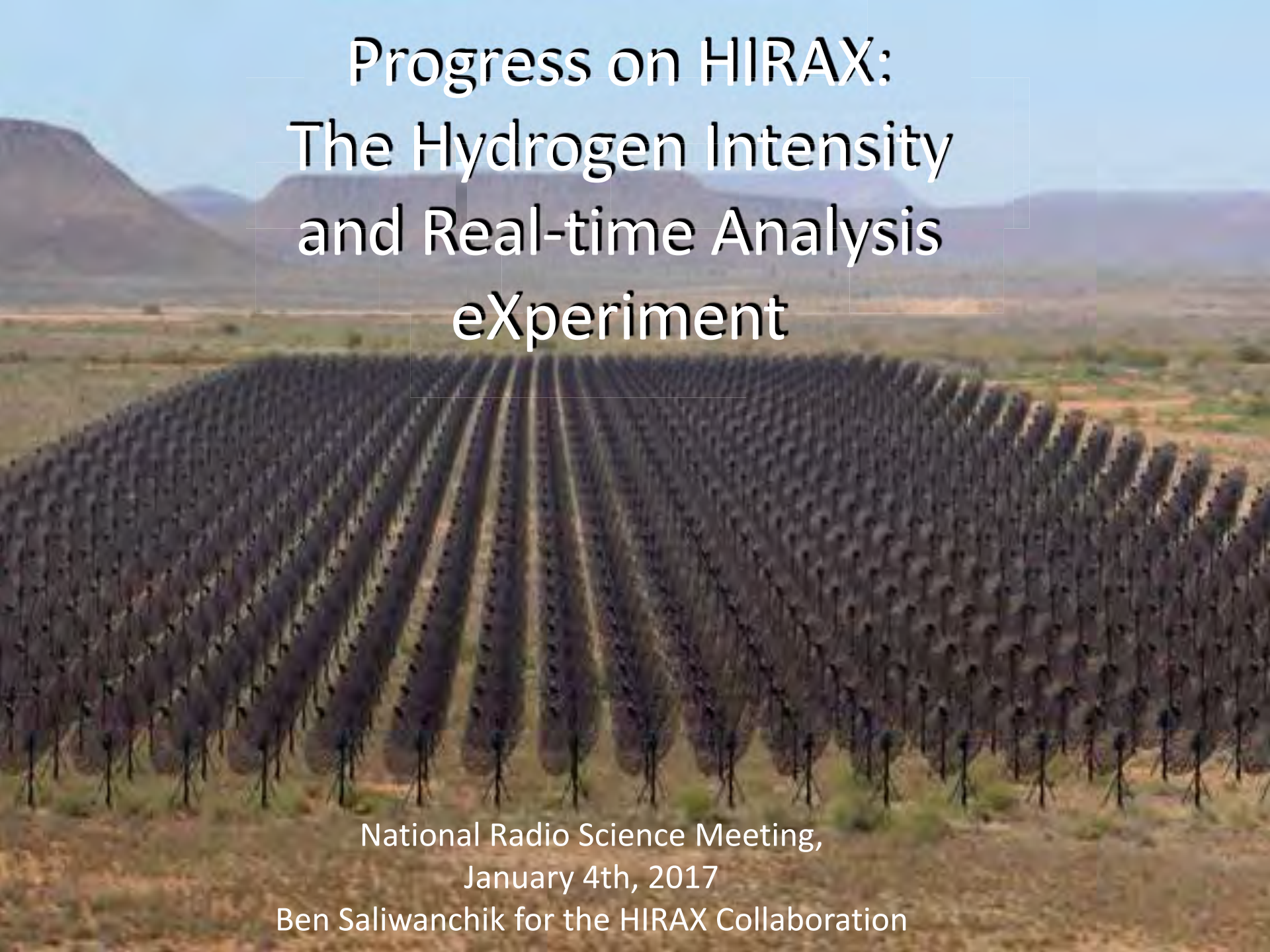
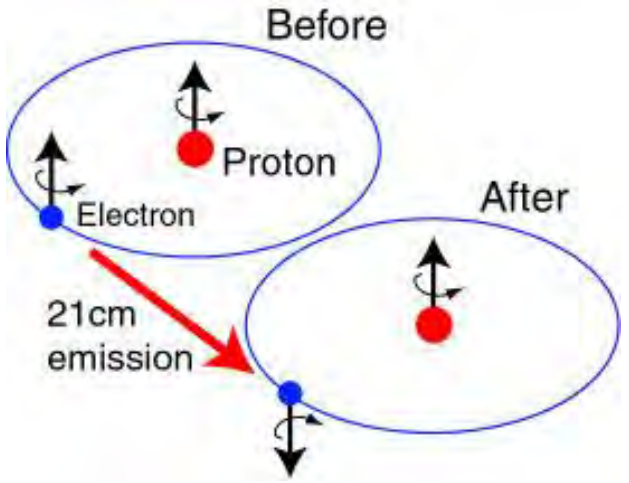
Progress on HIRAX: The Hydrogen Intensity and Real-time Analysis eXperiment



National Radio Science Meeting,
January 4th, 2017
Ben Saliwanchik for the HIRAX Collaboration

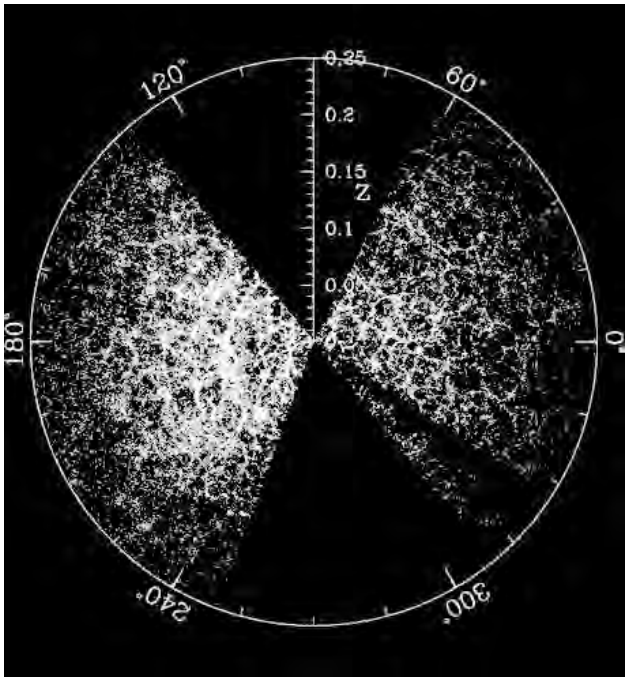
21 cm Line as Cosmological Probe

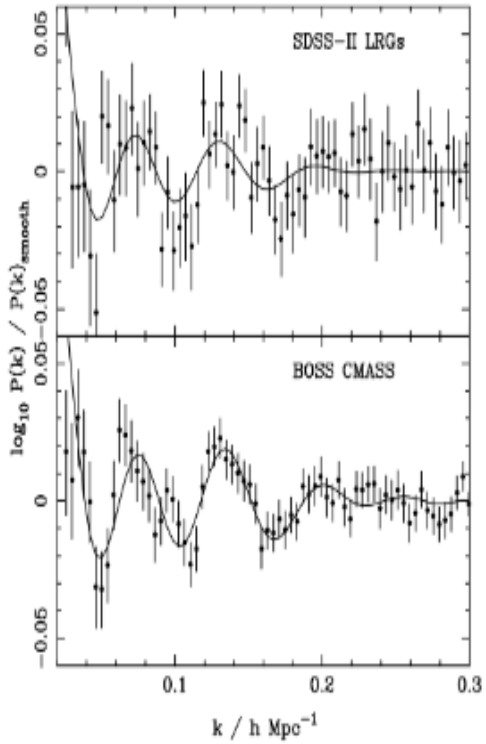
- 21 cm (1.4GHz) line becoming powerful cosmology probe.
- Hydrogen abundant, not much confusion from other lines.
- This is a “forbidden” transition, ~10Myr lifetime of excited state => observed frequency gives good measurement of redshift of emission.
- Can use 21 cm line to study history of matter and growth of structure in universe.



Baryon Acoustic Oscillations (BAO)

- Sound horizon at recombination produces characteristic length scale in density perturbations (~150 Mpc).
- Structures preferentially form in peaks of density field.
- Should see rings of correlation in galaxy positions.

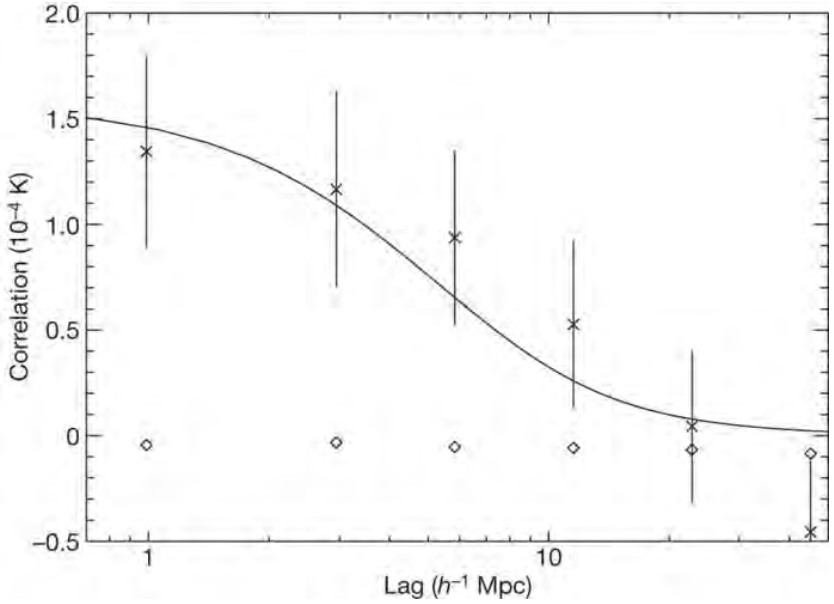




SDSS galaxy power spectrum (Image from SDSS).

Intensity Mapping

- Have ~10^5 L_* galaxies/BAO volume - individual galaxies not that important. Use aggregate signal from many galaxies with low resolution survey.
- Signal is O(0.1 mK), while galactic foreground is O(10^5 K)
- Sample variance limits => map sensitivity of 1-2μJy necessary



- First HI intensity mapping detection, DEEP2 density field x GBT HI brightness temperature cross correlation at z=0.8

T-C Chang *et al. Nature* **466**, 463-465 (2010) doi:10.1038/nature09187

HIRAX Collaboration

HIRAX Design and Goals

Instrument:

- 1024 close-packed 6-m stationary dishes (can be manually tilted)
- Operating frequency: 400 – 800 MHz, equivalent redshift = 0.8 – 2.5
- Survey area of 15,000 deg^2. Daily sensitivity of ~12μJy, repoint every 150 days, 4 years for full survey.

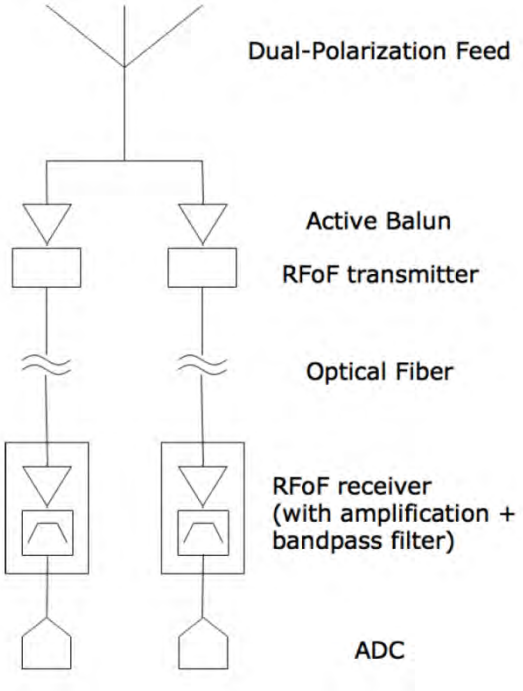
Science goals:

- Measure baryon acoustic oscillations with HI intensity mapping to characterize dark energy
- Radio transient searches
- Pulsar searches
- Neutral hydrogen absorbers
- Diffuse polarization of the Galaxy

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

Feed and Signal Chain

- Feeds are dual polarization cloverleaf dipole antenna based on CHIME feed
- Low loss (< 0.15dB) and small reflectivity (< -0.15dB) across wide band
- Consists of FR-4 dialectric (PCB) with metalized layer, PCB balun and support board.
- Ring choke circularizes beam, decreases crosstalk and ground spillover
- Fiber used to carry signal from dishes to correlator (~250m)
- ~70dB total gain, 50dB before RFoF Tx
- RFoF Tx relatively noisy, requiring high amplification before so that system noise is dominated by initial LNA.
- RFoF Rx also contains band defining 400-800 MHz filter.



Backend Electronics

- FX system, using FPGA ICE boards for channelization, GPUs for correlation.
- F-engine digitizes the input signals at 8-bit precision and channelizes to 1024 frequency channels. Each board handles 16 sky channels, 128 boards for full array.
- Data transferred from F to X engine with custom backplate which performs corner-turn operation. (Takes the channelized samples from individual inputs, and re-arranges and shuffles them into the format required for the X-engine, namely all sky inputs for a single frequency.)
- X-engine correlates all sky inputs for each of the 1024 frequency channels (4+4-bit precision), using GPU nodes.

Complementarity with CHIME

	CHIME	**HIRAX**
Site	DRAO, Canada	South Africa (lower RFI, no snow)
Telescope	Cylinder array	Dish array (easier to baffle)
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

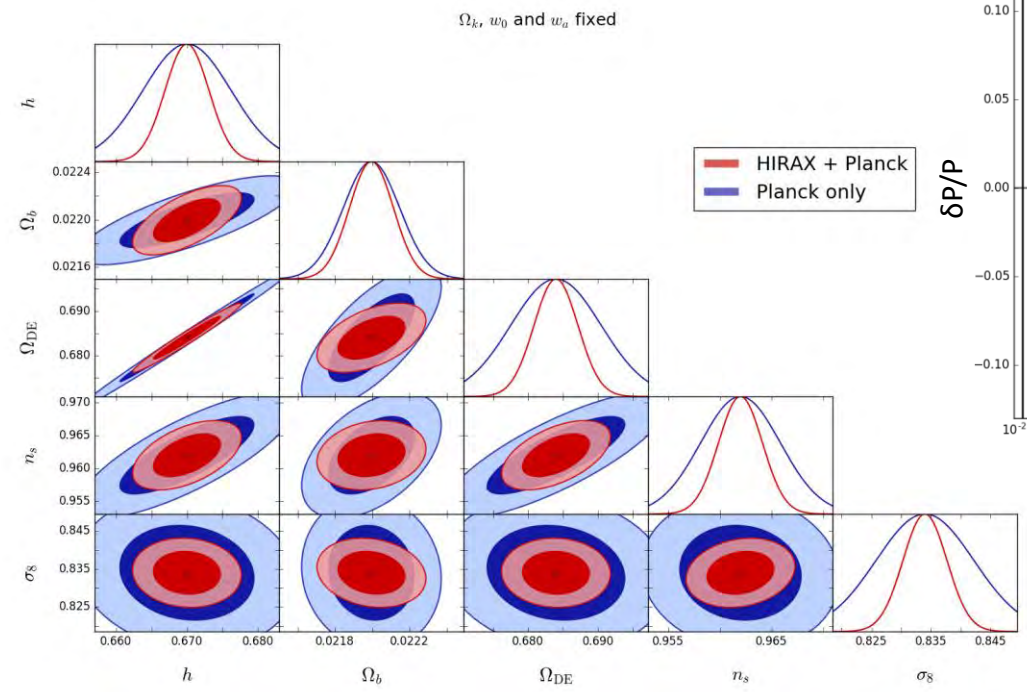
- Optical surveys in the south, esp. LSST: cross-correlate for foreground mitigation and other science. More pulsars in the south.

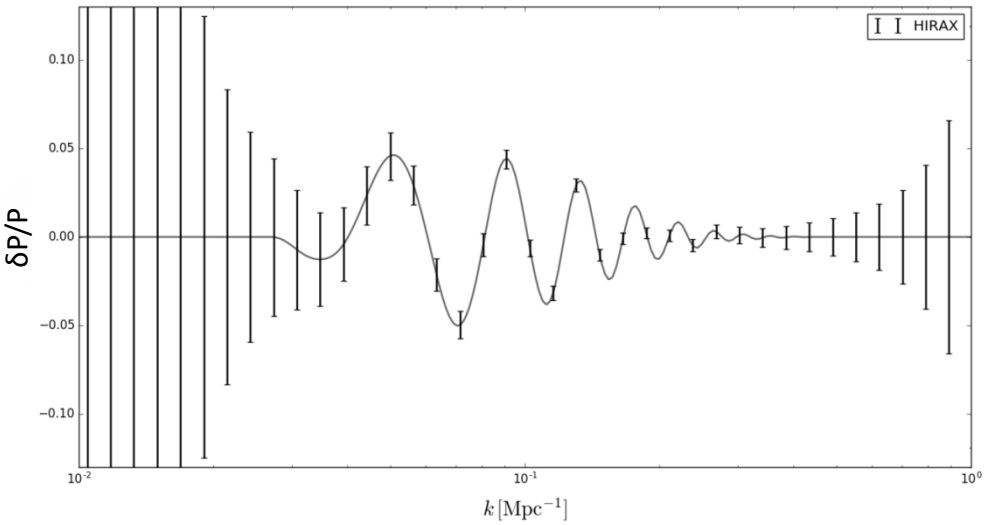
Calibration

- Currently using Mavrik drone, produced by Steadidron in SA. Can easily achieve far field. (For 6m dish, $2*D^2/\lambda$ is 100m at 400MHz, 200m at 800MHz)
- Valon 5009 dual frequency synthesizer. Frequency range of 23 MHz – 6 GHz. 20 MHz internal frequency reference, max output power +15 dBm.
- BicoLog 5070 broadband antenna. Frequency range of 50 MHz to 700 MHz, and an antenna factor of 20-33dB/m.
- ECHO software developed by Danny Jacobs and HERA for data taking and beam mapping.

Preliminary Parameter Forecasts

- Constraints based on 2000 sq deg survey with 1024 element array, 50K noise temperature, and 10,000 hours observing, with Planck priors.

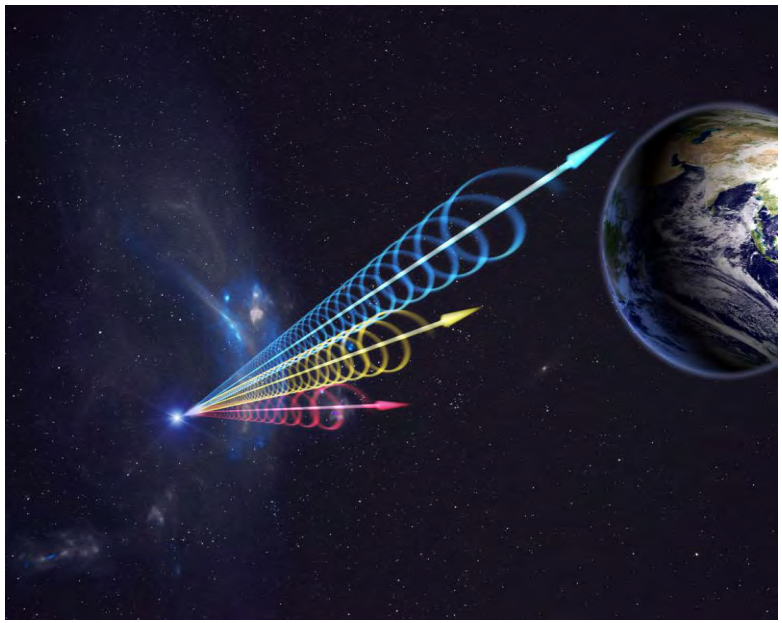


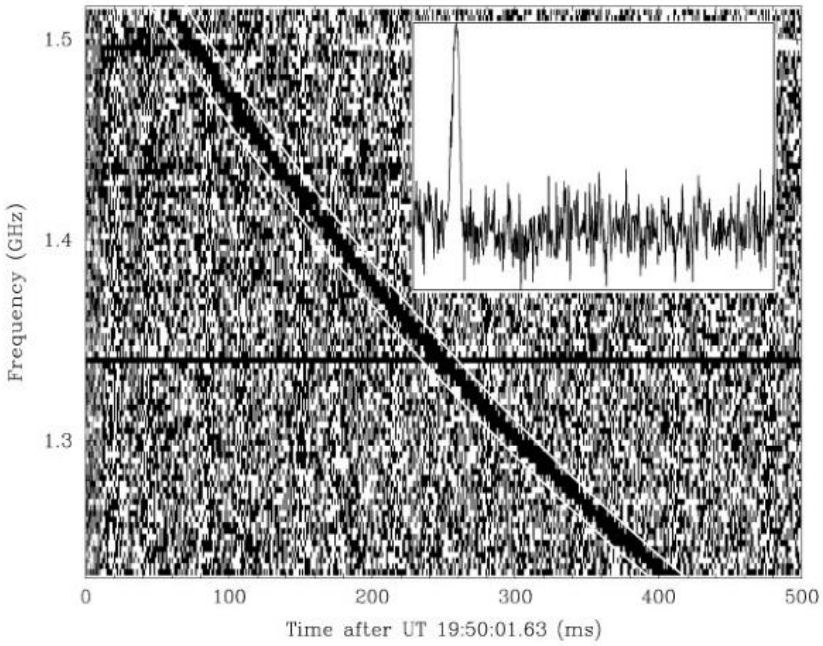


Newburgh et al. 2016
Plots by Amadeus Witzemann

Fast Radio Bursts

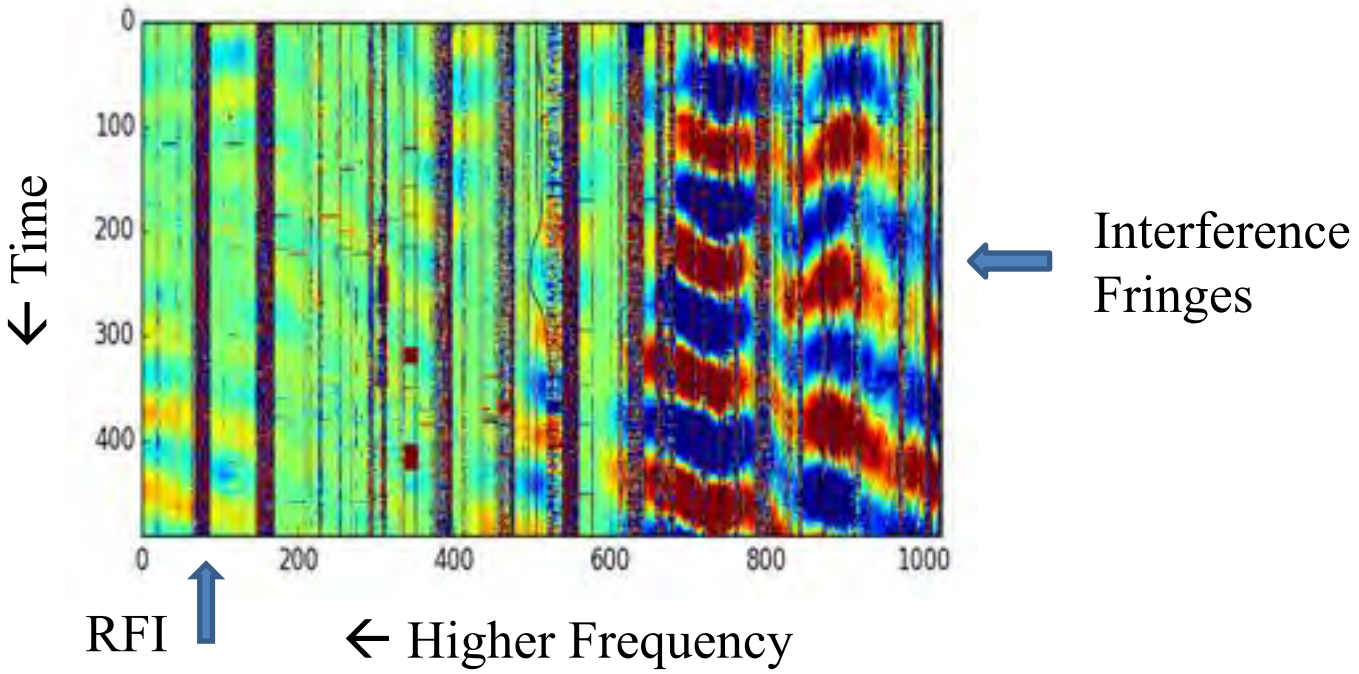
- Fast radio bursts: short (~ms), bright (~Jy) radio transients
- Distances are likely cosmological because of observed dispersion measure (integrated column density of free electrons between observer and source)
- Only ~20 detected to date, but total event rate is estimated to be 10^4 per day over full sky
- Event rate prop. to D_dish*N_beams, so should find dozens per day.





4-element Array

- Deployed four 3.7m dishes at HartRAO site in May.
- First test of complete hardware chain.
- First fringes!

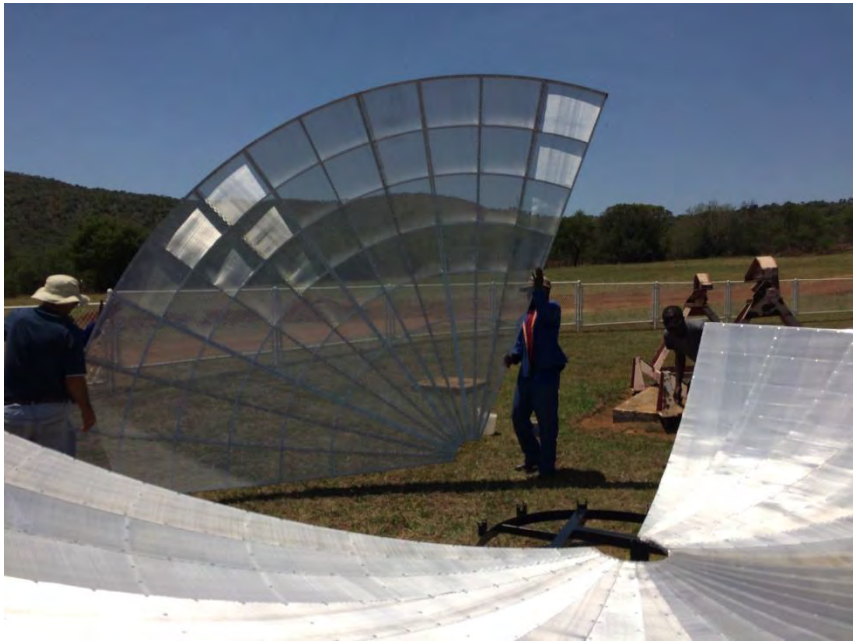


8-element Array

- Currently deploying 8-element array with first 6m dishes.
- Array surveyed and support posts installed in mid-December, dish installation and instrumentation in late January.

8-element Array

- 6m dishes produced by Beifang in China.
- Will also test new active balun feed design.
- 8-element array tests will inform future hardware revisions, surveying and installation best practices.

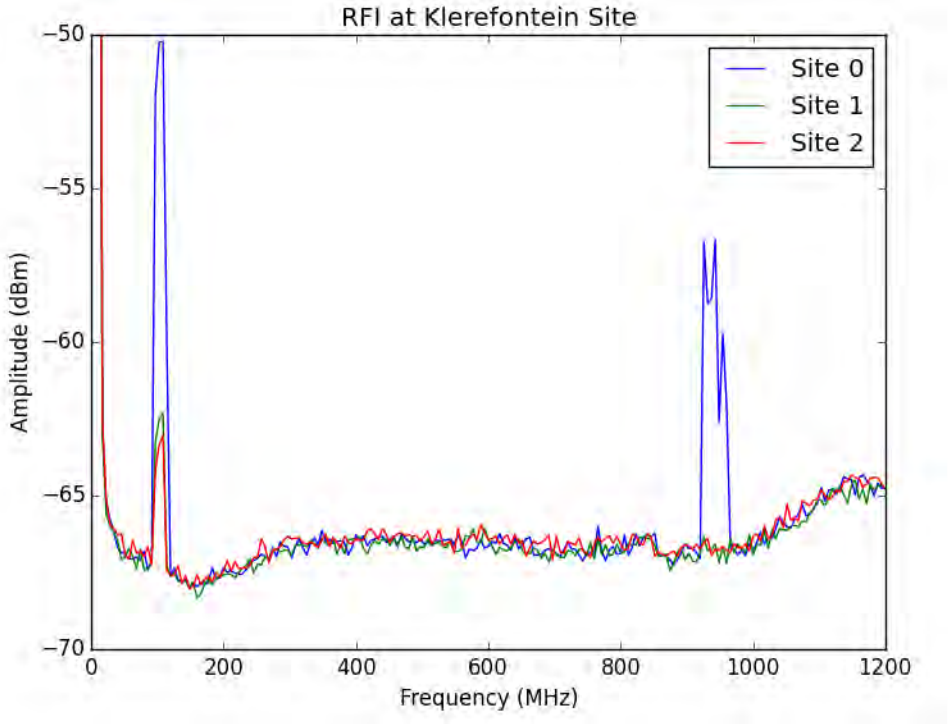


Laser-cut Dish Prototype

- Plan-B for dish design is laser cut steel frames, manufactured in South Africa
- Folded sheets for strength, joined by puzzle joints. Potentially easier to assemble (no welding).
- Fewer logistical issues with local supplier. Can be produced on very short timescale (~few weeks) once design is finalized.
- Counter point: likely more expensive (steel vs aluminum)
- Exploring design and cost reduction options.

Karoo Site Surveying

- First site testing at Klerefontein performed in December. Potential locations identified.
- RFI sources detected at ~100 MHz and ~1 GHz. Most likely local radio stations and cell phone transmissions respectively.
- 400-800 MHz HIRAX band clear to -65 dB.



Future Plans

- Approved by NRF, funded through 128-element pathfinder
- Currently deploying 8-element prototype array at HartRAO
- First drone beam maps in near future
- Next stage: 128-element pathfinder array
- See Newburgh et al. for more details: arxiv 1607.02059
  Or our website: http://www.acru.ukzn.ac.za/~hirax/