# CCD photometry of the first observed superoutburst of KP Cas in 2008 October

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## Abstract

We report CCD photometry and analysis of the first observed superoutburst of the SU UMa-type dwarf nova KP Cas during 2008 October. We observed two distinct superhump periods with a rapid transition and little or no phase change between them: 0.085544 +/- 0.000075 days which lasted one day and 0.085219 +/- 0.000007 days which lasted four days. Following this we saw an indication of a transition accompanied by a phase change to late superhumps with a shorter period. We measured the orbital period to be 0.0814 +/- 0.0004 days (1.95 hours) placing KP Cas just below the period gap. The superhump period excess $\varepsilon$ is 0.048 +/- 0.005 and, empirically, the mass ratio q is 0.20 +/- 0.02. The superoutburst lasted between 8 and 12 days, peaked around magnitude 14 with an amplitude above quiescence of 4 magnitudes, and faded for 4 days at a rate of 0.14 magnitudes/day. Close monitoring following the end of the superoutburst detected a single normal outburst 60 days later which reached magnitude 14.7 and lasted less than 3 days.

## What did we know about KP Cas?

According to IBVS 4896 [1], the variable we now refer to as KP Cas was first described by Hoffmeister in 1949 [2] and appeared on MVS chart N291 published by Hoffmeister in 1957 [3] with the name Sonneberg variable S 3865. This chart is available online [4]. Kinnunen and Skiff [1] identified the variable with an 18th magnitude very blue star in the USNO-A2.0 catalogue at position 0h 38m 54s.70 +61° 12' 59".9 (+/-0".5) (J2000) with colour index (B-R) = -0.2. They comment that identifications prior to this had been incorrect. They also report that the variable was recorded in outburst at magnitude 15.5-16 on POSS-II J plate (1989 September 1). The only previous outburst detected visually was by Kinnunen on 1997 September 26 at magnitude 15.6. A search of the AAVSO variable star database [5] found no positive detections above a fainter-than magnitude of typically 15.0 prior to the current outburst. However observation of KP Cas has been intermittent with long periods with no reported observations so it is quite possible previous outbursts have been missed.

KP Cas is catalogued in the GVCS [6] as a UGSS-type dwarf nova with a range 15.2p to 20p, while Simbad [7] lists the range as 15.2p to >17.5p. A search on VizieR [8] found entries for KP Cas in the USNO-A2.0, USNO-B1.0 and GSC 2.3 catalogues with B, V, and R magnitudes in the range 17.6 to 18.8. We will adopt 18th magnitude as the quiescent level of KP Cas for the purpose of this report.

## This outburst

The outburst described here was first detected by Yasuo Sano (Hokkaido, Japan) on 2008 October 25.534 and reported on a VSNET email list [9]. He recorded KP Cas at magnitude 13.1C using a 0.3-m f/4 reflector and BJ42L CCD camera. 4 days previously he had recorded nothing brighter than 15.5C at that location. The outburst was confirmed visually by Eddy Muyllaert (Oostende, Belgium) on October 27.760 at magnitude 14.0 and by Poyner on October 27.771 at magnitude 13.9.

We began time series CCD photometry on October 27 (JD 2454767) and immediately recorded superhumps confirming that KP Cas was a SU UMa-type dwarf nova and this was the first observed superoutburst. We recorded a total of 144 hours of data comprising 8412 observations on 8 of the next 11 days. Observations were generally made with either a V filter or unfiltered (C). The log of observations and the equipment used are listed in Tables 1 and 2 respectively. Figure 1 shows an image of the field of KP Cas taken on October 27.

## Photometry

All images were dark-subtracted and flat-fielded and instrumental magnitudes obtained using aperture photometry. Comparison stars were selected from the KP Cas field calibration data provided by Arne Henden from observations made at the Sonoita Research Observatory [10]. Selection criteria for comparison stars included as similar as possible magnitude and colour to KP Cas, proximity to KP Cas for field of view considerations, and separation from adjacent stars which might contaminate photometry. All selected stars were checked for constancy using photometry taken over several nights and one nearby bright star originally included as a comparison was eliminated because of variability. The comparison stars selected are listed in Table 3.

A light curve of the superoutburst is shown in Figure 2 including all our observations and the 3 early observations noted above. There is a discrepancy between the magnitude initially reported by Sano and the confirmatory visual observations by Muyllaert and Poyner. Comparing these three observations with the subsequent light curve, we conclude that the observation by Sano probably over-estimated the magnitude, possibly because of a different choice of comparison star. Assuming the quiescent level of KP Cas is ~18th magnitude, this superoutburst had an amplitude of ~4 magnitudes and lasted between 8 and 12 days, normal for an SU UMa-type dwarf nova. The beginning of the outburst was not observed. From the time we started observing it, the outburst declined at 0.14 magnitudes/day for 4 days before fading more rapidly towards quiescence.

V and R-band photometry obtained on October 27 near the peak of the outburst gave colour index (V-R) = 0.13 +/- 0.02 and on November 6 with Faulkes Telescope North when KP Cas was at magnitude 17.85V gave (V-R) = 0.45 +/- 0.19.

## Astrometry

Astrometry of KP Cas on 10 images obtained under good conditions on JD 2454767 using Astrometrica [11] and the USNO-B1.0 catalogue gave a mean position for KP Cas of 0h 38m 54s.82 +61° 13' 0".5 +/- 0".2 (J2000).

## Superhump timing analysis

Superhump evolution during the outburst is illustrated in Figure 3 which shows a selection of light curve segments, all at the same scale. These segments are aligned in superhump phase and have the same vertical magnitude scale. The vertical scale mark represents 0.1 magnitude. There is a slow decrease in amplitude from ~0.25 magnitude on JD 2454767 to ~0.15 magnitude on JD2454771 but the final observation on JD 2454776 shows a large increase in amplitude and also the development of a secondary hump between the primary superhumps, possibly indicating the presence of the first harmonic of the superhump signal.

We observed 41 superhumps with sufficient photometric precision that a quadratic fit to the light curve of each superhump provided a reliable measurement of its time of maximum. Altogether we obtained 60 superhump timings as several superhumps were observed by two observers. Heliocentric corrections were applied to all timings. A preliminary linear fit to all times of maximum enabled unambiguous superhump cycle numbers to be assigned to each superhump. A weighted linear fit was then made to all 60 times of maximum using these assigned cycle numbers and O-C (observed minus calculated) times computed for each superhump relative to the time predicted by the linear fit. These are shown in Figure 4. The slope of the linear fit gives the mean superhump period during the outburst which was 0.085306 +/- 0.000003 days (2.04 hours). We note, however, that this period does not correspond well to any particular segment of the O-C diagram as the superhump period changed during the outburst.

Inspection of Figure 4 shows that the superhumps appear to fall into three groups: a linear regime during JD 2454767 (cycles 0 to 7), a second linear regime from JD 2454768 to 2454772 (cycles 12 to 62) and a third regime containing the superhumps during JD 2454776 (cycles 110 to 112). Linear behaviour in the O-C diagram indicates a constant period, with a positive slope representing a longer period than a negative slope, while curvature indicates a changing period. Although the superhumps during JD 2454776 appear quite distinct from the second linear regime, we considered the possibility that they might form part of an extended second regime in which the superhump period was increasing. To test this we applied a weighted quadratic fit to all the timings between cycles 12 and 112. This gave a plausible fit with an implied rate of increase of the superhump period dP/dt = +3.3 +/- 0.3 * $10^{-5}$. According to Table 3 in [12] which lists rates of superhump period change for 40 SU UMa-type dwarf novae, only 3 of the 23 systems with superhump periods longer than 0.070 days and none of the 10 with periods longer than 0.080 days have a positive value of dP/dt. Given that our measured superhump period is 0.085 days, we conclude that a positive dP/dt in this regime is unlikely. We also tested the possibility that the period was steadily decreasing between cycles 0 and 62 by applying a weighted quadratic fit. This was a poor fit and we consider this hypothesis also unlikely.

We therefore consider the most likely interpretation of our data is that the superhump period was constant during JD 2454767 and then changed to a different constant value between JD 2454768 and 2454772 apparently with little or no change in phase. This was followed between JD 2454772 and 2454776 by a change in either the period or phase (or both) of the superhump signal. We applied separate weighted linear fits to the two linear regimes. These gave superhump periods of 0.085544 +/- 0.000075 days during JD 2454767 and 0.085219 +/- 0.000007 days in the interval JD 2454768-2454772. These fits had chi-squared probabilities of 0.47 and 0.27 respectively. The O-C values for the two fits are listed in Tables 4 and 5.

The apparent regrowth in superhump amplitude which we see in the data during JD 2454776 has been seen in other SU UMa-type dwarf novae [13] but has tended to occur in shorter period systems and during the superoutburst rather than after the end of the outburst as seen here. However, given our lack of observations in the preceding 3 days, we cannot say when this regrowth started.

## Frequency analysis

After subtracting linear trends from each dataset, we performed a Lomb-Scargle [14,15] frequency analysis on our combined time series data using Peranso [16]. The resulting power spectrum is shown in Figure 5. The strongest signal is at 11.72 +/- 0.02 cycles/day (0.08530 +/- 0.00015 days) and there are low amplitude 1 and 2 cycles/day alias signals around this as expected from a spectral window analysis. The strongest signal is consistent with the mean superhump period derived from the superhump timing analysis. There is also a smaller first harmonic signal at 23.44 +/- 0.02 cycles/day (0.04266 +/- 0.00004 days) as expected from the appearance of secondary humps in the superhump light curve towards the end of the outburst. Prewhitening to remove the base superhump signal leaves only low power signals, see Figure 6. The four strongest of these are 0.1 cycles/day above and below the base and first harmonic superhump signals and are probably due to incomplete removal of the superhump signal because of its small variation in frequency during the outburst. The next strongest signal is at 12.28 +/- 0.06 cycles/day (0.0814 +/- 0.0004 days). We interpret this signal as the orbital period of KP Cas. At 1.95 hours, it puts KP Cas just below the dwarf nova period gap.

We also performed separate Lomb-Scargle analyses on the time series data in each of the three regimes discussed in the superhump timing analysis, namely JD 2454767, JD 2464768-2454772 and JD 2464776. The superhump periods in each case are given in Table 6. These are also consistent with the results of the superhump timing analysis. Phase diagrams of the superhump signal folded on the periods in Table 6 for each of these regimes are shown in Figure 7.

## Discussion

The transition from common to late superhumps in IY UMa and other SU UMa-type dwarf novae occurred as the star declined from outburst and was marked by both a phase change in the superhump signal and a decrease in its period [17]. Also, in V1316 Cyg [18], the transition from common to late superhumps was associated with the appearance of the first harmonic of the superhump signal. Considering what appears to be a phase shift in Figure 4 between cycles 62 and 110, a possible reduction in superhump period in Table 6 at the same time, and the appearance of the first harmonic of the base superhump frequency in Figure 7c, it is tempting to consider there was a transition from common to late superhumps in KP Cas somewhere between JD 2454772 and JD 2454776 as the star declined from outburst. However, given the lack of data during this part of the outburst, this can only be speculation.

From the mean superhump period of 0.085306 +/- 0.000003 days and the orbital period of 0.0814 +/- 0.0004 days, we get a superhump period excess $\varepsilon = 0.048$ +/- 0.005, in line with results for other SU UMa-type dwarf novae with similar orbital periods [19]. If we assume KP Cas is a normal SU UMa-type dwarf nova with a white dwarf mass of ~0.75 solar masses, then using the empirical relationship $\varepsilon = 0.18*q + 0.29*q^2$ from [20] gives the secondary to primary mass ratio q = 0.20 +/- 0.02.

## Subsequent normal outburst

Following the superoutburst, Shears monitored KP Cas closely. On average he observed it every 3 days with the longest gaps between observations being 9 days (once) and 5 days. Surprisingly, given the long interval since the last recorded outburst of KP Cas, he detected another outburst on 2009 January 4 only 60 days after the end of the superoutburst. From fainter than magnitude 17.3C on January 3.806, it reached 15.5C on January 4.778, 14.6C on January 5.758 and by January 9.832 had returned to 17.7C. Time series photometry over 5 hours by Roger Pickard, Shears and Boyd on January 5 found it fading from magnitude 14.6C at a rate of 1 magnitude/day with no significant modulation. With this rate of decline near the peak of the outburst, we estimate that the duration of the outburst was probably less than 3 days. Its shorter duration, lower amplitude and lack of modulation indicate this was a normal outburst. We consider it unlikely that the January outburst was one of a series of echo outbursts as we would have been very unlucky not to have seen at least one of them.

## Conclusion

We report CCD photometry and analysis of the first observed superoutburst of the SU UMa-type dwarf nova KP Cas during 2008 October. Measurements of the times of superhump maximum revealed two distinct superhump periods: 0.085544 +/- 0.000075 days during JD 2454767 and 0.085219 +/- 0.000007 days in the interval JD 2454768-2454772. We saw little or no change in phase associated with the transition between those periods. We did see some evidence for a phase and period change in the interval JD 2454772 to 2454776 which might indicate a transition to late superhumps. This part of the outburst was not well enough observed to provide a reliable late superhump period. Frequency analysis of our time series data revealed the orbital period of KP Cas to be 0.0814 +/- 0.0004 days (1.95 hours). This places it just below the dwarf nova period gap. The superhump period excess ε is 0.048 +/- 0.005 and, empirically, we deduce the mass ratio q to be 0.20 +/- 0.02. The outburst lasted between 8 and 12 days, peaked around magnitude 14, an amplitude above quiescence of 4 magnitudes, and declined for 4 days at a rate of 0.14 magnitudes/day before fading more rapidly back to quiescence. This is normal superoutburst behaviour for a SU UMa-type dwarf nova. 60 days after the end of the superoutburst we detected a single normal outburst which reached magnitude 14.7 and lasted less than 3 days.

## Acknowledgements

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## References

[1] Kinnunen, T., Skiff, B., IAU Inform. Bull. Var. Stars, No. 4896, (2000) http://www.konkoly.hu/cgi-bin/IBVSpdf?4896
[2] Hoffmeister, C., Astron. Abh. Ergänzungshefte z.d. Astron. Nach., **12**, no. 1, A3 (1949)
[3] Hoffmeister, C., Mitt. Veränder. Sterne, No. 245 (1957)
[4] MVS chart N291, http://www.stw.tu-ilmenau.de/observatory/images/mvs/volume_01/291.png
[5] AAVSO, http://www.aavso.org/data/
[6] General Catalogue of Variable Stars, http://www.sai.msu.su/groups/cluster/gcvs/gcvs/
[7] Simbad, http://Simbad.u-strasbg.fr/Simbad/
[8] VizieR, http://vizier.u-strasbg.fr/viz-bin/VizieR-2
[9] vsnet-outburst 9599
[10] Henden, A., ftp://ftp.aavso.org/public/calib/master_sro_3.txt
[11] Raab, H., Astrometrica http://www.astrometrica.at/
[12] Uemura M. et al., Astron. & Astrophysics, **432**, 261 (2005)
[13] Kato T. et al., Publ. Astron. Soc. Japan, **55**, 989 (2003)
[14] Lomb N. R., Astrophys. Space Sci., 39, 447 (1976)
[15] Scargle J. D., Astrophys. J., 263, 835 (1982)
[16] Vanmunster T., PERANSO, http://www.peranso.com
[17] Patterson J. et al., Publ. Astron. Soc. Pacific., **112**, 1567 (2000)
[18] Boyd D. et al., J. Brit. Astron. Assoc., **118**, 149 (2008)
[19] Hellier C., Cataclysmic Variable Stars: How and why they vary, Springer-Verlag (2001)
[20] Patterson J. et al., Publ. Astron. Soc. Pacific., **117**, 1204 (2005)

| Start time (JD) | Duration (hrs) | Filter | Observer |
|---|---|---|---|
| 2454767.26039 | 7.70 | V+R | Boyd |
| 2454767.36072 | 4.10 | C | Shears |
| 2454767.61938 | 8.13 | V | Julian |
| 2454768.24024 | 7.14 | C | Shears |
| 2454768.26340 | 6.40 | C | Staels |
| 2454768.57255 | 10.48 | V | Koff |
| 2454769.22919 | 4.17 | C | dePonthiere |
| 2454769.23649 | 3.66 | C | Staels |
| 2454769.54403 | 10.60 | V | Koff |
| 2454769.60627 | 8.44 | V | Julian |
| 2454770.27623 | 8.24 | C | Boyd |
| 2454770.28947 | 5.77 | C | Shears |
| 2454770.53278 | 11.01 | V | Koff |
| 2454770.60228 | 8.54 | V | Julian |
| 2454771.23582 | 7.97 | C | Boyd |
| 2454771.26962 | 7.00 | C | Shears |
| 2454771.65566 | 7.56 | C | Krajci |
| 2454772.23536 | 1.56 | C | Shears |
| 2454772.42193 | 7.35 | C | dePonthiere |
| 2454776.58473 | 1.27 | C | Krajci |
| 2454776.63559 | 6.74 | C | Foote |
| 2454777.00235 | 0.04 | V+R | Boyd |

Table 1. Log of observations.

| Observer | Equipment used |
|---|---|
| Boyd | 0.35-m f/5.3 SCT + SXV-H9 CCD<br>2.0-m f/10 Ritchey-Chretien + E2V-4240 CCD |
| dePonthiere | 0.2-m f/6.3 SCT + ST-7XMEI CCD |
| Foote | 0.60-m f/3.4 reflector + ST-8e CCD |
| Julian | 0.30-m f/10 SCT + SBIG ST10XME CCD |
| Koff | 0.25-m f/10 SCT + Apogee AP-47 CCD |
| Krajci | 0.28-m f/10 SCT + ST-7E CCD |
| Shears | 0.1-m fluorite refractor + SXV-M7 CCD<br>0.28-m f/10 SCT + SXVF-H9 CCD |
| Staels | 0.28-m f/6.3 SCT + MX-716 CCD |

Table 2. Equipment used.

| RA (J2000) | Dec (J2000) | V | dV | (B-V) | (V-R) |
|---|---|---|---|---|---|
| 0 39 08.88 | +61 12 03.3 | 12.841 | 0.007 | 0.329 | 0.209 |
| 0 39 16.02 | +61 13 50.1 | 13.955 | 0.009 | 0.435 | 0.255 |
| 0 38 59.76 | +61 13 52.7 | 14.487 | 0.008 | 0.468 | 0.292 |

Table 3. Comparison stars used.

| Superhump cycle no | Observed time of maximum (HJD) | Uncertainty (sec) | O-C (sec) | Observer |
|---|---|---|---|---|
| 0 | 2454767.27984 | 42 | 44 | Boyd |
| 1 | 2454767.36425 | 42 | -54 | Boyd |
| 2 | 2454767.45074 | 38 | 28 | Boyd |
| 2 | 2454767.45072 | 67 | 26 | Shears |
| 3 | 2454767.53545 | 39 | -45 | Boyd |
| 5 | 2454767.70709 | 33 | 4 | Julian |
| 6 | 2454767.79224 | 51 | -30 | Julian |
| 7 | 2454767.87848 | 42 | 30 | Julian |

Table 4. Times of superhump maximum for JD 2454767 and O-C values relative to a weighted linear fit.

| Superhump cycle no | Observed time of maximum (HJD) | Uncertainty (sec) | O-C (sec) | Observer |
|---|---|---|---|---|
| 12 | 2454768.30680 | 54 | 10 | Shears |
| 13 | 2454768.39161 | 61 | -26 | Shears |
| 13 | 2454768.39360 | 44 | 147 | Staels |
| 14 | 2454768.47665 | 58 | -41 | Shears |
| 14 | 2454768.47792 | 39 | 69 | Staels |
| 16 | 2454768.64576 | 91 | -156 | Koff |
| 17 | 2454768.73274 | 93 | -4 | Koff |
| 18 | 2454768.81669 | 99 | -113 | Koff |
| 19 | 2454768.90335 | 64 | 12 | Koff |
| 20 | 2454768.98700 | 105 | -124 | Koff |
| 24 | 2454769.32882 | 52 | -42 | Staels |
| 24 | 2454769.32867 | 240 | -55 | dePonthiere |
| 27 | 2454769.58399 | 94 | -85 | Koff |
| 28 | 2454769.66976 | 75 | -37 | Julian |
| 29 | 2454769.75545 | 116 | 4 | Koff |
| 29 | 2454769.75577 | 78 | 32 | Julian |
| 30 | 2454769.84092 | 157 | 26 | Koff |
| 30 | 2454769.84124 | 81 | 54 | Julian |
| 31 | 2454769.92514 | 107 | -60 | Koff |
| 31 | 2454769.92562 | 87 | -19 | Julian |
| 36 | 2454770.35113 | 48 | -70 | Boyd |
| 36 | 2454770.35125 | 35 | -59 | Shears |
| 37 | 2454770.43733 | 49 | 15 | Boyd |
| 37 | 2454770.43753 | 36 | 33 | Shears |
| 38 | 2454770.52179 | 38 | -51 | Boyd |
| 38 | 2454770.52155 | 35 | -72 | Shears |
| 39 | 2454770.60681 | 68 | -67 | Boyd |
| 39 | 2454770.60826 | 121 | 57 | Koff |
| 40 | 2454770.69373 | 112 | 79 | Koff |
| 40 | 2454770.69330 | 87 | 42 | Julian |
| 41 | 2454770.77816 | 124 | 11 | Koff |

| | | | | |
|---|---|---|---|---|
| 41 | 2454770.77736 | 79 | -58 | Julian |
| 42 | 2454770.86373 | 101 | 41 | Koff |
| 42 | 2454770.86384 | 49 | 51 | Julian |
| 43 | 2454770.94860 | 102 | 11 | Koff |
| 43 | 2454770.94827 | 83 | -18 | Julian |
| 47 | 2454771.28884 | 52 | -44 | Boyd |
| 47 | 2454771.28971 | 29 | 32 | Shears |
| 48 | 2454771.37463 | 40 | 6 | Boyd |
| 48 | 2454771.37448 | 38 | -7 | Shears |
| 49 | 2454771.45905 | 54 | -63 | Boyd |
| 49 | 2454771.45960 | 30 | -16 | Shears |
| 50 | 2454771.54558 | 49 | 50 | Boyd |
| 50 | 2454771.54451 | 59 | -42 | Shears |
| 52 | 2454771.71551 | 34 | 7 | Krajci |
| 53 | 2454771.80155 | 42 | 77 | Krajci |
| 54 | 2454771.88680 | 46 | 80 | Krajci |
| 61 | 2454772.48567 | 211 | 282 | dePonthiere |
| 62 | 2454772.56686 | 240 | -66 | dePonthiere |

Table 5. Times of superhump maximum for JD 2454768-2454772 and O-C values relative to a weighted linear fit.

| JD interval | Period (day) |
|---|---|
| 2454767 | 0.0859 +/- 0.0017 |
| 2454768-2454772 | 0.0853 +/- 0.0002 |
| 2454776 | 0.0835 +/- 0.0098 |

Table 6. Superhump periods from separate Lomb-Scargle analyses of time series data in three intervals.

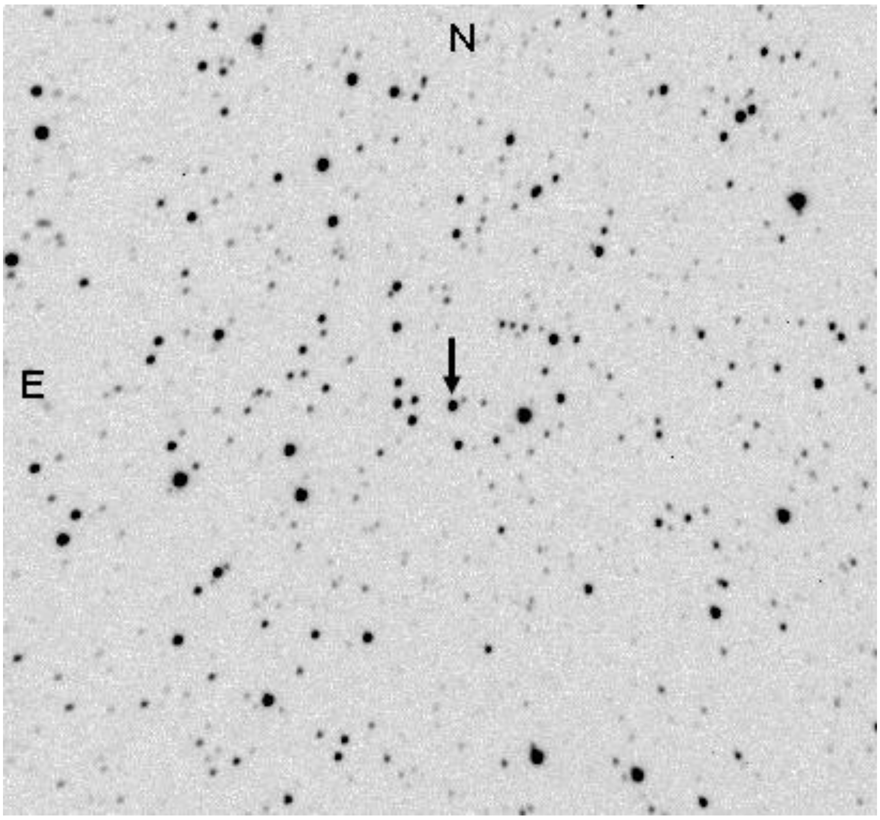

Figure 1. Image of KP Cas taken on October 27, field ~10x10 arcmin.

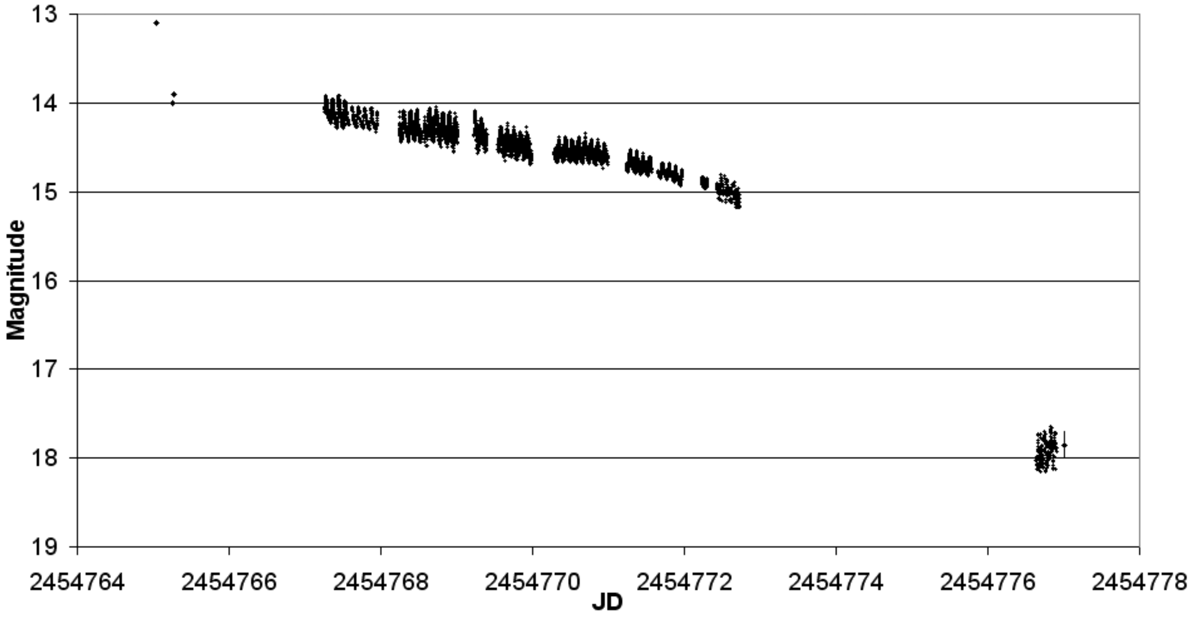

Figure 2. Combined light curve of the KP Cas superoutburst.

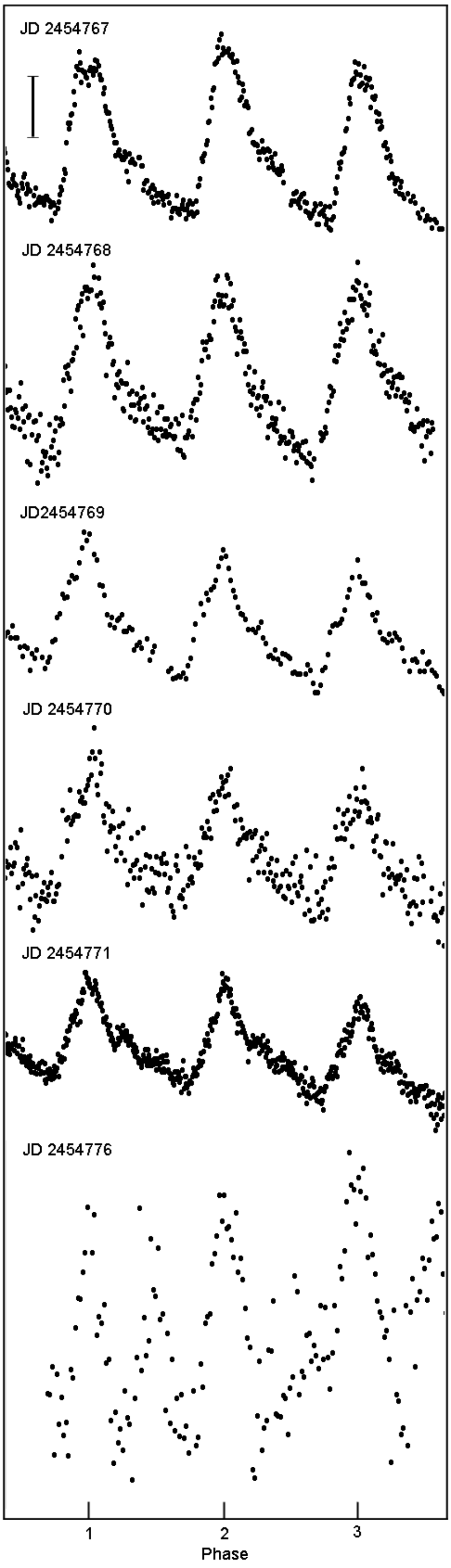

Figure 3. Superhump evolution during the outburst with time shown horizontally and magnitude vertically. All light curves are shown at the same scale in time and magnitude and are aligned in superhump phase. The vertical scale mark is 0.1 magnitude.

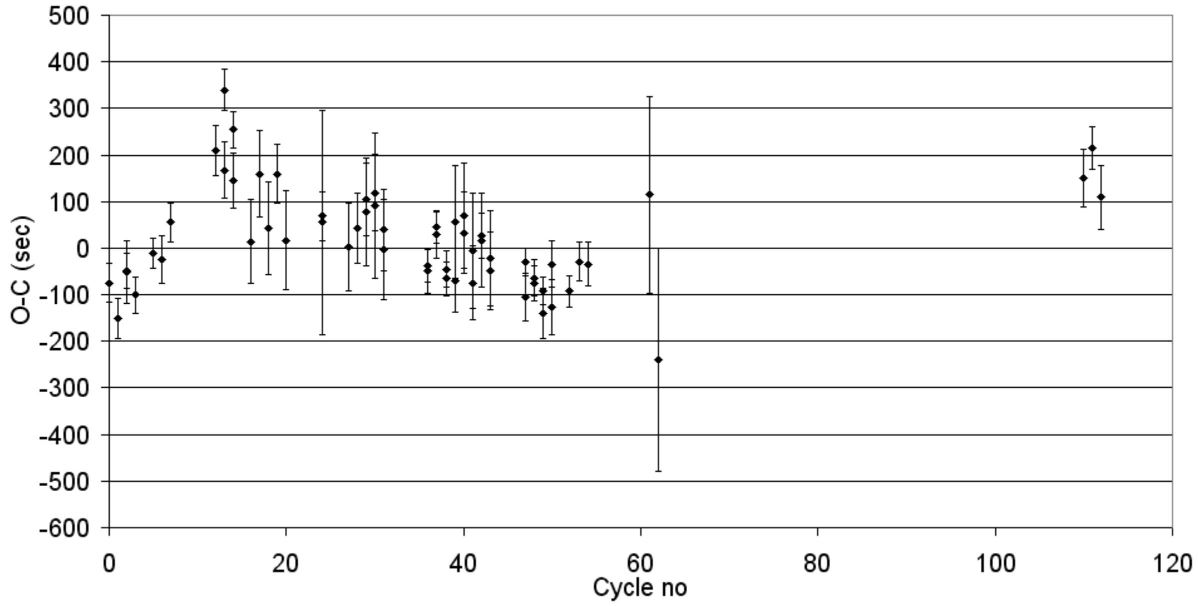

Figure 4. O-C times of 60 superhump maxima relative to the predictions of a weighted linear fit to all the times of maximum.

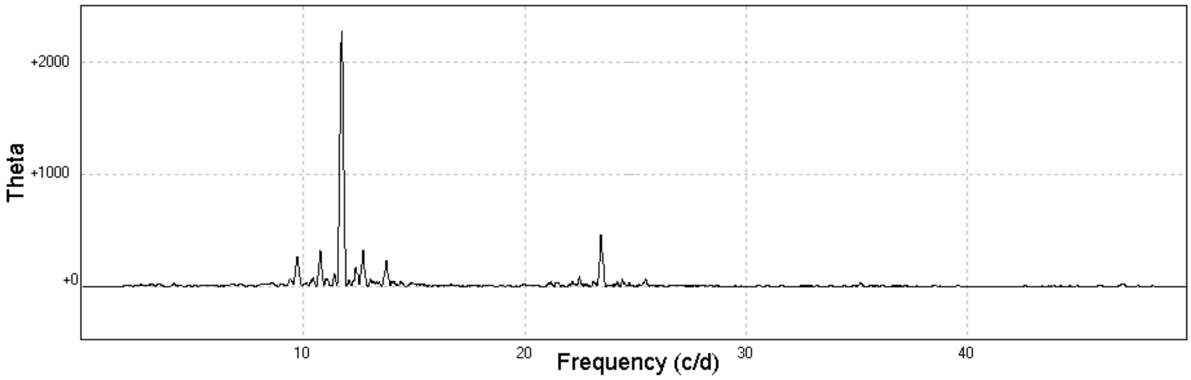

Figure 5. Power spectrum from Lomb-Scargle analysis of all time series data from JD 2454767-JD 2454776.

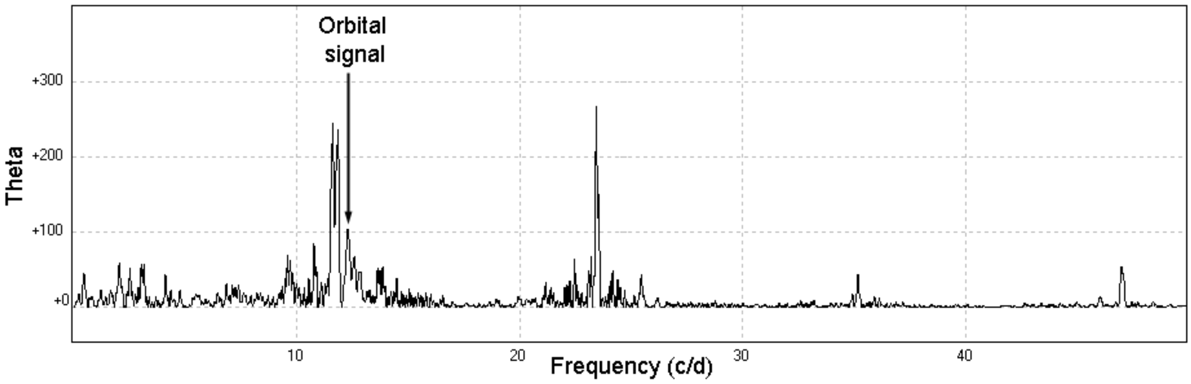

Figure 6. Power spectrum from Lomb-Scargle analysis after removing the superhump signal at 11.72 cycles/day.

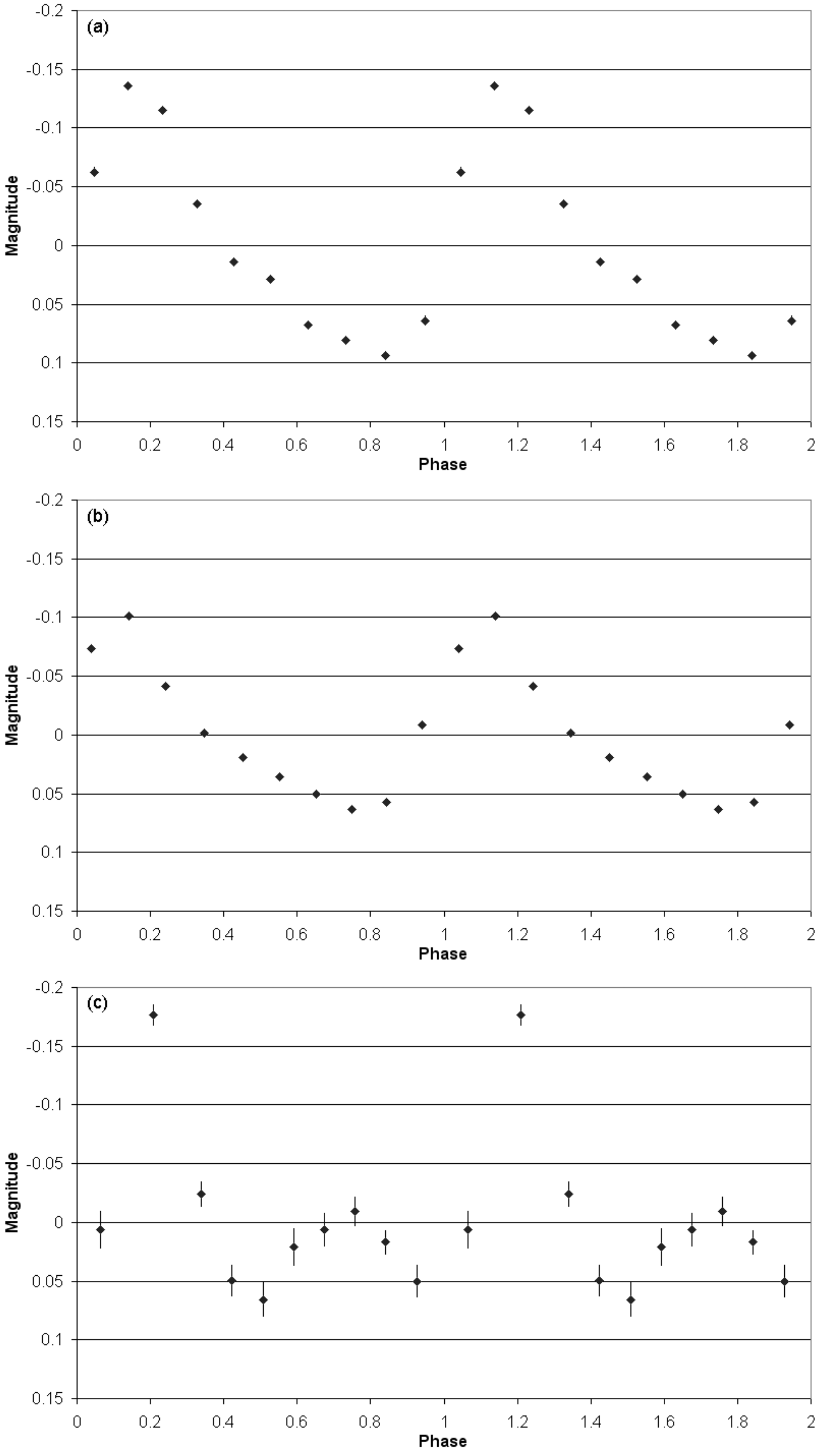

Figure 7. Phase diagrams of the superhump signal folded on the periods in Table 6 for (a) JD 2454767, (b) JD 2454768-2454772 and (c) JD 2464776 showing two cycles in each case.