Argus Observing

David Frayer (Green Bank Observatory)

Version 2020.02.03

GREEN BANK OBSERVATORY

Where to find observer information

- Argus Observer's Web page:

www.gb.nrao.edu/argus

- Example Argus observing scripts are located at:

/home/astro-util/projects/Argus/OBS

- Example Argus GBTIDL reduction scripts are located at:

/home/astro-util/projects/Argus/PRO

- Argus Calibration Information:

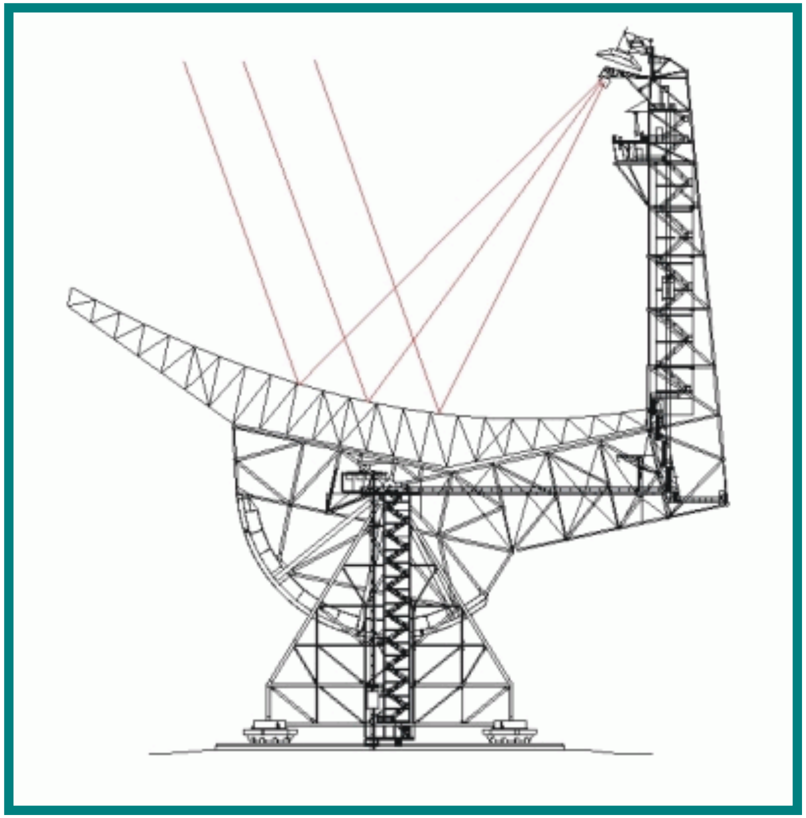
GBT Memo#302

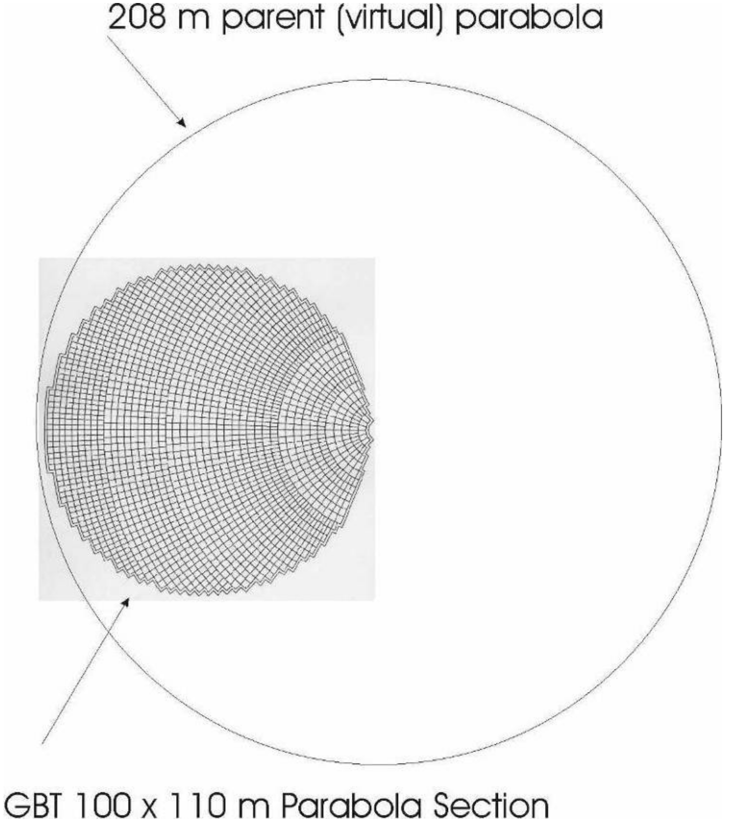
- Links for GBT observing and data reduction:

www.gb.nrao.edu/CDE2017

GBT Telescope Optics

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

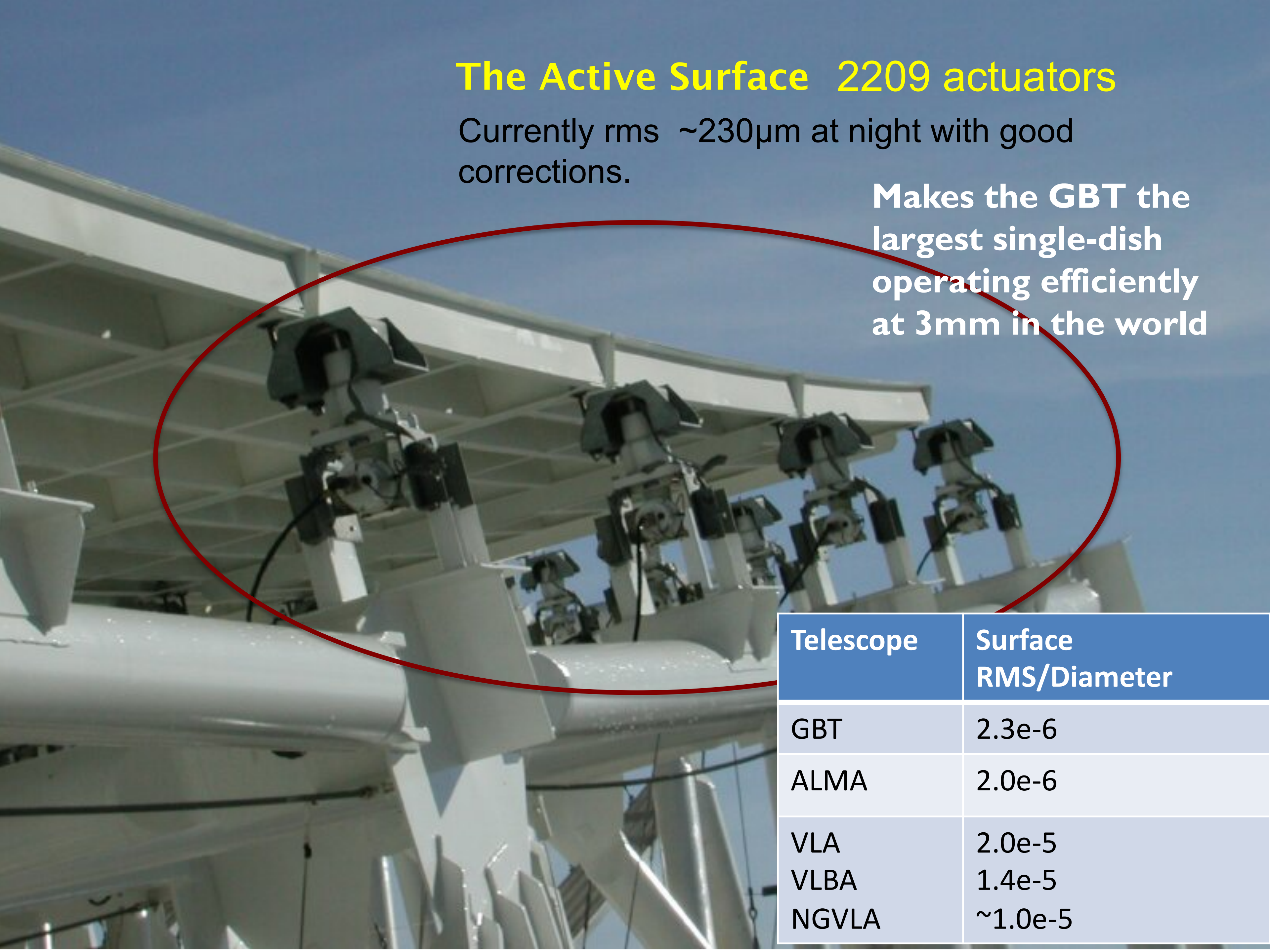




The Active Surface 2209 actuators

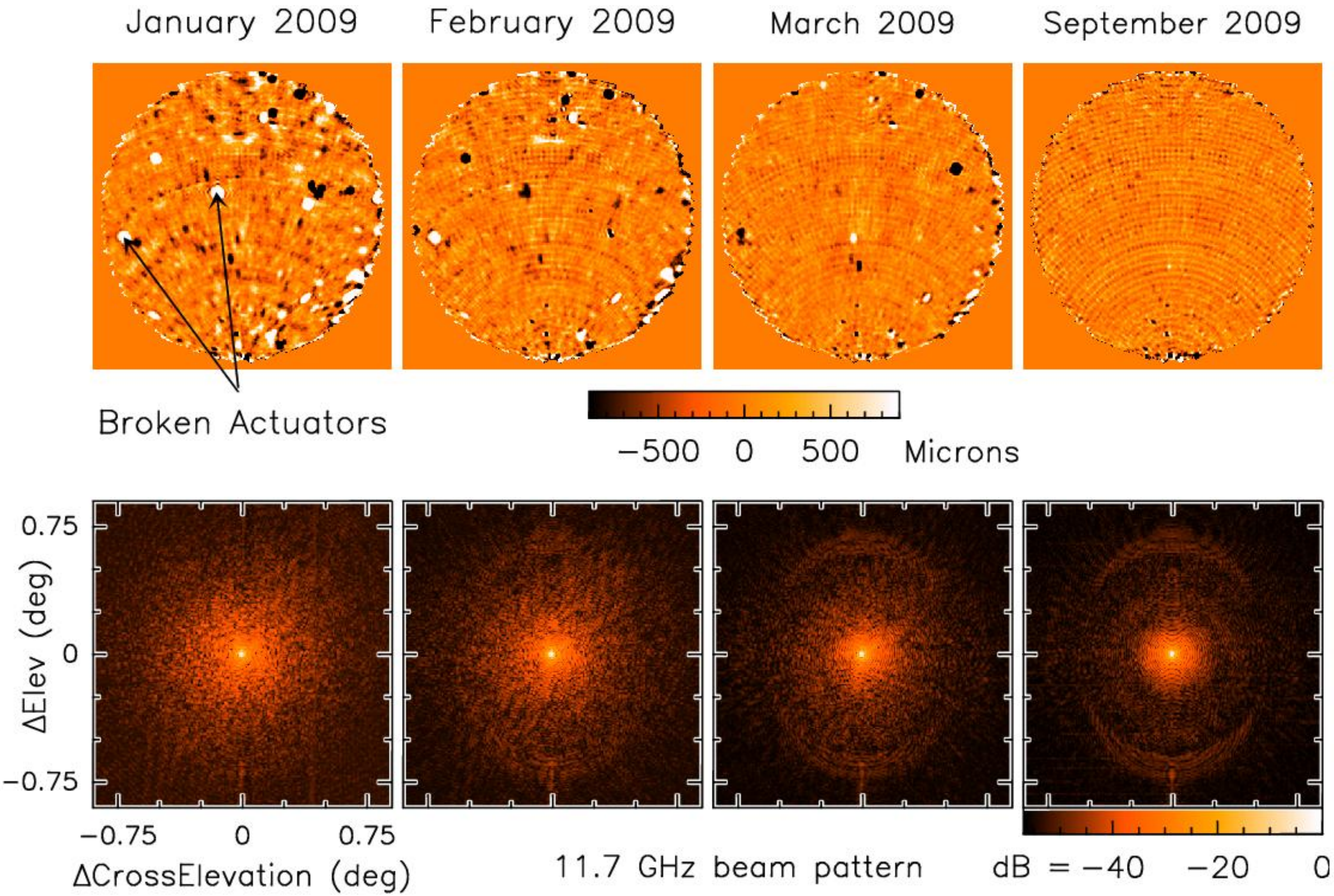
Currently rms ~230μm at night with good corrections.

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 Surface in 2009



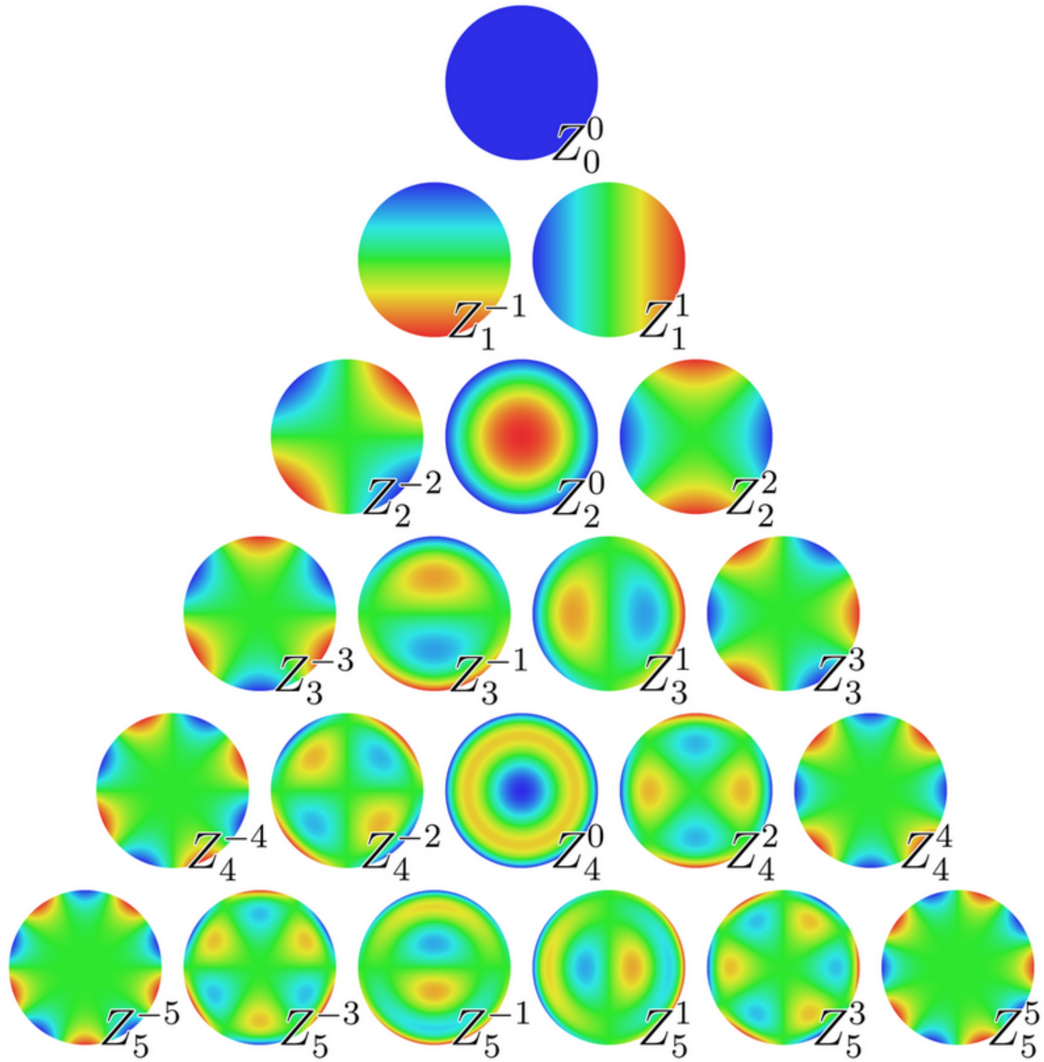
Model Surface Using Zernike Polynomials

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:

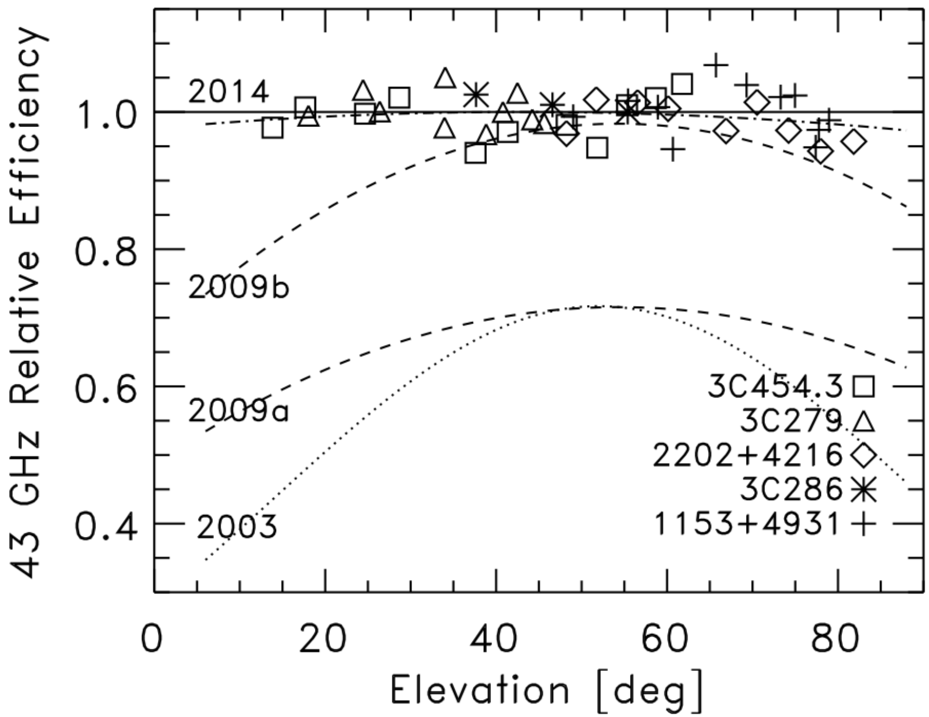
$$Z_n = A_n \sin(el) + B_n \cos(el) + C_n$$

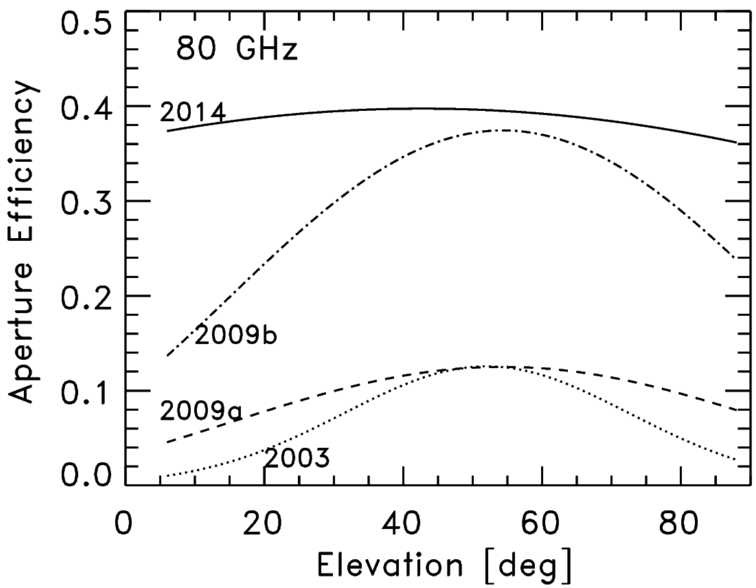
The updated 2014 gravity model improved telescope performance (PTCS PN#76)

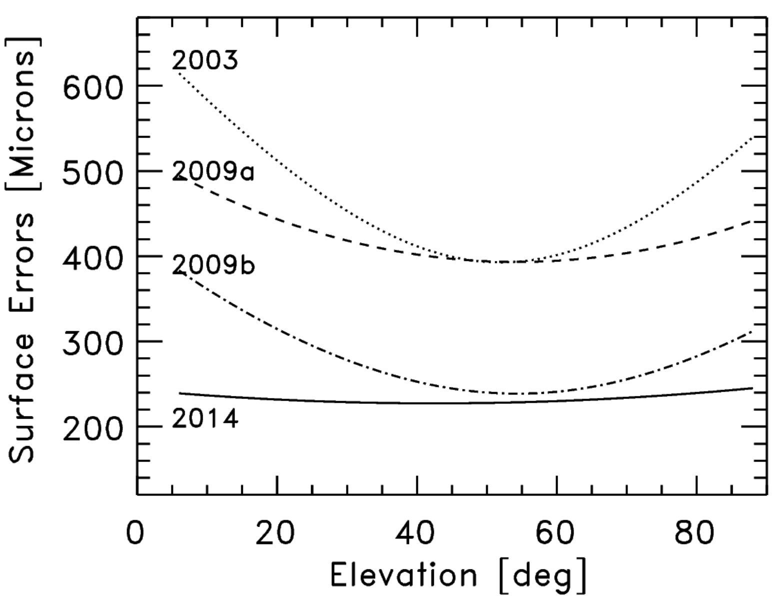
TABLE 1:

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



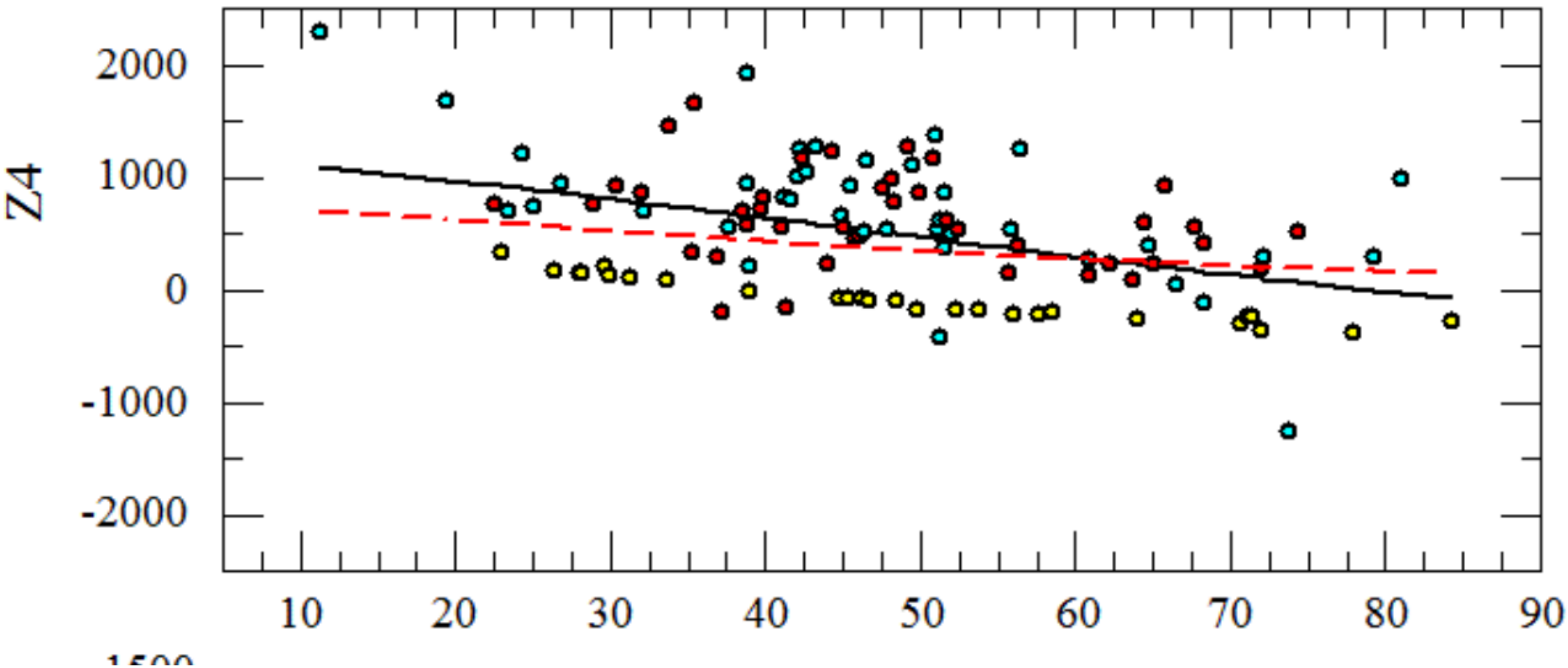




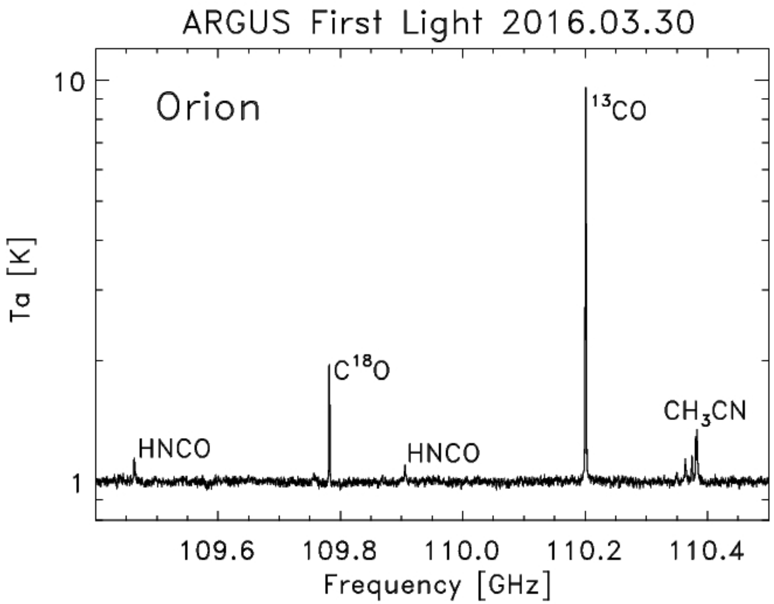
Improvements to the Zernike-Gravity model in 2014 yields a flat gain curve with elevation and has significantly improved the GBT performance at high-frequency (GBT Memo#301)

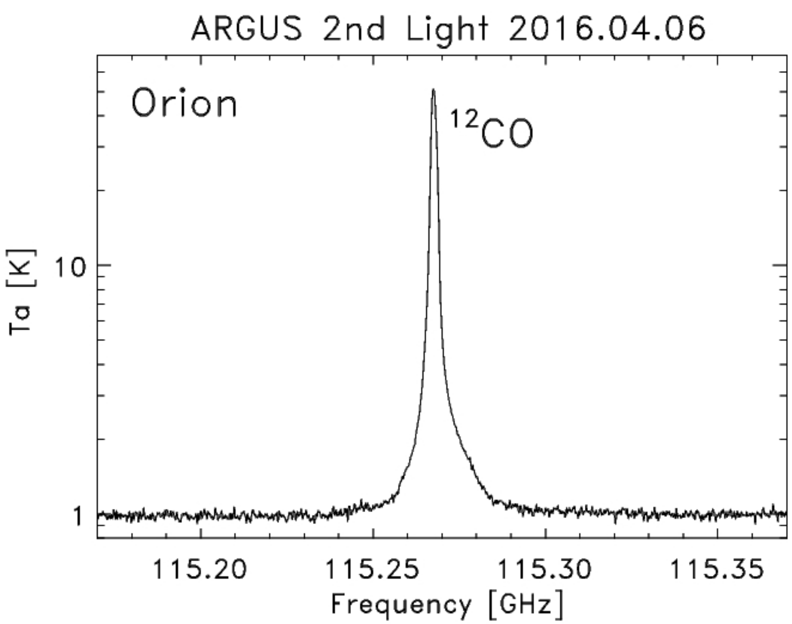
Some Zernike parameters depend strongly on the current ”Thermal” conditions of the antenna (large scatter) and require real-time corrections to the gravity model.

Zn(total) = Zn(gravity) + Zn(thermal)



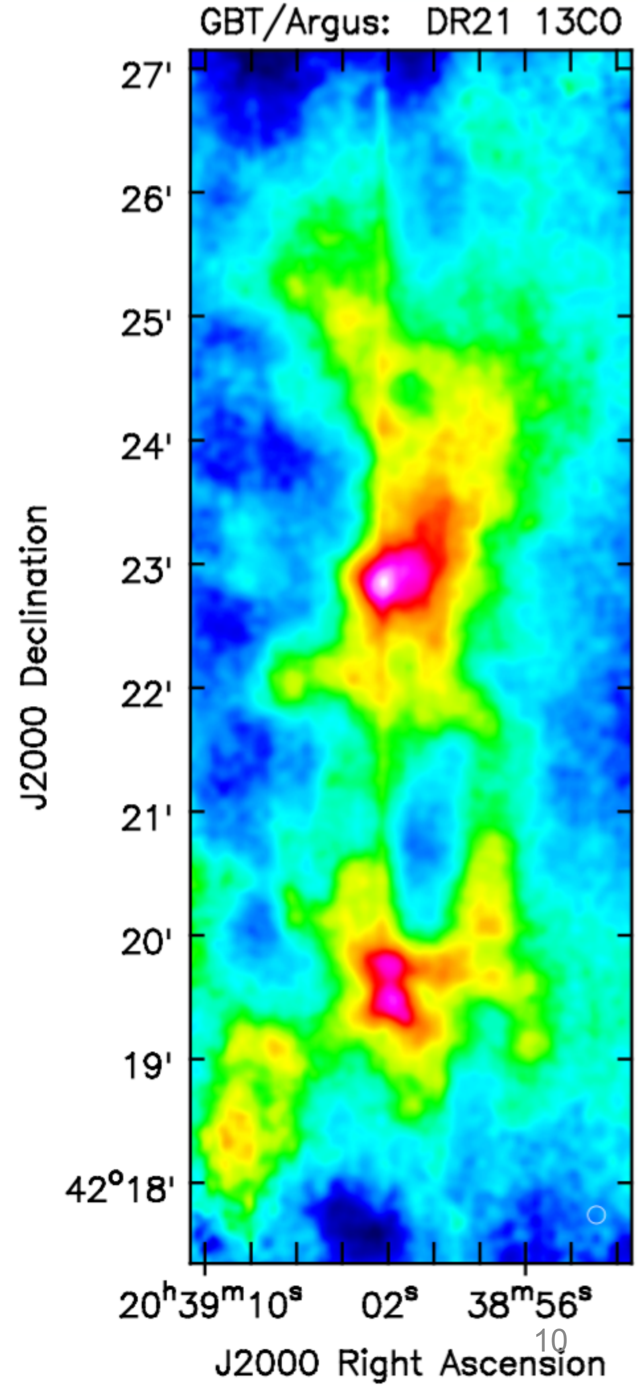
Argus early test observations:



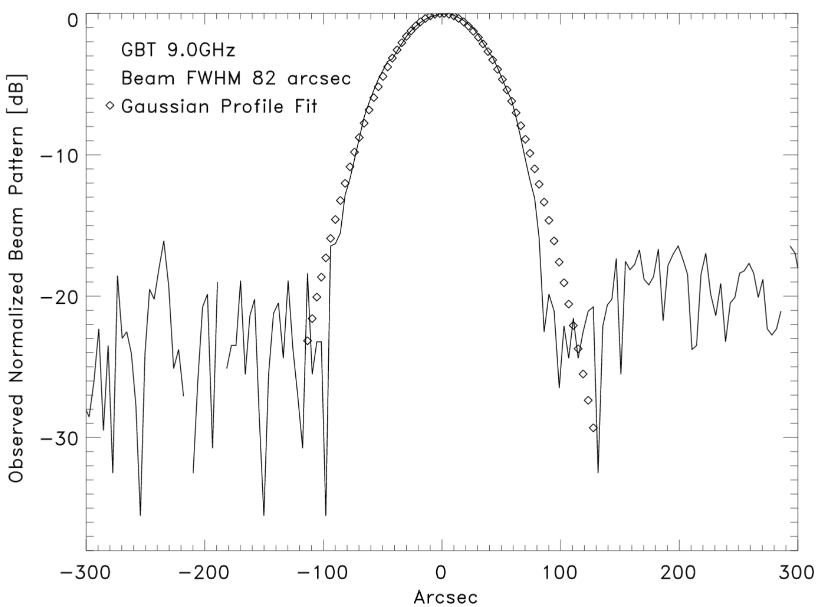


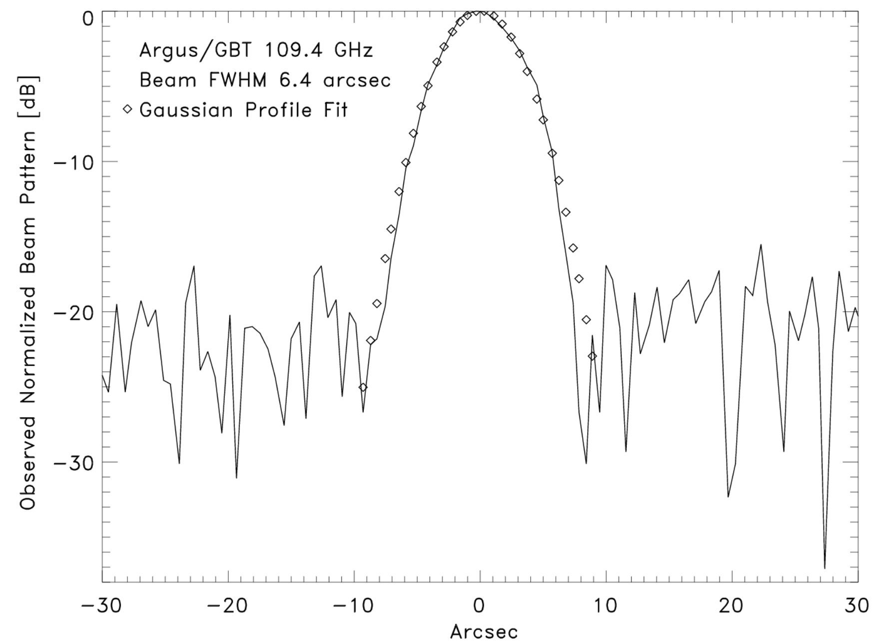
(left) 1st and 2nd light spectra taken of Orion.

(right) 13CO 10'x3' map of DR21 using all 16 beams taken in 40 min under marginal conditions tau=0.42



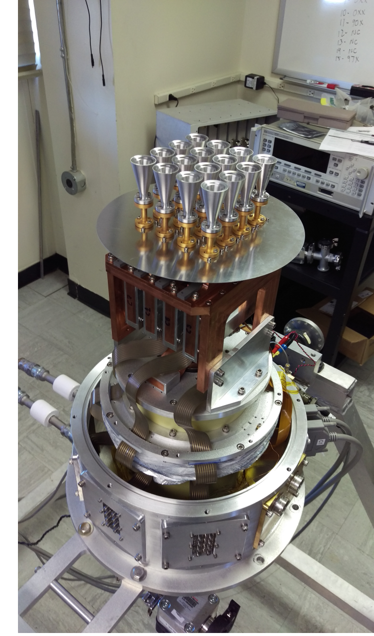
GBT Achieves Theoretical Beam with Argus at 109 GHz – GBT memo#296





Left is the GBT beam at 9.0 GHz and **Right** GBT at 109.4 GHz. With Argus, the GBT can achieve beam sizes of ~1.15--1.2 Lambda/D (in good conditions after OOF).

Argus Block Diagram



- 16 element
- single linear polarization
- Uses I-Q mixing scheme for side-band separation

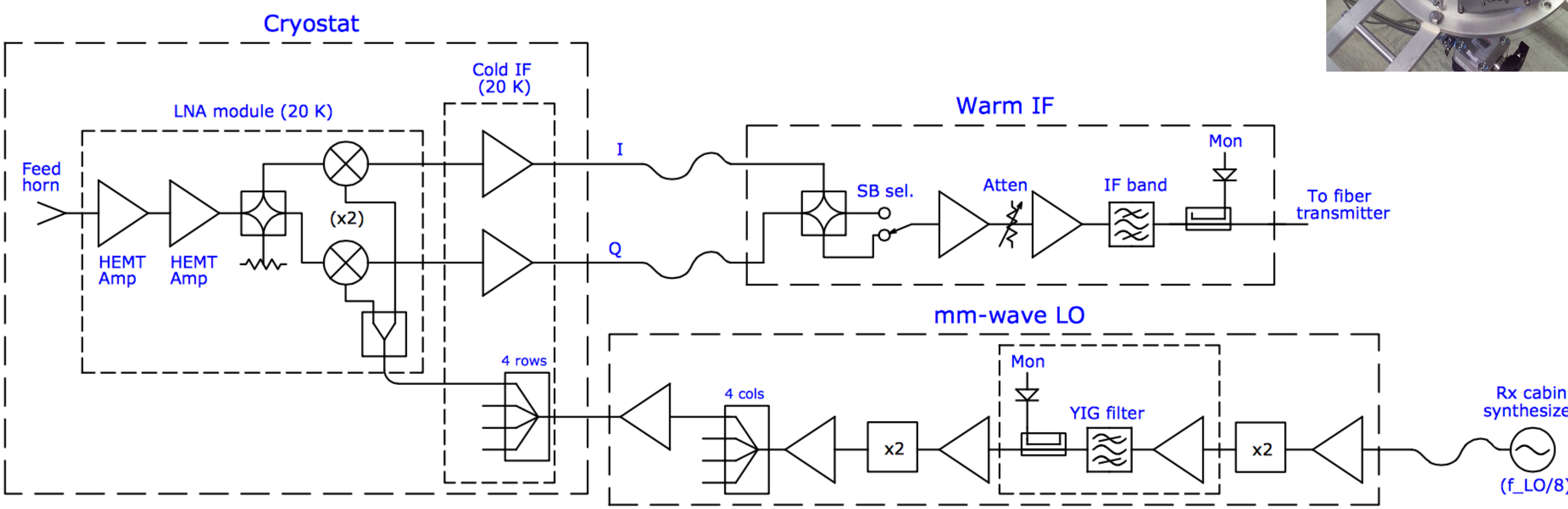


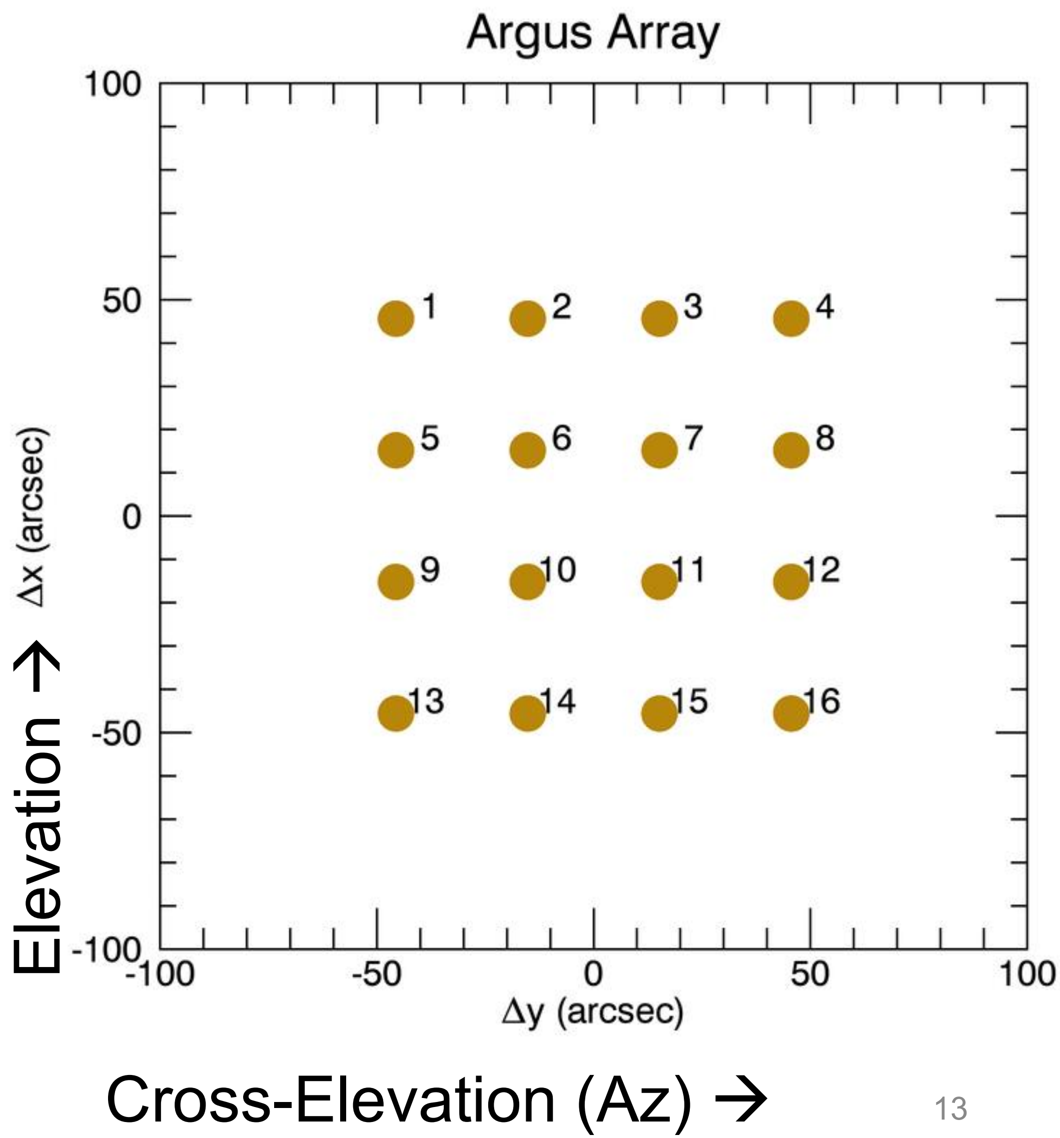
Figure 1: Schematic block diagram of Argus' signal path for a single receiver.

YIG-filter 50MHz wide needed for clean LO input

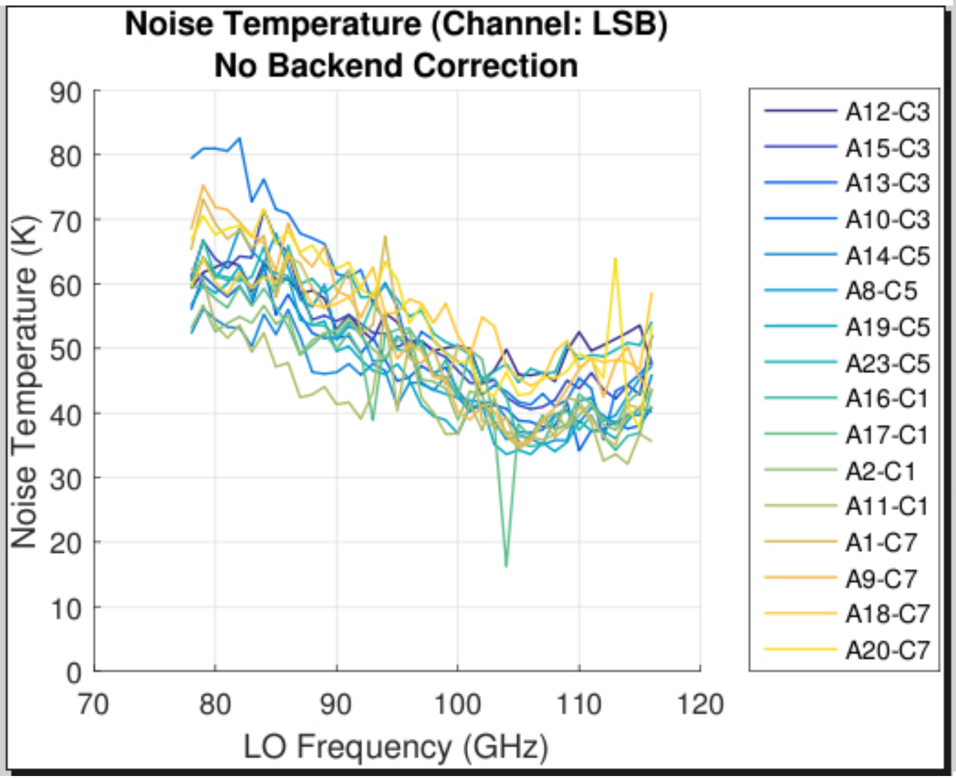
Argus Footprint on the Sky

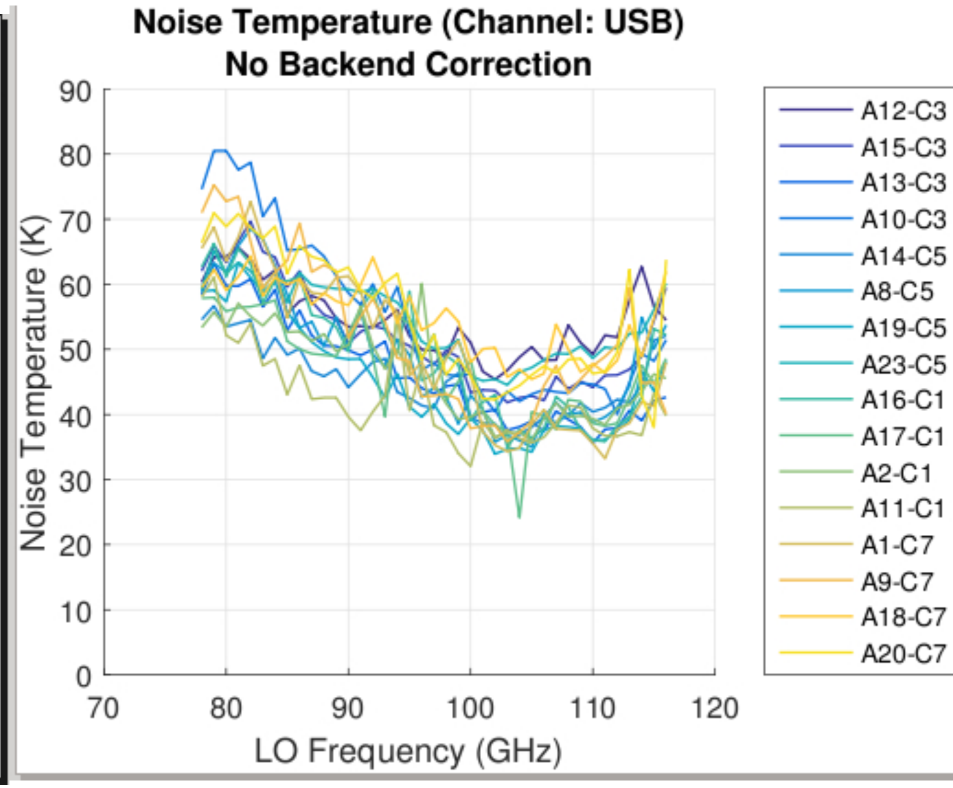
4x4 array with each beam separated by 30.4” on sky in El and xEl directions

- Only Beams 9-16 can be used with the DCR.
- Beam-10 is the default pointing/focus beam.
- All 16 beams can be used with VEGAS.
- Beam-8 has no side-band rejection.



Argus lab performance





Receiver temperature measurements of the LSB (left) and USB (right) as function of observing frequency for each of the 16 Argus channels.

Argus Performance on Sky

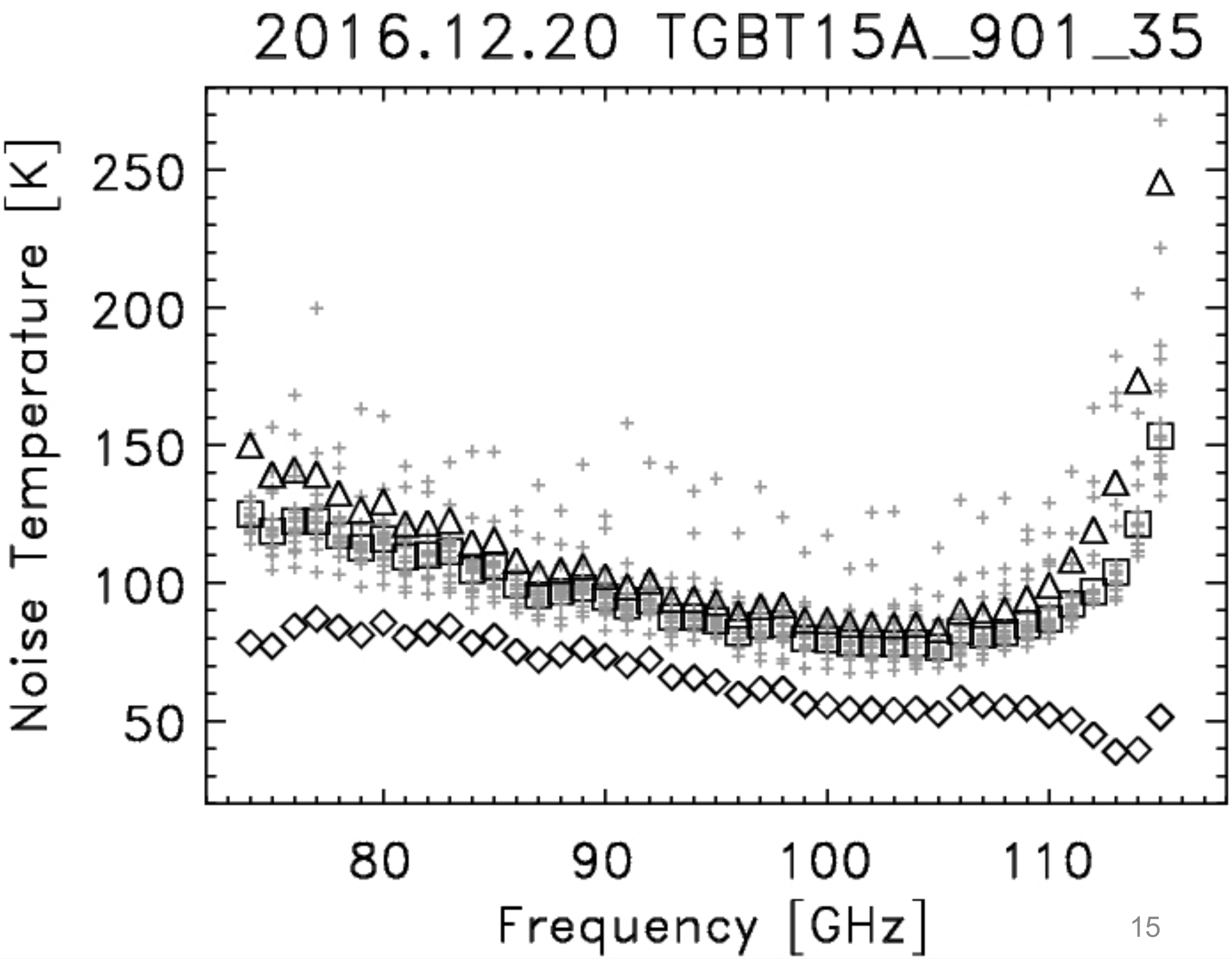
Measured noise on sky for Argus (zenith tau[90GHz]=0.06

Grey +'s are the individual Tsys measurements for each beam associated with Ta.

Boxes are median value of the Ta Tsys for Argus.

Triangles are median value for Tsys* which is the noise temperature associated with Ta*.

Diamonds are the inferred receiver noise after subtraction of the sky and estimated spillover.



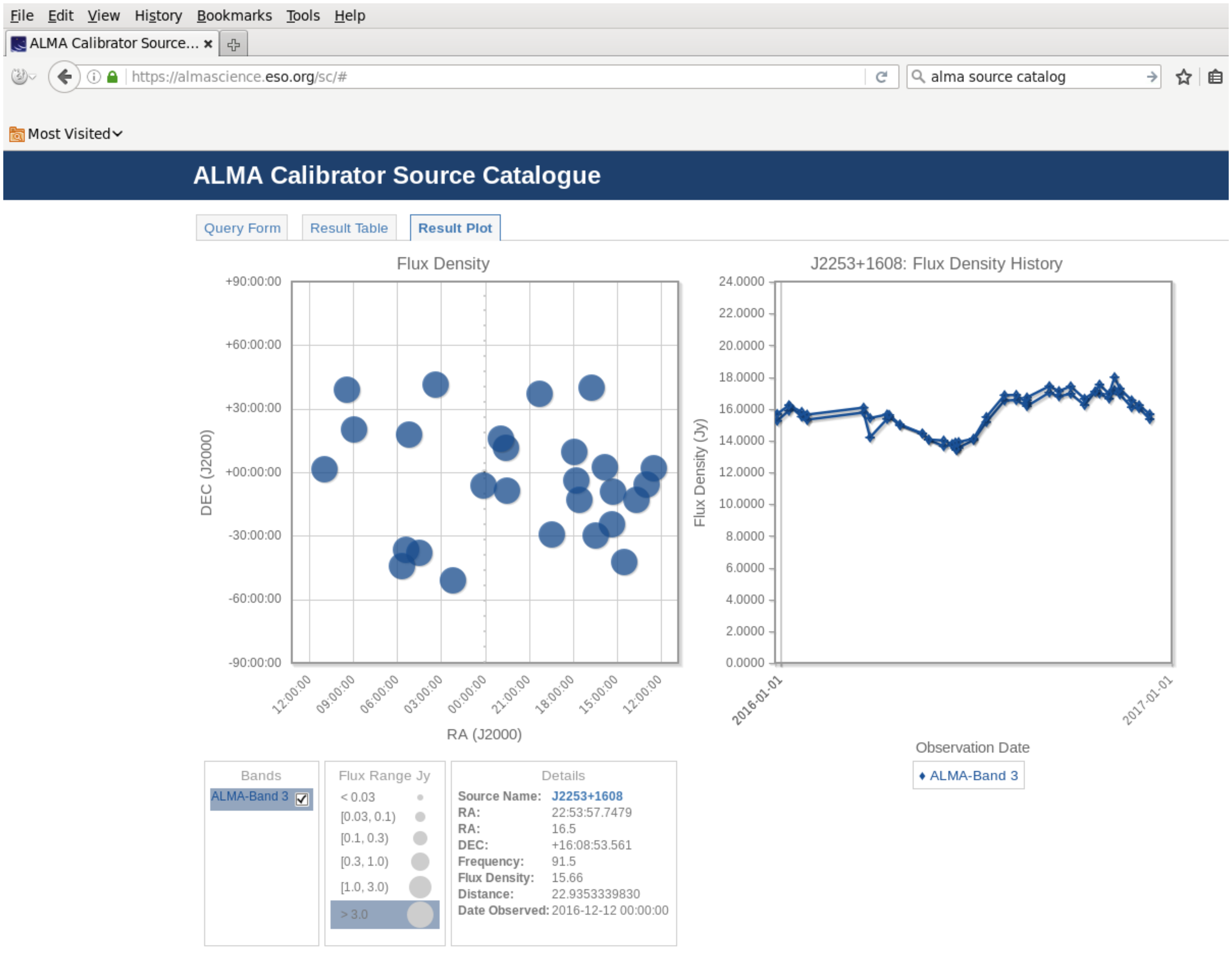
Argus-Specific Observing Information

- There are no noise diodes with Argus. Any data that you want to be calibrated requires vanecal observations after any new configuration or balance.
- It is best to observe similar frequencies together in time since it can take a few minutes for the YIG system to adjust to large frequency jumps. Frequency shifts of order a 1-2 GHz or less between observations are ok, but if you need to switch by a large amount (e.g., 4-10+ GHz), configure, wait a couple of minutes, and re-configure and balance again.
- Argus is able to observe from 74 -- 116 GHz.
- Only beams 9-16 that go through the IFRack can be configured with the DCR. All 16 beams can be configured with VEGAS using 8 dedicated optical-fibers for Argus beams 1-8.
- Beam 8 has no sideband rejection so signal from opposite sideband is seen.
- The continuum "Auto" procedures will run vanecal observations by default. You can skip the vanecal observations by using the calSeq=False keyword. At high-frequency, it is better to do the elevation pointing scans first since the pointing offsets in elevation tend to be larger than those in Az. This is done with the elAzOrder=True keyword. The default frequency for the Auto procedures is 86 GHz. Example command showing frequency, calSeq, and elAzOrder keywords: AutoPeak(source,frequency=90000.,calSeq=False, elAzOrder=True).
- For Argus, AutoOOF should be run with the vanecal (which is the default) since this will provide proper calibrated data from both beams for fitting the surface model.

Preparing for Observations

- Configuration file – frequency(ies), spectral resolution, observing mode (see GBTog and presentations on GBO web pages)
- Source catalog (RA, DEC, Velocity)
- Observing scripts (see GBTog)
- Picking OOF, pointing, focus, and calibration sources (use online ALMA Calibration Catalog for absolute flux calibration)

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



Configuration Parameters for Argus

- receiver = ’RcvrArray75_115’
- beam = ‘all’ (for all 16 beams with Vegas)
- swmode = ‘tp_nocal’ (or ‘sp_nocal’)
- sideband = ‘LSB’ (or ‘USB’)
- pol = ‘Linear’

➢ Argus is single linear polarization (X) for all 16 beams and has **no noise-diodes** (”nocal”). Argus allows choice of LSB vs USB. Sideband separation is 3.05 GHz. Above 110GHz use USB for slightly better performance, and use LSB at ~110 GHz and below for slightly better performance.

ObservationManagement - 1 | DataDisplay - 1 | GbtStatus - 1

Edit | Run

Project: TGBT15A_901

Scheduling Blocks:

- aArgus_VEGAS_LOOP_tsy
- aArgus_VEGAS_quick_LO
- argus_config_example
- argus_config_example_fs
- argus_monitor
- argus_quickfix
- argus_reboot
- argus_shutdown
- argus_startup
- argus_tip
- argus_vanecal
- autofocus
- autooof
- autopeakfocus
- Balance
- config_110
- config_110_fsw
- config_110_halfsec
- config_12co
- config_13co_map
- config_70000
- config_74000
- config_75000
- config_80000
- config_86000
- config_88900

Editor: You are currently editing argus_config_example

```
#
#Configure VEGAS mode-2 with ARGUS 16 beams
#HCN and HCO+
#dfrayer 2016.12.09
#
Configure("""
receiver    = 'RcvrArray75_115'
beam        = 'all'
obstype     = 'Spectroscopy'
backend     = 'VEGAS'
restfreq = 89000.
bandwidth = 1500
swmode      = 'tp_nocal'
swtype      = 'none'
swper       = 2.0
swfreq      = 0.0, 0.0
tint        = 2.0
vlow        = 0
vhigh       = 0
vframe      = 'lsrk'
vdef        = 'Radio'
pol         = 'Linear'
nchan       = 'high'
sideband = 'LSB'
vegas.subband=1
""")
#
Balance()
# Check the YIG status after configuration
yigvolt, sampleTime = GetSample("RcvrArray75_115", "YIGData,lo_power")
print "Yig voltage: ", yigvolt, ", Sample time:", sampleTime
```

Enter target frequencies

tp_nocal (no noise diodes)

swper >=0.4 for fsw

tint <~1sec for mapping

pick sideband

Check YIG-LO_power after configuration

Recommended Argus Observing Procedures

1) Startup **astrid** and relax heuristics for pointing and focus tab.
2) Go **online** with control in Astrid and run the **argus_startup** script (when given permission by operator).
3) Run **autooof** (where source is the brightest available quasar with el>~25deg and el<80). This step is needed if you want to correct the surface for thermal corrections which is important for sources sizes ~< beam size. If you do not need an AutoOOF, then the initial point should be done at a lower frequency receiver in order to find the initial pointing offsets for Argus. When available, use Ka+CCB for AutoOOF, since this provides a much higher S/N data.
4) Run **autopeak_focus** with Argus (where source is >~2 Jy source within ~20deg of the target region and choose frequency near science frequency to avoid large frequency jumps for the YIG filter). For best results, autopeak_focus should be run every 30-50 minutes depending on conditions. Avoid pointing in the "key-hole" (el>80). If your pointing source is weak or there are no sources nearby and/or if the weather is marginal, point and focus in X-band , K-band, or Ka-band and use these telescope solutions for Argus observing. It is best to be within 20deg of your target position to avoid large offset pointing errors.
5) Carry out target observations. Run the **argus_vanecal** script after configuration and balance. Observers can use cleo to check instrument parameters.
6) Check instrument performance by reducing the vanecal observations within gbtidl, e.g., **GBTIDL -> vanecal**,25,ifnum=3, for vane scan#25 and spectral-window “ifnum”=3.
7) For absolute calibration carryout **autopeak_calibrate** scans after applying good pointing and focus corrections for a source of known flux density (e.g., ALMA source catalog (https://almascience.eso.org/sc/). The ALMA calibrator catalog can also be used to check the strength of your pointing/focus source.

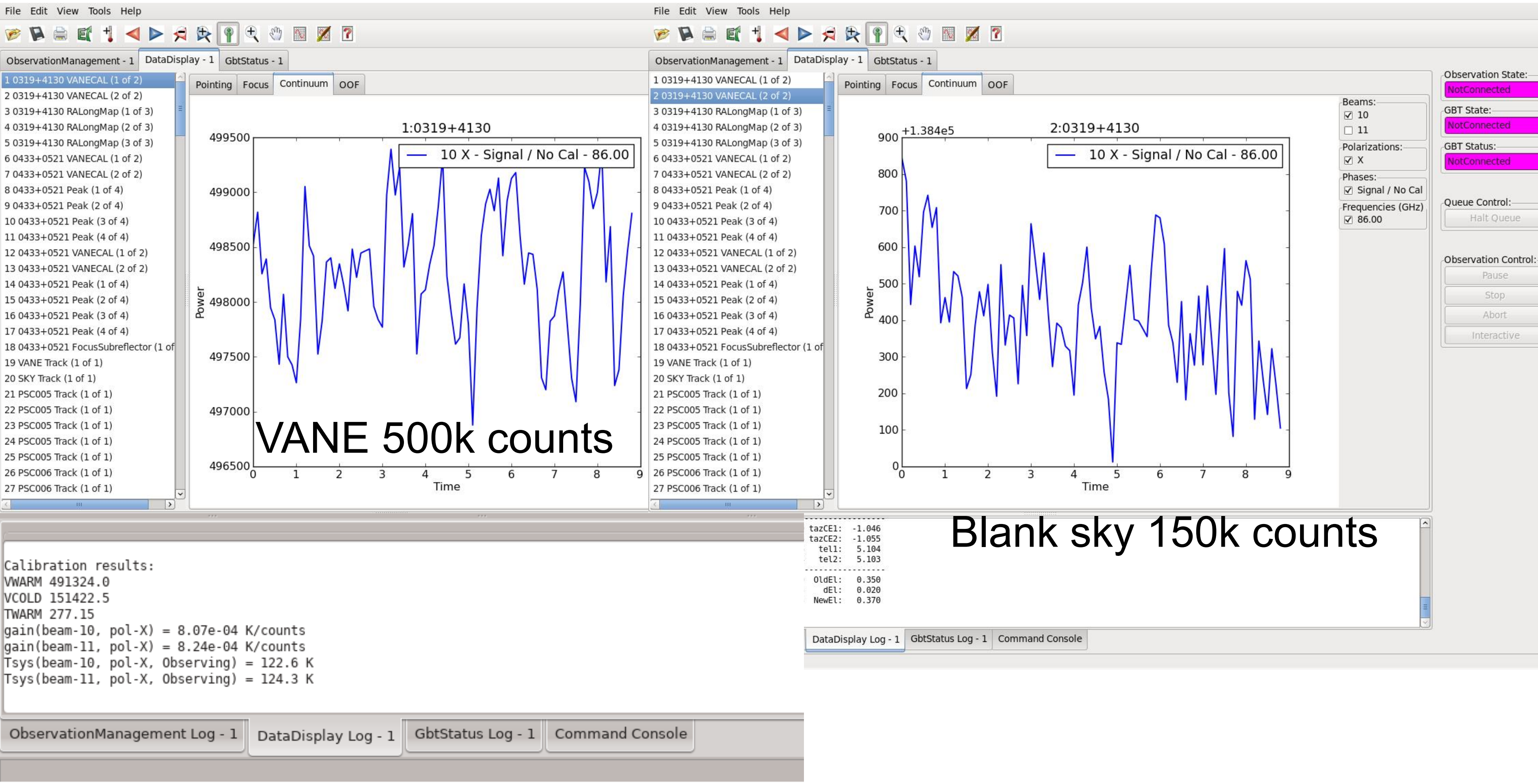
Telescope Corrections

- **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: Antenna Optimization

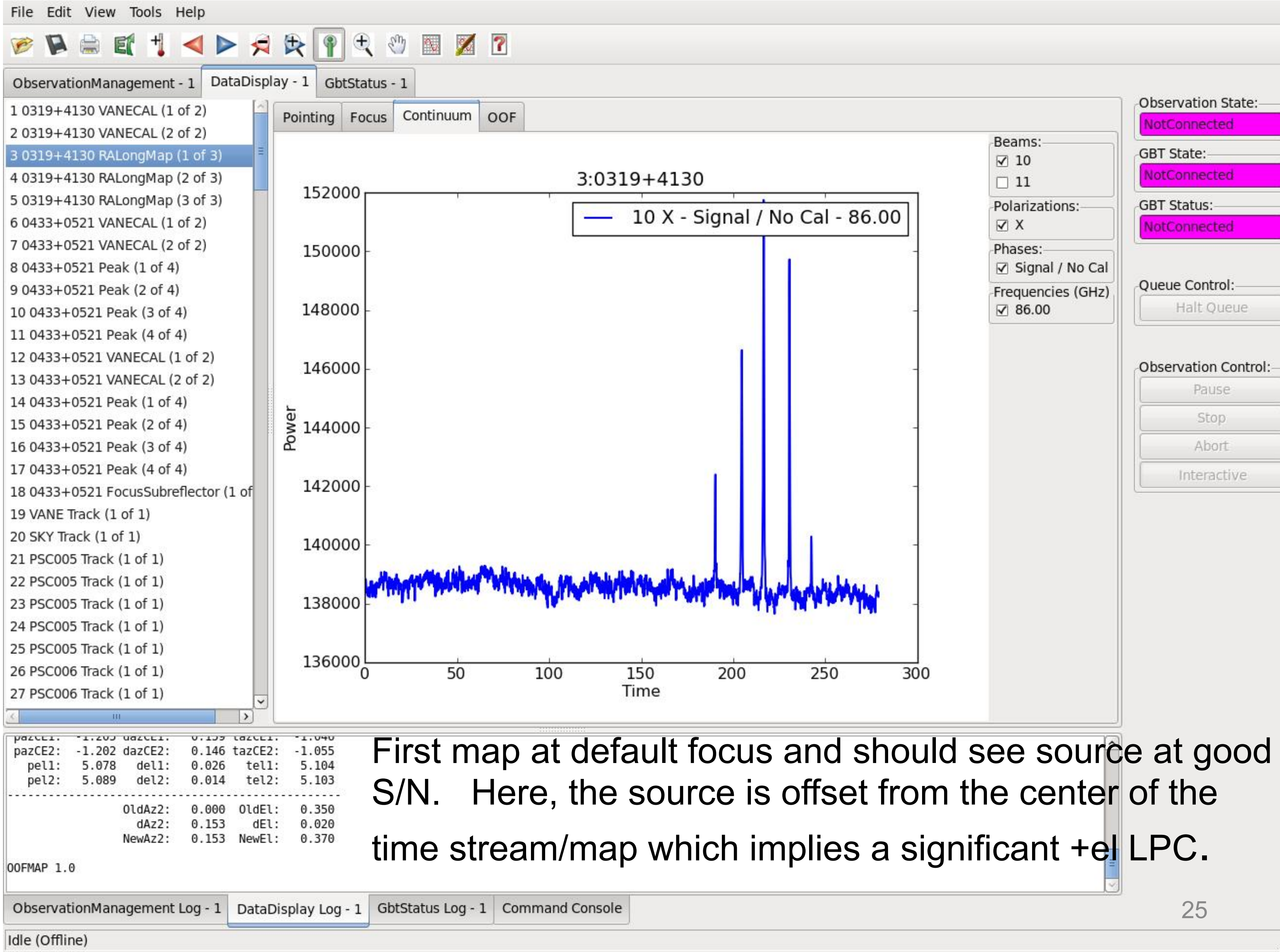
- Should point+focus (AutoPeakFocus) every 30min-50min depending on conditions (point+focus takes ~5min)
- AutoOOF (which takes ~30min) is used to correct the surface for thermal effects at night. During stable nighttime conditions, OOF solutions good for 4—8 hrs.
- Daytime surface changes on less than 1hr time scales, so it is typically not useful to use the OOF "thermal" corrections during the day. This may change in the future with LASSI project.

Example Argus AutoOOF data:
(scans 1+2) Vanecal-scans with the DCR



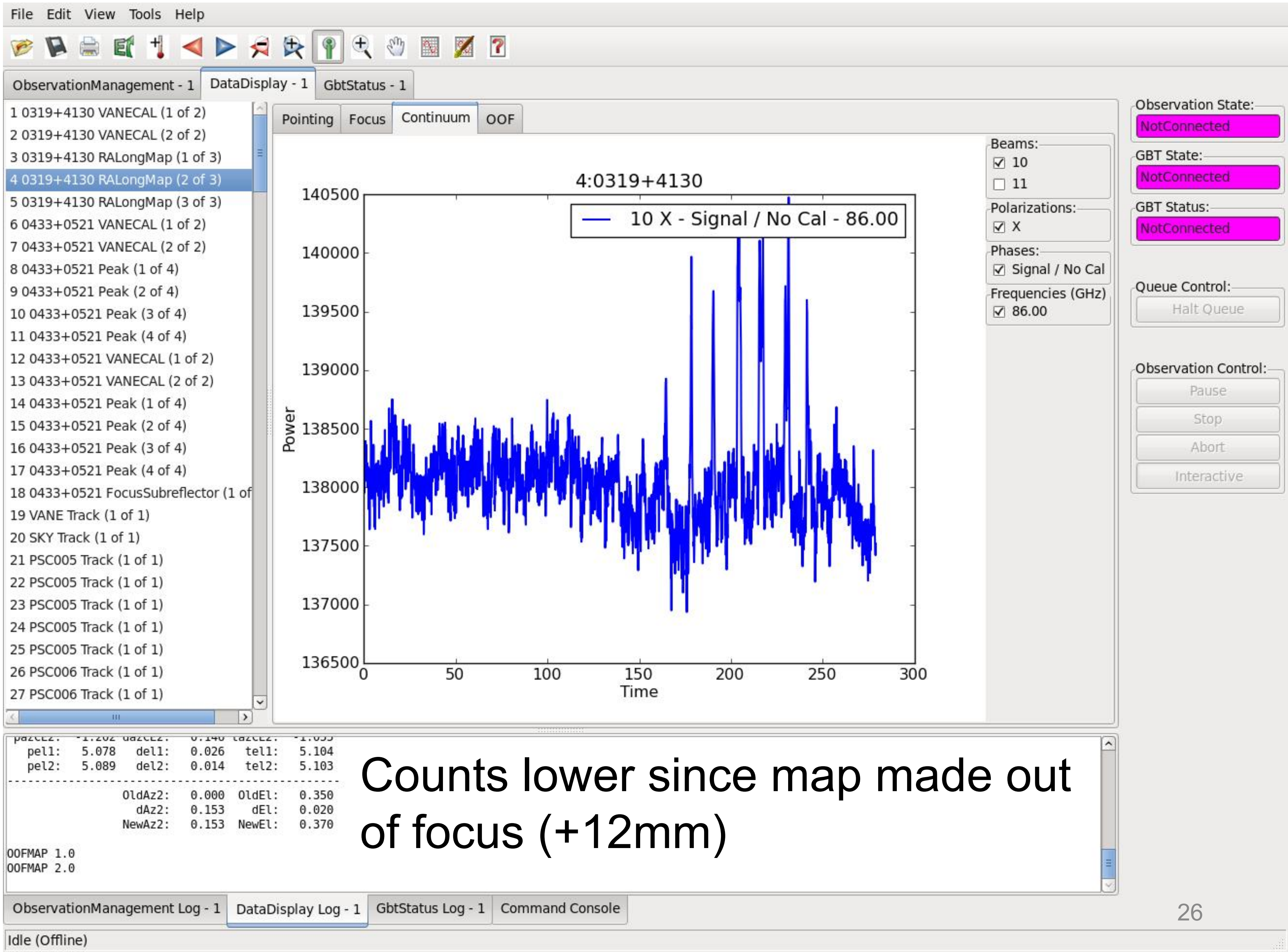
When clicking on a VANE scan taken by the DCR, astrid will report the calibration results in the DataDisplay Log at bottom and system temperatures for beam-10 and beam-11.

(scan 3) Argus OOF map-1 data



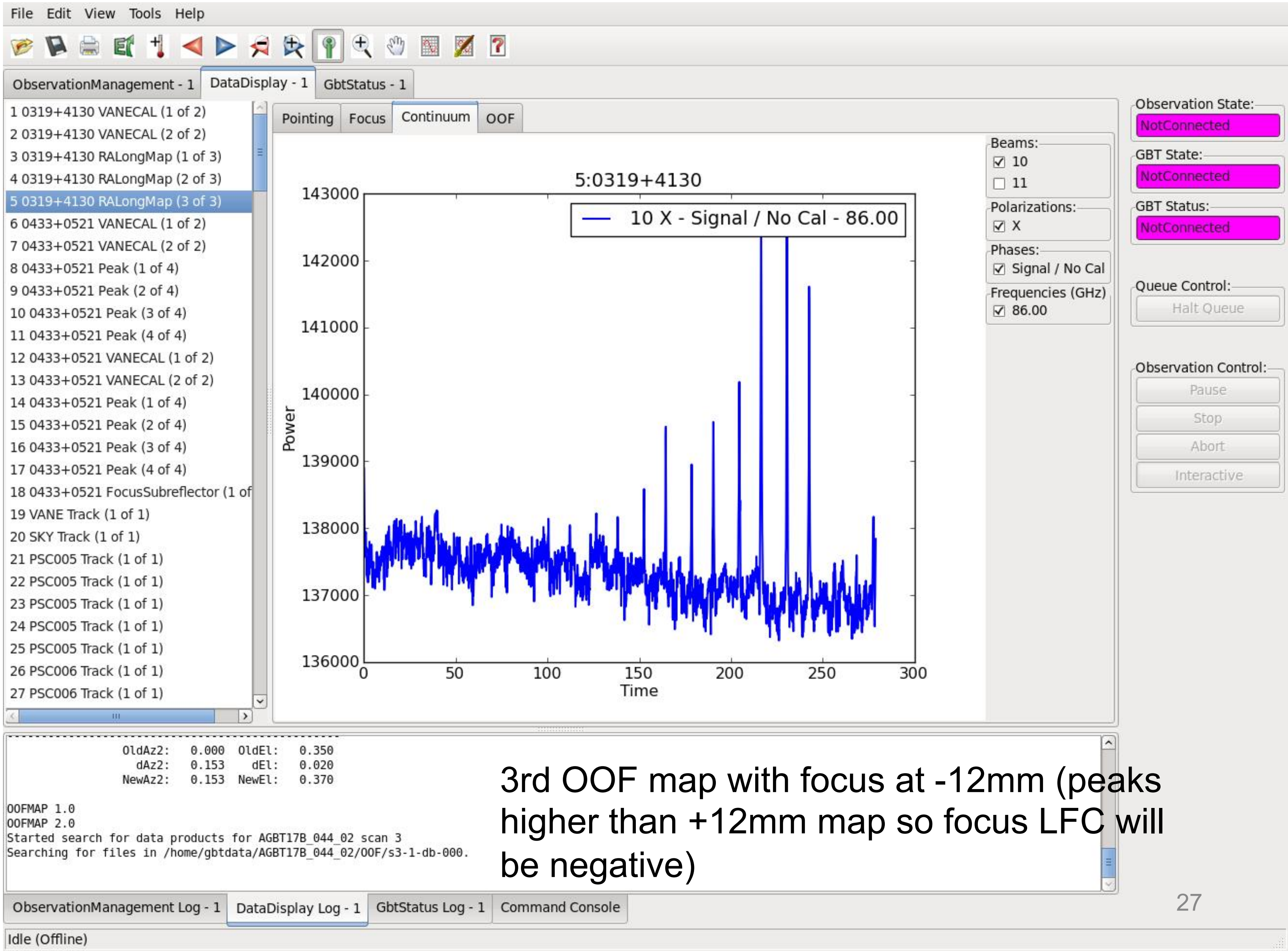
First map at default focus and should see source at good S/N. Here, the source is offset from the center of the time stream/map which implies a significant +el LPC.

(scan 4) Argus OOF map-2 data



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

(scan 5) Argus OOF map-2 data



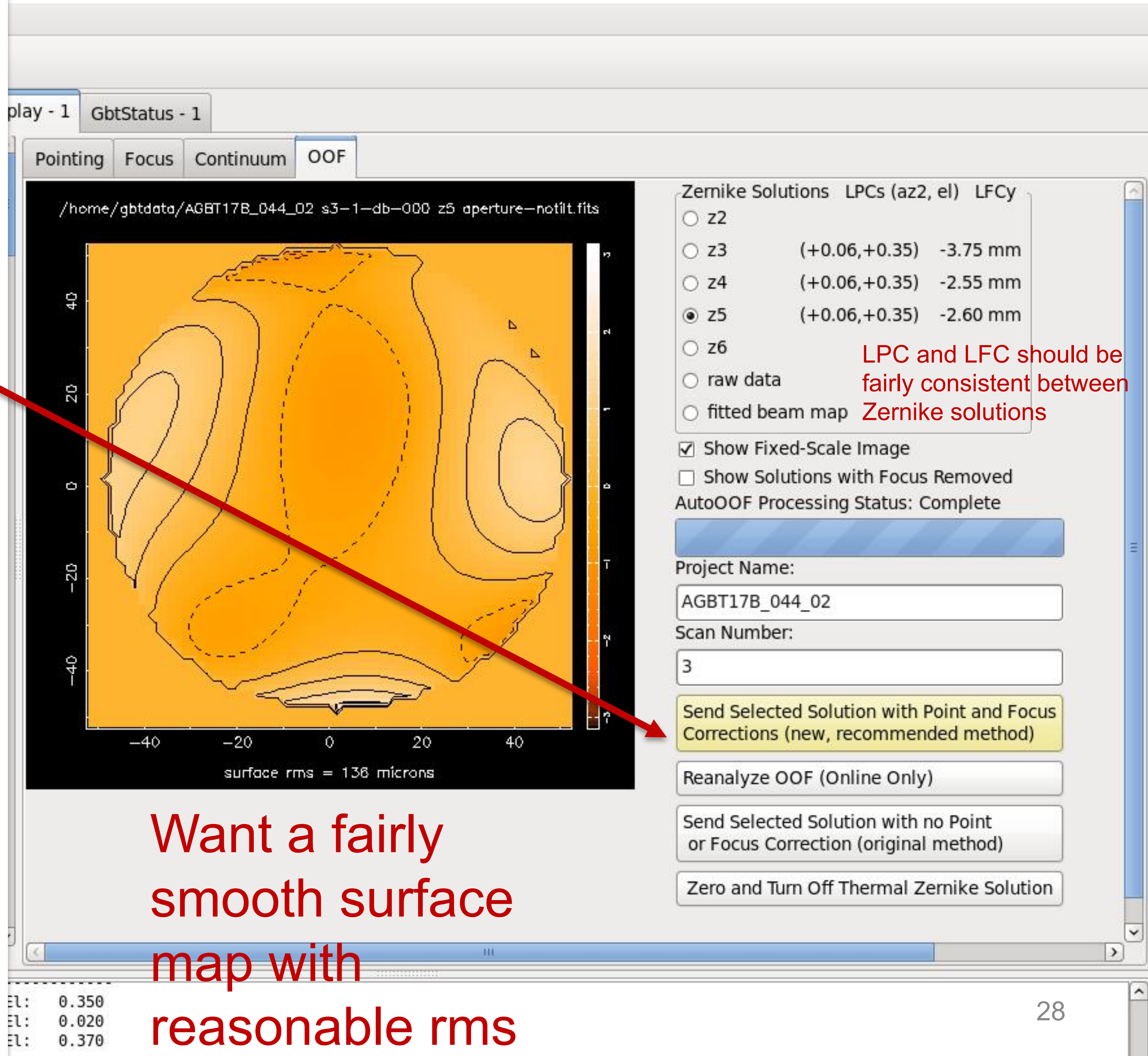
3rd OOF map with focus at -12mm (peaks higher than +12mm map so focus LFC will be negative)

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 can happen in windy conditions)

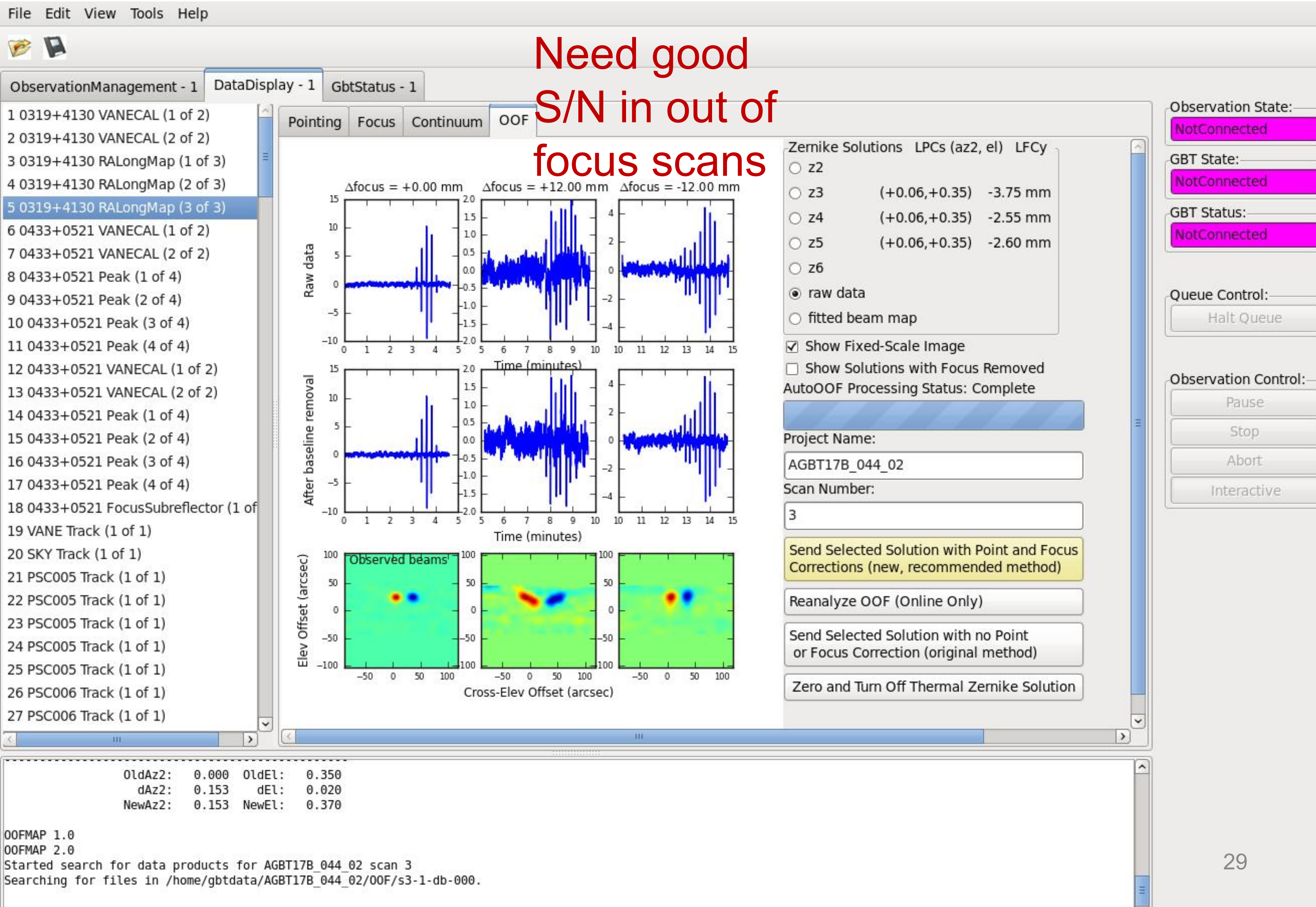


LPC and LFC should be fairly consistent between Zernike solutions

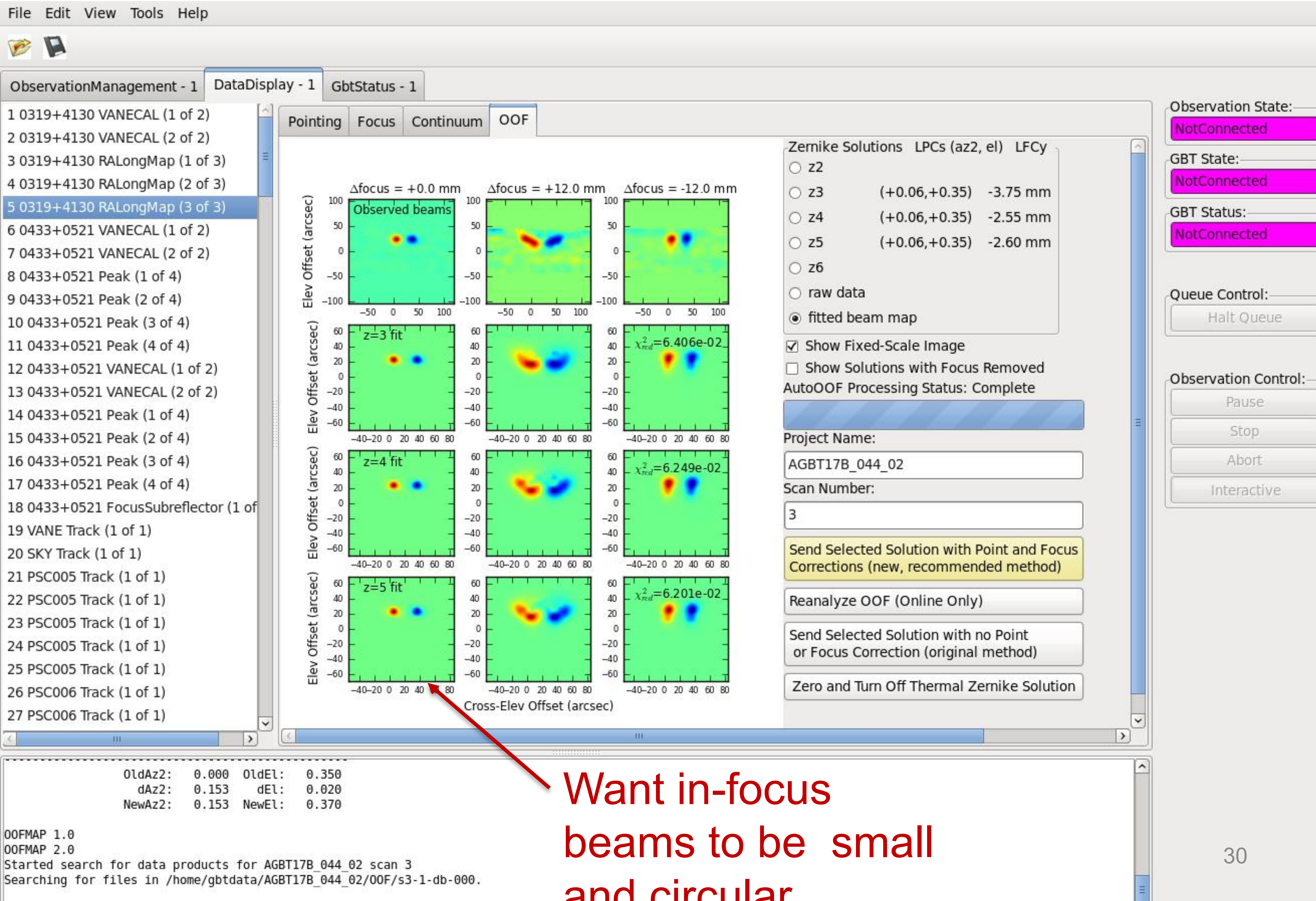
Want a fairly smooth surface map with reasonable rms

AutoOOF “Raw data”

Need good S/N in out of focus scans



AutoOOF Beam Fits



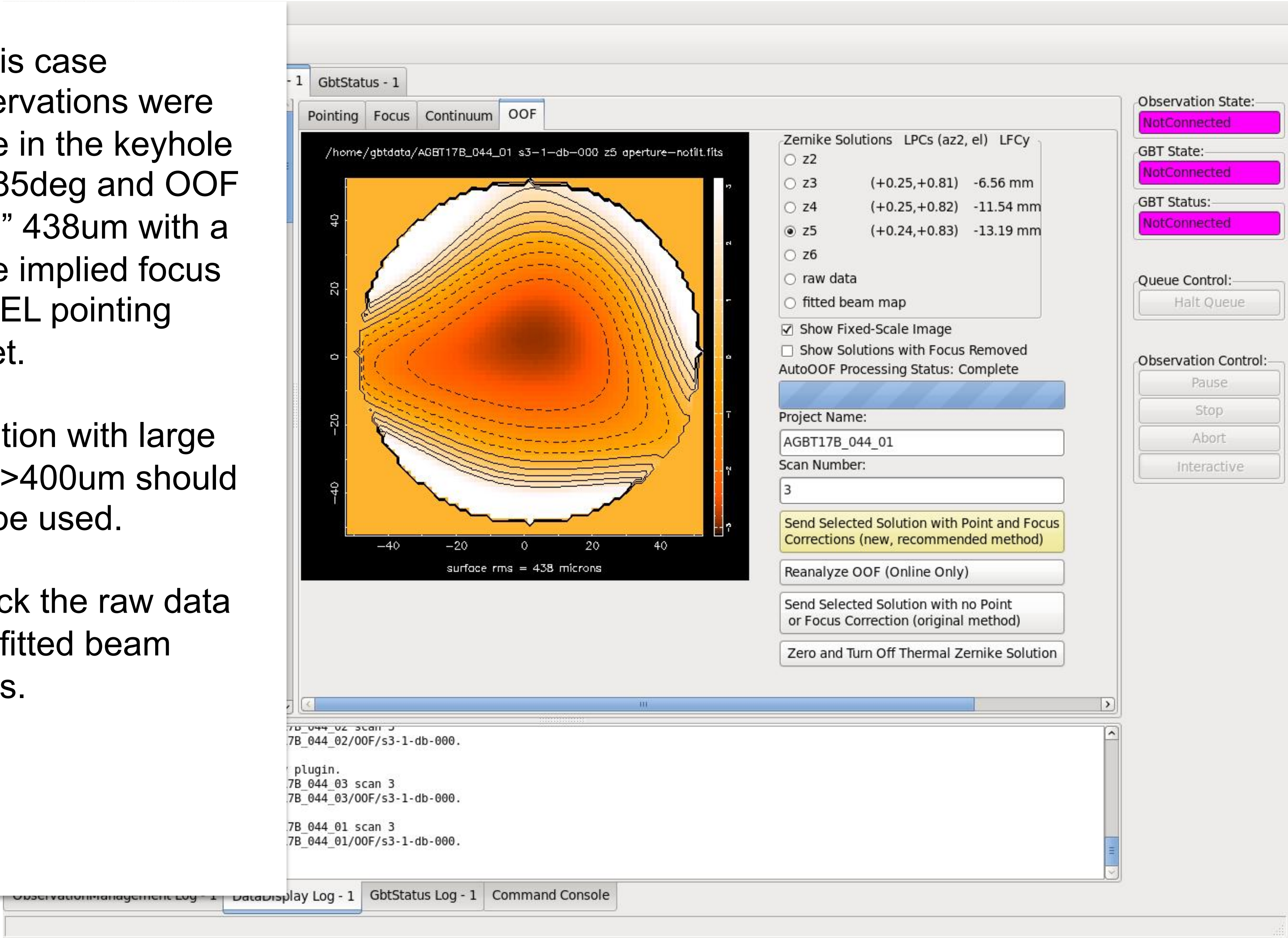
Want in-focus beams to be small and circular

Example of a Bad OOF

In this case observations were done in the keyhole at >85deg and OOF "rms" 438um with a large implied focus and EL pointing offset.

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

Check the raw data and fitted beam maps.

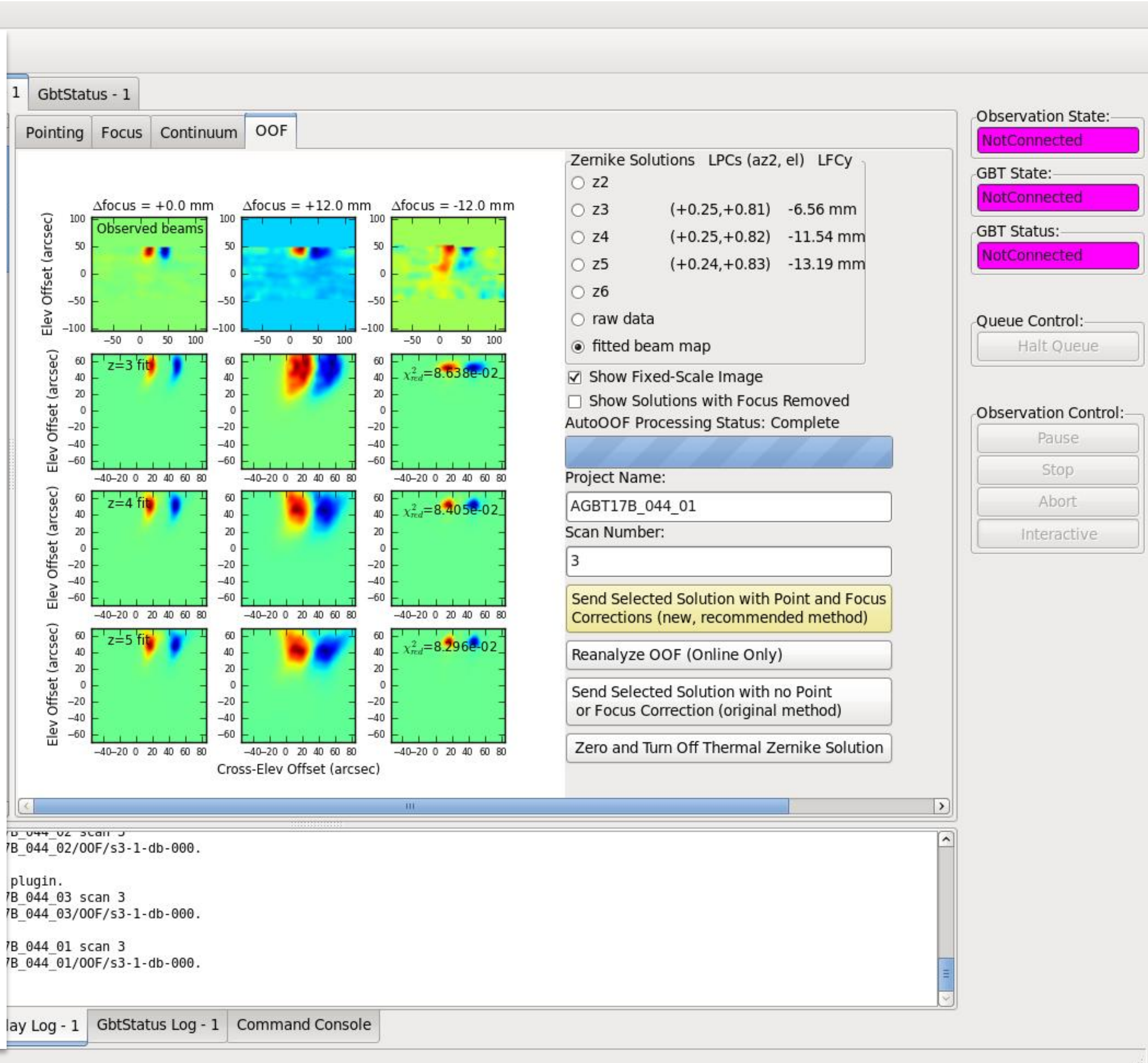


Beam Maps of Example Bad OOF

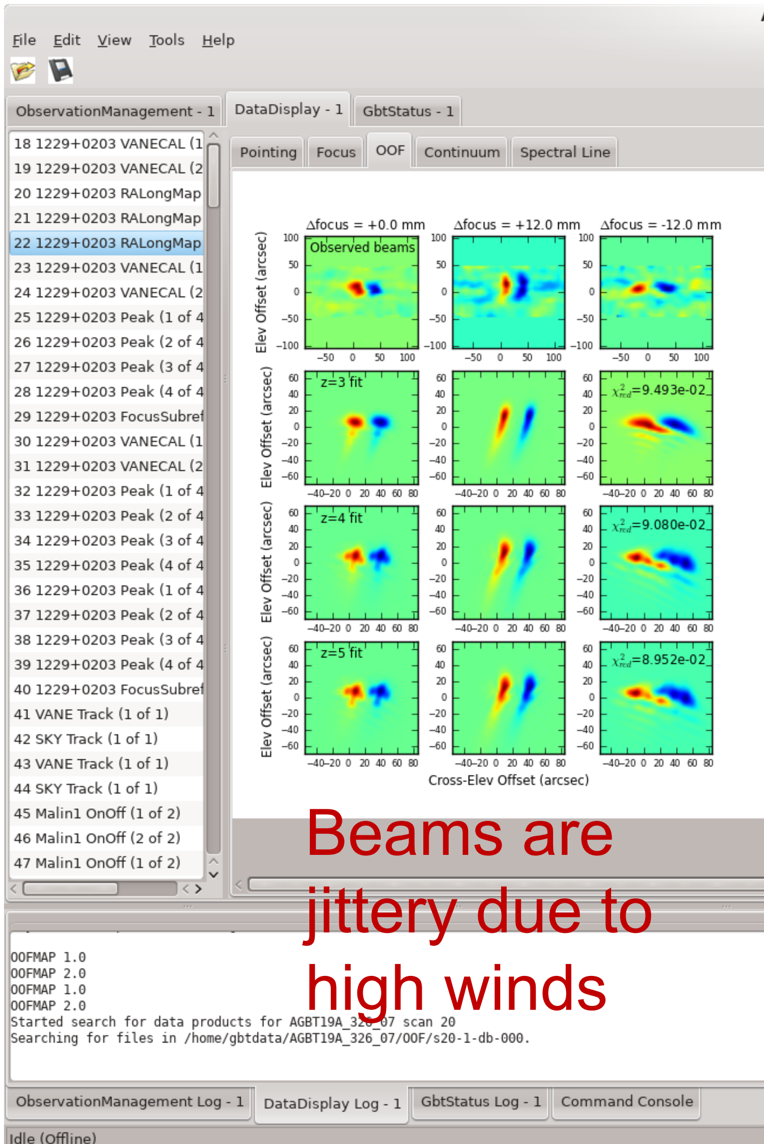
The "observed" beams should not be streaks or very elongated.

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

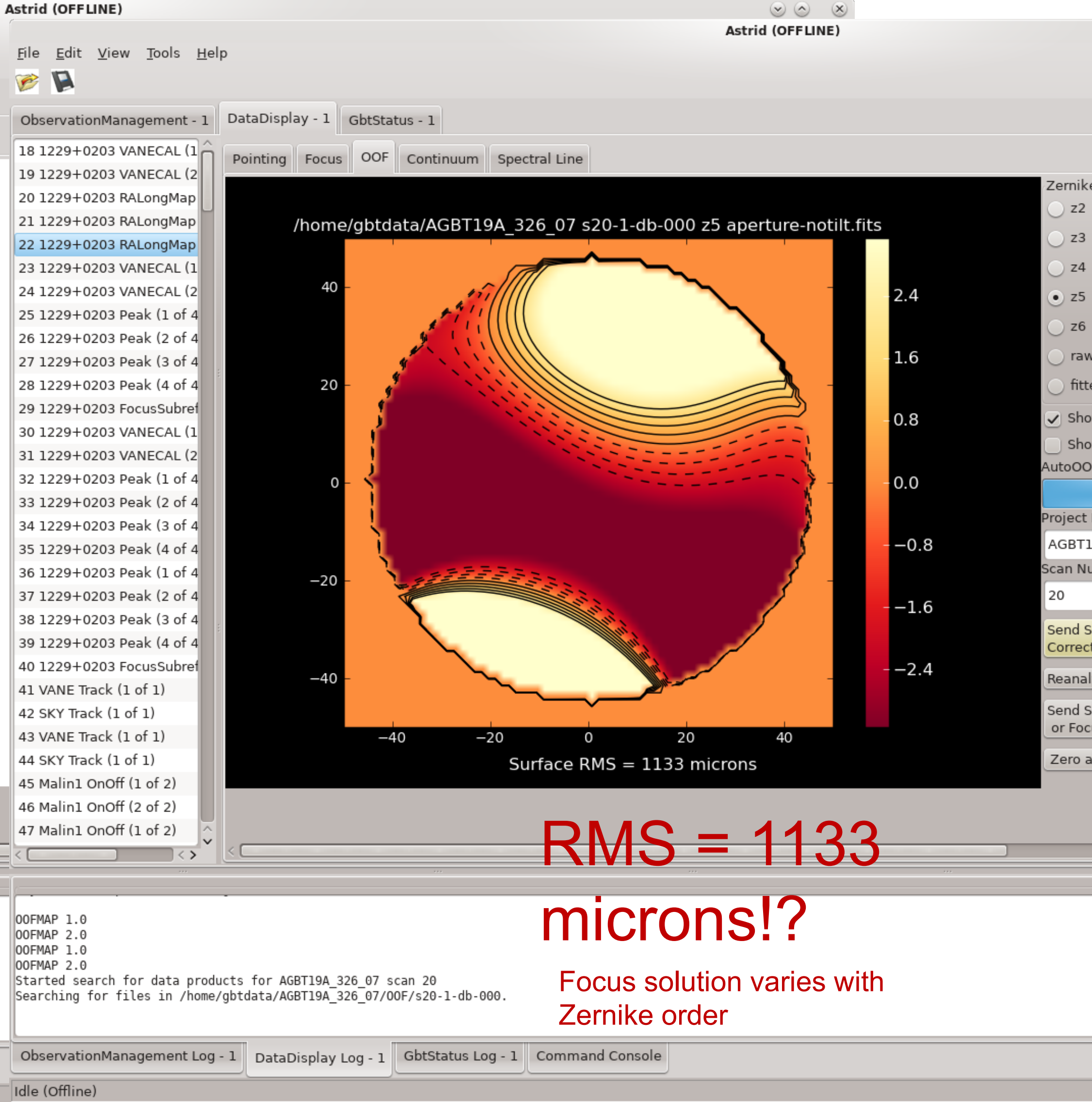
Do not apply OOF corrections if you cannot trust the results.



Bad OOF in Windy Conditions



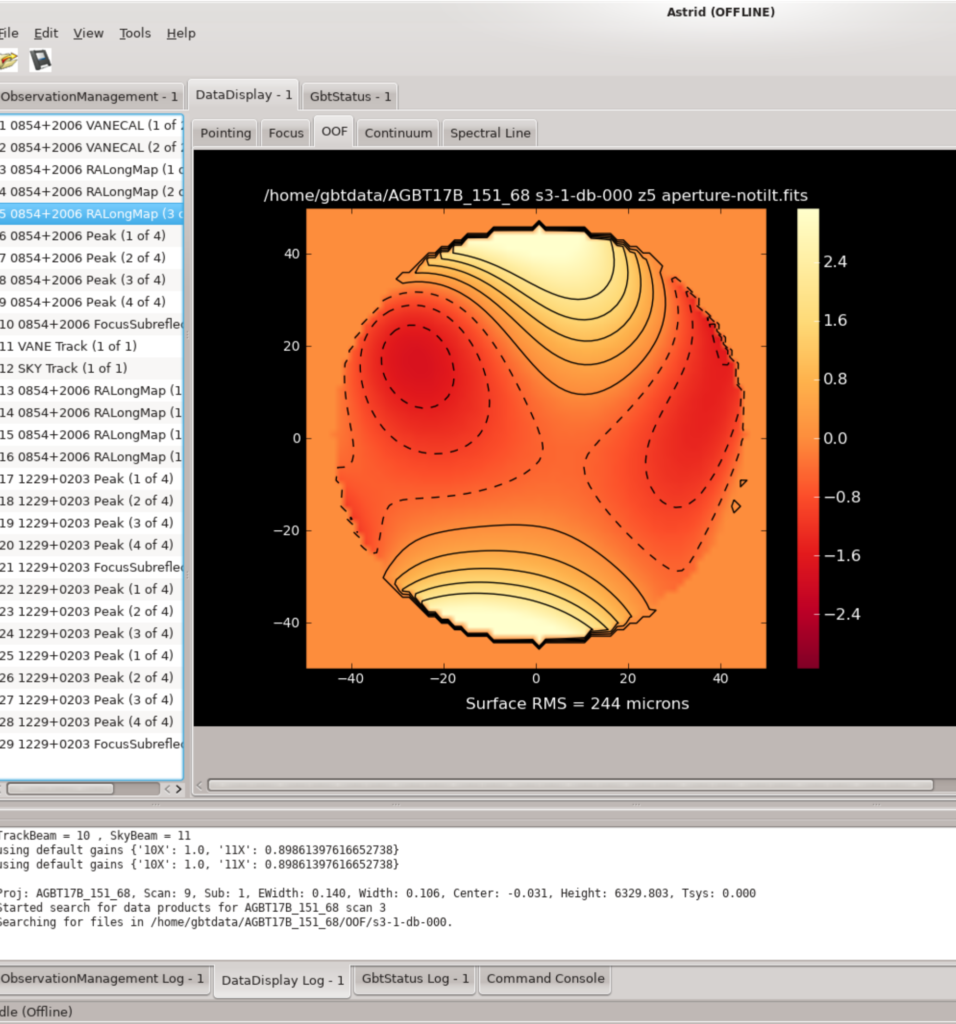
Beams are jittery due to high winds

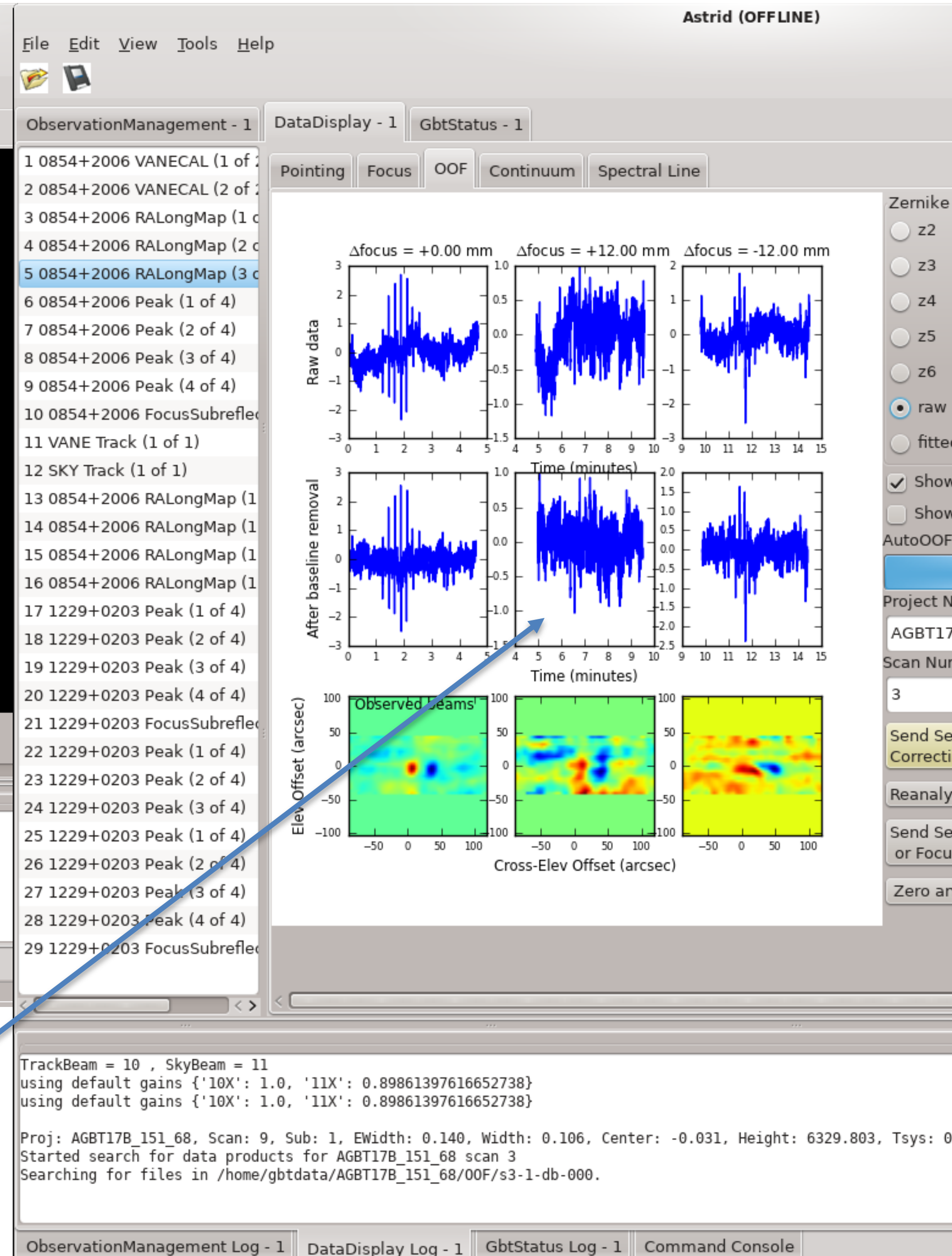


RMS = 1133 microns!?

Focus solution varies with Zernike order

Marginal OOF with borderline S/N

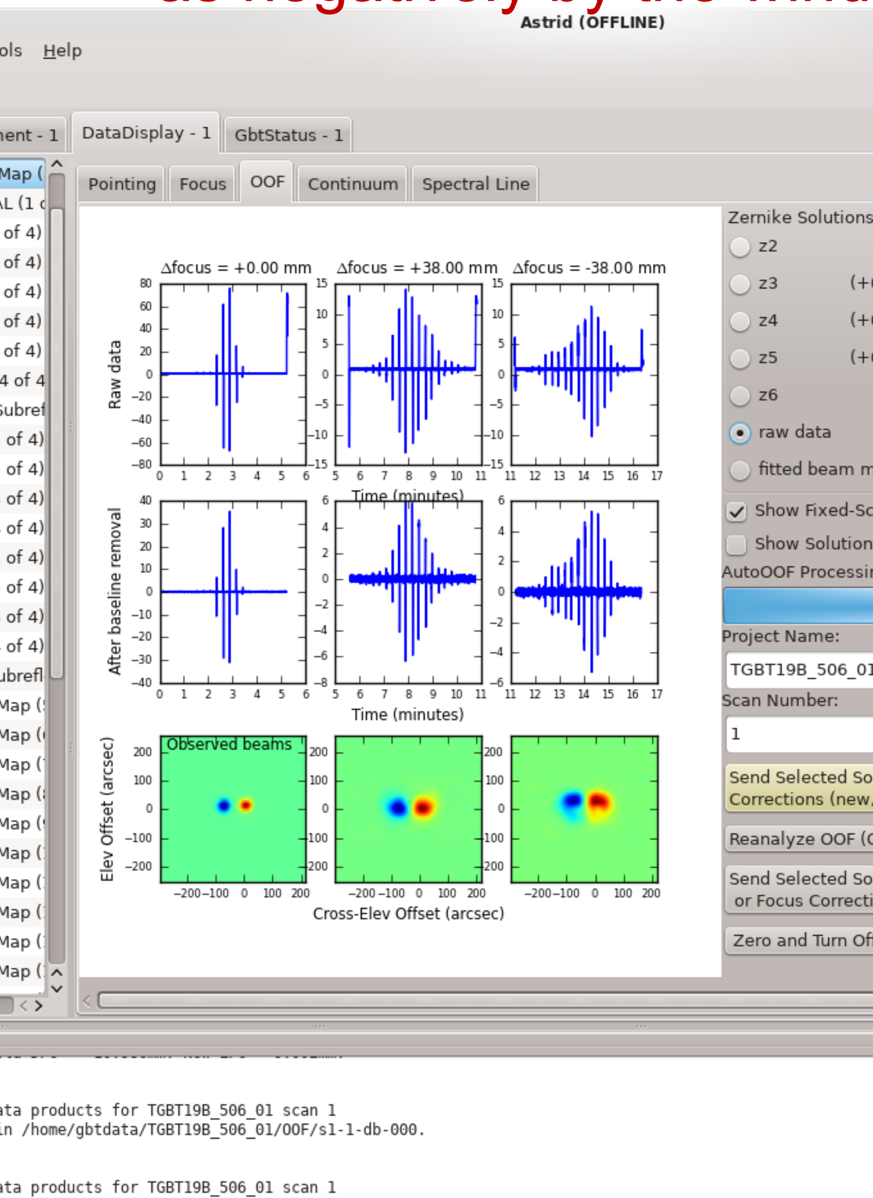


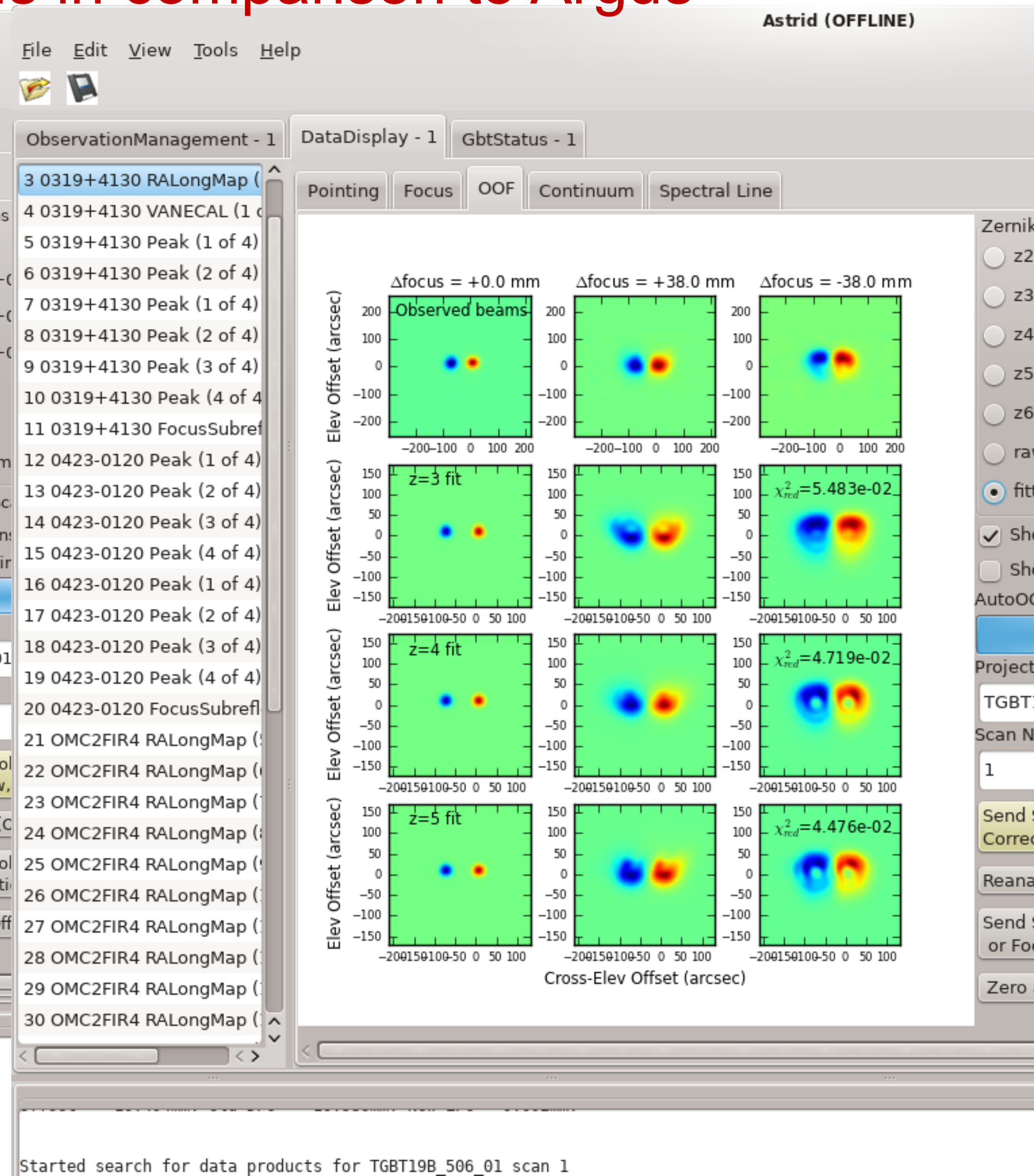


RMS=244microns
which is reasonable,
but S/N of data low

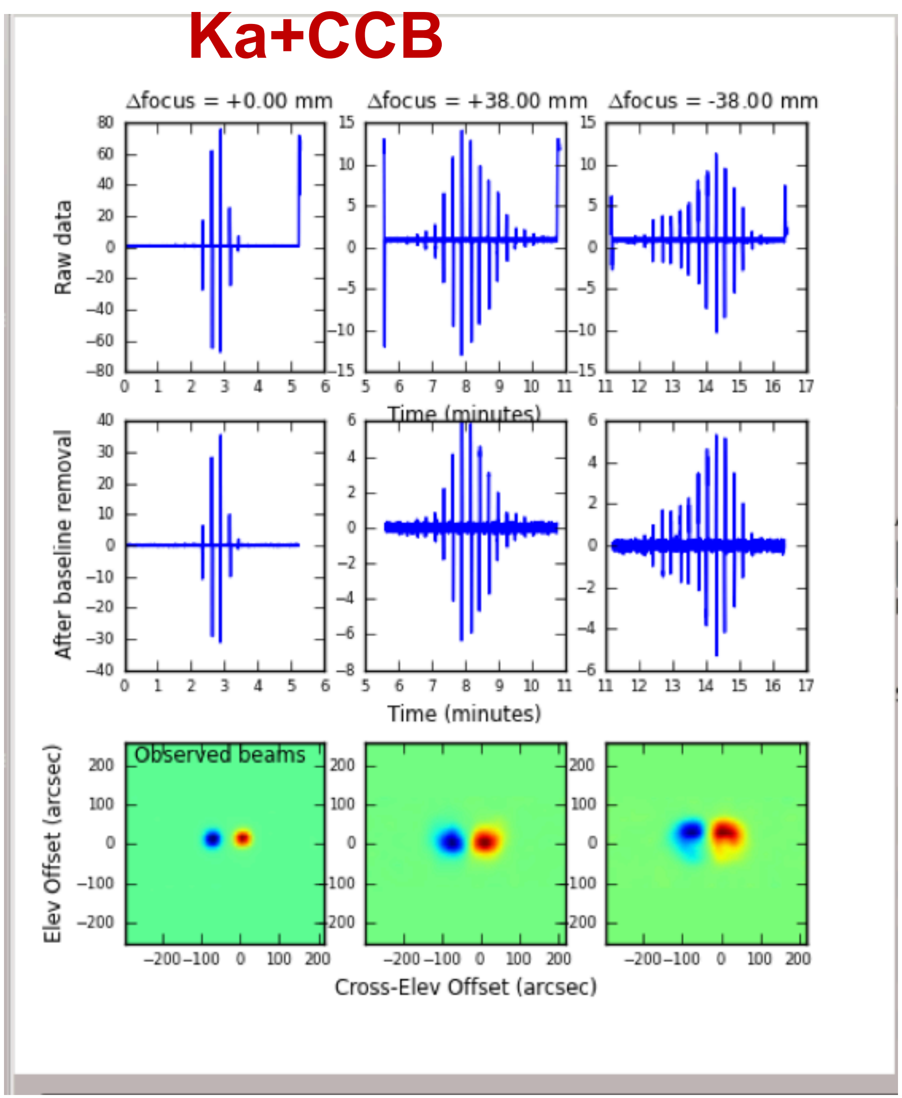
Example Ka+CCB OOF

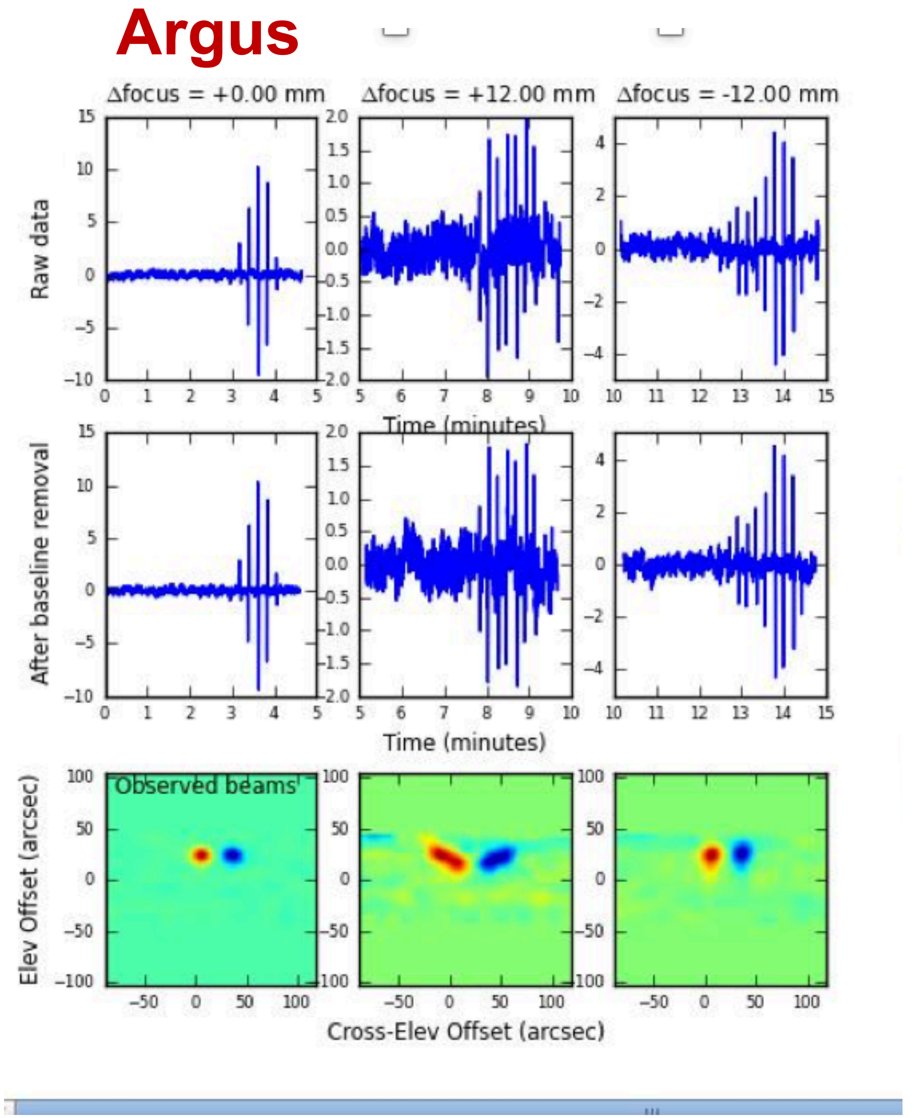
OOF solutions higher S/N in Ka-band and not affected as negatively by the winds in comparison to Argus





Same Source, comparison of S/N





Much higher S/N in Ka+CCB in raw data given by the upper blue line plots showing sig-ref beam data streams.

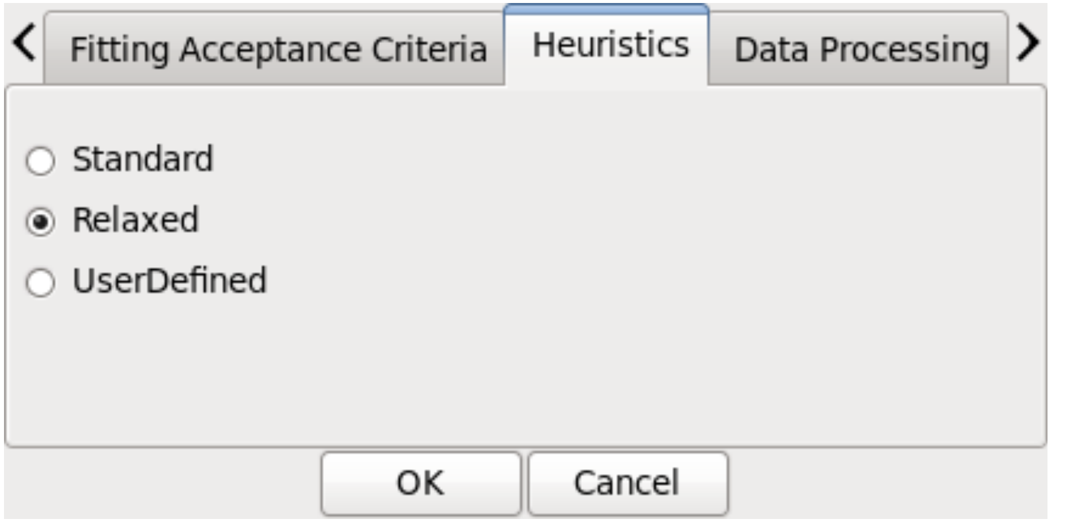
Pointing & Focus

- 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.**

Astrid/GFM

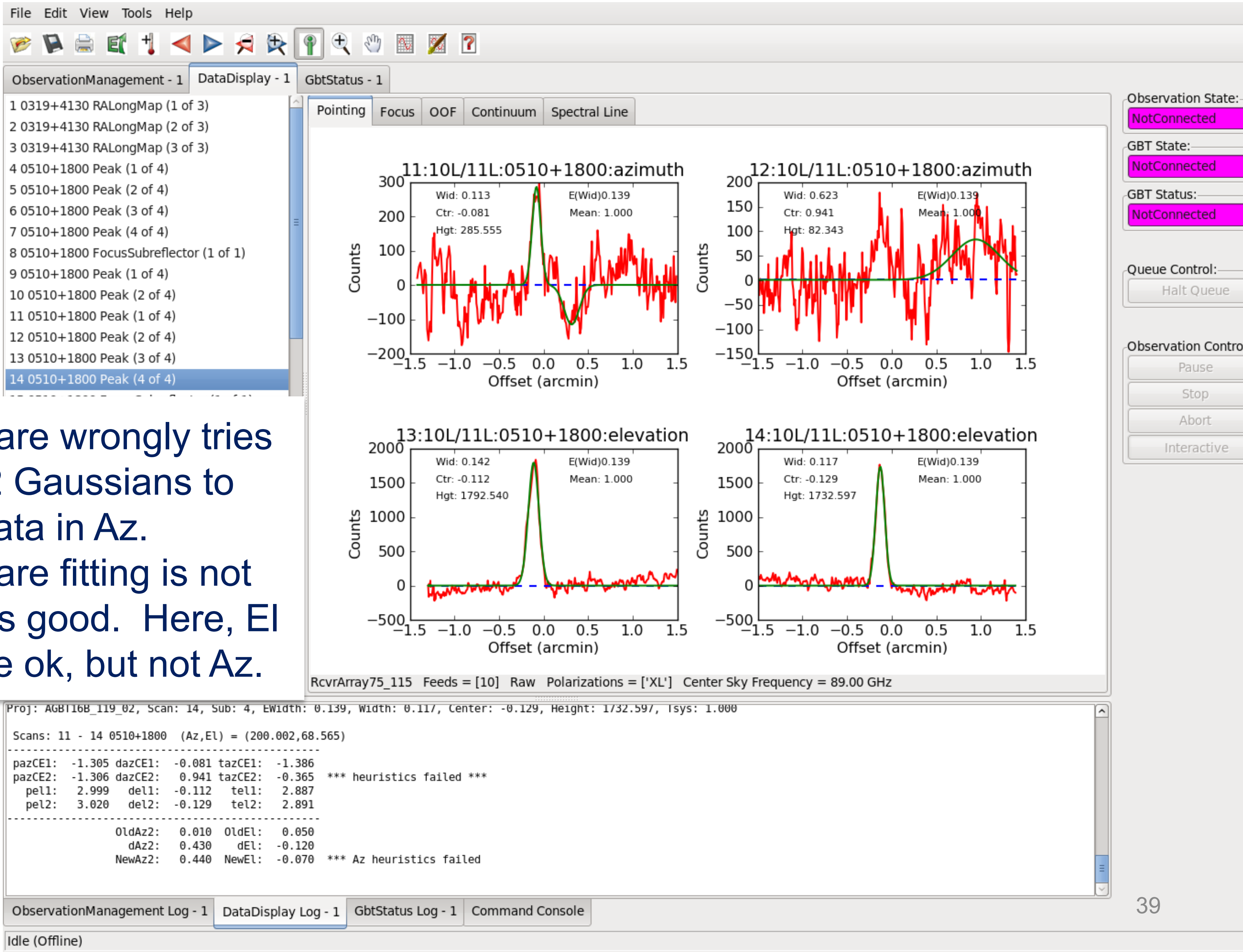
For Argus:

- Select Heuristics = "Relaxed"



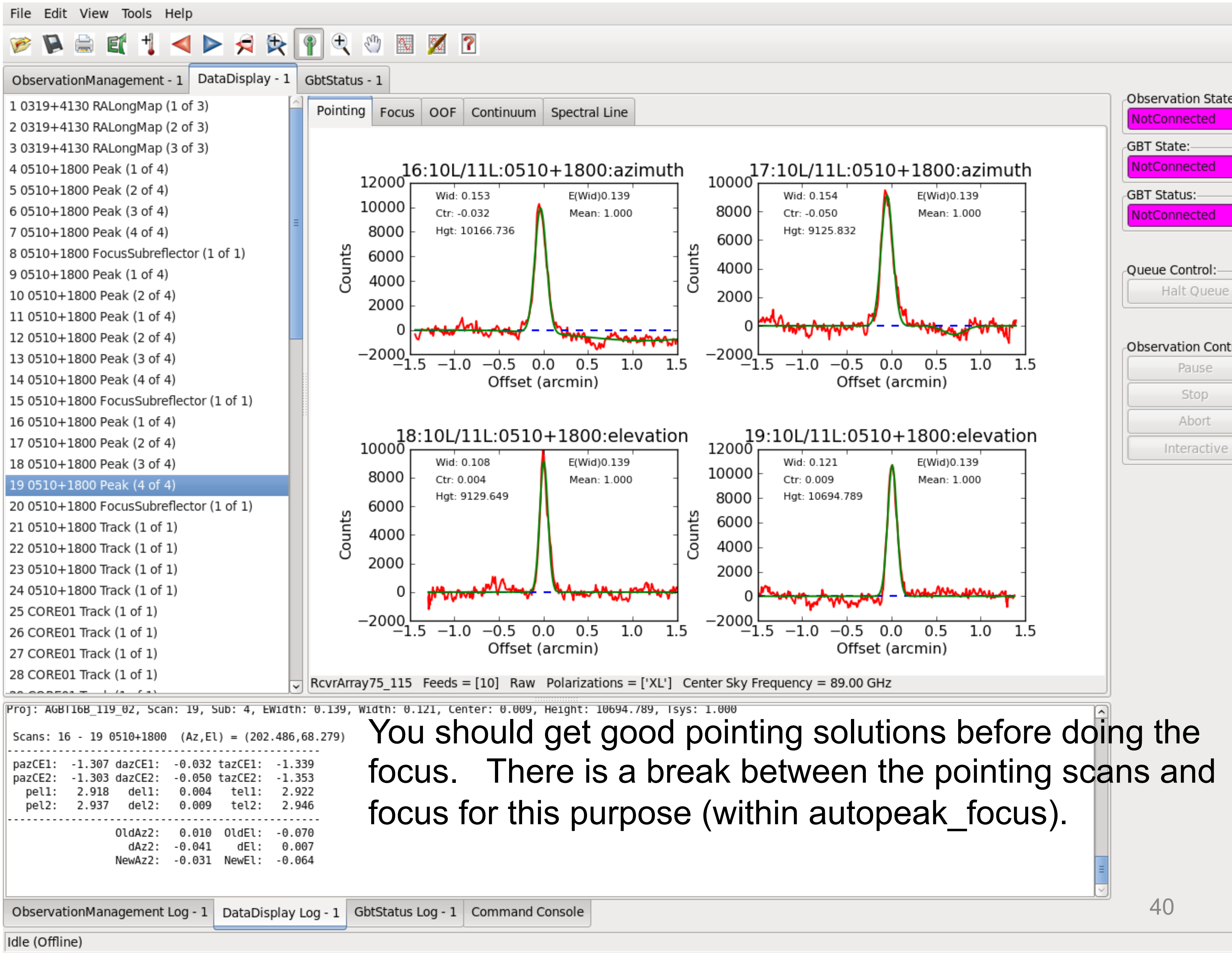
This should be done under both the pointing and focus tabs.

Example Pointing: El offset by 7-8" so source weak in Az scans



Software wrongly tries to fit 2 Gaussians to raw data in Az. Software fitting is not always good. Here, El fits are ok, but not Az.

After applying El corrections (previous point), this point was successful in both Az and El



You should get good pointing solutions before doing the focus. There is a break between the pointing scans and focus for this purpose (within autopeak_focus).

Sending Pointing (and focus) corrections to the telescope

5.1.3.4 Send Corrections

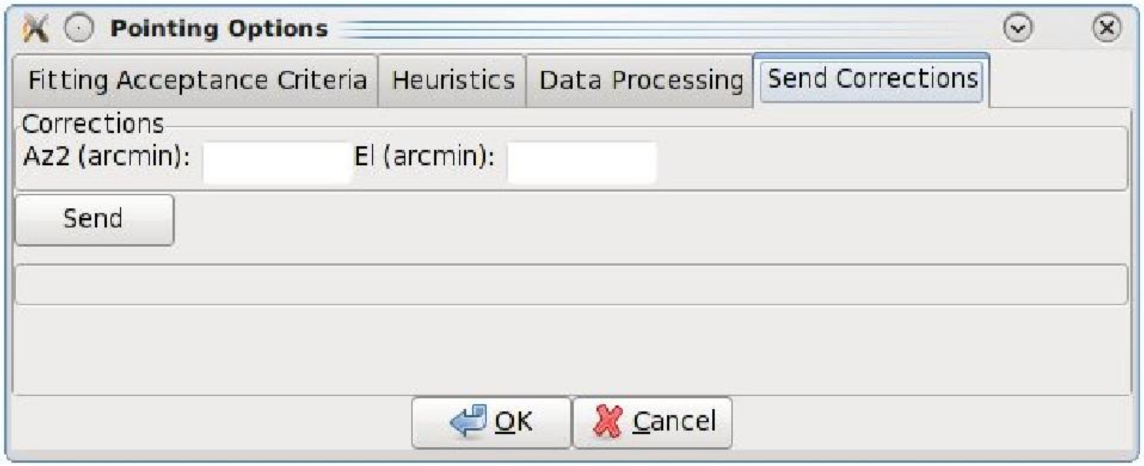
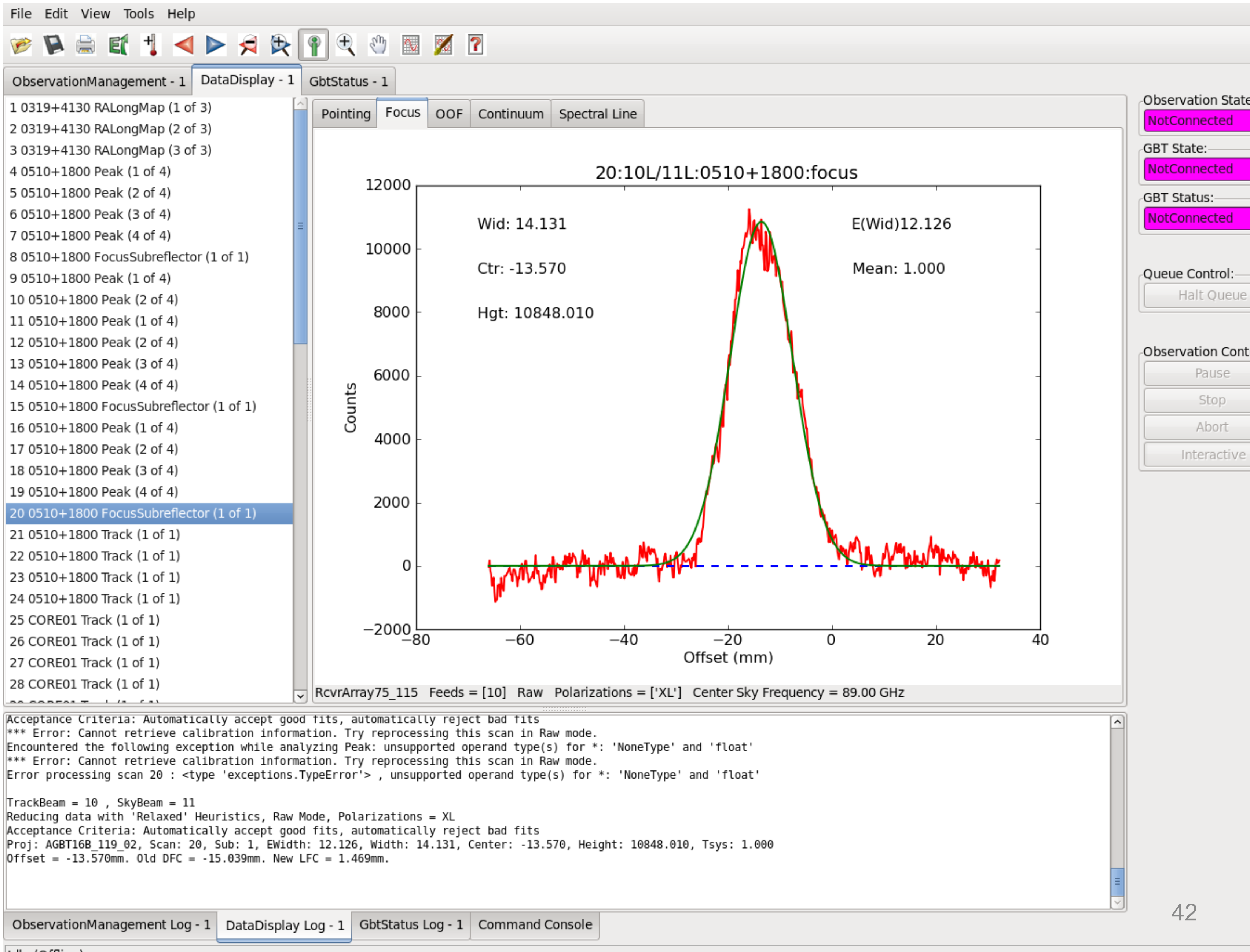


Figure 5.6: The pop–up menu to manually send pointing corrections to the telescope.

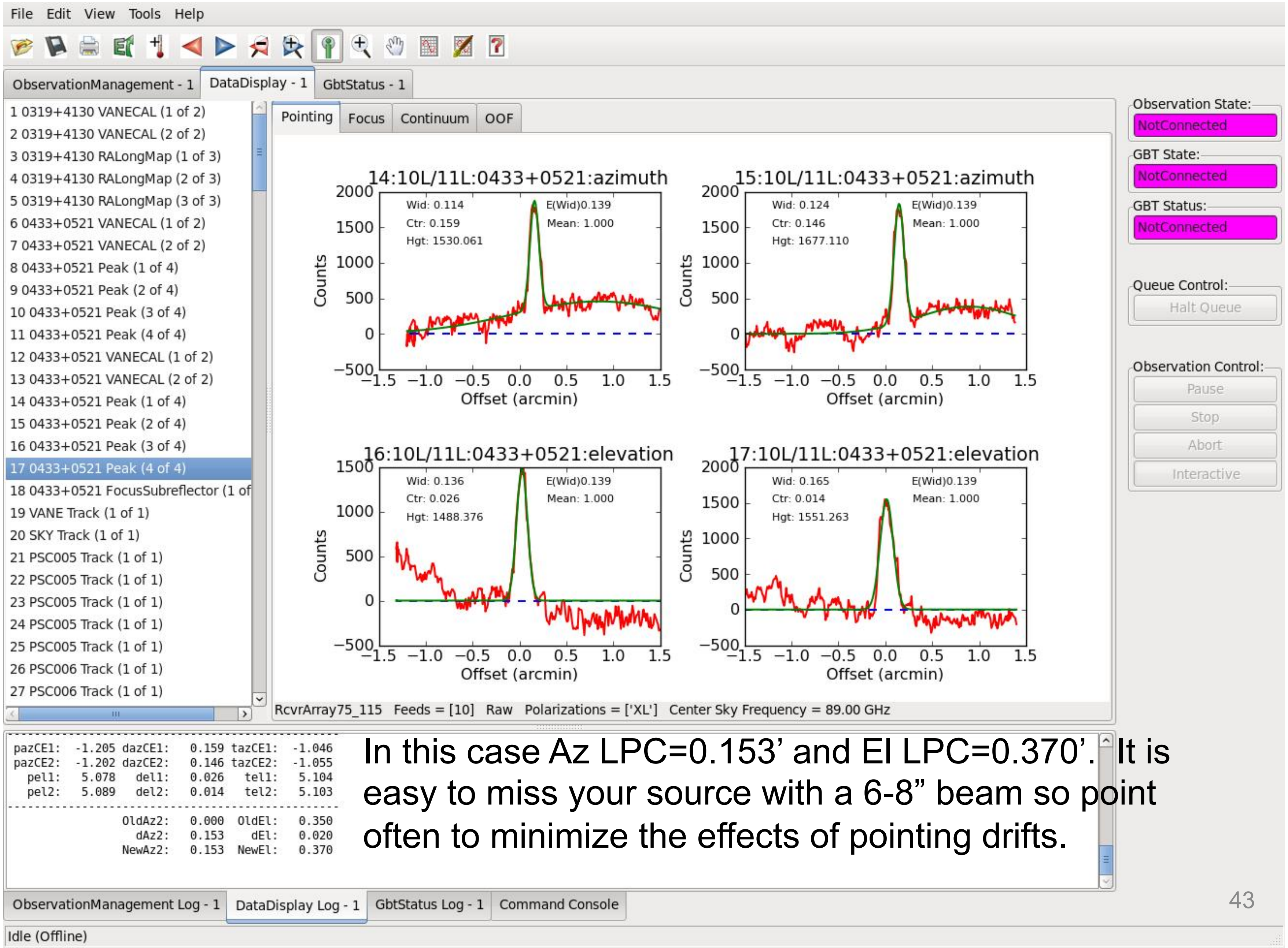
Users can send corrections manually to the telescope within GFM using Tools-> Options-> Send Corrections Tab.

One can move the cursor over the plot windows and GFM will display “X” position (arcmin for pointing window) in lower left. If needed, one can manually move the cursor over the peak and derive a solution by eye, e.g., New_LPC=Old_LPC+X.

Example Focus scan after good pointing corrections applied
(LFC typically within +/- 4 mm for Argus)

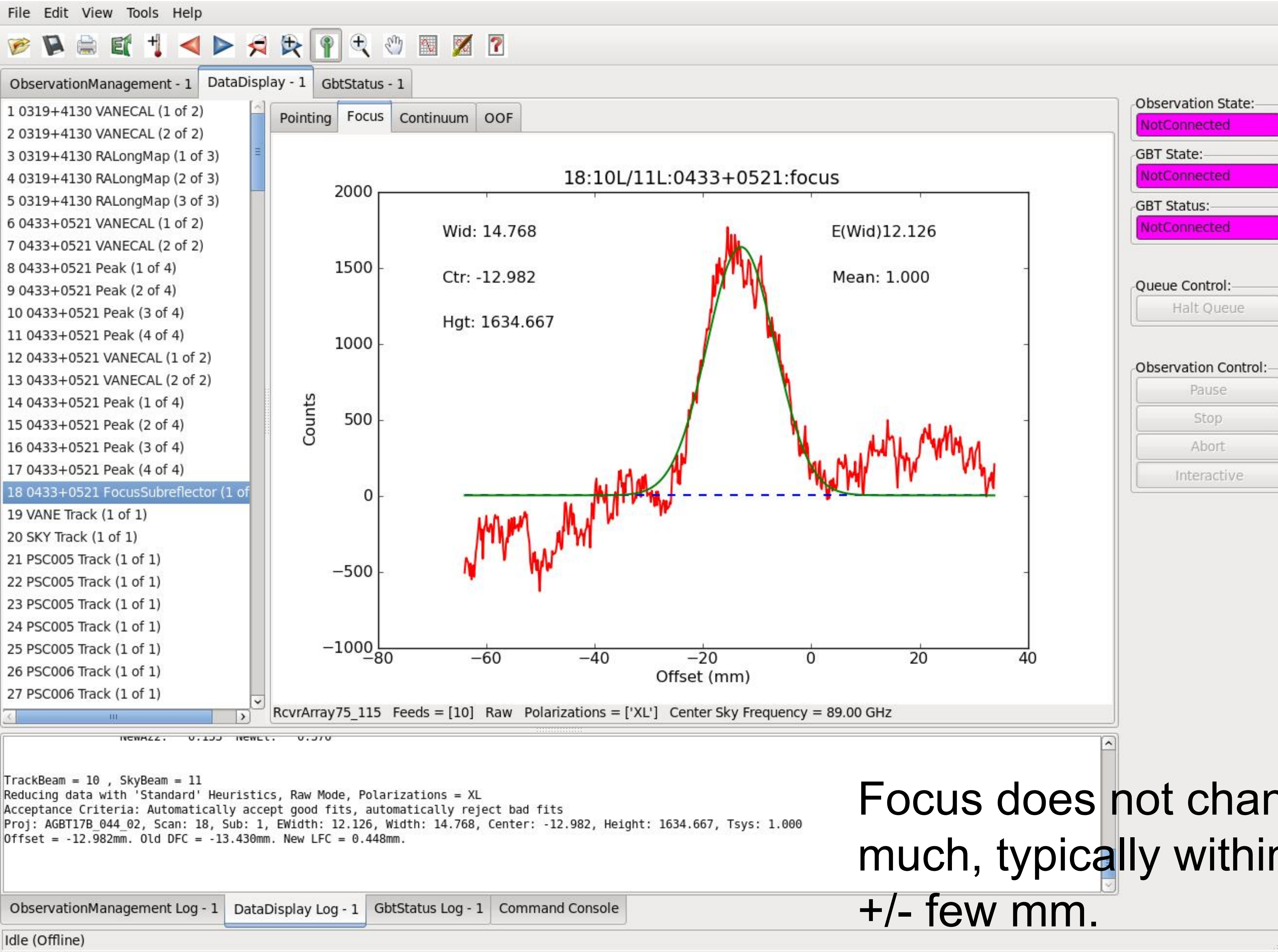


Another Good Pointing Example



In this case Az LPC=0.153’ and El LPC=0.370’. It is easy to miss your source with a 6-8” beam so point often to minimize the effects of pointing drifts.

Another Good Focus Scan

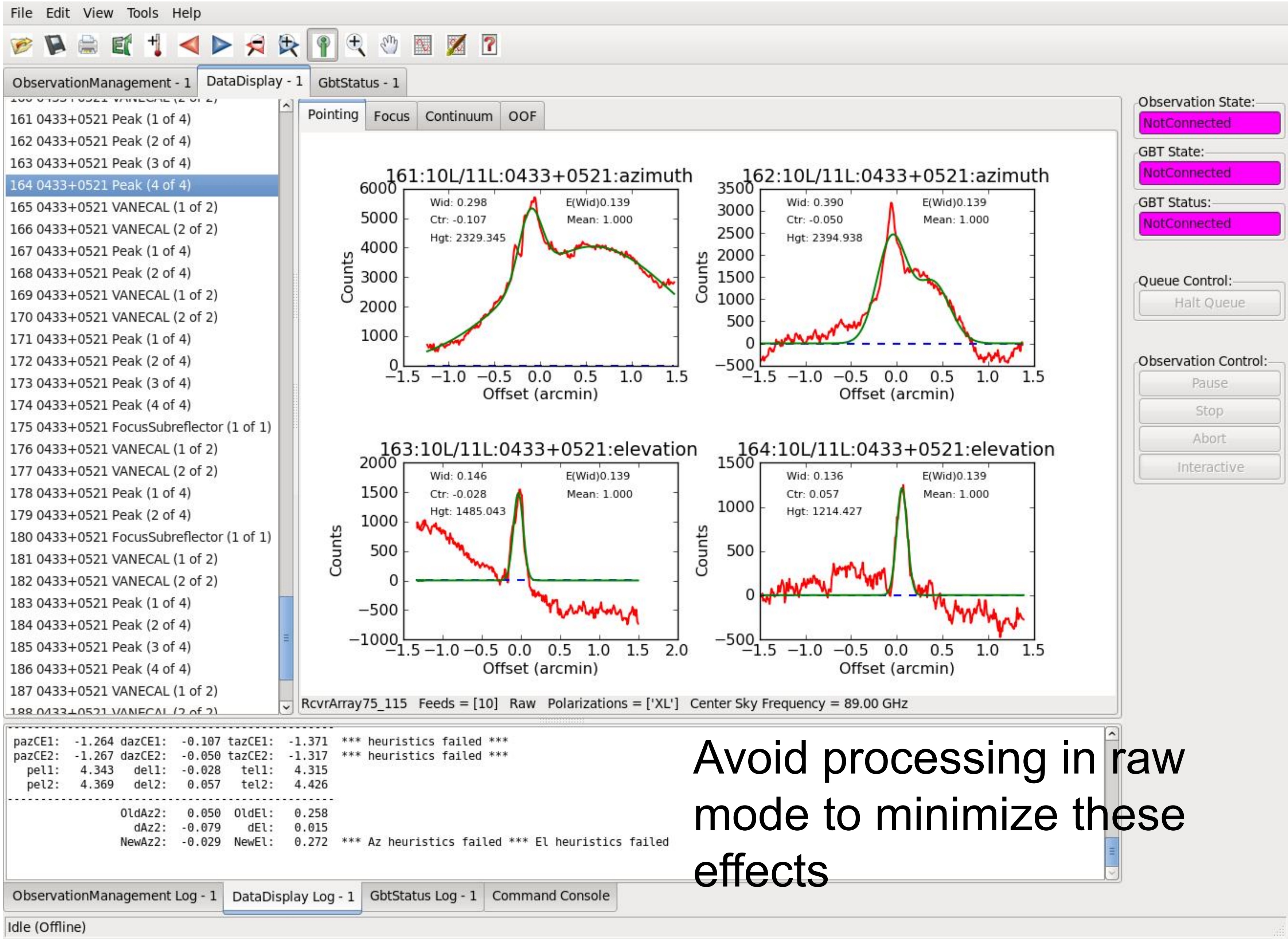


Focus does not change much, typically within +/- few mm.

Pointing Scans showing Servo-System Jitters

Avoid using solutions from bad scans 68&70 with servo issues and use good scans 69&70,
e.g., here:
NewAz2=0.133+ 0.016= 0.149
NewEl=0.391+ 0.006=0.397

Example pointing scans affected by changing sky



Avoid processing in raw mode to minimize these effects

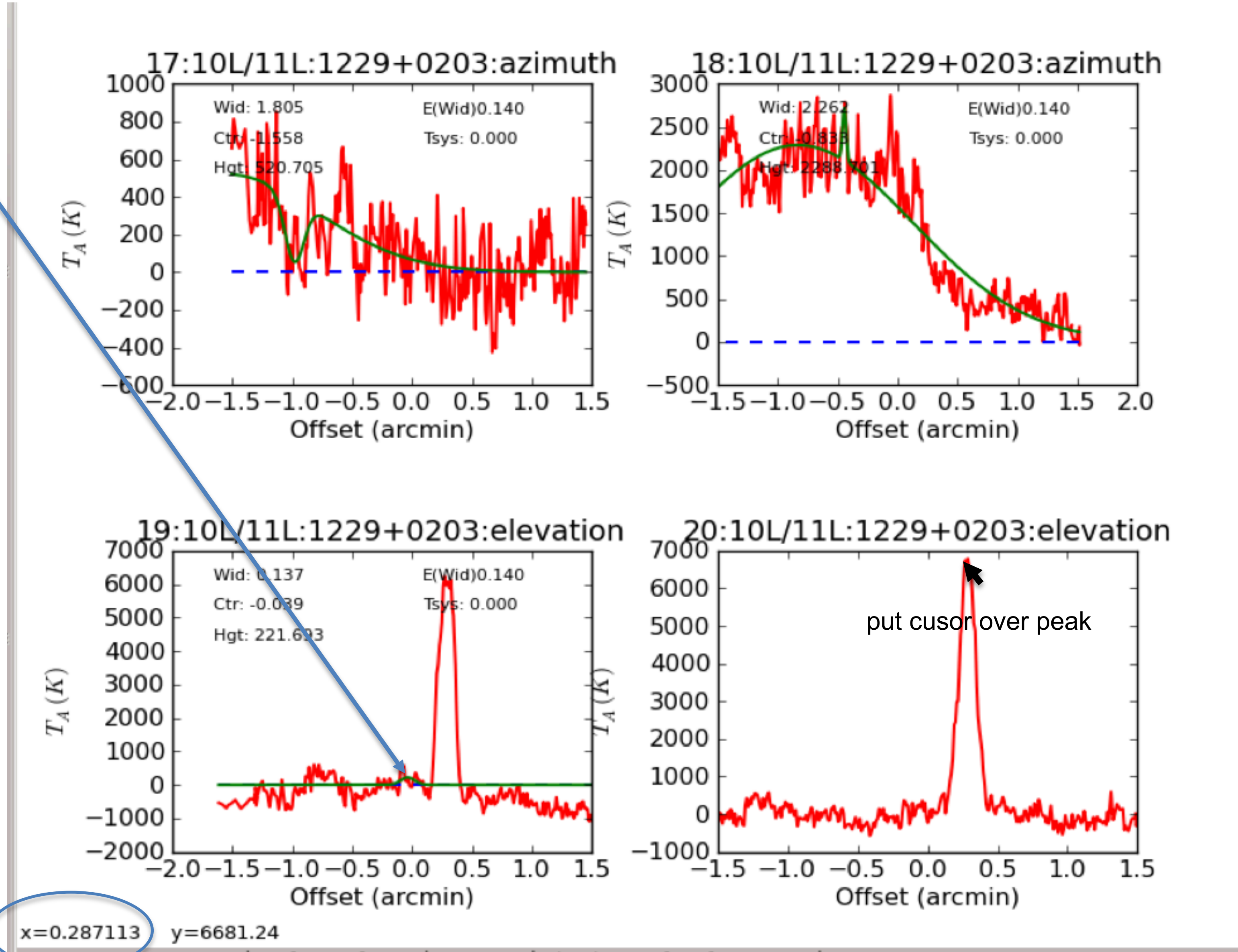
Manually finding solution when astrid gives a bad fit

Pointing off in elevation and software fits small noise bump near 0.0 in el and fails to fit bright source.

Move cursor over elevation peak and delta-solution is given by the cursor position in x

New El LPC = Old El LPC + X

Manually fitted solution given by x



Sending Pointing (and focus) corrections to the telescope

5.1.3.4 Send Corrections

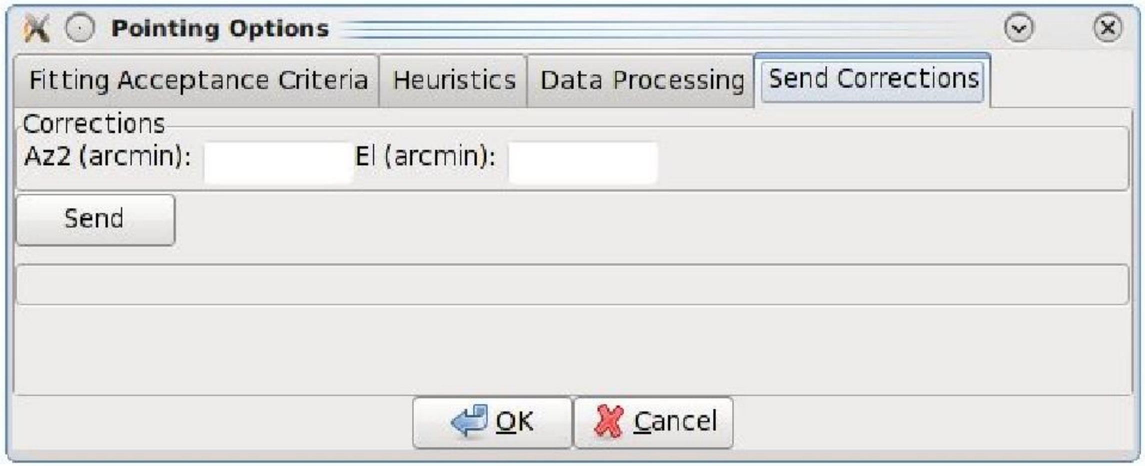
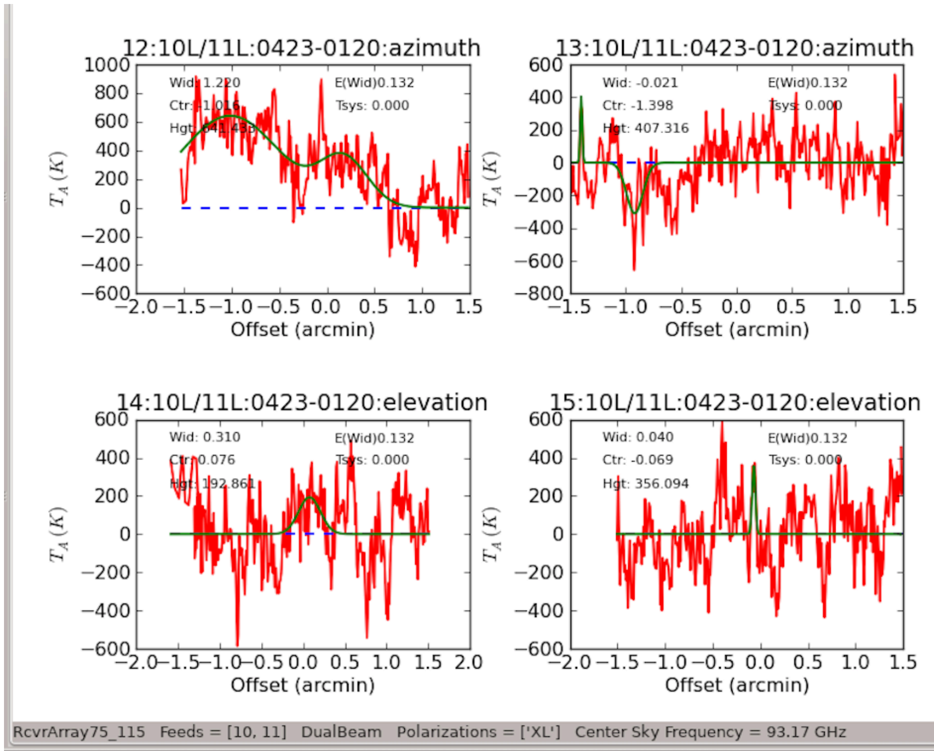


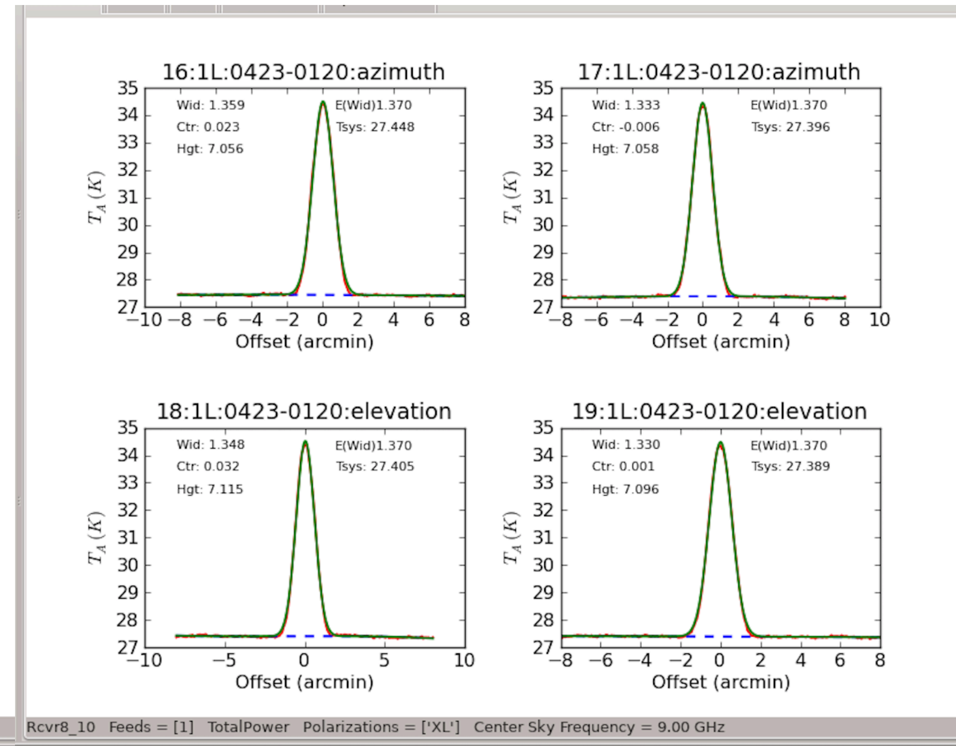
Figure 5.6: The pop–up menu to manually send pointing corrections to the telescope.

Users can send corrections manually to the telescope within GFM using Tools-> Options-> Send Corrections Tab.

One can move the cursor over the plot windows and GFM will display “X” position (arcmin for pointing window) in lower left. If needed, one can manually move the cursor over the peak and derive a solution by eye, e.g., New_LPC=Old_LPC+X.

Example low S/N with Argus➔ move to X-band





Argus

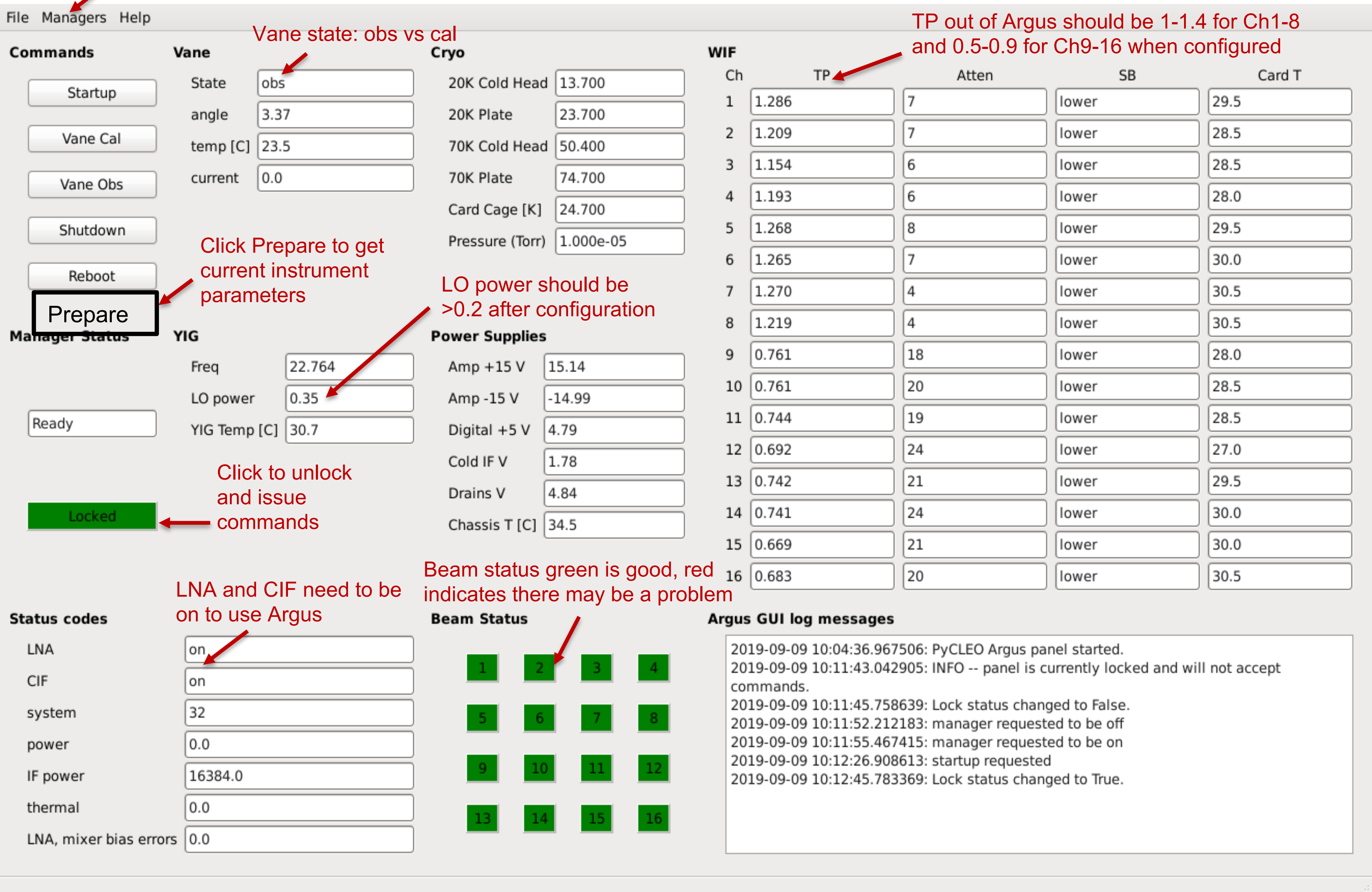
(green lines are a fit, the red lines are the observed data)

X-band pointing has higher S/N and more reliable in general.

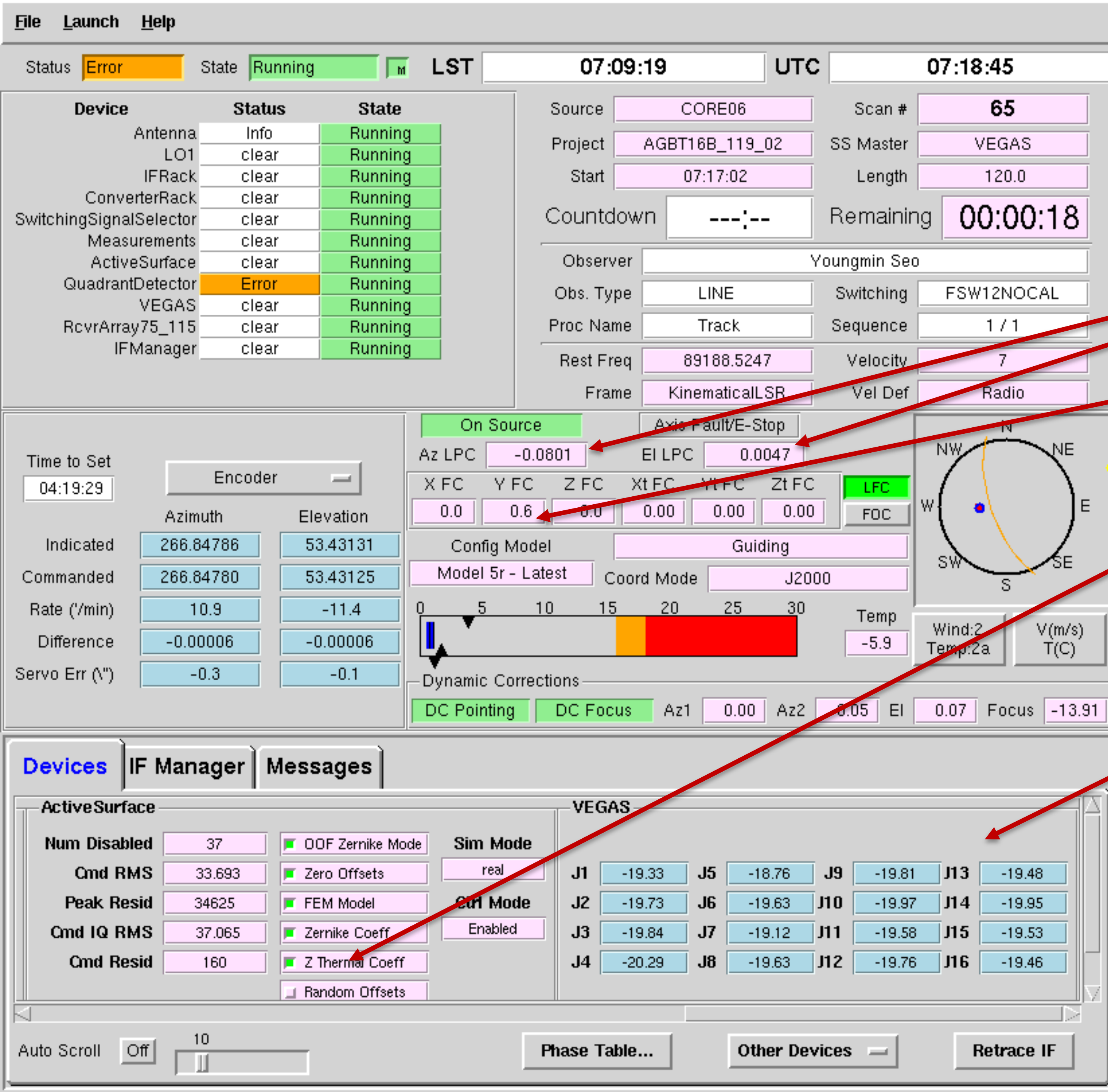
Monitoring Argus and Logs

- Cleo status: LPC’s, YFC, active surface
- Balancing: VEGAS levels -20.0, IFRack 1.5 V
- Cleo Argus: YIG LO_power ~0.1-0.6; vane_status: obs/cal
- Sampler Log files at: /home/gbtlogs/RcvrArray75_115*
- Argus Manager Log at: /home/gbt/etc/log/fire/RcvrArray75_115*
- Astrid Log can be generated via: getastridlog ProjectID

Argus Cleo Window



Cleo Status Window



Az,El LPCs
Focus YFC

Active Surface ON with Thermal corrections from OOF

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

Balancing Notes for Argus+Vegas

- All Argus channels balance across the full frequency range of the instrument. Optical-driver 4 runs out of attenuation for some frequencies, but is still within operational range, and some of the power levels going through the converter rack are marginal.
- **Vegas** should balance for all banks and all frequencies near the **nominal -20 value**. When the vane is covering the array, VEGAS will show values of about -15 if previously balanced on the sky (i.e., the vane is ~5dB (factor of ~3) brighter than the sky).
- The target levels for **the IFRack are 1.5 V.**

Mapping Argus Beams to VEGAS and IF Channels

VEGAS Bank	VEGAS (J)	Argus Beam	Converter Module CM	IFrack Optical Driver OD	Dedicated Fibers
A1	1	9	1	1	-
A2	2	11	5	3	-
B1	3	10	2	2	-
B2	4	12	6	4	-
C1	5	1	3	-	1
C2	6	3	7	-	3
D1	7	2	4	-	2
D2	8	4	8	-	4
E1	9	13	9	5	-
E2	10	15	13	7	-
F1	11	14	10	6	-
F2	12	16	14	8	-
G1	13	5	11	-	5
G2	14	7	15	-	7
H1	15	6	12	-	6
H2	16	8	16	-	8

Yig LO_power vs Frequency

Frequency [GHz]	Yig LO_power [V]
75	0.06
80	0.15
85	0.3
90	0.4
100	0.5
105	0.6
115	0.3

Argus Quick Trouble-Shooting

(1) Make sure cif and lan are both on (run startup script).
(2) Make sure vane is in desired position (e.g., obs for looking at the sky; cal for looking at the vane).
(3) Make sure there is LO power going to the YIG after configuration.
(4) The status of the instrument is checked before each scan and the scan will be aborted if there is not enough yig power. If low yig power, reconfigure and try again (it takes a few minutes for the yig to have sufficient power if changing frequency by a large amount [>5GHz]).
(5) If Argus is in a fault state after configuration and multiple attempts to collect data, then
   (a) Turn manager off and back on again and reconfigure.
   (b) If (a) does not work, then have operator restart turtle, and reconfigure.
   (c) If still having problems, then have operator call on-call support expert.

(See Section 13.4.3 of observer’s guide for a more extensive trouble-shooting guide)

Calibration with One Load, T_A^*

With a chopper wheel/vane and a simple temperature sensor, one can calibrate to the approximate Ta* scale without any knowledge of the sky (e.g., Kutner & Ulich 1981).

Ta* = Tcal [ON – OFF]/[Vamb– Vsky]

Tcal = [Tamb – Tsky]/eta_l * exp(tau_o A)

but with some algebra eta_l and tau_o drops out to first order (where Tamb = temperature of vane) and

Tcal = (Tatm – Tbg) + (Tamb-Tatm) exp(tau_o A)

The values Tatm and tau_o are derived from GBO weather database and the above expression is used for detailed calibration, but within about 3% **Tcal ~= Tamb** for most observations.

Temperature Scales

- $T_a = T_{sys}$ (ON-OFF)/OFF (GBT typically uses uncorrected antenna temperature)
- $T_a' = T_a \exp(\tau_o A)$ (corrected for atmosphere)
- $T_{mb} = T_a'/\eta_{mb}$ (η_{mb}~1.3 η_a)
- $T_a^* = T_a'/\eta_l$ (Argus uses Ta*, η_l=~0.985 for the GBT)
- $T_a'/S\nu = 2.84\ \eta_a$ (for the GBT)

Temperature scales can vary a lot.
Don’t blindly use Ta from sensitivity calculator.

Use Case: 12CO (115 GHz) in Galactic Center

Zenith opacity = 0.5

Airmass =3.5

Ta=100 mK

Ta* = 100 mK *exp(0.5*3.5)/0.985 = 580 mK

Tmb = 0.985 Ta*/eta_mb = 2.3 K

(Ta not equal to Tmb; in this case, Tmb/Ta= 23 which would correspond to an error of 500 in the integration time if using the Ta temperature scale when needing Tmb).

Calibration:
Flux Density vs Antenna Temp vs Main-Beam Temp

$P_{rec} = ½\, A_e\, S_\nu \Delta\nu = k\, T_a'\, \Delta\nu$

$A_e = \eta_a\, (\pi/4)\, D^2$

$S_\nu = 3520\, T_a' / (\eta_a\, [D/m]^2)$

➔ $\mathbf{T_a'/S_\nu = 2.84\, \eta_a}$ for the GBT (η_a=0.71 at low ν)

- Know S_ν (use ALMA calibration database available online) and derive η_a from measured Ta'
- Measure FWHM from good pointing scans or within your image to derived η_{mb} and Tmb; $\mathbf{Tmb = Ta'/\eta_{mb}}$
- $\mathbf{\eta_{mb} = 0.8899\, \eta_a\, (\theta_{FWHM}\, 100m/\lambda)^2}$ (assumes Gaussian beam, where beam FWHM is in radians)

Calibration GBT Memo#302

Table 2: 86GHz GBT Efficiency and Calibration Parameters

Dish Diameter........................	D	100 m
RMS Surface Accuracy	ϵ	$235 \pm 15\,\mu$m
Beam Size Parameter.................	κ	1.20 ± 0.02
Aperture Efficiency..................	η_a	0.347 ± 0.032
Main-Beam Efficiency	η_{mb}	0.442 ± 0.043
Corrected Main-Beam Efficiency.....	η_M^*	0.465 ± 0.035
Jupiter Beam Efficiency(43″diameter)	$\eta_{\rm Jupiter}$	0.53 ± 0.05
Moon Beam Efficiency (32′ diameter)	$\eta_{\rm Moon}$	0.814 ± 0.029
Rear Spillover Efficiency[a]	η_l	0.985 ± 0.015
Forward Spillover Efficiency[b]	η_{fss}	0.965 ± 0.020

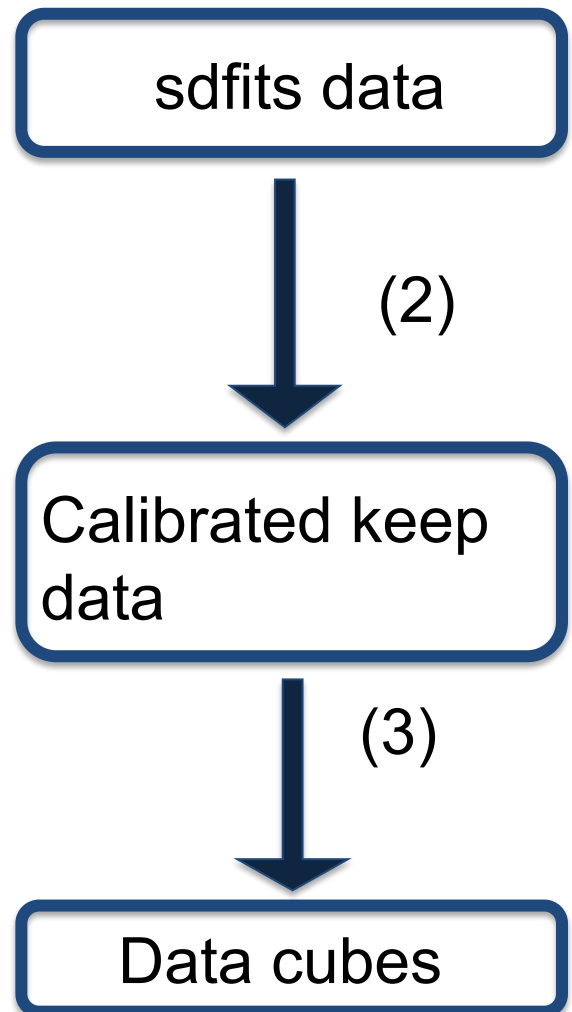
[a]Power in the forward 2π direction. [b]Factional power in the forward direction inside the $\sim 1^\circ$ diameter error pattern.

Argus Data "Flow" Chart

(1) The sdfits program is used to convert raw GBT and VEGAS data into a "sdfits" file.

(2) The sdfits data are calibrated to Ta* within gbtidl and saved to an output "keep" file.   The GBO weather database is used for Tatm and tau_o vs frequency and time.

(3) A map per frequency of the data is made using the gbtgridder program which outputs a data cube with associated weights.



GBO Data Directories

- Home area: /users/user_name
- Scratch data area: **/home/scratch**/user_name
- Raw gbtdata by project (e.g., AGBT16B_037_04): **/home/gbtdata**/AGBT16B_037_04
- Raw Vegas data by project: **/lustre/gbtdata**/AGBT16B_037_04/VEGAS
- sdfits data by project: **/home/sdfits**/AGBT16B_037_04

Public Data Processing Machines with lustre access:

- newton, planck, fourier (192GB ram)
- arcturus (132GB ram)
- Working data area:
- /home/scratch/user_name
- Extra temporary disk space on lustre (if needed): /lustre/pipeline/scratch/user_name

GBTIDL

- Data access (connecting to sdfits file)
  - gbtidl> online
  - gbtidl> offline,’AGBT16B_037_04’
  - gbtidl> filein,’mysdfitsfile.fits’
  - gbtidl> summary

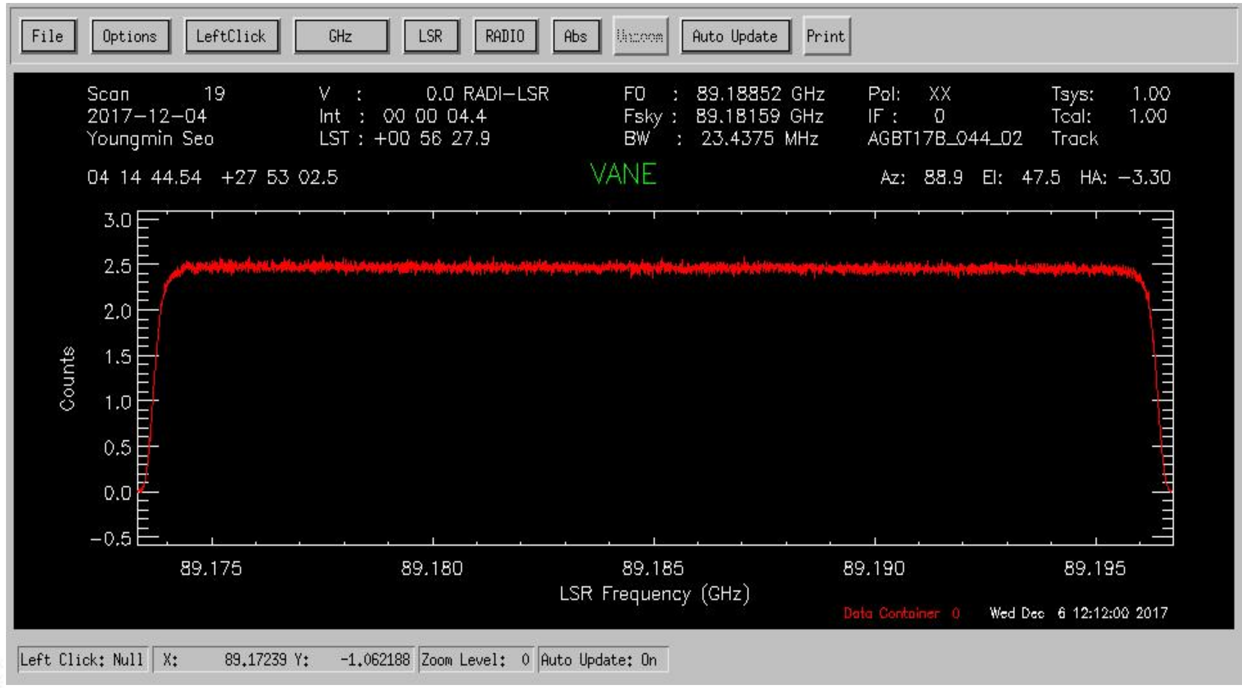
- User ”pro” directory used by gbtidl: /users/user_name/gbtidlpro

Argus GBTIDL scripts

/home/astro-util/projects/Argus/PRO:

- vanecal.pro – reduces vanecal observations and provides Tsys for all the beams
- getatmos.pro – returns opacity and ATM temperature for an input MJD and frequency
- argus_fsw.pro -- reduces frequency-switched scan
- argus_onoff.pro – reduces total-power ON-OFF scan

Checking Tsys in all 16 Beams



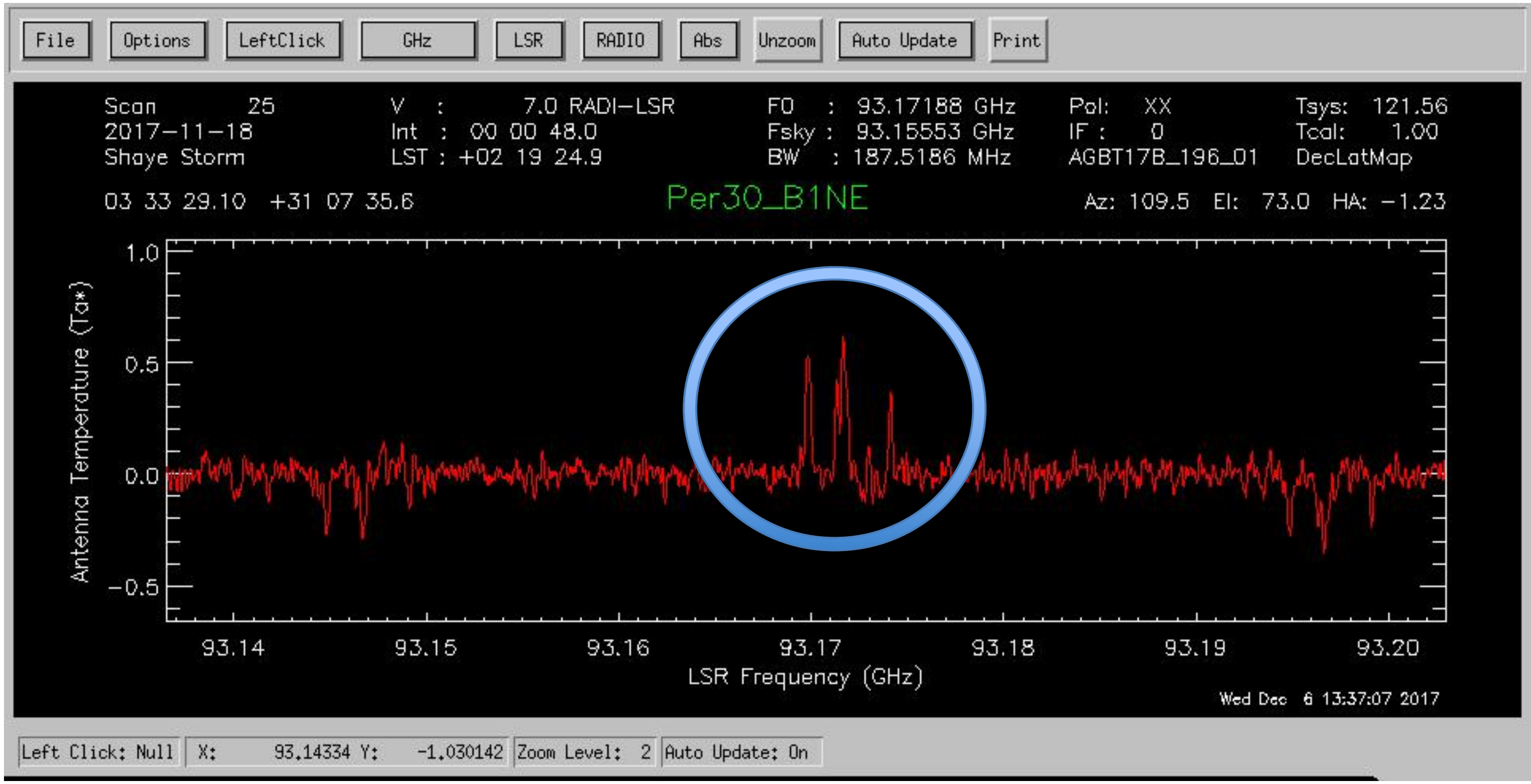
Run “vanecal” script in gbtidl. The VANE scan is 19 here.

```
GBTIDL ->
GBTIDL -> vanecal,19
% Compiled module: VANECAL.
Scan:    19 (IF:0 FD:10 PL:0)    Tsys:   1.00
% Compiled module: GETATMOS.
(zenith) Opacity(89.181592,58091.058) = 0.0754
AtmTsys(89.181592,58091.058) = 25.8880
Tatm(89.181592,58091.058) = 266.4082
beam, Tsys*[K]:         1        111.44295
beam, Tsys*[K]:         2        106.53290
beam, Tsys*[K]:         3        108.46513
beam, Tsys*[K]:         4        123.56812
beam, Tsys*[K]:         5        109.14355
beam, Tsys*[K]:         6        108.45131
beam, Tsys*[K]:         7        114.54882
beam, Tsys*[K]:         8        114.63135
beam, Tsys*[K]:         9        114.34038
beam, Tsys*[K]:        10        107.05890
beam, Tsys*[K]:        11        108.75631
beam, Tsys*[K]:        12        143.17644
beam, Tsys*[K]:        13        121.82879
beam, Tsys*[K]:        14        111.47134
beam, Tsys*[K]:        15        114.85225
beam, Tsys*[K]:        16        112.29262
Tcal, Twarm, tatm:       276.02470       277.54999       266.408
GBTIDL -> []
```

Returns weather information, e.g., zenith opacity (0.0754) and Tatm and computes Tsys* = Tcal x SKY/(VANE-SKY) for each beam. Note that Tcal ~ Twarm which is generally true.

Quick-Look of Data, example frequency switching

N2H+ transitions



GBTIDL>argus_fsw,25,18,fdnum=9

Reduces FSW scan 25 using VANE scan 18 for fdnum=9 (beam-10)

Mapping

- After calibration within gbtidl, users can make a data cube using the “gbtgridder” (eg.):

gbtgridder –c 11000:11251 –a 7 --noline –nocont –o myout mysave.fits

(grids channels 11000:11251, averaging over 7 channels) to make output cube and weight map.

➔myout_cube.fits, myout_weight.fits