A Space-Based Observational Strategy for Hydrogen Cosmology Using Dynamic Polarimetry and Pattern Recognition

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What is the 21-cm Global signal?

**Spectral Features:**

**A:** Dark Ages (test of standard cosmological model)

**B:** First stars ignite (Cosmic Dawn)

**C:** Black hole accretion begins

Models courtesy of Jordan Mirocha
Why is this a Challenging Observation?

Foreground Characteristics
- Spectrally smooth
- Spatial structure
- Polarized

Signal Characteristics
- Spectral structure
- Spatially isotropic
- Unpolarized

Weighting by antenna beam introduces spectral structure in foreground (e.g., Bernardi et al. 2015, Mozdzen et al. 2016)
How Can Polarimetry Help?


**Ideal Simulation of the Dynamic & Asymmetric Foreground**

- **A. 4 symmetric point sources** revolving about pointing center
- **B. 3 weak sources & 1 strong source** revolving
- **C. Actual sky map** (Haslam et al. 1982) centered on North Celestial Pole

*Remember:* No net polarization expected from isotropic global 21-cm signal
The Cosmic Twilight Polarimeter (CTP): Dynamic Polarimetry Testbed

Nhan, Bradley, & Burns, 2018

Operates over 60-80 MHz

Nhan, Bradley, & Burns, 2018
Initial Results from the Cosmic Twilight Polarimeter

Data consist of Stokes I,Q,U,V in frequency channels as a function of time at \( \approx 82 \) MHz.

After extensive RFI editing and averaging, Fourier transform binned data channels to measure dynamical frequencies \( (n) \) for Stokes Q,U.

\( n = 2 \) is expected twice diurnal signal and is tentatively detected in these data.

Caveats:

- Simulation only contains first order models of beam distortions due to ground and horizon effects.
- Very few clean channels due to severe RFI.
How can we extract the 21-cm signal?

Employ Pattern Recognition 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 at the meeting:
- Next talk by D. Rapetti, 312.03, *SVD/MCMC Pipeline for Separating the Global 21-cm Signal from Foregrounds/Systematics.*
- Poster by K. Tauscher, 319.05, *Characterizing the 21-cm absorption trough with pattern recognition and a numerical sampler.*
How much difference does polarization data make?

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:
  - **Blue curve:** Maximum cooling rate is the adiabatic rate, but occurring earlier.
  - **Red curve:** Cooling rate both lower and earlier.
  - **Magenta curve:** Cooling rate not monotonically declining (i.e. there is a ‘preferred epoch’ of excess cooling).

Models courtesy of Jordan Mirocha
The Dark Ages Polarimetry PathfindER (DAPPER): A Space-based SmallSat Testbed

- DAPPER will be placed in proximity to NASA’s Lunar Orbital Platform-Gateway to reduce Earth-based RFI.
- Operates over bandwidth of 15-30 MHz ($93 \geq z \geq 46$).
- Dual orthogonal $\approx 7$-m tip-to-tip wire dipole antennas deployed successfully many times (e.g., WIND/WAVES).
- Low noise amplifiers & dual channel receiver to measure all 4 Stokes parameters. Based upon FIELDS instrument to be flown on Parker Solar Probe (collaboration with S. Bale, Berkeley).
Summary and Conclusions

• 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.

• Applying this method to simulated 21-cm experiment data sets using dual-polarized antennas, we extracted a wide variety of input signals with a 95% confidence error of $\lesssim 30$ mK.

• The CTP ground-based prototype has tentatively detected the expected dynamic polarization signal from the Foreground.

• We are developing a SmallSat mission concept (DAPPER) to utilize both polarimetry and Pattern Recognition to detect the expected turning points in the Global 21-cm spectrum.