IMPORTANCE OF FUTURE GAMMA AND NEUTRON SPECTROMETERS AT MARS. Suniti Karunatillake,[1] Craig Hardgrove,[2] and James J. Wray,[3] [1]Rider University, Lawrenceville, NJ 08648 (wk43@cornell.edu), [2]Stony Brook University, NY 11794 (craig.hardgrove@stonybrook.edu), [3]Georgia Institute of Technology, Atlanta, GA 30332 (jwray@gatech.edu).

Introduction: Remote sensing instruments employing visible, near, and far infrared (VNIR) spectra are sensitive to surface composition, i.e., the uppermost tens to hundreds of microns depth. In contrast, the Mars Odyssey Gamma Ray Spectrometer (GRS) consisting of neutron and gamma subsystems provided the first regional scale insight into the subsurface at decimeter depths with nearly global coverage[1–4]. Such depth sensitivity enabled major constraints to be established both for bulk evolution of the Martian crust and regional scale processes. Furthermore, the GRS provided chemical information over regions that were made inaccessible to VNIR instruments by extensive mantles of fine material (hereafter called dust)[5].

Four exemplars of critical insight, unachievable without the GRS, include: elucidating the origin of low albedo regions in the northern lowlands of Mars[6]; constraining the evolution of the Mars Stealth region[7]; identifying the magmatic evolution of volcanic provinces on Mars[8]; and the first argon-based assessment of global atmospheric circulation models[9,10].

Bulk and thermal constraints were also established by the GRS, including: composition of the Martian crust[11]; constraints of crustal thickness[11]; geologic evolution of the radiogenic temperature gradient[12]; and significance of SNC compositions for the bulk crust[13].

Despite the conclusion of Odyssey GRS operations, cumulative data continue to provide new insight into processes of the Martian crust, as highlighted recently by the regional significance of hydrous iron sulfates in the midlatitudes of Mars[14,15]. Previously, midlatitudinal hydration was attributed primarily to clays[16], zeolites[17], Mg/Ca-sulfates[18], and subsurface ice[19].

Consequently, the GRS instrumentation has proven scientific heritage; without it, critical science insight would have been absent, retarding the progress of our understanding of the decimeters-deep Martian subsurface. In this context, GRS instruments will serve "Challenge Area 1, instrumentation and investigation methods." Sub-theme 1 of "Interrogating the shallow subsurface of Mars, both from orbit (remote sensing, active, or passive) and from the surface (e.g., sounding, drilling, excavating, penetrators, or other approaches)" would receive critical support from GRS type instruments.

Previous mission configurations: The multi-year GRS data accumulation and hundreds of km spatial resolution collectively provided mean annual regional insight at decimeter depths[1]. Future deployments in the same configuration as the Mars Odyssey GRS system would reveal any variations in highly volatile elements such as Cl, H, and S across decadal time scales. Seasonal modulation of the atmosphere determined with Ar variations[9] could be refined, enabling the Martian climate to be modeled accurately.

Furthermore, currently characterized regional variations in Rn[20] could be enhanced, potentially yielding insight into seasonal variability. This may clarify the temporal variation of other trace gases, such as methane,[21] at regional scales, complementing local observations by the Tunable Laser Spectrometer of the Curiosity Rover. Ongoing discussion[21–23] on the origin and seasonality of putative CH_4 plumes may then be concluded successfully.

Other configurations: Alternative configurations of the GRS may enhance the currently available data[2] for Cl, Fe, H, K, Si, and Th. A lower-orbit or aerial deployment of the gamma detector in particular would enhance spatial resolution perhaps to the point of resolving any compositional differences between intercrater and intracrater material. The intracrater layered deposits in Arabia Terra and elsewhere, such as Pollack[24] and Becquerel[25,26] craters, would be prime candidates, with the possibility of excess hydration relative to the intercrater terrain. If so, such locations might offer sedimentary evaporite deposits for future landed investigations as expected with Curiosity at Gale in 2012. This would advance the current state of knowledge of Arabia as an H-rich region[7,27] at the broadest scales, even though VNIR instruments such as Mars Reconnaissance Orbiter's CRISM cannot sample beneath the veneer of dust across most of the region.

Landing at a location with shallow ice would be valuable for future robotic missions seeking to expand on the Phoenix mission results, the site selection of which was in turn motivated by Mars Odyssey's GRS data.[28] This would be essential in human missions that are central to the reformulated Mars exploration program. A low-altitude neutron spectrometer[29] could potentially map isolated shallow ice deposits at relatively low latitudes. Recent evidence of such ice deposits[30] underpins hypotheses of Amazonian obliquity-driven glaciation cycles[31].

A prior concept study on airborne epithermal neutron detectors has shown that for an altitude of 1.5 km above the surface, a spatial resolution of ~2 km will be achieved.[32] While that study focused on epithermal neutrons, we consider the use of thermal neutron counts to isolate the H burial depth as well as the bulk absorption cross section in the top meter of soil.

On Mars, the primary high absorption cross section elements are Fe and Cl, which, in only ~0.5% mass fractions can significantly reduce the total number of thermal neutrons that reach the detector.[29] The bulk absorption cross section for the top meter of soil can be accurately determined through Monte Carlo modeling of thermal and epithermal neutron counts.[33] The bulk absorption cross section for the soil, however, is a single parameter that will incorporate the effects of both Fe and Cl. While the absorption cross section can be accurately determined by a Neutron Subsystem (NS), it cannot identify elements responsible for high absorption cross sections. Corresponding Gamma Subsystem (GS) spectral lines for Fe and Cl, however, can be used to determine their relative abundance, while the absorption cross section as determined by the NS will constrain the absolute abundance.

GS-NS synergism would allow for higher resolution geochemical characterization of the Martian surface, as locations with high Fe content (e.g., hematite-rich "blueberries" at Meridiani Planum) and high Cl content (e.g., hydrothermally deposited Eileen Deane-type soil at Gusev Crater's Columbia Hills) may represent distinct paleo-environments.

Low altitude platforms may be designed in several ways. Aerial platforms of gamma detectors have a commercial heritage on Earth for naturally radioactive elements[34]. This is exapandable to other elements activated by galactic cosmic particle derived neutrons on Mars owing to its nearly two orders of magnitude thinner atmosphere. Earth-based expertise could drive the design of economical airborne platforms[35] on Mars. Since minimal moving components reduce risk of mission failure, possible designs to consider include He-dirigible analogs with solar-powered propeller systems. Alternatively, a single-rotor system would facilitate gamma spectral analysis on the ground and at higher elevation. Varying altitudes would allow gamma and neutron spectra to be calibrated across a broad range of observing conditions; corresponding variation in spatial resolution would allow "nested" observations at key sites.

References:

[1] Boynton, W. V., et al., *The Martian Surface: Co pos tion, Mineralogy and Physical Properties* 105 – 124 (2008) [2] Boynton, W. V. *et al. J. Geophys. Res. Planets* **112**, E12S99 (2007) [3] Feldman, W. C. *et al. Geophys. Res. Lett.* **31**, L16702 (2004). [4] Feldman, W. C. *et al. J. Geophys. Res.* **110**, E11009 (2005). [5] Newsom, H. E. *et al. J. Geophys. Res. Planets* **112**, E03S12 (2007). [6] Karunatillake, S. *et al. J. Geophys. Res. Planets* **111**, E03S05 (2006). [7] Karunatillake, S. *et al.* **114**, E12001 (2009). [8] Baratoux, D. *et al. Nature* **472**, 338–341 (2011). [9] Sprague, A. L. *et al. J. Geophys. Res.* **112**, E03S02 (2007). [10] Nelli, S. M. *et al. J. Geophys. Res.* **112**, E08S91 (2007). [11] Taylor, G. J. *et al. J. Geophys. Res.* **111**, E03S10 (2006). [12] Hahn, B. C. *et al. J. Geophys. Res. Planets* **38**, (2011). [13] McSween, H. Y. *et al. Science* **324**, 736–739 (2009). [14] Karunatillake, S. *et al. AbSciCon* 5014 (2012). [15] Karunatillake, S. *et al. 43rd LPSC* **43**, 2940 (2012). [16] Wray, J. J. *et al. Geology* **37**, 1043–1046 (2009). [17] Dobrea, E. Z. N. *et al. J. Geophys. Res.* **115**, E00D19 (2010). [18] Vaniman, D. T. *et al. Nature* **431**, 663–665 (2004). [19] Jakosky, B. M. *et al. Icarus* **175**, 58–67 (2005). [20] Meslin, P.-Y. *et al. 43rd LPSC* **43**, 2852 (2012). [21] Mumma, M. J. *et al. Science* **323**, 1041–1045 (2009). [22] Zahnle, K. *et al. Icarus* **212**, 493-503 (2011). [23] Atreya, S. K. *et al. Planet. and Space Sci.* **59**, 133–136 (2011). [24] Ruff, S. W. *et al. J. Geophys. Res.* **106**, 23,921–23,927 (2001). [25] Lewis, K. W. *et al. Science* **322**, 1532–1535 (2008). [26] Rossi, A. P. *et al. 40th LPSC* **40**, 1588 (2009). [27] Dohm, J. *et al. Icarus* **190**, 74–92 (2007). [28] Smith, P. H. *et al. Science* **325**, 58–61 (2009). [29] Hardgrove, C. et al. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **659**, 442–455 (2011). [30] Byrne, S. *et al. Science* **325**, 1674–1676 (2009). [31] Dickson, J. L. *et al. Earth Planet. Sci. Lett.* **294**, 332–342 (2010). [32] Elphic, R. C. *et al. 37th LPSC* **37**, 2460 (2006). [33] Feldman, W. C. *et al. J. Geophys. Res.* **105**, 20,347–20,363 (2000). [34] Cook, S. *et al. Soil Res.* **34**, 183–194 (1996). [35] Braun, R. D. *et al. Aerospace Conference, 2004. Proceedings. 2004 IEEE* **1**, 6 vol. (xvi+4192) (2004).