
IRAM 30-m Telescope Spectral Line On-The-Fly Mapping

Identifier - Master URL: <http://www.iram.es/OTF/HTML/sl-otf.html>

Revision: sl-otf ,v 2.1

Date: 1999-03-04

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Audience: 1) user community; 2) staff astronomers

Publisher: IRAM, Granada

Subject and Keywords: 30-m, documentation, observing, on-the-fly, SL-OTF, user-manual, cookbook

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Description - about this document:

This is an overview of the current Spectral-Line On-The-Fly (SL-OTF) capabilities at the IRAM 30M telescope. It can be used as a “cookbook” for SL-OTF observing and data reduction.

It is intended for staff and visiting astronomers at the 30M telescope. We assume that the reader is familiar with the usual observing procedures and data reduction software.

This cookbook should help to decide if SL-OTF is a suitable observing mode for a project; to estimate observing times; to prepare and carry out SL-OTF observations; and to process the data.

Related documents:

30-m Manual (PostScript file): http://www.iram.es/Telescope/manuals/manual_v10.ps

OBS Observer’s Guide to the IRAM 30-m Radiotelescope:

<http://www.iram.es/Telescope/manuals/Observ/OBS/obs.html>

OBSINP manual (PostScript file): <http://www.iram.es/Telescope/manuals/Guru/obsinp.ps>

Acknowledgements:

We would like to thank everybody who has encouraged and supported our work on SL-OTF for the IRAM 30M radio telescope; in particular J. Cernicharo, M. Guélin, J. Mangum, and D. Muders, who shared with us their ideas for SL-OTF and experiences with SL-OTF at other observatories.

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1 Spectral-line OTF: Introduction

1.1 Summary.

During Spectral-Line On-The-Fly observing (SL-OTF) the telescope beam moves across the source at a constant velocity, while data are taken (“dumped”) every 1 or 2 sec, depending on the backends and number of frequency channels. Any scanning direction can be chosen and maps can be built up line by line. Individual lines can have any length; they can be preceded and/or followed by OFF-source REFERENCE measurements. This observing mode can achieve a better homogeneity of the data and a more efficient use of observing time.

Up to 4 receivers can be used simultaneously in the usual combinations. The backends can be the filterbanks and/or the autocorrelators.

A new version of `class` is suitable for SL-OTF, but the software is not yet free of bugs and several desirable features are still missing.

We recommend that you consult or collaborate with an astronomer who has experience with SL-OTF observations at the 30M telescope if you want to choose this observing mode. *Please note on the proposal form, front page, “special requirements”, if you want to use SL-OTF.* David Teyssier at IRAM Granada (email: teyssier@iram.es) is the first local contact for help with SL-OTF observing. Other astronomers in the IRAM Granada group will also be glad to assist.

Please send your comments on this SL-OTF cookbook to Hans Ungerechts (email: ungerechts@iram.es) .

1.2 Description of the spectral-line on-the-fly (SL-OTF) observing mode

SL-OTF. During standard spectral line observations a radio telescope tracks one position on the sky while taking data. While moving from one position to the next, no data are taken. In spectral line OTF, like in many continuum observing modes, the telescope scans over the sky during data acquisition and the spectra are sampled quickly enough to get several samples in the time the telescope moves by one beamwidth. (Note: we call this shortest unit of data acquisition “dump”, the integration time spent for it “dump-time”.)

In SL-OTF the 30M telescope can move in any direction on the sky, but only at a constant velocity and with a fixed dump-time.

Advantages. The major advantage of SL-OTF is that dead times to move between ON source positions are eliminated. This improvement of the observing efficiency is particularly dramatic when short integration times per beam are used.

This makes it possible to map quickly and to acquire several complete coverages of the region to be mapped, rather than only one coverage with a longer integration time per position. Moreover, hundreds of ON-source OTF dumps can be taken per off-source REFERENCE, significantly decreasing the percentage of time spent integrating on REFERENCE. The necessary total integration time is then

built up by averaging complete maps. Consecutive map-coverages can be scanned in orthogonal directions to reduce mapping stripes.

REference and CALibration. OFF-source REference positions and OTF data taken ON-source can be subscans of one scan; normally REference data are taken before and after an OTF-subscan.

CALibration measurements (CAL COLD) are done in the standard way. The off-line data processing software, `otfcal`, calculates calibrated spectra from CALs, REFs, and for each ON source dump in the OTF-scan, using the same algorithm as for position-switching or raster mapping.

Positions. The commanded position of the telescope at the end of each dump is recorded and used by the processing software.

Recommendations. SL-OTF in its current form at the 30M telescope is generally suited to map lines that are fairly strong and not too broad. Regions to map can be from a few beamwidths up to several times 10 arc minutes — possibly by concatenating several maps each of size on the order of 10 arc minutes. SL-OTF is not recommended to observe very weak (let's say $< \text{a few } \times 100 \text{ mK}$) or very broad (let's say $> 100 \text{ km s}^{-1}$) lines, because of possible problems in the spectral baselines. For a project that requires the best possible spectral baselines, it is preferable to use Wobbler switching rather than SL-OTF. Some projects have, however, successfully used SL-OTF to observe narrower lines of only a few 100 mK, and others mapped lines of a few K spread over ≈ 100 to 250 km s^{-1} .

2 Spectral-line OTF: Overview

2.1 Telescope control of SL-OTF in OBS

SL-OTF observations are controlled by the new command `OTFMAP` in OBS, see Section A.1 for the full help text.

OTFMAP. Takes 1 OTF-scan, which may comprise several subscans, some of which can be off-source REference. Parameters are the length of each OTF subscan, the DumpTime, the scanning direction in the descriptive/basis system, the size of the OTF map, and the separation between OTF subscans. Moreover, one can specify the off-source REference position, the integration time on REference and the number of OTF subscans between REFs. With the normal command OFF-SET, the center of the OTF map can be specified as offsets from the nominal source position in the descriptive system specified in the source catalog.

Examples are in Section 3.4.

SET REF_FILE offsets.otf. It is possible to use several different off-source REference positions with one `OTFMAP`. In this case a list of these positions has to be in a file in the project directory (see Section 3.4 and Section A.1). This option and the file are selected with `SET REF_FILE`.

Note: ON-source OTF and OFF-source REF. You can take several OTF (sub)scans and use (some) dumps in one of them as ON source data and (some dumps in) another OTF-subscan as OFF-source REF data. You can even use some dumps in one OTF scan as ON source data and other dumps in the same OTF scan as OFF-source REF data. In terms of data taking and data format there is no actual difference between OTF REF and OTF ON: this is only determined in the data processing stage.

Note: Cascade-controller. For SL-OTF observations the “Cascade”-controller, also known as “I”-controller, must be used for the telescope tracking: check with the operator before starting observations. The “Basic”-controller does not achieve a sufficiently accurate tracking, in particular at the start of an OTF sub-scan.

Scan Direction. The OTF scans can be in any direction relative to the source. In particular it is therefore possible to make two coverages of the same region, scanned in orthogonal directions.

When working, e.g., in galactic coordinates l and b , the OTF scans can be specified to be along $+l$, $-l$, $+b$, or $-b$.

Descriptive Coordinates. More generally, the scanning coordinates can have any orientation relative to the *basis* system by defining a *descriptive coordinate system* in the source catalog (see OBSINP manual). Once a descriptive coordinate system (LAM, BET) has been defined, OTFMAP allows scans along +LAM, -LAM, +BET, -BET.

On the other hand, if no *descriptive system* has been specified in the source catalog, i.e., only one of the *basis* systems has been selected with SBAS= ... in the source catalog, then the *descriptive* and *basis* system are identical and all scanning directions (and offsets) are in the basis system.

Documentation for the definition of a *descriptive coordinate system* can be found in the OBSINP manual.

Notes. Information about the definition of the descriptive coordinate system—and about the OFF-source REFERENCE position(s)—is not (yet) stored in the `class` header. If descriptive coordinates are used during the observations, the position offsets in `class` headers are offsets in the descriptive coordinate system.

2.2 Tracking, times and speed

Tracking. The mean tracking errors in azimuth and elevation are generally small, $< 1''$, when moving the telescope with the speeds currently used for OTF (see “speed”, below). During one test we found that strong winds, $> 10 \text{ m s}^{-1}$, can lead to maximum tracking errors of about $2''$. Note that the latter value is of the same order as residual pointing errors and receiver alignment errors. The mean tracking errors of each dump are recorded in the raw data, but up to now not used by the software.

Dump Time. The shortest dump time is 1 sec, possible with the filterbanks and a limited number of autocorrelator channels. To use the full number of autocorrelator channels the dump time has to be 2 sec or longer. (compare Section 2.3).

Length. There is no software limit on the length of the OTF scans. The length of each ON-source OTF scan will generally be set so that there are no drifts in the system that are detrimental to the data quality. Of course, the maximum usable time depends on the criteria used to determine what are “good” data. At 3mm we have successfully used OTF scans of about 5–10 minutes with REFs taken before and after; however, baselines of higher order (2–3) may have to be fitted to some spectra. At 1.3mm such long OTF scans may suffer from baseline ripple; and shorter scans may be preferable.

Integration times. The integration time on each REF will typically be set to be much longer than the dump-time, following the usual \sqrt{n} -rule of thumb for RASTER mapping. If, e.g., the OTF scans have 225 dumps of 1 sec each, the REF integration time will be at least 15 sec. In this case the noise in the spectrum processed from each dump will be dominated by the noise in the ON source data. [NB: this simple rule-of-thumb should be modified accordingly if you know that a certain number of these dumps will be averaged during gridding.]

Speed. To avoid a “smearing” effect caused by the moving beam, several dumps are taken during the time that the telescope moves by one beamwidth, usually 3 dumps per beamwidth may be sufficient.

With a given dump time, this determines a speed:

$$\text{Speed} = \text{BeamWidth} / (\text{DumpsPerBeam} * \text{DumpTime})$$

and, with a length in time for the OTF scan, its length on the sky becomes:

$$\text{LengthOTF} = \text{Speed} * \text{TimeOTF}$$

Examples:

BeamWidth	=	24	24	12	12	" (arc seconds)
DumpsPerBeam	=	6	3	6	3	
DumpTime	=	1	1	1	1	sec
AnglePerDump	=	4	8	2	4	"
Speed	=	4	8	2	4	"/sec
TimeOTF	=	300	300	150	150	sec
LengthOTF	=	1200	2400	300	600	"

2.3 Receivers and backends

Receivers. Up to 4 receivers can be used simultaneously in the usual combinations.

Filterbanks. The 100 kHz filterbank and the 1 MHz filterbank can be used in any configuration with dump times of 1 sec or longer.

Autocorrelators. The autocorrelators can be used in any configuration with dump times of 2 sec or longer. This is longer than the minimum dump time with the filterbanks, because the current processor boards in the autocorrelators cannot perform their calculations, FFT and clipping correction, fast enough to allow shorter dumps.

Using the autocorrelators with a limited number of channels, dump times of 1 sec are possible. We have successfully used the autocorrelators in a configuration with 3 parts of ≈ 400 channels each and dump times of 1 sec.

Due to the large number of possible configurations for the autocorrelators we have only been able to test a few selected cases. If you want to use a particular configuration, contact IRAM/Granada. We may be able to test what is the shortest reliable dump time.

Notes. The same dump time is used for *all* backends.

The maximum total number of backend “parts” currently is 12; this limit is not specific to OTF.

2.4 Data and processing

Raw data. SL-OTF data are stored on a disk on the VAX in the usual raw data format. This disk must hold data from all active observing projects. Its capacity is sufficient for the current SL-OTF, because the data are copied to the HP work station. Normally at the end of each observing shift, the operator makes a backup of all raw data on the VAX, and removes them from the VAX disk. You can request that they are kept on the VAX for a day or two, so that there is sufficient time to check that they have been completely copied to the HP work station mrt-ux1 (see Section 3.5).

SL-OTF produces large amounts of data: if you use the maximum number of backends, expect about 0.3-0.5 Gbyte in 8 hours.

No real-time display. There is no real-time processing or display of SL-OTF data. The off-line data reduction on the HP work station mrt-ux1 is fast enough to see the data from an OTF scan shortly after taking the data, typically while the following OTF scan is being observed.

Data Processing. All processing of SL-OTF data is done off-line on HP work stations. Software and sufficient disk space are available on the HP work station mrt-ux1 at the observatory.

A new version of the CAL software, `otfcal`, is used off-line to process the raw data into calibrated spectra. A new version of the `class` software includes possibilities to view and process SL-OTF data. It also uses a new expanded data format for SL-OTF data. It includes a GRID command

to re-sample SL-OTF data onto a regular grid and to create an image file with a data cube in the standard GILDAS format.

Standard GILDAS software can then be used to further process and view the data.

2.5 Restrictions, limitations, known bugs, and problems (at this time, i.e., Fall of 1998)

No Frequency Switching, no Wobbler. The current SL-OTF mode works analogous to ON-OFF Position Switching. It can not be combined with Frequency Switching or Wobbler Switching.

No mapping in Horizontal Coordinates (Azimuth or Elevation). We have not yet tested SL-OTF mapping in Azimuth, i.e., at constant elevation as is common with the Bolometer. No software exists so far to transform SL-OTF maps from Horizontal Coordinates to celestial coordinates, e.g., R.A. and Decl.

No Doppler tracking. There is no Doppler-Tracking of the frequency during an OTF subscan. For a long OTF-subscan differences in the Doppler-correction between start and end of an OTF-subscan can amount to a few times 0.1 km s^{-1} . (The Doppler velocities are recorded for each dump, but up to now not used.)

Timing for Autocorrelator. There is currently no hardware timing for the dumps read out from the autocorrelator. In spite of this, tests indicate that the timing is sufficiently good for the current dump rates. (NB: This problem does not exist for the filterbanks.)

Problems in data quality. SL-OTF is subject to some of the same potential problems as position switching or raster mapping, in particular:

- “bad” channels in the filterbanks.
- “platforming” in the autocorrelator when the spectrum is covered by combining several sub-bands.
- “baseline ripple”, e.g., the ripple corresponding to reflections between the receiver and the subreflector. Spectra at 1.3mm are more often affected by baseline ripple than those at 3 mm and 2 mm.

No “real-time” display of data. Because of the large data acquisition rate it is impossible for the VAX computer to generate a real-time display of the spectra; in fact it can not calculate calibrated spectra from the raw data. However, the off-line processing on the HP work station is fast enough, so that the observer can produce plots of the calibrated spectra soon after the observations: usually one can process and look at data from one OTF scan while the next OTF scan is being observed.

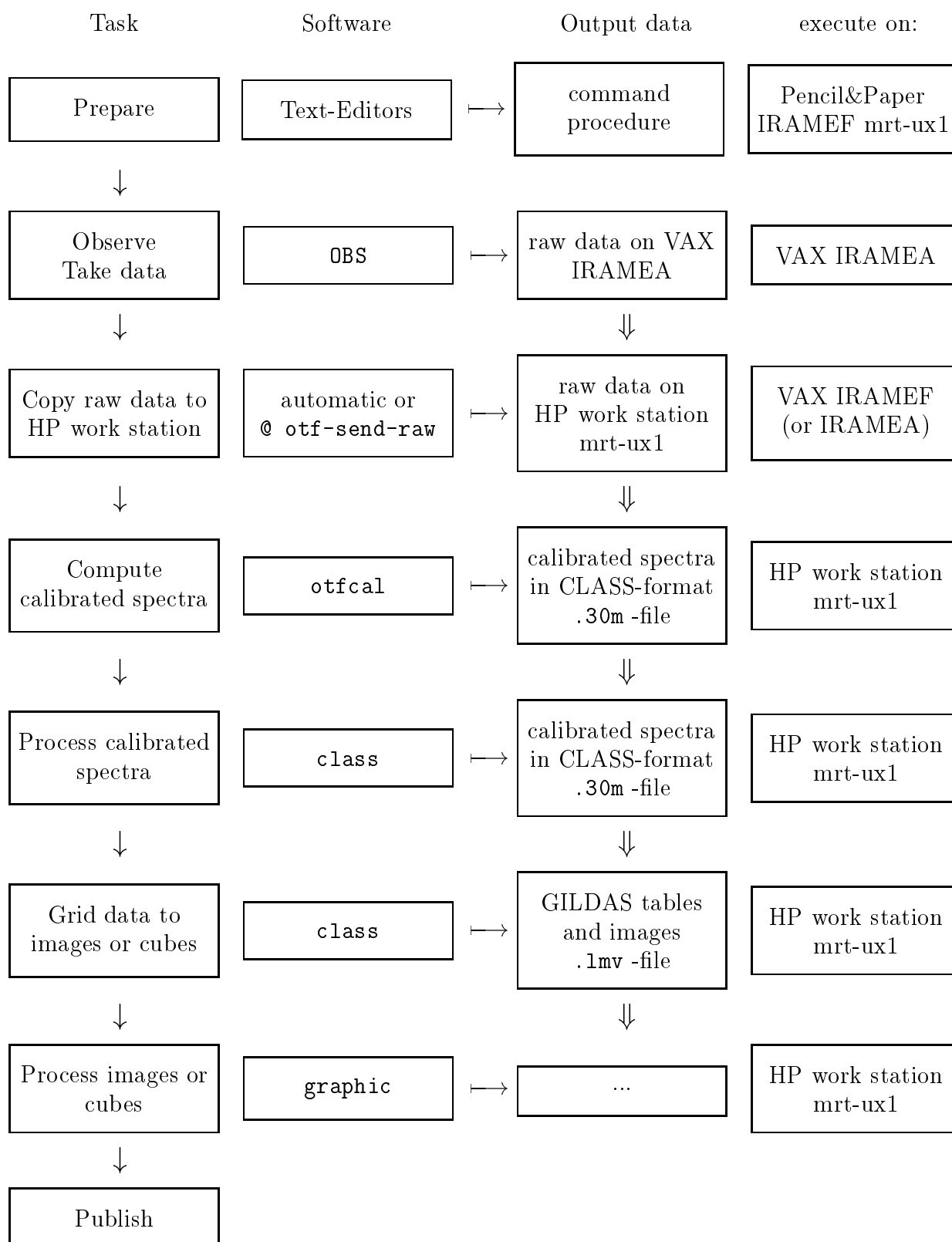
Data processing software.

- several `class` commands are not yet optimized for OTF scans.
- the software is not yet fully stable, i.e., crashes occasionally.
- there is no software correction for tracking errors, pointing errors, and receiver misalignment.
- there is no software implemented to convert SL-OTF maps from horizontal or descriptive coordinates to other coordinate systems.
- software methods to suppress mapping stripes is not yet implemented in the GILDAS software.

3 Spectral-line OTF: Recipes

3.1 Recipes: Overview

Overview. A typical sequence of tasks the observer has to execute for SL-OTF observations is sketched in the following diagram. The following (sub)sections explain some details and give examples.



3.2 Recipe: Noise and time estimates

Noise estimates. To compute the expected noise levels use the usual methods to estimate T_{sys} . If the integration time on the OFF-source REF position is much longer than the dump time, the noise per channel, Trms, in each dump will be approximately:

$$\text{Trms} = T_{\text{sys}} / \text{SQRT}(\text{NoiseBandWidth} * \text{DumpTime}) \text{ [*instrumentalFactors]}$$

Example:

```
Tsys           = 300    K
NoiseBandWidth = 1.4    MHz
DumpTime       = 1      sec
Trms           = 0.25   K
```

The noise in the final data cube will of course depend on how many dumps are taken per beamwidth and how the data are gridded (averaged). Keep in mind that some data with correlated noise may be averaged at this point.

Time estimates. SL-OTF eliminates a major source of dead-time: the time needed to move between ON source positions. This leaves the times for:

1. the ON-source OTF: $\text{TimeOTF} \sim \text{NumberOfDumps} * \text{DumpTime} (*1.02)$
(the factor 1.02 accounts for a slight overhead)
 2. the OFF-source REF: $\text{TimeREF} \sim \text{SQRT}(\text{NumberOfDumps}) * \text{DumpTime}$
 3. time to move between REF and start or end of OTF: TimeREFON
 4. time for CAL: TimeCAL
- (3 and 4 are the same as in normal RASTER mapping).

Example. For an observing cycle CAL-REF-OTF-REF, with an OTF scan of 300 sec and 300 dumps:

```
NumberOfDumps    = 300
DumpTime         = 1 sec
TimeCAL          ~ 60 sec
1/2 TimeREF      = 9 sec
TimeOTF          = 306 sec
1/2 TimeREF      = 9 sec
TimeREFON        = 30 sec (3*10 sec, estimate)
TimeTOTAL        = 414 sec
TimeTOTAL/TimeOTF = 1.38
```

$\text{TimeTOTAL}/\text{TimeOTF}$ is the ratio of the total time spent for the CAL-REF-OTF-REF cycle to the time taking data ON the source. Note that this ratio is significantly > 2 for simple Position Switching observations.

Of course, you have to add the usual times for startup, tuning, pointing, etc.

3.3 Recipe: Before Observing

Preparation. Options to plan before SL-OTF observations include:

- Receivers and backends to use; compare Section 2.3.
- Coordinate system to use; size and center of maps; direction of OTF scans; compare Section 2.1.
- Length in time (or speed) and dump time for OTF scans; compare Section 2.1 and Section 2.2.
- Sequence of CAL COLD, OFF-source REFERENCE and ON-source OTF.

Recommendations. These recommendations are based on our observing experience and following them has led to satisfactory results for several projects under good weather conditions and with stable receiver tunings. You may, however, find that they have to be modified substantially depending on your requirements.

- Use a restricted number of channels for the autocorrelator to allow a dump time of 1^{s} .
- Dump time as small as possible: 1^{s} or —if you need many autocorrelator channels— 2^{s} .
- Spacing between dumps (points) along a line in the map: at most $1/3$ beamwidth.
- Spacing between lines in the map: at most $1/2$ beamwidth.
- OFF-source REFERENCE before and after OTF; combine both REFs in the data processing.
- Use a REFERENCE position that is as close to the source as possible.
- Time of $\approx 300^{\text{s}}$ (or less) between OFF-source REFERENCE measurements for observations at 3 mm and 2 mm. Longer times may be possible under good conditions; shorter times may give better results, especially at 1.3 mm.
- Time between CAL COLD: as for normal measurements.
- Cover the region to be mapped at least twice, scanning in orthogonal directions.

Procedures. We recommend to prepare and use SIC command procedures for SL-OTF observations and data processing, to make efficient use of the possible flexibility. Some basic examples are discussed in the following sections. In general, of course, both the procedures for data taking (Section 3.4) and for data processing (Section 3.6) have to be edited and must describe the same sequence of CAL, REF and OTF.

3.4 Recipe: Observing

Preparation. Before OTF observations, do the usual steps:

- define source and line catalogs
- setup receivers
- point and focus
- setup backends, i.e., autocorrelator and/or filterbanks
- observe a calibration standard — probably in PSW
- check with the operator that the “Cascade” controller is active

OBS initialization procedure for SL-OTF. SL-OTF requires a few parameters to be set. Before any SL-OTF observations enter at the OBS prompt:

@ OTF-INI

The procedure `OTF-INI.PRO` is in your project account on the VAX. (NB: the contents of this procedure is not listed here and may change in the future.)

A typical sequence for OTF observations:

- CAL COLD calibration on the off-source REFERENCE position.
- OTFMAP scan with:
 - subscans on off-source REFERENCE
 - OTF subscans.

OBS procedure for SL-OTF. Here is an OBS procedure that will perform a CAL COLD and then an OTFMAP scan with off-source REFERENCE as well as OTF subscans. This example procedure `OTF-LAM.PRO` is in your project account on the VAX.

```
! *****
! Header: otf-lam.pro,v 1.2 99/02/25 15:27:25 ungerech Exp
! *****
! Usage:      in OBS:
!             @ OTF-LAM beta-offset
!
! Purpose: spectral-line on-the-fly mapping;
!           off-source REFERENCES and on-source OTF as subscans of one scan
```



```

!
! Sequence: CAL COLD          at offsets  -600"    600"
!       OTFMAP    centered at offsets  300"    &1"
!       OTFMAP    220"    long in scanning direction = +LAM
!                   40"    wide in orthogonal direction (BET)
!                   20"    interval between OTF subscans --> 3 OTF subscans
!                   110s   duration of each OTF subscan
!                   2s     duration of each OTF dump
!       -600" +600" offsets of REF position (also used for CAL)
!                   15s    integration time at REF
!                   3      on-source OTF subscans between REFs,
!                           i.e. subscan sequence: REF1-OTF1-OTF2-OTF3-REF2
!
! (optional: use several REF positions specified in file offsets.otf)
! *****
!
source your-source / cata your.cat    !! select source
!
define real beta_offset1              !!
!                                     !!
let beta_offset1 = &1                 !! parameter of procedure
exa beta_offset1                      !! = Beta offset center of OTF map
!
    set angle      seconds            !! all angles in arc seconds
    set offsets    basis              !!
!
    OFFSETS 300.0 beta_offset1 /basis  !! offsets for center of OTFMAP
!
!!SET REF_FILE  offsets.otf           !! (optional): name of file with
!                                     !! REF positions and times
!
OTFMAP      220  40  20-              !! length, size, interval for OTFMAP
/DIRECTION +LAM-                      !! scanning direction for OTF
/TIME       110   2-                  !! duration of each OTF-subscan and dump
/REFERENCE -600 600 DESCRIPTIVE-      !! offsets for CAL&REF
/RTIME      15-                       !! integration time on REF
/ON_OFF     3                          !! number of OTF-subscans between REFs
!                                     !! (i.e. REF at start and end of OTFMAP)
!
PAUSE " OK to do CAL COLD? [c/q]"
CAL COLD                             !! CAL COLD at /REFERENCE offsets above
!
PAUSE " OK to start OTF scan? [c/q]"
!!SET DOPPLERTRACK no                !! (optional) doppler correction fixed

```

```

SET FOCTRACK      no                !! keeps focus fixed during OTFMAP
START              !! start OTFMAP
!
BELL                !! sound a beep when finished
RETURN
!
! *****
! *****

```

To call this procedure enter at the OBS prompt, e.g.:

```
@ OTF-LAM -200
```

Notes on the example.

- All angles are in arc seconds.
- The parameter `beta_offset1 = &1` ($= -200$) specifies the BETa-offset of the center of the OTFMAP.
- The LAMbda-offset of the center of the OTFMAP is fixed at 300.
- The angular length of each OTF subscan along LAMbda is 220.
- The size of the OTFMAP in the orthogonal direction (BETa) is 40 and the separation between OTF subscans is 20 so there will be 3 OTF subscans.
- The first OTF subscan is in the direction +LAM .
- The time for each OTF subscan is 110 sec.
- The time for each OTF dump is 2 sec.
- The position offsets for CAL and REFs are fixed at $(-600, 600)$. Alternatively, one can use `SET REF_FILE offsets.otf` . In that case, off-source REFERENCE positions will be read from file `offsets.otf` (an example follows).
- The integration time for each REF is 15 sec.
- There are 3 OTF subscans between REF subscans; so the complete sequence of subscans is REF1-OTF1-OTF2-OTF3-REF2.
- `SET FOCTRACK NO` can help to decrease baseline ripples.
- LAMbda is the longitude in the descriptive/basis system. BETa is the latitude in the descriptive/basis system, see Section 2.1).

File with REF positions. It is possible to use several different positions for the OFF-source REF-erence subscans in an OTFMAP. They have to be specified in a file. The example file `OFFSETS.OTF` is in your project account on the VAX.

```
/ *****
/ Header: offsets.otf,v 1.2 99/02/25 15:28:35 ungerech Exp
/ *****
/ example for a file with REF positions
/ *****
/-----
/   off lam    ;   off bet ; rtim[s]
/ or off azm    ;   off elv    ; rtim[s]
/       -600"   ;       600"   ;   15           /first  ref
/       600"   ;       -600"   ;   15           /second ref
/-----
/ NOTES: after a / the rest of a line is interpreted as a comment
/       angle format as in the source catalogue (see OBSINP manual)
/       integration times are in seconds
/       there can be up to 20 lines in the REF-FILE
/ end of example
```

Notes on the example.

- To use positions in this file for off-source REFerence, specify `SET REF_FILE offsets.otf` at the OBS prompt.
- Each line (except comments) specifies LAMbda and BETa, and integration time (in seconds) for one off-source REFerence position.
- The off-source REFerence positions in the file are used cyclically, i.e. 1st, 2nd, ..., last, then 1st again, etc.

3.5 Recipe: Data

OTF Raw data. The Raw Data from SL-OTF observations are stored on a disk on the VAX IRAMEA. They are copied to a disk on the HP work station `mrt-ux1` where they can be processed into calibrated spectra and maps. If some data are not copied correctly, tell the operator. If you think there is a more serious problem with the automatic copying, inform the computer group.

OTF Raw data on the VAX. During observations, new Raw Data are stored on `MRT$NEW_DATA`: (sometimes the logical `MRT$NEW_DATA`: does not point to the correct directory; in this case look in `DATA: [RAWDATA]` or `DATA: [RAWDATB]`). (At the end of an observing shift you can

ask the operator to keep the Raw Data on the disk on the VAX. He will tell you in which directory they are kept, e.g., in `MRT$DATA:[A00]` . This gives you time to check that all Raw Data have completely arrived on the HP work station.)

After a few days the operator will delete the Raw Data on the VAX to make space for new observations.

OTF Raw data on the HP. On the HP work station `mrt-ux1` several hard disks are available to store SL-OTF data. Your project can have

a home directory `/vis_disk/nnn.yy/`;

a working directory for OTF `/vis_disk/nnn.yy/otf/`;

a directory `/mrt_data/nnn.yy/ryyyyymmdd/` for the Raw Data from each day;

and a directory `/tmp_data/nnn.yy/` for large data files.

(you may have to ask the operator or AOD to get write-access to

`/tmp_data/nnn.yy/` and `/mrt_data/nnn.yy/ryyyyymmdd/`.)

`nnn.yy` is the project number, `yy` & `yyyy` the year, `yyyymmdd` the date; e.g. `057_97` and `r19970716` for project 57-97 and raw data taken on 16-July-1997).

`/mrt_data/nnn.yy/` and its subdirectories `/mrt_data/nnn.yy/ryyyyymmdd/` are only for the Raw Data, `/tmp_data/nnn.yy/` only for large data files generated during the processing, i.e. the “.30m” files with the SL-OTF data. Files in `/mrt_data/nnn.yy/` and in `/tmp_data/nnn.yy/` will be deleted after an observing run to make space for new projects. Files in `/vis_disk/nnn.yy/` can be kept on disk for a few weeks after a project finishes. Observers should make their own backups of all their files.

Procedure to copy Raw data by ftp. We provide the following command procedure in case there is a serious problem with the automatic copying of the Raw Data from VAX to HP work station. It uses `ftp` to copy the data; it is fast and reliable, but not automatic. This example procedure is in your project directory on the VAX. We recommend to execute it from your project account on IRAMEF, i.e., the faster VAX.

```
$! *****
$!   Header: otf-send-raw.com,v 1.1 98/10/31 17:38:38 ungerech Exp
$!       send raw data files to HP by ftp
$! *****
$!  usage: at the VMS system prompt:
$!       @ OTF-SEND-RAW nscan
$!       SEND
$! *****
$!
$  send :=="ftp mrt-ux1/user=""v_nnn.yy""/passw=""password""/input=dummy.ftp
$!
$  set noon
$  delete    dummy.ftp;*
$  open  out dummy.ftp /write
$!
```

```

$ write out "image"
$ write out "case"
$ write out "cd /mrt_data/nnn_yy/ryyyyymmdd"
$ write out "send mrt$new_data:''p1' '*.*"
$!!!write out "send data:[rawdata]''p1' '*.*"
$!!!write out "send data:[rawdatb]''p1' '*.*"
$!!!write out "send mrt$data:[a00]''p1' '*.*"
$!!!write out "send          [.raw]''p1' '*.*"
$ write out "quit"
$ close out
$!
$      write sys$output " "
$      write sys$output "ftp command about to be executed: "
$      write sys$output " "
$      type dummy.ftp
$      write sys$output " "
$      write sys$output " enter SEND to send the files"
$! send
$!
$! *****
$! *****

```

To use enter at the VMS system prompt on IRAMEF (or on IRAMEA), e.g.:

```

@ OTF-SEND-RAW 341
SEND

```

Notes on procedure.

- The example will transfer the raw data files for all scans that have a scan number starting (alphabetically) with the digits 341, i.e., scans 3410 to 3419.
- For scan numbers below 1000 precede the scan number by a 0, e.g. for scan 123, say @ OTF-SEND-RAW 0123 .
- Replace `nnn_yy` by your project account, e.g., 057_97 .
- Replace `password` by your password on the HP work station mrt-ux1.
- Edit `ryyyyymmdd` so that `yyyymmdd` is the date of the observations, e.g., r19970716 .
- Check on the HP work station mrt-ux1 that the directory `/mrt_data/nnn_yy/ryyyyymmdd/` actually exists.
- Optional: uncomment the line `$! send` in the procedure, i.e., change it to `$ send` .

3.6 Recipe: Processing in otfcals

A new version of the CAL software, `otfcals`, is used to compute calibrated spectra from the raw data. The calibrated spectra are stored in a new extended `class` format. The processing from Raw Data to calibrated OTF spectra is done on the HP work station `mrt-ux1` working in directory `/vis_disk/nnn_yy/otf/`, where `nnn_yy` is the project number.

Preparation.

- Log in on the HP work station `mrt-ux1` under your project account.
- `cd /vis_disk/nnn_yy/otf/`
- `otfcals`
- `@ ini.otf` to start up, see below.
- `@ do-ss ...` for each OTF-subscan and backend, see below.

Startup commands for otfcals. This example procedure is on the HP work station `mrt-ux1` in your directory `/vis_disk/nnn_yy/otf/`.

```
! *****
! Header: ini.otf,v 1.2 99/02/25 15:31:40 ungerech Exp
! *****
! Usage:   in otfcals:
!          @ ini.otf
! *****
!
SET PLOT    H
SET FORMAT  F
SET CHAR    0.5
!
LAS\SET ANGLE S
!
sic        extension otf                !! default extension is cal
las\set extension 30m                  !!
!
shell "du -s    /mrt_data/nnn_yy/r*"    !! any raw data directories?
!
cal\directory "/mrt_data/nnn_yy/ryyyyymmdd/" !! specify directory
cal\show directory                      !! with raw data
!
file out "/tmp_data/nnn_yy/otf.30m" new  !! open new outputfile
```

```

!                                     !! in area for big data files
!
RETURN
! *****
! *****

```

Notes.

- Replace `nnn_yy` by your project number.
- Edit `ryyyyymmdd` so that `yyyymmdd` is the date of the observations.

otfcal Procedure for REFs and OTFs in one OTFMAP scan This procedure processes one CAL COLD scan and one OTF-subscan with 2 off-source REFERENCE subscans. The example procedure is on the HP work station mrt-ux1 in your directory `/vis_disk/nnn_yy/otf/`.

```

! *****
! Header: do-ss.otf,v 1.2 98/10/31 20:31:16 ungerech Exp
! *****
! usage:  in otfcal:
!         @ do-ss          be_code fly_scan ref_subscan1 fly_subscan ref_subscan2
! *****
!
define integer be_code fly_scan ref_subscan1 fly_subscan ref_subscan2
define integer          cal_scan
!
let be_code      = &1      !! =2: process 100khz, =3: 1MHz, =4: Autocorrelator
let fly_scan     = &2      !! number of OTFMAP scan with REF and OTF subscans
let ref_subscan1 = &3      !! subscan number of 1st off-source REFERENCE
let fly_subscan  = &4      !! subscan number of          on-source on-the-fly
let ref_subscan2 = &5      !! subscan number of 2nd off-source REFERENCE
!
exa be_code
exa fly_scan
exa ref_subscan1
exa fly_subscan
exa ref_subscan2
let cal_scan = fly_scan-1                !! scan # CAL COLD
exa cal_scan          !!
!
PAUSE " OK to go? [c/q] "
!
say " CAL COLD: SCAN "'cal_scan'
cal\cal cal_scan COLD      !! process CAL COLD

```

```

!
say " REF1: SCAN "'fly_scan' "subscan "'ref_subscan1'
cal\scan      fly_scan                      !! load 1st REF
cal\subscan ref_subscan1 /off 1              !! as ''OFF1''
say " REF2: SCAN "'fly_scan' "subscan "'ref_subscan2'
cal\scan      fly_scan NORESET              !! load 2nd REF
cal\subscan ref_subscan2 /off 2              !! as ''OFF2''
!
say " FLY : SCAN "'fly_scan' "subscan "'fly_subscan'
scan fly_scan NORESET
!
if (be_code.EQ.2) then
  say " 100khz:          "                  !! for 100khz
  cal\fly fly_subscan 100khz 999 /write /inter total  !! OTF subscan
endif
if (be_code.EQ.3) then
  say " 1MHz:           "                  !! for 1MHz
  cal\fly fly_subscan 1MHz 999 /write /inter total  !! OTF subscan
endif
if (be_code.EQ.4) then
  say " Autocorrelator: "                  !! for Autocorrelator
  cal\fly fly_subscan Auto 999 /write /inter total  !! OTF subscan
endif
!
RETURN
!
! *****
! *****

```

To use this procedure, enter in `otfcal`, e.g.:

```
@ do-ss.otf 4 5555 1 2 3
```

Notes.

- Parameter1: `be_code` = &1 = 4 selects backend to process.
- Parameter2: `fly_scan` = &2 = 5555 scan number of the OTF scan.
- Parameter3: `ref_subscan1` = &3 = 1 subscan number of the 1st REF.
- Parameter4: `fly_subscan` = &4 = 2 subscan number of the OTF.
- Parameter5: `ref_subscan2` = &5 = 3 subscan number of the 2nd REF.
- The procedure assumes the observing sequence: CAL COLD scan followed by OTFMAP scan with off-source REFerence and OTF subscans.

- Two REference subscans are used: the option `/inter total` of command `cal\fly` means that an interpolation between them is done to match the ON-source (OTF) and OFF-source (REF) power levels. This usually gives baseline levels close to zero.

3.7 Recipe: processing in class and gridding

The `class` software is used to process calibrated SL-OTF data, i.e., the output from `otfcal`.

Preparation.

- Log in on `mrt-ux1` under your project account.
- `cd /vis_disk/nnn_yy/otf/`
- `class`
- `file` in `"/tmp_data/nnn_yy/otf.30m"` to open a `class` file.

Processing. SL-OTF spectra generated with the `otfcal` procedure above, i.e., using the option `/inter total` of command `cal\fly` are often sufficiently good to be gridded directly into maps for a quick first look. In general, however, the data will be further processed in `class` before gridding. In particular:

- Subtract spectral baselines.
- Kill bad channels.
- Suppress baseline ripple.

Several `class` commands, e.g., `PLOT/SCAN`, `BASELINE`, `FFT`, have been rewritten to work efficiently on SL-OTF data.

class Procedure for gridding This example procedure is on the HP work station `mrt-ux1` in your directory `/vis_disk/nnn_yy/otf/`.

```
! *****
! Header: do-otf-grid-tdv.class,v 1.1 99/02/24 15:28:56 ungerech Exp
! *****
! usage:   in otfcal or class:
!          @ do-otf-grid-tdv name-of-your-map from_velocity to_velocity
! *****
!
define character fname*80                                !! name of output map
```

```

define real      from_velocity to_velocity
!
let fname        = &1                !! name of output map
let from_velocity = &2                !! from velocity
let to_velocity  = &3                !! to   velocity
!
say " ''fname'
say " grid integral from  ''from_velocity' to  ''to_velocity'
!
    PAUSE  " OK [y/q]? "
!
!
!                                !! grid integ. intens.
    grid 'fname' new tdv('from_velocity','to_velocity') /image -
beam 12 lam  37  37 -180  -10 bet  37 1 -180  10    !! specify grid
!
shell "ls -l *.lmv          "          !! list .lmv files
!
!
RETURN
!
! *****
! *****

```

To use this procedure, enter at the class prompt, e.g.:

```
@ do-otf-grid-tdv.class name-of-your-map -10 4
```

Notes on the example procedure.

- The first parameter `&1 = fname` specifies the name of the new image; extension: `.lmv`
- This procedure produces a map, i.e., a GILDAS image, of intensity integrated over velocity, for the velocity interval from `&2 = from_velocity` to `&3 = to_velocity`
- All the spectra in the current index (result of `FIND`) will be gridded.
- Instead of specifying the grid parameters, you can let the software pick reasonable defaults.

4 Spectral-line OTF: Results, experience

4.1 Examples, data quality and noise

OTF scans. In this section we have collected some results from SL-OTF observations. All examples were taken with the “old” receivers, i.e., before the major refurbishment of the receiver cabin in the summer of 1998.

Typical OTF data of good quality are in Figure 1. Note that each of the individual spectra has an on-source integration time of only 2^s.

OTF scans with baseline problems. Sometimes spectra observed in the same mode suffer from poor spectral baselines (Figure 2). Such baseline problems occur most easily in the 1.3 mm band, and can be worse than shown here. As the lines in this galactic cloud are rather strong and narrow, we found these data useful despite the baseline ripple. The amplitude of the baseline ripple tends to be smaller for smaller power offsets between off-source REFERENCE and ON-source. SET FOCTRACK NO can often help to decrease the baseline ripples.

Noise along an OTF-scan. The r.m.s. noise in OTF-scans of good quality does not vary during the scan and is consistent with noise estimates that assume an integration time on the off-source REFERENCE large compared to that per dump ON-source (Figure 3). [The variation of the power level is caused by drifts in the “old” receiver and in the atmosphere.]

Averaging OTF dumps. The data in different dumps of a single SL-OTF scan are NOT statistically independent because they share the same off-source REFERENCE. Only a limited number of dumps can be averaged before the noise contribution from the off-source REFERENCE becomes significant. For example, for the data shown before in Figure 3, only fewer than 10 dumps should be averaged (Figure 4).

Averaging OTF scans. Data in OTF-scans observed independently, i.e., with separate CAL COLD and REFERENCES, should be statistically independent. Indeed, when averaging n OTF scans of good quality, the rms drops approximately with $1/\sqrt{n}$ (Figure 5). The variations of the data points from the theoretical line are caused by variations in T_{sys} — the data averaged here were observed on several days.

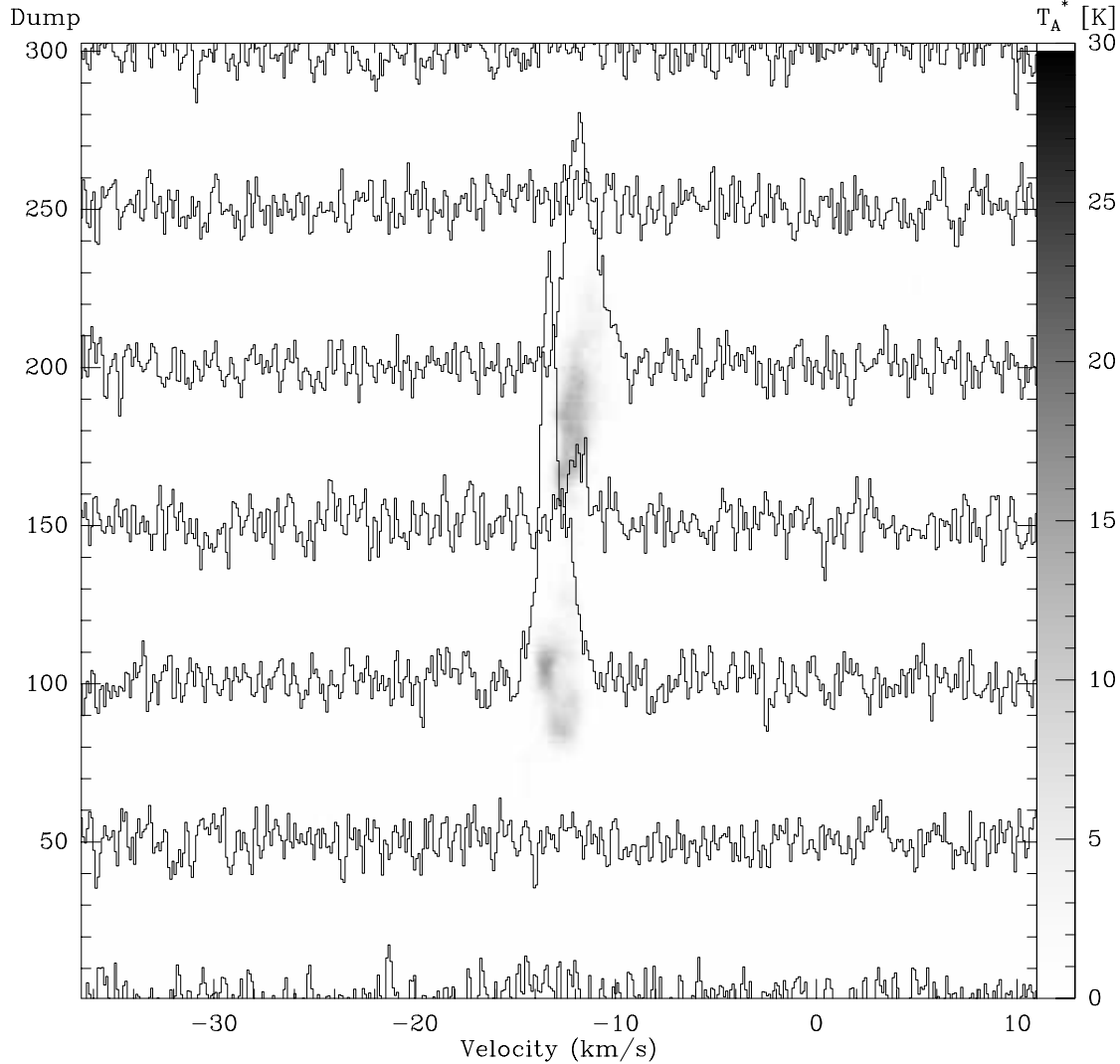
Based on this plot one expects that the noise level in SL-OTF data can indeed be decreased by averaging independent measurements. This is consistent with observations where 2–4 complete OTF maps were averaged — or gridded into one data cube. However, up to now there have not actually been any projects repeating a map on the order of 10 to 100 times and averaging.

It is not clear if averaging data from independent observations can similarly “improve” data that suffer from baseline ripple or other problems.

4.2 Sample OTF maps

Some typical maps observed using the SL-OTF mode at the 30M telescope are shown on our SL-OTF web page: <http://www.iram.es/OTF/otf.html>

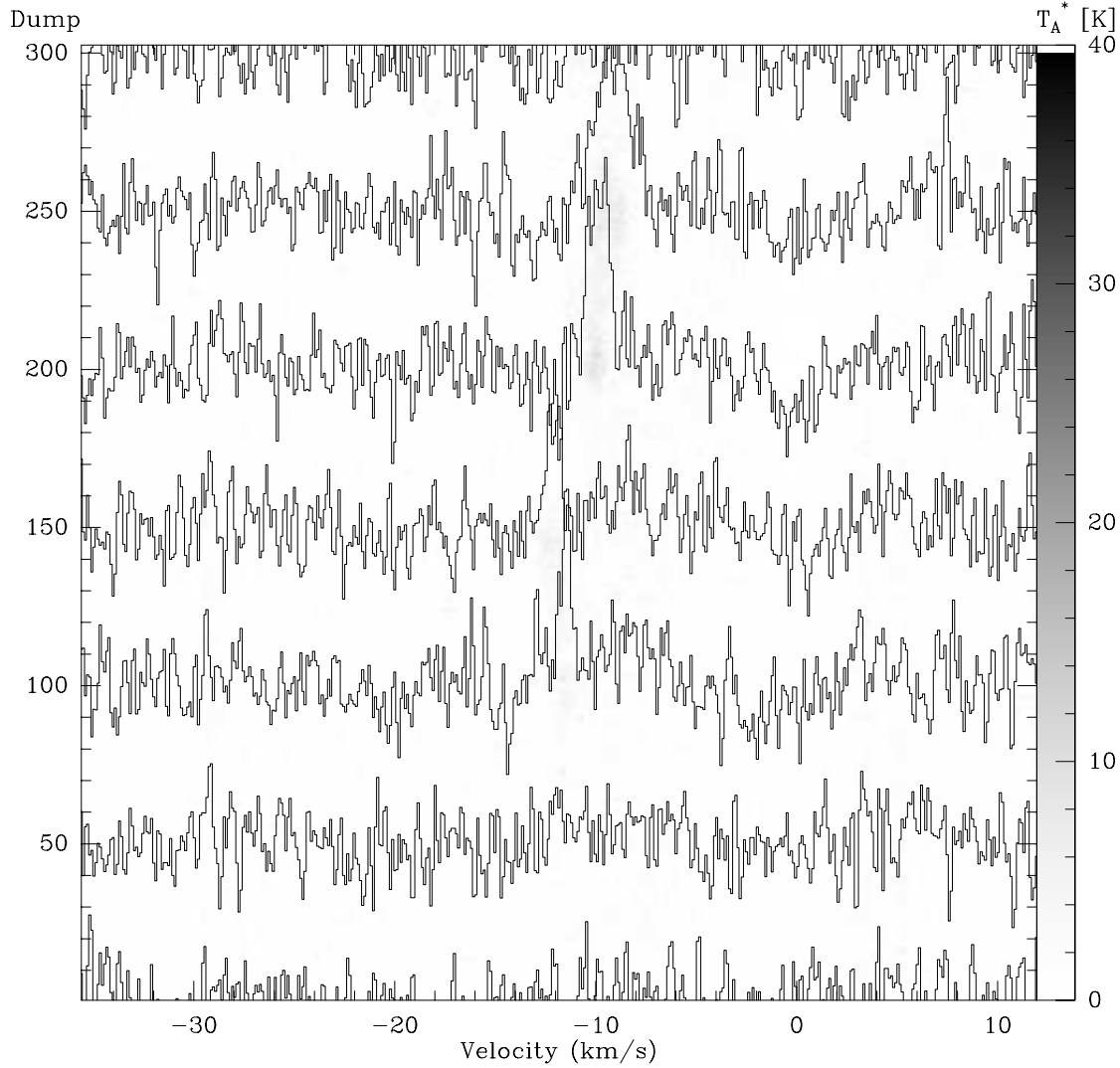
43452; 5 CEP-B 13CO(1-0) IRAM-30M-B43 O: 16-OCT-1997 R: 22-OCT-1997
RA: 22:55:08.703 DEC: 62:21:30.01 (1950.0) Offs: +896.100 -70.000 Eq
Unknown Tau: .1115 Tsys: 172.7 Time: 3.3333E-02 El: 52.03
N: 448 IO: 216.8 VO: -12.00 Dv: -.1065 Unkn
F0: 110201.370 Df: 3.9063E-02 Fi: 112777.939
B ef: .9200 F ef: .9200 G im: 1.0000E-03
H2O : 5.429 Pamb: 706.3 Tamb: 278.2 Tchop: 295.8 Tcold: 81.0
Tatm: 262.7 Tau: .1115 Tatm i: 260.7 Tau i: .1523
8806



17-FEB-1998 UNGERECH plot scan example.class

Figure 1: Typical spectra from an OTF-scan of good quality. Individual spectra for every 50th dump; grey-scale: intensity as a function of velocity and number of the dump/record. Observations with the 3MM2 receiver and the autocorrelator. Each OTF scan had 303 dumps of 2^s integration time. An off-source REfERENCE at offsets $(-600'', 600'')$ was observed for 30^s before and after the OTF-scan. Linear baseline subtracted from each spectrum, i.e., dump. (This plot was made in `class` using commands `PLOT/SCAN`, `RECORD`, `SPECTRUM`)

45408; 4 CEP-B 13CO(2-1) IRAM-30M-B45 O: 24-JUN-1997 R: 2-SEP-1997
 RA: 22:55:08.703 DEC: 62:21:30.01 (1950.0) Offs: -292.200 -415.000 Eq
 Unknown Tau: .2516 Tsys: 563.9 Time: 3.3333E-02 El: 47.33
 N: 449 IO: 226.6 VO: -12.00 Dv: -.1061 Unkn
 F0: 220654.686 Df: 7.8125E-02 Fi: 228657.710
 B ef: .8600 F ef: .8600 G im: 3.2000E-02
 H2O : 4.270 Pamb: 708.4 Tamb: 280.1 Tchop: 292.9 Tcold: 77.0
 Tatm: 266.3 Tau: .2516 Tatm i: 266.2 Tau i: .2656
 4108



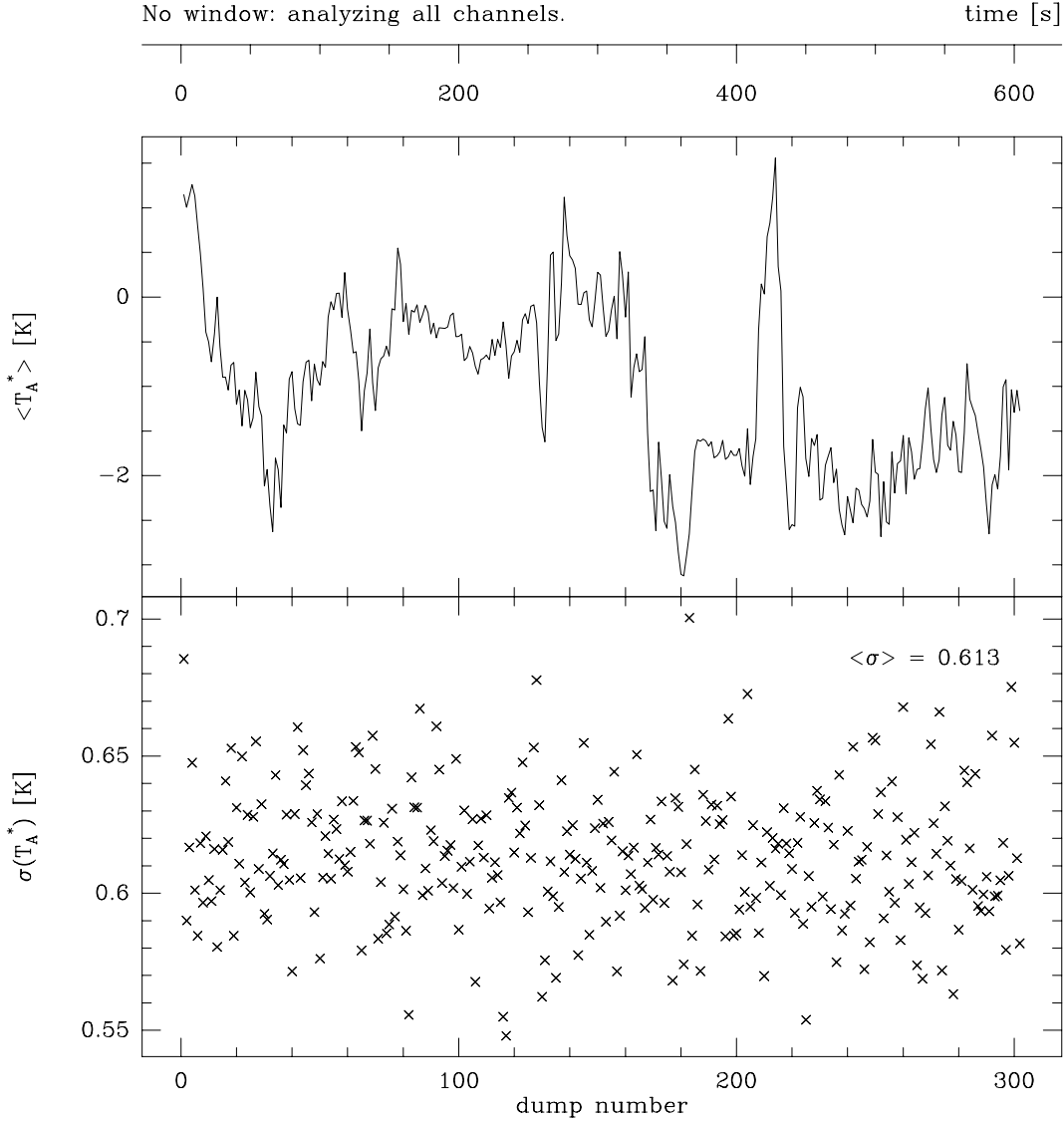
17-FEB-1998 UNGERECH plot scan example.class

Figure 2: Spectra from an OTF-scan with baseline problems. Individual spectra for every 50th dump. Observations with the 230G2 receiver and the autocorrelator. Each OTF scan had 303 dumps of 2^s integration time. An off-source REFERENCE at offsets (-600'', 600'') was observed for 30^s before and after the OTF-scan. Linear baseline subtracted from each spectrum, i.e., dump.

```

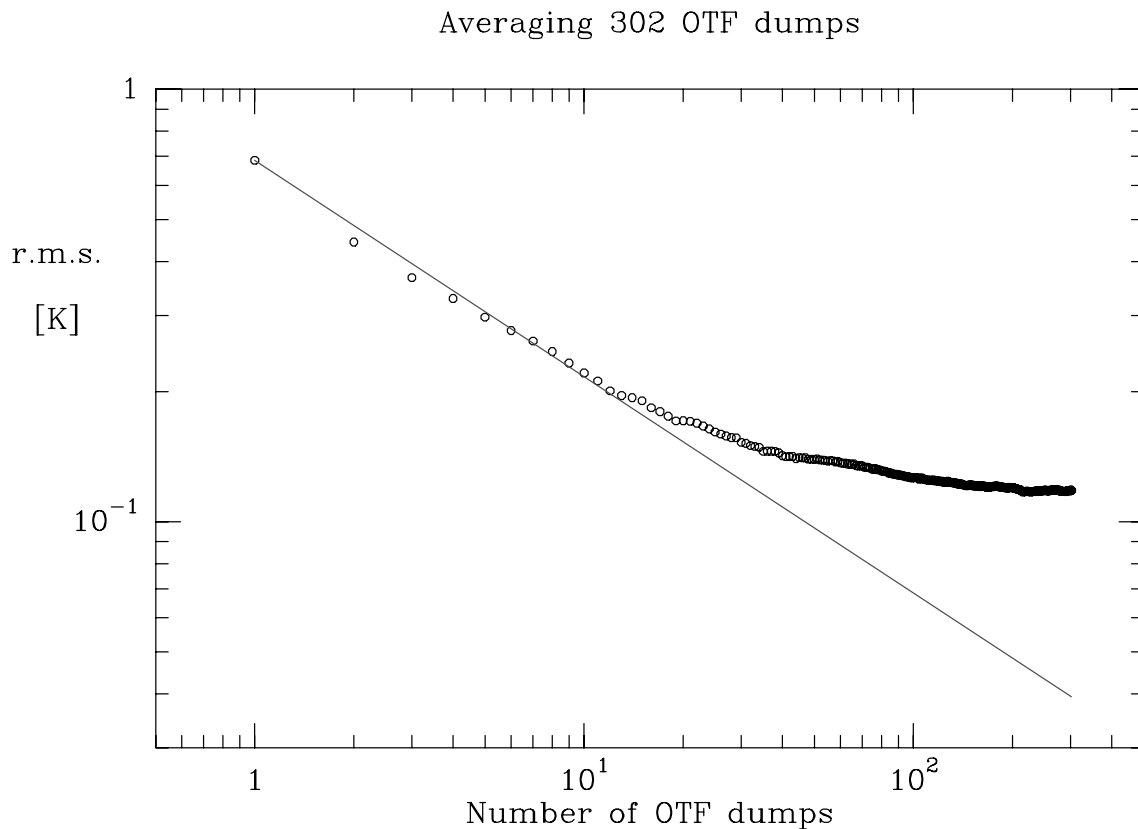
324; 1 CEP-B      C180(1-0)   IRAM-30M-B44 O: 24-JUN-1997 R: 29-AUG-1997
RA: 22:55:08.703 DEC: 62:21:30.01 (1950.0) Offs: +901.100 +240.000 Eq
Unknown Tau: .1075   Tsys: 203.7   Time: 3.3333E-02 El: 54.07
N: 448 IO: 221.6    V0: -12.00   Dv: -.1065   Unkn
      F0: 109782.182   Df: 3.9063E-02 Fi: 113197.008
      B ef: .9200     F ef: .9200   G im: 1.0000E-04
H2O : 5.780   Pamb: 708.2   Tamb: 285.8 Tchop: 295.3 Tcold: 81.0
      Tatm: 270.5 Tau: .1075   Tatm i: 268.6 Tau i: .1443
4234

```



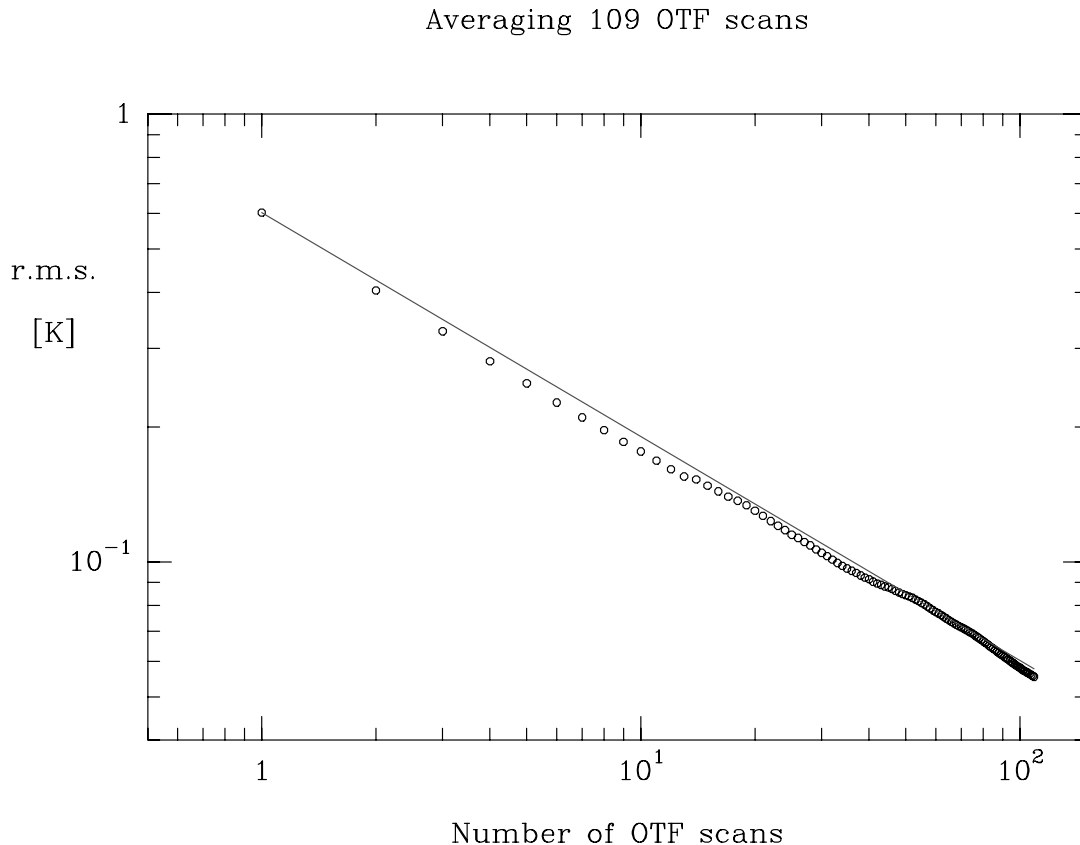
17-FEB-1998 UNGERECH plot stats.class

Figure 3: Mean T_A^* and r.m.s. noise in emission-free baseline channels for each dump along an OTF-scan. Observations with the 3MM2 receiver. The OTF scan had 302 dumps of 2^s integration time. An off-source REference at offsets $(-600'', 600'')$ was observed for 30^s before and after the OTF-scan. For this plot the 2 off-source REference measurements were used with equal and constant weights, and NO baseline was subtracted. [There was no detectable line in this particular scan.]



17-FEB-1998 UNGERECH plot ave dumps.class

Figure 4: Noise r.m.s. in emission-free baseline channels as a function of the number of OTF-dumps averaged. Observations with the 3MM2 receiver, and the autocorrelator with 448 channels of ≈ 39 kHz, at the frequency of the $\text{C}^{18}\text{O } J = 1 \rightarrow 0$ line, ≈ 109.8 GHz. The OTF scan had 302 dumps of 2^{s} integration time. An off-source REFeRence at offsets $(-600'', 600'')$ was observed for 30^{s} before and after the OTF-scan. The straight line indicates a $1/\sqrt{n}$ law; it was adjusted to match the noise level in the first single dump.



17-FEB-1998 UNGERECH plot ave rms.class

Figure 5: Noise r.m.s. in emission-free baseline channels as a function of the number of OTF-scans averaged. Observations with the 3MM2 receiver, and the autocorrelator with 448 channels of ≈ 39 kHz, at the frequency of the $\text{C}^{18}\text{O } J = 1 \rightarrow 0$ line, ≈ 109.8 GHz. Each OTF scan had 303 dumps of 2^{s} integration time. An off-source REFERENCE at offsets $(-600'', 600'')$ was observed for 30^{s} before and after each OTF-scan. The OTF-scans averaged here were observed at different positions in the cloud. The data were not regridded, i.e., no OTF dumps within an OTF-scan were averaged. The straight line indicates a $1/\sqrt{n}$ law; it was adjusted to match the noise level in the first single scan.

5 Spectral-line OTF: Future

Development of SL-OTF data taking has been “frozen” at this point (Fall of 1998). Other desirable features for SL-OTF will be considered in our plans for the new control system of the 30M telescope, see: <http://www.iram.es/FutureControl30M/Main.html>.

These possible developments include:

- Faster dumps with autocorrelator.
- Hardware timing for autocorrelator.
- Fast SL-OTF with shorter dump times.
- SL-OTF with frequency switching.
- SL-OTF with Wobbler switching.
- SL-OTF with Wobbler scanning.
- Data acquisition while slewing.

A **HELP**

A.1 Help for OBS commands for SL-OTF

OTFMAP

```
OTFMAP [d] [s] [int] [/DIRECTION dir [zigzag]] [/TIME t dt]
        [/REFERENCE offl offb system] [/RTIME tr] [/ON_OFF n]
        [/REFERENCE {NO|YES}]
```

Selects an 'On-The-Fly' mapping procedure for line observations.

d angular length of each OTF-subscan
s angular size of the map in the other (orthogonal) direction
 (= angular distance between the first and last OTF subscan)
int angular interval (distance) between subsequent OTF subscans

```
/DIRECTION dir (+LAM|-LAM|+BET|-BET) [zigzag (Z|N) ]
dir      scanning direction for the first OTF-subscan;
         dir must be one of the (text) codes: +LAM -LAM +BET -BET
zigzag   Z(IGZAG) and N(OZIGZAG) turn zigzag-mode on and off.
         If zigzag-mode is on (default),
         the sign of the direction alternates between subscans.
         If zigzag-mode is off,
         the direction of all subscans is specified by dir.
```

```
/TIME t dt:
t        duration of each OTF-subscan in seconds
dt       duration of each dump in seconds
         (minimum 2.0 for autocorrelator; 0.25 for filterbanks)
```

```
/REFERENCE offl offb system (DESCRIPTIVE|HORIZONTAL)
/REFERENCE {NO|YES}
```

offl longitude-offset of off-source REference position
offb latitude-offset of off-source REference position
system {DESCRIPTIVE|HORIZONTAL}
 System in which offl and offb are specified.
 Parameter System must be specified.
 With /REFERENCE NO, only OTF subscans will be taken.
 /REFERENCE YES re-activates off-source REference(s).

`/RTIME tr`

`tr` integration time on the off-source REference position

`/ON_OFF n`

`n` number of on-source OTF subscans between subscans on the off-source REference position(s).

Note:

(`s/int+1`) must be a multiple of `n`.

The scan starts with a subscan on REF. `n` defaults to 1.

Notes:

- `d`, `s`, and `int` are in current angle units (`SET ANGLE` command).
- Along each OTF-subscan a spectrum will be taken every `dt` seconds.
- The rectangular map is centered on the current offsets (`OFFSET`).
- The map consists of `s/int+1` OTF-subscans (lines).
- The map is done in descriptive coordinates (`LAMbda`, `BETa`) (or basis system -- as specified in the source catalog).
- It is possible to use several off-source REference positions; see command `SET REF_FILE file_name`.
In this case `offl` and `offb` are ignored for the REFs; but `offl` and `offb` are used for any CAL preceding the OTFMAP, and System specifies whether the positions in the REF_FILE are in the DESCRIPTIVE or HORIZONTAL system.

Note: Scan direction. The parameter of the option `/DIRECTION` is one of the 4 code words `+BET -BET +LAM -LAM` indicating respectively scans in the direction of increasing `BETa`, decreasing `BETa`, increasing `LAMbda`, decreasing `LAMbda`.

Note: Dump times. `dt` can be 2 seconds or larger for any combination of filterbanks and/or autocorrelator backends. `dt` can be 1 second if the only backends are: the filterbanks and/or the autocorrelator with a limited number of channels (less than about 1200); see Section 2.3. `dt` can be 0.25 seconds if the only backends are: the filterbanks.

Note: descriptive coordinates. If a descriptive coordinate system has been defined in the source catalog, and the parameter `system` of option `REFERENCE` is `DESCRIPTIVE`, then the `offl` and `offb` are in the descriptive coordinates system. If a descriptive coordinate system has been defined in the source catalog, and `BASIS` is specified as `System` for command `OFFSET`, then: the offsets specified

by OFFSET are in the descriptive coordinate system (LAMBda, BETa). (NB: see the OBSINP manual for explanation of descriptive coordinate systems.)

DOPPLERTRACKing

SET DOPPLERTRACK {YES|NO}

Turns DOPPLERTRACKing between subscans on (YES) or off (NO).
Default is DOPPLERTRACK YES, so that the Doppler-Correction (D.C.) is calculated and the L0s are adjusted at the start of each subscan. If DOPPLERTRACK is NO, the L0s will be kept fixed for all subscans of a scan, e.g., during the complete execution of a PSWITCH, RASTER, or OTFMAP command (up to 255 subscans).

Notes:

Independent of the status of SET DOPPLERTRACK:

- The D.C. is calculated and applied at the start of each scan.
- The applied D.C. and the L0s stay fixed during each subscan.

SHOW DOPPLERTRACK

Shows the current status of the SET DOPPLERTRACK option.

REFerence file

SET REF_FILE {file_name|NO}

If REF_FILE is set to the name of a file in the project directory, positions and integration times (in seconds) for off-source REFERENCE subscans are read from that file and used in cyclical sequence. Default for REF_FILE is NO; in this case the (single) off-source REFERENCE position must be specified with commands PSWITCH, RASTER/REFERENCE, or OTFMAP/REFERENCE.

NOTES:

- SET REF_FILE does not influence the position of CAL
- The syntax of the contents of the REF-file is not checked

before the observations start. If there is an error in the file,
an alarm sounds when the file is used, and data taking stops.

```
/  example for a file with REF positions
/-----
/    off lam    ;    off bet ; rtim[s]
/ or off azm    ;    off elv    ; rtim[s]
-1200"          ;          -10" ; 11          /first  ref
1200"           ;          10" ; 11          /second ref
/-----
/ NOTES: after a / the rest of a line is interpreted as a comment
/        angle format as in the source catalogue (see OBSINP manual)
/        integration times are in seconds
/        there can be up to 20 lines in the REF-FILE
/ end of example
```

OTFREF — OBSOLETE

```
OTFREF offl offb [system (BASIS|HORIZONTAL)] /TIME t dt
```

Selects an 'On-The-Fly' reference observation for line observations.

```
offl    longitude-offset of off-source REference position
offb    latitude-offset  of off-source REference position
system  {BASIS|HORIZONTAL}
        System in which offl and offb are specified.
```

```
/TIME t dt:
t        duration of each OTF-subscan in seconds
dt       duration of each dump in seconds
        (minimum 2.0 for autocorrelator; 0.25 for filterbanks).
```

Note: descriptive coordinates. If a descriptive coordinate system has been defined in the source catalog, and BASIS is specified as the 3rd parameter (System), then: (Offl, Offb) are offsets in the descriptive coordinates system (LAMbda, BETa).

Note: off-source REference position. The catalog source position (SOURCE in OBS) used for the off-source REference can be different from that for OTFMAP .

Note: OTFREF OBSOLETE. We recommend to use option OTFMAP/REFERENCE instead.

A.2 Help for selected otfc al commands

Note. The software for SL-OTF is still under development and not fully debugged. The current HELP information (as it follows) refers in part to conventional spectra (non-SL-OTF) and does not yet discuss all modifications for SL-OTF data.

DIRECTORY

CAL\DIRECTORY name

Define the directory where the raw data are. Default is your current working directory. Use "*" as argument to process files at Pico-Veleta. This will take into account the specific organisation of the tree directories.

Note. For SL-OTF scans the directory on the HP work station mrt-ux1 containing the raw data must be specified.

CAL

CAL\CALIBRATE Scan [METHOD]

CALIBRATE use the specified Scan to compute a new calibration for all backends found in the scan. Method is used to specified which type of processing to use for atmospheric parameters, and can be COLD, AUTO, MANUAL or TREC. The required atmospheric parameters must be specified using SUPPLY command. Default method can be specified using SUPPLY command. The TCAL is computed for each backend and each part of backend, using the standard chopper-wheel formula.

The new gain array and TCALs will be used in subsequent COMPUTE commands.

Note. For SL-OTF scans you do not need to specify the atmospheric parameters; they are now taken from the raw data headers. The computed gain array and calibration temperatures will be used in subsequent FLY commands, see below.

SCAN

CAL\SCAN [N] [mode]

Start processing scan N. If mode is RESET or not specified, the

signal array is initialised, if mode is NORESET the signal array is not initialised. The current subscan number is reset, and subscans may then be read in by the SUBSCAN /SIGNAL command. If N is not specified, the current value is increased by 1.

SUBSCAN

```
CAL\SUBSCAN [Isub] [/SIGNAL w1 w2 [...]] [/RECORDS] [/OFF n]
```

Read the subscan number Isub of the current scan. By default, Isub is the current subscan number incremented by one. The program will automatically process all line backends connected at the time of observations.

For LINE data, the /SIGNAL option is used to indicate how to increment the signal array by the weighted sum of the available phases in this subscan, with weights w1, w2, ...

For CONTINUUM data, the /SIGNAL option is ignored.

With the /RECORDS 1 to 20 21 to 91 by 5 ... (like FOR loops) and the /OFF n option, these "DUMPS" are added to the reference n, where n = 1 or 2.

Note. For SL-OTF scans data for 2 off-source REference measurements can be specified using the option OFF 1 or OFF 2. These two off-source REference measurements can then be used by FLY/INTER.

FLY

```
CAL\FLY Isub Backend [Max_no_of_dumps] [/RECORDS] [/INTER mode]
```

Reduces a complete On-The-Fly subscan Isub for a whole backend (all parts) and writes these to the output file.

Max_no_of_dumps is initially 500 and should be increased for subscans with more dumps.

```
/RECORDS 1 to 20 21 to 91 by 5 ... (like FOR loops)
```

Will reduce only these "dumps"

```
/INTER mode
```

If mode is total the reference 1 and 2 (see SUBSCAN command) are interpolated in total power. If mode is time, a linear interpolation

is done between the two references. If mode is not given only the first reference is taken.

A.3 Help for selected class commands

Note. The software for SL-OTF is still under development and not fully debugged. The current HELP information (as it follows) refers in part to conventional spectra (non-SL-OTF) and does not yet discuss all modifications for SL-OTF data.

PLOT/SCAN

```
LAS\PLOT [/SCAN]
```

Display the Observation in R. PLOT is equivalent to the following sequence of commands:

```
CLEAR BOX SPECTRUM TITLE
```

PLOT /SCAN will plot an on-the fly scan as a 2-dimensional image with velocity/frequency in the X axis, record number in the Y axis, intensity being rendered as grey/color scale. Entering command POPUP after PLOT/SCAN enables displaying a single spectrum, selected by clicking with the middle button of the mouse.

RECORD

W-HELP, No help for RECORD

Note. For SL-OTF scans RECORD *n* loads the dump (record) number *n*, which then can be plotted with PLOT or SPECTRUM.

BASE

```
LAS\BASE [Deg] [/PLOT] [/CONTINUUM [flux]]
```

```
LAS\BASE SINUS Amplitude Period Phase [/PLOT]
```

```
LAS\BASE LAST [/PLOT]
```

BASE copies R into T, then subtracts from R a polynomial baseline of degree Deg, or a sinusoidal baseline if the first argument is SINUS. In the latter case, SINUS must be followed by the Amplitude, Period and Phase (in the same unit as the period, usually km/s or MHz) of a trial sinusoid. Minimization will be done including also a linear baseline in addition to the sinusoid. Zones defined by the SET WINDOW command are not used to fit the baseline.

BASE LAST will use the last determined baseline instead of

computing a new one. It can be useful to find a baseline from one backend and apply it to another. This also applies for sinusoidal baselines.

/PLOT plots this baseline after the minimization.

BASE /CONTINUUM will divide the spectrum by the baseline rather than subtracting it. This is useful to keep the continuum level, when continuum is present and variations of atmospheric emission are properly subtracted out by fast enough switching. This is of course the case for correlation spectra (e.g. coming from an interferometer). The continuum level will be adjusted to the value of the argument 'flux', if present; e.g. /CONTINUUM 1.0 will produce a spectrum of line-to-continuum ratio. BASE /CONTINUUM does not work with BASE LAST or BASE SINUS.

For On-The-Fly scans, BASE subtracts a baseline on all the individual spectra.

Note. For SL-OTF scans BASELINE/PLOT does not work.

FFT

ANALYSE\FFT [/REMOVE]

FFT computes the Fourier Transform of R and plots it. R and T observations are unaffected. There is no control over the plot units, and no associated coordinate system (i.e. you cannot measure periods with the cursor). You can edit the Fourier Transform using the cursor. Strike key K to mark the beginning of an area to delete, move the cursor to the end of the area to delete and strike key K again. Then strike E to exit, and Fourier components are interpolated in module and phase from the boundaries of deleted areas.

Non interactive editing is also possible and can be useful for repetitive applications. The syntax is then FFT Start End [/REMOVE]

Additional Help Available:

/REMOVE

ANALYSE\FFT /REMOVE

Remove existing fits of the current method before computing the Fourier

transform. If the Fourier Transform is edited, fits are added back upon exit.

Note. For SL-OTF scans FFT works on all dumps (records).

GRID

```
ANALYSE\GRID [Filename] [NEW|APPEND] [MATH_EXPRESSION]
[/CHANNEL [C|V|F|I] min max]
[/IMAGE [BEAM beam] [LAM nx refx valx incx] [BETA ny refy valy
incy]] [LIKE tempfile]
[/PLOT [where]] [/SMOOTH fx fy]
```

This command builds a GILDAS table containing the following values

Column 1 X offset (in radians)

Column 2 Y Offset (in radians)

Column 3 Weight of the data

and

Column 4

... Spectral channel specified

Column N

or

Column 4 Result of the mathematical expression

from the current index of scans. It is up to the user to ensure that the current index concerns a single source and a single line, observed with a unique spectral resolution, with all spectra centered at the same velocity. Option /IMAGE is used to grid the data into a 3-d cube, option /PLOT to plot a map of channel-averaged data.

If "Filename" is not present the data is appended to the current table (the one opened by the last GRID command). If "APPEND" is given as the second argument the table Filename is opened and data is appended to it; otherwise "NEW" may be specified to open a new table; this is the default.

If "MATH_EXPRESSION" is present in the command line, Column 4 will contain the result of Math_expression applied for each spectrum. This is particularly handy when one use the SIC variables and functions (see *HELP CUBE Functions*, *HELP LAS\SET VARIABLE* and try the command *SIC\EXAMINE /FUNCTION*) in the Math_expression.

Option /CHANNEL can be used to limit the part of the spectra that will be included in the table (not used if you treat a Math_expression).

The resulting table can then be processed as a whole using the GILDAS (Grenoble Image and Line Data Analysis System) software. With /IMAGE a data cube is created from this table. GILDAS includes tasks to do the same job with more flexibility (GRID_SG and GRID_EXTEND), and transpose, reinterpolate, change the projection systems, make overlays with the IRAS point sources, contours and so on from data cubes. Call GRAPHIC at system level and then type EXPLAIN for more information on GILDAS tasks.

Additional Help Available:

/CHANNEL /IMAGE /PLOT [WHERE]

GRID /CHANNEL [CHANNEL|VELO|FREQ|IMAGE] min max

Select the channels to be used for the tabulation and gridding process. This fixes the third dimension of the final data cube. Use CHANNEL (the default) to give min and max in channels numbers, or one of the other units: Velocity, Frequency, or Image frequency.

GRID /IMAGE [BEAM beam] [LAM nx refx valx incx] [BETA ny refy valy incy] [LIKE tempfile]

Grid the tabulated data in a data cube (or a 2-d image if only one channel is processed, or a mathematical expression). The cube coordinate axes are normally defaulted from the position of the spectra, assuming that the angular resolution was 'beam' (in current angle units; a recommended default is taken for 30m telescope data); otherwise the LAMBDA and/or BETA axes may be forced by giving the number of pixels, the reference pixel, the coordinate value at the reference pixel, and the pixel size (all in current angle units). Finally both coordinate axes may be taken from a template image (LIKE tempfile).

In the APPEND mode, none of the /IMAGE arguments should be given, the current image (from the previous GRID/IMAGE command) is incrementally recomputed, adding the new data. This is intended for a real time display while observing.

GRID /PLOT [WHERE]

To be used only with /IMAGE. An image of the average of all the channels is plotted. WHERE plots GreG markers at the observed positions.

Note. For SL-OTF scans GRID in class is now more flexible than the gridding tasks in GILDAS. We recommend to use the command GRID in class to grid SL-OTF data.

B Definitions

B.1 Definitions

OTF: On-The-Fly. An observing mode in which the telescope beam moves (“scans”) across the sky relative to the source during data acquisition. The data are sampled quickly enough to get several samples in the time the telescope moves by one beamwidth. In particular, SL-OTF is such an observing mode for spectral lines.

SL-OTF: Spectral-line On-The-Fly.

Sampling: The rate at which independent spectra are read from the backends and stored. Currently the fastest values for SL-OTF at the 30M telescope: one spectrum every 1 or 2 seconds. In space: about 3 per beamwidth.

ON-OFF: Any observing mode where positions on source (ON) are observed alternating with one or more off-source REference positions. The spectra are computed as the difference of the signal observed ON minus the signal at REF. In classical position switching both ON and REF are taken at fixed positions. In OTF both REF and ON can generally be (parts of) lines.

ON = ON-source: In ON-OFF observing modes a position on the sky assumed to be on the source, i.e., to have a signal. Also the data taken at such a position.

REF = OFF-source REference: In ON-OFF observing modes a position on the sky used as “zero” or reference level to compute spectral intensities — normally a position known or assumed to be free of any signal. Also the data taken at such a position.

CAL COLD = Calibration: At the 30M telescope a standard calibration, including measurements on hot load, cold load, and blank sky

Scans and subscans. We use the following terms to refer to segments of data taken in specific time intervals. They are also often used to designate logical parts of the acquired data set or map.

Scan: All data that get assigned one Scan-Number by the telescope drive software. Normally this corresponds to the execution of one OBS command, e.g., POINTING or OTFMAP. During SL-OTF mapping at the 30M telescope a Scan consists of one or several Subscans, which can be off-source REference or ON-source OTF.

Subscan: Subunit of a scan. During SL-OTF mapping at the 30M telescope each Subscan corresponds to either one line in the map observed OTF, or to one off-source REference.

Dump: Shortest subunit of a (sub)scan. Shortest time interval for which data are written to disk and available to the data reduction software. During SL-OTF mapping at the 30M telescope each Dump corresponds to one point in the map. In the off-line processing the data are usually resampled (gridded) to a regularly spaced grid and then several dumps can contribute to each point in the gridded data set.

Dump time: Time between 2 consecutive dumps (\approx integration time for each dump.)

Maps and data sets. The following terms designate logical parts of the acquired data sets or maps:

Map: With SL-OTF at the 30M telescope a map normally consists of parallel lines with constant spacing between the lines. It is possible and recommended to cover the same region at least twice; taking the lines in the second coverage in a direction perpendicular to those of the first coverage.

Line: In a map: “straight” line on the sky, i.e., at constant longitude or latitude in the descriptive or basis system, along which the telescope moves at a constant speed while taking data. Normally corresponds to one subscan.

Point: In a map: one position of the map. In SL-OTF at the 30M telescope the position of the telescope at the end of each dump is recorded.

Pixel: In a map: one position in a regularly gridded data set (image). Normally for SL-OTF data from several dumps and (sub)scans contribute to the data at one pixel in the gridded data set.

C Contacts

C.1 Whom to contact with questions and about problems

Support for SL-OTF observing:	DT	David Teyssier	teyssier@iram.es
SL-OTF in General:	HU	Hans Ungerechts	ungerechts@iram.es
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Computers; data transfer:	WB	Walter Brunswig	brunswig@iram.es
otfcf, class:	RL	Robert Lucas	lucas@iram.fr

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