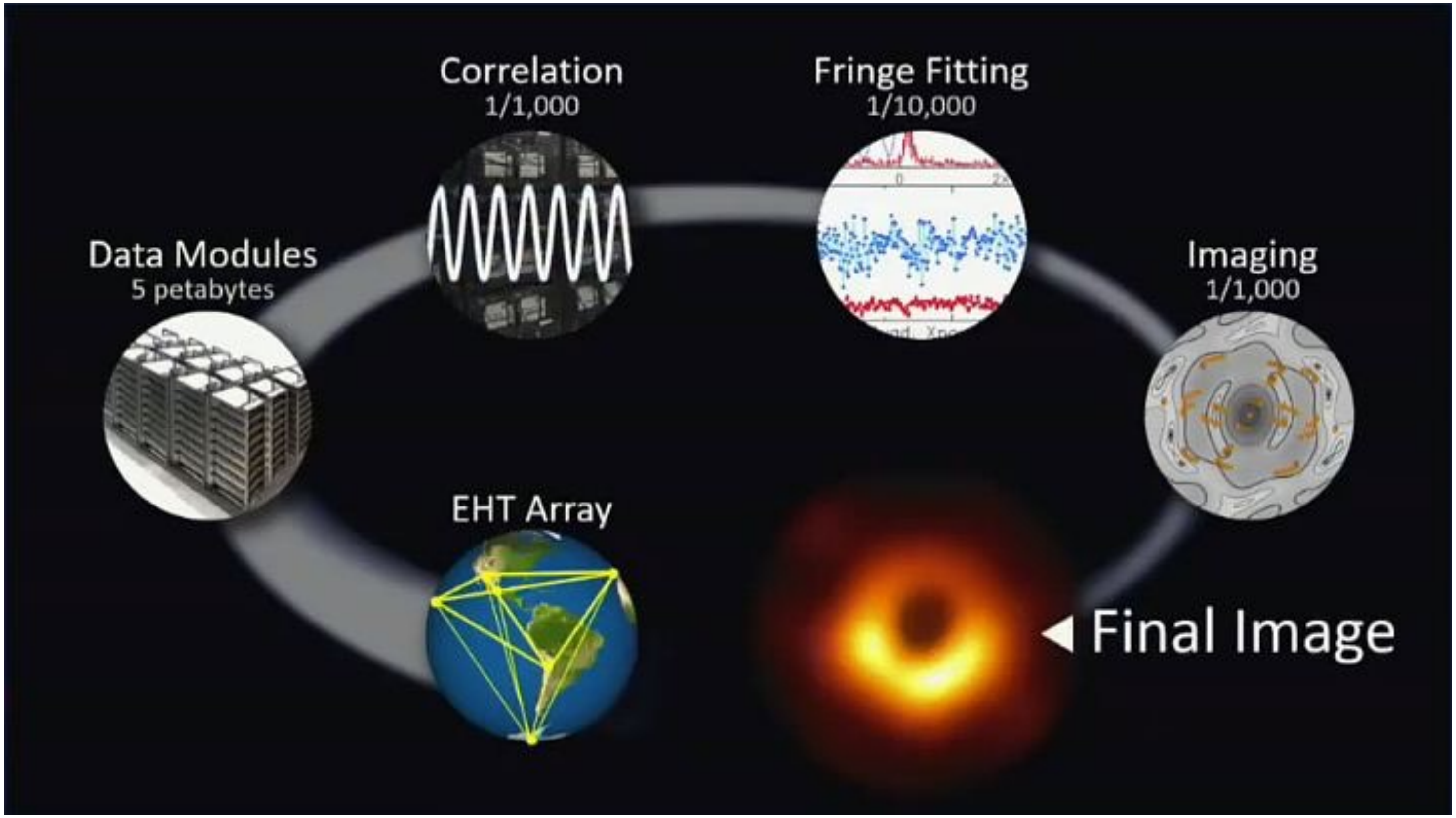
Antenna Gain Calibration

https://vlbi.org/2021/04/12/seminar-stations-amplitude-calibration/

Why is calibration important?



Why is calibration important?

- Surprisingly faint source → No detection → time wasted & bad data
- Surprisingly strong source → “Too good” → time wasted

- VGOS observe dual linear (H,V) polarisations
- Geodetic analysis simpler in circular polarisation
- Can convert from linear → circular using e.g. “polconvert”

- Monitoring source flux density is interesting for astronomy!
- Regular monitoring is hard to get with astro-VLBI networks.
- With ampcal in IVS, we may get astronomical discoveries “for free”.

VGOS goal – source structure…

Why is calibration important?

Experimental Astronomy (2022) 54:137–155
https://doi.org/10.1007/s10686-022-09867-4

ORIGINAL ARTICLE

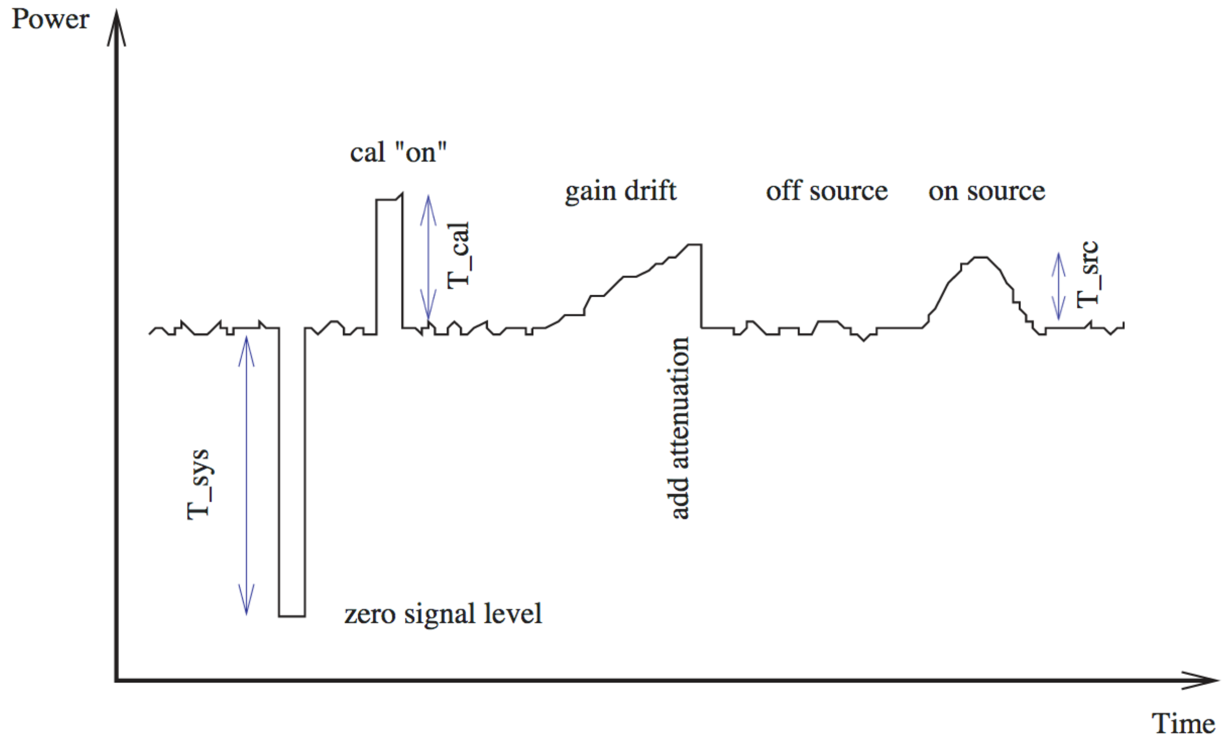
Broad band flux-density monitoring of radio sources with the Onsala twin telescopes

Eskil Varenius[1] · Francesco Maio[2] · Karine Le Bail[1] · Rüdiger Haas[1]

Received: 22 March 2022 / Accepted: 9 August 2022 / Published online: 23 August 2022

How can we deliver better calibrated data to the user/IVS?

- fivept (pointing)
- onoff (determine: noise diode and gain curve)
- gnplt (analyse result from onoff)



Important files

- flux.ctl /usr2/control
- *.rxg /usr2/control/rxg_files

Important files: flux.ctl

more flux.ctl

```
* flux.ctl - source flux control file
*
* source records:
*
* originally from John Conway based on (Casa, Cygnusa, TauA) from Baars et al
* 1977, AA, 61, 99 and (others) Ott et al 1994, AA 284, 331, see sflux.f
* subroutine, WEH 020813
*
* min freq on L band sources decreased to 500 per John Conway, WEH 0209xx
*
*             freq MHz  ---- flux 10** ----   "     FS
* source  type  min  max  log   log(f) 2log(f) size  model
  3c48     c    500 23780 2.465 -0.004 -0.1251   1.5 gauss 100    1s
  3c123    c    500 23780 2.525  0.246 -0.1638  23   gauss 100   23s 5s
  3c147    c    500 23780 2.806 -0.140 -0.1031   1   gauss 100    1s
  3c161    c    500 10550 1.250  0.726 -0.2286   3   gauss 100    3s
  3c218    c    500 10550 4.729 -1.025  0.0130  47   gauss 100   47s 14s
  3c227    c    500  5000 6.757 -2.801  0.2969 200   gauss 100  200s 50s
  3c249.1  c    500  5000 2.537 -0.565 -0.0404  15   gauss 100   15s
* virgo structure guessed from FS manuals, WEH 0208xx
  virgoa   c    500  2520 4.484 -0.603 -0.0280 200   gauss  80.8 40s 20s 19.2 10
m 10m
```

Important files: *.rxg

```
* RXG file
* calonc.rxg - c band receiver parameter definition
range  4100 4600
* Line polarizations available
*
* one of both of lcp and rcp
*
lcp rcp
*
*  DPFU (degrees/Jansky) for polarizations in previous line in order
*
0.085000 0.08500
*
*  gain curve (only one) for ALL polarizations in 4th line
*
ELEV POLY 6.01702E-01 1.49994E-02 -3.36413E-04 4.27259E-06 -2.11736E-08
*
* tcal versus frequency
*
lcp 4735.5 3.5290
lcp 4737.5 3.5580
lcp 4743.5 3.5835
rcp 4735.5 3.5130
rcp 4737.5 3.5370
rcp 4743.5 3.6100
```

ONOFF

- **Power on source [ONSO]**
- **Power on source with noise diode on [ONSC]**
- **Power off source with noise diode on [OFFC]**
- **Power off source with noise diode off [OFFS]**
- **Power off source with no signal for “zero” [ZERO]**

ACQUIR = Run many ONOFFs in sequence

ONOFF

```
2017.059.07:55:21.15;onoff
2017.059.07:55:21.27#onoff#    De      Center  TCal    Flux     DPFU     Gain    Product    LO     T   FWHM
2017.059.07:55:21.27#onoff#APR 1l     4829.49 3.842   369.43  0.085000 0.96336  0.081886 4100.00 c 0.16950
2017.059.07:55:21.27#onoff#APR 3l     4829.49 3.842   369.43  0.085000 0.96336  0.081886 4100.00 c 0.16950
2017.059.07:55:21.27#onoff#APR 5l     4893.49 3.644   363.19  0.085000 0.96336  0.081886 4100.00 c 0.16728
2017.059.07:55:21.27#onoff#APR 7l     4893.49 3.644   363.19  0.085000 0.96336  0.081886 4100.00 c 0.16728
2017.059.07:55:21.27#onoff#APR 9l     4957.49 3.978   357.13  0.085000 0.96336  0.081886 4100.00 c 0.16512
2017.059.07:55:21.27#onoff#APR bl     4957.49 3.978   357.13  0.085000 0.96336  0.081886 4100.00 c 0.16512
2017.059.07:55:21.27#onoff#APR dl     5021.49 3.794   351.24  0.085000 0.96336  0.081886 4100.00 c 0.16302
2017.059.07:55:21.27#onoff#APR fl     5021.49 3.794   351.24  0.085000 0.96336  0.081886 4100.00 c 0.16302
2017.059.07:55:21.27#onoff#APR 1u     4831.49 3.841   369.23  0.085000 0.96336  0.081886 4100.00 c 0.16943
2017.059.07:55:21.27#onoff#APR 3u     4831.49 3.841   369.23  0.085000 0.96336  0.081886 4100.00 c 0.16943
2017.059.07:55:21.27#onoff#APR 5u     4895.49 3.640   363.00  0.085000 0.96336  0.081886 4100.00 c 0.16721
2017.059.07:55:21.27#onoff#APR 7u     4895.49 3.640   363.00  0.085000 0.96336  0.081886 4100.00 c 0.16721
2017.059.07:55:21.27#onoff#APR 9u     4959.49 3.990   356.94  0.085000 0.96336  0.081886 4100.00 c 0.16505
2017.059.07:55:21.27#onoff#APR bu     4959.49 3.990   356.94  0.085000 0.96336  0.081886 4100.00 c 0.16505
2017.059.07:55:21.27#onoff#APR du     5023.49 3.788   351.06  0.085000 0.96336  0.081886 4100.00 c 0.16295
2017.059.07:55:21.27#onoff#APR fu     5023.49 3.788   351.06  0.085000 0.96336  0.081886 4100.00 c 0.16295
```

ONOFF

more onoff-seq.log

```
[ttcyg.local](\!) more onoff-seq.log
2017.059.07:55:26.98#onoff#ONSO     3.4   0.00000   0.00000 1l  15264.3    156.8 3l  15264.3    156.8
2017.059.07:55:26.98#onoff#ONSO     3.4   0.00000   0.00000 5l  16826.3    188.3 7l  16826.3    188.3
2017.059.07:55:26.98#onoff#ONSC     3.4   0.00000   0.00000 1l  16124.3    179.8 3l  16124.3    179.8
2017.059.07:55:26.98#onoff#ONSC     3.4   0.00000   0.00000 5l  17744.3    177.6 7l  17744.3    177.6
2017.059.07:55:48.50#onoff#OFFC    25.0   6.16823   0.00000 1l   9587.7      6.6 3l   9587.7      6.6
2017.059.07:55:48.50#onoff#OFFC    25.0   6.16823   0.00000 5l  10617.0     16.0 7l  10617.0     16.0
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 1l   8711.3     19.0 3l   8711.3     19.0
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 5l   9703.7     22.2 7l   9703.7     22.2
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 9l   8964.0      5.3 bl   8964.0      5.3
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 5u   9727.7     20.3 7u   9727.7     20.3
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 9u   8925.0     18.3 bu   8925.0     18.3
2017.059.07:55:48.50#onoff#OFFS    25.0   6.16823   0.00000 du   8953.7     12.4 fu   8953.7     12.4
2017.059.07:55:48.50#onoff#ZERO    25.0   6.16823   0.00000 1l      0.0      0.0 3l      0.0      0.0
2017.059.07:55:48.50#onoff#ZERO    25.0   6.16823   0.00000 5l      0.0      0.0 7l      0.0      0.0
onoff-seq.log (END)
```

ONOFF

- **Power on source [ONSO]**
- **Power on source with noise diode on [ONSC]**
- **Power off source with noise diode on [OFFC]**
- **Power off source with noise diode off [OFFS]**
- **Power off source with no signal for “zero” [ZERO]**

ACQUIR = Run many ONOFFs in sequence

```
2011.067.07:43:29.45#onoff#    source       Az   El   De I P   Center   Comp   Tsys   SEFD  Tcal(j) Tcal(r)
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 1u 1 l   4941.00 0.9850 57.62  736.3 193.744  1.05
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 2u 2 r   4941.00 0.9878 169.9  844.2  77.882  0.41
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 3u 1 l   4943.00 0.9938 57.61  729.9 193.649  1.04
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 4u 2 r   4943.00 0.9845 167.7  840.6  79.017  0.41
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 5u 1 l   4945.00 0.9851 57.66  729.9 193.592  1.04
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 6u 2 r   4945.00 0.9877 168.0  837.7  79.321  0.41
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 7u 1 l   4947.00 0.9833 57.81  727.6 190.954  1.03
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 8u 2 r   4947.00 0.9865 171.5  837.2  79.032  0.40
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 9u 1 l   4949.00 0.9959 58.03  718.5 187.139  1.02
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 au 2 r   4949.00 0.9907 172.8  839.8  78.740  0.40
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 bu 1 l   4953.00 0.9867 58.17  712.0 179.502  1.00
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 cu 2 r   4953.09 0.9939 171.5  834.4  77.979  0.40
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 du 1 l   4955.00 0.9900 58.04  713.0 175.949  1.01
2011.067.07:43:29.45#onoff#VAL cygnusa    161.7 72.8 eu 2 r   4955.00 0.9920 173.7  837.8  76.844  0.40
2011.067.07:43:29.45#onoff#    source       Az   El   De I P   Center   Comp   Tsys   SEFD  Tcal(j) Tcal(r)
```

$$\mathrm{Comp} = \frac{\mathrm{ONSC} - \mathrm{ONSO}}{\mathrm{OFFC} - \mathrm{OFFS}}$$

$$\mathrm{SEFD} = \mathrm{S} \times \frac{\mathrm{OFFS} - \mathrm{ZERO}}{\mathrm{ONSO} - \mathrm{OFFS}}$$

SEFD = 369.4 Jy x (8711.3-0)/(15264.3-8711.3) = 491 Jy

$$\mathrm{T_{sys}} = \mathrm{T_{cal}} \times \frac{\mathrm{OFFS} - \mathrm{ZERO}}{\mathrm{OFFC} - \mathrm{OFFS}}$$

$$\mathrm{T_{cal}(Jy) = S \times \frac{OFFC - OFFS}{ONSO - OFFS}}$$

$$\mathrm{T_{cal}(K) = DPFU \times gain(el) \times T_{cal}(Jy)}$$

$$\mathrm{T_{cal}(r) = T_{cal}(K)/T_{cal,rxg}(K)}$$

SEFD

- Example:

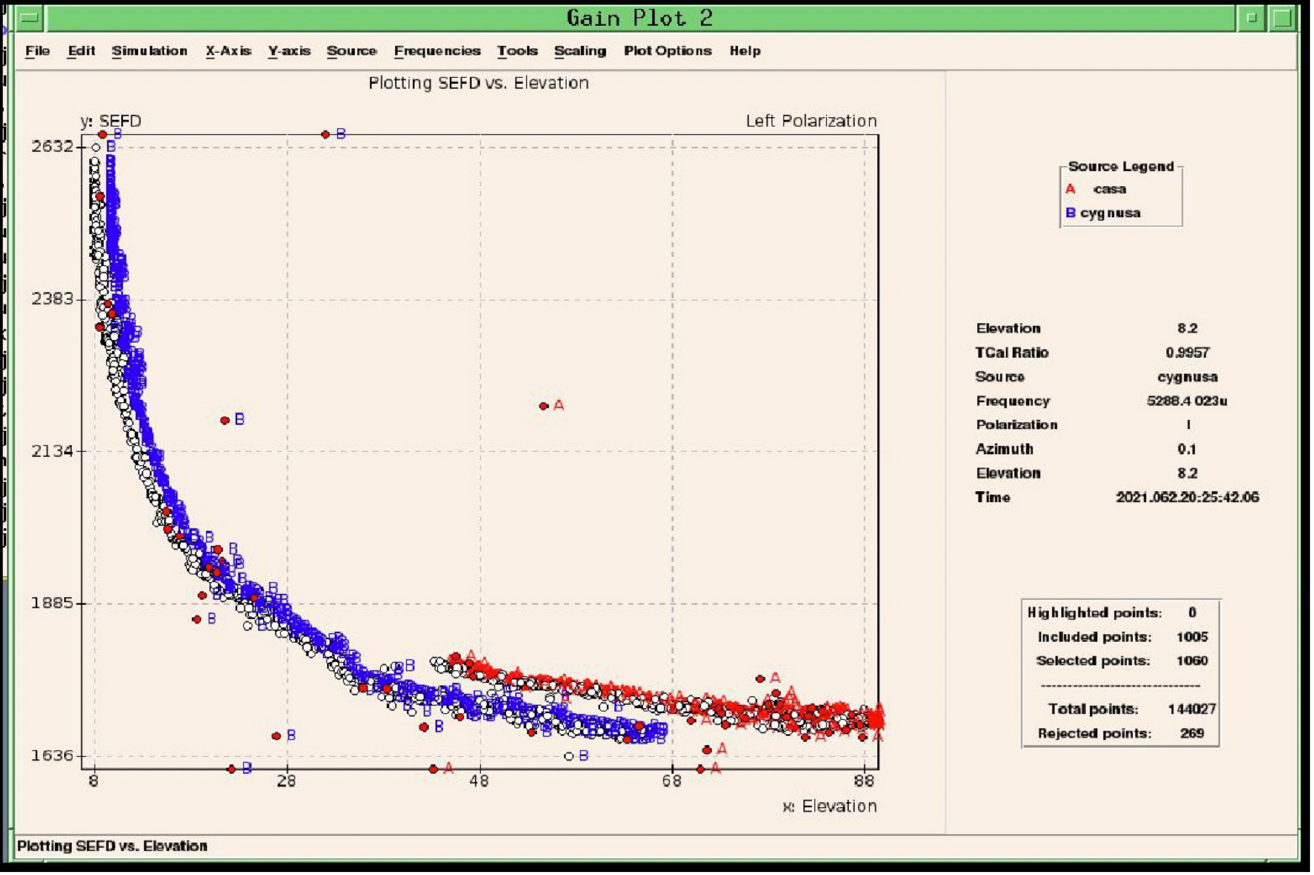
  ONSA13NE

  SEFD vs elevation

  H-pol

  5.3 GHz

  Cyg A + Cas A



Tsys

- Example:

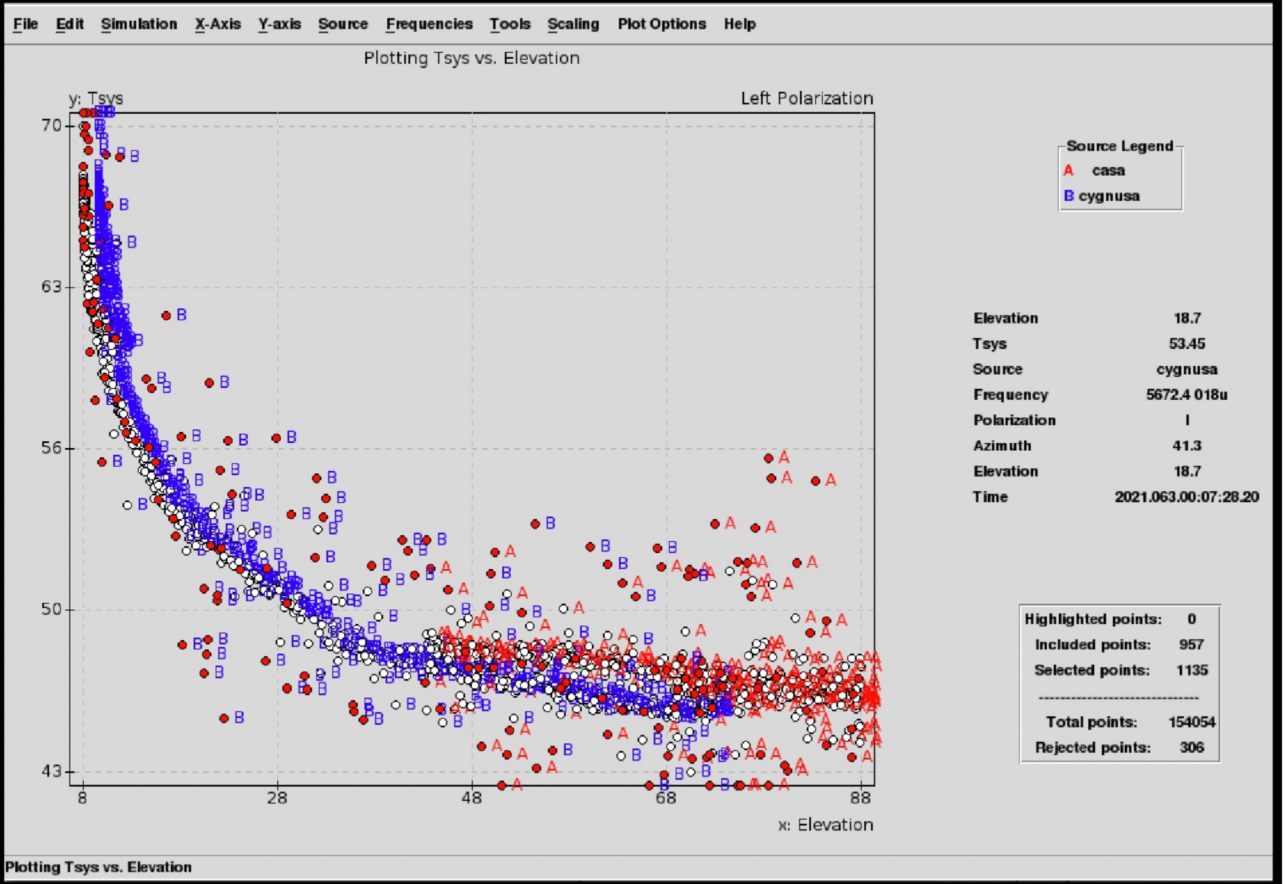
  ONSA13NE

  TSYS vs elevation

  H-pol

  5.7 GHz

  Cyg A + Cas A



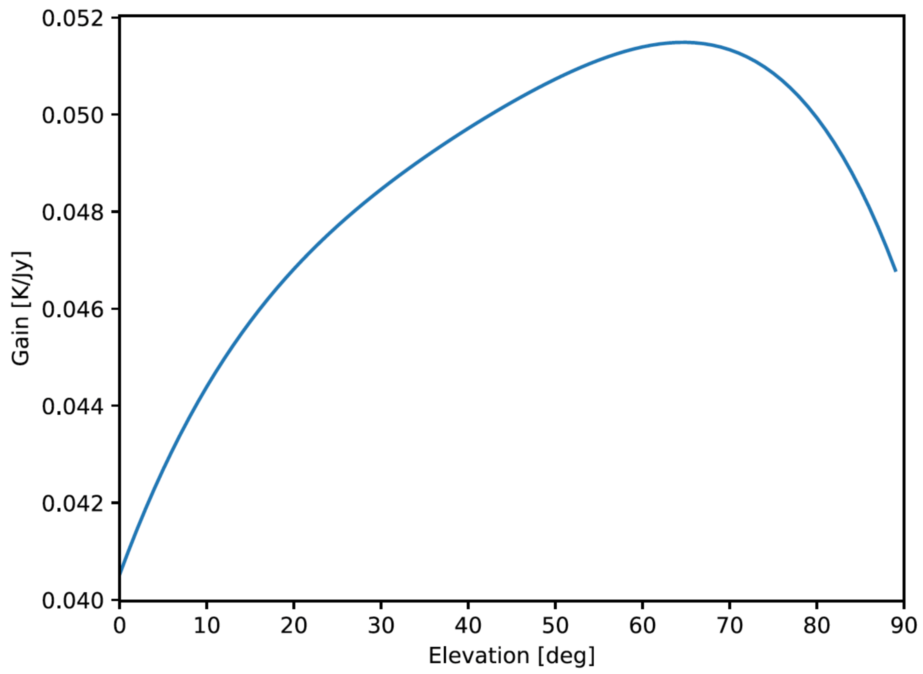
Gain curve

- Example:

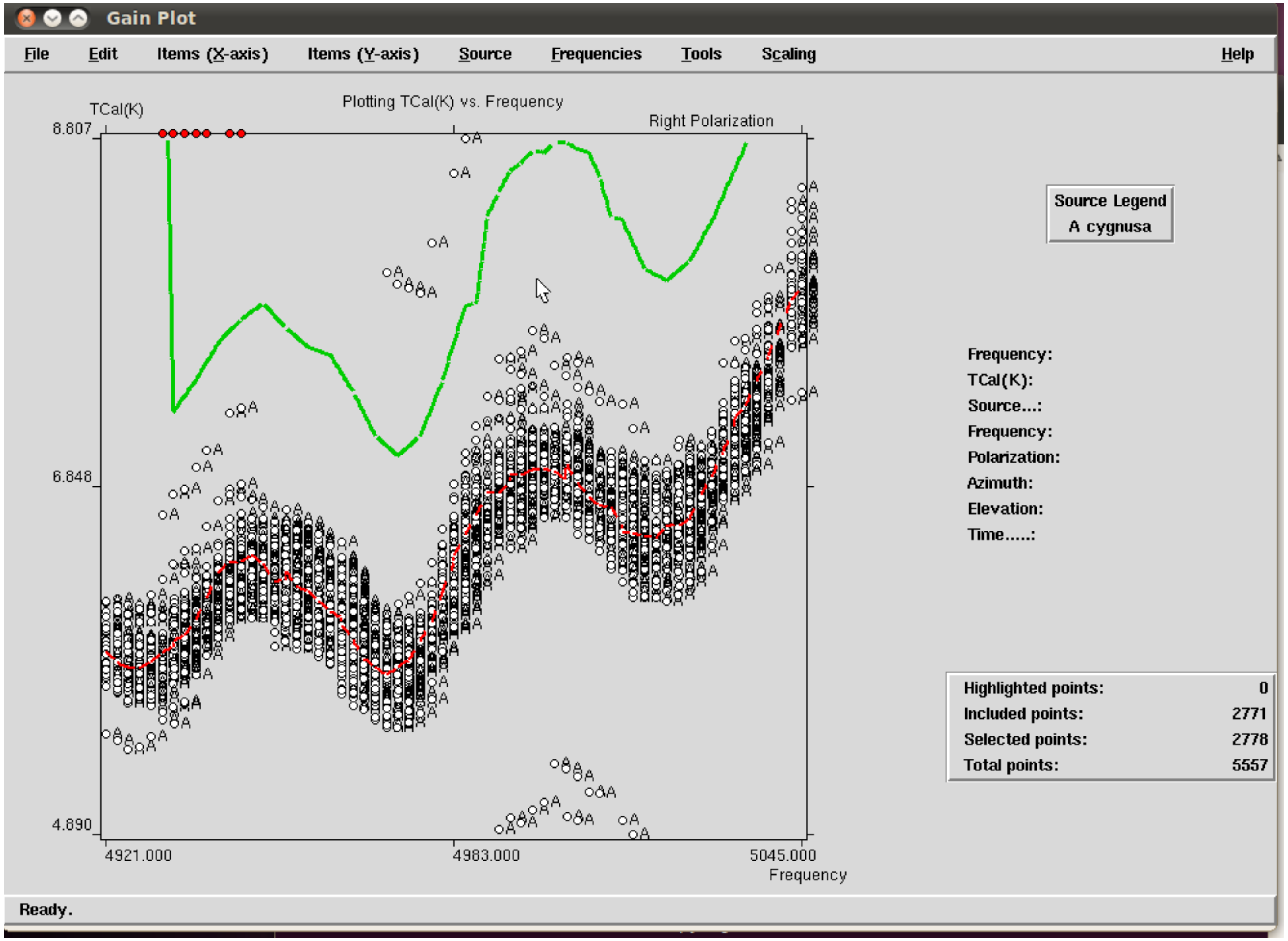
  ONSALA60

  X-band

  GAIN=DPFU* POLY(el)

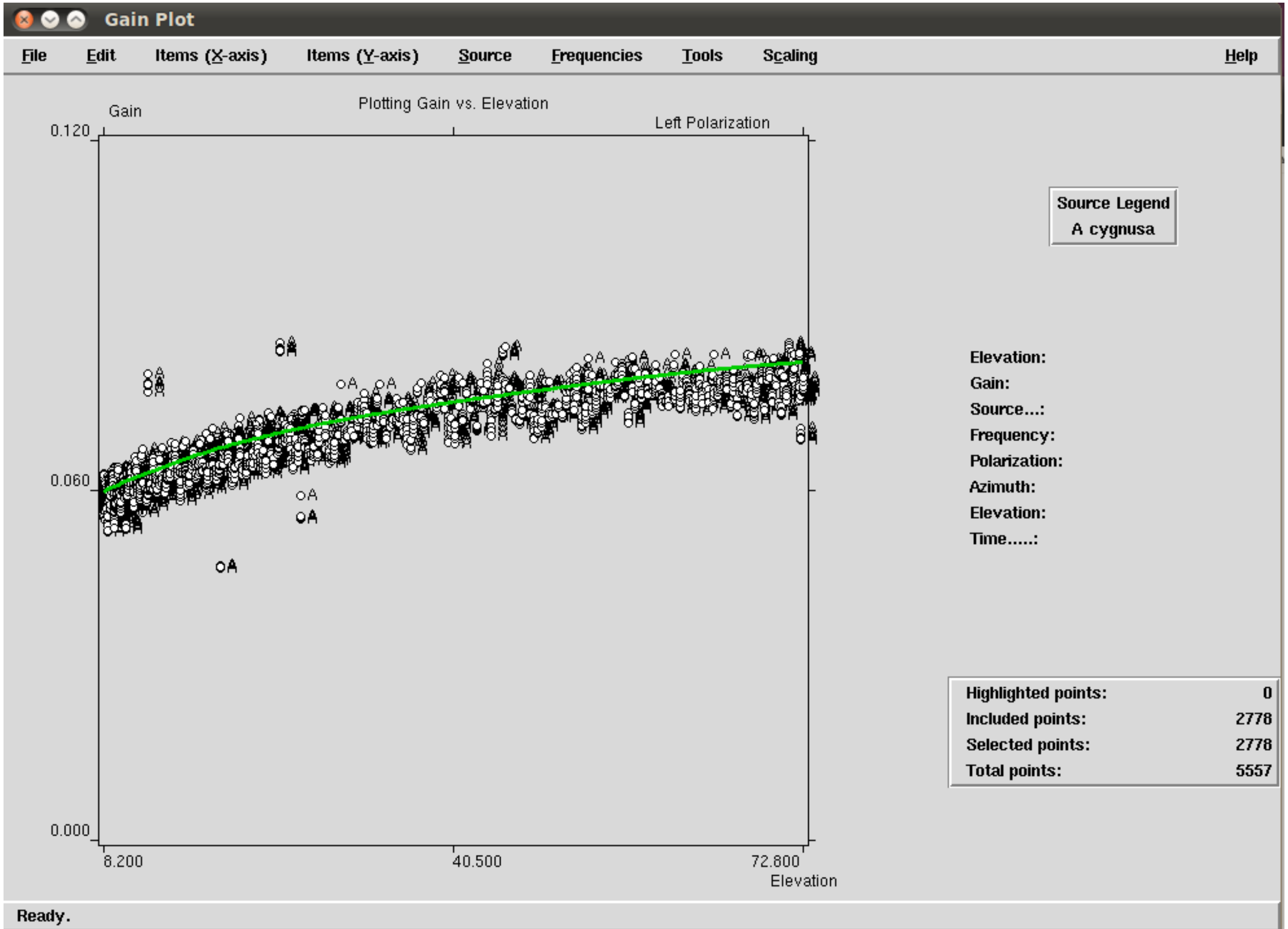


GNPLT



Gain Plot
File
Edit
Items (X-axis)
Items (Y-axis)
Source
Frequencies
Tools
Scaling
Help
Plotting TCal(K) vs. Frequency
TCal(K)
Right Polarization
8.807
6.848
4.890
4921.000
4983.000
5045.000
Frequency
Source Legend
A cygnusa
Frequency:
TCal(K):
Source...:
Frequency:
Polarization:
Azimuth:
Elevation:
Time.....:
Highlighted points: 0
Included points: 2771
Selected points: 2778
Total points: 5557
Ready.

GNPLT


Gain Plot
File
Edit
Items (X-axis)
Items (Y-axis)
Source
Frequencies
Tools
Scaling
Help
Plotting Gain vs. Elevation
Gain
Left Polarization
0.120
0.060
0.000
8.200
40.500
72.800
Elevation
Source Legend
A cygnusa
Elevation:
Gain:
Source...:
Frequency:
Polarization:
Azimuth:
Elevation:
Time.....:
Highlighted points: 0
Included points: 2778
Selected points: 2778
Total points: 5557
Ready.

EVN

```
 ----------------
 | PART 1   18cm |
 ----------------

CODE                    EVN   TELESCOPES                                                CORR    TOT    /ST     DAY UT-START     UT-STOP      COMMENTS
====== ============================================================================== ===== ====== ===== == === ======================= =================

N21L1  Jb1 Wb1 Ef Mc Nt On85 -- -- Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN    17.98  1.38 Eu 056 1200(25/02)-1500(25/02) 18cm NME

EH038A Jb1 Wb1 Ef Mc Nt On85 -- Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN    70.96  5.07 Eu 056 2000(25/02)-0700(26/02) -

ET045A Jb1 Wb1 Ef Mc Nt On85 -- -- Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN    41.92  3.23 Eu 057 0800(26/02)-1500(26/02) -

ES096A Jb1 Wb1 Ef Mc Nt On85 -- Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN    55.29  3.69 Eu 057 2230(26/02)-0630(27/02) -

CL21L1 Jb1 Wb1 Ef Mc Nt On85 -- Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- --- EVN     0.00  0.00 Eu 058 1000(27/02)-1400(27/02) 18cm FS CAL

EH038B Jb1 Wb1 Ef Mc Nt On85 -- Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN    70.96  5.07 Eu 058 2100(27/02)-0800(28/02) Ur ends at 0600UT

ER047F Jb1 Wb1 Ef Mc Nt On85 T6 Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- Ro70 MER EVN    84.48  5.53 Eu 059 1730(28/02)-0530(01/03) final epoch
                                                                                                    1.54 Ro 060 0135(01/03)-0455(01/03) Robledo

EN007B Jb1 Wb1 Ef Mc Nt On85 T6 Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- MER EVN   165.89 11.06 Eu 060 2300(01/03)-2300(02/03) 2nd epoch

EB081C Jb2 Wb1 Ef Mc Nt On85 T6 Ur Tr Hh Sv Zc Bd Ir Sr -- -- -- -- -- -- ---- --- EVN    69.12  4.61 Eu 062 0030(03/03)-1030(03/03) +Jb1; final epoch

 ---------------
 | PART 2   6cm |
 ---------------

N21C1  Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- --(Km)-- -- -- -- ---- MER EVN    38.71  2.76 Eu 062 1400(03/03)-1700(03/03) 6cm NME

CL21C1 Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- --(Km)-- -- -- -- ---- --- EVN     0.00  0.00 Eu 062 1800(03/03)-2200(03/03) 6cm FS CAL

EN006E Jb2 Wb1 Ef Mc -- On85 -- Ur Tr Hh Sv Zc -- Ir -- -- -- -- -- -- -- ---- --- EVN    40.55  3.69 Eu 062 2300(03/03)-0300(04/03) re-obs

EC071I Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- -- -- -- -- -- -- ---- --- EVN    71.88  5.53 Eu 063 0800(04/03)-1400(04/03) group 4

EM144B Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- -- -- -- -- -- -- ---- MER EVN    95.85  7.37 Eu 064 0400(05/03)-1200(05/03) 2nd epoch

EY036A Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- --(Km)-- -- -- -- ---- --- EVN    51.61  3.69 Eu 064 1300(05/03)-1700(05/03) -

EM148  Jb2 Wb1 Ef Mc -- On85 -- -- Tr -- -- -- -- -- -- -- -- -- -- -- -- ---- MER EVN    47.00  7.83 Eu 065 0100(06/03)-1800(06/03) -

ET045B Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- --(Km)-- -- -- -- ---- MER EVN    90.32  6.45 Eu 066 0730(07/03)-1430(07/03) -

ES096B Jb2 Wb1 Ef Mc -- On85 T6 Ur Tr Hh Sv Zc Bd Ir -- --(Km)-- -- -- -- ---- MER EVN   103.22  7.37 Eu 066 2200(07/03)-0600(08/03) -
```

- onoff
- gnplt

→ • rxg-file (Tcal(K), DPFU, gaincurve) → log-file+rxg-file

→ antabfs   antab-file to the user

Feedback from JIVE

Median of absolute errors in gain calibration

L band (Session 1, 2021)

Ar	Bd	Cm	Da	De	Ef	Hh	Ir	J1	J2	Km	Kn
N/A	0.13	0.15	0.3	N/A	0.07	0.09	0.14	0.10	0.17	N/A	0.2
Kt	Ku	Ky	Mc	Mh	Nt	O6	O8	Pi	Ro	Sr	Sv
N/A	N/A	N/A	0.10	N/A	0.10	N/A	0.09	N/A	N/A	0.13	0.2
T6	Tr	Ur	Wb	Ys	Zc						
0.4	0.14	0.2	0.17	N/A	0.4						

C/M band (Session 1, 2021)

Bd	Cm	Da	De	Ef	Hh	Ir	J1	J2	Km	Kn	Kt
0.12	0.10	0.13	0.14	0.04	0.08	0.07	N/A	0.10	N/A	0.13	N/A
Ku	Ky	Mc	Mh	Nt	O6	O8	Pi	Ro	Sr	Sv	T6
N/A	N/A	0.047	N/A	N/A	N/A	0.07	N/A	N/A	N/A	0.07	0.04
Tr	Ur	Wb	Ys	Zc							
0.04	0.16	0.09	N/A	0.07							

X band (Session 1, 2021)

Ar	Bd	Cm	Da	De	Ef	Hh	Ir	J1	J2	Km	Kn
N/A	0.14	N/A	N/A	N/A	0.10	0.08	0.11	N/A	N/A	0.17	N/A
Kt	Ku	Ky	Mc	Mh	Nt	O6	O8	Pi	Ro	Sr	Sv
N/A	N/A	N/A	0.052	N/A	0.3	0.14	N/A	N/A	N/A	N/A	0.11
T6	Tr	Ur	Wb	Ys	Zc						
0.06	N/A	0.10	0.10	0.11	0.3						

K band (Session 1, 2021)

Ar	Bd	Cm	Da	De	Ef	Hh	Ir	J1	J2	Km	Kn
N/A	0.3	0.2	N/A	N/A	0.07	0.3	N/A	N/A	0.3	N/A	N/A
Kt	Ku	Ky	Mc	Mh	Nt	O6	O8	Pi	Ro	Sr	Sv
0.14	0.16	0.18	0.08	0.20	N/A	0.12	N/A	N/A	N/A	0.057	0.19
T6	Tr	Ur	Wb	Ys	Zc						
0.13	0.2	0.3	N/A	N/A	0.3						

These are the session averages of the previous experiment-by-experiment values. Numbers are sensitive to how many experiments were averaged out. Orange: above 20% average errors. Red: >50%.

The table shows the median absolute amplitude error for EVN stations. These results were derived from the pipeline amplitude self-calibration results.

Feedback from JIVE

Closing notes (summary of 2021)

- A lot of experiments, good looking amplitudes, new antennas, receivers. EVN = Earth VBLI Network?
- Urumqi started sending ANTAB files regularly, implemented antabfs. However, Tsys values seem to be random and are not always usable.
- Gains look good, but one issue: opacity corrections for K/Q-band is done differently (or not done) at each station, causing large errors.
- Automatic ANTAB flagging and uploading to vlbeer? It would be good to share tools between antennas (there is a GitHub set up for this).
- Please continue uploading ANTABs and LOG files without JIVE asking for it. Please also check if they are valid or not. However, there were huge improvements in this over the year. Thank you!

Feedback from JIVE

Summary

- Amplitude calibration will be important for optimal geodetic results
- Requirements: a working noise diode and a backend capable of communicating TPI values (preferably with FS) every second
- Stations: Measure GAIN and TCAL (FS)!
- FS tools ONOFF, ACQUIR and GNPLT can help you – experiment!