1. Executive Summary (One Paragraph)

The Network for Exploration and Space Science (NESS) team led by P.I. Jack Burns at the University of Colorado Boulder is an interdisciplinary effort that investigates: the deployment of low frequency radio antennas in the lunar/cis-lunar environment using surface telerobotics for cosmological and astrophysical measurements of neutral hydrogen at the end of the Dark Ages, during Cosmic Dawn, and at the onset of the Epoch of Reionization; radio emission from the Sun; and extrasolar space weather and exoplanets. NESS develops instrumentation and a data analysis pipeline for the study of the first luminous objects (first stars, galaxies and black holes) and departures from the standard model of cosmology in the early Universe, using low frequency radio telescopes shielded by the Moon on its farside. The design of an array of radio antennas at the lunar farside to investigate the Dark Ages, Heliophysics, and Exoplanet Magnetospheres, is a core activity within NESS, as well as the continuous research of theoretical and observational aspects of these subjects. NESS develops designs and operational techniques for teleoperation of rovers on the lunar surface facilitated by the planned Lunar Gateway in cis-lunar orbit. New experiments, using rovers plus robotic arms and Virtual/Augmented Reality simulations, are being performed to guide the development of deployment strategies for low frequency radio antennas via telerobotics.

2. Team Project Report

2.1. Surface Telerobotics

2.1.1. Simulations of the Lunar Terrain to Assist in Lander Development

To support the development of an improved virtual reality lunar rover simulator, Co-I Fong collaborates with CU Boulder (SSERVI/NESS postdoc M. Menon) on techniques to improve real-time, photorealistic rendering of the lunar surface. The simulator supports mission studies such as rover-deployed antennas by creating approximate, but plausible visualizations of terrain geometry, regolith appearance, and solar illumination. Future work will include comparison of the CU Boulder virtual reality simulator (which is based on the Unity video game software system) to the NASA Ames lunar surface operations simulator.

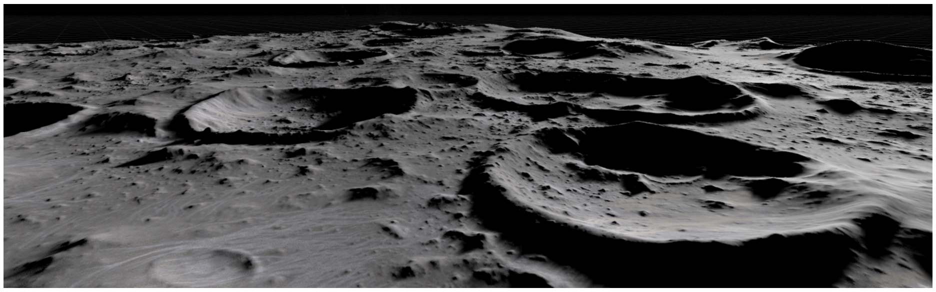

Figure 1: *Rendering of the lunar surface from the real-time simulator being developed with photometric models of the Moon's surface.*

2.1.2. Virtual and Augmented Reality Simulations of Robots on the Lunar Surface

Our group (Walker, Menon, Szafir, and Burns) is using game engines, simulators, augmented reality, and virtual reality (VR) technology to enhance interfaces used by scientists and astronauts during robotics missions. Stereoscopic displays built into VR headsets allow users to see with depth through the eyes of a real robot. By passing the dual video streams from a physical camera on a robot to a remotely located human operator, it is as if they were there themselves embodied as the robot. A virtual lunar environment simulator was created within a robust physics engine to provide a platform for evaluating and advancing algorithms that govern low-level robot autonomy and support interactive trade-offs between various levels of supervisory control. In this work we found that state-of-the-art computer vision algorithms, commonly used for autonomous robot localization and mapping, break down and fail to initialize or continuously estimate poses when a scientifically accurate photometric shader is introduced to a terrain model. The virtual environment may enable explorations into the design of new interfaces that support ground control and/or orbital station astronaut operation of surface robots.

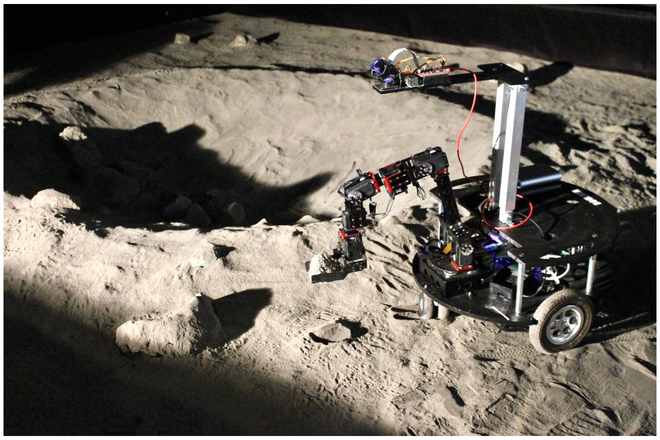

Figure 3: *CU-Boulder Armstrong rover with mounted mechanical arm and cameras in the simulated lunar landscape at NASA Ames Research Center.*

2.1.3. Assembly of Radio Telescope Components on the Lunar Farside: Experiments Using Laboratory-based Teleoperated Rover and Mechanical Arm

In 2019, the CU Telerobotics Laboratory finalized our Telerobotic Simulation System (TSS). The Lab team included three undergraduate engineering students (Kumar, Bell, Sandoval) and an M.S. aerospace engineering student (Mellinkoff) supervised by P.I. Burns. The TSS enables remote operation of our Armstrong Rover, a commercial off-the-shelf rover with a 6 degrees-of-freedom robotic arm. Two cameras were placed on Armstrong to provide video feedback to the operator. The hardware was supported by a control GUI consisting of video feeds, a real time updating model of the rover, and sliders indicating limits of the arm's movement.

Armstrong and the TSS were used in our most recent experiment designing a methodology that can accurately assess situational awareness and the cognitive load of an operator performing a telerobotic assembly task. As an analog to the FARSIDE mission concept, operators were tasked with assembling, deploying, and powering a small array of three antenna units. Each participant completed the assembly task under two conditions: remote teleoperation of Armstrong and local operation of Armstrong. Performance metrics measured in this experiment showed greater situation awareness and lower cognitive load in the local environment, supported by a 27% increase in the time required to complete the task when operating remotely. Results from this experiment refined our methodology to more accurately assess the human factors associated with telerobotic assembly.

2.2. Hydrogen Cosmology

2.2.1. Instrument Development

The Cosmic Twilight Polarimeter (CTP) concept, led by Co-I Bradley, saw major developments over the past year. While investigating and maturing the instrument stability and calibration of the CTP, we had an undergraduate summer student, Ellie White from Marshall University, help us set up a simple experiment to determine if induced polarization could be observed. This experiment was vital in verifying the basis of the polarimetric approach we are developing for cosmological 21-cm observations with the CTP and the Dark Ages Polarimetry Pathfinder (DAPPER) mission concept. Bordenave and Nhan continued with the development and data analysis from this test instrument.

This simple experiment relied on existing hardware from the Precision Array for Probing the Era of Reionization (PAPER) project and was set up in Green Bank, WV (Figure 4). It consisted of a single crossed-dipole antenna pointed towards zenith along with a wideband balun and a modified amplifier module used by the PAPER project. Although not ideal to detect the actual 21-cm signal, the higher frequency range (120-200 MHz) of the system allowed us to avoid much of the RFI typically found at low frequencies (<100 MHz). Additionally, this set-up also lacks absolute calibration and the system relies entirely on lab measurements of the active RF modules instead. Despite these instrumental shortcomings, White was able to obtain a very repeatable and clean total power measurement of the sky.

Given the good quality of this initial data, we decided to focus our efforts on upgrading the experiment for further study. The back-end of the instrument saw the most improvements with a new replacement Software Defined Radio (SDR) for data acquisition, an improved temperature monitoring system for calibrations, a new full stokes digital spectrograph, and a new data reduction pipeline. Additionally, a new balun and amplifier pair were characterized over temperature in the lab and the transducer gain models used for calibration were explicitly computed by microwave network theory. Following these upgrades, we were able to observe continuously for several weeks and found evidence of induced polarization that is stable in sidereal time and that follows the expected behavior of physical simulations (Figure 5). With the lessons learned by this experiment, we are developing a new purpose-built instrument for follow-up observations and expanding the current simulation model to include additional physical effects from the instrument, atmosphere, ionosphere, ground, and sky.

Figure 4: *Deployed PAPER antenna at Green Bank WV, set-up for zenith pointed drift scans.*

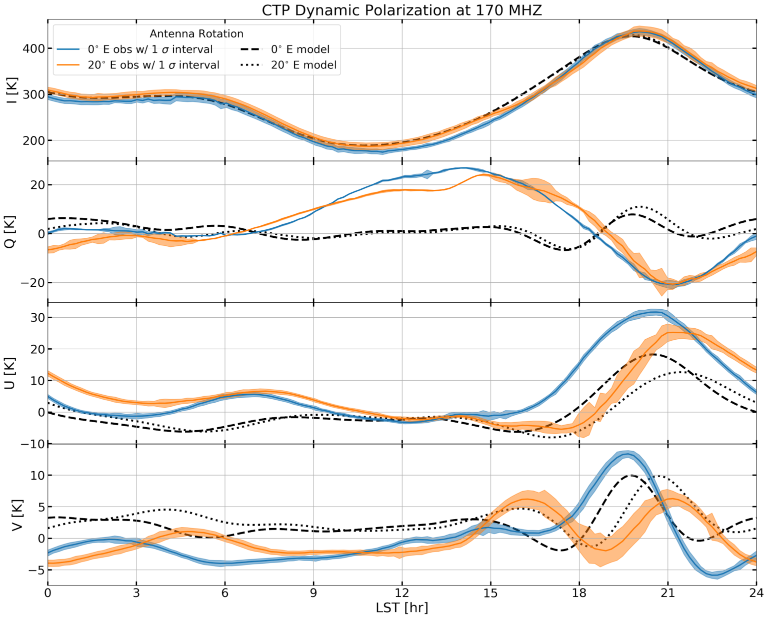

Figure 5: *Observed Stokes brightness temperatures and simulations over sidereal time. The colored curves show the observed Stokes brightness temperatures with 1-σ intervals for two configurations: (blue) x-pol aligned with grid north for one week, (orange) x-pol rotated in azimuth by 20 degrees east for two weeks. The black dashed and dotted curves show the simulated brightness temperature for the North and +20 east aligned antenna respectively. Note that the data generally tracks the behavior of the simulations and that the signal remains stable over weeks of observations. The greater deviation in Q Stokes likely stems from instrumental effects.*

2.2.2. Spaced-based Mission Concept and Data Analysis Pipeline

Within the first half of the year, the Colorado group led by Burns, completed and submitted (May 2019) an Astrophysics SmallSat concept study for the Dark Ages Polarimeter PathfindER (DAPPER). This study included developments in all key aspects of DAPPER, including the mission, spacecraft, instrument, and data analysis pipeline. DAPPER is well-aligned with NASA's current strategic plans for scientific research from the lunar environment. Working towards this goal, we developed a Statement of Work for instrument maturation that was presented to NASA leadership. This statement details a two-year plan for maturing the data analysis pipeline, the spectrometer/polarimeter and dipole antennas, the signal processing and calibration, and the digital signal processor development and evaluation platform, as well as all the corresponding interdependencies between these work packages.

We also completed the main structure of our data analysis pipeline of global 21-cm observations by incorporating the ability to convert the spectral constraints obtained analytically in the first segment of the pipeline (as described in Paper I of the series; Tauscher et al., 2018, ApJ, 853 187) into constraints on a nonlinear signal model of choice as presented Paper II (arXiv:1912.02205) by NESS team members Rapetti, Tauscher, Mirocha, and Burns. This second segment of the pipeline properly marginalizes over the linear description of the foreground model at each step of the Markov Chain Monte Carlo (MCMC) exploration of the nonlinear signal model of interest, allowing a faster, more efficient calculation.

2.2.3. <u>Low Frequency Lunar Arrays</u>

Several of the most pressing questions in astrophysics can be addressed by a low-frequency radio array telescope on the lunar farside. The key science goals of such an array include probing the growth of structure and thermal history of the universe during the cosmological Dark Ages using the 21-cm line of hydrogen. NESS's key astrophysics project aims to develop both technology and the motivating science for such an instrument. Technology development has been advanced through both full array concept design and detailed antenna design.

Existing radio astronomy antenna designs optimized for Earth-based arrays need to be modified for use in lunar radio telescopes to cover the desired frequency range and to account for the properties of lunar regolith. Deployment on the lunar surface is an additional functional constraint. The ASU team (Co-I Bowman, graduate student Mahesh) investigated antenna designs based on planar dipoles that could be deployed by rovers like those envisioned in the ROLSS concept. To optimize dipole antenna designs for a lunar telescope, the team used the well-understood beam patterns of the Experiment to Detect the Global EoR Signature (EDGES) low-band planar "blade" antenna as a reference. We assessed whether an EDGES-style experiment could be conducted on the lunar surface using a lunar radio array by modeling the antenna performance with and without an underlying ground plane. For the antennas without a ground plane (e.g. Figure 6), performance was found to be very sensitive to small changes in regolith properties. We investigated potential improvements to the antenna return loss of planar dipoles by 1) increasing the electrical path length for the currents on the surface and 2) by breaking the planarity requirement of the antenna, lifting the dipole panels at an angle from the regolith. Results are in preparation for publication.

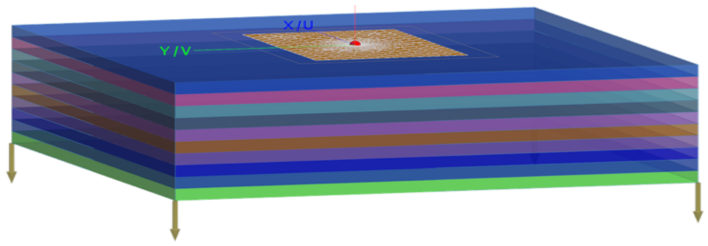

Figure 6: *Electromagnetic model of a dipole antenna on the lunar regolith with subsurface layering used to investigate the sensitivity of the antenna to variations in the electrical properties of the regolith and underlying bedrock to assess the feasibility of a lunar global 21-cm measurement.*

2.2.4. <u>Theoretical Predictions of the 21-cm Signal</u>

One of the primary goals of low-frequency lunar telescopes is to observe the Cosmic Dawn, when the first stars and black holes illuminated the universe. The radiation fields from these sources can be observed indirectly through the redshifted 21-cm line of neutral hydrogen, for which the lunar environment provides an ideal observing platform. This is an extraordinarily weak signal, so a clear understanding of the signatures will help design the most effective lunar telescopes.

In 2018, Co-I Bowman et al. (2018) detected the first spin-flip signal from this era with the EDGES experiment. At UCLA, Co-I Furlanetto has led the effort to model the 21-cm signal from the Cosmic Dawn, using the EDGES detection as an example to illuminate the astrophysics we hope to learn. In Mirocha & Furlanetto (2019), we showed that the EDGES signal requires star formation to begin much earlier than expected from extrapolations from known galaxy populations: otherwise the radiation backgrounds would be insufficient to "turn on" the 21-cm signal. However, it has long been expected that the first generations of star formation differ from those in observed galaxy populations. In Mebane et al. (2020), we showed that these so-called "Population III" stars *can* explain the timing of the EDGES signal. Mebane's models provide a new framework to make predictions for lunar radio telescopes, and we are now extending them to predict finer-scale structure in the spin-flip background. Additionally, undergraduate student Fu and collaborator Mirocha continued to examine whether another potential type of source, globular clusters, could explain the timing of the EDGES signal.

Finally, Furlanetto's group is also developing improved models of "normal" galaxies at high redshifts. Identifying the exotic physics of Population III stars during the Cosmic Dawn will require a clear understanding of the normal galaxies into which their hosts grow. This new suite of models will allow us to extrapolate the observed galaxy populations with a physical basis, providing a tool for identifying the most robust signatures of exotic stars and helping to optimize lunar telescopes to detect those effects.

2.3. Heliophysics

As part of the Heliophysics and Space Physics key project of NESS, we are working on various projects that will help to design a lunar radio astronomy array. Our NESS science goals for heliophysics are solved primarily by the capability to produce images of solar radio bursts at frequencies below the imaging possible by ground-based arrays. Typically, they cannot image solar radio bursts below frequencies around 20 MHz, which corresponds to the terrestrial ionospheric “cutoff” frequency. The electron density in the ionosphere blocks electromagnetic waves below a certain frequency and distorts the waves at frequencies above the “cutoff” frequency. The frequency of 20 MHz corresponds to solar radio burst emissions only a couple of solar radii from the solar surface, so ground-based observatory imaging only covers a small fraction of the inner heliosphere.

At Michigan, Co-I Kasper and his graduate student turned postdoctoral fellow Hegedus have progressed on the Sun Radio Interferometer Experiment (SunRISE) mission concept. SunRISE is a Heliophysics Mission of Opportunity that is currently in an extended Phase-A period, pending full acceptance from NASA. SunRISE would consist of 6 CubeSats with radio receivers that together form an interferometer. SunRISE would circle the Earth in a GEO graveyard orbit and sample the low radio frequency range 0.1-20 MHZ and make rudimentary images below the ionospheric cutoff for the first time. Data is recombined on the ground, forming a synthetic aperture. SunRISE’s primary science is to localize type II radio bursts within coronal mass ejections (CMEs) to identify the site of particle acceleration of solar energetic particles (SEPs), as well as to map the trajectories of energetic electron packets associated with type III bursts.

Deputy PI MacDowall leads a NASA lunar surface payload, called ROLSES, which is a radio frequency spectrometer to be delivered to the lunar surface by Intuitive Machines (Figure 7). It will measure the scale height of the lunar surface photoelectron sheath, detect solar and planetary radio emissions from the lunar surface, document the current levels of radio frequency interference from Earth arriving at the lunar nearside, and possibly detect interplanetary dust impacts and reflection of radio waves from structures below the lunar surface.

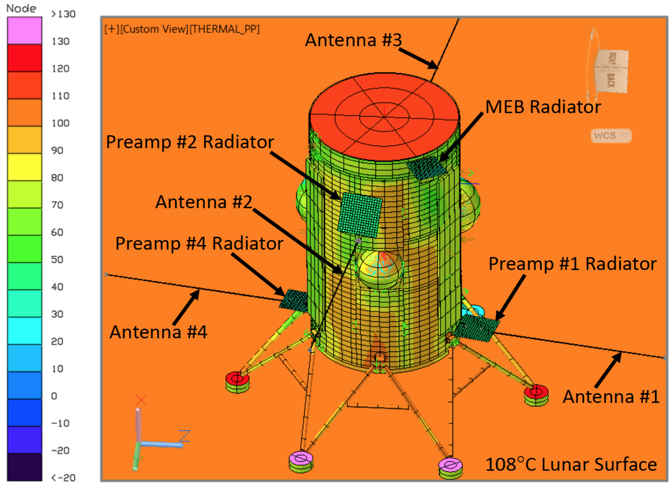

Figure 7: *Diagram of the GSFC thermal analysis (degrees C) of the Intuitive Machines NOVA-C lander on the lunar surface and the radiator components of the ROLSES instrument (Major Electronic Box and four preamps for the four Stacer antennas). The radiators keep the electronics in their survival temperature range.*

2.4. Lunar Near-Side Earth Observing Radio Arrays

Applications of science analysis pipelines were also employed to explore an underdeveloped area of research: benefits from lunar near-side Earth observing radio arrays. In a project led by Hegedus at Michigan, with the guidance of Kasper and MacDowall, simulations of large-scale radio arrays provided estimates on scientific return for various sized arrays under various assumptions. This resulted in a paper recently published in Radio Science and presented at the NASA Exploration Science Forum. A radio array on the near side of the Moon would always be facing the Earth, and would be well suited for measuring its low frequency radio emissions, including weaker synchrotron emission. The specific geometry and location of the test array were determined using the most recent lunar maps made by the Lunar Reconnaissance Orbiter. This array would give us unprecedented day-to-day knowledge of the electron environment around our planet, providing reports of Earth's strong and weak radio emissions, giving both local and global information. Figure 8 shows a summary of the simulated synchrotron brightness, the array layout, and the reconstructed image output by the array under realistic noise conditions. The simulated synchrotron brightness comes from French colleagues at ONERA employing the modern iteration of the Salammbo code. The total brightness of the synchrotron emission observed from the Moon is estimated to be 1.4-2.0 Jy between 500-1000 kHz.

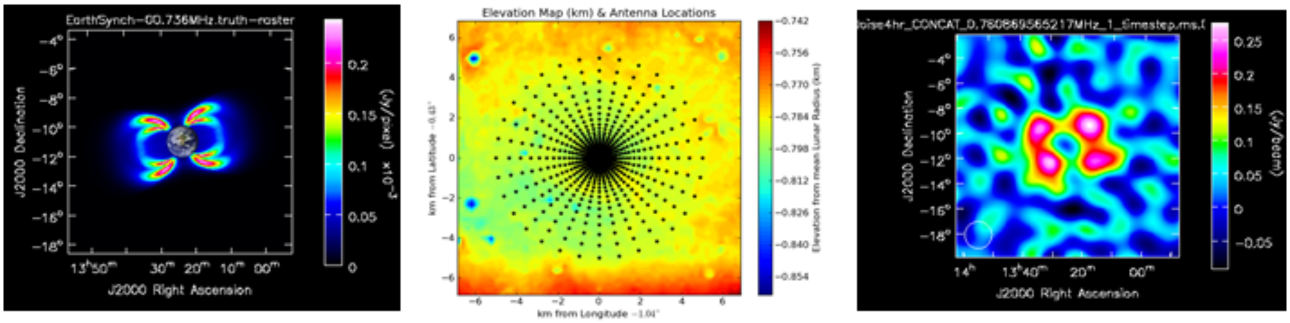

Figure 8: *Left: Salammbo global electron simulation derived synchrotron brightness from Earth's radiation belts at lunar distances. Middle: Logarithmically spaced circular configuration of antennas across 10 km as a nominal array layout, centered on the flattest 10x10 km patch near the sub-Earth point. Right: Reconstruction of a 16K element array over 10 km with a 4-hour integration assuming limited amplifier noise.*

It was found that for normal amplifier noise-limited observations, a 16K element array in a logarithmic circular configuration over 10 km could yield a 3-σ detection of the synchrotron brightness in 2 hours.

This figure may change depending on the level of quasi-thermal noise from free electrons on the lunar surface. Fortunately, this will be investigated by ROLSES, described in the section above. On top of this weak, stable, global synchrotron signal lies a vast zoo of transient signals. An array sensitive enough to detect the weak synchrotron emission would have no problem characterizing transient signals many orders of magnitude more powerful. This ability of a large-scale lunar near-side radio array to provide a high degree of localization for transient emissions like Auroral Kilometric Radiation is scientifically compelling and could be started with a smaller pathfinder array.

3. Inter-team/International Collaborations

Hegedus, MacDowall, and Kasper joined up with ONERA, the French Aerospace Lab on a project. The work outlines a large-scale radio array on the lunar near-side that could detect and image Earth's synchrotron emission from energetic electrons for the first time (see also Section 2.4). ONERA supplied the simulated synchrotron brightness using a modern iteration of the Salammbo code. Salammbo is a global electron simulator that uses the Time History of Events and Macroscale Interactions during Substorms/Solid State Telescope (THEMIS-SST) data set of electron distributions up to several hundred keV as an outer boundary condition. The output is a global model of the trapped electrons in the radiation belts from 1 keV to 100 MeV, which can then be analyzed to compute the synchrotron brightness from a given vantage point. This was used as a test model for a simulated lunar radio array to detect and image the emission. The collaboration resulted in a publication in Radio Science cited above.

International team members Falcke and Klein-Wolt are leading the Netherlands-China Low-Frequency Explorer (NCLE), a low-frequency radio experiment for the Chinese Chang'e 4 mission that is in a Lissajous orbit around the Earth-Moon L2 point. NCLE is considered a pathfinder mission for a future low-frequency Moon-based radio interferometer which has the detection and tomography of the 21-cm Hydrogen line emission from the Dark Ages period as the principal science objective. Low-frequency radio astronomy below ~30 MHz can only be performed well from space due to the cut-off in the Earth's ionosphere, and the human-made noise that makes sensitive measurements from ground-based facilities impossible. At the Earth-Moon L2 point, NCLE is relatively far away from terrestrial interference, which, however, is still detectable. With the Earth always in sight, we can measure and quantify this emission for the first time in 50 years in unprecedented detail. This will allow NCLE not only to study radio and plasma physics of the Earth-Moon system, but also to explore mitigation and calibration techniques for exploring radio emission from true lunar farside locations made by future missions.

NESS also includes ongoing collaborations with the EDGES team to integrate lessons-learned on antenna performance to minimize spectral effects from foreground structure in the sky.

4. Public Engagement

The ASU team supported several public engagement events to reach both traditional and underserved audiences in the Phoenix metropolitan area. These included three annual events at ASU that served 5,000 visitors collectively. At these events, NESS graduate student N. Mahesh presented ongoing research and engaged the public with radio-astronomy themed word games and puzzles. Mahesh was also a panelist for the Young Change Makers at the Inspire India Youth conference; developed cosmology course materials for prison education; presented two seminars; and was a facilitator for Girls Who Code at the Heard School in Phoenix.

NESS celebrated International Observe the Moon Night on October 5th at Fiske Planetarium of CU Boulder. On July 12, 2019, P.I. Burns presented "Our Future in Space: The Moon & Beyond" for the Apollo 11 50th Anniversary Celebration at Fiske Planetarium, and the next day during the Apollopalooza celebration at the Wings Over the Rockies Air & Space Museum.

Burns led a talk-back session on May 1, 2019 after the audience watched the film "Apollo 11," which is a cinematic space event film fifty years in the making, featuring never-before-seen large-format film footage of one of humanity's greatest accomplishments: travelling to the surface of the Moon. Burns did 14 press interviews related to the Apollo 11 anniversary through August 2019.

NESS participated in 'Astronomy Day' on April 6, 2019 organized by Fiske Planetarium and Sommers-Bausch Observatory. The theme of the event was "THE MOON - Appreciating our Nearest Neighbor." It was a full day of free family-friendly activities, telescope observing, light labs, scale Solar System tours, stomp rockets, comet labs, and planetarium shows focused on our Moon. NESS PI Burns delivered the keynote presentation for Astronomy Day titled "Our Future in Space: The Moon and Beyond" at Fiske Planetarium.

With supplemental outreach funding from SSERVI, NESS began a Public Engagement program centered around an immersive, full-dome planetarium video production featuring NASA plans for human and telerobotic exploration of the Moon using Orion, the Lunar Gateway, and Artemis infrastructure. The production highlights in-situ resource utilization, science research efforts, and long-duration operations in cis-lunar space. The project draws upon subject matter expertise from researchers affiliated with NESS along with two other SSERVI teams. In addition, Lockheed Martin, a primary contractor involved in development of Orion and the Gateway, is providing both in-kind expertise and financial support for the production. The 25-minute video will engage students and public audiences in a three-part story that a) starts with a vision for building infrastructure for lunar exploration and in-situ resource utilization, b) progresses to scientific research investigations enabled by lunar exploration, and c) extends lessons learned from lunar exploration as a guide for human exploration of Mars.

5. Student/Early Career Participation

Undergraduate Students

1. Kristy Fu (until Spring 2019), University of California Los Angeles, theoretical predictions of the spin-flip background.
2. Alex Sandoval (until graduation in May 2019), University of Colorado Boulder, Surface telerobotics - Instrumentation.
3. Arun Kumar, University of Colorado Boulder, Surface telerobotics - Instrumentation.
4. Mason Bell (beginning May 2019), University of Colorado Boulder, Surface telerobotics - Instrumentation.

Masters Student

5. Benjamin Mellinkoff (graduated May 2019 with an M.S.), University of Colorado Boulder, Surface telerobotics - Instrumentation.

Graduate Students

6. Richard Mebane, University of California Los Angeles, theoretical predictions of the spin-flip background.
7. Keith Tauscher, University of Colorado Boulder, Physics/Astrophysics/Cosmology, Dark Ages/Cosmic Dawn – Theory/Data.
8. Neil Bassett, University of Colorado Boulder, Astrophysics/Cosmology, Dark Ages/Cosmic Dawn – Theory/Data.
9. Joshua Hibbard (beginning August 2019), University of Colorado Boulder, Astrophysics/Cosmology, Dark Ages/Cosmic Dawn – Theory/Data.
10. Adam Trapp, University of California Los Angeles, Astrophysics, Cosmic Dawn-Theory.
11. David Bordenave, University of Virginia, Astrophysics/Cosmology, Dark Ages/Cosmic Dawn - Experiment.
12. Nivedita Mahesh, Arizona State University, Astrophysics, Cosmic Dawn - Experiment.

13. Michael Walker, University of Colorado Boulder, Surface telerobotics - Virtual Reality Telerobotics simulations.

Postdoctoral Fellows

14. Jordan Mirocha, McGill University, Astrophysics/Cosmology, Dark Ages/Cosmic Dawn - Theory.
15. Alex Hegedus (first nine months as a graduate student, then Postdoctoral Fellow), University of Michigan, Astrophysics, Heliophysics.
16. Bang Nhan, University of Virginia, Astrophysics, Cosmic Dawn - Experiment.
17. Midhun Menon, University of Colorado Boulder, Surface Telerobotics - Virtual Reality Telerobotics Simulations.
18. Marin Anderson, California Institute of Technology, Astrophysics, Cosmic Dawn – Theory/Data.

New Faculty or Staff Members

19. David Rapetti (about first eight months as a Senior NPP Fellow, then Visiting Scientist at NASA ARC), University of Colorado Boulder/NASA Ames Research Center/Universities Space Research Association, Astrophysics/Cosmology, Dark Ages/Cosmic Dawn – Theory/Data.
20. Stuart Bale (new to NESS), Professor of Physics, University of Berkeley, Plasma Astrophysics & Low Frequency Radio Astronomy - Experiment.

6. Mission Involvement

DAPPER: PI Burns-- a NASA-funded concept study of DAPPER led to the design of a science instrument consisting of dual orthogonal dipole antennas and a tone-injection spectrometer/polarimeter based on high TRL components from the Parker Solar Probe/FIELDS, THEMIS, and the Van Allen Probes. DAPPER will probe the Dark Ages for the early universe for the first time with a smallsat in orbit of the Moon.

FARSIDE: PI Burns-- the Farside Array for Radio Science Investigations of the Dark ages and Exoplanets is a Probe-class concept to place a low radio frequency interferometric array on the farside of the Moon. A NASA-funded design study, focused on the instrument, a deployment rover, the lander and base station, delivered an architecture broadly consistent with the requirements for a Probe mission.

SunRISE: Kasper and Hegedus have progressed on the Sun Radio Interferometer Experiment (SunRISE) mission concept. SunRISE is a Heliophysics Mission of Opportunity that is currently in an extended Phase-A period, pending full acceptance from NASA. SunRISE would consist of 6 CubeSats with radio receivers that together form an interferometer.

ROLSES: ROLSES is a selected CLPS payload. Led by MacDowall, the goals of the Radio wave Observations at the Lunar Surface of the photoElectron Sheath (ROLSES) include determination of the photoelectron sheath density above the lunar surface and demonstration of the detection of solar, planetary, and other radio emission from the lunar surface.

LuSEE: The Lunar Surface Electromagnetics Experiment (LuSEE), led by Bale, will study the magnetic and electric fields on the Moon's surface and how they interact with fine dust particles. LuSEE is a selected CLPS payload.

7. Awards

Nivedita Mahesh (ASU Graduate Student) was awarded a NASA FINESST (Future Investigators in NASA Earth and Space Science and Technology) fellowship based on her proposal to build on her NESS-supported research. She also earned the NASA Exploration Science Forum (NESF) Best Poster award in July (see photos in Figure 9).

Figure 9: *(Left) Nivedita Mahesh next to her poster awarded NASA Exploration Science Forum (NESF) Best Poster. (Right) Nivedita and others receiving awards at NESF.*