Calibration in practice

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(IRAM)

Outline

I. The Plateau de Bure interferometer

II. On-line calibrations

III. CLIC

IV. Off-line calibrations

Foreword

An automated data reduction pipeline exists for Plateau de Bure data. It is run automatically at Bure on all observed projects, and helps the astronomer on duty to assess data quality, project completeness, etc.

It also contains many useful informations for the visitor coming to IRAM to reduce data, and hence a first step is often to look at its results prior to really “reduce” data.

This talk will be illustrated with plots that can be found in the pipeline (especially the “show”, that displays system parameters), so you get familiar with it. This will be indicated with *Pipeline.*

I. The Plateau de Bure interferometer:

- Antennas and stations
- Receivers
- Signal transport
- IF Processor
- Correlators

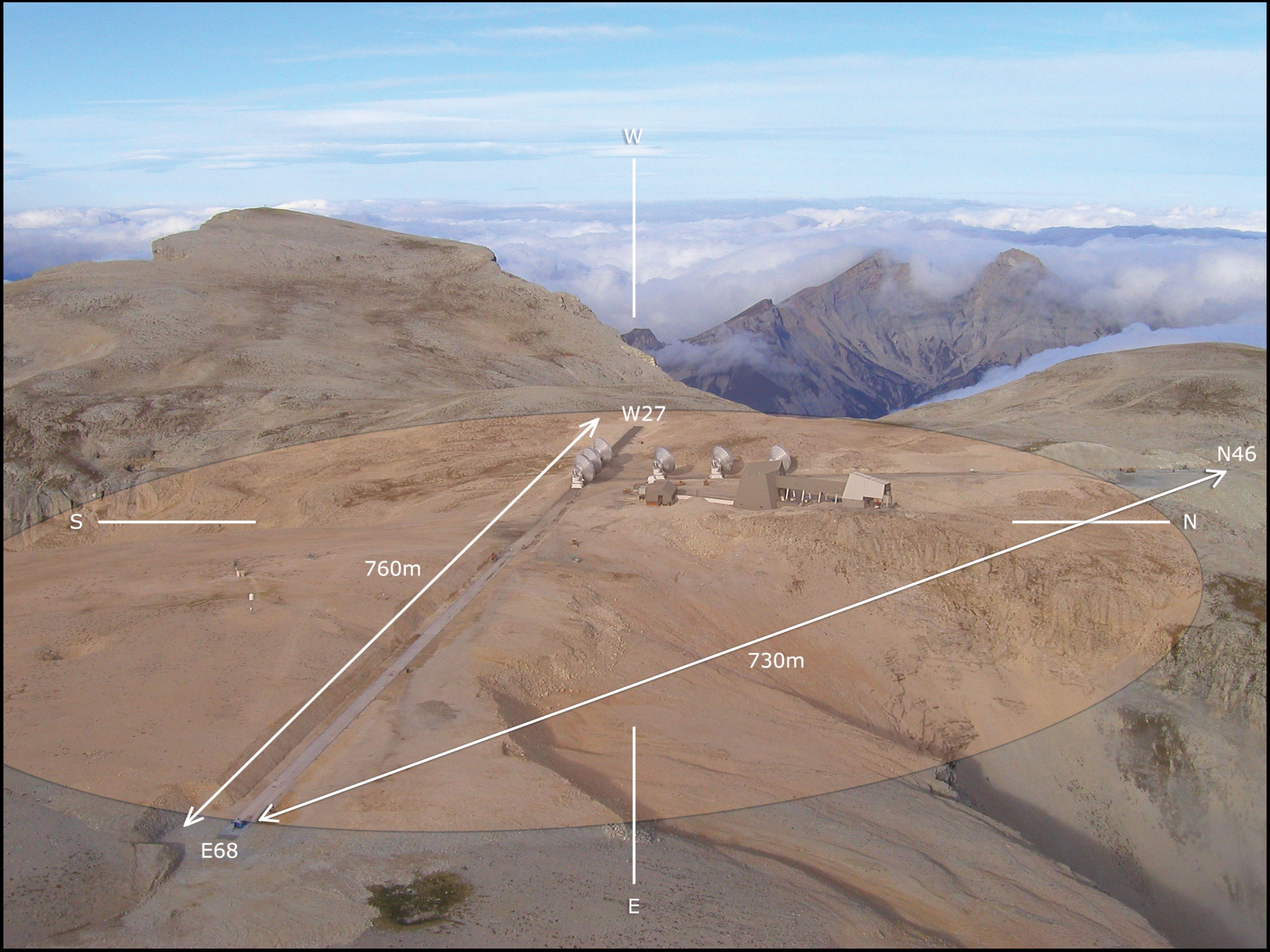
The Plateau de Bure interferometer: Antennas

6 antennas (on alt-az mounts) ...

... that can be put on 32 stations ...

... on 3 arms (W, N, E).

The interferometer arms



The Plateau de Bure interferometer: Antennas

6 antennas (on alt-az mounts) ...

... that can be put on 32 stations ...

... on 3 arms (W, N, E).

Each ...

... composed of 216 panels.

... weighting 130 tons

... measuring 15 m in diameter

Bure antenna with snow

Antennas in compact configuration

The Plateau de Bure interferometer: Receivers

Equipped with 3 (soon 4) receiver bands ...

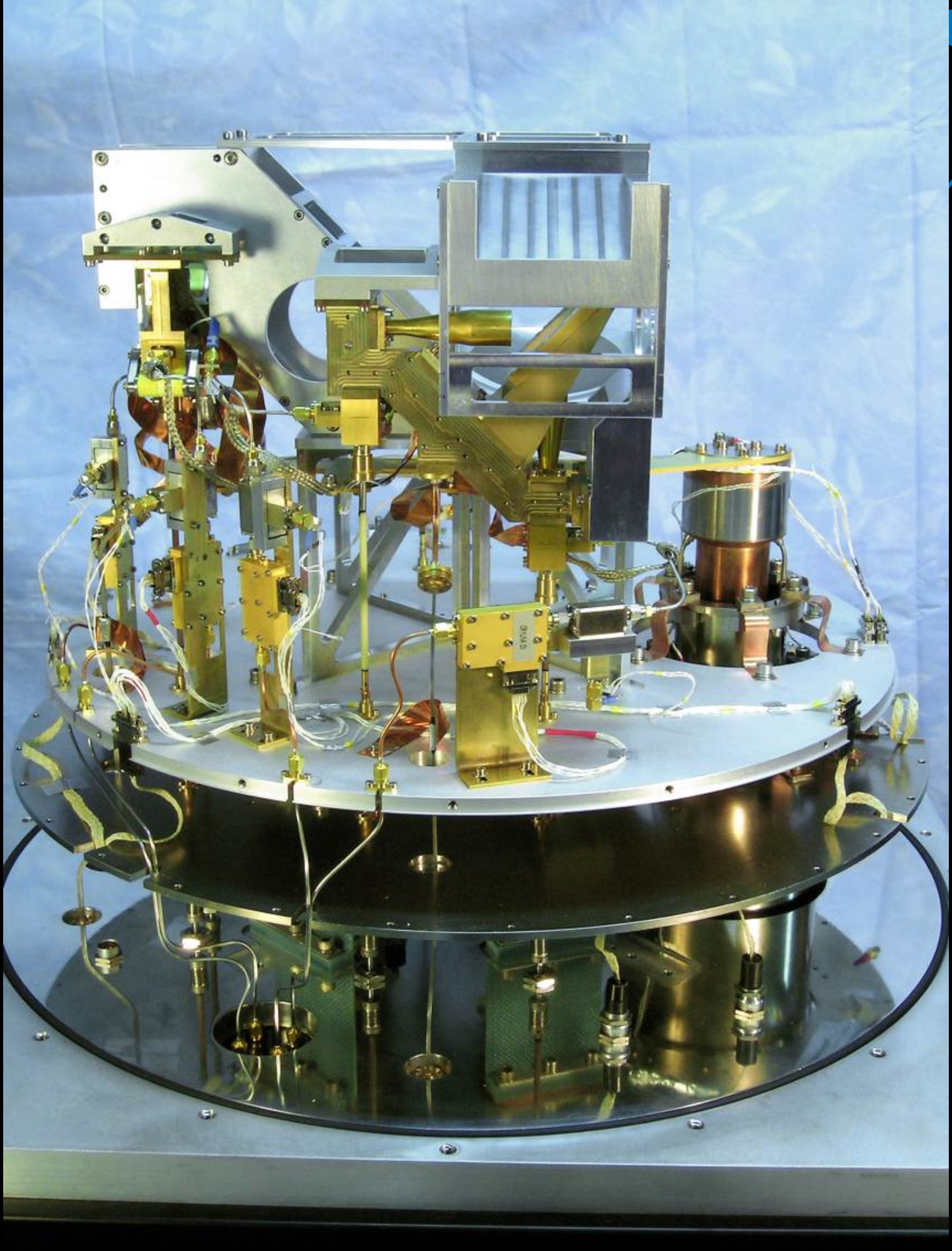
... which are Single-Side Band (SSB), with sideband rejection of the order of 10-20 dB.

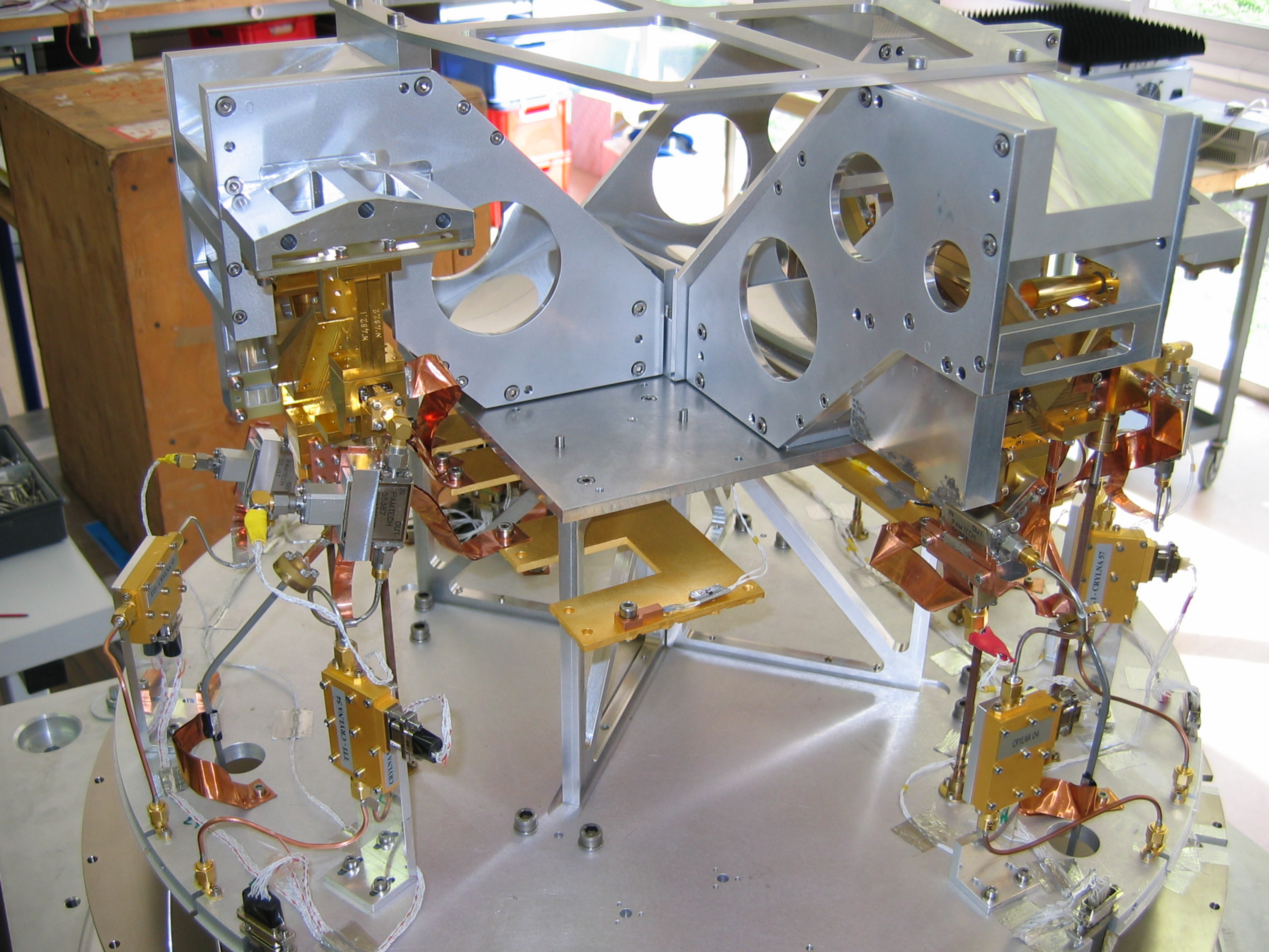
... and dual polarization (orthogonal linear polarizations, but quarter-wave plate available in Band 1).

... observing 2 x 4 GHz

... converting this bandwidth to an Intermediate Frequency (IF) of frequency 4-8 GHz.

Receiver:




N°482.1
N°482.2
IN
PAMTECH
55387
OUT
CRYLNA 04

The Plateau de Bure Interferometer:
Transporting the signal

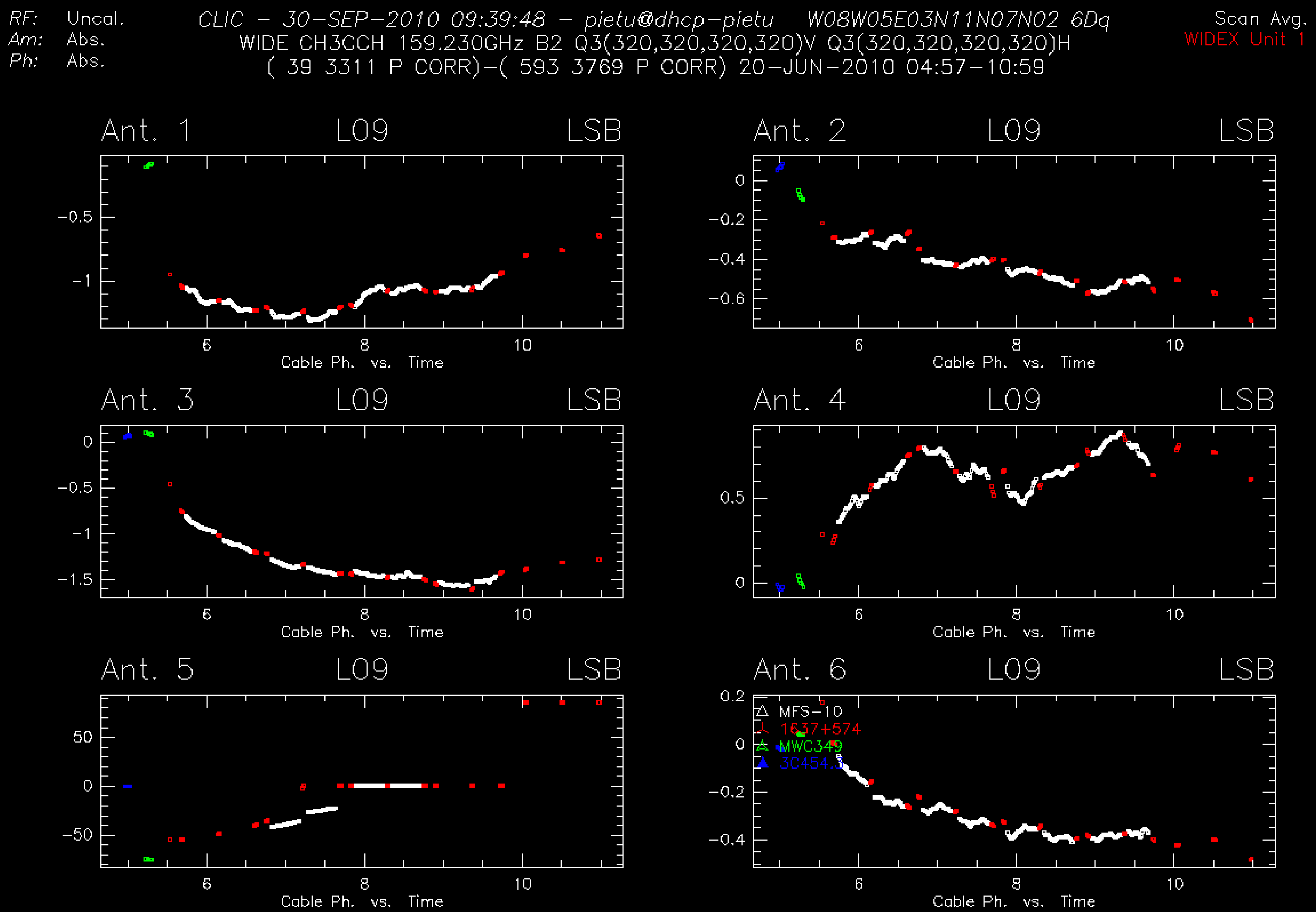
The electromagnetic incident wave has been converted in a electric analogical signal in the receiver (with a phase relation between the two).

The down-conversion is done by mixing the astronomical signal with a local oscillator (LO) which is a monochromatic wave with controlled phase.

The LOs in the different antennas are all generated from a common frequency synthesizer (located in the central building), and this frequency reference is transported through High-Q coaxial cables.

The pathlength of which has to be monitored

Pipeline: monitoring the cable phase.



The IF-processor

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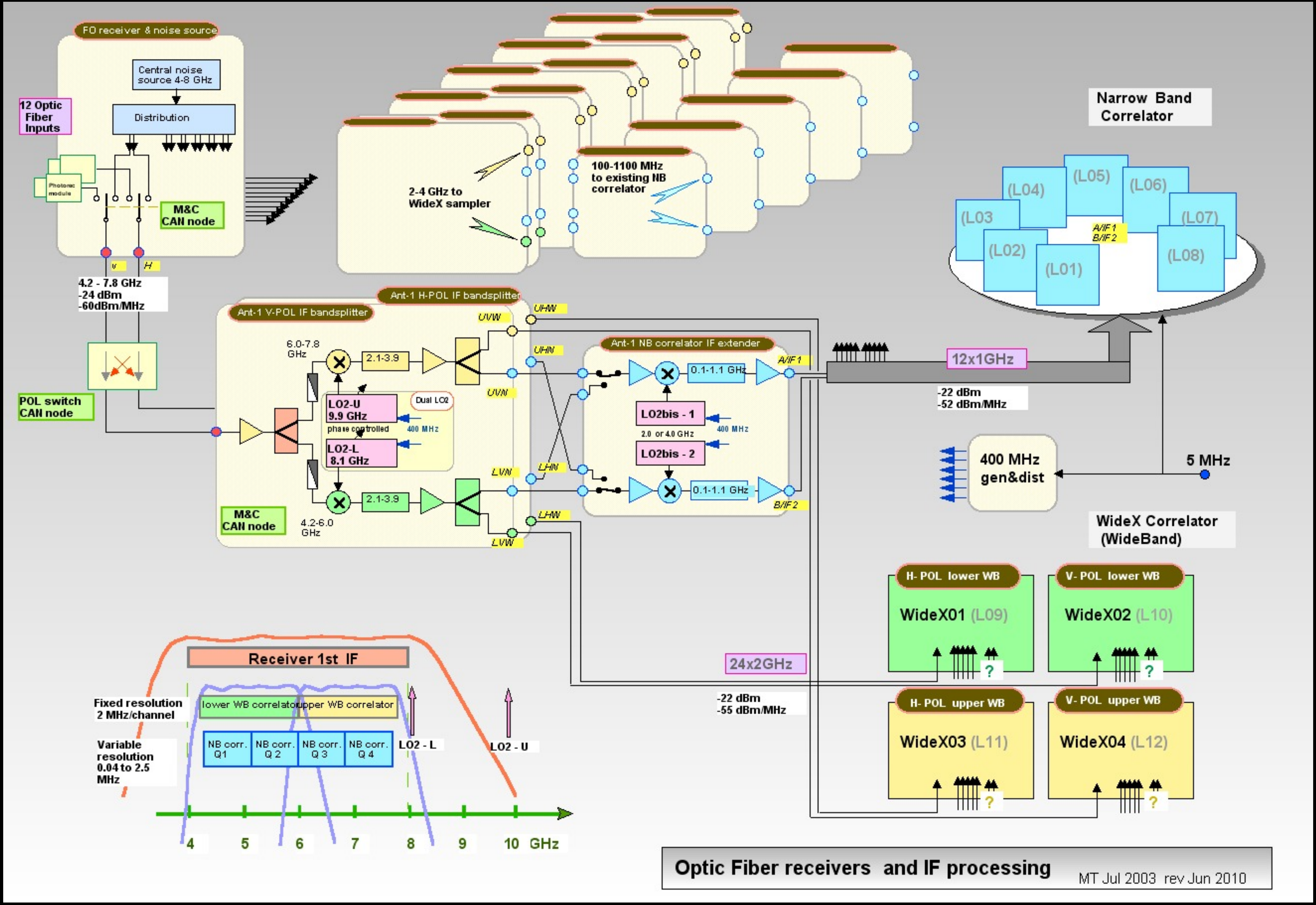
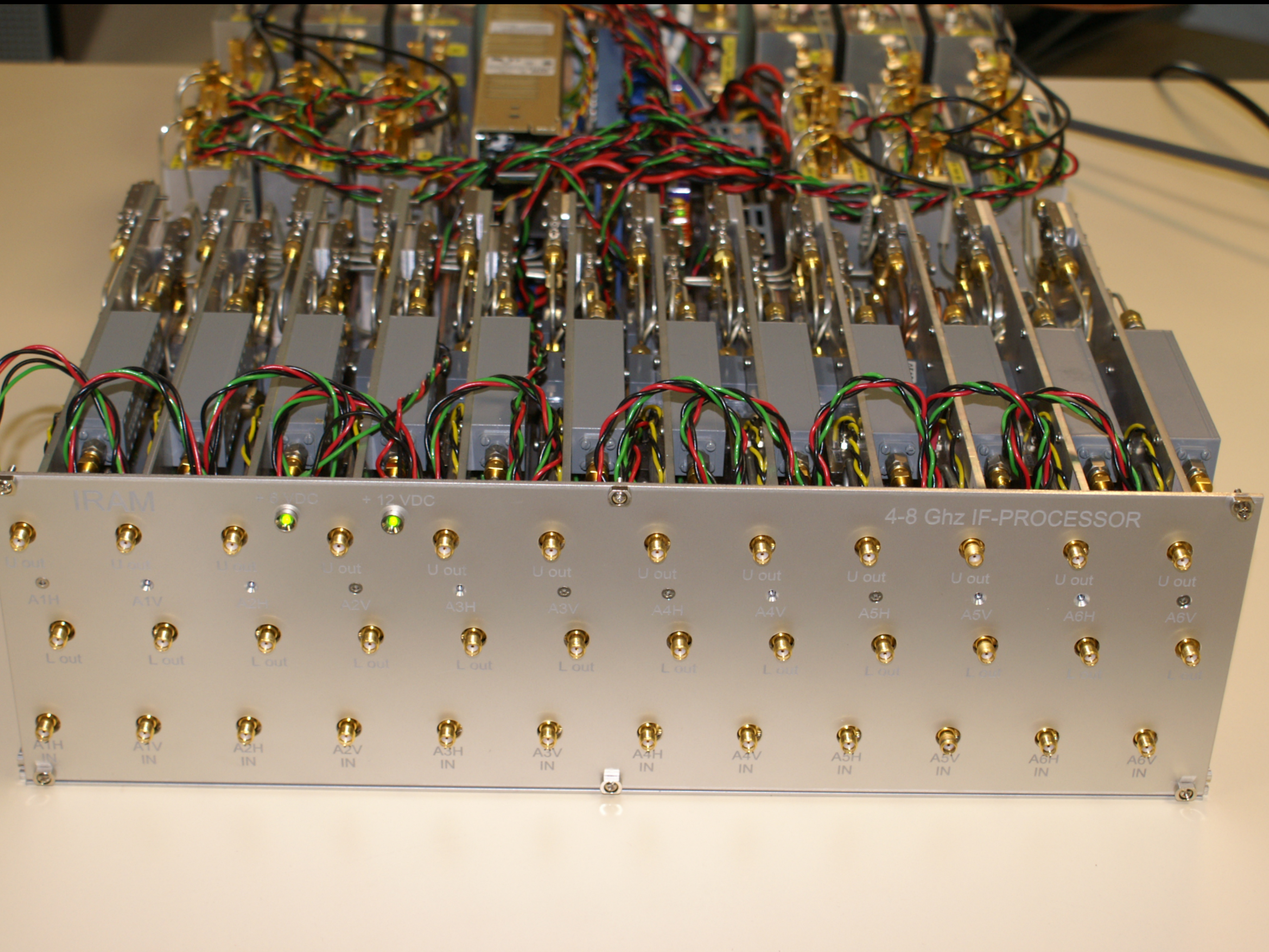
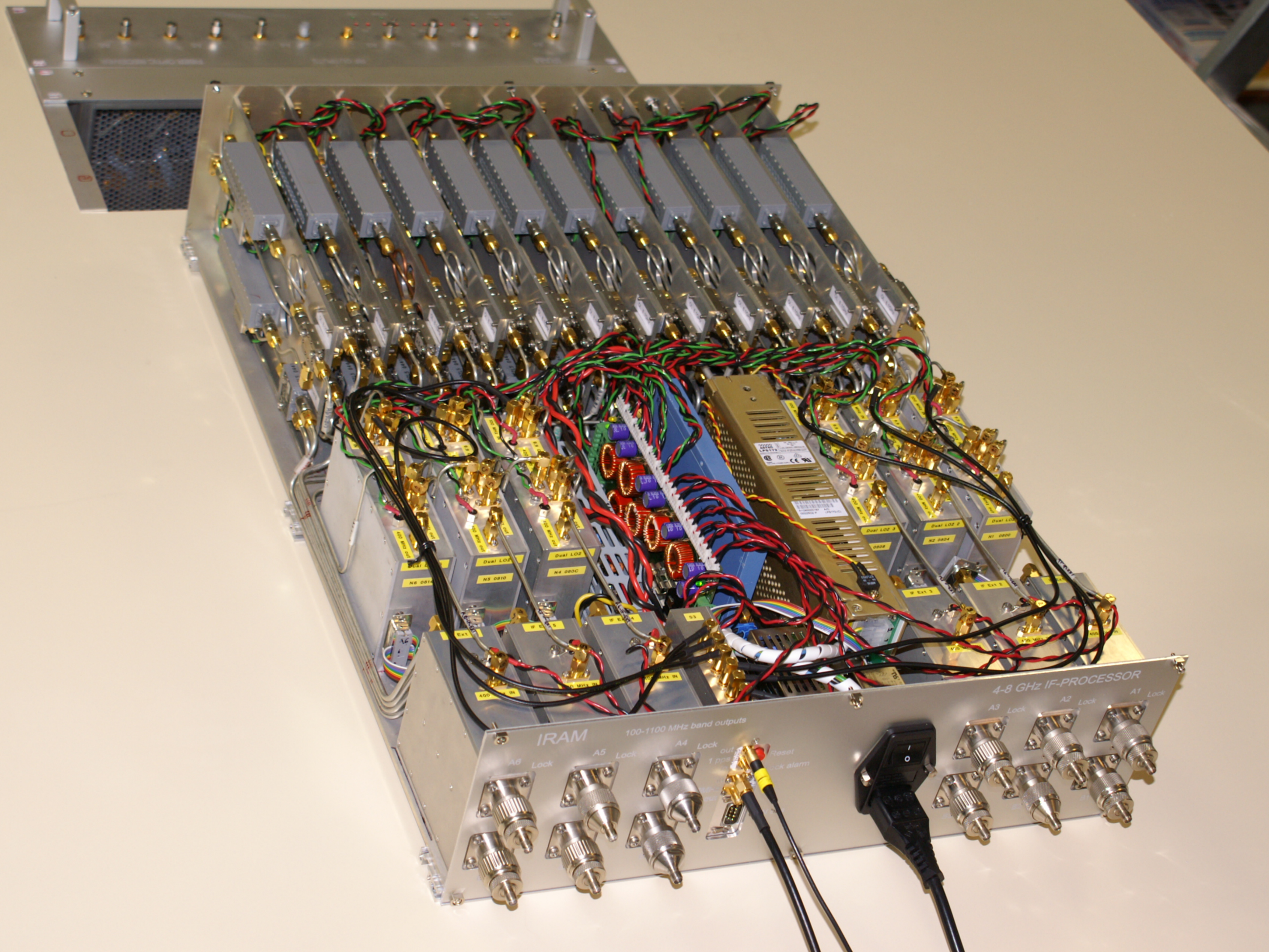
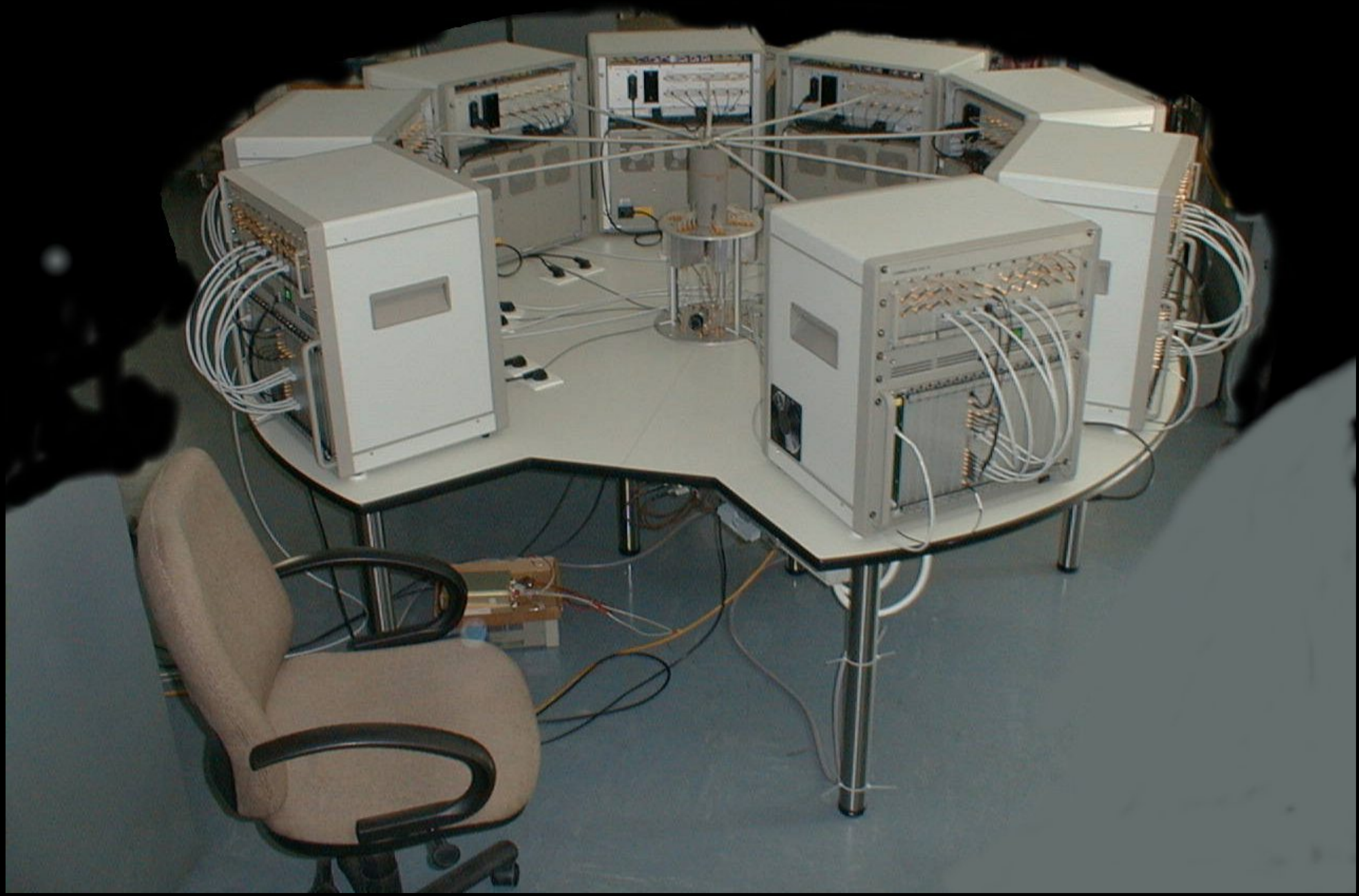



IRAM
+ 12 VDC
4-8 Ghz IF-PROCESSOR
U out
A1H
A1V
A2V
A3H
A3V
A4H
A4V
A5H
A5V
A6H
A6V
L out
A1H IN
A1V IN
A2H IN
A2V IN
A3H IN
A3V IN
A4H IN
A4V IN
A5H IN
A5V IN
A6H IN
A6V IN


4-8 GHz IF-PROCESSOR
IRAM
100-1100 MHz band outputs
A6
Lock
A5
Lock
A4
Lock
Reset
A3
Lock
A2
Lock
A1
Lock
Dual LO2
Dual LO2
Dual LO2 3
Dual LO2 2

"Narrow-band" correlator (a.k.a CAMEMBERT)

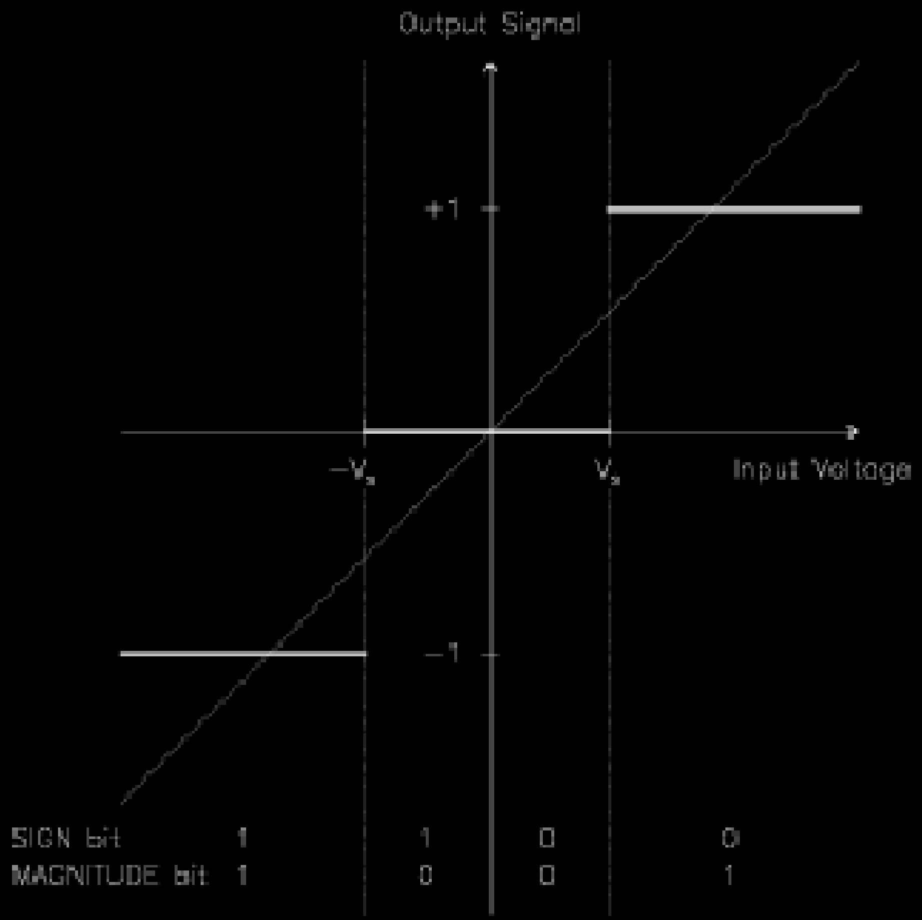


High-spectral resolution to zoom with enhanced spectral capabilities.

And the wide-band correlator (a.k.a. WIDEX)

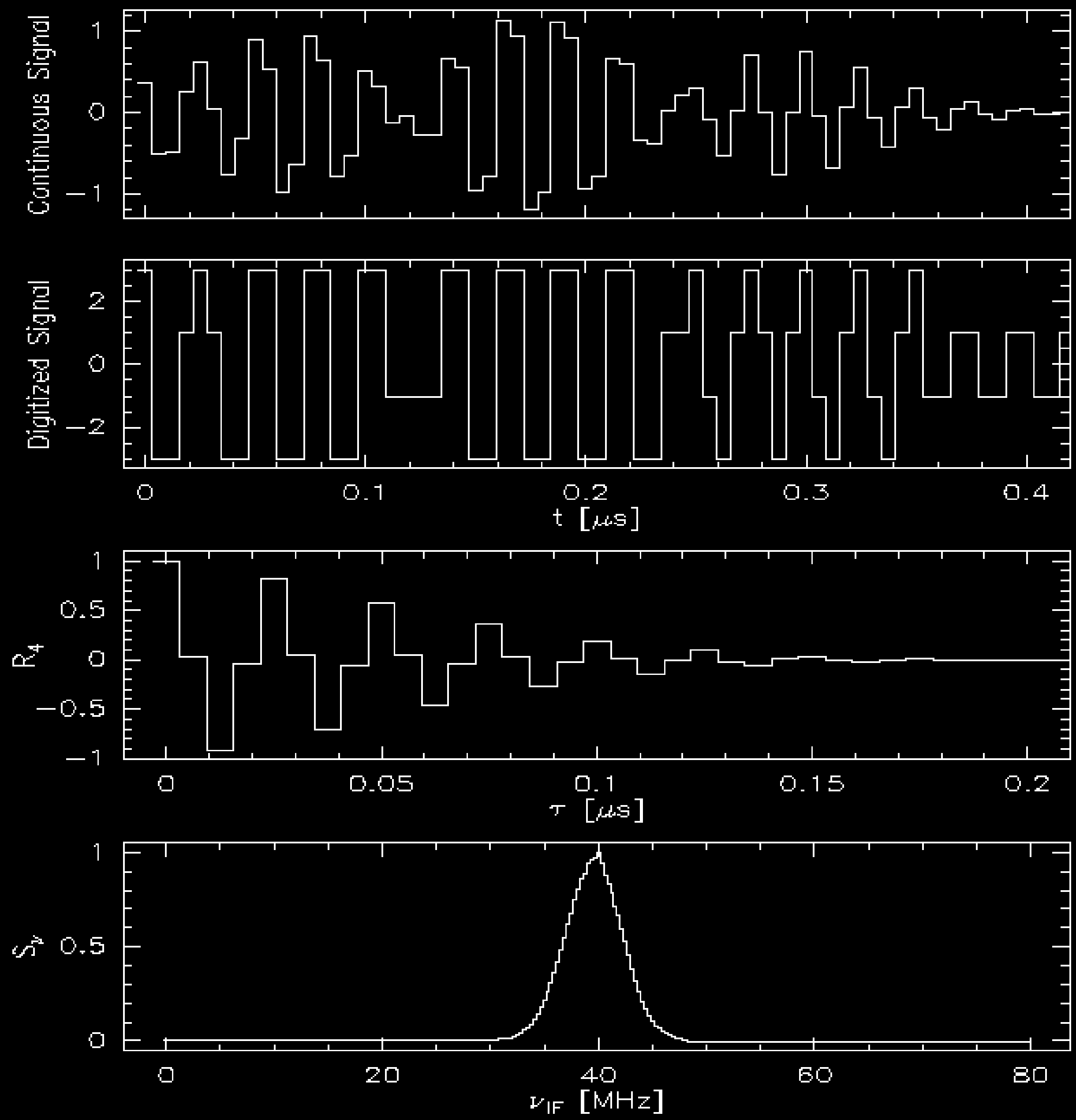
Large bandwith to cover all the receiver bandwidth and increase sensitivity

Quantization of the signal

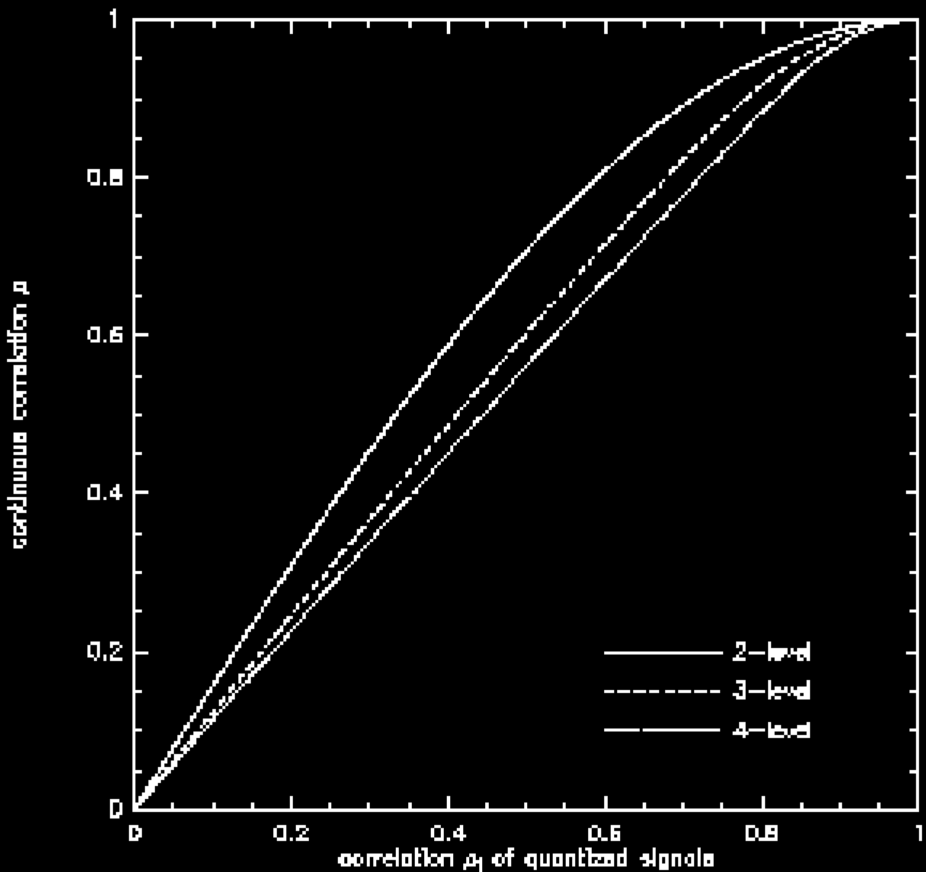


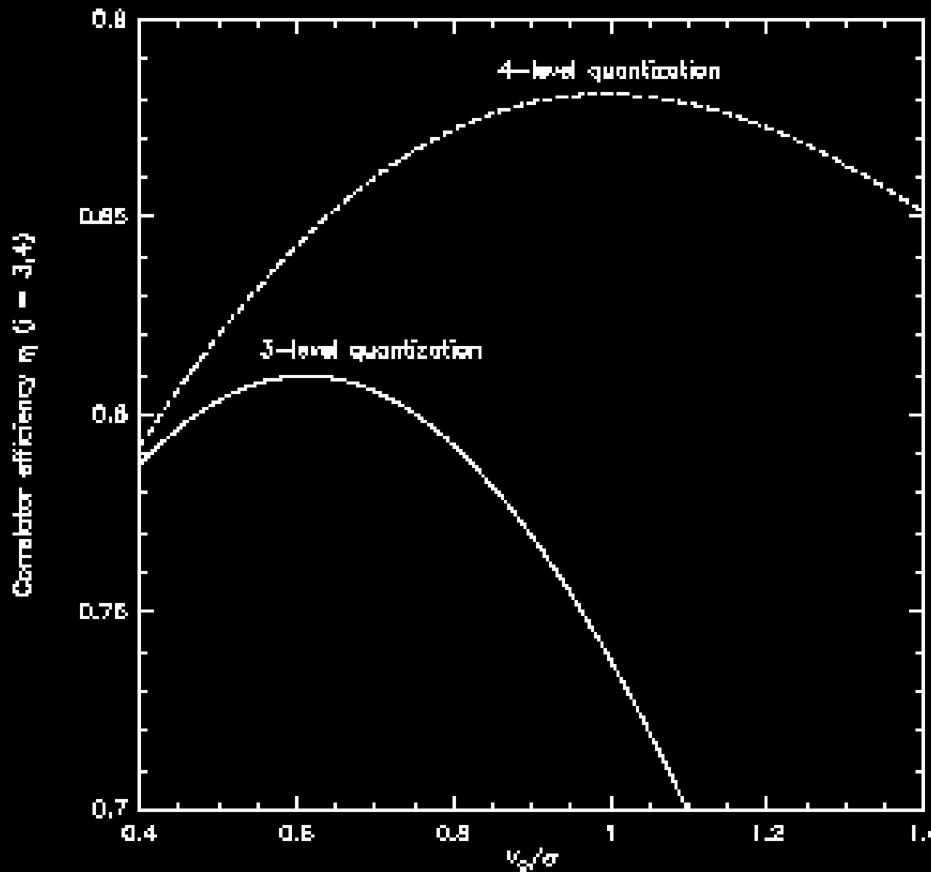
S(y)	M(y)	S(x) = 0, M(x) = 1	S(x) = 0, M(x) = 0	S(x) = 1, M(x) = 0	S(x) = 1, M(x) = 1
0	1	n^2	n	$-n$	$-n^2$
0	0	n	1	-1	$-n$
1	0	$-n$	-1	1	n
1	1	$-n^2$	$-n$	n	n^2

Quantization of the signal

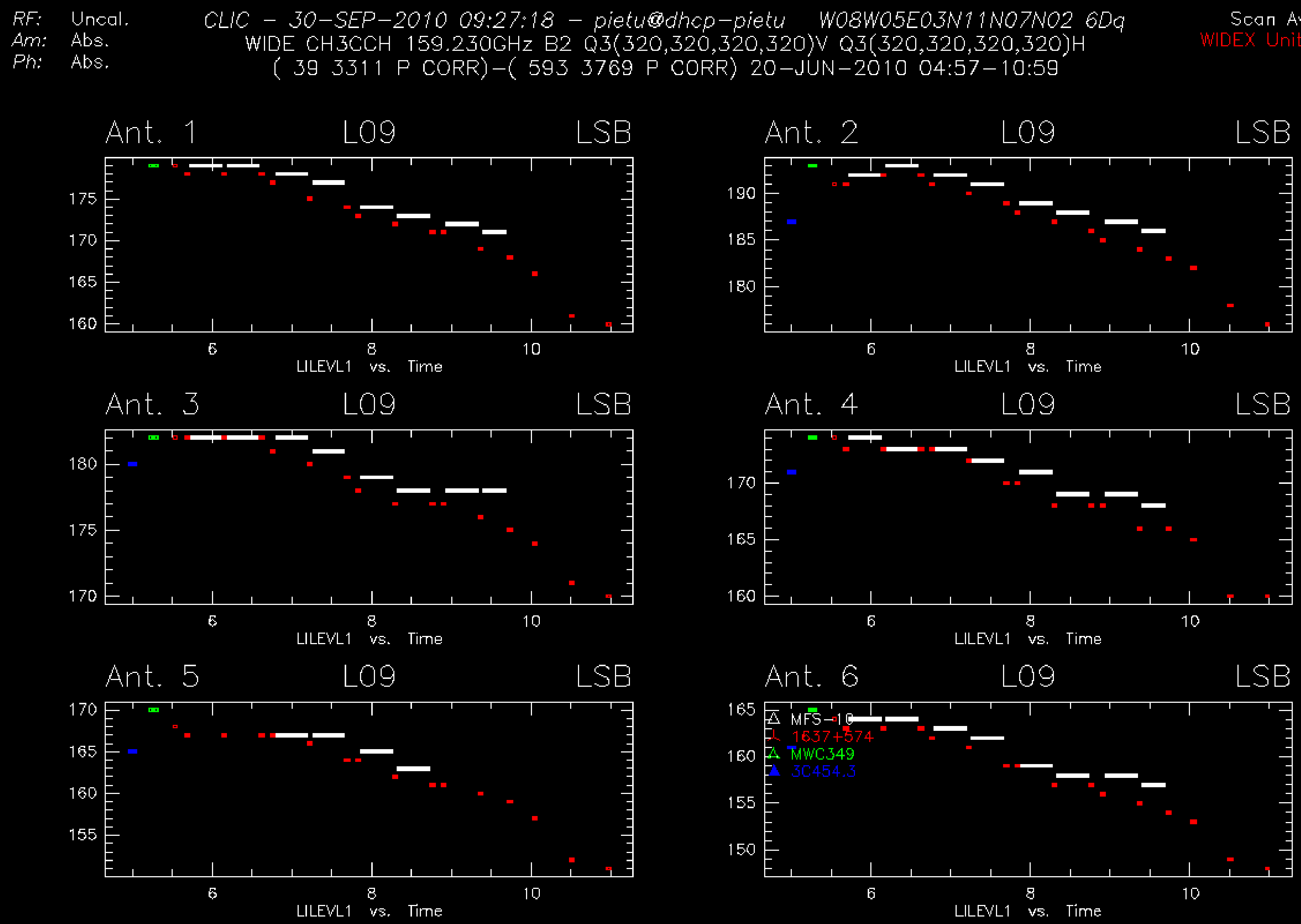


Why adjusting sampling levels ? (tweaking ...)

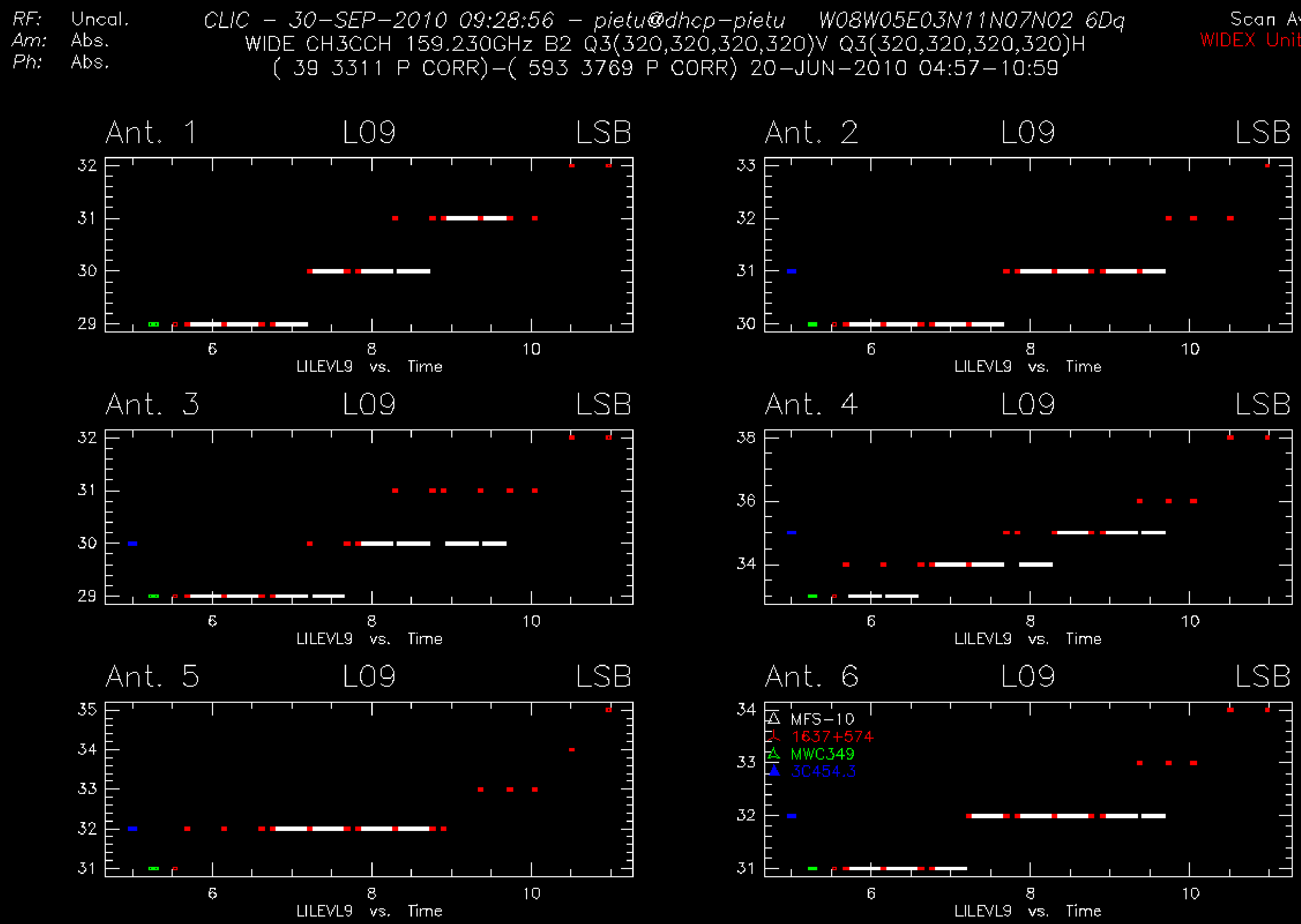




Pipeline: monitoring the tweak levels
Narrow: *gain* in the [1-256] range



Pipeline: monitoring the tweak levels
WIDEX: *attenuation* in the [1-64] range



II.a. On-line calibrations:

Atmospheric calibration
Pointing
Focusing
Measuring the instrumental delay

Atmospheric calibration.

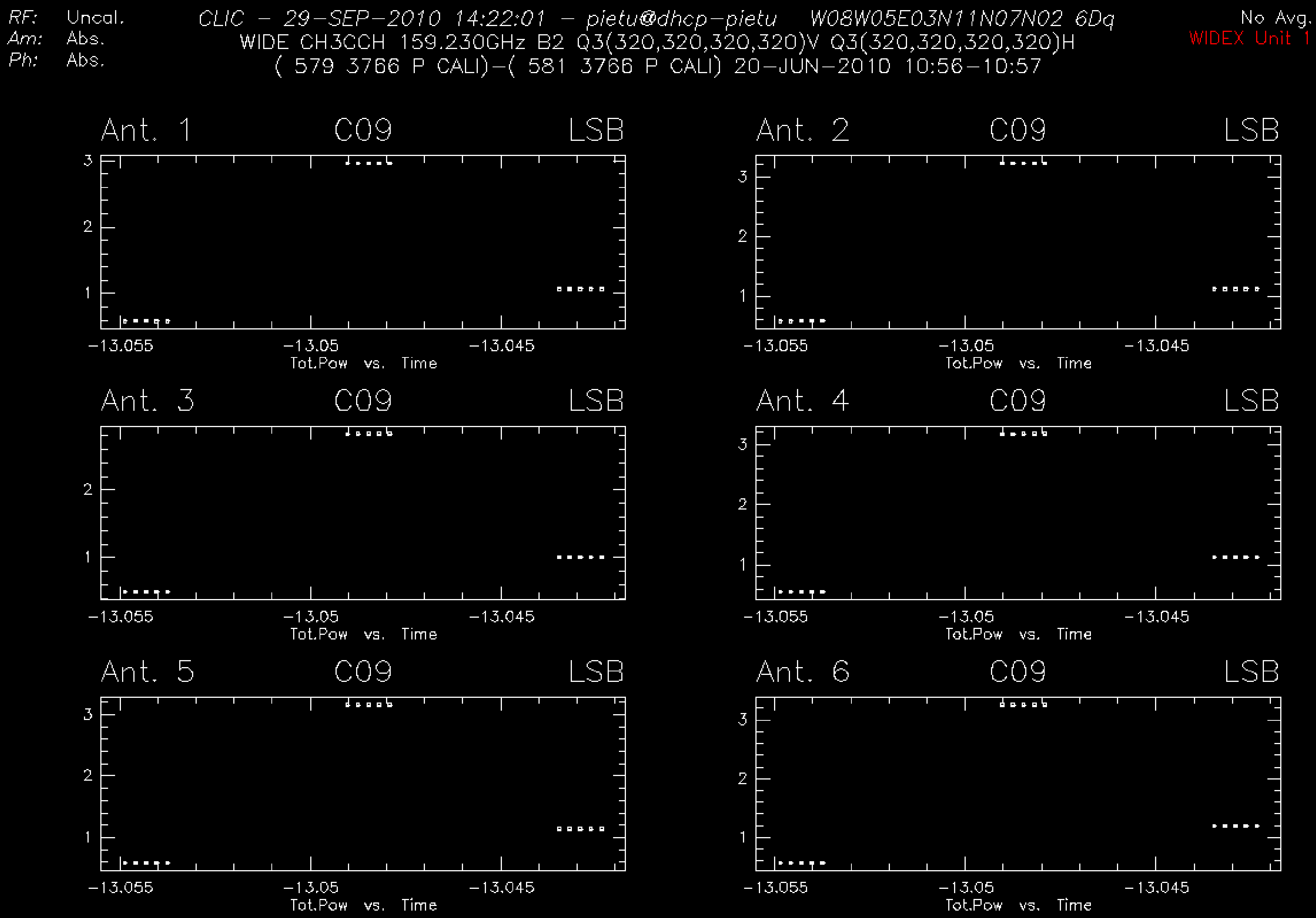
This is essential to convert the output of the correlators (counts) to a temperature scale.

This requires:

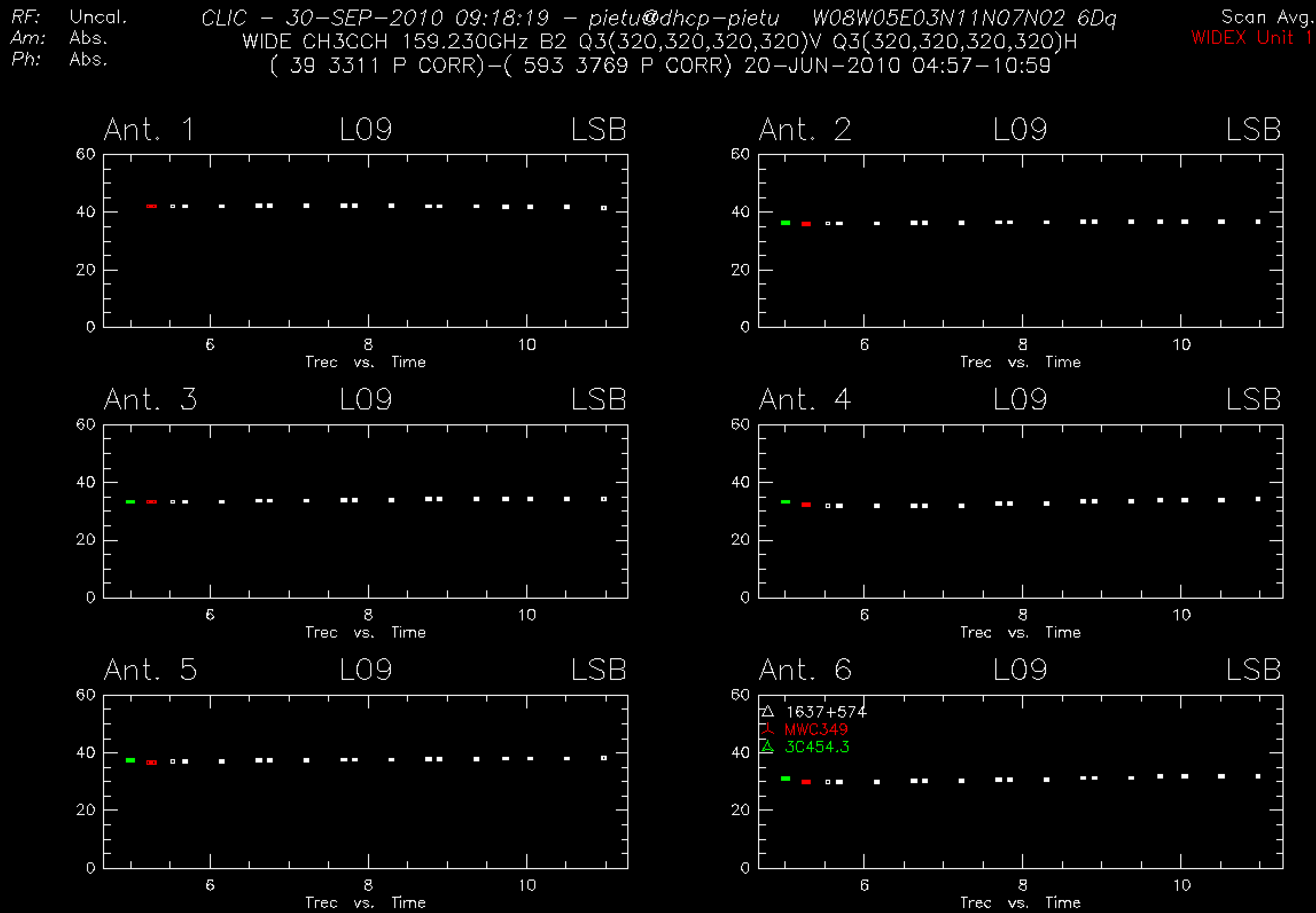
- Determining the system noise (receiver temperature).
- Determining the single-dish gain.
- Determining the atmospheric absorption.
- Linearity of the receiving system.

Chopper wheel method + use of an atmospheric model (ATM, *Cernicharo & Pardo*)

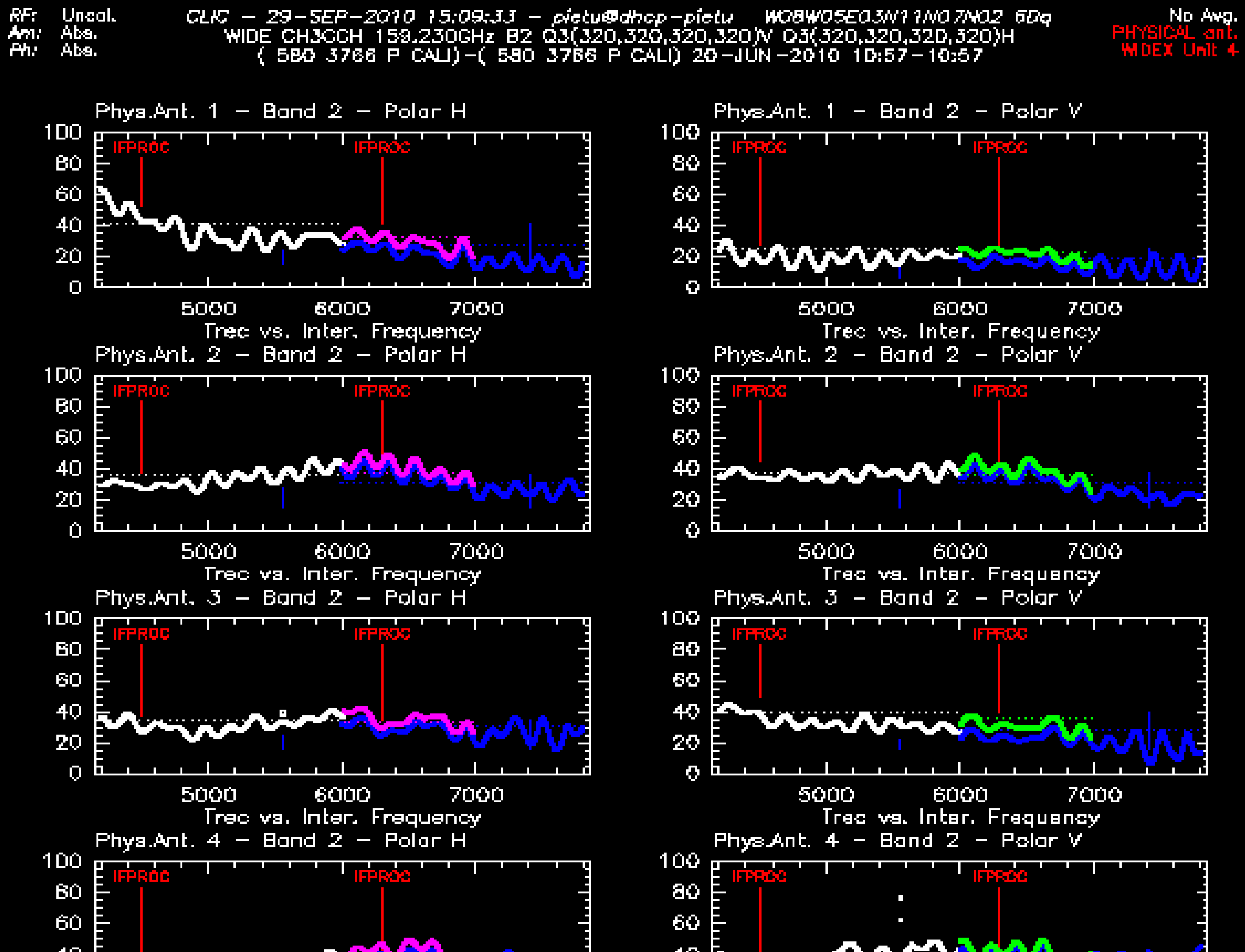
Measuring the receiver temperature



Pipeline: monitoring the receiver temperature (*vs* time)



Pipeline: monitoring the receiver temperature (*vs* freq.)

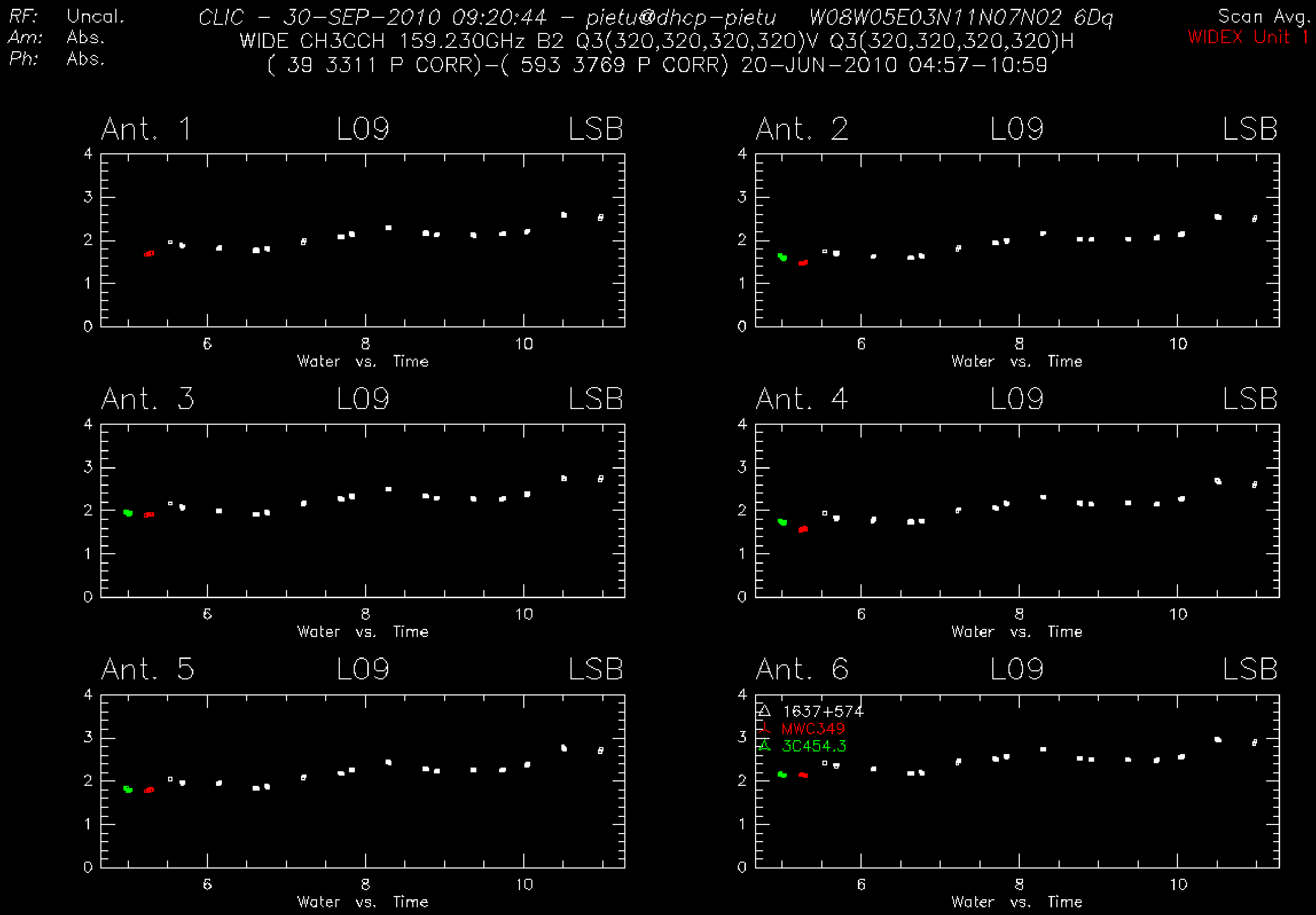


Atmospheric calibration: outputs

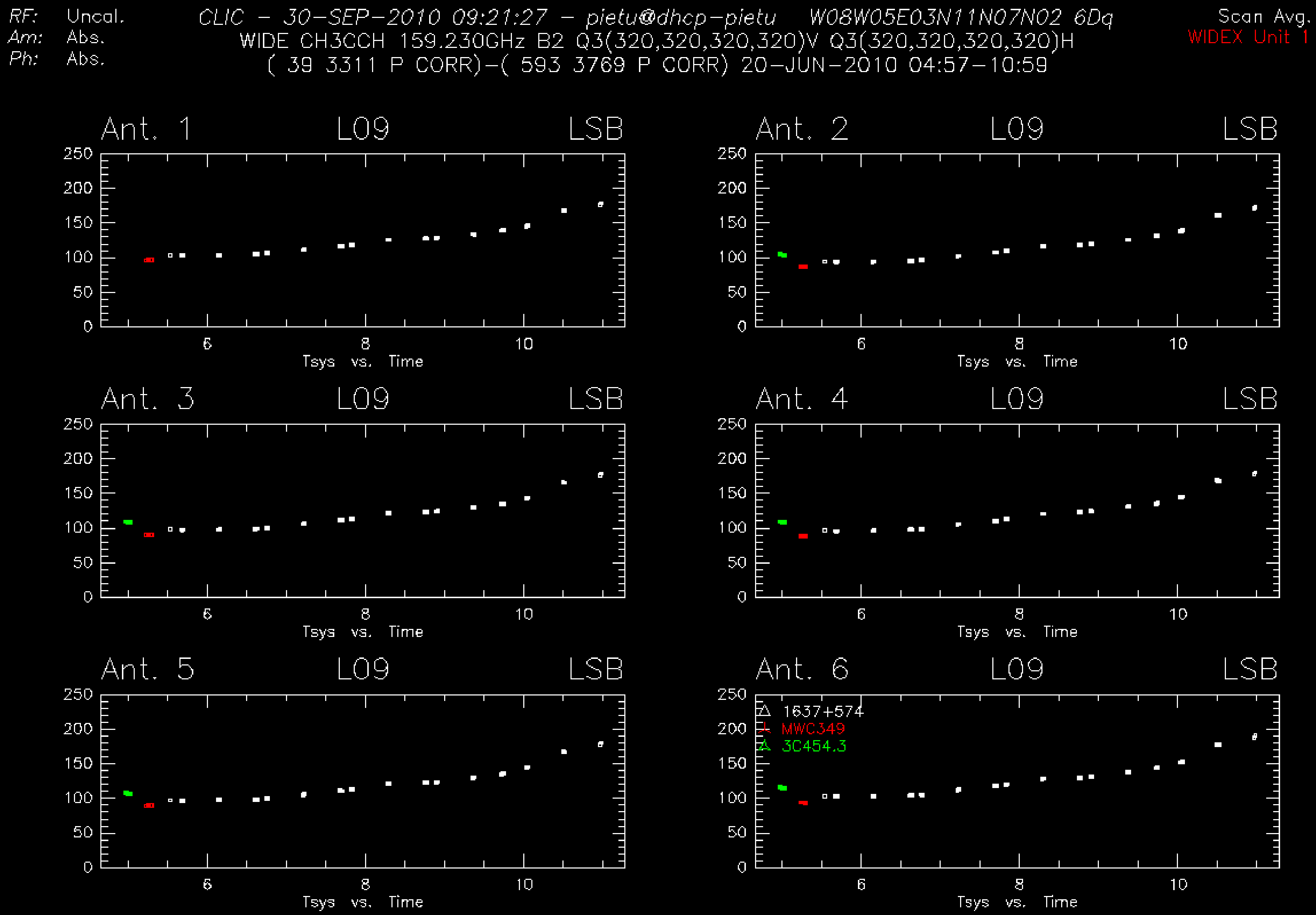
As a result of atmospheric calibration, we derive:

- The receiver temperature.
- The amount of water vapor (expressed as “precipitable water vapor”).
- The system temperature (*i.e.* the total noise of the atmosphere+telescope).

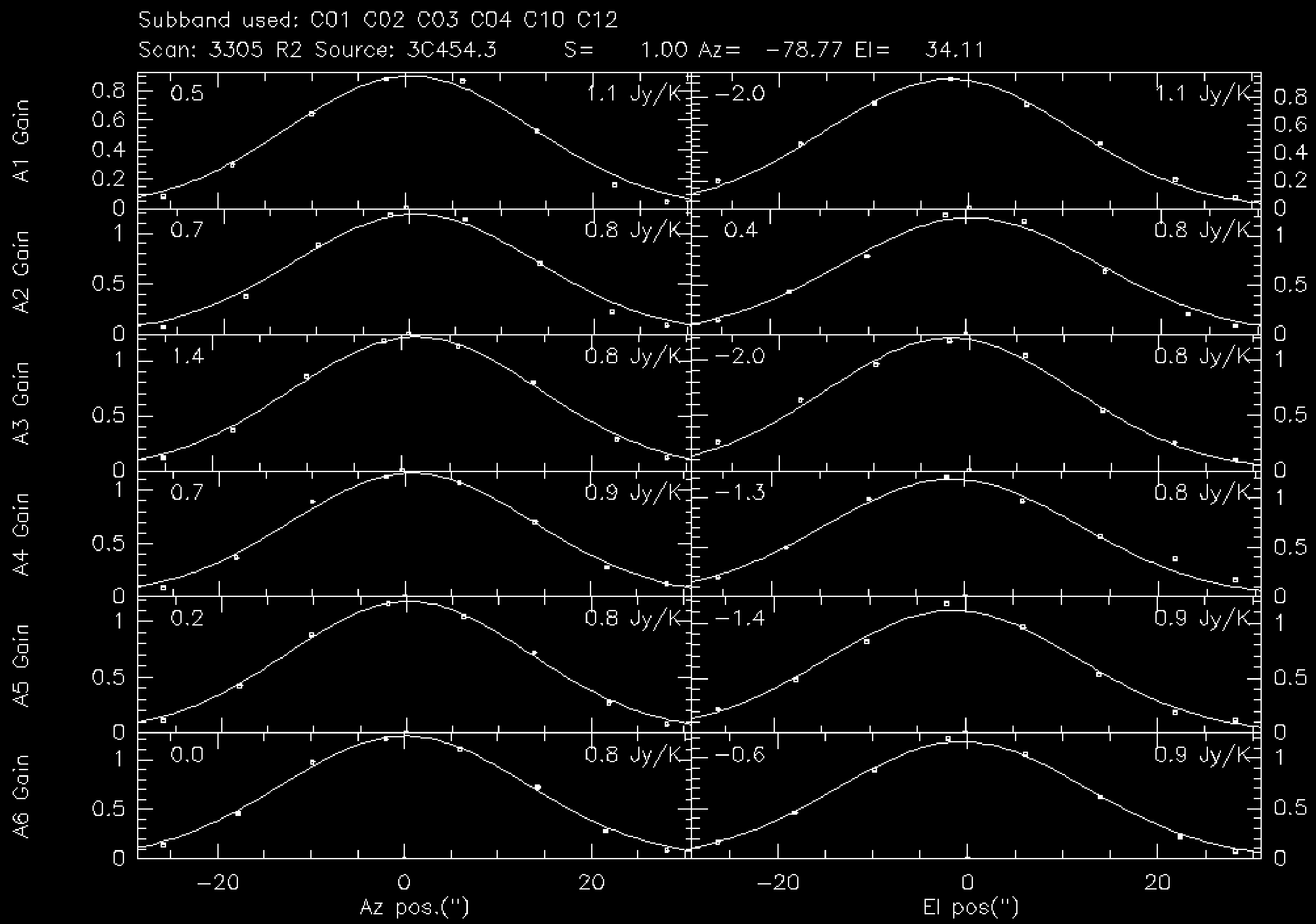
Pipeline: monitoring calibration parameters



Pipeline: monitoring calibration parameters

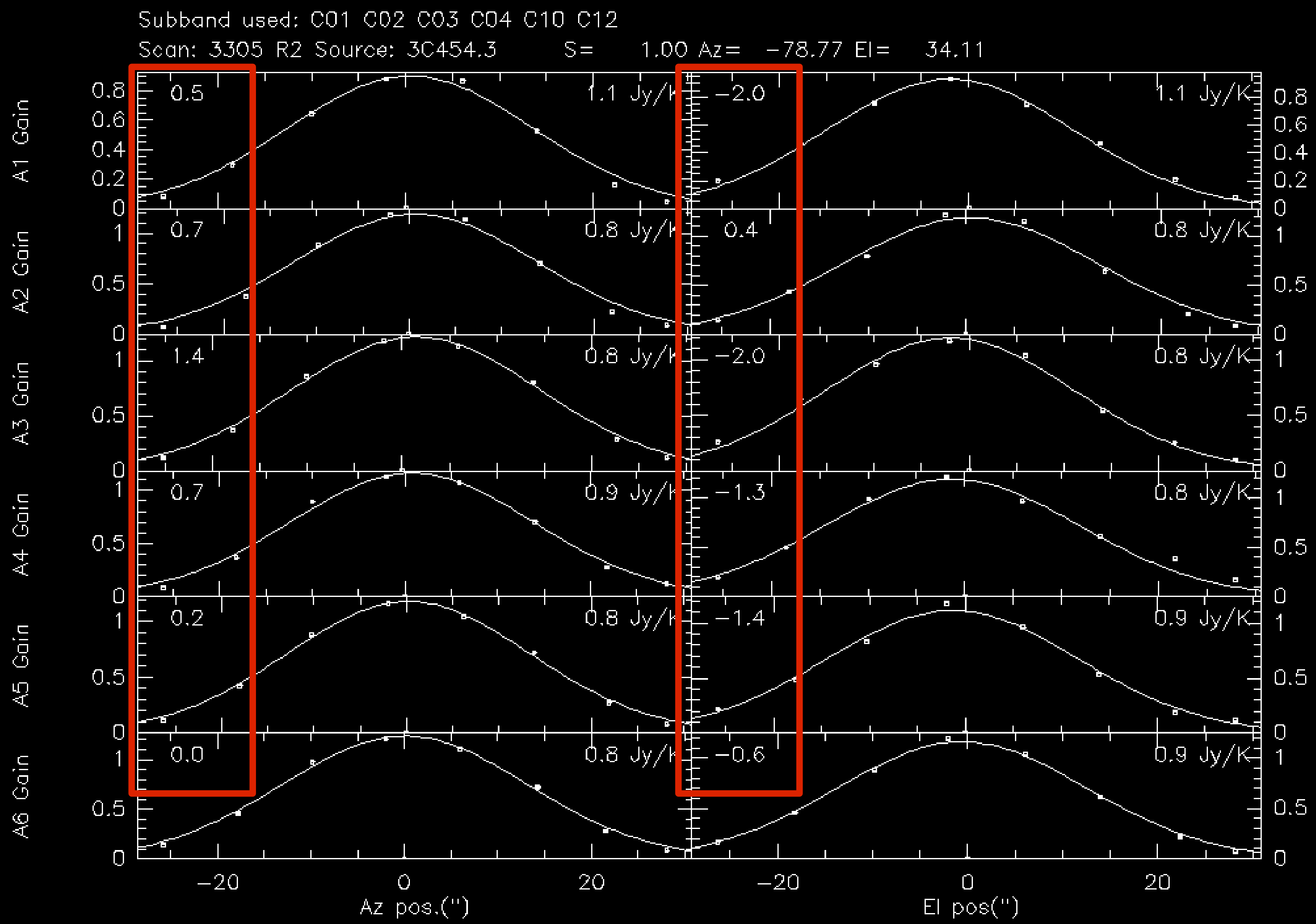


Pointing ....



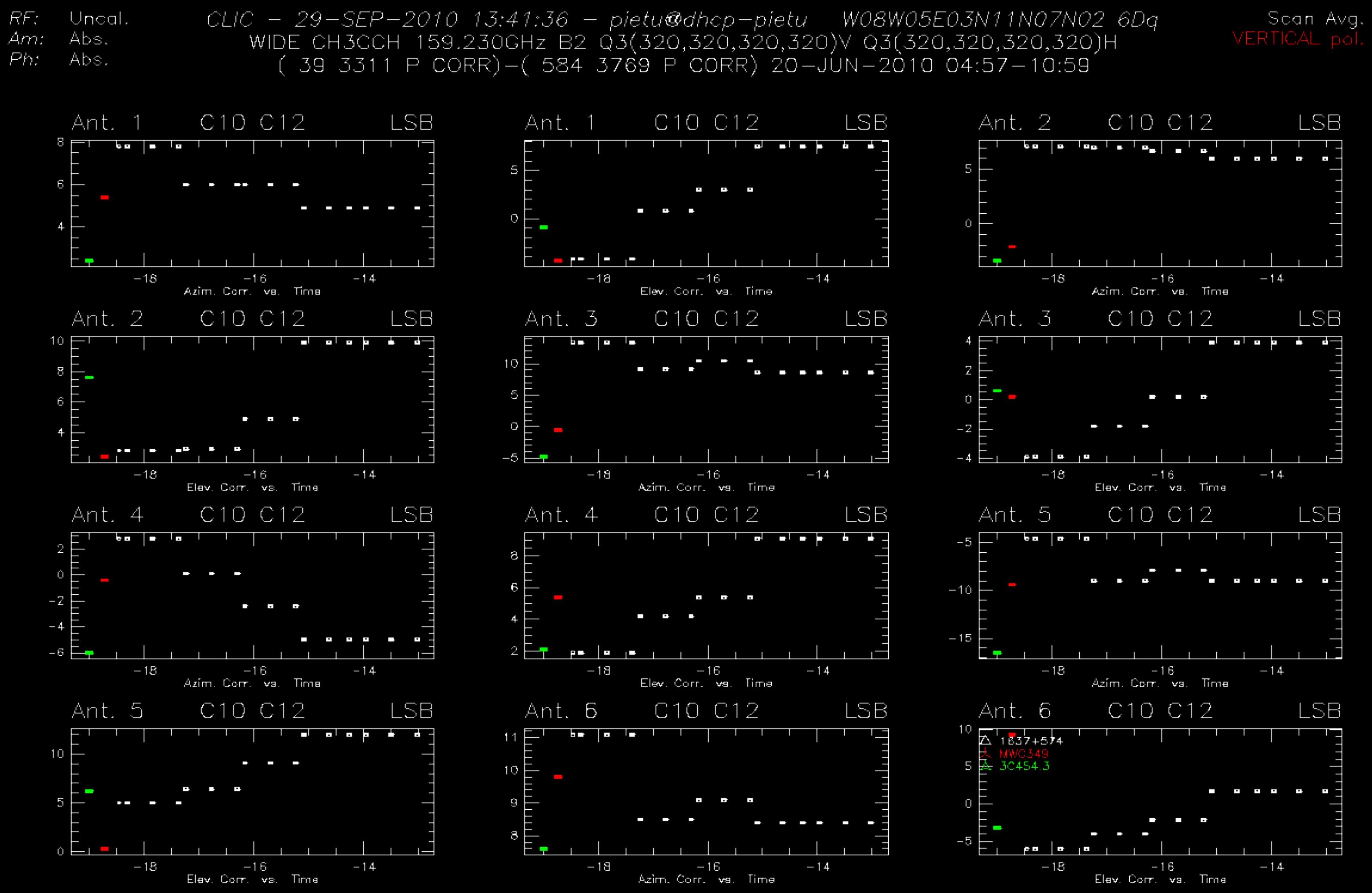
Subband used: C01 C02 C03 C04 C10 C12
Scan: 3305 R2 Source: 3C454.3 S= 1.00 Az= -78.77 El= 34.11
A1 Gain
A2 Gain
A3 Gain
A4 Gain
A5 Gain
A6 Gain
0.5
1.1 Jy/K
-2.0
1.1 Jy/K
0.7
0.8 Jy/K
0.4
0.8 Jy/K
1.4
0.8 Jy/K
-2.0
0.8 Jy/K
0.7
0.9 Jy/K
-1.3
0.8 Jy/K
0.2
0.8 Jy/K
-1.4
0.9 Jy/K
0.0
0.8 Jy/K
-0.6
0.9 Jy/K
Az pos.('')
El pos('')

Pointing ....

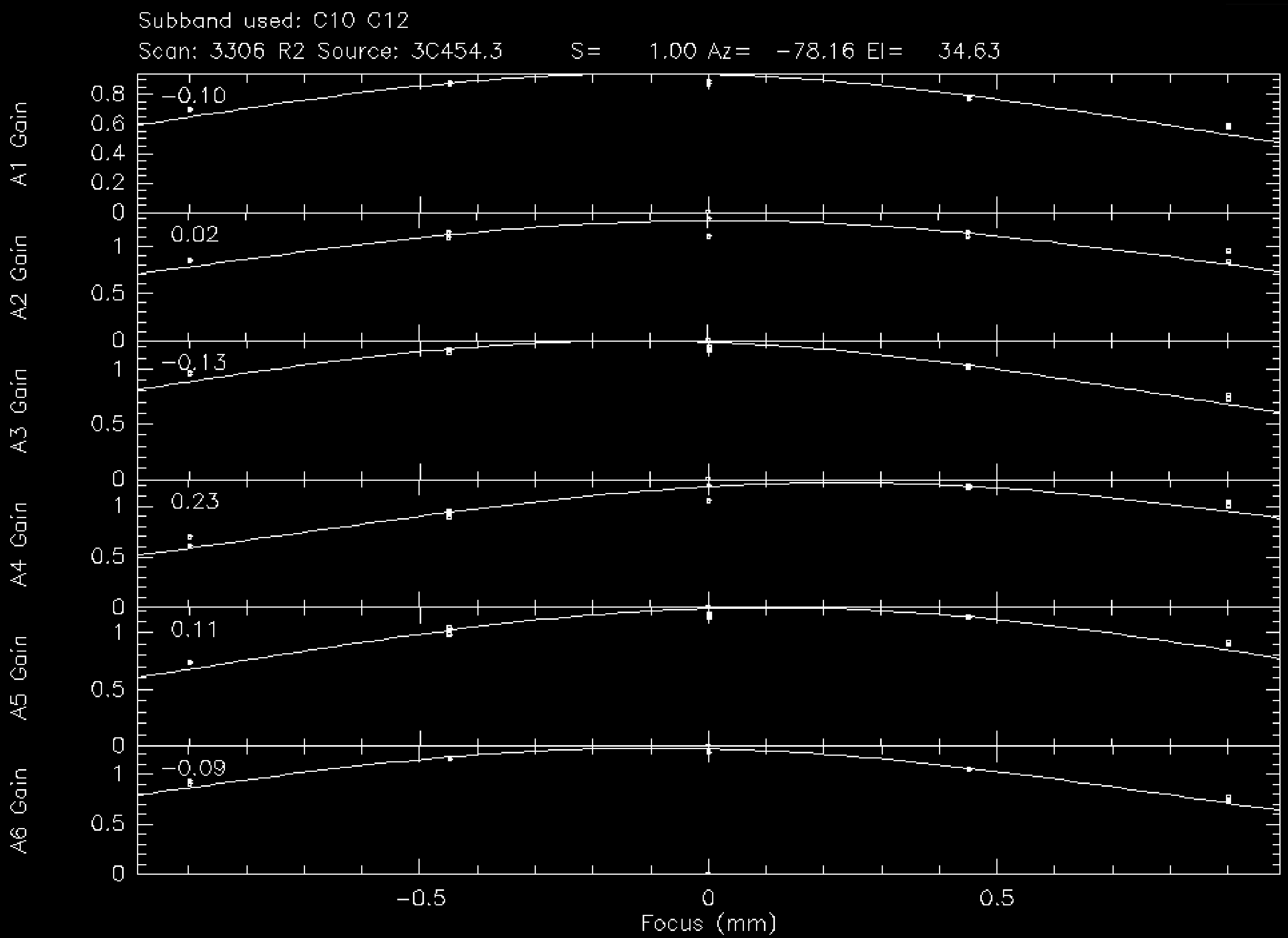


Subband used: C01 C02 C03 C04 C10 C12
Scan: 3305 R2 Source: 3C454.3 S= 1.00 Az= −78.77 El= 34.11
A1 Gain
A2 Gain
A3 Gain
A4 Gain
A5 Gain
A6 Gain
0.5
0.7
1.4
0.7
0.2
0.0
−2.0
0.4
−2.0
−1.3
−1.4
−0.6
1.1 Jy/K
0.8 Jy/K
0.9 Jy/K
Az pos.('')
El pos('')

Pipeline: monitoring the pointing corrections ....

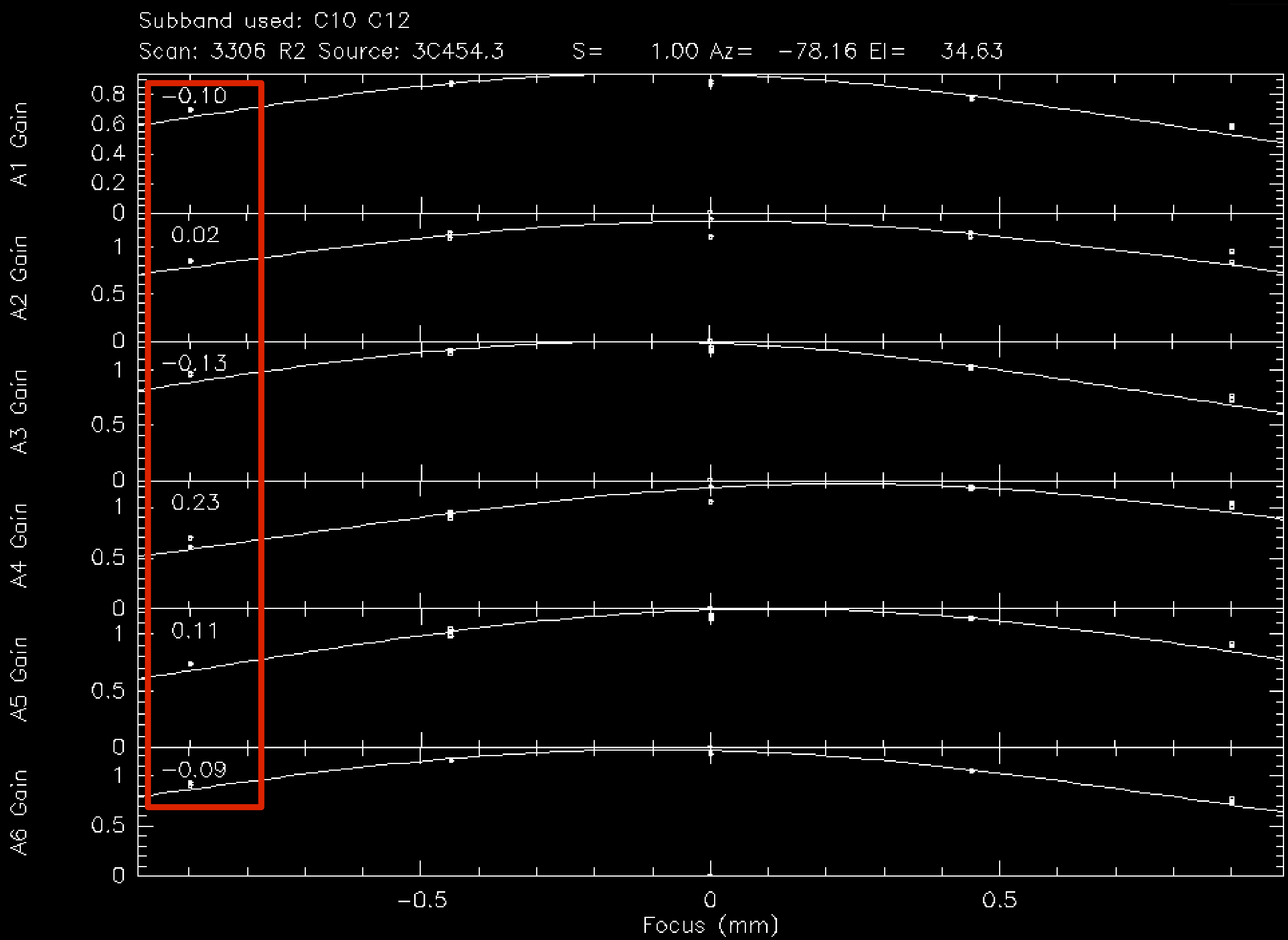


Focusing ...



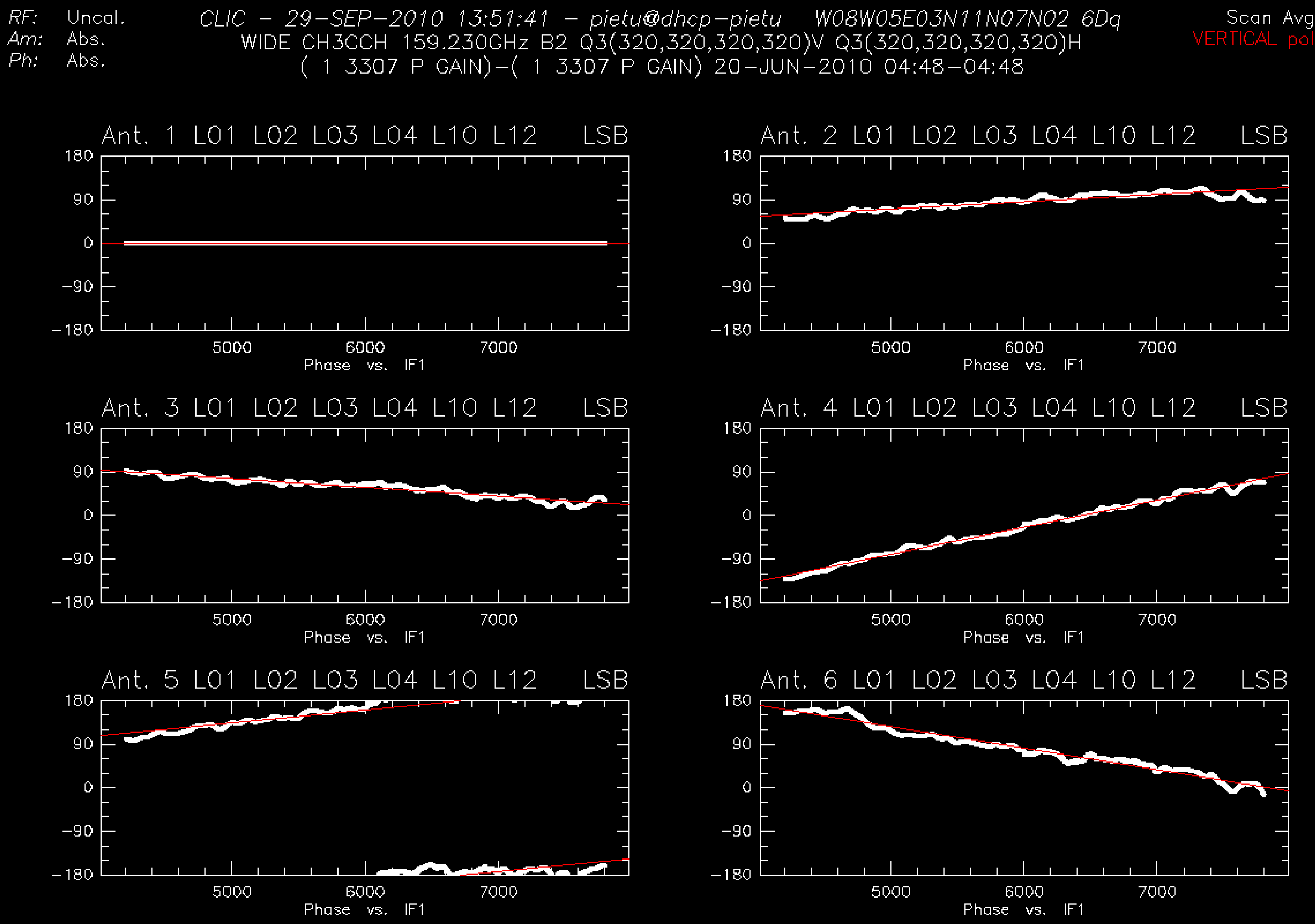
Subband used: C10 C12
Scan: 3306 R2 Source: 3C454.3 S= 1.00 Az= −78.16 El= 34.63
A1 Gain
A2 Gain
A3 Gain
A4 Gain
A5 Gain
A6 Gain
−0.10
0.02
−0.13
0.23
0.11
−0.09
0.8
0.6
0.4
0.2
0
1
0.5
−0.5
0.5
Focus (mm)

Focusing ...



Subband used: C10 C12
Scan: 3306 R2 Source: 3C454.3 S= 1.00 Az= −78.16 El= 34.63
A1 Gain
A2 Gain
A3 Gain
A4 Gain
A5 Gain
A6 Gain
−0.10
0.02
−0.13
0.23
0.11
−0.09
−0.5
0
0.5
Focus (mm)

Measuring the instrumental delay ...



Measuring the instrumental delay ...

```
I-SOLVE_DELAY,[3307] Delay offset for Phys.Ant. 1 :     0.000 +-   0.000 ns
I-SOLVE_DELAY,[3307] Absolute delay for Log.Ant. 1 :    0.000 +-   0.000 ns
I-SOLVE_DELAY,[3307]  2 Ant. 2 Ch. L01 L02 L03 L04 L10 L12 Band LSB rms       7.304
I-SOLVE_DELAY,[3307] delay=       0.042 ns.  phase=      -5.533

I-SOLVE_DELAY,[3307] Delay offset for Phys.Ant. 2 :    -0.042 +-   0.001 ns
I-SOLVE_DELAY,[3307] Absolute delay for Log.Ant. 2 :  242.958 +-   0.001 ns
I-SOLVE_DELAY,[3307]  3 Ant. 3 Ch. L01 L02 L03 L04 L10 L12 Band LSB rms       5.501
I-SOLVE_DELAY,[3307] delay=      -0.050 ns.  phase=     166.848

I-SOLVE_DELAY,[3307] Delay offset for Phys.Ant. 3 :     0.050 +-   0.000 ns
I-SOLVE_DELAY,[3307] Absolute delay for Log.Ant. 3 :  556.741 +-   0.000 ns
I-SOLVE_DELAY,[3307]  4 Ant. 4 Ch. L01 L02 L03 L04 L10 L12 Band LSB rms       5.049
I-SOLVE_DELAY,[3307] delay=       0.156 ns.  phase=      -0.798

[...]
```

Most of the delays come from the fiber optics.

III. The CLIC Software
(Continuum and Line Interferometric Calibration)

- Introduction
- Data format
- Useful commands

CLIC: part of GILDAS

Part of GILDAS (Grenoble Image and Line Data Analysis Software), developed and maintained mainly in Grenoble.

GILDAS composed of:

- Kernel:
  - SIC: command interpreter, computer
  - GREG: graphics
- Packages:
  - e.g. CLASS
  - CLIC

CLIC: what is CLIC ?

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CLIC is able to read/write file with a data format specific to the PdBI.

CLIC is able to plot various quantities stored (or derived from) in the data file.

CLIC is able to do various type of fits to the data, necessary for data/system calibration.

CLIC is able to store these corrections.

CLIC is able to export *uv* tables in the GILDAS .uvt format.

Data format

At the PdBI, an IPB file (.ipb or .IPB) is written:

- Collection of observations related to a single project ("track").
- Contains
  - An index of the observations.
  - Observations themselves.
- Binary format (metadata and data).

Those file are transferred to the database in Grenoble and archived (can be retrieved through the *getproj* command).

Data format

Observations contain:

- Observation header composed of section containing observations parameters (frequency plan, calibration parameters, source information etc ...)
- Data composed of records each having
  - A data header (for parameter changing each second).
  - The data (working with logical numbering).
- The records are:
  - Temporal: one dump every second (spectral averaged). Referred to as the continuum subbands: C01 [...] C12.
  - Spectral: two spectra at the end of the integration period (time averaged). Referred to as the line subbands: L01 [...] L12.

CLIC: miscellaneous

All information stored either in the observation header or the data headers can be accessed through SIC variables than can be used (and changed !) afterward

This allows the use of procedures which are of higher levels than the basic commands (called when clicking on widgets).

Calibration in done on a .hpb file, which contains only the observations header (among which the calibration sections).

CLIC, as part of GILDAS, has automatic keyword completion. System commands are called with $, procedures with @. Command options start with /.

CLIC: basic commands

Although use of widgets (hence procedure) is recommended, it may be required to know some commands.

HELP: help on CLIC or a specific command.

FIND: allow to build an index of observations (on which we will apply commands, e.g. plotting, fitting, storing ...).

LIST: list the content of the index.

SET: sets parameters (e.g. SET X TIME ; SET Y PHASE or SET SUBBANDS L01 to L04 ; SET AVER SCAN).

PLOT: plot the observations in the index.

SOLVE: make a fit to data (e.g. SOLVE PHASE /PLOT).

TABLE: writes a uv table.

III. Offline calibrations: procedures & widgets

- Select
- Autoflag
- Phcorr
- RF
- Phase
- Flux
- Amplitude

Select

Open the hpb file.

Find if there is source observations.

Find the used receiver band and sky sideband.

Find if configuration changed during observations.

Determine if receiver re-tuning (new GAIN scan).

Find the better bandpass (RF) calibrator.

Find the amp/phase calibrators.

Create internal (SIC) variables used by the subsequent procedures.

Useful variables

Variables created and updated after select:

'do_atm': enable/disable radiometric phase correction

'band_source': calibrator used for RF calibration

'phcal': calibrator for amp/pha calibration

'do_avpol': average pol (or not) for amp calibration

Can be overriden with let (e.g. let do_atm .false.)

Autoflag

Check for hardware/software failure (by comparing observing date with a database with known problems).

Check for possible timing error (scan too long/too short or UT update problem).

Check if source observations surrounded by flagged calibrator observations, and flag data if needed.

Phcorr

Determine if the phase-corrected (by use of the Water Vapor Radiometer at 22 GHz) data are better than the uncorrected data.

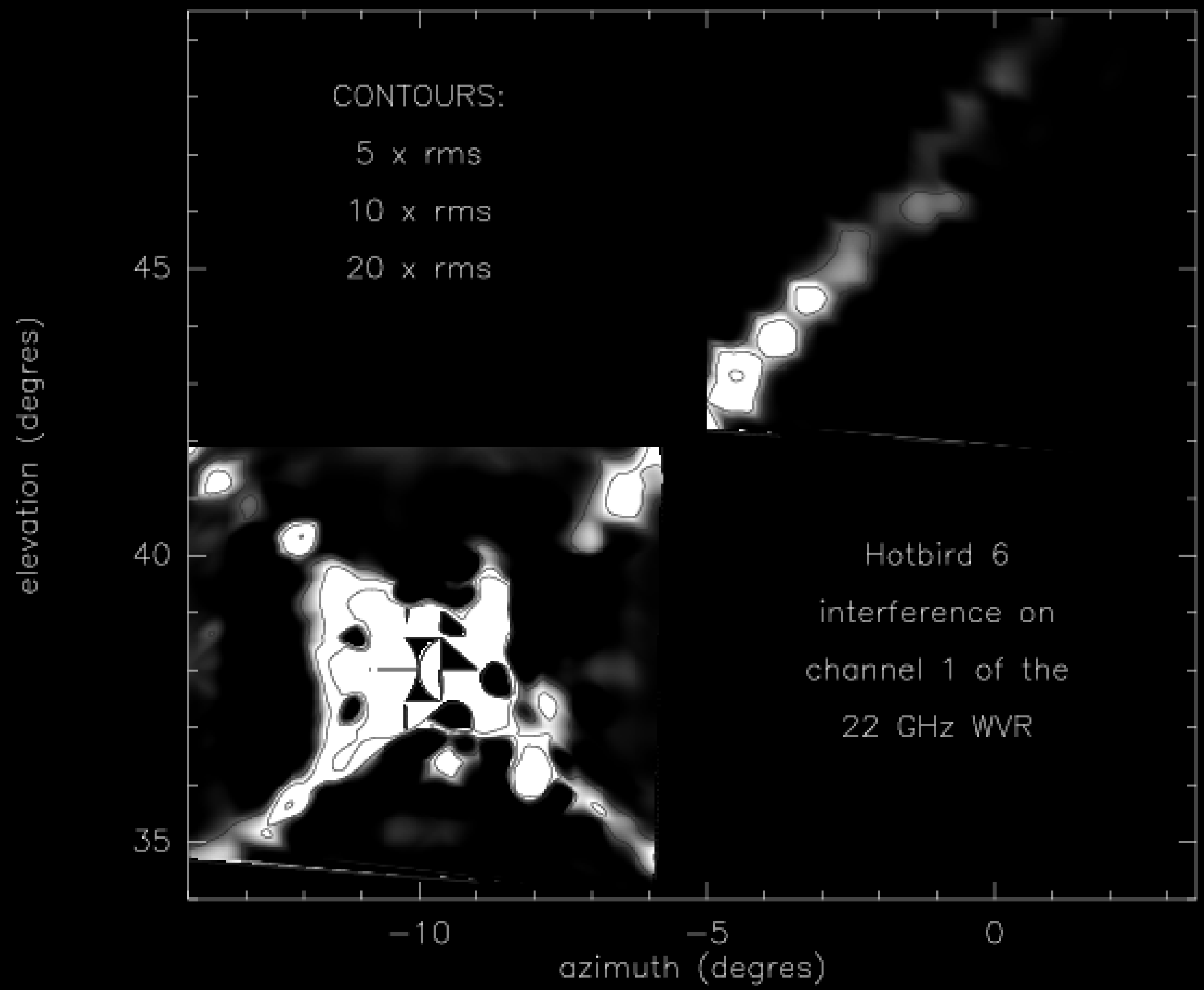
By comparing amplitude on the calibrator of the corrected and uncorrected data. Correction applied to the sources if closest (in time) calibrator found to be better.

Can be bypassed with:

STORE CORRECTION BAD|GOOD /ANT n

Check for possible interference in one of the 3 bands of the WVR (possible interference by Hotbird 6).

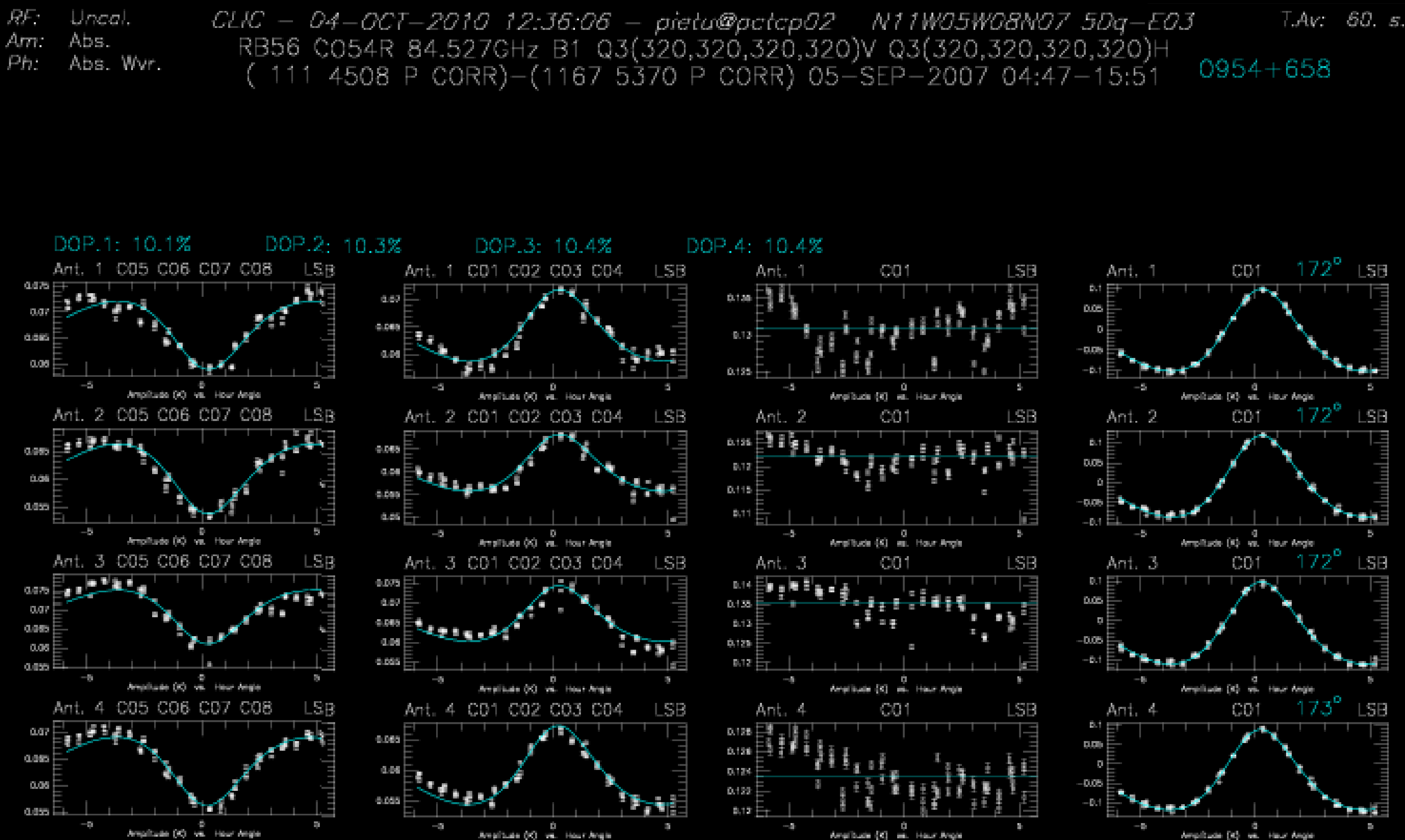
Avoiding Hotbird 6



Phcorr - ctd

Check if amplitude calibrator polarized.

Phcorr - ctd



RF: Uncal.
Am: Abs.
Ph: Abs. Wvr.
CLIC – 04-OCT-2010 12:36:06 – pietu@pctcp02 N11W05W08N07 5Dq-E03
T.Av: 60. s.
RB56 C054R 84.527GHz B1 Q3(320,320,320,320)V Q3(320,320,320,320)H
(111 4508 P CORR)-(1167 5370 P CORR) 05-SEP-2007 04:47-15:51
0954+658
DOP.1: 10.1%
DOP.2: 10.3%
DOP.3: 10.4%
DOP.4: 10.4%
Ant. 1 C05 C06 C07 C08 LSB
Ant. 1 C01 C02 C03 C04 LSB
Ant. 1 C01 LSB
Ant. 1 C01 172° LSB
Ant. 2 C05 C06 C07 C08 LSB
Ant. 2 C01 C02 C03 C04 LSB
Ant. 2 C01 LSB
Ant. 2 C01 172° LSB
Ant. 3 C05 C06 C07 C08 LSB
Ant. 3 C01 C02 C03 C04 LSB
Ant. 3 C01 LSB
Ant. 3 C01 172° LSB
Ant. 4 C05 C06 C07 C08 LSB
Ant. 4 C01 C02 C03 C04 LSB
Ant. 4 C01 LSB
Ant. 4 C01 173° LSB

RF: Radio Frequency bandpass calibration

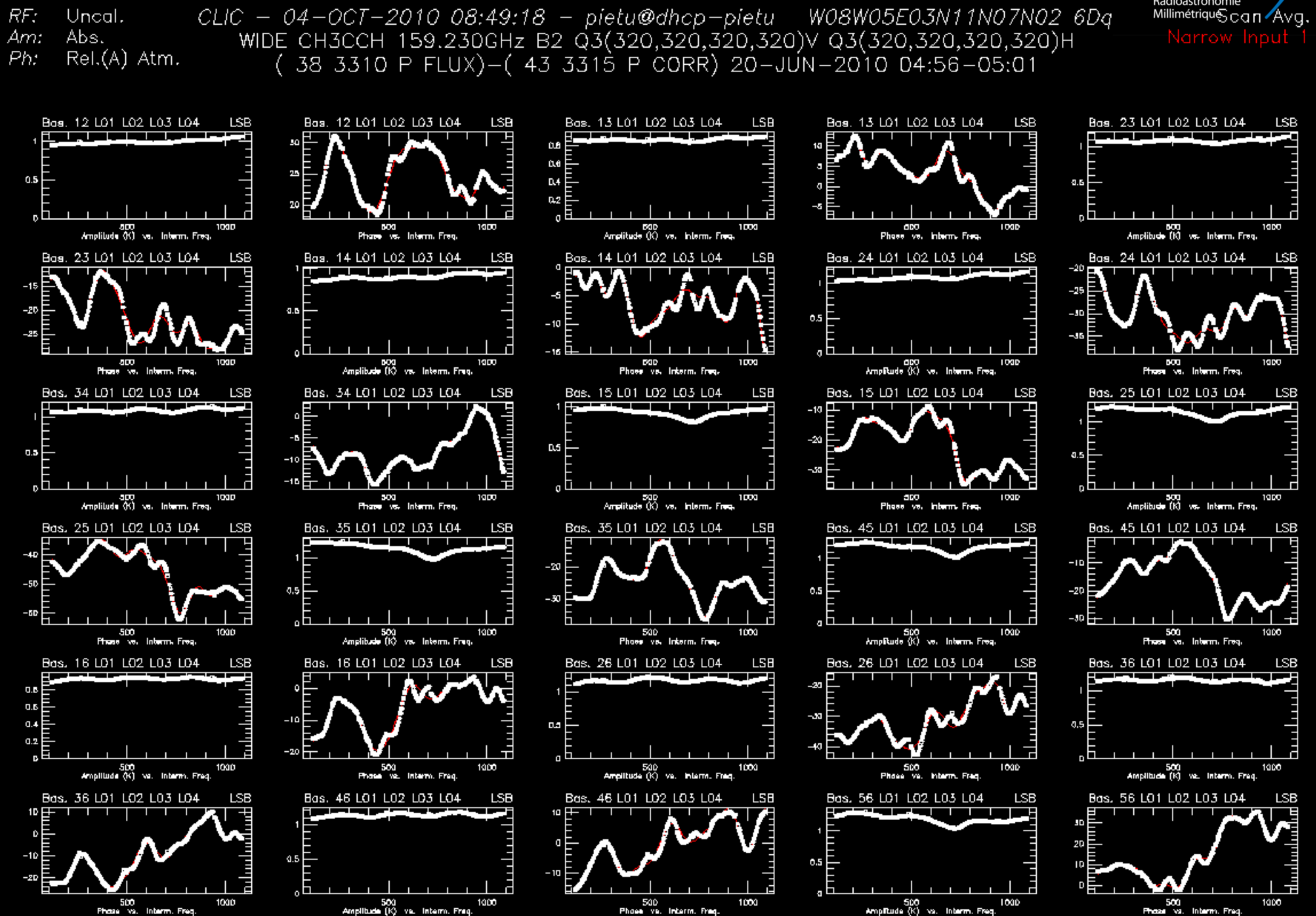
Goal: calibrate the radio-frequency bandpass (Intermediate frequency already calibrated by mean of of observations of a noise source – IFPB in file).

Assumption: no temporal dependance.

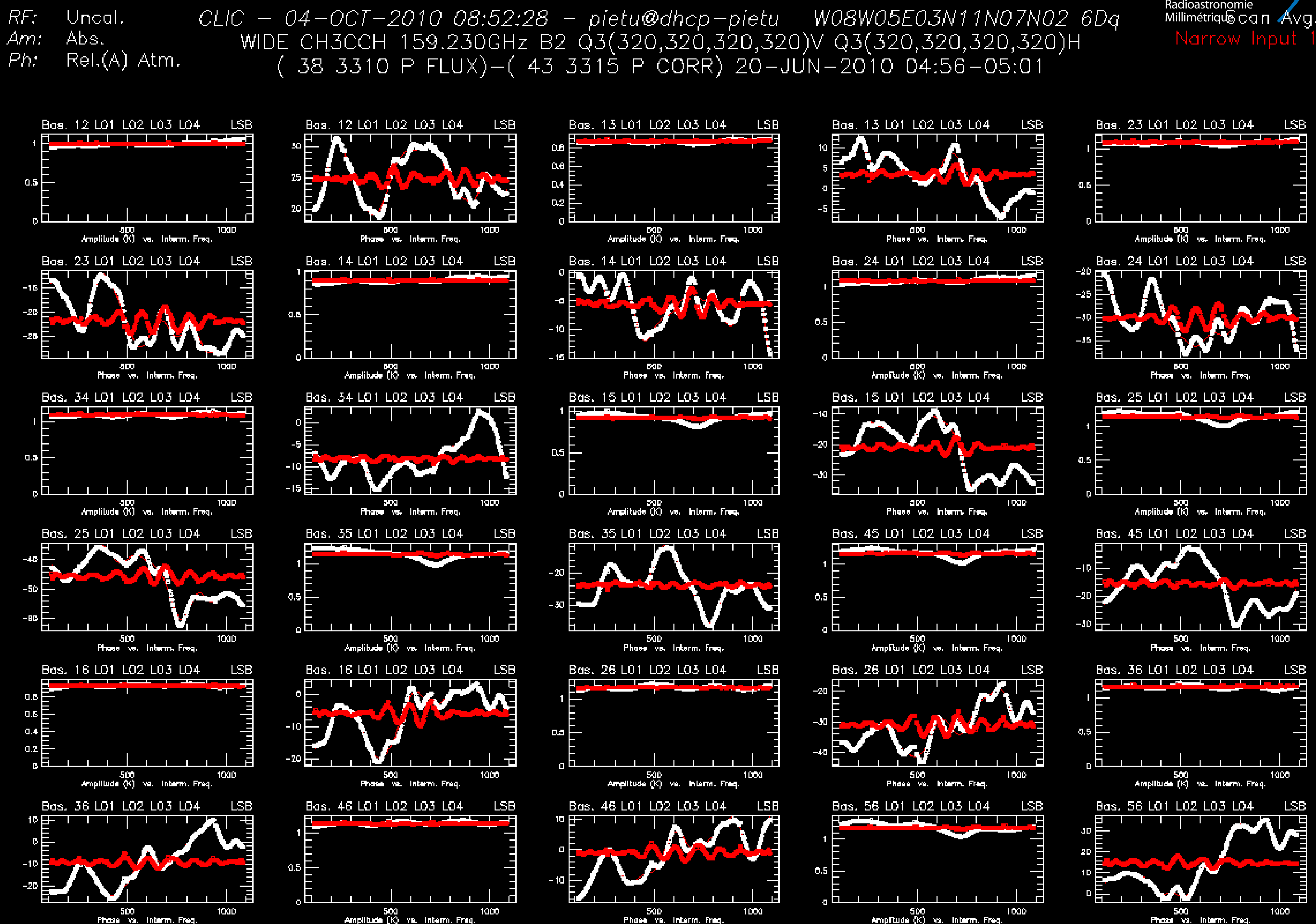
How:

- observations of a strong quasar
- Self-calibration and averaging
- fit of polynoms as a function of frequcency (leaving the average amp/pha unchanged) by antenna or baseline
- End precision needed depends on projects

RF calibration



RF calibration



Phase calibration

Goal: correct for temporal variations of

- Electronics
- Local oscillators
- Antenna position or time errors

... and estimate atmospheric phase noise

How: by using observations of unresolved calibrators

- Plot the quasar phase

  Should be zero if coordinates are precise enough

- Fit a spline to the antenna or the baseline gains

  SET PHASE ANTENNA|BASELINE

  Possibility to use polynoms (SOLVE PHA /POL degree)

- Store correction (scan based).

Phase calibration

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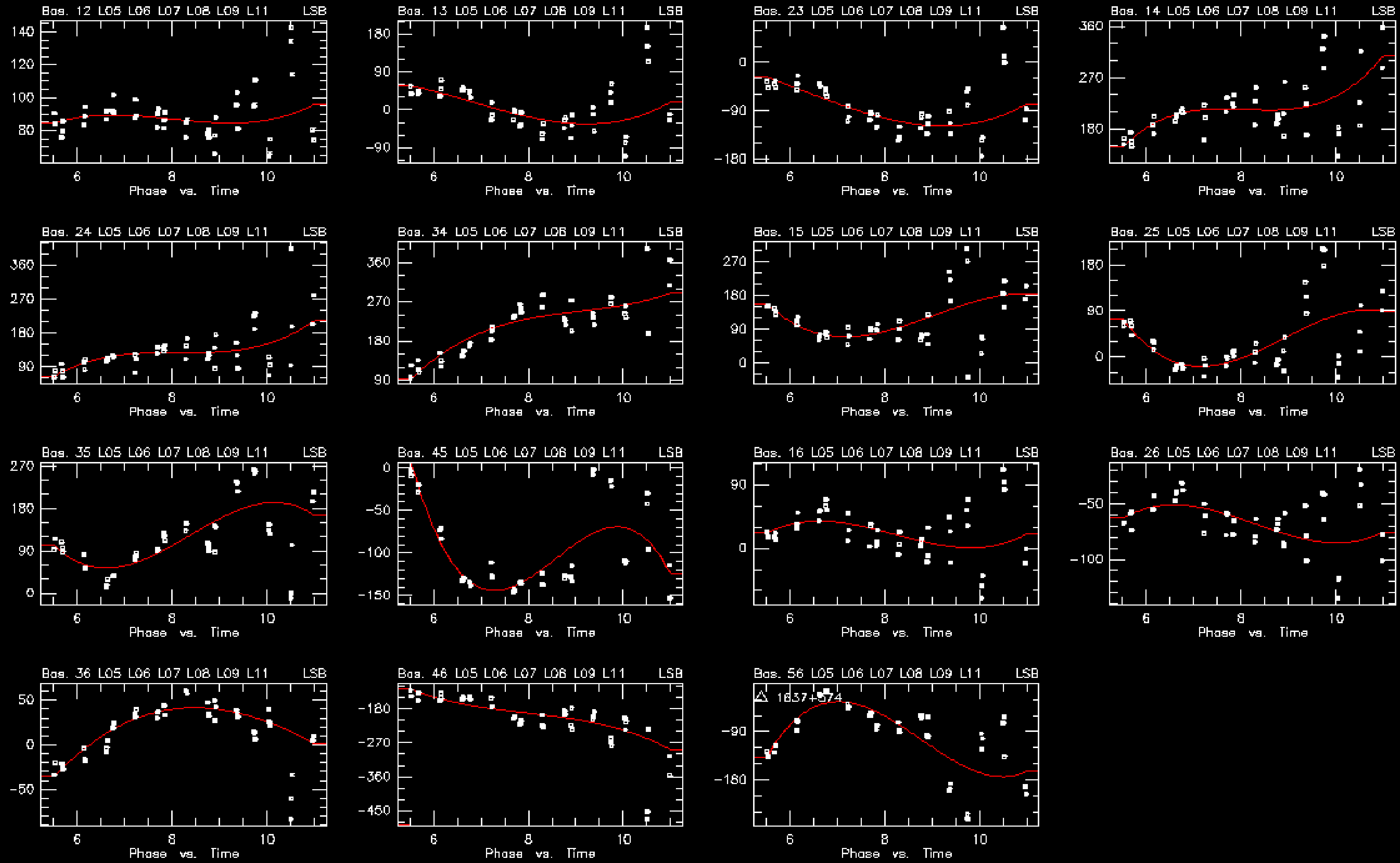
RF:	Fr.(A)
Am:	Abs.
Ph:	Abs. Atm.

CLIC – 04-OCT-2010 08:59:43 – pietu@dhcp-pietu W08W05E03N11N07N02 6Dq Scan Avg.
WIDE CH3CCH 159.230GHz B2 Q3(320,320,320,320)V Q3(320,320,320,320)H HORIZONTAL pol.
(96 3342 P FLUX)-(593 3769 P CORR) 20-JUN-2010 05:30-10:59



Flux calibration

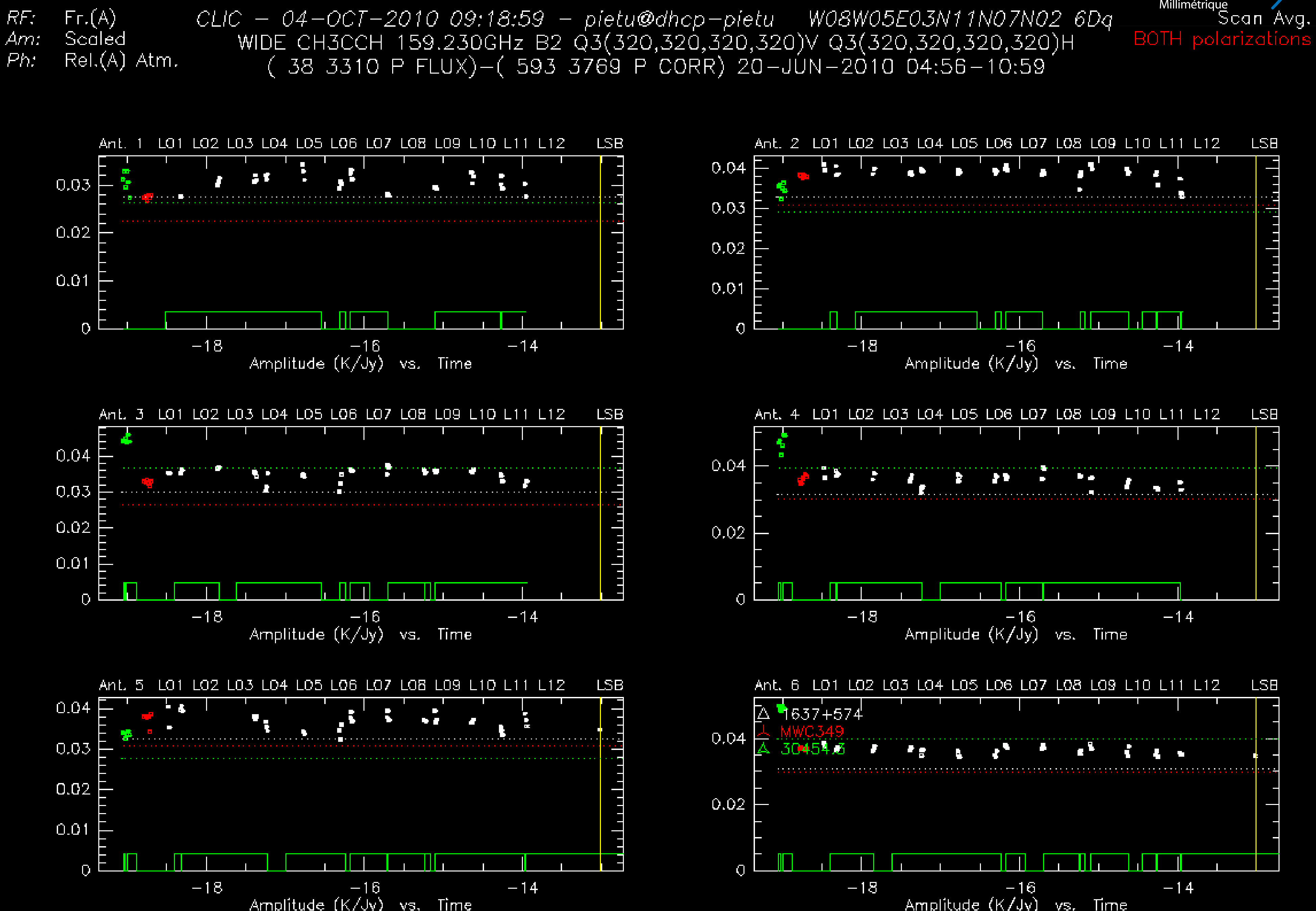
Critical point of the calibration !

Needs the *a priori* knowledge of at least one observed calibrator's flux.

How:

- Fix the flux of one calibrator (Jy).
- Derive the antenna efficiencies by dividing the fixed flux (Jy) by the observed antenna temperature (K).
- Select the 3 best antenna (lowest Jy/K)
- Use efficiencies to derive calibrators fluxes (K x Jy/K).
- Store calibrator fluxes

Flux calibration



Amplitude calibration

Goal: correct for temporal variations of

- Atmospheric decorrelation
- Antenna pointing/focusing
- Antenna efficiency (deicing on/off, etc ...)

By using observations of unresolved calibrators

- Plot the quasar amplitude (T_a*) divided by their flux (Jy).

  This is the inverse of the antenna efficiency

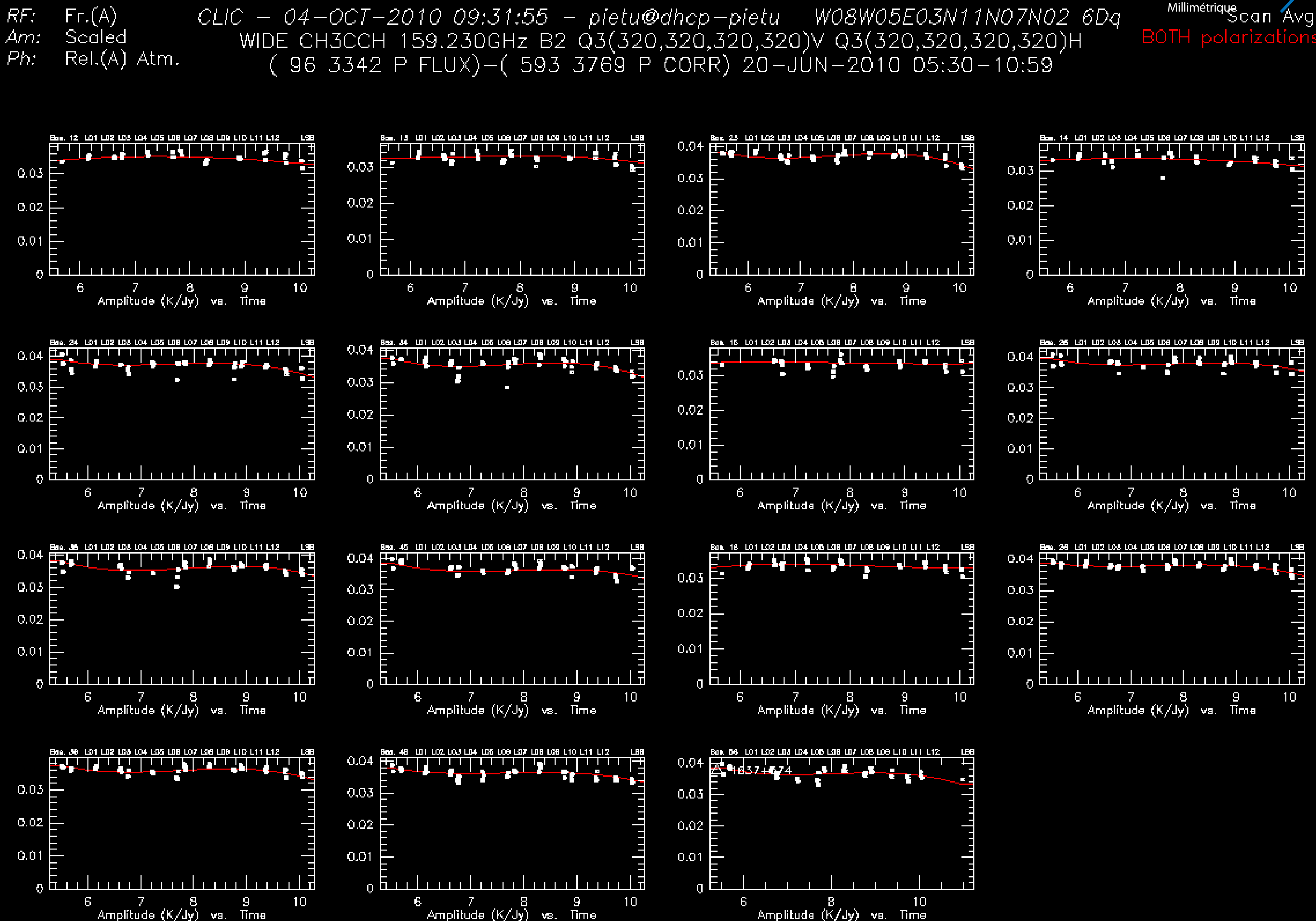
- Fit a spline to the antenna or the baseline gains.

  SET PHASE ANTENNA|BASELINE

  Possibility to use polynoms (SOLVE AMP /POL degree)

- Store correction (scan based).

Amplitude calibration



Creating a *uv* table

GILDAS *uv* tables (derived from GILDAS images).

Done with command TABLE

- Interface between CLIC and MAPPING
- Internal binary format
- Header+visibilities

Can be converted to fits if needed for use in other softwares.

Otherwise, next step occurs in MAPPING with imaging and deconvolution, or for uv-plane analysis.

Creating a *uv* table

Two modes:

- Continuum: produces one visibility per scan/baseline/correlator input
- Line: produces a spectra per scan/baseline

User selects data to be used

- SET SELECTION CONT|LINE LSB|USB|DSB L01 TO L04

Apply calibrations according to user choice

- SET ANTENNA RELATIVE|ABSOLUTE ANT|BASE ATM|NOATM
- SET AMPLITUDE [...] JANSKY|KELVIN
- SET RF ON|OFF FILE|MEMORY

Conclusions

All that is fine, but nothing's worth a good tutorial !