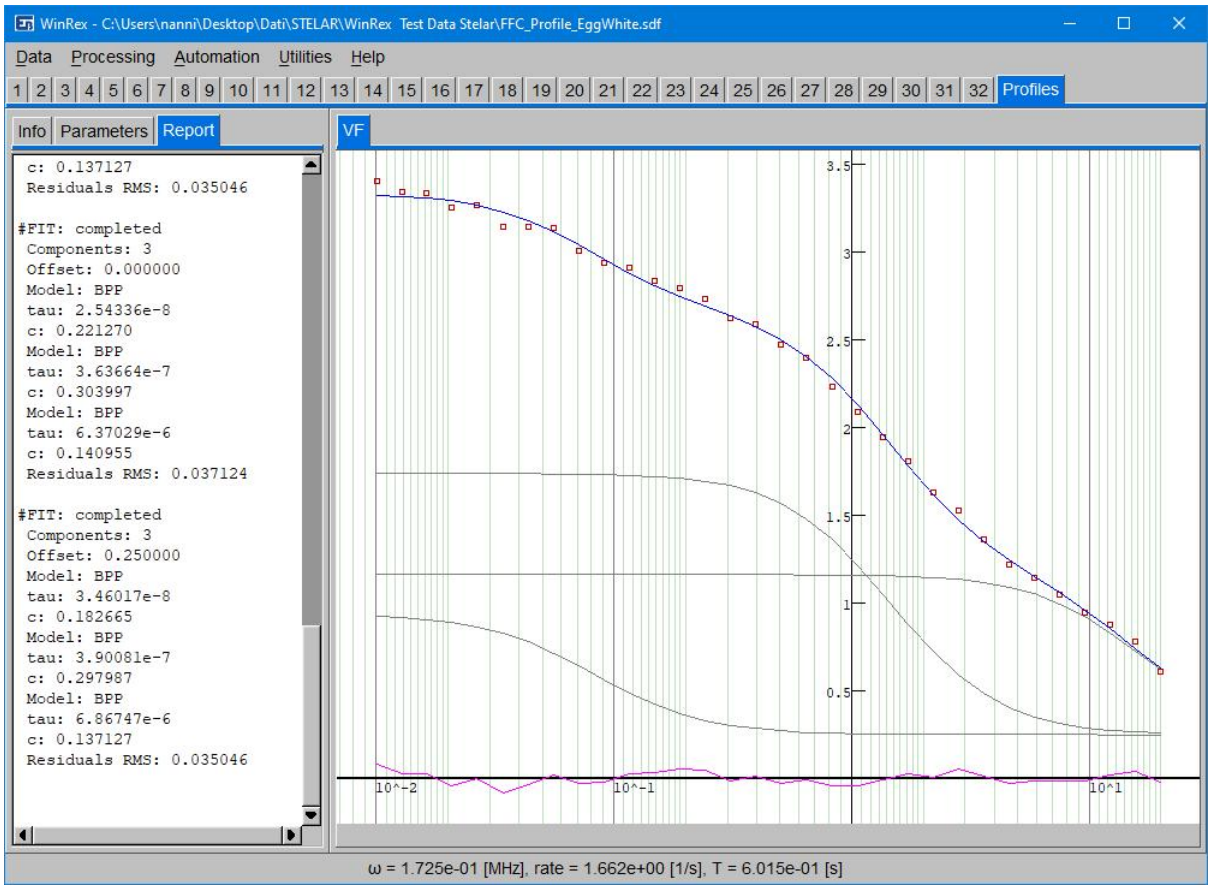
17 Oct 2022

WinRex

1.0.(517)

User Guide



Extra Byte srl
Piazza Mazzini 80
20022 Castano Primo (MI), Italy

www.extrabyte.eu
info@extrabyte.eu
P.IVA 10178380969

Extra Byte
>in spin we trust

Contents

What is Rex

Rex is a specialized software package for *processing NMR Relaxometry data*.

At present, Rex reads only data acquired on Stelar NMR relaxometers, but we plan to extend this to instruments of any make, produced by any OEM.

Rex is intended to be an Relaxometry software Tool

- Community-oriented
- Reading data from any source
- Strongly collaborative approach
- Fast developing under community requests

It is a tool for:

- Researchers in NMR++ relaxation phenomena
- Researchers in molecular dynamics
- Developers of relaxometry applications

Its current status: **c**overing much of what one can do with

- Fixed field TD NMR relaxometers
- FC and FFC relaxometers

Moving towards: **i**ntegration with

- FD Spectroscopy
- Diffusometry
- Other relaxometry methods (dielectric, ultrasound, …)
- Imaging

License

How to activate a license

Each Extra Byte Application, once installed, provides 30 days of free trial period starting from the first access. When the trial period is about to expire (<10 days left) the program sends a warning message about that at its launch.

When the trial period is over, the Application opens the Licensing interface. The same can be whenever opened by the user from the program main menu bar under the *Help* item. The License interface shows all the information about the user license: the personal data, if already registered, the *Computer ID*, the license key, if activated, the number of days left. Here user can activate a license by inserting a key. The key is provided by Extra Byte through an email exchange, after that the user has been registered and has made the payment, if required. A key can be used to activate a license on a unique computer.

The License interface allows user to register, by filling in the form with the proper entries (*Name*, *Surname*, *Institution*/*Organization*, *Email address*), and to send automatically an email, by clicking on the *Get key* button. This button opens the email client and prepares a new message to *licensing@ebyte.it* with a formatted text. If this should not happen, user has to send the message manually, inserting all the info above, included the *Computer ID* and the number of the Application version.

After sending the license key request, Extra Byte will reply to the user, providing invoice and payment details, if necessary. After payment, user will receive an email with an attached text file containing the key. He or she has to copy and paste it into the proper field in the License interface, then click the *Activate* button. The program notifies if the activation has been made successfully or not. In the next sessions, the program warns the user when the license is about to expire (<30 days left).

User is recommended to never modify the system time after the installation. This guarantees a correct execution of the program.

Overview

Main menu

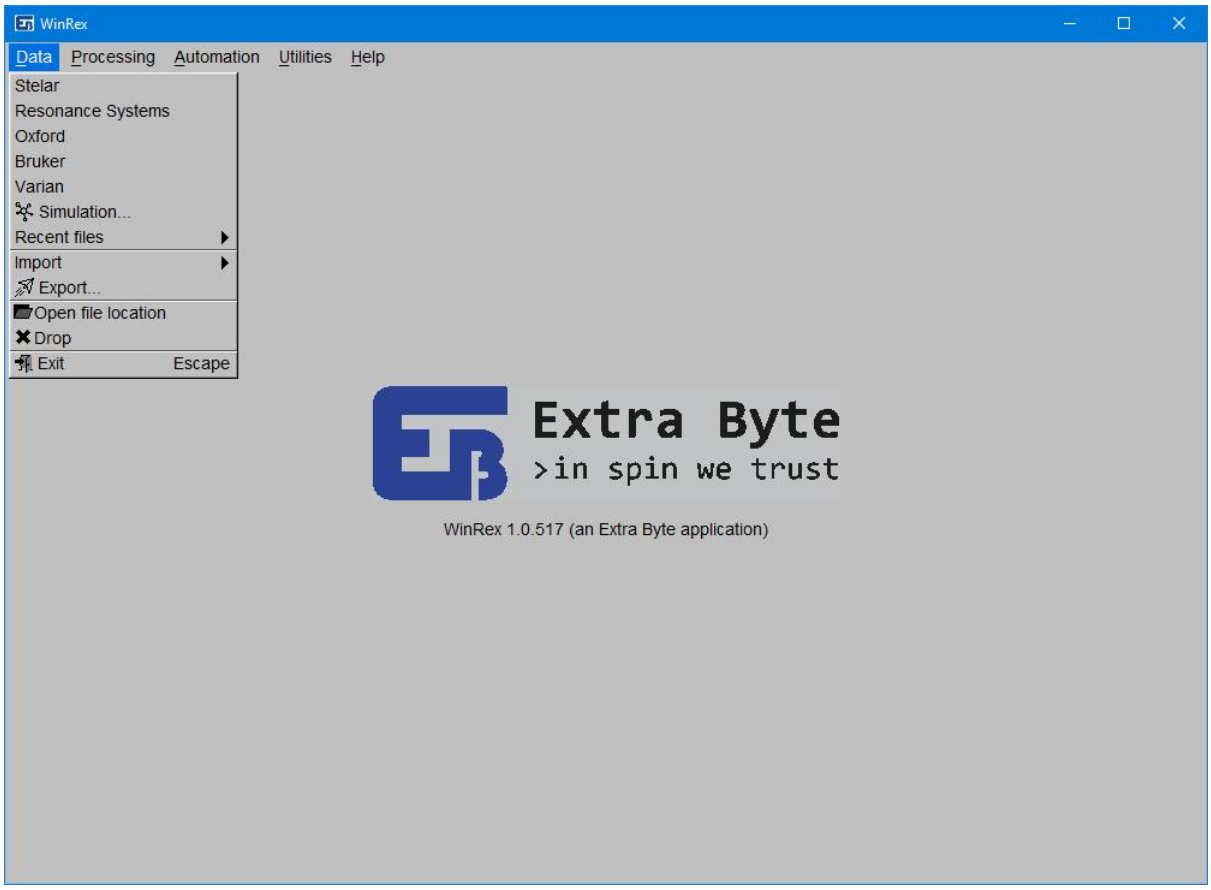


Figure 1. Main window appearance at program launch

WinRex main window (see Figure 1) presents a menu bar with the following commands:

Data

- "Stelar"
  Open a Stelar Data File (*.sdf*).
- "Resonance Systems"
  Open Resonance Systems files (extension *.TD-Rel*)
- "Bruker"
  Open Bruker data file (select *fid* or *ser*)
- "Oxford"
  Open Oxford Instruments data files (*.RiDat*)
  Only 1D experiments are supported up to this version.
- "Varian"
  Open Varian data files (*fid*)
- "Simulation…"
  Open the interface for simulating relaxometry experiments (see Paragraph Simulation).

- "Recent files"
  Chose to open a recent file from a list.
- "Import"
  Allow to import data from any text file (*.txt*, *.csv*, ...). Data must be encoded as two (or three) columns ASCII characters, and they may be preceded by blank lines or comments (lines starting with "//"). They can be imported as time-domain signal FID or CPMG, as a Relaxation curve or as a variable frequency/temperature profile ([1/s] vs [MHz] or [K]) profile.
- "Export…"
  Open a simple interface where user can decide what to export (Zones or Profiles data or Report) and the destination file format (Scalable Vector Graphic image (.svg), Comma-Separated Values text (.csv), or Stelar Data File (.sdf)).
- "Open file location"
  Open the directory of the loaded file.
- "Drop"
  Close current data file.
- "Exit"
  Exit the application.

Processing

- "Setup"
  Open the Setup interface (see Paragraph *Processing*) where user can set all processing parameters.
- "Undo"
  Undo last operation.
- "Restart"
  Restart processing from original data.

Automation

- "Plain"
  Run the plain list of commands selected in *Automation* section of the processing Setup window for all the selected zones. Attention: evaluation starts from the current state of the data, so, if it has to be repeated, commands “Undo” or “Restart” should be launched before.
- "Plain + Profile"
  Like "Plain", then build the Profiles page. The profile is built according to the options set in the *Profiles* section of the Setup. Relaxation curves must be built for the NMRD profile canvas in order to be created.

Utilities

- "NMR Calculator"
  Run some useful NMR tools (see Paragraph NMR Calculator)

Help

- "Manual"
  A link to a copy of this user Manual, which must be in the application folder.

- "Website"
  Open Extra Byte website with default browser.
- "Contact us"
  Open a draft message addressed to Extra Byte with default email client.
- "License"
  Show information about license. Here a license can be activated, providing a proper key.
- "About"
  Show information about WinRex current version and Extra Byte.

Graphic interface

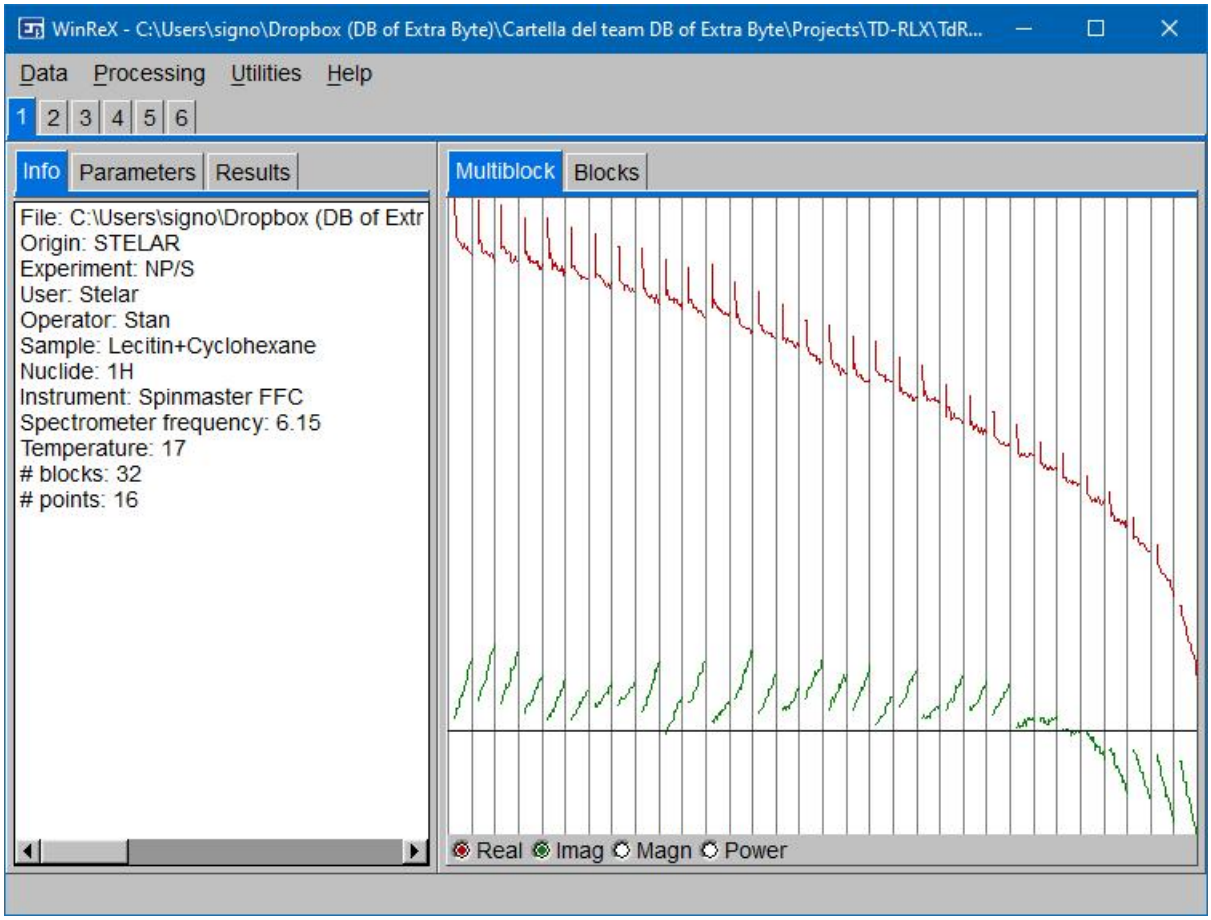


Figure 2. Main window appearance when data are loaded

When data are loaded successfully the file name is shown in the window title bar and a multi-tab panel useful for navigate through the pages appears just under the menu bar (see Figure 2).
Each page is divided in two sections. At left, a multi-tab panel includes some quick information about the current zone, a list of the acquisition/experimental parameters and a space where processing results are output. At right, there is a multi-tab panel for the graphical display of data. All possible canvas types that may appear, depending on the data end the evaluation, are *Multiblock* and *Blocks* for time domain data, *FT* for frequency domain, *Relax* for relaxation curves, *ILT* for the Inverse Laplace Transform, *VF* and *VT* for variable frequency and temperature NMRD profiles. Canvases appear dynamically during the evaluation.

After loading any file, raw data are plotted. Multiblock canvas displays vertically stacked blocks showing stacked experiments data (like in Inversion Recovery), while Blocks canvas displays singular blocks data, which can be browsed with the arrows in the tool bar, at the bottom of the canvas. The tool bar also includes buttons for toggle displayed arrays of data, like real and imaginary parts.

Other canvases will appear after some specific commands. When the relaxation curve of a 2D experiment is created (or imported from a text file), a new panel Relax appear. FT canvas appears when Fourier transform is executed and it shows frequency domain spectra. When the Inverse Laplace Transform is performed, either discrete or continuous, ILT canvas appear. At last, VT and VF Profiles canvas appears when profiles are built or imported from a text file. Profiles data are plotted as the relaxation rate [1/s] versus the frequency [MHz] (VF) or versus the temperature [1000/K].

All plots can be zoomed in by selecting a rectangle area with the mouse and zoomed out (horizontally) with 'Ctrl' button pressed down. They can be moved in any directions by dragging the mouse and pressing 'x' on the keyboard. They can be expanded vertically (changing the intensity) by using the mouse wheel, and horizontally in the same way while pressing 'Ctrl' button. All zoom states can be reset with a mouse double click. Wherever the mouse is, its coordinates are shown in the status bar, along with the closest point index (from 0 to n-1) and the block number (in case of Multiblock canvas).

A right click on any canvas opens a pop-up menu with the processing commands list. Commands are intended to run on the visible canvas of the current page.

Processing Setup and Commands

"Setup" menu item opens a window, as shown in Figure 3, where user can set the processing parameters.

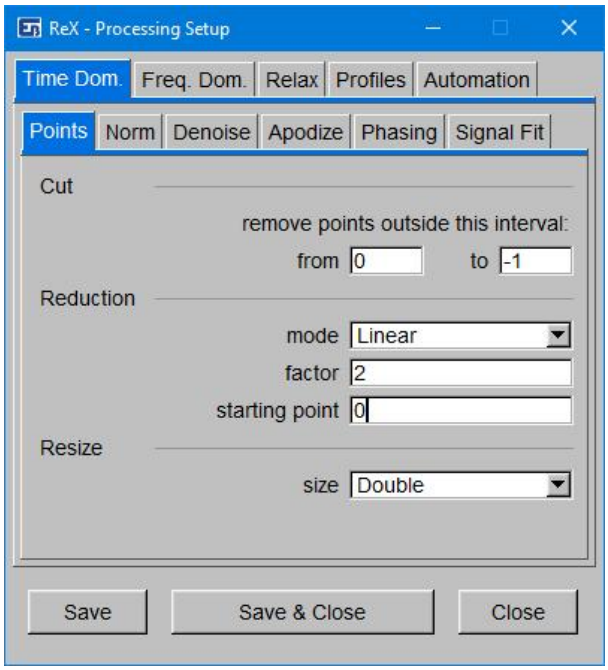


Figure 3. Processing setup interface

The Setup interface presents a multi-tab, each panel containing sections of commands parameters. Points indexes vary from 0 to n-1. If a bad number, like a negative index, is input, a default value is

used for that command. Generally, inputs have explanatory tooltip windows. Commands launch happens through a canvas pop-up menu, instead, and they are intended for that canvas. During that, the setup interface can remain opened. Only commands related to Automation section are launched from the menu bar in the main window, as they (may) refer to many zones and data set. Commands are launched with the last input parameters, even if not saved. "Save" button saves the current input parameters for the next Setup opening and also the next WinRex session. "Close" button closes the Setup window and restore the last saved parameters.

As mentioned above, commands are generally launched from a pop-up menu, which is opened by right-clicking on a canvas. Commands are executed on data related to that canvas, with the parameters currently set in the related section in the Setup. When each evaluation has terminated, a concise report is displayed in the Report panel, even if an error occurred.

A command which is common for all the canvas is **Report data**. This reports the data plotted in the canvas as tabulated values in the appropriate panel at the left side of the GUI.

Time Domain

The first panel present in the Setup contains sections of parameters for time domain data (canvases *Multiblock*, *Blocks* and *Signal*). "Points" section is intended to include parameters for all commands that change the blocks size (number of points). Command "**Cut**" removes points outside a certain range, e.g. with a range from 1 to -1 it just removes the first points (index 0). "**Reduction**" reduces blocks size by a factor, according to a grid type (only linear grid is available, while logarithmic is not implemented yet), starting from a certain index. This may be useful to reduce the points number before fitting a decay. At last, the effect of "**Resize**" command depends on the blocks size: if the input size is greater than the current blocks size then the blocks are zero filled, if smaller they are truncated.

"**Group Delay correction**" correct group delay artifact from Bruker FIDs. This avoids to obtain typical smileys in frequency domain spectrum.

"**Normalization**" section refers to just one command which apply a change in the intensity of the vertical scale. The input parameters are the rescaling reference, that is what is to be rescaled (only "Maximum" available for now), and the scale value (default is 1.0).

"**Denoising**" applies a denoising filter to the selected data. The only method implemented so far is the Savitzky-Golay filter (Savitzky & Golay, 1964).

Four **Apodization** functions are available:

- Stanning $$A(t) = \begin{cases} \cos^2(\alpha\, t) & \text{for} \quad \alpha t < \pi/2 \\ 0 & \text{for} \quad \alpha t \geq \pi/2 \end{cases}$$
  Input parameter: number of times the mean decay time at which is $\alpha t = \pi/2$.

- Exponential $$A(t) = e^{-\alpha t}$$
  This apodization corresponds to a convolution product in the frequency domain between the spectrum and a Lorentz function, whose width is the input parameter.

- Gaussian $$A(t) = e^{-\alpha t^2}$$
  This apodization corresponds to a convolution product in the frequency domain between the spectrum and a Gauss function, whose width is the input parameter.

- Sinc (Cardinal Sine) $A(t) = \sin(\alpha t)/\ \alpha t$
  This apodization mode corresponds to a convolution product in the frequency domain between the spectrum and a rectangle function, whose width is the input parameter.

Command "**Td-Phasing**" executes a phase correction which depends on the mode set in the related section. "Magnitude and Phase" and "Power and Phase" modes just convert the real and imaginary part of the signal into the magnitude (or power) and the phase, respectively. Flag "Regularized phase" can be selected to obtained a phase which drifts throughout the signal, if this occurs, otherwise it will always be within the interval $(-\pi;\pi]$.

Mode "Manual", instead, allows to correct the receiver phase, the frequency offset and/or the offset drift (only for FFC). Mode "Auto" does the same automatically, by calculating the parameters so that the imaginary part of the signal starts from zero (one coefficient), with null first derivative (two coefficients) and/or with null second derivative (three coefficients). The phase correction is calculated phase through a polynomial fit of the signal phase, in a range of points, with *n* input coefficients (from 1 to 3). It can be chosen a reference block used to fit the phase: the first or last block, the strongest block in magnitude; this phase is then used to correct all the blocks. Also, the blocks can be phased individually, with no reference block, or individually with maintaining the sign (so that negative real signal are not inverted). Unlike a point by point calculation of the phase, the fitting procedure does not distort the signal and allows to eliminate noise effects.

Time domain data can be **Fourier Transformed** to switch to frequency domain spectra.

At last, time-domain signals can be fitted. The available models are: multi-exponential (up to 8 components, also automatic), gaussian and a combination of an exponential and a gaussian. If "Complex" check box is selected, both real and imaginary parts of the signal are fitted with command "**Signal fit**", otherwise only the real part. Complex mode is available only for multi-exponential models (but not automatic).

Frequency Domain

This section is still empty. Implementation of baseline correction and frequency domain phasing are in progress.

Relax

"**Build Relax curve**" command quantifies the blocks of a staggered (2D) experiment and shows the quantification values in a new panel labelled "Relax". Real or magnitude channel can be quantified and the available modes are: arithmetic averaging of a window and extrapolation to zero with Savitzky-Golay method. For 1D experiment, instead, the command "**Promote to Relax curve**" builds the relaxation curve by copying the signal as it is. This is thought for single FIDs or CPMG, where user wants to run the inverse Laplace transform, which is available only for Relax curves.

Commands available in "Relax" panel includes those for (re)building and handling the relaxation curve, with the same parameters for operating on points, normalization and denoising as those in Time-Domain.

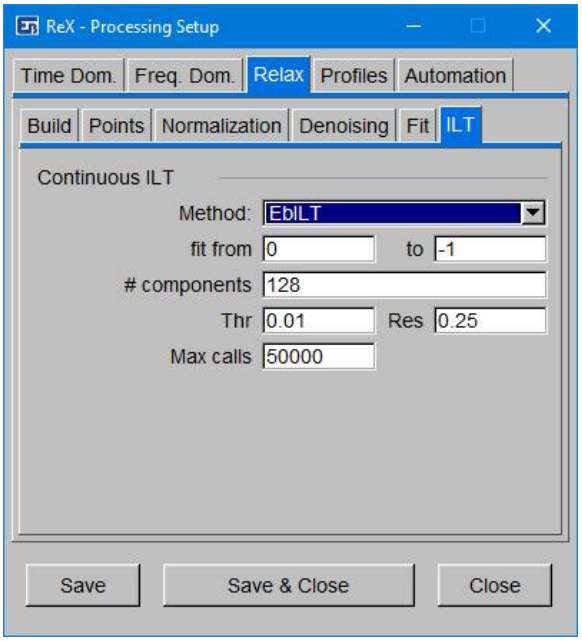
A command which is present in the menu of Relax canvas only for ANGLE experiment, is **Calibrate pulse**. This calculates the time width for a 90 and 180 degrees pulse.

Relaxation curve can be fitted as multiexponential with a discrete number of components or a continuous distribution. "Fit" section contains parameters for using a finite number of exponential

models with 1 up to 8 components, or using an automatic determination of the best multiexponential model. This is what is intended for **DILT** (Discrete Inverse Laplace Transform). The DILT fits both the relaxation rates and the weights (in addition to the offset) of the components.

In the continuous version (**CILT**), the rates values are fixed in a grid value settable from the GUI, so the weights and the offset are only to be found. Also, the problem reduces to the solution of the linear system $Mx = r$ where r is the signal and M is the Laplace kernel. But given the huge number of variables, the problem is ill-posed and an explicit solution cannot be found numerically through matrix inversion, and this determines the intrinsic instability of the Inverse Laplace Transform. Thus, a regularization has to be introduced.

Two methods are implemented so far:



- Truncated Singular Value Decomposition (**SVD**)
  The first one solves the linear system through a low-rank approximation. Matrix M is decomposed as $M = USV^{+}$ where U and V^{+} are unitary matrices and S is the diagonal matrix containing the singular values. The algorithm truncates S to include only values above a threshold, which is settable from the GUI (parameter "Thr"). This drastically reduces the dimension of M and the system can be solved. This method is fast but it is not guaranteed to obtain a positive distribution everywhere, as no constraint can be set on the weights sign.
- **EbILT**
  This iterative algorithm, based on UPEN (Borgia, Brown, & Fantazzini, 1998), performs a fit that minimizes the residuals, but also it includes constraints on the first and the second derivative. This allows to obtain a relatively smooth distribution of the relaxation rates. Parameter "Res" can used to adjust the initial resolution of the distribution, expressed in Neper, and "Max calls" to set the maximum number of calls of the objective function. Unlike SVD, this method guarantees a positive distribution.

Due to the instability of the ILT, the solution depends heavily on the initial condition and on the parameters used. User can set the range of points of the relaxation curve on which to perform the ILT, along with the number of components, while the limit values of times is set automatically.

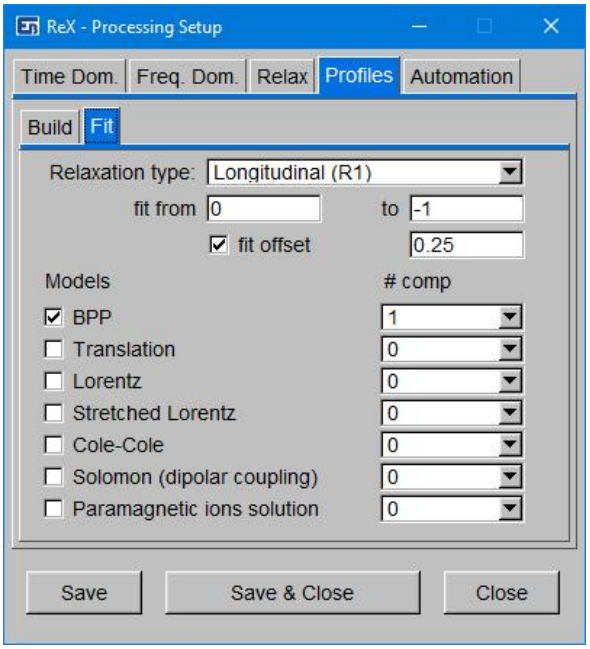
Profiles

NMRD profiles can be **built** by selecting the zones from a list (default selection is available). From the main window menu, command "Plain+Profile" executes, in addition to the commands selected in the *Automation* panel, the discrete ILT for all the selected zones according to the parameters set in *Relax->Fit* section in the setup. Then, it plots the profiles in a new dedicated canvas. The relaxation curves must be necessarily built before.

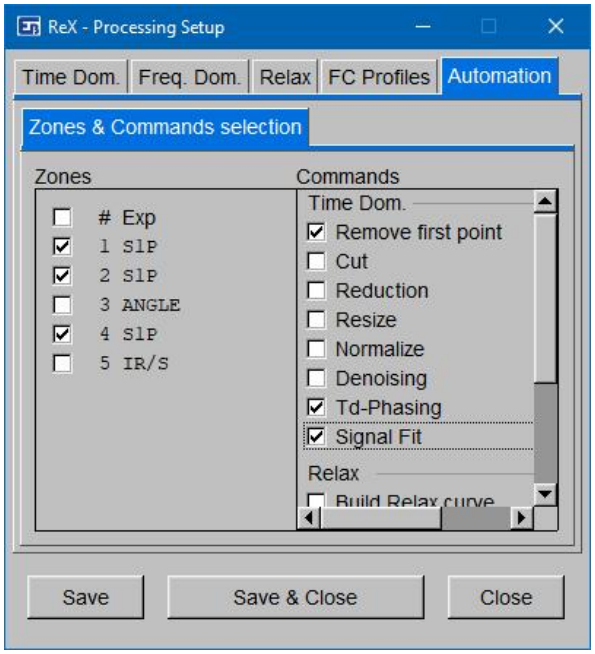
The **fitting models** available are:

- BPP (Abragam, 1961)

- Diffusional translation (Abragam, 1961)
- Lorentz.
  An empirical model based on Lorentz (Cauchy) distribution
- Stretched Lorentz
  Like a Lorentz distribution, with a different slope.
- Cole-Cole dispersion (Hallenga & Koenig, 1976)
- Solomon equation for dipolar coupling (Solomon, 1955)
- Gd(III)-based paramagnetic contrast agents solutions (Chapter 2: Gadolinium-based Contrast Agents, 2018)



Models can be selected and combined together. Of course, many models means many parameters, then less accuracy in the fit.



Automation

Each command can be launched individually from the canvas pop-up menu. This section allows to accelerate the processing, by creating a list of commands to execute in rows on any zones.

As show in the figure, at the left user can select the zones to process and, on the right, the list of commands. It can be run through the main menu bar, with "Automation->Plain" button. Instead, "Automation->Plain + FFC Profile" executes the same and creates Fast Field Cycling Profile chart at the end.

Simulation

WinRex lets you simulate simple relaxometry experiments data. Button "Simulation" in the menu bar opens the simulation interface, shown in Fig. 4.

In the General tab user can choose the experiment (or kind of synthetic data) and other general option, like the noise root mean square. Parameters present in 1D tab refers to *free induction decays* (FIDs) settings and those in 2D tab to other, like 2D experiments or CPMG. NMRD tab is only for FFC profiles. The available experiments are, according to Stelar names: S1P, IR/S, SR/S, CPMG, ANGLE.

- S1P (Single 1 Pulse) simulates an FID, whose pulse sequence consists of $90°_x$

- IR/S (Inversion Recovery-Staggered) is a 2D (staggered) experiment whose sequence is $180°_x$ - τ - $90°_x$ where τ is the varying parameter.
- SR/S (Saturation Recovery-Staggered) sequence is $90°_x$ - τ - $90°_x$. IR/S and SR/S 2D curves relax with T_1.
- CPMG (Carr-Purcell-Meiboom-Gill) is a 1D experiment composed of $90°_x$ and then a train of τ/2 - $180°_x$ (spin-echos sequence). CPMG signal relaxes with T_2.
- ANGLE is a 2D series of FIDs where the varying parameter is the B1 pulse width.

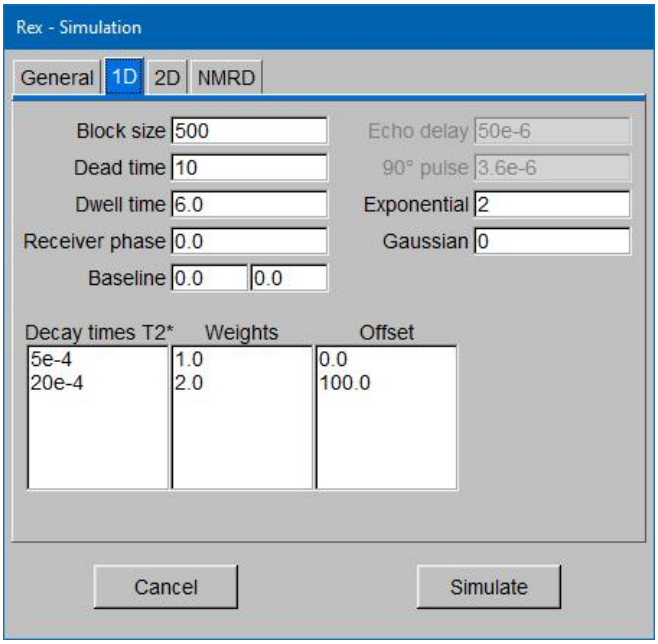
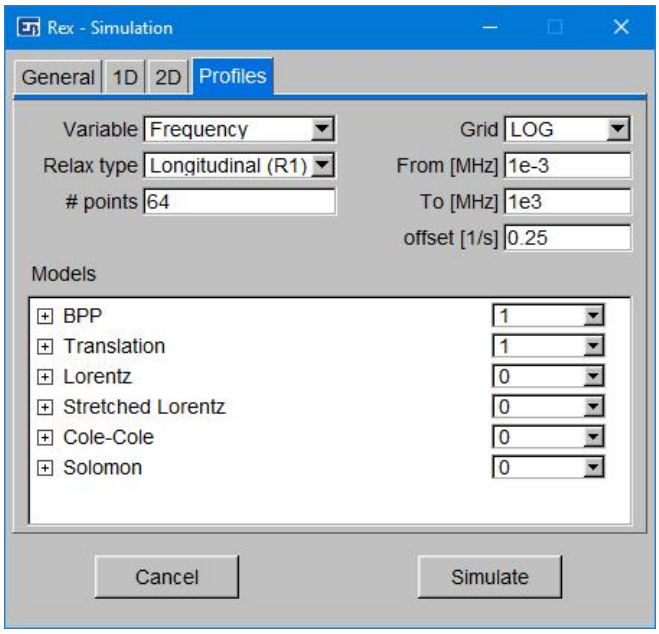


Figure 4 Experiments simulation interface

Other special synthetic data can be generated:

- Phantom Decay is a stack of S1P blocks, with noise root mean square as array parameter.
- Relax curve is a simple relaxation curve, directly simulated (not generated from raw data).
- NMRD profile is a profile directly simulated (not generated from raw data) by combining components from many models. Can choose between variable frequency or temperature. Only BPP and Lorentz models are available for VT profiles.



Each parameter is self-explanatory, with the help of tooltip windows. Details may be added about decay and relaxation times. These are input as a list of elements, along with their total weights. Decay times T_2* are intended as discrete (delta-shaped) components and they must be at least equal to the sum of "Exponential" and "Gaussian" parameters. Instead, relaxation times (either T_1 or T_2, depending on the selected experiment) must be equal to "N components" and may have finite width. In this case they are log-normally distributed and their width is expressed in Neper.

Data are simulated and displayed on the canvases and they can be treated exactly as they were loaded from a file.

NMR Calculator

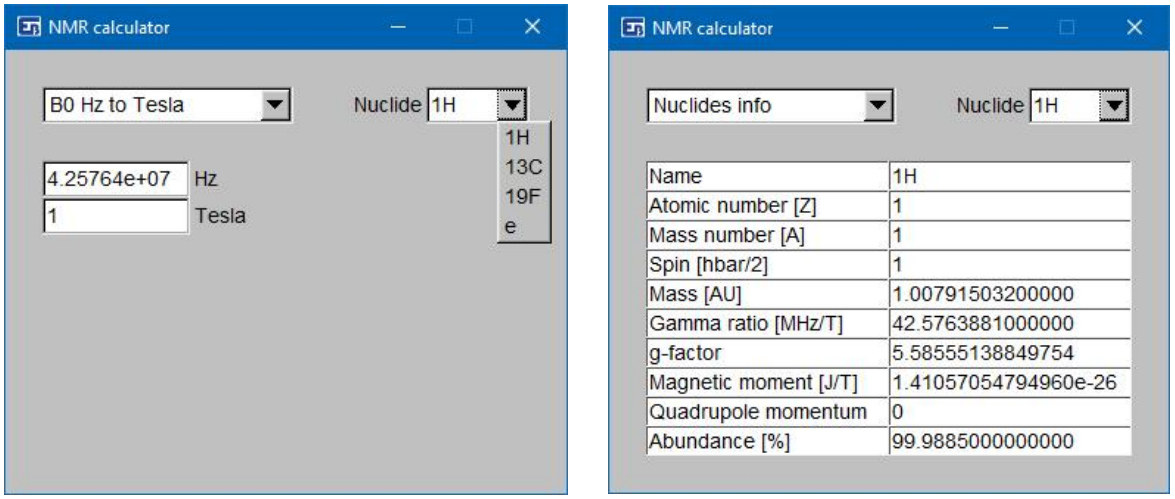


Figure 5. NMR Calculator

NMR Calculator is a simple utility for any NMRists. In the current version it can perform three kinds of calculation. First of all, it converts Larmor frequency from Hz to Tesla and vice versa according to a nuclide, which can be chosen or input with the keyboard (see Figure 5). Also, it calculates B1 field intensity from the time duration radio frequency pulse and vice versa, for the selected nuclide. At last, it displays information about a nuclide. More than 100 nuclides are available.

Tutorial

A presentation/tutorial that shows how to use WinRex is present in a separate document, along with some example data.

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