CLASS tutorial

I. Basics

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(IRAM/Obs. de Paris)
on behalf of the CLASS developers
S. Bardeau, S. Guilloteau

7th IRAM 30m Summer School
Sep. 13 - Sep. 20 2013, Pradollano
### Data exploration: I. What does the file contain?

LAS90> file in demo  
LAS90> find  
LAS90> list  
...

<table>
<thead>
<tr>
<th>ID</th>
<th>RA</th>
<th>DEC</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8600</td>
<td>B0355+508</td>
<td>12C0(1-0)</td>
<td>30M-V02-B100</td>
</tr>
<tr>
<td>8601</td>
<td>B0355+508</td>
<td>12C0(1-0)</td>
<td>30M-V02-B100</td>
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<td>30M-V02-B100</td>
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<td>30M-V02-B100</td>
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<td>30M-V02-B100</td>
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<tr>
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<td>12C0(1-0)</td>
<td>30M-V02-B100</td>
</tr>
<tr>
<td>8607</td>
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</tr>
<tr>
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<td>30M-V02-B100</td>
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<td>12C0(1-0)</td>
<td>30M-V02-B100</td>
</tr>
<tr>
<td>8614</td>
<td>B0355+508</td>
<td>12C0(1-0)</td>
<td>30M-V02-B100</td>
</tr>
</tbody>
</table>

⇒ Too many information.
Data exploration: I. What does the file contain?

LAS90> list /scan

<table>
<thead>
<tr>
<th>Scan</th>
<th>Front-end</th>
<th>Back-end</th>
<th>Frequency [MHz]</th>
<th>Central Frequency [MHz]</th>
<th>Radio Glitch [MHz]</th>
<th>Equation</th>
<th>Scan Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0355+508</td>
<td>12CO(1-0)</td>
<td>30M-V02-B100</td>
<td>-108.5</td>
<td>+108.8</td>
<td>+70.0</td>
<td>Eq 9626</td>
<td>73</td>
</tr>
<tr>
<td>B0355+508</td>
<td>12CO(1-0)</td>
<td>30M-V01-A100</td>
<td>-108.5</td>
<td>+108.8</td>
<td>+80.0</td>
<td>Eq 9627</td>
<td>73</td>
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<tr>
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<td>12CO(1-0)</td>
<td>30M-V01-A100</td>
<td>-109.4</td>
<td>+107.9</td>
<td>+90.0</td>
<td>Eq 9628</td>
<td>73</td>
</tr>
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<td>+107.7</td>
<td>+100.0</td>
<td>Eq 9629</td>
<td>73</td>
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</tbody>
</table>

⇒ One line per scan and front-end/back-end combination
Data exploration: I. What does the file contain?

LAS90> list /scan /brief
Current index contains:

9608: 146 9609: 146 9610: 146 9611: 146 9612: 146 9613: 146
9614: 146 9615: 146 9616: 146 9617: 146 9619: 146 9620: 146
9621: 146 9622: 146 9623: 146 9624: 146 9625: 146 9626: 146
9627: 146 9628: 146 9629: 146 9634: 146 9635: 146 9636: 146
9637: 146 9638: 146 9639: 146 9640: 146 9641: 146 9642: 146
9643: 146 9645: 146 9646: 146 9647: 146 9648: 146 9649: 146
9650: 146 9651: 146 9652: 146 9653: 146 9654: 146 9655: 146
9665: 146 9670: 146 9671: 146 9672: 146 9673: 146 9674: 146
9676: 146 9677: 146 9678: 146

⇒ Just the list of scans and the number of dumps per scans.
Data exploration: I. What does the file contain?

LAS90> list /toc

equivalent to

LAS90> list /toc source line telescope
Current index contains:
Number of sources....... 1
   B0355+508 8614 (100.0%)
Number of lines........ 1
   12CO(1-0) 8614 (100.0%)
Number of backends..... 2
   30M-V01-A100 4307 (50.0%)
   30M-V02-B100 4307 (50.0%)
Number of setups....... 2
   B0355+508 12CO(1-0) 30M-V01-A100 4307 (50.0%)
   B0355+508 12CO(1-0) 30M-V02-B100 4307 (50.0%)

⇒ Default table of content.
Data exploration: I. What does the file contain?

LAS90> list /toc obs scan
Number of observation dates  1
  12-SEP-2005  8614 (100.0%)
Number of scans.......  59
  9608  146 ( 1.7%)
  9609  146 ( 1.7%)
  9610  146 ( 1.7%)
  9611  146 ( 1.7%)
  9612  146 ( 1.7%)
  9613  146 ( 1.7%)
  9614  146 ( 1.7%)
...
Number of setups.......  59
  12-SEP-2005  9608  146 ( 1.7%)
  12-SEP-2005  9609  146 ( 1.7%)
  12-SEP-2005  9610  146 ( 1.7%)
  12-SEP-2005  9611  146 ( 1.7%)
  12-SEP-2005  9612  146 ( 1.7%)
  12-SEP-2005  9613  146 ( 1.7%)
  12-SEP-2005  9614  146 ( 1.7%)
...
LAS90>

⇒ Customized table of content.

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Data exploration: II. Is the data set in the current index consistent?

LAS90> set nomatch ! OTF data => disable consistency on spectra positions
LAS90> consistency

Consistency checks:
   Checking Data type and regular x-axis sampling
   Checking Source Name
   Checking Position information
   Leaving Offset position
   Checking Line Name
   Checking Spectroscopic information
   Checking Calibration information

Reference spectrum:
   Source Name : B0355+508
   Coordinate System : EQUATORIAL 2000.0
   Proj. Center (rad): lambda  1.044998, beta  0.889488, tolerance 4.8E-08
   Line Name : 12CO(1-0)
   Frequency (MHz) : rest 115.271E+03, resol 3.906E-02, offset  0.000E+00
   Velocity (km/s) : resol -1.016E-01, offset -1.000E+01
   Alignment (chan) : tolerance  10.0%
   Calibration : beeff 0.950,gain  0.010

W-CONSISTENCY, Obs #74 differs. Inconsistent:
W-CONSISTENCY, F range (left) :  1.1522356E+05,  1.1521357E+05 (-2.56E+02 channels)
W-CONSISTENCY, F range (right):  1.1532859E+05,  1.1531859E+05 (-2.56E+02 channels)
W-CONSISTENCY, V range (left) :  1.139119E+02,  1.399194E+02 (-2.56E+02 channels)
W-CONSISTENCY, V range (right): -1.592693E+02, -1.332617E+02 (-2.56E+02 channels)
E-CONSISTENCY, Index is inconsistent

⇒ Inconsistent spectroscopic information in index.
**Data exploration: II. Is the data set in the current index consistent?**

\[ \text{LAS90> consistency} \]

\[ \text{W-CONSISTENCY, Already checked Spectroscopic information: Inconsistent} \]

⇒ Check not repeated (it avoids long waiting time)
Data exploration: II. Is the data set in the current index consistent?

LAS90> find /tel 30M-V01-A100
LAS90> consistency

Consistency checks:
  Checking Data type and regular x-axis sampling
  Checking Source Name
  Checking Position information
  Leaving Offset position
  Checking Line Name
  Checking Spectroscopic information
  Checking Calibration information

Reference spectrum:
  Source Name       : B0355+508
  Coordinate System : EQUATORIAL 2000.0
  Proj. Center (rad): lambda 1.044998, beta 0.889488, tolerance 4.8E-08
  Line Name         : 12CO(1-0)
  Frequency (MHz)   : rest 115.271E+03, resol 3.906E-02, offset 0.000E+00
  Velocity (km/s)   : resol -1.016E-01, offset -1.000E+01
  Alignment (chan)  : tolerance 10.0%
  Calibration       : beeff 0.950,gain 0.010

I-CONSISTENCY, Index is consistent

- find enforces a new consistency check from scratch.

- Selection of a data subset  ⇒  Consistent index.
Data exploration: III. Where do we observe?

One point per spectrum
⇒ Lambda + Beta scanning
⇒ Mapping experiment
Data exploration: III. What does the data look like?

LAS90> set plot histogram => Spectrum will be plotted as an histogram
LAS90> set format long => Lot’s of information about the spectrum in the plot header
LAS90> set unit v f => Bottom axis in velocity, top axis in frequency
LAS90> get first => Get first spectrum of index
LAS90> plot

16: 4 B0355+508 12CO(1-0) 30M-V01-A100 0:12-SEP-2005 R:23-AUG-2009
RA: 03:59:29.74 DEC: 50:57:50.1 Eq 2000.0 Offs: -65.6 -100.0
Unknown tau: 0.324 Tsys: 212. Time: 1.87E-02min El: 76.0
N: 2689 I0: 1220.20 V0: -10.00 Dv: -0.1016 LSR
F0: 115271.204 Df: 3.9063E-02 Fi: 118267.104

- Line + Spike visible.
- LAS90> get next
LAS90> plot
LAS90> get next
LAS90> plot...
8000 times ⇒ a bit long...
Data exploration: III. What does the data look like?

LAS90> set nomatch ! Disable check about position consistency
LAS90> set align f c ! Toggle frequency resampling
LAS90> average ! Average all spectra in index
LAS90> plot

Line + Spike + platforming visible.
Data exploration: III. What does the data look like?

LAS90> set mode x 60 80 ! => Zoom on spike
LAS90> plot
LAS90> set mode x tot ! => Zoom back
LAS90> plot

RA: 03:59:29.74 DEC: 50:57:50.1 Eq 2000.0 Offs: +108.0 +60.0
Unknown tau: 0.334 Tsys: 236. Time: 72. min El: 51.8
N: 2689 10: 1220.20 VO: -10.00 Dv: -0.1016 LSR
F0: 115271.204 Df: 3.9063E–02 Fr: 118267.104

![Graph showing data exploration results]
Data exploration: III. What does the data look like?

LAS90> find /tel 30M-V01-A100
LAS90> load ! Load the spectra in the current index as an image
LAS90> plot /index ! Plot the image

- Line + Spike visible.
- Variation of continuum level before baselining.
- 4000 spectra displayed at the same time.
- Possibility to quickly swap between average and image:
  LAS90> plot
  LAS90> plot /index
  LAS90> plot
Data exploration: III. What does the data look like?

- Line + Spike visible.
- Image saturation due to variation of the continuum level.
Data exploration: III. What does the data look like?

All previous possibilities integrated in an exploration tool:
Look at the Explore Data File in the CLASS main menu.

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Data reduction: I. Windowing

LAS90> average
LAS90> plot
LAS90> set window -120 -105 -25 0 60 75 ! Define the windows
LAS90> draw window ! Overplot the windows

• One window to avoid the signal
• two windows to avoid the spikes
Data reduction: II. Selecting baseline order

LAS90> pen 1  ! Change pen color
LAS90> base 0 /plot  ! Fit 0-order baseline and overplot baseline polynomial
I-POLYNO, degree: 0 rms: 7.942E-02 area: 7.87 v0:-21.98 width: 0.000
LAS90> swap  ! Get back averaged spectrum before baselining
LAS90> clear segment  ! Clear overplotted baseline
LAS90> base 1 /plot  ! Increase baseline polynomial order and check residual rms
I-POLYNO, degree: 1 rms: 3.559E-02 area: 7.58 v0:-26.01 width: 0.000
LAS90> swap; clear segment
LAS90> base 2 /plot  ! Increase baseline polynomial order and check residual rms
I-POLYNO, degree: 2 rms: 2.292E-02 area: 7.02 v0:-25.84 width: 0.000
LAS90> pen 0  ! Reset pen color
LAS90> plot  ! Plot baselined spectra
Data reduction: III. Signal dependent window

LAS90> plot /index ! Plot the whole set of spectrum
LAS90> set window /poly 1 ! Define 1 polygon
Data reduction: IV. Baselining

LAS90> define real idx%sig /like idx%num /global ! Same size as the entry number array
LAS90> file out a100-base single /over ! Open output file in single and overwrite mode
LAS90> get zero ! Reset index counter to zero
LAS90> quiet ! Turn off informational messages
LAS90> for ient 1 to found ! Loop over the index entries
LAS90> get next ! Get next spectra in index
LAS90> base 3 ! Fit baseline and compute residual spectrum
LAS90> let idx%sig[ient] sigma ! Keep residual rms in array
LAS90> write ! Write residual spectrum in output file
LAS90> next ient
LAS90> verbose ! Turn on informational messages
Data reduction: V. Baseline RMS

LAS90> clear plot
LAS90> g\limit /var idx%num idx%sig
LAS90> g\box
LAS90> g\set marker 4 3 0.15
LAS90> g\point idx%num idx%sig
LAS90> g\label "Observation number" /X
LAS90> g\label "rms [K]" /Y
Data reduction: VI. “Despiking”

```plaintext
LAS90> file out a100-fill single /over
LAS90> find
LAS90> for ient 1 to found
LAS90>     get next
LAS90>     fill -120 -100 60 75 /noise ! File contaminated channels with Gaussian noise
LAS90> write
LAS90> next ient

1:   6  B355±508  1200(1-0)  30M-V=0-A100 0:12-SEP-2005 R=0-SEP-2009
RA:  03:59:29.74  DEC:  50:57:50.1  Eq 2000.0  Offs:  +108.0  +60.0
Unknown tau:  0.334  Toys:  235.  Time:  72.  min  El:  51.8
N:   2689  ID:  1220.20  VD:  -10.00  Dw:  -0.1016  LSR
Fo:  115271.204  Ef:  3.906E-02  Fv:  118267.104

03:59:29.74  DEC:  50:57:50.16  Eq 2000.0
Scan: 9600-9682  0: from 12-SEP-2005 to 12-SEP-2005
Npsector: 4307  OShift: ranges: (-109.8-418.8) (-109.9-418.5)
N:  2689  ID:  1220.2  VD:  -10.0  Dw:  -0.102  LSR
1200(1-0)  F0:  115271.204  Ef:  3.91E-02
Ref:  0.95  Ref:  0.95  Fv:  118267.104  Serr:  0.010
```
Data reduction: VII.1 Platforming diagnostic

Platforming affects a single scan (#9621)
⇒ Copy all the 2nd receiver data in a file where correction will happen in-place.

```
LAS90> set sort none
LAS90> file out b100-plat multiple /over ! Multiple occurences of one spectrum enabled
LAS90> copy
```

```
1826; 4 B0355+508 12CO(1-0) 3CM-V02-B100 0:12-SEP-2009 R:23-AUG-2009
Ra: 03:59:29.74 Dec: 50:57:50.1 Eq 2000.0 Offs: +107.8 +20.0
Unknown tour: 0.310 Toys: 209 Time: 1.2 min El 75.5
N: 2689 ID: 1476.20 V0: -10.00 Dev: -0.0165 LSR
F0: 115271.204 Df: 3.9063E-02 Fl: 118267.104
```

```
B0355+508 Ra: 03:59:29.74 Dec: 50:57:50.16 Eq 2000.0
Scan: 9621 0: from 12-SEP-2005 to 12-SEP-2005
Nospectra: 73 Offset ranges: (-109.5:+07.8) (+20.0:+20.0)
N: 2689 ID: 1476.2 V0: -10.0 Dev: -0.102 LSR
12CO(1-0) F0: 115271.204 Df: 3.91E-02
Ref: 0.95 Dev: 0.95 Fl: 118267.104 Gain: 0.010
```
Data reduction: VII.2 Platforming correction #1

LAS90> find /scan 9621
LAS90> get first
LAS90> define real ty /like ry ! Define an intermediate array of intensities
LAS90> get zero ! Reset index counter to zero
LAS90> get next
LAS90> plot
LAS90> set window -200 -42.3 -22 0 90 100
LAS90> base 2 /pl
LAS90> let ty ry /where rx.gt.-42.3

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Data reduction: VII.3 Platforming correction #2

LAS90> set window -95 -75 -42.3 +200
LAS90> base 0 /pl
LAS90> let ry ty /where rx.gt.-42.3
Data reduction: VII.4 After platforming correction

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J. Pety, 2013
CLASS tutorial

II. Imaging Single-Dish Data

Jérôme PETY
(IRAM/Obs. de Paris)
on behalf of the CLASS developers
S. Bardeau, S. Guilloteau

7th IRAM 30m Summer School
Sep. 13 - Sep. 20 2013, Pradollano
Typical data reduction:
I. Divide to conquer

LAS90> file in spectra0dp  ! Complex setup => Huge data file
LAS90> list in /toc       ! Check file content
LAS90> file out 12co21 single ! New file for a single line => Smaller data file
LAS90> find /line 12co21  ! Find everything concerning 12co21
LAS90> copy
LAS90> file in 12co21     ! From now on, work on the smaller data file
LAS90> find
LAS90> consistency       ! Start real work by checking the data consistency

...  

Merging data sets

LAS90> set tel *
LAS90> file out merged single /over
LAS90> file in spectra0dp1
LAS90> list in /toc
LAS90> find /line 12co21
LAS90> copy
LAS90> file in spectra0dp2
LAS90> list in /toc
LAS90> find /line 12co21
LAS90> copy
LAS90> file in merged
LAS90> list in /toc
Typical data reduction:

I. Extract to conquer

LAS90> file in spectra0dp  ! Complex setup => Huge data file
LAS90> list in /toc      ! Check file content
LAS90> file out 12co21 single ! New file for a single line => Smaller data file
LAS90> find /line 12co21 ! Find everything concerning 12co21
LAS90> extract ’115271.202-100’ ’115271.202+100’ f /index
LAS90> file in 12co21    ! From now on, work on the smaller data file
LAS90> find
LAS90> consistency      ! Start real work by checking the data consistency
...

Merging data sets

LAS90> set tel *
LAS90> file out merged single /over
LAS90> file in spectra0dp1
LAS90> list in /toc
LAS90> find /line 12co21
LAS90> copy
LAS90> file in spectra0dp2
LAS90> list in /toc
LAS90> find /line 12co21
LAS90> copy
LAS90> file in merged
LAS90> list in /toc
Typical data reduction:

II. Choose global baseline windows on averaged spectrum

LAS90> set nomatch ! Disable check about position consistency
LAS90> set align f c ! Toggle frequency resampling
LAS90> average ! Average all spectra in index
LAS90> plot
LAS90> set window...

RA: 22:02:43.29 DEC: 42:16:39.9 Eq 2000.0 Offs: +396.4 -213.6
Unknown tau: 0.122 Tsys: 263. Time: 2.26E+02min El: 27.1
N: 1833 10: 1424.20 V0: -1.000 Dv: -5.0797E-02 LSR
F0: 230537.990 Df: 3.9063E-02 Fr: 239054.288

- Line + Spikes.
- Baseline at negative level.
Typical data reduction:

III. Fit a low order baseline (0 or 1) on every dumped spectra

LAS90> define double idx%sig /like idx%num
LAS90> find
LAS90> for ient 1 to found
LAS90>     get next
LAS90>     base 0
LAS90>     write
LAS90>     let idx%sig[ient] sigma
LAS90>     next ient
Typical data reduction:

IV. Filter using clever statistical tools

LAS90> clear plot
LAS90> g\limit /var idx%num idx%sig
LAS90> g\box
LAS90> g\set marker 4 3 0.15
LAS90> g\point idx%num idx%sig
LAS90> g\label "Observation number" /X
LAS90> g\label "rms [K]" /Y
Typical data reduction:

V. Grid the data

LAS90> table 12co21 new /range -13 11 v
LAS90> xy_map 12co21
LAS90> let name 12co21
LAS90> let type lmv
LAS90> go view

If lucky: Stop here!

Else:

- Griding is a linear operation.
- Griding increases signal-to-noise ratio.
- Goal: Higher order baseline on grided data.
Typical data reduction:

VI. Import LMV file and import (or define) local baseline windows

LAS90> file out 12co21 single
LAS90> lmv 12co21.lmv
LAS90> file in 12co21
LAS90> find
LAS90> load
LAS90> plot /index

- One fixed window for spikes.
- Varying windows from another tracer (good quality 12co10 data): The 12co10 window widths are enlarged by 40% to avoid possible biases.
Typical data reduction:

VII. High-order baselining

LAS90> find
LAS90> for ient 1 to found
LAS90> get next
LAS90> set window /var windows[,ient] ! Load baseline windows from a SIC array
LAS90> base 5
LAS90> write
LAS90> next ient
Typical data reduction:

VIII. Place the baselined spectra in the original LMV grid

LAS90> find
LAS90> table 12co21-base /sigma
LAS90> let map%tele 30m ! Because the telescope field was lost during the previous LMV command
LAS90> let map%like 12co21.lmv
LAS90> xy_map 12co21-base /nogrid
LAS90> let name 12co21-base
LAS90> let type lmv
LAS90> go view
Visualization: I. GO VIEW

LAS90> let name 12co10
LAS90> let type lmv
LAS90> go view

Source: B0355+508  Line: 12CO(1−0)  Freq: 115.271204 GHz  Beam: 22.5 x 22.5 PA 0°

CLASS tutorial  J. Pety, 2013
Visualization: II. GO BIT

LAS90> let name 12co10
LAS90> let type lmv
LAS90> go bit
LAS90> input bit
Visualization: IV. GO ROT

LAS90> let name 12co10
LAS90> let type lmv
LAS90> let angle 45
LAS90> go rot
LAS90> go view

Source: B0355+508  Line: 12C0(1−0)  Freq: 115.271204 GHz  Beam: 22.5 x 22.5 PA 45°
Visualization: V. GO 3VIEW

LAS90> let name 12co10-rot45deg
LAS90> let type lmv
LAS90> go 3view
Analysis: Noise Estimation with **MEAN**

LAS90> let name 12co10
LAS90> let type lmv
LAS90> let first 1
LAS90> let last 1
LAS90> go bit
LAS90> poly
LAS90> mean

**I-MEAN**, Found 288 non-blanked pixels, of area: 7.7075E-07 Radians squared
**I-MEAN**, Integrated intensity:-1.678452E-08 (Map Units * Radians squared)
**I-MEAN**, Mean value: -2.17770E-02, r.m.s.: 0.16625
CLASS tutorial

III. Line surveys

Jérôme PETY
(IRAM/Obs. de Paris)

with

P. Gratier & S. Bardeau
Line survey example (Horsehead WHISPER, PI: J. Pety): 740 000 channels, i.e., as many information as in a $860 \times 860$ pixel image!
Line names: I. From observations

LAS90> set sort line
LAS90> file in red/survey-1
LAS90> find
LAS90> list /toc line
LAS90> set sort none

Number of lines........ 42

<table>
<thead>
<tr>
<th>Value</th>
<th>Count (Percentage)</th>
</tr>
</thead>
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<tr>
<td>100.5</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>105</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>105.9</td>
<td>36 (2.5%)</td>
</tr>
<tr>
<td>106.8</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>107.7</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>108.6</td>
<td>36 (2.5%)</td>
</tr>
<tr>
<td>109.5</td>
<td>36 (2.5%)</td>
</tr>
<tr>
<td>110.4</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>111.3</td>
<td>60 (4.1%)</td>
</tr>
<tr>
<td>112.2</td>
<td>48 (3.3%)</td>
</tr>
<tr>
<td>113.1</td>
<td>48 (3.3%)</td>
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<tr>
<td>130.8</td>
<td>10 (0.7%)</td>
</tr>
<tr>
<td>131.7</td>
<td>12 (0.8%)</td>
</tr>
<tr>
<td>132.6</td>
<td>24 (1.6%)</td>
</tr>
<tr>
<td>133.5</td>
<td>28 (1.9%)</td>
</tr>
<tr>
<td>134.4</td>
<td>20 (1.4%)</td>
</tr>
<tr>
<td>135.3</td>
<td>12 (0.8%)</td>
</tr>
<tr>
<td>136.2</td>
<td>12 (0.8%)</td>
</tr>
<tr>
<td>137.1</td>
<td>28 (1.9%)</td>
</tr>
<tr>
<td>138</td>
<td>20 (1.4%)</td>
</tr>
<tr>
<td>138.9</td>
<td>16 (1.1%)</td>
</tr>
</tbody>
</table>

139.8 16 (1.1%)
140.7 12 (0.8%)
141.6 32 (1.1%)
142.5 32 (1.1%)
143.4 24 (0.8%)
144.3 24 (0.8%)
145.2 32 (1.1%)
146.1 40 (1.4%)
147   32 (1.1%)
147.9 32 (1.1%)
148   90 (3.0%)
147.9 226 (7.7%)
148.8 66 (2.2%)
149.7 72 (2.4%)
150.2 150 (5.1%)
150.1 102 (3.5%)
151.4 114 (3.9%)
150.9 72 (2.4%)
152.0 72 (2.4%)
153.2 162 (5.5%)
158.3 120 (4.1%)
Line names: II. 2SB Receivers

LAS90> file in red/survey-1
LAS90> find /line 100.5
LAS90> list /toc
Number of setups.......  6

HORSEHEAD  100.5  30MEOHUI-F01  8  (16.7%)
HORSEHEAD  100.5  30MEOVUI-F02  8  (16.7%)
HORSEHEAD  100.5  30MEOHUO-F05  8  (16.7%)
HORSEHEAD  100.5  30MEOHL0-F06  8  (16.7%)
HORSEHEAD  100.5  30MEOVU0-F07  8  (16.7%)
HORSEHEAD  100.5  30MEOVLO-F08  8  (16.7%)
Line names: III. How to modify them

LAS90> set var spectro write
LAS90> file out red/survey-2 single /overwrite
LAS90> file in red/survey-1
LAS90> find
LAS90> quiet
LAS90> for ient 1 to found
LAS90> get next
LAS90> let r%head%spe%line min('frequency+rx[1]', 'frequency+rx[channels]') /format f12.1
LAS90> write
LAS90> next ient
LAS90> verbose
LAS90> set var spectro
Line names: IV. Result

LAS90> set sort line
LAS90> file in red/survey-2
LAS90> find
LAS90> list /toc line
LAS90> set sort none

Number of lines....... 94

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<tr>
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<th>Line</th>
<th>Count (%)</th>
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<th>Count (%)</th>
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<td>96459.6</td>
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<td>110820.4</td>
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<td>96840.0</td>
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<td>110920.1</td>
<td>12 ( 0.8%)</td>
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<td>16 ( 1.1%)</td>
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<td>98640.0</td>
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<td>99540.0</td>
<td>16 ( 1.1%)</td>
<td>112140.0</td>
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<td>10 ( 0.7%)</td>
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<td>12 ( 0.8%)</td>
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<td>16 ( 1.1%)</td>
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<td>101020.0</td>
<td>12 ( 0.8%)</td>
<td>113620.1</td>
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<td>84659.8</td>
<td>10 ( 0.7%)</td>
<td>101020.1</td>
<td>16 ( 1.1%)</td>
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<td>12 ( 0.8%)</td>
<td>101820.3</td>
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<td>87040.0</td>
<td>30 ( 2.0%)</td>
<td>102720.3</td>
<td>10 ( 0.7%)</td>
<td>130839.9</td>
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<td>102820.1</td>
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<td>10 ( 0.7%)</td>
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<td>12 ( 0.8%)</td>
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<td>16 ( 1.1%)</td>
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<td>136239.9</td>
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<td>104940.0</td>
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<td>137139.9</td>
<td>20 ( 1.4%)</td>
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<tr>
<td>90959.9</td>
<td>18 ( 1.2%)</td>
<td>105840.0</td>
<td>16 ( 1.1%)</td>
<td>138039.9</td>
<td>16 ( 1.1%)</td>
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<td>106740.0</td>
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<td>138939.9</td>
<td>16 ( 1.1%)</td>
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<td>108540.0</td>
<td>12 ( 0.8%)</td>
<td>142539.9</td>
<td>12 ( 0.8%)</td>
</tr>
</tbody>
</table>
Line names: V. Using the modified line names

```
LAS90> set sort line
LAS90> file in red/survey-2
LAS90> find
LAS90> quiet
LAS90> sic output freq-range
LAS90> for ient 1 to found
LAS90>   get next
LAS90>     say 'line' 'telescope' 'frequency+rx[1]' 'frequency+rx[channels]' -
LAS90->? /format a15 a15 f15.3 f15.3
LAS90>   next ient
LAS90> sic output
LAS90> verbose
LAS90> set sort none
LAS90> type freq-range.dat

81159.7  30MEOVLO-F08  81159.698  82979.751
81159.7  30MEOHLO-F06  81159.698  82979.751
82059.6  30MEOVLO-F08  82059.620  83879.682
82059.6  30MEOHLO-F06  82059.620  83879.682
82059.7  30MEOVLO-F08  82059.683  83879.738
82059.7  30MEOHLO-F06  82059.683  83879.738
82859.9  30MEOHLO-F06  82859.915  84679.968
82859.9  30MEOVLO-F08  82859.915  84679.968
82959.7  30MEOVLO-F08  82959.661  84779.718
82959.7  30MEOHLO-F06  82959.661  84779.718
83759.8  30MEOHLO-F06  83759.833  85579.923
83759.8  30MEOVLO-F08  83759.833  85579.923
83759.9  30MEOVLO-F08  83759.919  85579.971
83759.9  30MEOHLO-F06  83759.919  85579.971
83859.7  30MEOVLO-F08  83859.673  85679.729
83859.7  30MEOHLO-F06  83859.673  85679.729
...```

CLASS tutorial
Averaging: I. From

21; 2 HORSEHEAD 87939.96 30MEOHLI-F01 0:24—AUG—2011 R:24—AUG—2011
RA: 05:40:54.27 DEC: −02:28:00.0 Eq 2000.0 Offs: −5.0 +0.0
Unknown tau: 0.046 Tsys: 103. Time: 28. min El: 50.2
N: 37275 I0: 17614.0 V0: 10.50 Dv: −1.6485E−04 LSR
F0: 88800.0030 Df: 4.8828E−02 Fi: 101300.461
Averaging: II. To

1; 0 HORSEHEAD Unknown Unknown 0:23-SEP-2011 R:23-SEP-2011
RA: 05:40:54.27 DEC: -02:28:00.0 Eq 2000.0 Offs: -5.0 +0.0
Unknown tau: 0.046 Tsys: 118. Time: 2.13E+02min El: 50.2
N: 18844 To: -817.350 V0: 10.50 Dv: -0.1649 LSR
F0: 88800.0030 Df: 4.8830E-02 Fi: 101300.461
Averaging: III. Per observing setup

LAS90> set bad and
LAS90> file out red/survey-3 single /over
LAS90> file in red/survey-2
LAS90> find
LAS90> list /toc line tele off1 off2
LAS90> quiet
LAS90> for isetup 1 to toc%nsetup
LAS90> find /line 'toc%setup[isetup,1]' /tele 'toc%setup[isetup,2]' -
LAS90-? /offset 'toc%setup[isetup,3]' 'toc%setup[isetup,4]'
LAS90> if (found.ne.0) then
LAS90>   average /resample
LAS90>   write
LAS90> endif
LAS90> next isetup
LAS90> verbose
Stitching: I. Commands

LAS90> set bad and
LAS90> file out red/survey-4 single /over
LAS90> file in red/survey-3
LAS90> find
LAS90> list /toc off1 off2
LAS90> quiet
LAS90> define double frange[2,3]
LAS90> let frange[1] 80000 120000
LAS90> let frange[2] 120000 170000
LAS90> let frange[3] 200000 280000
LAS90> let lines "signal" "signal" "signal"
LAS90> let teles "3mm" "2mm" "1mm"
LAS90> for ifrange 1 to 3
LAS90> for isetup 1 to toc%nsetup
LAS90> find /freq 'frange[1,ifrange]' 'frange[2,ifrange]' -
LAS90> /offset 'toc%setup[isetup,1]' 'toc%setup[isetup,2]'
LAS90> if (found.ne.0) then
LAS90> stitch /line 'lines[ifrange]' /tele 'teles[ifrange]'
LAS90> write
LAS90> endif
LAS90> next isetup
LAS90> next ifrange
Stitching: II. Visualization

LAS90> file in red/survey-4
LAS90> find
LAS90> get f
LAS90> set unit f
LAS90> set format long
LAS90> plot

1: 0 HORSEHEAD Unknown Unknown 0:23–SEP–2011 R:23–SEP–2011
   RA: 05:40:54.27 DEC: -02:28:00.0 Eq 2000.0 Offs: -5.0  +0.0
   Unknown tau: 0.087 Tsys: 146. Time: 6.22E+03min El: 41.9
   N: 738900 Io: 138037. V0: 10.50 Dv: -0.1665 LSR
   F0: 87900.0020 Df: 4.8830E-02 Fl: 100400.482
Browsing through wide spectra: I. Zooming in frequency

LAS90> go browse

1; 0 HORSEHEAD Unknown Unknown 0:23–SEP–2011 R:23–SEP–2011
RA: 05:40:54.27 DEC: −02:28:00.0 Eq 2000.0 Offs: −5.0 +0.0
Unknown tau: 0.087 Tsys: 146. Time: 6.22E+03min El: 41.9
N: 738900 Io: 138037. V0: 10.50 Dv: −0.1665 LSR
F0: 87900.0020 Df: 4.8830E−02 Fi: 100400.482

unknown undetected doubtful detected

![Graph showing frequency spectrum with marked peaks and labels.](image-url)
Browsing through wide spectra: II. Zooming in intensity

LAS90> go browse

1: 0 HORSEHEAD Unknown Unknown 0:23−SEP−2011 R:23−SEP−2011
RA: 05:40:54.27 DEC: −02:28:00.0 Eq 2000.0 Offs: −5.0 +0.0
Unknown tau: 0.087 Tsys: 146. Time: 6.22E+03min El: 41.9
N: 738900 I0: 138037. V0: 10.50 Dv: −0.1665 LSR
F0: 87900.0020 Df: 4.8830E−02 Fi: 100400.482

unknown undetected doubtful detected

Rest Frequency (MHz)
Baselining: I. From

1; 0 HORSEHEAD Unknown Unknown 0:23–SEP–2011 R:23–SEP–2011
RA: 05:40:54.27 DEC: −02:28:00.0 Eq 2000.0 Offs: −5.0 +0.0
Unknown tau: 0.087 Tsys: 146. Time: 6.22E+03min El: 41.9
N: 738900 Io: 138037. Vo: 10.50 Dv: −0.1665 LSR
F0: 87900.0020 Df: 4.8830E−02 Fi: 100400.482
Baselining: II. To

1; 0 HORSEHEAD Unknown Unknown 0:23–SEP–2011 R:23–SEP–2011
RA: 05:40:54.27 DEC: −02:28:00.0 Eq 2000.0 Offs: −5.0 +0.0
Unknown tau: 0.087 Tsys: 146. Time: 6.22E+03min El: 41.9
N: 738900 I0: 138037. V0: 10.50 Dv: −0.1665 LSR
F0: 87900.0020 Df: 4.8830E−02 Fi: 100400.482
Baseline: III. Through

RA: 05:40:54.27 DEC: -02:28:00.0 Eq 2000.0 Offs: -5.0 +0.0

Unknown tau: 0.087 Tsys: 146 Time: 6.22E+03min El: 41.9

N: 738900 I0: 138037 V0: 10.50 Dv: -0.1665 LSR
F0: 87900.0020 Df: 4.8830E-02 Fi: 100400.482
Baselining: IV. Wavelets (Experimental!)

**Hypotheses**  Lines and baselines have different spectral signatures

```
LAS90> file out red/survey-5 single /over
LAS90> file in red/survey-3
LAS90> find
LAS90> quiet
LAS90> for ient 1 to found
LAS90> get next
LAS90> wavelet /base 5
LAS90> write
LAS90> next ient
LAS90> verbose
```
Baselining: V. Wavelet example #1
Baselining: V. Wavelet example #2
Baselining: V. Wavelet artefact #1
Baselining: V. Wavelet artefact #2

![Graph showing baseline adjustment in a spectral analysis context. The graph displays a baseline shift in the rest frequency spectrum, with a notable artefact. The x-axis represents Rest Frequency (MHz), while the y-axis shows the amplitude scale.]
Other problems

Spikes.

Limited sideband rejection.
Jérôme PETY
(IRAM/Obs. de Paris)
on behalf of the GILDAS developers

7th IRAM 30m Summer School
Sep. 13 - Sep. 20 2013, Pradollano
Scope: I. Softwares at IRAM

- Many different kinds of softwares at IRAM:
  1. Proposal and scheduling (statistics, dynamic scheduling, pool observing).
  2. Preparation of observations, e.g. setups.
  3. Data acquisition:
     3.1 Low level, e.g. hardware control (antennae, receivers, correlators, etc...)
     3.2 High level, e.g. operator and observer interface.
  4. Data archiving.
  5. Data reduction and analysis (single dish + interferometry).

- GILDAS deals only with a subset. Points: 2, 3.2, 5 and 6.
Scope: II. 30m time/sensitivity estimators
Scope: III. GILDAS at IRAM
425 000 executable lines

• Common facilities
  – Command line interpreter: SIC;
  – Graphical possibilities: GREG
    (1D: curves, 2D: images, 3D: spectra cubes).
  – Preparation of observations: ASTRO.

• 30m
  – Spectroscopy: TELCAL + MIRA + CLASS.

• PdBI
  – Calibration: CLIC;
  – Imaging + Deconvolution: MAPPING.

• ALMA
  – Simulator: MAPPING @ alma.map;
  – Holographies of ALMA antennae are
done in CLIC at San Pedro.
GILDAS Strengths

- Large range of supported systems: Linux, Mac/OSX, Windows.
- Light weight: Data reduction and analysis possible on laptops.
- 30 years of history ⇒ Accumulated expertise.
- Powerful advanced tools, e.g.
  - Interface to line catalogs;
  - Easy OTF processing;
  - Easy interferometric mosaicing;
  - General fitting routines.
GILDAS users

- IRAM AODs: Instrument monitoring, data pipelining.
- IRAM users: Data reduction.
- Others:
  - CLASS is used in many facilities (e.g. APEX, CSO, NANTEN2, GBT, HHT, Effelsberg, Kosma, ...); CLASS is partly used by Herschel/HIFI, SOFIA, 45m.
  - ALMA: (Single Dish characterization in San Pedro).

⇒ GILDAS evolutions must be thought with all users in mind.
People

- People participating in one way or another
  IRAM/Granada  H. Ungerechts, A. Sievers.
  LAOG/Grenoble  P. Hily-Blant, R. Lucas, S. Maret.
  L3AB/Bordeaux  S. Guilloteau.

- Large code contributors:  $\sim 5.0$ FTE/yr
  R. Zylka  MOPSIC.
  H. Ungerechts  PAKO.
  A. Sievers  MIRA.
  E. Reynier  kernel + PMS.
  V. Pietu  CLIC + RDI.
  J. Pety  kernel + TELCAL + CLASS + MAPPING.
  F. Gueth  CLIC + ASTRO.
  A. Castro-Carrizo  CLIC pipeline.
  S. Bardeau  kernel (including the python binding) + CLASS.
  P. Hily-Blant + S. Maret  CLASS/WEEDS.
  S. Guilloteau  Kernel + MAPPING.
An example of the GILDAS daily life: CLASS

- MODIFY BEAM now also scales the associated header parameters (e.g., Tsys, sigma) in addition to scaling the spectrum.
- FITS READ is now working again when the output file is of type MULTIPLE.
- It is now possible to copy a frequency subset of a given index through the following command sequence
  
  ```
  LAS> file out coucou single
  LAS> file in file1
  LAS> find
  LAS> extract 97000 97100 f /index
  LAS> file in file2
  LAS> find
  LAS> extract 97000 97100 f /index
  ...
  ```

  This is useful for instance when trying to reduce OTF observations of the same source observed several days in a row.
- The GET command was speed up significantly by a combination of two actions: 1) The access to SIC variables was made more efficient and 2) the redefinition of SIC variables associated to CLASS internal arrays now happens only when needed.
- The files necessary to read the SOFIA user section have been made available in any new GILDAS version. Up to now, they were available only in the may12 version.
- The Arizona Radio Observatory SubMillimeter Telescope (SMT) is now recognized in Class (support improved, in particular for Doppler computations).
- The Herschel/HIFI instrument is now recognized by the TABLE and XY_MAP commands.
- The logic of definition/usage of the telescope HPBW was clarified in the TABLE and XY_MAP commands. See the online help for details.
- Command LOAD now ignores inconsistent offsets: It implicitly implies a /NOCHECK OFFSETS.
- A message will display the average flux used by the command "BASE /CONTINUUM [Flux]", in order to avoid dividing by a value close to zero.
User support:

I. Documentation

Web page http://www.iram.fr/IRAMFR/GILDAS.

Memos at http://www.iram-institute.org/EN/content-page-161-7-66-161-0-0-0.html.

Mail to gildas@iram.fr.

IRAM Memo 2005-1

CLASS evolution: I. Improved OTF support

P. Hily-Blant¹, J. Pety¹,², S. Guilloteau³

¹ IRAM (Grenoble)
² LERMA, Observatoire de Paris
³ LAAS, Observatoire de Bordeaux

Dec. 28th 2005
Version 1.0

IRAM Memo 2009-4

Averaging spectra with CLASS

S. Bardoua¹, J. Pety¹,²

¹ IRAM (Grenoble)
² LERMA, Observatoire de Paris

July 20th 2009
Version 1.0

Abstract

CLASS evolution CLASS provides a set of commands capable to process two or more spectra. They provide easy averaging modes, presented elsewhere in this document. The different modes allow to perform internally and identify some important computations, namely resampling and weighted average. Combining these operations at the same time may imply some non-trivial effects described here.

On October 2008, it appeared that some particular combinations of the resampling modes were not behaving as expected (either in CLASS00 and in CLASS01). A complete clearing and factorization of the algorithm was performed, associated to exhaustive tests of all combinations. A test suite was also provided to check the output of each command and mode.

Reducing this confusion of the code, and the use of these capabilities to concentrate the new (PRO) spectra, it was decided to write this document in order to keep a trace of the modifications applied. This was also the occasion to investigate deeply the code and to examine the effects which can occur during all the possible processing.
INTRODUCTION

GILDAS is a collection of state-of-the-art softwares oriented toward (sub-)millimeter radioastronomical applications (either single-dish or interferometer). It is daily used to reduce all data acquired with the IRAM 30M telescope and Plateau de Bure Interferometer PDBI (except VLBI observations). GILDAS is easily extensible. GILDAS is written in Fortran-90, with a few parts in C/C++ (mainly keyboard interaction, plotting, widgets).

ACKNOWLEDGMENT IN PUBLICATIONS

The GILDAS team welcomes an acknowledgment in publications using GILDAS software to reduce and/or analyze data.

Please use the following reference in your publications: http://www.iram.fr/IRAMFR/GILDAS

RECENT MILESTONES

(detailed news here)

apr-13
The CLASS GET command is now 30% faster.

mar-13
CLIC is now backward compatible with data older than 2007 (previous receiver generation). It means that clic07 is obsolete, i.e., not supported neither distributed anymore.

feb-13
The Herschel/HIFI instrument is now recognized by the TABLE and XY_MAP commands of CLASS.

jan-13
MAPPING is able to handle unpolarized ALMA data. You just have to fill the calibrated visibilities into the MAPPING uv table format through a combination of the FITS commands and using GILDAS tools.
User support:

III. answers to gildas@iram.fr

- Total number of threads from new users: 150/year.
- Total number of threads from all users: 274/year.
- Number of emails per threads: 2.8.
- Median time to
  - First answer: 6h;
  - Final answer: 24h.
Hi,

I have just stumbled on an obnoxious bug which prevents me from making the discovery of the century. I will defend my PhD thesis tomorrow. Fix this bug in the coming minutes.

Toto.
Bug report: II. Right way

Dear Gildas team,

Your software is great. For the first time in my life, I encountered a segmentation fault using it. I succeeded to reproduce the bug with a simple list of commands. I attach the following information: version of gildas I am currently using, list of commands and the data set to reproduce the bug. I hope this will help you solve the bug in the coming months. Continue the great work.

Best regards, Toto.

***************************************************************************
gildas version: dev (07oct08 13:45) (x86_64-fedora6-ifort) source tree

List of commands:
LAS90> file in test
LAS90> find
Blablablabla...
Segmentation fault

Data set attached: test.30m

***************************************************************************
No software is the answer to all these:

- Best \textit{(i.e. most recent) computing technology.}
- Best \textit{portability.}
- Best \textit{speed.}
- Best \textit{ease of use (CLI and GUI).}
- Best \textit{(i.e. shortest) learning curve.}
- Best \textit{functionalities.}
  - Best \textit{data calibration methods.}
  - Best \textit{data mapping methods.}
  - Best \textit{(i.e. most complete) analysis methods.}
  - Best \textit{graphical possibilities.}
- Best \textit{cost.}
Strategy

- Maintain high-quality software for IRAM instruments while staying open to outside world.
  - Focused but generic developments;
  - In/out fillers;
  - Python binding.
Spectral Line Observing Strategies

Jérôme PETY
(IRAM/Obs. de Paris)

7th IRAM 30m Summer School
Sep. 13 - Sep. 20 2013, Pradollano
Switching Modes: I. Why switching?

Atmosphere emits and absorbs

\[ \text{Signal} = \text{Transmission} \times \text{Source} + \text{Atmosphere} \]

- **Optic**: \( \{ \text{Source} \gg \text{Atmosphere} \}\) \[\text{Transmission} \sim 1 \] \( \Rightarrow \) transparent;

- **Radio**: \( \{ \text{Source} \ll \text{Atmosphere} \}\) \[\text{Transmission can be small} \] \( \Rightarrow \) fog.

**Bad news**: Emission and transmission depends on weather and frequency.

**Varying transmission** \( \Rightarrow \) Gain calibration (hot/cold/sky).

**Atmosphere emission** \( \Rightarrow \) Switching mode.
Switching Modes: II. How to?

Position switching
- The telescope cyclically moves between two positions, ON (Source+Atmosphere) and OFF (Atmosphere). ⇒ Subtracting both positions should give you the source signal.
- Difficulties:
  - The OFF source must be devoid of signal ⇒ Sometimes wish to go far away (e.g. out of the Galactic plane).
  - The farther away you go, the more the atmosphere varies ⇒ bad baselines.

Wobbler switching
- The secondary cyclically and quickly moves between three positions: OFF - ON - ON - OFF.
- Advantage: Excellent baselines.
- Inconvenients:
  - Limited wobbling throw.
  - The wobbling direction rotates on the sky.
  ⇒ Your source must be compact.

Frequency switching
- The telescope is always ON source but the tuning frequency cyclically and quickly changes between two phases: $f_{\text{rest}} - f_{\text{throw}}$ and $f_{\text{rest}} + f_{\text{throw}}$.
- Advantages:
  - No need of OFF positions!
  - Lower noise for track observations (not true for On-The-Fly).
- Inconvenients:
  - Presence of atmospheric lines.
  - Negative ghosts.
  - Oscillating baselines (depending on $f_{\text{throw}}$).
Observing Modes (1)

Line surveys  Covering full atmospheric windows by multiple frequency settings along a single line of sight.
Example: Horsehead WHISPER (PI: J. Pety, see http://www.iram-institute.org/~horsehead)
Mapping  Imaging a given line over a given sky field of view. Example: M51 viewed in $^{12}\text{CO}$ ($J=1-0$) (PAWS project, PI: E. Schinnerer, see http://www.mpia-hd.mpg.de/PAWS/PAWS/Data.html)
Observing Modes (3)

**Line surveys** Covering full atmospheric windows by multiple frequency settings along a single line of sight.

**Mapping** Imaging a given line over a given sky field of view.

**Today cutting edge observing mode** Convergence of line surveys and mapping (because of wide bandwidth receivers + powerful spectrometers).

Sensitivity estimation (Pety et al., IRAM memo 2009-1)

Radiometer equation for a total power measurement

\[ \sigma = \frac{T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{n_{\text{pol}} d\nu t}}. \]  

(1)

Switching ⇒ ON and OFF measurements.

\[ \sigma = \sqrt{\sigma_{\text{on}}^2 + \sigma_{\text{off}}^2} = \frac{T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{n_{\text{pol}} d\nu t_{\text{sig}}}} \quad \text{with} \quad t_{\text{sig}} = \frac{t_{\text{on}} t_{\text{off}}}{t_{\text{on}} + t_{\text{off}}}, \]

(2)

Tracked observations  Frequency switching is twice as fast as position switching.

Frequency switching

\[ t_{\text{onoff}} = t_{\text{on}} = t_{\text{off}} \quad \Rightarrow \quad t_{\text{sig}} = \frac{t_{\text{on}}}{2} = \frac{t_{\text{off}}}{2} = \frac{\eta_{\text{tel}} t_{\text{tel}}}{2} \quad \Rightarrow \quad \sigma_{\text{fsw}} = \frac{\sqrt{2} T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{d\nu n_{\text{pol}} \eta_{\text{tel}} t_{\text{tel}}}}. \]

(3)

Position switching

\[ t_{\text{on}} = t_{\text{off}} = \frac{\eta_{\text{tel}} t_{\text{tel}}}{2} \quad \Rightarrow \quad t_{\text{sig}} = \frac{t_{\text{on}}}{2} = \frac{t_{\text{off}}}{2} = \frac{\eta_{\text{tel}} t_{\text{tel}}}{4} \quad \Rightarrow \quad \sigma_{\text{psw}} = \frac{2 T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{d\nu n_{\text{pol}} \eta_{\text{tel}} t_{\text{tel}}}}. \]

(4)
Sensitivity estimation (Pety et al., IRAM memo 2009-1)

Radiometer equation for a total power measurement

\[ \sigma = \frac{T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{n_{\text{pol}} d\nu t}}. \]  

Switching ⇒ ON and OFF measurements.

\[ \sigma = \sqrt{\sigma_{\text{on}}^2 + \sigma_{\text{off}}^2} = \frac{T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{n_{\text{pol}} d\nu t_{\text{sig}}}} \quad \text{with} \quad t_{\text{sig}} = \frac{t_{\text{on}} t_{\text{off}}}{t_{\text{on}} + t_{\text{off}}}, \]  

On-The-Fly observations Time spent per independent beams in the covered field of view. 
\( (n_{\text{beam}}: \text{number of independent beams})\).

Frequency switching

\[ \sigma_{\text{fsw}} = \frac{\sqrt{2} n_{\text{beam}} T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{d\nu n_{\text{pol}} \eta_{\text{tel}} t_{\text{tel}}}}, \]  

Position switching Sharing OFF among many ONs (ON-ON-ON-ON-OFF-ON-ON-ON-ON-OFF-...)

\[ \sigma_{\text{psw}} = \frac{\left( \sqrt{n_{\text{beam}}} + \sqrt{n_{\text{submap}}} \right) T_{\text{sys}}}{\eta_{\text{spec}} \sqrt{d\nu n_{\text{pol}} \eta_{\text{tel}} t_{\text{tel}}}}. \]  

Relative efficiency

\[ \frac{\sigma_{\text{psw}}}{\sigma_{\text{fsw}}} = \frac{1}{\sqrt{2}} \left( 1 + \sqrt{\frac{n_{\text{submap}}}{n_{\text{beam}}}} \right) \geq 1 \quad \Rightarrow \quad \frac{n_{\text{beam}}}{n_{\text{submap}}} = \frac{n_{\text{on/off}}}{n_{\text{off}}} \geq \frac{1}{3 - 2\sqrt{2}} \sim 6. \]
Observing Strategy with 2SB Receivers: I. Definition

2 polarizations x 2 sidebands x 2 intermediate frequency processors:

LAS90> file in red/survey-1
LAS90> find /line 100.5
LAS90> list /toc
Number of setups......... 6

HORSEHEAD 100.5 3OME0HUI-F01 8 ( 16.7%)
HORSEHEAD 100.5 3OME0VUI-F02 8 ( 16.7%)
HORSEHEAD 100.5 3OME0HU0-F05 8 ( 16.7%)
HORSEHEAD 100.5 3OME0HL0-F06 8 ( 16.7%)
HORSEHEAD 100.5 3OME0VU0-F07 8 ( 16.7%)
HORSEHEAD 100.5 3OME0VL0-F08 8 ( 16.7%)
Choose carefully whether to tune LSB or USB because receiver temperatures will not be identical.
Observing Strategy with 2SB Receivers: III. Ghost Lines

RA: 05:40:54.27    DEC: -02:28:00.0    Eq 2000.0    Offs: -5.0 +0.0
Unknown tau: 0.088    Tsys: 140.    Time: 45 min    El: 46.6
N: 37275 i0: 84794.3    VO: 10.50    Dv: -0.1455    LSR
F0: 100600.029    Df: 4.8829E-02    Fi: 113100.317

Spectral Line Observing Strategies
J. Pety, 2013
Observing Strategy with 2SB Receivers: III. Ghost Lines

98; 1 HORSEHEAD 96459.6 30MEOHLO-F06 0:26-SEP-2011 R:26-SEP-2011
RA: 05:40:54.27 DEC: -02:28:00.0 Eq 2000.0 Offs: -5.0 +0.0
Unknown tau: 0.088 Tsys: 140. Time: 45. min El: 46.6
N: 37275 Io: 84794.3 V0: 10.50 Dw: -0.1455 LSR
F0: 100600.029 Df: 4.8829E-02 Fi: 113100.317

Effect of a Regular Sampling On Mapping:

I. Periodic Replication

Image Plane

 uv Plane

Source brightness

Regular Sampling function

Result for a fine sampling

Result for critical sampling (Nyquist’s criterion)

Result for a coarse sampling

Spectral Line Observing Strategies

J. Pety, 2013
Effect of a Regular Sampling: II. Aliasing

Image Plane

\[ f(x) \]

\[ g(x) \]

\[ x \]

\[ \lambda \]

\[ D \]

\[ s_c \]

\[ s_d \]

\[ s \]

\[ F(s) \]

\[ \Rightarrow \]

Nyquist sampling: \( \frac{\lambda}{2D} \).

Aliasing = Folding of spatial frequencies outside the transfer function into it.

Gridding through convolution and resampling:
I. Kernel properties

2D Gaussian whose FWHM depends on the MAP\%RESO parameter.

MAP\%RESO = 0 (Default)
Kernel FWHM = \frac{10.7}{3} = 3.6''

MAP\%RESO = 15
Kernel FWHM = \sqrt{15^2 - 10.7^2} = 10.5''
Gridding through convolution and resampling:

II. Sampling results in image plane: 1. Fully sampled case

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ~ 0.9 K peak brightness.
- 4″ sampling between the rasters.
- 1″ sampling along the rasters.
- Default gridding kernel.

Observing grid: $\Delta_o = 4″$, $\Delta_p = 1″$

Point source offset: (0″,0″)  
Point source offset: (1″,1″)  
Point source offset: (2″,2″)

MAP%RESO = 0
Gridding through convolution and resampling:

II. Sampling results in image plane: 2. Undersampled case #1

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.9 K peak brightness.
- 8″ sampling between the rasters.
- 1″ sampling along the rasters.
- Default gridding kernel.

Observing grid: $\Delta_0=8\text{″}$, $\Delta_p=1\text{″}$

Point source offset: $(0\text{″},0\text{″})$  
Point source offset: $(2\text{″},2\text{″})$  
Point source offset: $(4\text{″},4\text{″})$

MAP%RESO = 0
Gridding through convolution and resampling:

II. Sampling results in image plane: 3. Undersampled case #2

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.9 K peak brightness.
- 12″ sampling between the rasters.
- 1″ sampling along the rasters.
- Default gridding kernel.

Observing grid: Δ₀=12″, Δₚ=1″

Point source offset: (0″,0″)

Point source offset: (3″,3″)

Point source offset: (6″,6″)

MAP%RESO = 0
Gridding through convolution and resampling:

**III. Sampling results in \( uv \) plane**

- Frequency: 230 GHz ⇒ 30m resolution: \( \theta_{\text{fwhm}} = 1.2 \frac{\lambda}{D} = 10.7'' \).

- Nyquist criterion: \( \frac{\lambda}{2D} \left( \neq \frac{\theta_{\text{fwhm}}}{2} \right) \).

---

**Sampling: 8''**

![Graph showing natural transfer and aliased power for 8'' sampling](image1)

**Sampling: 12''**

![Graph showing natural transfer and aliased power for 12'' sampling](image2)
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing
1. Fully sampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ~ 0.51 K peak brightness.
- 4″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 15″ equivalent to a 22m-telescope...

Observing grid: $\Delta_0 = 4''$, $\Delta_p = 1''$

Point source offset: (0″,0″)  Point source offset: (1″,1″)  Point source offset: (2″,2″)

MAP%RESO = 15
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing

1. Fully sampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.32 K peak brightness.
- 4″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 19″ equivalent to a 17m-telescope...

Observing grid: \( \Delta_o = 4″, \Delta_p = 1″ \)

Point source offset: (0″,0″)  Point source offset: (1″,1″)  Point source offset: (2″,2″)

MAP%RESO = 19
Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

1. Fully sampled case results in image plane

- Frequency: 230 GHz $\Rightarrow$ 30m resolution: 10.7$''$.
- Point source of 1 K brightness. Beam dilution $\Rightarrow \sim 0.22$ K peak brightness.
- 4$''$ sampling between the rasters.
- 1$''$ sampling along the rasters.
- Final resolution: 23$''$ equivalent to a 14m-telescope...

   Observing grid: $\Delta_o=4''$, $\Delta_p=1''$

Point source offset: (0$''$,0$''$)  Point source offset: (1$''$,1$''$)  Point source offset: (2$''$,2$''$)

MAP%RESO = 23
Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

1. Fully sampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.16 K peak brightness.
- 4″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 27″ equivalent to a 12m-telescope...

Observing grid: $\Delta_r = 4{''}$, $\Delta_p = 1{''}$

Point source offset: (0″,0″)  
Point source offset: (1″,1″)  
Point source offset: (2″,2″)

MAP%RESO = 27
Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

2. Undersampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ 0.51 K peak brightness.
- 12″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 15″ equivalent to a 22m-telescope...

\[ \Delta_o = 12'', \quad \Delta_p = 1'' \]

Point source offset: (0″,0″) Point source offset: (3″,3″) Point source offset: (6″,6″)

MAP%RESO = 15
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing
2. Undersampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ~ 0.32 K peak brightness.
- 12″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 19″ equivalent to a 17m-telescope...

Observing grid: \( \Delta_o = 12″, \Delta_p = 1″ \)

Point source offset: \((0″, 0″)\)  
Point source offset: \((3″, 3″)\)  
Point source offset: \((6″, 6″)\)

MAP\%RESO = 19
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing
2. Undersampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.22 K peak brightness.
- 12″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 23″ equivalent to a 14m-telescope...

Observing grid: $\Delta_\alpha=12''$, $\Delta_\phi=1''$

![Point source offset: (0″,0″)](image1)
![Point source offset: (3″,3″)](image2)
![Point source offset: (6″,6″)](image3)

*Spectral Line Observing Strategies* J. Pety, 2013
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing

2. Undersampled case results in image plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Point source of 1 K brightness. Beam dilution ⇒ ∼ 0.16 K peak brightness.
- 12″ sampling between the rasters.
- 1″ sampling along the rasters.
- Final resolution: 27″ equivalent to a 12m-telescope...

\[ \text{Observing grid: } \Delta_o = 12'', \Delta_p = 1'' \]

Point source offset: (0″,0″)  \hspace{1cm}  Point source offset: (3″,3″)  \hspace{1cm}  Point source offset: (6″,6″)

MAP%RESO = 27
Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

3. Undersampled case results in $uv$ plane

- Frequency: 230 GHz ⇒ 30m resolution: 10.7″.
- Final resolution: 15″ equivalent to a 22m-telescope...
Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

3. Undersampled case results in $uv$ plane

- Frequency: 230 GHz $\Rightarrow$ 30m resolution: 10.7$''$.
- Final resolution: 19$''$ equivalent to a 17m-telescope...

Gridding through convolution and resampling:

IV. Trying to rescue undersampled cases by smoothing

3. Undersampled case results in \( uv \) plane

- Frequency: 230 GHz \( \Rightarrow \) 30m resolution: 10.7″.
- Final resolution: 23″ equivalent to a 14m-telescope...
Gridding through convolution and resampling:
IV. Trying to rescue undersampled cases by smoothing

3. Undersampled case results in $uv$ plane

- Frequency: 230 GHz $\Rightarrow$ 30m resolution: 10.7''.
- Final resolution: 27'' equivalent to a 12m-telescope...

Spectral Line Observing Strategies  
J. Pety, 2013
Can you observe wider sky area through undersampling?

In general, no because sensitivity limited.

Only if If the limiting factor is the maximum telescope speed.

Does undersampling save observing time?

No Reaching a given sensitivity depends on the time spent per independent beam, not on the sky coverage (Pety, IRAM memo #2009-1, version 1.1).

Slightly Less overheads to cover the same sky area.

⇒ Drawbacks far outweigh advantages.
  ⇒ Undersampling is discouraged at IRAM.
Difficulties of blind deconvolution of error beams

Why deconvolving error beams? At high frequency, a large fraction of the flux comes from the error beams (e.g. \( \sim 50\% \) at 1 mm for the 30 m).

What is blind deconvolution? It uses only data and general a priori (e.g. positivity). It does not use other datasets.

Difficulties

- The beam shape may depend on elevation.
- Error beams can be extremely wide \( \Rightarrow \) missing information outside the mapped region.
- Non-uniform noise coverage \( \Rightarrow \) shift-variant telescope response.
- Baselining scheme (adaptative windowing) \( \Rightarrow \) shift-variant telescope response.