URSI AP-RASC, Sydney, Australia, 17 – 22 August 2025

CosmoCube, lunar orbiting radio telescope to detect the 21cm signal from Dark Ages

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CosmoCube is a collaborative effort led by the University of Cambridge, bringing together multiple institutions to develop a lunar-orbiting radio telescope for detecting the 21-cm hydrogen signal from the Dark Ages and Cosmic Dawn. This signal offers a unique observational window into the early Universe, providing insights into dark matter interactions, baryon density, and the formation of cosmic structures. However, ground-based observations of the 21-cm line are severely limited by ionospheric interference and terrestrial RFI that overwhelm the signal. To overcome these challenges, CosmoCube will operate in lunar orbit, where the Moon's occultation shields it from Earth-based noise, creating an ideal radio-quiet environment. By observing redshifts from 13 to 285, the mission aims to detect the global 21-cm signal and constrain key cosmological parameters while exploring exotic physics.

The radiometer payload includes a deployable wideband antenna, a low-noise amplifier, and a Dicke switch-based calibration system to maintain gain stability. The onboard RFSoC-based spectrometer digitizes and processes the incoming signal with high spectral resolution. Achieving a sensitivity of 10 mK requires rigorous calibration to mitigate instrumental systematics and an extensive integration time of over 1000 hours for 0.1 MHz channel bins. The payload is designed with thermal regulation, power management, and shielding strategies to ensure stability in the harsh lunar environment.

The CosmoCube spectrometer is optimized for high-resolution spectral analysis using an RFSoC platform, which integrates ADCs and digital processing in a compact and power-efficient system [1]. It employs a channelizer based on a polyphase filter bank with a bin width of 62.5 kHz, providing an effective number of bits of approximately 11.5 from 10 to 100 MHz. The system's spurious-free dynamic range exceeds 70 dBc across its operational bandwidth, ensuring the detection of weak cosmological signals, aligning with the 10 mK sensitivity target. The noise floor remains stable within ±0.2 dB under varying thermal conditions.

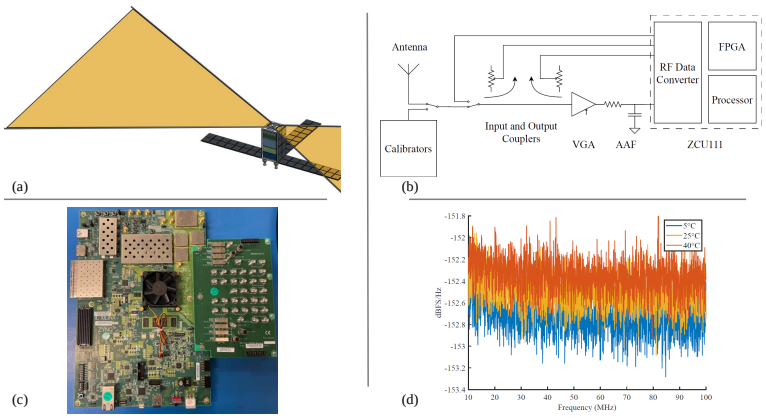

Figure 1. (a) CosmoCube payload with the antenna deployed, (b) the radiometer diagram, (c) the Xilinx RFSoC ZCU111 used for spectrometer development, and (d) the spectrometer noise floor variation with temperature.

References

[1] K. Artuc and E. de Lera Acedo, "The spectrometer development of CosmoCube, lunar orbiting satellite to detect 21-cm hydrogen signal from cosmic dark ages," *RASTI*, **4**, 2025, https://doi.org/10.1093/rasti/rzae061.

[2] J. Zhu, E. de Lera Acedo, K. Artuc, and X. Chen, "RFSoC receiver calibration system for 21-cm global spectrum experiments from space: the CosmoCube case," *RASTI*, **4**, 2025, https://doi.org/10.1093/rasti/rzae064.