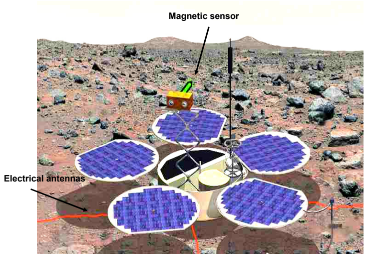

NetStation's heritage: Th NetLander GPR.

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The NetStation GPR: Lander-Based 3-D Investigations of Subsurface Structure, Stratigraphy, and Volatile Distribution in Planetary Environments.

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Introduction: The NetStation GPR (Ground Penetrating Radar) is a stationary, impulse, multiband HF GPR, designed to conduct geologic and volatile-related investigations of planetary environments in both the near- and deep subsurface (~10 - 10^3 m), whether employed as a single-station investigation or as part of a geophysical network on the Moon, Mars, Europa, or other planetary bodies.

An evolutionary refinement of the low-frequency GPRs developed for the original Mars NetLander and ExoMars missions, the NetStation GPR's enhancements include: (1) operation over a broader range of frequencies (~1.8 – 25 MHz, overlapping the range of both the MARSIS and SHARAD orbital radar sounders); (2) improved polarimetric and volume/3-D imaging capabilities; (3) measurement of surface permittivity and conductivity; (4) the potential for both monostatic and bistatic operation; and (5) the ability to stack up to 2^{31} coherent measurements (in monostatic operation), making it the most sensitive GPR ever built.

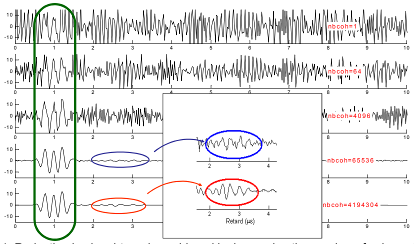
Fig. 1. Reduction in signal-to-noise achieved by increasing the number of coherent additions.

In its monostatic mode, the instrument offers the ability to investigate the electromagnetic properties of the subsurface, at moderate (~100 m) to high (~10 m) spatial resolution, in a broad cone-shaped region extending from ~10 m beneath the Lander to a potential maximum depth of ~1-2 km. When operated bistatically, in conjunction with an orbital radar sounder operating at the same frequency, the region of potential investigation can be expanded to a radial distance of up to ~1 km around the Lander.

With an extensive heritage from two prior low-frequency GPRs (the NetLander GPR and ExoMars EISS), the NetStation GPR has the ability to address a wide range of scientific objectives, many of which have already been demonstrated in the field. These include the 3-D characterization of local geology (structure and stratigraphy), the identification of transient near-surface or persistent deep-subsurface liquid water, and characterization of the electromagnetic activity of the atmosphere (including the frequency and intensity of electrical discharges, variations in the electron density profile and other properties of the ionosphere, and the ambient RF background noise).

Subsurface Sounding Mode: Subsurface sounding mode: In its Mars network and stand-alone configuration, the NetStation GPR is designed to operate over the combined frequency range of MARSIS (1.8-, 3-, 4- and 5-MHz, with a 1 MHz bandwidth) and SHARAD (20-MHz central frequency, with a 10-MHz bandwidth) – offering the opportunity for direct comparisons with data acquired by these orbital sounders as well as providing a good compromise between maximum depth of sounding, vertical resolution, and realistically deployable antenna size.

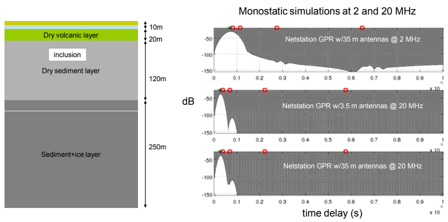

Fig. 2. Simulation demonstrating NetStation's multifrequency capability to resolve subsurface stratigraphy. Model stratigraphy on the left, simulations on the right -- demonstrating NetStation's use of four 35 m monopole antennas to operate at both 2- and 20-MHz.

The NetStation's antenna design, which consists of four orthogonal electric monpoles (to both transmit and receive) and a 3-axis magnetic sensor (to receive only), is a major contributor to the instrument's enhanced capabilities – enabling relatively high-resolution investigations of the structure and stratigraphy of the shallow subsurface, as well as the potential to sound to kilometer depths.

Monostatic 3-D investigations can be achieved in a cone-shaped region beneath the Lander by 'steering' the radiation pattern of the radar's transmitted pulse with phase adjustments of the four monopole antennas. The magnitude and direction of the propagation vector of the reflected signal can then determined by the simultaneous measurement of the signal's magnetic and electrical components – a capability demonstrated in Antarctic field tests of the NetLander GPR prototype [1,2]. In this way, the number, depth, orientation, and electromagnetic characteristics of reflectors beneath the Lander can be assessed.

Although designed primarily as a monostatic instrument, for operation from a fixed lander, the NetStation GPR can also be operated bistatically, in conjunction with radar instruments on other spacecraft. This capability was part of the original ExoMars mission design, where pulses, emitted by the GPR on the ExoMars Lander, were to be received on the ExoMars Rover, with the aid of a small magnetic sensor. Bistatic investigations of the region surrounding a NetStation-equipped lander can also be conducted by the reception of reflected signals from an orbital sounder (although this technique does limit the number of potential coherent additions). NetStation's ability to use bistatic measurements to investigate a multi-layered stratigraphy, was successfully demonstrated by a field test of an earlier instrument prototype in the West Egyptian Desert [3,4].

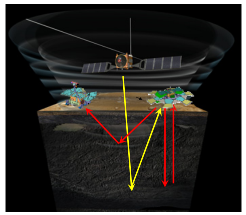
Fig. 3. Illustration of NetStation's ability to conduct both monostatic and bistatic investigations, in conjunction with a rover (employing a magnetic antenna) or orbital sounder.

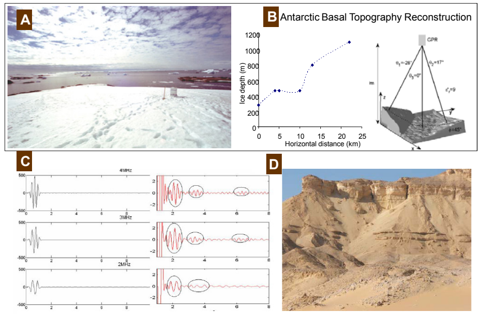

Fig. 4. (a and b) Field investigation of 3-D monostatic operation in Antarctica, measuring 2 electrical and 3 magnetic components of the reflected signal. (c) Soundings taken at 2-, 3- and 4-MHz by the EISS prototype on the FraFrah Plateau (d) in Egypt. The time delays associated with the first two circled reflections correlate well with the Plateaus's large-scale stratigraphy. The time delay associated with the 3rd reflection is consistent with the depth of the water table of the underlying Nubian Aquifer (~310 m).

When implemented as part of the standard payload of a multi-station geophysical network, the data acquired by the NetStation GPR will enable direct comparisons with the orbital sounding data obtained by MARSIS and SHARAD, at multiple locations, and with orders-of-magnitude improvements in sensitivity and horizontal resolution. The resulting knowledge of the electromagnetic properties and structure of the subsurface can be compared with the local- and regional-scale geology exposed in nearby outcrops, impact craters, and visible in the various orbital imaging and remote sensing data sets. Terrestrial experience has demonstrated that the acquisition of such 3-D GPR data, in conjunction with the contextual information provided by other remote sensing data sets, can significantly improve upon the ambiguity associated with the interpretation of 2-D radar profiles and can greatly assist in understanding the geology, geologic history, and hydrology of the crust (e.g., [5,6]).

Other operational modes: Other operational modes: In addition to its subsurface sounding mode, the NetStation GPR has an impedance measurement mode and a passive (receiver) mode, each of which addresses a different set of scientific objectives.

The permittivity of geologic materials reflects their composition, density, temperature, volatile content and volatile phase. The NetStation GPR can determine the permittivity of the shallow subsurface (averaged over the top few meters) from the impedance of the instrument's electrical antennas deployed on the surface, [2]. Large diurnal and seasonal variations in regolith permittivity may provide critical evidence of temperature- and time-dependent properties, such as the freezing and thawing of near-surface brines.

In its passive mode the NetStation GPR acts as a simple broadband receiver which can be used to: (1) detect electrical discharges in the atmosphere due to triboelectric charging (produced by dust grain collisions in dust storms and dust devils), (2) remote sensing of the lower ionosphere by monitoring diurnal variations in the intensity of the galactic EM background radiation -- which provides a measure of ionospheric absorption and its electron density profile, and (3) measure the natural RF background noise and EMI generated by the spacecraft.

Summary of Principal Science Objectives: Summary of Principal Science Objectives: Of the various approaches and techniques that might be used to investigate the subsurface geology and hydrology of Mars, terrestrial experience has demonstrated that geophysical techniques are best suited for this task [7,8]. Because ground penetrating radar is especially sensitive to the high dielectric contrast between liquid water and other geologic materials, such as rock and ice, the NetStation GPR is ideally suited for the detection of diurnally- and seasonally-occurring near-surface brines (utilizing its permittivity mode) and deep subpermafrost groundwater (using its deep-sounding mode), as well as the investigation of other large-scale crustal characteristics.

The data acquired by the NetStation GPR provides invaluable information about the geologic and hydrologic nature of the crust at a scale (~10 – 10^3 m) and resolution (~10 – 10^2 m) provided by no other readily-deployable geophysical investigation – outside of an active seismic array.

These capabilities make the NetStation GPR a powerful tool to address the following high-priority (and inherently overlapping) science objectives:

• Identify evidence of transient or persistent liquid water environments, and the occurrence of massive ground ice, that may support, or preserve evidence of, past or present life.

• Understand the geology and geologic evolution of the landing site, including its local lithology, stratigraphy and structure.

• Understand the distribution and state of subsurface volatiles, especially H_2O and, potentially, methane hydrate.

• Characterize the 3-D compositional, physical, and electromagnetic properties of the landing site – including the scale and magnitude of spatial heterogeneity – for comparison with those measured at larger scales by orbital remote sensing instruments, such as OMEGA, CRISM, MARSIS and SHARAD.

• Characterize the electromagnetic activity of the atmosphere and surface environment, including the frequency and intensity of atmospheric discharges, variations in the electron density profile and other properties of the ionosphere, and the ambient RF background noise.

• Identify potential hazards and in-situ resources of importance to future robotic and human exploration activity.

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