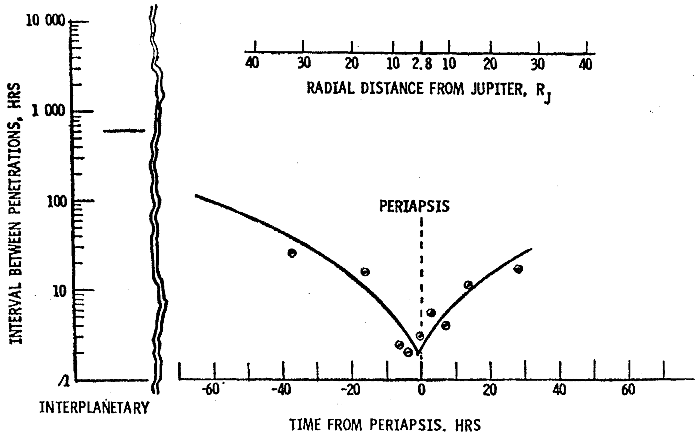

Fig. 2. Meteoroid detection experiment near-Jupiter data obtained during encounter.

anomaly caused the experiment to lose data from 126 cells, leaving 108 cells unaffected.

A micrometer-sized particle penetrating the 25-μm steel skin of the cell produces a leak which reduces the pressure inside the cell. A cold cathode device, essentially a nixie tube, mounted inside each cell conducts when the gas density drops to a predetermined value (*2*). This conduction phase is interpreted as a cell puncture.

The data obtained by the Langley experiment are presented in Fig. 1, which depicts cumulative number of cells punctured versus time on the lower scale and heliocentric distance on the upper scale. The data largely indicate a slowly decreasing flux of particles capable of puncturing the pressurized cells. Overall, this flux varies as $R^{-\beta}$, where R is teliocentric distance and $\beta \simeq 3/4$.

A closer look at the data uncovers three highly interesting observations. The data gap at 50 days is significant. From the flux rates before and after it, one would expect a gap that long to occur less than once every hundred missions. The gap extends from 1.14 to 1.34 A.U. and may be caused by orbit perturbations due to the earth and Mars. Jupiter causes analogous perturbations in the asteroid belt, resulting in the Kirkwood gaps.

The asteroid belt was noted for its absence in the data. The region of the asteroid belt, from 2.0 to 3.5 A.U., exhibited the same slow decrease in penetration flux that characterized interplanetary space from the earth to Jupiter.

The most surprising data were obtained at Jupiter encounter at 5.05 A.U. (756×10^6 km). Figure 1 shows that there were ten punctures during a very short period of time (64 hours).

Figure 2 presents the last 11 events on an expanded scale. The data are presented as time intervals between punctures (in hours) versus the time from Pioneer periapsis. The horizontal bar on the left shows that before encounter the average time between consecutive punctures was about 600 hours. The solid line represents a rough fit to the Langley data. The plot implies that Jupiter is much "dustier" than interplanetary space. Whereas the near-earth particulate flux showed very little increase over the interplanetary flux, the near-Jupiter penetration flux was over two orders of magnitude higher than the interplanetary flux. At present we do not know whether interplanetary particles attracted to Jupiter or particles in orbit about Jupiter caused this dramatic increase in the penetration flux. Both possibilities are currently being investigated.

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21 December 1973

Gravitational Parameters of the Jupiter System from the Doppler Tracking of Pioneer 10

Abstract. *Preliminary analyses of Doppler data from Pioneer 10 during its encounter with Jupiter indicate that the mass of Io is about 20 percent greater than previously thought and that Io's mean density is about 3.5 grams per cubic centimeter. A determination of the dynamical flattening of Jupiter* (a − b)/a (*where* a *is the semimajor axis and* b *is the semiminor axis*) *is found to lie in the neighborhood of 0.065, which agrees with the value determined from satellite perturbations.*

High-quality Doppler tracking data were obtained from Pioneer 10 during its encounter with Jupiter. Three 64-m antennas were used to track the Pioneer spacecraft in a two-way, phase-coherent mode at S-band ($\approx$ 2200 Mhz). These three antennas were operated, respectively, by stations of the Deep Space Net in Goldstone, California (station 14), Canberra, Australia (station 43), and Madrid, Spain (station 63), and nearly continuous two-way tracking coverage was achieved during the critical encounter period. As a result, much new information on the gravity field of Jupiter and on the masses of the four Galilean satellites will be obtained in the next few months from an analysis of the Doppler data.

Tracking was interrupted during the encounter when the spacecraft was occulted by Io at about 16 minutes after closest approach and again during the occultation by Jupiter. Occultation by the planet occurred about 78 minutes after closest approach and lasted for about 1 hour. However, a minimum of data was lost during the two occultations because of a careful planning and execution of station procedures.

The noise on the Pioneer 10 Doppler data, as inferred from the root-mean-square residuals from least squares fits, is about 0.005 hertz for a count time of 60 seconds. At an S-band frequency of 2200 Mhz, this amounts to a one-way range rate error of about 0.3 mm/sec.

The determination of the masses of the Galilean satellites has in the past been derived from observations of the mutual perturbations in the satellite system. The most recent determination is that of de Sitter (*1*). His estimate of the errors in the determination is about 8 percent for Io and Callisto and between 1 and 2 percent for Europa and Ganymede. The Pioneer data will make it possible to determine all four satellite masses to 1 percent or better.

Preliminary analyses of the data show

that the mass of Io is significantly larger than de Sitter's determination by about 20 percent. The masses of the other three satellites are in better agreement. The recent measurement of the radius of Io by means of the occultation of Beta Scorpii (*2*) in combination with the mass determined from the Pioneer data yields a mean density of 3.5 g/cm^3 for the satellite. This high a value for the density of the inner Galilean satellite definitely suggests that it is composed of heavier elements than Ganymede or Callisto. Further analyses of the data will specify the masses of the Galilean satellites more precisely and will also yield a value for Jupiter's mass, a quantity that has not been determined reliably from the Pioneer 10 data at this time.

Perhaps the most interesting results from the analysis of the Pioneer data lie in the determination of the gravity field of the planet to a greater accuracy than has been possible with the natural satellites. Preliminary determinations of the even zonal harmonic coefficients indicate that the dynamical flattening of Jupiter $(a - b)/a$ (where a is the semimajor axis and b is the semiminor axis) is definitely in the neighborhood of 0.065, which agrees with the dynamical value determined from the satellites (*3*).

Future analyses of the Doppler data obtained in the few hours around closest approach will concentrate on achieving better resolution in the gravity field of Jupiter. In particular, attempts will be made to determine or bound the third zonal harmonic coefficient (J_3) and the second-degree sectoral harmonics (C_{22}, S_{22}). Whatever the results of the gravity analysis, it is certain that Pioneer 10 will provide some very good boundary conditions on the interior models of Jupiter and will yield important clues on the distribution of mass in the outer layers of the planet.

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21 December 1973

Preliminary Results on the Atmospheres of Io and Jupiter from the Pioneer 10 S-Band Occultation Experiment

Abstract. *The preliminary analysis of data from the Pioneer 10 S-band radio occultation experiment has revealed the presence of an ionosphere on the Jovian satellite Io (J1) having an electron density peak of about* 6×10^4 *electrons per cubic centimeter at an altitude of approximately 60 to 140 kilometers. This suggests the presence of an atmosphere having a surface number density of about* 10^{10} *to* 10^{12} *per cubic centimeter, corresponding to an atmospheric surface pressure of between* 10^{-8} *and* 10^{-10} *bar, at or below the detection threshold of the Beta Scorpii stellar occultation. A measurement of the atmosphere of Jupiter was obtained down to the level of about 80 millibars, indicating a large temperature increase at about the 20 millibar level, which cannot be explained by the absorption of solar radiation by methane alone and can possibly be due to absorption by particulate matter.*

The Pioneer 10 spacecraft flew by Jupiter on 4 December 1973, on a remarkably precise trajectory which took it not only behind the disk of Jupiter but also behind the satellite Io (JI). This trajectory afforded an opportunity to study their atmospheres by the method of radio occultation which has been used in the past to study the atmospheres of Mars and Venus (*1*). The occultation of Io, occurring while the spacecraft was in the plane of Io's orbit, some 550,000 km from the satellite, established the presence of an ionosphere and hence of a neutral atmosphere on Io.

The existence of an atmosphere on Io has been suspected ever since anomalous brightenings of the satellite were discovered after eclipses by Jupiter (*2*). However, since that time many observations have produced conflicting evidence of this phenomenon, which was regarded as inconclusive or sporadic by most investigators (*3*). Some evidence of frost-like deposits on the surface was also obtained by polarization measurements (*4*). The occultation of Beta Scorpii by Io in 1971 provided no positive indication of an atmosphere, although an upper limit for the surface atmospheric pressure was determined to be between 10^{-6} and 10^{-7} bar (*5*).

A preliminary analysis of the "quick-look" closed-loop Doppler data obtained as the Pioneer 10 spacecraft was entering occultation by Io has produced a profile of the electron density as shown in Fig. 1. It shows an ionosphere extending for some 700 km above the surface of Io with an electron density peak of about 6×10^4 electrons per cubic centimeter and a topside plasma scale height of about 220 km. At the time of these observations Io was on the earth's side of Jupiter and the point of entry into occultation was facing away from Jupiter. The solar zenith angle at this point was approximately 81 deg. The planetary surface, as established from a crude estimate of the time of loss of signal, lies between 60 and 140 km below the ionosphere peak. A more accurate determination of the radius of Io is currently under way.

If an analogy with the ionosphere of Mars is permissible, then such an ionosphere should form at a number density level of neutrals of from 10^9 to 10^{11} per cubic centimeter. In that case the density at the surface would lie between about 10^{10} and 10^{12} per cubic centimeter. Again assuming a mean molecular weight lower than that of the Mars atmosphere, one obtains a surface atmospheric pressure ranging from 10^{-8} to 10^{-10} bar, which is below the threshold of detection of the Beta Scorpii stellar occultation observation (*5*).

The discovery of an ionosphere on

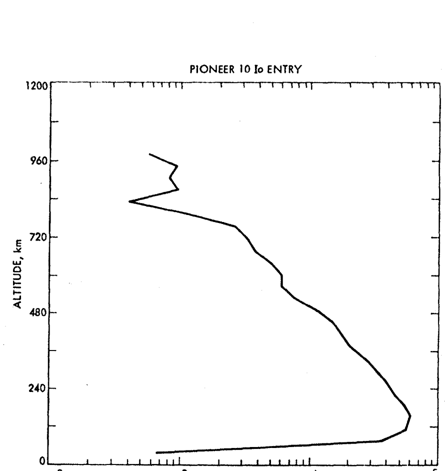

Fig. 1. Electron density in the ionosphere of Io observed at a solar zenith angle of about 81 deg. (The uncertainty in altitude above the surface is about ± 40 km.)