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ORBIT OF COMET C/1853 E1 (SECCHI)

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RESUMEN

El Cometa C/1853 E1 (Secchi) es uno dentro de un numeroso grupo de cometas con órbitas parabólicas. Puesto que hay suficientes observaciones del cometa, 91 en ascensión recta y el mismo número en declinación, se puede mejorar la órbita. La órbita del cometa Secchi es hiperbólica, la más hiperbólica de cualquier cometa salvo C/1980 E1 (Bowell). El cometa Secchi no está asociado de ninguna manera con el Cometa C/1664 W1.

ABSTRACT

Comet C/1853 E1 (Secchi) is one of a large number of comets with parabolic orbits. Given that there are sufficient observations of the comet, 91 in right ascension and the same number in declination, it proves possible to calculate a better orbit. Comet Secchi's orbit is hyperbolic, the most hyperbolic of any comet except C/1980 E1 (Bowell). Comet Secchi is in no way associated with Comet C/1664 W1.

Key Words: **CELESTIAL MECHANICS — COMETS: INDIVIDUAL (C/1853 E1 SECCHI)**

1. INTRODUCTION

This paper continues what may possibly become a series on orbits of comets with catalogued parabolic orbits but which nevertheless possess sufficient observations that we can do better. The chief reason for studying these objects resides in the possibility that a comet with a parabolic orbit may be a Near Earth Object (NEO). Comet C/1864 N1 (Tempel), for example, originally had a parabolic orbit (Marsden & Williams 2003), but passed within 0.0964 AU of the Earth in 1864. Only when a non-parabolic orbit is calculated can we known for sure. But an additional consideration addresses craftsmanship. It is esthetically displeasing to leave an orbit in a preliminary state, preliminary because many, perhaps most, parabolic orbits were calculated by Olbers method as a computational convenience, when better can be done. And a better orbit implies better statistics for studying the origin of comets.

The question to be addressed now is, why Comet Secchi? This comet was observed during the decades 1840–1860, a period when observations were precise enough to warrant detailed treatment of the orbits. The observations, moreover, are readily available in the leading journals of the period, found on the ADS database (http://adswww.harvard.edu/). To choose Comet Secchi rather than some other is dictated by there being a goodly number of observations available, apparently over 100, and by Secchi's importance in astronomy, one of the founders of astronomical spectroscopy. As Merrill (1940, p. 6), referring to the study of long period variable stars, aptly remarks, "In (a) [visual observations] the pioneer work of Padre Angelo Secchi is outstanding...." To let a comet named after such an important pioneer remain with a parabolic orbit seems unprofessional. One additional reason arises from there being a question whether Comet Secchi was really first observed as C/1664 W1. The *Monthly Notices RAS* (1853, Vol. 13, p. 164) remarks, "M. D'Arrest, who has calculated the elements of this comet, remarks that they exhibit a distinct resemblance to those of the comet of 1664 ... the agreement in this respect is *closer* than that which subsists between the elements of the new comet and those of any other comet whose orbit has been hitherto calculated." One should verify whether, in fact, the two comets are one and the same.

TABLE 1

DISTRIBUTION OF OBSERVATIONS AMONG OBSERVATORIES

Observatory	Obsns. in α	Obsns. in δ	Reference[a]
Kremsmünster, Austria	9	9	AN, 1853, Vol. 36, p. 337/8
Vienna, Austria	6	6	AN, 1853, Vol. 36, pp. 207/8,257/8,
Palsgaard, Denmark	1	1	AN, 1853, Vol. 36, pp. 303/4
Durham, England	8	8	AN, 1853, Vol. 37, pp. 91/2
Liverpool, England	3	3	AN, 1853, Vol. 36, pp. 347/8
Regent's Park, England	3	3	AN, 1853, Vol. 36, pp. 259/60
Altona, Germany	1	1	AN, 1853, Vol. 36, pp. 259/60
Berlin, Germany	11	11	AN, 1848, Vol. 26, p. 3
Bilk, Germany	2	2	AN, 1853, Vol. 36, pp. 259/60
Breslau, Germany	2	2	AN, 1853, Vol. 26, pp. 341/42
Hamburg, Germany	6	6	AN, 1853, Vol. 36, pp. 243/244
			AJ, 1853, Vol. 3, p. 78
Königsberg, Germany	3	3	AN, 1853, Vol. 36, pp. 243/244
Rome, Italy	11	11	AN, 1853, Vol. 36, pp. 205-206,381-382
Leiden, Netherlands	9	9	AN, 1853, Vol. 37, pp. 69/70
Cracow, Poland	3	3	AN, 1855, Vol. 40, p.351
Cambridge, USA	9	9	AJ, 1853, Vol. 3, pp. 69, 72
(Old) U.S. Naval, USA	4	4	AJ, 1853, Vol. 3, p. 64
Total	91	91	....

[a]AJ: *Astronomical Journal*; AN: *Astronomische Nachrichten.*

2. PRELIMINARY DATA REDUCTION AND EPHEMERIDES

I conducted a literature search of the journals published in the 19th century that include comet observations and also annual reports of some of the major observatories. Observations of Comet Secchi were found in *The Astronomical Journal, Monthly Notices RAS,* and *Astronomische Nachrichten.* This yielded a total of 124 observations. Many of the observations, however, were duplicates. (An observation was not considered a duplicate if the same comet observation had been reduced by different reference stars; this occurred with the Kremsmünster, Austria, observations, among others.) After eliminating these, 91 observations in right ascension

TABLE 2

ERRORS AND MISSING INFORMATION IN THE OBSERVATIONS OF COMET SECCHI

Reference	Date	Error or Missing data
AJ, 1853, Vol. 3, p. 60	March 8, 8^{h}	Reference star *a* really Tycho 325-00803-1
AJ, 1853, Vol. 3, p. 60	March 8, 9^{h}	Reference star *b* really Tycho 325-00436-1
AJ, 1853, Vol. 3, p. 64	March 15	Unidentified star is Tycho 4736-01061-1
AN, 1853, Vol. 36, pp. 207/8	March 19	α probably 68°59′13”
AN, 1853, Vol. 36, pp. 337/8	April 3	α probably $04^{h}31^{m}55.^{s}02$
AN, 1853, Vol. 36, pp. 337/8	April 3	α probably $04^{h}31^{m}55.^{s}36$
AN, 1853, Vol. 36, pp. 381/2	April 11	Sign of $\Delta\delta$ should be +

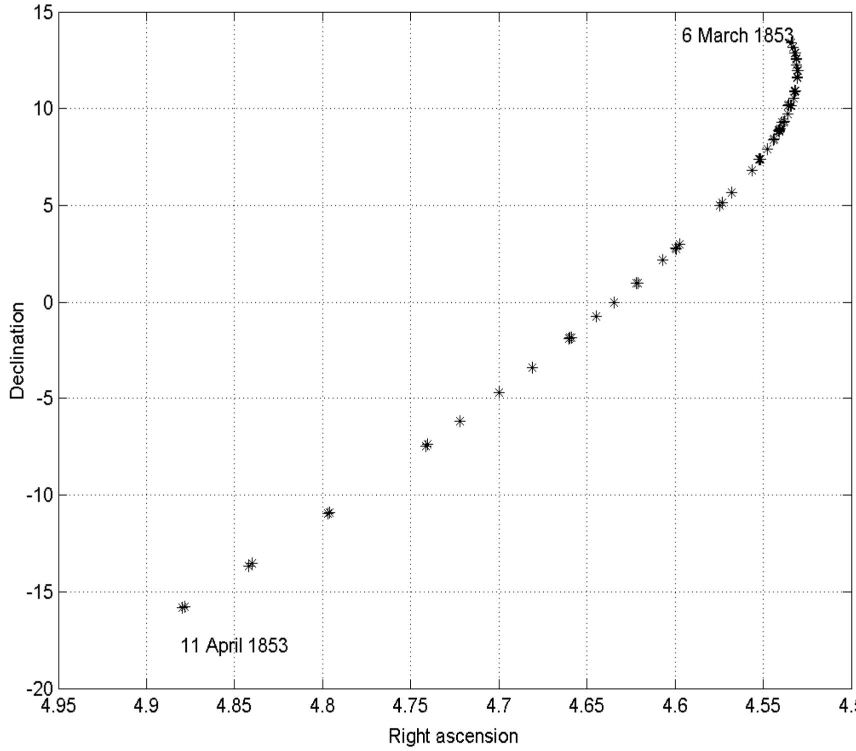

Fig. 1. The Observations

(α) and the same number in declination (δ) remained. Table 1 summarizes the distribution of observations for Comet Secchi among the observatories that made them, and Figure 1 graphs the observations.

The details of the treatment of the observations have been explained previously (Branham 2003). It suffices to say that all of the observations were reduced to the format of Terrestrial Time, α, and δ. Whenever a specific reference star was given to which the comet observation had been referred, its position was recalculated, with modern positions taken from the Tycho-2 catalog (Høg et al. 2000), using the algorithm in Kaplan et al. (1989). If differences in α and δ from the reference star, $\Delta\alpha$ and $\Delta\delta$, were given, they were applied, corrected for differential aberration, to the new position. If $\Delta\alpha$ and $\Delta\delta$ were not given, the differences in the positions between the older catalog and Tycho-2 were applied to the published positions of the comet. Because the observations are 19th century, they were corrected for the E-terms of the aberration. Rectangular coordinates needed to calculate (O-C)'s were generated along with numerically integrated partial derivatives to correct the comet's orbit.

3. ERRORS OR MISSING INFORMATION IN THE OBSERVATIONS

Table 2 exhibits the errors in the observations that could be corrected, by the actions indicated, for the benefit of anyone who wishes to further study and perhaps improve the orbit of this comet. But some remarks should be made about remaining errors. Both the sole Palsgaard observation and the three observations made at Cracow have large (O-C)'s. I could find no explanation (wrong reference star?, wrong sign of $\Delta\alpha$ or $\Delta\delta$?, or probable clerical error such as misinterpreting a 3 for a 5 or a 5 for an 8) for these (O-C)'s. The most likely explanation, at least for the Cracow observations, comes from comments from the observer himself, "The comet appears extraordinarily faint and therefore the observations enjoy no high accuracy." (My translation from German.) A few other large (O-C)'s could be eliminated, but only by my assuming that both the reference star and the time of observation were wrong, or that an error was made simultaneously in recording both minutes and seconds of α, or other unlikely combinations of circumstances. These observations were left alone.

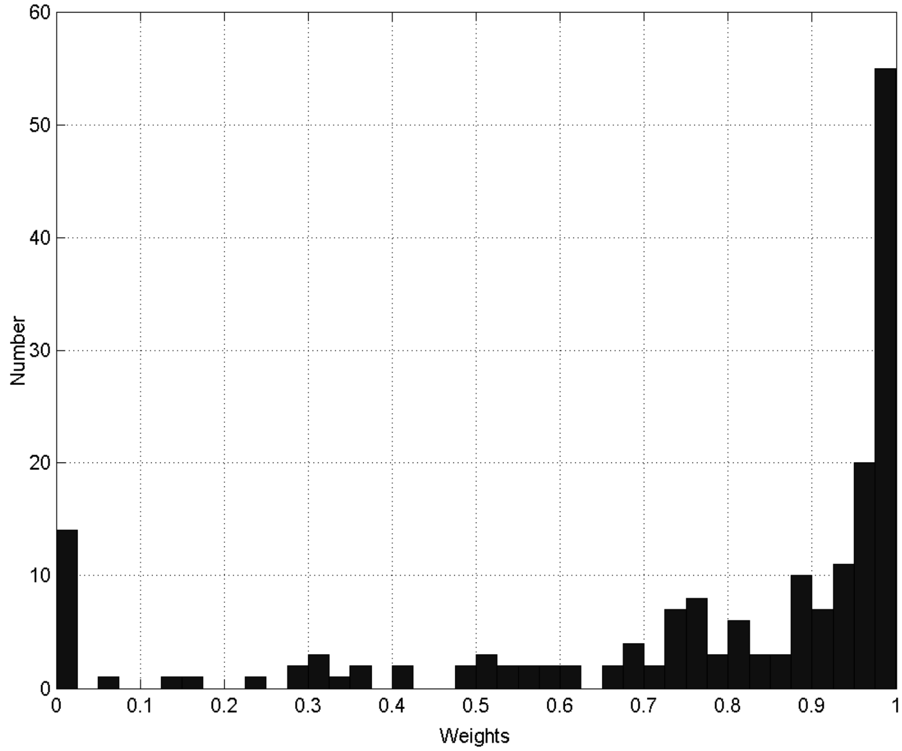

Fig. 2. Distribution of Weights

4. TREATMENT OF THE OBSERVATIONS

To weigh the observations I used the same impersonal weighting scheme as employed previously (Branham 2003), the biweight. One scales the post-fit residual r_i by the median of the residuals and assigns a weight wt as

$$\begin{gathered} wt = [1 - (r_i/4.685)^2]^2;\ r_i \leq 4.685 \\ wt = 0;\ r_i \succ 4.685. \end{gathered} \tag{1}$$

The robust L_1 criterion (Branham 1990, Ch. 6) calculates the first approximation. Because the first approximation is good, it becomes unnecessary to iterate the solutions. For Comet Secchi the median weight was 0.91. Figure 2 shows the distribution of the weights. 74.2% of the observations received weights between 0.7 and 1, 63.2% weights between 0.8 and 1, 51.1% weights between 0.9 and 1. Sixteen observations received weight of less than 0.1, of which eleven were 0.

Table 3 gives the complete set of observations for Comet Secchi along with the residuals *before* weighting by Eq. (1), the weight itself, and the equinox to which the observation is referred, either apparent or mean for 1853.0.

5. THE SOLUTION

Table 4 shows the final solution for the equatorial rectangular coordinates, x_0, y_0, z_0, and velocities, $\dot{x}_0$, $\dot{y}_0$, $\dot{z}_0$, along with their mean errors for epoch JD 2398000.5 and the mean error of unit weight, $\sigma(1)$. The mean error of ≈ 6" is relatively high and appears as a consequence of the presence of some large (O-C)'s; a number of (O-C)'s in α, for example, are near 1^s. But contemporary comparison stars were taken from catalogs that have large error compared with modern catalogs. Lalande's *Histoire Celeste Francoise* as updated by Baily sometimes shows errors over 1^s in α and 20" in δ compared with Tycho-2. If the observations were published

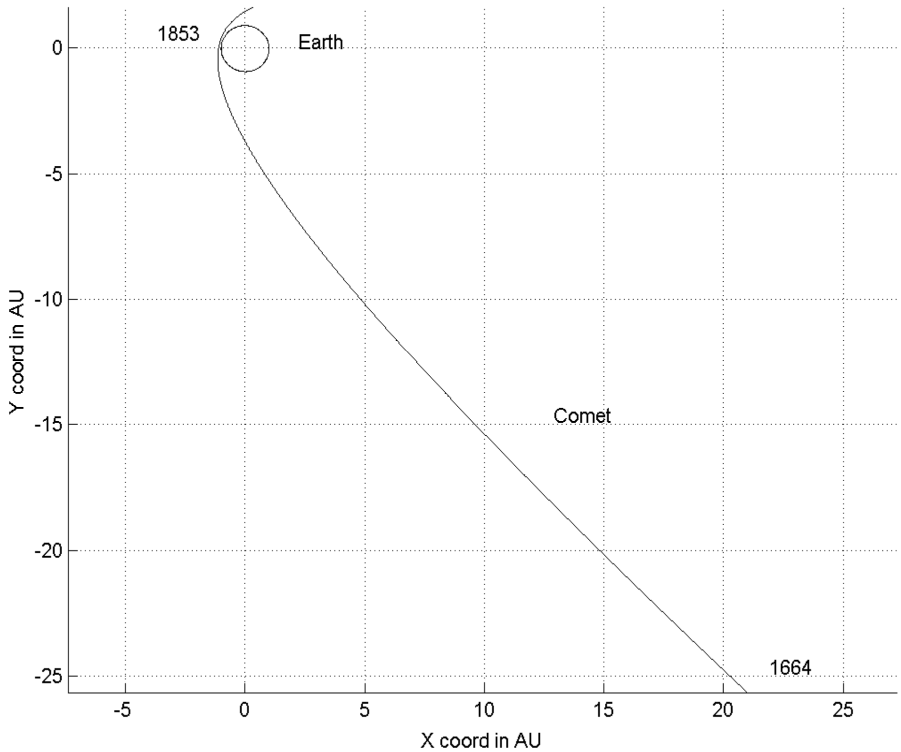

Fig. 3. Orbits of Earth and Comet Secchi, 1853–1664

as $\Delta\alpha$ and $\Delta\delta$ with respect to the reference star as well as apparent places, they could be referred to places calculated from Tycho-2. But this was not always possible, and one had to take the apparent or mean place as given by the observer. But even differential observations referred to an apparent place calculated from Tycho-2 contain some large errors because the comet itself was frequently difficult to observe, judged by comments of the observers themselves; I have already mentioned the Cracow observations.

Table 5 shows the covariances and the correlations. Although the correlations are high, the condition number of the matrix of the equations of condition, 3.4×10^4, is relatively low. The linear system, therefore, seems well-conditioned and should result in a reliable solution.

Table 6 gives the orbital elements corresponding with the rectangular coordinates of Table 4: the mean anomaly of perihelion passage, M_0; the eccentricity, e; the semi-major axis, a; perihelion distance, q; the inclination, i; the node, Ω; and the argument of perihelion, ω. Rice's procedure (1902) was used to calculate the mean errors for the elliptical elements. To express Rice's procedure in modern notation let $\mathbf{C}$ be the covariance matrix for the least squares solution for the rectangular coordinates and velocities. Identify the errors in a quantity such as the node Ω with the differential of the quantity, $d\Omega$. The error can be found from

$$(d\Omega)^2 = \sigma^2(1)\begin{pmatrix} \partial\Omega/\partial x_0 & \partial\Omega/\partial y_0 & \cdots & \partial\Omega/\partial \dot{z}_0 \end{pmatrix}\cdot\mathbf{C}\cdot\begin{pmatrix} \partial\Omega/\partial x_0 \\ \partial\Omega/\partial y_0 \\ \vdots \\ \partial\Omega/\partial \dot{z}_0 \end{pmatrix}. \qquad (2)$$

The partial derivatives in Eq. (2) are calculated from the well known expressions linking elliptical orbital elements with their rectangular counterparts. The solution shows a hyperbolic orbit, and not merely slightly hyperbolic but the most hyperbolic of any orbit with the exception of Comet C/1980 E1 (Bowell) with an eccentricity of 1.057322 (Marsden & Williams 2003).

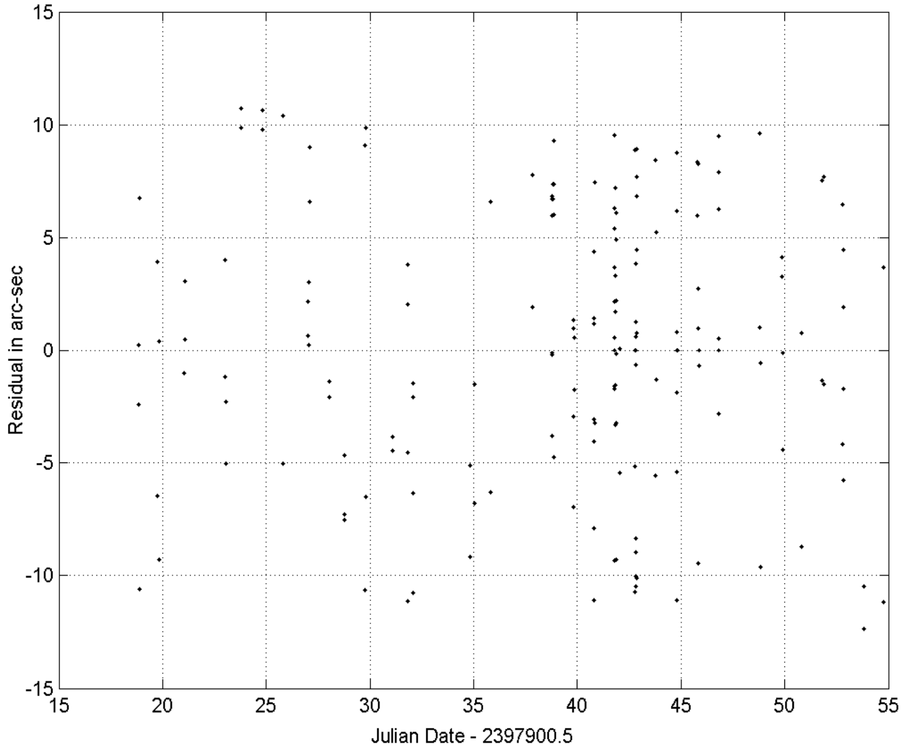

Fig. 4. Residuals from the Observations

Regarding the question of whether Comet Secchi was first observed in 1664 as Comet C/1664 W1, the answer is no. Although the elements q, i, Ω, and ω in Table 6 bear a superficial resemblance to the corresponding elements Marsden & Williams (2003) catalog for the 1664 comet, Secchi's orbit is non-periodic. Nor is this an instance of an initial elliptic orbit being transformed into hyperbolic by a close approach to Jupiter. The closest approach to Jupiter, 6.5 AU on 7 Aug. 1852, was too far away to cause a significant perturbation. Taking the rectangular coordinates from Table 3 and integrating backwards to 1664 shows that in that year Comet Secchi was scores of astronomical units from the earth. For convenience this is shown in Figure 3.

Figure 4 graphs the residuals weighted by Eq. (1). The residuals are random: a runs test shows 91 runs out of an expected 91 with standard deviation of 6.7. Random, but not normal. The residuals are skewed, factor of skewness = -0.073, platykurtic, kurtosis = -0.409, and lighter tailed than a normal distribution, Hogg's Q factor of 0.230 versus 2.580 for a normal distribution. But given that they are random one can consider the solution acceptable.

6. CONCLUSIONS

An orbit for Comet C/1853 E1 (Secchi), based on all available observations, 91 in α and 91 in δ, is given. The orbit is the most hyperbolic of that for any comet with the exception of C/1980 E1 (Bowell). Comet Secchi is in no way associated with Comet C/1664 W1.

I would like to dedicate this paper to the memory of a colleague and good friend, Juan Guillermo Sanguin. *Que en paz descanse.*

TABLE 3

THE COMPLETE OBSERVATIONS WITH RESIDUALS AND WEIGHTS

JD-2397900.5	Alpha	Residual	Weight	Delta	Residual	Weight	Equinox
18.83398	$4.^h87969$	$-0.^s322$	0.9401	$-15.^\circ84364$	$0.''94$	0.9977	App.
18.86741	4.87804	0.310	0.9444	−15.75600	−18.64	0.2997	App.
19.76659	4.84210	−0.608	0.7953	−13.65651	4.90	0.9385	App.
19.82250	4.84016	−0.998	0.5016	−13.52740	1.30	0.9956	1853
21.04664	4.79722	−0.156	0.9859	−10.96521	0.00	1.0000	App.
21.08539	4.79592	−0.053	0.9984	−10.89001	4.16	0.9555	App.
22.99254	4.74165	0.233	0.9685	−7.46355	−0.02	1.0000	App.
23.04229	4.74053	−0.389	0.9132	−7.38177	−1.14	0.9966	App.
23.80230	4.72205	0.960	0.5323	−6.18528	16.78	0.4006	1853
24.81318	4.70005	1.094	0.4217	−4.71145	17.37	0.3681	1853
25.79744	4.68098	0.981	0.5156	−3.38910	−3.84	0.9619	1853
27.01837	4.66001	0.184	0.9803	−1.90287	1.97	0.9899	App.
27.05859	4.65951	0.243	0.9657	−1.85372	1.54	0.9938	1853
27.09382	4.65860	0.764	0.6871	−1.81737	8.58	0.8174	App.
28.04748	4.64457	−0.039	0.9991	−0.75260	−0.76	0.9985	1853
28.77714	4.63438	−0.453	0.8834	0.00528	−3.43	0.9696	App.
28.77714	4.63438	−0.453	0.8834	0.00618	−6.65	0.8880	App.
29.77554	4.62196	−1.269	0.2788	0.97518	13.02	0.6071	App.
29.78950	4.62114	1.029	0.4758	0.99853	−23.85	0.0671	App.
31.08294	4.60694	−0.209	0.9746	2.15953	−25.66	0.0202	App.
31.83053	4.59943	−0.207	0.9751	2.77561	3.41	0.9699	App.
31.83516	4.59967	−1.222	0.3162	2.77879	5.27	0.9289	App.
32.07478	4.59723	0.003	1.0000	2.97749	−5.23	0.9299	1853
32.08306	4.59716	−0.037	0.9992	2.98595	−11.87	0.6666	1853
34.81230	4.57467	−0.220	0.9717	4.98428	−8.91	0.8039	App.
35.02178	4.57313	0.028	0.9996	5.12350	−5.77	0.9151	App.
35.83581	4.56786	−0.298	0.9486	5.64628	8.62	0.8156	App.
37.81808	4.55654	0.279	0.9550	6.82908	10.33	0.7412	App.
38.79620	4.55196	0.143	0.9880	7.36972	−2.53	0.9833	App.
38.79732	4.55221	0.139	0.9887	7.36904	7.81	0.8474	1853
38.79732	4.55206	0.668	0.7554	7.36873	8.94	0.8026	1853
38.84085	4.55162	0.666	0.7567	7.39023	9.70	0.7699	App.
38.85074	4.55181	0.738	0.7063	7.40059	-3.51	0.9682	1853
38.85213	4.55158	0.602	0.7989	7.39517	13.53	0.5797	App.
39.80537	4.54783	-0.039	0.9991	7.89616	−5.99	0.9085	App.
39.80663	4.54774	0.225	0.9705	7.89441	2.65	0.9817	App.
39.84071	4.54766	0.040	0.9991	7.91190	1.87	0.9910	App.
40.78104	4.54420	0.259	0.9612	8.37528	5.87	0.9122	App.
40.79678	4.54433	−0.389	0.9132	8.38385	2.50	0.9838	App.
40.80624	4.54439	−0.699	0.7338	8.38986	−2.82	0.9794	App.
40.81807	4.54416	−0.041	0.9990	8.39406	2.75	0.9803	App.
40.85300	4.54381	0.759	0.6906	8.41211	−1.94	0.9902	App.
41.77965	4.54135	0.207	0.9751	8.84724	3.50	0.9683	1853
41.77965	4.54125	0.564	0.8222	8.84679	5.10	0.9333	1853
41.78246	4.54110	0.061	0.9978	8.85420	−21.21	0.1715	App.
41.78970	4.54119	0.646	0.7704	8.84886	14.22	0.5427	1853

TABLE 3 (CONTINUED)

JD-2397900.5	Alpha	Residual	Weight	Delta	Residual	Weight	Equinox
41.80128	4.54106	0.053	0.9983	8.83656	72.53	0.0000	App.
41.83029	4.54104	0.739	0.7055	8.87193	−2.06	0.9889	1853
41.84176	4.54087	0.284	0.9533	8.87578	−2.03	0.9893	App.
41.84485	4.54093	0.064	0.9976	8.87532	4.70	0.9432	App.
41.85671	4.54093	−0.048	0.9986	8.87981	7.91	0.8436	App.
41.86078	4.54085	0.157	0.9857	8.88210	6.48	0.8935	App.
41.87945	4.54098	−0.500	0.8586	8.89140	3.52	0.9679	App.
42.03020	4.54036	0.174	0.9823	8.96249	−4.31	0.9522	App.
42.79381	4.53933	−3.254	0.0000	9.27304	100.88	0.0000	App.
42.79512	4.53834	1.223	0.3155	9.30624	−11.84	0.6678	1853
42.79623	4.53846	−0.177	0.9818	9.30171	1.30	0.9956	App.
42.80422	4.53853	−0.469	0.8753	9.31172	−22.27	0.1250	App.
42.81609	4.53852	−0.567	0.8204	9.31386	−11.26	0.6970	App.
42.82122	4.53823	0.443	0.8880	9.31227	2.58	0.9828	App.
42.82281	4.53831	0.127	0.9905	9.31311	1.89	0.9907	App.
42.83182	4.53778	1.948	0.0000	9.33031	−46.04	0.0000	App.
42.84622	4.53809	0.703	0.7311	9.32330	2.05	0.9891	App.
42.85127	4.53814	0.490	0.8641	9.32320	10.20	0.7470	App.
42.87246	4.53789	1.195	0.3378	9.33818	−10.57	0.7301	App.
43.78209	4.53621	0.929	0.5582	9.72572	−4.44	0.9494	1853
43.81498	4.53611	0.087	0.9956	9.73493	6.88	0.8805	App.
44.78068	4.53436	1.013	0.4889	10.13137	2.10	0.9885	1853
44.79137	4.53468	−0.187	0.9797	10.13980	−12.91	0.6129	1853
44.80337	4.53589	−5.571	0.0000	10.17298	−119.84	0.0000	App.
44.81615	4.53412	0.647	0.7694	10.15222	−26.77	0.0044	App.
44.83181	4.53574	−5.183	0.0000	10.20900	−208.88	0.0000	App.
45.79293	4.53251	1.320	0.2393	10.52369	7.75	0.8498	App.
45.81460	4.53280	0.248	0.9643	10.53274	4.06	0.9575	App.
45.84770	4.53257	0.908	0.5747	10.54906	−9.44	0.7812	App.
45.85014	4.53279	0.136	0.9892	10.53216	54.92	0.0000	App.
46.79390	4.53230	−1.755	0.0094	10.86274	132.61	0.0000	App.
46.80714	4.53189	0.664	0.7580	10.90263	10.47	0.7345	1853
46.80714	4.53201	0.221	0.9716	10.90037	18.62	0.3005	1853
48.78861	4.53057	0.258	0.9613	11.59583	14.62	0.5206	App.
48.82392	4.53078	−0.504	0.8565	11.61133	0.71	0.9987	App.
49.87193	4.53042	0.420	0.8991	11.95547	5.58	0.9204	App.
49.88945	4.53057	−0.105	0.9936	11.96234	1.15	0.9966	App.
50.81837	4.53115	−0.422	0.8984	12.25783	2.06	0.9890	1853
51.80835	4.53116	0.104	0.9937	12.55748	9.91	0.7605	App.
51.87488	4.53121	0.091	0.9951	12.57731	10.13	0.7504	App.
52.80496	4.53172	0.697	0.7354	12.85509	−2.96	0.9774	App.
52.84222	4.53186	0.328	0.9378	12.86631	−4.66	0.9441	App.
52.85101	4.53193	0.081	0.9962	12.86593	5.96	0.9097	App.
53.80996	4.53322	−1.154	0.3715	13.14374	−11.32	0.6938	App.
54.78240	4.53395	0.459	0.8804	13.41188	−13.19	0.5980	App.

TABLE 4

SOLUTION FOR EQUATORIAL RECTANGULAR COORDINATES AND VELOCITIES[a]

Unknown	Value	Mean Error
x_0	0.379060545116423	0.000441767430166962
y_0	1.64357776907128	0.00175483896161932
z_0	0.634470318396605	0.000622314973089107
$\dot{x}_0$	0.0154289774904836	2.93600209770127e-006
$\dot{y}_0$	0.00611903847551658	2.53691643748175e-005
$\dot{z}_0$	0.00746881625124822	1.06691199815307e-005
$\sigma(1)$	$6.''00$	

[a]For Epoch JD 2398000.5 and Equinox J2000.

TABLE 5

COVARIANCE[a] AND CORRELATION[b] MATRICES

	x_0	y_0	z_0	$\dot{x}_0$	$\dot{y}_0$	$\dot{z}_0$
x_0	230.249	913.021	321.601	1.513	13.199	5.524
y_0	0.998	3633.166	1281.172	5.974	52.506	22.002
z_0	0.992	0.994	456.911	2.076	18.469	7.832
$\dot{x}_0$	0.989	0.983	0.963	0.010	0.087	0.036
$\dot{y}_0$	0.998	0.999	0.992	0.986	0.759	0.317
$\dot{z}_0$	0.993	0.996	0.999	0.967	0.994	0.134

[a]Upper triangle; [b]Lower Triangle.

TABLE 6

ELLIPTIC ORBITAL ELEMENTS AND MEAN ERRORS[a]

Unknown	Value	Mean Error
M_0	$91.^\circ 5073930205590$ (24.49261 Feb.1853)	$19.^\circ 6861561842725$
a	−103.027921848876	25.8513855209412
e	1.01059859340310	0.0027173673941290
q	1.09195105284220	0.123494873639757
Ω	$129.^\circ 659157685437$	$4.^\circ 75758764236530$
i	$154.^\circ 676098927570$	$1.^\circ 36592406116164$
ω	$337.^\circ 870832375906$	$4.^\circ 78348319643260$

[a]For Epoch JD 2398000.5 and Equinox J2000.

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