Echoes of the Early Universe: Forecasts for 21cm & Galaxy Cross-Correlations

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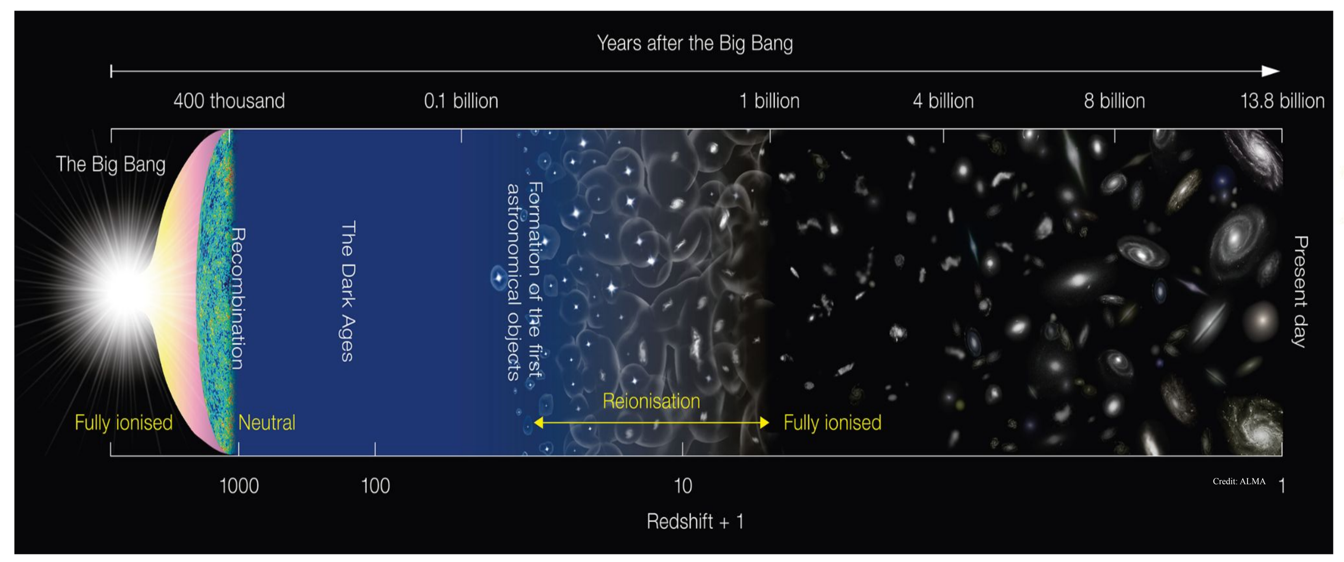
Overview

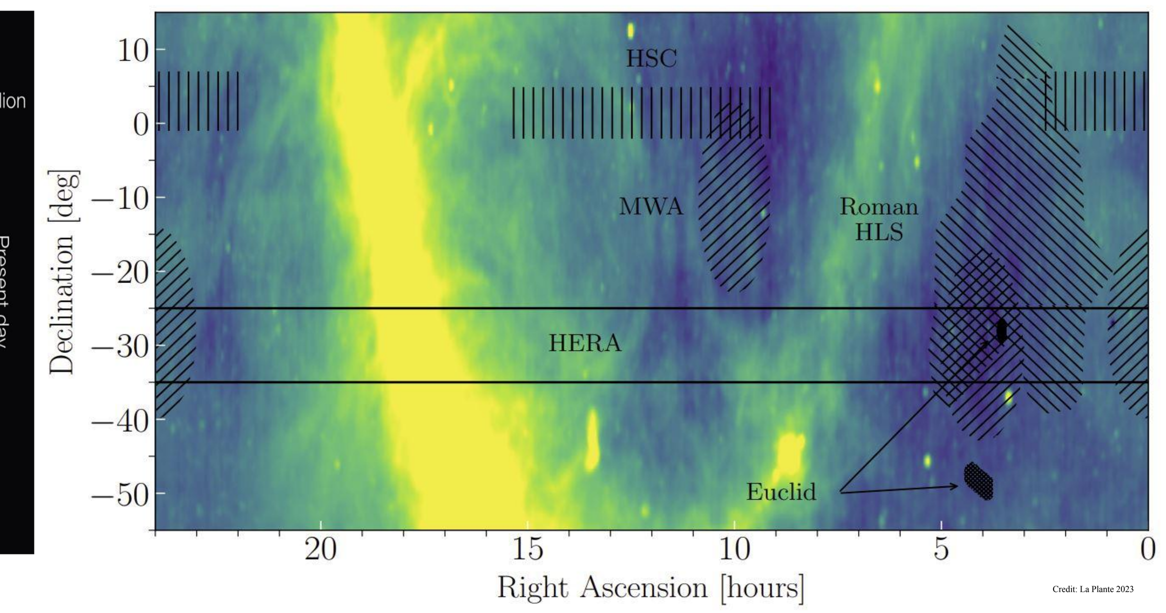
Cross-correlations are increasingly valuable in cosmology, especially for 21 cm analysis due to the signal's faintness and challenges in radio data processing. To complement upcoming 21 cm auto power spectrum measurements, we explore cross-correlation prospects between NASA's ROMAN Space Telescope and HERA. Prior studies suggest a promising detection, but we extend this by forward modeling the 21 cm signal into HERA-like visibilities and performing cross-power calculations with high-redshift galaxy maps.

Introduction

The Cosmic Dark Ages lasted from recombination (~400,000 years post-Big Bang) to the first stars and galaxies (~500 million years later), marking the Epoch of Reionization (EoR). The 21 cm transition of neutral hydrogen traces this era, with ionized regions suppressing the signal and creating detectable fluctuations. Radio interferometers like HERA aim to measure the 21 cm power spectrum with high sensitivity.

Studying the EoR reveals insights into early galaxies, cosmic evolution, and dark matter. This research cross-correlates simulated HERA and *ROMAN* data over their 500-square-degree overlap to estimate the cross-power spectrum. It tackles challenges like 21 cm foregrounds, thermal noise, and shot noise, improving our understanding of the EoR and the early cosmic structure.





Methodology

Generate Coeval Cubes of 21cm and Galaxy Fields

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Convert Cubes into HEALPix Maps and Generate Diffuse Sky Models:

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Calculate Visibilities for Radio Interferometers

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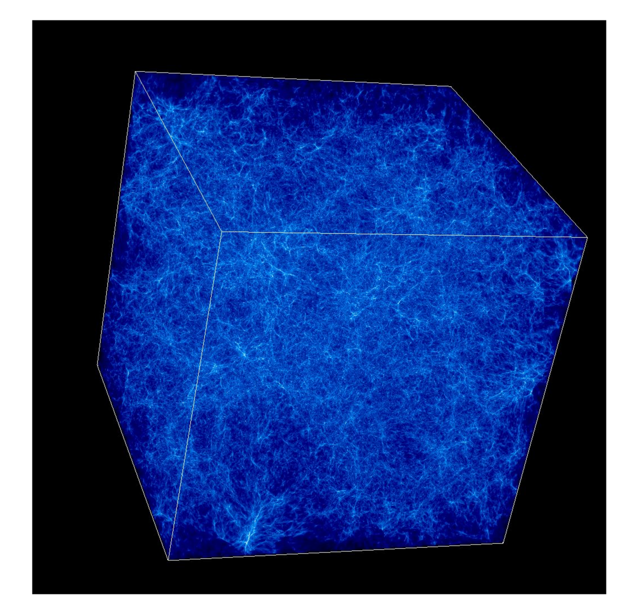
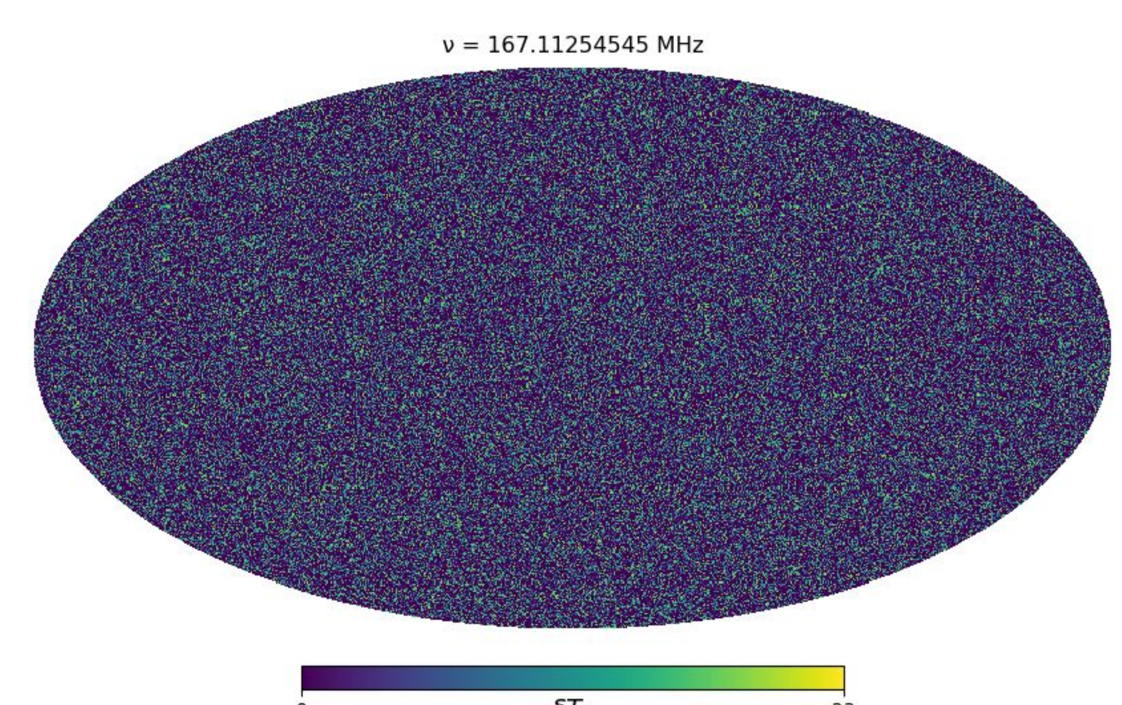
Generate Cross-Power Spectra in Visibility Space & Compute Signal-to-Noise Ratio

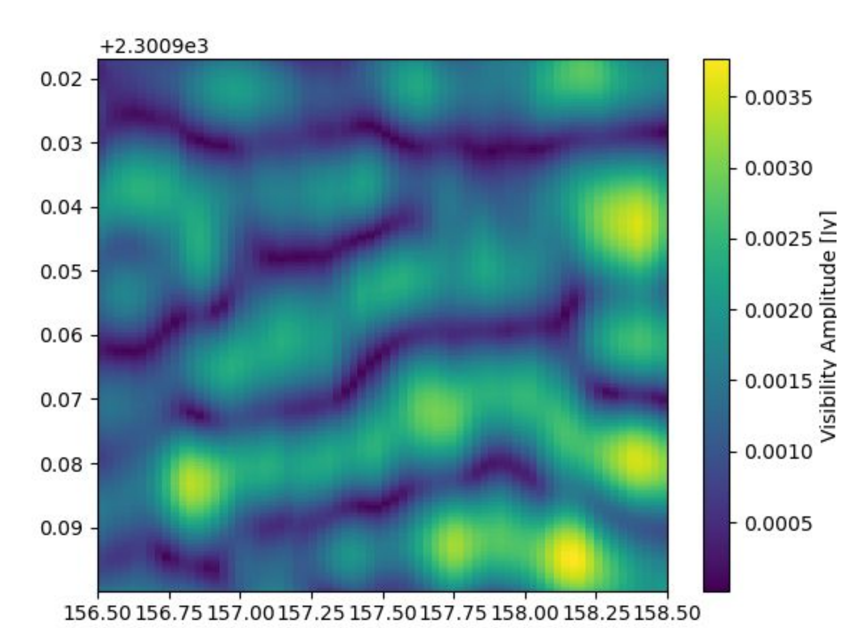
$$P_{21\,x\,gal}(k_{/\!/},k_{\perp}) \sim \tilde{V}_{21}(k_{/\!/},k_{\perp})\ x\ \tilde{V}^*_{gal}(k_{/\!/},k_{\perp})$$

$$\hat{s}(k_{\parallel},k_{\perp}) = \sqrt{N_{patch} dN(k_{\parallel},k_{\perp})} \frac{P_{21xgal}(k_{\parallel},k_{\perp})}{\sigma_{21xgal}(k_{\parallel},k_{\perp})}$$

$$\left(\frac{S}{N}\right)^2 = \sum_{k_{\parallel},k_{\perp},z} \hat{s}^2(k_{\parallel},k_{\perp},z)$$







Results

We aim for a ≥ 3σ SNR (99.7% confidence), validating cross-correlation as a key tool for future HERA and ROMAN data. SNR could reach 12σ, depending on factors like ionization history and redshift uncertainties (La Plante et al 2023). A 3σ detection would confirm this method's viability, aiding 21 cm signal analysis and verifying HERA's detections as an independent consistency check, enhancing our understanding of the EoR and early cosmic structures.

Discussion

Cross-correlating the 21 cm signal with galaxy surveys enhances our understanding of the EoR, improving sensitivity and disentangling foregrounds. Pairing with probes like the kSZ effect (Simons Observatory) and SPHEREx refines EoR models and reveals early galaxy formation and cosmic structure growth. These methods also shed light on dark matter, large-scale structure evolution, and ionization history. Future advancements with HERA and SKA will improve sensitivity, enabling clearer detections and deeper insights into cosmic evolution, dark matter, and inflation.

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