Early sungrazer comets

Kenelm J. England

Records of cometary apparitions were searched for early observations of comets belonging to the Kreutz sungrazer group. Sixty-two comets were found between 1375 BC and AD 1702 that had features common to these comets. Details of the observations of these comets are summarised together with a list of orbits. The original precursor comet may have had an orbital period of 5 centuries. Periods of 5.7 and 7.5 centuries are suggested for Marsden's Subgroups I and II. Other subgroups are tentatively identified.

Introduction

On 1843 February 5 a bright comet was discovered from the Southern Hemisphere. Details are vague, as there were few southern observers at the time. On February 27 the comet appeared in broad daylight just over a degree from the edge of the Sun's disk. It appeared as an elongated white cloud with a brilliant nucleus and a tail nearly 1° long. At the Cape of Good Hope it was observed to follow the Sun to the western horizon as 'a short, dagger-like object'. On March 1 the comet was still visible in daylight and became a spectacular object with a 30° tail in evening twilight. Over the next two weeks it was a brilliant object in the evening sky and was widely seen around the world. Then it faded rapidly in the second half of March and was only followed by astronomers until April 19.[1]

This comet (1843 I = C/1843 D1) had probably been seen by more people than any before and caused consternation among the general population.[2] In the scientific community the comet's orbit proved to be surprising, as the comet passed less than 100,000 km from the Sun's surface at perihelion. This had been the case with the bright comet of 1680, although the orbits of these two comets were quite different. Then another bright comet appeared in February 1880 (1880 I = C/1880 C1). At first it was thought that a single comet with a period of 37 years was responsible, although the observations suggested that the orbital period was much longer. Then two comets were seen in 1882, one briefly during the total solar eclipse of May 17 and another magnificent comet during September (1882 II = C/1882 R1). This second comet also displayed a feature that could explain all the sungrazer comets; its nucleus broke into four pieces and at least another two fragments were recorded. This spate of bright sungrazing comets ended with another bright comet in the second half of January 1887 (1887 I = C/1887 B1).[1]

In 1901 Carl Heinrich Kreutz investigated these nineteenth-century comets and also several seen at the end of the seventeenth century.[3] Although he considered it possible that it was a single comet with a relatively short period, he came to the conclusion that these were representing fragments of a comet with a relatively long period that was gradually breaking up each time it passed close to the Sun. There was a gap of nearly fifty years until comet du Toit (1945 VII = C/1945 X1) was seen briefly from the Southern Hemisphere. Three further comets belonging to the Kreutz sungrazer group were observed from the ground: Pereyra (1963 V = C/1963 R1), Ikeya–Seki (1965 VIII = C/1965 S1) and White–Ortiz–Bolelli (1970 VI = C/1970 K1). A number of smaller sungrazer comets were also recorded from space by the United States Air Force satellite P 78-1 Solwind (1979–1984), NASA's Solar Maximum Mission (1984–1989) and ESA's SOHO spacecraft (1996 onwards), although none were seen after perihelion.

The most extensive recent studies of the Kreutz sungrazer comets were made by Brian Marsden.[4,5] He found that the orbits of the nineteenth and twentieth century sungrazers fell into one of two groups from their orbital elements. He concluded that Subgroup I originally had an orbital period of about 3.7 centuries and were fragments of a comet that had been missed sometime in the second half of the fifteenth century. The comets of Subgroup II had a longer original period of about 7.7 centuries and were fragments of a comet returning at the beginning of the twelfth century. He considered it likely that this was seen in 1106, although this could have been a previous return of the Subgroup I progenitor. He also concluded that both subgroups were fragments of a single comet seen in 371 BC. He did propose that four comets seen in 1668, 1689, 1695 and 1702 were possible members but that the uncertainty in the observations did not allow this identification to be certain. Hasegawa published a list of possible early members of the sungrazer group from naked-eye observations made from the Far East.[6]

Investigation into past apparitions

From ground-based observations in the nineteenth and twentieth centuries it is clear that several Kreutz sungrazing comets can appear per century. As they are among the brightest comets seen, it would be very surprising if there were no earlier records. The comets of 371 BC and AD 1106 had often been considered as sungrazers, but no others had been generally accepted. Hasegawa noted several possible candidates recorded in Far Eastern records.[6] Kreutz sungrazer comets would have certain characteristics that would distinguish them from other bright comets:

i **Brightness.** Sungrazer comets can be extremely bright when near perihelion. Several have been seen in full daylight. Comet Ikeya–Seki (1965 VIII = C/1965 S1) may

have been as bright as magnitude −10. Such brightness would mean that the comet could be seen very low in the sky in twilight.

ii **Sudden appearance.** Because of the rapid approach to perihelion, sungrazer comets usually appear suddenly near the Sun. Even with the invention of telescopes they can escape detection until then and in the past naked-eye discoveries would be at or just after perihelion.

iii **Discovery near the Sun.** These comets have been observed close to the Sun during broad daylight. One was probably discovered during the total solar eclipse of 1882 May 17. A large number of small sungrazer comets have only appeared in coronagraphs aboard the Solwind, SMM and SOHO spacecraft. Comets seen in daylight or at eclipses would be prime candidates, although the Chinese–Byzantine comet of 418 (418 = C/418 M1), seen during the total eclipse of July 19, was not a sungrazer.

iv **Position in the sky.** Because of the orientation of the sungrazers' orbits, such comets are most easily seen in the evening sky after sunset in the late winter and spring. They would appear in Cetus or northern Eridanus (see Appendix). Sungrazers could also appear in the morning sky during the autumn, when they could be seen briefly in Virgo and Libra. Comets reaching perihelion in December may be very briefly seen to the south of the Sun in Scorpius. However, they are almost impossible to observe in the summer months, as they remain close to the Sun.[7] All sungrazers are more easily observed from the Southern Hemisphere, but astronomical records are lacking until the time of European colonies.

v **Tail length.** These comets pass very close to the Sun, and the intense solar heating makes the nuclei very active. Comets that survive perihelion produce a long, impressive tail or tails. These rapidly shrink as the comet moves away.

vi **Short period of observation.** As the comets move rapidly away from both the Sun and the Earth, they soon fade below naked-eye visibility.

vii **Motion across the sky.** A sungrazer's motion in the sky could distinguish it from other bright comets, if the observations were sufficiently accurate (see Appendix). The most favourable apparitions would be for sungrazers reaching perihelion between January and early May. They would appear in the evening sky at or soon after sunset and would rapidly cross through Cetus, northern Eridanus and Orion, before fading. Comets at perihelion from September to November would appear in the morning sky in Virgo and Libra and would then move south over the horizon.[7]

viii **Comet fragmenting.** Sungrazer comets are often seen to break up near perihelion. The nuclei of the bright comet of 1882 (1882 II = C/1882 R1) and Ikeya–Seki (1965 VIII = C/1965 S1) both broke into four pieces. However, to the naked eye these would not have been seen, as the comets never come closer than 0.8 AU from the Earth. A bright fragment of 1882 II was seen by Schmitt, but this was probably already separated at the previous perihelion passage. Two comets were recorded to have split in two (371 BC and AD 813) but these were probably meteorological effects, as the comets could be seen close to the horizon at sunset. The comet of 896 is likely to have been the only ancient comet to be observed to break up, possibly a short-period comet passing close to the Earth.

ix **Orbit.** The decisive factor to indicate whether a comet belongs to the Kreutz sungrazer group is the calculation of an orbit from the observations. Unfortunately, the lack of accuracy in positions and particularly the short observing arc means that no comet can be definitely assigned to the group before the Great Comet of 1843. The bright comet of 1680 (1680 = C/1680 V1) was also a sungrazer, but its orbit was significantly different and so not related to the Kreutz group.

Sungrazer comets before 1843

After searching through several sources for early comets, sixty-two were found to have one or more of the attributes of the Kreutz sungrazer group. Details of the observations together with any earlier discussions are listed. For each a ranking is given from 0 (not a sungrazer) to 10 (a comet with a definite sungrazer orbit calculated from the observations).

I 1375 BC Eclipse

During excavations at the ancient city of Ugarit in Syria, a small clay tablet (KTU 1.78) was found in a small room adjacent to the palace entrance in 1948. The tablet had been baked and blackened by a disastrous fire that destroyed the palace. The fire was recorded in an Amarna letter sent to Pharoah Akhenaten (1367–50 BC) and so dated to the mid-fourteenth century BC.[8]

The clay tablet seems to report an event recorded by the astronomer-priests responsible to Nikmaddu II, King of Ugarit. On one side it states: 'The day of the new moon of Hiyaru was put to shame. The sun goddess set with Rashap as her gatekeeper.' On the other side the priests recorded a remedy for this terrible omen. 'Danger. Two livers shall be examined.' Clearly the priests considered it such an unusual event portending catastrophe that they sacrificed two animals to divine the meaning.

The tablet records a total solar eclipse occurring in the month of Hiyaru, which corresponds to the period mid-April to mid-May. The generally accepted date for this event is 1375 BC May 3.[9] Rashap is identified with the planet Mars, which would have been visible during the eclipse. However, observers would have seen the planets Mars, Venus and Mercury grouped together in Gemini to the east of the eclipsed Sun. Mars (mag. +1.8) would have been considerably fainter than either Venus (mag. −3.9) or Mercury (mag. −0.8). Also, astronomers in the Middle East were already following the positions of the planets, so their appearance during the eclipse would not have been unexpected. Even the kingdom of Ugarit would have had this expertise, so the reaction of the priests would strongly suggest another unexpected and rather bright object.

One alternative explanation is that the report describes the total solar eclipse of 1223 BC March 5.[10] The Sun was eclipsed in the afternoon and at sunset it was followed by the planet Mars. However, the planet would still have been an indistinct object near superior conjunction. Rohl suggested that the object was in fact a nova in Taurus, possibly a pre-explosion of the Crab supernova.[8] This seems very unlikely, especially as he dates this to the eclipse of 1012 BC May 9. These dates would result in a drastic revision of Egyptian chronology, which is not supported by radiocarbon dating or historical documents.

A solution that does not seem to have been considered is the sudden appearance of a bright comet near the Sun during the total eclipse of 1375 May 3. Being close to the Sun, its curved tail would appear to threaten the safety of the city. A member of the Kreutz sungrazer group would appear close to the Sun's disk during the eclipse. Then it would have appeared with an impressive tail in the evening sky at sunset. The comet could be the progenitor of the Kreutz sungrazer group with perihelion on about May 1. It would have been lost in the Sun's glare after a few days.

Ranking: 4

2 *Late 2nd. millennium BC* *Eclipse*

There is a record on an oracle bone found at Anyang in Northern China.[9] It states: 'Three flames ate the Sun and a great star was seen.' This refers to a solar eclipse, and a comet may have been seen during the event. If so, then it is possible that this was a sungrazer. There is no date on the record but it is usually dated to the fourteenth or thirteenth century BC.

Ranking: 2

3 *371 BC* *Greek*

A great comet was seen in Greece in the winter of 372–71 BC, when the archon at Athens was Alcisthenes (Diodorus Siculus 15). It appeared in the west near the setting Sun and was very bright with a prominent tail. It may have been located in or had its tail stretch across the Plough and was distinctly brighter than any of its stars (so at least magnitude +1). Callisthenes recorded that it had a tail, which may have been reddish. Ephorus recorded that the comet split into two, an event which Seneca criticised him for but which is now an accepted cometary phenomenon. Diodorus also recorded a very bright comet in the following year, but this is almost certainly the same object, the mistake arising from converting Greek to Roman dates.[11]

Aristotle (*Meteorologica* 1,6) recorded that the comet was seen near Capella and moved west to east. The comet was lost near the belt of Orion, possibly near Canis Major. The appearance of this comet coincided with a major earthquake in central Greece and the Spartan disaster at the battle of Leuctra, so more notice than usual was taken of it. There may also be a reference to this comet by the prophet Joel (Joel 3, 3–4), who was writing at this time or shortly afterwards, when he mentions 'in the heavens... blood and fire, and pillars of smoke.' Certainly the comet was very prominent and easily the brightest for a century.

Although there are more details than are usually recorded, the lack of positional observations means that no independent orbit can be calculated. Its brightness would suggest a small perihelion distance. Pingré suggested that the perihelion direction was in Virgo or Libra and the orbital inclination about 150°.[12] Klinkerfues noted the similar features of this comet with the great sungrazer comets of the nineteenth century (1843 I, 1880 I, 1882 III).[3] In 1967 Marsden investigated the evolution of the sungrazer comets and found that the comet of 371 BC would match that of a hypothetical progenitor for the two main sub-groups.[4] Ephorus' report of the comet splitting seems vindicated. Various members of the group have been reported as splitting near perihelion, as the comet fragments are heated violently and tidally stretched. However, the description probably indicates meteorological phenomena, as the comet was very low near the western horizon. The comet's reported motion across the sky is relatively vague but tends to support a later date during the winter, probably February 371 BC. The comet would then have been seen shortly after perihelion, as it emerged from the Sun's glare. Apart from a definitive orbital determination, the comet shows all the characteristics of a Kreutz sungrazer comet.

Ranking: 7

4 *116 BC* *Eclipse*

The Greek philosopher Posidonius reported seeing a comet close to the Sun, which became visible during an eclipse (Seneca, *Naturales Quaestiones* 7.20.4). Born in about 135 BC, he travelled widely from his home city of Apamea in Syria to Spain, North Africa, Italy, Gaul, Sicily and the Eastern Adriatic. Eventually he settled down on the island of Rhodes, where he wrote a large number of books on science and geography.

Unfortunately, the date of this eclipse comet was not recorded. Several partial eclipses were visible in the Mediterranean area during the 100s and 90s BC,[13] but a comet appearing during one of these would have to be very bright and is likely to have been followed into the night sky. Posidonius may have seen the annular eclipse of 94 BC June 29, which was visible across the western Mediterranean, and indeed he may have travelled to the area to see the eclipse. At the time philosophers in the Seleucid kingdom of Syria had access to the astronomical knowledge of Mesopotamia on eclipses. This was the eclipse favoured by Barrett,[11] although the sky would still have been fairly bright. The comet would therefore have had to have been a very bright object.

Another possible event was the total solar eclipse on 116 BC August 29. This was visible across Spain and North Africa and would have produced dark skies, ideal for the sudden appearance of a comet. In this case Posidonius would have been a young man sailing around the western Mediterranean. In either case, there is a strong possibility that the comet was a member of the Kreutz sungrazer group, reaching perihelion at about the time of the eclipse. It would appear to the southwest (116 BC) or the southeast (94 BC) of the Sun's disk but would not be visible in the night sky afterwards.[7]

Ranking: 5

5 AD 110 Chinese

Chinese observers saw a comet in northern Eridanus, near γ, δ and ε Eridani, sometime between January 9 and February 6. According to *Hou Han Shu* its greenish-white tail pointed to the northeast and was about 10° long.[14] The sudden appearance and location of this comet is consistent with a member of the Kreutz sungrazer group just after perihelion at the end of January or the beginning of February.

Ranking: 3

6 AD 133 Chinese

On February 8 the Chinese saw a comet southwest of δ Eridani, recorded in Hou Han Shu. Its tail was white, about 3° wide and 75° long.[14] No further details are given, so the comet may not have remained visible for long. No independent orbit has been calculated for this comet. However, Hasegawa suggested from its brief and spectacular appearance that it might have been a member of the Kreutz sungrazer comet group, with perihelion on about February 5.[6]

Ranking: 5

7 AD 191 Great

According to *Hou Han Shu* Chinese astronomers discovered a very bright comet in Virgo, south of Spica and λ Virginis, sometime between October 6 and November 4. It possessed a straight white tail over 100° long stretching across the sky. The Koreans also saw the comet in the same position, recorded in *Samguk Sagi*.[14] The comet was also seen from Rome.[12]

No independent orbit has been calculated for this comet. In 1979 Hasegawa suggested from its prominent appearance that it might be a member of the Kreutz sungrazer group, appearing just after perihelion.[6] Certainly, a Kreutz sungrazer would appear in Virgo during the autumn.

Ranking: 4

8 AD 193 Roman

A comet may have been seen in April or May during the reign of the Roman emperor Didius Julianus. Two stars were seen near the Sun.[12] As Venus was favourably placed, it is likely to have been one of the objects. The other could have been a comet, which may have been as bright as magnitude –4. Both would have been in the morning sky in Pisces or Aries. This comet could have been a member of the Kreutz sungrazer group, if it lay further to the south in Cetus.

Ranking: 2

9 AD 252 Chinese

Chinese astronomers saw a comet with a white tail 75 to 90° long on March 24. According to *Chin Shu* it appeared in the west in Aries. The tail pointed south and crossed Orion. The comet remained visible for only twenty days until April 13.[12,14] No independent orbit has been calculated for this comet. However, the sudden bright appearance of the comet led Hasegawa to suggest that this might have been a member of the Kreutz sungrazer group, with perihelion on March 17.[6]

Ranking: 4

10 AD 254 Chinese

The Chinese saw a comet in Sagittarius sometime between November 27 and December 26, as recorded in *Chin Shu*. Its prominent tail was given as several degrees broad and stretching several tens of degrees across the sky from the horizon.[12,14] Schove suggested that it may have been an aurora.[15] The comet probably appeared in the morning sky close to Mercury towards the end of December, as the Sun was in Sagittarius during the month. It is possible that this comet was a member of the Kreutz sungrazer group.

Ranking: 4

11 AD 283 Chinese

The Chinese discovered a comet in the southwest on April 22, as recorded in *Chin Shu*. It had a tail 15 or more degrees long.[12,14] The position and description of this comet is consistent with it being a member of the Kreutz sungrazer group.

Ranking: 2

12 AD 302 Chinese–Korean

Chinese astronomers first discovered this comet in the morning daylight sometime between May 14 and June 11, according to *Chin Shu*. It is recorded in *Samguk Sagi* that the Koreans also saw the comet in daylight.[12,14] The brightness of the comet suggests a small perihelion distance and the short period of observation would be consistent with it being a member of the Kreutz sungrazer group, proposed by Hasegawa.[6] If so, then this may be the return of the second fragment of the comet seen in 371 BC. However, such a comet should appear in the evening sky after perihelion.

Ranking: 4

13 AD 334 Roman

Theophanes recorded that a bright object was seen from Antioch: 'In the middle of the day, there was seen a star from the 3rd. to the 5th. hour of the day.'[16] This seems to have been a report of a bright comet, possibly a member of the Kreutz sungrazer group. Another possibility is that it was a report of a bright meteor, which left a very long-lived smoke train.

Ranking: 2

14 AD 349 Great Chinese

This bright comet was first seen by the Chinese near ι and κ Virginis on December 2, as recorded in *Chin Shu*. It had a white tail about 15° long, pointing to the west. Observations continued into AD 350. The comet was still in Virgo on January 29 and possessed a white tail.[12,14] Pingré distinguished this comet from the comet seen on 350 March 30, while Ho considered them the same. It is possible that this was a member of the Kreutz sungrazer group, if the observation of January 29 was of another comet or a nova.

Ranking: 2

15 AD 423 Chinese

Chinese astronomers discovered this comet near γ Pegasi and α Andromedae on February 15, as recorded in *Sung Shu*. Its tail was white and more than 30° long. Another report placed the comet in the Andromeda–northern Pisces region with a tail 45° long. It moved southeast and reached central Eridanus, remaining visible for 20 days until March 5.[14] This may have been the comet recorded at Ravenna in Italy, presaging the death of the Roman emperor Honorius.[12]

No orbit has been independently calculated for this comet. However, in 1979 Hasegawa found that its track across the sky was consistent with it being a return of comet Ryves (1931 IV = C/1931 P1).[6] He also found that the comet could be a member of the Kreutz sungrazer group with perihelion on February 6. In 1997 Zhou and his colleagues published a parabolic orbit calculated from these observations.[17] However, the orbit did not represent the comet's motion or brightness well, as otherwise the comet should have been visible during the autumn. This would be a very good candidate as a Kreutz sungrazer comet because of its sudden, bright appearance.

Ranking: 5

16 AD 467 Chinese–Byzantine

The Chinese recorded a very prominent comet on February 6. It had a bright nucleus and two tails stretching halfway across the sky from the southwest to the southeast.[14] At Constantinople a large prodigy was reported during the year, which was visible for 40 days, recorded by the Byzantine chroniclers Theophanes and Michael Glycas. According to the *Chronicon Paschale* it appeared 'like a trumpet' and so had a broad tail. Hydatius recorded that the comet was observed from Italy and Portugal.[12,14]

Ho suggested that this might have been a bright aurora.[14] However, the fact that the comet lay in the southwestern sky would support the sudden appearance of a bright comet, as it moved away from the Sun. Perihelion would have taken place at the beginning of February and the perihelion distance was probably quite small. The comet's brightness, appearance and motion across the sky would support its being a member of the sungrazer group with perihelion on February 3.

Ranking: 5

17 AD 501 Chinese

The Chinese discovered a comet with a very bright, straight tail near the horizon on February 13. It lay between μ and 54 Eridani and appeared 'like a banner'. According to *Nan Shih* the tail stretched across the sky.[14]

Schove suggested that this may be a report of a bright aurora.[15] Hasegawa identified this comet with the next one.[19] However, the description of the comet is consistent with it being a member of the Kreutz sungrazer group with perihelion on about February 10. It would not have remained visible for two months.

Ranking: 3

18 AD 501 Chinese

The Chinese also saw a comet with a tail stretching across the sky on April 14, recorded in *Nan Shih*.[14] If the comet appeared in the evening sky, this could have been another member of the Kreutz sungrazer group, with perihelion on about April 11. Hasegawa identified this comet with the previous one, which would not then be a sungrazer.[19]

Ranking: 3

19 AD 560 Chinese–Frankish

Chinese astronomers discovered a comet on October 9, as recorded in *Sui Shu*. It had a tail or tails six degrees long, pointing to the southwest.[14] Gregory of Tours also noted that it was seen from France.[12] This comet's appearance would be consistent with a Kreutz sungrazer comet after perihelion on about October 6 appearing in the morning sky.

Ranking: 1

20 AD 582 Chinese–Frankish

The Chinese discovered a comet with a tail on January 15, recorded in *Chien Shu*. It was also seen in the southwest on January 20.[14] Gregory of Tours recorded that 'it appeared in such a way that round about it there was a great blackness; it shone through the dark as if set in a cavity, glittering, and spreading abroad its hair. And there issued from it a ray of wondrous size which from afar appeared as the great smoke of a fire. It was seen in the western quarter of the heavens at the first hour of the night.'[16] It is possible that this comet was a member of the Kreutz sungrazer group.

Ranking: 3

21 AD 612 Eclipse

From Ireland a star was seen at the 8th. hour of the day, early in the afternoon. This report is dated to 612 in the *Annals of Tigernach*, but to 614 in the *Annals of Ulster* and the *Annals of Ireland* and 617 in the *Annals of Clonmacnoise*. There was a total solar eclipse on 612 August 2. The object may have been Regulus, but a better candidate was Mercury (mag −1.4) to the west of the eclipsed Sun.[20] It is possible that a sungrazer comet could have appeared to the south of the Sun. It would have been badly placed, so no further observations would be possible.

Ranking: 2

22 AD 675 Chinese

Chinese astronomers discovered a comet in eastern Virgo near Spica on November 4. According to *Chiu Thang Shu* it had a tail 8° long.[14] Williams dated the comet to 676 January 3, following the date in another record, which Pingré interpreted as 676 January 4.[12] The comet's appearance and position in the sky in early November would be consistent with it being a member of the Kreutz sungrazer group.

Ranking: 3

23 AD 762 Byzantine

A comet was seen in the east from Constantinople. Theophanes described it as 'a beam', so the tail was long and straight.[12] There are no records from the Far East, so this could have been short-lived. A comet appearing in the

second half of the year would be consistent with a member of the Kreutz sungrazer group.

Ranking: 1

24 AD 813 Byzantine

From Constantinople a comet was seen on August 4 that 'resembled two moons joined together'. They separated and after various changes took on a single shape.[12] An uncertain description, perhaps the break up of a bright fireball. Pingré thought that this was a comet. If so, it may indicate a comet splitting in two. The object was recorded by Theophanes, Simeon and John Zonaras.[18] A bright comet splitting in two is consistent with a member of the Kreutz sungrazer group. However, it is more likely to result from atmospheric effects, as the comet would be low in the sky.

Ranking: 1

25 AD 815 Korean

The Koreans discovered a comet between Crater and Corvus on September 7. It had a large tail pointing west, which was about 9° long and about a quarter of a degree wide. Ho, Hasegawa and Yeomans all take this to be the comet, which the Chinese observed in April–May.[14,19,2] If the September date is accurate, however, it is unlikely to be the same object. This may have been the comet seen shortly before the death of Pope Leo III, which occurred on 816 June 8. It is possible that this comet was a member of the Kreutz sungrazer group.

Ranking: 3

26 AD 822 Byzantine

The Byzantines saw a very bright comet 'as a sort of two moons joined together', recorded by Genesius.[18] The comet was large with detachments seen in the tail and may have split in two. This may have been the disintegration of a bright fireball. The record may refer to one of the comets seen in 821. As a comet, it may be a candidate as a member of the Kreutz sungrazer group.

Ranking: 1

27 AD 840 Chinese

The Chinese discovered a comet with a tail in the east on December 3, recorded in *Hsin Thang Shu* and *Wen Hsien Thung Khao*.[14] It is possible that this comet was a member of the Kreutz sungrazer group.

Ranking: 1

28 AD 852 Japanese-Chinese

Japanese astronomers discovered a bright comet on March 14, recorded in *Dainihonshi*. It was seen in the west and had a tail 75° long. This was the comet that the Chinese recorded sometime between March 25 and April 22, probably towards the end of March, according to *Hsin Thang Shu* and *Wen Hsien Thung Khao*. The comet had a distinct tail and lay in Orion, perhaps close to Betelgeuse.[14]

No orbit has been independently calculated from these observations. In 1979 Hasegawa suggested from the comet's appearance and its path through the sky that the comet might be a member of the Kreutz sungrazer group. It would have been at perihelion on about March 7.[6]

Ranking: 5

29 AD 867 Japanese–Byzantine

The Japanese saw a comet with a distinct tail on December 22, according to *Dainihonshi*.[14] This may have been the comet seen from Constantinople at the end of the year.[12] The Koreans also saw a 'guest star' near Venus in January 868, recorded in *Samguk Sagi*. It remained visible for seventeen nights. The planet Venus was moving east through Scorpius in the first week of January and Sagittarius during the rest of the month.

Schove identified these as observations of the Great Comet of 868.[21] However, that comet was located near the north celestial pole. It is possible that the Koreans were reporting a different object, which may have been a nova in Sagittarius. The object seen on December 22 could have been a comet, possibly a member of the Kreutz sungrazer group, which had reached perihelion on about December 19. The apparition would have been very unfavourable, as the comet moved rapidly south of the Sun.

Ranking: 2

30 AD 892 Chinese

The Chinese saw a comet with a broad set of tails in the southwest after sunset on December 28, recorded in *Hsin Thang Shu* and *Wen Hsien Thung Khao*. It remained visible in Sagittarius, between ϕ Sagittarii and β Capricorni, until December 31.[14] The comet 'turned into a cloud' before fading away. Hsi suggested that this was a nova,[22] but the Chinese definitely record the presence of tails. It is just possible that this comet was a member of the Kreutz sungrazer group, visible for just a short period after perihelion on December 25.

Ranking: 3

31 AD 939 Italian

A comet was seen in July, appearing shortly after the solar eclipse on July 19. It was relatively bright and had several tails. The comet remained visible for eight days.[12] There are no records from the Far East. The comet's position was not written down. If it had been seen first during the eclipse and then appeared low in the morning sky, it might have been a member of the Kreutz sungrazer group.

Ranking: 2

32 AD 943 Chinese–German

Chinese astronomers discovered a comet in the east on November 5, as recorded in *Chiu Wu Tai Shih*. It had a tail 15° long pointing to the west. The comet was located just east of Spica.[14] This may have been the comet seen from Germany for 15 nights.[12] No orbit has been calculated for this comet. However, Hasegawa suggested that this may have been a member of the Kreutz sungrazer comets, with perihelion on October 28.[6]

Ranking: 3

33 AD 947 Japanese

The Japanese discovered a strange star in the west on February 20, recorded in *Dainihonshi*. This was a comet with a distinctive, straight tail, described as a 'lance star'.[14] It too could be a candidate as a Kreutz sungrazer comet because of its appearance and position.

Ranking: 3

34 AD 948 Japanese

Japanese astronomers found a comet with a tail in the southwest on March 2, recorded in *Dainihonshi*.[14,19] It is possible that this was the third sungrazer comet to be seen in five years.

Ranking: 2

35 AD 957 Japanese

The Japanese saw a white comet on March 6. Its tail was 15 to 30° long and a quarter of a degree wide.[19] No other records exist for this bright comet, which must have been very bright but shortlived. If it appeared in the evening sky after sunset, it would be a very good candidate as a member of the Kreutz sungrazer group.

Ranking: 4

36 AD 961 Japanese

The Japanese found a comet in the southwest on March 16. According to *Dainihonshi* it had a tail and was described as 'resembling a wild fire', suggesting a yellowish or reddish colour.[14] This comet was very bright and may have been a member of the Kreutz sungrazer group.

Ranking: 3

37 1034 Chinese-Japanese X/1034 S1

Chinese astronomers discovered a comet approximately between μ and ν Hydrae on September 20, recorded in *Sung Shih* and *Wen Hsien Thung Khao*. The tail was 10° long and ° wide. Japanese observers also saw a comet with a tail on September 28, according to *Dainihonshi*. It was also seen from Korea.[14] At Constantinople it appeared as a long, reddish tail rising from the eastern horizon, although this may refer to a bright aurora.[12] The Chinese observed the comet until October 2.

No independent orbit has been calculated for this comet. Hasegawa, however, suggested that this was a candidate for the Kreutz sungrazer group, with perihelion on September 8.[6]

Ranking: 4

38 1041 Korean–Byzantine

In September the Koreans discovered a very bright comet in the east. According to *Koryo-sa*, it possessed a tail about 45° long. The comet remained visble for more than 20 days.[14] This may have been the comet seen from Armenia in 1040 or 1041.[23] It may also have been seen from Constantinople, although this may be a report of a bright meteor shower.[18] It is possible from the brightness and length of tail that this was a sungrazer comet.

Ranking: 2

39 1041 Korean

Sometime between October 28 and November 26 the Koreans discovered another comet, recorded in *Koryo-sa*. It also appeared in the east and had a tail about 45° long. It remained visible for more than ten days.[14] The comet was also seen from Europe.[12] This may have been the comet seen from Armenia in 1040 or 1041.[23] It is possible from its brightness and length of tail that this was the second sungrazer comet of the year.

Ranking: 3

40 1056 Korean

The Koreans discovered a comet in Corvus during December.[19] From its position in the sky it is possible that this was a member of the Kreutz sungrazer group, if it appeared early in the month.

Ranking: 1

41 1077 French

Observers saw an object near the Sun on Palm Sunday (April 9), according to Sigebertus.[12,16] This may have been a bright comet, possibly a member of the Kreutz sungrazer group, or more likely Venus, which was near greatest western elongation. A number of comets were dated at Constantinople to the period 1071 to 1078; this may have been one of them.[18] It is also possible that there was a bright meteor shower.

Ranking: 1

42 1080 Chinese

The Chinese saw a comet with a tail near the sting of Scorpius on January 6, recorded in *Liao Shih* and *Hsu Wen Hsien Thung Khao*.[14] Hsi suggested that this may have been a nova,[22] but this is unlikely because of the Chinese description of the comet having a tail. It is possible from the comet's position that it was a member of the sungrazer group, with perihelion on January 2.

Ranking: 2

43 1106 Bright X/1106 C1

This comet was first seen in Europe on February 4, when it appeared as a bright star only two degrees from the Sun and bright enough to be seen in broad daylight.[1,12] Sigebertus recorded observing it from the third to the ninth hour of the day. It was lost in the Sun's glare, until it was observed again from Constantinople and Jerusalem at sunset on February 7. The Japanese discovered the comet in the southwestern sky on February 9, according to *Dainihonshi*, describing it as having a white tail 100° long and pointing to the east between ζ and π Ceti. That evening *Koryo-sa* reported that Korean astronomers found the comet in the southwest and estimated the tail as 15° long.[14] The Byzantine princess Anna Comnena mentioned the comet in her poem the *Alexiad*.

According to *Sung Shih* and *Wen Hsien Thung Khao*, the Chinese began their observations on February 10, when there were tails up to 90° long and 5° wide, pointing to the northeast. The comet lay in the Pisces–Andromeda border. The reference to fragments may refer to features in the tails but also to the possibility that the comet had broken into two or more pieces. The Japanese measured the tail as 15° long on Feb 11, and 5 to 6° long on Feb 12. On February 13 observers in Armenia found that the tail covered most of the sky and described it as 'like a flowing river.' This would suggest that there were a large number of rapidly-changing features in the tail structure. A European chronicle recorded a bright meteor seen on February 16, perhaps a reference to this comet. On February 20 the Japanese described it as having a tail 3° long.

Observers in the Far East and Europe followed the comet, as it moved east through Aries and past the Pleiades and the Hyades. It remained visible generally until the middle of March, when it dropped over the horizon. William of Tyre mentioned that the comet was last seen on March 25. An Armenian record noted that it was visible for 50 days, so the last observation could have been as late as April 4.

No orbit could be independently calculated for this bright comet. Halley thought that it was a return of the sungrazing comet of 1680 with a period of 575 years and identified it with the bright comet of 530 (actually a return of comet P/Halley). Kreutz found that this comet was more likely related to the great comet of 1843 and the other sungrazers.[3] Marsden followed this line and found that it could be an earlier apparition of the Subgroup I progenitor or more likely the previous return of the Subgroup II sungrazer, which then split to form the comets of 1882 and 1965.[5]

Ranking: 7

44 1137 German

On September 11 a new star was seen rising before dawn, where the Sun rose. This would place the object in Gemini or Cancer. It was recorded in *Canonici Wissegradensis*.[16] This may have been a nova or a comet near the Sun. Either would have had to have been bright and short-lived to be spotted in twilight. A doubtful candidate as a Kreutz sungrazer.

Ranking: 1

45 1148 German

A sign was seen near the Sun on February 20. It appeared like a thin crescent on its back with three stars around its lower rim. The object was recorded in *Annales S. Petri Erphesfurdensis*.[16] This may have been a daylight observation of a Kreutz sungrazer comet near perihelion.

Ranking: 1

46 1179 German

A star was seen near the Sun at the 6th hour of the day on August 1. The object was recorded in *Annales Colonienses Maximi*.[16] This could have been a daylight observation of a sungrazer comet, which would have been unfavourably placed to be seen in the night sky.

Ranking: 2

47 1184 European

A comet was reported on the Sun on May 1.[11] However, this is likely to have been a very large sunspot group. It is just possible that this was a bright sungrazer comet near the Sun.

Ranking: 1

48 1232 Chinese

The Chinese discovered a comet in the east between Spica and Corvus on October 17, recorded in *Chin Shih* and *Sung-shih-hsin-pien*. Its tail was white and curved 'like an elephant's tusk' and over 15° in length. The Japanese also saw the comet in the east on October 23, according to *Dainihonshi*, when the tail was more than 30° long. The comet moved south. The Chinese recorded the length of the tail as 30° on October 27 and over 60° on November 11. Moonlight had interrupted observations at the beginning of November. The comet was observed until December 14.[12,14]

The comet was very bright and may have passed perihelion in early October. The curved tail would suggest that the perihelion distance was quite small. Hasegawa suggested that this may have been a member of the Kreutz sungrazer group, as its motion across the sky and its prominent appearance were consistent with perihelion on October 13.[6]

Ranking: 4

49 1282 Byzantine

On March 30 George Pachymeres recorded that in the middle of the day a star appeared in the middle of the sky.[16] This may have been a comet, which could have been a member of the Kreutz sungrazer group.

Ranking: 2

50 1314 European

A comet was seen in Virgo during October. It remained visible for three weeks or, less likely, six months.[12] The comet's position would be consistent with it being a sungrazer comet.

Ranking: 2

51 1368 Korean-Japanese

Korean astronomers discovered a comet in the west on March 7. According to *Koryo-sa* it had a tail 15° long.[14] On the following evening the Japanese saw a comet in the northwest, which had a long tail.[19] At Rheims in Normandy a comet was seen in the northwest. It had a broad tail that was described as like a pyramid.[12]

This may have been the comet seen by the Chinese on February 7, although there are no intervening observations. The comet may have been seen by the Koreans in the west on April 4, but this was probably an observation of the bright comet during the year (1368 = C/1368 E1), which lay in the morning sky during February and March. No orbit has been calculated for this comet. It is possible from the location, brightness and tail length that this was a member of the sungrazer group.

Ranking: 4

52 1381 Korean

Korean astronomers discovered a comet in Libra on November 7. According to *Koryo-sa* it had a tail more than 15° long.[14] The Japanese may have seen the comet in November (recorded in the year 1380).[19] It may also have been seen from Europe from November 10 to 24 (again dated to 1380).[12] The Koreans continued observing the comet until November 22. No orbit has been independently calculated for this comet. In 1979 Hasegawa suggested that it might have been a member of the sungrazer group with perihelion on October 31.[6]

Ranking: 4

53 1392 Korean

On March 18 the Koreans saw a comet, whose tail stretched across the sky, recorded in *Koryo-sa*.[14] The sudden, impressive appearance would support its being a member of the Kreutz sungrazer group, if it had appeared in the evening sky. This is supported by the lack of any other observations, as the comet must have remained visible for only a short time.

Ranking: 3

54 1406 German

A comet was seen in the west sometime in the first half of the year. It was visible for several nights and possessed a blazing tail.[12] The appearance would be consistent with a Kreutz sungrazer comet during the spring. However, there are no confirmatory observations from the Far East.

Ranking: 1

55 1407 Chinese–French

Chinese observers saw a comet on December 15, recorded in *Ming Shih* and *Ming Hui Yao*. At the state of Chao the Director of the Astronomical Bureau described it as lying in the longitude of the Scorpius–Sagittarius border. It was also observed the following night.[14] Monks at the monastery of St Ange saw a comet with a main tail and two smaller ones, possibly more. This may have been a report of a bright meteor.[12] The position of the comet is consistent with a member of the sungrazer group arriving at perihelion early in December.

Ranking: 3

56 1434 Japanese

Japanese astronomers observed a comet in the east on September 11.[14] The position would be consistent with a sungrazer comet, but no other details were recorded.

Ranking: 2

57 1529 Chinese

The Chinese saw a comet with one or more tails stretching across the sky on February 9, recorded in *Ming Shih*.[14] This was the only observation, so the comet was short-lived. If it appeared in the evening sky after sunset, this would be consistent with it being a member of the Kreutz sungrazer group.

Ranking: 3

58 1587 Japanese

The Japanese saw a 'guest star' in daylight on August 30.[14] This may have been a nova. If it was a comet, it must have been very bright. No other observation was made. This would have been consistent with a Kreutz sungrazer, which would have remained very close to the Sun in the sky.

Ranking: 3

59 1668 Southern C/1668 E1

The comet was first seen in the southwest by observers at the Cape of Good Hope on March 3, when the comet was about magnitude 1. Two days later it was seen from Lisbon, where the comet's tail was reported to be 45° long. In Brazil P. Valentin Estancel (San Salvador) saw the comet at 7 p.m. local time below θ and η Ceti. On March 7 he saw the comet near θ Ceti. Between the 8th and the 11th he followed the comet as it moved to the Lepus–Eridanus border.[1,12]

The comet was best seen from the Southern Hemisphere. However, the Chinese began observing it on March 7 as 'a stretch of white light in the southwest', recorded in *Ching -shih kao*. The tail was 9° long and pointed towards the southeast. On March 10 Jean-Dominique Cassini and Montanari (Bologna, Italy) noted the comet with a tail 30° long stretching from Cetus to Eridanus. On the 10th and the 12th the tail was even longer, about 37° long. The Japanese saw the comet from March 10 to 16. Accurate positions of the head of the comet were made by Gottignies (Goa, India) between March 5 and 21. It was also seen from Surate between March 5 and 20. At the Cape the comet was observed until March 23. On March 18 the Chinese saw the comet in Eridanus with a tail over 60° long. They were the last to observe the comet on March 30.

From these observations Henderson calculated a parabolic orbit.[24] Klinkerfues noted that this comet had a similar orbit to the bright sungrazer comets of the nineteenth century. In 1901 Kreutz took up this suggestion and included this in his study of the sungrazers.[3] A parabolic orbit is usually given as the orbital solution. However, a Kreutz sungrazer would have an ellipse with a period of several centuries.

In 1967 Marsden re-examined the sungrazer comets. He found that the best orbital solution by Kreutz gave a perihelion distance of 0.30 AU, so that the comet was not a member of the Kreutz sungrazer group. He did consider it a Kreutz sungrazer nevertheless.[4] In 1989 Marsden included the comet in the sungrazer group from its appearance, brightness and motion but was unable to define its relationship to the other comets.[5]

Ranking: 8

60 1689 Southern C/1689 X1

Observers at the Cape of Good Hope saw a comet in the southeast morning sky on November 24 and 25. The comet was then lost, until Father Richaud (Pondicherry, India) saw the comet's tail in Centaurus. Both groups saw the comet on December 9, when the tail was more than 4° long. On December 14 the comet was magnitude 3 or 4 and the steeply-curved tail 60° long. The comet was also seen from

Japan. It continued south and was last seen at the beginning of January 1690.[1,12]

In 1784 Pingré published a parabolic orbit with a very small perihelion distance. The orbit was improved on by Holetschek in 1891.[24] The comet would have reached perihelion on November 30 (q = 0.064 AU). However, it was strongly suspected that the comet was a member of the Kreutz sungrazer group. Marsden gave a perihelion date of December 2 (q = 0.009 AU) and suggested that it belonged to Subgroup I.[4]

Ranking: 9

61 1695 Southern C/1695 U1

P. Jacob, a French Jesuit priest in Brazil, observed the comet's tail on October 28 an hour before sunrise. On October 30 Bouvet (Surat, India) independently discovered the comet. The head of the comet was in Libra and the tail stretched 30° into Virgo. The Chinese first saw the comet on November 2 with a tail stretching 15° above the horizon. The comet moved north, reaching its longest tail length (40°) on November 6. It was also seen from the Arabian Sea until November 17. The comet then began to fade and was last seen on November 19, just before Full Moon.[1,12]

The uncertainties in the positions have meant that parabolic orbit solutions vary in perihelion date from October 24 to November 19 (q = 0.04 to 0.84 AU). The earlier dates favour a smaller perihelion distance. Kreutz considered this to be a member of the sungrazing comet group, with perihelion on October 23 (q = 0.009 AU).[3] Marsden supported this with calculations in 1967, suggesting that it was a member of Subgroup I.[4]

Ranking: 9

62 1702 Southern X/1702 D1

The tail of a comet was seen in the evening sky on February 20 by Dutch navigators at the Cape of Good Hope. It was observed from South Africa and other southern sites on the 22nd, including Tenerife. From Bengal the comet's tail was seen half an hour after sunset on February 23. It had completely set 45 minutes later. The comet became easier to see, as it moved away from the Sun. Jacques Maraldi was able to see the tail from Rome at the end of the month. The tail reached 43° in length on February 28, which was estimated by observers in the Bay of Bengal. In America LaSueur (Louisiana) saw the comet on the evenings of February 27, 28 and March 1. The last observations were made on March 2.[1,12]

The comet must have been very bright to be seen in twilight at such a low elevation. It would have had to have been at least magnitude 0 and probably much brighter. The lack of accurate positions has meant that no orbit has been independently calculated. However, the comet's brightness and movement have meant that it was likely to be a member of the sungrazer group. Kreutz found a reasonable fit of a sungrazer orbit on the positions for February 27, 28 and March 1.[3] Perihelion would have occurred on February 15 (q = 0.01 AU). Marsden supported this identification and suggested that it might belong to Subgroup II.[4]

Ranking: 9

Discussion

The number of naked-eye comets has been fairly constant over the past 2000 years from figures based on Hasegawa's catalogue[19] with some minor alterations and additions (Figure 1). In the first millennium AD there was an average of 43.4 visible comets per century, mainly observed by astronomers in the Far East. From the fourteenth century European observers began to contribute observations, detecting rather fainter objects. The significant increase in the nineteenth century resulted from observers located in the Southern Hemisphere and earlier detection by comet hunters using telescopes. The invention of the telescope itself did not immediately increase the rate of comet discovery.

Over the same period the number of possible sungrazer comets has also varied, but an average of 3.4 sungrazers per century may have been seen (Figure 1). As they are relatively bright, they should have been spotted in pre-telescopic times, if they were favourably placed. Even as late as 1970 a sungrazer comet could reach naked-eye visibility before being discovered. The nine comets seen in the nineteenth and twentieth centuries include eight with well-defined orbits and the eclipse comet of 1882, which is very likely a Kreutz sungrazer. The appearance of sungrazer comets is very unpredictable, as five were seen within 45 years but none were observed in the period 1702 to 1843.

The four comets of the seventeenth and eighteenth centuries remain the best candidates for Kreutz sungrazers before the period when reliable positions were recorded. A list of all the published orbits for these comets is included in Table 1. In the case of the comet of 1668, Henderson calculated a rather low-inclination prograde orbit from the observations but found that a retrograde sungrazer orbit would also satisfy the comet's positions.[24] Kreutz calculated a number of orbits based on these two solutions and concluded that it was a sungrazer,[3] although he could not distinguish between the two main subgroups found in the nineteenth century (the last two orbits). Marsden tended to favour Subgroup I from the orbital elements.[5] Four orbits were published for the comet of 1689.[24] Although none were particularly similar, they did show that the comet passed very close to the Sun. Kreutz used two representative sungrazer orbits to compare with the observed positions. Again, for the comet of 1695 he tried a number of very different orbits, which could satisfy the comet's positions. His final four orbits were based on the assumption that the comet was a sungrazer. The observations of the first comet of 1702 were so vague that no orbit could be independently calculated.

Two other comets are widely considered to have been sungrazers, those seen in 371 BC and AD 1106. There are few details of the former, but Pingré noted that it could have passed very close to the Sun.[12] He was writing before any Kreutz sungrazers had been discovered but he knew about the bright and unrelated sungrazer comet of 1680. This was the one Halley identified with the bright comet of 1106. It was widely observed and a number of detailed descriptions were recorded. However, there was insufficient positional

Table 1. Orbits of the comets discussed in this paper

T = Time of perihelion (Julian calendar before 1572), decimal in UT
e = eccentricity
ω, Ω, i, L, B = orbital elements (reduced to 2000.0 equinox)
q = perihelion distance in AU
P = orbital period in years

No.	T	q	e	P	ω	Ω	i	L	B	Ref./ Notes
1	–1374 May 1	0.006	1.0		78	358	144	283	+35	
	–1374 May 1	0.006	0.9999	500	78	358	144	283	+35	Progenitor
3	–371 Winter	v small	1.0		119	302	150	179	+26	Pingré 1783[11]
	–371 Winter	v small	1.0		120	3	150	239	+26	Pingré 1783
	–370 Feb	0.006	1.0		78	358	144	283	+35	
	–370 Feb	0.006	0.9999	500	78	358	144	283	+35	Progenitor
4	–115 Aug 29	0.006	1.0		78	358	144	283	+35	
	–93 June 29	0.006	1.0		78	358	144	283	+35	
5	110 Feb 1	0.006	1.0		78	358	144	283	+35	
6	133 Jan 20	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	133 Feb 5	0.006	1.0		78	358	144	283	+35	
	133 Feb 5	0.006	0.9999	500	83	5	144	283	+35	Subgroup I
7	191 End Sep./early Oct.	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	191 Oct 1	0.006	1.0		78	358	144	283	+35	
8	193 Apr–May	0.006	1.0		78	358	144	283	+35	
9	252 Mar 17	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	252 Mar 21	0.006	1.0		78	358	144	283	+35	
	252 Mar 21	0.006	0.9999	620	78	358	144	283	+35	Subgroup Y
10	254 Dec 20	0.006	1.0		78	358	144	283	+35	
11	283 Apr 18	0.006	1.0		78	358	144	283	+35	
12	302 May–June	0.006	1.0		78	358	144	283	+35	
13	334 July	0.006	1.0		78	358	144	283	+35	
	334 July	0.008	0.9999	700	69	347	142	283	+35	Subgroup II
14	349 Nov 28	0.006	1.0		78	358	144	283	+35	
15	423 Feb 6	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	423 Jan 29	0.075	0.998	230	168	102	169	294	+2	Hasegawa 1979
	423 Feb 3.2	1.1054	1.0		264.00	310.60	42.95	212.4	–42.7	Zhou *et al.* 1997[15]
	423 Feb 6	0.006	1.0		78	358	144	283	+35	
	423 Feb 6	0.006	0.9999	800	78	358	144	283	+35	Subgroup Z
16	467 Feb 3	0.006	1.0		78	358	144	283	+35	
17	501 Feb 10	0.006	1.0		78	358	144	283	+35	
18	501 Apr 11	0.006	1.0		78	358	144	283	+35	
19	560 Oct 6	0.006	1.0		78	358	144	283	+35	
20	582 Jan 12	0.006	1.0		78	358	144	283	+35	
21	612 Aug 2	0.006	1.0		78	358	144	283	+35	
22	675 Nov 1	0.006	1.0		78	358	144	283	+35	
	675 Nov 1	0.005	0.9999	570	83	5	144	284	+36	Subgroup I?
	675 Nov 1	0.006	0.9999	1000	78	358	144	283	+35	Subgroup X?
24	813 July 31	0.006	1.0		78	358	144	283	+35	
25	815 Sept 3	0.006	1.0		78	358	144	283	+35	
27	840 Nov 30	0.006	1.0		78	358	144	283	+35	
28	852 Mar 7	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	852 Mar 7	0.006	1.0		78	358	144	283	+35	
	852 Mar 7	0.006	0.9999	600	78	358	144	283	+35	Subgroup Y
29	867 Dec 19	0.006	1.0		78	358	144	283	+35	
30	892 Dec 25	0.006	1.0		78	358	144	283	+35	
	892 Dec 25	0.006	0.9999	760	78	358	144	283	+35	Subgroup X?
31	939 July 19	0.006	1.0		78	358	144	283	+35	
32	943 Oct 28	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	943 Oct 28	0.006	1.0		78	358	144	283	+35	
33	947 Feb 16	0.006	1.0		78	358	144	283	+35	
34	948 Feb 26	0.006	1.0		78	358	144	283	+35	
35	957 Mar 2	0.006	1.0		78	358	144	283	+35	
36	961 Mar 11	0.006	1.0		78	358	144	283	+35	
37	1034 Sept 8	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	1034 Sept 8	0.006	1.0		78	358	144	283	+35	
38	1041 Sept 2	0.006	1.0		78	358	144	283	+35	

...continued overleaf

Table I *(continued)*

No.	*T*	*q*	*e*	*P*	*ω*	*Ω*	*i*	*L*	*B*	*Ref./ Notes*
39	1041 Nov	0.006	1.0		78	358	144	283	+35	
40	1056 Dec 1	0.006	1.0		78	358	144	283	+35	
41	1077 Apr 9	0.006	1.0		78	358	144	283	+35	
42	1080 Jan 2	0.006	1.0		78	358	144	283	+35	
43	1106 Jan 30	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	1106 Feb 5	0.00499	0.9999	380	86.42	8.06	144.65	282.4	+35.3	Marsden 1989[5]
	1106 Feb 5	0.00797	0.9999	770	68.18	345.79	141.70	282.8	+35.1	Marsden 1989
	1106 Feb 24.3	0.82215	1.0		317.61	154.28	60.23	129.9	−35.8	Zhou et al. 1997[15]
	1106 Feb 5	0.008	0.9999	775	69	347	142	283	+35	Subgroup II
44	1137 Sept 8	0.006	1.0		78	358	144	283	+35	
45	1148 Feb 20	0.006	1.0		78	358	144	283	+35	
46	1179 Aug 1	0.006	1.0		78	358	144	283	+35	
47	1184 May 1	0.006	1.0		78	358	144	283	+35	
48	1232 Oct 13	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	1232 Oct 13	0.006	1.0		78	358	144	283	+35	
	1232 Oct 13	0.006	0.9999	800	78	358	144	283	+35	Subgroup Z
49	1282 Mar 30	0.006	1.0		78	358	144	283	+35	
	1282 Mar 30	0.005	0.9999	570	83	5	144	284	+36	Subgroup I
50	1314 Oct	0.006	1.0		78	358	144	283	+35	
51	1368 Mar 3	0.006	1.0		78	358	144	283	+35	
52	1381 Oct 31	0.0054	1.0		86	8	145	283	+35	Hasegawa 1979[6]
	1381 Oct 31	0.006	1.0		78	358	144	283	+35	
53	1392 Mar 14	0.006	1.0		78	358	144	283	+35	
55	1407 Dec	0.006	1.0		78	358	144	283	+35	
56	1434 Sept 7	0.006	1.0		78	358	144	283	+35	
	1434 Sept 7	0.006	0.9999	600	78	358	144	283	+35	Subgroup Y
57	1529 Feb 5	0.006	1.0		78	358	144	283	+35	
58	1587 Aug 30	0.006	1.0		78	358	144	283	+35	
59	1668 Feb 25.282	0.25113	1.0		206.68	198.10	27.08	42.2	−11.8	Henderson[22]
	1668 Feb 29.3	0.00478	1.0		80.26	1.92	144.07	283.9	+35.3	Henderson
	1668 Mar 28.153	0.62365	1.0		237.54	352.18	132.57	125.4	−38.4	Kreutz 1901[3]
	1668 Feb 28.080	0.06660	1.0		109.81	3.21	144.38	249.3	+33.2	Kreutz 1901
	1668 Feb 29.599	0.00337	1.0		125.73	54.19	140.11	281.0	+31.4	Kreutz 1901
	1668 Feb 25.748	0.28229	1.0		220.34	185.41	33.55	40.7	−21.0	Kreutz 1901
	1668 Feb 26.362	0.29060	1.0		219.12	182.28	35.83	35.7	−21.7	Kreutz 1901
	1668 Feb 26.3785	0.29808	1.0		219.88	181.35	35.16	35.7	−21.7	Kreutz 1901
	1668 Feb 27.386	0.44520	1.0		243.51	172.74	40.47	49.5	−35.5	Kreutz 1901
	1668 Feb 23.239	0.35708	1.0		243.86	184.18	33.63	63.7	−29.8	Kreutz 1901
	1668 Mar 1.43264	0.00554	1.0		82.58	3.44	144.34	282.5	+35.3	Kreutz 1901
	1668 Mar 1.49766	0.00775	1.0		69.60	347.67	142.01	282.9	+35.2	Kreutz 1901
	1668 Mar 1.349	0.00508	0.9999	560	86.61	8.47	144.59	282.6	+35.3	Marsden 1989[5]
	1668 Mar 1.340	0.00552	0.9998	180	84.68	5.96	144.44	282.5	+35.4	Marsden 1989
	1668 Mar 1	0.006	0.9999	1000	78	358	144	283	+35	
	1668 Mar 1	0.006	0.9999	760	78	358	144	283	+35	
60	1689 Dec 2.1220	0.01689	1.0		59.99	328.09	110.75	296.6	+54.1	Pingré 1783[11]
	1689 Dec 2.6403	0.0103	1.0		73.02	348.63	149.62	278.1	+28.9	Peirce 1843[24]
	1689 Nov 29.7000	0.01893	1.0		180.79	94.79	120.92	274.4	−0.7	Vogel 1852[24]
	1689 Nov 30.6589	0.06443	1.0		78.13	283.77	63.20	348.8	+60.9	Holetschek 1891
	1689 Dec 1.44124	0.00554	1.0		82.58	3.46	144.34	282.6	+35.3	Kreutz 1901[3]
	1689 Dec 3.44124	0.00554	1.0		82.58	3.46	144.34	282.6	+35.3	Kreutz 1901
61	1695 Nov 10.20	0.8435	1.0		204	220	22	62	−9	Burckhardt 1815
	1695 Oct 29.751	0.75238	1.0		186.38	222.53	26.73	48.2	−2.9	Kreutz 1901[3]
	1695 Oct 19.439	0.54749	1.0		156.83	228.10	32.83	28.3	+12.3	Kreutz 1901
	1695 Oct 22.429	0.04982	1.0		59.11	288.34	89.71	288.8	+59.1	Kreutz 1901
	1695 Oct 20.324	0.17568	1.0		114.29	336.91	146.67	218.5	+30.1	Kreutz 1901
	1695 Oct 20.719	0.54303	1.0		156.83	228.10	33.99	28.6	+12.7	Kreutz 1901
	1695 Oct 23.768	0.04230	1.0		59.12	286.02	93.59	280.0	+58.9	Kreutz 1901
	1695 Oct 21.113	0.15417	1.0		118.58	342.04	145.40	218.5	+29.9	Kreutz 1901
	1695 Oct 21.54124	0.00554	1.0		82.58	3.44	144.34	282.5	+35.3	Kreutz 1901
	1695 Oct 23.54124	0.00554	1.0		82.58	3.44	144.34	282.5	+35.3	Kreutz 1901
	1695 Oct 22.1	0.00775	1.0		69.60	347.67	142.01	282.9	+35.2	Kreutz 1901
	1695 Oct 24.1	0.00775	1.0		69.60	347.67	142.01	282.9	+35.2	Kreutz 1901
	1695 Oct 23	0.00444	0.9999	590	87.18	9.00	144.63	282.5	+35.3	Marsden 1989[5]
	1695 Oct 23	0.00486	0.9999	210	85.01	6.22	144.48	282.3	+35.4	Marsden 1989
62	1702 Feb 18.5	0.00554	1.0		82.58	3.44	144.34	282.5	+35.3	Kreutz 1901[3]
	1702 Feb 15.1	0.00775	1.0		69.60	347.67	142.01	282.9	+35.2	Kreutz 1901

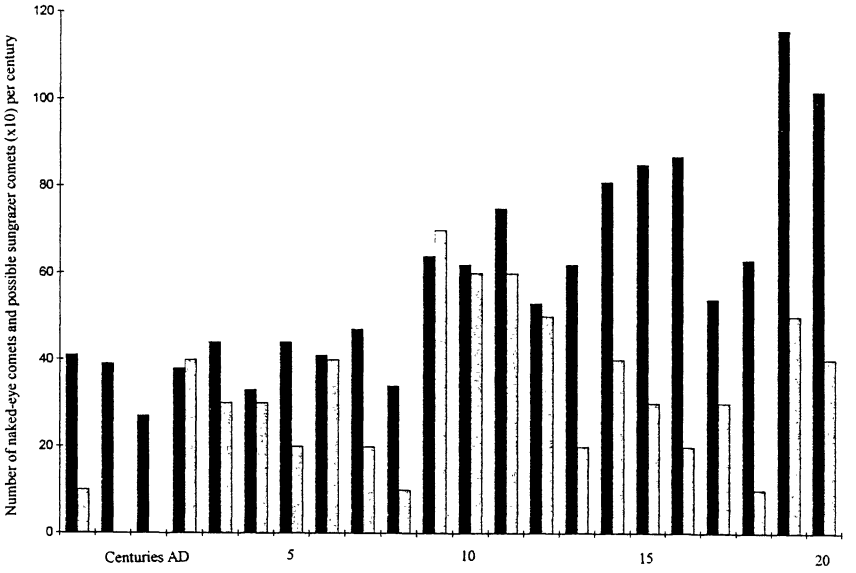

Figure 1. The frequency of naked-eye and sungrazer comets over the last two thousand years.

detail for a definite orbit to be calculated. Several writers have put this comet forward as a Kreutz sungrazer, and Marsden considered that it was likely the previous return of the comets of 1882 and 1965 (Subgroup II).[5] He concluded that at least two groups of comets had survived several revolutions and episodes of breakup, with the original comet appearing in 371 BC.

Hasegawa had previously noted a number of possible sungrazers from their appearance, position and motion across the sky.[6] He mentioned that they would have had a generalised sungrazer orbit. The last eight comets have relatively reliable orbits[25] (this excludes the many sungrazers observed by spacecraft, as most were observed for a very short time and their orbits are not well defined). The orbital elements of these can be compared (Figure 2), from which a general orbit can be reconstructed as well as possible progenitor orbits for the different subgroups. These have been applied where possible to each candidate on the assumption that they are sungrazers. Some tentative conclusions may be made from these. One is that the comets of 1375 BC, 371 BC and AD 133 represent the original progenitor of the sungrazers. It would have an orbital period of about 5 centuries, which is comparable to the observed orbital period of the Great Comet of 1843. The return in about 873 BC would not have been recorded, as this was in the middle of a poorly-documented period early in the Iron Age in the Mediterranean and the Middle East and before Chinese records became reliable. This orbital period is rather longer than Marsden's value of about 3.7 centuries for the main component of the sungrazers, which would develop into Subgroup I.[5]

The comet of 1843 (Subgroup I) had returned to perihelion several times in the past few millennia and should have become visible, if it was favourably placed. Candidates for this comet include 1282, 675 and 133, giving an orbital period of about 5.7 centuries. Marsden noted that on fragmentation secondary nuclei tend to have a larger orbital period.[5] This seems to have happened to Subgroup II, whose main components (comets 1882 and 1965) had a rather larger orbital period of about 7.5 centuries. This was very likely seen in 1106 and may have been observed as a daylight object in AD 334, perhaps in the summer, as it was not observed in the night sky. A further revolution would bring it back in 371 BC.

The comet of 1668 is difficult to account for in either main subgroup. Marsden found that the shorter the orbital period the less satisfactory the orbit became. If it had made two revolutions since 371 BC, it could be identical to the comet of 675 with a period of 10 centuries (Subgroup X). On the other hand, if it broke away from the comet of 133, it could have been identical to the comet of 892 with a period of about 7.6 centuries. Looking at the list of candidates, one comet may be responsible for the comets seen in 252, 852 and 1434 with an orbital period of about 6 centuries (Subgroup Y). Another may represent the comets seen in 423 and 1232 and have a period of about 8 centuries (Subgroup Z). Both would have broken away from the main component in 371 BC and could return in the second quarter of the twenty-first century. More detailed calculations would be needed to unravel the hierarchy of these comets. This is confused by the continuing fragmentation of the comets.

Over two and perhaps three millennia a brilliant comet has been repeatedly passing very close to the Sun, hurtling back into the outer reaches of the Solar System. Each time it has had to survive ferocious thermal and gravitational

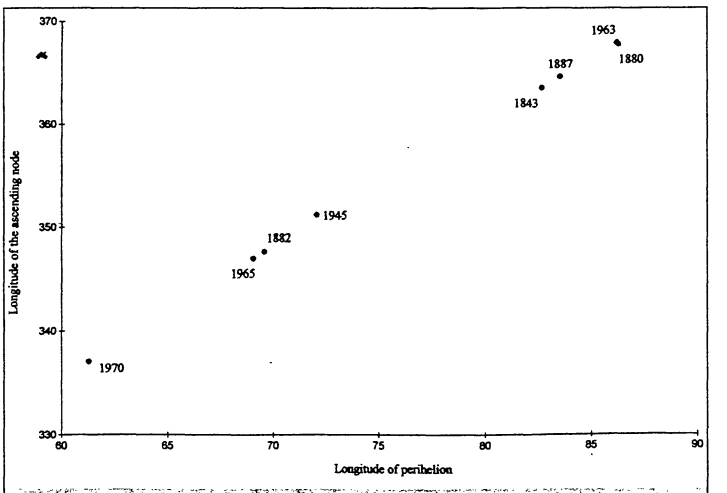

Figure 2. Orbital elements of the Kreutz sungrazer comets observed in the nineteenth and twentieth centuries.

forces, as it passes less than 100,000 kilometres from the surface of the Sun. The comet nucleus has been seen to break up into several pieces on a number of occasions. As these new components are formed, they in their turn can make a spectacular cometary display at the next return. The orbit does not bring them very close to the major planets. However, as they pass so close to the Sun, the gravitational perturbations of Jupiter and Saturn on the Sun can result in a comet crashing into the Sun's surface. This was most spectacularly seen in 1979, when comet Solwind 1 (1979 XI = C/1979 Q1) collided with the Sun on August 30 and scattered material into the solar corona.[1] On the other hand, the resulting nucleus can become so small that solar heating disrupts it completely. This happened to the comet of 1887 (1887 I = C/1887 B1), which 'faded out' as it approached perihelion. These two processes can remove sungrazers, so they have a finite lifetime, probably only a few millennia. However, apart from the last mentioned, all sungrazers seen in the night sky have survived perihelion, at least for one more revolution.

Acknowledgments

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Address: 28 Hudson Road, Woodley, Reading, Berks. RG5 4EW

Appendix

Kreutz sungrazer tracks

Kreutz sungrazer comets have a distinctive motion across the sky when observed from the Earth. The following tracks (Figures 3-6) have been calculated from the general sungrazer orbit for hypothetical sungrazers reaching perihelion at the beginning of each month (epoch 2000). They extend for 60 days at 2-day intervals

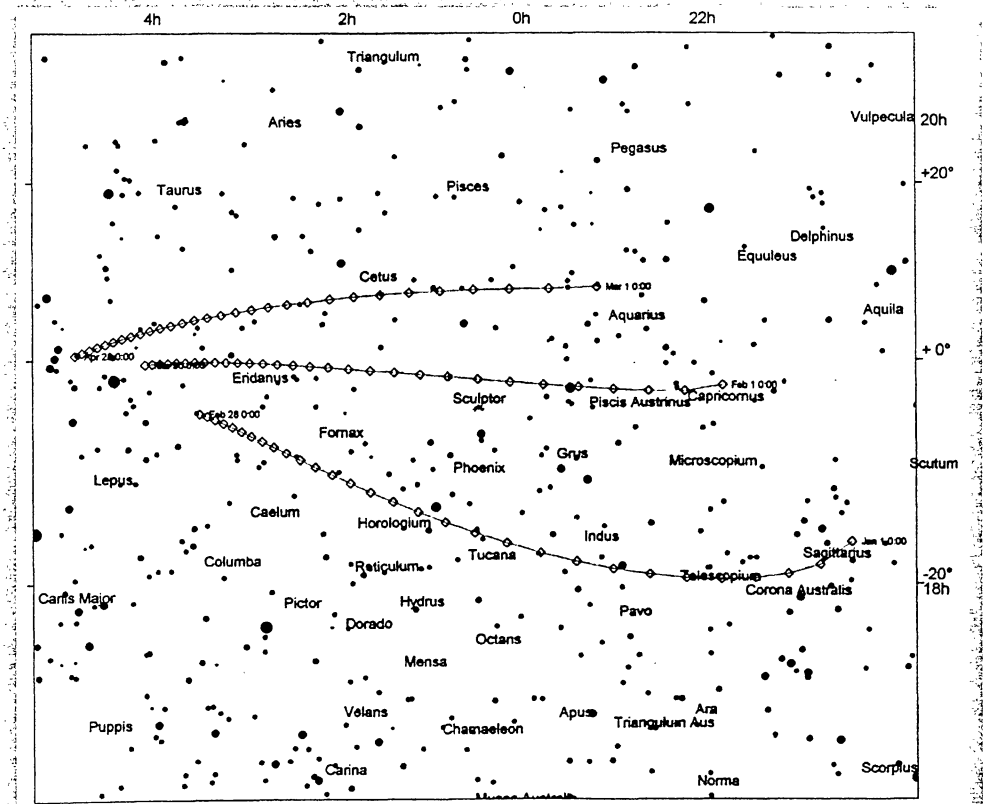

Figure 3. Paths of sungrazer comets reaching perihelion at the beginning of January, February and March (epoch 2000).

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from perihelion, calculated using the computer program *Megastar*.[26] The Sun would be located close to the comet at the time of perihelion. Pre-perihelion positions tend to follow these tracks, although sungrazers are rarely discovered more than a few days before perihelion. The comets are most favourably placed for observers from the Southern Hemisphere. Pre-telescopic records almost exclusively come from the Northern Hemisphere. The effect of precession in the Earth's orbit would lead to a sungrazer reaching perihelion at the beginning of March two thousand years ago following the track for one at the beginning of April now.

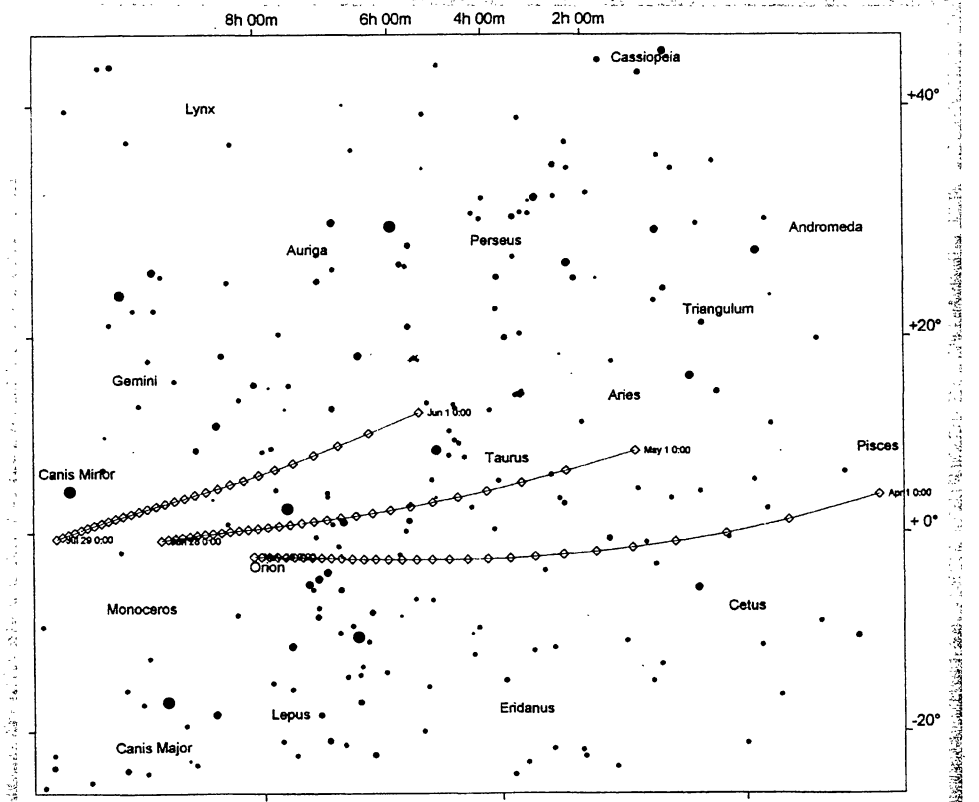

Figure 4. Paths of sungrazer comets reaching perihelion at the beginning of April, May and June (epoch 2000).

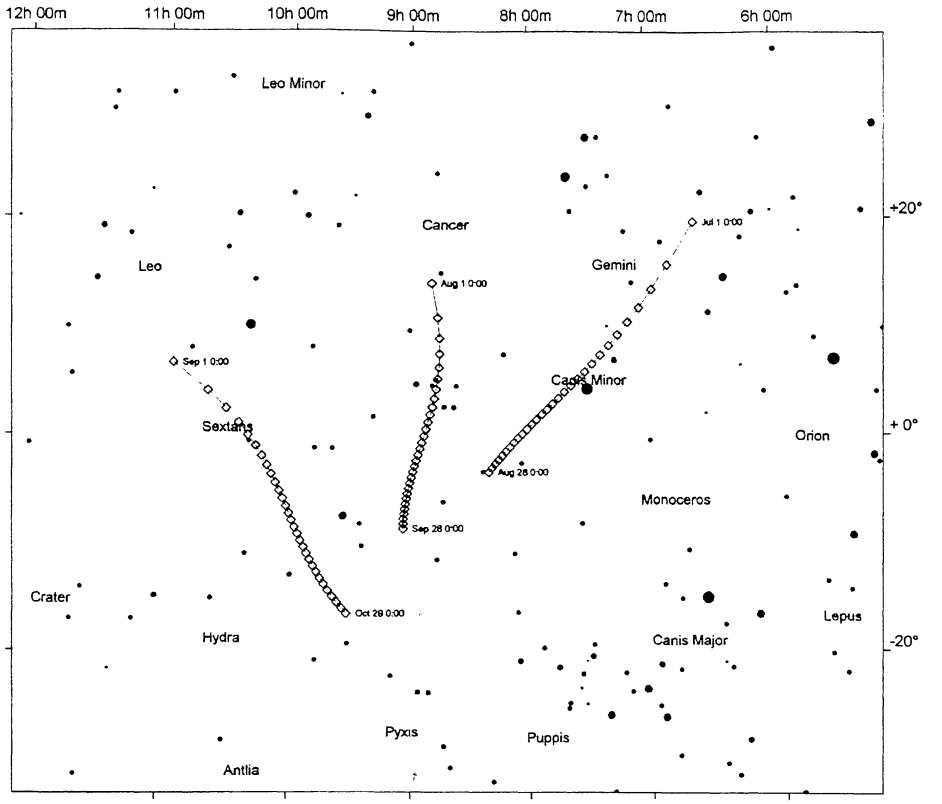

Figure 5. Paths of sungrazer comets reaching perihelion at the beginning of July, August and September (epoch 2000).

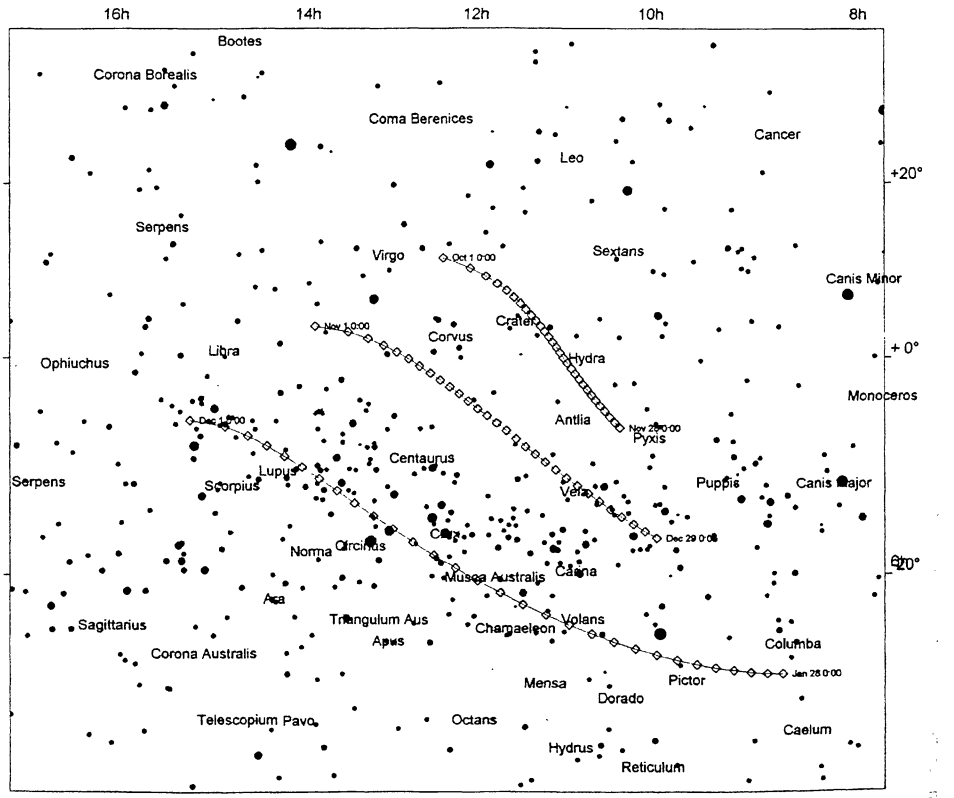

Figure 6. Paths of sungrazer comets reaching perihelion at the beginning of October, November and December (epoch 2000).

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Index to Volume 111

Prepared by R. A. Marriott

The *Subject Index* references items under general headings; where a contribution covers two or more clearly defined subjects, each is separately referenced, but otherwise sub-headings within the same topic are not included. Book reviews are indexed as such, but their subjects are not further cross-indexed. The *Author Index* details all named contributions, including talks at Ordinary Meetings, but not questions from the floor.

Abbreviations: ill. = illustration; ltr. = letter to the Editor; mtg. = meeting contribution; news = in 'Notes and News', 'BAA Update' or 'Notice board'; obit. = obituary; rvw. = publication review

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