TECHNOLOGY CHALLENGES FOR 21-CM COSMOLOGY

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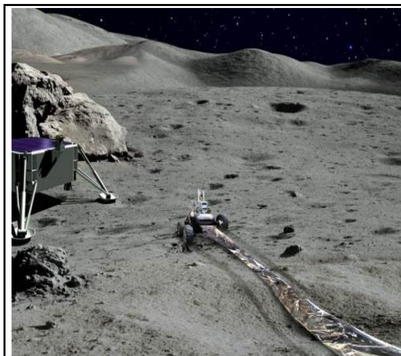
The Astrophysics Decadal Survey identified *Cosmic Dawn* as one of three priority science objectives. Specifically, the Survey stated "A great mystery now confronts us: When and how did the first galaxies form out of cold clumps of hydrogen gas and start to shine—when was our cosmic dawn? … Astronomers must now search the sky for these infant galaxies and find out how they behaved and interacted with their surroundings." The redshifted hyperfine 21-cm line of HI is the most powerful tool to probe the intergalactic medium from the Reionization epoch at z~10 (130 MHz) to the Dark Ages before the first stars at z>50 (<28 MHz) (see Lazio white paper). Human-made RFI and ionospheric absorption/refraction at ν<100 MHz have been shown to be magnitudes higher than the expected 21-cm signal, thus driving us to the Moon's farside to conduct these sensitive observations.

The DARE (Dark Ages Radio Explorer) mission concept envisions the first observations of *Cosmic Dawn* using a novel biconical dipole antenna in orbit of the Moon, observing the global 21-cm signal when above the radio-quiet farside at ν=30-120 MHz[1].

A more challenging and yet more powerful instrument will be an array on the lunar farside with angular resolution of a few arcminutes to probe structure in the 21-cm signal and to assist in removal of Galactic foregrounds. This progression from a single dipole to an array is similar to the CMB in moving from COBE to Planck. A modest prototype farside array could be deployed early in the next decade as part of an Orion mission at Earth-Moon L2 where astronauts teleoperate surface rovers to lay out polyimide antennas with up to 50-m baselines (producing 5° resolution at 75 MHz)[2]. A key requirement for any instrument designed for future lunar surface operations is that it not introduce systematic effects that could mask or obviate the Cosmic Dawn HI signal. This design requirement is well beyond the standard requirements for radio systems operating at frequencies relevant for Cosmic Dawn. Some of the technology challenges include:



Artist's impression of teleoperated rover on lunar farside deploying polyimide antenna.

- Receiver that is extremely sensitive to wideband features in the spectrum achieving a calibrated accuracy of 0.01%. This is orders of magnitude beyond current capability.
- Deployment of 1000's of low-mass antennas over ~20 km baselines. One possibility is polyimide film with metallic dipoles imprinted upon it. Such an array could then be robotically unrolled on the lunar surface. But, significant development is required to verify RF performance of dipoles and transmission lines, demonstrate interferometric fringes, and verify that the film can survive lunar conditions over years of operations[3].
- Ultra-low power (ULP), rad-tolerant electronics. This includes design and fabrication of field programmable gate arrays, integrated analog and digital ULP circuits on the same chip, and a power supply with 0.5 V output at 0.1 amps.
- High energy-density batteries to provide power to the array during the 2-week lunar night.
- Increased rover autonomy and/or enhanced telerobotics to deploy 1000's of dipoles.
- Sophisticated software routines (e.g., Markov Chain Monte Carlo) to distinguish the 21-cm signal from significant astrophysical foregrounds[4].

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1 Burns, J. O. et al., 2012, Adv. Space Res., 49, 433–450, http://arxiv.org/abs/1106.5194.

2 Burns, J. O. et al., 2013, J. Adv. Space Res., in press, eprint arXiv:1211.3462.

3 Lazio, T. J. W. et al., 2011, Adv. Space Res., 48, 1942.

4 Harker, G. J. A., Pritchard, J. R., Burns, J. O., & Bowman, J. D. 2012, MNRAS, 419, 1070.