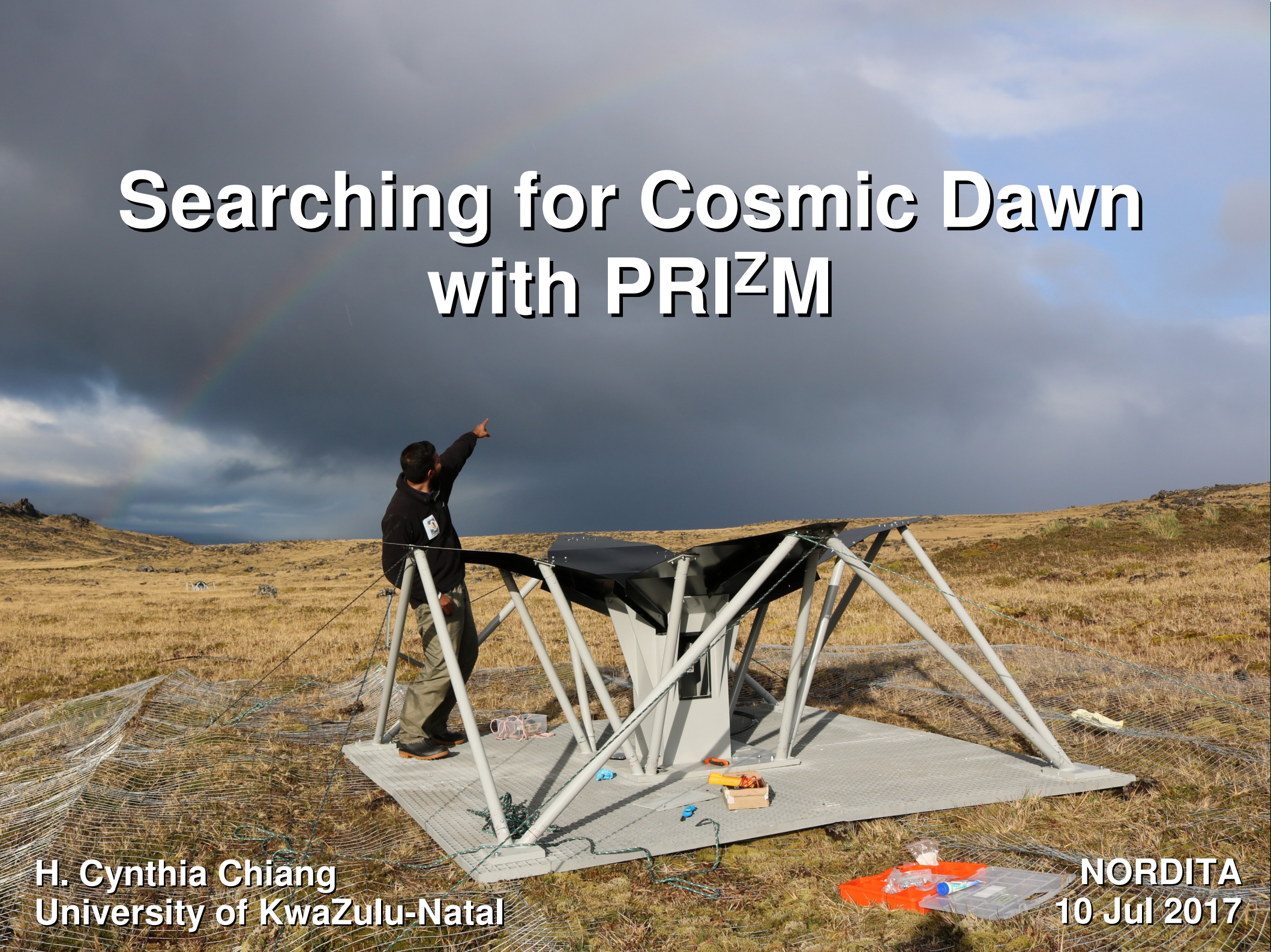
Searching for Cosmic Dawn with PRI^{Z}M



H. Cynthia Chiang
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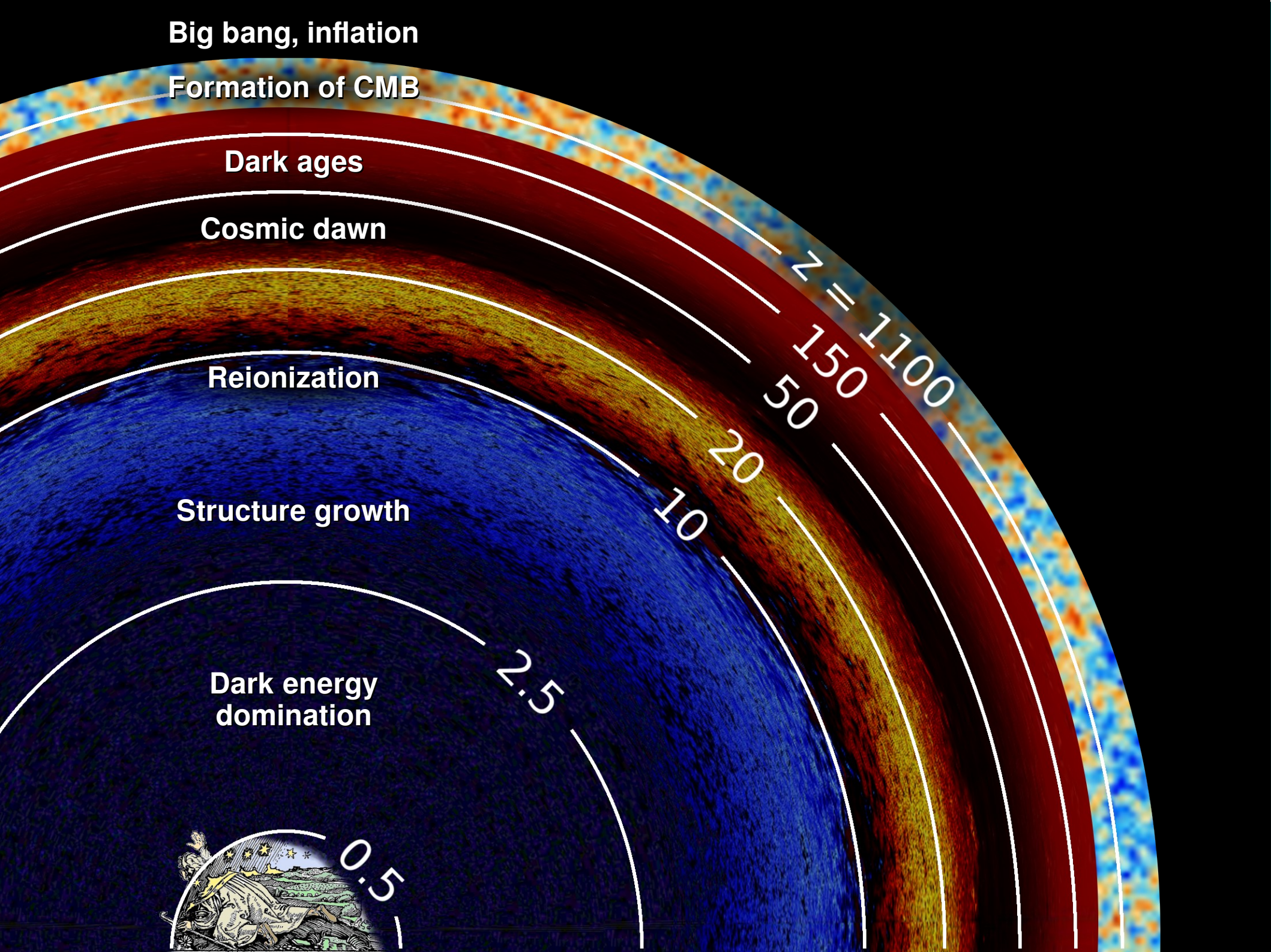
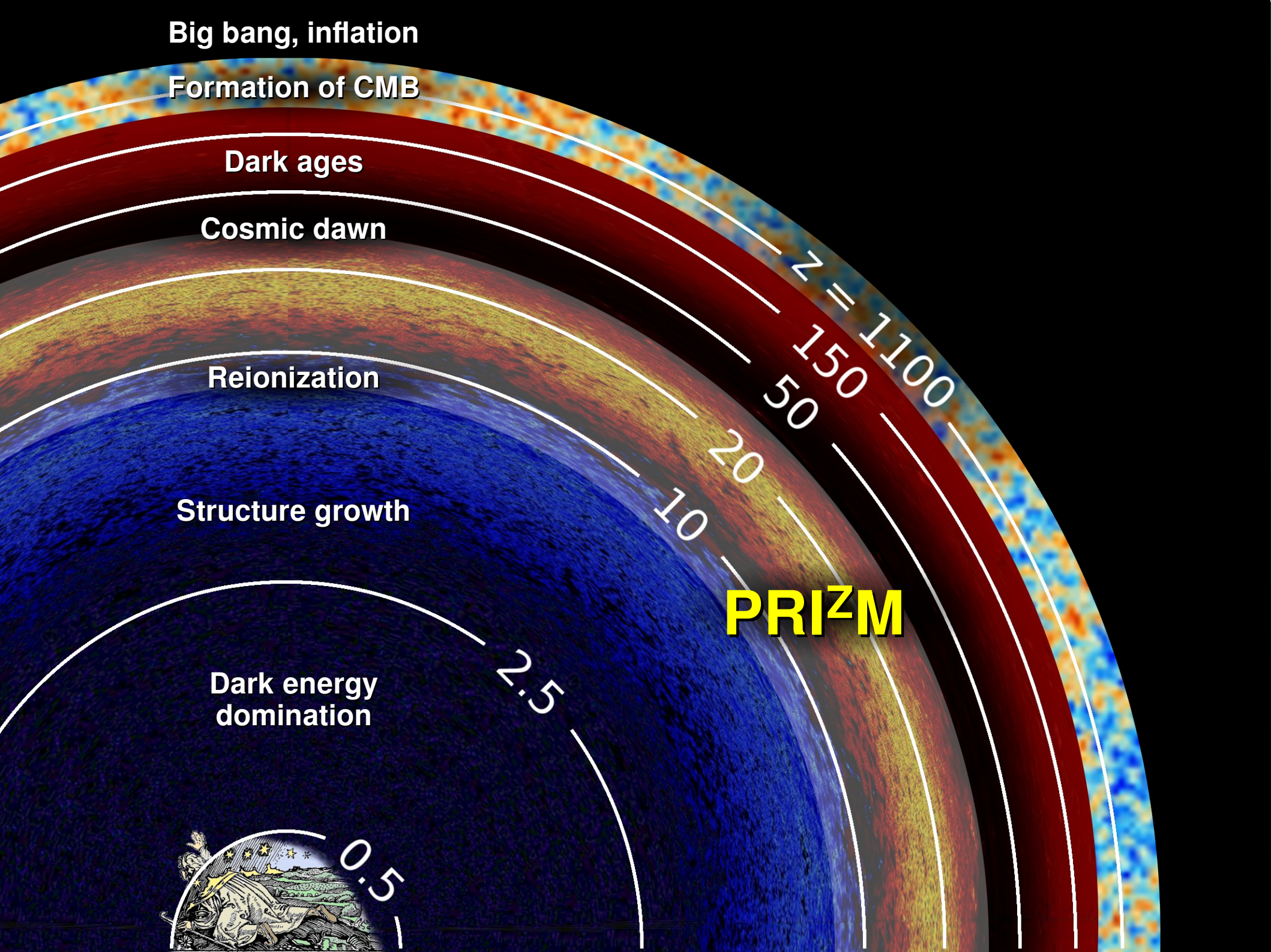
NORDITA
10 Jul 2017


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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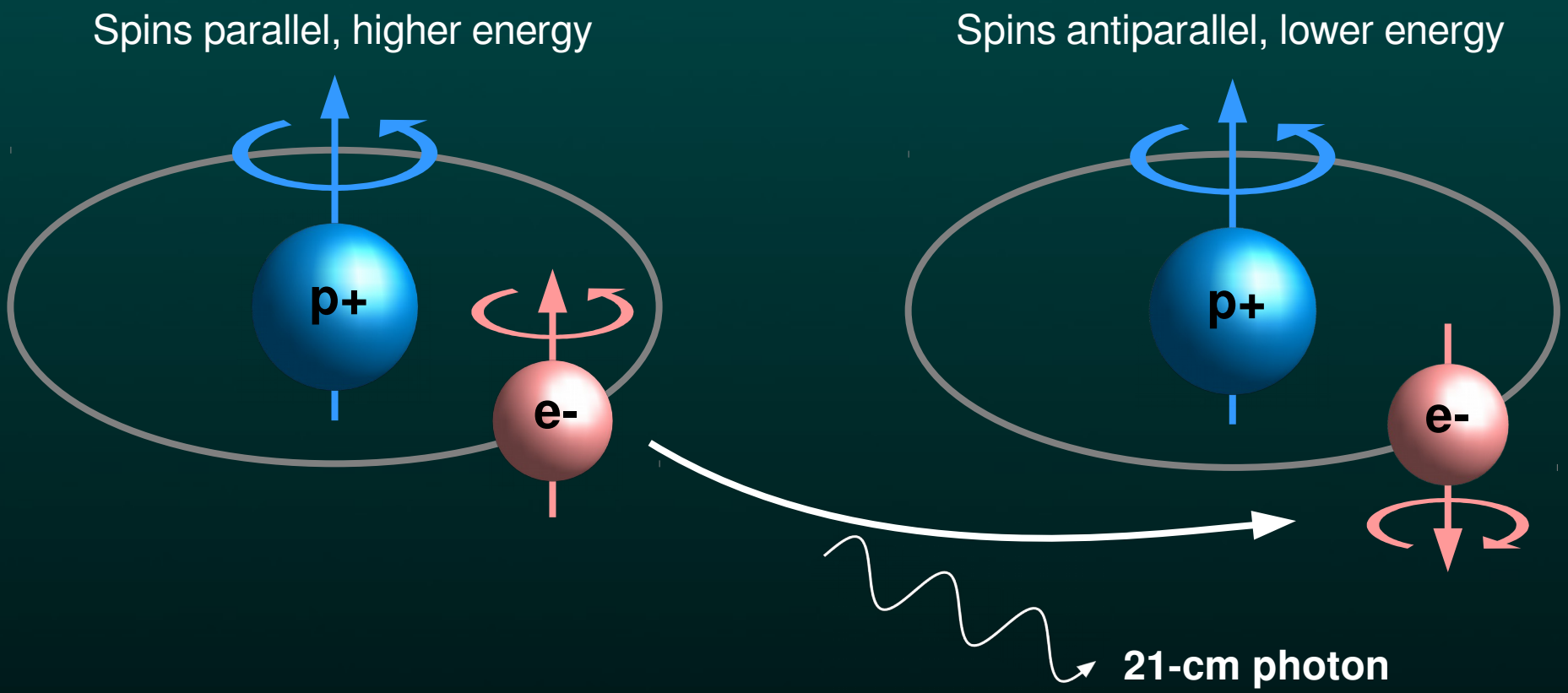
PRIZM

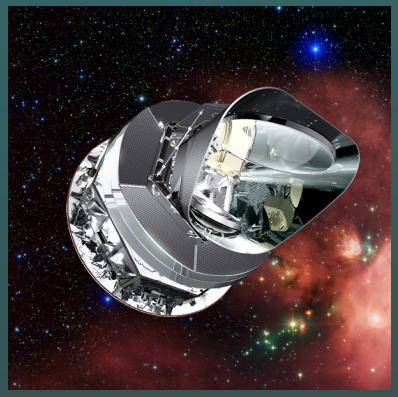
Redshifted 21cm emission

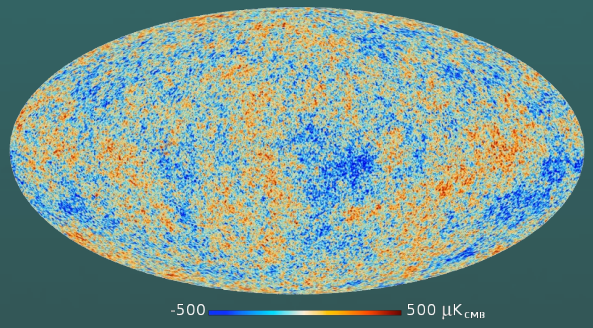


- Hyperfine transition in neutral hydrogen produces 21-cm (1.4 GHz) radiation (no emission from molecular or ionized hydrogen)
- Forbidden transition, lifetime of excited state ~10 million years
- 21-cm emission serves as a natural redshift marker for mapping hydrogen in the universe, tracer of large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

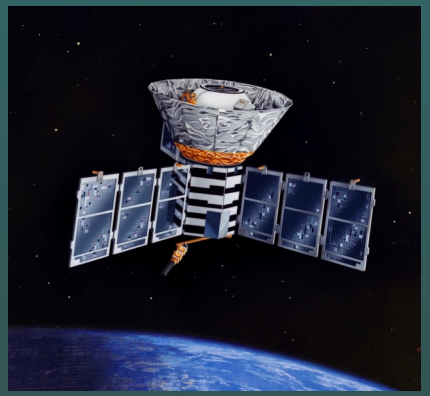
Fluctuations vs global signals

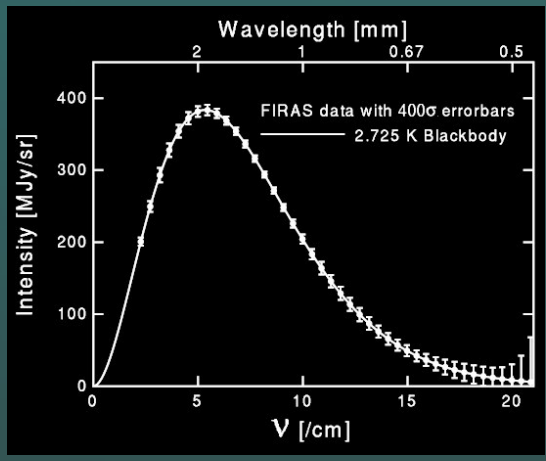
Planck, WMAP, etc



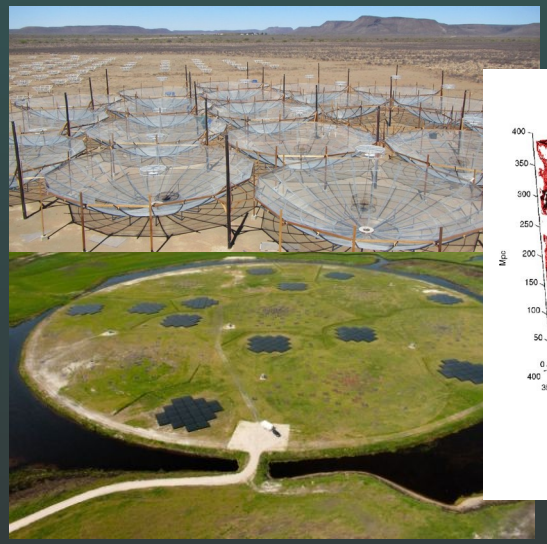


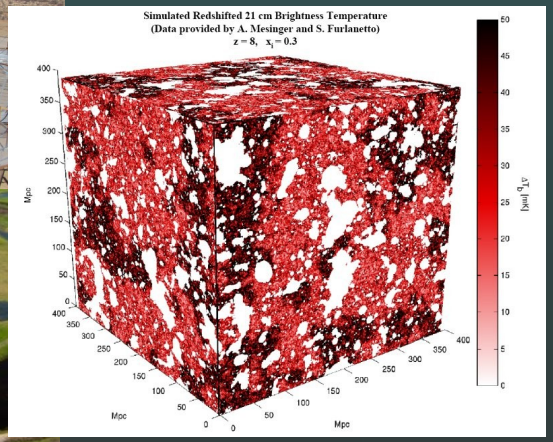
COBE/FIRAS



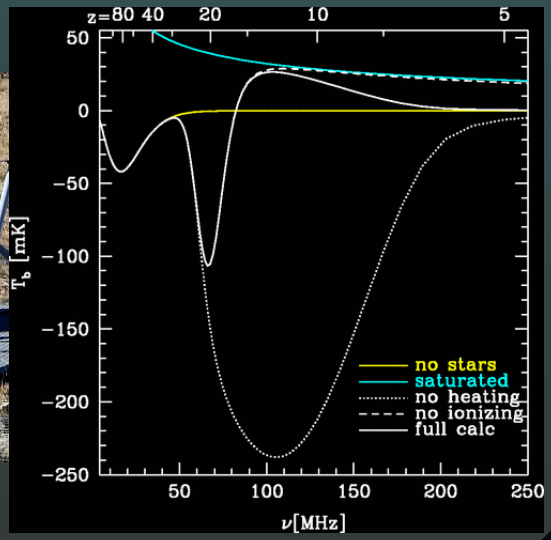


HERA, LOFAR, etc





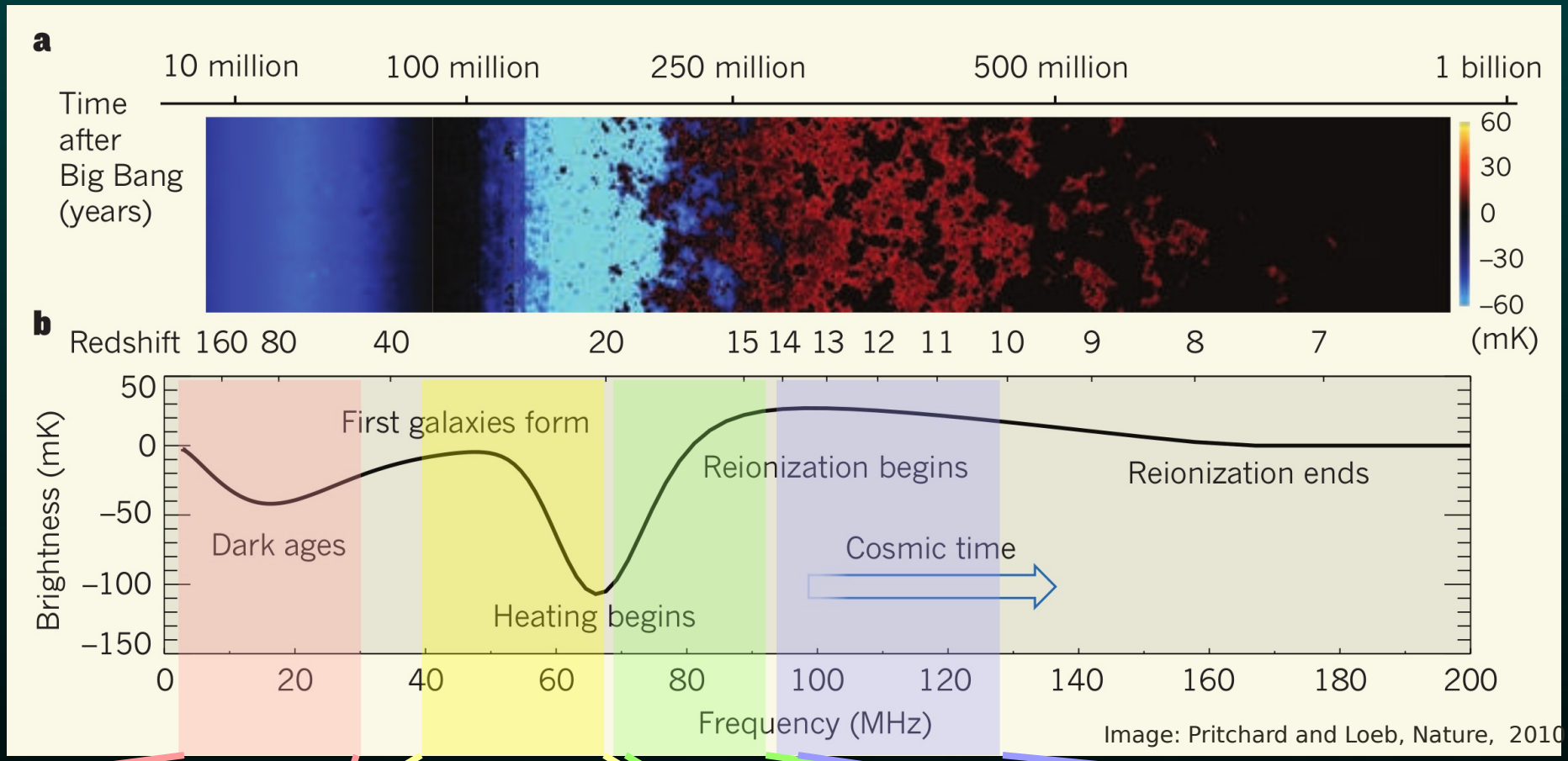
Global 21cm experiments



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 $T_S \rightarrow T_{CMB}$.

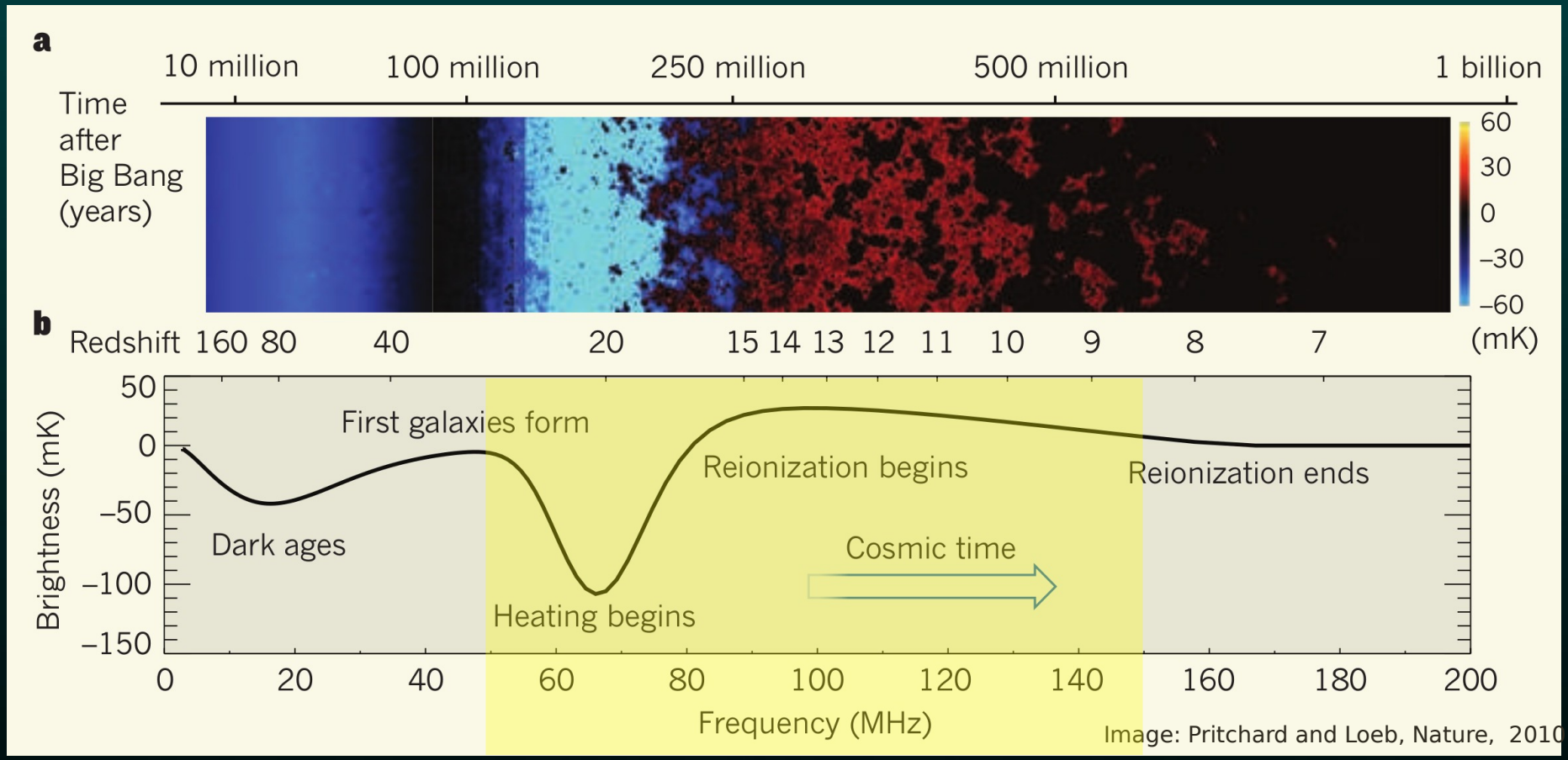
First stars form, Lyα photons couple T_K and T_S via Wouthuysen-Field mechanism

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

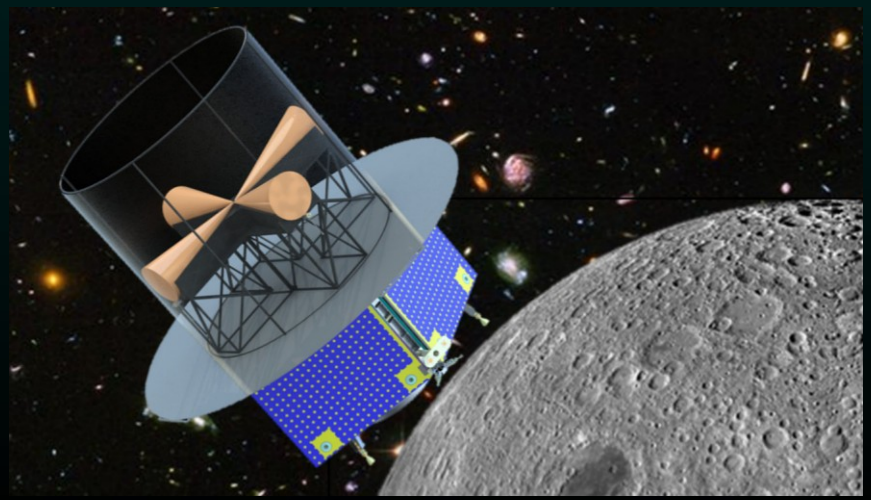
LEDA
30 – 88 MHz
Owens Valley

SARAS
87.5 – 175 MHz
Gauribidanur Obs., India

BIGHORNS
50 – 200 MHz
Western Australia

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

DARE
40 – 120 MHz
Dark side of the moon



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

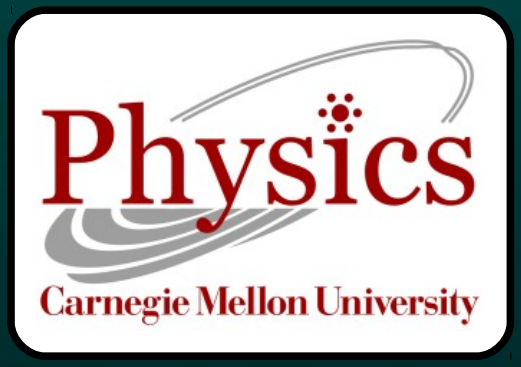
Cynthia Chiang

Jonathan Sievers

Liju Philip

Heiko Heilgendorff

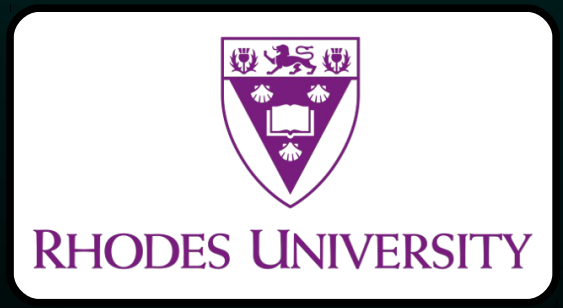
Austin Gumba



Jeff Peterson

José Miguel Jáuregui

Rupert Spann



Ridhima Nunhokee

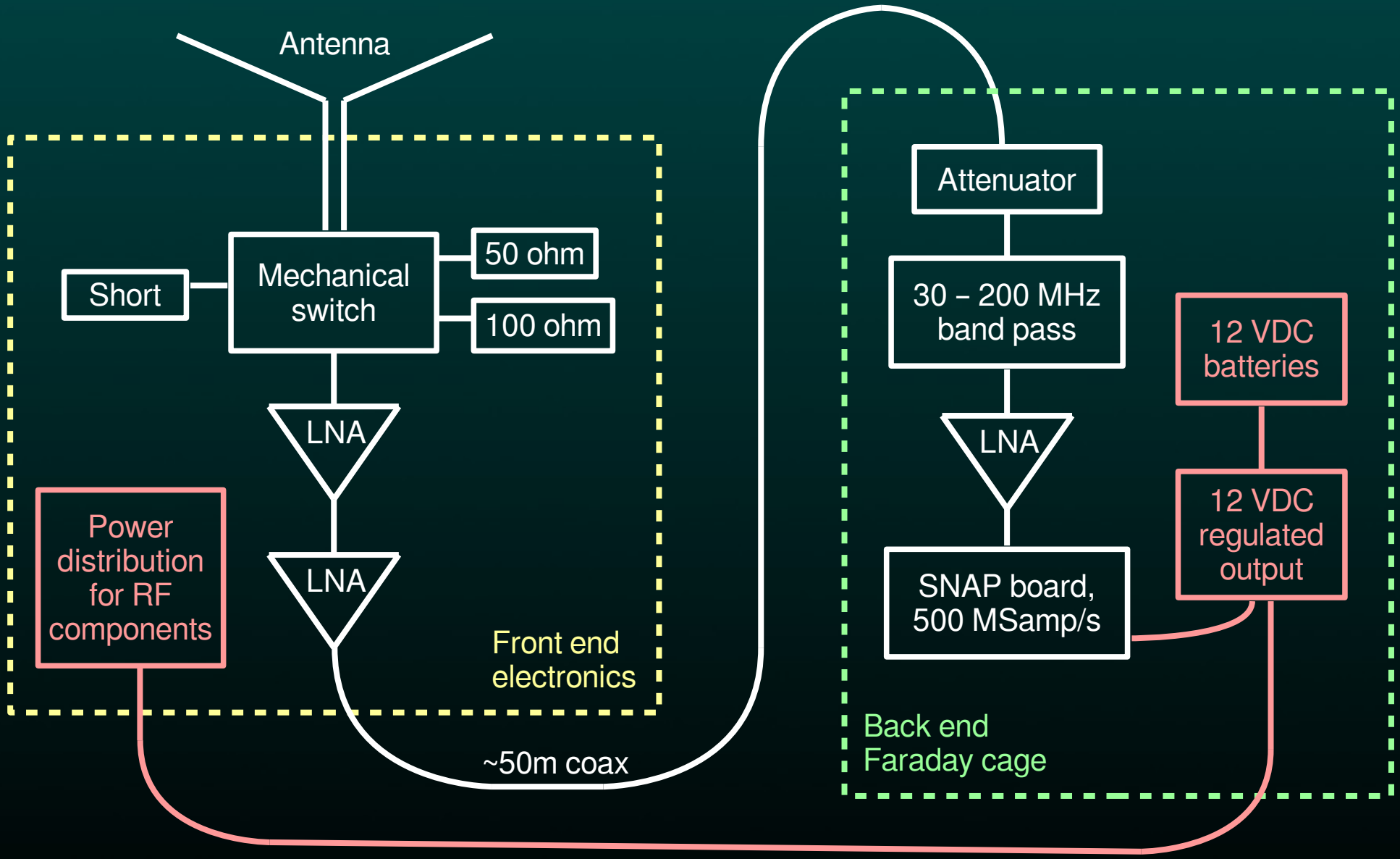
Jack Hickish

Zuhra Abdurashidova

Kagiso Malepe

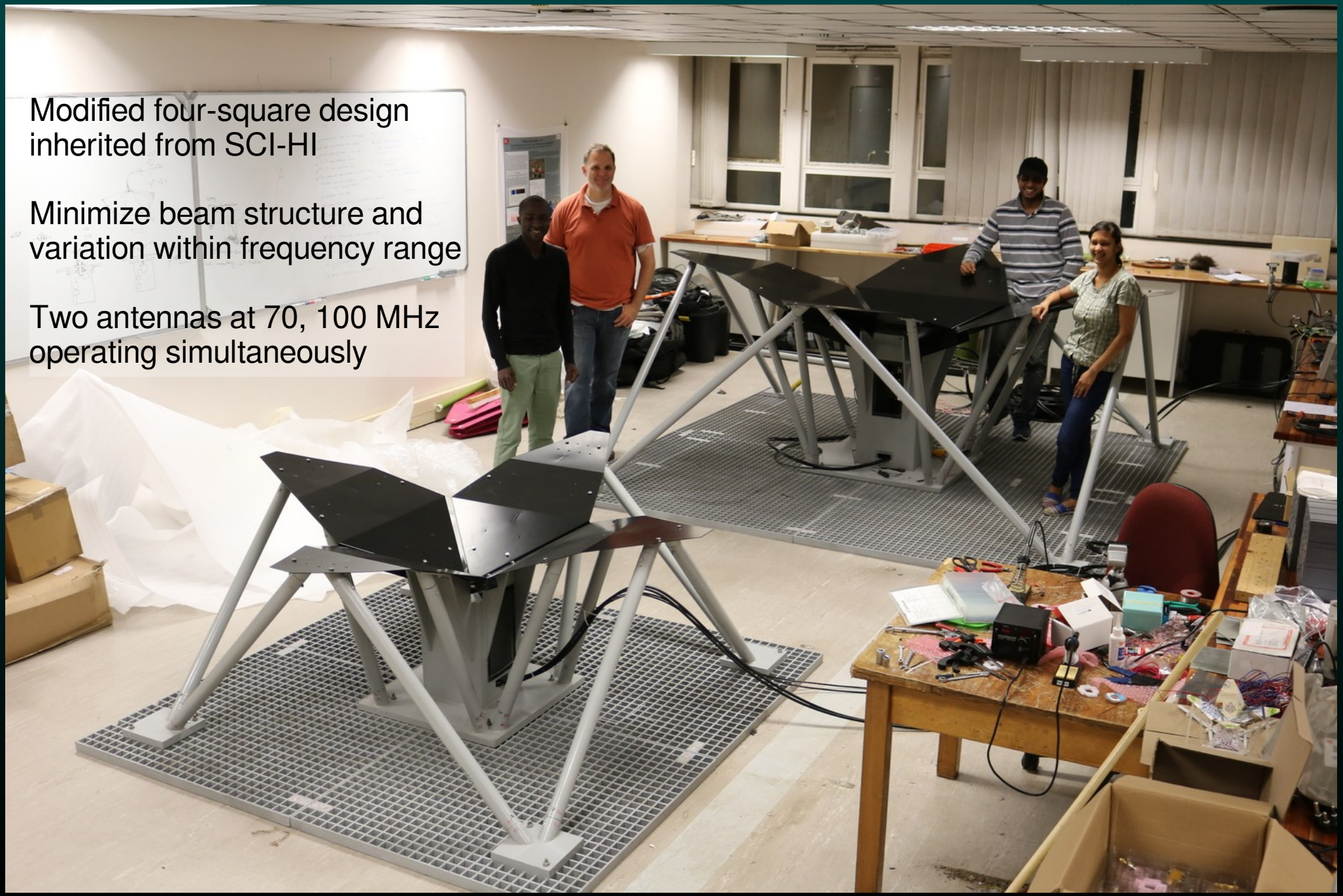
The PRIZM instrument

PRIZM block diagram

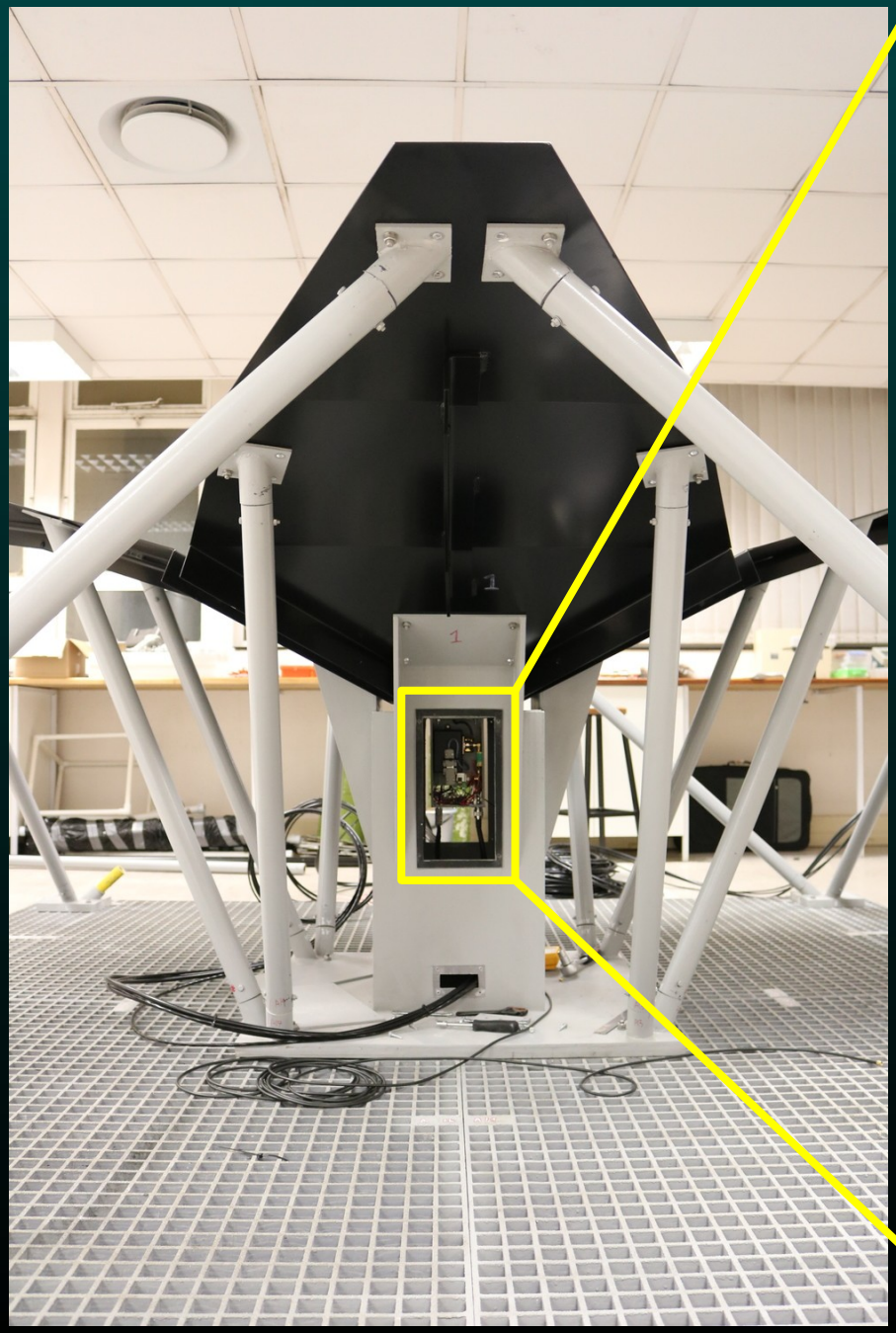


Single polarization shown above

PRIZM antennas



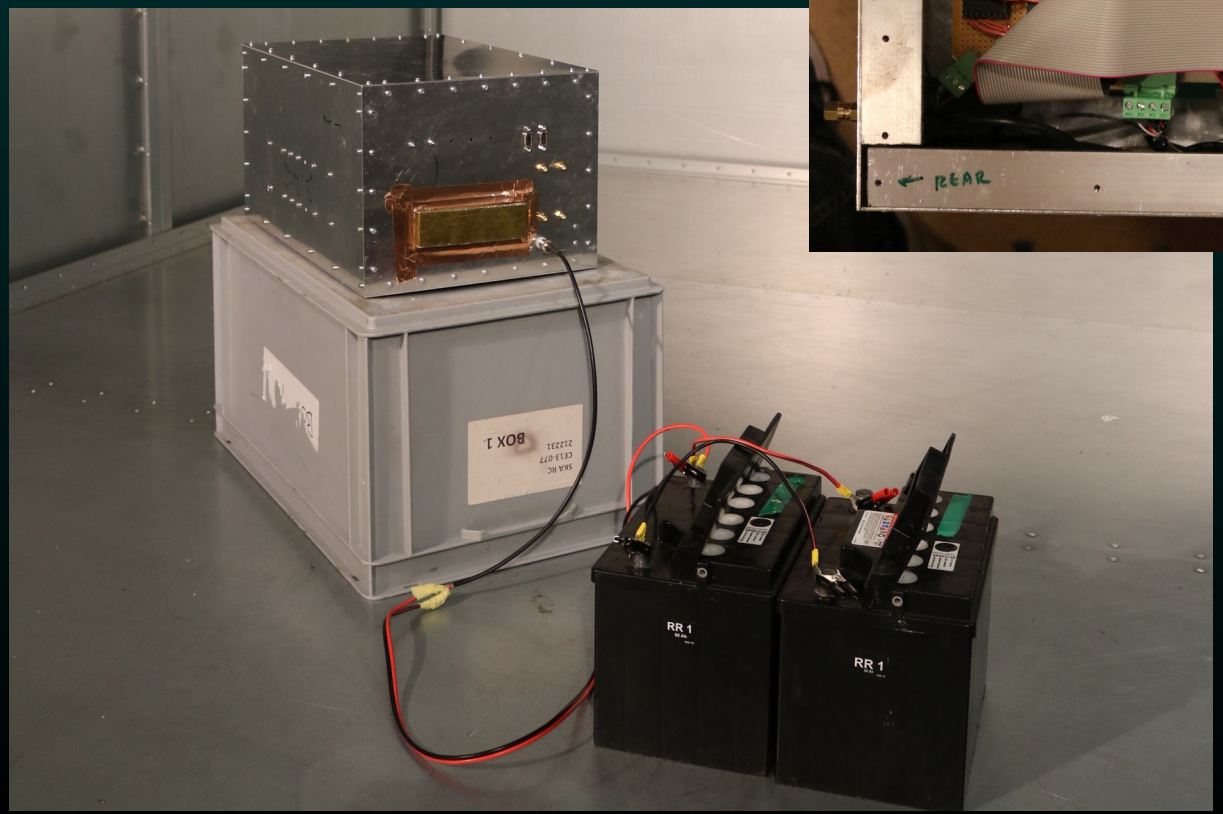
Front end RF electronics



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
8192 channels (30.5 kHz)
500 Msamp/s sampling



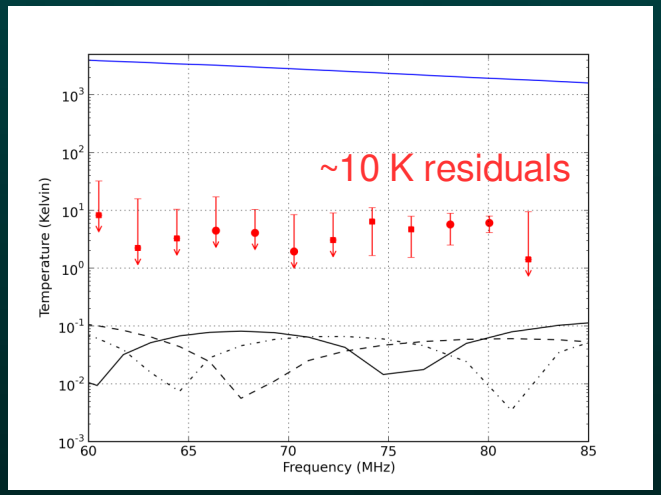
Total back end power draw ~80 W, max run time ~1 week on 8x lead crystal 170-Ah batteries

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

Experiment history and timeline

- **2013 – 2014** : SCI-HI = PRIZM predecessor



Voytek et al., ApJL 782, L9, 2014

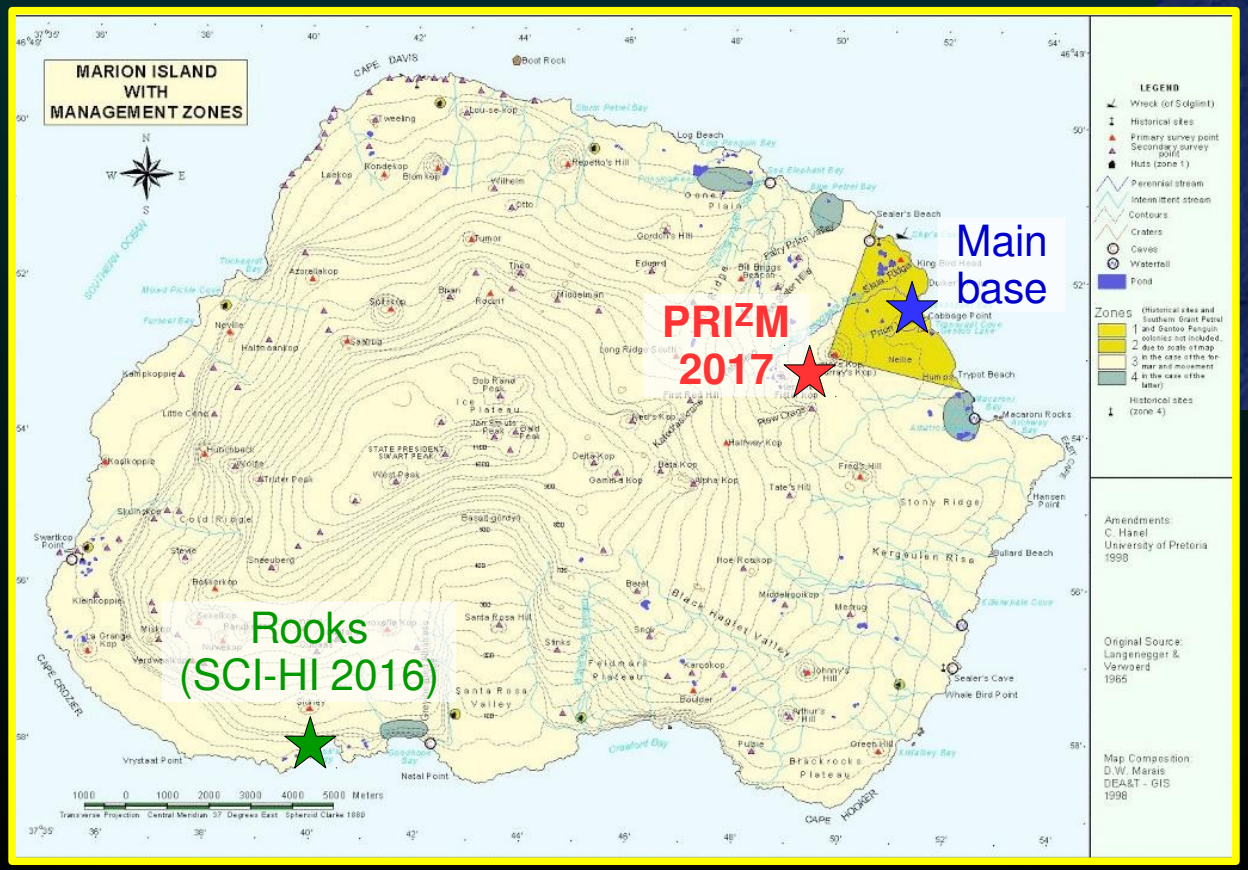
- **2015** : SCI-HI test run at SKA Karoo site
- **2016** : Initial deployment and engineering run at Marion Island with old SCI-HI front end, new PRIZM back end
- **2017** : First science run at Marion Island with full PRIZM system, experiment will continue observing through the Austral winter

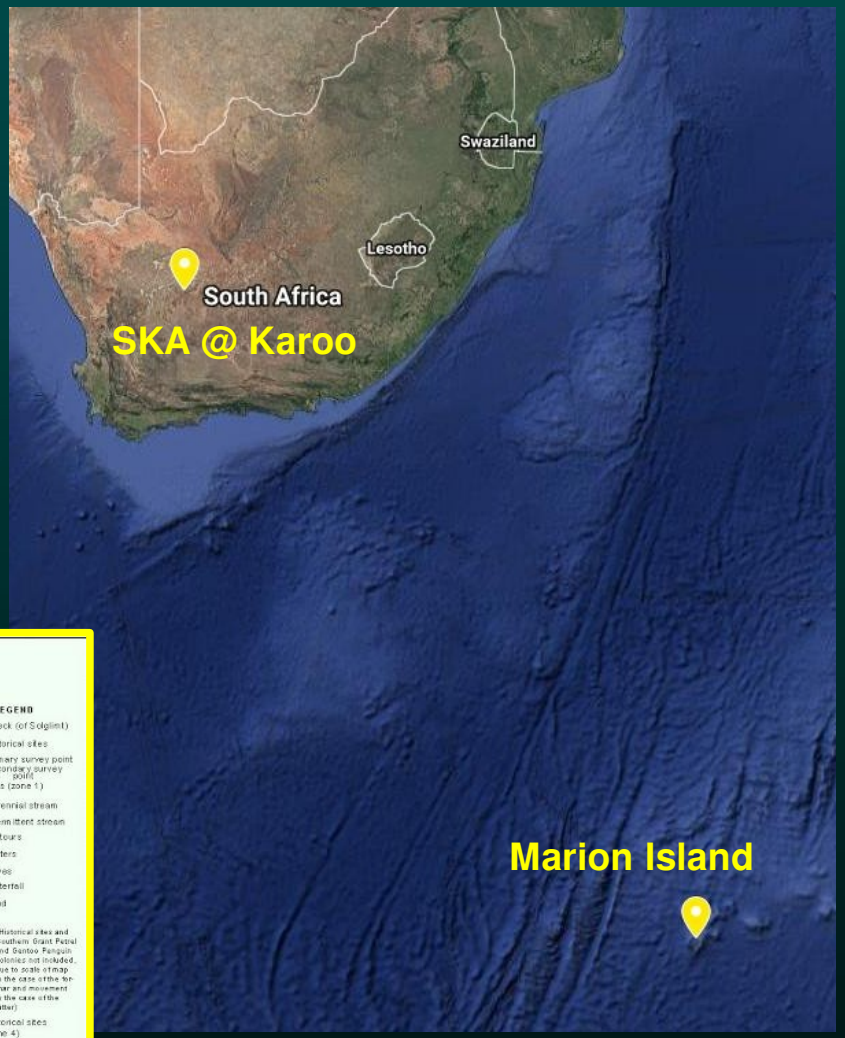
Marion Island

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

2000 km from nearest continental landmass (10x increase compared to Guadalupe)

PRI^{Z}M = first astro experiment on Marion!



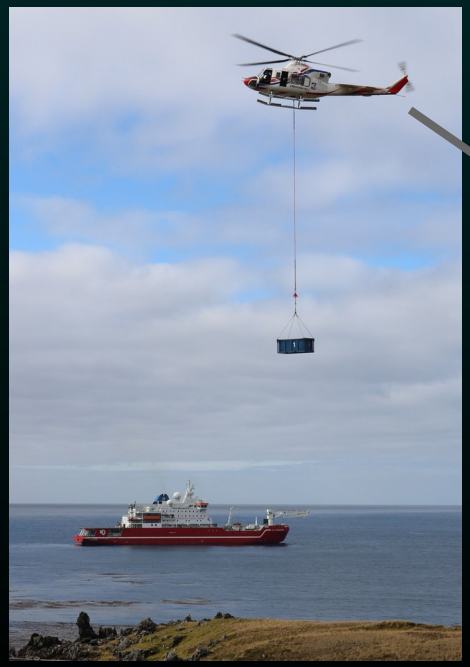


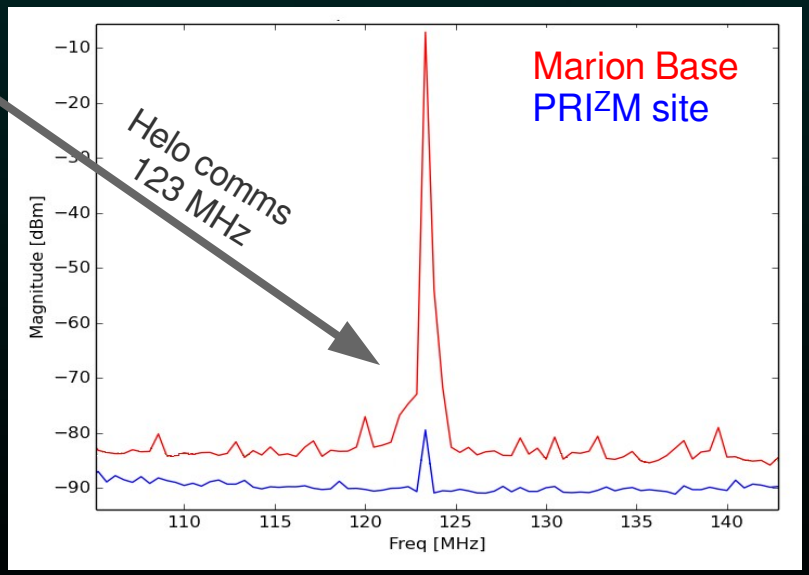
PRI^{Z}M 2017 location: ~4 km from base, behind Junior's Kop. 2 hr roundtrip hike through mires, lava rock, etc.

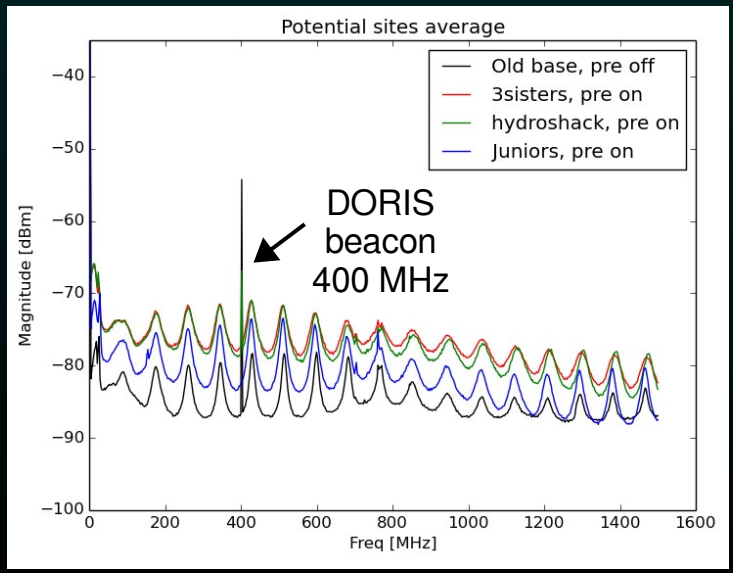
Future sites: hut stations on the perimeter of the island for larger distance from base

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 on surveying day shows ~60 dB level of shielding from base.
- Used DORIS beacon at 400 MHz to benchmark shielding at other locations







Three-week deployment in three slides

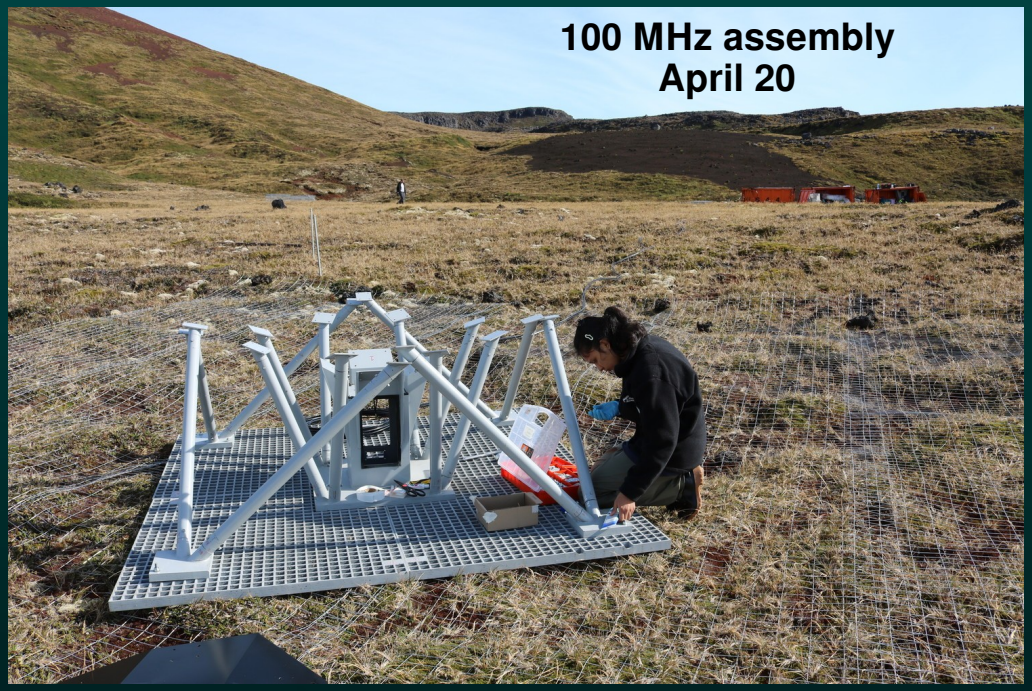
Departure from Cape Town
April 6

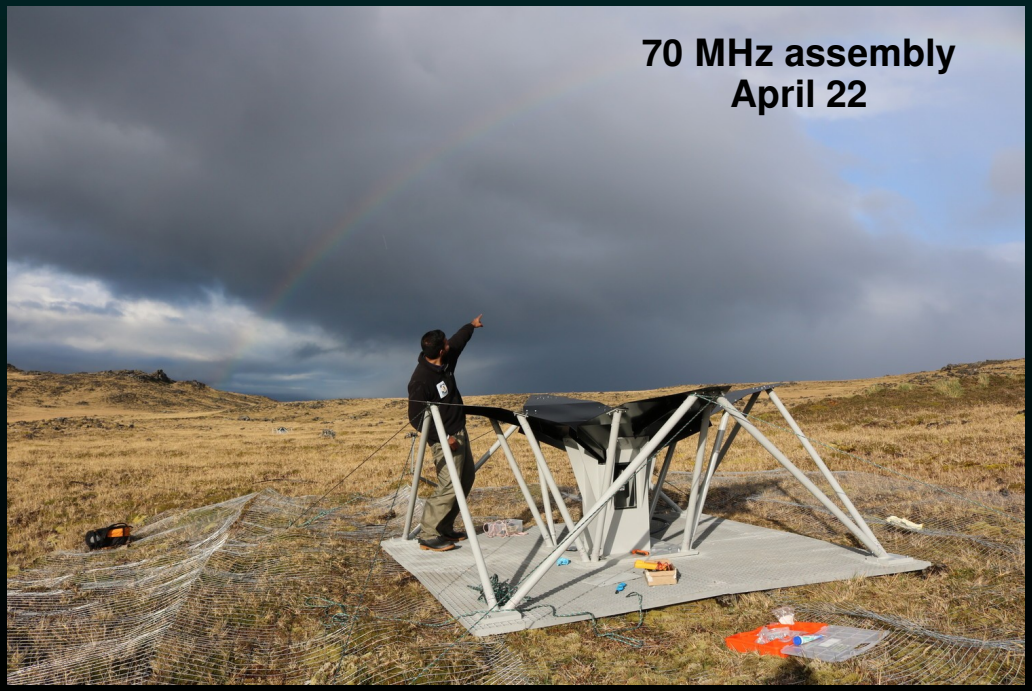
Arrival at Marion base
April 12

RFI surveying and site selection
April 14 – 15

Container delivery
April 19

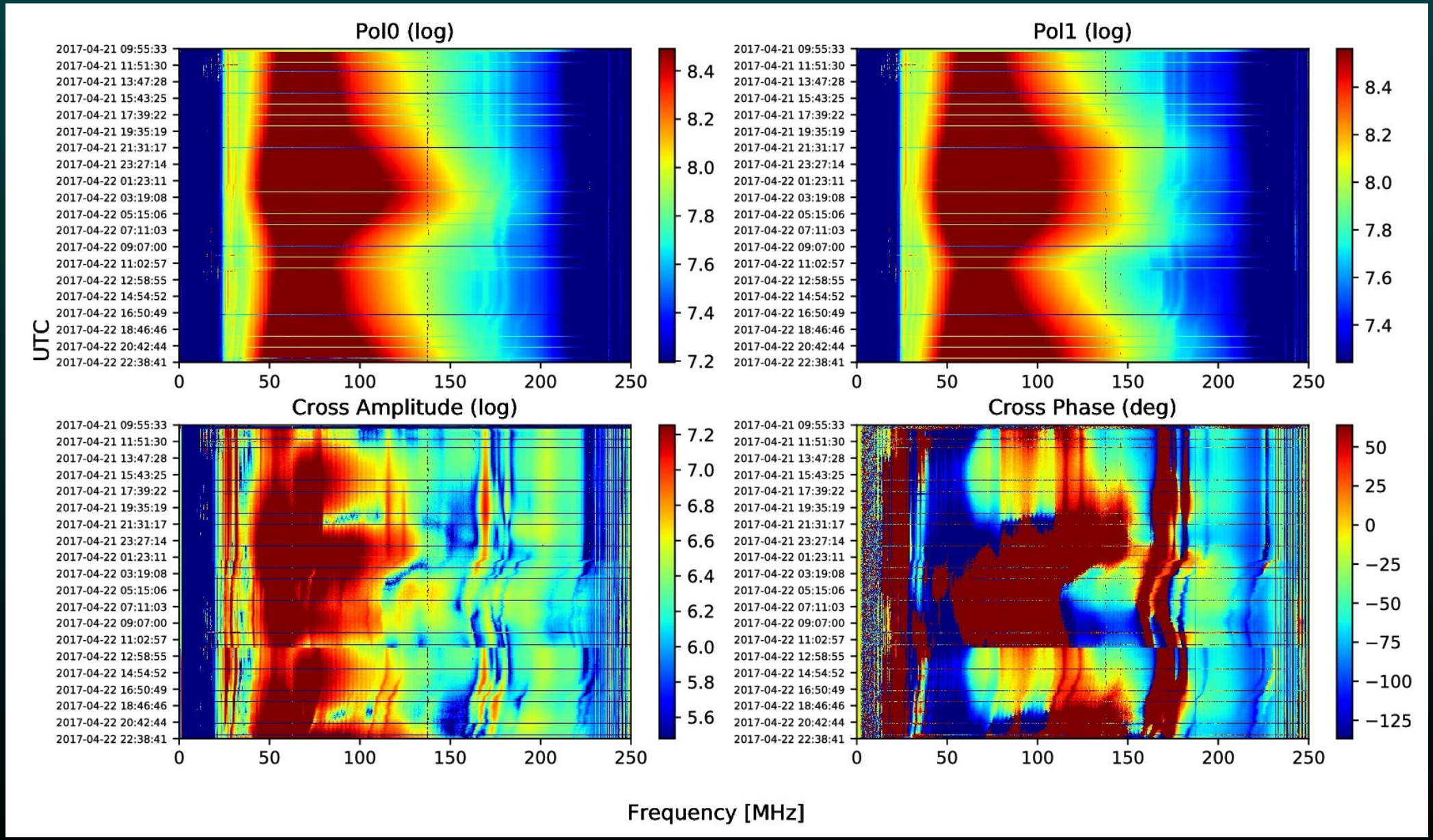
Three-week deployment in three slides





Three-week deployment in three slides

Preliminary PRIZM data at 100 MHz



Comparison: HERA-19 RFI flags from the Karoo

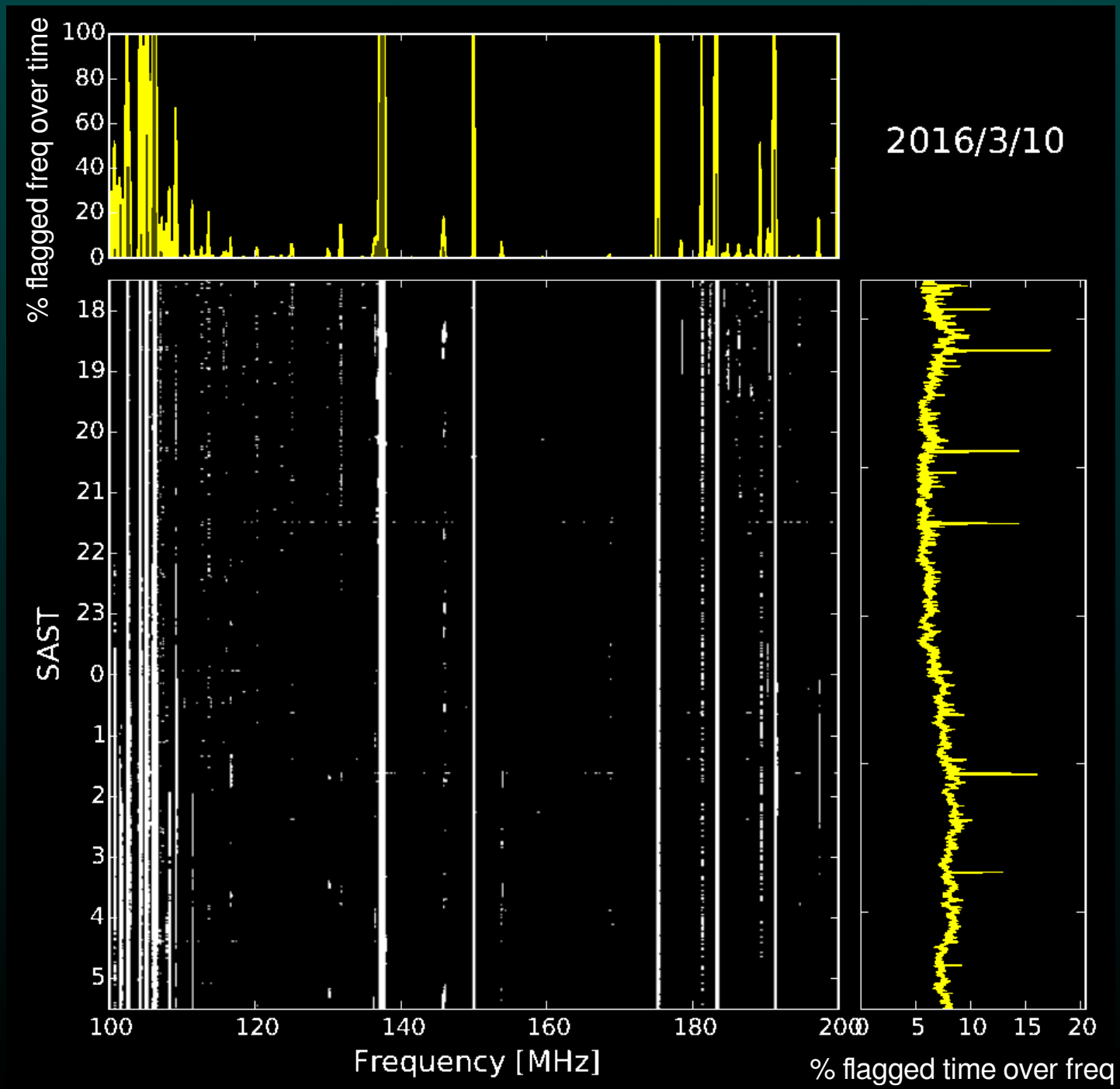
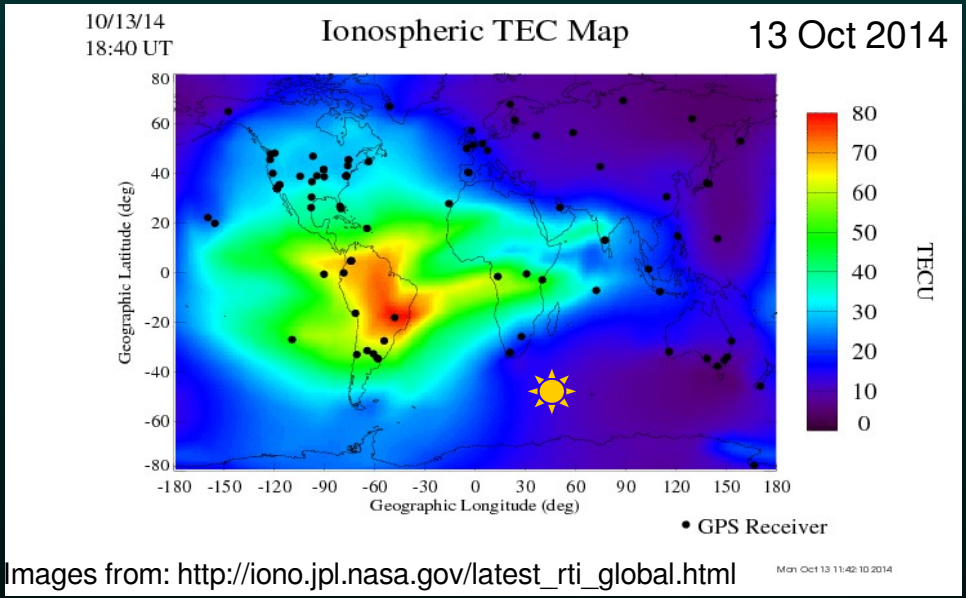


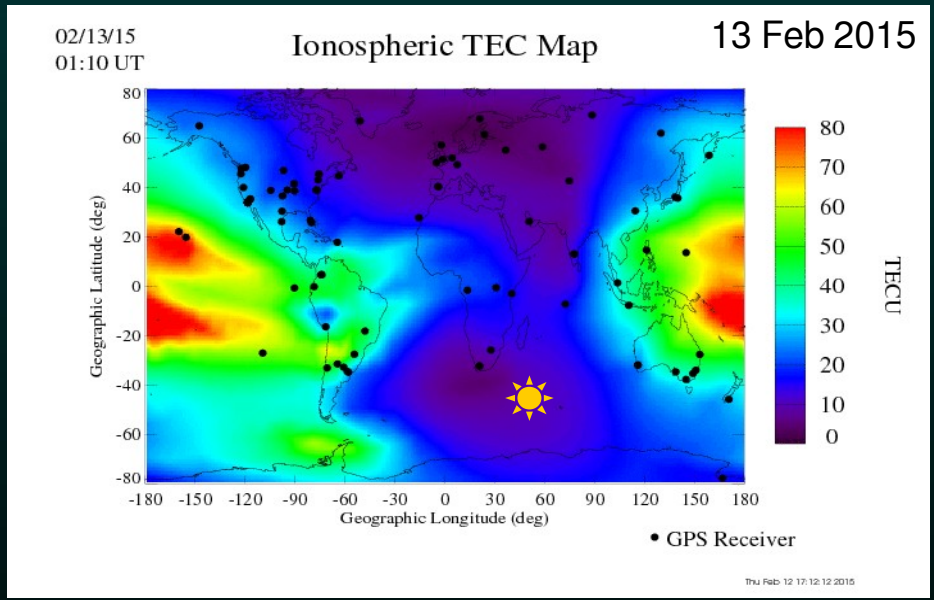
Figure: Saul Kohn

Future PRIZM plans

- Just submitted SANAP renewal proposal for next three years
- PRIZM upgrades: improve current antennas and continue to run, also deploy new antenna design (work in progress), beam map with drone
- Expansion to lower frequencies, push toward dark ages! Deploy antennas at hut stations, write lowest 10–20 MHz baseband to disk, correlate afterward.

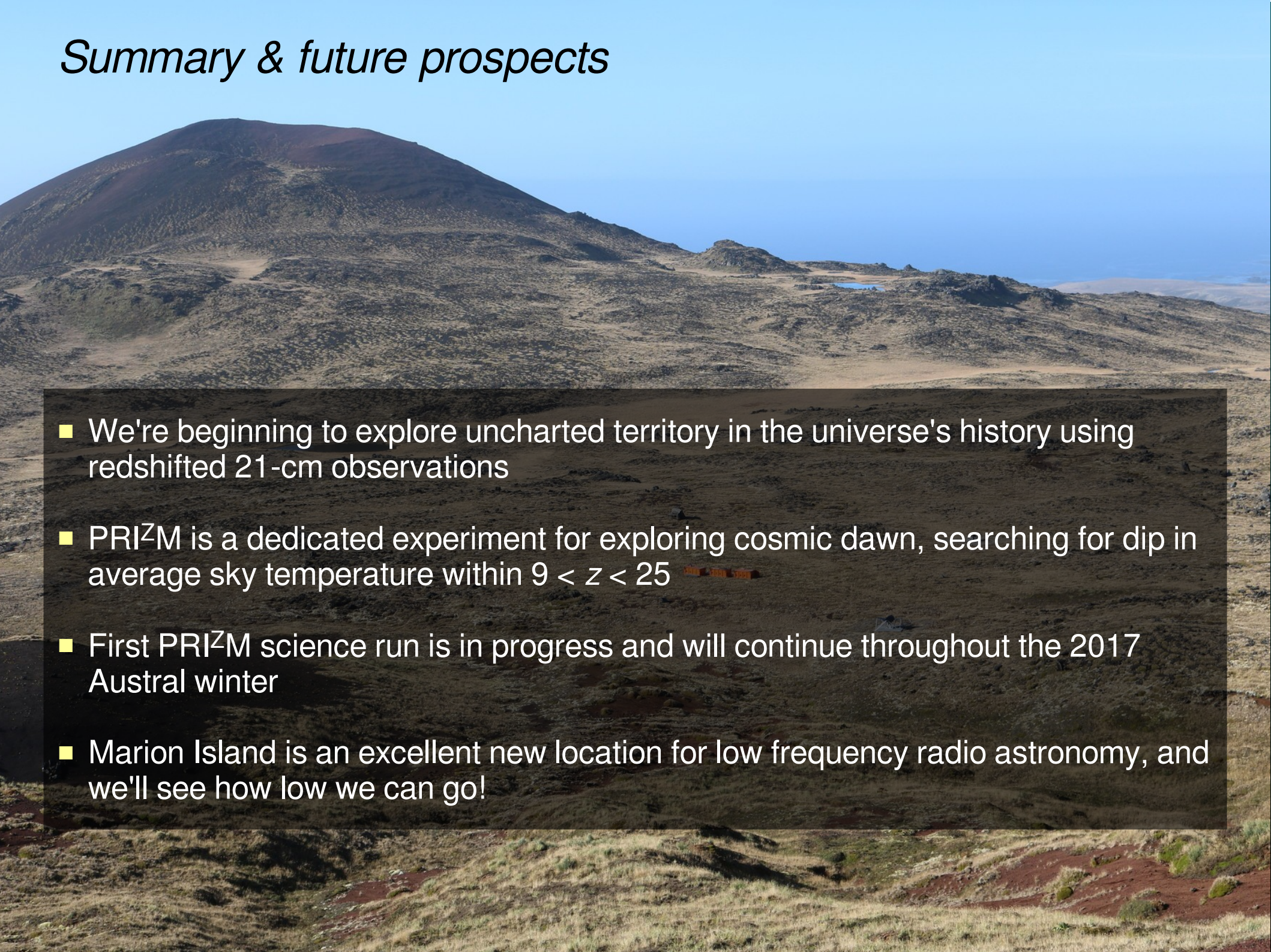


Images from: http://iono.jpl.nasa.gov/latest_rti_global.html



- Ionosphere causes attenuation and refraction. Temporal variation in total electron count (TEC) can create additional uncertainty in measured signal.
- Polar latitudes generally have lower TECs than mid-latitudes
- Ionosphere model (IRI) predicted 1.7 MHz plasma frequency during last solar minimum, and the next one is coming up. Lowest Antarctic plasma frequency = 1.55 MHz for comparison.

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 is in progress and will continue throughout the 2017 Austral winter
- Marion Island is an excellent new location for low frequency radio astronomy, and we'll see how low we can go!