ALBATROS

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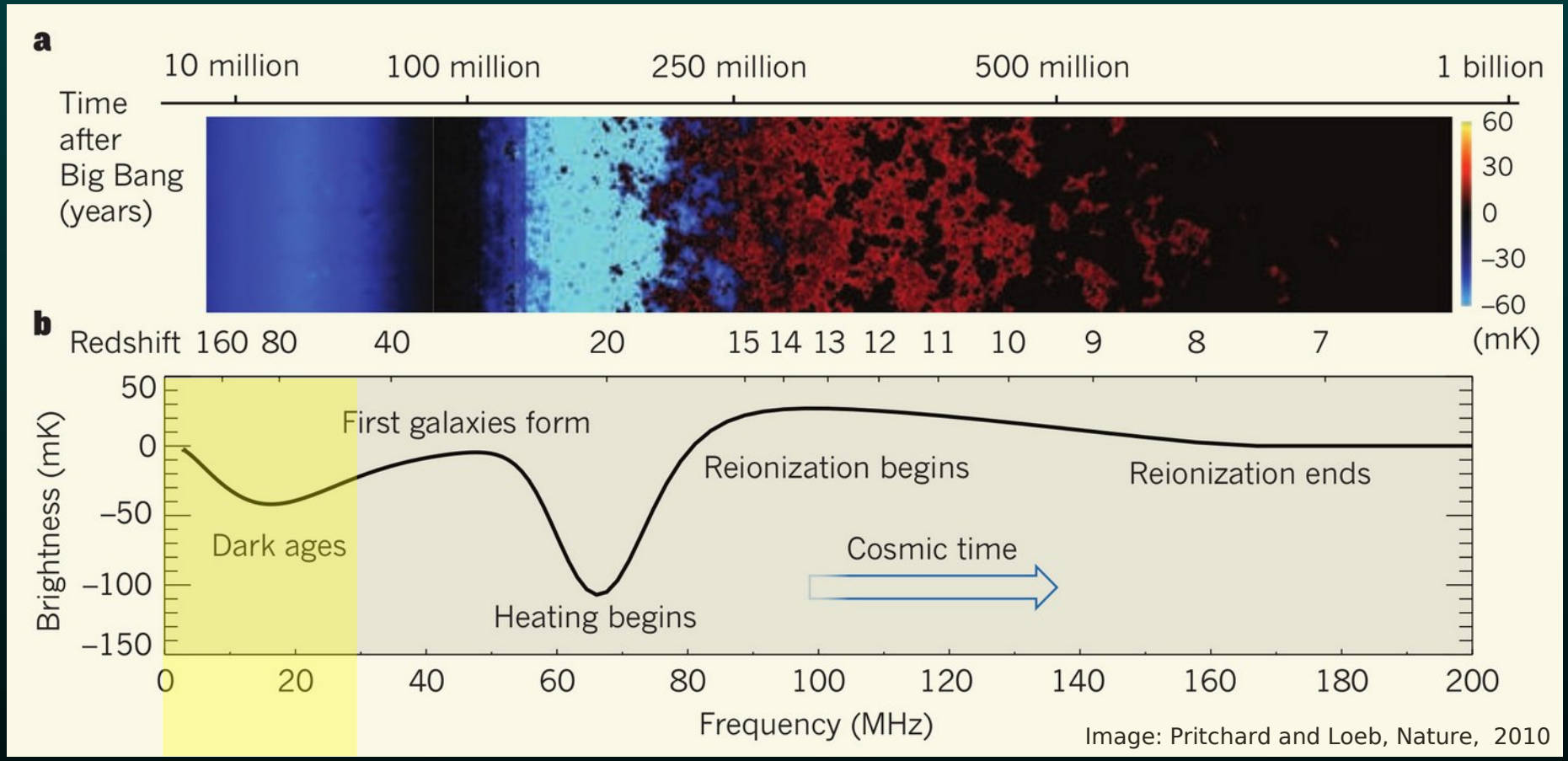
McGill University

LWA Users Meeting
2 June 2023

Exploring lower frequencies

$$\delta T_b \propto x_{HI} (1+z)^{1/2} (T_s - T_{CMB}) / T_s$$



What lurks down here…? New physics in cosmic dawn may also affect the dark ages.

The dream: lay groundwork for exploring dark ages

Ultimate dream: image the fluctuations

The state of the art at low frequencies

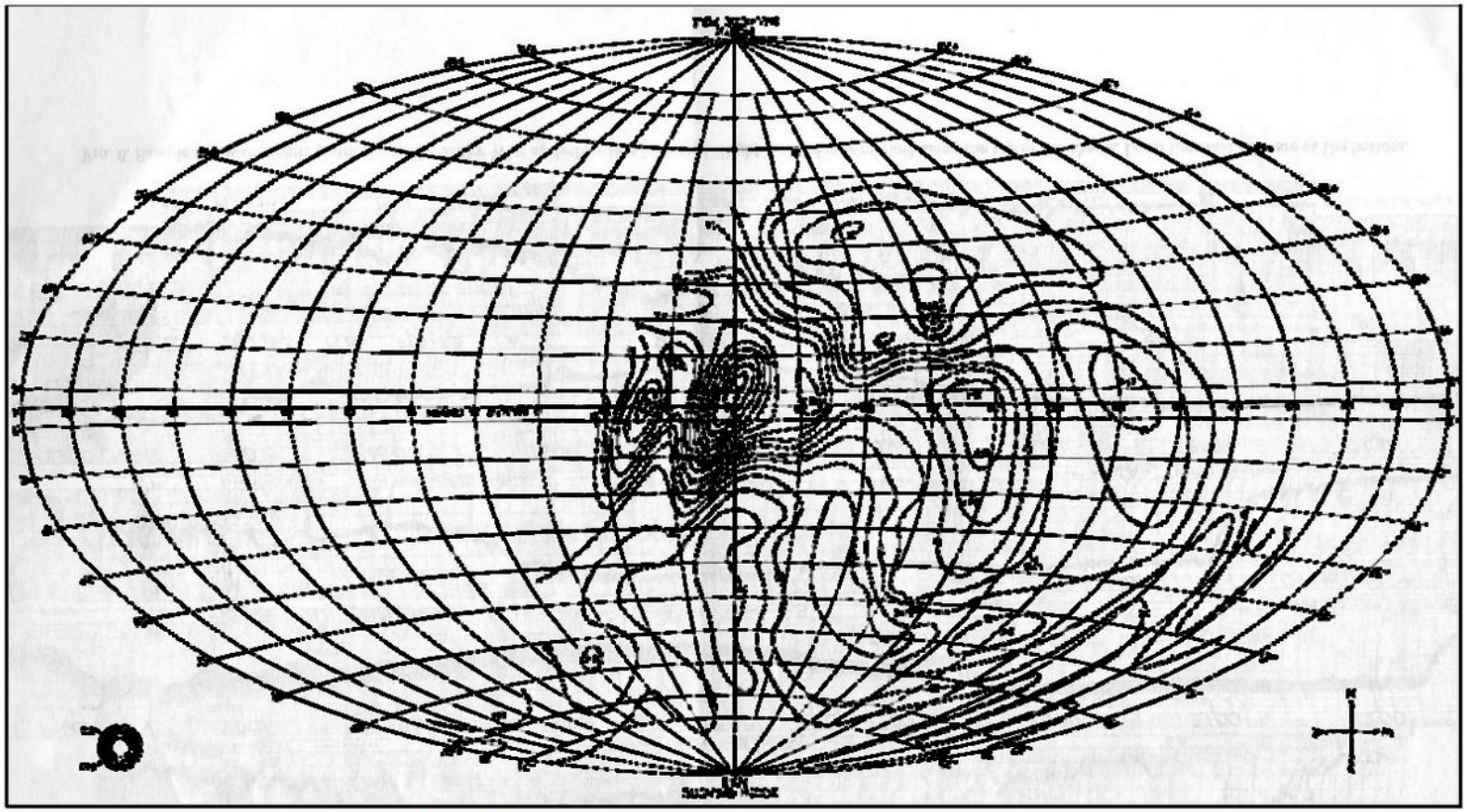


Figure 11: A 2.085 MHz contour map of galactic radio emission (after Reber, 1968: 10).

Experiment	Frequency	Resolution	Year
Grote Reber	2.1 MHz	~5 deg	1968
RAE-B satellite	4.7 MHz	~10 (??) deg	1978
DRAO	22 MHz	1.1–1.7 deg	1999
LWA	36.5 MHz	15 arcmin	2017

Science opportunities at low frequencies

- Future dark ages cosmology with 21cm power spectra:
  # independent samples ~ resolution^3
  Compare with CMB, # modes ~ resolution^2
- Galactic astrophysics: synchrotron self-absorption at <30 MHz can probe 3D cosmic ray structure
- Radio recombination lines for probing interstellar medium
- Ionosphere and space weather studies

Instrument requirements

- Interferometer with long baselines (~10 km) for high resolution imaging
- Low RFI: need to operate from remote locations
- Minimize ionospheric interference by observing from near-polar latitudes
- Directly correlating antennas over long distances in remote locations is hard...
- The plan: each antenna operates *autonomously* and saves 10–20 MHz baseband for *offline* correlation

ALBATROS = Array of Long Baseline Antennas for Taking Radio Observations from the Sub-antarctic / Seventy-ninth parallel

Instrument paper: HCC et al., JAI, 9, 2021 (arXiv:2008.12208)

McGill

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Physics
Carnegie Mellon University

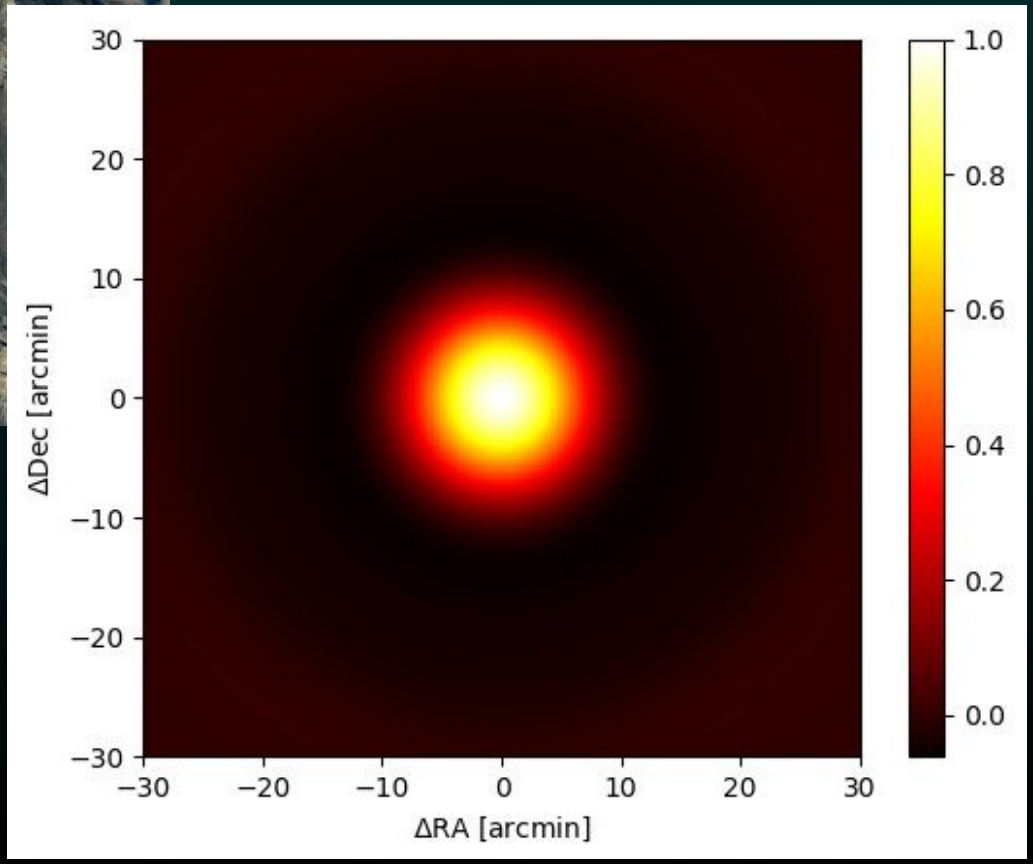
sansa
SOUTH AFRICAN NATIONAL SPACE AGENCY

ALBATROS sites

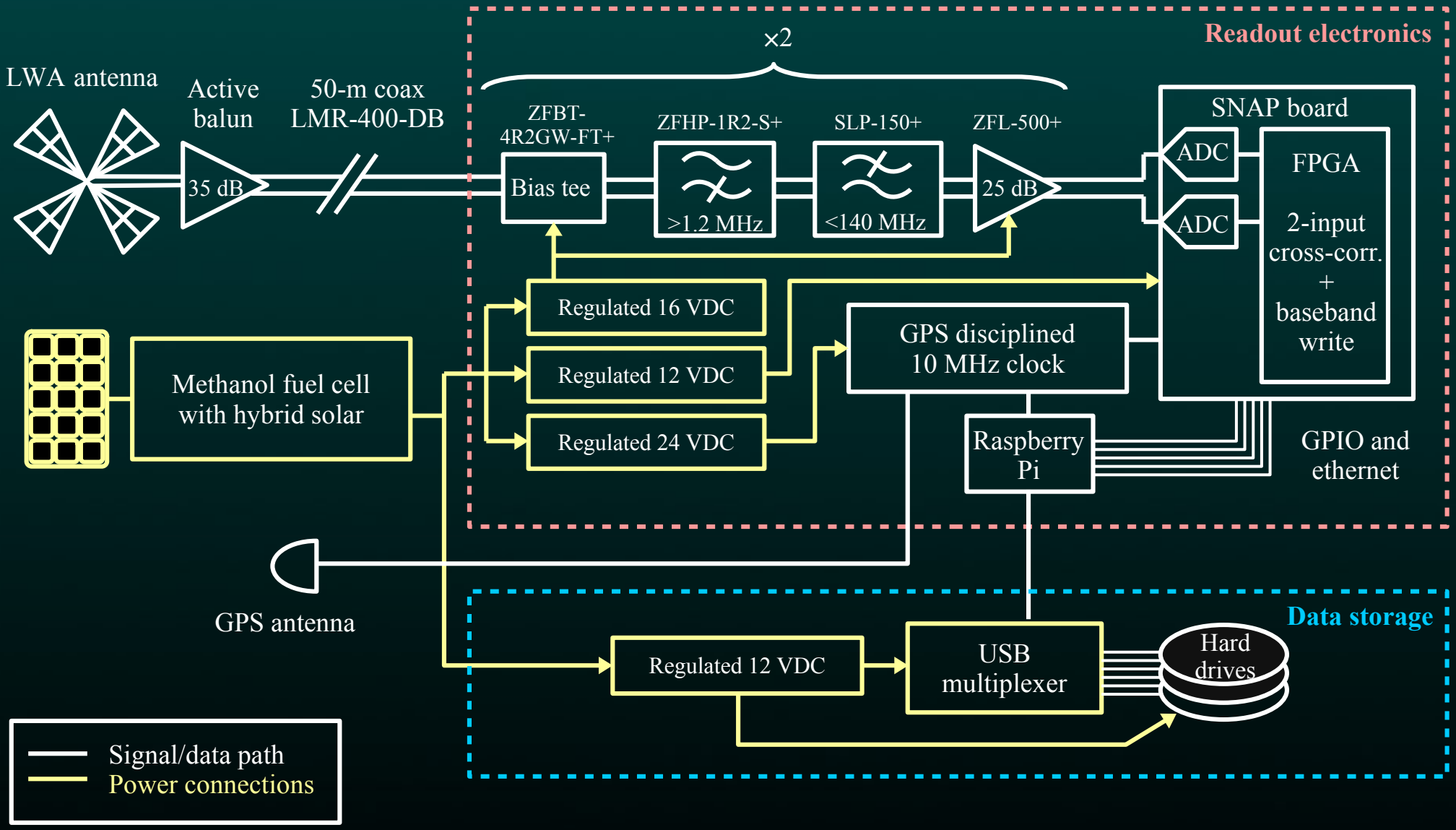
ALBATROS sites

Candidate installation sites in the Arctic

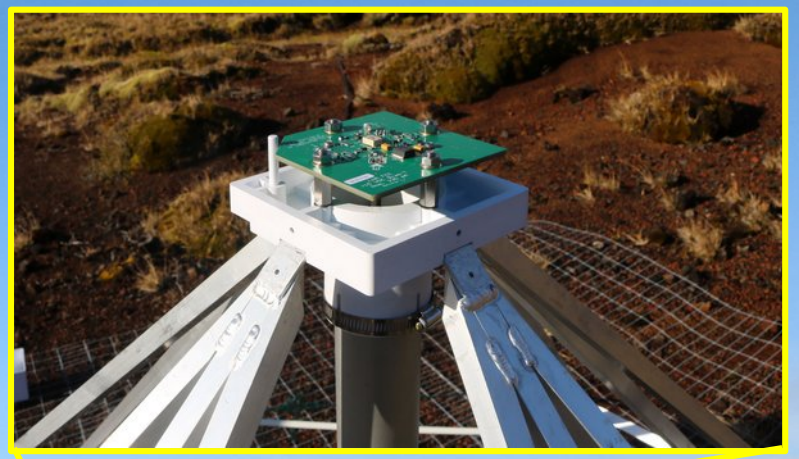
12' FWHM synthesized beam @ 5 MHz



Antenna station schematic



Antenna and front end electronics



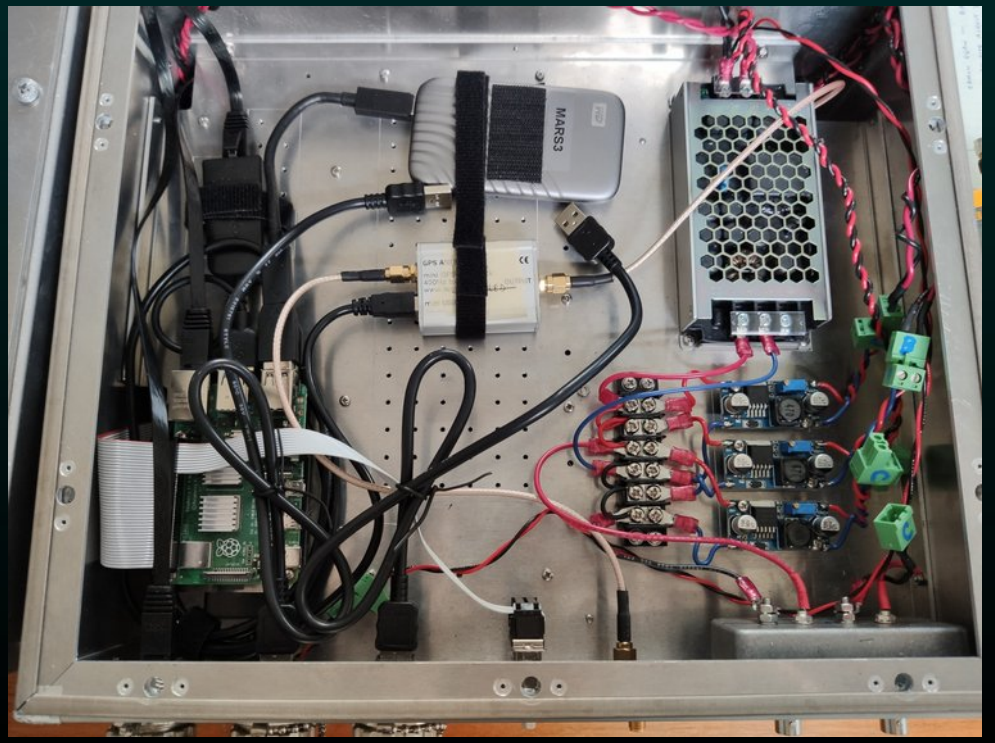
- LWA antennas: omnidirectional, design frequency range 5 – 90 MHz
- Long design history, easily available, robust
- Reasonable starting point, although not optimized for lowest frequencies

Second stage and readout electronics

RF tight enclosure with dividing shelf,
SNAP and RF electronics on one side,
power handling and GPS on other side

Spectrometer firmware on SNAP:
0 – 125 MHz
250 Msamp/s sampling
2048 channels (61 kHz)

2 input correlation and baseband dump
at 1, 2, or 4 bit, tunable frequency range



Total system power draw ~45 W

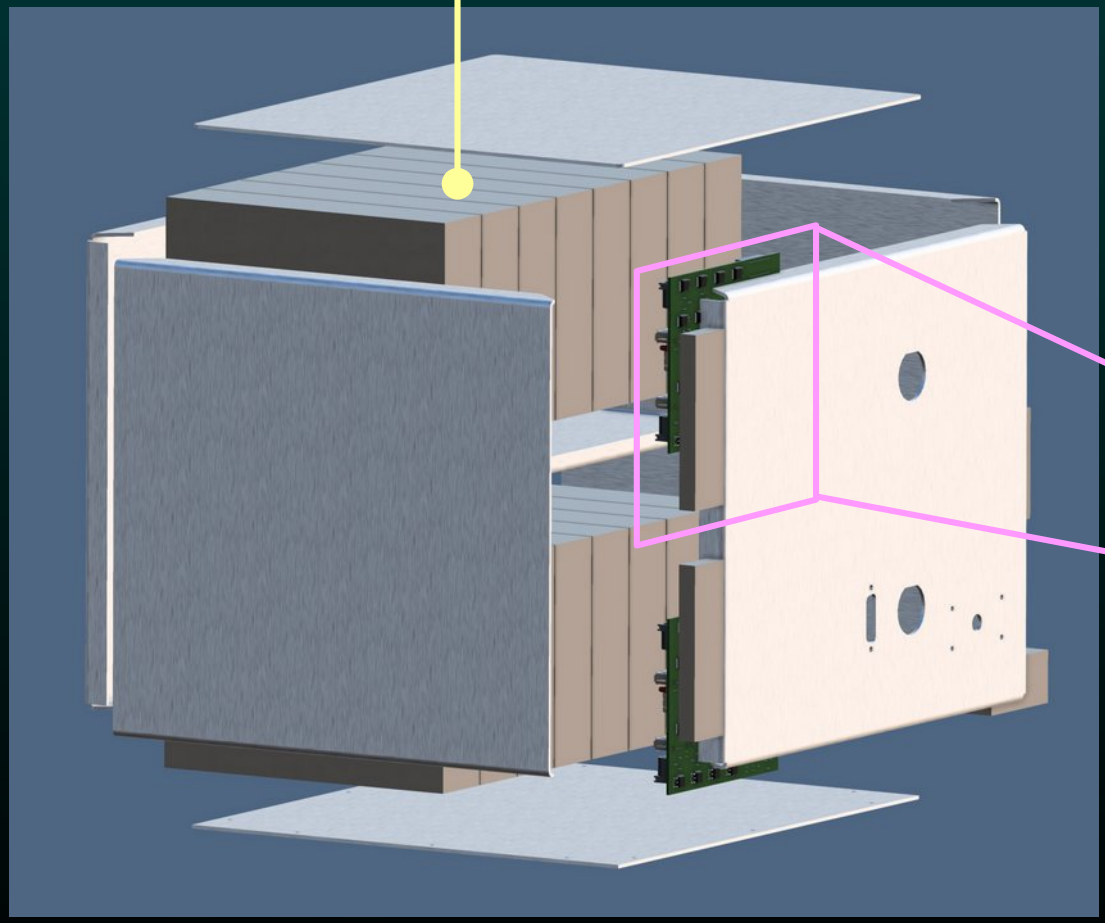
Enclosure can easily fit in a backpack

Whole assembly is placed ~30 m from the
antenna to reduce self-generated RFI

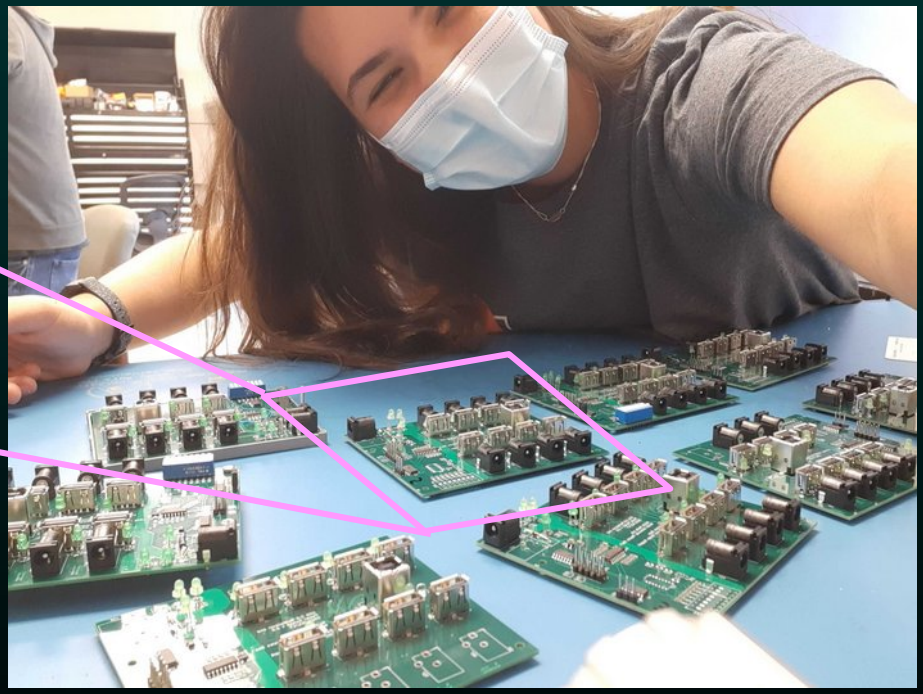
Data storage

Order of magnitude requirement: 1-bit baseband for 1 antenna, 1 year ~ 100 TB

16 x 16 TB hard drives
= 256 TB total storage



Custom USB multiplexer to power and write to only one hard drive at a time



Power autonomy

EFOY ProEnergyBox:
ruggedized fuel cell with hybrid solar

110W nominal power output

240L methanol for 1 year of operation

Rated to −40 °C

Insulated case accommodates readout electronics and data storage

Experimental timeline

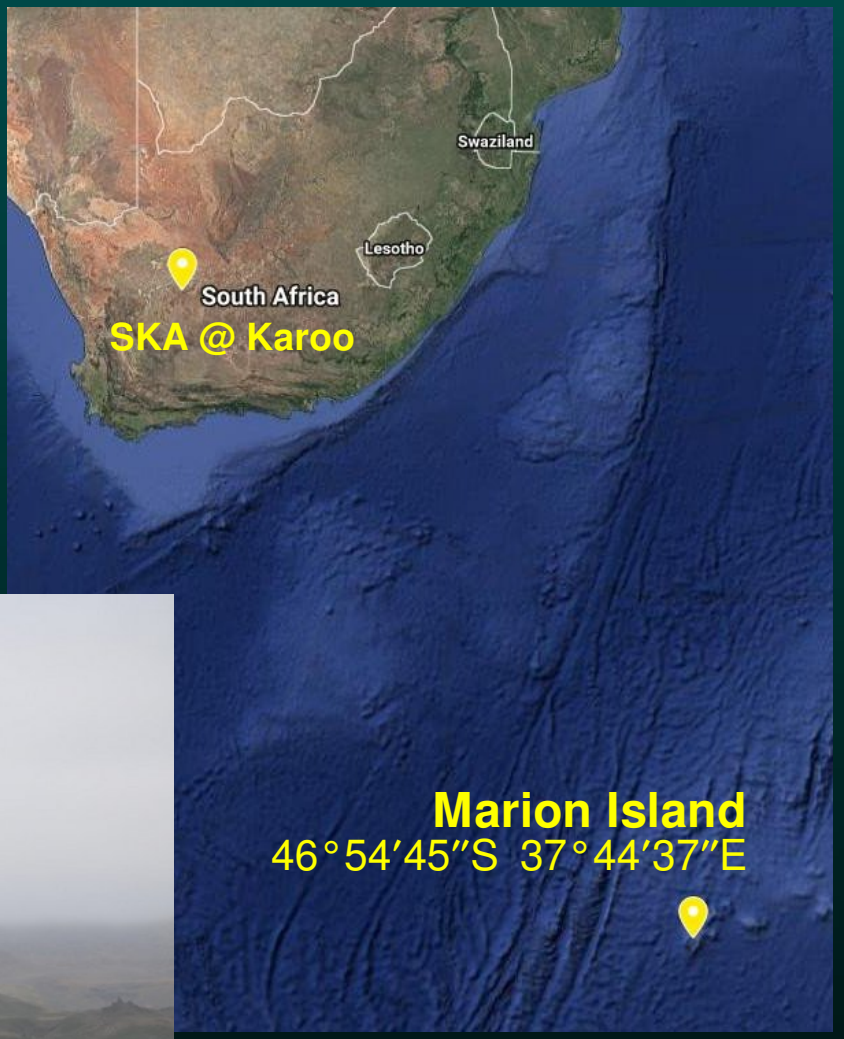
- 2018: Two-element pathfinder installed on Marion
- 2019:
  - First autonomous station on Marion
  - Site surveying in the Arctic
- 2020: 
- 2021:
  - Maintenance and upgrades on Marion
  - First autonomous station in the ~~Arctic~~ at Uapishka 
- 2022:
  - First 2 autonomous stations in the Arctic!
  - 3rd autonomous station on Marion
- 2023:
  - Decommissioned all Marion stations 
  - Planning 3 new stations in the Arctic (July trip)

Marion Island

Marion Island base is operated by the South African National Antarctic Programme

2000 km from nearest continental landmass

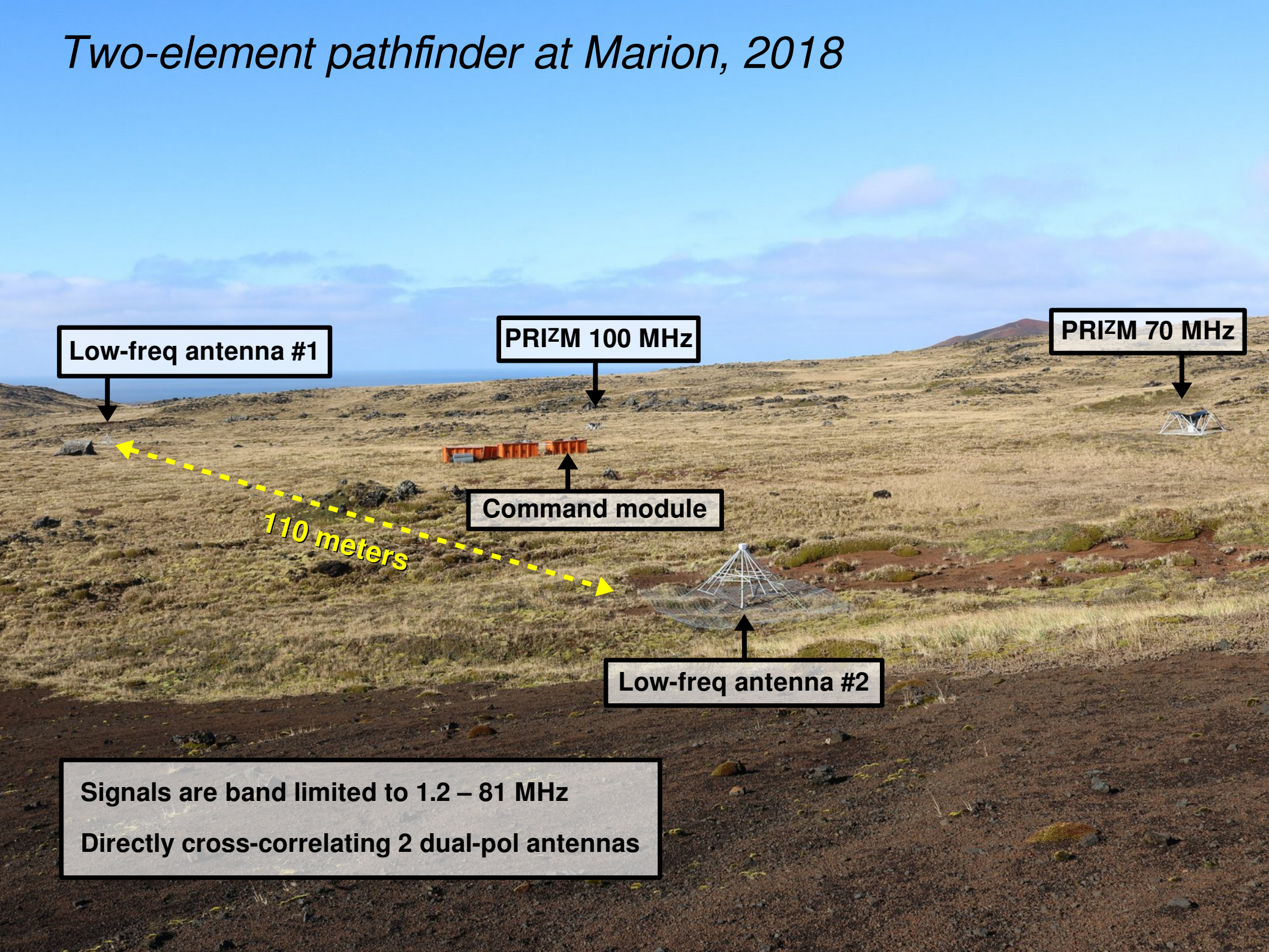
PRIZM = first astro experiment on Marion!
2016 engineering run, science ops 2017–2023



Superbly clean RFI environment, no visible FM contamination

...but very difficult access, harsh environmental conditions

Two-element pathfinder at Marion, 2018

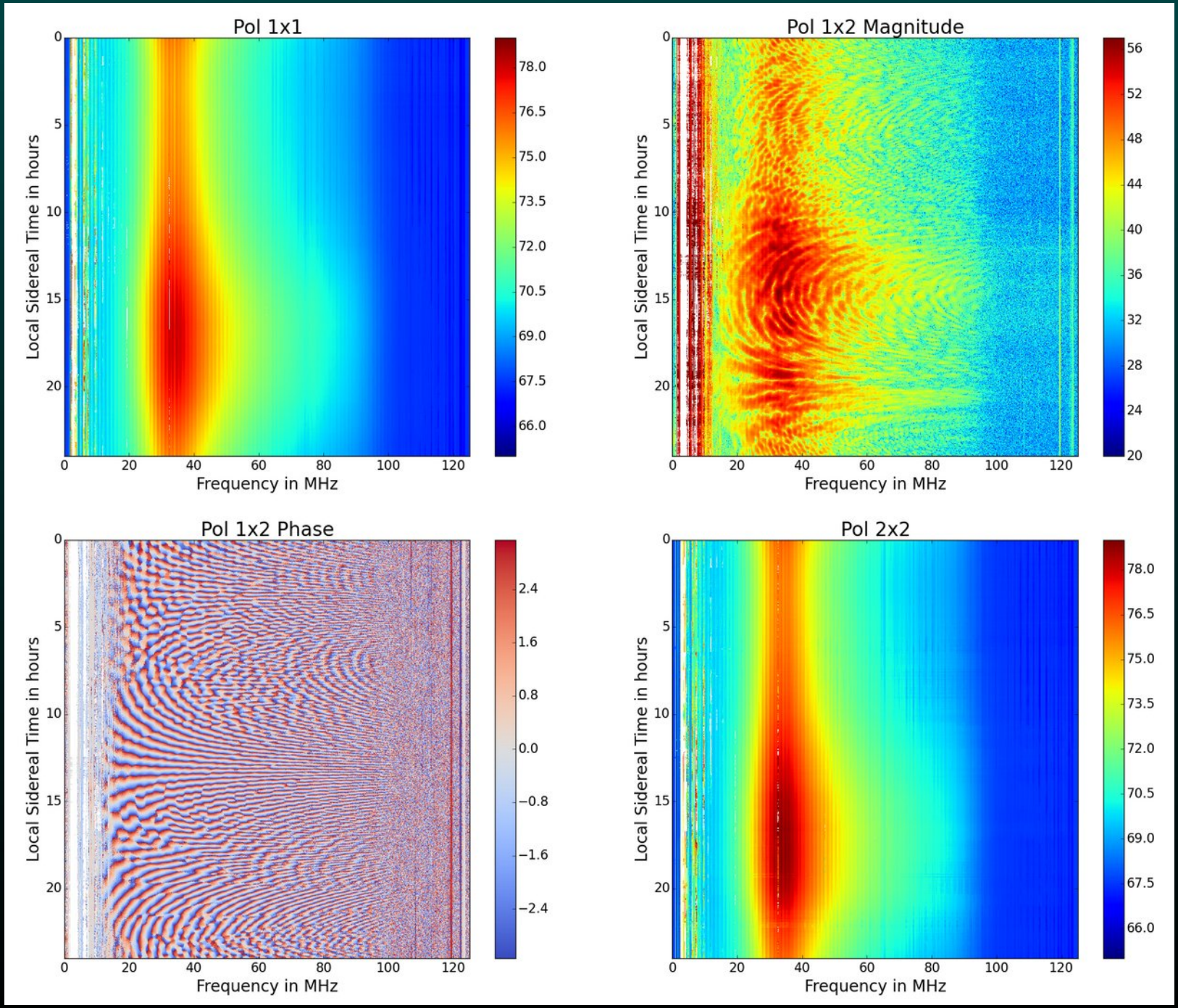


Signals are band limited to 1.2 – 81 MHz

Directly cross-correlating 2 dual-pol antennas

Two-element pathfinder data

Analysis: Felix Thiel

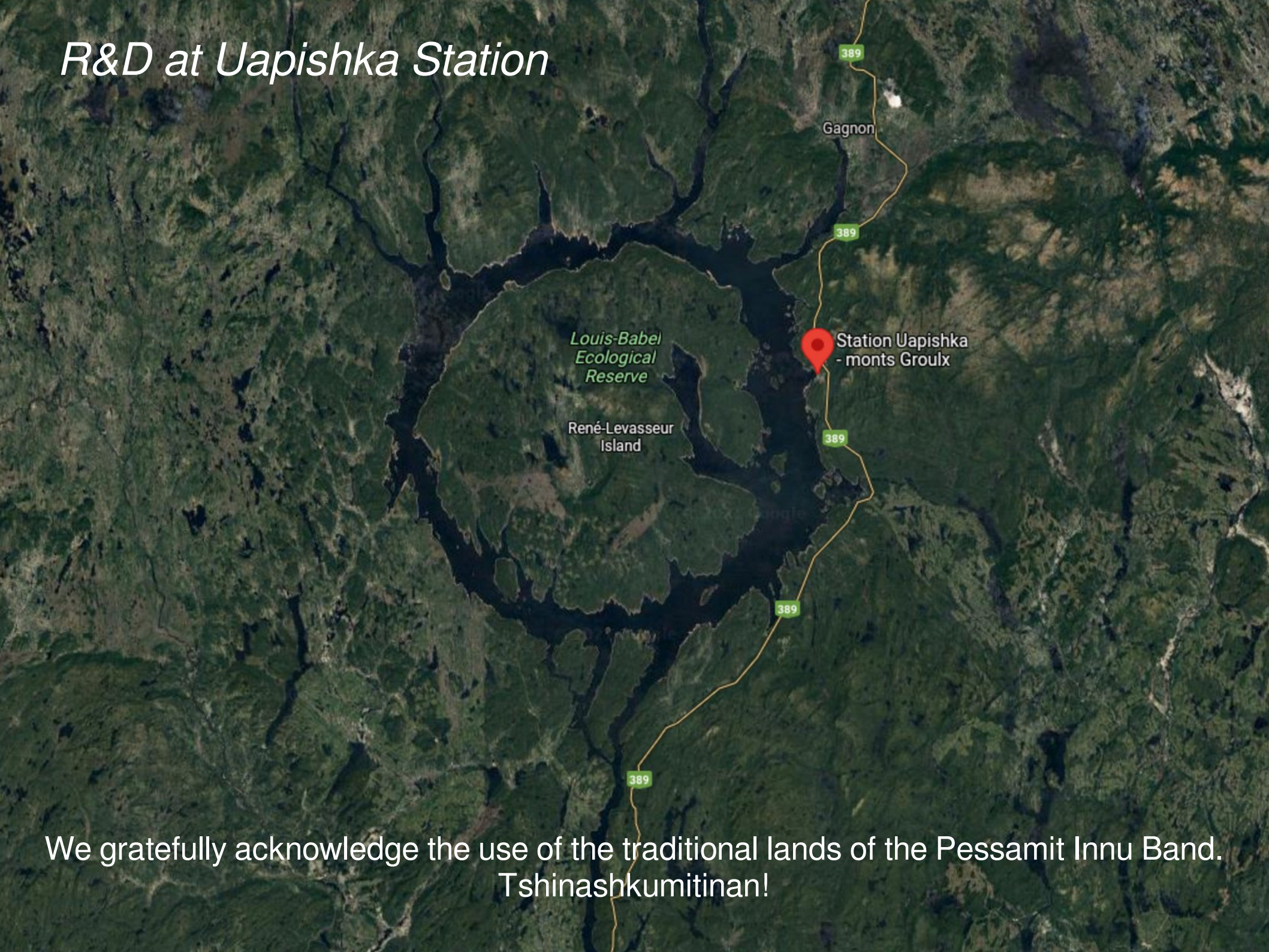


3rd ALBATROS station, 2023

- Powered by solar only (no fuel cells)
- Crew and data returned from Marion 2 weeks ago!
- Data includes our first 3-baseline measurements

Photo: Mohan Agrawal

R&D at Uapishka Station



We gratefully acknowledge the use of the traditional lands of the Pessamit Innu Band.
Tshinashkumitinan!

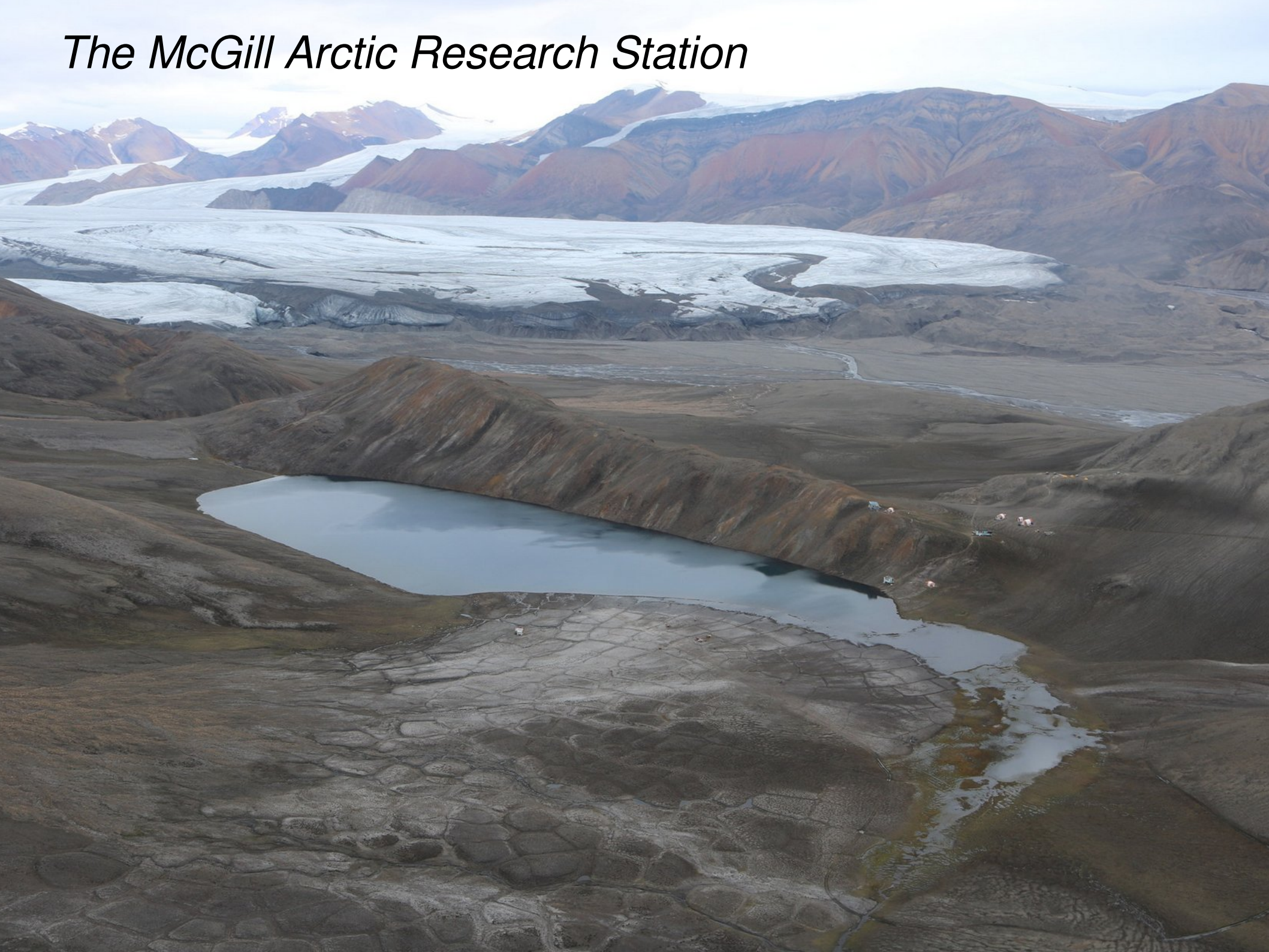
ALBATROS prototype at Uapishka, July 2021

First full system integration including data storage bank and fuel cell

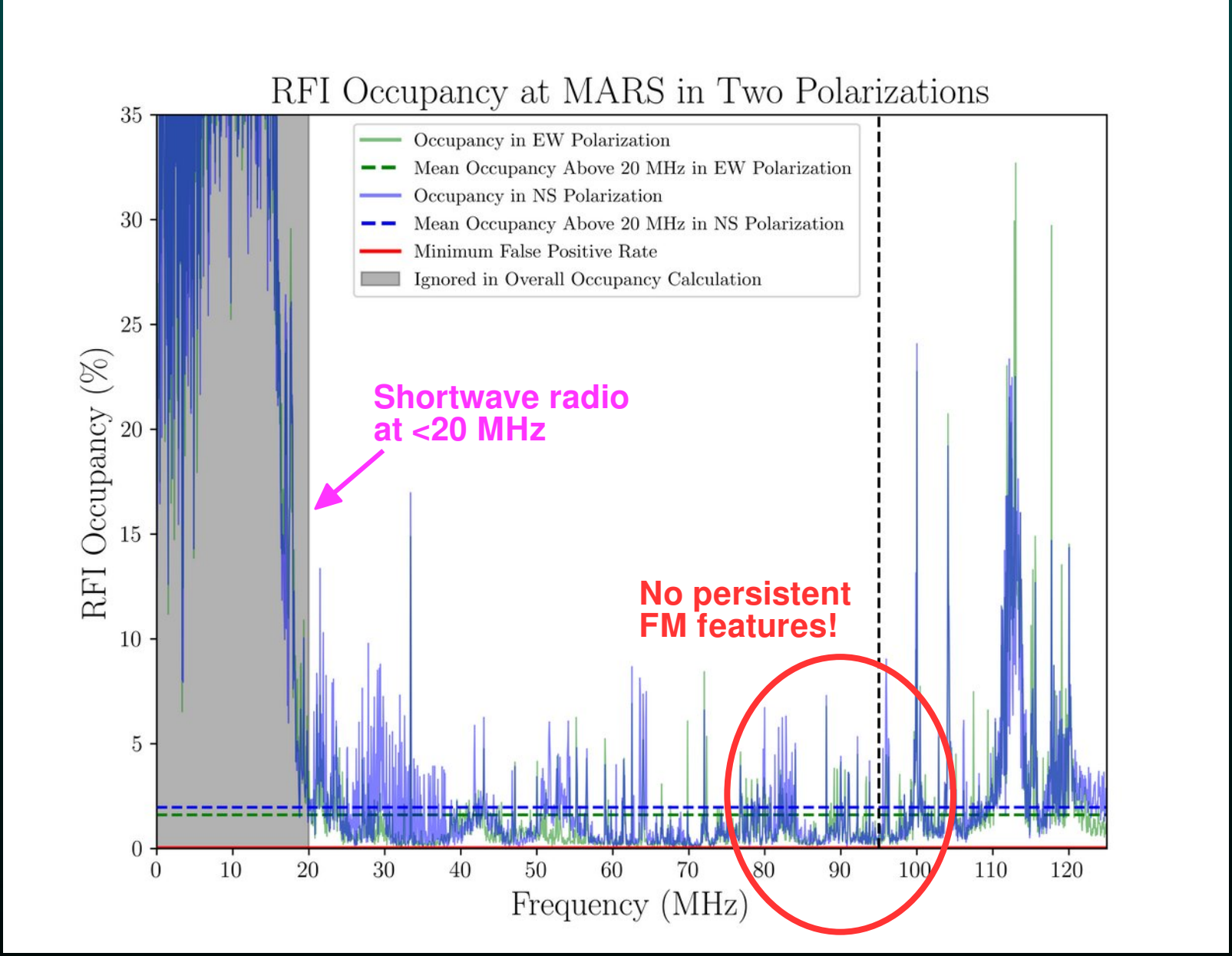
RFI qualification in a semi-quiet environment

Long-term robustness and stability testing throughout the winter

The McGill Arctic Research Station



Excellent RF-quiet environment!



T. Dyson et al., JAI, 10, 2021 (arXiv:2012.06521)

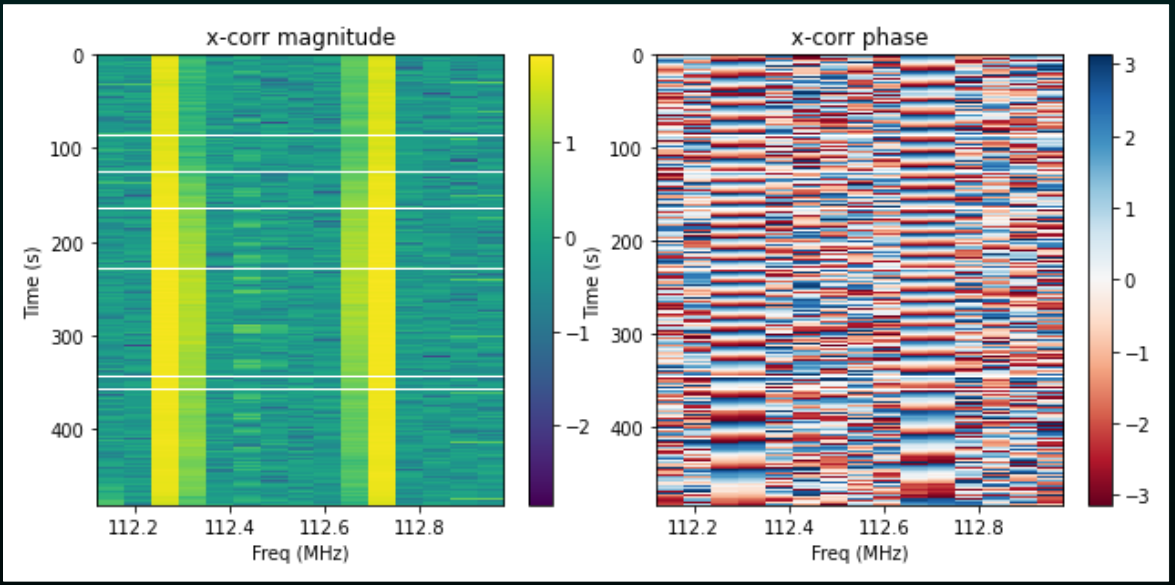
Two new antenna stations at MARS, 2022


April 2023


April 2023

Instrument milestones achieved

- Long-term, end-to-end autonomous operation demonstrated at Uapishka and through the Arctic winter
- New front-end electronics with boosted low-frequency response. First version tested at Uapishka and ready for 2023 Arctic deployment.
- Offline baseband cross-correlation is working – using ORBCOMM for syncing



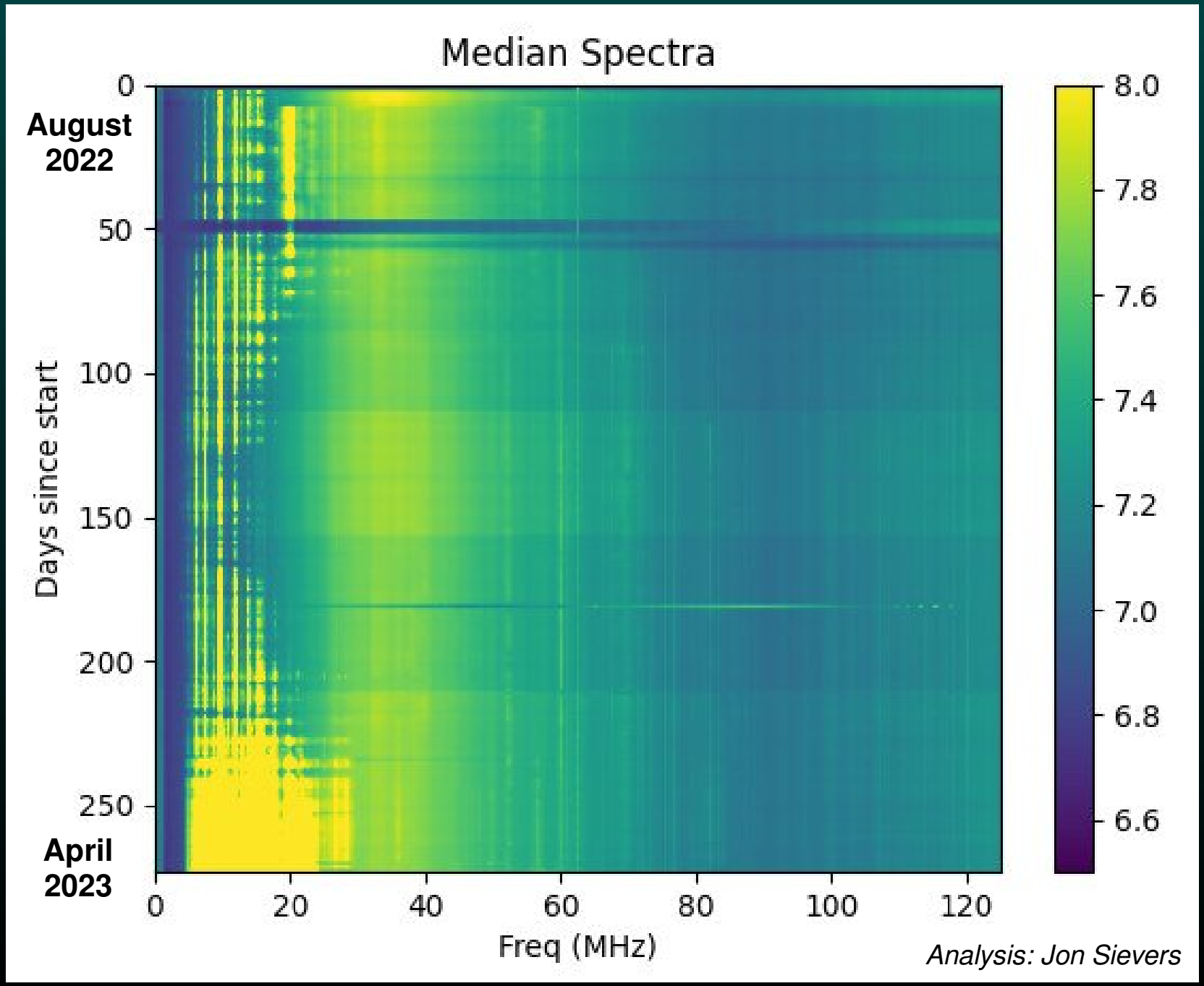
Analysis: Mohan Agrawal

RMS phase noise:
~0.3 rad at 138 MHz
~0.02 rad at 10 MHz

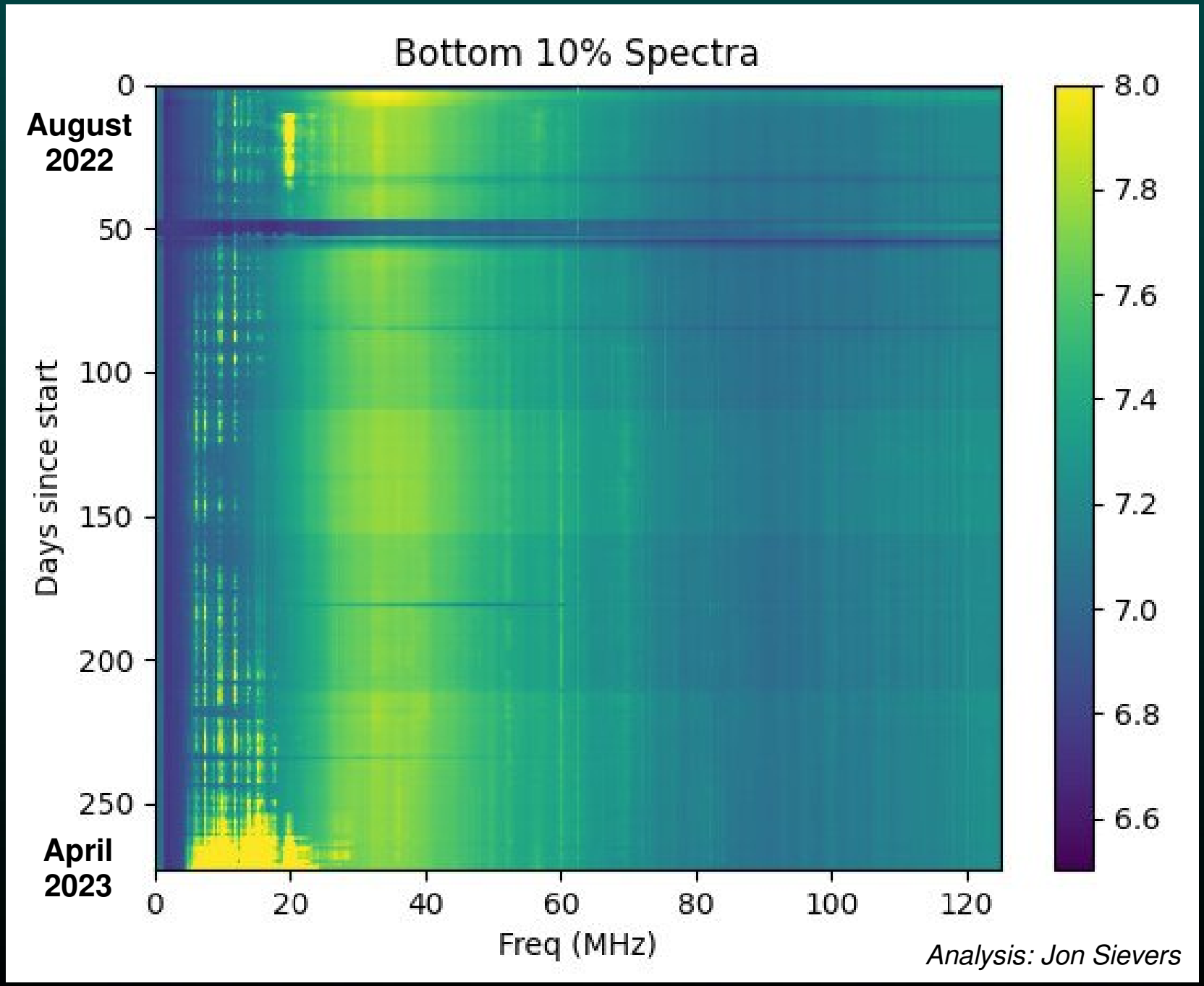
Clock stability is sufficient

- Next steps: more stations at MARS (including the first long baseline), Starlink integration for antennas to phone home, etc.

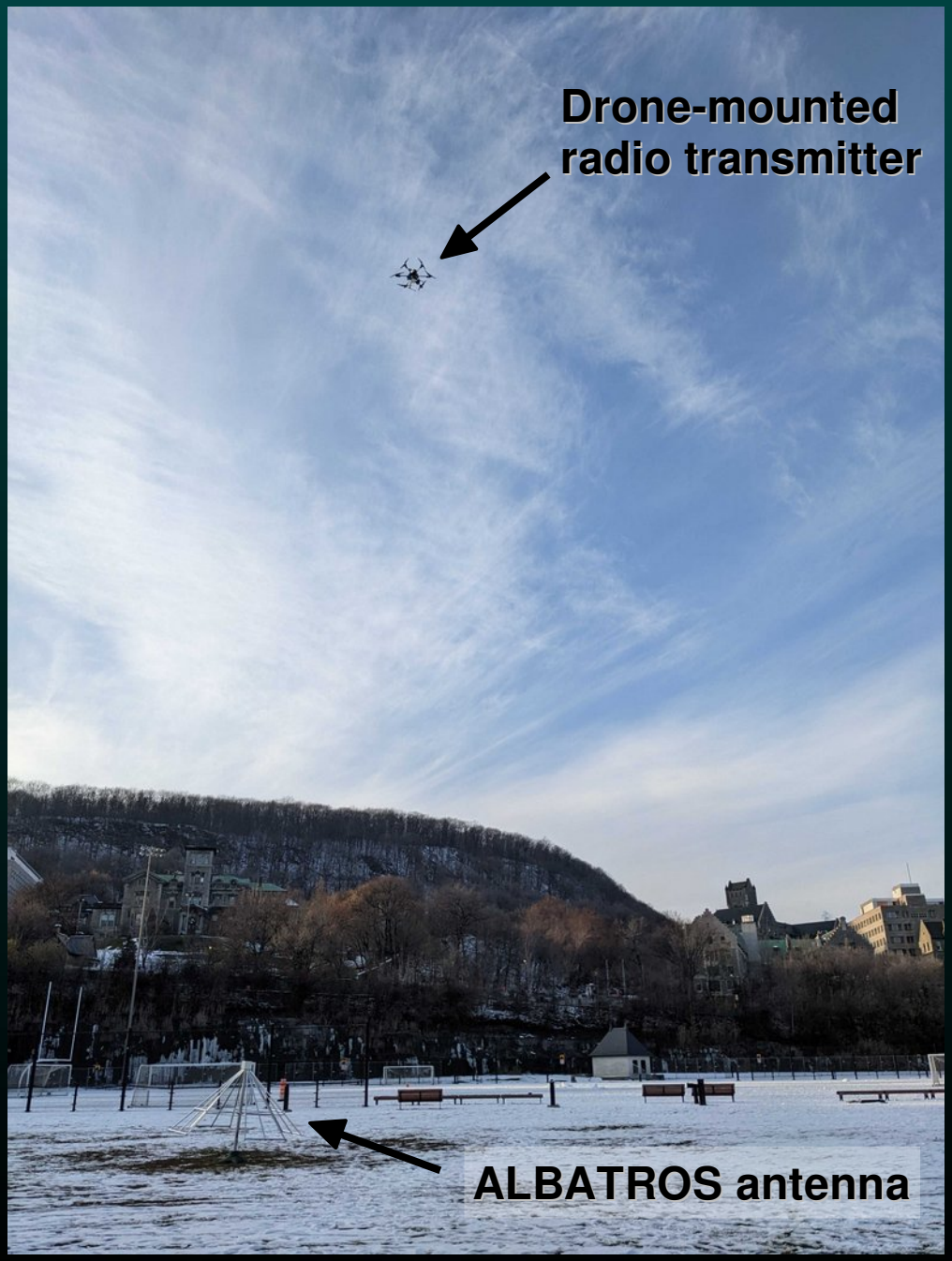
MARS 2022–2023 sneak preview



MARS 2022–2023 sneak preview



We also play with drones



Construction is based off ECHO design (see Danny's talk!)

Differential GPS (with magnetometer off) and cold weather flights tested, next test will be actual Arctic flights

Current design projects: low-freq TX antenna, basic ground/ice penetrating radar system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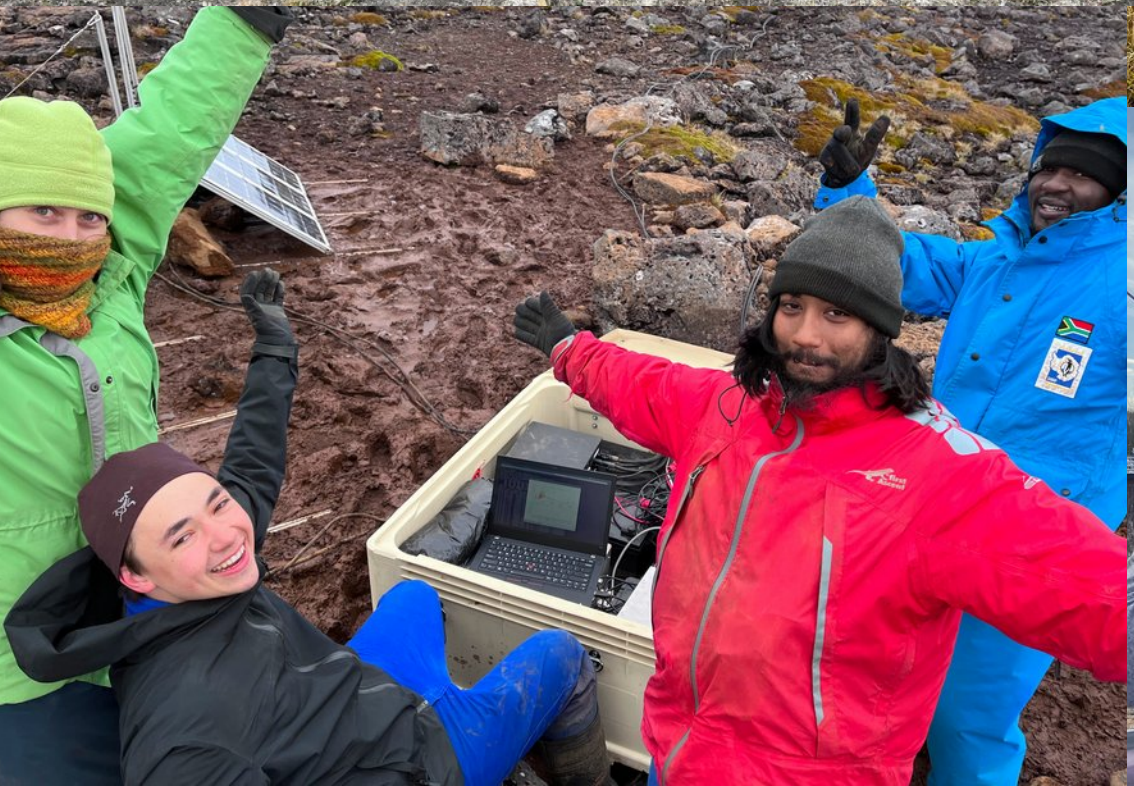
PHYSICS



Summary & future prospects

- Next Arctic deployment planned for July 2023, will install 3 new stations (2 existing), with first long baselines
- Ongoing R&D at Uapishka Station: clock stability and baseband tests, data storage, long-term power, RFI tests
- Marion Island: we have data from ~3 autonomous stations
- With carefully chosen sites and new instrumentation developments, we may be able to image the sky at 10s of MHz with an order of magnitude improvement in resolution over existing measurements
- More details available in Tristan Menard's MSc thesis: http://www.physics.mcgill.ca/~chiang/theses/menard.pdf