

# Wqed: A Lightcurve Analysis Suite

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**Abstract.** *Wqed* is a suite of programs designed to clean lightcurves created by aperture photometry to allow more sophisticated analysis, like Fourier transforms, to be performed. The data format for *Wqed* includes a header that allows users to keep all pertinent information about their data attached to the final light curve. *Wqed* was tested during the Whole Earth Telescope run on a DAV in 2008 and improved the ease and speed of data reduction. Visit <http://physics.udel.edu/darc/wqed> to download the current version of *Wqed* along with a full set of instructions on how to install and use the program.

## 1. Introduction

Analysis of astronomical time-series data is often complicated by atmospheric effects on the lightcurve. Clouds change the brightness of these stars, while extinction adds long-term trends. Removal of these effects is best done interactively. The Whole Earth Telescope (WET) conducts coordinated time-series observations of multiple targets using telescopes distributed across the globe, and requires a fast, light-weight, and easy to use software pipeline to reduce data as fast as it is obtained. In the early days, the WET used a DOS based program known as QED to reduce phototube data, but the increased popularity of CCD rendered this program obsolete.

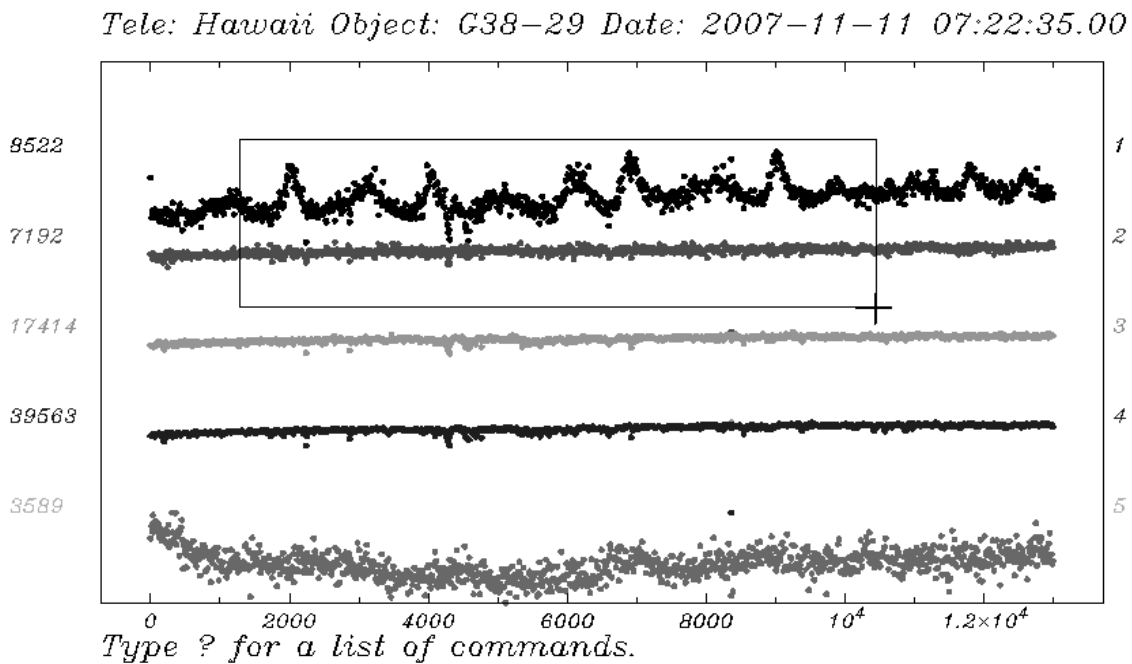
Currently, the WET uses the IRAF based *ccd\_hsp* package to extract raw lightcurves from CCD frames, and for the most recent WET run (XCov26, Thompson et al., this volume) we developed and successfully used a package for interactively removing atmospheric effects. This package, called *Wqed* (pronounced “Wicked”), allows the user to remove portions of the lightcurve, divide lightcurves, fit low order polynomials, and other useful tasks. While designed with multi-site data in mind, *Wqed* also conveniently serves the need of the single-site astronomer.

## 2. Usage

*Wqed* is designed to be quick to learn and easy to use. An intuitive interface based on the *pgplot* libraries allows the user to use the mouse to select and zoom in on regions of the lightcurve. A similar combination of mouse and keystrokes can remove irredeemably bad data from a lightcurve, divide the lightcurve of a target star by that of a reference to remove the effects of small cloud, fit and remove a polynomial to a lightcurve to remove long-term trends from the data, etc. Every action can be reversed using the undo function. Users of the old QED program will find the interface and design philosophy familiar.

Figure 1 shows a screenshot from a typical reduction. The screen is divided into three parts, information about the run extracted from the header (see §3) is displayed at the top, the

lightcurves are displayed in the middle, and at bottom, a message box provides feedback to the user. Each light curve is referenced by a channel number, listed on the left. The average counts of each channel are listed on the right. A list of available commands can be found by pressing the ? key.



**Figure 1.** Screenshot of *Wqed* and a box for zooming. Five different light curves are shown and their channel numbers are listed on the right. The average counts in each light curve are listed on the left. When the user decides to zoom in, the key **z** is typed to form a box around the desired region.

Figure 1 shows the lightcurve of a variable white dwarf star in black, three reference stars, the bottom lightcurve shows the sky brightness during the observations. The following is a brief list of commands frequently used in *Wqed*.

### *2.1. Zooming*

To examine a region of the lightcurve in greater detail, press the **z** key and select the region using the mouse.

### *2.2. Division*

To divide the target star (in channel 1) by a bright reference star (in channel 2), one simply must type four key strokes: **1 / 2 <CR>**. To divide by the sum of two light curves, type **1 / 2 3 <CR>**.

### *2.3. Garbage*

Because of clouds and cosmic rays, bad data points remain in the divided light curve. To garbage these points the user can create a box around these points by typing **g**. Similarly, to remove all points outside of the box, use the command **ctrl-g**.

#### *2.4. Fit Polynomial*

In differential astronomy of white dwarf stars, the reference star is usually redder than the target star. The result is some false curvature remaining in the divided lightcurve. To remove a low order polynomial from a lightcurve, the user must select the channel, type **f** and then the order of the polynomial to remove from the lightcurve, i.e type **1 f 2** to remove a 2nd order polynomial from channel 1.

#### *2.5. Write Data*

When ready to save the processed light curve, the user types **1 w e**; the entire first channel is written to a file with the extension **.lc1**. This file will have a header containing all the original header information, plus information about the **Wqed** reduction and the **Bjed** correction. The data will be in two columns, the first is time in seconds and the second is fractional amplitudes with a mean of zero.

### **3. Headers and Bjed Calculation**

The **Wqed** package encourages the use of headers on all light curve files. These headers are simply ASCII text placed at the beginning of the file. Each line contains a key, value and a brief comment. A detailed header is invaluable for archival data, especially when working with lightcurves taken several years ago. The headers are flexible so the user may add any information necessary to describe the observations. Some values are necessary for **Wqed** to fully function, others are important for future astronomers to understand the analysis of these data. A program called **Whiff**, supplied with the **Wqed** package creates a suitable header by extracting relevant information from the first raw fits image of the series. Refer to Figure 2 for an example of a **Wqed** header.

With the inclusion of the object name, date and time of observation in the header, **Wqed** will automatically calculate the barycentric correction based on the method of Stumpff (1980). This implementation has been tested against the JPL DE405 ephemeris and agrees to better than 0.05 seconds. **Wqed** expects the date and initial UTC of your data to have the form **yyyy-mm-dd** and **hh:mm:ss.ss** respectively. The right ascension and declination of the object are determined from the object name. **Wqed** recognizes most pulsating white dwarf stars, and additional stars can easily be added by the user.

### **4. Conclusion**

The **Wqed** package is an easy to use lightcurve manipulator that encourages the use of headers to keep track of the time, place and object of each observation. Those doing the data analysis for XCOV26, the 2008 WET run, (see Thompson et al. this proceedings) found the **Wqed** package very easy to learn, and helpful for data organization. **Wqed** was also recently used for the single-site observations that discovered two new DQVs (Barlow et al., 2008). **Wqed** comes with an extensive set of instructions on how to use and install the **Wqed** package. Several programs not described here are also provided with the package to plot and analyze variable star data.

We encourage anyone analyzing rapidly pulsating stars, such as white dwarf and subdwarf pulsators, to use **Wqed**. The program may be downloaded from the DARC web site at <http://physics.udel.edu/darc/wqed>.

### **Acknowledgments**

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```
#Telescope      =Hawaii          #Telescope Name
#Object         =G38-29         #Object Name
#Date          =2007-11-11     #Mid Exp. yyyy-mm-dd
#UTC           =07:22:35.00    #Mid Exposure UTC
#Filter        =BG40           #Filter Name
#Instrument     =Apogee Alta    #Instrument used
#Exptime       =10.000000000000000 #Exposure Time (s)
#MJD           =54415.307349537 #Mid Exposure MJD
#Observer      =set meo kt     #Observer
#TelCode       =hawa          #Short Tel. Code
#Runname       =hawa071111-07  #Wet Run Name
#IrafMJD       =54415.3073494998 #ccd_hsp zero MJD
#OrigFile      =g3928_hawaii_20071110_7..star-sky #Contains Aperture Size
#WQED          =wqed v1.0.1 2008-05-30 #Version of Wqed
#Channel       =1             #Outputted Channel
#WqedUser      =sthomp        #User who ran wqed.
#RA            =04 20 18.00    #From stars.dat (J2000)
#Dec           =+36 16 16.0    #From stars.dat (J2000)
#Bjed          =2454415.81329600 #with leapsecs(Stumpff80)
#BjedCorr      =0.00003323     #linear Bjed correction
#Leapsecs      =65.1840       #Total number accounted
#TimeUnits     =secs          #Units Time column
#Npoints       =1160          #Number pts in data
```

**Figure 2.** An example header of a Wqed lightcurve. Headers are denoted by a # followed by a key. The value of the key comes after an equal sign. A comment to describe the key or value comes after a second #. The last ten lines of the header were added after running Wqed, including the Bjed correction. A program called Whiff is provided to create these headers from the first fits file of the time series.

## References

- Barlow B N, Dunlap B H, Rosen R & Clemens J C 2008, ArXiv:0810.2140  
Stumpff P 1980, *A&A Suppl.*, **41**, 1