Searching for Cosmic Dawn with PRI^{Z}M

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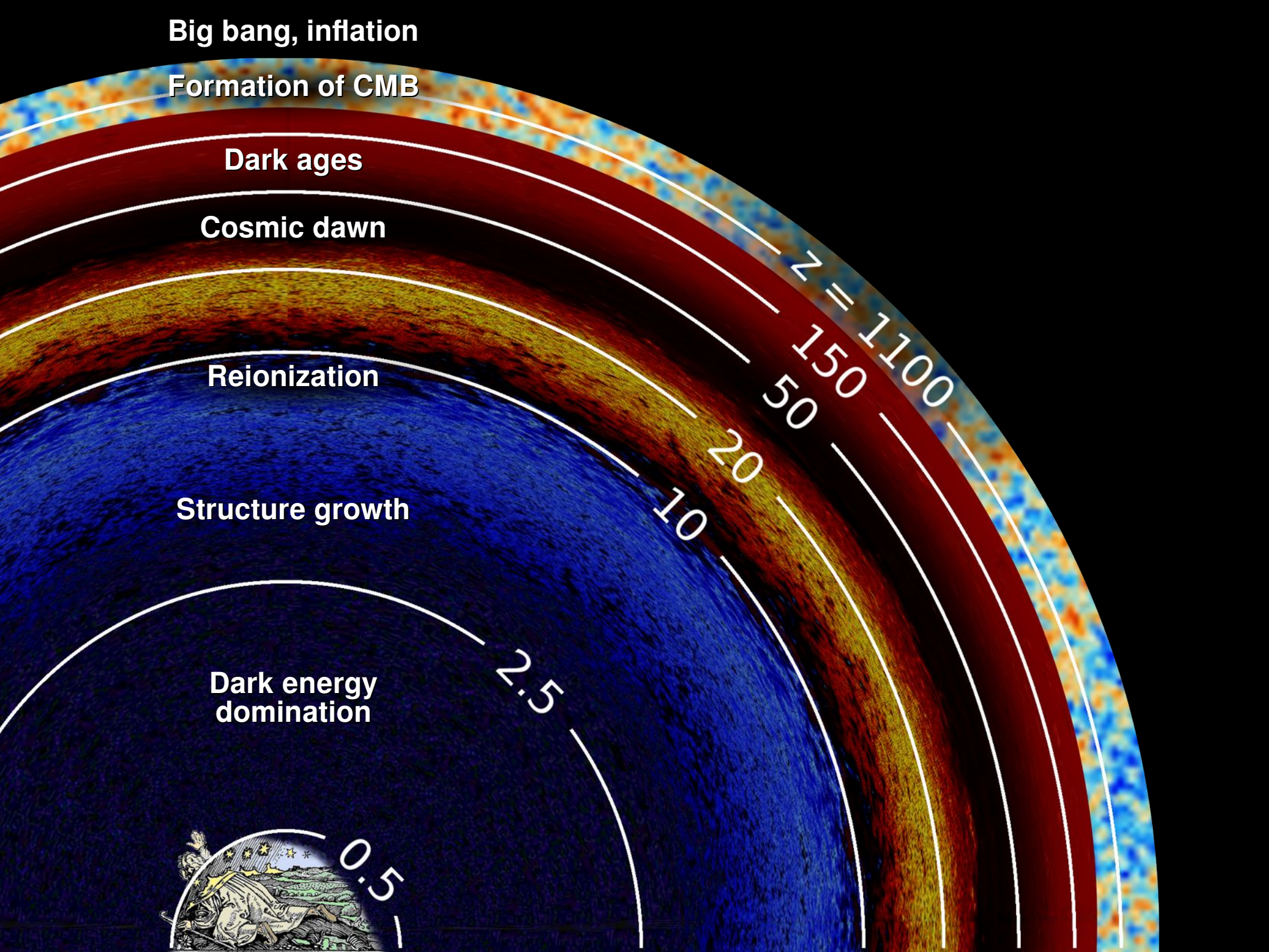
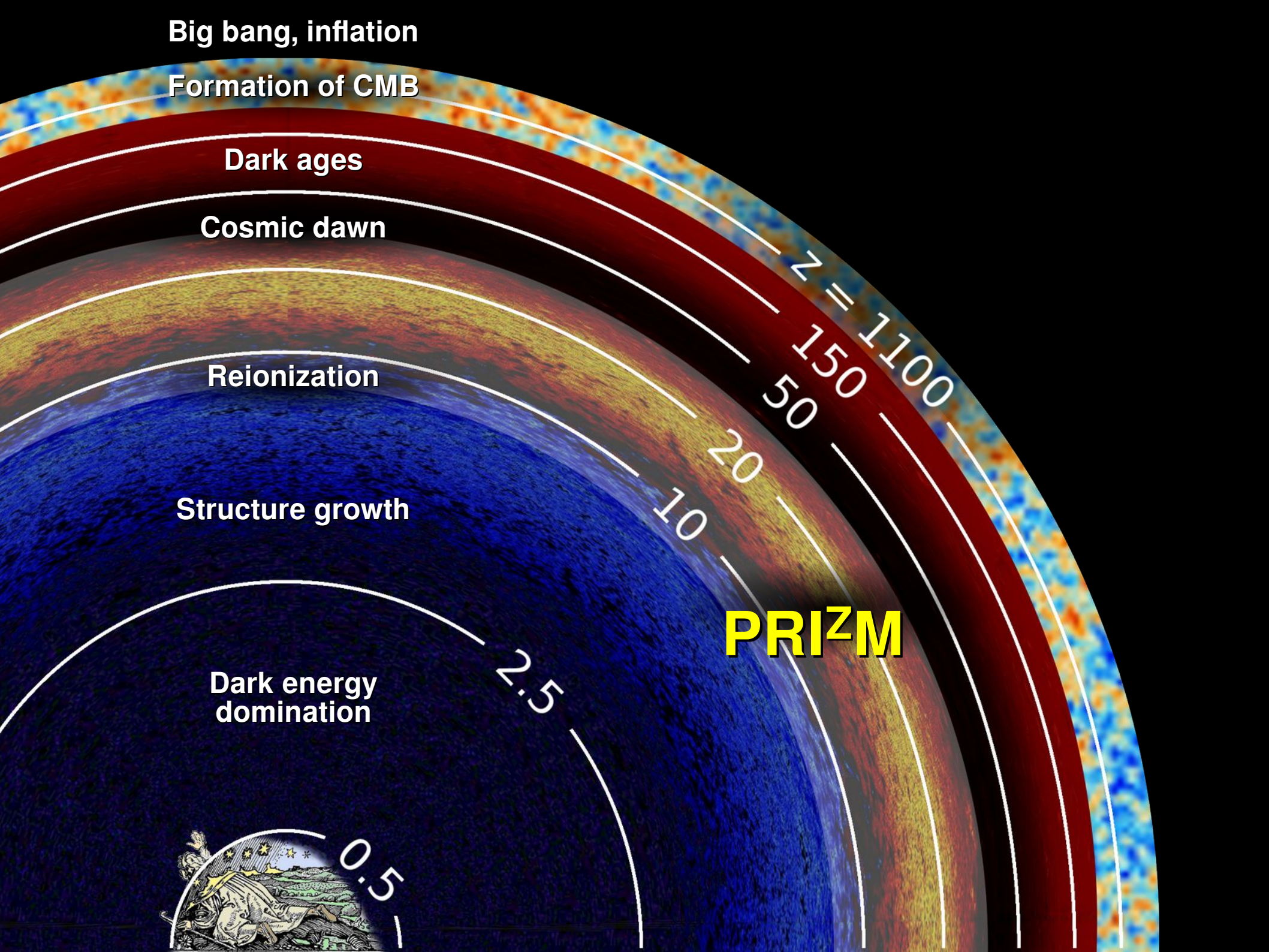
Rencontres du Vietnam
9 August 2018


Big bang, inflation
Formation of CMB
Dark ages
Cosmic dawn
Reionization
Structure growth
Dark energy domination
z = 1100
150
50
20
10
2.5
0.5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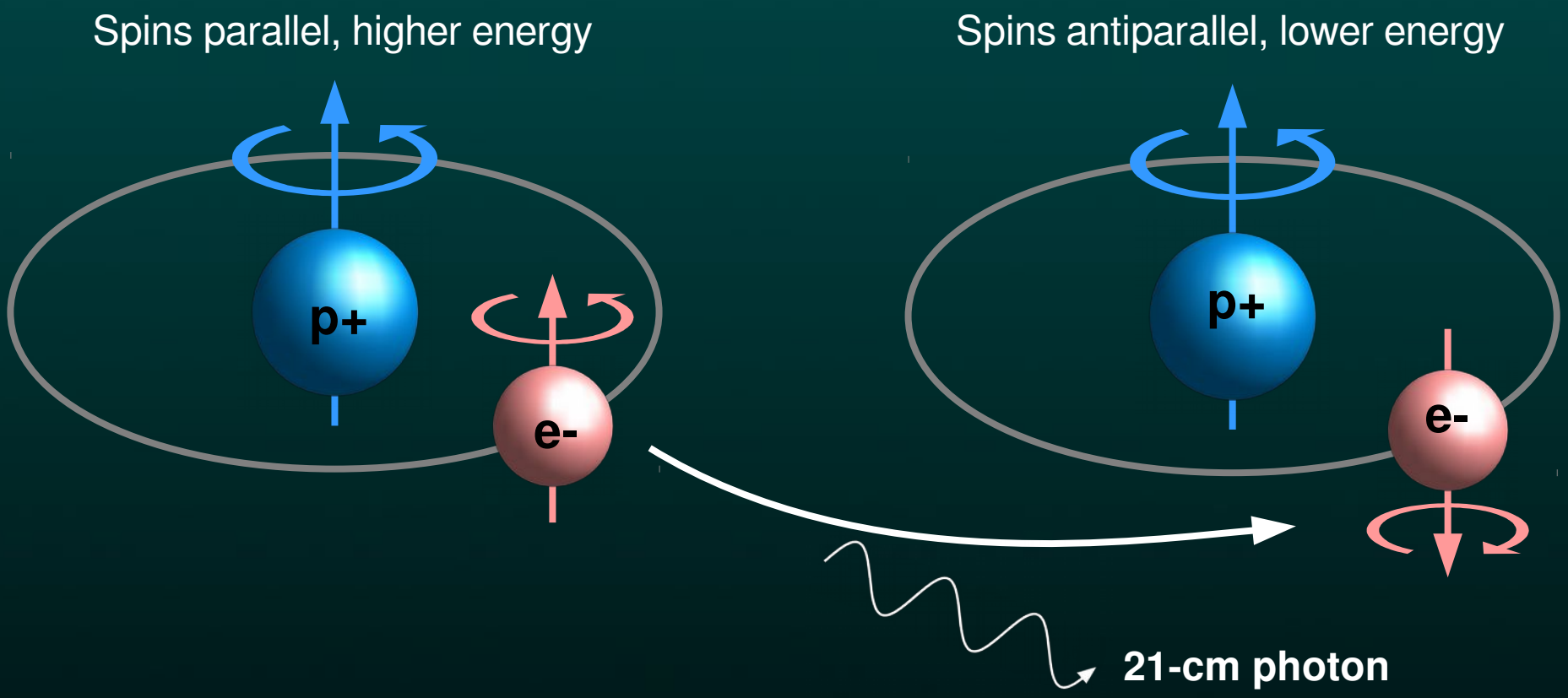
PRIZM

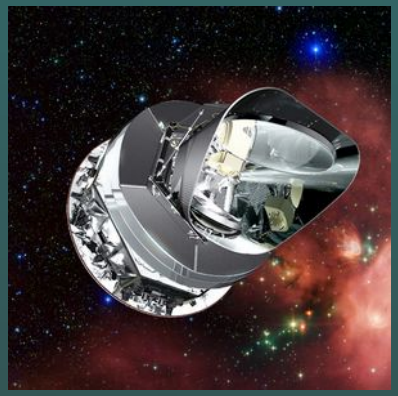
Redshifted 21cm emission

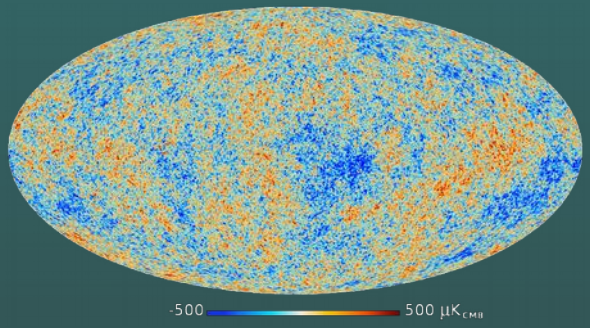


- Hyperfine transition in neutral hydrogen produces 21-cm (1.4 GHz) radiation (no emission from molecular or ionized hydrogen)
- Forbidden transition, lifetime of excited state ~10 million years
- 21-cm emission serves as a natural redshift marker for mapping hydrogen in the universe, tracer of large scale structure

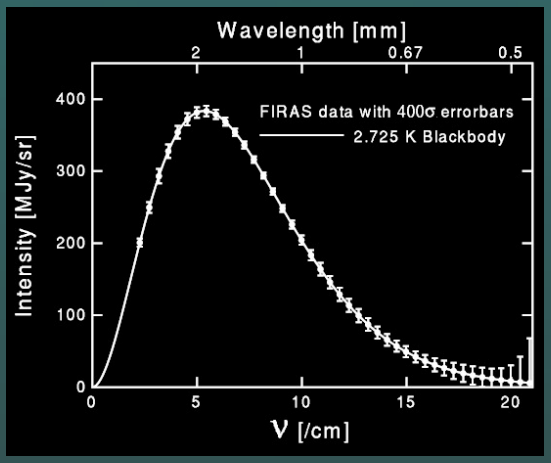
Fluctuations vs global signals

Planck, WMAP, etc

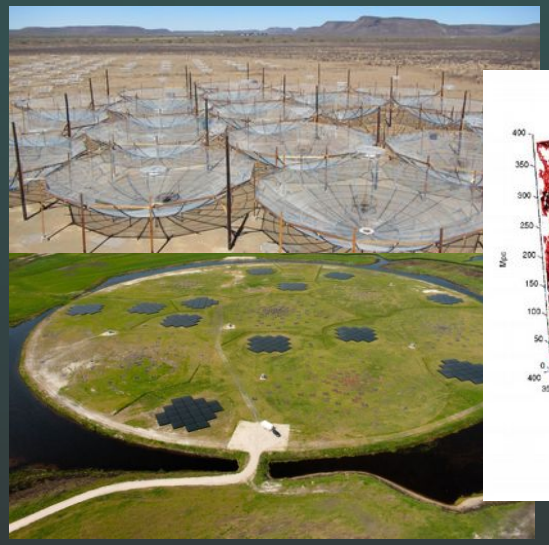


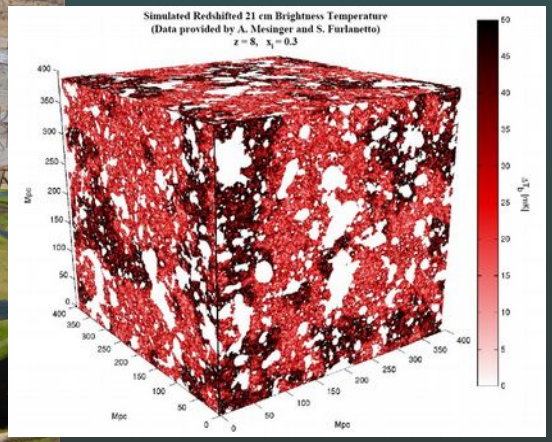


COBE/FIRAS

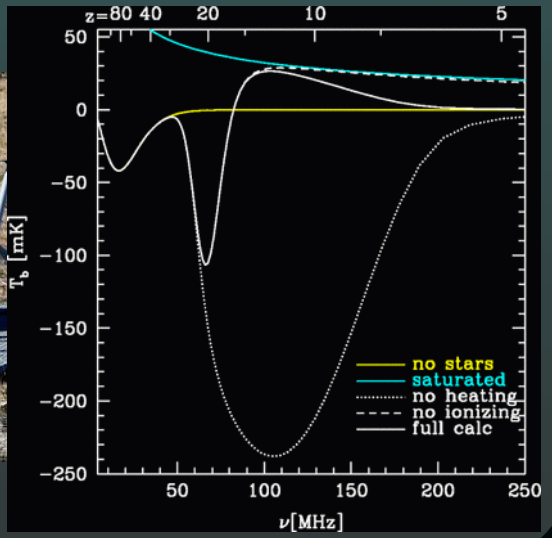


HERA, LOFAR, etc





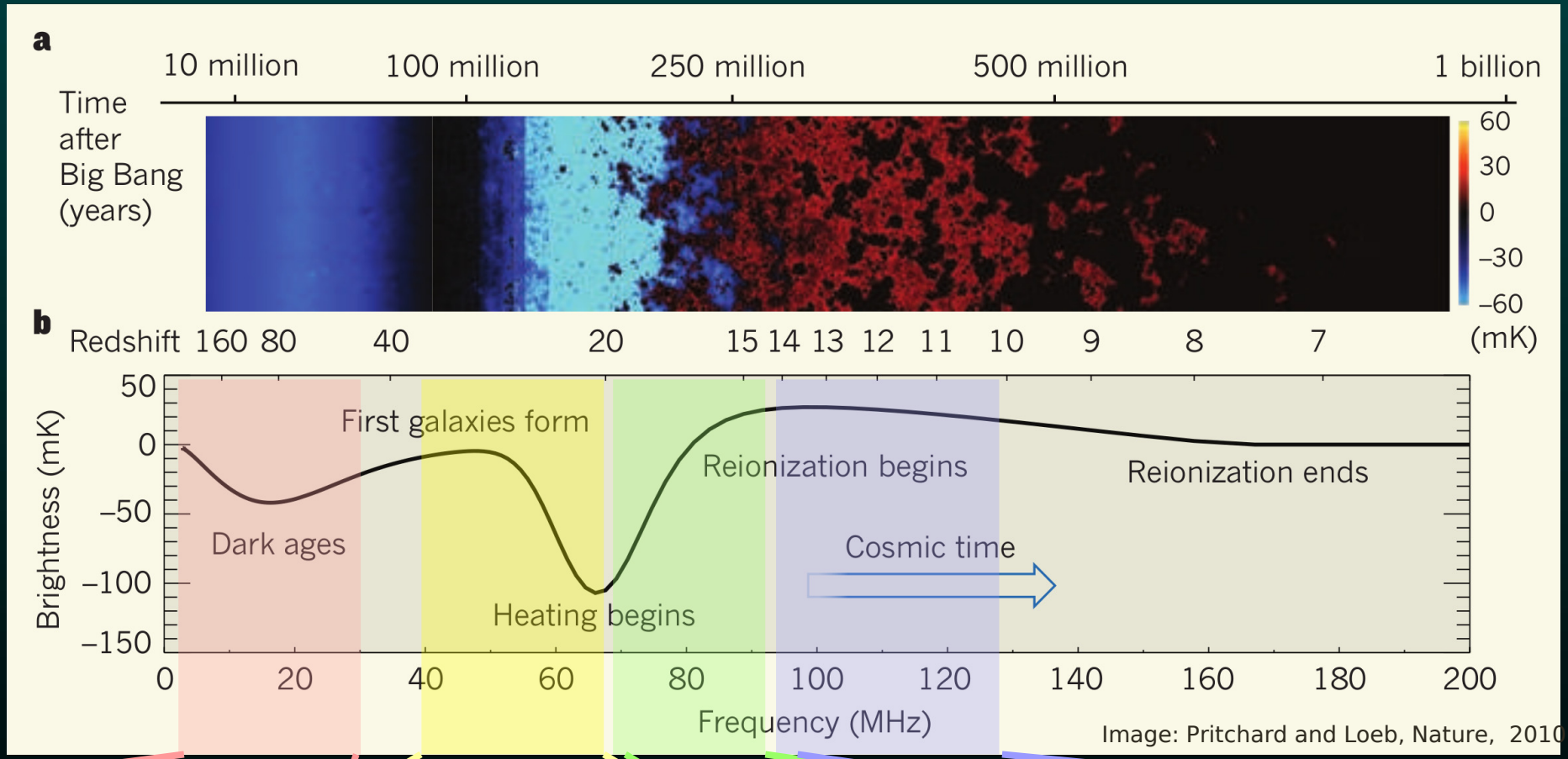
Global 21cm experiments



21cm signal evolution is a “thermometer” that can probe heating processes and energy injection in the early universe, depends on neutral hydrogen fraction and spin/kinetic temperature coupling

Global 21cm signal evolution

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



HI gas kinetic temp (T_K) below T_{CMB}. Collisions couple T_K and T_S at first. Later, CMB photons drive $T_S \rightarrow T_{CMB}$.

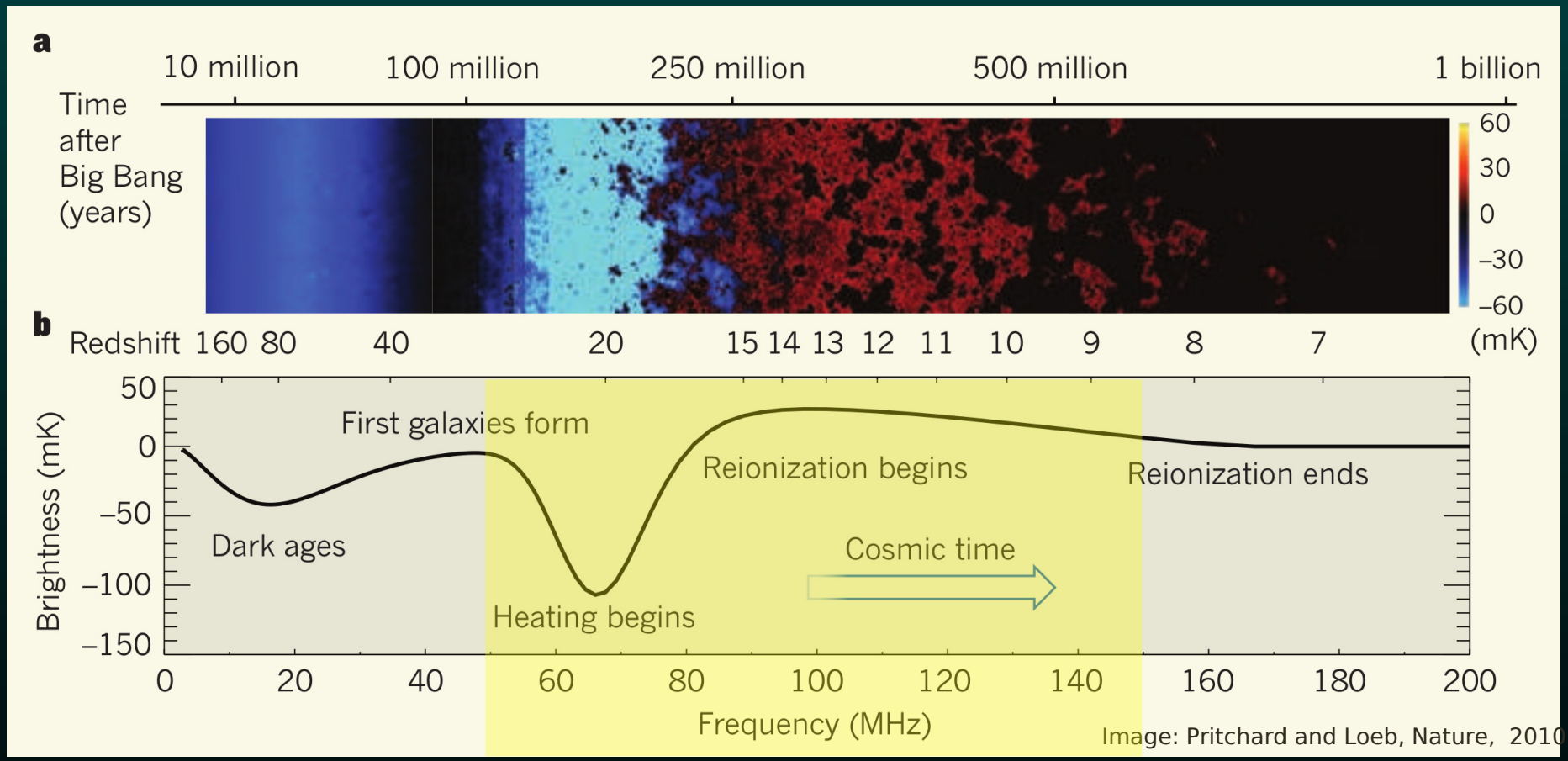
First stars form, Lyα photons couple T_K and T_S via Wouthuysen-Field mechanism

Heating by X-rays, gamma rays from first sources drives T_K above T_{CMB}

Reionization erases HI signal

Experimentalist's perspective...

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



Search for dip in the global sky signal, constrain models of first stars

$6 < z < 27$ corresponds to 200 – 50 MHz

Only need a few days' integration time (without systematics...)

Global 21cm experiments

EDGES
50 – 100, 100 – 200 MHz
Murchison Radio Obs.

BIGHORNS
50 – 200 MHz
Western Australia

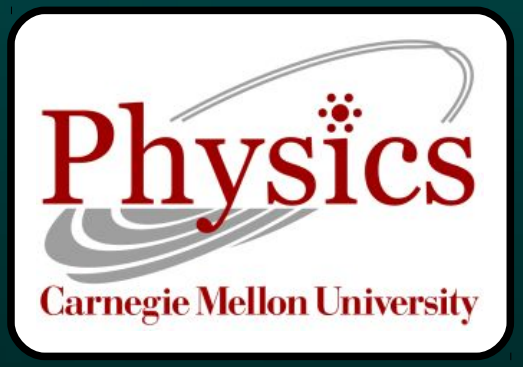
LEDA
30 – 88 MHz
Owens Valley

SARAS2
87.5 – 175 MHz
Gauribidanur Obs., India

HYPERION
30 – 120 MHz
Owens Valley

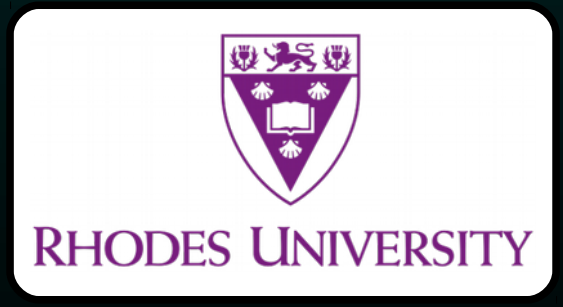
PRI^{Z}M: Probing Radio Intensity at high-Z from Marion

Cynthia Chiang
Jonathan Sievers
Liju Philip
Nivek Ghazi
Austin Gumba
Heiko Heilgendorff



Jeff Peterson
José Miguel Jáuregui

Rupert Spann

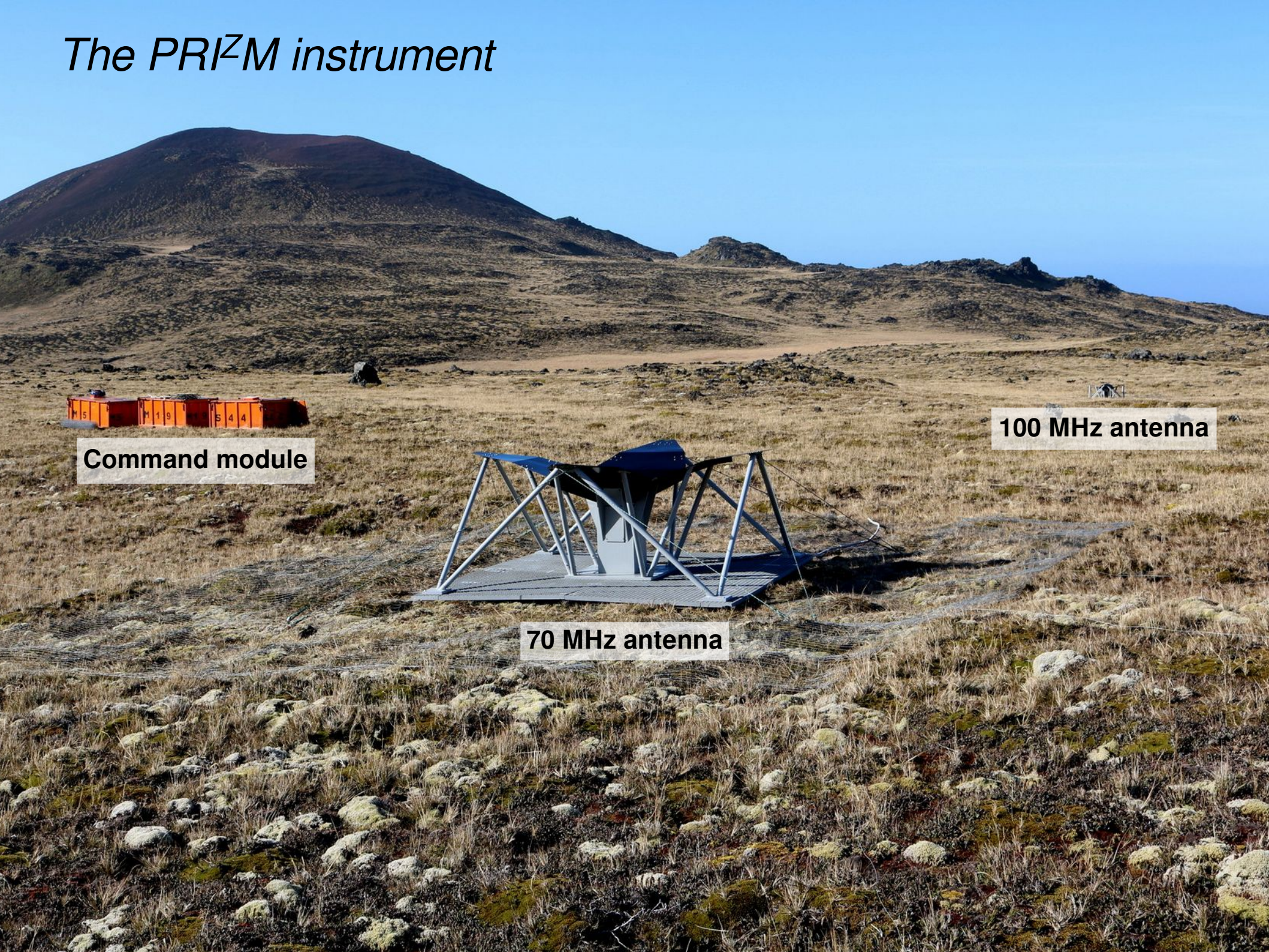


Ridhima Nunhokee

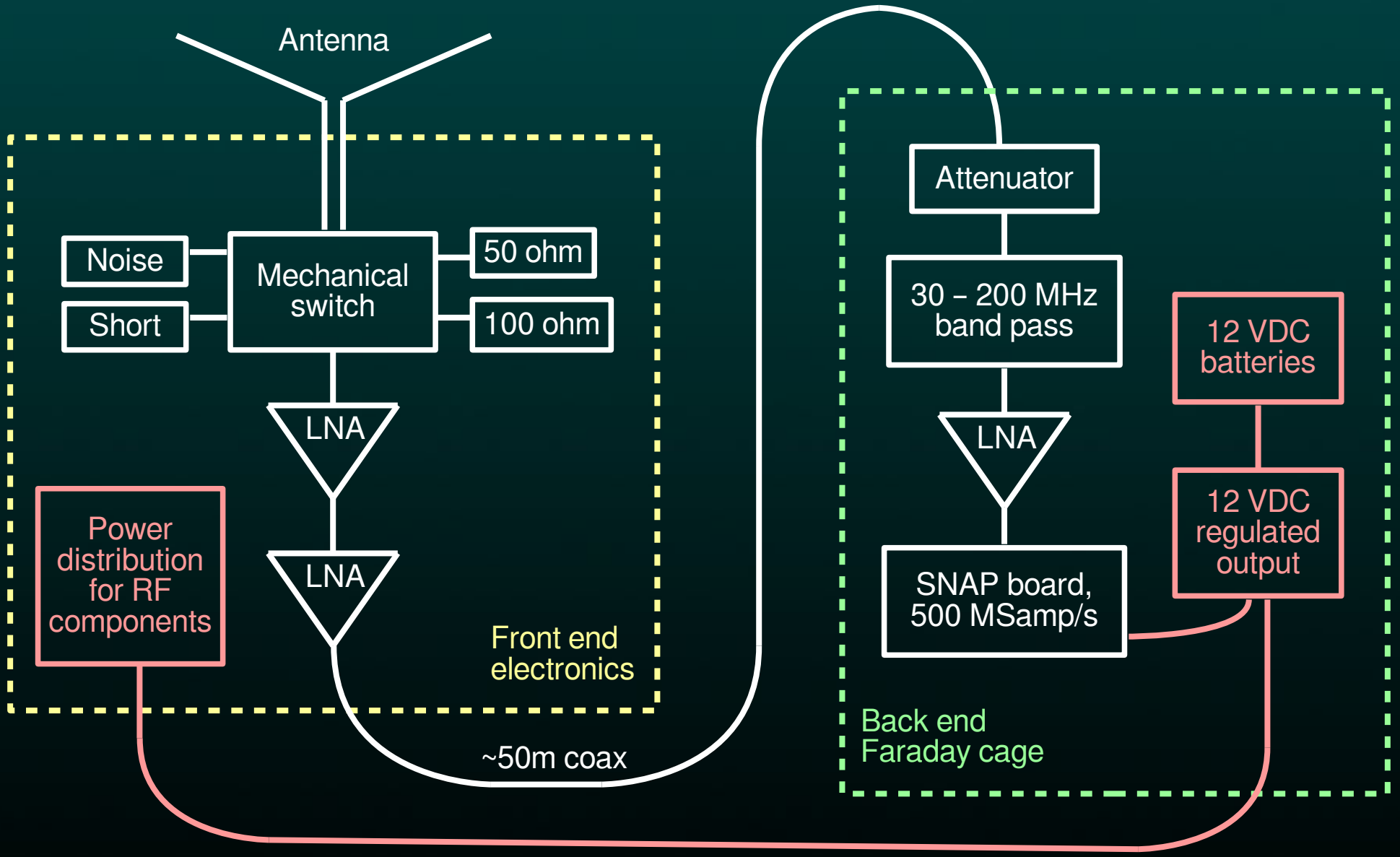
Jack Hickish
Zuhra Abdurashidova

Kagiso Malepe
Vhuli Manukha

The PRIZM instrument



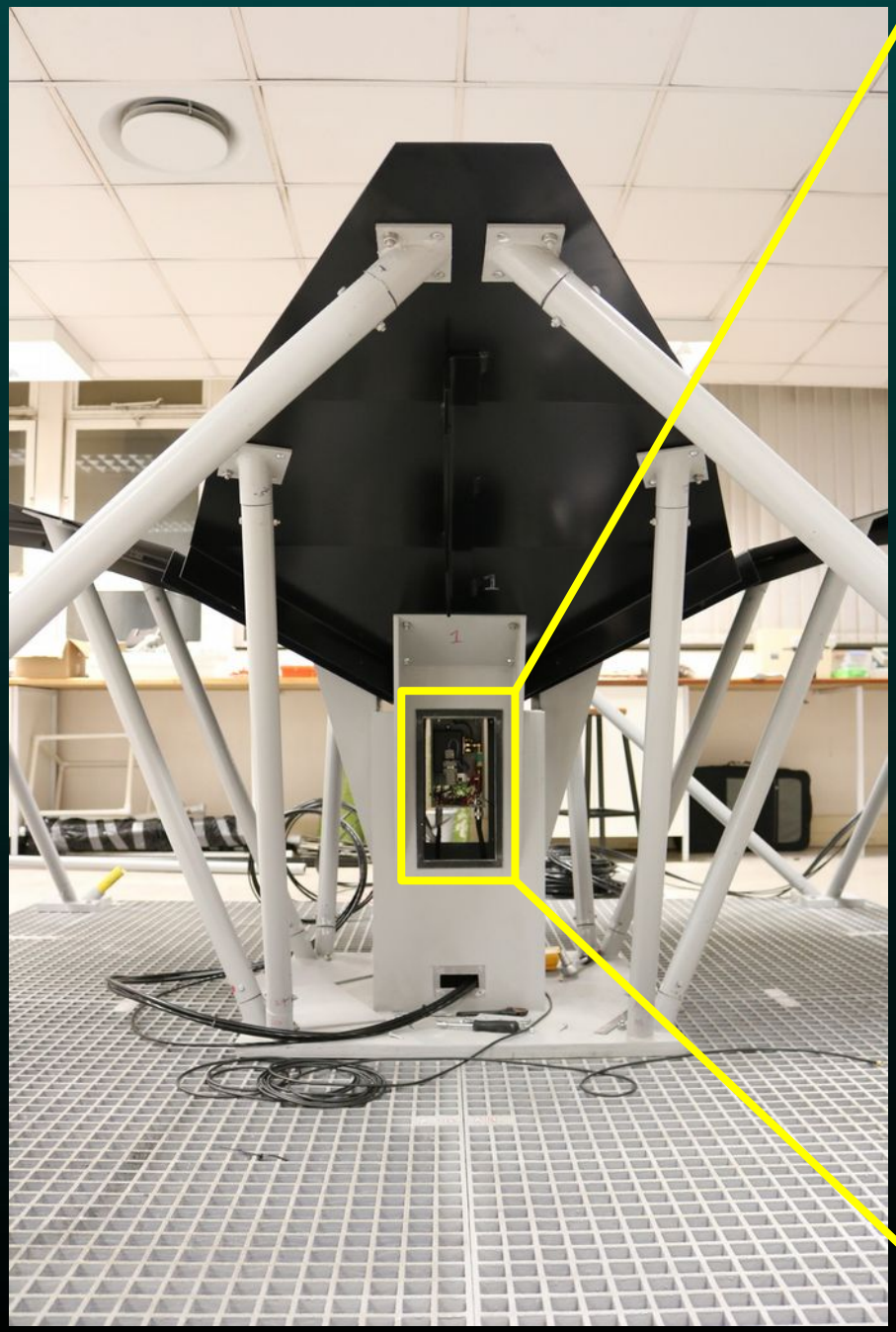
PRIZM block diagram



Single polarization shown above

PRIZM antennas

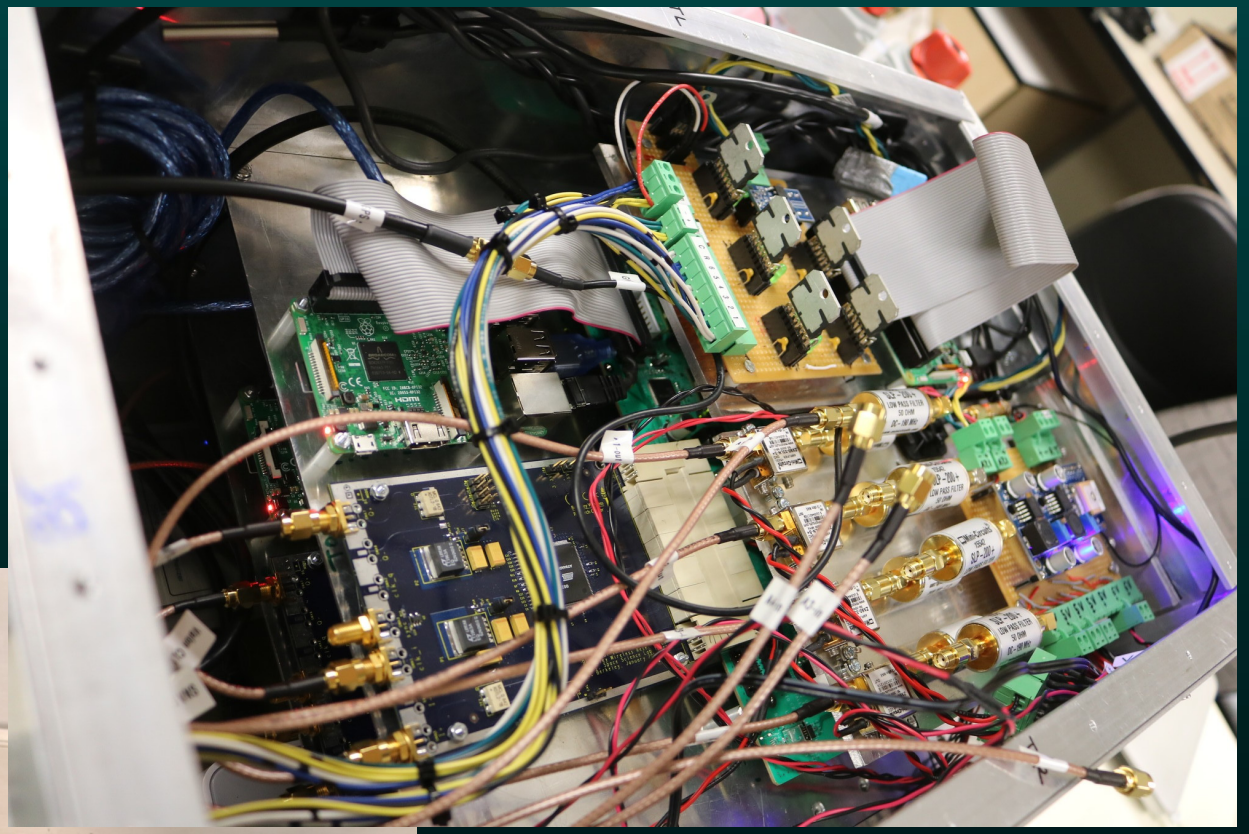
Front end RF electronics

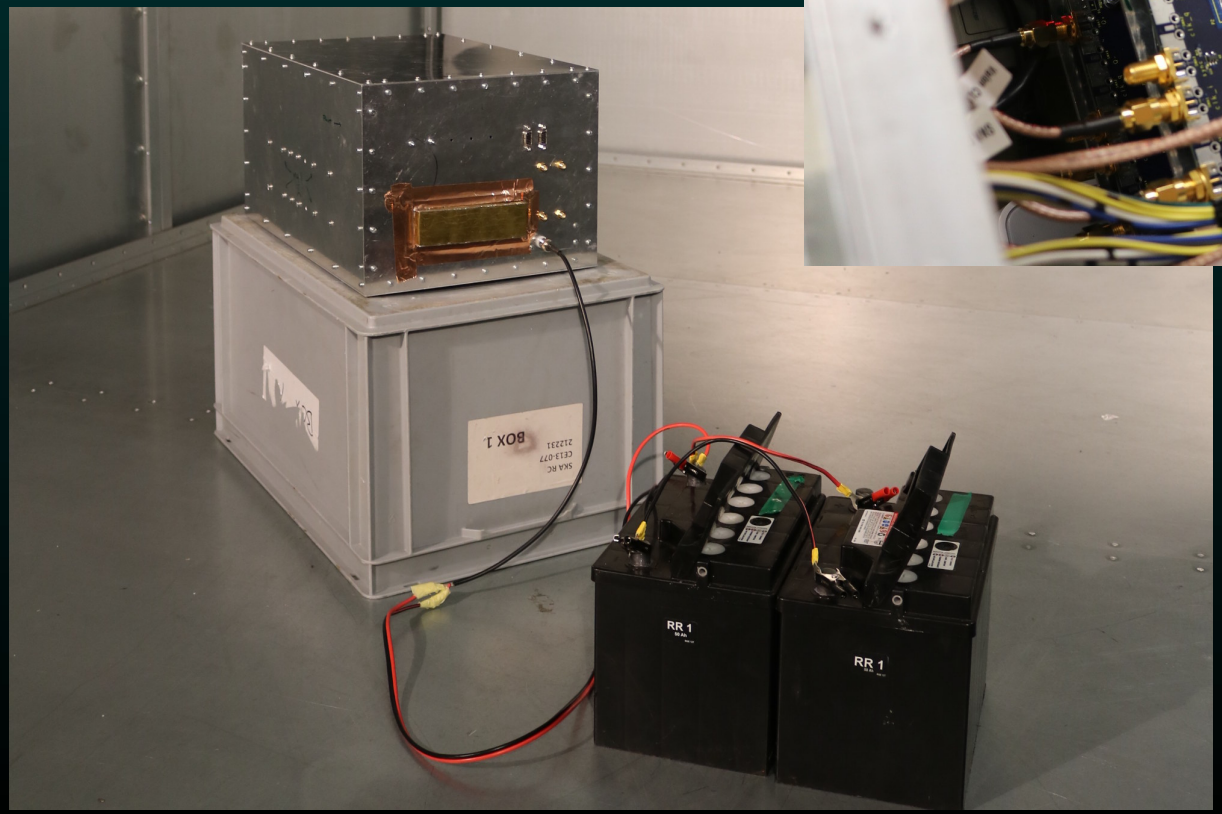


SNAP board data acquisition

2x SNAP boards with external ADCs, second stage amps, and housekeeping electronics in RF tight enclosure with filtered inputs

Spectrometer firmware on SNAPs:
0 – 250 MHz
4096 channels (61 kHz)
500 Msamp/s sampling





Total system power draw ~65 W, run time >1 week on 8x lead crystal 200-Ah batteries

Whole assembly is placed ~50 m from the antenna to reduce self-generated RFI

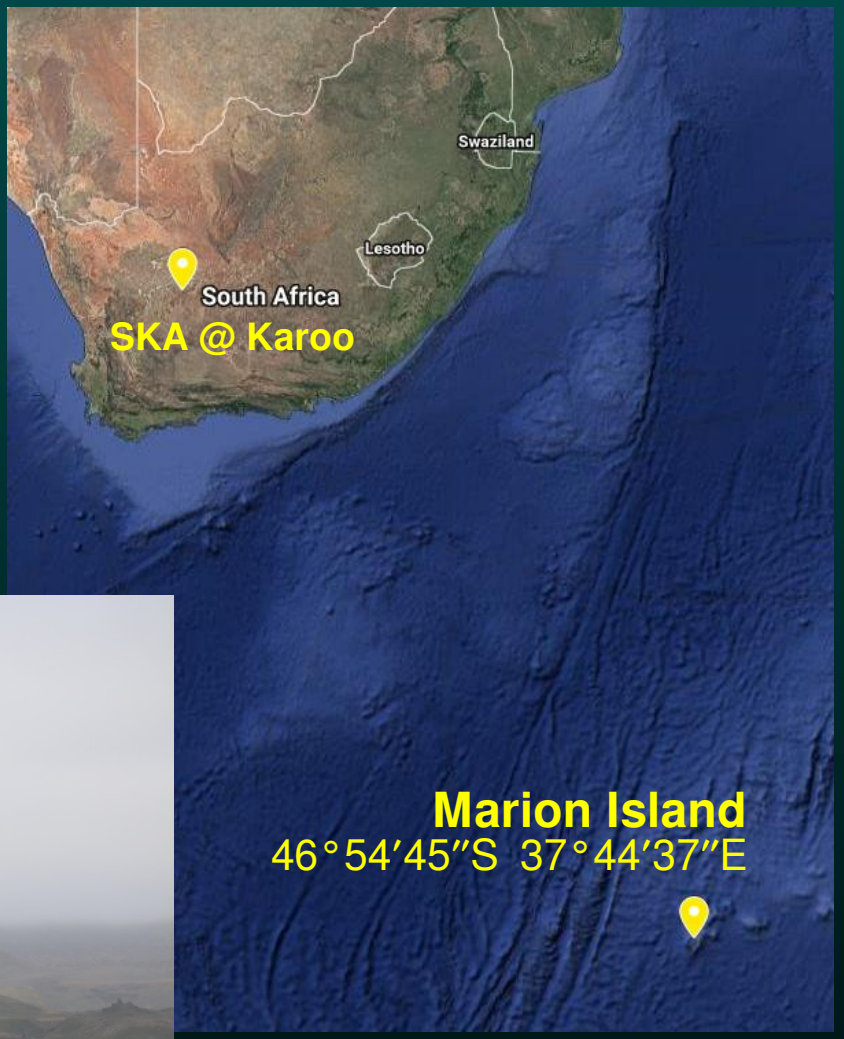
SNAP boards also used for HERA; UKZN PRI^{Z}M run was the first field deployment

Marion Island

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

2000 km from nearest continental landmass

PRI^{Z}M = first astro experiment on Marion!
2016 engineering run, science ops since 2017



Challenges:

Access once per year

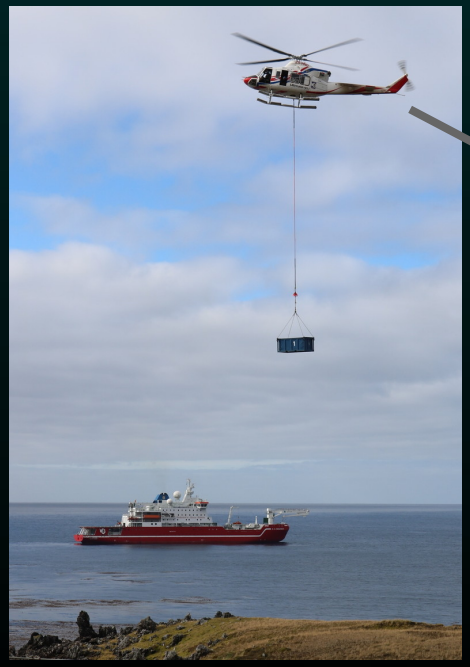
3 week deployment window

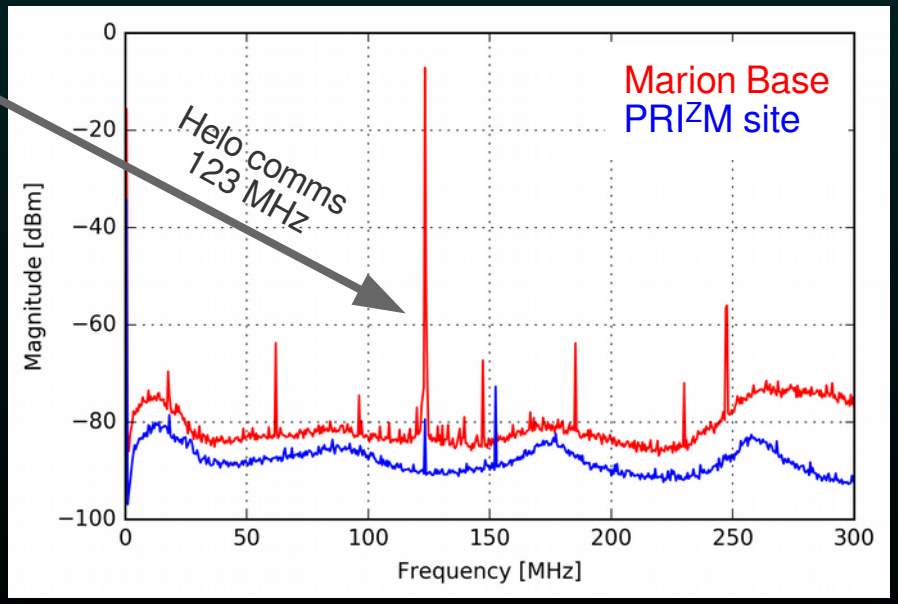
Roaring Forties weather

Mires and lava rocks

@#$% mice

RFI surveying and site selection





Site requirements: large distance from base for reduced RFI, but close enough for regular hiking. Flat space and workable terrain.

Final PRIZM site is shielded by Junior's Kop. Bonus helicopter transmission shows ~60 dB signal suppression from base.

Three-week deployment in three slides

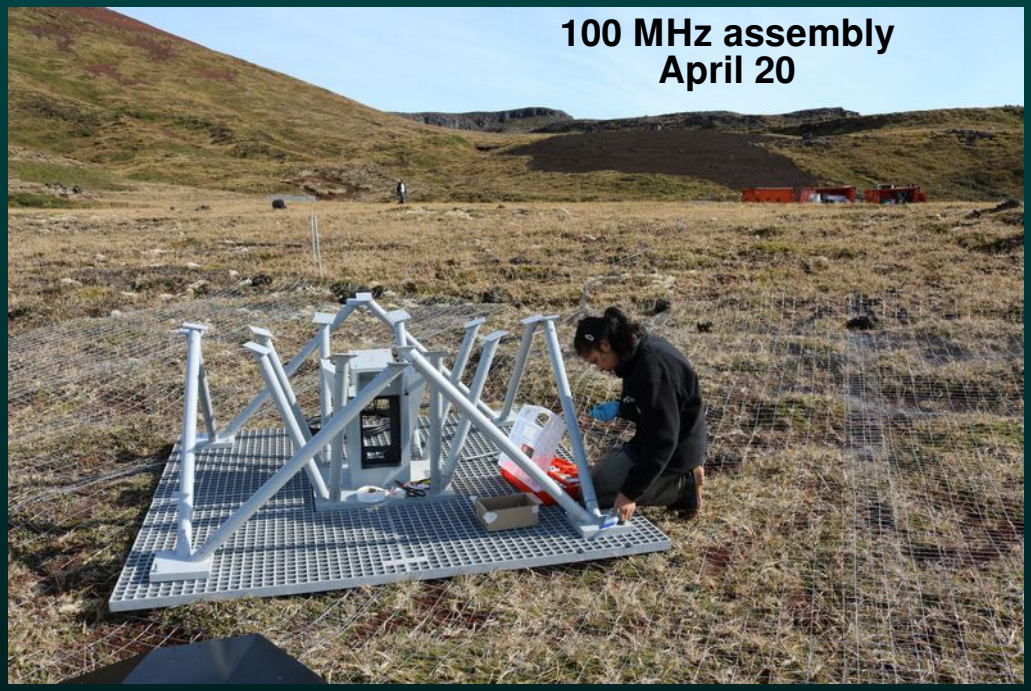
Departure from Cape Town
April 6

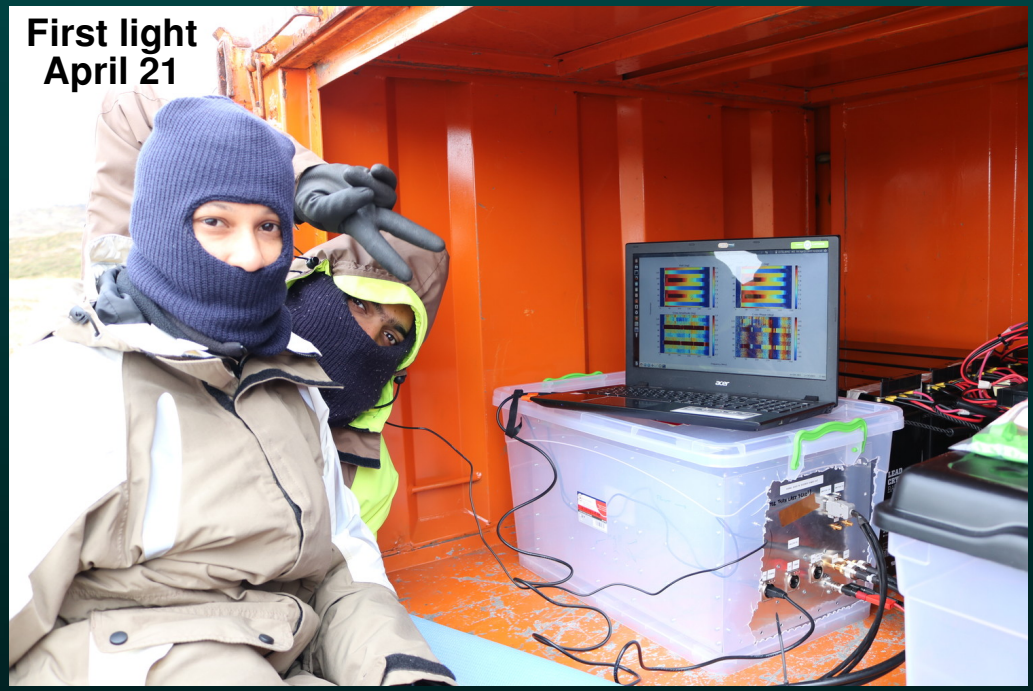
Arrival at Marion base
April 12

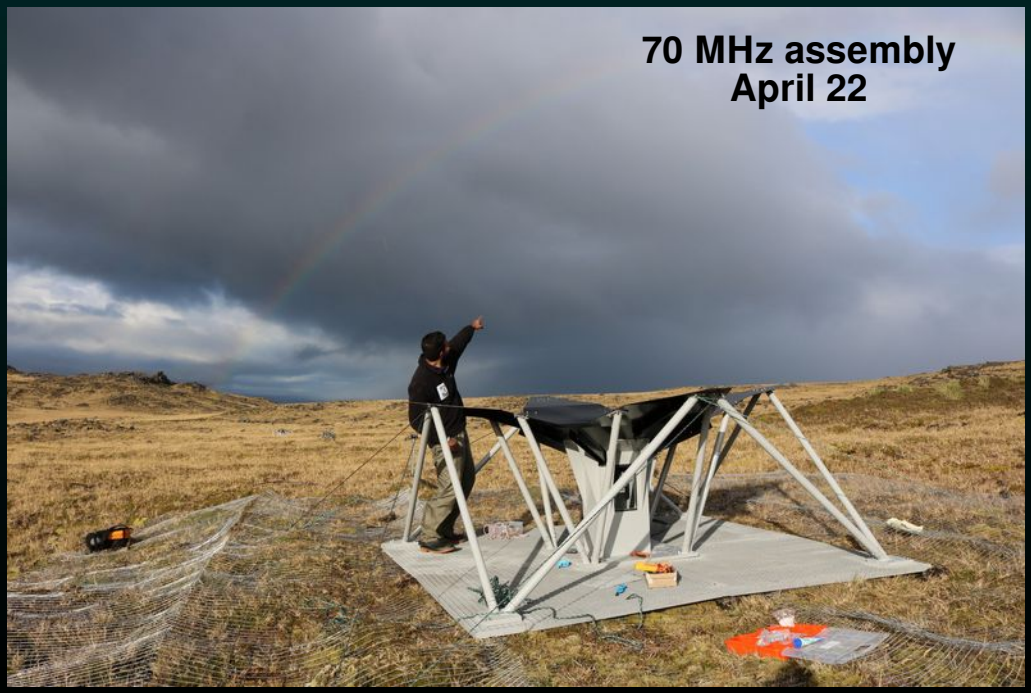
RFI surveying and site selection
April 14 – 15

Container delivery
April 19

Three-week deployment in three slides







Three-week deployment in three slides

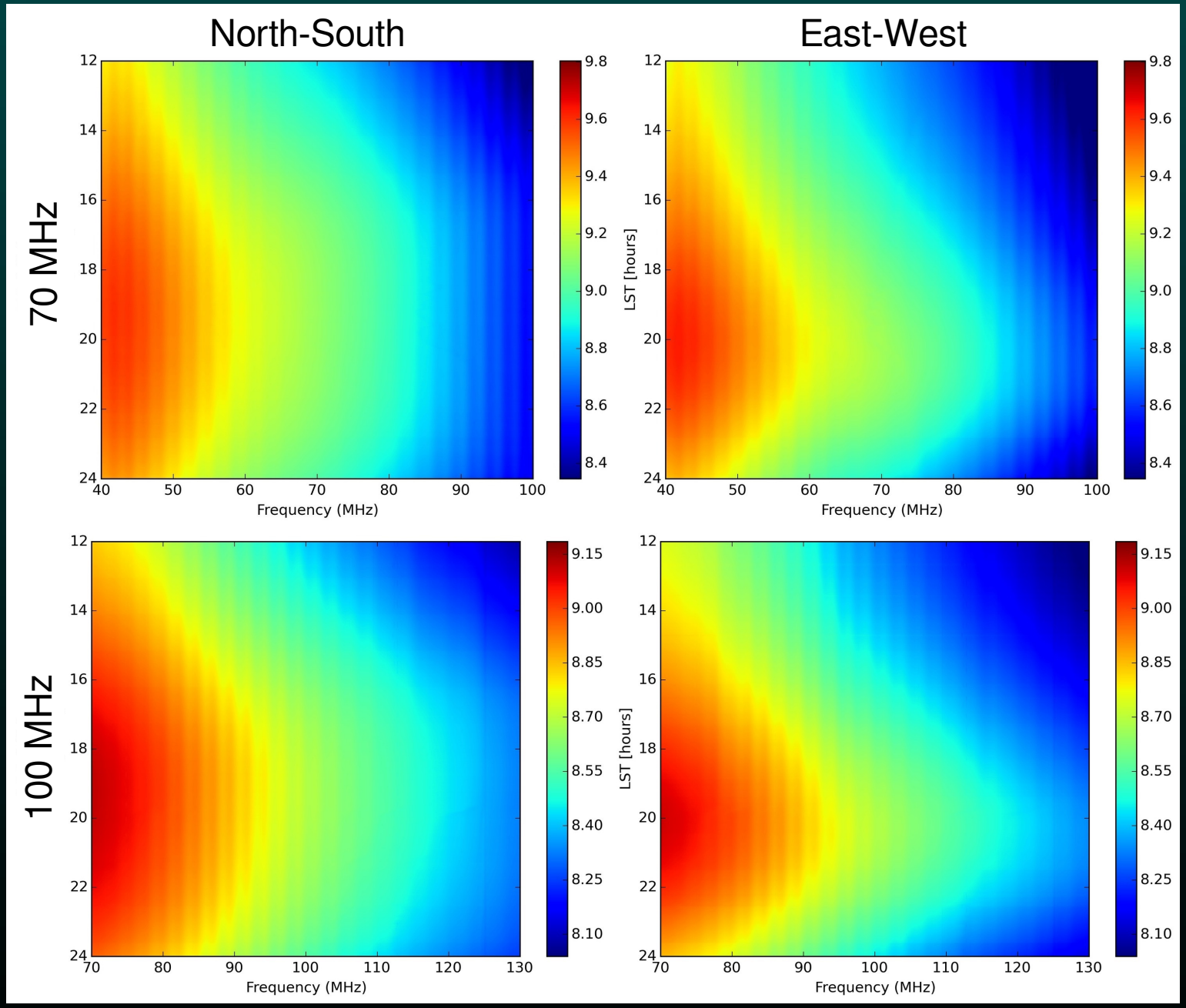
Winter operations

2017 overwinterer
Kagiso Malepe

2018 overwinterer
Vhuli Manukha

Preliminary PRIZM raw data

Instrument paper:
L. Philip et al. arXiv:1806.09531

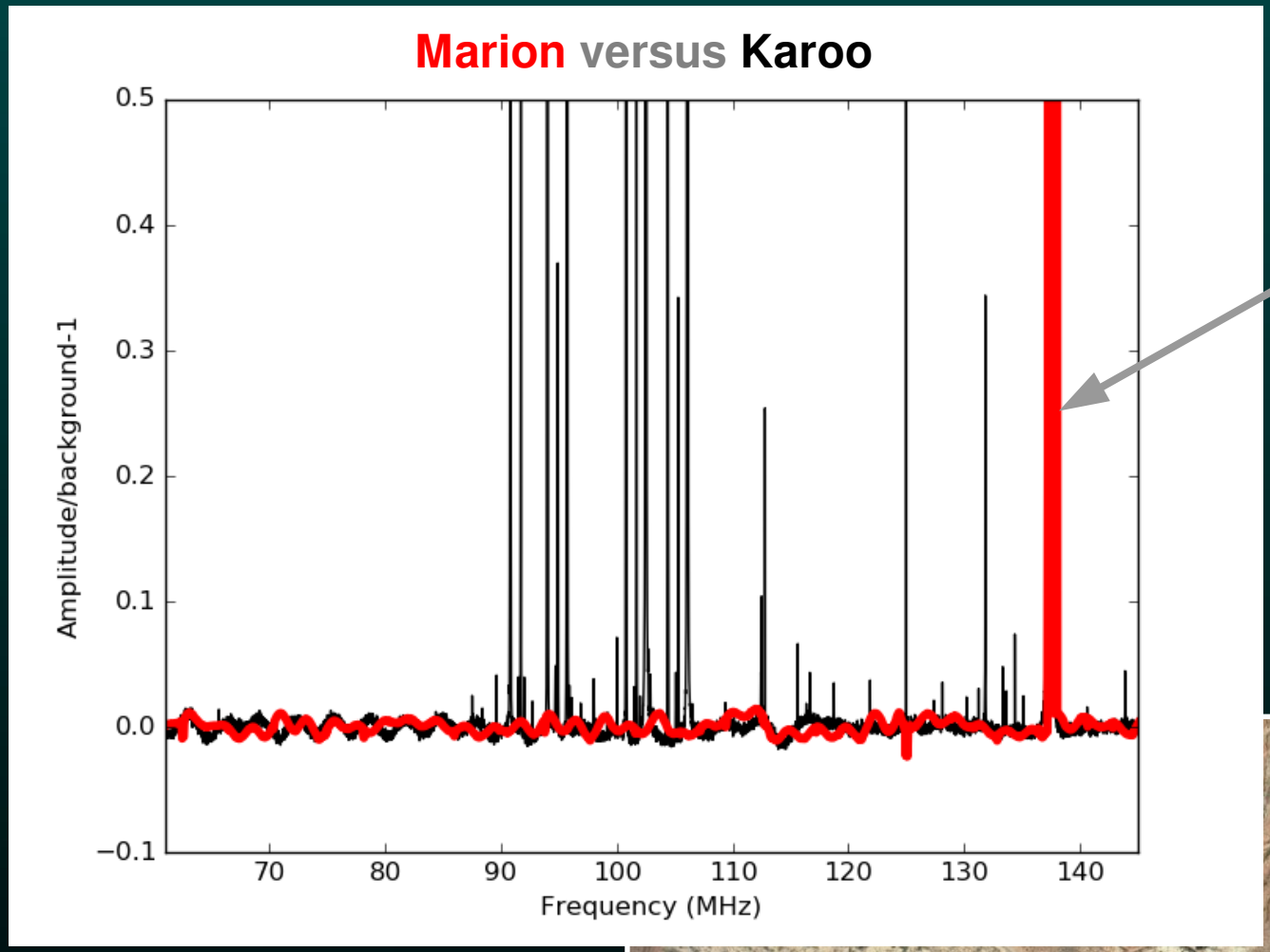


Time (12 hrs)

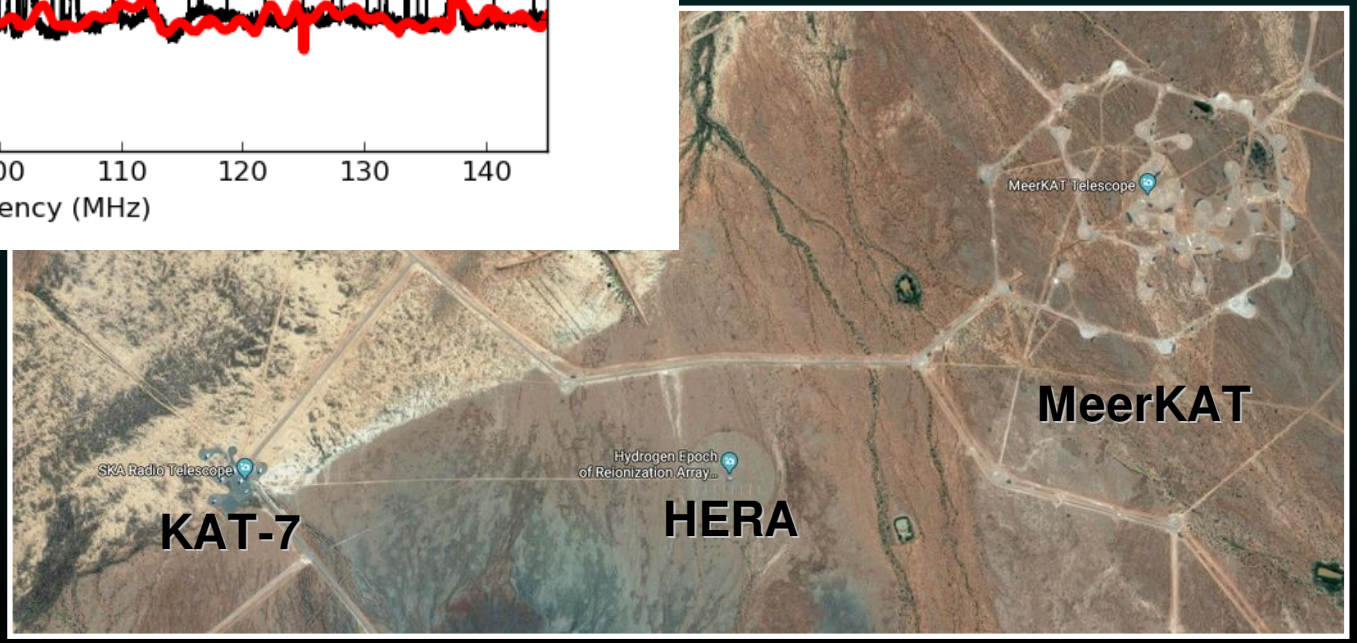
Frequency (70 – 130 MHz)

RFI comparison with Karoo

Instrument paper:
L. Philip et al. arXiv:1806.09531



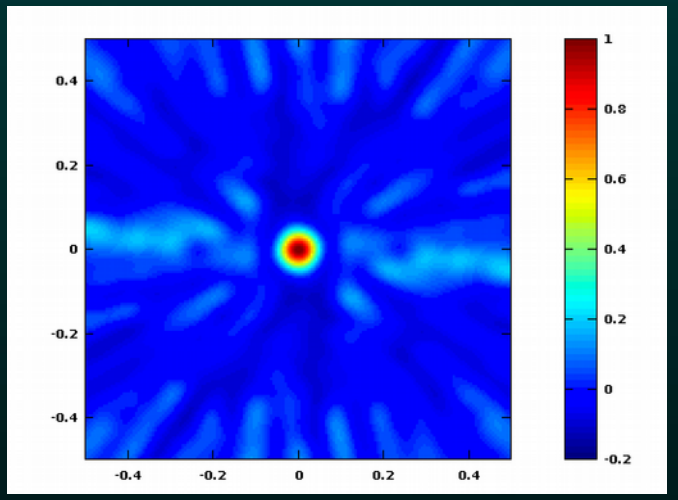
Only detectable feature at Marion is Orbcomm satellites (137–138 MHz)



Future PRIZM plans

- SANAP proposal has been renewed through 2020
- PRIZM upgrades: improve current antennas and continue to run, instrument characterization
- Expansion to lower frequencies, push toward dark ages! Deploy antennas at hut stations, write lowest 10–20 MHz baseband to disk, correlate afterward.

8' FWHM synthesized beam @ 5 MHz



- Ionosphere causes attenuation and refraction, temporal variation adds noise. Ionosphere model (IRI) predicted 1.7 MHz plasma frequency during last solar minimum, next one is coming up.

  Last ~2 MHz measurements were from Grote Reber, 1968, Tasmania (~5 deg resolution)

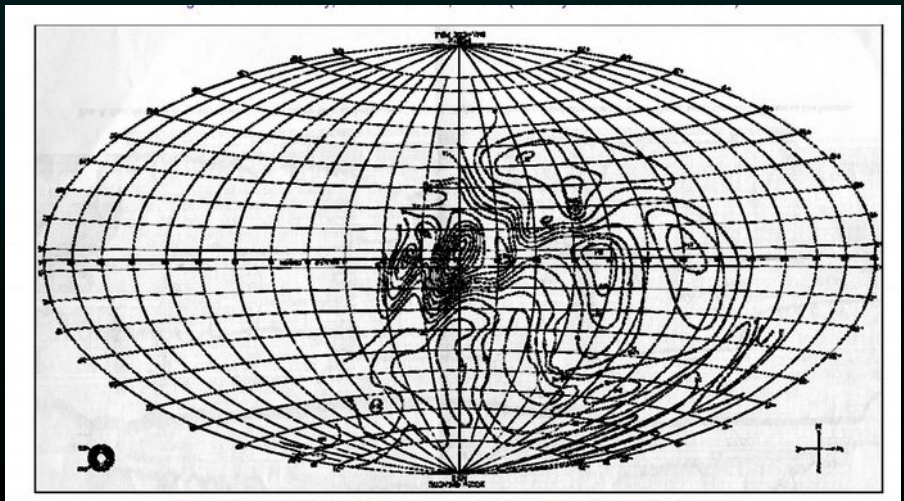
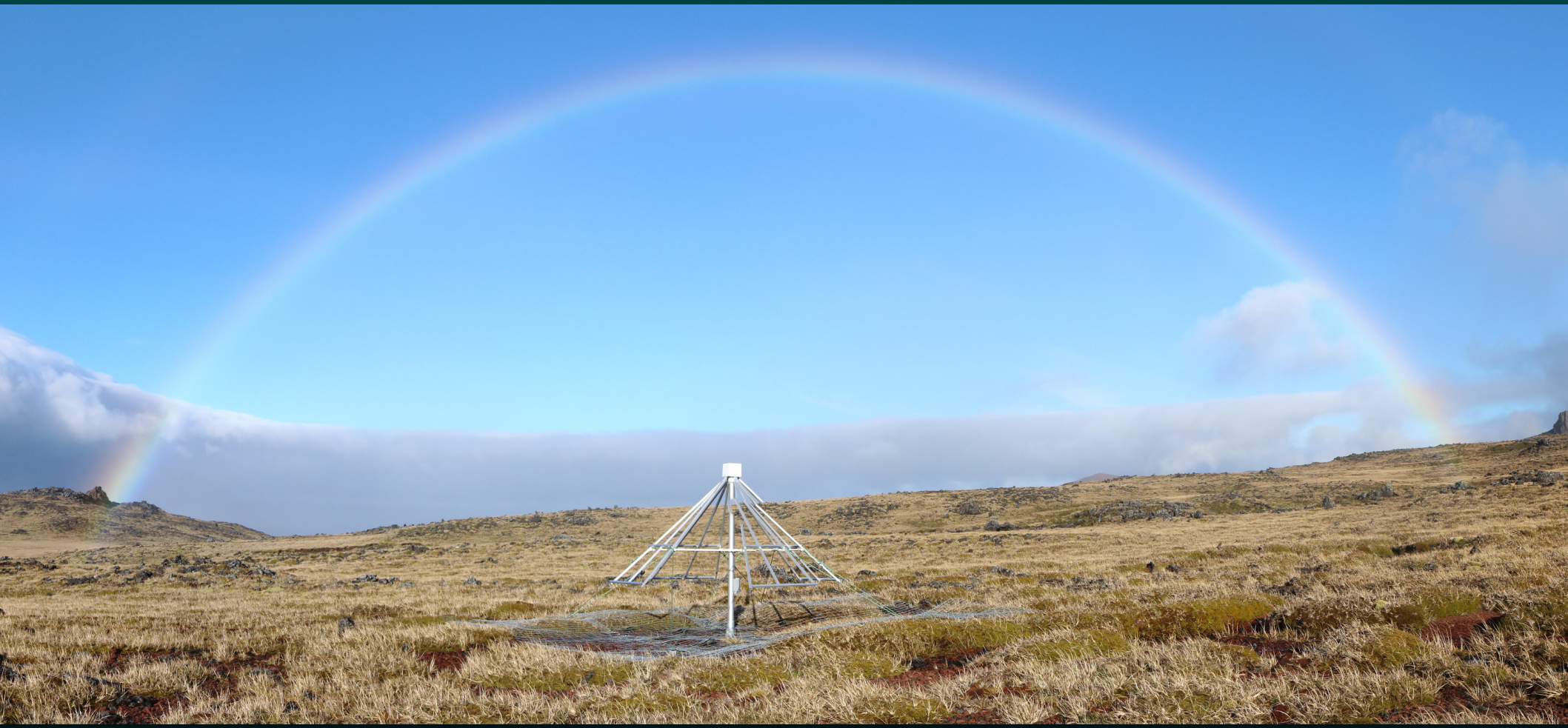


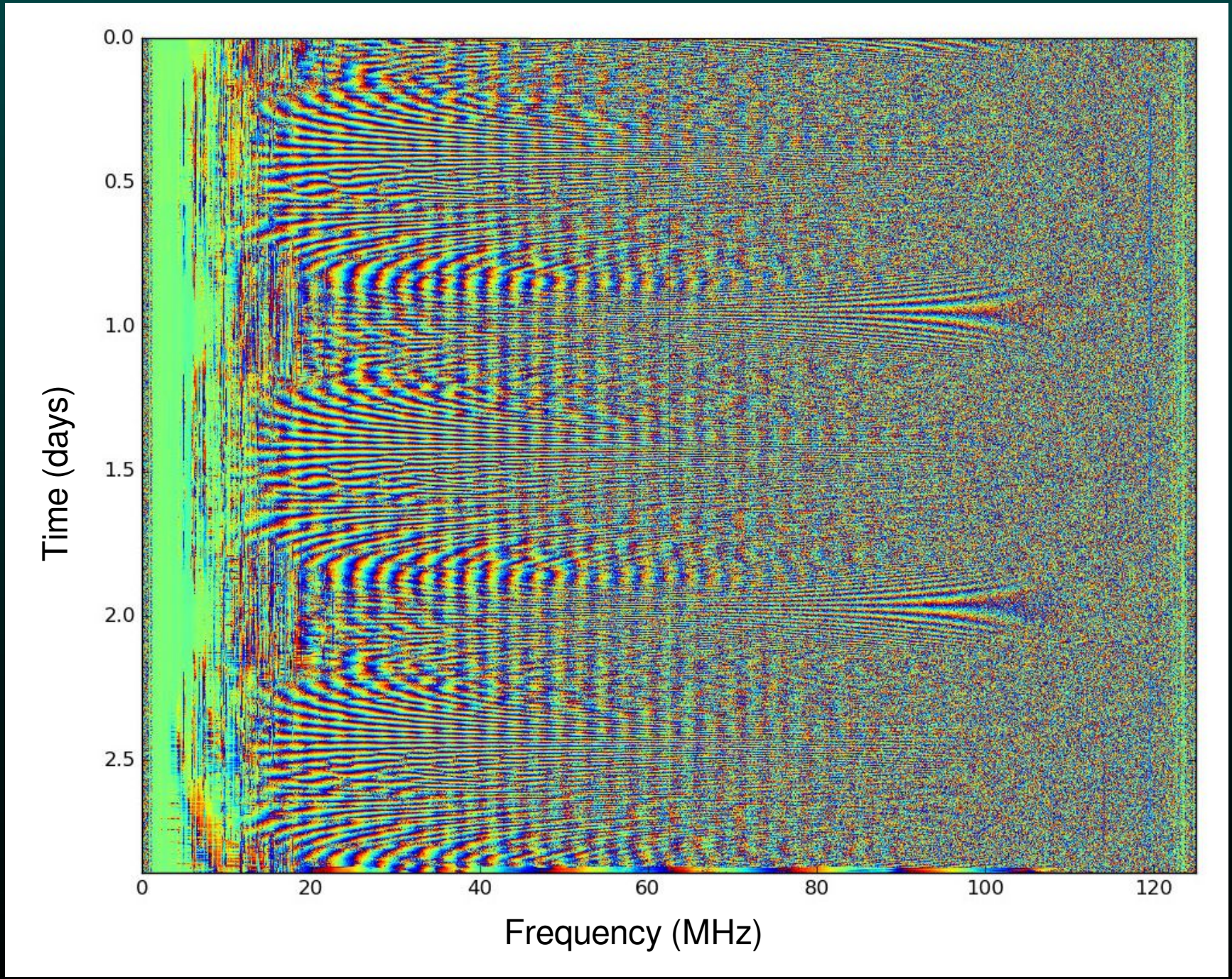
Figure 11: A 2.085 MHz contour map of galactic radio emission (after Reber, 1968: 10).

Pathfinder low frequency antennas



- Two LWA antennas installed on Marion in 2018
- Operating frequency: 1.2 – 80 MHz
- Measure all cross-correlations between 2 antennas x 2 polarizations

First fringes from low freq antennas



Summary & future prospects

- We're beginning to explore uncharted territory in the universe's history using redshifted 21-cm observations
- PRI^{Z}M is a dedicated experiment for exploring cosmic dawn, searching for dip in average sky temperature within $9 < z < 25$
- First PRI^{Z}M science run started in 2017 Austral winter, operations continue
- Two pathfinder low frequency antennas installed in 2018
- Marion Island is an excellent new location for low frequency radio astronomy, and we'll see how low we can go!