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V881 PERSEI – A SPOTTED, DETACHED ECLIPSING BINARY

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The optical variability of V881 Per [= GSC 2846-0404 = 1RXS J025952.4+380149, RA = $02^h59^m53^s.12$, Dec = $+38°01'48''.3$ (J2000)] was discovered as a by-product of the first Robotic Transient Search Experiment (ROTSE-1). The results were released in the Northern Sky Variability Survey (Wozniak, et al., 2004, available from SkyDOT – see reference below). The star was previously identified as a possible optical counterpart to an x-ray source (Li and Hu, 1998) but there seems to be no confirmation of that association since then. Follow-up observations of some 131 eclipsing systems – including V881 Per – by Otero et al. (2004) yielded improved light elements (HJD_0, Period) and V881 Per was designated as EW/KW. The system was then re-discovered as variable by Norton et al. (2007) from their SuperWASP photometric survey; they seem to have been unaware of the earlier discovery. They did, however, list the system as Pre-Main Sequence (PMS) and gave its V magnitude as 11.09.

Since the initial epoch, in 1999, by Otero et al. (2004), six times of minima have been determined by the author (4 have been previously published [Nelson, 2011a] and 2 are newly-reported here in Table 1).

Table 1: Newly determined times of minima for V881 Per

HJD−2400000	Error (days)	Type	Filter
55835.8376	0.0003	I	R
55848.8141	0.0002	II	R

The data are insufficient to conclude anything about possible period variation but do serve to refine the period (see Figure 1). The following elements were used:

$JD_{\rm hel} Min I = 2455848.6207 + 0.3873768(4)E$

See Nelson (2011b – updated annually) for the latest data and $O - C$ fit. Since the system has never had a full analysis, it was added to the author's observing programme.

A total of 118 frames in V, 116 in R_C (Cousins) and 126 in the I_C (Cousins) band were obtained by the author at his private observatory in Prince George, BC, Canada in July and September of 2010. (The telescope was a 33 cm f/4.5 Newtonian on a Paramount ME mount; the camera was an SBIG ST-7XME. See Nelson (2004) for more details.)

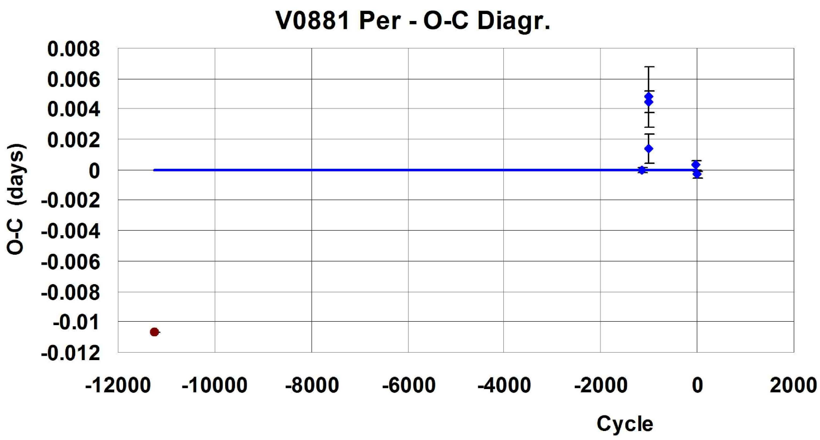

Figure 1. $O-C$ plot for V881 Per

Table 2: Details of variable, comparison and check stars.

Type of target	GSC 2846-	R.A. J2000	Dec. J2000	V (Tycho) Mags	$B-V$ Mags
Variable	0404	$2^{\rm h}59^{\rm m}53.^{\rm s}049$	$38^\circ01'48.''57$	10.69	1.398
Comparison	1254	$2^{\rm h}59^{\rm m}46.^{\rm s}874$	$38^\circ00'48.''67$	11.03	—
Check	0138	$2^{\rm h}59^{\rm m}54.^{\rm s}067$	$37^\circ56'42.''32$	11.33	—

Standard reductions were then applied. The comparison and check stars are listed in Table 2 (coordinates and V magnitudes are from the GSC catalogue, whereas the $B-V$ colour index is computed from the $V-R$ colour index taken from Norton et al., (2007) by the relation $(B-V) = 1.97(V-R) - 0.08$ due to Skiff (1998).

In September and October of 2010 the author took 10 medium resolution spectra at the Dominion Astrophysical Observatory (DAO) in Victoria, British Columbia, Canada using the Cassegrain spectrograph at the Plaskett 1.82 m telescope. The grating (#21181) was 1800 lines/mm, blazed at 5000 Å and used in first order, reciprocal linear dispersion = 10 Å/mm, resolving power = 10000. The camera was the SITe-2. The spectral range covered was from 5000 to 5260 Å, approximately.

The author then used the Rucinski broadening functions (Rucinski, 2004) to obtain radial velocity (RV) curves (see Nelson et al. (2006) and Nelson (2010b) for details). A log of DAO observations and RV results is presented in Table 3. The results were corrected 7.5% up in this case to allow for the small phase smearing in the following way: the RVs were divided by the factor $f = \frac{\sin X}{X}$ (where $X = \frac{2\pi t}{P}$ and t=exposure time, P=period). For spherical stars, the correction is exact; in other cases, it can be shown to be close enough for any deviations to fall below observational errors. This matter will be fully explored in a forthcoming paper.)

The author used the 2004 version of the Wilson-Devinney (WD) light curve and radial velocity analysis program with Kurucz atmospheres (Wilson and Devinney, 1971, Wilson, 1990, Kallrath et al., 1998) as implemented in the Windows front-end software WDwint (Nelson, 2010a) to analyze the data. To get started, a spectral type K0 (Li and Hu, 1998) and a temperature $T_1 = 5150 \pm 60$ K were used; interpolated tables from Cox (2000) gave $\log g = 4.476$; an interpolation program by Terrell (1994, available from Nelson 2010a)

Table 3: Log of DAO observations

DAO Image #	Mid Time (HJD−2400000)	Exposure (sec)	Phase at Mid-exp	V_1 (km/s)	V_2 (km/s)
17229	55466.9424	3600	0.702	143.6	−159.8
17252	55468.8752	3600	0.691	122.3	−178.8
17267	55469.0408	3600	0.118	−100.3	104.1
17283	55469.8306	3600	0.157	−132.1	148.1
17289	55469.9044	3600	0.347	−132.1	148.1
17318	55470.8482	3600	0.784	117.8	169.2
17330	55471.0065	3600	0.192	−142.7	171.4
17332	55471.0491	3600	0.302	−136.2	161.1
17371	55473.9191	1004	0.711	127.8	−166.6
17482−4	55475.8480	3102	0.690	131.7	−166.5

Table 4: Limb darkening values from Van Hamme (1993)

Band	x1	x2	y1	y2
Bol	0.646	0.628	0.170	0.151
V	0.794	0.797	0.140	0.016
Rc	0.729	0.753	0.187	0.104
Ic	0.642	0.667	0.1995	0.151

gave the Van Hamme (1993) limb darkening values; and finally, a logarithmic (LD=2) law for the extinction coefficients was selected, appropriate for temperatures < 8500 K (ibid.). (The stated error in T_1 corresponds to one half spectral sub-class.)

Mindful of the EW/KW designation (Otero, et al., 2004), the author started with mode 3 (overcontact). No fit was possible until he shifted to mode 5 (semi-detached – Algol) and mode 2 (detached). However, since an Algol system (containing as it does an evolved component) is unlikely to exist in the midst of a star-forming region, mode 2 was adopted. In any case, the latter gave better results.

Convergence by the method of multiple subsets was reached in a small number of iterations. Convective envelopes for both stars were used, appropriate for cooler stars (hence values gravity exponent, g = 0.32 and albedo, A = 0.500 were used for each). The limb darkening coefficients are listed in Table 4.

Early on, it was noted that the maxima between eclipses were unequal. This is the O'Connell effect (Davidge and Milone, 1984, and references therein) and is usually explained by the presence of one or more starspots. Accordingly, one was added first to star 1, but this gave a poor fit. Moving the spot to star 2 eventually gave a good agreement, calculated with observed.

The model is presented in Table 5. (Note that the uncertainty in temperature T_1 corresponds to one half a spectral sub-class, as noted before; this error in T_1 – when added statistically to the WD stated error in T_2 – yields a combined error of 65 K for T_2. In view of the uncertainty in spectra class, these errors are likely underestimated.) The light curve data and the fitted curves are depicted in Figure 2.

The presence of third light was tested for, but found not to be significant.

The RVs are shown in Fig. 3. A three dimensional representation from Binary Maker 3 (Bradstreet, 1993) is shown in Fig. 4.

Table 5: Wilson-Devinney parameters

WD Quantity	Value	error	Unit	W-D Quantity.	Value	error	Unit
Temperature T_1	5150	60	K	Potential Ω_1	3.675	0.017	—
Temperature T_2	4576	65	K	Potential Ω_2	3.412	0.019	—
$L_1/(L_1+L_2)$ (V)	0.6824	0.003	—	$q = M_2/M_1$	0.7928	0.0073	—
$L_1/(L_1+L_2)$ (R_C)	0.6513	0.003	—	Inclination, i	61.96	0.23	deg
$L_1/(L_1+L_2)$ (I_C)	0.6298	0.003	—	r_1 (pole)	0.3419	0.0021	orb. rad.
Semi-maj. axis a	2.793	0.017	Sol. rad.	r_1 (point)	0.3936	0.0054	orb. rad
V_γ	−4.0	0.75	km/s	r_1 (side)	0.3353	0.0025	orb. rad
Spot co-latitude	90	[fixed]	deg	r_1 (back)	0.3736	0.0033	orb. rad
Spot longitude	294	5	deg	r_2 (pole)	0.3359	0.0008	orb. rad
Spot radius	33.5	0.5	deg	r_2 (point)	0.4444	0.0027	orb. rad
Spot temp factor	0.8985	0.0077	—	r_2 (side)	0.3517	0.0008	orb. rad
Phase shift	0.0063	0.0005	—	r_2 (back)	0.3828	0.0008	orb. rad
$\Sigma\omega^2_{\rm res}$	0.00616	—	—				

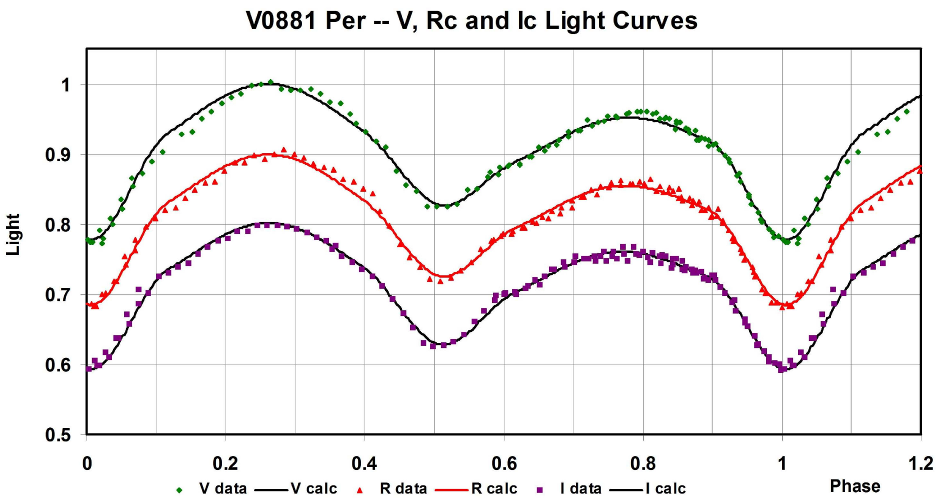

Figure 2. V881 Per: V, R_C, and I_C Light Curves – Data and WD Fit

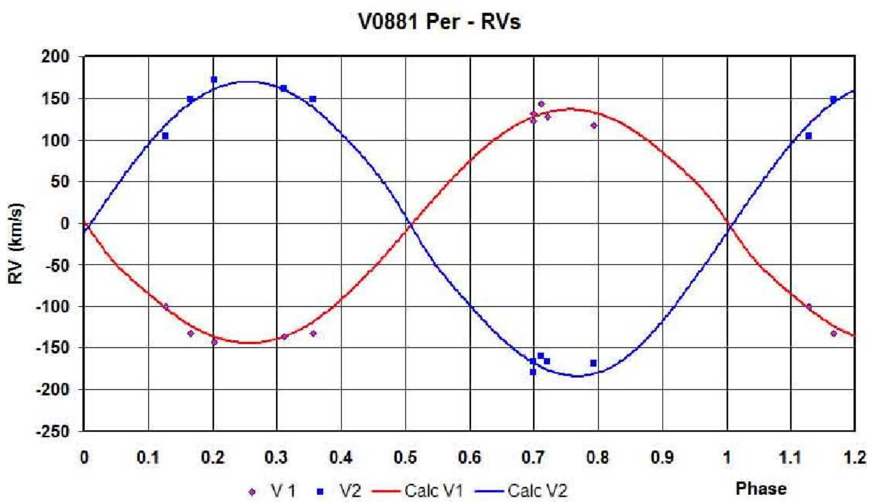

Figure 3. V881 Per: Radial Velocity Curves – Data and WD Fit.

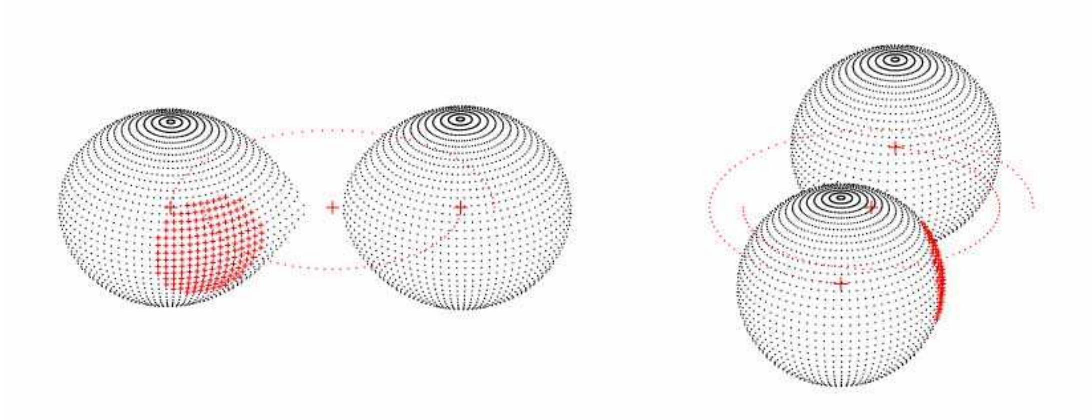

Figure 4. Binary Maker 3 representation of the system – at phases 0.75 and 0.97.

Table 6: Fundamental parameters

Quantity	Value	Error	unit
Temperature, T_1	5150	60	K
Temperature, T_2	4576	65	K
Mass, M_1	1.090	0.012	M_0
Mass, M_2	0.864	0.012	M_0
Radius, R_1	1.00	0.005	R_0
Radius, R_2	1.00	0.005	R_0
$M_{\rm bol}$, 1	5.29	0.11	mag
$M_{\rm bol}$, 2	5.80	0.11	mag
$\log g_1$	4.48	0.004	cgs
$\log g_2$	4.37	0.008	cgs
Luminosity, L_1	0.63	0.06	L_0
Luminosity, L_2	0.39	0.04	L_0
Distance, r	71	9	pc

The WD output fundamental parameters and errors are listed in Table 6. Most of the errors are output or derived estimates from the WD routines. In estimating the distance, galactic extinction was allowed for using the formula $A = 3E(B-V) = R[(B-V)_{\rm data} - (B-V)_{\rm tables}]$.

In conclusion, the fundamental parameters of this system have been determined. As to the suggestion that V881 Per might be a weak-lined T Tauri star (WTTS), there is little in the way of observables in this study that would either support or rule out the possibility (see Basri 2009, for a discussion of WTTS observable characteristics). The only things in favour would be the starspot, the late spectral type and the slight over-luminosity. Against that is the fact that erratic variations in brightness were not observed. Also, lithium (or any other) emission lines were not observed in the spectral range observed, although emission lines are more a characteristic of classical T Tauri behaviour and – while commonly seen for these stars – are not essential for the identification of the type.

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