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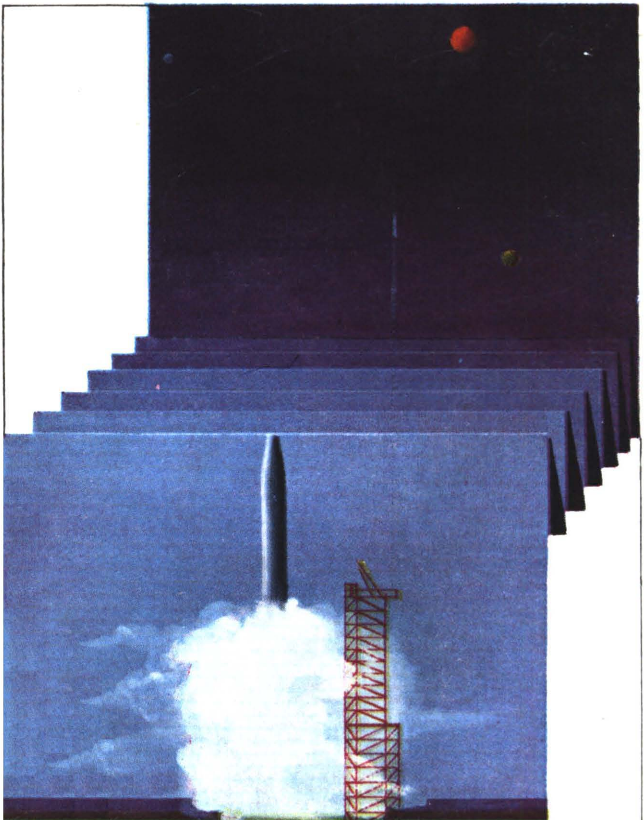
Mariner IV to Mars



THE FULL, FASCINATING STORY BEHIND THE JULY, 1965, AMERICAN SPACE FLIGHT THAT REVOLUTIONIZED SCIENCE'S TRADITIONAL CONCEPT OF MARS—INCLUDING THE FIRST CLOSE-UP PHOTOGRAPHS EVER MADE OF THE FAR-OFF PLANET.

Willy Ley

"MARINER TAKES FIRST MARS CLOSE-UPS TODAY"

"CRATER-FACED MARS A SHOCK TO SCIENTISTS"

"MARTIAN 'CANALS'—WILL MARINER BLAST THE THEORY?"

On July 14, 1965, Mariner IV, passing only a few thousand miles from the surface of the red planet, began to take the most revolutionary photos ever seen on earth. Headlines screamed the news as scientists evaluated the astonishing evidence. The proof sent by Mariner IV showed Mars to be a crater-faced, moonlike planet with a nearly nonexistent magnetic field and a thin atmosphere bombarded by solar radiation. Age-old scientific theory and romantic fantasy about Martian life seemed to be disproved.

In this engrossing book Willy Ley reexamines the evidence of Mariner's 22 photos. He begins with the historical background: the canals of Schiaparelli, the two moons of Jonathan Swift, and he covers Martian theory from Copernicus to H. G. Wells. Next he describes the flight of Mariner IV: the ship's construction, its instruments, its mission. With an hour-by-hour log of the last stages of Mariner's journey, Willy Ley tells how the spacecraft succeeded in taking its historic measurements and photos . . . and why Mariner's findings are a landmark in man's voyage to other worlds.

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MARINER IV TO MARS

Willy Ley

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MARINER IV TO MARS

FOREWORD

On July 14, 1965, when it was evening along the east coast of the United States, a device of unusual shape—half dragonfly, half windmill—passed near the planet Mars. Its designation was *Mariner IV,* and only 230 days earlier it had still been earthbound at Cape Kennedy.

Mariner IV, being trailed by a similar Russian device, was the first close contact with the most talked-about planet of our solar system. By the time the Russian device was approaching the planet it was already known that it would not work; sometime after takeoff its electrical power supply had failed for unknown reasons. As for Mariner IV, it was known that its power supply was working and a number of devices had functioned all through the trip. But the main question was undecided: would its cameras work and take pictures of the Martian surface that would be more than a thousand times as detailed as the very best pictures we could take from earth?

The cameras did perform, and so did the transmitter. The pictures were not only an important scientific advance, they were also a major scientific surprise. Just what they showed and why they were so surprising is told in this book.

October, 1965 WILLY LEY

Prologue

About a century and a half ago, Johann Wolfgang von Goethe, the great German poet, wrote two lines of doggerel which would look like this in English:

> Can't think of an invention more with promise brimming,
> Than candles that would burn without that constant trimming . . .

The complaint dealt with a peculiarity of the candles of the time of Napoleon—and of Goethe. The wicks of these candles were inefficient; they would stick out of the burning candle at great length, making the light reddish and flickering and sending plumes of black smoke to the elaborately draped ceilings. Whenever a wick did that one had to reach for the brass candle-scissors, specifically made for the purpose, and cut off the extra length of wick, usually cutting off too much so that the flame grew small and feeble for a while. Goethe's indignation tends to show that this usually happened at the very moment when the book one was reading was difficult to follow, or when one had reached a knotty part of one's own writing. No doubt Goethe would be very pleased with desk lamps that pour forth the light of sixty candles after flicking a switch—without smoke, without odor, and without constant adjustment.

But all progress demands payment of some kind. The city dweller of today who takes his indoor illumination for granted does the same with outdoor illumination, and if he finds one spot on his street where it is too dark to read his watch he is likely to complain. But because of this splendid illumination indoors and outdoors, the city dweller has lost his knowledge of the sky. A hundred and fifty years ago, a man who left his house after dark, provided the night was clear, could see all the brighter stars in the night sky without difficulty. And on moonless nights the Milky Way would run from horizon to horizon in mysterious splendor. No light on the ground interfered; at most, as Alexander von Humboldt mentioned once, one had to tell the servant who carried the lantern to fall behind by twenty paces. Humboldt wanted to look at the constellations he knew so well, and he wanted to remember the zodiacal light, which he could not see from Paris but which he had seen so often on board ships sailing the tropical seas.

In short, while our astronomers of today, who have had to take refuge on mountaintops to escape the bright city lights, know at least a hundred times as much about the universe around us as did the erudite and well-traveled Alexander von Humboldt, the average man of today has lost the knowledge of the sky that was commonplace to his grandfather's grandfather. Christian Feargod Breakstone, Vermont farmer of 1820, would not only have been familiar with the appearance of the Milky Way and all the more conspicuous constellations; he would also have known that every second year there was a prominent red star in the sky. It stayed brilliant for a number of weeks and then faded slowly, to reappear two years later. Farmer Breakstone would probably have known, too, that this red star was called Mars. If he was reasonably well-read and a little superstitious, he would have been convinced that the appearance of Mars in the sky meant war.

Mars has had this reputation since classical times, its reddish color suggesting conflagrations and blood. The oldest civilization that left records, the Babylonians, called Mars

Nerval and considered him the judge of the dead. Plato in classical Greece called it *pyróeis* (the fiery one), the ordinary Greek name was Ares (from *áro*, to kill), while the Romans used the name Mars, which is now internationally used. Needless to say, Mars was the Roman god of war; the sign for Mars (♂) is a combination of shield and spear.

By the end of the Middle Ages the astrological properties of the red planet were well organized:

> "Mars rules catastrophes and war, it is master of the daylight hours of Tuesday and the hours of darkness on Friday, its element is the fire, its metal is iron, its gems jasper and hematite, and it rules the color red. Its qualities are warm and dry, it rules the color red, the liver, the blood vessels, the kidneys and the gallbladder as well as the left ear. Being of choleric temper it especially rules males between the ages of 42 and 57."

These statements are taken from an unpublished manuscript of the fifteenth century, a so-called *Centriloquium*. The manuscript is in German, but most of it seems to be a translation from an older Latin manuscript. But the poem that follows this condensation of astrological rules is indubitably in the German of the period, and, equally indubitably, the "poet" was no poet—he merely made the lines rhyme. Imitating his style, the first twelve lines come out as follows:

Third planet am I, named Mars,
Fiercest and angriest of all the stars.
By Nature I am hot and dry,
Choleric my temper, though people sigh.
Of the twelve Signs not all are friendly
But Aries and Scorpio attend me,
While in their realms my fearful rays
Cause murders, wars and death all days.
My highest seat is Capricorn,
In Cancer of my might I'm shorn.
Through all twelve Signs I abound
And in two years sweep clear around.

By the time of Goethe and Humboldt in Germany, of the Chevalier de Lamarck and the Comte de Buffon in France, and of Sir William Herschel in England, astrological ideas had been dropped by learned men. They had come to realize that philosophical concepts rarely agreed with reality and that Nature and natural laws cannot be unraveled by mere speculation. They tried to replace speculation by observation, by calculation, and, wherever possible, by experimentation. But what astronomers had to say about the planet Mars in, say, 1820, was rather meager.

Mars, they knew, was the first planet in the solar system that had an orbit larger than the orbit of the earth. The diameter of the planet was roughly half the earth's diameter, and its day was about half an hour longer than the day of earth. It had no moons. Its surface showed darker areas in a light yellowish-reddish expanse that suggested desert. If one, as was logical, took the dark areas to be seas and the light areas to be land, one had the interesting result that the proportion of water to land was reversed on Mars. On earth the oceans cover just about three quarters of the surface while the remaining quarter is land. On Mars the dark areas, the presumed seas, covered only one quarter of the surface. Still, the distribution of the seas over the surface of the planet seemed to be such that an English astronomer, around the year 1860, wrote: "there is no portion of the planet Mars that cannot be reached by ship." [1]

It is interesting that one of the most important discoveries about Mars, namely the fact that its orbit is an ellipse, was based on measurements carried out by the Danish nobleman Tycho Brahe prior to the invention of the telescope. (See Chapter 2.) But even the sharpest eye could not distinguish any detail about the planet; hence the story of discoveries begins with the invention of the telescope.

Galileo Galilei, the first man to use the newly invented telescope for a systematic search of the starry sky, used it on Mars for a specific reason. If Copernicus was right and the planets moved around the sun instead of around the earth, and if the earth was only a planet among planets, several things should show in the telescope. Mercury and Venus, the two planets inside the earth's orbit, should show phases like the moon. There was no doubt that Venus did, and while his small telescope left the question open for Mercury,

[1] By now, if he were still alive, he could justify his statement by saying that he had, of course, meant a spaceship.

Galileo Galilei did not doubt that its phases would be seen in a better instrument. Mars, on the other hand, would never assume the sickle shape, since its orbit was larger than that of the earth and we would, therefore, always see its illuminated hemisphere. But in certain positions along its orbit the planet should look slightly gibbous. Galileo looked for this gibbous phase, but his instrument was too weak to show it.

We know that he looked because in a letter to an acquaintance—written in December, 1610—he explained why Mars should have a gibbous appearance from time to time and complained that he had not been able to see it.

Francesco Fontana did succeed in seeing the gibbous phase in the evening, in August, 1638. His drawing (see Figure 1) of the gibbous phase is exaggerated and betrays

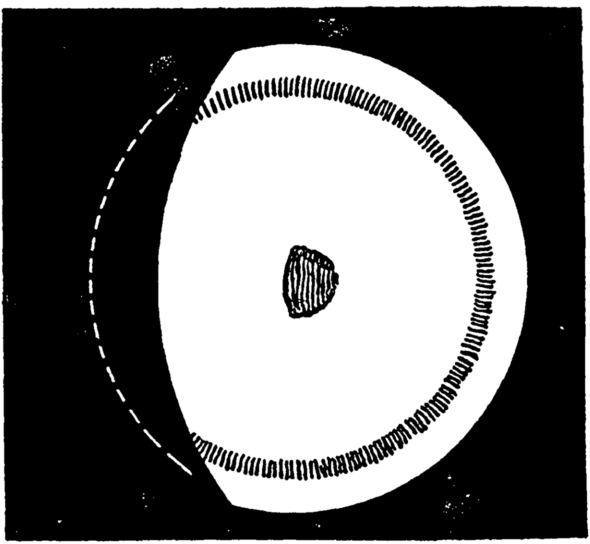


Fig. 1. Drawing of Mars, made by Francesco Fontana in 1638. The drawing shows Mars in its gibbous phase, but Fontana exaggerated; the broken white line indicates where the edge of the disk should be.

two facts: namely, that Fontana could not draw well and that his telescope had a flaw—it always put a dark spot in the middle of everything.

The first man to recognize surface features on Mars was the Dutchman Christiaan Huygens, who observed Mars repeatedly during the period from 1659 to 1683. He had an improved telescope, which he himself had conceived and designed, and he drew a triangular dark marking, almost certainly the one now labeled *Syrtis major,* on several of his sketches. A drawing he made in the evening hours of August 13, 1672, also shows the southern polar cap of Mars; it is the first drawing on which this conspicuous feature appears. But Huygens had not been primarily after the surface features; they were incidental to his real quest: namely, to find out whether Mars rotated on its axis. Mars did, and Huygens concluded that the length of the Martian day must be close "to 24 terrestrial hours."

Huygens came to this conclusion in 1659, and in 1666, Giovanni Domenico Cassini, professor of astronomy at the University of Bologna, decided to find out for himself. He found that Mars looked the same every evening, but that a precise agreement with the appearance of the previous night came about 40 minutes later. He concluded from this fact that the day of Mars must have a length of about 24 hours and 40 minutes.

Half a dozen years later, in 1672, Cassini's nephew, Giacomo Filippo Maraldi, began observing Mars, proving himself both a diligent and persistent observer. In 1704 he was convinced that Mars made a complete rotation in slightly less than 24 hours and 40 minutes, and he also noted down that Mars did not look precisely the same every time it could be seen. Both the white spots over the poles and the dark areas seemed to be of different sizes and shapes. But that is all he could contribute while his uncle was still alive. In 1719, seven years after Cassini's death, he told that he had seen changes occur on Mars while it was under observation—his statements sound as if he had seen what we now know to be a dust storm. He had also ascertained that the white spots over the poles were off center, meaning that the center of the white spot did not coincide with the Martian pole. (See Figure 2.) That the ice caps of our own poles are

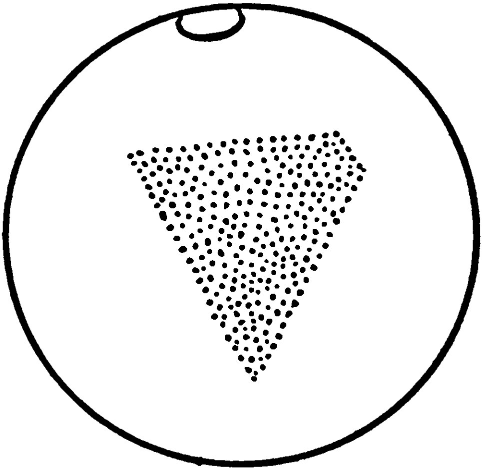


Fig. 2. Mars in 1719. Drawing made by Giacomo Filippo Maraldi. This simple drawing shows two important Martian features: the southern ice cap and the triangular dark marking now called *Syrtis major.*

also eccentric was, of course, unknown then. The area around the North Pole had not yet been investigated, and Antarctica was actually seen for the first time precisely a century later.

The next important observer to pay attention to Mars was a Hanoverian: Sir William Herschel. Whenever Herschel started to investigate something, he went as far as conditions and the available instrumentation permitted. And after he had gathered his results, he would compose a terse scientific report which differed remarkably from the loquacious reports of his contemporaries. He always saw to it that the title of his report was such that nobody could expect anything but what he would find, even if that title was a bit long. The title of the report on his observations of Mars, published in 1784 in the *Philosophical Transactions*, read: *On the remarkable appearances of the polar regions of the plan-*

et Mars, the inclination of its axis, the position of its poles, and its spheroidal figure; with a few hints relating to its real diameter and atmosphere.

Herschel determined the length of the Martian day to be 24 hours, 39 minutes, and 21.67 seconds (about 14 seconds too short); he found that the axis of Mars was inclined to the ecliptic by 59 degrees 42 minutes (about 3 degrees off); he confirmed that the polar caps were eccentric to the poles, and, while he was convinced that the caps consisted of snow and ice, he also said that they could not be very thick, for they melted away completely during the Martian summer. He noted the presence of an atmosphere and was the first astronomer to report on color changes on Mars while it was under observation.

Herschel's paper might well be called the sum total of the knowledge of Mars a hundred and fifty years ago.

There followed three quarters of a century of very slow progress, and, strange as that may seem, it may have been due to Herschel. Herschel had already gone ahead and made a great number of discoveries concerning the fixed stars. He had established that there actually were "double-stars" (now known as binaries); he had made long lists of the then mysterious and therefore intriguing nebulosities; and he had worked on the problem of where our sun is located in the Milky Way. He had tried to measure the distances between our sun and other stars but was unsuccessful in that quest; however, Bessel in Germany, Struve in Russia, and the Scotsman Henderson, temporarily in South Africa, had followed Herschel's lead and been successful. Since everybody wanted to see for himself what Herschel had seen, the planets were neglected for a while in favor of the fixed stars.

One good and careful observer, Dr. Johann Hieronymus Schroeter, in Lilienthal near Bremen—using a telescope made by Herschel—made a long series of observations of Mars extending over the years from 1785 to 1802. But owing to political complications caused by the Napoleonic Wars, Schroeter's manuscript was not printed immediately; the University of Leyden finally did publish it. But that was in 1881, nearly 80 years after the work had been completed, and publication was more of a posthumous honor for Schroeter then a contribution to science. While Schroeter's manuscript was forgotten, two men in Berlin, the banker Wilhelm

Beer—incidentally, a brother of the composer Giacomo Meyerbeer—and the astronomer Johann Heinrich von Mädler, tried to draw the first map of Mars. The two men, working in close collaboration for many years, had produced a very fine map of the moon, but their map of Mars deserves mention mainly for the reason that it was the first. It bears no resemblance to any later map of Mars. A number of years ago I had a photostatic copy made of this map and had it brought to the same size as later maps. I looked at it in the normal position, and upside down, and even sideways, trying to identify at least some of the features. But it was hopeless. If one specific feature looked like an out-of-focus approximation of a feature on a later map and identity seemed possible, all the other features did not agree at all.

Still, their sketches of detail must have been good, because J. H. von Mädler, by comparing the sketches made in 1832 with those made in 1830, calculated the length of the Martian day to be 24 hours, 37 minutes, and 23.7 seconds, only about one second too long.[2] Thirty years later, Frederick Kaiser of Leyden made a correction of 1.1 second, coming within less than one second of the true value.

Interest in Mars picked up a little during the years from 1858 to 1864 because there were a number of good "oppositions."[3] In Rome, the papal astronomer, Father Angelo Secchi, S.J., made the first color sketches of Mars, in yellow and green pastels. And the Reverend William Rutter Dawes in England—nicknamed "eagle eye" by his contemporaries —made a few sketches of Martian surface features which have rarely been surpassed. This short period of interest in Mars was climaxed, in 1867, by the publication of a map of Mars by the English astronomer Richard Anthony Proctor. Leaning very heavily on the Beer-Mädler map, Proctor named the Martian features—and was promptly criticized

[2] This is for the sidereal day of Mars, not for the solar day which Herschel had calculated. The solar day is the time that goes by from the moment the sun is in the zenith until the same moment on the following day. The sidereal day is the time that goes by between the two successive times when a given star is in the zenith. The reason why the solar day is longer—about two minutes in the case of Mars—is that the planet has moved along its orbit during that day so that the position of the sun in the heavens has shifted a little. For the currently accepted figures, see Appendix.

[3] For an explanation of this term, see Chapter 2.

for having given the names of English astronomers to the most prominent features, and especially for having a Dawes Ocean, a Dawes Continent, a Dawes Sea, and a Dawes Forked Bay!

Of course, by that time astronomers knew everything about the orbit of Mars and could predict that the year 1877 would be especially good for observations of Mars. The year 1879 would be good too, but 1877 was *the* year. As the time approached, several astronomers regulated their schedules in such a way that they could devote all their observing time to Mars; they would not be handicapped by anything else except the possibility of bad weather. Among those who were ready and waiting was a young Italian by the name of Giovanni Virginio Schiaparelli and a somewhat older American by the name of Asaph Hall.

The year 1877 came and went; the best month of the year for observation was August. Of course there was a little delay caused by the time it took to write up the results of the discoveries made and to have them printed. But when that was done, Mars was all of a sudden the most talked-about planet in the solar system.

To begin with, it was no longer "moonless." Asaph Hall had discovered that it had two very small moons. What made this discovery exciting to some people was that these two small moons had been "predicted." To this day, mystics cite this prediction as "proof" that the human mind has unknown powers—or else that extraterrestrials had been in touch with certain people in the past. That story will be told in Chapter 3.

But while Asaph Hall's discovery was exciting to some people, the report from Italy by Schiaparelli was exciting to *all* people. Schiaparelli, favored by a fine telescope, a clear Italian sky, and, most importantly, by the proximity of Mars, had made sketches far more detailed than anything ever seen before. He had seen a number of fairly straight darkish lines. Contrary to common belief, he was not the first to see such lines. The Reverend William Dawes had seen and drawn a few, Father Secchi had at least one on his color sketches of Mars, and Proctor's map also showed several. But Schiaparelli had seen more, and he used an intriguing designation. He called them *canali.*

Now the Italian word *canali* (which is the plural), has two meanings. It means grooves such as the grooves carpenters make in wooden boards for fitting furniture together. It also means canals of the type that connect a lake with the sea. When applied to natural features it means "channels," like the English Channel. Schiaparelli had used the word in this last sense, but to everybody else, whether he spoke English, French, German, or Russian, *canali* were "canals," man-made, indicating commercial needs and a certain amount of technology—a large amount of technology, judging from the length of the "canals" on Mars.

Mars, which up to 1877 had been a planet among others, distinguished mainly by its color, all of a sudden was *the* planet, the only one worth bothering about. Because it was an *inhabited* planet, as evidenced by the Martian technology, which anybody (or so the layman thought) could see just by looking through a telescope when Mars was near. And if we could only find a way of getting in touch with the inhabitants of Mars, we would probably learn something from them.

1. *The History of the Martians*

A friend of mine who gives "astronomer" as his occupation on Form 1040 saw to it for many years that he was simply introduced as Dr. So-and-so at private parties, hoping that the people he met would assume that he was a physician. He did not want his real profession to be known, because, as he said, "If people are told that I am an astronomer, they'll ask two questions. The first one is why astronomers do not believe in astrology, and the second is whether there are people on Mars. The answer to the first question is a one-hour lecture which I don't deliver unless I get paid for it. And the answer to the second question is that I don't know, and then people would ask 'why don't you?' and the answer to that would be another lecture."

The fact is that no astronomer, from about the year 1880 to the time of World War II, ever escaped the question of whether there are people on Mars. Depending upon the year the question was asked—and also, of course, on the astronomer's personal inclination—the answer to that question was a variable. From 1880 to the time of World War I, most astronomers would have said that at least some of their colleagues were convinced that Mars was inhabited by a highly intelligent and politically united race. Between 1914 and

1935, the answer would have been that the existence of intelligent Martians was in doubt, though one could not be certain.

Since then we have grown more doubtful still. At this moment it is important to point out that the idea of inhabitants of the planet Mars did *not* begin with the announcement of the *canali* by Schiaparelli.

The thought that Mars must be inhabited came into existence just as soon as the telescope had shown that Mars was actually a solid world and not just a light in the sky. Late in the seventeenth century, the Dutchman Christiaan Huygens talked about the inhabitants of other planets as a matter of course, and he even wrote a book in which he speculated on the organization of the bodies of the people of other planets. Nor did Huygens consider this attitude in any way unusual. He was a Christian not only by given name but also in his way of thinking, and there were many passages in the Bible that could be interpreted to mean that the earth had been created for the benefit of man. Now if one planet, the earth, had been created for the benefit of its inhabitants, it was only logical to assume that the other planets had been created for the benefit of *their* inhabitants. This, in turn, meant that they *did* have inhabitants.

Huygens, naturally, had read the classics, and he had found the same thought in the *Natural History* of Pliny the Elder, who was not a Christian and who had not read the Bible, since it had not yet been put together in his time. But Gaius Plinius Secundus, to use his full name, was also convinced that everything had been created to be of use to mankind; if it did not have a direct use, it at least taught a philosophical lesson of some kind. Even from a non-Christian point of view, therefore, it was logical to assume that the other planets had inhabitants. To avoid misunderstandings, I have to add that Pliny himself did not draw this conclusion; in his time, stars and planets were considered to be just lights in the sky—maybe the seats of gods and goddesses.

Practically everybody during the seventeenth and eighteenth centuries agreed with Huygens. The great philosopher Immanuel Kant, writing by flickering candlelight like Goethe, thought that "those planets that are not inhabited now, will be at some time in the future." And in his *General Natural History and Theory of the Heavens* (1755), he wrote: "In fact, the two planets earth and Mars are the middle links of the planetary system, and it may be suspected with fair probability of their inhabitants that they stand in the center between the extremes as regards physiology as well as regards morals." And in 1784, the great astronomical observer Sir William Herschel stated that Mars has an atmosphere "so its inhabitants probably enjoy conditions analogous to ours in several respects." Forty years or so later, the great mathematician Carl Friedrich Gauss suggested that we might send a signal to the Martians so that they would become aware of our existence and surmise that we suspected their existence.

Gauss even went into some detail. The signal should be such that it could not be an accidental event of nature, and it should be clearly understandable at the same time. Since the laws of mathematics must be the same anywhere in the universe, Gauss suggested a mathematical symbol, a right-angled triangle with squares over all three sides, the figure usually called "the Pythagoras." The Siberian tundra

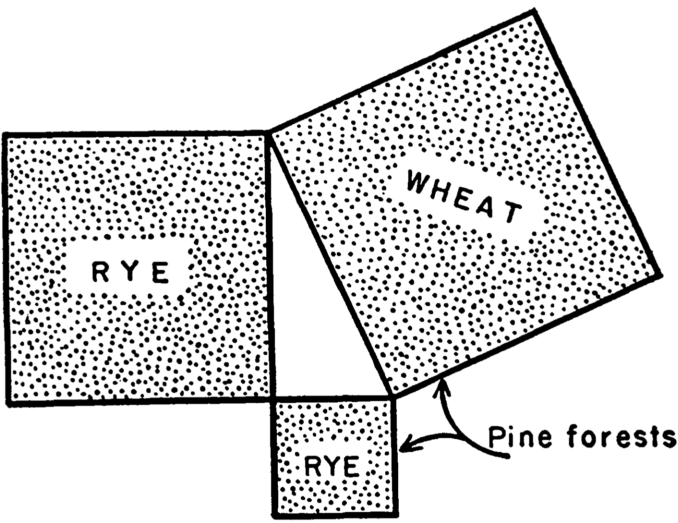


Fig. 3. The geometrical figure Carl Friedrich Gauss suggested we construct in the Siberian tundra as a signboard to the Martians.

seemed large enough; the lines of the figure would consist of dark pine trees and the interior of the squares, for contrast, might be seeded with wheat or another light-colored grass. (See Figure 3.) Since Mars is farther from the sun than we are, Gauss added, the Martians would be able to answer without too much effort: all they would have to do would be to arrange large geometrical figures with shiny sheet metal that would reflect the sun.

As science, and especially experimental science, began to hit its stride during the nineteenth century, every new discovery seemed to confirm older speculations, sometimes adding refinements. About the time Gauss thought of using the tundra as a colossal blackboard, the chemist Friedrich Wöhler made a so-called "organic" substance out of "inorganic" substances, proving that living matter did not differ fundamentally from "dead" matter. This discovery opened the way for a renewal of older speculations, namely that life *might* have sprung from a combination of nonliving matter. Later in the nineteenth century Gustav Adolf Kirchhoff and Robert Wilhelm Bunsen developed spectrum analysis, proving that the same chemical elements that we have on earth could be found in the sun and elsewhere in the universe.

So if some sections of Mars looked like desert sand in the telescope, one could in all honesty declare that they were sandy deserts like the Sahara. And if some areas looked reddish, one could say that the soil was colored red by the presence of iron oxides—just like here. True, Mars is smaller than the earth, so its surface gravity would be weaker. Mars is farther from the sun; the temperatures, therefore, would be lower. Mars evidently has less water than the earth; hence the deserts would be larger than ours. But it seemed to be a world where a man could live, even though probably with discomfort. However, the Martians would not be uncomfortable. They had grown up there—more, they had evolved there. "Over there, like here," a naturalist wrote, "natural origin of life sometime in the dim past, followed by evolution, with plants that absorbed carbon dioxide and produced oxygen, with animals that breathed oxygen and exhaled carbon dioxide; first water animals, then land animals, first with small brains then with gradually larger brains and finally the super-animal. . . ."

Thus thinking people who were reasonably conversant with the scientific accomplishments of their day were ready not only for the news that Mars, scientifically speaking, *could* be inhabited or that it, philosophically speaking, *should* be inhabited but for an announcement that said that it *was.* Schiaparelli's *canali* seemed to be that announcement.

Anybody who doubted this or that part, or all, of the whole story was evidently a reactionary, a backward and stubborn uncultured person, not worth listening to, a boor as well as a bore, somebody who would certainly fall behind and would probably be ground into dust under the wheels of the chariot of progress. Instead of wasting time on such people, it was much more amusing to speculate about the Martians, now "known" to exist. Maybe their lot was not easy, but that was a dangerous statement; the lot of an Eskimo is not easy either, but the Eskimos do not seem to be aware of that fact.

If you want to speculate you can go about it in two ways. You can write an essay in which all the possible alternatives have to be weighed and explained all the time, risking the gloom of dullness. Or else you can take one set of assumptions and describe what might be possible—not necessarily in the form of fiction, though this was the form chosen by practically all the writers. In that case, even if everything turns out to have been wrong at a later date, you at least provide entertainment. The people who had heard about the *canali* were quite willing to be entertained, and many writers were willing to oblige. A special kind of fiction, fiction dealing with the planet Mars and its inhabitants, came into being.

The first novel specifically devoted to the planet Mars was written by a British author by the name of Percy Gregg and published in 1880. The title was *Across the Zodiac.*[1] It was a story within a story: the author told that he, while in New York, had met a flag officer of the U. S. Navy who had had an interesting experience. While his ship was anchored off a coral island in the southern Pacific for some minor repair, a large and flaming meteor had fallen on the island, some pieces of it causing an enormous wave which destroyed his

[1] Taken literally, the title is nonsense, of course. One does not cross the zodiac on a voyage to Mars or to anywhere else, for the simple reason that the zodiac is made up of fixed stars at greatly varying distances from our solar system.

ship. He succeeded in reaching the shore and investigated the devastation as soon as there was daylight. He found a large impact crater and many pieces of a metal he did not know. Somewhere in the debris there was a very heavy metal box, relatively undamaged. He succeeded in opening it and found a manuscript inside. It was, or seemed to be, in an unknown language; in any event, he could not even read the letters. But browsing through it he had the feeling that the language might be Latin, and he reasoned that somebody who wants to send a manuscript to earth not knowing where it would land would write in Latin, since there are some people in every country who can read that language. Going under this assumption, the strange alphabet is deciphered quickly.

The writer of the manuscript tells that he, in the course of physical experiments, had come to realize that there must be two forms of gravity: the normal kind that pulls toward the center of a planet and an opposing kind that pushes things away. The latter he called "apergy," and he had succeeded, after many difficulties, to isolate apergy. Once he had apergy, the building of a spaceship was not an especially difficult engineering problem. Having built and tested it, he set out on a voyage to Mars, where he landed and soon made the acquaintance of the Martians, people like earth people but of somewhat smaller stature, the women being five feet tall on the average, the men rarely exceeding five feet five inches. His captors think that he is one of them, from a distant part of their own planet, because they cannot believe that a man could traverse space. Their ruling philosophy not only proclaims that the worlds are isolated from each other; it also holds that no other planet is inhabited.

While the earthman never convinces the Martians about the truth of his story, he is treated kindly as a stranger, presented with a house and a harem, and taken on sightseeing tours. All manual labor is performed by machines and by semi-intelligent animals bred and trained for the purpose; there is no servant class and no working class. Mars is divided into a number of areas, each one ruled by a governor, and the governors are, in turn, ruled by an autocrat. The official philosophy is atheistic, does not permit philosophical debate (but encourages research leading to inventions), and sees to it that no child ever learns the identity of its parents. Women have rights only insofar as they are derived from the status of their husbands, but they also have few duties, the foremost one being to enhance their natural beauty by all available means.

Though the manuscript is ostensibly written by an engineer, little is said about Martian technology and engineering—one assumes that Percy Gregg was not an engineer himself. But there is much talk about political intrigue, because there is a secret society that is both religious and progressive. Finally there is a revolution. During the short battle the earthman's favorite woman is killed, and he decides to return home. Whether the catastrophic landing is the landing of this return voyage or whether there was another voyage between the Mars trip and the final catastrophe is carefully left open; evidently Gregg had another story in mind.

The next major novel about the planet Mars was published in October, 1897. Its author was Kurd Lasswitz, who was professor of mathematics at Gotha and already well known in scientific circles as the author of several books on the history of some scientific ideas. When his Mars novel became an almost immediate literary success, Lasswitz checked through his daybooks and was able to tell reporters that he had started writing it early in November, 1895, and finished it on April 11, 1897. A decade later it had been translated into Swedish, Norwegian, Danish, Dutch, Spanish, Italian, Czech, Polish, and Hungarian—but no English translation was ever published.

At the time when Lasswitz started on his novel, the prototype of such stories had been firmly established by Jules Verne (who, incidentally, never wrote anything about Mars). But literary critics were reluctant to accept Jules Verne's books as "novels" because they were straight stories of adventure without any romance entering the picture. (Hollywood is still complaining about this.) In Lasswitz' story, a romance plays a decisive role; hence, critics acclaimed it as a novel. It also was Literature with a capital L. Its title was *Auf zwei Planeten (On Two Planets).*

Before going into the story itself, it might be useful to survey just how far the major inventions had progressed at the time it was written. The airplane was still to be invented, but seven different types of airships had been tested. (Strangely enough, every one of these early airship inventors was either French or German; no other nation contributed.)

The airships sometimes met with fair success, sometimes with disastrous results. Both telegraph and telephone existed, and the first "horseless carriages" were in the experimental stage. Wilhelm Konrad Roentgen had discovered the X ray two years before. Electric illumination existed, both in the form of the light bulb invented by Thomas Alva Edison in 1879, and in the form of the somewhat older arc light. Edison (in 1889) had also been one of the inventors of the motion picture but had lost interest in it. Heinrich Hertz had found what we now call radio waves about a dozen years earlier. Professor Augustin Bernard Mouchot in France and John Ericsson (the designer of the *Monitor*) in the United States had worked on the problem of converting sunlight into usable energy by way of reflectors, boilers, and steam engines. Chemists had started making synthetic dyes and synthetic food flavorings. Lasswitz knew about all these developments; at that time an intelligent man could keep up with scientific discoveries and technological applications by reading eight or ten scientific journals a month. And each one of these developments, so new on earth, was pictured in Lasswitz' book as having reached undreamed-of peaks and incredible refinement on Mars.

The fundamental reasoning behind the story was as logical as it was simple: if one accepted the *canali* as the result of engineering and planning, the Martians had to be superior to us in a number of respects, presumably because their culture was older. The planet-wide construction activities indicated planet-wide cooperation; presumably the whole planet was a political unit. Assuming that space travel was possible, logically the Martians would develop it ahead of us; consequently, it would be the Martians who came to earth instead of earthmen going to Mars.

A Swedish explorer, Salomon August Andrée, had just tried, at the time Lasswitz began his novel, to reach the North Pole by balloon, and Lasswitz began his novel with a similar try. Three scientists—Hugo Torm, a balloon expert, Karl Grunthe, a mathematician and astronomer, and Josef Saltner, a naturalist—are the members of the expedition, which has been paid for by a wealthy amateur astronomer, one Dr. Ell. As the balloon approaches the Pole, the three see a small open sea with some irregular islands and one regularly shaped island, perfectly circular, located at the presumed position of the Pole. As they come still closer, there can be no doubt that the island is artificial and, at least in part, built of metal. At the same time their balloon begins to deviate from the straight-line course it has been following. It drifts in a spiral path around the island, rising at the same time. Within a few minutes the balloon has climbed to an altitude of five miles, in spite of the frantic attempts of the three aeronauts to vent gas and lose altitude by reducing the balloon's carrying capacity. Some inexplicable force then drives the gondola upward faster than the balloon, which then enfolds the gondola. The three aeronauts lose consciousness. When Saltner and Grunthe come to, they find themselves on the artificial polar island in the custody of Martians. The third man, Torm, is missing.

The recovery of the two men does not take long, but their linguistic difficulties are great. However, two Eskimos, father and son, are living on the artificial island. When the Martians travel to this island, the Eskimos help them with physical work—the Martians, used to the gravity of their own planet which is only 35 percent of that of earth, are nearly helpless in the open. The daughter of one of the Martian engineers has learned a number of words of the Eskimos' language. The astronomer Grunthe has also learned a few Eskimo phrases as part of his preparation for the expedition to the Pole. But Eskimo is not a language in which a German astronomer and a Martian astronaut can exchange ideas, even if both are capable of speaking it fluently. Meanwhile the gondola of the balloon has been salvaged, and at the bottom of one basket they find a small notebook containing, in sequence, German words, their Martian equivalents in Latin characters, and then the same Martian word in Martian script. Grunthe recognizes the handwriting—it is Dr. Ell's—and both earthmen and Martians puzzle about the fact. But in the meantime they make good use of it, and after a few weeks they can converse freely. The earthmen then find out, among other things, why they had the accident that nearly killed them.

The Martians had invented space travel a little more than a century earlier. They were aided by the fact that they had a substance that is weightless itself and will make other substances weightless too, by "shielding" them when surrounding them. Moreover, they found that they could vary the degree of weightlessness (Lasswitz hints that electric currents will do that). Grunthe remembers that he had talked about the possibility of space travel with Dr. Ell once, and Ell had made the strange remark that a landing on another planet should always be at its poles, "for one does not jump on a train where it is in motion, but where it stands still." The Martians had, some time ago, made a few landings on earth—at the poles—but they learned that their wonderful "diabaric substance" was not ideal. By making their globular spaceships weigh just as much as the volume of air they displaced, they had, in effect, balloons. But the material weakened when it was heated too much, and it was corroded by moisture. That there might be enough moisture in an atmosphere to ruin a substance that was perfect in space was something that had never occurred to the Martian engineers.

While one group of researchers busied itself with modifications of the original substance so that it could withstand fairly high temperatures and not be attacked by moisture, another group worked out a method for circumventing the whole problem. This method consisted in having a space station above the pole, one earth-diameter from the center of the earth. This space station was held in place by electrical forces generated on the artificial island directly below. The globular spaceships landed on this station; contact with the earth below was made by a shuttle ship, which rose and fell by letting gravity act on it or else by reversing the gravitational field, as was required. At the moment the balloon was approaching the artificial island, the gravitational field had been reversed because the shuttle was on its way back to the space station. The reversed field had naturally caused a sharply rising air current which, in turn, had produced a vortex drawing flying things into it.

The earthmen soon learn the principles of space travel. The point here is that Lasswitz, who, after all, was a mathematician himself, developed a perfectly valid theory of space travel. It only lacked a substance that could be made weightless.

A Martian ship departing for Mars from the space station would make itself completely weightless at a moment calculated beforehand. Then the ship would be free of the gravitational pull of the earth as well as the gravitational pull of the sun. Of course it would still move with a velocity of 18½ miles per second, the velocity of the earth in its orbit; but it would move in a straight line, a line tangential to the orbit of earth. Even if its captain did nothing at all, the ship would reach the distance of the orbit of Mars. If the planet should be near the place where the ship reaches the orbit, the captain would simply make his ship "heavy" so that the planet Mars would pull it in. But this would make for a slow trip, and it would also limit trips to specific times, namely when the two planets have the relative positions necessary for such operation. The Martians therefore invented a method of steering, using the principle of reaction—that is, the rocket principle. But at first their method used solid chunks of matter weighing two hundred pounds which were ejected with varying velocities according to need. It was a dangerous way of traveling, and only shortly before Saltner and Grunthe reached the space station did a Martian scientist succeed in spreading the thrust out over a duration of minutes. Space travel was still a difficult job for them, but it was made safe.

While learning all this, Saltner grows more and more enthusiastic; he is an idealistic optimist. Besides, he has fallen in love with La, the girl who taught him his first Martian words. Grunthe, on the other hand, grows more and more worried. These shots that steered the spaceships—one of them, discharged at full power, could destroy a large city. True, the Martians are not only superior but adhere strictly to ethical principles and state that they are of good will. But Grunthe remembers what happened to native populations when they were visited by men with Christian principles and good will, especially when the natives possessed something that was valuable to the visitors. And he already knows that earth *is* valuable to the Martians. The Martians have learned to convert one form of energy into another with one hundred percent efficiency. They can convert heat into light, light into electricity, electricity into gravitational force—"gravitation is a wave form moving at one million times the speed of light waves"—but the basic energy they tap is the radiant energy coming from the sun. And square meter for square meter, earth receives about three times as much energy from the sun as Mars.

Both men expect to be invited to go to Mars. Saltner is only too willing, but Grunthe wants to go to Europe to warn the governments that the Martians have not only reached earth but have established a firm foothold.

In order to be prepared for the report that he intends to write to the governments of the large countries of the earth, Grunthe studies the Martians with the greatest intensity and the utmost suspicion. In appearance they differ little from North Europeans. They are of about the same size and have a light skin that does not tan easily. Their hair tends to be so light that it looks white to earth people; for example, the deepest shade, possessed by La, resembles that of the petals of a yellow rose. In the dark, their hair seems to luminesce. By contrast, their eyes are very dark and very large, able to see in a light that is far too dim for earthmen. Of course, the Martians who have been sent to the polar station are all superior specimens in intelligence and education; on Mars there are relatively unintelligent people and even some classes (formerly tribes) that do manual work, such as miners. But all have been brought up on the philosophy of Imm; criminal actions are a psychological impossibility. But that leaves one big question: will they consider earthmen as equals?

Their scientific accomplishments are things that Grunthe can learn, though not always understand. That the space station, by means of small flat elements attached to its outside, can receive solar energy and convert it into gravity that can be made to act in any direction is something he can learn. That they can change molecules around in any manner they please (for example, the very tasty Martian food is made directly from elements found in rocks, water, and air), is something he can understand, though he does not know all the phases of processing. That they can produce a powerful rocket blast seemingly from nothing is something Grunthe can only learn; how they calculate a trip from earth to Mars and how the trip is maneuvered is something he can understand. That they can project the picture seen through a telescope on a white screen and meanwhile increase the intensity of all wavelengths so that even a very strongly enlarged picture retains its original contrast Grunthe is just on the verge of learning and understanding.

A new ship has arrived, bearing the invitation to the earthmen to come to Mars. Grunthe refuses, disturbing the good will of the meeting. The new ship has brought something else, too—a small, streamlined ship built of an "adiabaric" substance which is not harmed by heat and moisture. And its exhaust-producing repulsor devices give this ship an airspeed of six hundred miles per hour.

Since it is psychologically impossible for the Martians to disregard Grunthe's decision to go home, they agree to transport him in one of their new ships, thereby revealing their presence on earth, though they would have preferred to wait a little longer. The ship arrives at Dr. Ell's residence in central Germany after a six-hour flight from the Pole, and something that both Grunthe and the Martians have been silently wondering about turns out to be true: hybrids are possible. Ell is the son of one of the earlier Martian astronauts who had to be left behind because of bad weather over Antarctica. In the meantime, the first serious misunderstanding between Martians and earthmen has taken place. Since the parachute which had been attached to the gondola of the balloon was missing, it was assumed that the third passenger, Torm, had used it, landed somewhere on the polar ice, and tried to make his way to an Eskimo settlement. Hence a smaller Martian atmosphere ship had been detailed to look for him. The ship did not find Torm but happened on a landing party of British sailors, two of whom had fallen to their death in a crevasse in a glacier. Two Martians hauled the bodies out to see whether they were still alive. To the other sailors it looked as if the two Martians had killed them. The sailors took the Martians as prisoners.

The ship that had brought Grunthe home then goes back to the Pole with Dr. Ell and Mrs. Torm aboard. On the way, they rescue the two imprisoned Martians by means of a short and bloodless battle: they fire their reaction charges around the British ship into the sea, causing such gigantic waves that the British captain, his ship already damaged, reluctantly surrenders the prisoners. Then, since winter is closing in over the Arctic, the whole party goes to Mars on the last spaceship to leave, Saltner being a guest of the federal government of the Martian states.

On Mars, Saltner learns what the *canali* seen from earth really are. They are canals, covered over to avoid loss of water by evaporation in the permanently dry air. But the covered canals produce thriving vegetation with tall trees, and the settlements of the Martians are strung out under this vegetation. Parallel to the canals run the Martian highways, half a mile wide, consisting of wide moving strips. The outermost strip moves at a speed of ten feet per second; the next one is ten feet per second faster, and so forth, so that the center strips are as fast as express trains. Pedestrians may ride the outer strips just by standing on them, but the normal method of traveling is a small electrically driven automobile, which is driven on the moving roads and has a range of about one hundred miles off the roads, traveling under its own power. But one can travel by renting small mobile rooms with sleeping accommodations. A gold coin rents such a cubicle for one day, with the right to be transported anywhere on Mars during this time. The traveler inserts the address of where he wishes to go into a small window, and an efficient organization that "sorts the cubicles the way our mailmen sort letters" does the rest. In fact, all Martian private homes are built in such a manner that they can also be transported on the moving roads; if a Martian moves, he moves with his home.

But Saltner is surprised by something else. When the Martians were on earth, they had looked like a unified force to Saltner. On Mars he learns that they not only form 154 separate states but that there are political parties that are in violent disagreement. To his surprise the Martians are proud of their diversity, and the language that Saltner had assumed to be uniform turns out to be an interstate language that everybody can write and speak; however, each state and even the larger clans have their own languages. Every Martian is obliged to read two newspapers issued by two different political parties every day, and Saltner, reading one of them, finds violent denunciations of the earth, its inhabitants, and all their works. Slowly he learns that there is not even a uniform attitude toward space travel. One large party had been opposed all along and now points out that the discovery of such inferior beings as earthmen proves once more that all the expenditures on space travel have been a waste of money. Another party agrees with the statement about the inferiority of earthmen but feels that this is a fine reason for taxing them. This "anti-human" party paints glowing pictures of the riches that will come from the exploitation of the earth. The third major party is the one whose teachings he had learned at the Pole and had thought to be universal; they are the ones who want to make the earthmen share in their knowledge. They are in the majority but only by a slight margin.

Then Saltner, having inadvertently entered forbidden territory, learns something that almost makes him agree with Grunthe: the Martians are developing secret weapons. The experience with the British warship convinced even the most pro-human Martians that the warlike earthmen might use their weapons out of misguided patriotism or just by force of habit. Hence the Martians are busy making themselves invulnerable. In their testing, first they built guns, including the heaviest naval rifles, and then they fired them at one of their own atmosphere ships resting on the ground. They had known all along that it should be possible to create a field of tension. Now they do it, and this field not only arrests all motion but destroys all matter; nothing can touch a ship surrounded by such a shield of "nihilite."

For a while everything seems to go well, because Dr. Ell convinces the Martians in charge of "the retrospective" to find the scene of the encounter between the English and the Martians. "The retrospective" is based on the fact that gravitational waves travel a million times as fast as light; hence they can overtake light waves, and everything that once took place under a clear sky in the open can be reconstructed this way. The instrument had been used for historical research; now it is put to political use. The reconstruction of the encounter proves that it was based on a misunderstanding.

But incidents keep piling up. The Martians had been negotiating with all the earth's great powers about the organization of Martian instruction for humans. But then England receives a request to punish the captain of the ship that had taken the two Martians prisoner. England refuses. Mars sends an ultimatum. England refuses and the Battle of Portsmouth takes place. The Martian atmosphere ships, nihilite fields under full power, just press against the stern of a battleship, dissolving armor, rudder and propellers, then taking a few gun turrets off to show what they can do. England has to capitulate and is declared to be an area under the protection of Mars. The other great powers, which had promised to remain neutral, fall heirs to the British Empire. The dominions declare themselves independent states and the other colonies are annexed by their colonial neighbors. But there are disputes and the humans reach for their guns.

Now, the number of Martians that are convinced that the humans are not "people" are in the majority. They declare that the whole earth is under the protection of Mars. All armies must be reduced to five percent of their existing strength.

The Germans don't want to give up their army and order a large-scale colorful military display with everybody in parade uniform and all buttons, boots, and guns polished—mainly for the purpose of showing that they like their own traditions. Martian atmosphere ships appear overhead with still another weapon: a gigantic magnet of incredible power. It pulls the rifles out of the soldiers' hands, it lifts the artillery into the air, it topples all horses because of their iron horseshoes. The weapons are done away with in a nihilite field, the German army has been humiliated, and the education of humanity begins. All former garrisons become schools for adults. Attendance is compulsory for a minimum of two hours a week, but half a dollar for every hour of attendance is paid to the pupils. Though the protectorate has been declared for the whole earth, the Martians concentrate on western Europe, which is small and densely inhabited, and has (for humans) a high degree of education. They neglect Russia because even elementary education is lacking there for ninety percent of all the people. And they do not even try to work in the United States—too large and too individualistic.

Of course, things go from bad to worse. Even well-meaning Martians grow irritable and autocratic; they find it impossible to remain rational in an atmosphere as moist as ours. And they are irritated by the smells and habits of domesticated animals. They succeed in ridding the cities of horses by introducing their automobiles, but the humans evade by subterfuge the summary death sentence for all dogs. The idea of one Martian, Captain Oss, to depopulate the earth by stopping its rotation, is considered, to the horror of other Martians. La, who has meanwhile married Saltner, permits earthmen to make replicas of her private atmosphere ship. The work is done secretly in the United States.

Once the Americans have a sufficiently large fleet, they provoke a break in relations with the Martians. While the Martians are busy occupying Washington and all state capitals, their own ships—the Martians, of course, think they are theirs—occupy the polar island and the space station, finally enforcing a truly just peace between the two planets, with equal rights for humans and Martians. And there the story ends.

One can easily see why this novel was so successful in its day. If you assumed that there were technologically advanced Martians, just such a thing was likely to happen—they would come to earth. And even if they meant well, they would no doubt be infected by our own admitted foolishness.

Just one year later, *The War of the Worlds* by H. G. Wells appeared (1898). Wells did not for a moment assume that the Martians might be well-meaning, and his novel still scared many thousands of Americans forty years later in a radio adaptation by Orson Welles.

H. G. Wells carefully established a background in the first pages of the first chapter:

> "Its [Mars'] air is much more attenuated than ours, its oceans have shrunk until they cover but a third of the surface, and as its slow seasons change, huge snowcaps gather and melt about either pole and periodically inundate its temperate zones. That last stage of exhaustion, which to us is still incredibly remote, has become a present-day problem for the inhabitants of Mars. The immediate pressure of necessity has brightened their intellects, enlarged their powers, and hardened their hearts. And looking across space with instruments, and intelligences we have scarcely dreamed of, they see, at its nearest distance only 35 million miles sunward of them, a morning star of hope, our own warmer planet, green with vegetation and gray with water, with a cloudy atmosphere eloquent of fertility, with glimpses through its drifting cloud wisps of broad stretches of populous country and narrow, navy-crowded seas."

Wells then went on to tell that "during the opposition of 1894, a great light was seen on the illuminated part of the disk, first at the Lick Observatory and then by Perrotin of

Nice. . . . I am inclined to think that this blaze must have been the casting of the huge gun. . . ." It may be mentioned at this point that Jules Perrotin of Nice was an actual French astronomer who specialized in observations of Mars; the names mentioned later on in the narrative are fictitious.

The story continues: During the next opposition something was seen that reminded observers of the muzzle flash of an enormous cannon. Flashes were seen for ten nights running. The narrator tells how he had seen one of them with an astronomer who "was full of speculations that night on the conditions of Mars, and who scoffed at the vulgar idea of its having inhabitants who were signaling us. His idea was that meteorites might be falling in a heavy shower upon the planet, or that a huge volcanic explosion was in progress."

Six years later, the first of the ten giant projectiles fell in England, not far from London. A local man who had seen it fall went searching for the suspected "meteorite" and soon found it in a sandpit which it had blasted by its impact. "The uncovered part had the appearance of a huge cylinder, caked over and its outline softened by a thick scaly dun-colored incrustation. It had a diameter of about thirty yards." Faint noises that seemed to come from inside the cylinder he explained to himself as being caused by uneven cooling. Then the ashy incrustation began to fall off near the end, and soon there could be no doubt that the end of the cylinder was being unscrewed. The following evening, in the presence of many spectators, the end of the cylinder fell off.

> "I think everyone expected to see a man emerge—possibly something a little unlike us terrestrial men, but in all essentials a man. I know I did. But, looking, I presently saw something stirring within the shadow: grayish billowy movements, one above another, and then two luminous disks—like eyes. Then something resembling a little gray snake, about the thickness of a walking stick, coiled up out of the writhing middle, and wriggled in the air towards me—and then another. . . . A big grayish rounded bulk, the size, perhaps, of a bear, was rising slowly and painfully out of the cylinder. As it bulged up and caught the light, it glistened like wet leather. Two large dark-colored eyes were regarding me steadfastly. . . ."

Though by this time everybody is convinced that the beings in the cylinder are from Mars, nobody is worried. In the first place, there is no reason to assume that the Martians would be hostile. In the second place, one can clearly see that they are helpless under terrestrial gravity. Obviously the next step, after the Martians have rested a bit, would be to try and establish communication.

But the Martians almost immediately begin firing heat rays at the onlookers, setting woods aflame, and destroying all houses within reach. A few small military units that can reach them are wiped out almost to the last man; the heat ray explodes the ammunition. By the time larger military forces have been mobilized, the Martians are no longer helpless; they are sitting in shells on top of moving tripods, a hundred feet tall. Mechanical tentacles hold heat-ray generators and drop canisters filled with poison gas. Though one Martian fighting machine is knocked out by a lucky shot with a 12-pounder gun, the humans are routed everywhere, with many people heavily contributing to the havoc by panicking. Another Martian fighting machine is brought down by the suicide attack of a naval vessel, but the Martians win everywhere. And every night another cylinder falls to reinforce their ranks.

The narrator happens to be hiding in a house that was partially wrecked by a falling cylinder and thereby gains an opportunity to watch the Martians at close hand. In addition to the tall fighting machines, they have another type of machinery which they brought along; the English later call it the "handling machine." It looks somewhat like a very large crab with a multitude of attachments, and it does many kinds of work when guided by a Martian riding it.

Wells did his best to make the Martians as different from any known terrestrial life form as possible:

> "They were huge round bodies—or, rather, heads—about four feet in diameter, each body having in front of it a face. This face had no nostrils—indeed the Martians do not seem to have any sense of smell, but it had a pair of very large dark-colored eyes, and just beneath this a kind of fleshy beak. . . . In a group around the mouth were sixteen slender, almost whiplike tentacles, arranged in two bunches of eight each. . . .

> Even as I saw these Martians for the first time they seemed to be endeavoring to raise themselves on them, but . . . with the increased weight of terrestrial conditions this was impossible. There is reason to suppose that on Mars they may have progressed upon them with some facility. . . . The internal anatomy . . . as dissection has since shown, was almost equally simple. The greater part of the structure was the brain, sending enormous nerves to the eyes, ear and tactile tentacles. Besides this were the bulky lungs, into which the mouth opened, and the heart and its vessels . . . all the complex apparatus of digestion which makes up the bulk of our bodies, did not exist in the Martians. They were heads—merely heads. Entrails they had none. They did not eat, much less digest. Instead they took the fresh, living blood of other creatures and *injected* it into their own veins. . . ."

Since the Martians needed human beings for sustenance they did not try to exterminate the humans. They just dealt with organized resistance and disrupted transportation and communication. And they did this very thoroughly in the south of England. All of a sudden their activities came to a standstill. Several Martian fighting machines were standing around in London, not doing anything. The Martians directing them were dead, having succumbed to infections by terrestrial bacteria. Apparently diseases had once existed on Mars but had been conquered so long ago that no Martian even remembered that there were such things.

Lasswitz and Wells are the two outstanding writers of Mars fiction at the turn of the century. Practically everything written later followed one or the other: either a highly advanced humanity (though different writers had different ideas about just what represented advancement) or else man-eating ogres and ghouls. The less-known German writer Karl Grunert might be mentioned; he wrote a few books of short stories around the year 1906, and of the short stories dealing with Martian invaders, two have interesting twists. In one of them a Martian works as an assistant to Percival Lowell, and his job is to destroy those astronomical plates on which Martian spacecraft have been caught. In another one of the short stories, a Martian spies on the research activities of a German university; he is invisible because he wears a cloak of living bacteria that always take on the coloration of the background at a moment's notice. The scientists catch him by writing little notes to each other, using Latin which the Martian has never learned.

The stream of Mars fiction was stopped by World War I, partly by diverting interest and partly by way of an acute paper shortage. But when the war was over, the Martians were considered again. Around 1900, very white spots of fairly short duration had been seen on Mars. Some astronomers (and most laymen) thought that they might be signals of the Martians; others just wondered what they might be. No such bright spots had been seen for a long time. But if there were intelligent Martians, they should have developed radio, and in 1922, a U. S. Government agency requested all radio stations to observe complete silence for some time on the day of opposition, so as not to interfere with any radio signals by which the Martians might wish to communicate with us.

The belief in a Martian humanity was still strong then, as shown in a not very well-known book by a Russian writer, Count Alexei Tolstoi—related to the more famous Leo Tolstoi. His Mars novel titled *Aëlita,* was published in the original Russian (still using Czarist orthography) in Berlin in 1923; a German translation appeared at the same time.[2] The novel begins unusually, with an American journalist reading a notice saying: "Engineer M.S. Los invites all who wish to fly with him to the planet Mars on August 18 to call on him between six and eight P.M. at [address]."

While he is noting down the address, another man, a Russian dressed like a discharged soldier, approaches the bulletin board and reads the same notice; the two get to talking. The Russian says that he is going to see this engineer; the American says the plan is preposterous, that the man must be a fraud. The Russian admits that it sounds far-fetched but says, "You never can tell." Both go to see the engineer

[2] Alexei Tolstoi left Russia in 1917 because of the Russian revolution, but in 1922 he made his peace with the bolshevists and returned. A somewhat shortened and edited version of *Aëlita* had meanwhile been published in the Soviet Union, and an English translation was published recently by the Foreign Language Publishing House in Moscow; quotations are from the latter edition.

(separately), first the American for an interview, then the Russian to offer his services. The American offers the engineer a fee for his memoirs and even writes a check for an advance payment. But engineer Los remains unhappy. "Pity you won't come with me, I haven't found a companion yet." Los is resigned to going alone when the ex-soldier walks in and offers his services. His name is Alexei Ivanovitch Gussyev, who "has been to school, knows something about motorcars, flew in an airplane as an observer, has been a soldier in the war and a revolutionary later and is now in the reserve."

The vehicle is egg-shaped, about 30 feet tall and 20 feet in diameter at the widest point. It works on the rocket principle, and the fuel is a new and very powerful explosive.

The two take off at sundown on the day of opposition, since engineer Mstislav Sergeyevitch Los expects to reach Mars in a little over ten hours. (The science in *Aëlita* is generally poor, not even at the level that had been attained in 1923.) They make a somewhat hard landing and go out to explore:

> "They pulled off their felt boots and fur-lined jackets. Gussyev fastened his revolver to his belt (just in case), chuckled, and swung open the lid. . . . The air was thin and dry. The spaceship lay in an orange-colored flat plain. The horizon was very close—almost within reach. There were large cracks in the ground. The land was overgrown with tall cactuses shaped like pronged candlesticks, which cast vivid purple shadows on the ground. A dry wind was blowing."

They walk on through a dry desert, occasionally seeing lizards and enormous spiders "such as live only at the bottom of the ocean on earth." They see what looks like a large bird, but it turns out to be a kind of flying machine, driven by an old man, very frail and thin, with white hair and a blue face.

Later on the two travelers are conducted to the city, presumably the only city on Mars. The Martians have aircraft of many types, they have a telephone system with television screen attached; they have, in short, a high technology, but it is a remnant of the past. Their lives are enmeshed in a religion that is also a remnant of the past. The story tends to become tedious even in this first part; it is carried along mainly by the comic relief of Gussyev's remarks, sometimes naive, sometimes shrewdly penetrating, and by his bragging about past military exploits. He also wonders whether one could not start a revolution and return home with Mars signed up as one of the republics of the Soviet Union.

Then they met Aëlita, the daughter of the autocrat. "Los observed that Aëlita was no higher than his shoulder, that she was as gentle and ethereal as the bittersweet flowers she had sent him that morning." Aided by a device that makes concentrated thoughts visible—Los concentrates on buildings in Leningrad, the embankment of the Neva river and such, while Gussyev shows battle scenes—they begin their language lessons. Finally Aëlita is able to tell Los the history of Mars: how there were several tribes of different colors, all manlike, who warred, united, learned, and finally built a civilization—but not yet a technological civilization. Then invaders from earth came, the Magatsitls, fleeing because their home, Atlantis, began to crumble. The Magatsitls

> "took the virgins of the Aols [the original inhabitants] and fathered the blue mountain tribe. And they began to build the sixteen giant reservoirs of Ro to collect the water that flowed down from the polar summits during the thaw. The barren plains were cut up by canals and irrigated. . . . Then the walls of Soatsera [the city] were built. The Magatsitls employed giant cranes which were operated by means of amazing mechanisms. Their knowledge enabled them to shift large stones and stimulate the growth of plants. They wrote their knowledge down in books with colored spots and star-shaped figures.
>
> "When the last man from the earth died, knowledge died with him. Only twenty thousand years later did we, the descendants of the mountain tribe, learn to decipher the mysterious books of the Atlantians."

Aëlita's father is convinced that his rule is the last era of civilization on Mars, and he wants to make it "golden." But his subjects revolt, without having a specific goal in mind. Gussyev, naturally, wants to transform the planless revolt into a Russian-style revolution and is nearly killed in the fighting. The revolt is beaten down and the two earthmen flee to their spaceship, making a narrow escape. Half-dead, they finally touch down near Lake Michigan, are nursed back to health and return home.

Looking back over these major Mars novels, one can easily understand why the books by Lasswitz and Wells were well received. Both were logical extrapolations from the belief of intelligent inhabitants of Mars. One happened to be optimistic and the other pessimistic, in accordance with the personalities of their authors. Why *Aëlita* was acclaimed as a great book is much harder to see. In spite of many beautiful poetic touches, it is rather shapeless as a narrative, and the logic of developments can be challenged in many places.

But it is an interesting case in one respect. I don't know whether Alexei Tolstoi actually believed in the existence of intelligent Martians and in the former existence of Atlantis. If he did, he wove his beliefs into a novel. If he did not, he started a trend: namely, for science-fiction writers to use the planet Mars as a convenient stage setting for their own imaginings. It no longer mattered what science said or thought. Mars was there, and it was a background people had heard about.

And now it is time to look at reality.

2. *The Orbit of Mars*

The place is a monastery somewhere in Italy, and the time is five hundred years ago. The students are young monks, and they are listening to a lecture on astronomy; it will be part of their duties to know as much as is known about the works of the Fourth Day of Creation.

"The red star now in the sky," the instructor says, "is one of the wanderers, the *planetes* as the ancients called them. In addition to the sun and the moon there are five such wanderers, named Mercury, Venus, Mars, Jupiter, and Saturn. They all go around our earth and none of them ever leaves the constellations of fixed stars, which are called the zodiac. Since the lights in the sky are perfect, they must move along the perfect curve, which is the circle. The name of such a circle is *deferens*. If your duties left you enough time to watch the path of the planet Mars among the fixed stars every night, you would see that it progresses by making a large loop. This loop is due to the fact that Mars does not move along the *deferens* directly. It is traveling along a smaller circle called the *epicycle,* and the center of the *epicycle* is traveling along the *deferens*. . . ." (See Figures 5 and 6.)

Let's now make a five-hundred-year leap through time and talk about these phenomena in present-day language. We'll

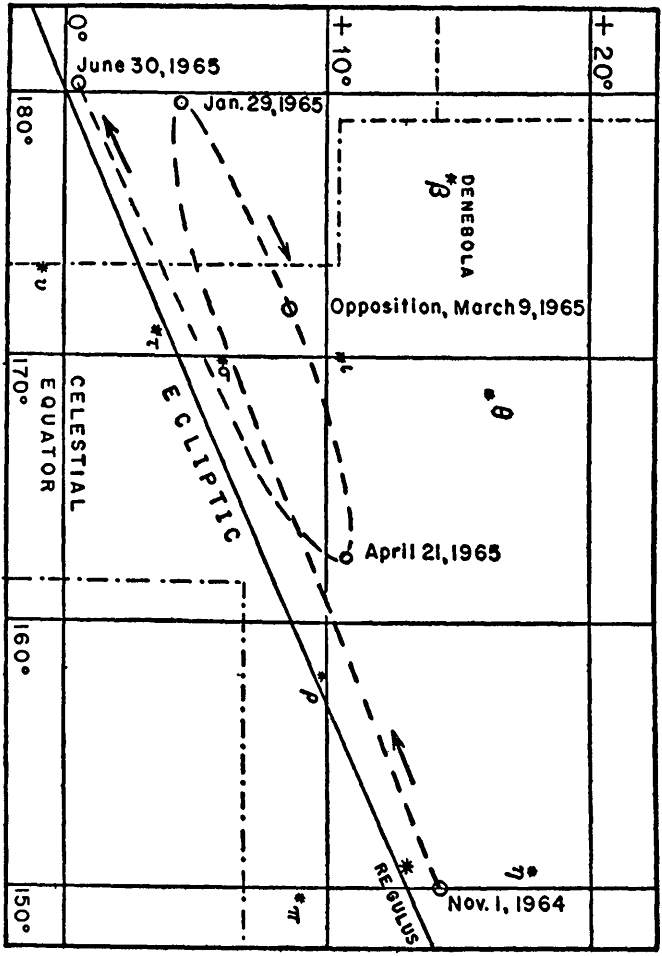


Fig. 4. The path of Mars among the fixed stars from November 1, 1964, to June 30, 1965. The center area of this chart is the area of the constellation Leo; the larger stars of this constellation are indicated by their Greek letters. Dot-dash lines indicate the boundaries of adjacent constellations.

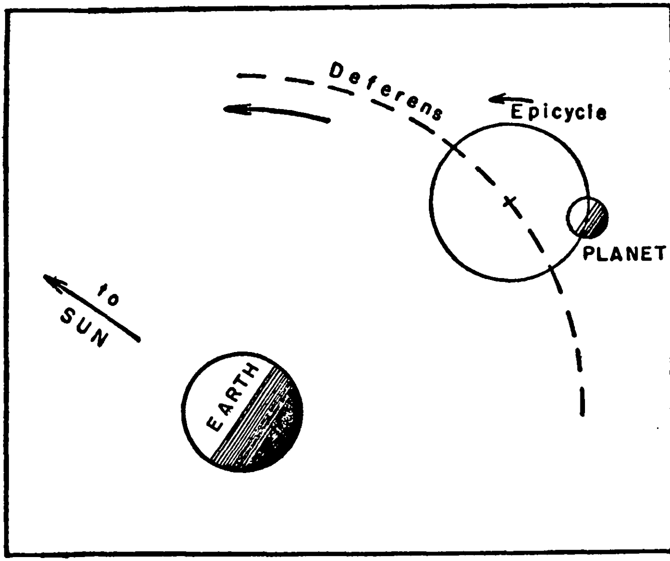


Fig. 5. The so-called Ptolemaic theory of planetary motion. The earth was in the center, unmoving and immovable; the planets (among them sun and moon) ran on epicycles with uniform velocities, while the centers of the epicycles ran on larger circles, also with uniform velocities.

find that the instructor described the observable facts well enough, but the explanation involving *deferens* and *epicycle* was wrong.

And, of course, the sun is in the center of the system, not the earth.

The explanation for the apparent loop made by Mars lies in the fact that the earth, being in a smaller orbit, has a higher orbital velocity. The earth's motion along its orbit is 18½ miles per second, while Mars moves at the rate of 15 miles per second. If we imagine that both planets are in the same sector of their orbits—as seen from the sun—but that

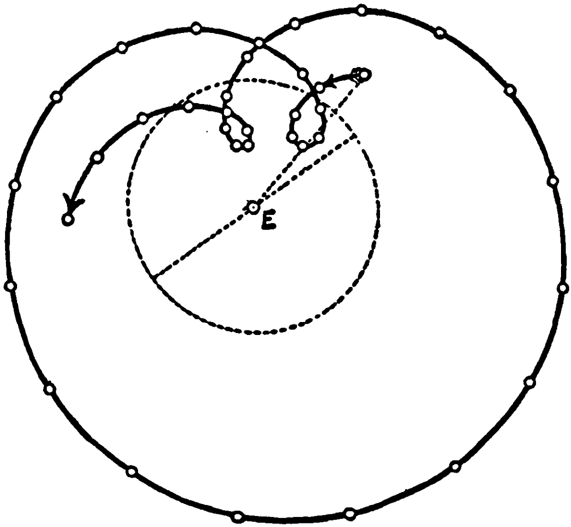


Fig. 6. The motion of Mars from 1888 to 1890 as it would have been constructed from the observations actually made if the earth were in the center. This diagram was made by a German astronomer in 1894, to prove to his students that Ptolemy's ideas agreed well with what could be seen.

the earth is some distance "behind" Mars, we can understand why things look the way they do. When the earth is a long distance behind, the motion of Mars looks perfectly normal. But then the faster earth begins to catch up, and that looks as if Mars were slowing down. Then a point is reached where Mars seems to stand still; the technical term for this is that it has become "stationary." Then, as the faster earth races ahead, Mars seems to move in the opposite direction; it has become "retrograde." And when the earth is sufficiently far ahead of Mars, the planet seems to resume its normal motion. The "loop" is actually only a kind of optical illusion, caused by our overtaking the other planet. It has nothing to do with the actual motion of Mars.

While it was Nicholas Copernicus who realized that the sun was in the center of the system, he still clung to the ancient idea that the planets must move along "perfect" circles. Therefore he maintained the system of *deferens* and *epicycle*. As a consequence of this belief, he failed to discover the true shape of the orbits of planets.

It was Johannes Kepler who realized that the orbit of Mars must be an ellipse, and he concluded, correctly, that the orbits of all planets were ellipses. But even with an elliptical orbit, the actual motion of a planet did not agree with reality if the sun was believed to be in the center of the ellipse. It did work out, however, if you placed the sun in one of the focal points of the ellipse. Hence Kepler stated that the planets move along elliptical orbits, with the sun in one of the focal points of the orbit. This is now known as Kepler's First Law.

Having arrived at this conclusion, Kepler needed a few new terms. In such an elliptical orbit there has to be one point that is closest to the sun—and one farthest from the sun. Using the Greek word *helios* for sun and the Greek words for "around" (*peri*) and "away" (*apo*), he designated the point closest to the sun "perihelion" and the one farthest from the sun "aphelion."

Kepler, having literally thousands of careful observations by Tycho Brahe as the raw material for his work, saw quickly that the speed of a planet differed at the two extreme points of its orbit. A planet at aphelion moved more slowly than at perihelion. Kepler jumped to the conclusion that this was due to the fact that it was the sun that somehow moved the planets; of course its "moving power" had to be weaker at a longer distance. This happened to be a guess that miscarried, but Kepler went on, looking for a way of describing the differences in orbital velocity. And there he found a useful and correct answer. If we draw a line from the sun to the planet—he called it the "radius vector"—we find that this line sweeps over equal areas for equal time intervals. Note that the radius vector for a given time, say 24 hours, sweeps over the same area, no matter where the planet is in its orbit. It does not sweep over the same angle—or rather, it would do so only if the orbit were a perfect circle. The motion of the radius vector is now known as Kepler's Second Law. (See Figure 7.)

All this is of the greatest importance when it comes to observing the planet Mars, and in order to see why this is so

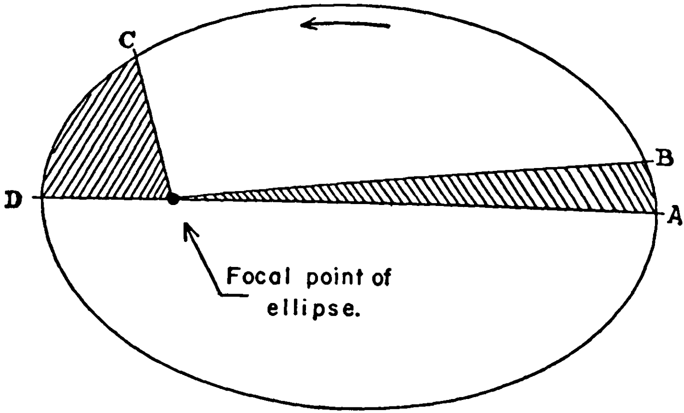


Fig. 7. Kepler's Second Law, also called the "equal areas" law. A body in an elliptical orbit around the sun would need as much time to go from A to B as it would need to go from C to D. The two shaded areas are equal.

important, we'll first investigate how things would be if both the earth and Mars did move along circular orbits. The so-called "mean distance" of the earth from the sun is 93 million miles; the mean distance of Mars is 141½ million miles. If the earth and Mars occupy points in their orbits that are in the same line of sight from the sun, their distance from each other would obviously be 141½ minus 93, or 48½ million miles. This would be the position where Mars=earth=sun form a straight line, with the earth in the middle. Seen from earth, Mars and the sun would be in opposite positions in the sky; for this reason we call it an "opposition." The opposite of an opposition is a "conjunction," when the line-up in space is earth=sun=Mars. The distance then would be 93 million miles (earth to sun) plus 141½ million miles (sun to Mars), making a total of 234½ million miles.

But both orbits are elliptical. In the case of the orbit of the earth the deviation is minor; earth's perihelion is 91½ million miles from the sun, while earth's aphelion is 94½ million miles from the sun. It is the ellipticity of the orbit of Mars that makes the real difference. Its distance from the sun at perihelion is 128 million miles, and at aphelion it is 154.1 million miles—a difference of 26.1 million miles. That means that the distance between the earth and Mars during an opposition is 61.5 million miles if the opposition takes place while Mars is at its aphelion. But the distance is slightly less than 35 million miles if the opposition takes place when Mars is at its perihelion.[1] It can be seen immediately that for observation purposes, a perihelion opposition is far preferable to an aphelion opposition, though the latter kind must not be neglected, for reasons that will be explained later.

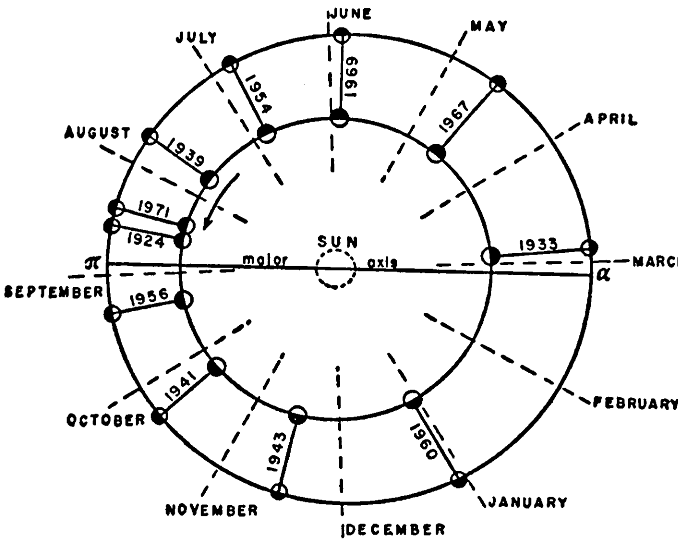


Fig. 8. Some oppositions of Mars. The diagram shows the orbits of earth and Mars drawn to scale, with the positions of both planets during a number of recent and future oppositions. The broken lines indicate the first of March, first of April, and so forth, showing the position of the earth in its orbit on these dates.

[1] Don't say that 35 million miles plus 26.1 million miles adds up to only 61.1 million miles, not to 61.5 million miles. Remember that the orbit of the earth is not *quite* circular; it is the true distance of the earth from the sun that accounts for those extra 400,000 miles.

However, let us forget for the moment that some oppositions are superior to other oppositions and just inquire how much time goes by between two oppositions. Since we need an arbitrary starting point for finding out, let us assume that we had an opposition at a time when Mars passed its perihelion; the date would be late in August of that year because, as shown in Figure 8, the earth passes the line from the sun to the perihelion of Mars every year at that time. One year, or, to put this more carefully, 365¼ days later, the earth passes this point again. But Mars needs 687 earth days to return to its perihelion; hence it still has 321¾ days to go, almost one earth year. In that time the earth almost completes another orbit around the sun; when Mars passes through its perihelion the second time, the earth is 365¼ minus 321¾ or 43½ days behind. In the 43½ days that it takes the earth to reach the sun-to-perihelion-of-Mars line, the planet Mars has moved too, and keeps moving. To catch up with it, thereby producing another opposition, takes the earth another 49½ days, or, in round figures, another seven weeks. The second opposition, then, takes place two years and seven weeks after the first, about 49 degrees of arc beyond the perihelion point.

Just because both planets travel somewhat faster in the perihelion sectors of their orbits and somewhat slower in the aphelion sectors of their orbits, the figure of two years and seven weeks is an average. Expressed in days, this average is 780 days; the actual value can vary from 761 days, which is the shortest possible time between oppositions, to 805 days, the longest possible interval. The actual date of the next opposition, therefore, has to be calculated from case to case. On page 60, the list of oppositions of Mars from 1937 to 1975 is based on precise calculation; it shows clearly how a good opposition is followed by oppositions that grow successively worse and then gradually better again. For example, the opposition of 1956 was clearly a good one; the one of 1958 was not so good. The one of 1963 was definitely poor; the one of 1965 just as poor; but from now on things will improve until the opposition of 1971, which will be even somewhat better than the one of 1956. (See Figure 9.)

Is there a way of telling, if a good opposition just took place, how long one will have to wait for another opposition just as good? Yes, there is, and all it needs is a little arithmetic. One Martian year equals 1.8808 earth years, so that

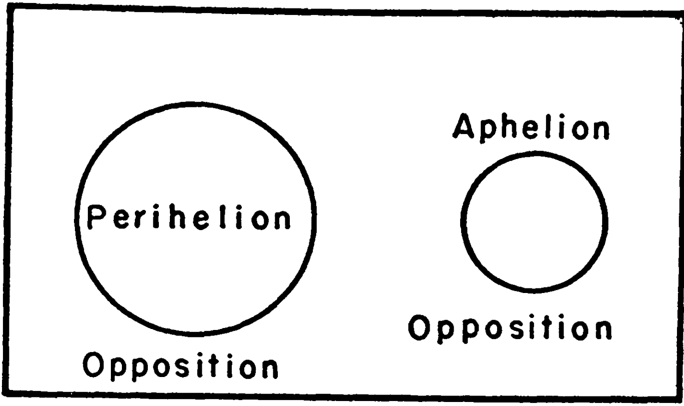


Fig. 9. Apparent size of Mars as seen through the same telescope during an especially favorable opposition (*left*) and a very poor opposition (*right*).

151 Martian years almost exactly equal 284 of our years. This means that a given opposition will repeat after 284 years, a rather long period of time. In reality, however, one doesn't have to wait that long, for 42 Martian years are 78.994 of our years, so that a given opposition will repeat in nearly the same manner after 79 years. If one wants only a very similar opposition, one can pick the intervals of 25 or 17 Martian years. The former equals 47.02 earth years, the latter 31.974 earth years. This calculation therefore boils down to the statement that after 32 years one will have a very similar opposition and a still closer repeat after 47 years.

The statement that the interval between two oppositions is two years and seven weeks is, as has been stressed, merely a rule of thumb—useful for quick estimates but not fully reliable. But the statement that a given opposition will repeat after 284 years is true within ⅓ of one degree of arc, less than the width of the full moon high in the sky. The opposition of 1640 was especially good—though the telescopes were still bad—and it repeated itself in 1924. The opposition of 1666 repeated in 1950, and the very good opposition of

List of Oppositions of Mars

Year	*Date*	*Distance between earth and Mars (miles)*
1937	May 19	48,000,000
1939	July 27	36,171,000
1941	October 3	38,508,000
1943	November 28	50,600,000
1946	January 9	59,800,000
1948	February 18	63,000,000
1950	March 24	60,700,000
1952	May 2	52,400,000
1954	June 25	40,300,000
1956	September 11	35,400,000
1958	November 16	45,100,000
1960	December 29	56,200,000
1963	February 3	61,800,000
1965	March 8	61,800,000
1967	April 13	56,200,000
1969	May 29	45,300,000
1971	August 6	34,600,000
1973	October 21	40,600,000
1975	December 13	53,100,000

1719 will repeat in 2003. But by that time we won't need good oppositions anymore, because we'll have landed on Mars and learned everything first hand!

So far, only the varying distances of Mars from the sun and from the earth have been mentioned, but that is not the whole story. Now we have to pay attention to the axis of the planet Mars and to the position of its orbit compared with that of earth.

Let us begin with the axis. Like the earth's, Mars' axis does not stand vertically on its orbit. The axis of the earth deviates from the vertical by 23 degrees and 27 minutes of arc; the corresponding figure for Mars is 24 degrees and 52 minutes of arc. The inclination is a bit greater but not much; if Mars actually were a planet that resembled the earth very closely, we would expect that this higher inclination would emphasize the contrast between the seasons a little. Mars being what it probably is, it won't make a difference. In addition to having a slightly higher inclination, the axis of Mars points to a different area of the sky. The axis of the earth, projected into the northern sky, very nearly points to the star Polaris in the Little Dipper, missing it by less than one degree of arc. The axis of Mars does not point to a conspicuous star; it does not even point to a star that could be seen with the naked eye by a human observer on Mars. The north celestial pole of Mars is about 10 degrees of arc from a conspicuous star, which is Deneb. This different position of the axis of Mars has some influence on what areas of Mars can be best observed.

The result of the position of the axis of Mars is that we can sometimes see the area around one pole and the territory around the pole equatorward, and sometimes the other pole and the area around it. When Mars is in perihelion opposition we have a fine look at its south pole and southern hemisphere; our best view of the north pole and the northern hemisphere is during an aphelion opposition. It is for this reason that the charts of Mars show more detail of the southern hemisphere. And for best results during an aphelion opposition, the observatory should be located in the northern hemisphere of our planet, while for best results during a perihelion opposition, we should use an observatory in the southern hemisphere of our planet.

The reason for this is that the orbits of the earth and of Mars are not precisely in the same plane. The ecliptic, which is the plane of the orbit of earth, and the orbit of Mars are inclined to each other by not quite two degrees of arc. If we draw a circle on a flat tabletop and declare that this circle is the orbit of earth, then the tabletop plane is the ecliptic. When in aphelion, Mars would be somewhat "above" the tabletop. Above means "north of the ecliptic"; hence it can best be observed from northern hemisphere observatories, which will have it high in the sky. When Mars is at perihelion, it is "below" the tabletop, or south of the ecliptic. This has the result that it does not rise very high above the horizon for the northern observatories but is high in the sky for the southern hemisphere observatories, of which there are still too few.

While the position in our sky and the distance from the earth are of great importance for telescopic observations, neither the distance nor the position in the sky make any difference when it comes to spacecraft going to Mars for a flyby or (later) for a landing. Of course the position of the planet and its distance must be known for purposes of calculating the orbit of the spacecraft, but the only other requirement is that Mars must be above the horizon for the receiving station. It does not even matter if the weather is bad.

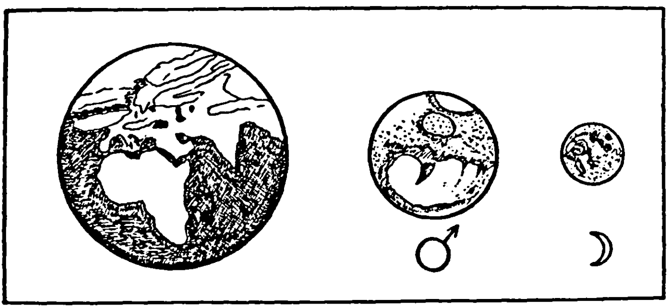


Fig. 10. Earth, Mars, and the moon, drawn to the same scale.

3. *The Moons of Mars*

The two tiny moons of Mars belong to the select company of heavenly bodies whose existence was predicted before they were actually discovered.

Now it is true that making predictions is, and always has been, part of the normal work of astronomers. But usually these predictions are predictions of *positions;* they tell when the sun or the moon will rise and set, when Venus will be morning star (or evening star), and when the sun, the earth and the moon will be along a straight line in space so that there will be an eclipse. But while this was the routine, another kind of prediction crept in once in a while.

In 1705, Dr. Edmond Halley handed the Royal Society of London a paper on comets. He had collected all the comet observations he could find and had tried to calculate their actual orbits—or rather the section of their orbits near the sun—from the observations. While doing this, he noticed that a bright comet had been seen at intervals of about 75 years. Moreover the orbits described in each case had been virtually identical. Halley drew a conclusion that was revolutionary for his time: the "four" comets of the years 1456, 1531, 1607 and 1682 were probably identical. But if this was the case, then the return of the same comet could be expected during the latter part of the year 1758. Dr. Halley died in the meantime, but "his" comet showed up as predicted; an amateur astronomer by the name of Johann Georg Palitzsch was the first to see it, from his farm near Dresden.

Another such case was that of the first of the planetoids, also called asteroids. The German astronomer Johannes Kepler, around the year 1600, had been surprised that the orbit of Jupiter outside of Mars was so much larger than the orbit of Mars. There seemed to be a definite gap in the arrangement of the planets around the sun. Kepler tried for some time to find a numerical system that fitted the actual distribution, without success. Then he became more courageous; after all it was quite possible that a member of the solar system had not yet been discovered. He assumed that there was an unknown planet in this gap. *"Inter Martem et Jovem planetam interposui,"* he wrote, meaning "between Mars and Jupiter I put a planet." But while the assumption made his mathematics work, it did not mean that the planet had actually been discovered.

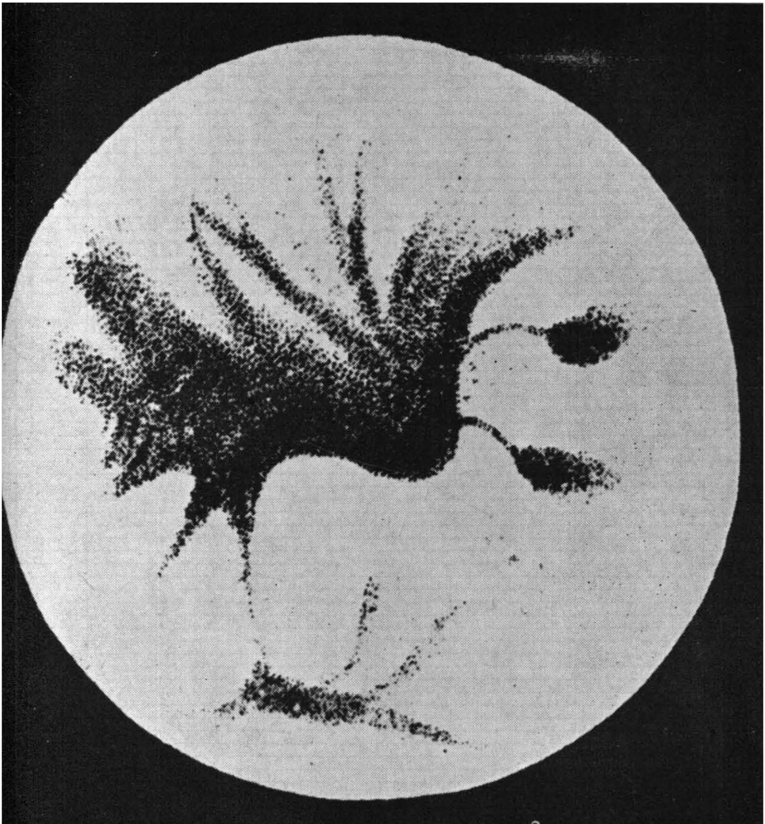
The case for the unknown planet was strengthened much later (in 1766) by the mathematician Johannes Daniel Titius, who found a rule that also would not work unless there was a planet between Mars and Jupiter.[1] At the time Professor Titius wrote down his rule, the planet Uranus had also not been discovered yet; but when Sir William Herschel found it in 1781 it, too, fitted the rule.

The fact that Uranus also fitted the rule was too much for Franz Xavier, Baron von Zach, the editor of an astronomi-

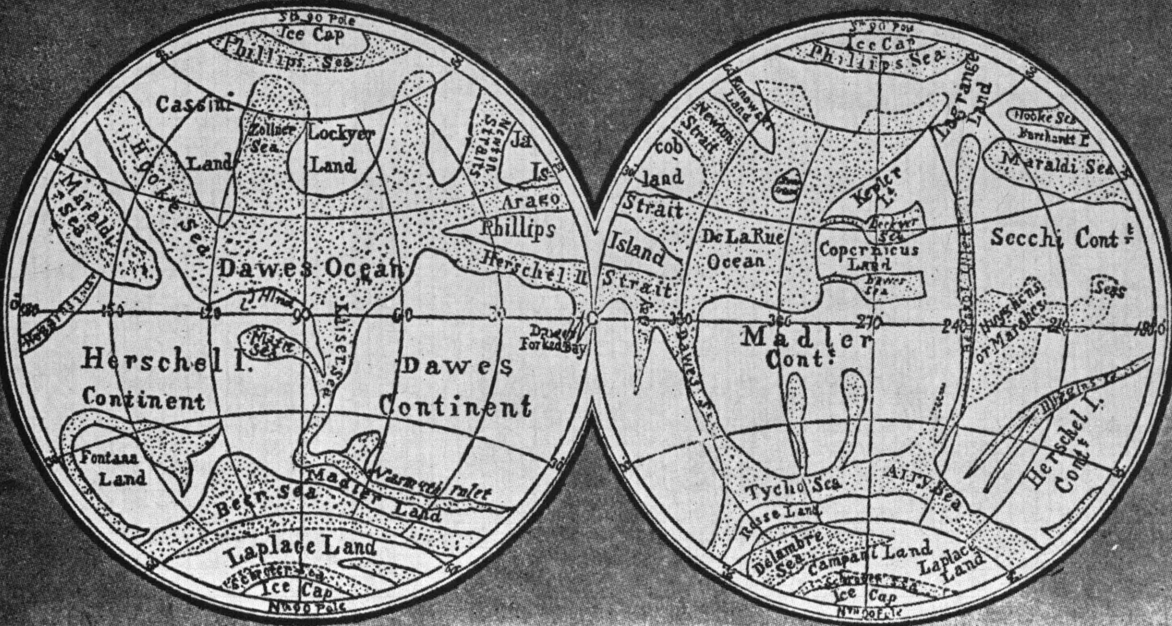
[1] Titius wrote his rule as an equation, but it is usually given in the form of a short table:

		Actual distance (in A.U.)*
$0.4 + (0 \times 0.3) = 0.4$;	Mercury	0.39
$0.4 + (1 \times 0.3) = 0.7$;	Venus	0.72
$0.4 + (2 \times 0.3) = 1.0$;	Earth	1.00
$0.4 + (4 \times 0.3) = 1.6$;	Mars	1.52
$0.4 + (8 \times 0.3) = 2.8$;	(Ceres	2.77)
$0.4 + (16 \times 0.3) = 5.2$;	Jupiter	5.20
$0.4 + (32 \times 0.3) = 10.0$;	Saturn	9.54
$0.4 + (64 \times 0.3) = 19.6$;	(Uranus	19.19)

* The letters A.U. stand for "astronomical unit," which is the mean distance of the earth from the sun, or 93 million miles.

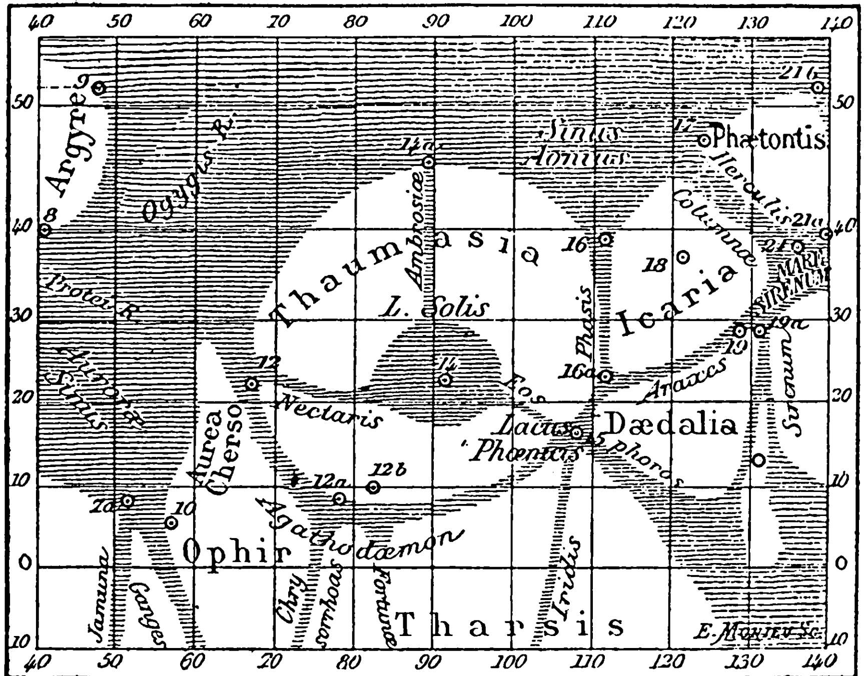


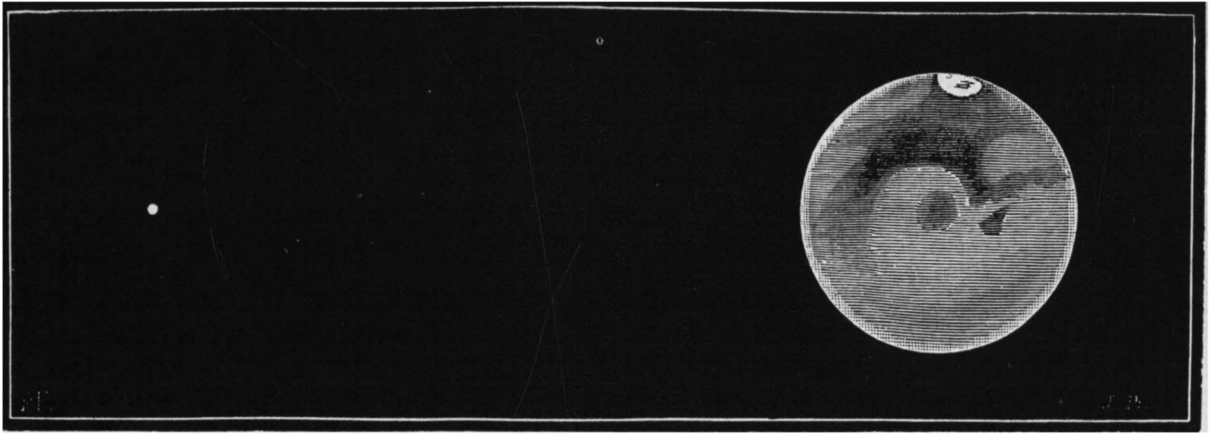
Drawing of Mars made by the Reverend William R. Dawes in 1864. To the left, the feature Proctor named "Dawes Forked Bay."


Ice Cap
Phillips Sea
Cassini
Land
Zollner Sea
Lockyer Land
Hooke Sea
Maraldi Sea
Newton Straits
Arago
Phillips
Herschel II
Dawes Ocean
Kaiser Sea
Herschel I.
Continent
Dawes
Continent
Dawes Forked Bay
Fontana Land
Beer Sea
Madler Land
Laplace Land
Ice Cap
Newton Strait
Strait
Island
De La Rue Ocean
Kepler
Copernicus Land
Lagrange Land
Hooke Sea
Maraldi Sea
Secchi Cont.
Madler Cont.
Tycho Sea
Airy Sea
Rosse Land
Delambre Sea
Campani Land
Laplace Land
Herschel I. Cont.
or Marshes
Seas

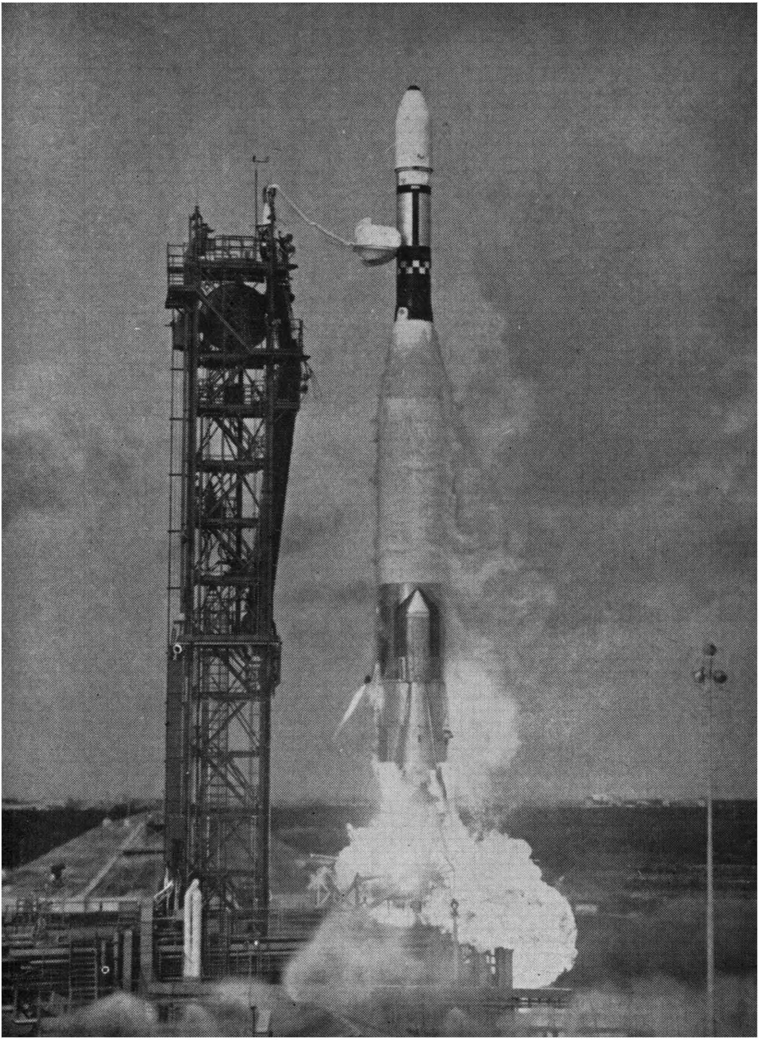
(*Above*) Map of the planet Mars, as published in 1867 by the British astronomer Richard Anthony Proctor. The names were given by Proctor and aroused much opposition because no less than four features were named after the Reverend Dawes. Except for Dawes Forked Bay, none of these names is in use anymore. All recent maps follow the names given by Schiaparelli, though not for every feature.

(*Right*) The area around *Lacus solis* in 1879, according to Camille Flammarion. At the turn of the century, this feature was believed by many to be the capital of the Martian government.

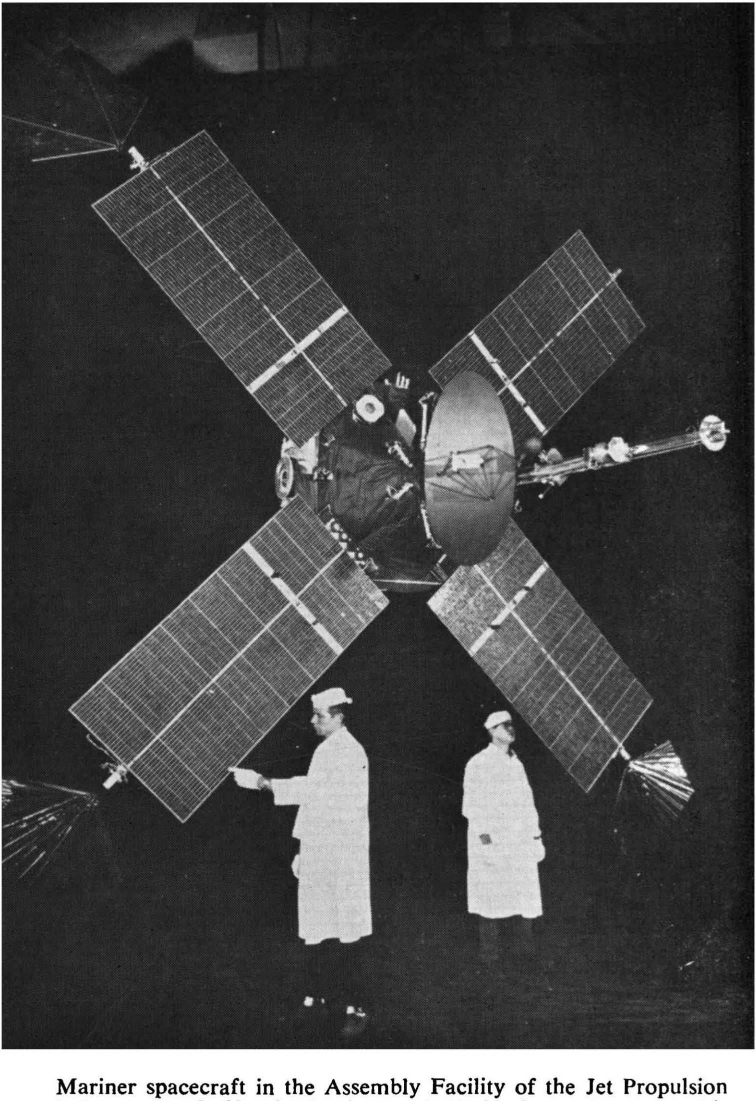




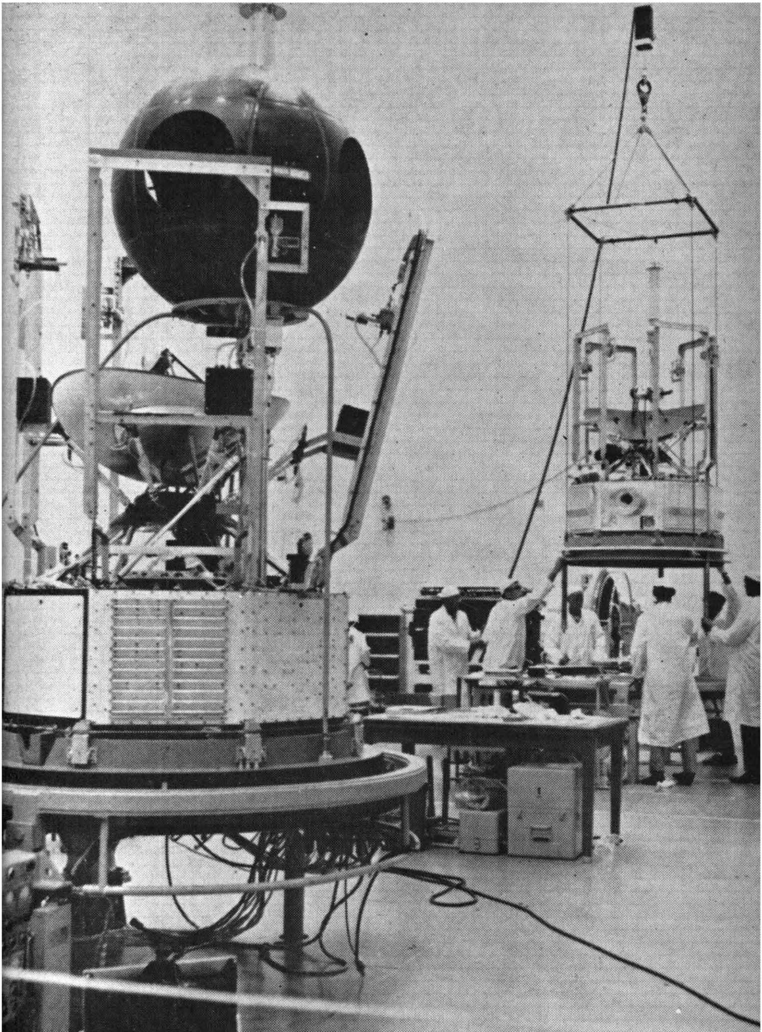
The first European observation of a moon of Mars, seen from France on August 27, 1877. The satellite is Deimos, and it is shown a bit too large and bright. The southern polar cap on the disk of Mars is clearly visible.



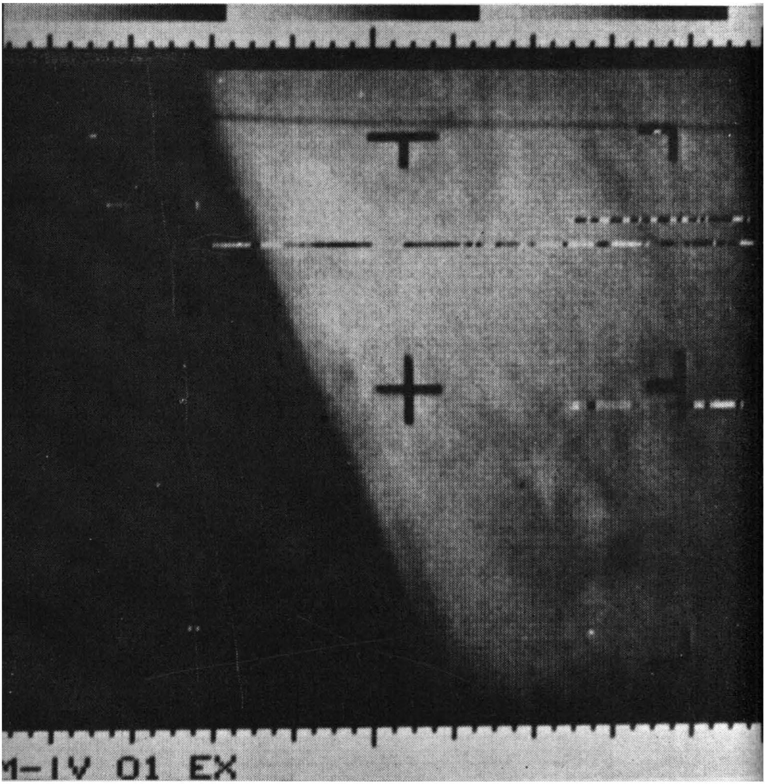
Takeoff of the Atlas-Agena rocket that carried spacecraft Mariner IV on the first step of its mission to Mars.



Mariner spacecraft in the Assembly Facility of the Jet Propulsion Laboratory, California Institute of Technology. Compare this photograph with Figures 22 and 23 in the text. *Courtesy: NASA*

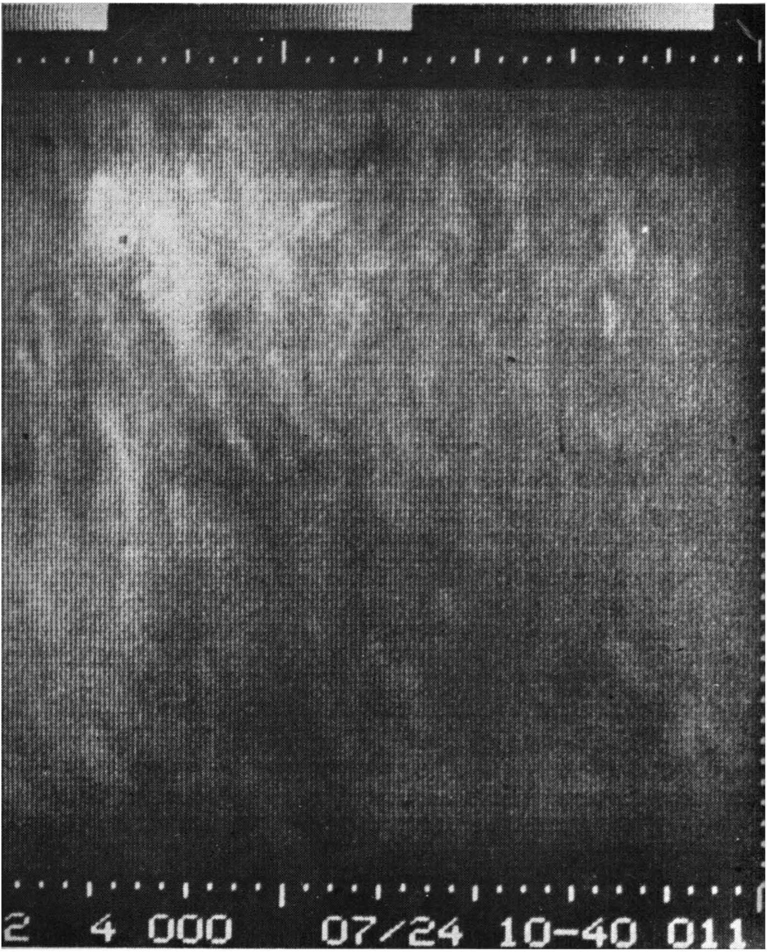


Several Mariner spacecraft during tests and checkout procedure at Cape Kennedy. The Mariners shown in this picture include the unsuccessful Mariner III and the successful Mariner IV. *Courtesy: NASA*

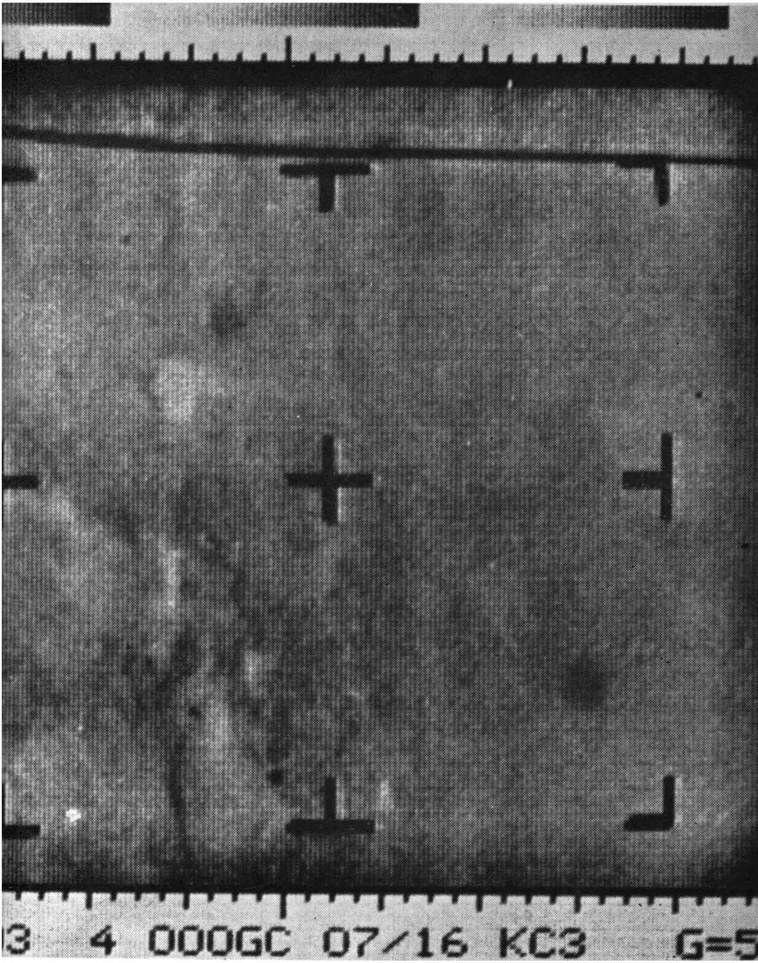


The first of the pictures taken by Mariner IV, over a slant range of 10,500 miles. This is a so-called raw print as it was assembled by the computer. *Courtesy: NASA*

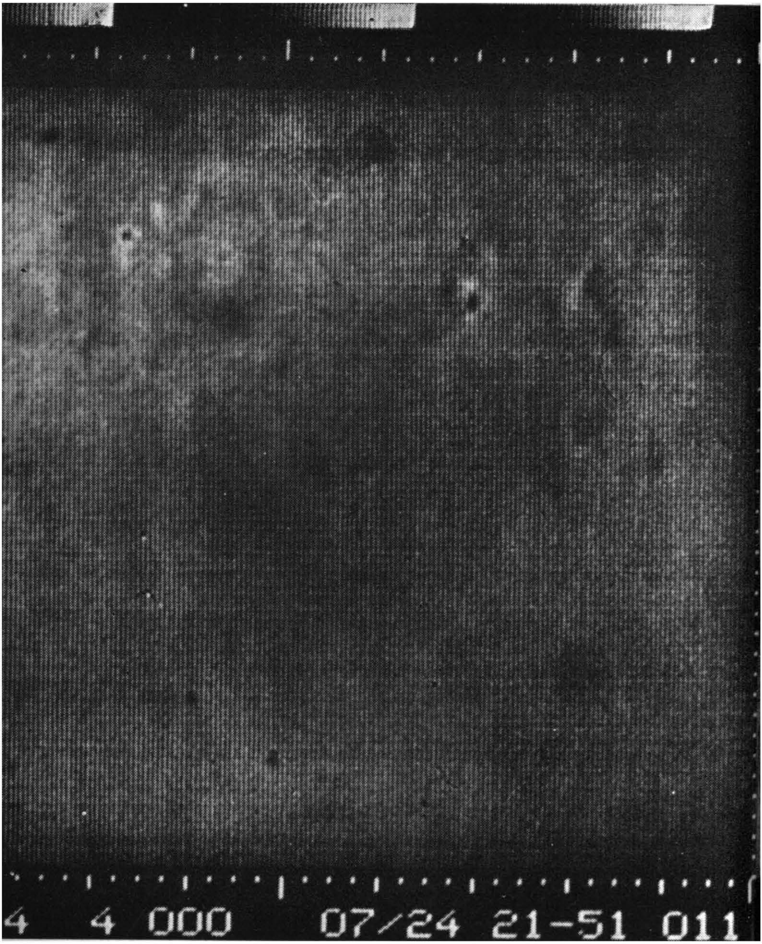
The same picture after removal of reference marks
and transmission flaws, with increased contrast.



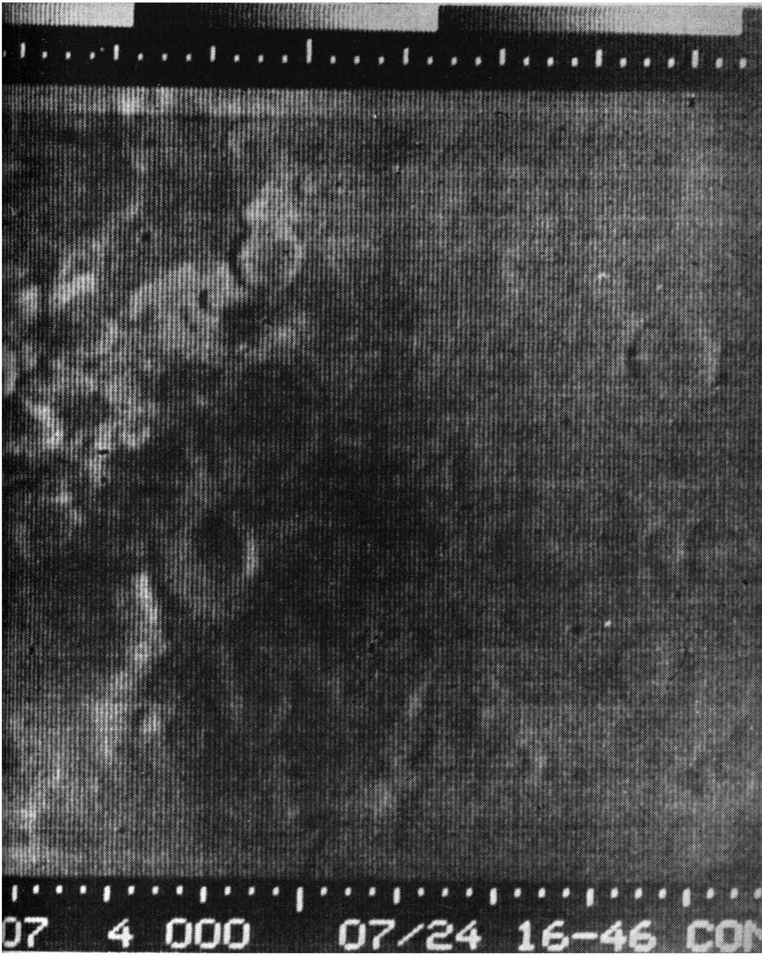
The second of the pictures taken by the Mariner IV spacecraft. Hardly any detail is showing. *Courtesy: NASA*



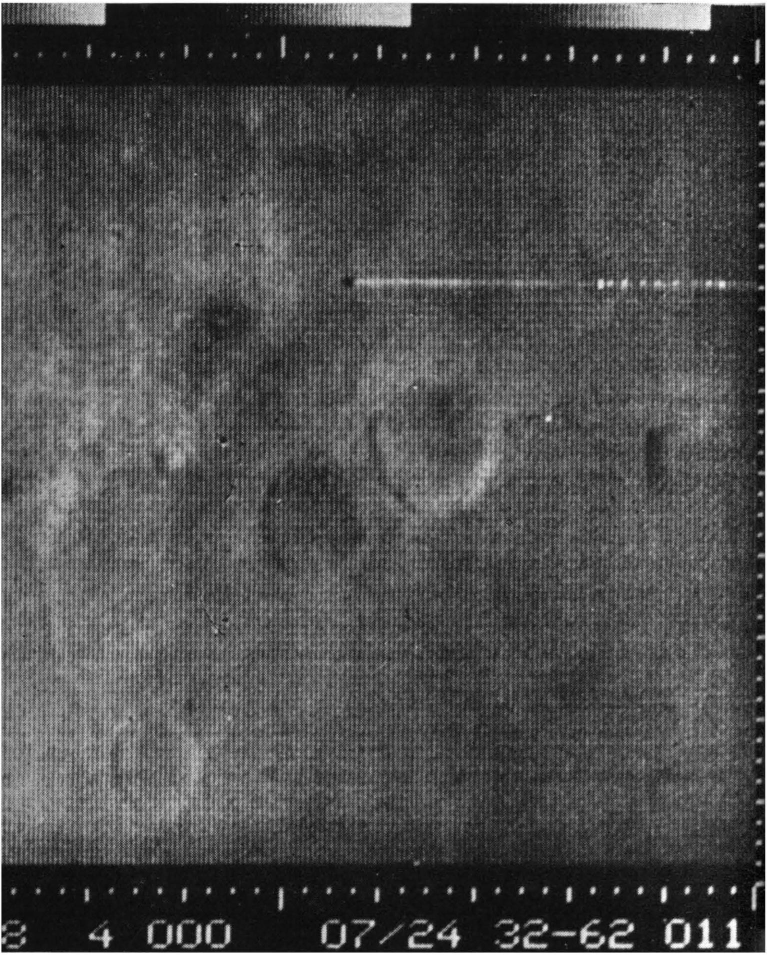
The third of the Mariner pictures. The general impression is that this is a desert, but features still lack all detail. *Courtesy: NASA*



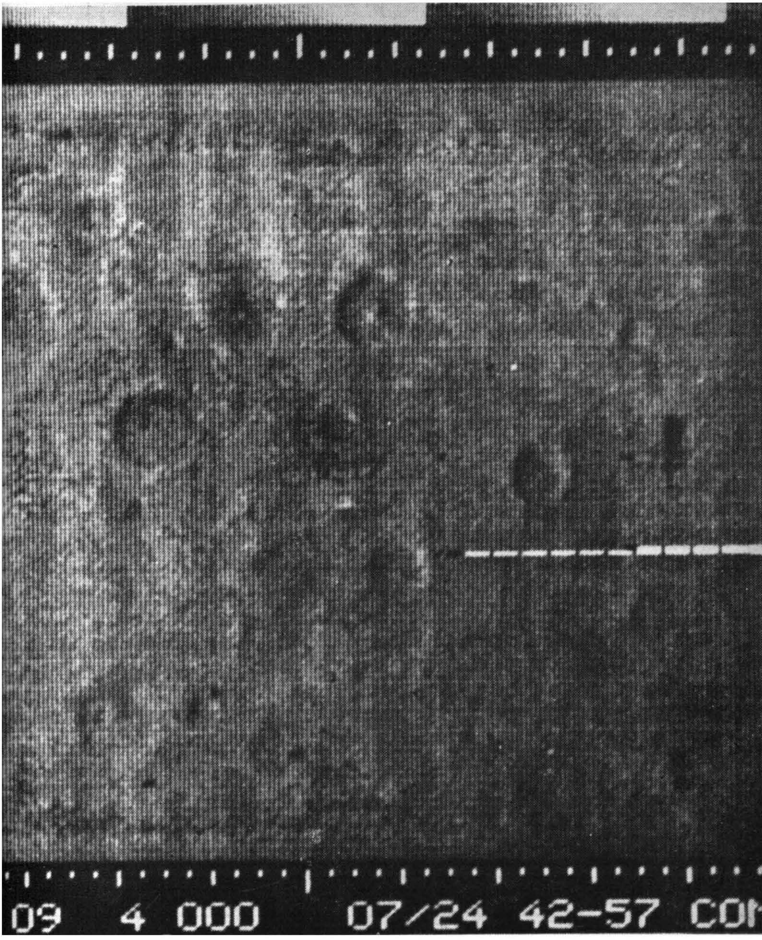
The fourth of the Mariner pictures. The surface detail is still quite poor, and if a few craters can be made out, it is mainly because the later and much better pictures make it clear that these shadings must be craters. *Courtesy: NASA*



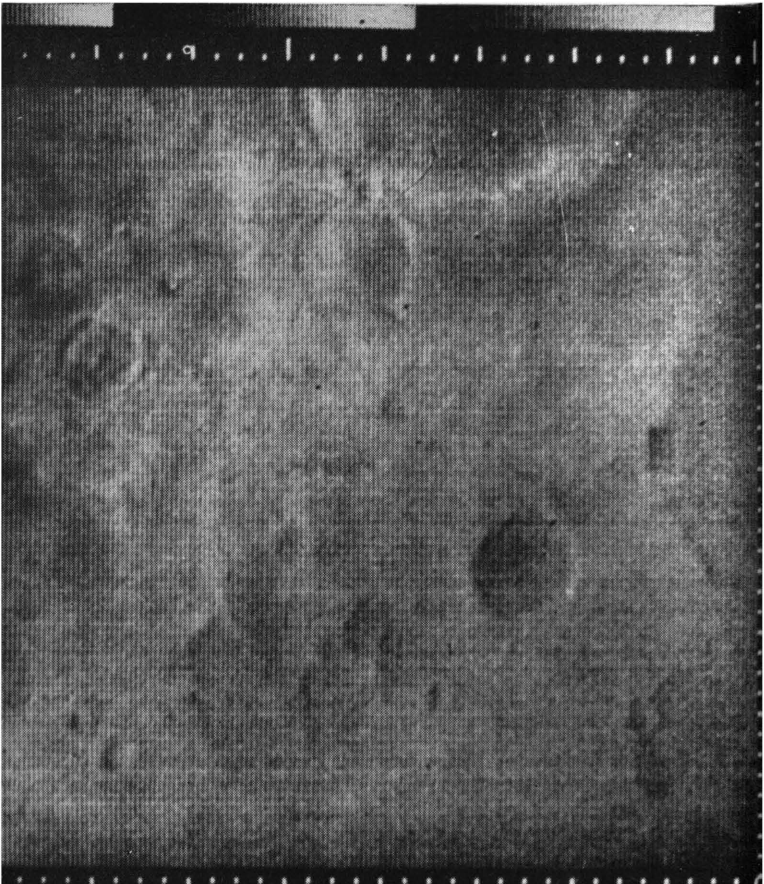
Picture number 7 of the Mariner series. Details begin to show now.
Courtesy: NASA



The eighth picture of the Mariner series. Surface features are becoming clearer with every picture from now on. *Courtesy: NASA*



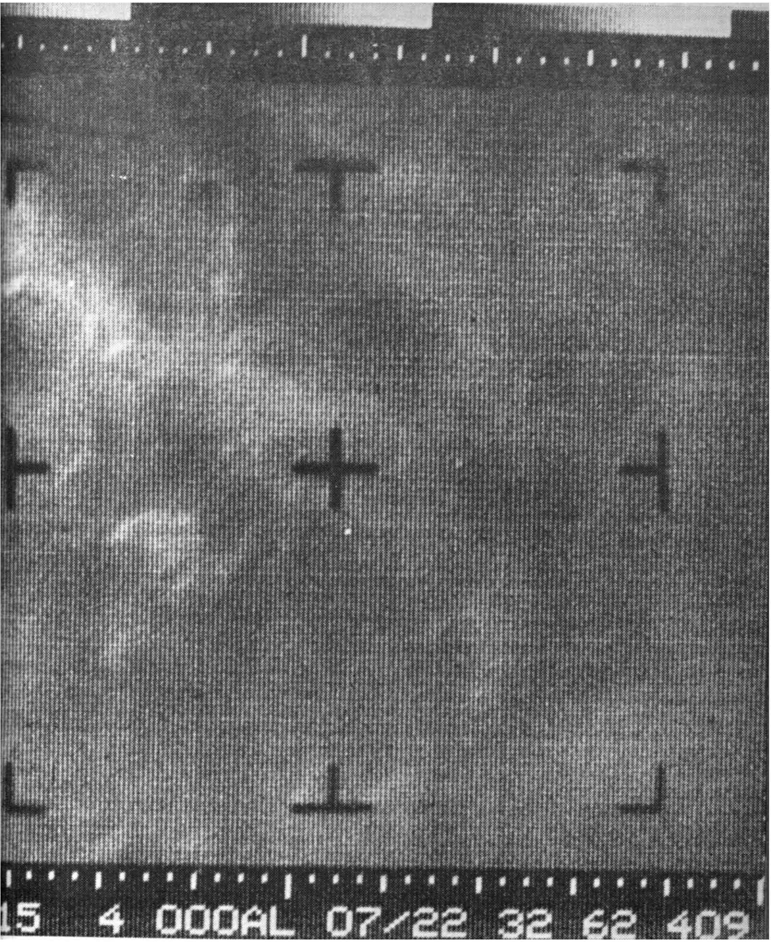
The ninth of the Mariner series. Craters are becoming more numerous; a few of them seem to have a central peak like many of the impact craters on our moon. White broken line is a flaw in the transmission, of course. *Courtesy: NASA*



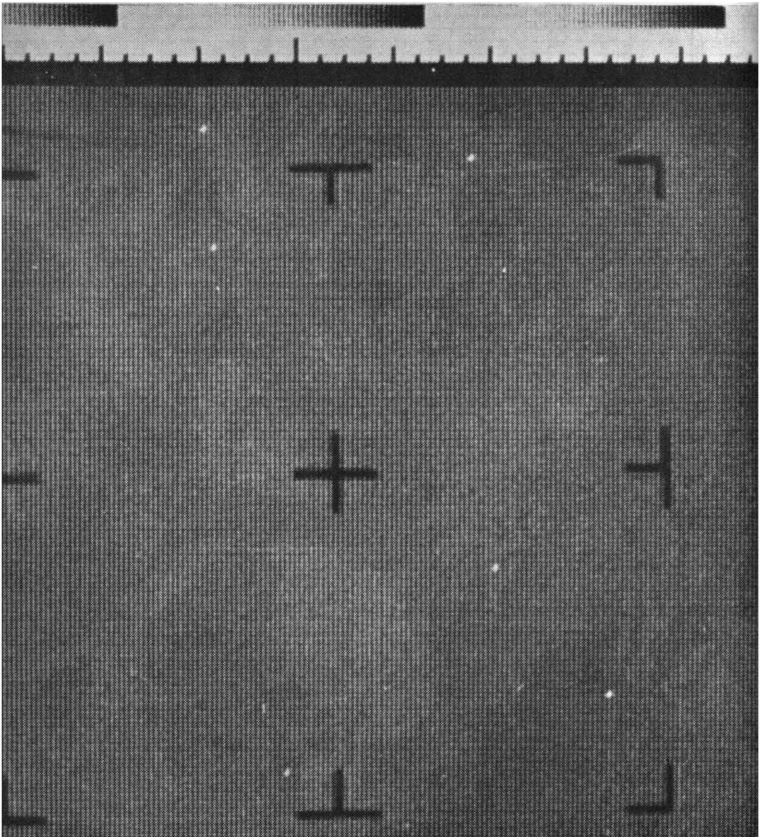
Mariner picture number 10, showing more craters and some frosting. The spacecraft began to approach the wintery hemisphere, in this case the southern hemisphere. *Courtesy: NASA*

Mariner picture number 11, the best of the whole run. Smaller impact craters can be seen inside a gigantic one. The whiteness is generally accepted to be frosting, though there is no way of judging the thickness of the layer. *Courtesy: NASA*

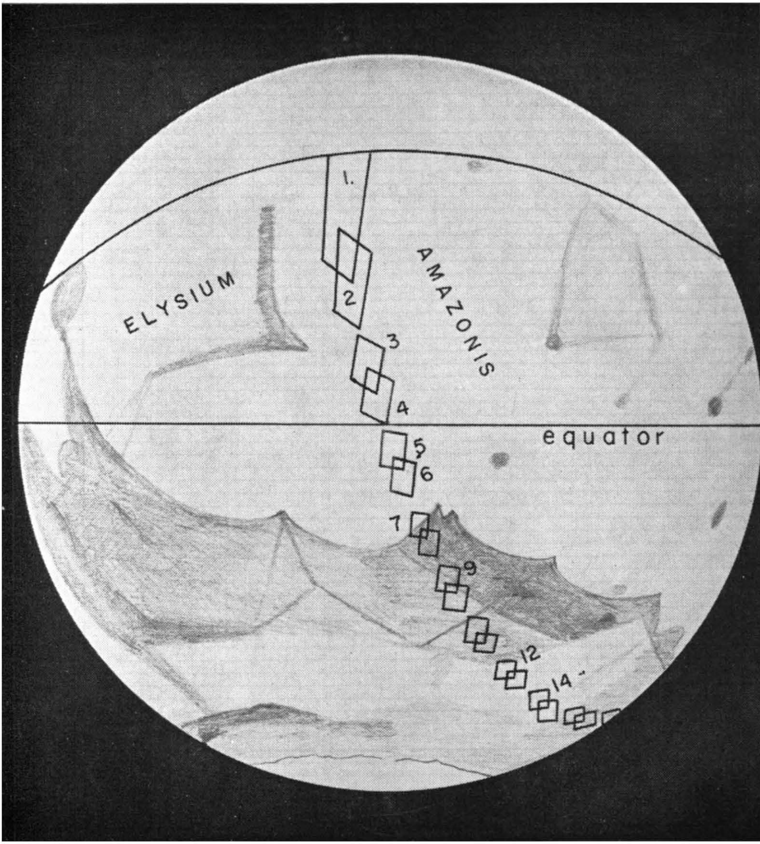
Mariner picture number 13, showing frost-rimmed craters and what may be a thin snowdrift, or else a frosted-over ridge of hills. It is winter in the southern hemisphere of Mars. *Courtesy: NASA*



The fifteenth of the Mariner pictures, the last of the useful ones. Some hoarfrost or snow, and what may be a deep hollow, can be seen. *Courtesy: NASA*



Picture 16 is quite weak, and only some whitish areas, indicating frost, can be discerned. A probable explanation was furnished by Dr. Clyde W. Tombaugh of the New Mexico State University Observatory, who observed Mars at the time Mariner IV took the pictures. He reported (*Sky and Telescope,* January, 1966, p. 30): "The planet's atmosphere seemed fairly clear, for dark markings such as Trivium Charontis and Mare Cimmerium showed good contrast. But the area south of Mare Cimmerium was quite white from either frost or cloud. The south limb showed bright in our red-light photographs and not at all in blue light, again suggesting frost or cloud. Such cloud may have contributed to the featureless character of Mariner's frames 16 and 17." *Courtesy: NASA*



The picture sweep of Mariner across the Martian surface. In this picture, north is on top and south at the bottom. The curved line in the upper portion of the planet's disk indicates the edge of Mars as seen from Mariner IV when the first picture was taken. Unfortunately the picture sweep did not pass over some of the most intriguing areas of the planet; it also did not include the southern ice cap.

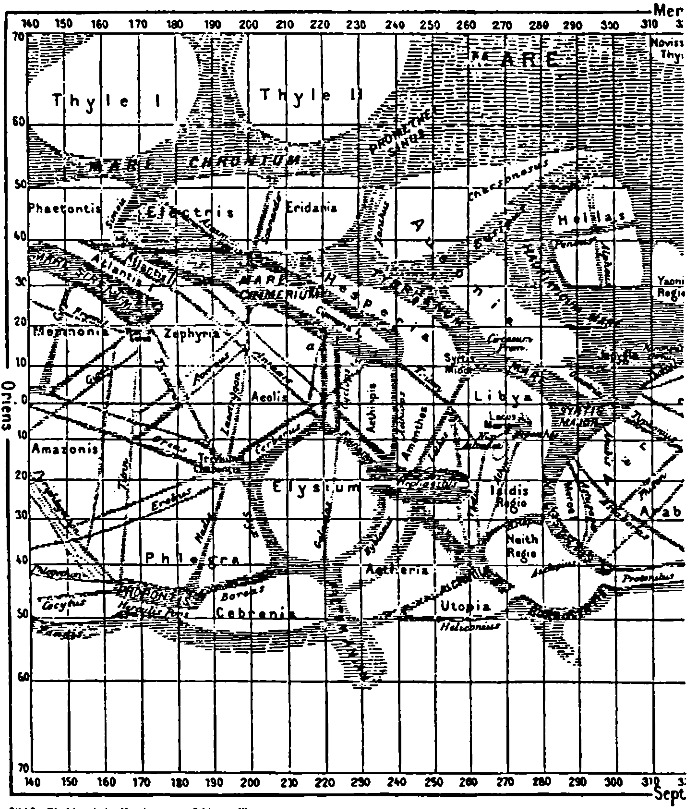
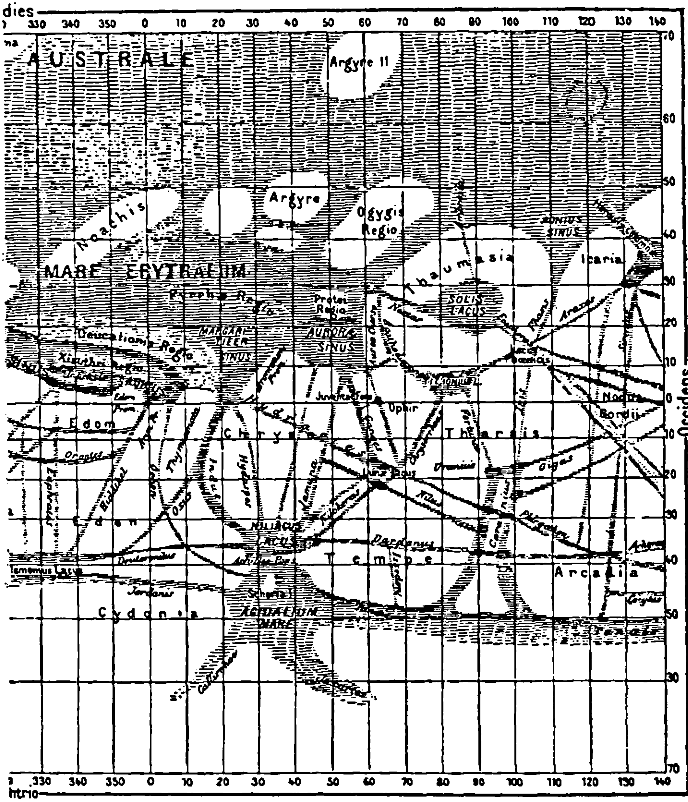
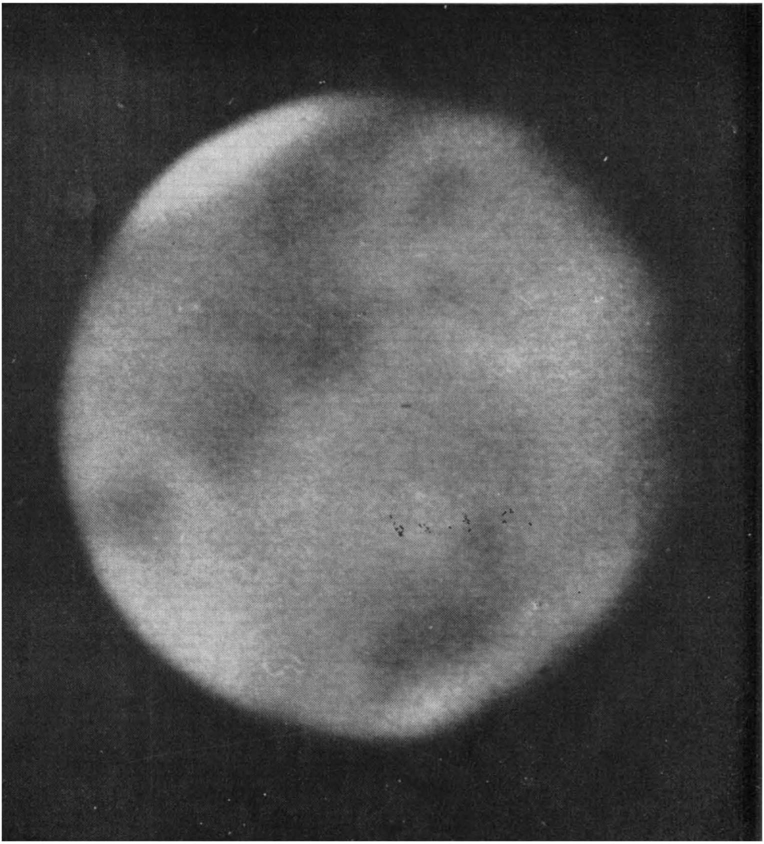


Bild 3: Die historische Marskarte von Schiaparelli

The historic map of Mars by Schiaparelli. This is the map of Mars published by Giovanni Virginio Schiaparelli in 1887, combining countless detail drawings that he had made during all the oppositions between 1877 and 1896. The map is in the Mercator projection, but South is at the top and East is at the left, since the astronomical telescope inverts the image.



By leaving the map inverted, later observers could directly compare it with their own sketches made at the telescope. Virtually all the names used by Schiaparelli are still in use, and all the more conspicuous canals seen by later observers could be fitted into Schiaparelli's map.



Mars on July 20, 1954. This photograph was taken by the Lick Observatory during the opposition of 1954. White arc at the top is the southern ice cap. Compare the positions of the dark areas to Schiaparelli's map in the preceding picture. Enlargement was made directly from the negative. *Courtesy: Lick Observatory* cal journal. In 1785 he calculated the orbit for a planet between Mars and Jupiter and published it in 1789 for the benefit of other astronomers. But in the meantime he looked diligently himself; it would be quite an accomplishment to find the "hidden planet," as he called it. Being unsuccessful, he thought of another method. The area where his "hidden planet" was hiding was obviously around the zodiac. If he divided the whole zodiac into 24 areas of equal size, and if he could find 23 willing collaborators, he could assign one such area to each of them and then the search was sure to be successful. He broached the idea to several other astronomers on the occasion of a small private get-together in 1800. They all thought it was a fine idea, and letters were drafted to astronomers in various countries, asking their cooperation. Among the recipients was Father Giuseppe Piazzi in Palermo, Italy. But Father Piazzi unwittingly spoiled the whole plan. During New Year's night 1800–1801, he accidentally discovered the "hidden planet" before Baron von Zach's letter even reached him! Father Piazzi's discovery was later named Ceres, and turned out to be the first (and largest) of the many tiny worlds that orbit the sun in the "gap" between Mars and Jupiter.

Uranus, discovered by Herschel, who at first thought that it might be just a comet, led to another prediction of that kind. It was carefully observed and its orbit carefully calculated. Everything was quite scientific and, as Argelander in Helsinki phrased it, "happy-making," but there was a minor problem: calculation and observation did not quite agree. About half a century after the discovery of Uranus, it occurred to several people that the discrepancy might be caused by an unknown planet, one orbiting outside the orbit of Uranus in the next position in the Titius table—that is to say, at about 30 A.U. During the years 1844 and 1845, two men decided to try and calculate the position of the unknown planet from the irregularities in the motion of Uranus.

One of the men was already established as an astronomer; he was Urbain Jean-Joseph Leverrier of the Paris Observatory. The other was a young Englishman by the name of John Couch Adams. Both carried out their calculations independently, both arrived at final conclusions early in 1846, and both were almost precisely correct. Adams, unfortunately, had bad luck. The observer entrusted with the search lacked enthusiasm and probably did not believe in the existence of an unknown planet. Or if he did, he doubted that it could be found by mere calculation. The observer, Challis by name, first delayed the search and then was inattentive.

As for Leverrier, he felt that the Urania Observatory in Berlin was better equipped for the search than any French observatory then in existence. He wrote a letter to Johann Gottfried Galle, giving him the results of his calculations. The letter, mailed on September 18, 1846, arrived in Berlin on September 23. Galle obtained routine permission from the director of the observatory, Johannes Franz Encke, to devote telescope time to the project. Since the night promised to be clear, he decided to start the same evening. He was assisted by a student by the name of Heinrich Ludwig d'Arrest who checked the charts, while Galle did the actual observing. Less than an hour after they began they found the unknown planet—it was later named Neptune.

Since this prediction had worked out so well, astronomers began to wonder immediately: was Neptune actually the outermost planet? Or was there another one? Naturally one had to wait for a few decades, because both Uranus and Neptune are slow-moving planets; their orbits had to be checked for a long time before the influence of another unknown planet—if any—could be discerned. After about half a century the time seemed ripe. The hunt for the still unknown planet turned into an all-America show. Percival Lowell became interested (and later obsessed) by the problem in 1905 and soon started a telescopic search. It was unsuccessful, and Lowell concluded that he had not done enough mathematical spacework. By 1909 William H. Pickering had done *his* mathematical preparation and began a telescopic search, also unsuccessful. By 1915 Lowell had his new set of calculations ready (bitterly criticizing Pickering's methods in the process), and he put his observatory to work. But this second search ended in November, 1916, when Lowell died. A third search—by the observatory that Lowell had built—was begun about a dozen years later, and this time it was successful. It was carried out by taking a photograph of a region of the sky and repeating the same photograph a week or several weeks later. Then the two plates were compared. Everything that was not a fixed star had moved during the time interval between the two pictures and then had to be identified. By comparing such a plate pair, a young astronomer, Clyde W. Tombaugh, found the unknown planet on February 18, 1929. It was named Pluto.

So this is the story of how planets have been predicted and then found.

The moons of Mars were predicted too. But how does one predict the existence of a moon? There is no rule like the Titius rule for the distances of moons from their planets. And a moon would not influence the orbit of its planet unless it were gigantic. Of course, a gigantic moon would be clearly visible and therefore need not be predicted.

The way the story is usually told is to begin with Jonathan Swift (1667–1745), creator of the immortal Captain Lemuel Gulliver. After traveling to Lilliput and to Brobdignac, Captain Gulliver visits the flying island of Laputa.[2] The Laputans, Captain Gulliver learns quickly, are exceedingly interested in astronomy and

> "spend the greatest part of their lives in observing the celestial bodies, which they do by the assistance of glasses far excelling ours in goodness. For this advantage hath enabled them to extend the discoveries much farther than our astronomers in Europe; for they have made a catalogue of ten thousand fixed stars, whereas the largest of ours do not contain above one-third part of that number. They have likewise discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half; so that the squares of their periodical times are very near in the same proportion with the cubes of their distance from the center of Mars, which evidently shows them to be governed by the same law of gravitation that influences the other heavenly bodies."

[2] The story was first published in 1726.

Now let's contrast this piece of fiction with the story of the actual discovery, as told by the discoverer, Professor Asaph Hall:

"My search for a satellite was begun early in August [1877]. At first, my attention was directed to faint objects some distance from the planet; but all these proving to be fixed stars, on August 10 I began to examine the region close to the planet, and within the glare of light that surrounded it. This was done by sliding the eyepiece so as to keep the planet just outside the field of view, and then turning the eyepiece in order to pass completely around the planet. On this night I found nothing. The image of the planet was very blazing and unsteady, and the satellites being at the time near the planet, I did not see them. The sweep around the planet was repeated several times on the night of the 11th, and at half past two o'clock I found a faint object on the following side [meaning trailing the planet] and a little north of the planet, which afterward proved to be the outer satellite. I had hardly time to secure an observation of its position when fog from the Potomac River stopped the work. Cloudy weather intervened for several days. On the night of August 15 the sky cleared up at eleven o'clock, and the search was resumed; but the atmosphere was in a very bad condition, and nothing was seen of the object, which we now know was at that time so near the planet as to be invisible. On August 16 the object was found again on the following side of the planet, and the observations of that night showed that it was moving with the planet, and, if a satellite, was near one of its elongations. On August 17, while waiting and watching for the outer satellite, I discovered the inner one. The observations of the 17th and 18th put beyond doubt the character of these objects, and the discovery was publicly announced by Admiral Rodgers. Still, for several days the inner moon was a puzzle. It would appear on different sides of the planet in the same night, and at first I thought there were two or three inner moons, since it seemed to me at the time very improbable that a satellite should revolve around its primary in less time than that in which the primary rotates. To decide this point, I watched this moon throughout the nights of August 20 and 21 and saw that there was in fact but one inner moon, which made its revolution around the primary in less than one-third the time of the primary's rotation, a case unique in our solar system."

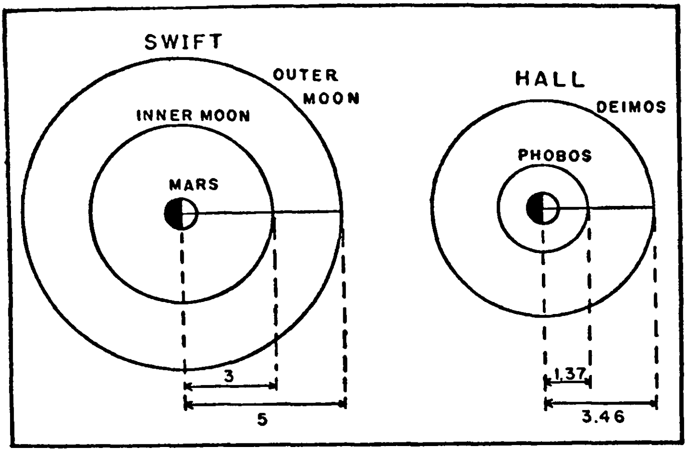


Fig. 11. Comparison between Swift's "prediction" and reality. The distances of the moons from the planet are given with the diameter of Mars as the measuring unit.

Elsewhere in his report Hall gave the figures for the distances and the periods of revolution [3] and when Swift's prediction and Hall's values were tabulated the agreement was truly astonishing. (See also Figure 11.)

Satellite	*Distance from the center of Mars (in Mars diameters)*		*Period of revolution*	
	Swift	Hall	Swift	Hall
Inner (*Phobos*)	3	1.38	10^h	$7^h\ 39^{min}$
Outer (*Deimos*)	5	3.46	$21½^h$	$30^h\ 18^{min}$

If the case is presented in this manner, one can only gasp with surprise. How could Swift possibly have known? It is absolutely certain that no telescope in existence anywhere in

[3] For the modern values, see Appendix.

his time could have revealed the Martian satellites to an observer.

But when presented in this manner, the story is not complete. Once you know the complete story there is still room for surprise, but the mystery is then not so profound.

It began with Johannes Kepler.

While engaged in the work that led him to interpose a planet between the orbits of Mars and Jupiter, he was bothered by one fact of nature, and that fact was our own moon. As far as Kepler or anybody else could tell, only the earth had a moon. Why, he wondered, had the earth been singled out? Of course, there was one possibility. Since this was before the invention of the telescope, nobody knew how large the other planets were, and while earth was a planet like Mercury, Venus, Mars, Jupiter, and Saturn, it was possible that earth was the biggest planet and that it might have a moon for that reason. No matter what Kepler thought, he had to accept the facts of nature, but the existence of only one moon in the whole solar system seems to have made him uneasy for a long time.

But then Jan Lippershey in the Netherlands invented the telescope, as a useful means of identifying ships at a distance. Galileo Galilei turned the new instrument skyward and wrote a little pamphlet full of the most astonishing discoveries. Where the naked eye saw half a dozen stars, the telescope revealed thirty. Where the naked eye saw dark spots on the moon, the telescope showed mountains and valleys. And where the naked eye saw the planet Jupiter blazing in the night sky, the telescope revealed that it had four companions, four moons.

Kepler received Galileo's pamphlet, the famous *Sidereus nuncius* ("Messenger from the Stars"), in 1610. He considered it wonderful news in every respect, but what impressed him most was the discovery of the moons of Jupiter. Earth was no longer singled out; another planet had moons, too. It had just been a question of the inability of the human eye to see them. Now this changed the whole case; now the orderliness of the solar system was at long last revealed. Mercury, the innermost planet, obviously had to be regarded as a moon of the sun. Venus, the second planet, was moonless; earth, the next planet, had one moon. Since Jupiter had four moons, the planet in between, Mars, had to have two moons. And Saturn, beyond Jupiter, would have either six or eight moons.

What is important for the story is that Kepler wrote a pamphlet explaining these ideas.[4] Everybody could read about his views, and the idea that Mars probably had two moons was planted. In 1643 the Capuchin monk, Anton Maria Schyrl, claimed to have seen them. Since we know this to be impossible, we have to conclude that Schyrl was deceived by two faint fixed stars which happened to show in the vicinity of Mars. But this claim, wrong though it was, proved that the idea had taken hold. Jonathan Swift, even if he had not read Kepler's pamphlet, must have known about it; if the Laputans discovered anything near Mars, it had to be *two* moons. Swift even made an oblique reference to Kepler by quoting "Kepler's Third Law" while talking about the relationship of the squares of the times of revolution and the cubes of the distances. Well, since Mars would have two moons but they had not yet been discovered, the next step was reasoning that they were very small. Also, they probably were very close to the planet, which would make them more difficult to see. All this was simple logical reasoning—it is unimportant whether Swift was speculating seriously or whether he did it just for story purposes—and the only arbitrary action was to assign distances to the two moons. Swift picked 3 and 5 diameters; the real distances are slightly less than 1½ and 3½. One can only decide for himself whether this is a very close agreement or not. (Or did Swift write "diameters" having "radii" in mind?)

The final discovery of the moons of Mars resulted in a short list of additional questions, the first of which was why they had been discovered so late. In 1834, the Viennese astronomer Joseph Johann von Littrow had called upon all astronomers to search for the two moons postulated by Kepler whenever Mars was in opposition. Presumably, many astronomers followed von Littrow's advice, but nobody came forward with a claim of discovery. In 1864, Heinrich Ludwig d'Arrest, the student who had helped to discover Neptune and who, meanwhile, had become a professor and director of the Copenhagen Observatory, made a painstaking search but also without any success. Because of d'Arrest's failure,

[4] It appeared in 1610 under the title *Narratio de Jovis satellitibus.*

someone voiced the suspicion that Mars actually had been moonless in 1864 but had succeeded in "capturing" two asteroids sometime between 1864 and 1877. Since Mars is quite close to the belt of the tiny planets, this thought was not unreasonable. But there was strong evidence that it was incorrect—evidence given by the orbits of the two moons.

Both orbits very nearly coincide with the plane of the Martian equator, and it is an established fact that all the moons in the solar system orbit their planets very nearly over their equators. Our own moon deviates from the earth's equatorial plane enough to be overhead as far as 28 degrees north or south of the equator, but our moon is exceptional in this respect; all the other moons are more closely above the equators of their planets. Obviously this has something to do with the process of their formation. We don't know how the moons formed, but whatever the process, it also applies to the Martian satellites. If the Martian satellites were captured asteroids, they would have any odd orbit around Mars; one might be inclined at a 45-degree angle and the other might even be in a polar orbit. *One* captured asteroid might accidentally have an equatorial orbit, but that two will do so is most unlikely.

Professor Simon Newcomb of the U. S. Naval Observatory, where Phobos and Deimos were discovered, did investigate the problem, approaching it from the point of view of available instruments. In a communication to the editor of the British astronomical journal *Observatory*, he said that the opposition of 1862 had been good enough for the discovery of the moons of Mars. But in that year there had been only two or possibly three telescopes powerful enough to show them. The 1864 opposition utilized by d'Arrest simply had not been good enough, and during the 1875 opposition Mars had been too close to the horizon for observers in the northern hemisphere. Thus 1877 was the first year in which a good opposition, a position high above the horizon, and sufficiently powerful telescopes had come together.

The next question in connection with the newly discovered moons of Mars did not originate among astronomers but came from interested laymen who wanted to know what a landscape illuminated by two moons might look like. Of course they were thinking of the type of moonlight we enjoy when the moon is full, so the answer must have been somewhat disappointing to them. Since the two moons are so close to their planet, there are large areas on Mars, namely the polar areas, from which they would never be seen. And there is another set of belts, one on the northern and one on the southern hemisphere of Mars, from which only the outer moon would be seen. To observe both moons well we would have to be in the Martian tropics. Well, let's pick a point along the Martian equator and see what can be seen.

Deimos, the outer moon, needs 30 hours and 18 minutes to complete one orbit around Mars. But the planet turns in the same direction, and therefore Deimos hangs in the sky in a given spot for a long time. It almost behaves like an artificial synchronous satellite. Deimos is, on the average, 14,600 miles from the center of Mars; if it were a little closer, namely 12,710 miles from the center, it would be synchronous and appear to be motionless in one spot of the sky all the time. As things are, it does travel slowly across the Martian sky, needing slightly more than 60 hours from

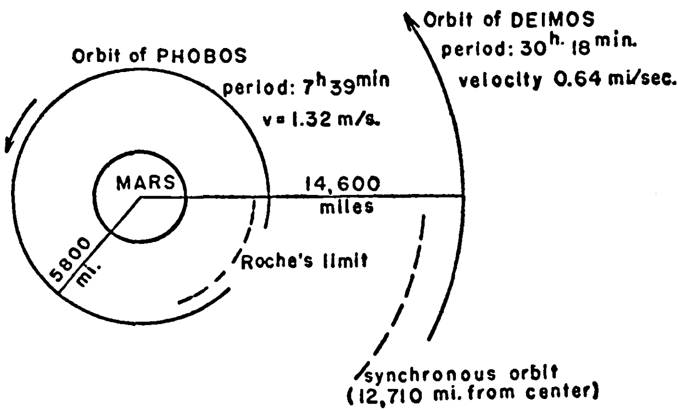


Fig. 12. Mars and its two moons; both the size of the planet and the orbits of the moons are drawn to scale. (The moons themselves are too small to show on this scale.)

moonrise to moonset. But because it is quite small—the estimated diameter is only five miles and may be as little as three—it would only look like a bright star, say like Venus when Venus is especially bright. A small telescope would enable an observer on Mars to see how Deimos gradually changes phases; to the naked eye these would appear as changes in brightness.

Phobos, the inner moon, completes slightly more than three orbits during a Martian day, but to an observer on the equator it looks like slightly more than two orbits per day, again because of the rotation of the planet. But even so, Phobos does overtake the motion of a given spot on the equator and, like our artificial satellites, rises in the west and sets in the east. (See Figure 12.)

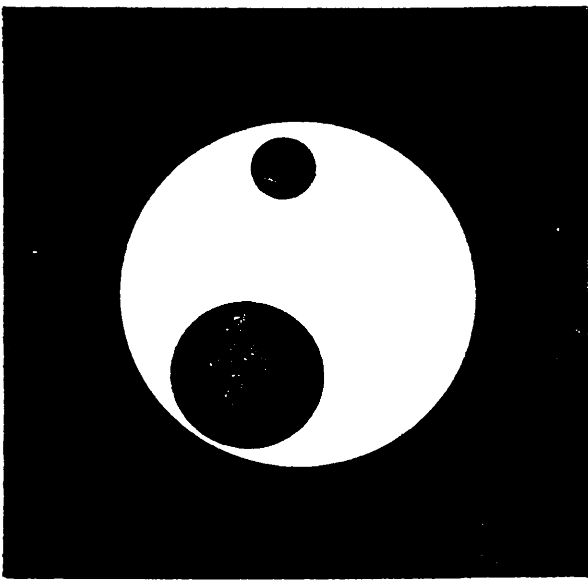


Fig. 13. Because the moons of Mars are so small, they cannot cause a true eclipse; they fail to cover all or even most of the solar disk. But an observer at the Martian equator could see both against the disk of the sun.

If an astronaut on Mars noted the moment of the moonrise of Phobos on his time sheet, he would see that Phobos rises again 11 hours and 6 minutes later. After climbing above the horizon Phobos needs 2 hours and 9 minutes to reach the zenith; while doing so it would noticeably increase in size. Since Phobos is larger than Deimos—about 8–10 miles in diameter—and is nearer to the ground, it would be seen as a small moon, with an apparent diameter of about one fifth of our moon. Another 2 hours and 9 minutes after reaching zenith it sets again, having grown smaller in the process and, of course, having gone through its phase changes. Both moons would be eclipsed very frequently because they often enter the shadow of Mars, but neither one could cause an eclipse of the sun. They are too small for that. Both Phobos and Deimos would just look like black spots on the face of the sun, and in the case of Phobos, an observer who wanted to watch this would have to be alert, for Phobos would cross the solar disk in just about 30 seconds. (See Figure 13.)

Aside from the strange performances of the two moons, the sky will look much the same from Mars as it does from earth, with one exception. An observer on Mars will have *two* morning and evening stars. One of them is Venus; the other and much brighter one is the earth. The larger asteroids, when Mars passes them, may show as medium bright stars for some time, but all the constellations will be the same as they are for us.

But we are not through with Phobos yet.

During the years just preceding World War II, the comparatively small number of astronomers devoted to work on the planets—most of them rarely think of our own solar system but work on problems of the stellar regions—noted that the orbital velocity of Phobos seemed to be on the increase. This means that its orbit is slowly shrinking. But to measure a tiny difference in the distance between the moon and the planet is far more difficult than to observe a small increase in velocity. However, a high velocity does mean that the moon must be closer to the planet than it was when Asaph Hall discovered it.

Such increase in velocity can be caused, strange as it may seem at first glance, by encountering some resistance along the orbit. But wouldn't resistance slow down an orbiting moon rather than speed it up? Whenever this question comes up in the classroom there is a sharp division of opinions between most students and their professor. The professor will say that "the orbital velocity increases because of resistance encountered," and the students will consider this a mistake. The students are wrong, mainly because they have not pursued the thought far enough. Of course, the first result of encountering resistance along the orbit will be to slow the movement of the moon. But the story does not stop there. What happens is this: The moon now is a bit too slow to stay in its orbit; its velocity is now insufficient to balance the gravitational pull of the planet *for that orbit*. Hence the moon will slant down toward the planet, and in doing so it gains velocity. Thus a new orbit is established nearer the planet, with a somewhat higher orbital velocity.

This point having been cleared up, the next problem is what causes the resistance. The obvious answer is "cosmic dust," and it is a good answer, except that it cannot apply in this case. If there were enough cosmic dust near Mars to cause resistance, it would obviously act on both moons. And if the cosmic dust has about the same density throughout the whole area, Deimos should be affected more than Phobos. Since Deimos is the smaller of the two moons, it has less mass, hence less kinetic energy; therefore it should show the effects of resistance to a greater degree. But Deimos just continues in its orbit without the slightest observable change. Hence cosmic dust cannot be the culprit. It must be something that is somehow tied up with the different distances of the two moons.

The next answer is "exosphere." This term has been invented to designate an area around our own planet that is beyond the atmosphere but still contains molecules of atmospheric gases. These molecules are too far apart from each other to form a continuous gas; one has to imagine that each molecule orbits the earth as a very tiny satellite. Since Mars has an atmosphere, it is reasonable to assume that it also has an exosphere. And this exosphere will influence nearby Phobos but not Deimos, which is too far away. It is very nice reasoning but it requires an exosphere several times as dense as our own at a comparable distance, something that simply does not go with the thinner Martian atmosphere.

Around 1960, a Russian scientist, the astrophysicist Dr.

Shklovsky, proposed an answer that solved all these problems with a considerable dash of audacity. Granted the exosphere of Mars cannot offer much resistance, said Shklovsky. But we are assuming all along that Phobos is a dense mass of rock. If Phobos were a comparatively small sphere, a mile or so in diameter, of very thin sheet metal, in effect a metal-foil balloon, it would be bright enough to look like a ten-mile sphere of rock. At the same time, its mass would be so small that it would be influenced by the Martian exosphere, thin as it is. But nature does not produce metal-foil balloons. Hence Phobos is an artificial satellite, put up by the Martians for navigational or communications purposes, probably orbited sometime between 1870 and 1875.

Until very recently there was nothing one could say about this assertion except that it was highly unlikely. Now one can be more definite. The measurements transmitted back by Mariner IV have proved that the Martian atmosphere is still thinner than even the most pessimistic earlier estimates. Therefore the Martian exosphere must be so tenuous that it would not influence even a metal-foil balloon.

But what about the change in orbital velocity that was being observed? Something must be causing it. Before Shklovsky startled everybody with his idea, a German scientist, Dr. Werner Schaub (a former president of the German "Society for Space Travel and Rocket Research") advanced a very ingenious hypothesis. We can't say whether it is true or not, but it is worth telling. It amounts, in short, to the suggestion that Phobos itself produces the dust that impairs its motion.

Before this can be explained in more detail, we have to go back a little more than a century for an idea that has caused (because it has been incompletely quoted) more misunderstandings than any other I can think of right now. This idea is known under the name of "Roche's Limit." A French mathematician by the name of H. Roche evolved it in 1848; it was published a considerable time later, in 1873, in the *Mémoires de l'Académie de Montpellier*. The main reason why I give year and place of publication is that hardly anybody else ever does; it looks to me as if whole generations of popular writers simply copied from each other. That would also explain the ever-growing amount of mistakes that have crept into popular books about Roche's Limit.

Roche stated that if a satellite is too close to a planet, it cannot stay in one piece because it will be broken up by the superior gravitational force of the planet. Beyond a certain distance the satellite will be safe, and that distance is Roche's Limit. It was said to lie at 2.44 radii of the planet, counting from the planet's center. Since we are talking about Mars, Roche's Limit for Mars might as well be mentioned here: it is 5148 miles from the center, or a little over 3000 miles from the planet's surface. Since Phobos is 5800 miles from the center of Mars, it is safely outside of Roche's Limit. But it has often been pointed out that no other satellite in our solar system is so close to the danger point.

This last statement is entirely the result of not knowing what Roche said originally. He carefully stated that he was talking about a *liquid* satellite, which was his way of saying that he had calculated the problem for a satellite of *zero tensile strength,* like a heap of dust. A satellite with tensile strength can stay inside this allegedly dangerous limit for any length of time, as has been demonstrated by hundreds of artificial satellites. This became known long before the first artificial satellite was put into orbit; the British astrophysicist Dr. Harold Jeffreys calculated in 1946 just how close a natural rocky satellite would have to come to be broken up. In the case of the earth, where Roche's Limit is 5700 miles from the earth's surface, a solid satellite would have to approach within 130 miles of the surface to be affected. Roche's Limit will probably go on infesting popular literature for a few more years to come, but for practical purposes we can safely ignore the whole story. However, it was thinking about Roche's Limit that led Dr. Schaub to investigate something else.

Of course, the earth will exert tidal forces on an artificial satellite. How closely would an artificial satellite have to orbit the earth so that these tidal forces become stronger than the gravitational force of the satellite itself? The answer is 1.3 radii of the planet, that is to say, three-tenths of the planet's radius above its surface, about 1200 miles in the case of earth. The figure of 1.3 radii applies strictly only if planet and satellite have the same density; if the density of the satellite is very low (let's say a burned-out liquid-fuel rocket body in orbit) the figure is considerably larger than 1.3. The next thing Dr. Schaub investigated was the question of how low the density of Phobos would have to be to make

Phobos fall within this limit in which the Martian influence would be greater than the surface gravity of Phobos. Dr. Schaub found that this would be the case if the density of Phobos were one half that of water. This is just possible if you are dealing with very porous rock. And what would happen if Phobos, or any other satellite, were inside "Schaub's Limit"? Something very interesting. The satellite itself would not be endangered in any way, but everything lying around loose on its surface would be lifted off and go into an orbit of its own. (See Figure 14.)

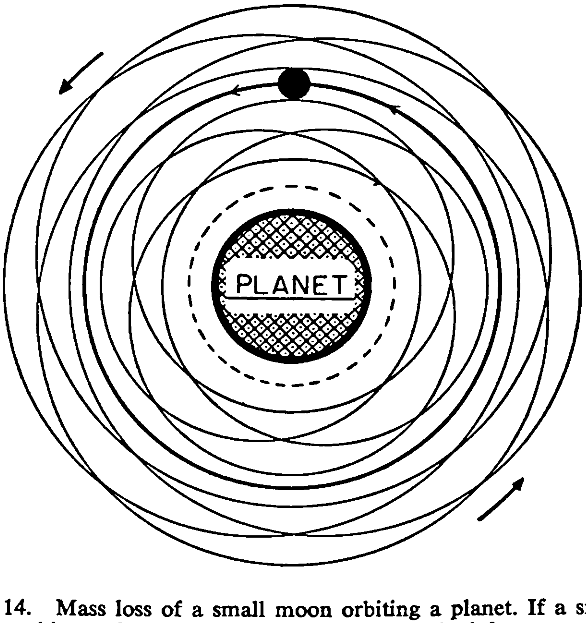


Fig. 14. Mass loss of a small moon orbiting a planet. If a small moon orbits a planet near Roche's Limit, the tidal forces exerted by the planet remove all loose material from its surface. In this diagram (which is not to scale), the dotted line indicates the limit of the exosphere, the heavy circle is the orbit of the satellite, and the fine lines show possible orbits of the separated material.

If Phobos is light enough to be inside "Schaub's Limit," all surface dust, gravel, and even larger rocks that are not anchored by anything but the feeble gravity of Phobos would be independently in space. The dust and debris would form two very tenuous rings along the orbit of Phobos, one outside its orbit and one inside the orbit. Each of these rings would have a thickness roughly equal to the diameter of Phobos and a width of about three times the diameter of Phobos. But since each one of the particles in these rings was pulled off Phobos at one time, each one has to touch the orbit of Phobos at one point and is then in the way of the orbiting moonlet. And each of the rings would lose mass by way of collisions between the particles, which would slow them down. As Dr. Schaub visualizes it, the outer ring would lose mass to the inner ring, and the inner ring would lose particles which would eventually graze the atmosphere of Mars and then unite with the planet.

This mechanism of mass loss provides a certain amount of dust and larger pieces of rock in and near the orbit of Phobos, and *only* near the orbit of Phobos. Deimos is too far outside the area in which such action can take place.

Whether this is the true explanation for the acceleration of Phobos' motions remains to be seen.

Only one small item can be added to the story of Phobos right now. When the flight path of the space probe Mariner IV was under consideration, it was suddenly realized that Phobos could ruin the whole mission. Even if everything went perfectly, the precise moment of the flyby could not be predicted; it might be an hour or two earlier or later than the calculated moment. But a few hours make a big difference in the position of Phobos in its orbit; a collision between the small moon and the spacecraft could not be ruled out. Hence Mariner IV should pass Mars closer than the orbit of Deimos, in order to get good pictures, but it should not come as close as the orbit of Phobos, since nobody could tell where Phobos might be at that moment. The thought that the spacecraft might approach Mars a little more closely than expected and run into Phobos must have been a recurrent worry for the scientists in charge during the 228 days the spacecraft was on its way.

4. *Five Views of a Planet*

(*1*) *Traditional*

The very fine opposition of 1877 was followed by a good opposition in 1879, and the next one, in 1881, was still reasonably useful. After that the oppositions grew poorer, and even the most diligent and indefatigable observer could hardly add anything new. But that did not matter too much. Astronomers used this relatively quiet time to look at their older sketches, to write up the results of their work, and to reason about what they had seen. Schiaparelli's first report, with the formidable title *Osservazioni astronomiche e fisiche sull' asse di rotatione e sulla topografia del pianeta Marte* ("Astronomical and physical observations about the axis of rotation and the topography of the planet Mars"), was published in 1878. A second and more leisurely report (with the same title) followed in 1881, and a third one in 1886.

Though Schiaparelli was by no means the only astronomer to report on Mars, it was generally conceded that his reports were the most important; the picture of Mars that dominated discussions was essentially that of Schiaparelli. (See Figure 15.)

In those days the so-called Kant-Laplace theory of the origin of the solar system was generally accepted. The theory itself was a fusion of the ideas of the German philosopher Immanuel Kant and the French mathematician Pierre Simon,

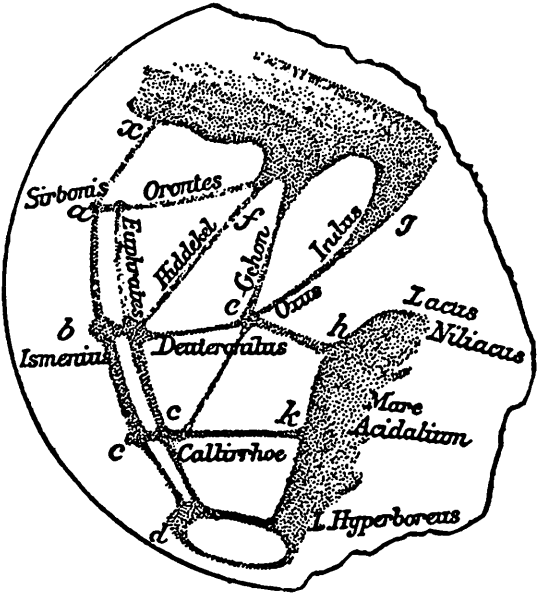


Fig. 15. Partial map of Mars, drawn May 28, 1888, by Schiaparelli. The elliptical area near the bottom of the picture is the northern polar cap.

Marquis de Laplace. Kant had died in 1804 and Laplace in 1827, and during the intervening half-century, several small modifications had been made by others so that Kant probably would not have recognized the theory that still bore his name and Laplace would have had grave misgivings about some details. But in 1880 and 1890, the so-called Kant-Laplace theory was the cornerstone of all thinking. This is what it said:

Originally, a very long time ago, neither the sun nor the planets existed; there was no solar system, and everything "was without form, and void darkness was upon the face of the deep." Expressed in more recent language, the sun and all the planets to come were part of a cosmic dust cloud that was cold and nonluminous. At least it had no luminosity of its own, though it may have been faintly illuminated by the light of nearby stars. But since each particle in the universe attracts every other particle, that dust and gas cloud could not last; the particles attracted each other and the cloud began to condense. In some manner the cloud also started to rotate. As it condensed, it rotated faster and faster—this the Marquis de Laplace could prove mathematically—and it was densest in the center. That dense center began to glow and became the sun, which quickly gathered up every last gas molecule and every last dust particle. But the sun rotated much faster than it does now, and it also was much larger by far than our present sun.

Because of the fast rotation, an equatorial bulge formed around the sun, and it was finally thrown off, at a distance from the center of the system that was roughly equal to the distance of the planet Neptune from the sun. This was no coincidence, for the solar bulge that had been thrown off contracted into a sphere, later the planet Neptune. In the meantime, the sun had condensed some more and had thrown off another bulge, later the planet Uranus. And thus it went on: Saturn was the next planet to be formed, then Jupiter,

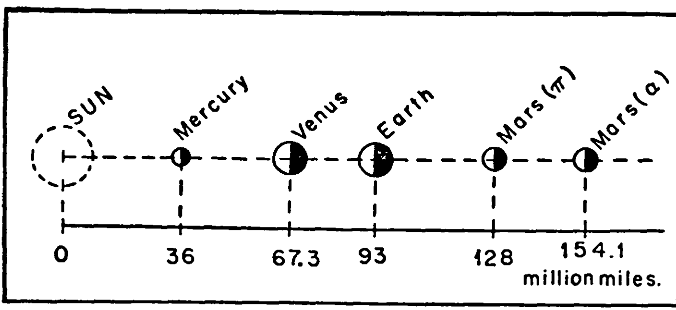


Fig. 16. The distances of the inner planets from the sun. Sizes of the planets are much exaggerated, but the distances are drawn to scale. Mars has been entered both in perihelion and aphelion positions.

then Mars, then the earth, after that Venus, and finally Mercury. The fact that the inner planets were much smaller than the outer planets could also be accounted for; they had been thrown off a steadily shrinking sun. (See Figure 16.)

That was the picture in the minds of scientists, and they could then go on and indulge in mathematical amusements, such as calculating at just what time in the past a certain planet, say, Jupiter, had been formed. Since this calculation depended on a number of assumptions, different mathematicians making the same calculations obtained different figures. But no matter whose figures you believed, or even if you distrusted them all, one fact was certain: Mars had to be older than the earth. Hence it had gone through the same development as the earth at an earlier time and now demonstrated a future era of the earth.[1]

The idea that Mars must be older than the earth had a number of important consequences. Mars might have started out with an atmosphere just like ours, but in the course of time it had lost a great deal of its atmosphere; that might be why its air was thinner than that of the earth. Mars might also have started out with as much water as the earth, but the extra time had been enough so that most of it had been lost. The atmosphere, of course, had been lost into space, while the water had disappeared into the ground. Strictly speaking, all the Martian water was still a part of the planet, but it had disappeared from the surface. That much of the surface was desert was easy to understand, if one followed this reasoning. But if all this was the case, then life should also have started earlier on the red planet.

So here we had an older and incidentally smaller planet which showed a number of features that looked familiar. There were, in the order of size: (1) the deserts, covering about three-quarters of the planet's surface; (2) the dark areas, looking sometimes greenish gray and sometimes blueish gray, taken to be seas; (3) the polar caps, but with the

[1] Current theories about the origin of the solar system also begin with a rotating and presumably cold cloud of cosmic dust and gas. The fundamental difference between these new theories and the one by "Kant-Laplace" is that the new theories assume that smaller condensations in the cloud began at the same time as the central condensation; in other words, that the sun and all the planets must be virtually of the same age. The sun, then, differs from the planets mainly by the fact that it was the only body massive enough to start an atomic reaction at its core.

difference that earth, if seen from the distance of Mars, would show two white polar caps at any time, while Mars had only one polar cap at a time; (4) yellow and sometimes white patches that obscured well-known surface features, evidently clouds, though they were rare; and finally (5) the *canali*, which were long and thin lines, usually gray and sometimes greenish. These *canali* were the mystery because earth had nothing like them.

One might say facetiously that most of Mars has never been the subject of controversy because most of Mars is desert, and nobody (with the exception of a few cranks) ever thought differently. Sir William Herschel took the yellow areas to be deserts, and so did the Reverend William R. Dawes. Schiaparelli said so also, and Percival Lowell agreed. And all living astronomers still take them to be deserts.

As for the second feature, the dark areas, the customary explanation, up to and including Schiaparelli, was that they were the remnants of the Martian oceans. But in 1892, the American astronomer William H. Pickering, observing from Arequipa, Peru, saw one of the *canali* inside a dark area; several others were seen soon afterward by several observers. That meant, of course, that the dark areas could not be seas, and an idea that had been tentatively uttered before, namely that the dark areas might just be areas covered by vegetation, came to the fore. For a while it was still believed that a dark area near the south pole named *Mara australis* ("southern sea") was actually a sea (and the only one on Mars), but then *canali* turned up in this area too.

The third feature, the polar caps, also caused little discussion. To quote from the book *Other Worlds* by the American astronomer Garret P. Service (published in New York in 1901):

> "From the time of Sir William Herschel the almost universal belief among astronomers has been that these gleaming polar patches on Mars are composed of snow and ice, like the similar glacial caps of the earth, and no one can look at them with the telescope and not feel the liveliest interest in the planet to which they belong, for they impart to it an appearance of likeness to our globe which at first glance is all but irresistible.

"To watch one of them apparently melting, becoming perceptively smaller week after week, while the general surface of the corresponding hemisphere of the planet deepens in color, and displays a constantly increasing wealth of details as summer advances across it, is an experience of the most memorable kind, whose effect upon the mind of the observer is indescribable."

That Mars had only one polar cap at a time, and that this polar cap disappeared completely as the season advanced proved once more that there was not much water on Mars. A polar cap that melted away could not be very thick —and this still is the prevailing opinion. The only thing that has changed is just what is meant by the term "thick." In 1890 they probably had in mind a snow cover of 100 feet or so in thickness; currently astronomers think of a few inches.

In regard to the next feature, the clouds, the need for a subdivision became apparent soon. The clouds that covered large areas were yellowish in color, but occasionally clouds of blinding white could be seen, and these were much smaller. It was not difficult to arrive at an opinion of what they had to be. The large yellowish clouds were no doubt dust or sand storms, easily understandable because of all that exposed desert area. The small white clouds then had to be clouds of floating ice crystals, like our cirrus clouds. Again, they were rare and small because there is not much water on Mars.

So far so good—but what were the *canali?*

First, let's find out just what was seen. Schiaparelli, writing in the French astronomical journal *L'Astronomie* (1882, pp. 217ff.), said:

"There are on this planet, traversing the continents, long dark lines which may be designated as *canali,* although we do not know what they are. Those lines run from one to another of the somber spots that are regarded as seas, and form, over the lighter, or continental, regions a well-defined network. Their arrangement appears to be invariable and permanent; at least as far as I can judge from four and a half years of observation. Nevertheless, their aspect and their degree of visibility are not always the same, and depend upon circumstances which the present state of our knowledge does not yet permit us to explain with certainty. In 1879 a great number were seen which were not visible in 1877, and in 1882 all those that had been seen at former oppositions were found again, together with new ones. Sometimes these canals present themselves in the form of shadowy and vague lines, while on other occasions they are clear and precise, like a trace drawn with a pen. In general they are traced upon the sphere like the lines of great circles; a few show a sensible lateral curvature. They cross one another obliquely, or at right angles. They have a breadth of 2 degrees, or 120 kilometers [74 miles] and several extend over a length of 80 degrees, or 4800 kilometers [ca. 3000 miles]. Their tint is very nearly the same as that of the seas, usually a little lighter. Every canal terminates at both its extremities in a sea, or in another canal; there is not a single example of one coming to an end in the midst of dry land.

"This is not all. In certain seasons these canals become double. This phenomenon seems to appear at a determinate epoch, and to be produced simultaneously over the entire surface of the planet's continents. There was no indication of it in 1877, during the weeks that preceded and followed the summer solstice of that world. A single isolated case presented itself in 1879. On the 26th of December, this year—a little before the spring equinox, which occurred on Mars on the 21st of January, 1880—I noticed the doubling of the [canal] Nilus between the Lakes of the Moon and the Ceraunic Gulf. These two regular, equal, and parallel lines caused me, I confess, a profound surprise, the more so because a few days earlier, on the 23rd and the 24th of December, I had carefully observed that very region without discovering anything of the kind.

"I awaited with curiosity the return of the planet in 1881, to see if an analogous phenomenon would present itself in the same place, and I saw the same thing reappear on the 11th of January, 1882, one month after the spring equinox, which occurred on the 8th of December, 1881. The duplication was still more evident

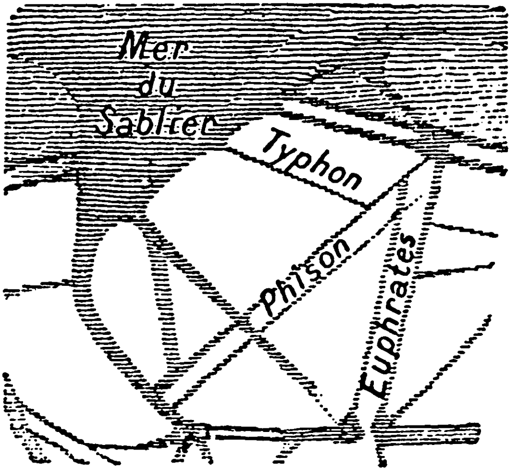


Fig. 17. An area of Mars, as drawn in 1890, showing the gemination of several canals. *Mer du Sablier* is the French name for *Syrtis major.*

at the end of February. On this same date, the 11th of January, another duplication [2] had already taken place, that of the middle portion of the canal of Cyclops, adjoining Elysium. Yet greater was my astonishment when, on the 19th of January, I saw the canal Jamuna, which was then in the center of the disk, formed very rigidly of two parallel straight lines, crossing the space which separates the Lake of the Nile from the Gulf of Aurora. At first sight I believed it was an illusion, caused by the fatigue of the eye and some new kind of strabismus, but I had to yield to the evidence. After the 19th of January I simply passed from wonder to wonder; successively the Orontes, the Euphrates, the Phison, the Ganges, and the larger part of the other canals displayed themselves very clearly and indubitably duplicated. There were not less than twenty examples of duplication, of which seventeen were observed in the

[2] Later on Schiaparelli referred to the doubling as "gemination," i.e., "twinning." (See Figure 17.)

space of a month, from the 19th of January to the 19th of February.

"In certain cases it was possible to observe precursory symptoms which are not lacking in interest. Thus, on the 13th of January, a light, ill-defined shade extended alongside the Ganges; on the 18th and on the 19th one could only distinguish a series of white spots, on the 20th the shadow was still indecisive, but on the 21st the duplication was perfectly clear, such as I observed it until the 23rd of February. The duplication of the Euphrates, of the canal of the Titans, and of the Pyriphlegethon also began in an uncertain and nebulous form.

"These duplications are not an optical effect depending on the increase of visual power, as happens in the observation of double stars, and it is not the canal itself splitting in two longitudinally. Here is what is seen: To the right or left of a preexisting line, without any change in the course and position of that line, one sees another line produce itself, equal and parallel to the first, at a distance generally varying from 6 to 12 degrees, i.e., from 350 to 700 kilometers [217 to 434 miles]; even closer ones seem to be produced, but the telescope is not powerful enough to distinguish them with certainty. Their tint appears to be a quite deep reddish brown. The parallelism is sometimes rigorously exact. There is nothing analogous in terrestrial geography. Everything indicates that here there is an organization special to the planet Mars, probably connected with the course of its seasons."

Though Schiaparelli, by present standards, was somewhat wordy, I have quoted the whole section on the *canali* from his article, which ended with the words: "I am absolutely certain of what I have observed." The reason for quoting Schiaparelli at length is threefold: in the first place, his original words have almost been forgotten; second, because paraphrasing always brings up the question of what he said himself; and third, in order to show that he did not attempt an explanation. At the time Schiaparelli wrote this article, the opinion that such lines must be the result of the engineering activities of intelligent inhabitants of the planet Mars was already widespread. Schiaparelli acknowledged that he was acquainted with these speculations and that he did not consider them "inherently impossible."

Personally, Schiaparelli never accepted the idea of intelligent Martians. Late in his life, in 1910 (only about five weeks before his death), he wrote in a personal letter: "I am of the opinion that the regular and geometric lines (the existence of which is still denied by many persons) do not yet teach us anything about the existence of intelligent beings on this planet."

So this was the traditional and cautious view of Mars held in 1890. Mars was an older planet, short of air and water, but perfectly understandable, except for the mysterious *canali*. The result of this view was, naturally, that all attention was focused just on these mysterious lines. One could not say anything new and profound about deserts or sandstorms or melting polar caps. Hence, if anybody wanted to say something about Mars, he had to talk of the *canali*.

Several explanations came to be repeated over and over again. The simplest, in great vogue with observers in northern Europe, was that they did not exist at all. More than one man said something like: "I have a telescope as good or better than Schiaparelli's instrument. My eyesight is perfect, and I spent many hours observing the planet. I never saw one of the *canali*. Therefore, there aren't any." Any suggestion that the failure might have something to do with the climate was rejected with indignation; wasn't it general knowledge that Europe had a better climate than any other continent? Better for comfort, yes, but better for astronomical observations?

The next explanation was that the *canali* were not "grooves" at all but low ridges of hills, and that we did not see the hills but only their shadows. The reply that *canali* had been seen while the sun was nearly vertical over the section of Mars where they appeared was rejected by saying that the shadows would, of course, disappear if the sun were *precisely* vertical above those hills. But it was only *nearly* vertical and could, therefore, still make shadows.

The next two explanations conceded that the *canali* were depressions in the surface of the planet, but in both cases big assumptions had to be made; they had the minor drawback that they were mutually exclusive. One party reasoned as follows: Mars is an older planet; therefore it can be assumed that it has cooled all the way through. Now the crust of Mars formed when only the crust was cold and the interior of the planet was still hot. Later on, when the core cooled too, it contracted so that spaces formed between the core and the crust. This led to tectonic breakdowns on a large scale. Probably all the dark areas are regions that settled on the smaller core, and the *canali* are just enormously long earthquake faults. The reason we don't have anything like that on earth is that the earth's core is still hot and the earth's crust therefore still fits. The proponents of this idea were quite willing to concede that water from the melting polar cap streamed through these earthquake faults into the low-lying areas, causing vegetation to spring up, and that we could see this is a form of a general darkening of the hemisphere that was moistened.

The other explanation came a little bit later, after the discovery of radioactivity. In that theory, Mars had formed a crust and lost its original heat. But radioactivity in its core kept producing more heat; hence the core of the planet began to expand. The rigid crust did not receive enough heat from the interior to expand at the same rate; hence it simply cracked in many places because of the expansion of the core. These cracks would be very deep and therefore look dark when seen from a distance. Of course if there was moisture it would collect in these cracks, and vegetation would darken them still more.

Of course, there was one more school of thought that reasoned that the *canali* had to have *some* explanation; one could not just let the problem hang in the air. Logic dictated that, here as anywhere else, the simplest explanation was the most likely explanation. Having long hilly ridges was no explanation at all, since there was nothing like it on earth. Operating with a shrinking or an expanding planetary core was possibly an explanation but not a simple one. Since no natural and simple cause for such long straight lines could be found, they had to have an unnatural cause. That meant that somebody had constructed them.

The main spokesman for this school of thought was Percival Lowell.

(2) *Optimistic*

Percival Lowell was born in Boston on March 13, 1855, of a patrician family that produced several distinguished people. One of Percival Lowell's brothers became president of Harvard University; his sister Amy became a well-known poet. After graduating from Harvard, Percival Lowell went to the Far East, mainly for business purposes. But while business was necessary for wealth, it bored him. He was a man who was at ease with classical authors in their original languages and who would almost miss a business appointment because he was engrossed in a book on advanced mathematics.

While still in the Far East, Lowell read about Schiaparelli's discoveries and decided that this was a subject of paramount interest that should be investigated. There should be an astronomical observatory that was not bothered by routine work, such as keeping track of time, making an almanac or a star chart, or predicting eclipses. There should be an observatory devoted specially to the planets—to Mars when it was in opposition, and to Mercury, Venus, and the other planets when Mars could not be observed. Having made this decision—and being able to carry it out financially—Lowell began to think about a location. Since he was an American, the observatory should be in America, of course. It should be in a dry area so that clouds, mists, and atmospheric moisture in general did not interfere. Well, there was the state the early Spaniards had actually called *arida zona,* where the air was dry. Still, near the ground the air was unquiet; hence the observatory was to be on a mountain (Percival Lowell is actually the father of the idea that an astronomical observatory should be on a mountaintop).

Lowell Observatory in Flagstaff, Arizona, was opened in 1894, a year when a good opposition was about to take place. Lowell himself was an indefatigable observer who amassed countless sketches of features of the Martian surface. Lowell saw the *canali* and described them as being so fine and so straight that only a line drawn on paper with a ruler could be considered a just representation, as he expressed it. He observed the gemination of the *canali* that Schiaparelli had described, and, like Schiaparelli, he found that a canal sometimes "hibernates." This term is used to mean that a canal which is a well-known and established feature of the planet's surface suddenly cannot be seen any more and remains invisible for several Martian years; then it reappears with equal suddenness. Several observers had noticed that there were round dark spots where several canals came together and had named these spots "lakes." Lowell found that at intersections of only two or three canals a much smaller round spot could be seen. He named these smaller spots "oases."

Percival Lowell soon decided that these canals could not have a natural explanation and that they must have been built by "intelligent creatures, alike to us in spirit, though not in form." He published this conclusion in his book *Mars* (published in Boston in 1895). His later books [3] defended the same idea, with more observational material and with somewhat increased passion.

Lowell was convinced that Mars represented the fate of the earth at some future date. At the time he wrote his last book, the traditional faith in the Kant-Laplace hypothesis of the origin and evolution of the solar system had grown somewhat shaky. It was at least doubtful whether one could accept Mars as older than the earth in terms of millions of years that had gone by. But because Mars was a smaller planet, it had "aged" faster and was older than the earth in its development, if not in actual age. Lowell looked with great concern at the desert areas of the world; to him they were the first signs of the aging of our own planet. "Palestine, the land that flowed with milk and honey, can now barely flow bad water," he wrote.

It is true that the desert areas of earth have expanded since early historical times and that all our deserts are, geologically speaking, of recent origin. What Lowell did not know then, was that there had been very extensive deserts in long past geological periods and that these deserts had been in areas that are not desert now. Modern

[3] *Mars and Its Canals*, New York, 1906, and *Mars as the Abode of Life*, New York, 1909. All quotations in this section are from the latter work. Since it appeared only seven years before Lowell's death, this book constitutes his final conclusions about Mars.

geologists will say that deserts apparently are the result of local conditions and that they do not necessarily indicate that our planet is aging. But Lowell thought so, and he also pointed out that at one time large areas of the North American continent had been covered by the sea; he took this as an additional proof that the water supply of the earth was slowly dwindling. It is quite true that America had been flooded repeatedly during the geological past, but the conclusion drawn in Lowell's time is no longer accepted as a matter of course. That the center of the North American continent, the western end of Asia—along a line now indicated by the river Ob—and most of Europe were flooded at one time does not necessarily prove that the earth had more water then. The flooded areas were large in extent, but the water was not very deep. If one assumes that the Pacific Ocean was less deep then than it is now, all the water needed for the flooding of the central section of the United States would be available.

However, the greater part of the geological knowledge that could be cited against Lowell was not available then, so that he had the knowledge of his time on his side when he made his case. In any event, if it was assumed that all the areas on Mars that now look dark are the ancient sea bottoms of that planet, one could state that Mars had much less water to begin with.

After many years of observation, Lowell had many interesting things to tell about the canals—statements that are still surprising and which have neither been explained in the meantime nor satisfactorily explained away. Some of the canals drawn by Lowell had a surprising length: "The Eumenides-Orcus runs 3450 miles from where it leaves the Phoenix Lake to where it enters the Trivium Charontis. Enormous as these distances are for lines that remain straight throughout, they become the more surprising when we consider the size of the planet on which they are found." Lowell had paid special attention to the width of such long canals and stated that none of them ever differed in width throughout its length. Practically every canal had a different width, but whatever it was, it was maintained from one end to the other.

Lowell and his staff had increased considerably the number of canals on the chart. "When Schiaparelli finished his life-work, he had detected 113 canals; this figure has now been increased to 437 by those since added at Flagstaff."

Of course Lowell was especially interested in the phenomenon of gemination:

"To begin by giving an idea of the phenomenon, I will select a typical example, which happened also to be one of the very first observed by me—that of the great Phison. The Phison is a canal that runs for 2250 miles between two important points upon the planet's surface. . . . In this long journey it traverses some 6 degrees of the southern hemisphere and about 40 degrees of the northern. In 1894 the canal was first seen as a single, well-defined line—not a line that admitted of haziness or doubt, but which was as strictly self-contained and slenderly distinguished as any other single canal on the planet. A Martian month or more after it thus expressed itself, it suddenly stood forth an equally self-confessed double, two parallel lines replacing the solitary line of some months before. Not the slightest difference in the character, direction, or end served was to be detected between the two constituents. Just as certainly as a single line had shown before, a double line now showed in its stead.

"Study of the doubles has been prosecuted for some years now at Flagstaff, and its prosecution has gradually revealed more and more of their peculiarities. The first thing this study of the subject has brought out is that duality, bilaterism, is not a universal feature of the Martian canals. Quite the contrary. It cannot be said in any sense to be even a general attribute of them. The great majority of the canals never show double at any time, being persistently and perpetually single. Out of the 437 canals so far discovered, only 51 have ever shown duplicity. From this we perceive that less than one-eighth of all the canals visible affect the characteristic, nor are these 51 distinguished in any manner, by size or position, from those of the other 386 that remain pertinaceously single. They are neither larger nor smaller, longer nor shorter, nor anything else which would suffice on a superficial showing to distinguish their strange inherent potentiality from that of those which do not possess the property.

"Now, this fact directly contradicts every optical theory of their formation. If the doubles were products of any optical law, that law should apply to all canals alike. . . .

"The next point is that the width of the gemination—the distance, that is, between the constituents of the pair—is not the same for all the doubles. Indeed, it varies enormously. Thus, we have at one end of the list the little narrow Djihoun, the constituents of which are not separated by more than 2 degrees; while at the other end stands the Nilokeras, with its members 11 degrees apart. That is, we have a parallelism of 75 miles in one case, and one of 400 in another. This fact disposes again of any optical or illusory production of the lines; for were their origin such, they would all be of the same width."

But while Lowell could not tell whether a certain canal might geminate from its appearance, he had found out something very peculiar about those that did geminate. Practically all of them could be found in what on earth would be the tropics; all of them were located between 20 degrees southern and 40 degrees northern latitude, though a few of them extended into regions beyond these limits. (See Figure 18.)

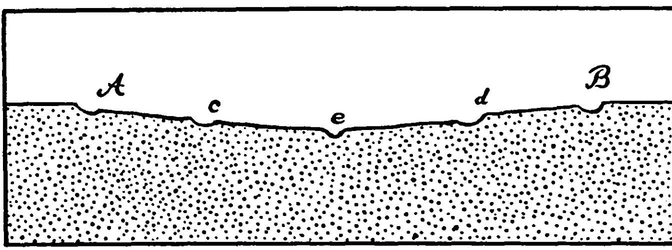


Fig. 18. An attempt to explain the gemination of the canals. In times of normal water supply, only canal A or canal B is in use. But if water is plentiful, both A and B are flooded. The water may then overflow into the subsidiary canals—c, d, and e—causing the whole area to look like one of those wide lines drawn by Pickering.

Speaking of the canals in general, not just the doubles, Lowell wrote:

"Regard for positioning is one of the most significant characteristics of the lines. They join all the salient points of the surface to one another. If we take a map of the planet and connect its prominent landmarks by straight lines, we shall find, to our surprise, that we have counterfeited the reality. That they are so regardant of topography on one hand, and so regardless of terrain on the other, gives a most telltale insight into their character; it shows that they are of later origin than the main markings themselves. . . . Since the seas probably were seas in function as in name once upon a time, the superposition must have occurred after they ceased to be such; for clearly the lines could not have been writ on water, and yet be read today. We are thus not only furnished with a datum about the origin of the canals, but with a date determining when it took place. The date marks a late era in the planet's development, one subsequent to any the earth has yet reached. This accounts for the difficulty found in understanding them, for as yet we have nothing like them here."

Lowell had many reasons to consider the canals to be artificial. Of course, we don't see the canal itself, he said, especially since they are not likely to be canals for the transportation of goods. In fact, he thought it quite probable that the canal itself would be covered with something to minimize water losses by evaporation. The only purpose of the canals was to irrigate the land, and what we did see was the vegetation nourished by the water in the invisible canals. That different canals had different widths was an indication of the amount of water they could carry. Likewise the "lakes" and the "oases" had their sizes determined by the area a given set of canals could irrigate.

But if one looked at the whole network of irrigation canals, one could see that the arrangement was not as efficient as it could have been made. There was no clearly visible "master plan"; the pattern looked more like the pattern of roads in a given piece of surface of our own earth. Even that could be explained:

"A planet's water supply does not depart in a moment. Long previous to any wholesale imminence of default, local necessity must have begun the reaching out to distant supply. Just as our large cities today go far to tap a stream or a lake, so it must have been on Mars.

Probably the beginnings were small and inconspicuous, as the water at first locally gave out. From this it was a step to greater distances, until necessity lured them even to the pole. . . . The thing was not done in a day, and by that very fact stamps the more conclusively its artificial origin."

The name of William H. Pickering was mentioned previously as the first to see a canal in a dark area. Pickering, also a Bostonian and only three years younger than Lowell, was a graduate of the Massachusetts Institute of Technology; he became a staff member there and later joined the department of astronomy of Harvard University, finally going to Arequipa to work in the observatory that Harvard University maintained there. Pickering was just as assiduous an observer of Mars as Lowell, and sometimes he was quite as daring as Lowell in his explanations and predictions. But when it came to Mars, the two did not agree.

In the year after Lowell's death—Pickering was still very much alive—the American astronomer Campbell wondered whether one could not approach the problem of the canals by a kind of confrontation between Pickering and Lowell. Both had been good observers, though the published sketches indicated at the very least that they had very different styles of drawing. Where Lowell drew hairlines, Pickering drew broad lines, sometimes almost smudges. Campbell, by going over the published work of both men—both men being represented by two decades of work on Mars—made a comparison that was published in 1918 by the Astronomical Society of the Pacific.

An excerpt from the comparison follows here:

Percival Lowell	William H. Pickering
Geometry	
They indubitably follow "great circles," or else they are combinations of portions of "great circles."	Most of the canals have a curvature that does not fit "great circles"; many are too short and too broad to decide this point.

Width

Fine lines 25 to 30 miles broad, often even finer (12 to 20 miles).

Gray "traces" of considerable width, between 100 and 250 miles, a few even wider.

Gemination

Only about one eighth of all canals were ever observed to geminate. Distances between the two components, 100 to 120 miles.

Occasionally seen for durations of seconds, they then appear as two very fine parallel lines about 60 miles apart. If the seeing is good, gemination does not take place; it may be due to atmospheric influences.

Shifting of the canals

Shifts in position do not take place! There are many more canals than is generally believed, and one sees sometimes the one and sometimes the other.

The same area can be seen crossed by a canal running north to south, and in another year by one running east to west. The canals shift by as much as several hundred miles, about 15 miles per day.

Presence of water

The water resulting from the melting of the polar caps moves toward the equator and causes vegetation to grow. Since these waters cross the equator, and nothing like this happens on earth, one is forced to conclude that the canals are artificial. The movement of the water takes place at the rate of about two miles per hour.

The "canals" are traces of precipitation. Mars, like the earth, has a low-pressure belt around the equator, and the atmosphere contains considerable amounts of water vapor. The pole that has spring and summer is a high-pressure area. Consequently, the winds go from the "summer pole" to the "winter pole." Because of the rotation of the planet, the winds are deflected, the equator is not crossed.

The two observers, one has to conclude sadly, might just as well have been talking about two different planets—the comparison attempted by Campbell did not settle the issue at all.

As a matter of fact, it is still unsettled. The list of astronomers who had never succeeded in seeing a "canal" and were ready to put it all down as optical illusion or eye strain, and who then had to revise their opinion because all of a sudden they did see a canal, is a rather long list. One cannot escape the conclusion that the canals will be seen when Mars is in a good position in the sky and when our atmosphere is exceptionally clear and quiet. There must be something on Mars that either forms straight lines and/or at least gives the appearance of straight lines when seen from a distance. (See Figure 19.)

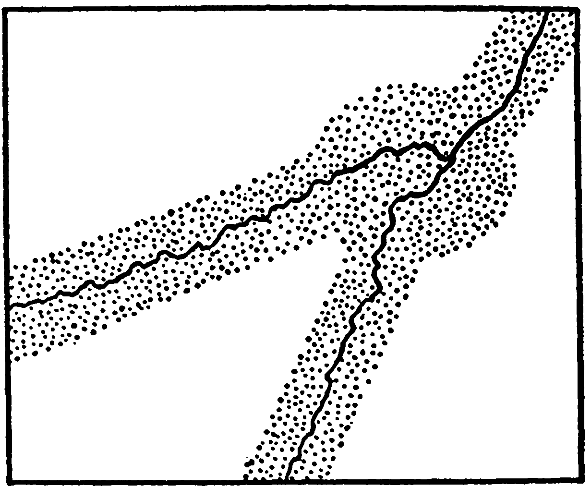


Fig. 19. An explanation of why the canals look so straight. Assuming that the actual canals are either rivers that are dry much of the year or earthquake cracks, they would be invisible from earth. But the vegetation they cause to grow would "even out" all the irregularities, and to us it would look like two straight canals joining at an oasis.

But by now nobody will risk his scientific reputation by attempting to explain them.

(3) *Skeptical*

Svanté August Arrhenius was born in Wijk near Uppsala in Sweden, on February 19, 1859. From the day he entered grade school until the day he entered the University of Uppsala, he was always at the head of his class and always the youngest member of the class as well. While a student at the university, he became interested in the relationship between electric current and chemical reactions, the field now known as electrochemistry, which then, of course, did not exist.

It was known in his time, however, that pure water did not conduct an electric current; that water containing salt did conduct electricity and that water containing sugar did not. Arrhenius set out to find out why, ending up with the conviction that the atoms of those substances that made water conduct electricity had to carry an electric charge themselves. This idea was so new that the instructors refused to believe it, and when Arrhenius applied for his doctorate there was a problem. The young man was defending an impossible idea, but the way he went about it was of scientific rigidity in the best academic style and tradition. And a four-hour oral examination left no doubt that he knew his chemistry. The professors compromised with their scientific consciences by awarding him a doctorate but with many reservations. Arrhenius just barely made it.

While Arrhenius' own professors were lukewarm, the great Wilhelm Ostwald in Germany agreed with him, and some six years after the date of the long examination, radioactivity was discovered. *Now* it was all of a sudden possible for an atom to have an electric charge; this was the main chemical news of 1890. Five years later Arrhenius was a professor himself, and in 1903 he was awarded the Nobel Prize in Chemistry for the same thesis that had been reluctantly accepted nineteen years earlier.

In the meantime Arrhenius had made other contributions, and in every case his ideas had been new and usually brilliant. Small wonder that anything Arrhenius said was listened to with great care. Being interested in the history of astronomy, Arrhenius slowly drifted more and more into astronomical disciplines as time went on. Since his best-known book in the United States is *The Destinies of the Stars* (Swedish original, 1915; American translation, 1917), many Americans don't even know that he was mainly a chemist.

Arrhenius had thought about the conditions on Mars for a number of years, and in 1910 he published his conclusions, writing in the German popular scientific magazine *Kosmos*. As could be expected of a chemist, he went in heavily for chemical explanations of the observed phenomena, causing the old Schiaparelli to remark that "they are more complicated than Dr. Arrhenius believes."

He began by citing a calculation that had been made by the astronomer Christiansen in Copenhagen in 1890. Christiansen had come to the conclusion that the influx of solar radiation on Mars could not raise the surface temperature of the planet above *minus* 33 degrees Fahrenheit. Since Christiansen had stated in detail just how he had made the calculation, Arrhenius checked it and then said that it probably gave a temperature that was too low. If the same method were applied to the earth, the temperature would be found to be an average of 44 degrees Fahrenheit, which is less than what we know the average temperature of the earth to be, namely about 62 degrees Fahrenheit.

"One could hope, therefore," Arrhenius said, "that the actual temperatures on Mars are somewhat higher, but that the difference between the calculated and the actual values should be on the order of 40 to 50 degrees can hardly be assumed. Only the fact that the snow cover around the Martian pole disappears during the summer and that the nearby 'sea' then assumes a blueish color, which we know only as the color of liquid water, helped to maintain the belief that the Martian temperatures had to be similar to those on earth. In an effort to support this idea, I once suggested that the Martian atmosphere might contain large quantities of heat-retaining gases, such as carbon dioxide."

By the time he wrote this article, Arrhenius had come to the conclusion that large bodies of water, with or without ice cover, did not exist on Mars. He pointed out that the positions of earth, Mars, and the sun had often been such that an observer should have seen the reflection of the sun in a Martian ocean, but that nobody had ever succeeded in seeing this, either by accident or when looking for it.

He then quoted some American work, carried out in 1908, that had tried to estimate the water-vapor content of the Martian atmosphere from which an idea about the temperature could be derived. E. C. Slipher, working in Lowell Observatory, had found that the content of water vapor near the surface of Mars was about 2.1 grams per cubic meter. This vapor content, in a moist climate near the seashore, would indicate a temperature of about 14 degrees Fahrenheit, but in a very dry desert climate the same water-vapor content would indicate 42 degrees Fahrenheit. But the astronomer Campbell, taking similar measurements during the same opposition from the top of Mount Whitney in California, arrived at values which were only about one-third of Slipher's.

"My estimate," Arrhenius continued, "based on Campbell's measurements, is that the vapor content must be 0.4 grams per cubic meter or slightly less. This means that the temperature in a dry desert would be around 2 degrees Fahrenheit. This is valid for midsummer on Mars, and it is likely to be the mean daytime temperature. This is 35 degrees higher than Christiansen's calculation of the mean temperature of Mars. On earth the value for the mean temperature in July is around 82 degrees, and Christiansen's calculated value is 44 degrees. The difference, therefore, is 38 degrees Fahrenheit, almost the same as the difference between Christiansen and Campbell for Mars; this similarity speaks in favor of calculations based on Campbell's findings."

Arrhenius then went on to say that the difference between day- and night-time temperatures of the air in a desert climate can easily be 60 degrees Fahrenheit, while the temperature of the soil may show a difference twice as large. "It is therefore entirely possible that the temperature of the soil can climb to a reasonable degree above the melting point of water; this, in combination with the low air pressure, which Lowell estimates to be one-twelfth of that on earth, can cause rapid evaporation or even the melting of snow."

Having established that temperatures are very low, Arrhenius said in so many words: *"Mars is indubitably a dead world."* But while he felt convinced about this particular aspect, he still had to explain in some manner what had been seen by the observers.

Beginning with the deserts, he stated that they were no doubt old, even by the million-year yardsticks of the geologists. Because of their great age, meteoric material had had time to accumulate in these deserts:

> "Meteorites contain a great deal of iron; some of them consist of nearly pure iron. After these meteoritic particles had arrived on Mars they were oxidized by the oxygen in the Martian atmosphere. This process produces iron oxide, a substance that assumes different colors according to grain size.
>
> "The finest dust is yellow in color; somewhat larger grains show the well-known orange-red ocher color which is characteristic for Mars . . . still larger pieces are plain red, and the largest crystals show a violet tint. The larger the grain size, the darker the color; wetting them acts like an increase in grain size. It has often been observed that details of large areas of the Martian surface are hidden by a yellow veil, evidently desert dust carried by winds; Lowell gave this explanation too. It is obvious that the thin air can carry only the fine yellow dust, only rarely orange-colored dust.
>
> "When a canal that had disappeared reappears again, one often sees, as Schiaparelli stated, a red line in the pink surroundings. Evidently the desert sand was moistened before the typical dark green color of the canal became visible. On other occasions one can see that the area is covered by a gray mist; later, when the mist has disappeared, the canals can be seen. No doubt the canals are low-lying areas into which the cold misty air flows, as it also happens on earth. Again a slight moistening produces a 'canal'; this does not require a large quantity of water."

Like others, Arrhenius explained the darkening by moistening, but others thought that the moistening caused the growth of a desert vegetation, while Arrhenius tried to explain it by purely chemical means. He followed the same method of reasoning with regard to larger darkish areas:

> "The lakes that form in the low-lying areas are, like

desert lakes on earth, very shallow, with very salty water. Often they dry up completely. When this happens the relatively insoluble salts are deposited first along the lake shore. Considering the low temperature these must be sulfates and carbonates. Farther inside the lakes ordinary salt and magnesium chlorate will form crystals; in the deepest places the hygroscopic salt calcium chlorate will finally crystallize. But this drying up could also be caused by freezing . . . salt solutions like these freeze only at temperatures far below the freezing point of water. The freezing point for a saturated solution of ordinary salt lies at minus 8 degrees Fahrenheit and that for a saturated solution of calcium chlorate at minus 67 degrees Fahrenheit. When such solutions are frozen they form crystals of ice or crystals of the salts; in other words, the surface is not smooth . . . the so-called 'oases' probably resemble the salt steppes of the earth, large plains of strongly salty soil."

One point stressed by Arrhenius was that ranges of hills must exist, and such hills would impede the flow of liquid water from the melting, or rather evaporating, polar cap. But if the moisture from the polar cap moved in the form of fog, or possibly airborne ice crystals, low hills would not interfere with the flow.

The overall view of Mars, then, as seen by a great chemist, was: A world where the temperature does not rise above the freezing point of water, except locally. A world with very little water which, even if it assumes the liquid state, is very salty. But the slight moistening that does exist has the results of making certain crystals change color.

No vegetation, no Martians, no life at all—"indubitably a dead world."

(4) *Fantastic*

Even before Arrhenius published his article in which he declared Mars to be a dead world, another European had tried to find an explanation of the observed features without intelligent Martians. His name was Adrian Baumann, and his book appeared in Zürich, Switzerland, in 1909. I have not been able to find out much about Baumann. I don't know, for example, whether he was a climatologist or a geologist or a "philosopher." At any rate, he worked by inverting much of the earlier reasoning.

Mars was a cold world; the temperature only rarely rose above the freezing point of water and then only locally. But the important point, Baumann stressed, was that Mars was not a cold world only at the present time. It had always been cold. Hence its water had never been able to seep away into the interior of the planet because it stayed frozen all the time, except for some minor melting at the surface on rare occasions. Therefore Mars had at least as much water as the earth. The areas called continents by Schiaparelli were frozen oceans of fresh water—since all the water had always been frozen there had been no rivers to leach out salts and to carry them to the sea, making it salty—with a few islands in them. These islands all were volcanic in origin, and some of the volcanoes were still active. When they erupted, they produced the yellow clouds labeled dust storms by Schiaparelli and others. Of course the volcanic clouds settled after some time and covered the frozen oceans; that's why they look like deserts to us.

The true continents on Mars were the dark areas; they looked dark because of vegetation which had adapted itself to a cold climate, as had the vegetation of the Siberian tundras. It was even possible that similarly adapted animal life existed in these areas. As regards the polar caps and the white clouds, they were ice crystals; the clouds consisted of ice crystals, but as for the polar caps, one could not tell whether they consisted of a deposit of hoarfrost on the ground or were merely an accumulation of white clouds. (It must be remarked here that a Martian polar cap, because of the contrast of blinding white against the black sky and of the darkish surrounding land, often looks as if it were detached from the planet. This illusion is especially pronounced in photographs.)

The canals were chasms in the frozen ice, cracks caused by powerful volcanic eruptions in the past. Once they had formed they would be permanent, since there was no melting and so little atmospheric precipitation that the little snow that might fall from time to time would never fill them up. Of course dust from the volcanic eruptions would also fall into these cracks, but since they were so deep it would simply disappear from view.

(5) *Recent*

The belief in intelligent Martians slowly faded away during the years following World War I, but this was not due to a specific theory, such as the one by Svanté Arrhenius, or because of a specific discovery. In retrospect, it looks as if astronomers had simply grown weary of the problem; all the arguments pro and con had been published a dozen times or more, and there was nothing new that could be said.

That a certain nostalgia in favor of intelligent Martians lingered on, even to this day, cannot be denied. As little as a year ago, a scientist (biologist, not astronomer) wrote plaintively in a private letter to me "that many things about Mars could be best explained if one could still postulate the existence of intelligent inhabitants."

Of course, the idea that the canals might have been the work of intelligent inhabitants of the past occurred to quite a number of people. The reasoning went more or less along the lines expressed by Lowell, but it was carried one step farther. Let's suppose that at some time in the past the Martians did have to start to husband their water supply, ending up with the full network described by Lowell. But by now it seems to be clear that there is not enough water left even to fill the canal system. That would mean that in looking at the canals we look at the once useful ruins of ancient people; the Martians themselves finally succumbed to the universal drought, but their handiwork survived them. Others, thinking along the same lines, were unwilling to subscribe to the idea that a "people"—no other word will do the job as quickly—that had progressed to a planet-wide irrigation system would simply die off. They might be reduced in numbers, but they must have made all the inventions we have made and some others on top of it. Did they leave their planet in spaceships and go elsewhere? Obviously they had not traveled to earth, probably because earth was "too wet" for them (they had lived with drought conditions for many millennia). Or did they literally go underground, having cities below the surface, where they could regulate the air pressure and temperature to suit their preferences?

All these thoughts were written down and published at one time or another.

While writers could indulge in such speculations, the astronomers, that is, those astronomers interested in the planets of our solar system (they form a fairly small minority) doggedly pursued their studies, trying to find out whether the dark areas at least consisted of plant life. One of the first measurements made after World War I turned out to be quite encouraging. There was the excellent opposition of 1924, and new instruments and new methods were brought to bear on Mars by the astronomers staffing the observatory founded by Lowell. The new methods permitted measuring the surface temperature of the planet. The results were published by the Bureau of Standards (Scientific Paper No. 512, 1925), and they would have surprised Arrhenius. The surface temperature at sunrise was *minus* 49 degrees Fahrenheit; the temperature at high noon near the Martian equator was around the freezing point of water, running from 14 to 41 degrees Fahrenheit for the desert areas, but from 50 to 68 degrees for the dark areas. The temperature at sunset (for an equatorial region) was down to 32 degrees. Since these temperatures were measured from the outside through the Martian atmosphere, one could estimate that the actual ground temperatures would be higher by a few degrees. This certainly seemed warm enough to permit specially adapted plant life to thrive. Some twenty years later it was seen that a new dark area, somewhat larger than Texas, had appeared. Apparently Mars was not as dead as some had supposed.

But then the question came up whether one could simply accept the dark areas as vegetated areas just because it had become traditional to do so. It was an Esthonian astronomer, Ernest Öpik, who had a very simple answer. Dark areas are often covered up by the yellow windborne dust, and they then disappear. But after two weeks or so they are back, looking dark again. If the darkness were that of minerals, Öpik said, they would stay covered up. But plants would simply grow through the thin dust layer.

While this was generally admitted to be true, there was still room for doubt. If the dark areas were hard basaltic lava flows, they would not stay covered up. A windy day would wipe them clean, as could be observed on such lava flows here at home.

Somebody then thought that he had obtained spectroscopic evidence of substances that are formed by plants but are not formed otherwise. Other chemists conversant with spectroscopic methods could say, however, that this might have been a mistake, citing a number of technicalities. So even that was no proof.

In between, a few other ideas were suggested. In 1955, Dean B. McLaughlin published a paper in which he tried to account for at least some of the dark areas by suggesting that they might be deposits of volcanic ash. Lowell had already pointed out that the dark areas of Mars show a curious resemblance to the continents of earth. All the continents, save for Antarctica, have either a triangular shape or, in the case of Australia, at least a triangular point, in this case Tasmania. This would not be too unusual in itself, but all the points are at the southern ends of the continents; all the triangles point toward the South Pole. The dark areas of Mars also show triangular points, and they also point in the same direction, except that in the case of Mars all the triangles point toward the Martian North Pole.

Dean McLaughlin's idea was that the points of the Martian dark areas might be active volcanoes, and that the triangular markings were made by windborne ash and cinders from these volcanoes. He strengthened his argument by calling attention to the fact that the dark areas are darkest at their pointed ends and that the color gradually becomes less pronounced with distance. It was, in a way, an amusing thought, but interest in the idea did not last long. Meteorologists could not conceive of wind patterns that would be so consistent that the volcanic ash would not be blown in almost any other direction as well. And the argument that volcanic ash, when covered up by a dust storm, would stay covered up, was brought up at a moment's notice.

Still more radical than Dean McLaughlin's volcanic ash theory was one advanced in 1960, which reminded readers immediately of Arrhenius; it was one more attempt to explain all the changes on the planet by way of chemical interactions. The authors of the theory were Doctors C. C. Kiess, Harriet K. Kiess, and C. H. Corliss, and their reasoning was based on the then current estimates of the composition of the Martian atmosphere. It was believed to consist of 98 percent nitrogen, one percent argon, not quite one percent carbon dioxide and traces of oxygen and water vapor. Now, the compound nitrogen tetroxide is chalky white in color; the polar caps, therefore, consisted of this compound. The seasonal spread of darker color—the "wave of darkness" of Schiaparelli and Lowell—was explained by the spread of heavy gaseous nitrogen tetroxide. Clouds of crystals of this substance would look very white; they are the white clouds. But the heat of the sun will change nitrogen tetroxide into nitrogen dioxide, which looks yellow, and is, therefore, the cause of the yellow clouds. Since all nitrogen oxides are poisonous, this explanation completely ruled out all forms of life. In the case of Dean McLaughlin's theory, one could still have volcanic ash and plant life side by side; in fact, they go well together since volcanic ash is quite fertile. But the Kiess-Kiess-Corliss theory had a totalitarian character; if you had the nitrogen compounds you could not have anything else.

Nobody paid more than passing attention to the idea.

Coincidence willed it that just about that time some Russian work on Mars became available. It had been carried out by the rather elderly Professor G. A. Tikhov and his collaborators.

If one accepted the dark areas as vegetated areas, which is what most astronomers were willing to do, there was a little obstacle that was considered serious by some and unimportant by others. The Martian plants reflected sunlight, the same sunlight that is reflected by our plants. But the Martian plants reflected it in a different manner. Our plants reflect visible light of certain wavelengths, *plus* invisible infrared (heat) rays. The Martian plants reflected a few wavelengths of visible light only. If one considered this a fairly minor difference, one only had to say, "Well, the plants on Mars are different from earth plants." If one considered this an important difference, one had to wonder whether they were plants at all.

Tikhov knew about this, of course. In fact, he himself had collected evidence that the reflection was different and had wondered why. Then somebody suggested that the difference might be due to the fact that all the earth plants—usually forests—that had been used for comparison lived in fairly mild climates; naturally, the astronomers had used the forests around their observatories. Tikhov then saw to it that cold-climate plants, plants of the High Pamir range and of the northern Siberian tundra were investigated. He found that these cold-climate plants reflected light like the Martian plants. They could not afford to reflect infrared rays because it was too cold. Naturally, Martian plants could afford even less to waste infrared rays.

By 1960 it had become clear that research on Mars had gone as far as it could with instruments based on earth. To advance some more it would be necessary to investigate Mars with instruments not handicapped by our atmosphere.

One possibility was an astronomical camera orbiting the earth and taking pictures of Mars—along with other measurements—from above our atmosphere. The other possibility was to send a picture-taking probe to Mars.

5. *Mariner To Mars*

The Mission

On November 1, 1962, a Russian rocket carrying a planetary probe designated Mars I was in orbit around the earth. As the carefully calculated moment for breakout of the parking orbit arrived, a radio command flashed invisibly through the atmosphere. The rocket ignited and pushed Mars I into the orbit that would carry it to Mars. Everything went well, and the Russian scientists felt certain that their 1940-pound probe would pass within 600 miles of the Martian surface in mid-June, 1963. At various intervals Mars I reported by radio, the automatic signals indicating that everything was going well—the probe was on course, the instruments functioned, and the transmitter had enough power to bridge the ever-increasing distance. On March 31, 1963, just ten weeks before the expected flyby, the transmitter stopped reporting. Nothing was ever heard of Mars I again.

Russian scientists do not really know themselves what happened. They have settled for the theory that the probe, possibly because of a meteorite impact, started tumbling, making its radio beam sweep wildly and uselessly through space. The probe must be in an orbit around the sun by now, but that is all that can be said with any certainty.

There could not be another Mars probe for some time because of the motions of the two planets involved. Just as there is a period for the visual observation of Mars, namely five or six weeks before opposition and five or six weeks afterward, there is a specific period for sending a planetary probe to the red planet. This period has received the name of "launch window," and the next one after the one used by Mars I would be from November 4 to December 2, 1964. Both the U.S.A. and the U.S.S.R. prepared probes for that next launch window.

On November 5, 1964, the United States launched Mariner III for Mars. At first everything went well; the rocket carrying Mariner III took off on schedule and the probe achieved open space. But then it failed to obey orders; none of the radio signals flashed at it produced any response or reply. A careful analysis of what had not taken place revealed a comparatively small malfunction which, however, was such that it ruined the whole mission. For passage through the atmosphere, the probe had been encased in a capsule that is technically known as its shroud. After achieving space, this shroud is to be jettisoned; then the space probe can unfold itself, mainly for collecting energy from sunlight. The lack of response indicated that the shroud had not been jettisoned, so that the probe stayed imprisoned and unable to do anything.

Fortunately, a backup probe was available, and Mariner IV could still take off during the same launch window. It did take off on November 28, 1964. This time the shroud was thrown clear on schedule, and the first messages from Mariner IV were received soon, indicating that the first crucial maneuver had been carried out successfully. By the time these messages were received, the Russians launched their Mars probe, named Zond II. The date was November 30, 1964. Only three weeks later the Russians sent out a puzzled announcement, saying that their probe developed only about 50 percent of the electric current. This did not yet spell failure, since one can transmit messages over very long distances through empty space with surprisingly little power; one half of the power that had been expected might be enough for success. It could be taken for granted that the Russians had designed their power-generating units with a comfortable safety margin. But another five weeks later they had to admit that their power had dropped to zero. Zond II was still on course, but it had become a useless piece of machinery, just like Mariner III. Mariner IV continued on its voyage.

A "launch window" for a space probe is equivalent to an opposition for visual observation, but it is not the same. Opposition means that the planet is close to the earth, and the closer it is, the better the opposition. For a space probe, the distance is unimportant; the launch window is just the time when one can send a space probe to the other planet with the knowledge that it will reach the orbit of the other planet *at a time when the planet is in that point of its orbit.*

The limitation is produced by the fact that both planets move. The earth orbits the sun with an orbital velocity of 18½ miles per second; evidently the space probe, after it has achieved space, still moves around the sun with the same velocity, since it was a part of the earth originally. If no velocity were added to the space probe, it would simply keep orbiting the sun in an orbit quite similar to that of the earth. But if a certain amount of velocity is added, the space probe slowly moves farther and farther away from the orbit of earth along a slanting curve (which is a portion of an ellipse) and approaches the orbit of Mars.

In 1914, the whole problem was investigated for the first time in detail by a young German engineer, Dr. Walter Hohmann. In August of that year World War I started, but the great political and military events did not stop him; they merely slowed him down by causing him some extra work. By early fall of 1916, his "investigations of the orbits that would be traveled by spaceships," as he privately called his work, had been completed. But Hohmann reasoned that this was not the time to publish such a book, so he put his manuscript away and did not return to it until 1924, providing a final polish. In 1925 it was printed; by that time Dr. Hohmann was city architect of the city of Essen on the Ruhr. He remained in his post, and it is very likely that he never learned that big rockets were being built during the last years of his life. He was killed in a bombing raid during the last month of World War II. But now certain types of interplanetary orbits are officially known as "Hohmann orbits."

Mariner III as well as Mariner IV, and also Zond II, traveled along Hohmann orbits.

The way Hohmann approached the problem was this: If one has two orbits like those of the earth and of Mars, two orbits that can be considered as concentric circles for the first attempt at investigation, it looks at first glance as if the simplest connecting orbit were a straight line between them. That would be the case if you were standing still (with regard to the sun) on the inner of these two orbits and just wanted to go from orbit to orbit. But you are not standing still on the inner orbit, and you don't want to go from orbit to orbit, you want to go from planet to planet. Keeping this in mind, that apparently simple connecting orbit turns out to be loaded with practical difficulties.

First of all, you have to get free of the gravitational pull of the earth, which requires a velocity close to 7 miles per second. Having expended that much energy, you are still moving with the (fairly distant) earth around the sun, so that motion has to be killed. It means a velocity change of 18½ miles per second, namely from that velocity to zero. Now you need an energy expenditure to move from the orbit of the earth to the orbit of Mars against the gravitational pull of the sun (let's say 3 miles per second, since you don't want to spend too much time in space). Now you have arrived at the orbit of Mars, and the planet is rushing at you with its orbital velocity of 15 miles per second; if you wish to survive you better acquire 15 miles per second in a hurry. Then you have to land on Mars against the gravitational pull of that planet, which is 3.1 miles per second.

Adding up all the velocity changes required for the "simple" connecting orbit, you get the following horrifying result:

1. Takeoff from earth	7	miles per second
2. Eliminating earth's orbital velocity	18.5	"
3. Traversing distance between orbits	3	"
4. Acquiring orbital velocity of Mars	15	"
5. Landing on Mars	3	"
6. Reserve for safety and corrections	1.5	"
Total velocity changes	48	miles per second

And then you are marooned on Mars, with no fuel for take-off and for the return trip.

Hohmann realized immediately that this could not be done and rejected the straight-line orbit as an impossibility.

Well, how about an orbit like the one shown in Figure 20? This is a slanting curve connecting the two orbits, which means that the earth's orbital velocity would not have to be eliminated; rather one would have to add to it and at the same time veer away from the earth's orbit at a sharp angle.

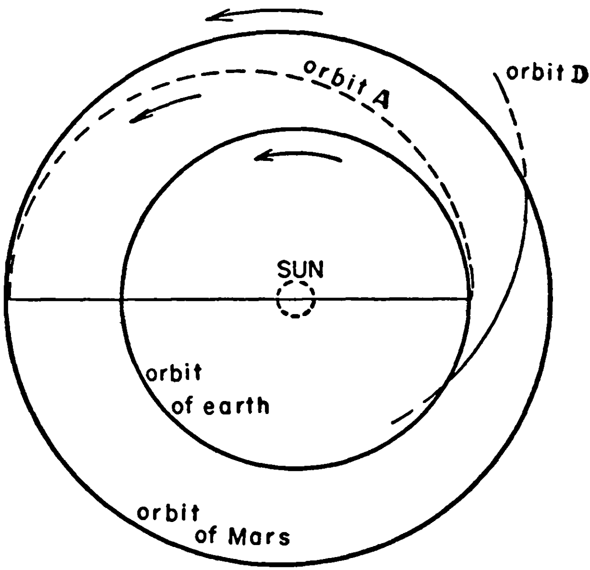


Fig. 20. The most favorable orbit for space travel from earth to Mars is the one Dr. Walter Hohmann labeled Orbit A. Orbit D, also shown, is highly inefficient.

This would also provide the velocity for climbing to the orbit of Mars against the sun's gravity, but the final result would be that the ship would be much faster than the planet Mars when it arrived there. Then the big energy expenditure would be to adjust to the other planet's velocity.

Such an orbit still looked much too expensive in fuel consumption, but it certainly was superior to the straight line across. Obviously things could be improved some more if the angle of veering away from the earth's orbit was made still smaller. Hohmann started on his next calculation and found, in the end, that the most efficient connecting orbit was along one half of an ellipse that just touched the two planetary orbits at both ends. He referred to this as the "A orbit"—it is now called the "Hohmann orbit."

Once he knew which orbit was the most efficient—and therefore likely to be chosen if we should ever progress to spaceships—he worked it out in some more detail. Traveling along the A orbit, the spacecraft would need 258 days to go from orbit to orbit. This meant, of course, that the trip would have to begin at a time when the planet Mars was 258 days away from that point of its own orbit when it would be intersected by the spacecraft.

The easiest way of expressing the motions involved is by looking at them from the sun. The earth needs 365¼ days to traverse the full circle of 360 degrees; hence it moves through a little less than 1 degree of arc per day; more precisely, 0.983 degree of arc per day. The slower Mars, needing 687 (earth) days to traverse a full circle,

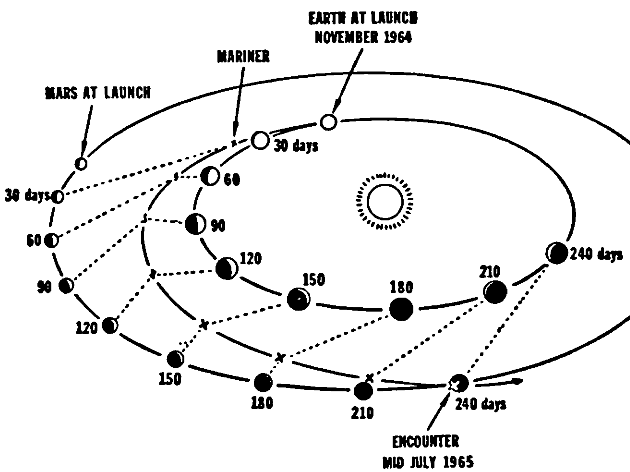


Fig. 21. The orbit of Mariner IV. This diagram shows that the orbit traveled was almost precisely the one called Orbit A by Dr. Hohmann. *Courtesy: NASA*

moves through 0.523 degree of arc per day; the space probe has the intermediate velocity of 0.7 degree of arc per day.

At the moment of takeoff from earth, as shown in Figure 21, the planet Mars must be 258 times 0.523 degree of arc, that is, 135 degrees of arc from the rendezvous point. Or, which is the same thing, Mars must be 45 degrees of arc "ahead" of the earth. The space probe, during this time, describes an angle of 180 degrees. The earth, which is faster, will move through an angle of 253.6 degrees in 258 days. Therefore, the earth, though it was 45 degrees of arc "behind" Mars when the flight began, will wind up 73.6 degrees of arc "ahead" of Mars when the flight is over.

Like the figure of two years and seven weeks for the interval between two oppositions, the figures just derived are averaged figures that do not apply strictly in reality. In calculating them, the situation was simplified by considering the two planetary orbits as concentric circles. No attention was paid to the somewhat different velocities at perihelion and at aphelion, and the fact that the distances differ was neglected, too. Therefore the actual Mars probe did not need 258 days for its trip. It only needed 228 days. And since

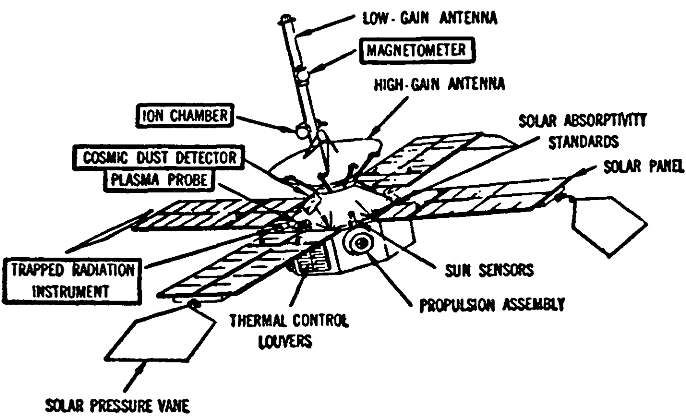


Fig. 22. Spacecraft Mariner IV. This diagram shows the elements of the spacecraft located above the solar vanes. *Courtesy: NASA*

it was not supposed to land on Mars, it did not matter that the velocities at the other end failed to match precisely.

The Mariner IV Mars probe (see Figures 22 and 23) had a weight of 575 pounds, without the protecting shroud. The body of the spacecraft was an octagonal box, measuring 50 inches across. From this body four "solar panels" with

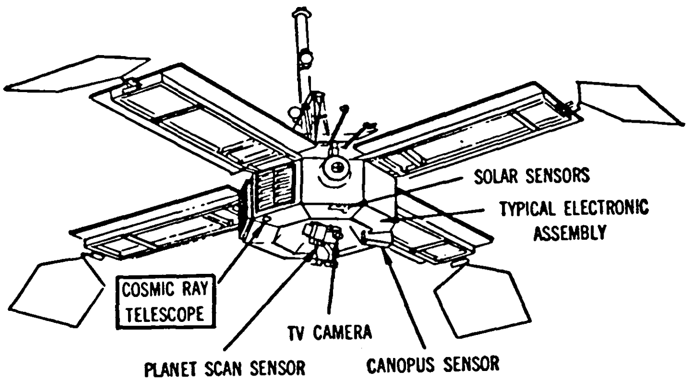


Fig. 23. Spacecraft Mariner IV. This diagram shows the elements of the spacecraft located below the solar vanes. *Courtesy: NASA*

"solar pressure vanes" at their tips extended outward in flight, forming a cross. The four panels held a total of 28,224 solar cells for converting sunlight into electric current.[1]

Fully extended, the solar panels with the extra vanes measured 22 feet 7½ inches across. Power from the solar cells was fed into a storage battery that provided a reserve for the comparatively short periods when the solar panels did not produce power—for example, when they did not face the sun during course corrections and while going through the shadow of Mars. The solar pressure vanes at the ends of the panels had the purpose of compensating for the faint

[1] Mariner II, which went to Venus in 1963, and the Ranger lunar probes had only two solar panels each; their number was increased to four for the Mars probe because at the orbit of Mars sunlight is only about half as strong as it is near the earth.

radiation pressure from the sun which, while mild, will exert an influence on the orbit of the spacecraft during long voyages. The octagonal structure of the spacecraft was topped by a mast carrying several scientific instruments, with a so-called omnidirectional antenna—one that radiates radio signals in all directions—at its upper end. The distance from the tip of this antenna to the base of the octagon was 9 feet 6 inches.

One especially ticklish problem was the control of the "attitude" of the spacecraft, its position while traveling to Mars. For maximum power, the solar panels had to face the sun all the time; for best transmission, the so-called high-gain antenna—one that focuses radio waves into a beam somewhat like a searchlight—had to point to the earth all the time. Another device had to face a certain star, namely Canopus, all the time. Keeping this device pointed to that star was a navigational aid, similar to sailing a boat while keeping a certain lighthouse abeam to starboard, but with the difference that Canopus is so far away that the spacecraft could not "pass" it. Keeping the solar panels wide open to the sun was up to the "sun sensor," which flashed an electric signal to "attitude control" if the panels received less light than they should. This signal released a jet of compressed nitrogen to correct the position. The Canopus sensor did a similar job but a much more difficult one, as we'll see. Of course, the whole spacecraft had been designed in such a way that *if* the Canopus sensor pointed to Canopus, the high-gain antenna would point to earth and the camera would point toward Mars.

Including the scientific instruments, the spacecraft was made up of a total of 138,000 parts. The worry that each one of them had to function was relieved to some extent by the fact that many of the instruments reported back often during the flight, some of them continuously. The most worrisome part was the camera. It could make only 22 exposures, and it could not be tested while Mariner IV was underway. An attempt to test the camera would not only have resulted in the loss of one exposure; it would also have been inconclusive, because there was nothing big enough for a test while the spacecraft was halfway between the planets.

The scientific mission involved two kinds of "experiments," as they are called—for most of them the term "measurements" would have been more descriptive—namely, those to be performed while in transit and those to be performed near the planet Mars.

The devices carried were the following:

(1) *Ionization Chamber.* This consisted of a sphere, 5 inches in diameter, filled with the gas argon. Its main purpose was to measure the intensity of the so-called "cosmic rays." Cosmic rays are actually fast-moving particles, mainly nuclei of hydrogen (protons) and nuclei of helium (alpha particles), though nuclei of heavier elements are occasionally encountered. When such a particle entered the sphere, it stripped electrons off the argon atoms. The loss of one or several electrons means that the atom which is normally "electrically neutral" acquires a positive charge.

Atoms carrying an electric charge are "ionized," and the degree of ionization reveals the energy of the cosmic-ray particle that caused it. A Geiger-Müller tube associated with the chamber furnished a count of the number of ionization-causing particles that entered the chamber; both instruments together provided a count of the particles and measured their intensity.

(2) *Trapped Radiation Detector.* This instrument reported on radiation in space; its more specific purpose was to discover whether Mars has radiation belts (Van Allen belts) like the earth. These radiation belts consist of subatomic particles that originally came from the sun and were captured ("trapped") by the earth's magnetic field. The discovery of a Van Allen belt around Mars would indicate all by itself that Mars has a powerful magnetic field. Just to be doubly sure, there was also a magnetometer on board.

(3) *Cosmic-Ray Telescope.* This instrument collaborated with the ionization chamber in detecting cosmic rays, but it could also detect particles that were not energetic enough to cause ionization in the chamber. The name was derived from the fact that the three detectors were arranged like lenses in a telescope. A weak particle would penetrate only the first detector, a more energetic particle would penetrate two, and a high-energy particle would penetrate all three.

(4) *Magnetometer.* This instrument detected the strength and direction of magnetic fields in space. In a way it collaborated with the trapped radiation detector; the possibility existed that Mars might have a magnetic field that was not powerful enough to cause a well-defined Van Allen belt. But a magnetic field would be discovered by the magnetometer if the radiation detector could not find a Van Allen belt.

(5) *Micrometeoroid Detector.* Micrometeoroids are tiny particles of solid matter in space; the term means the same as "cosmic dust." The number of dust grains in space near earth is comparatively large; they were at one time, so to speak, caught in the gravitational field of the earth one by one, and are now orbiting the earth. Mariner II, during its voyage to Venus, had reported that the number of micrometeoroids in free space was very small—only about one for every ten thousand in the vicinity of the earth. But Mariner IV was expected to encounter larger numbers for two reasons. One was that it would cross several known meteoroid streams, the so-called Geminid and Ursid streams in December, 1964, and the Tuttle-Giacobini-Kresak stream in March, 1965. All three are composed of particles that once belonged to the nuclei of comets that gradually dissolved in space, as small comets are known to do. The other reason for expecting more micrometeoroid impacts on Mariner IV was that just beyond the orbit of Mars there is the so-called asteroid belt, an area in which a dozen or so large and many thousands of small asteroids orbit the sun. It can be expected that there are glancing collisions between the smaller asteroids which would produce dust that would then gradually approach the sun. In other words, Mariner IV was flying toward a suspected source of cosmic dust; hence the expectation for an increased number of impacts.

(6) *Solar-Plasma Probe.* Our sun emits a steady stream of subatomic particles, mainly electrons and protons (hydrogen nuclei), in all directions. This phenomenon has been called the "solar wind," but is also referred to as "solar plasma." (The word "plasma," when used by a physicist, means a mixture of ionized and unionized

nuclei and atoms.) The instrument was to measure density, velocity, temperature, and direction of the solar plasma; there is an interaction between the solar plasma, magnetic fields, and cosmic rays.

These six instruments were to be used during the trip as well as during the flyby near Mars. But during the flyby, two other things were to be done. While close to Mars, the camera was to go into action and take its twenty-two pictures. Then, as seen from earth, the spacecraft would sweep behind Mars which would be an especially interesting and valuable moment. At that time the radio signals sent out by Mariner IV would go through the Martian atmosphere, which would, in some manner, distort the transmission; the distortion would provide a clue to the density of the Martian atmosphere. After the spacecraft had passed behind Mars, the pictures were to be transmitted. Because the distance would be better than 130 million miles, the line-by-line transmission that had been used by the Ranger spacecraft when sending back pictures of the lunar surface could not be employed. There was not enough power available. Therefore each picture was divided into 200 lines, and each line into 200 points; the characteristics of each point would be transmitted separately. Naturally such a point-by-point transmission is time-consuming, and each picture would need about six hours to be relayed to earth.

We now know, of course, that there were pictures to be transmitted and that the transmission was done successfully. But the people in charge of the instrumentation had 228 days to wonder about that question, and they could not be absolutely certain of success until the first few lines of the first picture transmission had been received.

Since Mariner IV was not a manned spaceship with a log kept aboard, the log had to be kept on the ground, and for the first week of the flight there were quite a number of entries. It began, of course, with the liftoff of the Atlas Agena D rocket from its pad at Cape Kennedy.

The log entries for November 28, 1964, were:

9:22:01 A.M. (Eastern Standard Time) liftoff
9:27:20 separation of Agena and Mariner from Atlas

9:27:23	shroud ejection
9:28:00	ignition of Agena rocket
9:30:00	cutoff of Agena
10:02:00	second ignition of Agena
10:04:27	second Agena cutoff (Mariner was now in the orbit that would lead it to Mars; at that moment it was 122.8 miles from the ground, and Mars was 127.7 million miles away. Tracking disclosed that Mariner moved 7 miles per hour faster than intended.)
10:05:51	spacecraft enters earth's shadow
10:07:10	separation of Mariner from Agena
10:15:05	solar panels deployed, sun sensor alerted
10:17:35	spacecraft leaves earth's shadow
10:31:00	sun sensor locked on sun, panels wide open to sun.
1:59:00	P.M. automatic command to Canopus sensor to find star
2:07:00	Canopus sensor momentarily locked on fainter star Markab, then hunted again and locked on Alderamin, a star only one fourth as bright as Canopus

Mariner IV was now on its way but was pointing its star sensor to a wrong star. Since this did not influence its flight path, it was unimportant for the moment. On the next day the sensor "lost" Alderamin and started hunting automatically at 8:13 in the morning, locking itself 16 minutes later on Regulus, a nice bright red star but again the wrong one.

On November 30, at 4:14 A.M., the Goldstone radar in California ordered a renewed search for Canopus. At 4:21 the sensor did lock on a star, again a wrong one. At 5:45 the Goldstone radar sent out another search command. Just one minute later the sensor thought it had done its job, but it was locked on a small three-star cluster. At 5:58 another search command caught up with Mariner, and precisely at 7:00 A.M. it finally locked on Canopus.

Three days went by without any action, except for proceeding along the flight path. By then, tracking had shown just how the course had to be corrected; without such correction the spacecraft would pass at a distance of about 150,000 miles. The course correction was intended to change the flight path so that the spacecraft would pass at a distance of 5000 miles from the Martian surface, only a little more than the diameter of the planet. But things were a little difficult on December 4, 1964. The first command was sent out at 8:05; one and a half hours later it was observed that the spacecraft was rolling, and the next command inhibited the planned maneuver. During the next two hours the Canopus sensor was clearly confused; it repeatedly locked on stars that weren't even on the chart. What probably happened is that the rolling had shaken a few dust flakes off the spacecraft, and these dust motes, brightly illuminated by the sun, looked like stars to the sensor. At 11:25 A.M. it was decided to abandon the course correction for that day, but another search command was sent to the Canopus sensor.

The sensor repeatedly tried to lock on the three-star cluster and had to be prodded again and again by new commands; at 6:40 P.M. it finally locked on a star, Regulus again. Being ordered to search some more, the sensor twice tried to lock on the star known to astronomers as *gamma* Velorum; finally, at 6:59:22 P.M., it *did* find Canopus.

On December 5, at 8:05 A.M., the command sequence for the correction started all over again, and after 11:00 A.M. the log read:

11:01:19	stop roll
11:09:09	start rocket motor for course correction
1:09:29	stop rocket motor
11:15:11	automatic command to sun sensor to find sun
11:02:07	sun sensor locked on sun, solar panels receive full power
1:21:07	automatic command to Canopus sensor to find Canopus
11:44:39	Canopus sensor locks on star *gamma* Velorum
11:52:00	renewed search command
11:54:57	sensor locked on Canopus

December 6 passed without new developments. On December 7, at 7:30 A.M., Canopus was "lost" once more. At about the same time—there was no connection between these two events—the signals from the plasma probe became unintelligible; they had to be disregarded, and the plasma probe was written off as a failure. By 8:15 A.M. the Canopus sensor was locked on *gamma* Velorum again. Nothing was done about it for some time; it was likely that there were still dust particles around that would only confuse the sensor. On December 13, the order to switch from one amplifier to another was given, increasing the transmitter output from 6½ to 10½ watts.

On December 17, the command to search for Canopus was repeated at 11:00 A.M., and just 3 minutes and 2 seconds later Canopus was found by the sensor. A little over an hour later, the command that would prevent the sensor from turning on the gyroscopes was given, in case more illuminated dust motes passed in front of it. On January 3, 1965, another command changed the rate at which the information was transmitted. Up to that time 33⅓ "bits" of information had been transmitted per second; the rate now was only 8⅓ bits per second.

On February 11, various commands to test parts of the equipment were given. Among them was one that removed the lens cover of the TV camera. It was thought that this removal would free additional bits of dust. Therefore, it was safer to let the spacecraft travel for a few months with an uncovered lens, giving possible dust particles ample time to drift away from the spacecraft. By the end of February 12, a total of 42 ground commands had been sent to the spacecraft and the situation was this: spacecraft was on corrected course, telemetry reporting on the function of the spacecraft was on, telemetry for reports of those scientific instruments that were to work during the cruise was on, the platform for the scanning camera was in proper position for the flyby, lens cover was off, Canopus sensor was no longer inhibited.

On March 3, the plasma probe became intelligible again; this was explained as being due to the lower "bit" rate. But on the same day, the Geiger-Müller tube became unintelligible. On March 5, transmission was switched from the omnidirectional antenna to the high-gain antenna, which increased the signal strength 40 times. And on March 17, the ion chamber failed; the reason is not known.

By then the instruments had already gathered a considerable harvest of scientific data. More important, every incoming radio signal proved that Mariner IV was on course; it would make its flyby.

On July 14, 1965, at 10:28 A.M., Eastern Standard Time, the first of a series of final commands were sent out. It took the signal 12 minutes to reach the spacecraft, and the return signal, indicating that the command had been received, also took 12 minutes travel time to reach the big receivers on earth. At that moment Mariner IV was still a little over 100,000 miles from Mars; the actual flyby would be during the evening hours of that day. (See Figure 24.)

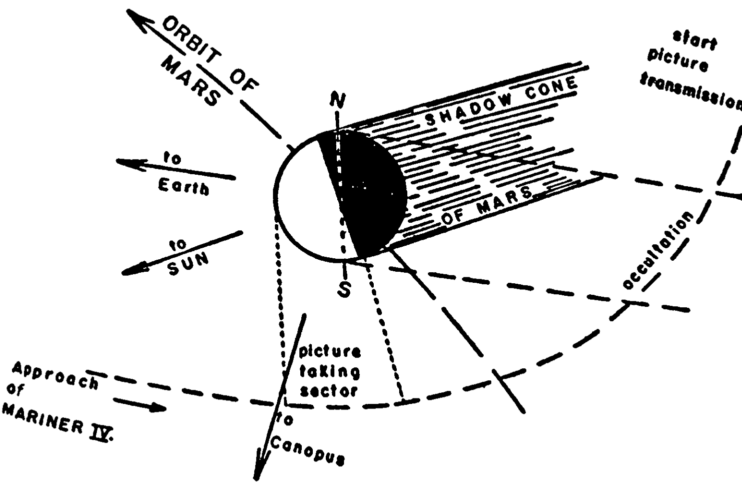


Fig. 24. The flyby of Mariner IV near Mars on July 14, 1965.

At 7:52 P.M. the spacecraft crossed over that meridian of Mars that had noon at that instant; the distance was 8910 miles. Closest approach took place at 8:13 P.M., the distance being 8202 miles; the camera should be taking pictures at that moment. At 9:31 P.M., the distance from the planet had already grown to 16,031 miles; that was the moment when it disappeared behind the disk of Mars. It reappeared at 10:25 P.M.; its distance from the planet at that instant was 24,420 miles.

On July 15, 1965, at 6:41:52 A.M., Eastern Standard Time, transmission of the pictures was ordered, and half an hour later the computers began to store the first return signals.

The mission to Mars was over.

6. *Mariner To Mars*

Results and Discussion

Months before Mariner IV reached Mars, on April 19, 1965, NASA held a press conference on the West Coast for the purpose of acquainting the public with what had been accomplished up to that time. Most of what was said at the conference could not be of much interest to the public because it dealt with such topics as the flow of subatomic particles in space and similar scientific topics that are hard to explain because the results are still tentative. In some cases, the scientists themselves were still formulating future experiments in the search for verification of still tentative theories.

But there were two interesting discussions during that conference. One dealt with particles of atomic dust in space; the other was a more personal discussion with Dr. James A. Van Allen.

W. M. Alexander of the Goddard Space Flight Center reported on the number of micrometeoroid impacts. At that time, Mariner IV, after 3350 hours in space, had counted 95 impacts, but this was a misleading figure. The spacecraft had already gone through the so-called Geminid meteor stream which seemed not to have produced a single impact. In reality, the Geminids must have hit the spacecraft, but because of a peculiar set of circumstances they did not register. The Geminids were going sunward, while the spacecraft traveled with its solar panels wide open to the sun. Therefore the Geminids struck the backs of the solar panels and the bottom of the octagonal body, "protecting" the detecting panel which was mounted on top of the body.

Though the figures released then covered only the first half of the trip, there seemed to be a slight increase in the number of impacts as the spacecraft moved toward Mars. This might be called a faint support of the idea that many, or most, micrometeoroids orginate in the asteroid belt beyond Mars.

Dr. James A. Van Allen, answering questions, declared that the findings of Mariner IV in the vicinity of the earth only corroborated the findings made by artificial satellites. Asked by another reporter whether he meant to say that there was no hazard to manned flight in the region of the Van Allen belts, he replied: "We have known there is no substantial hazard for a quick pass, and that is confirmed. The total exposure on the Mariner IV pass, which might be considered representative of the manned escape trajectory, was something like 10 or 15 roentgens under a fairly thin skin.[1] That is substantially the same data we gave in 1958, as a matter of fact."

The discussion then veered to the question of a radiation belt around Mars, with a reference to an earlier statement that the magnetometer aboard the spacecraft could detect a magnetic field of only three percent of the strength of the earth's magnetic field. The questions and answers were as follows:

> Q. "Dr. Van Allen, I wonder if you could give us the case for and against a substantial magnetic field on Mars, and tell us which of those you favor."
>
> A. "I would say it is almost a matter on which you can take bets right now; there is so little known about it either way. I think the best estimates sort of spring from some studies which Gordon MacDonald has made on the internal structure of Mars, which I think he is the first to agree are quite conjectural. He estimates

[1] The implication was that inside a manned spacecraft, which would have a much thicker skin, the radiation exposure would be even less.

that Mars may have a liquid core of the order of one-tenth of the mass of that of earth.

"The understanding of the origin of the earth's general magnetic field is so poor, however, you can only take this as a vague suggestion that Mars might have a magnetic moment at most of the order of one-tenth of that of the earth. But that is a very conjectural thing. I think one has to regard this as almost entirely an observational question at the present time. The consequences will be of a good deal of interest, whether they are positive or negative, on the internal structure of Mars as a planet."

Q. "Just to pursue this a little further: You say it is almost a question of taking bets right now. Which way would you put your money down?"

A. "I am really betting on a weak magnetic field, something probably less than ten percent that of the earth."

Q. "But above three percent?"

A. "Possibly."

It turned out that Mars has no measurable magnetic field at all. The detectors that scanned for captured electrons and protons forming a radiation belt reported zero. The magnetometer reported zero. Mars was as devoid of a magnetic field as our moon.

It is impossible that the detectors might somehow have overlooked a weak magnetic field, because such a field betrays itself in a number of ways. If there had been a magnetic field not quite powerful enough to form Van Allen belts, one should still have discovered what is known as the "bow shock," for Mariner IV flew through the area where it should have existed.

To explain what is meant by the term "bow shock," we have to look at our own planet and see what its magnetic field does to nearby space. It has been mentioned earlier that the sun sends out a steady stream of subatomic particles, which are collectively known as the solar wind. When these particles arrive in the vicinity of the earth, they encounter the earth's magnetic field, which will deflect all non-energetic particles. This deflection creates a disturbance in the smooth flow of the solar wind, just as a large rock sticking out of a shallow river will disturb the smooth flow of the water. The earth actually leaves a "wake" in the solar wind, the length of which is not yet known. What is of interest here is the beginning of this disturbance. The deflection of particles of the solar wind begins at a distance of about 40,000 miles on the sunward side of the earth; it forms a kind of half-sphere around the earth at the sunward side. This is the bow shock, and if Mars created one it would have been discovered.[2]

The sequence of the crucial measurements near Mars was dictated by natural laws. The magnetic field, the bow shock, and the radiation belts were all to be measured some distance from Mars, prior to closest approach, which was the natural time for taking the photographs. Then Mariner IV would be "occulted" by Mars, as astronomers call it; it would disappear behind the planet, with the result that its radio signals had to pass through the planet's atmosphere. They would do so once more when the spacecraft emerged on the other side. There was still some time left for a renewed look for magnetic phenomena before the pictures were to be transmitted. As this needed all the electric power available, everything else was shut off.

Checking on the radio signals that had passed through the atmosphere of the planet was the first opportunity in all history to make a direct measurement of the density of the Martian atmosphere. Until about ten years ago, it had been customary to say that the pressure of the Martian atmosphere at ground level was probably the same as in our atmosphere at a height of 20,000 feet. During the last few years this estimate had been revised, and Mariner IV confirmed these revisions. Pressure at ground level was found to be slightly below 10 millibars, which means about one percent of sea-level pressure on earth, corresponding to our atmosphere at a height of 90,000 feet. This figure was derived under the assumption that the Martian atmosphere consists mainly of carbon dioxide, or represents a mixture of about 80 percent carbon dioxide with the remainder being nitrogen and argon. It is likely that these figures will be somewhat refined by continuing analysis, but there is no reason to

[2] A very detailed description of the instrumentation of the spacecraft and the measurements obtained can be found in the journal *Science*, September 10, 1965.

believe that the "final figures" will differ substantially from these preliminary values.

The combination of the lack of a magnetic field and a very thin atmosphere leaves the surface of Mars virtually "undefended" as far as radiation from space is concerned. Again, we have to look at our own planet for comparison. The earth, like Mars, is subjected to an unceasing bombardment of many millions of subatomic particles every second, but the earth has defenses. All particles of comparatively low energy are deflected in the area of the bow shock. Those particles that are somewhat more energetic are captured inside the bow shock by the Van Allen belts. Only particles of exceptionally high energy will penetrate directly, and these run into the armor formed by the earth's atmosphere. There the incoming particles—technically known as "primaries"—collide with molecules in the atmosphere; the molecules are broken up and ionized, and a series of collisions results in a cascade of "secondaries"; but the energetic primary has been stopped and has been incorporated into our atmosphere. Only a very few primaries manage to reach the ground relatively unscathed, and that is the main reason why they were discovered so late. In addition, almost as a side job, our atmosphere also absorbs virtually all the X rays coming from space and filters out the bulk of the ultraviolet rays, using up their energy by changing ordinary two-atoms-per-molecule oxygen (O_2) into three-atoms-per-molecule ozone (O_3).

Mars shows no magnetic field to deflect or trap incoming subatomic particles, and its thin atmosphere is only a very feeble armor. The atmosphere might be able to screen the surface of the planet from X rays—especially since the sun is rather feeble when it comes to the emission of X rays—but everything else will strike the ground full force. The result must be that the production of "secondaries" takes place *in the ground,* probably a few inches below the actual surface.

This must result in the production of comparatively large quantities of radioactive substances. But since we do not know the chemical composition of the Martian soil, it is impossible to say just what atomic transformations are likely to take place. Most of the radioactive atoms produced are probably in short-lived transition stages between stable atoms, and one of the by-products must be heat. Therefore the soil a number of inches underground is likely to be warmer than the surface itself.

All this could have been reasoned out beforehand under the assumption of a very thin atmosphere, but the pictures transmitted by Mariner IV constituted the main surprise. The camera, as programmed, took a total of 22 photographs, but the last three of them happened to be of the nightside of Mars, so they are useless. The first picture, which caught only a small section of Mars, can be called useless, too. This first picture shows a very faint smudge of lighter color than the background. The first guess was that this smudge might be one of the high, thin ice-crystal clouds of Mars, but the experimenters feel more inclined to consider it a minor flaw, possibly caused by a trace of moisture in the lens system. As the slant range over which the pictures were taken decreased, the area covered by each picture grew smaller and the definition became better. (See Table I.) Toward the end of the run, the pictures deteriorated in quality; the illumination near the so-called terminator—the border between daylight and nightside—fell off rapidly, and the camera could not adjust to the loss of light. It had been foreseen that this would happen, but the loss of illumination was greater than expected.

The best pictures, therefore, are those of the middle of the run, and each of the good ones shows a landscape that looks like a close-up photograph of an area of our moon. There are smaller and obviously more recent impact craters overlapping the rims of earlier and larger craters, there are small impact craters inside larger craters—in short, all the topographical features that we have become accustomed to think of as typical for the moon.

The second of the Mariner pictures did not yet show this; the vague light areas suggest sand dunes. This also goes for the third picture. The fourth one does show a few depressions that are called craters because the later pictures show them so clearly. If we had only the fourth picture, we would say that this is a desert landscape with a few roundish spots that might be dried-up lakes. The main reason why picture number 4 does not reveal much is that it was almost noon in that spot when Mariner IV passed overhead. With the sun high up in the sky there are no

Table I
The Mariner Pictures

No.	*Universal time**	*Latitude*	*Longitude*	*Slant range (miles)*	*Extent E to W*	*Extent N to S*	*Filter*
1	0:18:33	+35°	188°	10,500	410	800	orange
2	0:19:21	+27°	186°	10,100	290	530	green
3	0:20:57	+13°	183°	9,500	220	310	green
4	0:21:45	+ 7°	181°	9,300	210	270	orange
5	0:23:21	— 2°	179°	8,900	190	220	orange
6	0:24:09	— 6°	177°	8,700	190	200	green
7	0:25:45	—13°	174°	8,400	180	180	green
8	0:26:33	—16°	173°	8,300	180	170	orange
9	0:28:09	—23°	169°	8,100	170	160	orange
10	0:28:57	—26°	168°	8,000	170	160	green
11	0:30:33	—31°	163°	7,800	170	150	green
12	0:31:21	—34°	161°	7,700	170	150	orange
13	0:32:57	—39°	155°	7,600	170	140	orange
14	0:33:45	—41°	152°	7,600	170	140	green
15	0:35:21	—45°	144°	7,500	180	140	green
16	0:36:09	—47°	139°	7,500	190	140	orange
17	0:37:45	—50°	128°	7,400	200	140	orange
18	0:38:33	—51°	122°	7,400	210	140	green
19	0:40:09	—51°	107°	7,500	240	150	green
20	beyond terminator, useless.						
21	same						
22	same						

* Universal time counts 24 hours around the clock to avoid the designations A.M. and P.M. and is used by astronomers in all countries. O o'clock U.T. corresponds to 7 P.M. Eastern Standard Time on the previous evening; 12 o'clock noon E.S.T. is 17:00 U.T.

shadows. Beginning with the fifth picture, surface detail becomes somewhat clearer and a little more so on the sixth picture. It was the seventh picture which had a dramatic effect at the time it was received. It was the first one that showed that the roundish spots of the earlier pictures were definitely impact craters. Picture number 8 showed two craters—measuring about 20 miles in diameter—side by side in its center, and a few smaller craters elsewhere in the picture. Number 9, showing at least twenty craters of assorted sizes, was the first one strongly resembling an area of the moon. The tenth picture showed about a dozen smaller craters with the edges of two big ones jutting into the picture frame, and the eleventh showed a large crater, about 75 miles in diameter, with smaller ones on its floor. The twelfth picture happens to be pretty featureless, while the thirteenth shows several 20-mile-diameter craters and probably a section of the rim of a very large one that must measure over 150 miles in diameter, provided, of course, that what has been photographed is actually a portion of a crater rim and not just a mountain range that happens to be somewhat curved. The way the light changed in crossing this ridge or rim made it possible to arrive at an estimate of its height. Of course, no "heights above sea level" can be given on oceanless Mars, so that the figure of 13,000 feet means the height difference between the peaks of this rim and the low-lying area bordering it. This is the largest height difference that could be found on any of the pictures.

Picture number 13 is the first picture in the sequence in which crater rims begin to show white, as if they were covered with snow or hoarfrost at their highest elevations. By the time this picture was taken, Mariner IV was over fairly high southern latitudes, and it was the southern hemisphere of Mars that had winter at the time. The fourteenth picture also shows what looks like frosted crater rims, and, in addition to that, it shows a number of very bright spots. The scientists who examined the pictures made sure that these white spots were real. Some of the earlier pictures showed absolutely straight white streaks, which could easily be recognized as being due to faulty transmission. But the white spots of the fourteenth picture were not from faulty transmission; they do exist, and there can be little doubt that they are snow or hoarfrost. But just what surface features are marked by these iced-over patches is not known. They could be icy peaks as well as snow-filled depressions. If they are peaks, they should cast shadows, of course, but the picture does not show shadows; beginning with number 14 the picture quality began to decline, growing darker and less useful. Number 15 shows whitish areas that suggest a thin snow cover and faint surface features that can still be recognized as craters.

The sixteenth picture is virtually featureless, except for some whitening in some places; from the seventeenth picture on, what can be seen is mainly electronic noise.

Unfortunately Mariner IV did not pass over the southern polar cap. One or two pictures of the polar cap would have been of great value and might have decided a few doubtful points, mainly as far as the thickness of the polar cap was concerned. The picture sweep covered light areas as well as dark ones, and one of the pictures is of an area where visual observers of the past have noted a "canal," but nothing unusual is visible in that picture. This can be due to several factors. First, the season was unfavorable; canals do not show well while there is winter. Second, the picture from the spacecraft may show whatever it is that makes a canal in so much detail that we do not recognize it. Third, the canals show themselves mainly by color contrast, and the black-and-white Mariner pictures might simply have erased such color contrasts; a dark gray area and a blueish-green area can both have the same intensity.

So these pictures simply do not tell us anything about the *canali*. The main novelty is the abundance of impact craters, which had not been—but should have been—suspected. Since Mars is at the inner edge of the asteroid belt, the likelihood that it would collide with asteroids of almost all sizes is high indeed. Even in our own time, when most of the maverick asteroids that had orbits that could lead to collisions with the major planets have disappeared from space, Mars is much more likely to be hit by a small asteroid than is the earth.

The interesting fact is that such a collision seems to have been observed a few years ago by a lucky Japanese astronomer. He is Tsuneo Saheki of the Osaka Planetarium. His report, written in English, read:

> "On December 8, 1951, at 21.00 U[niversal] T[ime] [corresponding to 4:00 P.M. Eastern Standard Time], I saw a sharp, bright, glaring spot suddenly appear on Tithonius Lacus. It was as brilliant as a sixth magnitude star—decidedly brighter than the north polar cap—and shone with scintillation for about five minutes. Fad-

ing rapidly, by 21:05 it looked like a whitish cloudlet, as large as Tithonius Lacus. At 21:10 it was barely visible as a very faint and large white spot, and by 21:40 this part of the Martian surface had returned to its normal state.

"On July 1, 1954, at 13:15 U.T. [corresponding to 8:15 A.M. Eastern Standard Time], I saw Edom Promontorium suddenly brighten, but only about five seconds later it had faded back to its normal appearance—a bright yellow spot. The maximum brilliance of this shining spot was estimated as about half that of the south polar cap. The same night Ichiro Tasaka was observing Mars with a 12½ inch reflector at Shinga City, about 110 kilometers to the south, but he missed this strange phenomenon. He did specifically record that Edom Promontorium looked very bright."[3]

Naturally Dr. Saheki wondered what it was he had seen and he added some careful remarks on possible interpretations:

> "We can rule out the possibility that these flares were sunlight reflected from a hypothetical water surface on Mars—their locations on the planet with respect to earth and sun preclude this. Reflection from an ice-covered mountainside is free from that objection, but cannot explain the formation of a cloud just after the disappearance of the light, as in 1951. A meteorite fall on Mars might produce both light and a cloud, but meets difficulty in accounting for flare durations as long as five minutes. . . . A fourth interpretation that may be rejected as unreasonable is an artificial origin, for this requires 'Martians,' of whose existence there is no scientific evidence. A remaining possibility is volcanic eruptions. These may explain the light and the dust-cloud formation. However, the observed duration of the light may be too short, and the probable scarcity of water on Mars may raise difficulties—terrestrial volcanoes eject large quantities of steam."

Since we now know that meteorite impact craters are numerous on Mars, Dr. Saheki's second possibility seems to be

[3] The report was published in *Sky and Telescope,* February, 1955, pp. 144ff.

the most likely explanation. The impact of a large meteorite would certainly throw up a cloud of debris consisting of shattered ground material as well as fragments of meteorite. Since all these particles would vary in size from fine dust to gravel and brick-sized pieces (as well as still larger ones), all the heavier pieces would settle fast because the thin Martian air would not support them. This would explain the appearance as well as the duration of what was observed, and the one difficulty cited by Saheki, namely, the flare duration of five minutes, is not insurmountable. At first glance one would expect the flare to be of very short duration, probably because of the similarity of such an impact to the impact and explosion of an artillery shell. But this comparison might be a mistake. After all, nobody has ever observed the actual impact of a large meteorite—except, probably, Saheki—and it is by no means impossible that the shattered material, having been heated to incandescence by the impact, will glow visibly for several minutes.

Sudden bright flares on Mars have been seen again and again since about 1890, and practically every one of the possibilities cited by Saheki has been mentioned as the explanation. They were accepted, in turn, as signals by the Martians meant to attract our attention; as reflections of the sun off watery surfaces on Mars; as reflections from snowfields that had thawed superficially and frozen over again during the following night so that they acquired a glassy crust; and, finally, as reflections of sunlight off high white ice-crystal clouds that were still illuminated by the sun while the ground below was already in darkness. Of course, it would be absurd to insist that one and the same explanation has to account for all the flares. Some of them may have been high clouds; others may have been reflections of sunlight from snowfields. But flares accompanied by short-lived cloud formations were probably meteorite impacts.

The first reaction of interested observers to the Mariner IV Mars pictures was intense surprise. The reaction that followed the surprise was a kind of gloom.

The planet Schiaparelli had pictured—with a scant atmosphere, small oceans, and large deserts—the concept of the "aged earth" which then had been augmented by Lowell with intelligent beings that made do with what was left—these had been given up decades ago. But the mental picture that replaced the early concepts was still one of a very interesting little planet with large areas of well-adapted and thriving vegetation. Since all animal life on earth is parasitic on plant life, and since there was plant life on Mars, one did not have to hesitate to imagine some kind of animal life that would be parasitic on the Martian vegetation. And if space explorers of the near future should report that they found ruins of past accomplishments of something that had been intelligent, a good many people would still say that this might have been expected.

But Mariner IV showed a world with an atmosphere that amounted to one percent of our own, peppered with impact craters like our moon, still displaying impact craters that must be very old so that one had to conclude that Mars had never possessed enough water to erase such scars by erosion. The surprise had been followed by gloom, and some went from gloom to resignation. If that is Mars, why bother with it?

This succession of reactions was a kind of repetition of something that had happened on earth not quite two centuries ago. For many, many years, seagoing mankind had dreamed of a large, fruitful, and beautiful continent in the southern hemisphere, where large colorful parrots inhabited palm forests, where strange large flowers grew, and where the beaches were strewn with rubies and emeralds. *Terra australis incognita* had been the name of that continent, the Great Unknown Southland. Strange that it was so difficult to find *Terra australis*. Whenever a navigator sighted a promising coast, it always turned into just an island or a group of islands; the searched-for continent was always farther to the south than had been expected. The second expedition—from 1772 to 1775—of Captain James Cook destroyed the dream. Cook had sailed around the South Pole as closely as floating ice permitted, and that was quite close to the Antarctic Circle. The result of this difficult and often unpleasant voyage was that an antarctic continent, if there was one, had to lie inside the Antarctic Circle. If it existed at all, it would be a fairly small continent, and, of course, it would be a cold continent.

Europeans, when they read the news, did not know whether to praise Captain Cook for his navigational exploit or to moan that their dream of the Great Southland had to be abandoned forever. The famous French naturalist Georges de Buffon, at that time nearly seventy years of age, is reported to have wept and to have declared that the kind of continent that was still possible was not *worth* discovering!

Well, is the Mars revealed by Mariner IV still worth exploring? The answer is a plain and loud "yes." Just as the actual Antarctica, though it bore no resemblance to the Great Southland of wishful European thinking, was still an interesting continent to explore and is a continent that may still prove worthwhile in several respects, so the "new Mars" is still an interesting planet.

Finding out what gases compose its atmosphere will be an interesting scientific job; learning about the "atomic" transformations that take place under its surface will be of extraordinary scientific interest. We still have to learn what causes its deserts to be reddish-yellow in color. Most experts are agreed that of all the minerals known on earth, the one called limonite (its molecule is composed of two iron and three oxygen atoms, Fe_2O_3) comes closest to the optical characteristics, such as reflectivity, of the Martian desert. And it is quite likely that Svanté Arrhenius was correct when he considered the Martian desert dust as being an oxide of cosmic iron.

There are interesting problems everywhere. If the desert dust is oxidized cosmic iron, there must have been oxygen present in order to oxidize it. At present, the existence of oxygen in the Martian atmosphere is denied on the basis of very good evidence. But that goes for the atmosphere as a whole. It is not impossible that it contains a noticeable percentage of oxygen at and near ground level. But if there is oxygen at ground level, another phenomenon must take place. Just as, at a certain height in our own atmosphere, oxygen is changed into ozone by the action of ultraviolet light from the sun, the ground-level oxygen on Mars must be converted into ozone. But ozone is far more active chemically than plain oxygen, and this could account for the fact that no oxygen is found elsewhere in the Martian atmosphere. Whenever oxygen is formed in some manner, the ultraviolet light from the sun converts it immediately into highly active ozone, and the ozone immediately combines with something else to form oxides.

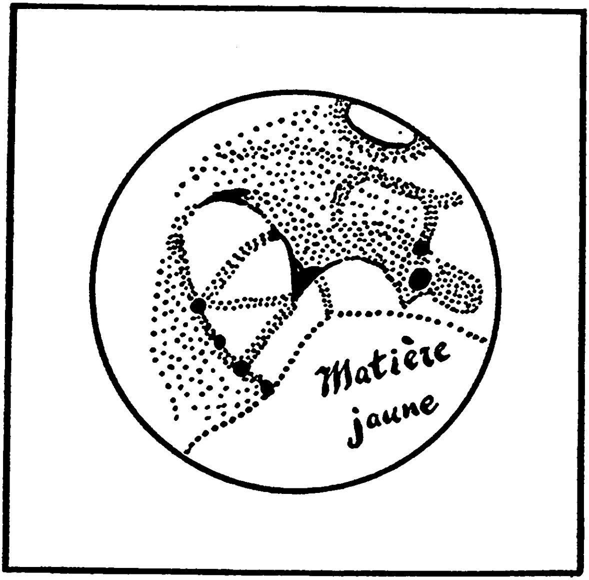


Fig. 25. A drawing of Mars made by E. M. Antoniadi during the 1909 opposition. A large area was covered by a dust storm, labeled *Matière jaune* (yellow matter) by Antoniadi.

These are some of the chemical problems to be investigated. There are also some physical problems in addition to the strange physical problem of the subsurface radioactive transformations, which *must* release some heat and *may* release some oxygen. One of the most baffling problems is the fact that yellow dust clouds stay aloft in the thin Martian atmosphere for some time. (See Figure 25). True the gravitational pull of the planet is less than that of earth, but the air is still far thinner even in proportion to the reduced gravity. How fine must these dust grains be to float in this very thin air? Or are they kept aloft by a different process, for example, by repelling electrical charges?

These are some of the interesting new problems that have been brought to the fore by the confirmation of the very low atmospheric pressure on Mars.

And the fact that there are some new problems does not mean that the old ones have gone away quietly. The lines called *canali* still call for some explanation other than the assertion that they do not exist. For they do exist; they can be seen whenever Mars is near and our own atmosphere is quiet along the line of sight.

The biggest problem is still why about one-quarter of the planet looks darker than the other three-quarters. In spite of the findings about low atmospheric pressure, probable lack of oxygen, and very low moisture content of the planet as a whole, the simplest and most satisfactory explanation is still that the dark areas are vegetated areas. Only vegetation will produce the color changes that conform to the cycle of the seasons, and these changes have been seen so often. Only vegetation can account for resumption of the dark appearance after the area has been covered up by a dust storm. Only vegetation can easily account for some of the peculiarities of reflectivity of the dark areas.

But what about the Mariner photographs? They did not show anything that could be called vegetation. True enough, but the point is that they were never expected to do so. The closest slant range over which these pictures were taken was a little less than twice the diameter of Mars; by coincidence, the slant range was about equal to the diameter of our own planet. But the Tiros satellites that orbit the earth do so at a distance about equal to six percent of the earth's diameter; they are far closer both proportionally and in terms of mileage, and yet they never transmitted a picture of the earth that would be accepted as evidence for life on earth. If more than 25,000 pictures from nearby Tiros satellites fail to show signs of life on earth, we cannot expect the seven or eight good pictures from Mariner IV to show evidence of life on Mars, especially in view of the longer distance.

How close one can come to the surface of the earth and still fail to detect signs of life was demonstrated by a botanist, Professor Frank B. Salisbury of Colorado State University, only a few years ago. Professor Salisbury had an airplane fly over the Colorado desert at an altitude of 10,000 feet above ground, taking numerous color photographs of the area below. These photographs showed no trace of life, though it is known that some of the blueish-gray areas in the pictures are copses of small trees and bushes, growing along water courses that do not carry water all year round. One area of these pictures looks just like a Martian desert, as far as color is concerned; Salisbury then took a color photograph of such a desert spot on the ground, and this picture shows healthy-looking desert plants spaced a few feet apart, as far as the eye can see.

The problem of plant life on Mars, therefore, has not been touched by the photographs taken from space.

Several years before the flyby, the same Professor Salisbury wrote an article entitled *Martian Biology,*[4] in which he summarized what the plants on Mars would have to be and do in order to produce the phenomena observed telescopically from earth.

> "(1) The suspected organisms must be visible or must form visible colonies which cover the ground rather extensively.
> (2) The suspected organisms must account for the color (the light-reflecting properties in general) and the observed color changes. The color changes should take place in response to increases in temperature and atmospheric moisture.
> (3) The suspected organisms must account for the observed changes in size and shape of the Martian areas—that is, they must migrate or grow with some rapidity, and they should be able to reemerge from a covering of yellow dust.
> (4) The suspected organisms must exhibit these various responses within the Martian environment, which is characterized by low temperature and great diurnal fluctuations in temperature—an extremely thin atmosphere, containing a considerable amount of carbon dioxide but only traces of oxygen and water, and occasionally penetrated by ultraviolet light.
> (5) The suspected organisms must conform to certain fundamental principles of ecology, such as the cycling of elements. . . ."

These are the requirements. Now let us look at terrestrial vegetation, point by point:

[4] Published in *Science,* April 16, 1962.

(1) Every forest, jungle or grassy plain will form visible colonies—visible in the sense that the ground would show a different color if these colonies were not there. Martian observers, though, would have difficulty in seeing them because of the shifting cloud cover of earth, and if there were Martian astronomers, they would complain about the terrestrial atmosphere just as bitterly as do our own astronomers.
(2) All terrestrial plants produce color changes through the seasons; they do this in response to temperature and humidity. Of course, the color changes of terrestrial plants are different from those observed on Mars.
(3) Some terrestrial plants grow very slowly, while others grow with amazing rapidity at certain times of the year. It may be significant that the fast-growing, or fast-changing, species on earth are desert plants.
(4) Some terrestrial plants, especially those of mountainous regions and elevated desert plateaus, exhibit great tolerance against diurnal changes in temperature. Others show great tolerance to low temperatures, though they are not called on to survive rapid changes.
(5) Point (5) is self-evident for plants on earth—but the ecology would be different on the two planets.

It can be seen from this comparison that plant life on our own planet, taken as a whole, can conform to all these points. But only when taken as a whole. No single type of terrestrial plant life—e.g., trees, grasses, ferns, or flowering plants—can conform to all of these specifications. But the fundamental ability to do so exists in our plants. The different environments of various parts of earth just made different demands, and evolution conformed to these demands. The environment of Mars seems to be more uniform—we may learn differently when we get there for firsthand inspection—and made different demands; hence evolution on Mars proceeded along different lines. Probably no terrestrial plant species could survive on Mars, but one might as well expect a fish from the bottom of the Indian Ocean to survive in a freshwater fish tank in a living room.

Of course we cannot say anything about the appearance of Martian plant life, except for some generalities like stating that a flat-leaf shape is the best shape for catching what sunlight can be had. That the leaves may roll up into a "stick" during the cold night may be assumed, but a mechanism that would have the same result would be a flat-leaf rosette during sunlit hours, contracting into a tight sphere after sunset. Likewise, we cannot say anything about the biochemistry of the Martian plants. Plants, like animals, need oxygen, but in our own plants the process of photosynthesis produces far more oxygen than is consumed by the plants, so that our plants, during daylight, give off far more oxygen than they use up. The Martian plants may have evolved means of retaining the oxygen produced during the day, or else they may have learned to split the iron oxides of the soil into iron and free oxygen.

These are things biologists can only guess at, but they are also things the same biologists would like to investigate, and a strong case for plant life on Mars can still be made. Mars may have become a somewhat different planet after the flyby of Mariner IV, but it is still an interesting one.

Epilogue

What Next?

The voyage of Mariner IV has not changed our concepts of general climatic conditions and the probability of vegetation on Mars as much as was thought at first.

But it certainly has changed all of the ideas of what would be done after the first flyby. Previously, everybody had been convinced that the next step—at any rate, one of the next steps—would be a landing device, instrumented to detect the presence of life. Even the instruments to be carried were in the preliminary design and experimental stages. But all this reasoning had been based on the expectation of a ground-level pressure of 60–75 millibars. An atmosphere of this density could have been utilized for aerodynamic braking and would have helped to accomplish a soft landing on the planet. The actual ground-level pressure of about 10 millibars is useless for this purpose. This means that the soft landing of an instrument package on the surface of Mars has suddenly become a much more difficult job.

To make the situation somewhat worse, there are now nagging doubts as to whether the proposed life-detecting devices would do their part under Martian conditions. They were all planned on the assumption that the biochemistry of Martian bacteria was similar to that of bacteria on earth. The actual means of detection depended on the acceptance of terrestrial nutrients by Martian bacteria; the changes produced by these bacteria in the nutrients were the items to be watched by the instruments. But what could be concluded if there were no changes in the nutrients? One could conclude that there had been an instrument failure, that things had not worked as they should have because the landing had been too hard, or three dozen other things. One could conclude that there was no life on Mars, not even bacteria. One could also conclude that the Martian life forms were not interested in terrestrial nutrients. Detecting alien life forms chemically was not the best of ideas to begin with, and the main reason why a great deal of thought was spent devising them was that they could be made small and light.

An optical system for the detection of alien life would be far superior; if you see that something grows, or that it moves deliberately in some manner, or if you see something attacking something else, you can be sure that you are watching life forms in action. But such an optical system would have to be heavy if it were to be versatile—remember that the life forms might be as small as bacteria or as large as the average potted plant—and it would require a good deal of electrical power to transmit its findings.

For all these reasons, a landing device instrumented for the detection of life forms is certainly not the next step in our exploration of Mars. It is several steps removed from the "simple" flyby.

The next step is obviously a device that can be sent to Mars and can then be made to go into an orbit around Mars, preferably at a low altitude of a hundred miles or so, far inside the orbit of Phobos. This maneuver alone would require a good deal of fuel, since an excess velocity of nearly 1½ miles per second would have to be neutralized. Fortunately, much larger takeoff boosters are available now, so that the weight restrictions given by the Atlas-Agena rocket no longer apply. Sending a probe with an earth weight of 4000 or 5000 pounds to the vicinity of Mars is now a possibility. Such a greater weight not only permits the carrying of a large supply of fuel for putting the device into an orbit around Mars (and for later changes of orbit if this should be desirable), it will also permit a very considerable increase in the power supply. The "Super Mariner" might carry six or eight solar panels, each one with a greater power output than the four panels of the original model.

Because of the greater power supply, the "Super Mariner" could take and transmit pictures in color; color is a prime requirement when it comes to Mars. The pictures from Mariner IV might have looked less strange if they had been in color. And they could be fitted into the map of Mars only by calculation, since they were what might be called "sudden detail." They might be compared to pictures of rooftops taken by a low-flying helicopter; such pictures also would have to be fitted into a map of a city by calculation. It would be very useful, to put it mildly, to have pictures of a gradual approach, pictures like the ones transmitted by the Ranger shots to the moon.

The ideal performance of a flight by a "Super Mariner" would be to start taking pictures (*in color!*) at a distance of, say, 50,000 miles from Mars. Then there should be pictures every 5000 miles until the spacecraft has approached the planet to a distance of 15,000 miles. From then on the number of pictures should be increased to whatever rate the designers can build into the equipment.

This would produce a sequence that begins with pictures comparable to what can be seen with a telescope under ideal conditions with finer and finer detail.

Finally, after orbit around Mars has been achieved, we would get fine detail, gradually accumulating into a close-up map of Mars. Ideally, the "Super Mariner's" orbit around Mars should be a polar orbit. In such an orbit, rather minor adjustments of the position of the orbit in space—relative to the stars—would see to it that the spacecraft is always exposed to the sun's rays and does not enter the shadow of the planet. And from a polar orbit the whole planet could be charted, not just a belt around the equator, as would be the case with an equatorial orbit.

Such a performance would end all the debates about *canali*, "oases," seasonal changes, melting or evaporation of the polar caps, height of the dust clouds above the Martian surface, and so forth. No doubt some new and unexpected problems will crop up in the pursuit of this investigation, but once these basic facts have been settled, we shall know how to proceed.

Appendixes

The Main Facts About Mars

Distance from sun		
mean	1.5237 A.U.	141,500,000 miles
perihelion (minimum)	1.3826 A.U.	128,000,000 miles
aphelion (maximum)	1.6658 A.U.	154,100,000 miles
Distance from earth		
minimum (perihelion opposition)		34,797,000 miles
maximum (aphelion conjunction)		340,000,000 miles
Orbital velocity		
mean		14.98 miles/second
at perihelion (fastest)		16.45 miles/second
at aphelion (slowest)		13.64 miles/second
Escape velocity		3.13 miles/second
Circular velocity (at surface)		2.21 miles/second
Equatorial diameter	4194 miles*	(4220 miles)
Polar diameter	4163 miles*	(4175 miles)
Length of day, sidereal	24 hours 37 minutes	22.668 seconds
solar	24 hours 39 minutes	35.247 seconds
Length of year	686.979 earth days	668.599 Mars days
Eccentricity of orbit	0.093368	
Inclination of orbit to ecliptic		1 degree 50 minutes 59.8 seconds
Inclination of Martian equator to its orbit		25 degrees 10 minutes
Mass (earth=1)	0.108	
Surface area (earth=1)	0.278	
Gravity at surface (earth=1)	0.38	
Density (earth=1)	0.737 or 4.1 gram/cc.*	(0.71 or 3.91 gram/cc.)

* These figures are according to NASA Memo RM-3999 (January, 1964); formerly accepted values are given in parentheses.

The Satellites of Mars

	Phobos	*Deimos*
Discoverer	Asaph Hall	Asaph Hall
Date of discovery	August 17, 1877	August 11,1877
Distance, from center of planet	5820 miles	14,615 miles
Distance from surface of planet	3604 miles	12,493 miles
Synchronous orbit for Mars (from center of planet)	———	12,710 miles
Period	7 hours 39 minutes	30 hours 80 minutes
Orbital eccentricity	0.0210	0.0028
Inclination of orbit to Martian equator	0 degrees 57 minutes	1 degree 18 minutes
Diameter (estimated)	10 miles	6 miles

Flight Performance of Mariner IV

(Selected dates—the distance from earth at 9 A.M., Eastern Standard Time; total distance traveled at 3 P.M., Eastern Standard Time for the dates given)

Date 1964	*Days elapsed since takeoff*	*Straight line distance from earth (miles)*	*Distance traveled along orbit (miles)*	*Straight line distance to Mars (miles)*
Dec. 28	30	5,097,388	52,405,965	
— 30	32	5,443,671	55,856,811	
1965				
Jan. 15	48	8,563,346	82,950,644	
— 25	58	11,303,032	101,009,177	
Feb. 10	74	16,241,084	124,819,350	
— 25	89	22,784,846	147,671,170	
Mar. 10	102	29,792,086	166,718,190	
— 20	112	35,967,651	180,912,930	
— 31	123	43,479,864	196,094,740	
Apr. 10	133	50,897,358	209,528,220	

Date 1965	*Days elapsed since takeoff*	*Straight line distance from earth (miles)*	*Distance traveled along orbit (miles)*	*Straight line distance to Mars (miles)*
Apr. 30	153	67,034,878	235,445,095	
May 10	163	75,645,610	247,980,100	
— 27	180	90,780,532	268,736,040	
June 10	194	103,499,720	285,383,610	
— 20	204	112,586,940	297,100,000	5,857,220
— 30	214	121,606,448	308,600,000	3,446,013
July 5	219	126,064,300	314,300,000	2,255,612
— 6	220	126,950,210	315,500,000	2,018,246
— 7	221	127,834,408	316,600,000	1,781,048
— 8	222	128,715,870	317,800,000	1,543,989
— 9	223	129,595,530	318,900,000	1,307,037
— 10	224	130,474,570	320,700,000	1,069,131
— 11	225	131,349,910	321,900,000	832,262
— 12	226	132,233,060	322,800,000	595,357
— 13	227	133,094,110	324,000,000	358,291
— 14	228	133,963,540	325,100,000	120,638
— 14	228	flyby during the evening hours		
Aug. 20[1]	265	163,162,460	365,000,000	8,622,011
Sept. 24[2]	300	187,152,860	410,000,000	17,606,438

A Calendar for Mars

The cycle of the seasons on Mars is determined in the same manner as the seasons on earth. But while the orbital velocity of the earth is virtually uniform, the orbital velocity of Mars changes greatly, depending on whether the planet is near its aphelion or its perihelion. This has the result that the differences between the number of days in a season are more pronounced than they are on earth. The following table shows the duration of the seasons both on earth and on Mars:

[1] At 10:30 P.M., Eastern Standard Time.
[2] At 8:00 P.M., Eastern Standard Time.

Season		*Duration*	
Northern *Hemisphere*	*Southern*	*Mars (Martian days)*	*Earth (days)*
Spring	Fall	194.54	92.9
Summer	Winter	177.10	93.6
Fall	Spring	140.92	89.7
Winter	Summer	156.04	89.1
		668.60	365.3

But it is difficult to do justice to the different lengths of the seasons in a calendar if you want to keep it simple. The main purpose of a calendar is to keep track of the year (that is, the orbital period) and to make a provision of some kind for accommodating the fraction of a day at the end of the year. As is the case with the earth, the Martian orbital period is not an even multiple of the number of revolutions of the planet on its axis.

Of course, there are several ways of making a calendar for earth, and there are also several choices of a Martian calendar. Since such a calendar is likely to be used by transplanted humans who are used to a twelve-month year and a seven-day week, Dr. I. M. Levitt, director of the Fels Planetarium in Philadelphia, maintained both in his proposal. Of course, the seven-day week is completely arbitrary on Mars; on earth it represents approximately one quarter of the time that goes by between one new moon and the next.

The Martian calendar, then, would consist of twelve months, each with eight seven-day weeks, except that the eighth week is only six days long for four months. A scheme of this calendar, designed to fit a wallet, would look like this:

January
April
July
October

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49
50	51	52	53	54	55	56

February
May
August
November

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49
50	51	52	53	54	55	56

March
June
September
December

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49
50	51	52	53	54	55	—

This adds up to 668 (Martian) days per year, or 6/10 of a day too short. If the discrepancy were 5/10 of a day, this could be easily corrected by making every second year 669 days long, but that extra 1/10 of a day per year complicates matters. Dr. Levitt's solution of the problem consisted is a calendar comprising a five-year cycle, with 668/669/669/669/668 calendar days. This adds up to 3343 days, and 668.6 multiplied by five also results in 3343 days. This would be perfect if the Martian year contained precisely 668.6 days, but the figure of 668.6 is merely a convenient approximation. In reality it represents a mistake of 0.00095 day per year, but it needs 10,000 years to add up to one full day. Every tenth century, therefore, the five-year cycle would have to contain 668/668/669/669/668 calendar days to adjust it to reality.

Some Books About Mars

(Only works in English are listed in this bibliography. For a more complete bibliography, containing all the important foreign publications, see *The Exploration of Mars* by Willy Ley and Wernher von Braun. New York: Viking Press, 1961.)

Cyr, Donald Lee. *Mars Revisited.* Philadelphia: Dorrance & Company, Inc., 1959. Illustrated by Arthur D. Beeman. Mr. Cyr was the first author to state the opinion that impact craters must be numerous on Mars. He first said so in a small book entitled *Life on Mars,* published in 1944 by the *Desert Magazine Press* in El Centro, California.

Branley, Franklyn M. *Mars.* New York: The Thomas Y. Crowell Co., 1955. Illustrated by Anne Marie Jauss. This is a book for beginners, written for the lower grades of junior high school. Out of date in a number of respects by now.

Housden, C. E. *The Riddle of Mars, the Planet.* London: 1914. Mr. Housden assumed that all the dark areas on Mars were artificially irrigated, and he also assumed that the polar caps had an average thickness of five feet. The book is an engineering study of the number of pipes needed for carrying this amount of water, of the energy required for pumping it, and so forth.

Jackson, Francis, and Moore, Patrick. *Life on Mars.* London: Routledge & Kegan Paul, Ltd., 1965. Patrick Moore is an astronomer while Francis Jackson, though an amateur astronomer, is professionally a research bacteriologist. The book is a survey of the theories about Mars from the biological point of view, with a summary report on experiments with small organisms subjected to Martian conditions, carried out by Jackson.

Levitt, I. M. *A Space-Traveler's Guide to Mars.* New York: Henry Holt & Co., Inc., 1956. Dr. Levitt is the director of the Fels Planetarium in Philadelphia; his book is a very fine introduction to the problems of Mars.

Ley, Willy, and von Braun, Wernher. *The Exploration of Mars*. New York: Viking Press, 1956 and 1961. Paintings by Chesley Bonestell. The first four chapters, by Willy Ley, give a history of the exploration of Mars by telescope. The other chapters, by Wernher von Braun, outline the fundamentals of a manned expedition to Mars with vehicles that could be built soon. Of the 40 plates, 16 are in color.

Lowell, Percival. *Mars*. Boston: 1895.

———. *Mars and Its Canals*. New York: The Macmillan Company, 1906.

———. *Mars as the Abode of Life*. New York: The Macmillan Company, 1909. These three preceding books are the famous works of Percival Lowell, in which he argued for the existence of intelligent inhabitants of Mars.

Pickering, William H. *Mars (Studies in Science)*. Boston: The Gorham Press, 1921. Reprint of 17 papers on Mars and Martian phenomena written by Professor Pickering, beginning in 1892; the papers were revised in 1920 for publication in book form.

Richardson, Robert S. *Exploring Mars*. New York: McGraw-Hill Book Co., Inc., 1954. This is actually a survey of the solar system for the purpose of comparing the other planets to Mars and to the earth.

———, and Bonestell, Chesley. *Mars*. New York: Harcourt, Brace & World, Inc., 1964. Large size, with 32 plates in black and white and 11 plates in color, the latter by Chesley Bonestell. Dr. Robert S. Richardson was for many years with the Mount Wilson Observatory in California; he is now with the Griffith Observatory in Los Angeles, California.

Slipher, Earl C. *The Photographic Story of Mars*. Edited by John S. Hall. Cambridge, Mass.: Sky Publishing Corporation, Harvard College Observatory, 1962. In folio, with numerous photographs on 48 plates, plus several color photographs of Mars. By the famous observer of Lowell Observatory.

Strughold, Hubertus. *The Green and Red Planet*. Albuquerque, N.M.: University of New Mexico Press, 1953. Hubertus Strughold, M.D., Ph.D., is Professor of Aviation Medicine at the U. S. Air Force School of Aviation Medicine. The book has the subtitle "A physiological study of the possibility of life on Mars"; it can be read by anybody with a high school education.

Vaucouleurs, Gérard de. *The Planet Mars.* Translated from the French by Patrick A. Moore. New York: The Macmillan Co.; London: Faber & Faber, Ltd., 1950. Gérard de Vaucouleurs, who is now in the United States, is considered the outstanding expert on Mars in our time. This is a popular volume.

———. *Physics of the Planet Mars.* London: Faber & Faber, Ltd., 1954; New York: The Macmillan Co., 1955. This is a thorough discussion of all observed Martian phenomena (except for the canals). Difficult for beginners. The French original appeared one year earlier.

Wallace, Alfred Russel. *Is Mars Habitable?* London: 1907. This book began as a review of Percival Lowell's *Mars and Its Canals* and became a small book itself. Wallace reached the conclusion that the canals are not artificial and that the planet is not only uninhabited but uninhabitable.

Webb, Harold B. *Observations of the Planet Mars.* Privately printed, 1936.

———. *Observations of Mars and Its Canals.* Privately printed, 1941. Both books listed by this author contain numerous drawings of the planet and of specific surface features.

Webb, Wells Alan. *Mars, the New Frontier; Lowell's Hypothesis.* San Francisco: Fearon Publishers, 1956. This work has the subtitle: "Does analysis of the network of canals on Mars indicate intelligent design?" The author comes to the conclusion that it does. The most recent book still defending the existence of intelligent inhabitants of Mars.

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WILLY LEY was a founding member of the early German Rocket Society and its vice-president from 1928 to 1933. He came to the United States in 1935 and became a naturalized citizen in 1944. A free-lance writer since 1927, he has been an information specialist for the Office of Technical Services of the United States Department of Commerce since 1947. Dr. Ley is a Fellow of the British Interplanetary Society, and a member of the Society of American Military Engineers. His many books include *Ranger to the Moon; The Exploration of Mars* (with Wernher von Braun); *Satellites, Rockets, and Outer Space;* and *Missiles, Moonprobes, and Megaparsecs.*

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