

Technological readiness of High Redshift 21cm receivers

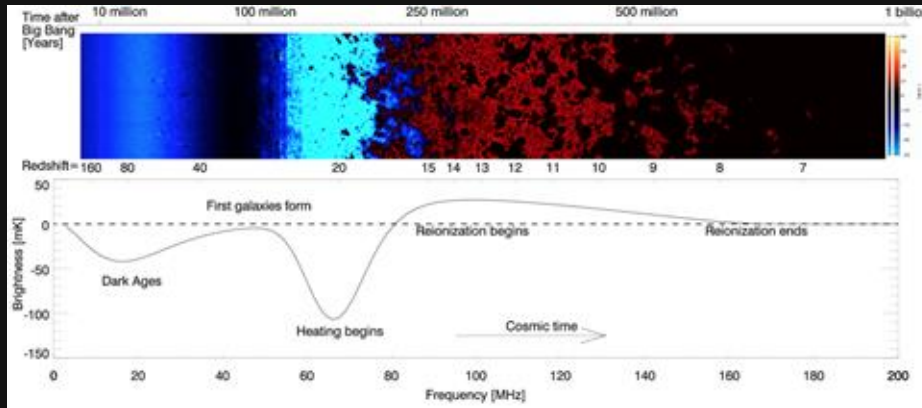
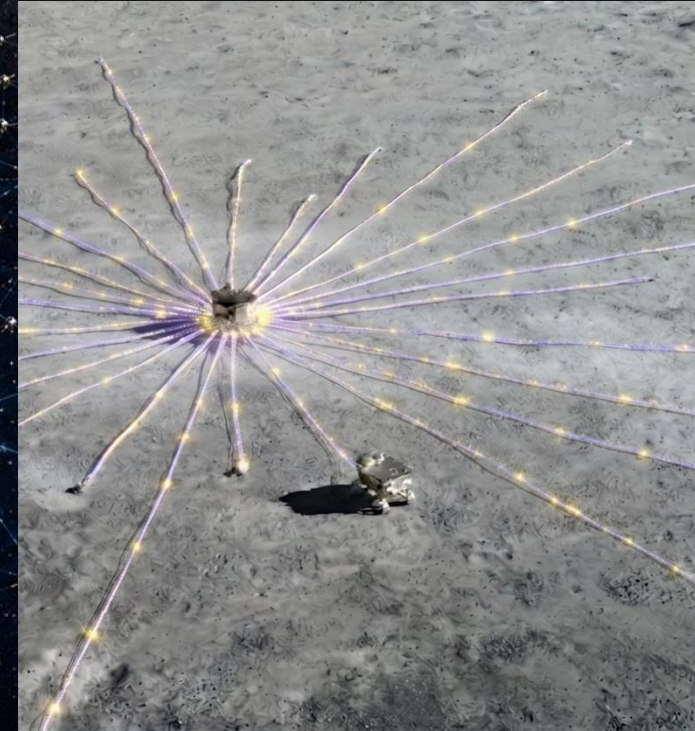
ASTRA Community Science Workshop

Danny Jacobs (ASU)

Low Frequency Mission Concepts include high redshift 21cm

Megawave

FARSIDE\FARVIEW



>>>Both missions will attempt to detect both the global and fluctuation component.

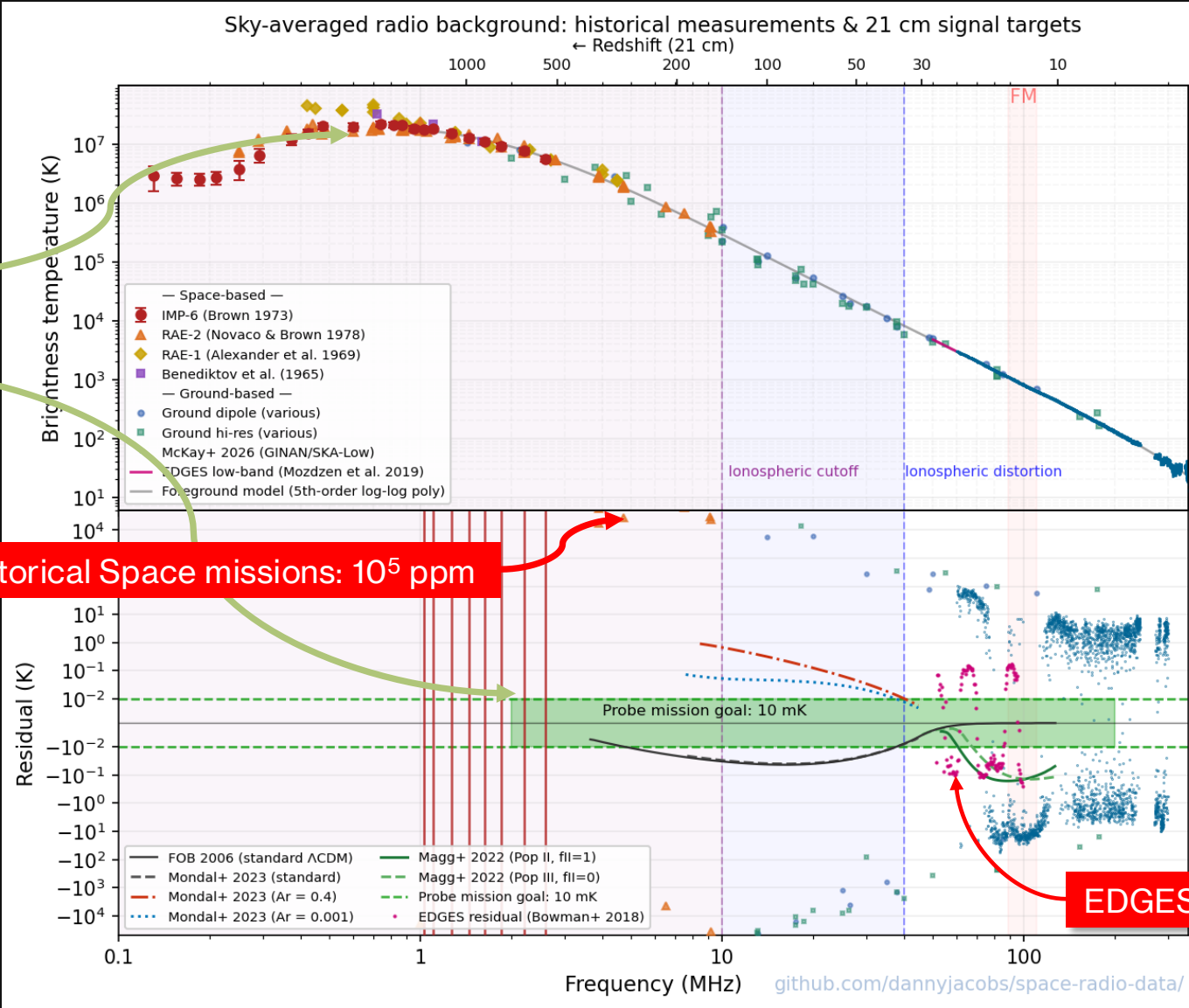
Current state of the art in precision radio measurements

Mean power: 10^6 K

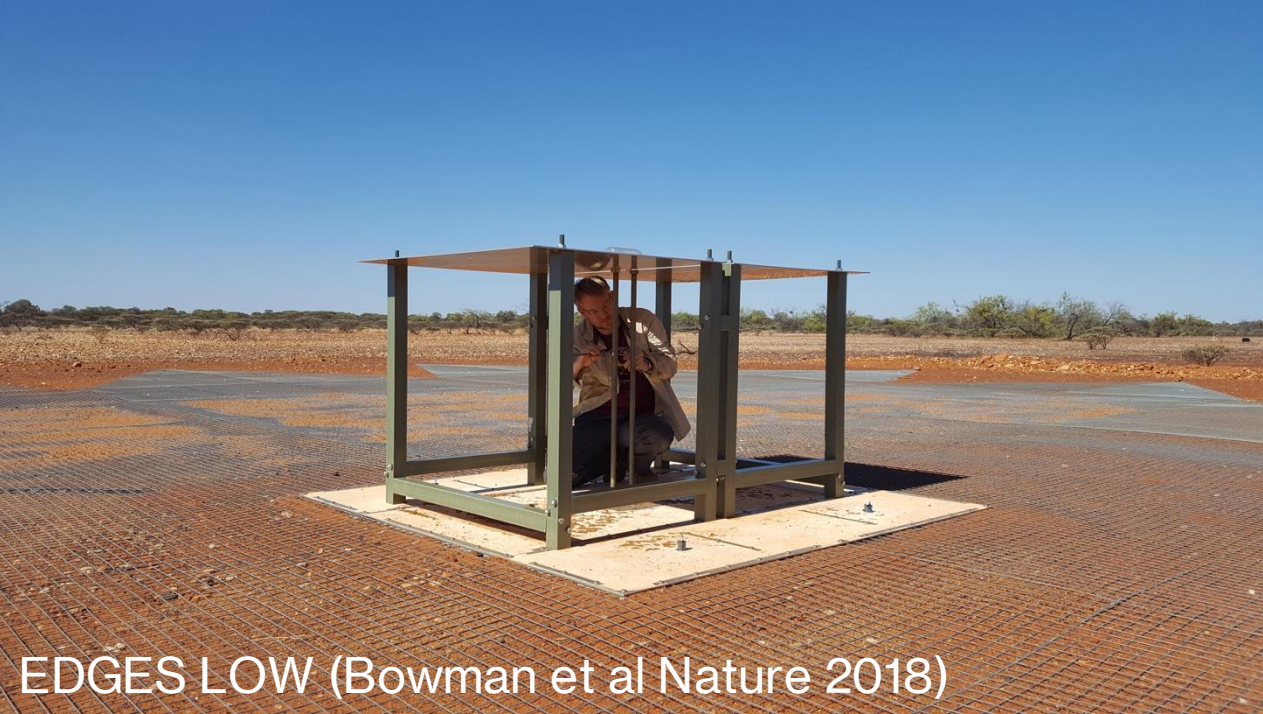
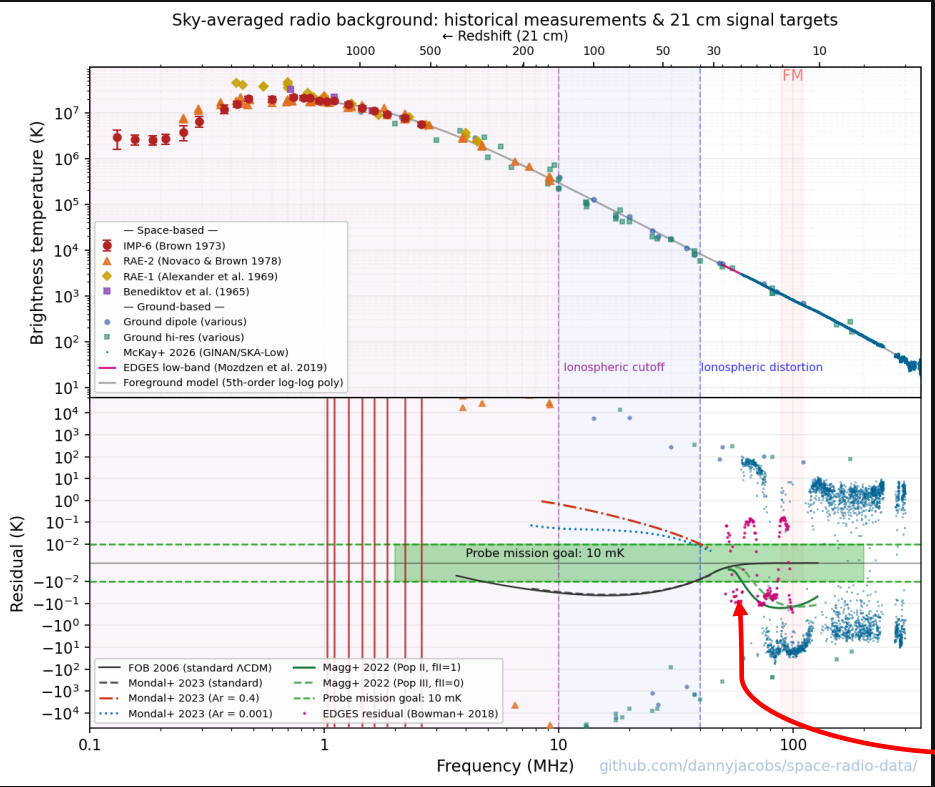
Precision requirement: 10mK
RMS

$10\text{mK}/10^6\text{K} = 0.1 \text{ ppm}$

Historical Space missions: 10^5 ppm



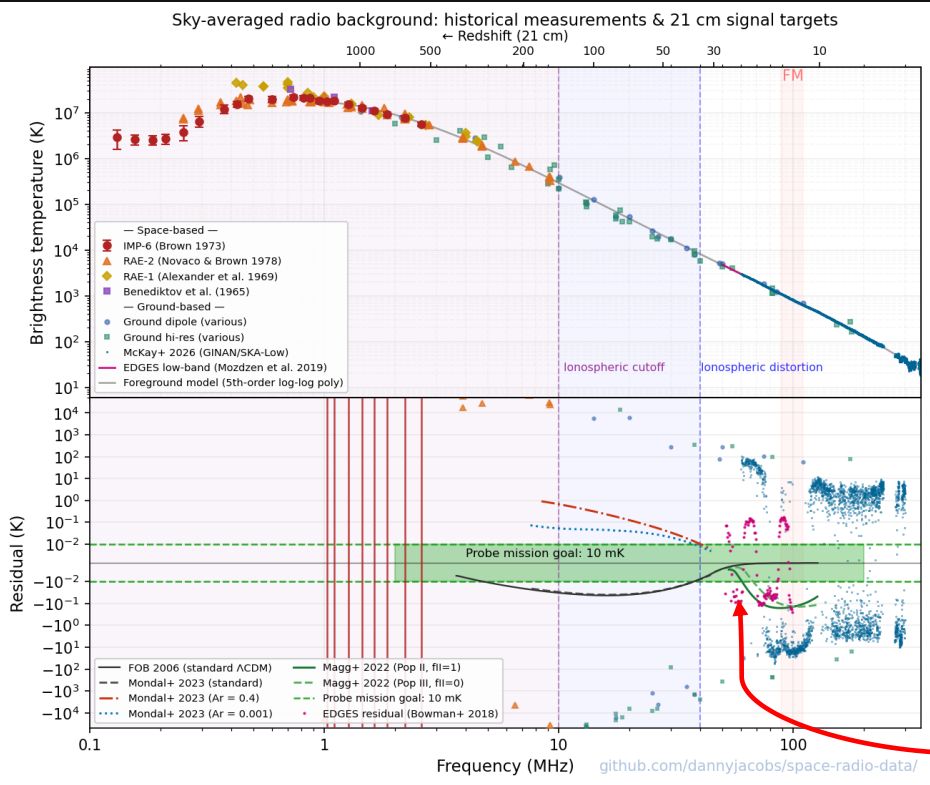
Development of technology for high precision radiometry



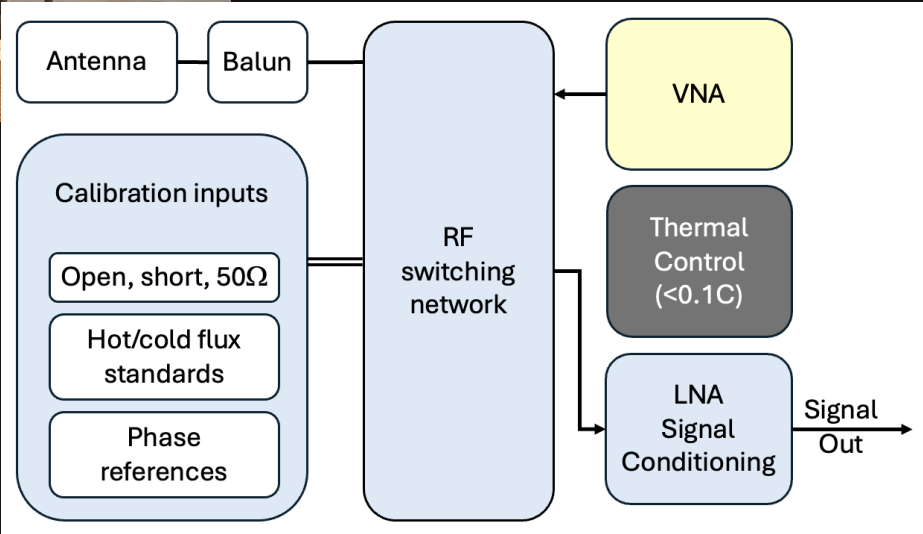
EDGES LOW (Bowman et al Nature 2018)

EDGES: 33ppm

Development of technology for high precision radiometry

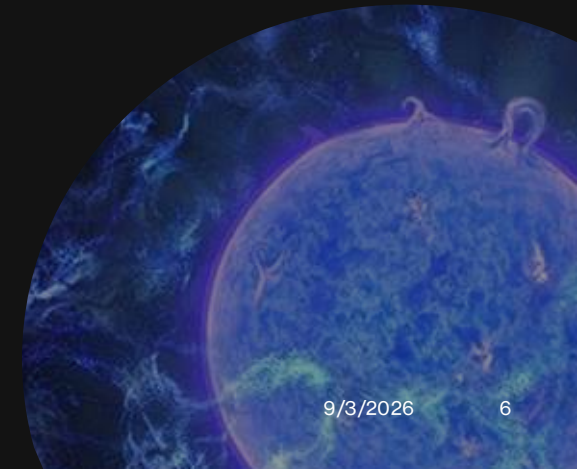


EDGES: 33ppm



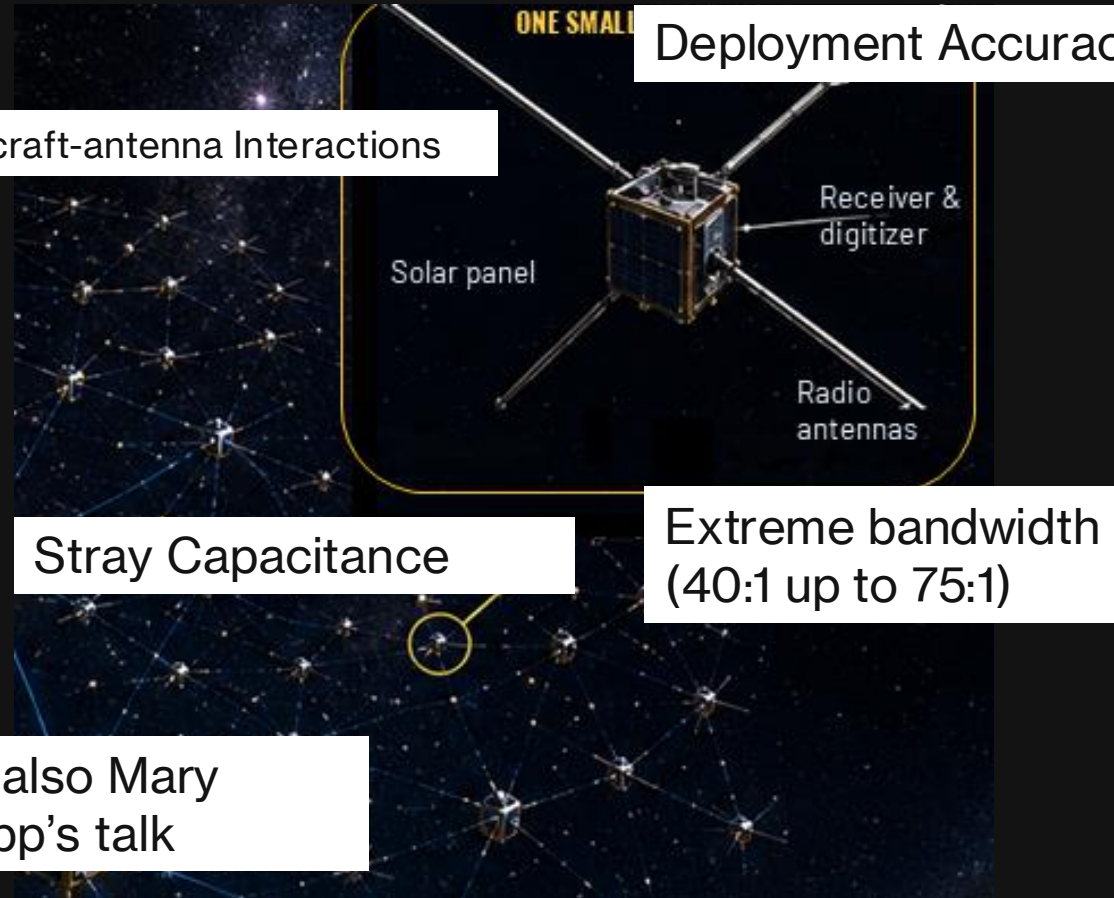
What do you identify as the most critical or key enabling technology required for your mission concept?

The two technology gaps most directly related to the science capability of any array are the self-calibrating receiver and “environmentally aware” precision antennas

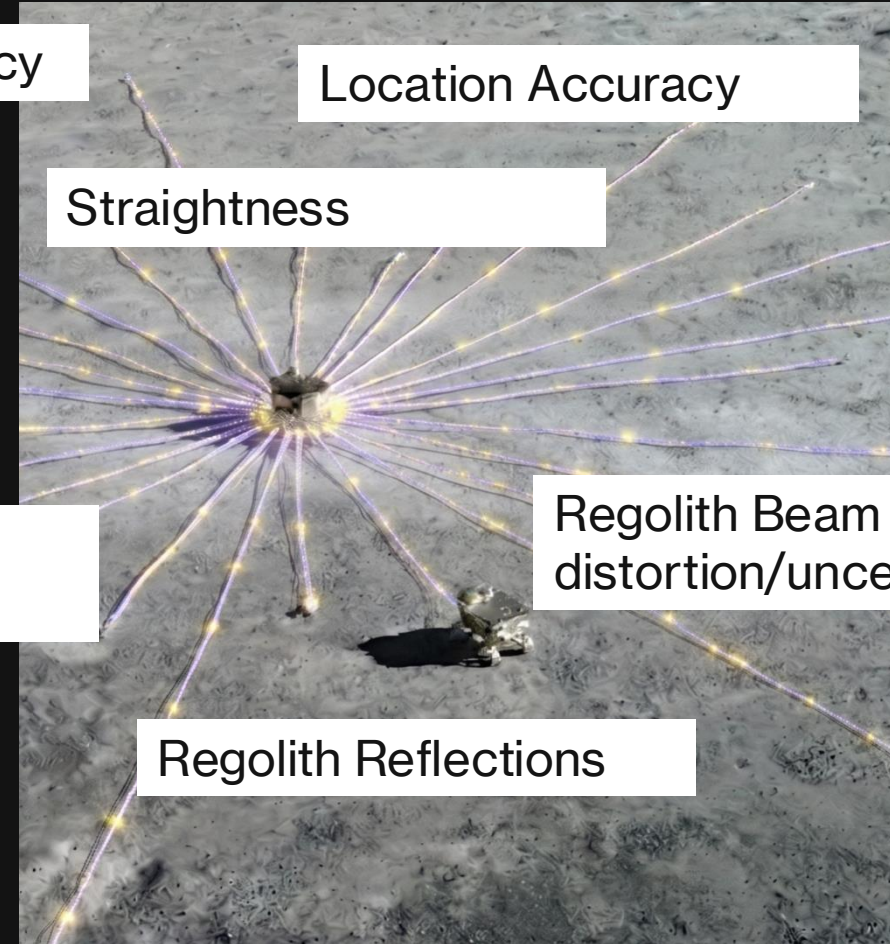


Precision Antenna

At 0.1ppm this is not standard engineering



Megawave



FARSIDE\FARVIEW

Precision Antenna technology development plan

1. Simulation studies



Lunar

- Lusee Night (Varoush 2026)
- FARVIEW (Smith, Pober, et al 2026)



Free flight

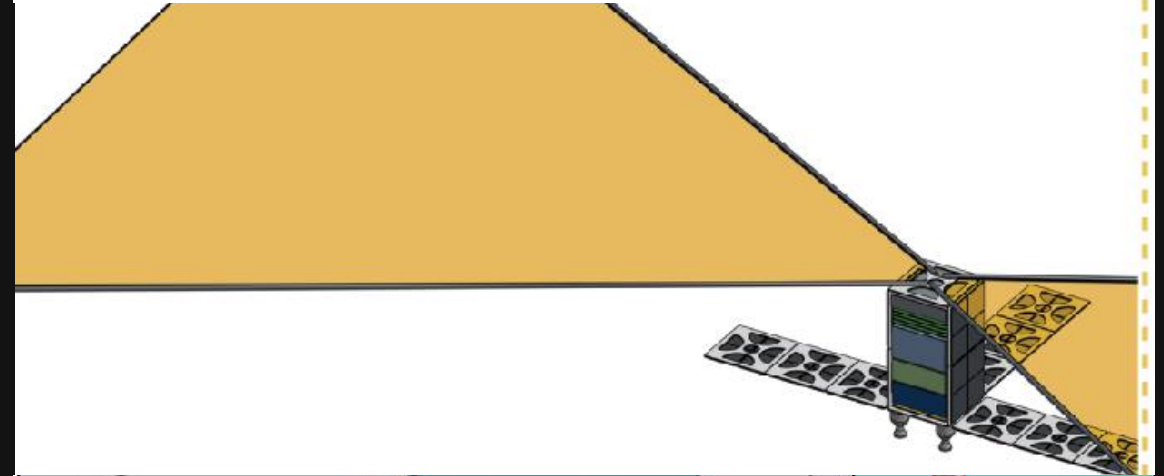
- Vector sensor (Knapp et al 2016)
- Pratush (Rao 2025)

Open Questions:

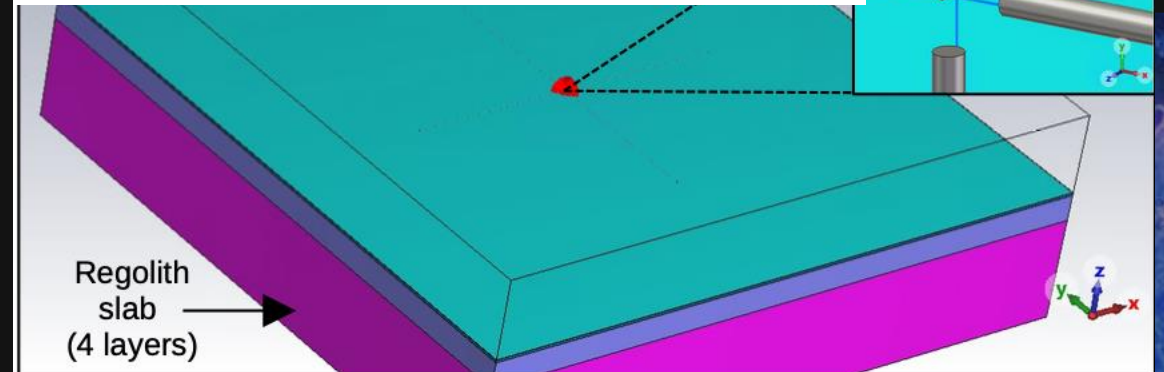
- Simulate deployables that scale
- Requirements for large structure deployment
- coupling between antennas
- Integrate with self-calibrating receiver/VNA

de Iera Acedo et al (Nature Astronomy, 2026)

Cosmocube Broadband Concept

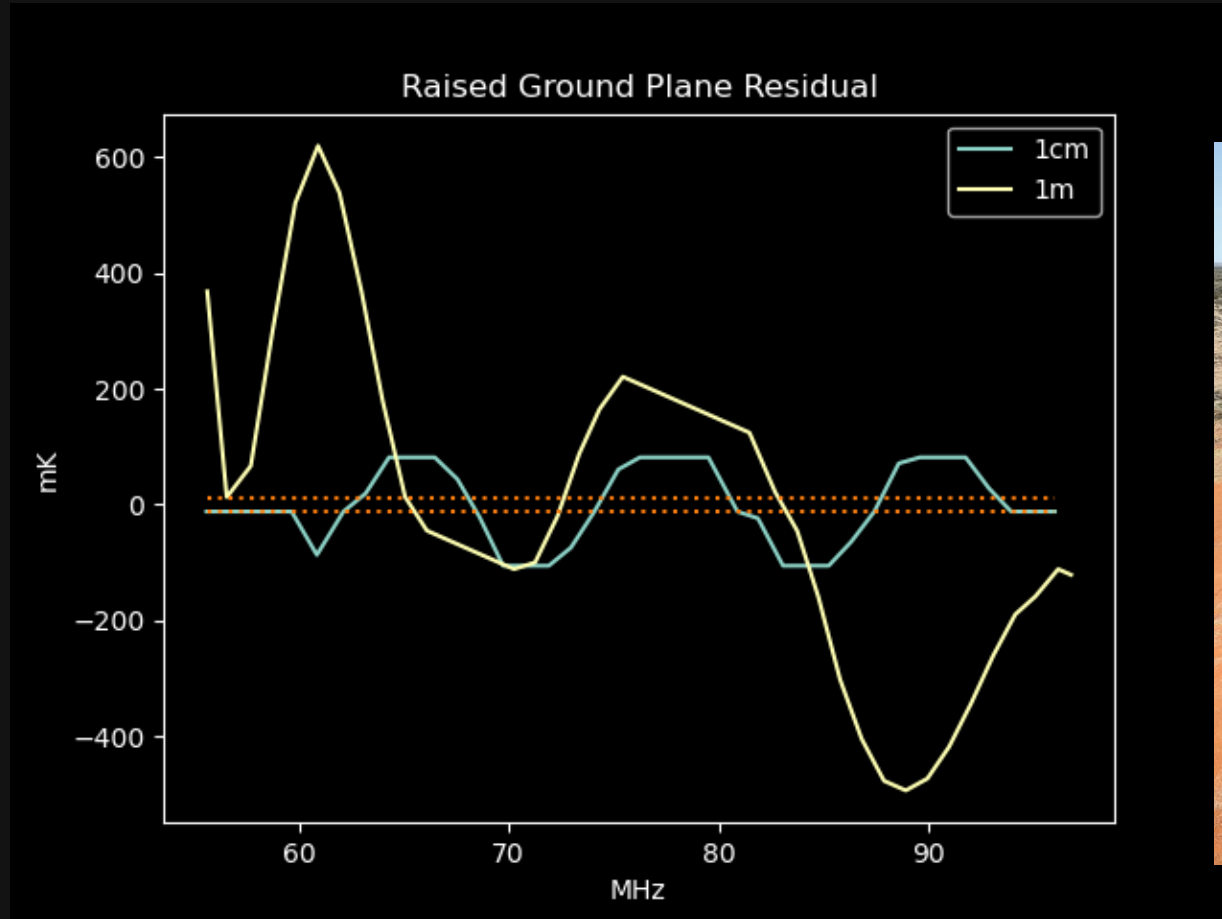


FARVIEW Dipole on regolith simulation



Sample antenna precision issue. gap under ground plane

Illustrates the impact
of a small change in
the antenna
performance



Rogers, 2023, EDGES Memo 436



Antenna technology development plan

1. Simulation studies

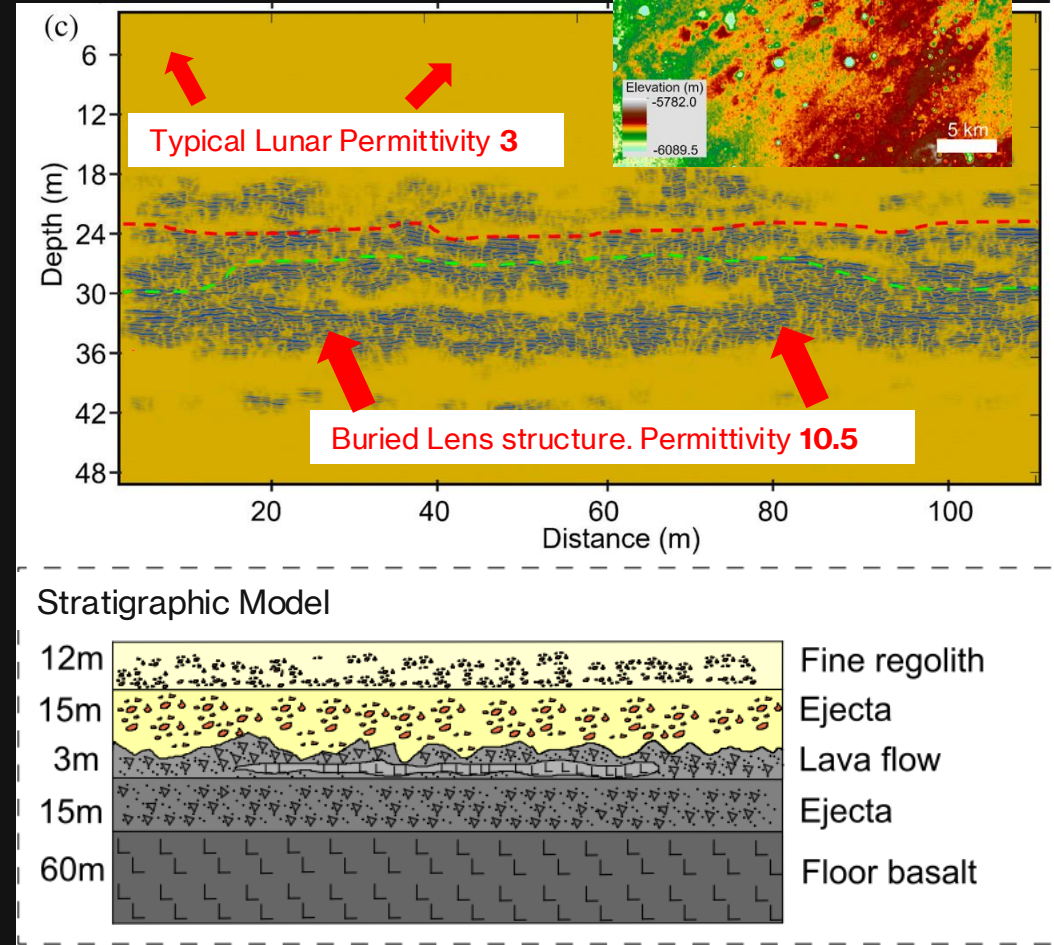
2. In-situ: Antenna must fit environment

FARSIDE/FARVIEW: The Moon is part of the antenna

Regolith characterization

- Cheng-e 4 Yutu-2 rover (2018-2025)
- GPR on Lusee night rover (expected 2026)
- 2+ proposed PRISM missions would expand on this
- Recommend radar from orbit for site downselect
 - See Radio Tomography technology from Lunasonde. (higher fidelity than typical GPR)
- Followup with landed site validation. Need smooth layer-free regolith.

Yutu-2 GPR from Aitken Basin on the Far side



Ding, Li, and Hu (IEEE 2023)

Antenna technology development plan

1. Simulation studies

2. In-situ: Antenna must fit environment

FARSIDE/FARVIEW

MEGAWAVE:

Detailed engineering of antenna concepts for real spacecraft

- Size and shape of host spacecraft
- Sensitivity to endpoint capacitive coupling
- Sensitivity to solar panel geometry, etc

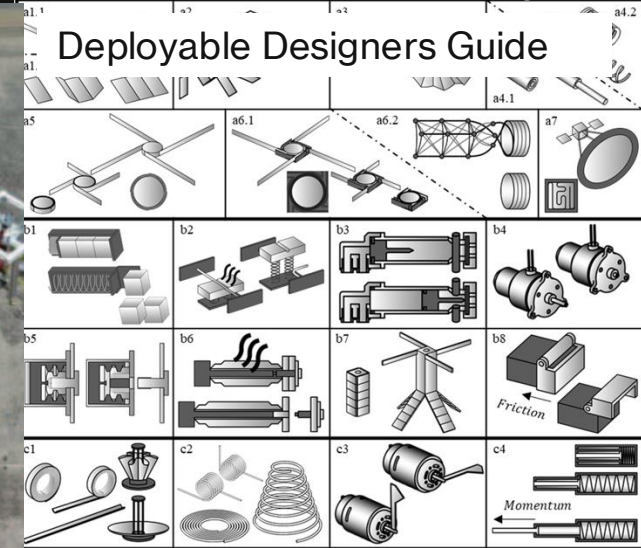
Knapp et al IEEE 2016

Vector Sensor

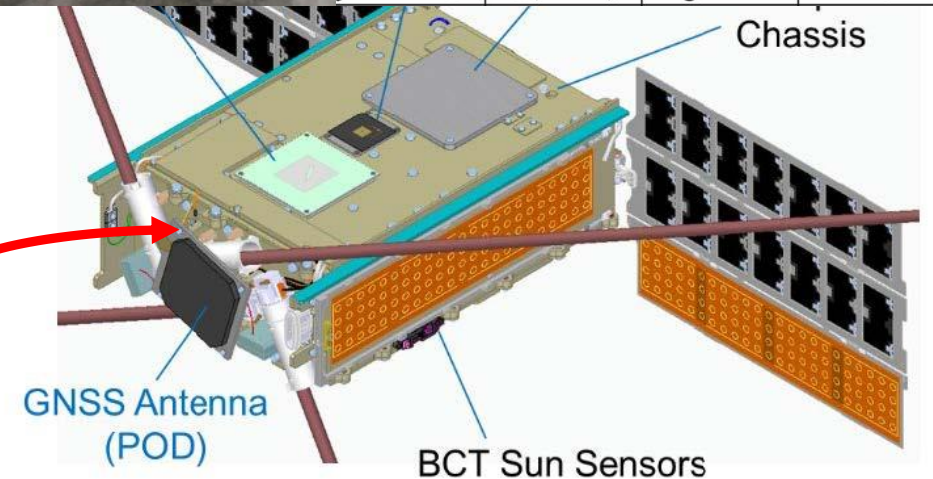


Sauder et al Nature Com Eng. 2024

Deployable Designers Guide



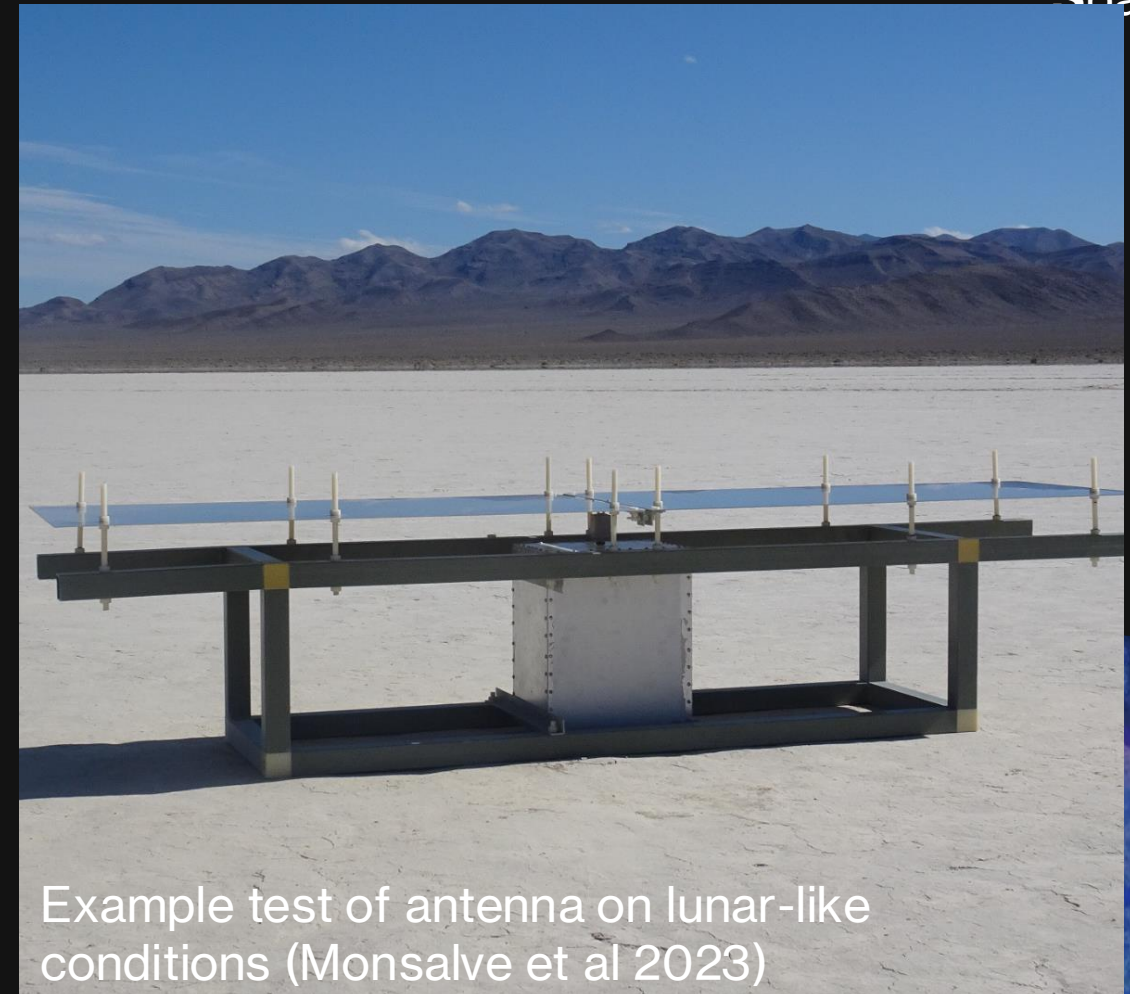
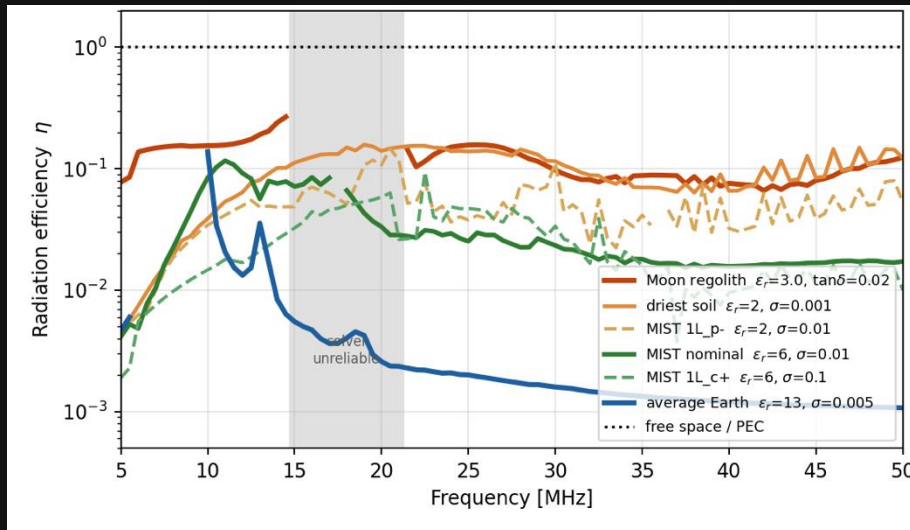
Capacitive coupling to nearby components



www.nanosats.eu/sat/sunrise

Antenna technology development plan

1. Simulation studies
2. In-situ: Antenna must fit environment
3. Antenna prototype and in-situ demonstration
 - FARSIDE/FARVIEW: Test of surface antennas in analog environments



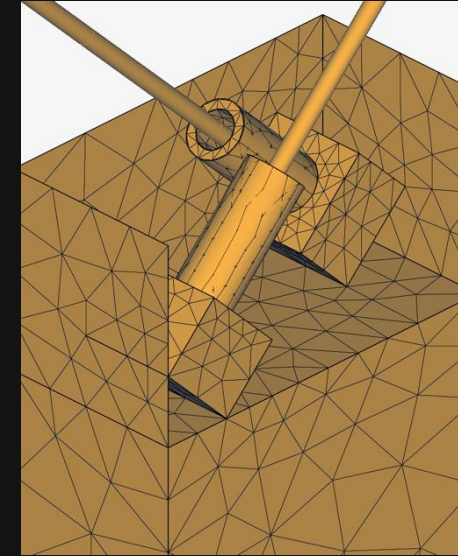
Example test of antenna on lunar-like conditions (Monsalve et al 2023)

Antenna technology development plan

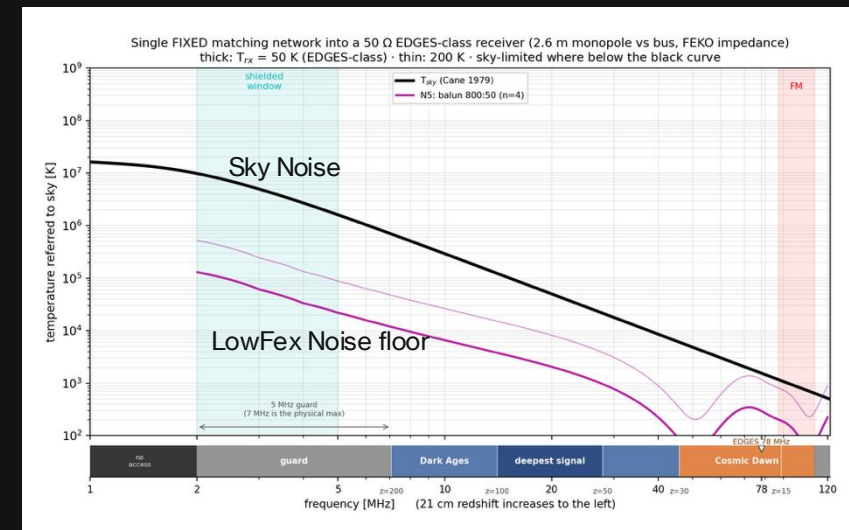
1. Simulation studies
2. In-situ: Antenna must fit environment
3. Antenna prototype and in-situ demonstration
 - FARSIDE/FARVIEW: Test of surface antennas in analog environments
 - MEGAWAVE: Demonstration flights for candidate antenna technology
 - SunRISE (2026)
 - Cosmocube (in development UK)
 - PRELUDE (proposed 2026)
 - LowFex (proposed 2026)

Sky limited
match possible
across most of
the 21cm band

LowFex Concept



SunRISE antennas in a 6U dipole configuration

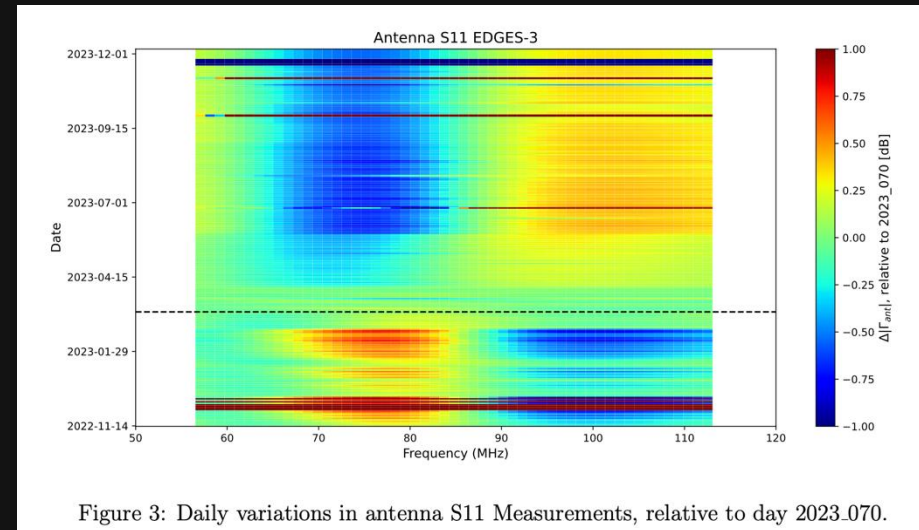


Antenna technology development plan

1. Simulation studies
2. In-situ: Antenna must fit environment
3. Antenna prototype and in-situ demonstration
4. Antenna monitoring via VNA in self-cal receiver

VNA measures antenna
or environment changes.

Requires calibration
better than factory.



Vydula EDGES Memo 209

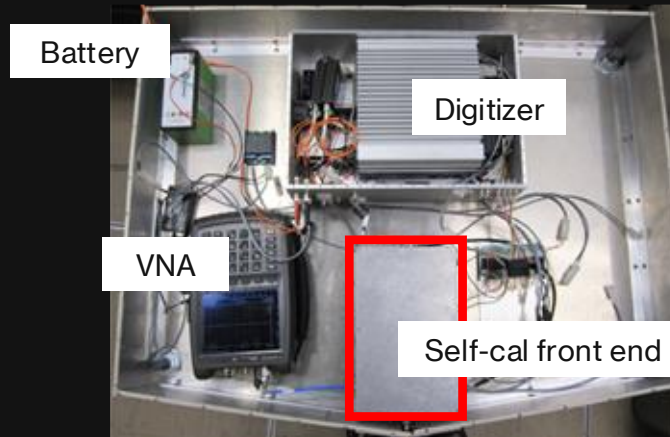
Self-calibrating Receiver Technology Development Roadmap

- Make ground-based instruments **space worthy**
- Miniaturize and demonstrate calibration

Receiver inside blade of EDGES3 Antenna



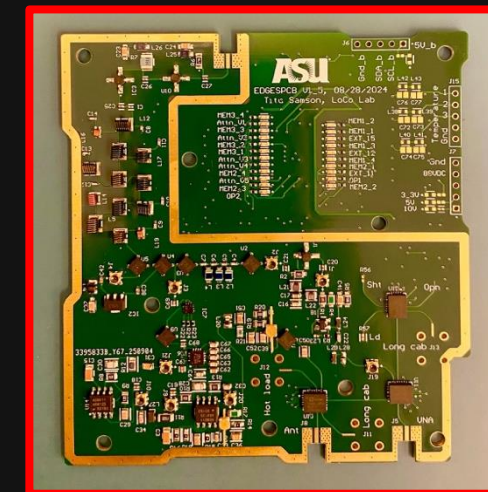
EDGES3 ASU/Haystack



70cm

Miniaturization
program

Single board “mini-EDGES”

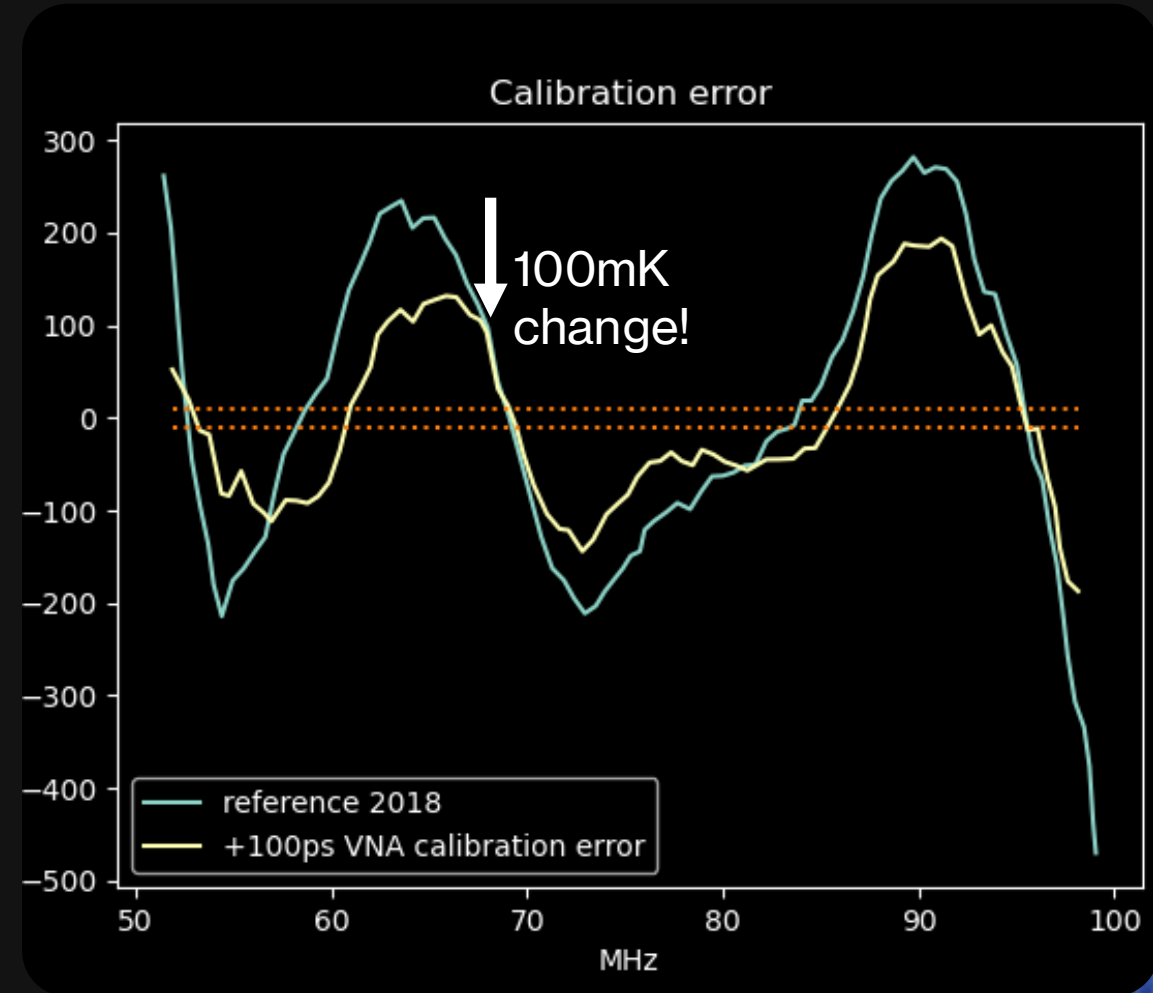


9cm

github.com/edges-collab/edges-front-end-board

Self-calibrating Receiver Technology Development Roadmap

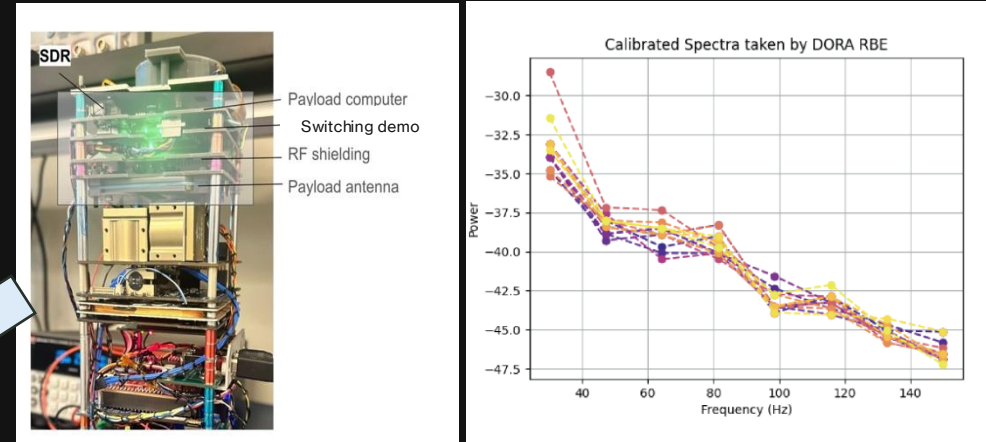
- Make ground-based instruments space worthy
 - Miniaturize and improve reliability
 - Convert **lessons** from ground instruments into requirements



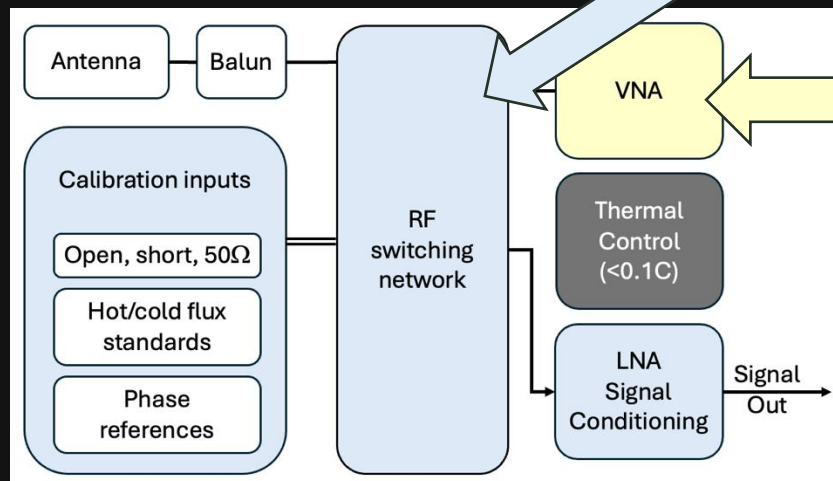
Self-calibrating Receiver Technology Development Roadmap

- Make ground-based instruments **flight capable**
- Miniaturize and improve reliability
- Convert lessons from ground instruments into requirements
- Flight Test
(Examples here, more needed)

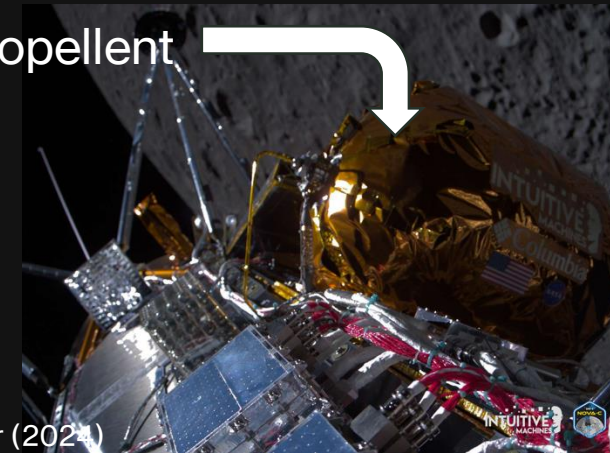
DORA 2024 LEO Technology Demonstrator



Zhao et al IEEE Aero 2025



VNA propellant gauge



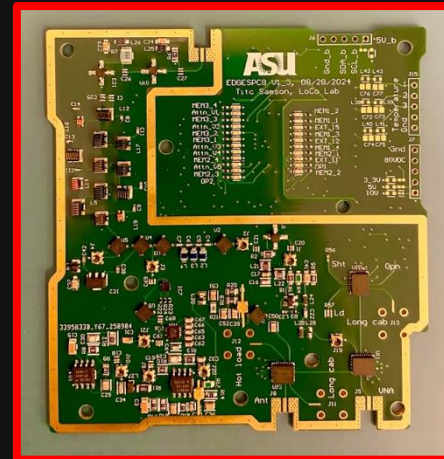
IM-1 lander (2021)
Zimmerli et al JSR 2026

Summary: Technology Gaps for Radio Arrays 21cm Science

NASA Tech Categories Interferometer: Precision Metrology New Detector Technologies

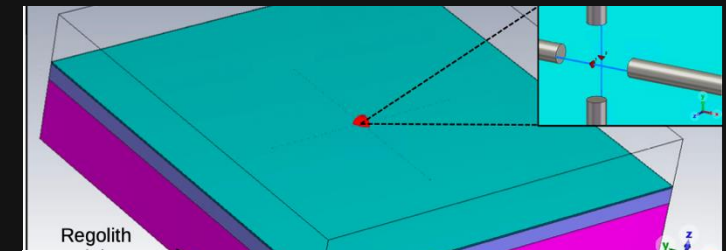
- Megawave –free-flight antenna performance (deployment, spacecraft match) systematic calibration formation flying, timing, and interconnect (not discussed here)
- Farside/Farview – lunar surface precision deployment and interconnect antenna performance (deployment, regolith) systematic calibration

self-calibrating receiver.



Miniaturized EDGES self-calibrating receiver (2026)

Ultra-precise antennas



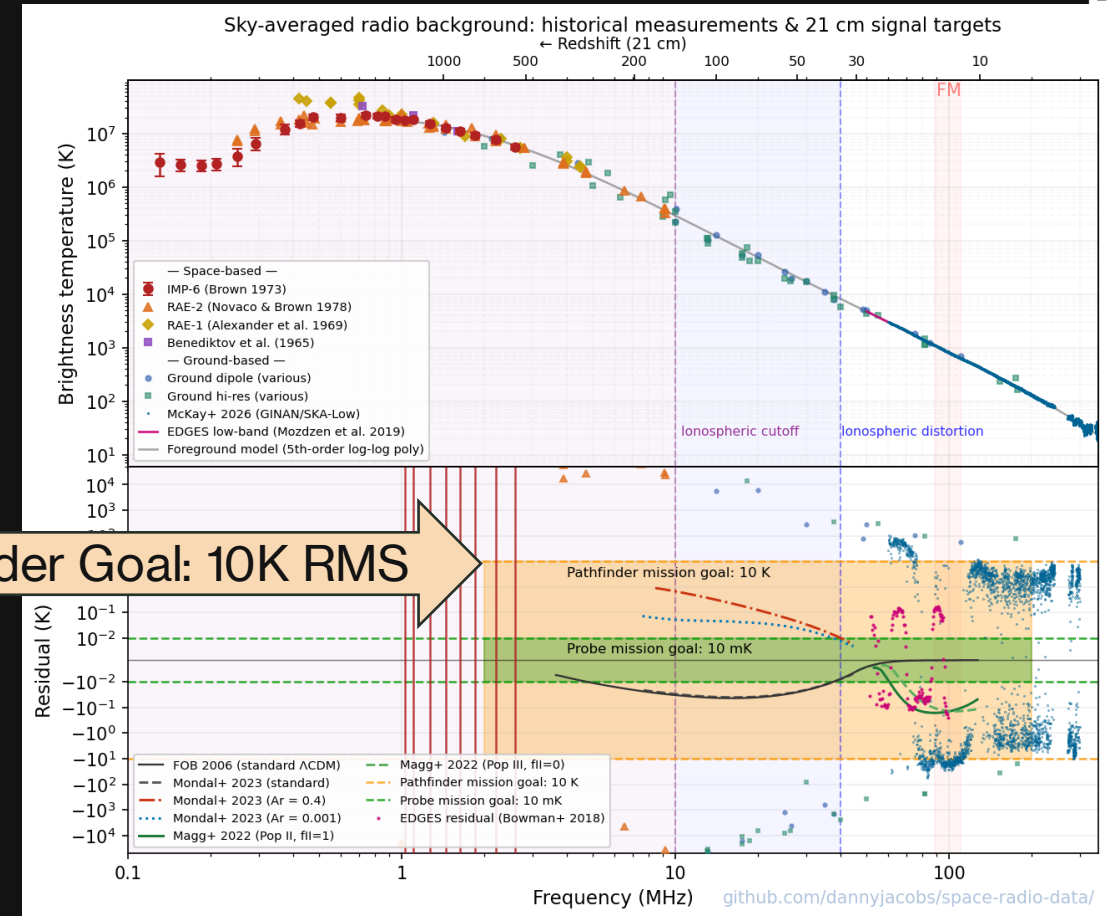
Environment coupling simulation (Smith 2026)



Analog testing location (Monsalve 2022)

Antenna + Receiver Pathfinder Technology Demonstration

- Combine Antenna and Receiver Technology (They are a unit and must be tested together)
- Pathfinder Mission:
 - 10K RMS (3 out of 6 needed orders of magnitude)
 - Demonstrate self-calibrating receiver performance
 - Demonstrate in-situ high precision antenna monitoring
 - Fill in spectrum.
 - Identify spectral lines to avoid
 - Build better foreground map



Leveraging Industry, Artemis

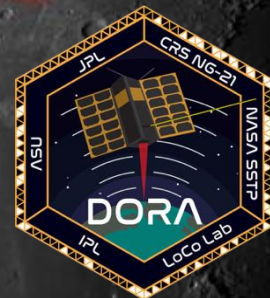
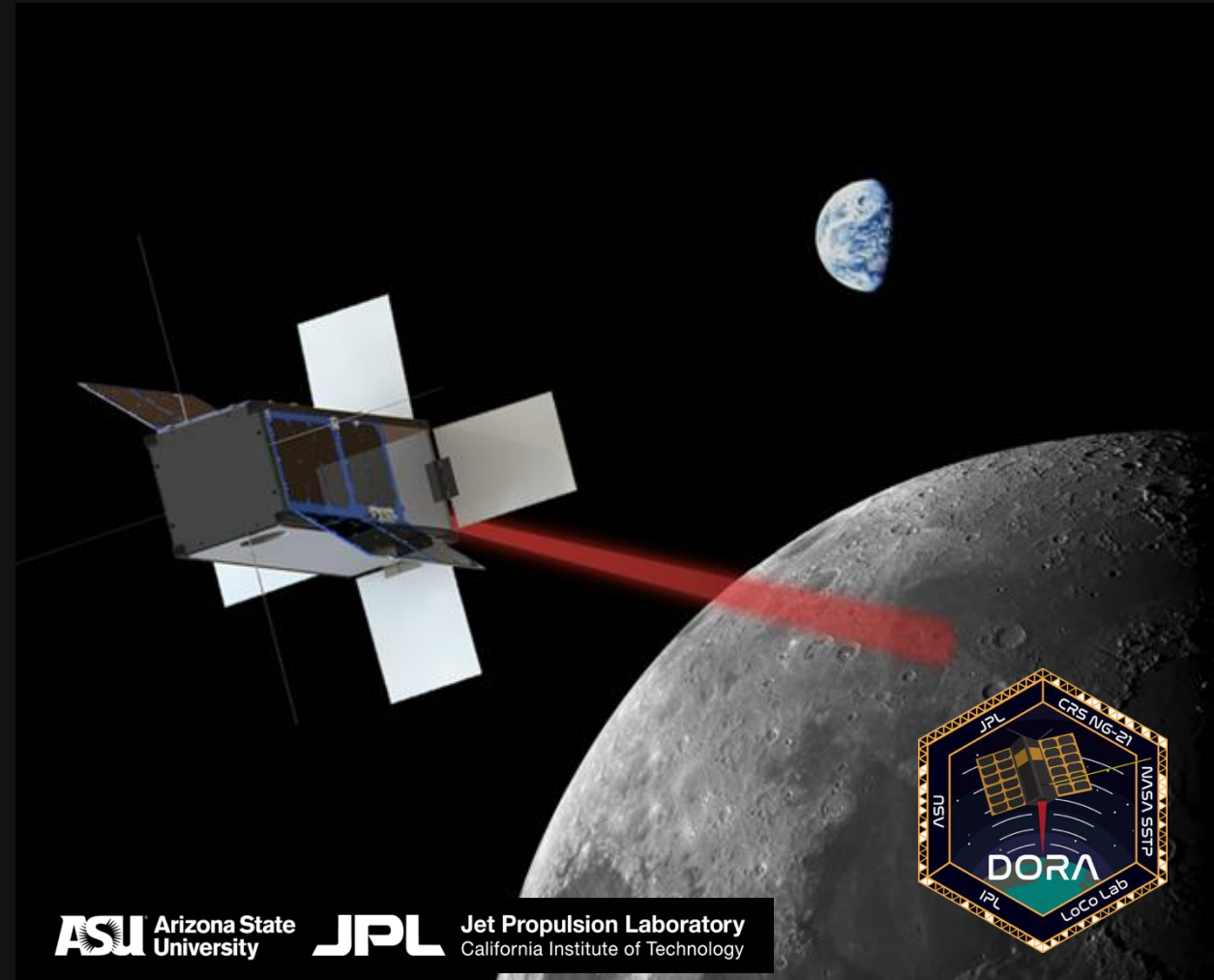


EDGES
Receiver
In
Space

- Vigorous use of smallsat industry and rideshares for demonstration observing and test opportunities
- Smallsat technology partnerships/Artemis Technology development in areas of precision radio technology
- Consider adding industry/university partnership opportunities
- mini-EDGES proposed for 2026 PRISM and 2026 SMEX

Example: DORA

Smallsat Technology Program, Lunar Networking category
Laser Technology spun off into startup CHASCI
Mini-EDGES included as a secondary payload
Enabled by finding congruent Artemis goals



Summary

Technology gaps needed for 21 science

1. Precision Antennas
2. Self-calibrating receiver

- Self-cal technology developed for EDGES has been miniaturized and is nearing readiness for use in smaller missions.
- Antenna precision requires simulation, analog testing, and scouting
- A Pathfinder mission is needed to demonstrate the core self-cal and antenna metrology technology

Current Best Ground	10-500mK
Current Best Space	10^6 K
Pathfinder Goal	10 K
Dark Ages Req	10 mK