High Frequency GBT Corrections

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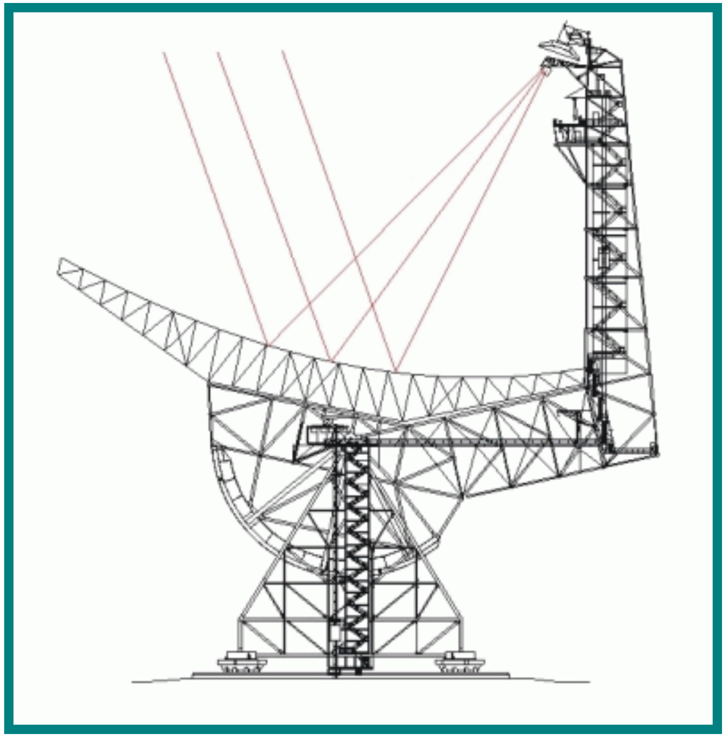
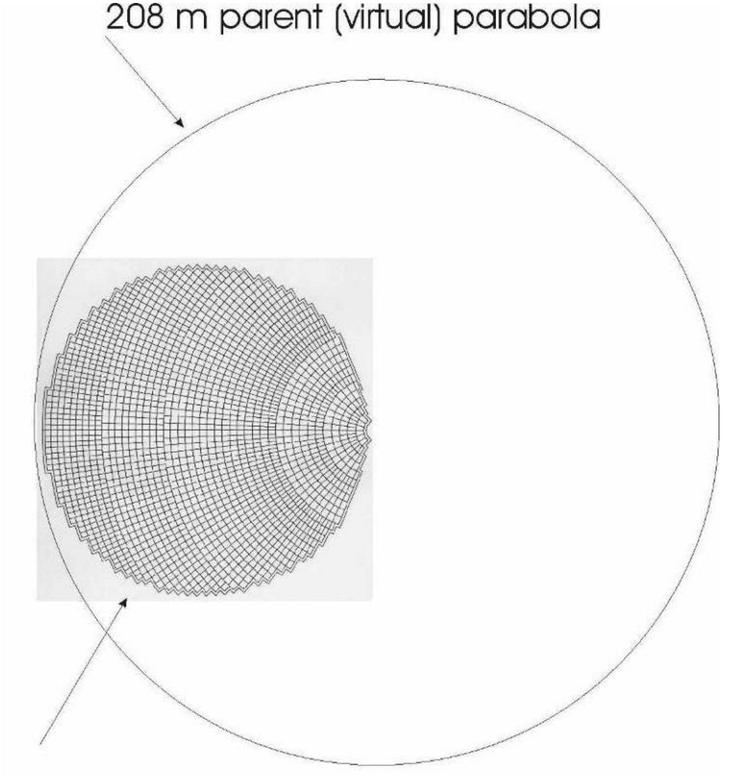
GBT Telescope Optics

- 110m x 100m of a 208m parent paraboloid
  - Effective diameter: 100 m
  - Off axis - Clear/Unblocked Aperture (low sidelobes, high dynamic range imaging)

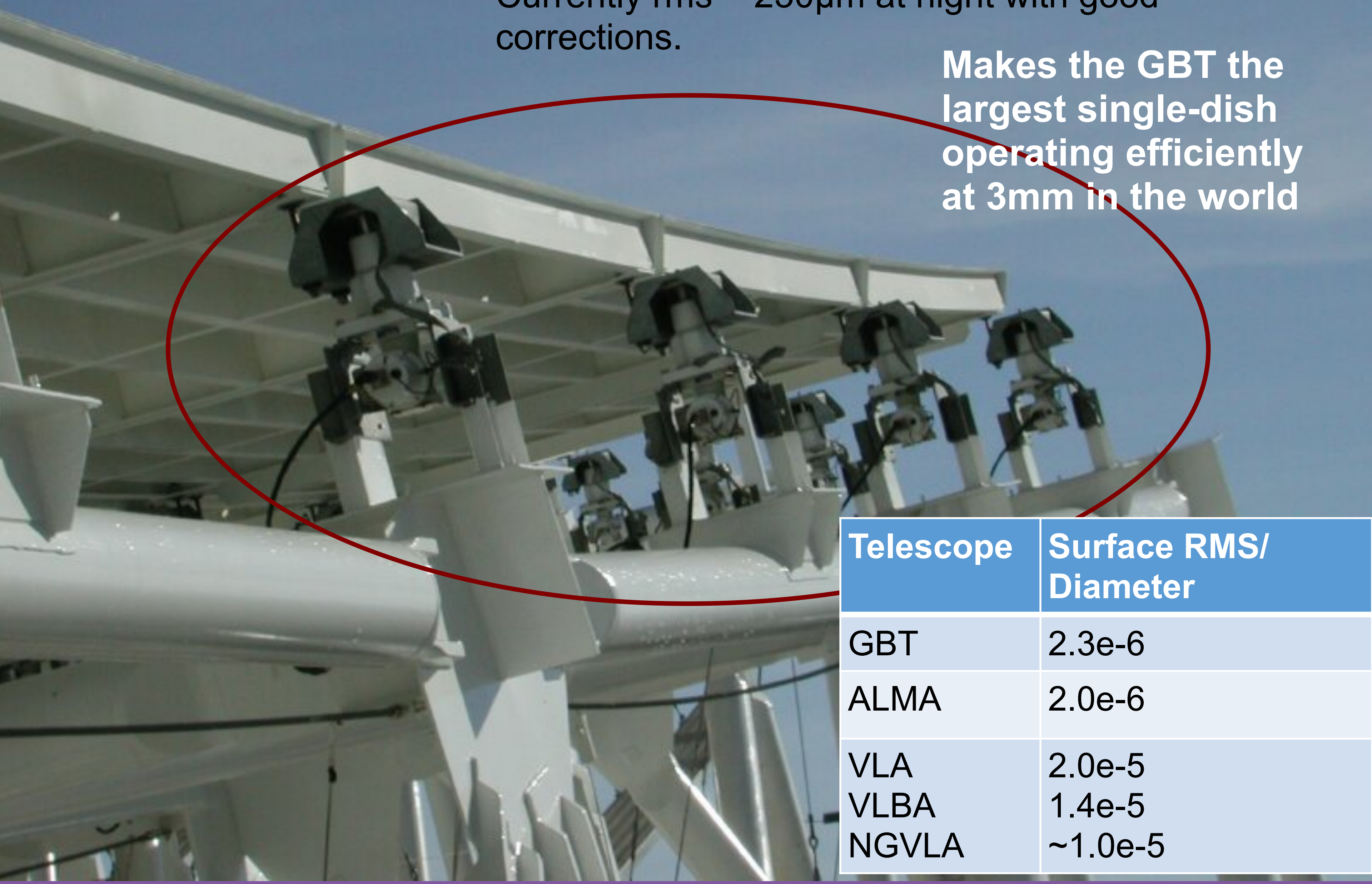




The Active Surface   2209 actuators

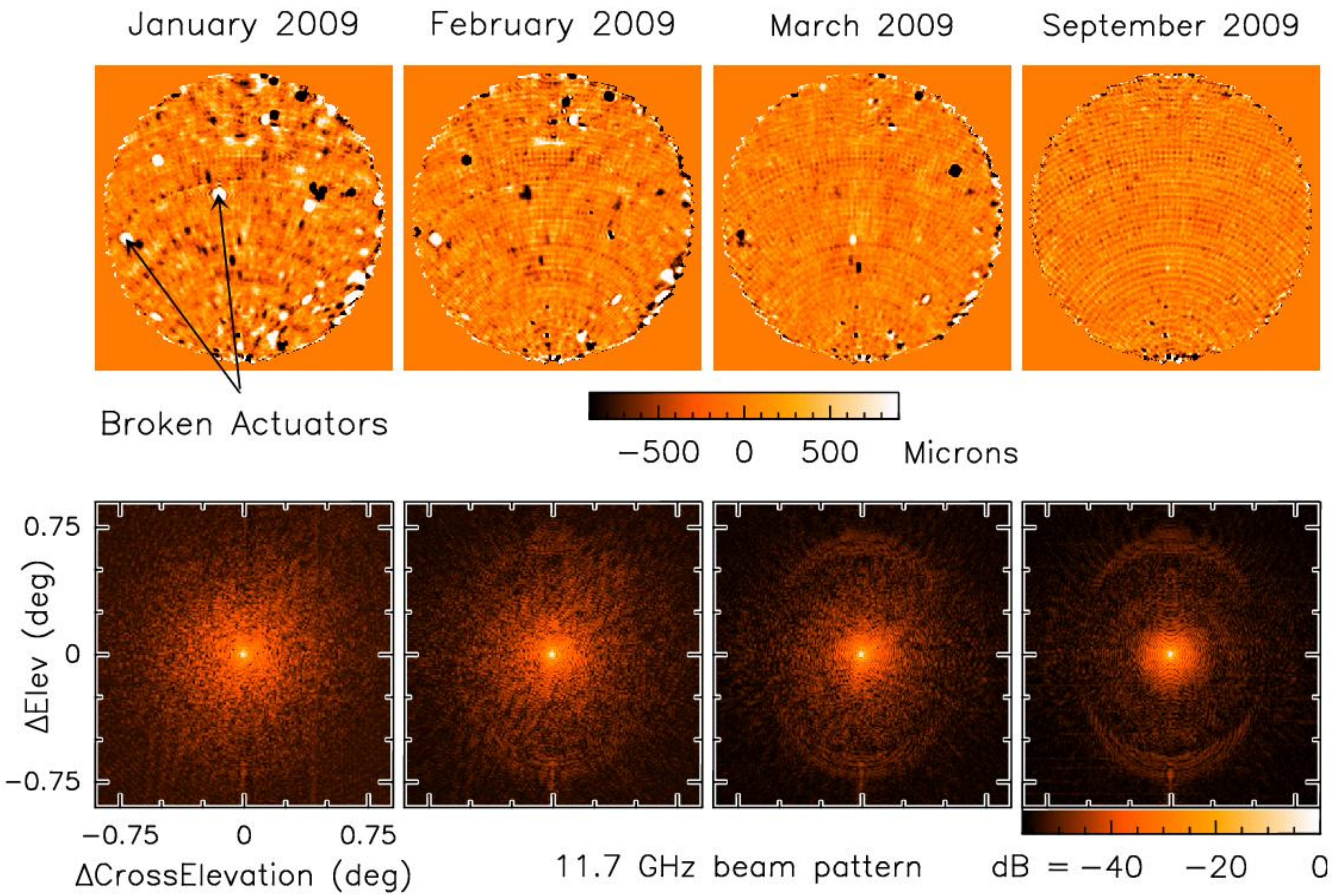
Currently rms ~230μm at night with good corrections.

Makes the GBT the largest single-dish operating efficiently at 3mm in the world



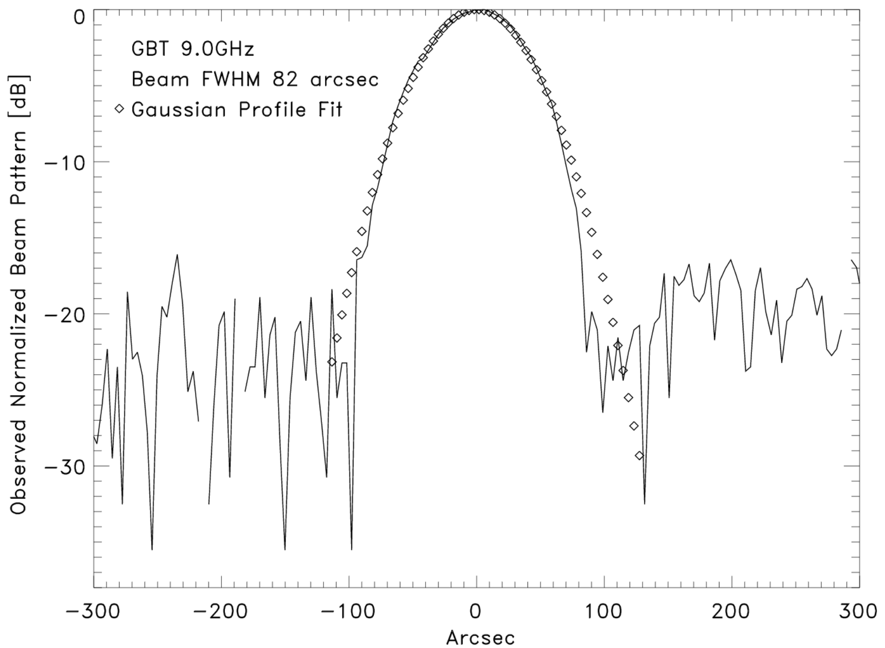
Telescope	Surface RMS/ Diameter
GBT	2.3e-6
ALMA	2.0e-6
VLA VLBA NGVLA	2.0e-5 1.4e-5 ~1.0e-5

Improvements to Active Surface in 2009

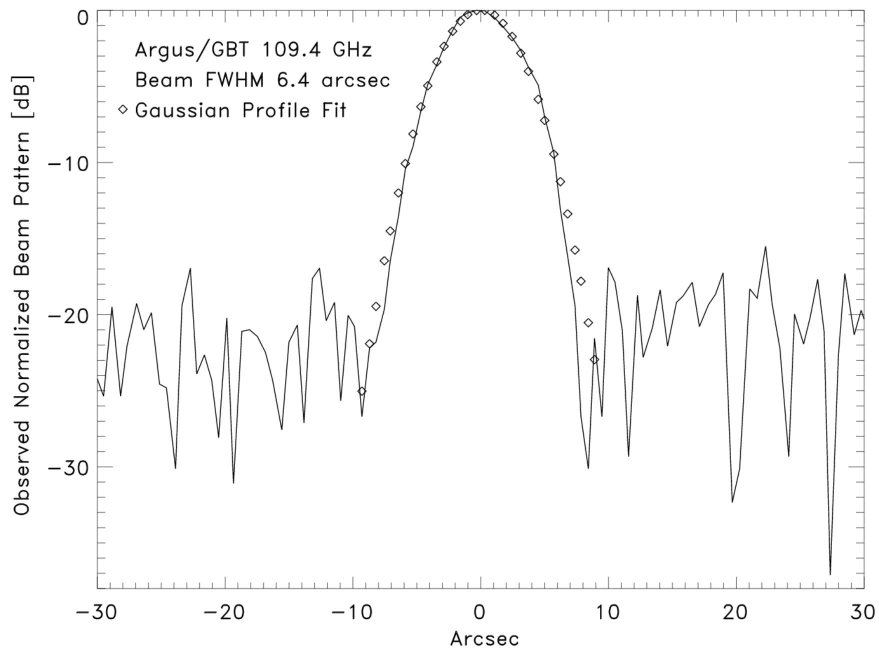


The GBT Achieves its Theoretical Beam at 110 GHz

GBT memo #296 – demonstrates the success of the pointing-and-control system, the gravity and thermal modeling with active surface corrections – lots of work by many people over the last decade….



GBT/X-band 9.0 GHz

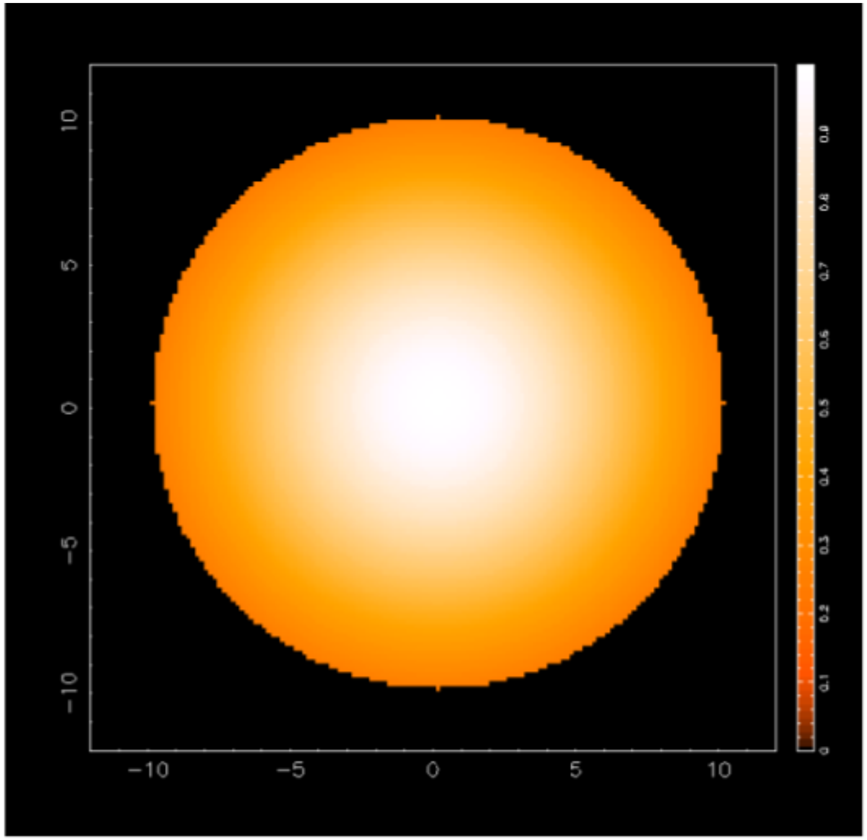


GBT/Argus 109.4 GHz

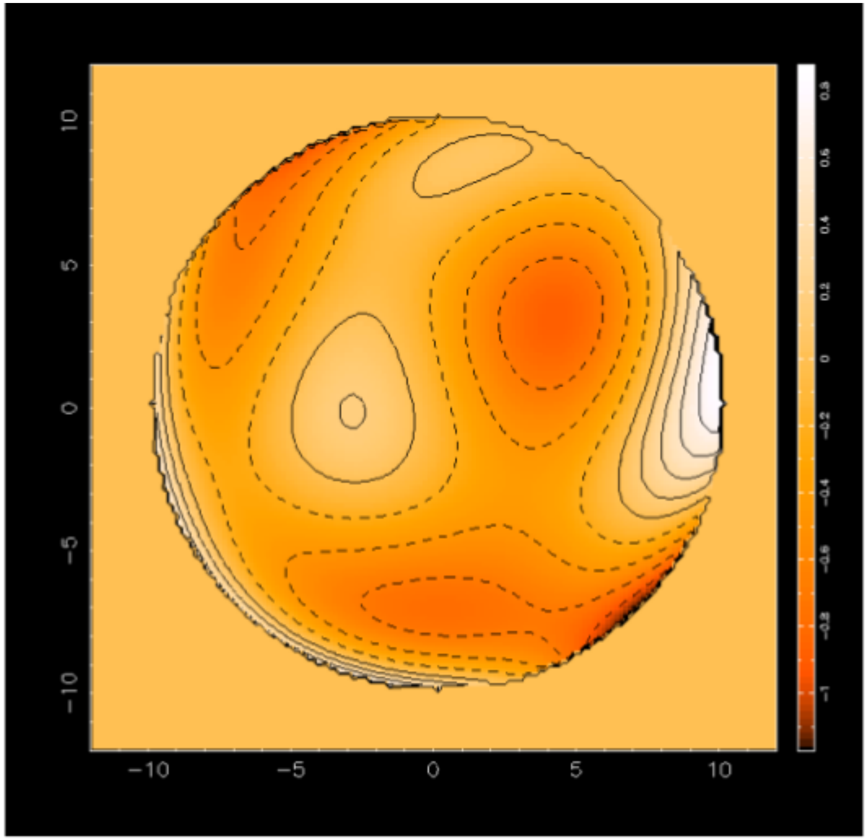
Unblock GBT aperture ➔ first side-lobe predicted at -27dB

A Surface with random large-scale errors

Receiver Response
(Taper/Apodization/…)



Surface Errors
(Projected to an imaginary surface)



Model Surface Using Zernike Polynomials

Derived by Frits Zernike in1934 (a won him the Nobel Prize in 1953)

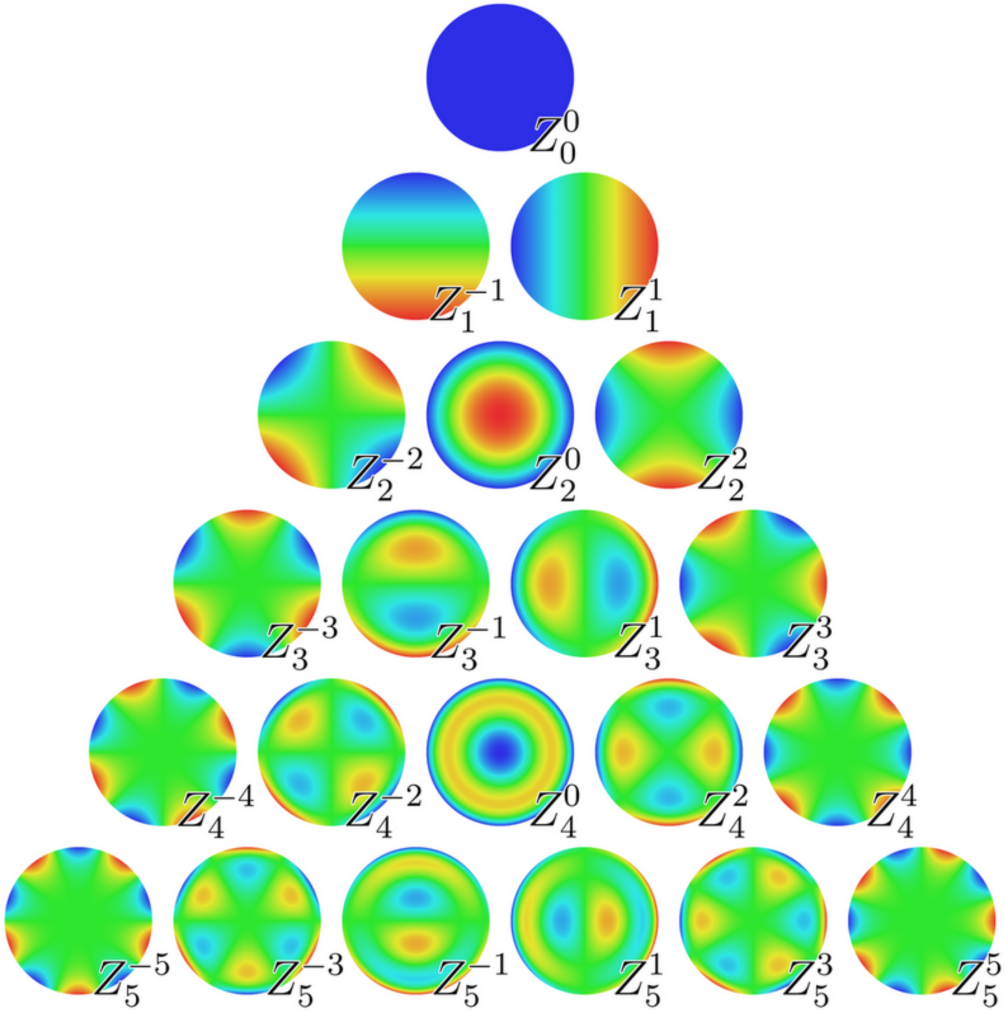
Essential in determining beam optics

Zernike polynomials [edit]

The first few Zernike modes, with OSA/ANSI and Noll single-indices, are shown below.

$$\int_0^{2\pi}\int_0^1 Z_j^2\,\rho\,d\rho\,d\theta=\pi.$$

	OSA/ANSI index (j)	Noll index (j)	Radial degree (n)	Azimuthal degree (m)	Z_j
Z_0^0	0	1	0	0	1
Z_1^{-1}	1	3	1	−1	$2\rho\sin\theta$
Z_1^1	2	2	1	+1	$2\rho\cos\theta$
Z_2^{-2}	3	5	2	−2	$\sqrt{6}\rho^2\sin 2\theta$
Z_2^0	4	4	2	0	$\sqrt{3}(2\rho^2-1)$
Z_2^2	5	6	2	+2	$\sqrt{6}\rho^2\cos 2\theta$
Z_3^{-3}	6	9	3	−3	$\sqrt{8}\rho^3\sin 3\theta$
Z_3^{-1}	7	7	3	−1	$\sqrt{8}(3\rho^3-2\rho)\sin\theta$
Z_3^1	8	8	3	+1	$\sqrt{8}(3\rho^3-2\rho)\cos\theta$
Z_3^3	9	10	3	+3	$\sqrt{8}\rho^3\cos 3\theta$
Z_4^{-4}	10	15	4	−4	$\sqrt{10}\rho^4\sin 4\theta$
Z_4^{-2}	11	13	4	−2	$\sqrt{10}(4\rho^4-3\rho^2)\sin 2\theta$
Z_4^0	12	11	4	0	$\sqrt{5}(6\rho^4-6\rho^2+1)$
Z_4^2	13	12	4	+2	$\sqrt{10}(4\rho^4-3\rho^2)\cos 2\theta$
Z_4^4	14	14	4	+4	$\sqrt{10}\rho^4\cos 4\theta$



GBT Zernike-Gravity Model

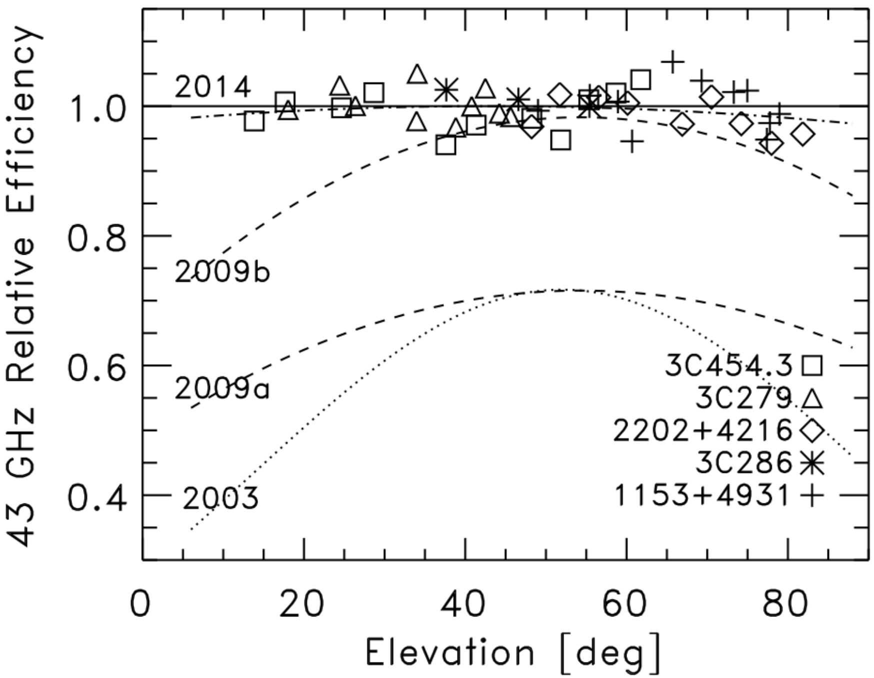
Each Zernike parameter fitted as a function of elevation:

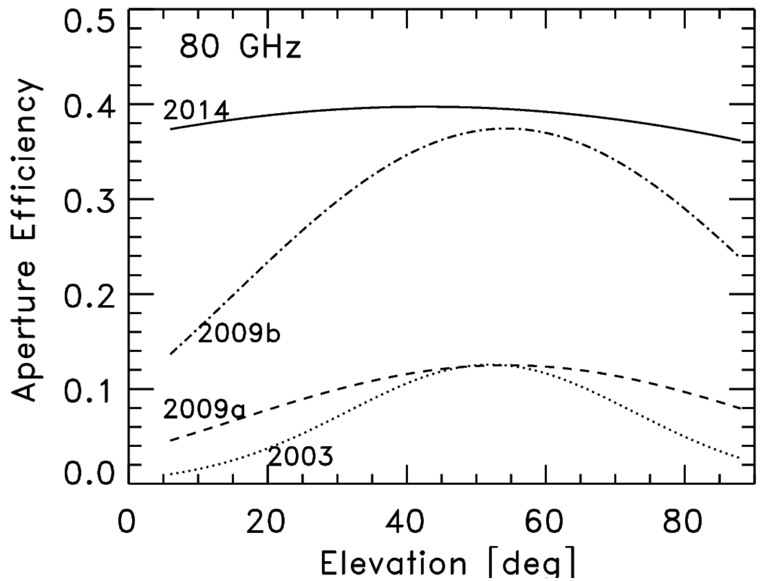
$$Z_n = A_n \sin(el) + B_n \cos(el) + C_n$$

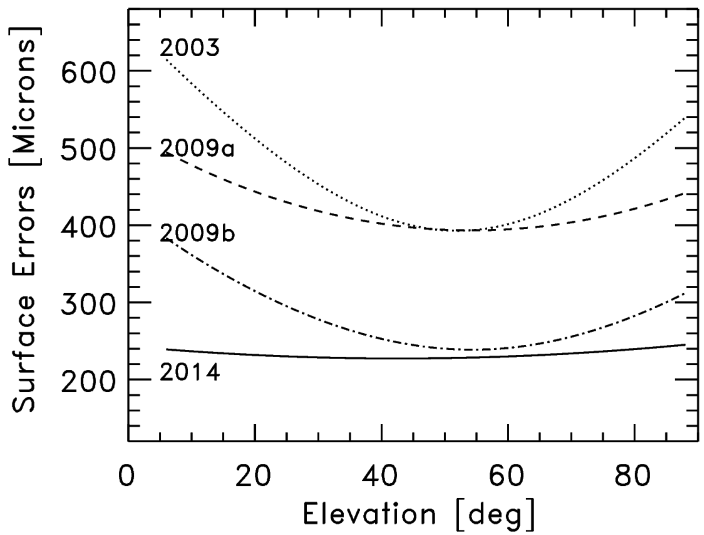
The updated 2014 gravity model improved telescope performance (PTCS PN#76)

Z	A	B	C	σ_A	σ_B	σ_C	rms
4	-697.71	697.91	550.68	905.87	775.82	1137.56	517.55
5	-148.22	-482.95	136.07	540.74	463.11	679.05	308.94
6	319.46	154.68	-535.72	319.70	273.80	401.46	182.65
7	-554.68	-327.02	632.92	378.25	323.95	475.00	216.11
8	-65.60	53.89	108.34	268.56	230.01	337.25	153.44
9	588.39	1305.77	-1063.37	341.03	292.07	428.25	194.84
10	932.92	542.64	-1119.48	481.14	412.07	604.20	274.89
11	136.83	923.46	-288.13	329.68	282.35	414.01	188.36
12	-532.04	-177.33	440.51	238.51	204.27	299.52	136.27
13	360.71	62.38	-94.13	160.01	137.04	200.94	91.42
14	-38.56	15.16	-160.13	188.20	161.18	236.34	107.52
15	-622.70	-414.96	744.87	288.93	247.45	362.83	165.07
16	121.80	-38.60	16.58	293.75	251.58	368.89	167.83
17	-210.31	-198.02	203.98	161.70	138.48	203.05	92.38
18	71.68	3.62	-266.29	142.96	122.44	179.53	81.68
19	579.23	-51.98	-392.41	178.29	152.70	223.89	101.86
20	243.95	-121.70	-6.45	194.88	166.91	244.73	111.34
21	593.36	1065.48	-1287.78	304.57	260.84	382.46	174.01

Surface Improvements with Zernike-Gravity Model







Improvements to the Zernike-Gravity model in 2014 yields a flat gain curve with elevation and has significantly improved the GBT performance at high-frequency (GBT Memo#301)

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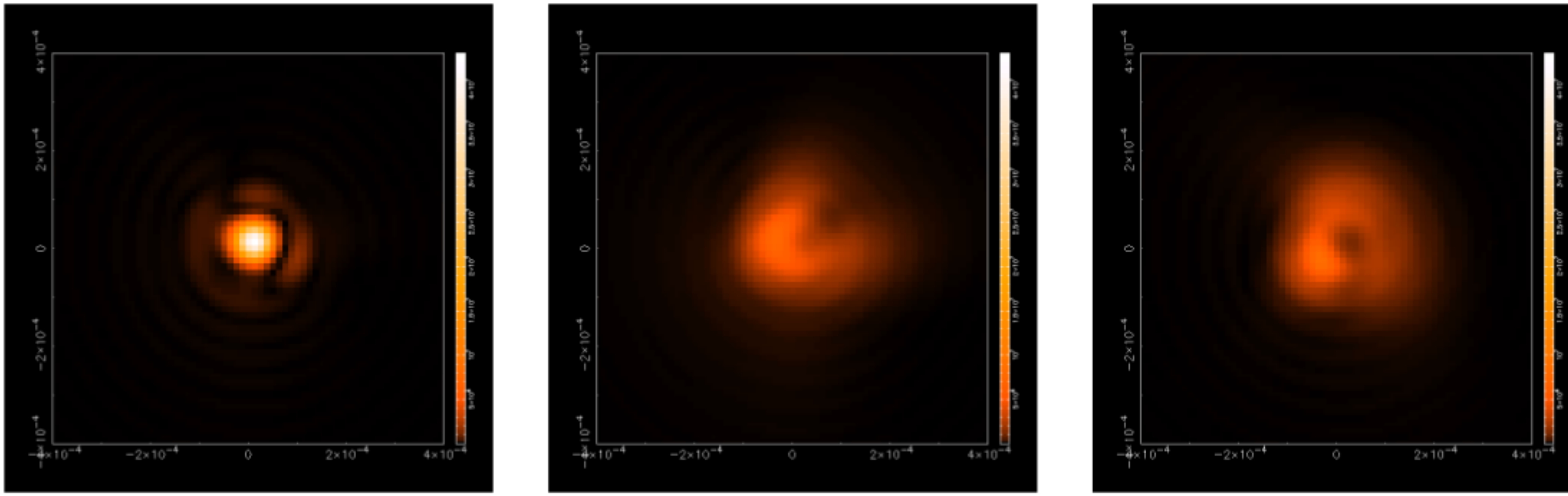
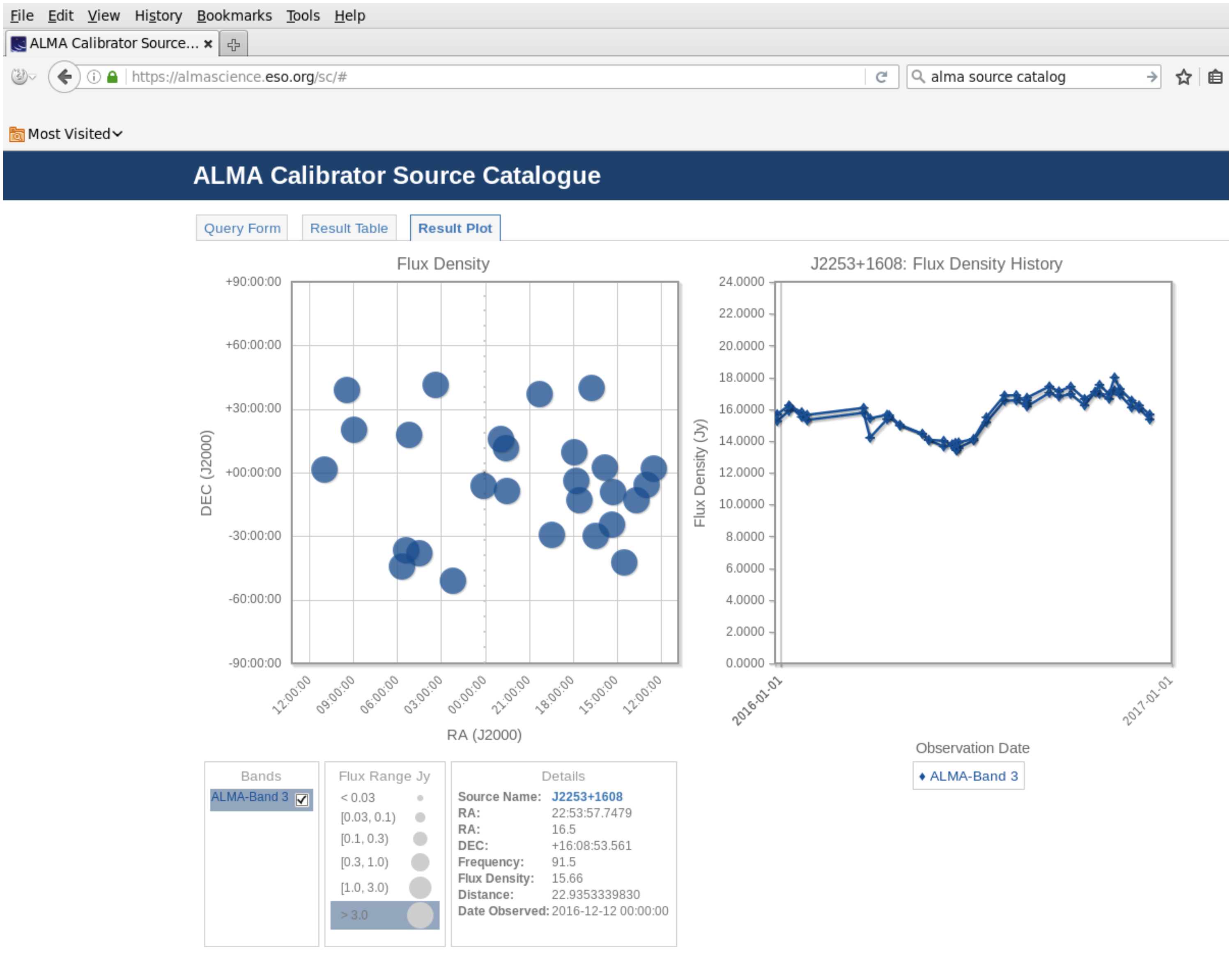
Surface Improvements with Zernike-Gravity Model

Use Out Of Focus (OOF) mapping observations of bright point sources to derive Zernike parameters

In-Focus | -ve De-Focus | +ve De-Focus

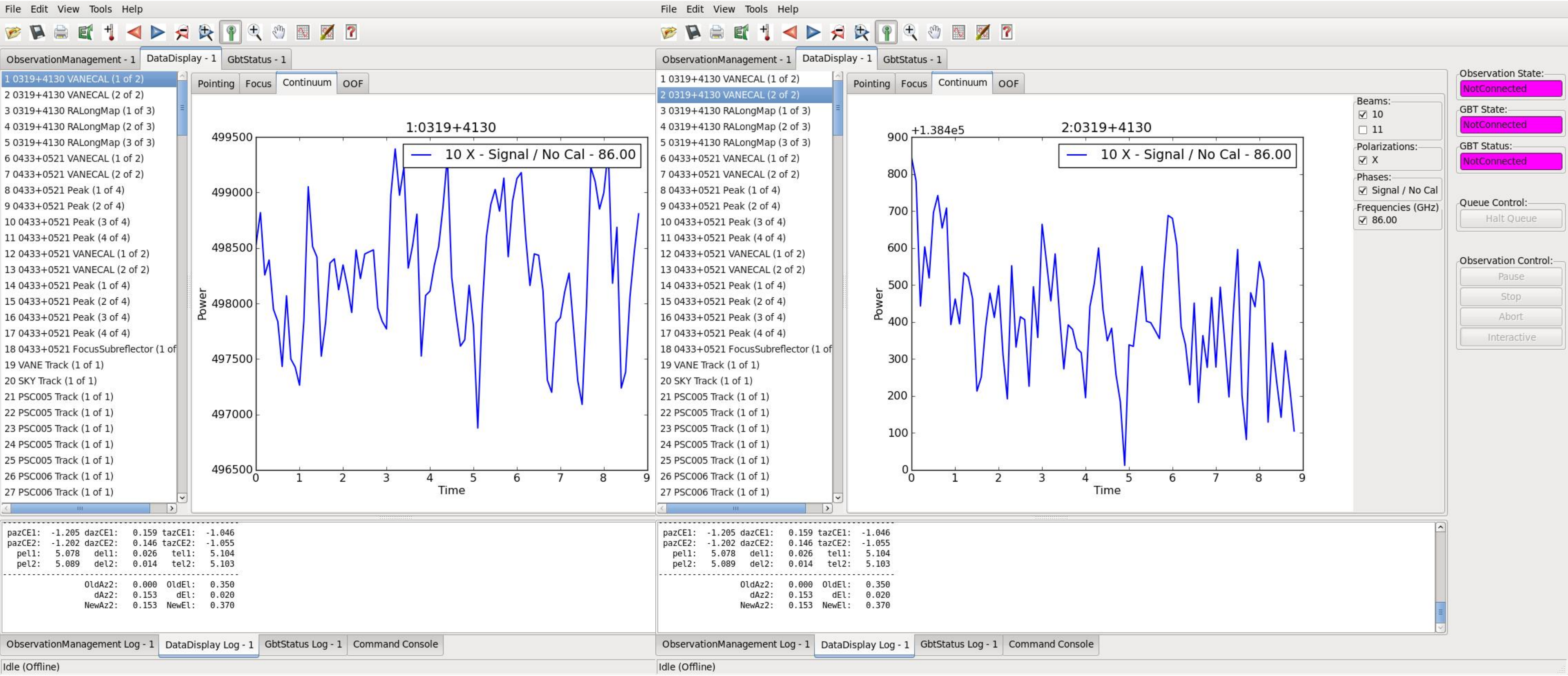


Use the **ALMA Calibrator Source Catalogue** to find pointing source and for absolute calibration



Example of Argus AutoOOF Observations:

(scans 1+2) Vanecal-scans with the DCR

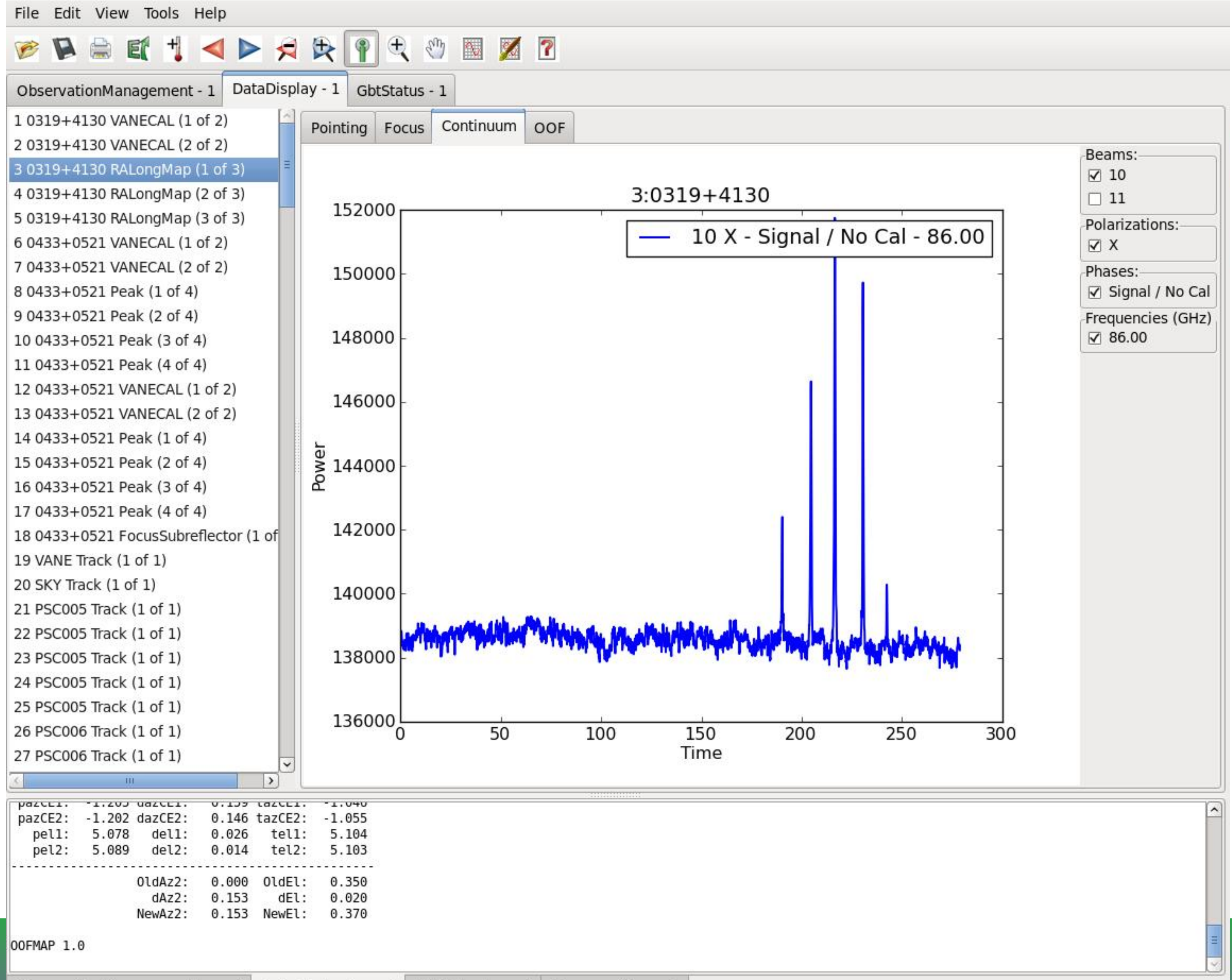


Vanecal scans with the DCR – first scan is with VANE (4.985e5 counts) and second scan is on SKY (1.354e5+500 counts).   Tsys~Twarm(SKY/(VANE-SKY)) = 104 K for Twarm~270.   **Should have VANE/SKY>~3 in good conditions**.

Example of Argus AutoOOF Observations:

(scan 3) Argus OOF map-1 data

First map at default focus and should see source at good S/N.   Here, the source is offset from the center of the time stream/map which implies a significant +el LPC.



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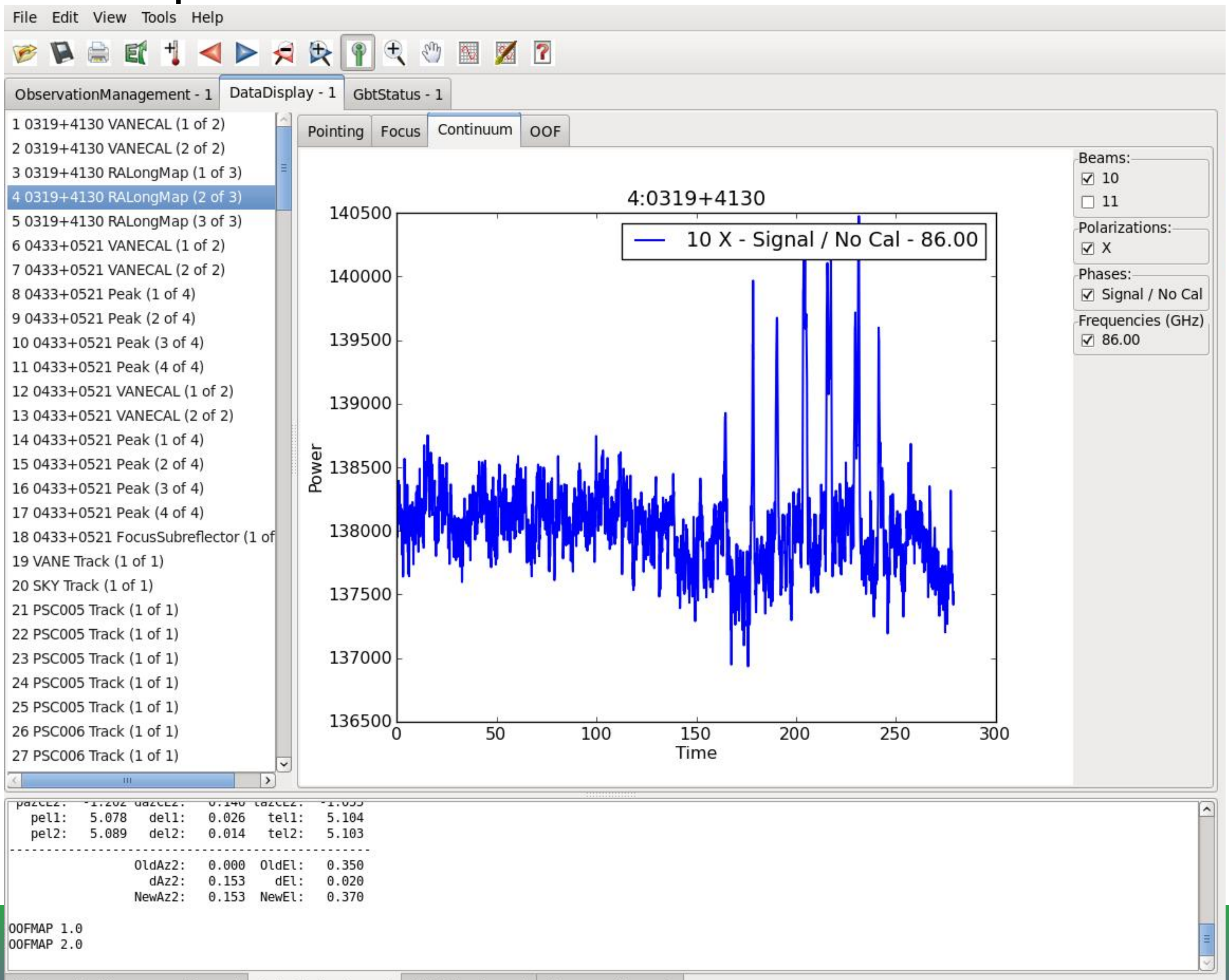
Example of Argus AutoOOF Observations:

(scan 4) Argus OOF map-2 data

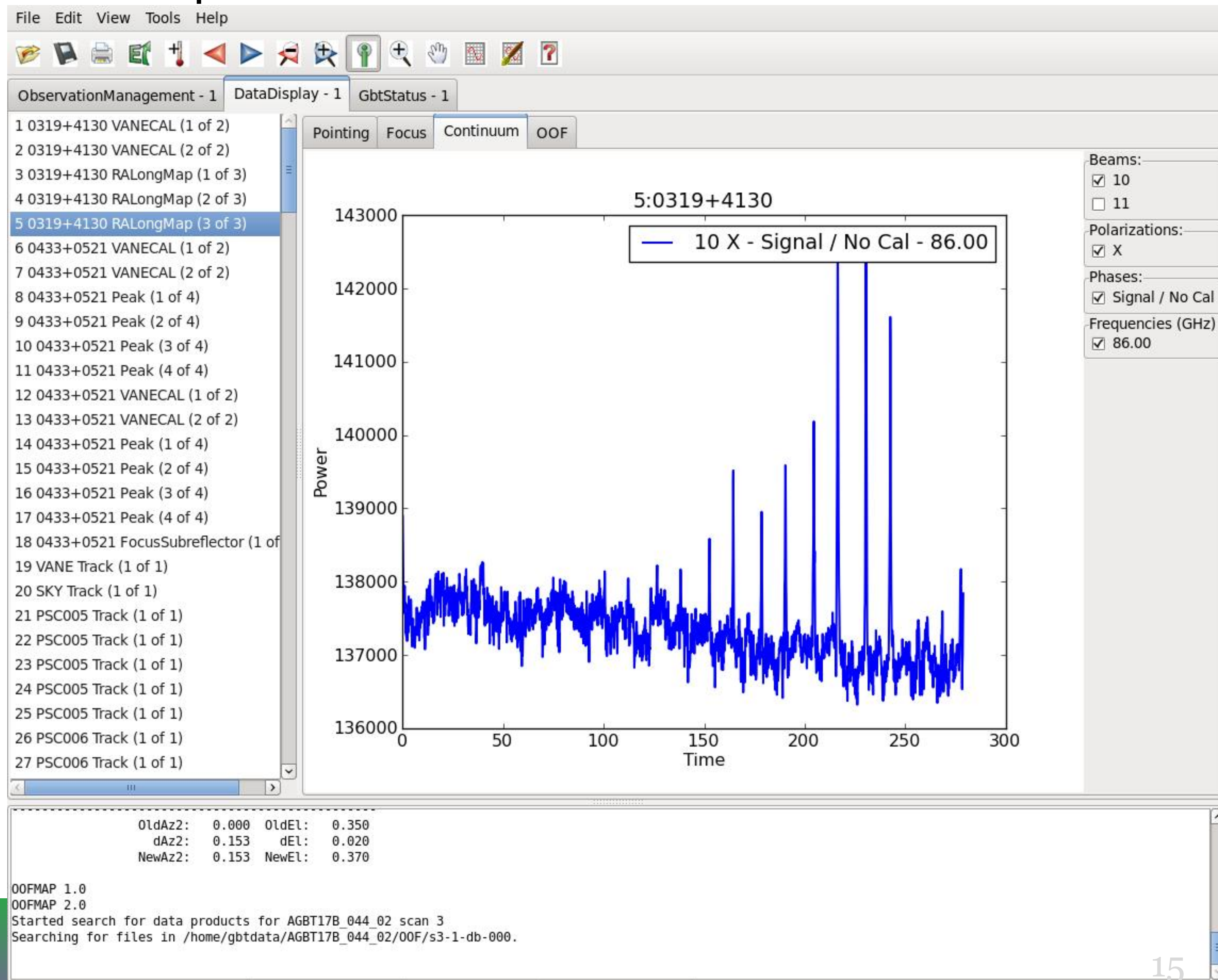
Counts lower since map made out of focus (+12mm)



Example of Argus AutoOOF Observations:

(scan 5) Argus OOF map-3 data

3rd OOF map with focus at -12mm (peaks higher than +12mm map so focus LFC will be negative)

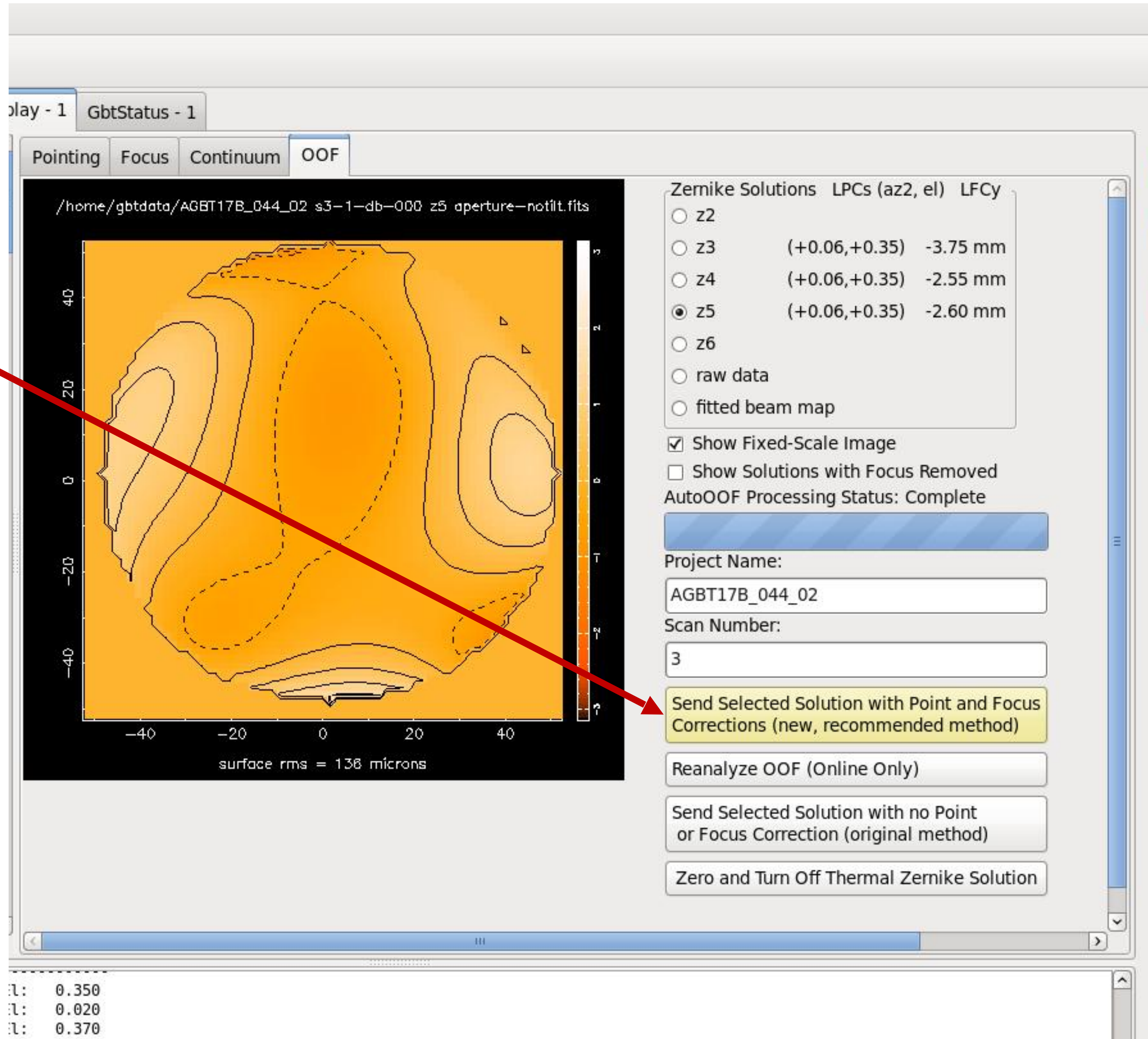


AutoOOF Solutions

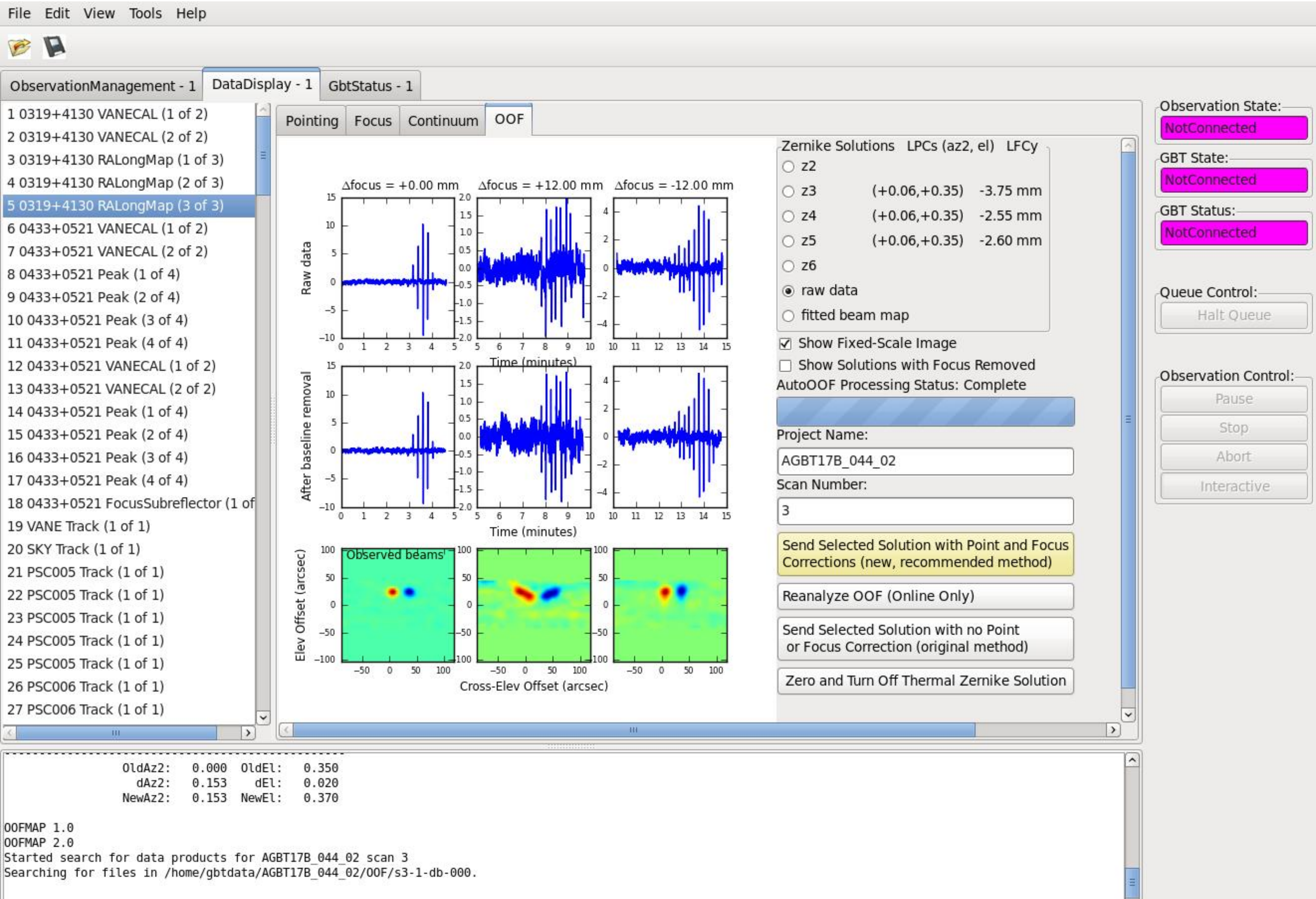
Click yellow button after OOF processing to send corrections to GBT and turn on the thermal zernike's.

Typically pick between z4,z5,z6 based on residual rms and beam fits (z5 default).

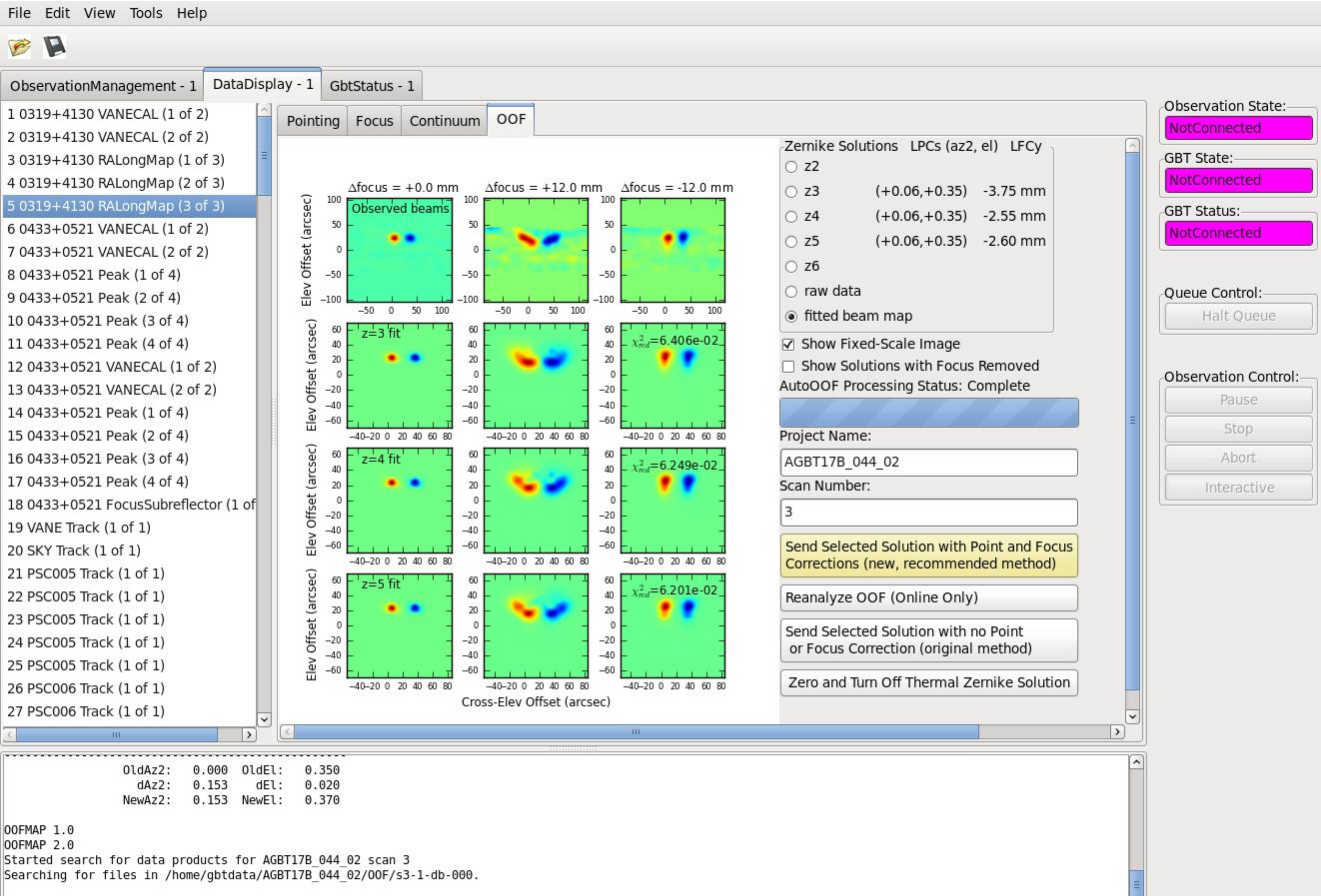
Be weary of “rms” >350 microns (which happens in windy conditions)



AutoOOF ‘Raw Data’

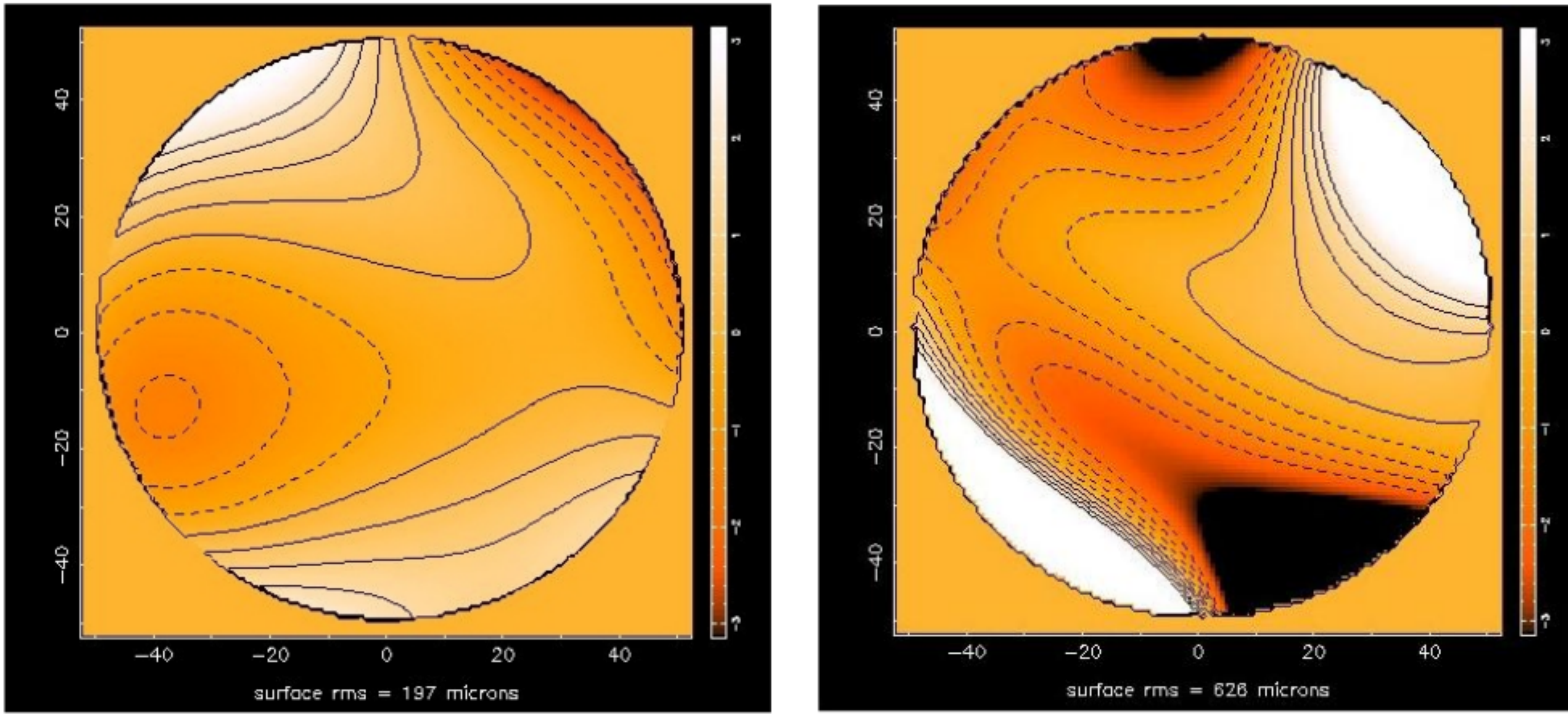


AutoOOF Beam Fits



AutoOOF Example Solutions

Acceptable OOF results typically have an RMS of less than 400-microns in comparison to the gravity model

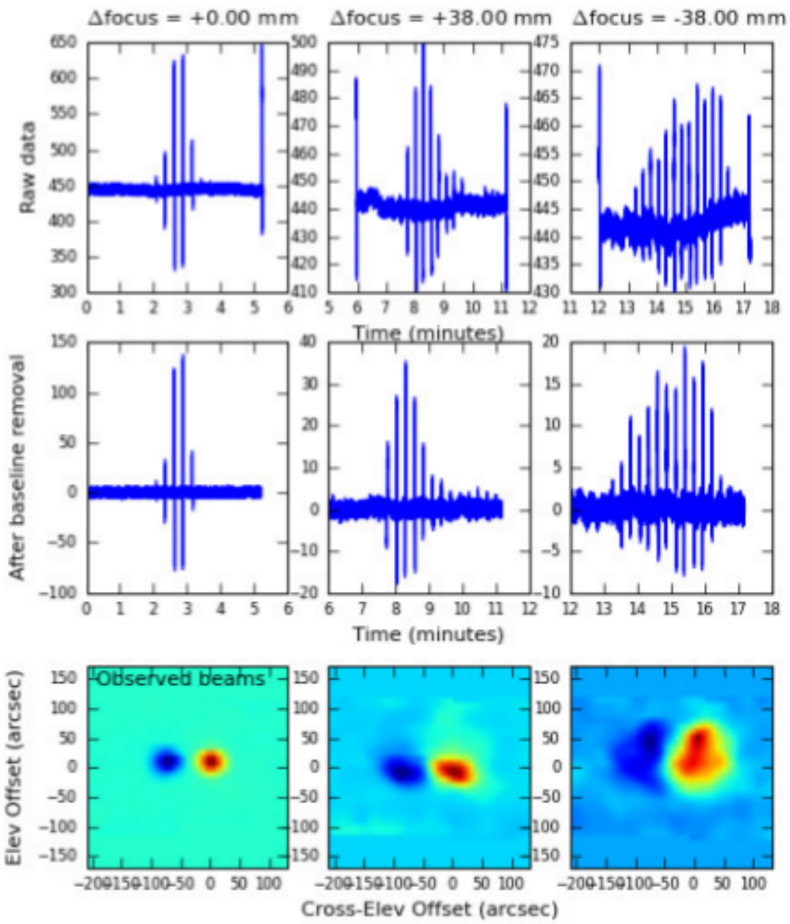


(a) Acceptable OOF solution.

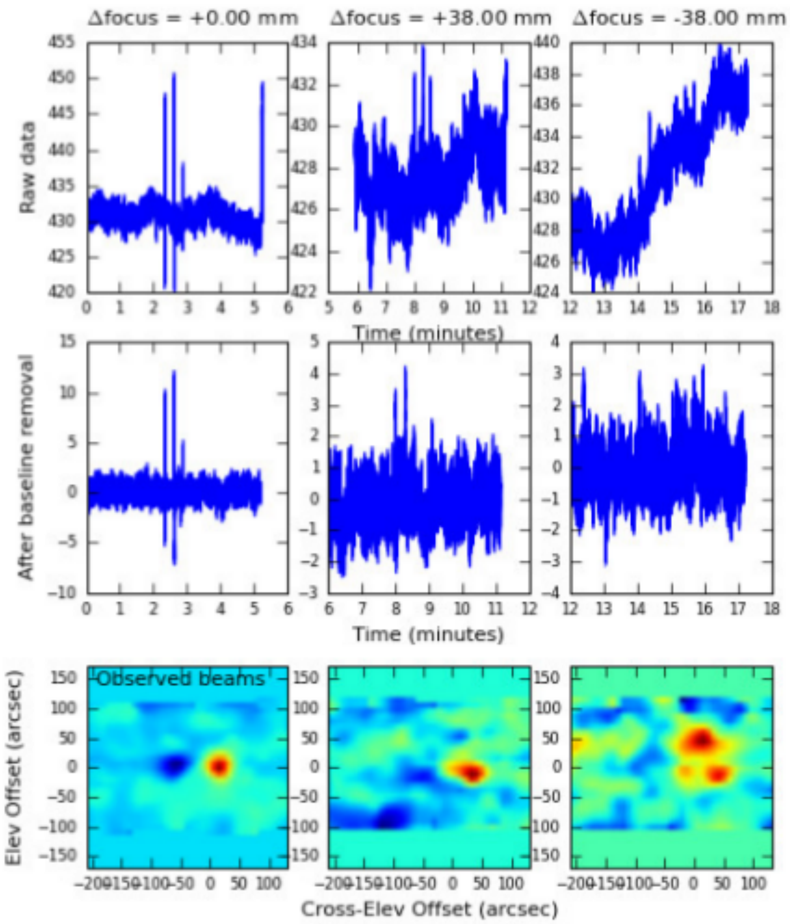
(b) Unacceptable OOF solution.

Figure 5.8: Figure 5.8a shows broad features (±1.5 radians of phase) with a surface rms of 197 μm. Figure 5.8b shows steep contour lines (±15 radians of phase) and a surface rms of 626 μm. This is likely the result of poor quality raw data and should not be used.

AutoOOF 'Raw' Data Streams



(a) A plot of the raw OOF data on a fairly clean Ka–band/CCB dataset.



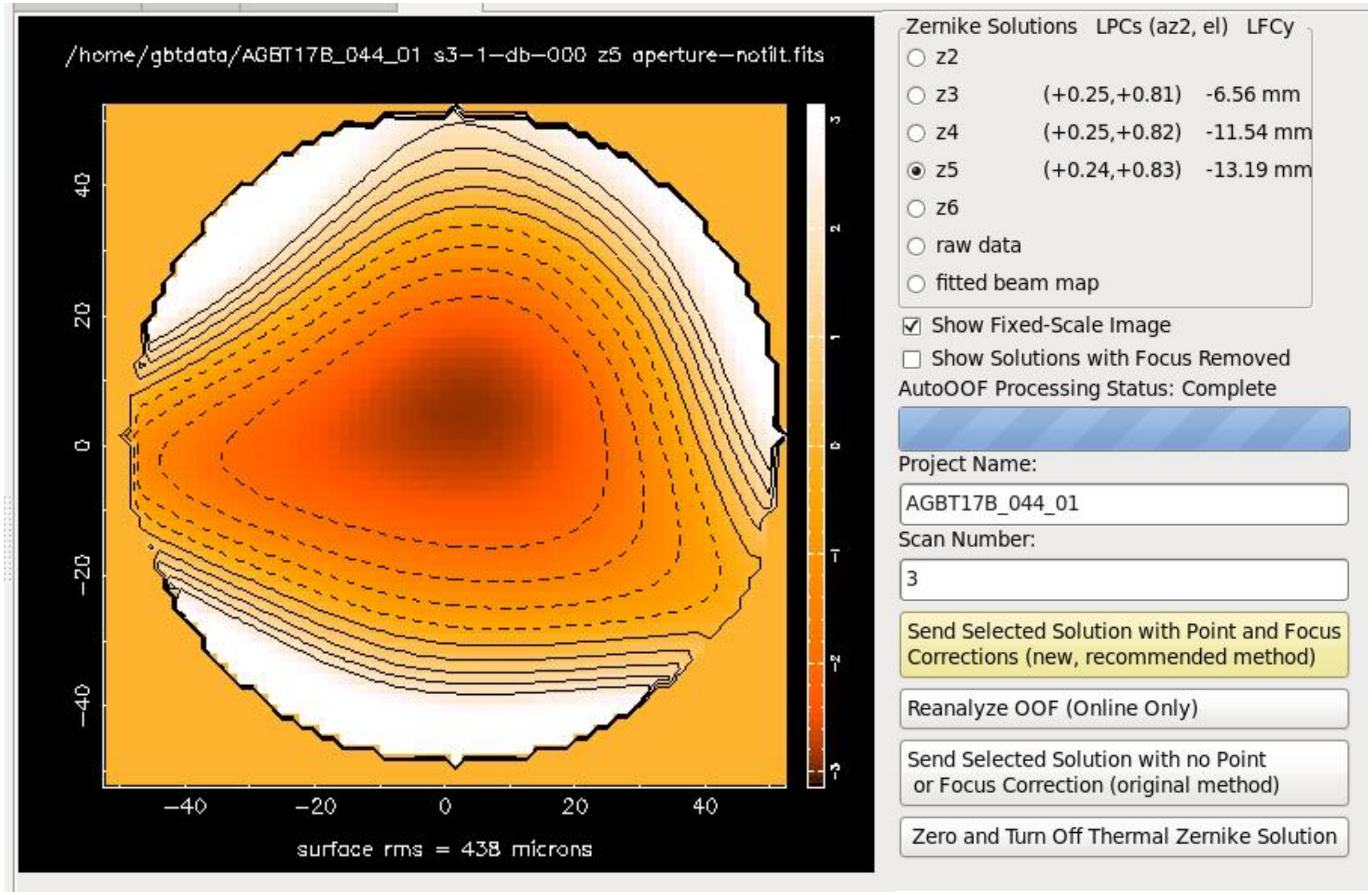
(b) A plot of raw OOF data on a source which is too faint.

Example of a Bad AutoOOF Solution

In this case observations were done in the keyhole at >85° and OOF “rms” 438 µm with a large implied focus and EL pointing offset.

Solution with large rms >400 µm should not be used.

Check the raw data and fitted beam maps.

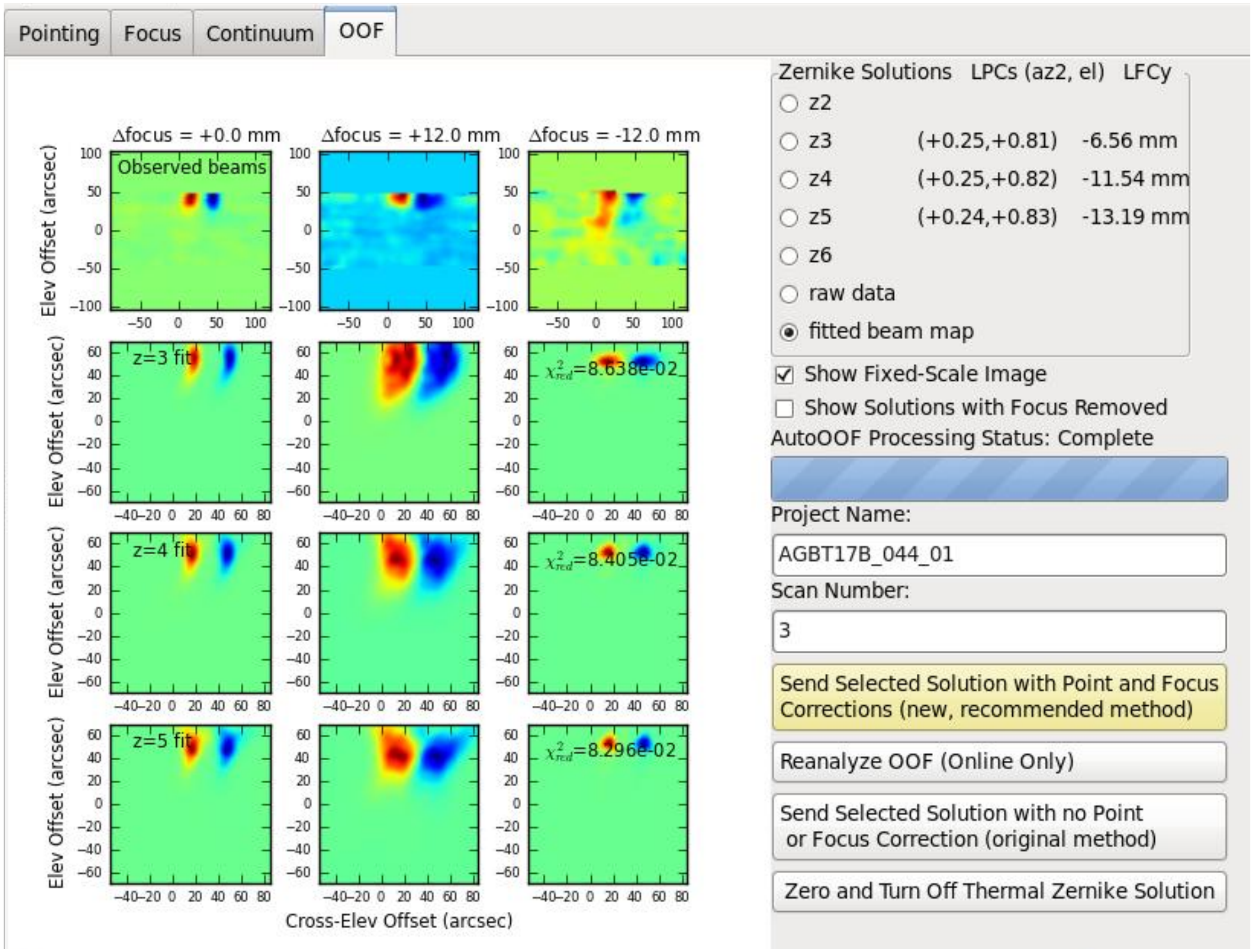


Beam Maps of Example Bad OOF

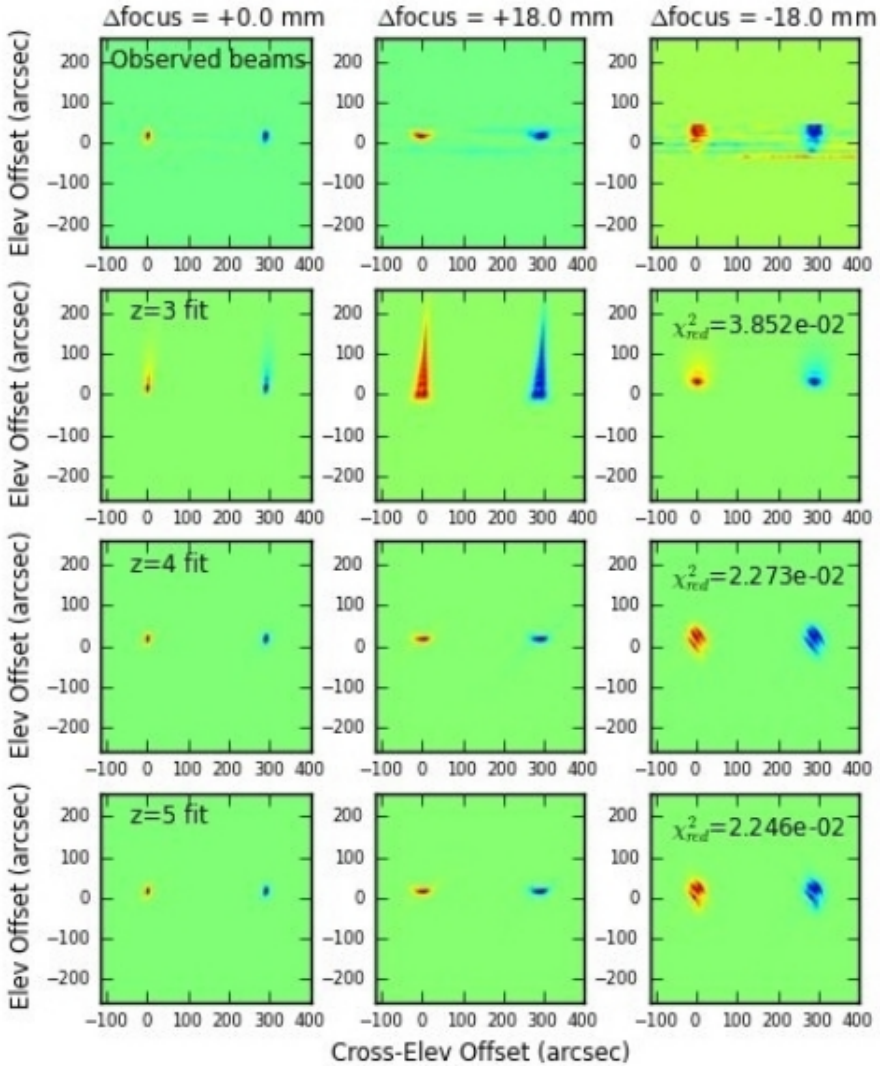
The "observed" beams should not be streaks or very elongated.
This can happen in windy conditions.

In this case data were taken in the keyhole causing the apparent focus correction to be very large and a large EL LPC.

Do not apply OOF corrections if you cannot trust the results.



Another Bad OOF (avoid Z3 Solution)



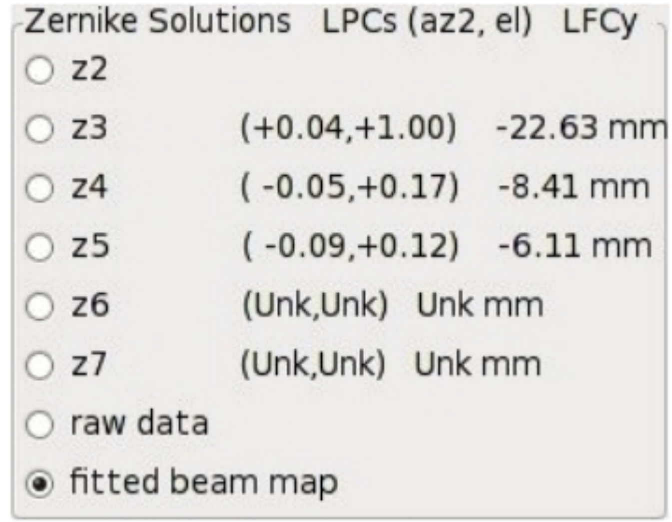
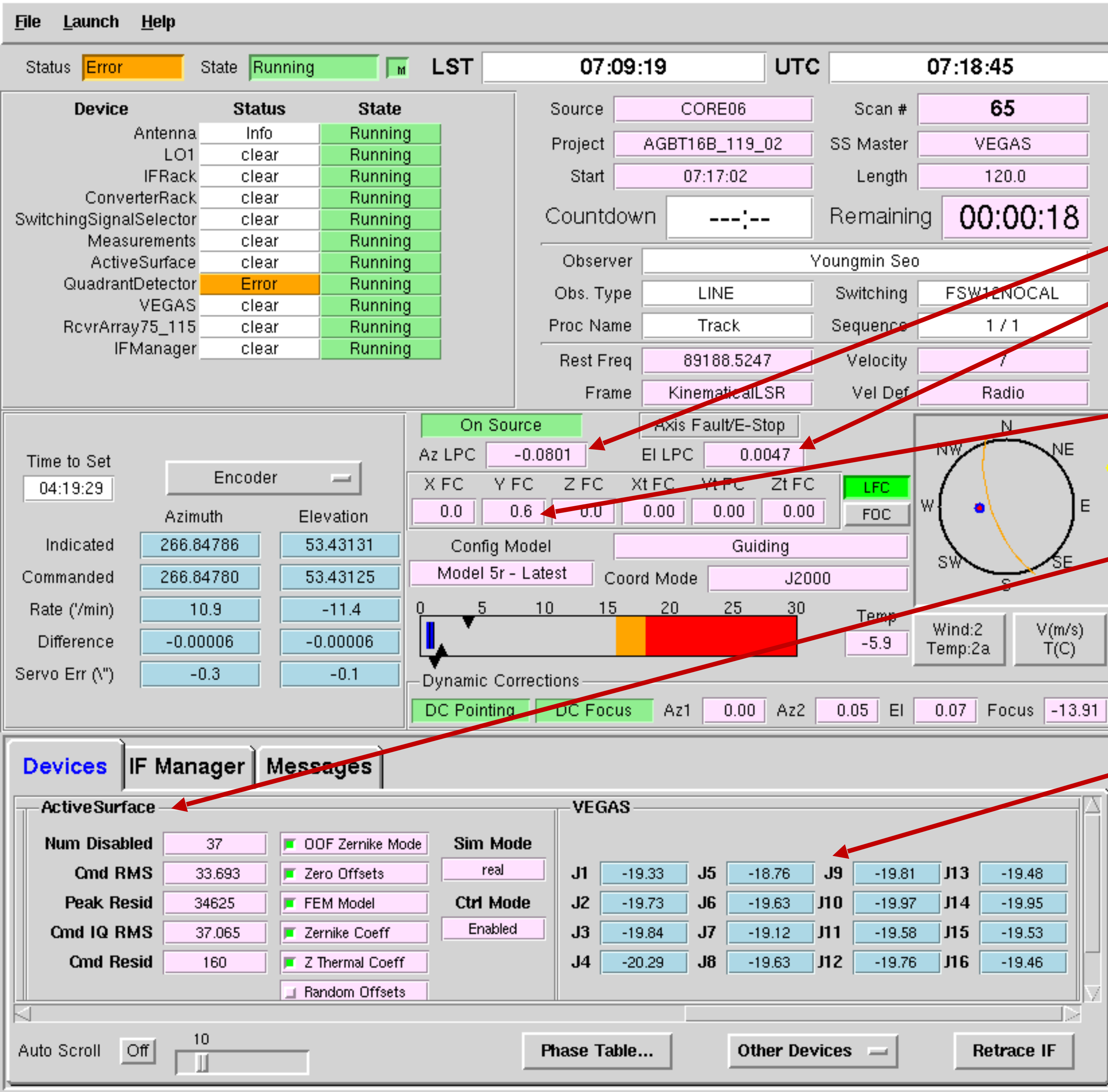


Figure 5.10: The AutoOOF fitted beam maps (left). The observed beams are plotted on the top row with the z3, z4 and z5 fits to the observed beams plotted below. The z3 solution (2nd row down) shows an obvious artifact and should not be used. Also note the significant jump in LPCs and the LFC between the z3 and z4 solutions (above).

Cleo Status Window



Az,El LPCs

Focus YFC

Active Surface ON with Thermal corrections from OOF

VEGAS balance values on sky: ~-20(+/-3)

Telescope Corrections

- **For successful Argus observations, one must obtain and maintain good telescope corrections (pointing, focus, surface)**
- OOF surface corrections should be done with Ka+CCB system if available for highest S/N, but can also be done with Argus if Ka+CCB is not available
- Pointing and focus corrections can be done with Argus or at lower frequency (e.g., X-band)
- Users can struggle and waste a lot of time trying to point/focus with Argus (e.g., faint sources/marginal conditions). You should point+focus in X-band if problems arise or if in doubt.

Observing Strategies: Antenna Optimization

- Should point+focus (AutoPeakFocus) every 30min-50min depending on conditions (point+focus takes ~5min)

- AutoOOF (which takes ~20min) is used to correct the surface for thermal effects at night.

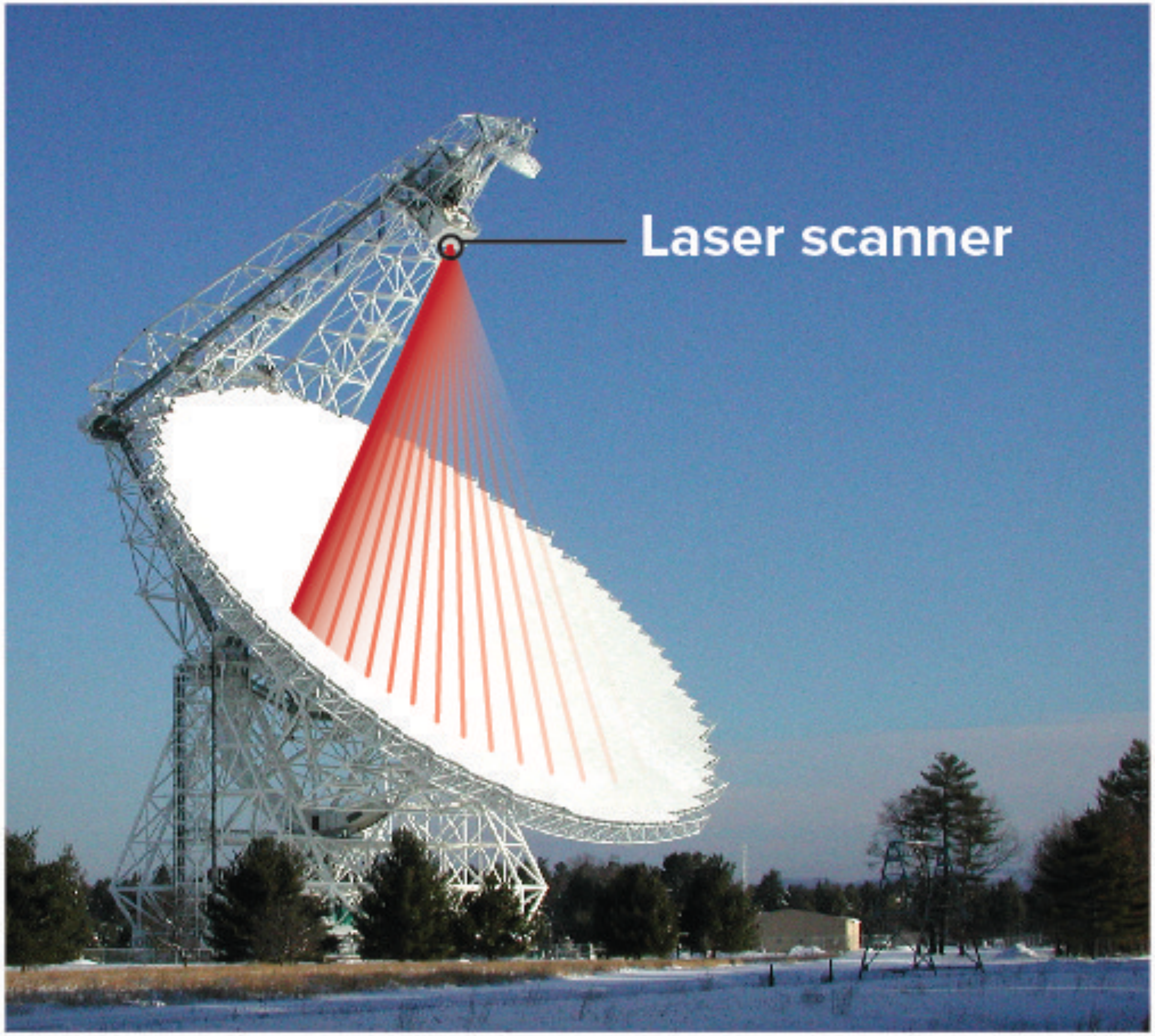
- Daytime surface changes <1hr time scales and the AutoOOF solutions can cause more harm than good during rapidly changing conditions from the AutoOOF (so it is typically not useful to use the “thermal” corrections during the day).

LASSI: Laser Antenna Surface Scanning Instrument

A Terrestrial Laser Scanner
- emits laser signals to calculate distances based on the time delay of the returned laser pulses

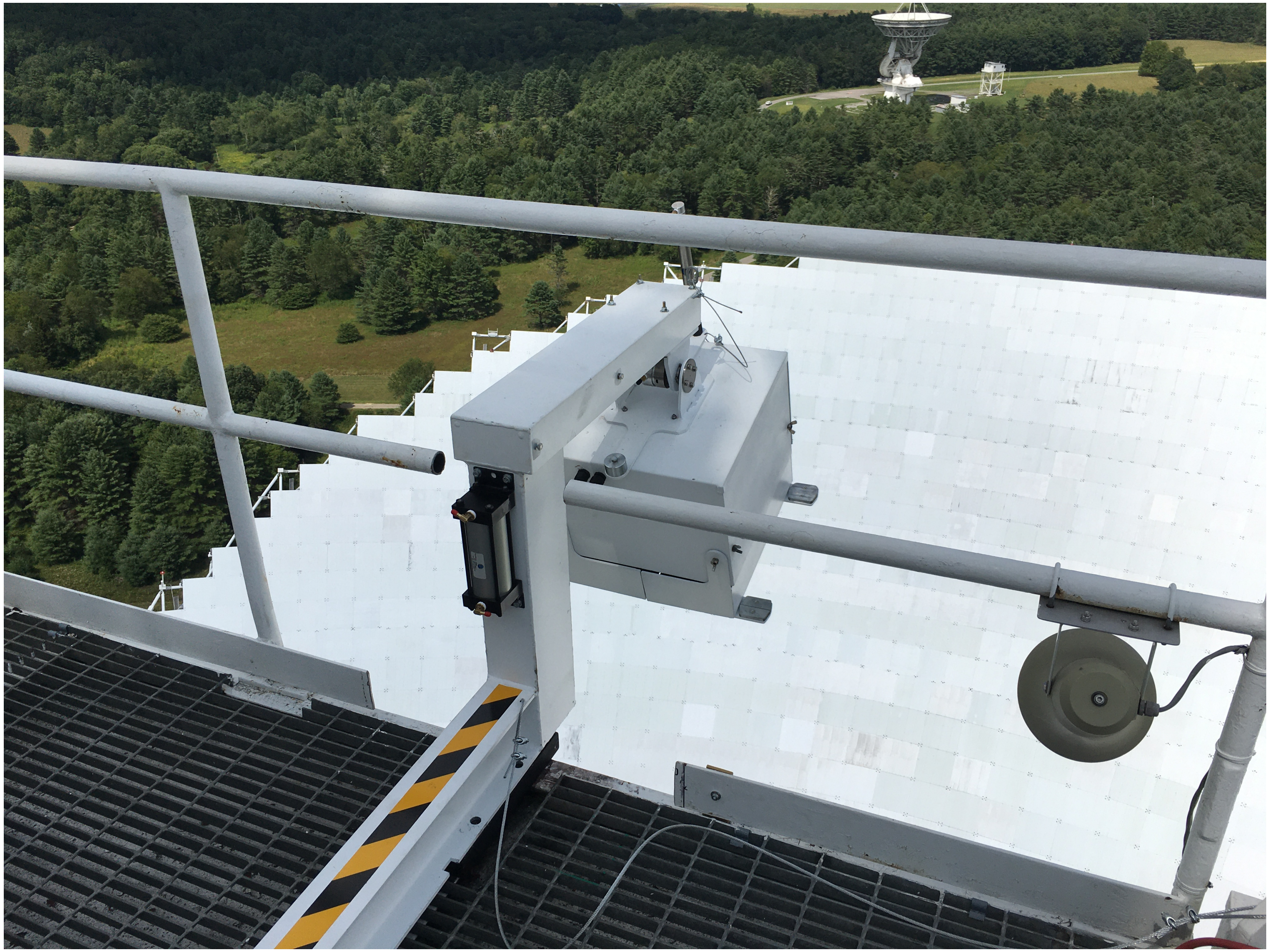
Opens up more day time observing for high frequency

Processing time takes 6 minutes (compared to the 20-30 minutes for OOF scans)

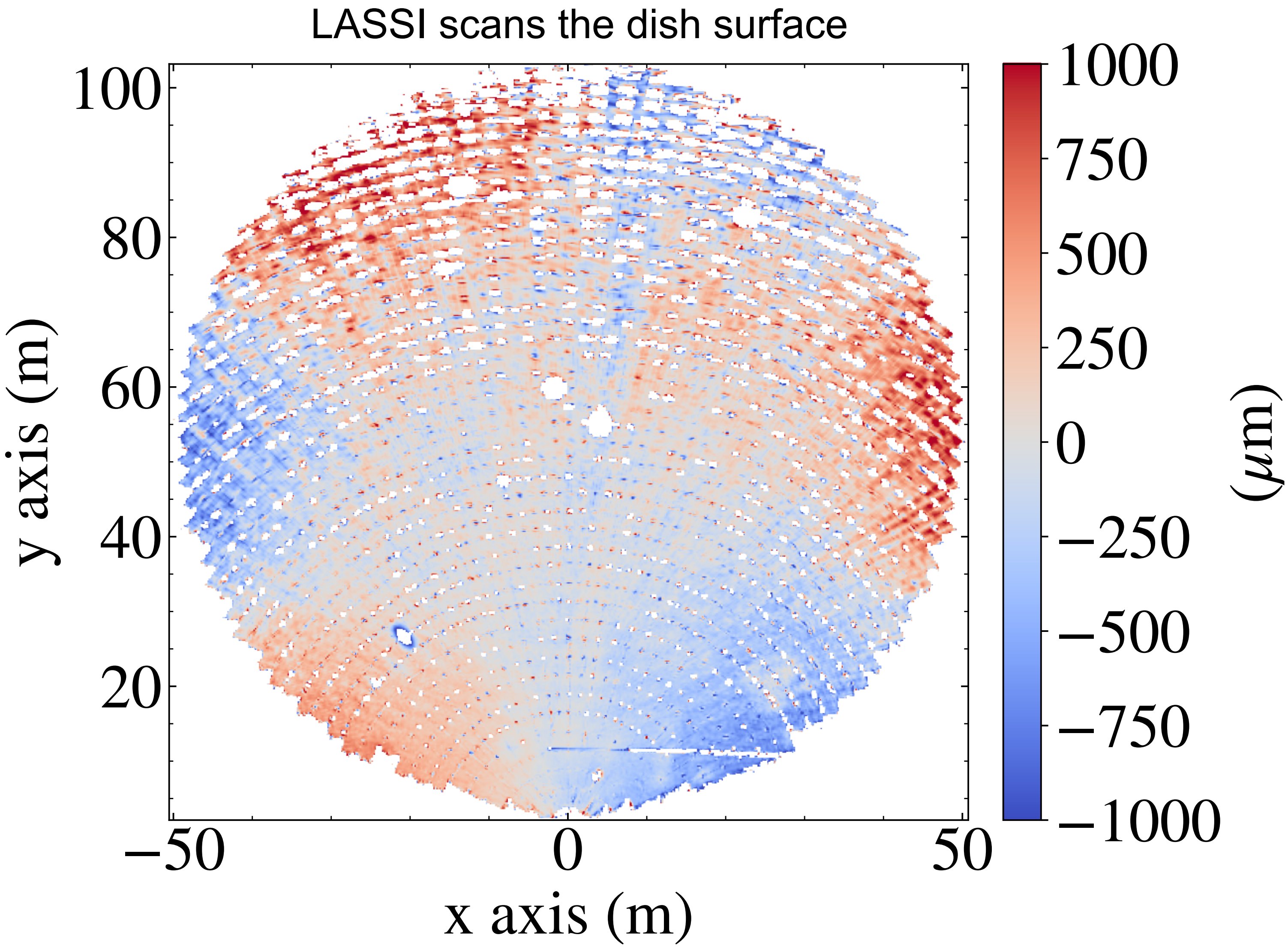


LASSI: Laser Antenna Surface Scanning Instrument

Photo of LASSI installed on the GBT



LASSI: Laser Antenna Surface Scanning Instrument



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greenbankobservatory.org

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Pointing & Focus

- Peak and focus on sources within 30deg and brighter than 1.5 Jy with Argus. Brighter sources are better than closer sources since the GBT pointing model is very good.
- The point/focus frequency should be the approximate frequency of your science frequency with VEGAS.
- For best results, **autopeak_focus should be run every 30-50 minutes** depending on varying conditions.
- It is very important to get good pointing (and focus) solutions if you want to observe your target position. **You should monitor every set of pointing+focus scans in real-time,** and not assume that the automatic astrid-defaults will produce the good solutions.
- **If in doubt, point+focus with X-band.**

Surface Improvements with Zernike-Gravity Model

Some Zernike parameters depend strongly on the current "Thermal" conditions of the antenna (large scatter) and require real-time corrections to the gravity model.

$$Z_n(\text{total}) = Z_n(\text{gravity}) + Z_n(\text{thermal})$$