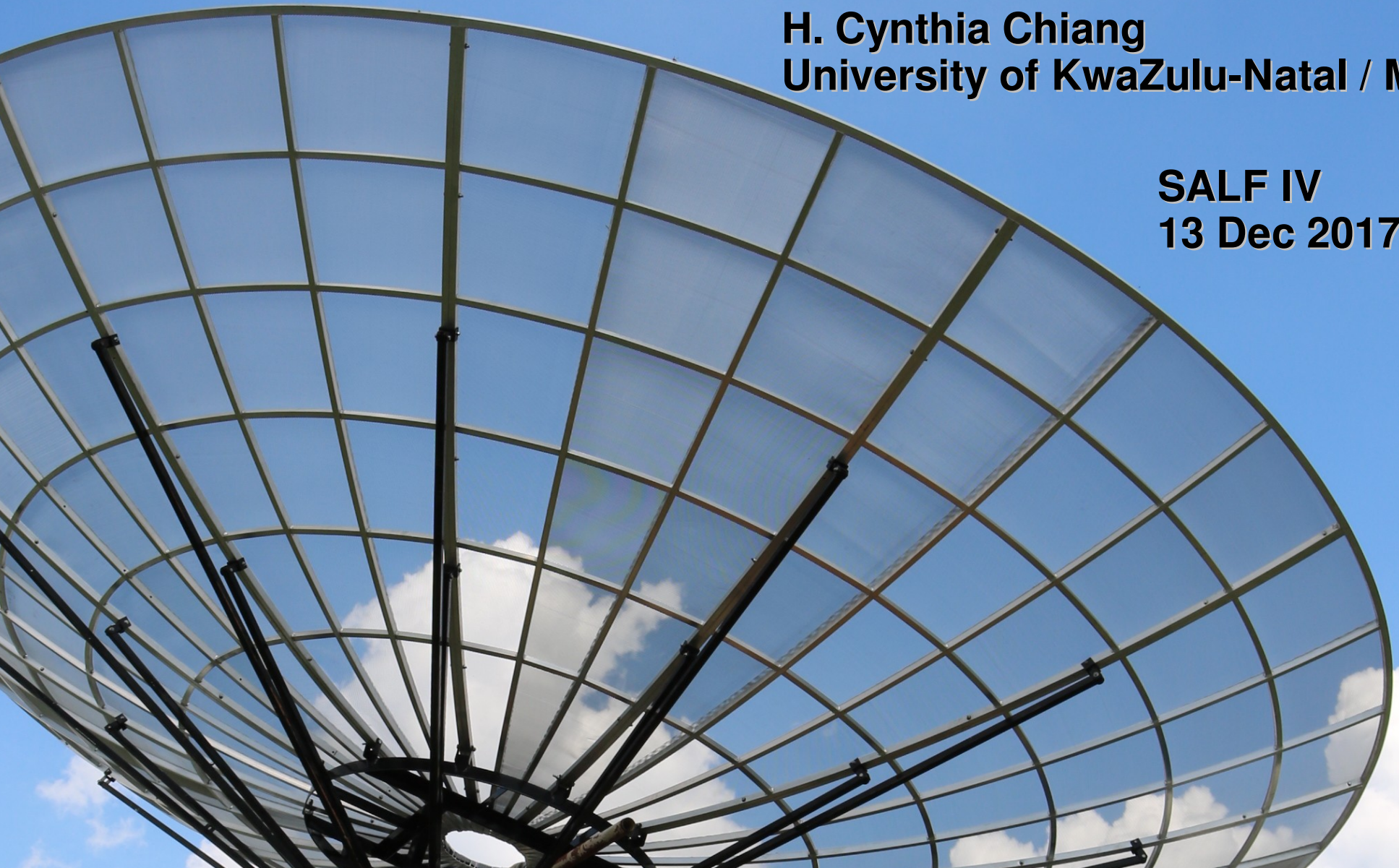


The Hydrogen Intensity and Real-time Analysis eXperiment

**H. Cynthia Chiang
University of KwaZulu-Natal / McGill**

**SALF IV
13 Dec 2017**



Big bang, inflation

Formation of CMB

Dark ages

Cosmic dawn

Reionization

Structure growth

Dark energy domination

$z = 1100$
150

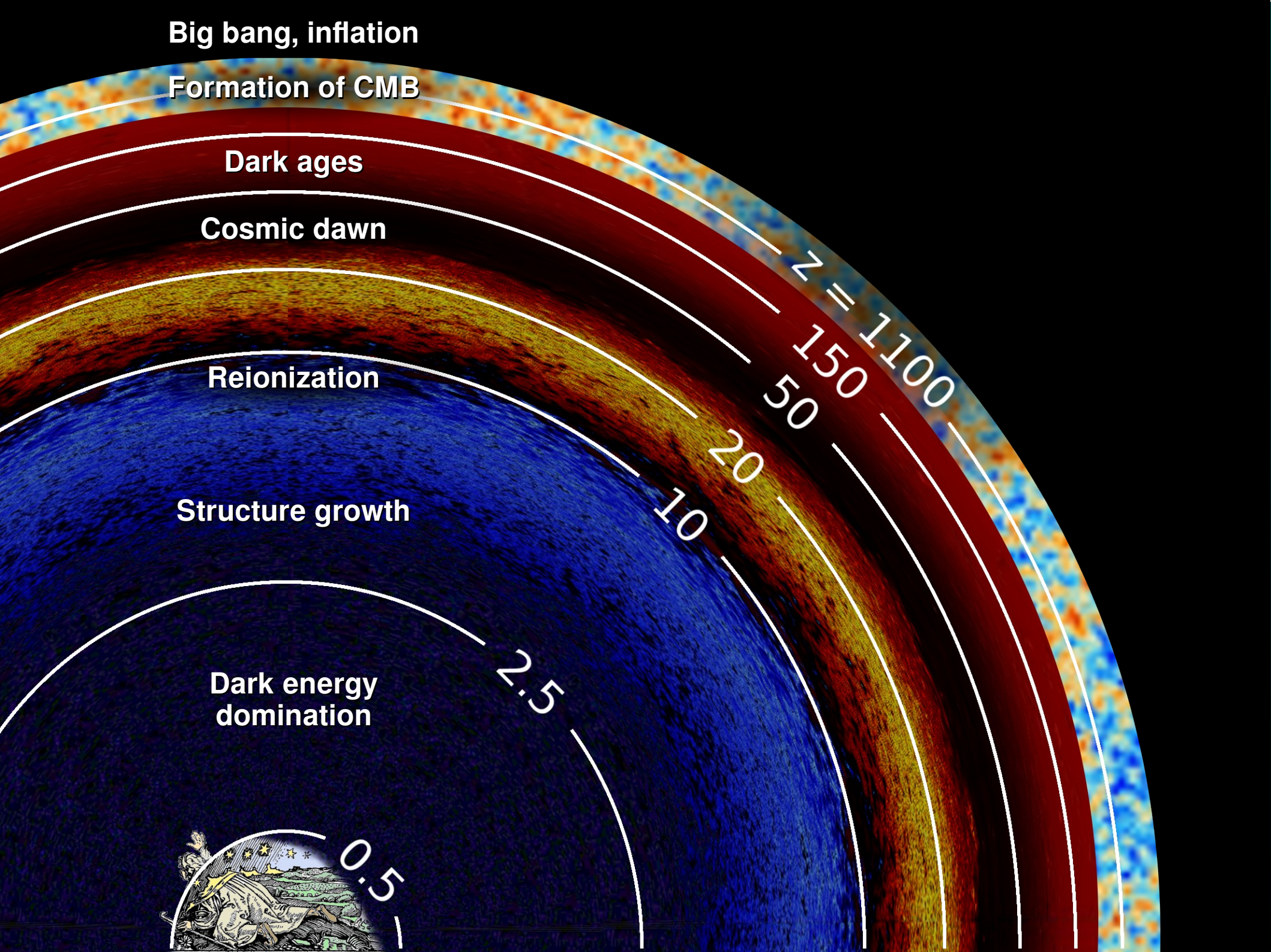
50

20

10

2.5

0.5



Big bang, inflation

Formation of CMB

Dark ages

Cosmic dawn

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Structure growth

Dark energy domination

HIRAX



$z = 1100$
150

50

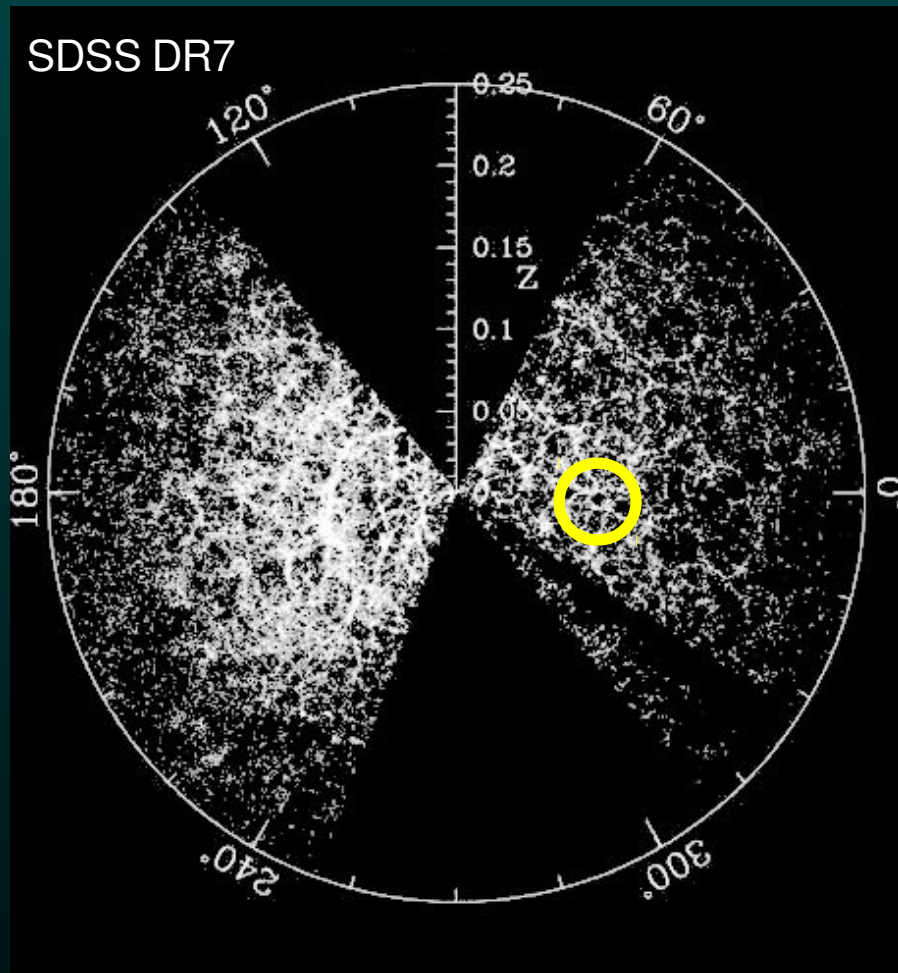
20

10

2.5

0.5

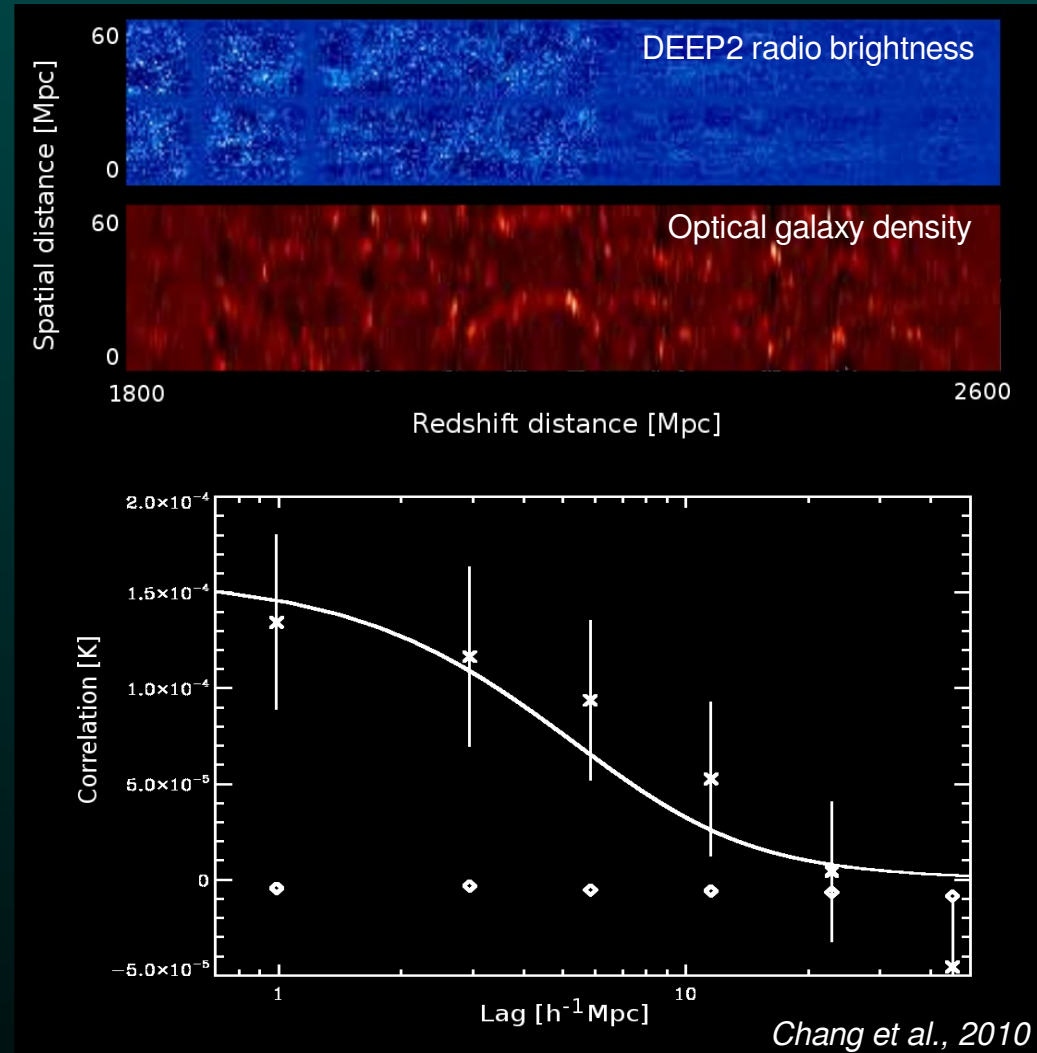
BAOs with hydrogen intensity mapping



We want large volumes (large sky, large z range) for precision cosmology

...but counting individual galaxies is hard, and getting to high redshifts is challenging

150 Mpc scale is big (degree scale)



Throw away resolution: use HI intensity mapping to measure matter distribution AND obtain redshift information.

Use BAO peak as a standard ruler to chart the universe's expansion history, probe dark energy.

The Hydrogen Intensity and Real-time Analysis eXperiment

Science goals:

Measure baryon acoustic oscillations with HI intensity mapping

Characterize dark energy

Radio transient searches

Pulsar searches

Neutral hydrogen absorbers

Diffuse polarization of the Galaxy

Instrumental approach:

1024 close-packed 6-m dishes

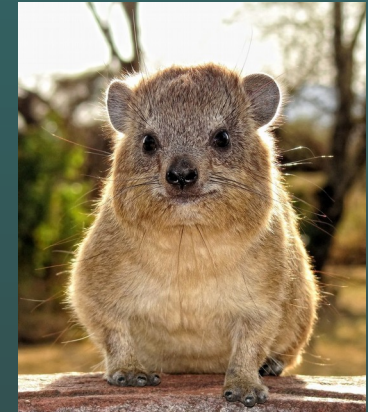
Dishes are stationary but can be tilted

Operating frequency: 400 – 800 MHz,
equivalent redshift = 0.8 – 2.5

Working closely with CHIME:
channelize with FPGA ICE boards,
correlation with GPUs

Location: SKA/Karoo (site agreement
in progress)

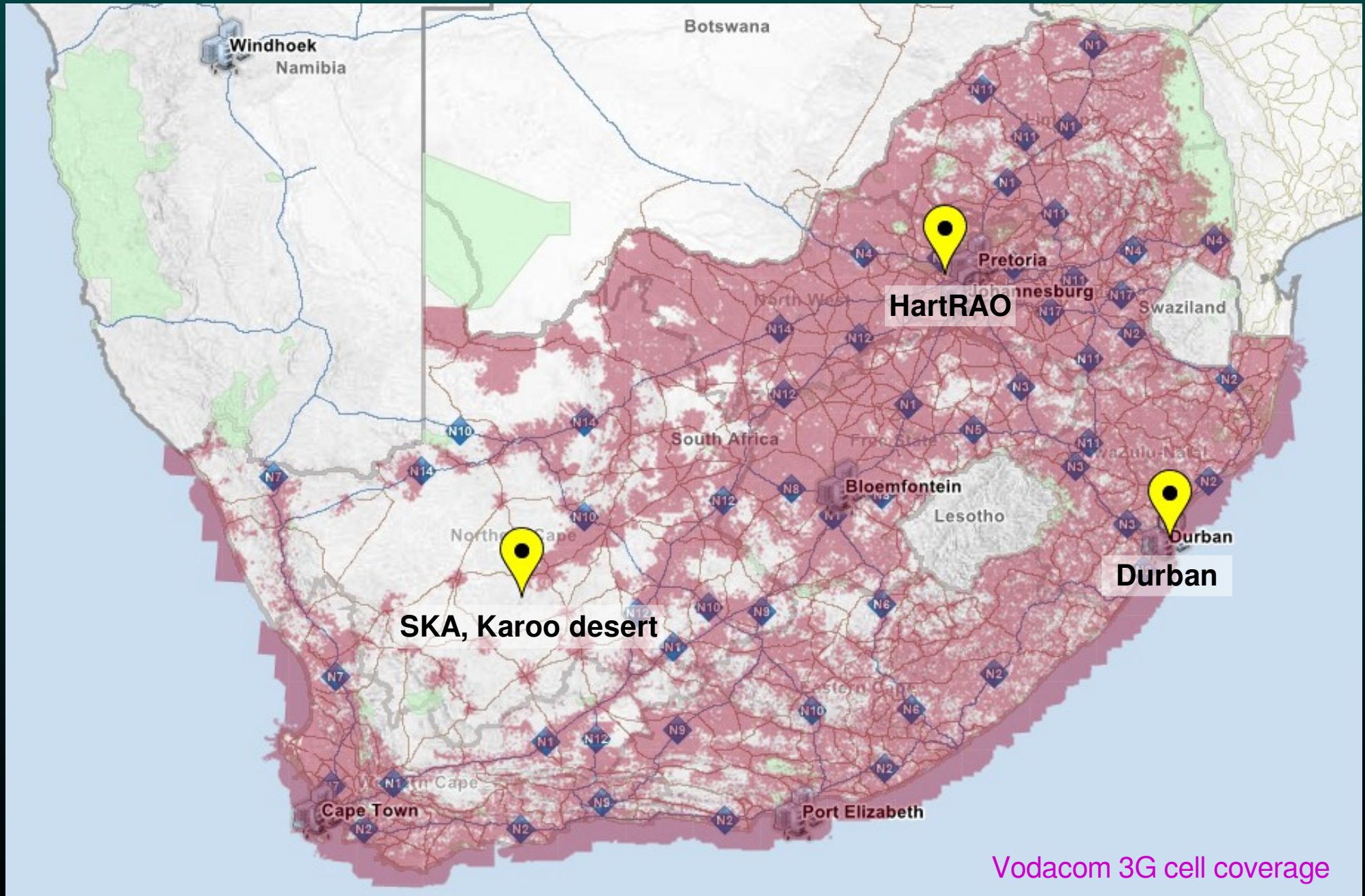
The acronym:



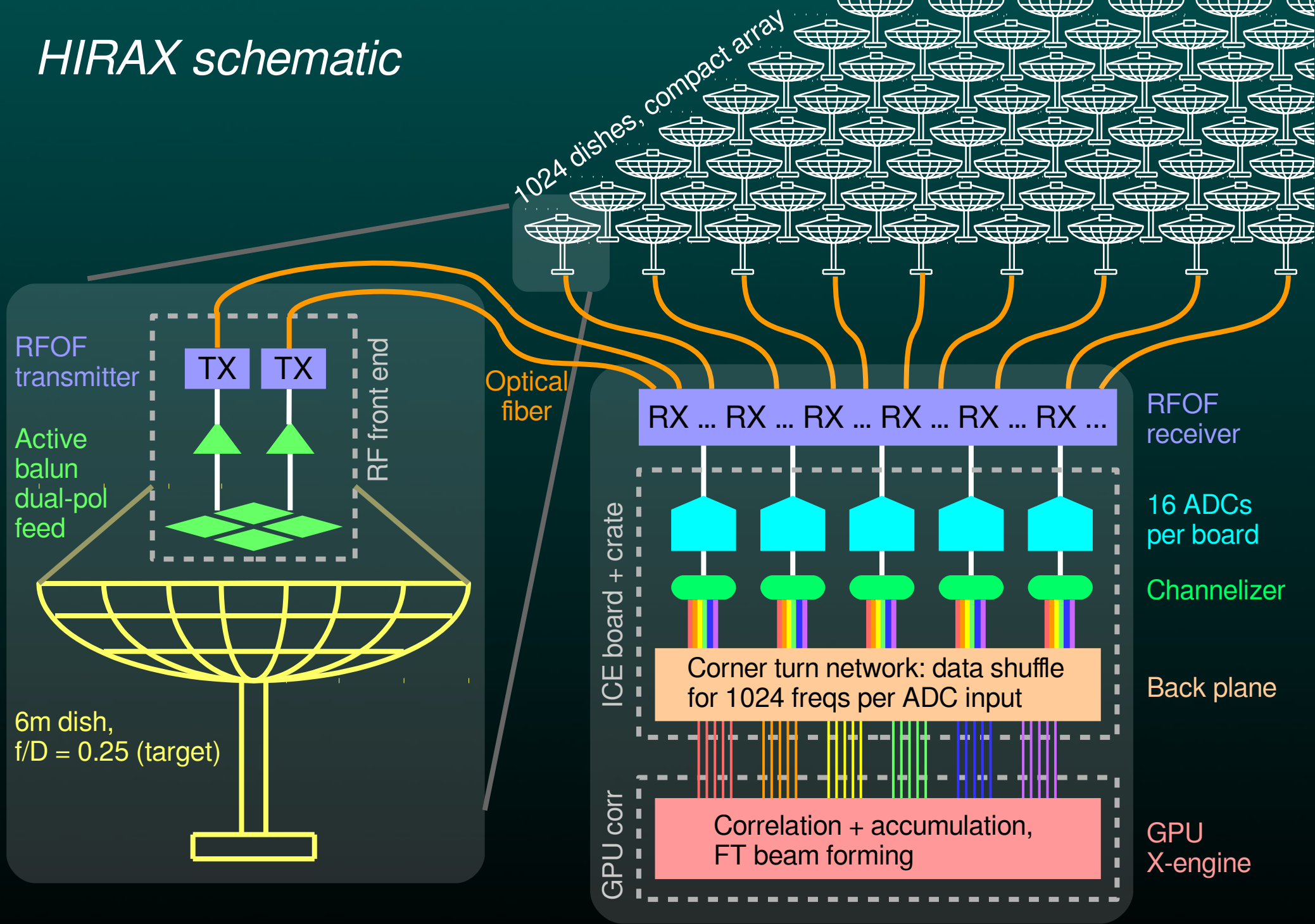
Rock hyrax / dassie



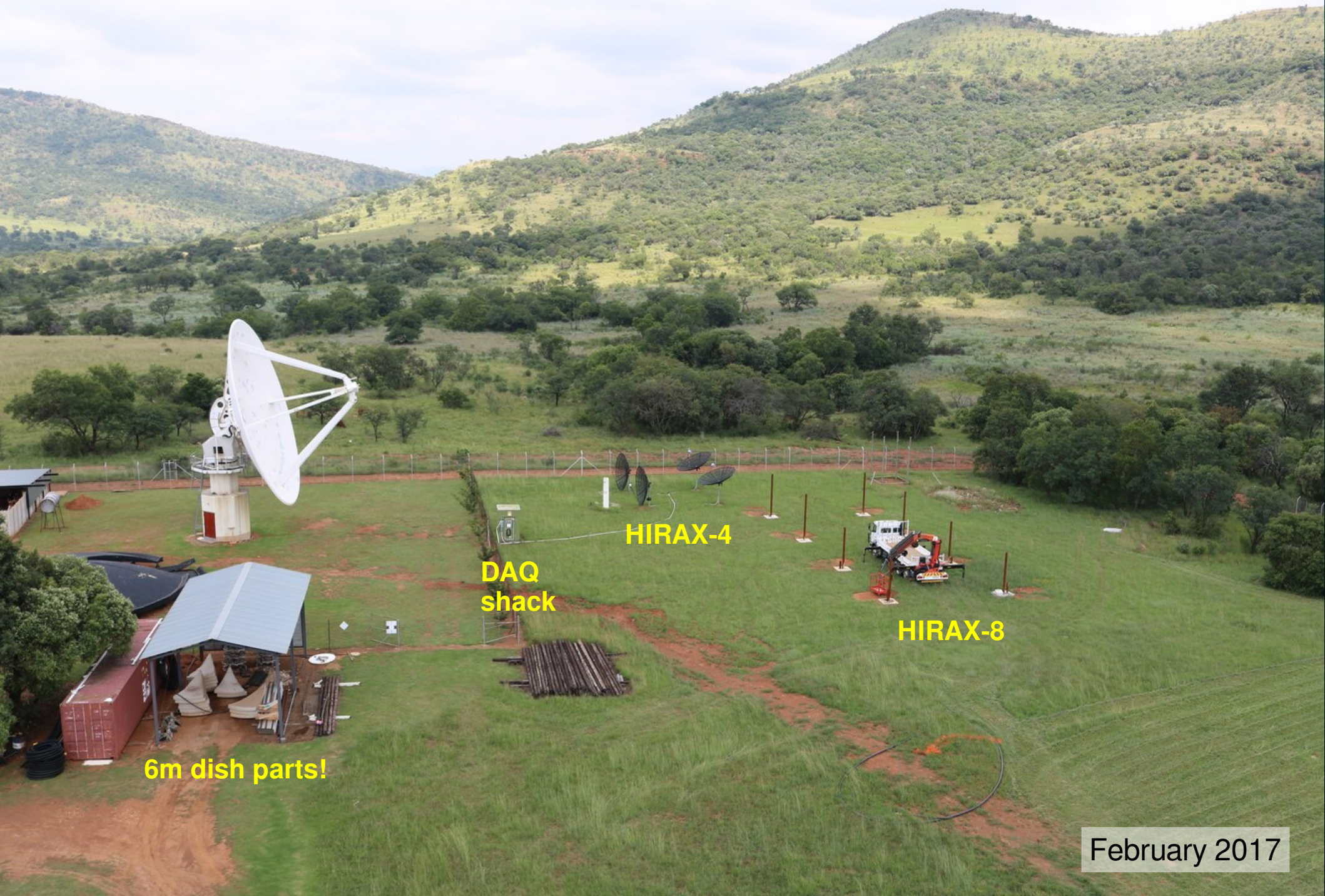
Where we are in South Africa



HIRAX schematic



HartRAO eight element 6m prototype



6m dish parts!

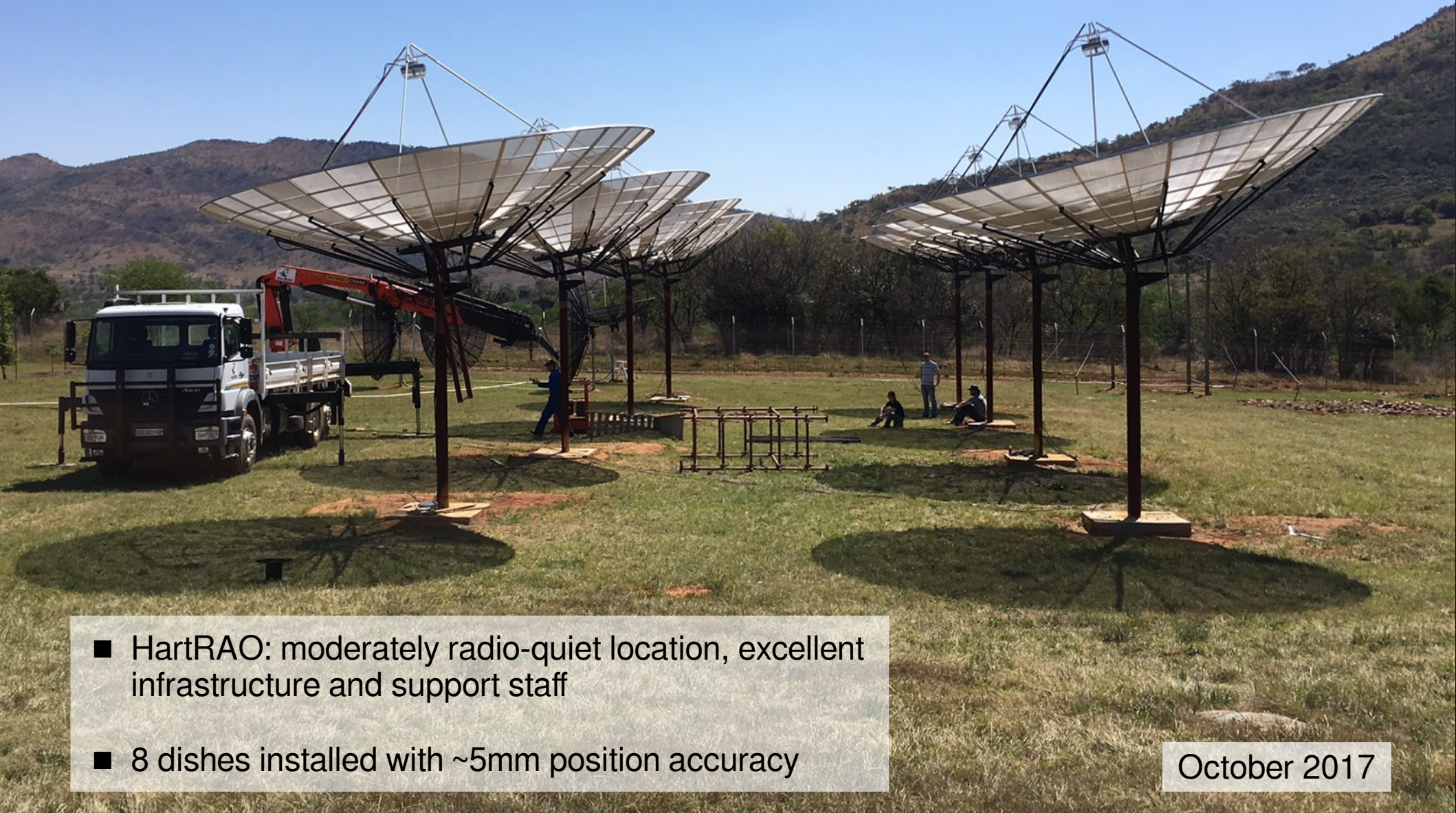
DAQ
shack

HIRAX-4

HIRAX-8

February 2017

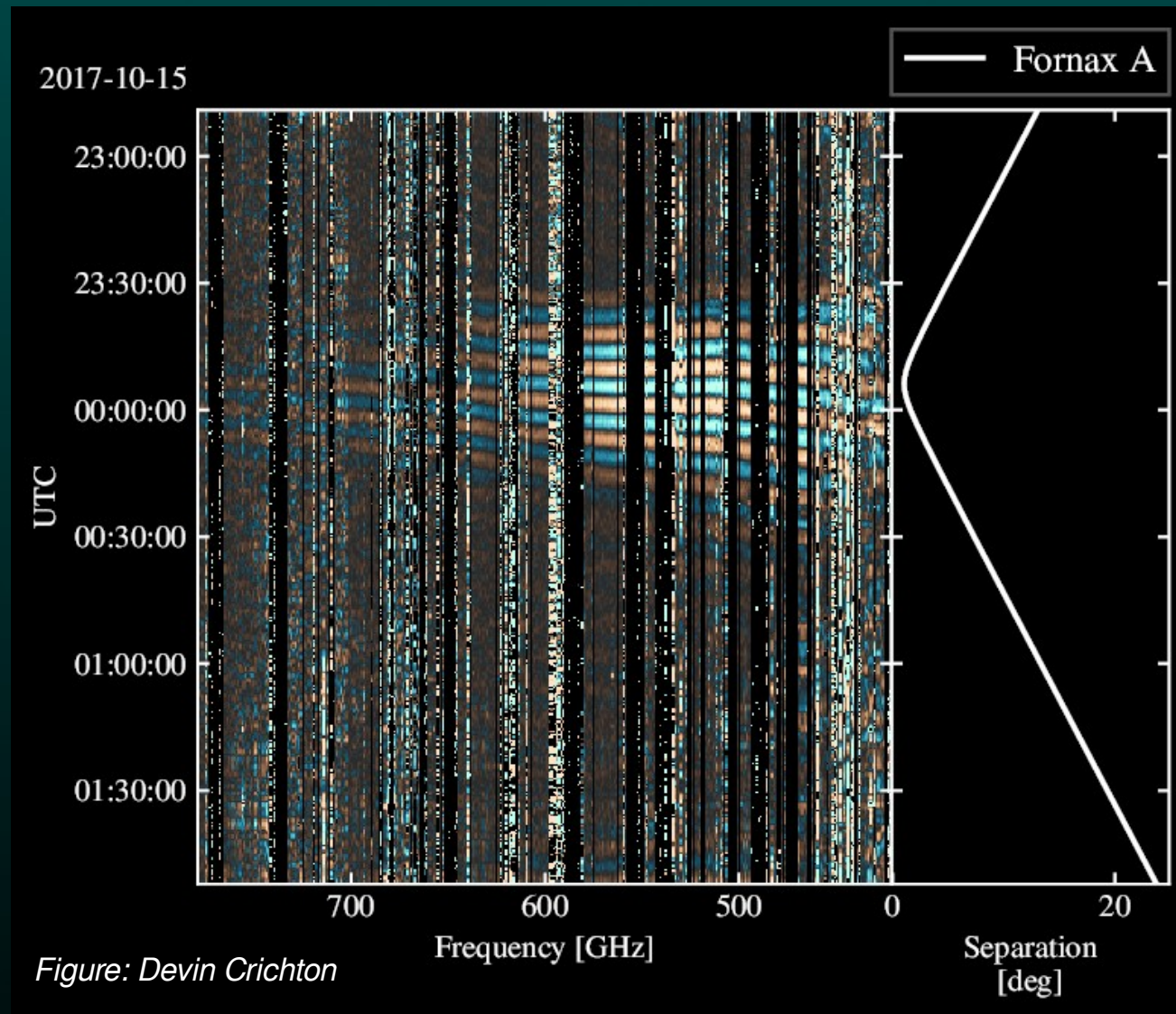
HartRAO eight element 6m prototype



- HartRAO: moderately radio-quiet location, excellent infrastructure and support staff
- 8 dishes installed with ~5mm position accuracy

October 2017

HIRAX-8 commissioning in progress

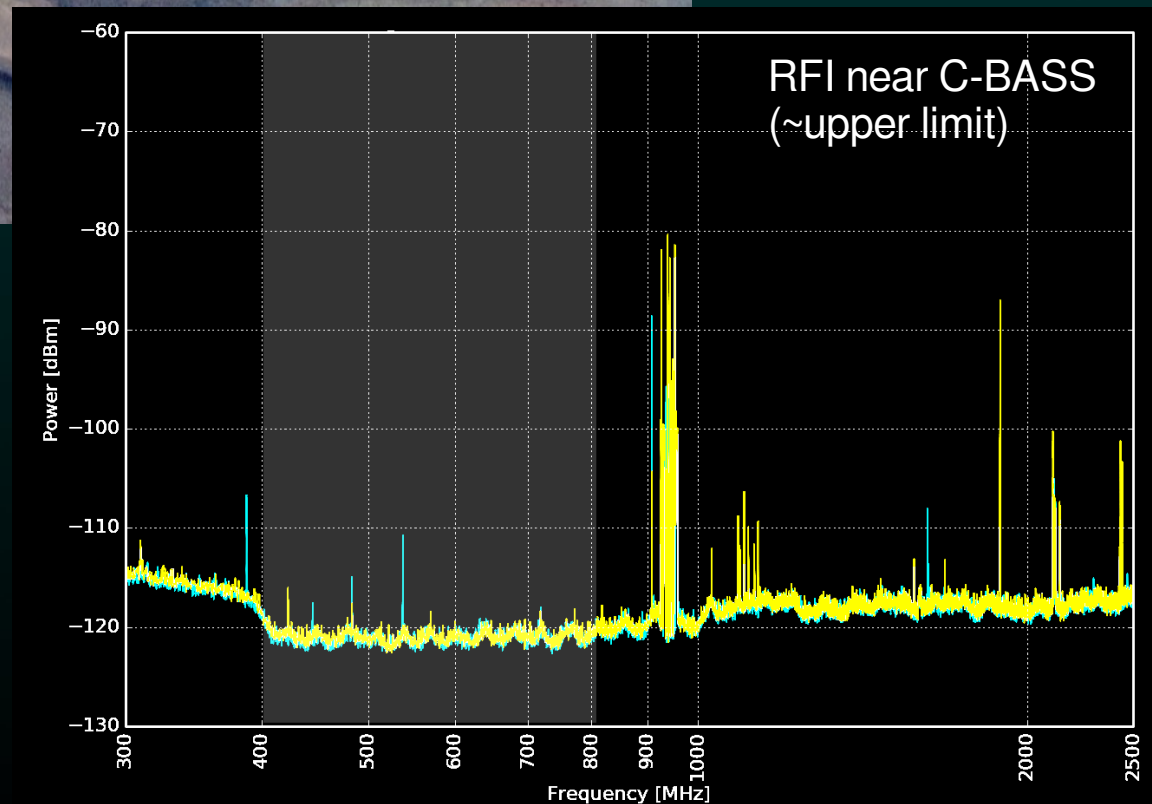


- All dishes instrumented, commissioning and troubleshooting in progress
- First tests of active-balun feeds, RFOF modules, ICE board, GPU correlator
- We've seen fringes! But lots of work ahead...
- Current plan: buildout to 32 dishes at HartRAO for further subsystem tests

Next phase: 128 element array in the Karoo

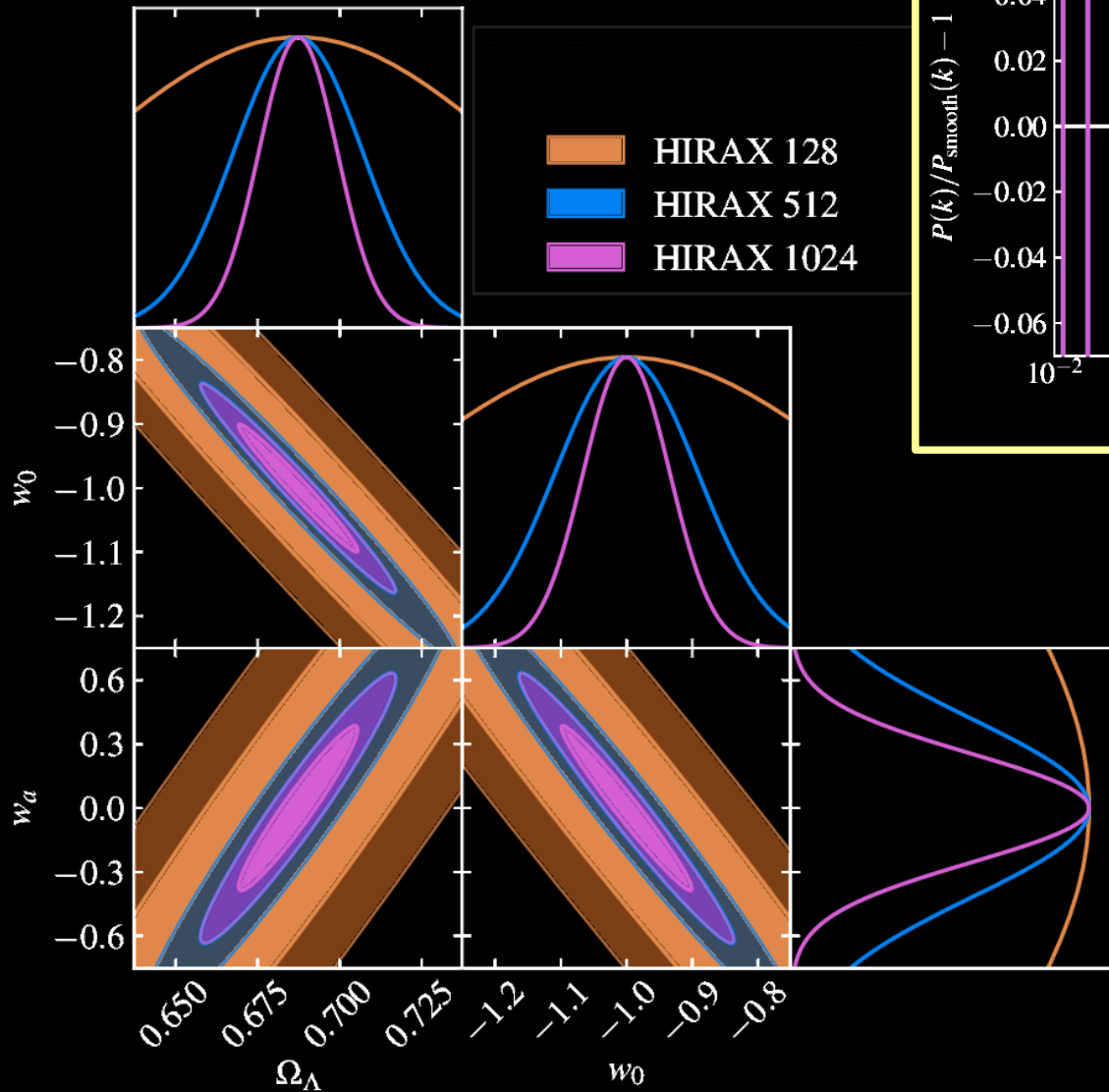


- Full HIRAX site: Karoo desert, working with SKA to finalize
- Representative RFI levels at Klerefontein look great, UHF TV in the area has been turned off
- HIRAX-128 construction estimated start in 2019, eventual expansion to 512, 1024

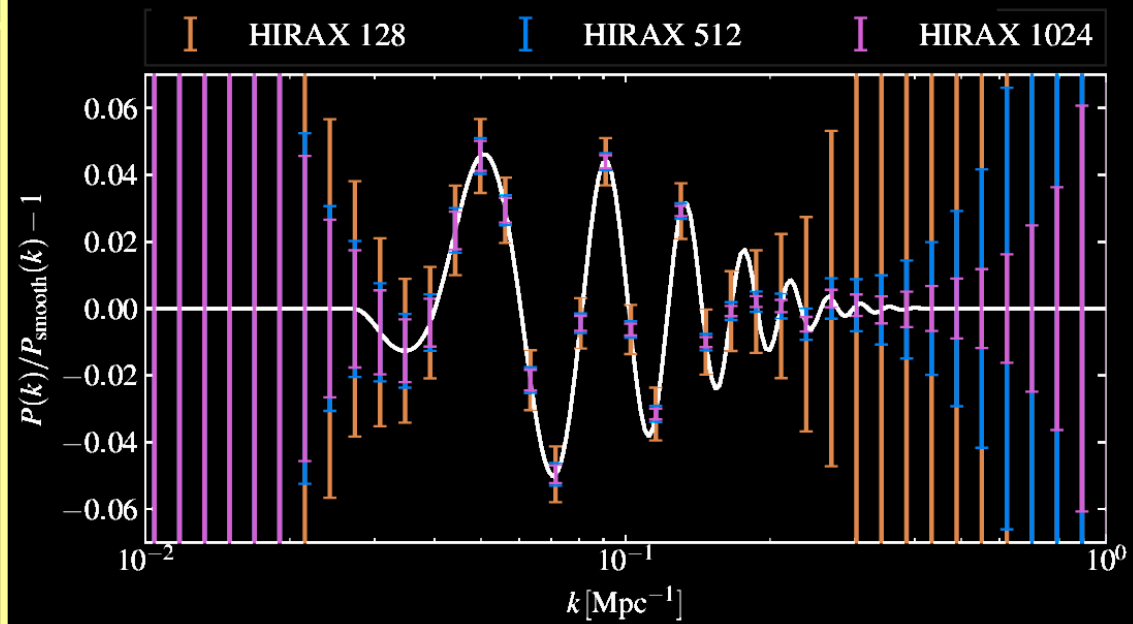


Parameter forecasts

Dark energy constraints 4 year survey (50% eff.), 15,000 deg²



BAO power spectrum constraints



Dark energy figure of merit:

HIRAX 128 : 9

HIRAX 512 : 103

HIRAX 1024 : 285

Fast radio bursts

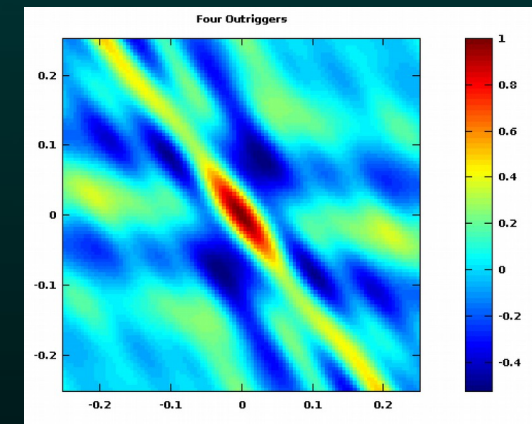
- Fast radio bursts: short (\sim ms), bright (\sim Jy) radio transients. Distances are likely cosmological because of observed dispersion.
- Fast de-dispersion code developed for HIRAX and tested on archival GBT data: bonus detection!
- HIRAX: estimated \sim 10 FRB detections per day, possible coordinated observations with HERA

Outrigger stations:

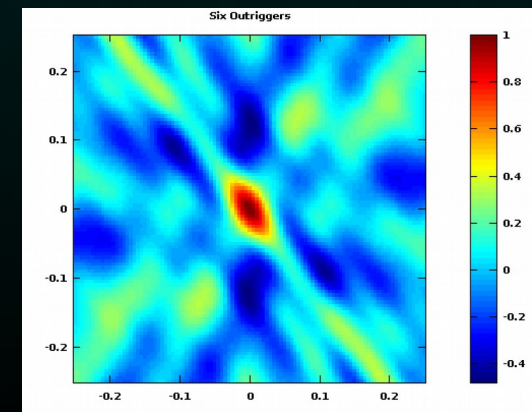
\sim 1000 km baselines for VLBI positions for HIRAX events



4 outriggers



6 outriggers



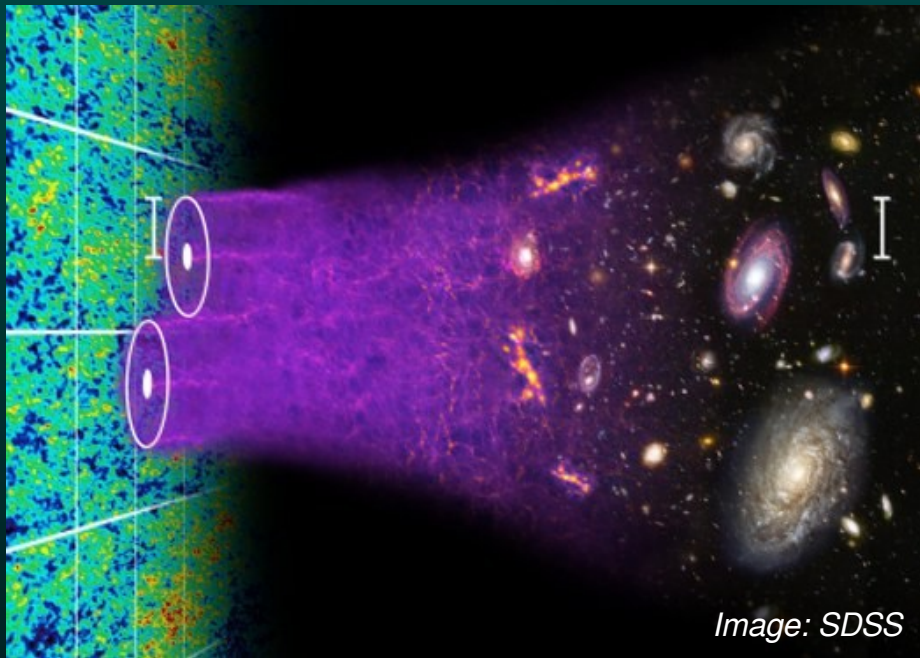
Summary & future prospects



- HIRAX will do hydrogen intensity mapping to study BAOs and the universe's expansion history at $0.8 < z < 2.5$
- Eight element prototype is being commissioned at HartRAO, have obtained first fringes
- Next phase: 128 elements in the Karoo, aiming for 2019
- Outrigger station site testing has begun

Extra slides

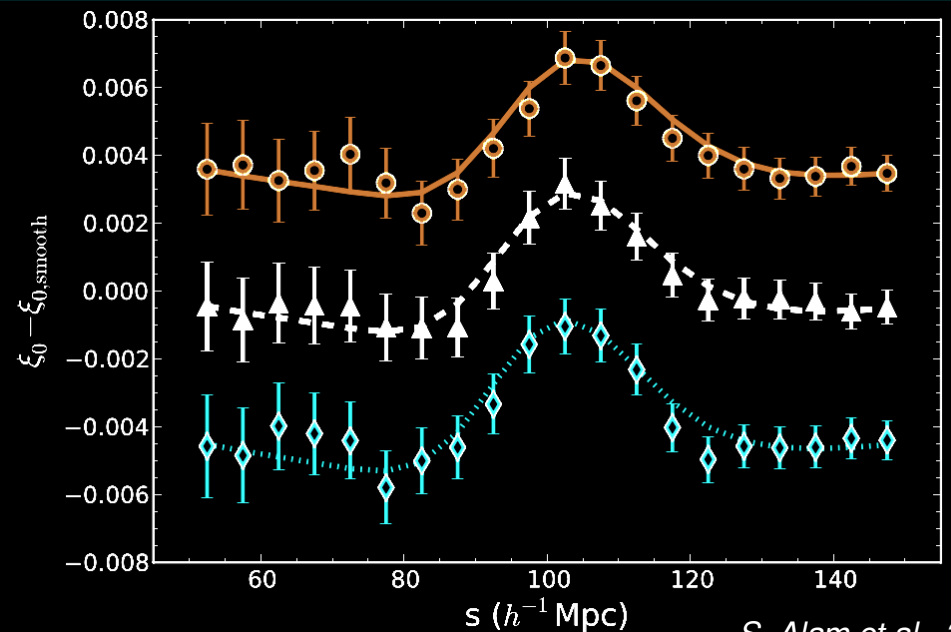
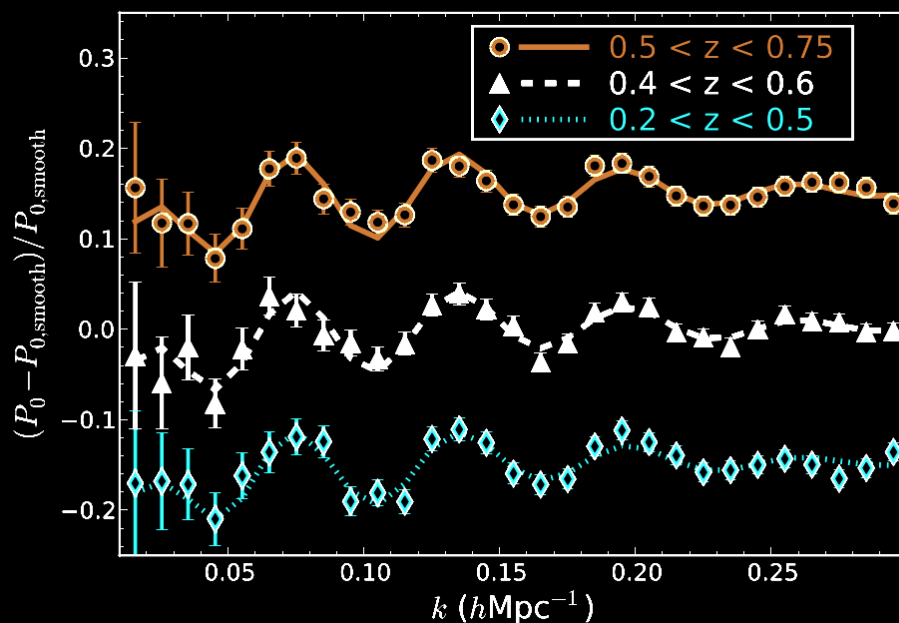
Baryon acoustic oscillations



Galaxy positions “remember” acoustic waves from the early universe: sound horizon sets characteristic 150 Mpc scale

Measure galaxy positions → should see ripples in the power spectrum, peak in the correlation function

DR12 release from SDSS-III shown below, redshift range $0.2 < z < 0.75$



Required specs for BAO intensity mapping



- Maximize sensitivity on scales of interest
→ Use compact array geometry
- Redshift range of interest: $0.8 < z < 2.5$ to capture dark energy domination at $z \sim 2$
→ Required frequencies: 400 – 800 MHz
- BAO 150 Mpc angular scale: 3 – 1.3 degrees at $0.8 < z < 2.5$
→ Required baseline lengths: 15 – 60 meters
- BAO scale along line of sight: 20 – 12 MHz at $0.8 < z < 2.5$
→ Required freq resolution: minimum ~ 100 channels, more for foregrounds and higher order peaks
- BAO signal level: ~ 0.1 mK
→ Low system temperature, large collecting area

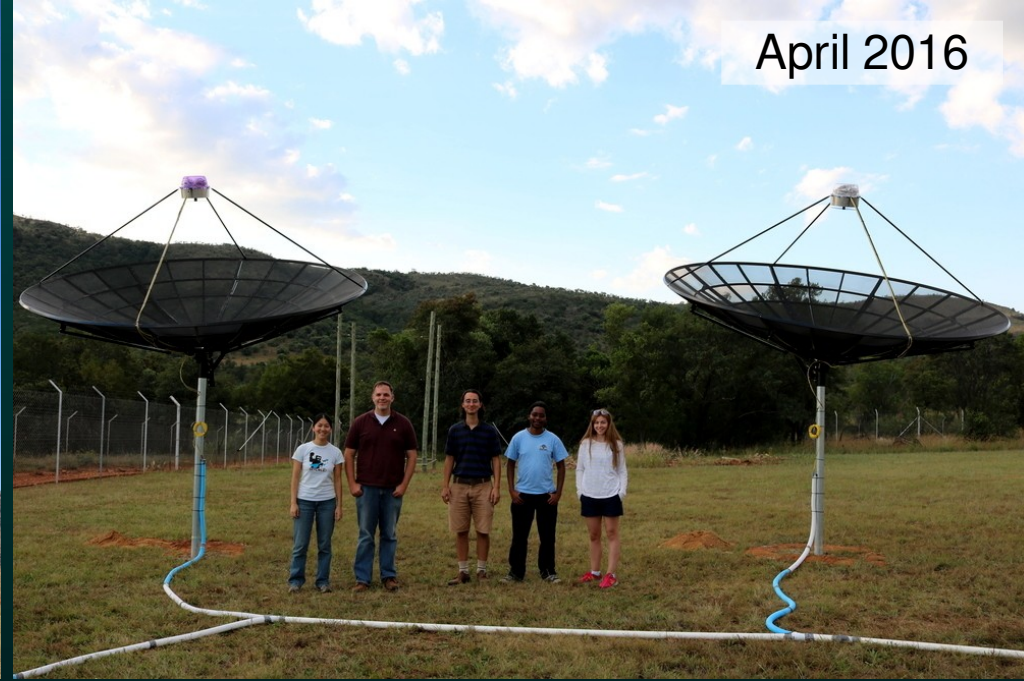
Complementarity with CHIME



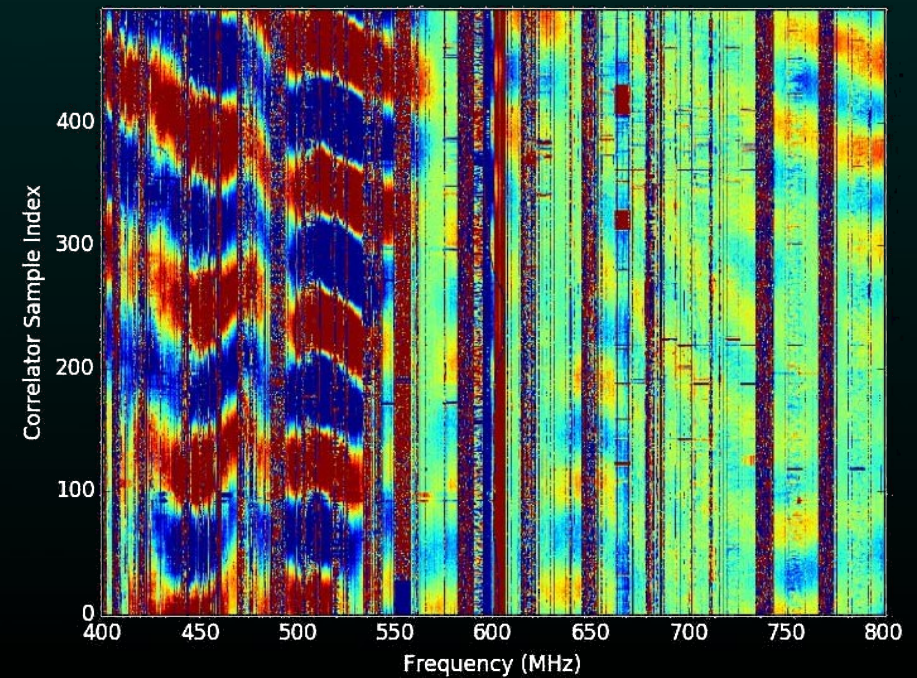
	CHIME	HIRAX
Site	DRAO, Canada	Karoo (lower RFI, no snow)
Telescope	Cylinder array	Dish array (different systematics)
Field of view	100° NS, 1° – 2° EW	5° – 10° deg
Beam size	0.23° – 0.53°	0.1° – 0.2°
Collecting area	8000 m ²	28,000 m ²
Sky coverage	North	South

↑
Optical surveys in the south, esp. LSST: cross-correlate for foreground mitigation and other science. More pulsars in the south.

HartRAO four element 3.7m prototype



- HartRAO: moderately radio-quiet location, excellent infrastructure and support staff
- End-to-end test including 2 RFOF modules and 2 coax chains, first ICE board, GPU correlator
- From hardware install to first fringes: ~1 week



Calibration

- Galactic foregrounds >1000 times brighter than cosmological signal \rightarrow need to precisely characterize gains, phases, beam shapes...
- Quasi-redundant calibration developed for HIRAX, will be tested soon
- Beam measurements: developing drone calibrator in collaboration with HERA (Danny Jacobs; ECHO)
- Far field is 100 – 200 meters for HIRAX, easy to achieve; long flight times with moderate payload mass are more difficult
- First mapping tests will happen soon at HartRAO with HIRAX-8



Parameter forecasts

