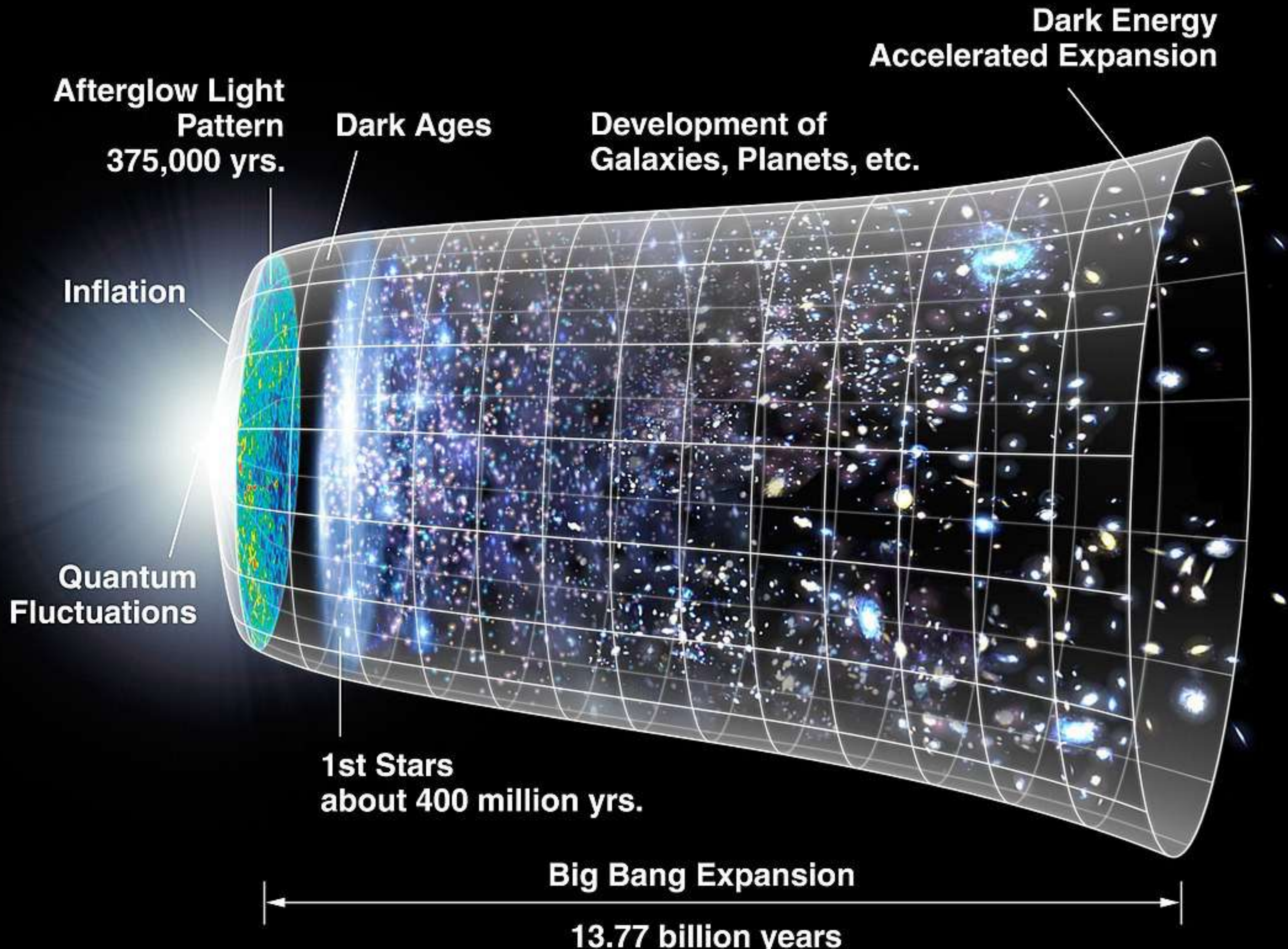
The first radio telescope on Marion Island

Liju Philip

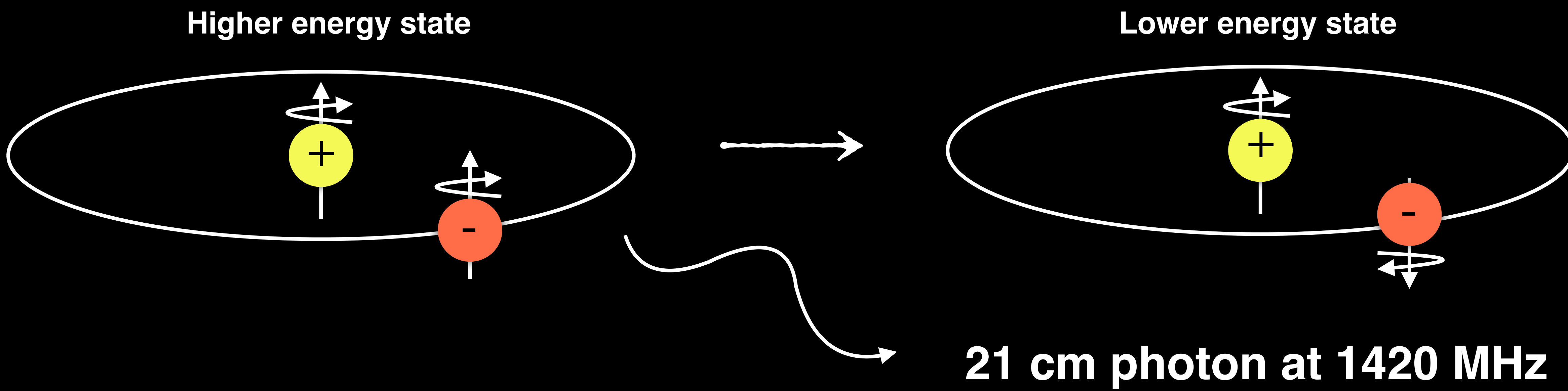
University of KwaZulu-Natal
South Africa

GNU Radio Conference
September 21, 2018

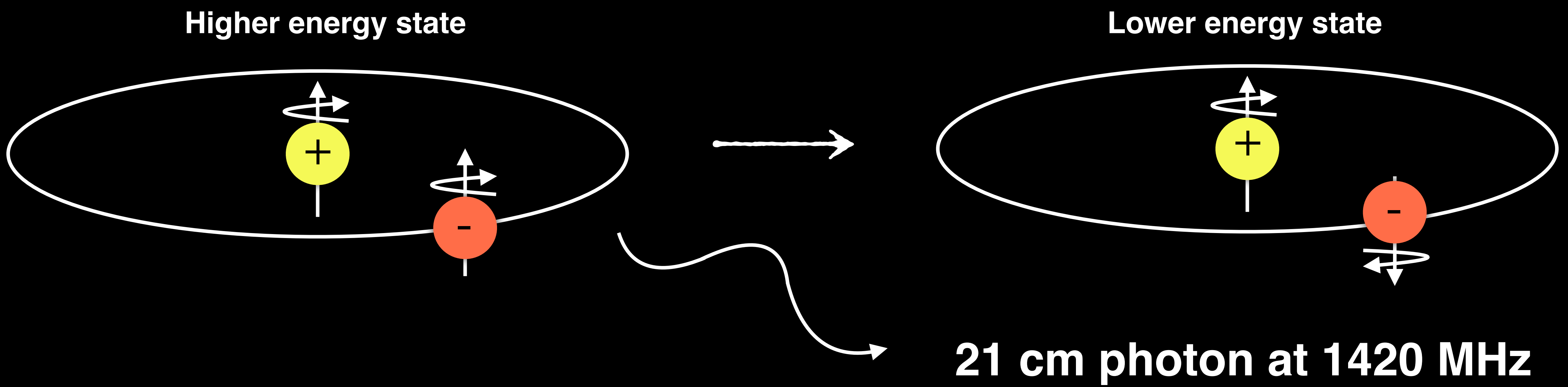
The story so far…



The 21 cm signal from neutral hydrogen



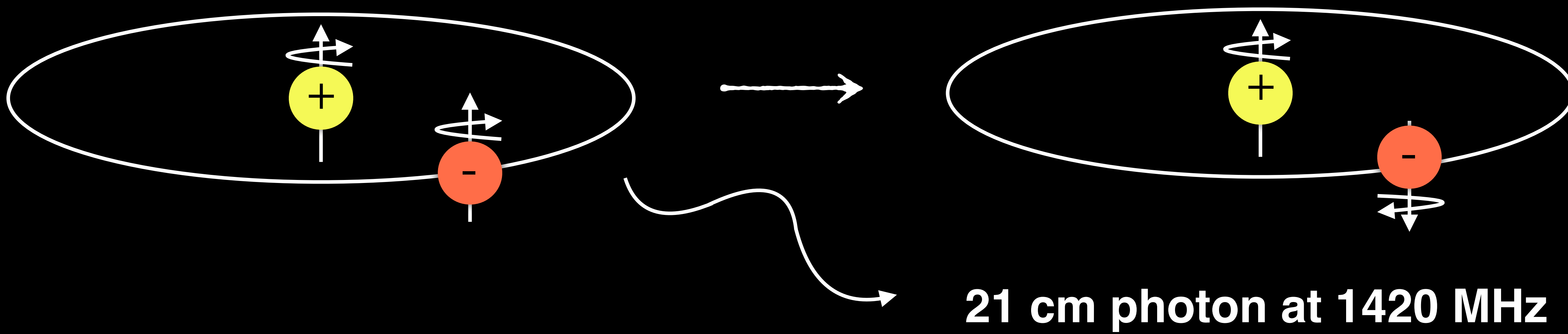
The 21 cm signal from neutral hydrogen

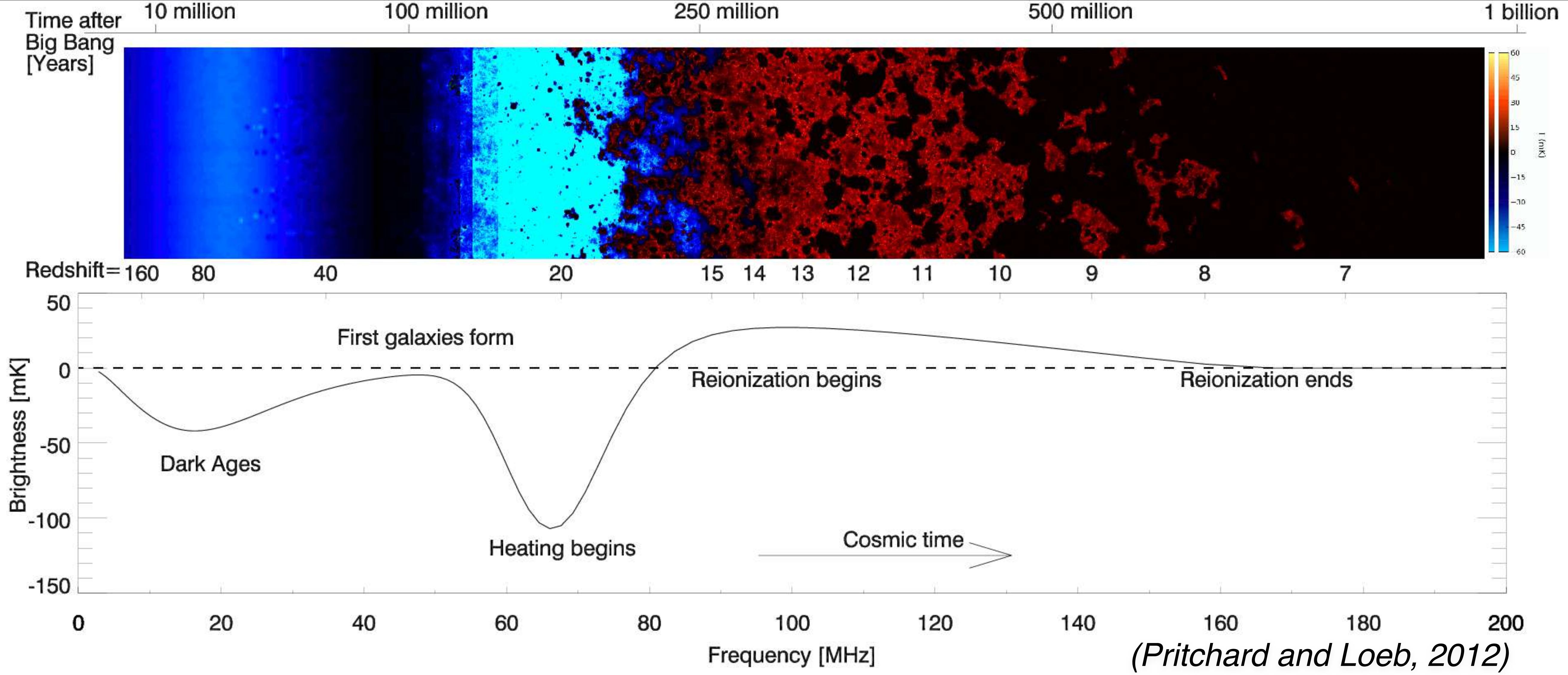


neutral hydrogen = HI , pronounced as H1

ionized hydrogen = HII , pronounced as H2

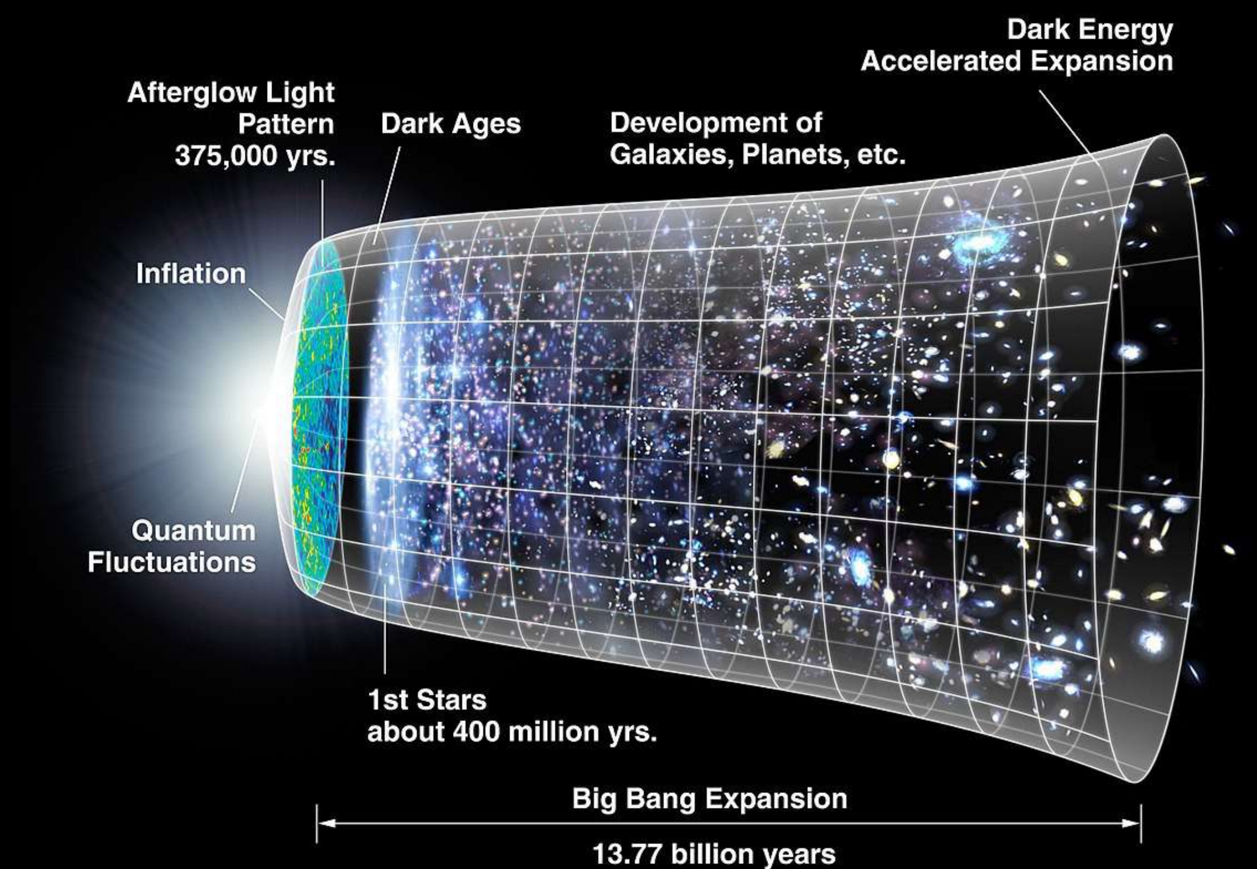
The evolution of 21 cm HI signal

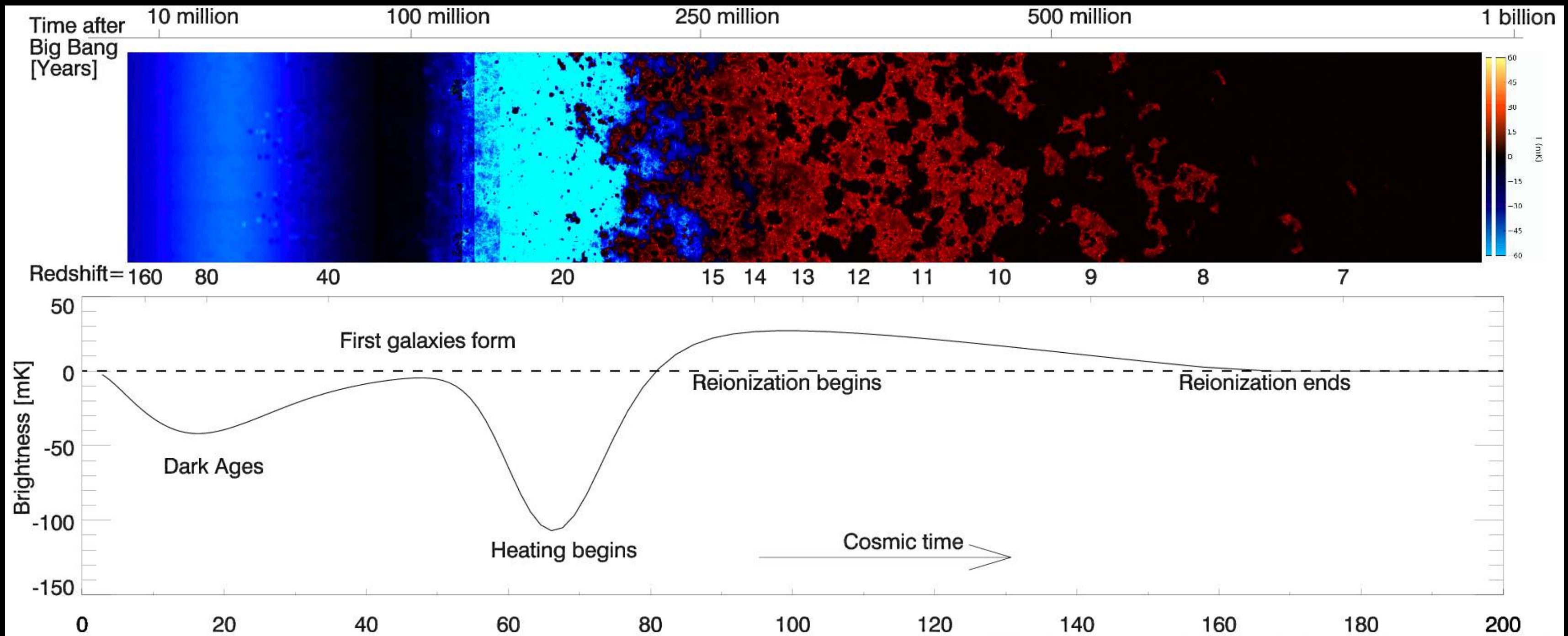




(Pritchard and Loeb, 2012)

21 cm HI signal as a cosmological probe

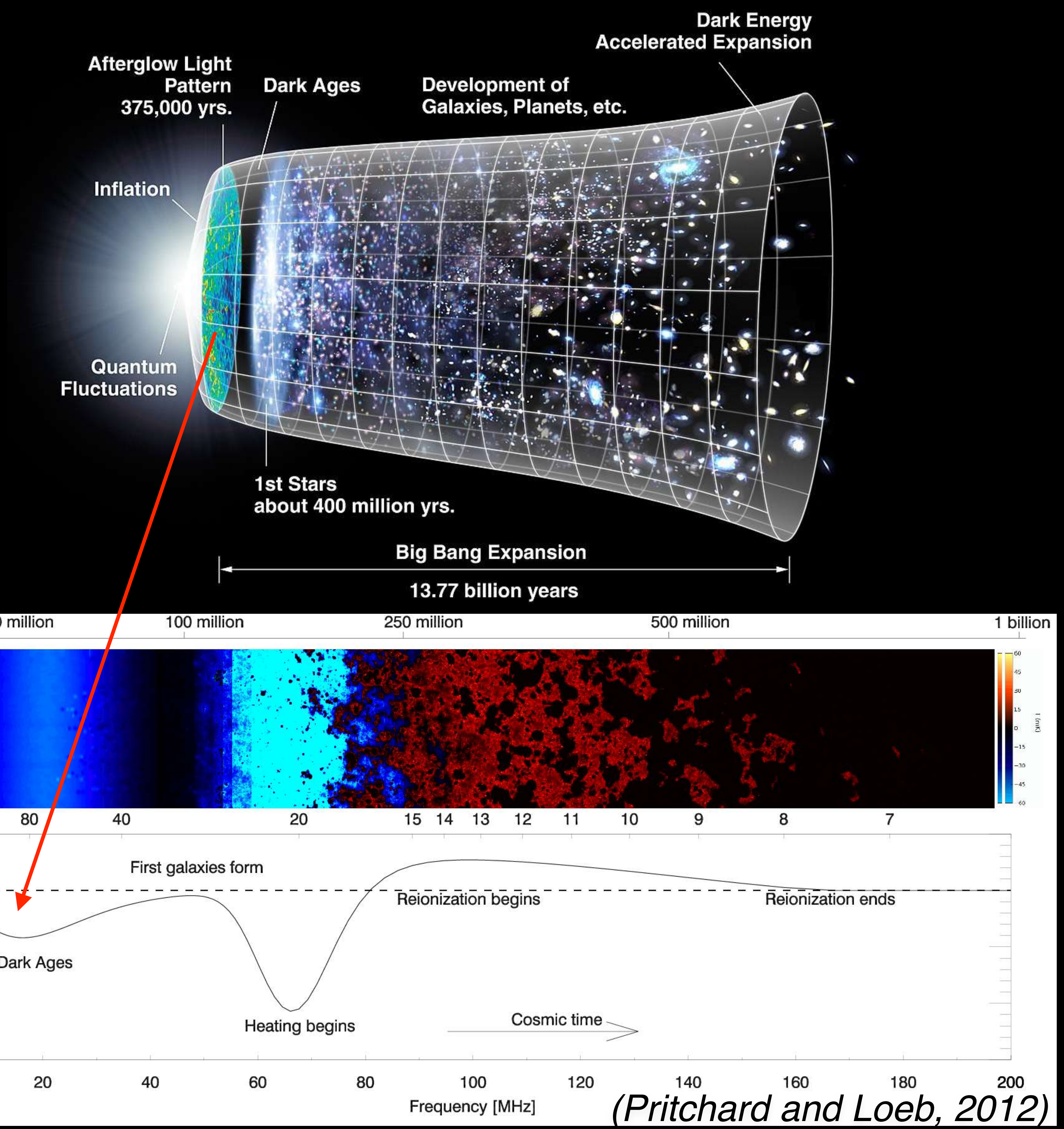




(Pritchard and Loeb, 2012)

lower frequencies = higher redshifts

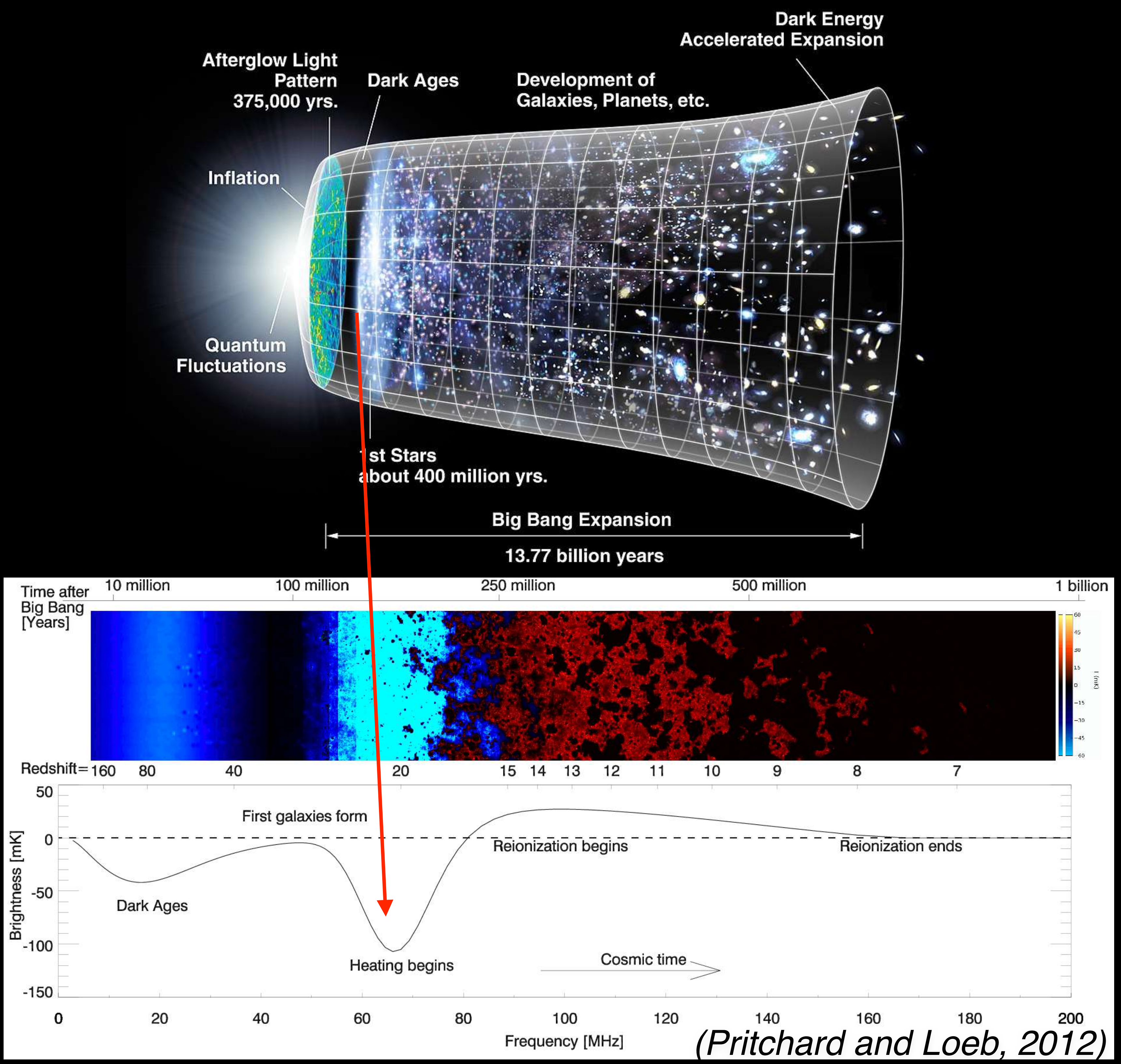
21 cm HI signal as a cosmological probe



H-H collision

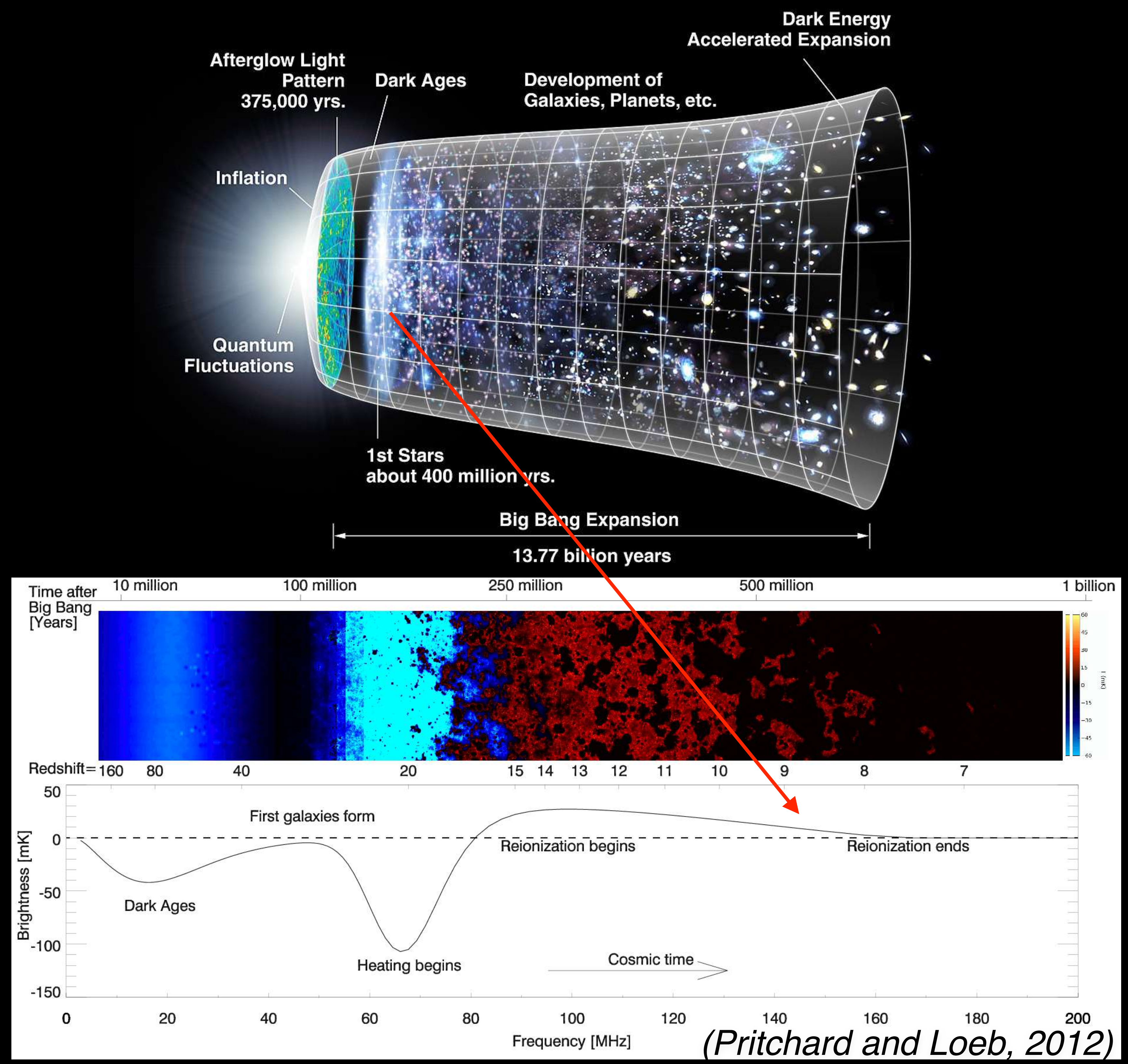
(Pritchard and Loeb, 2012)

21 cm HI signal as a cosmological probe



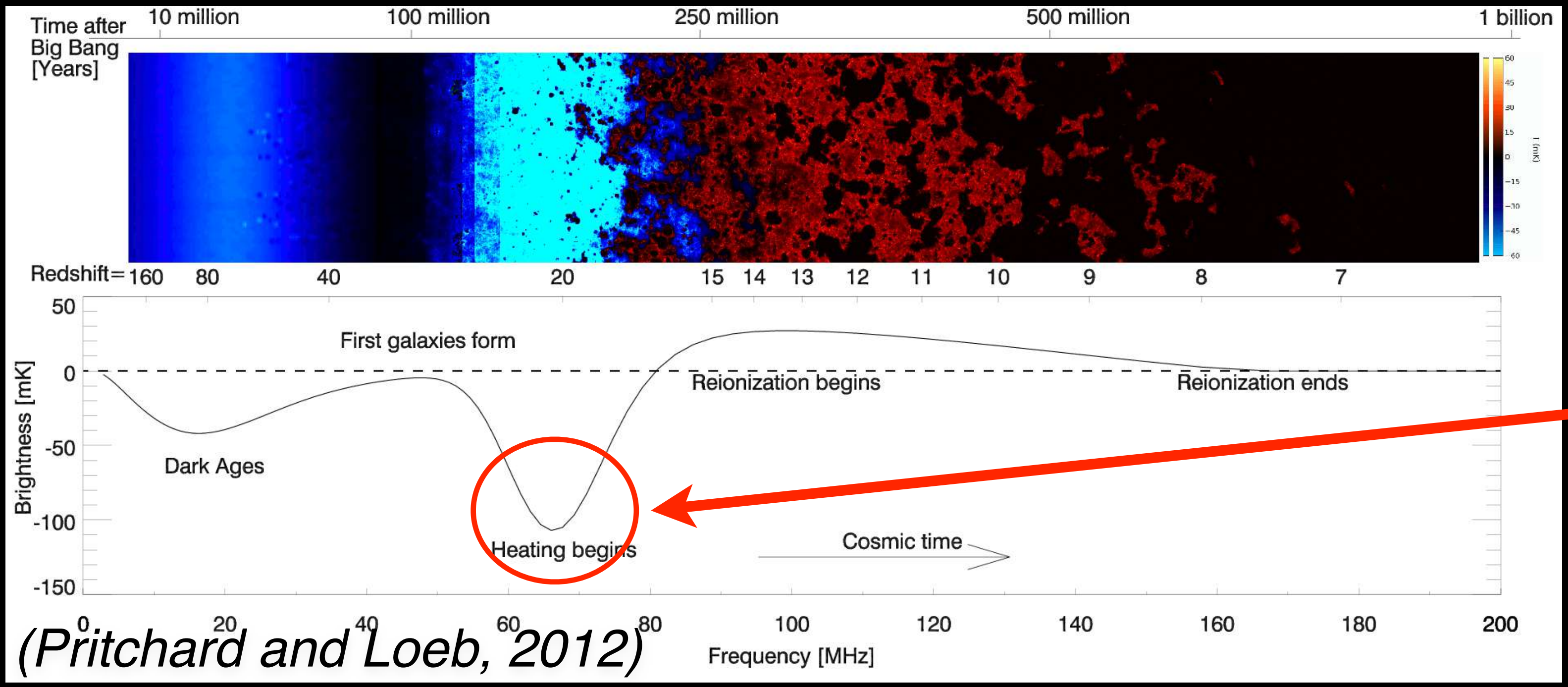
first luminous sources

21 cm HI signal as a cosmological probe

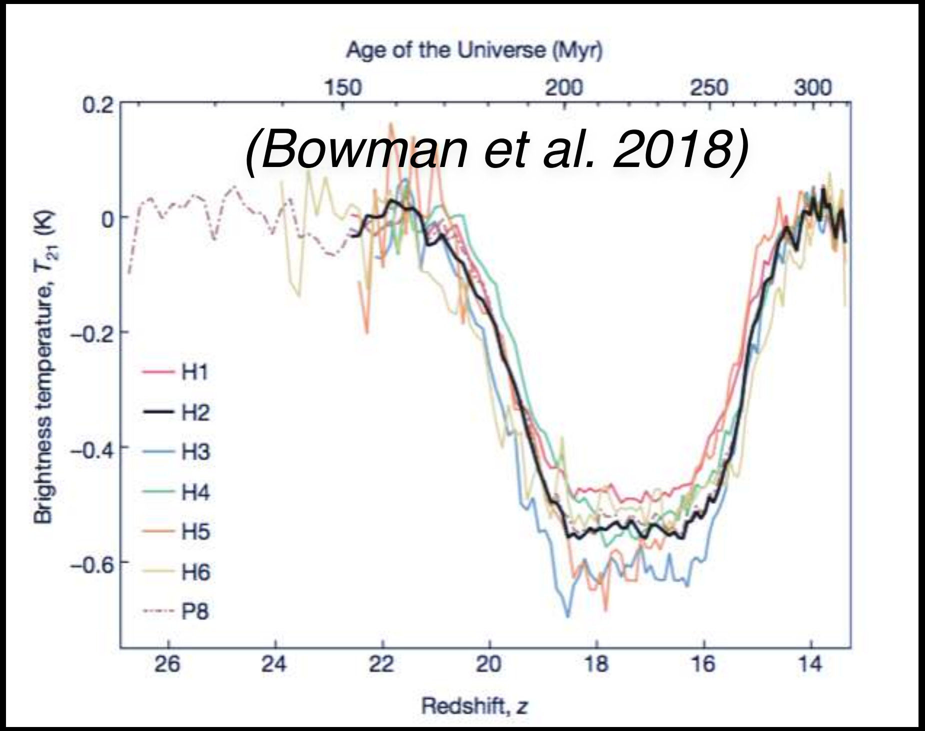


all HI are ionized

Recent detection by the EDGES experiment



(Pritchard and Loeb, 2012)



(Bowman et al. 2018)

Requires independent confirmation by similar experiments

SARAS 2
40—200 MHz
Bangalore, India

LEDA
40—85 MHz
OVRO, California

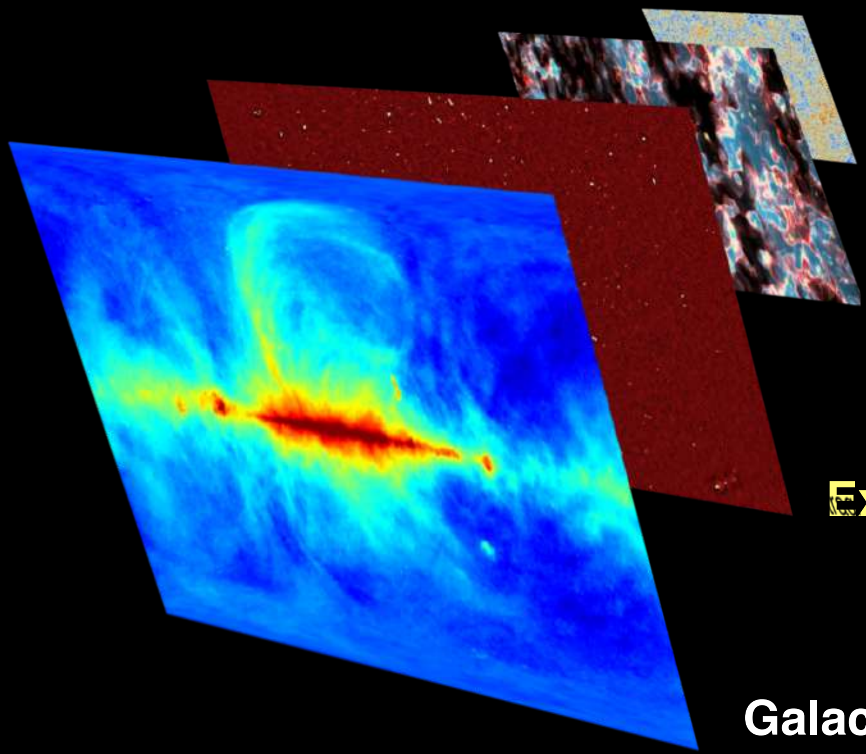
BIGHORNS
50—200 MHz
Western Australia

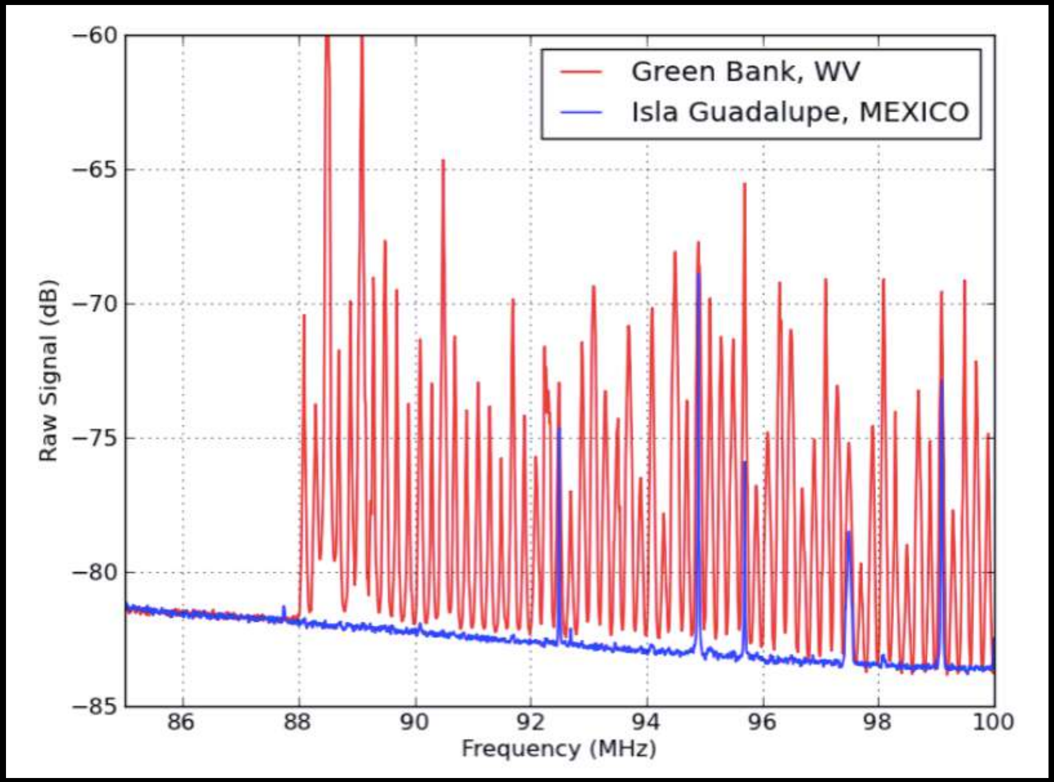
Challenges

Astrophysical foreground

4-5 orders of magnitude

brighter than the 21 cm signal





Terrestrial RFI

FM radio, TV, cellphone etc.

Ionosphere

Free electrons in the ionosphere modifies EM wave propagation

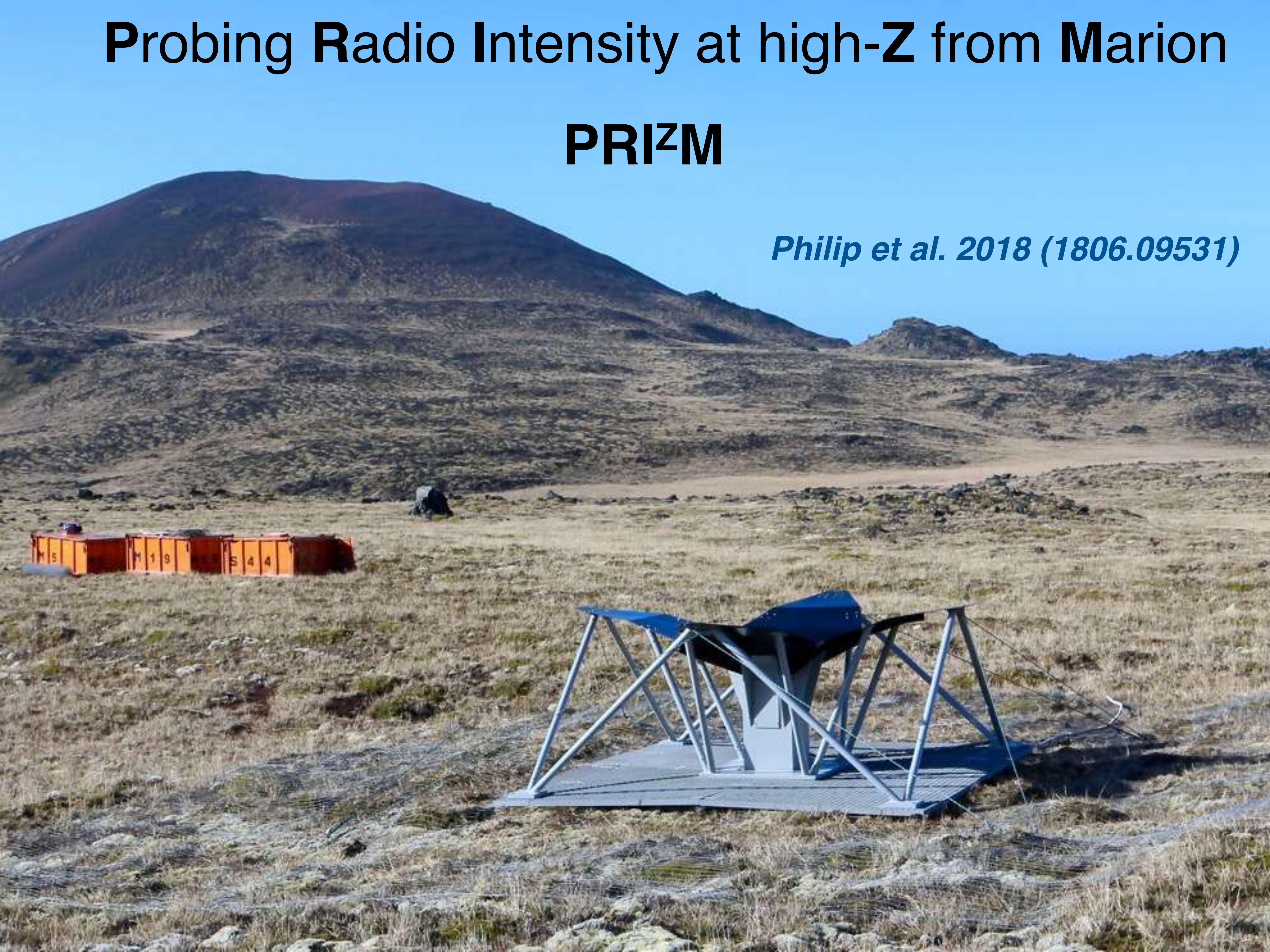
Overcoming the challenges

- Observing from remote radio-quiet locations on Earth
- Observe during quieter ionospheric condition
- Accurate modeling of the astrophysical foregrounds
- Precise instrument characterization

Probing **R**adio **I**ntensity at high-**Z** from **M**arion

PRI^{Z}M

Philip et al. 2018 (1806.09531)



The team

University of KwaZulu-Natal / Inyuvesi Yakwazulu-Natali

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Liju Philip
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Austin Gumba
Nivek Ghazi
Veruschka Simes

Carnegie Mellon University

Jeff Peterson
José Miguel Jáuregui

sansa — South African National Space Agency

Kagiso Malepe
Vhuli Manukha

Berkeley — University of California

Jack Hickish
Ridhima Nunhokee
Zuhra Abdurashidova

SKA Africa — Square Kilometre Array

Rupert Spann

PRI^{Z}M overview

Two antennas : centre frequencies of 70 and 100 MHz

Operating frequency : 0—250 MHz

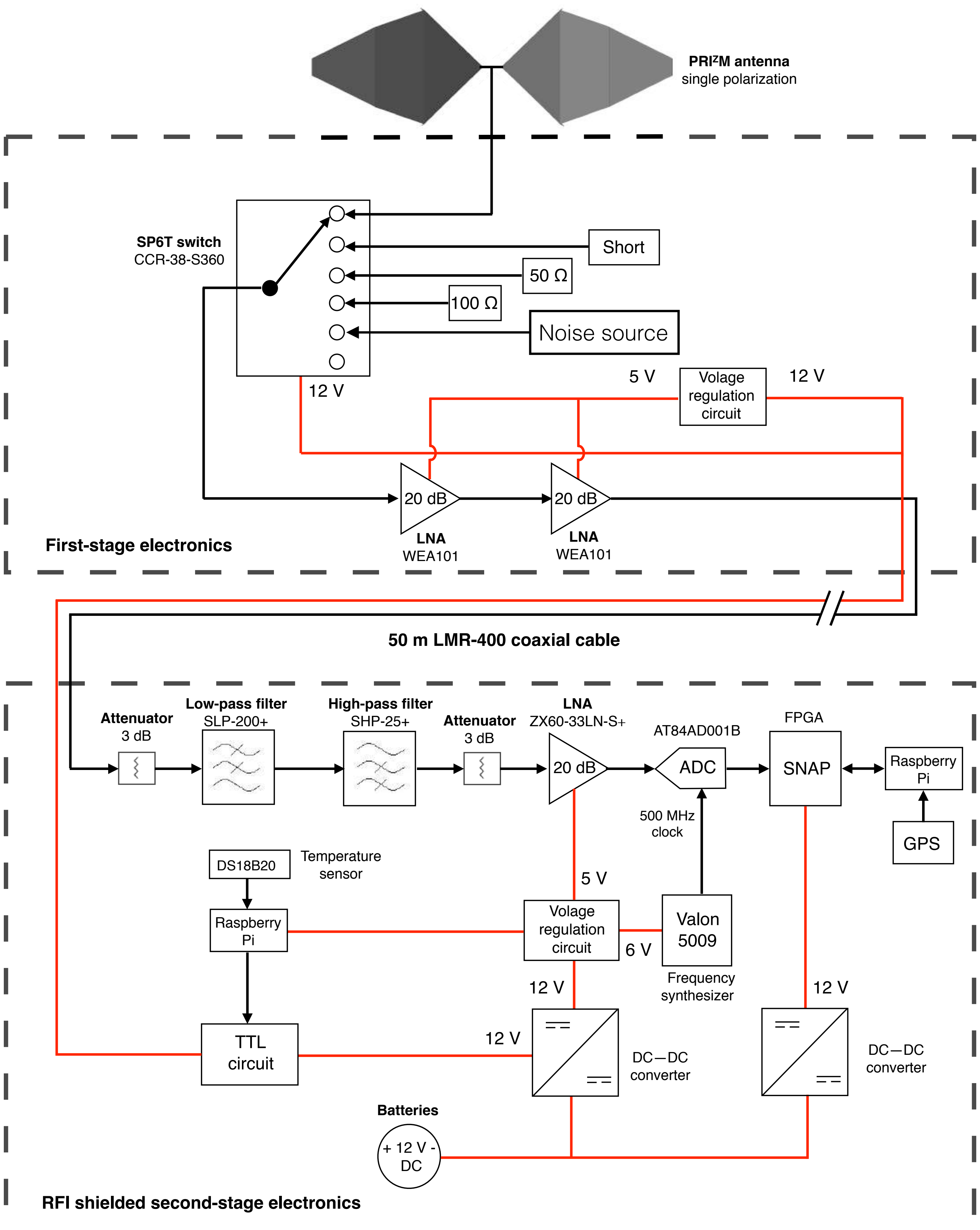
Band limit : 30—200 MHz

Observing location : Marion Island

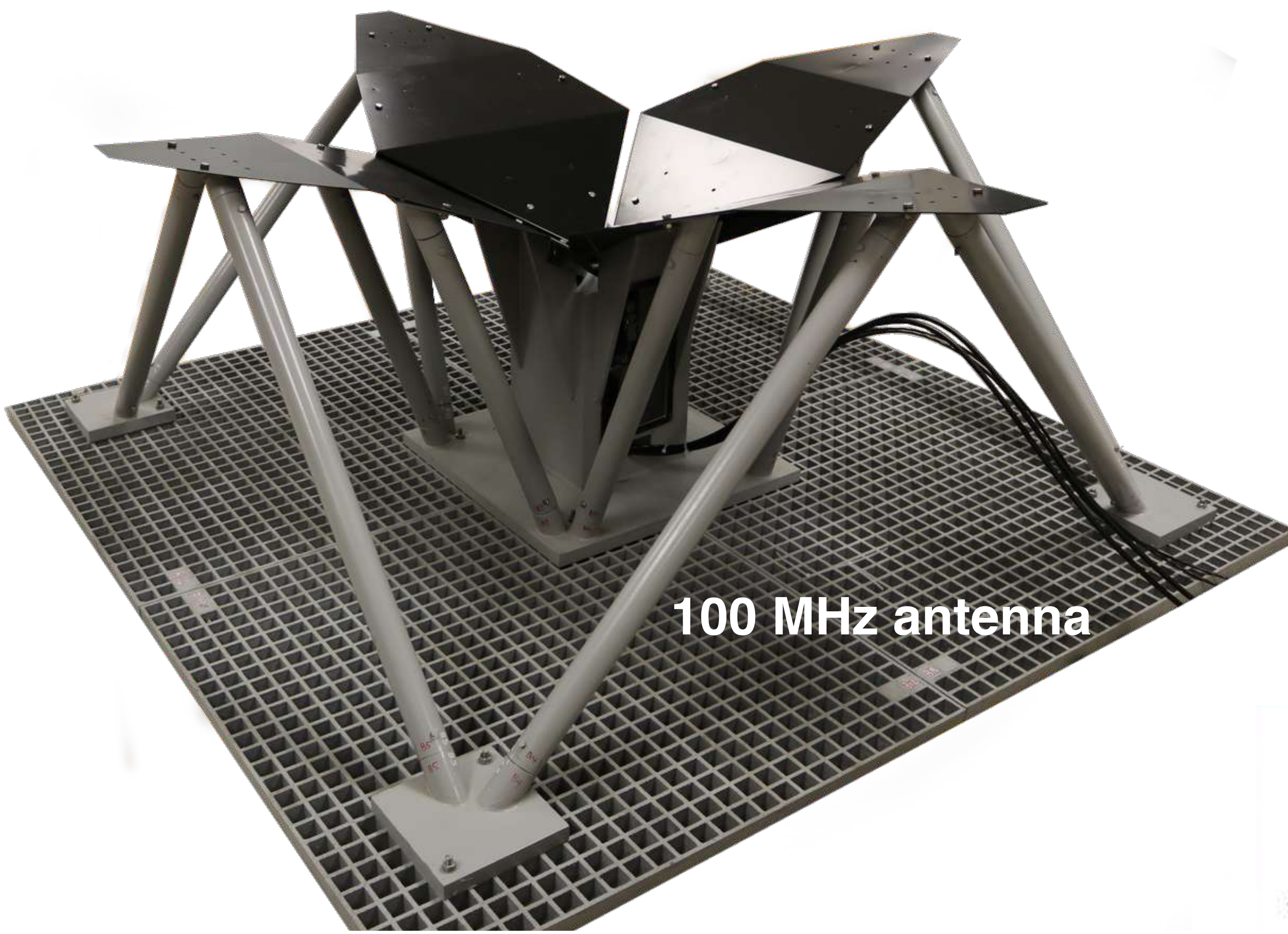
Marion access : ~3 weeks in April each year

Experiment timeline : 2016 — first engineering run
: 2017 — antennas installed for first over-winter science run
: program currently funded through 2020

Instrument overview

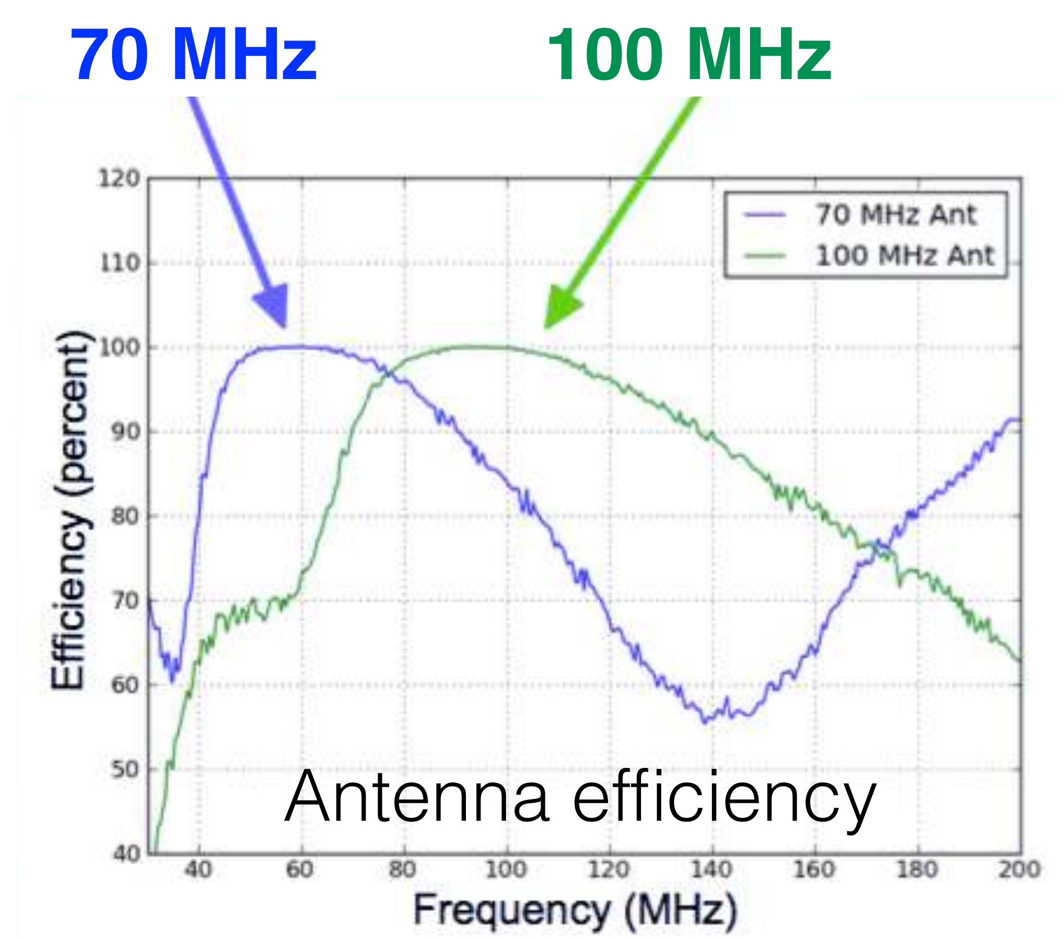


Antenna



Crossed-dipole

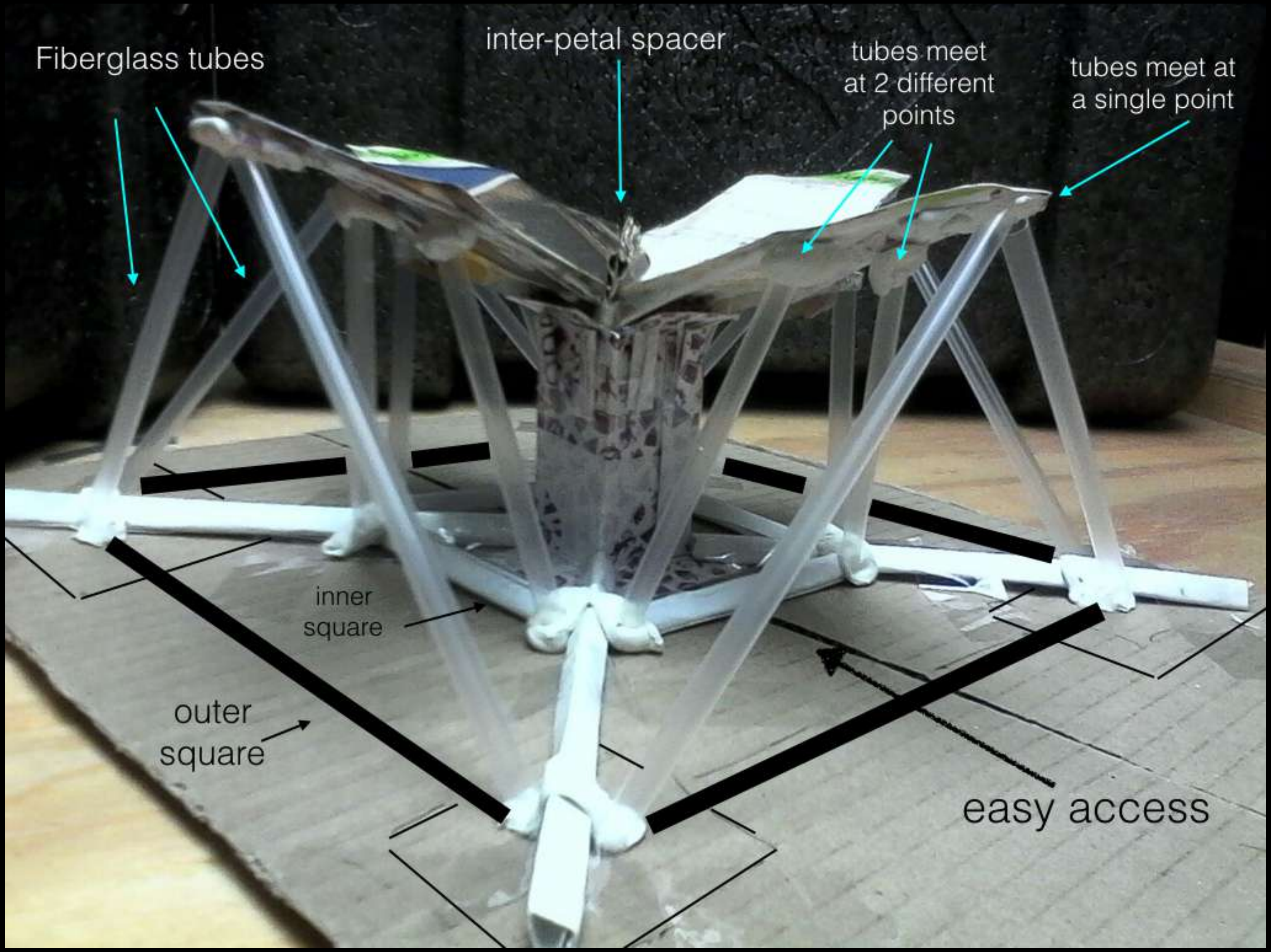
Modified version of a four-square antenna
(Ja´



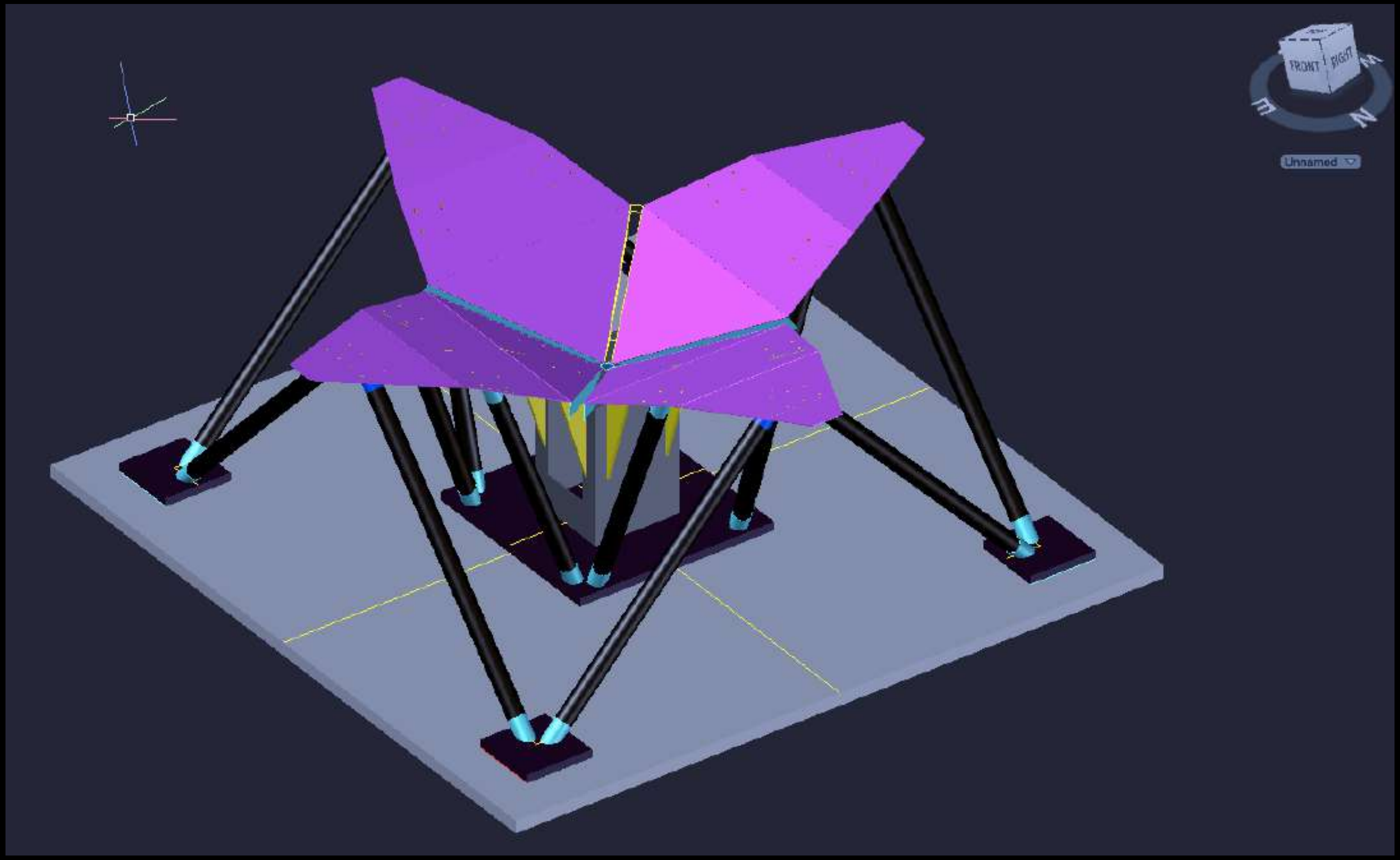
Minimized beam variation across the observing frequency range

Optimized with FEKO

1/10th model using cardboard and plastic straws



CAD drawing




a radio…what?
RHO-TECH
Tel : 031-9140966


scihi_FV1.pdf
scihi_FV2.pdf
scihi_PV1L.pdf
scihi_PV1R.pdf
scihi_PV2R.pdf
scihi_PV2L.pdf
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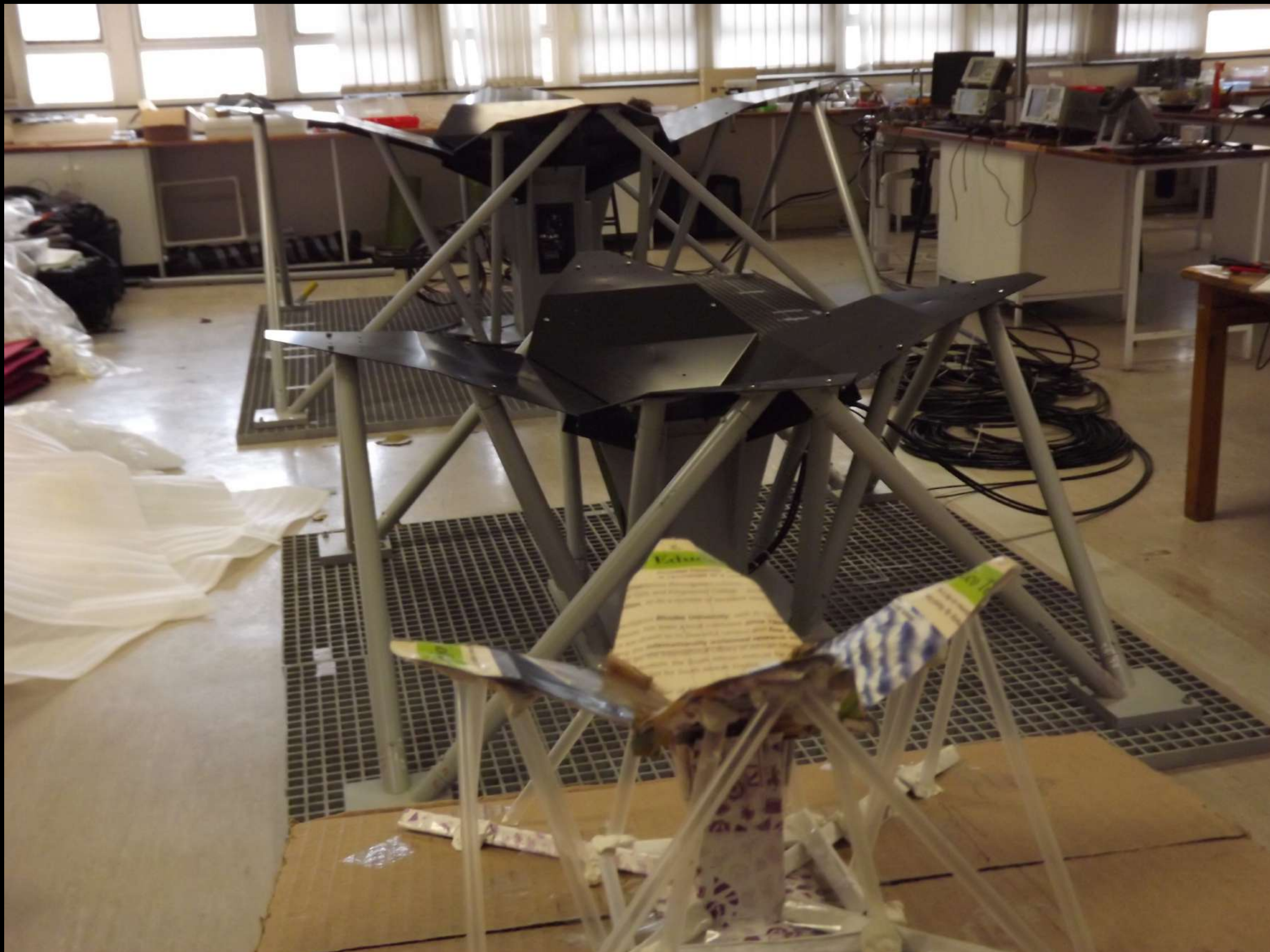
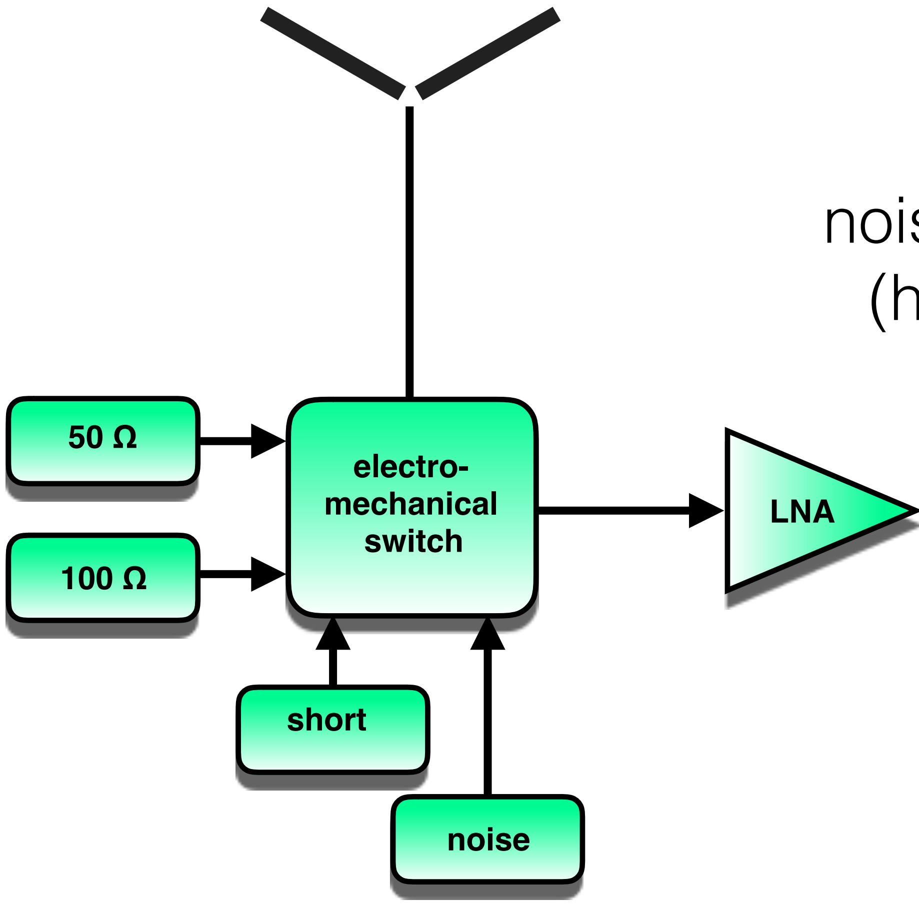
scihi_antenna.pdf

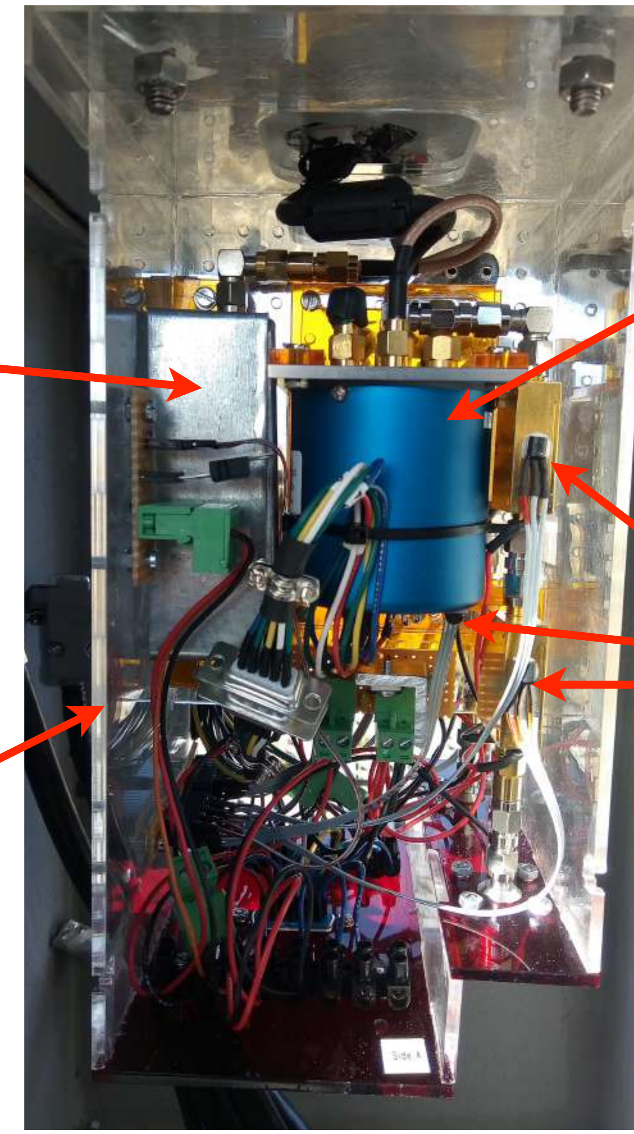


First stage electronics



noise source
(hot load)

laser-cut
acrylic box

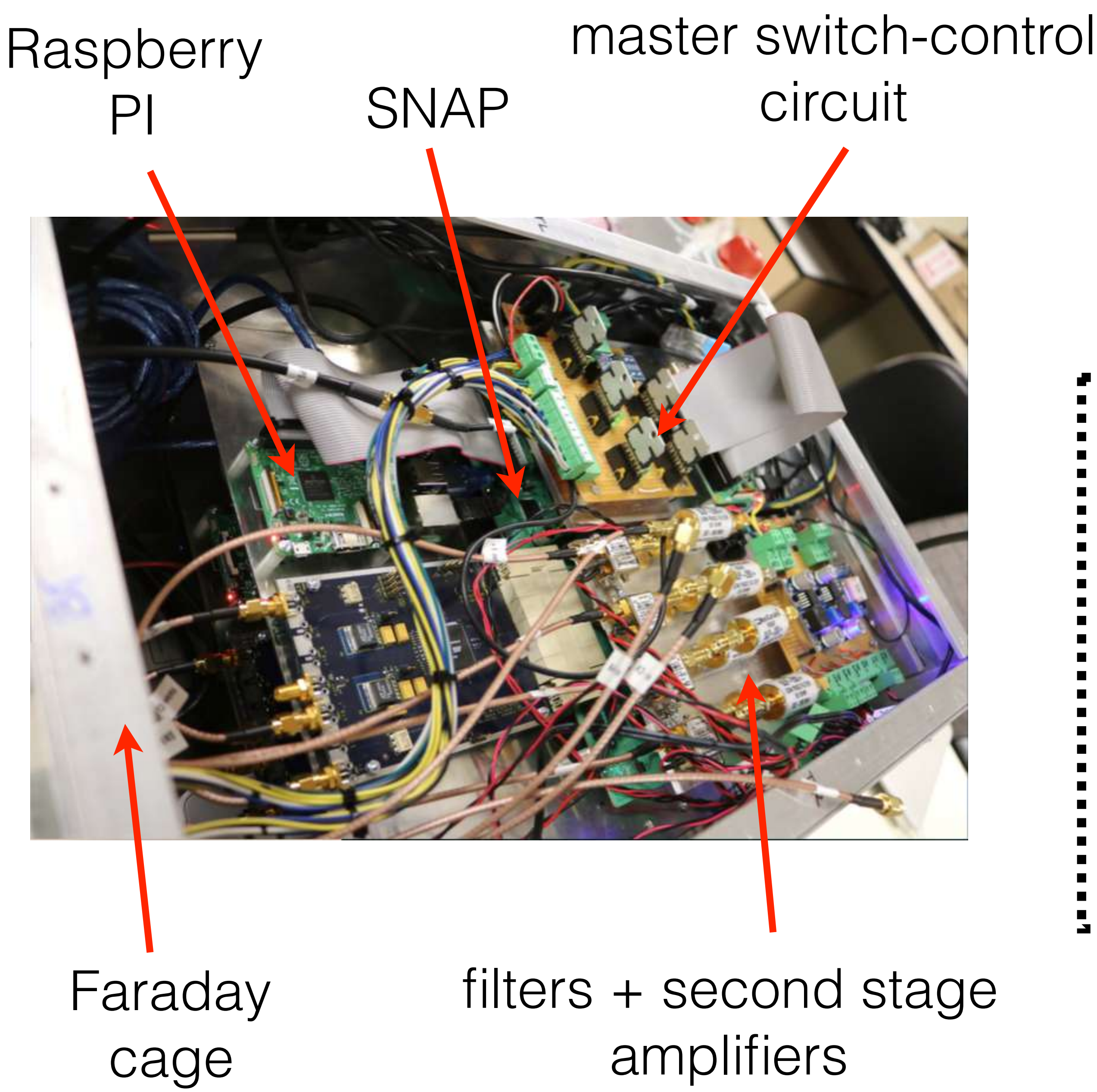


latching
switch

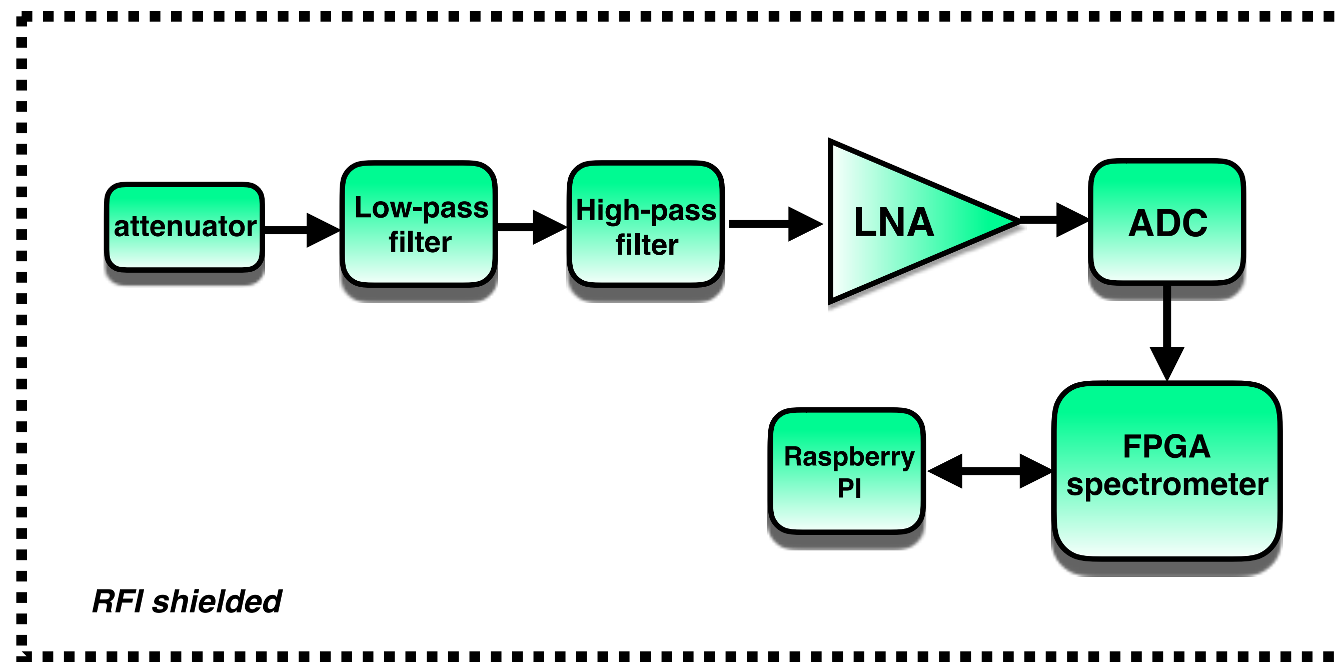
temperature
sensors
(total 9)

Sits directly underneath the
antenna petals

Second stage electronics



Placed 50 m away from the antenna to avoid contamination from self-generated RFI

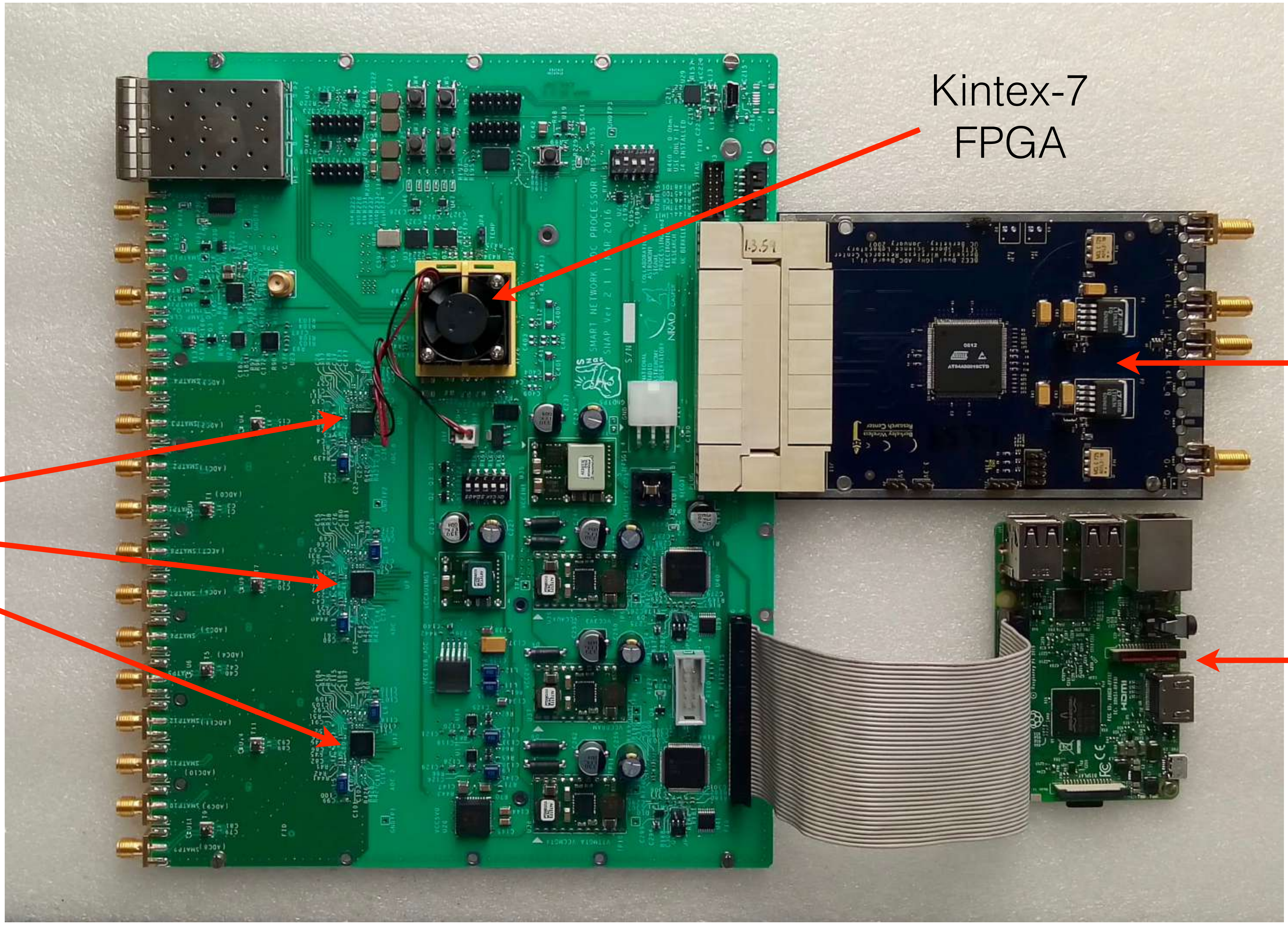


- ADC : sampling rate 500 MHz
- SNAP board : 4096 frequency channels
- Bandpass : 30 - 200 MHz

Power distribution

- 8 x lead crystal batteries 200 Ah each
- NO observation during battery charging
- ~1 week of uninterrupted observation when batteries are fully charged
- both systems combined power draw is ~65W

Smart Network ADC Processor (SNAP)



visit : https://casper.berkeley.edu/wiki/SNAP

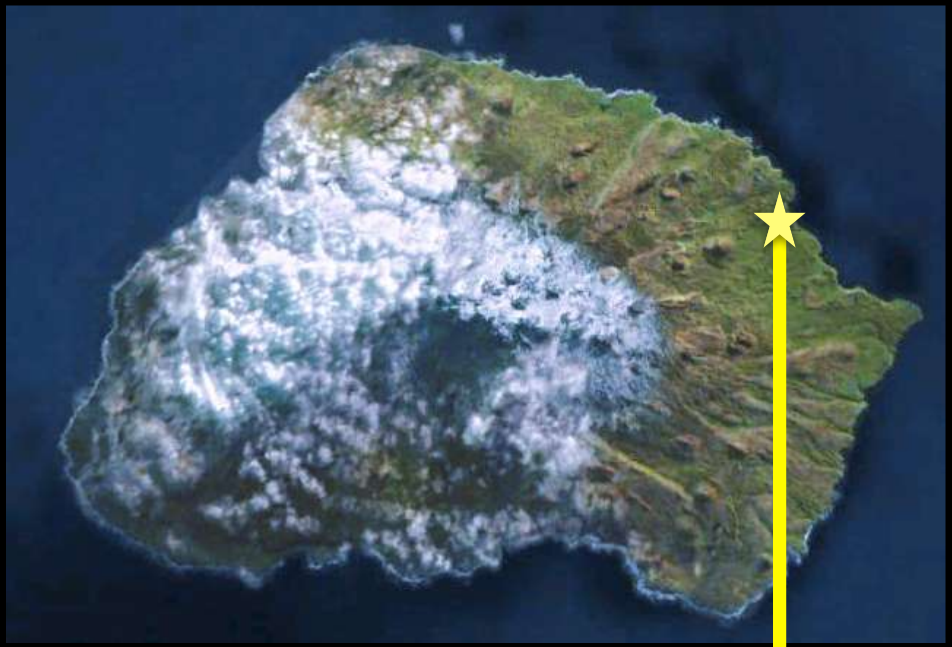
Packing for the voyage…

Marion Island

>2000 km from the nearest mainland

halfway between Africa and Antarctica

20 km x 12 km

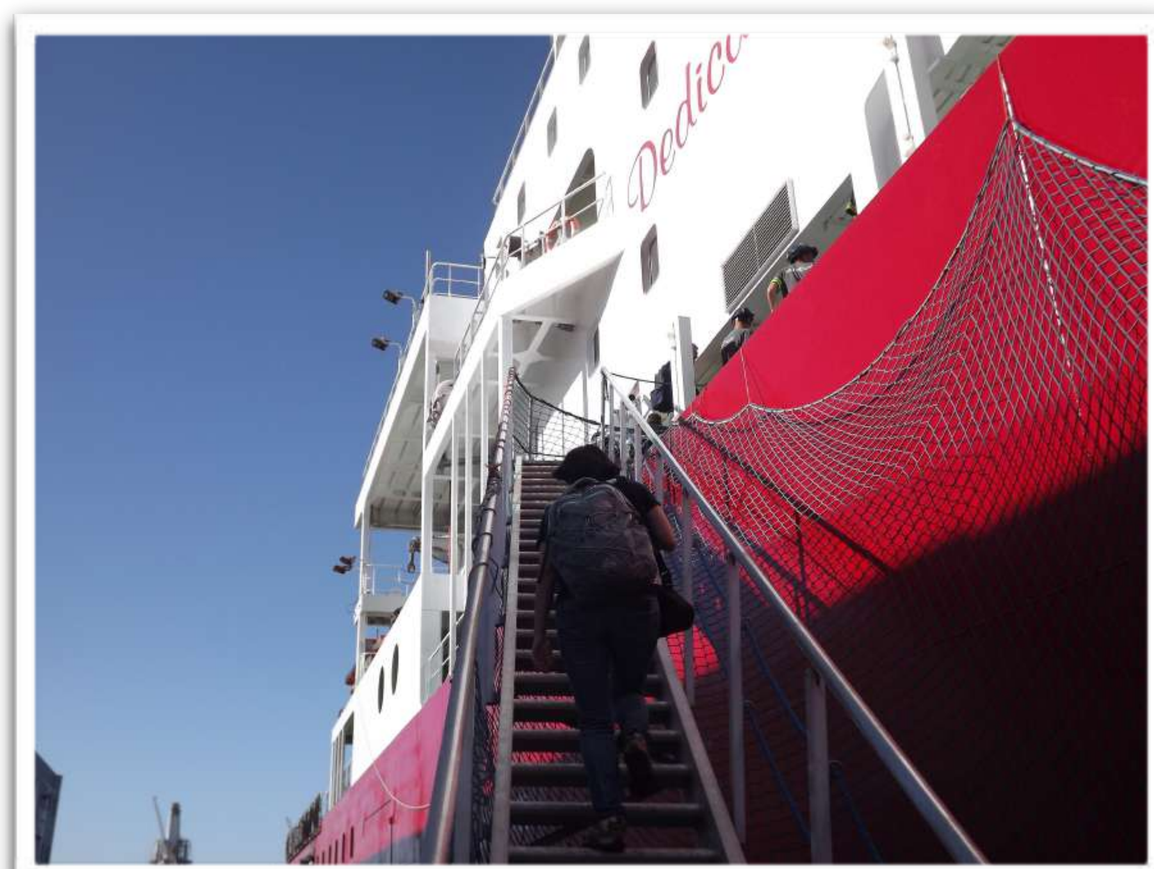


Cold : mean minimum temp. ~ 2.8 deg C
Windy : 80 knots gusts, horizontal rain etc.
lava rocks
mice

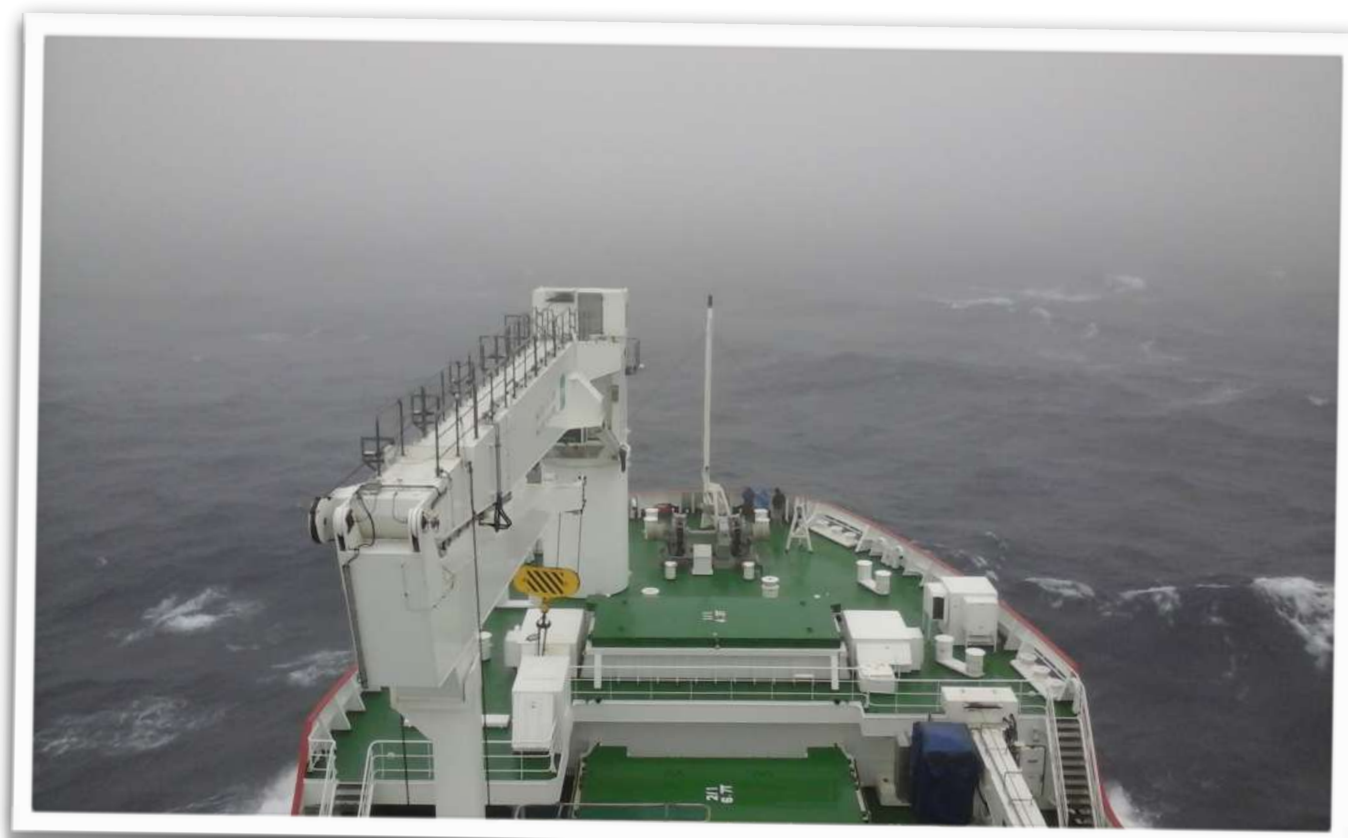
Serviced annually by SA Agulhas II

Takeover : 3 weeks
Winter-overing : 13 months

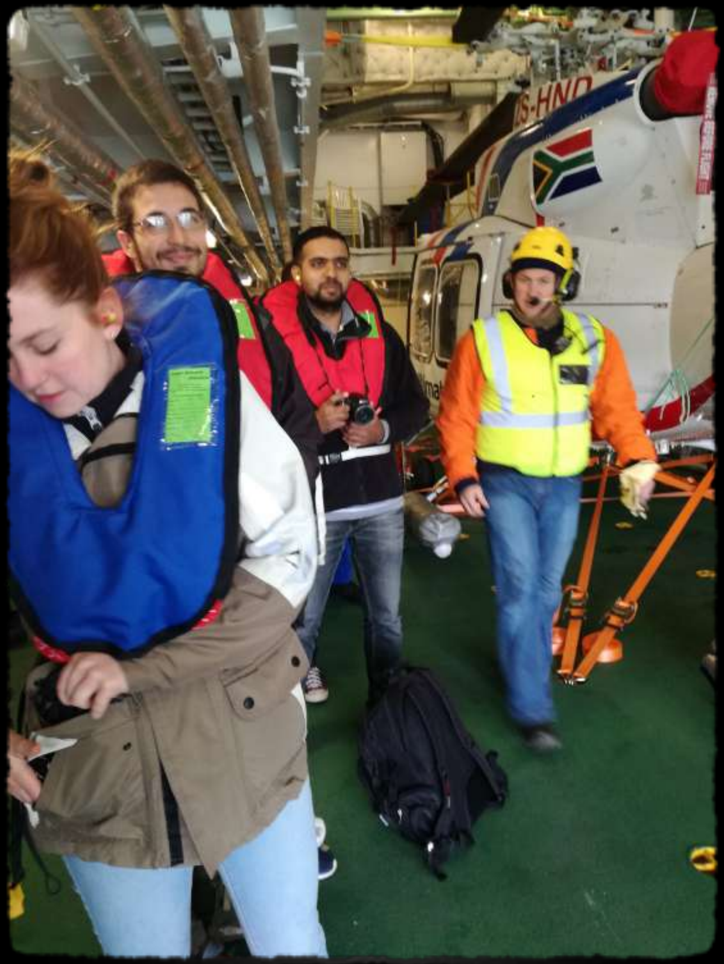
Starting point — Cape Town harbor



The journey…



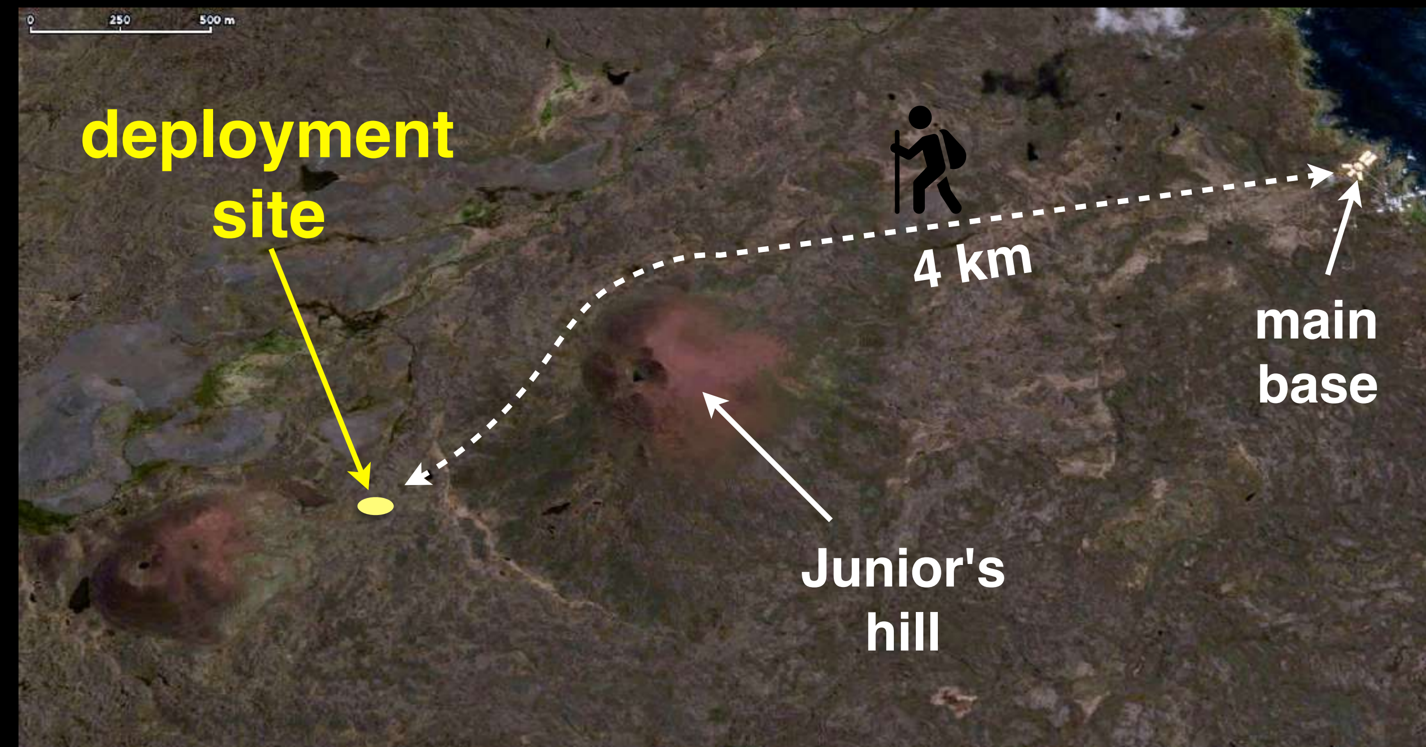
Get to the chopper!

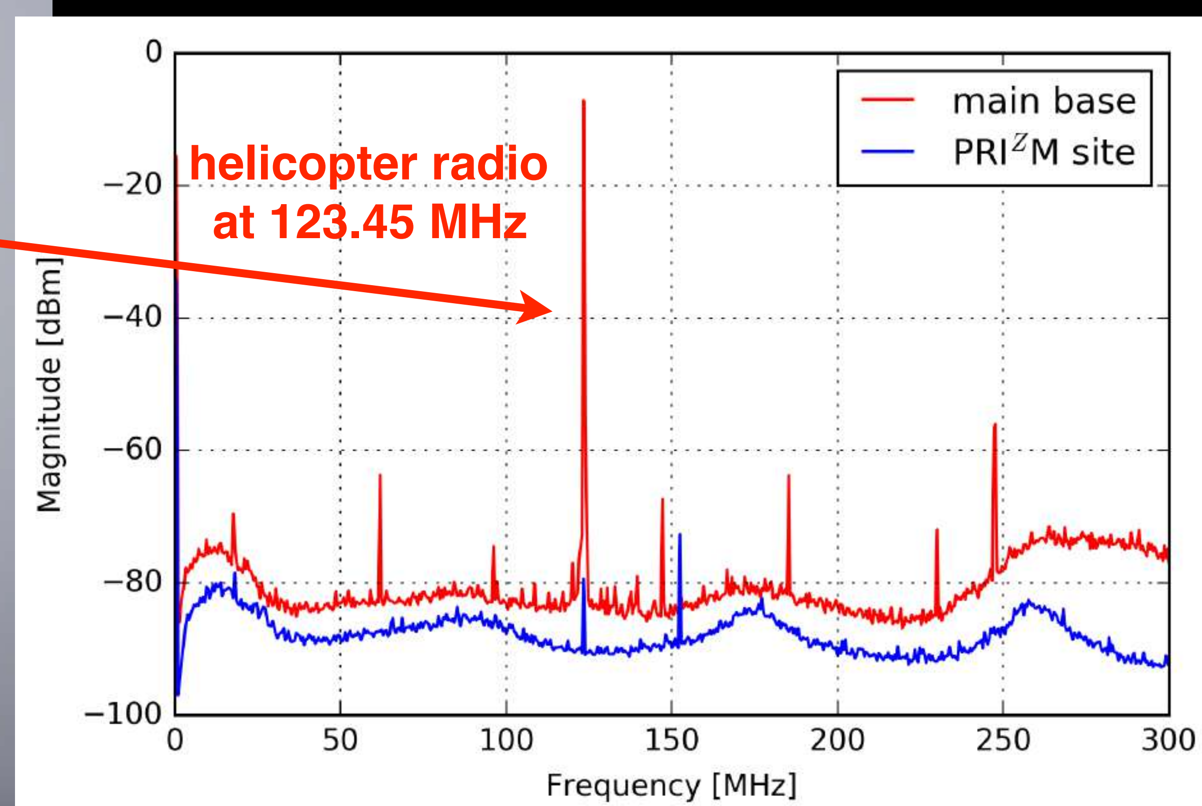


Cargo slinging

Where do we install the telescopes?

RFI survey — site selection





~60 dB difference between the deployment site and base

~40 dB attenuation due to Junior's hills and ~20 dB due to distance from the base

Installation timeline — 2017

on-site paraphernalia

2 containers are connected by PVC tubing

3 cargo containers

210 cm x 130 cm x 90 cm

Command center

Backend electronics
battery banks
charging setup
morale booster box

Generators & spares

fuel and other useful equipment

mouse-proofing

finely woven steel mesh wrapped around our cables

Marion mice eat almost anything — wire insulation, electrical tape, our lunch, live birds, etc.

we protect our precious experiment using — steel mesh, scourer pads, silicon sealant and a lot of vengeance.

live mouse traps were installed in 2018

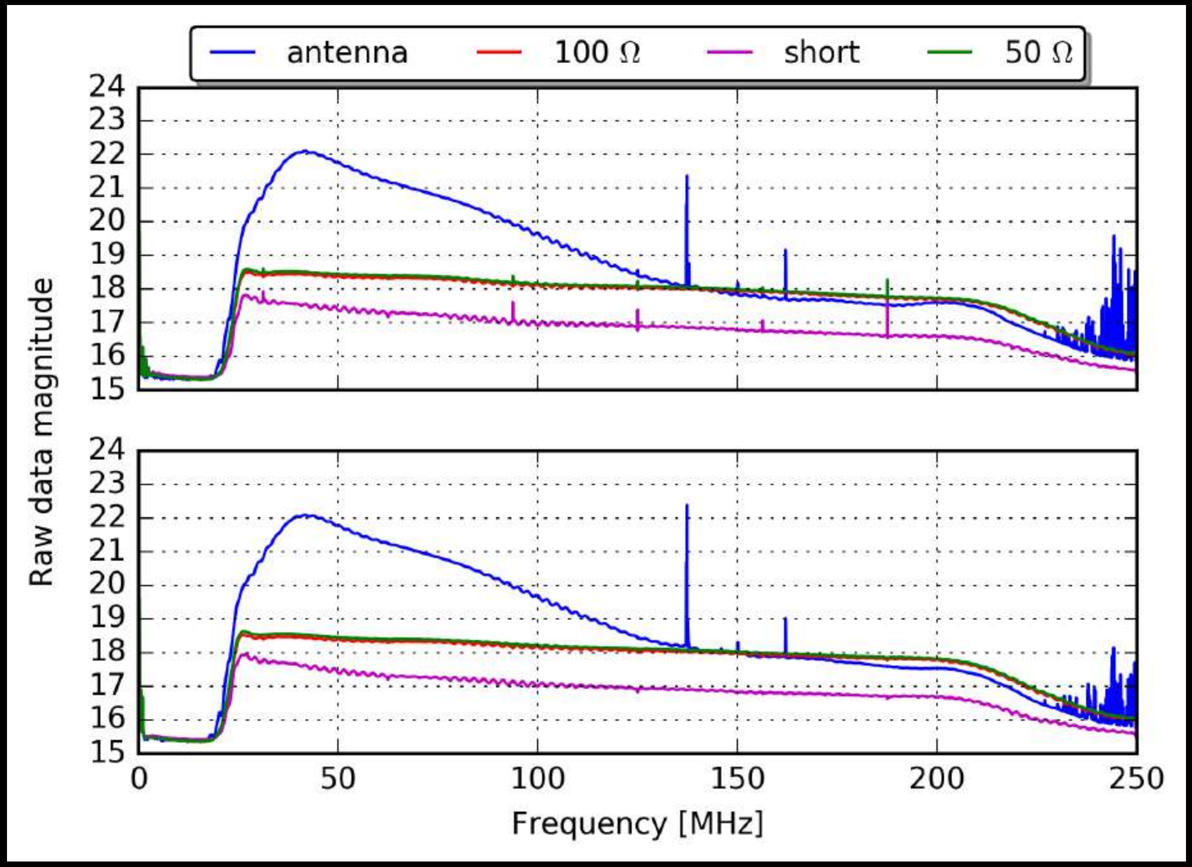
Winter operations

Supported by the South African National Space Agency (SANSA)

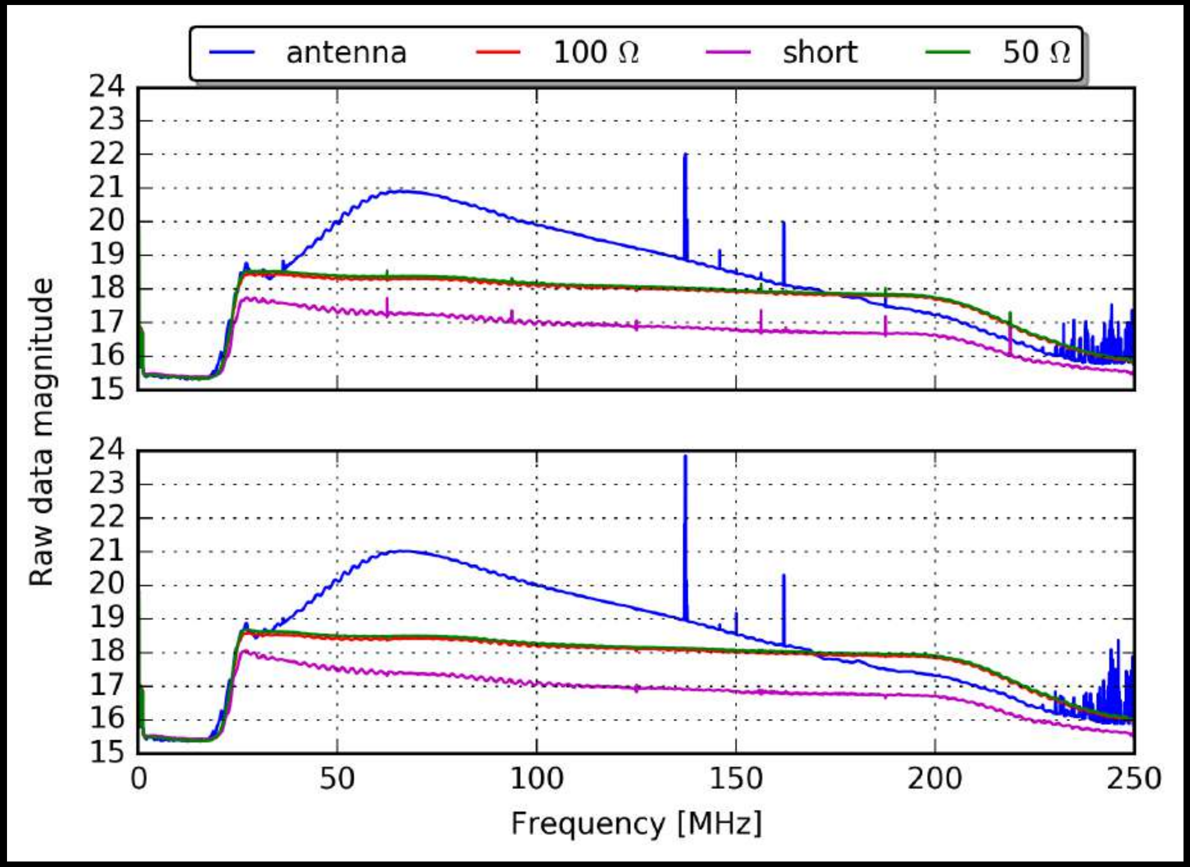
Marion has an excellent radio-quiet environment and a few challenges…

- Access — ~3 weeks per year (takeover voyage)
- Completely weather driven
- Data retrieval is once a year
- Debugging happens via a SANSA engineer (he takes care of a dozen other projects too)
- RSA—Marion communication can be slow at times

Raw data — 2017



70 MHz



100 MHz

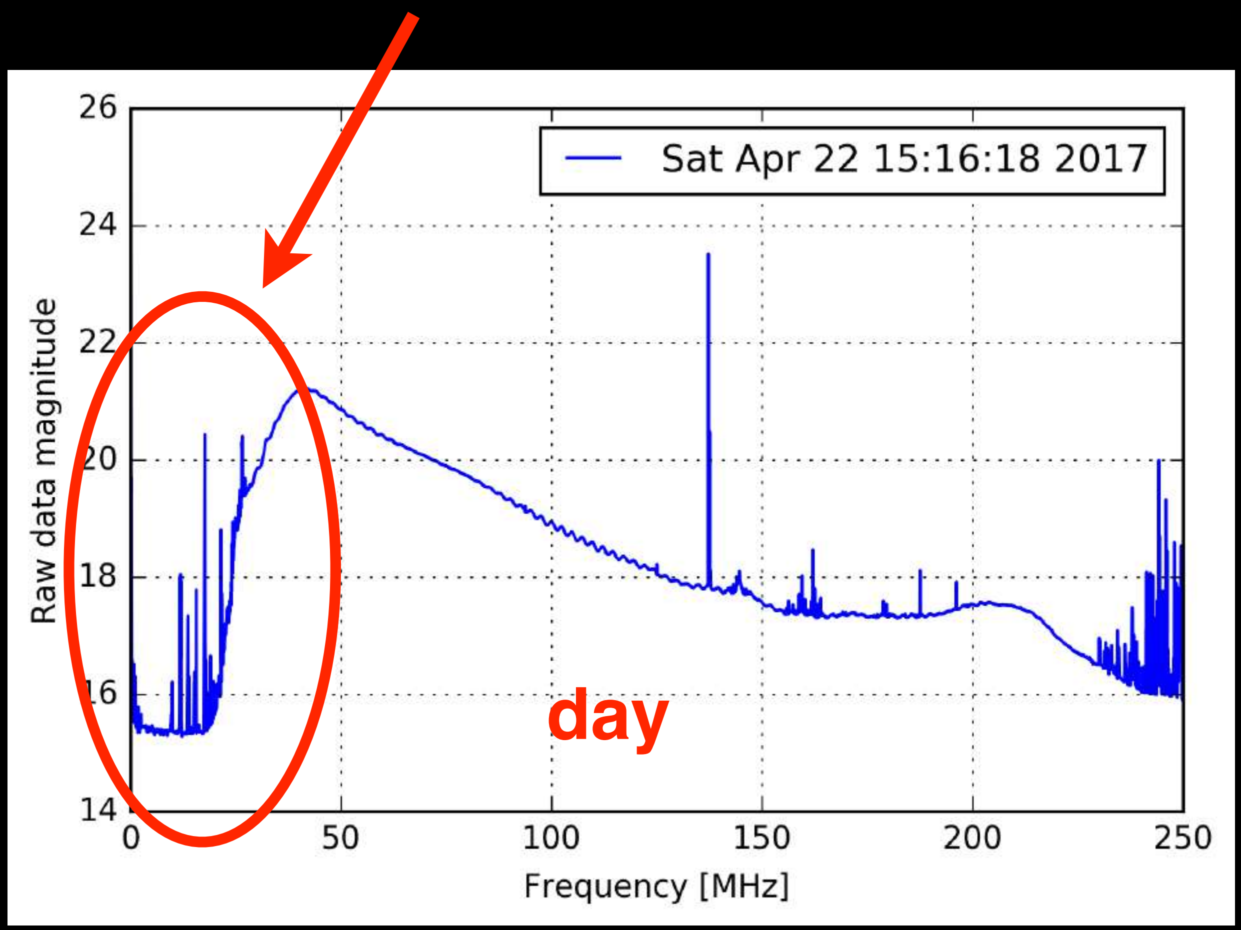
Data rate ~900 MB per day, both systems combined

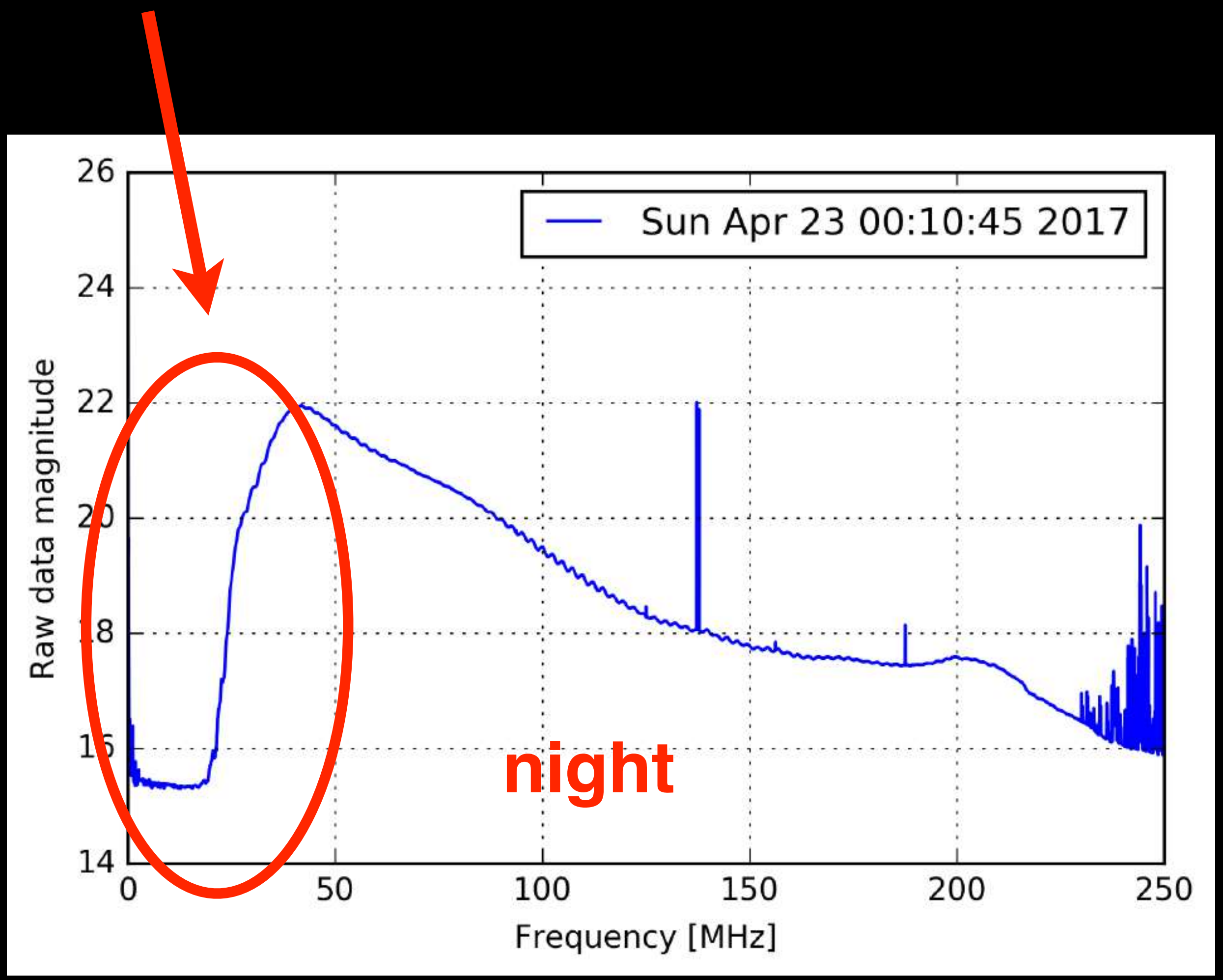
Data stored on a micro-SD card on the Raspberry PI.
Several months of data can be stored on a 128 GB card.

Quieter ionosphere during the night

Shortwave reflecting off the ionosphere

Shortwave reflection significantly reduced at night



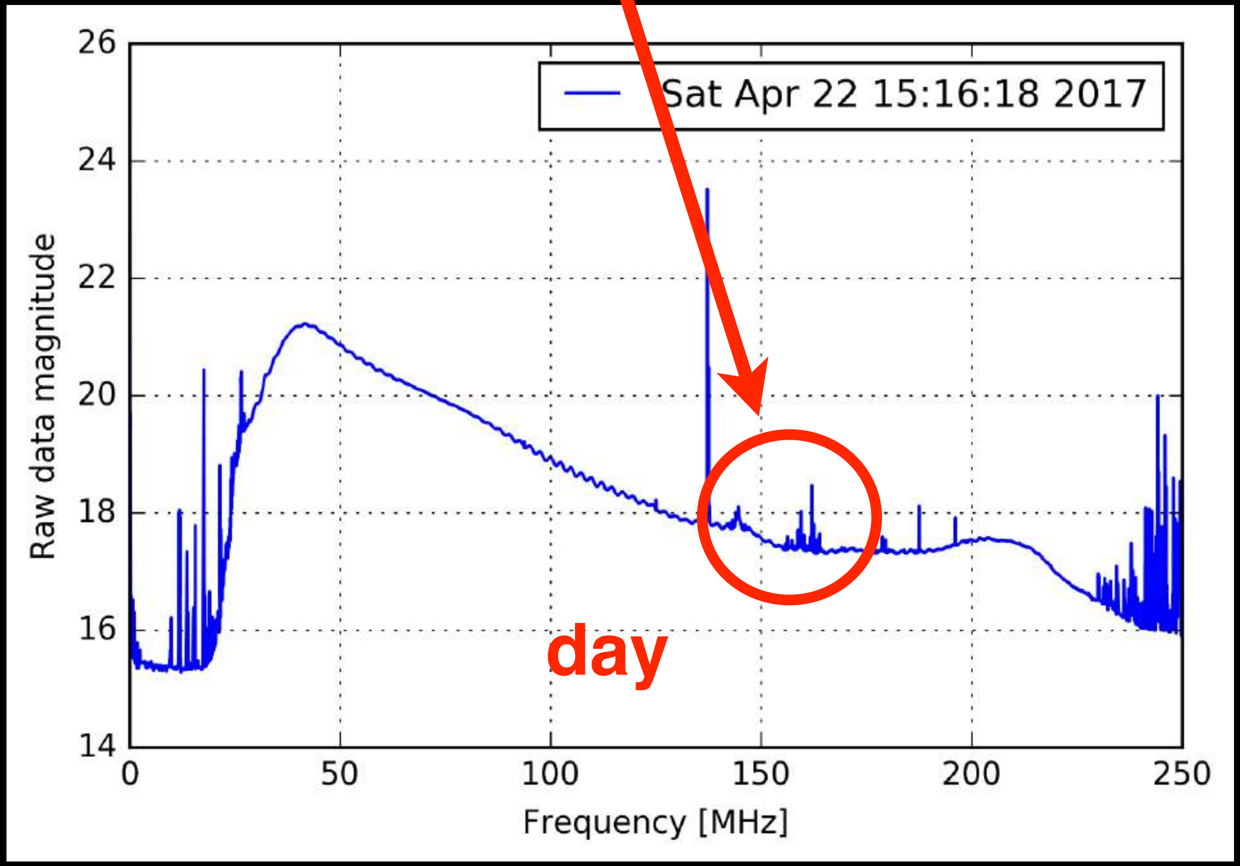


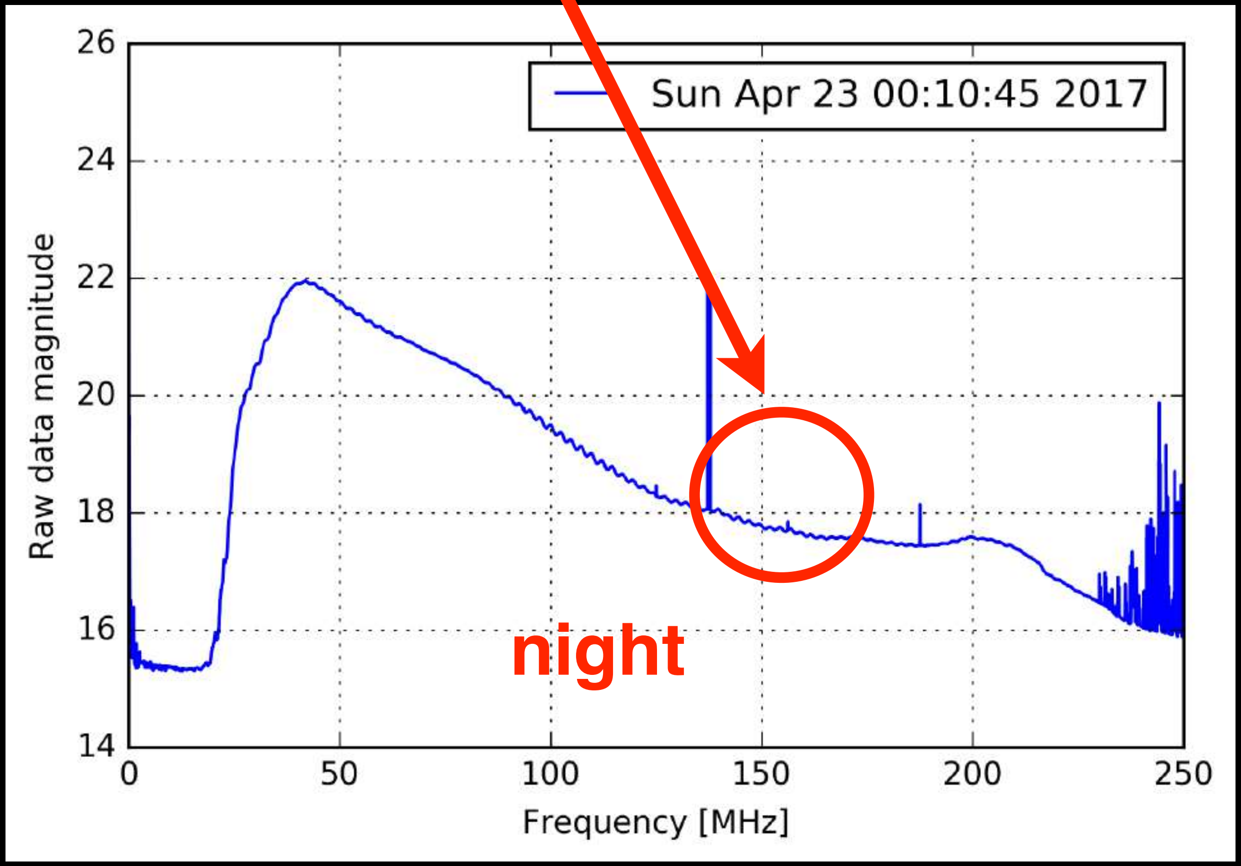
70 MHz antenna data

Quieter nights during takeover

People using handheld radios

…and when they sleep





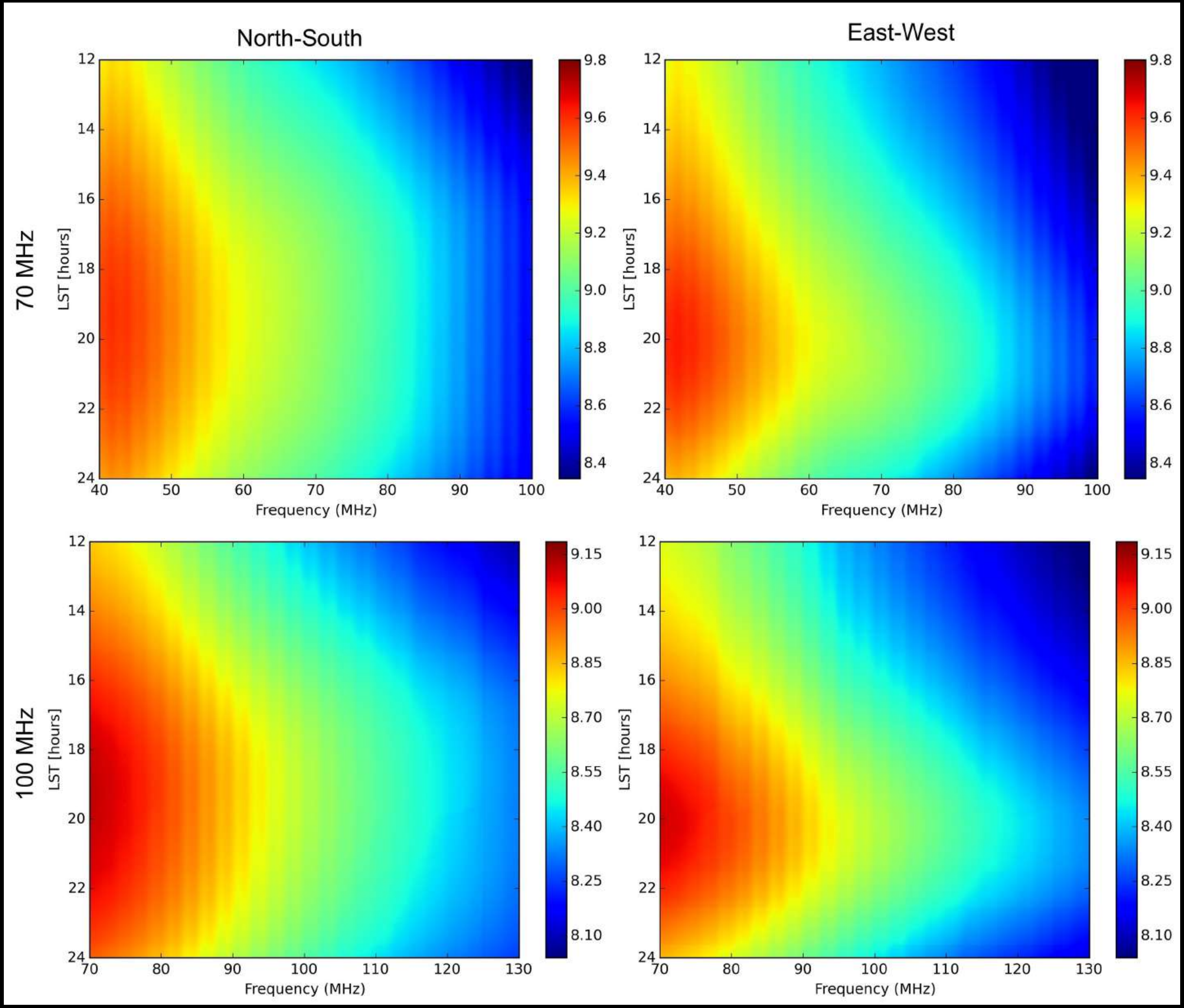
70 MHz antenna data

There are very minimal radio communications on the island except during the takeover period

12 hour waterfall plot — 2017

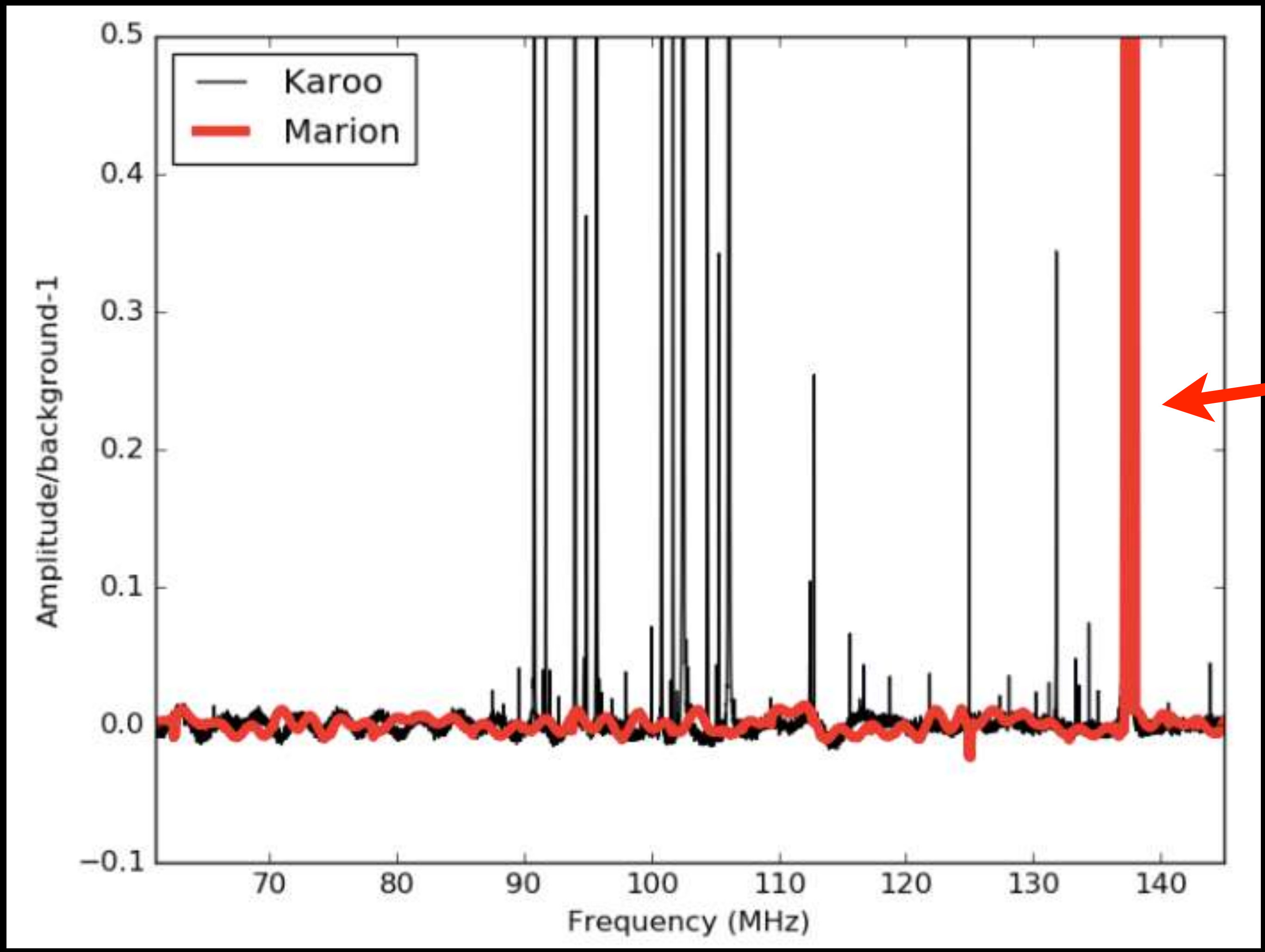
70 MHz

100 MHz



North-South **East-West**

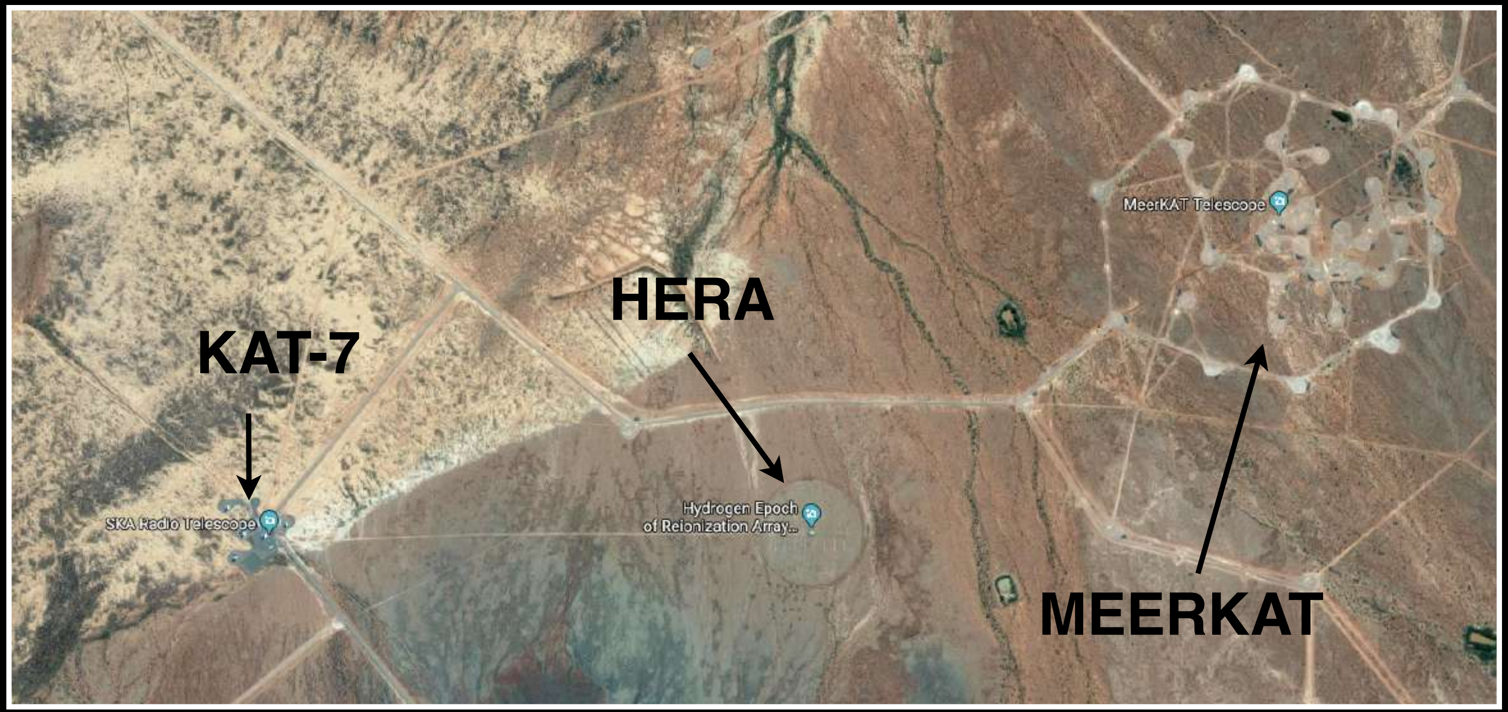
RFI levels — Marion vs SKA site (RSA)



Orbcomm satellite
137—138 MHz

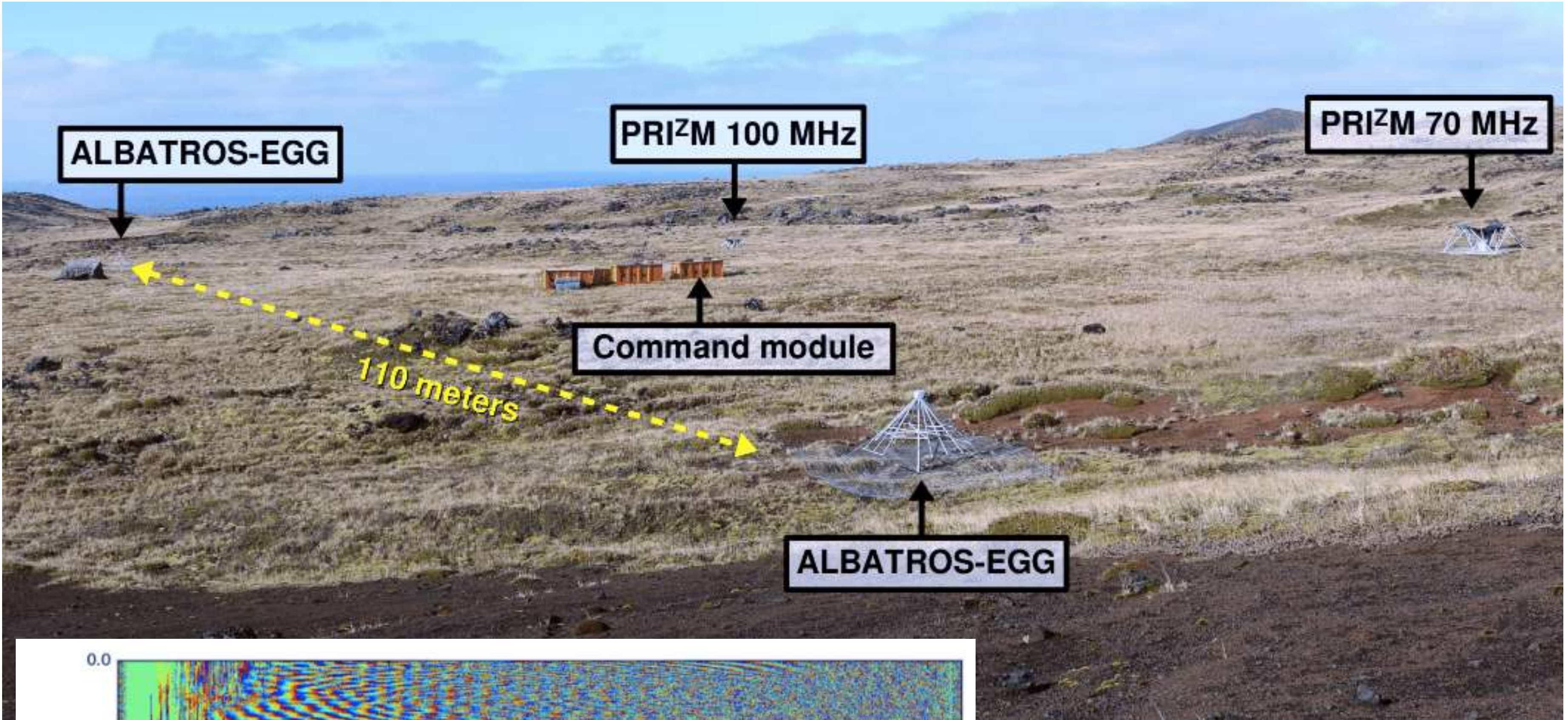
Marion has pristine radio-quiet FM band

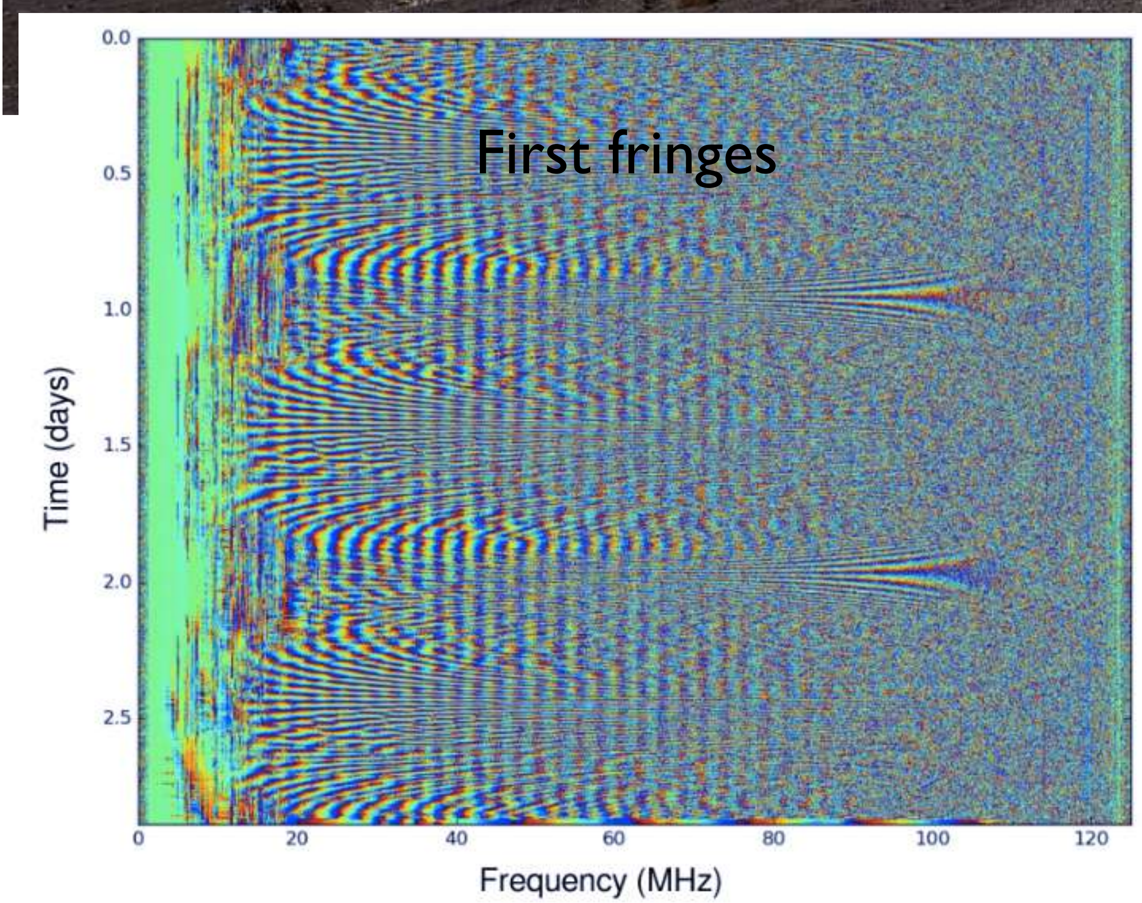
Karoo desert will host the upcoming SKA radio telescopes in South Africa

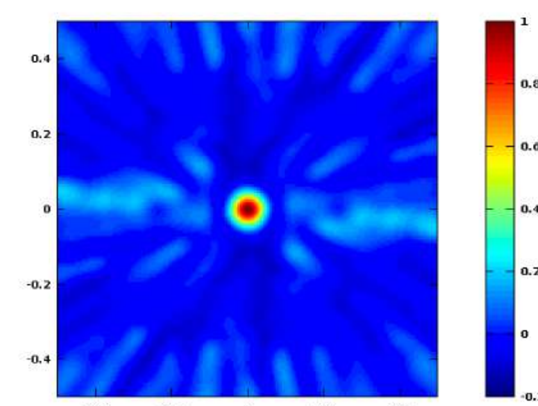


Philip et al. 2018 (1806.09531)

Expanding to lower frequencies







5 MHz beam from Marion, 8' FWHM

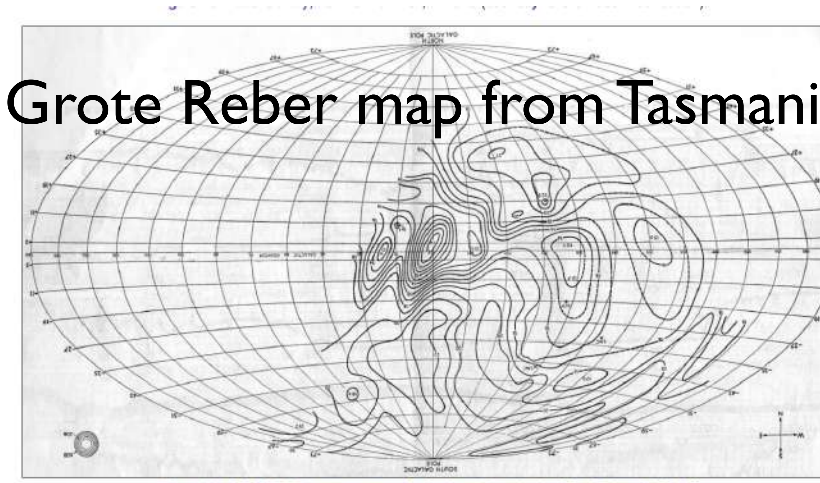


Figure 11: A 2.085 MHz contour map of galactic radio emission (after Reber, 1968: 10).

Proposed sites

<u>**ALBATROS**</u> : **A**rray of **L**ong **B**aseline **A**ntennas for **T**aking **R**adio **O**bservations from the **S**ub-Antarctic

<u>**EGG**</u> : **E**xploratory **G**izmo on the **G**round

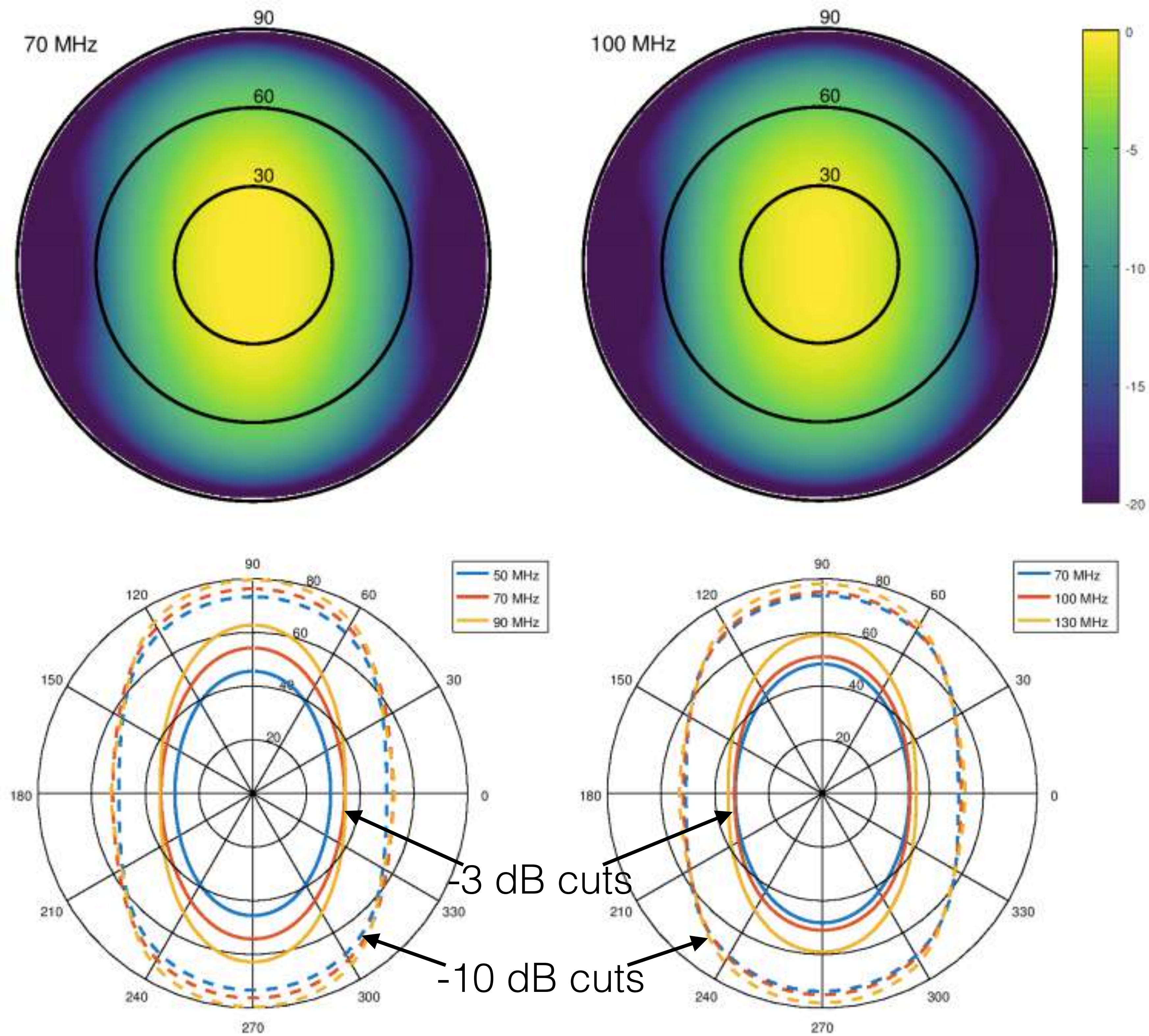
Thank you!

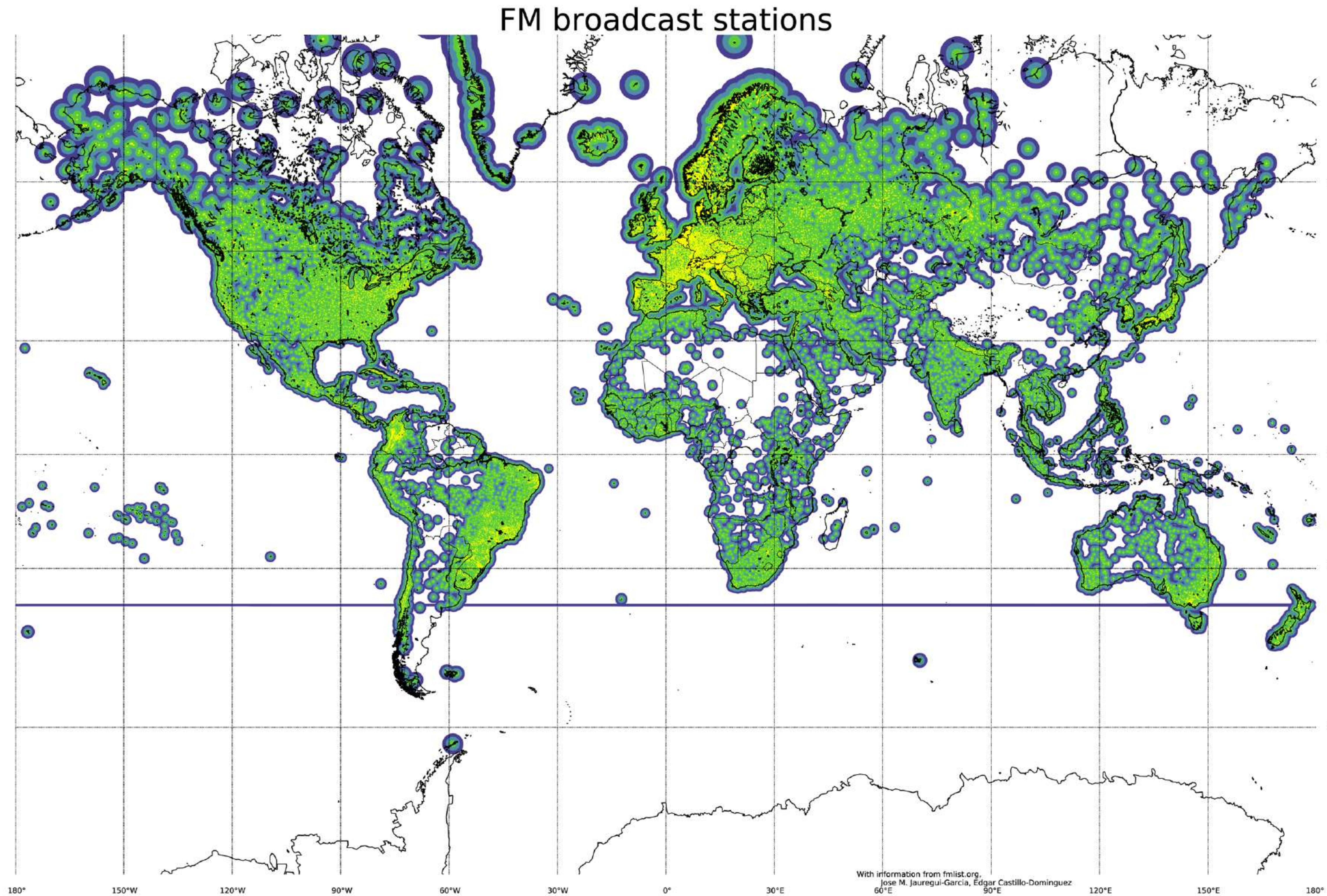
lijuphil@gmail.com

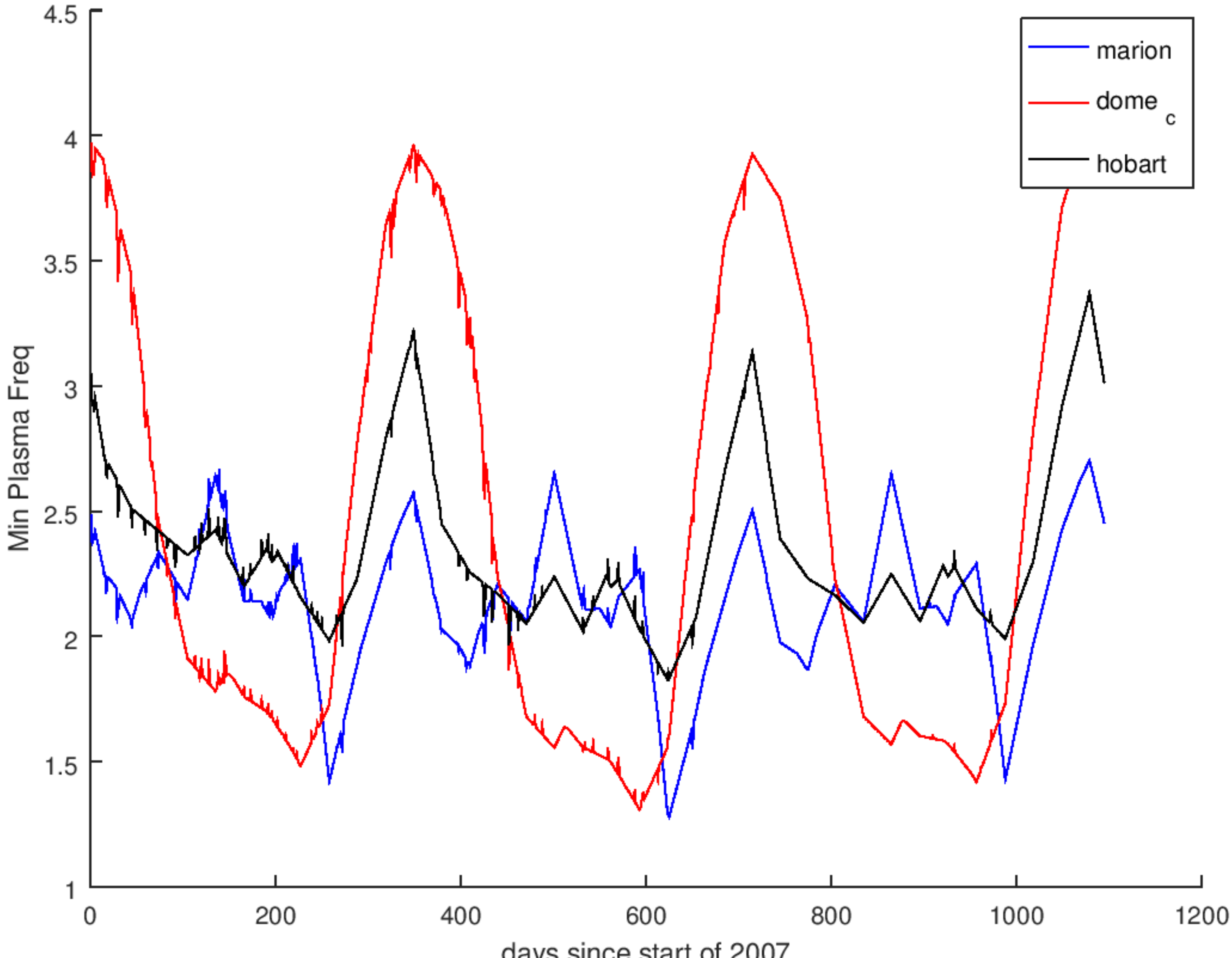
https://acru.ukzn.ac.za/liju-philip/

Extra slides

FEKO simulated antenna radiation pattern




FM broadcast stations
60°N
30°N
0°
30°S
60°S
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
With information from fmlist.org,
Jose M. Jauregui-Garcia, Edgar Castillo-Dominguez



4.5
4
3.5
3
2.5
2
1.5
1
0
200
400
600
800
1000
1200
Min Plasma Freq
days since start of 2007
marion
dome c
hobart