The Ohio Argus Array

A presentation to the Breakthrough Listen science team at the University of California, Berkeley's SETI Research Center

Presented by:

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Bob's overview of the history of the Ohio Argus Array

- Operating continuously since 2003
- 24 spiral elements in a planar configuration
- Continuously sees entire sky; no scanning, no moving parts
- Simultaneous detection of narrowband and pulsed signals
- Tunable 1000-2000 MHz
- Beamwidth 5 degrees, right circular polarization
- Constructed and maintained solely by volunteers
- Operates totally unattended, except for occasional visits by Russ.

**The Ohio Argus Array elements and amplifiers.
Note: the calibration source mast
is at the upper-left.**

An Argus antenna element
The preamplifier is connected directly to the center of the PCB spiral. Note the stepped groundplane(s).

History of the Telescope

- I conceived of the idea around 1988.
- I gave many papers and conference presentations 1988-1999.
- Then Prof Steve Ellingson became interested and developed the design.
- He gave many papers and conference presentations 1999-2008.
- In the meantime, grants from SETI Institute 2000-2003 to construct the telescope.
- Aided by NAAPO volunteers.
- Russ volunteered to take over further development and operation in 2003.

Argus was a Greek mythology guard being that had 100 eyes and could see in all directions.

Modern Renditions of Argus

Hermes tötet den Argos in Gegenwart des Zeus, Vase in London (?) nach *Annali d. I.* 1865 Tav. d'agg. I K; s. Sp. 277, 6 ff.

From a fifth century BC vase

Other independent uses of the name Argus

Arthur C. Clark in the novel Imperial Earth

Carl Sagan in the novel Contact

Star Trek the Next Generation, where it was located at the edge of Federation Space.

The project called Project Argus is entirely different; Project of the SETI League, consisting of amateur backyard small home dishes, operating independently.

Russ Childers will now give an overview of the Ohio Argus Array hardware, software, interesting array observations, and resources.

Ohio Argus Array Block diagram

Antenna elements

Receivers

Calibration control/source

Data collection computer

Two ethernet networks

Beamformers:

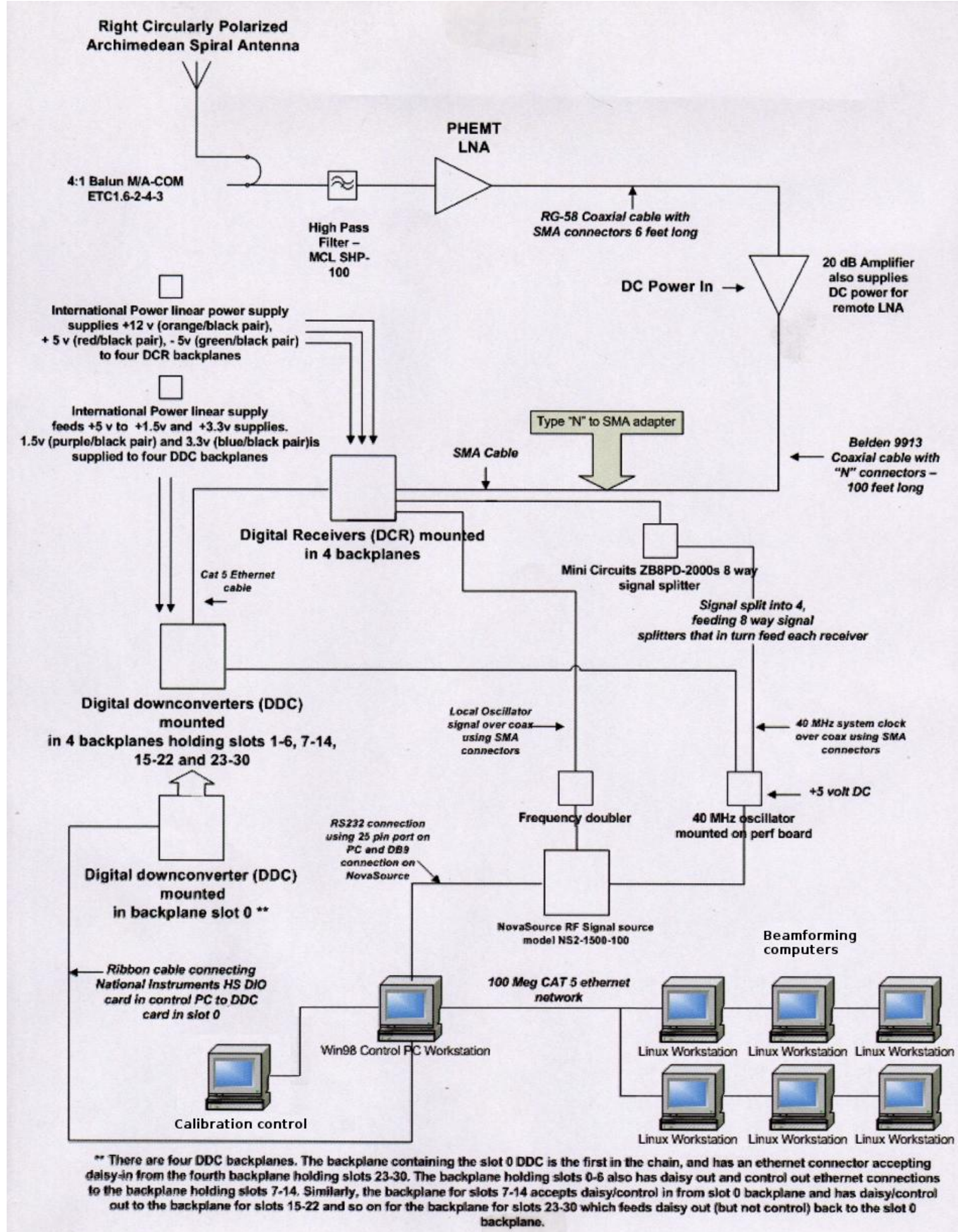
- **Long integration broadband**
- **Medium integration broadband**
- **Millisecond broadband**
- **Medium integration narrowband**

Data storage computer

Waterfall display computer

Web/email server:

- **Interface to the internet**
- **Beamformer statistics archive**



Technical information:

<u>The entire system and observations:</u>

S.W. Ellingson, G.A. Hampson, and R.K. Childers, "Argus: An L-Band All-Sky Astronomical Surveillance System", IEEE Trans. Antennas & Propagation, Vol. 56, No. 2, February 2008, pp. 294-302.

<u>The method to generate the pointing vector:</u>

S.W. Ellingson, "Detection and Localization of Tones and Pulses using an Uncalibrated Array", Technical Memo, January 24, 2002.

ohioargus.org "Technical" "Show-and-Tell"

Processing of data

- Radio data down-converted to baseband via LO and DDC
- Bandpass filtered to be 64 kHz. Sampled at 78.125 kHz. Complex I/Q samples
- Of this, 16384 samples (snapshots) are used
- 16384/78125=.210 seconds of array snapshots
- Data is sent to beamformers for one second of processing
- Then the next set of 16384 snapshots are sent
- Note that 78125/16384=4.77 Hz in a narrowband channel
- Frequency set manually, to stay close to the hydrogen line and away from RFI/birdies; no automatic frequency hopping because of a phase stability issue

Source detection and localization

- Use eigenanalysis (Power Method) to convert array snapshots into a 24-element complex pointing vector
- Broadband and narrowband analyses use the same Power Method technique
- Finds the "best" eigenvector (largest eigenvalue)
- Pointing vector phases are matched against the set of possible alt/az pointing vector phases from the calibrated array
- A good phase match generates a strike (for narrowband and millisecond broadband analyses)

A note on creating the "calibrated array"

- **A broadband noise source is positioned at a known location over the array**
- **Switches on once every 60 acquisitions (once/minute) under computer control**
- **The physical distance between the noise source antenna and each array element, plus the frequency being observed, gives a theoretical phase which each element should see (with respect to a reference element).**
- **The difference between the theoretical phase and what is actually observed provides the calibration.**
- **Traditional phased array beamforming math is used to create ideal beam phases for altitude/azimuth pairs, and then the calibration phase difference is added to enable the match between the pointing vector and the array.**

Four beamformers run continuously:

1. **Narrowband: .210-second results; 64 kHz bandwidth; 4.77Hz channel bandwidth**
2. **Millisecond (1.6 ms) integration broadband: 16384 snapshots are broken down into 128 128-snapshot chunks; best eigenvector on a chunk is the winner**
3. **Medium (.210 s) integration broadband: 16384 snapshots**
4. **Long (2.10 s) integration broadband: 163840 snapshots; sees the Sun and Cygnus Complex**

One additional beamformer: Interference fringes; total power in each element; targeted RA/declination of interest

One computer displays the output of the synthesized beam from narrowband beamformer (time/frequency waterfall); saves the screen once per minute

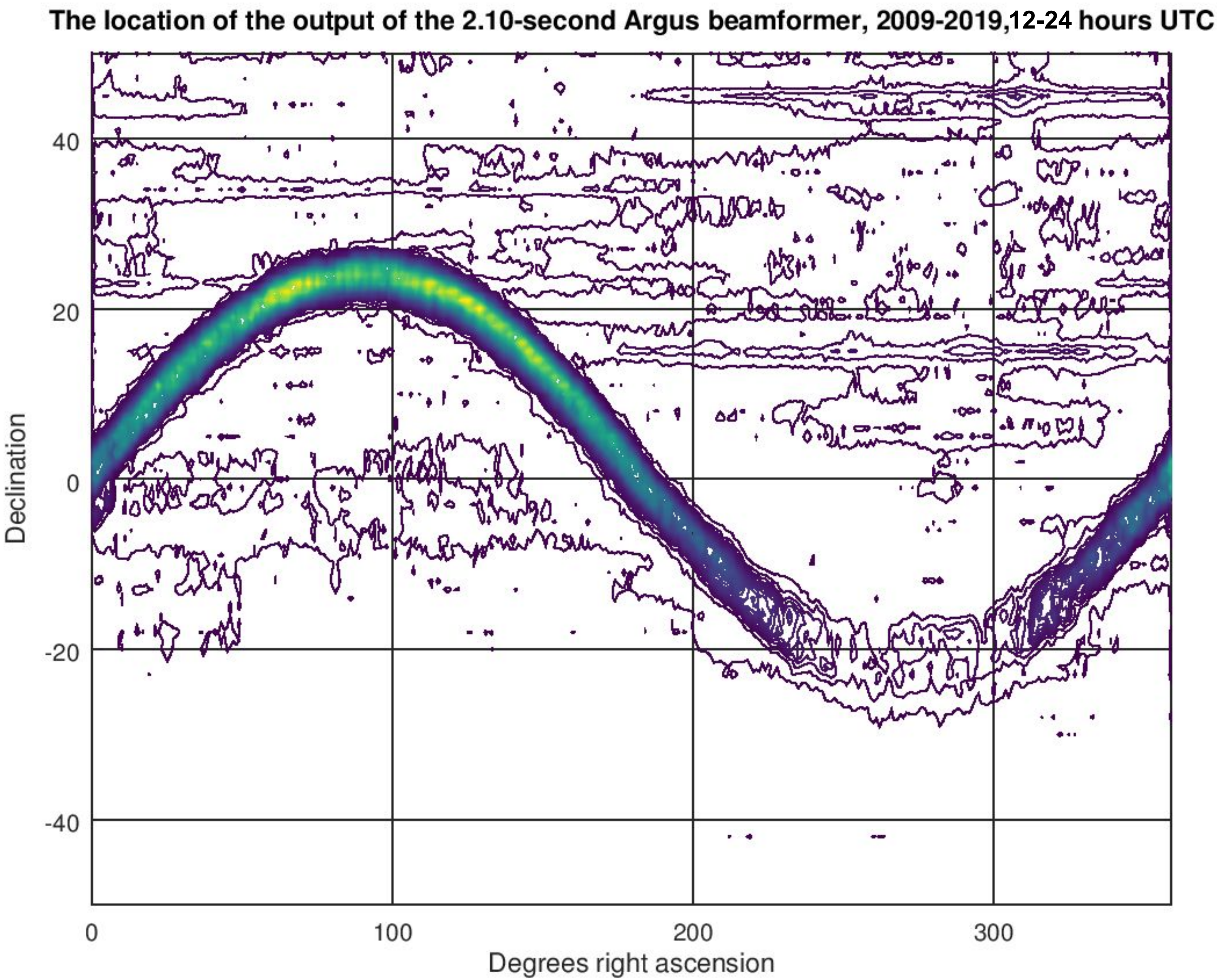
One computer saves 5 minutes of raw data if it is interesting:

1. Checks narrowband and millisecond computers for a special file
2. Appends that file to the log of “interesting” events
3. Saves the time/frequency screen
4. Sends an email to Russ with the event statistics and screen URL

See ohioargus.org/displays.html for real-time data

The following slide is a two-dimensional histogram

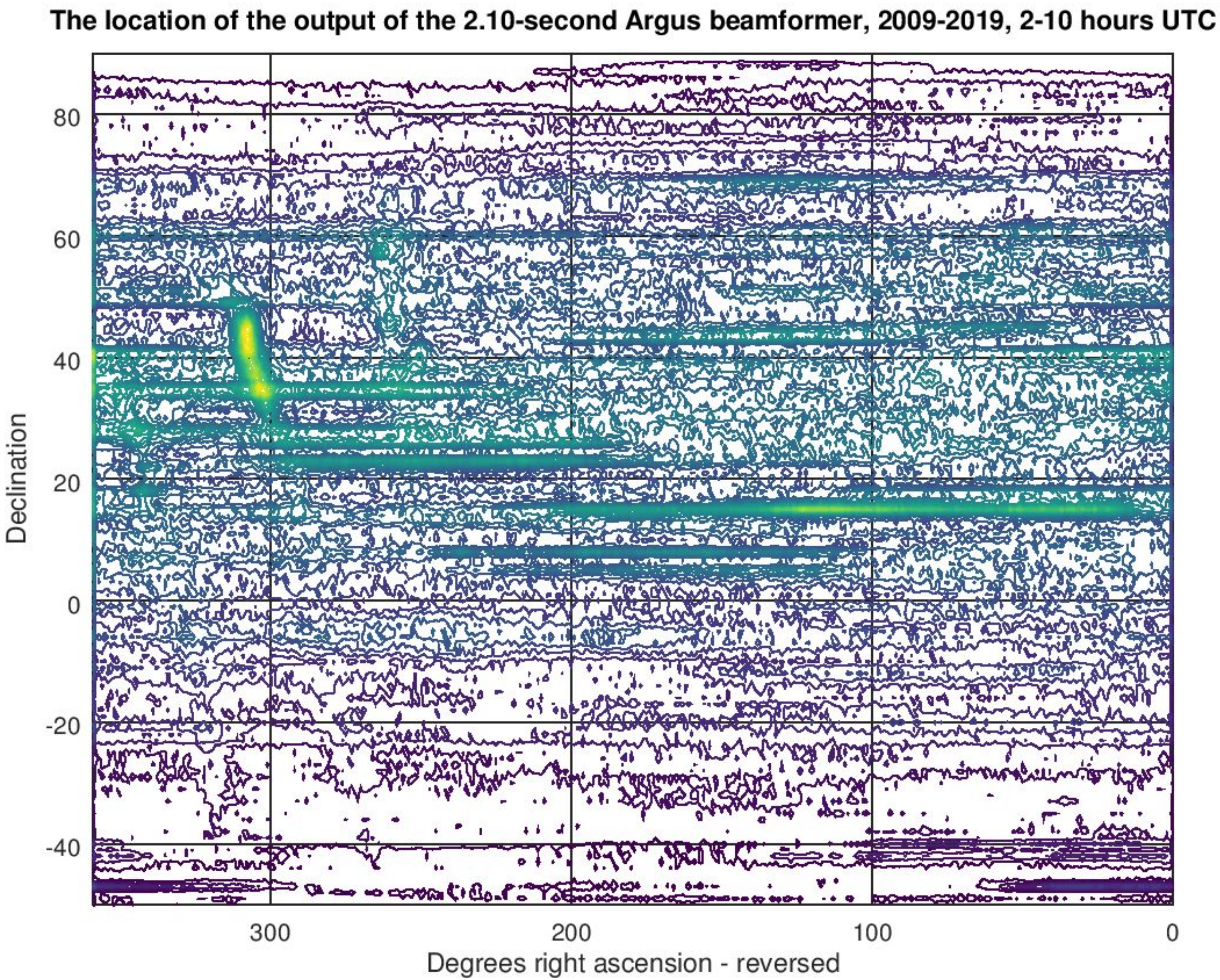
- All of the right ascension / declination pairs from the long-integration time (2.10 s) broadband beamformer
- UTC 12h - 24h (local time 7 AM - 7 PM EST; 8 AM - 8 PM EDT) 2009-2019
- The Sun dominates the detections in this long integration time broadband beamformer during the day
- The right ascension (RA) has been converted to degrees.
- Note that if you consider the RA to be the days since the vernal equinox, then the sinusoid traces out nicely the equinoxes and solstices.
- The spotty trace at RA=270 is due to the Sun being low in the sky in mid-December at Argus's latitude (+40 degrees)
- Reminder: Argus is not making sky maps. These are independent analyses occurring every 10 seconds.

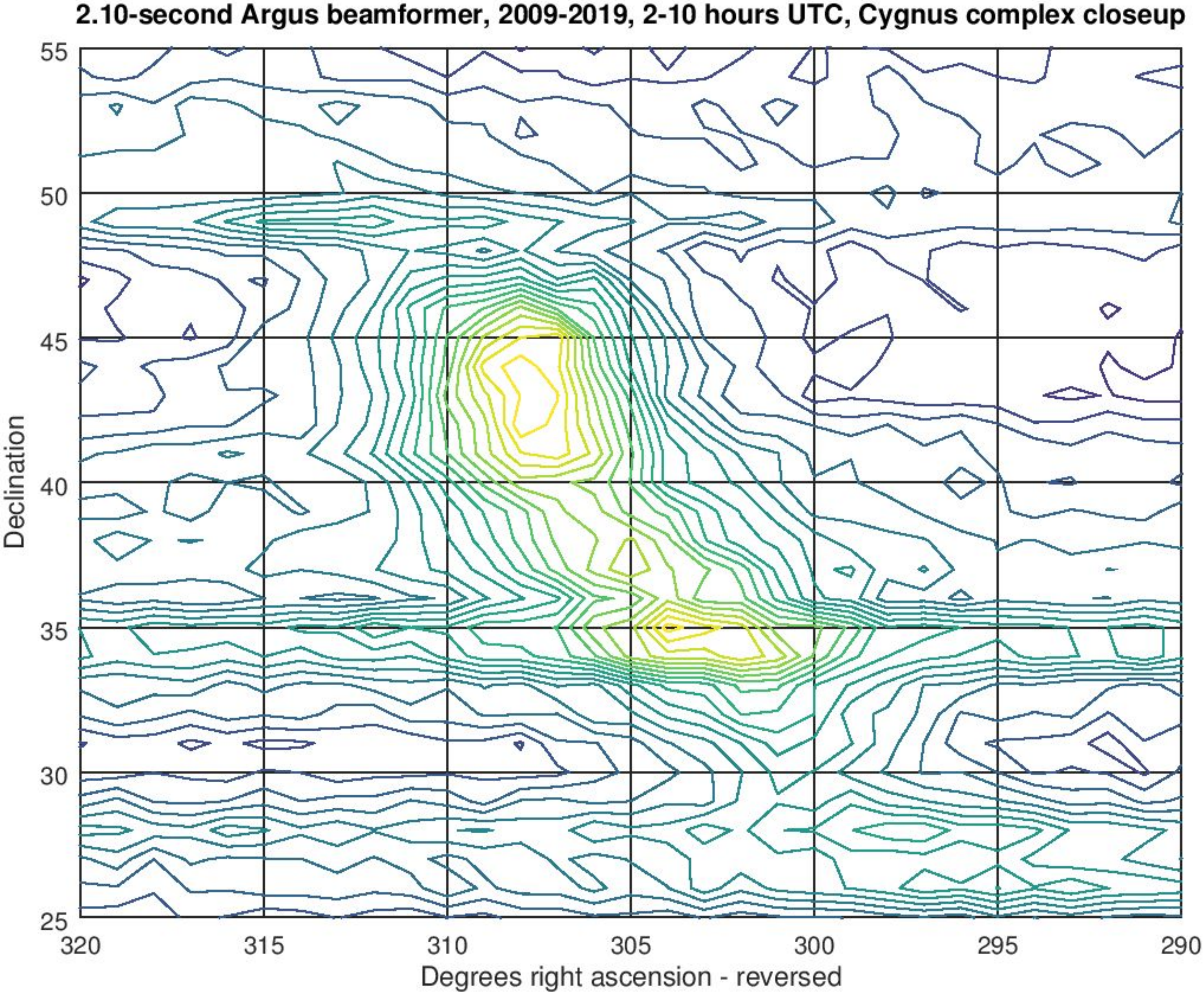


The location of the output of the 2.10-second Argus beamformer, 2009-2019,12-24 hours UTC
40
20
0
-20
-40
Declination
0
100
200
300
Degrees right ascension

The following is also a two-dimensional histogram.

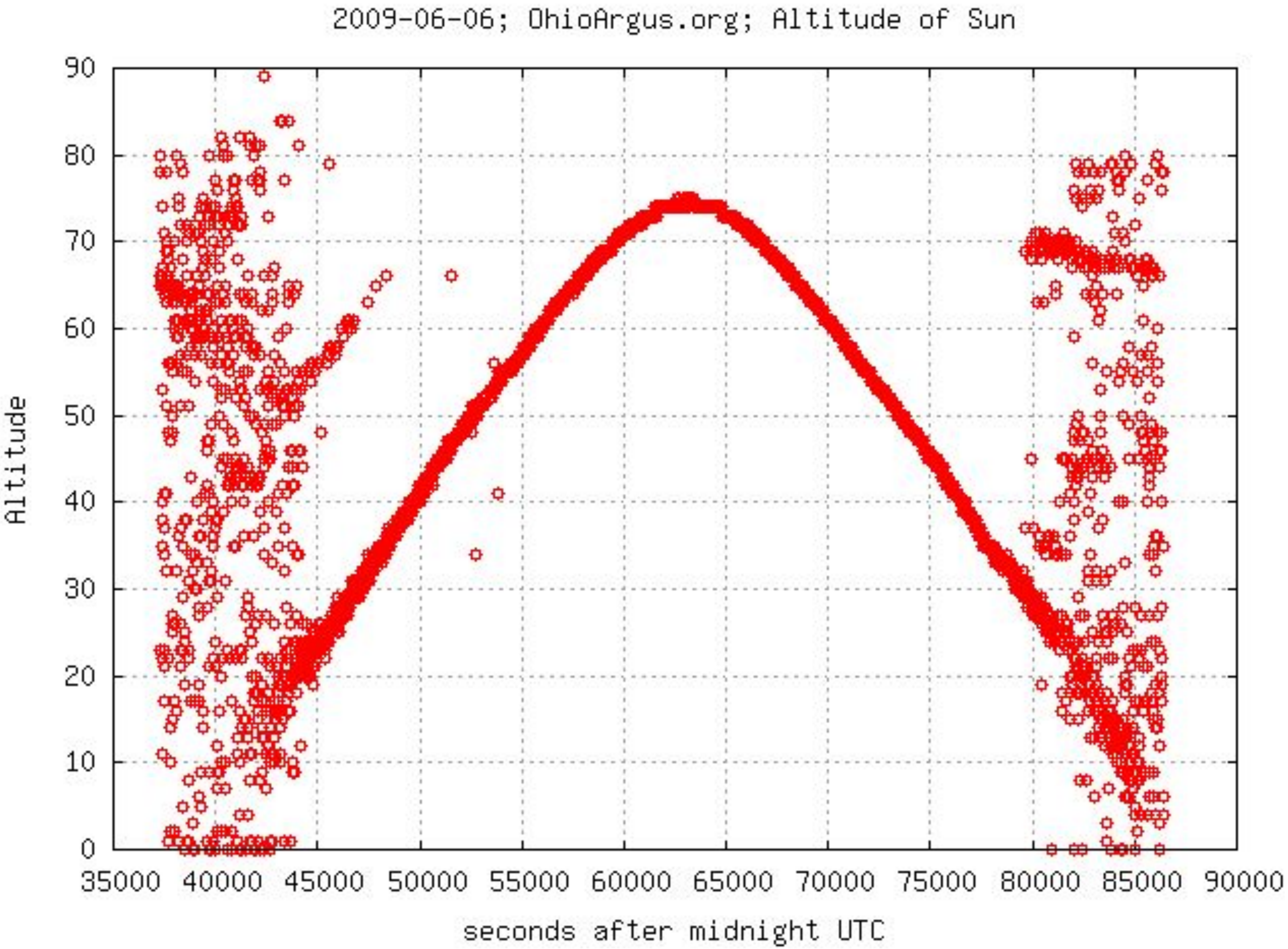
- All of the right ascension / declination pairs from the long-integration time broadband beamformer
- UTC 2h - 10h (local time 9 PM - 5 AM EST; 10 PM - 6 AM EDT) 2009-2019
- The Cygnus Complex is obvious in the upper-left corner, including Cygnus X-1 and Cygnus OB2
- The right ascension (RA) has been converted to degrees, and is flipped to the familiar configuration that astronomers are used to
- No other broadband celestial objects are obvious, probably due to the narrow 64 kHz bandwidth and high (1-2 GHz) observing frequency
- Reminder: Argus is not making sky maps. These are independent analyses occurring every 10 seconds
- The slide following this is a closeup of the Cygnus Complex

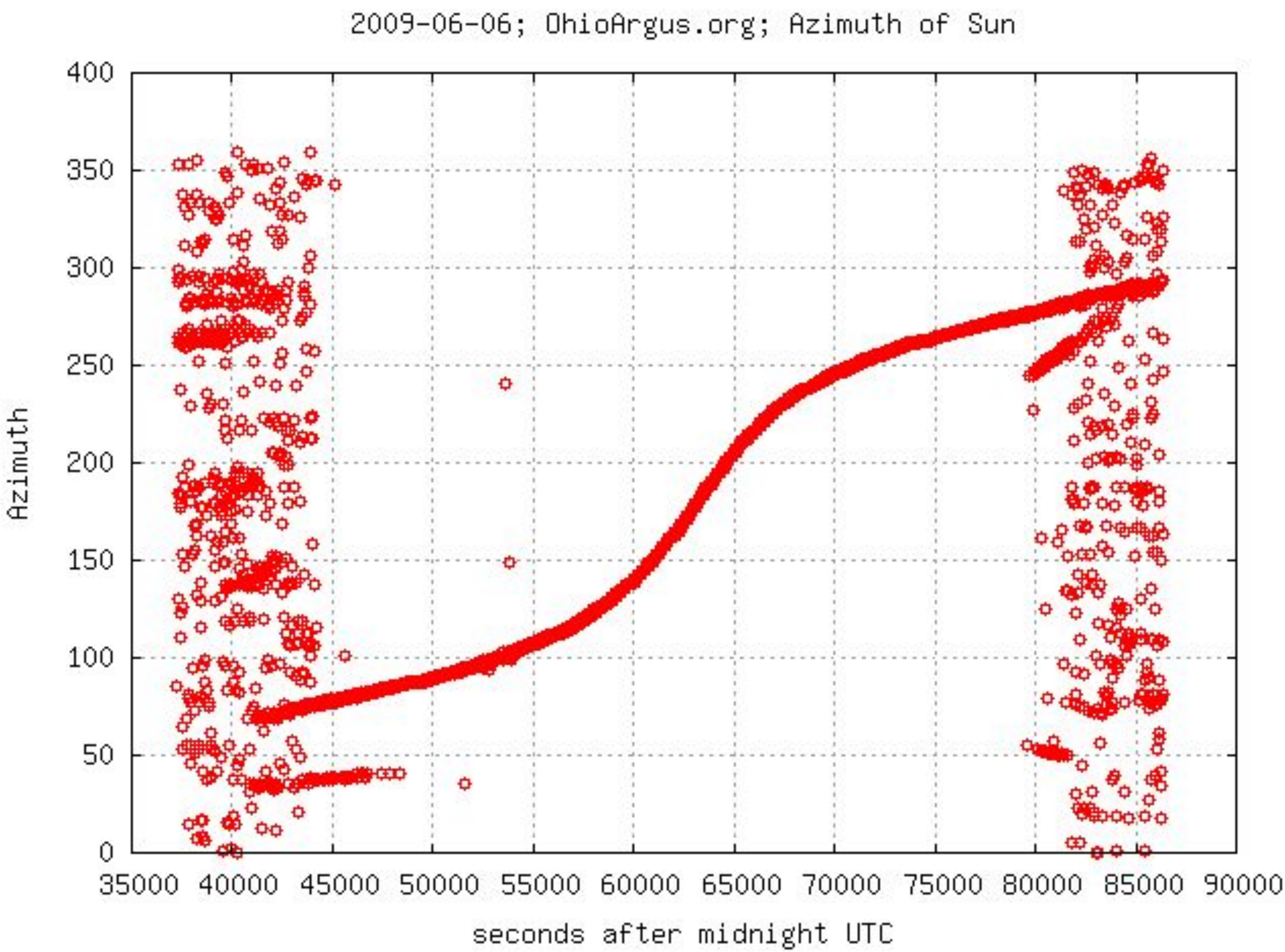

The location of the output of the 2.10-second Argus beamformer, 2009-2019, 2-10 hours UTC
80
60
40
20
0
-20
-40
Declination
300
200
100
0
Degrees right ascension - reversed


2.10-second Argus beamformer, 2009-2019, 2-10 hours UTC, Cygnus complex closeup
Declination
55
50
45
40
35
30
25
320
315
310
305
300
295
290
Degrees right ascension - reversed

The two slides which follow are the altitude and azimuth of the Sun on June 6, 2009. They are typical of other mid-summer days.

- **The first plot shows the maximum altitude is around 74 degrees**
- **The first plot shows Sun transited the meridian at about 63000 seconds UTC (17h 30m; 13h 30m EDT)**
- **Consulting the ephemeris for the Argus observing site (about +40 degrees latitude; 83 degrees West longitude), the Sun transited the meridian at 13h 30m EDT at an altitude of 73 degrees**
- **This is an excellent confirmation that Argus is calibrated correctly**
- **The prior plot showing the daytime RA/declination uses this data: when alt/az are converted to RA/dec, flat lines result (constant RA and constant declination), and the two-dimensional histogram gets a lot of accumulation in one RA/dec bin**

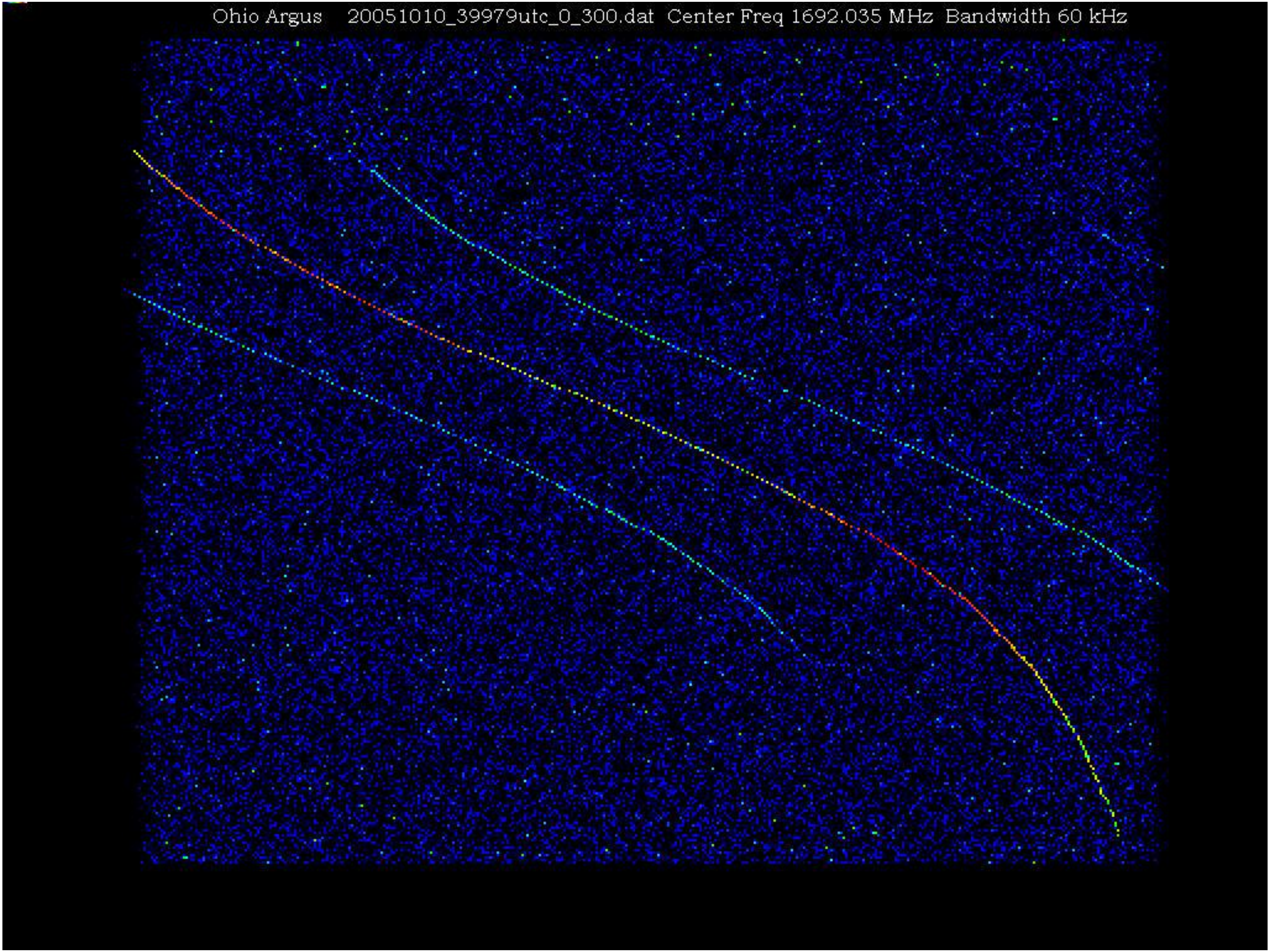

2009-06-06; OhioArgus.org; Altitude of Sun
Altitude
0
10
20
30
40
50
60
70
80
90
35000
40000
45000
50000
55000
60000
65000
70000
75000
80000
85000
90000
seconds after midnight UTC

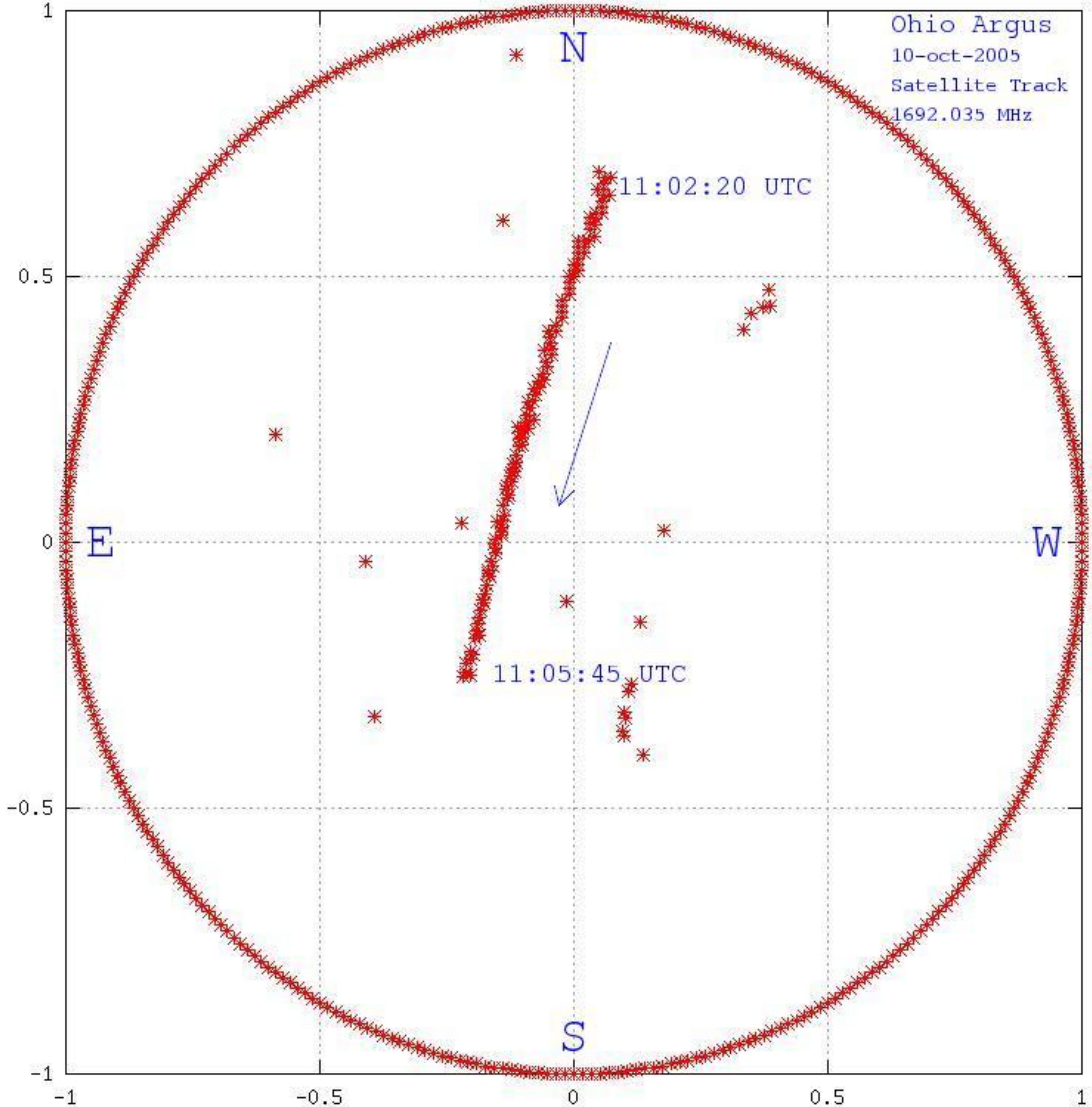


2009-06-06; OhioArgus.org; Azimuth of Sun
Azimuth
seconds after midnight UTC
0
50
100
150
200
250
300
350
400
35000
40000
45000
50000
55000
60000
65000
70000
75000
80000
85000
90000

The following two slides show a satellite passing overhead and demonstrate Argus's ability to detect narrowband phenomena

- The first slide shows a time/frequency waterfall with the most recent time at the top; the highest frequency is to the right
- Each row is a one-second acquisition
- This is about six minutes of data
- The center frequency is 1692 MHz; bandwidth 64 kHz
- There are sidebands of the central carrier
- There is a maximum Doppler shift of about 400 Hz, so in the 0.210 sampling interval there is an 84 Hz Doppler shift (18 4.77 Hz channels)
- Remember that Argus is not tracking: each 1-second acquisition is independent
- The second slide shows the altitude/azimuth of the source and its path overhead
- The data stops abruptly when the satellite's carrier frequency passes outside of the passband


Ohio Argus 20051010_39979utc_0_300.dat Center Freq 1692.035 MHz Bandwidth 60 kHz


Ohio Argus
10-oct-2005
Satellite Track
1692.035 MHz
N
S
E
W
11:02:20 UTC
11:05:45 UTC
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1

So where is E.T.?

The Ohio Argus Array is operating near the Hydrogen Line, is looking at narrowband channels, and is able to see transient sources which pop up anywhere overhead.

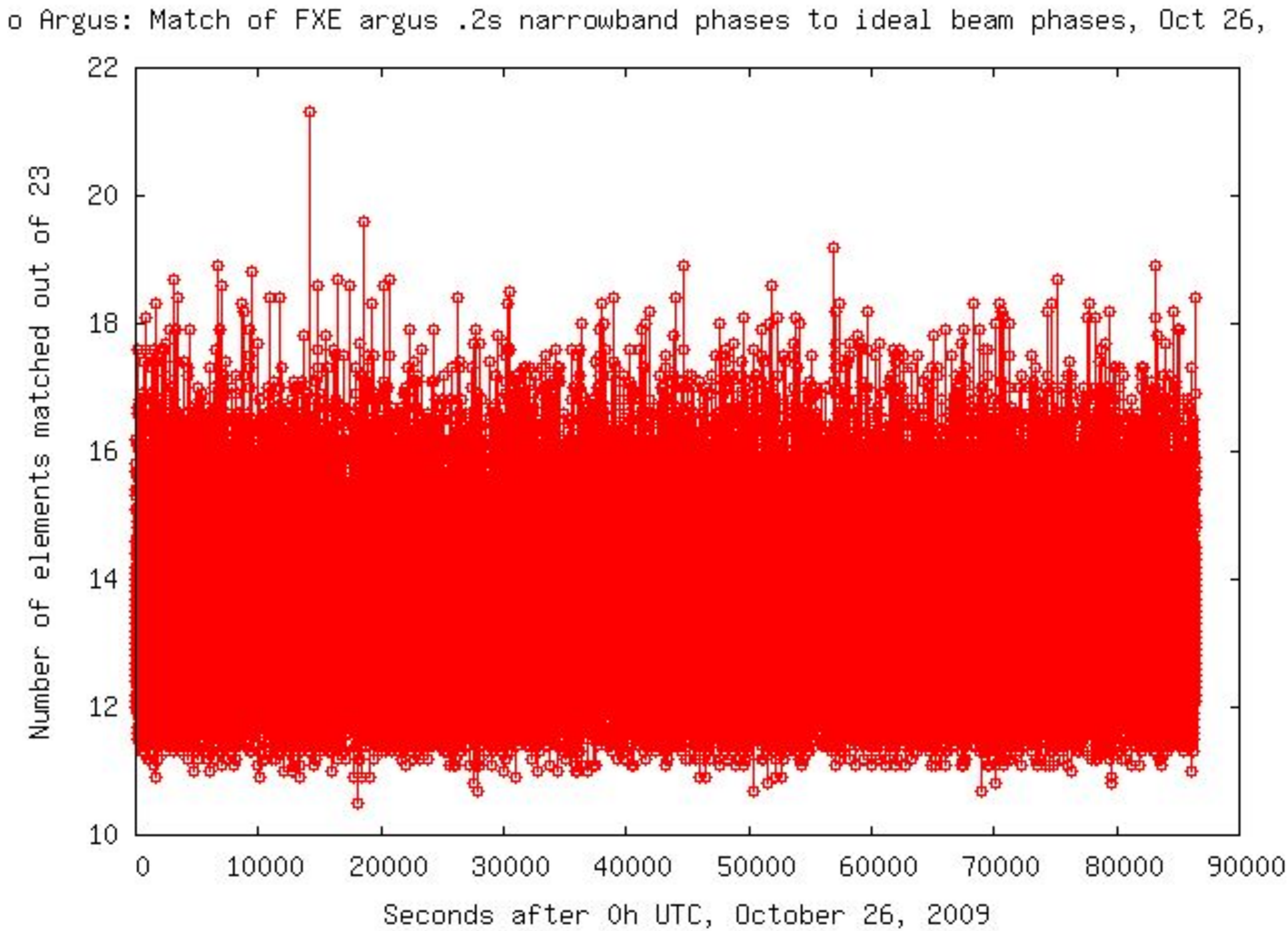
On October 26, 2009 (UTC), Argus detected a narrowband source high overhead (well within the Argus field of view) which lasted for only one 0.210 second acquisition.

While a repeated or continuous signal would be preferred, this one event is nevertheless very interesting.

The event matched 21.3 out of 23 elements; was about 20 Hz in bandwidth; was at alt/az 76/98; RA/dec 01h 52m / +37. The time of the strike was 03:56 UTC, or 11:56 PM EST on October 25, 2009 (night).

The following slides show this brief narrowband event from different perspectives.

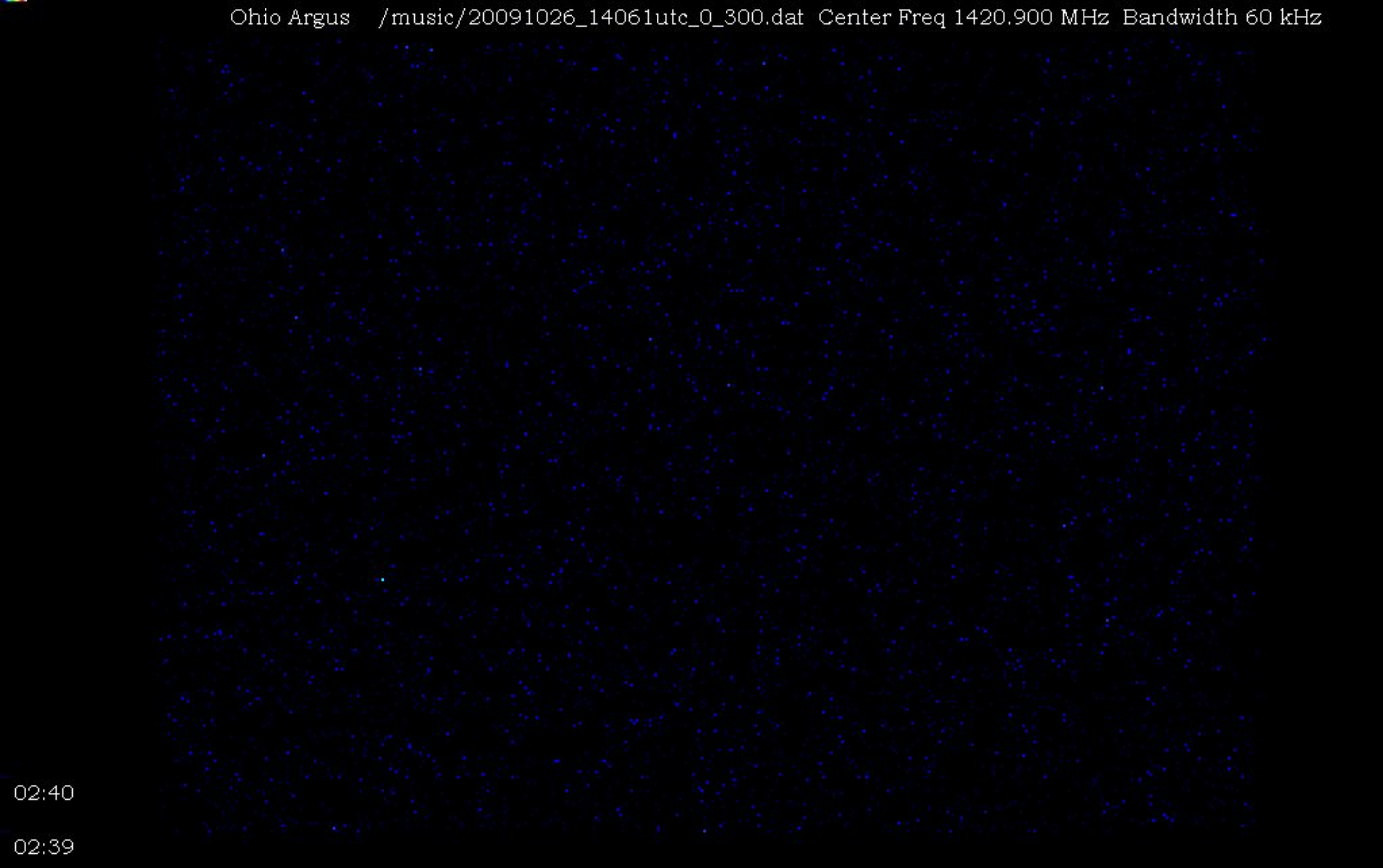
The first slide shows the number of array elements which matched the calibrated array (out of 23 operating at the time). The plot is for all 86400 acquisitions over the entire day. Note how the spike at around 11500 seconds UTC sticks out above all the rest, matching 21.3 elements. This is the detection, which Argus emailed me about (and stored the raw data), right after it happened.

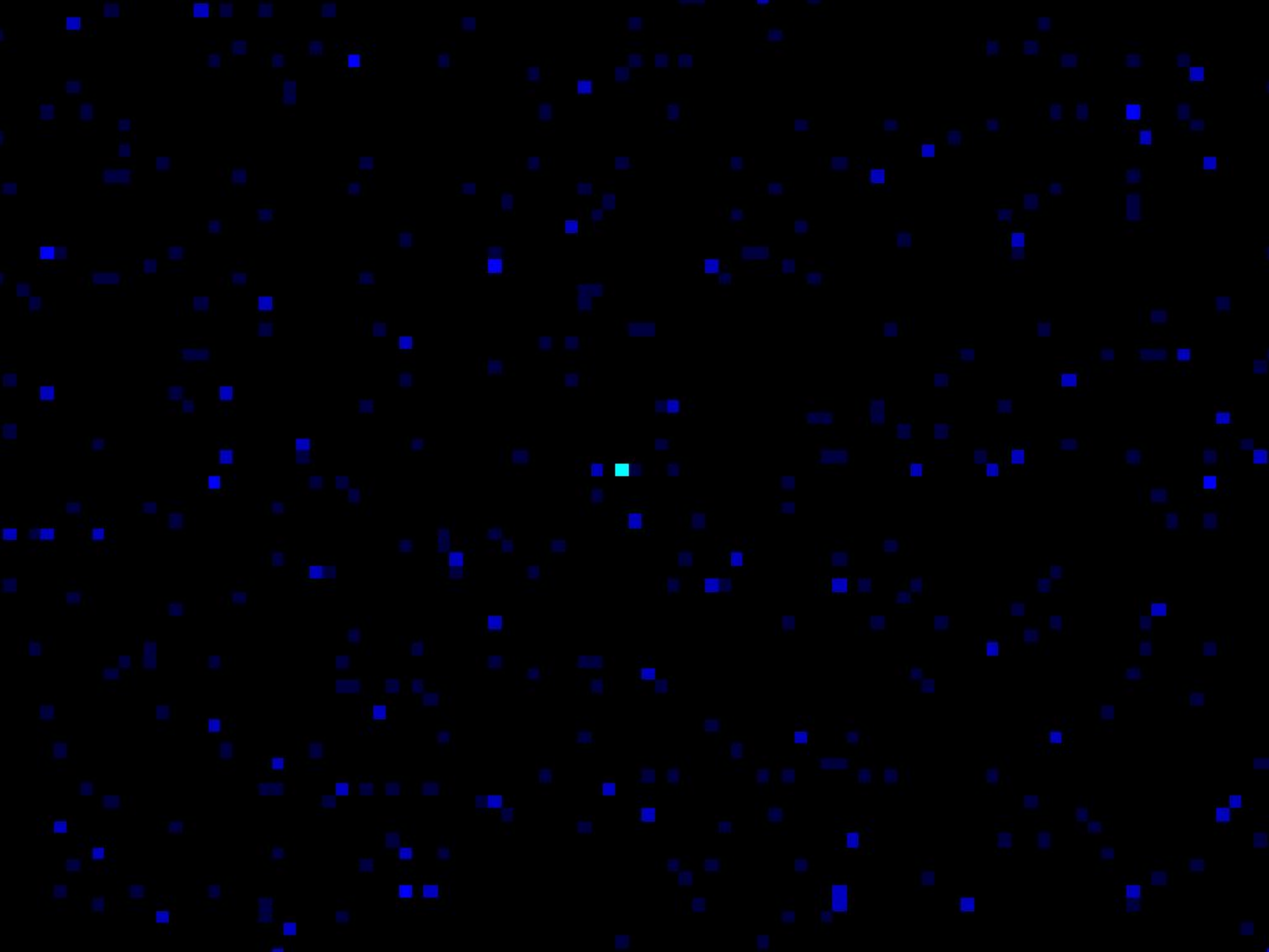


o Argus: Match of FXE argus .2s narrowband phases to ideal beam phases, Oct 26,
Number of elements matched out of 23
22
20
18
16
14
12
10
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
Seconds after 0h UTC, October 26, 2009

The second slide is post-processed data. It shows the frequency spectrum in a time/frequency plot. I programmed the data analysis program to synthesize a beam directly at the RA/declination of the interesting source. Note that the 5-minute plot is quiet, except for a tiny green dot toward the lower-left. This is the interesting source.

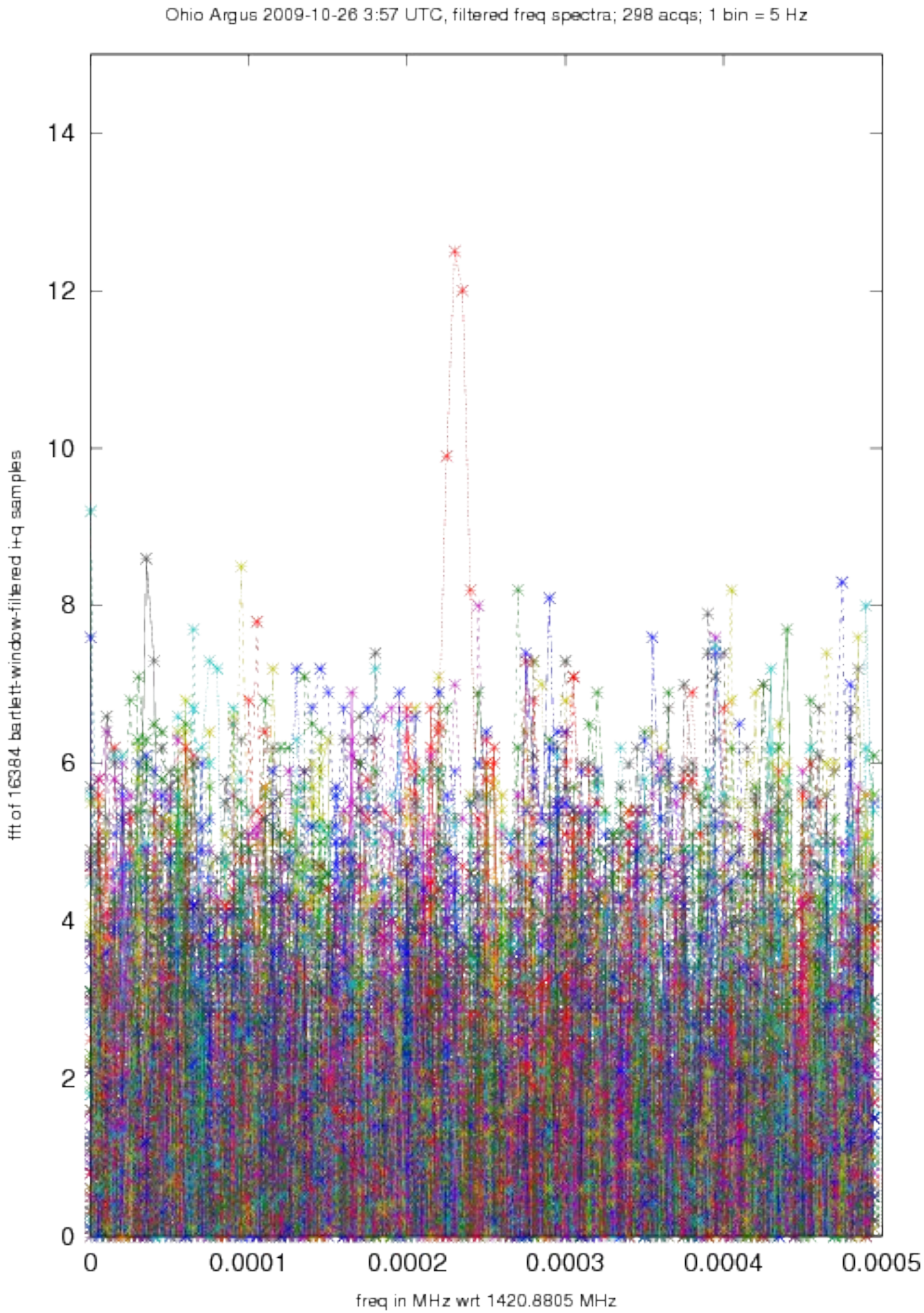
The third slide shows a closeup of the dot.


Ohio Argus /music/20091026_14061utc_0_300.dat Center Freq 1420.900 MHz Bandwidth 60 kHz
02:40
02:39



The fourth slide shows what is basically the time/frequency plot seen edge-on.

- **The bandwidth of this plot is 500 Hz (105 4.77 Hz channels).**
- **All 300 acquisitions in the 5-minute stored raw data are plotted.**
- **The one central peak is the power as seen in the one acquisition which triggered the "strike" (the green dot). Each asterisk is a 4.77 Hz frequency bin.**
- **We see that no other acquisition had powers rising above the noise, either above/below in frequency or at the same frequency.**



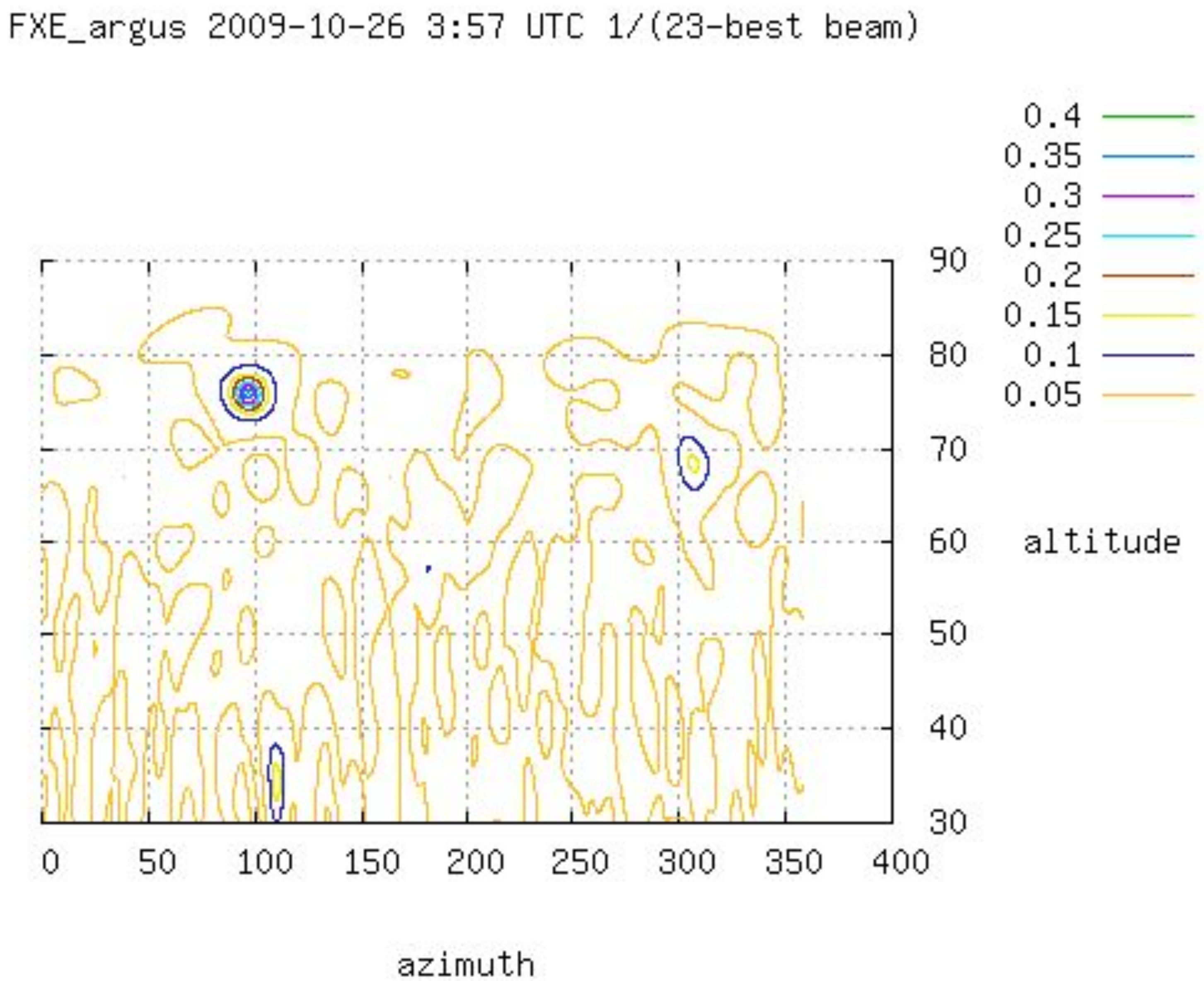
Ohio Argus 2009-10-26 3:57 UTC, filtered freq spectra; 298 acqs; 1 bin = 5 Hz
fft of 16384 bartlett-window-filtered i+q samples
0
2
4
6
8
10
12
14
0
0.0001
0.0002
0.0003
0.0004
0.0005
freq in MHz wrt 1420.8805 MHz

The fifth and last slide shows the pointing vector for the "strike", and its difference from all the vectors in the calibrated array.

- **This contour plot shows the highest match at alt/az 76/98 - right where the narrowband event was reported.**

- **This is basically what the pointing vector-matching algorithm does when determining the best match. It walks through all alt/az combinations of the calibrated array, and picks off the best match and records that.**

- **The other contours are the sidelobes of the array when a source is at alt/az 76/98.**



FXE_argus 2009-10-26 3:57 UTC 1/(23-best beam)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
90
80
70
60
50
40
30
altitude
0
50
100
150
200
250
300
350
400
azimuth

Further follow-up at the frequency and coordinates of this interesting strike have come up empty. It's possible that the source has Doppler-shifted out of the passband. It's also possible that since 1.0-.21=.79 seconds out of every 1-second acquisition is ignored, then a brief pulse has slipped through the cracks.

But given the unique capability of Argus to see the whole sky without beamforming and without physically pointing, at least the "where to look" problem has been solved.

ohioargus.org
flagofearth.org
bigear.org
w8jk.org
naapo.org

End of presentation