Eclipse Modeling of the Nova-Like Variable LX Serpentis and the Classical Nova QU Vulpeculae

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Multicolor B, V, R, and I eclipse light curves of the nova-like variable LX Ser and the classical nova QU Vul were analyzed with a parameter-fitting eclipse model. The results are analyzed to see how well constrained the model parameters are and to look for any correlations between the parameters. It is found that LX Ser is a well constrained system with relatively low correlation between model parameters, while the parameters of QU Vul on the other hand are less well constrained, and show a higher correlation. Our primary result is that the accretion disks in both systems have a flatter temperature profile than that expected for steady-state accretion disks.

Introduction

Classical novae and nova-like variables are a subclass of the cataclysmic variable stars, consisting of a late-type, near-main-sequence star (the secondary star) that fills its Roche lobe and transfers mass via an accretion disk to a more massive white dwarf companion (the primary star). In classical nova systems material accreted onto the surface of the white dwarf experiences a thermonuclear runaway leading to a nova eruption. Nova-like systems are similar to quiescent nova binaries in structure, and may represent classical novae with unrecorded eruptions. In this paper we analyze eclipses in the light curves of the classical nova QU Vul (Nova Vulpecula 1984#2) and the nova-like variable LX Ser in order to study the radiative properties of the system components (the primary and secondary stars, and the accretion disk).

Observations and Reduction

Observations of LX Ser were taken from May 2003 to May 2004 using the 1 m reflector at Mount Laguna Observatory. Observations of QU Vul were taken from May 2006 to June 2007 using the 90" Steward telescope in Arizona. For both systems a series of exposures were taken through either a Johnson-Cousins *B*, *V*, *R*, or *I* filter (see Bessel 1990). The images were then reduced using standard IRAF reduction procedures. The point of mideclispe was found on each image and using the orbital period the images were converted to orbital phase from $-0.2 < \varphi < 0.2$. The multicolor light curves were then normalized to unity using out-of-eclipse light levels and offset for clarity to mean levels of 1, 2, 3 and 4 for *B*, *V*, *R*, and *I* respectively.

Analysis

The LX Ser and QU Vul data have been analyzed using the latest version of a parameter-fitting eclipse modeling program described in Shafter & Misselt (2006). This program takes into account four sources of light for the system, the white dwarf, the accretion disk, the secondary star, and the bight spot where the mass transfer steam impacts the disk. The model light curve flux is then computed by summing up the contributions from the secondary star, and the uneclipsed regions of the reaming three sources. The accretion disk is assumed to radiate as an optically thick blackbody having a radial power-law temperature profile described in Warren, Shafter, and Reed (2006). Since the brightness temperature profile is not the same as the effective temperature it may be possible to have a steady state accretion that is not characterized by $\alpha = 0.75$.

The model input parameters and are summarized in Table 1. There are two types of parameters, with some of them computed and held fixed in the modeling process, while others are allowed to vary during the fitting process (see Warren, Shafter, and Reed 2006 for a description of the parameters). The orbital inclination of the system was calculated using the phase width and mass ratio and then varied around the calculated inclination.

Table 1: Model Input Parameters

Parameters	Description	LX Ser Values	QU Vul Values
P	Orbital Period	3.802 hr	2.68 hr
q	Mass Ratio	0.3, 0.5	0.2, 0.3, 0.5
$\Delta\varphi$	Eclipse phase width	0.079	0.055
i	Orbital inclination	Variable (78.0 – 80.5)	Variable (79.0 - 82.0)
α	Disk temperature Parameter	Variable (0.00 – 0.80)	Variable (0.00 – 0.80)
R_d	Outer disk radius	Variable (0.30 – 0.70)	Variable (0.35 – 0. 75)
h_r	Disk rim parameter	0.05, 0.10	0.00, 0.05, 0.10
T_d	Temperature of disk perimeter	Variable (5000 – 13000 K)	Variable (5000 – 13000 K)
T_1	Temperature of white dwarf	Variable (10000 – 50000 K)	Variable (10000 – 50000 K)
T_2	Temperature of secondary star	3400 K	3300 K
X_s	Bright spot temperature factor	Variable (1.0 – 2.6)	Variable (1.0 – 2.6)

The temperature of the secondary star was estimated prior to beginning the modeling process. Smith & Dhillon (1998) found an empirical relation between the orbital period and spectral type of the secondary star. Knowing the orbital periods of both systems we can use this relationship to find the spectral types of both secondary stars and from their spectral types we can estimate their temperatures.

To begin the fitting process we selected plausible ranges for the variable parameters. Each parameter is varied one at a time while the other parameters remain fixed. In this way a resulting six-dimensional parameter space of models is created. To check the goodness of fit a standard χ^2 test is used. The deviation between the model and the data is calculated for each color separately and then combined with each color having equal weight. The range of each parameter is selected such that all plausible values are sampled.

Before finding the best fit for QU Vul we had to adjust the R band light curve. We found the R band light curve to be far too shallow and believe it to be due to uneclipsed $H\alpha$ light. To correct for this contamination we subtracted 20% and 25% light from the R band light curve and found that subtracting 20% provided the best fit to the data. Tables 2 and 3 give the values of the variables for the best fitting models of each system. Since the overall error is not known for the observation the χ^2 value is a normalized value. Artificial errors are assigned such that the minimum χ^2 values found are near unity. The best fitting models are shown in Figures 1 and 2

In order to see how well constrained the variables are we want to see the frequency of each value that provided a suitably low χ^2. Therefore a χ^2 was selected such that the 100 best models could be graphed in order to examine the variable distribution and see how well the variables are constrained. Figures 3 and 4 show the distributions as histograms with the dark bar representing the best fit value. The white dwarf temperature in both systems is not well constrained, and this is because from the data one sees that the white dwarf does not contribute much light to the system (unlike in dwarf nova systems). LX Ser shows much better variable constraints than does QU Vul. The disk radius and bright spot factor are very well constrained for LX Ser and the bright spot is well constrained for both systems.

χ^2	1.3156
Q	0.50
h_r	0.10
I	79.0
T_s	3400
R_d	0.600
T_d	9000
Λ	0.30
χ_s	1.6
T_{WD}	10000

Table 2: LX Ser best fitting parameters

χ^2	0.8229
q	0.20
h_r	0.05
i	80.75
T_s	3300
R_d	0.500
T_d	5000
α	0.00
χ_s	1.0
T_{WD}	10000

Table 3: QU Vul best fitting parameters

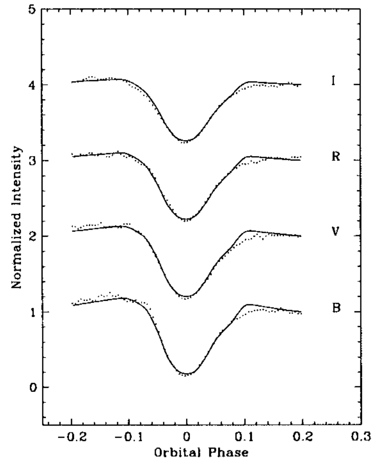

Figure 1: LX Ser best fit model

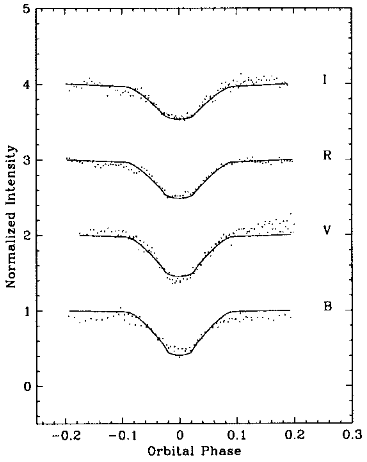

Figure 2: QU Vul best fit model

In QU Vul it seems that even though the best fit has a low value of α and a low disk radius, there are still many solutions that can have a high α and a high disk radius. This hints at a possible correlation between these variables.

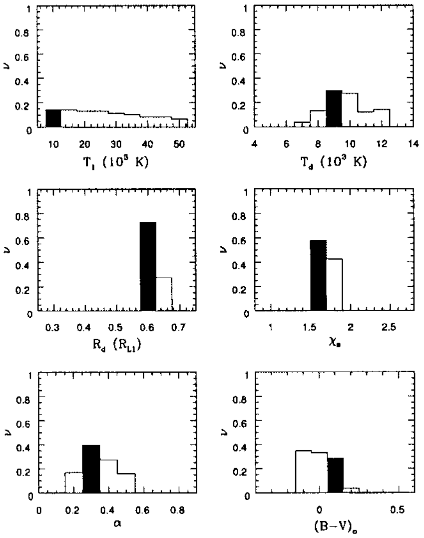

Figure 3: LX Ser Variable Distributions

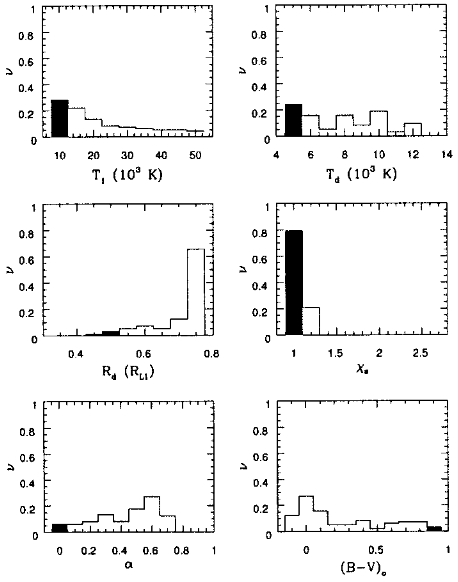

Figure 4: QU Vul Variable Distributions

To check for any correlations between the variables, we ran a program that holds three of the five variables fixed at their optimum position and then allows the other two to vary. In this was we can see if any of the variables are correlated. A total of ten relationships were tested and the results are plotted in Figures 5 and 6. In LX Ser most of the variables are not highly correlated, however in QU Vul several of the variables show strong correlation. As noted before one of the stronger correlations is between α and the disk radius. This is because as the disk radius increases less of the disk is being eclipsed by the secondary star so less light is being eclipsed. In order to compensate for this α must increase resulting in a hotter center of the disk, thus the same fractional amount of light is being eclipsed.

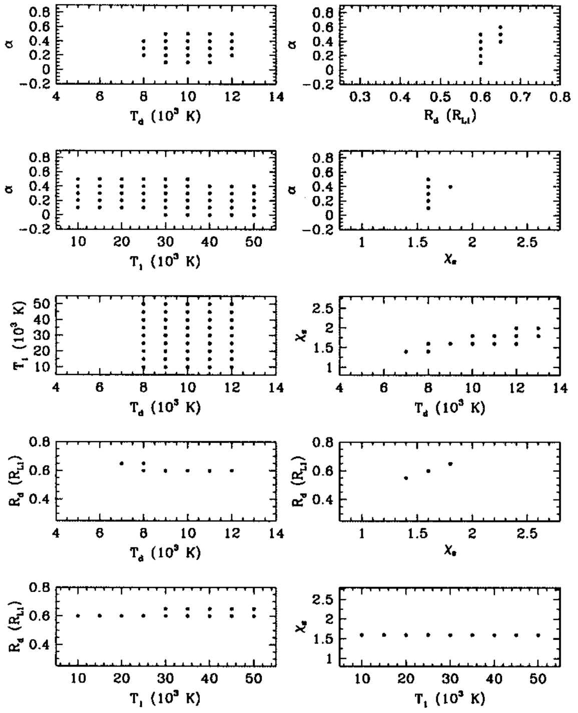

Figure 5: LX Ser Variable correlations

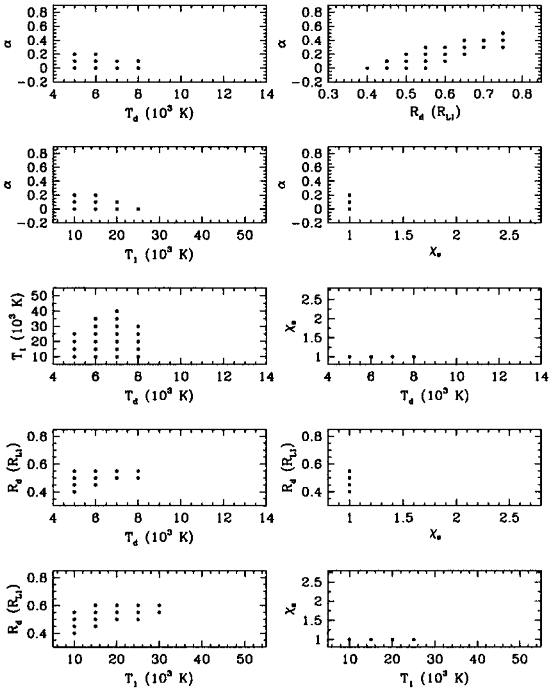

Figure 6: QU Vul Variable correlations

Conclusions

We find that mass ratios of 0.50 for LX Ser and 0.20 for QU Vul represent plausible values for these systems. A disk height (h/r) of 0.10 for LX Ser and 0.05 for QU Vul provide the best fits to the data. In general LX Ser has tightly constrained variables with little correlation between the variables. QU Vul has less well constrained variables, in part due to its high correlation between the disk radius and α. In both systems the accretion disks have a flatter temperature profile than is to be expected for stead state accretion. More data must be taken for QU Vul, specifically in the R band to see why the R band light curve is so shallow. A spectroscopic study done at the same time as future photometric studies could be used to see if indeed excess Hα light is the cause of the shallow eclipse.

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