Towards a lunar farside hydrogen cosmology telescope: characterizing the absorption trough observed by EDGES

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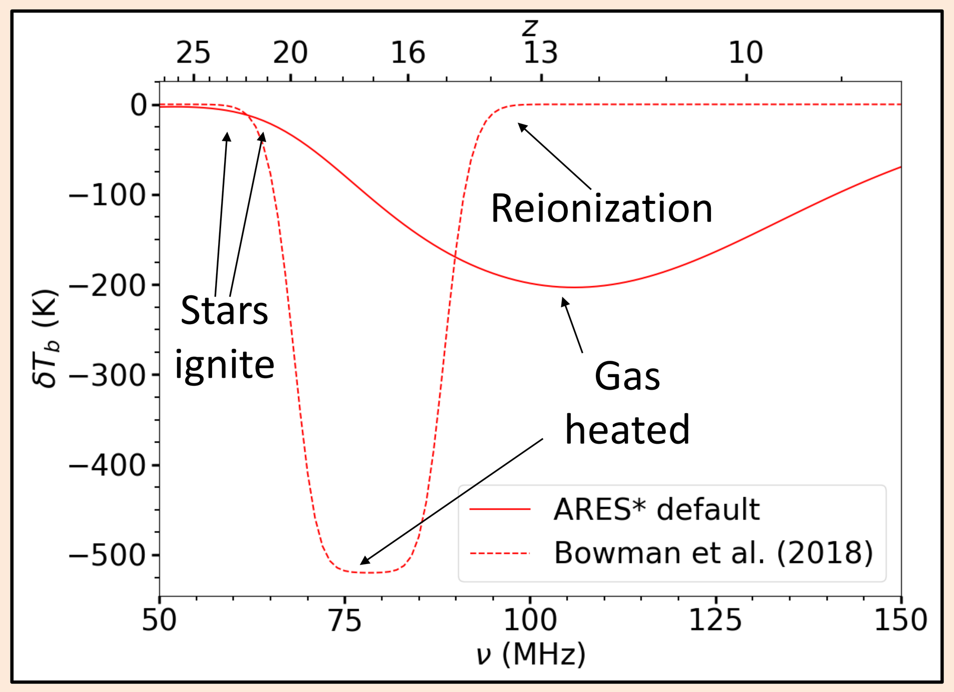
Background

Hydrogen's 21-cm line, highly redshifted and averaged over the sky,—known as the global 21-cm signal—reveals information about cosmology and the statistical astrophysics of the first stars and black holes. Since frequency is directly related to redshift, it can be read (from low to high frequency) as a history. The ideal location from which to measure the signal—used in simulations here—is the Lunar farside, due to Earth-based radio interference and ionospheric effects.



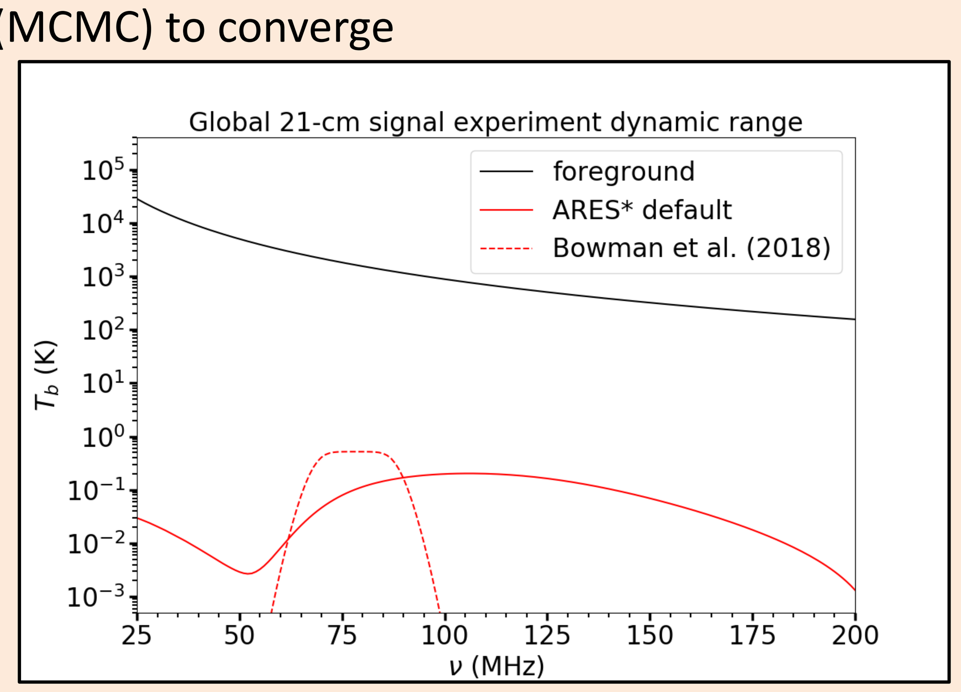
Analysis challenges

1) Radiation from Milky Way >10^4 times larger than the signal

2) Spectrally smooth foregrounds contaminated by beam variations

3) No obvious justified models for separating signal from foregrounds and systematics

4) Physical models too slow for methods such as a straightforward Markov Chain Monte Carlo (MCMC) to converge



*https://bitbucket.org/mirochaj/ares

Full data analysis pipeline

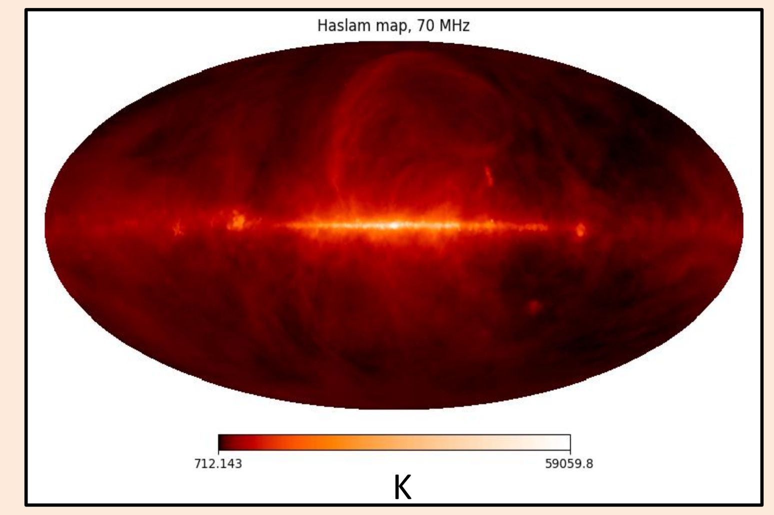
data

Training set simulation: Using realistic Galaxy maps and instrument model, assemble a set of curves which best characterizes the foreground and systematic effects in the data.

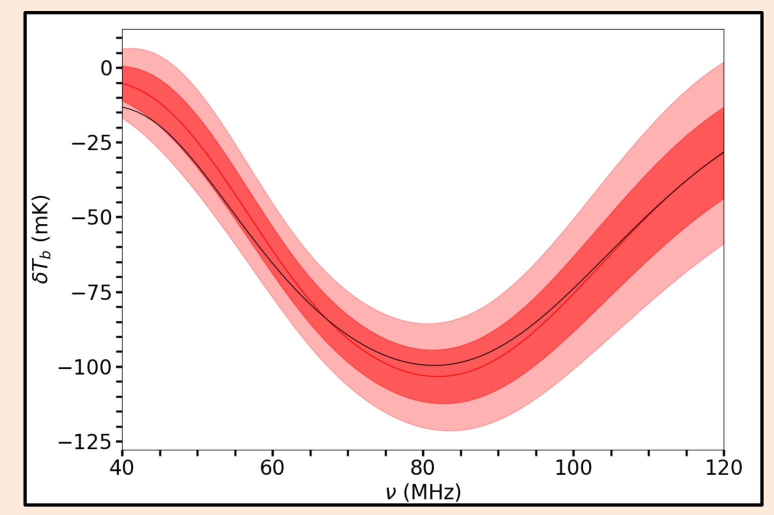
Linear fit with *pylinex*†: Use Singular Value Decomposition (SVD) to extract the main modes of variation from training set and use them in fit, separating signal from foreground and systematics.

Signal parameter distribution estimation: Perform a least squares fit of a physical signal model to the global signal estimated with *pylinex*, yielding preliminary parameter values with uncertainties.

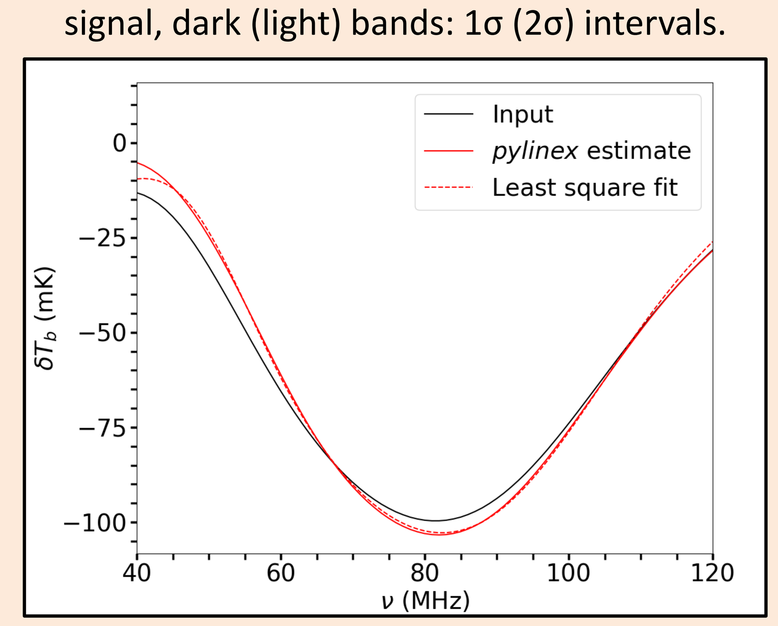
Numerical likelihood exploration: Using the distribution from the previous step as a starting point, initialize a Markov Chain Monte Carlo (MCMC) sampler to systematically explore the distribution of parameters of the first stars.



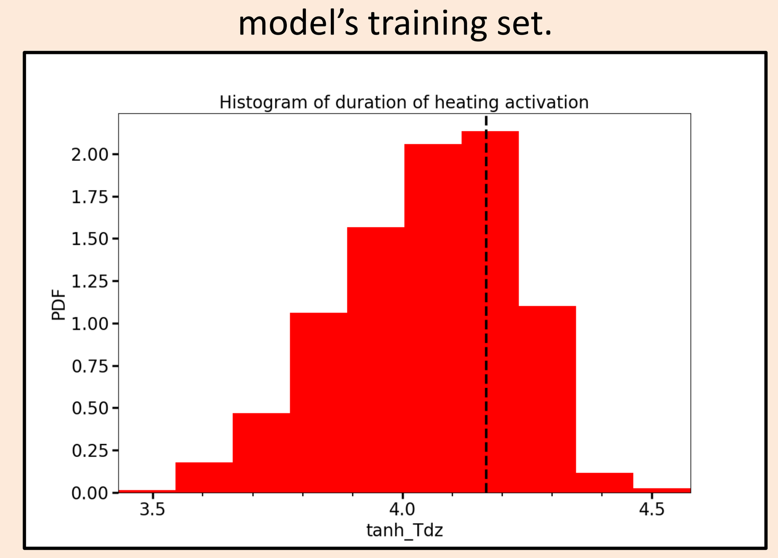
Galaxy map (Haslam et al. 1982) scaled to 70 MHz using a -2.5 spectral index.



Simulated *pylinex* signal fit in a case with polarization to provide signal-free measure of foreground (see Nhan et al 2018). Black line: input signal, red line: maximum likelihood signal, dark (light) bands: 1σ (2σ) intervals.



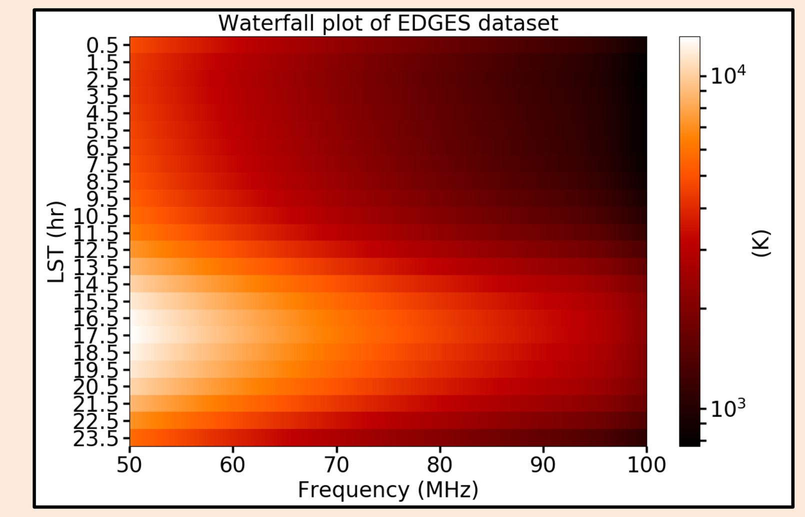
Least square fit of the physical signal model to the pylinex signal fit obtained from the model's training set.



A histogram of a physical parameter describing how quickly the first stars and black holes heated up the universe, computed with the pipeline's sampler.

†https://bitbucket.org/ktausch/pylinex, see Tauscher et al. (2018)

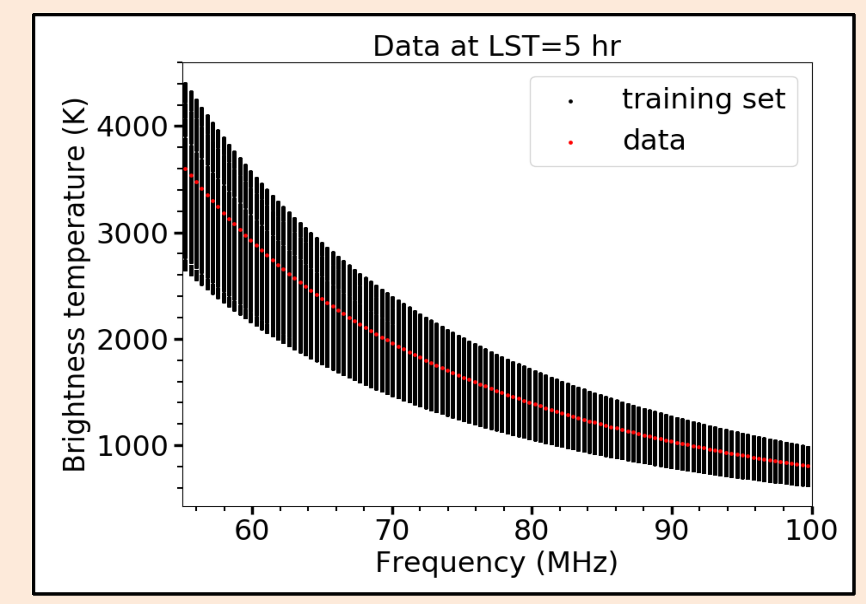
Applying to EDGES



Plot of the time-binned EDGES data, presented in Bowman et al. (2018), which is in the process of being reanalyzed with the pipeline presented here.

Training set realism

1) Multiple simulated beams
2) Uncertain rotation of beam about zenith
3) Haslam map with errors
4) Simulated LST dependence



Current best foreground training set for EDGES data. Only a single spectrum is shown here, but multiple spectra (corresponding to multiple LSTs) are simulated for each case to take advantage of time dependent structure.

Conclusions

We have based an analysis pipeline around a pattern recognition technique (SVD) which separates the 21-cm global signal from systematic effects by taking advantage of structure in the data and a MCMC initialization procedure which yields physical parameters with consistent uncertainties and quick convergence. We are currently applying this pipeline to EDGES data.

Acknowledgements & References

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Haslam, C.G.T., Salter, C.J., Stoffel, H., Wilson, W.E. *AASS* 47, 1982.
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