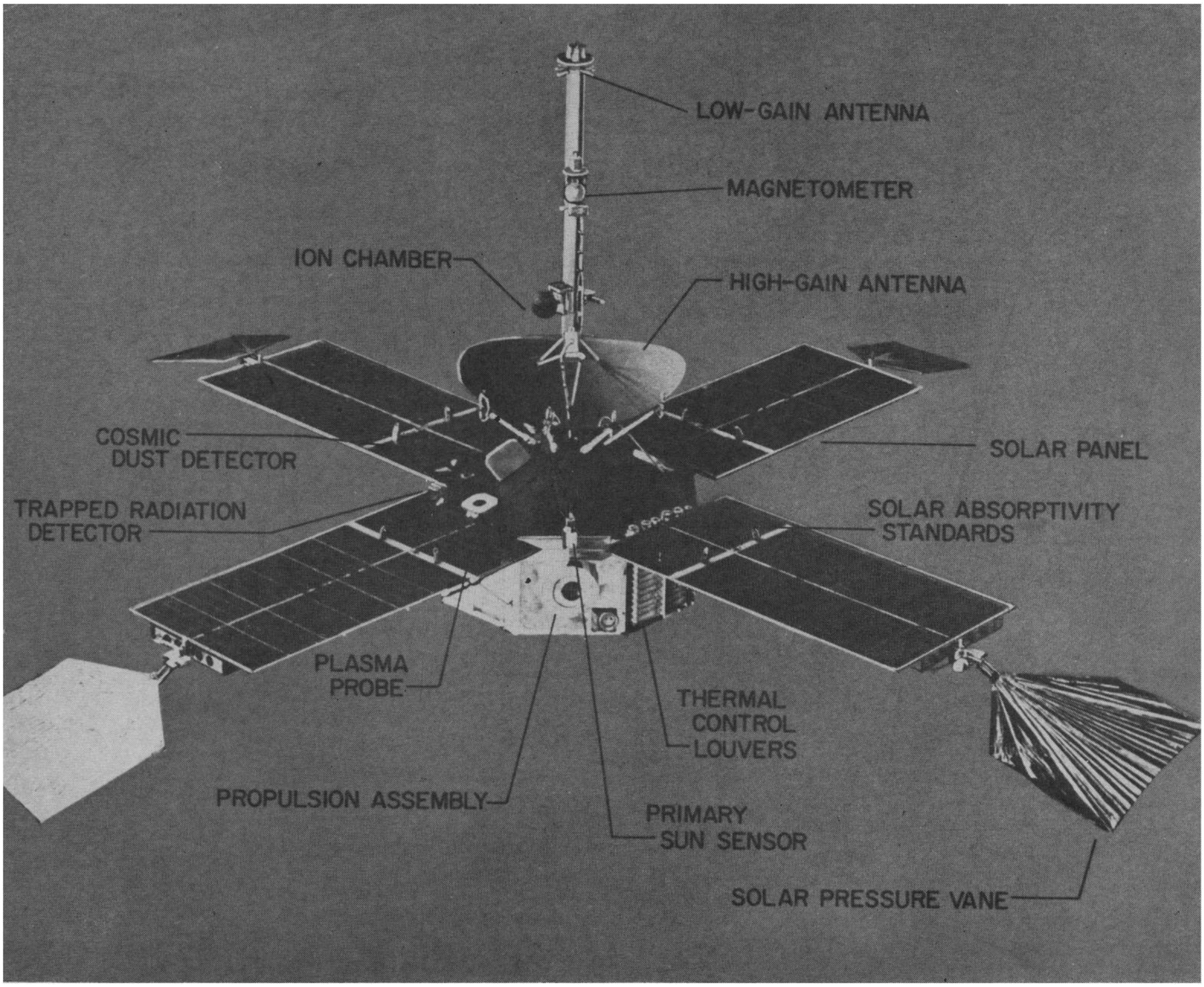

Mariner Mars spacecraft looking counter to its direction of motion around the sun. The rod-like omnidirectional antenna waveguide points toward the sun. The greatest dimension, between ends of the "Solar vanes," is 6.9 m. [Jet Propulsion Laboratory–National Aeronautics and Space Administration]

Mariner IV Measurements near Mars: Initial Results

Spacecraft Description and Encounter Sequence

The Mariner IV spacecraft was launched from Cape Kennedy at 1422 Universal Time, 28 November 1964, and power was applied to the "fields-and-particles" experiments at 1507. Data from these experiments have returned to Earth continuously since that time, except during commanded operations such as the midcourse correction, until 1154 U.T., 15 July 1965, when transmission of the tape-recorded pictures of Mars began. Initial results of the television experiment are described by Leighton *et al.* (*1*). In the following reports measurements made of the magnetic field and the various particle fluxes near Mars during the approximately 24 hours preceding picture transmission are described. The final report describes the occultation experiment, in which the behavior of the radio signal transmitted by the spacecraft as it passed behind Mars is used to infer properties of the planet's atmosphere.

With the exceptions of the TV system and portions of the data automation system (DAS), the spacecraft and the experiments operated in the same way during encounter as during the cruise phase of the mission. The attitude of the spacecraft has been controlled throughout the flight since roll stabilization at 0710, 29 November 1964, by optical sensors and cold gas jets.

The roll axis of the spacecraft is aligned with the radial vector from the sun so that the solar panels remain normal to this vector. Orientation about the roll axis is maintained by keeping the spacecraft aligned so that an optical sensor, whose axis is approximately perpendicular to the roll axis, points at the bright star Canopus, near the south ecliptic pole. In this attitude the beam of the fixed, directional antenna lies approximately in the plane of the ecliptic and was pointed continuously at Earth from 5 March through encounter. The attitude-control gyros were used only during certain operations early in the mission; the optical sensors kept the spacecraft stabilized within 0.5° at all other times.

The spacecraft transmits 10 watts at a frequency of 2300 Mcy/sec; it employed an information rate of $33\frac{1}{3}$ bit/sec from launch to 1700 U.T., 3 January 1965, and $8\frac{1}{3}$ bit/sec thereafter. At the latter rate, the basic data cycle, consisting of 280 bits of science data and 140 bits of engineering data, occupies 50.4 sec. The DAS conditions and commutates data from the six experiments into these "data frames." Four three-axis magnetic measurements are telemetered in each such frame; the cosmic-dust detector and cosmic-ray telescope require two frames for each complete measurement, the ion chamber requires four, the trapped-radiation detector eight, and the solar-plasma detector 36. Only the TV camera data are stored on board.

The entire spacecraft weighs 261 kg and consumes about 170 watts in the cruise mode of operation. About 340 watts are generated by the solar cells at Earth's orbit. The six fields-and-particles experiments and the DAS weigh 21.3 kg and use 15.4 watts. The instruments are located as follows:

Magnetometer: on the waveguide leading to the omnidirectional antenna.

Ion chamber: on the waveguide leading to the omnidirectional antenna, nearer the body of the spacecraft.

Table 1. Areocentric equatorial coordinates of Mariner IV. The coordinates are centered on Mars, and the principal plane is Mars's equator. Local time is computed by use of 15° longitude per hour.

Position of observation	U.T. at Earth	Radial distance (km)	Latitude (deg)	Local time (hr)	Sun-Mars-probe angle (deg)
		14 July			
Incoming asymptote	<1812	>116,000	+8	0946	34
Cross equatorial plane	2207	53,400	0	1000	33
		15 July			
Cross noon meridian	0052	14,500	−49	1200	65
Closest approach	0113	13,200	−65	1442	86
Enter occultation	0231	25,800	−31	2058	136
Exit occultation	0325	39,300	−20	2122	142
Outgoing asymptote	>1012	>147,500	− 5	2150	146

Trapped-radiation detector: on body, with counter-axes pointing 70° and 135° from the solar direction.

Comic-ray telescope: inside body, pointing in antisolar direction.

Solar plasma detector: on body, pointing 10° from the solar direction.

Cosmic-dust detector: on body, with microphone plate approximately perpendicular to plane of orbit. The spacecraft has been fully described (*2*).

The ion chamber ceased functioning on 17 March. The other five experiments operated through encounter as they did in the cruise mode. The special events in the encounter sequence (U.T.) are as follows: 14 July, 1453, turn on TV camera; 2235, switch to encounter-data mode, which commits entire 420-bit frame to scientific instruments, adding additional cosmic-ray telescope, magnetometer, and plasma samples to each frame; 15 July, 0030, start taking TV pictures; 0055, stop taking TV pictures; 0055, return to cruise-data mode; 0113, closest approach to Mars; 0231, enter occultation; 0325, exit occultation; 1154, start picture transmission (cruise experiments off). The signals from the spacecraft propagated from Mars to Earth in 12 minutes.

Mariner IV's elliptical interplanetary orbit was inclined 0.12° to the ecliptic, with perihelion near Earth at launch and aphelion near Mars at encounter. Mars overtook the spacecraft (in ecliptic longitude) in such a way that in an areocentric system the spacecraft

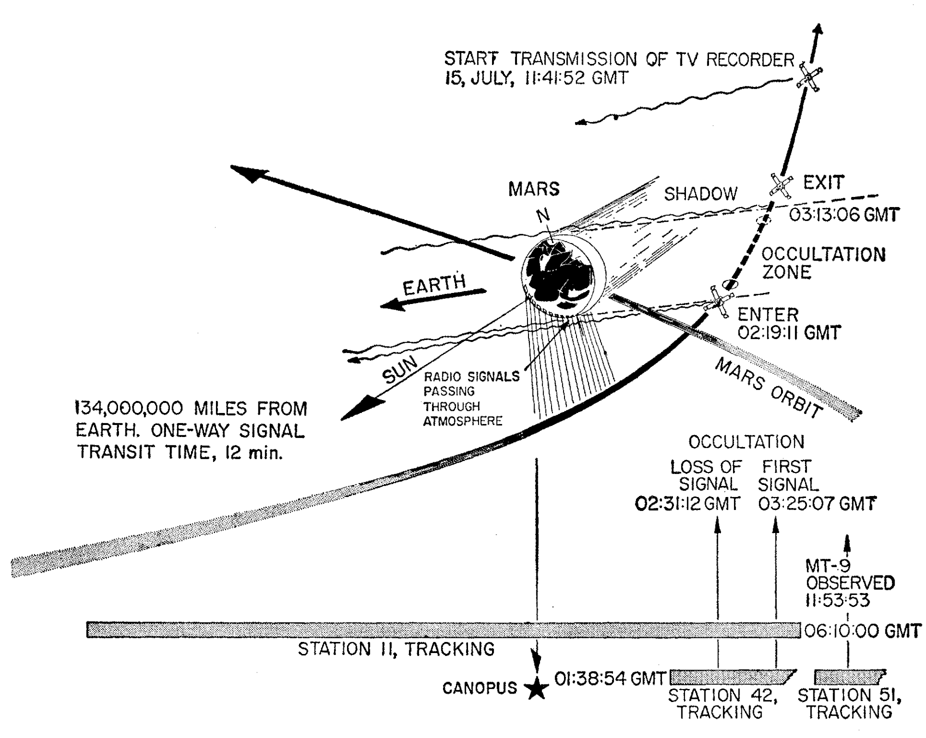

Fig. 1. Mariner IV encounter sequence and trajectory.

approached the planet at 4.5 km/sec from a local time of 0946 and nearly in the plane of Mars's orbit (Fig. 1). Mars's orbit is inclined 1°51′ to the ecliptic, and its equatorial plane makes an angle of 25°12′ with its orbital plane. On 14 July, Mars's north pole was tipped in the direction of orbital motion and toward the sun so that the subsolar point lay at 15.3°N latitude. Mars was 216 × 10^6 km from Earth, 232 × 10^6 km from the Sun (1.55 AU), and the Earth-Sun-Mars angle was 64°. The spacecraft passed over Mars's southern hemisphere. Shortly after the time of closet approach, it passed behind the planet as seen from Earth ("occultation"), but without entering the shadow of the planet. Some useful trajectory parameters appear in Table 1.

The fields-and-particles experiments were turned off during picture transmission from 1154, 15 July, to 2 August. Interplanetary results obtained before encounter and after 2 August will not be reported now.

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References and Notes

1. R. B. Leighton, B. C. Murray, R. P. Sharp, J. D. Allen, R. K. Sloan, *Science* **149**, 627 (1965).
2. J. R. Casani, A. G. Conrad, R. A. Neilson, *Astronaut. Aeronaut.* **3**, 16 (1965); J. D. Schmuecker and J. N. Wilson, *ibid.*, p. 26; J. N. James, *ibid.*, p. 34; W. S. Shipley and J. E. Maclay, *ibid.*, p. 42; R. A. Welnick and F. H. Wright, *ibid.*, p. 50.
3. The Mariner IV project was managed by JPL/CIT for NASA under contract NAS7-100.

16 August 1965

Absence of Martian Radiation Belts and Implications Thereof

Abstract. *A system of sensitive particle detectors on Mariner IV showed the presence of electrons of energy* (E_e) *less than 40 kiloelectron volts out to a radial distance of 165,000 kilometers in the morning fringe of the earth's magnetosphere but failed to detect any such electrons during the close encounter with Mars on 14–15 July 1965, at the time when the minimum areocentric radial distance was 13,200 kilometers. This result can mean that the ratio of the magnetic dipole moment of Mars to that of the earth* (M_M/M_E) *is surely less than 0.001 and probably is less than 0.0005. The corresponding upper limits on the equatorial magnetic field at the surface of Mars are 200 and 100 gammas, respectively. It appears possible that the solar wind interacts directly with the Martian atmosphere.*

There is not yet a quantitative theory of the origin of the earth's radiation belts despite a large body of observational knowledge on (i) the distributions and energy spectra of the constituent particles and the time variations thereof; (ii) the geomagnetic field and its variations; (iii) natural radio waves in the ionosphere; (iv) the atmosphere of the earth; and (v) the solar wind in its vicinity. Thus it is clearly impossible to predict the detailed nature of the radiation belts of a planet of arbitrary magnetic moment at an arbitrary distance from the sun. Nonetheless it is apparent that the planet must be magnetized sufficiently strongly and it must be exposed to the flow of hot, ionized gas from the sun (the solar wind) in order that it have radiation belts resembling those of the earth. Under the latter requirement we are neglecting the minor component of the earth's radiation belts due to the radioactive-decay products of cosmic-ray-produced neutron albedo. Since the earth at 1.0 AU (astronomical unit, or 1.495985 × 10^8 km) and Jupiter at 5.2 AU from the sun both have intense radiation belts it is reasonable to expect that Mars at the intermediate distance of 1.52 AU has radiation belts also, *if it is a sufficiently magnetized body*. The criterion for sufficiency, in approximate terms, is that the outward pressure of the planet's magnetic field ($B^2/8\pi$) equals the inward dynamic pressure of the solar wind (nmv^2) at a radial distance R exceeding that to the top of its appreciable atmosphere. In the foregoing, B denotes the magnetic field strength ($B \sim M/R^3$); and n is the number density of charged particles of mass m and directed velocity v in the solar wind. In the case of the earth (magnetic dipole moment $M_E = 8.06 \times 10^{25}$ gauss cm^3), the stagnation point occurs at a radial distance of some 65,000 km on its sunward side.

Understanding of the configuration of the external magnetic field of a planet subjected to the flow of the solar wind dates from the classical theoretical work of Chapman and Ferraro in the 1930's. In recent years, this understanding has been improved by advances in the theory and endowed with detailed physical validity by a large variety of satellite and space-probe observations.

Not so clearly anticipated by the theory have been the observational findings (*1–3*) of the presence of electrons having energies of the order of tens of kev in the transition region between the (hypersonic) shock front and the magnetopause, and in the magnetospheric tail (in addition to the now well-known distribution of durably trapped electrons and protons interior to the magnetopause).

Outside of the shock front, the presence of the earth is undetectable by either magnetic measurements (*4*) or particle measurements (*2*). Within the transition region, there are turbulent magnetic fields of the order of 30 gammas (1 gamma = 10^{-5} gauss) (*5*) and an irregular distribution of electrons having energies from ~1 kev to some tens of kev. Interior to the magnetopause, there are regular magnetic fields and large intensities of durably trapped electrons and protons of energies up to several Mev.

On the strength of this massive observational knowledge of the earth's environment and of supporting theoretical considerations (*6*), it is assumed here that the appearance of detectable intensities of electrons having energies of some tens of kev is an inevitable and universal consequence of the quasi-thermalization of the solar wind (collisionless conversion of directed kinetic energy into random kinetic energy) as its forward motion is arrested by impact against a planetary magnetic field.

To the extent that this assumption is valid, a sensitive magnetometer and a sensitive detector of low-energy electrons are equivalent devices for the detection of a planetary magnetic field.

The search for radiation belts of Venus and of Mars was proposed in detail by us in 1959. Our simple low-energy-electron detector was carried on Mariner II which flew past Venus on 14 December 1962 at a minimum radial distance of approach of 41,000 km on the sunward side of the planet. No planetary effect was detected. This negative result was originally inter-