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Jack Burns, University of Colorado Boulder

Co-Investigators:
Stuart Bale, U. California at Berkeley
Richard Bradley, NRAO

NASA Lead Center:
NASA Ames Research Center
# DAPPER Project Team Members

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Position</th>
<th>Affiliation</th>
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<tr>
<td>1.</td>
<td>Jack Burns</td>
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<td>2.</td>
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<td>Data Pipeline</td>
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<td>9.</td>
<td>Rich Bradley</td>
<td>Co-I: Receiver; High-band Antenna</td>
<td>NRAO</td>
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<td>10.</td>
<td>David Bordenave</td>
<td>Antennas/receiver</td>
<td>NRAO</td>
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<td>NRAO</td>
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<td>PM-UCB</td>
<td>UC Berkeley</td>
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<td>16.</td>
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<td>UC Berkeley</td>
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<tr>
<td>17.</td>
<td>Marc Pulupa</td>
<td>Receiver Engineer</td>
<td>UC Berkeley</td>
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</tbody>
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Radio wave Observations at the Lunar Surface of the photoElectron Sheath = ROLSES

- **Science Goals:**
  - determine the photoelectron sheath density from ~1 to ~3 m above the lunar surface.
  - demonstrate detection of solar, planetary, & other radio emission from lunar surface
  - detect dust impacting NOVA-C lander or antennas
  - measure reflection of incoming radio emission from lunar surface and below
  - Measure RFI from terrestrial transmitters
  - Aid development of lunar radio arrays.

- **Team:** Robert MacDowall, William Farrell, Damon Bradley, Nat Gopalswamy, Michael Reiner, Ed Wollack, Jack Burns, David McGlone, Mike Choi, Scott Murphy, Rich Katz, Igor Kleyner

- **Status:** ROLSES scheduled to land on lunar nearside in October 2021 using Intuitive Machines Nova-C lander.
OBJECTIVE 1:
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

<table>
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<tr>
<th>Redshift (z)</th>
<th>Time (billions of Years)</th>
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<tr>
<td>100</td>
<td>~0.004</td>
</tr>
<tr>
<td>30</td>
<td>~0.5</td>
</tr>
<tr>
<td>20</td>
<td>~1</td>
</tr>
<tr>
<td>15</td>
<td>~9</td>
</tr>
<tr>
<td>12</td>
<td>~13</td>
</tr>
<tr>
<td>7</td>
<td></td>
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</table>

EM Spectrum
- 10 MHz
- 60 MHz
- 120 MHz

OBJECTIVE 2:
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

Will the observed behavior of redshifted neutral hydrogen redefine the standard cosmological model?

21-cm spectrum has broad absorption troughs corresponding to the Dark Ages and Cosmic Dawn.

DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.

DAPPER separates Galaxy foreground from 21-cm signal using differences in spectral shapes, spatial structure, and polarization.
Mission Overview

- 2 Frequency Bands: 18-40 MHz and 60-110 MHz.
- Measure all 4 Stokes parameters.
- Spin spacecraft at 2-5 rpm for dynamic polarimetry.
- Integration time: 5000 hrs at low band and 500 hrs at high band to achieve ~20 mK thermal noise.
- Low 50×125 km equatorial lunar orbit to maximize time in radio quiet cone.

DAPPER Low Band Antenna

Four deployable wire antenna units (\(~3.5\text{-}m\) length), arranged in two, orthogonal co-linear pairs.

These four physical monopoles function as two cross-dipoles, meeting the requirement for dual polarization.

The thin wire antennas are wound on spools and deployed by commanded motor-drive in the spin-plane of the spacecraft.
Low Band Wire Antenna Heritage

DAPPER will use fine wire, rather than a wire harness, simplifying the design.

The DAPPER antenna enclosure will be designed to optimize antenna impedance.

A THEMIS/EFI spin plane boom system. The THEMIS mission successfully deployed 20 of these units on orbit. The DAPPER wire boom antennas derive directly from the THEMIS/EFI and Van Allen Probe (RBSP) units.
Low Band Wire Antenna Beams

18 MHz

27 MHz

36 MHz

45 MHz
High Band Patch Antenna Design

Baseline Design
A rendering of the baseline design made from solid dielectric materials is shown in Fig. 3 along with a cut-away view, where the middle layer of metal and the four terminal connections are visible.

Figure 3: Rendering of the baseline patch antenna. Panel a) is an overall view, and b) is a cutaway showing the middle metal layer and feed connections.
BaTiO$_3$ is the most widely used ferroelectric material, and even sixty years after its discovery, it is the most important multilayer ceramic dielectric.
Beam Patterns (65, 85, 95, 110 MHz)
**Patch Antenna Heritage**

Galileo in-orbit patch. Four stacked layers of Kapton.

Patch antennas have been used primarily for TT&C and ISL applications.

Table 79: Constellation ISL Comparison

<table>
<thead>
<tr>
<th>Mission</th>
<th>Link</th>
<th>Band</th>
<th>Antenna type</th>
<th>Data-rate</th>
<th>Distance</th>
<th>Link margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROSETTA</td>
<td>Orbiter-Lander</td>
<td>S</td>
<td>Patch</td>
<td>16 kbps</td>
<td>150km</td>
<td>14,8 dB</td>
</tr>
<tr>
<td></td>
<td>Lander-Orbiter</td>
<td>S</td>
<td>Patch</td>
<td>16,38 kbps</td>
<td>150 km</td>
<td>15,5 dB</td>
</tr>
<tr>
<td>PRISMA</td>
<td>RRFR</td>
<td>S</td>
<td>X-pole</td>
<td>12 kbps</td>
<td>30 km</td>
<td>18,1 dB</td>
</tr>
<tr>
<td>CanX 4&amp;5</td>
<td>ISL</td>
<td>S</td>
<td>Patch</td>
<td>10 kbps</td>
<td>5 km</td>
<td>19,2 dB</td>
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<tr>
<td>NODES</td>
<td>ISL</td>
<td>UHF</td>
<td>Monopole</td>
<td>9,6 kbps</td>
<td>100 km</td>
<td>33,8 dB</td>
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<tr>
<td>TSX-TDX</td>
<td>P-P @90°@</td>
<td>S</td>
<td>Patch</td>
<td>31,25 kbps</td>
<td>1,25 km</td>
<td>12,0 dB</td>
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<tr>
<td>Sar-Lupe</td>
<td>Low rate</td>
<td>S</td>
<td>Patch</td>
<td>300 kbps</td>
<td>50 km</td>
<td>13,5 dB</td>
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<tr>
<td></td>
<td>High Rate</td>
<td>S</td>
<td>Patch</td>
<td>6000 kbps</td>
<td>50 km</td>
<td>0,5 dB</td>
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Following from https://directory.eoportal.org/
DAPPER Receiver Design

Four Channel Correlation Receiver

Diagram showing the components and flow of a DAPPER receiver design, including Low Band Wire Antenna (18-40 MHz), High Band Patch Antenna (60-110 MHz), Four Channel Receiver, Temperature Controller, Switch, Battery Charger, 4 Ch ADC, Burst Buffer, 4 Ch Correlation, Signal Processor, Battery Supply & Conditioning, Data Package & Storage, Atomic Clock, Monitor & Control Computer, Spacecraft Attitude Monitor, and Science Instrument.
Receiver Concept

Current Status

- Initial test of 310 MHz POC completed
- First set of ADS models completed
- Final 310 MHz Rcvr board completed
- Correlation tests to begin shortly
- Initial 60-110 MHz Rcvr design started
DAPPER Heritage
Cosmic Twilight Polarimeter – Initial Tests of Dynamic Polarimetry

Bunker Mode - Diagram

- In order to correct for long-duration drifts in timing, a closed-loop controller is proposed.
- Between each set of observations, the controller will adjust the
- Duration of the previous bunker mode is timed by the payload.

**Diagram:**
- **Bunker Mode Controller**
- **Bunker Circuit Thermistor**
- **Payload Timer**
- **Platform Avionics**

**Flowchart:**
- Current temperature
- New target time
- Reset duration
- Awake signal
- Post-bunker report on bunker duration
- Time Correction
Signal Extraction and Parameter Constraints

Observation strategy (polarization and time dependence; Paper III)

Measured data

Frequency space signal fitting using training sets (Paper I)

Parameter space signal fitting using MCMC (Paper II)


See also Workshop talks by Rapetti, Tauscher, Basset, & Hibbard
Simulated DAPPER observations including statistical plus systematic uncertainties. DAPPER will distinguish at $>5\sigma$ between a standard cosmology model and exotic physics models.
Summary & Conclusions

• NASA Commercial Lunar Payload Services (CLPS) program will deliver radio science payload to the lunar surface next year (ROLSES).
• DAPPER will take advantage of transportation & communication infrastructure associated with NASA’s Artemis.
• DAPPER will make spectral observations from lunar orbit of the Dark Ages & Cosmic Dawn using the highly redshifted 21-cm signal.
• Instrument development continues to refine antenna designs, receiver, & data pipeline.
Mechanical Mode Effects on Electromagnetic Performance: Tuning

Antenna Tuning for several wire twist angles

Efficiency for several wire twist angles
Chromaticity of the DAPPER Antennas

DAPPER Beam Solid Angle

- Blue line: 7.57m Wire Dipoles (18-45 MHz)
- Orange line: Patch Antenna (65-110 MHz)

\( \frac{\Omega_B}{4\pi} \) vs. \( \nu \) (MHz)
The 21-cm Global signal

Spectral Features:

A: Dark Ages: test of standard cosmological model
B: Cosmic Dawn: First stars ignite
C: Black hole accretion begins