

Advanced L-band Phased Array Camera for Astronomy (ALPACA)

BYU:

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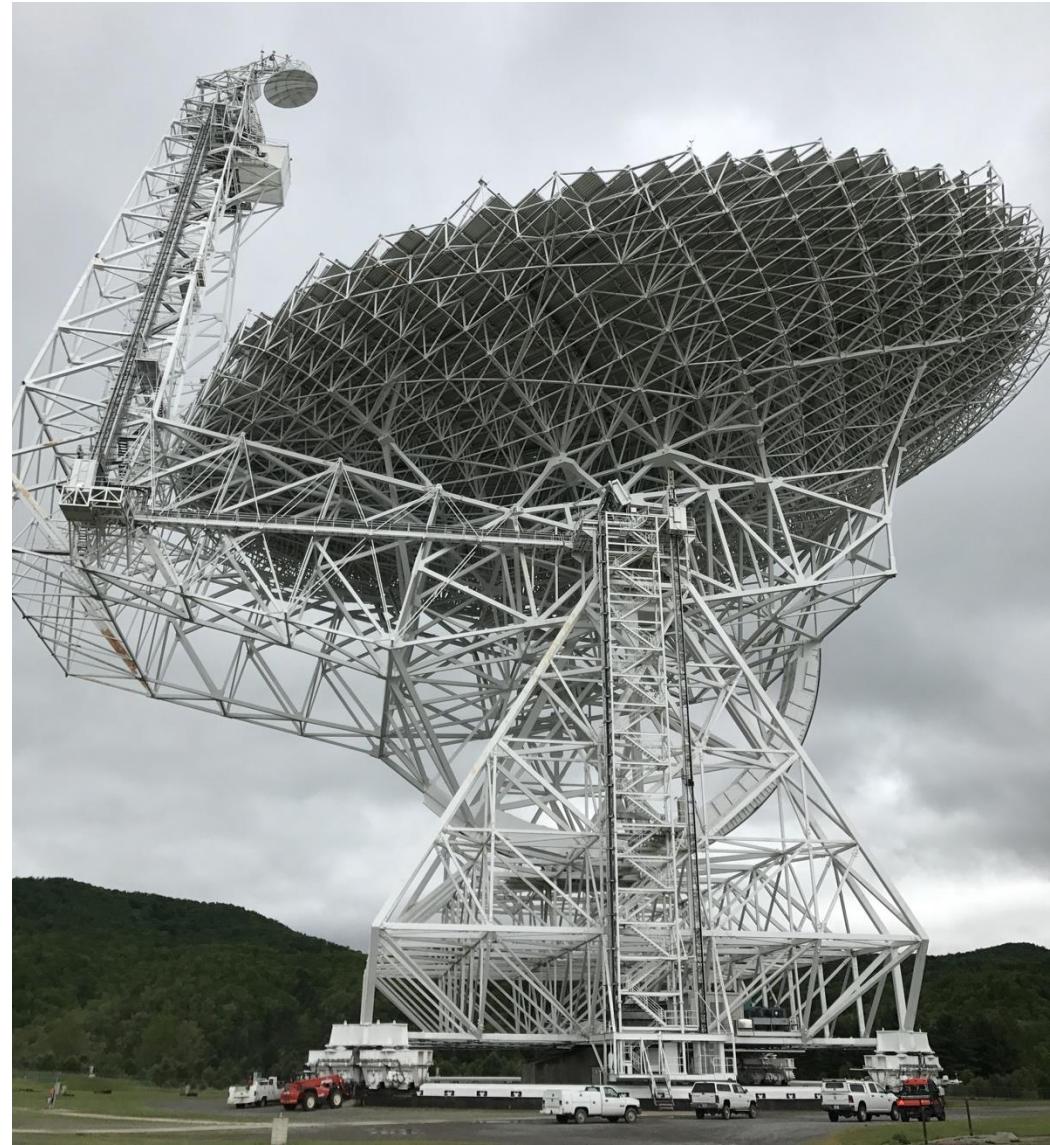
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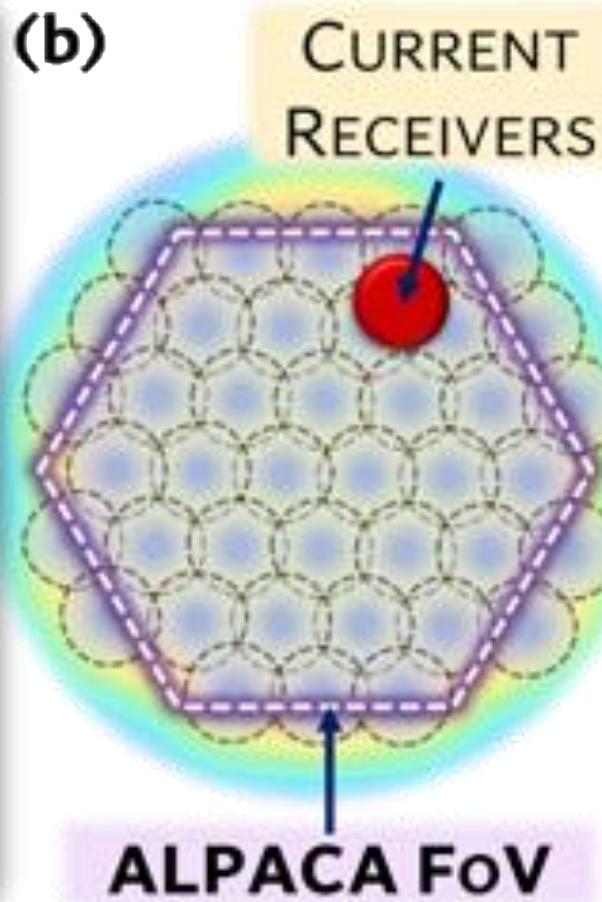


ALPACA and the GBT?

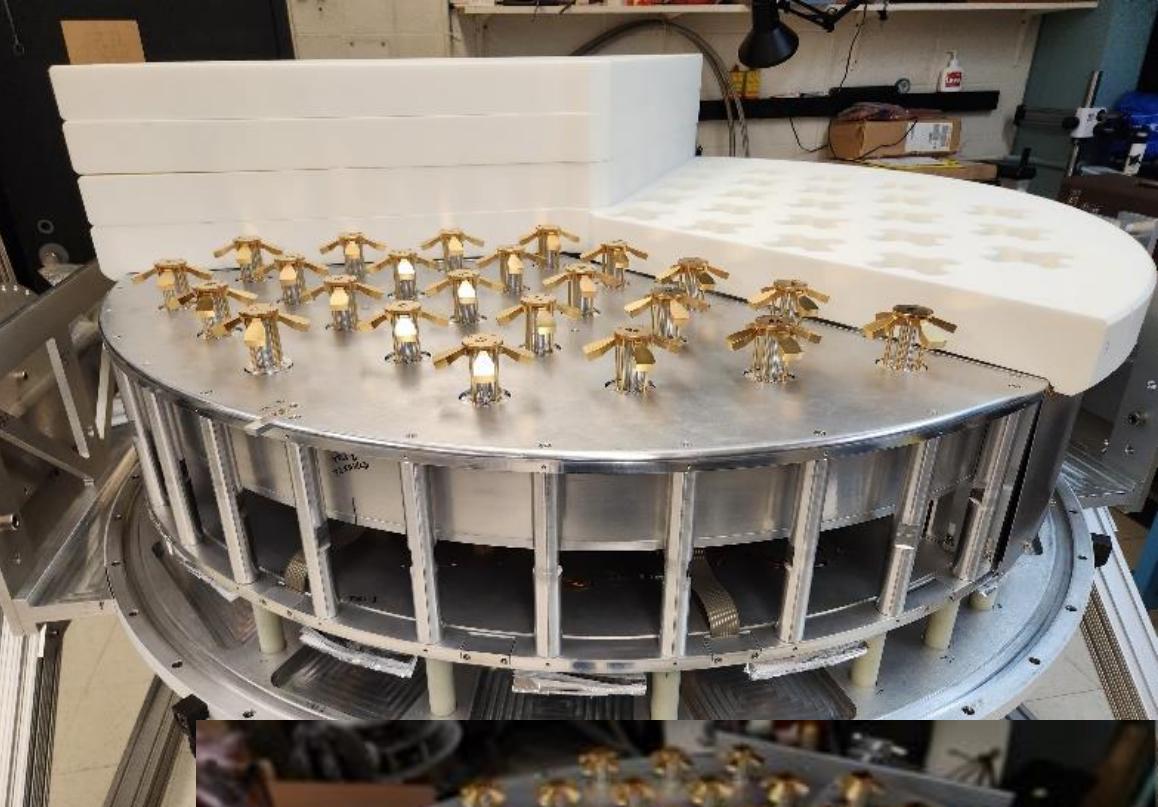
- Project originated with the Arecibo Telescope as the host platform
- ALPACA array & cryostat size (1.46m diameter) and dish f/D are a good match for GBT
- Feb. 2022: Sub-award issued to GBO to support hosting ALPACA on the GBT
- Front-end Cryostat electronics & mount are configured for the GBT
- June 2025: AUI / GBO withdrew from ALPACA proposal efforts and any other participation
 - Cited low probability of attracting private funds, NRAO/GBO passing through tough times, and their need to focus on own key priorities



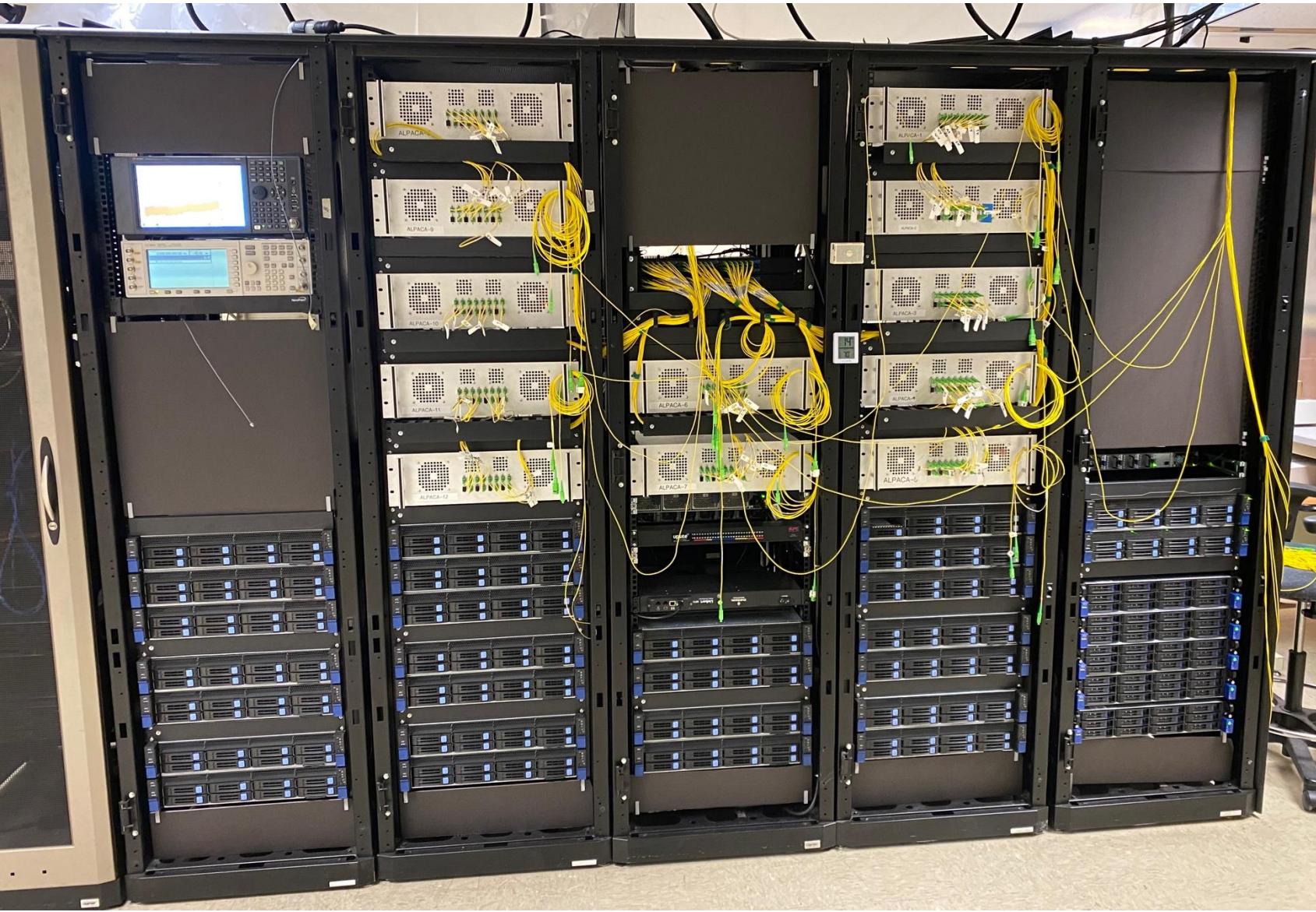
ALPACA Field of View on the GBT



(a) The ALPACA front end cryostat and receiver electronics. (b) 40 on-sky beams. (c). The GBT



Digital Receiver, Correlator / Beamformer Back End

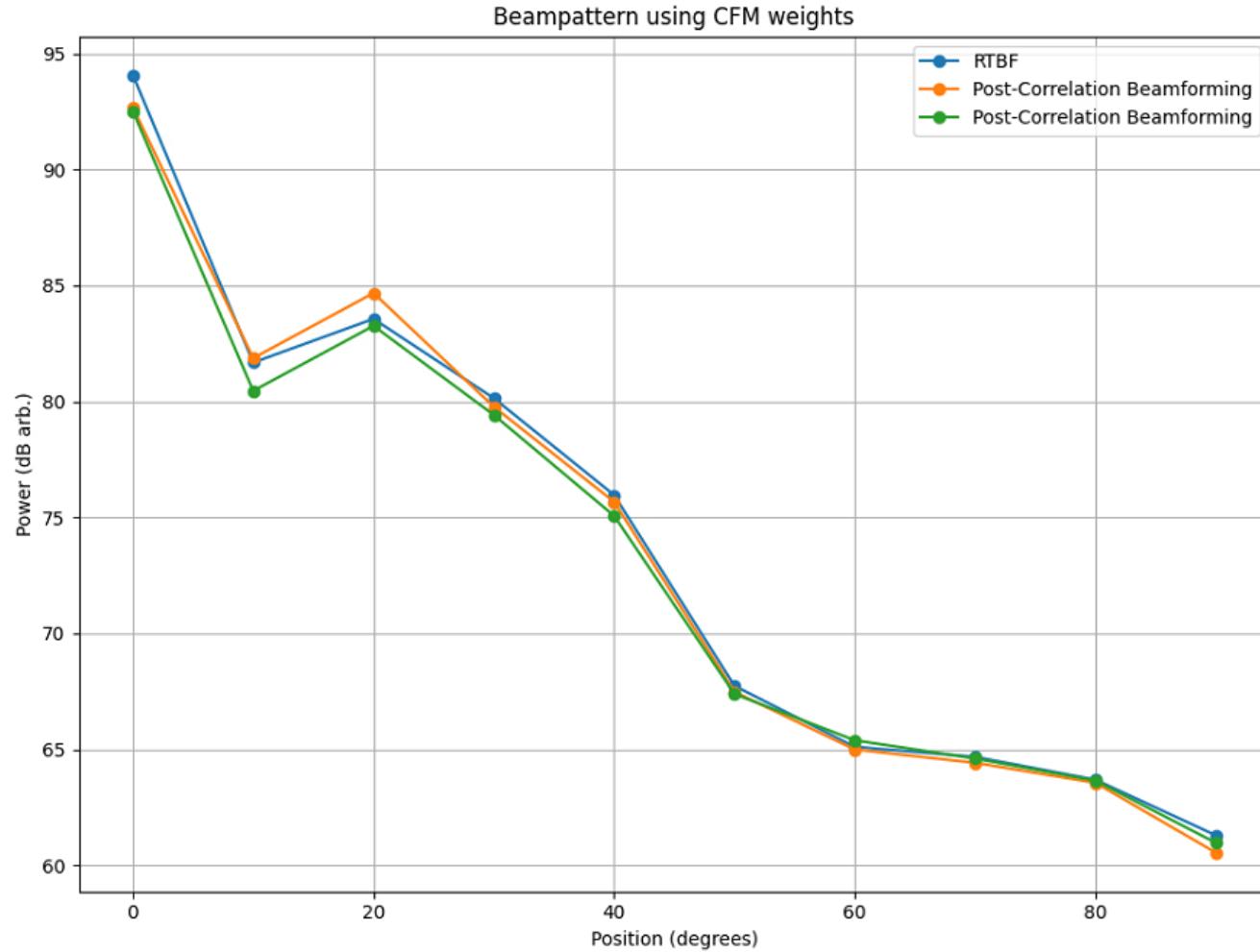


- F Engine:
 - 12 ZCU216 RFSoCs
- XB Engine:
 - 25 AMD dual CPU servers
 - 50 Xilinx A10 GPUs
- Network:
 - 60-port 100 GbE switch
 - 32-port InfiniBand EDR/100 Gb switch
- Integration Test Storage
 - BeeGFS, 3 servers
 - High speed SSD, 20 TB
 - 80 TB spinning disks

Bare Array Beamforming Pattern Tests

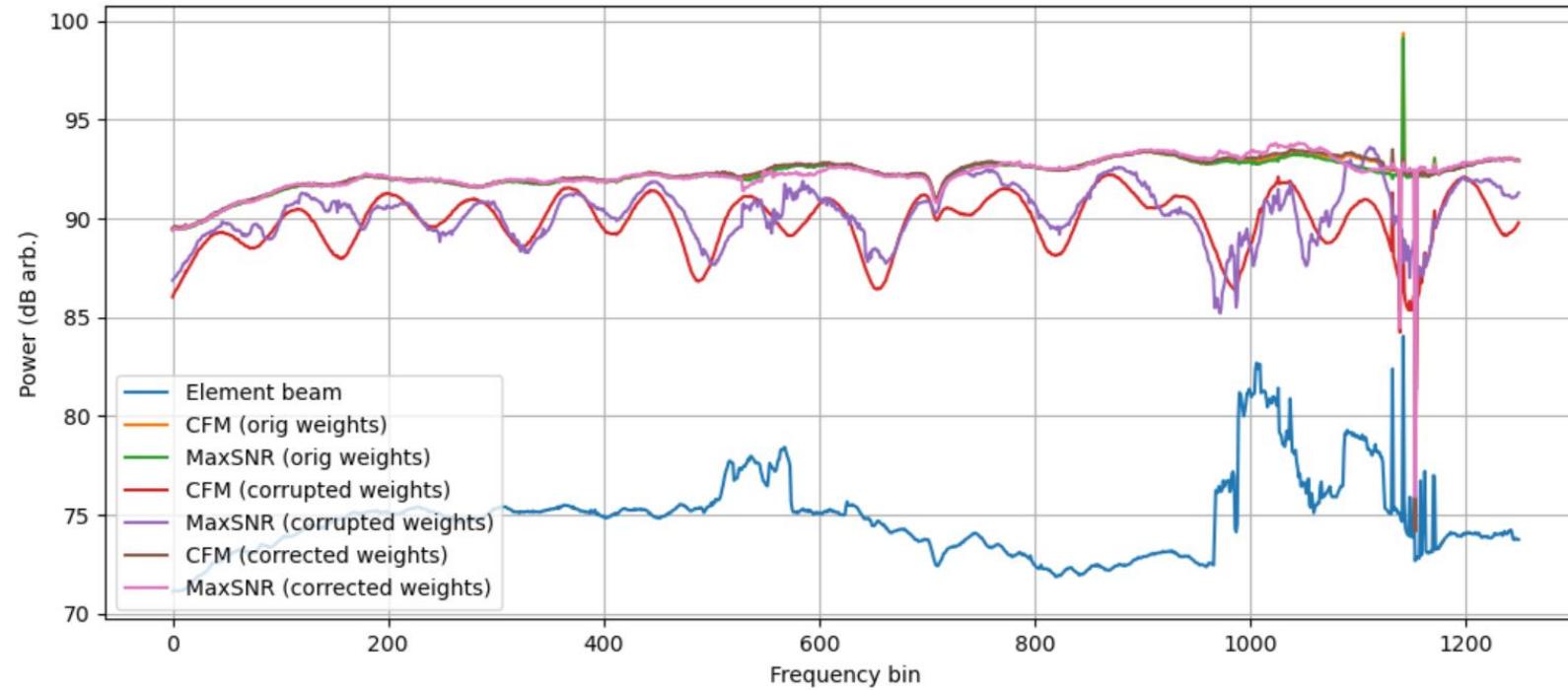


Beampattern Measurements



Beampattern at 1445.57 MHz using real-time beamforming (blue) and two runs of post-correlation beamforming (orange and green).

Rapid Update Beamformer Calibration System



Blue curve: a single antenna capture of the signal.

Orange & green: beamformer weights calibrated with extra fiber lengths inserted.

Red & purple: weights calibrated without the extra fiber used when extra fiber is inserted.

Brown & pink: weights calibrated without the extra fiber, but corrected with rapid calibration.

- Response to broadband source matches Orange & Green

ALPACA Capabilities (1)

Performance Characteristic	Specification
Array design (with replaceable antenna-LNA modules)	Hexagonal grid, optimized broadband dual pol. dipoles
Noise performance	Cryo-cooled antennas and LNAs, $T_{sys}/\eta = 33K$
Frequency coverage (tunable within this range)	1300 – 1720 MHz (420 MHz total BW)
Beamformer digital real-time processing bandwidth	305.2 MHz
Number of real-time simultaneous beams	40
Full Stokes integrated PSD output per beam, per channel	XX pol (real int), YY pol (real int), XY pol (complex int)
Pulsar / Transient mode:	
Number of OSPFB frequency channels BW per channel	1250 coarse chan. 244.1 kHz sep., 325.5 kHz bins
Shortest integration dump interval	64 μ s
HI Spectral Line (zoom spectrometer) mode:	
Total PFB frequency channels BW per channel	Up to 240,000 (total BW max 305.2 MHz) 1.27 kHz bins
Shortest integration dump interval	100 ms

ALPACA Capabilities (2)

Performance Characteristic	Specification
Beamformer calibration mode:	
Covariance matrix outputs per 1250 coarse channels	144x144 matrices, 500 ms max dump rate
Receiver features:	
Analog mixer LO and IF frequencies	NONE: direct ADC sampling of RF, digital mix to baseband
ADC sample rate resolution Noise Spectral Density	2,000 Msamp/s 14 bits (10 enob) -147 dBFS/Hz
Complex baseband sample rate for beamformer	500 Msamp/s
1 st stage PFB FFT length oversample ratio	2048 channels 4/3 oversampled
2 nd stage (zoom) PFB length oversample ratio	256, pruned to 192 non-overlapped channels 1/1
Peak I/O data rates:	
Output data rate per RFSoC board input rate per HPC	81.8 Gbps 39.3 Gbps (8 bit real + 8 bit imag. samples)
Total combined output rate from 50 GPUs to disk in pulsar spectrometer mode at minimum dump rate of 64 μ s	50.0 Gbps = 6.25 GBps 2 16-bit int real & 1 32-bit int complex (16r + 16i)
Total combined rate with Stokes / only, dump rate of 64 μ s	12.5 Gbps = 1.563 GBps

ALPACA Science on the GBT

- Aligns with Astro2020 Decadal Review: Wide FOV radio cameras
- GBT with ALPACA  Premier US survey and mapping instrument
 - 40 beam wide field of view
 - 100m unblocked aperture
 - full sky view
 - radio quiet zone
 - high dynamic range
 - mid latitude northern location
- Science Cases:
 - Technosignature Search
 - Pulsar searches, MSPs for gravity wave timing, binary systems, etc.
 - Radio transients, RRATs, FRBs, long-period sources
 - Mapping circumgalactic medium
 - Mapping molecular hydrogen with thermal OH
 - Λ CDM and the Local Group
 - Dark & extremely diffuse galaxies
 - Radio recombination lines
 - Polarization studies need wide FOV
 - 20 to 30 x speedup: impossible studies now practical!

Project Status

- Instrument design and fabrication are done
- Completed full-system integration testing at BYU:
 - Front End functionality
 - Back End functionality
 - End-to-end signal integrity and rate
 - Expert user M&C Software
 - Beamforming: Real-time and post - processing
 - Beampattern evaluation
 - Cryogenic operations
- Integration test punch list issues being addressed:
 - Oversampled PFB frequency channelizer sample timing skew across RFSoCs: Fix by 11/31/25. CSPFB channelizer being used now
 - Full-system MCS tests for phase stability over power cycles
 - HDPE top hat redesign to improve vacuum integrity