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Parameter Solutions for the System AP Leonis

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Abstract

The eclipsing binary system AP LEO is an overcontact binary of W UMa type with low surface temperature and a short period of 0.43 days and with a mass ratio well below unity. Monitoring lightcurves published in 1989 and 1993 displayed changes to this contact system uncommon in such a short period. New CCD photometric lightcurves in the V and R bands are presented. O-C values have been computed using thirteen new times of light minimums along with 62 minimums previously published in the literature. A sinusoidal trend is apparent and several authors have interpreted this small amplitude cyclic oscillation to a triple system containing a third component. This shallow sine curve is superposed on an increasing secular period. The most recent spectroscopic study classified the spectral type as F7-8 V. Photometric solutions of the lightcurve and computed parameters are compared with five other investigations of the binary system. The changes in the parameters in such a brief time indicate the orbital period variations are caused by mass transfer from the primary star to the secondary causing a decrease or change in angular momentum loss.

1. Introduction

AP Leonis was discovered as a variable by Stohmeier & Knigge in 1961 and the first photoelectric lightcurves were acquired by Mauder (1972). Zhang (1989) acquired lightcurves in 1985, 1991 and again in 1992 and 1993 and all exhibited a highly variable nature. One spectroscopic and several photometric orbital solutions have been studied by authors since the variations of the lightcurves were reported. All times of minima in the literature since 1961 have been used to construct an O-C diagram in Figure 1.

These O-C values have been computed from visual, photographic and CCD times of minima and contain a large scatter prior to April 1976 and cannot be used to compute a real period change or trend of the system. In this paper to correctly analyze the orbital trend only 62 previous CCD photometric times of minima after April 1976 were used. Thirteen new CCD times of minima, which are symmetric, were computed for this paper and have been added, Figure 2.

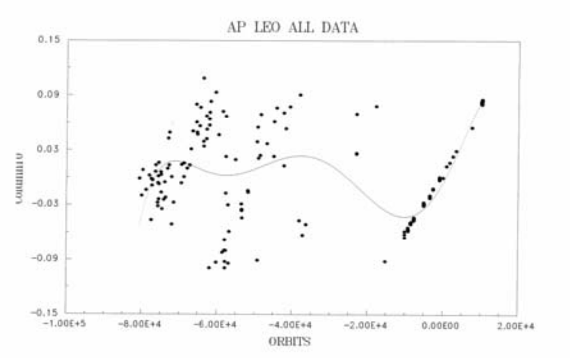

Figure 1. AP LEO All Data

The lightcurves in R and V were analyzed with Binary Maker 3 which uses the W-D code Wilson & Devinney (1971). The V lightcurve is shown in Figure 3. Photometric solutions and parameters were computed based on these symmetric lightcurves. These computed system parameters are compared with five other published papers, Cristescu (1979), Zhang (1992), Lu & Rucinski (1999), Pribulla (2003) and Qian (2007), and data collected by the Hipparcos satellite in Table 1. Accurate spectroscopic mass ratio, M /M = q = 0.297 was obtained by Lu & Rucinski in 1999 and a mass ratio, q = 0.404, was computed from the 2006 lightcurve this paper. Lu & Rucincki also classified the spectral type as F7-8 V type and $M_1 \sin^3$ (i) = 1.368 M_{sun} and M_2 $\sin^3$ (i) = 0.406 M_{sun}.

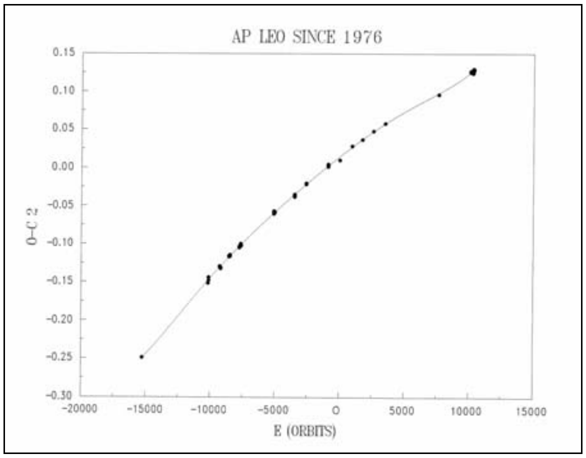

Figure 2. AP LEO Since 1976

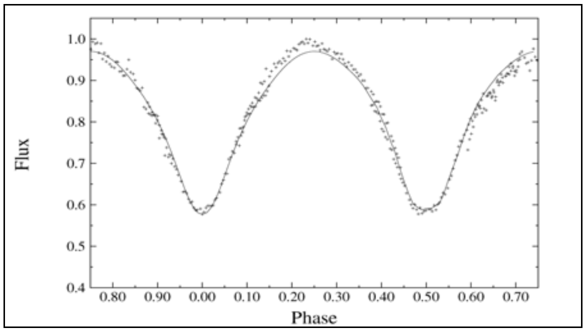

Figure 3. AP LEO Normalized Lightcurve, Polynomial Fit.

2. Observations

AP Leo was observed at two observatories during the 2006 session. The Paradise View Observatory utilizes a Meade 14” LX200GPS with an STL-1301 SBIG camera maintaining 2007mm (79”) focal length and field of view of 1.49 arcsec/pixel. The Kings Canyon Observatory uses a Meade 12” LX200 Classic with an SBIG ST-9XE yielding a 1920mm (75.6”) focal length and FOV of 2.18 arcsec/pixel. All data was obtained in the V and R color system approximating the standard Johnson UBVRI photometric system. Since the comparison stars are on the same CCD images as the variable, extinction corrections for the data were not made.

The lightcurve in the V band is displayed in Figure 3 and is symmetric as is the R band lightcurve. These curves are of typical W UMa-type and the depths of both minima are nearly the same. Data was obtained at the telescope using the MPO Connections Software and reduced using the MPO Canopus Software.

3. Spectroscopic and Photometric Solutions

Previous authors of the AP Leo system have used spots on the components because the lightcurves were not symmetric which required spots to make the modeling coincide with the lightcurves. Some curves also showed the O’Connell effect, O’Connell (1951), where the maximum following the primary minimum is lower than the maximum following the secondary minimum which is usually considered an indication of star spots. The lightcurve in Figure 3 is symmetric, as is the R curve, which did not require incorporating spots to adjust the modeling to fit the curve, which allowed for reliable parameters to be derived. Figure 4 displays the geometrical relationships of the surfaces of AP Leo at phase 0.24. Table 1 list five published parameters for AP Leo for comparison purposes along with some computations by Hipparcos and those parameters computed in this paper.

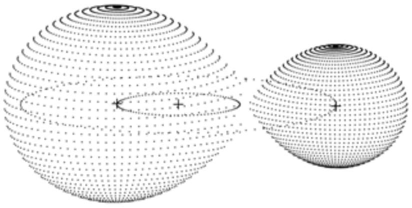

Figure 4. Geometric Structure AP Leo.

The parameters computed from the lightcurves, Figure 3, set the mass ratio to the most accurate spectroscopic values acquired by Lu & Rucinski (1990) of M_2 /M_1 = q = 0.297. Temperature for star 1 eclipsed at primary minimum was set at T_1 = 6150º K for a spectral type F7-8 V, Lu & Rucinski (1999). Limb-darkening coefficients were set at R band x_r = 0.544 and V band x_v = 0.432 and gravity-darkening coefficients g_1 = g_2 = 0.32. The bolometric albedo was set at A_1 = A_2 = 0.5. The adjustments to model the lightcurves were to the orbital inclination (i) and Temperature for star 2 = T_2. The photometric solutions carried out found the inclination of 79.6º which was close to the values derived by others and the temperatures of both stars were close but the derived mass ratio of q = 0.404 was 36% higher than the spectroscopic value. The best modeled photometric mass ratio was determined by measuring the lightcurve residuals using different ratios until the smallest sum of the squares was obtained. This is not the most accurate but is close for modeling purposes. With the mass ratio increasing from $q = 0.297$ to $q = 0.404$ would indicate mass transferring from the primary, star 1, to the secondary, star 2, which could be the cause of the Angular Momentum Gain (AMG) and orbital period increase of AMG = $dP/dt = +0.044$ sec yr $^{-1}$ or a period increase of +4.4 sec century^{-1}. This rapid increase in the mass ratio has occurred in seven years since 1999 and is indicated on the plot of the O-C minimum times, Figure 2, and indicates the system stars are equalizing their masses, which would increase their orbits around each other till their masses were stabilized.

4. Orbital Period Variations

The O-C diagram in Figure 1 includes all the available CCD, photoelectric and visual eclipse times of minimum and were calculated with the linear ephemeris,

$$\text{Min. I} = 2{,}449{,}428.715 + 0.4303482E \text{ days.} \quad \mathbf{(1)}$$

As was stated earlier these times of minimum display a large scatter of up to ± 0.11 days. A polynomial fit indicates a small periodic cyclic sinusoidal change which has been interpreted as being caused by a triple system. These variations appear to occur every 22.5 years. A least-squares solution yields the quadratic ephemeris,

$$\begin{aligned}\text{Min. I} = {} & 2{,}449{,}428.727374 \pm 0.0058 \\ & + (0.43035022 \pm 4.424 \times 10^{-7})\,E \\ & + (2.7985 \pm 2.017 \times 10^{-6}) \times 10^{-11}\,E^2 \text{ days} \quad \mathbf{(2)}\end{aligned}$$

A look at the O-C diagram shows another rapid linear increase in the orbital period which started April 1976 and the data is all from CCD photometric data. Considering the unreliability due to the large scatter of all the data an analysis of this increase in the period was pursued and plotted in Figure 2. The light elements, equation 1, were used to compute quadratic light elements:

$$\begin{aligned}\text{Min. I} = {} & 2{,}449{,}428.715009 \pm 0.0028 \\ & + (0.430341806 \pm 2.467 \times 10^{-7})\,E \\ & + (3.009 \times 10^{-10}) \times 10^{-10}\,E^2 \text{ days} \quad \mathbf{(3)}\end{aligned}$$

This quadratic term reveals a continuous and constant period increase with a rate of $dP/dt = +0.044125$ sec yr^{-1}, which equates to a period increase of 5.11×10^{-6} days yr^{-1}.

5. Conclusion and Discussion

The lightcurve and period of the AP Leo system is highly variable with abrupt cyclic changes and can be classified as an overcontact W UMa-type eclipsing binary. In April 1976 an abrupt increase started and continues at present. The lightcurve indicates this increase is linear, has occurred before and is increasing at a rate of $dP/dE = +6.0 \times 10^{-10}$ days per cycle. This rate is compared to other short-period W UMa-type binaries with long-term continuous increases that have been studied. See Table 2, Wolf (2000), where this computed rate has been placed in descending order. The orbital period change of AP Leo is above the average for W UMa-type overcontact binaries and as Table 2 indicates these systems also have highly variable changes. The mass ratios of these system do not appear to be constant indicating mass transfer thru the Lagrangian point between the stars causing angular momentum gain or loss which in turn effects the orbital time of the system.

If a third body is effecting the system as some studies indicated than further investigations with lightcurves will indicate shortly a decrease in the orbital period and overtime will confirm a third body system.

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

PARAMETER	**CRISTESCU et al. (1979)**	**ZHANG et al. (1992)**	**Lu & Rucinski (1999)**	**QIAN et al. (2007)**	**PRIBULLA et al. (2003)**	**SNYDER THIS PAPER**	**HIPPARCOS (1997)**
Mass Ratio (solar units) q (M2/M1)	0.211	0.3013	0.297	0.297	0.078	0.404	
Omega 1				2.4134		2.586110	
Omega 2				2.4134		2.657630	
Omega inner		2.4648		2.4596		2.657630	
Omega outer		2.2820		2.2743		2.419230	
Fillout 1 %		23.5		24.9	0.23	.30	0.24
a1			2.237				
a2			0.665				
Mass (solar units) Primary			1.368		1.774		
Mass (solar units) Secondary			0.406				
Temperature (K) Primary	6608	6000		6150	6000	6250	
Temperature (K) Secondary	6586	6074		6201	6074	6200	
Orbital inclination (deg)	83.131	79.863		77.54	79.9	79.6	
Surface gravity (cm/s^2)	0.25	0.32		0.32		0.32	
x1 R				0.544		0.47	
x1 V	0.6			0.642		0.63	
x2 R				0.544		0.432	
x2 V	0.6			0.642		0.595	
Spectral type 1	G0		F7-8 V				
Spectral type 2	G2						

Table 1. Parameter Solutions AP LEO.

BINARY SYSTEM	**dP/dE x 10^{-10} days / cycle**
AP AUR	**18.13**
BX DRA	**11.12**
XY BOO	**6.20**
UZ LEO	**6.07**
AP LEO	**6.00**
V839 OPH	**3.46**
AH VIR	**2.66**
GO CYG	**2.26**
V401 CYG	**1.48**
441 BOO	**1.24**
DK CYG	**1.15**
CT ERI	**1.02**

Table 2. Rate of Long-Term Continuous Increase of Period W Uma-Type.

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