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DO COMETS C/1861 G1 (THATCHER) AND C/1861 J1 (GREAT COMET) HAVE A COMMON ORIGIN?

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RESUMEN

Con el objeto de mejorar la órbita de Oppolzer de 1864, se calcula una nueva órbita para el Cometa C/1861 G1 (Thatcher), el cual está asociado a la lluvia de estrellas de las Líridas. La nueva órbita se basa en 649 observaciones hechas entre el 11 de abril y el 7 de septiembre de 1861, 326 en ascensión recta y 323 en declinación. La órbita final utiliza los residuos calculados con la función de ponderación de Welsch. El período del cometa, 416 ± 0.56 años, concuerda con el de Oppolzer, 415 años, pero otros elementos orbitales, como la inclinación, discrepan. Si bien los residuos post-perihelio se presentan relativamente al azar, con una probabilidad del 52.1% de serlo, los residuos pre-perihelio no son azarosos, lo cual indica posibles desviaciones del movimiento kepleriano debidas a la expulsión de material meteorítico. El Cometa Thatcher no está relacionado con el Gran Cometa de 1861.

ABSTRACT

A new orbit is calculated for Comet C/1861 G1 (Thatcher), associated with the Lyrid meteor shower, to replace Oppolzer's orbit of 1864. The new orbit is based upon 649 observations, 326 in right ascension and 323 in declination, made between 11 April 1861 and 7 Sept. 1861. The final orbit uses residuals calculated with the Welsch weighting function. The comet's period of 416.87 ± 0.56 yr agrees with Oppolzer's period of 415 yr athough other elements such as the inclination differ. Although the post-perihelion residuals are relatively random, 52.1% probability of randomness, pre-perihelion residuals lack randomness indicating possible deviations from Keplerian motion caused by ejection of meteoritic material. Comet Thatcher is unrelated to the Great comet of 1861.

Key Words: celestial mechanics — comets: individual — methods: data analysis

1. INTRODUCTION

Comet C/1861 G1 (Thatcher), although not a great comet, was discovered the same year as Comet C/1861 J1 (Great comet of 1861). I recently published an improved orbit of the Great comet (Branham 2014) to replace Kreutz's orbit of 1880. There are certain similarities in the orbits of the two comets, and one might suspect that they may have a common origin. Dr. Galina Ryabova of the Tomsk State University, Russia, pointed this out to me (personal communication). Although the two comets do not satisfy Tisserand's criterion, the criterion is not precise and one should not rule out the possibility of a common origin until such a hypothesis has been discarded. Weiss (1867) recognized that Comet Thatcher is the source of the Lyrid meteor shower. The orbit of the comet, however, has not been improved since the time of Oppolzer (1864), the orbit still given in the Marsden and Williams catalog (2003) and in the JPL Small-Body Database Browser (http://ssd.jpl.nasa.gov/sbdb). Good astrometric observations for this comet exist only for 1861 nor has any identification with a previous comet been made. Arter and Williams (1997) feel that this precludes checking and improving the published orbital elements, but such an assertion is not strictly true; the orbit can be improved. Orbit calculation has changed greatly since the days of Oppolzer. The

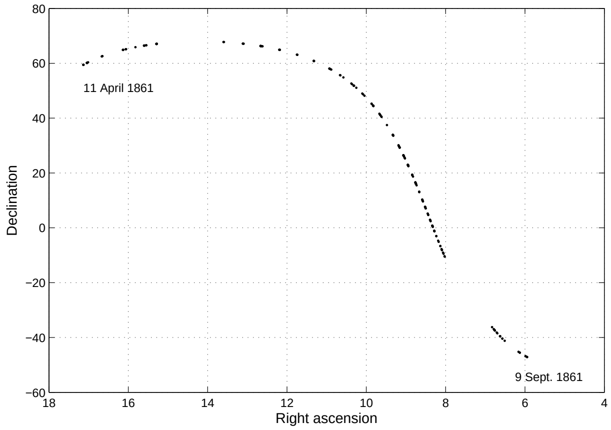

Fig. 1. The observations.

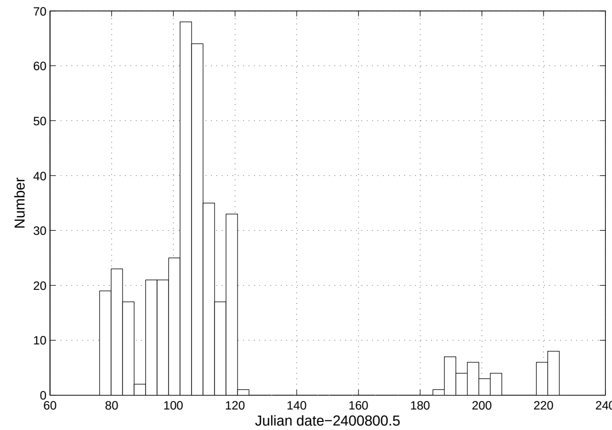

Fig. 2. Histogram of Julian dates.

orbit for Comet Thatcher should be based on what modern computing technology and statistical analysis offer, not on what was in use during the American Civil War or, for those of us living in South America, the War of the Triple Alliance.

Modern orbits make no use of normal places, a computational expedient previously necessary but which degrades, if only slightly, the solution. Modern orbits also efficiently implement techniques such as robust estimation for processing the observations, and allow one to include all perturbing planets, not just the main contributors. Because most 19th century observations are differential, measuring with a micrometer the comet's position with respect to a reference star, one can re-reduce the observation taking the reference star from a modern catalog. One thus obtains a more precise observation than that published by the observer.

This paper proposes to address whether Comet Thatcher shares a common origin with the Great comet of 1861. Even if answered negatively an improved orbit of Comet Thatcher will benefit meteor astronomers in their quest to study the evolution of the Lyrid shower.

2. THE OBSERVATIONS AND THEIR TREATMENT

A.E. Thatcher discovered the comet that bears his name in New York on 4 April 1861. The first precise astrometric observation was made on 10 April and the last on 6 Sept. at the Cape Observatory (11 April and 7 Sept. when corrected for the difference between the astronomical and the civil day). Using largely the ADS database (http://adswww.harvard.edu/) I was able to collect 326 observations in right ascension (α) and 323 in declination (δ) for this comet. The observations were made by equatorial telescopes with ring or filar micrometers and a few with the transit circle. The observations made at the (old) U.S. Naval Observatory were used in their unaveraged form. The declination differences were published as micrometer readings rather than $\Delta\delta$ differences, but could be converted. The Vienna observations were also processed as unaveraged measurements.

Figure 1 graphs the observations, and Table 1 shows their distribution among observatories. The distribution of the observations with respect to time is hardly uniform. Figure 2 shows a histogram of observations versus Julian date, with an evident concentration near JD 2400905.5 (10 May 1861). Also evident is the gap between the pre-perihelion ($\approx$JD 2400930.5, see Table 5) and post-perihelion observations, with far fewer of the latter and all in the southern hemisphere.

Processing 19th century observations presents difficulties and becomes far from trivial. See Branham (2011) for details, although two should be mentioned here. Because the observations are 19th century those published as mean positions were corrected for the E-terms of the aberration. See Scott (1964) for a discussion of the E-terms. Meridian observations were not corrected for geocentric parallax because such observations have traditionally been reduced to the geocenter. All observations were reduced to the common format of: Julian Day (JD), Terrestrial Time (TT), right ascension, and declination.

3. EPHEMERIDES AND DIFFERENTIAL CORRECTIONS

The procedure for calculating coordinates, velocities, and partial derivatives for differential corrections has been given in previous publications of mine. See Branham (2005), for example.

TABLE 1

OBSERVATIONS OF COMET C/1861 G1 (THATCHER)

Observatory	Obsns. in α	Obsns. in δ	Reference[1]
Vienna, Austria	35	35	Annalen Wien, 1863, 75, 88
Santiago, Chile	12	11	AN, 1862, 58, 205-206
Paris, France	8	8	Annal. Paris, 1863,17, 156
Altona, Germany	2	2	AN, 1861, 191-192,237-238
Berlin, Germany	6	6	AN, 1862, 57, 177-178
Bonn, Germany	5	5	AN, 1861, 55, 233-234
Danzig, Germany	6	6	AN, 1862, 57, 21-22
Köingsberg, Germany	8	7	AN, 1862, 58, 71-72
Mannheim, Germany	12	12	AN, 1861, 55, 251-252
Athens, Greece	8	8	AN, 1861,55, 257-258
Armagh, Ireland	3	3	MN, 1861, 21, 240
Florence, Italy	4	4	AN, 1861, 55, 375-376
Padua, Italy	6	6	AN, 1861, 55, 299-300
Rome, Italy	2	2	AN, 1861, 56, 67-68
Leiden, Netherlands	8	7	AN, 1861, 56, 139-140
Christiana, Norway	5	5	AN, 1861, 56, 137
St. Petersburg, Russia	3	3	AN, 1861, 55, 247-248
Cape, South Africa	8	8	MemRAS, 1863, 31, 41
Cambrige, Mass., USA	4	4	AN, 1861, 299-300
Albany, NY, USA	6	6	MN, 1861, 21, 24
Clinton, NY, USA	22	22	AN, 1863, 60, 113-114
Washington, D.C., USA	153	153	Wash. Obs., 1, 247
Total	326	323	

[1]AN: Astron. Nachr.; MN: Monthly Notices RAS; MemRAS: Memoirs RAS.

The first two differential corrections were based on the robust L_1 criterion, minimize the sum of the absolute values of the residuals, and are hence insensitive to discordant data. Having the initial observed minus calculated position, (O-C)'s, one can search for discordant observations, some of which could be corrected. Table 2 lists some errors for the comet (mostly misidentified reference stars) that could be corrected along with reference stars previously unidentified. Many observations could not be corrected and the large (O-C)'s accepted as genuine outliers.

Various weighting schemes are possible once one has post-fit residuals from a differential correction. Modern schemes usually assign higher weight to smaller residuals and zero weight to large residuals, recognizing them as errors rather than genuine but improbable residuals. Among these robust weightings I chose the Welsch (Branham 1990, Section 5.5). Let $\mathbf{A}$ represent the matrix of the equations of condition, here of size 649×6, $\mathbf{d}$ the right-hand-side, $\Delta\mathbf{x}$ the solution for correction to the osculating rectangular coordinates and velocities $\mathbf{x}$, and $\mathbf{r}$ the vector of the residuals, $\mathbf{r} = \mathbf{A}\cdot\Delta\mathbf{x} - \mathbf{d}$. After a solution has been calculated one should check for the randomness of the residuals.

Welsch weighting accepts all residuals, but assigns low weight to large residuals, so low as to become less than the machine ϵ for extremely large residuals,

$$wt = \exp[-(r_i/2.985)^2]; |r_i| < \infty. \qquad (1)$$

Welsch weighting rejects 8.4% of the residuals less than the machine $\epsilon, 2.2 \cdot 10^{-16}$ for the Intel processor used for the computations; this falls within the range of 5%-10% that Stigler (1977) has found reasonable for data from the exact sciences. 18.3% of the residuals receive a weight less than 0.1 and 25.6%

TABLE 2

ERRORS AND MISSING INFORMATION FOR THE COMET THATCHER

Observatory	Reference[1]	Date or ref. star no.	Error or missing data
Vienna, Austria	Ann. Wien, 1863, Vol. 12, p. 77	10 May	2nd ref. star Tycho 1400 02296 1
Vienna, Austria	Ann. Wien, 1863, Vol. 12, p. 77	12 May	Ref. star Tycho 1393 01786 1
Mannheim, Germany	AN, 1861, No. 55, pp. 251-251	6 May	Ref. star d Tycho 1400 02363 1
Mannheim, Germany	AN, 1861, No. 55, pp. 251-251	8 May	Ref. star e Tycho 2500 00713 1
Mannheim, Germany	AN, 1861, No. 55, pp. 251-251	10 May	Ref. star h Tycho 1400 02363 1
Athens, Greece	AN, 1861, Vol. 55, pp. 257-258	19 May	Ref. star Tycho 4849 02011 1
Athens, Greece	AN, 1861, Vol. 55, pp. 257-258	24 May	Ref. star δ Tycho 5417 00086 1
Athens, Greece	AN, 1861, Vol. 55, pp. 257-258	24 May	Ref. star ϵ Tycho 5417 00024 1
Athens, Greece	AN, 1861, Vol. 55, pp. 257-258	24 May	Ref. star ζ Tycho 5430 02063 1
Athens, Greece	AN, 1861, Vol. 55, pp. 257-258	24 May	Ref. star η Tycho 5417 00611 1
Florence, Italy	AN, 1861, Vol. 55, pp. 375-376	11 May	Ref. star unidentifiable
Christiana, Norway	AN, 1861, Vol. 56, pp. 139-140	13 July, $11^{h}10^{m}22.^{s}8$	Ref. star unidentifiable
Cape, South Africa	MemRAS, 1863, 31, 42	18 Aug.	Ref. star 1 unidentifiable
Cape, South Africa	MemRAS, 1863, 31, 42	1 Sept.	Ref. star 4 unidentifiable
Cape, South Africa	MemRAS, 1863, 31, 42	6 Sept.	Ref. star 6 unidentifiable

[1]AN: Astronomische Nachrichten; MN: Monthly Notices RAS; MemRAS: Memoirs RAS.

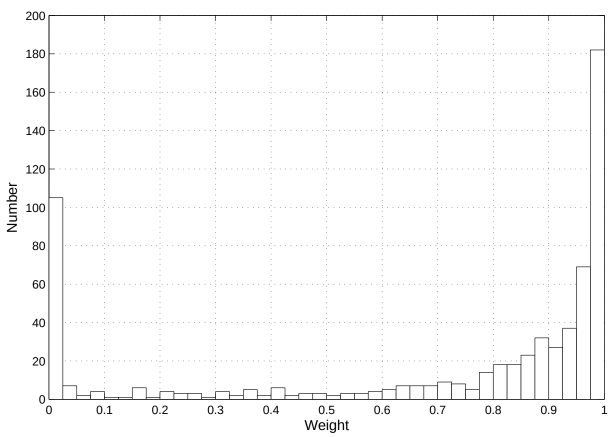

Fig. 3. Histogram of Welsch weights.

a weight less than 0.5. Figure 3 shows a histogram of the weights. The mean error of unit weight, $\sigma(1)$, becomes $5.''07$.

4. THE SOLUTION

Table 3 shows the final solution for the rectangular coordinates, x_0, y_0, z_0, and velocities, $\dot{x}_0$, $\dot{y}_0$, $\dot{z}_0$, along with their mean errors and also the repeated mean error of unit weight $\sigma(1)$ for the comet. Table 4 gives the corresponding covariance and correlation matrices. The highest correlation, 99.7% between z_0 and $\dot{z}_0$, although significant along with certain other correlations, nevertheless does not imply an unstable solution because the condition number of $6.4{\cdot}10^3$ for the data matrix shows that the solution is stable. Table 5 converts the rectangular coordinates to elliptical orbital elements using the well known expressions linking orbital elements with their rectangular counterparts. The orbit represents a high eccentricity ellipse and differs, significantly in some instances such as the inclination, from Oppolzer's orbit.

The calculation of the mean errors of the orbital elements proceeds via a modernized version of Rice's procedure (1902). See Branham (2005).

5. DISCUSSION

Having a solution from the L_1 criterion and then from Welsch weighting allows one to study the residuals. One should first use the L_1 residuals because Welsch weighting flattens their distribution and distorts the statistics. Figure 4 shows a histogram of the residuals smaller that $\pm 100''$, 616 altogether. The residuals are skewed, coefficient of skewness 1.08, leptokurtic, 3.64 versus 3 for a normal distribution, and lighter tailed, Q factor of 0.45 versus 2.11 for a normal distribution. They also evince fewer runs, 270 out of an expected 319. Given m perfectly random residuals with an approximate normal distribution, there will be $\approx m/2$ runs with a variation of $\approx (m-1)/4$; see any statistics textbook for this information. This lack of runs must be explained. Could there be a systematic difference between the α and the δ measurements? Given that over 47% of the observations were made at the (old) Naval

TABLE 3

SOLUTION FOR RECTANGULAR COORDINATES AND VELOCITIES*

Unknown	Value	Mean Error
x_0 (AU)	5.7740737e-001	8.0104988e-006
y_0 (AU)	6.093843e-001	2.8096679e-005
z_0 (AU)	-1.2395580e+000	2.7023498e-005
$\dot{x}_0$ $(AU\ day^{-1})$	1.6545537e-002	7.4163145e-008
$\dot{y}_0$ $(AU\ day^{-1})$	1.0630386e-002	5.0394770e-008
$\dot{z}_0$ $(AU\ day^{-1})$	-1.8044676e-003	3.9199133e-007
$\sigma(1)$	5.″07	

*For Comet Thatcher: epoch JD 2401000.5 (13 Aug. 1861), equinox J2000.

TABLE 4

COVARIANCE (DIAGONAL AND LOWER TRIANGLE) AND CORRELATION (UPPER TRIANGLE)*

1.3074e-001	-7.5370e-001	-6.1403e-001	-5.3378e-001	5.7931e-001	-5.7804e-001
-3.4561e-001	1.6084e+000	9.2748e-001	9.4255e-001	-6.5162e-001	8.9879e-001
-2.7081e-001	1.4347e+000	1.4878e+000	9.4185e-001	-8.1365e-001	9.9739e-001
-6.4608e-004	4.0015e-003	3.8458e-003	1.1206e-005	-6.8969e-001	9.2597e-001
4.7647e-004	-1.8798e-003	-2.2576e-003	-5.2517e-006	5.1742e-006	-8.3117e-001
-3.6980e-003	2.0168e-002	2.1526e-002	5.4845e-005	-3.3452e-005	3.1306e-004

*Matrices for Comet Thatcher.

TABLE 5

ELLIPTIC ORBITAL ELEMENTS AND MEAN ERRORS*

Unknown	Value	Mean Error
T_0	JD2400930.39278 03.89012 June1861	$0.^d00072$
P (yr)	416.87	0.56
a (AU)	55.803112	0.07083898
e	0.983501	0.2066707e-004
q (AU)	0.9206964	0.10467093e-002
Ω	31.°81523	0.°156305e-001
i	99.°769406	0.°085161e-001
ω	302.°842281	0.°1153853e+000

*For Comet Thatcher: epoch JD 2401000.5 (13 Aug. 1861), equinox J2000.

Observatory with a filar micrometer, which has separate measuring screws for the two coordinates, this possibility cannot arbitrarily be discarded. But the right ascension residuals exhibit 128 runs out of an expected 159 for non-zero residuals and the declination residuals 124 runs out of an expected 156. There is, therefore, no difference in the lack of runs given by the coordinates separately.

Figure 5 graphs the L_1 residuals versus Julian date and Figure 6 does the same for the residuals from the solution with Welsch weighting. Figure 5 shows a possible explanation for the problem. The 39 post-perihelion residuals are random, 18 runs out of an expected 20, a 52.1% chance of being random. The 610 pre-perihelion residuals, however, show only 252 runs out of an expected 299, nearly 0% probability of being random. Because we know that Comet Thatcher is associated with the Lyrid meteor shower it may be that there was some out-gassing up to perihelion, but having passed perihelion the motion

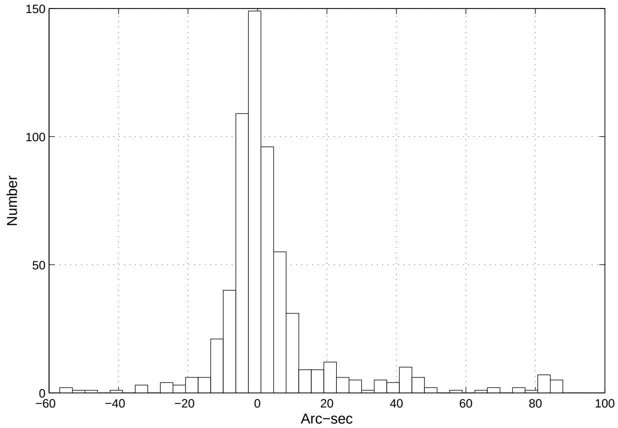

Fig. 4. Histogram of L1 residuals.

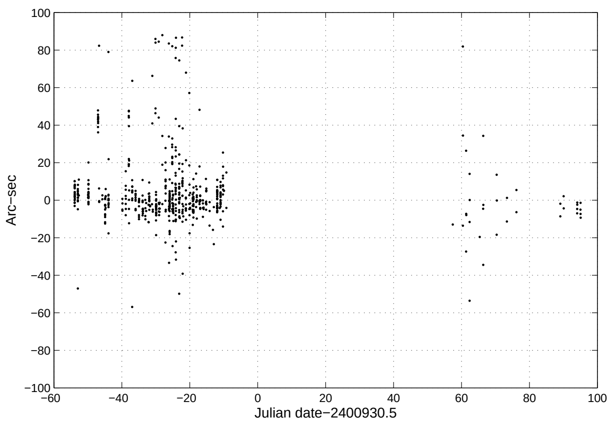

Fig. 5. Julian date versus L1 residuals.

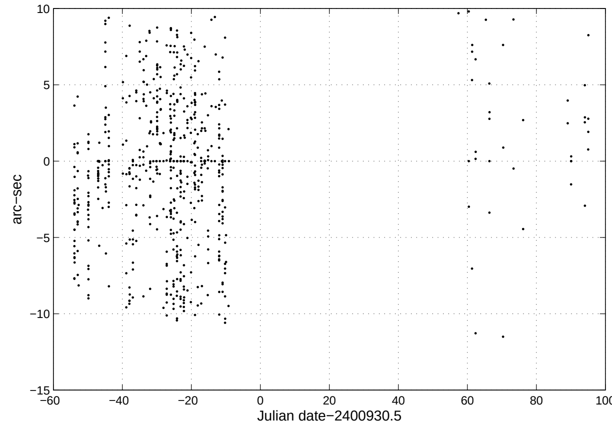

Fig. 6. Julian date versus Welsch residuals.

became nearly Keplerian. I tried a nongravitational force model used to verify if Comet C/1853 E1 (Secchi) could be influenced by such forces (Branham 2012), but the results still showed a paucity of runs.

Could it be that we have to use a more sophisticated force model? I tried adding a transversal as well as a radial force, such as Królikowska and Dybczyński use (2010), but the runs still remained at 252 out of an expected 299. The median difference between the gravitational and nongravitation heliocentric distances for 2,000 days around periheliom was $1.9{\cdot}10^{-6}$ AU, but this apparently is insufficient to significantly affect the runs.

Also tried was fitting a separate orbit to the preperihelion observations, but the lack of runs, 247 out of an expected 299 for non-zero residuals, still remains noticeable. Because the Great Comet of 1861, unassociated with any meteor stream and many of whose observations were made by the same equipment used for Comet Thatcher, shows far more runs with respect the number of observations, the likely explanation for the lack of runs for Comet Thatcher still remains the random ejection of meteoritic material prior to perihelion passage. Such an ejection, admittedly speculative, would be difficult to model deterministically.

Or perhaps the lack of runs is not as serious as one supposes. The standard runs test assumes approximate normality of the residuals. Knuth has developed a more sophisticated runs test (1981, pp. 65-67), implemented in the IMSL Numerical Libraries "DRUNS" routine (www.roguewave.com), that calculates a covariance matrix, and a chi-squared statistic for the probability of the null hypothesis: the residuals are chosen at random. The test relies on a covariance matrix calculated from a sequence of the runs, from the longest to the shortest. Thus, no assumption of even approximate normality enters. With the Knuth runs test the probabilty that the pre-perihelion residuals arise from a random distribution is 11.5%. For the post-perihelion residuals the probability becomes 84.0%. Thus, one can say that although the pre-perihelion residuals still show a lack of runs, one cannot discard with high confidence the null hypothesis that the residuals are in fact random.

Interestingly, Oppolzer's orbit (1864) also exhibits a deficiency of runs. He computed 347 residuals with, according to my calculations, 134 runs out of an expected 174, also a nearly 0% chance of being random. Of course, Oppolzer used 7 normal places to calculate the orbit and thus some deviation from randomness becomes likely, but the magnitude of the deviation nevertheless remains stark and with probably the same cause.

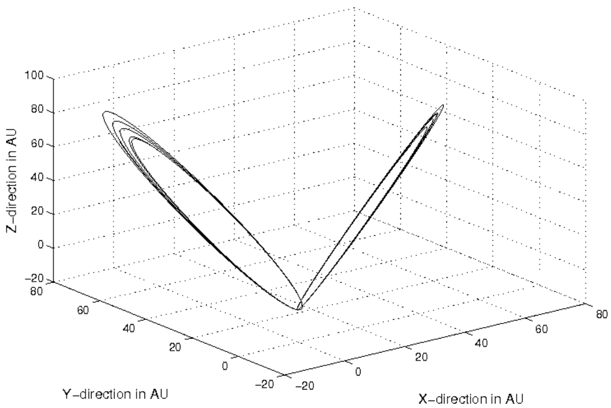

Fig. 7. Graphs of Great Comet of 1861 (left) and Comet Thatcher (right) between -58 and 1861.

6. DO COMET THATCHER AND THE GREAT COMET OF 1861 HAVE A COMMON ORIGIN?

There are certain similarities between the orbit of Table 5 and the orbit for the Great Comet of 1861 published in Branham (2014), particularly the inclination, eccentricity, and time of perihelion passage. Tisserand's criterion,

$$1/2a + \sqrt{a(1-e^2}\cos i = C, \tag{2}$$

where C is a constant yields -0.0122 for the Great Comet and -0.2201 for Comet Thatcher, not too similar. But Tisserand's criterion is not precise. To integrate both orbits backwards a few revolutions seems the best way to decide the question.

Figure 7 shows the results from integrating backwards to JD 1700000.5 (5 June -58) from JD 2401000.5, more than four revolutions for both comets. It seems obvious that the two are not the same. At their closest approach in 1861 the minimum distance between them is still 0.6 AU.

7. CONCLUSIONS

Comet Thatcher (C/1861 G1) is a comet distinct from the Great Comet of 1861. Some evidence exists for non-Keplerian motion prior to perihelion passage, but such motion remains difficult to model. The comet's period of 416 years assures that it will not be seen again until 2,277 AD. Because of use of a greater number of observations and modern statistical treatment of the data, the orbit of Table 5 nevertheless remains an improvement over Oppolzer's orbit of 1864. The new orbit may be of use to meteor astronomers trying to investigate the Lyrid meteor shower.

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