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The identification of comets in Chinese historical records

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The historical records of astronomical phenomena may play a significant role in comet identification. Getting an accurate result is based on many factors, of which the calculation of orbital elements is the most important. This paper presents a "Cross Reference" method in which the perturbation of Jupiter is the only considered factor used to attempt an efficient way of comet identification with ancient Chinese historical records. In this method, the records before and after the calculated result from orbital determination within the error range are compared with the historical records to find the correlated perihelion time, and then, with five other orbital elements at the perihelion time, the ephemeris is calculated. If the calculated ephemeris matches the historical records, it is concluded that the comet determined by orbital calculation is the same as the one recorded in history. With this method, three comets with four historical records have already been found.

celestial mechanics, methods: numerical, comets: general

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1 Introduction

In ancient China, the appearance of a comet was recorded as a mysterious phenomenon in astrology. The identification of the comets in Chinese history is significant for both modern astronomical research and historical chronology work. If the historical comet records are affirmed to relate with a certain comet explored today, these records can provide circumstantial evidence of chronology and be used to research the physical characteristics, dynamics and magnitude evolution of the comet [1]. If the reliability of those records could be affirmed through the work of identification, circumstantial evidence of chronology can be provided.

2 The method used in this identification work

In recent studies, two kinds of methods have been used in comet identification: one is calculating the comet's orbital elements based on observational data and then searching for comets having similar orbits; the other is the numerical integration method using orbital elements of known comets as the initial conditions to solve the equations of motion for the comet.

2.1 Comparison between these two methods

Both methods are widely used by many researchers. But, the validity of those results is seldom properly investigated. Each method has its own advantages and disadvantages, which will be discussed in the following subsections.

2.1.1 Using historical data to calculate the comet's orbit

The exact calculation of the comet's orbital elements is considered to be the most important step in each method. The advantage of this method comes from its making use of comprehensive data, which calculates orbital elements accurately. However, this method is unreliable when using Chinese historical data. The main reasons are:

(1) The description of the comet's position in Chinese historical records is not accurate enough. Most of the re-

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cords are too short. Therefore, calculating a comet's position with those records will make the results have bad accuracy and hence the right ascension and declination of the comet cannot be estimated well enough.

(2) Compared with the modern constellation system, the ancient Chinese one had its own special rules that make it hard to form an analogy with the modern one. This aspect makes it difficult to get a highly precise track of the comet from those data and star catalogs.

(3) The reliability of those records needs to be demonstrated. In the past, the records of special phenomena served for astrology. Therefore, the possibility that some records were fabricated for political or other reasons cannot be excluded.

In conclusion, because of the uncertainty of Chinese historical records, it is difficult to make a quantitative study. Besides, the orbital elements of a comet may change from time to time. The method of identification through comparison between the calculated results and present orbital elements is still under debate, because it cannot be confirmed how many orders of discrepancy there are between these two orbital elements, which are the criteria for identification of the same comet. Although Japanese researcher Hasegawa had once utilized Chinese, Japanese and Korean historical records to calculate some orbits and to identify some comets, he mentioned little about how he got those results [2,3]. It is hard for us to judge the accuracy of his previous works. From the reasons mentioned above, at least, the method he used and the reliability of historical star catalog are still under debate.

2.1.2 Numerical method

As for the development of celestial mechanics, the second method is superior to the first one for its feasibility and veracity. First of all, solving the equation of motion of a comet:

$$\ddot{\boldsymbol{r}} = -k^2 \frac{\boldsymbol{r}}{r^3} + \boldsymbol{f}_p + \boldsymbol{f}_n + \boldsymbol{f}_r,$$

where $\ddot{\boldsymbol{r}}(\ddot{x}, \ddot{y}, \ddot{z})$ is the acceleration of comet; k is the Gaussian gravitational constant; $\vec{r}(x, y, z)$ and $r = |\boldsymbol{r}|$ are the heliocentric position and distance of the comet. Furthermore, $\boldsymbol{f}_p$ represents the perturbation of planets:

$$\boldsymbol{f}_p = k^2 \sum_j m_j \left(\frac{\boldsymbol{r}_j - \boldsymbol{r}}{\rho_j^3} - \frac{\boldsymbol{r}_j}{r_j^3} \right).$$

In this expression, $\boldsymbol{r}_j(x_j, y_j, z_j)$ are positions of all the perturbing masses; m_j is the mass from Mercury to Neptune with units of solar mass; ρ_j are the distances between the comet and the planet; and $r_j = |\boldsymbol{r}_j|$ are the planetary distances from the solar center; $\boldsymbol{f}_n$ represents the non-gravitational effect which is correlated with the characteristics of the comet, and is an empirical value. Marsden presented the model of $\boldsymbol{f}_n$ while he calculated the orbit of 109P/Swift-Tuttle [4]. This model is now adopted generally by many investigators:

$$\boldsymbol{f}_n = (A_1 \hat{r} + A_2 \hat{T}) \left\{ \alpha \left(\frac{r}{r_0} \right)^{-m} \left[1 + \left(\frac{r}{r_0} \right)^n \right]^{-1} \right\},$$

where $\hat{r} = \frac{\boldsymbol{r}}{r}$ is the unit vector which is along the Sun-comet radius vector; $\hat{T} = \frac{(r\dot{\boldsymbol{r}} - \dot{r}\boldsymbol{r})}{h}$ is the transverse unit vector in the direction of comet's motion, and is normal to the orbital plane; $h^2 = (y\dot{z} - z\dot{y})^2 + (z\dot{x} - x\dot{z})^2 + (x\dot{y} - y\dot{x})^2$ is the square of the angular momentum of the comet. The non-gravitational parameters (A_1, A_2) are determined by the orbital elements, and these two values could not be confirmed unless this comet has appeared at least three times [5]. In the equation, $\boldsymbol{f}_r$ comes from relativistic effects as [6]:

$$\boldsymbol{f}_r = \frac{k^2}{c^2 r^3} \left[4k^2 \frac{\boldsymbol{r}}{r} - (\dot{\boldsymbol{r}} \cdot \dot{\boldsymbol{r}}) \boldsymbol{r} + 4 (\boldsymbol{r} \cdot \dot{\boldsymbol{r}}) \boldsymbol{r} \right],$$

where c is the speed of light. However, in the present calculation, relativistic effects can be ignored because the final result is not affected by these effects. The equation of motion can be solved with numerical integration methods. At last, the orbital elements and the ephemerides can be calculated from the results. At this step it is possible to compare the recorded position with the calculated ephemerides to identify whether the calculate results and the historical records describe the same comet.

2.2 The method used in this work

Because the purpose of this identification is to find some correlated records of comets in Chinese historical astronomical literatures, it is more credible to adopt the second method: numerical integration. A reduced model is used to achieve this purpose. For comets, the major perturbation is from Jupiter. Hence, only the perturbation of Jupiter is considered and the non-gravitational and relativistic effects are excluded.

Moreover, the mass of comets is much less than that of the Sun and Jupiter. Therefore, the perturbation of comet from the Sun and Jupiter can be neglected. In such approximation, the two major objects obey Keplerian motion with gravitational force. In this case, a three-body model can be adopted [7].

After confirming the equation of motion of a comet, the Runge-Kutta-Fehlberg method [8,9] is chosen to solve this equation. In order to maintain accuracy, the truncation error is defined to be around 1×10^{-22} (different values can be set for different comets). Other important factors are the masses and positions of planets; the planetary orbital data adopted in this identification work and the newest orbital elements of comets are taken from the Minor Planet & Comet Ephemeris Service (MPCEs: http://cfa-www.harvard.edu/iau/MPEph/MPEph.html), which are used as the initial conditions to calculate the orbits.

During the calculations, we noticed that the perihelion time is the most unreliable value among the six orbital elements. Most errors are accumulated from the perihelion time. The errors would be brought by non-gravitational effects and the perturbation of other planets. Considering this situation, the method of "cross reference" is presented in this work: firstly, the records before and after the calculated result within the error range are all compared with historical records and correlated with perihelion time according to the record in available literatures. Secondly, the other five orbital elements at the perihelion time can be used to calculate ephemeris. Finally, if the calculated ephemeris and the records match each other, it can be concluded that they described the same comet.

Subsequently, 1P/Halley and 153P/Ikeya-Zhang, which have been previously identified, are utilized to demonstrate the feasibility and reliability of the proposed method.

(1) The identification of 1P/Halley. The truncation error is 1×10^{-22}, and the initial conditions are shown in Table 1.

Using the method described above, the orbital elements are calculated. The results are listed in Table 2.

For comparison, the orbital elements calculated by Yeomans & Kiang (1981) [10], are given in Table 3.

For the reappearance of Comet Halley in 1759, for instance, we found the record in *Qing Shi Gao • Tian Wen 14*, the astronomical part of the official history of the Qing Dynasty (AD 1616–1911), edited in AD 1914, by Ke Shao-Min et al. Here we translated the original record as follows: "On the day of Wu-Chen in the fourth month, a comet appeared in the southwest sky, and it was above the second star of Zhang; on the day of Ji-Si, it was six degrees from Zhang, and was as big as a filbert, the color was yellow; its tail was seven meters long, pointed to the southeast, and moved directly; on the day of Ren-Shen, it became smaller than before; on the day of Ding-Chou, it was smaller and smaller; on the day of Ji-Mao, it trended towards disappearing; on the day of Ren-Wu in the next month, it could not be seen again".

"The day of Wu-Chen in the fourth month" is 13-05-1759. From the calculated ephemeris, the comet was in Sextant at that moment, and Sextant is just above the second star of Zhang, which is the fifth constellation of southern Phoenix and in the southwest. This agrees with the record. In addition, the tail of this comet pointed to the southeast, and the comet was along its prograde orbit. Hence, we consider that the comet described in this record is 1P/Halley.

(2) The identification of 153P/Ikeya-Zhang. The truncation error is 1×10^{-22}, and the initial values are shown in Table 4.

With the same method, the orbital elements are given in Table 5.

For example, for the reappearance in 1273, one record is found in *Yuan Shi • Shi-Zhu 5*, the official history of the Yuan dynasty (AD 1206–1368), which was edited by SHONG Lian et al. in AD 1368. The translation is: "A guest star which was blue and white, which looked like a floccus, was located in Bi, and then crossed to the north of Wuche; it went back to Wenchang a few days later, and crossed

Table 1 The initial condition of 1P/Halley

JDT	T	i	e	ω	Ω	q (AU)
2446470.95895	1986 Feb. 9.4590	162.2422	0.967277	111.8657	58.8601	0.587104

Table 2 Orbital elements of 1P/Halley

JDT	T	P (yrs)	e	q (AU)
2418790.20995	1910 Apr.28.70995	76.056564±0.01	$0.9672602\pm1.30\times10^{-6}$	$0.5872636\pm1.34\times10^{-5}$
2391601.05177	1835 Nov.18.57177	76.26416±0.03	$0.9669830\pm3.73\times10^{-5}$	$0.5924611\pm2.00\times10^{-4}$
2363608.55870	1759 Mar.29.05870	76.26416±0.03	$0.9669316\pm1.22\times10^{-4}$	$0.5902855\pm8.89\times10^{-4}$

JDT	T	i	ω	Ω
2418790.20995	1910 Apr.28.70995	162.2341±0.0002	111.9300±0.006	58.81323±0.004
2391601.05177	1835 Nov.18.57177	162.4007±0.0109	110.1148±0.535	57.00298±0.493
2363608.55870	1759 Mar.29.05870	162.6923±0.0430	109.1708±0.640	55.97665±0.595

Table 3 Orbital elements of 1P/Halley [10]

JDT	T	P (yrs)	e	q (AU)	i	ω	Ω
2418781.67771	1910 Apr.20.17771	76.08	0.9672968	0.5871888	162.21507	111.71703	57.84670
2391598.93871	1835 Nov.16.43871	76.27	0.9673860	0.5865423	162.25518	110.68555	56.8025
2363592.56075	1759 Mar.13.06075	76.89	0.9676792	0.5844466	162.36893	110.68990	56.52871

Table 4 The initial condition of 153P/Ikeya-Zhang

JDT	T	i	e	ω	Ω	q (AU)
2452351.27489	2002 Mar.17.7749	27.9903	0.990140	34.8433	93.3262	0.511750

Table 5 Orbital elements of 153P/Ikeya-Zhang

JDT	T	P (yrs)	e	q (AU)
2327793.99529	1661 Mar. 6.59529	341.0328±0.15	$0.9898514\pm2.45\times10^{-5}$	$0.5079702\pm1.79\times10^{-3}$
2186110.74479	1273 Mar.30.24479	387.5672±10.4	$0.9896547\pm9.36\times10^{-4}$	$0.5190326\pm2.68\times10^{-3}$
JDT	T	i	ω	Ω
2327793.99529	1661 Mar. 6.59529	28.09949±0.18	34.62097±0.27	93.85669±0.15
2186110.74479	1273 Mar.30.24479	27.58126±0.22	35.58291±0.36	92.76806±0.24

Dou-shao and Geng-he; its tail was pointed towards Zuo-sheti; it stayed in the sky for 21 days."

By simulation of comet tracks in 1273, we found that 153P/Ikeya-Zhang had once gone through Taurus, Auriga, Ursa Major and Boötes from 09-04-1273; here Bi, which corresponds to Taurus, is the fifth constellation of western White Tiger; Wu-che represents the Auriga-β, Dou-shao means Yu-heng, Kai-yang and Yao-guang which belong to Ursa Major. Moreover, Geng-he and Zuo-sheti are in Boötes. It is confirmed that 153P/Ikeya-Zhang returned in 1273, and this result corresponded with the work of Hasegawa & Nakano (2003) [8].

3 The identification of comets

Some short-period comets have been identified in other researches, hence this time, we want our identified objects to mainly be long-period comets ($P > 200$ years). The earliest Chinese historical record of comets is about from the years of 636 BC–628 BC (the Chun-qiu Period in Chinese history). This phenomenon was recorded in *Lun Heng*, an important piece of literature in Chinese history, written by WANG Chong (AD 27–97). The translation is: "Jingwengong was at war with Chu-chengwang in the Pu prefecture, and a comet appeared in the sky of Chu".

Considering the density of comets in the historical records, the upper limit of the period of a comet that can be considered is defined as 2500 years.

The purpose of this study is to find corresponding comets in historical records, and the apparent brightness of comets must be considered. This means that the phenomena of comet appearance could be observed with naked eyes. The apparent brightness of a comet can be described by

$$M = H + 5\log\Delta + G\log r, \quad (1)$$

where H is the absolute magnitude; Δ is the distance between the Earth and the comet and r is the distance between the Sun and the comet; H and G are strongly correlated with r and the size of the comet; usually, G is defined to be 10, and H is defined to be 6 [8]. Because of lack of information about comet size, only those comets with a small perihelion distance q (< 1.5 AU) were considered. According to the condition above, 12 comet candidates from 1970 to 2006 are selected:

(1) Long-Period Comets: C/1975 T2, C/1992 W1, C/1993 Y1, C/1997 O1, C/1998 K5、C/1998 U5, C/1999 A1, C/2004 F2, C/2004 K3, C/2005 P3.

(2) Short-Period Comets: 6P/d'Arrest, 35P/Herschel-Rigollet.

3.1 Results of identification

Four records of three comets have been found through the identification processes mentioned in the previous section.

3.1.1 *Long-period comets*

From the calculated ephemeris, the return in 09-11-1539 showed that C/1975 T2 rose and disappeared with the Sun. It was impossible for the ancient observers to record it. In the second period (16-05-1077), no records in literature have been found.

However, in its third reappearance, on 09-01-595, the position of this comet was

$R.A. = 21^h45^m13.4^s \pm 2^m31.4^s$, $Dec. = +08°25'13'' \pm 0.44°$.

In Chinese ancient atlases, it was between Xu and Wei of the Northern Turtle. After that, it passed Pisces. During that time, its tail pointed to Kui and Lou of the western White Tiger. We found only one possible record in *Sui Shu • Tian Wen Zhi*, the astronomical part of the official history of the Sui Dynasty (AD 581–618), edited by Wei Zheng et al. in AD 629. The translation is: A comet appeared in the position which is between the Xu-Wei and Kui-Lou.

However, we still cannot be certain whether this statement can be correlated with C/1975 T2 because of the uncertainty of calculation and the lack of sufficient information in the records. It just presents a possibility that C/1975 T2 was recorded by our ancestors.

In addition, the historical records which can correspond with other long-period comets such as C/1992 W1, C/1993

Y1, C/1997 O1, C/1998 K5, C/1998 U5, C/1999 A1, C/2004 F2, C/2004 K3, and C/2005 P3, were not found.

3.1.2 6P/d' Arrest

Taking the same method, correlated records of two periods were found:

The first one was found in *Dengzhou Fu Zhi*, the local Chronicle of Deng city in the Qing Dynasty. The translation is: “A comet appeared in the southwest sky; it had a three meter tail, looked like a broom, and moved to the direction of Bei-dou (Ursa Major). It disappeared a month later.”

The recorded year was 1678. This result is the same as the work done by Carusi (1991) [9].

The other one may be recorded in *Huaiyuan Xian Zhi*, the local chronicle of Huaiyuan county in the time of Yong-zheng (AD 1723–1736) in the Qing Dynasty. The translation is: “ A comet appeared in the southwest sky; the tail was decades of meters long; and it disappeared two months later.”

The recorded year was 1671.

3.1.3 35P/Herschel-Rigollet

In its first appearance, this comet passed its perihelion on 07-11-1784; it was just visible in winter. From its ephemeris, during this time, 35P/Herschel-Rigollet was between Hercules and Lyra, and was in the southwest. We just find one record which might be about 35P. It was in ⟨Chaoyang Xian Zhi⟩, the local Chronicle of Chaoyang county in the time of Qianlong (AD 1736–1796) in the Qing Dynasty. Here is the translation: “A comet appeared in the southwest.”

This record was recoded in the winter of the forty-ninth year of Qian-long in the Qing Dynasty (1784). We find nothing related to this comet during other periods.

From the calculation in section 2, one can notice that for short-period comets, the uncertainties of periods and positions are less than 0.5 year and 0.05 degree, respectively. These values are less than the uncertainties of the records in those possible literatures, in which only brief times and directions were recorded. Therefore, it is reasonable to think that the records described above stated the appearance of these two short-period comets.

4 Analysis and discussion

From the identified candidates above, the corresponding records in history are usually short. We considered that there are five reasons for this fact:

(1) The superior transits of some comets were during the day or they were not in the Northern Hemisphere when they came back to perihelion. The recurrence of some comets is this kind of situation, so they were unobservable and were consequently not recorded.

(2) In the present work, the apparent brightness of comets is not considered for two reasons: first of all, the apparent brightness is based on sufficient observed data, and the apparent duration of many comets is short. Hence, the data confirm that the formula of their magnitude-change is not sufficient. Secondly, each comet has its own change of magnitude. The change of brightness of some comets may reach one magnitude during two recurrences [11]. Considering this situation, the possibility that they may get brighter or darker suddenly cannot be excluded. Another uncertainty factor is weather. If it was rainy, cloudy or plenilune when a certain comet came back, the lack of a comet’s record is natural.

(3) Using this method of identification, only the perturbation of Jupiter is considered because it is the main factor that causes perturbation. For comets in Jupiter’s family ($P <$ 20 years), their perihelion points of orbits are inside Jupiter's orbit. It is enough to consider the perturbation of Jupiter only. However, most short-period comets ($P >$ 20 years) are from the Kuiper Belt which is outside of the orbit of Neptune. Although perturbation of other planets is far less important than that of Jupiter, the errors during the numerical integration could not be ignored while integrating many periods. On the other hand, long-period comets are mostly from the Oort Cloud which is 3×10^3–5×10^4 AU away from the Sun. The perturbation on those comets is more complex. For instance, the movements of objects that affect them have great uncertainty. It is hard to solve the problems with classical mechanics. In one or two periods, the errors could be corrected by historical record; however, with more periods, the error can run up to 40 – 100 years. The non-gravitational effect is neglected in the present work, and the error of integration was corrected by “cross reference” with historical records. We found that this method still has great uncertainty and low efficiency, especially for Jupiter - family comets. 6P/d′ Arrest, for instance, was integrated to one hundred periods, and the error had run up to 1.4 years. The more periods that are integrated, the more quickly the error accumulated. When it was integrated to 160 periods, the error was around 2.2 years. That is, non-gravitational effects could not be ignored in orbital calculations of short-period comets.

(4) The results would also be affected by using different planetary systems [10]. Because of the limitation of our calculation system, only one Jupiter coordinate was adopted in the calculation. No quantitative results are given to confirm how errors would be introduced due to that fact. An ideal method is to study the long-term ephemeris of Jupiter, and the Jupiter coordinate when a comet's return is selected as the initial condition.

(5) Whether or not the observation is the first time that the candidate long-period comet appears needs to be demonstrated. The orbits of objects in the Oort Cloud would be changed because of some passing stars (there are 10–12 stars which may pass through the position which is 2×10^5 AU from the Sun per million years). Some of these objects came into the solar system, and became the new comets

which were observed. In this situation, we consider that those candidate long-period comets may appear for the first time. Hence, no record of them is explainable.

5 Conclusion

In this identification study, three comets with four records are found. They are C/1975 T2, 26P/d′Arrest, and 35P/Herschel-Rigollet. We also confirm the degree of reliability of identification and the error bars.

Historical records were taken from The collection of Chinese historical phenomena records. Although this literature collected comprehensive records, whether those records are from official history or a local chronicle is not clear, and the reliability of the records is not certain. In some years, the appearance of comets was only recorded in local chronicles. In Chinese historical records, even for bright comets, the difference between these two kinds of records is obvious in time and position. Therefore, the identified work may be misleading. Moreover, the range of literature will also be extended. For example, the literature of the supernova records can be searched. Because in ancient China, supernovae and comets were both called “guest stars”, the possibility of using them for further study can not be excluded. AD185, for instance, had originally been thought to be a supernova, but after identification, it was actually a comet [12]. At last, other countries’ records can also be used as circumstantial evidences of identification. In the following study, non-gravitational effects will be added into the equation of motion. For long-period comets and Halley’s comet, the perturbations from many other planets need to be considered. A more accurate planetary system will be adopted to get more precise results for long-term evolution of a comet. In conclusion, only when precise orbital elements are calculated, and sufficient researches about historical literature are made, may a reliable answer be reached.

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