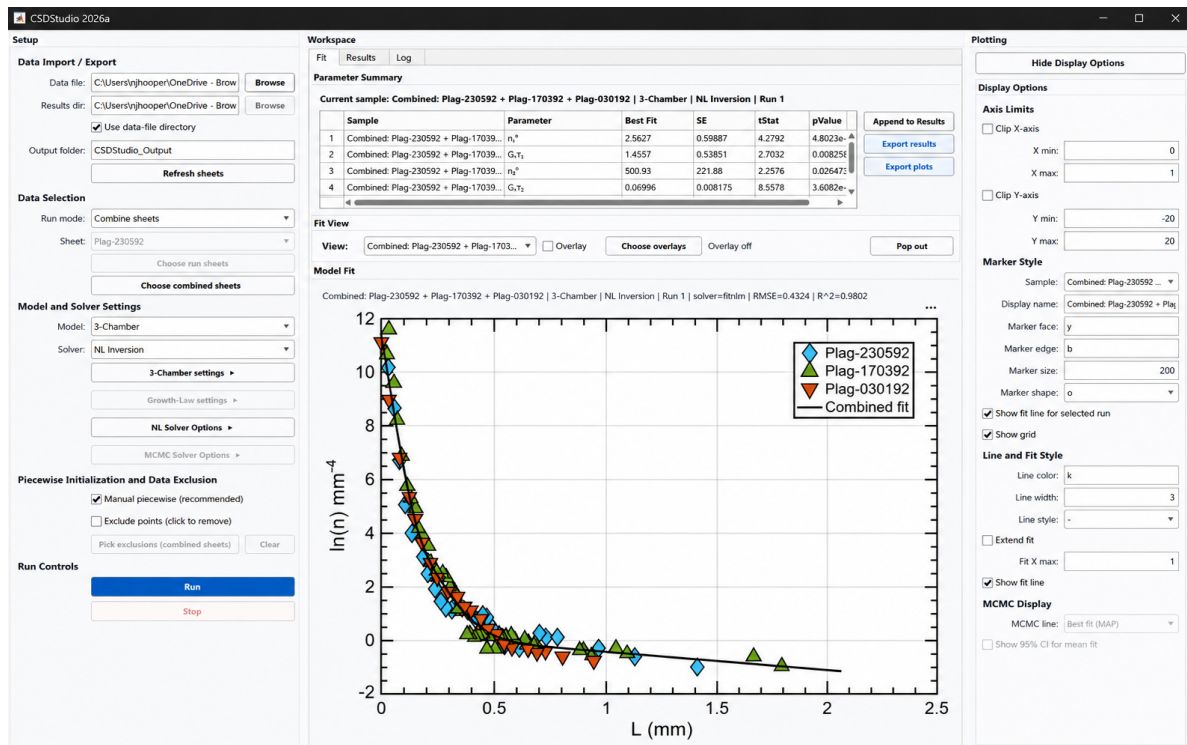


CSDStudio User Manual

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Example crystal size distribution model output from CSDStudio 2026a using plagioclase data from Fig. 3 of Armienti et al. (1994).

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1 Quick Start Guide

1.1 Installing CSDStudio 2026a

CSDStudio 2026a is distributed with separate installers for **Windows OS** and **macOS**. Users should download the installer that matches their operating system and follow the on screen installation instructions. The installer will download and install both the **CSDStudio 2026a** application and the required **MATLAB Runtime**. After installation, CSDStudio can be opened from the installed application shortcut, application folder, or installation directory, depending on the operating system. For **Windows OS** the application is installed into your *Programs* directory by default.

macOS startup note: The first time opening *CSDStudio 2026a* on macOS may be slower than on Windows. This is normal for MATLAB compiled applications since macOS may perform additional security checks on downloaded applications while the MATLAB Runtime is initialized. After the first successful launch, subsequent openings are typically faster. We also recommend moving the *CSDStudio 2026a* application into the *Applications* folder before opening it.

1.1.1 Running the open-source MATLAB code

In addition to the compiled application, the open-source MATLAB code for CSDStudio 2026a is also provided. To run the source code directly, download the **CSDStudio_2026a.m** source code, open it in MATLAB, and run the script. Running the source-code version requires a MATLAB installation. The following MATLAB products are required:

- **MATLAB 2023a or newer**
- **Optimization Toolbox**
- **Statistics and Machine Learning Toolbox**

The compiled installation package does not require the user to own MATLAB or these toolboxes. These requirements apply only to those who want to run or modify the open-source MATLAB code directly.

1.2 Example dataset

CSDStudio 2026a includes an example dataset, compiled from Armienti et al. (1994), that can be used to test the application and become familiar with the standard workflow. The example dataset follows the required format for imported CSD data and can therefore be used both as a test file and as a template for preparing new datasets. We recommend that new users run the example dataset before importing their own data. After opening the application, use the workflow below to load the example file, run a model, inspect the fit, and export the results.

1.3 Minimal workflow

1. Open CSDStudio.
2. Click Browse next to **Data file** and select the Excel workbook containing the CSD data.
3. Choose a **Results dir**. This is where exported results and plots will be written.
4. Set the **Output folder**. By default, this is `CSDStudio_Output`. The folder is automatically created inside the selected results directory.

5. Choose the **Run mode**: Single sheet, Selected sheets, Combine sheets, or All sheets.
6. Choose a **Model**: 2-Chamber, 3-Chamber, Growth-Law, or Linear.
7. Choose a **Solver**: NL Inversion or MCMC.
8. Adjust the relevant solver settings if needed.
9. Select manual piecewise fitting and/or point exclusion if needed. If point exclusion is selected, click **Pick Exclusions** to remove selected data points before running the model. If manual piecewise fitting is selected, the piecewise-selection window will open automatically after clicking **Run**. In this window, choose the model segments in order from the largest grain-size fraction to the smallest grain-size fraction. For example, in a two-chamber model, segment 1 corresponds to the shallower slope at larger grain sizes, whereas segment 2 corresponds to the steeper slope at smaller grain sizes.
10. Click **Run**.
11. Inspect the fit in the **Fit** window. Use **View** to switch between stored runs.
12. Click **Append to Results** for each fit you want to export.
13. Click **Export results to Excel** to save appended result sheets.
14. Click **Export plots** to save plots for appended results.

2 Input Data Requirements

2.1 Excel workbook structure

CSDStudio reads one Excel workbook. Each worksheet in the workbook is treated as one sample. The sheet name becomes the sample name used in CSDStudio for legend labels, output table names, and plot folders. The data reader expects the following structure:

Excel location	Required content	Notes
Column A	L (mm)	Crystal size in (mm)
Column B	$\ln(n)$ (mm^{-4})	Population density in natural log space and (mm^{-4}).
Row 1	Optional headers	Ignored by the fitting routine.
Rows 2 onward	Numeric data	CSDStudio reads data beginning at row 2.
Columns C–D	Ignored	Can hold notes or additional data not used in fitting routine.

The basic sheet layout should look like:

A	B
L (mm)	ln(n)
0.025	17.3
0.050	15.9
0.075	14.6

2.2 Recommended input checks

Before fitting, check that:

- L values are numeric and in millimeters.
- $\ln(n)$ values are numeric, in natural log, and in units mm^{-4} .
- The sheet name is short and descriptive.

3 Data Import/Export Controls

3.1 Data file

Use **Data file** to select the Excel workbook containing CSD data. Click to choose or change the workbook.

3.2 Results directory

Use **Results dir** to choose the base directory for exported outputs. **Use data-file directory** is checked by default, and the results directory automatically follows the selected data-file directory. If it is unchecked, you can manually select any output directory.

3.3 Output folder

The **Output folder** is automatically created inside the selected results directory. For example, if:

```
Results dir = C:\Users\Name\Project\CSD
Output folder = CSDStudio_Output
```

then exports are written to:

```
C:\Users\Name\Project\CSD\CSDStudio_Output
```

The application does not automatically export results or plots during a run. Exports occur only when you click or after first hitting .

3.4 Refresh sheets

Click before selecting a new data file or for wanting to clear CSDStudio. Refreshing sheets reloads the sheet list and clears the workspace.

Important: Refreshing sheets is a reset operation. If you have results you want to keep, append and export them before refreshing the workbook.

4 Data Selection

4.1 Run mode

CSDStudio supports four run modes.

Run mode	Behavior
Single sheet	Fits only the sheet chosen in the Sheet dropdown.
Selected sheets	Fits multiple selected sheets, respectively.
Combine sheets	Combines data from multiple sheets into one pooled fit.

All sheets

Fits every worksheet in the selected Excel workbook.

5 Model Settings

CSDStudio currently supports four mixing model families: 2-Chamber, 3-Chamber, Growth-Law, and linear. The model controls (3-Chamber or Growth-Law settings) determine the parameterization used by both the NL and MCMC solvers.

5.1 2-Chamber model

The steady-state solution for the two-magma reservoir is a sum of two exponential functions:

$$n_{mix}(L) = A \exp\left(-\frac{L}{G_1\tau_1}\right) + (n_{mix}^0 - A) \exp\left(-\frac{L}{G_{mix}\tau_{mix}}\right), \quad (1)$$

where

$$A = \frac{n_1^0 G_1 \tau_1}{G_1 \tau_1 - G_{mix} \tau_{mix}}. \quad (2)$$

Here, L is crystal length, $n_{mix}(L)$ is the crystal number density for the shallow magma reservoir. The 2-Chamber model has four fitted parameters:

Parameter	Meaning
n_1^0	Nucleation density for deep-seated magma reservoir 1.
$G_1\tau_1$	Characteristic crystal length for deep-seated magma reservoir 1.
n_{mix}^0	Nucleation density for shallow magma reservoir or conduit.
$G_{mix}\tau_{mix}$	Characteristic crystal length for shallow magma reservoir or conduit.

See Liang (2026) for more details.

5.2 3-Chamber model

The steady-state solution for the three-magma reservoir model is a sum of three exponential functions:

$$n_{mix}(L) = A_1 \exp\left(-\frac{L}{G_1\tau_1}\right) + A_2 \exp\left(-\frac{L}{G_2\tau_2}\right) + A_3 \exp\left(-\frac{L}{G_{mix}\tau_{mix}}\right), \quad (3)$$

where

$$A_1 = \frac{\alpha_1 n_1^0 G_1 \tau_1}{G_1 \tau_1 - G_{mix} \tau_{mix}}, \quad (4)$$

$$A_2 = \frac{\alpha_2 n_2^0 G_2 \tau_2}{G_2 \tau_2 - G_{mix} \tau_{mix}}, \quad (5)$$

$$A_3 = n_{mix}^0 - A_1 - A_2. \quad (6)$$

Here, L is crystal length, $n_{mix}(L)$ is the crystal number density for the shallow magma reservoir, and α_1 and α_2 are volume fractions of the magma delivered from deep-magma reservoir 1 and 2 to the shallow magma reservoir or conduit. These volume fractions satisfy that

$$\alpha_1 + \alpha_2 = 1. \quad (7)$$

The 3-Chamber model has six fitted parameters plus two fixed mixing fractions, α_1 and α_2 :

Parameter	Meaning
n_1^0	Nucleation density for deep-seated magma reservoir 1.
$G_1\tau_1$	Characteristic crystal length for deep-seated magma reservoir 1.
n_2^0	Nucleation density for deep-seated magma reservoir 2.
$G_2\tau_2$	Characteristic crystal length for deep-seated magma reservoir 2.
n_{mix}^0	Nucleation density for shallow magma reservoir or conduit.
$G_{\text{mix}}\tau_{\text{mix}}$	Characteristic crystal length for shallow magma reservoir or conduit.

Open 3-Chamber settings to edit α_1 . The app automatically updates α_2 by enforcing $\alpha_1 + \alpha_2 = 1$. This settings panel is disabled unless the selected model is 3-Chamber. See Liang (2026) for more details.

5.3 Growth-Law model

The Growth-Law model follows the steady-state CSD model of Abegg et al. (1968). The general growth law is

$$G = G_0(1 + aL)^b, \quad (8)$$

where L is crystal length, G_0 is the growth rate at $L = 0$, and a and b are constants. The corresponding steady-state CSD solution is

$$\frac{n(L)}{n^0} = (1 + aL)^{-b} \exp \left[\frac{1 - (1 + aL)^{1-b}}{aG_0\tau_0(1-b)} \right]. \quad (9)$$

In CSDStudio, the product $aG_0\tau_0$ is constrained to equal 1. Therefore,

$$a = \frac{1}{G_0\tau_0}. \quad (10)$$

Substituting this constraint into the growth-law solution gives the simplified model:

$$n(L) = n^0 \left(1 + \frac{L}{G_0\tau_0} \right)^{-b} \exp \left[\frac{1 - \left(1 + \frac{L}{G_0\tau_0} \right)^{1-b}}{1-b} \right]. \quad (11)$$

Here, $n(L)$ is the crystal number density of the mixed magma, n^0 is the nucleation density, b is the growth exponent, and $G_0\tau_0$ is the characteristic crystal length. The Growth-Law model has three fitted parameters:

Parameter	Meaning
n^0	Nucleation density.
b	Growth exponent.
$G_0\tau_0$	Characteristic crystal length.

5.3.1 Fixing $\ln(n^0)$

Often, the Growth-Law model does not find a reasonable nucleation density, n^0 . To address this, CSDStudio allows the user to manually fix the intercept. To do this, open **Growth-Law settings** when the selected model is **Growth-Law**. Check **Fix $\ln(n^0)$** to hold n^0 fixed, and enter the desired value in natural log units. When this option is active, both NL and MCMC runs treat n^0 as fixed.

5.4 Linear model

The Linear model follows the steady-state CSD formulation of Marsh (1988):

$$n(L) = n^0 \exp\left(-\frac{L}{G\tau}\right), \quad (12)$$

where L is crystal length, $n(L)$ is the crystal number density of the magma reservoir, n^0 is the nucleation density, and $G\tau$ is the characteristic crystal length. The Linear model has two fitted parameters:

Parameter	Meaning
n^0	Nucleation density.
$G\tau$	Characteristic crystal length.

6 Solver Selection

The **Solver** dropdown chooses between nonlinear(NL) inversion and MCMC.

6.1 NL Inversion

The NL Inversion solver is intended for fast, best-fit estimations using a nonlinear least squares regression method. It returns a best-fit parameter vector, fit diagnostics, and coefficient statistics using the MATLAB package *fitnlm*.

Open **NL Solver Options** to edit:

Control	Default	Meaning
NL starts	1	Number of initial starts used in the nonlinear search.
NL max iter	10000	Maximum nonlinear iterations.
NL func tol	10^{-10}	Function tolerance for convergence.
NL step tol	10^{-10}	Step-size tolerance for convergence.

6.2 MCMC

The MCMC solver is based on the Metropolis-Hastings Markov chain Monte Carlo method that uses repeated random sampling to constrain posterior parameter distributions. It is slower than NL inversion but provides uncertainty estimates from the posteriors.

Open **MCMC Solver Options** to edit:

Control	Default	Meaning
MCMC iterations	100000	Total MCMC iterations.
MCMC burn-in	10000	Initial samples discarded before posterior summaries are calculated.
MCMC step frac	0.03	Proposal step size.
MCMC noise σ	0.1	Assumed observational noise scale in $\ln(n)$ units.
MCMC seed	12345	Random-number seed for reproducibility.
Randomize MCMC seed	–	Replaces the seed with a random integer.
MCMC UI stride	500	How often the progress dialog updates. Larger values reduce GUI burden for longer iteration.
Offset seed per sheet	checked	Adds a offset so that each sheet receives a different random seed.

6.2.1 MCMC acceptance and tuning

MCMC output includes an acceptance percentage in the fit metadata. Very low acceptance usually means the proposal step is too large or the model is poorly initialized. Very high acceptance may mean the step size is too small and the chain is moving slowly. If a run is unstable, try:

- improving the manual piecewise initialization for mixing models;
- reducing **MCMC step frac**;
- increasing **MCMC iterations**;
- checking whether excluded points or outliers are controlling the fit.

7 Initialization: Manual Piecewise and Auto Piecewise

For the mixing models, the nonlinear solver and MCMC sampler need reasonable starting parameters. CSD data are often sparse or have unclear segments, so an automatic starting guess can fail. The **Manual piecewise** option allows the user to define approximate linear regions of the CSD by clicking points. These piecewise segments are then converted into initial parameter guesses.

7.1 Using manual piecewise initialization

When **Manual piecewise** is enabled, CSDStudio prompts for segment selection during the run if no valid manual picks are already stored for that sheet. The number of piecewise regions depends on the model:

Model	Piecewise regions used for initialization
2-Chamber	Two regions.
3-Chamber	Three regions.
Growth-Law	Manual piecewise is disabled.

During manual piecewise selection, click points belonging to the requested segment. Press **Enter** when finished with that segment. Repeat until all segments are defined. Each segment should include at least three points.

Important: When selecting Segments 1–3, assign the segments in order from the largest size fraction to the smallest. For example, Segment 1 should correspond to the largest crystal-size range, Segment 2 to the intermediate range, and Segment 3 to the smallest range.

7.2 Auto piecewise initialization

If **Manual piecewise** is unchecked, the app searches for breakpoints automatically and uses the best piecewise linear initialization. This is convenient but less reliable for complex CSDs. Use auto initialization for quick screening and manual initialization for final runs.

8 Point Exclusions

The **Exclude points** tool lets you remove individual data points from analysis without editing the source Excel workbook. This is useful for obvious outliers.

8.1 Workflow

1. Set **Run mode** to Single sheet, Selected sheets, Combined sheets, or All sheets.
2. Check **Exclude points (click to remove)**.
3. Click **Pick exclusions**.
4. In the selection window, click points to toggle exclusion. Press **Enter** when finished.
5. Run the mixing model.

Use **Clear** to remove selected exclusions.

9 Running Mixing Models

9.1 Run

Click **Run** to start the solver. A progress dialog shows the active sheet and progress.

9.2 Stop

Click **Stop** to request cancellation. CSDStudio stops at the next safe checkpoint. Long MCMC runs may not stop instantly because the sampler checks for cancellation during iteration updates.

10 Fit Tab

The **Fit** tab is the main inspection area after running a model.

10.1 Fitted-parameter table

The fitted-parameter table changes depending on the solver.

10.1.1 NL Inversion table

For NL inversion, the table columns are:

Column	Meaning
Sample	Result label.
Parameter	Model parameter name.
Best Fit	Best-fit parameter estimate.
SE	Standard error.
tStat	test statistic
pValue	p-value

10.1.2 MCMC table

For MCMC, the table columns are:

Column	Meaning
Sample	Result label.
Parameter	Model parameter name.
Posterior Mean	Mean of the post-burn-in posterior samples.
Best Fit	Maximum-posterior or lowest-misfit sampled parameter set.
SD	Standard deviation of the posterior samples.
−95% CI	Lower 95% confidence interval.
+95% CI	Upper 95% confidence interval.

10.2 View selector

Use **View** to switch between stored fits. Each result is labeled by sample, model, solver, and run number.

10.3 Overlay

Check **Overlay** to plot multiple runs together. Click Choose overlays to select which results to display. Overlay mode is useful for comparing:

- NL versus MCMC fits for the same sample;
- 2-Chamber versus 3-Chamber fits;
- Growth-Law versus 2- or 3-model fits;
- multiple sensitivity tests with different exclusions.

10.4 Pop out fit

Click Pop out fit to draw the current fit in a separate MATLAB figure window.

10.5 Append to Results

Click **Append to Results** after inspecting a fit you want to keep. Appending does not write a file immediately. It stores the selected result in the **Results** tab and in the internal export list. If overlay is active, **Append to Results** appends all currently selected overlay results. If overlay is off, it appends the single result shown in the **View** dropdown.

11 Exporting Results

CSDStudio exports only appended results. The intended workflow is:

1. Run a fit.
2. Inspect it in the **Fit** tab.
3. Click **Append to Results**.
4. Repeat for any additional fits you want to export.
5. Click **Export results to Excel**.

11.1 Excel export

Click **Export results to Excel**. The save dialog opens in the configured output folder. The default filename is:

CSDStudio_Appended_Results_yyyymmdd_HHMMSS.xlsx

The exported workbook contains one sheet per appended result. Each result sheet contains:

1. A run summary:

Result	Sample	Model	Solver	Run	RMSE	R2	Exported Date
--------	--------	-------	--------	-----	------	----	---------------

2. A fitted-parameter table.
3. Fit-line data for separate plotting outside of CSDStudio.

11.2 Fit-line data in Excel

The fit-line export depends on solver and model:

Run type	Fit-line data written
NL chamber models	L and $\ln(n)$ for the fitted curve.
NL Growth-Law	L and $\ln(n)$ for the fitted Growth-Law curve.
NL Linear Model	L and $\ln(n)$ for the fitted linear line.
MCMC chamber models	L and $\ln(n)$ for both posterior mean fit and best-fit curve.
MCMC Growth-Law	L and $\ln(n)$ for the best-fit Growth-Law curve.

12 Plotting Options

Open **Display Options** to control plotting styles for current sample or multiple samples if you are overlaying multiple results.

12.1 Axis controls

Control	Behavior
Clip X-axis	If checked, uses the specified X_{\min} and X_{\max} limits.
Clip Y-axis	If checked, uses the specified Y_{\min} and Y_{\max} limits.
Show grid	Toggles grid visibility on plots.
Extend fit curve	Extends the fit curve to the specified X-axis value .
Show fit line	Globally shows or hides fit lines.

12.2 Marker and line style

The style controls allow the user to edit the selected sample/result display. Available controls include:

- Display name
- marker face color
- marker edge color
- marker size
- marker shape
- line color
- line width
- line style
- show/hide fit line for the selected run

Color entries can be MATLAB color letters such as **k**, **r**, **b**, **m**, or numeric RGB triplets such as `[0.2 0.4 0.8]`.

12.3 MCMC display controls

The MCMC plotting controls are active only when the selected solver is MCMC.

Control	Behavior
MCMC fit line	Choose Best fit (MAP) or Mean. The default is best fit.
Plot 95% CI	If plot 95% CI box is checked in plotting options and the fit line is set to Mean , the app plots the posterior 95 percent confidence intervals.

If the posterior is skewed, the mean curve and best-fit curve can differ.

13 Exporting Plots

Click Export plots to save plots. If results have been appended, the app exports plots for the appended result list.

13.1 Standard exported plots

Every exported result receives:

Plot	Description
ModelFit.png	Data and fitted model curve.
Residuals.png	Residuals, defined as observed minus fit.
Diagnostics.png	Exponential contribution plots.

13.2 MCMC-only exported plots

MCMC results also receive:

Plot	Description
MCMC.Trace.png	Trace plot for each fitted parameter.
MCMC.PosteriorMarginals.png	Marginal posterior histograms for each parameter.
MCMC.Pairwise.png	Pairwise posterior scatter plots.

13.3 Saving figures from pop-out windows

Individual figures can also be saved directly from the pop-out figure windows. After opening the desired plot, use the figure-window toolbar to select **Save As**. The user can then choose the preferred output format, including .png, .pdf, .svg, .tif, or .jpeg. Additionally, you can choose to change the output resolution or scale.

14 Troubleshooting

14.1 No sheets appear after selecting the workbook

Confirm that the selected file is an Excel workbook and that the standalone CSDStudio can access it. Close the workbook in Excel if it is locked. Then click Refresh sheets again.

14.2 The fit fails or parameters are unrealistic

Try the following:

- Enable manual piecewise initialization for mixing models.
- Check that L is in mm and $\ln(n)$ is already natural log transformed and in units mm^{-4} .
- Remove obvious outliers with the exclusion tool.
- Reduce model complexity: try 2-Chamber before 3-Chamber.
- For MCMC, reduce the step fraction or increase iterations.
- For Growth-Law, test whether fixing $\ln(n^0)$ improves stability.

14.3 MCMC acceptance is too low

Low acceptance usually means proposals are too large or the chain is starting in a poor region. Decrease **MCMC step frac**, improve manual initialization, or increase **MCMC noise** σ if the assumed observational uncertainty is too small.

14.4 MCMC trace plots do not mix

If trace plots show strong drift or long flat regions, the posterior was not adequately sampled. Increase iterations, adjust step fraction, rerun with a different seed, or simplify the model.

14.5 Excel export has fewer sheets than expected

Only appended results are exported. Make sure each desired result has been added with [Append to Results](#) before clicking [Export results to Excel](#).

14.6 Check log

If error is not apparent, check the log window to see if any errors were thrown.

14.7 Any other issues

Feel free to send an email with any questions or issues.

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