Mars Riometer System

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1 Introduction

A riometer (relative ionospheric opacity meter) measures the intensity of cosmic radio noise at the surface of a planet. When an electromagnetic wave passes through the ionosphere collisions between charged particles (usually electrons) and neutral gases remove energy from the wave. By measuring the received signal intensity at the planet's surface and comparing it to the expected value (the *quiet-day curve*) a riometer can deduce the absorption (attenuation) of the trans-ionospheric signal. Thus the absorption measurements provide an indication of ionisation changes occurring in the ionosphere.

To avoid the need for orbiting sounders riometers use the cosmic noise background as a signal source. Earth-based systems are not subject to the challenging power, volume and mass restriction that would apply to a riometer for Mars. Some Earth-based riometers utilise phased-array antennas in order to provide an imaging capability.

Ground-based imaging riometer system located in northern Finland.

2 Scientific goals

To understand radio wave propagation in the Martian atmosphere

This is important for communications links including orbiter-lander links, cross-surface communication for sensor networks and for use of radio systems for remote sensing of the surface from orbiters. It will be crucial in the long-term if the various exploration initiatives lead to deployment of planetary satellite navigation systems similar to GPS.

Remote sensing of electrical discharges in the lower atmosphere of the planet

These discharges (e.g. lightning) produce high frequency radio waves that can be detected by a riometer. This is a serendipitous product of the riometer technique but one that adds value by enabling studies of the occurrence of hazardous electrical discharges.

Validation of models of the shielding of cosmic radiation by planetary atmospheres

Atmospheric ionisation is a direct product of the shielding process so shielding models can be used to estimate ionisation levels and thus be compared against measurements from riometers.

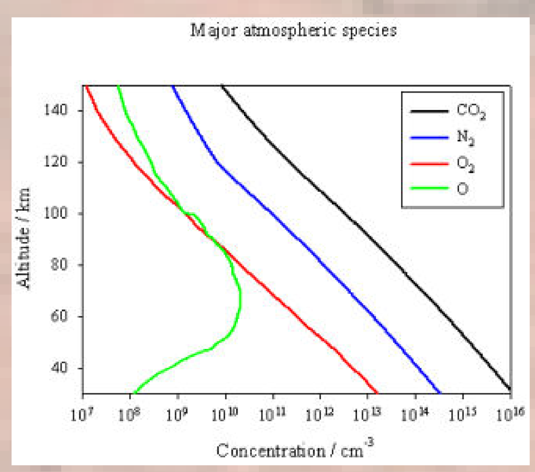
Broader scientific knowledge of the space environment around the planet

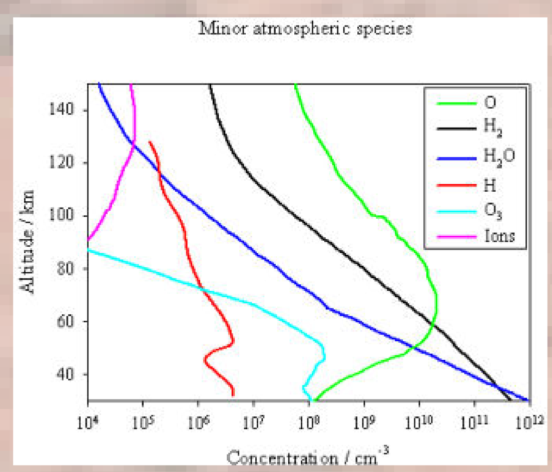
Especially the ionosphere and its interaction with the thermosphere.

Background: first colour image from Viking Lander 1, July 21 1976; image courtesy NASA/JPL-Caltech.

3 The Martian atmosphere

Compared to Earth the Martian atmosphere is mostly CO_2, with little O_2, H_2O or O_3. It has similar ion/electron densities and a similar density in the 80–100km region.





http://www.chem.leeds.ac.uk/JMCP/mars.htm

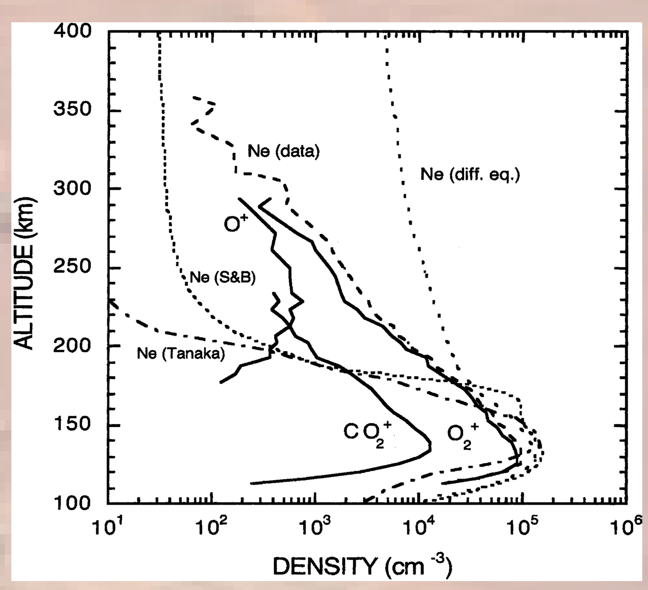
4 The Martian ionosphere

The Martian ionosphere is dominated by a layer of electron densities with a vertical profile characteristic of a Chapman layer. The layer is centred at a sub-solar altitude of between 115 and 135 km and the neutral scale height varies between 11 and 14 km. The peak density in the sub-solar region is about 1.4 x 10^5 cm^{-3}. A study of sub-solar density as a function of time (over a 3 month period) showed it exhibited a sinusoidal variation with a period equal to the solar rotation period, implying it is solar radiation which controls the density layer (Nielsen et al., 2006; Morgan et al., 2008).

5 Previous observations

Viking 1 and 2 observations

The earliest Martian ionospheric density profiles were observed with the radio occultation technique and from the landings of Viking 1 and 2. Occultation measurements have shown that the ionosphere below the density maximum is characterized by one or possibly two more layers. A secondary density peak was revealed a few tens of kilometres below the primary peak (≈110 km) with a maximum density typically half that of the primary maximum (Kliore, 1992). This secondary layer is thought to be the result of ionization by soft solar X-rays (Fox and Dalgarno, 1979). Thus, there are two components of the solar radiation controlling the Martian ionosphere, EUV and X-ray fluxes.



Major ion and electron densities obtained from Viking 1. Shinagawa 2004, doi:10.1016/j.asr.2003.06.028.

MARSIS observations

One of the most surprising results from Mars Express has been the discovery of an ionosphere above the planet's dark hemisphere, by the MARSIS instrument. MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) transmits low frequency radio waves towards the planet's surface and records the echoes of the different layers. The received echoes are weakened, delayed and dispersed, depending on the electron density in the ionosphere directly below the spacecraft.

Morgan et al. (2006) found that intervals of absence of ground reflection indicated radio wave absorption lasting up to two weeks. These coincide in time with high fluxes of solar energetic particles in the 10MeV range. The events are observed at solar zenith angles up to 113°, well into the night side of Mars.

Nielsen et al. (2007) calculated radio wave absorption in the Martian background ionosphere, the first time such calculations have been tested by observations. Comparison with a realistic model of the primary density peak showed that agreement between prediction and observations could not be achieved. The predicted absorption was too low by ≈20 dB, indicating a further source of absorption in addition to the primary peak. Adding a secondary layer reduced the discrepancy.

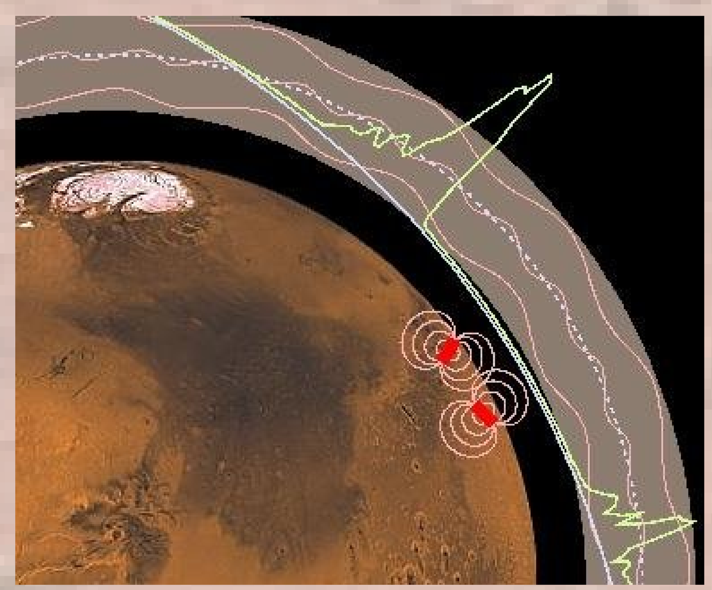
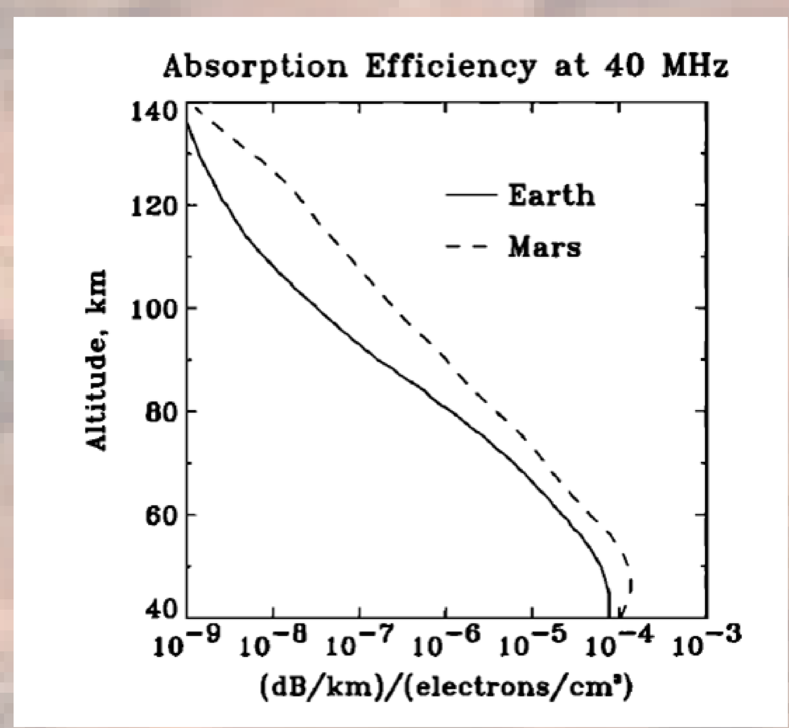


Image from http://www.windows.ucar.edu/tour/link=/mars/images/MGS_sc_magdata2_jpg_image.html

6 Cosmic noise absorption on Mars

The primary and secondary layers are strong absorbers of radio waves. The reason for the high absorption is the high collision frequency between electrons and the CO_2; it is a factor of ≈100 times larger than for collisions with NO in Earth's ionosphere. As a result riometry should work particularly well in the Martian environment.



Fry et al, 2006, doi:10.1029/1999RS900103.

7 Technical challenges

There are considerable technical challenges to be overcome to design a riometer system sufficiently small and light enough for a Mars mission. The table below (Fry et al, 2000) compares the current state-of-the-art ground based systems with that needed for space use.

Parameter	Current ground based	Proposed specs.
Power	≈ 1 W	≤ 0.1 W
Volume (RX)	≈ 0.5 L	≈ 0.1 L
Receiver mass	≈ 0.5 kg	≈ 0.1 kg
Antenna mass	≈ 5 kg	≈ 0.1 kg