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Adventure into Space

E. Margaret Burbidge

I have chosen the subject of the adventure into space for two reasons other than its appeal to me as an astronomer. One is a recognition of a basic drive of human beings to find out about the world we live in. This is an inborn urge, as is well known to anyone who has watched a baby explore the expanding reachable world of toes and fingers, crib, living-room floor, and backyard. What is more natural than to look toward an ultimate goal—exploration of the entire universe, even though mostly by reasoned analysis of the data, since the far universe is indeed almost incomprehensibly far.

The synergistic and dramatic recent advances in high technology and our entry into the space age have produced a ferment of excitement in the once-quiet field of astronomy. The pot is kept bubbling by a flow of new concepts, new ideas, and above all, new observations, leading to discoveries which are sufficiently exciting to capture everyone's interest. The large number of new descriptive astronomy books aimed at the general reader, in addition to best-selling fictional books on space ventures, must bear witness to this arousal of public interest. Of course, most of the astronomy books are enhanced by many beautiful pictures because astronomy is a science of visualization as well as analysis and theory.

There is a dark reverse side to the coin, however, and that is the same technological advances have given us the capability of extinguishing life on Earth in a nuclear holocaust, or of smothering it in waste. That is my second reason for choosing this topic. I shall return to it later.

Summary. The exploration of the universe has captured mankind's interest since the earliest attempts to understand the sun, moon, planets, comets, and stars. The last few decades have seen explosive advances of knowledge, sparked by technological advances and by our entry into the space age. Achievements in solar system exploration, discoveries both in the Milky Way and in the farther universe, and challenges for the future are discussed. Of major concern worldwide is the need for people of goodwill in all nations to concentrate on the peaceful uses of outer space and on international collaboration.

Exploring the Solar System

With all the frontiers on the earth broached, the next frontier for exploration is above the earth's surface—the frontier with the rest of our solar system. And here I have to point out that exploring this frontier is an expensive operation. My favorite commentary on this is given by a B.C. cartoon [by Hart] that appeared several years ago, in which the conversation ran as follows:

"The secrets of all creation, secrets that could mean the salvation of mankind, are locked in those stars."

"Gosh!"

"Why can't we reach out and unlock those secrets?"

"The keys are not ours to have."

"How come?"

"It ain't in the budget!"

However costly, though, the budgets for the exciting ventures of the past two decades, and those planned for the remainder of this century, are but a tiny fraction of the U.S. military budget—some three to four times 10^{-3} for fiscal year 1984 (*1*, *2*). Also, the expenditures during the past 20 years have pushed technology in many useful fields, especially the development and miniaturization of computers and instruments, advances in the science of communications, and the flow of data from the Landsat and weather satellites. The most expensive ventures are obviously those involving manned space flight. Yet those who watched on television the Apollo 11 landing on the moon will never forget the thrill of seeing those first steps, by astronauts Aldrin and Armstrong. For myself, I cannot look at the moon at night without thinking "We have been there," and without reflecting regretfully that, had I been born one or two centuries later, I might have been able to step in those footprints.

The Apollo mission was mainly one of exploration. Only a small part of the lunar surface was explored; nevertheless, some intriguing results were obtained, especially concerning the moon's seismology and the chemical and isotopic composition of a small part of the surface material, enough to give a tantalizing glimpse into the past history of the solar system (*3*).

Going farther out into the solar system, to the nearest large bodies beyond the moon, we pass beyond today's goal for manned space flight, into the realm where carefully designed and constructed unmanned space vehicles can reveal as much information about Mars, Venus, and Mercury as we have about the moon. Mariner 10 showed that Mercury has a surface like the moon's, cratered by meteoritic bombardment. Close as it is to the sun, where it receives a heavy dose of solar wind charged particles, it has a magnetosphere in which Mariner 10 observed intermittent intense bursts of high-energy particles. The U.S.S.R. Venera landers on Venus and the U.S. Mariner and Pioneer flybys have shown that the hot, enormously dense and dynamic atmosphere of Venus has huge quantities of CO_2, very little water, and is topped by clouds of sulfuric acid. It is

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Fig. 1. View of the surface of Venus as seen by the U.S.S.R. Venera 14 lander on the surface. [Photography courtesy of C. Sagan, Center for Radiophysics and Space Research, Cornell University]

indeed an inhospitable place for manned exploration. The little of Venus's surface topography that has been unveiled (Fig. 1) shows past volcanic activity and whets the appetite for more detailed knowledge. A proposed Venus Orbiting Imaging Radar has had to be shelved because, to quote B.C. again, "It ain't in the budget," but a Venus Radar Mapper of reduced scope, without an atmospheric probe, is planned for 1988 (*4*).

The least inhospitable of our neighboring planets is Mars, and NASA's Viking lander showed unweathered craters produced by past meteoritic bombardment, like those on the moon and Mercury, yet also showed dry river channels, suggesting the flow of water or some other liquid in the past. Again, the preliminary studies of the geography and climatology of Mars are the incentive for more detailed study by orbiters planned by NASA for the 1990's.

Perhaps the most spectacular planetary studies have been those made by Voyager 1 and Voyager 2, flying around and past Jupiter and Saturn, their satellites, and Saturn's fantastic ring system. These have been triumphs of planning and technological skill, in the accuracy of placings of the Voyagers and the superb operation of their communications systems. And there is more to come when the space odyssey reaches Uranus, twice as far out as Saturn. The variety displayed by Jupiter's and Saturn's satellites (*5*) again gives tantalizing hints about the early history of the solar system. Here again, heavy bombardment by meteorites occurred in the past, while Saturn's largest satellite, Titan, is unique in having a thick atmosphere—mostly nitrogen, some methane, possibly argon, some simple organic molecules, and also atmospheric aerosols that may be more complex organic molecules (*6*). Active volcanoes on the innermost large Jovian satellite, Io, were a surprise indeed. Once again, the planned return to Jupiter with NASA's satellite Galileo has been scaled down because of current budgetary considerations, but one can look further into the future and aim for flyby and probe investigations of Jupiter, Titan, Saturn, Uranus, and eventually Neptune (*4*). How exciting it would be to discover what is at the "bottom" of the Great Red Spot on Jupiter that enables this weather system to persist for hundreds of years (*7*).

The planets and their satellites by no means comprise all the objects of interest in the solar system. The smaller components—asteroids and comets—are candidates for intensive study by satellites that actually make rendezvous with them. The asteroids—solar system debris—are conceivably useful sources of raw materials (*8*). (I return to this possibility later.) In any case, chemical, spectroscopic, and isotopic analysis of more than one asteroid will yield interesting data on their origin, their place in the history of the solar system, and their possible use in the eventual colonization of space.

Because of the fear and awe they have inspired in primitive and prehistoric peoples, and indeed also in more recent centuries, comets have always been objects of intense interest and study. They continually surprise us: while people were thinking and writing about the famous Halley's comet, due to reappear in 1985 and already detected at Palomar Observatory as a very faint object, and while we were deploring the fact that NASA was unable to include a dedicated comet mission in its budget, there appeared in the May skies an unpredicted comet that passed very close to the earth. It is the first comet whose name includes that of a space satellite—Comet IRAS-Araki-Alcock—because the Infrared Astronomy Satellite IRAS (*9*) made the first observation of it.

Comets can be quite diverse. The beautiful 1976 Comet West passed close to the sun and developed a spectacular tail, while Comet IRAS (Fig. 2), which passed close to the earth but not to the sun, was bright, fuzzy, but without much of a tail. Aside from the known periodic comets, there may be many that start sunward from a "cloud" far beyond the orbit of Pluto. Whether some comets provide a sample of truly interstellar matter is still an open question.

Beyond discovery and exploration, the ultimate goal of studies of the solar system is to unravel the secrets of its origin and early history, and to learn whether planetary systems around sunlike stars are common or rare.

Beyond the Solar System

I turn now to the realms beyond the solar system—the farther universe, including fields studied in my own research. This kind of voyage of discovery cannot be made through direct exploration but must be carried out through the synthesis of data received on the earth by state-of-the-art and future instrumentation on telescopes covering the entire electromagnetic spectrum, both from satellites in earth orbit and from the ground.

Astronomers are accustomed to planning far ahead both in the research programs to be tackled and in the instruments with which to carry out the research. For example, the Space Telescope (*10, 11*) with its 2.4-meter mirror, to be launched in 1986 by the Shuttle, has been decades in the planning. In orbit above the earth's atmosphere, it will reveal the ultraviolet spectrum of objects from our nearest neighbors to the most distant galaxies and quasars, and with a spatial resolution better than ten times that achieved with ground-based telescopes.

The long-term nature of astronomical research and the fact that we are always scrounging for that last little photon and the utmost improvement in signal-to-noise ratio that our instruments will yield have been drivers toward international cooperation. Science is done jointly by the United States, the U.S.S.R., Europe, Canada, South America, Mexico, Australia, Japan, and South Africa. Expensive space programs are particularly suitable for international cooperation, and very long lead times are needed in their planning.

The report of the Astronomy Survey Committee to the National Academy of Sciences (*12*) is such a planning document. It presents an in-depth account of the current state of knowledge about the universe and of the spearheads for advancing that knowledge and understanding. It recommends a set of programs that the committee judged to be priorities for the 1980's, and proposes the instruments with which to carry out these programs. Its final chapter looks further ahead and discusses planning for programs that have exceptional promise for the 1990's and beyond. To take a brief look at some of those goals and plans, let us move out of the solar system, into the realm of the Milky Way, our home galaxy.

During the past 30 years the physical properties of stars during the main part of their lifetimes have become quite well understood, from a combination of theory with observations of the energy outputs, surface temperatures, chemical compositions, and masses of a great variety of stars at different evolutionary stages. The least well understood stages, about which we would like to know more, are the beginning and end phases.

Throughout most of their existence, stars function well as self-regulating thermonuclear fusion reactors, such as our sun. Trouble comes when the nuclear fuel (first hydrogen, then helium, carbon, and so on) begins to be exhausted and the star can no longer maintain its balance between pressure and gravity by a constant generation of energy in its interior. Such a star can die quietly, shedding its outer layers and contracting its core, and eventually becoming an extremely dense white dwarf that continues to radiate by cooling. The well-known planetary nebula in Lyra, the Ring Nebula, is an example of a star in this process. Or a star can die in a catastrophic collapse—implosion, followed by explosion, as a supernova. Such an event in A.D. 1054 was documented by ancient Chinese astronomers, who saw a star that became so bright that for some weeks it could be seen in the daytime. It has left us the expanding remnant of the explosion, the Crab Nebula—perhaps the most interesting object in the sky. When radio astronomy was a young science, in the 1940's, the Crab was one of the first astronomical radio sources to be detected. The origin of the radio waves was understood to be radiation by high-energy charged particles accelerated in magnetic fields.

This was not all the radio astronomers discovered about violent star death. With technical improvements and a capability for high time resolution, they discovered that one of the central stars in the nebula is not shining constantly but is emitting spurts of radiation 30 times a second (*13*). This central object must be the remnant of the imploded original stellar core, crushed into matter of extremely high—in fact, nuclear—density, so that it forms a neutron star. Conservation of angular momentum causes this object, whose radius is only some 15 kilometers, to rotate with a 30-millisecond period. The enormous compressed magnetic field and its interaction with charged particles from the surface produces a beam of radiation that sweeps past the earth 30 times a second.

Given the period, optical astronomers could look and see the same beaming in visible light (*14*). But the Crab has even more wonders to offer. It was recognized by an ingenious early rocket experiment to be a source of diffuse x-radiation (*15*). A point x-ray source at the center was discovered to be an x-ray pulsar, and the HEAO 2 (Einstein) satellite has produced beautiful images of it in its "on" and "off" phases (*16*). The neutron star is thus a radio, optical, and x-ray pulsar.

Radio astronomy and optical astronomy can continue through the next several decades from the ground, but x-ray astronomy needs a satellite because observations must be made from above the earth's atmosphere. Consequently, an Advanced X-ray Astrophysics Facility (AXAF) for imaging and spectroscopic work is a first-priority goal. AXAF is planned to have a sensitivity up to 100 times greater than that of any previous x-ray mission. It will extend the revelations of the Einstein satellite, which showed the sky to be peppered with x-ray sources—single and double stars in the Milky Way, remnants of old supernovae, and, outside the Milky Way, active galaxies, quasars, and diffuse hot material in clusters of galaxies, reaching to the bounds of the observable universe.

I cannot leave the subject of x-ray astronomy without a few words about an amazing and, so far, unique x-ray object known as SS 433. Appearing as a 14th-magnitude star at the position of an x-ray source, it had already been cataloged as unusual in having strong emission lines in its spectrum. Intensive study by B. Margon and many others showed it to have the extraordinary property described by the news media as "coming and going at the same time" (*17, 18*). A graph of velocities measured from the Doppler shift of its spectral lines looks like that of any ordinary double star until one reads the figures on the velocity axis, which show a total range of 85,000 kilometers per second or about a quarter of the velocity of light. A preliminary and a later artist's conception of what is going on, shown in the two popular review articles (*17, 18*), indicated a double

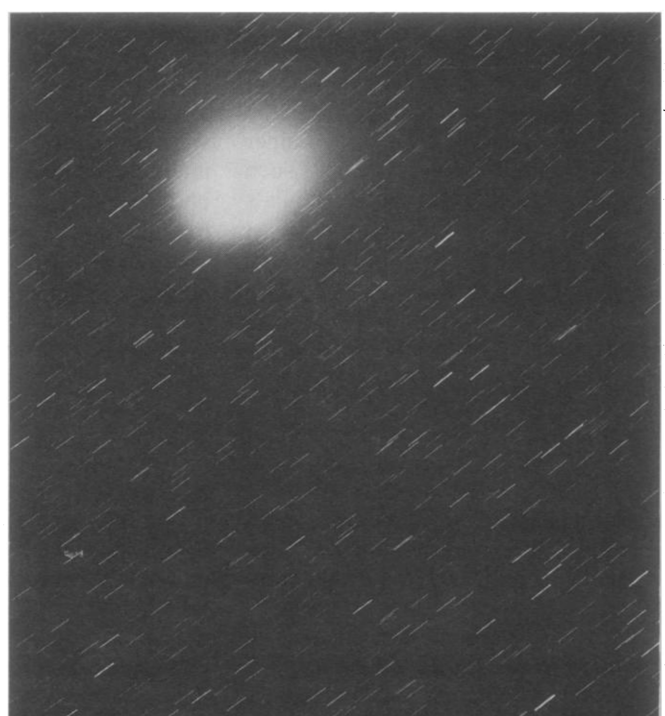

Fig. 2. Comet IRAS-Araki-Alcock, photographed on the night of 8–9 May 1983 by G. MacAlpine of the University of Michigan with the Case Western Research Schmidt telescope at Kitt Peak National Observatory. The faint ion tail of the comet, formed by light particles blown out of the coma by the solar wind, extends 2° toward the southwest. Trailing of the stars is due to the fast motion of the comet during this 10-minute exposure. [Photograph courtesy of AURA, Inc., Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation]

star, one of which has collapsed and is sucking material off its companion. The infalling material is heated to x-ray–emitting temperatures, and the collapsed object, rotating about a precessing axis inclined to the axis of the orbital plane of the pair of stars, squirts out jets of matter in opposite directions, which are seen by us as the material "coming and going at the same time."

I now turn to that other little-understood part of a star's life history—its formation. This is, of course, very relevant to our attempts to decipher the formation and early history of the solar system and to the question of whether planetary systems about stars are common or rare. It is known that massive hot stars are short-lived in comparison to stars like our sun, which is some 5 billion years old and only halfway through its main sequence lifetime. Thus, it has long been recognized that stars are continually forming in the Milky Way (and in other similar galaxies). The well-known Orion Nebula is one such region of recent star formation: young stars are embedded in a vast complex of hot and cold gas and dense molecular clouds and clouds of dust. The Lagoon Nebula in Sagittarius is another such region.

The best instruments for penetrating the shielding clouds of dust are those that detect infrared radiation, and recent technology has produced many such telescopes, which are used on high mountains and in airplanes so that they can be above much of the water vapor that obscures the infrared. These instruments are providing a wealth of information, both on new stars in the process of formation and on old stars beginning to shed their outer material in clouds of dust. A composite infrared picture of the Orion Nebula made from the Kuiper Airborne Observatory (*4*) shows such protostars coalescing out of the nebula's gases. The most recent observatory at work is the IRAS, to which I referred earlier as the discoverer of a comet. This is a truly international, and highly successful, satellite that is now mapping the heavens for infrared sources, as the Einstein satellite did for x-ray sources.

Detailed study of the infrared sources detected by IRAS (both within and outside the Milky Way) will be carried out by instruments planned for the future; among them are a Shuttle Infrared Telescope Facility and a Large Deployable Reflector (*9, 12*).

Let us move beyond the confines of the Milky Way. Among external galaxies, there are some which are intense sources of radio radiation. The activity that produces the high-energy charged particles necessary to emit radio radiation originates in the central nucleus of the galaxy. The high-energy particles are usually beamed out in two opposite jets, into what become two radio lobes well outside the visible galaxy. As calculated many years ago by G. Burbidge (*19*), the particle and magnetic field energies demand the release of a huge quantity of energy in the central region—as much as the rest-mass energy of 10^8 solar masses in some cases. The beaming mechanism may work like an enormously scaled-up version of what goes on in SS 433. It is sometimes remarkably constant in direction, as in the radio galaxy NGC 6251 (*20*). In other cases, the direction shifts, perhaps because of interaction of the particles with an extragalactic medium.

I have said nothing yet of the radio telescopes that obtain such detailed maps. The large-scale, high-resolution observations of NGC 6251 were made with the National Science Foundation's Very Large Array at the National Radio Astronomy Observatory, a set of 27 dishes that move on Y-shaped tracks with a fullest extent of some 30 kilometers. The full array can produce resolutions better than the best ground-based optical telescopes. Color-coded pictures of several cosmic jets, emanating from radio galaxies, may be seen in a descriptive article by Blandford *et al.* (*21*).

To improve resolving power still further, radio astronomers have developed very long baseline interferometry (VLBI), in which signals from radio dishes spaced at intercontinental distances are combined in the computer. This produces a resolution 1000 times higher than the best optical ones, and a proposed extension and upgrading of the system—a Very Long Baseline Array—will do still better. This type of operation is truly international because, in carrying out an observational sequence with VLBI, data from the United States, Canada, Europe, and the U.S.S.R. are combined; this involves collaboration of scientists at all these telescope sites.

Radio, microwave, infrared, x-ray—these data could not be deciphered without the all-important optical telescopes. Here again, we pin our hopes for better understanding these objects and for making new discoveries on future instruments. The Space Telescope will reveal the ultraviolet and will give us far sharper pictures than we can get from the ground today. But it is limited in size; its mirror is only 2.4 meters in diameter. Optical astronomers are therefore planning new very large telescopes on the ground, to work in conjunction with the space instruments. Figure 3 shows models of two concepts for a future National New Technology Telescope under study by the National Science Foundation. The models were constructed by the engineering group at Kitt Peak National Observatory, under the direction of KPNO Director Geoffrey Burbidge. Such a telescope, with an effective mirror diameter of about 15 meters, dwarfs the model on the same scale of the largest existing national telescope, the Kitt Peak 4-meter telescope.

I was describing cosmic activity in external galaxies and cannot end without a few words about two of my favorite objects, in which it seems that bullet-like lumps of plasma are shot out of the nuclei of galaxies. The first is well known and was one of the earliest radio sources to be detected (*22*). It is a galaxy known as M87. A seemingly ordinary spherical conglomeration of stars, if one looks at a strongly exposed photograph, it is found to be much more interesting when looked at visually through a large telescope. A blue jet thrusts out from the center, strikingly outlined against the yellowish stars of the galaxy. A short-exposure photograph in visible light shows this jet; it turns out to be a stream of blobs containing high-energy charged particles in a magnetic field. M87 is also a strong x-ray source—another astronomical wonder that provides something for everyone. The second object is a radio galaxy, perhaps akin to M87, which is emitting plasma blobs in a jet and apparently producing an extensive and complex additional radio source that encompasses a quasar and ultraviolet objects, whose nature a group of us are trying to decipher (*23*).

The Earth

This section brings me back to that dark side of the coin to which I referred at the beginning, my second reason for choosing this topic. However, it also enables me to look into the future and to say something about the possibility of constructing giant space colonies to which adventurous human beings may travel and in which they may live comfortably.

In the early 1960's the first pictures of the earth as seen from outside were obtained from the Apollo flights, and Rachel Carson's book *Silent Spring* (*24*) was published. The Apollo pictures brought home, as nothing else could, the fact that we inhabit a bounded surface, in an environment which we can cherish or violate and which is home to an ever-growing human population whose everincreasing waste products it must house. Carson's book focused on toxic waste products and the havoc they can cause to all life on the earth. It was written after our entry into the nuclear age, but before the proliferation of nuclear weaponry in several continents and the problem of nuclear waste disposal. Its main concern was chemical toxic wastes, but the problem of radioactive fallout from atmospheric testing of nuclear bombs was also addressed. In dedicating the book to Albert Schweitzer, Carson quoted him as saying, "Man has lost the capacity to foresee and to forestall. He will end by destroying the earth."

A positive action was taken in 1963, the year after the publication of *Silent Spring*: President Kennedy delivered his famous speech at American University in which he announced the end of nuclear tests in the earth's atmosphere and laid the groundwork for the test ban treaty and the first nuclear arms limitation agreement. The speech was one of the highlights of his career.

The cessation of nuclear bomb testing in the atmosphere and in space outside the earth has not, however, lessened the accumulation during the past two decades of nuclear waste from military nuclear activities, and it is this problem which I want to address now. In preparing this section I have been helped and advised by two of my colleagues, Hannes Alfvén and Robert B. Livingston, and I thank them for the material and references they provided.

Alfvén pointed out the physical impracticality of an early idea of mine, that nuclear waste materials could be loaded into sun-bound satellites and fired off into the sun's atmosphere, where they would be harmlessly absorbed into its massive hot interior. He pointed out that elementary celestial mechanics shows the impossibility, energywise, of such a project. So, if we must find ways to dispose of nuclear waste within the confines of the earth itself, how will this important problem be tackled?

It is heartening to see the growing awareness on the part of scientists, politicians, and the public of the acuteness of the problem. It is, of course, linked with the sword of Damocles hanging over the world—the threat of nuclear war. The attention being given by AAAS to all aspects of the problem is demonstrated by the number of symposia devoted to it at the 1983 Annual Meeting and by the continuing concern of its committees and council. Also, many thoughtful books and articles have appeared, among which I would like to draw attention to papers by Alfvén (*25*) and Lester (*26*) and to a book by Shapiro (*27*). In his foreword, Shapiro recalls an experience in high school when the teacher asked the class what their first step would be if they were assigned the task of producing "an acid so powerful it would dissolve any substance." None of the students gave the correct response, which was "Suppose you ever got such an acid . . . what could you keep it in? The first thing you have to determine in any experiment is, when you get whatever it is you're going after, what are you going to keep it in?" Shapiro gives the quantities and locations of various radioactive waste materials, the half-lives of the dangerous radioactive species, and the estimated costs for safe disposal.

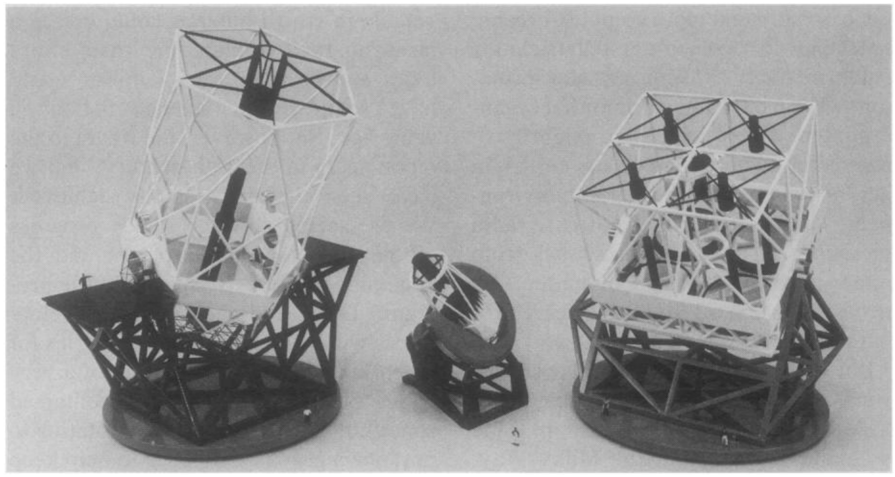

Fig. 3. Models of two design concepts for the National New Technology Telescope. (Left) Design with a 15-meter primary mirror consisting of 60 hexagonal segments; (right) multiple-mirror design with four individual 7.5-meter primary mirrors; (center) the Mayall 4-meter Kitt Peak telescope to the same scale. Scale is also indicated by human figures near each telescope. Models were built by Kitt Peak National Observatory engineering and technical staff members.

I turn now to the threat of nuclear war, which grows as the arms buildup grows and as new nations enter the nuclear arena, and which can be averted only by a dedicated effort toward international communication and cooperation. It is time for all responsible people to realize the impossibility of "limited nuclear war." It was shocking to discover that there were those who could contemplate the aftermath of a nuclear war with 20 million humans killed in the United States. Astronomers are used to large numbers and to attempting to depict them to nonastronomers. Such a toll of bodies, at an average height of 5½ feet per person, would form a line stretching around more than eight-tenths of the equatorial circumference of the earth. I must believe that men and women of good will have reached a consensus that nuclear holocaust must be avoided.

The consequences of such a disaster have, of course, been explored in fiction. Aldous Huxley, in *Ape and Essence* (*28*), wrote of the discovery of a movie script set in the year 2108, in which a group of men and women embark from New Zealand on a "rediscovery expedition to North America" following their isolation from the Northern Hemisphere for more than a century. The Northern Hemisphere had been devastated but not totally depopulated by a third world war, and Huxley imagined a remnant of human survivors, totally brutalized and suffering from grotesque genetic mutations caused by nuclear irradiation. Nevil Shute, in *On The Beach* (*29*), also wrote of the aftermath of a nuclear war in the Northern Hemisphere. Australia was again spared temporarily because of the separate wind circulations in the two hemispheres. An expeditionary group set out to investigate what seemed to be a coherent message being tapped out somewhere in North America. They discovered a total absence of life: the "message" was the random tapping of an electric cable blowing in the wind. Shute's book ends on a far more pessimistic note than Huxley's, with the extinction of life all over the earth.

Before leaving this somber subject and turning to positive goals for the future, I must comment on the thoughts of several scientists interested in the question of whether intelligent life exists elsewhere in the universe. I have briefly discussed the birth of new stars in the Milky Way, and it is widely recognized that there may be stars in the solar neighborhood which have planetary systems like ours. Indeed, it is hoped that the Space Telescope can devote time to investigating these nearby stars for dark, planet-sized companions. As advances in microwave and infrared technology reveal the existence of more and more complex organic molecules in dense interstellar clouds which are likely sites for new star formation, we can envision a primordial organic mixture out of which life might have evolved elsewhere than on the earth—in fact, anywhere having the right environment. Thus, it is worthwhile to use radio telescopes in a search for signals from outer space. The Field Committee (*12*) included a panel on SETI, the search for extraterrestrial intelligence.

But the speculation that radio signals from extraterrestrial intelligence might be detected has led to the question: If life is common throughout the Milky Way, why haven't we already detected it? And that leads to the further question: For what length of time could living creatures in another solar system exist, once they had the necessary technology to send out signals (*30, 31*)? As several authors have commented, perhaps the development of highly organized living creatures is always accompanied by competition, struggle for scarce resources, and warfare. Acquiring the technology to send out strong enough radio or microwave transmissions would presuppose an advanced knowledge of physics, including nuclear physics and the ability to build nuclear bombs. Perhaps any such civilization has but 50 years or so (on our time scale) before it annihilates itself. Should we ask instead whether the development of a civilization as contentious as ours is an unavoidable consequence of the possession of "intelligence" and, if so, how many such civilizations have had the wisdom to pass safely through the dangerous warfaring phase to an era of cooperation? This is a task for all of us, and especially scientists, to address, and we should do so in the belief that we shall succeed. In his 1963 speech at American University (*32*) after the Cuban missile crisis, President Kennedy warned that we should not "see conflict as inevitable, accommodation as impossible and communication as nothing more than an exchange of threats." He urged: "Let us focus . . . not on a sudden revolution in human nature but on a gradual evolution in human institutions. . . . Peace is a process—a way of solving problems."

I am going to assume that we will achieve peace and cooperation and that this will free our resources to face the frontier of space. Here again I have had the benefit of help, advice, and material from one of my colleagues, James R. Arnold, and I refer the reader to his article entitled "The frontier in space" (*8*).

The idea of constructing a giant space vehicle in which humans could create a pleasant environment, live their entire lives, and bring up their families would have sounded like science fiction 50 years ago. So, however, did travel to the moon seem in the 19th century, and we have seen that successfully achieved. We are seeing now the steady progress of the Soviet Salyut program and the beginning of the U.S. Space Shuttle program. These and their future developments will be necessary preliminaries for embarking on the construction of a very large, perhaps toroidal, self-contained space colony, perhaps slowly rotating to produce a gravity-like force to help keep the colonizers comfortable and healthy. I prefer to envisage this rather than the construction of military satellites as a goal for both the Salyut and Space Shuttle programs.

Besides Arnold at the University of California, two physicists at Princeton University, G. K. O'Neill and Freeman Dyson, have written and lectured extensively on space colonization. O'Neill (*33*) considered the mechanics of mining raw materials from the asteroids and the moon and using them for the construction of a vehicle in situ, in earth orbit. Arnold (*8*) also considered the chemistry of the materials that would be needed; he discussed the Apollo data on the compositions of lunar soil samples and analyses of meteorites that probably indicate the compositions of earth-approaching asteroids. He also discussed the task of gathering enough solar energy to supply power for separating the useful elements from asteroids and the lunar soil. Dyson (*34*) looked at the costs of such ventures, in a delightful comparison with the costs of the Plymouth Colony in 1620 and the Brigham Young expedition in 1847. One should read chapter 11 of Dyson's book in the belief that, when it is a question of survival or extinction, human beings of all nations will take the rational path and demand the replacement of conflict and confrontation by cooperation and collaboration. Then the enormous worldwide military expenditures can be directed into constructive channels, both for improving the quality of life on earth for all and for tackling the adventure into space.

Conclusion

I have given a quick and selective account of achievements in space science, the exploration of our solar system, and a look at future space missions to the planets. I have taken a very brief and even more selective look at the challenge of the far universe, where both earth-orbiting telescopes and space instrumentation and telescopes on the ground will, I hope, take us on the further road to exploration and discovery in the universe. Costly as these ventures will be, the estimates for a program for fiscal year 1984 are only a few thousandths of the proposed U.S. military budget.

I have expressed my hopes for the future, for the replacement of conflict and confrontation by the start of a truly international cooperative and collaborative effort which would open up the frontier with space. This vision of the future is born of my personal interest in astronomy but is also a recognition of a common human trait—the desire to explore and to find out about the world. To achieve such a goal, it is necessary to tackle the multifaceted problems on the earth, within nations and between nations. In contrast to the opinion expressed in the quotation from Schweitzer mentioned earlier, I believe we have the capacity to foresee and forestall. Scientists of all nations are in a position to forecast the perils, and can educate and lead in the endeavor to rid the world of nuclear perils and improve conditions of life for all humans.

I close with a quotation from a 1924 story (*35*) set in the early 19th century in the border country between England and Wales. The narrator is watching a fire burn up the entire corn harvest at a farm and utters words that express a warning to today's world: "So it will surely be when the world is burned with fervent heat in the end of it all. It will go rolling on, maybe, as it ever has, only it will be no more a kindly thing that mists about it, a pleasant painted ball with patterns of blue seas and green mountains upon its roundness. It will be a thing rotten with fire as an apple is rotten when the wasps have been within, light and empty and of no account."

References and Notes

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Science and the Urban University

David Adamany

Summary. The potential for science to contribute to economic and civic life is of particular importance to urban centers with economic decline. For urban universities, the ability to adapt to changing needs and seize new opportunities has become vital. These universities must take the lead in curricular revision, research emphasizing the application of knowledge, arrangements with private economic enterprises, and public service to improve science and mathematics training in the schools.

An examination of the topic "Science and the Urban University" is sustained by the size of both academic and applied science in the Detroit metropolitan area. This area houses a remarkable array of institutions of higher learning—six community colleges, a fine technical institute, and an exceptional center for creative studies, seven 4-year colleges, three regional state universities, a major sectarian university, and, in Wayne State University, one of the nation's principal public research universities—and it is also one of the world's centers of durable goods manufacture, where the scope of the scientific enterprise in private economic institutions is matched by that in only a few places across the nation. But another factor makes this examination compelling: there is no major city in America that has suffered as much in the current economic recession as has Detroit. Unemployment is still more than 15 percent, and it is certain that the gradual rebound in this area's traditional manufacturing enterprise will never fully restore its economic health. In this environment, where national economic recovery will not provide a minimally acceptable response to economic distress, the potential for science to contribute to economic and civic life is being tested as nowhere else in America. The role of science is likely to be similarly expanded in other urban centers with structural economic decline, especially the major cities of the Midwest and Northeast.

A Utilitarian Approach to Science

While the advancement of pure science in the expansion of knowledge will certainly continue in Detroit as well as elsewhere, of special interest in Detroit and other industrial cities will be the applications of science to relieve human economic misery and to revitalize social institutions—both public and private—that are essential to mobilize human talent and capital. Such uses of science stir unease among academic scientists, including those of us in the social sciences. We are more comfortable in laboratories and libraries, pursuing pathways that do not necessarily direct us to well-defined, short-term objectives. In Detroit, however, we cannot indulge ourselves exclusively in scientific endeavors because they have attained prestige in academic disciplines. From necessity, we are today concerned in this urban area and ultimately, I believe, in all industrial centers in the Northeast and Midwest principally with the implications and applications of scientific advances for the benefit of humankind.

This starkly utilitarian approach to science may, in a sense, be only a precursor of the direction of much scientific activity in the world at large. I recently heard Harold Shapiro, president of the University of Michigan, one of this nation's world-class universities, comment on the closing gap between universities and business enterprises. He remarked on the extraordinary shortening of the time between the development of an idea and its useful application. The time between the development of the principles underlying the combustion engine and their application in automobiles was relatively long, and the life of the industry thus spawned has also been relatively long. But the period required for the advancement of electronic computing from an idea into a major industry has been only a few decades. Scientific principles and ideas are now moving to useful applications in only a few years and to product manufacture in only a few years more.

Under these conditions of rapid progress from discovery to application to enterprise, it is inevitable that universi-

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