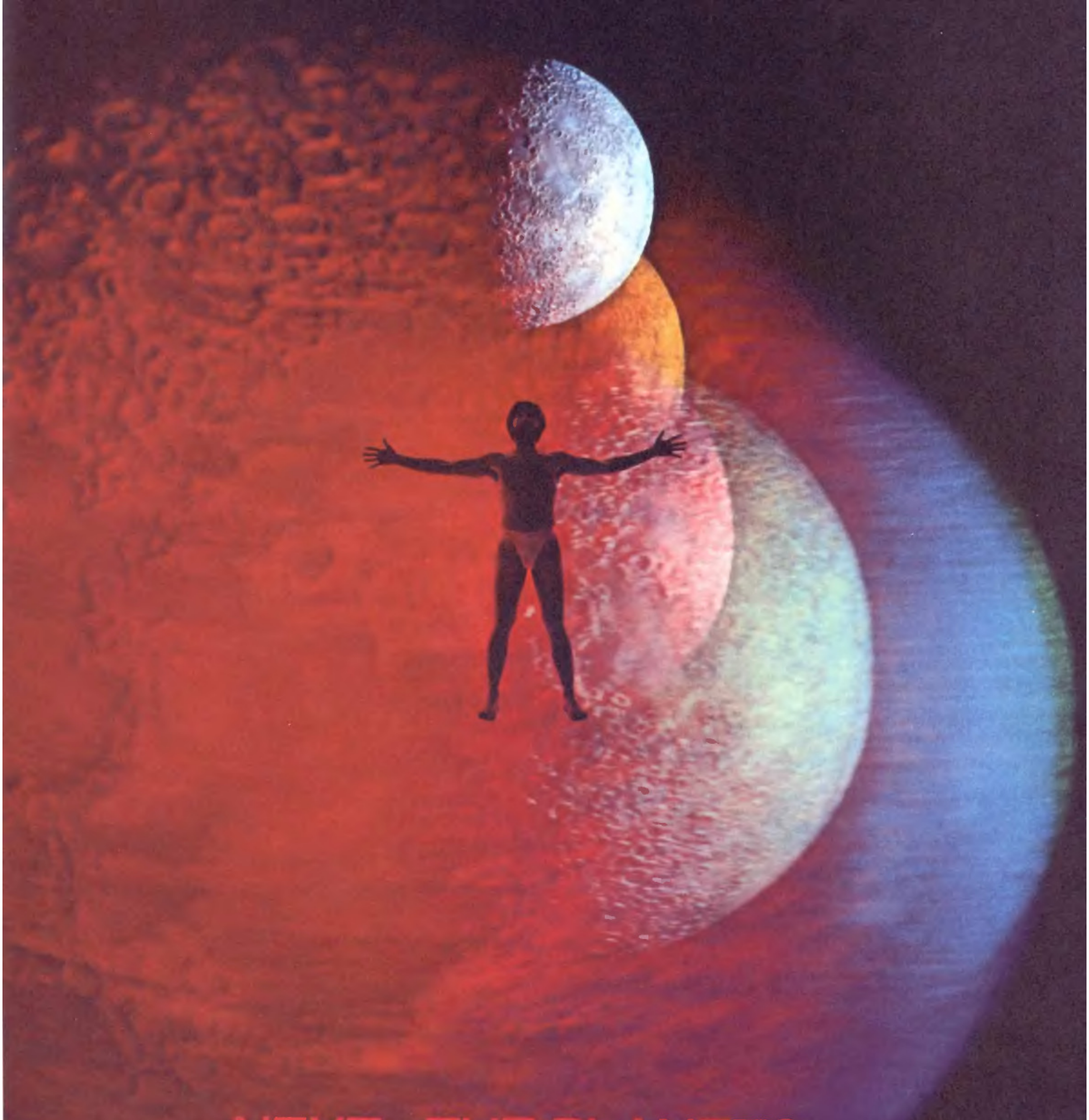

NEXT—THE PLANETS

with conquest of the moon virtually accomplished—and breakthrough discoveries at our disposal—we can now start planning exploration of the entire solar system

article By ARTHUR C. CLARKE IT HAS BEEN SAID that history never repeats itself but that historical situations recur. To anyone, like myself, who has been involved in astronautical activities for over 30 years, there is a feeling of familiarity in some of the present arguments about the exploration of space. Like all revolutionary new ideas, the subject has had to pass through three stages, which may be summed up by these reactions: (1) "It's crazy—don't waste my time"; (2) "It's possible, but it's not worth doing"; (3) "I always said it was a good idea."

As far as orbital flights, and even journeys to the Moon, are concerned, we have made excellent progress through all of these stages, though it will be a few years yet before everyone is in category three. But where flights to the planets are involved, we are still almost where we were 30 years ago. True, there is much less complete skepticism—to that extent, history has *not* repeated itself—but there remains, despite all the events of the past decade, a widespread misunderstanding of the possible scale, importance and ultimate implications of travel to the planets.

Let us start by looking at some fundamentals, which are not as well known as they should be—even to space scientists. Forgetting all about rockets and today's astronautical techniques, consider the basic problem of lifting a man away from the Earth, purely in terms of the work done to move him against gravity. For a man of average mass, the energy requirement is about 1000 kilowatt-hours, which customers with a favorable tariff can purchase for ten dollars from their electric company. What may be called the basic cost of a one-way ticket to space is thus the modest sum of ten dollars.

For the smaller planets and all satellites—Mercury, Venus, Mars, Pluto, Moon, Titan, Ganymede, etc.—the exit fee is even less; you need only 50 cents' worth of energy to escape from the Moon. Giant planets such as Jupiter, Saturn, Uranus and Neptune are naturally much more expensive propositions. If you are ever stranded on Jupiter, you'll have to buy almost $300 worth of energy to get home. Make sure you take enough traveler's checks!

Of course, the planetary fields are only part of the story; work also has to be done traveling from orbit to orbit and thus moving up or down the enormous gravitational field of the Sun. But, by great good luck, the Solar System appears to have been designed for the convenience of space travelers: All the planets lie far out on the gentle slope of the solar field, where it merges into the endless plain of interstellar space. In this respect, the conventional map of the Solar System, showing the planets clustering round the Sun, is wholly misleading.

We can say, in fact, that the planets are 99 percent free of the Sun's gravitational field, so that the energy required for orbital transfers is quite small; usually, it is considerably less than that needed to escape from the planets themselves. In dollars and cents, the energy cost of transferring a man from the surface of the Earth to that of Mars is less than $20. Even for the worst possible case (surface of Jupiter to surface of Saturn), the pure energy cost is less than $1000.

Hardheaded rocket engineers may well consider that the above arguments, purporting to prove that space travel should be about a billion times cheaper than it is, have no relevance to the practical case—since, even today, the cost of the fuel is trivial, compared with the cost of the hardware. Most of the mountainous Saturn 5 standing on the pad can be bought for, quite literally, a few cents a pound; kerosene and liquid oxygen come cheap. The expensive items are the precision-shaped pieces of high-grade metals and all the little black boxes that are sold by the carat.

Although this is true, it is also, to a large extent, a consequence of our present immature, no-margin-for-error technology. Just ask yourself how expensive driving would be if a momentary engine failure were liable to write off your car—and yourself—and the fuel supply were so nicely calculated that you couldn't complete a mission if the parking meter you'd aimed at happened to be already occupied. This is roughly the situation for planetary travel today.

To imagine what it may one day become, let us look at the record of the past and see what lessons we can draw from the early history of aeronautics. Soon after the failure of Samuel Langley's "aerodrome" in 1903, the great astronomer Simon Newcomb wrote a famous essay, well worth rereading, that proved that heavier-than-air flight was impossible by means of known technology. The ink was hardly dry on the paper when a pair of bicycle mechanics irreverently threw grave doubt on the professor's conclusions. When informed of the embarrassing fact that the Wright brothers had just flown, Newcomb gamely replied: "Well, maybe a flying machine *can* be built. But it certainly couldn't carry a passenger as well as a pilot."

Now, I am not trying to poke fun at one of the greatest of American scientists. When you look at the Wright biplane, hanging up there in the Smithsonian Institution, Newcomb's attitude seems very reasonable, indeed; I wonder how many of us would have been prepared to dispute it in 1903.

Yet—and this is the really extraordinary point—there is a smooth line of development, without any major technological breakthroughs, from the Wright "flier" to the last of the great piston-engined aircraft, such as the DC-6. All the many-orders-of-magnitude improvement in performance came as a result of engineering advances that, in retrospect, seem completely straightforward and sometimes even trivial. Let us list the more important ones: variable-pitch airscrews, slots and flaps, retractable undercarriages, concrete runways, streamlining, and supercharging.

Not very spectacular, are they? Yet these things, together with steady improvements in materials and design, lifted much of the commerce of mankind into the air. For they had a synergistic effect on performance; their cumulative effect was much greater than could have been predicted by considering them individually. They did not merely add; they multiplied. All this took about 40 years. Then there was the second technological breakthrough—the advent of the jet engine—and a new cycle of development began.

Unless the record of the past is wholly misleading, we are going to see much the same sequence of events in space. As far as can be judged at the moment, the equivalent items on the table of aerospace progress may be: refueling in orbit, air-breathing boosters, reusable boosters, refueling on (or from) the Moon and lightweight materials (e.g., composites and fibers).

Probably the exploitation of these relatively conventional ideas will take somewhat less than the 40 years needed in the case of aircraft; their full impact should be felt by the turn of the century. Well before then, the next breakthrough or quantum jump in space technology should also have occurred, with the development of new propulsion systems—presumably fission-powered but, hopefully, using fusion as well. And with these, the Solar System will become an extension of the Earth—if we wish it to be.

It is at this point, however, that all analogy with the past breaks down; we can no longer draw meaningful parallels between aeronautics and astronautics. As soon as aircraft were shown to be practical, there were obvious and immensely important uses for them: military, commercial and scientific. They could be used to provide swifter connections between already highly developed communities—a state of affairs that almost certainly does not exist in the Solar System and may not for centuries to come.

It seems, therefore, that we may be involved in a peculiarly vicious circle. Planetary exploration will not be really practical until we have developed a mature spaceship technology; but we won't have good spaceships until we have worthwhile places to send them—places, above all, with those adequate refueling and servicing facilities now sadly lacking elsewhere in the Solar System. How can we escape from this dilemma? Fortunately, there is one encouraging factor.

Almost all of the technology needed for long-range space travel will inevitably and automatically be developed during the exploration of *near* space. Even if we set our sights no higher than 1000 miles above the Earth, we would find that by the time we had perfected the high-thrust, high-performance surface-to-surface transports, the low-acceleration interorbital shuttles and the reliable, closed-cycle space-station ecologies, we would have proved out at least 90 percent of the technology needed for the exploration of the Solar System—and the most expensive 90 percent, at that.

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had better deal here with those strange characters who think that space is the exclusive province of automatic, robot probes and that we should stay at home and watch TV, as God intended us to. This whole man–machine controversy will seem, in another couple of decades, to be a baffling mental aberration of the early space age.

I won't waste much time arguing with this viewpoint, as I hold these truths to be self-evident: (1) Unmanned spacecraft should be used whenever they can do a job more efficiently, cheaply and safely than manned vehicles; (2) Until we have automatons superior to human beings (by which time, all bets will be off), all really sophisticated space operations will demand human participation. I refer to such activities as assembling and servicing the giant applications satellites of the next decade and running orbital observatories, laboratories, hospitals and factories—projects for which there will be such obvious and overwhelming commercial and scientific benefits that no one will dispute them.

In particular, medium-sized telescopes outside the atmosphere—a mere couple of hundred miles above the Earth—will have an overwhelming impact on Solar System studies. The recent launching of OAO II—the initials stand for "Orbiting Astronomical Observatory"—was a promising beginning. Until the advent of radar and space probes, everything we knew about the planets had been painfully gathered, over a period of about a century and a half, by astronomers with inadequate instruments, hastily sketching details of a tiny, trembling disk glimpsed during moments of good sighting. Such moments—when the atmosphere is stable and the image undistorted—may add up to only a few hours in an entire lifetime of observing.

In these circumstances, it would be amazing if we had acquired any *reliable* knowledge about planetary conditions; it is safest to assume that we have not. We are still in the same position as the medieval cartographers, with their large areas of "*Terra Incognita*" and their "Here Be Dragons," except that we may have gone too far in the other direction —"Here Be *No* Dragons." Our ignorance is so great that we have no right to make either assumption.

As proof of this, let me remind you of some horrid shocks the astronomers have received recently, when things of which they were quite sure turned out to be simply not true. The most embarrassing example is the rotation of Mercury: Until a couple of years ago, everyone was perfectly certain that it always kept the same face toward the Sun, so that one side was eternally dark, the other eternally baked. But now, radar observations indicate that it turns on its axis every 59 days; it has sunrise and sunset, like any respectable world. Nature seems to have played a dirty trick on several generations of patient astronomers.

Einstein once said: "The good Lord is subtle, but He is not malicious." The case of Mercury casts some doubt on this dictum. And what about Venus? You can find, in the various reference books, rotation periods for Venus ranging all the way from 24 hours to the full value of the year, 225 days. But, as far as I know, not one astronomer ever suggested that Venus would present the extraordinary case of a planet with a day longer than its year. And, of course, it *would* be the one example we had no way of checking, until the advent of radar. Is this subtlety—or malice?

And look at the Moon. Five years ago, everyone was certain that its surface was either soft dust or hard lava. If the two schools of thought had been on speaking terms, they would at least have agreed that there were no alternatives. But then Luna 9 and Surveyor 1 landed—and what did they find? Good honest dirt.

These are by no means the only examples of recent shocks and surprises. There are the unexpectedly high temperature beneath the clouds of Venus, the craters of Mars, the gigantic radio emissions from Jupiter, the complex organic chemicals in certain meteors, the clear signs of extensive activity on the surface of the Moon. And now Mars seems to be turning inside out. The ancient, dried-up sea beds may be as much a myth as Dejah Thoris, Princess of Helium; for it looks as if the dark *Maria* are actually highlands, not lowlands, as we had always thought.

The negative point I am making is that we really know nothing about the planets. The positive one is that a tremendous amount of reconnaissance—the essential prelude to *manned* exploration —can be carried out from Earth orbit. It is probably no exaggeration to say that a good orbiting telescope could give us a view of Mars at least as clear as did Mariner 4. And it would be a view infinitely more valuable—a continuous coverage of the whole visible face, not a signal snapshot of a small percentage of the surface.

Nevertheless, there are many tasks that can best be carried out by unmanned spacecraft. Among these is one that, though of great scientific value, is of even more profound psychological importance. I refer to the production of low-altitude oblique photographs. It is no disparagement of the wonderful Ranger, Luna and Surveyor coverage to remind you that what suddenly made the Moon a real place, and not merely an astronomical body up there in the sky, was the famous photograph of the Crater of Copernicus from Lunar Orbiter 2. When the newspapers called it the picture of the century, they were expressing a universally felt truth. This was the photograph that first proved to our emotions what our minds already knew but had never really believed—that Earth is not the only world. The first high-definition, oblique photos of Mars, Mercury and the satellites of the giant planets will have a similar impact, bringing our mental images of these places into sharp focus for the first time.

The old astronomical writers had a phrase that has gone out of fashion but that may well be revived: the plurality of worlds. Yet, of course, every world is itself a plurality. To realize this, one has only to ask: How long will it be before we have learned everything that can be known about the planet Earth? It will be quite a few centuries before terrestrial geology, oceanography and geophysics are closed, surprise-free subjects.

Consider the multitude of environments that exists here on Earth, from the summit of Everest to the depths of the Marianas Trench—from high noon in Death Valley to midnight at the South Pole. We may have equal variety on the other planets, with all that this implies for the existence of life. It is amazing how often this elementary fact is overlooked and how often a single observation or even a single extrapolation from a preliminary observation based on a provisional theory has been promptly applied to a whole world.

It is possible, of course, that the Earth has a greater variety of more complex environments than any other planet. Like a jet-age tourist "doing Europe" in a week, we may be able to wrap up Mars or Venus with a relatively small number of "landers." But I doubt it, if only for the reason that the whole history of astronomy teaches us to be cautious of any theory purporting to show that there is something special about the Earth. In their various ways, the other planets may have orders of complexity as great as ours. Even the Moon—which seemed a promising candidate for geophysical simplicity less than a decade ago—has already begun to unleash an avalanche of surprises.

The late Professor J. B. S. Haldane once remarked—and this should be called Haldane's Law—"The universe is not only stranger than we imagine, it is stranger than we *can* imagine." We will encounter the operation of this law more and more frequently as we move away from home. And as we prepare for this move, it is high time that we face up to one of the more shattering realities of the astronomical situation. For all practical purposes, we are still as geocentrically minded as if Copernicus had never been born; to all of us, the Earth is the center, if not of the Universe, at least of the Solar System.

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Well, I have news for you. There is really only one planet that matters; and that planet is not Earth but Jupiter. My esteemed colleague Isaac Asimov summed it up very well when he remarked: "The Solar System consists of Jupiter plus debris." Even spectacular Saturn doesn't count; it has less than a third of Jupiter's enormous mass—and Earth is a hundred times smaller than Saturn! Our planet is an unconsidered trifle, left over after the main building operations were completed. This is quite a blow to our pride, but there may be much worse to come, and it is wise to get ready for it. Jupiter may also be the *biological*, as well as the *physical*, center of gravity of the Solar System.

This, of course, represents a complete reversal of views within a couple of decades. Not long ago, it was customary to laugh at the naïve ideas of the early astronomers—Sir John Herschel, for example—who took it for granted that all the planets were teeming with life. This attitude is certainly overoptimistic; but it no longer seems as simple-minded as the opinion, to be found in the popular writings of the 1930s, that ours might be the only solar system and, hence, the only abode of life in the entire Galaxy.

The pendulum has, indeed, swung—perhaps for the last time; for in another few decades, we should know the truth. The discovery that Jupiter is quite warm and has precisely the type of atmosphere in which life is believed to have arisen on Earth may be the prelude to the most significant biological findings of this century. Carl Sagan and Jack Leonard put it well in their book *Planets*: "Recent work on the origin of life and the environment of Jupiter suggests that it may be more favorable to life than any other planet, not excepting the earth."

The extraordinary color changes in the Jovian atmosphere—in particular, the behavior of that Earth-sized, drifting apparition, the Great Red Spot—hint at the production of organic materials in enormous quantities. Where this happens, life may follow inevitably, given a sufficient lapse of time. To quote Isaac Asimov again: "If there are seas on Jupiter . . . think of the fishing." So that may explain the mysterious disappearances and reappearances of the Great Red Spot. It is, as Polonius agreed in a slightly different context, "very like a whale."

Contrary to popular thinking, gravity on Jupiter would not pose insurmountable difficulties. The Jovian gravity is only two and a half times Earth's—a condition to which even terrestrial animals (rats in centrifuges) have managed to adapt. The Jovian equivalent of fish, of course, couldn't care less about gravity, because it has virtually no effect in a marine environment.

Dr. James Edson, late of NASA, once remarked, "Jupiter is a problem for my grandchildren." I suspect that he may have been wildly optimistic. The zoology of a world outweighing 300 Earths could be the full-time occupation of mankind of the next 1000 years.

It also appears that Venus, with its extremely dense, furnace-hot atmosphere, may be an almost equally severe yet equally promising challenge. There now seems little doubt that the planet's average temperature is around 700 degrees Fahrenheit; but this does not, as many have prematurely assumed, rule out all possibility of life—even life of the kind that exists on Earth.

There may be little mixing of the atmosphere and, hence, little exchange of heat between the poles and the equator on a planet that revolves as slowly as Venus. At high latitudes or great altitudes—and Venusian mountains have now been detected by radar—it may be cool enough for liquid water to exist. (Even on Earth, remember, the temperature difference between the hottest and the coldest points is almost 300 degrees.) What makes this more than idle speculation is the exciting discovery, by the Russian space probe Venera IV, of oxygen in the planet's atmosphere. This extremely reactive gas combines with so many materials that it cannot occur in the free state—unless it is continuously renewed by vegetation. Free oxygen is an almost infallible indicator of life: If I may be allowed the modest cough of the minor prophet, I developed precisely this argument some years ago in a story of Venusian exploration, *Before Eden*.

On the other hand, it is also possible that we shall discover no trace of extraterrestrial life, past or present, on any of the planets. This would be a great disappointment; but even such a negative finding would give us a much sounder understanding of the conditions in which living creatures are likely to evolve; and this, in turn, would clarify our views on the distribution of life in the Universe as a whole. However, it seems much more probable that long before we can certify the Solar System as sterile, the communications engineers will have settled this ancient question—in the affirmative.

For that is what the exploration of space is really all about; and this is why many people are afraid of it, though they may give other reasons, even to themselves. It may be just as well that there are no contemporary higher civilizations in our immediate vicinity; the cultural shock of direct contact might be too great for us to survive. But by the time we have cut our teeth on the Solar System, we should be ready for such encounters. The challenge, in the Toynbeean sense of the word, should then bring forth the appropriate response.

Do not for a moment doubt that we shall one day head out for the stars—if, of course, the stars do not reach us first. I think I have read most of the arguments proving that interstellar travel is impossible. They are latter-day echoes of Professor Newcomb's paper on heavier-than-air flight. The logic and the mathematics are impeccable; the premises, wholly invalid. The more sophisticated are roughly equivalent to proving that dirigibles cannot break the sound barrier.

In the opening years of this century, the pioneers of astronautics were demonstrating that flight to the Moon and nearer planets was possible, though with great difficulty and expense, by means of chemical propellants. But even then, they were aware of the promise of nuclear energy and hoped that it would be the ultimate solution. They were right.

Today, it can likewise be shown that various conceivable, though currently quite impracticable, applications of nuclear and medical techniques could bring at least the closer stars within the range of exploration. And I would warn any skeptics who may point out the marginal nature of these techniques that, at this very moment, there are appearing simultaneously on the twin horizons of the infinitely large and the infinitely small, unmistakable signs of a breakthrough into a new order of creation. To quote some remarks made recently in my adopted country, Ceylon, by a Nobel laureate in physics, Professor C. F. Powell: "It seems to me that the evidence from astronomy and particle physics that I have described makes it possible that we are on the threshold of great and far-reaching discoveries. I have spoken of processes that, mass for mass, would be at least a thousand times more productive of energy than nuclear energy. . . . It seems that there are prodigious sources of energy in the interior regions of some galaxies, and possibly in the 'quasars,' far greater than those produced by the carbon cycle occurring in the stars . . . and we may one day learn how to employ them." And, if Professor Powell's surmise is correct, others may already have learned, on worlds older than ours. So it would be foolish, indeed, to assert that the stars must be forever beyond our reach.

More than half a century ago, the great Russian pioneer Tsiolkovsky wrote these moving and prophetic words: "The Earth is the cradle of the mind—but you cannot live in the cradle forever." Now, as we enter the second decade of the age of space, we can look still further into the future.

The Earth is, indeed, our cradle, which we are about to leave. And the Solar System will be our kindergarten.