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V1061 Tauri: Analysis of a Newly Discovered Eclipsing Binary

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ABSTRACT. We present the first light curve of the newly discovered eclipsing binary V1061 Tauri (HD 31679), consisting of 376 observations in the V passband. The primary eclipse appears to be flat bottomed, indicating a total eclipse, but the eclipse is only 0.35 mag deep. An examination of more than 600 Harvard College Observatory patrol plates yielded 30 times of primary minimum, and we present an ephemeris for the system. Analysis of the light curve with the Wilson–Devinney program reveals that the system may contain a large amount of third light, the origin of which is presently unknown.

1. INTRODUCTION

The eclipsing nature of V1061 Tauri (HD 31679, BD +24°719) was recently discovered by Kaiser (1990). The spectral type of the primary is listed as B5 in the HD catalog, and the star is located at $\alpha=4^{\rm h}\ 55^{\rm m}\ 50^{\rm s}$ and $\delta=24°\ 25'\ 14''$ (1950). Preliminary observations by Williams et al. (1990) showed well-defined eclipses and a large amount of ellipsoidal variation, although the light curve was incomplete, most noticeably at primary minimum. The authors also published a preliminary ephemeris showing that the system had a period of about 1.38 days.

In this paper, we report new observations of the system with more complete coverage, especially at primary minimum, which appears to be a total eclipse. If the eclipse is indeed total, then a large amount of third light is necessary to accurately model the light curve. We also discuss a partial-eclipse solution that does not require third light.

2. OBSERVATIONS

The photoelectric observations listed in Table 1 were obtained by D.B.W. with a 28-cm Schmidt-Cassegrain telescope and Optec SSP-3 solid-state photometer. All measures were made through the V filter using standard differential techniques. Atmospheric extinction was measured explicitly on some nights and estimated using seasonal mean values on the remaining nights. The observing site on the outskirts of a major city suffered from significant skyglow.

The comparison star was 98 Tauri. Measures of the check star HR 1575 on 11 nights indicated a constant difference (check–comparison) of $\Delta V=+0.536$, the standard deviation of a single observation being ± 0.005. The variable is almost 2 mag fainter than the composition and shows significantly more scatter. Each observation of the variable has been corrected for differential extinction and transformed to V of the UBV system using the color difference (in the sense variable–comparison) $\Delta(B-V)=+0.34$ reported by Williams et al. (1990).

Single-night photometry provided coverage of both branches of one primary and one secondary minimum. The times of mid-eclipse, determined by the tracing-paper method, are listed in Table 2. The image of V1061 Tau was also examined by D.B.W. on more than 600 Harvard College Observatory patrol plates exposed during the intervals 1900–1950 and 1976–1989. Normally, variations of less than 0.4 mag would be difficult to define from simple photographic estimates. In this case, however, nearby comparison stars closely matched the variable at maximum and minimum, making the detection of minima more certain than would otherwise be possible.

A phase plot of these observations clearly distinguished the primary and secondary minima. This plot was used to identify 30 times of faintest observations during primary minimum, which are listed in Table 3. The 2.3-h interval of constant light at minimum, plus phase smearing from the long exposure times, and the accidental errors of estimation produce a large uncertainty in the times of the individual plate minima. However, the number of minima and the extended time span of the observations permit the period to be determined with reasonable precision. A least-squares solution of the 30 times of minima from Harvard plates (weight =0.05) plus the two photoelectric minima (weight=1.0) yields the following ephemeris:

$$\text{Primary Minimum}=\text{HJD } 2449017.571(20) + 1^{\rm d}.3852189(11)E,$$

where the numbers in parentheses represent the mean errors in the last two digits of the quantities. As seen in Fig. 1, the O−C plot does not reveal significant variation of the period during the past 90 years, within the large scatter of the available data.

TABLE 1
Observations of V1061 Tauri

HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV	HJD 2400000+	ΔV
47869.7375	2.211	47954.6038	2.166	48323.5486	2.501	48983.7462	2.281	47943.5738	2.187	48235.6898	2.374	48983.5704	2.310	49020.5250	2.186
47869.7409	2.176	47954.6062	2.185	48323.5524	2.480	48983.7476	2.283	47943.5751	2.169	48235.6917	2.362	48983.5730	2.321	49020.5276	2.190
47869.7441	2.195	47954.6076	2.172	48323.5692	2.497	48983.7500	2.266	47943.5795	2.148	48235.6944	2.344	48983.5742	2.318	49020.5291	2.185
47869.7629	2.188	47954.6102	2.193	48323.5707	2.485	48983.7515	2.266	47943.5809	2.148	48235.6961	2.346	48983.5767	2.327	49020.5417	2.183
47869.7645	2.191	47954.6116	2.181	48323.5736	2.491	48983.7539	2.275	47943.5984	2.167	48235.7105	2.315	48983.5780	2.321	49020.5431	2.194
47869.8251	2.289	47971.5467	2.184	48323.5753	2.485	49017.5080	2.369	47943.5997	2.143	48235.7124	2.315	48983.5903	2.364	49020.5458	2.215
47869.8265	2.285	47971.5482	2.173	48323.5787	2.497	49017.5096	2.378	47943.6021	2.171	48235.7150	2.315	48983.5916	2.358	49020.5474	2.183
47869.8290	2.285	47971.5508	2.187	48323.5803	2.484	49017.5123	2.402	47943.6034	2.162	48235.7167	2.298	48983.5942	2.380	49020.5500	2.188
47877.6342	2.373	47971.5524	2.179	48330.5421	2.511	49017.5138	2.396	47943.6057	2.155	48235.7195	2.290	48983.5958	2.369	49020.5515	2.188
47877.6382	2.336	47971.5548	2.213	48330.5457	2.486	49017.5168	2.419	47943.6084	2.149	48235.7213	2.297	48983.5983	2.373	49020.5539	2.183
47877.6396	2.297	47971.5563	2.191	48330.5473	2.483	49017.5191	2.413	47943.6187	2.133	48237.6688	2.479	48983.5997	2.368	49020.5555	2.175
47877.6741	2.237	47976.5551	2.402	48330.5502	2.497	49017.5217	2.407	47943.6200	2.135	48237.6705	2.481	48983.6021	2.385	49020.5739	2.174
47877.6756	2.233	47976.5566	2.370	48330.5524	2.478	49017.5232	2.412	47943.6246	2.132	48237.6733	2.500	48983.6036	2.394	49020.5754	2.171
47877.6783	2.244	47976.5628	2.426	48330.5552	2.484	49017.5301	2.439	47943.6260	2.141	48237.6749	2.487	48983.6148	2.394	49020.5776	2.168
47877.6797	2.235	47976.5644	2.392	48330.5568	2.479	49017.5317	2.447	47943.6521	2.135	48237.6785	2.501	48983.6162	2.399	49020.5791	2.158
47942.5273	2.251	47976.5700	2.401	48330.5713	2.474	49017.5342	2.442	47943.6535	2.138	48237.6803	2.499	48983.6189	2.397	49020.5814	2.171
47942.5288	2.261	47976.5715	2.405	48330.5746	2.482	49017.5357	2.450	47943.6558	2.136	48237.6873	2.483	48983.6205	2.375	49020.5828	2.156
47942.5300	2.260	47976.5740	2.409	48330.5763	2.466	49017.5421	2.465	47943.6571	2.139	48237.6890	2.494	48983.6233	2.384	49020.5982	2.154
47942.5321	2.265	47976.5754	2.392	48330.5794	2.435	49017.5437	2.482	47943.6593	2.135	48237.6916	2.496	48983.6247	2.392	49020.5997	2.139
47942.5332	2.266	47976.5780	2.417	48330.5811	2.418	49017.5534	2.484	47943.6610	2.129	48237.6933	2.484	48983.6272	2.398	49020.6022	2.166
47942.5339	2.280	47976.5796	2.394	48330.5842	2.430	49017.5550	2.491	47953.5412	2.179	48237.7057	2.483	48983.6285	2.392	49020.6036	2.145
47942.5472	2.294	47976.5825	2.408	48330.5859	2.433	49017.5579	2.501	47953.5425	2.179	48237.7074	2.484	48983.6462	2.392	49020.6061	2.149
47942.5485	2.316	47976.5839	2.425	48330.6192	2.320	49017.5595	2.482	47953.5448	2.199	48237.7104	2.504	48983.6477	2.375	49020.6076	2.144
47942.5493	2.318	47976.5864	2.439	48330.6229	2.308	49017.5622	2.473	47953.5462	2.192	48237.7122	2.492	48983.6499	2.386	49020.6098	2.137
47942.5519	2.313	47976.5880	2.398	48330.6265	2.308	49017.5638	2.459	47953.5486	2.210	48237.7148	2.507	48983.6513	2.388	49020.6113	2.130
47942.5532	2.310	47977.5498	2.164	48330.6299	2.304	49017.6436	2.481	47953.5501	2.205	48237.7166	2.478	48983.6536	2.391	49023.5159	2.135
47942.5539	2.323	47977.5513	2.169	48331.5880	2.152	49017.6452	2.444	47953.5613	2.202	48237.7199	2.493	48983.6549	2.397	49023.5174	2.112
47942.5719	2.374	47977.5538	2.143	48331.5916	2.134	49017.6452	2.470	47953.5628	2.205	48237.7215	2.488	48983.6575	2.405	49023.5198	2.129
47942.5732	2.377	47977.5554	2.134	48331.5951	2.135	49017.6476	2.475	47953.5666	2.210	48290.5329	2.204	48983.6588	2.405	49023.5213	2.120
47942.5773	2.399	47977.5692	2.137	48331.6014	2.135	49017.6492	2.451	47953.5680	2.220	48290.5364	2.197	48983.6767	2.388	49023.5236	2.119
47942.5787	2.394	47977.5706	2.123	48331.6030	2.123	49017.6517	2.453	47953.5863	2.230	48290.5403	2.190	48983.6780	2.396	49023.5250	2.135
47942.5974	2.474	47977.5732	2.140	48331.6059	2.139	49017.6532	2.423	47953.5877	2.207	48290.5441	2.237	48983.6807	2.398	49023.5277	2.129
47942.5987	2.478	47977.5747	2.126	48331.6095	2.124	49017.6555	2.440	47953.5925	2.216	48290.5738	2.153	48983.6821	2.374	49023.5427	2.115
47942.6009	2.491	47978.5457	2.256	48331.6111	2.118	49017.6571	2.422	47953.5938	2.225	48290.5755	2.158	48983.6846	2.390	49023.5453	2.144
47942.6023	2.491	47978.5470	2.267	48348.5704	2.487	49017.6702	2.387	47954.5433	2.265	48290.5783	2.163	48983.6862	2.393	49023.5468	2.140
47943.5304	2.183	47978.5497	2.271	48348.5730	2.484	49017.6717	2.371	47954.5450	2.231	48290.5799	2.150	48983.6889	2.383	49023.5490	2.121
47943.5317	2.189	47978.5512	2.257	48348.5757	2.473	49017.6742	2.376	47954.5474	2.216	48290.5826	2.146	48983.6903	2.381	49023.5506	2.136
47943.5369	2.195	47978.5543	2.273	48570.8418	2.415	49017.6768	2.367	47954.5489	2.207	48290.5843	2.148	48983.7174	2.351	49023.5529	2.120
47943.5382	2.186	47978.5558	2.290	48570.8453	2.380	49017.6792	2.360	47954.5513	2.216	48290.5873	2.149	48983.7190	2.362	49023.5544	2.116
47943.5404	2.186	47978.5668	2.334	48570.8488	2.401	49017.6812	2.345	47954.5528	2.214	48290.5891	2.154	48983.7217	2.341	49023.5689	2.143
47943.5416	2.181	47978.5683	2.314	48570.8521	2.390	49017.6840	2.348	47954.5718	2.210	48290.5956	2.162	48983.7233	2.322	49023.5704	2.129
47943.5509	2.164	47978.5712	2.339	48570.8554	2.389	49017.6856	2.330	47954.5726	2.192	48290.5973	2.141	48983.7259	2.330	49023.5727	2.156
47943.5522	2.194	47978.5729	2.339	48570.8589	2.399	49020.5154	2.203	47954.5749	2.205	48298.5322	2.268	48983.7272	2.342	49023.5743	2.142
47943.5547	2.176	48235.6765	2.416	48570.8619	2.397	49020.5172	2.213	47954.5764	2.187	48298.5358	2.258	48983.7298	2.338	49023.5772	2.143
47943.5559	2.170	48235.6784	2.401	48983.5652	2.291	49020.5196	2.215	47954.5789	2.222	48298.5374	2.261	48983.7312	2.322	49023.5787	2.142
47943.5583	2.183	48235.6813	2.388	48983.5667	2.313	49020.5210	2.204	47954.5804	2.231	48298.5403	2.282	48983.7423	2.292	49023.5812	2.151
47943.5597	2.171	48235.6830	2.373	48983.5691	2.320	49020.5234	2.211	47954.6024	2.177	48323.5446	2.492	48983.7437	2.294	49023.5827	2.136

3. PHOTOMETRIC SOLUTION

Preliminary fits to the light curve were made using Terrell's PC Interface program, which is a front end for the light-curve (LC) portion of the Wilson–Devinney (Wilson 1979; Wilson 1990) program.[1] It was quickly discovered that a total eclipse could be produced for the primary minimum only if there were large amounts of third light in the observations. With third light, a reasonable fit was achieved and

TABLE 2
Epochs of Minimum Light from Photoelectric Photometry (Weight=1.0)

Primary	Secondary
2449017.5912 +/- 0.0009 (s.e.)	2448983.6523 +/- 0.0010 (s.e.)

[1]Contact the lead author for distribution information on the PC Interface.

TABLE 3
Epochs of Primary Minimum from Harvard Patrol Plates (Weight=0.05)

HJD-2400000	HJD-2400000
16061.805	22321.667
16417.769	23019.824
16460.748	23799.670
16823.727	24942.552
17528.776	27345.892
17977.599	33548.859
18682.685	42786.724
18988.745	43954.527
19326.787	45702.754
19337.866	46079.574
19412.671	46378.816
19725.685	46709.824
20092.790	46788.662
20398.880	46845.582
21217.691	47593.551

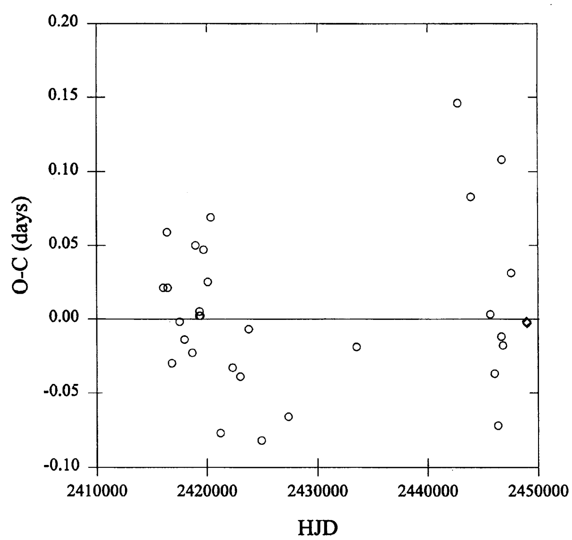

FIG. 1—O-C diagram for V1061 Tauri, based on the minima listed in Tables 3 and 4, and the ephemeris given in the text. Photographic values are plotted as circles and photoelectric ones as diamonds.

TABLE 4
Photometric Elements of V1061 Tauri for Total Primary Eclipse

Parameter	Value	Probable Error
i	89°.9	3°.0
g_1	1.0	-
g_2	1.0	-
A_1	1.0	-
A_2	1.0	-
x_1	0.58	-
x_2	0.58	-
T_1	15,000 K	-
T_2	12,265 K	46 K
q	2.407	0.010
Ω_1	5.781	0.015
$L_1/(L_1+L_2)$	0.41	-
l_3[a]	0.440	0.004
r_1 (pole)	0.288	0.001
r_1 (side)	0.301	0.001
r_1 (back)	0.336	0.002
r_2 (pole)	0.432	0.001
r_2 (side)	0.462	0.002
r_2 (back)	0.490	0.002

the parameters were then input into the differential-corrections (DC) portion of the WD program. Initially, no assumptions were made concerning lobe filling, but corrections to the parameters led to the situation where the system was in an overcontact configuration, and we continued the iterations in the appropriate program mode (Mode 3).

The parameters adjusted were Ω_1 (modified surface potential of the primary, which is the value for the common envelope in an overcontact configuration), L_1 (monochromatic luminosity of the primary), T_2 (mean surface temperature of the secondary), q (mass ratio, secondary to primary), i (orbital inclination), and l_3 (third light). Correlations among the parameters were relieved by using the Method of Multiple Subsets as discussed by Wilson and Biermann (1976).

Certain parameters were held fixed at their expected theoretical values. The mean surface temperature of the primary was set equal to 15,000 K based on the B5 spectral type. The gravity-darkening exponents and bolometric albedos were set equal to unity as expected for stars with radiative envelopes. Limb-darkening coefficients were taken from Van Hamme (1993).

The DC program achieved a good fit to the observations as can be seen in Fig. 2. The final parameters for this solution are given in Table 4. The system is in an overcontact configuration, with the secondary component being significantly more massive (q=2.4). Naturally one would like to have radial velocities to confirm the mass ratio, but two circumstances increase the confidence in the photometrically determined mass ratio—the overcontact configuration combined with a total eclipse. For a total eclipse, the ratio of the stellar radii is strongly determined. Since we also have the constraint that the surface potentials are equal, the result is a strong determination of the mass ratio because the ratio of

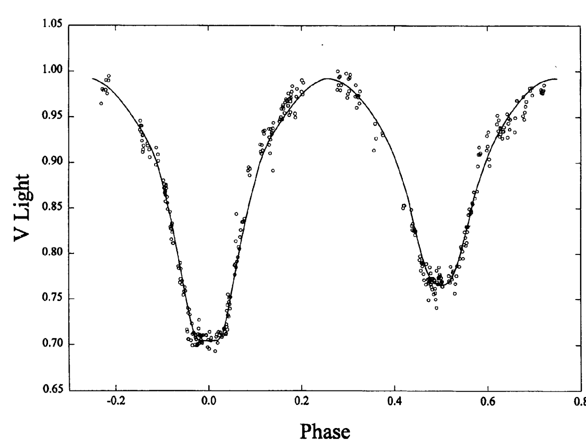

FIG. 2—V observations of V1061 Tauri with the computed curve from the elements of Table 4 (total eclipse).

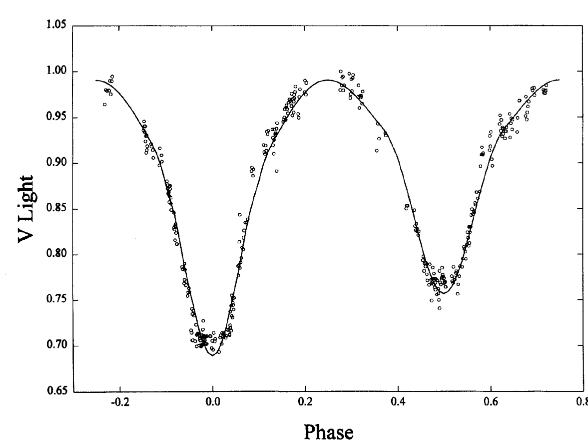

FIG. 3—V observations of V1061 Tauri with the computed curve from the elements of Table 5 (partial eclipse).

TABLE 5
Photometric Elements of V1061 Tauri for Partial Primary Eclipse

Parameter	Value	Probable Error
i	69°.8	0°.3
g_1	1.0	-
g_2	1.0	-
A_1	1.0	-
A_2	1.0	-
x_1	0.58	-
x_2	0.58	-
T_1	15,000 K	-
T_2	12,330 K	68 K
q	0.496	0.006
Ω_1	2.943	0.020
Ω_2	2.945	0.025
$L_1/(L_1+L_2)$	0.75	-
l_3	0.0	-
r_1 (pole)	0.403	0.003
r_1 (point)	0.493	0.008
r_1 (side)	0.425	0.003
r_1 (back)	0.449	0.004
r_2 (pole)	0.286	0.004
r_2 (point)	0.352	0.014
r_2 (side)	0.297	0.005
r_2 (back)	0.323	0.008

the radii is uniquely determined by the mass ratio.

Of course, given the scatter of our light-curve data, it is quite possible that the primary eclipse is not total. An attempt was made to fit the light curve with no third light and $q<1.0$. The fit resulted in a detached configuration for the system. The computed curve and observations can be seen in Fig. 3. It is apparent that the fit is much worse than the third-light solution especially at the bottoms of the eclipses. A total primary eclipse cannot be reproduced while simultaneously fitting the eclipse depths and the outside-eclipse variations. Table 5 gives the final parameters for the partial-eclipse solution. Attempts to adjust third light in the partial-eclipse solution always resulted in very small corrections, so no third light was included in the final solution.

4. CONCLUSIONS

V1061 Tauri appears to be a very interesting system since there are relatively few systems known to share a common radiative envelope. Although there may be contamination by third light, the totality of primary minimum, if confirmed by higher-precision observations, would strengthen the light-curve solution. A radial-velocity study of this system would be very useful even if the system is only single lined because we have a well-determined photometric mass ratio in the case of a total eclipse. And, of course, if the system is double lined, that will only strengthen the determination of the mass ratio and the resulting fundamental quantities like the individual masses and radii. Further photoelectric observations in several passbands would also facilitate a simultaneous light and velocity solution. The solution presented here should be judged preliminary until further observations are made. We hope that observers will consider this potentially important system for their radial-velocity and light-curve observing programs.

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