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SPECTROSCOPIC AND PHOTOMETRIC ORBITS OF EE PEGASI

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SPECTROSCOPIC AND PHOTOMETRIC ORBITS OF EE PEGASI

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Abstract

Spectroscopic and photoelectric observations of this binary system made in 1953 and earlier are recorded here. Improved orbital elements have been obtained as compared with those derived by Wellmann and Beyer (1953). The photometric observations were made in three colours, but the individual observations are of low quality. For this reason the means of the three colour observations have been tabulated.

Introduction

The eclipsing system of EE Peg (H.D. 206155, $\alpha(1900)\ 213^h5^m.1$, $\delta(1900)\ 8°44'$) was discovered by Hoffmeister (1935) and has been described as an Algol-type variable. From visual observations by Gomi (1940) a preliminary period of 5.256 days has been found. Both spectroscopic and visual observations by Wellmann and Beyer (1953) have shown that the actual period is half of that derived by Gomi.

Wellmann's orbital elements were based on 44 blue-sensitive spectrograms with a dispersion of 65 A./mm. at $H\gamma$ and on ten red-sensitive plates with a dispersion of 156 A./mm. at $H\alpha$ covering the period from June 12, 1951, to January 5, 1952. Furthermore, with the aid of 211 visual estimates within the same time interval a light-curve was derived.

The present observations were made at the David Dunlap Observatory. The spectroscopic material consisted of 48 plates with a dispersion of 66 A./mm. at $H\gamma$ of which 26 were taken by the late F. S. Hogg in 1936–39. The remaining plates were taken in 1952 and 1953. In addition, the star was observed photoelectrically with the earliest version of a photometer attached to the 19-inch reflector. Because an unstabilized power supply was used and the intensity measures were read off a galvanometer the scatter of individual measurements is larger than expected in photoelectric photometry.

The Spectrographic Orbit

The radial velocity measurements have been summarized in Table I. It gives the plate number, the Julian date of observation and the

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TABLE I

Plate No.	J.D.	Radial Velocity km./sec.	Phase P^{-1}	O−C km./sec.
1081	2428360.776	− 52.4	.844	− 8.1
1094	362.788	−102.9	.601	− 4.5
1160	375.774	− 95.8	.551	− 6.7
1168	377.776	+ 28.2	.312	+ 9.6
1186	380.736	− 40.5	.439	− 7.5
1195	381.723	− 69.9	.814	−11.6
1208	387.706	+ 60.0	.091	− 8.5
1221	389.732	− 27.4	.862	+ 7.9
1296	400.692	+ 46.2	.032	− 5.0
1304	404.711	− 95.5	.563	− 3.8
1315	408.654	+ 50.0	.061	−11.2
1359	425.576	− 89.4	.500	−15.6
1390	431.628	− 54.4	.802	+ 9.0
1422	440.601	+ 51.0	.216	− 9.3
1556	503.456	+ 68.0	.132	− 4.8
1565	510.469	− 72.1	.800	− 7.7
2514	800.697	+ 60.8	.227	+ 4.1
2742	8864.458	− 62.6	.488	+ 6.7
3821	9179.508	− 00.6	.359	+ 5.8
4590	432.843	− 86.8	.749	− 4.2
4714	465.826	+ 24.5	.299	− 0.8
4735	469.744	− 65.0	.790	+ 2.9
4741	470.732	+ 72.0	.166	+ 1.0
4747	472.781	+ 5.4	.945	− 4.0
4753	476.749	− 54.4	.455	+ 1.2
4790	2429486.755	+ 43.0	.262	0.0
19329	2434217.864	− 27.8	.377	−11.4
20151	551.854	− 50.0	.455	+ 5.6
20168	555.853	+ 42.9	.977	+17.2
20177	557.858	− 88.4	.740	− 3.3
20185	561.855	+ 43.3	.260	− 0.5
20193	563.808	+ 46.0	.004	+ 6.0
20203	565.866	− 50.2	.787	+18.6
20223	569.867	+ 28.0	.309	+ 7.8
20297	576.869	+ 16.0	.973	− 8.3
20321	580.875	− 62.0	.497	+10.7
20337	583.874	− 96.6	.638	+ 2.9
20339	584.772	+ 33.9	.980	+ 6.2
20345	586.883	− 64.4	.783	+ 6.6
20352	589.889	− 6.5	.927	− 6.2
20392	600.624	+ 60.5	.012	+17.6
20400	600.866	+ 79.3	.104	+ 8.7

TABLE I—(*Concluded*)

Plate No.	J.D.	Radial Velocity km./sec.	Phase P^{-1}	O−C km./sec.
20405	2434601.668	− 34.4	.409	− 1.1
20410	601.872	− 67.1	.486	+ 1.4
20418	603.891	+ 45.0	.255	− 0.9
20445	609.624	− 48.8	.436	− 2.0
20454	610.810	− 21.0	.887	+ 1.1
20526	2434622.640	− 30.0	.388	− 7.9

radial velocity reduced to the sun. The phase was calculated by means of the formula

$$\text{Phase} = (\text{J.D} - .2400000)P^{-1}$$

where $P^{-1} = 0.3804848$/day corresponding to the period $P = 2.6282253$ days. This period was found from both photometric and spectroscopic data. The last column gives the $O-C$'s.

According to Wellmann the spectral type of EE Peg is A4V. On an average about 15 lines were measured for radial velocity determination including the K line, the calcium line at λ4227, the Mg II line at λ4481, and a large number of iron lines. The hydrogen lines were generally broad and therefore less suitable for accurate measurements.

Preliminary orbital elements have been obtained graphically. For a definitive orbit differential corrections to the elements have been calculated by the method of least squares. The final elements and their mean errors are given in Table II. The velocity curve has been plotted in figure 1.

The calculated velocity curve gives a good representation of the observed velocities by both Wellmann and the writer. However, Wellmann's points exhibit a much larger scatter. The run of the writer's $O-C$'s as a function of time has been plotted in figure 2. The mean value of Wellmann's $O-C$'s has been indicated by an open circle at J.D. 3800. It appears from figure 2 that the earlier $O-C$'s are predominantly negative while the later are positive as shown by the crosses, their mean values. On the other hand, Wellmann's mean of 44 observations is definitely negative. At any rate it would require only a slight adjustment of the adopted period to make the mean $O-C$'s zero.

Photometric Orbit

A single comparison star was used, H.D. 205923 of spectral type A2 and magnitude 8.2 about 40 minutes of arc north of the variable. The

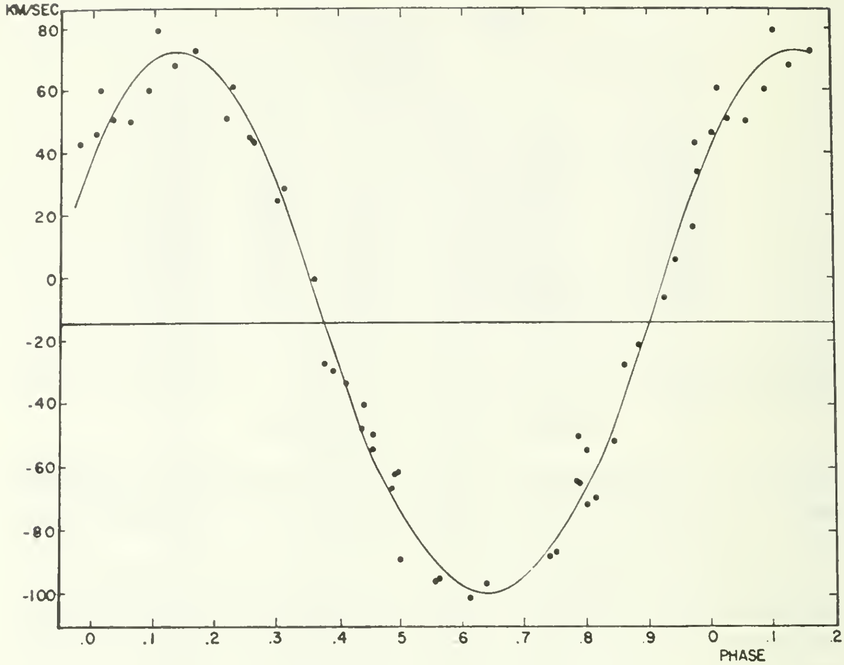

FIG. 1—The velocity curve of EE Pegasi.

observations were made in three colours: blue, green and yellow spectral range. The effective wave-lengths of these colours were λλ4300, 4900 and 5200. Originally the inclusion of two more regions, the UV and the red, was planned; however, the measured deflections were small and the measurements unreliable. Since the photometer had no provision for selective shunting of the galvanometer, the sensitivity of the instrument was adjusted by changing the voltage of the photomultiplier tube on practically every night. Because the

TABLE II

SPECTROGRAPHIC ELEMENTS OF EE PEGASI

Periastron passage	T = 2429486ᵈ408 ± .023
Period	P = 2ᵈ6282253
Velocity of the system	γ = −13·43 km./sec.
Semi-amplitude	K = 86·15 km./sec. ±0.29
Longitude of periastron	ω = 357°71 ± 3°15
Eccentricity	e = 0·03 ± 0·003
Semi-major axis	a sini = 3·11.10^6 km.
Mass-function	f(m) = 0·174 ☉

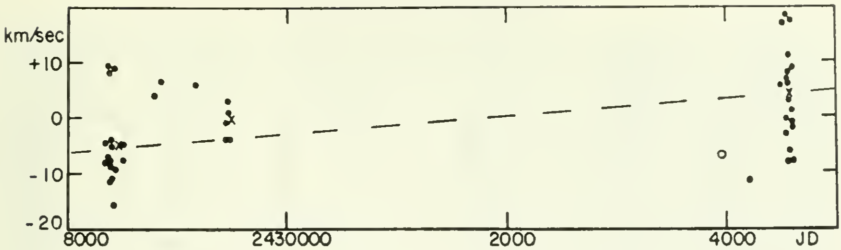

FIG. 2—The run of O – C as a function of time.

colour difference between the variable and the comparison stars is zero and observations were limited to moderate hour angles no correction for differential extinction appeared to be necessary. Also, since the light curves in all three colours appeared to be identical they were combined into a single light curve for which the individual points as a function of phase can be found in Table III. In figure 3 the mean light curve has been plotted, the Δm versus the phase. The latter was computed by the same formula as in the previous section.

TABLE III

J.D.	Phase	Δm	J.D.	Phase	Δm
2434582.677	0.183	−1.272	2434595.744	0.154	−1.263
.693	.189	−1.269	4600.739	.055	−1.272
.713	.193	−1.271	.758	.062	−1.274
.730	.203	−1.276	.775	.069	−1.281
.747	.209	−1.269	.792	.075	−1.275
.762	.215	−1.266	.814	.083	−1.277
4582.779	.222	−1.272	.829	.089	−1.286
4583.739	.587	−1.276	.845	.095	−1.278
.756	.593	−1.276	.863	.102	−1.278
.774	.600	−1.286	4600.881	.109	−1.279
.791	.607	−1.284	4603.733	.194	−1.275
.823	.619	−1.290	.747	.199	−1.275
.839	.625	−1.276	.762	.205	−1.271
4583.857	.632	−1.263	.776	.210	−1.265
4586.638	.690	−1.274	.791	.216	−1.277
.654	.696	—1.268	.804	.221	−1.280
.670	.702	−1.270	.820	.227	−1.272
.686	.708	−1.265	.836	.233	−1.272
4586.704	.715	−1.270	.851	.239	−1.271
4595.687	.133	−1.255	4603.872	.247	−1.264
.708	.141	−1.272	4605.715	.948	−1.272
.729	.149	−1.278	.731	.954	−1.279

TABLE III—*Continued*

J.D.	Phase	Δm	J.D.	Phase	Δm
2434605.748	0.961	−1.278	2434621.644	0.009	−1.283
.764	.967	−1.278	.661	.015	−1.296
.790	.977	−1.280	.680	.023	−1.295
.807	.983	−1.280	.693	.028	−1.288
.826	.990	−1.282	.709	.034	−1.286
4606.629	.296	−1.273	.724	.039	−1.293
4606.648	.303	−1.261	.741	.046	−1.290
.684	.317	−1.273	.756	.051	−1.284
.715	.329	−1.270	.772	.058	−1.272
.730	.334	−1.262	.786	.063	−1.274
.746	.341	−1.246	4622.561	.358	−1.051
.764	.347	−1.199	4622.573	.362	−0.925
.780	.353	−1.132	.588	.368	−0.838
.802	.362	−1.001	.602	.373	−0.762
.818	.368	−0.840	.617	.379	−0.654
.833	.374	−0.688	.633	.385	−0.598
.849	.380	−0.610	.647	.390	−0.601
.866	.386	−0.595	.681	.403	−0.892
4606.881	.392	−0.617	.693	.408	−0.981
4607.724	.713	−1.272	.706	.413	−1.059
.742	.719	−1.272	.720	.418	−1.142
.756	.725	−1.269	.735	.424	−1.200
.771	.730	−1.262	.748	.429	−1.234
.786	.736	−1.264	.763	.435	−1.261
.801	.742	−1.271	.777	.440	−1.270
.819	.749	−1.270	.793	.446	−1.276
4607.835	.755	−1.274	.807	.451	−1.272
4614.764	.391	−0.611	4622.822	.457	−1.270
.779	.397	−0.716	4623.573	.743	−1.260
.795	.403	−0.879	.586	.748	−1.255
.811	.409	−0.972	.602	.754	−1.266
.831	.417	−1.124	.615	.759	−1.267
4614.849	.424	−1.218	.632	.765	−1.262
4618.588	.846	−1.236	.646	.771	−1.273
.602	.851	−1.196	.661	.776	−1.270
.620	.858	−1.155	.681	.784	−1.270
.638	.865	−1.140	.696	.790	−1.270
.652	.870	−1.127	.709	.795	−1.268
.668	.877	−1.091	.722	.799	−1.273
.718	.896	−1.115	.735	.804	−1.276
4618.732	.901	−1.157	.749	.810	−1.258
4621.586	.987	−1.273	.762	.815	−1.266
.600	.992	−1.251	.776	.820	−1.235
.614	.997	−1.266	.805	.831	−1.236
.627	.002	−1.276	4623.818	.836	−1.227

TABLE III—*Continued*

J.D.	Phase	Δm	J.D.	Phase	Δm
2434626.617	0.901	−1.158	2434630.716	0.461	−1.275
.634	.907	−1.223	.729	.465	−1.267
.653	.915	−1.237	.743	.471	−1.272
.669	.921	−1.258	.756	.476	−1.279
.686	.927	−1.248	.772	.482	−1.272
.699	.932	−1.278	.785	.487	−1.270
.712	.937	−1.280	.798	.492	−1.282
.725	.942	−1.284	.812	.497	−1.275
.744	.949	−1.274	4630.827	.503	−1.275
.758	.955	−1.295	4631.580	.789	−1.275
.776	.961	−1.305	.592	.794	−1.281
.791	.967	−1.297	.606	.799	−1.281
.806	.973	−1.278	.620	.805	−1.281
4626.820	.978	−1.279	.641	.813	−1.275
4628.556	.639	−1.276	.656	.818	−1.246
.572	.645	−1.279	.670	.824	−1.257
.591	.652	−1.278	.682	.828	−1.242
.606	.658	−1.275	.697	.834	−1.259
.624	.665	−1.274	.711	.839	−1.229
.640	.671	−1.274	.727	.845	−1.221
.659	.678	−1.290	.740	.850	−1.195
.672	.683	−1.274	.756	.856	−1.172
.686	.688	−1.274	4631.788	.868	−1.116
.697	.692	−1.272	4635.546	.298	−1.266
.708	.697	−1.274	.558	.303	−1.260
.720	.701	−1.264	.575	.309	−1.260
.737	.708	−1.277	.583	.312	−1.256
.753	.714	−1.277	.597	.318	−1.260
.768	.719	−1.274	.611	.323	−1.257
.782	.725	−1.270	.628	.329	−1.260
.797	.730	−1.269	.639	.334	−1.260
.813	.737	−1.283	.656	.340	−1.245
4628.828	.742	−1.262	.667	.344	−1.235
4630.551	.398	−0.753	.680	.349	−1.191
.563	.402	−0.910	.690	.353	−1.153
.577	.408	−1.028	.704	.358	−1.051
.589	.412	−1.100	.717	.363	−0.945
.606	.419	−1.157	.729	.368	−0.858
.619	.424	−1.184	.740	.372	−0.776
.638	.431	−1.234	4635.754	.377	−0.686
.649	.435	−1.262	4637.692	.115	−1.281
.663	.440	−1.261	.704	.119	−1.275
.675	.445	−1.270	.718	.125	−1.272
.687	.450	−1.276	.733	.130	−1.283
.699	.454	−1.270	.763	.142	−1.280

TABLE III—*Concluded*

J.D.	Phase	Δm	J.D.	Phase	Δm
2434637.774	0.146	−1.292	2434647.605	0.886	−1.078
.788	.151	−1.268	.616	.891	−1.110
4638.548	.440	−1.275	.629	.896	−1.124
.562	.446	−1.283	.640	.900	−1.139
.615	.466	−1.265	4647.652	.904	−1.197
.627	.471	−1.261	4648.538	.241	−1.273
.638	.475	−1.261	.550	.246	−1.274
.649	.479	−1.261	.565	.252	−1.278
.663	.484	−1.268	.580	.257	−1.270
.674	.488	−1.269	.613	.270	−1.263
.688	.494	−1.269	.624	.274	−1.270
.699	.498	−1.274	.636	.279	−1.273
.715	.504	−1.274	.642	.281	−1.273
.726	.508	−1.268	.660	.288	−1.273
.738	.513	−1.270	.672	.292	−1.276
.749	.517	−1.275	.686	.298	−1.273
.763	.522	−1.272	.697	.302	−1.266
.774	.526	−1.269	.714	.308	−1.266
4638.788	.532	−1.279	.726	.313	−1.256
4643.545	.342	−1.192	.739	.318	−1.268
.579	.355	−1.090	.752	.323	−1.260
.595	.361	−0.958	.765	.328	−1.262
.609	.366	−0.856	4648.778	.333	−1.273
.620	.370	−0.778	4649.536	.621	−1.273
.631	.374	−0.692	.547	.625	−1.267
.644	.379	−0.627	.562	.631	−1.269
.668	.389	−0.593	.576	.636	−1.266
.680	.393	−0.642	.594	.643	−1.271
.697	.400	−0.754	.606	.648	−1.274
.711	.405	−0.927	.618	.652	−1.268
.724	.410	−1.025	.629	.657	−1.268
.736	.414	−1.119	.648	.664	−1.269
4643.788	.434	−1.260	.660	.668	−1.277
4647.527	.857	−1.193	.674	.674	−1.273
.539	.861	−1.145	.684	.677	−1.274
.552	.866	−1.138	.699	.683	−1.270
.563	.870	−1.116	.713	.689	−1.265
.581	.877	−1.086	4649.727	.694	−1.271
.593	.882	−1.076			

There are 12 epochs of primary minima available including those observed by Wellmann covering a total of 290 periods. These have been listed in Table IV, together with the $O-C$'s based on the period derived by the writer. The systematically decreasing deviations in

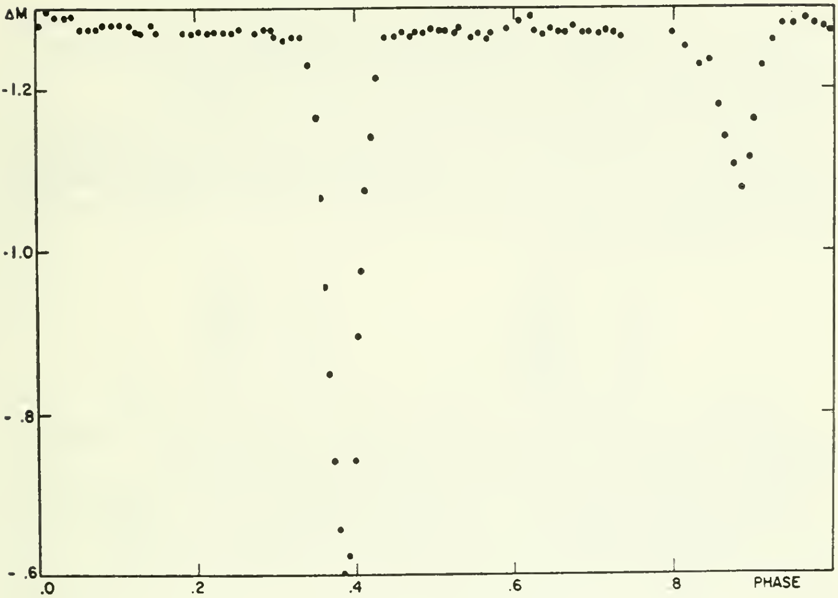

FIG. 3—The mean light curve of EE Pegasi.

TABLE IV

EPOCHS OF PRIMARY MINIMA

J. D.	No. of Periods Elapsed	O−C
243 3881.509	−290	+0ᵈ.038
889.394	−287	+0.039
910.400	279	+0.019
923.537	274	+0.015
931.417	271	+0.010
939.297	268	+0.005
947.176	265	0.000
3960.316	260	−0.001
4606.863	14	+0.002
622.633	−8	+0.003
635.770	−3	−0.001
643.656	0	0.000

Wellmann's observations are within the uncertainty of visual estimates of the times of minima.

The light curve shows two unequal minima, the secondary minumum being quite shallow and, in addition, not too well observed. Consequently, only the primary minimum was used for a solution of the photometric orbit, with the added information for the depth of the secondary minimum. It appears that the eclipse is either partial or grazing. Outside eclipses the brightness remains constant.

Following the Russell-Merrill (1950, 1952) method for the derivation of preliminary orbital elements, it appears that the primary eclipse is a transit with α_0 very close to 1. Assuming a limb-darkening coefficient $x = 0.6$ the light curve during the primary minimum can be represented by the following elements:

$$k = 0.85 \qquad L_g = 0.784$$
$$r_g = 0.166 \qquad L_s = 0.216$$
$$r_s = 0.141 \qquad \Delta M = 1^m\!.40$$
$$i = 88^\circ\!.57$$

Since the spectral type of the primary component is A4V, the secondary component is of the spectral type about F5V.

It should be pointed out that the new orbital elements differ from those derived by Wellmann. It has been found that for the same value of α_0 and the limb-darkening coefficient Wellmann's ratio of the radii, $k = 0.666$, is too small to match the observed and the computed light curve adequately. The deviations are quite large in the wings of the primary minimum. On the other hand, the present value for k should be considered as tentative until a more accurate light curve has been derived.

Conclusion

There is a need for new and more accurate photometric observations of this eclipsing system. Although this writer's data are better than the visual estimates of Wellmann, sections of the light curve have been covered inadequately or not at all. Also, new observations would provide additional epochs for improving the period of the system.

References

Gomi, K. 1940, *Beob. Zirk.*, vol. 22, p. 39.
Hoffmeister, C. 1935, *Astr. Nach.*, vol. 255, p. 401.
Merrill, J. E. 1950, *Princeton Contr.*, no. 23.
Russell, H. N. and Merrill, J. E. 1952, *Princeton Contr.*, no. 26.
Wellmann, P. 1953, *Zs. f. Ap.*, vol. 32, p. 81.