Constraining the unexplored period between the dark ages and reionization with observations of the global 21 cm signal

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Why Global?

- Simpler, lower cost
  - Single Dipole Experiment
- Higher redshifts
  - JWST, GMT, ELT, TMT may provide glimpses from $z \sim 12$ to $z \sim 20$
Absorption Signal

- For IGM gas temperature less than CMB temperature.
- Why do we see an absorption signal?
- How do we cool below CMB temperature?
Redshifted 21 cm

- The 1420 MHz signal is redshifted to a corresponding 50-200 MHz for \( z = 6-27 \).

\[
T_b \approx 27 x_H \left( \frac{T_s - T_\gamma}{T_s} \right) \left( \frac{1 + z}{10} \right)^{1/2}
\]

- Why neglect the fluctuation terms?
Five events in 21 cm history

- Collisional coupling becoming ineffective.
- Ly\(\alpha\) coupling becoming effective.
- Heating occurring
- Reionization beginning
- Reionization ending
Foregrounds

- In tomography, inhomogeneities fluctuate rapidly.
- Only the largest modes of signal are in danger of being removed.
- In global signal, the smoothness of the signal makes it a concern when throwing out the foreground.
Foregrounds
Fisher Matrix

- Hard to quantify the ability of 21 cm measurements to constrain astrophysical parameters with Monte Carlo.
  - Large space of model parameters
- Can use Fisher matrices if the likelihood is \( \sim \) Gaussian

\[
F_{ij} = \frac{1}{2} \text{Tr} \left[ C^{-1} C_{,i} C^{-1} C_{,j} + C^{-1} \left( \mu_{,i} \mu_{,j}^T + \mu_{,j} \mu_{,i}^T \right) \right]
\]
Fisher Matrix

- Covariance matrix is taken to be diagonal. Why?
- Best parameter constraints are given by the Cramer-Rao inequality. Which is?
Reionization

- Want to constrain the evolution of $x_H$
- Have constraints from Ly$\alpha$ forest and CMB optical depth. How?
- Reionization is expected to be relatively extended
- Toy model: tanh with midpoint $z_f$ and duration $\Delta z$.
- Assume: 21 cm spin temperature is saturated. Valid?

$$T_b(z) = \frac{T_{21}}{2} \left( \frac{1+z}{10} \right)^{1/2} \left[ \tanh \left( \frac{z - z_f}{\Delta z} \right) + 1 \right]$$
Tanh reionization models
First Sources

- This region in z-space is unconstrained by existing observations.
- Parametrize by the turning points in the evolution
  - Minimum from ineffective collisional coupling
  - Maximum from Lyα pumping
  - Minimum as heating becomes important
  - Maximum from saturation
First Sources

- Only the turning point corresponding to the heating has a large area in $T_b$-$v$ space.
- Other turning points are constrained by cosmology choice, and emissivities.
- This makes observations constraining this point extremely helpful to constrain different models and parameter spaces.
Dark Ages

- At these low frequencies, global measurements are more feasible than tomographic measurements.
- Easier to launch a single dipole experiment than the large area of interferometers.
- Would still need ~1000 hrs of integration time to get 4 mK sensitivity with one dipole
Conclusions

- Global measurements are cheaper and simpler than tomographic measurements.
- 21 cm signal is a sensitive thermometer.
- Galactic foreground fitting takes at least 3rd order poly.
- Fisher matrix formalism works very well.
- Deepest absorption trough provides best observational target.
- Detecting absorption in dark ages requires long integration times.