An Introduction to the IRAM Plateau de Bure Interferometer

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October 1, 1999

Version 3.5–00

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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 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.

Contents

1 Description

The Plateau de Bure interferometer is located in the South of the French Alps, near St Etienne en Dévoluy in the Département of 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

- Five antennas of 15-m diameter (Antenna 6 is under construction),
- one north-south track 232 m long (Extension to 410 m is under way),
- one almost east-west track 408 m long,
- a flexible spectral correlator, made of 6 independent units, with resolution ranging from 0.039 MHz to 2.5 MHz, and between 64 and 256 channels per baseline.
- two receivers per antenna: a 3mm receiver tunable between 80 and 115 GHz band, and a 1.3mm receiver tunable between 210 and 250 GHz.
- computers for real time acquisition and data processing.

The interferometer consists of five antennas that can be positioned on 30 stations arrayed along a "T" shaped track (see Figure 1). The north-south arm is 232 m long, and the almost east-west arm extends 216 m west and 192 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 of 60 μm rms. The antenna mounts incorporate self propelled transporters for moving the antennas along the tracks between stations. The antennas are equipped with dual-frequency receivers at 1.3 and 3 mm. The 3 mm SIS mixers cover the frequency range 81-115 GHz and have typical receiver noise temperature between 30 K and 50 K. The 1.3 mm SIS mixers cover the frequency range 208-250 GHz and have typical receiver noise temperature between 40 K and 60 K.

The receivers IF frequency is about 1.550 GHz, slightly variable by up to 50 MHz because one synthesizer is used to generate both the first and second local oscillator frequencies. For transmission through cables from the antennas to the correlator room, the signal is down converted to a 100-600 MHz baseband with the second local oscillator in each antenna. Additional oscillators (third LOs) select what section of the baseband is analyzed by the spectral correlator.

Six correlator units are available. Each unit is a totally independant, flexible entity, capable of processing 10 baselines (5 antennas). Full 2-bit sampling scheme is used to give 88 % efficiency. For details of the unit capabilities, see Section 5.2.

The receivers upper and lower sidebands are separated by the correlators using a phase switching technique. Rejections of better than 25 dB are obtained. The sideband gain ratio depends on receiver tuning, the ratio USB/LSB changing typically between < 0.01 and 5.0.

An HP J200 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. A second HP J200 workstation is available for offline data reduction with the CLIC calibration program, and data archive before transfer to Grenoble.

Each interferometer "configuration", the 5 antennas on given stations, simultaneously provides 10 baselines (or UV tracks). Since most projects will require more UV coverage than this, the

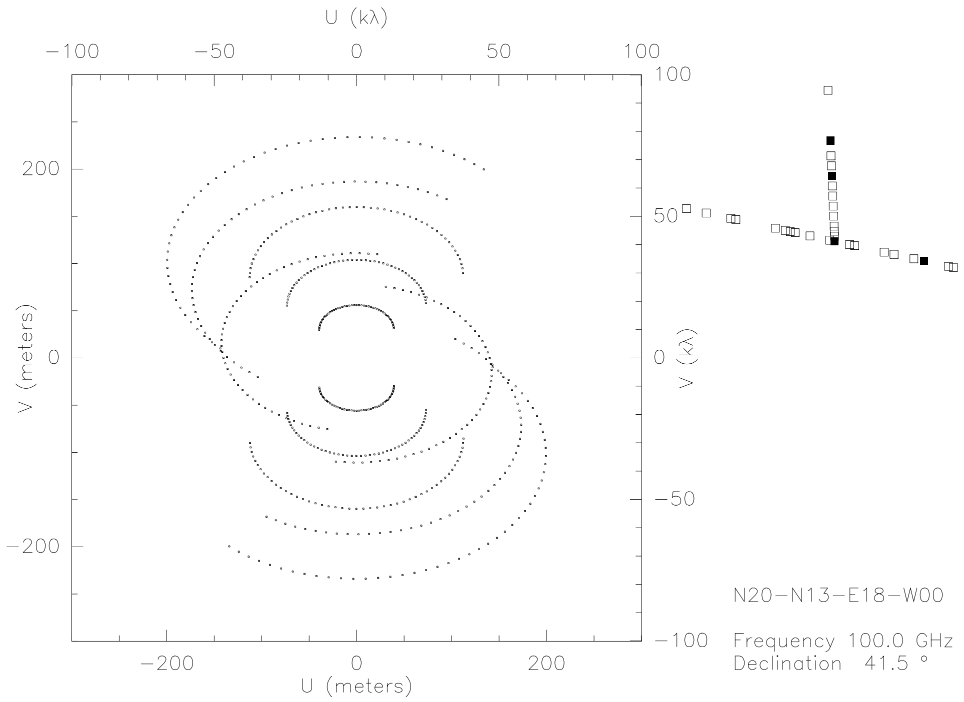

Figure 1: Example of UV coverage and interferometer station layout, as produced by the **ASTRO** `UV_TRACK` command.

interferometer is run with several (about ten) projects progressing in parallel. All active projects that require a given configuration will be observed before the antennas are moved. Depending on the weather, configurations are changed every two to three weeks, so a project that requires four configurations will take at least two months to complete.

2 Capabilities

2.1 Spatial Resolution

There are 6 primary configurations (see Table 1), which can be combined to produce 5 different angular resolutions.

The combinations, named AB, BC, CD and DD are reasonably suited for all declinations (see Table 1 to 5).

- **D** – the compact configuration with just the D array which yields a beamsize twice that of the CC configuration. The goal of this is to enable studies of CO(2–1) and CO(1–0) at virtually the same resolution.

- **CD** – the next most compact configuration which combines the C2 and D arrays. One 24 meter baseline is duplicated but the beam is generally quite circular. The pair C1 + D could also be used and yields a marginally lower resolution and less circular beam but has slightly lower sidelobes.

Configuration	Stations				
D	E03	W00	W05	N05	N09
C1	E10	W01	W05	N07	N13
C2	E10	W09	W12	N05	N15
B1	E23	E18	W12	N13	N20
B2	E12	W12	W23	N17	N29
A1	E24	E16	W23	W27	N29

Table 1: Plateau de Bure configurations with 5 antennas

- **CC** – a relatively compact configuration using the C1 and C2 arrays above and which gives a resolution similar to that of the "old" 4-antenna CD configuration, with marginally higher sensitivity (20 baselines instead of 18).
- **BC** – a combination of the B1 and C2 arrays which gives a resolution almost identical to that of the "old" 4-antenna BC array, with 4 less baselines. It is to be used for relatively strong sources.
- **BB** – the B1, B2, and C2 arrays are combined for a total of 30 baselines. This provides better sensitivity than the BC configuration.
- **AB** – the most extended configuration, made up of the A1, B1, and B2 arrays and which gives a resolution of $\sim 1.3''$ at 115 GHz. Several short baselines (32m, 40m, 56m, 64m) have been included to facilitate calibration (less decorrelation) and give some sensitivity to extended structure, although this is clearly not the primary goal of the AB configuration.

Mosaicing is usually done with D or CD, but the combination BC+D can also make sense for high resolution mosaics. Lower spatial resolution projects will usually not be considered given the limited field of view of the IRAM interferometer. The antenna beam size is 50" at 100 GHz and the shortest possible 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 30" are heavily resolved at 110 GHz.

Non imaging projects, such as detection experiments, size measurements, snapshots, etc., should use a subset of the standard configurations. This subset can either be specified by the observer, or left undefined until final scheduling if any configuration is appropriate (a detection experiment for example).

Table 2-5 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 are shown in Figure 2-4.

Beam sizes for configuration D							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	12.16	7.90	8.99	5.84	4.49	2.92	-173.
0	8.21	7.58	6.07	5.60	3.04	2.80	64.
20	7.99	6.40	5.91	4.73	2.95	2.37	-97.
40	8.01	6.13	5.92	4.53	2.96	2.27	-94.
60	7.97	6.32	5.89	4.67	2.95	2.33	267.
80	7.91	7.12	5.85	5.26	2.92	2.63	88.

Beam sizes for configuration CD							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	9.85	4.38	7.28	3.23	3.64	1.62	0.
0	6.20	4.57	4.59	3.38	2.29	1.69	2.
20	4.93	4.72	3.65	3.49	1.82	1.74	13.
40	4.93	4.46	3.65	3.30	1.82	1.65	89.
60	4.97	4.33	3.68	3.20	1.84	1.60	91.
80	5.00	4.64	3.69	3.43	1.85	1.71	92.

Beam sizes for configuration CC							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	8.09	3.37	5.98	2.49	2.99	1.24	6.
0	5.19	3.57	3.83	2.64	1.92	1.32	13.
20	4.20	3.65	3.10	2.70	1.55	1.35	32.
40	3.97	3.61	2.93	2.67	1.47	1.34	68.
60	3.94	3.51	2.91	2.59	1.46	1.30	-100.
80	3.94	3.69	2.91	2.73	1.46	1.36	86.

Beam sizes for configuration BC							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	6.46	2.03	4.78	1.50	2.39	.75	11.
0	4.16	2.16	3.07	1.59	1.54	.80	-159.
20	3.25	2.27	2.40	1.68	1.20	.84	30.
40	2.78	2.35	2.06	1.74	1.03	.87	44.
60	2.62	2.33	1.94	1.73	.97	.86	62.
80	2.57	2.42	1.90	1.79	.95	.90	75.

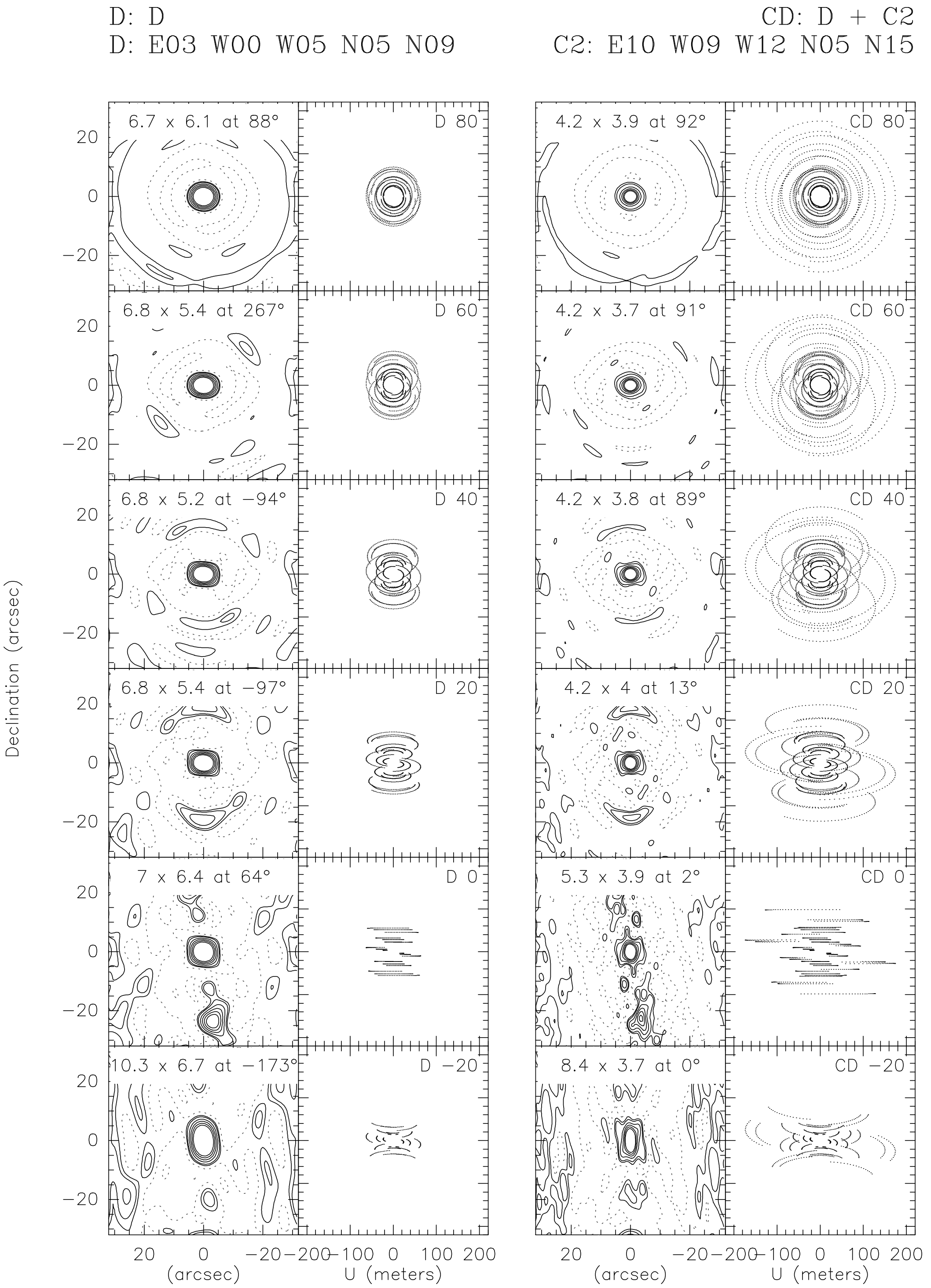

Figure 1: *uv*-plane coverage and beamshapes for the CD and D (5 antenna) configurations.

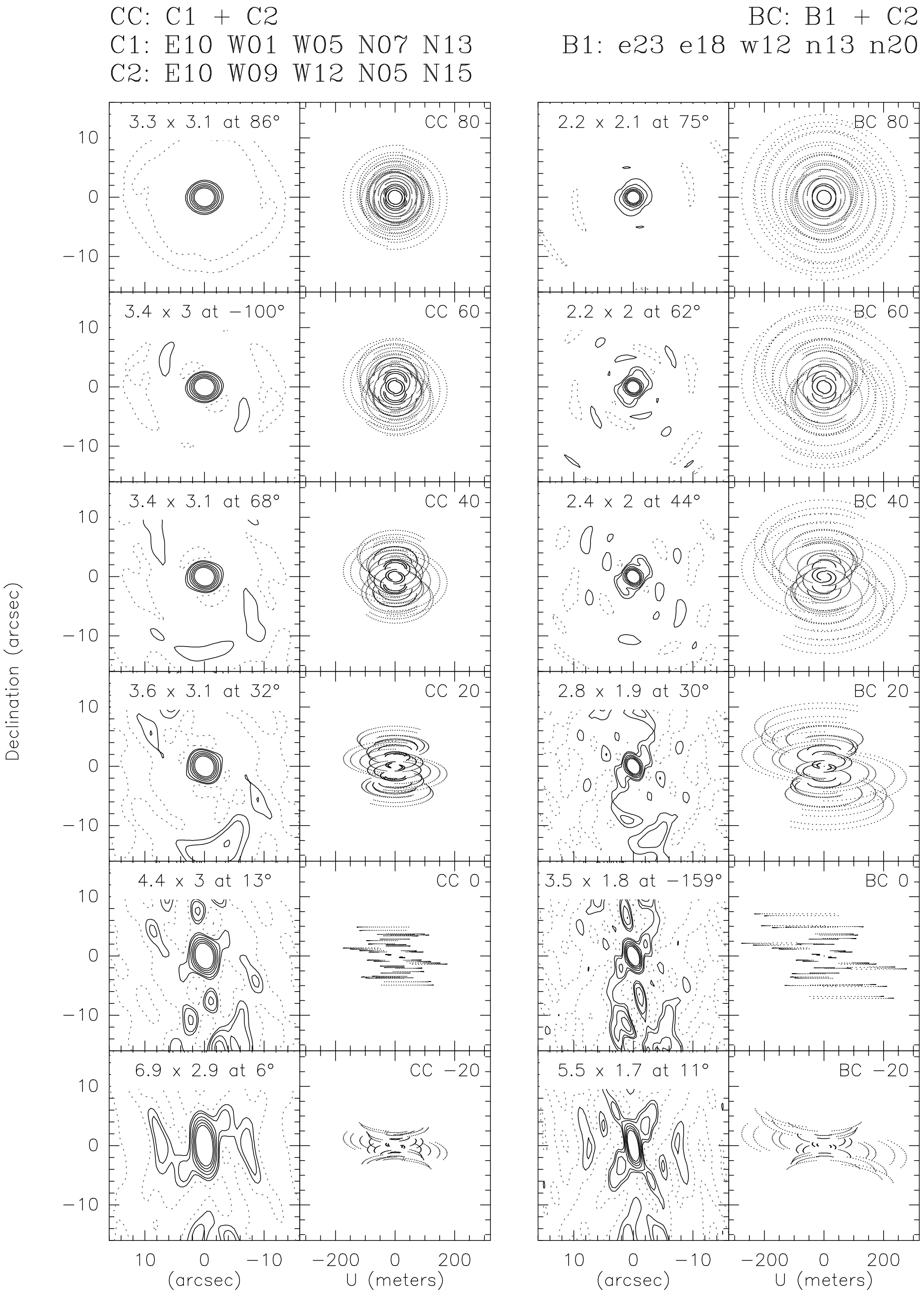

Figure 2: *uv*-plane coverage and beamshapes for the BC and CC (5 antenna) configurations.

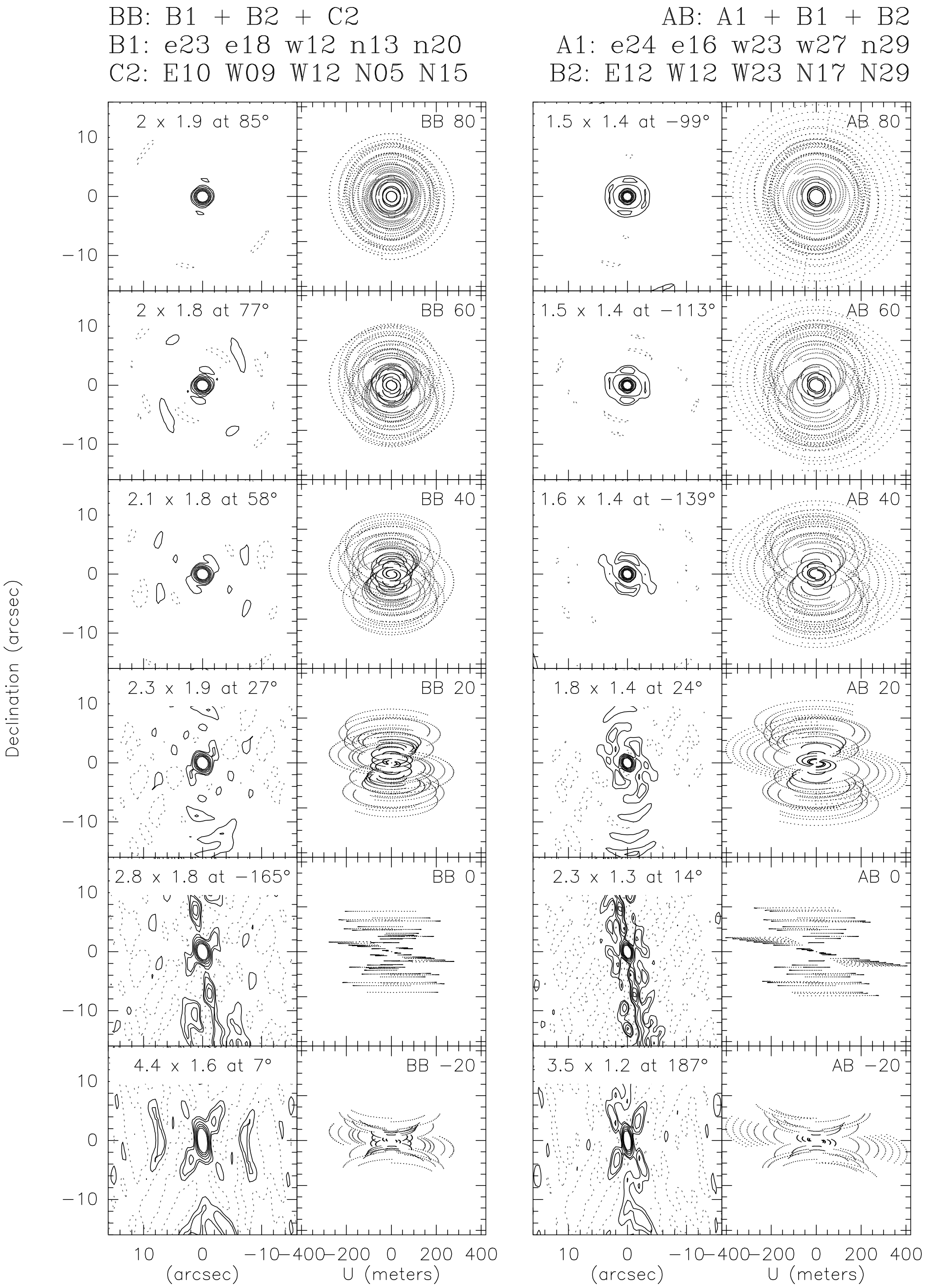

Figure 3: uv-plane coverage and beamshapes for the AB and BB (5 antenna) configurations.

Beam sizes for configuration BB							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	5.14	1.94	3.80	1.43	1.90	.72	7.
0	3.29	2.09	2.44	1.54	1.22	.77	-165.
20	2.66	2.19	1.96	1.62	.98	.81	27.
40	2.42	2.17	1.79	1.61	.89	.80	58.
60	2.35	2.10	1.74	1.55	.87	.78	77.
80	2.34	2.19	1.73	1.62	.86	.81	85.

Beam sizes for configuration AB							
Dec.	85 GHz		115 GHz		230 GHz		PA
	Maj.	Min.	Maj.	Min.	Maj.	Min.	
-20	4.14	1.42	3.06	1.05	1.53	.52	187.
0	2.75	1.54	2.03	1.14	1.02	.57	14.
20	2.12	1.63	1.57	1.21	.78	.60	24.
40	1.87	1.66	1.38	1.23	.69	.61	-139.
60	1.77	1.61	1.31	1.19	.65	.60	-113.
80	1.75	1.66	1.30	1.23	.65	.61	-99.

2.2 Spectral Resolution

The IRAM interferometer is equipped with 6 independent, nearly identical, correlator units. Each unit can be operated in four modes, as shown in Table 6. 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.

Each unit can be placed anywhere in the baseband (100-600 MHz), by steps of 0.625 MHz. All connections are remotely controlled by the **OBS** program. Because of channel shape, the effective resolution is slightly broader than the channel spacing (by about 1.3).

The spectral correlator configuration is selected with the **OBS** program, by command

```
OBS\SPECTRAL Unit Bandpass IF2_Frequency [/CONTINUUM Band_C IF2_C]
```

where
`Unit` is the correlator unit number (1 to 6)
`Bandpass` indicates the contiguous bandpass to be analyzed (in MHz: 10, 20, 40, 80 or 160).
`IF2_Frequency` is the center frequency of the bandpass analyzed by the correlator unit, in the second IF (100-600 MHz).

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 `IF2_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 6 units for a (presumably) typical project.

```
!     Covers the [ 60,220] IF band with pseudo-continuum of [110,210]
SPECTRAL 1 160 140/CONTINUUM 100 160/RECEIVER 1
```

Table 6

Mode	Bandwidth (MHz)	Channels	Spacing (MHz)
1	160	64	2.5
2	80	128	0.625
3	40	256	0.156
4	20	256	0.078
5	8	200	0.039

Note: Modes 1,2,3,4 are available on all units. Mode 5 is only available on unit 5.

```
!     Covers the [200,360] IF band with pseudo-continuum of [210,330]
SPECTRAL 2 160 280/CONTINUUM 120 270/RECEIVER 1
!     Covers the [340,500] IF band with default pseudo-continuum [350,490]
SPECTRAL 3 160 420 /RECEIVER 1
!     Covers the [480,640] IF band with pseudo-continuum of [490,590]
SPECTRAL 4 160 560/CONTINUUM 100 540/RECEIVER 1
!     Now samples a relatively narrow line centered at 340 MHz in the IF
SPECTRAL 5 20 340  /RECEIVER 1
!     And another one at 420
SPECTRAL 6 20 420  /RECEIVER 1
```

This configuration covers more than the full bandwidth of the receivers in broad-band mode, with some overlap at the band edges of the units. Not how the pseudo-continuum mode is selected to avoid the (presumably) strong line in the [330,350] MHz band.

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. Figure 5 gives another example of frequency coverage.

2.3 Sensitivity

2.3.1 Detection experiments

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

$$\delta S = \frac{\rho_e T_{sys}}{\eta_c \eta_p \eta_j \sqrt{N(N-1)}\sqrt{\delta\nu\delta t}} \tag{1}$$

where

- T_{sys} is the system temperature outside the atmosphere, i.e. corrected for atmospheric transmission (typically 150 K SSB below 110 GHz, but 250 K at 115 GHz, and 400 K at 230 GHz),
- 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 (25 Jy.K^{-1} at 85 GHz, 40 Jy.K^{-1} at 230 GHz),
- η_c is the correlator efficiency (0.88)
- 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

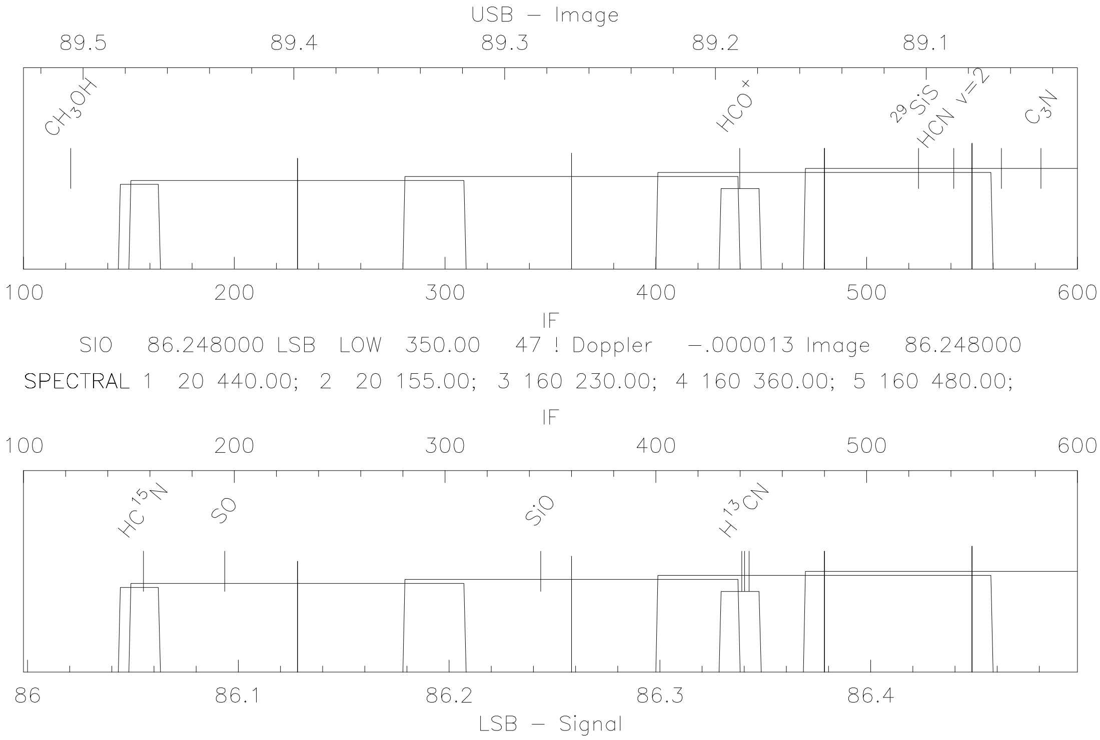

Figure 5: Example of spectral coverage, as produced by the **ASTRO** `LINE` as produced by the **ASTRO** `LINE` command.

- 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).

For the correlator, $\delta\nu$ is the noise equivalent bandwidth, equal to 1.87 times the channel separation; the effective channel width is 1.60 times the channel separation.

The instrumental phase jitter σ_j typically ranges between 10 and 25 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, ranging up to 60 degrees on the longest baseline under "not optimum" conditions (7 mm water vapor). 15 degrees is more typical for short (< 100 m) baselines.

With typical values for Plateau de Bure we find at 90 GHz $\delta S = 0.8$ mJy (best) to 2 mJy (worst) for a one hour integration. For a full synthesis (3 configurations, or 18 hours on source), this goes down to about 0.2 mJy. 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 3 to 6 mJy in one hour (0.8 mJy to 1.5 mJy in a complete synthesis).

2.3.2 Mapping

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

$$\delta T_m = \frac{\rho \lambda^2}{\theta_1 \theta_2} \delta S \tag{2}$$

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 $\delta T_{BC} = 0.35$ K and $\delta T_{CD} = 0.15$ K, for 0.625 MHz channel spacing with the spectral correlator, with the same assumption 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. Because the PdBI has few antennas, and hence poor UV coverage, uniform weighting is often useless.

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

$$\delta T_s = \frac{2 T_{sys}}{\eta_c \sqrt{\delta\nu \delta t}} \tag{3}$$

which is typically $\delta T_s = 12$ mK in one hour (for a channel spacing of 0.625 MHz).

The mapping sensitivity is roughly related to δT_s by

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

where B the size of the antenna primary beam. Then $\delta T_{CD} = 60 \delta T_s$, $\delta T_{BC} = 160 \delta T_s$, and $\delta T_{AB} = 360 \delta T_s$. In practice, a source that is well detected but unresolved at the 30-m telescope can be imaged at the Plateau de Bure interferometer.

3 Array Operation

Since projects are spread over typically two 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 `staff contact`, the `on-duty astronomer`, an IRAM staff member present on the site, and the array `operator`. The `staff contact` is an IRAM astronomer assigned to each project. His 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 `staff contact`. Note that monitoring the progress of a project (that is checking results obtained in a given configuration, making intermediate data reductions, etc.) is the responsibility of the `observer`, not of the `staff contact`. Facilities such as remote login to the Grenoble computers, fast shipping of data, faxes, or E-mail, will become available to help the `observer` 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 may (or even should) have a look at the data as soon as possible after the observations are performed.

3.1 Interferometer Setup

The physical setup of antennas onto stations is the responsibility of the operators and technical team. The astronomical setup of the interferometer involves a number of steps that are done **under the joint responsibility of the array operator and on-duty IRAM astronomer**. These include:

- Antenna Pointing: after a configuration change, the "minor" antenna pointing parameters (Azimuth axis inclinations and encoder zeros) must be redetermined. The operator makes the necessary observations and reduces the data using a standard procedure, with help from the on-duty astronomer if required. Both operator and on-duty astronomer must agree on the results before setting up the new parameters. Major pointing parameters (e.g. collimations) are monitored on longer time intervals (1 to 2 months) during dedicated test time, and should only be changed if approved by the IRAM astronomer responsible for antenna pointing (J. Wink or S. Guilloteau).

- Delay measurements: the zero delay (cable length difference after geometric path length compensation) is measured by the operator using a standard procedure.

- Baseline measurements: the accuracy of positioning an antenna on a station is of the order of 2 mm, insufficient for precise phase tracking. Actual baseline lengths are measured to a fraction of a mm by observations of point sources of known positions. As with antenna pointing, these observations and the associated data reduction are done by the operator and the result must be approved by the on-duty astronomer.

- Receiver tuning is done by the operator. The performance of the receiver (T_{sys} and image gain ratio) must be checked by the operator and on-duty astronomer before starting scientific observations.

- Focussing is also a joint responsibility of the operator and on-duty astronomer.

Only after all this setup is the array ready for astronomical observations.

3.2 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 5.

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 staff contact.

Non-standard observations (snapshots, etc.) may require the `observer` to be present on the site, or a specific arrangement with the `staff contact` or `on-duty astronomer`.

3.3 Data Handling

Raw data, corresponding to individual dumps of the correlator buffers every integration time (typically 1 minute) 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 later 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 calibrations measurements required by the observing procedure. `Observers` will have exclusive access to their data for a fixed amount of time (yet to be specified), but no exclusive rights over the calibration data, which are duplicated in special data files to monitor a posteriori the performance of the interferometer.

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

4 Documentation and Help

4.1 Documentation

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 calibration program. Although relatively complete, 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. To be read by any `observer` who wants to observe more than one spectral line simultaneously.
- PdBI: Flux Measurements:
  This documentation describes how fluxes of the strongest quasars are monitored at Plateau de Bure. Intermediate reports on the results are available on-line on the computers.
- 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 receipes 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.

4.2 Help

For more information, you will have to ask to somebody from the Grenoble or Bure staff. The Plateau de Bure staff includes

- Station Manager: Thierry Crouzet
- Cable car and infrastructure: Bernard Aubeuf, René Gontard, Henri Gontard, and Patrick Vibert
- Cooks: Muriel Schmidt, Eliane Barbagin and Jacqueline Grilli
- Maintenance: Iris Cervera, Thierry Crouzet, Alain Grosz, and Bernard Rossini

- Operators: Patrick Chaudet, Michel Dan, Sophie Léonardon, André Rambaud, and Didier Robert

In Grenoble, all astronomers are working with the interferometer. Astronomers with a special involvement in the interferometer are: Anne Dutrey (flux measurements), Stéphane Guilloteau (scientific coordinator), Robert Lucas (software development), Roberto Neri (scheduling), Jorn Wink (pointing).

Depending on your problem contact the following people (in priority order, for the mentioned area, people marked with a * are in Grenoble, others are at Bure):

- any question
  - your `staff contact`, the `on-duty astronomer`, or the `operator`. Ask the `operator` first if your are on the site, or your `staff contact` if you are reducing data in Grenoble.
  - if none of them can answer your question, one of the experts for the topics mentioned below.
  - if you cannot identify or find an expert, or if he was unable to answer your question, contact Stéphane Guilloteau* or Robert Lucas*, * as the last chance.
- Interferometer Infrastructure, Antennas: Thierry Crouzet, Iris Cervera, B
- Backends: Alain Grosz, Bernard Rossini, Marc Torres*
- Receivers: `operators`, Thierry Crouzet, Jacques Blondel*
- Computers: Alain Perrigouard*
- Observations: Roberto Neri*
- Data Calibration: Robert Lucas*
- Mapping: Stéphane Guilloteau*
- Data Handling, archive: Roberto Neri*
- Scheduling: Roberto Neri*
- Practical Life: at Bure, the operator or the cook, in Grenoble, the receptionist.

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 observation
- Observing frequencies, and especially the choice of USB or LSB receiver tuning. If only one line is to be observed, this choice may be postponed to select the optimum sensitivity according to receiver performance; this should be mentioned explicitely. If more than one line should be observed simultaneously, consult the "Frequency Setup" document for details.

- Required spatial and spectral resolution, and estimate of required sensitivity.
- The bandpass calibrator and two phase calibrators selected, if possible, from the standard IRAM list.
- Required dynamic range (spectral and spatial).
- 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 `staff contact`. Non standard observations may require a visit in Grenoble to prepare the observing procedure, or even participation in the observations.

The following procedures are standard ones which can be used for "normal" projects (full scale mapping on one object).

6.1 Definitions

The `PR:DEFINE.OBS` procedure contains all general definitions used in the setup, startup and observation procedure

```
! PR:DEFINE.OBS                Define general variables
!----------------------------------------------------------------------
DEFINE CHARACTER PROJECT*4/GLOBAL       ! Project name
DEFINE CHARACTER NAME*12/GLOBAL         ! source name
DEFINE CHARACTER CALIBRATOR_1*12/GLOBAL ! main calibrator
DEFINE CHARACTER CALIBRATOR_2*12/GLOBAL ! suppleant
DEFINE CHARACTER CALIBRATOR_B*12/GLOBAL ! Bandpass calibration
DEFINE REAL LOW_LIMIT/GLOBAL
DEFINE REAL LST_DEFLIM/GLOBAL           ! Default LST_DEFLIM
DEFINE INTEGER N_SCANS/GLOBAL           ! Number of scans on source
DEFINE INTEGER N_SUBSCANS/GLOBAL        ! Number of subscans per scan
DEFINE INTEGER N_DUMPS/GLOBAL           ! Number of dumps averaged
! Setup defaults
LET LOW_LIMIT 15.                       ! 15 degrees
LET LST_DEFLIM 12.                      ! 12 hours
LET N_SUBSCANS 240                      ! 4 minutes scans
LET N_SCANS 5                           ! 5x4 = 20 minutes on SOURCE
LET N_DUMPS 15                          ! 1 minute integration time
SYMBOL PC "@ PR:PHASE-CAL"              ! Phase calibration procedure
SYMBOL BC "@ PR:BAND-GAIN"              ! Bandpass & Gain calibration
```

```
SYMBOL LAST "@ PR:PHASE-LAST"           ! Last phase calibration
SYMBOL END "@ PR:END"                   ! Finish project
```

6.2 Setup Procedure

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

```
! PR:SETUP-A001.OBS  ! Setup procedure for project A001
!-----------------------------------------------------------------------
LET PROJECT = A001            ! Specify project number for further
SYMBOL GO "@ PR:OBSERVE A001" ! data processing
SIC\SAY "Project 'PROJECT' starting"
LET LOW_LIMIT 15.             !* ! Low elevation limit 15 degrees
LET NAME "CRL618"             !**! Source name
LET CALIBRATOR_B "3C84"       !**! RF Bandpass calibrator
LET CALIBRATOR_1 "3C84"       !**! 1st phase calibrator
LET CALIBRATOR_2 "NRAO150"    !**! 2nd phase calibrator
LET N_SUBSCANS 240            !* ! Scan length (in seconds)
LET N_SCANS 5                 !* ! Number of scans on SOURCE (5x4 = 20 minutes)
LET N_DUMPS 15                !* ! Number of subscans to be averaged for
!                                  data compression
!
! Define correlator configuration: standard continuum-mode for units 1-4
SPECTRAL 1 160 140/CONTINUUM 100 160    !* !
SPECTRAL 2 160 280                      !* !
SPECTRAL 3 160 420                      !* !
SPECTRAL 4 160 560/CONTINUUM 100 540    !* !
! Define correlator configuration: line(s) of interest for unit 5-6
SPECTRAL 5 80 350                       !**!
SPECTRAL 6 20 350                       !**!
!
LINE HCN 88.632 LSB LOW 350 46!**! Define observing frequency
SOURCE 'NAME' /TYPE OBJ       !
LOAD/FREQUENCY                ! Load frequency, but don't move antenna now
SAY "Frequency sent, receivers may be tuned"
SAY "Execute all observations by typing GO"
SAY "Type END when project is finished"
RETURN
```

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 `staff contact`, usually). The project number (A001 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 usefull. This small "dossier" will be updated by the `operator` and `on-duty astronomer` during observations, and a copy of it will be sent to the `observer` as soon as possible after a configuration has been used for a project (not only at project completion). The original will be kept at IRAM to prepare observations in the following configurations.

6.3 Startup procedure

Before starting observations, a check up is required to verify proper operation of the interferometer. Some additional calibrations are also required. Bandpass calibration (in phase and amplitude) of the receivers and correlators is necessary to improve the sensitivity and spectral dynamic range, and the receiver sideband gain ratio must be measured for correct spectral line calibration.

```
! PR:BAND-GAIN.OBS             ! Bandpass and Gain calibration procedure
!------------------------------------------------------------------------
SOURCE 'CALIBRATOR_B'/TYPE BAND
LOAD
BANDPASS       ! Make an IF Bandpass calibration first
FOR 1 TO 3
    CALIBRATE  ! Atmospheric transmission calibration
    GAIN       ! Cross correlation on source, allowing receiver sideband
               ! gain measurement and RF bandpass calibration
    PAUSE      ! Wait for input of new gain ratio, or QUIT if converged.
NEXT
```

Some projects may require more specific procedures here, such as taking a single-dish spectrum on the source, or checking the frequency setup on a reference source for spectral line observations.

6.4 Observing procedure

The procedure `PR:OBSERVE.OBS` is used to perform standard observations

```
! PR:OBSERVE Project_Number [LST_limit]
!
! Check the required project has been specified
IF (PROJECT.NE."&1") THEN
    SAY "Wrong project 'PROJECT', expected &1"
    RETURN
ENDIF
!
DEFINE CHARACTER ARG*12
LET ARG "&2"
IF (ARG.NE." ") THEN
    LET LST_LIMIT &2
ELSE
    LET LST_LIMIT LST()+12.
ENDIF
SOURCE 'NAME' /TYPE OBJ
IF (ELEV(0).LT.LOW_LIMIT) THEN
    SAY "Source not up, retry later"
    RETURN
```

```
ENDIF
IF (LST().GE.LST_LIMIT) THEN
    LET LST_LIMIT = LST_LIMIT+24.
ENDIF
!
SET INTEGRATION N_DUMPS
FOR/WHILE (ELEV(0).GE.LOW_LIMIT).AND.(LST().LE.LST_LIMIT)
! Normal phase calibration
    @ PR:PHASE-CAL
    SET SUB N_SUBSCANS
    SET SCAN N_SCANS
!
! Now Source observation
    SOURCE 'NAME' /TYPE OBJECT
    LOAD
    BANDPASS
    CALIBRATE
    START  ! Automatic loop of N_SCANS
NEXT
!
! Last phase calibration
@ PR:PHASE-LAST
! And says project is finished
@ PR:END
```

The procedure PR:PHASE-CAL.OBS is used to perform standard phase calibrations, selecting one of the two phase calibrators:

```
SOURCE 'CALIBRATOR_1' /TYPE PHASE
SET SUB 60
SET SCAN 4
IF (ELEV(0).GE.LOW_LIMIT).AND.(LST().LE.LST_LIMIT) THEN
    LOAD
    BANDPASS
    CALIBRATE
    START
ELSE
    SOURCE 'CALIBRATOR_2' /TYPE PHASE
    IF (ELEV(0).GE.LOW_LIMIT).AND.(LST().LE.LST_LIMIT) THEN
LOAD
BANDPASS
CALIBRATE
START
    ENDIF
ENDIF
SET SUB N_SUBSCANS
SET SCAN N_SCANS
```

The procedure PR:PHASE-LAST.OBS is similar, but does not check the time limit and accepts lower elevation:

```
SOURCE 'CALIBRATOR_1' /TYPE PHASE
SET SUB 60
SET SCAN 4
IF (ELEV(0).GE.LOW_LIMIT) THEN
    LOAD
    BANDPASS
    CALIBRATE
    START
ELSE
    SOURCE 'CALIBRATOR_2' /TYPE PHASE
    IF (ELEV(0).GE.5.0) THEN
        LOAD
        BANDPASS
        CALIBRATE
        START
    ENDIF
ENDIF
SET SUB N_SUBSCANS
SET SCAN N_SCANS
```

The procedure `PR:END.OBS` just notifies the system that the project is complete:

```
IF (PROJECT.NE." ") THEN
    NOTE "Project 'PROJECT' complete"
    DELETE/SYMBOL GO
    LET PROJECT " "
ENDIF
```

6.5 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 densitiy is followed by the spectral index or 0 if no measurement is available. 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 0.2 Jy sources are sufficiently strong as phase calibrator at 3mm. At 1.3mm, sources above 1 Jy should be preferred.

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`.