Z Chamaeleontis

Z Chamaeleontis (Z Cha) is a cataclysmic variable star and was discovered to be an eclipsing binary in 1969 [Mumford].

Z Cha consists of a primary white dwarf star and a secondary red dwarf star that has filled its roche lobe. A stream of gas is transferred from the secondary via the inner langranian point forming a hot accretion disk around the primary star. The stream of gas forms a bright spot where it meets the accretion disk around the primary. Periodically cataclysmic stars go into outbursts increasing brightness by several magnitudes. Z Cha is no exception which goes into outburst on average every 80 days [Vogt]. Outburst typically last for 3 days but occasionally prolonged outbursts occur which have the presence of superhumps. There have been 2 of these in the last 12 months as shown on the American Association of Variable Star Observer (AAVSO) website. These superhumps are characteristic of the SU UMa type cataclysmic variables which Z Cha is a member. Z Cha is also special in that it is one of the few cataclysmic that is an eclipsing binary star. Z Cha was a much studied star as it helped determine the nature of cataclysmic variable stars due to its eclipsing nature. This was determined by Warner in 1974 [Warner]. Z cha shows the eclipses of the primary, secondary, bright spot, and accretion disk.

Z cha was monitored over several nights between March 9th 2010 and May 22nd 2010. The majority of the observations were unfiltered with an exposure time of 20 seconds to maximise the resolution for determining its orbital period. 3 nights were observed with a V filter when Z cha was in outburst. BVR filters were also used on many nights with a 60 second exposure.

Z Cha was located using a chart from the AAVSO website. It lists its position as RA: 8:07:28.22, Dec -76:32:01.39. This also lists several comparison stars. The star referenced as ‘134’ was used as the reference star being of a similar colour to Z Cha. A chart of Z Cha, reference and check stars appear below. The other comparison stars on the AAVSO chart were not suitable being a different colour. Three other stars were chosen of similar colour and brightness to Z Cha in the field to use as check stars.

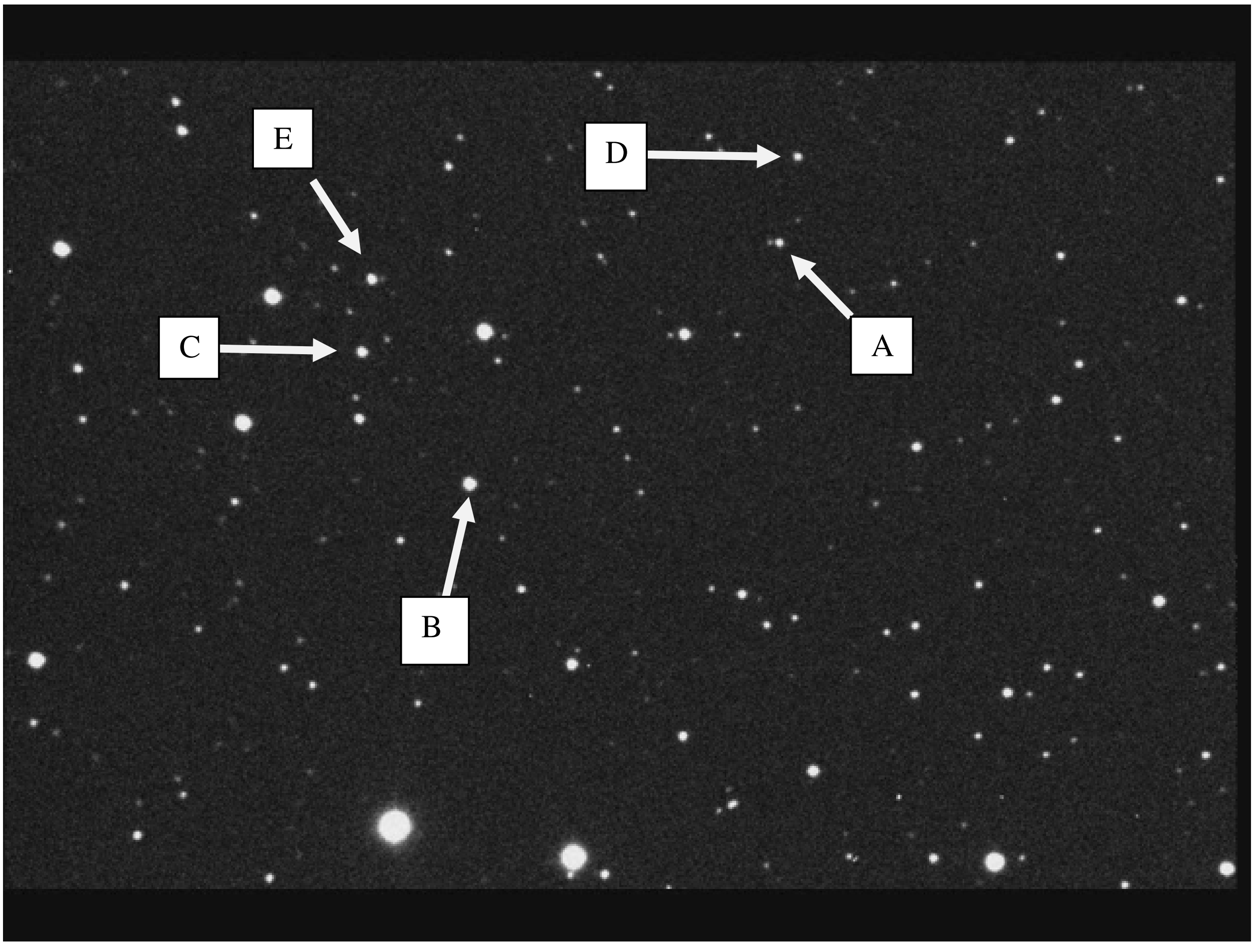

Figure 1: Location of Z Cha and comparison stars

			Magnitude	B mag	V mag	BV
A	Target	Z Cha	11.5-16.2(V)*	16.10**	15.47**	0.63
B	Reference	134*		14.210*	13.390*	0.82
C	Check			15.22**	14.46**	0.76
D	Check			16.59**	15.44**	1.15
E	Check			15.22**	14.59**	0.63

- * Sourced from AAVSO website, reference table 2394fzi.
- ** determined from observation

36 eclipses were observed. The data was calibrated by subtracting dark frames from all light images. Flats were collected each observing night. Each nights flats were median combined and the master was used to calibrate the corresponding nights light images.

Figure 2 shows a light curve of Z Cha obtained on March 13 2010. Z Cha is in blue. The green curve is a comparison star that is not variable and has a similar colour to Z Cha. The variability in brightness of the comparison star indicates the degree of error which is about 0.2 magnitudes. This is high due to the air mass and the short exposure time but as mentioned the short exposure time is needed to get the time resolution to determine the period.

On the surface, the light curve shows a repeating pattern of broad humps followed by a sharp deep minimum. The period between minima is about 107 minutes but varies slightly.

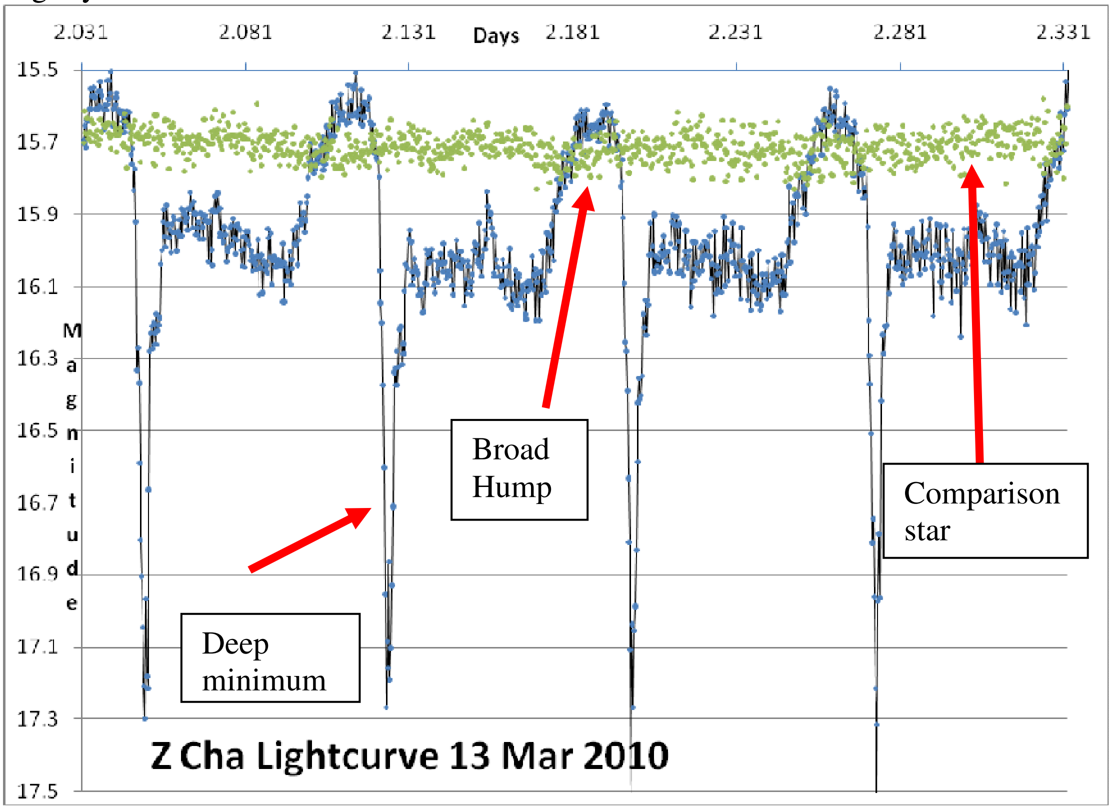

Figure 2: Z Cha light curve, observed on 13th of March 2010, unfiltered but calibrated to V magnitude of comparison star 134.

Figure 3 shows the light curve expanded and shows that there is a lot more structure in the deep minimum. The light curve is quite complex and the system is something more than a simple binary star. The deep minimum is made up of 2 sharp declines in brightness with a short pause between. There is a pause at minimum followed by a rapid increase in brightness similar to the first drop in brightness. The second increase is slower and quite variable with every repeating light curve.

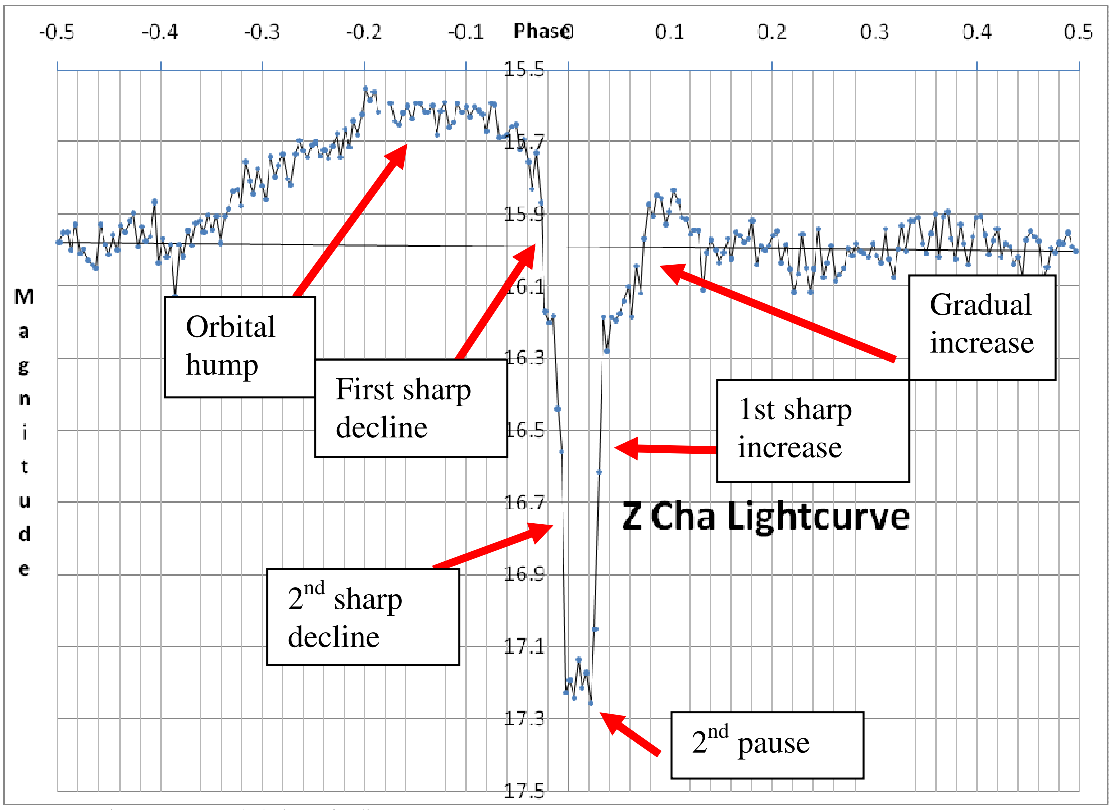

Figure 3: Expanded view of eclipse.

Many parts of the light curve are not totally repeatable with the exception of the 0.5 magnitude increase in brightness after the broad hump and the first rapid increase in brightness after the minimum. The time at midpoint between these two points was set at and named phase 0. All light curves were folded and is depicted below in figures 4 & 5.

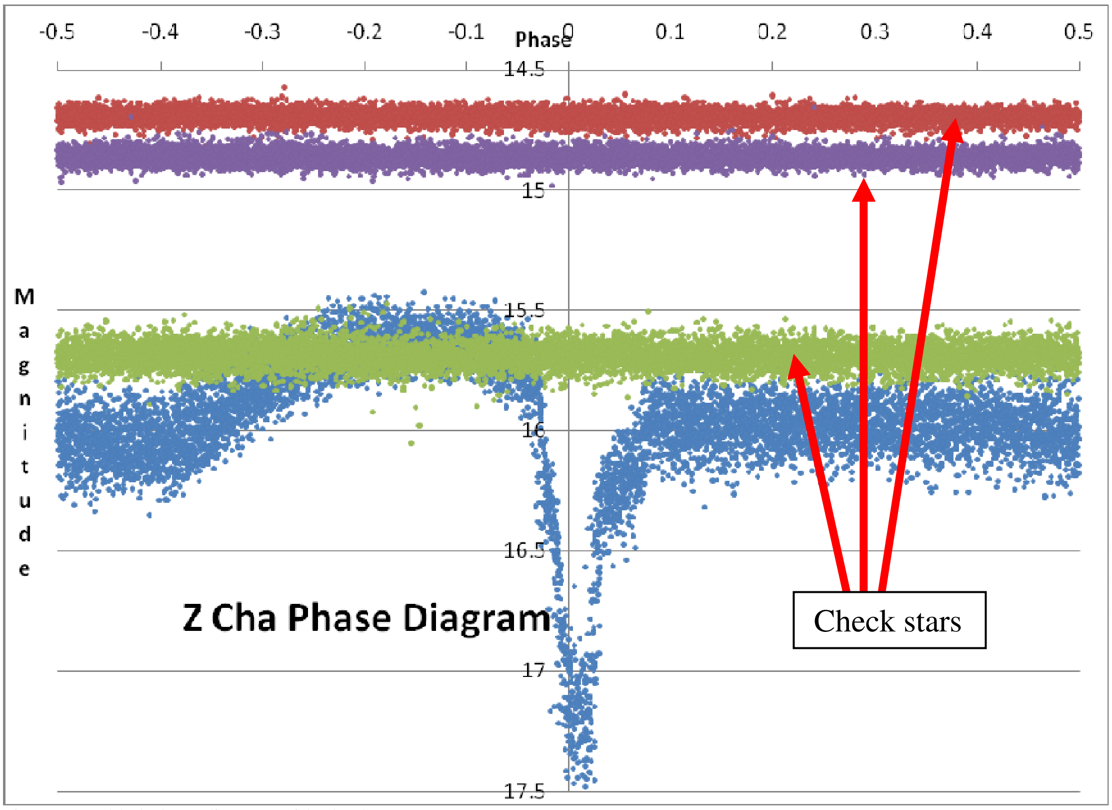

Figure 4: Folded phase diagram with check stars

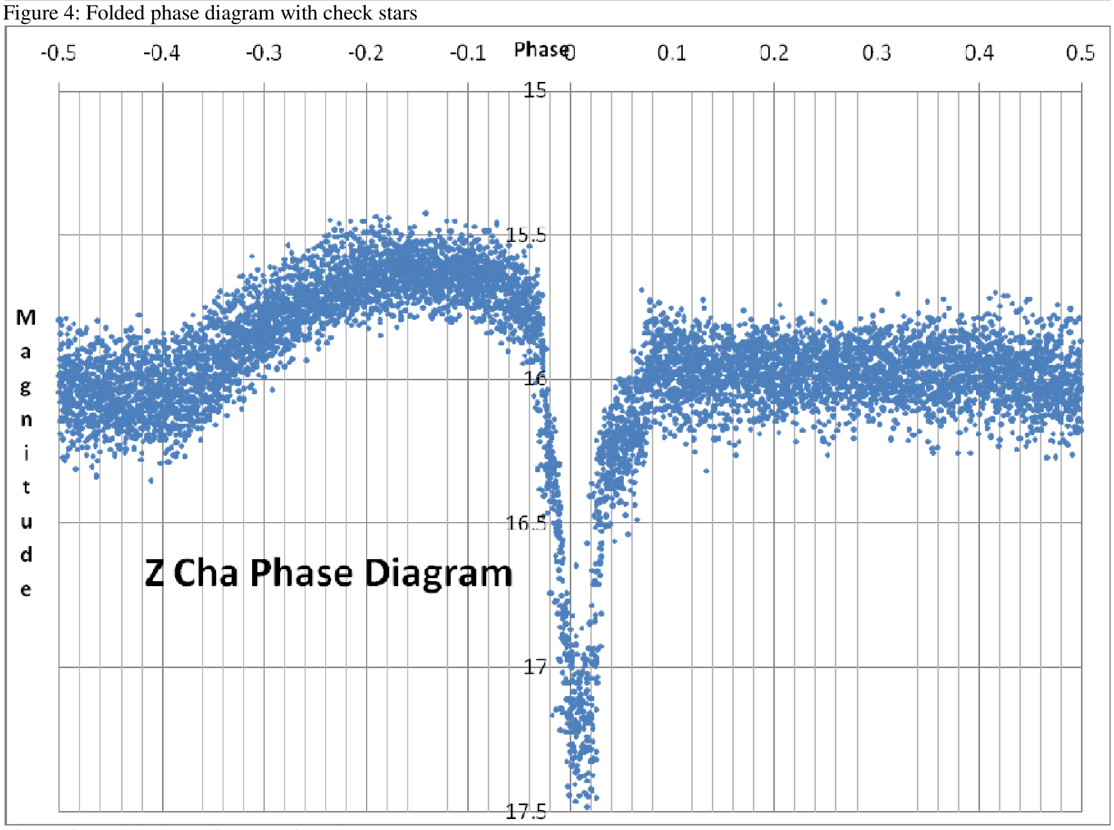

Figure 5: Folded phase diagram of Z Cha

The curve is quite noisy with a variation of +- 0.15 magnitudes but it does show clearly the changing nature of the light curve. Longer exposures could have been taken to increase the signal to noise however resolution would have been lost.

50% of the light curve centres on magnitude 16 from phase 0.1 through to 0.5.

There is a slight dip in brightness at phase 0.57 (-0.43 on the graph) of only 0.1 magnitude. This may or may not be real it is not mentioned in any literature on Z Cha. It may be due to a limb darkening affect or what I think could be a partial eclipse of the bright spot by the white dwarf primary.

The light curve shows the hump increasing from phase from phase 0.64 and peaking at -0.15. before starting to dip. This is the brightest part of the light curve with the average maximum at magnitude 15.6. All objects in this system are in maximum view and not eclipsed. This hump appears that it should gradually dim back to the flat part of the curve to magnitude 16 at phase 0.1 but is interrupted by a sharp fall in brightness which is the start of one of the components being eclipsed at phase 0.964. The hump lasts for 40% of the period but would be 50% if it was not for the sharp drop.

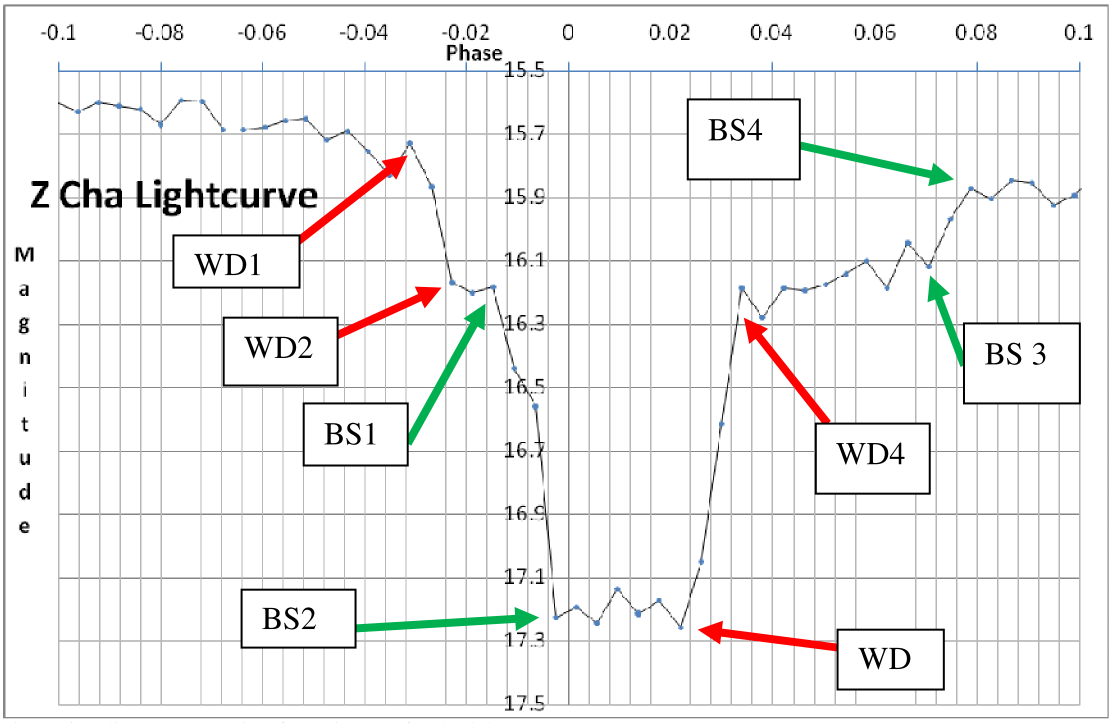

Figure 6: Eclipse contact points for white dwarf and bright spot.

Figure 6 shows an expanded view of the deep minimum and its structure.

The sharp decrease in brightness starts at phase -0.03 and goes to phase – 0.023. The phases for every light curve were tabled with the median values being phase 0.9682 and 0.9774 respectively. The phase range is 0.008234 which equates to 53.0 seconds. The standard deviation being 0.58 seconds. The standard deviation for the first point is 0.00029 and 0.00037 for the second point showing good precision. This is a very short timeframe and very repeatable. This indicates a very compact object. This object is relatively bright as it causes a large drop in brightness. The brightness was measured with B and V filters giving a B-V of 0.732, however the light is still a combination of different objects in the system. This object is likely to be a white dwarf. This part of the light curve is the ingress of the white dwarf star being eclipsed by the secondary star.

White Dwarf primary contact	Median 32 Eclipses (phase)	Standard deviation of 32 eclipses	Median Magnitude	Standard Deviation Magnitude	Warner data 1980*
WD1	0.9682	0.29×10^{-3}	15.78	0.0752	0.9691
WD2	0.9774	0.37×10^{-3}	16.28	0.098	0.9769
Mid eclipse	0.0000	-			
WD3	0.0233	2.45×10^{-3}	17.07	0.193	0.0237
WD4	0.0319	2.42×10^{-3}	16.27	0.113	0.0303
Bright Spot contact					
BS1	0.9842	0.29×10^{-3}	16.28	0.0752	0.9814
BS2	0.9983	4.33×10^{-3}	17.16	0.150	0.0130
Mid eclipse	0.0648				
BS3	0.0688	5.06×10^{-3}			0.0762
BS4	0.0806	4.32×10^{-3}			0.0946

Table 2: Phase and magnitude of contacts in white dwarf and bright spot eclipses.

- 1980 data [Cook & Warner]

The white dwarf ingress is labelled WD1 and WD2 and is the first contact and second contact of the eclipse.

The time difference of 53.0 seconds relates to the diameter of the white dwarf.

WD2 is now used to determine the period of the binary star. Subtracting WD1 on period 981 from WD1 on period 1 gives a period of 0.0744986 days or 107 minutes, 16.7 seconds. This compares closely to the published value of 0.07449315 days differing by 0.06 seconds. This is a very fast eclipse meaning that the stars are very close to each other.

There is a pause in the light curve after WD2. This length of this pause varies with each light curve and sometimes missing altogether with wd2 lost as well.

The median figure for where the pause ends is 0.9842. The pause lasts for 52 seconds before another sharp decrease in brightness. This point is labelled BS1. This is contact 1 of the next eclipse from a 3rd object which we now know as the 'Bright Spot'. The light curve reaches a minimum at magnitude 17.16 at phase 0.9983. This phase does vary with the standard deviation being ten times more than that of WD1 and WD2. The hot spot ingress averages 79 seconds but with a standard deviation of 26 seconds. The bright spot appears that it can be within a range of locations from eclipse to eclipse.

The white dwarf and bright spot are now both eclipsed by the secondary star. This magnitude is close to the detection limit of CCD with this exposure time. The secondary star appears to contribute little light to the Z Cha system but is big enough to eclipse both the white dwarf and bright spot. The absence of a secondary minima supports that the secondary star is very dim. The eclipse has a flat bottom showing that the eclipse is total and lasts till phase 0.0233. This is point WD3 where the white dwarf emerges from behind the secondary. The pause lasts for 157 seconds with a standard deviation of 30 seconds.

The brightness increases rapidly to WD4 when the white dwarf has fully emerged behind the secondary at phase 0.0319.

The diameter of the secondary is measured by the phase change between WD3 and WD1 or WD4-WD2. 340.0 and 340.6 seconds respectfully. This is 6.54 times longer than that of the white dwarf star meaning that the secondary star is about 6.54 times wider than the white dwarf star. This star is likely to be a low mass red dwarf due to its relative size and relative brightness. The distance these stars are apart is proportional to the period of the system which is known but also depends on the masses of each star. An upper limit can be placed on the white dwarf as they cannot be more than 1.4 solar masses.

The white dwarf egress has been measured at 52.0 seconds, one second less than that of the white dwarf ingress. This would be within error considering the exposure time is 20 seconds not including readout time of the CCD.

The sharp increase in brightness after the main eclipse is very repeatable and is the egress of the white dwarf from behind the secondary star. The egress takes 53.1 seconds, almost identical time to the ingress confirming that it's the same object. The 52 – 53 second timing gives an indication of the diameter of the primary.

The time of the whole eclipse of the primary by the secondary (primary contact 1 to primary contact 4) is 406.8 seconds.

After WD4 the bright spot starts to emerge. The timing of this varies more so than on ingress. Sometimes it's very defined with a drop of 0.3 magnitudes, but just as often its not seen at all and there is a just a gradual increase in brightness. The median value determined for BS3 and BS4 is at 0.0688 and 0.0806 phase.

The whole white dwarf eclipse lasts for 6.37% of the period. The bright spot eclipses is longer at 9.64% of the period. The difference maybe because the bright spot is hidden sometimes by the accretion disk at it emerges from behind the secondary. Perhaps the bright spot also changes position during a period.

There is a slight dip in brightness at phase 0.57 (-0.43 on the graph) of only 0.1 magnitude. This may or may not be real it is not mentioned in any literature on Z Cha. It may be due to a limb darkening affect or what I think could be a partial eclipse of the bright spot by the white dwarf primary as the white dwarf is in front of the secondary and the bright spot will be between the white dwarf and the secondary. As the bright spot is bigger than the white dwarf as seen from BS2-BS1, the eclipse is only partial.

The light curve shows the hump increasing from phase from phase 0.64 and peaking at -0.15. before starting to dip. This is the brightest part of the light curve with the average maximum at magnitude 15.6. Here the bright spot is fully in view not been obstructed by the accretion disk. All objects in this system are in maximum view and not eclipsed. This hump appears that it should gradually dim back to the flat part of the curve to magnitude 16 at phase 0.1 but is interrupted by a sharp fall in brightness which is the start of one of the components being eclipsed at phase 0.964. The hump lasts for 40% of the period but would be 50% if it was not for the sharp drop.

On April 20 there was a large increase in brightness of Z Cha as well as the shape of the light curve. Z Cha was observed in quiescence 2 nights before. The brightness has increased from magnitude 15.5 to magnitude 13.2 or 8.32 times brighter. The eclipse has changed showing only a single eclipse.

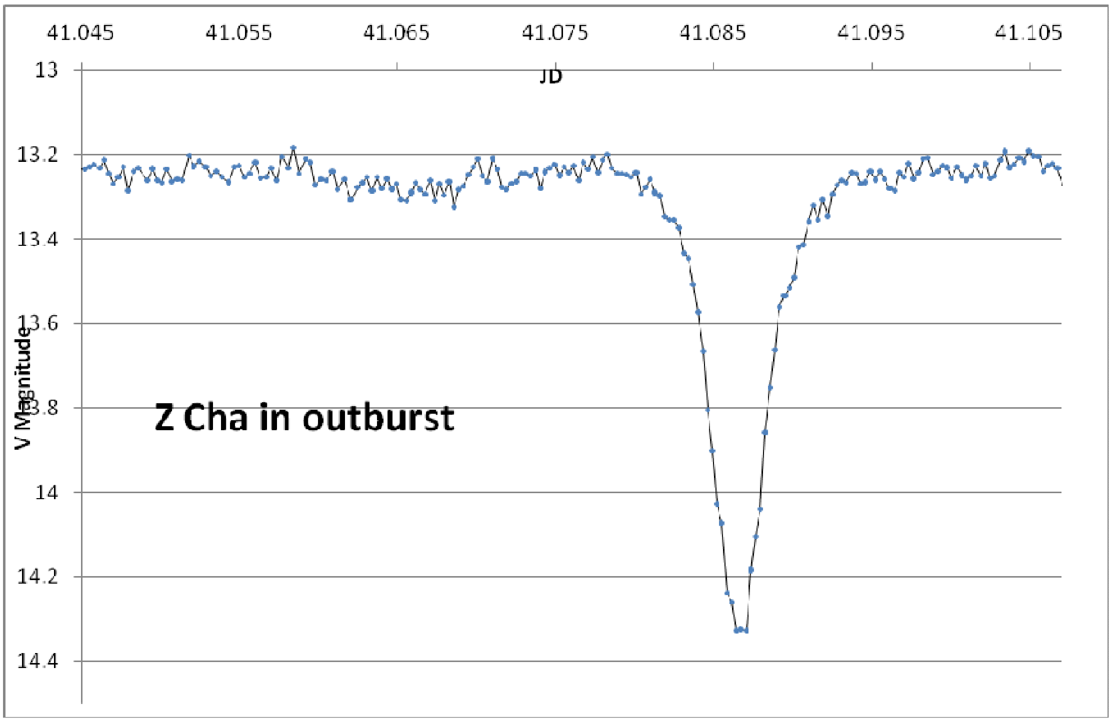

Figure 7 Z Cha in outburst 20 April 2010

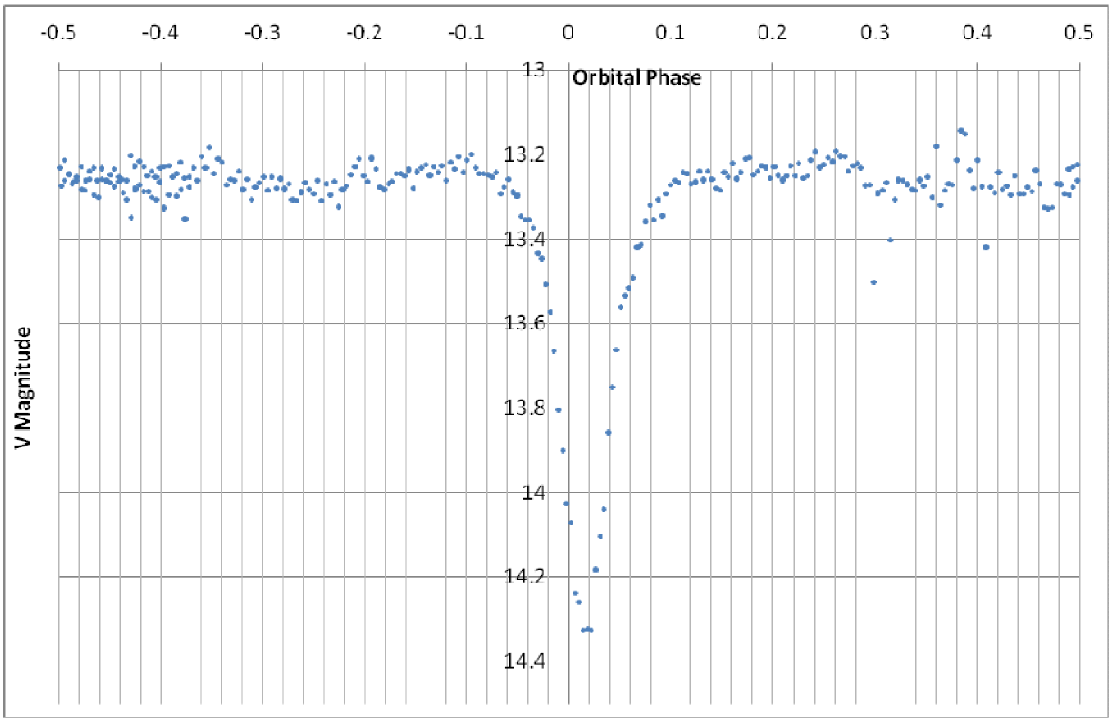

Figure 8: Phase diagram of Z Cha outburst.

It is theorised that the accretion disk around the white dwarf becomes unstable and rapidly increases in brightness. This outshines the white dwarf and bright spot, enough so that they are not visible in the light curve. The accretion disk is being eclipsed by the red dwarf secondary star. This is known as an outburst. It may have occurred at any time in the last 2 days. It is likely it went into outburst on April 19th as the outbursts usually reach magnitude 12.5. But with the cloud cover any no entries by any other observer in the AAVSO database, it was not noticed.

If the outburst originates from the accretion disk one would expect the eclipse minimum to be centred on phase 0 (mid eclipse of the white dwarf). This is not the case here with the minimum appearing at phase 0.014. This maybe because I determined the mid eclipse of the white dwarf incorrectly, or the accretion disk is not symmetrical or brighter on one side. This could be the case if the bright spot is contributing light to one side of the disk.

Figure 9 shows day 2 of the outburst with the light intensity decreased to magnitude 14. Two eclipses were observed. The decline of brightness can easily be seen here in just a matter of hours. The accretion disk is gradually settling down to its normal state. The eclipses are not quite as symmetrical as in day one and they are 0.6 magnitudes deeper. The minima depth being larger may mean that the brightest regions of the accretion disk is getting smaller and can be eclipsed behind the secondary more easily. Figure 9 shows evidence of the white dwarf showing that the increase in light during outburst is not symmetrical about the white dwarf. There is no orbital hump visible so it's not the bright spot either but must be due to an unsymmetrical (in brightness) accretion disk. This was noted in Jeremy baileys observations in 1978 [Bailey].

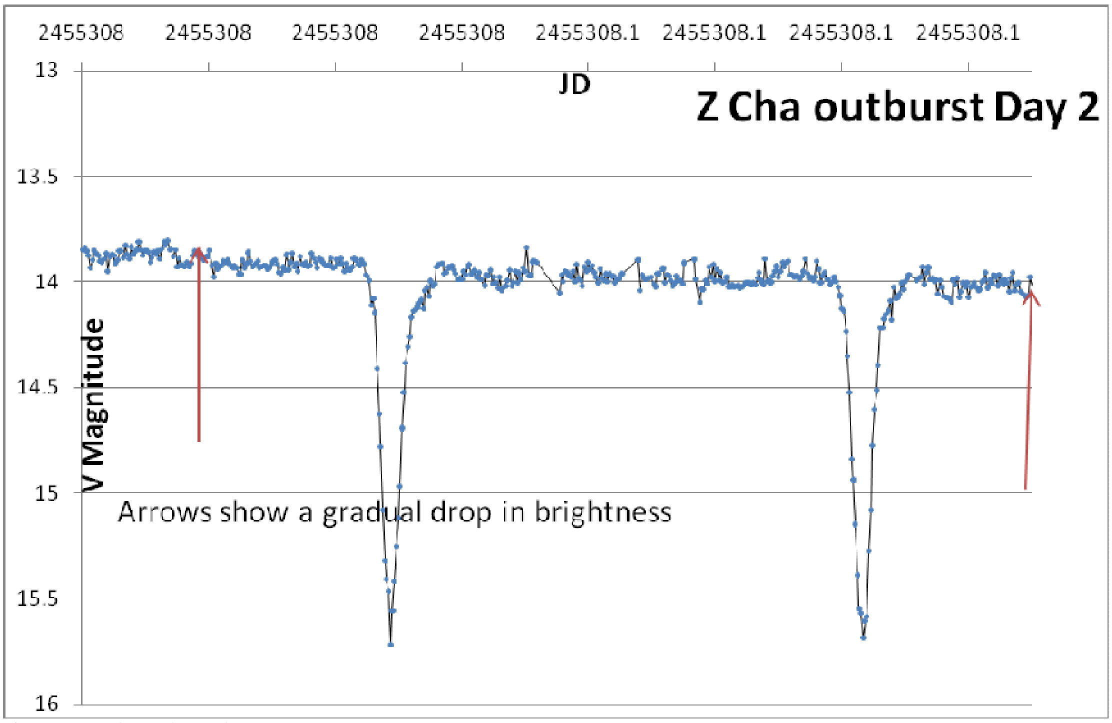

Figure 9: Z Cha outburst day 2.

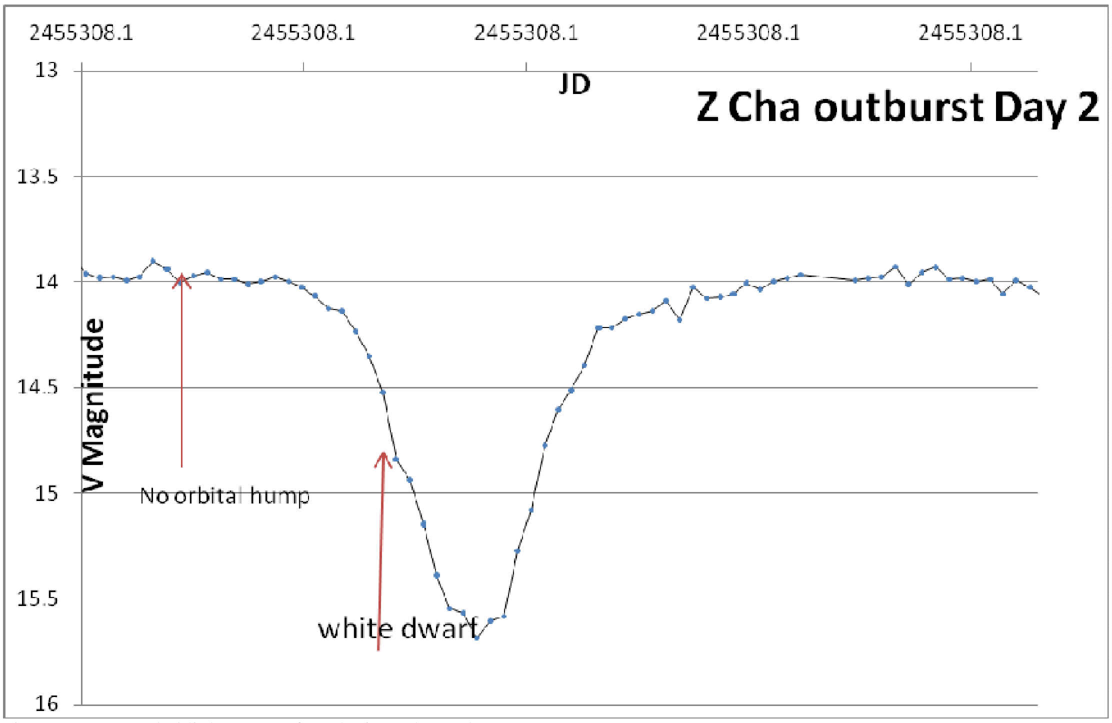

Figure 10: Expanded light curve of Z Cha in outburst day 2

Day 3 of the outburst was not observed due to cloud cover. Figure 10 shows days 4 and 6 with Z Cha back to normal.

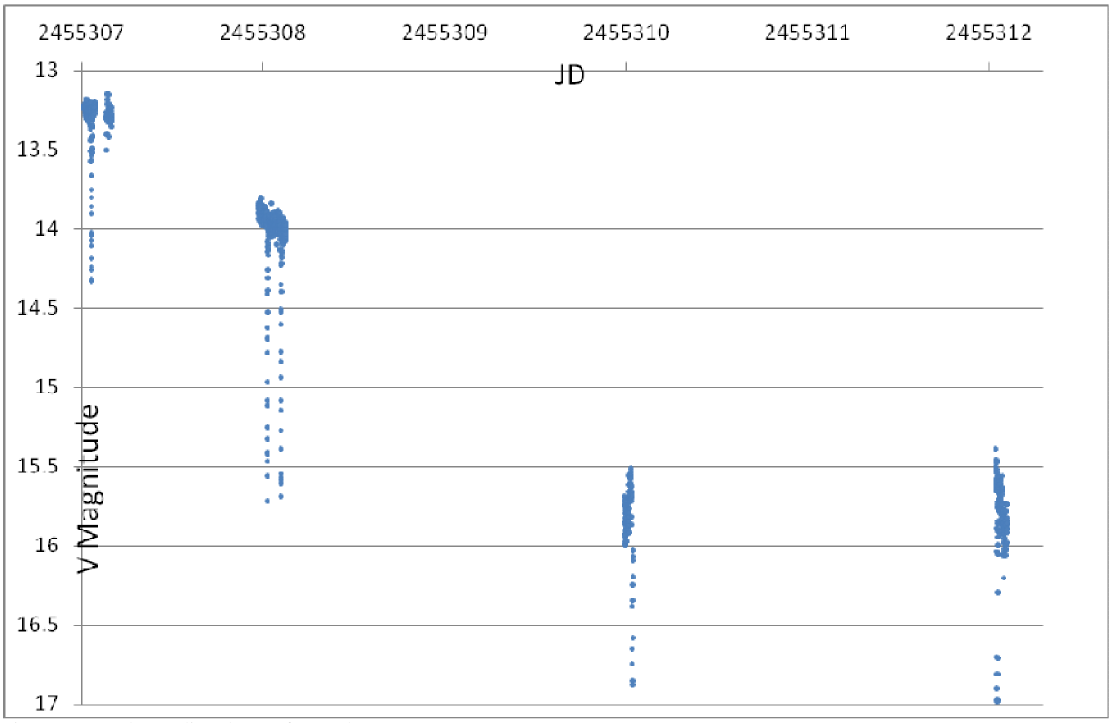

Figure 11: Z Cha settling down after outburst.

Analysis of errors
Below is a table of each of the check stars and their statistics for 8,937 observations. The error bars were determined from +- 3 standard deviations from the mean value. The error for Z cha at maximum light is +- 0.08 magnitudes but at minimum is +-0.12 magnitudes.

Star	Standard Deviation	Mean	Min	Max	Range	SNR 20 sec exp	Mean-3 std dev	Mean + 3std dev	Error Range
C	0.02559	14.69	14.57	14.82	0.25	82	14.61	14.77	0.16
D	0.04802	15.69	15.47	16.05	0.58	45	15.58	15.83	0.24
E	0.02799	14.86	14.65	14.98	0.33	86	14.78	14.94	0.16
B	-	-	-	-	-	321	-	-	-

Mass limits can be placed on the stars. The white dwarf may range from 0.5 to 1.4 solar masses. It is unlikely to be at the higher range as white dwarf at 1.4 solar masses accreting more material would become a supernova and it obviously has not done that. It has been deduced that the red dwarf is of low mass so may fall between 0.1 and 0.2 solar masses.

Keplers 3rd law states the square of the period is proportional to the cube of its semi major axis.

$$P^2 \alpha a^3$$

This is a straight forward equation when calculating orbits of the minor planets about the Sun. To calculate the semi major axis of the orbit of a binary star we need to know the mass of the binary. Unfortunately we only know the period of the orbit from the light curve.

The mass can be calculated using the gravitational force equation

$$F = mv^2/r = G(M_1+M_2)/r^2$$

Spectroscopic observations are needed to determine the radial velocity of the stars in order to determine the combined mass of the binary.

Combining with Keplers law

$$P^2/a^3 = 4\pi^2/[G(M1+M2)]$$

The period of Z Cha has been determined as 0.0744986 days. The combined mass may range somewhere between 1.4 and 0.6 solar masses. This would give a semi major axis range between 0.43 and 0.58 million km. Both stars orbit inside the diameter of the Sun!

Wood determined the masses in 1986, the primary is 0.84 +_ 0.009 solar masses. The secondary 0.125 +- 0.014 solar masses [Wood].

The eccentricity of the orbit cannot be calculated as there is no secondary eclipse minimum in the light curve.

Inclination cannot be determined either but as the stars are eclipsing it is near 90 degrees. The inclination is 81.7 degrees [Robinson].

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