TELEROBOTIC DEPLOYMENT AND OPERATION OF A LUNAR FARSIDE LOW RADIO FREQUENCY COSMOLOGY TELESCOPE FROM THE DEEP SPACE GATEWAY. R. A. Monsalve[1] , J. O. Burns[1], K. Tauscher[1] , and D. Rapetti[1] , [1]Center for Astrophysics and Space Astronomy, University of Colorado, UCB 391, Boulder, CO 80516, raul.monsalve@colorado.edu.

Introduction: This abstract is part of a series that describes using the Deep Space Gateway (DSG) to enable low-frequency 21-cm cosmology from the Lunar environs. Here, we describe using the DSG to support an instrument that measures the global 21-cm signal from the Lunar surface. The abstract by Burns et al. provides an overview of the scientific and technological opportunities offered by the DSG. In Tauscher et al. we discuss deploying a global 21-cm instrument at the DSG itself, and in Rapetti et al. we describe analysis algorithms for the 21-cm measurements.

The Cosmic Dawn in the Early Universe: Understanding the transformational period of the Universe when the first structures, galaxies, and black holes formed is one of the central objectives in cosmology. In the standard model, this occurred in the first few hundred million years after the Big Bang, corresponding to redshifts z>15, when the Universe left the "Dark Ages" and entered into the "Cosmic Dawn". Although the new large ground- and space-borne observatories such as GMT, E-ELT, and JWST will be sensitive enough to probe objects through the reionization epoch (z<15), at higher redshifts they will be limited not only by instrumental effects but also by the smaller population of weaker sources. A different type of measurement is necessary to access the key physical processes that drove the Universe through this large-scale phase transition. This measurement corresponds to the 21-cm line from neutral hydrogen gas in the intergalactic medium (IGM), in between the early compact sources. This measurement will contribute in an independent and totally complementary way to explore the early Universe [1]. Specifically, this measurement can access higher redshifts by characterizing perturbations expected in the 21-cm spectrum relative to the cosmic microwave background (CMB). A key component of these perturbations is its monopole term, found through a sky-average, or “global” measurement. Spectral perturbations produced in the redshift range 30>z>6 are due to UV and X-ray radiation from the first generations of galaxies and black holes impacting the IGM [2]. Perturbations expected earlier, at z ~ 80, during the Dark Ages themselves, are due to the evolving density of the hydrogen gas, which coupled in different degrees the 21-cm line with the physical temperature of the gas, which at the time was lower than the CMB temperature. With no astrophysical sources involved, this early perturbation is purely cosmological and its precise detection and characterization would strongly test our understanding of the evolution of the Universe on the largest scales [3]. See Figure 1 for a reference global 21-cm model.

Measuring the Cosmological 21-cm Signal Monopole from the Lunar Farside: Due to cosmological expansion, the 21-cm line (1,420 MHz) from the early Universe has to be observed at υ_{obs} = 1,420 / (1+z) MHz. Therefore, exploring z > 15 requires measurements at υ_{obs} < 90 MHz. More specifically, the early, z ~ 80 feature has to be measured at ~ 20 MHz. Accurate observations from the Earth become particularly challenging at these frequencies due to the effect of the ionosphere, which significantly attenuates and refracts signals, in addition of representing itself a source of emission. These effects are more severe as frequency decreases, making the detection of the cosmological feature impossible from the Earth [4]. On the other hand, the pristine environment of the Lunar Farside during nighttime is an ideal place for such observation. Moreover, the Moon acts as a shield to artificial radio transmissions from the Earth, which could potentially corrupt the low-frequency spectrum beyond the levels acceptable for extracting the science. Conducting the measurement from the Lunar Farside becomes an imperative for completing the picture of the Universe's evolution between the Big Bang and the present.

Cosmology Enabled by the Deep Space Gateway: In this talk we will discuss how the DSG can support our concepts for a global redshifted 21-cm line experiment deployed on the surface of the Lunar Farside to detect and characterize the signal from the early Universe. The observational strategy considered for this instrument enables precise determination and removal of astrophysical foregrounds from the measurement [5]. However, it benefits significantly from observing from latitudes as close as the Lunar poles as possible [6]. The Farside, especially toward the poles, imposes a variety of technical and logistical challenges that could be addressed and solved with the support of the DSG. They include: 1) The wireless transmission, or "beaming", of power to the instrument during its science observation runs, which have to be conducted in Lunar nighttime as the effect of direct Solar radiation on radio waves has to be avoided. The continuous power requirements are estimated below 200 W, and the DSG could be used as a power supply during complete or partial runs, as it could be supported by a solar panel power station deployed on the surface, in the proximities of the instrument, which stores power when

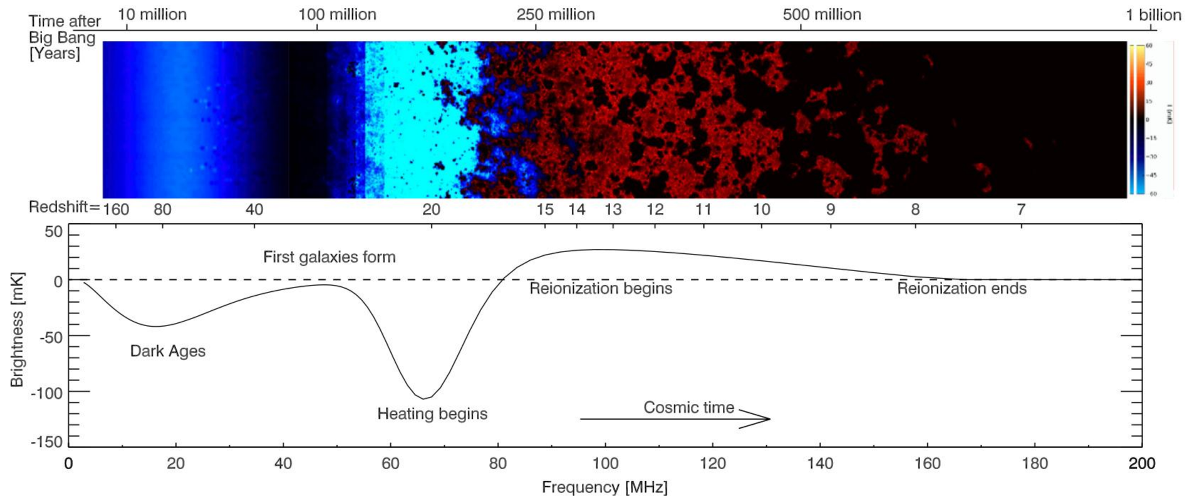

Figure 1. Reference 21-cm model from [3]. The top panel shows the large-scale evolution of the Universe, starting from an isotropic neutral hydrogen gas (in blue, on left hand side) through the formation of structure (red, middle), and the reionized IGM (black, right hand side). The bottom panel shows the equivalent sky-average, or global, 21-cm signal that the DSG will enable to measure from the lunar environs.

the Sun is visible. 2) The transmission of data from the Moon to the Earth. As envisioned, the instrument should conduct the digitization and most of the low-level data reduction on-site. Since it will gather data continuously, a requirement is imposed to send the data to Earth continuously at a similar rate. These data will include all the Stokes polarization parameters of the sky radiation, as well as calibration data and environmental readings, which are expected to amount to < 1 GB of data per day, or ~ 12 kB/s for continuous uninterrupted communication. 3) The deployment of the instrument itself, which involves the landing and precise alignment of the antenna and electronics, as well as the power reception and data transmission units. Power and signal connections between the different parts of the instrument could be done through telerobotics [7], supported by operators on Earth communicating through the DSG, or located in the DSG itself, while a few highly refined antenna alignment maneuvers, also carried out remotely through mechanisms developed by Ball and Lockheed Martin, can be commanded from or through the DSG. As the landing and observation locations become identified more precisely, the possibility for astronauts sent from the DSG, tasked with specific, more intense deployment activities, will be considered. Additional requirements on the DSG include low self-generated EMI for it not to represent an obstacle in the precise determination of the cosmological spectrum. These requirements are consistent with the table in the abstract by Burns et al.

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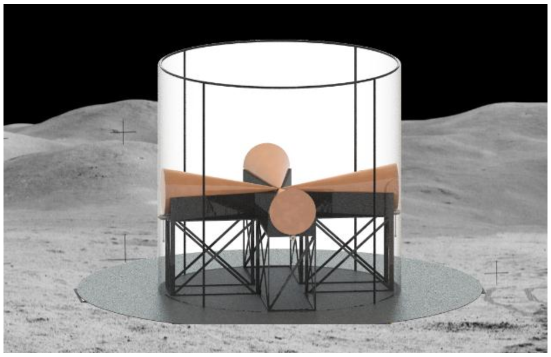

Figure 2. Global 21-cm experiment conception, observing from the surface of the Lunar Farside. For reference, the dipole antenna length is < 10 m.

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