Observing with Argus

David Frayer (Green Bank Observatory)

Version 2017.12

GREEN BANK OBSERVATORY

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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:

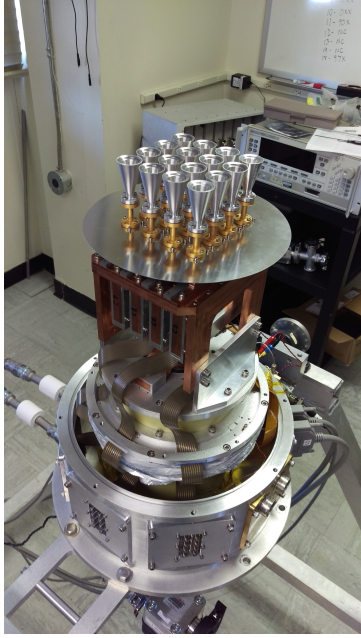
/home/astro-util/projects/Argus/PRO

- Links for GBT observing and data reduction

www.gb.nrao.edu/CDE2017

Argus Block Diagram

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



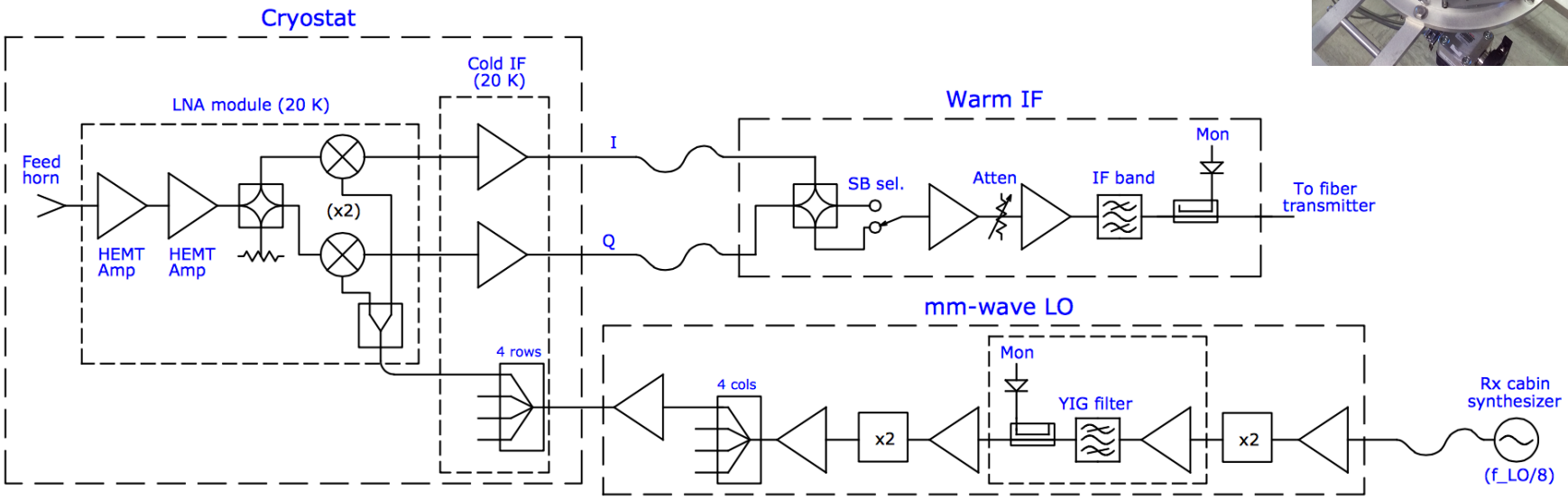


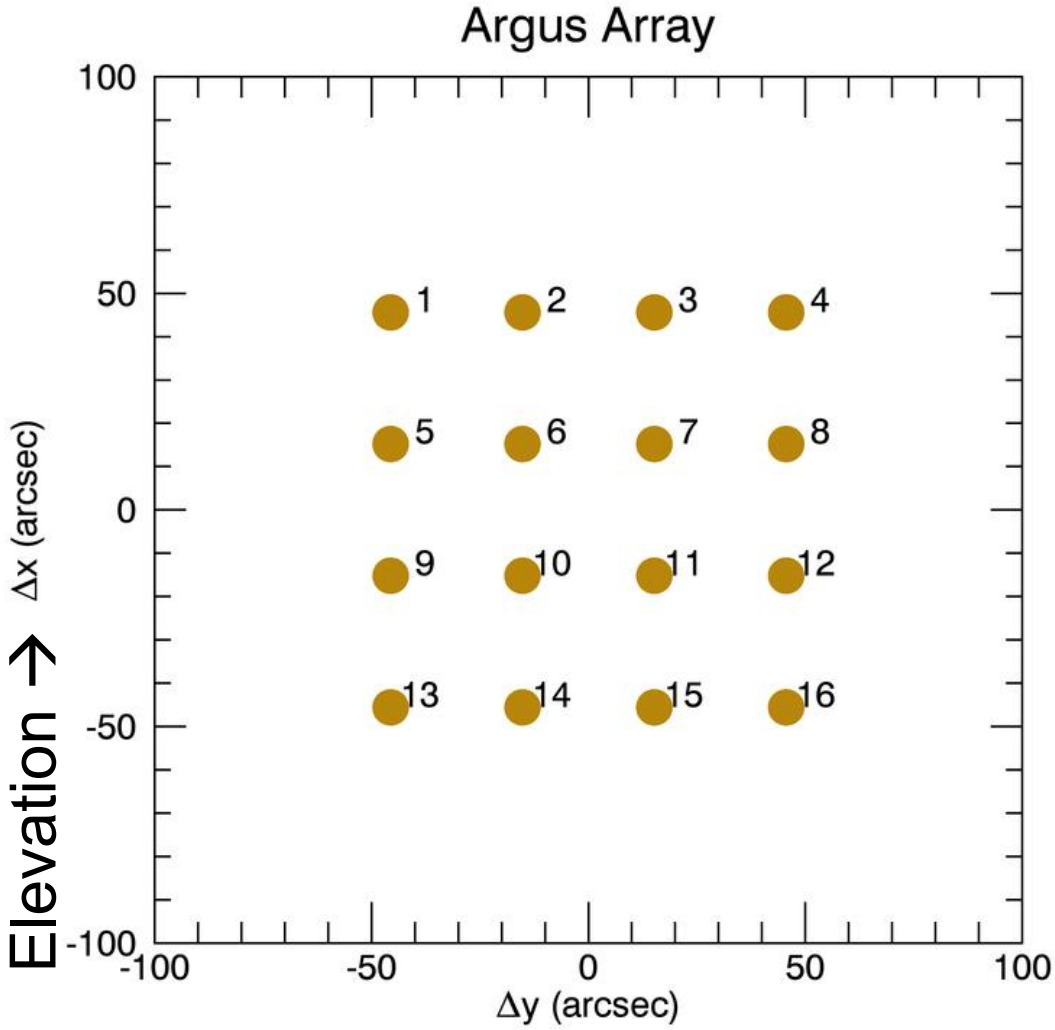
Figure 1: Schematic block diagram of Argus' signal path for a single receiver.

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

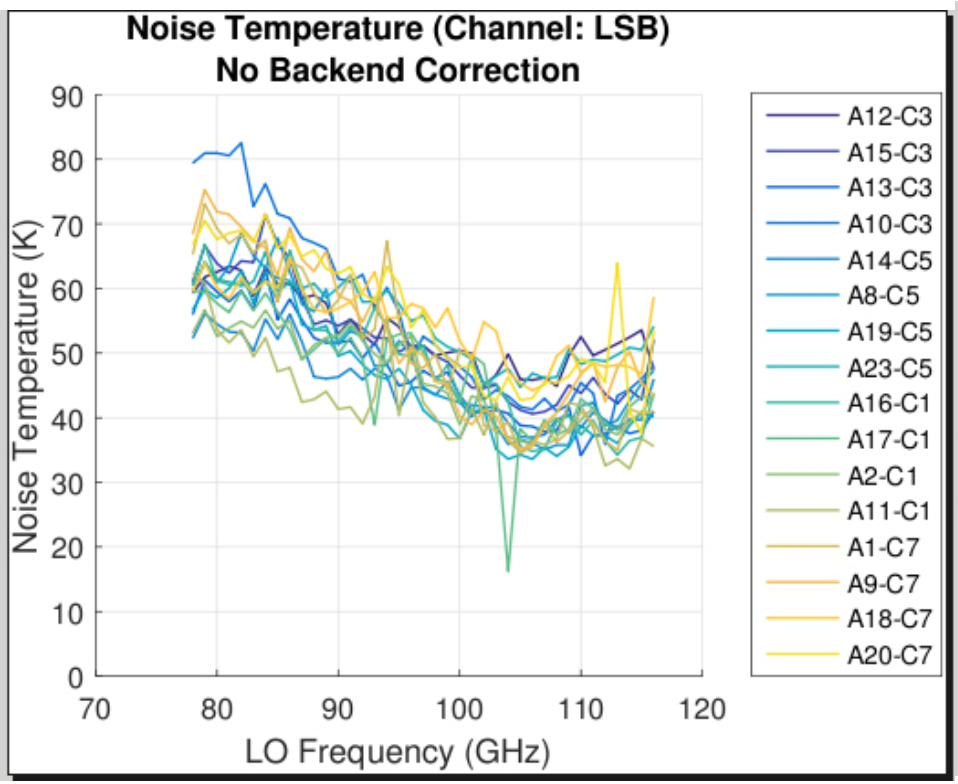
- Only Beams 9-16 can be used with the DCR.
- Beam-10 is the default pointing/focus beam.
- All 16 beams can be used with VEGAS.
- Beams 1 and 12 tend to show higher noise than the other beams, depending on frequency
- Beam-8 has no side-band rejection.

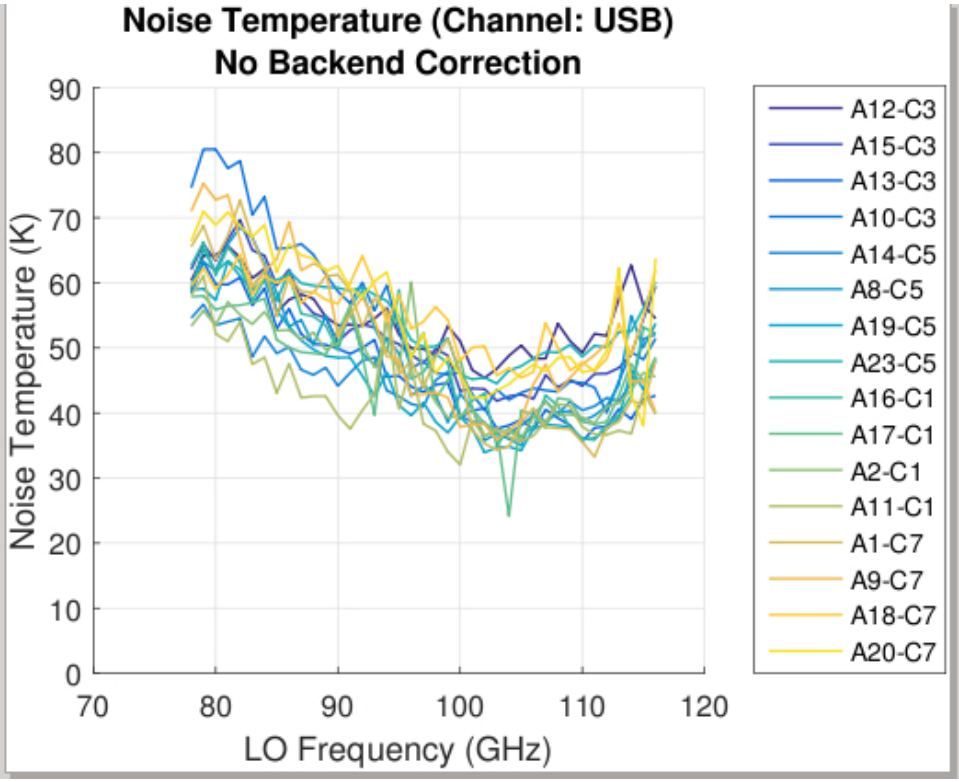


Elevation →

Cross-Elevation (Az) →

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

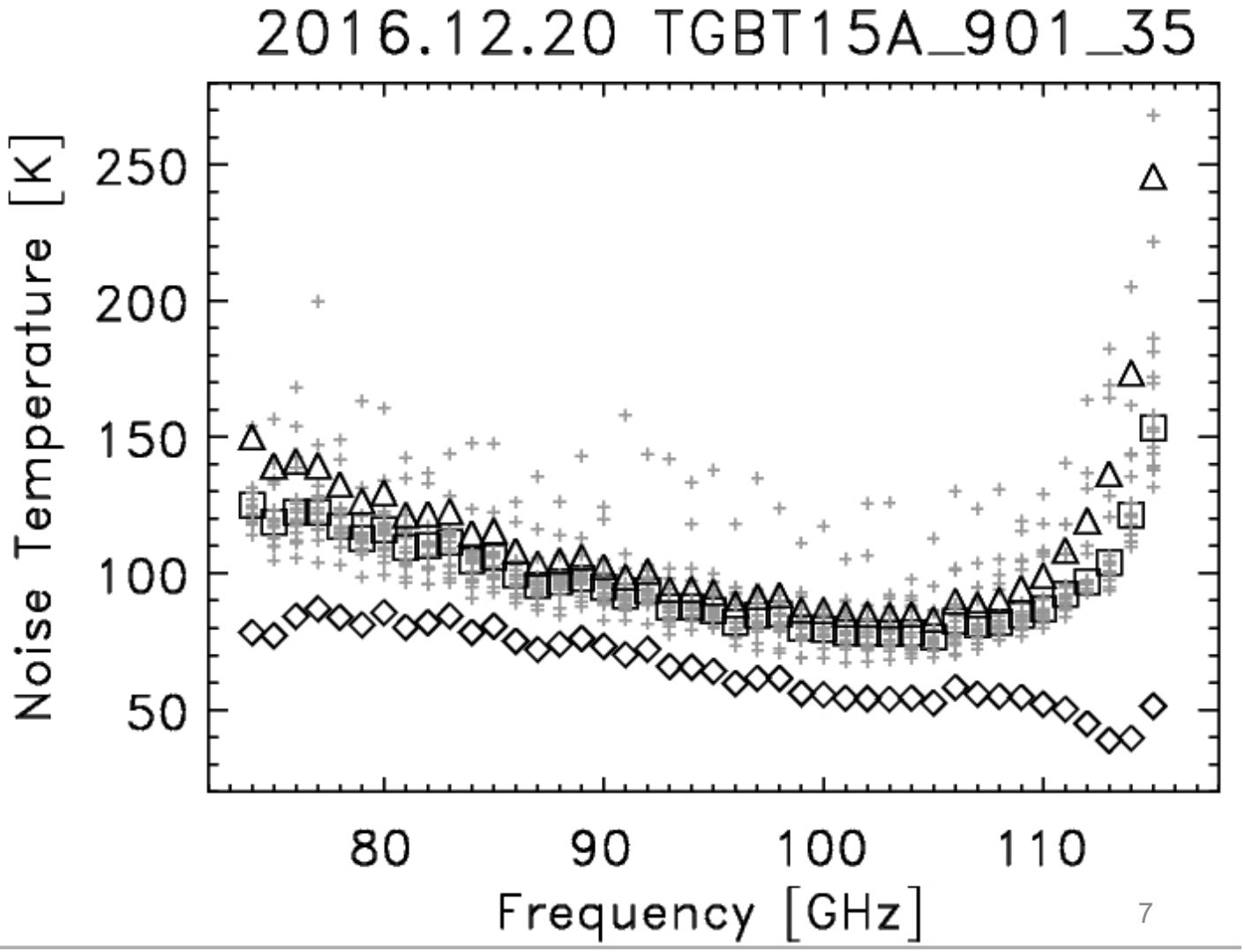
Measured noise on sky for Argus (zenith tau[90GHz]=0.06

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

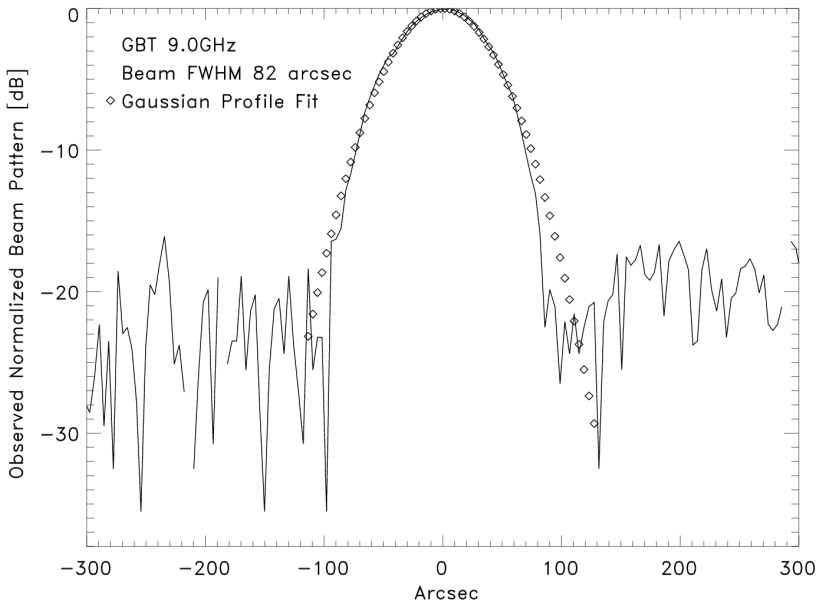
Boxes are median value of the Ta Tsys for Argus.

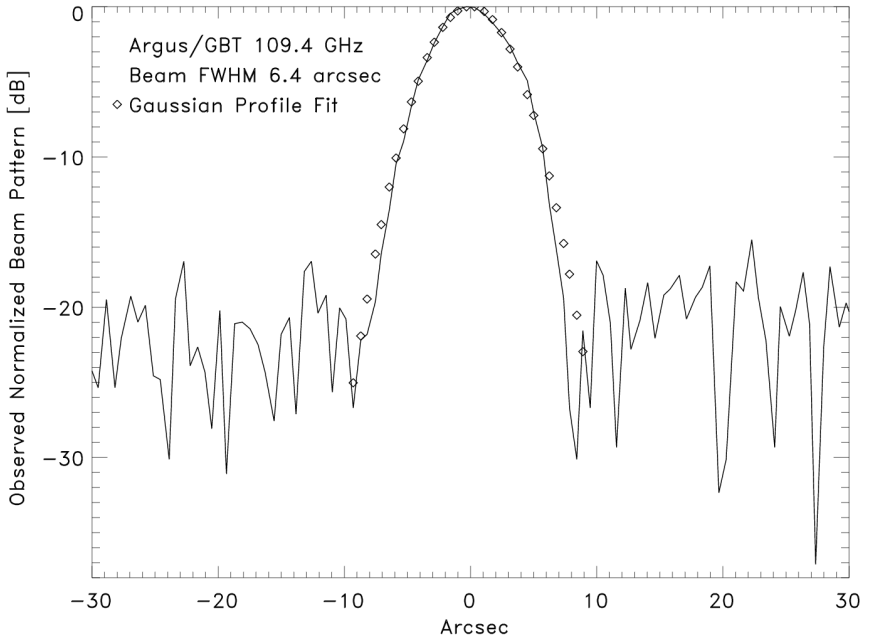
Triangles are median value for Tsys* which is the noise temperature associated with Ta*.

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



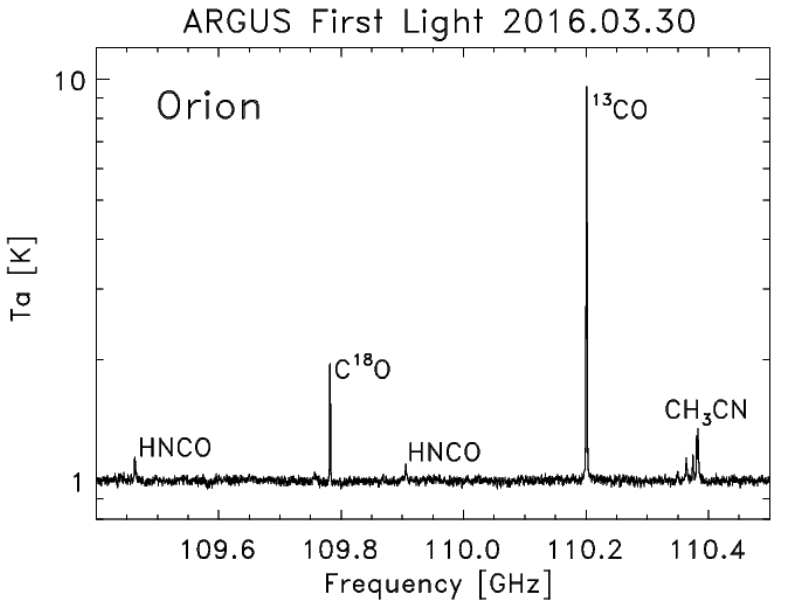
GBT Achieves Theoretical Beam with Argus at 109 GHz – GBT memo#296

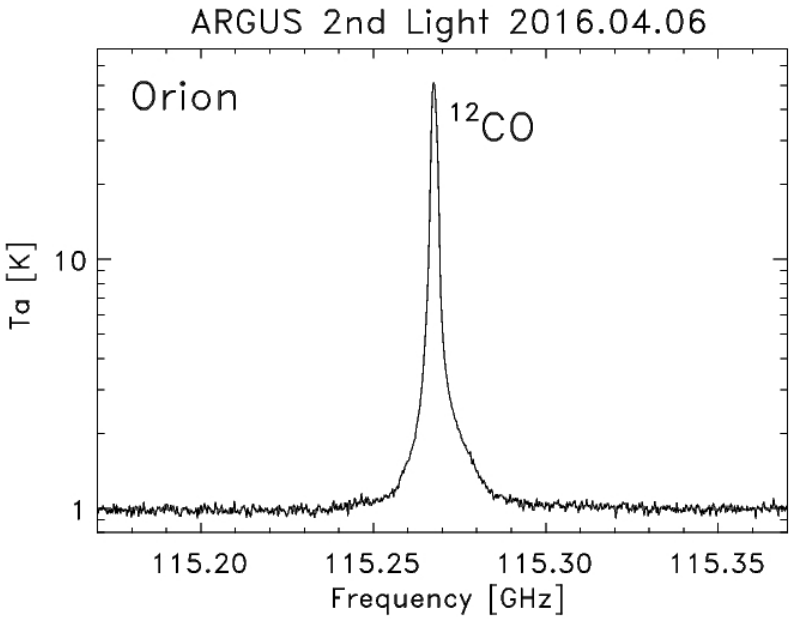




Left is the GBT beam at 9.0 GHz and **Right** GBT at 109.4 GHz. With Argus, the GBT can achieve beam sizes of ~1.15--1.2 Lambda/D (in good conditions after OOF).

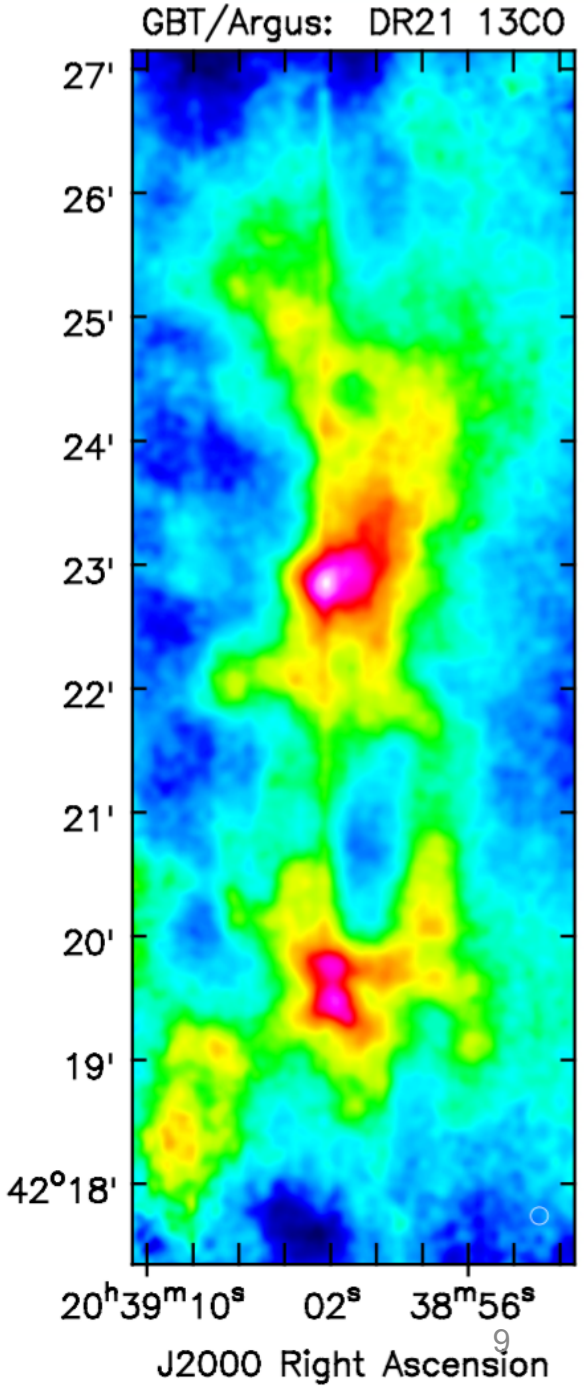
Argus early test observations:





(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



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.
- For Astrid/GFM processing of the pointing and focus scans to work, the data processing needs to be done in "Raw" mode and you should relax Heuristics. Use the .sparrow file to avoid to set “RAW” processing in advance when starting astrid . Also, watch for the Astrid pop-ups. Generally do not abort the peak procedure just because astrid says the Az fit(s) "fail", continue with El scans. Manually send corrections to the telescope and repeat peak as needed. Focus after getting good pointing solutions.
- 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. To save time during the initial pointings/focus that do not need to be calibrated, use the calSeq=False keyword in your observing scripts, e.g., AutoPeak(source,frequency=90000.,calSeq=False). If your frequency is not set, the default frequency for the Auto procedures for Argus is 86000 MHz (units are MHz, not GHz).
- Run AutoOOF with with the vanecal (default) since this will use calibrated data from both beams for fitting the surface model.

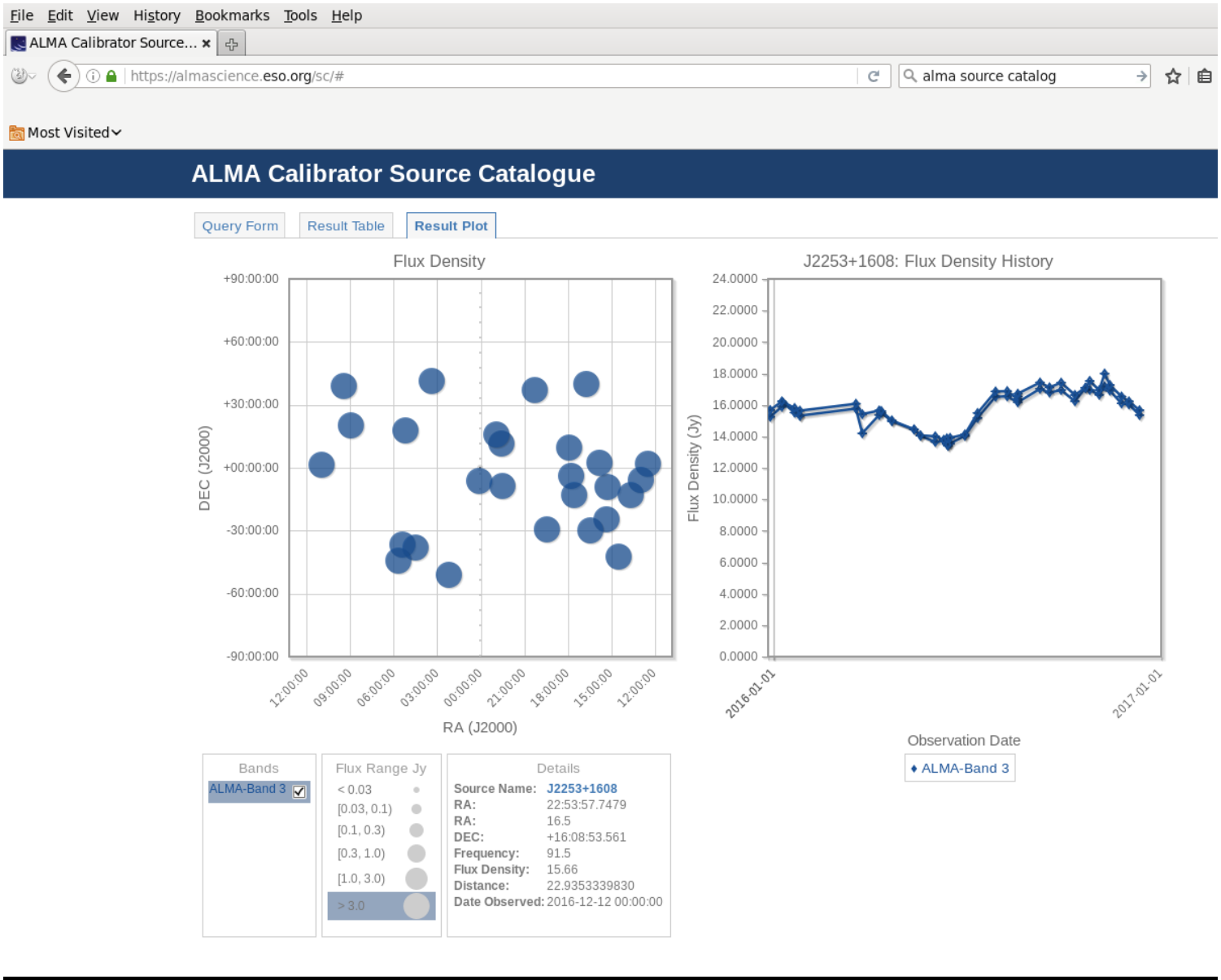
Recommended Argus Observing Procedures

1) Copy w.sparrow file into **~/.sparrow** before starting astrid. This tells astrid to process data in Raw mode to avoid errors/delays in GFM processing.
2) Startup **astrid** and relax heuristics for pointing and focus tab.
3) Go **online** with control in Astrid and run the **argus_startup** script (when given permission by operator).
4) 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. If Ka+CCB is available use this for AutoOOF.
5) Run **autopeak_focus** with Argus (where source is >1 Jy source within ~30deg of target region; brighter sources are better than closer sources since the GBT pointing model is accurate, and choose a frequency that is the approximate frequency of your science frequency). For best results, autopeak_focus should be run every 30-50 minutes depending on conditions (point more often during the day and after sunrise and sunset). Avoid pointing in the "key-hole" (el>80.0).
6) Carry out target observations. Run the **argus_vanecal** script after configuration and balance. Check the LOpower for the YIG. Check that the vane is in the obs position (seeing the sky) before collecting target data. Observers can use device explore to check instrument parameters.
7) Check instrument performance by reducing the vanecal observations within gbtidl, e.g., **GBTIDL -> vanecal**,25,ifnum=3. Note that the Tsys* is the effective Tsys which is applicable for Ta* and includes the atmospheric correction, Tsys* = Tsys x exp(tau_o*Airmass)/eta_l.
8) 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.

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

```
1  #
2  #Configure VEGAS mode-2 with ARGUS 16 beams
3  #HCN and HCO+
4  #dfrayer 2016.12.09
5  #
6  Configure("""
7  receiver    = 'RcvrArray75_115'
8  beam        = 'all'
9  obstype     = 'Spectroscopy'
10 backend     = 'VEGAS'
11 restfreq = 89000.
12 bandwidth = 1500
13 swmode      = 'tp_nocal'
14 swtype      = 'none'
15 swper       = 2.0
16 swfreq      = 0.0, 0.0
17 tint        = 2.0
18 vlow        = 0
19 vhigh       = 0
20 vframe      = 'lsrk'
21 vdef        = 'Radio'
22 pol         = 'Linear'
23 nchan       = 'high'
24 sideband = 'LSB'
25 vegas.subband=1
26 """)
27 #
28 Balance()
29 # Check the YIG status after configuration
30 yigvolt, sampleTime = GetSample("RcvrArray75_115", "YIGData,lo_power")
31 print "Yig voltage: ", yigvolt, ", Sample time:", sampleTime
```

Enter target frequencies

tp_nocal (no noise diodes)

swper >=0.4 for fsw

tint <~1sec for mapping

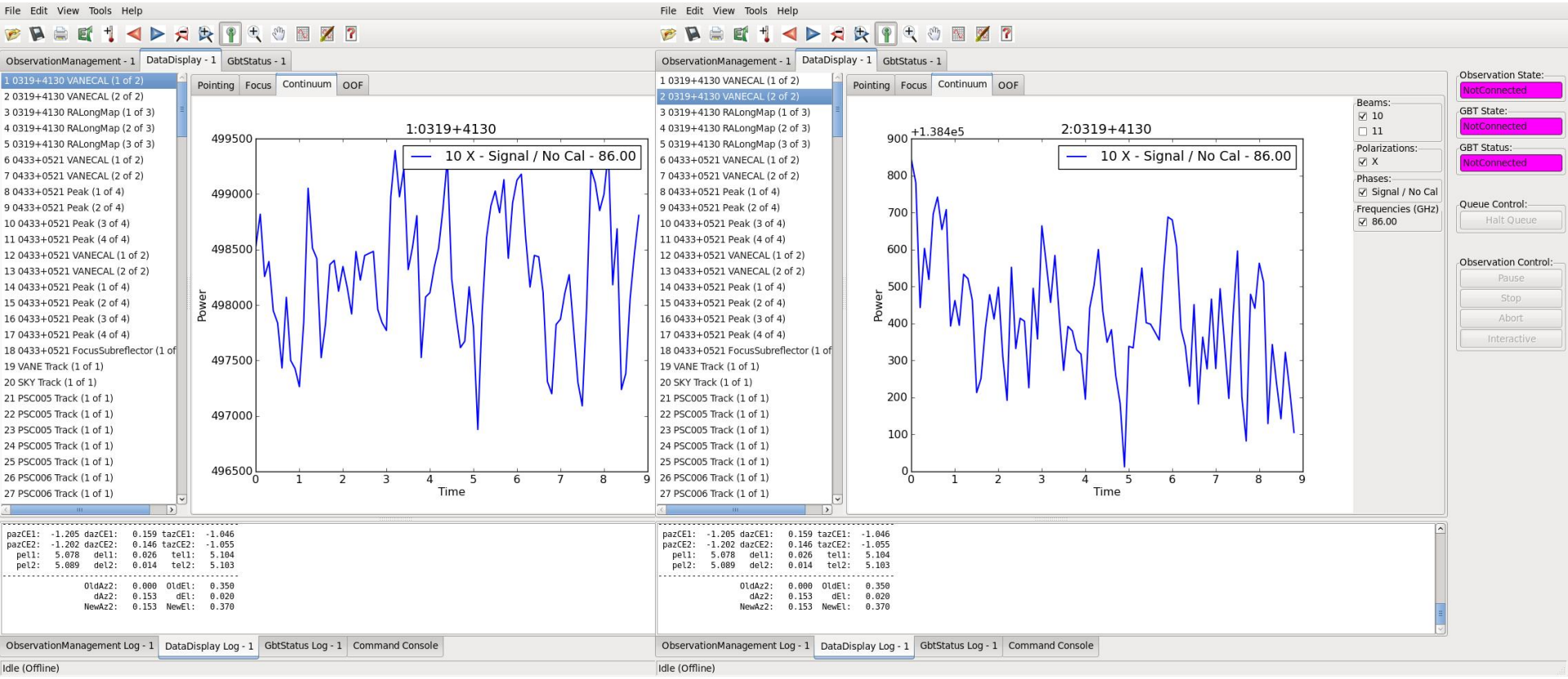
pick sideband

Check YIG-LO_power after configuration

Observing: Antenna Optimization

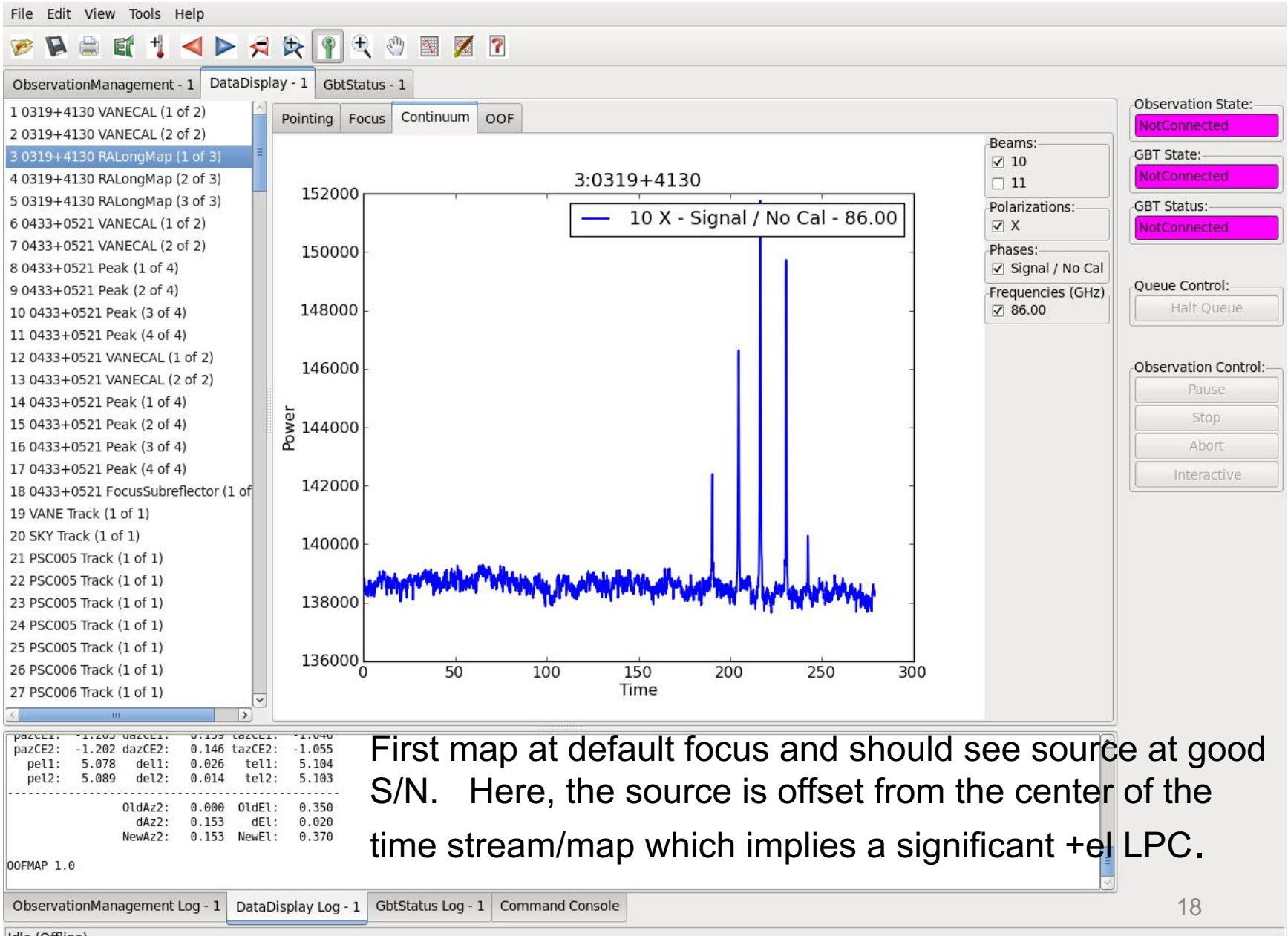
- Should point+focus (AutoPeakFocus) every 30min-50min depending on conditions (point+focus takes ~5min)
- AutoOOF (which takes ~20min) is used to correct the surface for thermal effects at night.
- Daytime surface changes <1hr time scales and the AutoOOF solutions can cause more harm than good during rapidly changing conditions from the AutoOOF (so it is typically not useful to use the “thermal” corrections during the day).

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



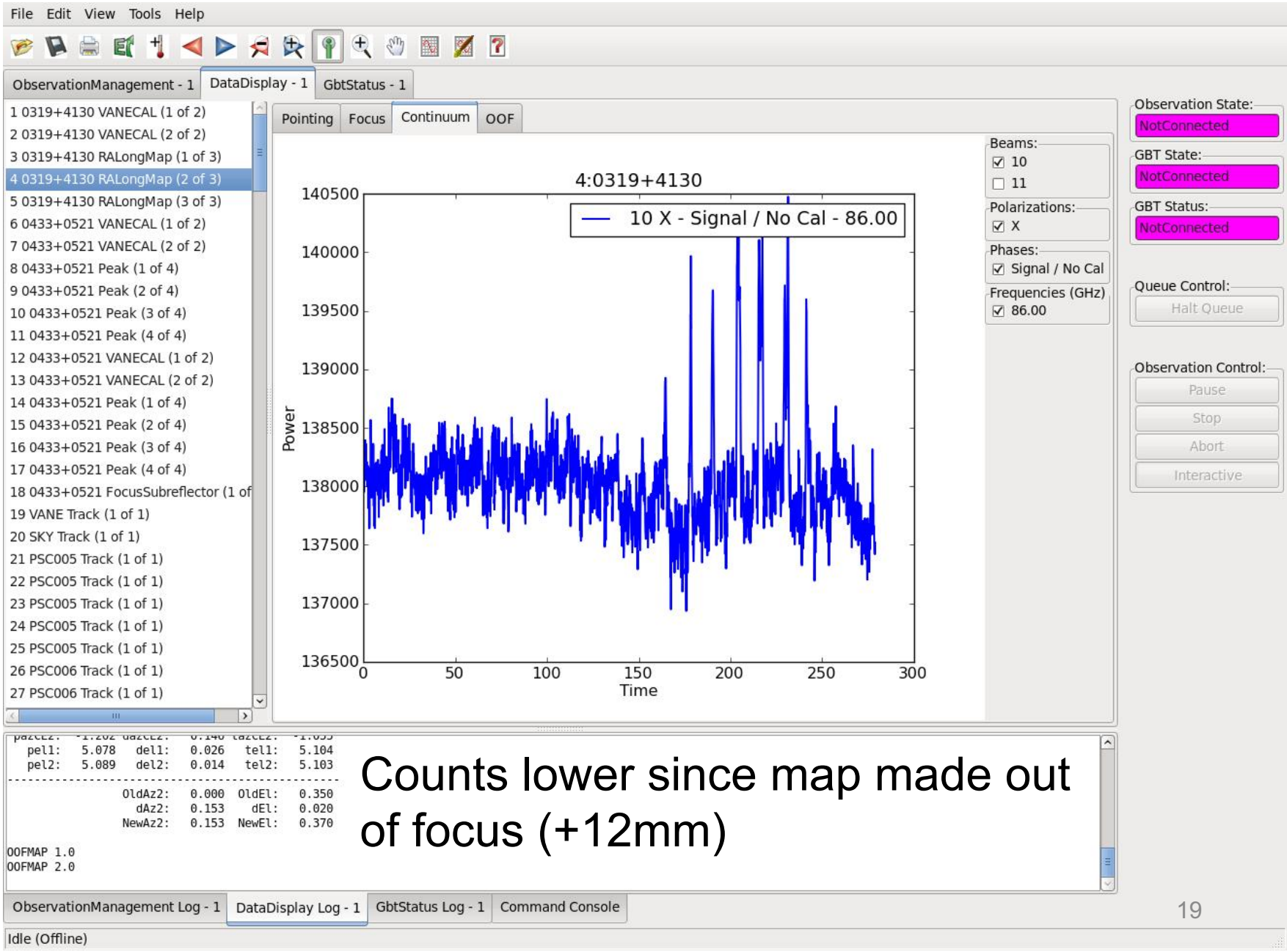
Vanecal scans with the DCR – first scan is with VANE (4.985e5 counts) and second scan is on SKY (1.354e5+500 counts). Tsys~Twarm(SKY/(VANE-SKY)) = 104 K for Twarm~270. **Should have VANE/SKY>~3 in good conditions**.

(scan 3) Argus OOF map-1 data



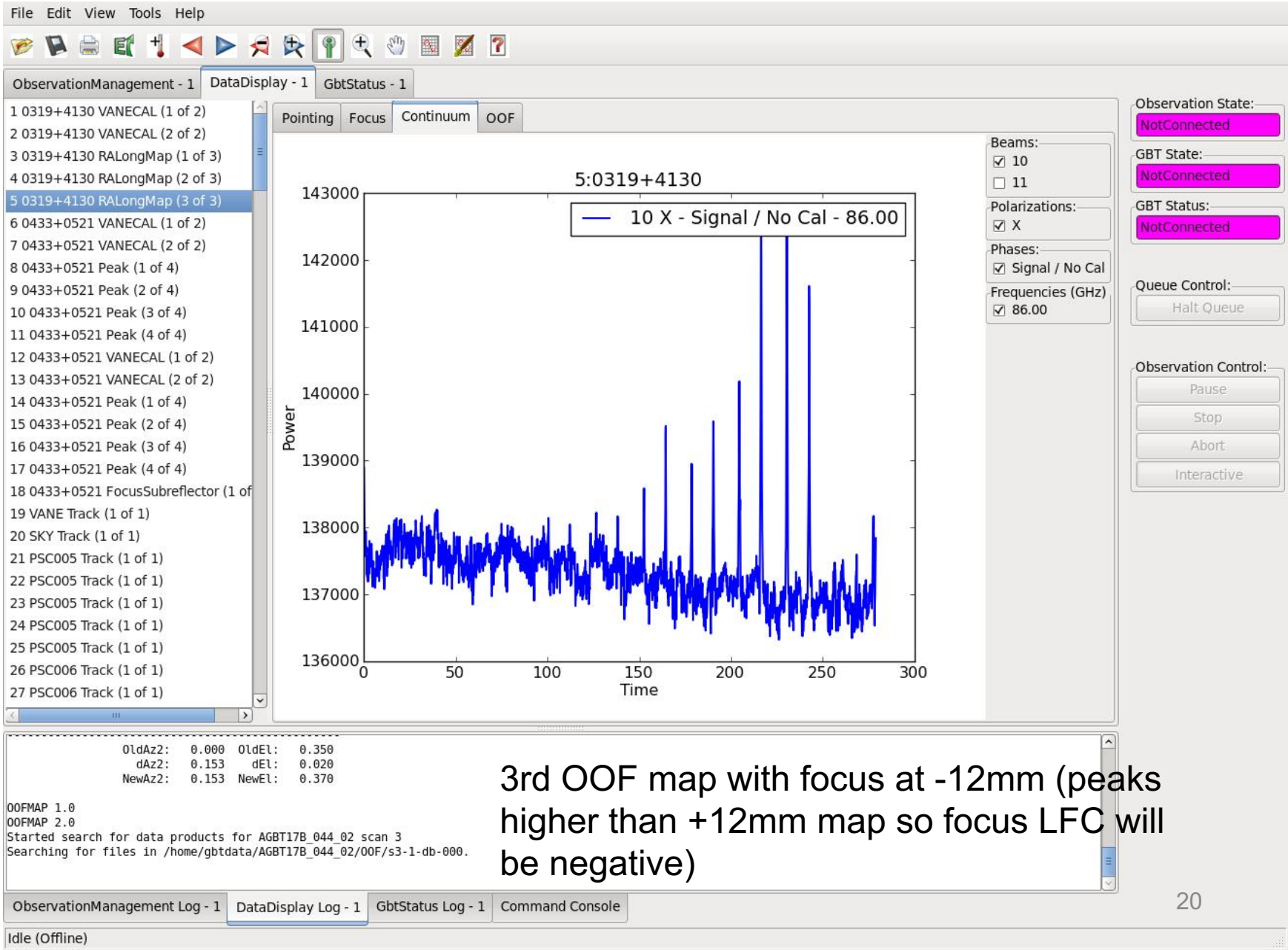
First map at default focus and should see source at good S/N. Here, the source is offset from the center of the time stream/map which implies a significant +el LPC.

(scan 4) Argus OOF map-2 data



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

(scan 5) Argus OOF map-2 data



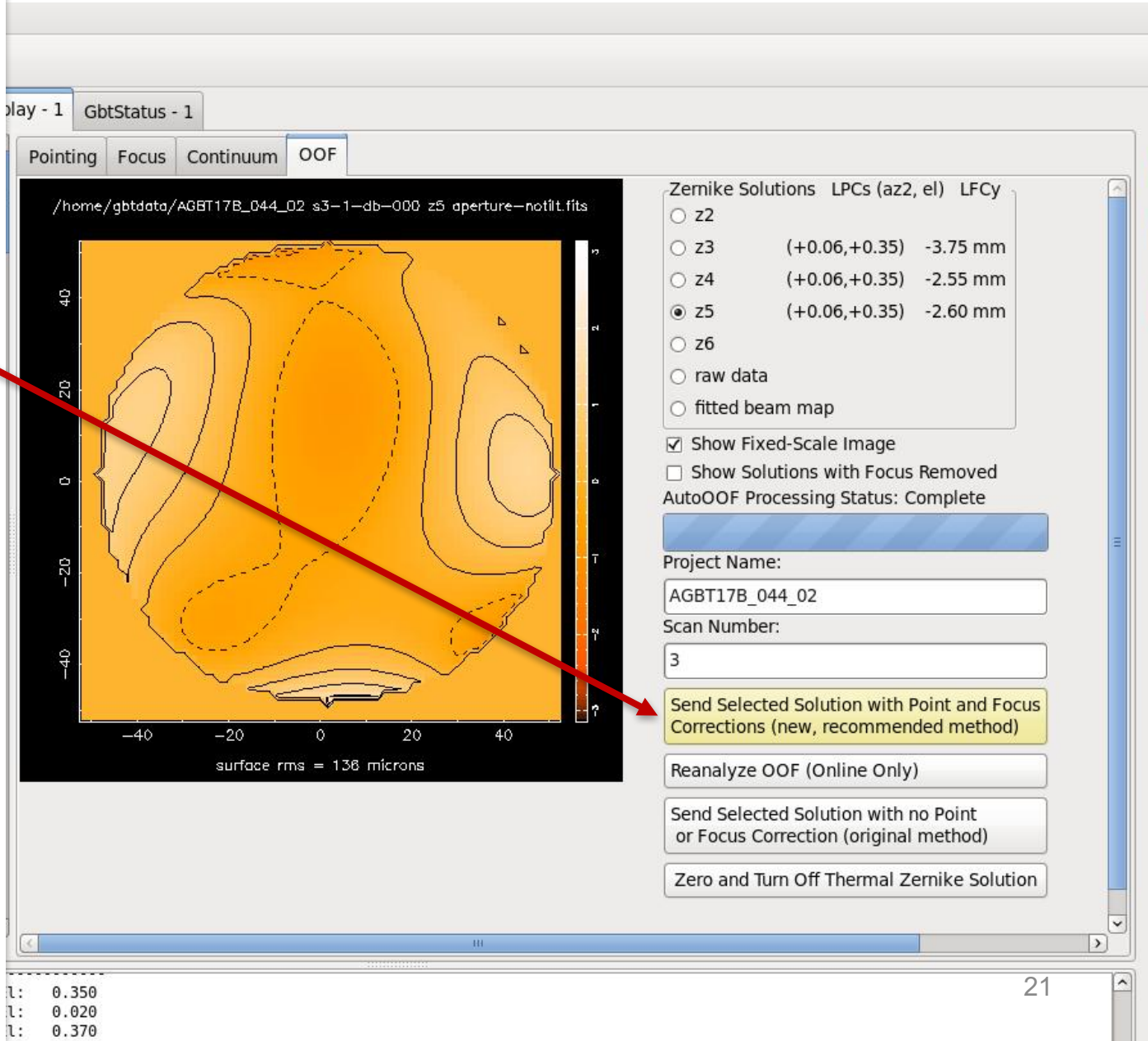
3rd OOF map with focus at -12mm (peaks higher than +12mm map so focus LFC will be negative)

AutoOOF Solutions

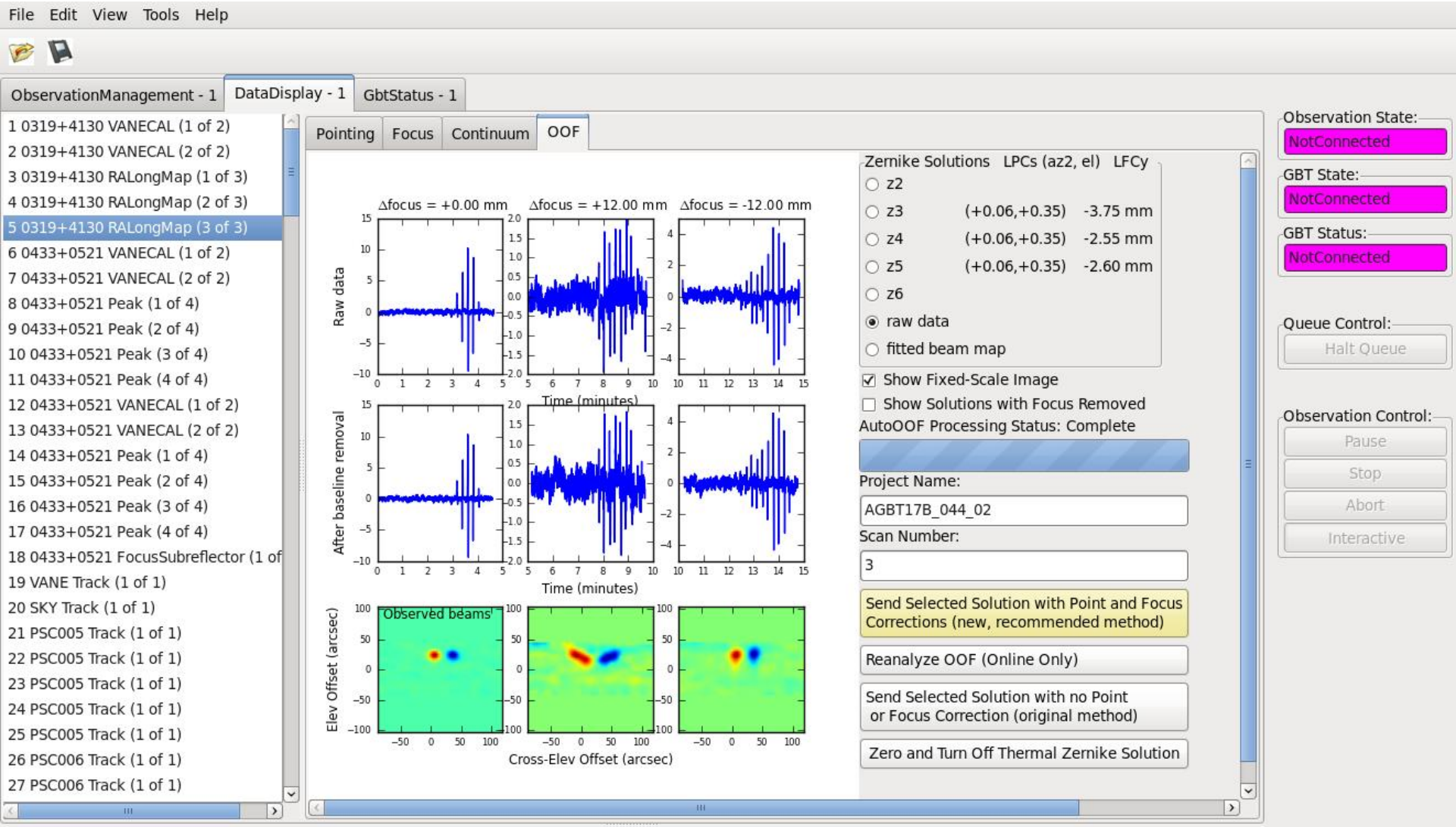
Click yellow button after OOF processing to send corrections to GBT and turn on the thermal zernike's.

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

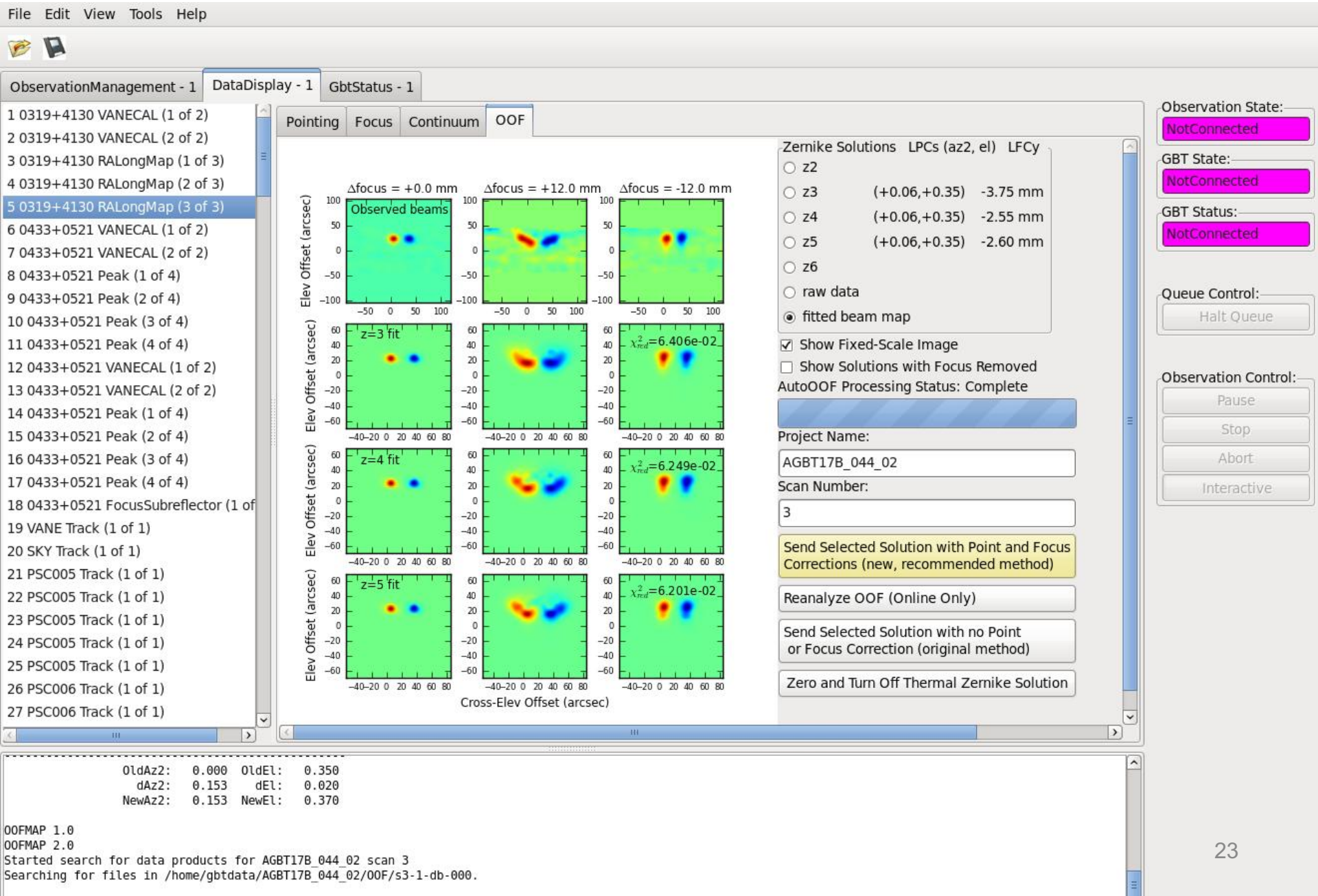
Be weary of "rms" >300 microns (which happens in windy conditions)



AutoOOF "Raw data"



AutoOOF Beam Fits

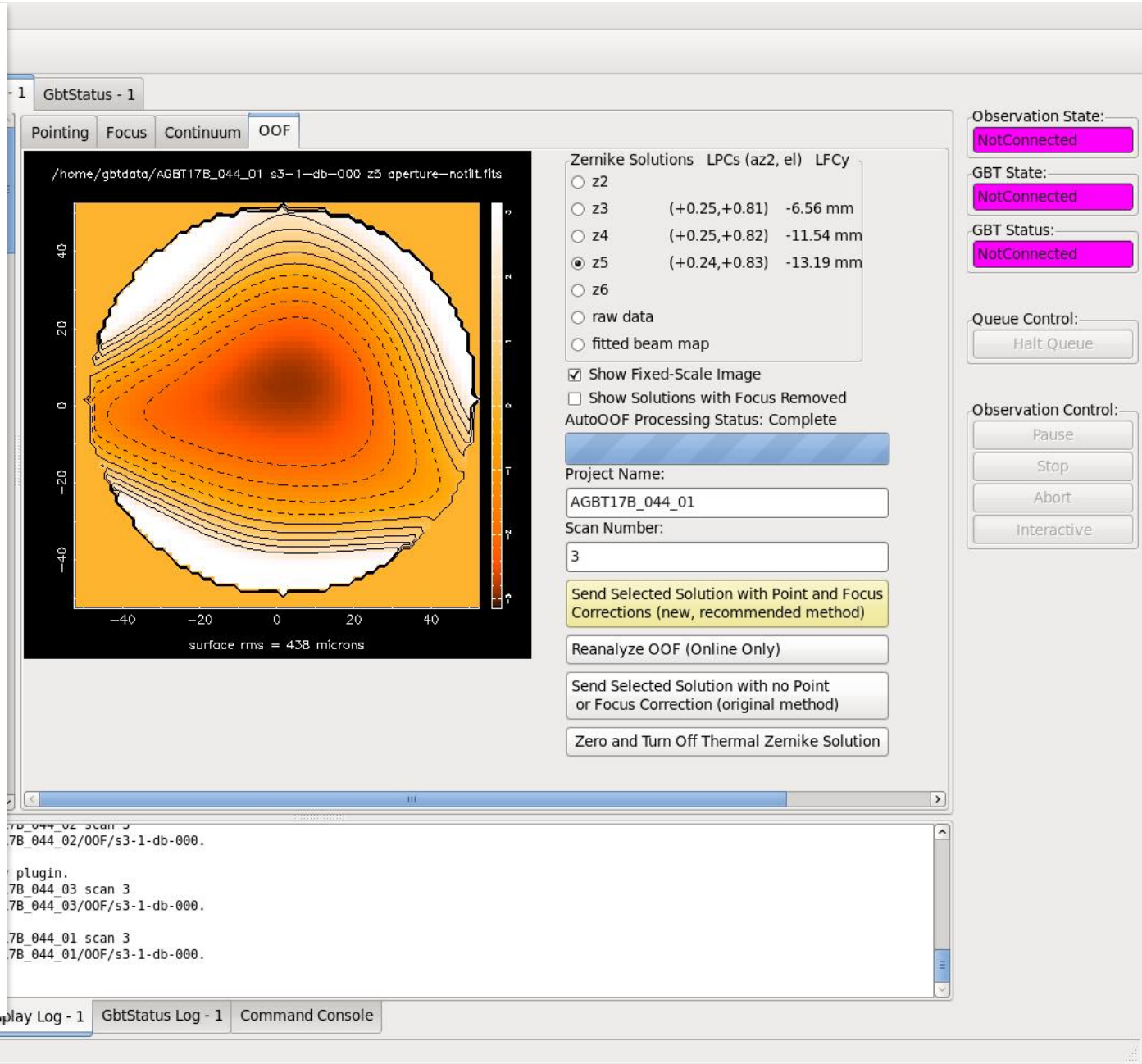


Example of a Bad OOF

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.

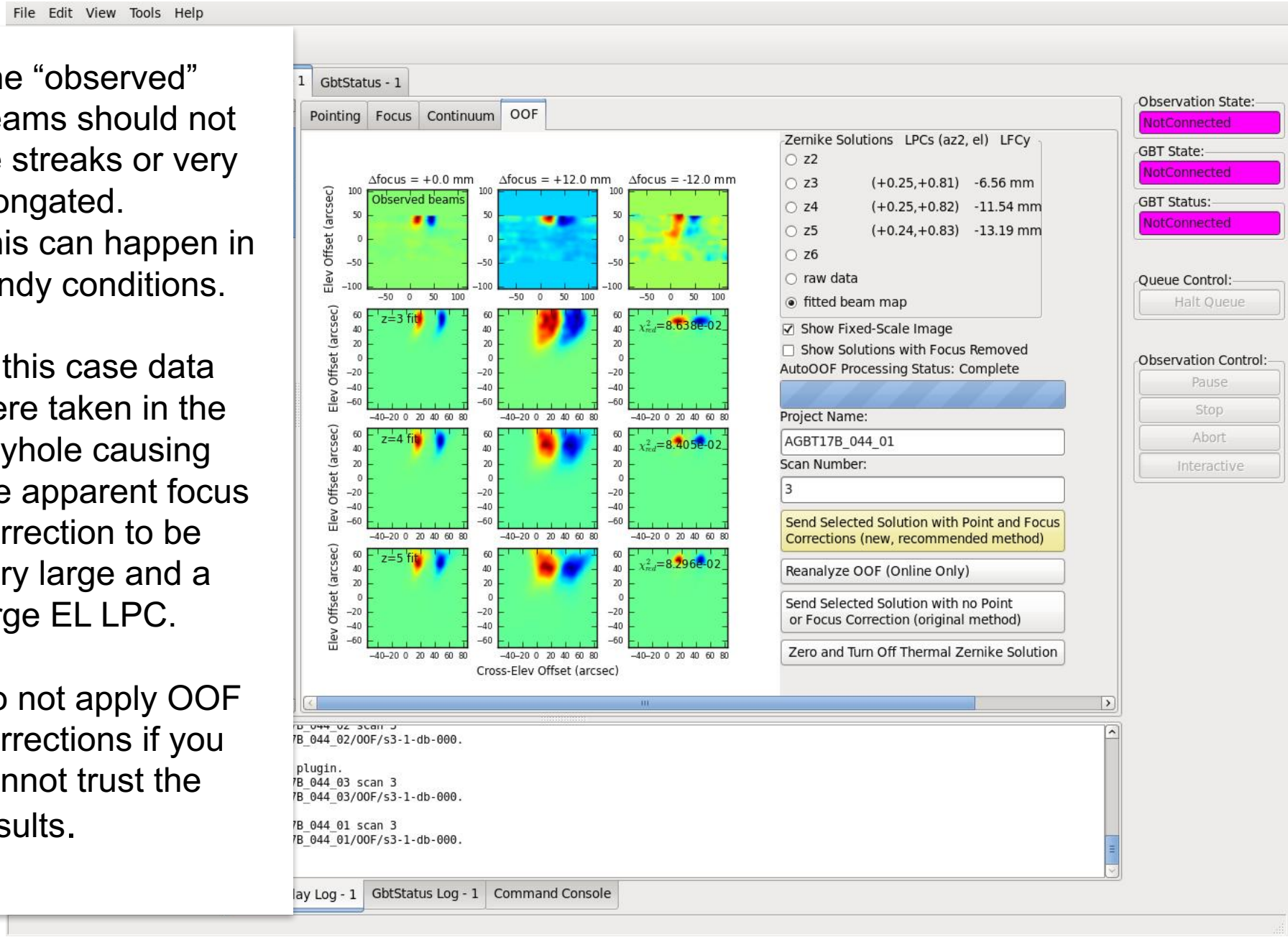


Beam Maps of Example Bad OOF

The “observed” beams should not be streaks or very elongated.
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.



Brightest OOF Sources 2016/2017

Source	Snu (91.5 GHz) [Jy]
0319+4130	24.3
0854+2006	6.7
1058+0133	6.6
1229+0203	9.9
1256-0547	10.6
2253+1608	15.7

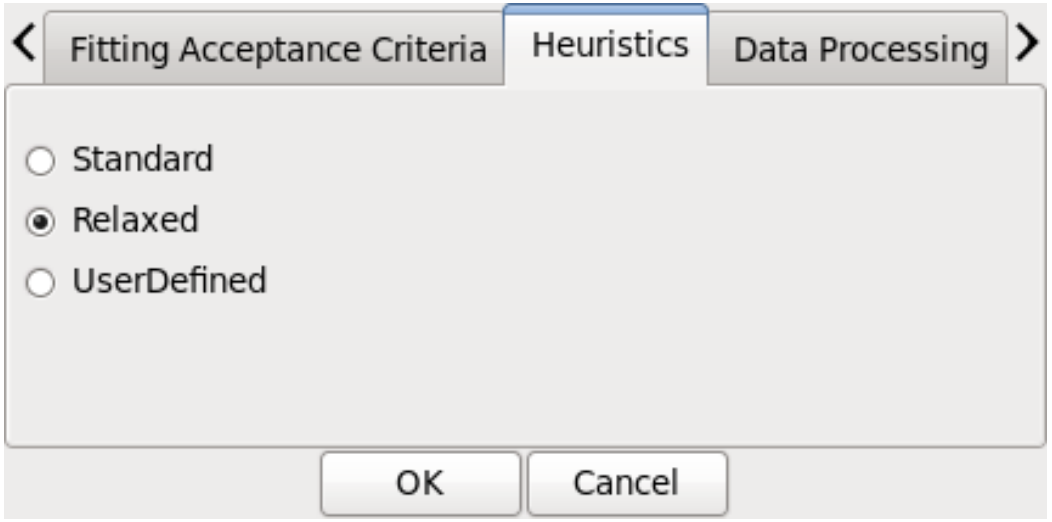
Pointing & Focus

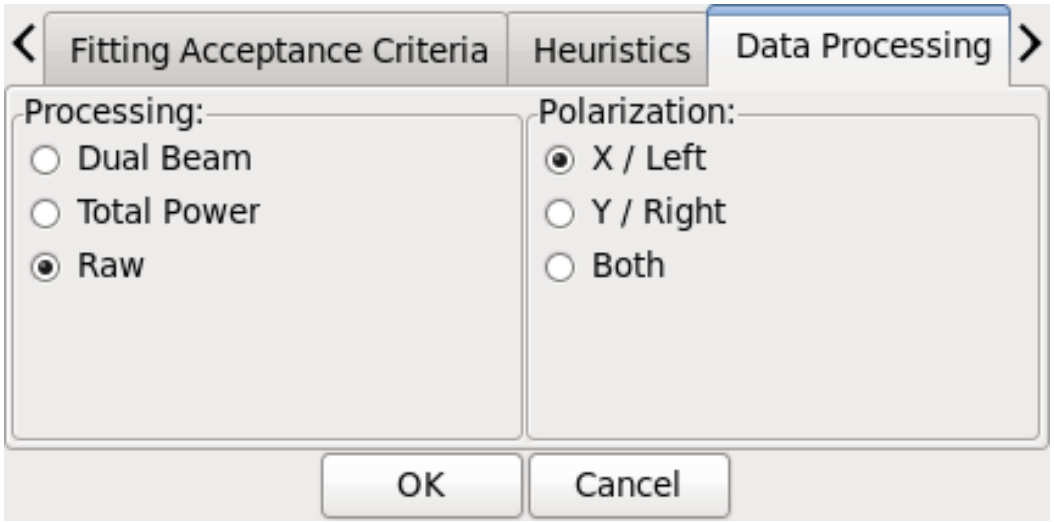
- Peak and focus on sources within 30deg and brighter than 1 Jy. Brighter sources are better than closer sources since the GBT pointing model is very good.
- The point/focus frequency should be the approximate frequency of your science frequency with VEGAS.
- For best results, **autopeak_focus should be run every 30-50 minutes** depending on varying conditions.
- Astrid/GFM requires processing data in ”Raw mode” and using relaxed Heuristics
- 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.

Astrid/GFM

For Argus:

- Select Heuristics = “Relaxed”
- Select Data Processing = “Raw”

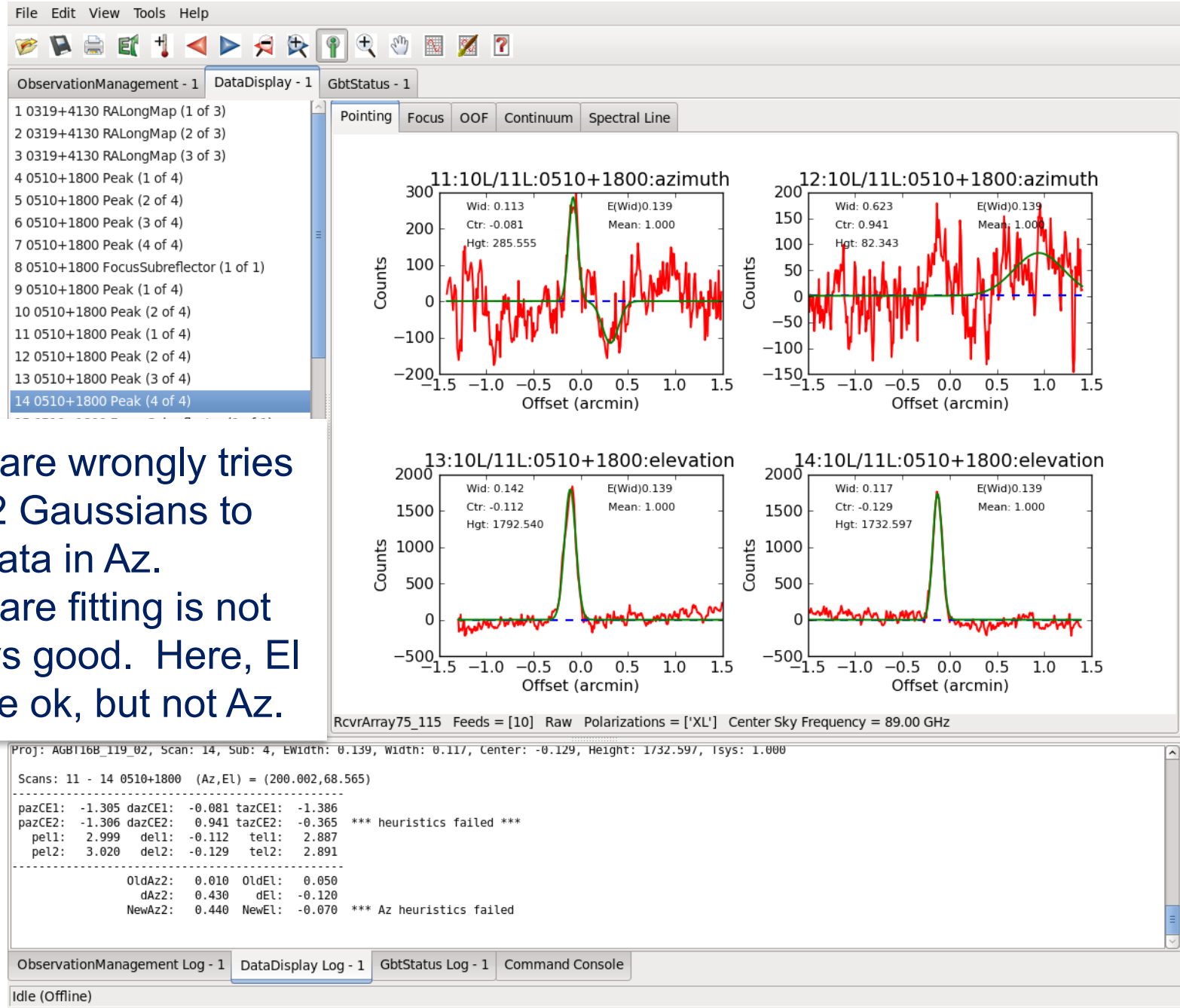




If Raw not selected, you will get an error as shown (avoid this by using the ”.sparrow ” file.

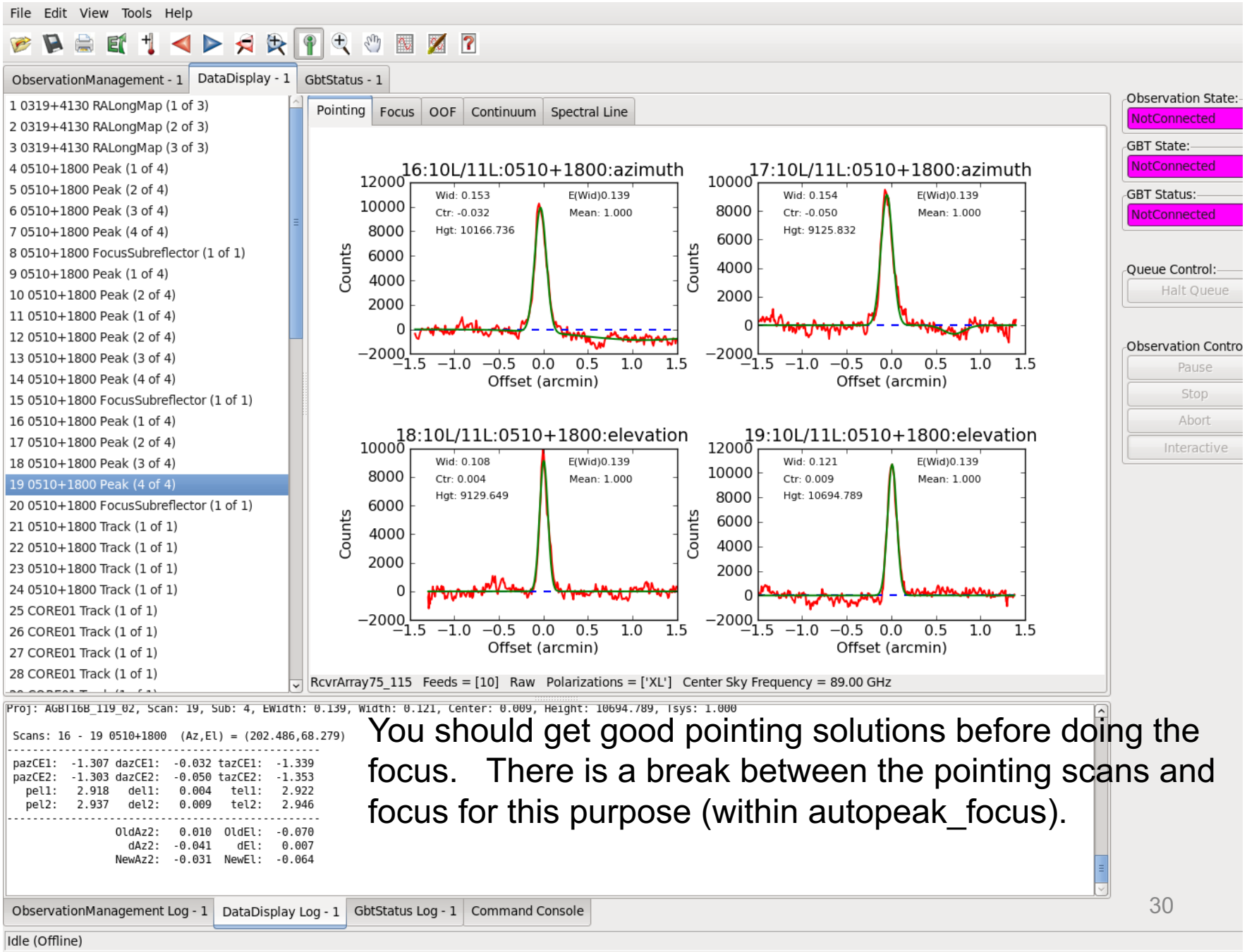
```
TrackBeam = 10 , SkyBeam = 11
Reducing data with 'Standard' Heuristics, DualBeam Mode, Polarizations = XL
Acceptance Criteria: Automatically accept good fits, automatically reject bad fits
*** Error: Cannot retrieve calibration information. Try reprocessing this scan in Raw mode.
Encountered the following exception while analyzing Peak: unsupported operand type(s) for *: 'NoneType' and 'float'
*** Error: Cannot retrieve calibration information. Try reprocessing this scan in Raw mode.
Error processing scan 20 : <type 'exceptions.TypeError'> , unsupported operand type(s) for *: 'NoneType' and 'float'
```

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

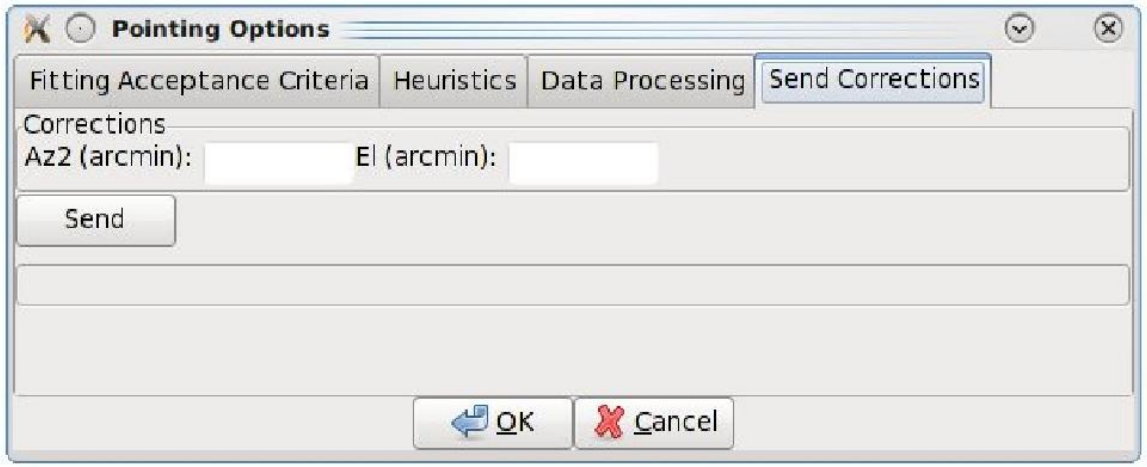
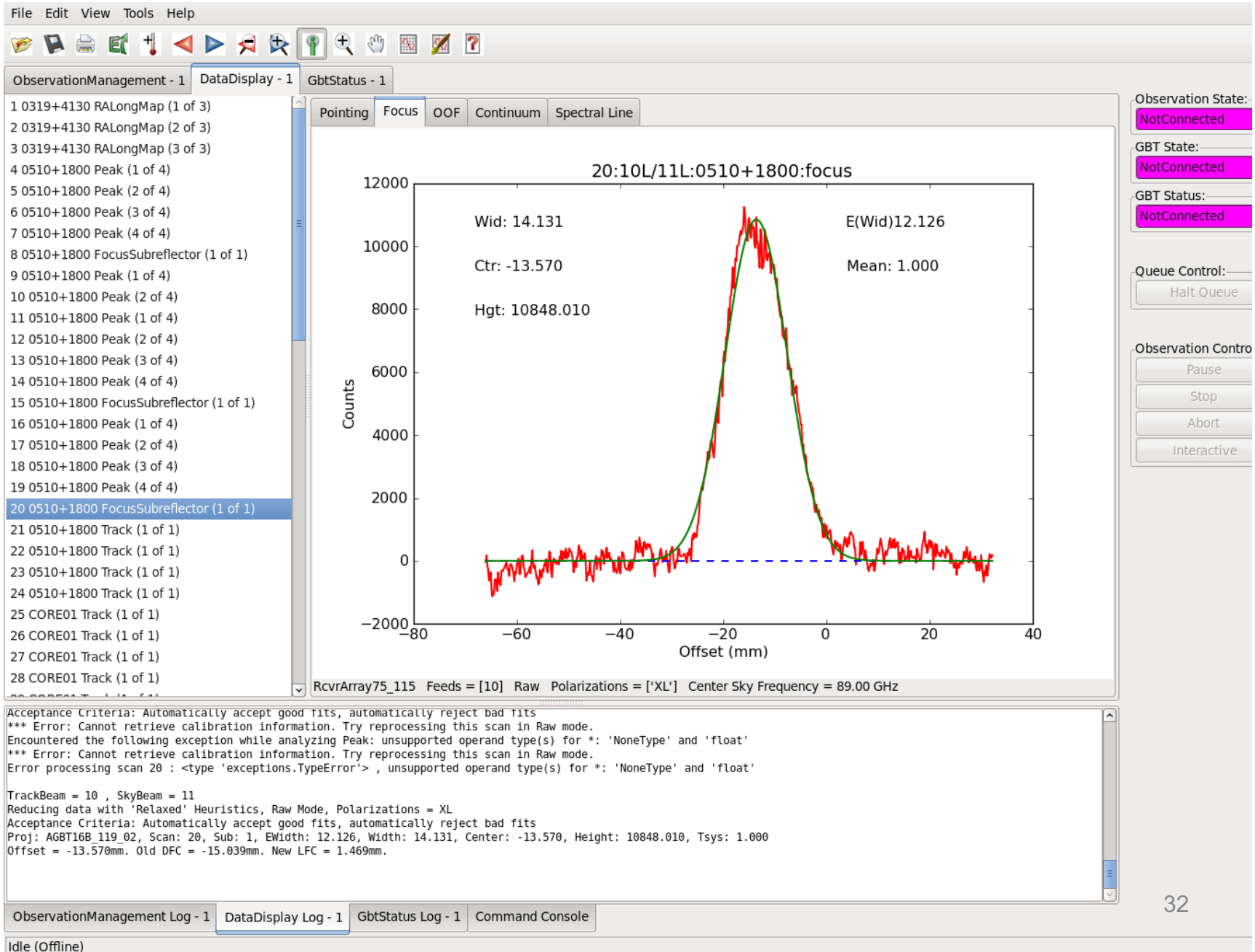


Figure 5.6: The pop–up menu to manually send pointing corrections to the telescope.

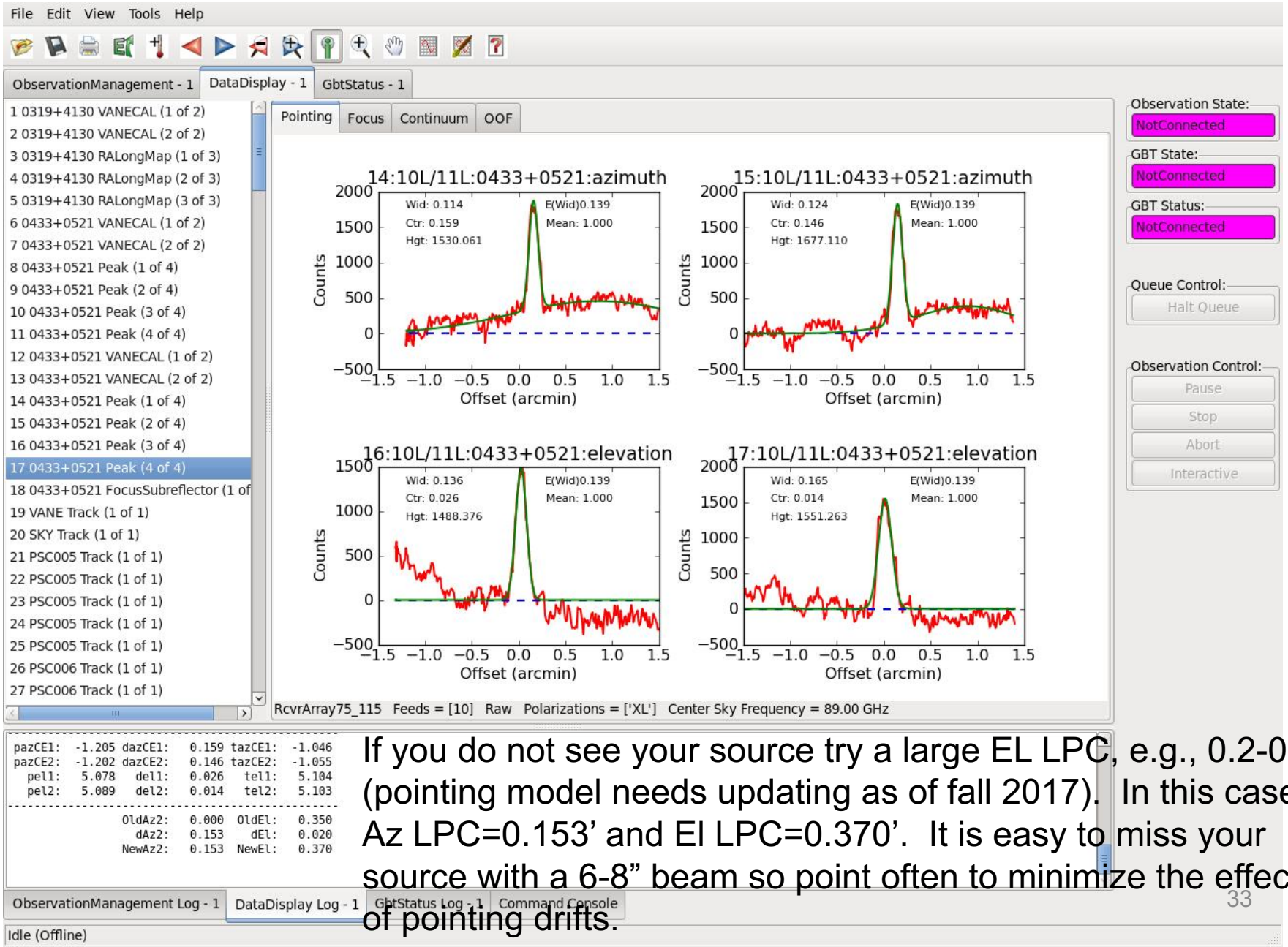
Users can send corrections manually to the telescope within GFM using Tools-> Options-> Send Corrections Tab.

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)

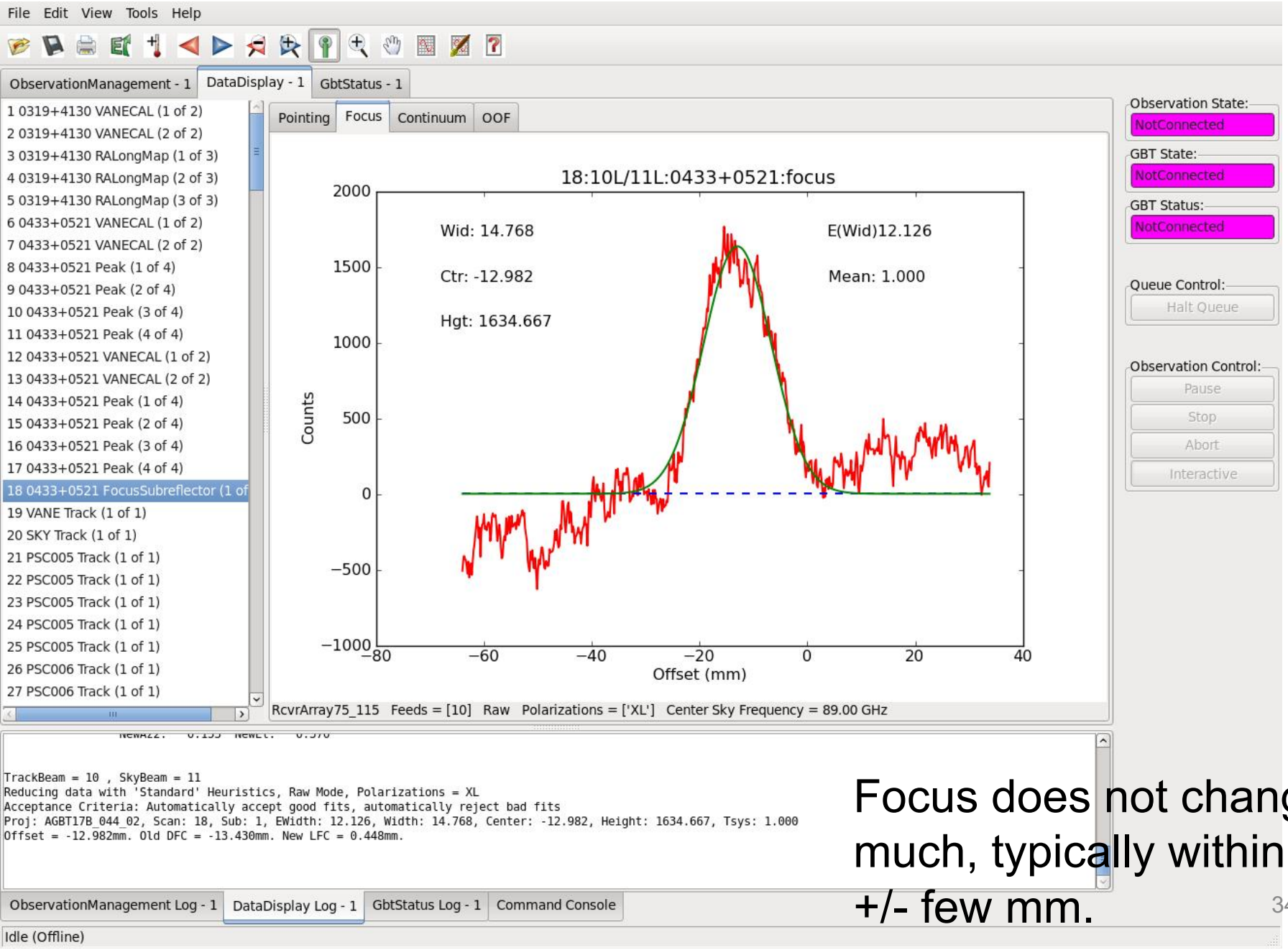


Another Good Pointing Example



If you do not see your source try a large EL LPC, e.g., 0.2-0.4 (pointing model needs updating as of fall 2017). 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.

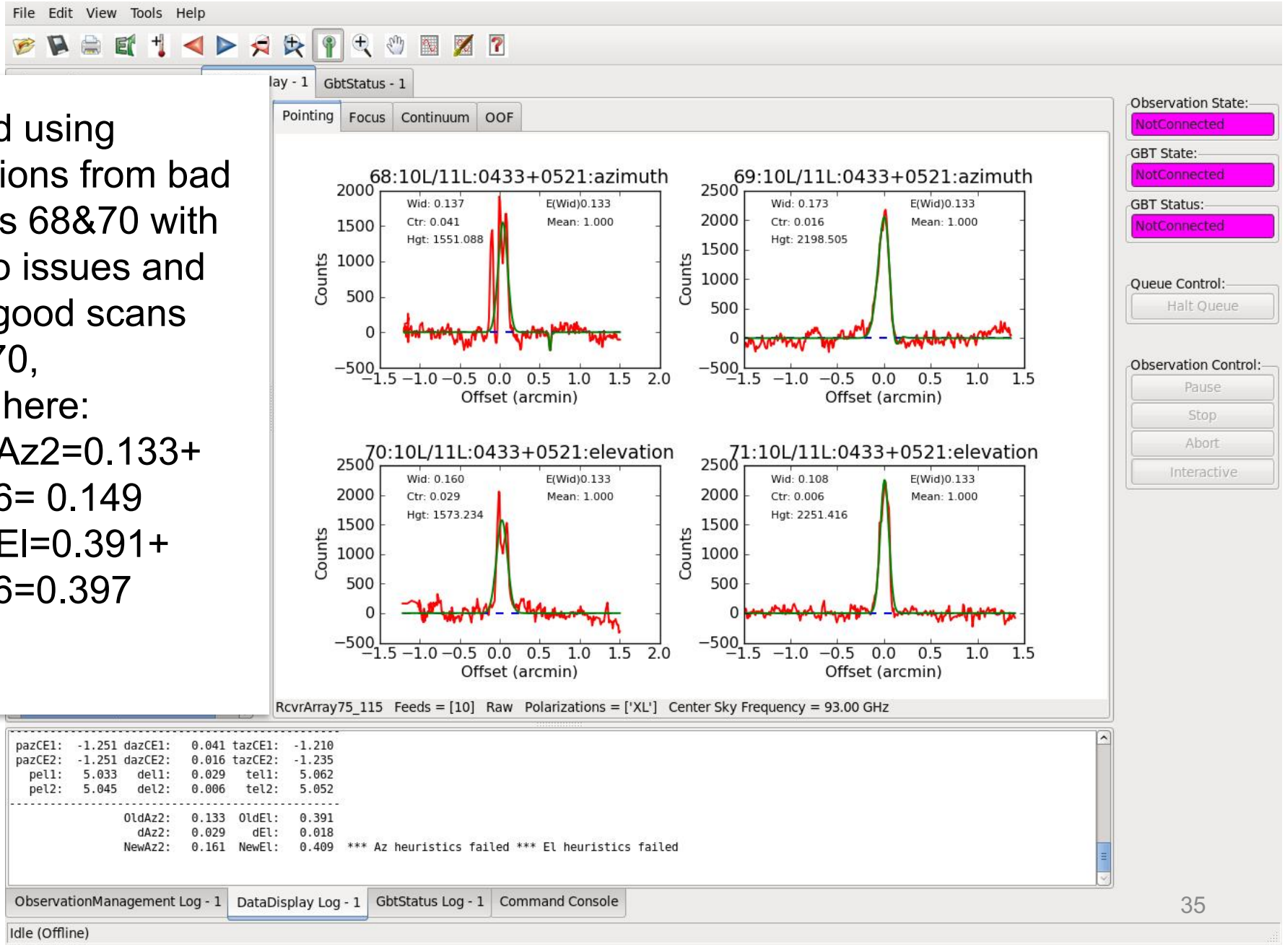
Another Good Focus Scan



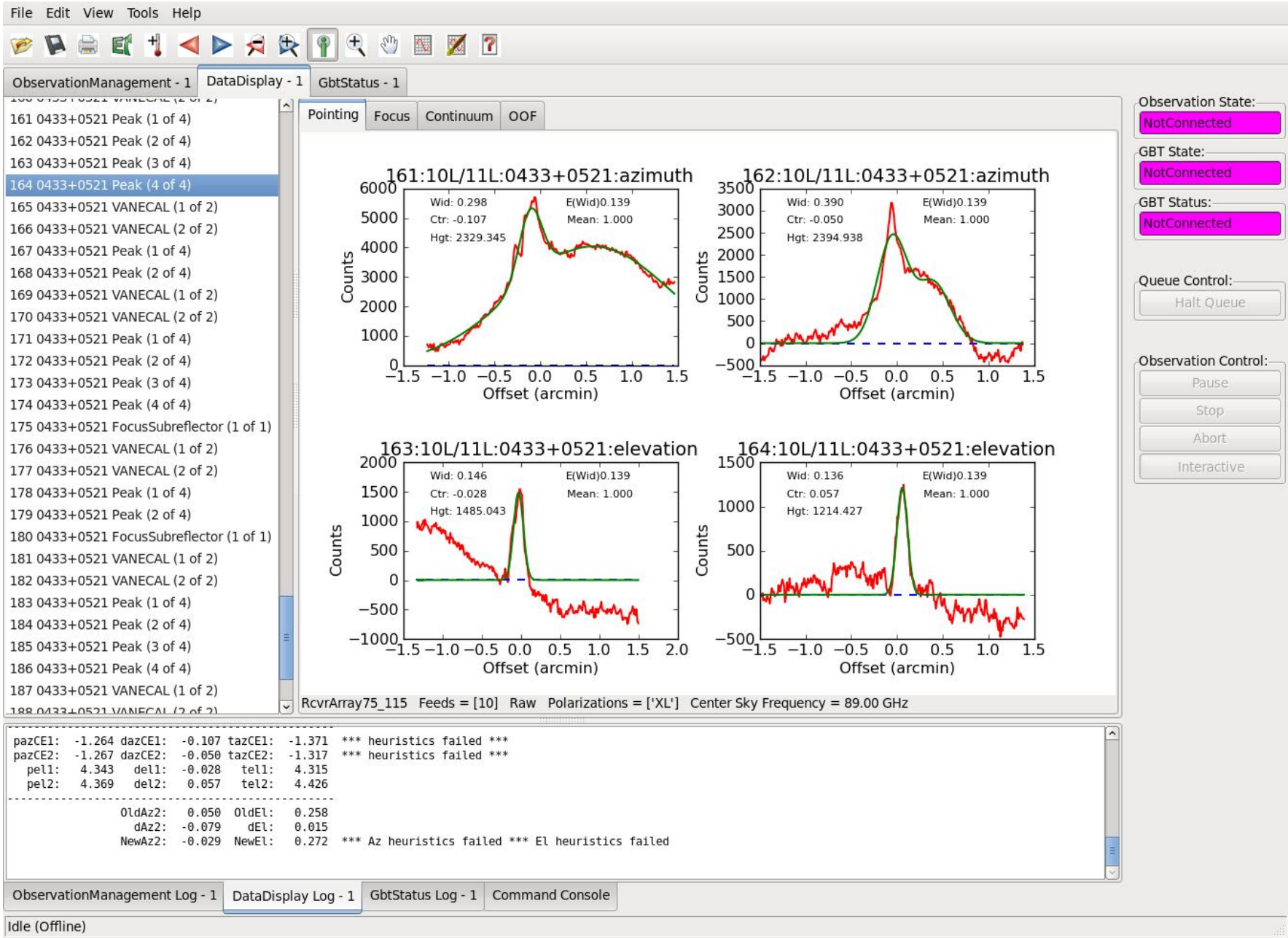
Focus does not change much, typically within +/- few mm.

Pointing Scans showing Servo-System Jitters

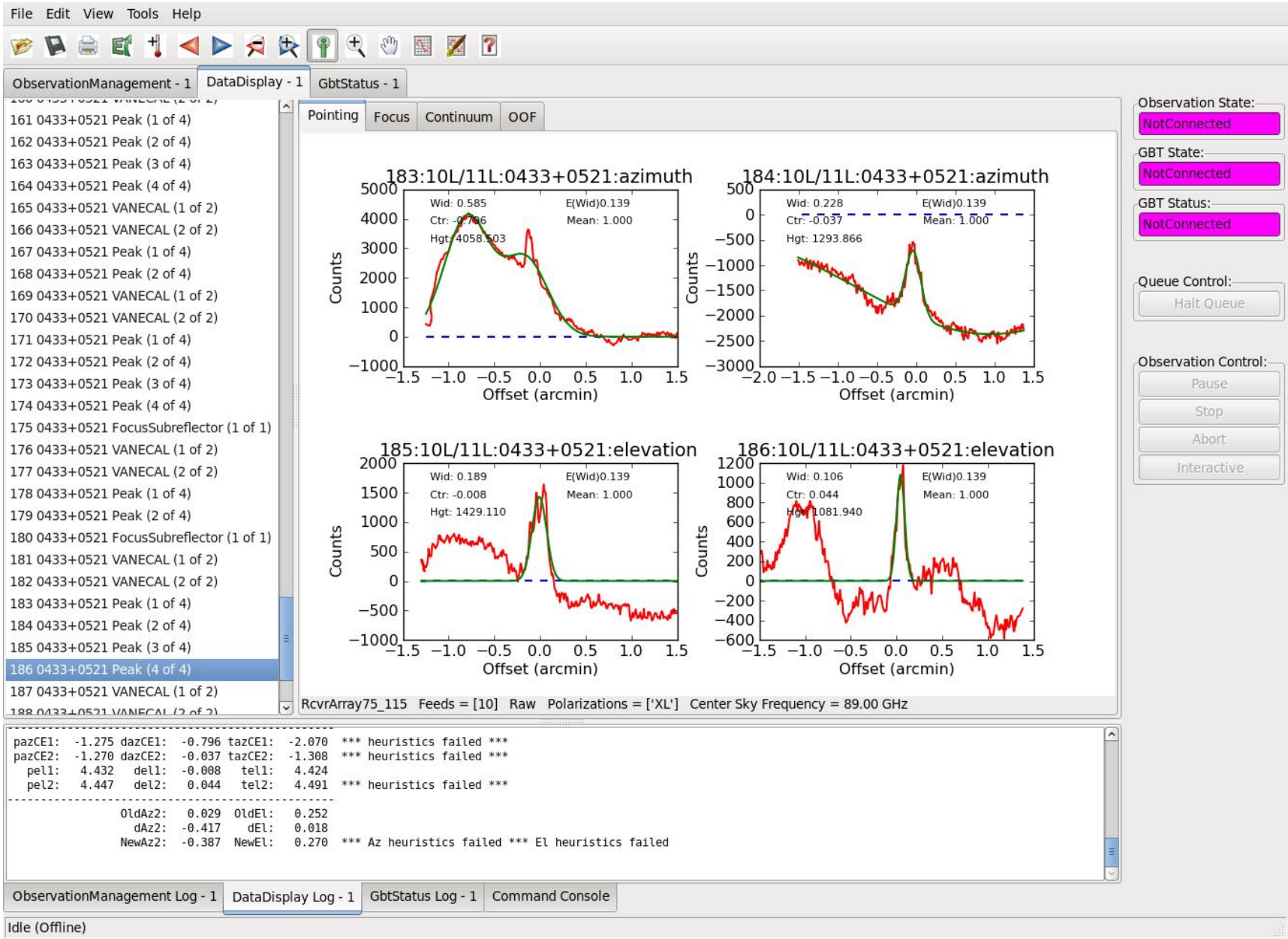
Avoid using solutions from bad scans 68&70 with servo issues and use good scans 69&70,
e.g., here:
NewAz2=0.133+ 0.016= 0.149
NewEl=0.391+ 0.006=0.397



Example pointing scans affected by changing sky



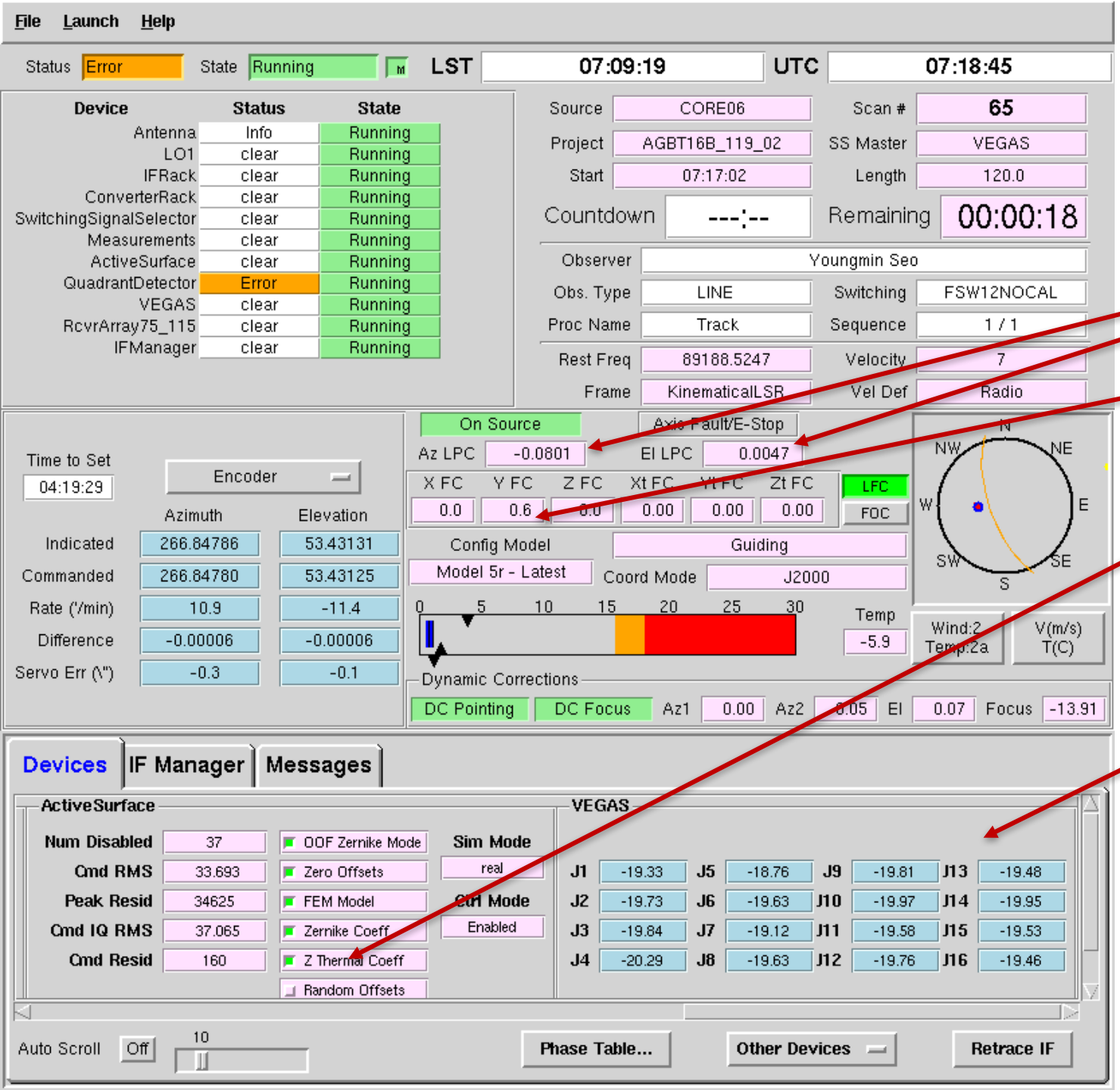
Another example of variable sky during pointing scans



Monitoring Argus and Logs

- Cleo status: LPC's, YFC, active surface
- Balancing: VEGAS levels -20.0, IFRack 1.5 V
- Cleo Device-Explorer: 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

Cleo Status Window

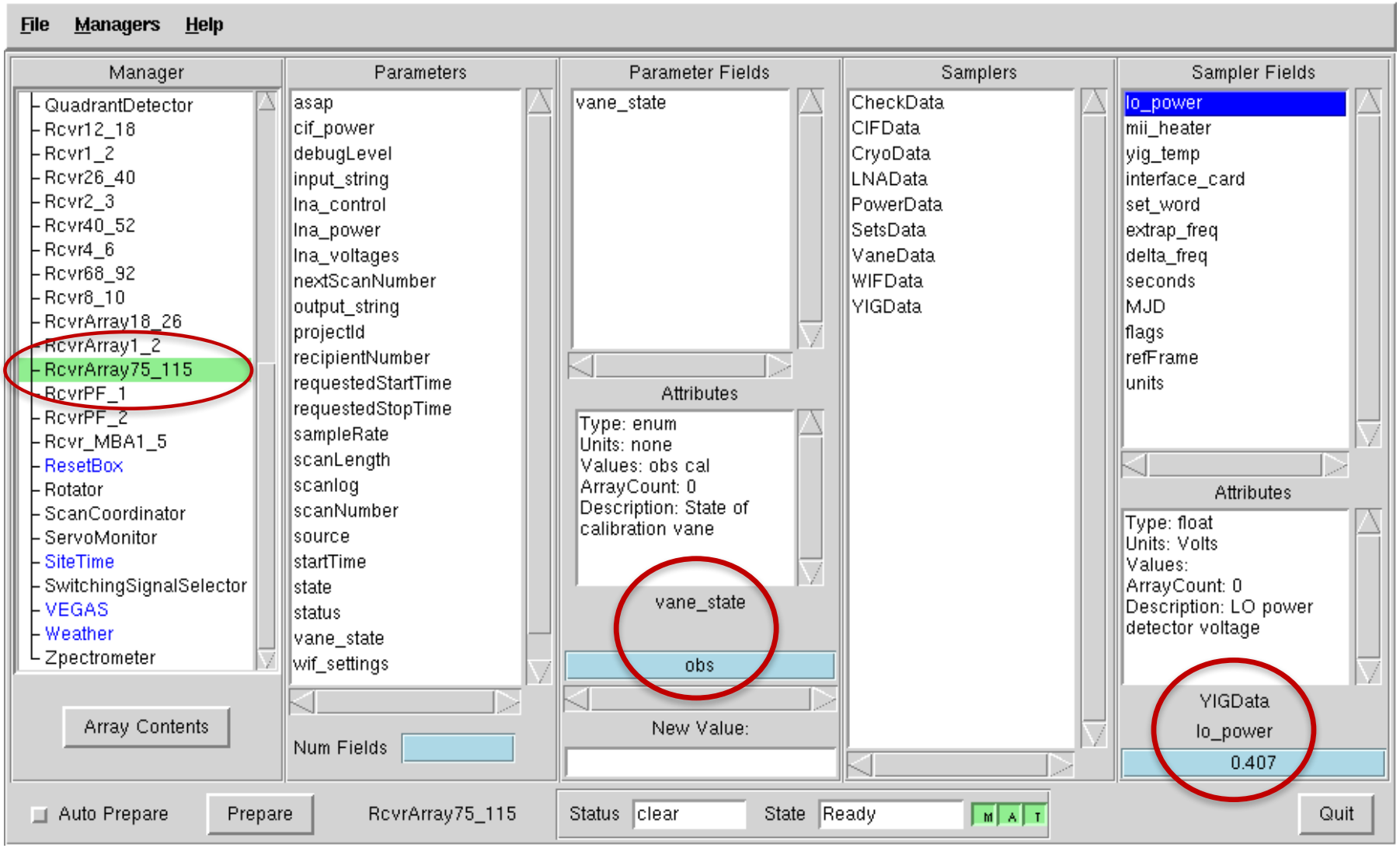


Az,El LPCs
Focus YFC

Active Surface ON with Thermal corrections from OOF

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

Device Explorer: Monitor the LO_power into the Yig after configuration and the Vane _state obs/cal when calibrating



Select RcvrArray75_115 (far left) to show Argus parameters.
Select vane_state parameter to show whether the vane is in the “obs” vs “cal” position
Select YigData under Samplers and lo_power in Sampler Fields to see Yig LO power

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 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]).

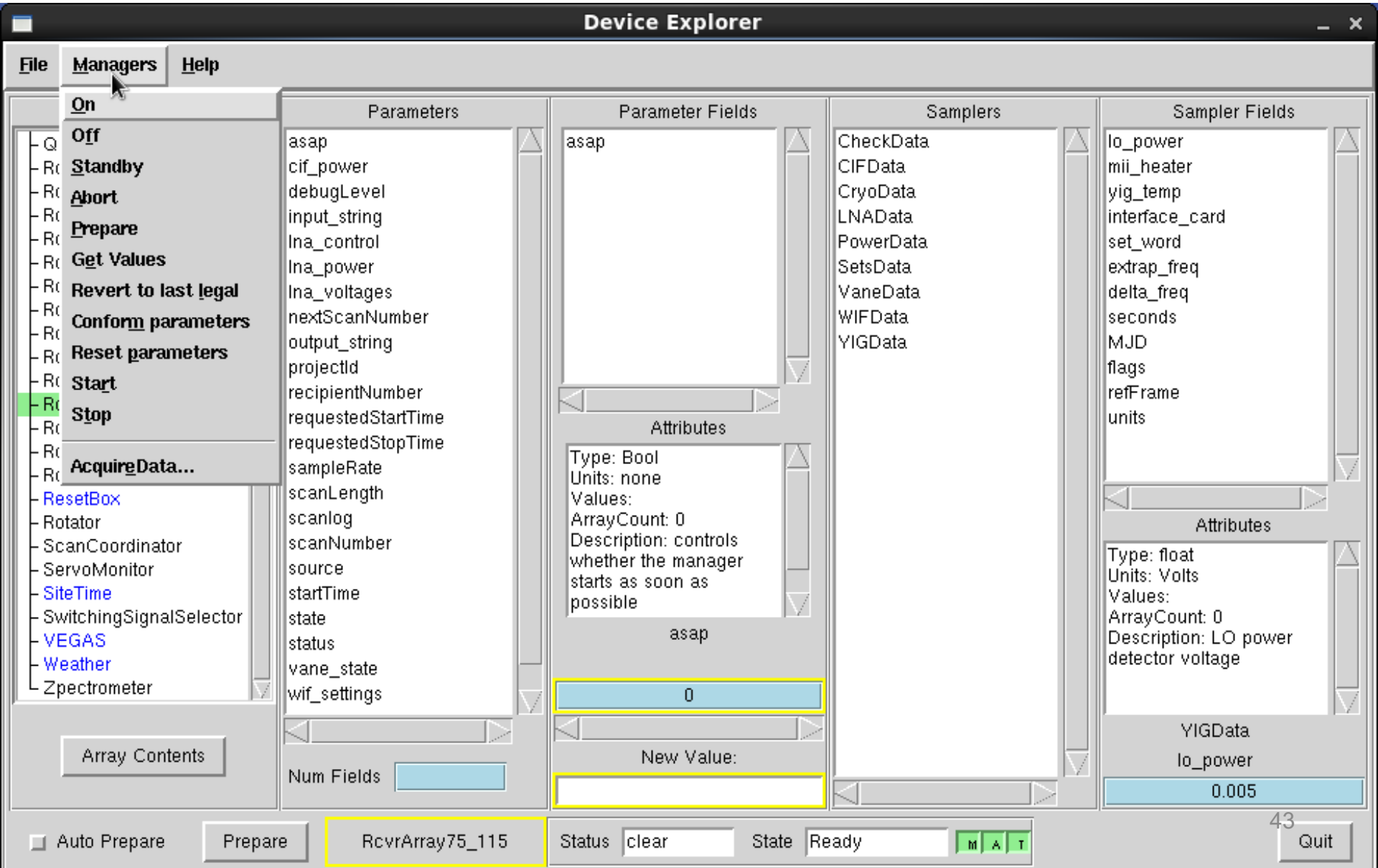
(5) If Argus remains in a fault state after configuration and multiple attempts to collect data, then

(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 call an Argus instrument expert.

If RcvrArray75_115 (Argus) reports and error that puts the instrument in a "Fault" state, then turn the manager "Off" then back "On" within Device Explorer (select RcvrArray75_115 at far-left first)



Balancing Notes for Argus+Vegas

- After the commissioning work, all Argus channels balanced across the full frequency range of the instrument. Optical-driver 4 runs out of attenuation, but is still within range at the ends of the band (75 GHz and 115 GHz).
- 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).
- A few converter modules associated with the dedicated fibers can sometimes show low power which could impact the data and result in failed balancing. Report cases of this to your project friend. We have fixed this in the past by un-connecting and re-connecting the optical fibers.
- 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

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 5% **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)
- $T_{mb} = T_a'/\eta_{mb}$ ($\eta_{mb} \sim 1.3\ \eta_a$)
- $T_a^* = T_a'/\eta_l$ (Argus uses T_a^*, η_l=~0.99 for the GBT)
- $T_a'/Sv = 2.84\ \eta_a$ (for the GBT)

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)

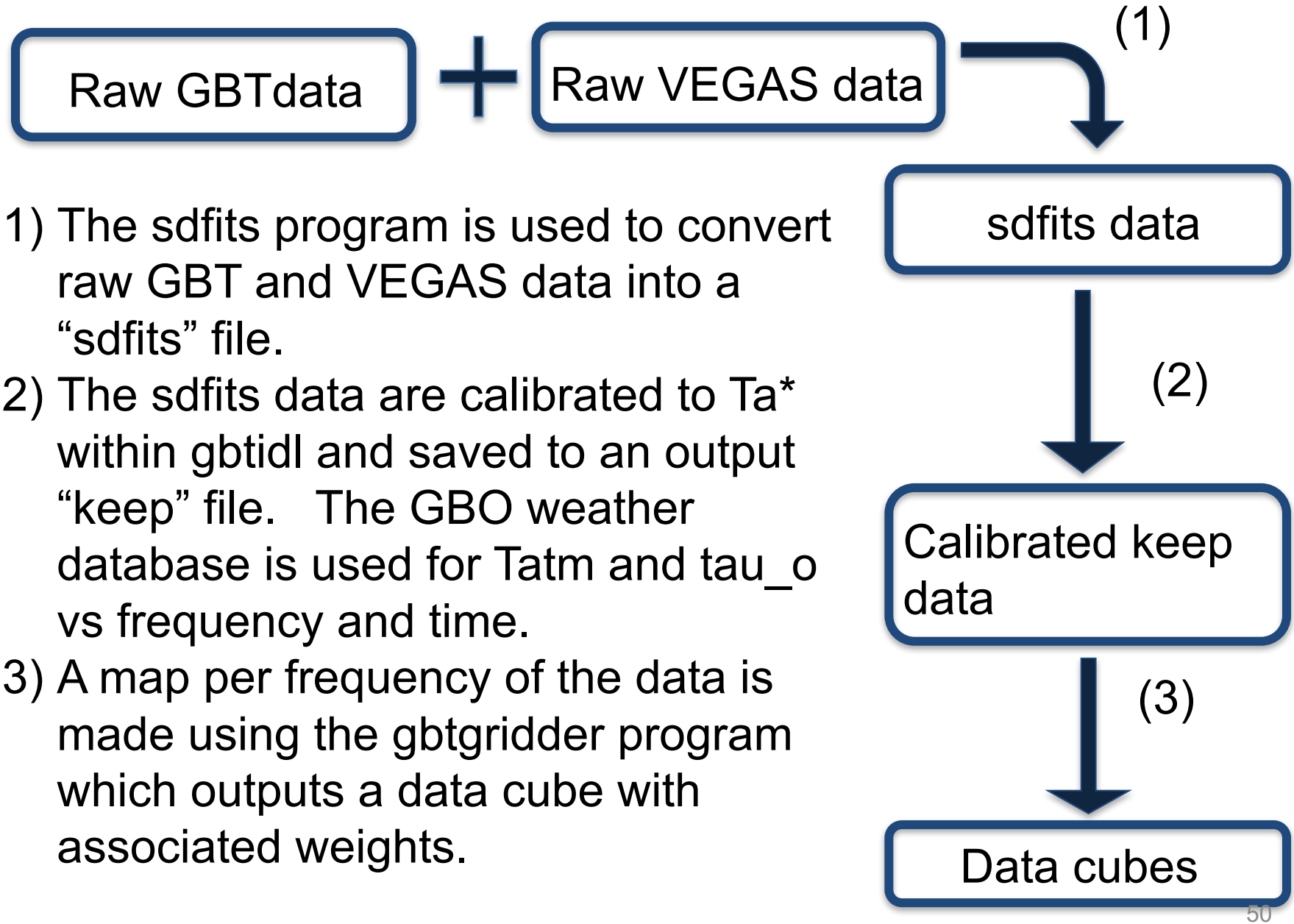
- Know S_ν (use ALMA calibration database available online) and derive η_a from measured Ta'
- Measure FWHM from good pointing scans or within your image to derived η_{mb} and Tmb; $\mathbf{Tmb = Ta'/\ \eta_{mb}}$
- $\mathbf{\eta_{mb} = 0.8899\ \eta_a\ (\theta_{FWHM}\ 100m/\ \lambda)^2}$ (assumes Gaussian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

Example Calibration

86 GHz:
Aperture efficiency: 36% (230um effective rms)
Beam efficiency: ~46% (beam =1.2 Lambda/D)
Moon efficiency: ~89%
Forward efficiency: ~99%

So at ~86 GHz, ~46% of the power is in beam, ~43% is in near side-lobes, ~10% is scattered in the forward direction, and ~1% is in rear-spillover.

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

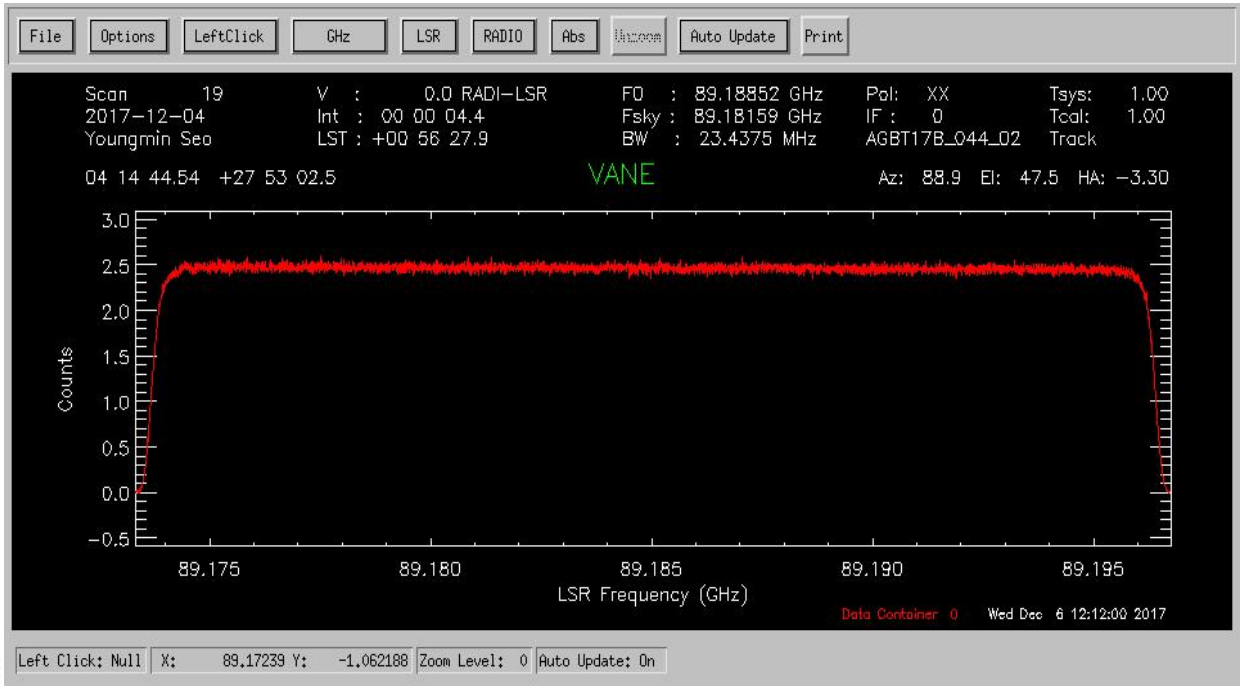
Argus GBTIDL scripts

/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.

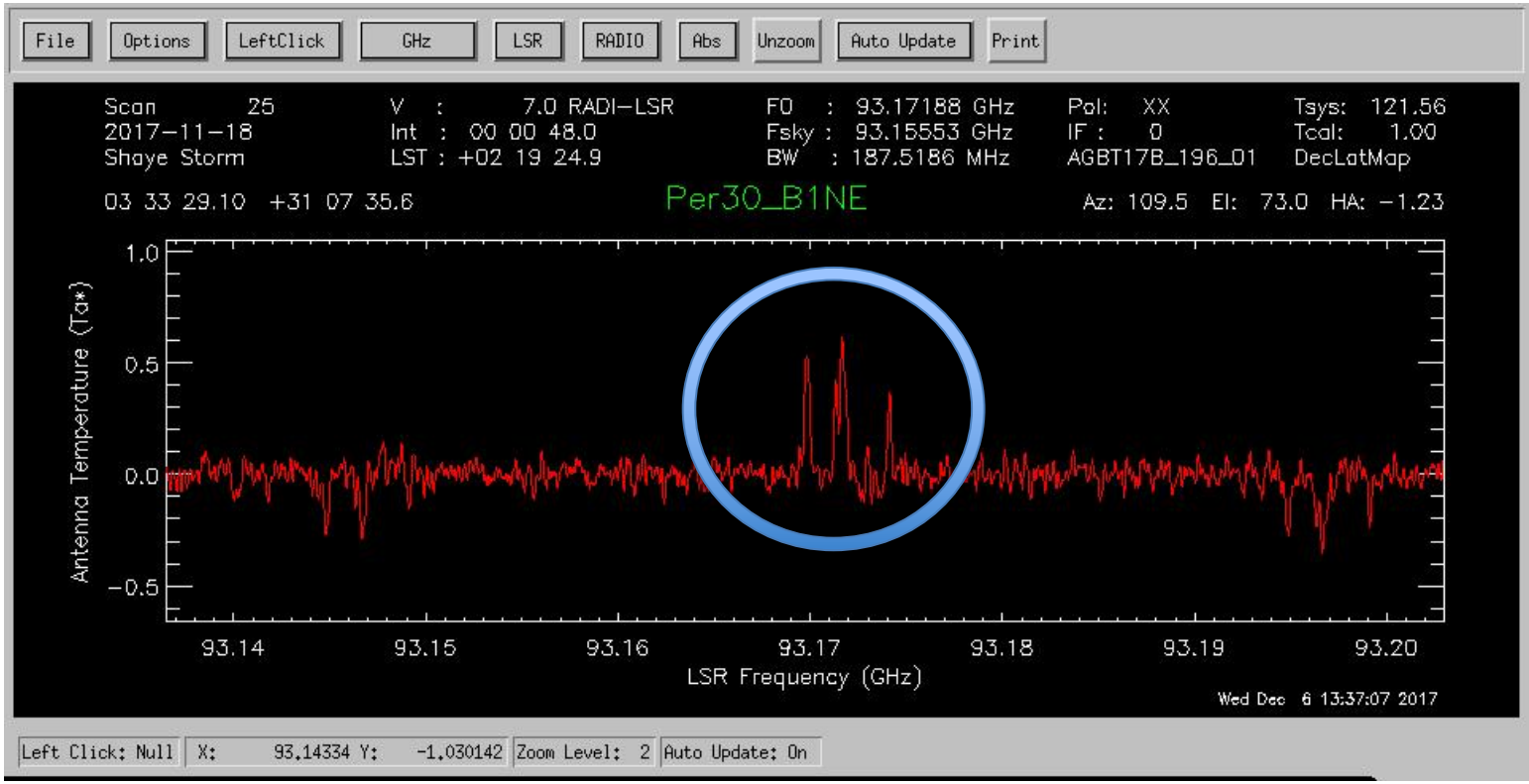



```
GBTIDL ->
GBTIDL -> vanecal,19
% Compiled module: VANECAL.
Scan:    19 (IF:0 FD:10 PL:0)    Tsys:   1.00
% Compiled module: GETATMOS.
(zenith) Opacity(89.181592,58091.058) = 0.0754
AtmTsys(89.181592,58091.058) = 25.8880
Tatm(89.181592,58091.058) = 266.4082
beam, Tsys*[K]:        1        111.44295
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