Apr 1st, 8:00 AM

Pioneer Missions To Jupiter

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April 17, 1974

ABSTRACT

The Pioneer 10 mission to Jupiter is described. Included are a discussion of the scientific objectives of the mission and a summary of the scientific findings related to the Asteroid Belt and Jupiter. The spacecraft and instruments are described and the effects of the Jupiter environment on their performance is discussed. The Pioneer 10 trajectory is described as well as the post-Jupiter trajectory for Pioneer 11.

PIONEER 10/11 MISSIONS

The broad objective of the Pioneer 10/11 missions is to increase man's knowledge and understanding of the environment in which he lives, in this case, the solar system and perhaps the galaxy. Specific scientific objectives are:

> To conduct exploratory investigations beyond the orbit of Mars of the interplanetary medium, the nature of the Asteroid Belt, and the environmental and atmospheric characteristics of the planet Jupiter.

The first objective, exploration of the interplanetary medium, has as its items of principal interest: (a) The characteristics of the magnetic fields, solar winds, and solar and galactic cosmic rays; (b) The interaction of these particle and field phenomena; (c) The location of the heliospheric boundary; and (d) The properties of interplanetary dust. For Pioneer 10, meeting these objectives started with its launch on March 3, 1972, and will not be completed until about 1977 when the spacecraft nears the orbit of Uranus and the signal from the spacecraft becomes too weak to be heard at ground receivers. For Pioneer 11, meeting these objectives started with its launch on April 6, 1973, and will not be completed until about 1980 after it crosses the orbit of Saturn and the electrical power from the Radioisotope Thermoelectric Generators becomes less than that required to operate the spacecraft.

The second scientific objective, investigation of the nature of the Asteroid Belt, was accomplished by the measurement of the size, mass, flux, velocity, and orbital characteristics of the small particulate matter within the Asteroid Belt. Another, and equally important, objective was to determine the extent of any hazards to spacecraft caused by the matter within the Asteroid Belt since in the foreseeable future all spacecraft going to Jupiter and beyond will have to traverse the Belt. Pioneer 10 accomplished these objectives between July 1972 and February 1973; Pioneer 11 accomplished the objectives between August 1973 and March 1974.

The third scientific objective, the investigation of environmental and atmospheric characteristics of Jupiter, was accomplished by Pioneer 10 during November and December 1973 when: (a) In situ measurements of the characteristics of the magnetic field and radiation belt were made; (b) Measurements of the heat balance of the planet were made; (c) A search for helium in the planet atmosphere was conducted; (d) Photometry and polarization measurements of the light reflected from the planet were made; (e) Close-up spin-scan imaging of the planet's surface was accomplished; (f) Measurements of the ionosphere of Jupiter and Io were made; and (g) The mass of Jupiter and the Galilean satellites was determined. For Pioneer 11, similar measurements will be made in November and December 1974.

THE SCIENTIFIC PAYLOAD

To accomplish the aforementioned scientific objectives, Pioneer 10 has a complement of 11 instruments and Pioneer 11 has 12. These instruments, the Principal Investigator, and the Institution providing them are given in Table 1 on Page 2. In addition, two scientific investigations shown in the table, S-Band Occultation and Celestial Mechanics, require no special instrumentation on the spacecraft, but instead use the S-band telemetry signal from the spacecraft. The Helium Vector Magnetometer measures fields from as small as 0.016 gamma to as large as 140,000 gamma and, therefore, is capable of measuring fields in interplanetary space as well as near Jupiter. The Fluxgate Magnetometer measures fields in the range from 1,000 gamma to 1,000,000 gamma. It was added to Pioneer 11 after the Pioneer 10 launch in order to be able to explore the Jovian magnetic field in the event that Pioneer 11 passed closer to Jupiter than Pioneer 10 and the strength of the magnetic field would exceed the range of the Helium Vector Magnetometer.

TABLE 1

PIONEER 10/11 PAYLOAD

INSTRUMENT	PRINCIPAL INVESTIGATOR	INSTITUTION
MAGNETOMETER (HELIUM VECTOR)	E. J. SMITH	JPL
MAGNETOMETER (FLUXGATE: PIONEER 11 ONLY)	N. F. NESS	GSFC
PLASMA ANALYZER	J. H. WOLFE	ARC
CHARGED PARTICLE DETECTOR	J. A. SIMPSON	U. CHICAGO
GEIGER TUBE TELESCOPE	J. A. VAN ALLEN	U. IOWA
COSMIC RAY TELESCOPE	F. B. McDONALD	GSFC
TRAPPED RADIATION DETECTOR	R. W. FILLIUS	UCSD
ULTRAVIOLET PHOTOMETER	D. L. JUDGE	USC
IMAGING PHOTOPOLARIMETER	T. GEHRELS	U. ARIZONA
INFRARED RADIOMETER	G. MUNCH	CIT
ASTEROID/METEOROID DETECTOR	R. K. SOBERMAN	G.E.
METEOROID DETECTOR	W. H. KINARD	LaRC
S-BAND OCCULTATION	A. J. KLIORE	JPL
CELESTIAL MECHANICS	J. D. ANDERSON	JPL

The Plasma Analyzer has a medium resolution and high resolution quadrispherical electrostatic analyzer system. The system covers the charge particle plasma regime for protons from 100 to 18,000 eV and for electrons from 1 to 500 eV over a range of fluxes from approximately 1×10^2 to 3×10^9 particles per cm^2-sec.

The Charged Particle Detector, Geiger Tube Telescope, Cosmic Ray Telescope, and Trapped Radiation Detector measure the flux of high energy electrons and protons. Although there is some overlap in the various energy ranges covered by these four instruments, the types of sensors used in any instrument are, in general, considerably different from those in the other three. In addition, the primary objective of the Cosmic Ray Telescope is the investigation of interplanetary phenomena, whereas that of the Geiger Tube Telescope and Trapped Radiation Detector is the investigation of phenomena within the Jovian radiation belt. The Charged Particle Detector covers both objectives. Considering the four instruments as a group, the energy threshold for the various electron detectors covers a wide range from about as small as 0.06 MeV to as large as about 40 MeV, and the proton detectors cover a range from about 1 MeV to about 800 MeV.

The Ultraviolet Photometer is a two-channel photometer designed to observe the resonance emissions from atomic hydrogen and helium at 1216 Å and 584 Å, respectively.

The Imaging Photopolarimeter provides the capability for making photometry and polarization measurements in two colors, red and blue, over a wide range of light intensity from the dimness of gegenschein and zodiacal light to the brightness of Jupiter at closest approach. In addition, the instrument performs spin-scan imaging in two colors, red and blue. One of three focal plane diaphragms can be selected by ground command depending on the types of measurements being made; a 2.3° by 2.3° diaphragm is used for zodiacal light measurements, a 0.5° by 0.5° diaphragm for planet photometry and polarimetry, and a 0.03° by 0.03° diaphragm for imaging.

The Infrared Radiometer measures emissions from Jupiter and its satellites in two wavelengths, 14 to 25 and 29 to 56 microns.

The Asteroid/Meteoroid Detector contains four independent optical telescopes which are aligned approximately parallel. The field of view of each is about 7.5° and partially overlaps those of the other three. The instrument measures the contribution to sky brightness in white light from the aggregate of particles in the field of view and the brightness and time of entrance and exit from each field of view of individual particles.

The Meteoroid Detector is a penetration-type detector having 108 pressurized cells on Pioneer 10 and 234 on Pioneer 11 at the time of launch. Each cell has an effective penetration area of 24.5 cm^2. The skin thickness of the cells is 0.0025 cm and 0.005 cm on Pioneer 10 and 11, respectively.

THE SPACECRAFT

A sketch of the Pioneer 10/11 spacecraft is shown in Figure 1. Except for the scientific payload, both spacecraft are identical. The spacecraft with payload weigh nearly 258 kg each, and the diameter of the high-gain antenna reflector is 2.75 m. The spacecraft spins about an axis parallel to the axis of the reflector at about 4.8 rev/min. Small thrusters using hydrazine and located at the edge of the reflector are used for making in-flight velocity adjustments, altering the spin rate and changing the direction of reflector pointing so that it points toward Earth thus allowing high communication data rates.

Most of the spacecraft equipment is located in the hexagonally shaped compartment beneath the reflector. Extending from one side of this compartment is another smaller hexagonally shaped compartment containing most of the sensors and electronics for the instruments. The sensors for the Magnetometers, Asteroid/Meteoroid Detector, and Meteoroid Detector are outside the compartment as are the sensors and electronics of the Plasma Analyzer and Cosmic Ray Telescope.

The Magnetometer sensor is located at the end of a boom approximately 6.1 m from the center of the spacecraft. At this location, the magnetic field induced by the spacecraft is less than 0.05 gamma.

Electrical power is supplied by four Radioisotope Thermoelectric Generators (RTG) located at the end of two truss works extending from the body of the spacecraft. The center of each pair of RTGs is about 2.75 m from the center of the spacecraft. Each RTG generates about 40 watts of power at launch. The output of the complete system reduces about 9 to 10 watts per year due to the buildup of helium within the hermetically-sealed generator from the decay of the fuel, the degradation of the thermoelectrics, and the small reduction in thermal output of the fuel. The fuel is Pu_{238} and each generator develops about 650 thermal watts at launch. The fuel used in the RTGs gives off gamma radiation and neutrons. During the development of the Pioneer 10/11 spacecraft and payload, tests were performed wherein a spacecraft mock-up was fabricated and the instruments were subjected to radiation and emission levels simulating those which would be obtained during the mission. As a result of these tests, modifications were made to the Charged Particle Detector and Cosmic Ray Telescope so that their sensors would not be affected by such levels. As a result of these tests and the associated design modifications, it was concluded that the scientific measurements from the four high-energy particle counters would not be adversely affected by radiation from the RTGs.

Pioneer 10/11 are the first NASA spacecraft depending on RTGs exclusively to provide electrical power.

Eight data rates, from 8 to 2048, are selectable by ground command so as to optimize the data rate with respect to distance from Earth and the size of the ground antenna receiving the signal. During the Jupiter encounter, the data rate was 1024 bits/sec.

Approximately 250 discrete commands are available to control from the ground the operating modes of the spacecraft and instruments. 256 magnitude commands are also available for controlling from the ground the magnitude or timing of events on the spacecraft.

The spacecraft uses both passive and active thermal control. The latter is accomplished with thermal control louvers on the bottom of the equipment compartment which automatically open or close to reject or retain internally-generated heat and maintain a shelf temperature of between approximately 10°C and 30°C.

Figure 1 shows the spacecraft in its cruise attitude with the magnetometer boom and RTG supports extended. During launch, the magnetometer boom is folded against the equipment compartment and held by the magnetometer boom supports and the RTGs are slid underneath the high-gain antenna reflector. After separation from the launch vehicle, the RTG supports and magnetometer boom are automatically deployed.

TRAJECTORY

The launch vehicles for the Pioneer 10/11 mission were:

(a) Pioneer 10: Atlas SLV 3C/Centaur D/ TE-M-364-4

(b) Pioneer 11: Atlas SLV 3C/Centaur D-1A/ TE-M-364-4

The Pioneer launches were the first in which a third stage solid-fuel motor was used with the Atlas/Centaur. The combination was necessary to achieve the high velocities required by the Jupiter mission; at separation, the velocity of the spacecraft was about 14.3 km/sec.

The interplanetary trajectory for Pioneer 10 is shown in Figure 2. The trajectory is inclined about 2° to the ecliptic plane; at Jupiter encounter, the celestial latitude of the spacecraft was about -0.8°. The trajectory is elliptical, and were it not affected by Jupiter, would have an aphelion of 5.86 A.U. and a perihelion of 0.99 A.U. However, due to the effects of Jupiter's large mass on the trajectory, the heliocentric velocity of the spacecraft was increased from 10.6 km/sec (before entering the Jovian influence) to 22.1 km/sec (after leaving the Jovian influence). The latter velocity exceeds that required to escape from the solar system at Jupiter's distance from the Sun. Pioneer 10 thus becomes the first man-made object to escape from the solar system. After leaving the solar system, Pioneer 10 will have a heliocentric velocity of about 11.3 km/sec and will be heading in the direction of the Constellation Taurus.

Figure 2 indicates that Pioneer 10 entered the Asteroid Belt about 140 days after launch and remained therein for about seven months.

The interplanetary trajectory for Pioneer 11 is essentially the same as that for Pioneer 10 although the Pioneer 11 trip time from Earth to Jupiter is about a month shorter.

The far-encounter trajectory of Pioneer 10 in the Jovian frame of reference and projected to the ecliptic plane is shown in Figure 3. It is noted therein, that Pioneer 10 passed behind Callisto, the outer Galilean satellite.

The near-encounter trajectory of Pioneer 10 in the Jovian frame of reference and projected to the ecliptic plane is shown in Figure 4. It is noted that Pioneer 10 crossed ahead of Ganymede and Io but behind Europa. These are the other three Galilean satellites. Not shown on Figure 4 is the orbit of the innermost Jovian satellite, Amalthea. The radius of its orbit is only 2.54 R_j; the distance of Pioneer 10 at closest approach was 2.84 R_j. During the hour before and after the time of closest approach, Pioneer 10 and Amalthea were moving almost side-by-side.

Shown also in Figure 4 is the distance of Pioneer 10 from the reference plane (solid curve), the plane passing through the center of Jupiter and parallel to the ecliptic.

EVENTS AT ENCOUNTER

The time of closest approach to Jupiter by Pioneer 10 was 2:26 AM on December 4, 1973 (GMT). The first indication of the presence of Jupiter near the Pioneer 10 spacecraft was obtained about a month earlier when tracking of the spacecraft showed the commencement of perturbations to the interplanetary trajectory. At that time the spacecraft was about 400 R_j from Jupiter. Shortly after, bursts of high energy electrons and protons lasting about two days and having peak fluxes about 100 times the interplanetary quiet time levels were observed by the Charged Particle Detector. It is believed that these high energy particles had escaped from the bow shock or magnetosphere of Jupiter.

Between November 4 and November 11, Pioneer 10 crossed the orbits of the outer four moons of Jupiter, and on November 22, the orbits of the middle three moons were crossed. On November 26, a spacecraft attitude maneuver was commanded from the ground so that the spacecraft high-gain antenna would be pointing exactly toward Earth on December 4. This maneuver was the last made before the time of closest approach so as to prevent any on-board activities from affecting the trajectory and the precision tracking which would be performed to measure the mass of Jupiter and its satellites.

On November 26, when Pioneer 10 was about 109 R_j from Jupiter, the Jovian bow shock was crossed, an event observed by the Magnetometer, Plasma Analyzer, and high-energy-particle detectors. A day later when Pioneer 10 was about 96 R_j from Jupiter, Jupiter's magnetosphere was entered, an event again observed by the above instruments. Both events were expected, although the time of their occurrence had been predicted only to within several days.

An unexpected event occurred on December 1 when the spacecraft was about 50 R_j from Jupiter. For a period of about 11 hours, the Magnetometer and particle detectors observed characteristics suggesting that the spacecraft had emerged from the magnetosphere and was again in the region between the bow shock and magnetosphere. It has been suggested that this second observation of the magnetosheath during the approach to Jupiter was due to external solar wind conditions causing a compression of the Jovian magnetosphere to a position inside that of Pioneer 10.

The time of closest approach to Jupiter by Pioneer 10 occurred at 2:26 AM on December 4 (GMT). Sixteen minutes later, Pioneer 10 was occulted by Io, an event lasting 1.5 minutes. Then an hour later at 3:42 AM, the spacecraft was occulted by Jupiter and remained so for 65 minutes.

The surprising characteristic of the Jovian magnetosphere, as evidenced by the dual entry during the inbound portion of the encounter, was more dramatically demonstrated during the outbound portion of the encounter when the magnetopause and shock were each observed on three separate occasions. Following are the distances from Jupiter at which the crossings occurred:

(a) Magnetopause: 98 R_j, 130 R_j, 150 R_j

(b) Bow Shock: 124 R_j, 127 R_j, 189 R_j

The final crossing of the bow shock occurred on December 18, 1973.

SCIENTIFIC RESULTS

A summary of preliminary scientific results from the Pioneer 10 encounter with Jupiter is presented in this section. This information has been obtained from Reference 1.

Magnetic Field. The magnitude of the Jovian magnetic field as averaged over one-hour intervals for the 10 days after crossing the bow shock is shown in Figure 5. The results show the sharp increase in field strength associated with the crossing of the bow shock and magnetopause. The field inside the magnetosphere showed a persistent southward orientation indicating that the field lines were probably closed and the orientation of the planetary dipole is directed opposite to that of the Earth's. In the outer magnetosphere, the field was strongly distended such that its direction was not dipole-like but was elongated parallel to the magnetic equator.

Beginning on December 3 (Day 337), when Pioneer 10 was about 25 R_j from Jupiter, the field strength began to rise monotonically and the direction became more dipolar. Periodic effects having a 10-hour period then became evident and appeared to correlate well with the changing magnetic latitude of Pioneer 10 based on nominal radio astronomy indications of a dipole tilted with respect to the planet's spin axis.

The observations of Jupiter's magnetic field in the range between 6 R_j and 2.84 R_j from the planet and a longitude excursion of about 140° were used to model the planetary dipole. The location and attitude of the dipole, based on the best least squares fit of the data, are shown in Figure 6. The strength of the dipole moment is also indicated.

Because of the 15° tilt of the magnetic dipole relative to the axis of Jupiter and the 10-hour rotation period of the planet, the distance from the spacecraft to magnetic equatorial plane varied over a wide range during the encounter with Jupiter. This effect is shown by the dotted line in Figure 4. The 10-hour periodicity of this effect is quite evident in Figure 4.

Electron and Proton Flux. The measurements of the electron flux by the four particle detectors on Pioneer 10 were similar and indicated the same typical characteristics. The electron flux in the outer magnetosphere of Jupiter appeared to be highly concentrated near the magnetic equatorial plane. The intensity of the flux varied with a period of 10 hours leading to the conclusion that the equatorial zone of high fluxes is inclined with respect to the planet spin axis which is consistent with the magnetic field measurements.

The hard trapping region for electrons was observed to be within about 20 R_j of Jupiter. Typical results within this region are shown in Figure 7. The 10-hour periodicity in the intensity of the flux is clearly evident in these data. In addition, a distinct dip in the counting rate of the lower energy detectors was observed as the spacecraft crossed the magnetic shell through the orbit of Europa on the inbound leg of the trajectory (L equal to 9.4 R_j). Other typical results of the electron flux measurements are shown in Figure 8. These data show a dip in the flux when the spacecraft crossed the magnetic shell through the orbit of Io (L equal to 5.9 R_j) on both the inbound and outbound portions of the trajectory. Similar results were observed by one or more of the detectors when the spacecraft crossed Ganymede's magnetic shell, but none associated with Callisto were observed.

With approaching distance to Jupiter within 10 R_j, the flux of electrons increased steeply. Near periapsis, maximum intensities of 5×10^8 electrons per cm^2-sec for electrons having energies greater than 3 MeV were observed (Figure 8). It is estimated that the integrated dose of electrons received by Pioneer 10 during the encounter was about 400 to 500 times the lethal dose for a human.

The flux of high energy protons (greater than 30 MeV) is also shown in Figure 8. As with the electron flux, the proton flux in the outer magnetosphere appeared to be highly concentrated near the magnetic equatorial plane, and the 10-hour periodicity in intensity variation was also observed. In contrast to the electron flux, the sharp increase in proton flux with reducing distance to Jupiter did not start until about 10 R_j from the planet and a maximum intensity of 4×10^6 protons per cm^2-sec was observed at about 3.6 R_j from the planet. Between 3.6 R_j and 2.8 R_j, the flux reduced by a factor of about 10. A second but smaller maximum was reached at about 3.6 R_j on the outbound portion of the trajectory. The difference in the maximum values at 3.6 R_j measured during the inbound and outbound portions of the trajectories is attributed to the fact that Pioneer 10 was much closer to the magnetic equatorial plane during the inbound portion. (See Figure 4.)

The reason for the reduction in flux inside of 3.6 R_j is believed to be due to absorption by the satellite Amalthea which was very close to Pioneer 10 near periapsis. It is estimated that the integrated dose of protons received by Pioneer 10 during the encounter was about 100 times the lethal dose for a human.

During late February, a "Workshop" was conducted at Ames Research Center which was attended by the Pioneer 10 particle and field experimenters. The purpose was to attempt to develop an empirical analytical model of the Jovian radiation belts. Preliminary results indicate that the electron and proton fluxes can be expressed reasonably well by an equation of the following form:

$$J = k e^{-\left[\frac{L-c}{d}\right]} \left[\frac{E}{3}\right]^{-[a+bL]} \left[\frac{\cos^6\lambda}{\sqrt{4-3\cos^2\lambda}}\right]^{m/2}$$

where

J = omni-directional flux, particles per cm^2-sec

$L = R/\cos^2\lambda$

R = radial distance from Jupiter, R_j

λ = magnetic latitude

E = energy, MeV

k, a, b, c, d, m = empirical constants

Sufficient data over a wide range of L and E were available to give confidence that the exponential and power-law dependence of flux on these parameters is a reasonable approximation. The same degree of confidence cannot be associated with the term expressing the latitude dependence, since for a given value of L and E, data were obtained at only two values of magnetic latitude during the encounter. The term within the brackets for latitude dependence was selected since it is the ratio of the strength of a dipolar magnetic field at the magnetic equator to that at latitude along the same L shell.

It is anticipated that the results of this "Workshop" will be published as a NASA SP document in the near future.

Ultraviolet Photometry. Preliminary results from measurements by the Ultraviolet Photometer on Pioneer 10 indicate a Jovian hydrogen glow with a brightness of about 1,000 rayleighs and a helium glow with a brightness of 10 to 20 rayleighs. Helium emissions from Jupiter had not been previously observed although its presence had been speculated for many years.

Ultraviolet emissions from Io were also observed by the hydrogen channel of the photometer. It is thought that these emissions correspond to the H Lyman-α line (1216 Å) since the surface of Io is believed to have hydrogen-bearing ices.

Hydrogen-channel signals were also observed from the equatorial plane of Jupiter when neither the planet nor its satellites were in the field of view of the instrument. These emissions of several hundred rayleighs in intensity are tentatively interpreted as due to a toroidal cloud of neutral hydrogen in orbit around Jupiter and centered at approximately the orbit of Io.

Infrared Radiometry. Preliminary thermal maps of Jupiter made by the Infrared Radiometer on Pioneer 10 show structure closely related to the visual appearance of the planet. Peak brightness temperatures of 126°K and 145°K were measured on the South Equatorial Belt of Jupiter for the 20 and 40-micron channels. Corresponding values for the South Tropical Zone are 128°K and 138°K.

Measurements were made on both the illuminated and non-illuminated regions of Jupiter on the evening terminator side of the planet. No differences in temperature were evident from these measurements.

Calculations using the measurements and a simple radiative equilibrium model were made which indicate that Jupiter is radiating thermal energy about 2 to 2.5 times that which it receives from the Sun.

S-Band Occultation. Preliminary analysis of data from the Pioneer 10 S-Band Radio Occultation Experiment revealed the presence of an ionosphere on Io having an electron density peak of about 60,000 electrons per cm^3. This suggests the presence of an atmosphere having a pressure at the surface of about one-billionth that of the Earth.

A measurement of the atmosphere of Jupiter was also obtained down to a level corresponding to about 80 millibars pressure. The results indicate a large temperature at the 20 millibar level, about 275°K, which cannot be explained by the absorption of solar radiation by methane alone and can possibly be due to absorption by particulate matter.

Celestial Mechanics. Preliminary analysis of Doppler data from Pioneer 10 during encounter indicates that the mass of Io is about 20% greater than previously thought and that Io's mean density is about 3.5 gm/cm^3, slightly larger than that of the Moon. The densities calculated for Europa and Ganymede were within 3% of previous estimates, and that for Callisto within 10% of previous estimates.

The mass of Jupiter appears to be slightly larger by an amount equal to the mass of the Moon than the previously accepted value, although within the tolerance band of that value.

Imaging. A large number of images of Jupiter in the red and blue colors were made during the Pioneer 10 encounter. Two of these taken in the blue color are shown in Figures 9 and 10. Figure 9 was made during the approach to Jupiter when Pioneer 10 was about 2.5 million kilometers from Jupiter. This image shows the Red Spot, the shadow of Io, and considerable cloud structure. Figure 10 was made on the outbound portion of the encounter when Pioneer 10 was almost 3 million kilometers from the planet. Again the banded structure of the Jupiter clouds is evident.

PERFORMANCE OF PIONEER 10

Pioneer 10 successfully crossed the Asteroid Belt without any apparent damage or anomalous performance. In March of 1974, Pioneer 11 duplicated this performance. Results from the Meteoroid Detector on Pioneers 10 and 11 indicated no increase in particle flux in the Asteroid Belt, but rather a steady decrease in flux with increasing distance from the Sun. Overall, the data indicate that within the Asteroid Belt the flux varies as $R^{-\beta}$ where R is the heliocentric distance and β is about 3/4.

While in the Jovian radiation belt, the spacecraft equipment and instruments were subjected to a severe radiation environment and both permanent and temporary damage was experienced. In the former category, the spacecraft Stellar Reference Assembly suffered a greater than 10% reduction in sensitivity and as of now is no longer able to detect Canopus, the reference star. It has been able to detect Jupiter indicating that the damage is not 100%. The glass in the photomultiplier tubes of the Asteroid/Meteoroid Detector was also darkened so that its response is now degraded by a factor of four. In addition, some of the electronic circuits or sensors in the Cosmic Ray Telescope have suffered permanent damage so that certain operating modes of the instrument are no longer usable.

In the category of temporary damage while in the radiation belt, the RTGs experienced a 2% increase in voltage, a 1.5% decrease in current, and a 1% increase in hot junction temperature. The rf power amplifier experienced changes of 3% and 10% in cathode and helix current, respectively, and a 2% reduction in output power. In addition, a 3 parts per million change in the frequency of the spacecraft receiver and transmitter stable oscillators was measured. The imaging Photopolarimeter experienced about 10 uncommanded mode changes while in the intense portions of the radiation belt, which were believed to be the result of exposure to radiation. In addition, the background counting rate of the Ultraviolet Photometer increased significantly near periapsis and remained high for about a week. Since the encounter, the operation of this instrument and those spacecraft components experiencing damage has returned to normal and the Imaging Photopolarimeter has experienced no further uncommanded mode change.

PIONEER 11 ENCOUNTER TRAJECTORY

On February 19, 1974, NASA top management approved the recommended encounter trajectory for Pioneer 11 and a midcourse velocity maneuver will be made in April 1974 so as to change the target point from the interim point selected after the launch to the presently selected point.

A number of options for Pioneer 11 targeting at Jupiter had been selected so that they would not have to be exercised until after the Pioneer 10 encounter. Based on Pioneer 10 encounter results, the list was reduced to two having the following characteristics:

(a) "High-Latitude Right-Hand (HLRH) Option. The spacecraft would approach Jupiter at a high southerly latitude, pass Jupiter in the direction of planet rotation, and eventually escape from the solar system.

(b) Saturn Option. The spacecraft would approach Jupiter at a high southerly latitude, pass Jupiter in a direction counter to the planet rotation, return toward the Sun, and encounter Saturn.

The Saturn Option was selected primarily because the results obtained at Jupiter as well as during the transfer orbit from Jupiter to Saturn would be those most complementary to those obtained with Pioneer 10. For example, Figure 11 shows the variation of magnetic latitude near Jupiter for the two options in comparison to that of Pioneer 10. Both options satisfy the desire to obtain radiation belt data at higher latitudes and closer to the planet than obtained with Pioneer 10 so that a better understanding of the latitude dependence of electron and proton flux can be obtained.

Figure 12 shows the variation of longitude near Jupiter for the two options in comparison to that of Pioneer 10. In this case, the Saturn option is best. The larger longitudinal excursion should provide a better definition of the location and tilt of the magnetic dipole than either the HLRH option or as obtained from Pioneer 10.

Figure 13 shows the transfer trajectory. As indicated, the spacecraft will go considerably above the ecliptic plane and be the first spacecraft to explore this region. A heliocentric latitude of about 17° will be reached during the transfer from Jupiter to Saturn.

Lastly, the Saturn option provides the additional bonus of being able to explore the environment of Saturn in the same manner that Pioneers 10 and 11 did or will do at Jupiter.

REFERENCES

1. Reports. "Science" Periodical, Vol. 183, No. 4122, January 25, 1974.

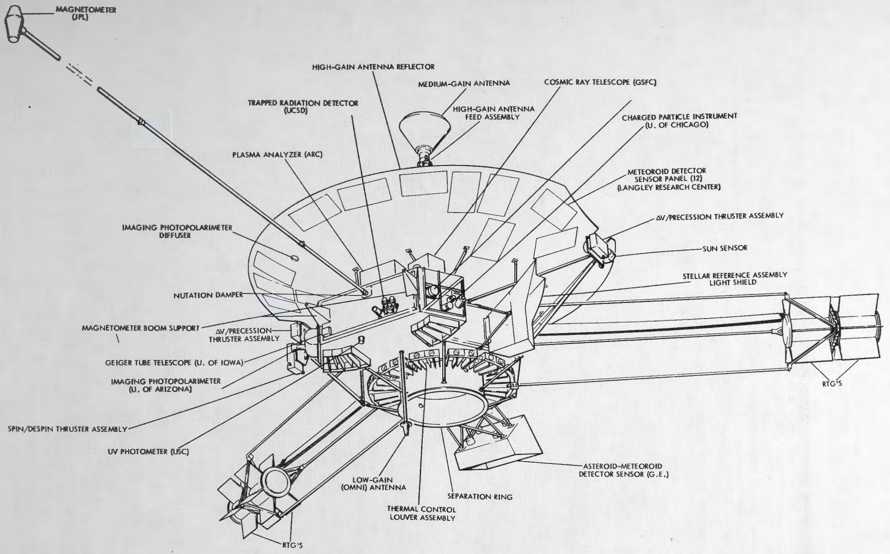


FIGURE 1. - PIONEER 10/11 SPACECRAFT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

PIONEER 10/11 TRAJECTORY

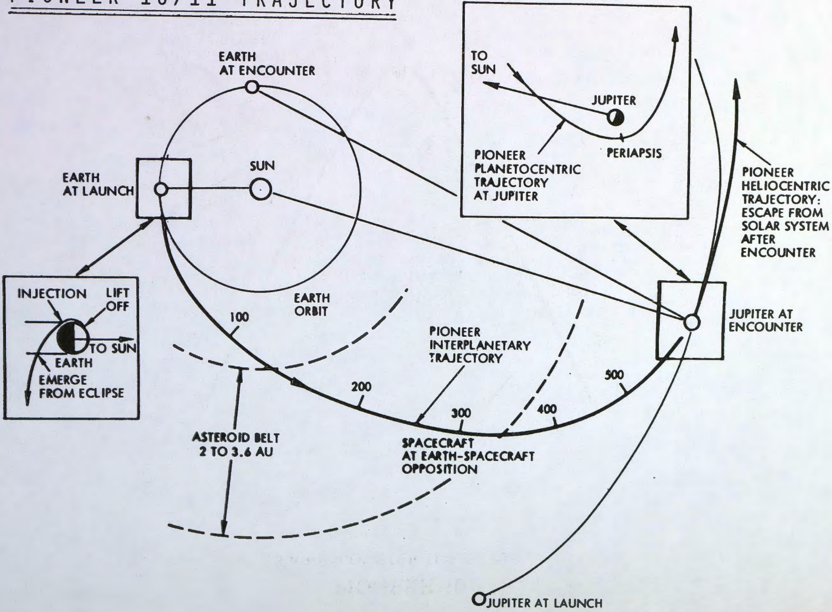


FIGURE 2

PIONEER 10
FAR-ENCOUNTER TRAJECTORY

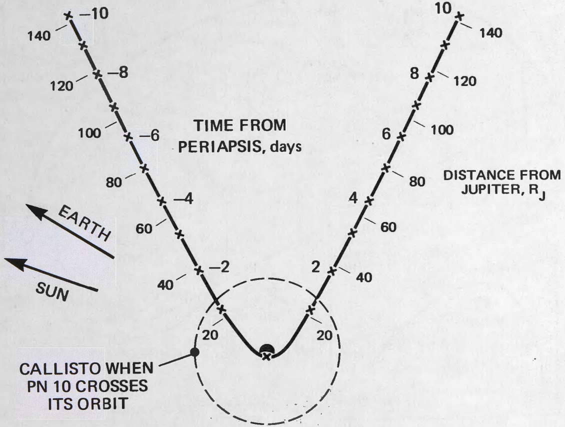


FIGURE 3

PIONEER 10

NEAR-ENCOUNTER TRAJECTORY

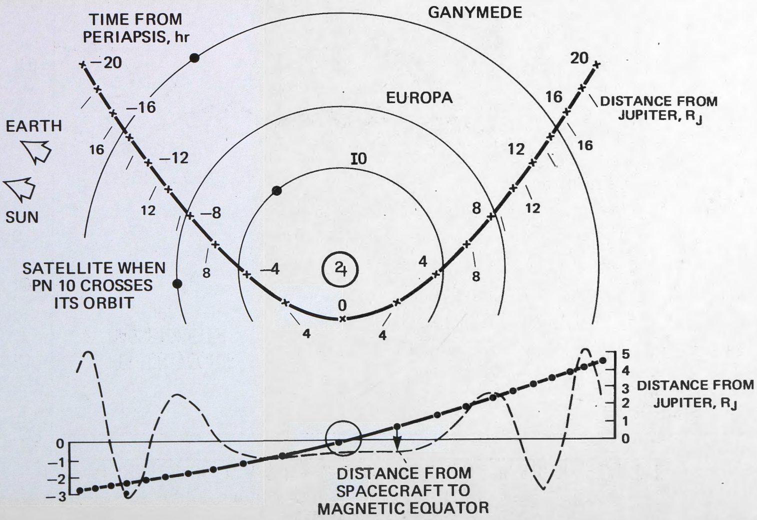


FIGURE 4

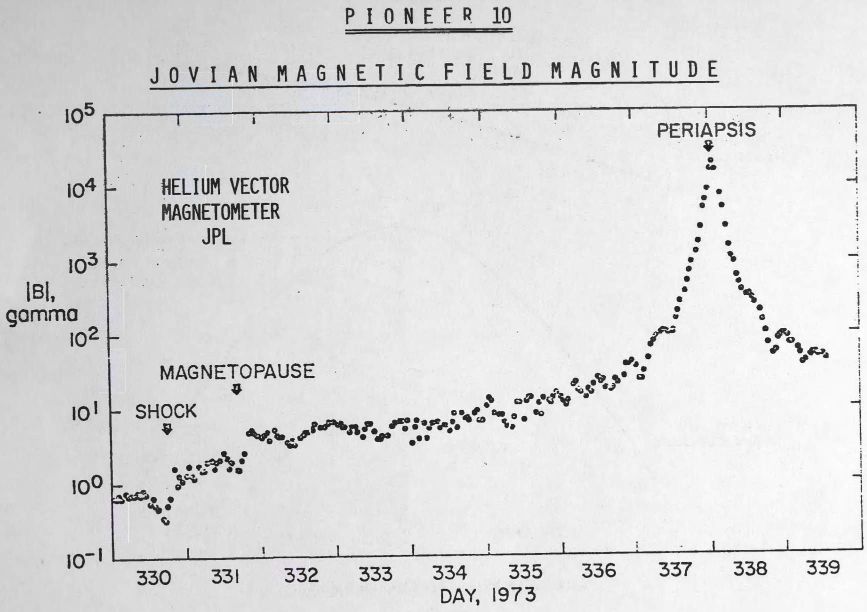

PIONEER 10
JOVIAN MAGNETIC FIELD MAGNITUDE
HELIUM VECTOR MAGNETOMETER JPL
PERIAPSIS
MAGNETOPAUSE
SHOCK
|B|, gamma
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
330
331
332
333
334
335
336
337
338
339
DAY, 1973

FIGURE 5

PIONEER 10

LOCATION OF JOVIAN MAGNETIC DIPOLE

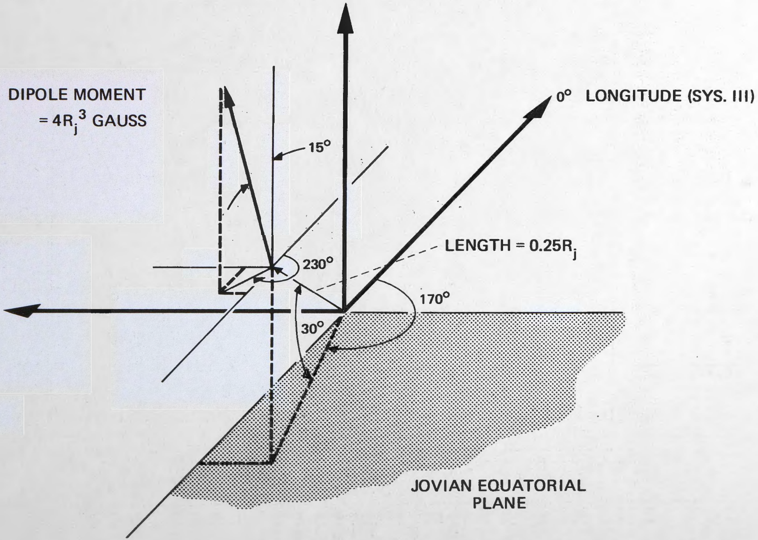
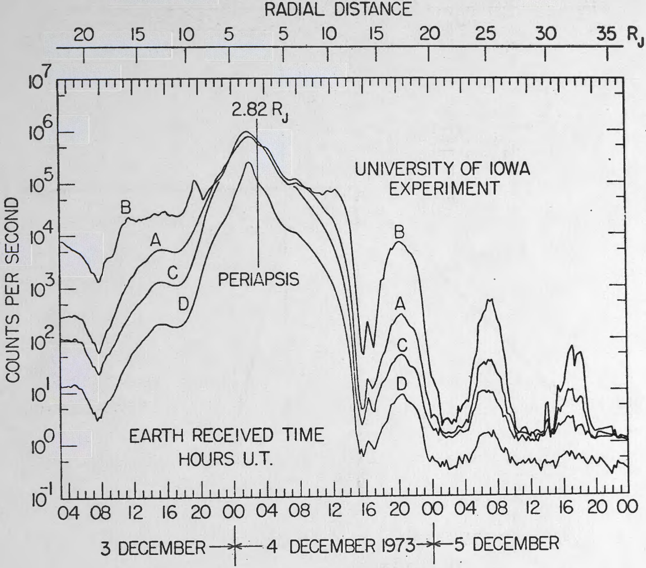


FIGURE 6

PIONEER 10

ELECTRON FLUX-JOVIAN RADIATION BELTS



Det	Energy
A	> 8 Mev
B	> 0.4 Mev
C	> 35 Mev
D	> 45 Mev

To convert counts per second to counts per cm^2-sec, multiply

A by 300
B by 300
C by 8
D by 20

FIGURE 7

PIONEER 10

ELECTRON AND PROTON FLUX - JOVIAN RADIATION BELTS

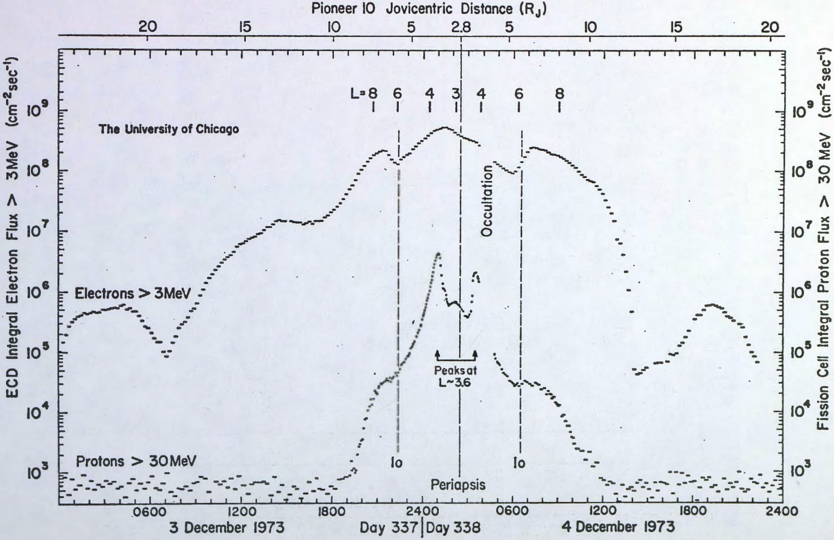
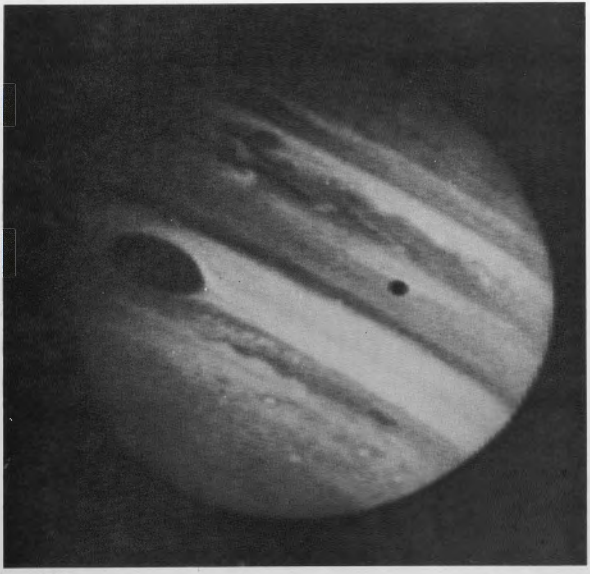


FIGURE 8



NASA ARC JUPITER UNIV ARIZONA

PIONEER 10 DATE: 02DEC73 PHASE ANGLE: 29.8DE
BLUE IMAGE TIME: o7H 20M RANE: 2527063KM
10 73 336 072135 7 B BXXX BBZZZZZZZZZZ 8704 8704 J 1

FIGURE 9

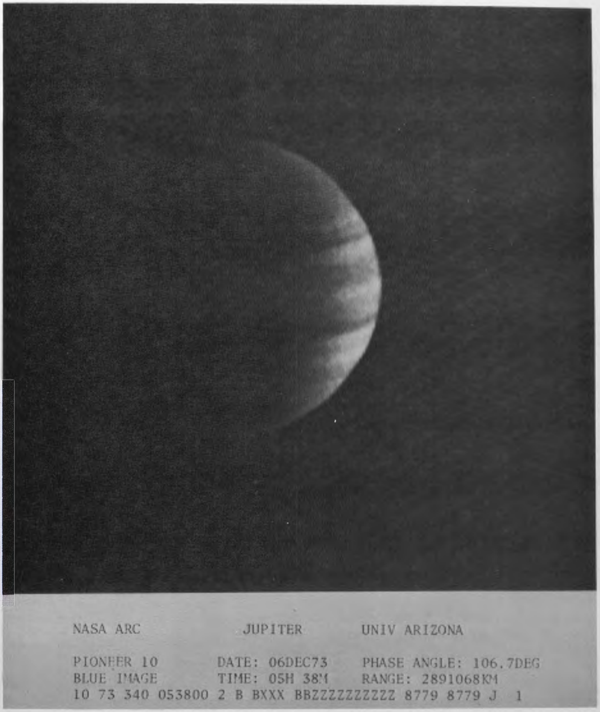

NASA ARC JUPITER UNIV ARIZONA
PIONEER 10 DATE: 06DEC73 PHASE ANGLE: 106.7DEG
BLUE IMAGE TIME: 05H 38M RANGE: 2891068KM
10 73 340 053800 2 B BXXX BBZZZZZZZZZZ 8779 8779 J 1

FIGURE 10

PIONEER 11
MAGNETIC LATITUDE

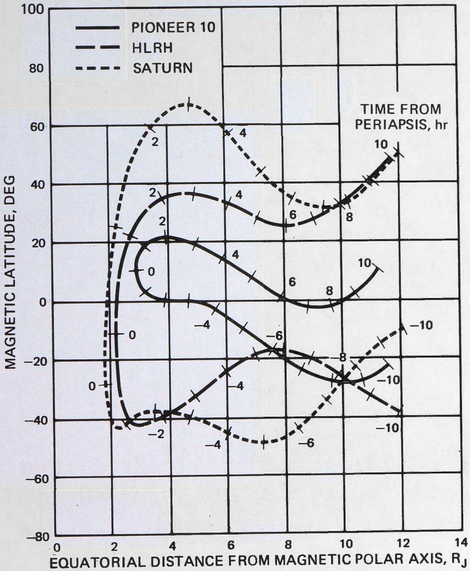


FIGURE 11

PIONEER 10/11
COMPARATIVE RANGES OF LONGITUDES WITHIN FIVE HOURS OF PERIAPSIS

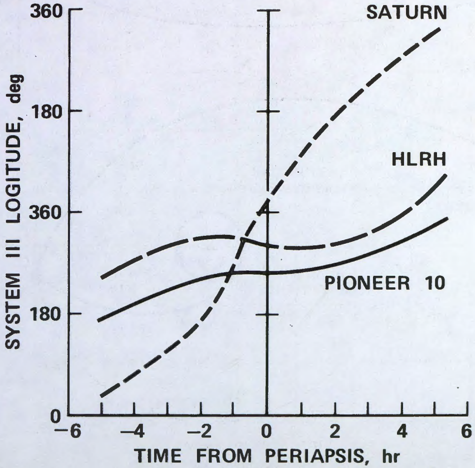


FIGURE 12

PIONEER 11

SATURN TRANSFER TRAJECTORY

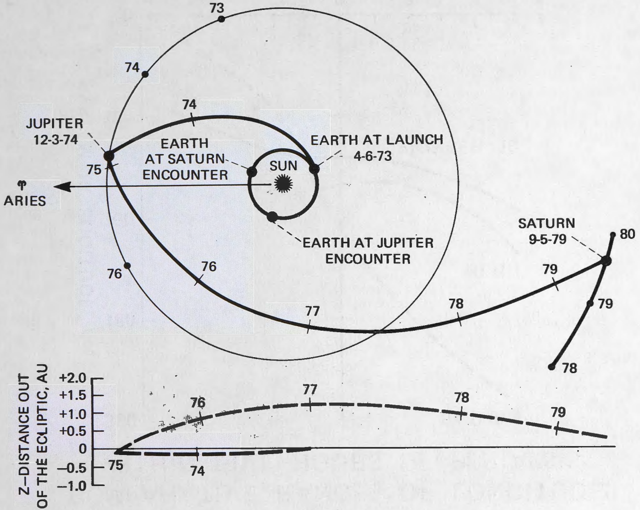


FIGURE 13