The Hydrogen Intensity and Real-time Analysis eXperiment: Mapping the Southern Sky (in 21cm emission)

Kavilan Moodley (UKZN) for the HIRAX Collaboration

Cosmic Visions Dark Energy Workshop, LBNL

14 November 2017

Overview

- Multi-institutional international collaboration
- Current flagship project funding (~$1.5M) from UKZN and South African NRF/DST - (more than) sufficient for 128 elements
- Applying for further NRF funding to build up to 512 elements
- Goal: build 1024 6m dishes operating at 400-800 MHz, nominal 4 year survey
- To be sited in the Karoo Radio Astronomy Reserve in SA

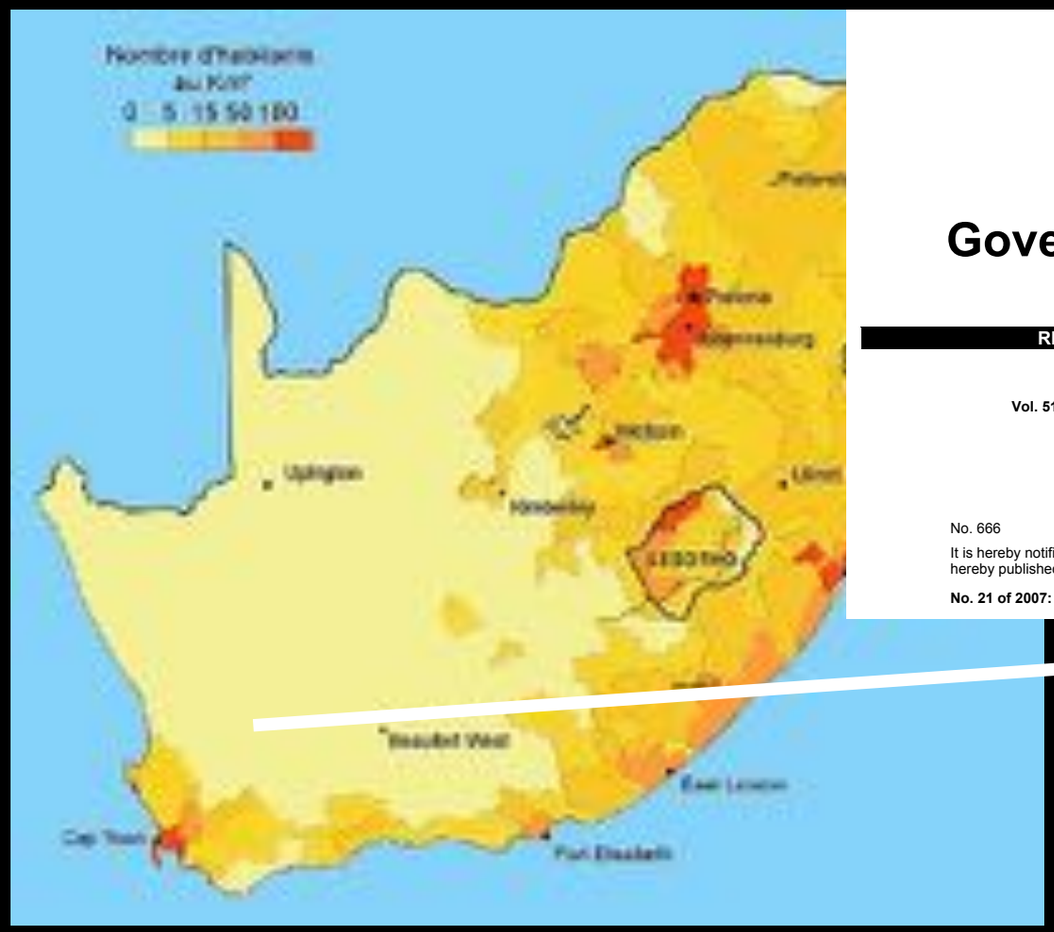
UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

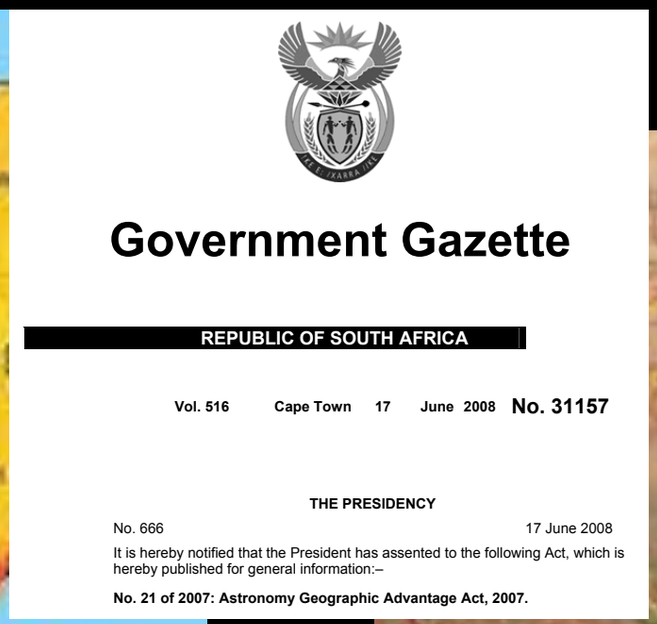
Astrophysics & Cosmology Research Unit
ACRU

Kavilan Moodley (UKZN)
for the HIRAX Collaboration

HIRAX

Karoo Astronomy Reserve





Government Gazette

REPUBLIC OF SOUTH AFRICA

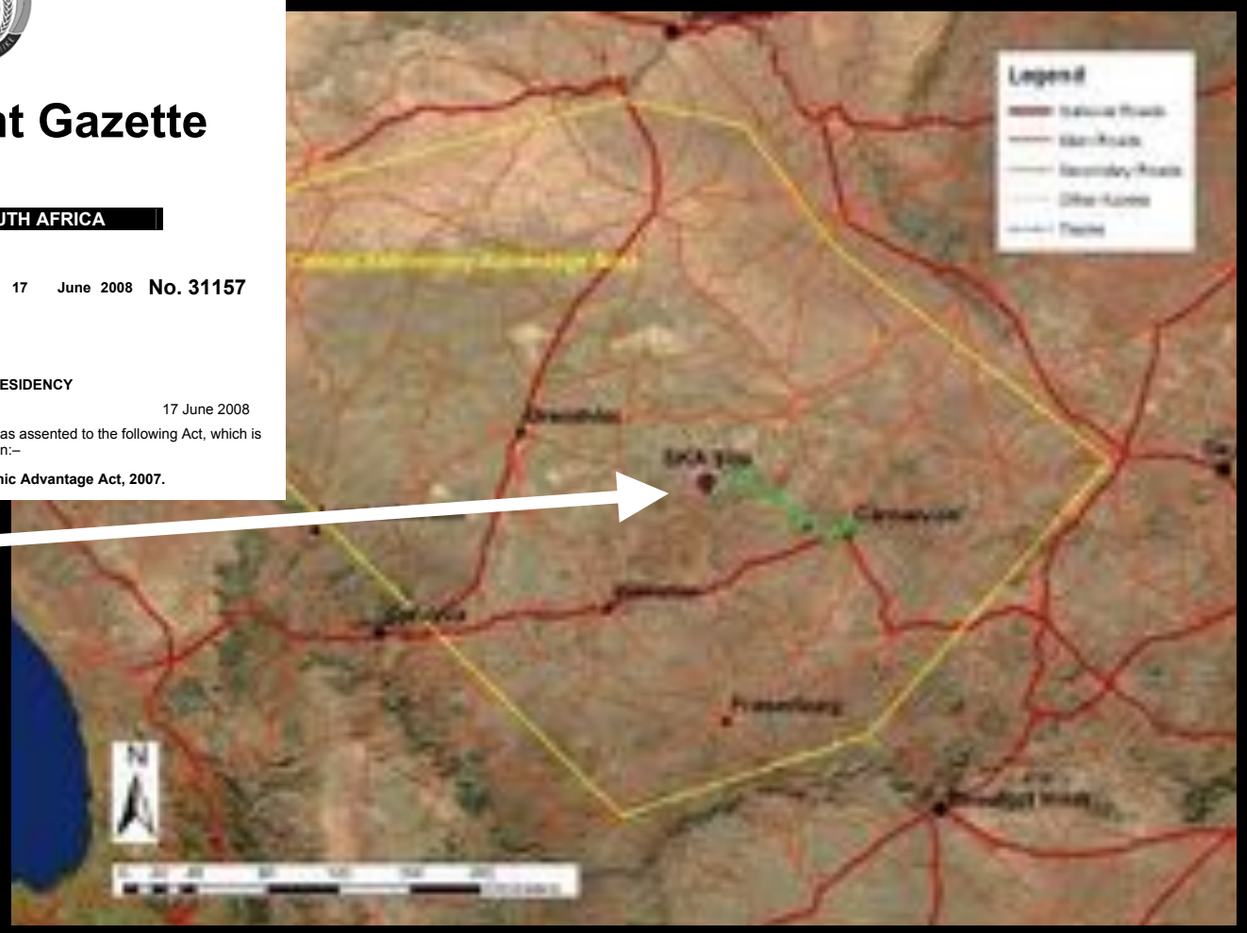
Vol. 516 Cape Town 17 June 2008 No. 31157

THE PRESIDENCY

No. 666 17 June 2008

It is hereby notified that the President has assented to the following Act, which is hereby published for general information:–

No. 21 of 2007: Astronomy Geographic Advantage Act, 2007.



- Karoo astronomy reserve protected by Astronomy Geographic Advantage Act.
- Investment in site infrastructure for MeerKAT and SKA - roads, power, data line.

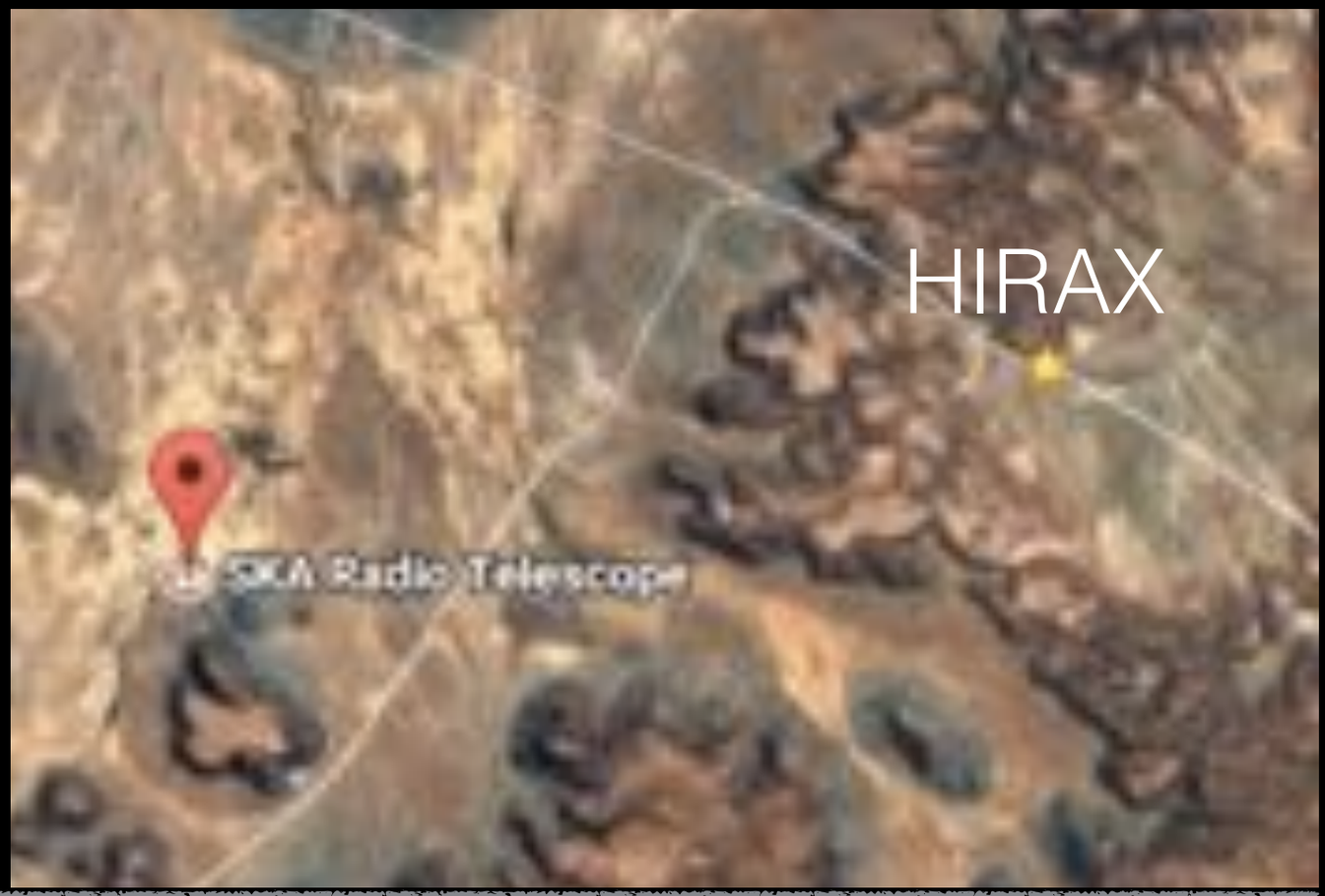
UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

Astrophysics & Cosmology Research Unit ACRU

Kavilan Moodley (UKZN)
for the HIRAX Collaboration

HIRAX

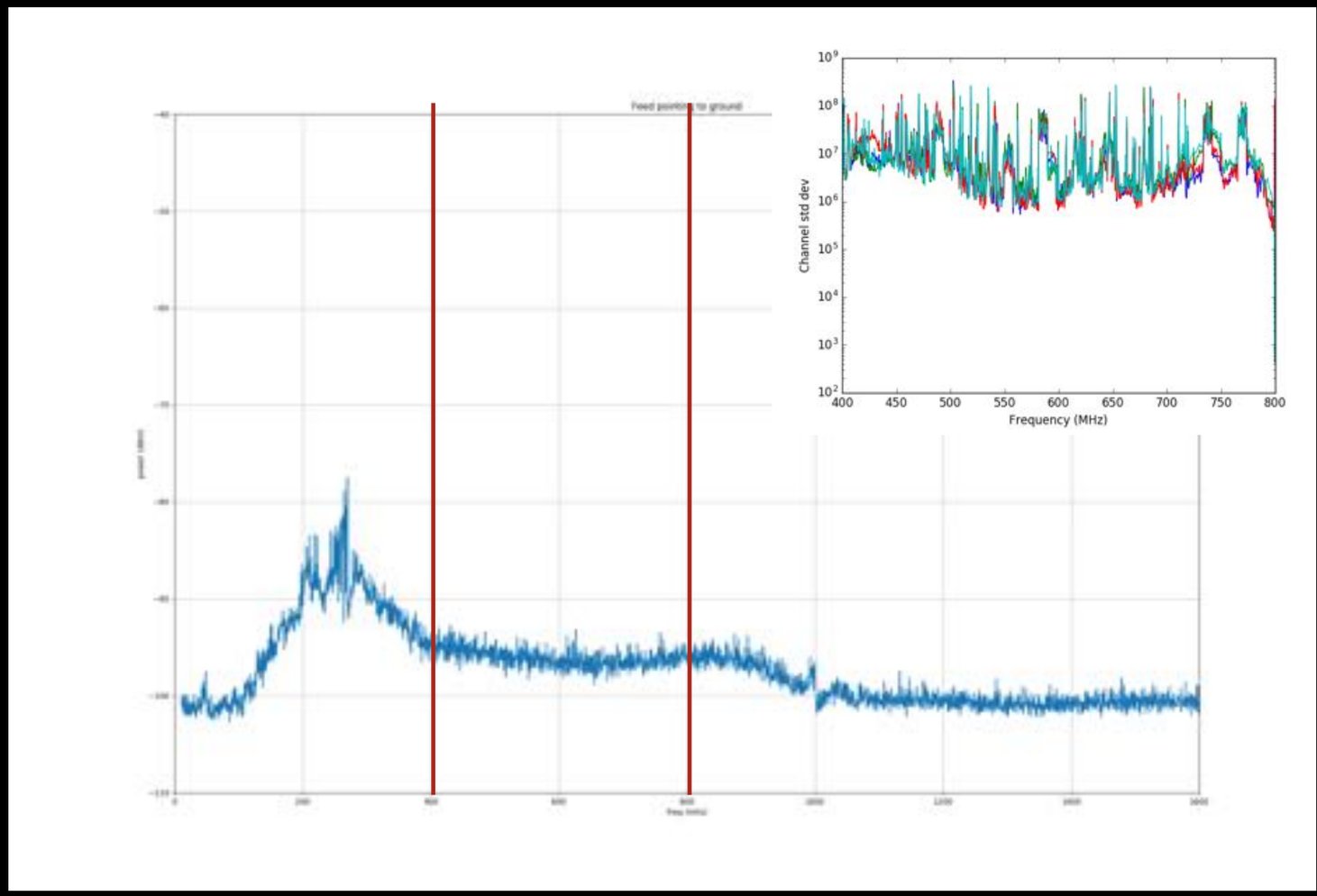
Site



Kavilan Moodley (UKZN)
for the HIRAX Collaboration

Site RFI

Jeff Peterson at HIRAX site in Karoo. Conditions look spectacular! (Inset - interference at HartRAO)



UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit
ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

Telescope

Frequency Range	400–800 MHz
Frequency Resolution	390 kHz, 1024 channels
Dish size	6 m diameter, f/D=0.25
Interferometric layout	32×32 square grid, 7 m spacing
Field of View	15 deg^2–56 deg^2
Resolution	∼5'–10'
Beam Crossing Time	17–32 minutes
System Temperature	50 K

Newburgh et al (1607.02059)

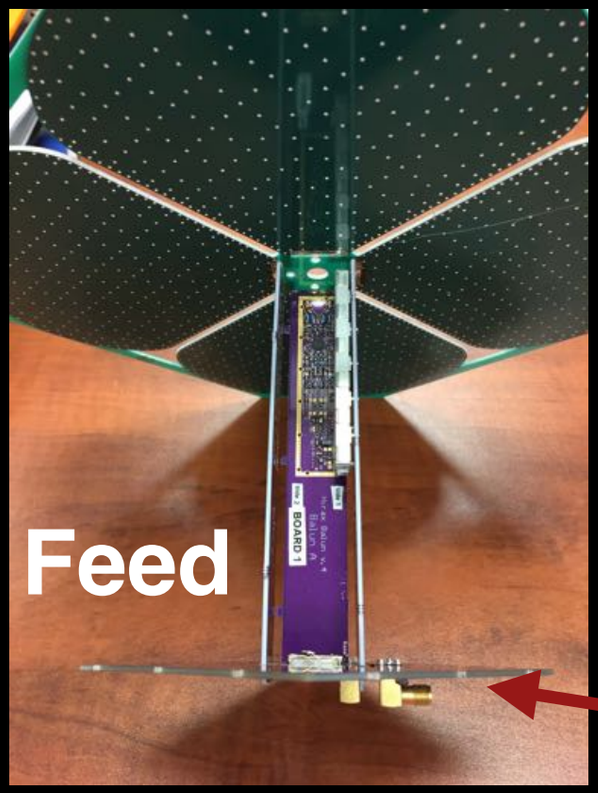
UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

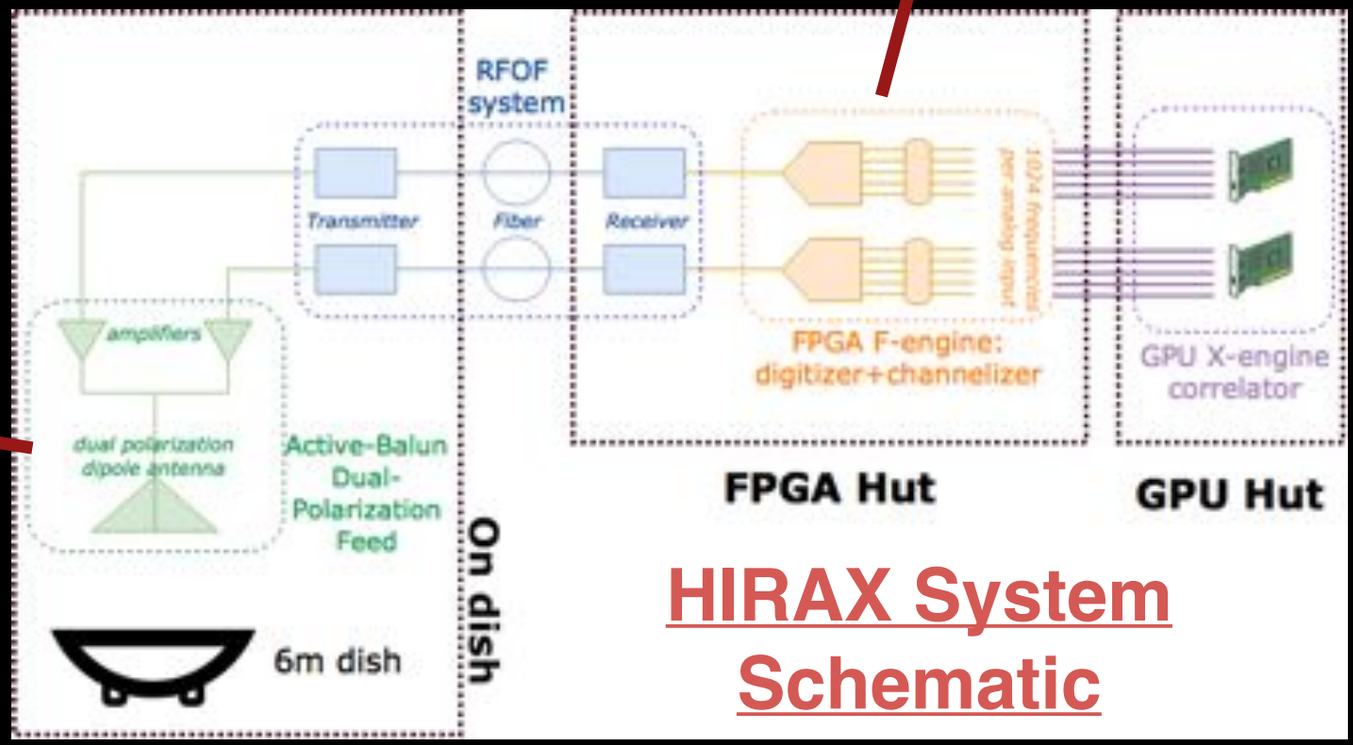
Design Plan

- 1024 close-packed 6m dishes.
- Operate between 400-800 MHz, 1000 channels
- Channelizing on FPGA ICE boards (Matt Dobbs, McGill)
- Correlation on GPUs (Keith Vanderlinde, Toronto).
- Dishes tilt N/S: when “deep enough” on a strip, tilt over to increase f_{sky}. Get to $f_{sky} \sim 0.35$ in 4 years.
- Beamform in correlator for FRBs; small subset of beams (~20) to external processing for pulsar search + monitoring, HI absorbers…

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

Instrumentation





HIRAX System Schematic

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

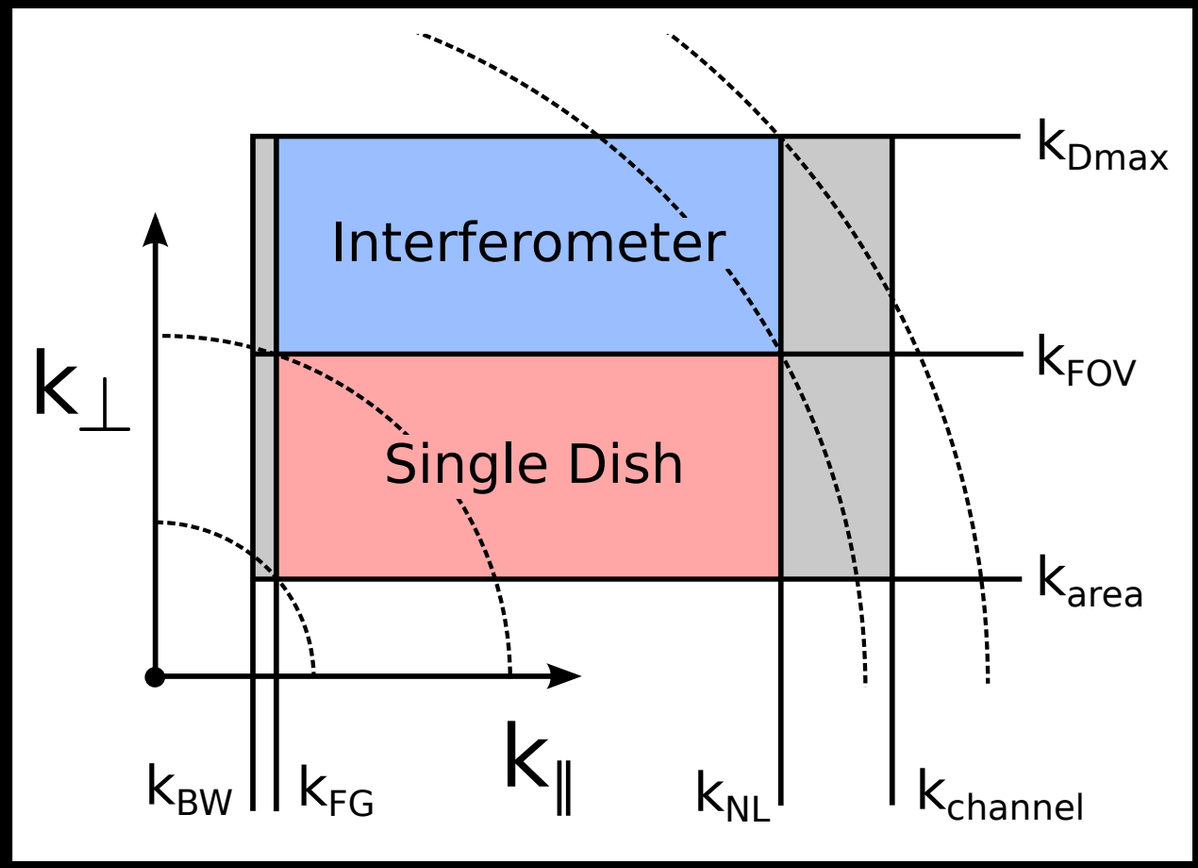
Astrophysics & Cosmology Research Unit ACRU

Kavilan Moodley (UKZN)
for the HIRAX Collaboration

HIRAX

Cosmological Modes

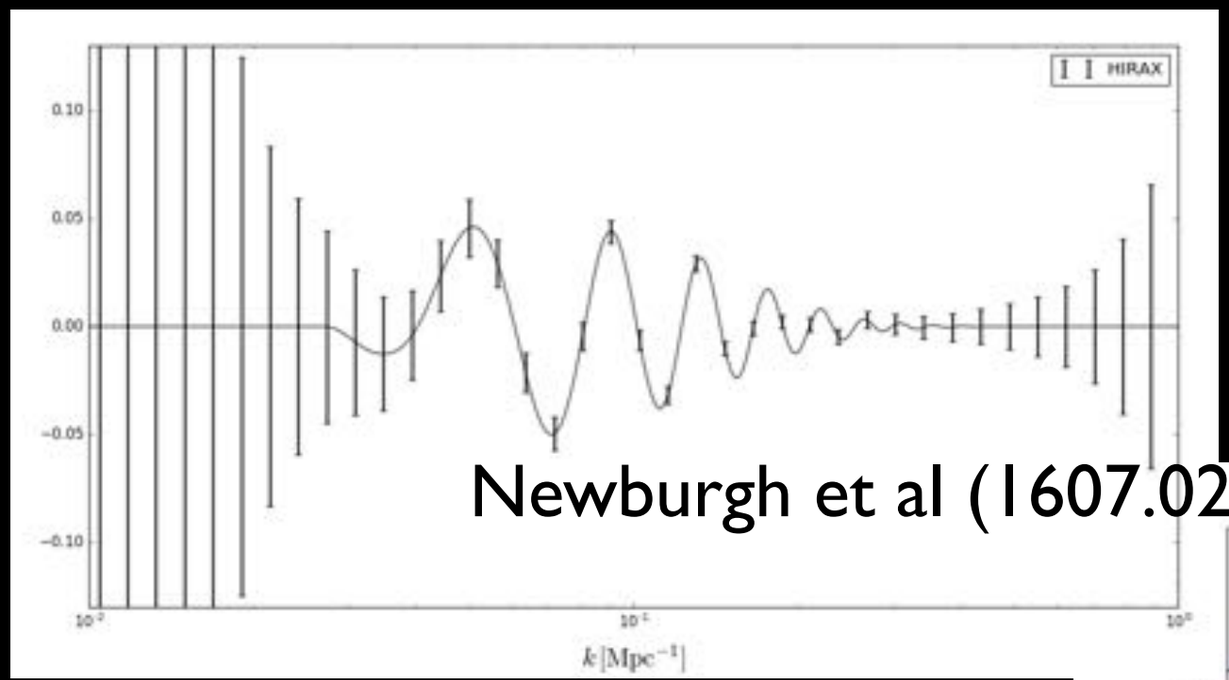
- Wide redshift coverage: z ~ 0.8 : 2.5
- Survey area: target ~15,000 deg^2
- Angular coverage: ℓ ~ 40 - 2000 ; k_{perp} ~ [10^{-2}, 1] h Mpc^{-1} at z~1
- Frequency coverage: y ~ 20 - 20000 ; k_{par} ~ [10^{-3}, 1] h Mpc^{-1} ; limited by foregrounds and nonlinearities.
- Sensitivity: 12 uJy/beam daily, 1 uJy/beam full survey



Bull et al (1405.1452)

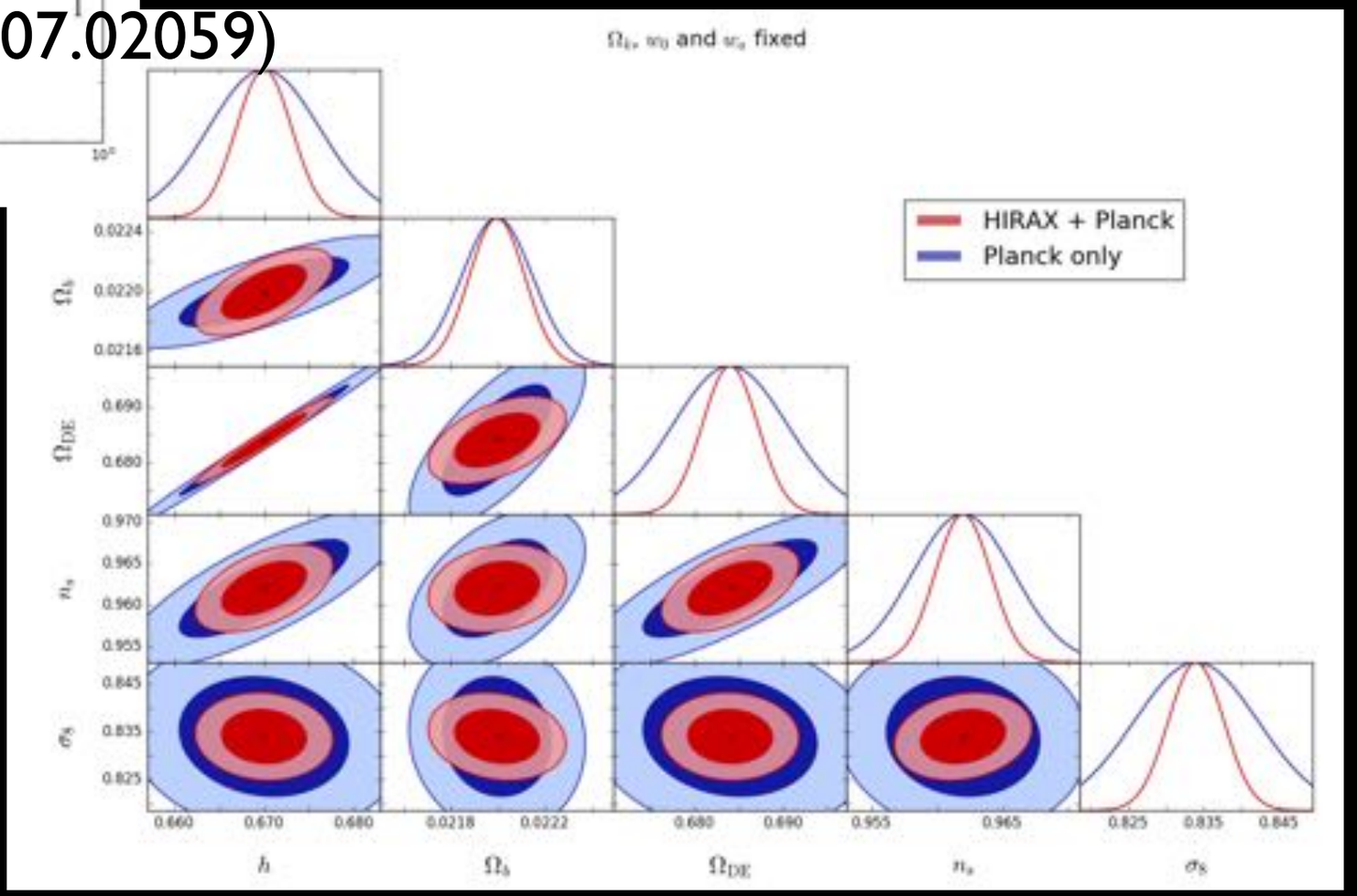
UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

BAOs and Cosmology



Newburgh et al (1607.02059)

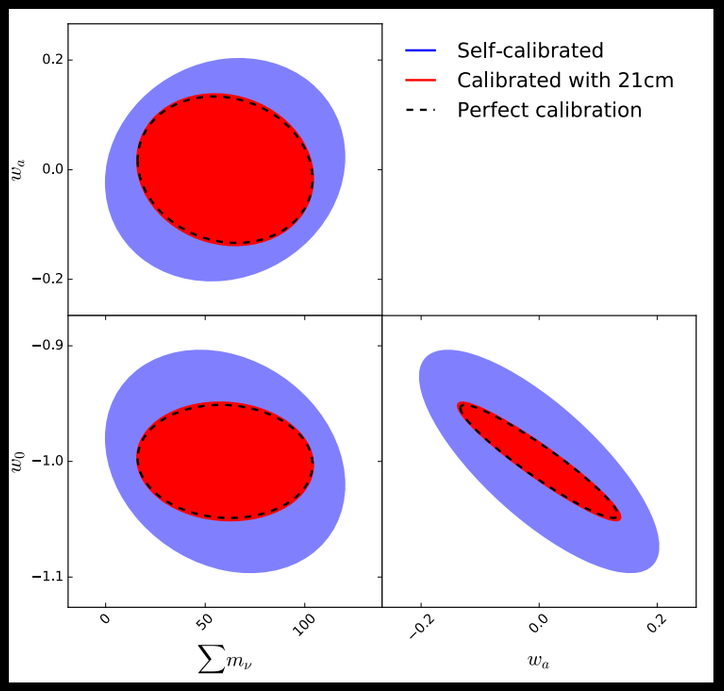
10,000 hr survey with 1024 element forecast with fsky=0.05. Aim is to complete 4 year survey with fsky~0.35.

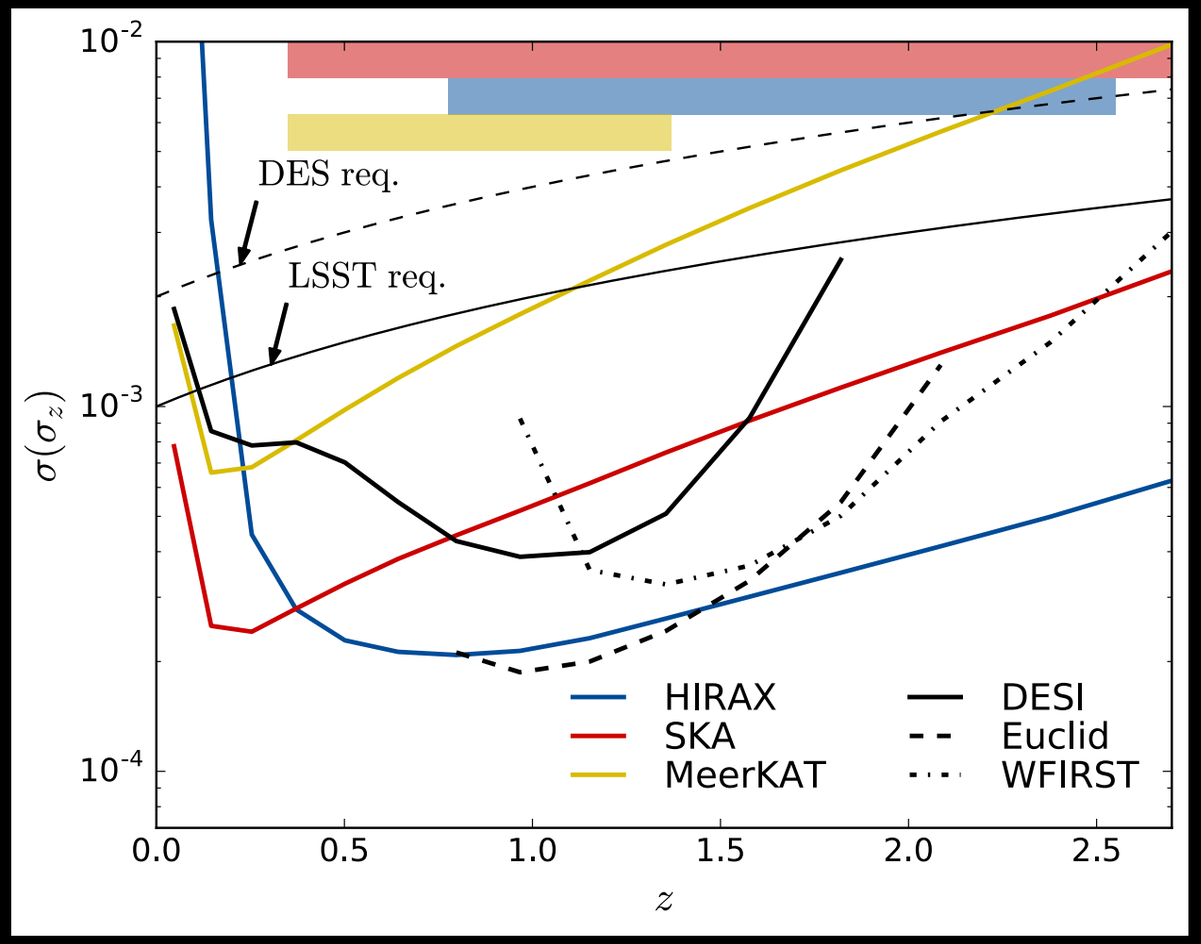


Kavilan Moodley (UKZN)
for the HIRAX Collaboration

Photo-z calibration

- Cross-correlation with LSST photometric survey can provide photo-z calibration via the clustering redshifts method (Alonso et al, 1704.01941) and improve parameter constraints.

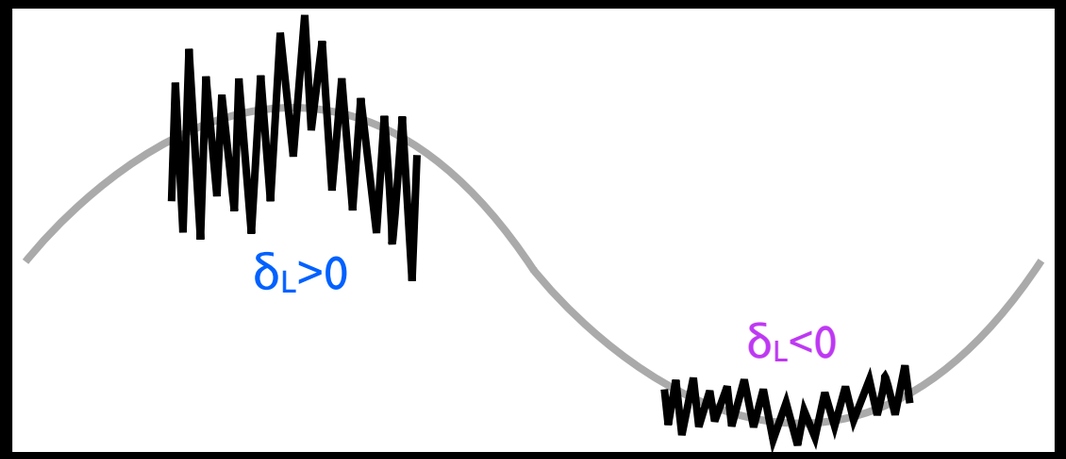


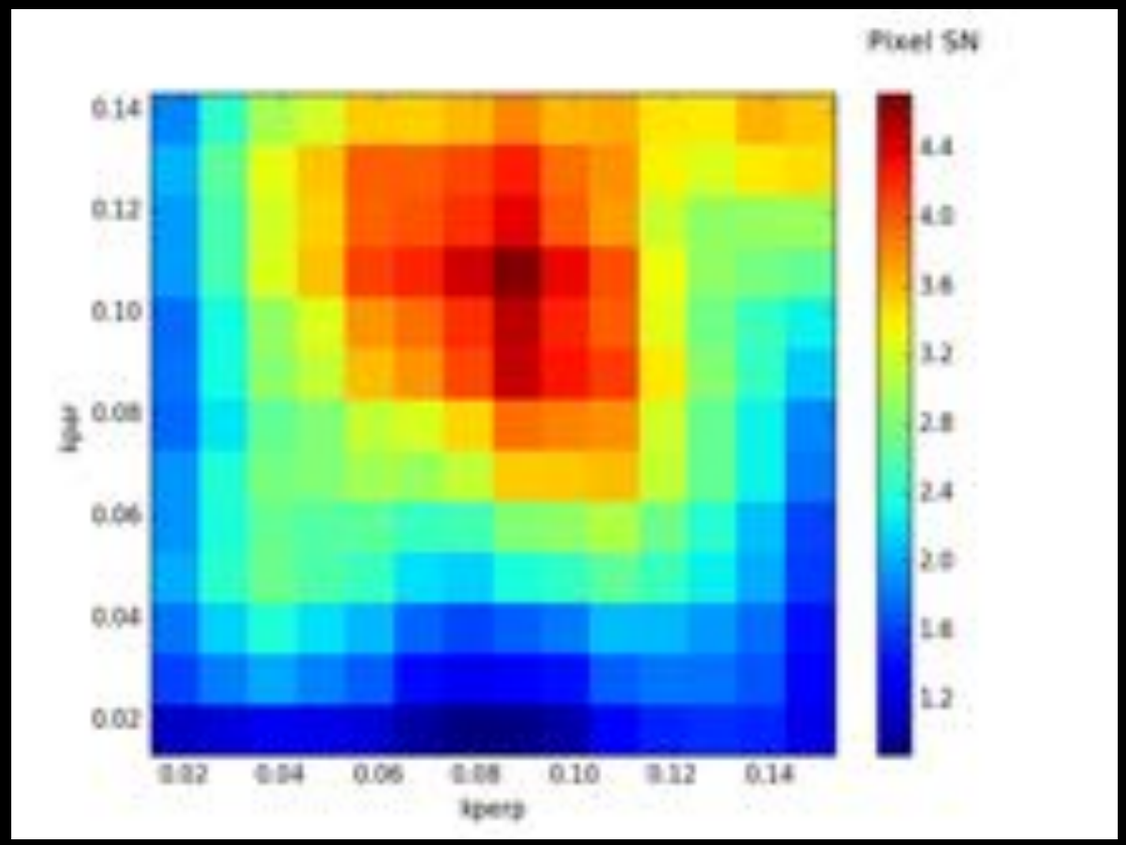


Kavilan Moodley (UKZN)
for the HIRAX Collaboration

21cm-CMB lensing cross-correlation

- Direct 21cm-CMB lensing correlation vanishes because of loss of low k_{par} 21cm modes
- Construct a bispectrum estimator that uses two copies of the 21cm intensity field and one copy of the CMB lensing field.
- Estimator relies on modulation of small-scale 21cm modes by large-scale (super-sample) modes to recover the line-of-sight long wavelength modes that are required for correlation with CMB lensing.
- Signal to noise is promising - can derive useful cosmological constraints (Moodley et al *in prep*).





UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

HIRAX Prototype @ HartRAO

Top Left: HartRAO technician Andrew Masiteng, UKZN PhD student Onkabetse Sengate and UKZN MSc student Kabelo Kesebonye assemble 6m dish

Top Middle: Yale student Emily Kuhn and HartRAO technician Jacques Grobler Install feeds.

Top Right: Onkabetse Sengate, Nivek Ghazi and Cynthia Chiang work on RFI testing, while Austin Gumba works on RF over fibre.

Right: Jon Sievers, Ben Saliwanchick,Jeff Peterson pose with just-assembled dish.

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

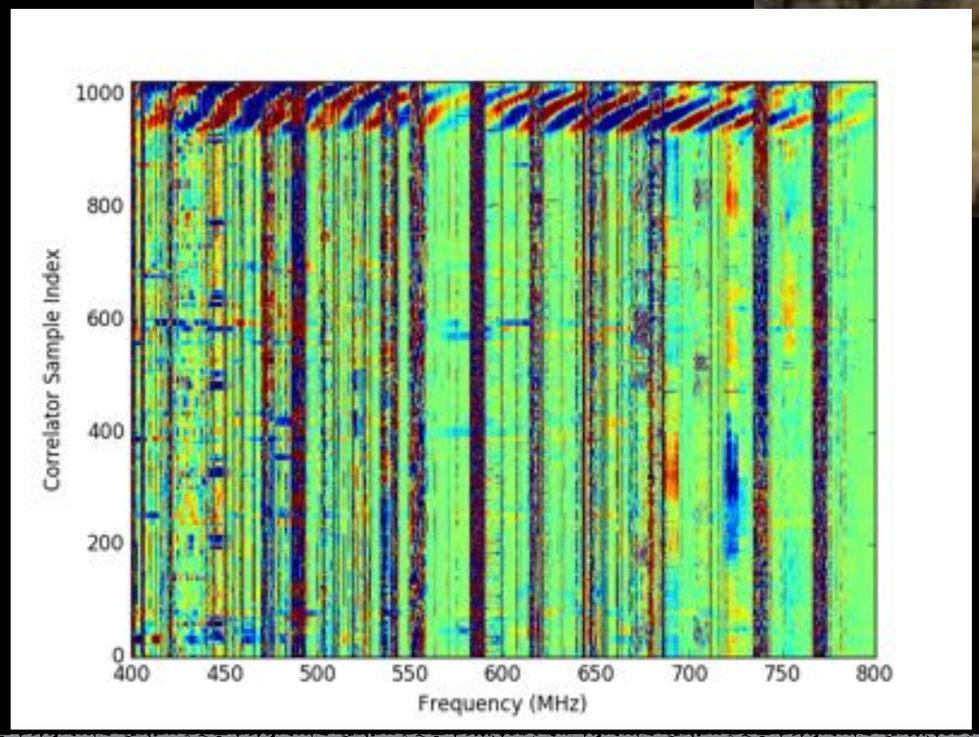
Astrophysics & Cosmology Research Unit
ACRU

Kavilan Moodley (UKZN)
for the HIRAX Collaboration

HIRAX

HIRAX Prototype @ HartRAO

- All eight dishes fully instrumented.
- Six dishes currently taking data.

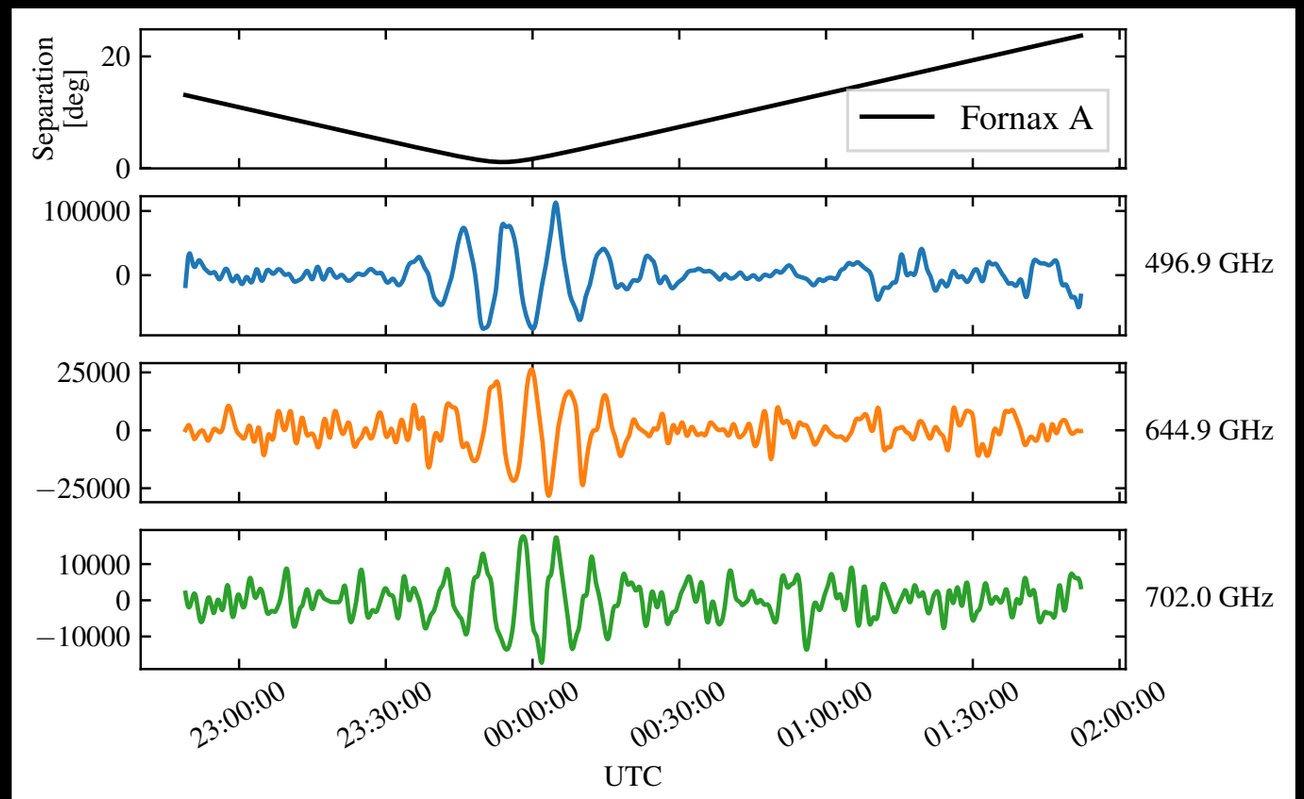


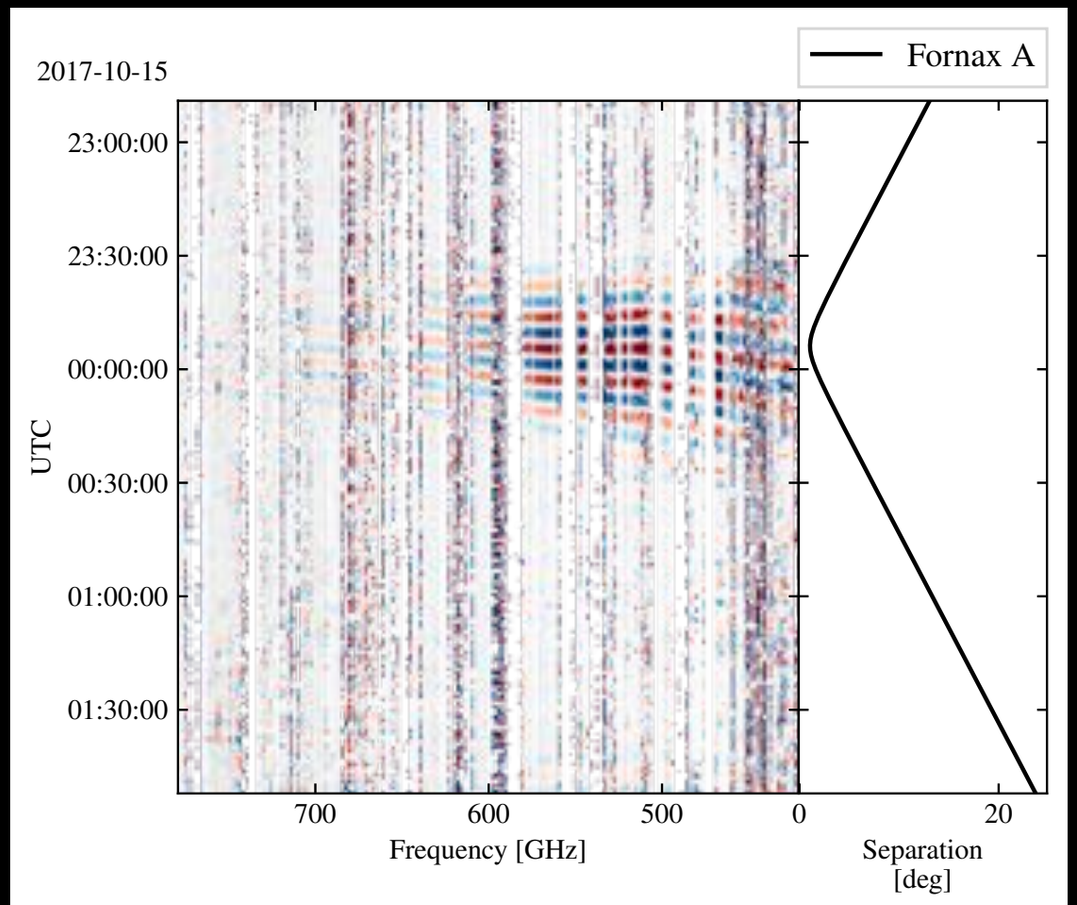
Devin Crichton &
Heiko Heilgendorff

Kavilan Moodley (UKZN)
for the HIRAX Collaboration

Prototype Data Analysis

- We see fringes!
- Currently characterizing instrumental properties from the data





UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI
Astrophysics & Cosmology Research Unit ACRU
Kavilan Moodley (UKZN)
for the HIRAX Collaboration
HIRAX

Current Status & Plans

- Funded for 128+ elements. Applying for funding to build up to 512 elements then 1024 elements.
- 8 elements built at HartRAO, with feeds.
- Core site in Karoo, construction can start Q3 2019
- In the interim plan to expand HartRAO to 32 dishes and build 2-3 outrigger stations. Will use f/D 0.25 dishes - currently being designed.
- HartRAO+outriggers should be enough to find ~1 FRB/ month *with accurate positions*.