Cosmology from the Moon: The Dark Ages Radio Explorer (DARE)

Jack Burns for the DARE Team
University of Colorado Boulder

Exploration Science Forum
NASA Ames Research Center
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The First Half-Billion Years

Science Questions

- When did the First Stars ignite? What were these First Stars?
- When did the first accreting Black Holes turn on? What was the characteristic mass?
- When did Reionization begin?
- What surprises emerged from the Dark Ages?
The 21-cm Global Signal Reveals the Birth & Characteristics of the First Stars & Galaxies

**B: ignition of first stars**
- When did the First Stars ignite? What were these First Stars?
- What surprises emerged from the Dark Ages?

**C: heating by first black holes**
- When did the first accreting black holes turn on? What was the characteristic mass?

**D: the onset of reionization**
- When did Reionization begin?

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uncertainties in 1st star models
certainties in 1st black hole models

Adapted from Pritchard & Loeb, 2010, *Phys. Rev. D*, 82, 023006
Astrophysics Decadal Survey & Astrophysics Roadmap identify **Cosmic Dawn** as a top Science Objective

- “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?” *New Worlds, New Horizons (NRC 2010)*

- How Does our Universe Work? Small Mission: “Mapping the Universe’s hydrogen clouds using 21-cm radio wavelengths via a lunar orbiter observing from the farside of the Moon” *NASA Astrophysics Division Roadmap (2013)*

“Its first objects to light up the Universe and when did they do it?” We can uniquely address this mystery with DARE in orbit above the lunar farside.
DARE Project Team

Principal Investigator: Jack Burns, University of Colorado Boulder
Deputy Principal Investigator: Joseph Lazio, JPL/Caltech
Project Manager: Butler Hine, NASA Ames
Deputy Project Manager: Jill Bauman, NASA Ames
Spacecraft Project Manager: John Jonaitis, Ball Aerospace
Instrument Project Manager: Karen Lee, JPL/Caltech

Science Co-Investigators:
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  Richard Bradley, National Radio Astronomy Observatory
  Abhirup Datta, University of Colorado Boulder
  Steven Furlanetto, UCLA
  Dayton Jones, JPL/Caltech
  Justin Kasper, University of Michigan
  Abraham Loeb, Harvard University

Collaborators:
  Michael Bicay, NASA Ames
  Geraint Harker, University College London
  Jonathan Pritchard, Imperial College
  Michael Seiffert, JPL

Graduate Students:
  Jordan Mirocha, University of Colorado
  Bang Nhan, University of Colorado

Currently under review by NASA's Small Explorer Program
## DARE Baseline Mission Concept

| **Time in radio-quiet, solar eclipse cone** | ≈1000 hrs over 2 years |
| **Instrument** | 3-meter length biconnical antennas; correlation receiver; digital spectrometer; operates at 40-120 MHz |
| **Launch Date** | Q3/4 2020 |
| **Launch Vehicle** | Secondary payload on ULA Atlas V |
| **S/C Structure** | 60-inch ESPA as S/C structure and Faraday cage |
| **Instrument I/F** | Stack second ESPA to house instrument |
| **Launch Injection Orbit** | GTO |
| **Earth-to-Moon trajectory** | Translunar injection with lunar flyby |
| **Propulsion** | Regulated monoprop capable of delivering $\Delta v = 2200 \text{ m/s}$ (includes: TLI, TCMs, Lunar Targeting, LOI, orbit maintenance) |
| **Lunar Orbit** | 125 km circular, ≈0° inclination |
Spacecraft Concept

- **2200 m/s of ΔV**
  - Trans-lunar injection from GTO, lunar orbit insertion, trajectory correction maneuvers, orbit maintenance, momentum management
- **Ability to launch as a secondary on a ULA Atlas V with a 4000 kg primary PL**

**DARE performance margins are substantial in all areas**

<table>
<thead>
<tr>
<th>Requirements and Margins</th>
<th>Requirement</th>
<th>Performance</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observatory Wet Mass</td>
<td>1.600 kg</td>
<td>1.155 kg</td>
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<tr>
<td>Science Data Storage Capacity</td>
<td>1.6 GB</td>
<td>4 GB</td>
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<tr>
<td>Power generation during science</td>
<td>257 Watts</td>
<td>361 W EOL</td>
<td>40%</td>
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<tr>
<td>Pointing Knowledge (3-sigma/per axis)</td>
<td>1 degree</td>
<td>0.028 deg</td>
<td>3471%</td>
</tr>
<tr>
<td>Pointing Control (3-sigma/per axis)</td>
<td>1 degree</td>
<td>0.028 deg</td>
<td>3471%</td>
</tr>
<tr>
<td>Propellant Load</td>
<td>565 kg</td>
<td>714 kg</td>
<td>21%**</td>
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<tr>
<td>Propellant Tank Capacity</td>
<td>714 kg</td>
<td>959 kg</td>
<td>34%</td>
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<tr>
<td>EMI</td>
<td>100 dB shielding</td>
<td>106 dB shielding</td>
<td>6 dB</td>
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</tbody>
</table>
**Science Instrument: Baseline Design**

**Antenna:** Dual, deployable bicones to accommodate launch volume
- Mast deploys bicones above S/C deck
- Bicones deploy to achieve length
- Jib Radials deploy to form ground plane

**Receiver:** Pseudo-correlation Architecture + Reflectometer
- Heritage from WMAP, Planck, Microwave Limb Sounder on UARS.
- Thermally controlled front-end receiver electronics enclosure

**Spectrometer**
- Achieves $10^6$ dynamic range
- Uses space-qualified FPGAs.
Characterizing the First Stars & Galaxies

DARE will bound the properties (e.g., mass, spectra) of the first generation of stars, black holes, & galaxies for the first time.
DARE is designed to address:

- When did the First Stars ignite? What were these First Stars?
- When did the first accreting Black Holes turn on? What was the characteristic mass?
- When did Reionization begin?
- What surprises emerged from the Dark Ages?

DARE will accomplish this by:

- Constructing first sky-averaged spectrum of redshifted 21-cm signal at 11<z<35.
- Flying spacecraft in lunar orbit & collecting data above lunar farside -- only proven radio-quiet, ionosphere-free zone in inner solar system.
- Using biconical dipole antennas with smooth response function & Markov Chain Monte Carlo method to extract spectral turning points in the presence of bright foregrounds.
- Using high heritage spacecraft bus & technologies/techniques from DARE engineering prototype.
- DARE was submitted to NASA as a SMEX proposal in December 2014.

http://lunar.colorado.edu/dare/