The Upper Atmosphere and Ionosphere of Mars

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SUMMARY

The Dynamic Atmosphere of Mars

The Martian atmosphere is believed to be highly variable and dynamic, much more so than the atmosphere of Earth. Figure 1 illustrates certain aspects of this dynamic behavior. High winds blowing over high relief surface features produce density variations, usually identified as gravity waves, having peak to peak amplitudes of 15 to 20%, as is evident from the Viking 1 and 2 Lander measurements shown in Figure 2. These structures grow as they propagate upward into the thermosphere and ionosphere (>80 km) where they deposit energy and momentum that should drastically affect the thermal and chemical structure of Low Mars Orbital (LMO) environment; i.e, the region between about 100 and 400 km.

Possible Similarities with Earth and Venus

The upper atmospheres of the terrestrial planets are all known to be highly dynamic. Knowledge of this behavior at Mars is very meager, but the upper atmospheres of the other two (Earth and Venus) have been rather thoroughly measured. Earth satellites like the Atmosphere Explorers[1] have shown that upper atmosphere density disturbances are most prevalent at high latitudes (Figure 3). At Venus, the Pioneer Venus Orbiter[2] Neutral Mass Spectrometer has shown that high amplitude gravity wave structure is common at the terminators, and that this behavior is not associated with any particular surface features (Figures 4 and 5). Many Space Shuttle flights carrying sensitive accelerometers have measured similar features between 60 and 160 km during reentry (Figures 6). A new Earth upper atmospheres mission, called TIMED[3], is now being planned to study more carefully the coupling between the upper atmosphere and the thermosphere/ionosphere. The comparable regions at Mars have yet to be explored globally.

The Atmosphere and Ionosphere of Mars

Much more is known about the lower and middle atmosphere of Mars than about its upper atmosphere, including the thermosphere and exosphere. More is known about the electron density in the ionosphere, since that parameter can be measured by radio occultation measurements without passing into the ionosphere. Temperature profiles of the lower atmosphere up to about 30 km were obtained in 1970 and 1971 by the Mariner 9 IR limbscanning experiment[4], and radio occultation measurements of the ionosphere provided hundreds of electron density vs height profiles of the ionosphere between about 100 km and 400 km[5] (Figure 7). A striking result was the great orbit to orbit variability of the altitude of the ionospheric peak (Figure 8), a result that is believed to reflect the great variability of thermospheric density that is to be expected from the variability seen at lower altitudes.

Solar Wind Interactions

The Phobos-2 spacecraft did not penetrate the ionosphere or thermosphere of Mars (periapsis ~ 870 km), but did perform many valuable measurements[7] that shed light on the nature of solar wind interactions with the planet and on its energetic particle environment at its circular orbit altitude of about 6000 km. Figure 9 is a cartoon showing the suspected escape of O^+ ions down the Martian tail as a result of solar wind interactions. Figure 10 shows the measurements of the energetic O^+ ion fluxes measured some 6000 km down the tail, apparently escaping the planet. These energetic ions represent part of the energetic particle environment to be expected in Mars orbit.

Future Approved Missions

Mars Observer is expected in 1993 to extend the gas temperature measurements to somewhat higher altitudes than those achieved by Mariner 9 limbscanning, but its sun-synchronous orbit will provide measurements at only two opposing local times (02 and 14 hrs). MO will leave the thermosphere largely unexplored, since it will have no related in situ measurements, but it will obtain additional electron density profiles via radio occultation. The Soviet Mars-94 mission provides the only hope of learning more about the composition and temperature of the Martian ionosphere, but its perigee altitude (>300 km) will probably only an occasionally dip into the upper ionosphere, and this will not be low enough to permit in situ measurements of the thermosphere itself. A topside sounder should provide additional electron density profiles down to the altitude of the peak density.

Possible Future Mission

Past missions, and the missions now being implemented will have left unaddressed most of the important questions about the nature of the LMO environment. The global variations of thermospheric and ionospheric composition and temperature will

remain unknown. The temporal variations of the density, temperature, composition and winds in the thermosphere and ionosphere (local time, seasonal, solar cycle, response to local and global dust storms) remain almost totally unknown. Nor are the amplitudes and scale sizes of smaller scale structures (such as gravity waves) known for the upper atmosphere and thermosphere. Viking 1 and 2 confirmed their existence but their global distribution, local time distribution, and frequency of occurence is completely unknown. The martian contribution to the energetic particle environment in LMO is also almost completely unknown.

As for new missions that will help cure our ignorance of the LMO environment, none are currently approved. A long advocated Mars Aeronomy Orbiter[8] has been proposed to study this region. In its initial elliptical orbit phase, it would be a deep diver capable of making both in situ measurement of the height variations down to the vicinity of 120-130 kilometers and remote measurements of the middle and lower atmosphere, including dust. Figure 11 shows a low passage of MAO through such a wave train The path of an entry probe which could be deployed from such a satellite is also shown traversing the same wave train at lower altitudes. Such measurements will also reveal the amplitude of the density enhancements that are believed to accompany local or global dust storms. Figure 12 illustrates an MAO and entry probe traversal of a region perturbed by an underlying local dust storm. Figure 13 shows the Strawman payload recommended for MAO to make such measurements.

Later in the MAO mission, aerobraking maneuvers will be used to circularize the orbit to provide a more global view of the atmosphere, ionosphere, and particles and fields environment at altitudes above about 130 km. Ion and neutral mass spectrometers and various cold plasma probes would measure the altitudinal and global variations in the ionosphere and thermosphere, as well as define the amplitude and scale sizes of the gravity wave structures. They will also be able to determine whether such structures are associated with specific surface features or are locked into a diurnal pattern, as found at Venus[2]. MAO fields and particles instruments would illucidate the role of solar wind interactions as a source of energy and dynamics of the ionosphere and thermosphere and the importance of atmospheric escape in the continuing evolution of the Martian atmosphere.

The MAO mission, while essentially focused on scientific questions about planetary atmosphere processes, will have important spinoffs for future manned and robotic explorations of the planet[9]. It will define the atmospheric drag environment to be encountered in LMO. It will identify the most dynamic atmospheric regions that perhaps should be avoided when selecting potential targets for aerobraking or aerocapture maneuvers. It will add to our meager knowledge of the energetic particle environment in LMO.

Specific MAO Spinoffs for Knowledge of the LMO Environment

- Chemical erosion of s/c surfaces: Define the spatial and temporal variations of atomic oxygen, the major constituent above about 200 km.

- Electrical design of spacecraft: Define the ionospheric medium to evaluate the need for isolation of future s/c power systems from the conducting plasma to avoid unnecessary s/c charging and leakage currents.

- Orbital lifetimes: Define the atmospheric densities and their variations to permit accurate orbital lifetime predictions and propulsion requirements to offset drag effects.

- Aerobraking and Aerocapture: Identify dynamic regions of the Martian atmosphere that should be avoided as aerocapture targets to assure a safer, smoother ride and a more predictable initial orbit.

- Impact Ionization Effects   Measure the electrons, ions, and airglow produced by the spacecraft as it dives deeply into the lower thermosphere (~100-130 km).

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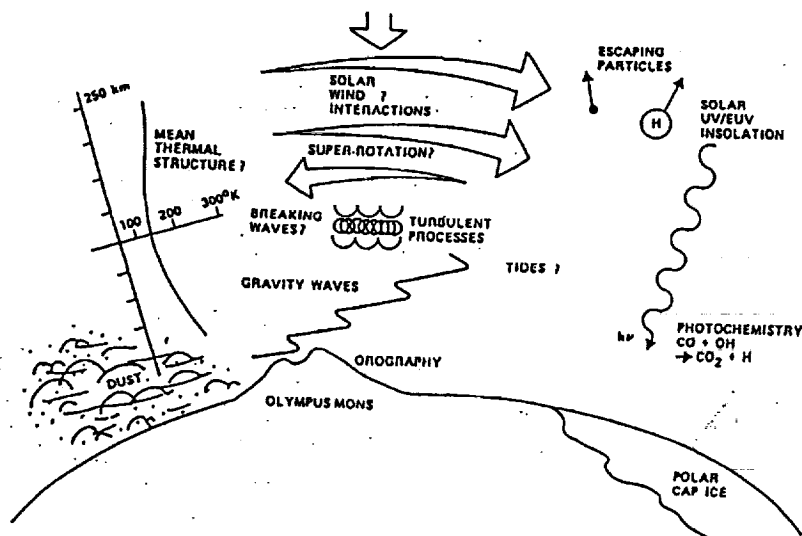
Figure 1. A cartoon showing the dynamic atmospheric processes that would be invest
igated by the Mars Aeronomy Orbiter. (from the MAO Science Team
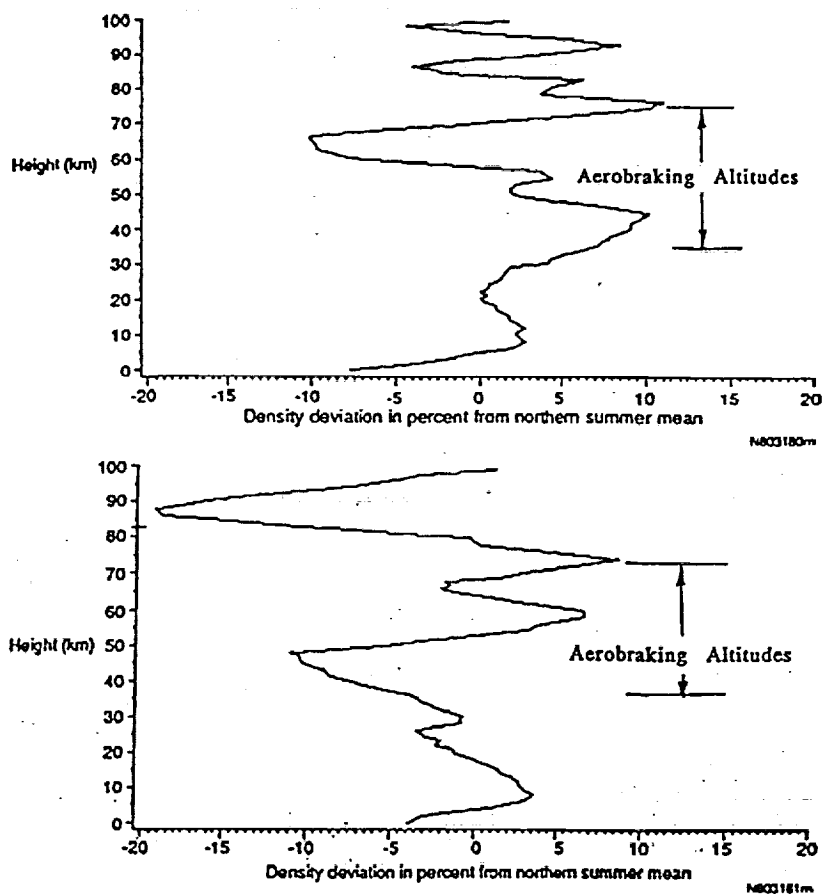Report, NASA Tech. Memo 89202).

Figure 2, Viking 1 and 2 Lander measurements of density normalized by the
COSPAR model atmosphere. Large waves were present at aerobraking
altitudes. This is the only hard information we have about the wave structure
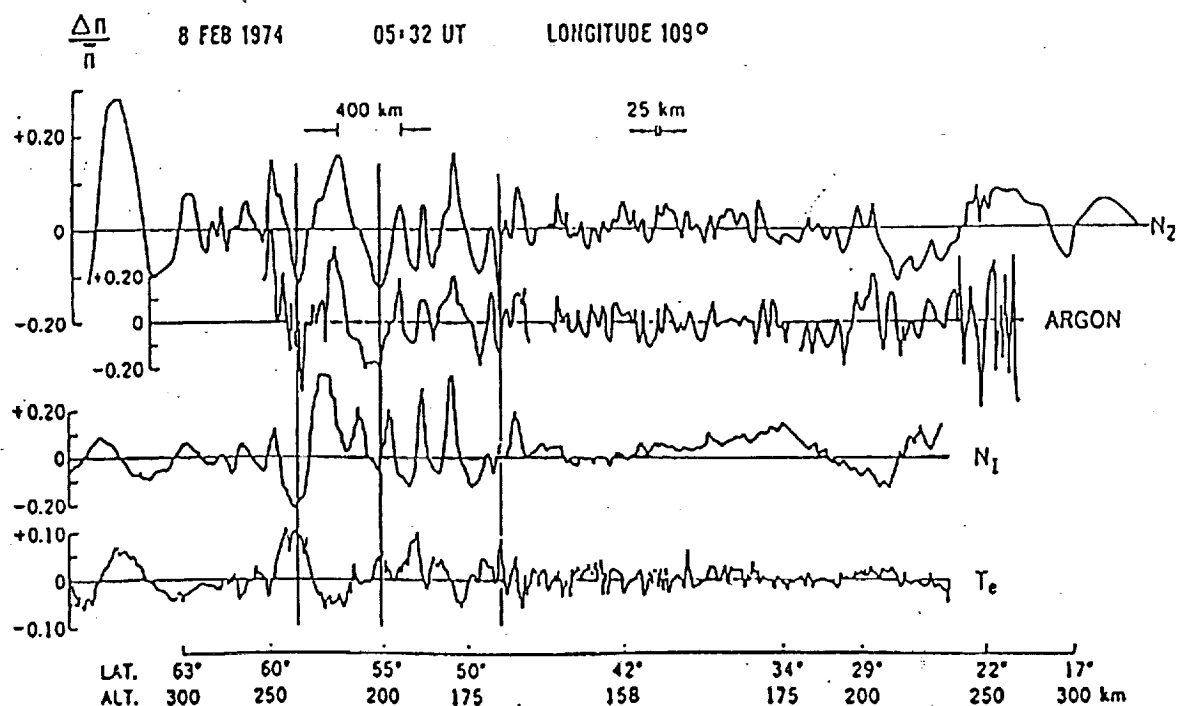at these altitudes. (from Environment of Mars, 1988)

Figure 3. Density variations (upper panel) in the Earth's themosphere measured by Atmosphere Explorer-C. The greatest wave amplitudes are found at higher latitudes where auroral energetic particles heat the atmosphere.

C.A. Reber et al., J. Geophys. Res., Vol. 80, No. 34, 4576-80, 1975, copyright by the American Geophysical Union.
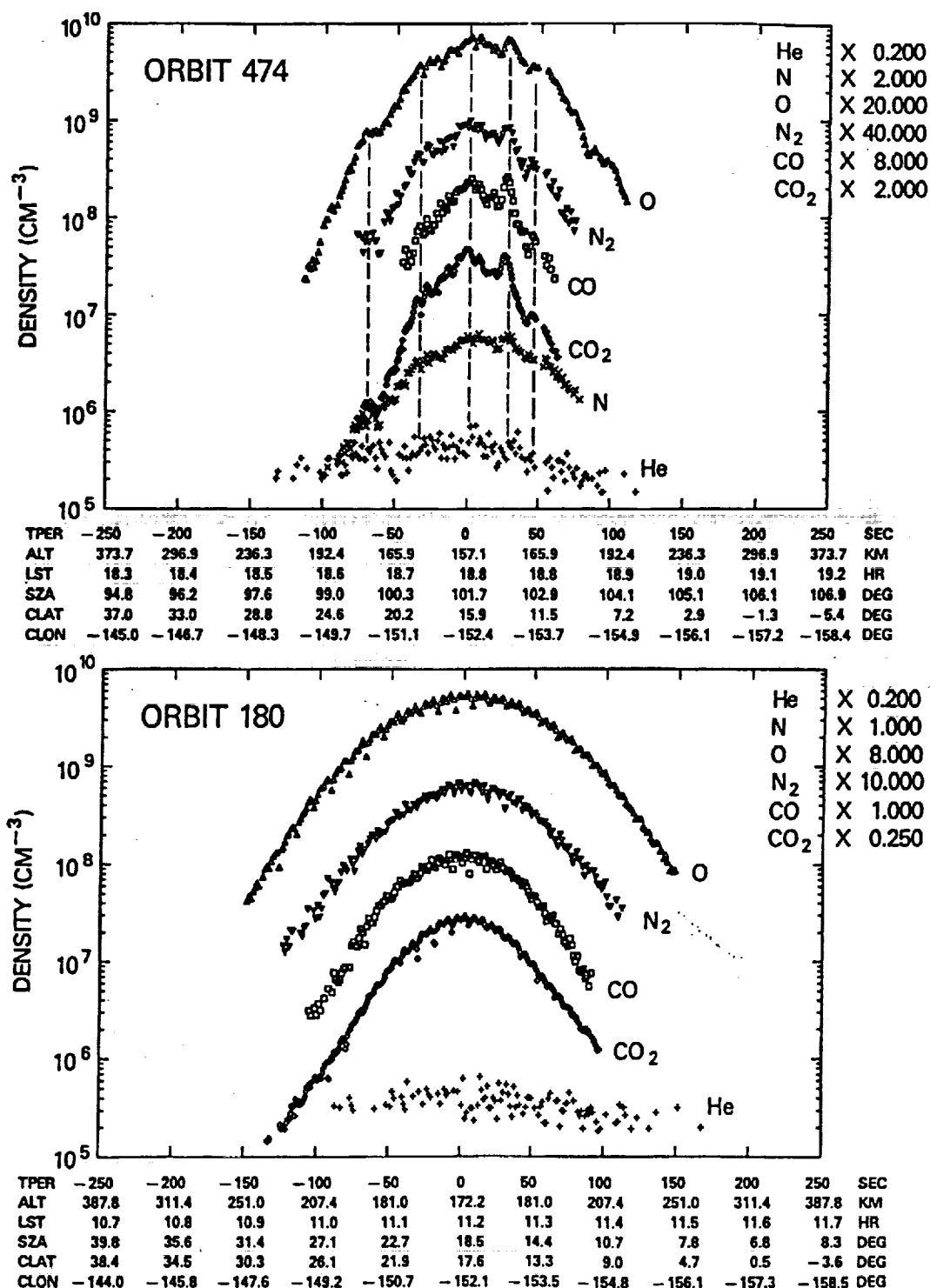
Figure 4 Plot of ambient density versus time from periapsis for He, N, O, N_2, CO, and CO_2 measured on orbits (bottom) 180, near noon, and (top) 474, near the terminator. The densities have been scaled by the factors shown. Atomic nitrogen was not routinely measured prior to orbit 190. The points below the main data line in orbit 180 for O, N_2, CO, and CO are due to a partial shadowing of the ion source by the spacecraft antenna at extreme angles of attack.

W.T. Kasprzak et al., Geophys. Res. Letts., 7, 106, 1988, copyright by the American Geophysical Union.

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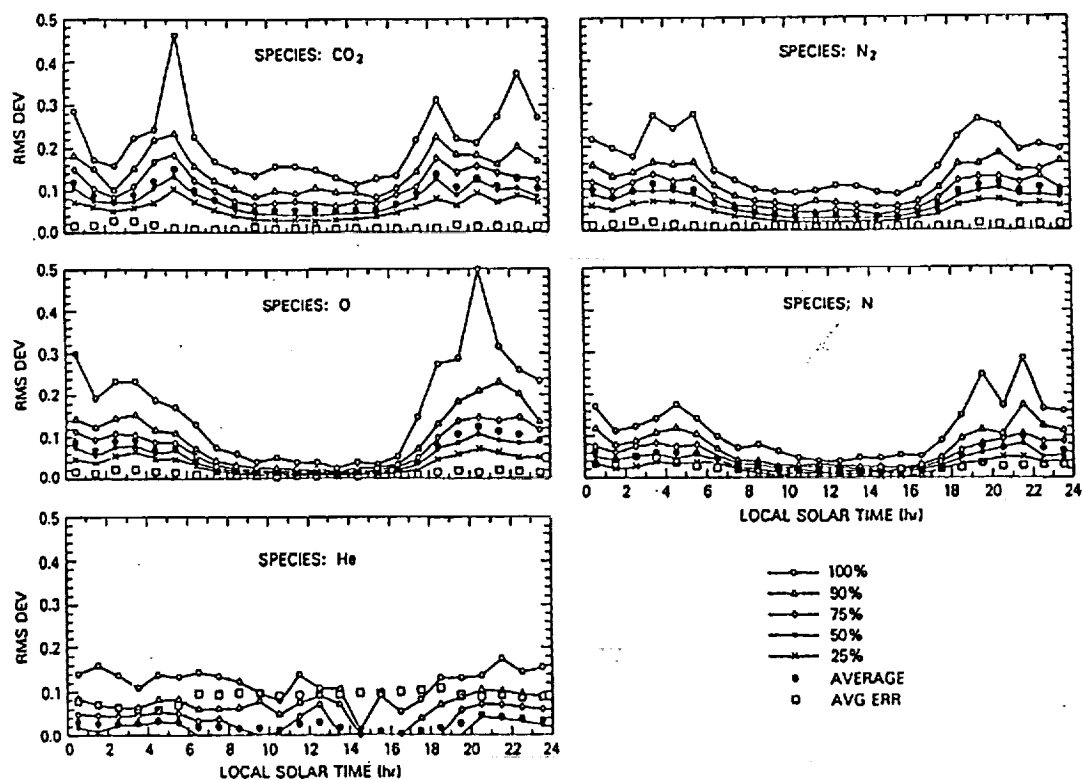
Figure 5. The statistical amplitudes of density waves in the Venus thermosphere shows that the atmosphere is most dynamic near dawn and dusk, and on the night-side in general. The dayside is quite smooth. Similar information is not available for Mars.

W.T. Kasprzak et al., Geophys. Res. Letts., 7, 106, 1988, copyright by the American Geophysical Union.
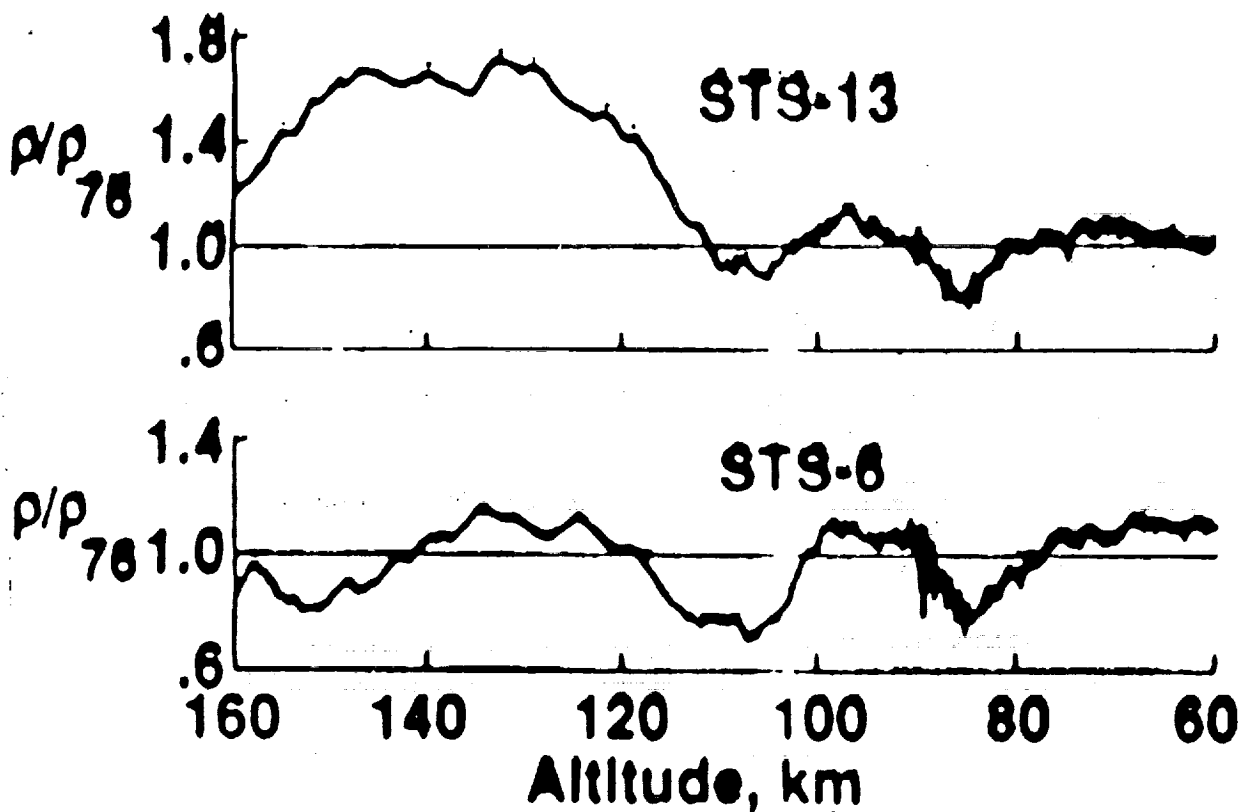
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Figure 6. The ratio of the atmospheric density (ρ) to a 1978 model density based on STS-13 and 6 accelerometer measurements. These measurements reveal large amplitude gravity wave structure at aerobraking altitudes in the Earth's upper atmosphere.
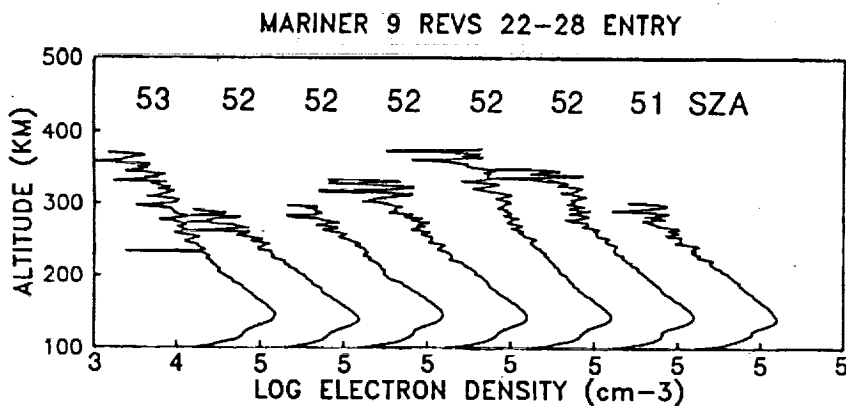

Figure 7. Examples of altitude profiles of dayside ionospheric electron density at Mars, derived from the radio occultation experiment on Mariner 9 [from Zhang et al., 1990a]. SZA is the solar zenith angle at which the profile was obtained (subsolar is SZA = 0; SZA = 90 is the terminator).

Zhang et al., J. Geophys. Res., 95, No. 89, 14,829-14,839, 1990, copyright by the American Geophysical Union.

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Mars Ionosphere Peaks

Figure 8. Plots of the density (bottom) and altitude (top) of the peaks in the electron density profiles observed at Mars as a function of solar zenith angle (adapted from *Zhang et al.* [1990b]).
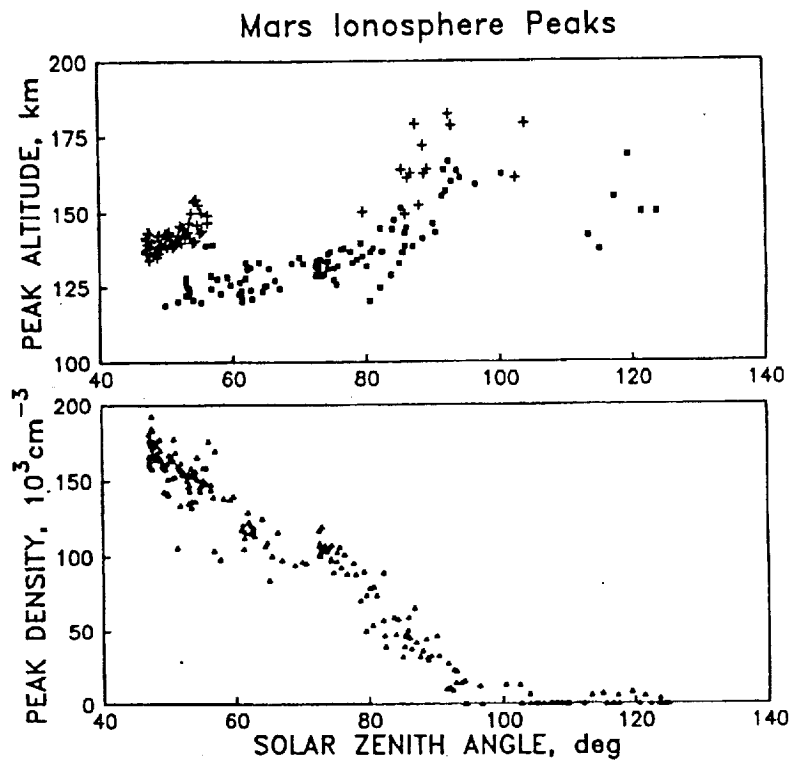
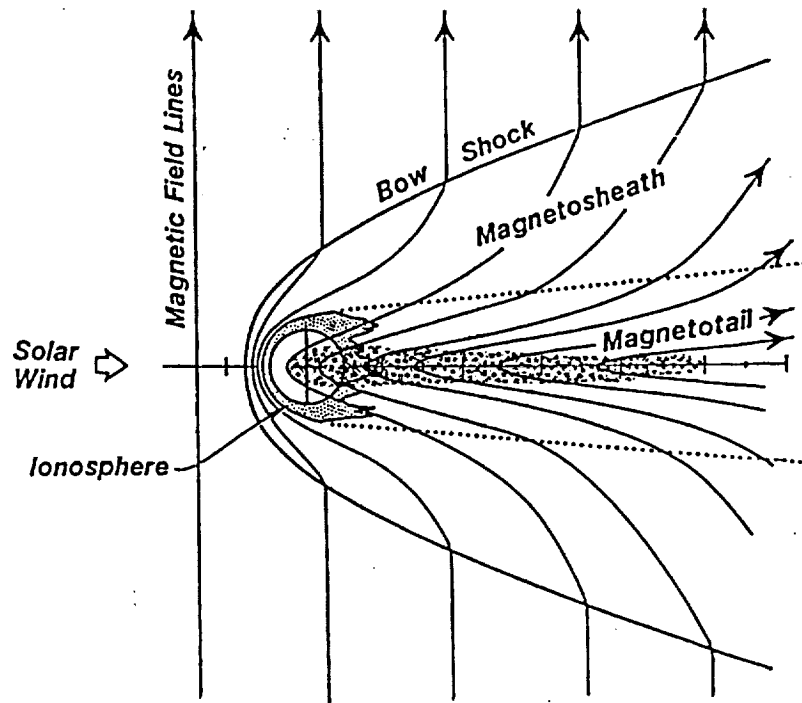Zhang et al., J. Geophys. Res., 95, No A10, 17,095-17,102, 1990, copyright by the American Geophysical Union.

Figure 9. A cartoon illustrating the escape of energetic O+ ions from Mars, based on Phobos 2 measurements such as those shown in Figure 10.
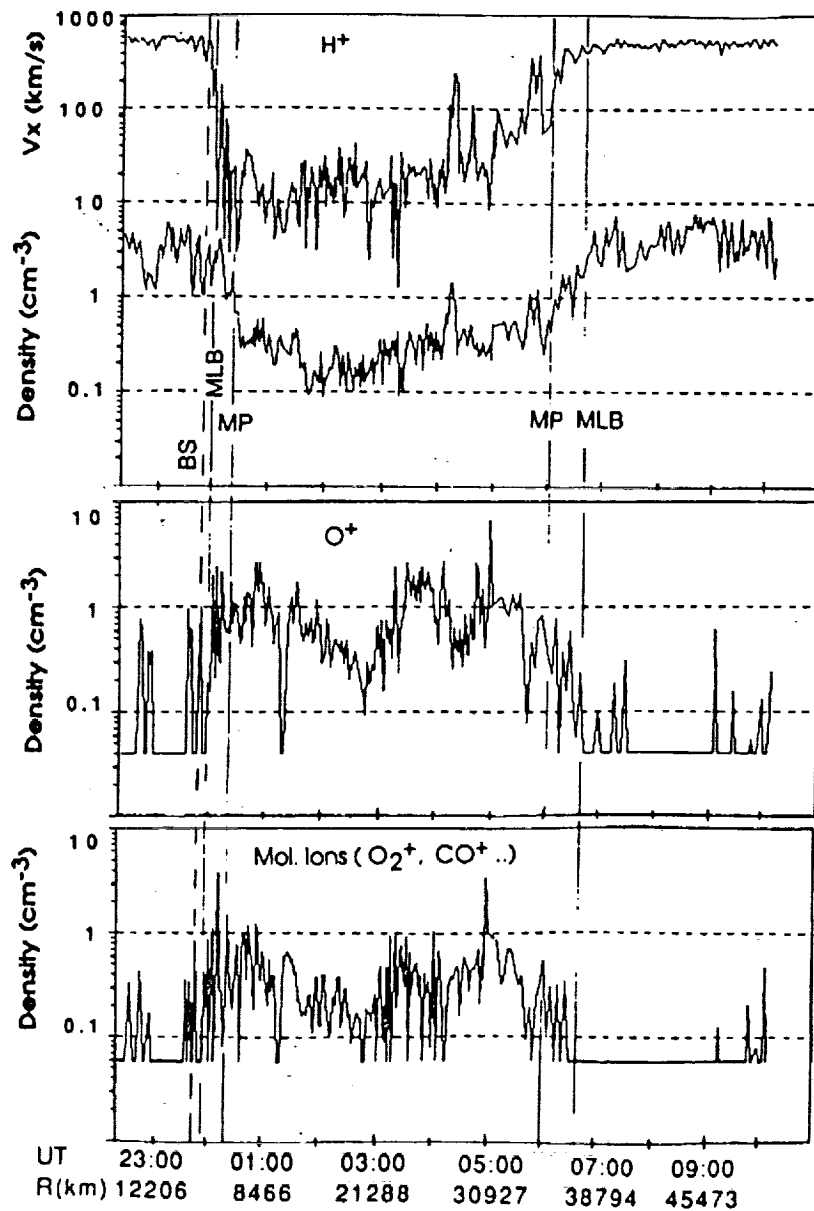
Figure 10. ASPERA measurements from Phobos 2 showing energetic ions escaping down the Martian tail. These ions contribute to the energetic particle environment to be encountered in Mars orbit.
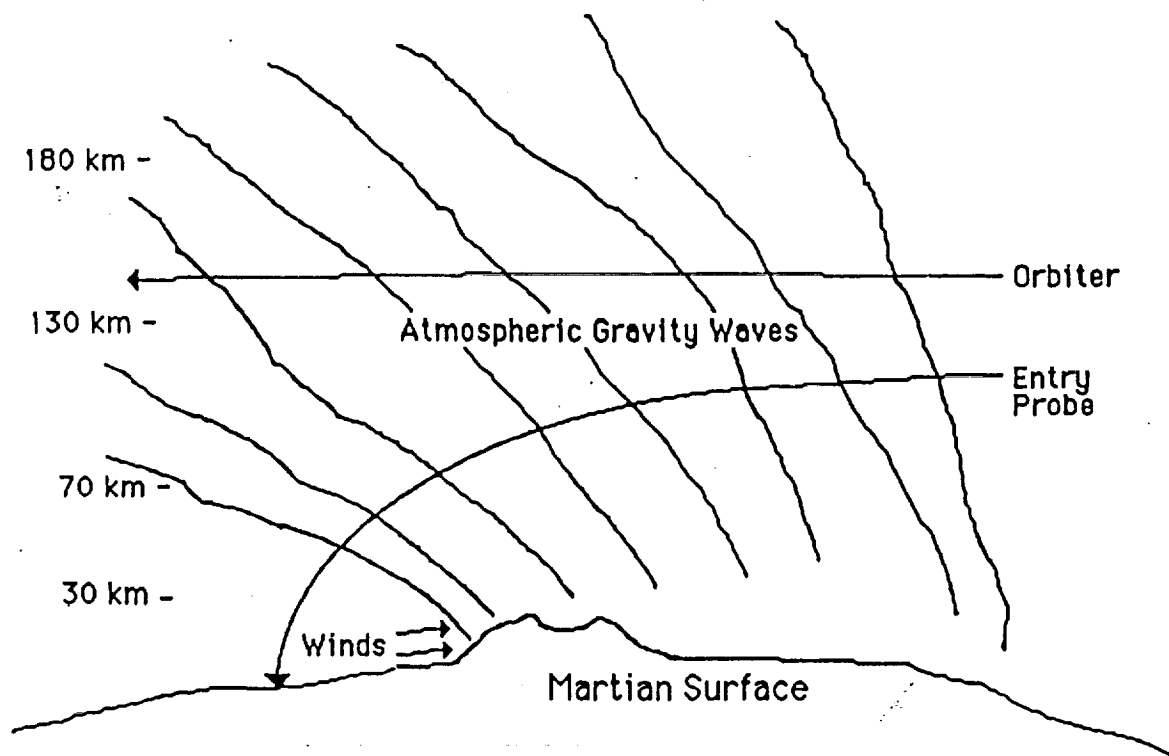
Figure 11. The trajectory of MAO, and an entry probe, through a series of gravity waves propagating upward out of the Martian lower atmosphere.
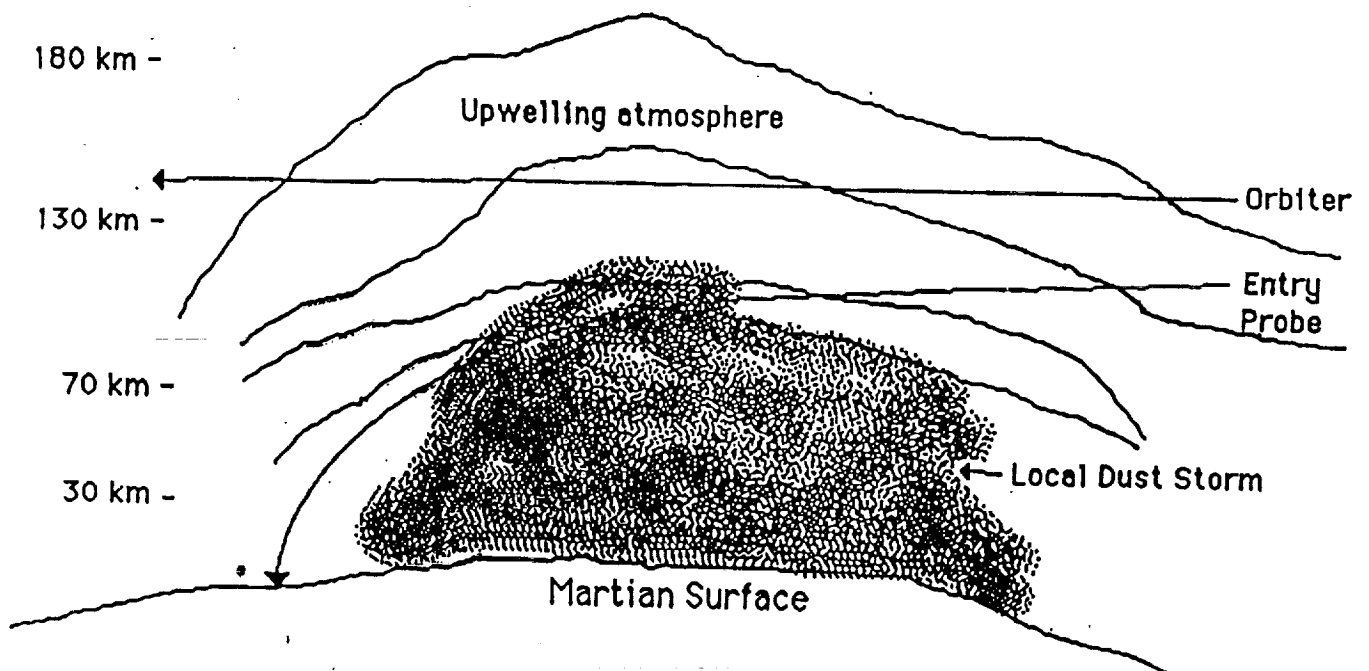

Figure 12. The trajectory of MAO, and an entry probe, through the upwelling atmosphere produced by heating associated with a local dust storm at Mars.

TABLE V.1 MAO SWT RECOMMENDED INSTRUMENTS

	MASS	POWER	TELEMETRY[1]
CORE PAYLOAD			
Neutral Mass Spectrometer[2] (NMS)	10.0	8.5	180
Fabry-Perot Interferometer (FPI)	13.5	5.5	30
UV + IR Spectrometer (UV + IRS)	5.0	7.0	130
Ion Mass Spectrometer (IMS)	2.5	1.5	60
Retarding Potential Analyzer + Ion Driftmeter (RPA + IDM)	4.5	4.0	80
Langmuir Probe (ETP)	2.0	4.0	30
Plasma + Energetic Particle Analyzer (PEPA)	10.0	9.0	320
Magnetometer (MAG)	3.0	3.5	200
Plasma Wave Analyzer (PWA)	5.5	3.5	130
Radio Science[3] (RS)	4.5	12.5[4]	–
	60.5 kg	59.0 W	1160 bps
SECONDARY PAYLOAD			
Infrared Atmospheric Sounder (IAS)	8.0	7.5	260
UV + Visual Synoptic Imager (UV + VSI)	9.0	8.0	1000
Neutral Winds/Temperature (NWTS) Spectrometer	10.0	9.0	180
	27.0 kg	24.5 W	1440 bps
TOTAL	87.5 kg	83.5 W	2600 bps

[1] Individual instrument rates can be highly variable and will depend upon the final payload and orbit selection. The rates listed are based upon typical duty cycles for each experiment and they have been averaged over the orbit (i.e., 6,000 x 150 km orbit has been assumed).

[2] Includes limited wind measuring capability.

[3] Consists of S-band transponder and stable oscillator.

[4] 10 W (continuous) for the stable oscillator and 25 W (10% duty cycle) for the S-band transponder.

Figure 13. The MAO Recommended Instrument Payload (from the MAO Pre Phase A Study)