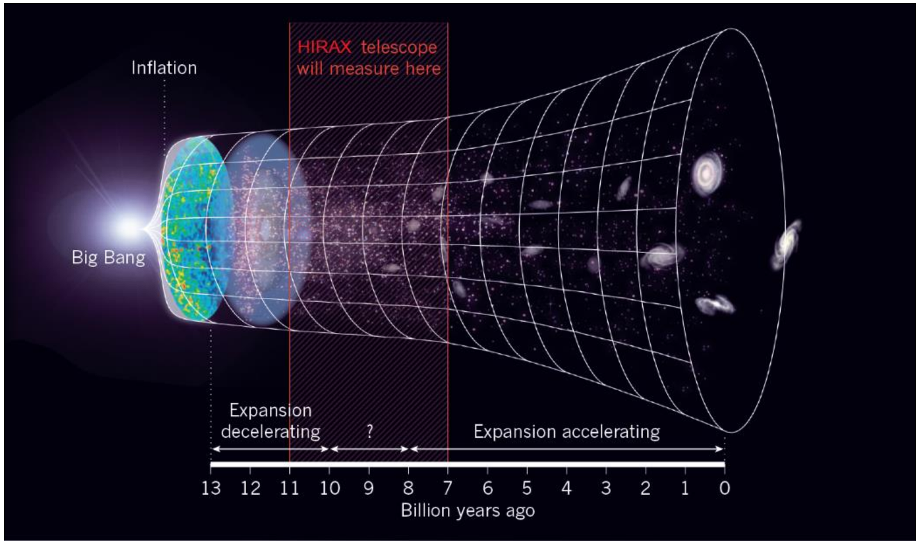
HIRAX Design and Status

PUMA/21cm Workshop, August 19th 2020

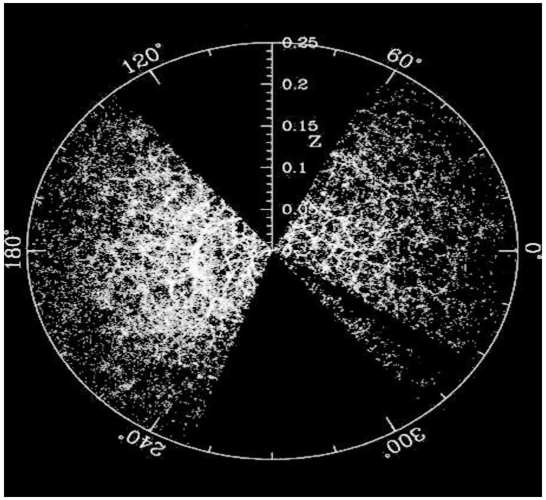
Benjamin Saliwanchik

21 cm Line as Cosmological Probe

- Can use 21 cm hyperfine transition in HI to study LSS and growth of structure in universe
- Dark energy drives expansion of universe in late times: can measure with standard ruler (BAO)
- Signal known to exist, but faint: O(0.1 mK), while galactic foreground is O(10^5 K)
- Achieving sensitivity of 1-2μJy necessary, requires large interferometric array.



0.8 < z < 2.5



HIRAX: Who are we? Where are we?

HIRAX Design and Goals

Instrument:

- 1024 close-packed 6-m stationary dishes
- Operating frequency: 400 – 800 MHz, equivalent redshift = 0.8 – 2.5
- Survey area of 15,000 deg^2. Daily sensitivity of ~12μJy
- Manually repoint every 180 days, 4 years for full survey (~1μJy)

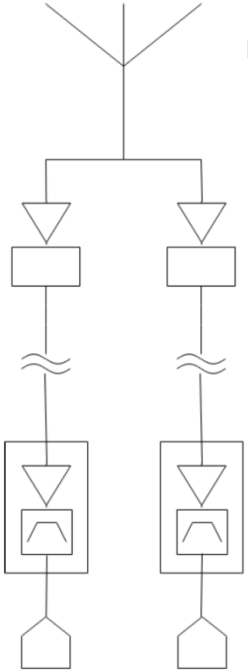
Science goals:

- 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

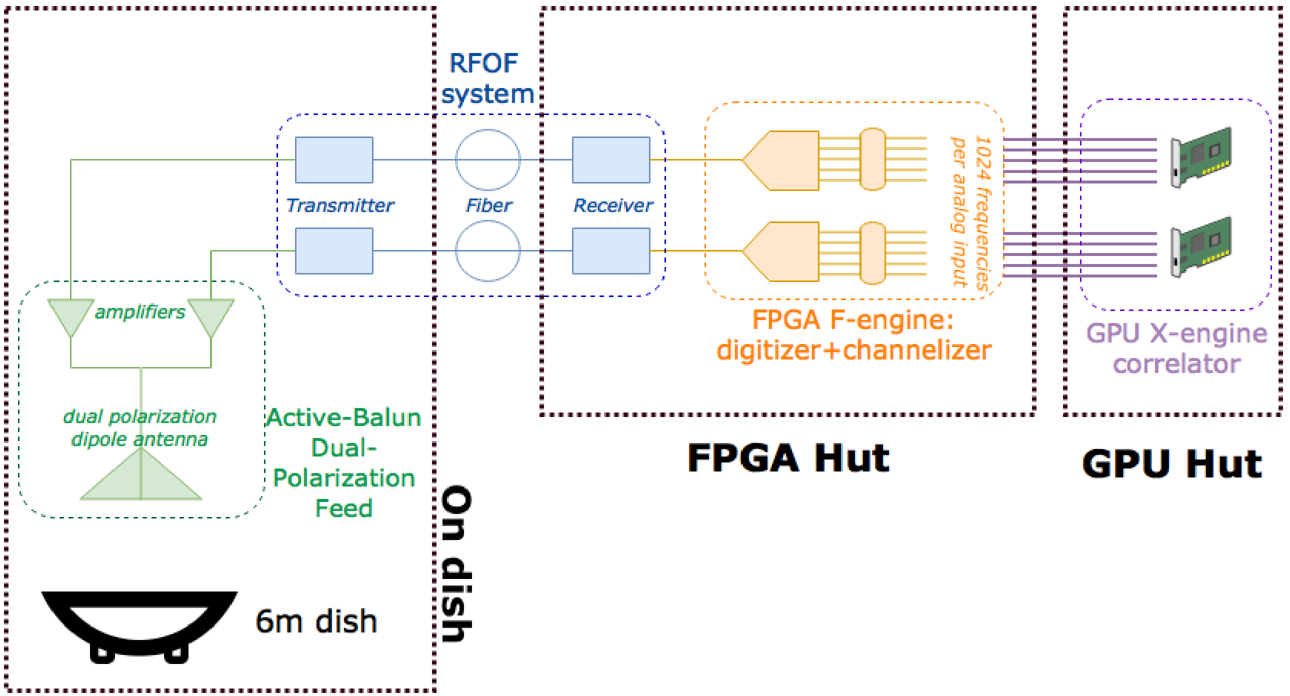
Feed and Signal Chain

- Feeds are dual polarization cloverleaf 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
- 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



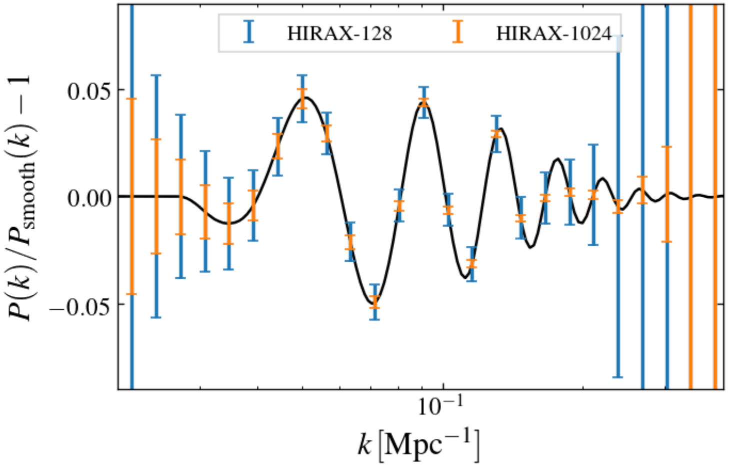
Backend Electronics

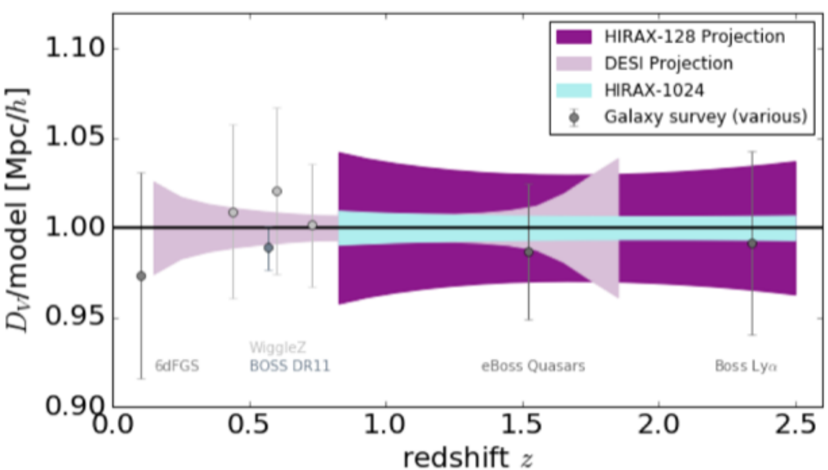
- FX system: FPGA ICE board channelizer, GPU correlator.
- F-engine digitizes at 8-bit precision, channelizes to 1024 frequency channels. 16 sky channels per board, 128 boards for full array
- Custom backplate for corner-turn operation (Transform from input of all freq. channels on single dish to bundles of single freq. from all dishes)
- X-engine correlates all sky inputs for 1024 frequency channels at 4+4-bit precision

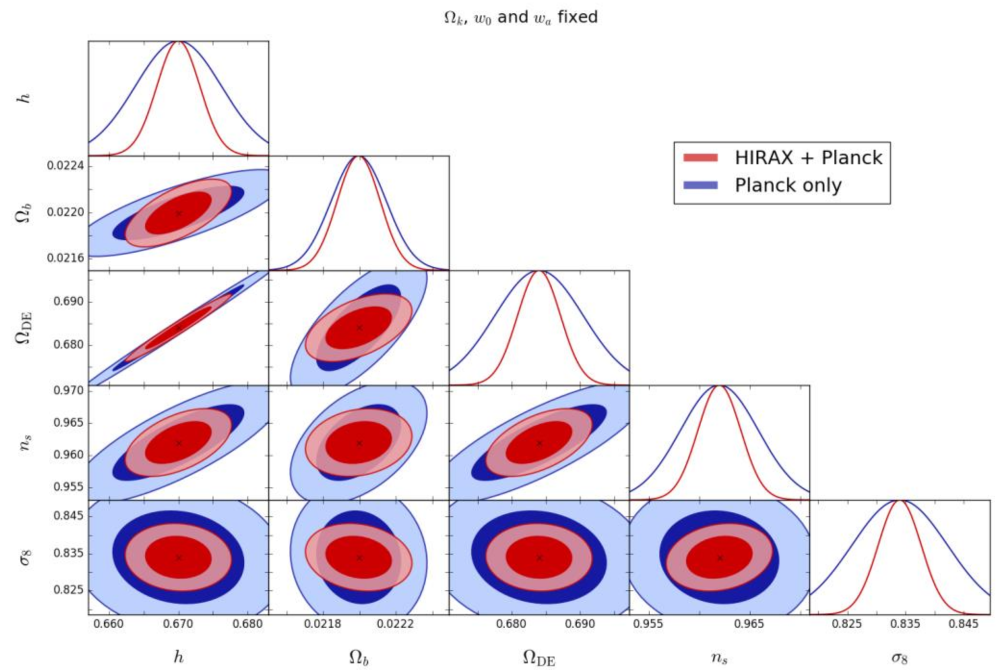


Preliminary Parameter Forecasts

- Constraints based on 15,000 sq deg survey with 128 and 1024 element array, 50K noise temperature, 4 years of observing with 50% efficiency (17500 hrs).

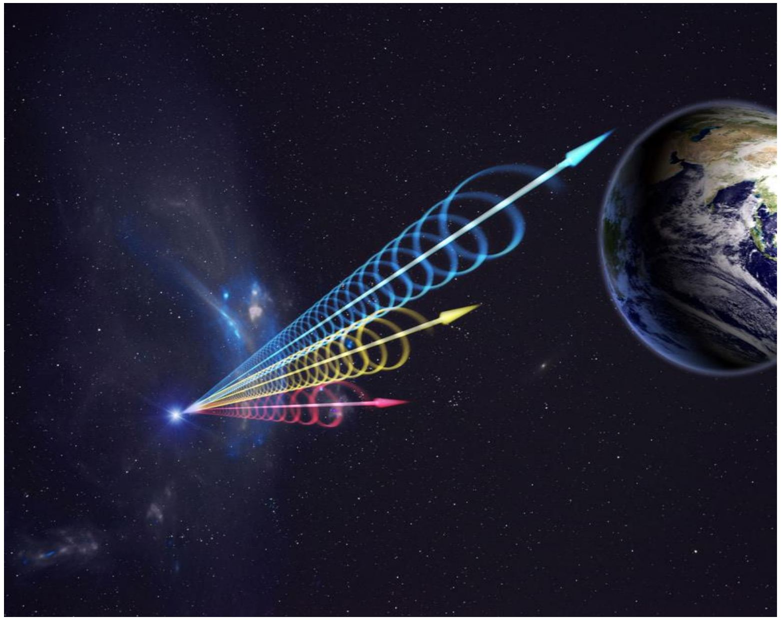


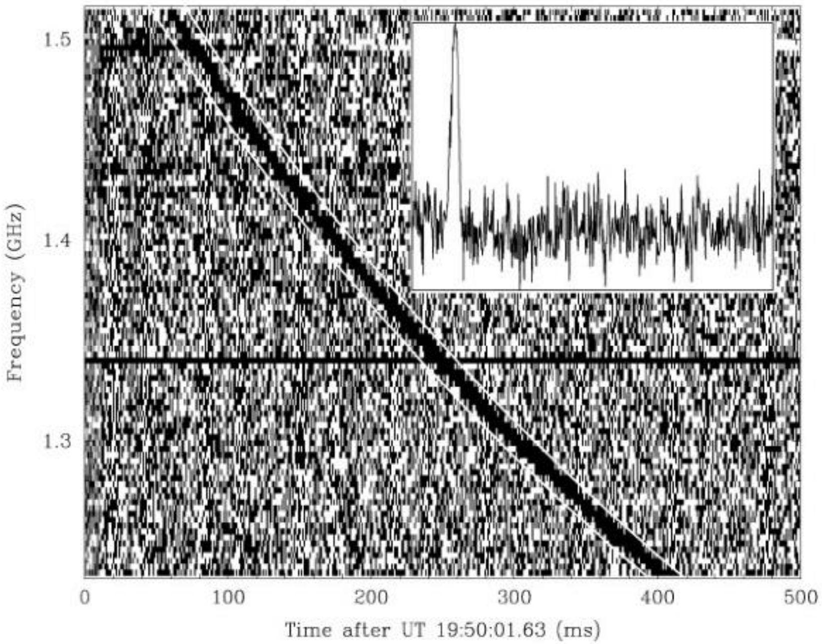




Fast Radio Bursts

- 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)
- Total event rate is estimated to be 10^4 per day over full sky
- CHIME is demonstrating high event rate can be achieved down to 400 MHz



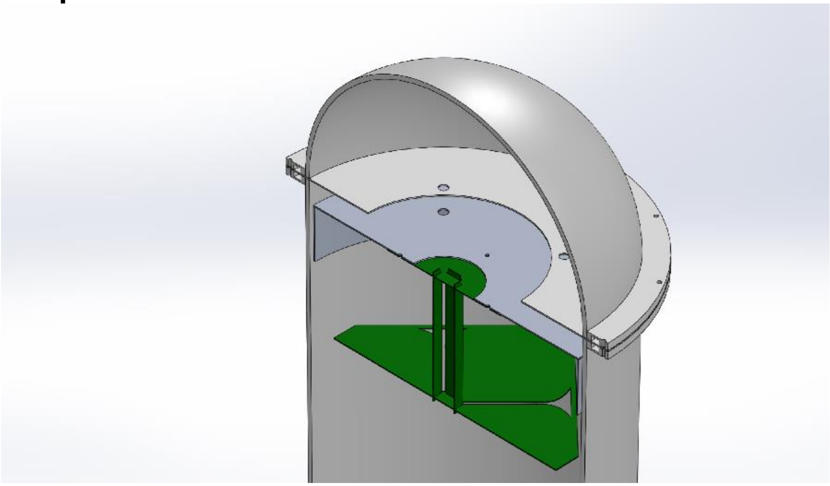


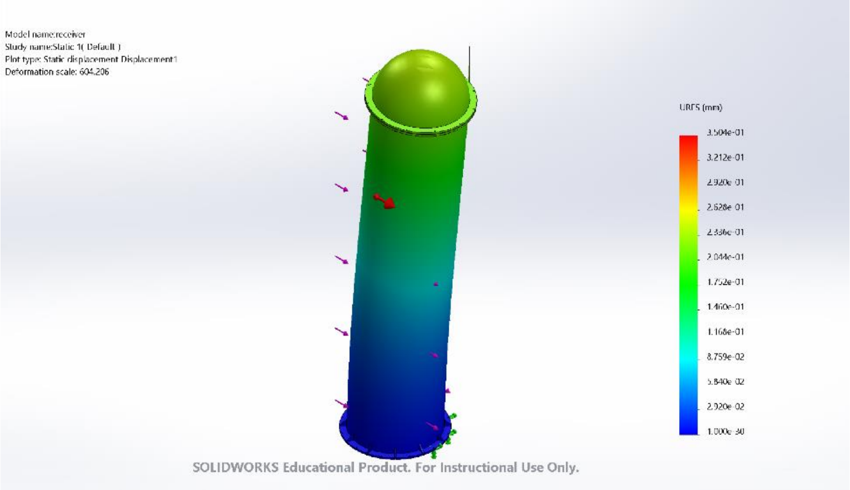
HIRAX Status: 10-element Array

- 10 element array at HartRAO, SA
- Currently testing f/D = 0.25 dishes, active feed design, new radomes, RFoF modules
- Array will eventually be incorporated as outrigger site for full HIRAX array to improve angular resolution (for FRBs)

Receiver Design

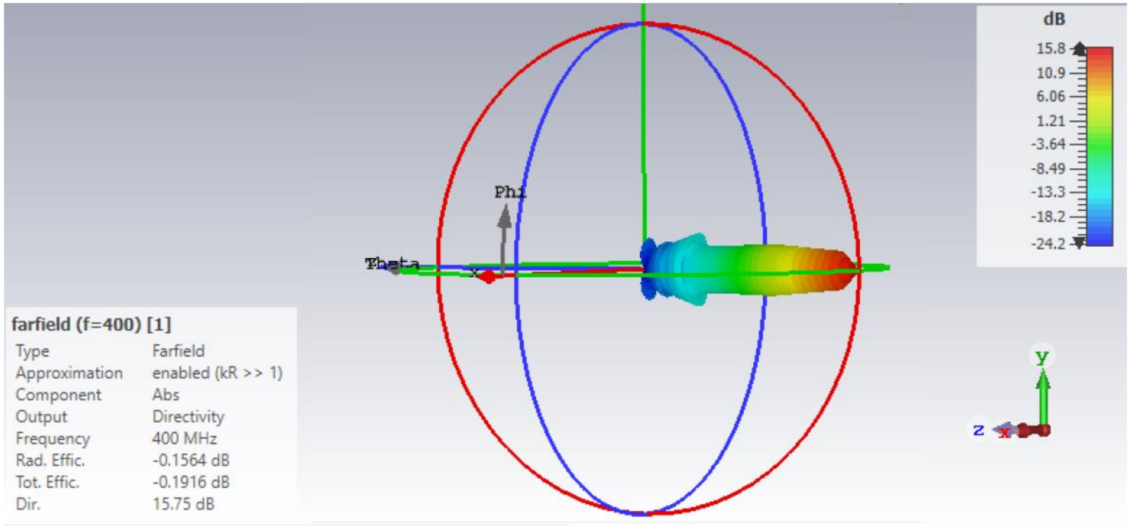
- Designing fiberglass receiver column to replace Al feed legs currently used.
- Simulations say extremely robust, safety factor of 100 and feed displacement <1mm relative to dish under SA record wind speeds.
- Easier to position feed, adjust focal point.





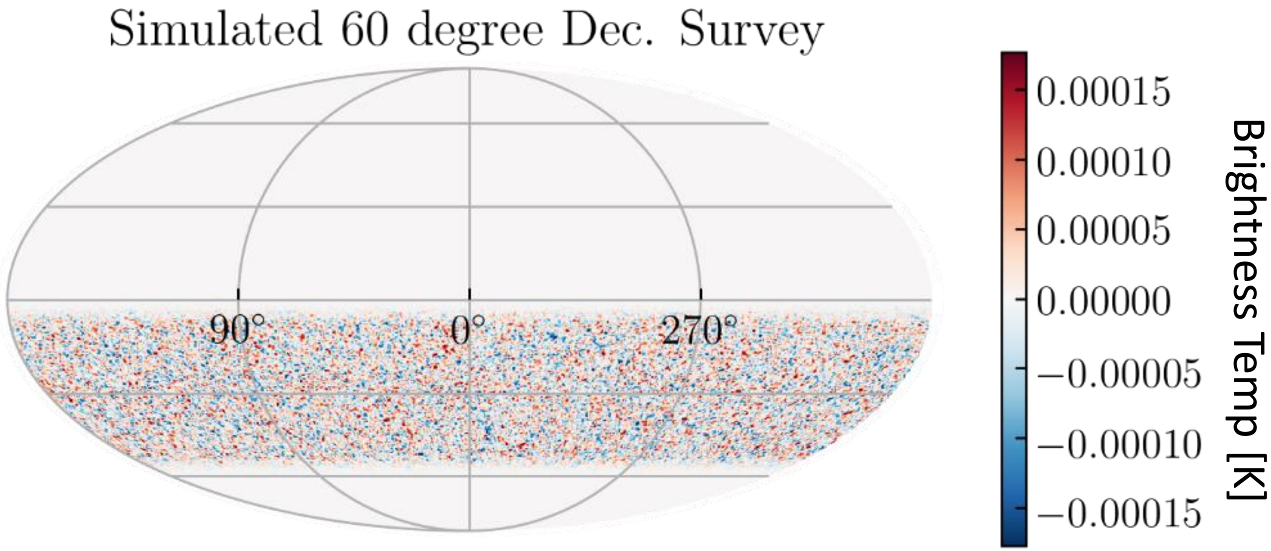
CST EM Simulations

- Aaron Ewall-Wice (Caltech) optimizing feed-can dimensions, examining array effects.
- I discovered current feed legs and cabling produce polarized features in beam, further motivation for fiberglass receiver column, optimizing layout of cabling.
- I am establishing specifications for manufacturing and alignment of dish and dish+feed system



Cosmology Simulations

- Devin Crichton (UKZN) developing cosmo sim pipeline for HIRAX
- Produces synthetic visibilities by mock observing simulated skies, uses m-mode analysis of Shaw et al. (https://arxiv.org/abs/1401.2095)
- Exploring the influence of survey design and systematics on our power spectrum sensitivity, and working towards a understanding how this will affect our ability to remove foregrounds.
- Ongoing project: importing CST beams from simulated dishes for end-to-end, instrument to cosmology modeling (Aaron, Devin, Ben)



HIRAX Prototype at DRAO

- Faculty and staff from McGill University (Cynthia Chiang, Deniz Olcek, Dallas Wulf) are developing a HIRAX prototype array with f/D = 0.25 dishes with D = 3m at the Dominion Radio Astronomy Observatory (DRAO) in Canada.
- Called the Deep Dish Development Array (D3A), this array will test new feed designs, instrumentation, and calibration techniques.

Feed Noise Temperature Measurements

- Emily Kuhn (Yale) designed cryogenic RF-chamber for making y-factor measurements of feed
- Differential measurement between hot (300K) and cold (77K) loads: T_sys = (T_h – y*T_c)/(y-1) where y = P_h/P_c
- Optimized cryostat and absorber dimensions, taking into account warm operation, and reflections off an LN_2 layer when operating cryogenically.
- Developed fabrication methods for 1.6 m diameter, 500+ L liquid cryostat

Feed Range Measurements

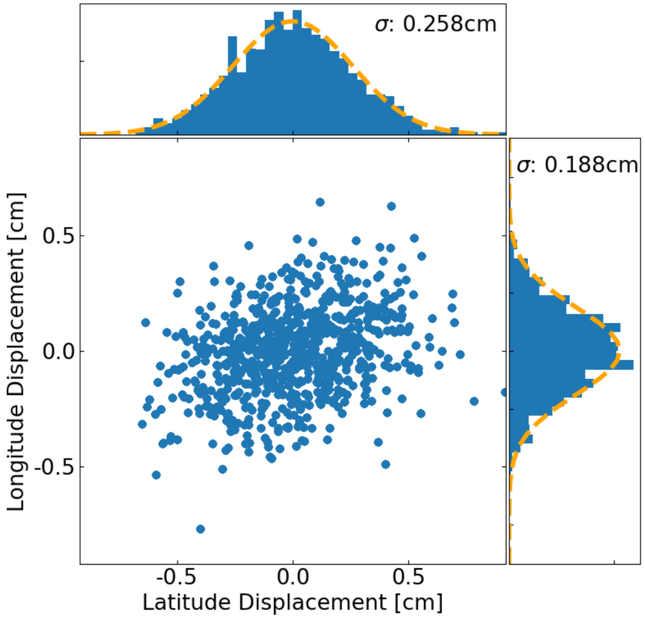
- Performed beam measurements at JPL MESA and North Carolina State University
- Measured CHIME (passive), HIRAX (amplified), and biconical (calibration) antennas
- Verified antenna simulated beam widths and gains

Yale Drone System

- Yale currently using DJI Matrice drone. Can easily reach HIRAX far field. (For 6m dish, $2*D^2/\lambda$ is 200m at 800 MHz)
- Uses custom broadband noise source and biconical antenna
- Performed dish calibration measurements of DSA-10 at OVRO (top photo), and BMX at BNL (bottom)

Yale Drone System

- Chief difficulty is measuring position and rotation of drone
- Real Time Kinematic (RTK) differential GPS provides RMS < 1cm



Drone position measurements by Maile Harris and Annie Polish (Yale)

Future Array Plans

- Antenna y-factor measurements at Yale starting now.
- First drone beam maps from HIRAX prototypes at DRAO in Canada and HartRAO in SA when international travel is possible.
- Next development stage: First dishes in Karoo.

- See Newburgh et al. for more details: arxiv 1607.02059

  Or our website: http://www.acru.ukzn.ac.za/~hirax/
- Presenter email: benjamin.saliwanchik@yale.edu