The Light Curve Fitter: A novel application for deconvolving two superimposed sinusoidal waves developed using the Agile Software Development Lifecycle

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Abstract

The Galway Ultra-Fast Imager (GUFI) located on the 1.8m Vatican Advanced Technology Telescope (VATT) was tasked to monitor tight brown dwarf binaries. However, due to the close separation between the components in these binaries, the GUFI photometer could not image each component of binary systems as a point source in our campaign. Therefore, we developed and employed our novel application, the 'Light Curve Fitter', which is capable of distinguishing two superimposed sinusoidal waves. This application allows users to untangle the secondary component's variability signature from that of the dominant primary variability.

Light Curve Fitter (LCF)

The photometric aperture used enclosed the combined flux of tight binary components due to the close separation of the members. The presence of two periodically varying sources in the data produces superimposed variability and a complex light curve shape. Therefore, we wrote a Python-based script called Light Curve Fitter capable of distinguishing two superimposed sinusoidal waves, to untangle the secondary component's variability signature from that of the dominant primary variability.

The LCF application was accomplished using a combination of Least Square Fitting (LSF) and χ^2 techniques. The function LCF is given by:

$$LCF = \underbrace{\left(A_1 \sin\left(\frac{2\pi t}{P_1} + \emptyset_1\right) + O_1\right)}_{Primary\ Star} + \underbrace{\left(A_2 \sin\left(\frac{2\pi t}{P_2} + \emptyset_2\right) + O_2\right)}_{Secondary\ Star}$$

The approach of LCF

To explain the approach of LCF, consider the scenario of a binary star as a single source (for example 2MASS J0746+2000AB is an L dwarf binary with a separation of ~2.7 AU), where we run Lomb–Scargle Periodogram LS and Phase Dispersion Minimization PDM on the combined flux of each observation epoch and then on all epochs combined, and the detected period represents the dominant source. Subsequently, to seek for the elusive secondary period a sinusoidal signal is set to the dominant rotation period in each of the original light curves (Fig 4). This fit is then subtracted out, and the LS and PDM are re-applied to the residual data points. This method can therefore identify the possible presence of an underlying period from the weaker member. If true, then this is repeated on the original time series, or on the time series with one or both signals removed - for example, refining the strongest variability parameters, by using a sinusoidal model fit set to the period of the detected weaker signal. The LCF algorithm can determine the mean amplitude variability of the target light curve via sinusoid fitting, which permits variation in the amplitude and phase of the sinusoidal function. In addition, it is also possible to use this technique as an additional evaluation of the period solutions obtained from the LS and PDM analyses of single and binary stars, based on the correlation of the model sinusoidal fit with the real light curve data.

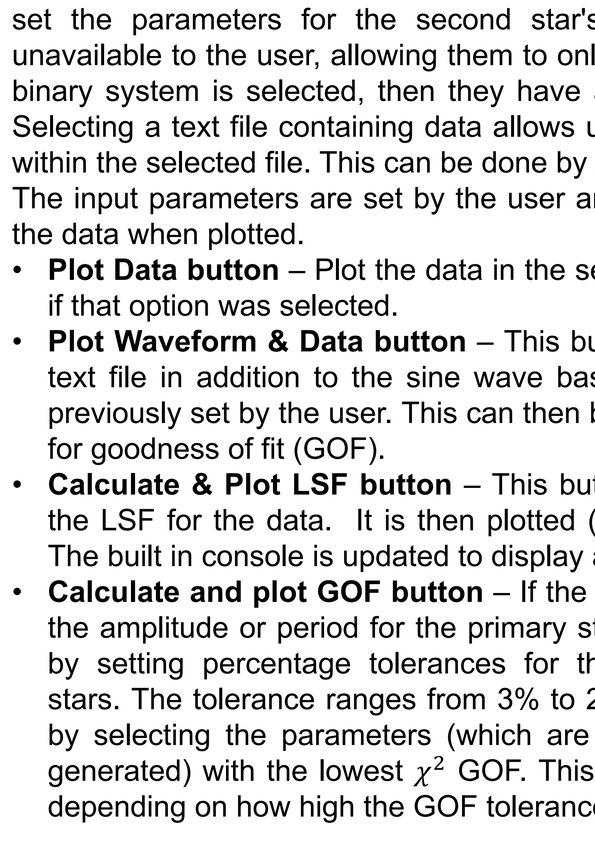

Fig. 3 GUI outlining the sequence of steps to calculate and plot the LSF for data. The output of this sequence is illustrated in Fig 4.

How it works

The operational flow diagram for LCF software is described and illustrated in Fig. 1 & Fig. 3. LCF was developed using the Agile software development lifecycle (Fig. 2) as outlined in Fitzgerald et al. (2019). The Graphical User Interface (GUI) is designed to be as intuitive as possible for users and does not require any previous training. The following follows a path within the operational flowchart diagram (Fig. 1).

The user must select one of the radio buttons informing the application whether they want to use data with/without error bars. If Single Star is selected then the fields that set the parameters for the second star's amplitude, period and phase will be unavailable to the user, allowing them to only set the parameters for the first star. If a binary system is selected, then they have access to set parameters for both stars. Selecting a text file containing data allows users to plot and view the data contained within the selected file. This can be done by selecting the Plot Data button.
The input parameters are set by the user and can be used to ascertain a good fit to the data when plotted.

- **Plot Data button** – Plot the data in the selected text file and will include error bars if that option was selected.
- **Plot Waveform & Data button** – This button will plot the data within the selected text file in addition to the sine wave based on the system type and parameters previously set by the user. This can then be used to determine a better LSF and χ^2 for goodness of fit (GOF).
- **Calculate & Plot LSF button** – This button will take the parameters to calculate the LSF for the data. It is then plotted (see Fig. 3) and a χ^2 GOF is calculated. The built in console is updated to display all results.
- **Calculate and plot GOF button** – If the user knows (or even if they do not know) the amplitude or period for the primary star, they can then determine the χ^2 GOF by setting percentage tolerances for the amplitude, period and phase of the stars. The tolerance ranges from 3% to 20% for the amplitudes, and is calculated by selecting the parameters (which are determined based on the combinations generated) with the lowest χ^2 GOF. This can take a considerable amount of time depending on how high the GOF tolerance (%) is set by the user.

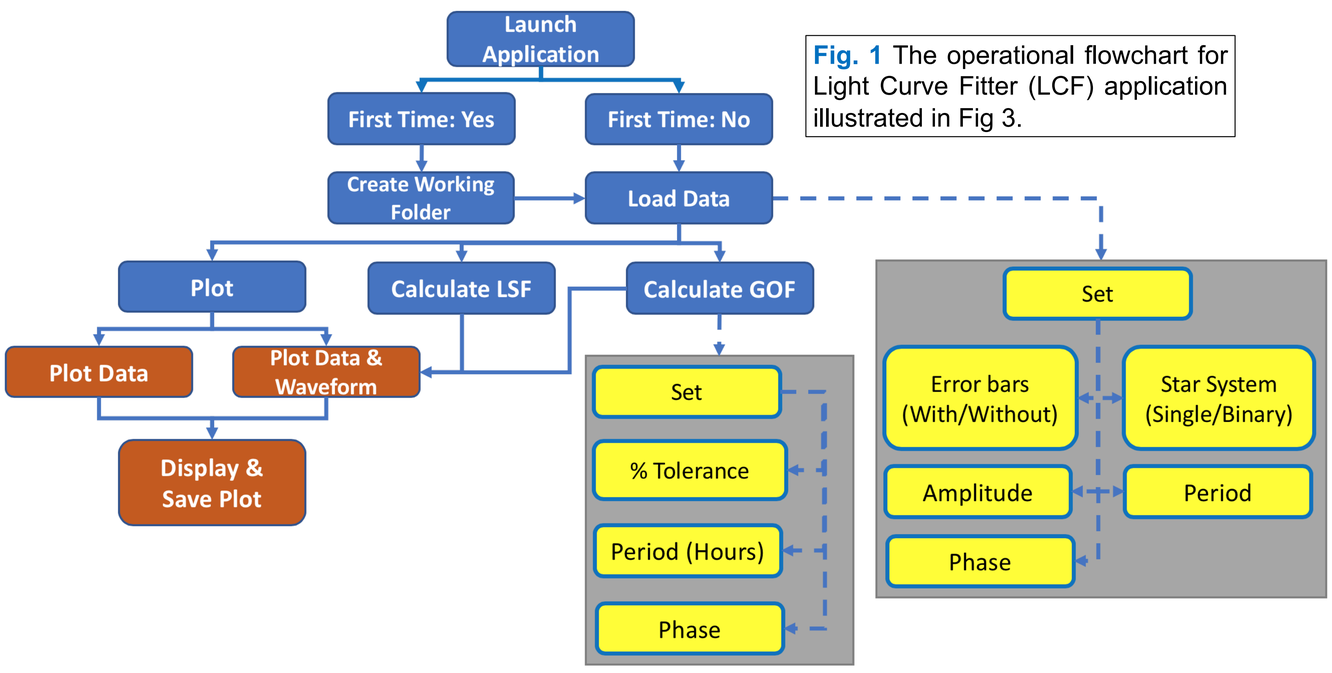

Fig. 1 The operational flowchart for Light Curve Fitter (LCF) application illustrated in Fig 3.

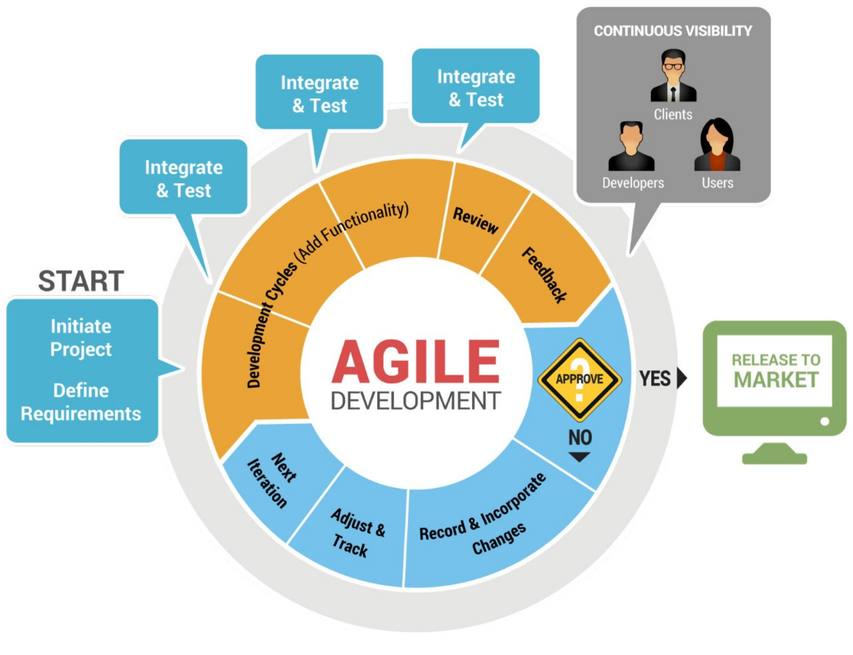

Fig. 2 The Agile Software Development Lifecycle. Image reproduced from https://pnghut.com/png/tTx317Q44P/systems-development-life-cycle-agile-software-process-computer-testing-transparent-png

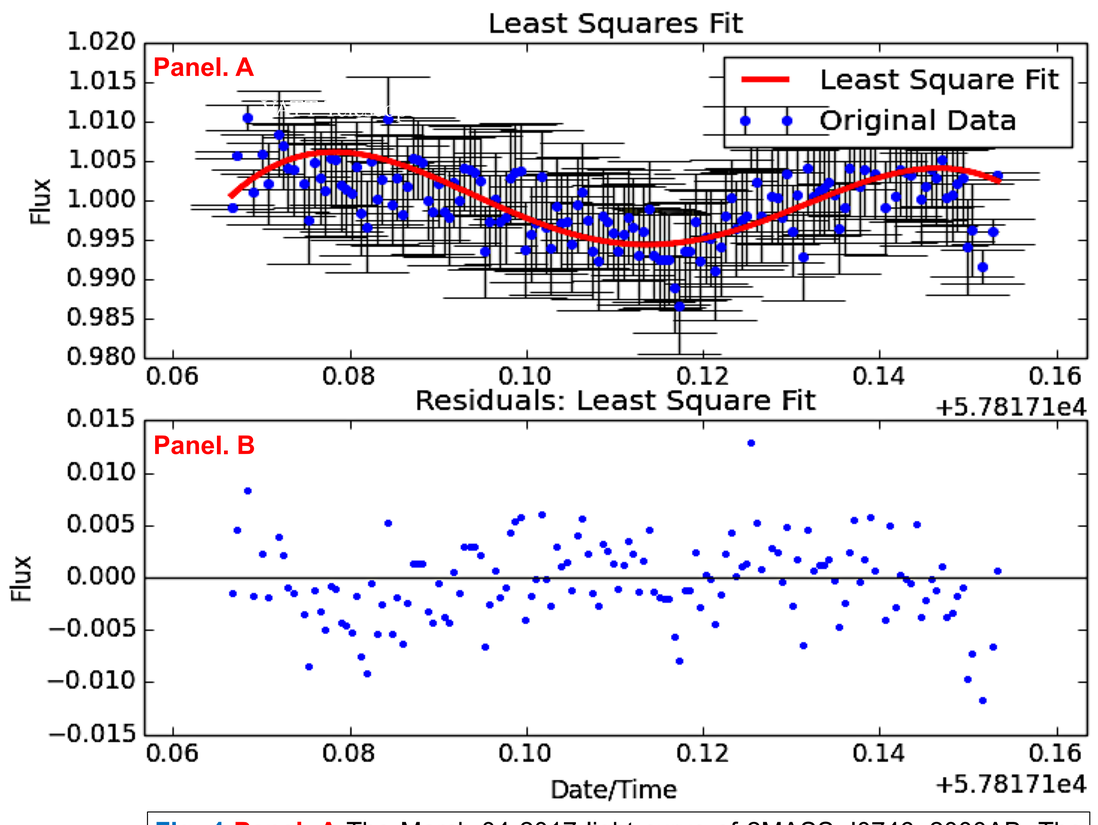

Fig. 4 Panel. A The March 04 2017 light curve of 2MASS J0746+2000AB. The red model sinusoid (the primary period) over-plotted is the best fit using the Least Squares Fit LSF in LCF routine. **Panel. B** The residual data (the secondary signal) after subtracting out the primary component, this secondary signal is consistent with that derived by Qicheng et al. 2020.

References

Dulaimi et al. (2020) in preparation.
Dulaimi , 2020 (PhD Thesis).
Fitzgerald et al. (2019).
Qicheng et al. 2020