Searching for Cosmic Dawn with PRI\textsuperscript{ZM}

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Big bang, inflation

Formation of CMB

Dark ages

Cosmic dawn

Reionization

Structure growth

Dark energy domination

PRIZM
Redshifted 21cm emission

- Spins parallel, higher energy
- Spin antiparallel, lower energy

- 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

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

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

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

First stars form, Ly\(\alpha\) 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.
$\delta T_b \propto x_{HI} (1+z)^{1/2} (T_s - T_{CMB}) / T_s$

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
PRZM: Probing Radio Intensity at high-Z from Marion

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The PRI$^Z$M instrument

Command module

100 MHz antenna

70 MHz antenna
Single polarization shown above
**PRI\textsuperscript{Z}M antennas**

Modified four-square design inherited from SCI-HI

Minimize beam structure and variation within frequency range

Two antennas at 70, 100 MHz operating simultaneously
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 PRIZM run was the first field deployment
Experiment history and timeline

- **2013 – 2014**: SCI-HI = PRI$^2$M predecessor

- **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 PRI$^2$M back end

- **2017**: First science run at Marion Island with full PRI$^2$M system, experiment will continue observing through the Austral winter

![Map of Isla Guadalupe](image)

Voytek et al., ApJL 782, L9, 2014

- ~10 K residuals
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\textsuperscript{2}M = first astro experiment on Marion!

PRI\textsuperscript{2}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 PRI\(^2\)M 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

First light
April 21

100 MHz assembly
April 20

70 MHz assembly
April 22

All systems go!
April 22
Three-week deployment in three slides

Mouseproofing, robustifying...
April 23 – May 4

Penguin break
May 3

Last day of summer ops
May 4

Departure from Marion
May 5
Preliminary PRI$^Z$M data at 100 MHz
Comparison: HERA-19 RFI flags from the Karoo

Figure: Saul Kohn
Future PRI²M plans

- Just submitted SANAP renewal proposal for next three years
- PRI²M 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.

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.


13 Oct 2014

13 Feb 2015
We're beginning to explore uncharted territory in the universe's history using redshifted 21-cm observations.

PRI²M is a dedicated experiment for exploring cosmic dawn, searching for dip in average sky temperature within $9 < z < 25$.

First PRI²M 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!