SARAS-3 Probing Cosmic Dawn and Epoch of Reionization

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RRI

Shaped Antenna measurement of the background RAdio Spectrum (SARAS)

87.5-175 MHz

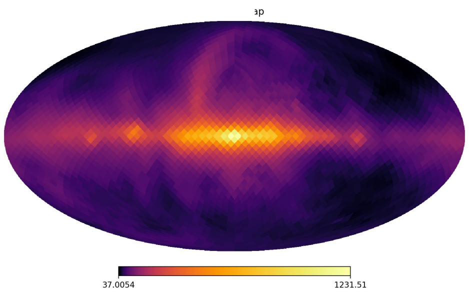
110-200 MHz

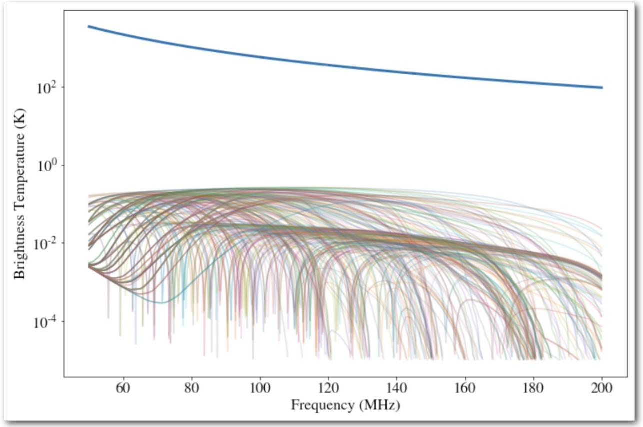
40-110 MHz

SARAS aims to measure global 21-cm signal from cosmic dawn and epoch of reionization

Challenges involving the foreground

80 MHz Map





- Dominated by synchrotron radiation from Milky Way
- Could be 10^5 times brighter than the signal!

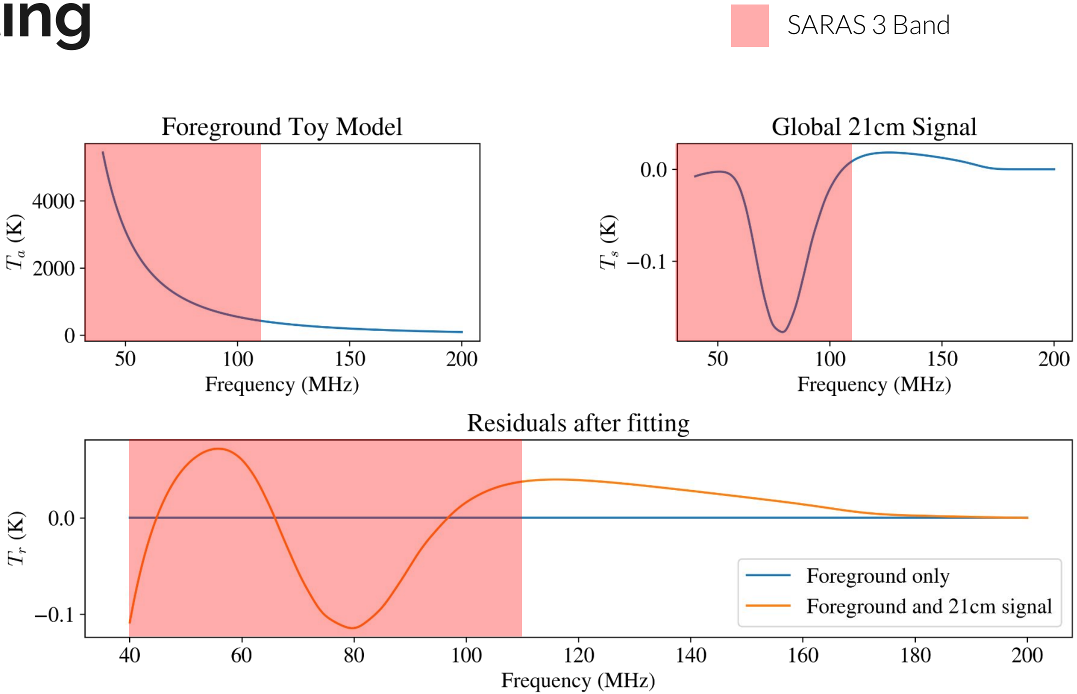
- We exploit the spectral nature of foregrounds to separate it from the global signal.
- Foreground comprises low frequency modes unlike the expected global signal.

Foreground Modeling

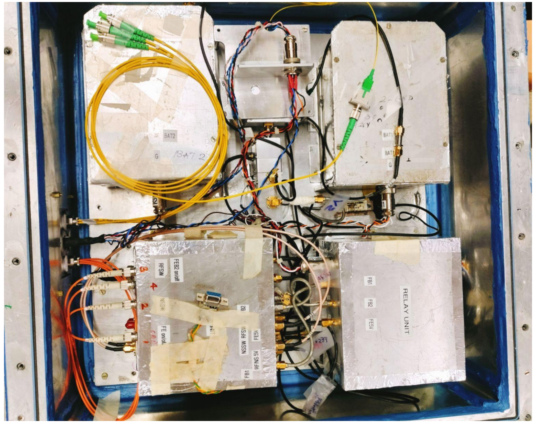
Based on the nature of emissions we expect from the foreground; it can be modeled with a maximally smooth function.

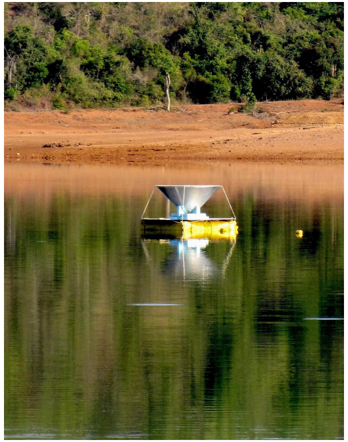
Condition for maximally smooth function,

$$\frac{d^m y}{dx^m} \geq 0 \text{ or } \frac{d^m y}{dx^m} \leq 0$$



SARAS 3 Experiment





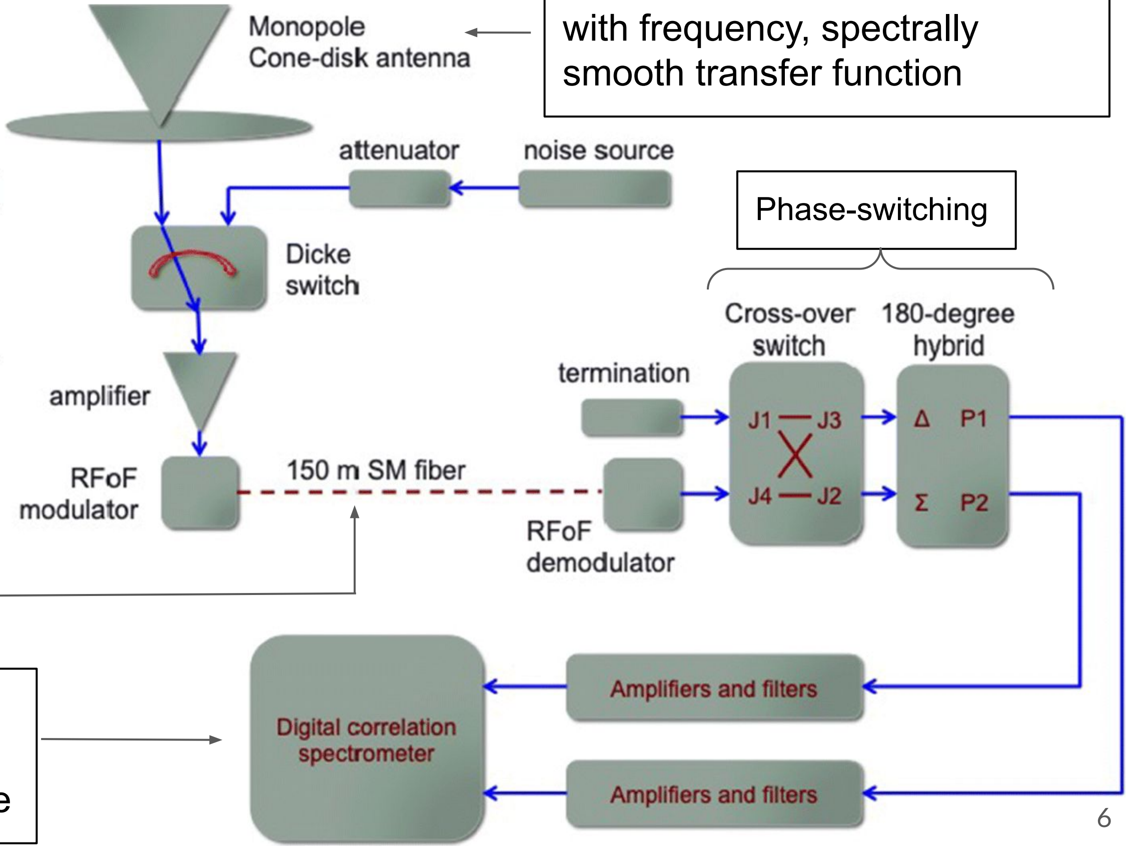
SARAS radiometer is an in-house experiment designed in order to explore into the era or Cosmic Dawn and Epoch of reionization. Its present configuration enables probing within the wavelength range of 40 MHz to 90 MHz.

SARAS architecture

State	Noise source	Dicke switch	Cross-over switch
OBS00	OFF	0	0
OBS11	OFF	0	1
CAL00	OFF	1	0
CAL01	OFF	1	1
CAL10	ON	1	0
CAL11	ON	1	1

Minimal variation of field of view with frequency, spectrally smooth transfer function

Phase-switching



Optical isolation

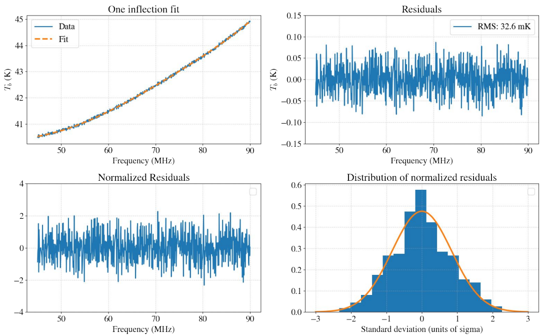
Electromagnetic shielding, negligible inter-frequency leakage

Battery powered for remote sites

Assessing receiver systematics

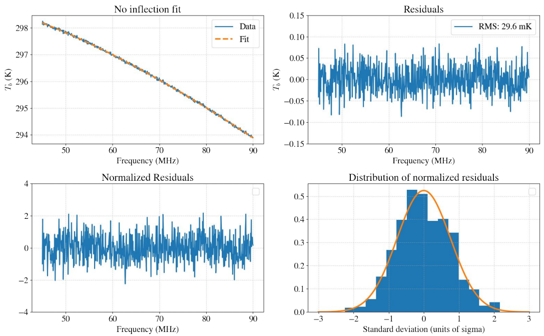
Short Termination

1. Complete reflection
2. Phase inversion.



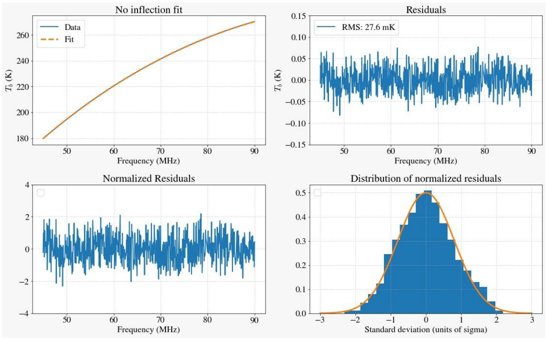
50 Ohm Termination

1. Best Impedance match
2. No reflection



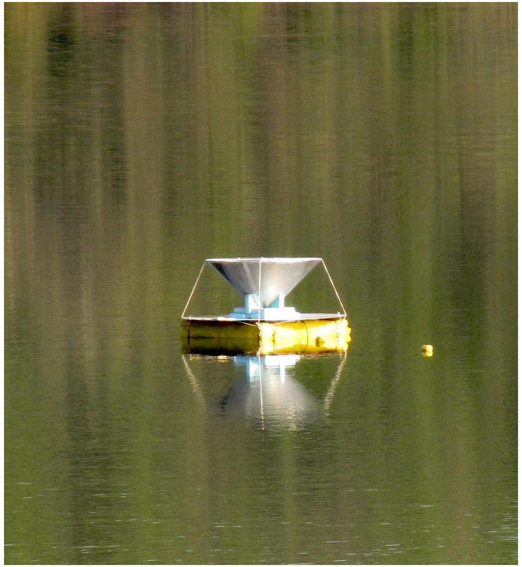
RLC termination Test

Designed to be mimicking actual antenna impedance

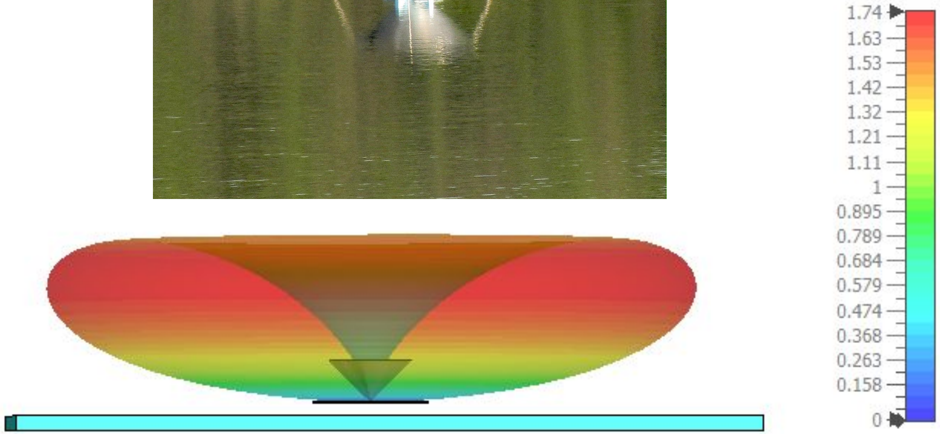


Assessing antenna systematics

1. Toroidal Monopole
2. Azimuthal symmetry
3. Peaks at 67° from zenith
4. Null at Zenith
5. Slow variation with frequency



$$T_W(\nu, t) = \frac{\int_0^{2\pi}\int_0^{\pi} T_B(\theta, \phi, \nu, t) G(\theta, \phi, \nu) \sin\theta d\theta d\phi}{\int_0^{2\pi}\int_0^{\pi} G(\theta, \phi, \nu) \sin\theta d\theta d\phi}.$$

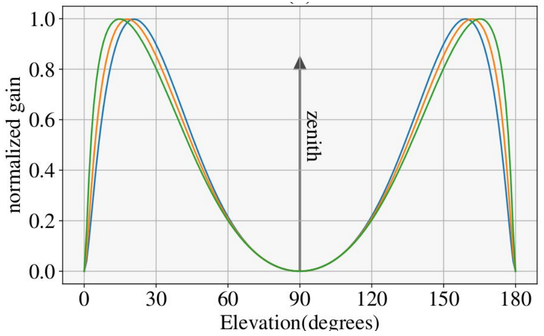


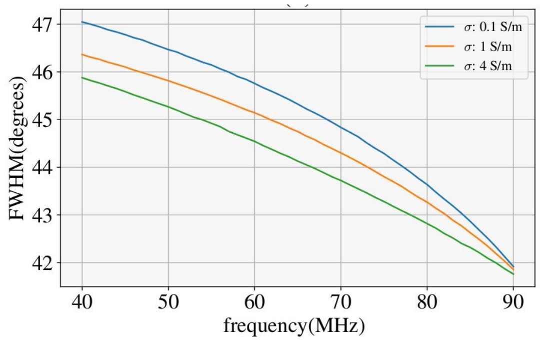
Beam at 90 MHz

Image credit: Kavitha K.

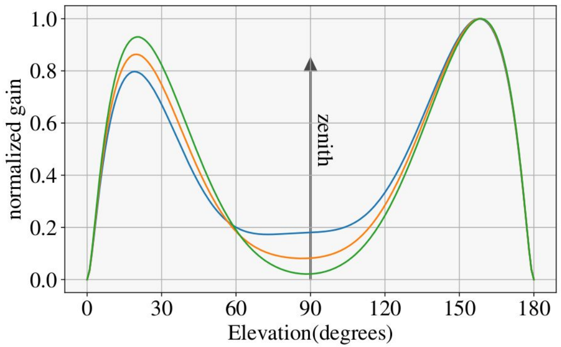
Beam Variations with antenna parameters

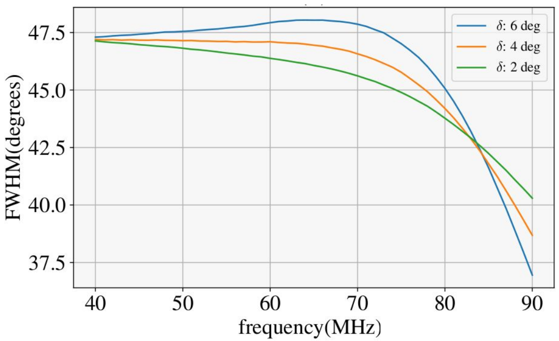
Conductivities



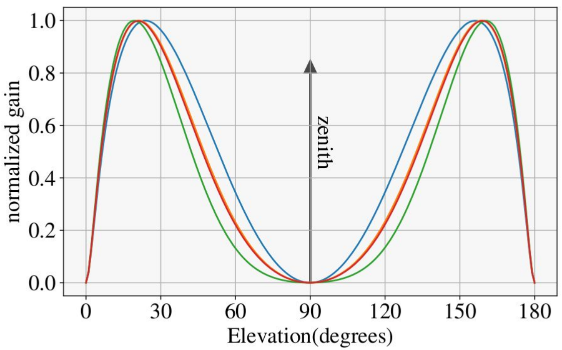


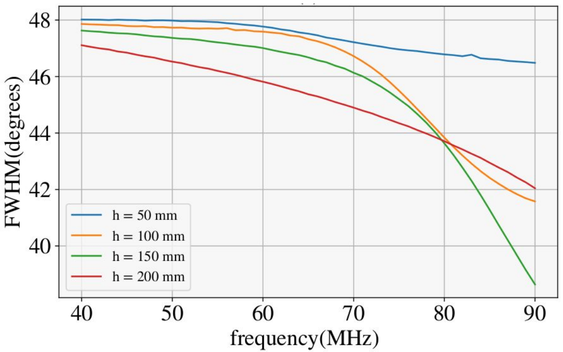
Raft Tilts





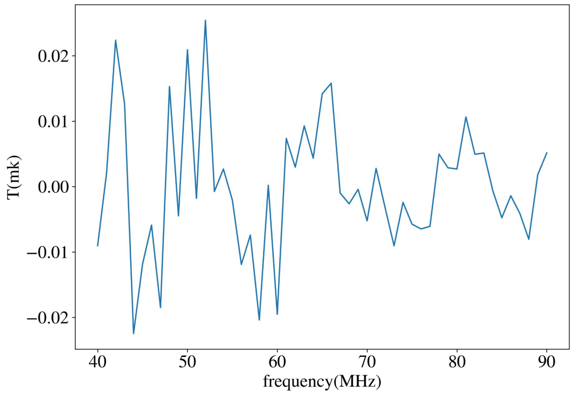
Raft Height



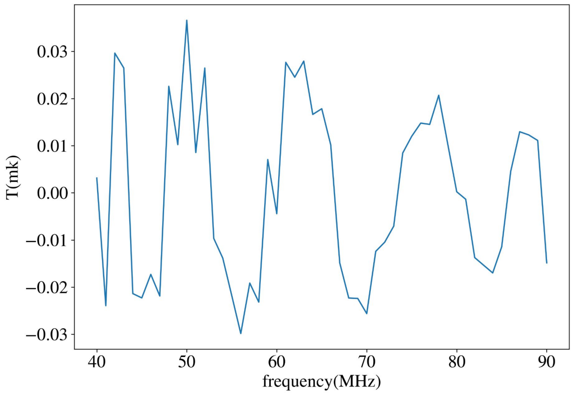


Foreground Residuals

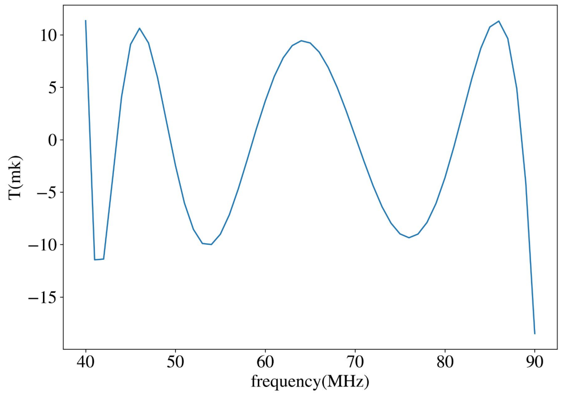
Conductivity 0.1S/m



Raft Tilts 6 deg



Raft Height 150mm



Beam Derivatives

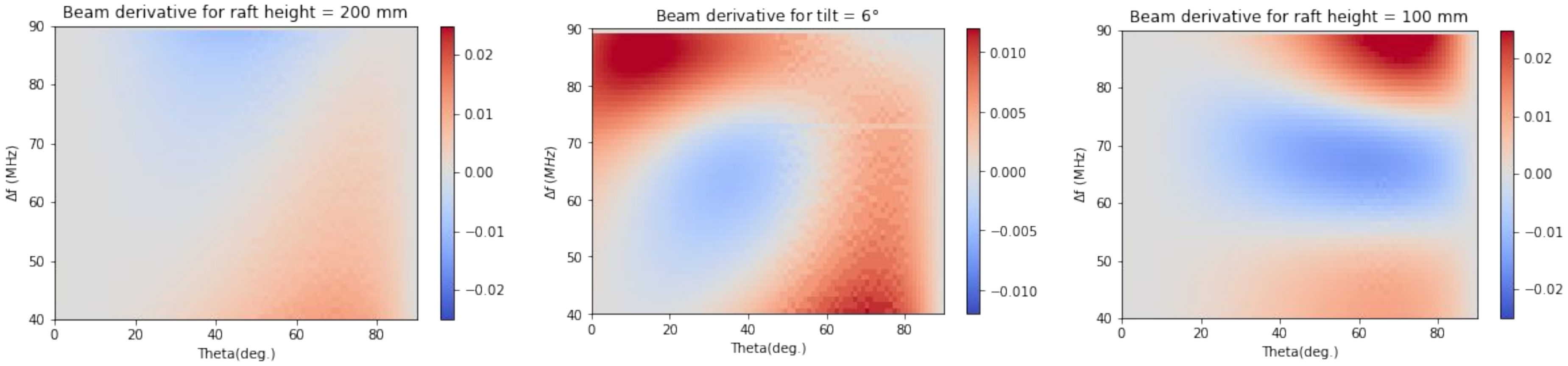
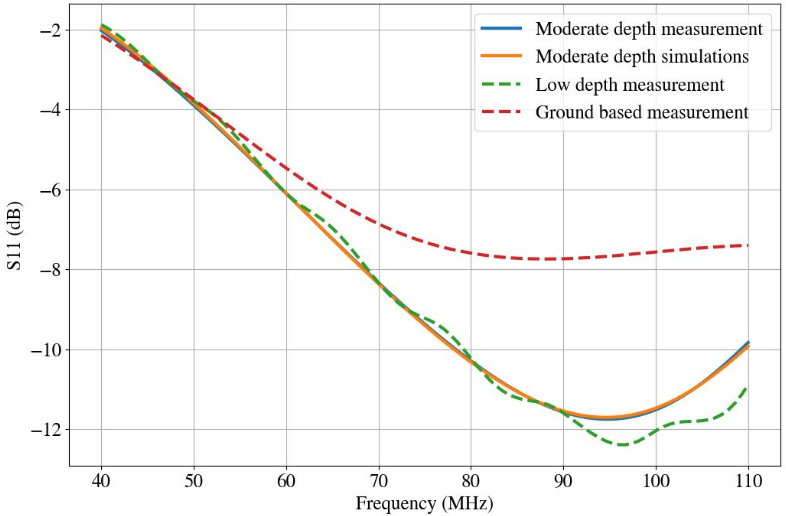
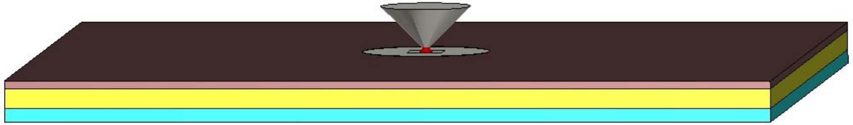


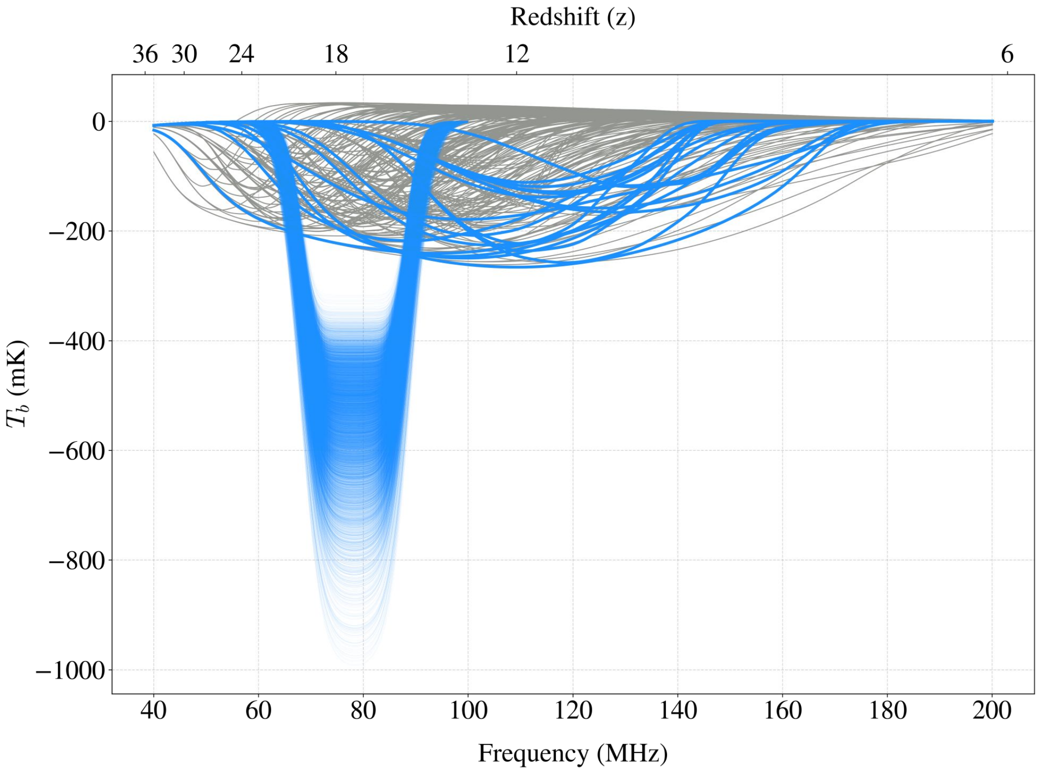
Figure credit: Kavitha K.

Return loss variations and measurement



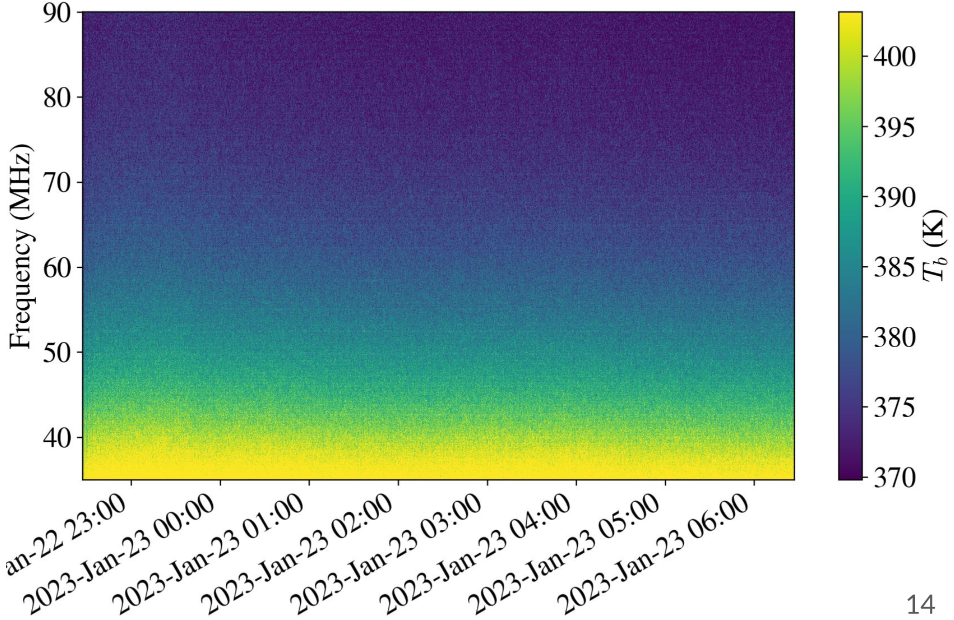


SARAS constraints on cosmic dawn and EoR



Past deployment feedbacks and upgrades

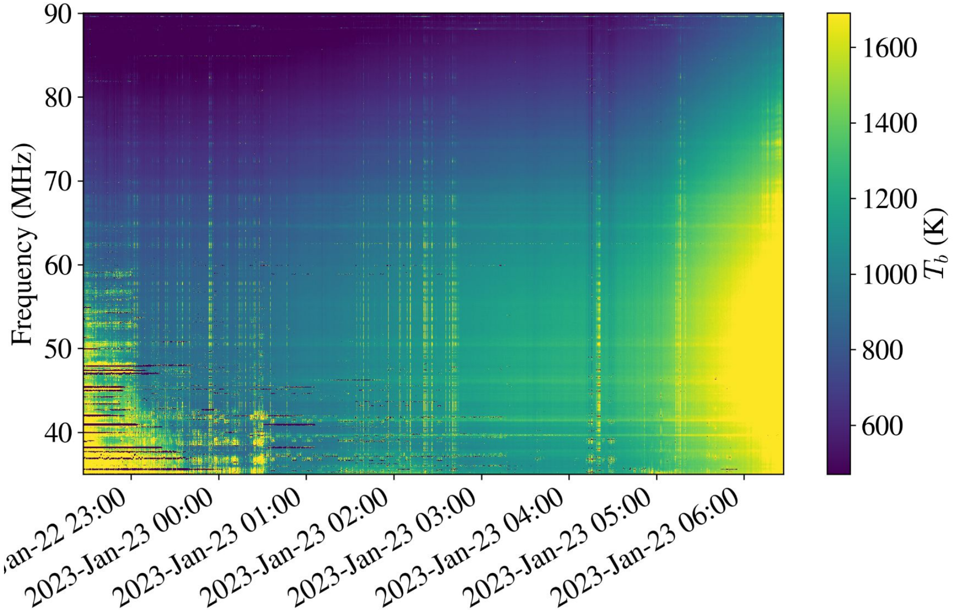
1. System stability
2. RFI



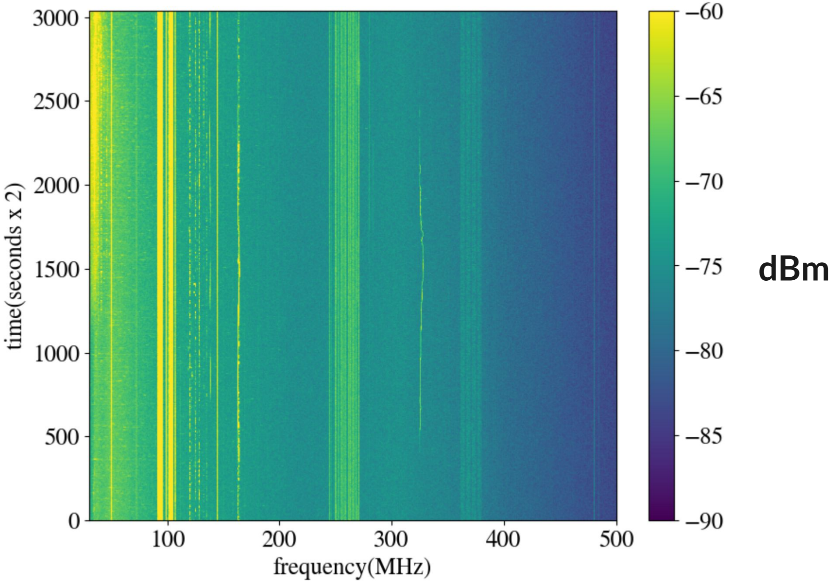
Recent test deployment

First test science deployments with upgraded system!

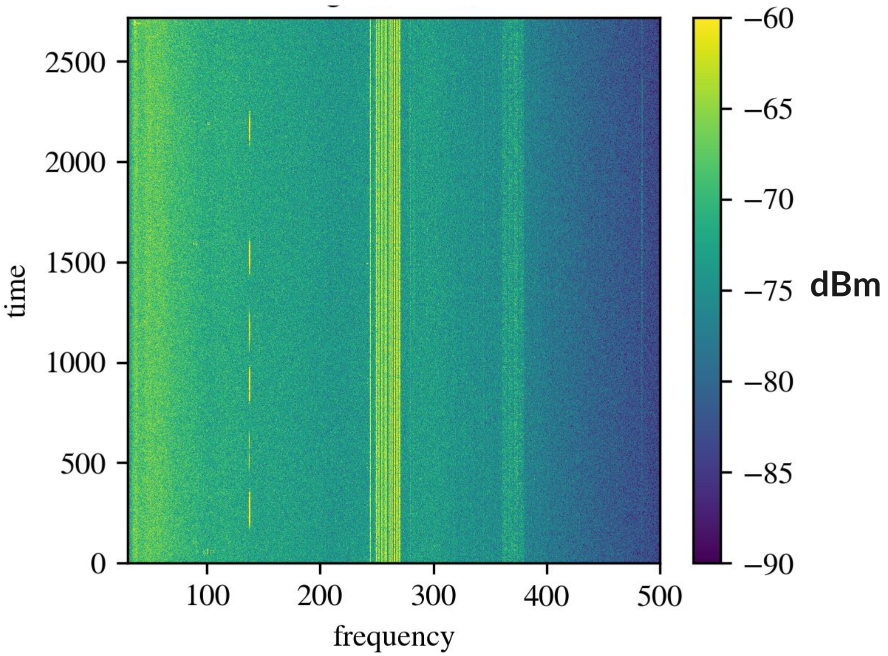
- RFI has got worse since past deployment.
- The system performance has been stable
- This calls for looking for better sites.

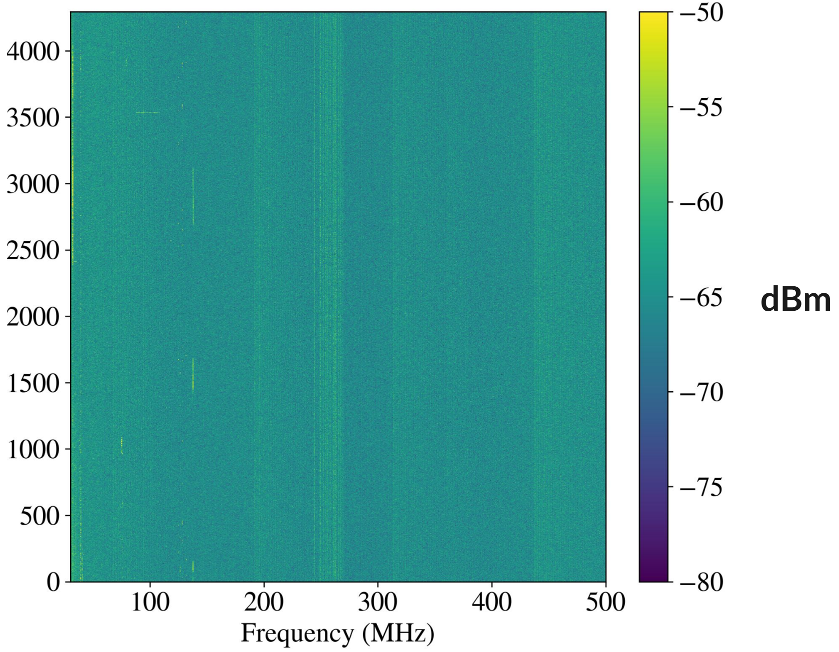


Several RFI expeditions

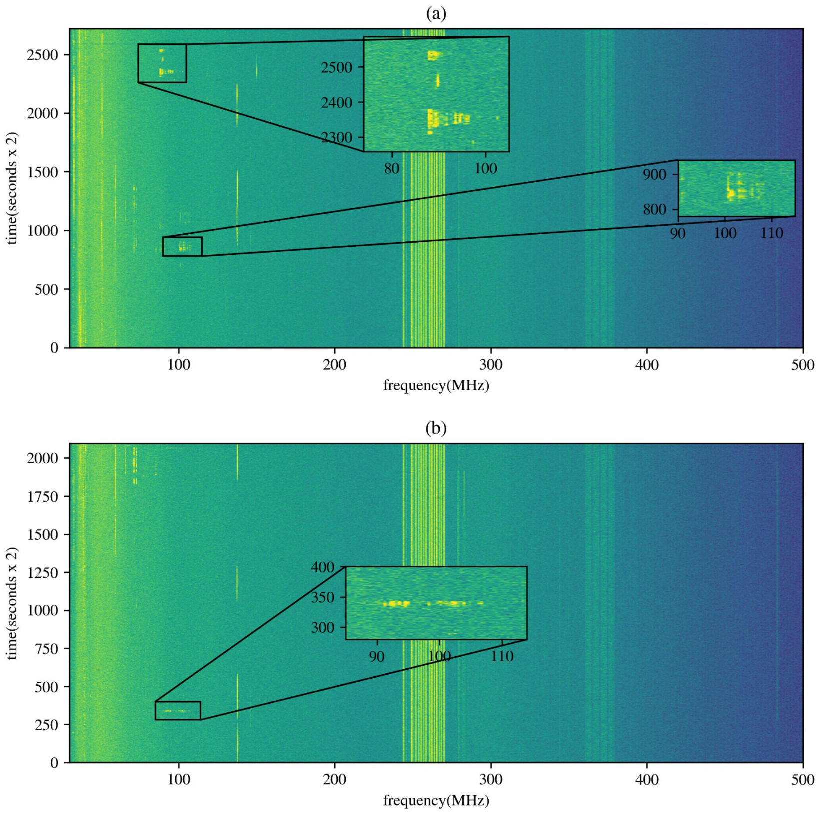


Shortlisted radio quiet locations



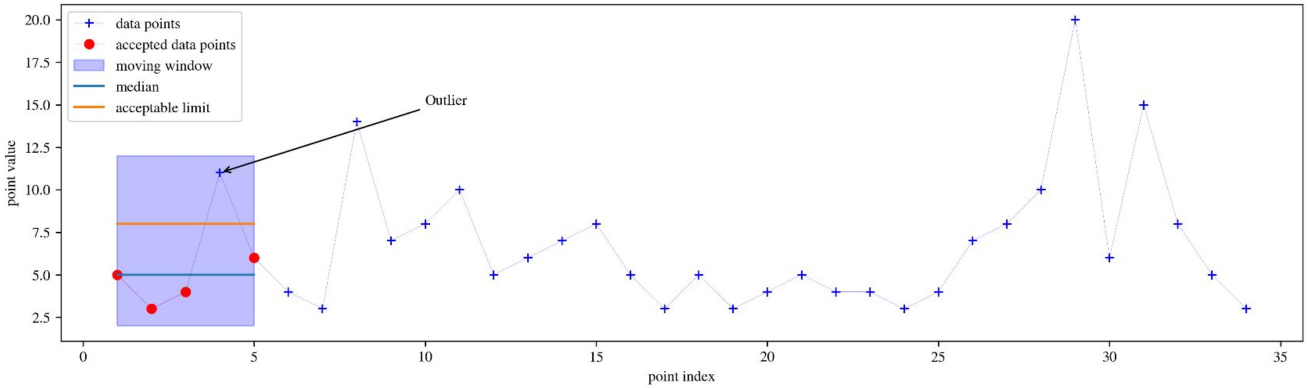


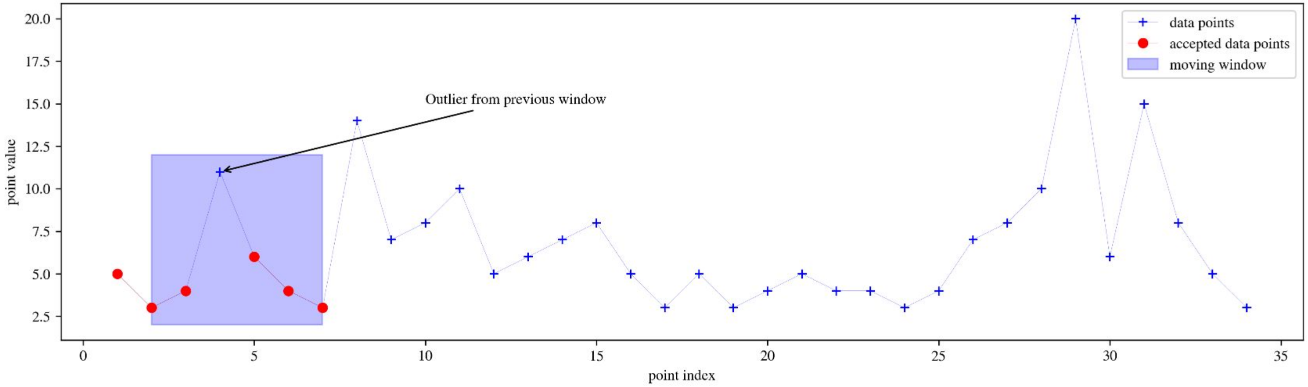
Transient RFI



Flagging RFI

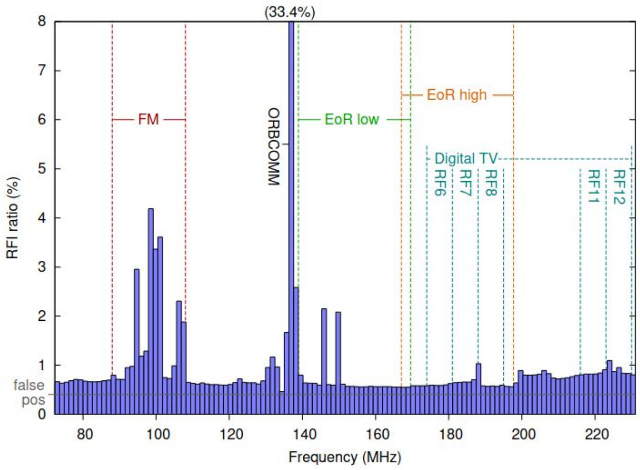
Employs a Hampel filter to detect and flag outliers.





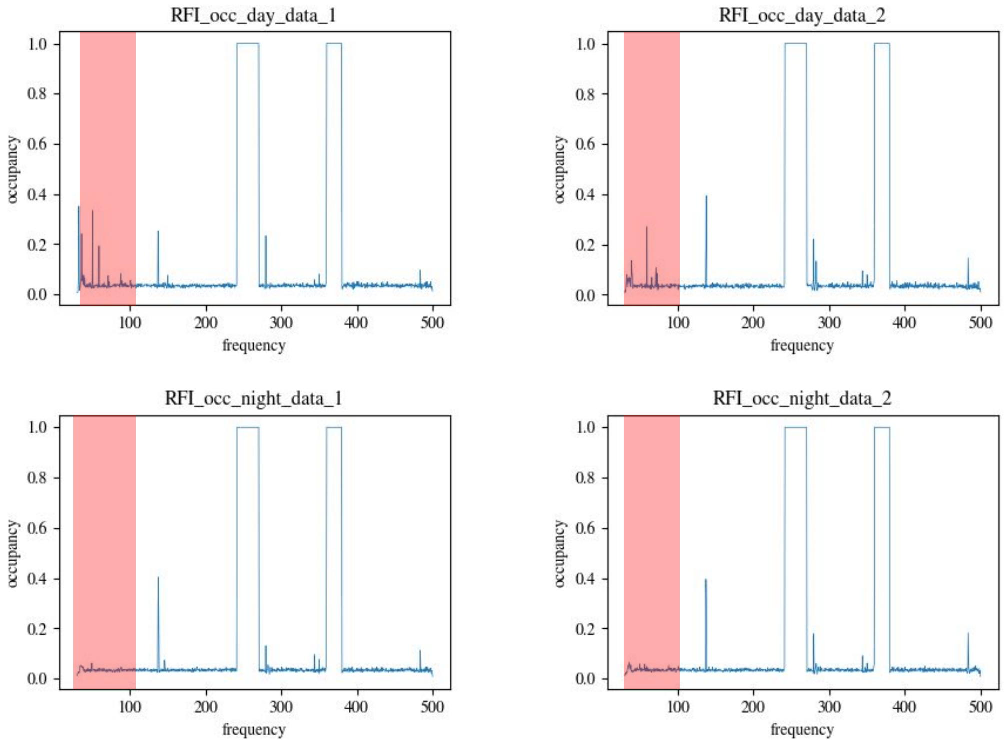
RFI Occupancy

RFI occupancy at MWA site



Offringa et al 2015

SARAS 3 Band



Next season of observations: Land and water based deployments

Analysis in progress for the last land-based deployment

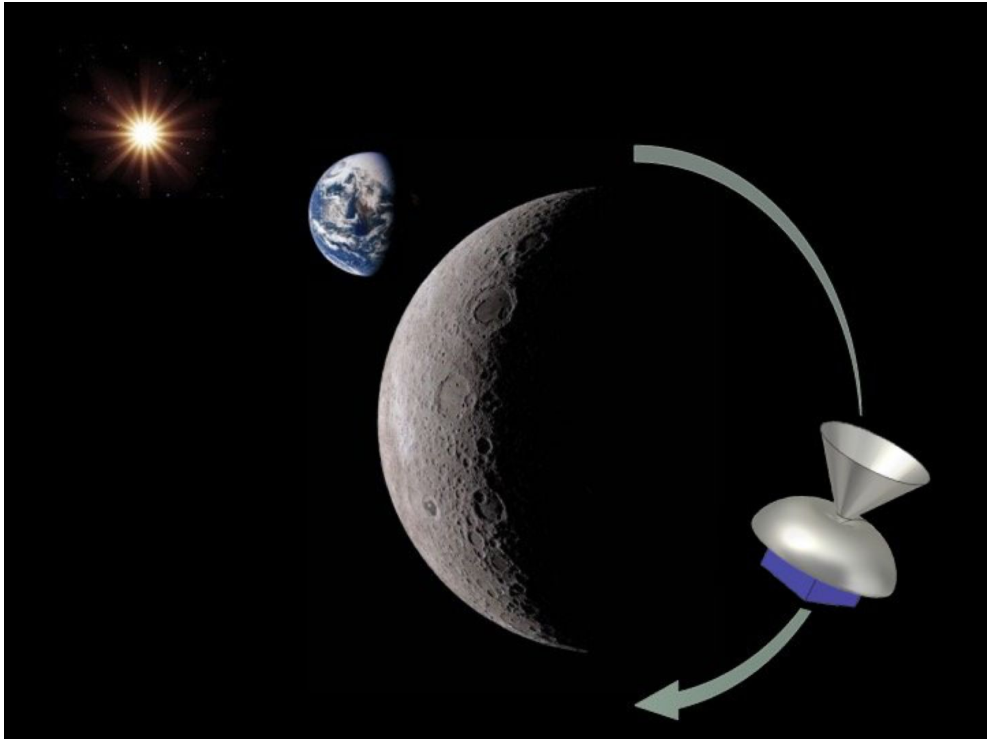
Probing ReionizATion of the Universe using Signal from Hydrogen (PRATUSH)

Advantages

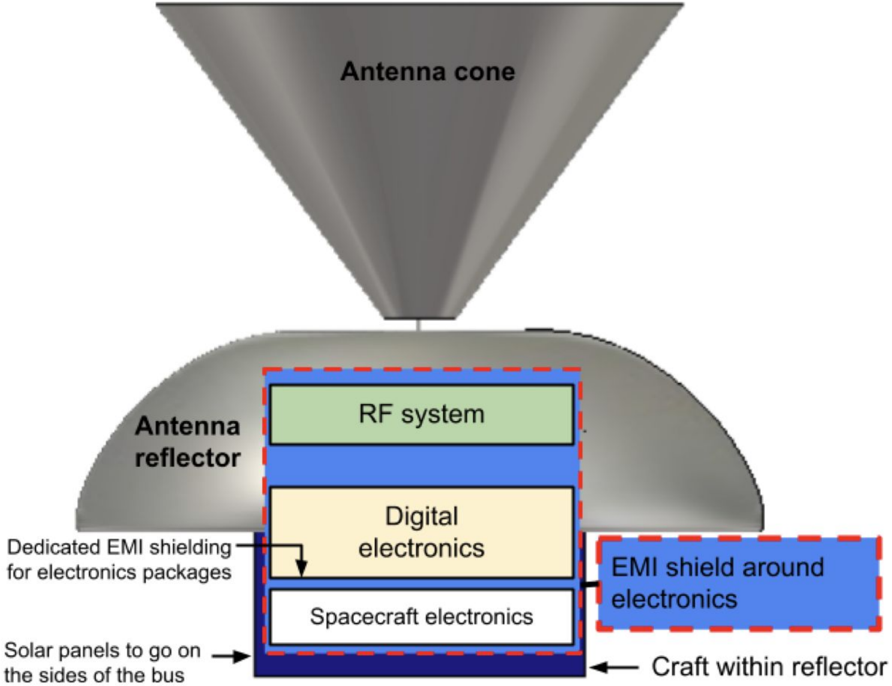
1. Free of RFI
2. Free of Ionosphere
3. Free of dielectric coupling

Unique set of challenges

1. Self generated RFI
2. Bus becomes part of antenna

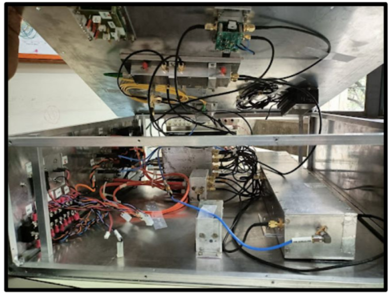


PRATUSH design

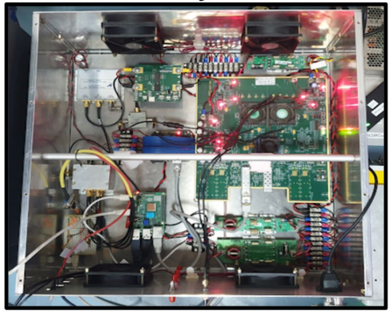


PRATUSH concept model hardware

Antenna



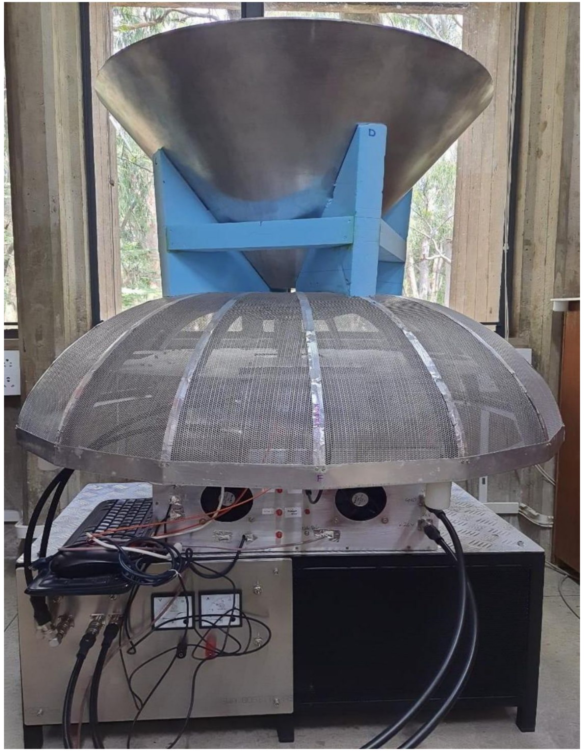
RF system



Digital Receiver

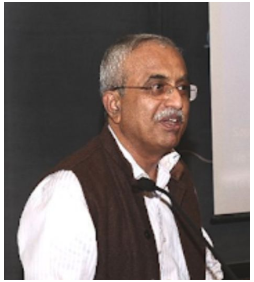
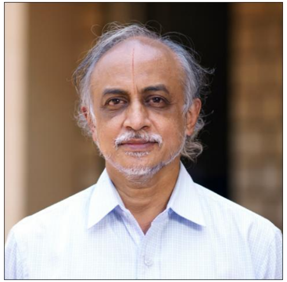
Current Status

- PRATUSH is funded for pre-project studies by the Indian Space Research Organisation (ISRO) since 2019
- Laboratory model is ready
- Expected to fly in 2 phases: **Phase I** as a Low Earth Orbiter and **Phase II** as a Lunar Orbiter in far side

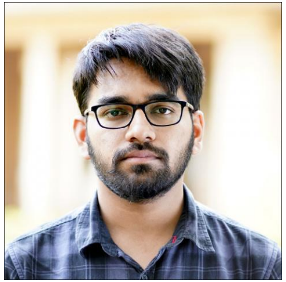


Team Pictures





Summary

- The foregrounds exhibit fewer spectral features compared to the anticipated global signal, allowing for separation through modeling.
- SARAS operates based on the principle of maintaining maximum smoothness in its systematics to preserve the spectral integrity of foregrounds.
- Various antenna parameters impact the beam's chromatic characteristics and systematics, with some exerting more influence than others.
- The SARAS system has effectively demonstrated its ability to manage and control systematics.
- Extensive site characterization and surveys for Radio Frequency Interference (RFI) have led to the discovery of new radio-quiet locations.
- PRATUSH complements SARAS observations from space.