INTRODUCTION

This part of the manual describes the processing DOSY spectra with Gifa. Two main techniques are available to process DOSY experiment, and, more generally, to process sums of damped exponentials: the fit of different components, based on the general fitter available in Gifa; and the inverse Laplace transform approach, performed here by Maximum Entropy. The mathematical problem handled here is much more general than the processing of the DOSY experiments, but includes also any data-sets (such as relaxation measurement experiments) that can interpreted in terms of exonential decay.
This manual first present a theoretical introduction, which presents the principle of the inverse Laplace transform, and how this problem can be solved using Maximum Entropy; then the user set-up, implemented for DOSY problems, is presented.

THEORY

Laplace transform is the mathematical operation which relates a decaying signal with the distribution of dampers which created it.

$$G(s) = \int_{\delta_{min}}^{\delta_{max}} A(\delta) \exp(-s\delta) d\delta$$ eq[1]

In the terms of this manual, G(s) is said to be in the direct space (experimental data); whereas A(δ) is in the reciprocal space.
When there is only one well-defined dampers, the equation 1 simplifies to
$G(s) = A\exp(-\delta s)$ eq [2]
The general problem consists in determining the damper distribution A(δ), given the measured signal G(s).
In the case where eq [2] is a correct description of the measured signal (diffusion of monodisperse solutions for instance), Determination of the parameters (A and δ) can be simply performed by a least-square fit of the signal G(s). When the equation 1 is to be used (polydisperse solutions), then the Laplace transform has to be inversed. This is a well-known numerically difficult method, the whole purpose of this module is to realise this inversion.
The inverse Laplace analysis permits to describe the complete distribution of dampers A(δ) as used in eq 1. This permits to analyze with the same ease, single exponential decays (that will appear as a distribution with one single peak , whose width is related with the accuracy of the estimate), but also sums of exponential (with no assumption needed on the number of components) or even continuous distribution.

IMPLEMENTATION,

The possibility in Gifa to handle DOSY spectra and Laplace transform has needed the implementation of additional data representations as well as a set of additionnal commands.

Using the general fitter - dosyfit - dosyfit_2

The fit techniques, consists simply in using the `FITGENE` command, which is able to fit the data held in the 1D buffer, to one or two damped exponentials.
The two macros, `dosyfit` and `dosyfit_2` realizes this fit. Note that these macros realizes this fit in such a way that the result is independent on the `DMIN DMAX` parameters. The noise level however, should be determine with care.

MaxEnt implementation

Direct space data-sets can be handled in memory in two representations : as a regular sampling of the direct space, or as a tabulated data-set, i.e. data-points measured at arbitrary locations of the direct space.

Direct space : regular sampling

When regularly sampled, the direct space is assimilated to a time space. So seconds are the natural unit, and the spacing of points in the buffer is determined by the spectral width (`SPECW`).

Direct space : Tab_buffer, showtab

When using tabulated data-sets (sampled at arbitrary locations), the location of the sampled points are stored in a special buffer 'TAB' designed for this purpose. The `tab_buffer` macro :

- reads a plain ascii file (one value per line, # and ; are comments) as a 1D data-set (`load` macro),
- calculates the square of a 1D data-set,
- puts the 1D data-set in a TAB buffer (`PUT TAB` command).

The `GET TAB` command realises the opposite, and copy the TAB buffer to the current working 1D buffer. When handling tabulated data, the current UNIT can be set to TAB in order to locate points in this natural unit rather than in index. The macro `showtab` has been written to display the normal view of such data-sets.

Reciprocal space : DMIN, DMAX, DFACTOR, calibdosy, dosy_setup

Values in the reciprocal space (damping amplitudes) are always stored in a geometrical series, the slower decay on the left, the faster on the right. The smallest value (lower index) is given with the context `DMIN`, and the largest with `DMAX` (`DMIN` and `DMAX` values are stored, in the data file header, as `DMIN`/`DFACTOR` and `DMAX`/`DFACTOR`). This decribes the values as they will be used in the Laplace transform, along with the direct space values. However, one might want to correlate the reciprocal space values to a physical constant (such as diffusion for instance), for this purpose, a calibrating factor is added which is multiplied to the actual value when computing the coordinate : `DFACTOR`. The macro calib has been adapted to permit `DFACTOR` calibration from a known signal, on the other hand, the macro `calibdosy` tries to set `DFACTOR` from the experimental parameters of the DOSY experiment itself (Wu, D.H., Chen, A.D. and Johnson, C.S. (1995) *J. Magn. Reson. Ser. A*, **115**, 260-264).

$$D_{factor} = \frac{10^8}{\gamma^2 a^2 \left(\Delta - \frac{\delta}{3} + \frac{\tau}{2}\right)}$$ eq[3]

were γ, δ and Δ are respectively the gyromagnetic ratio of the observed nucleus, the length of the gradient pulse and the duration of the diffusion delay. a is the gradient area and is equal to $g\delta$ (g : intensity in G/cm of a nominal gradient of 1.0) for square gradients. τ is the inter-pulse delai in the bipolar-pulse LED sequence and is equal to 0 in the LED sequence
The dosy_setup macro creates an interactive environment which permits to set most of the pertinent parameters more easily.

Specific actions

LAPLACE, TLAPLACE

These two commands perform the direct Laplace transform from a reciprocal space distribution, to either a regularly sampled direct space data-set (`LAPLACE`) or to a tabulated one (`TLAPLACE`). Both commands prompt for the final data-set size, which is completely independent of the starting size. Sizes do not have to be powers of 2.

INVLAP, INVTLAP, INVLAPCONT, INVTLAPCONT

These commands actually implements the Maximum Entropy Laplace inversion. `INVLAP` and `INVTLAP` starts the inversion. They both prompt for the final size, and should be issued with the direct-space data-set (damped data) in the current 1D buffer. They will start for `ITER` number of iterations. Information on the process will be issued every `NDISP` iterations, if display is enabled, the progress of the process is also displayed on screen. `INVLAP` is for regularly sampled data-sets, whereas `INVTLAP` is for tabulated data-sets.
When the number of iterations is reached, it is possible to increase the `ITER` context, and the `INVLAPCONT` and `INVTLAPCONT` commands permit to continue the process, restarting from the current state.

TRANSLAP, TRANSTLAP

In the Maximum Entropy theory, the transpose of the Laplace transform appears in the computation of the derivative. These commands implements this transform, they may be needed in certain cases.

dosy2d, dosy3d

These two realise the Laplace inversion of the actual DOSY experiments. `dosy2d` is for the processing of a 2D DOSY experiment : a set of 1D spectra, weighted by the diffusion coefficients; `dosy3d` is for a 3D DOSY : a set of 2D spectra weighted by the diffusion coefficients.
Both macros require 5 parameters : nature of the data-set (regular or tabulated); the processing to do; the final size, a noise threshold which permits to determine which slices will be processed; and finally the name of the output file.
For the processing you can choose to use MaxEnt, fit or fit with 2 components. The fit technique extract a parameter rather than a diffusion profile, in this case, the profile is reconstructed from the fitted parameters, using a FT algorithm. The error on the position is used to reconstruct the width of the line in reconstructed profile. Note however that this width is usually rather optimistic as based solely on the noise level, and not on the other artefacts that may appear in the data. The noise threshold is used to determine wich column to process by considering the initial spectrum of the data-set, the diffusion dimension is processed only if the related point in this initial data-set is higher than the noise level time the threshold.
`dosy3d` also asks for a input file-name (initial 3D dataset, in memory) and a output file-name, in order to create a file in which the result will be stored (in memory).

USAGE

- Principle
- Tips

Principle

Usage of the DOSY module is actually quite simple. First acquire a DOSY experiment (either 2D or 3D). Then process it in a regular fashion along the spectroscopic axes (note that you will not be able to use the easy2D module, but will have to go through the elementary operations yourself). Then estimate the noise in a signal free region. Preset the various Laplace parameters : `DMIN`, `DMAX`, TAB buffer, etc... as well as the MaxEnt parameters : `ITER`, `LAMBSP`, etc... Then start the complete processing (which can be quite lengthy, even on a fast computer) with `dosy2d` or `dosy3d`.

Tips

- Be careful to use a very good baseline correction before trying to apply the inverse Laplace transform. You should not use the polynomial baseline correction for this purpose, since peak intensity is varying from one row to the other. Rather use the spline baseline correction.
- You might find a good idea to practice on 2 or 3 typical 1D slices taken out of the complete experiment.
- Some care must be taken in choosing the `DMIN DMAX` range. It must encompass the range of actual decays observed in the experiment. However note that `DMIN` and `DMAX` are in the reciprocal unit of the direct space unit. This means that if you use regularly sampled, `DMIN` and `DMAX` are in sec-1 (thus related with `SPECW`), but if you use tabulated values, they are in inverse of the tabulated values (be carefull with those strange Gradient units). `DMIN` and `DMAX` determine completely the reciprocal space, `DFACTOR` is only used when displaying the unit to the user, and has no effect on the processing.
- You may want to check the range either by generating a fake data-set (eg : `ZERO` and `SETVAL` to generate a delta function, `LAPLACE` or `TLAPLACE` to generate direct space data-set), or by trying directly an inversion with `INVLAP` or `INVTLAP`.

DOSY MENU

This menu is defined in the /usr/local/gifa/macro/env_dosy.g macro and permits to access most of the needed commands.

Tab_buffer

Equivalent to calling the load macro, which permits to read a plain ascii file into the 1D buffer. Raise to square the content of the 1D buffer, needed when using tabulated gradient values, before loading them into the TAB buffer (performed by copying the data temporary to DATA). The `PUT TAB` command which copies the current 1D buffer to the TAB buffer, used for tabulated Laplace transform.

Showtab

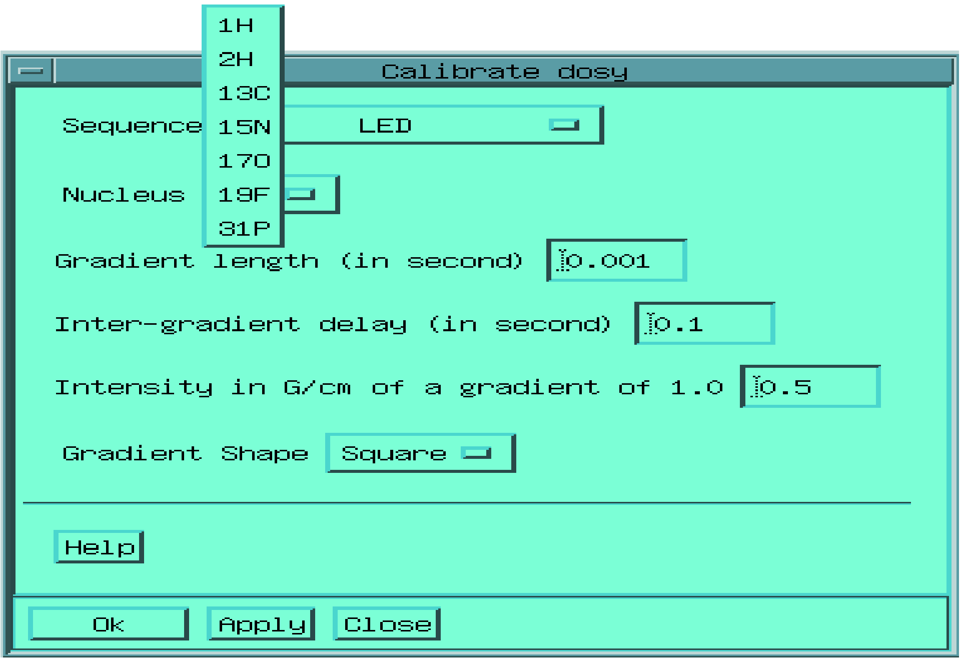
Displays the content of the 1D buffer as a tabulated data-set. Xi, Yi are plotted, where Xi is taken from the TAB buffer, and Yi from the current data-set.

Eval noise

Evaluate the noise of the experiment in a signal free region. Needed by the MaxEnt processing. Actually calls the `evaln.g` macro.

Calibdosy

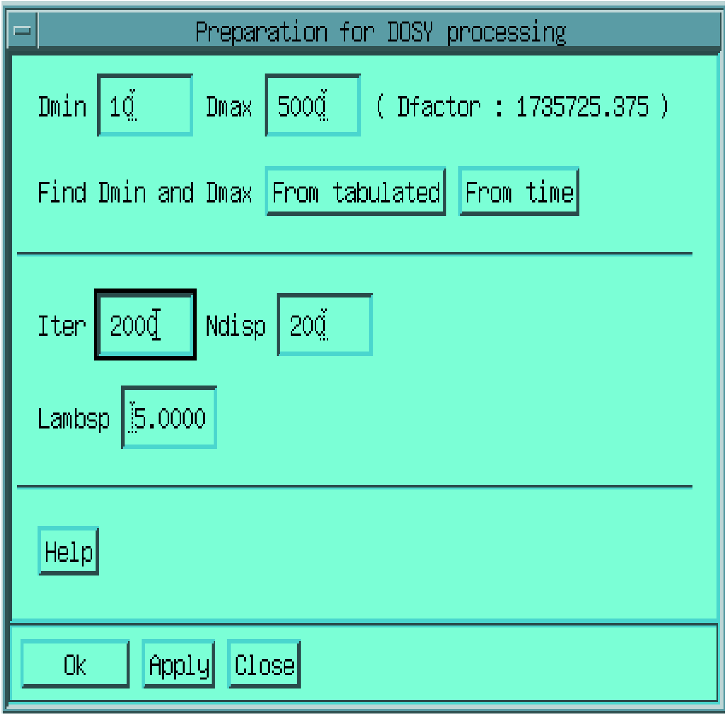
Brings a form that permits to describe the acquisition parameters, in order to determine the correct diffusion coefficients in $\mu m^2 \sec^{-1}$ unit (sets `DFACTOR`).



Chose the used pulses sequence and the observed nucleus. Enter the length, the duration of the diffusion delay, the value in G/cm of a gradient coded as 1 in the TAB buffer and the shape of your gradient pulse (shape defined by ascii file can be used).

Dosy_setup

Brings a form that permit to set most of the relevent parameters for DOSY processing.



- The DMIN DMAX range must encompass the range of actual decays observed in the experiment.
- Access to the `ITER` context, which determines the number of iterations for fit and for the MaxEnt inversion. 30-50 is certainely fine for fit, much more is needed for MaxEnt (200 seems a minimum).
- The context `NDISP` which determines the screen refresh rate during MaxEnt processing.
- Control for MaxEnt, the context `LAMBSP` which determines the speed at which the GIFA algorithm will converge (a large value may generate instabilities in the processing).

dosyfit (1 comp.)

Evaluates the current 1D buffer as one exponential damping, sampled as described in the TAB buffer.

dosyfit_2 (2 comp.)

As dosyfit, but assuming 2 exponential dampings.

Inv Laplace

Starts the MaxEnt processing for computing the inverse Laplace transform of the current data-set, considered as a regularly sampled one. Equivalent to the `INVLAP` command.

continue

Increments ITER and continue the preceding processing, uses the `INVLAPCONT` command.

Inv tab Laplace

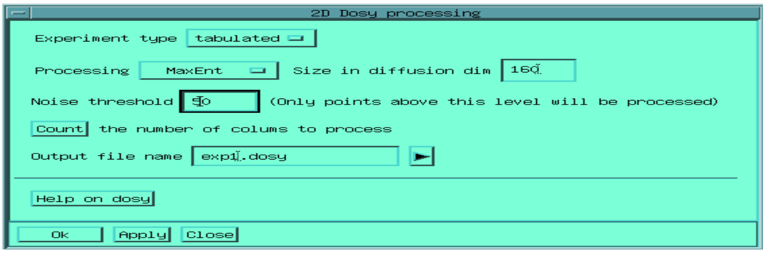
Starts the MaxEnt processing for computing the inverse Laplace transform of the current data-set, considered as a tabulated sampled one. Equivalent to the INVTLAP command.

continue

Incremnts ITER and continue the preceding processing, uses the INVTLAPCONT command.

Dosy2D

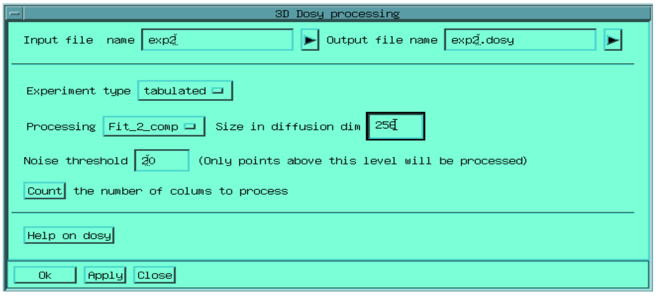
This will bring a box in which the user can simply enter the parameters for the dosy2d processing.



The dosy2d processing requires 4 parameters : nature of the data-set (regular or tabulated); the processing to do (MaxEnt, fit or fit with 2 components); the final size and a noise threshold which permits to determine which slices will be processed. `Count` buttom determines how many columns will be processed (initial data-set higher than the noise level time the threshold). Starts the dosy2d macro which performs the complete processing of the current 2D data-set.

Dosy3D

From this form you can set-up parameters for the processing of 3D DOSY datasets (set of 2D, wighted by the diffusion). The processing is done on-file.



The parameters are the same than for 2D. You will have to give a input filename (from which the data will be taken) as well as the output filename.Starts the dosy3d or te dosy3d_on_file macros which perform the complete processing.

RELATED CONTEXTS

```
$DMIN $DMAX $DFACTOR $SI_TAB $TAB[i] $CHI2
$P1, $P2, ... $P1_ERR, $P2_ERR, ...
```

all MaxEnt Related contexts

DOSY Processing

Processing DOSY spectra in Gifa

DOSY Processing - Sommaire