# First Results of Imaging, Super Stereo, and Other Upgrades on the Kodiak Radar

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**SuperDARN Workshop, June 2, 2008**

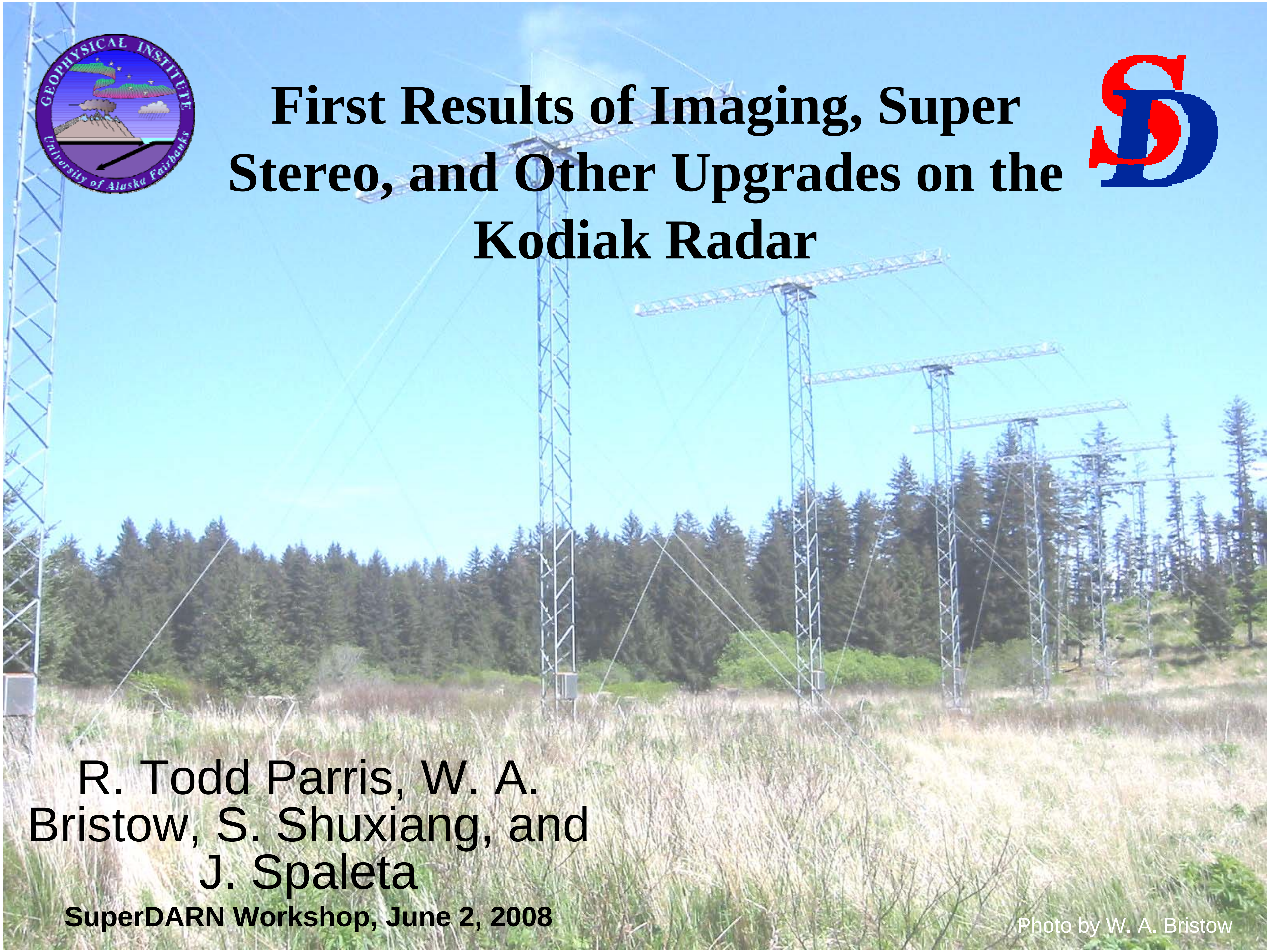


Photo by W. A. Bristow

# Recent Hardware Upgrades

- September, 2007
  - New DIO system
  - New Timing System
    - Separated timing critical signals like ‘ScopeSync’, ‘T/R’, ‘TX’, etc, from non timing critical signals like ‘Test Mode’, ‘ACG fault’, ‘LowPwr’, etc.
  - GPS triggering
    - Not currently working, GPS computer/card has problems
  - Direct Digital Synthesis up-converters
- Last week, May 2008
  - Imaging receivers
- Kodiak radar is now all digital

# New DIO system

- Access PCI-DIO-48/48S
  - 48 Bits of I/O
    - 32 bits for new phasing matrix
      - 13 bits for beam codes
      - 13 bits for programming beam codes
      - 5 bits for addressing cards
      - 1 bit to enable beam code programming
    - 8 bits for standard DIO operations
      - 4 bits for addressing transmitters
      - 4 bits for control and status of transmitters (T/R, TM, LP, AGC)
    - 4 bits for old phasing matrix
      - We still use old phasing matrix in Kodiak for some experiments
- Driver written under QNX Neutrino 6.3
  - TCP message passing for communication with ROS
- Running since September, 2007

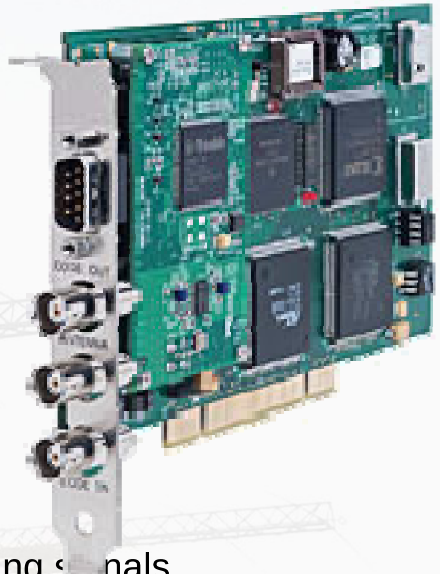
Photo from www.accessio.com

# New Timing System

- ADLink NuDAQ PCI-7300A 80MB Ultra High Speed 32-CH Digital I/O Board
  - 32 bit, 33 MHz PCI card
    - Time critical signals only
    - Signals: ‘Atten’, ‘T/R’, ‘TX’, ‘ScopeSync’, Phase’, and ‘FIFO almost empty’
  - 16kSample deep FIFO
    - Driver written to continually load arbitrarily long timing sequences
    - Unpacked timing sequence state time of 1$\mu$s
  - Clocks DIO states at set rate
    - External 10 MHz clock used
      - Requires modification of the card
  - Driver written under QNX Neutrino 6.3
    - TCP message passing to communicate with ROS
- Running since September, 2007

# GPS Triggering

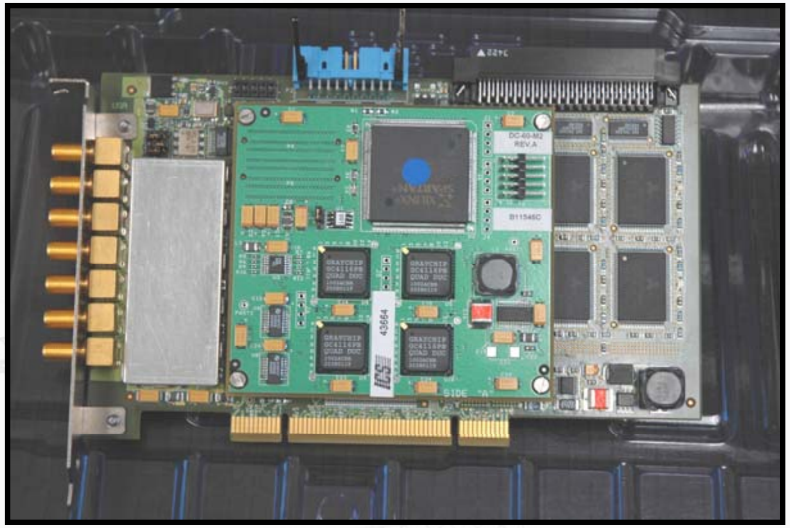
- Symmetricom GPS-PCI 2U
  (formerly a True Time product)
- GPS accuracy to better than 1$\mu$s
- Driver written under QNX Neutrino 6.3
  - TCP message passing to communicate with ROS
  - Sets system time on all computers via NTP
  - Provides scheduled triggering of Tx and Rx
    - Can be scheduled for arbitrary start times
    - Can be set as GPS synchronized rate trigger
    - Provides <1$\mu$s accurate record of triggering
    - 10 MHz  GPS synchronized reference for Tx, Rx, and timing signals



- Ran from September 2007 through January 2008
  - Computer and/or GPS card crashed
  - Will be reinstalled as soon as card/computer can be fixed
- Permits extremely accurately synchronized experiments with HAARP
- Permits calculation of lags between pulse sequences

Photo from www.symmetricom.com

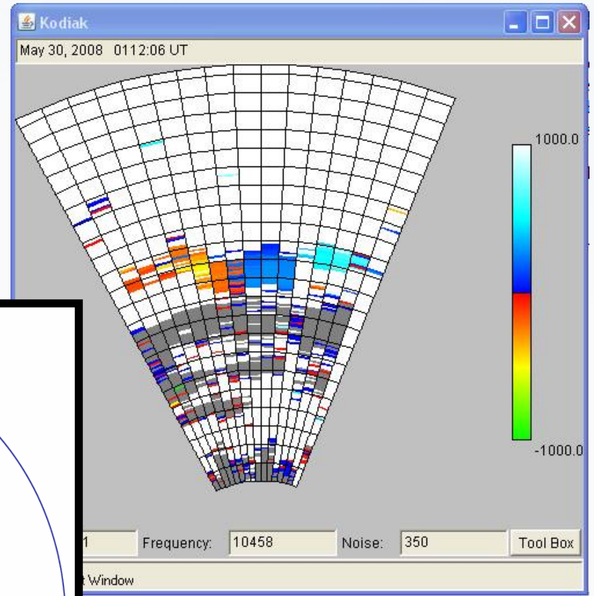
# Direct Digital Synthesis Up-Converters

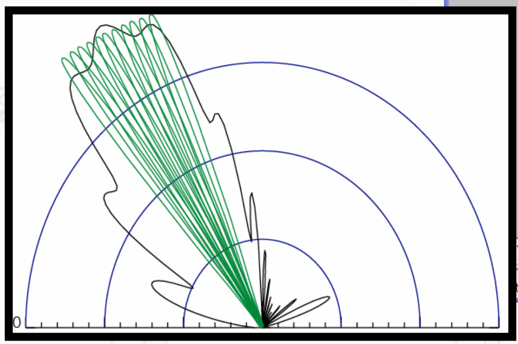


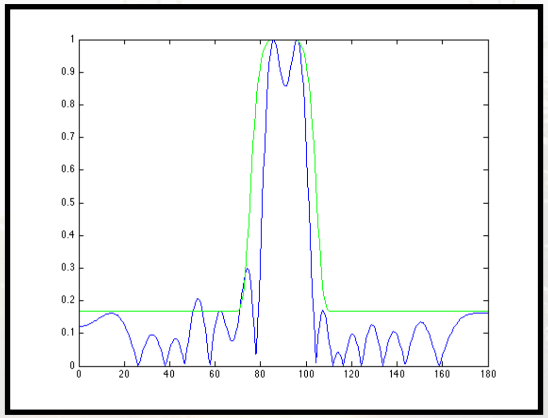
- Four ICS-660B DDS Cards
  - Four digital-to-analog converters
  - Four GC4116 digital up-converter chips per card
    - Four independent up converter channels per chip, one chip per DAC
    - 64 total DDS channels, four per Tx antenna
    - Permits ‘super stereo’ Tx
  - Full TX waveform control
- Drivers written under QNX Neutrino 6.3
  - TCP message passing to communicate with ROS
- In operation since September 2007

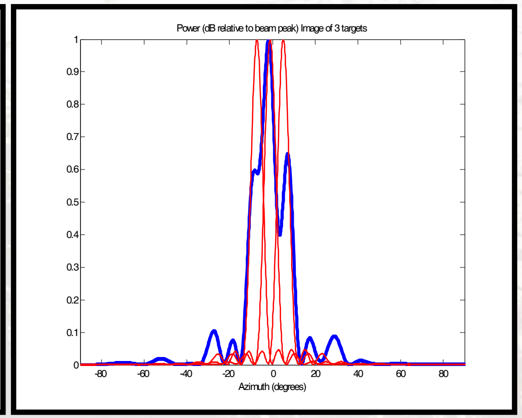
# Some benefits of DDS on each antenna

- Phase coding
  - Binary, Quadrature, etc.
  - Phase coding modes have already been run for extended times
- Adaptive beam forming
  - Work in progress
  - Shown to work in lab
  - S. Shuxiang currently working on implementing adaptive beam forming on the Kodiak radar
  - Adapt Tx beam to ionospheric and noise condition to maximize observations (both temporally and spatially)
  - Image within TX beam for high spatial resolution measurements



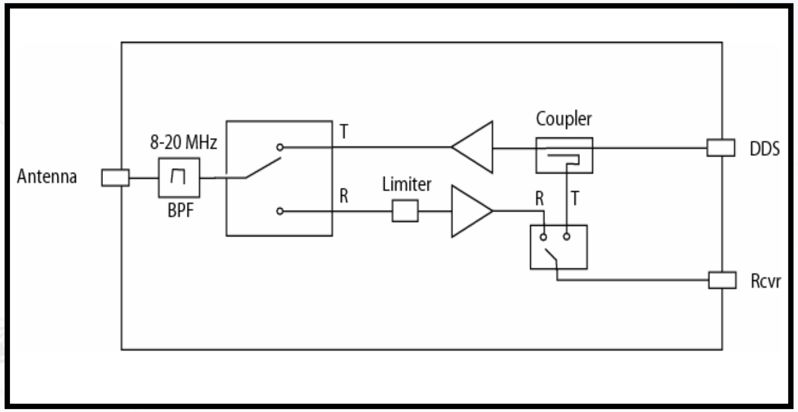



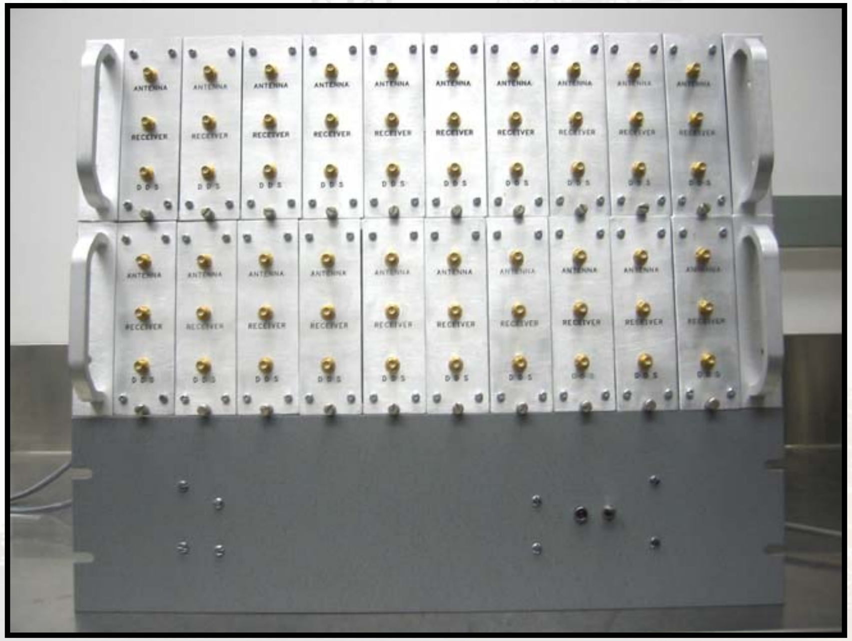


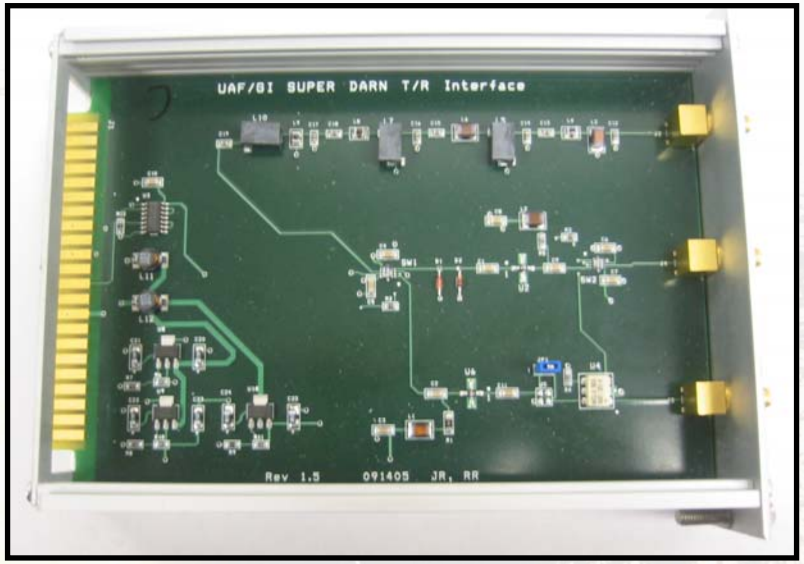


# DDS/Digital Receiver interface hardware

- New hardware interfaces the receivers and DDS up-converters with amps, filters, and antennas
- Couplers allow direct sampling and characterization of the TX signal

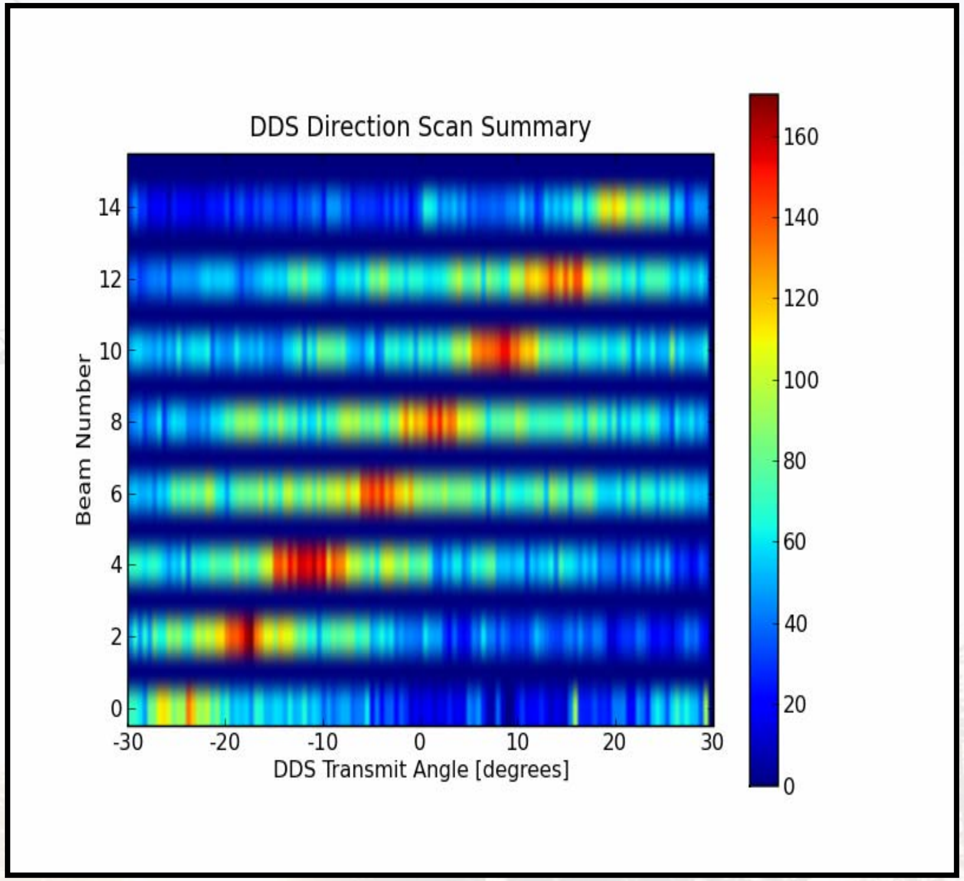




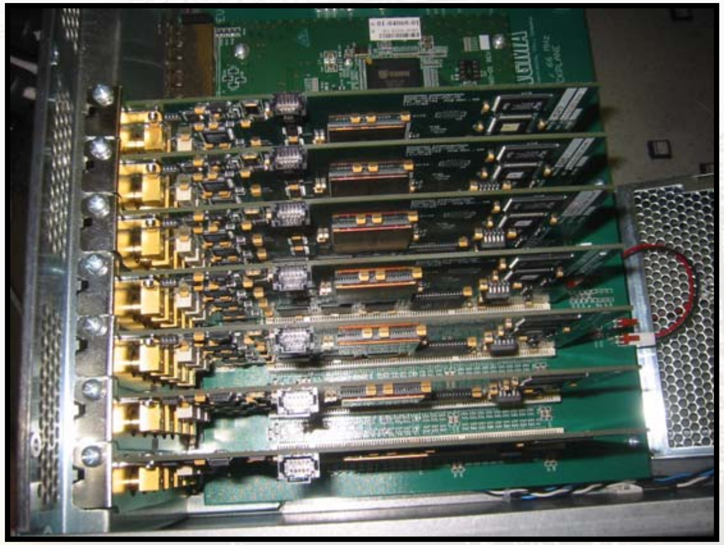
# Beam direction verification

- Verification of DDS Beam directions vs. Phasing matrix
  - Phasing matrix still connected and used for some experiments
  - A number of transmitters were not working, and have subsequently been fixed



# Digital Imaging Receivers

- For our implementation, we have chosen the Echotek GC314-PCI/FS
  - 3 analog inputs and A/Ds
  - 100 MHz sampling
  - 4 receiver channels per antenna
    - Allows ‘super stereo’
  - Up to 2 MHz BW per channel
  - 7 GC314s total
- 1021 sample FIFOs on each channel
  - Can only move 12 MB/sec off of these cards over PCI bus, which limits our achievable continuous sample rate
    - Less than 150 kS/s for single channel
    - Less than 75 kS/s for double channel
    - Less than 38 kS/s for quad channel
  - Can collect up to 1021 samples at any rate up to 2 MS/s
  - Still uses old GC214-PCI/TS with phasing matrix for some experiments
  - Currently using GC214 and phasing matrix for clear frequency search
- Sample DDS signals directly (via coupler)



# Digital Imaging

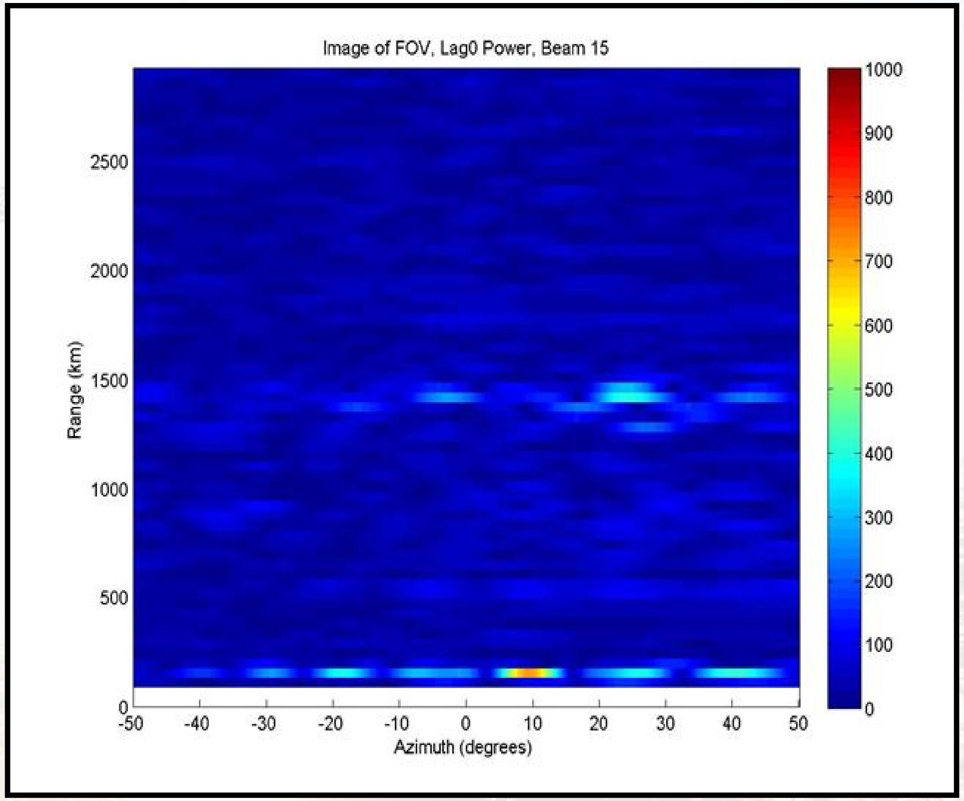
- Sample all antennas simultaneously
- Take FFT across array to get Bartlett estimation of brightness distribution

$$S_k(t) = \sum_{n=0}^{15} s_n(t) e^{-\frac{2\pi}{N} ink} \qquad k=0,\ldots,N\text{-}1$$

This is the digital analog of Using phasing matrix for many Directions at the same time

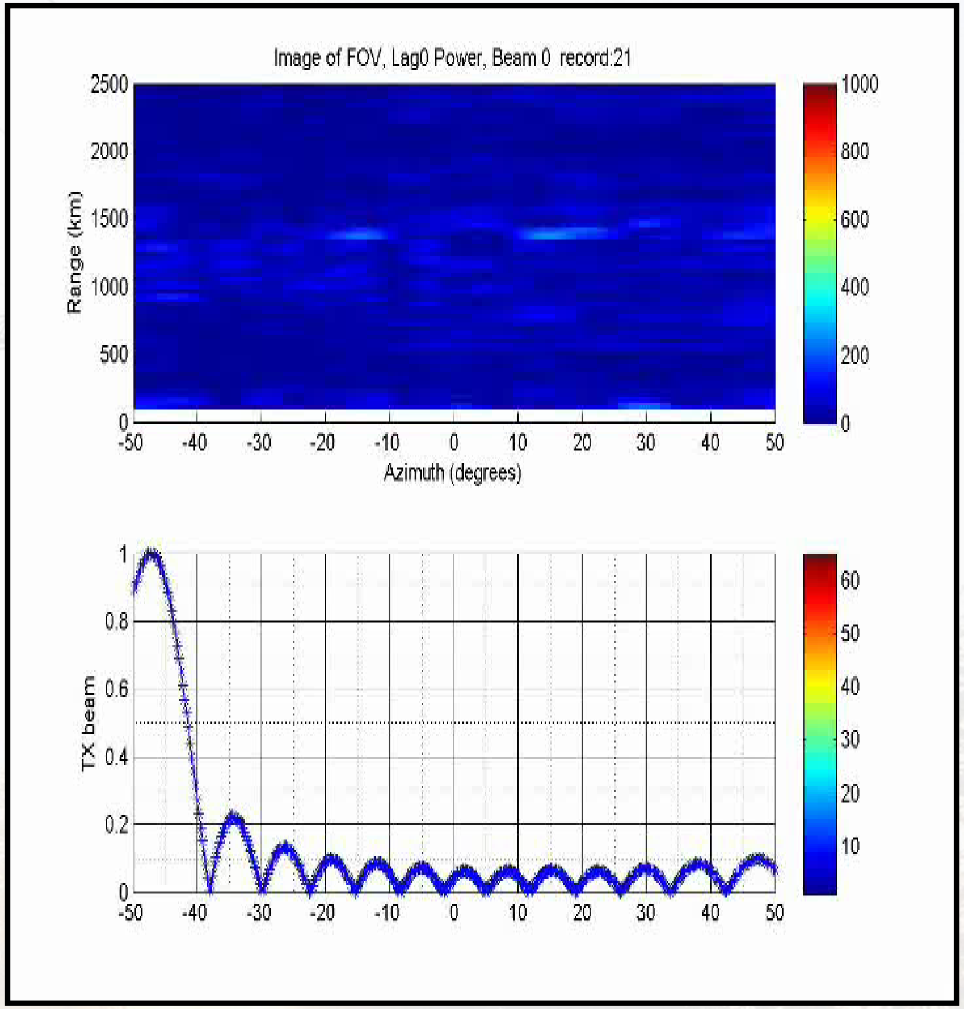
- Use some other spectral estimation to get higher resolution brightness distribution
  - Yule-Walker
  - Modified Co-variance
  - MUSIC
  - Many others….

One of the first image from Kodiak



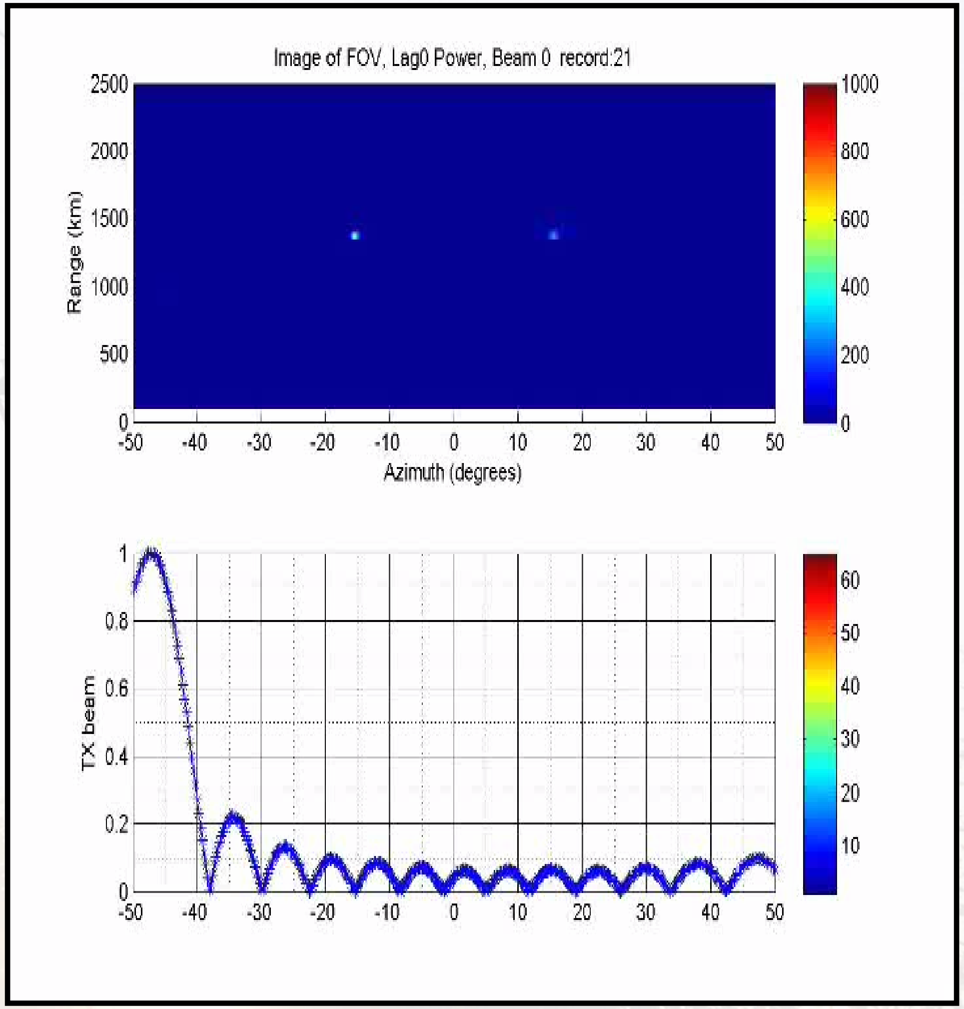
# First Images

- These are very preliminary results
- Imaging receivers just installed last week
- Radar parameters for images shown here;
  - Normalsound-fast
  - 10.4-10.7 MHz band
- TX beam shown is signals provided to transmitter
  - Actual TX signal depends on state of transmitters
  - Data shown was collected after all transmitters were fixed and calibrated

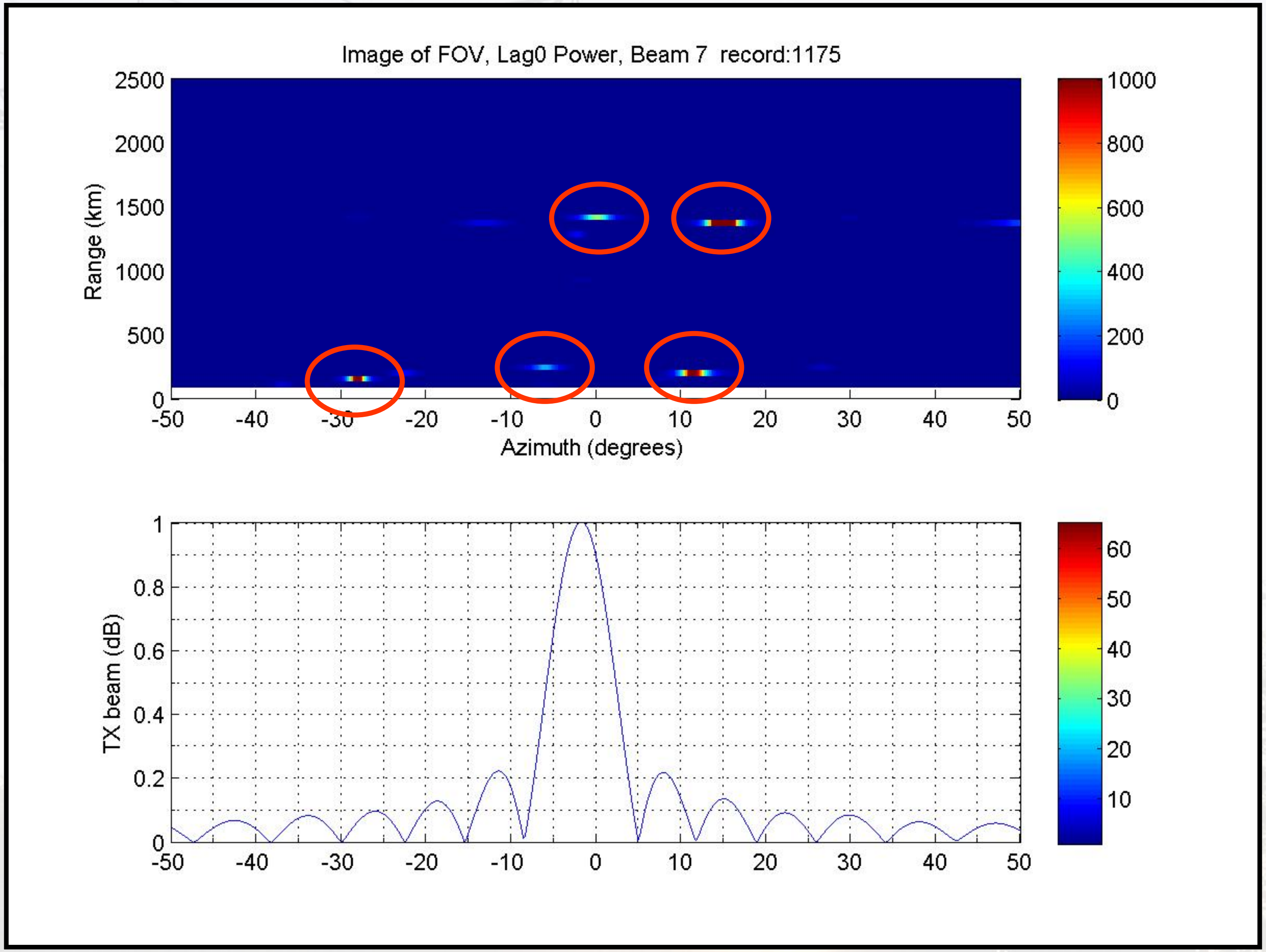


# Higher resolutions

- Other brightness distribution estimators can be used to increase azimuthal resolution
- Modified covariance estimator is shown
- Others;
  - Yule-Walker
  - MUSIC
  - De-convolutions
  - Etc.
- Achievable resolution is determined by SNR, not antennas

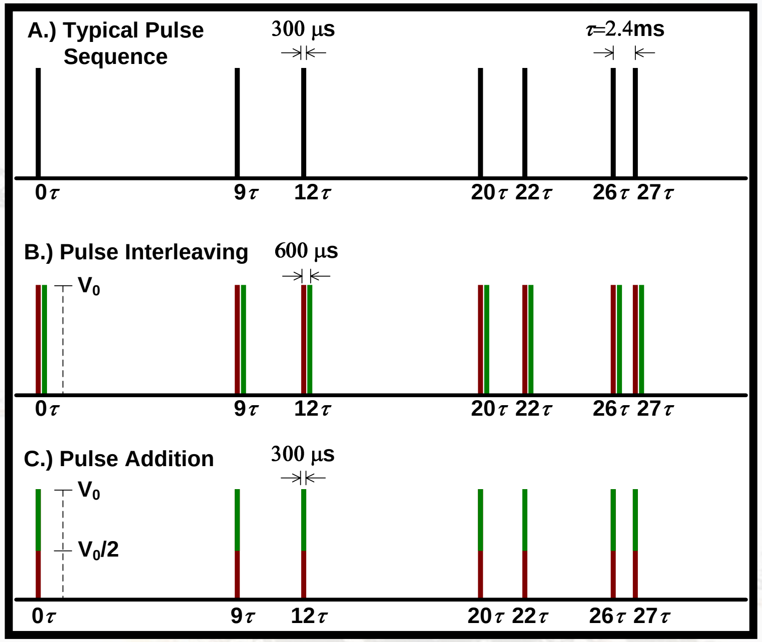


# Interesting Images



# Super Stereo

- One new capability of having four DDS up-converters and four digital receiver channels on each antenna is the ability to run multiple radar channels
  - Have written and tested code for Stereo operation (two channels), using the code from the Blackstone radar as a basis
    - Works in lab
    - has yet to be run on radar
  - Started ROS framework for four channels
  - This is intended to support HAARP, where we typically have very strong backscatter
    - Departing from time interleaving of TX pulses
    - Transmitting multiple frequencies in single pulses
  - Ultimately intend to have truly independent radar channels (different pulse sequences, phasing, etc.)



Questions?