THE NETSTATION GPR: A TOOL FOR CONDUCTING LANDER-BASED 3-D INVESTIGATIONS OF MARTIAN SUBSURFACE STRUCTURE, STRATIGRAPHY, AND VOLATILE DISTRIBUTION. V. Ciarletti[1], S. Clifford[2], D. Plettemeier[3], A. LeGall[1] and M. Biancheri-Astier[4]. [1]LATMOS/IPSL, Guyancourt, France (valerie.ciarletti@latmos.ipsl.fr), [2]Lunar and Planetary Institute, Houston, TX, USA, [3]Technische Universität Dresden, Dresden, Germany; [4]Interactions et Dynamique des Environnements de Surface, Orsay, France.

The NetStation GPR (Ground Penetrating Radar) is a stationary, impulse, multiband polarimentric 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.

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 frequency range (~1.8 – 5 MHz and 15 – 25 MHz, overlapping both MARSIS and SHARAD); (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.

The NetStation GPR's low mass (~ 1 kg) and low average power consumption (~ 7 W), make it well-suited for deployment on a single lander or as part of a multi-station geophysical network. In monostatic operation, the instrument offers the ability to investigate the electromagnetic properties of the subsurface, at moderate (~100 m) to high (~10 m) 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 bisticly, in combination with either a rover or frequency compatible orbital radar sounder, this region of potential investigation can be expanded up to a radial distance of ~0.5 km around the lander.

With an extensive heritage from two prior low-frequency GPRs (Netlander and ExoMars), the NetStation GPR has the ability to address a wide range of scientific objectives, many of which have already been successfully demonstrated in the field.

In the context of the Concepts Workshop, the NetStation GPR addresses the following two challenges:

1. Interrogating the shallow subsurface from orbit.
2. Lightweight and low-cost in situ instrumentation to identify and triage high-priority materials for analysis.
11. Lightweight, low-cost, probes or platforms (single or multiple), suitable to be carried by larger orbital or landed vehicles.

providing important insights into the geologic evolution of the planet, as well as the distribution of subsurface volatiles and surface and subsurface geologic hazards that will be of critical importance to future human explorers.

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.

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.

NetStation's antenna configuration enables it to conduct full polarimetric investigations of the subsurface – transmitting with single-, dual-, or right circular polarization and receiving the H- and V- components (and their phase difference) coherently – to calculate the four Stoke's parameters and Circular Polarization Ration (CPR) in a manner similar to the Mini-RF on the Lunar Reconnaisance Orbiter, [1]. High CPR (>1) is a radar characterisitic of both very rough surfaces and icy environments, a measurement that has been used to identify the presence of ice in the permanently shadowed regions of the Moon [2] and Mercury [3]. Such a technique, will greatly enhance NetStation's ability to distinguish between high-porosity sediments and high volume fraction subsurface deposits of water ice.

The antenna design also enables NetStation to conduct monostatic 3-D investigations 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 [4, 5]. In this way, the number, depth, orientation, and electromagnetic characteristics of reflectors beneath the lander can be determined.

Although designed primarily as a monostatic instrument, for operation from a fixed lander, the NetStation GPR can also be operated bistaticly, 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 3-axis 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 (i.e.,

[6], although the motion of the spacecraft does place a limit on 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 tea st of development prototype in the West Egyptian Desert [7,8].

When implemented as part of the 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 electro-magnetic properties and structure of the subsurface can be compared with the local- and regional-scale geology visible in nearby outcrops, impact craters, orbital images and other 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, can significantly reduce the ambiguity often associated with the interpretation of 2-D radar profiles -- greatly assisting in understanding the geology, geologic history, and volatilee stratigraphy of the crust (e.g., [9,10]).

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, [5]. 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 the EMI generated by the spacecraft.

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 [11,12]. 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.

Within a radius of several hundred meters around the lander, the NetStation GPR will provide invaluable information about the geologic and hydrologic nature of the crust, at a scale of ~10 – 10^3 m and at a spatial resolution of ~10 – 10^2 m – a capability provided by no other readily-deployable geophysical investigation – outside of a more massive and operational complex 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, ground ice and groundwater.*
- *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.*

References: [1] Nozette et al., Space Sci Rev (2010) 150: 285–302, DOI 10.1007/s11214-009-9607-5 [2] Spudis et al., Geophys. Res. Lett. 37, L06204, doi:10.1029/2009GL042259, 2010 [3] Slade et al., Science 258, 635 (1992); [4] Berthelier et al., GRL, 32, L22305, doi:10.1029/2005GL024203, 2005. [5] Le Gall et al. (2008) IEEE Transactions on Geosciences and Remote Sensing, Volume 46, Issue 12, p 3975-3986, doi: 10.1109/TGRS.2008.2000718. [6] Clifford et al., these abstracts, 2012; [7] Ciarletti et al., 37th Lunar and Planetary Science Conference, Abstract #2238, 2006. [8] Ciarletti et al., 38th Lunar and Planetary Science Conference, Abstract #1838, 2007. [9] Grasmück, M. and A.G. Green, Eng. Geosci. II, 195–200, 1996. [10] Makkawi, M. H., J. Geophys. Eng. 1 56-62 doi: 10.1088/1742-2132/1/1/007, 2004. [11] McNeill, J.D. 1990, in Geotechnical and Environmental Geophysics, Vol I (ed. S.H. Ward) Society of Exploration Geophysicists. Tulsa, pp. 191–218. [12] Yoshikawa et al.(2006). Journal of Geophysical Research 111, E06S19. doi:10.1029/2005JE002573.