Research Plan

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1 Convergence of MCMC (RBFI version)

I have developed a script that runs a Markov chain Monte Carlo to find the best-fit parameters to the EDGES data. This script has two main versions, which use different methods for finding the theoretical global 21cm curve. The older version runs the ARES module in each step. On the other hand, the more recent version uses a radial basis function interpolation of ARES to simulate the curve. This way, the run time is decreased by a factor of 100.

Currently, we have a converged RBFI-based chain with 10^7 steps. However, we aim to make the MCMC converge in 10^3 to 10^4 points. Two methods can be used to gain this result: the effect of the long chain's covariance matrix or combining the Levenberg Marquardt algorithm and MCMC.

According to Jon's suggestion, we can construct the covariance matrix from a converged long chain, then draw an arbitrary number of samples from it and consider them a new change for MCMC. With the help of this new shorter chain, you can have an MCMC that converges way sooner.

The LM algorithm is another path to find the covariance matrix and is more precise than the one described before. It uses the local gradient of chi-square to find the covariance matrix.

After we are done with these two, the RBFI needs to be updated to the latest version with the five-parameter phase space (This new version uses the more realistic galaxy model from ARES).

2 MCMC (ARES version)

Once we have a reasonably converged MCMC with RBFI, we use the same parameter space to run an MCMC with ARES. The run time for an MCMC, which calls ARES, is approximately 4 seconds per step. Therefore, I expect that the whole run time will take nearly 11 hours. This run time is lower than Niagara's limit of 24 hours; thus, we will not face any difficulties regarding this case.

3 Understanding the physical explanation of MCMC results

Once we have the MCMC results in hand, we need to understand what this point in parameter space physically means and what are the cosmological/astrophysical consequences of these specific parameter values.

4 Comparing with other works

Finally, We can check our final results with the previous similar studies! Below, you may find a list of related papers with a brief discussion over their content. This list might be updated in future.

- 21CMMC: an MCMC analysis tool enabling astrophysical parameter studies of the cosmic 21 cm signal [4]

  Based on the brief literature review that I have done, this is the most similar study to ours. They have developed an MCMC algorithm based on 21cmFast which uses two different EoR scenarios. I noticed two main differences with our project: 1. Use of 21cmFast instead of ARES, 2. They did not use real data (EDGES) for the MCMC.

Also, I found the following papers interesting:

- Constraining beyond CDM models with 21cm intensity mapping forecasted observations combined with latest CMB data [1]
- Parameters Estimation from the 21 cm signal using Variational Inference [5]
- CosmoReionMC: a package for estimating cosmological and astrophysical parameters using CMB, Lyman- absorption, and global 21cm data [3]
- Bayesian model selection with future 21cm observations of the epoch of reionization [2]

5 Welcome to the non-Standard Physics Realm!

Now that we are done with the standard physics part, we need to theoretically understand the effect of cosmic string wakes on our 21cm signal (which we already know from previous studies). Then, We need to figure out which parameters (from ARES/21cmFast parameter list) will be affected if we add this new segment to the underlying physical processes.

6 Repeat on Section 3

With this information available, we can again redo our step of understanding the physical explanation of MCMC results, but this time concerning the effects of cosmic string wakes. Moreover, we can check if the parameter values from our MCMC match the values that we theoretically expect from a 21cm signal affected by non-standard physics.

7 Adding the effect of cosmic string wakes to ARES and 21cmFast

In this step, we update these two modules to include the effect of cosmic string wakes and compare the outcome to the standard results (without the effect of cosmic string wakes).

References

[1] Maria Berti et al. "Constraining beyond ΛCDM models with 21cm intensity mapping forecasted observations combined with latest CMB data". In: *Journal of Cosmology and Astroparticle Physics* 2022.01 (2022), p. 018.

[2] T Binnie and JR Pritchard. "Bayesian model selection with future 21cm observations of the epoch of reionization". In: *Monthly Notices of the Royal Astronomical Society* 487.1 (2019), pp. 1160–1177.

[3] Atrideb Chatterjee, Tirthankar Roy Choudhury, and Sourav Mitra. "CosmoReionMC: a package for estimating cosmological and astrophysical parameters using CMB, Lyman-α absorption, and global 21 cm data". In: *Monthly Notices of the Royal Astronomical Society* 507.2 (2021), pp. 2405–2422.

[4] Bradley Greig and Andrei Mesinger. "21CMMC: an MCMC analysis tool enabling astrophysical parameter studies of the cosmic 21 cm signal". In: *Monthly Notices of the Royal Astronomical Society* 449.4 (2015), pp. 4246–4263.

[5] Héctor J Hortúa, Riccardo Volpi, and Luigi Malagò. "Parameters estimation from the 21 cm signal using variational inference". In: *arXiv preprint arXiv:2005.02299* (2020).