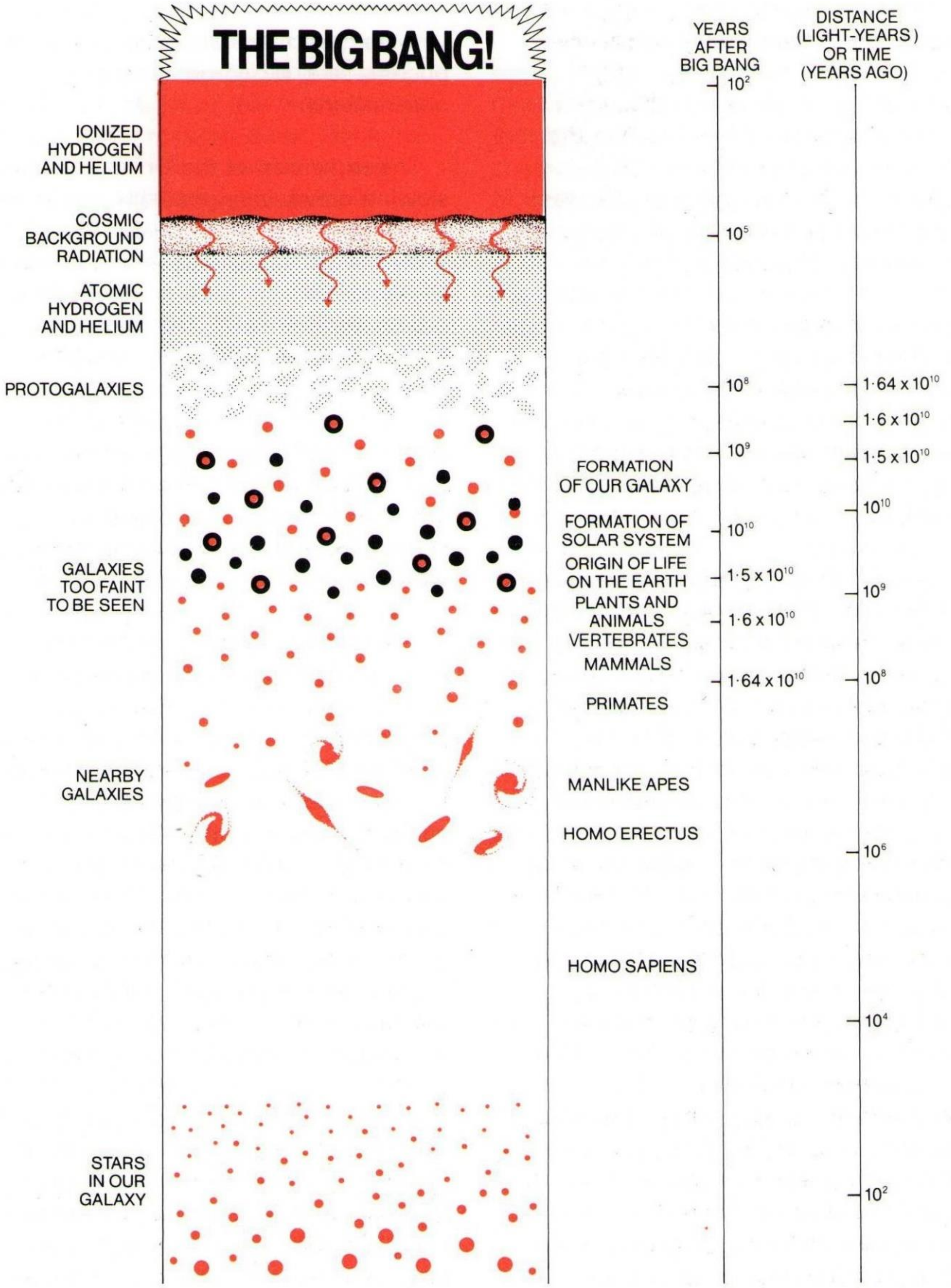
How did the Universe begin, and what will be its fate? The world's great religions all have picturesque accounts of the Creation and predictions for the "Day of Judgement". Historically science has had no shortage of picturesque accounts either; indeed there were usually rather more theories than facts to base them on. But twentieth century astronomy was to produce a wealth of evidence on which to base a sound scientific theory of the Creation. Science now claims that the origin of our present Universe was heralded by the *Big Bang*—the cataclysmic release of the matter and energy from which the stars and galaxies were to be formed.

If one was asked to highlight the single major contribution to our current understanding of the origin of the Universe, it would have to be the observations which led to the realisation that the Universe is expanding. At the turn of the century, the vast majority of scientists believed that the Milky Way represented the entire Universe. The "galaxies" were thought by most astronomers to be star conglomerates within the Milky Way, rather than the distinct "island universes" advocated by just a few. But, distinct "island universes" lying far beyond the boundary of the Milky Way they proved to be! The scientific detective work which led to this conclusion divided the scientific world and precipitated one of the "great debates" of modern times. All the galaxies were found to be receding from the Milky Way at enormous speeds, the more distant they were the greater the speed of recession. This did not suggest that the Milky Way was at the centre of the expansion (and consequently at the centre of the Universe) but rather that it was merely part of a general expansion so that all other galaxies thus appeared to be in relative recession from it.

If the galaxies are presently all receding from each other, then it is obvious that there must have been a time when all the matter of the Universe was closely packed. We can try to estimate when this was by pretending to "run-back" the present expansion, like running a movie backwards. On the assumption of an expansion which has proceeded uniformly, then 10 to 20 thousand million years ago all the material of which the Universe is now composed must have been closely compacted. Thus 10 to 20 thousand million years ago, the *Big Bang* of creation blasted the compacted "Universe" to smithereens.

It is wrong to visualize matter created in the *Big Bang* as being hurled out into a void—an "empty space Universe" which already existed. The expanding Universe of modern cosmology is a true

Fig. 5. The astronomer can look back in time towards the start of the Universe (the 'Big Bang') by observing objects so distant that their light has taken thousands of millions of years to reach our galaxy.


THE BIG BANG!
YEARS AFTER BIG BANG
DISTANCE (LIGHT-YEARS) OR TIME (YEARS AGO)
IONIZED HYDROGEN AND HELIUM
COSMIC BACKGROUND RADIATION
ATOMIC HYDROGEN AND HELIUM
PROTOGALAXIES
GALAXIES TOO FAINT TO BE SEEN
NEARBY GALAXIES
STARS IN OUR GALAXY
FORMATION OF OUR GALAXY
FORMATION OF SOLAR SYSTEM
ORIGIN OF LIFE ON THE EARTH
PLANTS AND ANIMALS
VERTEBRATES
MAMMALS
PRIMATES
MANLIKE APES
HOMO ERECTUS
HOMO SAPIENS
10^2
10^5
10^8
10^9
10^{10}
$1{\cdot}5 \times 10^{10}$
$1{\cdot}6 \times 10^{10}$
$1{\cdot}64 \times 10^{10}$
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$1{\cdot}5 \times 10^{10}$
10^{10}
10^9
10^8
10^6
10^4
10^2

expansion of space itself, not just an expansion of the material substance of the Universe. Thus the *Big Bang* initiated the universal expansion of space; the matter released in the *Big Bang* was forced to follow this expansion. In the process matter was randomly accumulated under the action of the force of gravity to form the galaxies of stars we now see receding from us. It is space itself which continues to expand, dragging the material Universe with it. Today, sensitive measuring instruments can still detect the weak remnant radiation from the *Big Bang*—the faint echo of the creation.

The *Big Bang* might also be visualized as the origin of time, since we have no way of knowing what existed before the *Big Bang.* Perhaps the present Universe was created from the burnt-out cinders of some previous Universe? Perhaps our own Universe is but one of many "mini-universes" within some grander, but unobservable cosmos? Another unanswered question is what, or who, initiated the Creation? Whose was the "hand" on the "plunger" of the *Big Bang?* But such questions are beyond the scope of science, which is concerned with making predictions based on patterns of behaviour within the *observable* Universe. The unobservable is not open to scientific interpretation, and must therefore be ignored by science. Rather such questions lie within the realm of the philosopher or the theologian. But science legitimately can and does speculate about the evolution of the Universe and make predictions about its possible fate, based on current observations.

The expansion of the Universe may be slowing down, very gradually, under the action of gravity. It is *gravity,* the universal attractive force acting between all matter, which holds the Moon in orbit about the Earth, the Earth and other planets in orbit about the Sun, and the Sun and other stars in orbit about the centre of our galaxy. Although considered weak within the terrestrial domain, on the universal scale it is gravity which forms the stars, shapes the galaxies, and binds them within clusters.

Will the expansion of the Universe continue for ever, or will gravitational attraction between the clusters of galaxies eventually bring the expansion to a halt and indeed reverse it? Consider for a moment the analogy of firing a projectile vertically upwards. It would fall back to ground, unable to escape the Earth's gravitational hold, unless it was projected with sufficient velocity to escape the effect of the Earth's gravity entirely. This limiting velocity is called the Earth's *escape velocity*. All astronomical bodies have an escape velocity, the value of which depends on the body's density. Thus the future behaviour of the Universe depends on the density of the material within the Universe, and this remains somewhat uncertain. Only a small fraction of the material within the Universe is trapped within the stars, the rest existing as tenuous gas lying, often in clumpy clouds, between the stars and between the galaxies. Much of this *intergalactic* and *interstellar* material is not visible to us and it is the exact amount of this "missing mass" that will determine whether the expansion of the Universe will eventually halt. If 99 per cent of the mass of the Universe is invisible, then eventually space will "turn-in" on itself and the galaxies will be dragged towards each other in a universal contraction. Scientists speculate that such infall could eventually precipitate another *Big Bang* as the galaxies are crushed together, giving birth to a new expanding Universe out of the debris of the old. This is the basis of the "oscillating Universe" theory, in which a *Big Bang* and an expansion phase of the Universe (lasting, it is conjectured, about 100 thousand million years) is followed by a contraction phase of equal duration and the initiation of another *Big Bang* and a next generation Universe. This theory has the attraction of providing the Universe with a permanency such that it requires no true beginning and no ultimate end, but comprises merely a series of creative epochs punctuated by *Big Bangs* and interspersed with periods of expansion and contraction—a Universe with an infinite future and an infinite past. One of the most pressing challenges to contemporary astronomy is to decide whether the Universe is *open,* so that it will continue its presently observed expansion for ever, or *closed* and possibly "oscillating".

In the Beginning . . .

It is rather a remarkable fact that the scientist's present understanding of natural processes is sufficiently good that it may be used to produce a self-consistent description of the evolution of the Universe back to a fraction of a second of the *Big-Bang.* It is only in the first one-hundredth of a second of the Universe's being that the temperatures and densities which must have existed then belie description in terms of known physical laws.

The basic building blocks of all matter are *atoms,* the smallest recognisable components of the 92 known naturally occurring elements. Atoms themselves are composed of protons and neutrons, closely bound within a central nucleus, with minute electrons (a mere two-thousandth of the mass of the protons or neutrons) orbiting the central nucleus. It is the number of protons within the nucleus which identifies an atom as being that of a particular element. Thus, for example, the simplest elements are hydrogen and helium, with just one and two protons respectively—carbon atoms have 6 protons, oxygen 8, iron 26, copper 29, gold 79, lead 82, uranium 92, etc. In their so-called "neutral" state, atoms have the same number of orbiting electrons as protons within their central nuclei. The number of neutrons in an atom is usually about equal to or slightly greater than the number of protons.

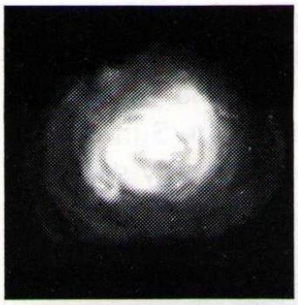
In the seconds following the *Big Bang,* the Universe must have been a dense "soup" of protons, neutrons, and electrons bathed in intense radiation. The temperature was too extreme for the sub-atomic particles to combine to form atoms. Within a few minutes, however, the expanding celestial soup would have cooled to the point where protons and neutrons could combine singly to form deuterium nuclei (a type of hydrogen; normal hydrogen has no neutron in its nucleus), and combine in pairs to form helium nuclei. Physicists conclude that within the first 15 minutes of its creation, 25 per cent of the Universe by mass must have been helium—a figure verified by modern observation. It was to be at least a million years, however, before the Universe had cooled to the point where electrons could combine with the hydrogen and helium nuclei to form true neutral atoms—this was the *epoch of neutralization.* The nascent Universe was still almost entirely hydrogen and helium (with a minor component of deuterium). The more familiar heavier atoms still awaited their creation in the centres of the yet to be formed stars.

Following the epoch of neutralization, galaxy formation commenced. Imagine a region of the evolving Universe where the density of matter was slightly higher than elsewhere, so that it eventually underwent gravitational collapse as the universal expansion continued. As this so-called *protogalaxy* collapsed, it fragmented and the first generation of stars formed within the fragments. Gravity then organised the stars and remaining gas into the galactic forms we now observe, and organised the galaxies into clusters. While the presentation of this scenario has been grossly simplified here, it is a theory of galaxy and initial star formation that has considerable theoretical and observational appeal—although alternative theories still attract the attention of many cosmologists. To follow the further evolution of the Universe, and the creation of the elements, we must now focus our attention on the evolution of individual stars.

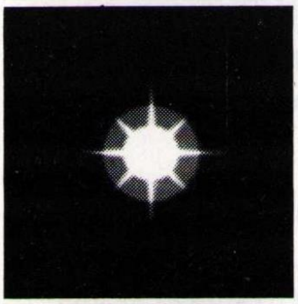
The Formation of Stars

As an isolated fragment ("cloud") of gas (predominantly hydrogen and helium) collapses under the effect of gravity, the energy of infall is converted into heat, so that the cloud soon attains an extremely high temperature—of the order ten million degrees. At such extreme temperatures certain "nuclear burning" reactions can take place in the central core of the collapsing gas cloud. These reactions are referred to as *nuclear fusion.* In a newly forming star, hydrogen nuclei in the core of the cloud are "fused" together to form the heavier helium nuclei with the release of energy. The liberation of this so-called *thermonuclear energy* increases the pressure in the mass of gaseous material to the point where gravitational contraction is halted. A star is born. The young star soon settles down to the relatively stable state in which it spends most of its active life. During this long period of stability, the star's self-gravity acting inwards is balanced by the pressure pushing matter out. This

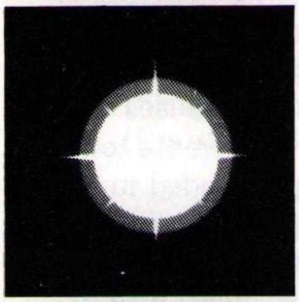
Fig. 6. The Formation of Stars



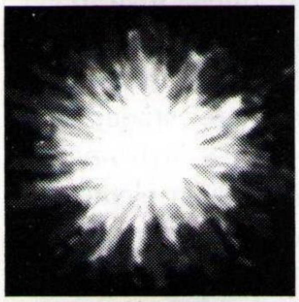
A Sun-like star begins life as a cloud of interstellar material shrinking under the force of gravity. On becoming highly compressed, thermonuclear reactions start up which transform the star's hydrogen supply into helium – after 100 million years the star begins to shine.



The shining phase lasts for 10,000 million years.



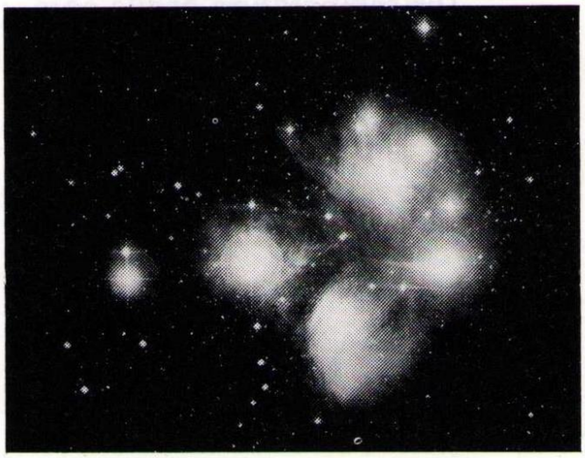
As the hydrogen is used up, the star swells up and shines more brightly as helium starts to burn.



Becoming unstable, the star sheds matter.

The star ends its life as a white dwarf.

The Great Nebula in Orion (M42) where new stars are in the process of being formed. (Photo: RGO).



The Pleiades is a cluster of 300 to 500 young stars. (Photo: ROE).

delicate stellar balancing act is maintained at the expense of the loss of nuclear fuel. In a star like our Sun about 655 million tonnes of hydrogen are transformed into about 650 million tonnes of helium each second—the lost mass is converted to the energy eventually radiated from the star's surface.

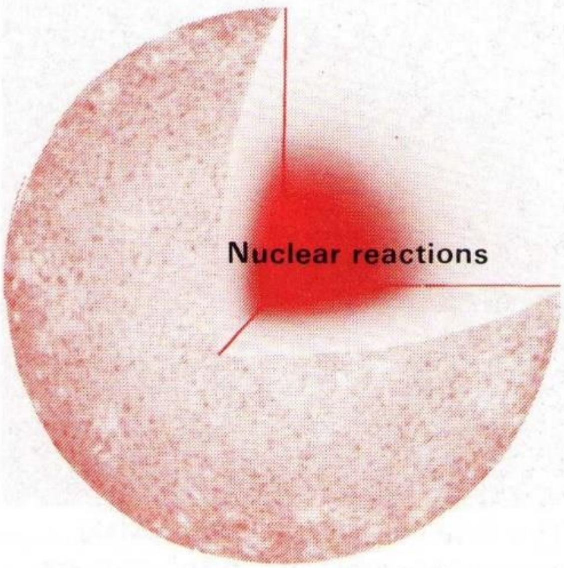
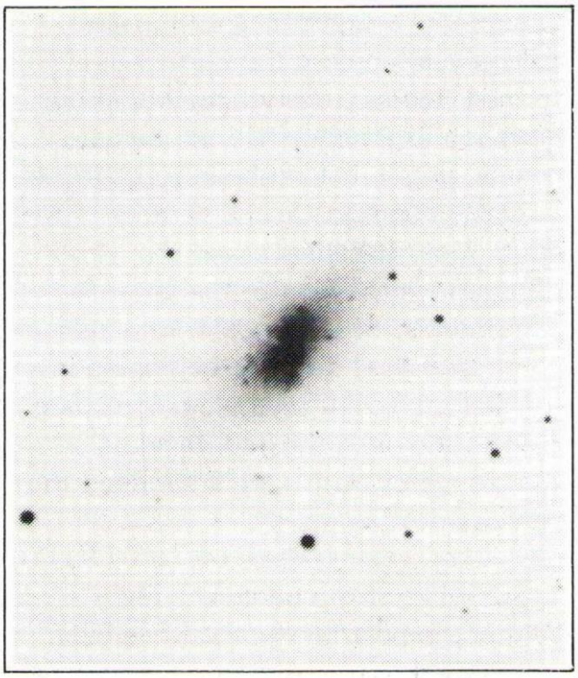


Fig. 7. Our Sun is a typical star. The temperature of the core rises to 14 million degrees. It is here that the nuclear transformations take place.

And so it is with all the stars. The loss of mass and the generation of thermonuclear energy provide the answer to the question that challenged the curiosity of man over the millennia—"What makes the Sun and stars shine?" The secret energy source utilized with potentially catastrophic consequences by modern man in the building of the thermonuclear (hydrogen) bombs is the very energy source successfully harnessed and controlled in the central furnaces of the stars.

Although the nuclear fuel reserves of a star are enormous, they are not unlimited. When the hydrogen in the central core of the star is expended, gravity again takes control. As the core starts to contract again it causes the internal temperature to increase to about the 200 million degrees needed to start the nuclear burning of the helium ash left over from the earlier hydrogen transmutation. Helium nuclei fuse to form the heavier elements carbon and oxygen. When all the helium in the core is in its turn expended, later stages of nuclear burning may follow involving the fusion of successively heavier elements all the way to iron, when no further reactions can extract energy.

Thus the long sought after goal of the medieval alchemist, to change the elements from one form to another, has indeed been achieved on the cosmic scale since the moment of creation. But if the heavier elements such as carbon, nitrogen, oxygen, magnesium, sulphur,



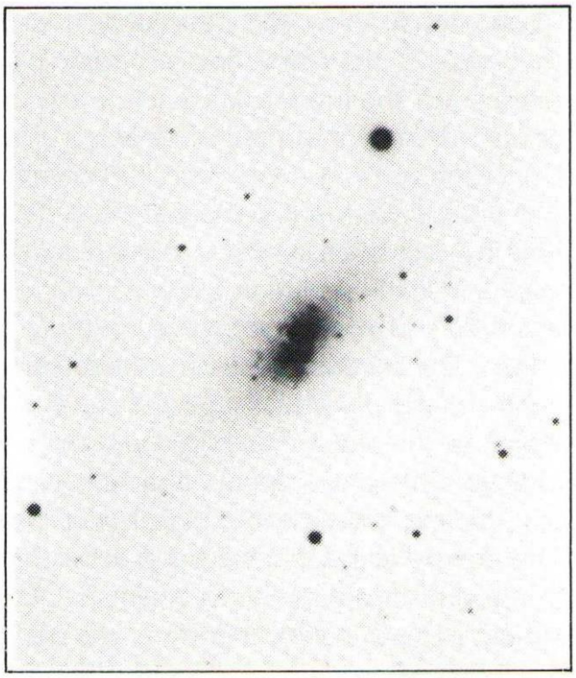


Fig. 8. Appearance of a supernova: The left-hand picture shows the galaxy NGC5253. The supernova which blazed forth near the outer reaches of this galaxy in 1972 is clearly seen in the right-hand photograph. (Courtesy South African Astronomical Observatory).

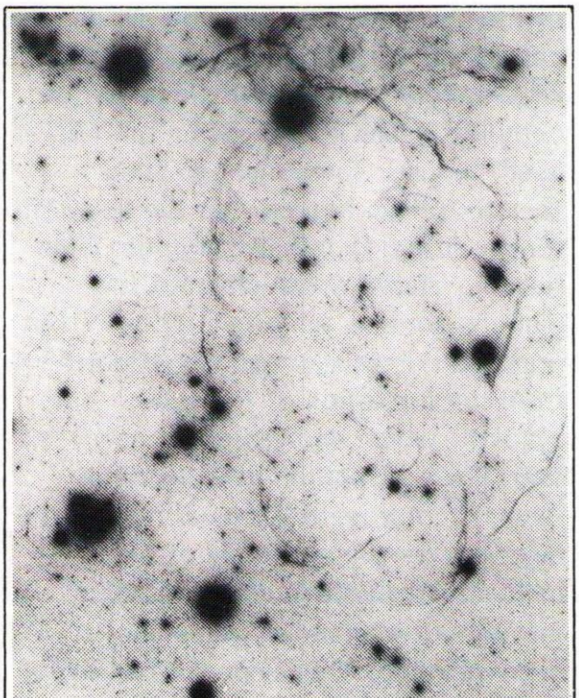


Fig. 9. Vela Supernova remnant: The fine traceries of filaments on this photograph are part of the aftermath of the blast wave produced, millenia ago, by the detonation of a supernova. (Photo: ROE).

nickel, cobalt, iron, etc., are formed in the inside of the stars, how are they released to the interstellar medium to contribute to the formation of new stars, planetary systems, and life-forms? There are two possible mechanisms. The first involves stars which at certain stages of their evolution become unstable and shed part of their outer fabric. The second is due to the violent death-throes of certain types of stars which at the end of their normal existence blow themselves apart in gigantic explosions called *supernovae.* The energy released in these spectacular displays of celestrial pyrotechnics is almost beyond comprehension, and in the extreme conditions of these acts of stellar suicide elements heavier than iron, such as platinum, silver, gold and uranium may be formed. Thus as a fraction of each successive generation of stars undergo supernova explosions, the interstellar medium is further enriched with elements other than the hydrogen and helium of the primordial Universe. Scientists' interpretation of astronomical alchemy is now complete. Hydrogen and helium were formed shortly after the *Big Bang*; common elements less massive than iron were subsequently formed in the inside of the stars and fed to space in giant stellar explosions, the extreme conditions of which led to the production of the rarer, heavier elements. Such precious metals as gold and silver only have rarity value because the phenomena that produce them, the supernovae, are comparatively rare events. The uranium now mined to fuel the nuclear power stations was formed in supernova explosions a thousand million years before the Earth was formed. Indeed, everything within our common experience had an ultimate cosmic origin, having been forged from primeval hydrogen in the centres of the stars. Most sobering of all, the carbon, nitrogen and oxygen of the organic compounds, of which each of us is composed, had its basic beginning in the stars. Ancient mythologies relating Man to the stars thus contained a semblance of truth – we are indeed the "children of the stars".

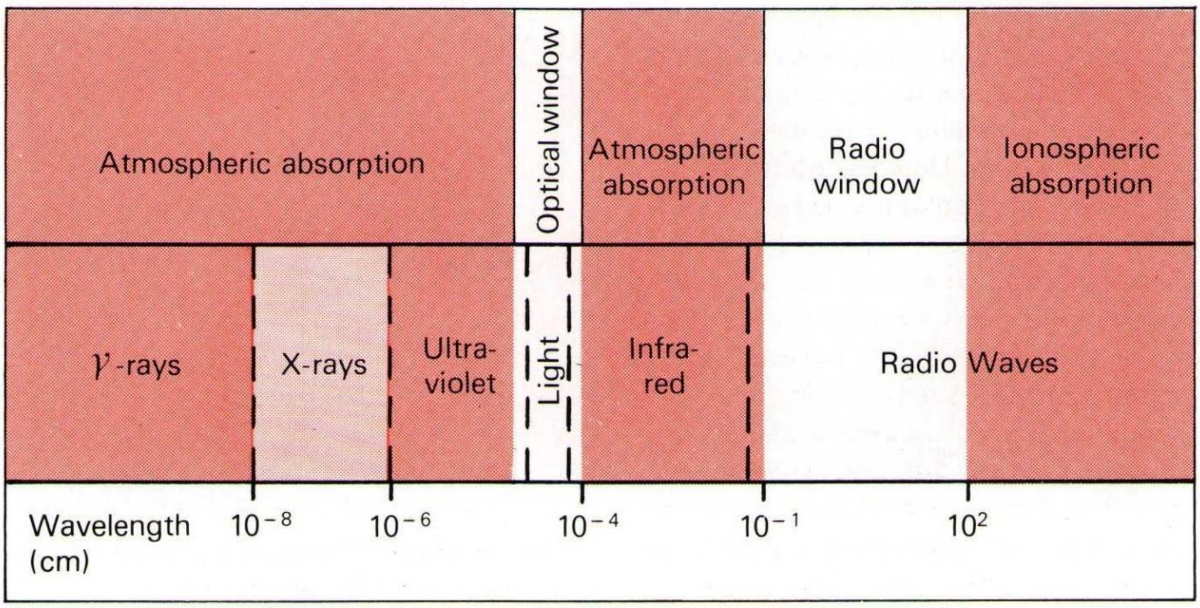
But what of the origin of "life"? Within the past few years it has been established that in the tenuous material of interstellar space, carbon, nitrogen and oxygen produced in stars at earlier epochs combine with primordial hydrogen (still the dominant component of the Universe, representing almost 75 per cent by mass of all matter) to form a wide variety of organic molecules, the complex pieces of the jigsaw of "life" itself. Indeed, some distinguished scientists have argued that the likely site for the fitting together of the essential building blocks of life was not this planet's surface, as long supposed, but on small comet-sized bodies—debris from the formation of the solar system—which showered the newly born planet. Such an interpretation remains controversial. Nevertheless, the evidence for the existence of pre-biological material in vast quantities throughout interstellar space is overwhelming. This evidence has come not from optical astronomy, but through the study of radio waves from outer space.

The Universe in Different Colours

Radio waves and visible light are both forms of *electromagnetic radiation* as indeed are ultraviolet radiation, infrared radiation, gamma rays and X-rays. Historically these various types of radiation were discovered before the realisation that they were of a similar nature, all travelling through free-space with the same velocity and differing only in their so-called *wavelength* (''colour''). As far as Mankind is concerned, the only thing special about visible light is that this is the most intense radiation from the Sun which penetrates the Earth's atmosphere, with evolution ensuring that it is the radiation to which the human eye is sensitive.

In present-day astronomy, the detection and analysis of all types of electromagnetic radiation are important. All are produced by celestial objects in varying degrees, with each telling something different about the nature of the Cosmos. Thus, for example, certain radio waves originate from objects undergoing violent change, X-rays from particularly hot regions and infrared radiation from comparatively cool regions. Of the various types of electromagnetic radiation, only visible light, some infrared radiation and radio waves from outer space can penetrate the Earth's atmosphere to be detected at ground level. Astronomical observations

Fig. 10. The electromagnetic spectrum: To observe radiations outside the optical and radio 'windows', modern astronomers send instruments high above the Earth's atmosphere.



at other wavelengths have been made possible over the past two decades by lifting equipment above the atmosphere on high-flying aircraft, balloons, rockets or satellites.

The story of Man's present cosmic quest is therefore one which involves the most sophisticated instruments technology is able to devise to extend the limited scope of the human senses. The meagre light-gathering capacity of the fully dilated pupil of the human eye is dramatically enhanced by giant optical telescopes capable of gathering a million-fold more light and focussing it for human view. Detectors of exceptional sensitivity are then used to enhance images far below the limit of detection of the eye, and preserve these images from the depths of space for posterity. Massive radio telescopes, with dimensions measured in kilometres rather than metres, provide astronomers with "radio spectacles" through which they can "view" the heavens. The picture given of a Universe undergoing violent upheaval and change is dramatically different from the apparently quiet Universe Man has observed since antiquity as he looked with unaided vision out into the night sky. Futuristic spacecraft now probe the depths of space for radiations that could never be observed from the Earth's surface, again complementing the "multi-coloured" panorama of the Universe modern astronomy continues to paint. The cosmic canvas may never be completed, however, since the true complexity of the Universe may be beyond the ultimate capability of human understanding. Nevertheless, our attempts to understand the nature of the Universe and Man's celestial heritage must surely represent one of the great human challenges, comparable with the most courageous exploits of adventurers throughout the ages who sought to explore the unknown. It is Man's capacity to understand and utilize his terrestrial environment which has set him apart from other earthly creatures. Perhaps it will be his capacity to partially understand his universal environment as he seeks his ultimate "roots" amongst the stars that may eventually set him apart from other celestial civilizations.

Footnote: The ROE photographs are courtesy of the Schmidt Telescope Unit.

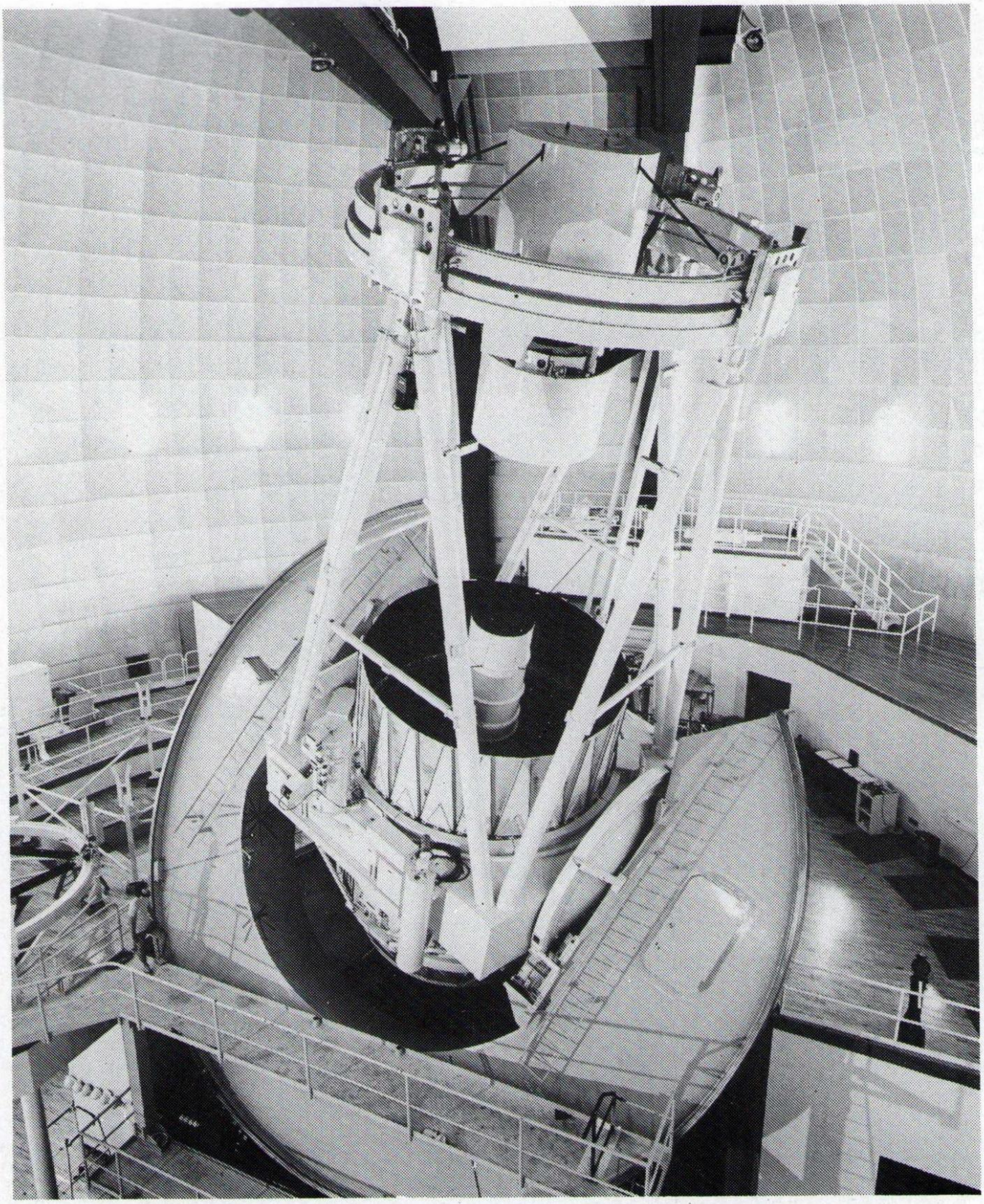
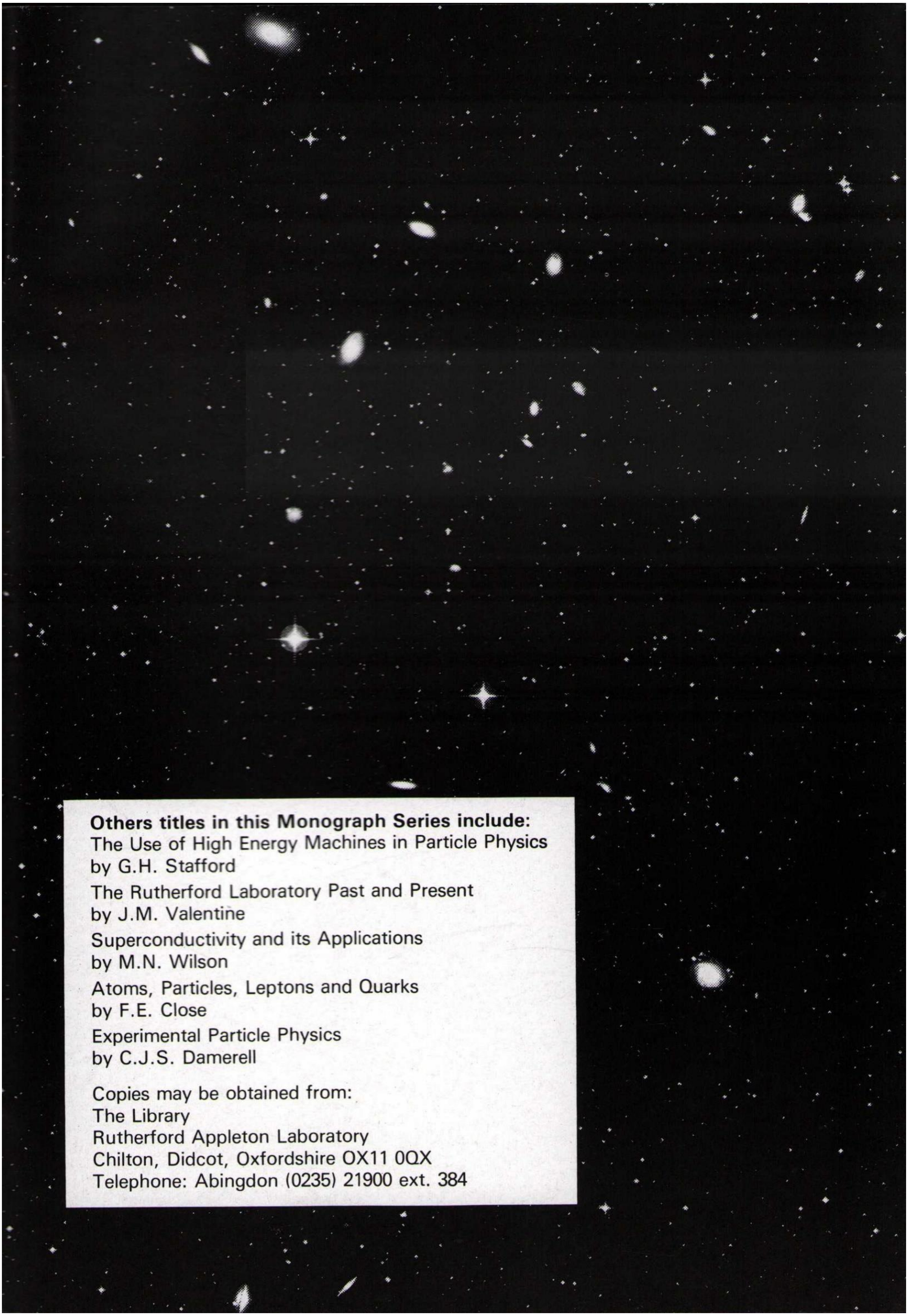


Fig. 11. The 3.9m Anglo – Australian Telescope, supported jointly by SERC and the Australian government (Photo: ROE).



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