

ON THE RADIAL-VELOCITY VARIATION OF THE CEPHEID VARIABLE FF AQUILAE*

By ROSCOE F. SANFORD

ABSTRACT

Light-variation.—FF Aquilae is a Cepheid with a period of $4^d.5$ and a visual light-range of 0.44 mag., the interval from maximum to minimum being $1^d.99$, or $0.445 P$.

Short-period velocity variation.—Observations of 1932 and 1933 establish a velocity variation whose curve is a reflection of the light-curve and whose amplitude is about 14 km/sec.

Long-period velocity variation.—The mean residuals for the other observing seasons are systematic and seem to be consistent with a change of 15.5 km/sec. in the systemic velocity in a period of 4109^d . Owing to gaps in the observations, the evidence is not conclusive and a definitive answer must be left to the next few years' observations. A maximum departure from the 1932–1933 curve apparently should occur within the next year or two. The corresponding velocity of the system as a whole would be approximately -22 km/sec.

Companion star.—The Go companion, at least 6.5 mag. fainter than FF Aquilae, must be a dwarf if the two stars form a physical system and if the absolute magnitude of FF Aquilae is to agree with that called for by the period-luminosity law.

The circumstances of the discovery of the variability of FF Aquilae are concisely stated by C. M. Huffer:

The star HR 7165 was first used as a comparison star in a group for testing the spectroscopic binary HR 7267. The first observations were made on May 14, 1926, and June 6, 1927. After further observations, it became apparent by August 1, 1927, that HR 7165 was variable and that HR 7260 and 7267 were constant. All subsequent observations were made using the last two stars for comparison.¹

Curiously enough, all three stars had shown velocity variations and appear in Table I of Moore's *Third Catalogue of Spectroscopic Binaries*.²

Huffer's observations extended from July, 1927, to October, 1929, and revealed the Cepheid type of light-variation having the elements

$$\begin{aligned} \text{Max} &= \text{J.D. } 2425065.32 + 4^d.4714E \text{ (G.M.T.)} \\ \text{Max} - \text{Min} &= 1^d.99 \\ \text{Range} &= 0.443 \text{ mag.} \end{aligned}$$

HR 7165 was subsequently designated as FF Aquilae.³

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 508.

¹ *Pub. Washburn Obs. U. Wisconsin*, 15, 205, 1931. ² *Lick Obs. Bull.*, 11, 141, 1924.

³ Boss 4817; HD 176155; BD +17°3799; mag. 5.4; F5; 1900, α 18^h53^m8, δ +17°13'6. There is a 12-mag. comp. at 6'' distance in p.a. 132°.

J. H. Moore⁴ had announced the variability of its radial velocity on the basis of a range of 11 km/sec. shown by the early Lick three-prism spectrograms. Comparable ranges in the early values determined at the Mount Wilson and the Dominion Astrophysical observatories corroborate this conclusion, although, by themselves, they would not establish the variability.

Observations recommenced at Mount Wilson in 1931 further confirmed the velocity variation and showed that the period is that of the light-variation and that the velocity minimum and light-maximum are approximately synchronous, furnishing added proof of the Cepheid character of the light-variation. Observations during 1932, however, pointed to a change, at least in the velocity of the system. It appeared that a few spectrograms with the higher three-prism dispersion used at the Lick Observatory would supply desirable, independent evidence on this point. Through the kindness of Dr. Moore, 13 well-distributed spectrograms were specially taken for use in the investigation, thus making a total of 17 from the Lick Observatory. Six velocities determined at the Dominion Astrophysical Observatory were kindly called to my attention by W. E. Harper. Later observations, in 1933 and 1934, increased the total of Mount Wilson velocities to 36. Table I lists the results for each observatory separately, C as usual indicating observations with the one-prism spectrograph and 18-inch camera at the 100-inch reflector, and γ those obtained with similar equipment at the 60-inch reflector. V denotes the ultra-violet three-prism spectrograph, which, for all cases in Table I, was equipped with a 10-inch camera. The mean dispersion of the Lick spectrograms is about 10 A/mm, or approximately three times that of the others. All the velocities depend upon micrometer measures of prominent arc and spark lines for stars of spectral class F, selected on the basis of velocity consistency.

An assembly of all the observations about a single epoch by means of the period of light-variation showed an excellent agreement between the Lick velocities for 1933 and those from Mount Wilson in 1932 and the fore part of 1933, but a systematic departure for the other groups. None of the data bearing on the performance of the Mount Wilson spectrographs in 1914 and 1931 gave any evidence of

⁴ *Pub. A.S.P.*, 36, 145, 1924.

TABLE I
 RADIAL-VELOCITY OBSERVATIONS OF FF AQUILAE

Plate	Date	G.M.T.	Phase	Obsd. Vel.	Curve Vel.	O—C
Mount Wilson Observatory						
				km/sec.	km/sec.	km/sec.
γ 3336.....	1914 May 3	21 ^h 50 ^m	3 ^d 655	-20.6	-7.6	-13.0
3362.....	10	23 30	1.782	32.0	18.6	-13.4
3409.....	June 3	22 33	3.385	17.7	7.2	-10.5
3535.....	July 10	21 10	0.085	20.0	15.0	-5.0
3616.....	Sept. 1	17 31	3.748	22.9	7.5	-15.4
18419.....	1931 Sept. 1	18 49	2.027	23.3	17.0	-6.3
18423.....	3	18 35	4.017	15.3	9.0	-6.3
18450.....	26	17 04	0.126	20.6	15.3	-5.3
V 40.....	27	16 04	1.085	26.0	21.5	-4.5
γ 18462.....	28	16 20	2.096	18.6	16.3	-2.3
18868.....	1932 May 25	20 07	0.797	20.8	20.9	+0.1
C 6061.....	June 23	20 54	3.002	(2.5)*	9.1	.....
γ 18925.....	25	20 00	0.493	17.6	18.9	+2.3
V 203.....	July 19	17 13	2.020	16.7	17.0	+0.3
γ 18970.....	Aug. 10	17 19	1.667	22.9	19.5	-3.4
18978.....	11	16 24	2.628	12.4	12.0	-0.4
18991.....	13	17 52	0.219	18.8	16.4	-2.4
19015.....	16	19 58	3.306	7.6	7.5	-0.1
19019.....	17	18 19	4.237	8.2	11.1	+2.9
V 224.....	18	16 19	0.683	20.1	20.3	+0.2
264.....	Oct. 22	14 23	3.002	4.9	9.0	+4.1
270.....	Nov. 16	14 23	1.174	20.0	21.5	+1.5
275.....	17	14 39	2.181	15.0	15.6	+0.6
282.....	18	14 43	3.188	8.4	8.0	-0.4
γ 19515.....	1933 Mar. 3	1 36	0.328	17.2	17.5	+0.3
19523.....	5	0 47	2.294	(20.6)*	15.0	.....
γ 19587.....	Apr. 5	23 26	2.937	8.6	9.4	+0.8
19647.....	May 6	22 54	2.616	14.5	12.0	-2.5
19707.....	June 30	19 36	3.821	10.0	7.9	-2.1
V 420.....	Sept. 9	14 48	3.078	14.4	8.5	-5.9
456.....	Nov. 6	14 35	2.941	19.1	9.5	-9.1
469.....	8	14 30	0.466	29.1	21.4	-7.7
475.....	27	15 14	1.612	24.8	19.9	-4.9
γ 20276.....	1934 Mar. 25	0 36	2.746	18.1	10.9	-7.2
20347.....	Apr. 24	0 32	1.443	27.0	20.7	-6.5
20412.....	May 24	23 16	1.091	33.9	21.5	-12.4
20489.....	June 28	19 27	0.160	23.3	15.7	-7.6
20494.....	July 1	18 28	3.119	-13.7	-8.3	-5.4
Lick Observatory						
1918 Oct. 23	15 41	0.863	-23.7	-21.0	-2.7	
1919 June 10	19 34	1.692	22.4	19.3	-3.1	
1922 June 11	22 52	0.158	14.7	15.6	+0.9	
July 21	19 49	4.256	-12.1	-11.4	-0.7	

* Velocity from a plate of very poor quality.

RADIAL-VELOCITY VARIATION OF FF AQUILAE 135

TABLE I—Continued

Plate	Date	G.M.T.	Phase	Obsd. Vel.	Curve Vel.	O—C
Lick Observatory—Continued						
				km/sec.	km/sec.	km/sec.
20282W....	1933 May 15	22 ^h 22 ^m	2 ^d 648	-10.4	-11.6	+ 1.2
20302W....	23	21 21	1.660	17.1	19.5	+ 2.4
20319W....	28	21 48	2.205	15.4	15.5	+ 0.1
20403Q....	June 20	22 50	2.900	11.0	9.6	- 1.4
20447W....	July 5	22 18	4.460	13.7	13.6	- 0.1
20454N....	6	21 32	0.955	21.7	21.4	- 0.3
20455W....	7	22 1	1.975	17.8	17.2	- 0.6
20470M....	10	22 9	0.510	19.3	19.0	- 0.3
20479W....	11	21 32	1.482	20.5	20.7	+ 0.2
20492X....	13	21 12	3.468	6.9	7.2	+ 0.3
20504W....	15	21 48	1.021	22.0	21.5	- 1.4
20518M....	18	17 26	3.839	11.8	8.0	- 3.8
20524Q....	20	17 24	1.366	-20.9	-21.0	+ 0.1
Dominion Astrophysical Observatory						
1922 June 14†	.....	3.079	-16.9†	- 8.5	- 8.4	
17†	.....	1.618	24.8†	19.9	- 4.9	
Sept. 7†	.....	2.991	20.1†	9.1	-11.0	
1930 Oct. 27§	.....	1.401	26.6	21.0	- 5.6	
Nov. 1§	.....	0.874	17.8	21.1	+ 3.3	
4§	.....	3.883	-11.7	- 8.1	- 3.6	

† *Pub. Dom. Ap. Obs.*, 2, 199, 1924.

‡ A systematic correction of +2.2 has been applied.

§ *Pub. Dom. Ap. Obs.*, 6, 189, 1934.

the necessity for a systematic correction to the velocities obtained during these years. Further, almost all the Mount Wilson measures of 1933 and 1934 are checked by standard velocity stars observed on the same nights. Finally, since the first three values from the Dominion Astrophysical Observatory include the systematic correction of +2.2 km/sec., noted by Harper,⁵ we can only conclude that the persistent departures from the velocity variation of 1932 and 1933 must be real. The excellence of the spectrum does not admit accidental errors of the magnitude involved. It therefore became necessary to look for a variation, presumably of much longer period, upon which the velocity corresponding to the Cepheid change is superposed.

⁵ *Pub. Dom. Ap. Obs.*, 2, 199, 1924.

The Lick observations of 1933 and those from Mount Wilson for 1932 and the fore part of 1933 were accordingly represented by a velocity-curve based on the fourteen normal places listed in Table II, wherein each good Lick plate was given twice the weight of a

TABLE II
NORMAL PLACES FOR FF AQUILAE

No.	Phase	Vel.	O-C	Wt.	Plate Nos. from Table I
		km/sec.	km/sec.		
1.....	0.274	-18.0	-1.2	1.0	γ 1899I, 19515
2.....	0.510	19.3	-0.3	1.0	Lick 20470M
3.....	0.658	19.5	+0.6	1.5	γ 18925, V 224, γ 18868
4.....	0.988	22.3	-0.9	2.0	Lick 20454N, 20504W
5.....	1.174	20.0	+1.5	0.5	V 270
6.....	1.503	19.5	+1.0	2.5	Lick 20524Q, 20479W, 20302W
7.....	1.956	18.2	-0.7	1.5	γ 18970, V 203, V 275
8.....	2.090	16.6	-0.2	1.5	Lick 20455W, 20319W
9.....	2.727	11.8	-0.8	1.5	γ 18978, 19647, 19587
10.....	2.774	10.7	-0.1	1.5	Lick 20282W, 20403Q
11.....	3.165	7.0	+1.1	1.5	V 264, V 282, γ 19015
12.....	3.468	6.9	+0.4	1.0	Lick 20492X
13.....	4.029	9.1	+0.1	1.0	γ 19707, 19019
14.....	4.460	-13.7	-0.1	1.0	Lick 20447W

TABLE III
ELEMENTS OF FF AQUILAE FOR 1932-1933

Preliminary Elements	Corr.	Adopted Elements
P =period, 4 ^d .4714.....	.....	4 ^d .4714
e =eccentricity, 0.20.....	- 0.13	0.07
ω =angle of periastron, 97°.....	- 12°86	84°14
K =amplitude of velocity variation, 7.60.....	- 0.49	7.11 km/sec.
T =time of periastron passage, J.D. 2425064.736.....	- 0.255	5064.481
γ =velocity of system, -14.11.	- 0.26	-14.37 km/sec.

Mount Wilson plate. The corresponding preliminary elements derived by the methods of H. N. Russell⁶ and E. S. King⁷ were corrected by a least-squares solution made in accordance with Schlesinger's⁸ procedure (Table III). The least-squares solution reduces Σpv^2 by

⁶ *Ap. J.*, 40, 282, 1914.

⁷ *Harvard Ann.*, 81, 231, 1923.

⁸ *Pub. Allegheny Obs.*, 1, 33, 1910.

60 per cent, and none of the final residuals (fourth column, Table II) much exceeds 1 km/sec. The upper part of Figure 1 shows the representation of the normal places (circles) by the velocity-curve based on the adopted elements, while Huffer's light-curve appears in the lower part. FF Aquilae is evidently an excellent example of a Cepheid with a velocity-curve which is practically the mirror-image of its light-curve. The phases given in Tables I and II and those used in

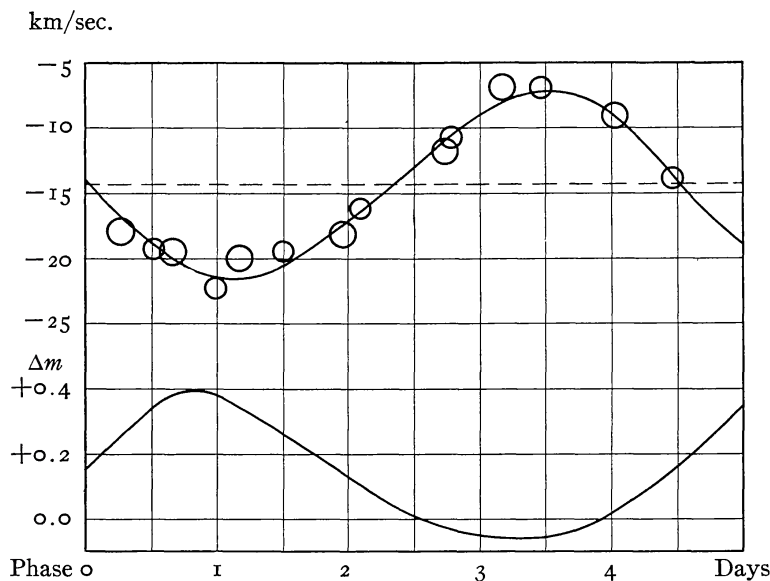


FIG. 1.—Above, radial velocity-curve for FF Aquilae. Smaller circles represent normal places from Lick observations; the larger, those from Mount Wilson observations (Table II). Broken line shows the velocity of the system. Below, Huffer's light-curve. Ordinates are differences from the comparison stars.

Figure 1 are reckoned from the adopted time of periastron passage, J.D. 2425064.481.

The velocities corresponding to the adopted elements, as scaled from the curve in Figure 1, are given in the sixth column of Table I. The residuals in the last column are satisfactory for all the observations used in deriving the elements; for the other measures they are, with few exceptions, negative. Unless the shape of the velocity-curve changes radically, the systemic velocity from the 1932-1933 measures is higher than for any of the other seasons.

The mean residuals by seasons, which appear in Table IV, are

assembled in Figure 2 with the aid of a period of 4109 days. Although there are gaps and the run of the residuals is none too smooth, the short-period velocity variation apparently oscillates about an axis which rises and falls with this period of 4109 days throughout a total range of about 15 km/sec.

The velocity of the system obtained for 1932-1933, -14.35 km/sec., is a maximum value. To obtain the velocity of the system as a

TABLE IV
MEAN SEASONAL RESIDUALS FOR FF AQUILAE

J.D.	O-C km/sec.	J.D.	O-C km/sec.
2420315.....	-11.5	2426893.....	-0.5
2021.....	-2.9	6984.....	+1.5
3255.....	-4.9	7195.....	-0.4
6281.....	-2.0	7375.....	-7.5
6603.....	-2.0	7557.....	-7.8

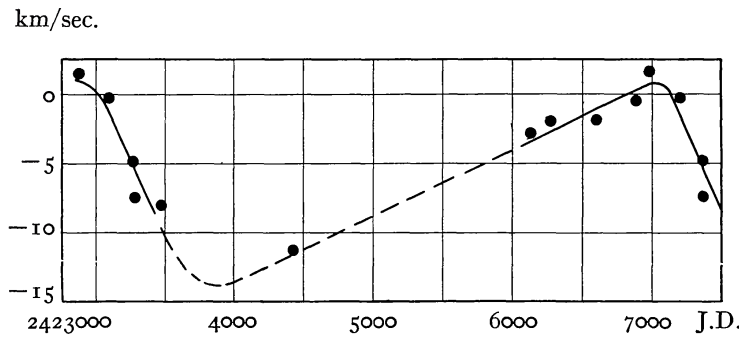


FIG. 2.—Curve of long-period change in velocity of the system of FF Aquilae. Points represent seasonal means of the residual velocities.

whole, this value should be decreased by approximately 7.5 km/sec., giving -22 km/sec. If Figure 2 is a correct picture of the variation in the center of mass velocity of the Cepheid star, a minimum is to be expected during 1935. The confirmation of this variation would establish the resemblance of the variable to the Cepheid system Polaris, in regard to a long-period variation in the velocity of the center of mass, as well as in period and spectrum.

It may be added that Huffer's observations are confined to an in-

terval during which not a single radial velocity was obtained and are centered about the mid-point of the rising branch of Figure 2. There is no particular reason to suspect spectral changes except during the short period of Cepheid variation, but on this point the evidence of our data is inconclusive. Observations covering the next seven or eight years will be needed to establish the result pictured (perhaps with overconfidence) in Figure 2 and to settle the questions of spectral changes during the longer period.

The spectrum of FF Aquilae (classified at Mount Wilson as cF6) includes many excellent lines, which are, however, less numerous than those in such stars as δ Cephei, and hence presumably less likely to be troubled by blends. This circumstance and the star's apparent brightness (mag. 5.0-5.4) render it particularly suitable for observation with high dispersion.

The companion star.—A single low-dispersion spectrogram of the twelfth-magnitude companion star in p.a. 132° is of course insufficient to determine whether the velocity of the companion agrees with that of FF Aquilae or not and is of little use in finding the absolute magnitude, but it does establish the type as G0. If the fainter star is a dwarf having the most frequent absolute magnitude for this type, the assumption that the two form a physical pair leads to an absolute magnitude for FF Aquilae that agrees with the period-luminosity law within the uncertainties in the assumptions; if a giant, the assumption of physical relationship will give for FF Aquilae an absolute magnitude that is almost certainly several magnitudes too bright. The value $+0.3$, given in *Mt. Wilson Contr.* No. 199, is in error, having been obtained on the same basis as for the general run of F stars before FF Aquilae was recognized as a Cepheid.

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