ExoPhotoCurve 1.1.0 User Manual

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Contents

ExoPhotoCurve — Overview

ExoPhotoCurve is a program designed to create, inspect, correct, and analyze photometric light curves of exoplanet transits.

The program performs all the three essential steps in time series analysis of transiting exoplanets:

1. **Data reduction and alignment** of the reduced frames optimized to preserve the photometric information. Monochrome and color data handling and channel extraction from Bayer matrix for OSC camera.
2. **Light curve construction from calibrated and aligned FITS sequence**, via differential aperture photometry. Interactive image viewer, automatic and manual selection of the best comparison stars, and visual feedback to help detect the right initial sample of comparison stars.
3. **Light curve analysis.** Plot updated in real time. Comparison stars optimization, detrending, meridian flip handling, semi-physical fit modeling and comparison with the physical model extracted from the embedded exoplanet catalogs (NASA and ExoClock)

These modules are independent from each other. If you already have a reduced sequence you can skip the step 1). If you already have a light curve to analyze, you can start from step 3).
Although is is not mandatory to perform all these three steps with ExoPhotoCurve, is is strongly recommended, especially for data reduction. Unless you use other science grade software, such HOPS or AstroImageJ, other programs such PixInsight are not optimized to preserve the science information during the reduction step, and the resulting light curves are usually more noisy and unstable.

Purpose of the program

The goal of ExoPhotoCurve is to let the user go from raw images and the relative calibration frames (at least dark, bias and flat field) to a corrected, modeled, and documented light curve.

The program helps the user control:

```
comparison stars
rejected points
detrending
timing
transit model
light-curve quality
final report
```

In this way, the analysis becomes more reproducible and less dependent on undocumented manual trial and error.

1. Starting the program

Start ExoPhotoCurve by running the main Python script or the Windows executable.

The main window contains:

- a control panel on the left;
- the light-curve plot on the right;
- several working tabs: Data, Comp stars, Cleaning, Detrend, Transit modeling, Statistics, Plot, Style, and Binning.

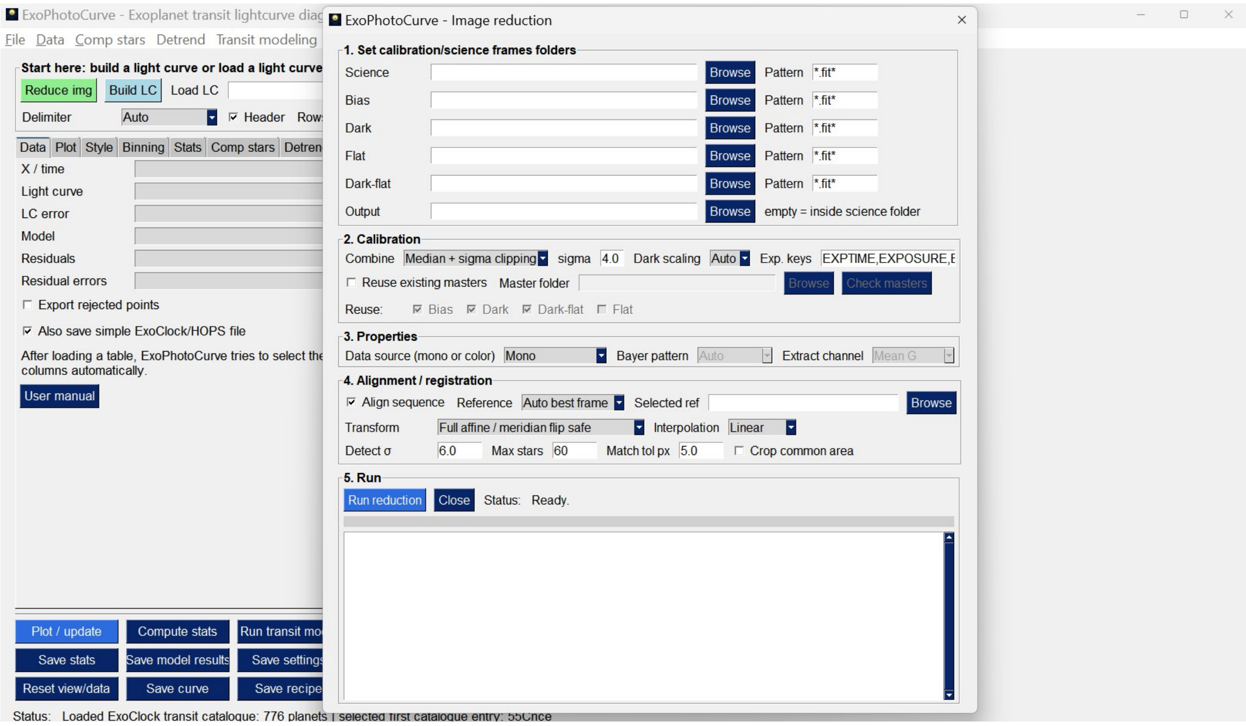
If you already have a light curve, you can load it directly and start the analysis.
If you want to start from the raw image sequence, use:

```
Reduce img
```

If you want to create a light curve from FITS reduced images, or after the “Reduce img” step, use:

```
Build light curve
```

2. Image Reduction Tool



ExoPhotoCurve includes a dedicated image reduction tool designed to prepare raw FITS image sequences for aperture photometry and light-curve extraction.

This tool performs only conservative scientific operations required before photometric analysis. It does not apply aesthetic image processing. In particular, it does not perform background extraction, denoising, sharpening, gradient removal, histogram stretching, or any other operation that may alter the scientific photometric content of the images.

The goal of this tool is to provide a simple, reproducible, and scientifically transparent way to reduce exoplanet transit image sequences directly inside ExoPhotoCurve.

2.1 Opening the Image Reduction Tool

To open the image reduction tool, click the **Reduce img** button in the main ExoPhotoCurve window.

This opens a separate window where you can select the science frames, calibration frames, reduction options, and alignment settings.

The image reduction tool is independent from the light-curve analysis pipeline. After the reduction is complete, you can use the final calibrated and aligned FITS sequence as input for the **Build LC** tool.

2.2 Input Frames

The tool can use the following types of FITS images:

- **Science frames**: the raw images of the exoplanet transit field.
- **Bias frames**: zero-exposure or very short-exposure frames used to remove the detector offset.
- **Dark frames**: dark exposures used to correct for dark current and detector offset.
- **Flat frames**: uniformly illuminated frames used to correct pixel-to-pixel sensitivity variations and optical vignetting.
- **Dark-flat frames**: dark frames taken with the same exposure time as the flat frames.

Only the science folder is strictly required. However, for accurate photometry, it is strongly recommended to use the appropriate calibration frames whenever available.

Each image type has its own folder selector and file pattern field. The default pattern is:

```
*.fit*
```

This usually includes files with extensions such as .fit, .fits, and .fts.

Important: Your files must be stored in separate folders, one folder for group: science (the raw images), dark, flat, bias, and so on.

2.3 Calibration Logic

The calibration procedure follows a conservative scientific workflow.
If bias frames are provided, ExoPhotoCurve creates a master bias.
If dark frames are provided, ExoPhotoCurve creates a master dark. When both bias and dark frames are available, the program also computes the dark signal after subtracting the bias contribution. This allows safe dark-current scaling when the dark exposure time is different from the science exposure time.

If flat frames are provided, ExoPhotoCurve creates a normalized master flat. The flat-field correction is handled as follows:

- if dark-flat frames are available, the flats are corrected with the master dark-flat;
- otherwise, if bias frames are available, the flats are corrected with the master bias;
- if neither dark-flats nor bias frames are available, the flats are normalized without offset correction, and a warning is written in the reduction report.

If both bias and dark-flat frames are provided, the flats are corrected with the dark-flats, while the bias is still used for the science and dark calibration.

The calibrated science frames are then computed by subtracting the appropriate bias/dark contribution and dividing by the normalized master flat, when available.

2.4 Combining Calibration Frames

The calibration frames can be combined using different methods:

- **Median + sigma clipping**
- **Median**
- **Mean + sigma clipping**
- **Mean**

The default method is **Median + sigma clipping**, which is robust against cosmic rays and outliers. For very large datasets, using **Median** can be faster while still providing a reliable master calibration frame in many cases.
The sigma value controls the rejection threshold when a sigma-clipping combination method is selected.

2.5 Dark Scaling

The **Dark scaling** option controls how dark frames are handled when the dark exposure time is different from the science exposure time.

The available options are:

- **Auto**
- **Off**
- **On**

Dark scaling is applied only when it is scientifically safe. In particular, ExoPhotoCurve scales only the dark signal after the bias contribution has been removed. A raw dark frame that still includes the detector offset is not scaled, because scaling it would also scale the bias level and could introduce a systematic error.

If the dark and science exposure times differ and the program cannot safely scale the dark signal, a warning is written in the reduction report.

2.6 Reusing Existing Master Frames

The image reduction tool can reuse previously created master calibration frames with ExoPhotoCurve. This is useful when you want to reduce the same sequence again, or when some calibration masters, such as bias or dark frames, are valid for multiple reductions.

To enable this option, activate:

`Reuse existing masters`

Then select the folder containing the master frames. You can select either the masters folder itself or a previous ExoPhotoCurve reduction folder containing a masters subfolder.

You can choose which master frames to reuse:

- **Bias**
- **Dark**
- **Dark-flat**
- **Flat**

This selection is intentionally manual. In particular, the master flat is usually valid only for the same optical configuration and often only for the same observing session. For this reason, you should reuse a master flat only when you are sure it is appropriate for the current dataset.

The tool searches for standard ExoPhotoCurve master-frame names, such as:

`master_bias.fits`

`master_dark_raw.fits`

`master_dark_signal_minus_bias.fits`

`master_darkflat.fits`

`master_flat_normalized.fits`

Click **Check masters** to inspect which master frames are available and whether they are compatible with the current science frames.

If a selected master is not found, ExoPhotoCurve tries to create it from the calibration folders provided in the current reduction. If neither a reusable master nor the corresponding calibration frames are available, the program continues without that correction and writes a warning.

Reused master frames are copied into the new reduction folder, so that every reduction remains self-contained and reproducible.

2.7 Mono and Color Bayer Data

The image reduction tool can work with both monochrome cameras and one-shot color cameras using a Bayer color filter array.

Use the **Data source** selector to choose:

- **Mono**
- **Color Bayer**

For monochrome data, no Bayer extraction is applied.

For color Bayer data, ExoPhotoCurve can extract one real detector channel from the Bayer matrix. The available channels are:

- **Mean G**
- **G1**
- **G2**
- **R**
- **B**

The recommended option for most exoplanet transit work with color cameras is usually **Mean G**, because the green channel often provides a good compromise between signal-to-noise ratio and atmospheric sensitivity.

ExoPhotoCurve does not perform RGB debayer interpolation. Instead, it extracts real CFA pixels and produces a compact half-resolution image. This avoids introducing interpolated values into the scientific photometry.

2.8 Image Alignment

After calibration, the tool can align the sequence automatically.

Activate:

```
Align sequence
```

The available reference-frame options are:

- **Auto best frame**
- **First frame**
- **Middle frame**
- **Selected file**

In most cases, **Auto best frame** is recommended. The program selects a reference image based on the number of detected stars and basic quality indicators such as FWHM and elongation.

The available transform modes are:

- **Shift only**
- **Shift + rotation/scale**
- **Full affine / meridian flip safe**

For exoplanet transit sequences, especially when a meridian flip occurred during the night, **Full affine / meridian flip safe** is recommended. This mode can handle translation, rotation, scale changes, and reflected geometries caused by a meridian flip.

The alignment process uses detected stars in the field and writes alignment diagnostics to the reduction report.

2.9 Common Crop

If **Crop common area** is enabled, the aligned images are cropped to the common valid region covered by all frames.

This can be useful when the sequence contains large shifts, rotations, or a meridian flip. However, cropping changes the final image size. If you prefer to keep the original reference-frame size, leave this option disabled.

2.10 Output Folders

Each reduction creates a new output folder with a timestamped name. The output folder contains:

`masters`

`calibrated`

`aligned`

`reports`

The **masters** folder contains the master calibration frames created or reused during the reduction.

The **calibrated** folder contains the calibrated science images before alignment.

The **aligned** folder contains the final image sequence. This is usually the folder you should use as input for the **Build LC** tool.

The **reports** folder contains the reduction report, settings file, and warnings file when applicable.

2.11 Reduction Report

ExoPhotoCurve writes a reduction report in CSV format. This report includes quality-control information for the calibrated and aligned frames, such as:

- filename;
- exposure time;
- filter name, when available;
- image shape;
- sky background;
- sky noise;
- maximum pixel value;
- number of detected stars;

- FWHM;
- elongation;
- alignment shift;
- rotation;
- scale;
- flip detection;
- alignment RMS;
- alignment status.

The program also writes a JSON settings file containing the reduction configuration used for the run. If warnings are generated, they are saved in a separate warnings file.

These files are important for reproducibility and should be kept together with the reduced image sequence.

2.12 Recommended Workflow

A typical workflow is:

1. Click **Reduce img**.
2. Select the science image folder.
3. Select the available bias, dark, flat, and dark-flat folders.
4. Choose the appropriate camera mode: **Mono** or **Color Bayer**.
5. For color cameras, select the Bayer pattern and extraction channel.
6. Keep **Align sequence** enabled.
7. Use **Full affine / meridian flip safe** if the sequence includes a meridian flip.
8. Click **Run reduction**.
9. When the reduction is complete, use the final files in the **aligned** folder as input for **Build LC**.

For a new dataset, it is usually better to create new flats rather than reuse an old master flat. Bias and dark masters may be reused more often, but only when the camera settings, temperature, gain, offset, and image size are compatible.

2.13 Useful Notes

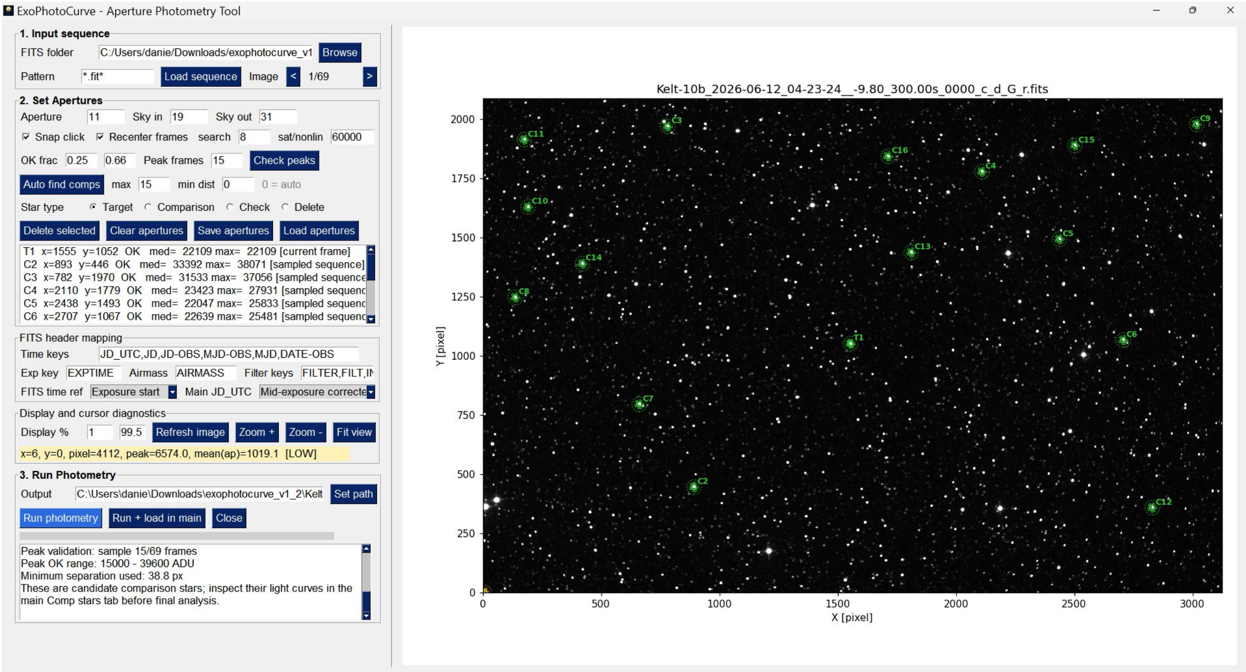
The image reduction tool is designed for photometric reliability, not for visual enhancement.

Do not expect the reduced images to look aesthetically processed. The goal is not to create visually attractive astronomical images, but to preserve the relative flux information needed for accurate aperture photometry.

For this reason, ExoPhotoCurve avoids operations that may change the background structure, alter stellar profiles, or modify the noise properties of the images.

The final reduced sequence should be considered a scientifically calibrated input for light-curve extraction, not a processed deep-sky image.

3. Build a light curve from FITS images



The **Build light curve** button opens the independent aperture photometry tool.

This tool creates a photometric table compatible with the main ExoPhotoCurve pipeline. The output table uses column names similar to those produced by AstroImageJ, so it can be loaded and analyzed directly by the main program.

3.1 Image requirements

The FITS images must already be:

- bias/dark/flat calibrated;
- aligned;
- preferably all the same size;
- correctly ordered in time;
- equipped with reliable timing information in the FITS header.

This tool does not perform calibration and image alignment. Here you must use the reduced sequence generated from the Image reduction module of ExoPhotoCurve, or any calibrated and aligned sequence in fits format reduced with other program.

3.2 Loading the FITS sequence

First in the "1. Input folder" frame , select the folder containing your FITS images. This folder should contain only the reduced and aligned fits of your sequence. The program will select any fit(s) file in this folder regardless their origin and properties!

The program loads the sequence and displays a reference image, usually the first one in chronological order. You can move through the sequence using:

```
arrow keys
previous/next buttons
Shift + mouse wheel
```

You can inspect the image using zoom and pan:

```
mouse wheel        = zoom
click + drag       = pan
Fit view           = show full image
```

3.3 Choosing the apertures

Set the aperture parameters:

```
aperture radius
sky inner radius
sky outer radius
search radius
```

The inner circle is the stellar aperture.
The outer annulus is used to estimate the sky background.

You can change the aperture sizes at any time until you close the window, even after selecting the target and comparison stars. The new aperture sizes are calculated automatically and shown in the image window.

When you move the mouse over the image, the program shows the aperture at the current position. This helps you check whether the selected radius is appropriate for the stars. The aperture is color-coded according to the peak luminosity measured in the inner circle: yellow means that the selected star has low luminosity and probably a low signal-to-noise ratio. Green means that the selected star is within the optimal luminosity range, which is set by default between 0.25 and 0.66 of the dynamic range of a standard 16-bit FITS image (roughly between 18,000 and 35,000 ADU). You can change this range in the “OK frac” field. Red means that the star is approaching saturation and probably falls within the nonlinear range. Always avoid red apertures!

This color feedback is based only on the luminosity of the stars in the selected image. After selecting the apertures, use the “Check peak” button. By default, it measures the peak luminosity in a subsample of 15 images and updates the aperture colors if at least one aperture falls outside the optimal range in at least one image.

The program also displays useful information about the region under the cursor, such as the pixel value, peak value, and mean signal inside the aperture.

3.4 Selecting the target and comparison stars

Before clicking on the image, choose which type of star you want to add:

```
Target
Comparison
Check
```

Then click near the star.

If **Snap click** is enabled, the program automatically moves the aperture to the local centroid of the nearest star within the search radius. This means you do not need to click exactly at the center of the star.

The selected apertures remain visible on the image. You can delete or modify apertures before running the photometry. You can also try automatic comparison-star selection by pressing the “Auto find comps” button. After you have manually selected the target, this option selects comparison stars that meet the following constraints: peak luminosity in the green range and no contamination from nearby stars.

Whether you select comparison stars manually or automatically, it is advisable to start with a broad range of suitable comparison stars. A finer selection will be made later in the main program, under the “Comp stars” tab.

3.5 Saving and loading apertures

ExoPhotoCurve automatically saves the aperture set to an external file once you run the photometry, but you can also save the aperture file manually with a custom name and in custom location in your computer.
This is useful if you want to repeat the photometry on the same sequence, or if you want to change only a few parameters without selecting all stars again.
When you reload an aperture set, the program restores the saved positions and displays them on the image. Also for the loaded apertures you can change the sizes. ExoPhotoCurve will automatically upload in real time the new sizes for all the stars.

If Recenter frames is enabled, the program recalculates the centroid of each star in every image during photometry, within the selected search radius.

3.6 Recentering apertures during photometry

The option:

```
Recenter frames
```

makes the program search for the centroid of each star in every image. This compensates for small alignment errors or small drifts of the field.
If the images are perfectly aligned, you can disable this option, but in most cases it is safer to keep it enabled.

3.7 Timing information in FITS images

Timing is one of the most important aspects of transit photometry.

Many FITS files store `DATE-OBS` or `JD_UTC` as the **start of the exposure**, not the mid-exposure time. For 300-second exposures, the difference between exposure start and mid-exposure is:

```
150 seconds = 2.5 minutes
```

This can produce a visible offset in the measured O-C.
In the photometry window, choose:

```
FITS time ref:
- Exposure start
- Mid-exposure
- Exposure end
```

Then choose which time should be exported as the main `JD_UTC` column:

```
Main JD_UTC:
- Header time
- Mid-exposure corrected
```

A safe workflow is:

```
FITS time ref = Exposure start
Main JD_UTC = Mid-exposure corrected
```

3.8 Running the photometry

When the apertures are ready, set the name and the path of the photometry file to be saved with the button “Set path”. If you put the name of the planet in the filename, ExoPhotoCurve will recognize it automatically in the analysis step. Then, click one of these buttons:

```
Run photometry
Run + load in main
```

The first option runs the photometry only and saves the file. The second option runs the photometry, saves the file, closes the window, and automatically loads the raw photometry file in the main program.

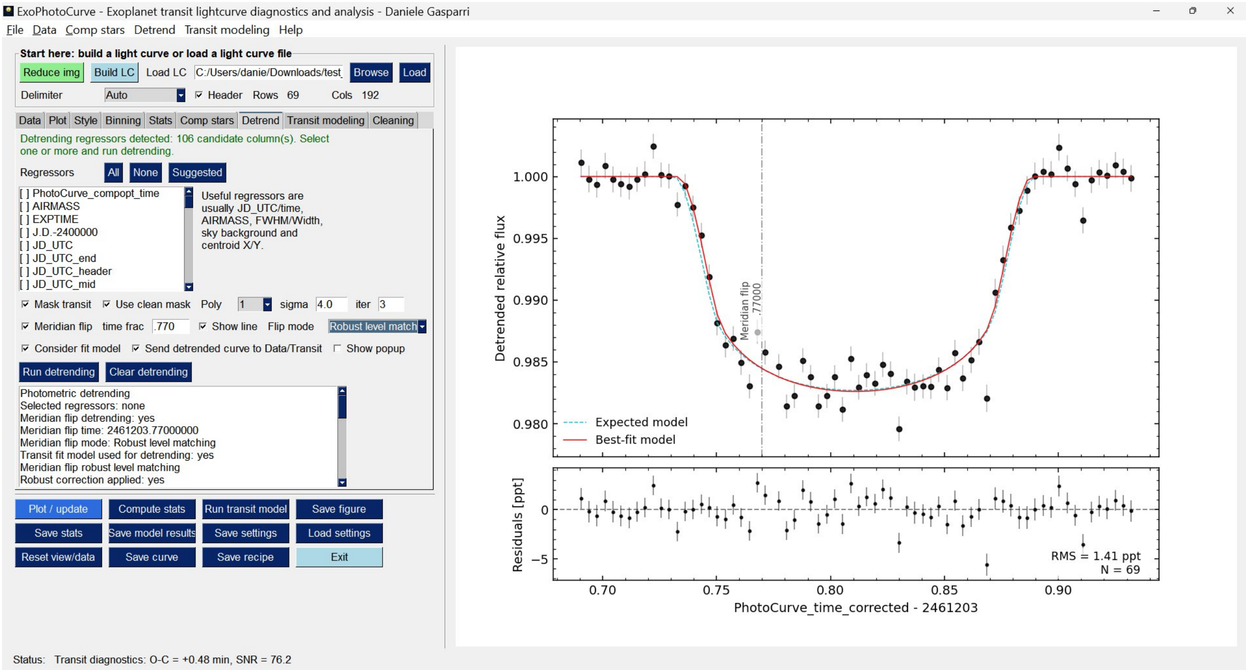
The output file can contain columns such as:

```
JD_UTC
JD_UTC_header
JD_UTC_start
JD_UTC_mid
JD_UTC_end
AIRMASS
EXPTIME
FILTER
Source-Sky_T1
Source_Error_T1
Source-Sky_C2
Source_Error_C2
Source-Sky_C3
```

```
Source_Error_C3
rel_flux_T1
rel_flux_err_T1
```

From this point on, the light curve is analyzed using the standard ExoPhotoCurve pipeline.

4. Analyzing a light curve



If you have generated or already have a light curve, you can load it directly into the main window.

Click:

```
Browse
Load table
```

The program reads the table and tries to identify the main columns automatically.

For ExoPhotoCurve generated files, common columns are:

```
JD_UTC
JD_UTC_B
BJD_TDB
rel_flux_T1_dfn
rel_flux_err_T1_dfn
rel_flux_T1_dfn_model
rel_flux_T1_dfn_residual
```

If some columns are not recognized correctly, you can select them manually in the Data tab. In general, the photometry file should use column names without special characters, such as #.

4.1 Data tab

The **Data** tab is used to choose which columns are used for plotting and analysis.

The main columns are:

```
X / time
Light curve
Light-curve error
Model
Residuals
Residual errors
```

If your file does not contain a model or residuals, leave those fields as:

```
-- None --
```

The model can be generated later in the **Transit** tab.

4.2 Comp stars tab

The Comp stars tab is used to select the best comparison stars when the loaded file contains individual stellar fluxes. If you created the raw light curve with the Build light curve tool, use this tab to check and select the final set of comparison stars from the group selected during photometry. This is a very important step: in most cases, you need to inspect the comparison stars carefully and remove those that are unsuitable because they are variable or unstable over the sequence. You will rarely end up with the same number of comparison stars that you selected during photometry.

This applies to complete AstroImageJ tables and to files generated by the ExoPhotoCurve aperture photometry tool.

The tab becomes active only if the program detects columns such as:

```
Source-Sky_T1
Source-Sky_C2
Source-Sky_C3
Source_Error_T1
Source_Error_C2
Source_Error_C3
```

If these columns are not present, the tab displays a warning and cannot be used.

4.2.1 Manual comparison-star selection

The list shows the available comparison stars.

You can activate or deactivate each star by clicking on its name.

You can also view the light curve of any comparison star by activating the “Plot selected comp” option.

When the subset changes, the light curve is recalculated automatically.

This allows you to quickly check the effect of each comparison star on the final light curve.

Suggested workflow:
- Start by looking at each check star individually with the “Plot selected comp” option enabled, and deselect stars with clearly variable or nonlinear behavior. For now, keep stars that show only a linear trend.
- Continue the fine selection by observing the target light curve with “Plot selected comp” disabled while activating and deactivating one comparison star at a time. If the curve improves when you deselect a comparison star, leave it deselected and move to the next comparison star until you reach the end of the list. Repeat this step from the first active comparison star, considering only the comparison stars that are still active. For a reliable light curve, at least three comparison stars should be used. Using more than 10-15 comparison stars is usually not useful.

4.2.2 Automatic comparison-star optimization

The program can automatically search for the subset of comparison stars that produces the cleanest light curve. This is an experimental feature and should be used with extreme caution.

You can use two workflows:

```
manual selection → automatic optimization
automatic optimization → manual refinement
```

In the first case, you manually exclude poor comparison stars and then let the optimizer work only on the remaining active stars.

In the second case, the program selects a subset automatically and you refine it manually afterwards.

4.2.3 Sending the optimized curve to the pipeline

If:

```
Send optimized curve to Data/Transit
```

is enabled, the optimized curve is automatically selected as the main light curve in the Data tab.

You can then proceed with cleaning, detrending and transit fitting.

4.3 Detrend tab

The **Detrend** tab is used to correct systematic trends in the light curve.

You can use one or more regressors at the same time, as in AstroImageJ.

Examples of possible regressors are:

```
JD_UTC / time
AIRMASS
```

```
FWHM
Sky background
X/Y centroid
Peak
Meridian flip
```

The detrending is applied multiplicatively:

```
corrected flux = observed flux / baseline
```

This is appropriate for relative-flux light curves.

For better results, consider fitting the transit first. Then activate the “Consider fit model” option, which will give you better results with any detrending method, especially with the meridian flip.

4.3.1 Choosing regressors

By default, no regressor is active.

You can select regressors manually, or press Suggested to let the program enable likely useful regressors.

You can use several regressors together, for example:

```
JD_UTC + AIRMASS
```

or:

```
JD_UTC + AIRMASS + FWHM
```

4.3.2 Masking the expected transit during detrending

For exoplanet transits, it is usually recommended to use:

```
Mask expected transit
```

This tells the program not to use in-transit points when estimating the baseline.

This reduces the risk that the detrending will distort the transit depth.

4.3.3 Meridian flip

If the telescope performed a meridian flip during the sequence, you can use the dedicated correction.

A meridian flip may introduce a jump in flux level or a change in trend, because the field moves to a different region of the detector.

In the **Detrend** tab, enable:

```
Meridian flip
```

and enter only the decimal part of the flip time, as in AstroImageJ.

Example:

```
JD_UTC flip = 2461203.771
```

In the program, enter:

```
.771
```

You can press:

```
Update line
```

to display a vertical line in the plot at the flip position. This is only a visual check.

To actually apply the correction, click:

```
Run detrending
```

Available modes are:

```
Step only
Step + after-flip slope
Robust level match
```

The recommended mode is **Robust level match**, because it corrects a flux-level jump without adding too much freedom.

Use **Step + after-flip slope** only if there is a clear change in slope after the flip.

4.3.4 Removing detrending

If you want to return to the curve before detrending, click:

```
Clear detrending
```

This does not reset the full program. It removes only the detrending and returns to the source curve.

4.4 Transit modeling tab

The **Transit modeling** tab is used to model an exoplanet transit and produce a diagnostic report.

The typical workflow is:

```
1. Select the planet
2. Select the filter
3. Enter the exposure time
4. Select the input time system
5. Select whether the time stamps correspond to exposure start, mid-exposure, or exposure end
```

```
6. Enter the observatory coordinates
7. Click Run transit model
```

4.4.1 Planet catalogs

ExoPhotoCurve can use different catalogs:

```
NASA
ExoClock
custom catalog
```

You can quickly switch between NASA and ExoClock using the dedicated buttons.

The ExoClock catalog is often useful for updated ephemerides.
The NASA catalog can provide geometric parameters useful for the physical transit model.

You can also load a custom catalog, as long as it uses a compatible column format.

4.4.2 Automatic planet detection

When a file is loaded, ExoPhotoCurve tries to detect the planet from the filename.

Examples:

```
hats24b_20260606_lightcurve.txt → HATS-24b
wasp-15b_lightcurve.txt → WASP-15b
```

Always check that the selected planet is correct before running the fit.

4.4.3 Photometric filter and limb darkening

The selected filter is used by the physical model to choose approximate limb-darkening coefficients.

Changing the filter should not drastically change the transit, but it can slightly affect:

```
transit shape
ingress and egress
estimated Rp/Rs
residuals
```

The report shows the filter, limb-darkening law, and coefficients used.

4.4.4 Time system and BJD_TDB correction

Transit timing requires careful time handling.

ExoPhotoCurve can convert `JD_UTC` times to `BJD_TDB` using:

```
target coordinates
observatory coordinates
exposure time
time-stamp reference
```

If the time column is `JD_UTC`, select:

```
Input time system = JD_UTC
```

If the times are already in `BJD_TDB`, select:

```
Input time system = BJD_TDB
```

The field:

```
Time stamp reference
```

defines whether each point represents:

```
Exposure start
Mid-exposure
Exposure end
```

This choice is very important. With 300-second exposures, confusing exposure start with mid-exposure produces a 2.5-minute timing error.

4.4.5 Fit baseline

In the **Transit** tab, you can choose a baseline model:

```
Constant
Linear
Quadratic
```

This baseline corrects small remaining trends during the transit fit.

If you have already applied a good detrending in the **Detrend** tab, **Constant** is often sufficient.

If residual trends remain, try **Linear** or **Quadratic**.

Use the quadratic baseline with caution if there is limited out-of-transit coverage. Usually, Quadratic will overestimate the transit depth, especially if you have already performed detrending in the “Detrend” tab.

4.4.6 Detrended or raw display

ExoPhotoCurve can display the transit fit in two ways:

```
Detrended flux
Raw flux with baseline
```

The recommended mode for final plots is:

```
Detrended flux
```

In this mode, the program shows the baseline-corrected light curve and clean transit models.

The mode:

```
Raw flux with baseline
```

is useful for checking how the baseline fits the original data.

4.7.7 Timing markers in the plot

You can show timing labels in the plot:

```
Predicted times
Calculated times
```

If **Predicted times** is enabled, the plot shows:

```
Predicted start
Predicted Tmid
Predicted end
```

If **Calculated times** is enabled, the plot shows:

```
Calculated start
Calculated Tmid
Calculated end
```

If both are enabled, the program also displays the O-C between the predicted and measured mid-transit times.

4.4.8 Tmid ref

The field:

```
Tmid ref
```

allows you to manually enter a predicted mid-transit time in `BJD_TDB`.

Use this only if you have a predicted mid-time for the specific transit observed.

Do not enter an old ephemeris T0 here unless it corresponds to the observed transit.

4.5 Cleaning tab

The **Cleaning** tab is used to remove problematic points.

There are two main methods:

```
automatic sigma clipping
manual point rejection
```

4.5.1 Sigma clipping

Sigma clipping identifies outliers based on their distance from the curve or from the residuals.

For exoplanet transits, use this function carefully, because overly aggressive clipping may remove real transit points.

A reasonable starting point is:

```
Target: Residuals
Sigma threshold: 3
Center: Median
Scale: MAD
```

For more accurate sigma clipping, consider fitting the transit first in the “Transit modeling” tab.

4.5.2 Manual point rejection

You can enable manual point editing.

When it is active, clicking near a point in the plot excludes or restores that point.

Manually rejected points are removed from the plot, statistics and transit fit, unless you explicitly choose to export rejected points.

4.6 Transit report

After **Run transit model**, ExoPhotoCurve produces a report containing:

```
planet
filter
exposure time
time system
BJD_TDB correction
target coordinates
observatory coordinates
catalog used
T0 and period
predicted Tmid
observed Tmid
O-C
Rp/Rs
depth
duration
residual RMS
transit SNR
autocorrelation
diagnostic quality flags
```

The O-C is defined as:

```
O-C = observed Tmid - predicted Tmid
```

A positive O-C means that the transit occurred later than predicted.
A negative O-C means that it occurred earlier than predicted.

4.7 Reproducibility recipe

ExoPhotoCurve also saves a complete recipe of the analysis.

The recipe includes:

```
loaded file
catalog used
selected columns
active comparison stars
rejected points
sigma clipping settings
detrending regressors
meridian flip settings
fit baseline
filter
time-stamp settings
observatory coordinates
main final parameters
```

You can save:

```
Save model results
```

to save the complete diagnostic report, or:

```
Save recipe
```

to save only the operational recipe.

This makes the analysis reproducible.

4.8 Saving the final light curve

The button:

```
Save curve
```

exports the light curve in its current analysis state.

The file can include:

```
JD_UTC
time_input
time_bjd_tdb
time
flux
flux_error
model
residual
baseline
point masks
```

To load the result into ExoClock, usually use:

```
JD_UTC
flux
flux_error
```

If you manually rejected points, ExoPhotoCurve saves only the points used in the analysis by default.

Enable:

```
Export rejected points
```

if you want to save rejected points as well, together with mask columns.

4.9 Other secondary tabs

4.9.1 Binning

The **Binning** tab allows you to overplot binned points on the original light curve.

Binning is useful for visualizing the general shape of the transit, but it should not replace the analysis of the original data points.

You can choose the number of points per bin and the style of the binned points.

4.9.2 Statistics

The **Statistics** tab computes basic quantities for the selected light curve, such as:

```
number of points
time span
median cadence
mean and median flux
RMS
amplitude
median error
RMS / median error
```

This is useful for quickly checking the quality of the light curve.

4.10 Reset and useful controls

ExoPhotoCurve includes several controls for reverting changes:

`Reset view/data`

restores the loaded table and removes temporary products, fits, binning, clipping, and generated columns.

`Clear detrending`

removes only the detrending, while keeping the rest of the setup.

`Show transit fit on plot`

shows or hides the transit model in the plot.

4.11 Recommended workflow for an existing light curve

```
1. Load table
2. Check the columns in the Data tab
3. Use Comp stars if the file contains individual stellar fluxes
4. Remove problematic points in Cleaning
5. Apply detrending if needed
6. Select planet, filter, exposure time and time-stamp reference in Transit
7. Run transit model
8. Check plot, residuals, RMS and O-C
9. Save model results, Save recipe and Save curve
```

4.12 Practical advice

For reliable results:

- use well-calibrated images;
- avoid saturated stars;
- choose stable comparison stars that are not too faint;
- always check the time system;
- verify whether the FITS time is exposure start or mid-exposure;
- use meridian flip correction only when needed;
- avoid overly aggressive detrending if the transit is poorly covered;
- always inspect the residuals, not only the fitted curve;
- save the analysis recipe.

A good fit is not only a model passing through the data. A good analysis should have small residuals, no obvious trends, consistent timing, and a reproducible procedure.

5. Program limitations

ExoPhotoCurve is designed for differential photometry, diagnostics, and operational/preliminary exoplanet transit analysis.

It does not perform:

```
plate solving
PSF photometry
full MCMC analysis
advanced physical modeling
```

The program is designed to be simple, transparent, and practical. For final professional analyses, the results can be used as a basis or comparison, but they should be interpreted carefully.