Dark Cosmology: Investigations of Dark Matter with the Dark Ages Polarimeter Pathfinder (DAPPER)

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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?

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
Extrapolation into the Dark Ages based upon EDGES Results

- **68 and 95% (dark and light gray) bands:** EDGES measurements of Cosmic Dawn.
- **Black, dashed curve:** Example of the standard astrophysical models inconsistent with EDGES results.
- EDGES results (Bowman et al. 2018, Nature, 555, 67) require exotic physics such as e.g. interactions between baryons and dark matter particles.
- **Beyond-standard-physics** models of the **Dark Ages** trough consistent with the EDGES Cosmic Dawn signal:
  i. **Blue curve:** Maximum cooling rate is the adiabatic rate, but occurring earlier.
  ii. **Red curve:** Cooling rate both lower and earlier.
  iii. **Magenta curve:** Cooling rate not monotonically declining (i.e. there is a ‘preferred epoch’ of excess cooling).
The Dark Ages Polarimeter PathfinderER (DAPPER): A Space-based SmallSat Testbed

- **Science Objectives:**
  - Search for deviations from the standard cosmological model & impact of exotic physics
  - Verify EDGES results
- DAPPER will launch from NASA’s Lunar Gateway & transfer to a $50 \times 125$ km low lunar orbit
- Operates over primary bandwidth of $17-30$ MHz ($83 \geq z \geq 46$) and sparse secondary sampling from $30-100$ MHz ($46 \geq z \geq 13$)
- Bandwidth determined by antenna resonances from 3 length deployments of thin-wire, spinning, dual orthogonal dipole antennas (TRL=8) ranging from 4.4-7.6 m tip-to-tip
- 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
The Dark Ages Polarimeter PathfindER (DAPPER)
DAPPER: Internal RFI Mitigation Strategy

- **Active Control**
  - Faraday Cage + Polyphase Filters
  - Crystal Oscillator Masking of Internal RFI

- **Knowledge-Based Measurement of RFI**
  - Frequency-Tone injection system to accurately measure gain variations
  - Neural Network Separation of RFI from Sky + 21-cm spectrum
How can we extract the 21-cm signal?

Employ Pattern Recognition + Dynamic Polarimetry Techniques:

• Extract basis vectors from training sets using **Singular Value Decomposition (SVD)**
• SVD is a machine learning tool equivalent to:
  • Principal Component Analysis (PCA)
  • EigenVector Decomposition (EVD)

See also talks by:
• Rapetti+, *Full Data Analysis Pipeline*, J4-15, 11:40
• Tauscher+, *Challenges of Global EoR Detection*, J5-3, 13:45
• Bordenave+, *The Cosmic Twilight Polarimeter*, J5-9, 15:30
What is the expected DAPPER Performance?

DAPPER will measure amplitude of 21-cm spectrum to the level required to distinguish (at >5σ) the standard cosmological model from that of additional cooling derived from current EDGES results.
# Team Members & Recent Publications

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<tr>
<th>Team Member</th>
<th>Expertise &amp; Experience</th>
<th>Role</th>
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<tr>
<td>J. O. Burns, U. Colorado</td>
<td>cm, meter-wave observations; CTP; data processing; cosmology simulations</td>
<td>PI. Ensures mission success, mission reporting; data analysis</td>
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<tr>
<td>S. D. Bale, UC Berkeley</td>
<td>P.I. for Parker Solar Probe FIELDS and STEREO/WAVES; meter-wave instrumentation</td>
<td>Co-I. Instrument scientist</td>
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<tr>
<td>R. Bradley, NRAO</td>
<td>Meter-wave instrumentation; CTP; PAPER, HERA</td>
<td>Co-I. Polarimeter; receiver</td>
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<tr>
<td>NASA Ames Research Center</td>
<td>Extensive lunar mission experience including LADEE and LCROSS</td>
<td>Mission Design; management, Navigation</td>
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<tr>
<td>J. Bowman, ASU</td>
<td>Meter-wave instruments; P.I. EDGES; HERA</td>
<td>Collaborator; RF instrument</td>
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<tr>
<td>H. Falcke, Radbound U.</td>
<td>Meter-wave instrumentation; NCLE lunar radio experiment</td>
<td>Collaborator; RFI environment</td>
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<tr>
<td>S. Furlanetto, UCLA</td>
<td>21-cm cosmology theory</td>
<td>Collaborator; modeling of DAPPER spectrum</td>
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<tr>
<td>M. Klein- Wolt, Radbound U</td>
<td>Meter-wave instrumentation; NCLE lunar radio experiment</td>
<td>Collaborator; RFI environment</td>
</tr>
<tr>
<td>R. MacDowall, GSFC</td>
<td>Meter-wave space instruments; Solar Probe, STEREO, WIND</td>
<td>Collaborator; RFI environment; RF instrument</td>
</tr>
<tr>
<td>J. Mirocha, McGill U.</td>
<td>21-cm cosmology theory</td>
<td>Collaborator; modeling of DAPPER spectrum</td>
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<tr>
<td>B. Nhan, U. Virginia</td>
<td>Meter-wave instrumentation; CTP</td>
<td>Collaborator; polarimeter</td>
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<tr>
<td>D. Rapetti, U. Colorado</td>
<td>Signal extraction &amp; modelling</td>
<td>Postdoc; data analysis pipeline</td>
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<tr>
<td>K. Tauscher, U. Colorado</td>
<td>Signal extraction &amp; modelling</td>
<td>Graduate student; data analysis</td>
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Summary and Conclusions

• The redshifted 21-cm Global Spectrum at \( \lesssim 30 \text{ MHz} \) offers the prospect of probing the nature & character of Dark Matter in the Dark Ages.
• These observations need to be conducted in space, in orbit of the Moon, to eliminate Earth ionospheric & RFI effects.
• Projection-induced polarization provides an independent measure of the galactic foreground.
• We developed a method which transforms the 21-cm signal extraction task from one where *absolute knowledge of system parameters* is required to one of *composing training sets where knowledge of the modes of variation* are used.
• We are developing a SmallSat mission concept (DAPPER) to utilize both polarimetry and pattern recognition to detect deviations from the standard cosmology model.