Imperial College London

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Glimpsing the Cosmic Dawn

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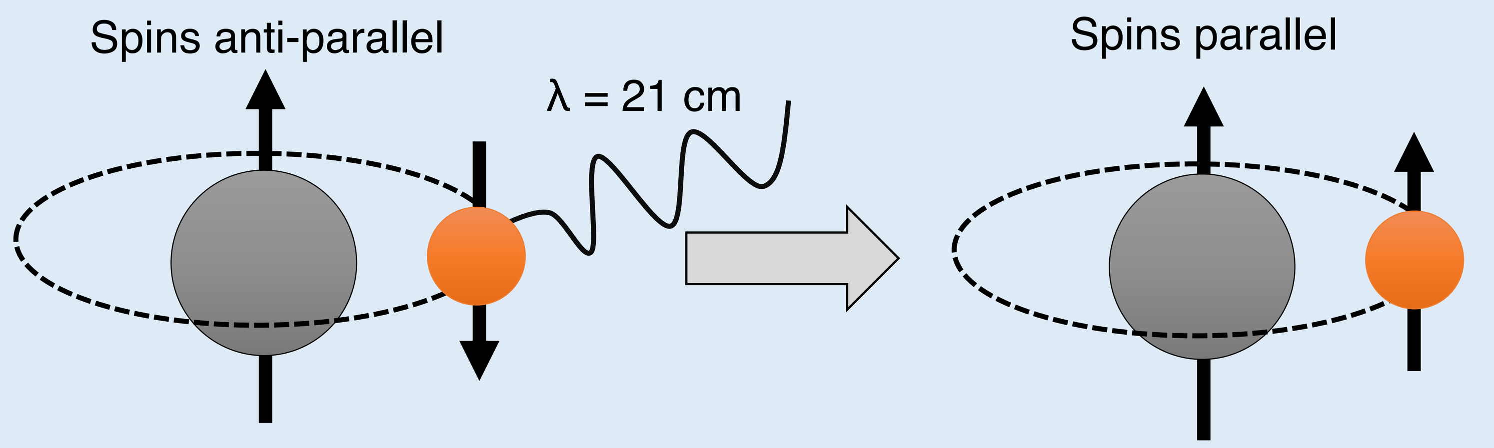
21 cm Hydrogen Line



About 75% of the intergalactic medium consists of hydrogen, which can be observed from the spectral line due to the **spin-flip transition** of its hyperfine ground state levels.

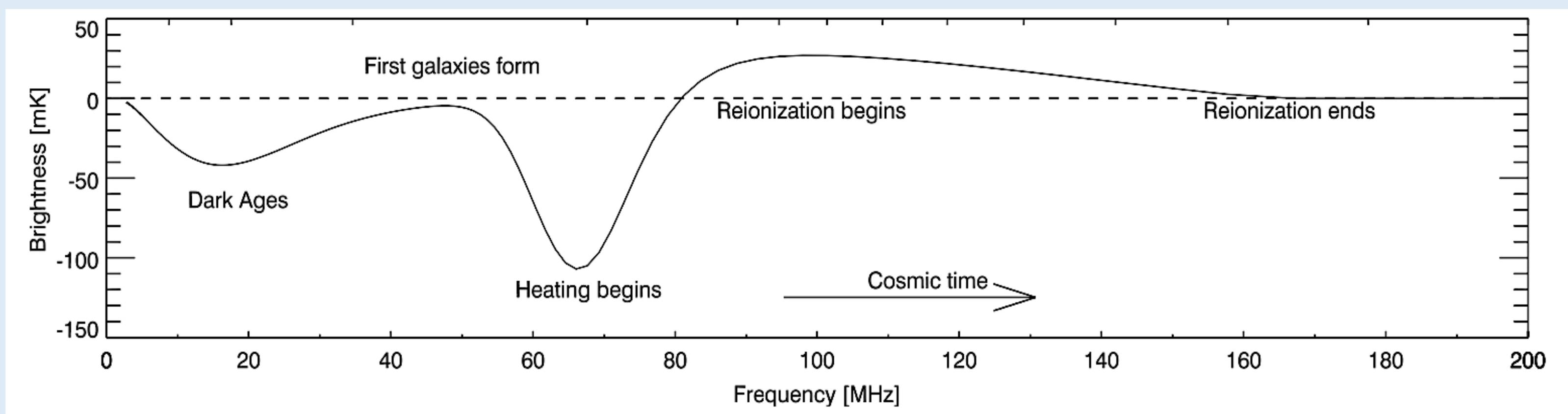
The transition corresponds to a **wavelength of 21 cm** and **energy of 1.4 GHz**.

Today, due to cosmological redshift, this spectral distortion would be observable at frequencies in the range **< 200 MHz**.

Global 21 cm Signature

The evolution of the brightness temperature of the 21 cm signal with frequency can be used to determine different epochs of cosmic history.

The **Cosmic Dawn** is when the first stars, black holes and galaxies form. In this era, 'spin-flip' radiation is emitted from hydrogen abundant throughout the universe due to UV radiation from the first luminous sources.

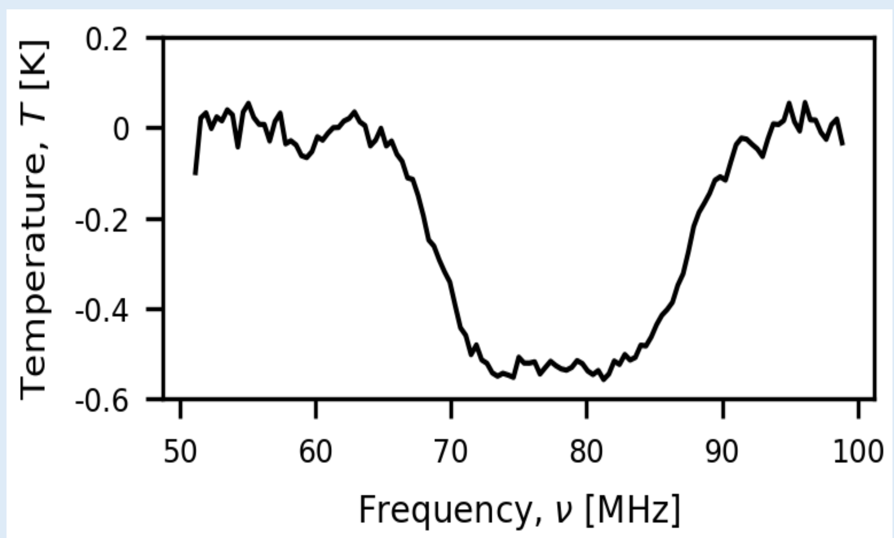


Evolution of the global 21 cm brightness temperature with frequency across cosmic time [1].

Detection?

In 2018, the Experiment to Detect the Global EoR Signature (EDGES) reported a detection of an absorption profile consistent with 21 cm signal expectations [2].

Square Kilometer Array (SKA) [3].



21 cm EDGES model with residuals.

However, analysis by Hills *et al.* revealed inconsistencies with the analysis, such as sub-zero Kelvin parameters and model degeneracies [4].

Project Aim

To simulate a simple model of the 21 cm model and explore techniques to robustly separate it from galactic foregrounds.

Build up a model of a dipole looking up at the radio sky and employ Bayesian statistics for the data analysis.

Bayesian Nested Sampling

Bayesian Inference

$$posterior = \frac{likelihood \times prior}{evidence}$$

Parameter Estimation

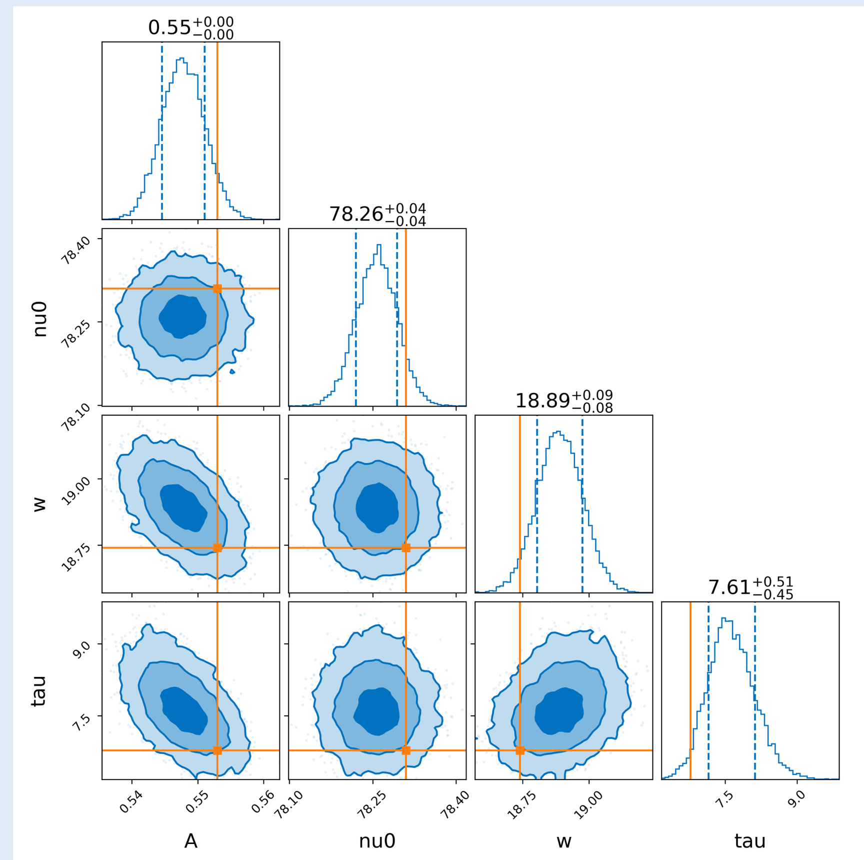
Constraining parameters using both simulated and observational data for the 21 cm signal. Theorised physical models are fit to the data.

Model Selection

Comparing different models to decide which is best at describing the data.

The Code

A modular sampling approach enables us to take advantage of the capabilities of different samplers for different problems.



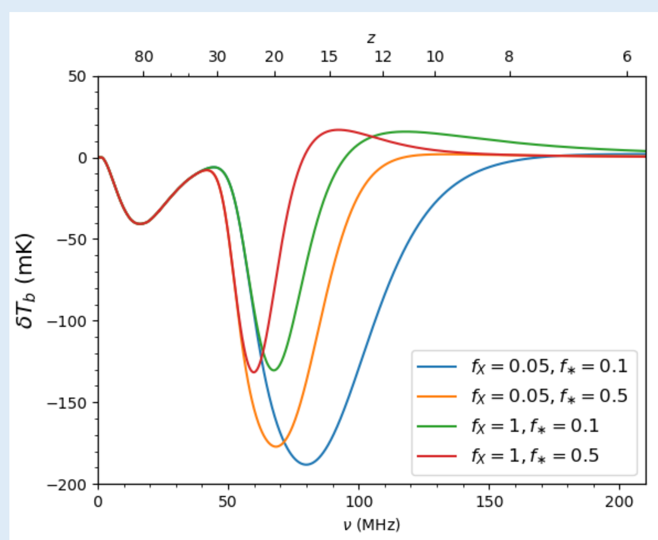
Corner plot for parameters of a flattened gaussian trough sampled from EDGES data.

Simulating the 21 cm Signal

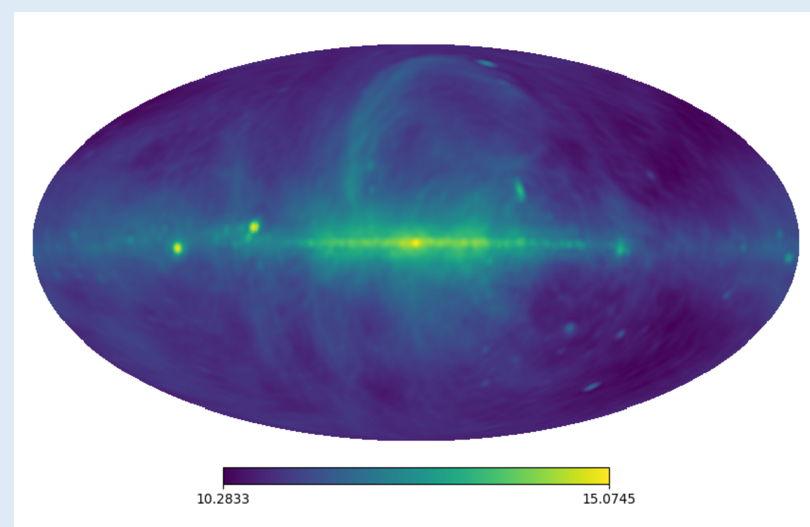
ARES (Accelerated Reionisation Era Simulations)

Generates 21 cm signal simulations with variable physical parameters.

Holds a library of physical models from literature which can be selected to provide simulated data. Provides data and a model set to perform model selection.



ARES 21 cm simulations [6].



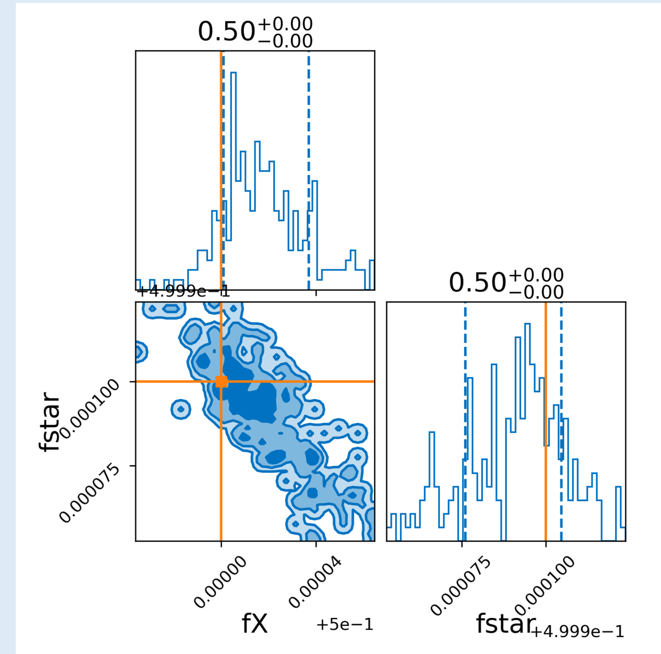
PyGDSM foreground simulation at 75 MHz [7].

PyGDSM (Python Global Diffuse Sky Model)

Produces all-sky maps of diffuse galactic radio emission at specific frequencies.

Simulation is integrated into set-up to provide foreground noise component of signal.

Results & Next Steps



Proof of concept

Null test for parameter estimation. Using mock data composed of a simulated ARES signal and a normal error distribution to simulate noise.

Injection parameters X-ray and Lyman-alpha emissivity, *fX*, and star formation efficiency, *fstar*, for a toy ARES model were successfully identified by the sampler from noisy data.

We intend to extend this to more complex physical models.

Next steps

The base code is now built with the modularised sampling package and the ARES simulation package integrated. Next:

- Integrate PyGDSM into the sampling environment to **simulate a more accurate galactic foreground noise**.
- Test and compare the **efficacies of various nested samplers** to demonstrate capabilities and strengths for different problems.
- Employ **model selection** to identify which models best suit some simulated data.

Motivation

Successful constraining of cosmological parameters by analysis of 21 cm signal models will provide a key window into the Cosmic Dawn, a poorly understood epoch of cosmic history. This will shed new light on the processes responsible for the formation of the first luminous sources within the Universe.

Data is becoming available from a range of low-frequency radio instruments such as LOFAR and MWA [8,9]. It is essential to devise robust statistical techniques to interpret the data from these experiments.

References

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[5] Gregory Ashton et al 2019 ApJS 241 27
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