Chapter 4

Bolometer observations at the SMTO

By Michael Dumke

4.1 Introduction

In this chapter we explain the use of the continuum receivers available at the HHT: the Four-Color-Bolometer and the 19-Channel-Bolometer-Array. These receivers are already introduced in chapter 3. Here we give an overview of the preparation of bolometer observations, the available observing strategies and procedures (see also chapters 2 and 6) and the reduction of your bolometer data.

Currently there are two major programs available at the HHT for the general handling of bolometer observations: **NIC** and **MOPSI**. Both have their advantages and disadvantages. For On-Off-scans we still provide the **ONOFF21** program on the VAX.

- **NIC** is a collaborative project of the CEA de Saclay, the MPIfR Bonn, the Observatoire de Grenoble, and IRAM. It provides full access to the **SIC** monitor and the **GreG** libraries, and has a command structure very similar to those of other **GILDAS** programs, like **CLASS**, **GRAPHIC**, ... It uses the NMB format (ascii or binary) as input and writes out RG image files that can further be processed by the **GRAPHIC** or **MAPPING** software.

- **MOPSI** is written by Robert Zylka (ITA Heidelberg), and was originally planned just for his private purposes to reduce spectroscopy and continuum maps. It used the so-called TD format for input, and the new version installed at the HHT can even read the telescope's raw data format. The output maps are usually in NOD2 format, which can either be analysed within **MOPSI** up to publication-quality plots (this program uses also the GreG libraries), or can be written out and transformed into GDF or FITS format.

Concerning the data formats, ascii NMB data (suffix `.asc`) can be easily produced from the telescope raw data, and data conversion utilities between GDF, NOD2, and FITS are also available. Both **NIC** and **MOPSI** are capable of handling command files. There is some agreement in the bolometer community that with **MOPSI** you have more possibilities to customize your data reduction, what finally leads to better results. On the other hand, many people prefer **NIC** because of its better documentation and the availability of its source code.

Further reading:

- The **NIC** Users' Manual is available in the control room at the telescope. You may also try the online version at *http://maisel.as.arizona.edu:8080/nic*, or, to get the local copy at the telescope, use *http://jever.as.arizona.edu/ smtop/nic*
- The **MOPSI** pocket cookbook is also available at the telescope, but it is really only a cookbook .... However, a postscript version is provided at *http://maisel.as.arizona.edu:8080/documents/mopsi_manual.ps*
- To efficiently use the plot commands available in both **NIC** and **MOPSI**, you may have a look at the **GreG** Manual. **NIC** further uses some **GILDAS** tasks and the **SIC** monitor. Online manuals for all programs of the **GILDAS** package are available at the web site of IRAM Grenoble (*http://iram.fr/GS/gildas.html*).
- General information about data formats, continuum calibration and other things are provided in the numerous binders at the telescope. Ask the FoT if you're searching for something.

4.2 Preparation of bolometer observations

4.2.1 Basic rules

If you want to use the bolometers (and especially the 19-Channel-Array) really efficiently, you need to think a bit about possible observing modes and observing strategies. Since these will influence the preparation of your observing run, we will introduce some "golden rules" for bolometer observations already in this section about the preparation.

There are two basic observing modes which are (currently) supported by the SMTO telescope control software: ON-OFFs and ON-THE-FLYs.

- On-Offs:
  On-Offs are the preferred observing mode for point-like sources. You can of course also observe extended sources in this way, but then you will not be able to eliminate the correlated sky noise with the 19-Channel-Array.

- On-The-Flys:
  A few years ago everybody would have said "Maps", but since On-The-Flys are now also possible for heterodyne observations, this word has become so popular that it's also widely used for continuum mapping. It is basically used for extended sources. This type of information needs a bit more planning than On-Offs:

  – Mapsize: To cover the whole source with the whole array, we recommend at least the following map size:

  $$\begin{aligned}\Delta_{\mathrm{Az}} &= \mathrm{arraysize} + \mathrm{beamseparation} + \mathrm{sourcesize} \\ \Delta_{\mathrm{El}} &= \mathrm{arraysize} + \mathrm{sourcesize}\end{aligned}$$

  The size of the 19-channel array is about $200''$, and the beam separation is typically $60'' - 120''$ (corresponding to a wobbler throw of $\pm 30''$ to $\pm 60''$), depending on the source extend. Hence a typical map size would be $450'' \times 300''$, which will take about 40 minutes when following the basic guidelines for subscan disctance and scanning velocity. If you need to cover a larger region, you may increase the azimuth size. To keep the map duration short, you may consider a mosaic instead of increasing also the elevation size. This will keep map distortions and atmospheric fluctuations small within one map.

  – Wobbler throw: as small as possible, as large as necessary. You should avoid to wobble into your source. The latter point is also valid for On-Offs of sources which are not point-like.

  – Map orientation: Use the skew parameter to place your map edges parallel to the source (see further below).

Equipped with this information, we can go ahead and use the available software to prepare our observing run.

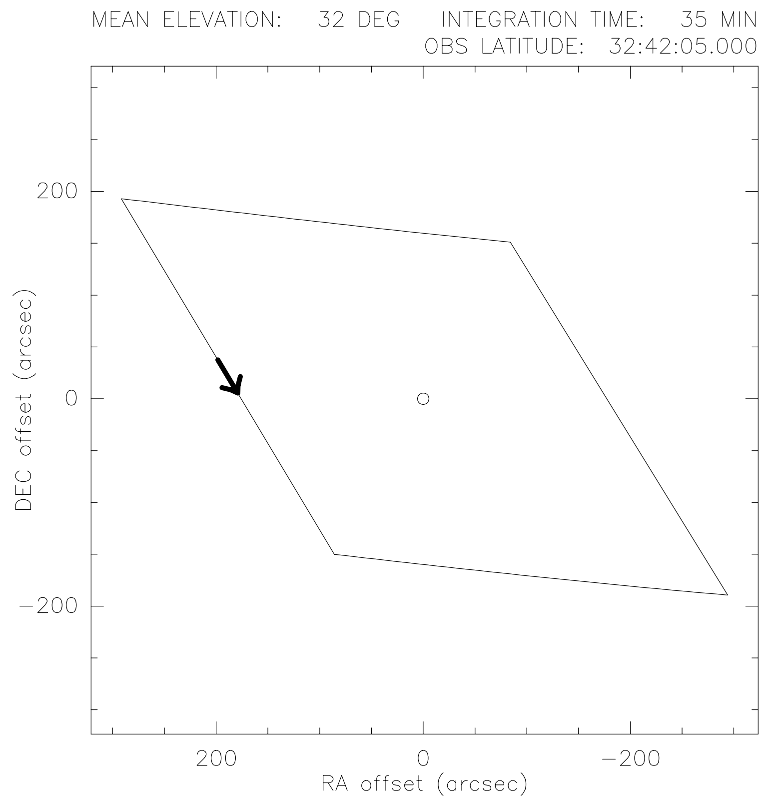

Figure 4.1: An example for the FIELD command in **NIC**. This map would be optimally placed for an elongated source oriented at a position angle of about 80°

4.2.2 Preparing OTF observations using NIC

Within **NIC**, observations of On-The-Fly maps can be prepared using the command `field`. This command uses some default parameters for the telescope, which are appropriate for Mt. Graham (the built-in program default is the IRAM 30-m telescope, but it is changed upon startup to the HHT). Start the **NIC** program from your subdirectory by

```
smtobs@jever> nic
```

Then open a plotting device and have a look at the online help within **NIC** to see what options are possible for the FIELD command:

```
NIC> device image white
NIC> help field
```

As an example, you may try the following:

```
NIC> field /decl 13 /size 400 300 /hour -4 /skew 6
```

This command will plot the region of the sky covered by a map of size $400'' \times 300''$, if you observe an object at 13° declination at an hour angle of -4, i.e. at an LST four hours earlier than the transit. The output of this example can be seen in Fig. 4.1, with the arrow indicating the scanning direction (azimuth). The `skew` parameter defines the amount (in arcseconds) by which each subscan is shifted with respect to the preceding one. Since the "golden rule" of bolometer mapping requires the scanning direction inclined to the source elongation, the above observation would be appropriate for an elongated object oriented on the sky with a position angle of about 80° (ccw from north). Try the various options of this command within **NIC**, and always have the extent and the orientation of your source in mind, as well as the time schedule (available hour angles).

Just to show how important ist is to check the map shape prior to the observations, we plotted in Fig. 4.2 an example which should never occur in practice. The declination is chosen for a source that transits near the zenith, the mapping defaults were changed to the 30-m telescope (takes longer due to the smaller pixel separation), and the actual command was

```
NIC> field /decl 32.8 /size 320 180 /hour 0.5 /skew 3
```

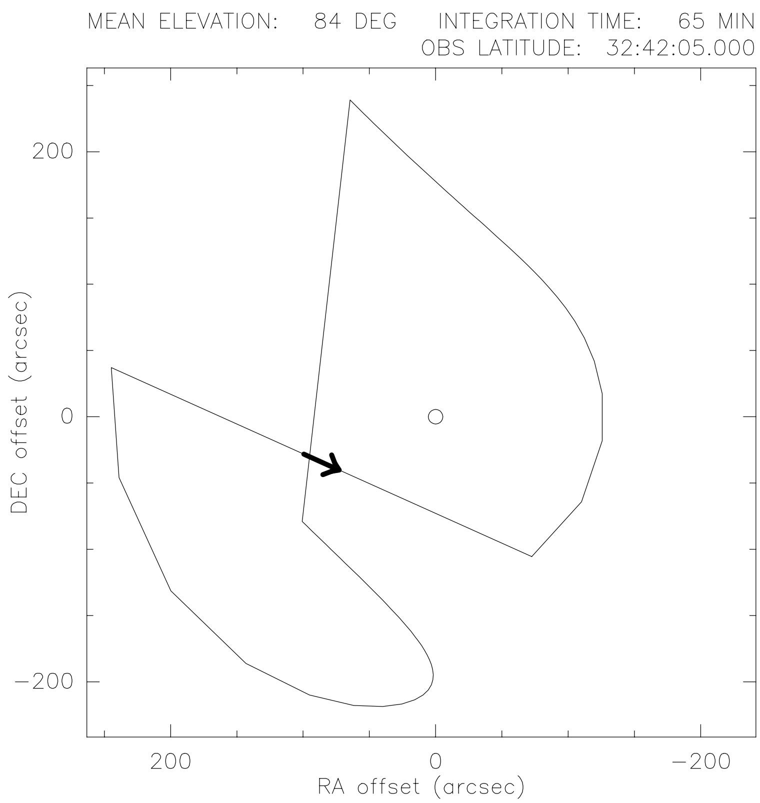

Figure 4.2: Another example for the FIELD command. In this case the planned observation should be postponed for 1 or 2 hours, in order to avoid the map distortion due to Earth's rotation

Use either **ASTRO** or **PARAL** to calculate the elevation of your source at a given LST range.

4.2.3 Preparing OTF observations using MOPSI

If you want to use **MOPSI** to prepare your observation, start the program by typing

```
smtobs@jever> mopsi
```

and open up a plot window in the same way as within the **GILDAS** programs:

```
MOPSI> device image white
```

Unfortunately, **MOPSI** has no detailed online help (that's the reason why I'm writing this chapter ...). The `help` command just gives you a list of available commands with a short (!) description. The command that allows you to plot the covered field at the sky is called `show ae_maps`. In the case that you have a map of your source with you (use `ftp` to get one from your home institution), you can even plot the covered field on top of this map. If you have it in .nod-format, great – but .fits or .gdf is also fine. Then you have to use the `file in`, `read`, and perhaps `nod` commands within **MOPSI** instead of just `nod`. We have also some data conversion utilities - see Section 4.6.5 for details) you may consider to plot it first. If your file is called `<filename>.nod` (the suffix is mandatory for **MOPSI**), type

```
MOPSI> nod <filename>
MAP> extr /co                ! to see the extrema, for level setting
MAP> level 50 to 400 by 50  ! ... just an example
MAP> rgm                     ! to plot a contour map
```

Don't worry about the change of the prompt; this will happen several times when you are working with **MOPSI**, and depends on the kind of data **MOPSI** has in memory. If you want to change the contour levels, just use `clear plot` and `rgm` again, as in **GRAPHIC**.

In order to show the Az-El map to be observed, use the following sequence of commands:

```
MAP> show ae_map
 SHOWAEM> help               ! to show ae_map submenu
 SHOWAEM> st_start hh mm ss ! start LST (hh:mm:ss)
 SHOWAEM> telescope hht     ! define the telescope
 SHOWAEM> extend <az> <el>  ! map size in Az El (in arcseconds)
 SHOWAEM> show
```

This plots the covered area and also tells you how long it will take to observe this map. An example of a plot created in this way is shown in Fig. 4.3. Look at the online help (in `show ae_map`) to see the possible commands and options. If you loaded array data (e.g. your observations from the night before), `show ae_map` can also include the bolometer array in the plot.

If you don't have a map of your source available, it's a bit more work, since you have to define plot limits (in ″) and projection center:

```
smtobs@jever> mopsi
MOPSI> dev ima whi
MOPSI> greg\limit <ra_east> <ra_west> <dec_south> <dec_north>
MOPSI> greg\set box match
MOPSI> box
MOPSI> schow ae_map
 SHOWAEM> st_start hh mm ss
```

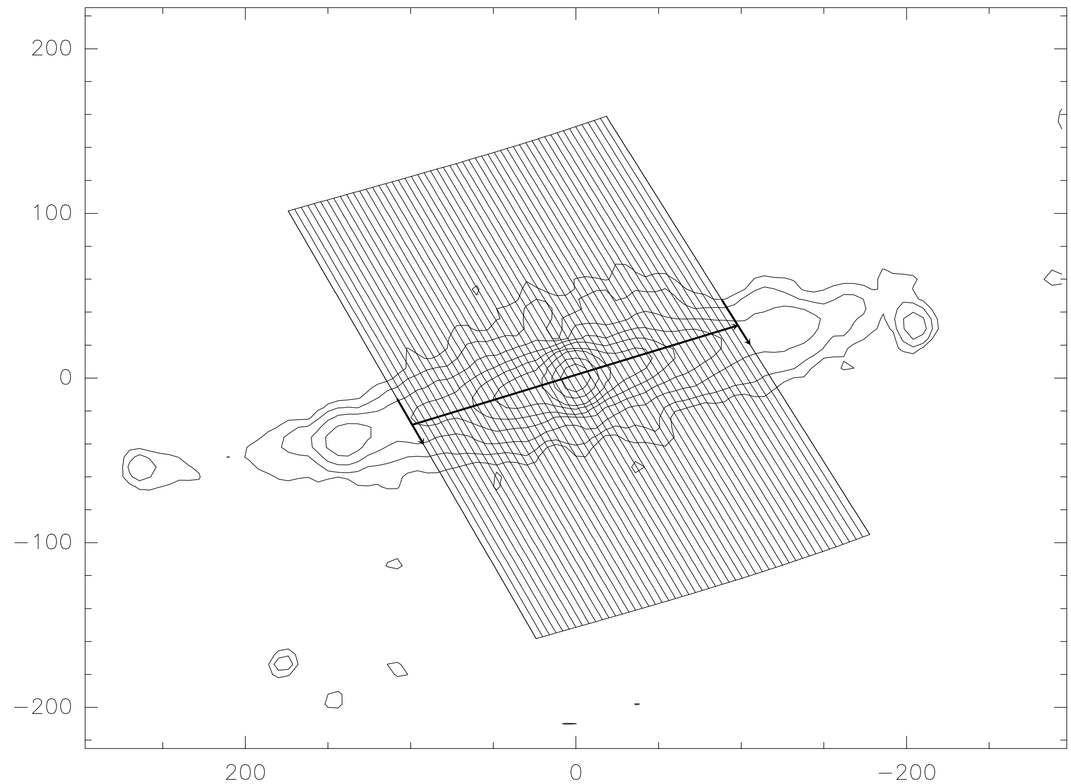

Figure 4.3: A plot created by the `show ae_map` subroutine of the **MOPSI** program. This map is again optimally placed

```
SHOWAEM> telescope hht
SHOWAEM> extend <az> <el>
SHOWAEM> projection hh mm ss dd am as
SHOWAEM> show
```

Remarks for using `show ae_map`:

- You MUST define the telescope when you have loaded a map before, otherwise `show ae_map` will use that in the header of the map, which may be anything (30-m, Effelsberg, ...). This would lead to wrong results.
- You can define/set a lot of things in `show ae_map`, e.g. a different date, skew, scanning velocity, ... Just play a bit with the different options.

4.2.4 More sophisticated topics

The basic observing modes introduced above are well suited for two kinds of sources: Point-like sources can be observed in the On-Off mode, while extended sources (with an extent of a few arcminutes) should be mapped in On-The-Fly mode. It is obvious that OTF mapping wastes a lot of observing time when used for sources wich are smaller than the size of the array (i.e. $\sim 3'$), since a significant amount of time is used scanning along blank sky. Here a series of On-Off scans is more appropriate, where the gaps between individual bolometer channels are filled with On-Off scans shifted by only a few arcseconds (in order to ensure a full sampling). Due to the rotation of the array relative to the sky, the optimum offsets are not trivial to calculate.

On the other hand, the normal OTF mode is only useful for a certain map size, because with the standard mapping parameters a map larger than e.g. $10' \times 10'$ takes already longer than the atmosphere can be considered stable.

These issues are addressed in this subsection.

4.2.4.1 The "Jiggle-Mode" at the SMT

...still to be written ...

4.2.4.2 Fast On-The-Fly Mapping

The idea behind Fast OTF Mapping is to drop the requirement that every of the 19 individual maps obtained during one mapping observation has to be completely sampled. One can instead obtain a sufficient sampling by adding up all 19 channel maps, with the sky positions of the data points observed in one channel falling in between those observed with the other channels. This significantly decreases the amount of time needed to complete one coverage of a given region.

More detailed information about this technique can be found in the SMTO Working Report: Fast On-The-Fly Mapping at the Heinrich-Hertz-Telescope using the 19-Channel Bolometer Array.

4.3 Observing with the Bolometers

There are two basic observing modes with both the Four-Color-Bolometer and the 19-Channel-Array. These are ON-OFFs for point-like sources, and ON-THE-FLYs (or MAPs) for extended sources. Due to the lower sensitivity of the (Single-Channel-) Four-Color-Bolometer, you may also want to observe selected points in extended objects in ON-OFF-Mode, due to the longer on-source integration time. Here we describe both observing modes, as well as some other observing procedures which are necessary for proper data calibration. The commands are described in detail in chapter 6.2, here we give rather examples and some (maybe important) remarks.

Be aware that several parameters in **OBST** have to be set differently in maps than in other observing modes. This will also be described below.

Since continuum observations can't make use of a calibration scheme similar to heterodyne observations, there are some points to consider when observing with the bolometers:

To avoid getting lost on startup, you may copy an example setup file to your directory, e.g.

```
<FRANKE.OBS.XY> copy [-.md]19chan.pro example.pro
```

Note that the brackets here are part of the VMS directory identifier and need to be entered, while in other examples throughout this manual they may indicate an optional input. Execute this startup script within **OBST** by

```
OBST> restore example
```

Then you can check all parameters by the `show` command, and change them according to your needs or as described below. Useful are `show wobb`, `show drumb`, `show rx`. See Chapter 6.2 for possible items to show. If necessary, type `set preinteg_c 1 1 1` (should be already done by `example.pro` and set your wobbler throw by `set w_pos +<value> -<value>`. `<value>` will be the half beam separation in your maps. Note that for continuum observations the first number must be positive. Make sure that you have focus and pointing offsets set for the correct receiver – you should probably ask the staff or the previous observer about his/her values.

The parameter `w_beam` in OBST describes if the reference position is to be centered on the on-beam (`set w_beam 2 2`, which is the case for almost all obsrvations) or between the on- and off-beam (`set w_beam 1 2`, only for CMAPs, because of the restoration process). When you choose one of the bolometers as receiver (19 channel array or 4-color), it is set automatically to `1 2`. For On-Offs, pointing and focus observations, it is set *temporarily* to `2 2` and reset to `1 2` after the observation has started. You may check this setting via the `show` command when you change receivers, but you should avoid to manually enter any values for `w_beam`.

4.3.1 Calibration observations

- Pointing:
  For continuum observation we obviously cannot use any line-pointing techniques,

and the number of continuum pointing sources in the submillimeter range is rather small. Fortunately, the bolometers are more sensitive than heterodyne receivers. Good pointing sources are planets, the strongest quasars and some galactic sources (3Cxxx , W3 OH, ...). Use **Xephem** to find an appropriate pointing source close to your target.

Start the pointing by

```
OBST> set w_pos 100 -100
OBST> set bolo <gain>        !  or: > drumbe /bolo <value>
OBST> source <source> [/cata cat:smtbolo]
OBST> point [/time <int_time>]
```

The relatively large wobbler throw of `100 -100` is chosen to avoid seeing the negative beam in the azimuth subscans, what may otherwise happen especially for big planets like Jupiter and Saturn. If the pointing source is rather weak (< 5 Jy), you should increase the integration time per subscan with the `/time` option in order to get a better S/N.

If the pointing fits are convincing, take the values by `corr f f`. The `<gain>` is actually an attenuation. It is set (and reset) automatically to 9 for skydips, and should be 1 for all sources except strong planets; recommended values are 2 (for Mars), 5 (for Jupiter) and 4 (for Saturn). This attenuation is set to avoid a saturation of the backend. Note that the values depend on the weather and the current flux density of the planets. The limit at which saturation occurs is about 4,000 on the Toolbox window, corresponding to 400,000 on the Online CHEF display.

- Focus:
  For focus observations with continuum receivers there are no particular difficulties – but be aware that you don't forget to change the pointing and focus constants when changing the receiver. A focus is usually done after a pointing (or, more precisely, between two pointings, since you should do one after the focus has been corrected). Type:

```
OBST> zfocus                ! radial focus
OBST> corr * * f
OBST> xfocus                ! vertical focus
OBST> corr * * * f
```

- Skydips:
  The Earth's atmosphere is a much stronger emitter in the submillimeter range than objects of astronomical interest. Furthermore, the opacity may change rapidly in time and elevation. You **must** do regular skydip measurements as described in chapter 6 for a proper data calibration. Depending on elevation and atmospheric stability at least once every 1 to 2 hours. To start a skydip, just type

```
OBST> skydip [<az_value>] [/airmass <max> <min>]
```

If you have to go to a different source anyway, you can also specify the azimuth by `skydip <az_value>`. You should also specify the azimuth explicitly when you're observing in northern direction, since you should avoid to observe the trees, what happens easily for lower elevations. You can also restrict the elevation range by explicitly entering a maximum and minimum airmass with the `/airmass` otion, like `skydip /airmass 2.3 1.05`. Note that you have to give the maximum airmass first, although the measurement starts at high elevation (low airmass).
Press the `Restart` button at the on-site radiometer just when you start the skydip measurement. This will allow you to estimate a ratio of $\tau(225\,\mathrm{GHz})/\tau(\nu_{\mathrm{obs}})$, and therefore to interpolate the opacity between skydip measurements, if necessary.
We should note that fit parameters in the various skydip reduction programs (**SKYDIP** on the VAX, in **MOPSI** and **NIC**), vary, and so do the results. Compare and correct them, as it seems necessary.

- Flux calibration:
  When you see your data on the computer, they are calibrated in "counts". You must observe a planet during your observing session to estimate a proper counts-to-Jy conversion factor. If no planet is available while you are observing, ask other observers around (if they are using the bolometer as well) for their calibration observations - we strongly encourage different groups at the telescope to cooperate as far as calibration is concerned. As a last resort you still have the option to observe a few secondary calibrators. (see Subsection 4.3.5).

  The calibration observation can be an On-Off, since the S/N ratio is higher for On-Offs, but you should also do an On-The-Fly of a planet at least once during your stay at the observatory which will yield an independant flux measurement and is also necessary to estimate/verify the array parameters (offsets and relative gains).

4.3.2 On-Offs

As already noted, an On-Off is useful for point-like sources.

```
OBST> set time_cono 10 10
OBST> source <your_source> /cata <your_catalog>
OBST> set w_pos 50 -50
OBST> conoff 100 0 /sub 20 f [/time 10 10]
```

This will make 20 on- and 20 off-measurements, the latter 100″ away in azimuth, with an integration time of 10 seconds each. Most (if not all) parameters can be supplied by the `set` command or as an option, like `time` in the example above – so you need to specify it only once. The "`f`" is mandatory to start with an on-phase – otherwise your measured counts will be negative.

An important point is that the offset in the `conoff` command and the wobbler throw have to correspond to each other: In the example above, with `w_pos 50 -50`, the total beam separation is 100″ – thus this has to be the offset! Or, if your wobbler throw was `w_pos 80 -80`, the correct command would be `conoff 160 0`. Got it?

4.3.3 On-The-Flys

For On-The-Flys, the most important difference to the other routines is that the zero-position must be in the center between the on- and off-beam, `set w_beam 1 2`, which is, as mentioned above and in contrast to earlier years, set automatically. Further you should increase the wobbler throw if your source is very extended:

```
OBST> set wpos +<0.5*wob> -<0.5*wob>
```

Before you enter the `cmap` command, you should check if you need a skewed map (see section 4.2). You also need a bit thinking about the scanning velocity. For the 19-channel array with a beam size of about 23″ at 345 GHz, we recommend a pixel size of 8″. Since a data point (including on- and off-phase) is dumped every 0.5 seconds (for a wobbler frequency of 2 Hz, which should not be changed), the scanning velocity can be 16″ per second. We recommend, however, since the data are taken continuously, a smaller velocity to avoid smearing in azimuth direction: About 8″ per second seems to be more appropriate. Hence `time_cm` should be about `az_size/8`, e.g. 50 seconds for a typical map with a subscan length of 400″

To start the observations, select a source and go ahead:

```
OBST> source <your_source> /cata <your_catalog>
OBST> cmap /time 50 /maps <az_size> 8 <el_size> 8 /skew <val>
OBST> start
```

The first "8" above does not have any effect, since you give the sampling by `<az_size>` and `time`, and the second is the recommended subscan separation `SINT` for the 19-channel array. If you want to do a mosaic, what means you also need maps at offset positions, you may consider typing `set off <ra_off> <dec_off>` before entering the `cmap` command.

Another way to realize offset positions is to use a different source name instead, e.g. "source_sw" (with different R.A./Dec. coordinates) if you want a position shifted somewhat to the southwest, and add it to your source catalog.

4.3.4 Advanced mapping techniques

As mentioned earlier, very large maps cannot be observed in the conventional On-The-Fly mode. If you have sources which are larger than about 10′ in both direction, you should consider using Fast OTF Mapping. Fortunately, the command syntax is the same as for normal maps, just the numbers are different:

```
OBST> cmap /maps 1600 8 1080 54 /time 100 /skew 27
OBST> start
```

will observe a skewed $27' \times 18'$ map (edges skewed by 45°) with 21 subscans and a total integration time of 35 minutes.

Another option of mapping is to scan not along Azimuth, but rather along Right Ascension, or – even this is possible – along a coordinate rotated by a certain angle relative to Right Ascension. This gives you full control over the orientation of your map on the sky and may be useful to optimally place your map for a certain source. The corresponding command includes the scanning direction as fifth parameter of the `/mapsize` option and could be for example:

```
OBST> cmap /mapsize 1200 10 1200 50 LAM /time 80
```

This would perform a rectangular map of $20' \times 20'$ in R.A.-Dec. or – if you have defined your source in the catalog in descriptive coordinates, i.e. using `SBAS 1D` or `SBAS -1D` and `SLOP`, `SBOP`, and the angle `SKOP` intead of `SLAM` and `SBET` – in a source-specific coordinate system. See Section 6.8.9 for the various mapping options, and ask the FoT how to set up your catalog sources with a descriptive coordinate system.

Important: Since the data reduction software currently available uses the EKH algorithm for map restoration, it can only handle maps where the scanning direction is the same as the wobbling direction. In other words: You must scan in Azimuth if you want to use NIC or MOPSI for data reduction! If you want to use any other scanning direction, you have to provide your own data reduction software. In this case, please contact the SMTO staff well in advance to make sure that your software will run on our computers and to discuss data format issues.

4.3.5 Secondary calibrators & pointing sources

If during your observing run no planets are available, or they are too close to the sun, you should observe secondary calibrators in order to properly calibrate your data. Most sources with $S \geq 5$ Jy in the following table are also excellent pointing sources. Ask the FoT on duty if you're not sure about a particular source.
The last entry in each line gives the measured flux density at 345 GHz.

```
SNAM= W3 OH           ; SLAM= 2 23 16.50 ; SBET= 61 38 57.0 ;! 27.1 +- 0.6
SNAM= 0316+413 3C84   ; SLAM= 3 16 29.56 ; SBET= 41 19 51.9 ;!  1.6 +- 0.1
SNAM= GL490           ; SLAM= 3 23 39.22 ; SBET= 58 36 35.6 ;!  6.3 +- 0.3
SNAM= NGC1333         ; SLAM= 3 26 04.80 ; SBET= 31 03 14.0 ;!  9.4 +- 0.2
SNAM= 0415+379 3C111  ; SLAM= 4 15 00.60 ; SBET= 37 54 19.0 ;!  2.4 +- 0.1
SNAM= 0439+360 CRL618 ; SLAM= 4 39 33.80 ; SBET= 36 01 15.0 ;!  4.4 +- 0.1
SNAM= IRC2            ; SLAM= 5 32 47.03 ; SBET=-05 24 23.9 ;!  188 +- 7
SNAM= 0607-157        ; SLAM= 6 07 26.00 ; SBET=-15 42 03.1 ;!  1.3 +- 0.5
SNAM= CWLEO IRC+10216 ; SLAM= 9 45 14.84 ; SBET= 13 30 40.5 ;!  5.3 +- 0.3
SNAM= 1156+295        ; SLAM=11 56 57.79 ; SBET= 29 31 25.7 ;!  1.2 +- 0.1
SNAM= 1226+023 3C273  ; SLAM=12 26 33.25 ; SBET= 02 19 43.3 ;!  3.0 +- 0.1
SNAM= 1228+127 VIRGOA ; SLAM=12 28 17.60 ; SBET= 12 40 02.0 ;!  1.1 +- 0.1
SNAM= 1244-255        ; SLAM=12 44 06.71 ; SBET=-25 31 26.5 ;!  2.8 +- 0.1
SNAM= 1253-055 3C279  ; SLAM=12 53 35.84 ; SBET=-05 31 08.0 ;!  9.2 +- 0.2
SNAM= 1334-127 OP-158.3;SLAM=13 34 59.81 ; SBET=-12 42 09.8 ;!  4.0 +- 0.1
SNAM= 1629-24         ; SLAM=16 29 21.05 ; SBET=-24 22 15.5 ;! 10.5 +- 0.2
SNAM= 1641+399 3C345  ; SLAM=16 41 17.61 ; SBET= 39 54 10.8 ;!  2.2 +- 0.1
SNAM= 1749+096 4C09.57; SLAM=17 49 10.39 ; SBET= 09 39 42.8 ;!  1.2 +- 0.1
SNAM= 1757-240 OH5.89-0.39;SLAM=17 57 26.80;SBET=-24 03 57.0;! 31.2 +- 0.4
```

```
SNAM= G34.3           ; SLAM=18 50 46.17 ; SBET= 01 11 12.6 ;! 58.7 +- 0.2
SNAM= G45.1           ; SLAM=19 11 00.42 ; SBET= 10 45 42.9 ;!  7.1 +- 0.2
SNAM= K3-50A          ; SLAM=19 59 50.10 ; SBET= 33 24 19.4 ;! 11.9 +- 0.3
SNAM= ON1             ; SLAM=20 08 09.91 ; SBET= 31 22 42.3 ;!  6.2 +- 0.1
SNAM= MWC 349         ; SLAM=20 30 56.85 ; SBET= 40 29 20.2 ;! 2.59 +- 0.06
SNAM= DR21CONT        ; SLAM=20 37 14.37 ; SBET= 42 08 56.5 ;! 12.5 +- 0.4
SNAM= CRL2688         ; SLAM=21 00 19.90 ; SBET= 36 29 45.0 ;!  6.2 +- 0.1
SNAM= 2223-052 3C446  ; SLAM=22 23 11.08 ; SBET=-05 12 17.8 ;!  1.6 +- 0.1
SNAM= 2230+114 4C+11.69;SLAM=22 30 07.80 ; SBET= 11 28 22.8 ;!  1.5 +- 0.1
SNAM= 2251+158 3C454.3; SLAM=22 51 29.52 ; SBET= 15 52 54.3 ;!  1.3 +- 0.1
SNAM= 2254+617 Ceph A ; SLAM=22 54 19.00 ; SBET= 61 45 47.2 ;! 18.1 +- 0.3
SNAM= NGC 7538        ; SLAM=23 11 36.66 ; SBET= 61 11 49.6 ;! 19.7 +- 0.3
```

Please note that while we try to provide reliable flux density values for these sources, we do not monitor them. Some sources, like 3C279, may be variable. We remind you that proper data calibration is your responsibility!

4.4 Data Reduction with NIC

The **NIC** version installed at the HHT has some features which were not part of the official releases before May 2001. These are the correct rotation of the array parameters with elevation, the correct reduction for the kind of skydips taken at the HHT, and a few others. **Use only the new version of NIC for data reduction!**

4.4.1 Before you start

In order to make it easy for the FoTs to help you in case of problems, we suggest that you keep a certain (sub-)directory structure under the smtobs account. Since you're usually working in a directory called `/home/smtobs/<your_initials>`, create two subdirectories there where you store the raw data and the `.asc`-files:

```
smtobs@jever> cd ~/<your_initials>
smtobs@jever> mkdir bolo-raw
smtobs@jever> mkdir bolo-asc
```

Then, ftp the raw data (which originally reside on a VMS disk) into the `bolo-raw` subdirectory:

```
smtobs@jever> cd bolo-raw
smtobs@jever> ftp frankenheim
Name (frankenheim:smtobs): obs
Password: ...
ftp> cd kraw:[smt.data]
ftp> bin
ftp> get <filename>   (or ftp> mget <scan#_with_wildcards>t.raw)
ftp> ...
ftp> bye
```

If you don't find your data, ask the FoT – maybe he's made a backup in the meantime and moved your data to a different directory.

If you have decided to use **NIC** for your data reduction, you have to create first the `.asc`-files which are readable by **NIC** from the telescope raw data. This is done by the program **HHT2NIC**:

```
smtobs@jever> cd ~/<your_initials>/bolo-asc
smtobs@jever> hht2nic
```

The program will ask you to enter the raw data directory, which is set to `../bolo-raw` by default, thus usually you just need to hit `<Return>`. You further have to enter the scan number. We provide a shell script called `tonic` which allows you to convert a series of scans at once.

You can then load and display this file in **NIC** with the following command sequence:

```
smtobs@jever> nic
NIC> sic log BOLO_DATA: "/home/smtobs/<your_initials>/bolo-asc/"
NIC> dev im w
NIC> signal <scan#>
```

While starting, **NIC** also runs a startup file that sets all necessary variables and some default settings for the HHT (the built-in defaults in **NIC** are for the 30-m telescope on Pico Veleta). If you're lost, you can always get these defaults typing `hht` within **NIC**.

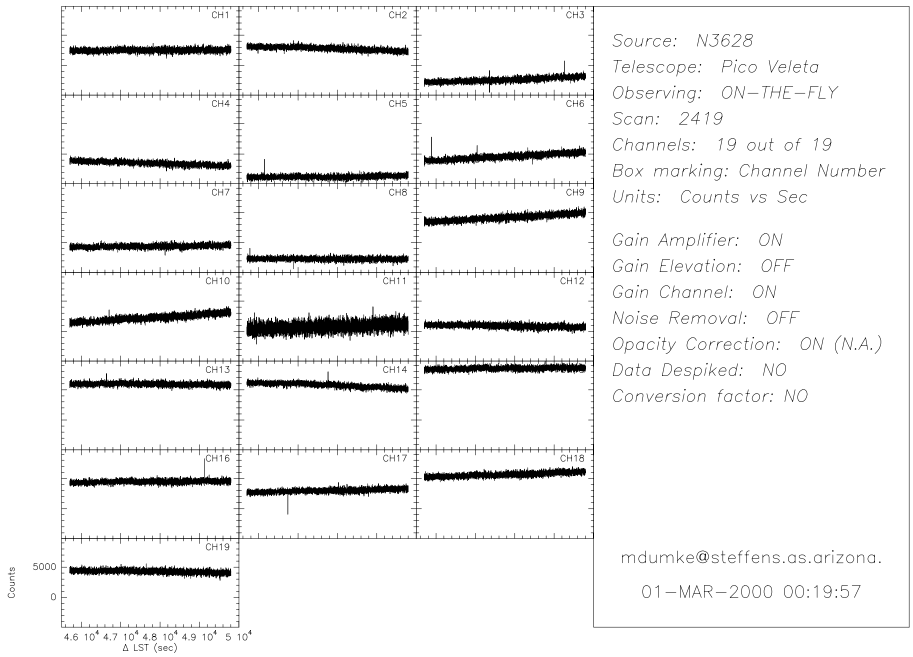

Figure 4.4: A plot produced by the `signal` procedure within **NIC**. You can easily identify some spikes in this data set, as well as one "bad channel" (number 11)

4.4.2 Calibration scans

Besides the observations of target or calibration sources, which are either On-Offs or On-The-Flys, you should also have observed several pointing, focus, and skydip scans. While you may need the first two only to check your pointing and focus corrections *after* the observation, and their use is therefore limited, the Skydips are essential during data reduction to correct your measured intensities for the atmospheric extinction.

To solve the given data type, just type `solve`. For skydips, the total power channel (which is not accessible via the `signal` command) is automatically selected, and the fit results can be written into the file `nic.sky` when typing

```
NIC> solve /file [/band]
```

Upon startup, **NIC** searches for this file in your working directory and loads it, which avoids duplicated reduction of skydip.

Pointing scans can also be reduced with the command `solve`.

Similarly, you can also reduce your focus scans.

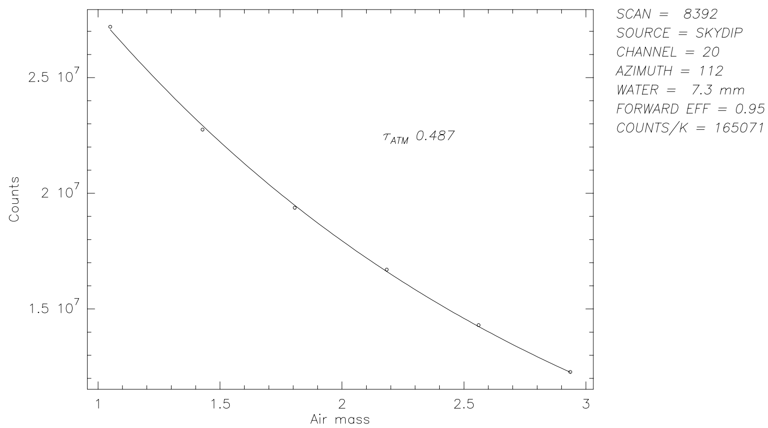

Figure 4.5: A plot produced by the `solve` command after loading skydip data in **NIC**. The Counts/Kelvin conversion factor is currently useless for HHT data.

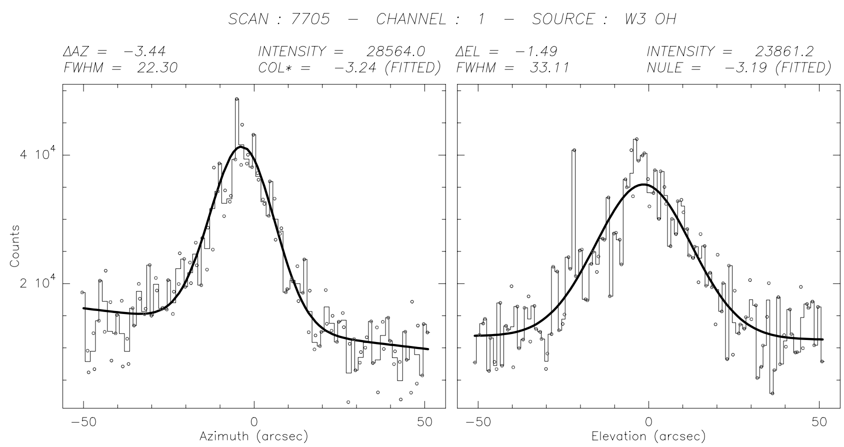

Figure 4.6: A plot produced by the `solve` command after loading pointing data in **NIC**.

4.4.3 Reducing On-Offs

On-Offs can already be reduced on the VAX using the program **ONOFF21**, since this is basically the production of a list (or a file) with countrates. But we recommend to use either **NIC** or **MOPSI** for this purpose. First, in order to avoid any unnecessary computing on the VAXes. Second, the other reduction software packages offer more possibilities to improve your data.

For the reduction of On-Offs using **NIC**, we provide a command that is called `oo`:

```
NIC> signal <scan#>.asc
NIC> oo
```

This command performs basically the following commands, which can of course also be entered by hand:

```
NIC> load_rcp              ! load array parameters for HHT
NIC> let onoff_mode -1     ! On-Offs at the HHT are unsymmetric
NIC> onoff
```

When you call `oo` the first time, it sets also the following:

```
NIC> let onoff_fit_dist 120
NIC> let onoff_beam 23.5
NIC> let noise yes
```

which can be changed by the user for the next calls of `oo`. Type

```
NIC> input onoff
```

to get a summary of the current settings.

When you run `onoff`, you'll get a table with countrates on screen and in the file `<scan#>.onf`. Further **NIC** produces a plot like the one shown in Fig. 4.7, illustrating the location of the individual channels and the countrates as a function of the position on the sky. Check on your plotting device if the opacity correction etc. was applied or not.

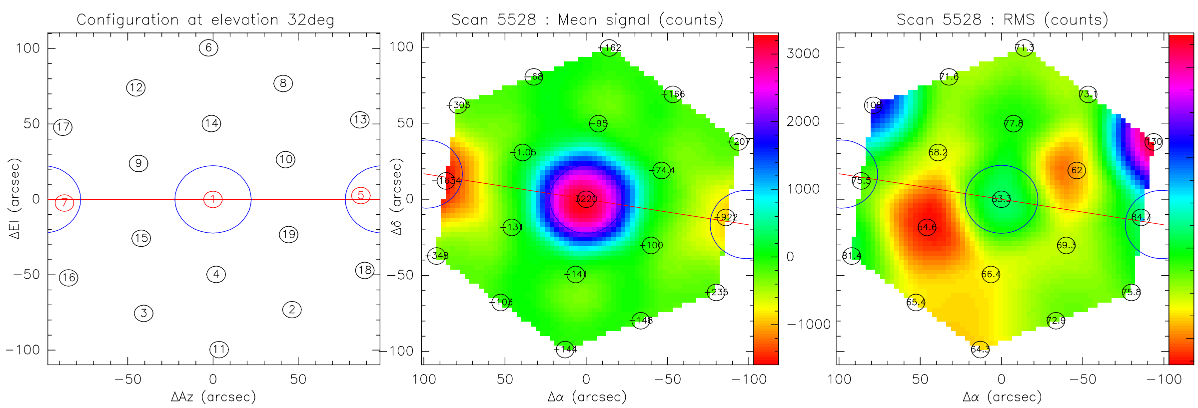

Figure 4.7: A plot produced by the `onoff` procedure within **NIC**. This plot shows the channel location in the Az-El system, as well as the countrate distribution on the sky. It indicates further the wobbler positions for the different phases

Remarks:

- In rare cases the `scan_type` may be set incorrectly by the **HHT2NIC** program. Check it on the plot or by `say 'scan_type'`. If necessary, set it to On-Off by `NIC> let scan_type 1`.

- The advantage of multi-beam array is that (in theory) all channels see the same atmosphere, but a different region on the sky. Hence all signal which is correlated between different channels should be of atmospheric origin and can be removed. For On-Offs, this can be done by `NIC> let noise yes` before you run `onoff`. However, check the resulting countrates; the algorithm implemented in **NIC** is still experimental.

- This section cannot cover all details of NIC. Have a look at the **NIC** Manual for details.

4.4.4 Reducing On-The-Flys. I. The Basics

While you're observing, you may want to get a look at the incoming data as soon as possible. This can be done using **NIC** with a series of commands. After loading and displaying the data (see above), you may already be able to see the source coming up in the plots (which show number-of-counts versus time) for the individual channels – at least when you are looking at a planet.

Before you continue, you should probably check if the channel parameters (offsets and relative gains) are correct. They are used by a few commands, e.g. `baseline`, and they are necessary for the `convert` task later. We set up a symbol and a small macro which allow you to load the "official" HHT parameters by

```
NIC> load_rcp
```

The next step now is to look for bad channels. If for one or more channels the noise seem to be much higher than for the others, flag these e.g. by the command:

```
NIC> flag /chan 13
```

or whatever your bad channels may be. Usually, there are no bad channels at the 19-channel bolometer in use at the HHT, but you may ask the FoT on duty if some channels have shown excess noiserecently.

Individual spikes (which are unavoidable) can be deleted now by typing

```
NIC> despike [/func <1,2,3>] [/chan <chan_num>] [/iter <iter>]
```

a few times, until the most severe spikes are removed. Then continue by defining a support region to be ignored for baseline fitting:

```
NIC> support
```

Without options, the support region is defined by default up to 12″ from the map edges.

Then you should subtract baselines from the data by typing

```
NIC> baseline /order 2
```

Don't think about the various baseline options at this stage. After subtracting baselines, you can go ahead and produce double-beam maps from your data with the MAKPLAN task:

```
NIC> makplan
```

Then you can either continue directly with the task RESTORE, or by defining a more "sophisticated" support region by the command

```
NIC> support /cursor
```

Good results (for this preliminary reduction) can usually be obtained when defining the support as it is shown in Fig. 4.8, i.e. by leaving about 30″ on either side in azimuth direction, but covering the whole field in elevation. The support may be smaller for point sources (which, on the other hand, should have been observed using On-Offs instead of On-The-Flys). After defining a support, you may type

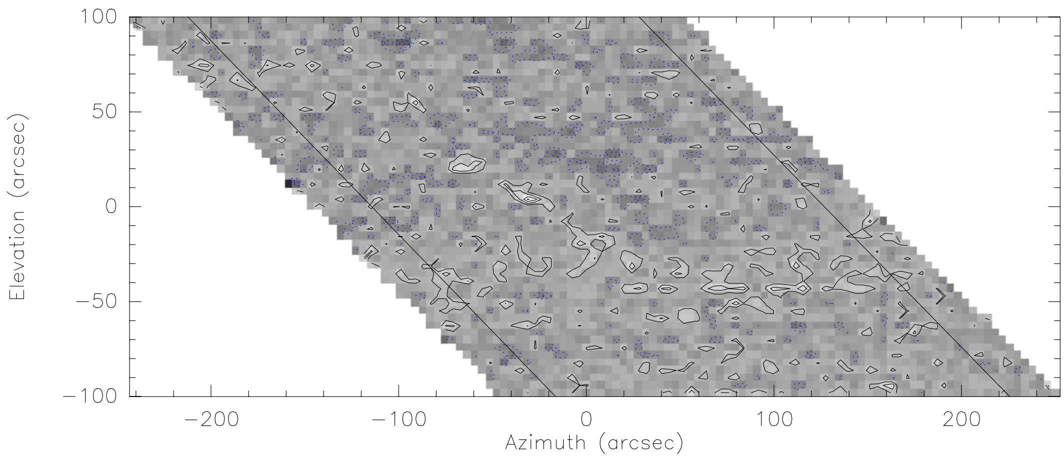

Figure 4.8: A support region defined within **NIC** during the first data reduction steps. The upper and lower edges of the support are not shown since this region covers the whole elevation range. In azimuth, edges are shown by thin black lines on the left and right

```
NIC> let do_support yes
```

which will always plot the defined support when you are plotting your maps with the MAP task.

Then just continue with

```
NIC> restore
```

which restores the double-beam maps to single-beam maps, using the Emerson-Klein-Haslam algorithm. To shift all 19 channels to a common central position and to rotate the map in the equatorial coordinate system, you will need the channel parameters (relative gains and offsets), since those implemented in **NIC** are only preliminary. So if you have not loaded the "official" parameters before (see above), you should do it at latest now by

```
NIC> load_rcp
```

which calls a macro that reads in the correct values. If you want to verify these parameters with your own planet maps, you can do this as described in the **NIC** manual. Finally type

```
NIC> convert
```

to convert the data into an equatorial coordinate system and to shift the individual channels to a common central position. The final map will then appear on the screen.

At this stage you should be able to identify your source on the plot, not only to make sure that your observing time estimates were correct, but also to define an "even more sophisticated" support for the baseline command. As a rule, the support region should be as small as possible, but covering at least all emission. This is probably a very difficult task, since the S/N may still be too low to judge if a certain region is emission-free or not. To give an example: the intergalactic cold dust in the NGC 4631 group (Neininger & Dumke 1999, PNAS 96, 5360) would probably have not been detected with a small support region covering only the main disk of NGC 4631 ....

Define the support by

```
NIC> support /cursor /file <filename> new
```

in order to save the defined support to the file `<filename>` for further use.

To improve your data reduction with the new support (however, this can be postponed to a later time, since the preliminary reduction described above should be sufficent to verify the obtained data), you have to go back to the `signal <scan #>` command. You must supply the scan number again, in order to reload the data (otherwise the old, reduced signals are plotted). Do the same data reduction steps as noted above with the new support. This will override the files which were produced in the first reduction sequence. Since the results will be again overriden with the next, more sophisticated trial, you should probably save the file you have obtained at the current stage by e.g.

```
smtobs@jever> cp <scan#>.cnv <scan#>_first.gdf
```

This file can later be used to compare the results you get with different reduction options, which will be presented in the following subsection.

4.4.5 Reducing On-The-Flys. II. Optimizing the data reduction

Now we will start to improve our results. In order to automize the data reduction, and also to keep track of what you have done (and not of what you think that you have done ...), you should create a procedure in which you can add comments, change options just by editing it with a usual text editor, etc. See subsection 4.4.5.3 for an example.

You can start be trying some options of standard commands. E.g. if the DESPIKE procedure does not find any more spikes, but you see some in the plot, try

```
NIC> despike /function 3 <level> /interpolate
```

Do not set the `<level>` value too low, otherwise you will delete (and interpolate) too many bad data, which reduces the rms noise and increases the weight for this particular (spiky) channel. You also can directly edit the SIGNAL variable within **NIC** using **SIC** commands.

After MAKPLAN, have a look at the support size. You may improve your baseline subtraction by

```
NIC> support /file <filename>   ! load the previously saved support
NIC> baseline /order 5
```

or even by

```
NIC> baseline /order <n> /bysubscan
```

what will subtract a baseline for each individual subscan. Use only order 0 for this, unless you have for each channel sufficient baseline points on either side of your support in azimuth direction. But you may use a higher order for individual channels, where this requirement is given, by

```
NIC> baseline /order <n> /bysubscan /channel <chan_num>
```

Obviously you have to try a bit. **Note:** This option deletes the support buffer for all other channels – reload it by repeating the support command before you continue!

In order to obtain a final map of your source, with all On-The-Fly scans averaged, you have to provide a list of scan numbers in the variable scan_list:

```
NIC> let scan_list "<scan#1> <scan#2> <scan#3> ..."
NIC> convert
```

Then the output file will be <source>.cnv and contain a weighted average of the three scans.

4.4.5.1 The Shift-And-Add Algorithm

The shift-and-add algorithm does not perform a restoration on the double-beam maps. It rather shifts for each azimuth scan the positive image and the negative image to the same reference position and averages them after multiplication of the negative image with –1. This method usually leads to lower noise in the final maps. It should, however, only be used if there is a clear separation between the two images. Hence it may be recommended for point-like sources and for almost one-dimensional sources (e.g. edge-on galaxies). See the **NIC** manual for further information about this task.

4.4.5.2 Deskynoising – Removal of correlated noise

The advantage of multi-beam arrays is that (in theory) all channels see the same atmosphere, but a different region on the sky. Hence all signal which is correlated between different channels should be of atmospheric origin and can be removed.

Within **NIC**, the way how "deskynoising" is used depends on the kind of data you have. For On-The-Flys, it is part of the baseline command:

```
NIC> baseline /noise [<# of points> [<beam separation>]]
```

Please have a look at the **NIC** manual if you want to use it. This process and its usage will basically result from various "trial and error" runs. You should always compare the result with maps obtained without deskynoising, because you are always in danger of removing your source if parameters are not properly set.

Anyway: Good luck!

4.4.5.3 Examples for command procedure

To reduce the data of an astronomical object, for which you have several individual coverages, you can use a file like this:

```
! file n3628.nic: Reduction of NGC3628 with NIC
!
hht
!
signal 8864.asc
```

```
@ reduce_8864
signal 8866.asc
@ reduce_8866
.
. (further scans)
.
!
let scan_list "8864 8866 ... (further scans) ..."
convert
let contour yes
let axis rel
let size 600
let levels abs
let spacing -1
levels -100 100 200 300 400
map n3628
!
```

where the reduction of the individual coverages is performed by procedures similar to the following:

```
! file reduce_8864.nic
!
load_rcp
set opacity off
let do_map no
let do_support yes
let contour no
despike /iter 4 /int /func 2
support /file base3628.pol
baseline /or 2
signal
baseline /noise 61
signal
despike /iter 3 /int /func 3
signal
baseline /order 5
signal
set opacity on
set jansky on 1100
!
 let map_cell 8 8
 !let taper parabolic
 let smooth_el no
makplan
 let beamsep 99
```

```
 !let rotation 0
 !let unbal 1
 let restore_filter YES
 !let comb_teeth 0
restore
 !let ra_extent 0
 !let dec_extent 0
 let radec_cell 8 8
 let cutoff 0.1
 let taper 1 ! Gaussian
 let contour yes
 let size 600
 let levels abs
 level -200 200 to 1200 by 200
convert
```

4.5 Data Reduction with MOPSI

Since the **MOPSI** program was written by Robert Zylka for his private data reduction purposes, it lacks a documentation and an online help. Therefore the use of this program needs some experience if you want to get optimal results, but it can also be used with a few commands for a quick data reduction. The best thing would be to have a collaborator experienced with **MOPSI** who can set up a commandfile for a quick *and* efficient data reduction for you. In general, you have more possibilities to access and manipulate the data than in **NIC**, and via command procedures you can completely reduce your data starting from the raw data files (see below) to publication-quality plots.

We maintain currently two versions of **MOPSI**: The new one (called by `mopsi`) can read the raw data directly and offers more features, while the old one (called by `oldmopsi`) needs the `.atd` files and is well tested. We recommend to use the new version, unless you don't trust anything which is new. Note that the following recipes are optimized to be used with the new version. We should say that this new version is dated from March 2000. Since then **MOPSI** has evolved a lot — more options were included, and maybe some old commands do not work anymore. The big disadvantage of newer version of **MOPSI** is, however, that they cannot read the telescope raw data. Due to ongoing discussions about how to merge **MOPSI** and **NIC** into a more powerful program and the lack of manpower at the SMTO we don't support the more recent versions of **MOPSI**. See subsection 4.6.6 on where to get these if you are interested.

One remark: You will notice that your working directory will be filled with logfiles and message files from **MOPSI** (which are called `MOPSI.LOG<n>` and `MOPSI.MES<n>`) when you repeatedly use this program. We've created a simple command called `delmopsi` which will delete all these files if you don't need them.

4.5.1 Reading the raw data in MOPSI

The latest version of **MOPSI** available at the SMT cannot read `.atd` format, but (what is probably even better) is able to read the old raw data format directly. Copy the raw data files with `ftp` (faster than `cp`) to your desired directory on the Unix machines:

```
smtobs@jever> cd /home/smtobs/<your_initials>/bolo-raw
smtobs@jever> ftp frankenheim
Name (frankenheim:smtobs): obs
Password: ...
ftp> cd kraw:[smt.data]
ftp> bin
ftp> get <filename>   (or ftp> mget <scan#_with_wildcards>t.raw)
ftp> ...
ftp> bye
```

Even if the new **MOPSI** cannot read `.atd` files, it still can write them out. This is not necessary – but if you find it more convenient . . . but be aware that you can read them only with old **MOPSI** versions (or with versions more recent than March 2000 - but none of these is installed at the SMT).

4.5.2 Calibration scans

MOPSI is capable of reducing all kinds of calibration scans you observed during your run: pointing, focus, ... You may think about them re-reducing offline, in order to see if you need to introduce some corrections. However, if you made some notes during the observations (which is highly recommended), this is not necessary, with one exception: skydips. Furthermore, you may need some planet observations to estimate the array parameters.

4.5.2.1 Skydips

If you do not want to supply the zenith opacity for every On-The-Fly or On-Off, the skydips can be reduced in the same session as your other data. The results are stored in memory and are applied to your target scans. You can also write out the calculated opacities using the `write taus` command, and reload them for the reduction of your target sources.

Before you start, you should create a list of your observations (i.e. a list of your raw data files). Do this by typing

```
smtobs@jever> ls *t.raw > rawdata.LIST
```

in your raw data directory, that it looks like the following:

```
2419t.raw
2420t.raw
2421t.raw
...
2508t.raw
```

Then copy the file `rawdata.LIST` into your working directory. If you don't use a list, the general input command for **MOPSI** is `read <filename>`.

When you create this list differently, you only need to make sure that all Skydips and all target observation (On-Offs and On-The-Flys) are in the list. You may also want to include planet observations (which you should have been made for calibration purposes).

Reduce the Skydips by the following command sequence (let's assume that your list file is called `skydips.LIST` and your raw data are in the subdirectory `./bolo-raw`):

```
smtobs@jever> mopsi
MOPSI> device image white
MOPSI> in-dir "./bolo-raw"
MOPSI> init in-list
MOPSI> list skydips
MOPSI> sort list
MOPSI> select SKYDIP
MOPSI> for i 1 to last
MOPSI>   read next skydip
MOPSI>   take rc 20
MOPSI>   clear plot
MOPSI>   skydip
MOPSI> next
MOPSI> write taus <filename>
```

We have created a template macro for skydip reduction, which uses basically the above commands, and placed it in `/home/smtop/gag/bolo/examples/skydips.MOPSI`. Copy this file into your working directory, look at it with `more skydips.MOPSI` to know how it works, and use it within MOPSI by `@ skydips`. This macro should usually work fine. If you encounter any problems, remove the scan number which causes trouble from your file `rawdata.LIST` and look at this scan in detail. Either the weather was very strange, and no useful fit to the data points is possible, or the data are corrupted, e.g. for aborted scans.

After typing the above commands or using `@ skydips`, the results are now in memory. If you've written the results into a file (which is recommended, to compare them with results from **NIC** and to edit them if necessary), you can recover and apply them using

```
MOPSI> taus <filename> <interval>
MOPSI> corr extinc
```

in your On-Off and On-The-Fly reduction. `interval` gives the time interval around your target observation in which a skydip is considered. A value of 10000 should be okay.

When you later exit MOPSI, you can copy the file `MOPSI.LOG<n>` to `<yourname>.MOPSI` to produce your individual data reduction macro, which can then be edited (you usually will enter some more sophisticated commands and comments) using a normal text editor.

4.5.3 Reducing On-Offs

On-Offs cannot be reduced with the old **MOPSI**. Using the new version, you can also work with lists, or you can read the data manually. We show here the second case:

```
MOPSI> in-dir "/home/smtobs/<your_initials>/bolo-raw"
MOPSI> read <scan#>th11x.001
MI_oo> dele rc 20 21
MI_oo> oo
```

However, before calling `oo`, you may want to improve your data by baseline subtraction, despiking or eliminating correlated noise. Further you should correct for the atmopsheric extinction. These items will be described in subsection 4.5.4, in order to avoid some duplication here. When you exit **MOPSI** after calling `oo`, the results will be written to a file called `<SOURCE>.OO`.

If you have several On-Offs for the same source, and you have reduced the first as above, you can do the second and all other (probably in a loop) with command `oo add`, which will force **MOPSI** to average the results and write the new averages on the screen and in the output file.

4.5.4 Reducing On-The-Flys

Okay, now comes the tricky part. However, the "basic" reduction is simple and consists only of a few steps:

```
MOPSI> in-d "/home/smtobs/<your_initials>/bolo-raw"
MOPSI> read <scan#>th11x.001
```

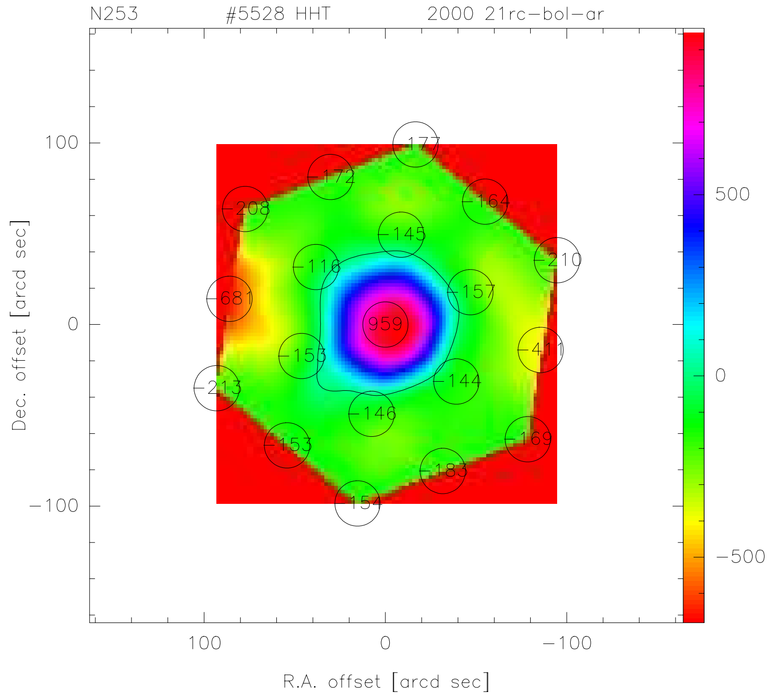

Figure 4.9: A plot produced by the **oo** command within **MOPSI**. This plot shows the channel location in the Az-El system, as well as the countrate distribution on the sky

```
MAP> dele rc 20 21                       ! or bad-rc 20 21
MAP> base-rang out 100 /syst equ /proj <hh mm ss> <dd am as>
MAP> base-surface 0
MAP> store weight rms2 in base-range
MAP> restore <wob_throw -1> !
MAP> convert
MAP> plot
MAP> file out <yourfile>.nod
MAP> write
MAP> close out
```

These steps are:
1) Read the data. You can also use a sequence consisting of file in <filename> and read, which allows you to use the various options of the read command, but the above is shorter.
2) Flagging bad channels. These must be at least numbers 20 and 21, since they are not used for your astronomical data.
3) Setting a base range. The above uses everything more than 100″ away from the projection center. If you don't want to type too much at this stage, use base-range out 100 /syst hori. You must define a base-range to subtract a baseline and thereby estimating the noise and weighting of the individual channels.
4) base-surface 0 ist the least destructive way of setting baselines ...
5) Store the channel noises in some internal buffer.
6) Restore your double-beam map. The exclamation mark is necessary if you have blanked

points in the data (which is almost always the case). The actual beam-separation is somewhat smaller than the wobbler throw chosen during the observations – the difference is about $1''$. Supply this value to improve the restoration process.
7) Rotate the Az-El-maps into the equatorial system and adds up the individual channels to one final map. 8) Plot your results and write them out. Don't forget to close the output file.
All the above results can be appended to the command file you have probably already created from one of the `MOPSI.LOG<n>` logfiles.

4.5.4.1 Atmospheric extinction

We recommend to correct for the atmospheric extinction in the very beginning of your data reduction. When you reduced the skydips as described in subsubsection 4.5.2.1, the results should be in the memory, and you can apply them directly after reading the data. However, we recommend to write them into a file and apply them by

```
MAP> tau <filename> 10000
MAP> corr ext
```

When you later look into your data in more detail, e.g. to estimate levels where you want to cut possible spikes, it is important to make this correction *always before* or *always after* every intensity-dependant action in your commandfile. An example: If you estimate that spikes can be cut off at a level of 2000, verify if you have estimated this level before or after the extinction correction, and set the corresponding command at the appropriate place in your command file. Since we recommend to make the correction in the beginning, this requires to do it always after reading the data, before you edit them e.g. with the `strip` subroutine.

4.5.4.2 Displaying and evaluating your data

Within **MOPSI**, you can always use the command `plot` to display the data. A different way is the subroutine `strip`, which gives you a linear ($S = \mathrm{f}(x)$) plot for individual (or all) channels. To give an example, the following sequence of commands diplays channel 7 off scan no. 6978:

```
[ MOPSI> @ skydip_reduction ! ... see above ... ]
  MOPSI> atd 6978
[ MAP> tau skydip 10000                         ]
[ MAP> corr ext                                 ]
  MAP> strip
   STRIP> column 1 last
   STRIP> row 1 last rc1
   STRIP> limits -1.2E5 1.2E5
   STRIP> histogram
   STRIP> box
```

As a reminder, I included in this example the skydip reduction steps within `[ ]` – they are of course not necessary to use `strip`. The result of the above sequence is shown in Fig. 4.10. The `limits` command without values will cause `strip` to calculate the plot limits; you can adjust them later.

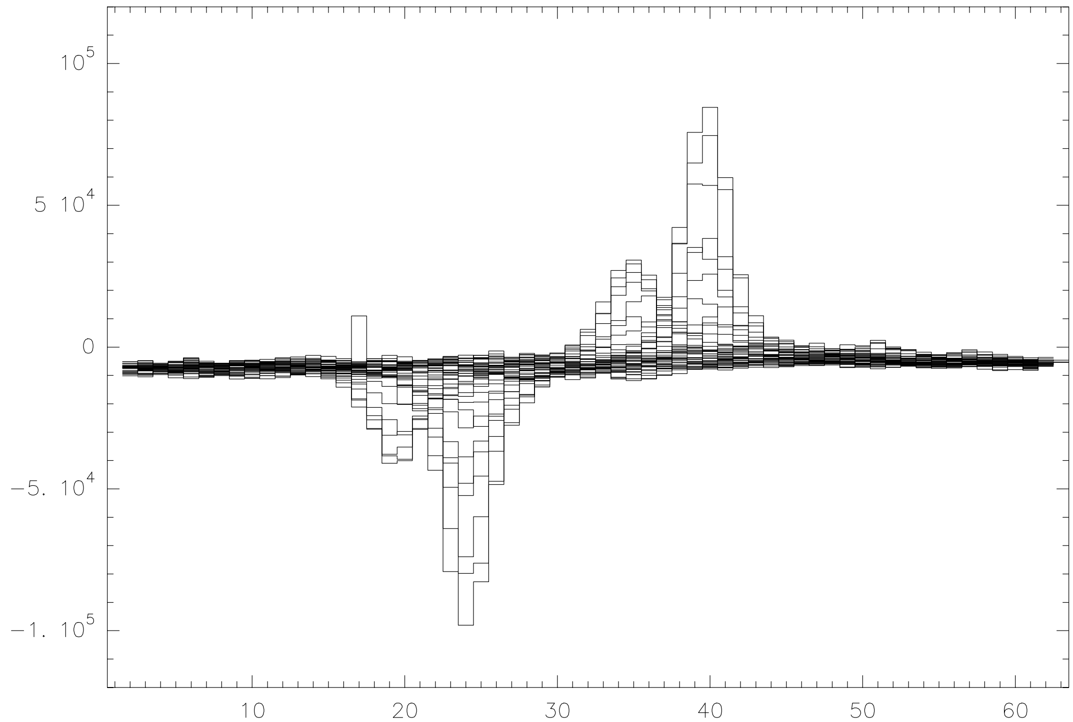

Figure 4.10: The `strip` command can be used to visualize your data and to check intensity values. The source shown here is strong enough to reveal the double-beam structure resulting from the wobbling seecondary mirror. Further you see one spike at $x = 17$ which should be located using the command `histogram /single` and deleted during the data reduction process

4.5.4.3 Baseline subtraction

Before you can subtract a baseline (whatever kind), you have to define a region where **MOPSI** estimates the baseline. This region should obviously not contain any emission, in order to get a correct zero-level.

You have several possibilities to define the `base-range` (see also the `help` command in **MOPSI**):

`base-range out <value> /system hori`:
sets the base range outside a circle with radius `<value>`, in the horizontal system. Useful for planets. When observing compact sources, exchange the `system` as in the following example.

`base-r az < -<val1> > <val2> /pa <ang> /sys equ /pro hh mm ss.s dd am as.s`
sets the bas-range outside a certain azimuth range (defined by `<val1>` and `<val2>` of a line going through the given projection center at angle `<ang>` (ccw from north). Useful for

linear sources, e.g. edge-on galaxies.

```
polygon <name>.pol
mask out /syst equ /proj hh mm ss.s dd am as.s
```

sets the base range outside a polygon which must (in this case) be defined in the equatorial system. The "best" possible base range, but you need already a preliminary map to decide how to define the polygon.

After defining the base range, you can set `base-l` (row by row), `base-s` (surface), or `base-t` of various order. The latter does not need a defined `base-r`, since it works in time. Be careful with higher orders for `base-l` when your `base-r` is set rather large.

4.5.4.4 Despiking

Spikes are unavoidable. After `init spike_pointer`, you can cut them above `<value>` by the command `high <value>`, and similarly by `low <value>` for negative spikes. Use the subprogram `strip` to determine these values, but take care if you have already applied the opacity correction or not. It is also possible to give a multiple of the rms instead of a fixed value. Further you can use `mask spike` or `interpol spike` to further improve the data. See the **MOPSI** help for more information, and play around with the parameters.

4.5.4.5 Masking irrelevant regions

In **MOPSI**, you can mask regions far away from the source, because in the restoration process they will only contribute to the noise. See the `help` command and the "pocket cookbook" for details.

4.5.4.6 Mask-and-Shift Restoring

Mask-and-Shift is the **MOPSI** version of what is called "Shift-and-Add" in **NIC**. It is recommended only if there is a clear separation between positive and negative beam in the double-beam maps, which means for very compact sources (e.g. QSOs) or narrow, one-dimensional sources (e.g. edge-on galaxies) when observed at a "good" hour-angle (that means scanning-direction more or less perpendicular to the source orientation). The reduction is identical to the normal restore until the double-beam filtering. But in the Mask-and-Shift case the edited data are written out unrestored, and then read in, restored and converted (and perhaps averaged) at once within **HORTOEQ** (called by **convert**).

Here we give the sequence of necessary commands. The new **MOPSI** under Solaris seems not to be able to do this with a list, so I give the "extended" version here:

```
in-d "/home/smtobs/<your_btd_directory>"
read <scan1>.btd
conv /comm
  ext <ra-ext> <dec-ext>
  blc <ra-of> <dec-of>
  proj <hh mm ss.s> <dd am as.a>
  mask az > <value> /pa <angle> /proj <hh mm ss.s> <dd am as.a>
  shift az <0.5*wob_throw>
```

```
  run
read <scan1>.btd
  mask az < -<value> /pa <angle> /proj <hh mm ss.s> <dd am as.a>
  shift az <-0.5*wob_throw>
  mul -1.0
  run
read <scan2>.btd
  mask az > <value> /pa <angle> /proj <hh mm ss.s> <dd am as.a>
  shift az <0.5*wob_throw>
  run
read <scan2>.btd
  mask az < -<value> /pa <angle> /proj <hh mm ss.s> <dd am as.a>
  shift az <-0.5*wob_throw>
  mul -1.0
  run
... (further scan)
  quit
file out <filename>_saa.nod
write
close out
```

4.5.4.7 Removal of correlated noise

For the 19-channel array, all channels look through the same atmosphere, but at a different region in your target source. Hence the astronomical signal is uncorrelated, while the noise introduced by the atmosphere should be the same for each channel. You can use the `skynoise` command to eliminate this correlated noise, but be careful since `skynoise` is (and will ever be) in an experimental stage. I made good experiences with `skynoise /iter 3 3 /mode 9 7`, but don't ask me what these modes mean ... you have to play with, but always compare the result with what you get without `skynoise`, and if your source structure changes significantly, forget it. Even if the author of **MOPSI** has not recommended to use `skynoise` for very weak sources or large mosaics, it is especially useful for weak sources to improve the signal-to-noise ratio. As far as I know, it is possible to define a source model/polygon to avoid that `skynoise` eats up your source. A possible commandline often used is

```
MOPSI> skynoise iter 3 0 dr 51 no plot
```

You must supply `dr 51` – it gives the search radius for the algorithm which is set by default for the bolometer array at the 30-m telescope, which has a much smaller angular distance between the individual channels (20″) compared to the array at the HHT (about 50″).

4.5.5 Some examples for command procedures

In order to provide a starting point for your data reduction, we will list in the following a simple command procedure, and will explain thereafter how you can improve your reduction by adding more and more features. We recommend that you enter all commands by hand at least once, in order to learn about **MOPSI**. Note that values given in this example are only . . . examples – you have to adjust them to your data.

Let us assume you have created a file called `examlist.LIST` with all maps of one source and all skydips surrounding these map measurements. It will probably look like:

```
7706th11x.001
7707th11x.001
...
7712th11x.001
```

A basic reduction file would then be the following. This example is already an enhanced version, since it creates the lists by itself (if the directory structure is okay) and uses some despiking:

```
!  Example procedure for OTF reduction
!  Version: 03/2000, Procedure: restore
!  Source: N2146
!
in-d "/home/smtobs/kont/raw2146"
sys "!test -f raw2146.LIST && /bin/rm raw2146.LIST"
sys "!cd ../raw2146;ls *th11x.001 > ../mopsi/raw2146.LIST;cd ../mopsi"
init in-list
init out-list
list raw2146
select type map skydip
select N2146* SKYDIP
sort list
show list
!
! Reduction Skydips
!
for i 1 to las
  read next skydip
  clea plot
  take rc 20
  skydip
next
sys "test -f n2146.sky && /bin/rm n2146.sky"
write taus n2146.sky
!
! Reduction Maps
!
out-d "/home/smtobs/kont/mopsi/n2146"
sys "!test -f ./n2146/*b2_res.btd && /bin/rm ./n2146/*b2_res.btd"
for i 1 to las
```

```
  read next map
  dele rc 20 21
  taus n2146.sky 10000
  corr ext
  base-t 2
  base-r az < -60 > 60 /pa 128 /proj 6 10 40.1 78 22 23.0
  base-s 2
  init spike_pointer
  low -13000
  high 13000
  base-r az < -60 > 60 /pa 128 /proj 6 10 40.1 78 22 23.0
  base-s 2
  mask spike 18000
  base-r az < -60 > 60 /pa 128 /proj 6 10 40.1 78 22 23.0
  base-s 2
  base-l 0
  store wei rms2 in base-r
  db_f -98 !
  restore -98 /nofilter !
  write .btd -th11x +b2_res
next
!
! Rotation to Az-El and Summation
!
in-d "/home/smtobs/kont/mopsi/n2146"
out-d "/home/smtobs/kont/mopsi"
read 7707b2_res.btd
convert /comm
  ext 700 700
  blc 350 -350
  proj 6 10 40.1 78 22 23.0
  run
read 7708b2_res.btd
  run
read 7710b2_res.btd
  run
  quit
sys "test -f n2146_res.nod && /bin/rm n2146_res.nod"
file out n2146_res.nod
write
close out
clea plo
plot
sys "test -f n2146.ps && /bin/rm n2146.ps"
hardc n2146.ps /dev eps col
```

```
!
```

This procedure will produce the following files:
1) A table of skydips, called `n2146.sky`
2) restored `.btd` data of your maps, in files named e.g. `7708b2_res.btd`
3) a restored, converted, and co-added output-map in the file `n2146_res.nod`
4) a plot of the final map in `n2146.ps`

If you use the Shift-And-Add method, it looks very similar until the double-beam filtering (`db_f -98 !`), except the file names which should somehow indicate that the written `.btd` files are not restored. We give the second half of an appropriate file below:

```
  ...
  db_f -98 !
  write .btd -th11x +b2
next
!
! Rotation to Az-El and Summation
!
in-d "/home/smtobs/kont/mopsi/n2146"
out-d "/home/smtobs/kont/mopsi"
read 7707b2.btd
convert /comm
  ext 700 700
  blc 350 -350
  proj 6 10 40.1 78 22 23.0
  mask az > 10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az 49
  run
read 7707b2.btd
  mask az < -10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az -49
  mul -1.0
  run
read 7708b2.btd
  mask az > 10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az 49
  run
read 7708b2.btd
  mask az < -10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az -49
  mul -1
  run
read 7710b2.btd
  mask az > 10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az 49
  run
```

```
read 7710b2.btd
  mask az < -10 /pa 128 /proj 6 10 40.1 78 22 23.0
  shift az -49
  mul -1
  run
  quit
sys "test -f n2146_saa.nod && /bin/rm n2146_saa.nod"
file out n2146_saa.nod
write
close out
!
```

4.6 Miscellaneous

Using either **NIC** or **MOPSI**, you should be able to reduce your bolometer data and should get good results.

However, we're always searching for possibilities to improve the results coming out of our telescope. Therefore we are currently testing several programs of the NOD2 package if they are usable for bolometer reduction. Even if this may complicate things a bit, we may in the future perhaps recommend to do some steps of the reduction using one program, and other steps using another program. Furthermore we will investigate (not today or tomorrow, however ...) the possibilities offered by **AIPS++**. And of course you're welcome to "play" with NOD2 programs like **PLAIT** or **OZMAPAX** if you want to improve your results.

While observing, it is your responsibility to obtain all information which is necessary to properly calibrate your data. In the following two subsection we describe the procedures you will need for this purpose.

4.6.1 Calibration. I. Array Parameters

Usually, the array parameters should have been estimated and stored during several test runs made by the SMTO staff. They are stored in a file called `2000s_21.rcp` for **MOPSI** and `2000s_21.nic` for **NIC** (where "2000" denotes the year, and "s" means "spring", so this will obviously change in autumn ...) in the directory `/home/smtop/gag/bolo/rcp`. The environment variable `ZYLKA_RCP`, which is necessary for **MOPSI** to find the parameters, is set to this directory by default. To update the channel paramters in **NIC**, we provide the `load_rcp` command, which searches for the correct array parameters after reading the `DATE_OBSERV` variable from the current data set.

However, you can estimate the array parameters by yourself from maps of strong point sources (usually planets) – but be aware of statistical differences between your results (fitted from one data set) and the long-term test measurements made by the SMTO staff.

Use the following commands to get the array parameters in **NIC**. If not already done, open the plotting device first. Note that you have to reduce the skydips first.

```
NIC> sic log BOLO_DATA: "/home/smtobs/<your_initials>/bolo-asc/"
NIC> signal <scan#>
NIC> set opacity on
NIC> flag /reset
NIC> set gain_channel off
NIC> support
NIC> baseline /order 0
NIC> makplan
NIC> fit
NIC> restore
NIC> fit /file sc<scan#>_nic.fit new
```

We recommend to estimate the channel parameters with NIC first, since the first fit procedure above (on the .mdb file) directly gives the beam separation you have to provide for the restoration in MOPSI.

In **MOPSI**, use the following:

```
MOPSI> in-d "/home/smtobs/<your_initials>/bolo-raw"
MOPSI> read <scan#>t.raw no-rcp
MAP> base-range 1 last
MAP> base-surface 0
MAP> dele rc 20 21                      ! or "bad-rc" with oldmopsi
MAP> taus <filename> <interval>
MAP> corr ext
MAP> init gfits
MAP> restore <beam_sep> !
MAP> rc-p gfits
MAP> write rc-p sc<scan#>_mopsi.rcp  ! to save them on disk, or
MAP> store rc-p                         ! to store them in memory
```

If you don't type the `restore` command, it will be called automatically by `rc-p gfits`. But then you cannot correct for the fact that the real beam-separation is $1'' - 2''$ smaller than the wobbler throw. The effect of this correction on the results, however, is rather small.

To get back the parameters, use the `fit2rcp` and `rcp2nic` programs to convert the `.fit` file produced by **NIC** into a macro which loads these parameters back into the program (ask the FoT about details). In **MOPSI**, use the following commands:

```
MOPSI> rc-p stored                  ! for those in the memory, or
MOPSI> rc-p <filename>              ! for parameters from a file, and
MOPSI> apply rc-p
MOPSI> rc-p                         ! to print them on the screen
```

The last command in the above sequence is just to confirm that the applied parameters are those you want to use.

If you want to use your parameters, stored in a file, instead of the default, type

```
smtobs@jever> setenv ZYLKA_RCP .
```

or any other directory where **MOPSI** will find the file `2000s_21.rcp`.

Usually these parameters should not change over a short period of time. Again, you should use those supplied by the staff. You may also consider observing a planet every day (not a bad idea ...) and averaging the results.

4.6.2 Calibration. II. Absolute intensity scale

When you reduce your data, the final values in your maps or in the tables with results of On-Off-measurements are calibration in counts (as a result of the voltage-to-frequency conversion by DRUMBEAT). In order to get intensities in astronomical units (Jansky), you have to determine a counts-to-Jansky conversion factor with the help of planet observations. You should make On-Off- and On-The-Fly-measurements of 2 or 3 different

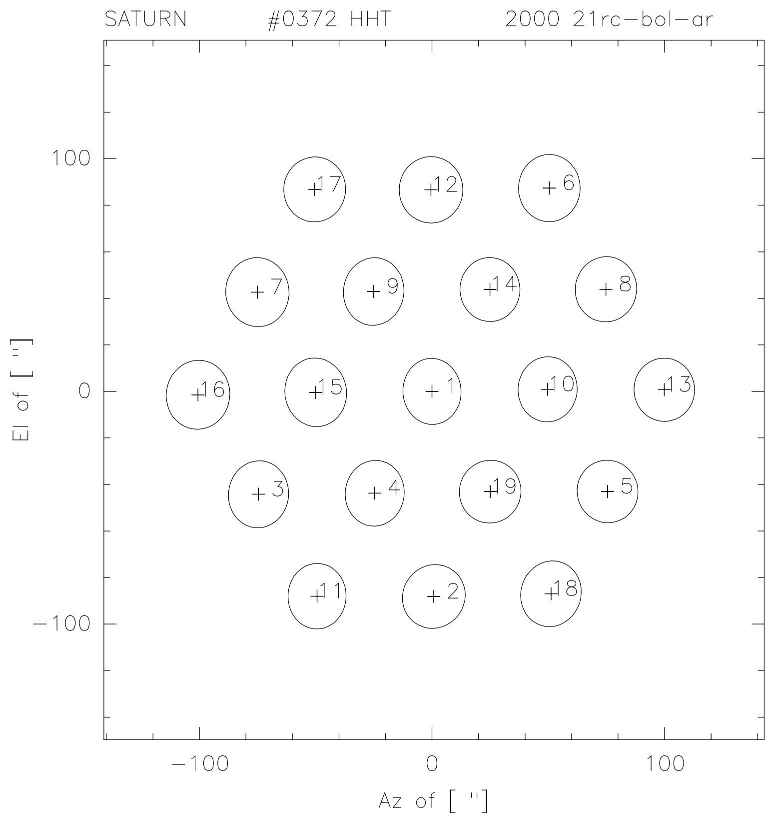

Figure 4.11: The location of the individual array channel on the sky, or the "channel parameters", as obtained with an appropriate set of commands with **MOPSI**. Note that the total size of the array is about 200″ and therefore larger than that of the arrays at the 30-m telescope

planets (if possible) during your observing run. Reduce the scans as described earlier in this chapter – however, the details of the reduction (what baseline-order, deskynoising or not etc.) are less critical. But in any case you *must* correct your data for atmospheric extinction – make sure that you have reliable skydip measurements before and after your planet observation.

Be aware that **MOPSI** recalculates the relative gains for the individual channels to ensure that their average is 1.0, while **NIC** normalizes in a way that the relative gain for channel 1 is 1.0. We kept this convention, so if you're using either program in your home institution, you get the same results. However, the counts-to-Jansy conversion factor mentioned above will differ for the two software packages: that applied to data reduced with **NIC** has to be (currently) 1.07 times larger than that used for **MOPSI**-reduced data.

To get a flux density value for a chosen planet, you can use the subroutine PLANETS within **MOPSI**. Upon entering, you have to answer a few questions. The default may be okay for most, except for the beam width (22.″4 for the 19 channel array) and the geocentric distance of the planet. The latter is available from the Astronomical Almanac. You will then get the intensity (i.e. Jy/beam) of this planet at the pointing position as well as its total flux density at the given frequency. Since planets are no point sources, use the former to calibrate your data.

4.6.3 Spectral response of the bolometers

The knowledge of the spectral response (the bandpass) of a bolometer is important not only for proper data calibration (since the effective observing frequency can change with varying atmopsheric transition), but also to estimate the contribution of spectral lines to the bolometer signal.

The spectral response of a bolometer receiver is a function of many parameters. It can be measured by using the bolometer to take a spectrum of a source of known emissivity (a black body) with a spectrometer of known efficiency (a Martin-Puplett-interferometer).

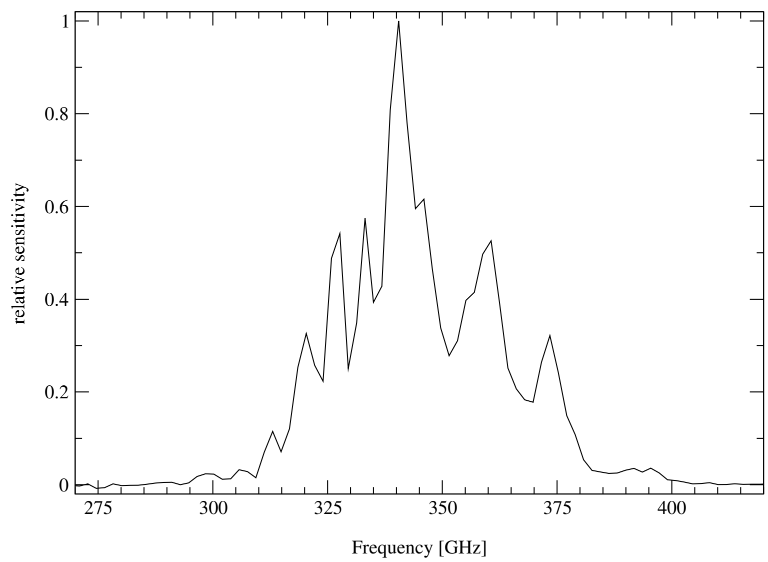

Figure 4.12: The spectral response of the central channel of the 19 channel bolometer array. The variation of the bandpass shape for the different channels is typically below 5 %

4.6.4 Data organization

On the VAX, the raw data are stored in the directory `KRAW:[SMT.DATA]`, or, if the data are somewhat older, in `KRAW:[SMT.OLD_DATA<n>]`, with `<n>` either nothing or $1-9$. These raw data can directly be read by the **MOPSI** program. You can access the raw data while they reside on the VAX, but we recommend to ftp them to Jever.

In your directory on jever, which should be `/home/smtobs/<your_initials>`, we recommend that you store the `.atd`-files (if you use them) in the subdirectory `./bolo-atd`, the `.asc`-files in `./bolo-asc`, and the raw data format files (which were ftp'd or copied from the VAX) in `./bolo-raw`. You can control the access to these directories through environment variables or via the commands `in-d` in **MOPSI** and `sic log BOLO_DATA:` in **NIC**.

4.6.5 Conversion utilities for continuum data

You may have noticed that several different data formats are available in the astronomers' community. While the topic "data formats" may need its own manual thicker than that

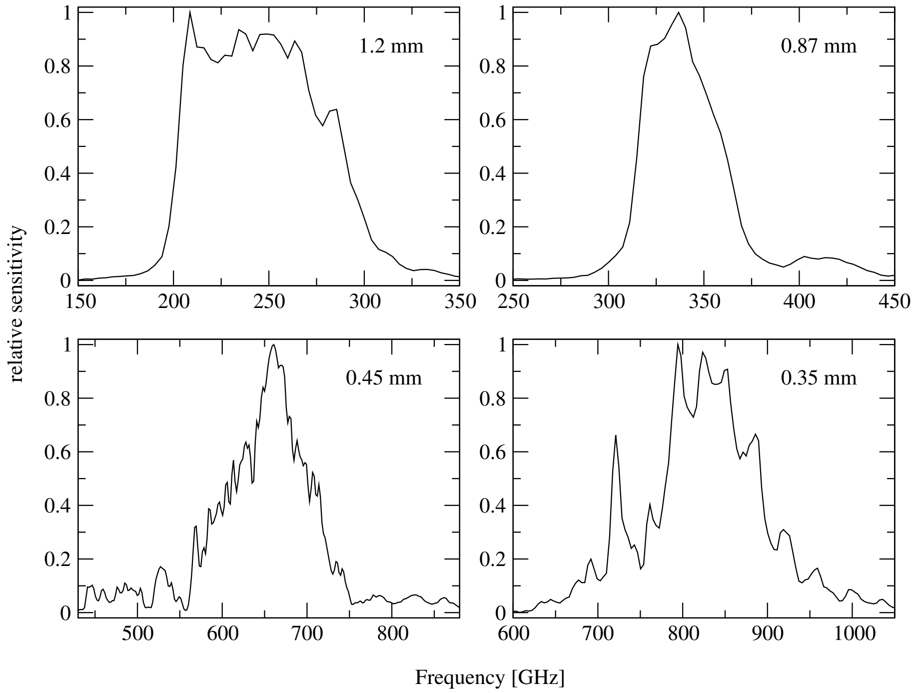

Figure 4.13: The spectral response at the different wavelengths of the 4 Color Bolometer system

for the SMTO, a few data types are of special interest when dealing with continuum maps:

- FITS: the standard, used by AIPS, nothing more to say about ...
- GDF: the Gildas Data Format. This is used especially by the Grenoble software. It can be data cubes in four dimensions. If only the first two are used (only 1 plane), we can use it for continuum maps (usually a weighting function is stored in a second plane).
- NOD2: the continuum data format used at those large telescopes where german astronomers are involved: Effelsberg, Pico Veleta, and also HHT.

Regardless what data format you prefer to use, the standard for data exchange between different institutions and telescopes is probably FITS. The **NIC** software described in this chapter produces its output in GDF format, while the **MOPSI** program writes NOD2 maps. We provide a set of data conversion utilities between these different formats.

Remark: This section does not cover the data conversion for spectral line data. Look at the **CLASS** Manual to know how to convert your CLASS spectra into FITS files.

4.6.5.1 The MOPSI output – NOD2

If you prefer to use **MOPSI** for your bolometer data reduction, there is in fact no need to transform your data – install **MOPSI** at your home institution and continue your data analysis with it. Nevertheless, here are some recipes for data conversion.

- NOD2 → GDF:

```
smtobs@jever> mopsi
MOPSI> file in <filename>.nod
MOPSI> map 1
MOPSI> read
MAP> put
MAP> greg set angle second
MAP> put
MAP> greg write image <filename>
MAP> exit
```

will produce a file `<filename>.gdf` which can be loaded and analysed in **GRAPHIC** or **MAPPING**. You may also type `MAP> extr /co` to check if the values are reasonable.

- NOD2 → FITS:
Unfortunately **MOPSI** cannot write out FITS files, hence it is recommended to produce a `.gdf` file in **MOPSI** and produce a FITS file in **GRAPHIC** with the task GILDAS_FITS. However, by default the projection type written by **MOPSI** is *RADIO* instead of *AZIMUTHAL*, which will appear as Sanson-Flamsteed projection (`CTYPEi` = ...`--GLS`) in the FITS file, which is not really useful for most applications. Change the projection first by the following command sequence (in **GRAPHIC**):

```
GRAPHIC> define image a <oldfile>.gdf read
GRAPHIC> define image b <newfile>.gdf real /like a
GRAPHIC> let b% a%
GRAPHIC> let b%ptype 3
GRAPHIC> header /update
GRAPHIC> let b a
GRAPHIC> del /var a
GRAPHIC> del /var b
```

and then `GRAPHIC> run gildas_fits /edit` with `<newfile>.gdf` as input. Use −32 for `BITPIX`.

- NOD2 → NOD2:
Since **MOPSI** stores the weighting function in a different way than other NOD2 programs, only simple, unweighted maps can be transferred between these two, and you must specify that you want to write out an unweighted map. Since you usually want to keep as much information as possible, this is only recommended in addition to writing out your results as weighted map:

```
MOPSI> file out <filename>.nod
MOPSI> no weight
MOPSI> write
MOPSI> close out
```

Interestingly, plane #2 is not deleted, but combined with plane #1 (the data) as an extension in declination. Use the MPSIZE subroutine (# 7) of the **OZMAPAX** program to cut off this extension.

4.6.5.2 The NIC output – GDF

If you use **NIC** for your data reduction, you may probably continue with **GRAPHIC** or **MAPPING**, which is okay. Nevertheless, here we explain how to convert your data into other formats.

- GDF → FITS:
  This is easy and straightforward using the GILDAS_FITS task. In **GRAPHIC**, type

  ```
  GRAPHIC> run gildas_fits /edit
  ```

  enter the requested variables and go ahead.

- GDF → NOD2:
  Since **MOPSI** can read both `.gdf` and `.fits` data, they can be loaded in **MOPSI** without problems. To get a file in NOD2 format, you should do the following in **MOPSI**:

  ```
  MOPSI> file in <oldfile>.gdf
  MOPSI> map 1
  MOPSI> read
  MAP> file out <newfile>.nod
  MAP> nod
   TONOD> help
   ...
   TONOD> quit
  MAP> write
  MAP> close out
  ```

  The subroutine TONOD translates the input data into NOD2 format, and provides several options to supply values for several header variables which are perhaps lost during the previous data conversions.

  Don't forget `no weight` if you want to further analyse your data with NOD2 programs other than **MOPSI**.

4.6.6 Getting the Software

What if you have got several nights of good weather and did not manage to reduce all your data? The **GILDAS** software (including **NIC**) is probably installed at your home institution. However, the official releases until February 2000 are *not* capable of reducing the 19-channel data from the HHT.

To get the **GILDAS** software, go to the IRAM ftp site, *ftp://iraux2.iram.fr/dist/soft*, ftp all files in the subdirectory containing the latest release, and install it as described. To customize **NIC** and to add the commands you are using at the telescope, we provide a few initialization files which will supply your **NIC** session with the HHT defaults and some enhanced functionality. Get these files from the SMTO website:
http://maisel.as.arizona.edu:8080/ftp/nic.

The **MOPSI** program needed some adjustment, too. Since the source code of this software is not public, we only provide an executable for Unix (Solaris 2.6 or higher) which is available at *http://maisel.as.arizona.edu:8080/ftp/mopsi/hhtmopsi.gz*. If you're working on another system, please contact the author, Robert Zylka to obtain the program.