Optimizing Lunar Radio Telescopes: Reliable Extrapolations of the First Galaxies

A.C. Trapp, Steven R. Furlanetto

UCLA

Overview:

The Universe's Hydrogen underwent a phase transition – from neutral gas to plasma – at an age of around 1 billion years. Galaxies are the likely culprit, but getting direct evidence will be an extreme challenge. Instruments such as JWST will observe galaxies in this era, and 21-cm experiments such as HERA and the SKA (on Earth) and FARSIDE (on the Moon) will measure the ionization state of Hydrogen in the early Universe. We propose a model that connects galaxies and the ionization field surrounding them. This model will help us find an efficient way to combine galaxy and 21-cm observations despite their large differences in scale.

The Analytic Model

Current analytic galaxy models and re-ionization models are both built on excursion set formalism (Lacey & Cole et al., 1993). Our model will combine these approaches in a self-consistent way. Under simple assumptions, our galaxy models can predict how many ionizing photons are produced per baryon in a given region. We then calculate the ionization state of the region, assuming all ionizing photons that escape from galaxies in that region are absorbed by the IGM, and that no photons from neighboring regions leak in. These assumptions are reasonable as long as the mean free path (mfp) of an ionizing photon is much smaller than the size of the region. The mfp is likely < 20M pc at redshift 6 (see D'Aloisio et al., 2018).

Our models will then simultaneously predict the galaxy population and distribution of ionization states at each redshift.

Combining Observations

Beardsley et al. (2015) develop a method for picking out regions in 21-cm maps that are more likely to be ionized than neutral, which can then be targeted by JWST for study. We would like to build on the informative power of this work by introducing our models.
Suppose a 21-cm experiment identifies one such region that is likely to be ionized, and one that is likely to be neutral. Our model predicts the difference in the galaxy population between those two regions. These predictions can be used to inform the amount of JWST time that would be required to distinguish the regions based on galaxy population, as well as the sensitivity and resolution required of 21-cm experiments such as FARSIDE to make this comparison.

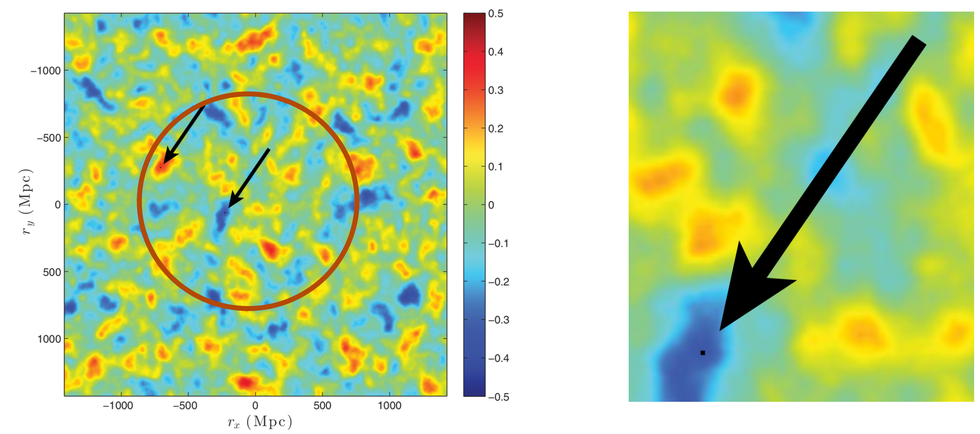

Figure 1. The difficulty of combining galaxy observations with 21-cm observations. *Left:* the ionization state of the Universe from a simulation. The red circle indicates the potential angular resolution of HERA (~1 deg). *Right:* A zoom-in of the left panel, showing the field of view of JWST (~10 square arcmin). This scale mismatch is the primary obstacle in combining these measurements.

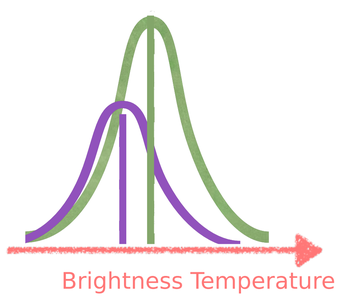

Figure 2. Beardsley et al. (2015) propose a method that mitigates this scale mismatch. If an individual pixel has a very high brightness temperature, it is much more likely to be an actual ionized region (green distribution) than simply noise (purple distribution), even if the noise and ionization signal overlap significantly. These high-brightness temperature pixels can be followed up with JWST.