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ABSTRACT

Presented is one of a series of National Aeronautics and Space Administration (NASA) facts about the exploration of Mars. In this publication, emphasis is placed on the planet Mars as a member of the Solar System and a detailed description is given related to historical accounts of the planet's existence and its travels. The physical characteristics are described as well as those of its satellites. Photographs as seen by Mariner 9 from space and diagramatic figures showing position and distances related to earth and sun are included in the article. Five student projects are given as well as suggested readings. (EB)

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NASA Facts

An Educational Publication of the National Aeronautics and Space Administration

NF-59/12-75

MARS AS A MEMBER OF THE SOLAR SYSTEM

One of a series of NASA Facts about the exploration of Mars.

Mars in the Skies of Earth

Outermost of the Earth-like planets, Mars was one of the seven "planets" known to the ancients; the others being Mercury, Venus, Jupiter, Saturn, the Sun, and the Moon. The Sun and the Moon were included because they, too, like the planets, appear to move from west to east among the constellations of the "fixed" stars. The word "planet" is derived from the Greek *planetes* which means "a wanderer."

Approximately every two years Mars becomes a very brilliant star-like object in the midnight sky of Earth, when it shines with a steady, reddish light. To the ancients this light suggested blood and fire, so they associated the planet with war and gave it martial names—Nergal (Master of Battles) in Chaldea, Ares (God of War) in Greece, and Mars (God of War) in Rome. While Mars is generally the modern name for the planet, the earlier name, Ares, is perpetuated by scientists when they refer to areography (geography of Mars) and areocentric (centered on Mars). Even the symbol for Mars, ♂, suggests a spear and a shield.

Mars orbits the Sun outside the orbit of the Earth. Accordingly it is referred to as a superior planet, as contrasted with the inferior planets, Mercury and Venus, which revolve around the Sun inside the Earth's orbit. The orbit of Mars departs farther from a circle, i.e. is more elliptical, than that of the Earth.

Because Mars travels along an ellipse it moves between two extremes of distance from the Sun (Figure 1). At closest approach, perihelion, Mars is 206.66 million kilometers (128.41 million miles) from the Sun. At aphelion, the most distant part of its orbit, Mars is 249.23 million kilometers (154.86 million miles) from the Sun. While Mars' distance from the Sun thus varies by 42.5 million kilometers (26.45 million miles), Earth's distance from the Sun varies by only 5.2 million kilometers (2.22 million miles).

Mars takes 687 Earth days to revolve completely around the Sun, compared with the 365¼ days of Earth's solar year. When a superior planet, such as Mars, is directly opposite to the Sun in the skies of Earth, it is said to be in opposition (Figure 2). At such time the Earth is between the Sun and the planet, and since the planet is then closest to Earth it shines its brightest in the southern sky at midnight.

Oppositions of Mars take place once every 2 years and 2 months approximately (every 780 days on the average). Mars' velocity along its orbit varies from fast at perihelion to slow at aphelion. These variations cause the dates of oppositions also to vary slightly either side of the mean period of 780 days. For example, when Mars is at opposition close to its aphelion, the time between oppositions is only 764 days, whereas when oppositions are close to perihelion the time between them increases to 811 days.

Also, oppositions close to the perihelion of Mars bring the planet much closer to Earth, to 55.81 million kilometers (34.68 million miles), compared with 101.3 million kilometers (62.3 million miles) at an aphelic opposition. Thus, the diameter of the disc of Mars as seen in a telescope from Earth is nearly twice as large at a favorable opposition as at an unfavorable opposition.

Close approaches of Mars, i.e. perihelic oppositions, occur every 16 years on the average. At the most recent of these approaches in August 1971, Mars was separated from Earth by 56.2 million kilometers (34.92 million miles). The next perihelic opposition will occur in September 1988, when Mars will be slightly farther away; 58.4 million kilometers (36.3 million miles).

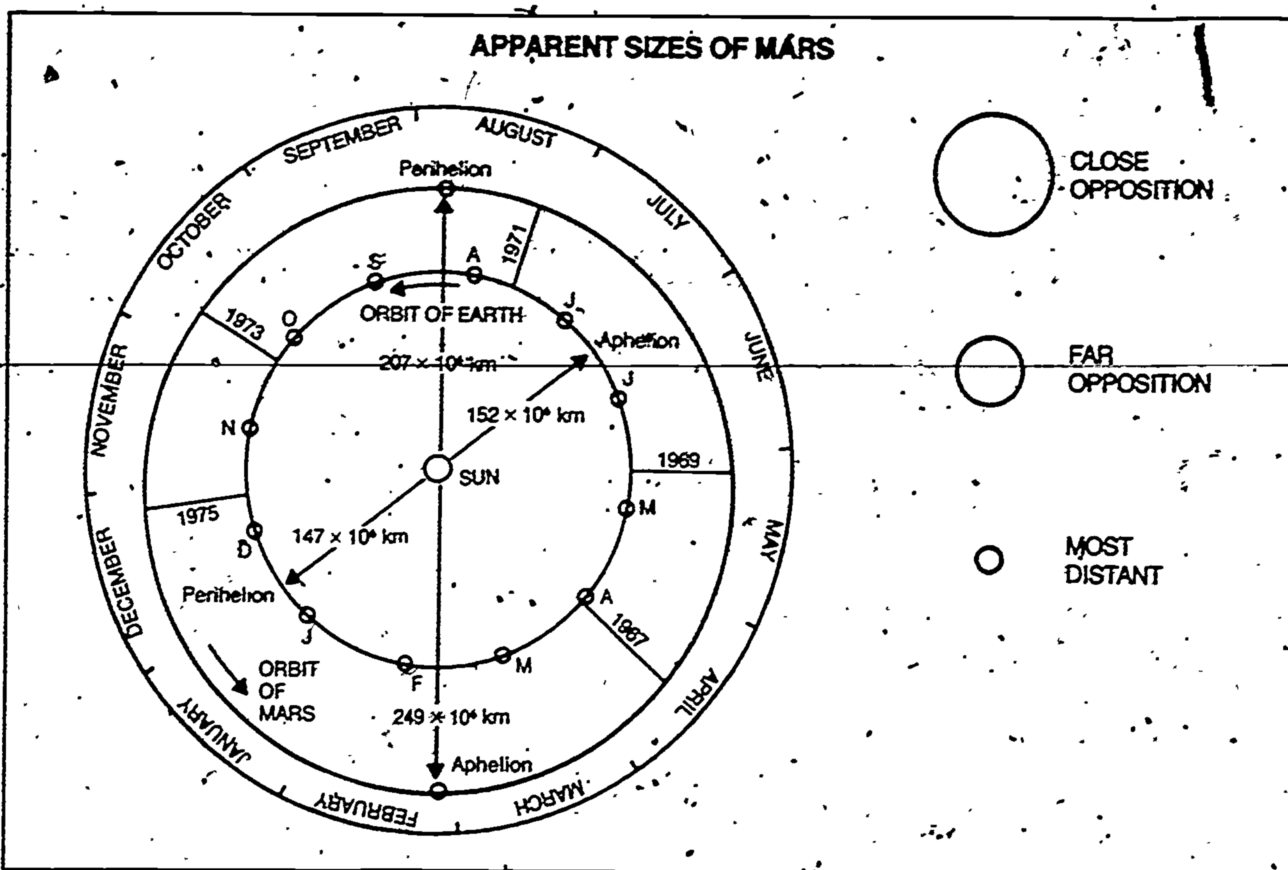


Figure 1. Orbits of Earth and Mars, showing aphelion and perihelion positions and distances.

Unfortunately for astronomers based in the northern hemisphere, favorable oppositions always occur in the month of August, when Mars is very low in the southern sky at midnight. This condition arises from two astronomical facts. First, the planets all revolve around the Sun in nearly the same plane as the plane of the Earth's orbit, which is called the *plane of the ecliptic*. As seen from Earth the planets appear to move through the stars very close to the projection of the Earth's orbit on the star sphere, which is called the *ecliptic* —an imaginary line on the celestial sphere passing through those twelve constellations known as the Zodiacal constellations.

Second, since the Earth spins on an axis inclined 23½ degrees to the poles of its orbit, the ecliptic arches across Earth's sky at an angle which changes over each twenty-four hours (due to the spin of the Earth), and over each year (due to the revolution of the Earth around the Sun). At midnight during northern hemisphere summer, the ecliptic is low across the southern sky, whereas at noon it is high in the southern sky. In winter the opposite is true. As a consequence, a planet at opposition is low in the midnight sky in summer and high in the midnight sky in winter. But when Mars is at opposition in the winter sky it is always an unfavorable opposition and the planet is far away and difficult to observe. When the planet is closer to the Earth at a summer opposition, it is, unfortunately, low in the sky and more distorted by atmospheric effects.

Conjunction of a superior planet occurs when it is on the far side of its orbit, beyond the Sun as seen from Earth. The planet is then most distant from Earth and most difficult to observe. It is also close to the Sun in the sky. Even radio signals from a planet close to conjunction are difficult to receive because they must pass close to the turbulent outer atmosphere of the Sun which causes them to become distorted.

Physical Characteristics of Mars

Mars is the outermost of the Solar System's rocky inner planets of which Mercury, Venus, Earth and Moon are the other family members. Mars is not a large planet; it is between Mercury and Earth in size. Its equatorial diameter is 6786 kilometers (4217 mi.) compared with Earth's 12,756 kilometers (7926 m.). It rotates on its axis, as does Earth, but in 24 hours 39 minutes. So day and night on Mars are almost the same lengths of time as on Earth. The Martian day has been

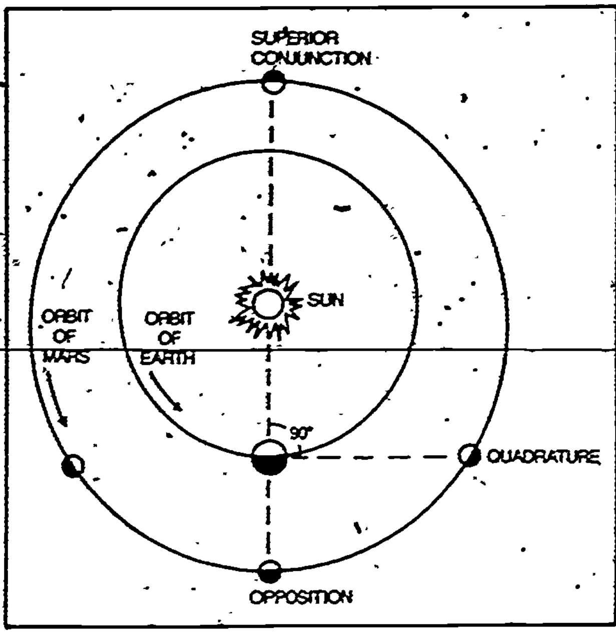


Figure 2. Conjunction, opposition, and quadrature of Mars.

called a Sol by space experimenters planning expeditions to the Martian surface. A Mars year consists of 670 Sols, i.e. 687 Earth days.

Mars' axis, like that of the Earth, is not perpendicular to the plane of its orbit. It is tilted 25 degress compared with Earth's axial tilt of 23½ degrees. So Mars, too, experiences seasons as one hemisphere then the other tilts towards the Sun because of the movement of Mars around its orbit. But, because Mars' distance from the Sun varies considerably during a Martian year, the Martian seasons are more complicated than seasons on Earth.

Mars is closest to the Sun during spring in the planet's southern hemisphere; thus southern hemisphere spring on Mars is always warmer than northern hemisphere spring. Summer in the northern hemisphere is also long because Mars is moving slowly along its orbit close to aphelion, but it is a cool summer. Mars receives about 44 percent more solar radiation per unit area of surface at perihelion than at aphelion; surface temperatures can thus vary considerably. The south polar cap of Mars almost disappears during the hot, southern hemisphere summer, whereas the north polar cap has never been observed to disappear as viewed from Earth. Actually neither cap disappears completely; there is a small permanent cap even at the southern polar region of the planet. This is discussed in a subsequent booklet of this series.

The combination of axial inclination and orbital ellipticity leads to northern hemisphere winters that are short and warm, and summers that are long but cool, with southern hemisphere winters that are long and cold, and summers that are hot and short.

Satellites of Mars

Mercury and Venus do not have satellites. Earth has its unusually large Moon. Mars has two very small satellites that can be observed in large telescopes at a close opposition of the planet. At the 1971 opposition they appeared in a 24-inch telescope as tiny spots of light almost hidden in the glare of the planet itself.

In 1610 Johannes Kepler predicted that Mars might have two satellites based on the fact that the Earth has one and Galileo had seen four satellites of Jupiter. It was a wild guess, but it probably was known to Jonathan Swift, the English satirist, who in his *Gulliver's Travels*, published in 1726, wrote of two lesser stars or satellites revolving around Mars. But these two satellites were not actually seen until 1877. Asaph Hall, their discoverer, named the two tiny worlds Deimos and Phobos after the horses that draw the chariot of Mars (Flight and Fear, respectively).

These Martian moons revolve very close to their planet. Phobos, the inner satellite, revolves in 7 hours and 40 minutes in an almost circular orbit only 6005 kilometers (3700 m.) above the surface

Figure 3. Mariner 9 Photo of Phobos

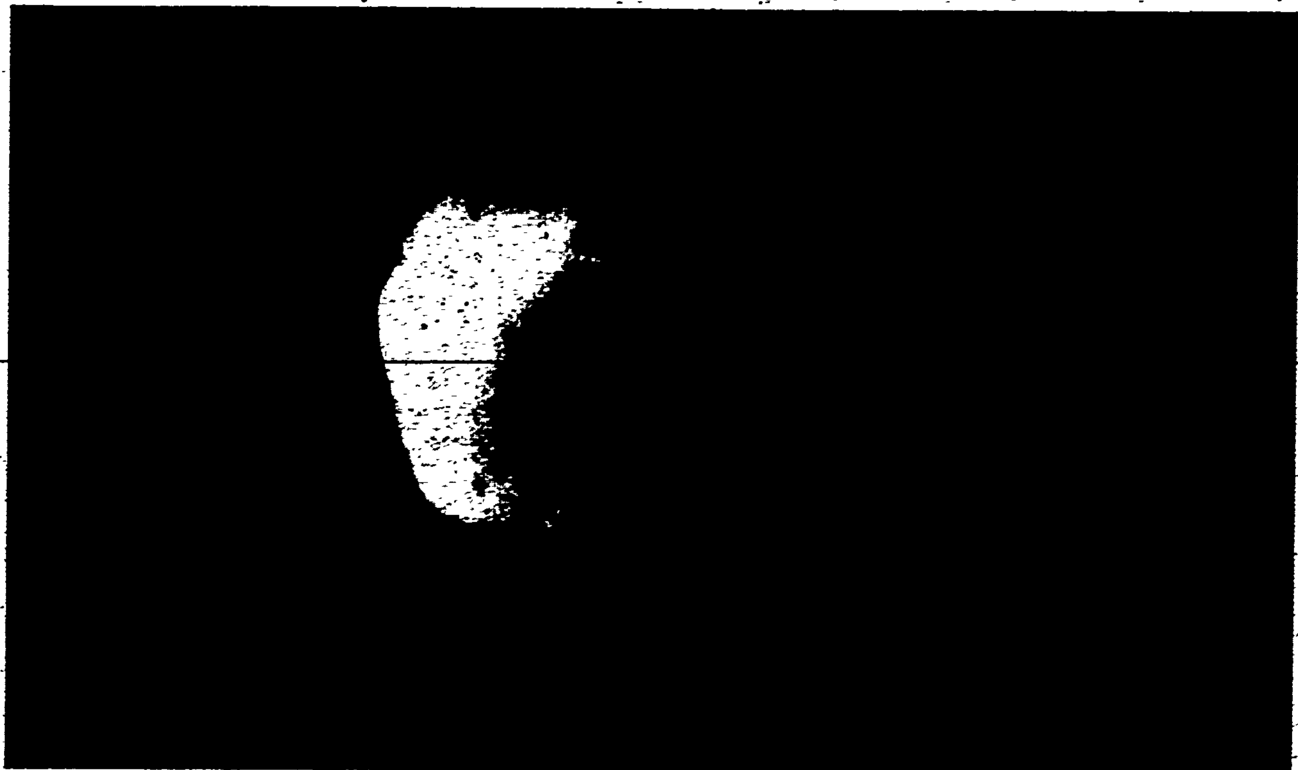


Figure 4. Mariner 9 Photo of Deimos

of Mars. The tiny, odd-shaped satellite is about 27.2 kilometers (16.9 m.) long and 19.4 kilometers (12.0 m.) wide. Deimos orbits at 23,500 kilometers (14,600 m.) in 30 hours and 18 minutes. It is even smaller than Phobos—16 kilometers (9.9 m.) long, and 11 kilometers (6.8 m.) wide. From the dark appearance of these satellites and their heavily cratered and irregular shapes as seen by close-up photography from NASA's Mariner spacecraft, scientists conclude that Deimos and Phobos were formed perhaps 3 or 4 billion years ago and possibly are captured asteroids (Figures 3 and 4).

Deimos is too small and too far away from Mars to cause an eclipse of the Sun. When it does pass between Mars and the Sun anyone standing on Mars would see Deimos as an irregularly-shaped black object silhouetted against the bright solar disc. Phobos, however, can cast a shadow on Mars (Figure 5). If an observer were standing on the Martian surface within the path of that shadow he would see the Sun eclipsed, just as the Moon eclipses the Sun on Earth. But because of the rapid motion of the inner satellite of Mars, such an eclipse would last for about one second only.

Moreover, Phobos cannot be seen from some parts of Mars. It is so close to the planet that the curve of the surface of Mars hides it from view of observers located beyond 70 degrees north and south latitude. If you were standing on the surface of Mars and looking up at Phobos hurtling directly overhead it would appear about two-thirds the size of the Moon we see in Earth's sky.

Sightings and Motions of Mars, 1975/76

The most recent opposition of Mars was on December 15, 1975. It was not a close opposition since at its closest, on December 8, Mars was 84.6 million kilometers (52.57 million m.) from Earth.

Mars is easy to identify in the night sky because of its steady reddish brilliance and because it does not twinkle like the stars. This year, two Viking spacecraft are on the way to Mars. They are unmanned but automated and carrying many scientific experiments.

From launch to rendezvous of the Vikings, Mars will have moved along the ecliptic through the Zodiac from Taurus to Virgo, passing in turn through Gemini, Cancer, and Leo (See Figure 6). Around the months close to opposition, however, the motion of Mars in the night sky changes. Instead of traveling each day further to the east, it halts its eastward motion about November 1975 when close to the star Eta Geminorum, and retreats westwards, back into Taurus. Then again, at the beginning of February 1976, the motion changes. Mars halts its backward, or retrograde, motion, and resumes its motion to the east. Thus, around opposition, Mars appears to loop among the stars. This loop is caused by the relative motions of

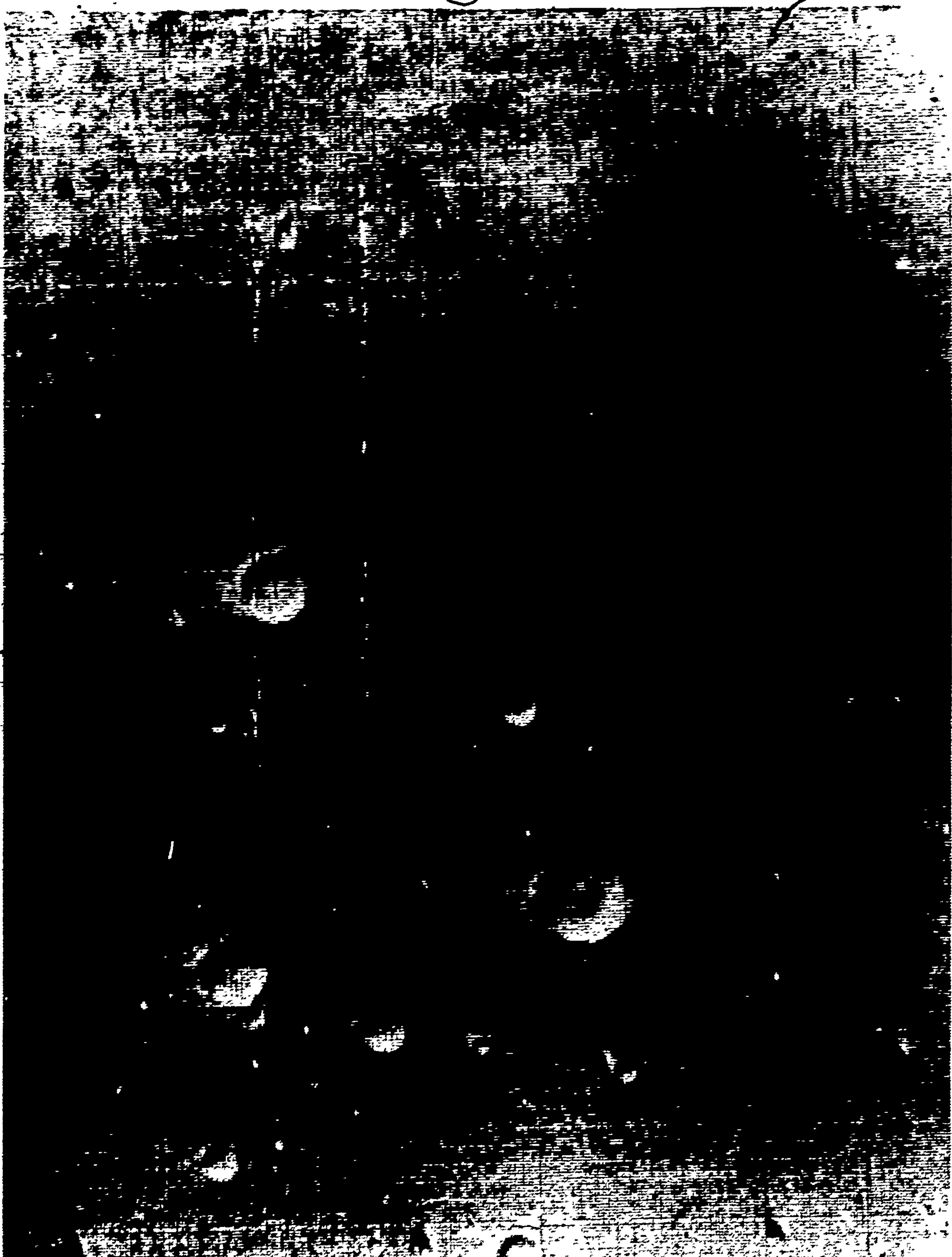


Figure 5. Shadow of Phobos on Mars; an eclipse of the Sun on Mars as seen by Mariner 9 from space.

Earth and Mars, Earth moving faster in its orbit, catches up with Mars, and as Earth moves past Mars the outer planet seems to be moving backwards; it is like watching a slow car from a fast car overtaking it. The slow car appears to move backward relative to the observer in the fast car. But later, as the orbits curve around the Sun, Mars is seen in its true motion around its orbit as viewed from Earth (Figure 7). At the time of the Nation's bicentennial, Mars will be in the constellations Leo and Virgo as the first NASA spacecraft lands in July and the second in September 1976.

Figure 8 shows the position of Mars among the constellations and where it can be observed in the night sky at the times of Viking launch and arrival at Mars, and at the time of Mars' opposition.

STUDY PROJECTS

Project One

Refer to an astronomical star atlas, such as Norton's, and make a map of the Zodiacal constellations Taurus through Virgo; i.e. from right ascension 3 hours to 14 hours. Use the following information of right ascension and declination of Mars each month to trace the movement of Mars from Viking launch (August 1975) to their rendezvous with Mars (July and August 1976). Use Figure 6 as a guide. Note, you will have to plot the positions of the stars on your map in terms of their coordinates of right ascension (comparable with longitude on Earth) and declination north and south (comparable with latitude on Earth). Place only the brightest stars on the map.

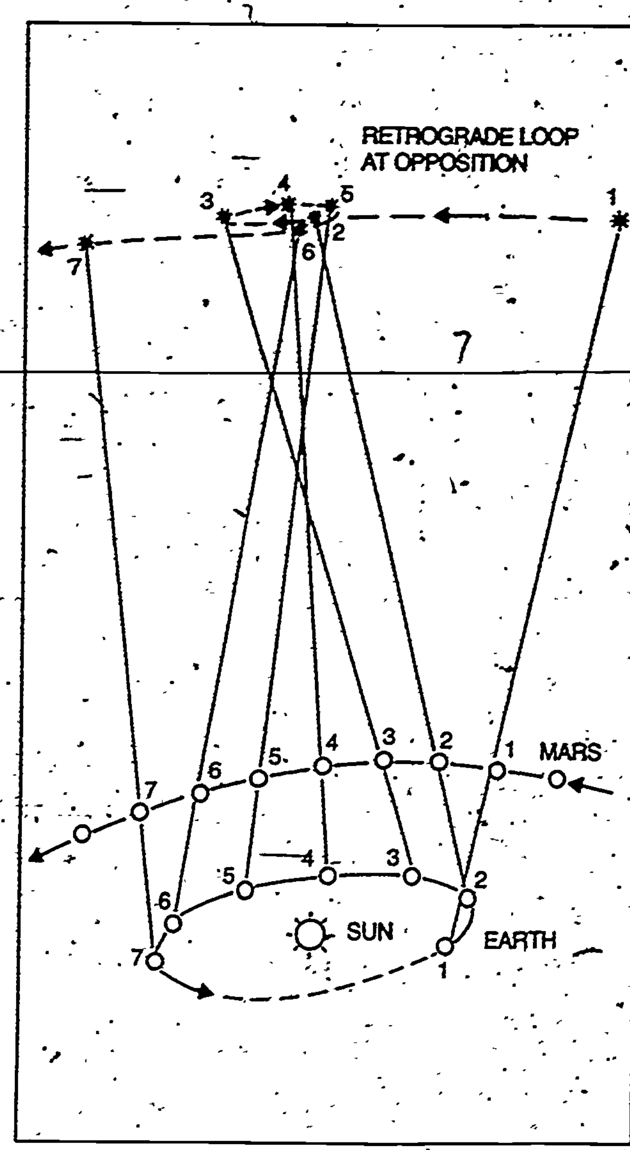


Figure 7. How Mars makes a retrograde loop in the sky about the time of opposition.

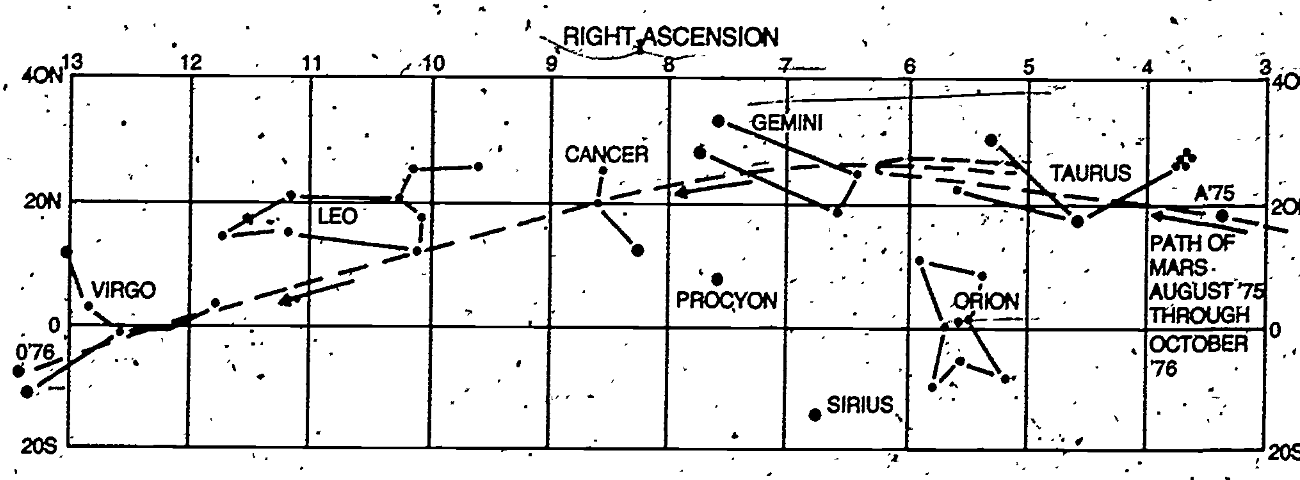
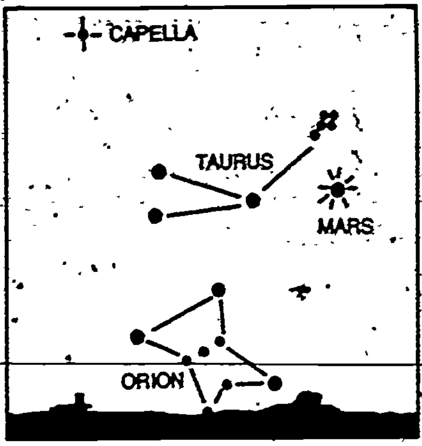
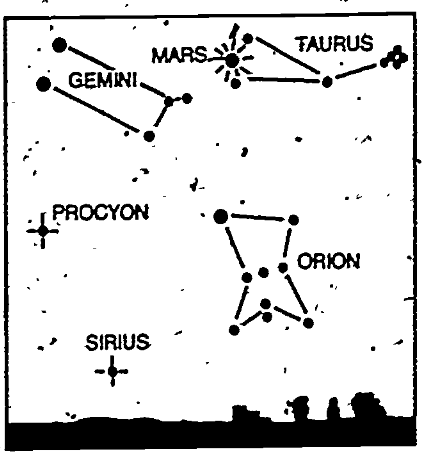


Figure 6. Path of Mars through the Zodiacal constellations during the flight of Viking to Mars.



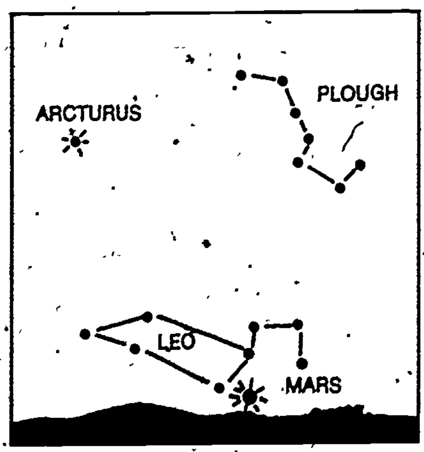
EAST
MID-AUGUST 1975
4:00 A.M.
DAYLIGHT TIME

VIKING LAUNCH



SOUTH
MID-DECEMBER 1975
MIDNIGHT
STANDARD TIME

MARS OPPOSITION



NORTH WEST
4 JULY 1976
10:00 P.M.
DAYLIGHT TIME

FIRST VIKING LANDS

Figure 8. The positions of Mars in the constellations at the time of Viking 1 launch and arrival at Mars and at the time of the opposition of Mars, December 1975. Note the position of the ecliptic, shown as a dotted line.

Positions of Mars about the first day of each month, 1975/1976

Month	Right Ascension Hours	Minutes	Declination Degrees
Aug 1975	3	28	17 N
Sept	4	44	21
Oct.	5	40	23
Nov	6	12	24
Dec	5	52	26
Jan 1976	5	8	26
Feb	5	4	25
Mar	5	32	26
Apr	6	28	25
May	7	28	23
June	8	40	19
July	9	48	13
Aug	11	4	6
Sept	12	24	2 S
Oct	13	44	10 S
Nov	15	8	17 S

Note: Solar conjunction takes place close to November 15, 1976, when Mars cannot be seen from Earth. Also, for several weeks either side of conjunction, radio signals cannot be received from a spacecraft at the planet.

Project Two

As necessary refer to an astronomical textbook and draw a plan map of the Solar System showing the Sun and the orbits of Earth and Mars. Indicate on these orbits the positions of the Earth and Mars at the beginning of each month, corresponding to the positions of Mars in the sky that you have indicated on your star map of Project One.

Make sure that the orbits are carefully drawn to scale, and remember that the perihelion of Earth is close to the point on Earth's orbit where the Earth is in January each year. The perihelion of Mars' orbit is on a line from the Sun through the position of the Earth in the middle of August each year.

Place marks on the orbit of Mars to show its approximate position at the beginning of each month, working either side of Mars' perihelion.

To relate Earth's dates to Mars' dates, work from the position at Mars' opposition on December 15, 1975. To find this position, draw a line from the Sun through the Earth at its position on December 15 and extend the line to the orbit of Mars. The point at which the line crosses Mars' orbit is where Mars will be December 15, 1975. Now add dates to the monthly position marks you made along the orbit of Mars. By comparing these dated positions on Mars' orbit with the dated positions on Earth's orbit, you will be able to see how Mars and Earth move round the Sun relative to each other during 1975 and 1976, and why Mars appears to move backward along the ecliptic at opposition.

Make lines between Earth and Mars at their positions on the first day of each month; the lengths of these lines provide the relative distances between the planets on the first of each month. Note that by the time Earth comes level with Mars at the December 15, 1975 opposition, Mars has moved outward from the Sun and is more distant than at perihelion; so the 1975 opposition is not a close one. Mark the positions of Earth and Mars on their orbits at the times Viking A and B are launched and at the time the spacecraft arrive at Mars.

Project Three

On or about the first day of each month, go out on a clear night and look for Mars. Check its position among the stars with the map you made for Project One. If you have access to a small telescope, either privately or by visiting a planetarium, watch how the disc of the planet becomes large as the lines between Earth and Mars you drew in Project Two, grow shorter and shorter. Calculate, on the basis of the lengths of these lines, the relative diameters of the discs of Mars as you should be able to see them each month through the telescope. Make the closest approach a disc one inch in diameter. Does the disc of Mars seen in the telescope correspond in relative size to the disc size you have calculated for each month?

Project Four

The plane of the orbit of Mars is not exactly the same as the plane of the Earth's orbit; they differ by 1.85 degrees. Draw an end-on view to scale showing the relative sizes of the two orbits and the positions of the planet Mars at its highest and lowest points above and below the plane of the Earth's orbit. Note that these points do not correspond to aphelion and perihelion of Mars; instead, the point where Mars is highest (most northerly above the plane of Earth's orbit) occurs when Mars is 249 million kilometers (155 million m.) from the Sun, and the point where it is at its lowest occurs when Mars is 206 million kilometers (128 million m.) from the Sun.

Calculate, either by trigonometry or by drawing to a large enough scale, how many millions of kilometers (and million of miles) Mars will be: a) above Earth's orbit and b) below Earth's orbit at these two extreme positions.

If we had an absent-minded navigator of a spacecraft flying from Earth to Mars, and he forgot about this plane change, these distances would be the kilometers (or miles) he would be off from his target, Mars.

Project Five

Imagine that you are a Martian and that you have calculated the orbital path of Phobos and found that both Phobos and the Sun will be exactly overhead at your location on Mars (latitude and longitude) at the time; i.e. you will be able to see an eclipse of the Sun by Phobos. Calculate how long this eclipse will last; assume that Phobos crosses the Sun's disc with the long axis of the satellite aligned along its orbit, and that it is the time in the Martian year when the solar disc has a diameter of one third of a degree (20 minutes of arc).

Calculate the time between first contact (when the satellite begins to show as a black 'bite' out of the solar disc), to second contact (when all the solar disc is covered), then the period of total eclipse, and finally the time to the end of the eclipse from the end of totality. How would these times differ if Phobos happened to be traveling across the Sun's disc with the satellite's short axis aligned along its orbit?

Make a series of drawings showing how these two types of eclipse might look to a Martian observing the eclipse through special darkened glass to protect the eyes.

Suggested Reading

THE BOOK OF MARS, S. Glasstone, NASA SP-179, 1968, U.S. Govt. Printing Office.

NORTON'S STAR ATLAS, Gall and Inglis, London, many editions

MARS, Robert S. Richardson and Chesley Bonestell, George Allen and Unwin, London, 1965

LAROUSSE ENCYCLOPEDIA OF ASTRONOMY, L. Rudaux and G. De Vaucouleurs, Prometheus Press, New York, 1959.

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