

An Introduction to the IRAM Plateau de Bure Interferometer

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This document introduces the IRAM Plateau de Bure Interferometer to potential users. It contains general information about the capabilities and performance of the interferometer and on related documentations.

Related information is available in:

- IRAM Plateau de Bure Interferometer: OBS Users Guide
- IRAM Plateau de Bure Interferometer: Foreign Commands
- IRAM Plateau de Bure Interferometer: Trouble Shooting Guide
- IRAM Plateau de Bure Interferometer: Frequency Setup
- IRAM Plateau de Bure Interferometer: Atmospheric Calibration
- IRAM Plateau de Bure Interferometer: Flux measurements
- CLIC: Continuum and Line Interferometric Calibration
- ASTRO: Astronomical Software To pRepare Observations
- GILDAS: Grenoble Image and Line Data Analysis Software
- IRAM Plateau de Bure Interferometer: Calibration Cookbook
- IRAM Plateau de Bure Interferometer: Mapping Cookbook

Revision 4.0: NGR system and extended array configurations

Revision 3.7: New configurations

Revision 3.6: Antenna 6; New correlator; Linux computer

Revision 3.5: Antenna 5

Revision 3.4: New configurations

Revision 3.3: Baseline extension and correlator upgrade

Revision 3.2: Dual-frequency receivers

Revision 3.1: 4 antenna configurations

Revision 3.0: Continuum and Berkeley correlators replaced by 6 flexible spectral units.

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1 Description

The Plateau de Bure interferometer is located in the South of the French Alps, near St Etienne en Dévoluy in the Département Hautes Alpes. The interferometer's altitude is 2560 m at the intersection of the Azimuth and Elevation axes of the telescopes, and its longitude and latitude are 05:54:28.5 E and 44:38:02.0 N at the array phase center. The interferometer comprises

- Six antennas of 15-m diameter,
- one north-south track 368 m long,
- one east-west track 760 m long,
- a flexible spectral correlator, made of 8 independent units, with resolutions ranging from 0.039 MHz to 2.5 MHz, and with 128 to 512 associated channels per unit and baseline,
- dual polarization single sideband receivers: a 3 mm receiver band tunable between 80 and 116 GHz, and a 1.3 mm receiver band tunable between 201 and 267 GHz. The 2 mm band (129 to 174 GHz) is available since December 2007, and a 0.8 mm receiver band (277 to 371 GHz) should become available in 2009 observing period.

The six antennas of the interferometer can be positioned on 32 stations arrayed along a “T” shaped track (see Figure 1).

The north-south arm is 368 m long, and the east-west oriented arm extends 216 m west and 544 m east of the intersection. The angle between the arms is 75 deg. The station names are taken from the arm orientation and a two digit code indicating the distance from the track intersection (station W00) in 8 m units.

Each antenna is a 15 m diameter Cassegrain telescope constructed largely of carbon fiber. The primary mirrors have a surface accuracy below $60 \mu\text{m}$ rms. The antenna mounts incorporate self propelled transporters for moving the antennas along the tracks between stations. The antennas are currently equipped with three receiver bands, observing in dual polarization in the 1.3 mm, 2 mm, and 3 mm atmospheric windows, respectively. The 3 mm SIS mixers have typical SSB receiver noise temperature between 40 K and 55 K, the 2 mm mixers have typical noise temperature between 30 K and 60 K, and the 1.3 mm SIS mixers have typical receiver noise temperature between 40 K and 60 K. More details about the receivers are given in Sect. 2.2, a summary can be found in Table 7.

The two IF-channels (one per polarization), each 4 GHz wide, are transmitted by optical fibers to the central building. Details on the IF transport and processing are given in Sect. 2.3.1.

Eight correlator units are available. Each unit is a fully independent, flexible entity, capable of processing 15 baselines (6 antennas). Full 2-bit sampling scheme is used to give 88 % efficiency. For details of the unit capabilities, see Section 2.3.2.

A 64-bit Linux computer and several embedded processors control the interferometer and acquire the data. The user interface is a variant of OBS, familiar to most users of the IRAM 30-m telescope. Additional Linux PCs are available on site to the operator and on-duty astronomer for offline data reduction with the CLIC calibration package and for data archiving before transfer to Grenoble.

Each interferometer “configuration”, the 6 antennas on given stations, simultaneously provides 15 baselines (or uv-tracks). The interferometer is run with several projects progressing in parallel, allowing for a flexible scheduling of the observations well adapted to the actual meteorological conditions. Depending on the weather and on the season (antenna maintenance period in the

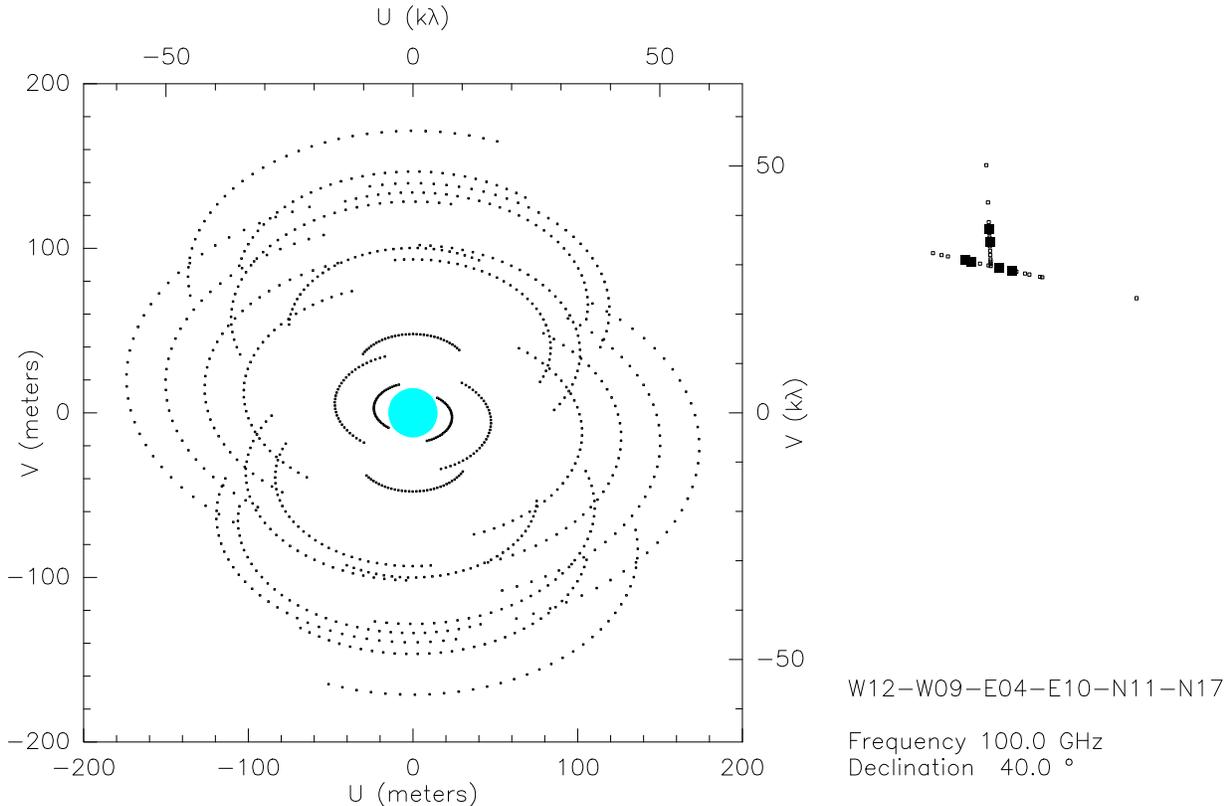


Figure 1: Example of uv-coverage (left) and interferometer station layout (right), as produced by the ASTRO UV_TRACK command. The hatched circle at the center shows the antenna shadowing region

summer semester, i.e. the array is observing in its 5 antenna D configuration), configurations are changed every two to six months, so a project that requires two configurations will on average take about four months to be completed.

2 Capabilities

2.1 Spatial Resolution

Four primary 6 antenna configurations (see Table 1) are available that can be combined to produce maps with different angular resolution. All four configurations are usually scheduled during the course of a year. During the summer period (May until September) each antenna undergoes a thorough maintenance and the interferometer is operated in the 5 antenna D configuration (equal to the 6 antenna D configuration given in Table 1 but without station N02).

The combinations, named AB, BC, CD are reasonably suited for all declinations above 0° (see Tables 3 to 5) For lower source declinations, the beam becomes increasingly elliptical. Sources lower than -25° declination cannot reasonably be observed from Plateau de Bure.

- **D** – the compact configuration with just the D array for maximum sensitivity. This configuration is best suited for detection experiments and coarse mapping. It provides the lowest phase noise and is the configuration best suited to observe sources at low declination.

Table 1: Plateau de Bure 6 antenna configurations

Configuration	Stations					
D	W08	W05	E03	N02	N07	N11
C	W12	W09	E04	E10	N11	N17
B	W27	W12	E12	E23	N20	N46
A	W27	E04	E24	E68	N29	N46

- **C** – the next most compact configuration provides a fairly complete coverage of the uv-plane (low sidelobe level) and is well adapted to be combined with D for low angular resolution studies ($\sim 3.5''$ at 100 GHz, $\sim 1.5''$ at 230 GHz) and with B for higher resolution ($\sim 1.7''$ at 100 GHz, $\sim 0.7''$ at 230 GHz). C alone is also well suited for snapshot size measurement and detection experiments at low source declinations.
- **B** – the second most extended configuration yields $\sim 1.2''$ at 100 GHz and, in combination with A provides an angular resolution of $\sim 1.0''$ at 100 GHz. It is mainly used for relatively strong sources.
- **A** – the most extended configuration is well suited for mapping or size measurements of very compact, strong sources. It provides a resolution of $0.8''$ at 100 GHz, $\sim 0.35''$ at 230 GHz.

The four configurations can be used in different combinations to achieve complementary sampling of the uv-plane, and to improve on angular resolution and sensitivity. Mosaicing is usually done with D or CD, but the combination BCD can also be requested for high resolution mosaics. Lower spatial resolution projects will usually not be considered given the limited field of view of the IRAM antennas. The antenna half-power beam size is $50''$ at 100 GHz and the shortest possible antenna spacing is 24 m to avoid collisions between two antennas. Even taking into account projection effects that shorten the effective baseline, sources larger than about $15''$ are already heavily resolved at 100 GHz. In these cases, additional short-spacing observations should be acquired by observing a raster- or OTF- (On-The-Fly) map using the IRAM 30 m telescope. The short-spacing information can then easily be added to the uv-tables obtained from the interferometer by means of the GILDAS MAPPING software.

Tables 2-6 gives a summary of beam sizes for natural weighting and various observing frequencies. Observing was supposed to be limited to 6 hours before and after transit and to elevations higher than 20 degrees. Typical uv-coverages and resulting beam shapes for the six-element array are shown in Fig. 2 (D and CD), 3 (BCD and BC) and 4 (A and AB).

Table 2: Beam sizes for configuration D

Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
80	6.41	5.88	4.74	4.35	2.37	2.17	92.
60	6.45	5.45	4.77	4.03	2.38	2.01	96.
40	6.45	5.54	4.77	4.09	2.38	2.04	104.
20	6.13	6.04	4.53	4.46	2.26	2.23	91.
0	7.35	6.12	5.43	4.52	2.71	2.26	-18.
-20	11.43	5.68	8.44	4.20	4.22	2.10	-6.

Table 3: Beam sizes for configuration CD

Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
80	4.48	4.15	3.31	3.06	1.65	1.53	-90.
60	4.35	3.86	3.21	2.85	1.60	1.42	86.
40	4.44	4.02	3.28	2.97	1.64	1.48	89.
20	4.42	4.21	3.26	3.11	1.63	1.55	40.
0	5.41	4.23	4.00	3.12	2.00	1.56	6.
-20	8.38	3.82	6.19	2.82	3.09	1.41	-178.

Table 4: Beam sizes for configuration BC

Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
80	2.12	1.96	1.56	1.45	0.78	0.72	79.
60	2.15	1.86	1.59	1.37	0.79	0.68	80.
40	2.20	1.93	1.62	1.42	0.81	0.71	69.
20	2.40	1.96	1.77	1.45	0.88	0.72	37.
0	3.39	1.99	2.50	1.47	1.25	0.73	-166.
-20	4.60	1.89	3.40	1.40	1.70	0.70	6.

Table 5: Beam sizes for configuration AB

Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
80	1.21	1.12	0.89	0.83	0.44	0.41	84.
60	1.21	1.05	0.89	0.77	0.44	0.38	74.
40	1.25	1.06	0.92	0.78	0.46	0.39	59.
20	1.40	1.06	1.03	0.78	0.51	0.39	37.
0	1.74	1.02	1.28	0.75	0.64	0.37	22.
-20	2.66	0.98	1.97	0.72	0.98	0.36	10.

D: W05 W08 E03 N02 N07 N11

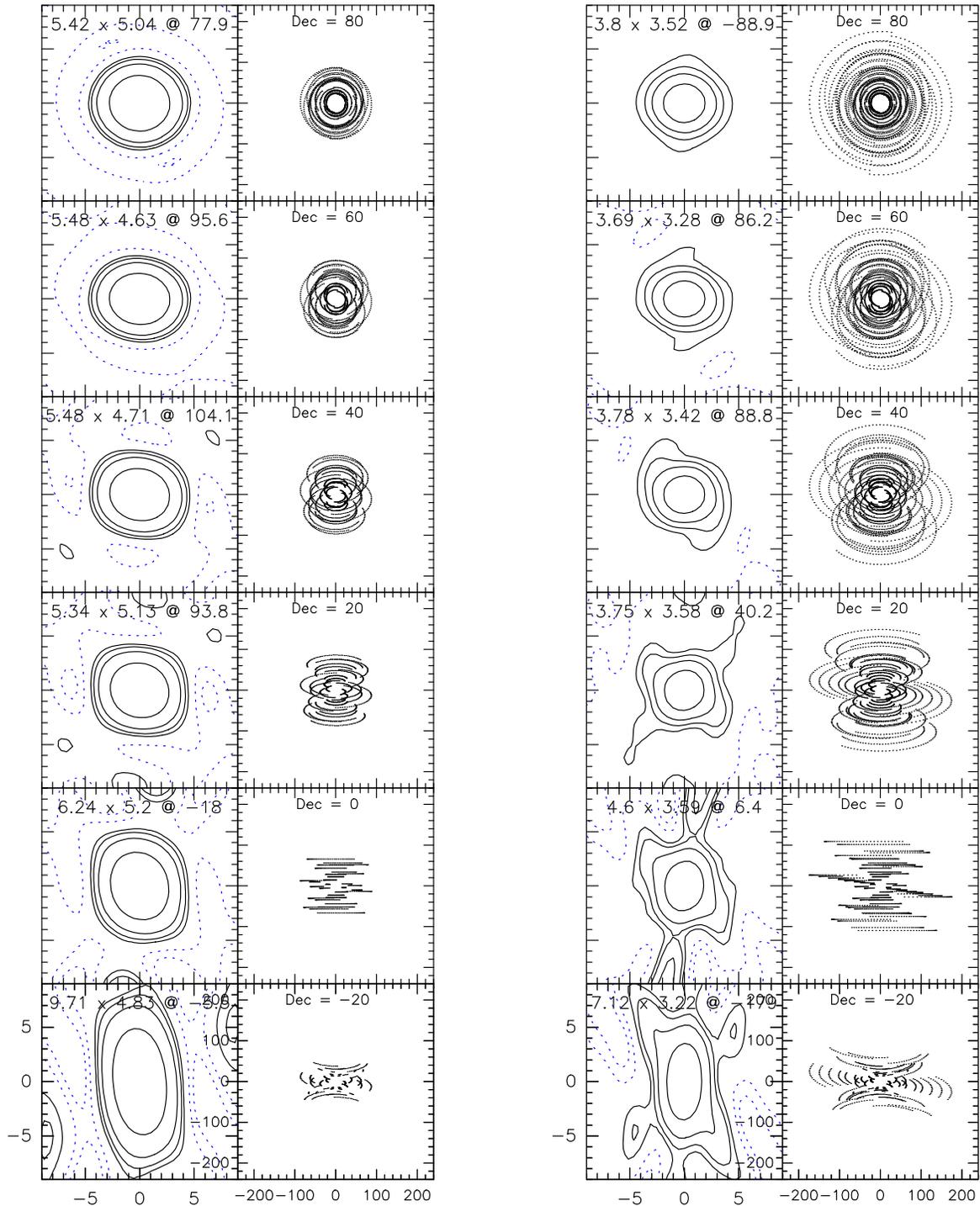
CD: W12 N17 E10 W09 E04 N11
W05 W08 E03 N02 N07 N11

Figure 2: uv-plane coverage and beamshapes for the D and CD (6 antenna) configurations. Contour levels are at 5%, 10%, 20%, and 50%. Frequency is 100 GHz.

BCD: W27 N46 E23 W12 E12 N20 W12 N17 E10 W09 E04 N11
 W05 W08 E03 N02 N07 N11

BC: W27 N46 E23 W12 E12 N20 W12 N17 E10 W09 E04 N11

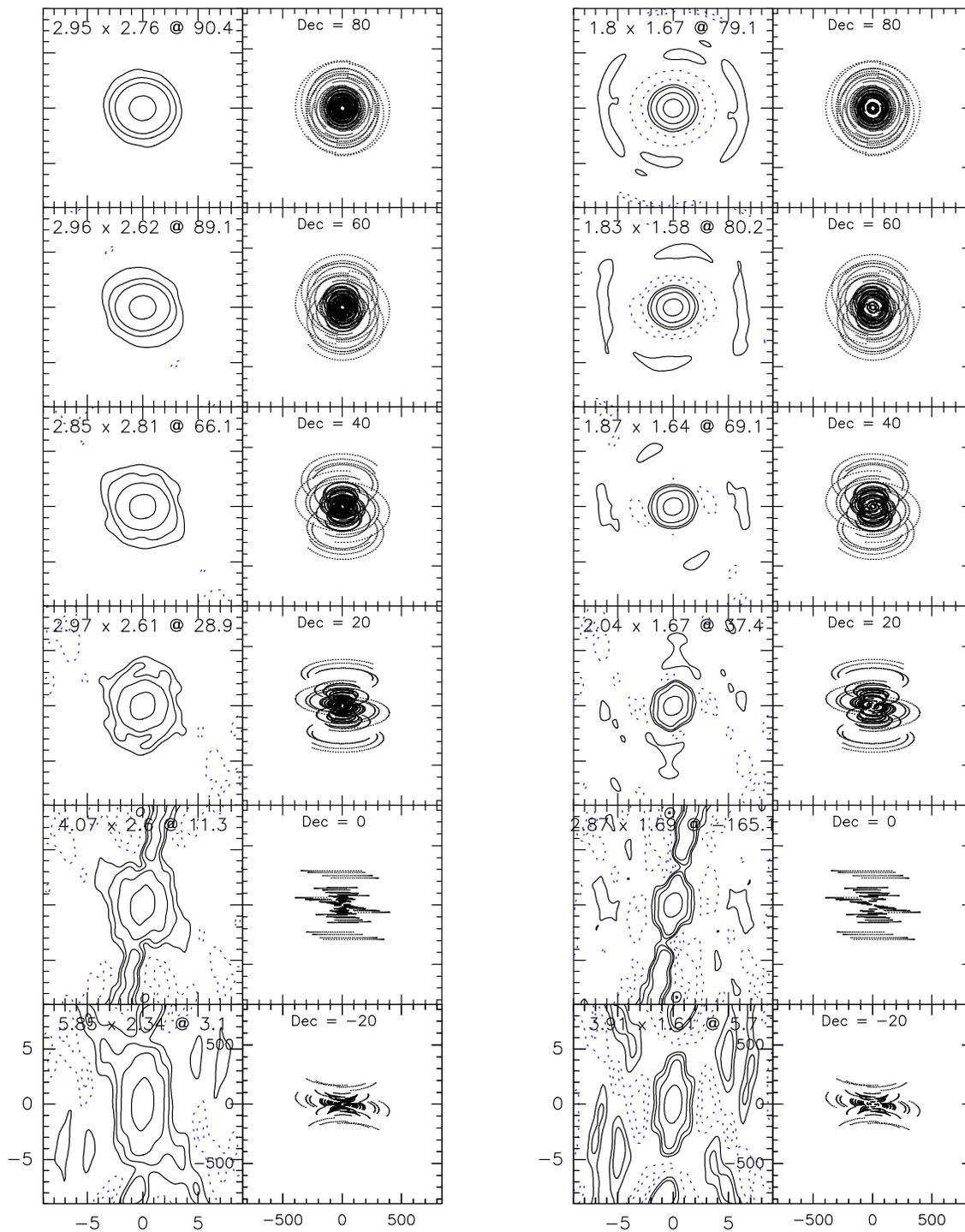


Figure 3: uv-plane coverage and beamshapes for the BCD and BC (6 antenna) configurations. Contour levels are at 5%, 10%, 20%, and 50%. Frequency is 100 GHz. Note the different scaling of the uv-plane with respect to Fig. 2

AB: W27 N46 E68 E24 E04 N29
 W27 N46 E23 W12 E12 N20

A: W27 N46 E68 E24 E04 N29

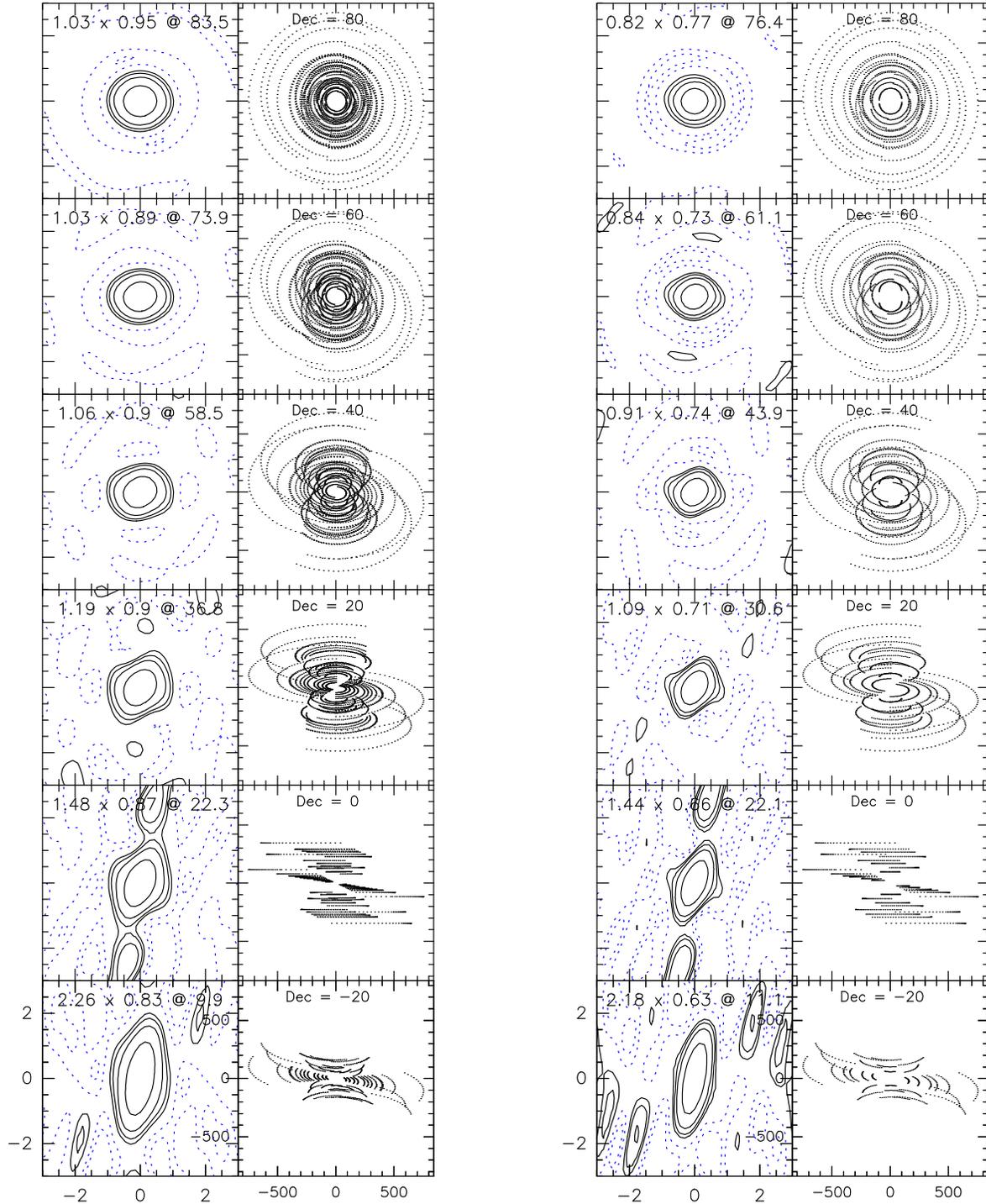


Figure 4: uv-plane coverage and beamshapes for the AB and A (6 antenna) configurations. Contour levels are at 5%, 10%, 20%, and 50%. Frequency is 100 GHz. Note the different scaling of the beam maps with respect to Figs. 2 and 3

Table 6: Beam sizes for configuration A

Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
80	0.97	0.91	0.71	0.67	0.35	0.33	76.
60	0.99	0.86	0.73	0.64	0.36	0.32	61.
40	1.07	0.87	0.79	0.64	0.39	0.32	44.
20	1.29	0.84	0.95	0.62	0.47	0.31	31.
0	1.70	0.78	1.25	0.57	0.62	0.28	22.
-20	2.58	0.74	1.91	0.54	0.95	0.27	12.

2.2 Receivers

Since December 2007, all antennas are equipped with dual polarization receivers for the 3 mm, 2 mm, and 1.3 mm atmospheric windows. The frequency range is 80 GHz to 116 GHz for the 3 mm band, 129 GHz to 174 GHz at 2 mm, and 201 GHz to 267 GHz for the 1.3 mm band.

Each frequency band of the receivers is dual-polarization with the two RF channels observing at the same sky frequency. The mixers are single-sideband, with a typical image rejection of 10 dB. Only one frequency band (dual polarization) can be connected to the IF transmission lines at any time. Because of this reason and due to pointing offsets between different frequency bands, only one band can be observed at any time. One of the other bands is in stand-by (power on and local oscillator phase-locked) and is available, e.g., for pointing and focusing. Time-shared observations between frequency bands cannot be offered presently.

The two IF-channels (one per polarization), each 4 GHz wide, are transmitted by optical fibers to the central building. At present, the 4 GHz bandwidth can be processed only partially by the existing correlator, through a dedicated IF processor that converts selected 1 GHz wide slices of the 4-8 GHz first IFs down to 0.1-1.1 GHz, the input range of the existing correlator. Further details are given in Section 2.3.1.

Table 7: PdBI receiver specifications. The tuning ranges refer to a centering of the respective sky frequency at the center of the IF band at 6 GHz

	Band 1	Band 2	Band 3
RF coverage	80–116	129–174	201–267
T _{rec} LSB	40–55	30–50	40–60
T _{rec} USB	40–55	40–80	50–70
G _{im}	-10 dB	-12 -10 dB	-12 -8 dB
RF range LSB	80–104	129–168	201–267
RF range USB	104–116	147–174	

2.3 Correlator

2.3.1 IF processor

At any given time, only one frequency band is used, but with the two polarizations available. Each polarization delivers a 4 GHz bandwidth (from IF1=4 to 8 GHz). The current correlator accepts as input two signals of 1 GHz bandwidth, that must be selected within the 4 GHz delivered by the receiver. In practice, the new IF processor splits the two input 4–8 GHz bands in four 1 GHz “quarters”, labeled $Q1...Q4$ (see Fig. 5). The system allows the following choices:

- first correlator entry can only be Q1 HOR, or Q2 HOR, or Q3 VER, or Q4 VER
- second correlator entry can only be Q1 VER, or Q2 VER, or Q3 HOR, or Q4 HOR

where HOR and VER refers to the two polarizations:

Quarter	Q1	Q2	Q3	Q4
IF1 [GHz]	4.2 - 5.2	5 - 6	6 - 7	6.8 - 7.8
input 1	HOR	HOR	VER	VER
input 2	VER	VER	HOR	HOR

How to observe two polarizations? To observe simultaneously two polarizations at the same sky frequency, one must select the same quarter (Q1 or Q2 or Q3 or Q4) for the two correlator entries. This will necessarily result in each entry seeing a different polarization. The system thus gives access to 1 GHz x 2 polarizations.

How to use the full 2 GHz bandwidth? If two different quarters are selected (any combination is possible), a bandwidth of 2 GHz can be analyzed by the correlator. But only one polarization per quarter is available in that case; this may or may not be the same polarization for the two chunks of 1 GHz.

Is there any overlap between the four quarters? In fact, the four available quarters are 1 GHz wide each, but with a small overlap between some of them: Q1 is 4.2 to 5.2 GHz, Q2 is 5 to 6 GHz, Q3 is 6 to 7 GHz, and Q4 is 6.8 to 7.8 GHz. This results from the combination of filters and LOs used in the IF processor.

Is the 2 GHz bandwidth necessarily contiguous? No: any combination of two quarters can be selected. Adjacent quarters will result in a continuous 2 GHz band. Non-adjacent quarters will result in two independent 1 GHz bands. Note that in any case, the two correlator inputs are analyzed independently.

Where is the selected sky frequency in the IF band? It would be natural to tune the receivers such that the selected sky frequency corresponds to the middle of the IF bandwidth, i.e. 6.0 GHz. However, this corresponds to the limit between Q2 and Q3. It is therefore highly recommended to center a line at the center of a quarter (see Section “ASTRO” below). At 3 mm and 2 mm, the receivers offer best performance in terms of receiver noise and sideband rejection in Q3 (i.e. the line should be centered at an IF1 frequency of 6500 MHz) whereas at 1 mm best performance is obtained in Q2 (i.e. the line should be centered at 5500 MHz).

Table 8: Configurations of the correlator

Spacing (MHz)	Channels	Bandwidth ¹ (MHz)	Mode ²
0.039	1 x 512	20	SSB
0.078	1 x 512	40	SSB
0.156	2 x 256	80	DSB
0.312	1 x 256	80	SSB
0.625	2 x 128	160	DSB
1.250	1 x 128	160	SSB
2.500	2 x 64	320	DSB

- ¹: Note that 5% of the passband are lost at both ends of each subband.
- ²: Default Mode is LSB. There is no practical difference between an LSB or a USB setting. DSB Mode provides twice as many channels than Mode LSB or USB for the same bandwidth but the central channels suffer from the Gibbs effect. Note, that in this context, “LSB”, “USB”, “DSB” has *nothing* to do with the tuning of the receivers; it is just an unfortunate coincidence of the same terms.

2.3.2 Spectral units of the correlator

The correlator has 8 independent units, which can be placed anywhere in the 100–1100 MHz band (1 GHz bandwidth), by steps of 0.25 MHz. Each unit can be operated in seven modes, as shown in Table 8. Each mode is characterized in the following by couples of total bandwidth/number of channels. In the 3 DSB modes (320MHz/128, 160MHz/256, 80MHz/512 – see Table 8) the two central channels may be perturbed by the Gibbs phenomenon if the observed source has a strong continuum. When using these modes, it is recommended to avoid centering the most important part of the lines in the middle of the band of the correlator unit. In the remaining SSB modes (160MHz/128, 80MHz/256, 40MHz/512, 20MHz/512) the two central channels are not affected by the Gibbs phenomenon and, therefore, these modes may be preferable for some spectroscopic studies. Because of signal apodization, the effective spectral resolution is slightly broader than the channel spacing (by about a factor 1.6 in the standard case on Plateau de Bure, that uses a Welch time-lag window).

In addition to the spectra produced every integration time (`subscan` in the OBS terminology), the correlator units output every second the visibility for a pseudo-continuum channel created by averaging data from several spectral channels.

The 8 units can be independently connected to the first or the second correlator entry, as selected by the IF processor (see above). Please note that the center frequency is expressed – as in the old system – in the frequency range seen by the correlator, i.e. 100 to 1100 MHz. The correspondence to the sky frequency depends on the parts of the 4 GHz IF1 bandwidth which have been selected as correlator inputs: Use the ASTRO software (see Sect. 2.3.3) to display the relation between sky- and IF1 frequencies.

The spectral correlator configuration is selected with the OBS program, by the two commands

```
OBS\NARROW Qi Qj /RECEIVER Band_Number
OBS\SPECTRAL Unit Bandpass IF3_Frequency /NARROW Narrow_input -
                                         [/CONTINUUM Band_C IF3_C] -
                                         [/BAND Mode] -
                                         /RECEIVER Band_Number
```

where

- Qi Qj are the two 1 GHz wide “quarters” to be analyzed by the correlator (see Sect. 2.3.1 for more details).
- Band_Number is the band to which the unit should be connected (1 =3 mm, 2 =2 mm, 3 =1 mm).
- Unit is the correlator unit number (1 to 8).
- Bandpass indicates the contiguous bandpass to be analyzed (in MHz: 20, 40, 80, 160 or 320).
- IF3_Frequency is the center frequency of the bandpass analyzed by the correlator unit, in the third IF (100-1100 MHz).
- Narrow_input is the IF output (1 or 2).
- Band_C is the bandpass to be used to produce the temporal data (in MHz: contiguous section of Bandpass).
- IF3_C is the center frequency to be used for Band_C (same units as for IF3_Frequency).
- Mode is used to indicate the sideband code: USB, LSB, DSB (see Table 8 for more details).

The /CONTINUUM option can be used to specify a pseudo-continuum channel to be generated from a subset of the bandpass analyzed by the correlator unit. This subset is defined by Band_C, the pseudo-continuum channel width in MHz, and IF3_C, the center frequency of the pseudo-continuum channel. If not specified, a pseudo-continuum channel containing 87.5 % of the sampled bandwidth is produced.

Here is an example of commands showing how to configure the 8 units for a (presumably) typical 3 mm project.

```
NARROW Q1 Q3
!   Selects the 4.2 GHz - 5.2 GHz and 6 GHz - 7 GHz windows of the 4-8 GHz
!   IF1 band. Polarization is HH.
!
SPECTRAL 1 160 1020 /CONTINUUM 100 1000 /NARROW 1 /RECEIVER 1
!   Correlator unit #1 covers the [940,1100] IF3 band on the first IF input
!   (4.2\,GHz - 5.2\,GHz) with pseudo-continuum of [950,1050]
!
SPECTRAL 2 20 210 /NARROW 1 /RECEIVER 1
!   Correlator unit #2 samples a relatively narrow line centered at 210 MHz in the IF3
!   band of the first correlator input
!
SPECTRAL 3 20 770 /NARROW 1 /RECEIVER 1
!   Correlator unit #3 samples another one at 770 MHz
!
```

```

SPECTRAL 4 160 350 /CONTINUUM 50 395 /NARROW 1 /RECEIVER 1
!   Correlator unit #4 covers the [270,430] IF3 band on the first correlator input
!   with pseudo-continuum of [370,420]
!
SPECTRAL 5 160 475 /NARROW 1 /BAND DSB /RECEIVER 1
!   Correlator unit #5 covers the [395,555] IF3 band on the first correlator input
!   with default pseudo-continuum [405,545]
!   Provides twice as many channels as the previous setting, but the
!   central two channels are affected by the Gibbs phenomenon
!
SPECTRAL 6 40 750 /NARROW 2 /RECEIVER 1
!   Correlator unit #6 covers the [730,770] IF3 band on the second IF input
!   (6\,GHz-7\,GHz)
!
SPECTRAL 7 320 400 /NARROW 2 /RECEIVER 1
!   Correlator unit #7 covers the [240,560] IF3 band on the second correlator input
!
SPECTRAL 8 320 925 /NARROW 2 /RECEIVER 1
!   Correlator unit #8 covers the [765,1085] IF3 band on the second correlator input

```

Figure 6 displays this example of frequency coverage.

Given the flexibility of the correlator, no general rules exist to configure it. Please refer to the documents “Frequency Setup” and “OBS Users Guide” for more details.

2.3.3 ASTRO

The software ASTRO can be used to simulate these OBS commands. Astronomers are urged to download the most recent version of GILDAS at `../IRAMFR/GILDAS/` to prepare their proposals.

The old LINE command has been replaced by several new commands (see internal help; the following description applies to the current receiver system). The behavior of the LINE command can be changed by the SET PDBI 1995|2000|2006 command, that selects the PdBI frontend/backend status corresponding to years 1995 (old receivers, 500 MHz bandwidth), 2000 (580 MHz bandwidth), 2006 (new receivers and new IF processor). Default is 2006:

- LINE: receiver tuning
- NARROW: selection of the narrow-band correlator inputs
- SPECTRAL: spectral correlator unit tuning
- PLOT: control of the plot parameters.

A session to design the above correlator setup would be:

```

LINE HCOP-HCN 87.0 LSB LOW 6500
! Define the receiver tuning
NARROW Q1 Q3
! Choice of the correlator windows

```

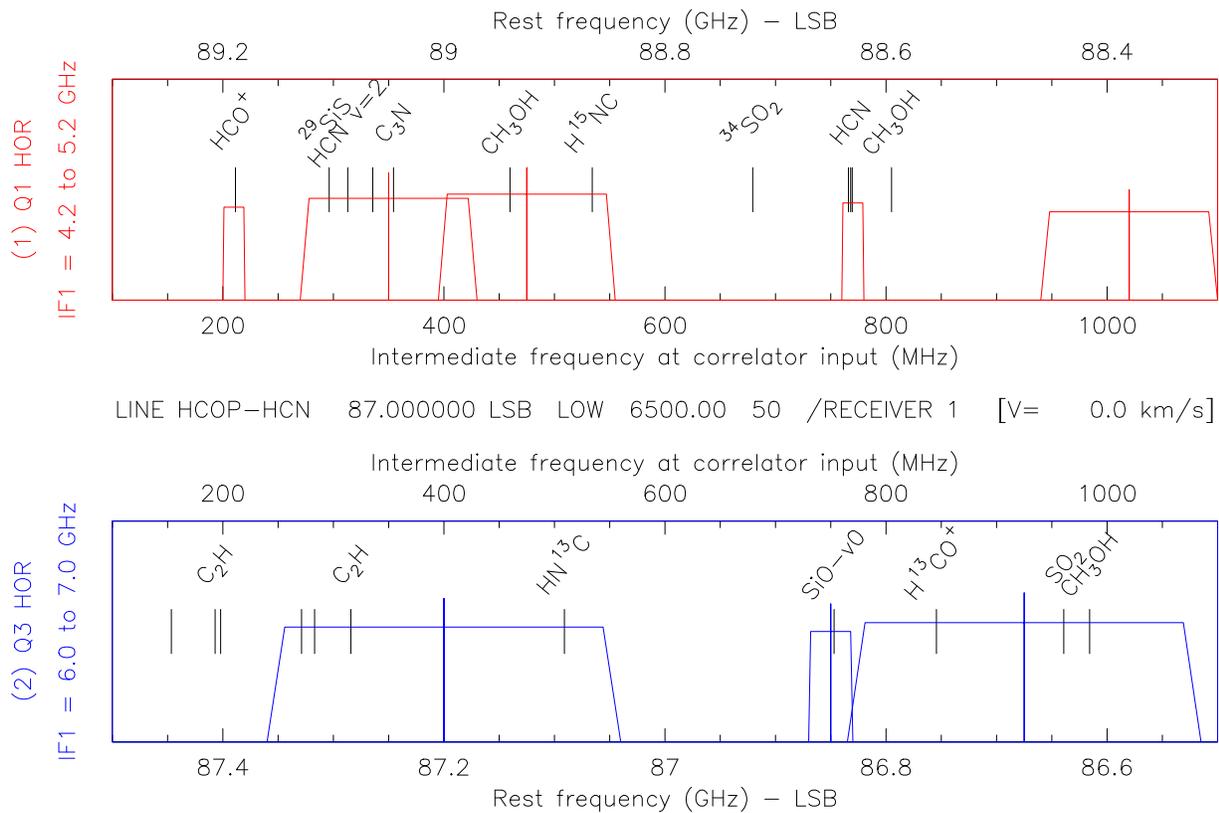


Figure 6: Example of spectral coverage, as produced by the ASTRO LINE command.

```

SPECTRAL 1 160 1020 /NARROW 1
SPECTRAL 2 20 210 /NARROW 1
SPECTRAL 3 20 770 /NARROW 1
SPECTRAL 4 160 350 /NARROW 1
SPECTRAL 5 160 475 /NARROW 1
SPECTRAL 6 40 750 /NARROW 2
SPECTRAL 7 320 400 /NARROW 2
SPECTRAL 8 320 925 /NARROW 2

```

2.4 Sensitivity

2.4.1 Detection experiments

The point source sensitivity (one σ level) for an N antenna array, over a bandwidth $\delta\nu$ in a time δt is given by

$$\delta S = \frac{\rho_e T_{sys}}{\eta_p \eta_j \sqrt{N(N-1)} \sqrt{\delta\nu \delta t}} \cdot \frac{1}{\sqrt{N_{pol}}} \quad (1)$$

where

- T_{sys} is the system temperature outside the atmosphere, i.e. corrected for atmospheric transmission (typically 100 K SSB below 110 GHz, but 180 K (170) at 115 GHz, 180 K (150) at 150 GHz, and 250 K (200) at 230 GHz in summer. (Values in brackets are for typical winter conditions),
- ρ_e is the antenna efficiency (Jy K⁻¹) i.e. $2k/(\eta_a A)$ with η_a the aperture efficiency, A the antenna collecting area, and k the Boltzmann constant (22 Jy.K⁻¹ at 85 GHz, 29 Jy.K⁻¹ at 150 GHz, and 35 Jy.K⁻¹ at 230 GHz),
- η_j is the instrumental decorrelation coefficient, related to the oscillator phase jitter by $\eta_j = e^{-\sigma_j^2/2}$ (0.90 to 0.98), and
- η_p is the atmospheric decorrelation coefficient, related to the atmospheric phase noise by $\eta_p = e^{-\sigma_p^2/2}$ (0.6 to 0.98).
- N_{pol} is the number of polarizations: 1 for single polarization and 2 for dual polarization (see Section 2.3.1 for details).

For the correlator, $\delta\nu$ is the noise equivalent bandwidth, equal to 1.88 times the channel separation; the effective channel width for standard apodization (using a Welch time-lag window) is 1.60 times the channel separation.

The instrumental phase jitter σ_j typically ranges between 3 and 5 degrees at 90 GHz, and increases linearly with frequency. The short and long term atmospheric phase fluctuations σ_p depend on the baseline length and water vapor content. 15 degrees is a typical value for short (< 100 m) baselines.

With typical values for Plateau de Bure and assuming 6 antennas, we find at 90 GHz $\delta S = 0.16$ mJy ($\eta_j * \eta_j = 0.96$) to 0.28 mJy ($\eta_j * \eta_j = 0.54$) for a one hour integration in a 1000 MHz bandwidth and using both polarizations. For a full synthesis (2 configurations, or 11 hours on source), this goes down to about 0.05 mJy ($\eta_j * \eta_j = 0.96$) to 0.08 mJy ($\eta_j * \eta_j = 0.54$). At 115 GHz, the sensitivity is degraded by about a factor 2 because of higher system noise and atmospheric phase fluctuations. At 230 GHz, the expected rms noise is 0.50 to 1 mJy in one hour (0.15 mJy to 0.26 mJy after 11 hours in average winter conditions).

2.4.2 Mapping

The rms brightness temperature is related to the point source sensitivity by

$$\delta T_m = \frac{\rho \lambda^2}{\theta_1 \theta_2} \delta S \quad (2)$$

where λ is the wavelength in millimeters, θ_1 and θ_2 are the beam major and minor axis in arcseconds, δS is the point source sensitivity in Jy, and $\rho \simeq 15$ for untapered maps with natural weighting.

For a typical experiment with configuration BC or CD, tracking the source for 8 hours (but spending 2 hours on calibration) on each configuration, we obtain $\delta T_{BC} = 0.11$ K and $\delta T_{CD} = 0.03$ K, for 0.625 MHz channel spacing with the spectral correlator, with the same assumptions as above at 90 GHz. The factor ρ is increased by uniform weighting and tapering: the amount depends on the uv-coverage and on the phase noise as a function of baseline lengths (1 to 3), but tapering also increases the synthesized beam size.

An equivalent way to look at noise in a map is by comparison to the single-dish sensitivity (given here for position switching)

$$\delta T_s = \frac{2T_{sys}}{\sqrt{\delta\nu\delta t}} \cdot \frac{1}{\sqrt{N_{pol}}} \quad (3)$$

which is typically $\delta T_s = 4.5$ mK in one hour (for a channel spacing of 0.625 MHz and a frequency below 110 GHz).

The mapping sensitivity is roughly related to δT_s by

$$\delta T_m = \frac{B^2}{(\theta_1\theta_2)\eta_j\eta_p\sqrt{N(N-1)}} \delta T_s \quad (4)$$

where B the size of the antenna primary beam. Then $\delta T_{CD} = 40\delta T_s$, $\delta T_{BC} = 190\delta T_s$, and $\delta T_{AB} = 590\delta T_s$. In practice, a source that is well detected but unresolved at the 30-m telescope can easily be imaged at the Plateau de Bure interferometer.

3 Array Operation

Since projects are spread over typically four months, the presence of visiting astronomers when their observations are scheduled is practically impossible to guarantee. In the course of observations and data processing, four “people” will play a role: the **observer**, i.e. any member of the team that proposed the observations, the **local contact**, the **on-duty astronomer**, an IRAM staff member present on the site, and the **array operator**. The **local contact** is an IRAM astronomer assigned to each project that does not have in in-house collaborator. His/her role is to help the **observer** in preparing the observations and in properly calibrating the data. In case of any problem, question, or doubt, the **observer** should contact his **local contact**. The **observer** can monitor the progress of his project on the web: <http://www.iram.fr/IRAMFR/PDB/ongoing.html>; this page is updated three times per day. Note that checking results obtained in a given configuration, making intermediate data reductions, etc. is not the responsibility of the **local contact**. In certain cases, and upon request, remote login to a VISITORS account on the Grenoble computers can be granted to the **observer** to help him in this task.

The array is regularly operated by one **operator** and one **on-duty astronomer**. The **operator** has responsibility for conducting all observations, following pre-established observing procedures or under the supervision of the **on-duty astronomer** in case of unanticipated events. **Operators** have also full authority for all safety measures. Receiver tuning is done by the **operator**. The **on-duty astronomer** must assess the data quality during the observations by monitoring the array performance on standard calibrators. The **observer** usually will not be present on the site, but is expected to come to Grenoble for data calibration, once his project is finished.

3.1 Observations

The observer must specify all aspects of his program in an observing procedure. This must include RF bandpass, atmospheric, and phase calibrations and appropriate time intervals. Standard observations can be made using the general, parametric procedures listed in Section 6.

The operator will execute the observing procedure, and the on-duty astronomer will monitor the data quality by examining the observations of phase calibration sources. In the case of peculiar observing conditions (high or exceptionally low phase drifts, calibrators too weak, etc.), the on-duty astronomer has full authority to modify the parameters of the observing procedures. He will, of course, try to consult with the `observer` or `local contact`.

Non-standard observations may require a specific arrangement with the `local contact` or `on-duty astronomer`.

3.2 Data Handling

Raw data, corresponding to individual dumps of the correlator buffers are not stored. Instead, a real-time job applies automatic calibrations (clipping corrections, atmospheric model, etc.) before writing on disk. This pre-calibrated data is archived daily, and sorted on a project by project basis.

Except for specific experiments, `observers` will only have access to the sorted data, which contains the source data and all the calibration measurements acquired by the observing procedure. `Observers` will have exclusive access to their data, but no exclusive rights over the calibration data, which are duplicated in special data files to monitor a posteriori the performance of the interferometer.

Off-line calibration (RF bandpass, phase, flux, and secondary amplitude calibration) is the `observer's` responsibility. It is also possible to recalibrate the data for atmospheric transmission and receiver temperature. Recalibrating the IF bandpass is not possible.

4 Documentation and Help

The Plateau de Bure interferometer is a complex instrument. Previous knowledge of interferometry is necessary to use it correctly, and reading a standard textbook for this field is highly recommended (e.g. Thompson, A.R., Moran, J.M., and Swenson, G.W., 1986 *Interferometry and Synthesis in Radio Astronomy*, John Wiley & Sons, Eds.) Information specific to the IRAM Plateau de Bure Interferometer (PdBI) is available in the following documents:

- PdBI: OBS Users Guide
In principle, only the `operator` (and occasionally the `on-duty astronomer`) directly use the OBS program to perform observations. However, a minimum knowledge of OBS is required to provide non-standard observing procedures.
- PdBI: CLIC Users Manual
Detailed documentation of the off-line calibration program. It assumes the user has previous knowledge of interferometry.
- GILDAS Users Manual:
Documentation of the mapping and display software. GILDAS is an image processing system with many capabilities, and the documentation assumes the user has a basic knowledge of image processing.

- PdBI: Frequency Setup:
A special purpose documentation describing some nasty details about the frequency setup of the Plateau de Bure interferometer.
- PdBI: Flux Measurements:
This documentation describes how fluxes of the strongest quasars are monitored at Plateau de Bure.
- PdBI: Atmospheric Calibration:
A general description of atmospheric transmission calibration, valid for both the 30-m and the 15-m antennas.
- PdBI: ASTRO Users Guide:
ASTRO is a graphic program to help planning observations. It is quite useful for complex observing programs such as series of snapshots on many sources.
- PdBI: Calibration Cookbook:
A hitch-hiker's guide to calibrating Plateau de Bure interferometer data with CLIC .
- PdBI: Mapping Cookbook:
A hitch-hiker's guide to produce and analyze images from the Plateau de Bure interferometer with the GILDAS software.
- PdBI: Trouble Shooting Guide:
A list of recipes and guidelines to find out why the interferometer is no longer working. In practice, reserved for operators or on-duty astronomers.

Although these manuals are updated relatively frequently, only the on-line help within the programs has the latest revisions.

5 Proposal Preparation

Because of peculiarities of the interferometer, proposals must be written with special care. Even at the proposal stage, it is of the utmost importance to provide the following parameters:

- A source list with accurate coordinates
- A source list with velocities and line width for spectral line observations
- Observing frequencies.
- Required spatial and spectral resolution, and estimate of required sensitivity.
- For special cases: Required accuracy of the bandpass calibration (e.g., a weak line on a strong continuum, high precision relative astrometry)
- Dates to be avoided during scheduling, because of sun avoidance (a circle of 45 degree radius), phase stability requirements (daytime is often useless in summer), or other reasons (specify).
- Any other stringent constraint (e.g. coordinated observations).

This information is absolutely required to decide the feasibility of the program, a prerequisite before the program committee can consider the proposal.

6 Observing Procedures

After a proposal has been accepted, observing procedures will have to be prepared. All choices have to be finalized. This implies some additional work with your local contact. Non standard observations may require an in-house collaborator.

The following procedure is a standard one which can be used for “normal” projects (full scale mapping on one object).

6.1 Setup Procedure

The standard setup configures the spectral correlator, selects the observing frequency, and leaves the system ready for receiver tuning.

```

!-----
!
! PR:SETUP-zzzz.OBS      ! Setup procedure for project "zzzz"
!
!   - Date:             Wed Dec 12 11:31:56 MET 2007
!   - Author:
!   - Loc Contact:
!   - Project:          zzzz
!   - Verified by:
!
!-----
! Do not edit directly, but copy first then
!
!   1: replace "zzzz" by the project number
!   2: enter the date and your name in the preamble
!
!   All lines marked !!! must be customized.
!   lines marked !* ! can be modified.
!
!-----
SET\END                ! Finish previous observation
@ PR:defaults          ! Restore defaults parameters
!
SET\PROJECT zzzz      !!! Specify project number for further
!
SYMBOL GO "@ PR:observe-all zzzz" !* ! data processing
CATA SOU INTER_BASE:iram.sou    !* !
CATA PHA INTER_BASE:phase-pdb.sou !* !
LET RECEIVER 1                !!! Choose observing receiver: receiver 1 @ 3mm
!                               receiver 2 @ 2mm
!                               receiver 3 @ 1mm
LET LOW_LIMIT 15.            !* ! Low elevation limit 15 degrees
SAY "Project 'PROJECT' starting" !
!
SYMBOL NAME "NNNN EQ 2000 00:00:00.00 00:00:00.00 LSR 0.0" !!! Source

```

```

!
LET N_SUBSCANS 45          !* ! Scan length (in seconds)
LET N_SCANS 30            !* ! Number of scans on SOURCE (22.5 minutes = 30*45sec)
LET N_SOURCES 1          !* ! use SYMBOL NAME if N_SOURCES.EQ.1
IF (N_SOURCES.GT.1) THEN
    !
    LET NAME_SOURCE[1:N_SOURCES]  ".." ".." !* Enter list of sources (maximum 20)
    LET N_SCANS_SOURCE[1:N_SOURCES] .. .. !* Enter time per source (in minutes)
ENDIF
!
LET CALIBRATOR_1 "....."    !**! 1st phase calibrator
LET CALIBRATOR_2 "....."    !**! 2nd phase calibrator
LET CALIBRATOR_3 "....."    !* ! 3rd phase calibrator (if necessary)
LET N_CALIBRATORS 2         !* ! Use 2 phase calibrators every N_SCANS
LET N_SUBS_CAL 45          !* ! Scan length on calibrator (in seconds)
LET N_SCANS_CAL 3          !* ! Nb scans on each calibrator (3 scans)

LET FSWI_CAL .FALSE.       !* ! No fast-switching by default

LET N_MOSAIC 0             !* ! No mosaic mode
IF (N_MOSAIC.NE.0) THEN
    DEFINE REAL X_MOSAIC[N_MOSAIC] Y_MOSAIC[N_MOSAIC] T_MOSAIC[N_MOSAIC] /GLOBAL
    LET X_MOSAIC .. ..      !* ! offsets in arcsec
    LET Y_MOSAIC .. ..      !* ! offsets in arcsec
    LET T_MOSAIC .. ..      !* ! in units of N_SUBSCANS
ENDIF
!
LET SOLVE_POINT YES
LET SOLVE_FOCUS YES
!
LET FOCUS_RECEIVER 'RECEIVER' !* ! Focusing on observing receiver
LET POINT_RECEIVER 'RECEIVER' !* ! Pointing on observing receiver
!
LET SOLVE_POLAR "B"        !* ! Solve point on Polar: B=both, V, or H
!
LET POINT_SOURCE_1 "....." !**! 1st pointing source
LET POINT_SOURCE_2 "....." !* ! 2nd pointing source
LET FOCUS_SOURCE_1 "....." !**! 1st focusing source
LET FOCUS_SOURCE_2 "....." !* ! 2nd focusing source
!
SET\UNLOCK
!
@ PR:spec-defaults        ! define standard correlator setup
!
NARROW Q3 Q3 /REC 'RECEIVER' !**! Define quarters to be connected to
!                          the two correlator inputs @ the chosen receiver band
!
SPECTRAL 1 20 600 /NARROW 1 /REC 'RECEIVER' !**! Define correlator configuration

```

```

SPECTRAL 2 320 300 /NARROW 1 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 3 320 600 /NARROW 1 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 4 320 900 /NARROW 1 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 5 20 600 /NARROW 2 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 6 320 300 /NARROW 2 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 7 320 600 /NARROW 2 /REC 'RECEIVER' !!! Define correlator configuration
SPECTRAL 8 320 900 /NARROW 2 /REC 'RECEIVER' !!! Define correlator configuration
!
LINE xxxx yyyy LSB LOW 6500 /REC 'RECEIVER' !!! Define observing frequency
!
IF (N_SOURCES.GT.1) THEN
  SOURCE 'NAME_SOURCE[1]' /TYPE OBJ
ELSE
  SOURCE 'NAME' /TYPE OBJ
ENDIF
!
LOAD /FREQUENCY ! Load frequency, but don't move antenna now
SET\RECE 'RECEIVER' /POLAR 'SOLVE_POLAR' ! Choose receiver band for the observation
!
SET\OBS
!
LET CHANGE_SPECTRAL .FALSE. !* ! .TRUE. if need to switch to broad_band
!
IF (CHANGE_SPECTRAL) THEN
  SPECTRAL /BROAD
ENDIF
!
SET SHOW OFF
! Make sure any changes in the spectral configuration will be detected:
SET\LOCK
!
TYPE PR:clean.obs
SAY "Project zzzz Type: Mapping / Category: 3mm, dual polarization" !!!
SAY " "
SAY " Tuning Receiver "'RECEIVER': LSB " !!!
SAY " "
!
! Insert here any other instructions to the operator/astronomer
!
SAY "Frequency sent, receivers may be tuned"
SAY "Execute all observations by typing GO"
SAY " "
SAY "Type END when project is finished"
SAY " "
SYMBOL PROCEED /INQUIRE "Type RETURN to remove this page: "
SET SHOW ON
!@ PR:check_cali zzzz 7 2 !!! prepare observing procedure to measure the

```

```

!   flux of the 7 closest calibrators from the
!   IRAM catalogue and the 2 closest ones the JVAS
!   Procedure will be executed only if the line
!   LET CALIBRATOR_1 "....." is left with dots.

```

All information appearing on lines marked **!!!** must have been supplied in the observing proposal, lines marked **!* !** will use default values if not specified. The remaining part of the procedure will be defined by IRAM personal (your **local contact**, usually). The project number (zzzz in this example) is assigned by IRAM when observing proposals are received.

After final checking by IRAM staff, this file will be given to the **operators**, together with a copy of the proposal and any accompanying information the **observer** may find useful. This small “dossier” will be updated by the **operator** and **on-duty astronomer** during observations, and a copy of it will be given to the **observer** when he visits Grenoble for data reduction after the project is completed. In particular, the **on-duty astronomer** will fill in a **NOTE file** that summarizes the individual conditions and particular problems encountered during each track observed. The **NOTE file** will provide some suggestions in cases where the data calibration is not straight-forward.

6.2 Phase Calibrator List

The current list of phase calibrators used at Plateau de Bure includes over 300 objects. Flux densities at 85 GHz flux are indicated in Jy. The flux density is followed by the spectral index, by the flux at 230 GHz if measured, or 0 if no measurement is available. The last column gives the date, at which the flux has been measured. Be careful: most if not all sources are variable (both flux and spectral index vary). All coordinates are equatorial J2000.0. Bandpass calibrators should be selected among the strongest phase calibrators, 4 Jy or more if possible, but even 0.5 Jy sources are sufficiently strong as phase calibrators.

The planets are not sufficiently point-like to be used as bandpass calibrators in any configuration.

To find phase calibrators for your source, use the **ASTRO** procedure name **PR:FIND_CALI.ASTRO**.

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