Focal Plane Array Developments at NRAO

China – USA Bilateral Workshop

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Types of FPA

- Independent Beams
  - Sparse - Arrays of Feedhorns
  - Fully Sampled - Arrays of “bare” bolometers

- Phased Array Feeds

Feedhorn Arrays

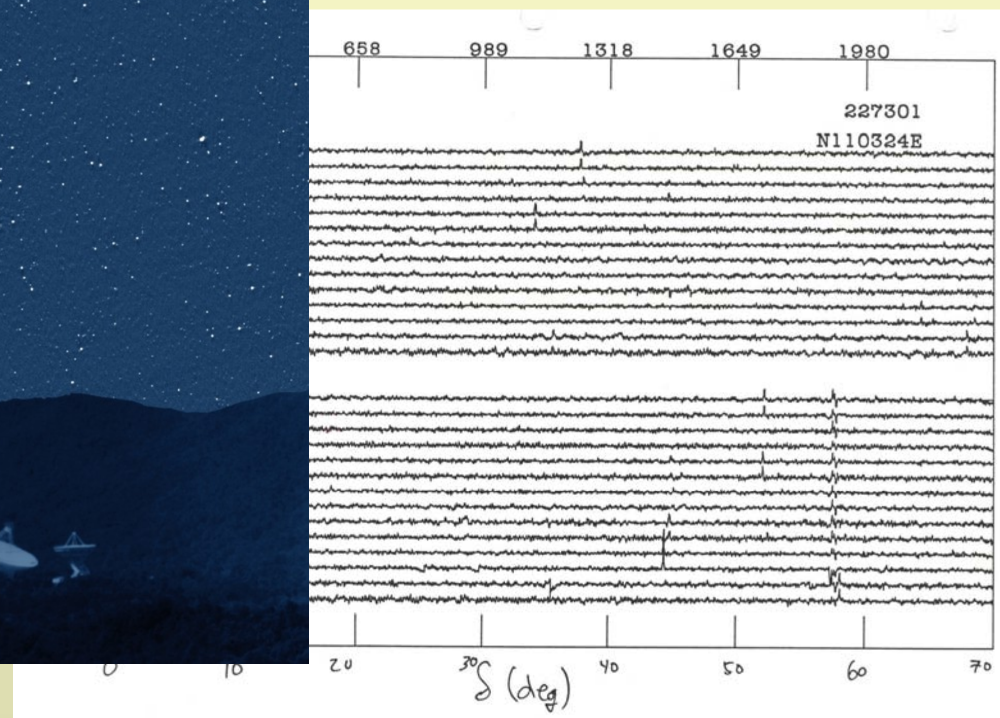
- Have been built for more than 30 years.
- Sparsely sample the focal plane.
  - 2 to 5 FWHM beam-to-beam spacings.
- Challenges are cost control, packaging, interconnections, and data acquisition.

Example: NRAO 7-Feed, 6cm Receiver

History with Feedhorn Arrays
7-Feed, 6cm Receiver

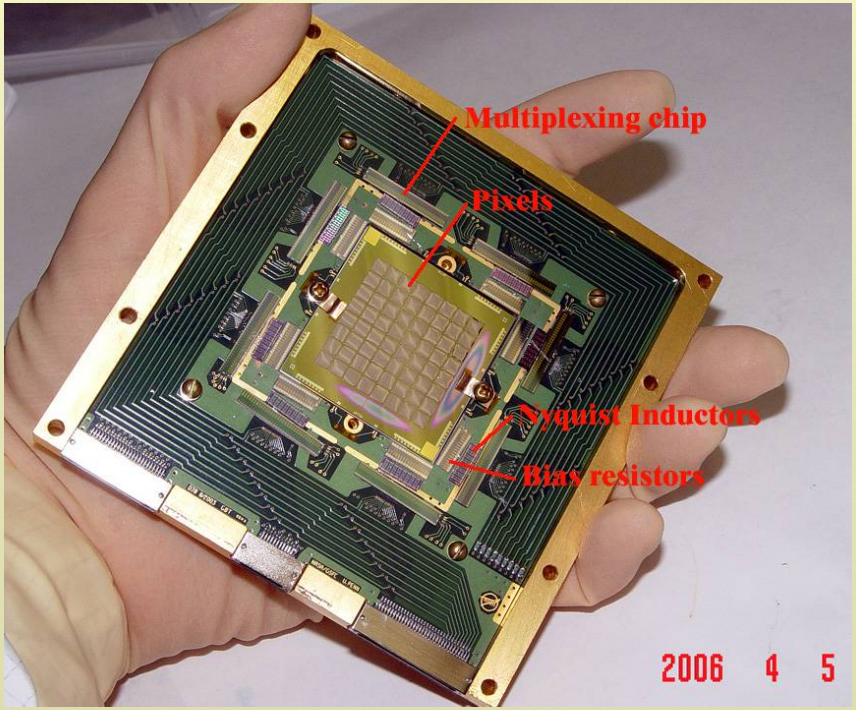
- Designed and built in the 1980’s
- Cryogenic GAsFET amplifiers
- Dual Circular Polarization
- Continuum Only, 500 MHz bandwidth
- Observed on the Green Bank 300’ Telescope, later at Parkes

Results
7-Feed, 6cm Receiver

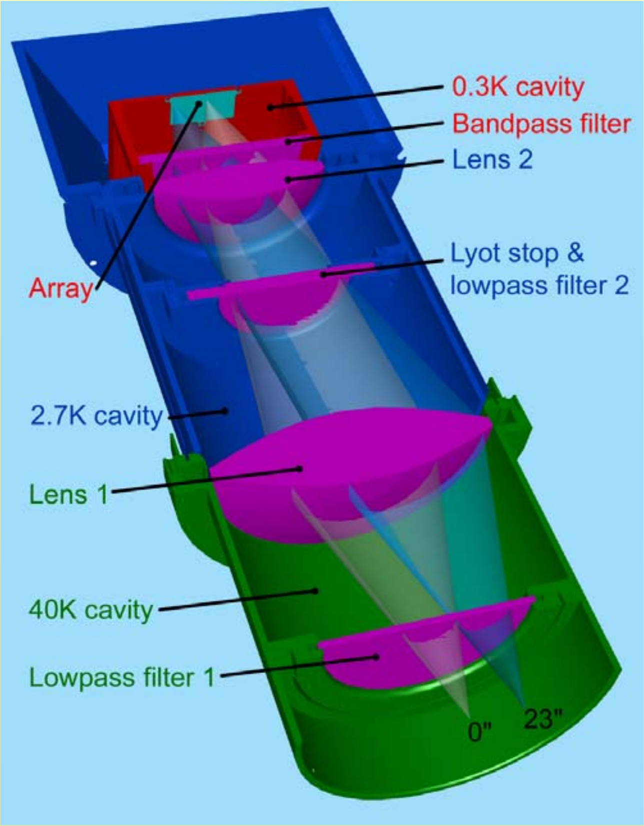


Recently Developed MUSTANG Bolometer Array

- 8 X 8 Array of TES elements
- Collaboration of University of Pennsylvania, NASA Goddard, NIST, Cardiff, and NRAO
- Designed for use on the GBT
- First light, engineering observations in 2006-2007
- First science observations winter 2008.



MUSTANG Receiver



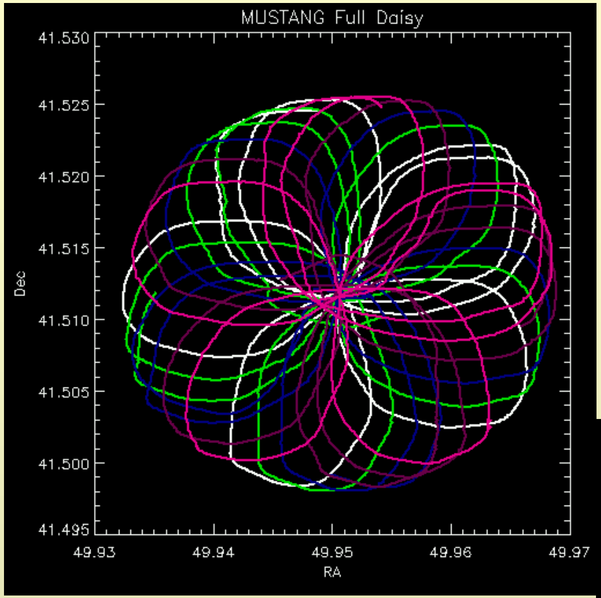
- Fλ/2 Sampling of Focal Plane, Array ~ 30 X 30 asec on sky.
- Uses lenses, filters, baffles to control illumination.
- Nominal 80-90GHz Bandpass
- Pulse Tube, He-4 & He-3 Sorption Refrigeration (300mK)
- Optics & Dewar allow expansion to larger array.

More Info: http://chile1.physics.upenn.edu/gbtpublic/

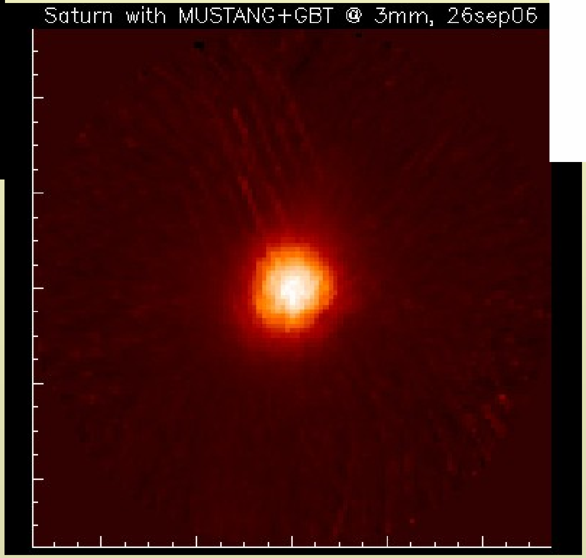
MUSTANG on GBT

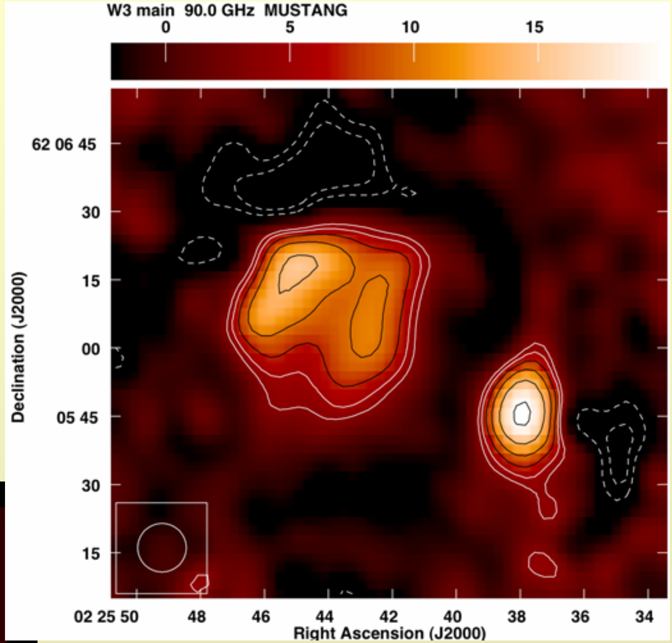
Challenges: Microphonics, cryogenics, sensitivity

Some MUSTANG Results



Mapping Pattern

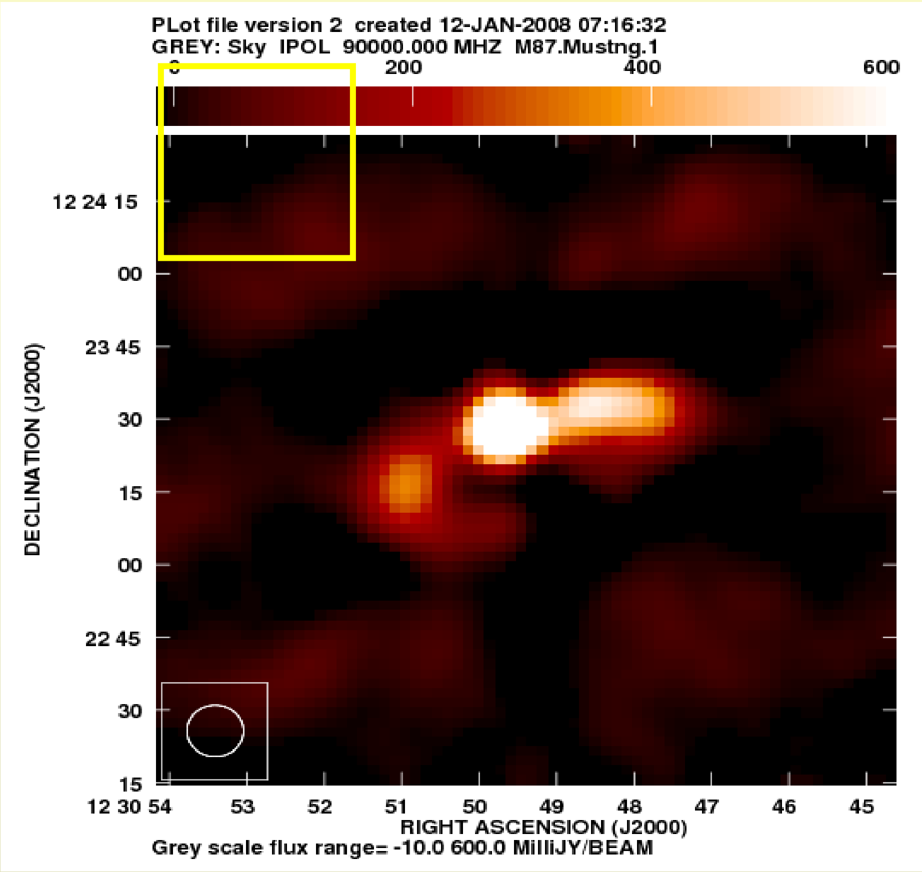


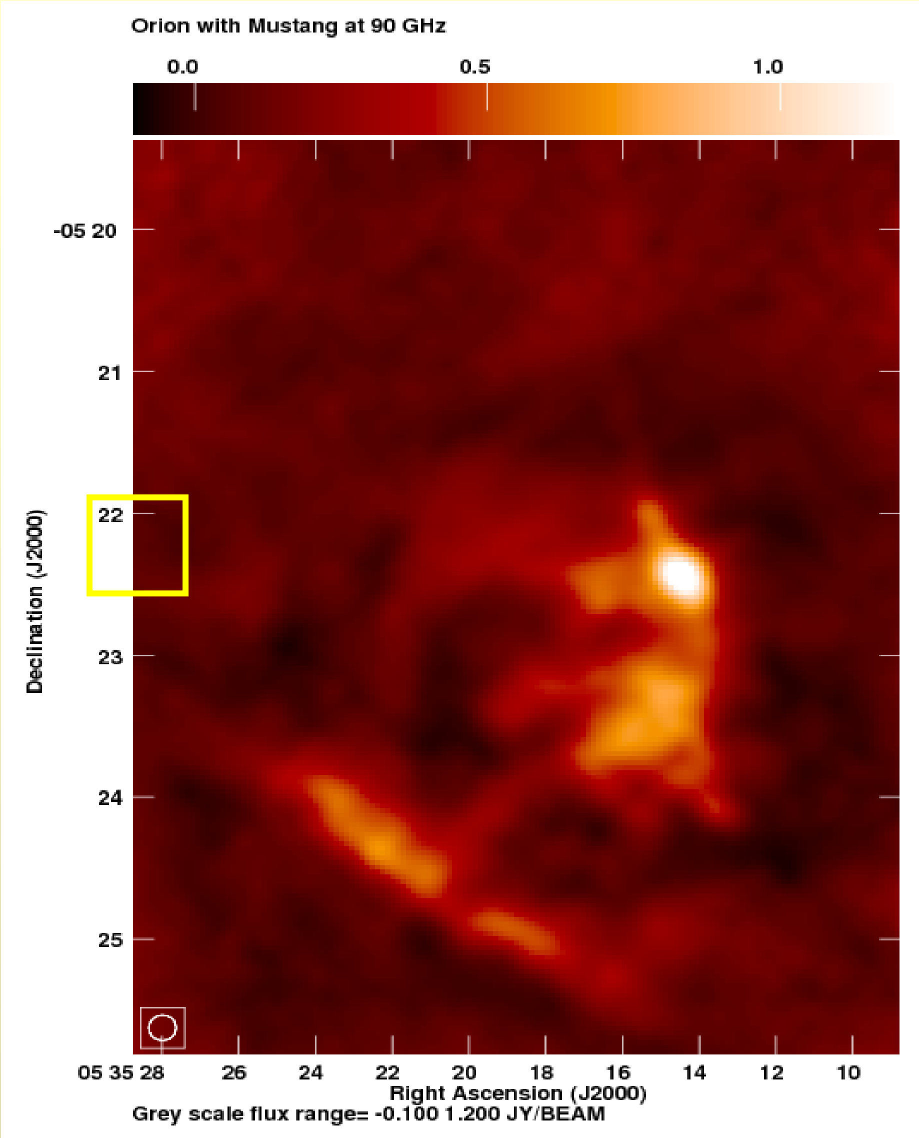


First Light Obs

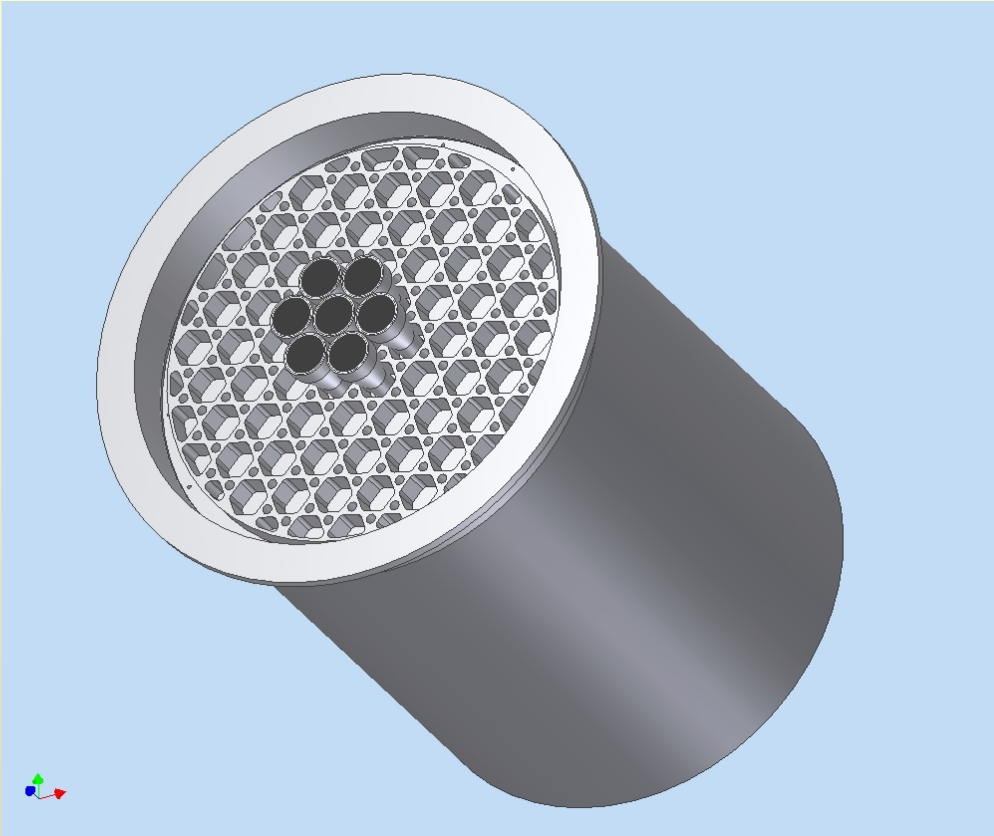
2006-07

MUSTANG Early Science Obs 2008



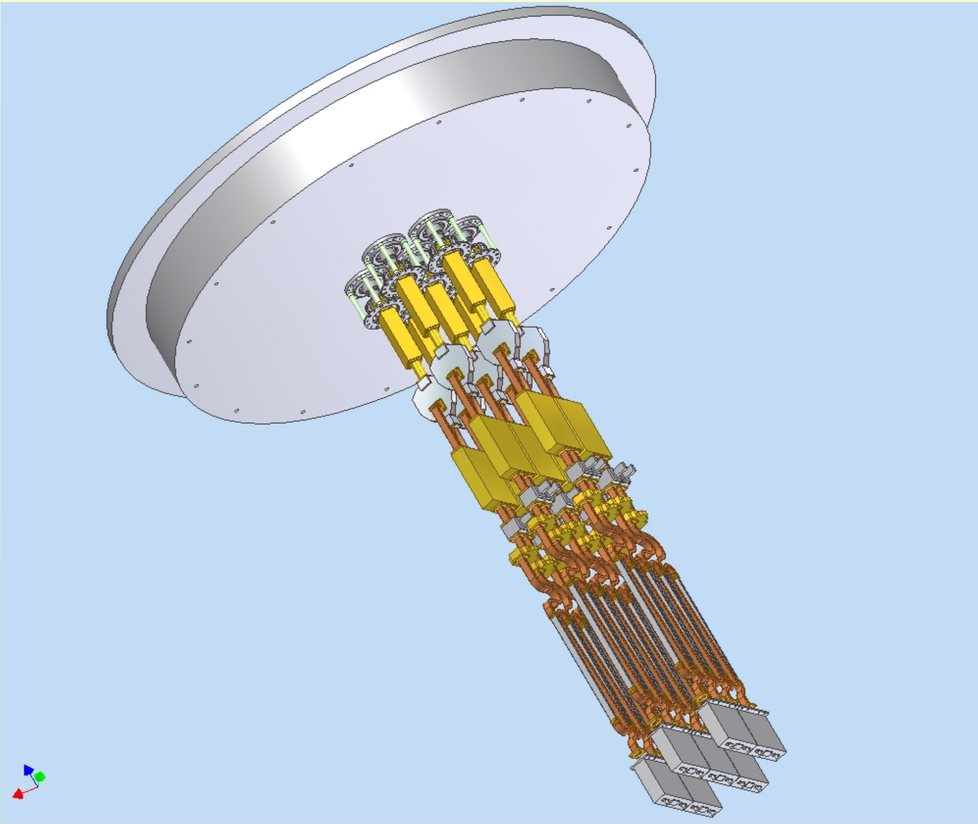


Under Development
K-Band FPA for GBT



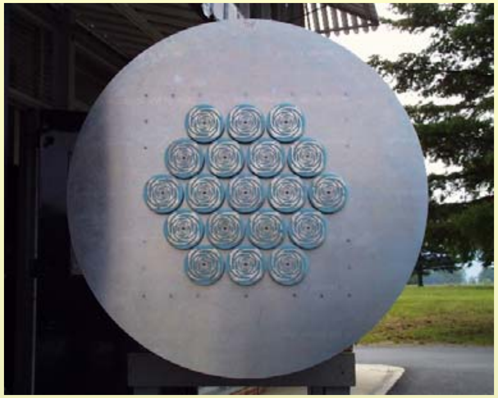
- Up to 61 Horns
- 18-26.5 GHz, Dual Pol
- 2.5-3 FWHM Beam Spacing. Outer beams' efficiency >90% of center's.
- Cryogenic InP HFET Amplifiers
- Primary role is spectral line mapping.

KFPA



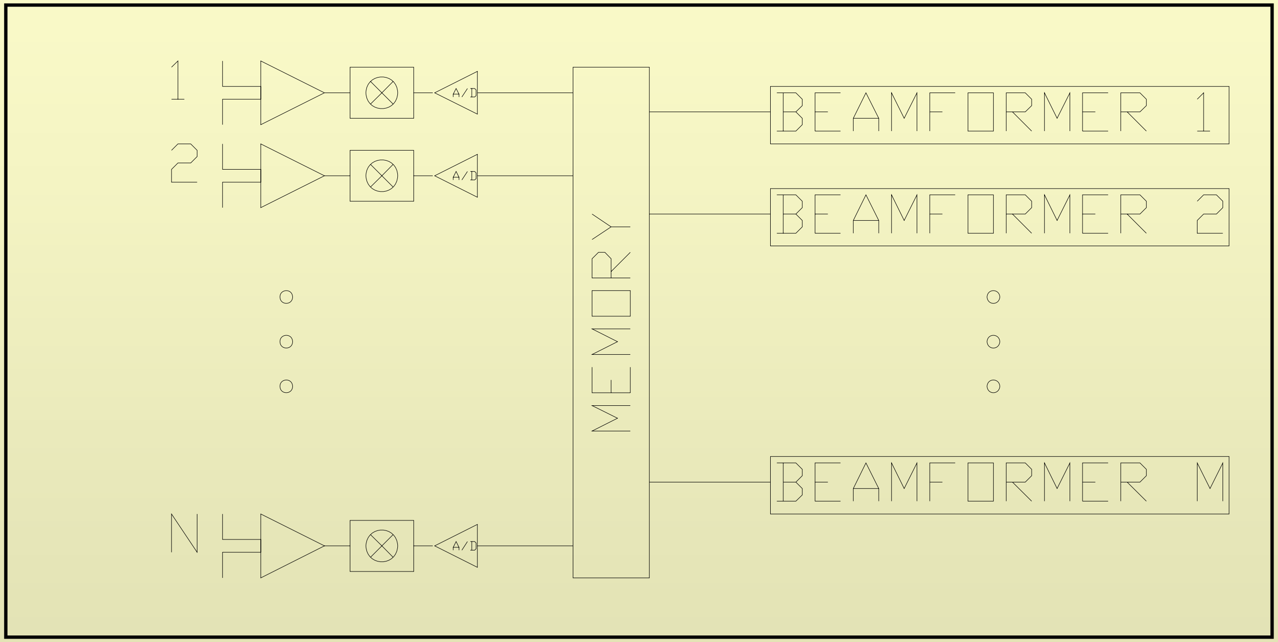
- Construction for 7 beam front-end is funded.
- First light expected Fall 2009.
- Initially will be used with existing GBT Spectrometer.
- Collaboration with U. of Calgary (Canada) for data analysis pipeline.

Phased Array Feed Research At NRAO



- Rick Fisher began research into PAFs for radio astronomy in the 1990’s. He and Rich Bradley built a small PAF using sinuous elements for experimental work.
- In 2000, Fisher & Bradley began a collaboration with Brian Jeffs & Karl Warnick, professors at Brigham Young University.

Digital Beamforming



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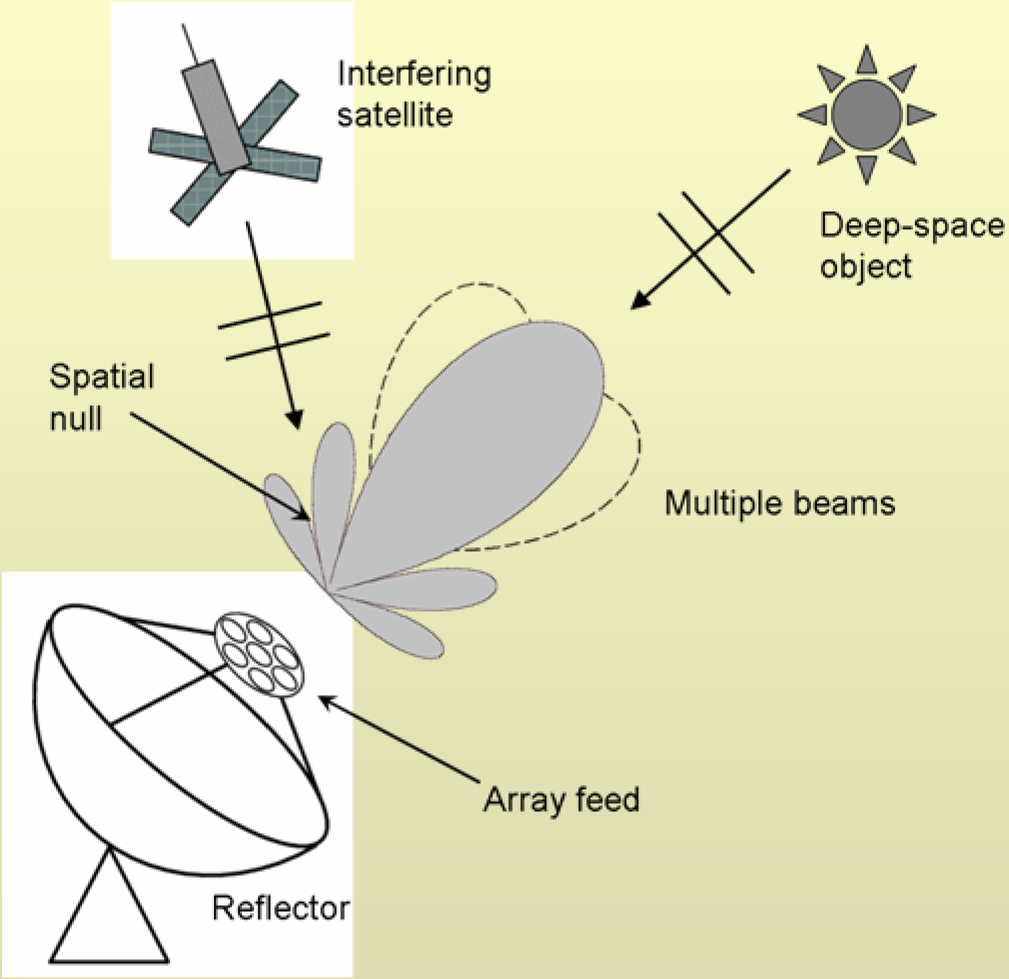
Digital Beamforming

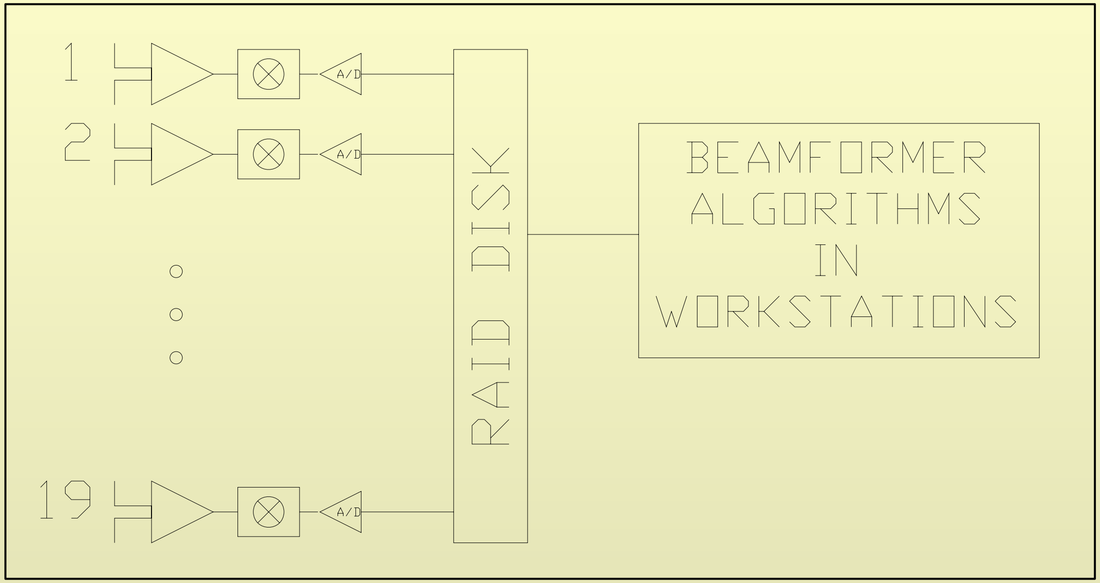
- For adequate FP sampling, radiating elements must be small => over illuminate the antenna. Beamformers must synthesize efficient illumination and steer the farfield beam as desired.
- Beamformers can adaptively place beam nulls on RFI sources.

Advantages of PAFs for Astronomy



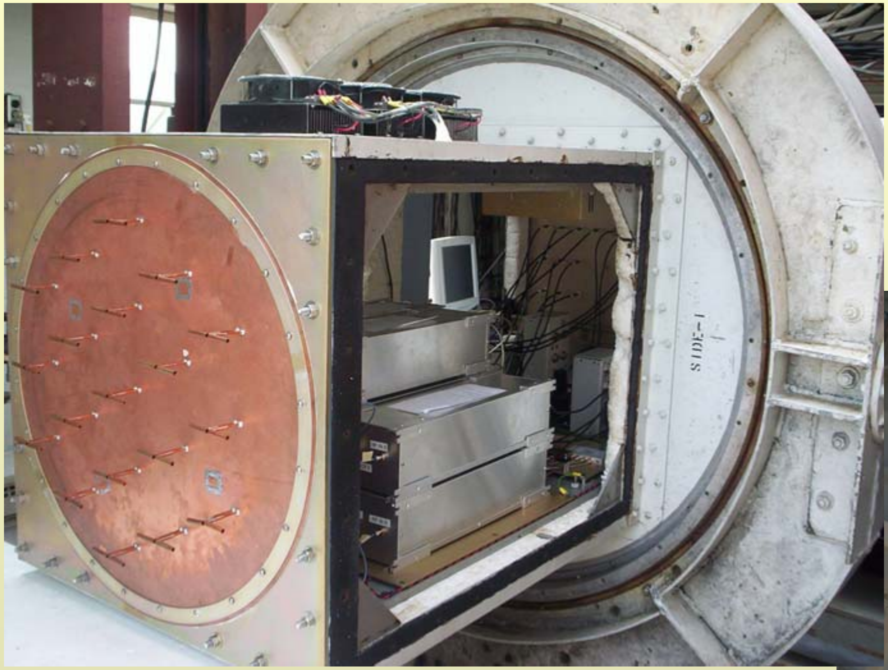
- Multiple simultaneously formed beams in different look directions
- Fast survey capability
- Adaptive beamforming to cancel RFI
- Direct and adaptive control of dish illumination pattern
- Increased sensitivity and spillover efficiency
- Proposed Square Kilometer Array (SKA) configurations may require array feeds to deal with RFI and survey requirements

BYU-NRAO 20m Experiment (2007)



Non-cryogenic array built by BYU students observed astronomical sources, in the presence of moving and stationary RFI sources.

BYU-NRAO 20m Experiment (2007)



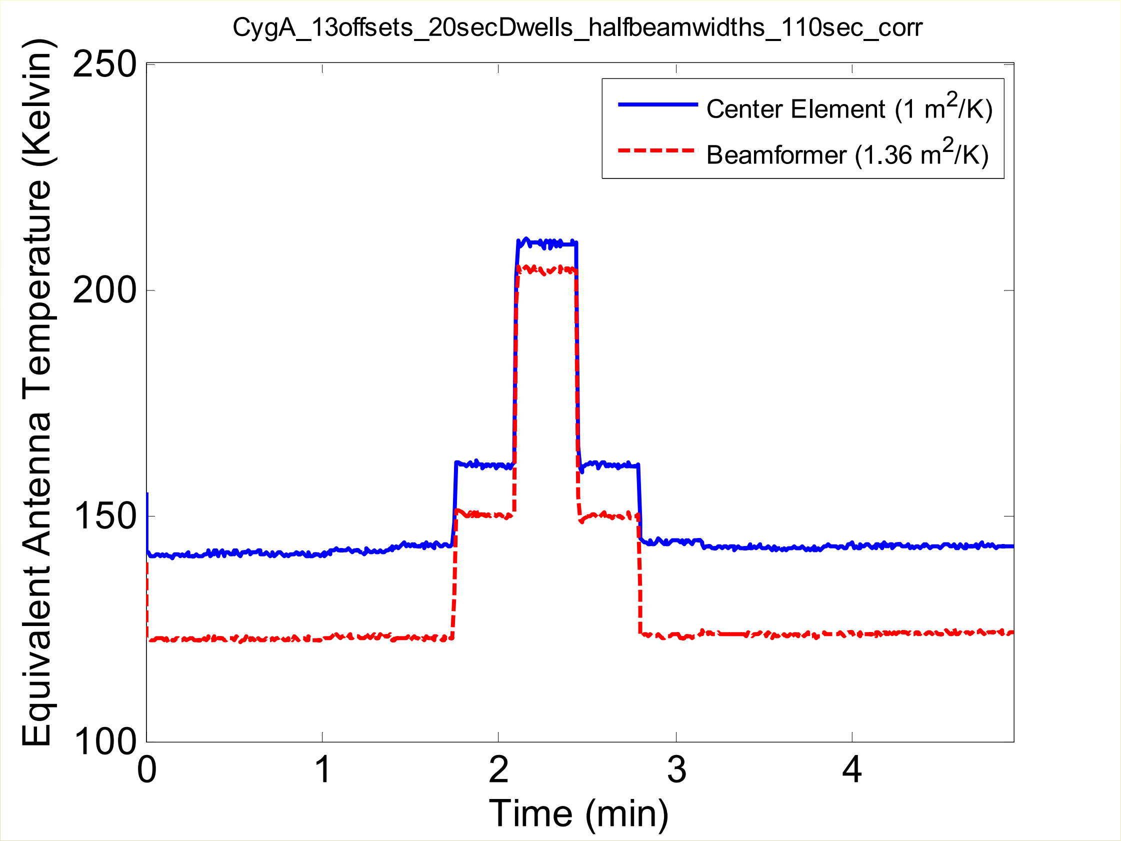
Calibration

Telescope steering:
- 24 arcmin steps (half beamwidth)
- 20 seconds per pointing

Beamformer:
- Calibrated using Cygnus A
- Maximum SNR

Source flux density: 1380 Jy

Preliminary T_{sys} calibration:
Gain: 0.06 $\pm$ 0.005 K/Jy
Aperture efficiency: 53% $\pm$ 5%

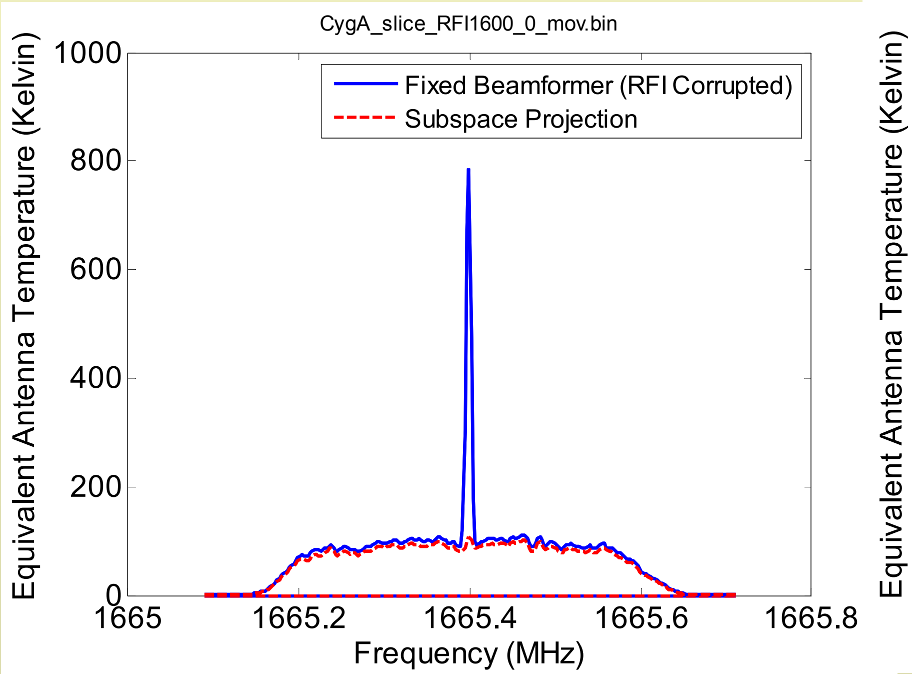


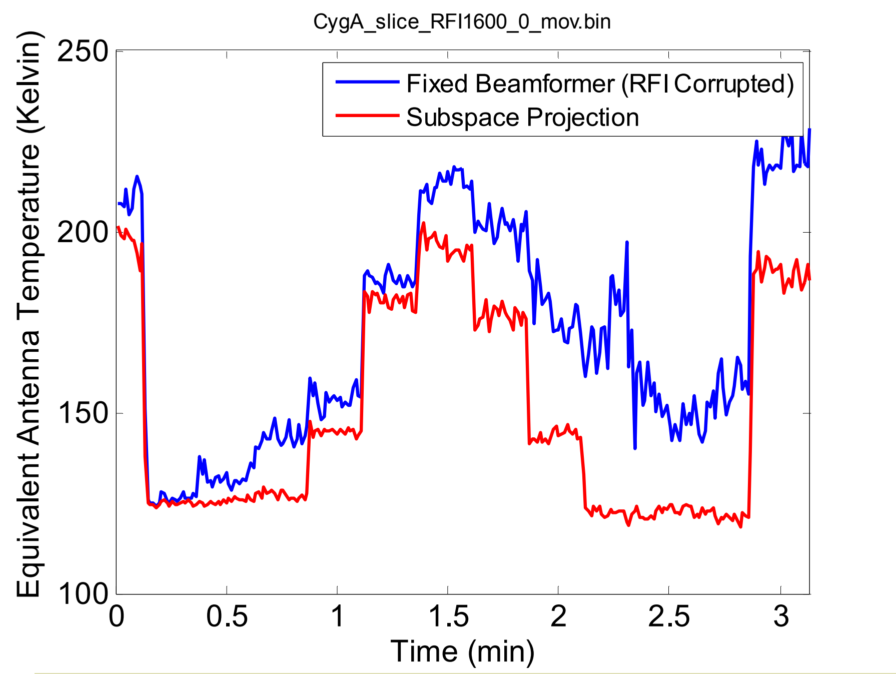
Adaptive RFI Mitigation

RFI Source: Artificial CW Tone, moving ground-based transmitter
  Significant multipath (simulates terrestrial source)

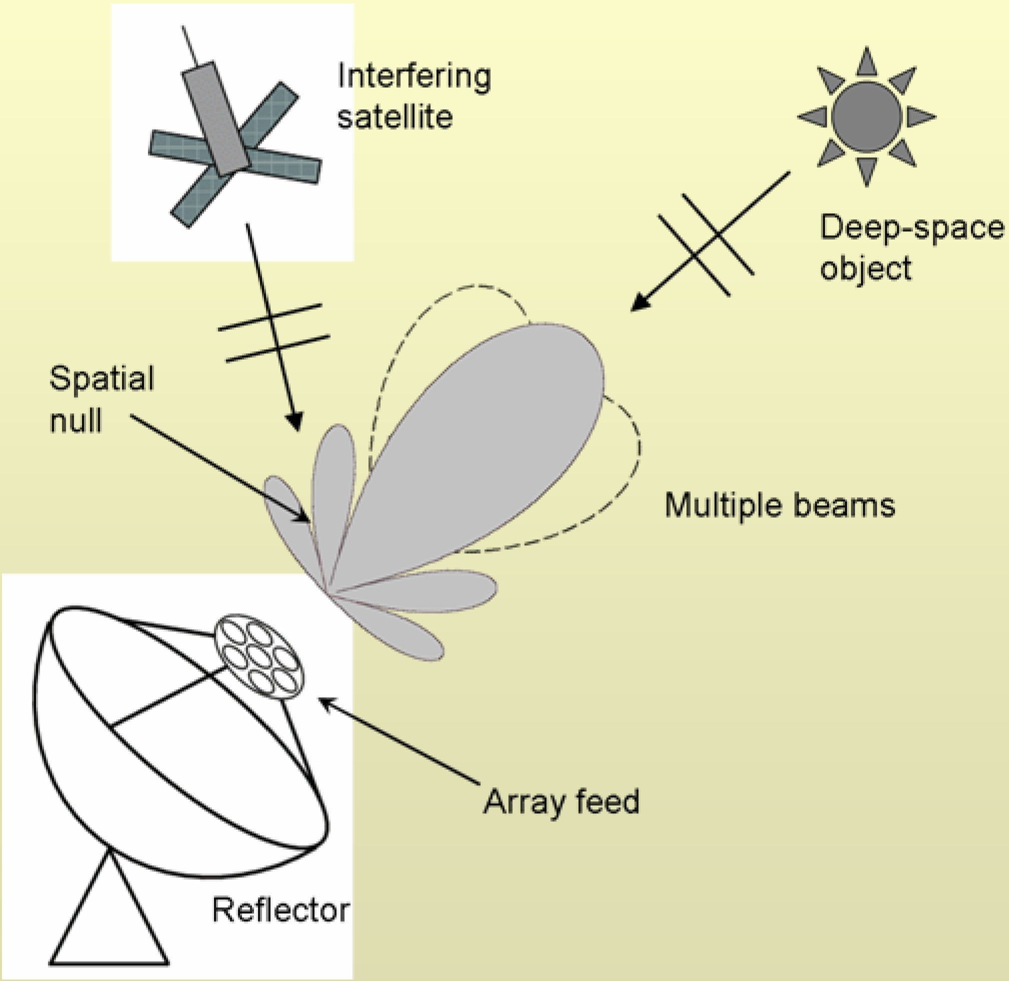
Quiescent beamformer: Maximum SNR

RFI Mitigation: Subspace Projection
  Projection operator nulls RFI subspace identified using dominant
    eigenvector of array response covariance
  4.9 ms short term integration (STI) time





PAF Challenges



- Receiver complexity
- Achieving low system noise
- Impedance matching and mutual coupling
- RFI cancellation null depth
- Adaptive signal processing to cancel moving interference causes pattern rumble
- Pattern fluctuations limit stable integration time and reduce sensitivity

PAF Research Path

- Focus on achievement of low-noise array technology, competitive with single beam.
- Understand mutual coupling, noise matching.
- Push algorithms for efficient multibeaming and stability in midst of RFI.