



# High Frequency GBT Corrections

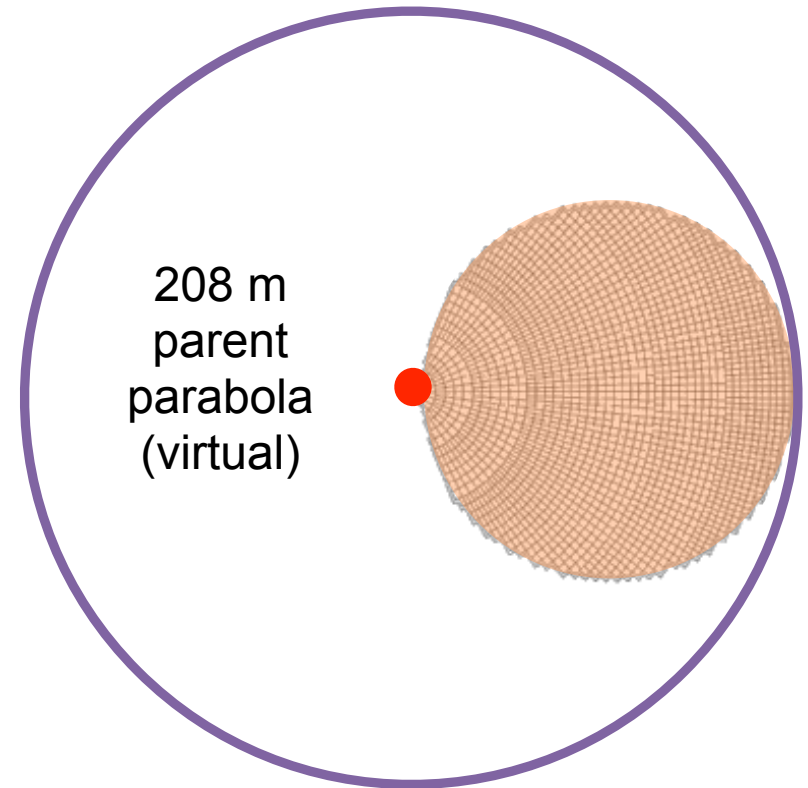
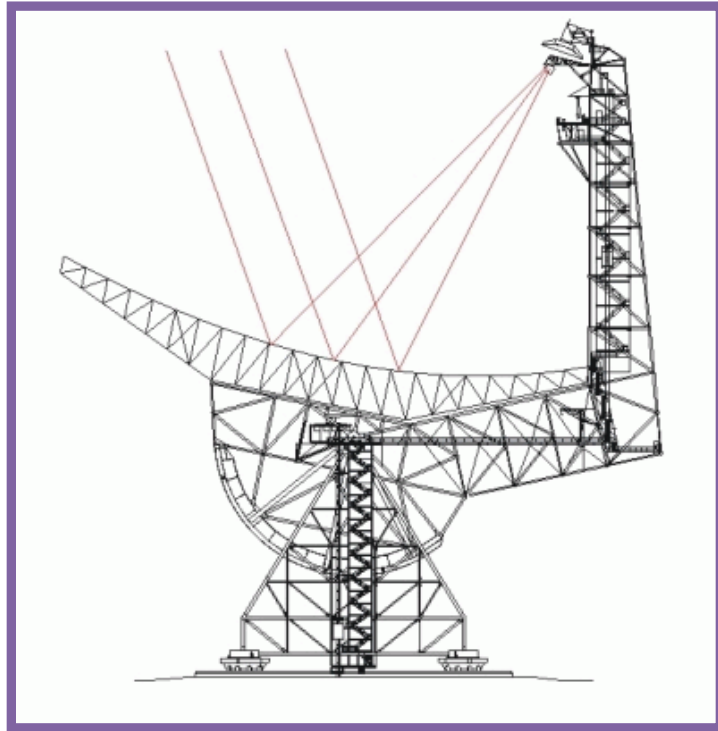
Emily Moravec (GBO Postdoc)

With thanks to Dave Frayer, Natalie Butterfield, Will Armentrout, and Anika Schmiedeke



# GBT Telescope Optics

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



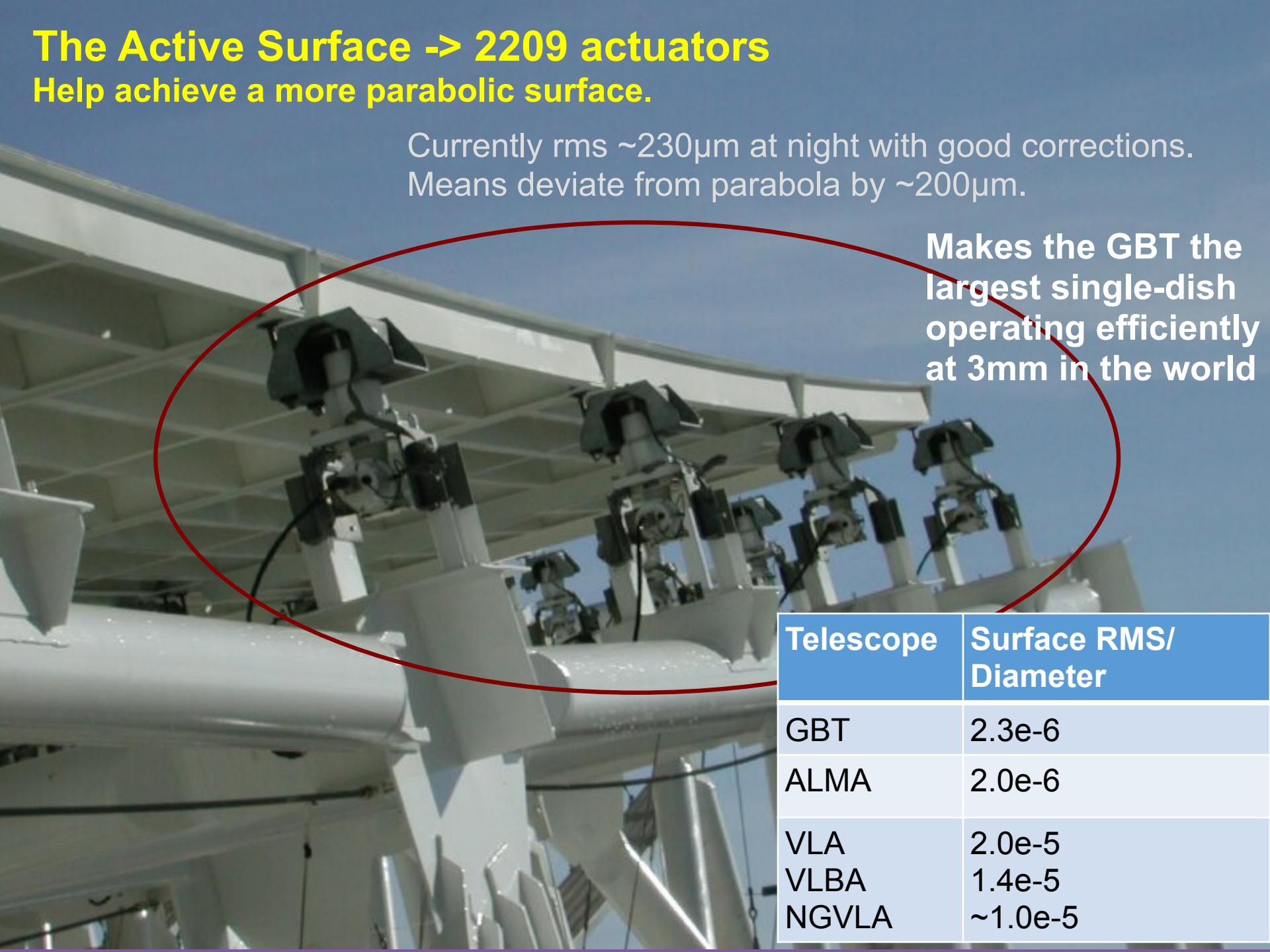


# The Active Surface -> 2209 actuators

## Help achieve a more parabolic surface.

Currently rms  $\sim 230\mu\text{m}$  at night with good corrections.  
Means deviate from parabola by  $\sim 200\mu\text{m}$ .

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	2.0e-5
VLBA	1.4e-5
NGVLA	$\sim 1.0\text{e-}5$

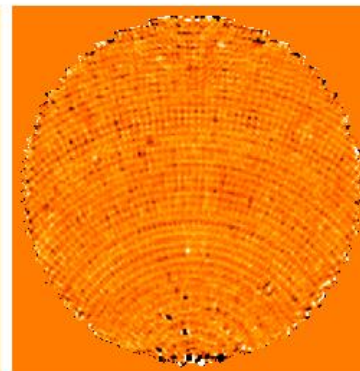
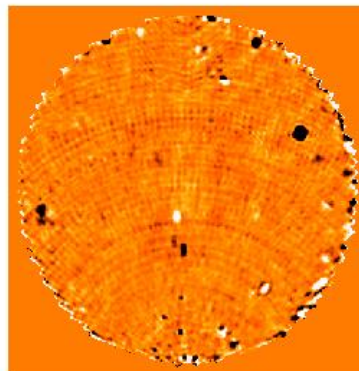
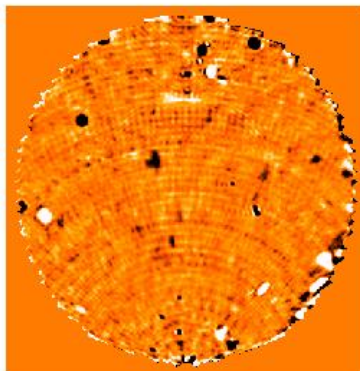
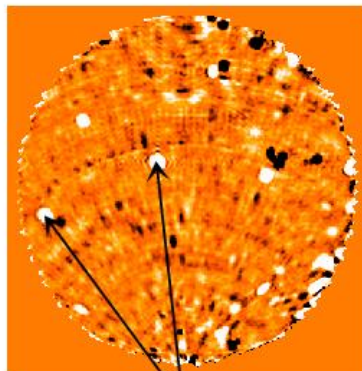
# Improvements to Active Surface in 2009

January 2009

February 2009

March 2009

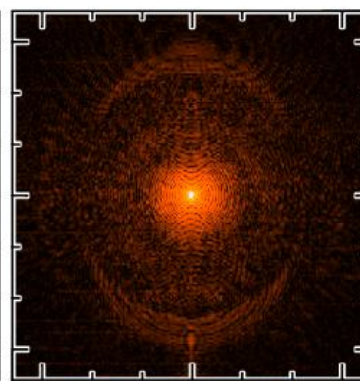
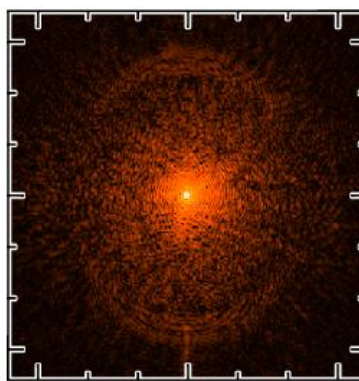
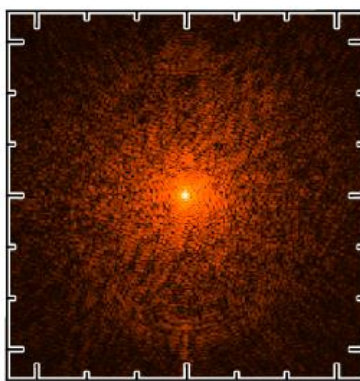
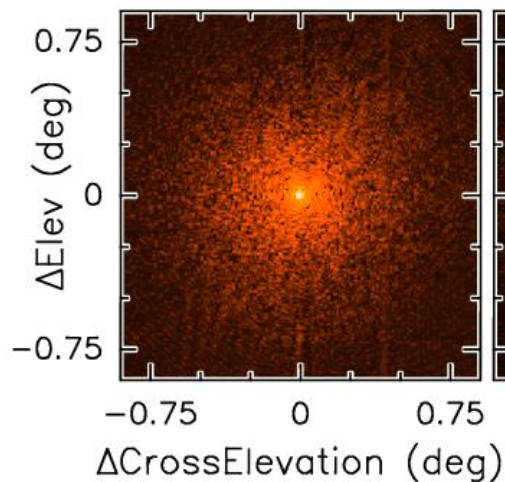
September 2009



Broken Actuators



-500 0 500 Microns

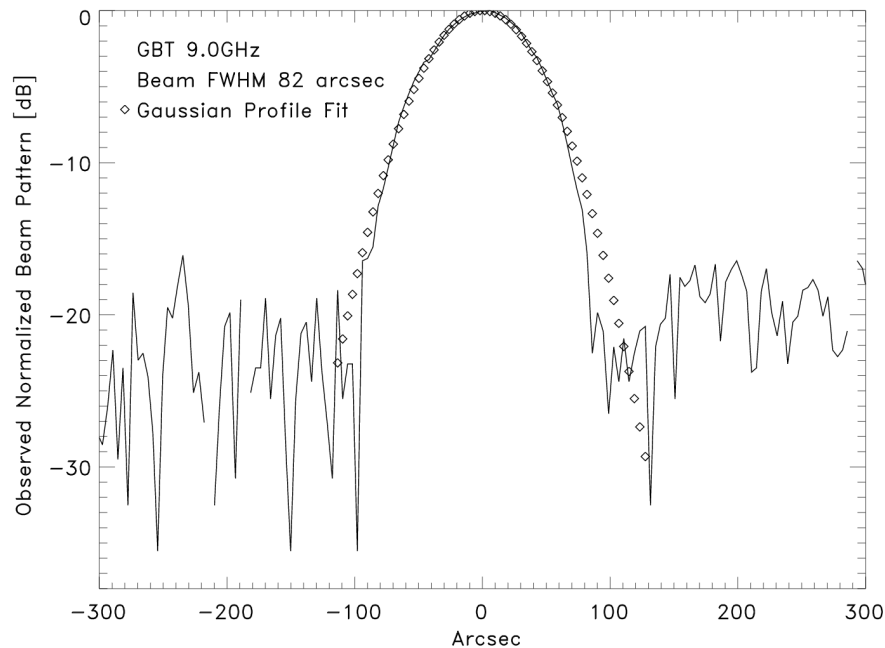


11.7 GHz beam pattern

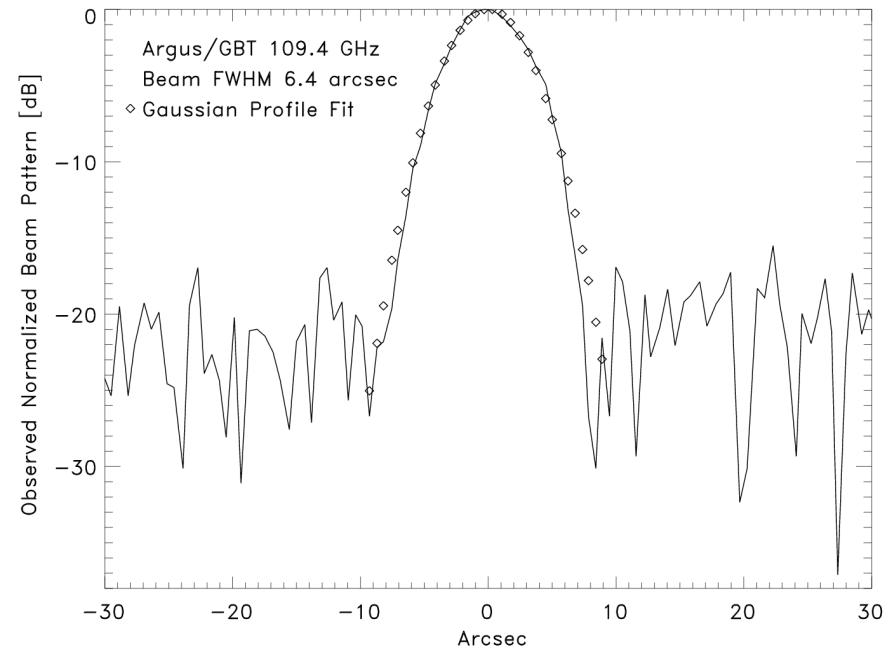
dB = -40 -20 0

# The GBT Achieves its Theoretical Beam at 110 GHz

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



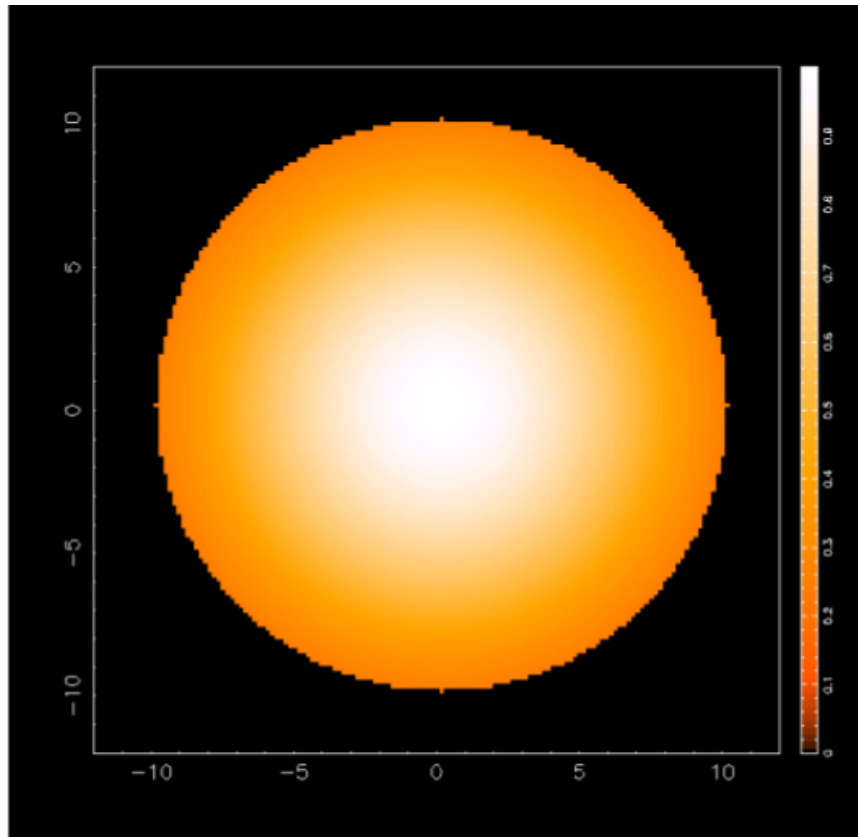
GBT/X-band 9.0 GHz



GBT/Argus 109.4 GHz

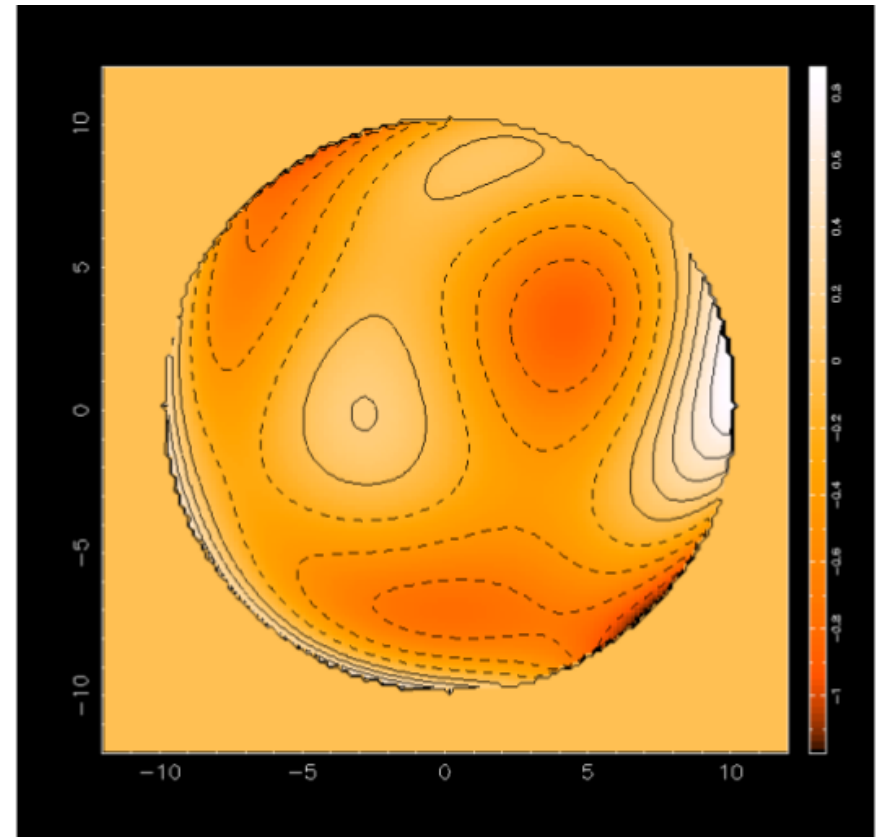
# A Surface with random large-scale errors

Receiver Response



(Taper/Apodisation/...)

Surface Errors



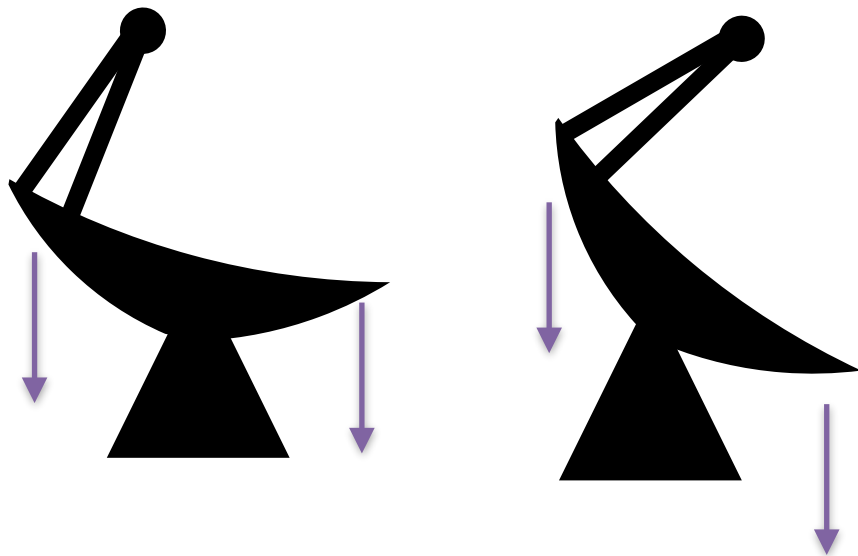
(Projected to an imaginary surface)



# What can cause deviations from perfect parabola and theoretical beam?

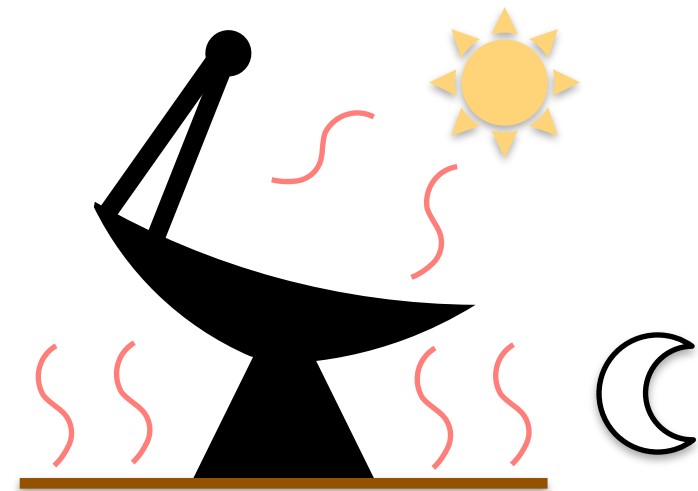
## Deformations caused by:

Gravity



Changes with elevation

Differential Heating



## Why do these deformations matter at high frequency and not at low frequency?

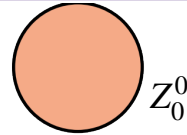
Quite simply, in the mm range this is where these deviations in the dish are larger than the wavelength.

# Model Surface Using Zernike Polynomials

Set of orthogonal polynomials that are used to reconstruct geometric features across a circular aperture. Derived by Frits Zernike in 1934 (Nobel Prize in 1953).

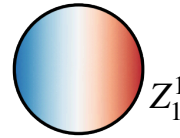
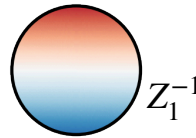
0th

offset



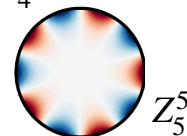
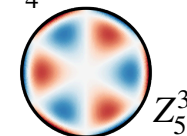
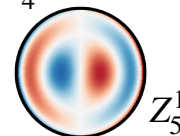
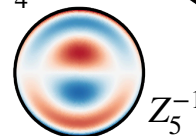
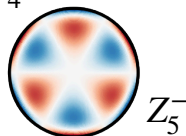
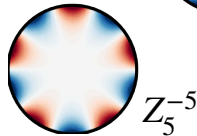
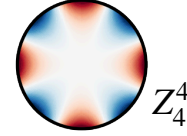
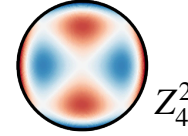
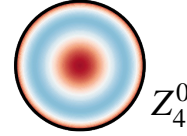
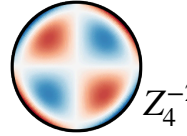
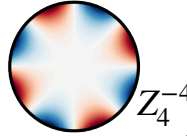
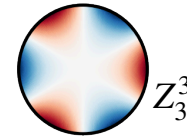
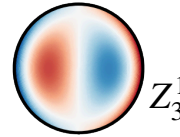
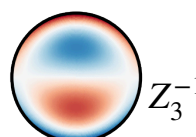
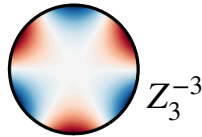
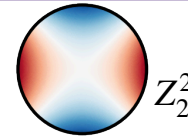
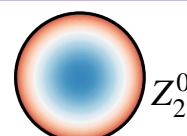
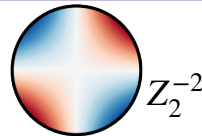
1st

gradient across



higher

more complex  
geometric  
shapes

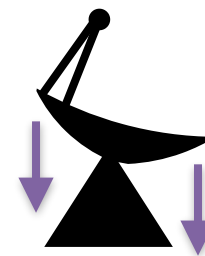




# GBT Zernike-Gravity Model

Each Zernike parameter fitted as a function of elevation:

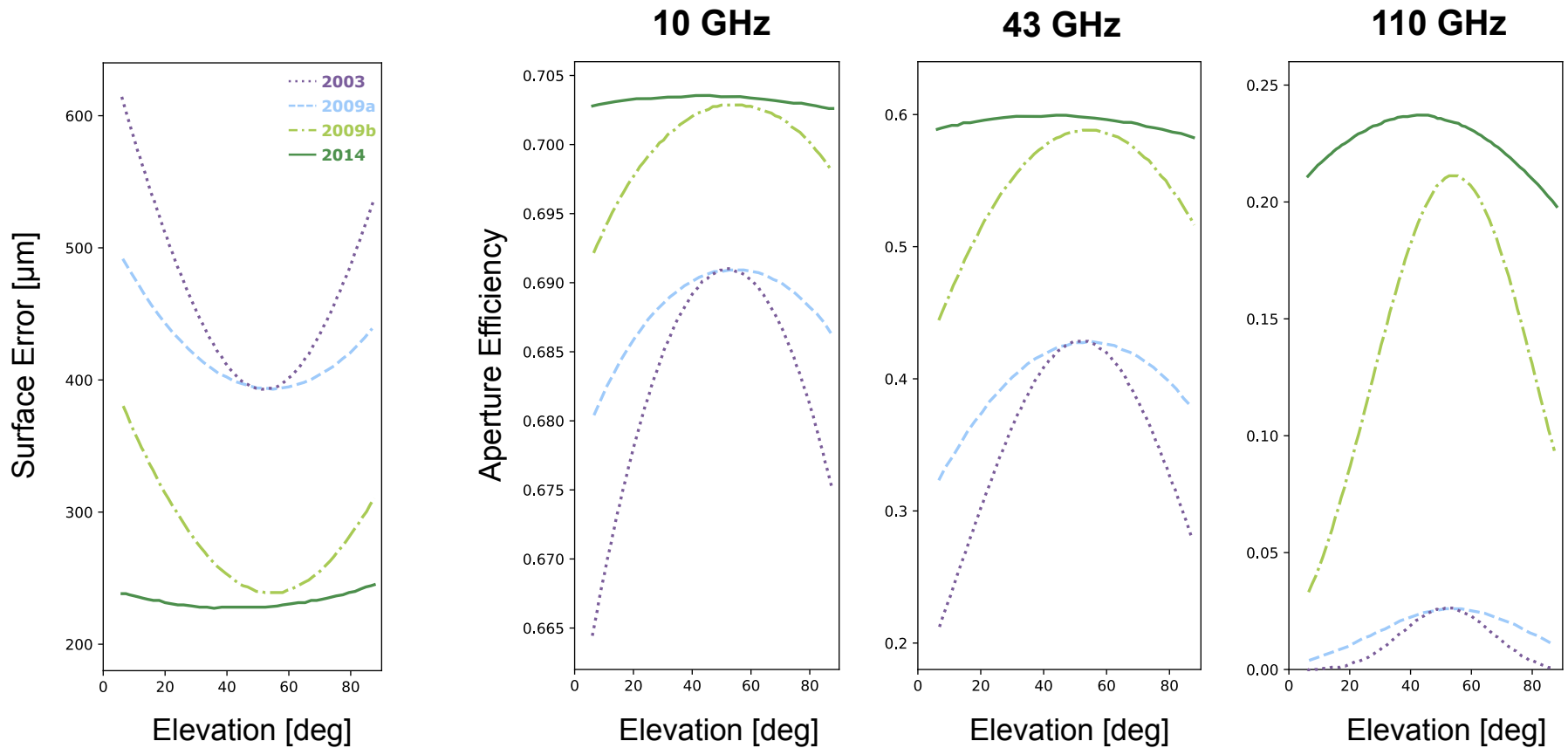
$$Z_n = A_n \sin(el) + B_n \cos(el) + C_n$$



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

Z	A	B	C	$\sigma_A$	$\sigma_B$	$\sigma_C$	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 Gravity Model + Active Surface



Source: GBT Memo #301

## But wait there is **STILL** more!

Accounted for:

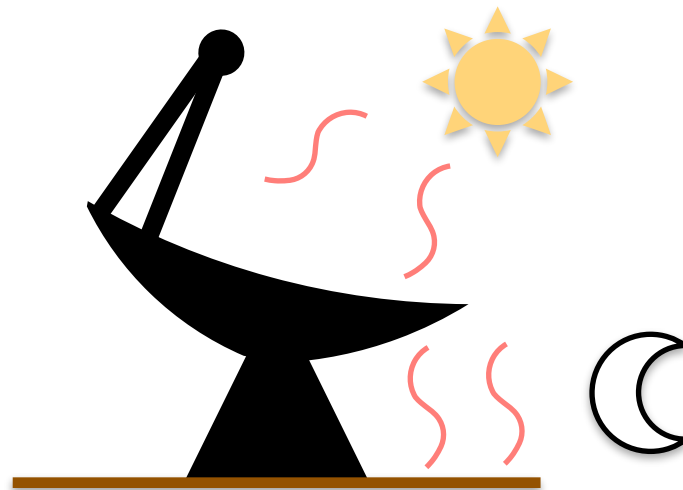
- Tracking model
- Gravity model

Fixed:

- Broken actuators
- Zero-point offset of actuators

There are still errors on surface!!

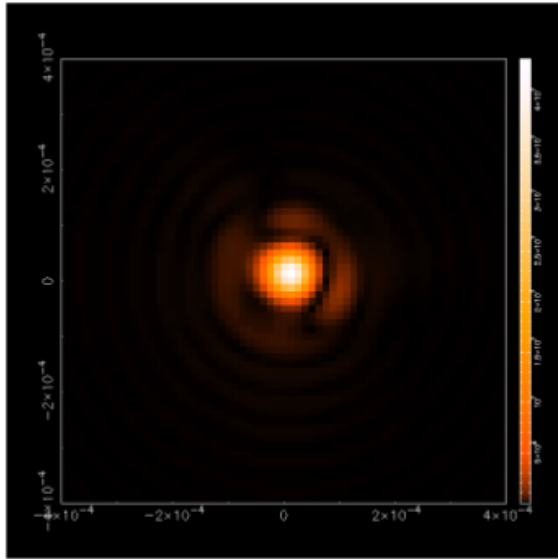
Differential Heating



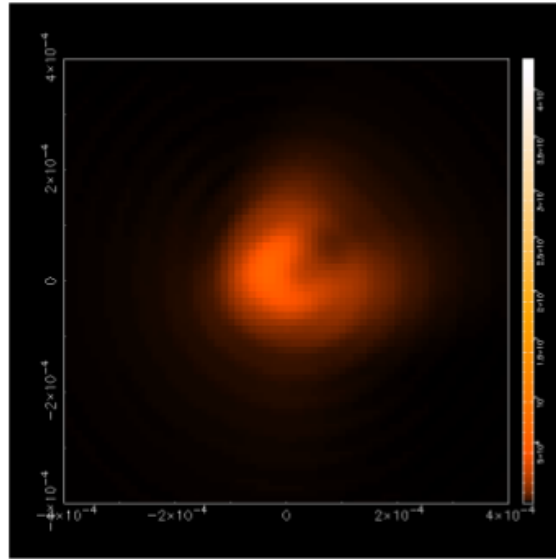
# Surface Improvements with OOF

Use Out Of Focus (OOF) mapping (holography) observations of bright point sources to derive Zernike parameters and correct for **all other** deviations in dish away from perfect parabola

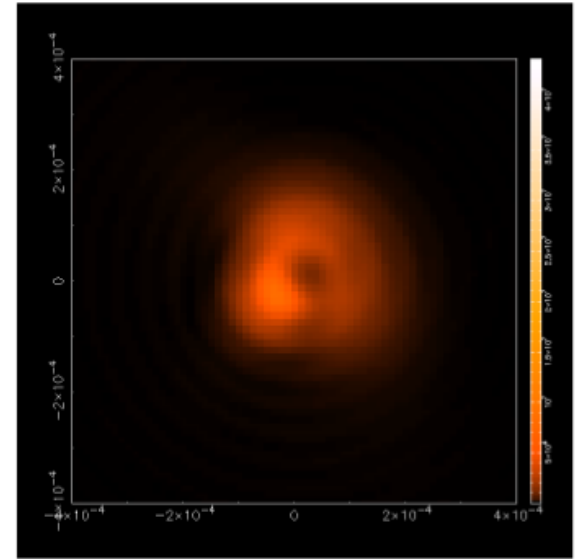
In Focus



-mm De-Focus



mm De-Focus



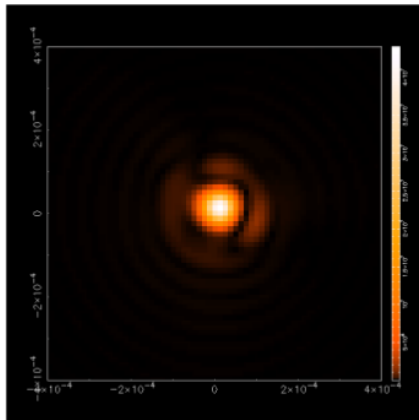
Only OOF for W, Q, ARGUS, and M2



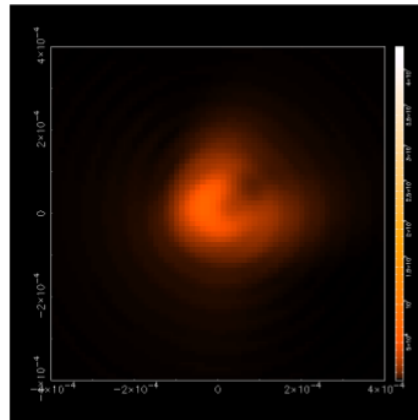
# Surface Improvements with OOF

Out Of Focus (OOF) - AutoOOF - active surface (RMS + map), pointing (Az,El), focus corrections (mm)

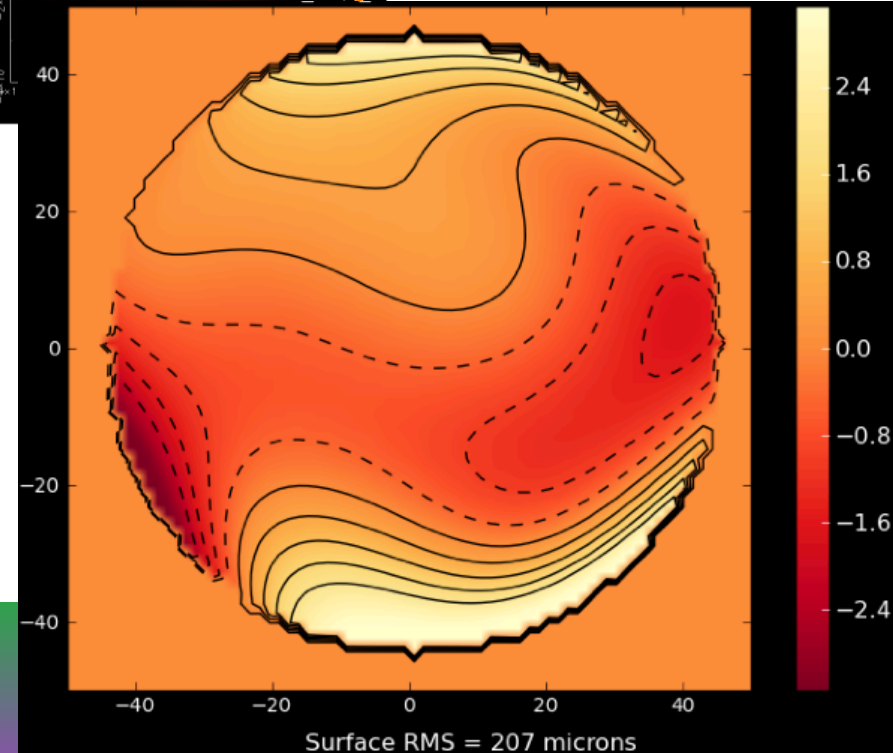
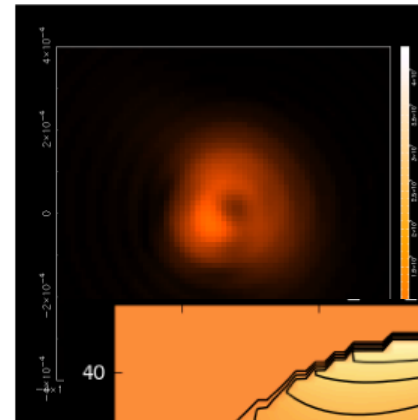
In Focus



- de-focus



+ de-focus

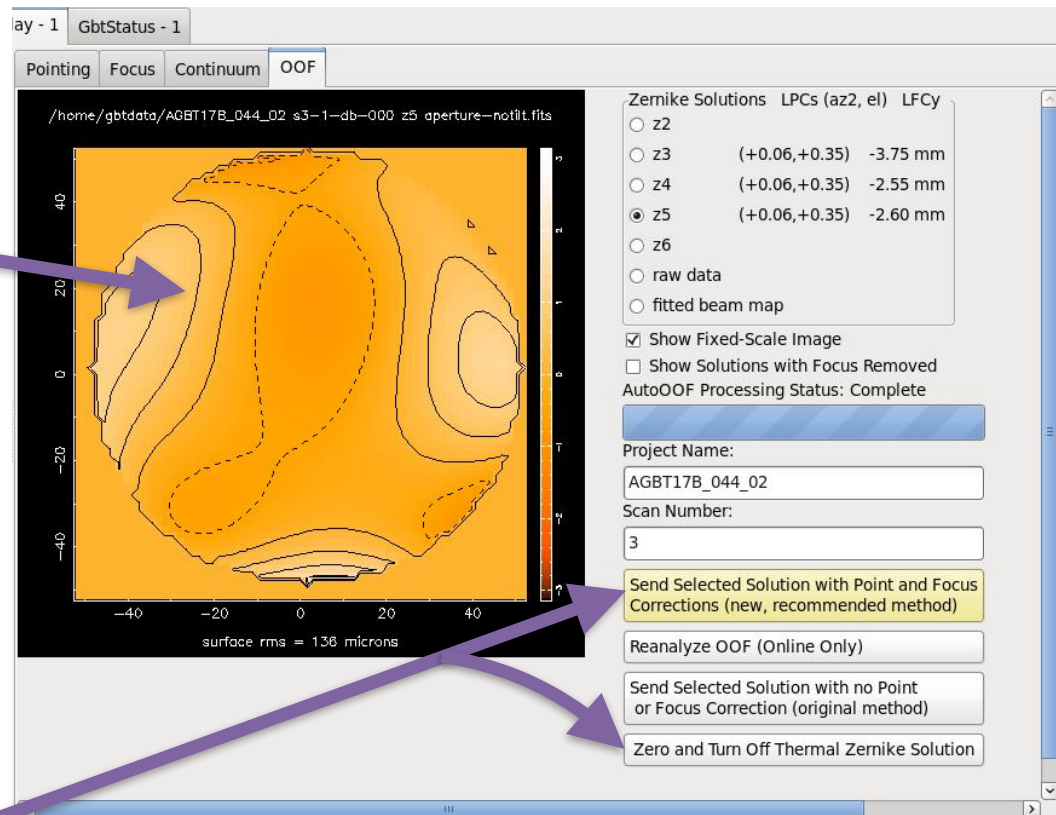


# AutoOOF Solutions

- **OOF image** - displays the measured  $\Delta$ 's from the current surface to the computed optimal surface. The algorithm takes raw data, fits Zernikes to that data, and produces the  $\Delta$  map (the combination of these Zernikes builds the surface corrections).

- $Z_{\text{tot}} = Z_{\text{grav}} + Z_{\text{thermal}}$

- OOF measures the  $z_{\text{tot}}$  at the elevation of your OOF target, refers to models for  $z_{\text{grav}}$  and then derives  $z_{\text{thermal}}$

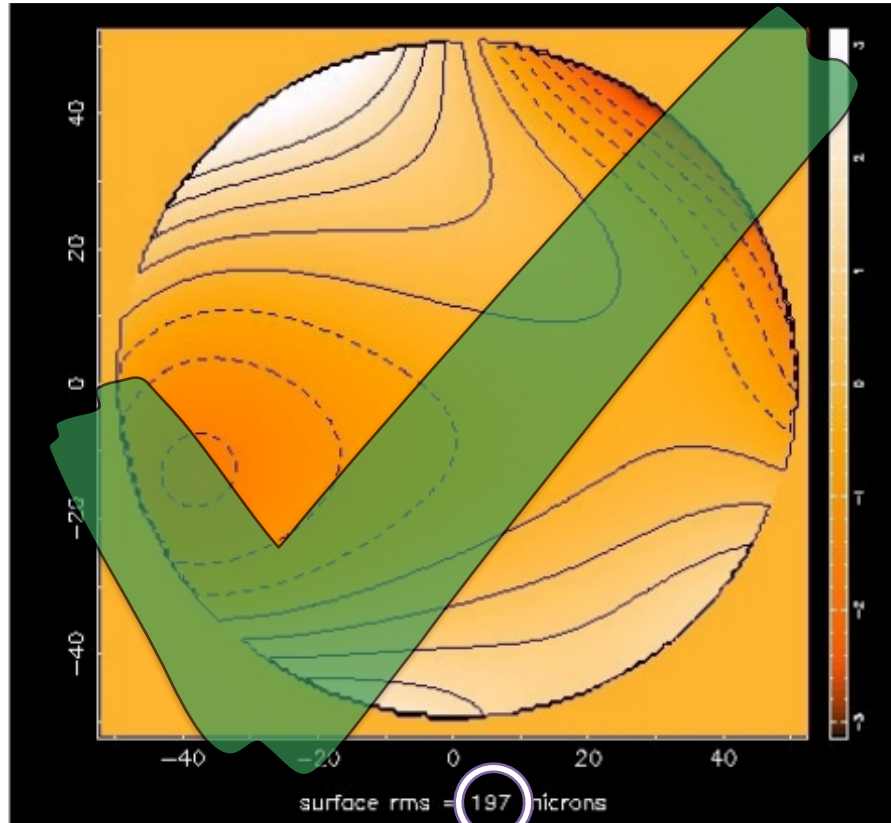


- $z_{\text{thermal}}$  is the difference between measured  $z_{\text{tot}}$  and the models ( $z_{\text{grav}}$ ).
  - Thus the **solutions** are often called “Zernike Thermal Solutions” or “Thermal Coefficients” for short

# AutoOOF Example Solutions

## Good solution

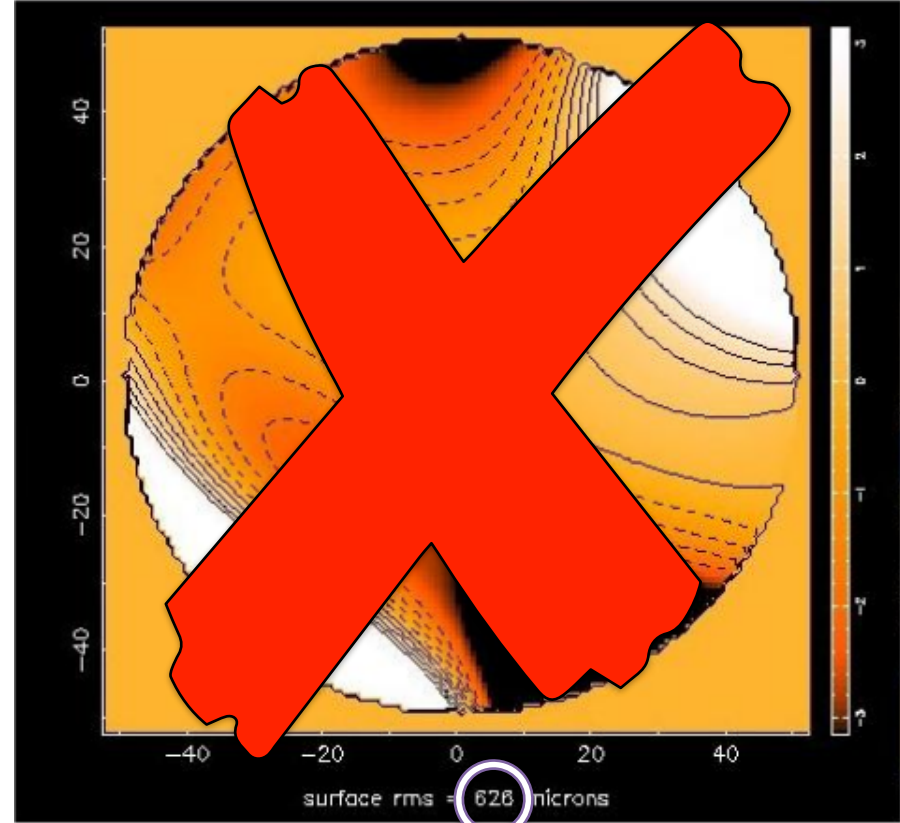
Broad features; low rms



Surface rms = 197  $\mu\text{m}$

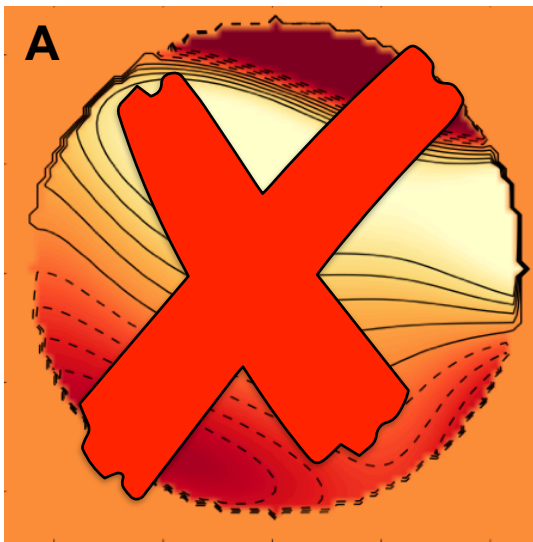
## Bad solution

Sharp features; rms >  $\sim 350\mu\text{m}$

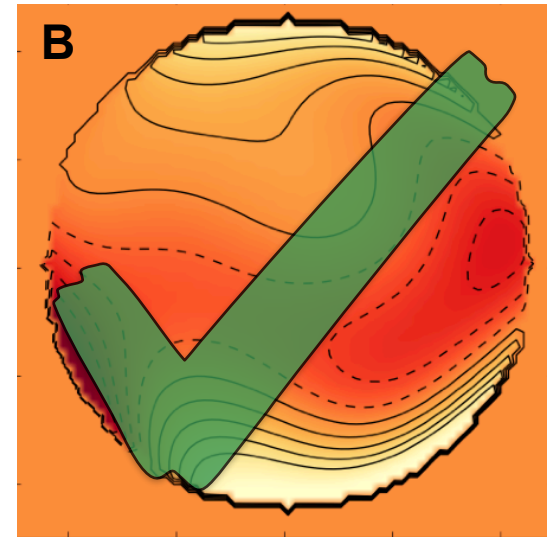


Surface rms = 626  $\mu\text{m}$

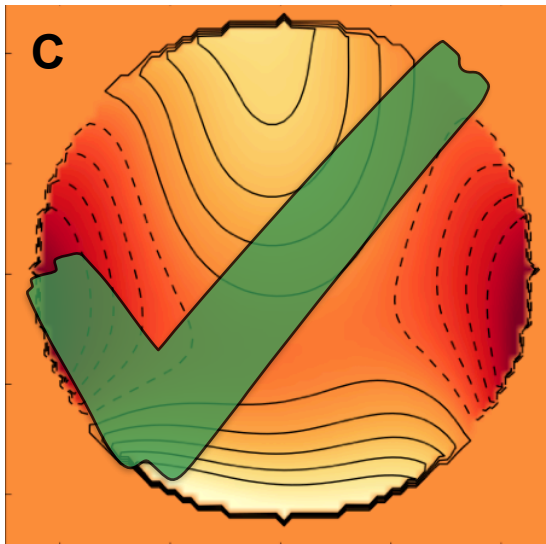
# Quiz Time



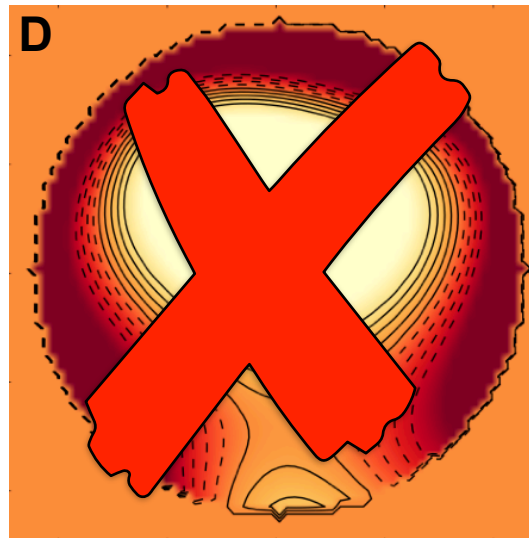
Surface rms = 638  $\mu\text{m}$



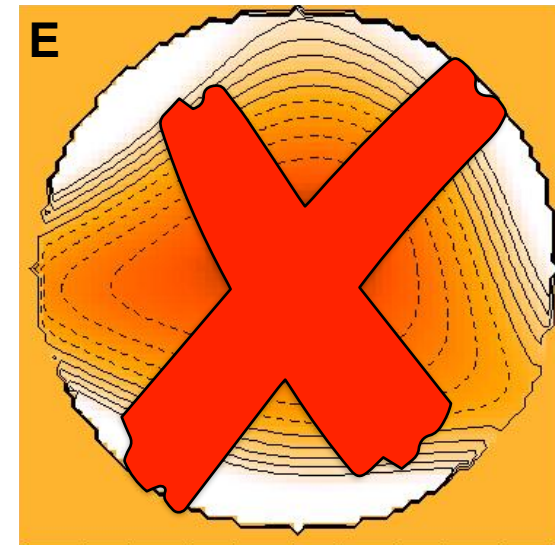
Surface rms = 207  $\mu\text{m}$



Surface rms = 226  $\mu\text{m}$



Surface rms = 879  $\mu\text{m}$

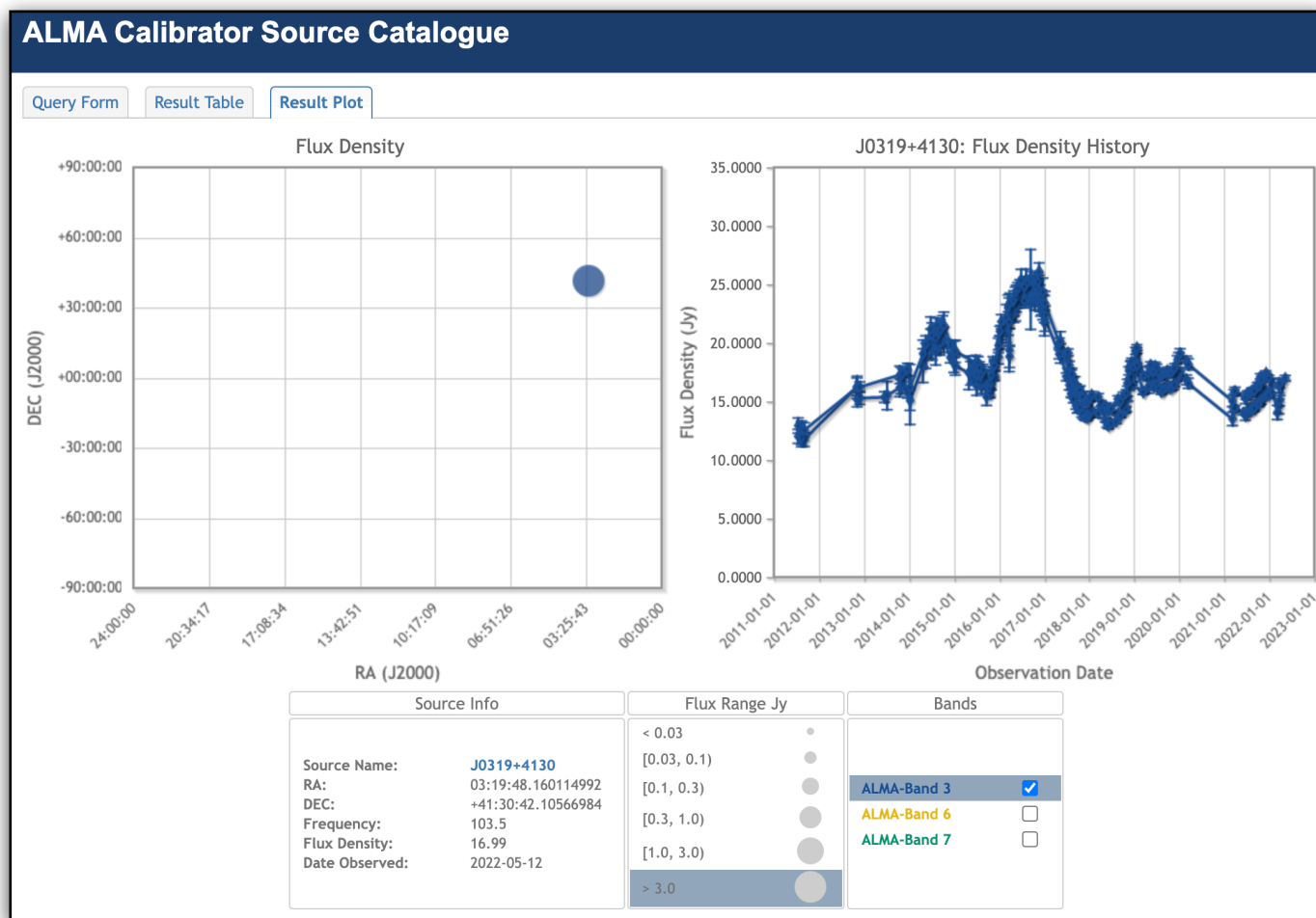


Surface rms = 438  $\mu\text{m}$



# How do you find a bright calibrator source?

## ALMA Calibrator Source Catalogue



<https://almascience.nrao.edu/sc>

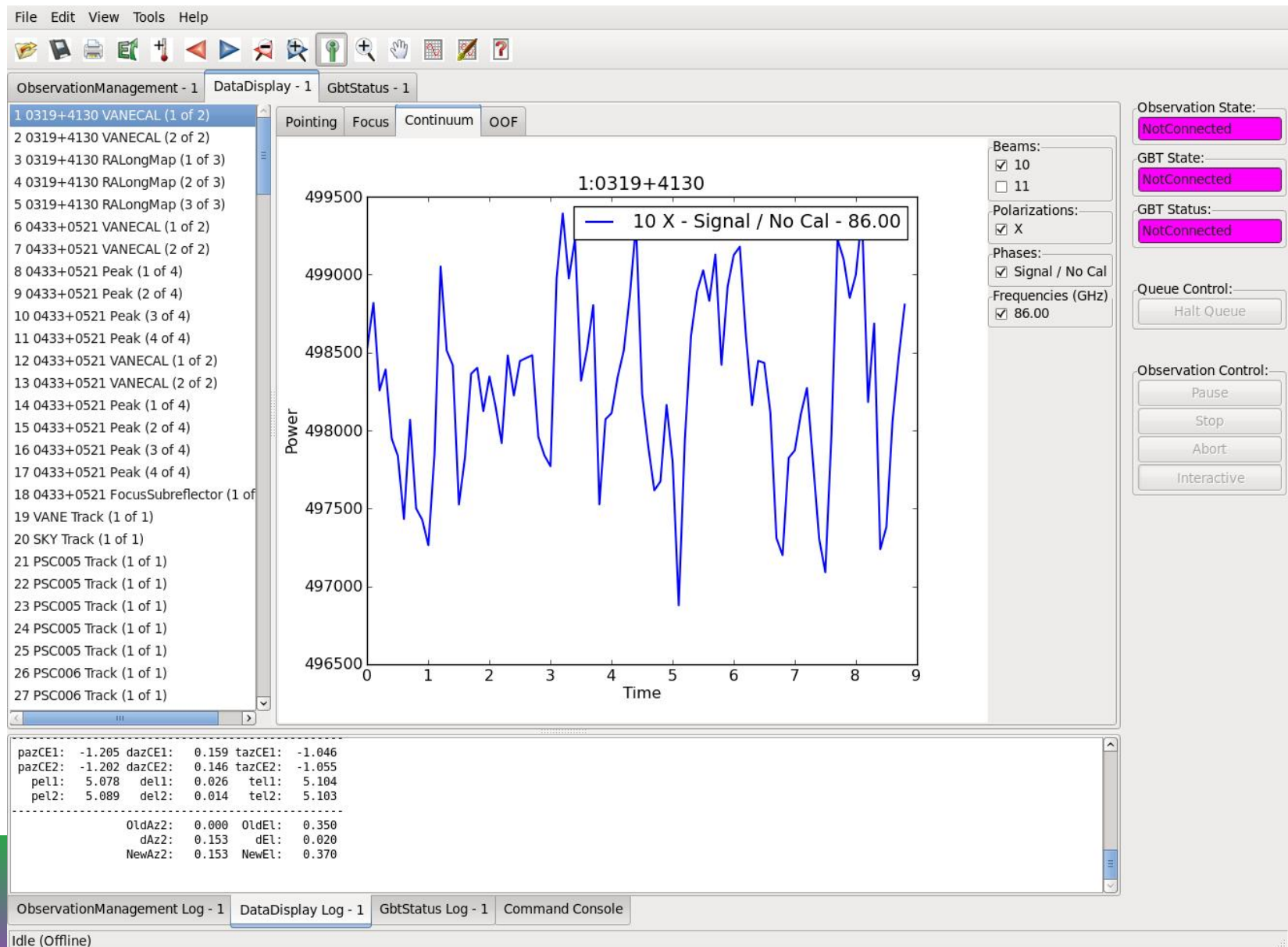
<https://almascience.eso.edu/sc>

<https://almascience.nao.ac.jp/sc>



# Example of Argus AutoOOF Observations:

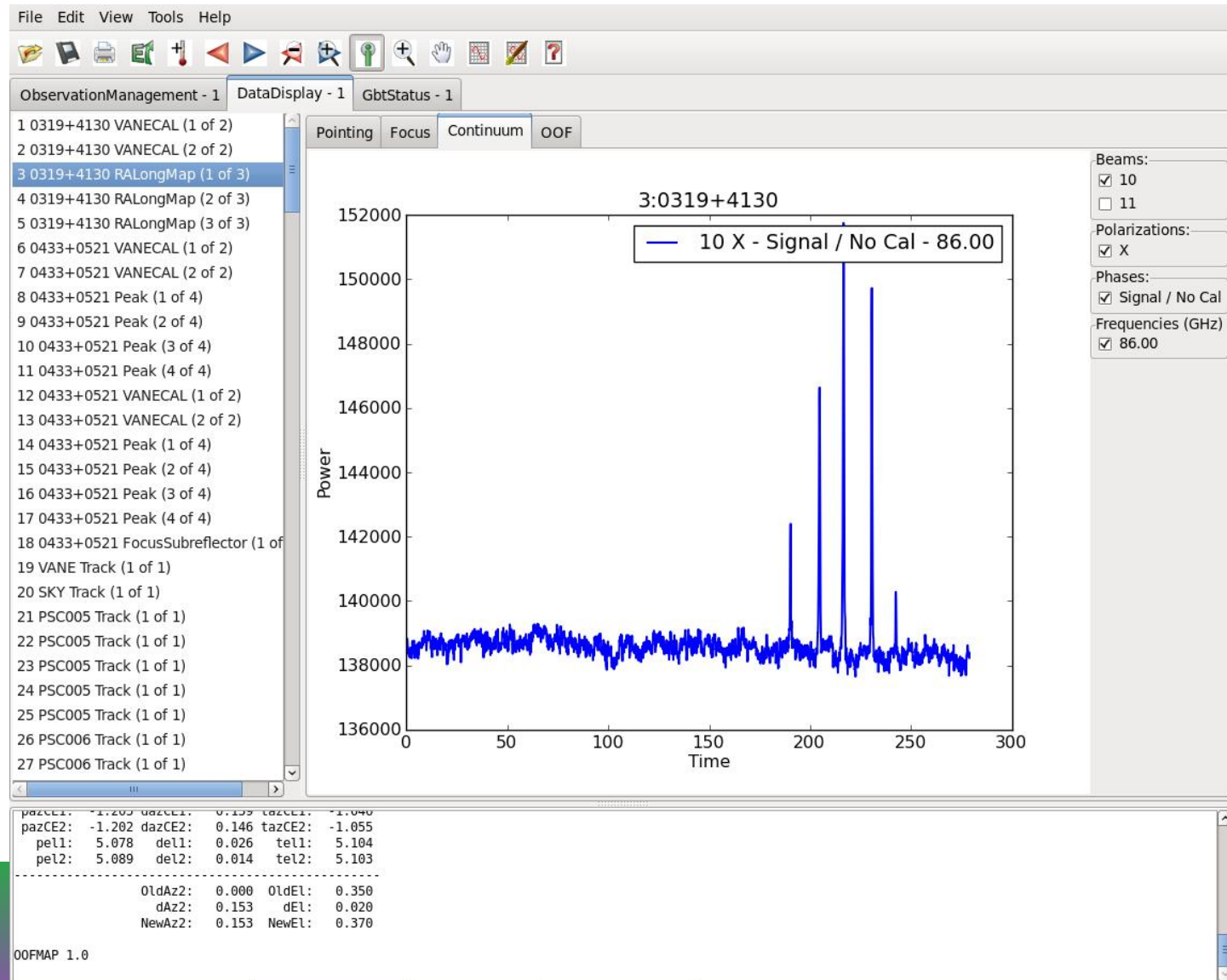
## Early Scans - setup



# Example of Argus AutoOOF Observations:

(scan 3) Argus OOF map-1 data - default focus

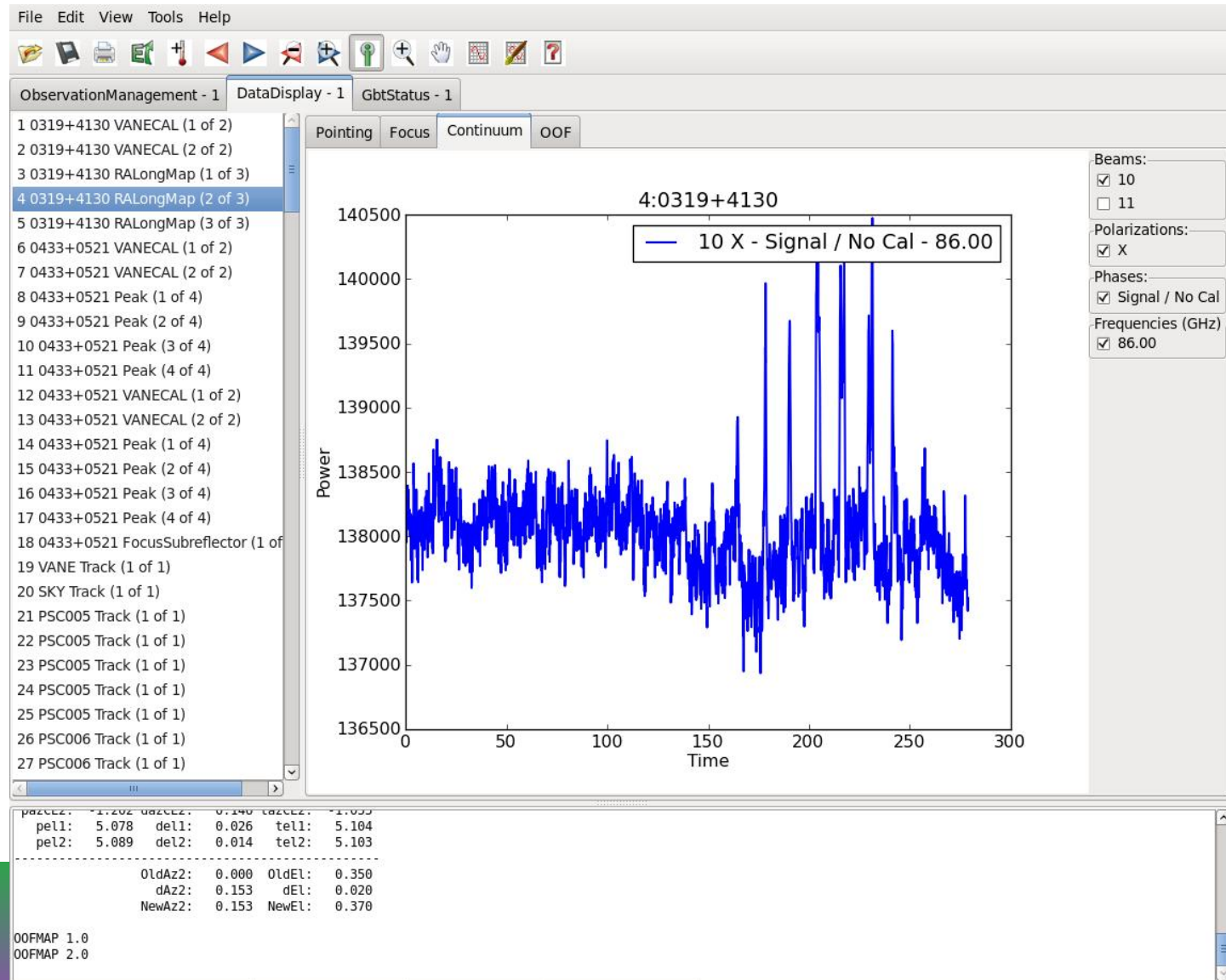
First map at default focus and should see source at good S/N.



# Example of Argus AutoOOF Observations:

(scan 4) Argus OOF map-2 data at +12mm

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



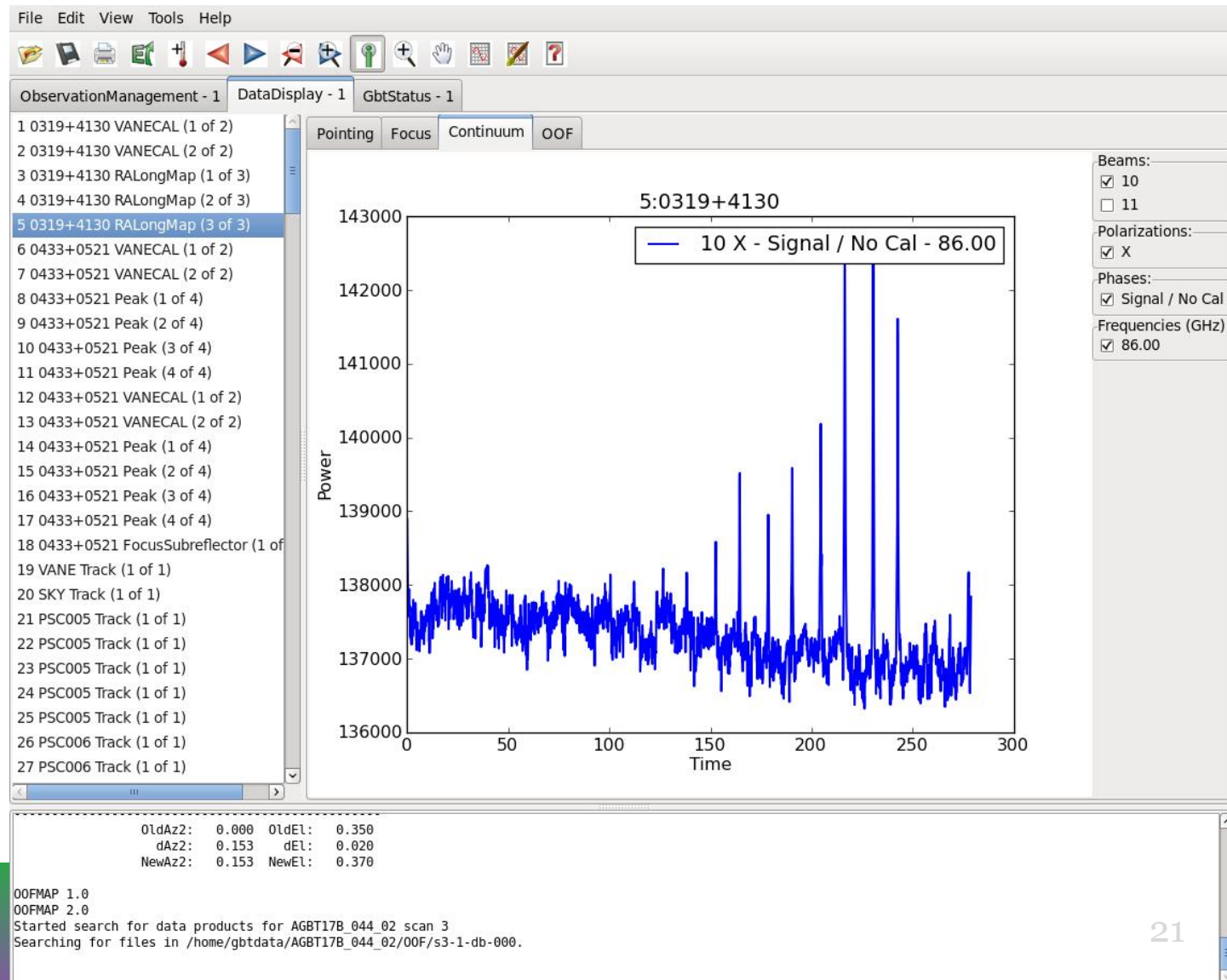


# Example of Argus AutoOOF Observations:

(scan 5) Argus OOF map-3 data at -12mm

3rd OOF map  
with focus at  
-12mm

peaks higher  
than +12mm  
map so focus  
LFC will be  
negative



# AutoOOF Solutions

20 min to complete

File Edit View Tools Help

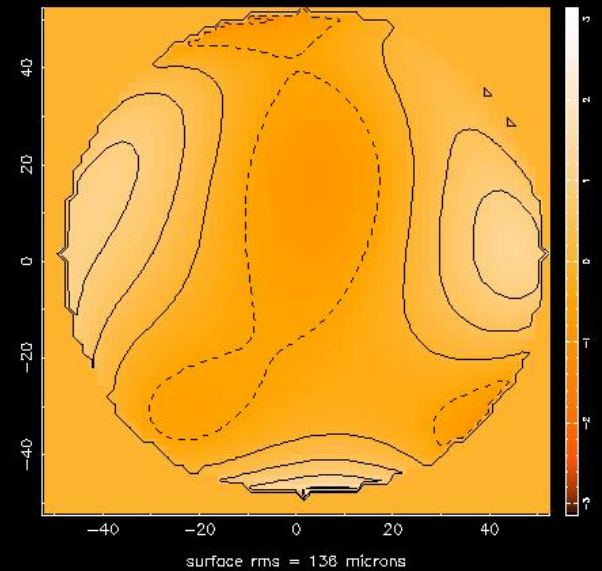


ObservationManagement - 1 DataDisplay - 1 GbtStatus - 1

- 1 0319+4130 VANECA1 (1 of 2)
- 2 0319+4130 VANECA1 (2 of 2)
- 3 0319+4130 RALongMap (1 of 3)
- 4 0319+4130 RALongMap (2 of 3)
- 5 0319+4130 RALongMap (3 of 3)
- 6 0433+0521 VANECA1 (1 of 2)
- 7 0433+0521 VANECA1 (2 of 2)
- 8 0433+0521 Peak (1 of 4)
- 9 0433+0521 Peak (2 of 4)
- 10 0433+0521 Peak (3 of 4)
- 11 0433+0521 Peak (4 of 4)
- 12 0433+0521 VANECA1 (1 of 2)
- 13 0433+0521 VANECA1 (2 of 2)
- 14 0433+0521 Peak (1 of 4)
- 15 0433+0521 Peak (2 of 4)
- 16 0433+0521 Peak (3 of 4)
- 17 0433+0521 Peak (4 of 4)
- 18 0433+0521 FocusSubreflector (1 of 1)
- 19 VANE Track (1 of 1)
- 20 SKY Track (1 of 1)
- 21 PSC005 Track (1 of 1)
- 22 PSC005 Track (1 of 1)
- 23 PSC005 Track (1 of 1)
- 24 PSC005 Track (1 of 1)
- 25 PSC005 Track (1 of 1)
- 26 PSC006 Track (1 of 1)
- 27 PSC006 Track (1 of 1)

Pointing Focus Continuum OOF

/home/gbtdata/AGBT17B\_044\_02 s3-1-db-000 z5 aperture-notilt.fits



Zernike Solutions LPCs (az2, el) LFCy

- ☐ z2
- ☐ z3 (+0.06,+0.35) -3.75 mm
- ☐ z4 (+0.06,+0.35) -2.55 mm
- ☒ z5 (+0.06,+0.35) -2.60 mm
- ☐ z6
- ☐ raw data
- ☐ fitted beam map

☒ Show Fixed-Scale Image

☐ Show Solutions with Focus Removed

AutoOOF Processing Status: Complete

Project Name:

AGBT17B\_044\_02

Scan Number:

3

Send Selected Solution with Point and Focus Corrections (new, recommended method)

Reanalyze OOF (Online Only)

Send Selected Solution with no Point or Focus Correction (original method)

Zero and Turn Off Thermal Zernike Solution

Observation State:

NotConnected

GBT State:

NotConnected

GBT Status:

NotConnected

Queue Control:

Halt Queue

Observation Control:

Pause

Stop

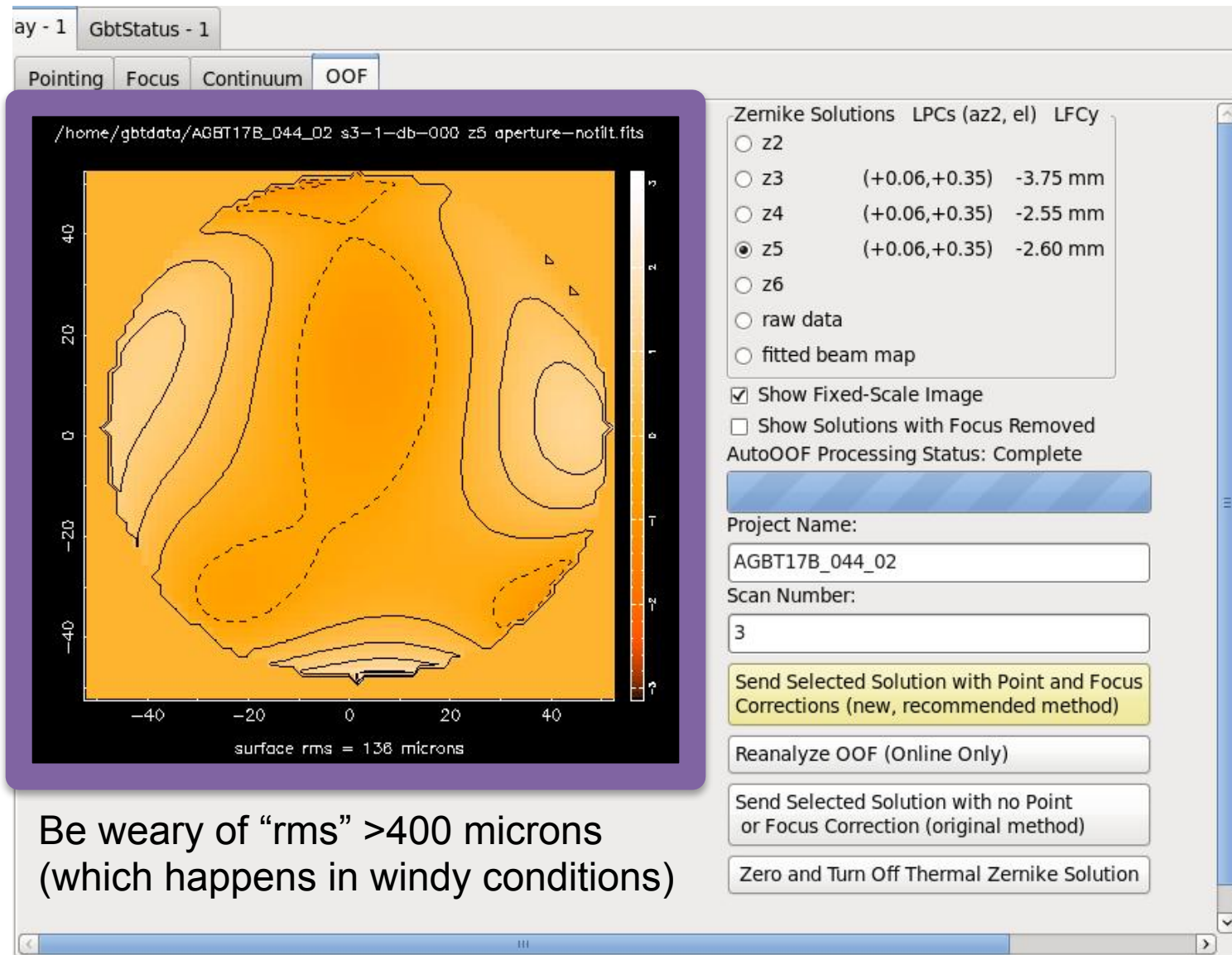
Abort

Interactive

OldAz2: 0.000 OldEl: 0.350  
dAz2: 0.153 dEl: 0.020  
NewAz2: 0.153 NewEl: 0.370

OOFMAP 1.0  
OOFMAP 2.0  
Started search for data products for AGBT17B\_044\_02 scan 3  
Searching for files in /home/gbtdata/AGBT17B\_044\_02/OOF/s3-1-db-000.

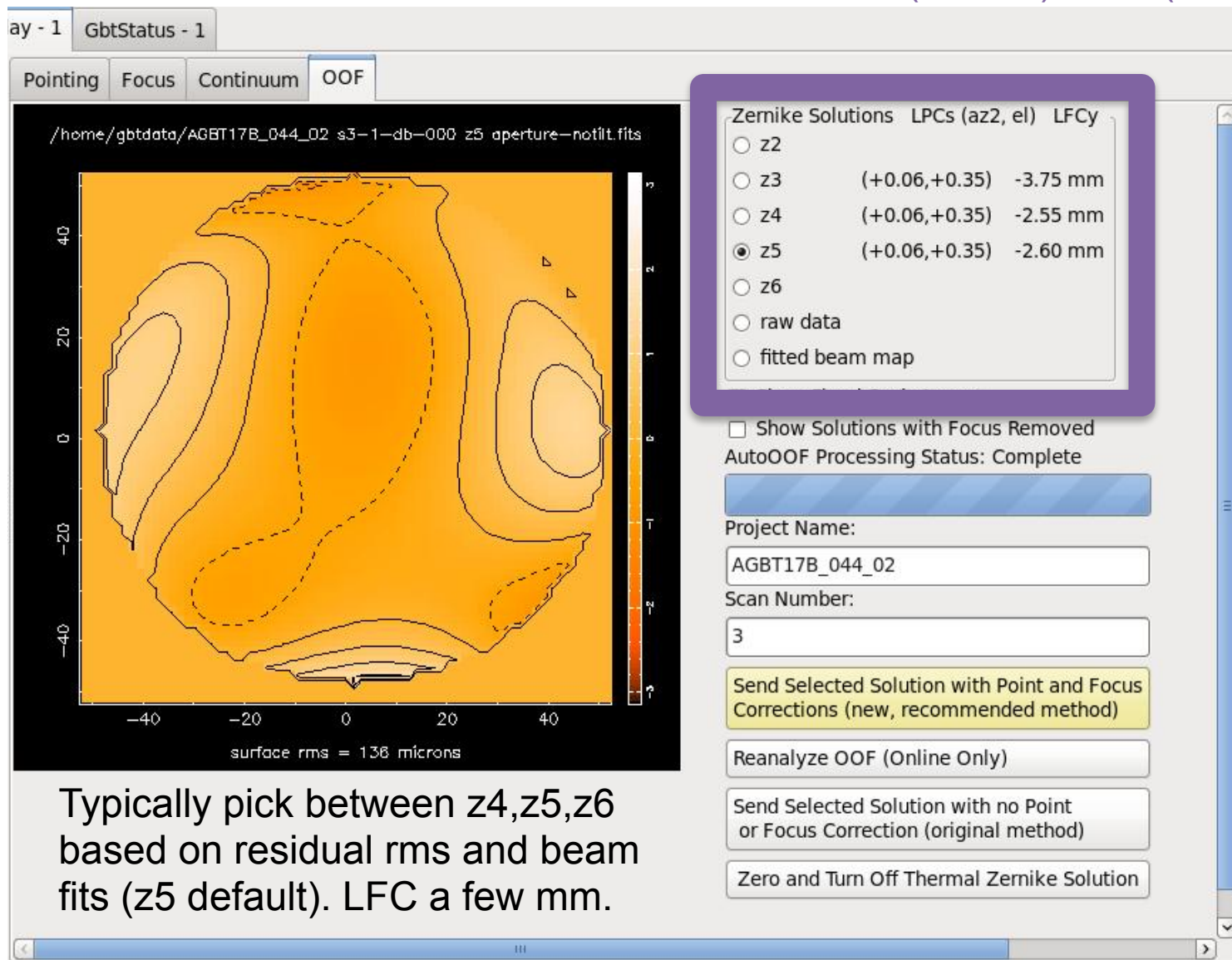
ObservationManagement Log - 1 DataDisplay Log - 1 GbtStatus Log - 1 Command Console



Be weary of “rms” >400 microns  
(which happens in windy conditions)

# AutoOOF Solutions

Zernike, LPCs (arcmin), LFC (mm)



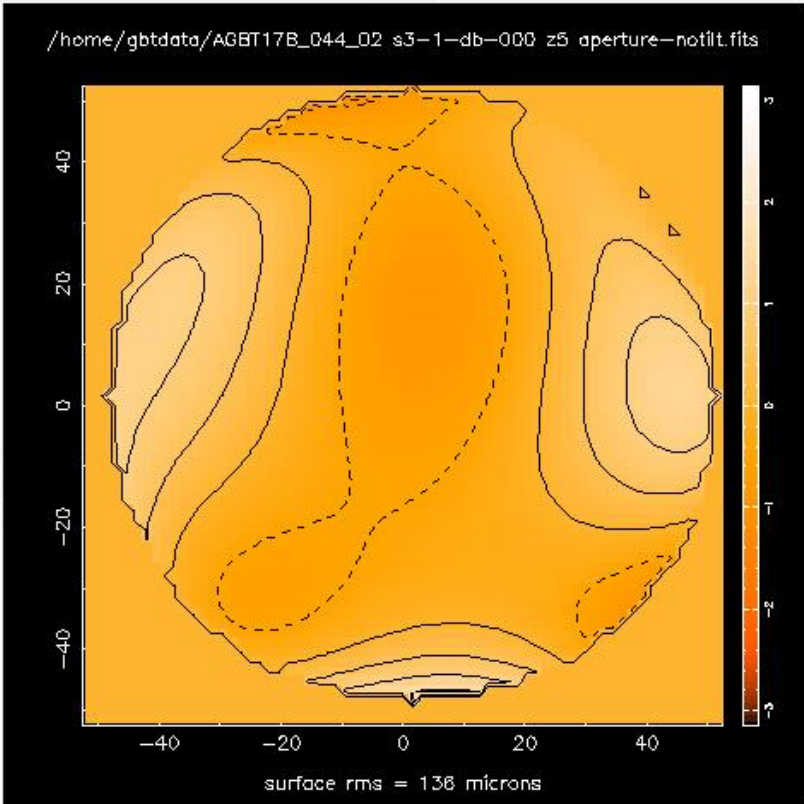
Typically pick between z4,z5,z6 based on residual rms and beam fits (z5 default). LFC a few mm.



ay - 1 GbtStatus - 1

Pointing Focus Continuum **OOF**

/home/gbtdata/AGBT17B\_044\_02 s3-1-db-000 z5 aperture-notilt.fits



surface rms = 138 microns

Zernike Solutions LPCs (az2, el) LFCy

- ☐ z2
- ☐ z3 (+0.06,+0.35) -3.75 mm
- ☐ z4 (+0.06,+0.35) -2.55 mm
- ☒ z5 (+0.06,+0.35) -2.60 mm
- ☐ z6
- ☐ raw data
- ☐ fitted beam map

☒ Show Fixed-Scale Image  
☐ Show Solutions with Focus Removed

AutoOOF Processing Status: Complete

Project Name:  
AGBT17B\_044\_02

Scan Number:  
3

**Send Selected Solution with Point and Focus Corrections (new, recommended method)**

Reanalyze OOF (Online Only)

Send Selected Solution with no Point or Focus Correction (original method)

Zero and Turn Off Thermal Zernike Solution

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

# Cleo Status Window

File Launch Help

Status **Error** State **Running** LST **07:09:19** UTC **07:18:45**

Device	Status	State
Antenna	Info	Running
LO1	clear	Running
IFRack	clear	Running
ConverterRack	clear	Running
SwitchingSignalSelector	clear	Running
Measurements	clear	Running
ActiveSurface	clear	Running
QuadrantDetector	<b>Error</b>	Running
VEGAS	clear	Running
RcvrArray75_115	clear	Running
IFManager	clear	Running

Source **CORE06** Scan # **65**

Project **AGBT16B\_119\_02** SS Master **VEGAS**

Start **07:17:02** Length **120.0**

Countdown **---:--** Remaining **00:00:18**

Observer **Youngmin Seo**

Obs. Type **LINE** Switching **FSW12NOCAL**

Proc Name **Track** Sequence **1 / 1**

Rest Freq **89188.5247** Velocity **/**

Frame **KinematicLSR** Vel Def **Radio**

Time to Set **04:19:29** Encoder **---**

Indicated Azimuth **266.84786** Elevation **53.43131**

Commanded Azimuth **266.84780** Elevation **53.43125**

Rate (°/min) **10.9** **-11.4**

Difference **-0.00006** **-0.00006**

Servo Err (") **-0.3** **-0.1**

On Source **Axis Fault/E-Stop**

Az LPC **-0.0801** EI LPC **0.0047**

X FC **0.0** Y FC **0.6** Z FC **0.0** Xt FC **0.00** Yt FC **0.00** Zt FC **0.00** **LFC** **FOC**

Config Model **Guiding**

Model 5r - Latest Coord Mode **J2000**

0 5 10 15 20 25 30 Temp **-5.9** Wind:2 Temp:2a V(m/s) T(C)

Dynamic Corrections

**DC Pointing** **DC Focus** Az1 **0.00** Az2 **0.05** EI **0.07** Focus **-13.91**

**ActiveSurface**

Num Disabled **37** **OOF Zernike Mode** **Sim Mode**

Cmd RMS **33.693** **Zero Offsets** **real**

Peak Resid **34625** **FEM Model** **Ctrl Mode**

Cmd IQ RMS **37.065** **Zernike Coeff** **Enabled**

Cmd Resid **160** **Z Thermal Coeff**

**Random Offsets**

**VEGAS**

J1	-19.33	J5	-18.76	J9	-19.81	J13	-19.48
J2	-19.73	J6	-19.63	J10	-19.97	J14	-19.95
J3	-19.84	J7	-19.12	J11	-19.58	J15	-19.53
J4	-20.29	J8	-19.63	J12	-19.76	J16	-19.46

Auto Scroll **Off** **10**

Phase Table... Other Devices **---** Retrace IF

Az,EI LPCs

Focus YFC

Active Surface ON with Thermal corrections from OOF

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

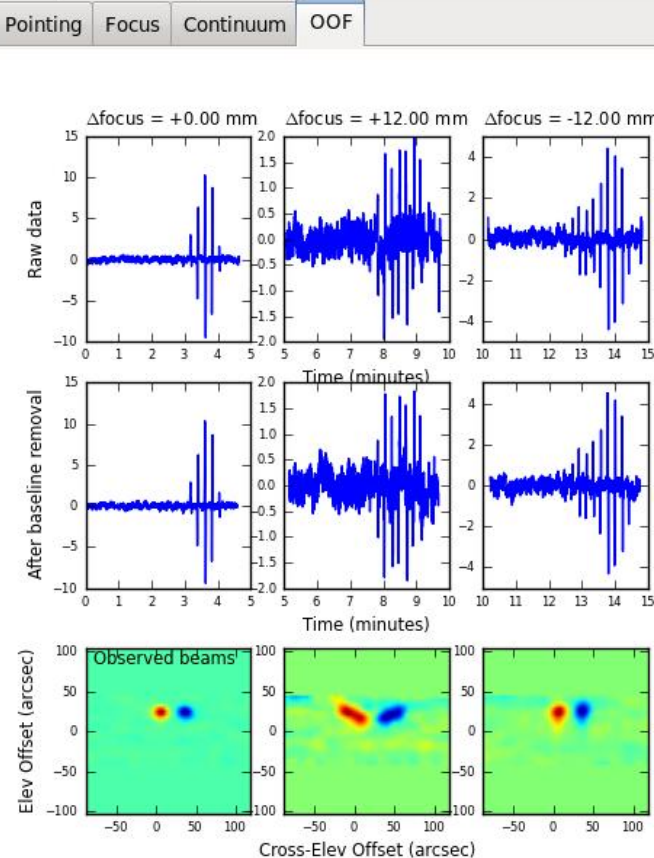


File Edit View Tools Help



ObservationManagement - 1	DataDisplay - 1	GbtStatus - 1
---------------------------	-----------------	---------------

- 1 0319+4130 VANECAAL (1 of 2)
- 2 0319+4130 VANECAAL (2 of 2)
- 3 0319+4130 RALongMap (1 of 3)
- 4 0319+4130 RALongMap (2 of 3)
- 5 0319+4130 RALongMap (3 of 3)
- 6 0433+0521 VANECAAL (1 of 2)
- 7 0433+0521 VANECAAL (2 of 2)
- 8 0433+0521 Peak (1 of 4)
- 9 0433+0521 Peak (2 of 4)
- 10 0433+0521 Peak (3 of 4)
- 11 0433+0521 Peak (4 of 4)
- 12 0433+0521 VANECAAL (1 of 2)
- 13 0433+0521 VANECAAL (2 of 2)
- 14 0433+0521 Peak (1 of 4)
- 15 0433+0521 Peak (2 of 4)
- 16 0433+0521 Peak (3 of 4)
- 17 0433+0521 Peak (4 of 4)
- 18 0433+0521 FocusSubreflector (1 of 1)
- 19 VANE Track (1 of 1)
- 20 SKY Track (1 of 1)
- 21 PSC005 Track (1 of 1)
- 22 PSC005 Track (1 of 1)
- 23 PSC005 Track (1 of 1)
- 24 PSC005 Track (1 of 1)
- 25 PSC005 Track (1 of 1)
- 26 PSC006 Track (1 of 1)
- 27 PSC006 Track (1 of 1)



Zernike Solutions	LPCs (az2, el)	LFCy
<input type="radio"/> z2		
<input type="radio"/> z3	(+0.06,+0.35)	-3.75 mm
<input type="radio"/> z4	(+0.06,+0.35)	-2.55 mm
<input type="radio"/> z5	(+0.06,+0.35)	-2.60 mm
<input type="radio"/> z6		
<input checked="" type="radio"/> raw data		
<input type="radio"/> fitted beam map		

☒ Show Fixed-Scale Image  
☐ Show Solutions with Focus Removed  
AutoOOF Processing Status: Complete

Project Name:

AGBT17B\_044\_02

Scan Number:

3

Send Selected Solution with Point and Focus Corrections (new, recommended method)

Reanalyze OOF (Online Only)

Send Selected Solution with no Point  
or Focus Correction (original method)

Zero and Turn Off Thermal Zernike Solution

Observation State: NotConnected

GBT State: NotConnected

GBT Status: NotConnected

Queue Control:

Observation Control:—

- Pause
- Stop
- Abort
- Interactive

OldAz2:	0.000	OldEl:	0.350
dAz2:	0.153	dEl:	0.020
NewAz2:	0.153	NewEl:	0.370

```
DOFMAP 1.0
DOFMAP 2.0
Started search for data products for AGBT17B_044_02 scan 3
Searching for files in /home/gbtdata/AGBT17B_044_02/DOF/s3-1-db-000.
```



# AutoOOF Beam Fits

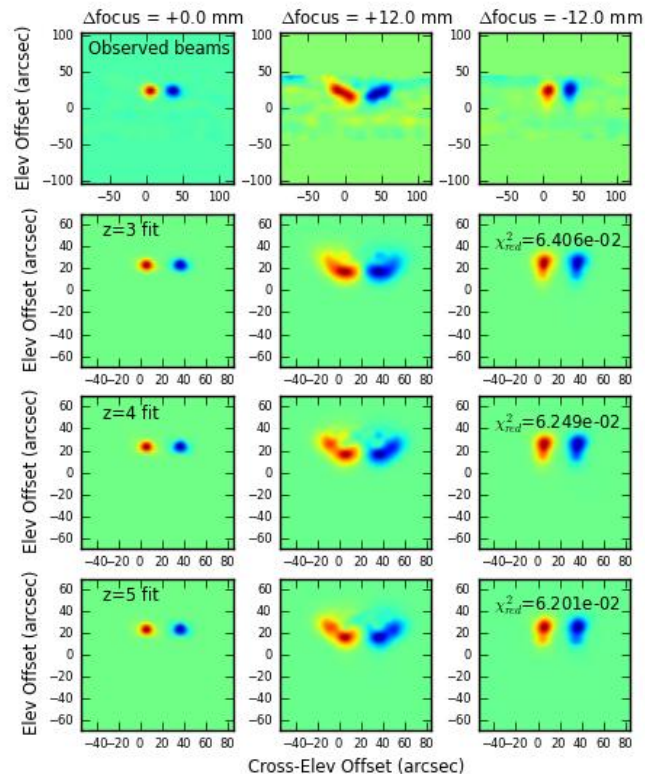
File Edit View Tools Help



ObservationManagement - 1 DataDisplay - 1 GbtStatus - 1

- 1 0319+4130 VANECA (1 of 2)
- 2 0319+4130 VANECA (2 of 2)
- 3 0319+4130 RALongMap (1 of 3)
- 4 0319+4130 RALongMap (2 of 3)
- 5 0319+4130 RALongMap (3 of 3)
- 6 0433+0521 VANECA (1 of 2)
- 7 0433+0521 VANECA (2 of 2)
- 8 0433+0521 Peak (1 of 4)
- 9 0433+0521 Peak (2 of 4)
- 10 0433+0521 Peak (3 of 4)
- 11 0433+0521 Peak (4 of 4)
- 12 0433+0521 VANECA (1 of 2)
- 13 0433+0521 VANECA (2 of 2)
- 14 0433+0521 Peak (1 of 4)
- 15 0433+0521 Peak (2 of 4)
- 16 0433+0521 Peak (3 of 4)
- 17 0433+0521 Peak (4 of 4)
- 18 0433+0521 FocusSubreflector (1 of 1)
- 19 VANE Track (1 of 1)
- 20 SKY Track (1 of 1)
- 21 PSC005 Track (1 of 1)
- 22 PSC005 Track (1 of 1)
- 23 PSC005 Track (1 of 1)
- 24 PSC005 Track (1 of 1)
- 25 PSC005 Track (1 of 1)
- 26 PSC006 Track (1 of 1)
- 27 PSC006 Track (1 of 1)

Pointing Focus Continuum OOF



Zernike Solutions LPCs (az2, el) LFCy

- ☐ z2
- ☐ z3 (+0.06,+0.35) -3.75 mm
- ☐ z4 (+0.06,+0.35) -2.55 mm
- ☐ z5 (+0.06,+0.35) -2.60 mm
- ☐ z6
- ☐ raw data

☒ fitted beam map

☒ Show Fixed-Scale Image

☐ Show Solutions with Focus Removed

AutoOOF Processing Status: Complete

Project Name:

AGBT17B\_044\_02

Scan Number:

3

Send Selected Solution with Point and Focus Corrections (new, recommended method)

Reanalyze OOF (Online Only)

Send Selected Solution with no Point or Focus Correction (original method)

Zero and Turn Off Thermal Zernike Solution

Observation State:

NotConnected

GBT State:

NotConnected

GBT Status:

NotConnected

Queue Control:

Halt Queue

Observation Control:

Pause

Stop

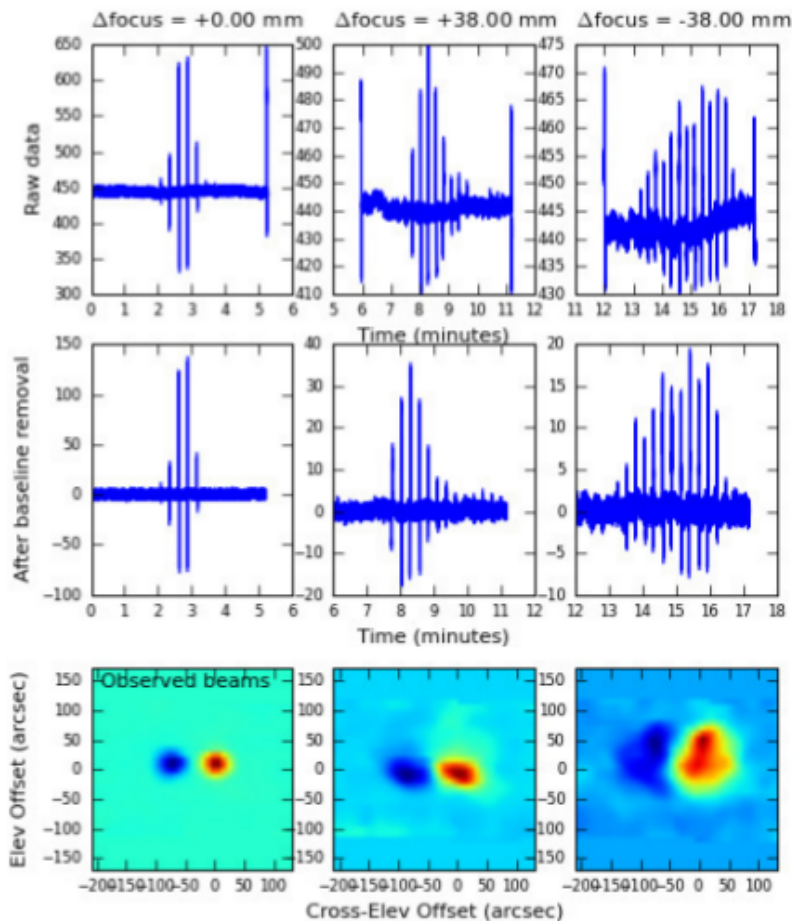
Abort

Interactive

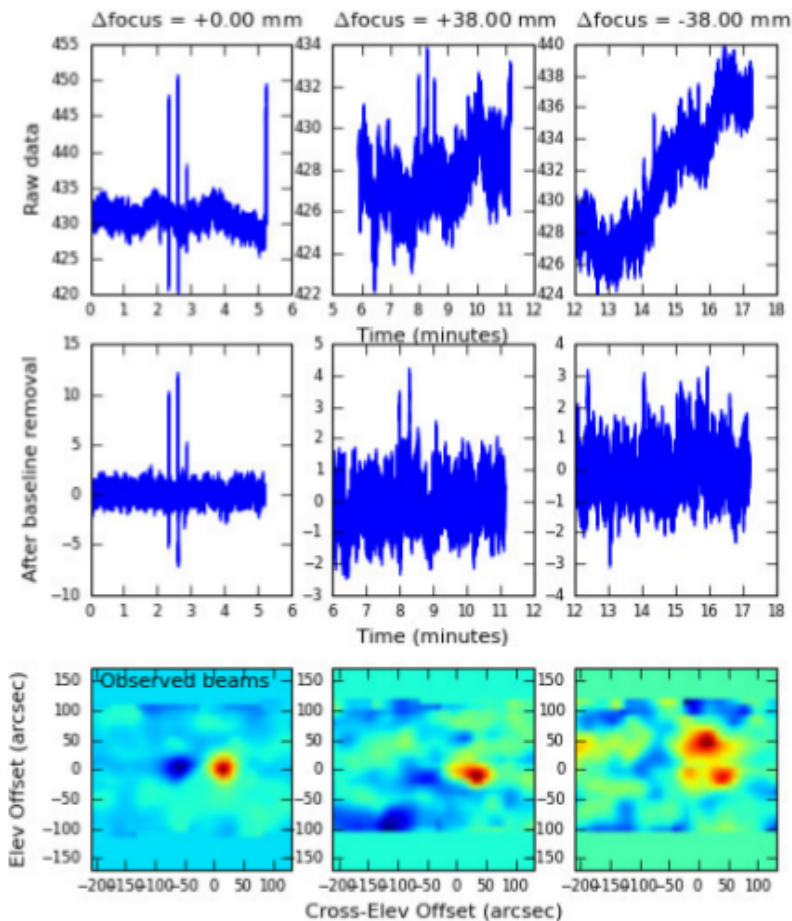
OldAz2: 0.000 OldEL: 0.350  
dAz2: 0.153 dEL: 0.020  
NewAz2: 0.153 NewEL: 0.370

OOFMAP 1.0  
OOFMAP 2.0  
Started search for data products for AGBT17B\_044\_02 scan 3  
Searching for files in /home/gbtdata/AGBT17B\_044\_02/OOF/s3-1-db-000.

# 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.

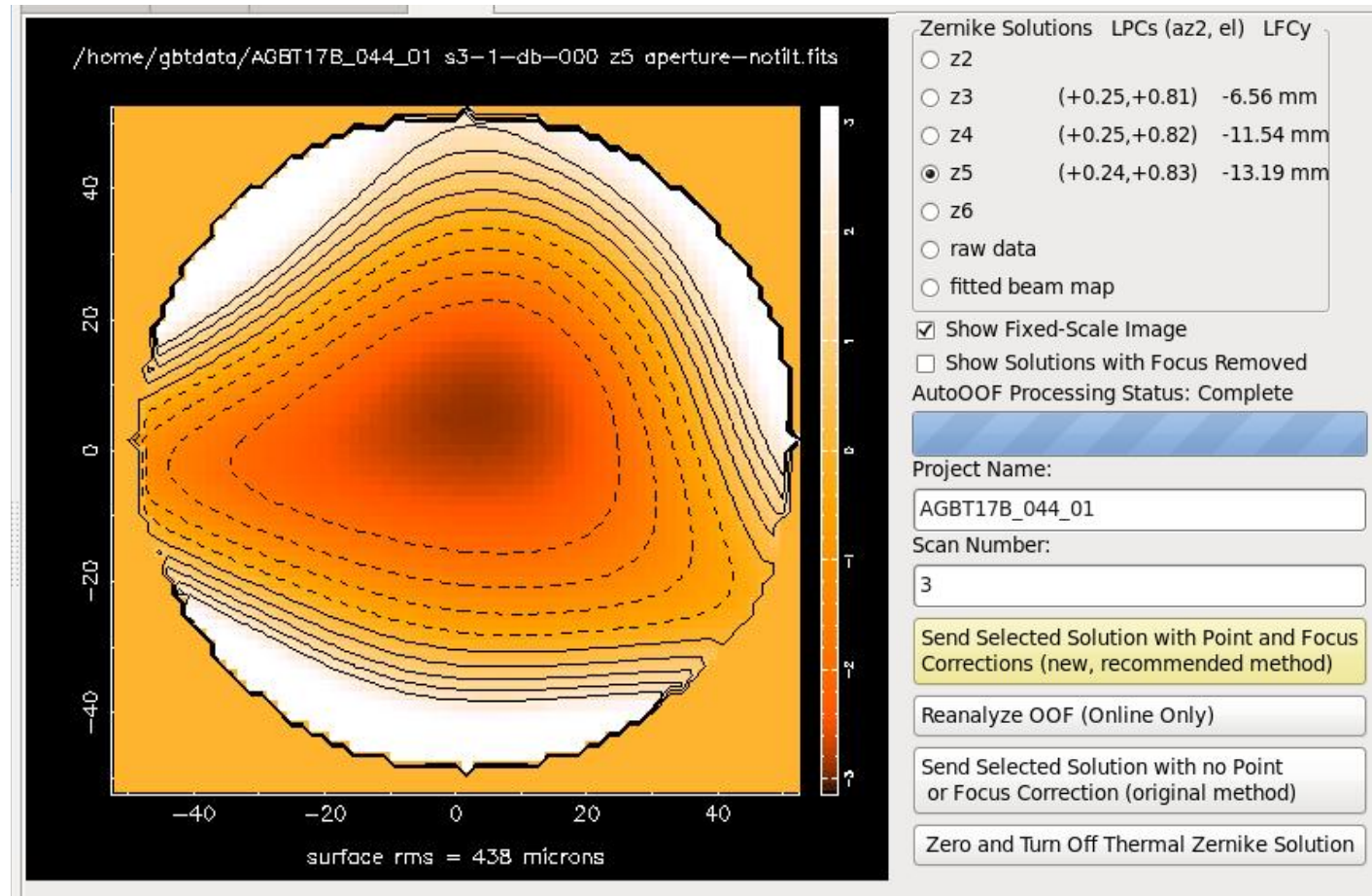


# Example of a Bad AutoOOF Solution

In this case observations were done in the keyhole at  $>85^\circ$  and OOF “rms”  $438\text{ }\mu\text{m}$  with a large implied focus and EL pointing offset.

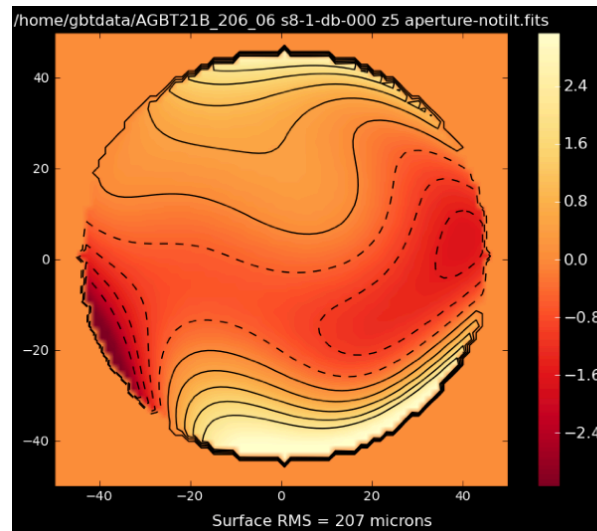
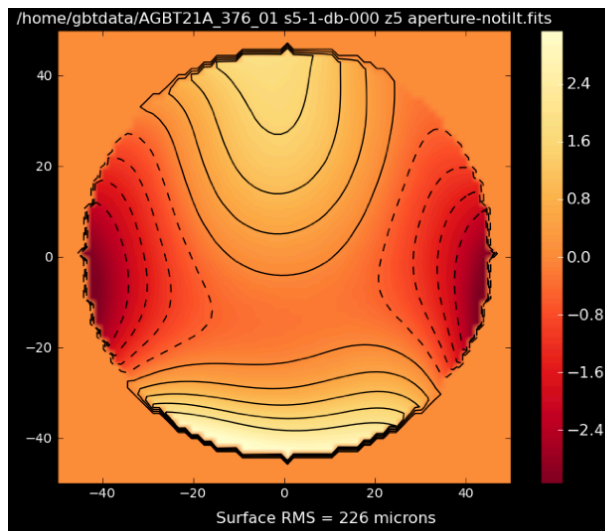
Solution with large rms  $>400\text{ }\mu\text{m}$  should not be used.

Check the raw data and fitted beam maps.

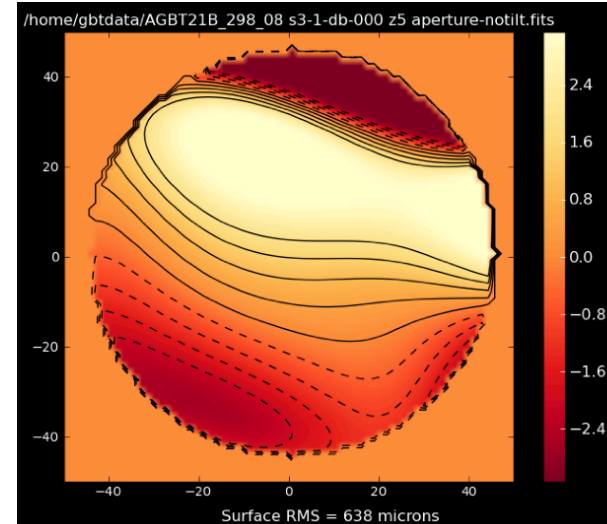
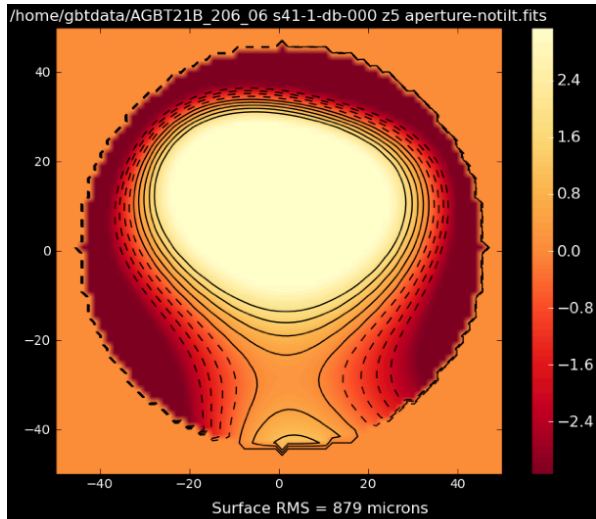
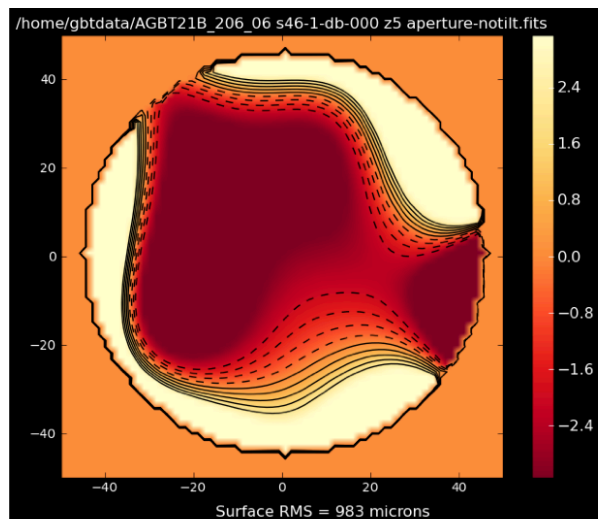




Good

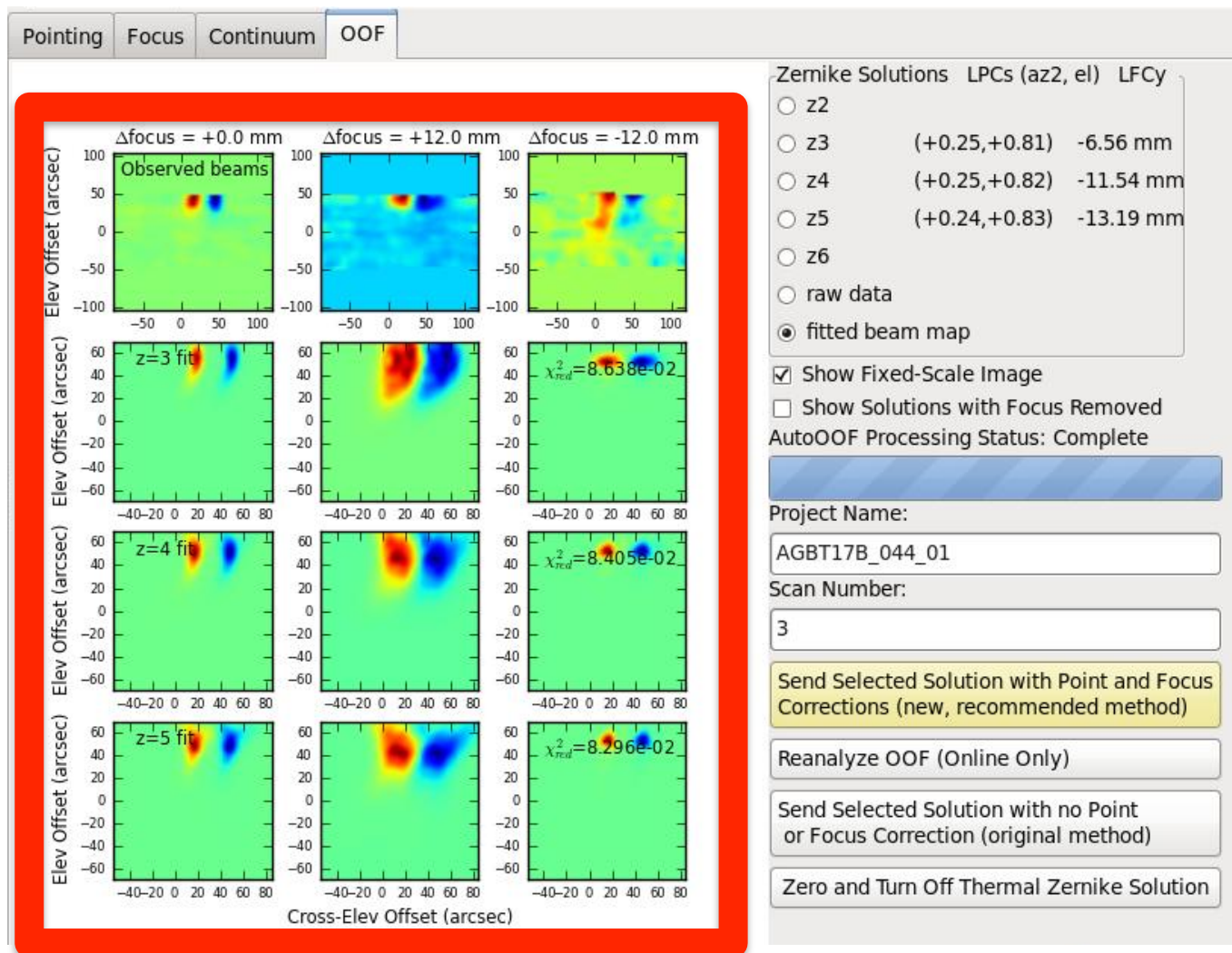


Bad



# Beam Maps of Example Bad OOF

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



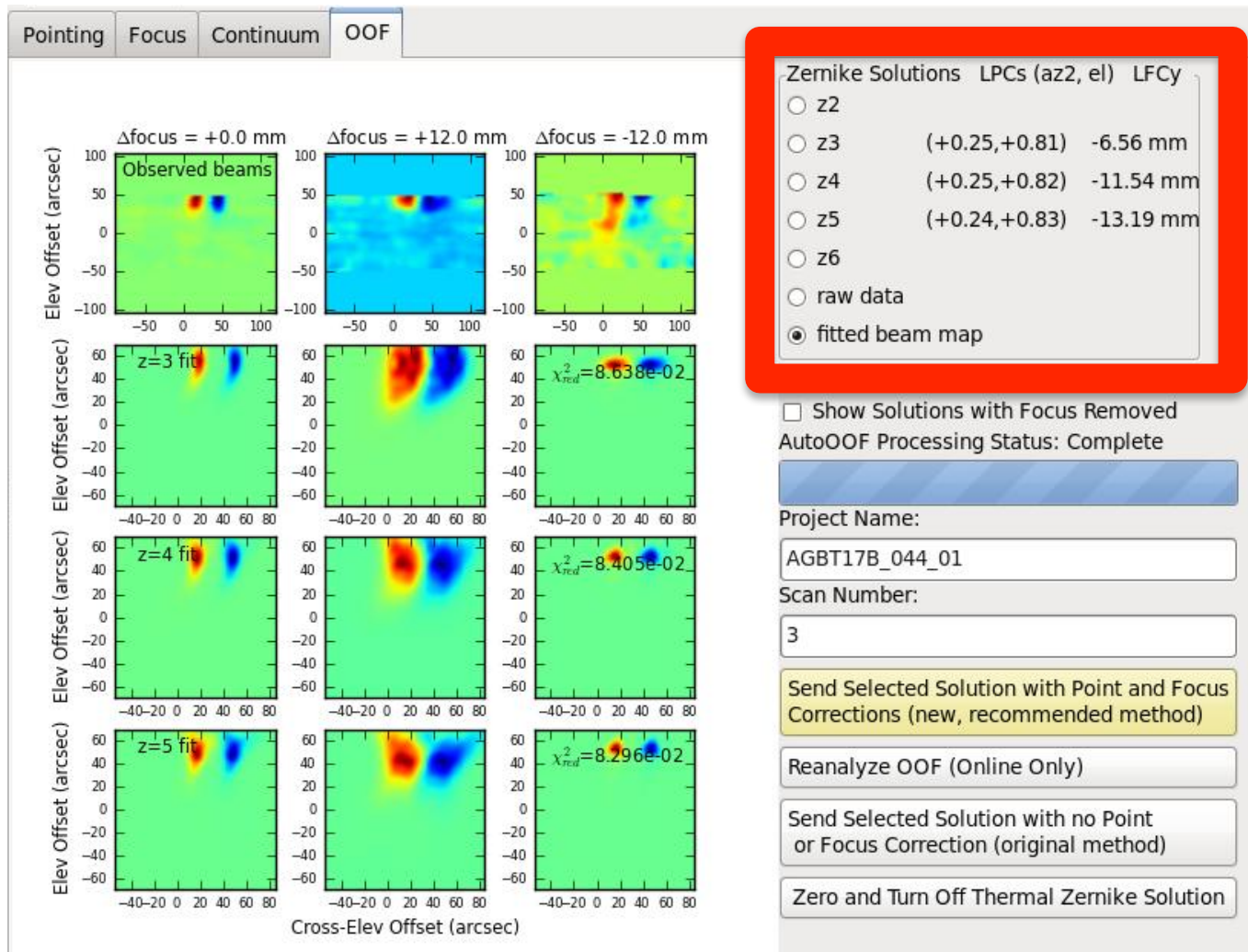


# Beam Maps of Example Bad OOF

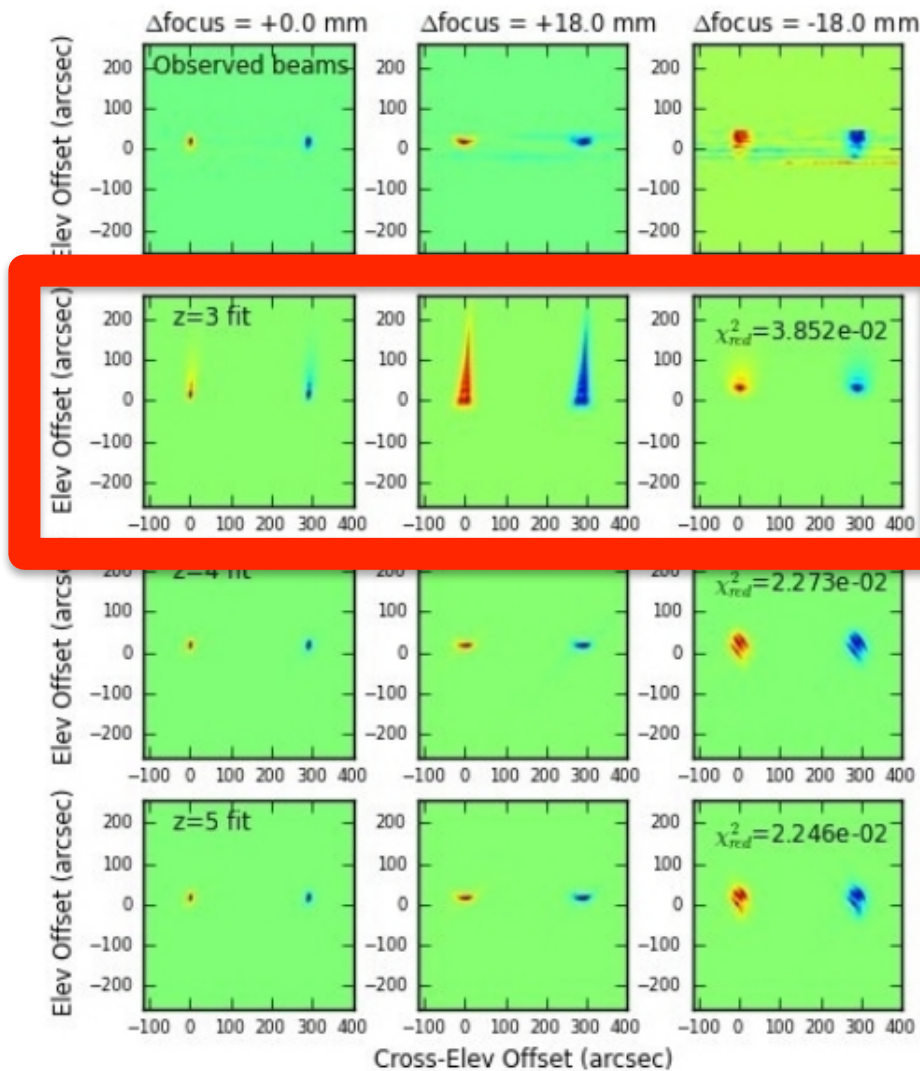
The “observed” beams should not be streaks or very elongated. This can happen in windy conditions.

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. Redo.



# Another Bad OOF (avoid Z3 Solution)



Zernike Solutions	LPCs (az2, el)	LFCy
<input type="radio"/> z2		
<input type="radio"/> z3	(+0.04,+1.00)	-22.63 mm
<input type="radio"/> z4	(-0.05,+0.17)	-8.41 mm
<input type="radio"/> z5	(-0.09,+0.12)	-6.11 mm
<input type="radio"/> z7	(Unk,Unk)	Unk mm
<input type="radio"/> raw data		
<input checked="" type="radio"/> fitted beam map		

Figure 5.10: The AutoOOF fitted beam maps (left). The observed beam maps are plotted on the top row with the z3, z4 and z5 fits to the observed beams plotted below. The z3 solution (2<sup>nd</sup> 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).

Take the solution that has better fitted beam maps and reasonable values. In this case z5.



# Bad OOF with ARGUS? What do you do?

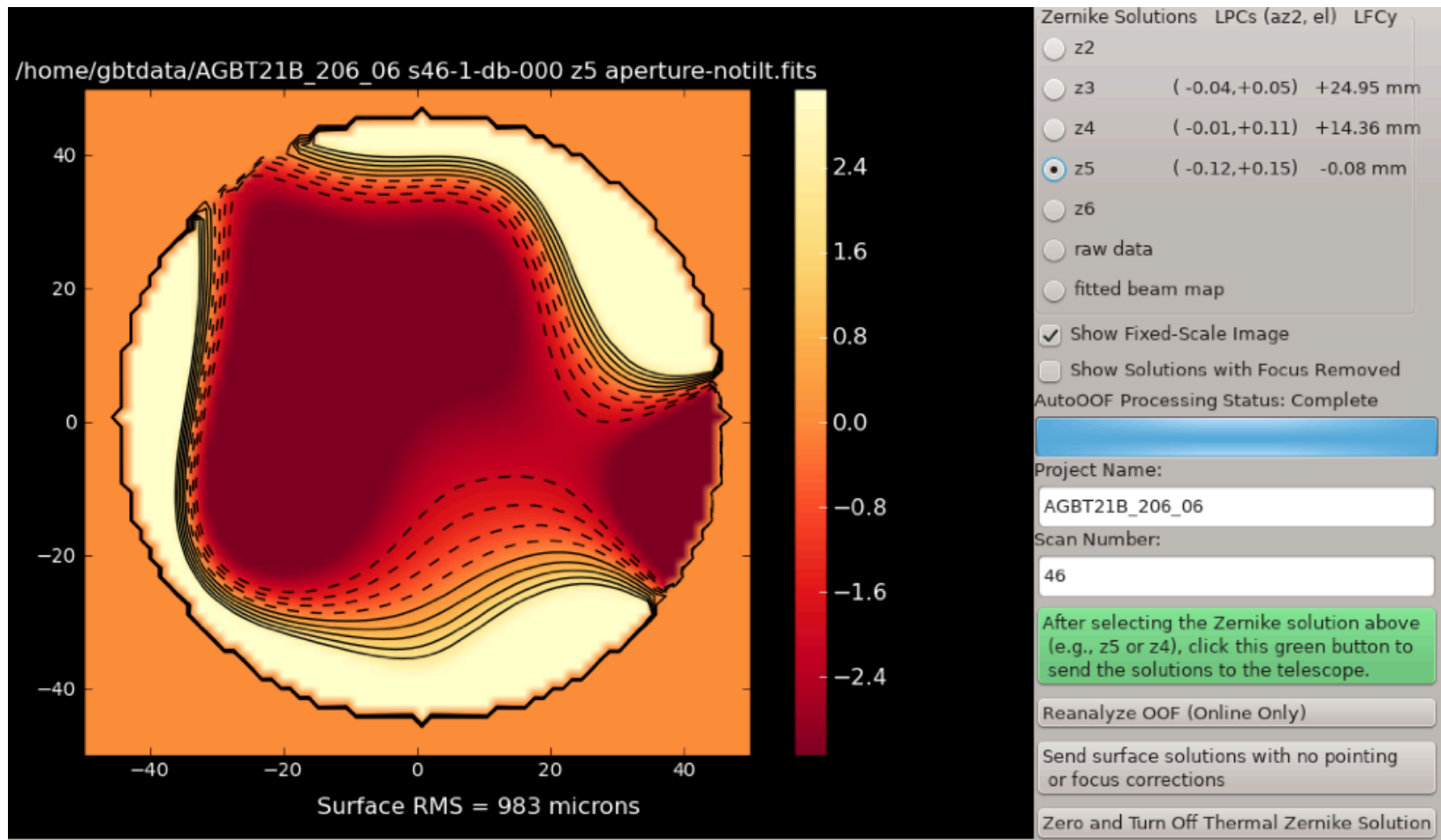
- ARGUS Example
  - Redo
  - Don't apply corrections
  - Recommended to OOF with Ka-band if on telescope

## Notes on Telescope Corrections When Using ARGUS

- 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.



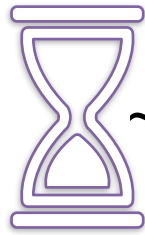
# Bad OOF with MUSTANG-2? What do you do?



Zero solutions AND LFCy (ask operator) and Re-OOF (submit OOF script again)

# Observing Strategies: Antenna Optimization

## Pointing & Focus



~ 5 – 10 min



every  
30 – 50 min

\*M2 every 30

## AutoOOF



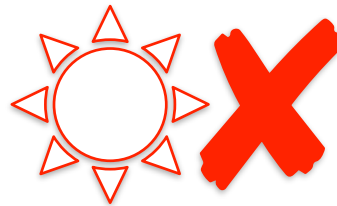
~ 20 – 25 min



ideally after  
21:00 or 22:00



solutions good  
for 2 – 6 h



surface changes on time  
scales < 1h

# Ways to continue to improve surface





# GREEN BANK OBSERVATORY

[greenbankobservatory.org](http://greenbankobservatory.org)

*The Green Bank Observatory is a facility of the National Science Foundation  
operated under cooperative agreement by Associated Universities, Inc.*

