LUNAR FARSIDE RADIO ARRAY PATHFINDER ENABLED BY THE DEEP SPACE GATEWAY. J. D. Bowman[1] and G. W. Hallinan[2], R. J. MacDowall[3], J. O. Burns[4], [1]Arizona State University, PO Box 876004, Tempe, AZ 85287, judd.bowman@asu.edu, [2]California Institute of Technology, 1200 California Blvd. Pasadena, CA 91125, [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771, [4]University of Colorado, Boulder, CO 80309.

Introduction: Two of the most pressing questions in astrophysics and heliophysics can be addressed by a radio array operating below 20 MHz on the lunar farside: 1) what is the habitability of exoplanets? and 2) how are energetic particles accelerated in solar bursts? The Deep Space Gateway (DSG) will enable such an array.

Science: The impact of stellar magnetic activity on planetary atmospheres, and the importance of planetary magnetic fields in negating such activity, may define exoplanet habitability. Kepler has shown that most M dwarf stars harbor terrestrial-scale planets, with approximately 2.5 planets of 1-4 Earth radii per star [1] [2]. However, many M dwarfs are known to be magnetically active, flaring frequently and with much higher energy than produced in solar flares [3] (see Figure 1). Studies of possible flares and coronal mass ejection (CME) events on planets orbiting such stars suggest that these events severely impact the ability of such planets to retain their atmospheres [4] [5]. However, no CME on a star other than the Sun has ever been detected. Similarly, direct detection of planetary magnetic fields has yet to be achieved and remains the most crucial ingredient in assessing planetary habitability in the context of stellar activity.

Both stellar CMEs and planetary magnetic fields can be probed via extremely bright radio emission at low radio frequencies. As an analogous example, the Sun produces intensely bright radio bursts (Type II bursts) typically at frequencies below 100 MHz and associated with fast CMEs. These bursts are attributed to plasma radiation, an intensely bright coherent emission process whereby accelerated electrons cause radiation at the electron plasma frequency. Thus, the characteristic drift in frequency often observed in the dynamic spectrum of a burst reflects the large-scale transport of a body of plasma through density gradients in the solar corona and/or interplanetary medium.

Solar bursts and space weather activity in our own Earth-Sun system are known to have important consequences for human activities on Earth and for spacecraft. Imaging of Type II and Type III solar radio bursts from our Sun would determine where and how the radiating particles are accelerated. Thus, a lunar radio observatory would also complement the upcoming NASA Parker Solar Probe and the ESA Solar Orbiter missions to the inner heliosphere, as it would image emission from electrons and shocks as they pass by and are measured directly by the spacecraft.

Figure 1. Artist's illustration of space weather in an extrasolar system. Understanding both stellar flares and planetary magnetic fields is key to determining exoplanet habitability. A lunar farside radio array enabled by the Deep Space Gateway will provide the first detailed characterization of large radio bursts from stellar flares in our two nearest-neighbor systems, Alpha and Proxima Centauri, thereby providing crucial insights into stellar magnetic fields and space weather beyond the local Solar System.

Pathfinder: The Earth's ionosphere absorbs astronomical radio emission below ~200 MHz and blocks it completely below ~30 MHz, necessitating a space-based array for solar and extrasolar burst monitoring and exoplanet habitability studies. A radio array in lunar orbit or on the lunar suface would avoid the the limitations imposed by Earth ionosphere. Locating the radio observatory on the lunar surface compared to orbit has a number of advantages, including fixed locations for the antennas that require no propulsion to maintain, simpler operations, and no terrestrial interference (on the lunar farside). The Moon's farside is uniquely shielded from human-generated radio interference.

The two nearest star systems beyond our Solar System are ideal targets for pathfinder stellar burst monitoring for exoplanet habitability studies. Alpha Centauri is a binary star system, containin G and K spectral type stars similar to our Sun, whereas Proxima Centauri is an M dwarf star with known exoplanets, including the Earth-sized Proxima b planet that has radius 1.27 Earth radii and mass 1.1 Earth masses. Both Alpha and Proxima Cetauri are about 1.3 pc from Earth.

The collecting area requirement for the pathfinder array is set by the sensitivity needed to detect the expected extrasolar bursts, which should be ~1 Jy below 20 MHz for the brightest flares from Alpha and Proxima Centauri. Sensitivity sufficient to detect these large flares could be accomplished with ~100 low-gain antennas tuned to 1-20 MHz. Solar bursts from our Sun are even brighter and will be easily detected by such an array.

The angular resolution requirement for the array is modest. Alpha and Proxima Centauri are separated by ~2° on the sky and the need is only to resolve from which star a burst originates. Similarly, candidate regions for particle acceleration by solar CMEs may be separated by many solar radii, hence high angular resolution is not required for solar burst imaging. Resolving potential sites of particle acceleration, e.g., the shock front or the flanks of a CME, also requires ~2°. Hence the array would need a radius of approximately 1 km to achieve the needed angular resolution to both image solar bursts and discern stellar bursts from our two nearest neighbors.

The pathfinder array will generate a raw data rate of 4 GB/s that must be collected at a single location for digital signal processing to form the interferometric products needed for imaging and burst detection. Digital signal processing is estimated to require between 10 and 100 W, which will be refined through further study. The DSG will provide key infrastructure as a communications hub and relay to collect and process raw and/or reduced data from the array. It could also provide a consistent power source for the processing unit if it is installed on the DSG or by beaming power to the array on the farside surface. Thus, the DSG can alleviate the challenge of powering and heating critical components of the array during the (two-week) lunar night.

Operational scenarios for the array consist of data acquisition during the lunar day, with daily data downlinks to coordinate with other space weather assets, and either hibernation or continued operation during the lunar night. A fully-functional pathfinder radio observatory could be based on the design for the Radio Observatory on the Lunar Surface for Solar studies [6]. Our team is presently undertaking a detailed trade study to identify optimized designs for a pathfinder array.

Summary of impact: An operational pathfinder radio array on the lunar farside utilizing the DSG as a communications hub, possibly combined with telerobotic array infrastructure deployments controlled from the DSG, would provide immediate scientific benefit on the high-priority science of exoplanet habitability and solar shock acceleration and enable crucial experience and investigation of the environmental and technical challenges of deploying and operating a large-area scientific station on the Moon.

References: [1] Dressing, C. D., and Charbonneau, D. (2013) ApJ, 767, 95. [2] Dressing, C. D., and Charbonneau, D (2015) ApJ, 807, 45. [3] Kowalski, A. F.; Hawley, S. L.; Holtzman, J. A.; Wisniewski, J. P. and Hilton, E.J. (2010) ApJ, 714, 98. [4] Khodachenko, M. L.; Ribas, I.; Lammer, H.; Grießmeier, J. M.; Leitner, M.; Selsis, F.; Eiroa, C.; Hanslmeier, A.; Biernat, H. K.; Farrugia, C. J.; Rucker, Helmut O. (2007) AsBio, 7, 167K. [5] Lammer, H.; Lichtenegger, H. I. M.; Kulikov,Y. N.; Grießmeier, J. M.; Terada, N.; Erkaev, N. V.; Biernat, H. K.; Khodachenko, M. L.; Ribas, I.; Penz, T.; and Selsis, F. (2007) AsBio, 7, 185L. [6] Lazio, T. J. W., MacDowall, R. J., Burns, J. O., et al. (2011) Adv. Space Res., 48, 1942.