Using induced polarization to measure the global 21-cm signal from the lunar farside

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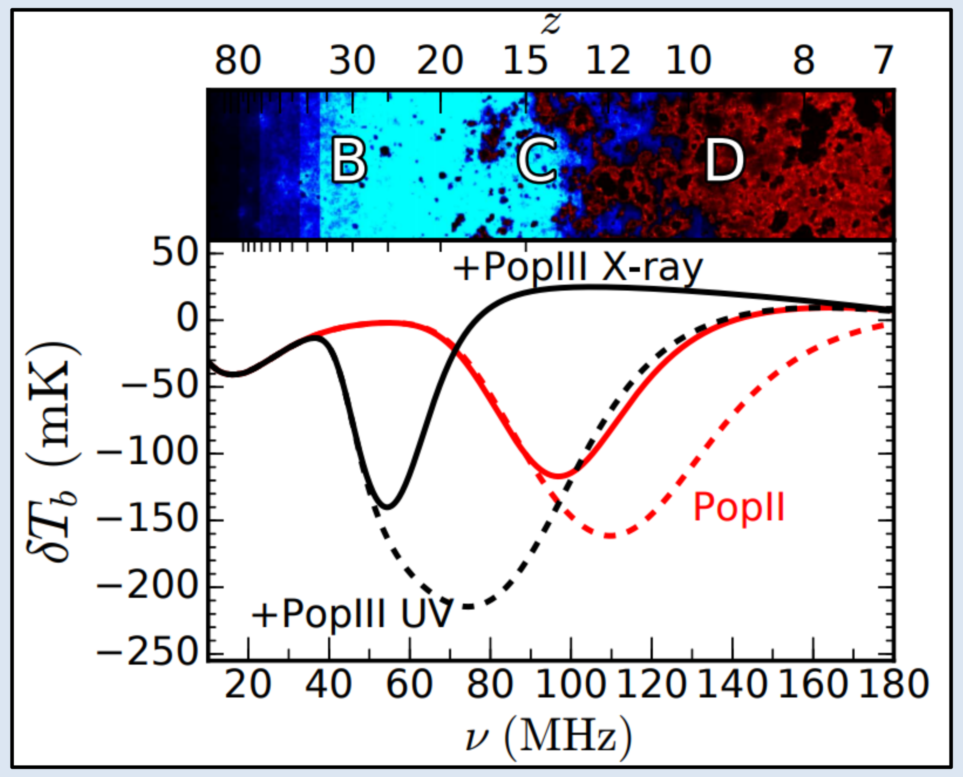
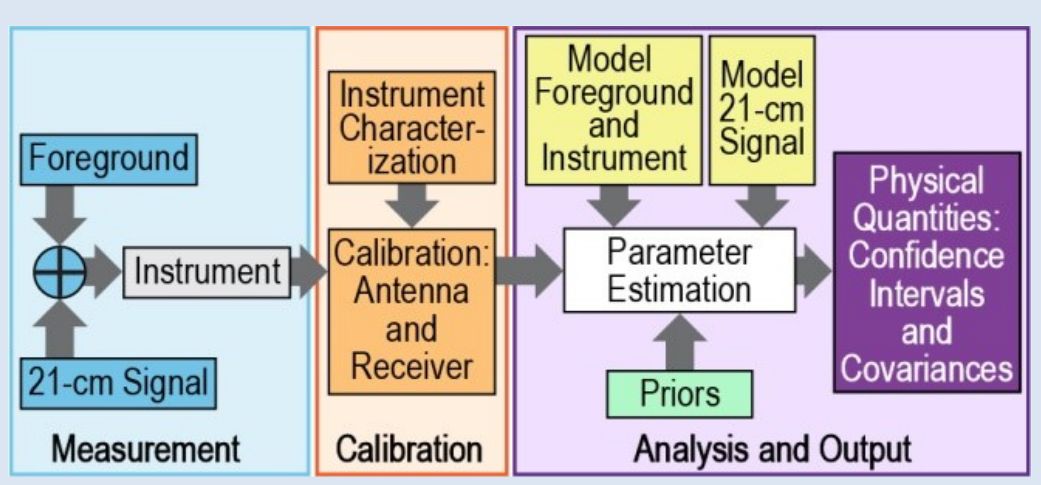
Background

The sky-averaged highly redshifted 21-cm line from the early Universe's neutral Hydrogen, known as the global 21-cm signal, is an imprint of the heating and ionization properties of the gas which makes up the InterGalactic Medium (IGM).



As part of the SSERVI's Network for Exploration and Space Science (NESS), we study the properties of the first stars and black holes in the Universe and how to infer them from this history, beginning to fill the gap in our knowledge of the Universe's history between t≈400 kyr and t≈1 Gyr. Between these times, the first stars ignited (region B in figure), the first black holes accreted (region C in figure), and the Hydrogen filling the Universe was ionized (region D in figure). There are currently no measurements corresponding to the events marking regions B and C and only weak limits on cosmic reionization.

Pipeline outline

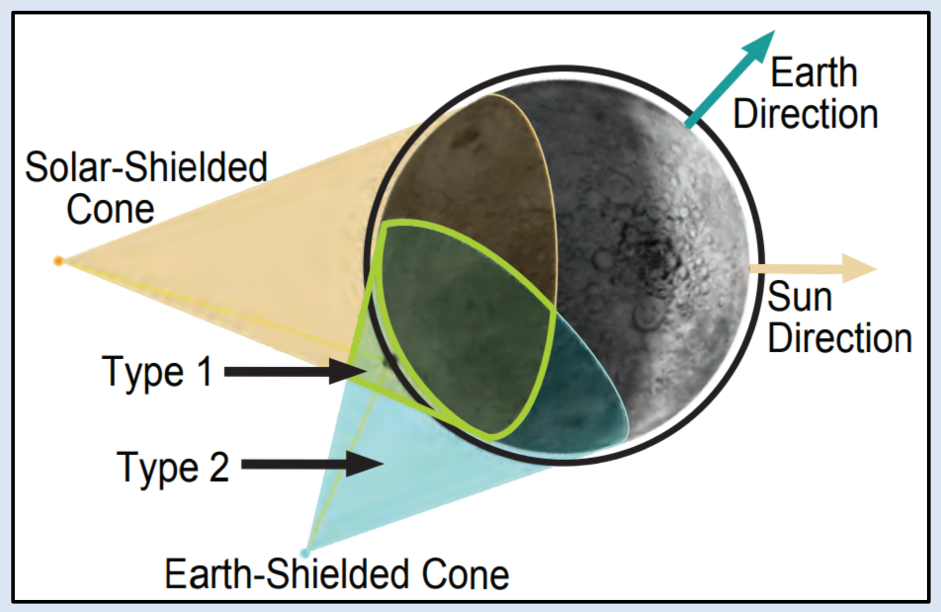


Flowchart outlining structure of signal extraction pipeline. The signal is measured in combination with the foreground through the instrument. The data is then calibrated before parameter estimation is performed. For more details on the pipeline, see Burns et al. (2017) and the companion poster by Rapetti et al.

Lunar farside advantages

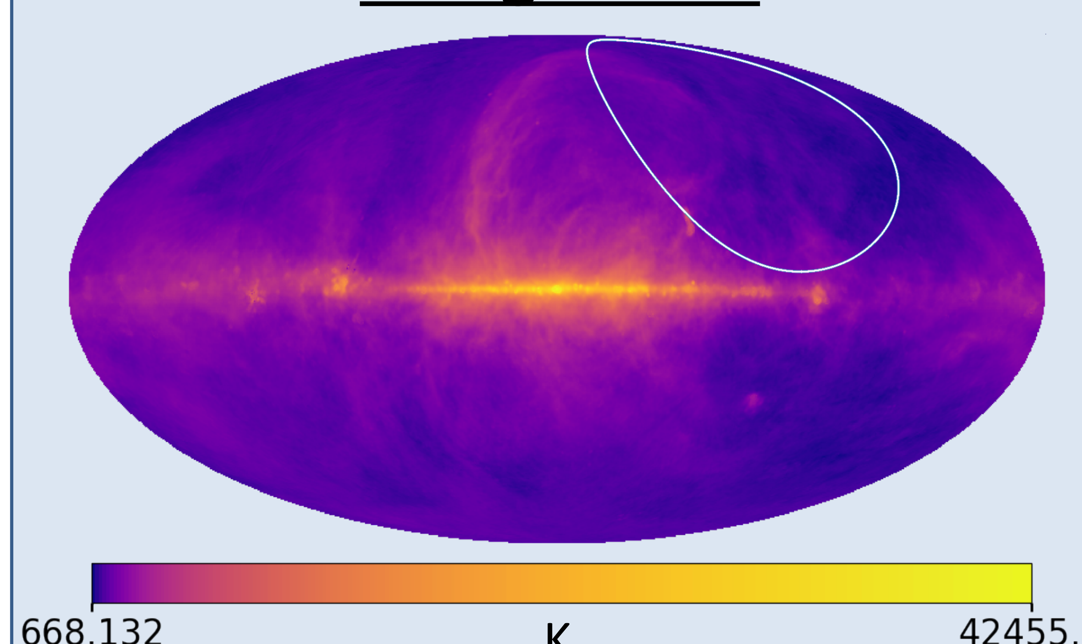
The ideal place from which to measure the 21-cm global signal is the lunar farside due to:

1. Unmatched isolation from human-generated Radio Frequency Interference (RFI)
2. No systematic effects from Earth's ionosphere
3. Close enough for high S/N beam calibration using Earth-based telescope (if observatory is orbiting)



Geometry of lunar shielding of Earth and the Sun. Optimal science occurs in the green region (labelled Type 1) where the Earth and Sun are both blocked. The Earth-shielded cone is fixed on the farside while the Sun-shielded cone rotates around the Moon with a period of 1 lunar month.

Foregrounds

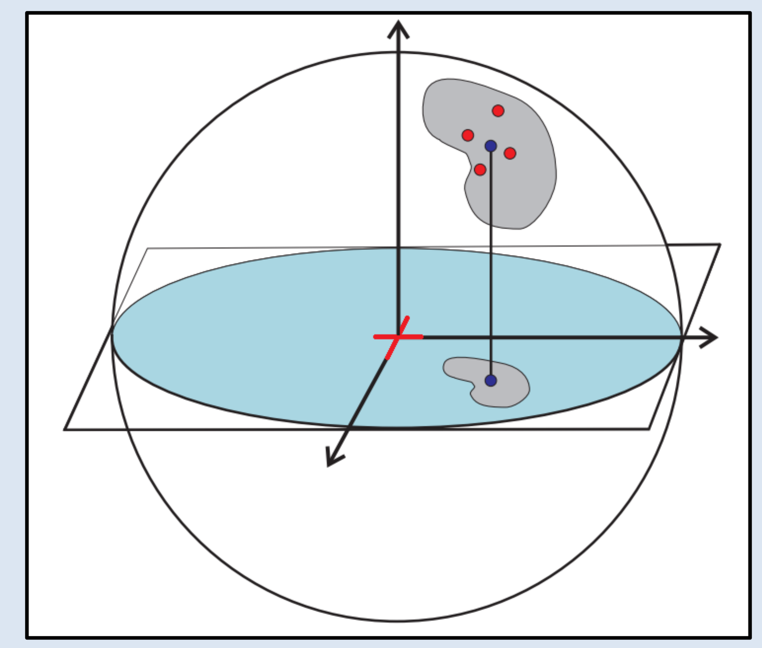


Map from Haslam et. al. (1982) scaled down to 80 MHz with a large (~80° FWHM) beam pointed away from the galactic plane. The color scale is logarithmic and perceptually uniform. The foregrounds are very large, so characterizing them independently of the signal is of utmost importance.

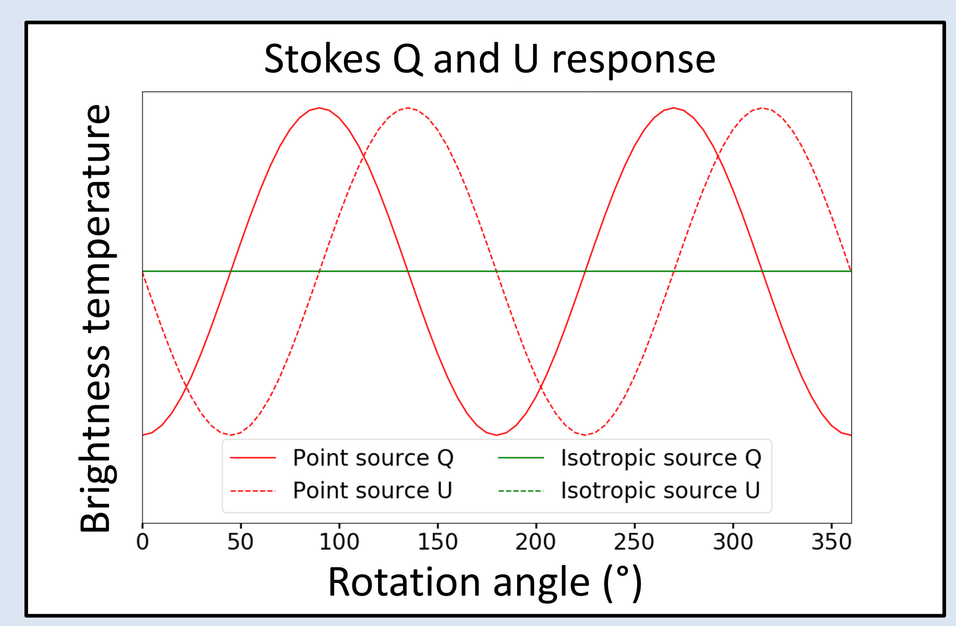
The spatial structure of the foreground allows for it to be better separated from the isotropic 21-cm global signal. Projection induced polarization can be used to take advantage of this difference.

Projection-induced polarization

Projection of sources onto the antenna plane causes polarization of incoming light to be measured even if the light is unpolarized. Knowing how this projection affects each of the two antennas allows us to constrain the foreground more independently from the signal.



The projection of sources onto the antenna plane distorts its shape, generating different responses from the two antennas which is observed as a signal in the polarized Stokes parameters. Figure from McEwen & Wiaux (2011). Isotropic sources like the 21-cm signal remain isotropic under this projection and thus produce no polarization response.



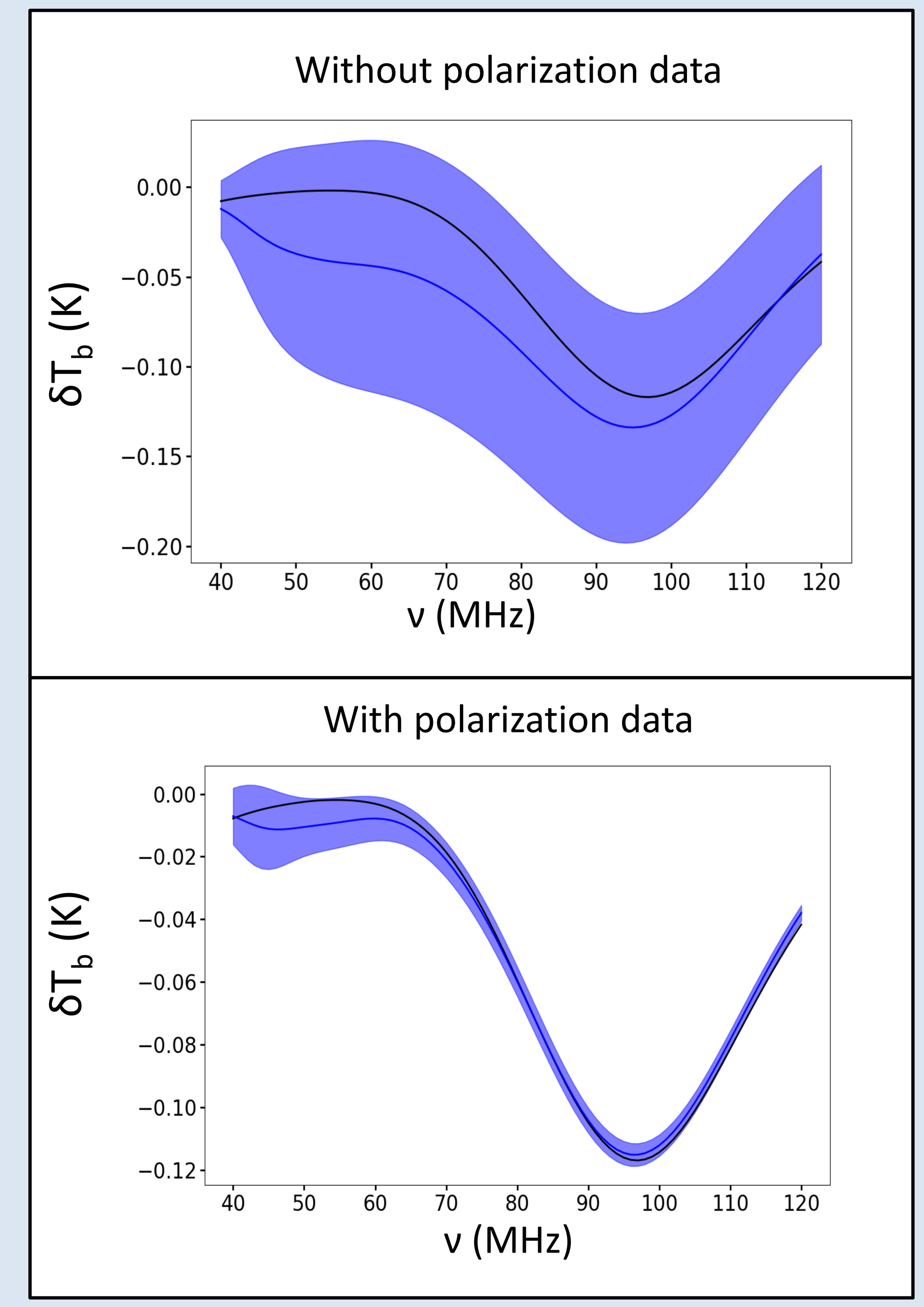
Projection induced polarization is insensitive to isotropic sources such as the 21-cm global signal but is sensitive to spatial anisotropies like those in the foreground (which can be viewed as an asymmetrical assembly of point sources).

Pipeline realism

The signal extraction pipeline uses a foreground model with spatially-varying spectral structure. It also includes the Moon through thermal emission covering 2π sr of the sky. The foreground is weighted and averaged using the antenna beam and the resultant signal is sent through a radiometer. The pipeline handles systematic effects from realistic instruments.

Results

The bias and error of the signal extraction decrease by an order of magnitude when the polarized Stokes parameter data are included, owing to the fact that the polarized response contains foreground but no global signal.



Conclusions

It is highly advantageous for measurements of the 21-cm global signal to be performed with dual antennas connected to receiver systems capable of handling polarization signals.

Acknowledgements

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References

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McEwen, J.D. & Wiaux, Y., *MNRAS* 413 (2011) 1318-1332.