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Solar Eclipses and Encke's Comet on Swedish Rock Carvings

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The prehistoric rock carvings in Sweden have been studied for more than a century without general consensus about their meaning. Using a program developed by the author between 1975-1985, the first identifications were made of total solar eclipses depicted on Swedish rock carvings from the Bronze Age, 1800-500 BC. The accuracy of the program has been checked by comparison with written records of total solar eclipses.

In 1991 the author found that important phenomena in the sky such as solar eclipses would have been dated in a calendar with six ships that carried the sun along the ecliptic. The ships have individual shapes and can be identified as constellations. A total solar eclipse was simply dated by a correct position of the symbol for the sun in the actual calendar ship. If planets were visible during the eclipse they were reproduced as cup-marks in correct position in relation to the sun.

A comet was visible during the two total solar eclipses in 1596 BC and 858 BC. The author has been able to identify this as the periodic comet Encke and its orbit has been checked by comparison with the Chinese chronicles. The earliest identification of Encke on the Swedish rock carvings goes back to 1758 BC.

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The rotation of the earth

The rotation of the earth is decelerated due to the braking effect of the tidal forces from the moon and the sun. However, the theoretical calculations are useless in this case and we must rely on empirical determinations based on ancient historical records of, preferably, total solar eclipses. The problem is that we can easily enter a situation with circular arguments because the historical chronology is often based on solar eclipses mentioned in the ancient texts and the time corrections that must be used in the computations of the dates for the eclipses are based on the same historical records. It is therefore necessary to use a more or less unbroken series of well-recorded solar eclipses from different parts of the world and avoid dubious records that cause confusion. The German astronomer Carl Schoch cooperated closely with archaeologists, historians, and linguists and could base his identifications of solar eclipses on the best available ancient texts. His formulas have been improved but his determination of the so called lunar orbital acceleration - 24.4 arc seconds/(century)² has been used in my computer program (Schoch 1931).

The computer program was constructed between 1975-1985 and has been carefully checked with all known relevant sources. These include Copernicus' personal copy of Calendarium Romanum Magnum published by Johann Stöffler in 1518, now in the library at the Astronomical Observatory in Uppsala, with his notations of the time for the main phases of five solar eclipses, medieval monastery chronicles, Classical Greek texts, Hittite annals and cuneiform tablets from Babylon (Schoch 1931), and Chinese oracle bone texts and chronicles (Pang 1988).

The most important of the cuneiform texts tells us about a total solar eclipse in Babylon in 136 BC April 11 (April 15 Julian Calendar), with the time given for the different phases of the eclipse. This eclipse is described on two separate tablets in the British Museum collection. The following translation of one of the texts is published in Historical Eclipses by F. R. Stephenson (1982) and is made by Abraham J. Sachs of Brown University (1974): "Twenty-four *us* after sunrise a solar eclipse [obscured] on the southwest side when it began.... Venus, Mercury and the normal stars [meaning those that were then above the horizon] were visible; Jupiter and Mars, which were in their period of disappearance [meaning the interval between setting with the sun and rising with the sun], were visible in that eclipse.... [The shadow] moved from southwest to northeast." The totality was reached after a further 18 *us* and the other text tells us that the duration of the entire eclipse was 35 *us*, in good agreement with the time for totality given by the first text. This is the best documented solar eclipse before the 18th century when the astronomers used telescopes.

The difference between the time recorded in the cuneiform text and my computed time is 0 ± 2 minutes. This cuneiform text is an independent check of Schoch's determination of the lunar orbital acceleration because it was completely unknown to him. The published computer programs that I have tested have an error of about 16 minutes, which makes the result of the computations useful only under the most favourable circumstances. The errors depend on the square of the time-interval before 1900 AD, which rapidly makes the results completely useless for exact identifications for more distant eras.

During the spring 1996 it became clear that no published computer program was even able to reproduce the total solar eclipse at sunrise in Athens 484 AD. However, my program shows that the eclipse was total in Athens and at the moment of maximum eclipse the lower limb of the sun was 0.3° above the horizon. A general review of the problems in the computations of ancient eclipses is given by Stephenson and L. V. Morrison (1984). The value -26.0 arc seconds/(century)² has been used as the lunar orbital acceleration in the "Atlas of historical eclipse maps, East Asia 1550 BC-AD 1900" (Stephenson & Houlden 1986). However, this choice of lunar secular acceleration has unfortunately not been successful.

It is very satisfying that my computer program can correctly reproduce the so called double dawn solar eclipse in Zheng, 899 BC April 11, described in the Chinese texts, because it overlaps in time with the youngest of the so far identified total solar eclipses, 858 BC July 5, on Swedish rock carvings from the Bronze Age. Because of the demonstrated great problems for the established authorities to compute ancient solar eclipses, I present the detailed results from my computations of this solar eclipse before sunrise in Zheng, see Appendix.

The Old Testament mentions three miraculous situations that can easily be explained as the partial solar eclipse in 700 BC, 2 Kings 20:9-11, the total solar eclipse in 1131 BC, Josh. 10:13, and the annular solar eclipse in 1207 BC, Josh. 10:12. Another important eclipse occurred in the Hittite capitol Boghazkoi, east of Ankara in Turkey, in 1335 BC, during the 10th year of the reign of king Mursilis II, Bo. 4802, Kol. IV, 25 (Bilabel 1927). These independent written sources give an overlap of more than 500 years with the Swedish rock carvings from the Bronze Age, and are necessary to avoid circular arguments.

The solar eclipses

In 1991 it was possible to identify some engravings on rocks in Sweden as observations of the total solar eclipses in 1666, 1596, 1460, 1411, 1366, 1230, 1185, 1169 and 858 BC (Henriksson 1991ab, 1992). The first identifications were made from reproductions of the rock carvings at Ekenberg in Norrköping by Arthur Nordén (1926). The eclipse in 1596 BC was spectacular and has been reproduced on rocks on several places along the zone of totality from Traprain Law, Midlothian, in southern Scotland (Bailey, Clube & Napier 1990) to Lake Onega in northwestern Russia (Hallström 1960), Figure 1. During this eclipse Venus, Mercury, and Saturn were visible to the left of the sun and Jupiter and the comet Encke to the right. The eclipsed sun was reproduced as a series of concentric circles and the planets as cup-marks. The comet was reproduced symbolically as a sword in some cases, but mostly as two close rays perpendicular to the outermost circle. One of the different types of comets in the classification by Pliny the Elder (77) is described as a sword.

The total solar eclipse in 1230 BC July 7, is presented in Figure 2 (Henriksson 1998).

The calendar ships

The author has found systematic combinations of the symbol for a total solar eclipse in unique positions in relation to specific types of ships in a series of six different ships. The conclusion was that the ecliptic has been reproduced as a series of six ships: five corresponding to 60 days and the biggest one to 65-66 days beginning with the summer solstice. The six ships can be interpreted as constellations, have individual shapes, and can therefore be recognised in the sky. They may have served in a calendar with six double months corresponding to two of the zodiacal signs. The position above the ship for the sun or the moon marked in which part of the double months something important happened, Figures 1-2. In the case of the moon the phase can even give the correct day. A more detailed presentation of this hypothesis is given in Henriksson (1998).



Figure 1. (a) The total solar eclipse on 1596 BC March 3, from the horizon of Ekenberg in Norrköping. The central phase occurred at 08.57.10 local mean solar time, and the duration of the total phase was 2min and 46sec. Four bright planets dominated the sky in the vicinity of the sun. But the most spectacular object was comet Encke, visible so close to the sun because of the total solar eclipse. The length of the tail of the comet corresponds to 1.0 AU. (b) The totally eclipsed sun with four planets and Encke in Aries-Pisces. Orion lifts the Gemini-Taurus ship. Rock carving at Ekenberg after Arthur Nordén 1926. (c) The area around the sun during the total eclipse 1596 BC March 3, at 08.57.10 am local mean solar time at Ekenberg. A unique combination of four bright planets and comet Encke must have made a strong impression on the people within the zone of totality. The length of the tail of the comet corresponds to 1.0 AU. (d) Fragment of a rock carving from the prehistoric cult place at Traprain Law, Midlothian, Scotland. This place was also situated within the zone of totality of the solar eclipse on 1596 BC March 3. After Bailey, Clube, and Napier 1990. (e) Rock carving at Lake Onega in eastern Russia, close to the southern limit of the total solar eclipse on 1596 BC March 3. After Gustaf Hallström 1960.



Figure 2. (a) The total solar eclipse on 1230 BC July 6, at 08.59.00 local time at Ekenberg in Norrköping. The sky was dark close to the sun, and it was possible to see planets and bright stars. The stars in Hydra correspond to the largest of the six calendar ships beginning with the summer solstice. The projection makes the upper part of the star map too wide. (The stars are brighter than magnitude 5.0.) (b) In 1869 the King's Custodian of Antiquities, Bror Emil Hildebrand, made the first investigation of this excellent example of Swedish rock carving at Ekenberg. He dated it to the older Swedish Bronze Age, 1800-1000 BC. The ship is for stylistic reasons dated to ca 1500 BC. The length is 2.2 meters. The author identified, in 1991, the scene above the ship as a record of the total solar eclipse on 1230 BC July 6, with the sun in front of Leo and with the planets visible reproduced as cup-marks. The sun was placed above the 14th rail-mark. If this corresponds to July 6, the first one could have been June 23. This may be interpreted as a dating of the eclipse as the 14th day after the summer solstice which took place on June 23 at 04:48 local time. After Hildebrand (1869).

The moon

While I was looking for a symbol for the moon I realised that the very common footprints often were depicted in similar positions in relation to the ships as the solar symbols. They are never arranged like the footsteps of a walking man, but appear mostly isolated as a left or right foot or as a pair of feet. My conclusion was that the full moon was reproduced as a pair of feet, the first quarter moon as a left foot and the third quarter moon as a right foot; always with the toes pointing downwards. A left hand with the thumb pointing upwards corresponds to the new moon and a left hand with the thumb pointing downwards corresponds to the waning phase, Figure 3. Sometimes the foot was depicted with all five toes and sometimes as a shoe sole but I cannot see any different meaning. There exist also naturalistic depictions of the moon as circles, left or right semi-circles or crescents, sometimes together with the corresponding footprint or hand symbols. This hypothesis has successfully been used to date depictions of the comet Encke and different phases of a supernova (Henriksson 1993ab, 1994, 1995).

Constellations

The constellation Orion has been identified as a celestial god that lifted the ecliptical sunship Gemini-Taurus over his head, Figure 1. This is a very common motif.

Leo can also be identified as a specific animal-like constellation above the calendar-ship I have called Leo-Cancer. This ship consists of the stars in Hydra, with the head of the Hydra as the decoration of the bow and with the brightest stars in Corvus as the stern, Figures 2-3. A more complete discussion of constellations is presented in Henriksson (1998).

The comet Encke

On the rock images of the total solar eclipses on 1596 BC March 3, and on 858 BC July 5 there is also a picture of a comet which was identified in 1994 as the periodic comet Encke. This was the result of a cooperative study with Dr Mats Lindgren, at the Astronomical Observatory in Uppsala, who computed the gravitational orbit of Encke back to 2000 BC. We used the subroutine RADAU as integrator and took into account the gravitational field from the sun, and all the planets including the centre of mass of the earth-moon system (Everhart 1986). The computed orbit has a very stable evolution with no close encounters with Jupiter. From this preliminary orbit I was able to compute empirical non-gravitational time-corrections and to determine the positions of the comet accurately enough for its identification with about ten comet observations in the old Chinese chronicles (Yoke 1962). The most useful Chinese observations were made in 47 BC and AD 222, 699, 1019, and 1376.

In December 1355 BC and January 1354 BC, the supernova mentioned above and the comet Encke were visible in the same part of the night sky. This dramatic celestial event was depicted on several Swedish rock carvings and can be used as an important double-check for both the correctness of the dating of the supernova and of the determination of the orbit of Encke (Henriksson 1995).

The oldest observation of comet Encke before this investigation was made in 1786 AD. It has now been possible to follow comet Encke back to 1758 BC. A series of four bright passages close to the earth and the sun 1662, 1652, 1646, and 1609 BC have been reproduced around the calendar ship Leo-Cancer which originally was drawn to commemorate the total solar eclipse on the day of the summer solstice, 1666 BC June 22. All these complicated situations eliminate the risk of circular arguments and fit very well with the positions given by the computer program.



Figure 3. Symbols and astronomical phenomena on Swedish rock carvings.

Appendix

The "Double Dawn" solar eclipse at Zheng, in China, 899 BC

In the Old Version of the Chinese Bamboo Annals it is written that "During the first year of King Yi the day dawned twice at Zheng". Yi was the king of Western Zhou and the first year of his reign can be dated to between 895-966 BC. In the encyclopaedia Kai yuan Zhan jing, a Tang Dynasty compilation of earlier astronomical texts, made in the 10th century, the same event is described: "According to Ji jung ji nien the day began twice at Zheng during the first year of King Yi."

The first modern scholar to recognise this passage as a record of a solar eclipse was probably Liu (1944). He identified it as a solar eclipse on 926 BC March 21. This study was followed by those of Tung (1952), who suggested the date 966 BC May 12, Pang (1987), who suggested the date 899 BC April 20, and Zhang et al (1982), who suggested the date of the eclipse as 919 BC October 26 or 903 BC August 3. All these dates are given in the Julian Calendar. These studies were dependant on the Canon of solar Eclipses by Oppolzer (1887), without corrections for the braking of the earth's rotation by the tidal forces of the Moon and the Sun.

Zheng was placed at 34.5° N, 109.8° E, by Tan (1982) in the Historical Atlas of China, 27 km to the west of the Hua Mountain Range which gives a natural horizon of an altitude of a few degrees in the east. As we shall see, this high horizon made it impossible for the people in Zheng to see that a solar eclipse had occurred before sunrise on the morning with the double dawn.

The text above is a summary of the paper by Pang (1988) in which he tried to prove his earlier hypothesis that the double dawn was caused by the annular solar eclipse of 899 BC. All the dates above are given in the Julian Calendar. I prefer the Gregorian Calendar because then the dates will fall in the correct season.

This double dawn eclipse is important for the determination of ΔT , the difference between Ephemeris time and Universal time.

I agree with Pang that the double dawn eclipse was the annular eclipse on April 11, Gregorian Calendar, 899 BC, but his determination of ΔT is not correct because it cannot explain the double dawn effect! According to Pang the central phase of the eclipse took place only 0.75° below the horizon and caused only a short decrease of the brightness of the very bright morning sky some minutes before sunrise. If Pang's solution is correct the people in Zheng must have realised that the explanation for the variation in the brightness of the sky was the solar eclipse they could observe later, up to an altitude of more than 10° above the horizon. Pang argues that the people in Zheng could not have observed the end of the solar eclipse because it was covered by the Hua mountains, but this was obviously possible in his solution.

In my solution the end of the eclipse took place 2° above the horizon and was therefore completely obscured by the Hua mountains.

The magnitude of the eclipse was 0.95 according to Pang and he writes: "The Δ T required for optimum solution is 20,900 sec or 5 hr 48 min, with an uncertainty of ±500 sec. These results have been independently verified by Fred Espenak of the NASA Goddard Space Flight Centre, who used a modified version of the U. S. Naval Observatory eclipse computing program; and by Rickey W. Parker of Parsec Software, Inc., who used a commercially available program called the 'Visible Universe' (personal communication, 1987)."

This is considerably smaller than 0.967 according to my computations. It is doubtful if an eclipse of magnitude 0.95 could cause anything but a short constant brightness of the sky, not the

striking and unexplained decrease in brightness that caused them to write that "the day began twice". One of my referees has pointed out that this criticism of Pang's interpretation is strongly supported by Stephenson (1992).

With magnitude 0.967 and the Eddington approximation of the limb-darkening of the solar disc, the computed brightness of the sky decreased to the same level that morning as during the nautical twilight with the sun 12° below the horizon. In fact the light level during the central phase corresponded to the light level with the sun 13° below the horizon during a normal morning, Figure 4.



Figure 4. (a) The Old Version of the Bamboo Annals mentions that "During the first year of King Yi the day dawned twice at Zheng". Yi was the King of Western Zhou. The first year of King Yi's reign can be dated to between 895-966 BC. The only possible solution between 800-1000 BC is the annular solar eclipse on 899 BC April 11, at 04:49 local mean solar time. The figure shows the logarithm of the horizontal component of the sky brightness during this solar eclipse as a function of the altitude of the sun. The straight line is the visually observed horizontal illumination of a cloudless sky according to A. Ljunghall (1949). (b) During the central phase of the annular solar eclipse on 899 BC April 11 the brightness of the morning sky in Zheng decreased to the same level as at the nautical twilight. The limb-darkening of the solar surface has been computed in the Eddington approximation.

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