OBSERVATIONS OF MARS 1950-1976 COMPARED TO EPHEMERIDES

R.L. Duncombe, The University of Texas at Austin
Y. Kubo, Hydrographic Department of Japan, Tokyo, Japan
P.K. Seidelmann, U.S. Naval Observatory, Washington, D.C.

The present basis for the ephemeris of Mars in the National Ephemerides is the theory of S. Newcomb (1898) as amended by the corrections of Ross (1917). These amendments by Ross, however, are empirical in nature and therefore the present ephemeris of Mars does not have a strictly gravitational basis. In order to provide a gravitationally consistent basis for the ephemeris of Mars, Clemence (1949,1961) constructed a new general perturbation theory based on the final elements of Mars as derived by Newcomb for the epoch 1850. To test the adequacy and accuracy of this new theory, Clemence compared it against 87 observations from 1802-1839 and 1931-1950. This provided provisional values of the constants (without secular variation) for his new theory. These provisional elements and Clemence's theory were used to produce a heliocentric ephemeris of Mars for the period 1800-2000 (Duncombe and Clemence 1960, Duncombe 1964).

Laubscher (1971) discussed all of the observational data of Mars from 1751 to 1969, and derived the definitive constants of Clemence's theory of Mars. These definitive constants were used in conjunction with Clemence's theory by Kaplan, Pulkkinen and Emerson (1975) to produce a new geocentric ephemeris of Mars. Soon after this new geocentric ephemeris of Mars was published, it was noticed that the meridian circle observations made by the six-inch Transit Circle, U.S. Naval Observatory, while agreeing in right ascension, showed marked discordances in declination. To locate the source of this discrepancy it was decided to compare the observations in the period 1950-1976, with three different geocentric ephemerides: One based on the theory of Newcomb, as amended by Ross which appears in the American Ephemeris, henceforth referred to as the A.E.; a second, based on the evaluation of Clemence's new theory with the provisional elements by Duncombe, and thirdly, a geocentric ephemeris based on the evaluation of Clemence's theory using the definitive values of the elements derived by Laubscher. It should be noted that the heliocentric ephemeris by Duncombe was computed with elements for the mean epoch 1850 without inclusion of secular terms.

R. L. Duncombe (ed.), Dynamics of the Solar System, 121–127.

These geocentric ephemerides were compared against 424 observations of Mars made with the six-inch Transit Circle of the U.S. Naval Observatory (Adams, et al 1964, 1967, 1968; Klock, et al 1970, 1973) and the Danjon Astrolabes at Paris, San Fernando and Grasse (CERGA) (Debarbat 1977, Pham-Van, et al 1978), covering the twelve oppositions from 1950-1976. The sum of the square of the residuals in right ascension and declination compared to these three ephemerides are shown for each opposition and for the entire period in Table I. It is evident that the residuals in right ascension are generally smaller for both the Duncombe ephemeris and the Laubscher ephemeris as compared to the Newcomb ephemeris in the A.E. In declination, however, the results are markedly different. Here the Newcomb ephemeris in the A.E. shows better agreement with the observations than either the Duncombe ephemeris or the Laubscher ephemeris. Figures I, II and III show in detail the comparison of the observations in declination with the three ephemerides for the opposition of 1971. It is at this opposition that we have the largest values of the declination residuals, although the same tendency can be seen at every opposition. These figures show that in declination, the Laubscher ephemeris is noticeably inferior to the Newcomb ephemeris. The Duncombe ephemeris computed for the epoch 1850 without secular terms falls between them.

Since the Newcomb ephemeris in the A.E. represents the declination observations fairly well, it was decided to form the difference in declination between the Laubscher ephemeris and the A.E. These differences are illustrated in Figure IV, for period 1966-1976. The largest differences in this figure correspond to the points in the orbit of Mars where the latitude is greatest, i.e., the points 90° from the nodes. To further check this result, a comparison was made of the differences in the heliocentric latitude of the Laubscher ephemeris minus the A.E. and the Duncombe ephemeris minus the A.E. These differences are shown in Figure V. It seems apparent from this figure that the discrepancy shown by the observations arises from the value of the inclination adopted in the Laubscher ephemeris. The Duncombe ephemeris based on elements without secular variations is seen to fall part way between Laubscher's ephemeris and the ephemeris in the A.E. This seemed to indicate that the error might be in the secular change of the inclination adopted by Laubscher.

To determine the empirical correction to Laubscher's inclination, at the mean epoch of the observations, residuals were formed against several ephemerides containing arbitrary corrections to the inclination. Minimizing the sum of the square of the residuals in declination formed from each ephemeris provided the optimum correction to the inclination at each opposition. The final value of the correction at epoch 1965.03 is determined to be $-0\overset{''}{.}51 \pm 0\overset{''}{.}05$. Following this lead, Seidelmann examined the original computations of Laubscher's analysis, and traced the error to an incorrect algebraic sign of the secular term in the expression for the correction to the inclination.

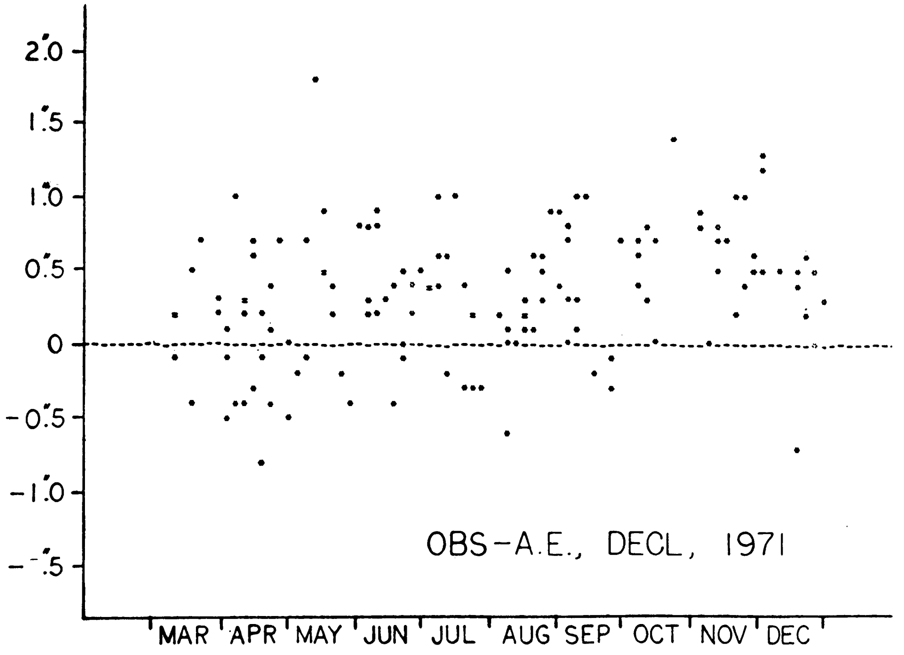

FIGURE I

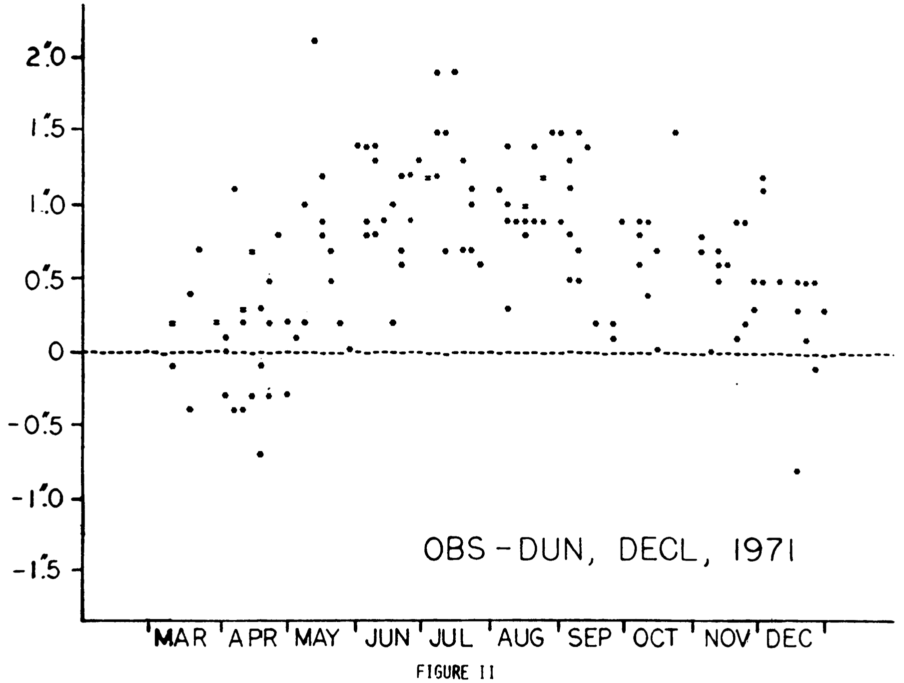

FIGURE II

https://doi.org/10.1017/S0074180900012614 Published online by Cambridge University Press

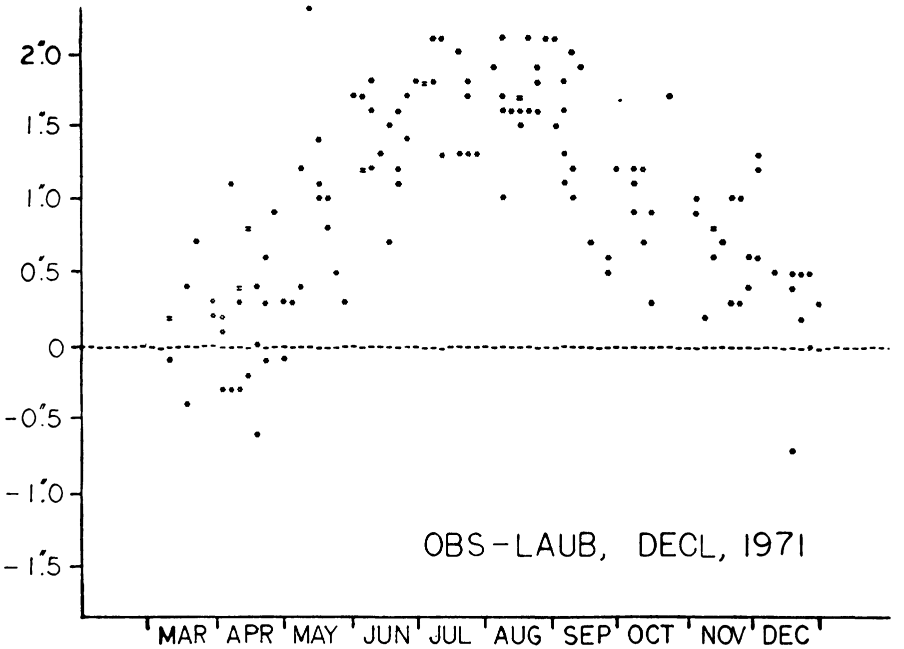

FIGURE III

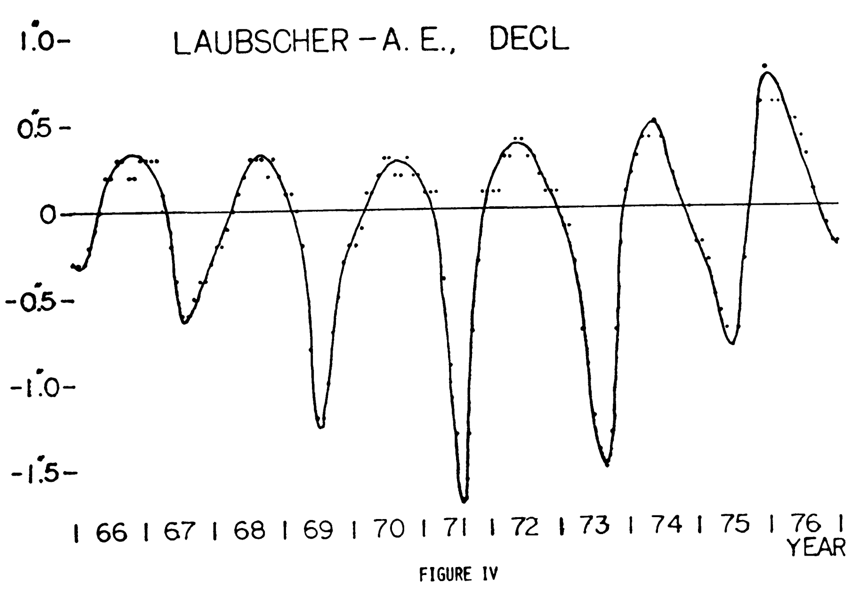

FIGURE IV

https://doi.org/10.1017/S0074180900012614 Published online by Cambridge University Press

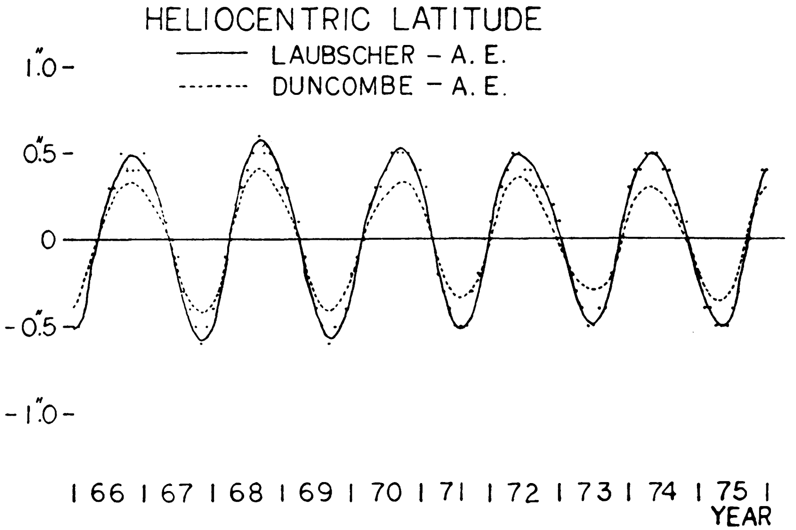

FIGURE V

TABLE I.

Opposition	N	Right Ascension AE	DUN	LAUB, O	LAUB, C	LAUB, N	Declination AE	DUN	LAUB, O	LAUB, C	LAUB, N
1950	20	$0^{s}035$	$0^{s}017$	$0^{s}043$	$0^{s}030$		$6''.39$	$6''.85$	$8''.42$	$5''.11$	
1952	22	0.025	0.015	0.022	0.023		3.19	3.32	3.68	3.02	
1954	25	0.123	0.024	0.019	0.017		6.83	23.47	37.34	21.80	
1956	25	0.457	0.252	0.129	0.051	$0^{s}049$	10.76	15.52	38.97	8.59	$8''.62$
1958	29	0.556	0.259	0.133	0.143	0.112	10.33	10.60	9.64	6.03	5.28
1960	24	0.240	0.136	0.118	0.117	0.087	3.12	9.25	16.43	2.69	3.10
1963	34	0.299	0.142	0.193	0.122	0.098	16.52	5.74	12.71	7.73	7.83
1965	29	0.119	0.071	0.122	0.064	0.058	4.90	11.51	18.08	1.80	1.99
1967	33	0.037	0.029	0.056	0.040	0.048	3.30	4.90	6.34	2.26	2.38
1969	17	0.037	0.033	0.034	0.040	0.050	1.62	3.90	6.81	1.50	1.59
1971	133	0.482	0.577	0.449	0.404	0.395	28.69	86.24	196.06	23.06	22.13
1975-76	33	0.780	0.121	0.070	0.092	0.063	2.74	10.66	19.57	2.64	2.84
SUM 1950-76	424	$3^{s}190$	$1^{s}676$	$1^{s}388$	$1^{s}143$		$98''.39$	$191''.96$	$374''.05$	$86''.23$	
SUM 1956-76	357	$3^{s}007$	$1^{s}620$	$1^{s}304$	$1^{s}073$	$0^{s}960$	$81''.98$	$158''.32$	$324''.61$	$56''.30$	$55''.76$

LAUB, O : Original Laubscher,
LAUB, C : Laubscher Differentially Corrected,
LAUB, N : New Laubscher

The correct expression is $\Delta i = (0\overset{''}{.}077 \pm 0\overset{''}{.}007) + (+0\overset{''}{.}197 \pm 0\overset{''}{.}010)T$, where T is reckoned from 1850.0. Comparison of observations against Laubscher's ephemeris with this correction to the inclination is shown in Table I in both right ascension and declination under the heading Laub,C. This correction to Laubscher's value of inclination produced improved agreement with the observations.

A new geocentric ephemeris of Mars based on Laubscher's elements with the correct expression for Δi was prepared at the U.S. Naval Observatory. Comparison of the observations against this new ephemeris is shown in Table I in both right ascension and declination under the heading of Laub,N. The slight difference between this column and the preceding one in both right ascension and declination is due to the use of a different ephemeris of the sun in the two cases. Since the new ephemeris did not extend to the oppositions of 1950, 1952 and 1954, the sums of the square of the residuals of the observations compared to all of these ephemerides have been formed again for the period 1956-1976 and are shown at the bottom of Table I in order to compare with the results from the new ephemeris. It is evident that the new ephemeris provides improved representation of the observations in both right ascension and declination. This confirms that Clemence's theory of Mars, evaluated with the correct constants, provides a superior standard for the comparison of observations. This analysis illustrates the value of, and the necessity for, consistent series of observations of the principal planets. Without the observations made at Paris, San Fernando, Grasse, and the U.S. Naval Observatory, it would have been extremely difficult, if not impossible at the present epoch, to pin down the source of the error in the ephemeris of Mars.

REFERENCES

Adams, A.N., Bestul, S.M. and Scott, D.K.:1964, U.S. Nav. Obs., Sec. Ser., Vol XIX, pt I.

Adams, A.N. and Scott, D.K.:1967, U.S. Nav. Obs. Circ. No. 115.

Adams, A.N. and Scott, D.K.:1968, U.S. Nav. Obs. Sec. Ser., Vol XIX, pt II.

Adams, A.N. and Scott, D.K.:1968, U.S. Nav. Obs. Circ. No. 118.

Clemence, G.M.:1949, Astron. Pap., Amer. Eph., Vol. XI, pt II.

Clemence, G.M.:1961, Astron. Pap., Amer. Eph., Vol. XVI, pt II.

Debarbat, S.:1977, Vistas in Astron., Vol 21, pp 93-106.

Debarbat, S., Pham-Van, J. and Sanchez, M.: "Ephemerides et position de Mars en 1975-1976," unpublished.

Duncombe, R.L. and Clemence, G.M.:1960, U.S. Nav. Obs. Circ. No. 90.

Duncombe, R.L.:1964, U.S. Nav. Obs. Circ. No. 95.

https://doi.org/10.1017/S0074180900012614 Published online by Cambridge University Press

Kaplan, G.H., Pulkkinen, K.F. and Emerson, B.:1975, U.S. Nav. Obs. Circ. No. 151.

Klock, B.L. and Scott, D.K.:1970, U.S. Nav. Obs. Circ. No. 127.

Klock, B.L. and Scott, D.K.:1973, U.S. Nav. Obs. Circ. No. 143.

Laubscher, R.E.:1971, Astron. and Astrophys., Vol 13, pp 426-436.

Newcomb, S.:1898, Astron. Pap., Amer. Eph., Vol VI, pt IV.

Pham-Van, J., Choplin, H., Delmas, C., Grudler, P., Guallino, G., Mignard, F. and Vigouroux, G.:1978, Astron. and Astrophys. Suppl., Vol 31, pp 171-173.

Ross, F.E.:1917, Astron. Pap., Amer. Eph., Vol IX, pt II.

DISCUSSION

Fricke: Was there any reason for excluding from your discussion the observations of Mars made with the 9"TC around 1940? Are these observations of minor quality than those made with the 6"TC?

Duncombe: We confined our analysis to observations made from 1950 to 1975. The 9"TC observations do not meet the standard set by the 6"TC.

https://doi.org/10.1017/S0074180900012614 Published online by Cambridge University Press