REACH:
Radio Experiment for the Analysis of Cosmic Hydrogen

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The Global 21cm Signal

REACH is an experiment designed to detect the global (sky-averaged) 21-cm signal from the Cosmic Dawn (CD) and Epoch of Reionization (EoR). The signal is produced by the transition between aligned and anti-aligned spins of the protons and electrons in HI gas. Detection of the mK signal is complicated by foregrounds of approximately 1×10^3 - 1×10^4 K.

The first luminous sources formed during the CD which is thought to have occurred around z~20-25. After this period most of the HI is re-ionized by ultraviolet emission during the EoR. However, there are a number of other processes that happen during this period. Most predominant are the decoupling of the HI gas temperature from the CMB temperature due to interactions with Lyman alpha photons (Wouthysen-Field effect) and gas heating via X-ray emission as shown in Fig. 1 (see [1]). This all occurs as the universe expands cooling adiabatically [2].

A detection will constrain properties on the ionizing efficiency of the first stars, the luminosity and X-ray emission of the first black holes and potentially constraints on dark matter particles [2].

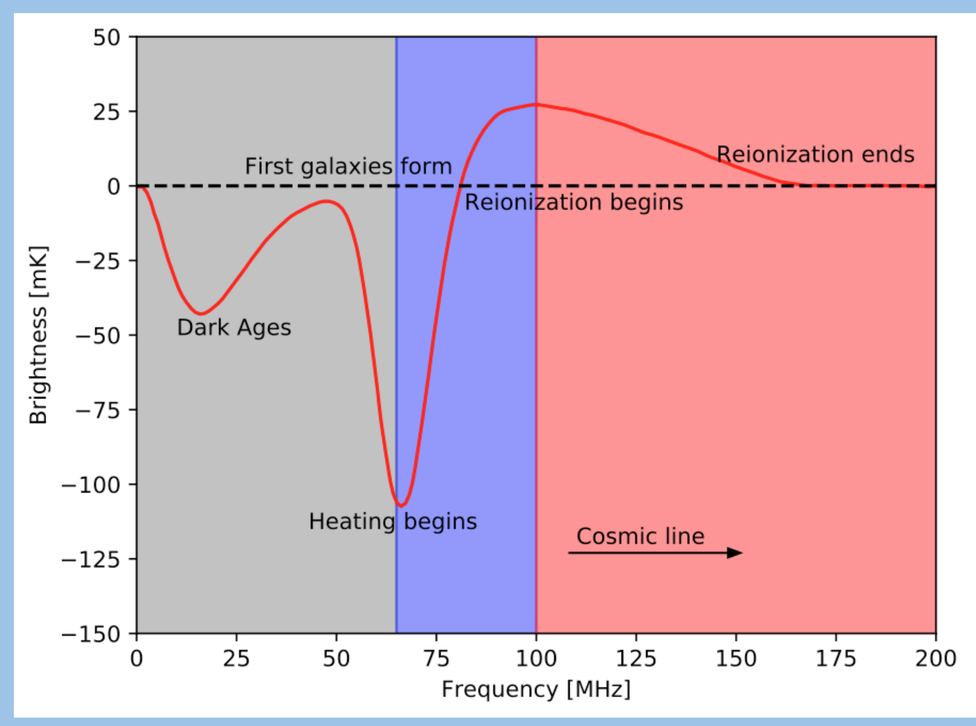

Figure 1: An example global 21-cm signal [1].

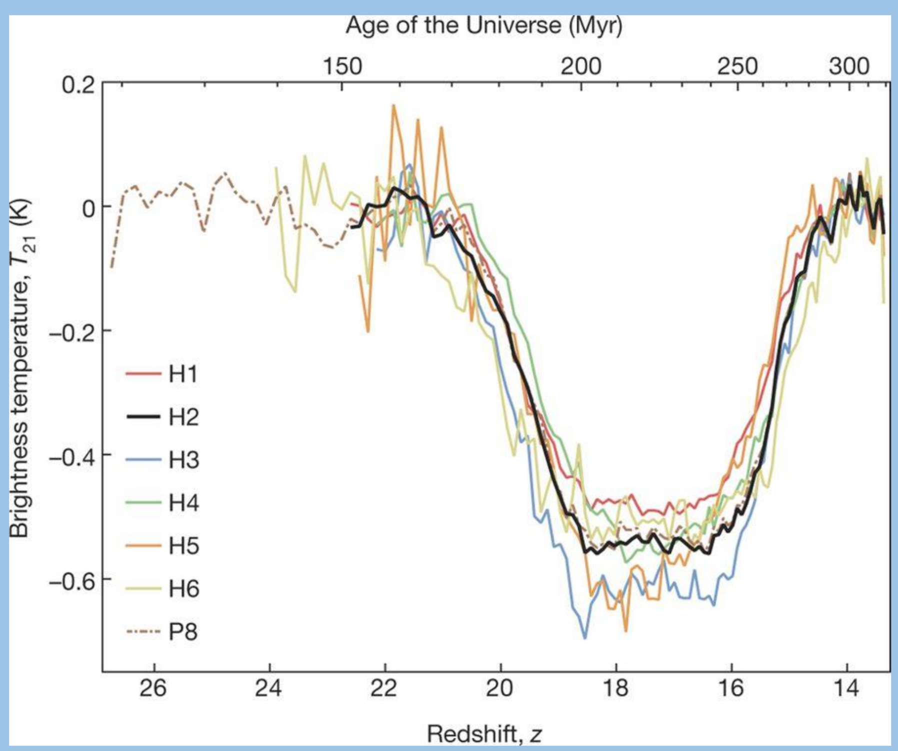

Figure 2: The reported detection from EDGES for different experimental configurations [3].

A First Detection

In 2018 the Experiment to Detect the Global Epoch of Re-ionization Signal (EDGES) reported the detection of an absorption profile potentially compatible with the aforementioned global signal, shown in Fig. 2 (see [3]). The detected signal is yet to be confirmed as there are a number of concerns on the data analysis [4, 5] and the nature of the signal itself.

The concerns related to the nature of the signal lie mostly in the depth and width of the trough that forms the signal. To explain the depth, which is approximately two times larger than that predicted by current models [2], then you would need a higher than expected level of background radio radiation or new physics surrounding interactions between dark matter and baryons in the early universe [3]. While the ARCADE-2 experiment measured a radio background higher than predicted by current models and source counts this has not yet reached a consensus [6].

Given the concerns on the physicality of foreground parameters [4] and potential residual systematics [5] in EDGES, a confirmatory detection is sought after and REACH aims to provide this. Other experiments operating over narrow bands (eg. SARAS-2 [7]) have also obtained data constrained sufficiently enough to rule out a subset of theoretical models [8].

What will REACH do differently?

REACH is not a global experiment with no systematics, but one where we can best explain those systematics. In order to achieve this, **REACH operates over an ultra wide frequency band (50-200 MHz)** allowing us to obtain **more information** compared to present systems, in order to constrain the foreground models as well as the 21-cm signal. **REACH also incorporates in to the analysis any chromatic effects left due to chromaticity of the beam pattern and features an in-field measurement system of the radiometer calibration sources.**

REACH uses physically motivated cosmological models, foreground models as well as system models aiming at explaining any residual effects on the data. For this, **REACH uses a suite of Bayesian analysis techniques to fit the recorded sky temperature with a complex high dimensional model** and account for any systematics left in the data. Bayesian analysis will allow us to compare the evidences of models when a signal is present and absent providing a robust identification. Finally, in the spirit of explaining systematic effects, **REACH phase 1 will include 2 distinct antenna types operating simultaneously: a simple wide-band dipole and a more complex but potentially better suited for the Bayesian analysis, high-gain conical log-spiral antenna (see Fig. 3 [9, 10])**

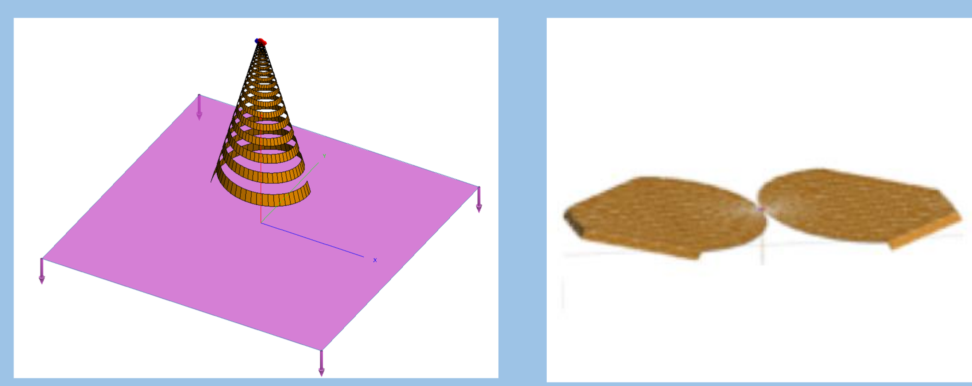

Figure 3: REACH antennas for phase 1[9, 10].

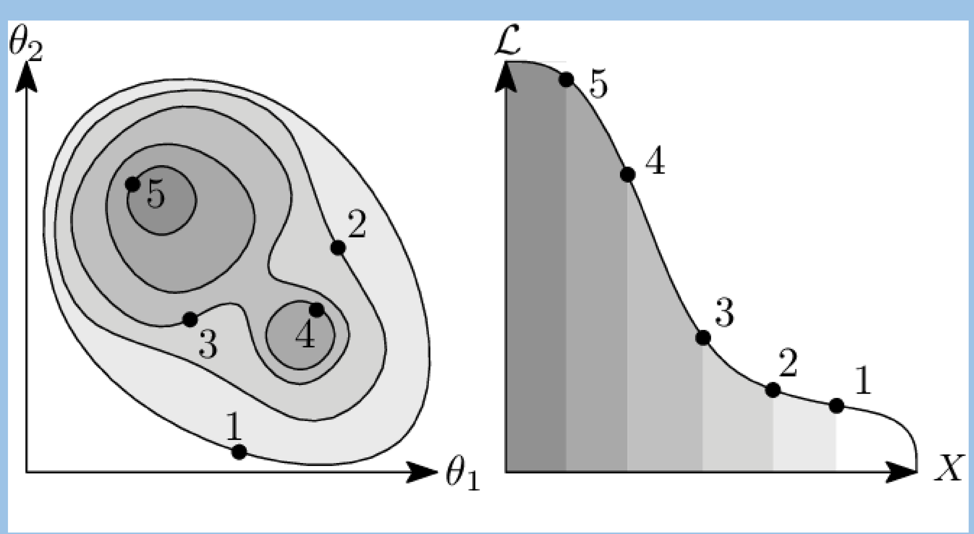

Figure 4: An example likelihood of a two parameter function used in estimating Bayesian evidence [11].

REACH: Fully Bayesian pipeline

REACH is developing a fully Bayesian pipeline for the system data analysis and science model fitting. This includes modelling the effects of the antenna beam as well as the analogue and digital receivers (based on a SKA TPM board) together with models of the foregrounds (eg. parametrized all-sky maps) and the 21-cm signal. The heart of REACH data analysis is PolyChord [11], a next generation nested sampling algorithm developed for astronomical data analysis. REACH also uses physics rooted models for the 21-cm signal (*21cmGEM* [12]).

This data analysis machine will be fed with state of the art physics-rooted models of the hardware, based on the work developed by the team for the SKA, HERA and MeerKAT projects.

Where next?

Upon deployment of the REACH system in early 2020 in the Karoo radio reserve in South Africa (see Fig. 5), a short observation time should provide useable data from which we can attempt to detect the global 21-cm signal. The primary focus of the collaboration (38 researchers, 13 institutions, 10 countries) presently is the development and deployment of 2 distinct antennas with sufficient properties to allow for a successful detection. Alongside this, work on developing a data analysis pipeline and the receiver continues.

Should REACH fail to detect a clear 21-cm signal, as described above, because the residual data after foreground subtraction is too noisy, it is still expected that clear constraints on conditions during the CD and EoR could be provided.

REACH: www.astro.phy.cam.ac.uk/research/research-projects/reach

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Figure 5: REACH location at the Karoo radio reserve in South Africa, ~15 km from the MeerKAT telescope.

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