**DAPPER**
The Dark Ages Polarimeter PathfinderER

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**Co-Investigators:**
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**NASA Lead Center:**
NASA Ames Research Center
# DAPPER Team

## Management & Organization

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<tr>
<th>Member</th>
<th>Role</th>
<th>Institution</th>
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</table>

Jill Bauman, ARC
Project Manager
What is 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
EDGES: Key Features

Q. How to amplify signal by a factor of 2-3?

\[ \delta T_b \simeq 27 \, \bar{x}_H \, (1 + \delta) \left( \frac{\Omega_{b,0} h^2}{0.023} \right) \left( \frac{0.15}{\Omega_{m,0} h^2} \, \frac{1 + z}{10} \right)^{1/2} \left( 1 - \frac{T_R}{T_S} \right) \, \text{mK} \]

1. Increase $T_R$ via Dark Matter decay or synchrotron radiation from black holes, galaxies.
   - Feng & Holder, Ewall-Wice et al., Fraser et al., Mirocha & Furlanetto

2. Alter the cosmology.
   - McGaugh, Costa et al., Hill et al.

3. Decrease $T_S$ via baryon-Dark Matter interactions which cools the hydrogen.
   - Barkana, Munoz & Loeb, Fialkov et al., Berlin et al., Slatyer & Wu
**Objective 1:**
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

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

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

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**Legend:**
- Dark Ages
- DAPPER measurement
- Cosmic Dawn
- Best-fit line
- Potential Model: Low Cooling
- Potential Model: Medium Cooling
- Potential Model: High Cooling
- Standard Model

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

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**DAPPER separates Galaxy foreground from 21-cm signal using differences in spectral shapes, spatial structure, and polarization.**
<table>
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<tr>
<th>Science Objectives</th>
<th>Science Measurement Requirements</th>
<th>Observable</th>
<th>Approach</th>
<th>Instrument</th>
<th>Projected Performance</th>
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<tr>
<td>Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages. (see §2.2).</td>
<td>Brightness temperature of neutral hydrogen (see §3.2).</td>
<td>Frequency range: 17-38 MHz (22-29 MHz).</td>
<td>Frequency range: 55-107 MHz (71-81 MHz).</td>
<td>Sample 55-107 MHz (71-81 MHz).</td>
<td>17-38 MHz (22-29 MHz).</td>
</tr>
<tr>
<td>Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn. Determine when the first stars &amp; black holes formed. (see §2.3).</td>
<td>Redshifted 21-cm spectrum from z= 12 to 25 (z=16-19). (see §3.2).</td>
<td>Spectral resolution to remove RFI: 50 kHz.</td>
<td>Noise: 20 mK.</td>
<td>&lt;2 mK.</td>
<td>40 kHz.</td>
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<tr>
<td></td>
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<td>Noise in 4 Stokes parameters: 20 mK RMS.</td>
<td>Other requirements same as above.</td>
<td>Other projected performance same as above.</td>
<td>15 mK RMS.</td>
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<td>Receiver gain: tracked to 5 ppm/sec. (see §3.3).</td>
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<td>1 ppm/sec.</td>
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</table>

- Acquire stable lunar orbit.
- Make observations in Moon’s RF shadow.5
- Deploy antennas to lengths (cm uncertainty) of 5.82 m, 7.57 m, 4.41 m. (Table 3.0-2).
- Science data integration times for each antenna deployment of 3457 hrs, 926 hrs, 231 hrs. (Table 3.0-2).
- RFI brightness temperature: <15 mK RMS (see §4.3).
- Thermal control: limit temperature variations for RFSP to ±1°C for each science integration period.
- Rotate S/C for duration of science phase.
- Single antenna pointing direction perpendicular to orbit plane with accuracy of ±10°.
- Provide power to payload during science observations.
- Downlink data after each antenna deployment.
Mission Overview

- DAPPER will deploy from vicinity of NASA’s Lunar Gateway & transfer to a $50 \times 125$ km low lunar orbit.
- Operates over primary bandwidth of 17-38 MHz ($83 \geq z \geq 36$) and sparse secondary sampling from 55-107 MHz ($25 \geq z \geq 12$).
- Low noise amplifiers & dual channel receiver to measure all 4 Stokes parameters. Based upon FIELDS instrument currently flying on Parker Solar Probe (TRL = 8).
- Projection-induced polarimetry used to independently constrain foreground.
- Baseline mission duration = 26 months.