Comparing Parameter Inference Techniques in the Context of Cosmic Reionization

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Comparatively little is known about the period of Cosmic Dawn and the Epoch of Reionization in the timeline of the universe. The onset of Cosmic Dawn is marked by the formation of the first luminous cosmic structures, such as star-forming galaxies. The photons emitted by these first sources of light then ionized the neutral hydrogen which predominantly made up the intergalactic medium (IGM), facilitating the last phase transition in the evolution of the universe.

Since Cosmic Dawn and Reionization took place so early in the universe's history, light emitted during that time is highly redshifted and extremely faint, making direct detection challenging. Consequently, the exact timing and duration of these epochs remain uncertain. However, with telescopes like the James Webb Space Telescope (JWST), we can better observe light emitted from these epochs at higher redshifts.

In this project, I work with the following mathematical model which was derived using radiative transfer simulations of Reionization [4] [2]:

$$\frac{R_{\rm ion}}{M_h} = A\,(1+z)^D \left(\frac{M_h}{B}\right)^C \exp\left[-\left(\frac{M_h}{B}\right)^{-3}\right] \tag{1}$$

Where $R_{\rm ion}$ is the ionization rate, M_h is solar mass, and z is redshift. The letters A, B, C, and D are free parameters where A is the amplitude of $R_{\rm ion}$, B is the minimum halo mass, C is the slope of the $R_{\rm ion} - M_h$ relation, and D is the redshift dependence of ionization rate for a given halo mass [4].

The goal is to calibrate the model parameters to reproduce a range of observational constraints on Reionization and Cosmic Dawn, including the volume-averaged neutral hydrogen fraction ($x_{\rm HI}$) of the IGM inferred from quasar absorption spectra and Lyman- emitters, the ionizing emissivity ($N_{\rm ion}$) compiled from the measurements of the mean Ly-α opacity and temperature of the IGM, and the optical depth to Thomson scattering (τ) measured from CMB observations by Planck [1].

I compare two Python packages, EMCEE and NAUTILUS, in this project. EMCEE is an implementation of the Markov Chain Monte Carlo (MCMC) method often used in astronomy [3]. NAUTILUS is a newer inference framework that employs nested importance sampling and leverages neural networks to improve sampling efficiency and convergence [5]. I compare their performance in the context of Reionization in our work and find that NAUTILUS is an alternative tool that can be integrated into the study of Reionization and broader cosmological analyses.

References

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