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Bayesian recovery of the excess radio background from HERA data

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In 2006 an excess radio background was measured by ARCADE 2 showing an extragalactic rise of 54 ± 6 mK at 3.3 GHz in addition to the CMB [1, 2]. Today, there is still no consensus on the underlying physics of the residual signal, however multiple explanations have been proposed [3, 4, 5]. From the ARCADE 2 team itself, the conclusion was that the anomaly is due to either a diffuse extragalactic background stemming from emission from discrete radio sources with a spectral index of -2.59, flatter than what you would expect from the faint end of the distribution of known sources — or unmodeled residual emission from our own galaxy. Alternatively, the residual signal could simply be due to an instrumental artefact, that needs to be corrected for.

To really understand this issue, we need a careful, statistical treatment in order to properly handle the impact of systematics. Crucially, measurements must also be expanded to a broader range of frequencies, to obtain more information on the possible additional diffuse signal. A number of low frequency arrays have been built to detect the neutral hydrogen 21 cm emission from Cosmic Dawn, which should in principle also be sensitive to any excess radio background. One such experiment is the Hydrogen Epoch of Reionization Array (HERA), which is a compact radio interferometer with many redundant baselines (i.e. of the same length and orientation). This compact, redundant design is not ideal for imaging as HERA only measures the sky at a discrete set of relatively large angular scales. It does, however, afford higher sensitivity to the sky brightness temperature on these scales. We have developed an algorithm that can use data from a compact array like HERA to constrain the amplitudes of spherical harmonic modes on large angular scales. In turn, this can be used to constrain the possible amplitude of radio backgrounds.

Within our Bayesian framework, which uses Gibbs sampling, it is possible to sample directly from the joint posterior distribution of the spherical harmonic modes, along with the instrumental and calibration degrees of freedom. This is done by sampling from the individual conditional distributions iteratively [6]. A particularly computationally-intensive step is sampling from the conditional distribution for the spherical harmonic coefficients themselves. Casting the entire problem as a linear system allows us to recover the diffuse emission signal – in a statistically robust manner – while aiming to bring down the computational costs to a tractable level. In this work, we present the mathematical formalism of our sampling framework, and a validation of it against simulations with known levels of excess background emission. Ultimately, this will enable us to investigate whether an ARCADE 2–like residual signal is present in the diffuse emission in the HERA data and improve our understanding of the radio background.

References

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