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SARAS: Radiometers with Shaped Antennas for the detection of redshifted 21-cm from Cosmic Dawn and Reionization

Ravi Subrahmanyan* [(1)], N. Udaya Shankar[(1)], Agaram Raghunathan[(1)], R. Somashekar[(1)], B. S. Girish[(1)], K. S. Srivani[(1)], Saurabh Singh[(1)], and Mayuri S. Rao[(1)]
(1) Raman Research Institute, C. V. Raman Avenue, Sadashivanagar, Bengaluru 560 080, India, e-mail: rsubrahm@rri.res.in; uday@rri.res.in; raghu@rri.res.in; som@rri.res.in; bsgiri@rri.res.in; vani_4s@rri.res.in; saurabhs@rri.res.in; mayuri@rri.res.in

The expansion and cooling of primeval plasma is believed to have led to the recombination of Helium and Hydrogen ions with free electrons thus transforming the gas to almost completely neutral state by cosmic time of about 40 kyr. The astrophysics in the subsequent 'Dark Ages', when the neutral gas continued to cool, and 'Cosmic Dawn', when the first stars formed in the ultra-faint galaxies, and 'Epoch of Reionization', when UV from the early star-formation reionized the intergalactic gas, is very uncertain. The populations of the singlet and triplet hyperfine states in neutral hydrogen during these epochs is determined by the gas kinetic temperature and ambient radiation field, and a detection of redshifted absorptions and emissions from this 21-cm hyperfine transition in neutral hydrogen is a key probe of the complex astrophysics and radiative transfer.

SARAS is an approach to the detection of the 21-cm signal in the 40-250 MHz band, using radiometers that have shaped antennas as sensors of the incident electromagnetic field. SARAS has evolved from shaped dipoles to shaped monopoles and from electrically large to electrically small antennas. The emphasis in design and choice of antenna structure has been towards frequency independent antennas, with reflection and total efficiencies that are smooth functions of frequency so as to limit spectral confusion from sky temperature structure and calibration errors.

The receiver is designed for accurate band pass calibration and for avoidance of spectral confusion from multipath propagation of receiver noise within the signal path. Offline signal processing algorithms reject narrow and wideband RFI using a suite of detection methods that examine the data with progressively coarser smoothing in 2D time-frequency domain. The data are examined for plausible 21-cm signals using likelihood ratio estimators and forward modeling using a frequentist approach. Deployed at radio quiet sites in India, SARAS has yielded significant constraints [1] on about 10% of currently allowed models, requiring a minimum X-ray emissivity in the first stars and ruling out models with rapid reionization.

The evolving design of the SARAS radiometer is presented, including recent upgrades to the system that have focused on enhancing radiation efficiency and reducing internal systematics, to improve the effective bandwidth of the system and progress the field by expanding the sensitivity in the parameter space of allowed astrophysics.

1. Saurabh Singh, Ravi Subrahmanyan, N. Udaya Shankar, Mayuri Sathyanarayana Rao, Anastasia Fialkov, Aviad Cohen, Rennan Barkana, B. S. Girish, A. Raghunathan, R. Somashekar and K. S. Srivani, "First Results on the Epoch of Reionization from First Light with SARAS 2," *The Astrophysical Journal Letters*, 845, L12, August 2017, pp. 1-6, doi:10.3847/2041-8213/aa831b