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2007 PHOTOMETRY OF UV LEONIS

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UV Leo is a member of the short period eclipsing group of RS CVn systems. McCluskey (1966) performed an early photometric study and summarized earlier work on UV Leo. Frederik and Etzel (1996) performed a complete optical photometric study of this system.

Kjurkchieva et al. (2007) performed an optical photometric and spectroscopic study of this system. Their photometry was on the nights of April 4, 14, and 15, 2007. For this work, I collected new optical photometry of UV Leo in 2007. This new photometry, collected about a month later, can tell us something about how rapidly the spots on UV Leo evolve.

I observed UV Leo with the San Diego State University 61-cm telescope on Mt. Laguna. The light curves were obtained on the nights of May 8, 9, 11, 13, 16, 23, & 28, 2007. I used SAO 99225 as the comparison star and SAO 99223 as the check. Using standards of Landolt (1983), I calibrated the comparison star magnitudes: $B = 9.26, V = 8.20$, R=7.61, and $I = 7.11$. The calibrated check star magnitudes are: $B = 8.77, V = 8.33, R = 8.04$, and $I = 7.77$. The complete four filter light curves, with 120 data points per filter, are plotted in Figure 1. The data are differential magnitudes (var-comp) in the standard Johnson-Cousins system. I used the ephemeris of McClusky (1966):

$$\phi_0 = 2438440.7275 + 0.6000855E.$$

Figure 1 shows considerable variations in the out of eclipse portion of the light curve between phases 0.6 and 0.9. To check if these variations are scatter in the data or changes in the light curve, Figure 2 shows the V band data divided into three groups. Group 1 includes the data from the first four nights, May 8, 9, 11, and 13. Group 2 includes the data from May 16, and Group 3 includes the data from May 23 and 28. It is apparent that the out of eclipse portions of the light curve changed during the nearly three weeks between the beginning and end of the observations.

Because the period is so close to 0.6 days the same phases are available to observe in a three night repeating cycle. It was therefore not possible to fill in the small gaps in the light curves that occurred when the phase at the start of a night was a little after the phase at the end of a previous night. Hence removing the later nights in Group 3 only slightly affects the phases covered, however the photometry is less dense. To completely cover the light curve, it was also necessary to observe at a higher than optimal air mass at the ends of the nights. Therefore the last few data points for each night have more scatter than most of the data for the night. These data are at phases are 0.80, 0.47, 0.57, 0.97, and 0.11. The data deviating most from the models in the clean fits (See Figure 4.) were at these phases. However removing these data would have made the light curves to be modeled even more sparse.

I modeled the 90 data points from Groups 1 and 2 using Budding and Zeilik's (1987) Information Limit Optimization Technique (ILOT). Initial values for stellar parameters were in most cases taken from Kjurkchieva et al. (2007). I used $k(=r_2/r_1)=0.9668$, $r_1=0.30$, $i=84\overset{\circ}{.}2$, $q(=m_2/m_1)=0.954$, $T_1=6000$, and $T_2=5970$. I adopted the limb darkening coefficients for each wavelength from Frederik and Etzel (1996). After the initial fit, the ILOT extracts a distortion wave which I then, in an iterative procedure, fit for two circular 3400K spots. The fits for each color are performed independently. The reported longitude, latitude, and radius of each spot are in degrees. The latitude is the most difficult spot parameter to fit. Attempts to fit the spot latitudes produced errors that were in some cases larger than the possible range of latitudes. The preliminary fits however yielded mid range latitude values, so I fixed the spot latitudes at 45° for the final spot models. Figure 3 shows the V band spot fit. For the spot fits I get:

Spot Fits

2007	B band	V band	R band	I band
Longitude$_1$	260.9±3.3	260.0±4.1	258.4±4.2	255.9±4.6
Radius$_1$	17.4±0.9	16.6±1.0	17.7±1.0	17.3±1.1
Longitude$_2$	47.8±7.6	47.4±9.4	41.2±7.7	40.7±8.4
Radius$_2$	9.8±1.5	9.4±1.7	12.1±1.5	12.4±1.6
χ^2	234.4	105.6	189.9	192.8

Kjurkchieva et al. (2007) find two spots near the equator at longitudes of 0° and 110° and radii of 27° and 24°. Because my data were taken only about a month after the Kjurkchieva et al. (2007) data, comparing the spot models tells us that the spots on UV Leo can changed considerably in this short time.

It should be noted that they used Binarymaker 3.0 to model their data, and this code uses a different convention for latitude and longitude than the ILOT code. The ILOT code measures latitude north and south from the equator and longitude from phase 0.0 increasing with phase. The Binarymaker code uses the Wilson-Devinney code convention. Latitude is measured south from the north pole, and longitude on the primary star is measured from the primary eclipse increasing in the direction of orbital motion. So longitude(Binmaker) = 360°- longitude(ILOT) and latitude(Binmaker) = 90°- latitude(ILOT).

The latitude comparison is not definitive because I used a fixed latitude.

To definitively compare the spot longitudes, one should note that I used the original McClusky (1966) ephemeris, while Kjurkchieva et al. (2007) cite an updated ephemeris. The ILOT clean fits, after correcting for the spots, compute the best fit for the phase correction correction needed so that the primary and secondary eclipses occur at phases 0.0 and 0.5. For these light curves, this correction is $-7\overset{\circ}{.}1$. Therefore the longitudes in the above table should be reduced by $7\overset{\circ}{.}1$ for direct comparison to the longitudes reported by Kjurkchieva et al. (2007). Hence the Kjurkchieva et al. (2007) spot at 110° longitude is at 250° longitude in the ILOT convention and is very nearly the same longitude as the 253° longitude of my spot corrected as above. The other spot however migrated nearly 40° from the primary eclipse in about a month. Hence one of the spot longitudes changed significantly.

The spots also became smaller in size, and at the same time cooler, during the month between the two sets of light curves.

The ILOT can estimate spot temperatures by comparing infrared models to visual models. Using the initial values of 0K spot parameters at a visual wavelength, I fit infrared data for the unit of light and flux ratio. The value of the spot temperature can be found from the flux ratio of the star's photospheric temperature and the spot temperature.

Comparing the R to V data did not give a valid fit. I compared the R to B, I to V, and I to B fits. The reported spot temperature is the average of these three comparisons. Doing so I find an average value of the spot temperature of $T_s = 3400 \pm 300$K. In an iterative procedure, I then fit the other spot parameters to 3400K spots. In this second iteration the spot longitudes and sizes differed from the values found in the first iteration by less than the reported errors. Hence, I made no further iterations. The spot parameters in the table above are for 3400K spots.

After the spot fits, I performed clean fits to the light curves removing the effects of the distortion wave from the spot as modeled in that filter. I fit each wavelength independently and averaged the color independent parameters. The mass ratio, q, is difficult to determine photometrically, so I fixed this parameter at q=0.954, the value found spectroscopically by Kjurkchieva et al. (2007). For the other color independent parameters, I get: $k(= r_2/r_1) = 0.920 \pm 0.007$, $r_1 = 0.291 \pm 0.002$, and $i = 83\overset{\circ}{.}4 \pm 0\overset{\circ}{.}2$. Figure 4 shows the V band clean fits.

My value for the inclination, $i = 83\overset{\circ}{.}4 \pm 0\overset{\circ}{.}2$, is between the values found by Kjurkchieva et al. (2007), $84\overset{\circ}{.}2$, and Frederik and Etzel (1996), $82\overset{\circ}{.}6$.

The ratio of the radii, $k(= r_2/r_1)$, provides the most astrophysically interesting comparison with previous results. In this work, I get $k = 0.920$. Frederik and Etzel (1996) find $k = 1.097$, so that the secondary star is larger, even though less massive, than the primary. Kjurkchieva et al. (2007), on the other hand, find that $k = 0.967 \pm 0.064$ ($r_1 = 0.30 \pm 0.01$ and $r_2 = 0.29 \pm 0.01$), which agrees to within the errors with my result. In any case the two components of this system are close to the same radius and mass.

This work shows that the spot structure on UV Leo can evolve on time scales of a few weeks. The modeled stellar parameters are consistent with previous work.

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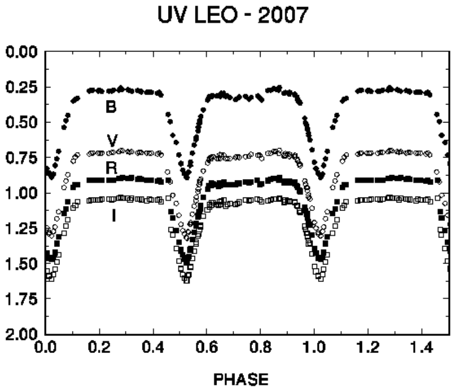

Figure 1. BVRI light curves of UV Leo

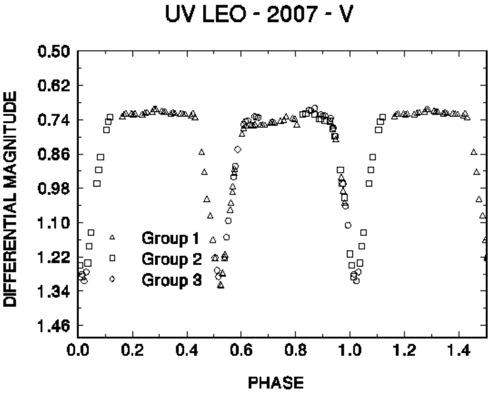

Figure 2. UV Leo V data grouped by date

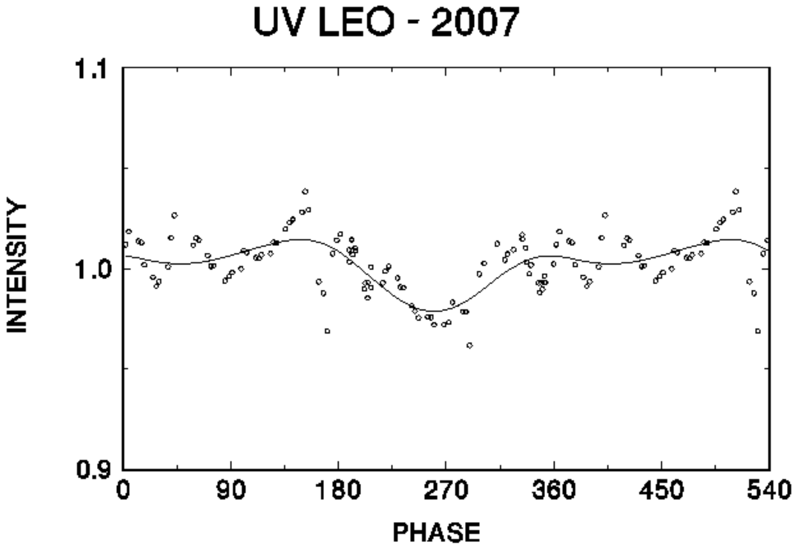

Figure 3. UV Leo V spot fit

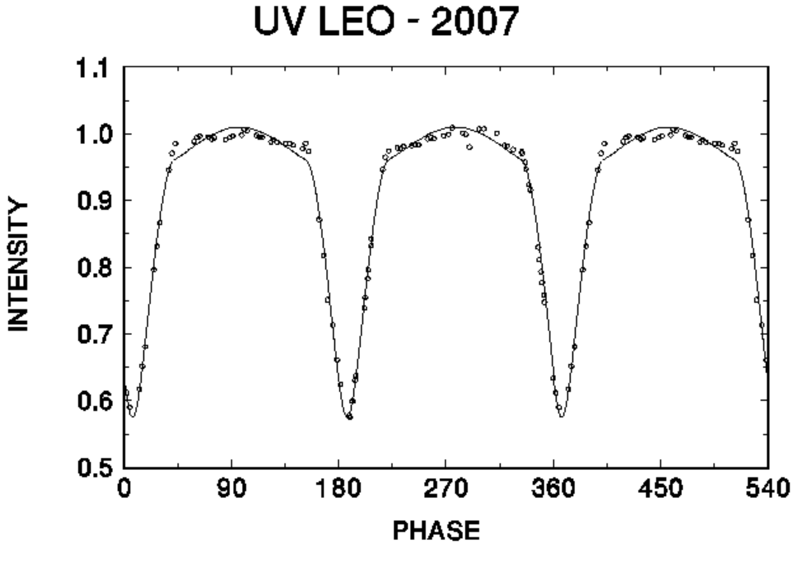

Figure 4. UV Leo V clean fit

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