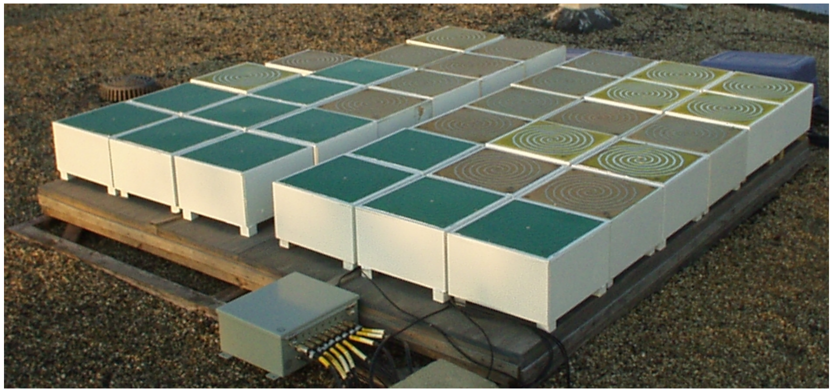
Detection & Localization of L-Band Satellites using an Antenna Array



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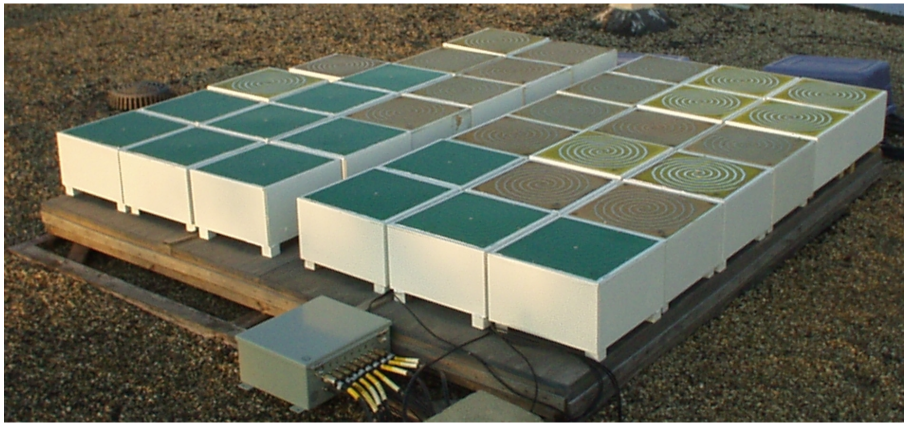
June 2004

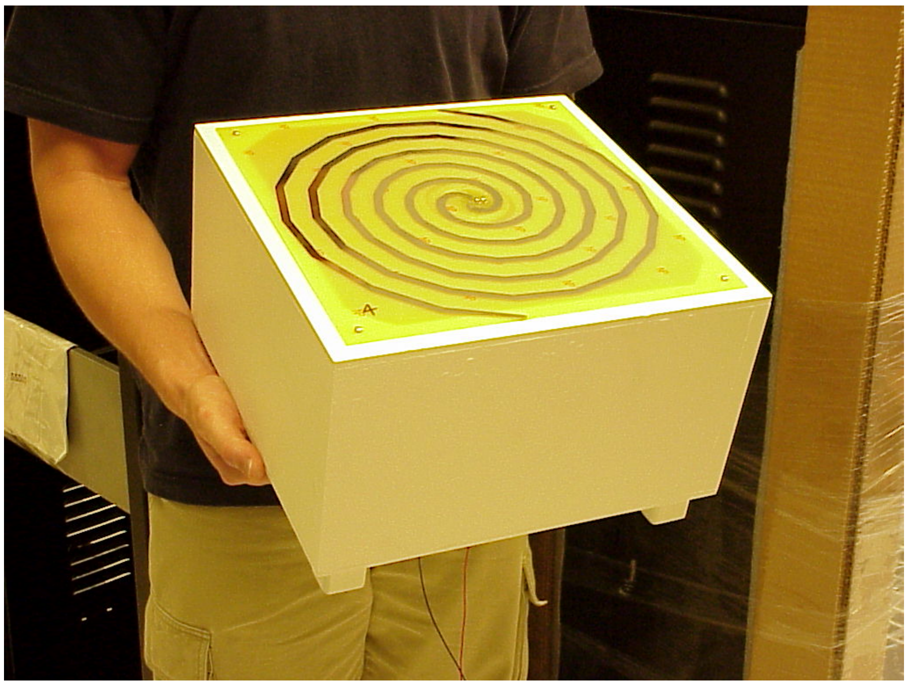
http://www.ece.vt.edu/~swe/argus

Introduction

- Traditional radio astronomy uses large, filled-aperture antennas to achieve high sensitivity and spatial resolution.
- The resulting field of view (FOV) is extremely narrow, which limits sensitivity to undiscovered transient astronomical sources.
- An alternative approach is to use instead large numbers of low gain (broadbeam) elements to achieve sensitivity over the entire sky.
- Our system "Argus" is a first step in that direction. The system has been continuously operational since Spring 2003.
- Here, we present some work in validating system performance using observations of earth-orbiting satellites.

Antenna Array





- 34 antenna units in array (currently in a pseudo-random configuration);

  24 are operational

- Element is planar spiral on FR4 with tiered ground plane

- A_e ~ 60 cm^2 per antenna @ 1420 MHz, zenith

- Integrated LNA powered through RF cable

- T_{sys} ~ 215 K per element

- Total useable range about 900-1700 MHz

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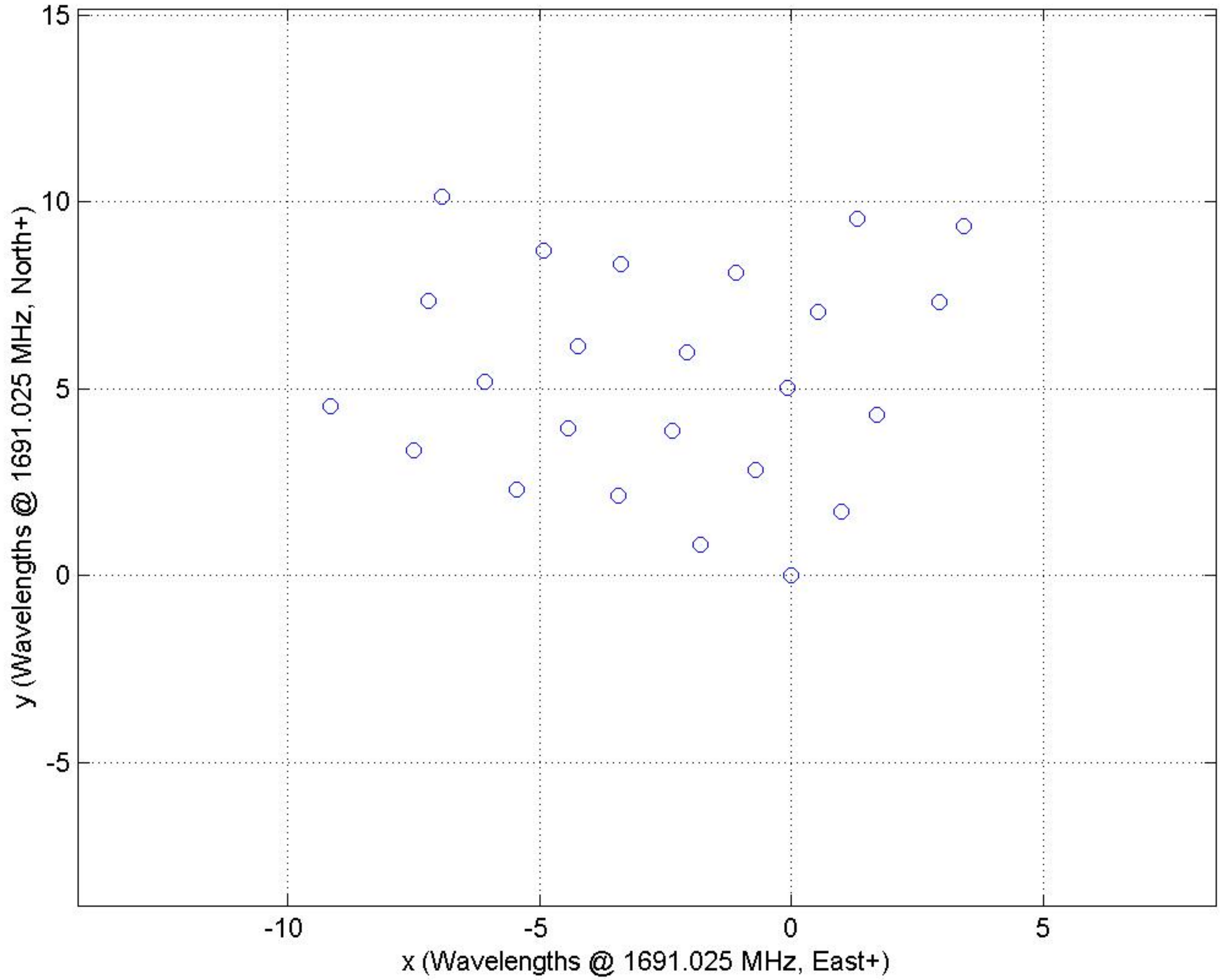

Array geometry.

Approximately random so as to mitigate aliasing as much as possible.
Dots represent phase centers of elements employed in this experiment.

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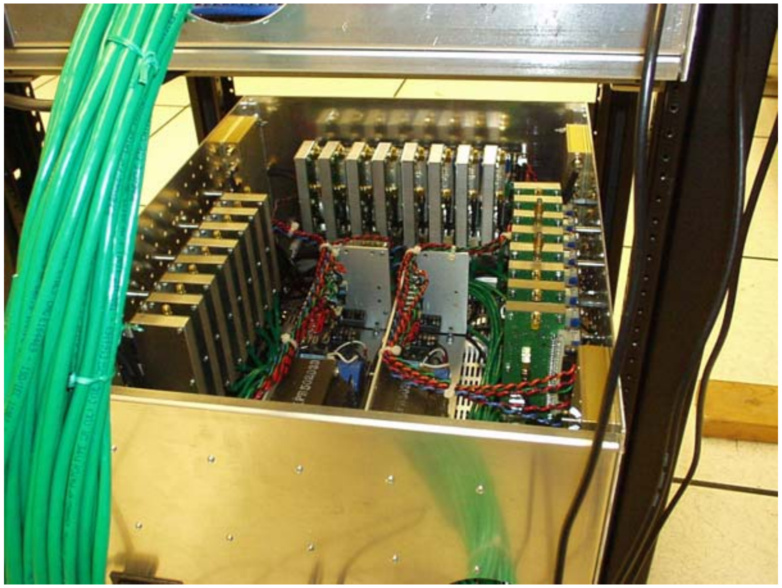
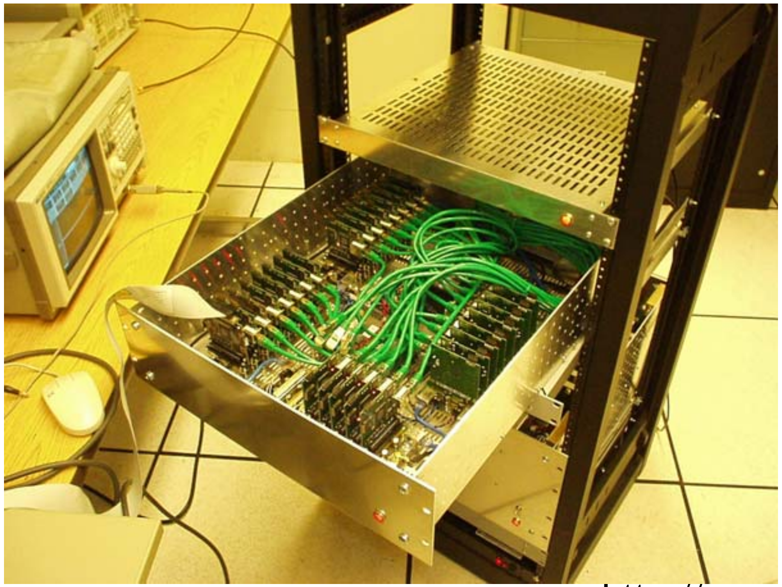
Receivers / Data Aggregation





Direct Conversion Receivers (DCRs)

- **Moves 14 MHz spectrum from L-band to baseband (I/Q)**
- **Digitizes 20 MSPS, 8-bit “I” + 8b “Q”**
- **Output at 320 Mb/s using serial LVDS**

Argus Narrowband Processor (ANP)

- **Corrects (small) I/Q imbalance from DCRs**
- **“Tune and Zoom” within 14 MHz digital passband: 60 kHz BW @ 78.125 kSPS**
- **Continuously aggregates 32 elements in a single data stream; further processing by a PC cluster**

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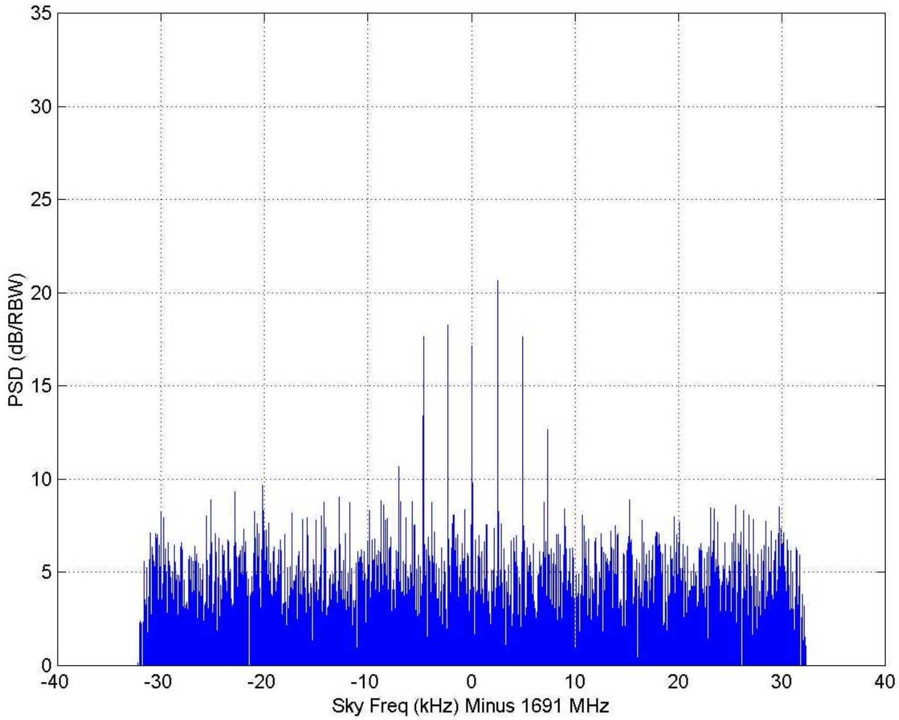
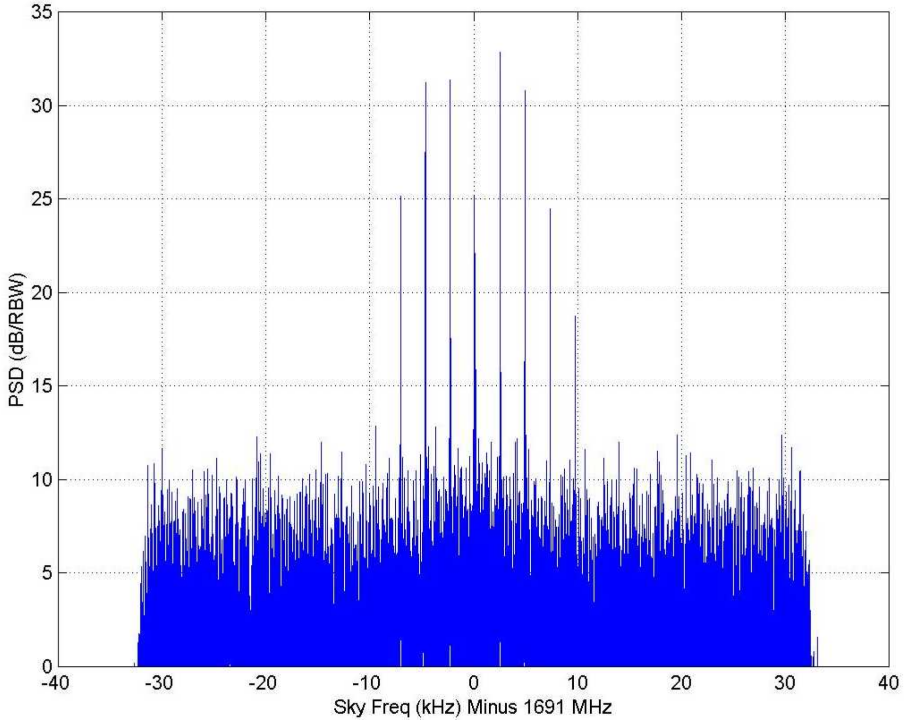
Adaptive Beamforming Example

- **1691 MHz (WEFAX) emission from geostationary satellite GOES-EAST**
- **Relatively weak signal (normally requires 1-m dish and good LNA)**



Signal from single element



Signal after beamforming with 24 elements, using adaptively estimated weights

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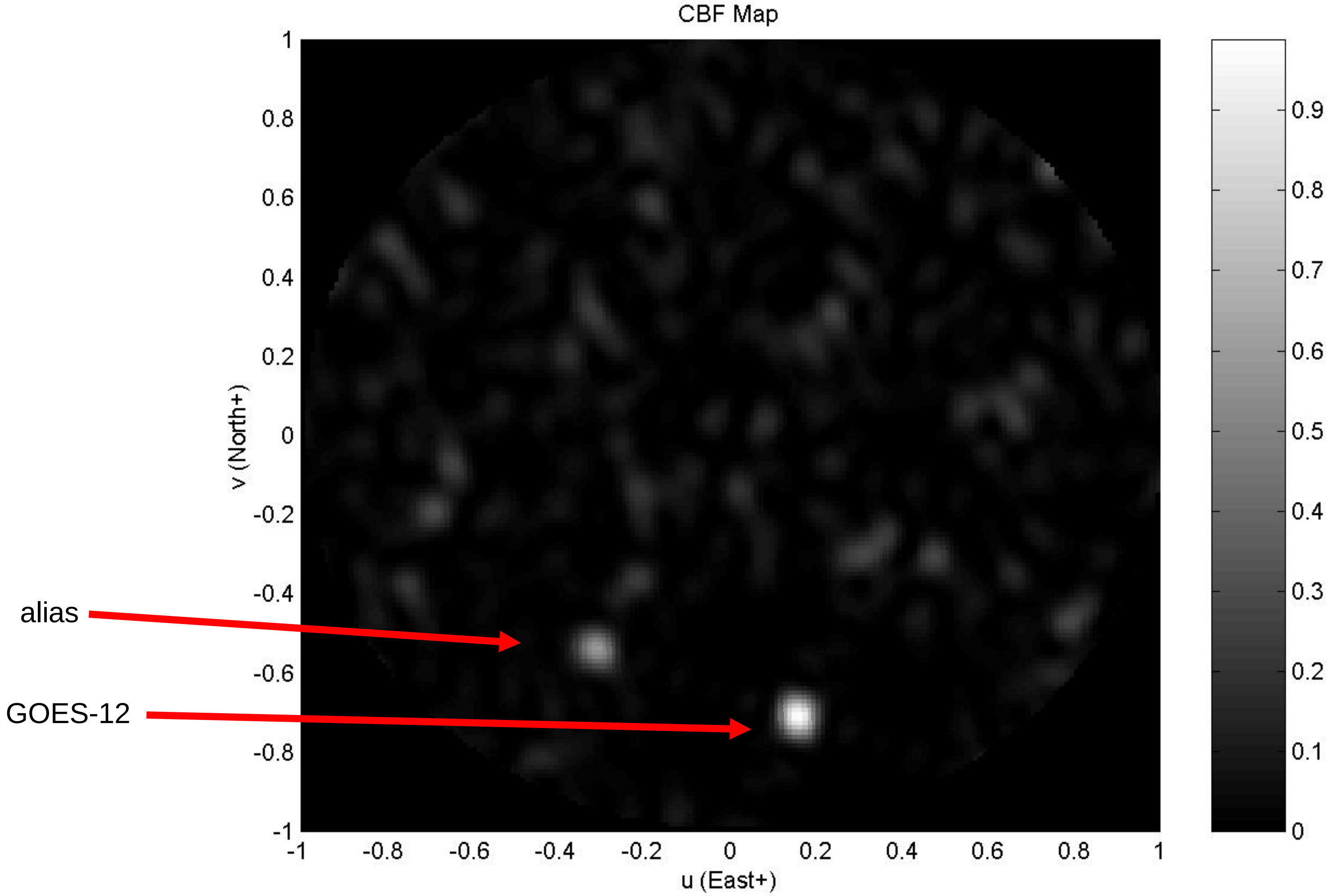
Imaging Example



<u>Predicted result</u> for GOES-12 (1691.0 MHz), **obtained from simulation**.
Note strong alias plus complex sidelobe structure.

<u>How to interpret image</u>: u (horizontal axis) and v (vertical axis) are "direction cosines": u=v=0 is the zenith, and $u^2+v^2=1$ is the horizon.

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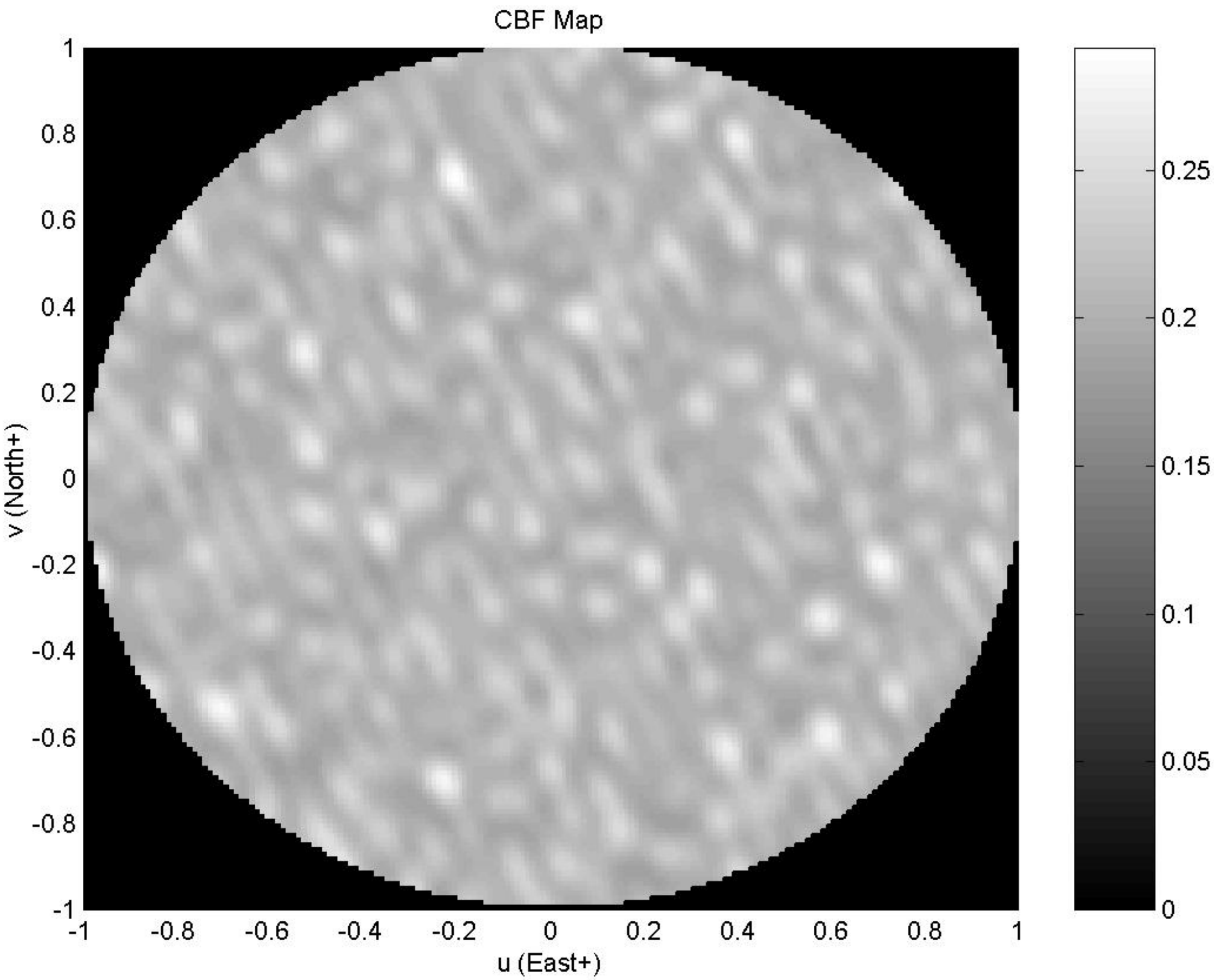

Actual measured result at 1691.0 MHz, 30 kHz bandwidth, <u>before calibration</u>.

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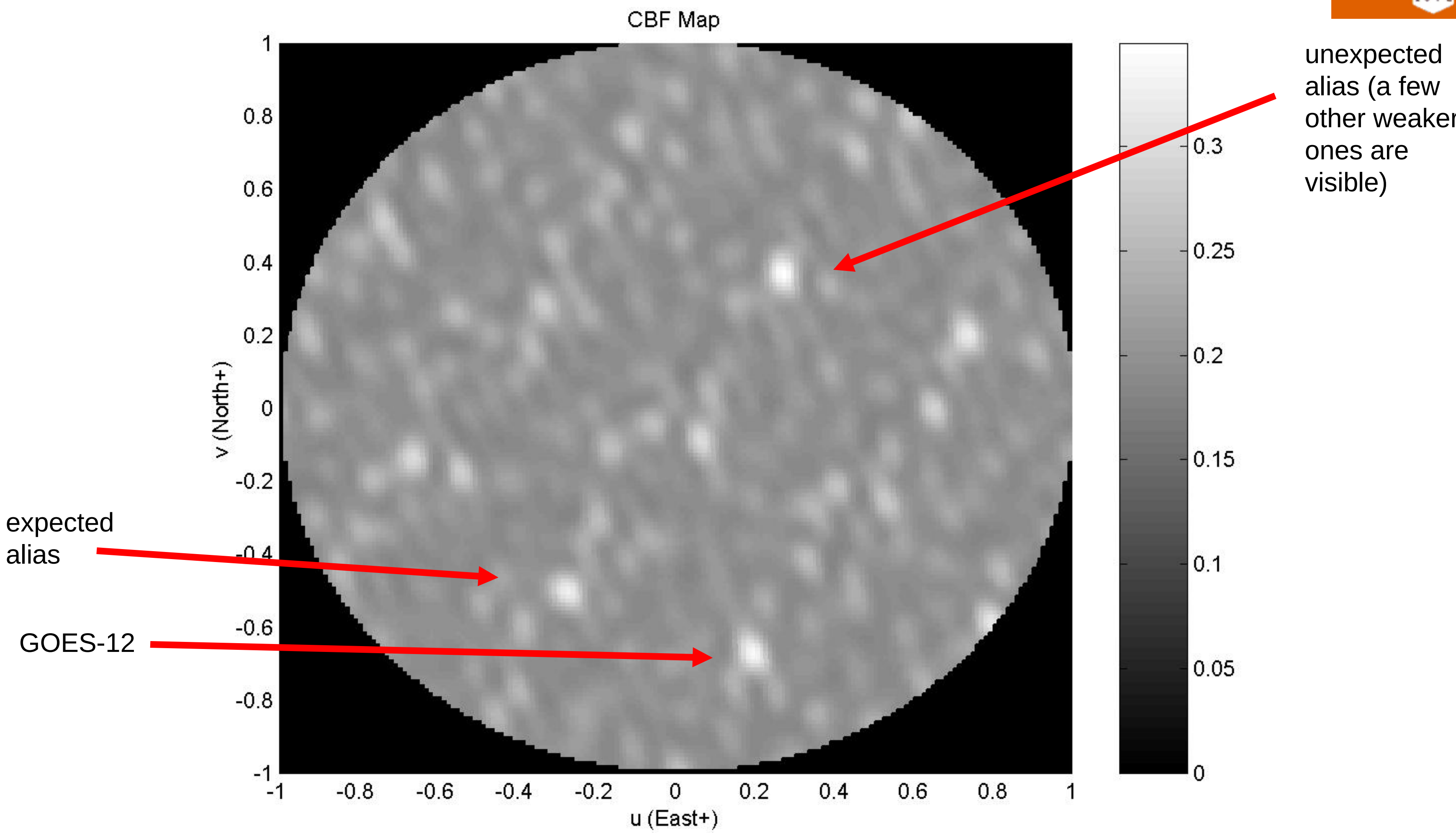

Actual measured result at 1691.0 MHz, 30 kHz bandwidth, <u>calibrated</u> using near-field noise source.

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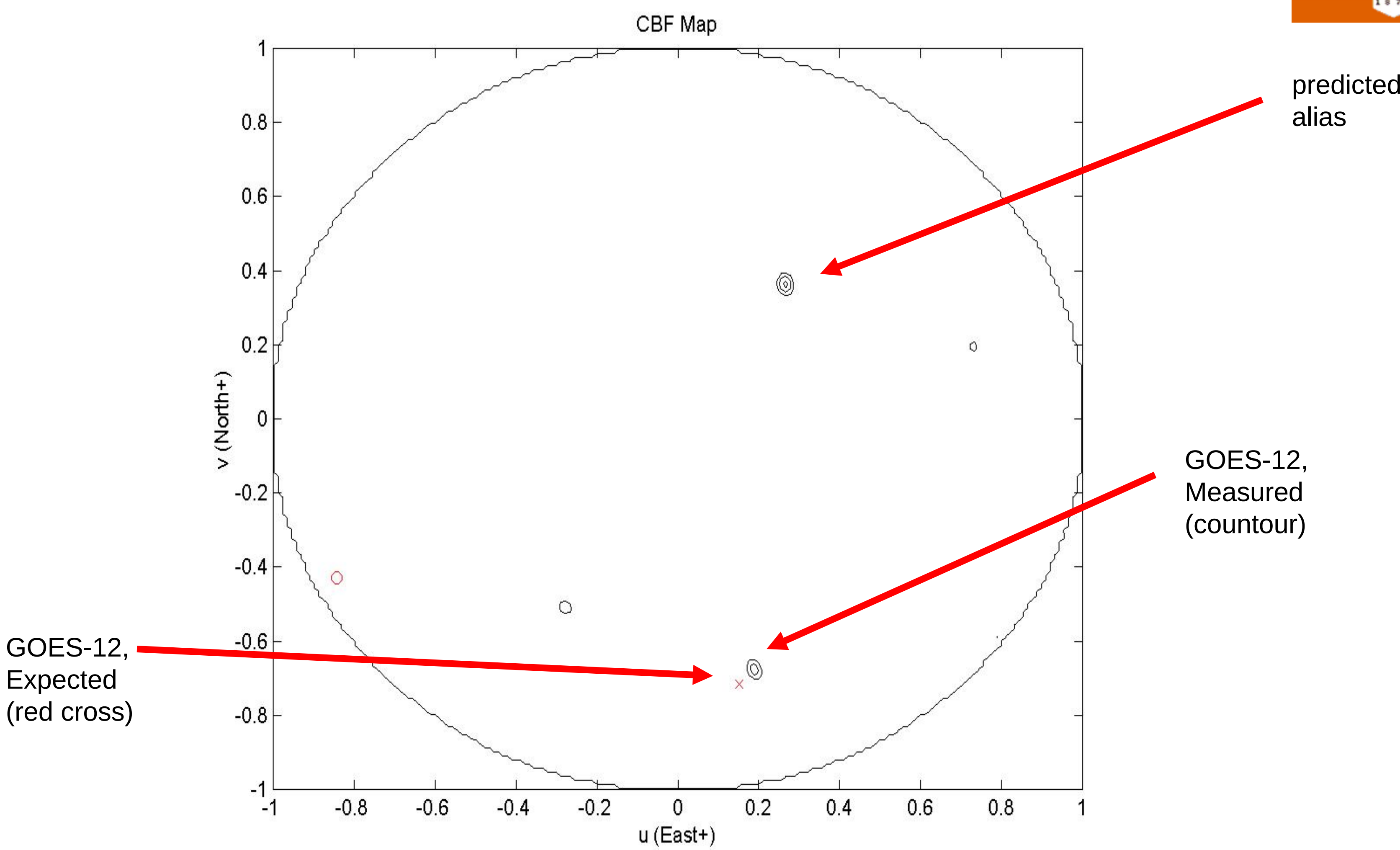
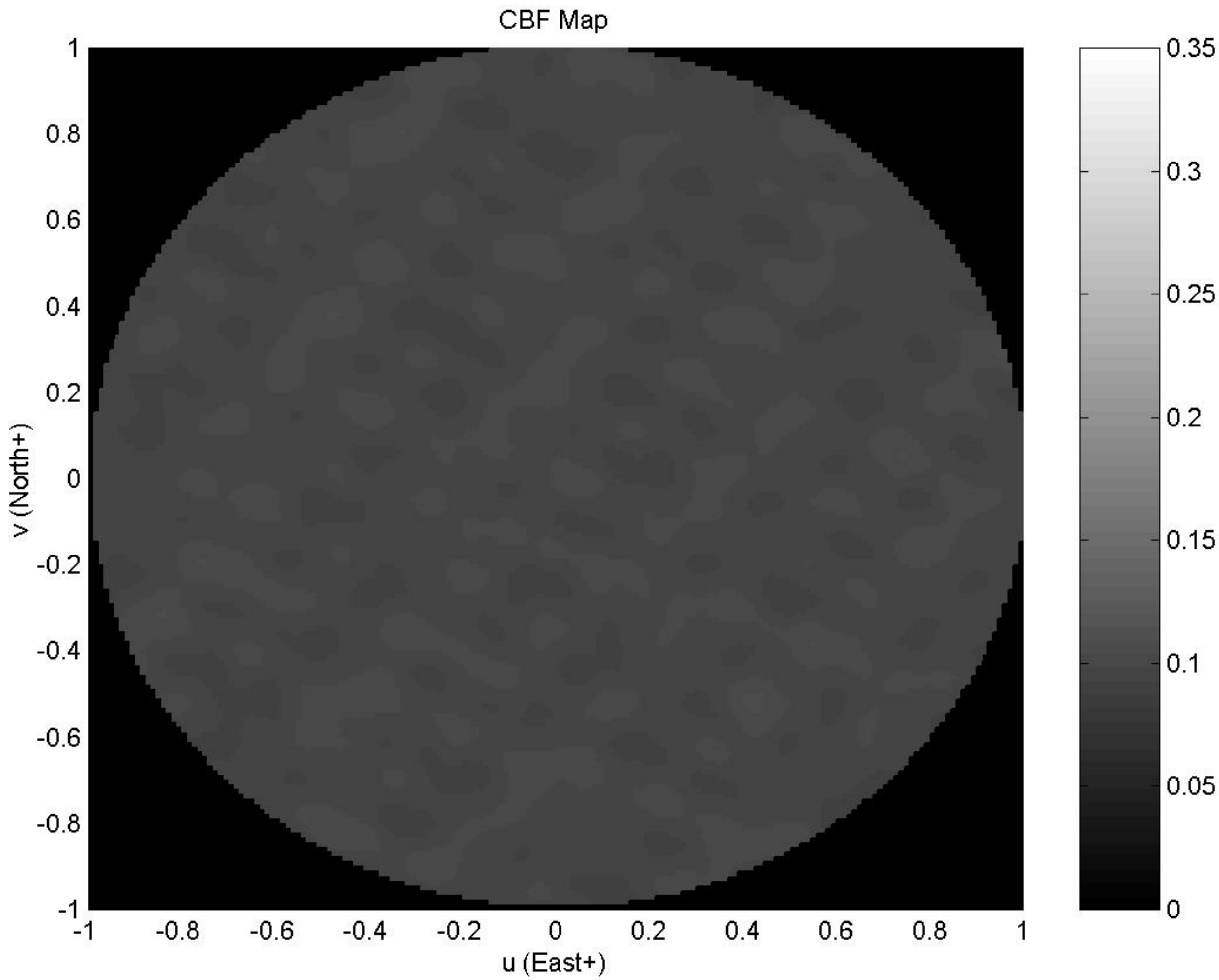


Actual measured result at 1691.0 MHz, 30 kHz bandwidth, calibrated.

This is a contour plot derived from the GOES-12 measured image, with contours at 0.99, 0.95, 0.90, and 0.10 times the brightest pixel.

Small misalignment is probably due to error in measuring array geometry.



Actual measured result at <u>1691.3 MHz</u>, 30 kHz bandwidth, calibrated.

By observing the adjacent 30 kHz channel, which is nominally signal-free, we confirm that the system is fairly well calibrated (indicated by the relatively flat image) and that all structure seen in the previous image is due to GOES-12.

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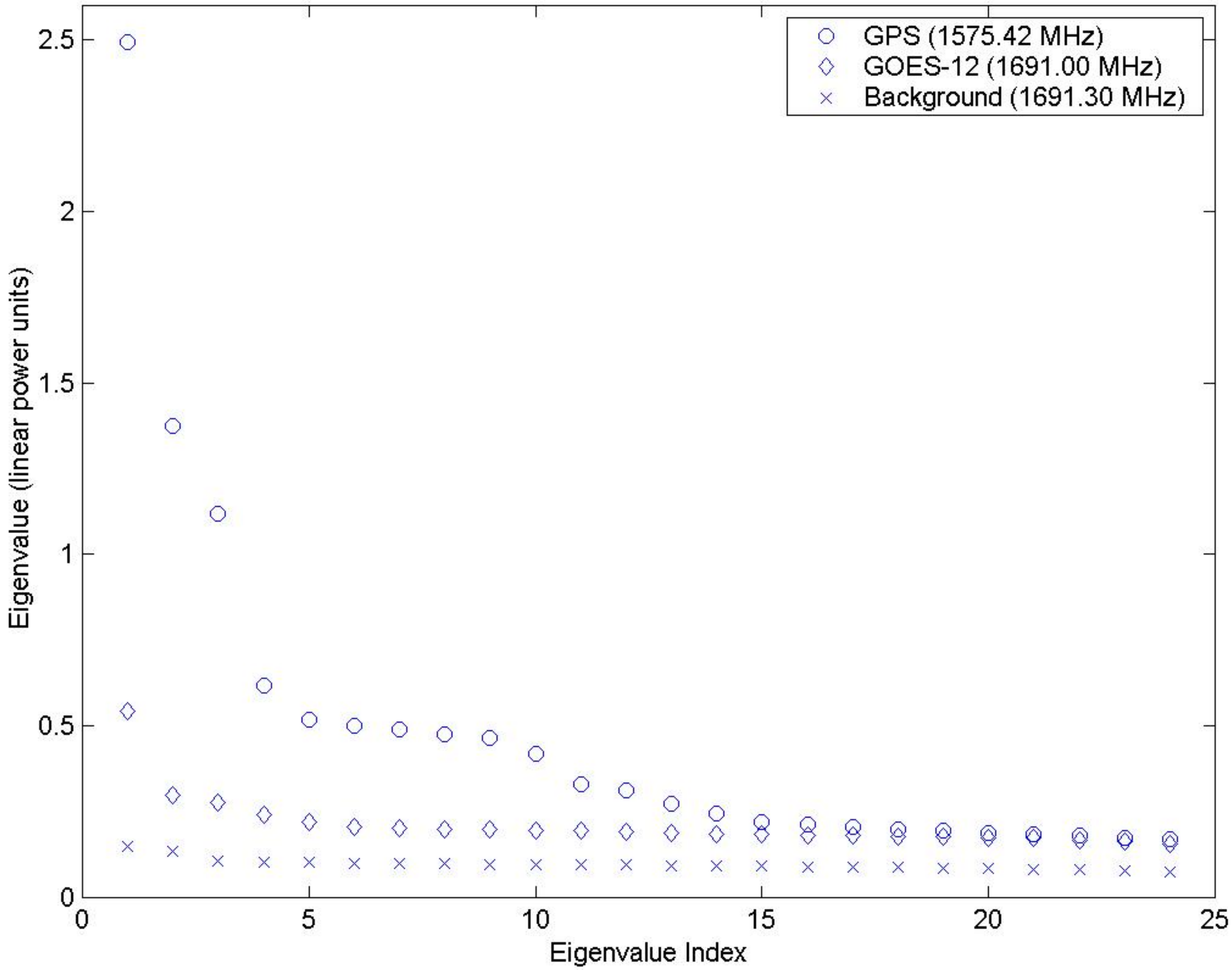
Detection by Eigenanalysis

- A 24 x 24 "spatial covariance matrix" R, tabulating the cross-correlations between all possible pairs of elements, is formed from a single 209-ms data record.

- Assuming perfect calibration, the absence of a signal means all of the eigenvalues of R are equal.

- Thus, detection can be defined as a condition in which the inequality of eigenvalues exceeds some threshold.

- The number of eigenvalues exceeding this threshold indicates the number of uncorrelated far-field sources detected.
  - At 1691.00 MHz, we should detect 1 signal (GOES-12 WEFAX)
  - At 1691.30 MHz, we should detect 0 signals (Cold sky)
  - At 1575.42 MHz, we should detect ~9 signals (GPS constellation)



Observed eigenvalue spectra, 209 ms integration

Observed signal to noise ratios are consistent with anticipated 215 K / element system temp.

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Concluding Remarks

- **Argus system functions and sensitivity have been validated using observations of earth-orbiting satellites**
  - **Sensitivity ~ (2.4 x 10^{-22} W m^{-2} Hz^{-1}) in 209 ms**
- **Should be noted that same detection performance can be achieved without calibration! (Only the difference relative to a "noise-only" spatial covariance is important.)**
- **Work continues on implementing a campaign to detect & localize astronomical transients**
  - **Present limitation is (ironically) interference from terrestrial- and space-based transmitters**
- **Same technology has many other applications**
  - **Interference surveillance and characterization**
    - Radio astronomy
    - Spectrum management / regulatory activity
  - **Passive multistatic radar**
    - Military / National security
    - Civilian aviation

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