A NEW AND IMPROVED ORBIT FOR COMET C/400 F1

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Abstract: Observations of comet C/400 F1 were recorded in late March and early April of 400 CE from China, Korea, Turkey and Italy. Although one previous orbit had been calculated, the publication of a book in 2008 provided more Chinese comet observations than any previous publication. It presented new observations for several comets, including this one. The new observations for C/400 F1 reveal that the previous orbit missed several key sky locations noted by the Chinese. A new orbit is presented.

Keywords: comets, Comet C/400 F1, orbits, magnitude, tail

1 INTRODUCTION

East Asian observations of comet from ancient and medieval times have long proved important in the study of comets. While Europeans reported seeing comets during these periods, their descriptions were usually fanciful and generally contained little information other than whether the comet was in the evening or morning sky. When dates were provided, modern investigators have shown that some may have been altered to give greater value to important events involving rulers, natural disasters, etc. In East Asia, and particularly China, things were different. According to Pankenier (Lehigh University),

> … many naked-eye observations were verifiable by others at court and attempting to mislead the emperor was a capital crime. Political rivalries virtually guaranteed that manipulation would be discovered. (D.W. Pankenier, pers. comm., 16 June 2021).

The Chinese history book *Tongjian Gangmu*, which was written by students of Zhu Xi in 1172, contained many accounts of comets and was translated into French by the missionary Joseph-Anne-Marie de Moyriac de Mailla (1777–1778). The Chinese encyclopedia *Wenxian Tongkao*, which was written by Ma Duanlin around 1317, also contained many accounts of comets and was translated into French by the missionary Antoine Gaubil, also in the eighteenth century. The translations of Mailla and Gaubil were used by Pingré (1783), when he wrote the first volume of his *Cometographie*. Pingré's book basically became the first introduction of Chinese comet observations to astronomers. A later translation of Ma's book was published by Biot (1843). This translation was used by many astronomers in the nineteenth and twentieth centuries, including John Russell Hind, J. Williams (1871), K. Hirayama (1911), and Knut Lundmark (1921). Perhaps the most notable use of Biot's translation was the series of papers written by P.H. Cowell and A.C.D. Crommelin during 1907–1908, when Chinese observations were used to better understand the long-term motion of Comet 1P/Halley.

A major advance for astronomers who specialized in comets came in 1962, with the publication of "Ancient and mediaeval observations of comets and novae in Chinese sources" by Ho Peng Yoke (1962). Ho (1962: 127) pointed out that Ma's book was "… anything but complete and not always very accurate." He then provided what became the most complete catalog of comet and nova observations from China, as well as Japan and Korea, at least up to that time. This catalog took on a greater importance in the 1970s, when these Asian observations were used by Tao Kiang (1972), to firm up the long-term motion of Comet 1P/Halley, and Ichiro Hasegawa (1979), to calculate the orbits of 38 comets spanning 147 BCE to 1557 CE.

One comet that Hasegawa calculated an orbit for was C/400 F1. Although the orbit did a reasonable job representing the observations, there was one significant observation that it did not satisfy. The Chinese reported that the comet passed through the 'bowl' of the Big Dipper. Hasegawa's orbit predicted the comet actually passed almost 6° outside of the 'bowl', and through the 'handle' of the Big Dipper.

Ho's work stood as the source for comet observations until 2008, when Pankenier, Xu and Jiang published *Archaeoastronomy in East Asia*. This source not only scoured all 24 of the official Chinese histories, but many lesser works as well, including local gazettes. For Comet C/400 F1, it provided new observations that were not available to Hasegawa. Where it had been known that Comet C/400 F1 generally passed from Andromeda, through Ursa Major and Leo, and into Virgo, the new observations were more specific, indicating the comet moved near certain stars and through or near several small asterisms after passing through the Big Dipper.

2 COMET C/400 F1 AS SEEN IN CHINA AND KOREA

This comet was reported in three official Chinese histories: The *Song shu* (compiled during 488–493), the *Wei shu* (551–554), and the *Jin shu* (646–648). These histories were compiled from official records, so the compilation dates do not diminish their importance. The *Jin shu* was the history of the Jin Dynasty, which reigned from 265–420. The *Song shu* was the history of the Liu Song Dynasty, which reigned from 420–479. The *Wei shu* was the history of the Northern Wei and Eastern Wei dynasties, which reigned from 386 to 550. Although it was the general practice for the succeeding dynasty to write the history of its predecessor, Emperor Taizong of the Tang Dynasty was not happy with the existing histories of the Jin Dynasty and ordered that a complete history be written, which was completed 229 years after the end of the Jin Dynasty. In 400 CE, the capital of the Eastern Jin dynasty was Jiankang (now Nanjing), while the capital of the Northern Wei Dynasty was Ping-cheng (now Datong). According to Pankenier (pers. comm., 8 May 2021), "… it's almost certainly the case that the observations were made in the capitals."

The *Song shu* records the following:

> 4th year of the Long'an reign period of Emperor An of the Jin Dynasty, 2nd month, day jichou; a star 3 zhang long became fuzzy in Kui [LM 15]. It ascended as far as Gedao and the western enclosure of Zigong, entered the bowl of Dou, and reached Santai, Taiwei, Dizuo, and Duanmen. (Pankenier et al., 2008: 52).

The 10th Chapter of the *Jin shu* records the following:

> 4th year of the Long'an reign period of Emperor An of the Jin Dynasty, 2nd month, day jichou; a star became fuzzy in Kui [LM 15] and Lou [LM 16], advancing as far as Ziwei. (Pankenier et al., 2008: 53).

The 13th Chapter of the *Jin shu* mentions the comet again, providing more information:

> 4th year of the Long'an reign period of Emperor An of the Jin Dynasty, 2nd month, day jichou; a star 3 zhang long became fuzzy in Kui [LM 15]. It ascended as far as Gedao and the western enclosure of Zigong, entered the bowl of Beidou, and reached Santai. In the 3rd month, it passed by Taiwei, Dizuo, and Duanmen. (Pankenier et al., 2008: 53).

The reign period, month, and day indicate a date of 19 March 400 CE. The measure of "3 zhang" for the tail indicates a length of about 30°. The fact that the object became "fuzzy" indicates a tailless comet. This contradiction of the comet having a 30° tail and yet being tailless will be discussed later. "Kui" is one of the 28 lunar mansions, which is basically a zodiac sign in China. Its determinative star is ζ Andromedae. A determinative star is the primary star used to establish the ecliptic longitude of a group of stars. Lunar mansions are actually quite large, extending northward and southward from the determinative star. On the indicated date, the constellations within Kui that were above the horizon included Andromeda, Cassiopeia, and Cepheus. Lou is another lunar mansion and the then visible constellations within it were Aries, Cassiopeia, and Cepheus. Gedao is an asterism in Cassiopeia, with the determinative star of ξ Cassiopeiae. The western enclosure of Zigong, also known as Ziwei, is another large region that includes stars in Draco, Ursa Major, and Camelopardalis. Its determinative star is κ Draconis. Dou actually indicates a part of the constellation Hercules which is far from this region and is likely an error. This is correctly given as Beidou in the first reference in the *Jin shu*, which is the Big Dipper. Its determinative star is α Ursae Majoris. Santai, known as the "Three Steps", are the three pairs of stars in the southern part of Ursa Major, which represent the feet of the bear. It is another large region, spanning about 30° in length and extending from the southeast to the northwest. Taiwei is the Supreme Palace enclosure and encompasses a very large region of the sky, containing stars in Virgo, Leo, Leo Minor, Coma Berenices, Canes Venatici, Lynx, Sextans, and Ursa Major. Dizuo is another confusing reference, as this also refers to stars in Hercules, but it seems likely that this should be Wudizuo, which is an asterism of five stars in eastern Leo, of which Denebola is the determinative star. Finally, Duanmen, which is the "Main Gate" for Taiwei, is represented by the stars β and η Virginis.

The *Wei shu* provides the following record:

> 3rd year of the Tianxing period of Emperor Taizu of the Northern Wei Dynasty, 3rd month; a star became fuzzy in Kui [LM 15] then passed by Gedao, reaching the western enclosure of Ziwei. It entered the bowl of Beidou, trespassed on Taiyang-shou, rounded Xiatai, overran Nangong, stepped on Dizuo, and then exited via Duanmen. (Pankenier et al., 2008: 53; correction D.W. Pankenier, pers. comm., 5 May 2021).

Two of the references provided in the *Wei shu* refer to the comet's passage by specific stars: Taiyangshou is χ Ursae Majoris and Xiatai is ν Ursae Majoris. This latter star is a considerable refinement over what was given in the *Song shu* and *Jin shu*, as those histories said the comet reached the large area known as Santai. Xiatai is a star within Santai. Another reference only provided by the *Wei shu* is Nangong, which are the stars 92 and 93 Leonis. Finally, although the *Song shu* and *Jin shu* mention Duanmen, the *Wei shu* states that the comet "… exited via Duanmen …", probably indicating it left the large area of Taiwei by passing between β and η Virginis, since, as noted above, Duanmen is the "Main Gate" of Taiwei.

The comet was also recorded in Korea, but the record does not provide any new information. It is mentioned in Chapter 25 of the *Samguk sagi*, completed in 1145, and Chapter 6 of the *Jeungbo munheon bigo*, published in 1907. Both texts state:

> 9th year of King Asin of Baekje, spring, 2nd month; there was a fuzzy star in Kui [LM 15] and Lou [LM 16]. (Pankenieret al., 2008: 52).

The indicated month spans 12 March to 9 April.

It is interesting that a further reference to this comet is mentioned in the 10th Chapter of the *Jin shu*. It states:

> 4th year of the Long'an reign period of Emperor an of the Jin Dynasty, 3rd month; a broom star appeared in Taiwei. (Pankenier et al., 2008: 53).

The indicated month is 10 April to 9 May. This is the only account that indicates the comet displayed a tail after it apparently vanished around mid-March.

3 COMET C/400 F1 AS SEEN IN ITALY AND TURKEY

The earliest texts containing references to this comet actually appeared early in the fifth century and most were probably written by people who saw the comet.

The first text was probably completed by Claudian, who was living in Italy, around 404. In his poem "The Gothic War" he said a comet preceded the invasion of Italy by Alaric I. This invasion took place in 401. He stated, "It appeared first in the east, where the rosy sun rises, and where old Cepheus shines with his star-spangled wife." (Claudian, 1922: 143). The wife of Cepheus was Cassiopeia. Therefore, it seems likely that Claudian is stating that the comet appeared in the morning sky, near where the Sun rises, in the vicinity of Cepheus and Cassiopeia. He then continues:

> … then it withdrew little by little to the constellation of Lycaon's daughter and with its errant tail dimmed the stars of the Getic Wain until at last its dying fires grew feeble and vanished. (Claudian, 1922: 145).

According to Greek mythology, Lycaon's daughter, Callisto, was a hunting companion to Artemis, daughter of Zeus. Callisto was raped by Zeus. His wife, Hera, subsequently turned Callisto into a bear. Later on, Callisto was in danger of being killed and Zeus saved her by putting her among the stars. She became the constellation Ursa Major, the Great Bear. So, this is the constellation the comet traveled towards. The "Getic Wain" is the Big Dipper. It is actually unusual for ancient European texts to provide an indication of how a comet moved across the sky and Claudian was the only writer to do so for this comet.

The next three texts to report this comet were all titled *Ecclesiastical History*, with all of the authors living in Constantinople. The text from all three report a comet that was seen immediately before Gaïnas attacked Constantinople, which occurred in April 400. Philostorgius finished his book around 425–433 and noted that the comet "… appeared in the form of a sword." (Photius, 1855: 510). The next book was written by Socrates, and was probably completed around 439. He wrote:

> Moreover, a comet of prodigious magnitude, reaching from heaven even to the earth, such as was never before seen, presaged the danger that impended over it. (Socrates, 1853: 308).

The account of Hermias Sozomen was not first-hand, as he was born around 400. His book was completed around 440–443, where he reports:

> His enterprise was pre-announced by the appearance of a comet directly over the city: this comet was of extraordinary magnitude, larger, indeed, than any that had previously been seen. (Sozomen, 1855: 308).

The phrase "directly over the city" can be misleading. While investigating accounts of other astronomical phenomena, including Comet 1P/Halley and bright meteors, I noted that this phrase does not necessarily mean the object was at or near the zenith. With the comet appearing above the eastern horizon, an observer west of Constantinople would see the comet "over the city", but not directly overhead.

4 THE ORBITS BY ICHIRO HASEGAWA

Hasegawa (1979) carefully looked over Ho's 1962 paper and found that he could calculate the orbits of 38 comets. This includes Comet C/400 F1; however, Ho only provided information contained in the *Jin shu* and the *Song shu*. With respect to the *Wei shu*, he wrote that it "… mentions the same comet but gives the third instead of the second month." (Ho, 1962: 161). This meant that Hasegawa did not have access to the additional observations provided by the *Wei shu*. Only one date is specifically given in the Chinese histories, yet Hasegawa said he used observations from 19 March and 10 April, as well as the comet's path to determine the orbit. Although we know the comet was in Kui on 19 March, Hasegawa does not specify a location for 10 April; however, Ho mentions that the comet "… went as far as …" Santai in the second month and then "… passed …" Dizuo and Duanmen in the third month. Since the third month began on 10 April, Hasegawa may have considered that the comet was in Dizuo on that date.

Hasegawa's orbit provides a good representation of the comet's motion, but there are problems. Although the Chinese accounts said the comet entered the 'bowl' of the Big Dipper, his orbit missed the 'bowl' by several degrees, although it did cross the 'handle'. The Chinese accounts also stated that the comet reached Santai, but Hasegawa's orbit misses this asterism by nearly 20°.

5 A NEW ORBIT

The biggest challenge in determining a new orbit for this comet was establishing dates for each observation. Overall, nine possible positions could be extracted from the three Chinese official histories. The only observation with a set date was the first, when the comet was situated in the lunar mansion Kui on 19 March. Although Ho mentioned that observations were made in both the second and third month, there was no real explanation as to where this information came from and it is not as clear-cut as he implied.

Although the *Song shu* and *Jin shu* provide the 19 March date, there is a discrepancy as to in what months the comet was seen. The *Song shu* indicates that the comet was completely seen in the second month, while the *Jin shu* specifically gives observations in the second and third months. The *Wei shu* only mentions the third month. In order to decide on how I should handle this situation, I turned to Pankenier, who made the following comments:

> The records are often inconsistent when it comes to noting a change of month when an observation straddles more than one month. In this case, the fact that the Jinshu record ... is most detailed and actually mentions both 2nd and 3rd months, it is safe to conclude that the Weishu is talking about the same comet and simply fails to note that the initial observation took place during the 2nd month and continued in the following month. It is apparent that the comet's passing through Taiwei, Dizuo and Duanmen did in fact occur in the 3rd month, not the 2nd. Clearly, the comet observation straddled both months. It is quirky that the two records summarize the observations on the one hand prospectively and the other retrospectively. (D.W. Pankenier, pers. comm., 25 June 2021).

Which observations were made in each month? The *Jin shu* states that the comet "reached Santai" in the second month and then "passed by Taiwei, Dizuo, and Duanmen" in the third month. As noted earlier, Taiwei is a very large region of the sky. It actually encompasses Dizuo and Duanmen. Santai is also part of Taiwei. The first asterism that the *Jin shu* mentions for the third month is Dizuo. But the *Wei shu* adds additional information at this point. It states that the comet "… rounded Xiatai, overran Nangong, stepped on Dizuo." As noted earlier, Xiatai is the star ν Ursa Majoris, which is part of Santai; however, Nangong was not mentioned in either the *Song shu* or *Jin shu*, but it is also contained within Taiwei. Because of its nearness to Dizuo, I chose to include it in the third month. Since the third month began on 10 April, it seems safe to accept that the comet's passage near or through Nangong, Dizuo, and Duanmen began on that date.

The next question was how do the five remaining positions fit into the timeline? It was time to start calculating orbits. I began with the five positions evenly spread out between 19 March and 9 April, keeping them exclusively in the second month. These orbits produced unacceptable mean residuals, with some positions being in error by at least 25°. Trials were then conducted that compressed the time period of the comet's movement through Ursa Major and the mean residuals greatly improved. New trials moved the dates of the Ursa Major positions closer to and farther away from the 19 March position. It soon became obvious that the majority of the observations occurred in April and that a large number of days separated the first observation in Kui on 19 March and the second observation in Gedao.

Something became obvious during the trials to establish the dates: even though perihelion dates ranged from 23 February to 3 March, all of the paths across the sky were somewhat similar to one another. The ascending node and inclination remained reasonably consistent for these various orbits; however, there were larger, systematic changes in the argument of perihelion and the perihelion distance, with respect to the perihelion date, and this is the reason the path across the sky changed very little. The driving force in lowering the mean residuals of the test orbits was the date of closest approach to the Earth, which trial and error eventually revealed was 6 April. Orbits showing the comet was closest to Earth on this date produced the lowest mean residuals.

The nine positions were now assigned to dates and further orbits revealed a mean residual of ±6° to ±7°. Could the residuals be im-

Table 1: Dates, positions and reference stars used in the orbital computation.

Date UT)		Right Ascension (2000)			Declination (2000)			Star
Day	Month	h	m	s	°	′	″	
18.9	March	00	47	20	+24	15	55	ζ Andromedae
30.8	March	01	20	04	+58	13	47	φ Cassiopeiae
05.8	April	12	33	27	+69	47	24	κ Draconis
06.8	April	11	03	42	+61	45	08	α Ursa Majoris
08.5	April	11	46	02	+47	46	51	χ Ursa Majoris
09.5	April	11	18	28	+33	05	44	ν Ursa Majoris
09.8	April	11	47	58	+20	13	13	93 Leonis
10.5	April	11	49	03	+14	34	25	β Leonis
11.5	April	12	08	00	+00	37	23	β and η Virginis

Table 2: Orbital elements of Comet C/400 F1, after Hasegawa and this paper.

T (UT)			Ω	(2000)		*q*	*e*	Reference
Year	Day	Month	(°)	Ω (°)	*i* (°)			
400 CE	25 ± 3	February	47 ± 10	38 ± 5	32 ± 5	0.21 ± 0.1	1.0	Hasegawa (1979)
400 CE	28.2	February	64.7	39.5	48.6	0.325	1.0	This paper

proved? Up to this point, the time for each position was set to 0 hours universal time. The orbit was entered into a planetarium program and the location was set to Pingcheng, as it was the probable observing location for the observations in the *Wei shu*. The hour of each position was adjusted to enable a night-time observation. New orbits using these adjusted dates improved the mean residuals by about 1°. The final dates and positions are listed in Table 1.

Two things should be noted about the above positions. First, the star 93 Leonis forms the asterism Nangong with 92 Leonis. Both stars are quite close together, but 93 Leonis was chosen as it was closer to the overall path of the comet and consistently had lower residuals than 92 Leonis or the midpoint between these two stars. The position for 11.5 April is actually the midpoint between β and η Virginis.

Despite the care in establishing accurate dates, it should be noted that the positions above are not the positions of the comet. These are generally the positions of stars and we do not know if the comet actually passed north, south, east, or west of these celestial signposts. When an orbit generated from the above positions was entered into the planetarium program and the comet was advanced along its path, slightly different dates were generated. Correcting the dates again, calculating a new orbit, and entering this into the planetarium program revealed slightly different dates. Ultimately, the dates were left as is, as they do at least represent accurate times when these stars and asterisms could have been seen during the night-time hours at Pingcheng. Some of these dates could actually shift by as much as a day depending on which orbit was used, but the basic orbit was changing very little.

Ultimately, I had two very similar orbits, which produced the lowest mean residuals of all of the calculations that were done. Each had a particular strength and weakness as to how close or far their calculated paths came to particular stars and asterisms. It was finally decided to settle on an orbit that was an average of these two. Table 2 presents Hasegawa's orbit (first) and my new, improved orbit (second).

These orbits are for equinox 2000.0. T is the perihelion date, ω is the argument of perihelion, Ω is the longitude of the ascending node, *i* is the inclination to the ecliptic in degrees, *q* is the perihelion distance in au, and *e* is the eccentricity of the orbit.

The new orbit represents all nine positions with a mean residual of about ±4° (see Figure 1). This might sound terrible, but, again, we are trying to find an orbit that can come close to each star and asterism mentioned in the Chinese histories. Although it was possible to obtain a lower mean residual by leaving out the first and third positions given above, that orbit shifted the overall path westward, so that the comet failed to enter the bowl of the Big Dipper. That orbit also caused the comet to pass closer to ψ Ursae Majoris than to χ Ursae Majoris. ψ is actually 0.7 magnitude brighter than χ. Since the *Wei shu* specifically said the comet "… trespassed on …" χ, it seemed likely that the comet needed to pass closer to it than the more prominent ψ.

Despite the fact that this orbit fits the observations adequately, especially concerning the observations from the *Wei shu*, there are issues with the reports of both the brightness and tail, issues that were not addressed by Hasegawa.

6 THE COMET'S BRIGHTNESS

One issue is the brightness. The only way to determine how bright this comet might have been is by beginning with a single threshold observation, the final observation reported in all three Chinese histories quoted above. Unfor-

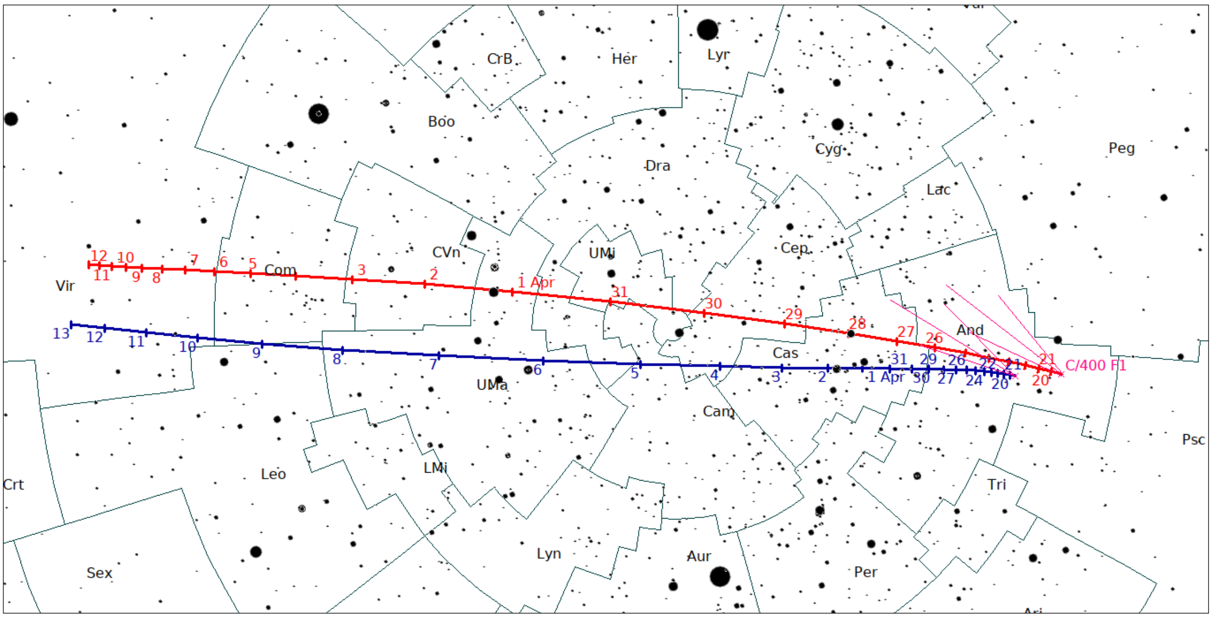

Figure 1: The path of Comet C/400 F1 plotted using the orbital elements of Hasegawa (red) and this study (blue) (courtesy: Maik Meyer).

tunately, no date was given, only a location, but, as noted earlier, I adopted 11.5 April as this final date.

Bortle and Morris (1984: 10) investigated the brightness behavior of Comet 1P/Halley at its previous apparitions and wrote the following:

> … we have adopted magnitude +5.0 as that at which the comet would generally become lost among the stars (given reasonable viewing conditions).

At the time Comet C/400 F1 was exiting Duanmen, it was at a maximum altitude of about 55°, as seen from Pingcheng. If the comet appeared to be magnitude 5, it is likely that the slightly thicker atmosphere at that altitude would reduce the brightness by 0.25 magnitude. With such an extinction, the actual magnitude of the comet would have actually been 4.75. Using the standard absolute magnitude formula, this would indicate an absolute magnitude of H_{10} = 9.75; however, this would produce a magnitude of 6.6 on 19 March, much too faint to be discovered.

Broughton (1979: 30) examined the brightness of Comet 1P/Halley back to 12 BCE. He concluded, "A visual magnitude of 3 or 4 might seem like a reasonable estimate …" for the accidental, naked-eye discovery of a comet. Bortle and Morris (1984: 10) generally agreed with these values. In order for Comet C/400 F1 to be bright enough for an accidental discovery at an altitude of about 11° would require it to have been no fainter than magnitude 2 or 3, after the nearly 1 magnitude extinction effect is applied; however, this comet seems to have been more than just a borderline, naked-eye object at discovery. It seems very reasonable to accept a magnitude closer to 1 at discovery. This would indicate an absolute magnitude of H_{10} = 4.30, producing a magnitude of −0.9 when closest to Earth and a magnitude of 1.3 when last recorded on 11.5 April.

This is where a problem emerges. To make an assumption that the comet had actually faded to about magnitude 4.5 by 11.5 April would require the abandonment of the standard absolute magnitude formula, where the term 'n', which represents the slope of the brightness curve, is automatically accepted as 4. The calculation of H_0 allows the alteration of the slope of the brightness curve. A discovery magnitude of 1 for Comet C/400 F1 and a magnitude of 4.5 when last reported would require absolute magnitude parameters of H_0 = 8.7 and n = 16.5. The value of 16.5 for 'n' would be a record, something that certainly hints at a problem. But there are two ways to make the absolute magnitude parameters less exotic.

First, although the head was very near the horizon on 19 March, the tail was extending above the horizon and may have actually been what caught the attention of observers in China. The tail would only have had to be a few degrees long to make the comet more prominent and this would reduce the requirement for the comet to have been as bright as magnitude 1 at discovery. But such a bright magnitude probably needs to be maintained because of how spectacular the comet seems to have been. In addition, the Chinese stated that the comet had become tailless by 19 March.

The second way to bring the absolute magnitude parameters to more reasonable levels would be to accept that the comet continued to be observed after passing through Duanmen. Although this would seem to be stretching things a little, there is actually a precedent in Chinese records 26 years before the appearance of Comet C/400 F1.

The *Song shu* and the *Jin shu* reported another bright comet in 374 CE. This comet was first seen on 4 March and was last mentioned on 2 April. This happened to be Comet 1P/Halley, a comet whose orbit is well known and whose brightness behavior has been well studied. Yeomans, Rahe, and Freitag (1986: 73) noted that this comet was probably still near magnitude −1.9 on 2 April at an elongation of 152°, still bright enough and far from the Sun to enable it to be observed. Bortle and Morris (1984: 11) suggested the comet might have remained visible until 1 May.

If we accept the fact that Comet C/400 F1, like the 374 apparitions of Comet 1P/Halley, was observed longer than indicated by the Chinese accounts, then the standard absolute magnitude parameter of H_{10} = 4.30 would work, indicating the comet may have remained visible until 28 April, when it would have faded to magnitude 4.6. The latter magnitude would have appeared more like magnitude 5.0, because the comet's maximum altitude of 39° would have contributed to a 0.4-magnitude fading due to atmospheric extinction.

But should we blindly accept that what seems true for Comet 1P/Halley would also be true for Comet C/400 F1? Is there a reason why details following the last recorded observation of each comet were not noted? Comets had an astrological significance. Both of these comets became quite bright as the result of passing close to Earth and might have looked quite spectacular with a larger than normal coma for a few nights. After the Chinese realized that these comets were fading and becoming smaller, they may have no longer worried about them and stopped recording details. But this is only my suggestion. Another possibility is that the Moon might have been a factor as it actually passed quite close to both comets a few days after their final recorded observations. In both cases, the Moon was in its waxing gibbous phase, about 75% to 85% full, when closest, but it would only have interfered for a few days.

There could also have been a non-astronomical reason why the comet was no longer being recorded. Nearly every spring, especially in the months of April and May, a meteorological phenomenon occurs that ancient Chinese records frequently refer to as ‘dust rain’. Dust from China, Mongolia, and Kazakhstan is picked up by high-speed surface winds creating dense clouds that typically drift over China, Korea, and Japan. In a study published in 2013, Chen et al. (2013) examined sediment cores taken from Lake Sugan and found “Frequent and/or intensive dust storms occurred … during the fourth and fifth centuries, when cold and windy climates were prevalent.” (Chen et al., 2013: 2158). Within the period of 360 to 420 CE, which encompasses the 374 apparition of Comet 1P/Halley and Comet C/400 F1, the core data suggested that dust storms occurred in 363, 377, 382, 387, 393, 399, 405, 410, 414, and 417 CE. In a follow-up study, Chen et al. (2020) examined sediment cores taken from Lake Gonghai, which is about 850 miles from Lake Sugan. Within the same period noted above, there are only four indicated dust storms: 364, 382, 401, and 419 CE. Admittedly, there are expected errors in the dating process going back this far, but the data were accurate enough for Chen et al. (2020: 1) to suggest that “Marked increases in dust storm activity coincided with unified dynasties with large populations during strong [Asian monsoon] periods.” They came to this conclusion after comparing their dust storm data with population and rainfall data, so the dust storm data are probably close enough to entertain the suggestion that the observations of both comets might have been cut short by dust storms.

7 THE COMET'S TAIL

Perhaps a more difficult aspect of the comet’s apparition to explain is the tail. It is obvious that a tail was reported by observers in Constantinople, Italy, and China. In particular, Socrates (in Constantinople) stated that the comet was of “… prodigious magnitude, reaching from heaven even to the earth.” But what is most interesting is that the *Song shu* and *Jin shu* state that on 19 March “… a star 3 zhang long became fuzzy in Kui.” The term “fuzzy” is translated from “xingbo”, sometimes given simply as “po”, and refers to a tailless comet. So, this implies that the comet had displayed a tail 30° long prior to 19 March, but that this was no longer visible.

The orbit reveals that the comet could have been visible for several days prior to 19 March, although the head would have been closer to the horizon at the beginning of astronomical twilight, being only 1° above the horizon on 11 March. I then turned to Andreas Kammerer to evaluate this comet, based on the orbit and the 30° tail length. Kammerer is well known for his analyses of comets for over two decades. He did two sets of calculations, one with a tail length of 30° on 10 March and a second with a tail length of 30° on 19 March. According to Kammerer (pers. comm., 14 July 2021), if the tail length had been 30° on 10 March, then the length would probably have decreased to about 20° by 23 March, and then increased to a maximum length of 42° by 4 April. If the tail length had been 30° on 19 March, then the length would have been about 39° on 10 March, would have decreased to about 29° on 23 March, and then increased to about 54° by 4 April.

Kammerer's calculation revealed that the tail would have been quite long, but why was it apparently absent by 19 March and during the days that followed?

Comets C/1983 H1 (IRAS-Araki-Alcock) and C/1996 B2 (Hyakutake) are two fairly recent examples of near-Earth comets, passing 0.0312 AU and 0.1017 au from Earth, respectively. Only one or two people reported a naked-eye tail for C/1983 H1, while a long, naked-eye tail was the most notable feature of C/1996 B2. Both of these comets exhibited a dust tail that was very hard to detect when closest to Earth. Unlike C/1983 H1, C/1996 B2 displayed a prominent gas tail when closest to Earth that was seen by observers around the world.

Tony Farnham (University of Maryland, USA) is a specialist on the physical and dynamical properties of comets. He stated the following as to why a gas tail might be more prominent than a dust tail for near-Earth comets:

> For a comet like Hyakutake, with a narrow tail that had structure (e.g. ion tail), it was very obvious because you could easily detect the edges and features. On the other hand, a broad tail with no obvious edges or structures (e.g. dust) that covers a large portion of the sky, may be bright near the nucleus, but fades away into the sky background at some distance from the center. It is not easy to detect gradual changes over a large expanse and with no defined edges, we may simply not see the tail that is there. (T. Farnham, pers. comm., 7 July 2021).

With this knowledge, it seems likely that Comet C/400 F1 did not exhibit a gas tail and that the once-prominent dust tail became more diffuse as the comet approached Earth. It should be noted that Kammerer (pers. comm., 14 July 2021) also determined the likely diameter of the coma on the night of its closest approach, finding it to have been about 3°. It could be that the increasing diameter of the bright coma could have contributed to either hiding any potentially visible portion of the tail or at least diverted attention from the diffuse dust tail.

Another interesting reference to the tail during this apparition came from Claudian, who wrote: "… its errant tail dimmed the stars of the Getic Wain …", which is the Big Dipper. With the tail apparently non-existent after 19 March, this event could not have happened. John T. Ramsey (University of Illinois in Chicago, USA), has some words of advice when dealing with European comet observations:

> My impression is that the Greco-Roman sources are less reliable in giving observational details … [and] Sometimes the size of a comet's tail will be described, even exaggerated, but more often than not, descriptions are impressionistic in contrast to Chinese and Babylonia records, which were composed by trained observers. (J.T. Ramsey, pers. comm., 7 July 2021).

Considering that Claudian was a contemporary of this comet's appearance, apparently seeing it just a few years prior to his death, it is hard to ignore his claim that the comet's tail dimmed the stars of the Big Dipper. Knowing that the above orbit indicates the comet went through the bowl of the Big Dipper around the time when it was closest to Earth and knowing that Kammerer's calculations indicate that the coma might have attained a diameter of 3°, one has to wonder if it was actually the coma of the comet that dimmed at least some of the stars in the Big Dipper.

8 CONCLUDING REMARKS

The addition of positions not previously available to Hasegawa has enabled the calculation of an improved orbit for comet C/400 F1 (see Figure 1). The Chinese reports of the comet's passage through the bowl of the Big Dipper, close approaches to the stars χ and ν Ursae Majoris, and the probable passage between β and η Virginis are all satisfied by this new orbit.

The evidence seems strong that the comet's period of visibility was longer than indicated by the Chinese observations. It could have been seen about a week or so prior to 19 March, when the most prominent feature of the comet was the tail and the head was at a low altitude in twilight. Using a standard absolute magnitude formula also implies that the comet could have been followed for at least two weeks after 11 April, which this paper establishes as the date of the final recorded observation, as the comet exited Duanmen. Reasons why the observations might have ended could be because the Chinese observers no longer saw the comet as a threat or maybe because of interference from moonlight, although the latter would only have been for a few days. Another intriguing possibility is the occurrence of springtime dust storms known to have been active over China during the fourth and fifth centuries.

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In 1992, Gary examined ancient Chinese observations and found that comets seen in 69 BC and AD 188 were previous observations of Periodic Comet 109P/Swift-Tuttle. In 2003, he discovered that observations of a comet made by the Reverend Leo Boethin in January 1973, but not seen by anyone else, were actually prediscovery observations of periodic comet 104P/Kowal, which was not discovered until 1979 (and Brian Marsden confirmed both of these findings and published the details on the *IAU Circulars*).

Gary was invited to participate on Leonid MAC 99, a NASA/US Air Force mission to study the Leonid meteor shower in 1999. The aircraft were equipped with a couple of dozen cameras to photograph the meteors using various filters to learn as much about this meteor shower as possible.

Minor planet '48300 Kronk' was named after him.