CLASS
Continuum and Line Analysis Single-dish Software

A GILDAS working group software

February 6, 2002

```
Continuum and Line Analysis Single-dish Software

                          or

                            Sensible
                            Simple
Continuum and Line Analysis Sophisticated System (*)
                            Sympathetic
                            Super
```

Version 4.0

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Contents

1 Introduction

CLASS is a software package for reducing spectroscopic data, and also continuum drifts obtained on a single-dish telescope. **CLASS** supersedes the older **LAS** program which was restricted to spectroscopic data.

The originality of **CLASS** with respect to similar systems already in use is in the way an observation may be identified. In addition to the traditional scan number which can be used to uniquely refer to an observation, the system also enables one to use *Selection Criteria* as in a data base management system. This faculty, added to a powerful command monitor, **SIC** , allows easy manipulation of large volumes of data ; the list of observation numbers to be added to get the mean spectrum at one position need no longer be typed in, but may be found by **CLASS** itself.

CLASS is divided in different parts, called "Languages", which have somewhat independent functions (*). Language LAS contains all the general utility functions to handle the data structure, plot the spectra or drifts and calibrate them. Language ANALYSE contains functions to analyse calibrated spectra in more detail. Language GTVL includes commands for basic graphic actions performed by the graphic library used by **CLASS**; the same library is used by **GreG** .

On a standard installation, **CLASS** is entered by just typing `CLASS`. In addition to this manual, the reader should consult the **SIC** manual, and for further processing, the **GILDAS** and **GreG** manuals.

2 Cookbook

This part is a list of recipes enabling the beginner or the occasional user the get on the air very rapidly, without losing his time searching the system's on-line HELP facility. A CLASSic session is the following:

```
DEVICE XLAND WHITE                       ! 1
FILE IN BRUT.BUR                         ! 2
SET LINE 13CO(1-0)                       ! 3
SET SOURCE IC348                         ! 4
SET TELESCOPE IRAM-30M-B30               ! 5
SET OBSERVED 15-AUG-1984                 ! 6
SET ANGLE SECONDS                        ! 7
SET COORDINATES EQUATORIAL               ! 8
FIND/OFFSET 0  25                        ! 9
SUM                                      ! 10
!
SET UNIT VELOCITY                        ! 11
SET MODE X -1 14                         ! 12
SET MODE Y -0.5 7.5                      ! 13
SET PLOT HISTOGRAM                       ! 14
PLOT                                     ! 15
HARDCOPY/PLOT                            ! 16
!
SET WINDOW 3 6 8 10                      ! 17
BASE 4/PLOT                              ! 18
PLOT                                     ! 19
!
LINES 0                                  ! 20
GAUSS                                    ! 21
FIT                                      ! 22
RESIDUAL                                 ! 23
PLOT                                     ! 24
!
FILE OUT REDUIT.30M NEW                  ! 25
SWAP                                     ! 26
WRITE                                    ! 27
!
SAVE IC348                               ! 28
EXIT                                     ! 29
```

2.1 Getting on the air

CLASS needs a data file, as well as (usually) a graphic output device. The first thing is then to define the device to be used, (command 1), here an X-window terminal, on which an landscape style window with white background is created. The input file containing spectra is then opened (command 2).

2.2 Adding Spectra

Usually one begins by adding up the individual spectra obtained at a single position on the sky. To do this, define the Selection Criteria of the spectra, including the Line Name (3), the Source Name (4), the Telescope and backend configuration used (5), and the date of observations (6). In this example we consider all the observations of the 13CO(1-0) transition performed using the IRAM 30-m telescope in the direction of IC348 on 1984 August 15th. Commands (7) and (8) further define the angular coordinate system to be used, and the corresponding units. Executing the `FIND` command (9) builds up an *Index* of these observations, where the selection criteria defined by the previous `SET` commands are further extended by the `/OFFSET` option which limits the search to the position (0.,25.) (in equatorial coordinates and arc seconds, as defined by (7) and (8)). The `SUM` command then adds up all the spectra of the current index.

2.3 Visualization

To see the result, command (11) defines the X axis units (here Velocity, but channel number or Frequency may be used). Then commands (12,13) define the plotting limits (in Velocity and Antenna Temperature respectively). Command (14) specifies that the spectrum will be plotted as a histogram, instead of the simpler, but less realistic, segmented line. The `PLOT` command (15) draws the axes, labels, the spectrum and its title. Each of these operations may be performed separately if needed.

A hardcopy of this plot can be obtained as in command line (16). This creates a file which is automatically sent to a plot spooler. The plot appears on the local system plotter device.

2.4 Calibration

Generally the spectrum baseline is not perfect. One may thus want to subtract a baseline, calculated by a least-squares fit, excluding the intervals defined in command line (17) 3-6 and 8-11 (in velocity units according to (11)) in which the observed line is supposed to be present. This is done by command line (18), which computes a 4th degree polynomial (argument of the `BASE` command), plots the result superimposed on the preceding plot, then subtracts this polynomial from the spectrum. The original version of the spectrum is copied in the second "memory" of the system (T memory). The result of the baseline subtraction, in memory R, is displayed by the `PLOT` command (19). Note that the limits defined in (12,13) stay in use.

2.5 Analysis

If the result is satisfactory, the spectrum is further analyzed by more sophisticated means, such as model-fitting by Gaussian curves. One defines the number of curves to be used (20); 0 means the automatic minimization with a single Gaussian, without initial values for the parameters. The `GAUSS` command (21) activates the minimization algorithm, which finally converges (yes it does !). One plots the fitted Gaussian by the `FIT` command (22). The residuals may also be determined by the `RESIDUAL` command (23) which first copies the R "memory" into the T "memory", then subtracts the Gaussian. These residuals are then plotted (in the current limits) by the `PLOT` command (24).

2.6 Writing

If everything seems OK, one usually saves the results of the fit. One must first open an output file (25) ; in this example the file is created by means of the last argument "`NEW`" ; to open an existing file, omit it. Then go back to the true spectrum, not the residuals, by exchanging "memories" R and T by the `SWAP` command (26), and copy the contents of the R "memory" onto the output file by the `WRITE` command (27). The limits of the plot, the baseline, the Gaussian parameters as well as the list of observations used to obtain this final result are automatically saved in the same operation.

2.7 End of session

You can simply get out by `EXIT` (29), but if you want to keep the current "environment" of **CLASS** , e.g. all the parameters defined by `SET` commands, use the `SAVE` command (28), which writes the corresponding `SET` commands on a command file (here `IC348.CLASS`). Later you will be able to re-execute all these commands and rebuild the previous environment, by entering : `@ IC348`, thus avoiding a lot of tedious typing.

That's it, you now know (nearly) everything. Good luck...

3 CLASS Manual

3.1 More about CLASS

3.1.1 Files

CLASS uses two files of data; one for input and one for output, which may be the same actual file. The input file is only used to read. An observation contains several independent sections. These file are defined by the command `FILE (IN,OUT,BOTH) Filename`, possibly followed by `NEW` if a new file is to be initialized. The default extension of files is site dependent : it is `.30M` at Pico Veleta, `.BUR` at the Groupe d'Astrophysique in Grenoble and on Plateau de Bure, and so on).

Commands `FIND` and `GET` operate only on the input file. Command `WRITE` operates only on the output file. When both are identical, `WRITE` creates physically a new version of the spectrum in the file, keeping the previous one. In some cases one may override the old version by the new one by the `UPDATE` command. To do this, the file must be used for both input and output, and each of the sections of the new version must fit in the space used by the old one. Other commands are subject to similar restrictions, in particular `KEEP` to save the gaussian fit results. If you want to play safe, always use `WRITE`.

CLASS also keeps a log file (named `SYS$LOGIN:CLASS.LOG`, created by the **SIC** monitor) and a message file `SYS$LOGIN:CLASS.MES`, which are systematically purged at the end of each session. These files may be used to keep track of a batch or interactive work. Finally the session environment may be saved as a command file containing a set of `SET` commands.

3.1.2 R and T Memories

CLASS keeps 2 observations in memory, one in an area called the R memory, the other in the T memory. The R memory is the only one that may be accessed directly ; the T memory is only used for operations on spectra (additions,...). This works like a HP calculator. The command `SWAP` exchanges both memories.

3.1.3 Observation and Version Numbers

Within **CLASS** , an observation should represent a single observing configuration, e.g. for spectra a single direction observed at a single central frequency with a single spectral resolution and in one polarization only. All versions of a given observation represent different stages of the data reduction. Each time the observation is modified (using `UPDATE` or `WRITE`) the version number increases. In principle, in **CLASS** , only the last version of a given observation is relevant. Previous versions are never deleted, with the exception of `UPDATE` command which overwrites the current version, so you can go back to previous stages of reduction in case of big mistakes.

Provided you respect this use of the version number, data reduction can be largely automated. Failing to do so, i.e. using the same observation number for very different things, implies that you have to remember yourself which version corresponds to which configuration. This was unfortunately the case for previous releases of the **OBS**erving program on the 30-m (See **CAL** manual), but should be solved in the new version for which Scan numbers and Observations numbers are different. Note that, for bookkeeping purpose, **CLASS** keeps also track of a Scan number, which can be used as a selection criterium.

3.1.4 Adding Spectra

Four parameters define the way spectra are added. These are the align mode, the combination mode, the integration weighting, and the behaviour with respect to bad channels.

Four alignment modes are available, by the means of the command
`SET ALIGN Mode :`

- `CHANNEL` in which spectra are added channel by channel. This is only useful when the spectra have been obtained in strictly identic conditions. Warning messages are given when this is not the case.
- `VELOCITY` in which the velocity scale is used to align the spectra. This enables you to add spectra of different origin. An interpolation is performed if needed. If individual spectra have differing spectral resolutions, the lowest spectral resolution is used for the result.

- FREQUENCY in which the rest frequency is used to align the spectra.
- POSITION, in which continuum drifts are aligned regarding to the position along the drift.

CHANNEL and POSITION only are relevant for Continuum observations, while CHANNEL VELOCITY and FREQUENCY are relevant for Line observations.

Two combination modes are possible with the command
SET ALIGN MODE Combination :

- INTERSECT where only the intersection of individual spectra is kept
- COMPOSITE where the reunion of the individual spectra is kept (as in a spectral scan for example)

Three weighting types may be used, with the command
SET WEIGHT Type :

- TIME for weights proportional to the observing time, divided by the square of the system noise ;
- SIGMA for weighting by the inverse square of the rms noise of each individual spectrum.
- NONE or EQUAL for equal weighting. Caution : equal weighting behaves differently in SUM and ACCUMULATE commands. SUM produces the average of spectra, while ACCUMULATE gives the sum of the two spectra. After division by the number of added spectra, ACCUMULATE will thus give the same result as SUM.

Bad channels are dealt with in two possible ways, defined by the command
SET BAD Mode :

- OR where resulting channels are declared bad if they were declared as such in at least one of the individual spectra ;
- AND where resulting channels are declared bad if they were bad in all individual spectra.

Default values are ALIGN CHANNEL INTERSECT, WEIGHT TIME, and BAD OR.

Two other parameters control whether summing spectra is allowed or not. Positions are checked according to SET MATCH Tolerance or SET NOMATCH. If (absolute) positions differ by more than the tolerance parameter, an error message is generated. The tolerance is specified in current angle units. The homogeneity of the calibration is checked according to the SET CALIBRATION Beam_Tolerance Gain_Tolerance or SET CALIBRATION OFF commands. Beam_Tolerance is the maximum difference allowed in the beam efficiencies to add spectra (default 0.02) and Gain_Tolerance the maximum difference between the gains in the image band (default 0, which means not checked).

There are two ways of adding spectra : the commands SUM and ACCUMULATE. SUM operates globally on all the spectra in the index, while ACCUMULATE adds the R and T memories into R. SUM is generally better for systematic methods, ACCUMULATE for special cases. The drawback of ACCUMULATE is in the need for initialization ; one needs a spectrum in T and a spectrum in R to begin with ...

3.1.5 Selection Criteria

Default selection criteria are defined by the SET command. For most selection criteria, an option to the FIND command exists, with the same name, which may be used to impose temporary values to the FIND command ; the default values are unchanged by the FIND options.

- SET TYPE Name is more than a selection criterium, since it specifies on which type of observations the **CLASS** program works. Name can be “Continuum”, “Line” or “Spectroscopy”, or “Skydip”.
- SET LINE Name for the line name to be used. A line name of the form ABC* indicates that all lines beginning by ABC are to be selected. The default is *, i.e. any line name.
- SET NUMBER n1 n2 for the range of observation numbers. Default is * *, i.e. any observation number ; * n2 specifies all observation numbers smaller than n2.

- `SET OBSERVED d1 d2` for the range of observing dates. A date is specified in the format `dd-mmm-yyyy`, e.g. 19-jan-1985. Default is `* *`, i.e. any date ; `19-JAN-1985 *` means any date later than January 19^th, 1985.
- `SET OFFSET o1 o2` for offsets of the position to be used (in the system and units specified by `SET COORDINATE` and `SET ANGLE`). Default is `* *`.
- `SET RANGE w e s n` is a less restrictive way to specify position offsets. A rectangular area of sky is defined by its west, east, south and north limits (in current angle units).
- `SET REDUCED d1 d2` for a range in reduction dates ; same specifications and defaults as for `SET OBSERVED`.
- `SET SOURCE Name` for the source name ; same specifications as `SET LINE`.
- `SET SCAN s1 s2` for a range of original scan numbers. Scan numbers should not be confused with Observation numbers (the numbers by which an observation is uniquely identified). They are essentially "historical" numbers defined by the acquisition system, but usually with different "observations" (in the **CLASS** meaning) for a single scan. The scan number is kept only for bookkeeping purpose.
- `SET TELESCOPE Name` for the Telescope name. For the IRAM 30-m telescope, the telescope name contains coded into the last 3 letters the backend used for the observations. Similar conventions are used for the POM-2 and IRAM 15-m telescopes.

The tolerance parameter defined by `SET MATCH` also influences on the position searches, since this parameter (in the current angle unit) is used to check agreement with the specified limits. Another option to the `FIND` command is `/ALL` which enables one to find all the versions of of observations satisfying the selection criteria (otherwise only the most recent version is selected). Note that the system is intended to work only with the last version of observations, so that the use of the `/ALL` option should remain exceptional.

3.1.6 The Plot

Plotting data is done by using **GreG**. All **GreG** commands are available in **CLASS**.

Plotting spectra is controlled by several parameters

- `SET UNIT Type` defines the unit of the X axis, which may be C (for Channel number), V (for Velocity), F (for Frequency) or I (for Image).
- `LAS\SET PLOT Type` defines the plotting type `PLOT` (Normal or Histogram) ; Normal gives straight lines connecting the data points (this is the default since it is faster). Histogram gives a more realistic representation of spectroscopic data.
- `SET MODE X (or Y) Type` defines the plotting limits in X or Y, where type stands for `TOTAL` (all channels plotted in X, complete scale in Y), `AUTO` (take the plotting limits in use when the spectrum was last written), or two numbers for fixed limits ; X or Y specify the axis on which the type is to apply. For X axis, the limits are in the current units (C, V or F). For F, specify the offset from the rest frequency in MHz (note: the caption and the numbers on the axis will refer to absolute rest frequencies).

Several commands result in plotting. These are :

- `BOX`, which plots the frame. The Y axes are labelled in temperature units ; the X axes may be in the following units : Velocity, Frequency, Image frequency, or Channel number. The upper X axis may be labelled in a different unit than that of the lower axis. Units for both axes are entered by the command `SET UNIT L U`, where L and U stand for the units of lower and upper axes and may be any of V, F, I, or C. The second parameter U is optional ; if not entered, it defaults to L.

  `BOX` accepts the option `/UNIT` which specifies a unit temporarily different from the current one (given by the `SET UNIT` command). The parameter `UPPER` will modify only the unit for the upper axis of the frame. For instance : `BOX /UNIT F UPPER` will give velocities on the lower axis (if this is the current unit specified by `SET UNIT V`) and rest frequencies on the upper axis.

- `SPECTRUM`, which plots the spectrum, in the current mode, clipped into the current box. An offset may be given as argument to plot two spectra above each other for comparison.
- `TITLE`, which writes a header above the frame. The title format is controlled by the `SET FORMAT` command.
- `PLOT`, which performs all of `CLEAR; BOX; SPECTRUM; TITLE` in a single operation.

3.1.7 Baselines

The `BASE` command subtracts polynomial baselines of degree < 30. The fitting algorithm uses Chebyshev polynomials, and does not allow any extrapolation outside the fitting range. It is thus important to fit the baseline out to the maximum extension of the wanted spectrum. If extrapolation is needed, a constant value will be used outside the fitting range, equal to the polynom value at the boundary. The algorithm warns if the polynomial degree is too high.

One first defines line windows by the command `SET WINDOW`. Values may be entered numerically as arguments :

```
SET WINDOW wl1 wu1 [wl2 wu2 [...]  ]
```

or graphically with the crosshair cursor if `SET CURSOR ON` has been selected. In this case enter the values in the same order as above by typing "N" or " " (space bar); "C" cancels the last value entered ; "H" types a help message and "E" terminates the operation.

Up to 20 windows may be defined. `BASE` then fits a polynomial to the rest of the spectrum. However, only the "visible" parts of the spectrum are used and bad channels are taken out. The degree of the polynomial is defined by `SET BASE n`, or temporarily by the `BASE` command itself with its argument. . The `/PLOT` option plots the fitted baseline in the current box. The area in the windows as well as the rms noise, are computed.

A baseline can be computed for one spectrum, and then subtracted from a different one using `BASE LAST`. This may be helpful for example at Pico-Veleta where you may remove from the 100 kHz backend the baseline determined from the 1 MHz one. Be sure that you do not change the X-unit between the time you computed the baseline and the time you remove it...

Sinusoidal baselines may also be subtracted, using the command

```
 BASE SINUS Amplitude Period Phase
```

where Amplitude Period and Phase are initial guesses for a minimization routine. A linear baseline is added to the sinusoid in any case.

3.1.8 Frequency Switching

Spectra obtained by Frequency Switching need to be folded before further processing. It is usually a good idea to remove a baseline before the spectra are folded in order to use as much baseline as possible. The folding is done by command `FOLD` which reads from the corresponding section all the necessary parameters. `FOLD` only operates in the R memory. The number of channels is decreased to keep only the relevant part of the resulting spectrum.

3.1.9 Profile Analysis

The **CLASS** user may analyse spectra by fitting profiles. The minimization method is taken from the MINUIT system of CERN, modified and optimised for this purpose. Reliability proves to be good. Five types of profiles are presently available, and can be selected by the `METHOD` command :

- `METHOD GAUSS`
  This is the default type of profile. One may use up to five gaussians, which might depend on each other as specified by a system of control codes associated with each variable. For each of these gaussians, the primary parameters are 1) Area, 2) Position, and 3) Width (FWHM). The current X

unit (for the lower axis) is used. Code 0 means that the parameter is adjustable ; 1 that it is fixed ; 2 that the parameter (head of group) is adjustable and that another parameter, coded 3, is fixed with respect to it ; 4 that the parameter is a fixed head of group.

- `METHOD SHELL`
  Profiles are like those encountered in envelopes of stars. The primary parameters are Area, Position, Width and Horn to Center ratio. The aspect of the profile varies from parabola (as obtain in optically thick lines) for Horn/Center = -1 to flat-topped lines (unresolved optically thin lines) for Horn/Center = 0 and double peaked profiles (resolved optically thin lines) for Horn/Center > 0. The profile is symmetric. Presently only code 0 and 1 can be used, and up to 5 independent lines can be fitted in a single spectrum. The X unit must be frequency.

- `METHOD NH3(1,1) or NH3(2,2) or NH3(3,3)`
  Profiles taking into account hyperfine structure of ammonia with a gaussian distribution of velocity are fitted. Primary variables are 1) The product (Main Group Opacity) times (Excitation Temperature minus Background Temperature) 2) Velocity 3) Line Width (FWHM) and 4) Main Group Opacity . Up to 3 independent lines can be fitted, and only codes 0 and 1 are allowed. The X unit must be Velocity.

- `METHOD HFS FileName`
  This method is similar to the previous one, but the HyperFine Structure parameters are read from a file instead of being known by **CLASS** . The first line of this file must contain the number of hyperfine components (< 40). The other lines must contain, for each component, the velocity offset and the relative intensity. The parameters are the same as for NH3 method.

- `METHOD CONTINUUM`
  This method is used for continuum drifts. It fits a gaussian and a linear baseline in the drift. If beam-switching was used and the reference beam is along the drift direction, two dependent gaussian are used to optimize signal to noise. The method does not require any user input.

The commands of this profile analysis system are :
`LINES, GAUSS, FIT, DISPLAY, ITERATE, RESIDUAL, KEEP.`

- `LINES N` defines the number of components and prompts for the initial values of the parameters for each component. This command has no effect for method `CONTINUUM`. Parameters are read in list directed format in the following order :

  ```
  Code, Intensity, Code, Position, Code, Width, [Code, Parameter 4]
  ```

  The code is an integer number between 0 and 4. Note that, though the program works on the area (or other quantities as for `NH3` methods), you have to give the intensity, since this quantity is more intuitive than area. The use of the list directed format makes things easier when only one parameter has to be modified (cf Fortran norms). The number of lines N may be zero ; in this case the program finds out reasonable starting values by itself.

  Values may be also entered graphically if `SET CURSOR ON` was selected. After entering `LINES N`, first point the cursor to one side of the line, strike one key, point the cursor the other side, strike another key. The program computes the moment of the spectrum between these boundaries and use it to set up starting values. Proceed like this for all components. One drawback of this way of entering values is that you cannot change the control codes. It should be used only for entirely independent and free lines.

- `GAUSS`
  activates minimization, then prints out the results after convergence. A Simplex method is first used to ensure convergence, then a Gradient method to refine the results, and compute the errors.

- `ITERATE`
  is similar to `GAUSS`, but starts from the previous minimization results. Only the Gradient method is used. Consequently, this command is only useful close to the minimum.

- `FIT N`
  plots the Nth component obtained by fitting ; if N is not given, the sum of all components is plotted.
- `RESIDUAL N`
  subtracts the Nth component from the current spectrum, or the sum of all components is N is not given). In this process, the R spectrum is first copied into T, then the difference is done in R.
- `DISPLAY`
  Prints the results of fitting from the current spectrum, without recomputing it ...
- `KEEP`
  Saves the fit results in the input file, which must be opened also for output. `KEEP` is in fact a reduced version of `UPDATE`, and to be used with the same care as `UPDATE`.
- `SET MASK ...`
  Defines masks in the spectrum for the fit. This commands has the same syntax and behaviour as `SET WINDOW`. Masked regions will not be used for the fit.

Fit results are always saved by a `WRITE` command.

3.1.10 Miscellaneous

- `DIVIDE` makes the ratio of the R and T spectra. The two spectra must have the same velocity scale.
- `FFT` plots the power spectrum of the current observation. It might help identify spurious ripples. Editing of the fourier transform is possible, so that these ripples may be suppressed.
- `NOISE` generates a gaussian noise as intense as in the current spectrum using the rms value determined by the `BASE` command, or using a rms value given as an argument. `NOISE Value NEW` will create a noisy spectrum of given noise level into R, after copying R in T.
- `RESAMPLE` resamples the R spectrum on the specified grid. If the final sampling is coarser than the original one, a smoothing occurs to the final sampling.
- `SMOOTH` operates a Hanning smoothing by default and divide the number of channels by two. Other arguments can be specified to use other methods. `SMOOTH AUTO` uses a sophisticated variable-resolution algorithm, but it requires the channels to be really independent and this is apparently seldom the case in radio astronomy. `SMOOTH GAUSS Width` convolves the spectrum by gaussian of given Width in current units ; it does not take care of bad channels. `SMOOTH BOX N` make the average of N adjacent channels and divides the number of channels by N.

3.2 Continuum Processing

3.2.1 Introduction

So far, we have handled only Spectroscopic data, but Continuum data can be processed by **CLASS** . Currently, only continuum drifts can be reduced. The basic idea is to treat continuum drifts as spectra would be. Accordingly, very few commands behave differently in Continuum and Spectroscopy modes.

Continuum mode is accessed by typing command
`SET TYPE CONTINUUM`
the prompt changes to `CAS>` (Continuum Analysis System). You can return to Spectroscopy mode later on typing command
`SET TYPE SPECTROSCOPY or LINE`
and the prompt changes to `LAS>` (Line Analysis System).

3.2.2 Differences between Continuum and Spectroscopy Mode

Some commands have slightly different behaviour in Spectroscopy and Continuum modes.

- `SET UNIT` has no effect in Continuum mode.
- `SET ANGLE` also controls the plotting units in Continuum mode.
- `METHOD` : only `GAUSS` and `CONTINUUM` methods are allowed in Continuum mode.
- `LINES` has no effect with `CONTINUUM` method.
- `HEADER` uses a different format for Continuum and Spectroscopy modes.
- `STRIP` produces a map from a set of parallel drifts. The index must define such an ensemble of drifts.
- FITS format support is experimental for continuum data.
- With `CONTINUUM` method, `PRINT FIT` command only outputs a single component, and the component number is not written.
- `SET ALIGN CHANNELS` and `SET ALIGN POSITION` are the only available alignment modes in Continuum mode.

Except for these restrictions, the behaviour of other commands is similar. Note that command `FIND` only selects data of the current type.

3.3 Skydip Processing

CLASS is able to reduce skydip data. Skydip mode must be selected using command `SET MODE SKYDIP` which also changes the prompt to `SAS>` (Skydip Analysis System). Commands `FIND, HEADER, GET, PLOT` and `WRITE` may be used as for Continuum and Line modes, but the only other valid command is `REDUCE` which fits the sky emission using atmospheric information available in the data, and displays the results.

3.4 On-the-fly Data Processing

The format of **CLASS** data files has been recently extended to allow the reduction of data obtained in the On-the-fly (OTF) mode by the 30-m telescope. In that mode the data is taken while the telescope beam is moving across the source to be mapped. The raw data is pre-processed (amplitude calibration) by the CAL program available at the telescope, and written in a **CLASS** file. Data from a scan across the source is written as a single observation, thus containing many spectra at different positions. Each spectrum is included in the observation as a 'record' or 'dump', labeled by time, and telescope position. This new kind of data is handled by **CLASS** in a way similar to the normal data, but a few commands behave differently:

- `GET` has an option `/RECORD n` to load an individual record of an OTF scan in the R buffer. After that this data may be plotted in the usual way.
- `PLOT` has an option `/SCAN` which displays the entire scan as a 2-dimensional image, with velocity/frequency in the X axis, record number in the Y axis, intensity being rendered as grey/color scale.
- `BASE`, `FFT`, `RESAMPLE` work on all the records of an OTF scan at once.
- `GRID` may be used to tabulate, grid and plot the OTF data into **GILDAS** data cubes that may be further processed with **GILDAS** tasks.

3.5 Map Processing: GILDAS

3.5.1 Maps of Spectra

Using the MAP command, it is possible to produce a plot of spectra in the current index, arranged in a map. Use the option /CELL Size_x Size_y to specify the size of a spectrum, in current angle units. Without this option a default is taken (the actual separation of the spectra). Option /GRID will produce frames around the spectra. The argument MATCH can be given to fix the aspect ratio of the boxes to the cell sizes.

The map size can be controlled using commands SET PAGE and SET BOX_LOCATION. Labels can be suppressed by option /NOLABEL (and ticks will not be drawn if of size 0.0). Option /NUMBER will add the observation number with each spectrum.

On multi-window displays (e.g. X-Window terminals), after the MAP command has been used, the POPUP command may be used to display in another window a spectrum selected either from its observation number or from its offsets. POPUP can also be used after the STAMP command. The STAMP command allows to display many observations at once, without requesting the X and Y axis scales to be fixed.

3.5.2 GILDAS Interface

For mapping purpose, **CLASS** is able to produce images at the **GILDAS** format. **GILDAS** (the Grenoble Image and Line Data Analysis System) is an ensemble of routines which is able to process images of up to four dimensions. It contains a variety of routines to transpose, resample, reproject, smooth, add, merge, divide, etc... images, and a superset of **GreG** which allows to produce contour plots from these images. Other programs can also do false color displays of the images on image processors.

3.5.3 Contour maps: Building a data cube

The command CUBE builds a 3-D image from the current index. It is assumed that the current index defines such an image (i.e. corresponds to a single line, observed with a single resolution, and towards a single source). The first axis of the cube corresponds to the current X unit, the second to RA (or L) and the third to DEC (or B). Projection information is written so that the coordinate system is automatically recognized when processed by **GILDAS** .

Please refer to the **GILDAS** documentation for later processing. The recommended first steps are i) a transposition (task TRANSPOSE to put the axes in RA,DEC,Velocity ordering and ii) the tasks FILL_CUBE (for undersampled data) or MAKE_CUBE (for oversampled data) to resample the data cube on a finer grid for nice contouring.

An alternative processing technique is to use command GRID, which creates a table suited for map making using the task GRID_CUBE. This route is recommended for oversampled data, while the use of MAP and FILL_CUBE is probably better for undersampled data.

Finally GRID /IMAGE will directly produce data cubes from oversampled or undersampled data, using a Gaussian convolution kernel for interpolation, and reasonable defaults for the cube size and pixel size in both axes.

CUBE and GRID can also produce images or tables of several mathematical functions of the input spectra rather than simple channel maps. Please refer to the internal help for details.

3.5.4 Velocity-Position Plots

Although by adequate use of transpositions, you can produce velocity-position plots from data cubes, it is also possible to create a 2-D image for processing by **GILDAS** to produce Velocity-Position plots by using command STRIP. This command works on the current index, which must correspond to a real strip. Relevant information is written to a 2-D image which can later be processed by **GILDAS** . The first axis corresponds to the current X unit (Velocity or Frequency or Channels) and the second axis to the offset.

3.5.5 Continuum Maps

Command STRIP can also be used to produce a continuum map from an ensemble of parallel continuum drifts. The index must define such an ensemble.

3.6 The PRINT Command

In addition to the previous commands, the command `PRINT` offers a way to list a number of additional informations. It has several functions :

- `PRINT FIT`, which prints the results of profile fits. For each spectrum, N lines are written (N being the number of fitted components), and each line contains in the following order (1) the component number, (2) then observation number, (3,4) the two cartography offsets, (5,6) area of gaussian and corresponding error, (7,8) same for position, (9,10) same for width, (11) intensity, (12,13) rms on the baseline and on the line. Offset are in the current coordinate system and units. The current method is used.

  For Continuum method, only a single gaussian is written. The written information is oriented towards pointing measurements : (1) the observation number (2,3) Azimuth and elevation (4,5) area of gaussian and error, (6,7) position, (8,9) width, (10) intensity, (11,12) rms on baseline and signal, (13,14) collimations. All angular values are in the current angle unit. The values are followed by the source name.

- `PRINT AREA`, prints the area of the line computed by the `BASE` command. Each line contains (1,2) offsets, (3) area, (4) rms noise.

- `PRINT AREA V1 V2 V3 V4 ...`, prints areas within velocity slices (if such is the current X unit, but one could use channels or frequencies). Ranges are V1-V2, V2-V3, V3-V4, ... etc. Each line will contain (1,2) the offsets, followed by the areas in order.

- `PRINT CHANNEL List`, prints values of channels in the list. The list is specified in the FOR n1 TO n2 BY n3 format. Total number of channels is however limited to 15.

- `PRINT MOMENT V1 V2 V3 V4 ...`, prints moments (area, position, width), of the data within the velocity (or channels or frequencies, depending on the current units) V1-V2, V3-V4, etc... Each line contains (1,2) the offsets, (3,4,5) the moments for V1-V2, (6,7,8) for V3-V4 etc...

- `PRINT POINTING`, prints results of CONTINUUM method fits printed in a format adapted to pointing constants measurements. The output is suited for further processing and determination of pointing constants using the **POINT** program.

- `PRINT FLUX`, prints results of CONTINUUM method fits printed in a format adapted to flux determination. The output is suited for further processing using the `FLUX` language in the **ASTRO** program.

As all commands using an ensemble of spectra, `PRINT` works on the whole current index. Output is by default printed on the screen, but may be directed onto a file by the `/OUTPUT Filename` option.

Alternatively, the same information may be written to a “Table” (a special kind of **GILDAS** image). The Table format is much faster and suppresses some of the limitations of the formatted output on the number of columns written. Table format is obtained using option `/TABLE Tablename`.

3.6.1 GreG Tables

The command `GREG` is intended to produce a direct interface with **GreG** for plots of spectra. It creates a **GILDAS** Table which can be read by **GreG** . The table contains the following columns for Spectra :

```
1. Intensity
2. Channel number
3. Velocity
4. Offset frequency
5. Rest frequency
6. Image frequency
7. Fitted profiles if any - fit(i),i=0,nline - in column 7+i,
for the current method.
```

The output table can be put later in a formatted way using **GILDAS** task `LIST` if needed. For continuum data, the table contains

```
1. Intensity
2. Channel number
3. Angular offset (radian)
4. Fitted profile if any.
```

The table may be used as input to **GreG** to produce fancy plots, or by the **GILDAS** software for other applications. In particular, the **SIC** monitor (command `LET`) is able to subtract any of the fits from the spectrum to produce residuals if needed. It is possible to merge different tables, add columns to a table, etc... For example, from two spectra at the same velocity resolution it is possible to merge the two tables and compute the ratio of the spectra, as well as the errors on this ratio.

3.7 Publication Quality Plots

With the hardcopy facility provided by the graphic library used by **CLASS** , and the `DRAW` command which allows most of the wanted annotations, it is perfectly possible to produce quality publication plots of spectra directly. Note that all **GreG** commands are available in **CLASS** to fully annotate plots, superpose spectra with related data, stack various plots ...

3.7.1 Hardcopy

The command `HARDCOPY` is the same as the **GreG** `HARDCOPY` command. Please refer to **GreG** documentation or the internal help for a description.

Note that you do not need a graphic terminal to prepare a plot. It is only much more convenient, but the plot and the way it is displayed are two completely independent things.

3.7.2 Annotations

Command `DRAW` can be used to annotate a plot. The basic operations performed by command `DRAW` are :

- `DRAW TEXT Xpos Ypos "Text" Centering`
  to draw a text at position (Xpos,Ypos) (in current units) with the specified centering code. This command works more or less like the **GreG** command of same name. Please refer to the **GreG** manual for details. In particular, you can include Greek letters and Symbols in the text using the escape character \. A strange thing may appear on the screen, but it is O.K. on the plot. If you have doubts, use `ZOOM REFRESH` before command `HARDCOPY` to see exactly what your plot looks like.

- `DRAW UPPER Xpos "Text"`
  to draw a vertically oriented text at position Xpos, with a vertical line connecting the beginning of the text to the current spectrum. This text and line are written at position Xpos, in units of the upper axis. Typically, this command is used to mark spectral line identifications.

- `DRAW LOWER Xpos "Text"`
  same as above, but with Xpos in units of the lower axis.

- `DRAW WINDOW [Level]`
  shows the current windows by marks on the graphic plot. Level is an optional arguments indicating at what Y value the marker should be put (Default 0).

- `DRAW MASK [Level]`
  same as above but for the current masks.

- `DRAW KILL [Channel]`
  kills the specified channel (current one if using the cursor) by attributing it the "blanking" or "undefined" value.

- `DRAW FILL [Channel]`
  Fills the specified channel (current one if using the cursor) by interpolation between the nearest non-blanked channels. The channel must have been killed before.

Any other character will not draw anything, but simply returns the cursor position, with corresponding values of the velocity, frequency, image frequency, channel number.

3.7.3 Plot Quality

CLASS is usually used for interactive look at spectra, hence its default values are all oriented towards fast plotting on screen. These defaults can be changed by command `SET`. If the value of a parameter is not controlled by **CLASS**, the command will be passed on to **GreG** for processing.

The following **GreG** presentation parameters are useful :

- `SET BOX_LOCATION`
  It can be set `to LANDSCAPE, PORTRAIT, SQUARE` or 4 numbers indicating the position of the box in the plot page (in centimeters).
- `SET CHARACTER Size`
  Control the size of characters in centimeters
- `SET FONT Quality`
  Select the character quality to be used, `SIMPLEX` or `DUPLEX`. The fonts are identical to the ones used by **GreG** , and the character handling is the same (in command `DRAW TEXT`).
- `GREG\SET PLOT ...`
  Define the plot page size. This command is identical to command `SET PLOT_PAGE` in **GreG** (but in **CLASS** , `SET PLOT` is already used to indicate whether spectra are broken lines of histograms). Refer to the **GreG** manual for details.
- `SET TICK Size`
  Define the tick size in centimeters

3.8 Variables

3.8.1 The Rope to Hang Yourself

CLASS makes use of **SIC** variables to allow more flexibility in the processing, in particular in procedures. **SIC** variables are extremely powerful, with the side effect that if you want, you can corrupt your data by overwriting some information. **CLASS** attempts to prevent the most disastrous errors by defining some of the most critical variables as `READONLY`. They cannot be overwritten by the user, but their values can be used in expressions, either arithmetic or logical. However, an unprotected mode is available for specific processing using the command SETVARIABLE.

3.8.2 Index Variables

The variable `FOUND` refers to the number of observations in the index. It is declared Read-Only of course. Its main use is as a test variable for actions which should be performed only if something exists in the index. As an example, the following procedure reduces a mapping observing run by averaging all spectra at each position, and requires only two user input : the two steps in Lambda and Beta.

```
SAY "Procedure MAP.CLASS : reduce mapping observations by averaging all" -
"spectra for each point. Input required from user : XSTEP and YSTEP" -
"the map spacings in both directions"
!
LAS\FIND
SIC\IF (FOUND.EQ.0) THEN
```

```
    SIC\RETURN
SIC\ENDIF
SIC\DEFINE DOUBLE XMIN XMAX YMIN YMAX XSTEP YSTEP ! Local variables
!
! Determine offset extrema.
LAS\GET FIRST
SIC\LET XMIN = OFF_LAMBDA
SIC\LET XMAX = OFF_LAMBDA
SIC\LET YMIN = OFF_BETA
SIC\LET YMAX = OFF_BETA
SIC\FOR I 2 TO FOUND
    LAS\GET NEXT
    SIC\LET XMIN = MIN(XMIN,OFF_LAMBDA)
    SIC\LET XMAX = MAX(XMAX,OFF_LAMBDA)
    SIC\LET YMIN = MIN(YMIN,OFF_BETA)
    SIC\LET YMAX = MAX(YMAX,OFF_BETA)
SIC\NEXT
!
! Now make map. XSTEP and YSTEP must be specified by user
SAY "Enter step in Lambda"
LET XSTEP =
SAY "Enter step in Beta"
LET YSTEP =
SIC\FOR XOFF XMIN TO XMAX BY XSTEP
    SIC\FOR YOFF YMIN TO YMAX BY YSTEP
        LAS\FIND/OFFSET XOFF YOFF
        SIC\IF (FOUND.GT.0) THEN
            LAS\SUM
            LAS\WRITE
        SIC\ENDIF
    SIC\NEXT
SIC\NEXT
SIC\RETURN
```

The `FIND` command does not return an error, but set `FOUND = 0`, if it finds nothing. A second variable related to the index is the `INDEX` array, of dimension `FOUND`, which contains the observation numbers of all observations in the index.

3.8.3 Default Header Variables

The most important header parameters are defined by default as **SIC** variables in a protected mode; the others, of less frequent use, can be accessed if required by the user (see “Advanced Processing”). The default variables are (RW means Read-Write variable, RO, Read-Only).

```
TELESCOPE      Character*12, RW, Telescope name
NUMBER         Integer,      RW, Observation number
VERSION        Integer,      RO, Version number
DATATYPE       Integer,      RO, Type of observation
                                 0 Line, 1 Continuum, 2 Skydip
QUALITY        Integer,      RO, Quality of data
SCAN           Integer,      RO, Original scan number
UTOBS          Double,       RO, UT of observation (Radians)
LSTOBS         Double,       RO, LST of observation (Radians)
AZIMUTH        Real,         RW, Azimuth of observation (Radians)
```

```
ELEVATION       Real,         RW, Elevation of observation (Radians)
TSYS            Real,         RW, System temperature
TIME            Real,         RW, Integration time (Seconds)

SOURCE          Character*12, RW, Source name
LAMBDA          Double,       RW, Longitude of source (Radians)
BETA            Double,       RW, Latitude of source (Radians)
OFF_LAMBDA      Double,       RW, Offset in longitude (Radians)
OFF_BETA        Double,       RW, Offset in latitude (Radians)
EPOCH           Real,         RW, Epoch of coordinates (Years)

LINE            Character*12  RW, Line name
CHANNELS        Integer,      RO, Number of channels
REFERENCE       Real,         RW, Reference channel
FREQ_STEP       Real,         RW, Frequency step by channel (MHz)
VELO_STEP       Real,         RW, Velocity step by channel (km/s)
VELOCITY        Real,         RW, Velocity of reference channel
FREQUENCY       Double,       RW, Rest frequency at reference channel
IMAGE           Double,       RW, Image frequency "   "   "   "

BEAM_EFF        Real,         RW, Telescope beam efficiency
FORWARD_EFF     Real,         RW, Telescope forward efficiency
GAIN_IMAGE      Real,         RW, Image to signal band ratio
WATER           Real,         RO, Water vapor content (mm)
PRESSURE        Real,         RO, External pressure (hPa)
AMBIENT_T       Real,         RO, External temperature (K)
CHOPPER_T       Real,         RO, Chopper temperature (K)
COLD_T          Real,         RO, Cold load temperature (K)
TAU_SIGNAL      Real,         RO, Opacity in signal band
TAU_IMAGE       Real,         RO, Opacity in image band
ATM_SIGNAL      Real,         RO, Atmospheric temperature
                                  in signal band
ATM_IMAGE       Real,         RO, Atmospheric temperature
                                  in image band

RX              Real[8192]    RO, X values of data points
RY              Real[8192]    RW, Y values of data points
```

8192 is currently the maximum size of the spectra, but the variables RX and RY are redimensioned to the effective number of channels for each spectrum.

3.8.4 Advanced Processing

All header parameters can be defined as **SIC** variables for specific processing of the data, either as Read-Only or as Read-Write, using the command `SET VARIABLE`. Read-Write mode is to be used with caution, since even critical variables (e.g. the number of channels) can be modified. Refer to command `SET`VARIABLE for more details.

By using the appropriate variables and the **SIC** mathematical and logical facilities, customized data processing becomes possible, as well as complete data editing.

Index