with data obtained when pressurized cell meteoroid detectors of the same material and sizes as the Pioneer 11 and Pioneer 10 detectors were used in Earth orbit on Explorer 23 (*3*).

The Pioneer 11 data confirm the existence of a gap in the meteoroid environment beginning near 1.15 A.U. Although the gap extended to 1.34 A.U. in the Pioneer 10 data, it is poorly defined for the larger particles detected by Pioneer 11 because of the low data rate. The penetration rate measured on Pioneer 11 between 2.3 and 5.0 A.U. is less by about a factor of 2.5 than that measured by Pioneer 10. The mass distribution in this region of space is therefore, to the accuracy established with the few meteoroid penetrations obtained, essentially the same as that near 1 A.U.

There were two meteoroid penetrations indicated on the channel 0 instrument while Pioneer 11 was near Jupiter. In addition, a spurious count was registered soon after the second penetration while the spacecraft was near periapsis and the radiation was high. This finding has raised some question about whether the two indicated meteoroid penetrations were actually penetrations or whether they also were induced by radiation. A more thorough investigation is required before any conclusions can be reached. It is clear, however, that no more than two meteoroid penetrations occurred in the channel 0 detectors during encounter.

The Pioneer 11 encounter trajectory was vastly different from that of Pioneer 10, and the encounter data cannot be compared directly. If the meteoroids near Jupiter are gravitationally focused toward the planet from solar orbits, the channel 0 instrument on Pioneer 11 should have registered about two penetrations during approach to periapsis and none after periapsis, which is what happened. Thus, the data obtained during the Pioneer 11 encounter are consistent with the concept that the high concentration of small particles near Jupiter is the result of the fact that meteoroids in solar orbits are gravitationally focused toward the planet.

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References

1. W. H. Kinard, R. L. O'Neal, J. M. Alvarez, D. H. Humes, *Science* **183**, 321 (1974).
2. R. L. O'Neal, *NASA Tech. Note D-7691* (1974).
3. ———, *NASA Tech. Note D-4284* (1968).

14 March 1975

Atmosphere of Jupiter from the Pioneer 11 S-Band Occultation Experiment: Preliminary Results

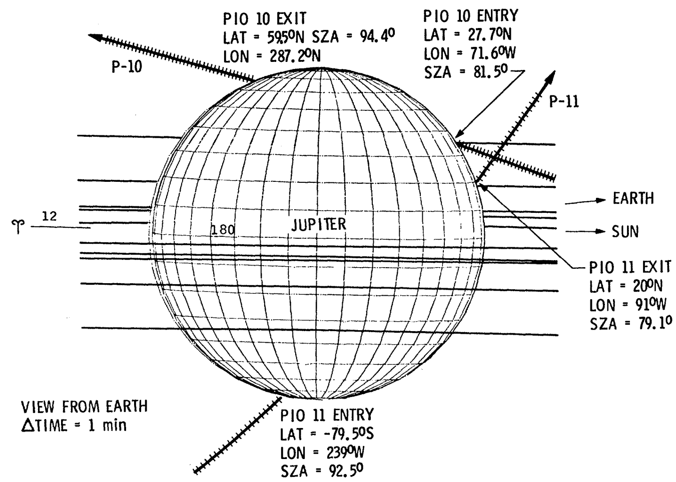
Abstract. *Two additional radio occultation measurements of the atmosphere of Jupiter were obtained with Pioneer 11. The entry measurement leads to a temperature profile that is substantially in agreement with those obtained with Pioneer 10, showing temperatures much higher than those derived from other observations. The exit measurement is not usable because of the discontinuous drift of the spacecraft auxiliary oscillator, presumably due to the trapped radiation belts of Jupiter. The combination of two Pioneer 10 measurements and one Pioneer 11 measurement yields an oblateness of 0.06496 at 1 millibar and 0.06547 at 160 millibars. Measurements in the Jovian ionosphere indicate a number of layers distributed over about 3000 kilometers, with a topside temperature of about 750 K.*

The Pioneer 10 spacecraft was the first to perform a radio occultation experiment in the atmosphere of Jupiter and its satellite Io (*1, 2*). Analyses of data from these occultations revealed the existence of an atmosphere on Io, as well as indications of unexpectedly high temperatures in the atmosphere of Jupiter amounting to about 400 K at a pressure of about 500 mbar as compared to approximately 130 K at comparable pressures as deduced from Earth-based spectroscopy and the Pioneer 10 infrared radiometry experiment (*3*). This obvious disagreement was difficult to explain; however, one possibility was the existence of obscuring dust layers in the upper levels of the Jovian atmosphere, a possibility that was supported by the observation in the Pioneer 10 occultation results of markedly higher temperatures at pressures of 1 to 30 mbar on the sunlit side, implying heating by sunlight absorbed by dust or other particulate matter suspended in the atmosphere. In view of the nature of the Pioneer 10 results, the Pioneer 11 measurements, taken at different latitudes and conditions of geometry, offered the prospect of elucidating the cause of the disagreement.

Pioneer 11 flew by Jupiter on 3 December 1974. The geometry of the occultation is shown in Fig. 1, which is a view of the Pioneer 10 and Pioneer 11 trajectories and Jupiter as seen from Earth. The closest approach of Pioneer 11 to Jupiter, which occurred near the time of the crossing of the orbital planes of the Galilean satellites, occurred at about 5:21:37 G.M.T. on 3 December while Pioneer 11 was behind Jupiter, thus precluding any further occultation experiments with the satellites. The entry into occultation occurred at a latitude of about 79.5°S and a longitude of about 239°W, on the dark limb of Jupiter where the solar zenith angle (SZA) was 92.5°. The exit occurred at a latitude of about 20°N, a longitude of about 91°W, and an SZA of about 79.1°. From Fig. 1 it is evident that Pioneer 11 was traveling about twice as fast as Pioneer 10, for a rate of change in the projected radial distance from the center of Jupiter of about 40 km per second. Thus, the time needed for the radio beam to traverse the distance from the top of the ionosphere to the lowest level of penetration was only about 2 minutes. The occultations occurred while the spacecraft was much closer to Jupiter than in the case of Pioneer 10, with the distance from the limb being about 98,000 km at entry and about 120,000 km at exit.

Occultation data were taken at Deep Space Network station 43 near Canberra, Australia, and station 14 at Goldstone, California. Both closed-loop and open-loop data were taken; however, because of the rapid changes in the frequency of the signal due to the high velocity of the spacecraft relative to Jupiter, no closed-loop data in the atmosphere of Jupiter were obtained and only open-loop data were used for analysis. These data were obtained from open-loop receivers having a bandwidth of about 16 khz and recorded by direct and FM recording on analog tape recorders. These data were then digitized at a rate of 40,000 samples per second and digitally filtered with a 300-hertz filter bandwidth, with the use of a local oscillator (L.O.) function derived from signal spectra computed from the raw digitized data. The decimated data were then passed through the digital phase locked loop receiver program, which computed the changes in frequency and amplitude of the received signal with time and provided the basic data for further analysis.

A series of spectra of the decimated signal as a function of time during the



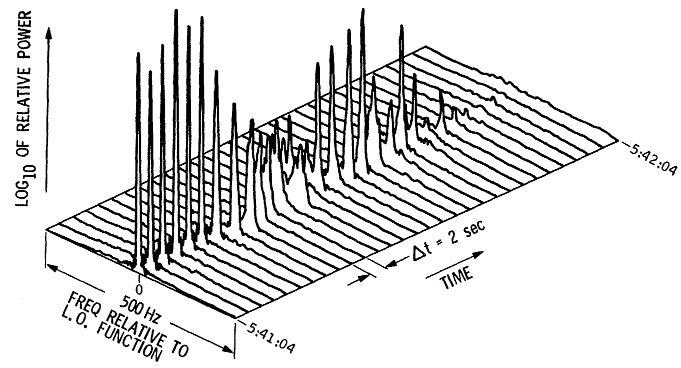


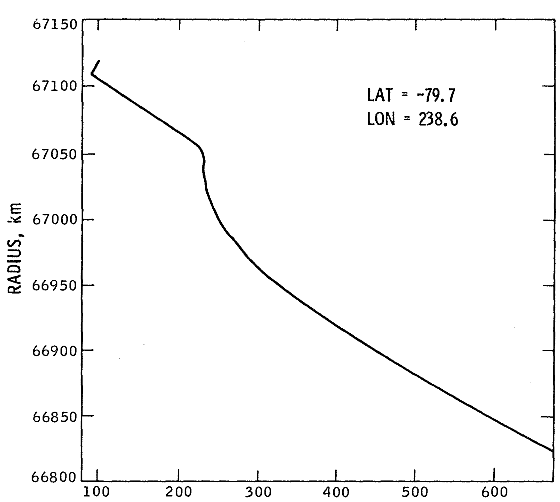
Fig. 1 (left). Geometry of Pioneer 10 and Pioneer 11 radio occultations as viewed from Earth. Fig. 2 (right). Spectra of the decimated open-loop signal during Pioneer 11 entry occultation.

entry into occultation is shown in Fig. 2. The ordinate of the plot represents a normalized logarithm to the base 10 of the power, and each spectrum is 500 hertz wide. The interval between spectra is about 2 seconds. The spectra show a considerable broadening and deformation due to multipath effects in the lower ionosphere which contains several layers with high gradients of refractivity. This is followed by a slight rise going into the top of the neutral atmosphere and then a precipitous drop due presumably to absorption and defocusing in the dense neutral atmosphere.

The frequency of the signal was compared to predictions based on the orbit of Pioneer 11, and the resulting residual effects in the frequency were then inverted to yield the refractivity as a function of radial distance from the center of Jupiter based on the use of inversion methods described earlier (*4*). The resulting refractivity profile was converted to mass density on the basis of an assumed composition for the neutral atmosphere, in this case one composed of 85 percent H_2 and 15 percent He. The density was then integrated in the hydrostatic equation to obtain a profile of pressure, and, with the use of the perfect gas law, the profile of temperature was also obtained. The temperature profile resulting from the Pioneer 11 entry measurement is shown in Fig. 3. Although this measurement was taken in the polar area, the temperatures are quite high and are similar to the entry temperature profile produced from the Pioneer 10 results (*2*). In particular, the appearance of the inversion at about 260 K is strikingly similar to the Pioneer 10 entry profile, although the Pioneer 11 measurement was obtained on the dark limb of Jupiter. Thus, the inversion cannot be ascribed to heating by particulate absorption of solar radiation, unless rapid circulation at the polar latitude is sufficient to maintain this effect across the terminator.

A comparison of the Pioneer 11 temperature profile with those derived from Pioneer 10 and from a model is shown in Fig. 4, which portrays the profiles in terms of pressure as a function of temperature. The profile labeled "IR Model" is based primarily on the Pioneer 10 infrared radiometer results (*5*). It is immediately obvious that the Pioneer 11 entry temperature profile is similar in nature to those obtained from Pioneer 10, although temperatures are higher at corresponding pressures. It is also obvious that the disagreement between these results and those of the infrared measurements are very large, with the only region of similar temperatures being at low pressures.

The data taken during the exit of Pioneer 11 from occultation have also been analyzed. However, because, in contrast to the entry, the exit was performed in a one-way mode, in which the spacecraft transmitter is referenced to the on-board auxiliary oscillator, these data were seriously affected by a discontinuously changing oscillator drift rate, apparently caused by the trapped radiation belts. This erratically chang-



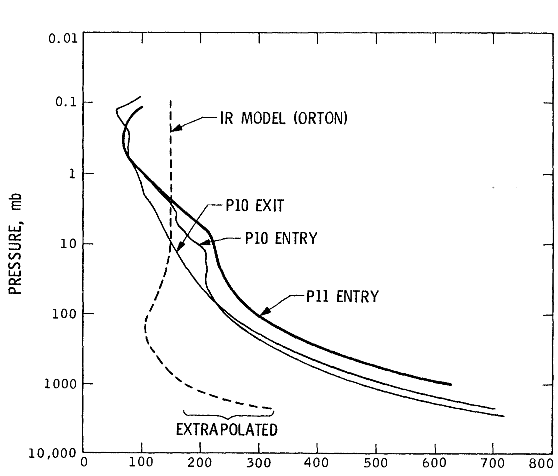


Fig. 3 (left). Pioneer 11 entry temperature profile. Fig. 4 (right). Comparison of Pioneer 10 and Pioneer 11 radio occulation temperature-pressure profiles with the model based on Pioneer 10 infrared radiometer results.

ing drift rate prevents the establishment of a base line for the removal of frequency bias, which has so far made the further analysis of the exit data impossible.

It has been mentioned previously that the temperature profiles derived from radio occultation and those derived from Earth-based and spacecraft spectroscopic observations can only be reconciled under one of two conditions. The first is the presence of obscuring layers high in the atmosphere of Jupiter, which in effect may cause the infrared observations to be taken at pressures of about 1 to 10 mbar. This explanation, however, is difficult to reconcile with the determinations of the abundance of H_2, CH_4, and NH_3 above the visible clouds on Jupiter, as well as the observations at microwave wavelengths, which also indicate a temperature of 130 K at a pressure of 0.5 atm (*6*).

The other explanation involved the presence of propagation effects other than pure refraction in the layers of Jupiter atmosphere probed by radio occultation. It must be pointed out that the process of radio occultation data inversion is strictly valid only under the assumption that all the phase change is being introduced by refraction in a homogeneous, spherically symmetrical atmosphere. Deviations from these assumptions will introduce errors in the results. Several such mechanisms have been suggested including turbulent scattering, ducting, and diffraction.

In order to help visualize the nature of the disagreement, the expected residual phase change as a function of time for an atmosphere corresponding to the IR model was computed and is shown in comparison with the observed Pioneer 11 entry data in Fig. 5. It is clear that in the actual data the phase always changes at a slower rate than that required by the IR model. Thus, any explanation of the IR–radio occultation disagreement must show a rate of phase change as a function of time lower than that expected under the conditions of atmospheric refraction only. It is apparent that explanations such as turbulent scattering would necessarily require that the total phase path be lengthened; hence, they are difficult to reconcile with the observation. The possibility of extraneous phase changes being introduced by diffraction around an NH_3 vapor absorption layer having a small scale height has recently been suggested (*7*) and is currently under investigation. It remains for the results

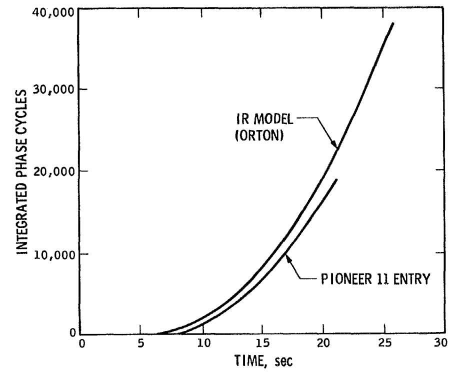


Fig. 5. Comparison of the residual phase expected from the Pioneer 11 trajectory with the IR model atmosphere and observed data.

of this investigation to determine whether or not this could be a possible explanation for the disagreement.

The Pioneer 11 profile of pressure versus radial distance from the center of Jupiter was combined with similar measurements from Pioneer 10 to determine the oblateness of the planet. Ellipses were fitted to the radii of equal pressure in a least-squares sense down to 1000 mbar. At the 1-mbar level the oblateness calculated was 0.06496 ± 0.0001, the equatorial radius was $71,610 \pm 6$ km, and the polar radius was $66,958 \pm 4$ km. At the 160-mbar level the calculated oblateness was 0.06547 ± 0.0001, the equatorial radius was $71,494 \pm 6$ km, and the polar radius was $66,812 \pm 4$ km. Using the results of the Pioneer 10 celestial mechanics experiment on the gravity harmonics J_2 and J_4, the mass of Jupiter (*8*), and the above values of the oblateness, we calculated the rotation period at the 1-mbar level to be 9 hours, 55 minutes, 46 seconds $\pm$ 1 minute, 6 seconds, which is in excellent agreement with the system II rotation of Jupiter. The rotation period at the 160-mbar level was calculated to be 9 hours, 50 minutes, 30.4 seconds $\pm$ 1 minute, 5 seconds, in good agreement with the ground-based observations of the system I rotation of Jupiter.

Ionospheric data were also obtained from both the entry and exit measurements. The new measurements confirmed earlier results obtained for Pioneer 10 (*2*) and show that Jupiter's ionosphere consists of a number of layers distributed over an altitude range of about 3000 km. A preliminary analysis indicates a topside plasma temperature of about 750 K on the assumption that H^+ is the principal ion.

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References and Notes

1. A. Kliore, D. L. Cain, G. Fjeldbo, B. L. Seidel, S. I. Rasool, *Science* **183**, 323 (1974).
2. ———, paper II-VII.1.4 presented at the 17th Committee on Space Research (COSPAR) meeting (São Paulo, Brazil), 24 June to 1 July 1974.
3. G. Münch, G. Neugebauer, A. Ingersoll, paper II-VII.1.5 presented at the 17th Committee on Space Research (COSPAR) meeting (São Paulo, Brazil, 24 June to 1 July 1974.
G. Fjeldbo and V. R. Eshleman, *Planet. Space Sci.* **16**, 1035 (1968); A. Kliore, in *Mathematics of Profile Inversion*, L. Colin, Ed. (National Aeronautics and Space Administration Publication TM X-63, 150, Washington, D.C., 1972), p. 3-1.
5. G. Orton, personal communication.
6. S. Gulkis, M. J. Klein, R. L. Poynter, in *Exploration of the Planetary System*, Woszczyk and Iwaniszewska, Eds. (Reidel, Dordrecht, Netherlands, 1974), p. 367.
7. S. Gulkis, personal communication.
8. J. D. Anderson, G. W. Null, S. K. Wong, *J. Geophys. Res.* **79**, 3661 (1974).
9. We thank C. F. Hall of the Pioneer Project Staff at NASA Ames Research Center and the Deep Space Network personnel and the Pioneer Navigation Team at the Jet Propulsion Laboratory (JPL) for the acquisition of our data. Special thanks is due to the Occultation Planning Group at JPL and NASA Ames Research Center. This work represents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract NAS 7-100.

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Gravity Field of Jupiter from Pioneer 11 Tracking Data

Abstract. *Significantly improved values of the zonal gravity harmonic coefficients* J_3, J_4, *and* J_6 *of Jupiter have been obtained from a preliminary analysis of Pioneer 11 spacecraft Doppler data taken while the spacecraft was near Jupiter. The new results, which will have an important application as boundary conditions for theoretical models of Jupiter's interior, are consistent with a planet in hydrostatic equilibrium.*

Two-way S-band Doppler data were obtained from Pioneer 11 during its Jupiter encounter by stations of the National Aeronautics and Space Administration–Jet Propulsion Laboratory Deep Space Network. Three 64-m antennas (at Goldstone, California; Canberra, Australia; and Madrid, Spain) provided data with a typical root-mean-square noise of 0.005 hertz for a 60-