Planetary and Space Science 204 (2021) 105282

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

About C/539W1 and C/1245D1 as the parent comet of 15-BOOTIDS

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ARTICLE INFO

Keywords:
Celestial mechanics
Meteoroids
Meteors
Small bodies
Comets
C/539W1
C/1245D1
Meteor showers
15-Bootids

ABSTRACT

In a recent paper published in this journal it was presented an interesting study on the 2019 outburst of the 15-Bootids and it was suggested the possibility that comet C/539W1 was the parent comet of this meteor shower. It was also deducted from the method employed that this parent comet could have had a first passage through perihelion around the year AD1260. In this paper, we review both assumptions and we propose the possibility that the previous perihelion passage of the parent comet of the 15-Bootids was observed and recorded as C/1245D1.

1. Introduction

In a recent paper Jenniskens et al. (2020) presented an interesting study on the 2019 outburst of the 15-Bootids and suggested the possibility that comet C/539W1 was its parent comet. This possibility was based on the fact that the orbit obtained for the meteor stream was that of a Halley-type or a Long-Period comet, and that the orbital elements resembled those of C/539W1.

For some years, we have devoted to compiling ancient European astronomical records, focusing our interest on the Middle Ages roughly considered as the period between the 5th and 15th centuries AD and on registers from narrative sources. That is, those that appear in non-scientific books such as chronicles. This has led us to compile an extensive record of astronomical phenomena, some of them not previously published. Among these records, the large amount of data referring to cometary observations stands out. Recently, we have started to use these records to, together with data from China, Japan and Korea, improve or, where appropriate, calculate comet orbits for the first time in the aforementioned time period.

In this context, we were struck by the proposal of comet C/539W1 as the parent comet of the 15-Bootids, as well as the calculation of a subsequent visit of this same comet around year AD1260 and we set out to check as much as possible if this was feasible from the historical and astronomical point of view. This paper is the result of this attempt.

It should be noted that, although there is evidence that points to the veracity of Jenniskens's hypothesis, it will never be possible to have complete security. The authors themselves are aware of this and they remark it in their paper. This is mainly due to the uncertainty surrounding the historical data, which we will deal with later.

In the first place, we will outline the method that we have followed in trying to identify the parent comet in the 13th century. Having accomplished this, we will discuss the historical records for both the 13th and 6th centuries and calculate its orbital elements comet for both periods.

Throughout this paper, the dates are given in Gregorian calendar after the 16th century and in Julian Calendar before the 16th century. All the calculations referring to the integration of the orbital elements have been carried out using the JPL HORIZONS on-line solar system data and ephemeris computation service (https://ssd.jpl.nasa.gov/?horizons).

2. Methods

Jenniskens et al. (2020) examined the outburst of the 15-Bootids (IAU shower 923, FBO) on April 21/22 reported by the global Cameras for All-sky Meteor Surveillance (CAMS). They obtained a set of average elements from the observations of the meteors and then proceeded to the search and identification of the parent comet following a strategy that led them to identify the properties that it should accomplish. Thus, the parent comet should correspond to a long period comet type with an orbital period of about 850 years. The method employed was specified in a previous article (Lyytinen and Jenniskens, 2003) and it is based on the

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https://doi.org/10.1016/j.pss.2021.105282
Received 25 January 2021; Received in revised form 9 March 2021; Accepted 7 June 2021
Available online 10 June 2021

backward integration the orbit of an observed meteoroid for an assumed semimajor axis an until one complete revolution to the previous perihelion passage, and the adoption of the found perihelion time as the time of ejection. In their case, they chose $a \approx 90$ AU, and the well-known relationship with the orbital period $a^3 = T^2$ provided a past return of the comet in ~1260 AD.

In this paper, we consider the averaged orbital elements of the 15-Bootids provided by Jenniskens et al. (2020) and then assume the possibility of a perihelion passage of the parent comet by the mid-13th century. Firstly, we performed a search among the records of ancient comets reported in that century, considering a wide range of time, between AD1230 and AD1290, trying to find a comet that presented a compatible orbit.

Once the candidate comet has been identified, we considered the elements for the 15-Bootids and we performed a backward integration in time until the 13th century. Then, we verified that the integration gave results that were compatible with the positions registered for the selected comet. Then we made a required correction in the time of the perihelion passage and we integrated backwards again until AD400 which led us to obtain a new passage through the comet's perihelion for the expected year AD539. Finally, we use the two sets of elements (those for AD1245 and AD539) to compare the resulting orbits of the comets with the available historical records.

3. Results

In their article, Jenniskens et al. (2020) pointed out that "given the relatively short orbital period of the 15- Bootids, it is possible that the comet has returned to the solar system more than once since 539 AD. Because those encounter dates are unknown, any changes in the comet orbit would be random" however, from the method followed there is the possibility of a return of the parent comet sometime around the year AD1260.

As mentioned above, we began by examining the historical records of comets between the years AD1230 and AD1290. The main source used for this was Kronk's book *Cometography* (1999), although we also used at some point our own compilation of European sources. In this period about fifteen comets were reported, most of them with registered positions incompatible with the orbital characteristics of the 15-Bootids. However, comet C/1245D1 did meet the required conditions in a first approximation, so we investigated this case further.

3.1. C/1245D1

The primary sources of information on C/1245D1 come from Japan and have been compiled by several authors, but we chose the recent translation given by Pankenier et al. (2008). These sources are the *Azuma kagami* (13th century), *Hyaku ren shō* (13th century) and the *Dai Nihon shi* (17th century), a brief summary of their content can be seen in Table 1.

From the above table it can be deduced that the comet's visibility period was between AD 1245 Feb 24, when it was detected in the SE, and April 4. Eastern astronomers divided the sky ecliptic into four regions, and for each region they defined seven Lunar Mansions (LM henceforth). These are defined by determinative stars and they correspond to the longitudes along the ecliptic that the Moon crosses during its orbital period around the Earth. See Kronk (1999) and Pankenier et al. (2008) for a discussion of the data.

On February 25 the comet was seen southeast of TIANSHIYUAN (Celestial Marketplace, ζ Oph) in the space of DOU [LM 8] (Southern Dipper, ϕ Sgr); On February 26 it was seen south of lunar mansion NIU [LM 9] (Draught Ox, β) where it would also remain on February 27 and 28, although on February 27 it could not be observed due to bad weather. This is followed by a period in which for some reason there are no records of the comet although, given that for March 30 it indicates that the sky was clear, perhaps the lack of records is due to a long period of bad weather conditions. Finally, on March 30, the comet was seen between SHI [LM 13] (Lay out the Hall, α Peg) and BI [LM 14] (Eastern Wall, γ Peg).

Table 1
Main data about C/1245W1 in the Japanese registers. We follow Pankenier et al. (2016) for the notation of Chinese constellations and asterisms. LM stands for Lunar Mansions (see text).

Source Date	Hyaku ren shō	Azuma kagami	Dai Nihon shi
Feb 24	Today at dawn a guest star was seen		A guest star was seen in the southeast
Feb 25		During the hour of chou [LT 1–3 h], a guest star was seen in TIANSHIYUAN at azimuth xun [SE] in the space of DOU [LM 8]	It was seen southeast of TIANSHIYUAN within the space of DOU [LM 8]
Feb 26		During the hour of yin [LT = 3–5 h], the guest star still was seen south of lunar mansion NIU [LM 9]	It was seen to the south of NIU [LM 9]
Feb 27			It did not appear due to dark clouds
Feb 28		The guest star was seen in the space of QIANNIU [LM 9]	It was seen within the space of QIANNIU [LM 9]
Mar 30	Today at dawn a broom star was seen in the East	During the hour of yin [LT 3–5 h], a broom star was seen between SHI [LM 13] and BI [LM 14], with a length of 2 chi.	A broom star 2 chi long was seen between SHI [LM 13] and BI [LM 14];
Apr 4	The broom star has not been seen.		It disappeared

This comet was also recorded in a contemporary European source, the *Annales Stadenses* (1826) which is a 13th century source written between 1240 and 1256 by Alberto, abbot of the Blessed Virgin Mary convent in Stade, near Hamburg (Germany).

Circa ascensionem Domini orta est versus meridiem quasi in capricornio stella quaedam ad instar Luciferi, magna, clara, sed rubea; et sicut unus planetarum certum singulis diebus ortum tenuit et ocasum; (…) Stella vero iam dicta post diem Iacobi ulterius adeo lucida visa non est, sed de die in diem tam magnitudinem quam claritatem perdidit.

The fragment states that a new reddish star never seen before appeared about the time of the Ascension, in the area of Capricorn. Like the planets, it rose and set. Later, he also points out that people mistook it for Mars and he states that it could not be Jupiter, since Jupiter was in Virgo. He adds that an eclipse of the sun occurred on the day of Santiago (July 25) that same year and that the star was no longer visible at that time, since it had lost its magnitude day after day.

The astronomical data cited in the previous record are accurate. According to the calculated orbit the comet rose and set as seen from Stade, Jupiter was between Virgo and Leo and the annular eclipse of the sun (which was partial in Germany) on July 25, 1245 is also correctly referenced. However, the Feast of the Ascension took place 40 days after Easter, on April 16 that year, which brings us to around May 26. It is a bit too late for the comet, but since there is no other comet recorded for those years and that the position in Capricorn coincides with that of C/1245D1 we can assume an error in the date on the part of the copyist.

Hasegawa (1979) calculated a parabolic orbit for this comet, as we can see in Table 2. Completely independently and in our process of recomputation of orbits of ancient comets, we obtained the orbital elements shown in the same table.[1] In our case, we took into account that when the position of a comet is given with respect to a lunar mansion, the ancient author could only mean that the comet is in the longitude of the

[1] To obtain the orbital elements, the authors used their own programs, but they also relied on the Find_Orb code (https://www.projectpluto.com/), which is widely used in this context.

Table 2
Different orbits calculated for comet C/1245D1. To enable comparison, the mean elements of the 15-Bootids given by Jenniskens et al. (2020) are also shown. As previously stated, the dates are given in Gregorian calendar after the 16th century and in Julian Calendar before the 16th century.

	Ω	Ω (2000.0)	*i*	*Q*	*e*	*Author*
1245 Apr 1	87	180	20	0.5	1	Hasegawa
1245 Apr 12	252	52	26	0.61	1	Martinez&Marco (This work)
2019 Apr 21	254.8	31.309	19.2	0.637	0.985	15-Bootids

lunar mansions and not exactly inside the lunar mansion (see Needham (1959) and Xu et al. (2000) for a general review). The orbit that we computed has characteristics similar to those shown by the 15-Bootids, which are also included in the table for comparison.

The significant similarity between the orbit we obtained and that of the 15-Bootids led us to think about the possible relationship between the comet of the year AD1245, that of AD539 and the parent comet of 15-Bootids. Jenniskens et al. (2020) had outlined a strategy to try to find and, when appropriate, identify the parent comet of the 15 -Bootids: "The motion of the dust trail's orbital node over the years can be calculated from the planetary perturbations on a stream of meteoroids entering the solar system from a distance. Not knowing the exact orbit and orbital period of the parent comet, a good approximation can be made by using the orbit measured from the 2019 meteoroids and by assuming ejection at an arbitrary date far enough into the past, i.e. for a semi-major axis in the range $a \approx 50–100$ AU (Lyytinen and Jenniskens, 2003)". They chose $a \approx 90$ AU, which would correspond to a past return of the comet around AD1260.

In order to try to find more evidence that C/1245W1 could correspond to the parent comet of the 15-Bootids, we carried out a backward integration in time considering as initial elements those provided in Tables 2 and 3 for 15-Bootids. For this, we carried out different tests to choose the most suitable semi-major axis resulting in $a \approx 92$, which led us to assume an $e \approx 0.993$. The selected initial elements for epoch AD2019 are displayed in Table 3 as C/1245D1*.

The results for epoch AD1245 are displayed in the third row of Table 3. The significant planetary perturbations are only expected to be provided by Jupiter due to the relatively low inclination of the orbit, but we also checked and dismissed the possibility of other close encounters with bodies of the solar system. The orbital elements turned out to be very stable, although the date of the perihelion differs from the expected year, but given the rough approximation that we have initially made, such an error is not unexpected. The positions that these elements would yield by varying the perihelion date by taking a perihelion passage around 1245 April 9 are totally comparable to the positions registered from the original orbit provided by Hasegawa (1979). See Fig. 1.

3.2. Link to C/539W1

In order to establish a link between comets C/1245D1 and C/539W1, we start from the elements shown in the first row of Table 4 for the former, where the time of the perihelion passage has been corrected to make it coincide with the one observed and we carry out the blackward integration again until year AD539. To illustrate the complication of calculating the orbital elements of a comet from historical records (see the recent paper of Neuhäuser et al. (2021) to expand this topic), and for the sake of completeness, we also show in Table 4 the different values for the orbital elements of C/539W1 obtained by several authors. The orbital elements computed by integration for C/539W1 from those of comet C/1245B1 listed in Table 3 are represented as "C/539W1. This paper". They correspond to those expected with the exception of the date of the perihelion passage, for which a slightly earlier date than expected has been obtained. This discrepancy could be due to a slight error in the date of perihelion initially considered for the 13th century or to the uncertainties in the considered elements of C/1254D1.

As for C/539W1 comet, there are several literary sources from Europe and Asia, which collect different observations. As usual, the most detailed ones come from China and have been commented on by numerous authors, so we only include a summary of the data from Pankenier et al. (2008), where the translation of the original text can be consulted. The oldest text are the *Wei shu* (572), and the *Sui shu* (636), and both of them indicate that the comet appeared on 539 November 17 in NANDOU [LM 8] (Southern Dipper, ϕ Sgr) pointing SE. It disappeared after reaching LOU [LM 16], (Hillock, β Ari). Furthermore, the *Wei shu* also states that at the end of November the comet passed at a distance of 3° from Venus. Again, it should be noted that when talking about lunar mansions, it is possible that this does not imply that the comet was in them, but instead could only mean that the comet was in the same longitude.

In addition, there are some European records highlighting among them the well-known contemporary from the *History of the Wars* by Procopius (553):

The comet appeared, at firts as long as a tall man, but later much larger. And the end of it was toward the west and its beginning toward the east, and it followed behind the sun itself. For the sun was in Capricornius and it was it Saggittarius. And some called it the sworfish, because it was of goodly length and very sharp at the point, and others called it the bearded star; it was seen for more than forty days.

From where an approximate date of December 27 for the end of the comet's visibility can be obtained (Kronk, 1999). This paragraph also led Hasegawa (1979) to state the date of 540 January 30 for the last sighting of the comet, but because the month is missing in the Chinese accounts, an alternative date of last visibility could be 539 December 1. However, this date is considered unlikely given the long visibility interval provided by all the records.

Regarding the data provided by Procopius, oddly, the positions of the Sun and the comet are reversed for the end of November, being the sun entering in Sagittarius and the comet in Capricornius, just above Venus. The time in which Procopius places the comet, after the fall and destruction of the city of Cassandria that occurred between AD539 and AD540, leaves no doubt that he refers to C/539B1.

Although this is the best known, it is not the only available contemporary source. The comet also appears in *The Chronicle of Edessa (1864)*, which is generally agreed to have been written c. AD540–550. We reproduce the fragment, but we omit the discussion about the error in the dating of the Seleucid calendar employed.

In An. 13 of the reign of Justinian, which was the year 850, indiction deutra (the second), a sign like a spear appeared in heaven on the 5th of Tishrin the former.

In this chronicle, the comet appears to have been detected in the month of Tishrin the former (October) and not in November, but it seems doubtful that the comet was ignored when it reached its maximum brightness in November. Perhaps the author was referring to the month of Tishrin the latter (November).

Later, other authors collected more reports in their compilations or chronicles, although without providing more significant details. Among the oldest authors, it can be highlighted Bar Hebraeus (1226–1286) who in his *Chronography* (Bar Hebraeus, 1932) places the comet in the eleventh year of Justinianus, at the time of the breaking of Justinian's peace

Table 3
Initial elements for the backward integration and results for the first perihelion passage of the parent comet of the 15-Boots in AD1245.

T_p	ω	Ω (2000.0)	*i*	*Q*	*e*	*Notes*
2019 Apr 21	254.8	31.309	19.2	0.637	0.985	15-Bootids
2019 Apr 21	254.8	31.309	19.2	0.637	0.993	C/1245D1*
1241 Aug 6	254.5	31.691	19.4	0.630	0.993	1st Perihelion

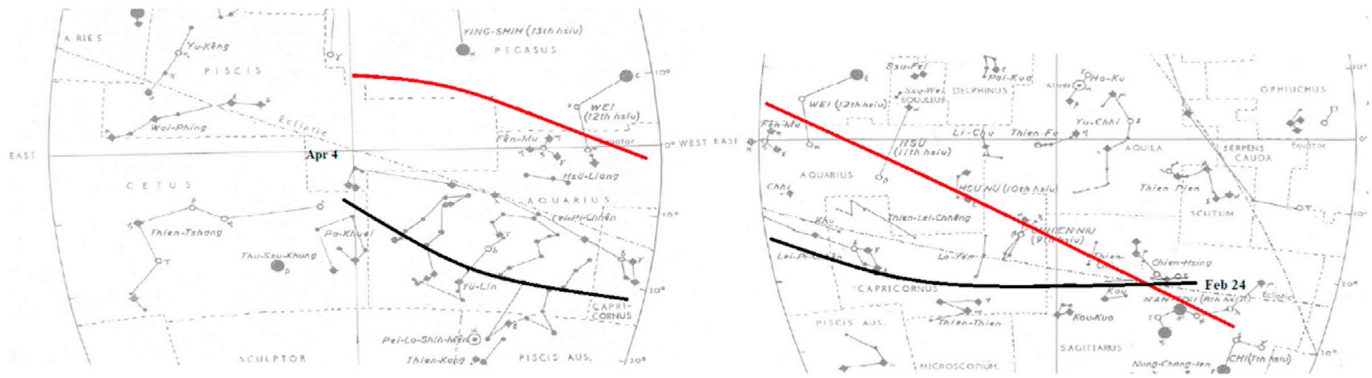

Fig. 1. Comparison of the positions for C/1245W1 considering the orbital elements calculated by Hasegawa (in red) and those obtained by integration (in black). Although the positions differ, they are compatible with the Japanese observations if it is taken into account that these could refer to the longitudes of the LM and not to the fact that the comet is exactly in them. Notice that the first observation is on Feb 24th on the right hand side and the path continues until April 4th in the image on the right. Reprinted from Ho Peng Yoke, "Ancient and mediaeval observations of comets and novae in Chinese sources". *Vistas in Astronomy*, 5, 1962.

Table 4
Initial elements of integration, results after integration and sets of orbital elements obtained by different authors.

T_p	ω	Ω (2000.0)	*i*	*q*	*e*	*Notes*
9 Apr 1245	254.42	31.70	19.35	0.6267	0.9924	C/1245B1. This paper
15 Sep,539	253.35	33.27	19.19	0.6300	0.9930	C/539W1. This paper
6 Nov, 539	246	33	19	0.16	1	Hasegawa (1979)
25 Oct, 539	254.75	31.30	19.24	0.6368	0.985	15-Bootids
22 Oct, 539	250.26	83.30	15.69	0.31	1	Martinez&Marco (unpubl)
21 Oct. 539	256	60	10	0.341	1	Burckhardt (1800)
21 Oct. 539	75	240	10	0.341	1	Burckhardt (1800)
1.5 Nov. 539	262	55	14	0.28	1	Sicoli (2020)

with the Persian king Kosroes and he states that it was visible in the afternoon many days.

Other sources were already mentioned by Jenniskens et al. (2020), such as A. Danduli (1306–1354), slightly later than Bar Hebraeus:

Anno autem Justiniani XIII in diversis Galliarum locis varia signa visa sunt; cometa apparuit in Paschate, Coelim arderé visum est.

In the fragment, he places the comet at Easter, although it could refer to Christmas Easter, which already appears with that name in texts from the late 11th century. Other records are much later and usually appearing in compilations of cometary records (Alstedio (1624) and Ricciodi (1651) among others). None of them provide more data than those already mentioned: the comet was seen in the time of Justinian, it appeared in December in Sagittarius, it was followed by an earthquake and that it was the harbinger of famines and plagues but several of them contain errors in the dates. Consider, as an example, AD541 in *Kometographia* (Mather, 1613).

To calculate the orbital elements of this comet, most of the authors assumed that the comet's passage near Venus occurred to the North of this planet, and a position of great proximity with respect to the lunar mansions. This led to proposing orbits (See Table 4) that present magnitude problems, as will be seen below. It should be remarked that the orbital elements calculated by P. Sicoli would not present the magnitude and visibility problems that the rest do present to a greater or lesser extent.

The already mentioned discussion about the end of the comet's visibility period is also long and can be consulted in Kronk (1999). Some authors stated that the comet vanished on December 1, while for others the end date would be January 30. The most reasonable date for the end of the visibility period is around December 27 for European observations and January 30 for the Eastern ones.

As can be seen, the orbital characteristics calculated for the 15-Bootids provided an orbit that closely resembled that of C/539W1 whose initial parabolic orbit calculated Hasegawa (1979) also may be seen in Table 4. The perihelion distance is significantly smaller than that derived from the 15-Bootids and this difference in *q* provides an earlier perihelion passage as Jenniskens et al. (2020) stated.

One of the biggest problems presented by the orbits previously calculated by other authors is the question of the comet's magnitude and its visibility in the days or months prior to its passage through perihelion. Let us examine this question. Kronk (1999) took a magnitude of $H_{10} = 0.5$ for the comet using the orbit of Hasegawa under the assumption that the Chinese followed the comet until it was no longer visible due to its magnitude. That would mean that on January 30 the comet's magnitude must have been around 5.5. In any case, assuming normal brightness behavior, the comet would have been perfectly visible in September at sunrise as Kronk (1999) points out, even reaching a negative magnitude in October with an elongation that would have made it clearly visible even in the twilight.

The comparison of the magnitude curves for Hasegawa's orbit and the one obtained in this paper shows that the new orbital elements would fit a less bright comet (under the given assumptions for the orbit obtained in this paper we get an $H_{10} = 0.8$) (see Fig. 2). In addition, this comet would have been impossible to see in the months before perihelion because of its proximity to the sun.

4. Conclusions

Starting from the fact that the parabolic orbit calculated by Hasegawa bears many similarities to the 15-Bootids orbit calculated by Jenniskens, we have shown by backward integration that there is a great possibility that C/539W1 is the parent comet of the meteor stream. Furthermore, we have pointed out the possibility that comet C/1245B1 corresponds to the expected 13th century perihelion passage of the same comet. Unfortunately, although the data seem to support this conclusion, it is not possible to affirm this fact with complete certainty due to the inaccuracies coming from working with historical data collected with the usual inaccuracies of the time.

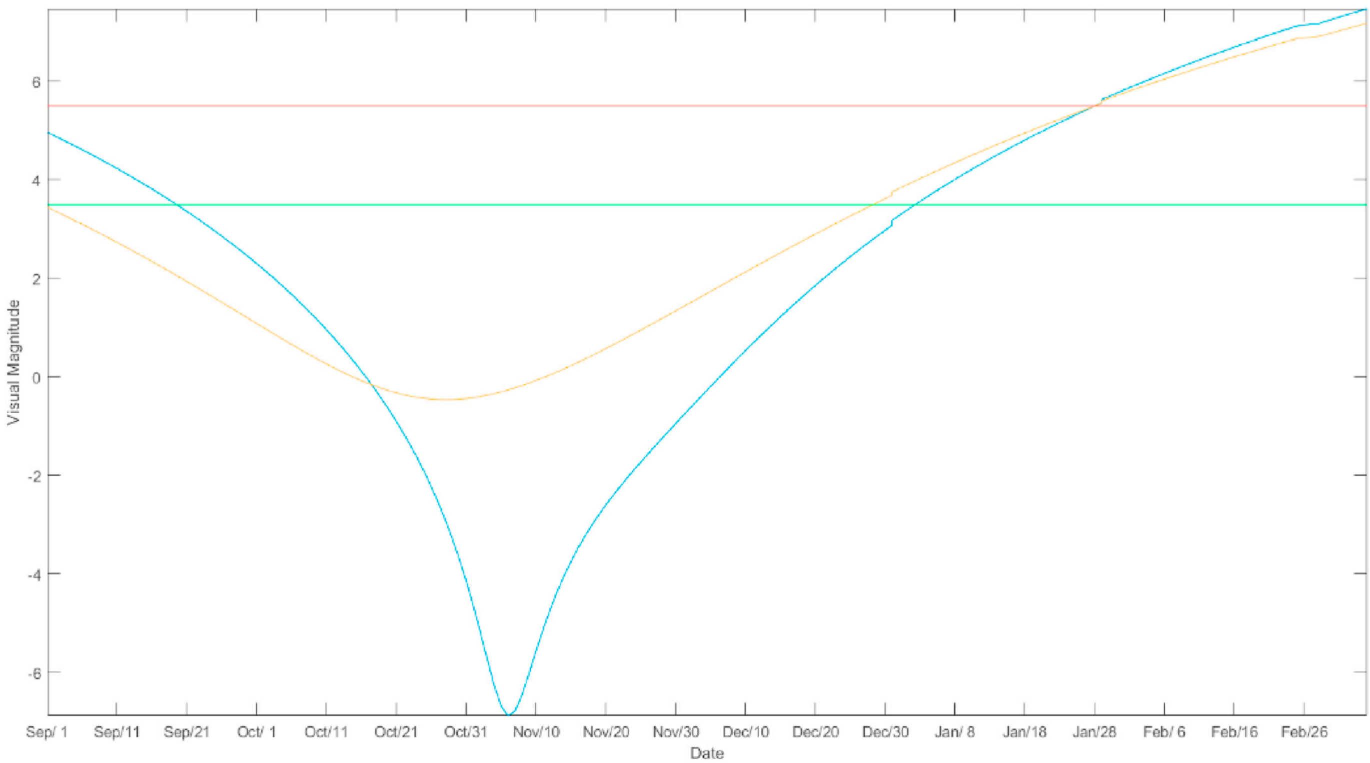

Fig. 2. Comparison of the apparent magnitude for comet C/539W1 using the Hasegawa orbital elements (blue) and those obtained in this paper (orange). The red horizontal line represents the limit of naked eye visibility ($m_v = 5.5$), the green horizontal line stands for $m_v = 3.5$.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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