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Joint analysis constraints on the physics of the first galaxies from upper limits on the 21-cm power spectrum and sky-averaged signal

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We present a first of its kind joint analysis of data from the 21-cm power spectrum experiment HERA (redshift $z \approx 8$ and $z \approx 10$) and data from the sky-averaged 21-cm experiment SARAS3 ($z \approx 15 - 25$). We disfavour scenarios in which enhanced radio background models of the power spectrum are ≥ 126 mK^2 at $z = 25$ and the sky-averaged signals are ≤ -277 mK at 95% confidence (see Fig.1). The power spectrum limit is below the projected sensitivity of the upcoming NenuFAR experiment, and we note that the sky-averaged signal limit is approaching that of standard astrophysical models with a CMB only radio background. The work leads to the best constraints to date on the star formation efficiency, halo mass, radio and X-ray luminosities of galaxies 200 million years after the Big Bang. We disfavour at 68% confidence a population of early galaxies with X-ray luminosities $\lesssim 33$ times and the radio luminosities $\gtrsim 32$ times the values for present day galaxies. Further, we disfavour galaxies with minimum halo masses for star formation to occur $\lesssim 45 \times 10^6$ M$_\odot$ and star formation efficiencies $\gtrsim 2$% at 68% confidence. We find that individually the two experiments allow for physically motivated signals with depths that are consistent with the EDGES absorption feature, but together they rule out these scenarios at > 95% confidence.

We introduce a new method to perform the joint analysis which uses the products of the existing analysis for each experiment to prevent the need to sample 'nuisance' parameters, such as those modelling the SARAS3 foreground. Through the combination of constraints from the two different experiments, we have improved our understanding of the properties of the first galaxies and our confidence in the constraints over a wide range of redshifts. We note the importance of performing joint analysis between different probes of the high redshift Universe, including 21-cm experiments and data from JWST. We believe that the method proposed here will become increasingly more powerful for the next generation of 21-cm experiments, which aim to fully describe their data including instrumental effects with more complicated likelihoods.

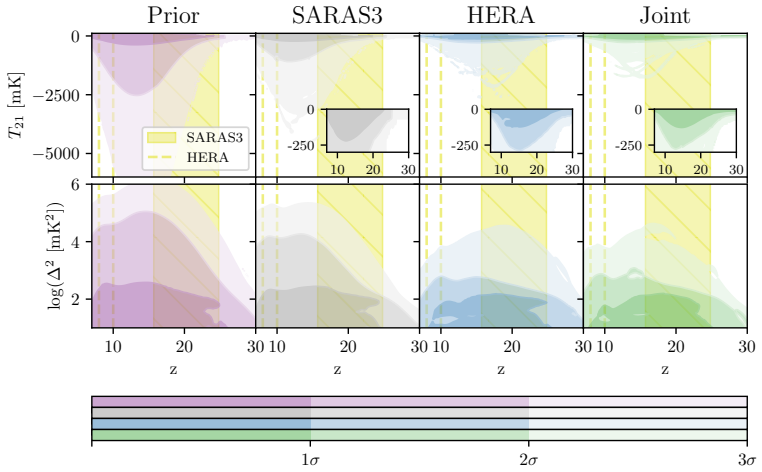

Figure 1. The functional constraints on the sky-averaged 21-cm signal (top row) and power spectrum (bottom row) from SARAS3 (grey), HERA (blue) and the joint analysis (green). We also show the allowed theoretical parameter space, the prior, (purple) and the redshifts of the HERA and SARAS3 observations (yellow).