PRATUSH

Mayuri S.Rao on behalf of team PRATUSH
McGill U, 09-Oct-2019

RRI

This talk will

Cover

- an introduction to PRATUSH
- Why space (and far side of the moon)?
- Major concerns : discussion
- Secondary science : discussion

Not cover

- Introduction to reionization and the global redshifted 21-cm signal
- Details of ground-based predecessors (other talks, especially SARAS talks)
- Details of foreground separation and methods of modeling data

What is PRATUSH?

- To do science: step 1, get the acron**y**m right

Probing **R**eioniz**AT**ion of the **U**niverse using **S**ignal from **H**ydrogen

Precision radiometer to detect and measure the redshifted 21-cm global signal from reionization in a lunar-orbit, observing in the radio quiet environment on the dark side of the moon.

Why go to space?

- Confusion from antenna interaction with the Earth beneath -- soil hard to model in EM simulations (e.g.: It is dynamic (moisture content changes with time), Earth comes in layers and is usually inhomogenous as in boulders, pebbles)
- Terrestrial RFI - Line of sight & reflections from meteors
  - Hence motivates us to go to the far side of the moon and not just above the atmosphere
- Ionosphere.

A tip of the hat to …

- RAE-2 -- the most we know about lunar radio environment
- Change-e 4 (Low Frequency Spectrometer) and Queqiao (Netherlands-China Low-Frequency Explorer)
- Dark Ages Reionization Explorer http://lunar.colorado.edu/dare/
- Dark Ages Polarimeter Pathfinder (DAPPER) https://www.colorado.edu/ness/dark-ages-polarimeter-pathfinder-dapper

There are a (hopefully)only a finite number of ways to do good global 21-cm EoR science from space. If we independently converge on similar design, methods, etc.. that’s a good thing!

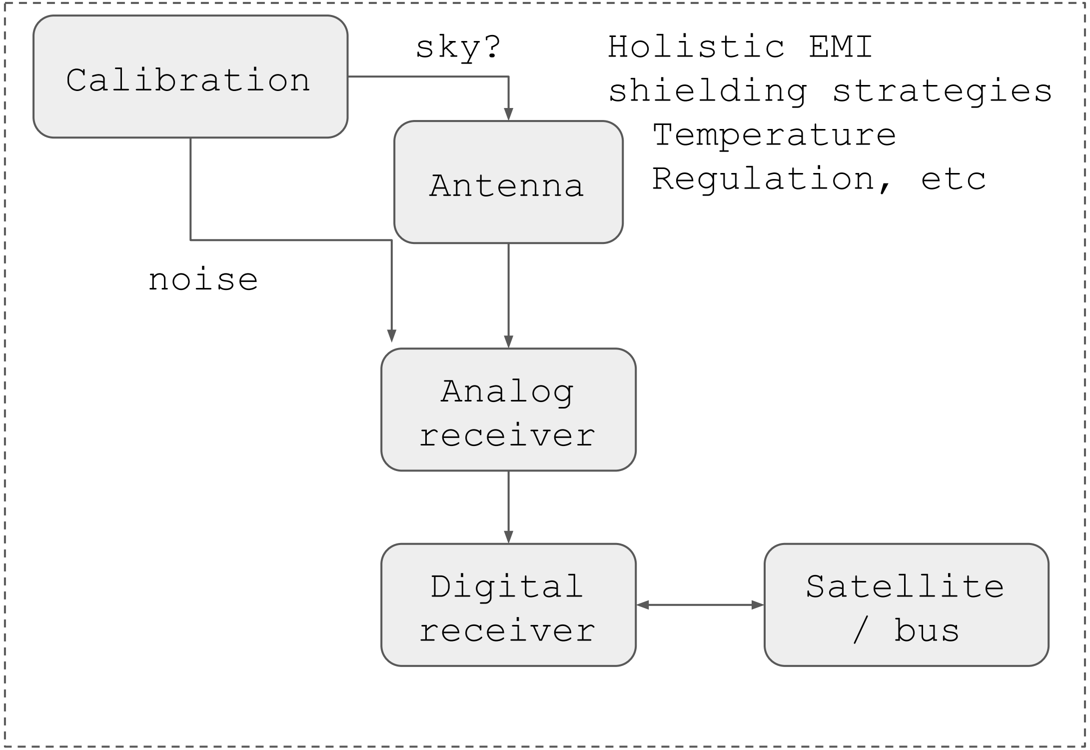
SARAS : ground-based heritage

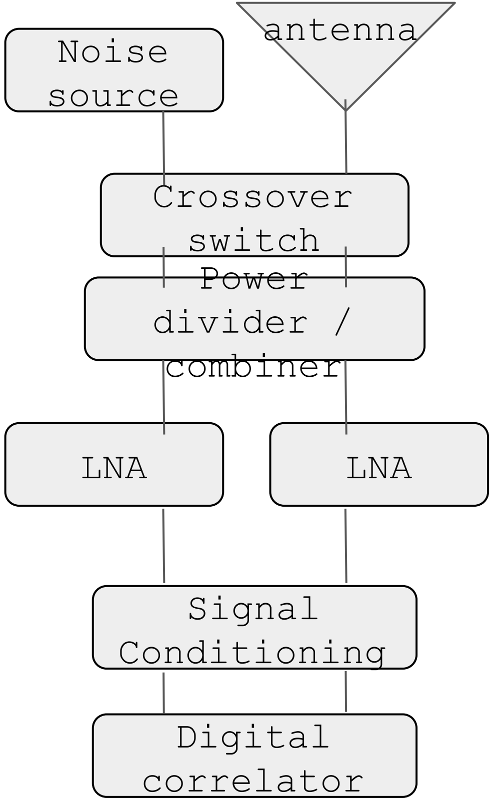
SARAS : Shaped Antenna measurement of the background RAdio Spectrum

From the Raman Research Institute (talks by Ravi Subrahmanyan and Saurabh Singh)

PRATUSH is the space-based counterpart of SARAS. It is its own experiment although it is certainly going to be designed keeping in mind lessons learned from (ongoing) experience with SARAS.

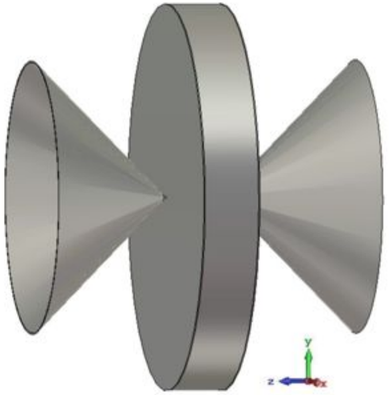
Strawman design, block diagram

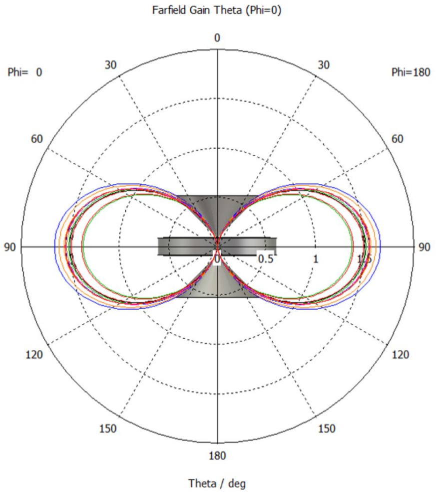




An integrated flight module - example

- Biconical dipole antenna; arms are separated by a cylindrical drum in which receiver electronics is housed





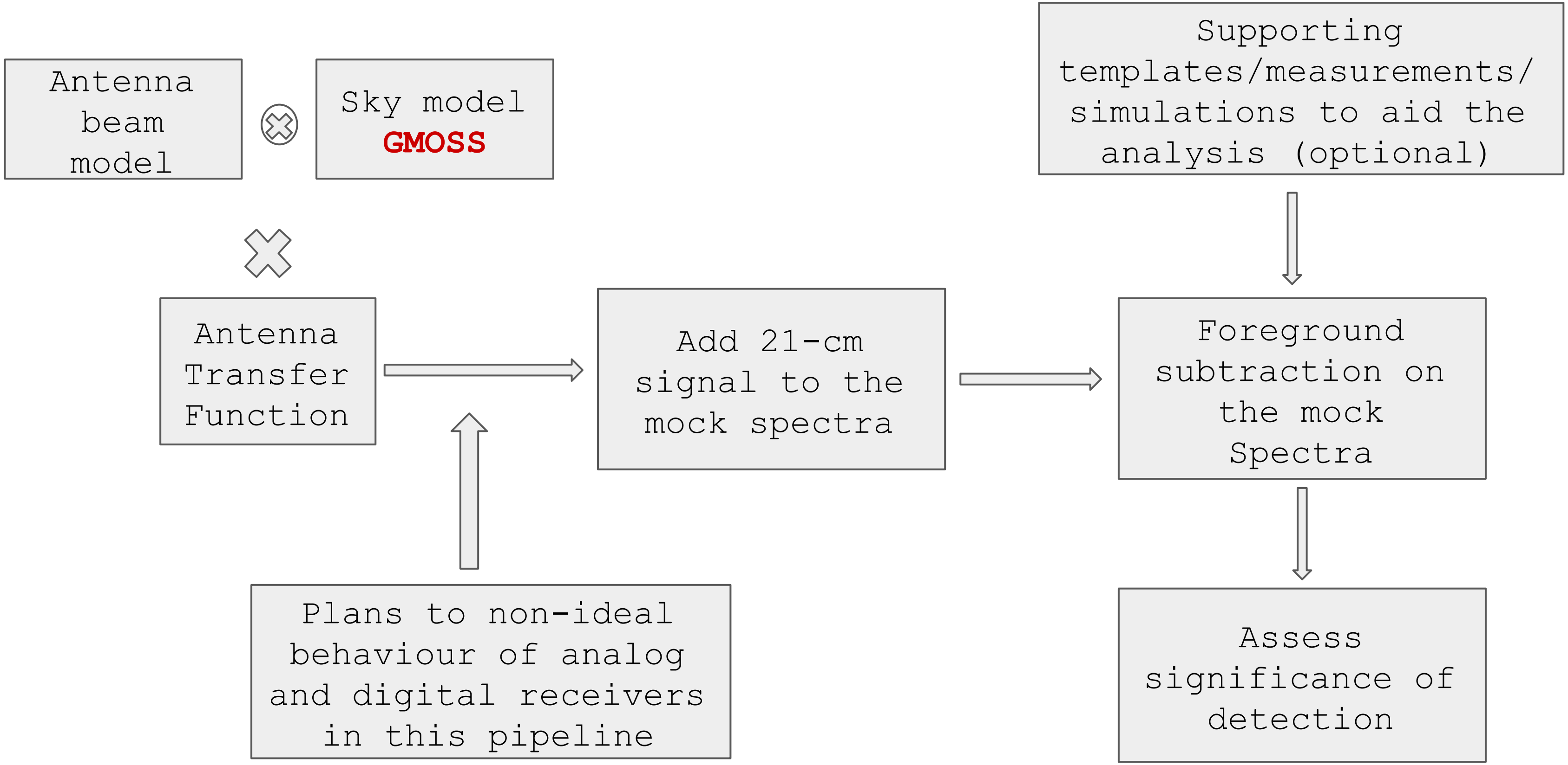
- The cone structures are hollow, and may hold the house-keeping electronics and communications to bus (not shown)

Exploring other designs as well that provide a significant signal detection for range of astrophysical models

Design philosophy

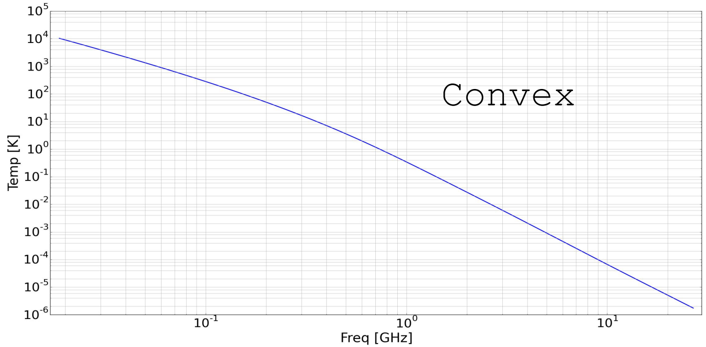
- Many principles derived from the ground-based counterpart SARAS experience -- continual ongoing feedback
- Antenna (Ravi’s talk on SARAS3): Frequency independent beam pattern, Maximally smooth reflection efficiency, High efficiency (no Earth beneath)
- Calibrated receiver bandpass -- Maximally Smooth
- Noise injection calibration scheme
- Correlation spectrometer (nominally FX)

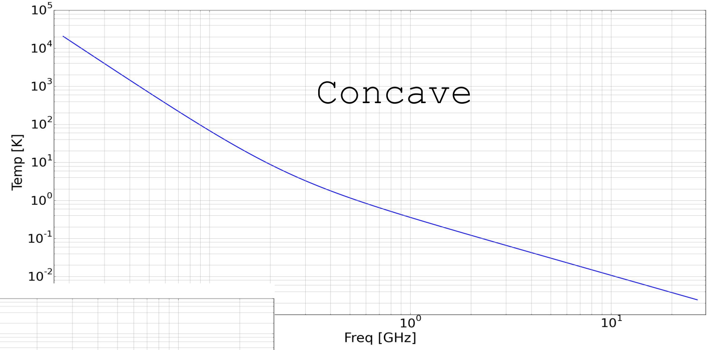
Design evaluation : Existing pipeline

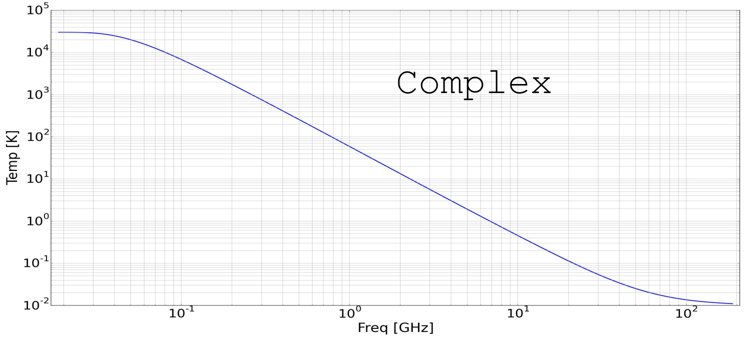


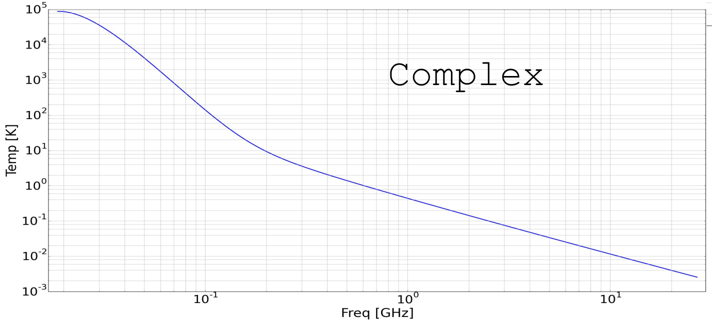
GMOSS: Global MOdel for the radio Sky Spectrum

- We have – data, 5 degree pixels (3072)
  - All sky maps 22 MHz, 45 MHz
  - 150 MHz, 408 MHz, 1420 MHz, 23 GHz
- Physics
  - Galactic synchrotron
    - Possible break
    - Different source populations
  - Free free emission
  - Absorption
- Beam averaged spectrum simulations show that the sky is maximally smooth to ~mK and Galactic plane has more spectral complexity









Sathyanarayana Rao, M., et.al. 2017a, AJ, 153, 26

Sathyanarayana Rao, M., et.al. 2017b, ApJ,840,33S

Where we are now:

Pre-flight studies have been funded for one year by Indian Space Research Organization (ISRO) March 2019-2020. Goals for year 1: antenna design, power and timing optimization for digital backend, compact analog electronics.

Antenna design simulations are on-going -- Simulations of full sky-spectrum adopting GMOSS sky-model, antenna beam (including frequency dependence), and return loss. If the mock-spectrum can be described by a maximally smooth function we accept, else reject design. Propagate full model to include science signal(s) and test sensitivity to models.

Actively working on calibratable receiver system, including in-situ s11 measurement of antenna (+receiver?).

Synthesis and implementation of FX correlation spectrometer (self, auto) on space-qualified FPGA platform. Working on timing and power estimation.

Support from space agency

The Raman Research Institute and the Space Applications Center (SAC) of the Indian Space Research Organized signed a memorandum of understanding for “Joint research on the cosmic microwave background: developing space radiometers at MHz, GHz, and THz frequencies”.

A deliverable as listed in the MoU is to develop ‘Radiometers with integrated, compact and space qualified electronics integrated, compact and space qualified electronics in the 10-250 MHz band ...’. The objectives of the MoU are naturally aligned with PRATUSH.

If your question is: “ Are you worried about..??”

- Calibration
- Spin-stability
- EMI shielding
- Additive systematics
- Lunar ground and ionosphere
- Space plasma
- Antenna backlobe
- … insert concern here …

The answer is very likely ‘YES’.

Top concerns

- Receiver systematics (additive components)
  - Also a concern for ground based instrument design -- learn from SARAS, ground based experiments
- Antenna design -- beam chromaticity, efficiency, return loss, unknown-unknowns (difficult to simulate EM environments)
  - Lessons learned from ground based experiments apply + rigorous testing of prototypes in addition to simulations as we have done before
- EMI shielding of antenna from ‘noisy’ electronics
  - Not a single step solution. Feedback to full system design, packaging, materials, to name a few. Iterative process
- Limited subset of space-qualified parts. For example ADC sampling rates -- difference in spec of commercial vs space-qualified versions
- Power, mass, (volume) limits

Secondary science goals

- For the primary science goal we will likely have:
  - Poor spatial resolution (~60 deg FWHM)
  - High spectral resolution (~10s kHz, say 60 kHz for now)
  - Wide bandwidth (100+ MHz, ideally 40 - 200 MHz)
  - Moderate timing resolution (integration time a function of instrument, calibration stability)
  - Lunar orbit (spends a significant fraction of duty cycle on the far side)
- We are open to secondary science goals that will fit this instrument design (not considering piggyback instruments at this moment)
  - Radio Recombination Lines (RRLs)in diffuse ISM
  - Improved low-frequency sky-spectrum studies
- Open to discussions with EoR + astronomy + space weather community

PRATUSH summary

- **Primary Objective:** Detection of global 21-cm signal from Cosmic Dawn and Epoch of Reionization
- **Frequency Range:** 50-200 MHz
- **Orbit:** Circumlunar, far side observing, near side communication
- **Qualification model:** 2 years
- **Flight model:** 3 years
- **In-orbit lifetime:** 2 years

The team

- Mayuri S.Rao
- Saurabh Singh
- Jishnu Nambissan

- A. Raghunathan
- Srivani . K.S.
- B.S. Girish
- Somashekar. R

Questions?
Discussion?

BACK-UP SLIDES

GMOSS: Global MOdel for the radio Sky Spectrum

Model 1:

Diffuse warm ionized gas

Emission

$$T(\nu) = C\left(\nu^{-2}\left(\gamma^{2\alpha_1-3}\int_{x(\gamma_{min})}^{x(\gamma_{max})} F(x)x^{-\frac{p_1-3}{2}}\,dx + \gamma^{2\alpha_2-3}\int_{x(\gamma_{min})}^{x(\gamma_{max})} F(x)x^{-\frac{p_2-3}{2}}\,dx\right) + T_x\nu^{-2.1}\right) e^{-\left(\frac{\nu_t}{\nu}\right)^{2.1}} + T_e\left(1 - e^{-\left(\frac{\nu_t}{\nu}\right)^{2.1}}\right)$$

Synchrotron steepening

Absorption

Normalization

Model 2:

Diffuse warm ionized gas

Normalization

Absorption

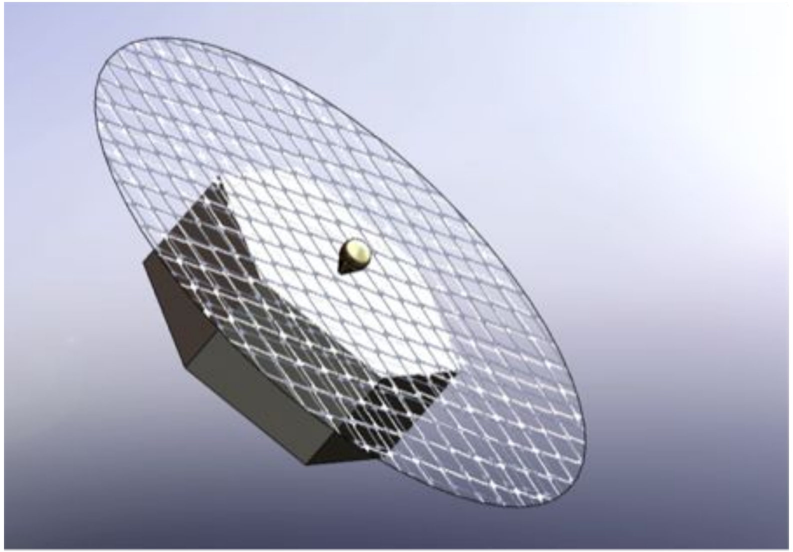
Emission

$$T(\nu) = C1\left(\nu^{-\alpha_1} + \frac{C_2}{C_1}\nu^{-\alpha_2} + T_x\ \nu^{-2.1}\right)e^{-\left(\frac{\nu_t}{\nu}\right)^{2.1}} + T_e\left(1 - e^{-\left(\frac{\nu_t}{\nu}\right)^{2.1}}\right)$$

Different source populations

Example 1: payload + bus flight module

- Spherical monopole antenna with a metallic reflector plate
- The reflector plate can potentially be realized as a mesh that unfurls in space
- The electronics would be housed beneath the reflector plate in a shielded enclosure



- In this model, the bus along with power sources, house-keeping electronics and communications would be housed beneath the antenna

The team

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- Saurabh Singh
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- Ravi Subrahmanyan
- N. Udaya Shankar
- S. Seetha

- A. Raghunathan
- Srivani . K.S.
- B.S. Girish
- Somashekar. R

\+ 3 new hires, interns, and with support from Raman Research Institute facilities (mechanical workshop, electronics engineering group, Gauribidanur field station)