Mon. Not. R. astr. Soc. (1968) **141**, 69–75.

EARLY JAPANESE ASTRONOMICAL OBSERVATIONS

F. R. Stephenson

(Received 1968 March 11)

Summary

Three occultations, recorded by the Japanese in the seventh century A.D., are analysed. Perhaps the most notable observation is that of an occultation of a new star by the Moon on A.D. 642 August 10. The other two records involve a 'star', whose name or position is not given and the planet Mars.

The apparent occultation of Mars is shown to be merely a very close conjunction of the planet with the Moon; that of the 'star' was however well-observed and the star is identified as Aldebaran. Only for the latter event is there a definite error of a day. These results confirm the accuracy of seventh century Japanese chronology, a conclusion arrived at by E. B. Knobel in 1905 from a study of eclipses. An attempt is made to deduce the present position of a 'guest-star', occulted by the Moon in A.D. 642. Comparison with the modern place of a radio source in the constellation of Ophiuchi leads to the suggestion that the guest-star may perhaps be a preliminary outburst of the supernova seen by Kepler nearly a millenium later.

1. *Introduction.* In 1905 E. B. Knobel gave a list of astronomical observations made in Japan during the seventh century A.D. These were taken from the Nihongi, the standard native history of Japan, which was written in A.D. 720. The observations are of apparitions of eclipses, occultations, a planetary conjunction, comets, meteors and the aurora borealis. Knobel mentions that the chronology of the early part of the Nihongi had been shown to be entirely false by various historians in the late nineteenth century. It was Knobel's aim, in discussing the astronomical references in this work, to compare the recorded dates of as many as possible of the observations with the astronomically derived dates. This comparison would then provide information on the reliability of Japanese chronology in the seventh century, but he could make no comment about earlier times.

For each event the Nihongi gives the date, i.e. year of emperor, month, and day of month, together with a short description of the phenomenon. Knobel derived the corresponding Julian date with the help of various chronological tables.

The eclipse records were examined by Knobel using the Canon of Eclipses by von Oppolzer (1887). This work gives the date (Julian or Gregorian), time of ecliptic conjunction of Moon and Sun, and other important details for almost all solar and lunar eclipses from 1208 B.C. to A.D. 2161. In computing the eclipse data Oppolzer used erroneous orbital elements for the Moon and Sun. However, as Knobel's requirements were simply the date and approximate visibility of the eclipses which he discussed, the Canon was quite suitable.

Occultations of bright stars and planets are too frequent to justify the production of a Canon similar to that of Oppolzer; Knobel consequently left undiscussed the three occultations and also the conjunction of Mars and Jupiter. However, the results of Knobel's eclipse examination are most satisfactory. Of the eleven solar eclipses he found that one observation was in error as no eclipse could have taken place. Of the remainder, the Japanese date is precise in nine cases. The other observation was recorded one day late. Both of the lunar eclipse dates prove to be correct.

The accuracy of the eclipse dates provides evidence that, for the seventh century, at least, the chronology of the Nihongi is very reliable. It is the purpose of this paper to examine the agreement between modern computations and the recorded circumstances of the three occultations. The records are summarized in Table 1.

TABLE I

Summary of Nihongi astronomical records

Date	Year of emperor	Type of observation
A.D. 640 March 6	Jomei—12th	Occultation of star
A.D. 642 August 10	Kōgyoku—1st	Occultation of guest-star
A.D. 681 November 3	Temmu—10th	Occultation of the planet Mars

2. *The occultations of Mars and the 'star'*. The accurate analysis of an occultation requires precise knowledge of the place of observation. In Japan, as in China, the astronomical centre was at the capital, although reports occasionally came from elsewhere. As already mentioned, there was no fixed Japanese capital during the seventh century A.D. The places of origin of the Nihongi records are thus unknown. The Yamato Plain, near Nara and Kyoto, is the most likely situation. In this paper, in order to have a fixed place for calculation, Nara ($34° 40'$ N, $9^h 3^m$ E) was selected. The distance between Nara and the true place of observation is probably small.

Computation of the lunar places was undertaken with the elements and principal inequalities listed in the tables of Brown (1919). The empirical corrections obtained by Spencer-Jones in 1939 were employed. It is probable that these corrections only approximately describe the lunar motions at this distant epoch, but errors should not be sufficiently large to alter any fundamental conclusions.

Occultations of bright stars and planets by the Moon occur quite frequently, as seen from any one part of the globe. However, as these phenomena are not very spectacular, it is probably not surprising to find only three such observations. The Japanese descriptions of the occultations of Mars and the star are as follows:

1. 'Twelfth year of Emperor Jomei, spring, second month, seventh day. A star entered the Moon.' Knobel reduces this date to A.D. 640 March 6.

2. 'Tenth year of Emperor Temmu, ninth month, seventeenth day. The planet Mars entered the Moon.' The date is equivalent to A.D. 681 November 3.

Analysis of each observation requires a different method of approach; the statements are of widely different character.

The most promising occultation observation seems to be that of Mars, because the planet is identified. Using the historical date as a guide, a preliminary location of the approximate time of conjunction in longitude of the Moon and Mars was made. The lunar topocentric latitude and longitude, as well as semi-diameter and altitude, were computed at two-hour intervals near this time. The results are given in Table II.

Tuckerman (1964) gives the longitude of Mars at 16^h U.T. on November 3 ($1^h 03^m$ on November 4 at Nara) as $71°{\cdot}30$ with an hourly variation of $+0°{\cdot}01$. The corresponding latitude was $+1°{\cdot}28$; this may be regarded as constant. The closest approach of Mars to the centre of the Moon was accordingly $0°{\cdot}34$ at $2^h 10^m$. As seen from Nara, the planet passed within $0°{\cdot}06$ of the Moon's northern limb at $2^h 10^m$ on November 4. Further calculation shows that Mars must have been very

TABLE II

Lunar co-ordinates (degrees) at Nara, near conjunction of Moon with Mars on A.D. 681 November 4

Local time	Long.	Lat.	S.D.	Alt.
0^h	70°·43	+0°·73	0°·28	67°
2	71°·27	+0°·93	0°·28	77
4	72°·12	+1°·04	0°·28	57

bright (magnitude −1·1) on this day. However, as the Moon was also brilliant (only two days after full), the record is probably satisfied. Only a very large correction to the lunar mean longitude would ensure actual contact.

The calculated date of the close approach of Mars to the Moon (November 4) disagrees with the stated date (November 3). Whether the discord of about two hours can be classified as a calendar error or as a timing error is difficult to judge; two hours is a large error for a clepsydra, the usual instrument for measuring time. However, as times are seldom given in the Nihongi for any of the phenomena, it seems quite possible that times were not normally noted by the Japanese astronomers. If this inference is true, some degree of confusion in the dates of night observations is to be expected.

At first sight the description of the ' star ' occultation in A.D. 640 appears most uncertain; the star is not named and its position is not described. However, as there is only a solitary record and occultations of stars are of frequent occurrence, it is reasonable to suppose that the star was very bright. In the ecliptic zone there are only five stars brighter than magnitude +2·5. These are Aldebaran (magnitude +1·1), Regulus (+1·4), Spica (+1·2), Antares (+1·3) and σ Sag. (+2·1). These stars are widely spaced along the Zodiac; even if the Japanese date is a day in error, the correct star may be specified.

In order to identify the star which was stated to be occulted on March 6, the procedure adopted was to calculate the longitude and latitude of the Moon with low precision near that day. This enabled Aldebaran (α Tau) to be identified. As the lunar latitude varies slowly, it was evident that no other star brighter than magnitude +4 could have been occulted near March 6. However, the longitude of the Moon on March 6 was about 20 degrees greater than that of Aldebaran; it is necessary to assume that the star entered the Moon on A.D. 640 March 4.

Allowing for precession, etc. and proper motion, the longitude and latitude of Aldebaran on March 4 were found to be 50°·83 and −5°·57 respectively. Variations of these co-ordinates are negligible. The lunar topocentric co-ordinates for Nara near the time of conjunction in longitude are to be found in Table III.

According to the details in Table III, Aldebaran passed about 0°·08 below the Moon's centre very close to 9 p.m. at Nara on March 4. The occultation began at

TABLE III

Lunar co-ordinates (degrees) at Nara, near conjunction of Moon with Aldebaran on A.D. 640 March 4.

Local time	Long.	Lat.	S.D.	Alt.
18^h	49°·73	−5°·48	0°·25	57°
20	50°·45	−5°·47	0°·25	35
22	51°·31	−5°·52	0°·25	12

about 8·25 p.m. and ended rather over an hour later. The Moon was then a crescent, five days after new. Apart from the date, the Japanese report is thus fully confirmed. As well as the familiar discrepancy of a few hours for night observations, the recorded date must be one day in error.

3. *Occultation of the 'guest-star'*. The remaining observation in the list in Table I is the occultation of the so-called 'guest-star' which is stated to have occurred on August 10 in A.D. 642. The Japanese description of this event is as follows:

'First year of Emperor Kōgyoku, autumn, seventh month, ninth day. A guest-star entered the Moon'.

In Chinese and Japanese literature the term 'guest-star' means a star which has newly appeared in the sky. A nova or, rarely, a supernova, is the usual interpretation. If a comet is small and without a tail it may be recorded as a guest-star, but if any motion is specified or even suggested, the interpretation is obvious. The sighting of this particular star is mentioned in the Dainihonshi (a Japanese history written in 1715), and is one of the records collected by Ho Peng Yoke (1962). The Dainihonshi states that a guest-star was seen on A.D. 642 August 9, but gives no further details.

Although the true nature of the object cannot be decided with certainty, the Nihongi description has the attraction that the modern position of the star, if 'fixed', can be determined within close limits. Of the many novae and supernovae seen in ancient times, only a small number can be identified because of an inadequate description of location. A notable exception is discussed by B. R. Goldstein in the *Astronomical Journal* for 1965 and by several other contributors to that volume.

In the calculation of the present position of the guest-star of A.D. 642 it is assumed that the date recorded in the Nihongi is correct. As has been shown, this assumption is true for five of the seven observations already discussed. The recorded date of the occultation is confirmed to a certain extent by the entry in the Dainihonshi, but this only mentions the sighting of the star itself. In order to allow for the uncertainty in the date of a night observation it will here be supposed that the occultation took place at some time during the hours of darkness between sunset on August 9 and sunrise on August 11, A.D. 642. This period of about 36 h is much reduced when the visibility of the Moon is considered. Unless the star was unusually bright, the occultation would most likely begin when the moon was more than about 5 degrees above the horizon. For a dark sky a depression of the Sun of about 8 or 9 degrees below the horizon (about the middle of nautical twilight) is probably necessary. These limits are, of course, quite arbitrary, but they provide useful criteria.

Sunset at this time of the year occurred at about $18^h\ 50^m$. The required degree of darkness would therefore be reached at about $19^h\ 30^m$. A rough calculation based on the elongation of the moon from the Sun (105 degrees on the evening of August 10) indicates that the Moon set shortly before midnight on the two nights. Calculations of the topocentric lunar longitude and latitude for Nara together with semi-diameter and altitude were made at two-hourly intervals from 6 p.m. to midnight on August 9 and August 10. These details fully cover the period of 36 h already referred to. The results are given in Table IV.

By interpolation, the Moon was at least 5 degrees high in a dark sky from 7.30 p.m. to 10.50 p.m. on August 9 and from 7.30 p.m. to 11.30 p.m. on August 10. Times are expressed to the nearest 10 min.

TABLE IV

Lunar co-ordinates (degrees) at Nara on the evenings of A.D. 642 *August* 9 *and August* 10

Date	Time	Long.	Lat.	S.D.	Alt.
August 9	18ʰ	229°·69	+3°·30	0°·27	+40°·5
August 9	20	230°·44	+3°·16	0°·27	+31°·9
August 9	22	231°·29	+3°·09	0°·27	+13°·7
August 9	24	232°·29	+3°·10	0°·26	− 8°·6
August 10	18	243°·60	+2°·38	0°·27	+35°·3
August 10	20	244°·36	+2°·22	0°·27	+33°·3
August 10	22	245°·17	+2°·15	0°·27	+19°·4
August 10	24	246°·13	+2°·14	0°·27	− 0°·7

In order to find the modern (1968.0) place of the star, the interpolated lunar co-ordinates from 7.30 p.m. to 10.50 p.m. on the first night and from 7.30 p.m. to 11.30 p.m. on the second night were corrected for precession, etc. These current places are shown diagrammatically in the figures. The shaded regions are zones of uncertainty, bounded by the limb of the Moon.

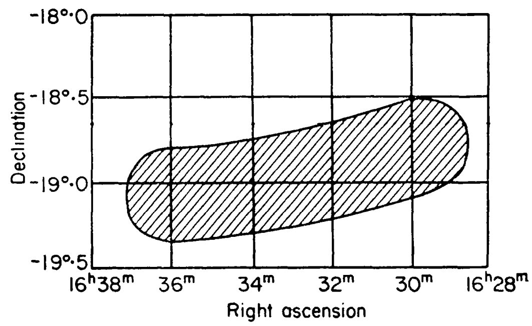

FIG. 1. *Current position of 'guest-star' if occulted on A.D.* 642 *August* 9.

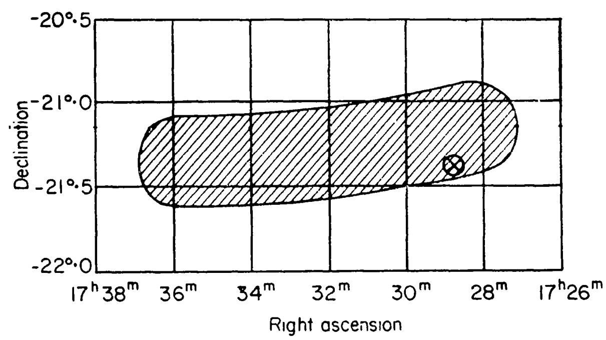

FIG. 2. *Current position of 'guest-star' if occulted on A.D.* 642 *August* 10.

Assuming that the guest-star has zero proper motion, its present (1968.0) place should be within, or very close to, one of the shaded areas in the two diagrams—Fig. 2 if the Japanese date is correct, Fig. 1 if it is a day in error resulting from a timing discrepancy. It is unlikely that the star will be far from these positions unless there is a definite calendar error; the occultations of Aldebaran and Mars were quite well observed.

Instances in which a new object is recorded clearly as a nova in China and as a comet in Japan, or vice-versa, are very rare. It seems much more probable that the

A.D. 642 guest-star was a nova rather than a comet since no tail or change of position is mentioned.

No details concerning the brightness of the new star of A.D. 642 are given in the Dainihonshi or Nihongi and the star was apparently not seen in China. However, on account of its low declination (about -19° on both nights) the star must have been rather bright for it was discovered when quite close to the half Moon. Comparison with the other two occultations supports this conclusion. The occultation of Mars occurred when the planet was very bright (about magnitude -1) and in a large northern declination ($+23^\circ$). That of Aldebaran was also well placed for observation at Nara (magnitude $+1$ and declination $+13^\circ$). As observations of this type are rare, it is probable that the guest-star was of similar brightness to these objects, especially in view of its much inferior visibility. A magnitude somewhat brighter than zero seems necessary. After the occultation the gradual advance of the Sun would mean that the star would never be prominent in the evening sky.

The only known radio source close to the path of the Moon near the recorded date of A.D. 642 August 10, is the powerful source 3C 358; this is in a direction close to that of the galactic centre (Shakeshaft *et al.* 1955). Its position, approximately $\alpha = 17^h\,26^m\,24^s$, $\delta = -21^\circ\,22'$ at 1950.0, agrees well with that of a small patch of nebulosity in Ophiuchi, if a permissible positive lobe shift in right ascension is applied. The next nearest radio source is more than $1^\circ\!\cdot\!5$ from the nebula, while others are much more remote. The co-ordinates of the centre of the nebula were $\alpha = 17^h\,26^m\,42^s\!\cdot\!8$, $\delta = -21^\circ\,25'\,54''$ at 1935.0; the diameter is probably about 100 seconds of arc (Baade 1943). The 1968.0 place of this object, roughly $\alpha = 17^h\,28^m\!\cdot\!7$, $\delta = -21^\circ\,24'$, is shown in Fig. 2, coinciding with the centre of the small cross.

From the viewpoint of Nara on the evening of A.D. 642 August 10, the nebula in Ophiuchi would enter the Moon at about 7.20 p.m. and emerge about 40 min later. For the remainder of the evening, until the Moon set at about midnight, the nebula would be to the west of the bright lunar limb. As civil twilight ended at about 7.20 p.m. the whole occultation would occur in a rapidly darkening sky. The shaded area in Fig. 2 occupies only about two square degrees; it seems possible that the guest-star of A.D. 642 and the nebula and, consequently, the radio source 2C 1485 are related. No other radio source passed close to the Moon near the recorded date of August 10.

The nebula in Ophiuchi was shown by Baade (1943) to be the remnants of the supernova seen by Kepler and many other astronomers in early October, A.D. 1604 In spite of its bad position, the supernova, which reached a maximum magnitude of about -2, was readily observed by the seventeenth century astronomers; the new star appeared very near to both Mars and Jupiter, which were then in conjunction. The co-ordinates of this supernova, deduced from the observations of Kepler and others ($\alpha = 17^h\,26^m\,44^s\!\cdot\!9$, $\delta = -21^\circ\,25'\,55''$, when reduced to 1935.0) agree remarkably well with those of the nebula. The very close correspondence between the position of this star and that of the new star of A.D. 642 August 10 is striking. It is suggested that perhaps the guest-star represented an outburst preceding the main explosion nearly a millenium later.

Department of Geophysics and Planetary Physics,
School of Physics,
University of Newcastle upon Tyne.
1968 *March.*

References

Baade, W., 1943. *Astrophys. J.*, **80,** 119.
Brown, E. W., 1919. *Tables of the Motion of the Moon*, New Haven.
Goldstein, B. R., 1965. *Astr. J.*, **70,** 105.
Ho Peng Yoke, 1962. Ancient and mediaeval observations of comets and novae in Chinese sources, *Vistas in Astronomy*, Vol. 5, Pergamon Press, Oxford.
Knobel, E. B., 1905. *Mon. Not. R. astr. Soc.*, **66,** 67.
Oppolzer, T. R. von., 1887. *Canon der Finsternisse,* Wien. Reprinted as *Canon of Eclipses,* Dover, New York (1962).
Spencer-Jones, H., 1939. *Mon. Not. R. astr. Soc.*, **99,** 541.
Shakeshaft, J. R., Ryle, M., Baldwin, J. E., Elsmore, B. & Thomson, J. H., 1955. *Mem. R. astr. Soc.*, **67,** 106.
Tuckerman, B., 1964. Planetary, lunar and solar positions, A.D. 2 to A.D. 1649, *Mem. Am. phil. Soc.*, **59.**

Additional note. Since my writing of this paper, Dr J. Needham, F.R.S. of Cambridge University has kindly brought to my notice a review of the Nihongi astronomical records by S. Kanda in 1935.

In his book, *Japanese Historical Astronomical Observations*, Tokyo (1935) (in Japanese), Kanda collected observations of eclipses, occultations, etc. recorded in Japan between about A.D. 600 and 1600. For each event he gives the record and date, converted to the Julian Calendar, with several corrections to Knobel's reductions of the Nihongi dates.

Kanda classified the A.D. 642 guest-star in his list of comets, but without justification. His dates for the three occultations are as follows:

Mars	A.D. 681 November 3 (as given by Knobel).
Star	A.D. 640 March 4 (in place of March 6).
Guest-star	A.D. 642 August 9 (in place of August 10).

For the occultation of the star, identified in this paper as Aldebaran, the historical date deduced by Kanda and the astronomical date are in agreement; in the case of Mars there is still a discrepancy of a day. If identity of the guest-star with the new star seen by Kepler is assumed, an error of one day in the historical date must be supposed. Such a discrepancy is quite possible but it follows that this identity cannot be proved. However, the close agreement in the positions of these two objects is extremely striking and is accordingly worthy of attention.

1968 *May* 24.