<u>Period analysis of eclipsing binary IR Com</u>

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Abstract

The period was determined for the eclipsing binary IR Com and a corrected ephemeris was made. Using images taken in I and R-bands, a relative flux against time graph was made from which a Gaussian fit was applied in order to minimise and find the period of the system. Using this minimisation and bootstrapping methods, the period was found to be 0.0871 ± 0.0016 days which is in agreement with previously published values.

Introduction

Eclipsing binaries can be classed as a type of cataclysmic variable (CV) which is a system where a white dwarf (WD) accretes matter from a main sequence (MS) companion star nearby via a process called Roche lobe overflow. This causes an accretion disc to form around the WD that can be a source of a hot spot at the point where matter interacts with the disc. In systems such as IR Com, where the two interacting stars are close enough to be seen as a single point of light, one star can totally eclipse the other causing a reduction in light intensity which can be analysed by plotting a light curve. The eclipses can only be seen if the inclination is roughly 70° or greater so that the system is being viewed close to the orbital plane. [1][2]

In an eclipsing binary, there will be a WD and MS star orbiting at a distance α with a gravitational potential in the shape of a figure of eight when viewed side on, as shown below.

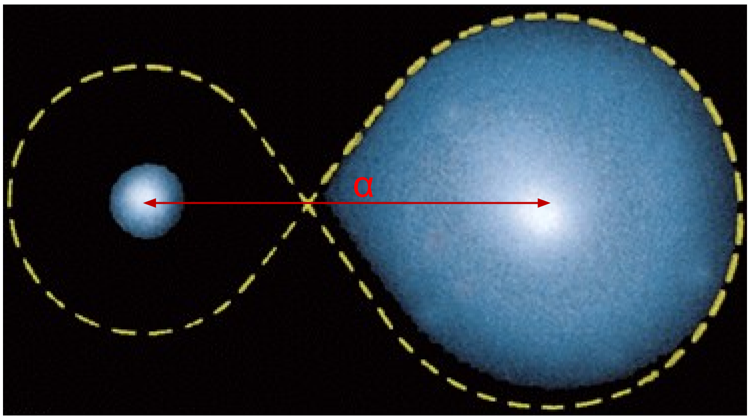

Figure 1: A semi-detached eclipsing binary system of a WD (with radius and mass of R_1 and M_1) and a MS star (R_2, M_2) separated by a distance α [3]

The MS star is distorted by gravity into a teardrop shape and when it fills it's Roche lobe then it becomes unstable, and overflows to the WD forming an accretion disc. The size of the MS Roche lobe depends on the mass ratio of the system as follows:

$$\frac{R_2}{\alpha} \text{ is a function of } q = \frac{M_2}{M_1}$$

Henceforth, if the period and then radius can be found, an estimate of the mass ratio can be made.

Distances are essential parameters in Astronomy. One of the main motivations to study eclipsing binaries is that by measuring characteristics of them, they can be used as a type of standard candle. This makes them an independent method to calibrate the distance scale and consequently estimate the Hubble constant [4]. However due to the low luminosity of some of these sources this may not be possible. Another reason to study them is that by looking at orbital parameters, constraints on the masses, mass transfers, and radii can be made for the constituent stars.

Studies by Feline et al., (2005) have determined through a linear least squares fit that the orbital ephemeris for IR Com is [5]:

$$HJD = 2449486.4818691 + 0.08703862787*E. \qquad (1)$$

$$\pm 26 \qquad\qquad \pm 20$$

The compact eclipsing binary IR Com was selected based on it's short period of 2.089 hours, and low maximum apparent magnitude of 15.9 in comparison with other possible targets (e.g. GY Cnc). A summary of the known parameters of IR Com are given in Table 1 below.

Object	IR Com (CV)
Right Ascension	12 39 32.02
Declination	+21 08 06.2
Period	0.0870386 days
Inclination	80°
Apparent Magnitudes at Max, Mid Eclipse, and Outburst	15.9, 18.4, 13.5
Distance	300 pc
Epoch at time of observation	87638

Table 1: Known parameters of IR Com. RA and Dec from SIMBAD. [6] Period, Inclination, Apparent Magnitudes, Distance, and Epoch adapted from Feline et al., 2005. [5]

Observations

The images were acquired on Mount Teide at the Observatorio del Teide on the nights of the 1st and 2nd of April 2015. Additional data was compiled from the previous year in order to get a more accurate value for the period. The telescope used was the 0.8-metre IAC-80 which has a CCD camera with a field of view of 10x10 arcmin where 1 pixel corresponded to 0.304 arcsec. A 1x1 binning was used and R and I filters were used because they were the broadest filters and only light intensity was required to plot the light curve. SIMBAD [6] was used to locate the binary using it's astronomical coordinates whilst STARALT was used to determine when it would be visible. From the ephemeris equation (1), the exact time of eclipse was calculated and used to plan the observing schedule for each night.

Table 2 below shows a summary of the observations taken with a further explanation underneath.

Date and Time	Images Taken	Filter	Exposure Time/s	Average Airmass and seeing
1/4/2015 at 02:03:00	13	R	60	1.033 and 1.152
1/4/2015 at 02:25:00	151	I	45	1.398 and 1.228
2/4/2015 at 02:56:16	96	I	45-90	1.359 and 1.389

Table 2: Summary of images taken with the IAC-80 showing number of images, filter used, exposure time, average airmass, and seeing.

On the night of April 1st, starting at 2:03:00 AM, 13 R-band images were taken but it was found that light variations were clearer in I-Band so a further 151 images were captured with this filter, with exposure times of 60 and 45 seconds respectively. The average air mass and seeing was 1.398 and 1.228 respectively whilst the dark current stayed at 0.0003 electrons/pixel/sec due to the CCD being cooled at -106°C.

On the night of April 2nd, starting at 2:56:16 AM, 96 I-band images were taken with exposure times varying from 45-90 seconds. Towards the end of the observing slot, cloud cover increased which is why exposure time had to be lengthened. For the first hour, the target was 24° from the moon which caused dark flat-like patches on the images. There were 21 bias frames taken each night and 11 flats for each filter. No dark frames were taken because the CCDs were cooled and so this would not cause a large error. In total over the 2 days of observing, 6 images had to be removed due to tracking failure or cosmic rays/satellites interfering with the image.

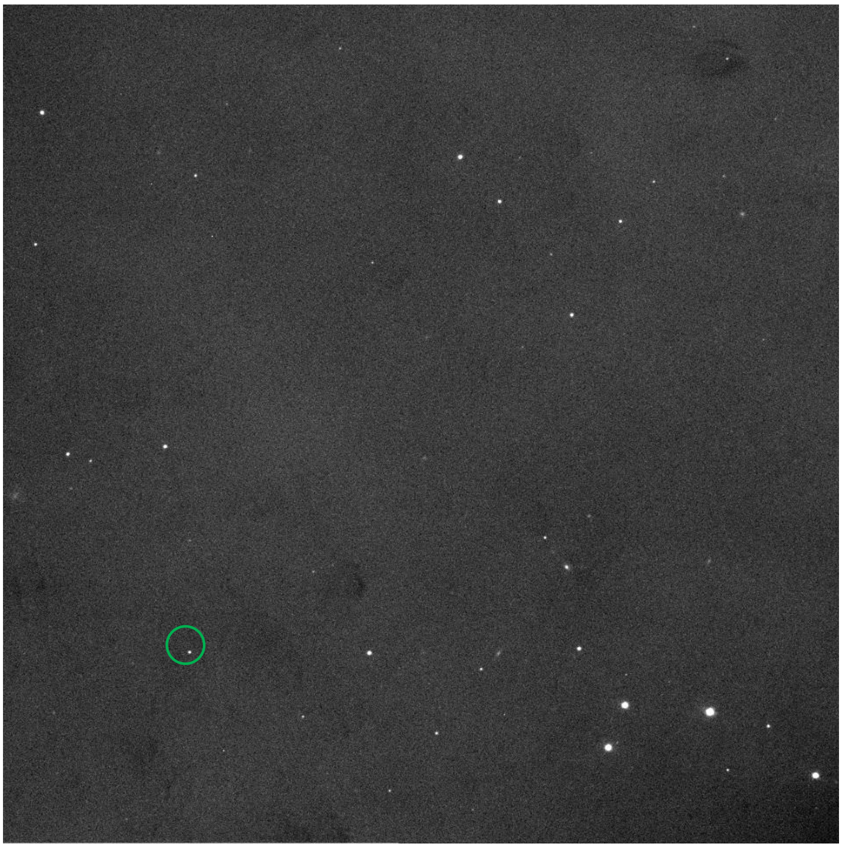

Figure 2: A reduced I-band image of IR Com (circled) with FOV 10x10 arcmin.

Data Analysis and Discussion

The data was first reduced before being aligned and stacked using AstroImageJ in order to clean it up for analysis. Next, aperture photometry was carried out with 7 apertures including the target, with a radius of object aperture of 10, inner radius of background annulus of 20 and outer radius of background annulus of 30. The comparison stars were chosen carefully using SIMBAD to check that they were not varying in flux. This gave an output table for the target star of total counts (relative flux), the errors involved, and the time of observation. Using these parameters a light curve was graphed for the consecutive eclipses on the 2nd of April and the data from the previous year. These are shown below in Figures 3 and 4.

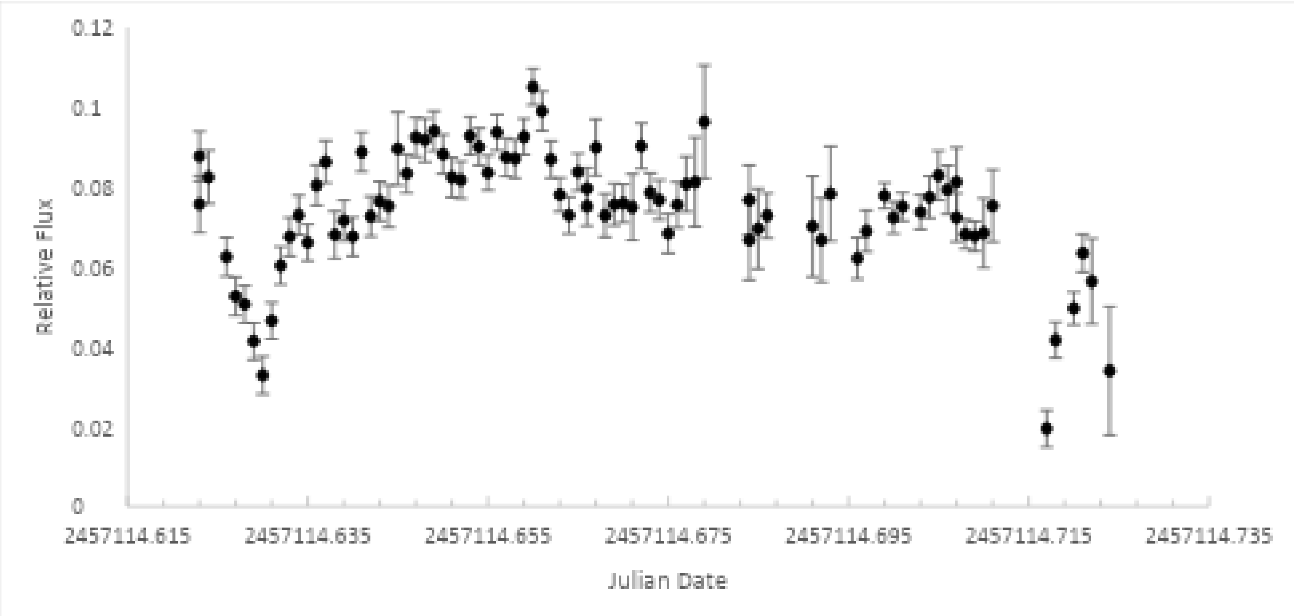

Figure 3: Light curve plotted for observations on the 2nd of April 2015. The first eclipse is prominent however the second is lacking data points prior to the total eclipse.

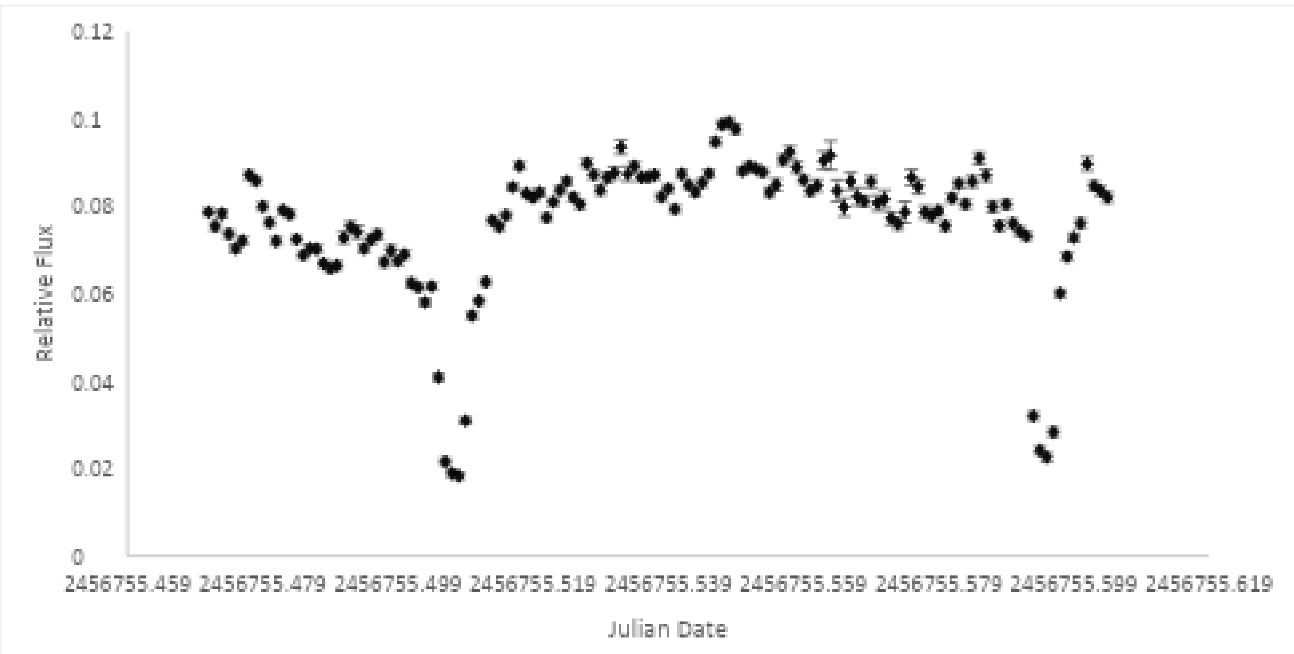

Figure 4: Light curve plotted for observations from the previous year (2014). Both eclipses are prominent.

As illustrated in Figures 3 and 4, the absolute errors on the relative fluxes for the 2014 are lower than for the 2015 eclipse. The average error from 2014 being ±0.001115 compared to ±0.005978 in 2015, which may be due to the seeing on the particular dates.

These curves were then analysed using Python. The eclipses were individually isolated and a Gaussian curve was fitted to the data. A polynomial was also applied but it was found that the reduced chi squared for the Gaussian curve showed that the data fitted this better. The reduced chi squared values for each of the 4 fitted Gaussians shown in figures 5 and 6 are as follows: 1st eclipse of 2014 = 22.807, 2nd eclipse of 2014= 30.340, 1st eclipse of 2015 = 1.371, 2nd eclipse of 2015= 1.767. They are much lower for the second set of data from 2015, and the suggested reasoning for this is that the errors on this data were much larger, and may even be underestimated on the previous year. Although the first 3 eclipses showed good fits to the Gaussian, the final eclipse has a lack of data points before the eclipse and so values from this minimisation may have larger errors than calculated through bootstrapping.

The fits were minimised in order to find the approximate value for the Julian Date at full eclipse so that when compared to the Julian Date of the other eclipses, a value for the period could be calculated. This was done on Python using the function 'scipy.optimize.minimize' and the Powell method for minimising. The Nelder-Mead was applied first but it was found that Powell gave better chi squared values. The Powell method is a way of finding a minimum by changing one parameter at a time and without calculating derivatives [7].

Figures 5 and 6 show the process of fitting a Gaussian model to the data in order to find the period.

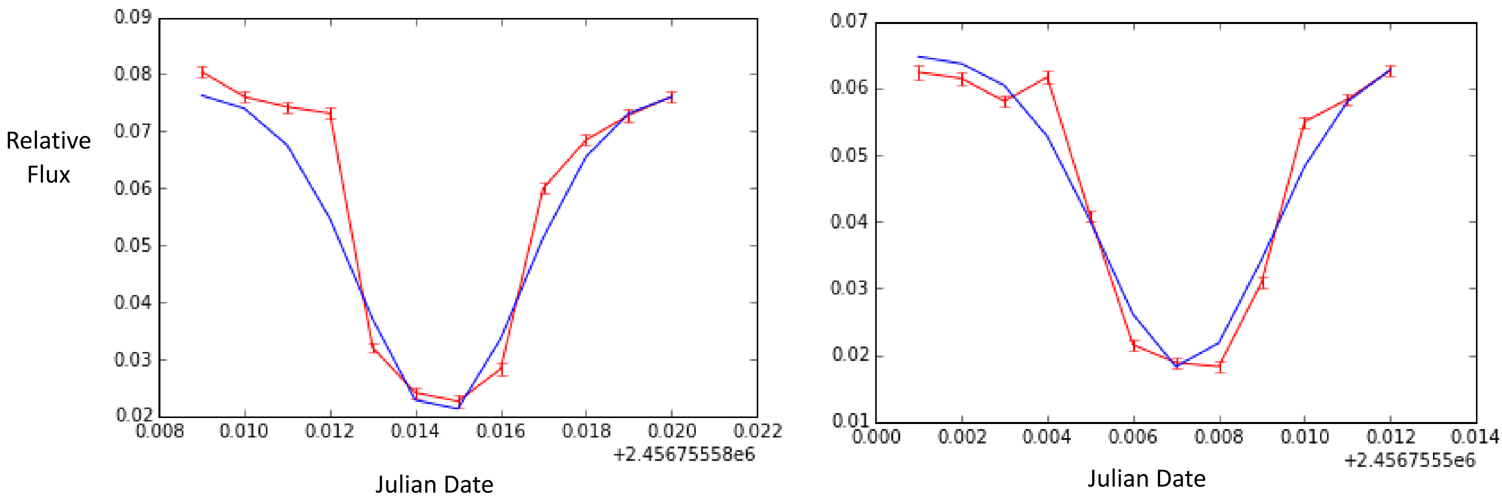

Figure 5: The first (left) and second (right) eclipses from the 2014 data with the fitted Gaussian model (blue) overlaid on the actual data points (red).

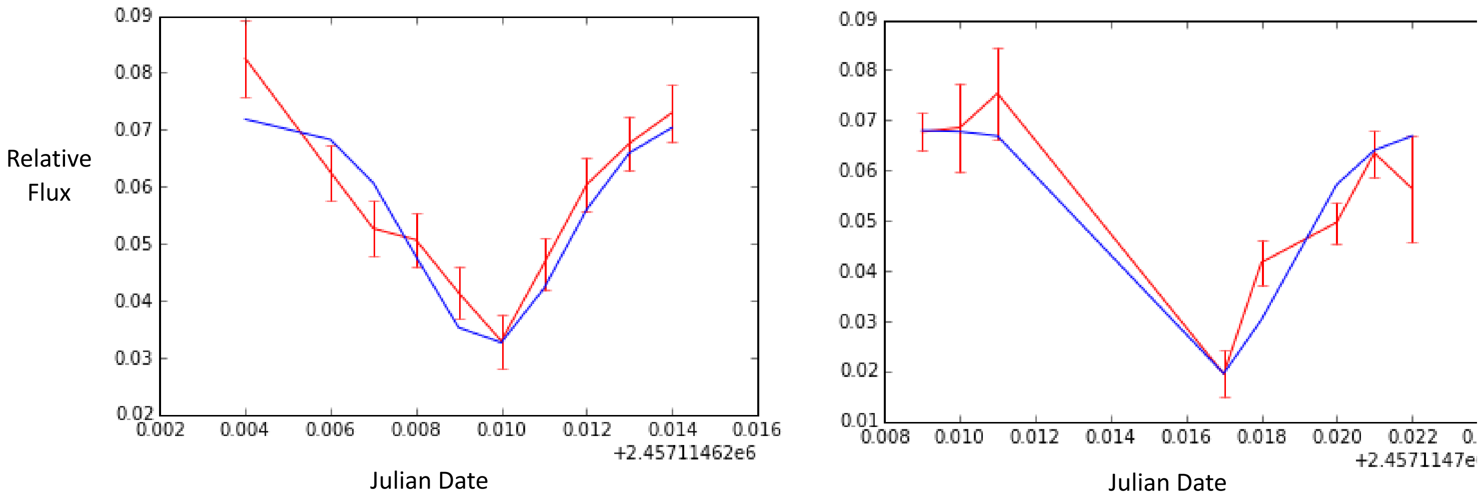

Figure 6: The first (left) and second (right) eclipses from the 2015 data with the fitted Gaussian model (blue) overlaid on the actual data points (red).

A bootstrapping of all of the eclipses was then carried out in order to find the error in the eclipse HJD. This used a Powell minimising technique and returned the following results:

2014: 1st Minimum at: 2456755.5072 ± 0.0002429 (HJD)

2nd Minimum at: 2456755.5947 ± 0.0003281 (HJD)

2015: 1st Minimum at: 2457114.6295 ± 0.0001922 (HJD)

2nd Minimum at: 24571114.7167 ± 0.0008027 (HJD)

Figure 7 shows bootstrapping of all the eclipses in the data set.

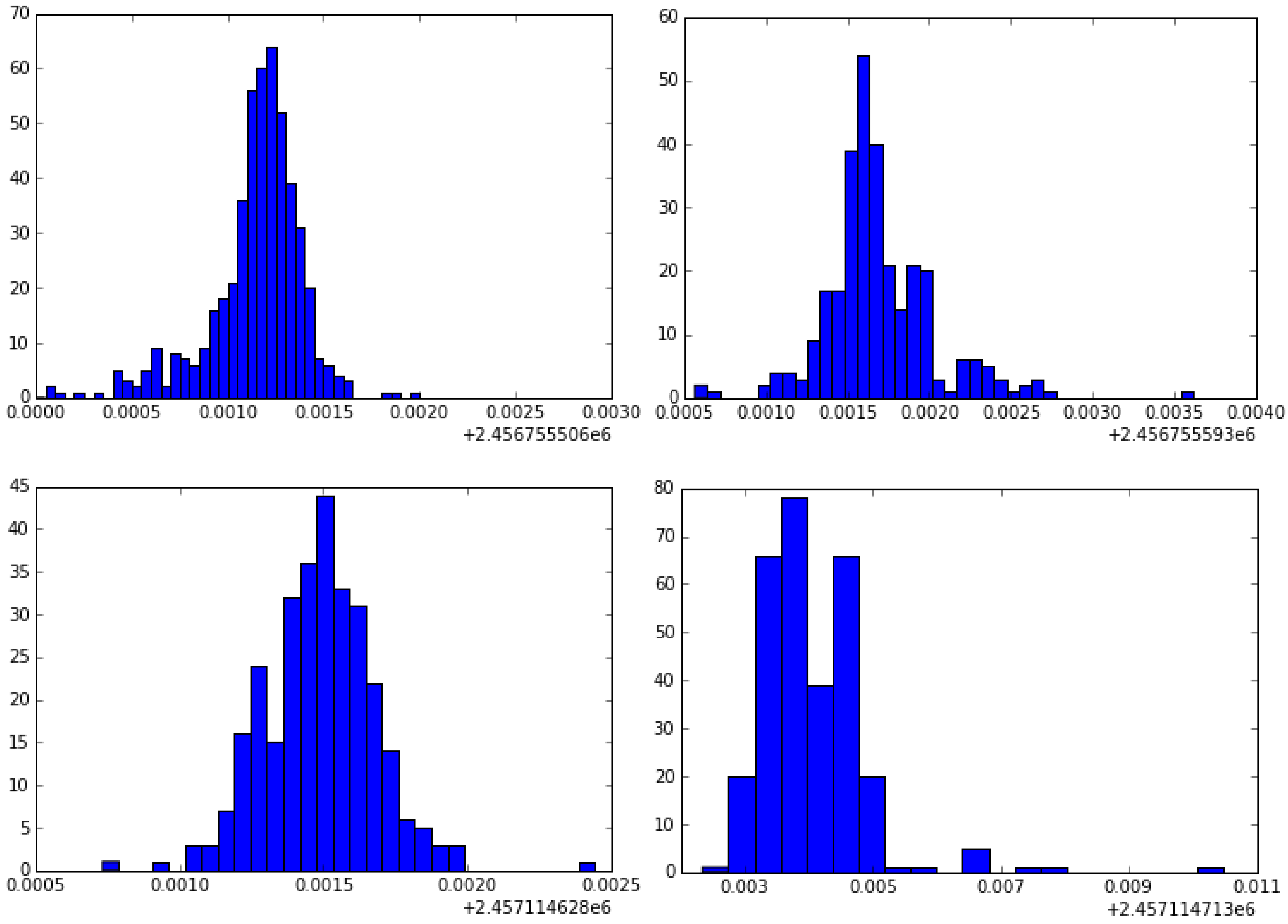

Figure 7: Graphs showing the bootstrapping of data from the 1st and 2nd eclipses of 2014 and 2nd and 1st eclipses of 2nd April 2015 as seen clockwise from the top left corner. Binning of 40, 40, 30 and 20 were used respectively.

Using these values and the ephemeris equation (1), an estimation for the period was made, including propagated errors. The value of the calculated period was 0.0871 ± 0.0016 days. This is within range of the period given in Feline et al. (2005), and the large uncertainty may be from the fact that the Gaussian fits did not fit the data very well due to a lack of data points taken. The adjusted ephemeris equation is as follows:

$$HJD = 2449486.4818691 + 0.0871 * E. \qquad (2)$$

$$\pm 26 \qquad \pm 16$$

Using this calculated period, the data for all eclipses was phase folded to produce the plot in Figure 8 which clearly shows the variation of the light curve for IR Com. The eclipses shown in Figures 5 and 6 are representational of the eclipse of the disc not just the white dwarf. Only if the data was good enough to show variations in flux due to the white dwarf itself would I be able to put a constraint on the relative masses and radii of the system.

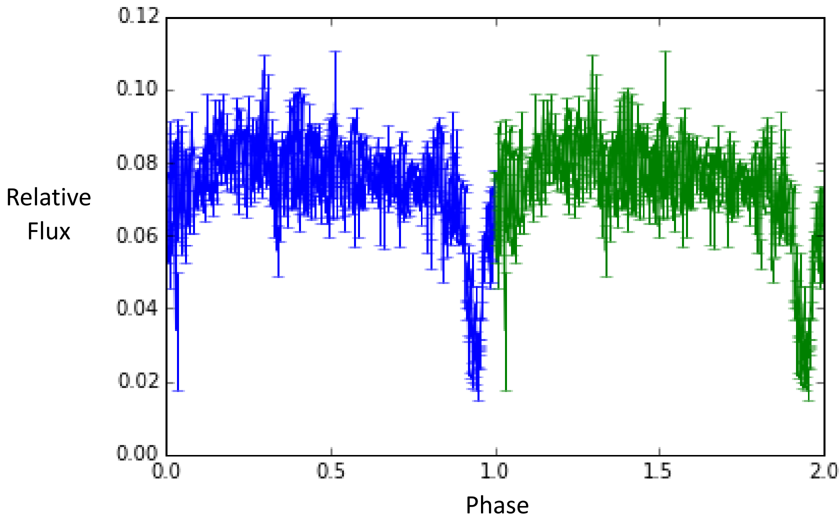

Figure 8: Phase folded plot of all data using the calculated period of 0.087144 days. Two periods are shown.

Conclusion

Using data from the previous year, and from observations on the 2nd of April 2015, a light curve was plotted for IR Com spanning 2 eclipses in each case. From this, a Gaussian model was applied to minimise the curve and find a period of 0.0871 ± 0.0016 days. It was found that the reduced chi squared value was very high suggesting that the errors were underestimated. The data from all eclipses was phase folded with the calculated period and plotted to show relative flux against phase. To further this project, if a more detailed eclipse showing the white dwarf and disc eclipse separately could be seen, the FWHM of the eclipses could have been found and by using the inclination of the system and geometry arguments, the radii and masses of the stars in the system could have been calculated by relating q and I (given in the Introduction).

References

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[5] Feline W. J. et al., 2005, ULTRACAM photometry of the eclipsing cataclysmic variables GY Cnc, IR Com, and HT Cas, MNRAS, 364, 1158.

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[7] Powell M. J. D., 1964, An efficient method for finding the minimum of a function of several variables without calculating derivatives, *The Computer Journal*, 7, 155-162.