Interpretation of the historic Yemeni reports of supernova SN 1006: early discovery in mid-April 1006?

R. Neuhäuser1 *, D.L. Neuhäuser2, W. Rada3, J. Chapman4, D. Luge1, and P. Kunitzsch5

1 Astrophysikalisches Institut und Universitäts-Sternwarte, Friedrich-Schiller Universität Jena, Schillergäßchen 2-3, 07745 Jena, Germany (e-mail: me@astro.uni-jena.de)
2 Schillbachstrasse 42, 07743 Jena, Germany
3 Hilla University College, Babylon P.O.B. (386), Iraq (deceased August 2015)
4 Center for East Asian Studies, Stanford University, 521 Memorial Way, Stanford, CA 94305-5001, United States
5 LMU Munich, Germany (retired); home: Davidstrasse 17, 81927 München, Germany

Received 2015, accepted 2016
Published online

Key words supernova - SN 1006

The recently published Yemeni observing report about SN 1006 from al-Yamānī clearly gives AD 1006 Apr 17 ± 2 (mid-Rajab 396h) as first observation date. Since this is ~ 1.5 weeks earlier than the otherwise earliest reports (Apr 28 or 30) as discussed so far, we were motivated to investigate an early sighting in more depth. We searched for additional evidences from other areas like East Asia and Europe. We found that the date given by al-Yamānī is fully consistent with other evidence, including: (a) SN 1006 rose several times half an hour after sunset (al-Yamānī), which is correct for the location of Shanā in Yemen for the time around Apr 17, but it would not be correct for late Apr or early May; (b) the date (3rd year, 3rd lunar month, 28th day wuzī, Ichidai Yoki) for an observation of a guest star in Japan is inconsistent (there is no day wuzī in that lunar month), but may be dated to Apr 16 by reading wu'ūd date rather than a wuzī date; (c) there is observational evidence that SN 1006 was observed in East Asia early or mid April; for the second half of April, a bad weather (early monsoon) period is not unlikely – there is a lack of night reports; (d) the observer in St. Gallen reported to have seen SN 1006 for three months, which must have ended at the very latest on AD 1006 Jul 10, given his northern location, so that his observations probably started in April. We conclude that the correctly reported details give quite high confidence in the fully self-consistent report of al-Yamānī, so that the early discovery date should be considered seriously.

1 Introduction: SN 1006

Historic observations of supernovae (SN) are essential to understand SNe, neutron stars, and SN remnants (SNR): Historic reports can in principle deliver the date of the explosion (hence, the age of the SNR and, if existing, the neutron star) together with a light curve (hence, possibly the SN type), sometimes the colour and its evolution, and the position of the SN, which is needed to identify the SNR and, if existing, the neutron star. Such historic observations have been used very successfully for SNe 1006 (from East Asia, Europe, and Arabia), 1054 (from East Asia and Arabia), 1181 (only from East Asia), and SNe 1572 and 1604 (from East Asia and Europe), plus a few more SNe from the 1st millenium AD (see Stephenson & Green 2002, henceforth SG02, and references therein). While the Arabic report of SN 1054 merely confirms a bright new star in Gemini/Taurus around AD 1054, the reports of SN 1006 present a lot of detailed information (Goldstein 1965), which were used to identify the SNR (Gardner & Milne 1965).

The transient celestial object of AD 1006 was listed as comet in Pingre (1783). Humboldt (1851) lists it as new star, based on the St. Gallen chronicle, dated incorrectly to AD 1012, and placed incorrectly in Aries. Schönfeld (1891) corrects the date to AD 1006 (consistent date shift in St. Gallen chronicle) and the location to Scorpius (previous misreading of the Syriac `aqrabā for Scorpius as `emrā for Aries in Bar Hebraeus); he already used the chronicle of Bar Hebraeus and its source, namely the annals of Ibn al-Athīr.

Convincing evidence for SN 1006 was presented first by Goldstein (1965) based on the Arabic reports; Ālī ibn Riddān (lived from AD 988 or 998 until 1061 in Cairo, Egypt; indeed, it was considered seriously before that he observed SN 1006 at an age of only eight years, the calculations could have been done later) reported the ecliptic longitude (15th degree of Scorpius), strong scintillation (it twinkled very much ... large ... round in shape), the size and/or brightness (2.5 or 3 times as large as Venus ... the intensity of its light was a little more than the quarter of that of moonlight), the duration of the observations (some four months until conjunction with the Sun), that it did not move relative to the stars (It remained where it was and it moved daily with its zodiacal sign) and that he observed it

1 In the report by Lynn (1891), an English summary of the paper by Schönfeld (1891), which was written in German, it is said that Schönfeld (1891) would have corrected the date from AD 1006 to 1012, but the opposite is true.
as an eyewitness during the beginning of my studies ... all I have mentioned is my own personal experience: he listed the (calculated) positions of the planets as well as those of the Sun, the Moon, and its ascending node, from which Goldstein (1965) deduced the date of his observations to be the evening of AD 1006 Apr 30, the earliest certain observation accepted in SG02. Ali ibn Ridwān also mentioned that Sun and Moon met in the 15th degree of Taurus when the transient object first appeared; only from that statement we can conclude that it appeared close to the conjunction of moon and sun (new moon on AD 1006 Apr 30 at 9:08h UT), so that SN 1006 was probably sighted (by him) on the evening of Apr 30.

Goldstein (1965) presented another Arabic report of SN 1006 from Ibn al-Jawzī (a historian, who lived AD 1116-1201 in Baghdad, Iraq) and, based on Ibn al-Jawzī, also by Ibn al-Athīr (a historian, who was born AD 1160 in Jazirat Ibn Umar, now Cizre in Turkey, and who died in 1233 in Mosul, Iraq), both about a very bright new star – as well as a report from Morocco[2] mentioning a great star [najm] among the comets and a nayzak (spectacle or guest star or transient celestial object, see Kunitzsch 1995). While the reports of Ibn al-Jawzī (and Ibn al-Athīr) give the date of first appearance as Friday, the 1st day of the Muslim month of Sha‘bān of the Muslim year 396h (and visibility until Dhū al-Qa‘dah, i.e. roughly three months), the Moroccan report mentions that it began to appear in the beginning (i.e. 1st) of Sha‘bān and that it lasted for a period of six months (Goldstein 1965), i.e. from early May 1006 (Sha‘bān 396h) until October; however, SN 1006 was in conjunction with the Sun in October, so that they could have observed it until at most the heliacal setting in the middle of September; it is more likely that this period of six months were meant as rough statement (like about half a year) than that they observed heliacal rising in November.

The Islamic date of 1 Sha‘bān 396h corresponds to AD 1006 May 2/3, evening to evening (e.g. Goldstein 1965), but only in the calculated Islamic calendar, while the real start of a month was fixed by observations (not by a calculated calendar); Muslim dates run from one evening to the next evening, a month starts with the evening of the first sighting of the crescent of a new moon. It was confirmed in Rada & Neuhäuser (2015) that the conversion of 1 Sha‘bān 396h to AD 1006 May 2/3 is correct when considering the first observation of the crescent (and also regarding the given week-day). In general, unless more information is available, the conversion from the calculated Islamic calendar to the Julian or Gregorian calendar has an uncertainty of some 2 days due to (a) uncertainty in the start of the Hijra era (one day), (b) uncertainty as to which months and years in history had one extra day (in addition to 354 days in 12 lunar months – given that a synodic month is not exactly 29.5 days), and (c) uncertainty as to when the new crescent moon was sighted first (e.g. Spuler & Mayr 1961, Spuler 1963, Neuhäuser & Kunitzsch 2014). Goldstein (1965) also gives the Arabic texts for the four Arabic reports presented.

Goldstein (1965) also gives an English translation of a Syriac report of SN 1006 by Bar Hebreaus (born AD 1226 in Malata in Turkey, died 1286 in Maragha, now Iran), where it was specified that the new star was observed in the zodiacal sign of Scorpius. Cook (1999) presented another Arabic report of SN 1006 from Yahyā ibn Sa‘īd al-Anṭākī, Patriarch of Antioch (now Antakya, Turkey), who extended the chronicle of Eutychius of Alexandria (Egypt) for the time since circa AD 939 and died in AD 1066, according to which the new star was seen for four months since Saturday, 2nd day in Sha‘bān of the year 396h (AD 1006 May 3/4). Most recently, Neuhäuser, Ehrig-Eggett, and Kunitzsch (2016) presented another original report about SN 1006, namely written by Ibn Sinā (Avicenna).

From the ecliptic longitude of the SN as given by Ali ibn Ridwān (and an error bar from Ali ibn Ridwān’s assumed measurement precision) together with the declination limit from a St. Gallen observation of this SN (Goldstein 1965) and the Chinese right ascension range (from the Chinese lunar lodge), it was then possible to constrain the location of the SN and to identify the SNR (Gardner & Milne 1965).

SN 1006 is believed to have taken place on AD 1006 Apr 30 or earlier (see Rada & Neuhäuser 2015) in the constellation of Lupus with the following basic parameters:

- distance being 2.18 ± 0.08 kpc from the proper motion of ejecta in mas/yr and the shock velocity of filaments in km/s (Winkler et al. 2003)[3]
- extinction being A_V = 0.32 ± 0.03 mag (Schaefer 1996 from various techniques) or A_V = 0.31 ± 0.10 mag (Winkler et al. 2003) from the reddening of the very blue sub-dwarf (Schweizer & Middleditch 1980) showing strong, broad absorption lines due to the SNR, so that

[2] By the author Abū ʿI-Ḥasan ʿAbd allāh b. Abī Zarʿ al-Fāṣī (short: Ibn Abī Zarʿ, died in or after AD 1326) in the book entitled Al-ʾAntīs al-maṭrid bi-rauḍat al-qirṭās fi akhbār maṭrid al-maghrīb wa-tāṭkh mādhnat Fāṣī, the mentioned town of Fāṣī is now called Fez in Morocco, an edition of the work appeared in 1972 in Rabat, Morocco.

[3] The Islamic year 396 hijra (396h) started 396 lunar years after the Islamic year 1 hijra (1h). The Islamic date of 1 Sha‘bān 396h corresponds to AD 1006 May 2/3, evening to evening (e.g. Goldstein 1965), but only in the calculated Islamic calendar, while the real start of a month was fixed by observations (not by a calculated calendar); Muslim dates run from one evening to the next evening, a month starts with the evening of the first sighting of the crescent of a new moon. It was confirmed in Rada & Neuhäuser (2015) that the conversion of 1 Sha‘bān 396h to AD 1006 May 2/3 is correct when considering the first observation of the crescent (and also regarding the given week-day). In general, unless more information is available, the conversion from the calculated Islamic calendar to the Julian or Gregorian calendar has an uncertainty of some 2 days due to (a) uncertainty in the start of the Hijra era (one day), (b) uncertainty as to which months and years in history had one extra day (in addition to 354 days in 12 lunar months – given that a synodic month is not exactly 29.5 days), and (c) uncertainty as to when the new crescent moon was sighted first (e.g. Spuler & Mayr 1961, Spuler 1963, Neuhäuser & Kunitzsch 2014). Goldstein (1965) also gives the Arabic texts for the four Arabic reports presented.

[4] The distance determination by Jiang & Zhao (2007), ~ 1.56 kpc, is highly uncertain: it was obtained by interpreting a presumable observation of SN 1006 in AD 1016 as an effect of re-brightening of parts of the SNR, while SG02 argued that this late observation date is a mistake in a historical document.
it is located in the background at 1.05-2.1 kpc (Burleigh et al. 2000) to 1.5-3.3 kpc (Schweitzer & Middelitch 1980),

– peak apparent brightness being \(-7.5 \pm 0.4\) mag from distance for a SN type Ia (Winkler et al. 2003), and

– the apparently young SNR G327.6+14.6 was identified as its remnant (Gardner & Milne 1965, Reynolds et al. 1994).

While Damon et al. (1995) and Firestone (2014) claim that a $^{14}$C signal from SN 1006 was observed (in AD 1009), Menjo et al. (2005) argued that the $^{14}$C amplitude around AD 1009 may be consistent with typical Schwabe cycle modulation. (A $^{14}$C detection three years after the SN might be possible due to the carbon cycle, which takes a few years.)

2 Arabic text(s) of SN 1006 from Yemen

Most recently, Rada & Neuhäuser (2015) presented two more Arabic reports of SN 1006 in both Arabic and English translation, namely by the Yemeni historians al-Yamānī and Ibn al-Dayba\(^c\). An English translation of the latter text was first presented in SG02 quoting private communication with one of us (WR). In Rada & Neuhäuser (2015), the dating of the observations is discussed in detail.

The date given by both al-Yamānī and Ibn al-Dayba\(^c\), mid-Rajab meaning 15th of Rajab, converts in the calculated Islamic calendar to AD 1006 Apr 17 \(\pm 2\). The dating uncertainty arises only from the uncertainties in the conversion from the Islamic to the Julian calendar and the observation of the crescent new moon. The additional information from al-Yamānī, that the new star was rising half an hour after sunset, is best fulfilled on Apr 17. While the full moon rose before SN 1006 on Apr 16, which could have made an observation of SN 1006 more difficult, the moon rose after SN 1006 since Apr 17, as seen from Yemen. See Table 1 in Sect. 3.3. On the other hand, the Islamic observer in Yemen probably observed on Apr 16 (full moon was on Apr 16 at 9:35h UT) in the evening in order to check whether it is full moon; until the 14th of the lunar month, the date is specified in historic Arabic texts by giving the number of days since the last crescent new moon, then the 15th of the month is specified as mid of the month, and then, since the 16th of the month, the date is specified by giving the number of days or nights expected until the next crescent new moon, assuming that the month has 30 days (de Blois 2000). The middle day of a month must not necessarily be the full moon day, because the Arabic lunar month does not start with new moon, but with the first observation of the crescent; however, if this particular month lasted 30 days (for the observer in Yemen), the date of mid-Rajab would correspond to Apr 16 evening to Apr 17 evening. SN 1006 was probably already observable on Apr 16 given its separation from the moon – of course depending on its brightness that evening.

While the other Arabic and East Asian observations all were obtained between the geographic latitudes of 30\(^\circ\) and 35\(^\circ\) north, we discuss here in detail this additional observation from Šan‘ā’, the capital of Yemen, i.e. at 15.3\(^\circ\) north. We repeat briefly the English translations of the Arabic texts (Sect. 2). In Sect. 3, we discuss in detail the evidence for an early discovery in mid (or even early) April. We conclude our findings in Sect. 4.

If the early observation of SN 1006 in mid-April in Yemen can be shown to be plausible, this could have important consequences for the light curve and SN type.

The first (earlier) text is from the book entitled Bahjat al-zaman fi tārikh al-Yaman written by al-Yamānī (died AD 1342, more details about him in Rada & Neuhäuser 2015); the edition of al-Hubaisi & al-Sanabāni (1988) was used. The Arabic text is shown in figure 1 in Rada & Neuhäuser (2015).

We repeat the English translation here (with an unlikely text variant given in square brackets):

In the night of mid-Rajab (or: 15th of Rajab),

in the year 396h, a star appeared from the east at half an hour after sunset. It was four times as large as Venus. [It was as large as Venus and rose several times after sunset.] It was not circular, but nearer to an oblong. At its ends, there were lines like fingers. It showed a great turbulence as though it was seen in disturbed water. Its light rays were similar to sunlight. It appeared in the zodiacal sign [burj] of Libra in Scorpius and remained unchanged like that. In the night of mid-Ramadān, its light started to decrease and gradually faded away.

The 2nd (later) text is from the book entitled Kitāb Qurrat al-‘ayyān fi akhbār al-Yaman al-ma‘āmīn about the history of Yemen, written by Ibn al-Dayba\(^c\) (AD 1461 - 1537, more details about him in Rada & Neuhäuser 2015). Rada & Neuhäuser (2015) used manuscript number 416 from the Wadod Center for indexing and edited books; this manuscript is a copy written in AD 1680; see figures 2 & 3 in Rada & Neuhäuser (2015) for the Arabic text. There is also an edition of Ibn al-Dayba\(^c\)’s work Qurrat al-‘ayyān by al-Akwa’a’ al-Hiwal as publication of the Hiwali Yamani Library (Ṣan‘ā’, Yemen).

The text by Ibn al-Dayba\(^c\) (first presented in SG02) is clearly derived from al-Yamānī as already shown in Rada & Neuhäuser (2015). It does not add any additional information. In the following interpretation, we will consider mainly the al-Yamānī text.

The last sentence of al-Yamānī (In the night of mid-Ramadān, its light started to decrease and gradually faded away), and also even in Ibn al-Dayba\(^c\) (its light diminished and it gradually faded away), both for mid June, does not say that the brightness dropped suddenly – as was reported by ‘Ali ibn Ridwān: it ceased all of a sudden at a time between mid-Aug and mid-Sep 1006, when the Sun was in sextile with the new star\(^5\). It does not mean that the

\(^5\) In Rada & Neuhäuser (2015), July was given for the end of the observation by ‘Ali ibn Ridwān as mistake.
Yemeni observations were restricted to those two months from mid-April to mid-June, but rather that SN 1006 remained roughly constant until mid-June, and then started to get fainter.

3 Discussion of the early observation

It would be quite surprising if the observer, who is the original source for the reports of the Yemeni authors, really has observed and detected SN 1006 already several days before the other Arabic observers (e.g. Apr 30 by ʿAlī ibn Rīḍwān), and all East Asian observers, so that this early date was rejected by SG02 as artificial (based only on the text by Ibn al-Daybaʿ).

We would now like to discuss several arguments which can be interpreted in favour of an early observation, at least not excluding an early observation:

3.1 Yemen: half an hour after sunset

The text of al-Yamānī says:

In the night of mid-Rajab (or: 15th of Rajab), in the year 396h, a star appeared from the east at half an hour after sunset. It was four times as large as Venus.

The position of SN 1006 indeed did rise half an hour after sunset at the location of Ṣanʿāʾ in the middle of April 1006, while this statement would not be true at the end of April or early May. We cannot exclude that al-Yamānī (and Ibn al-Daybaʿ or their source) calculated much later that SN 1006 rose half an hour after sunset at the given night of mid-Rajab 396h (AD 1006 Apr 17), which may not be impossible (as ʿAlī ibn Rīḍwān had probably also calculated the positions of Sun, Moon, and planets as given in his report several decades after SN 1006, Goldstein 1965, SG02), but this would appear more doubtful. There are otherwise no obviously calculated facts in the report. The report by our most original and earliest Yemeni source, al-Yamānī, is self-consistent regarding the early date and rising time. We should therefore consider it seriously.

3.2 Southern location of Ṣanʿāʾ

Since Ṣanʿāʾ is at 2400 m sea level and since it has a clear horizon towards the south—an observation from here earlier than all other known observations may not appear impossible: going from such a large height to roughly sea level, where most of the other, later observers were located (e.g. Cairo, Japan, China) can change the atmospheric extinction for object low on the horizon by some 4 mag (Schaefer 1993); the limit for serendipitous discovery of a new star on the sky by naked-eye is some 0 to 2 mag according to Clark & Stephenson (1977) and Strom (1994).

This consideration does not exclude that other observers at low altitude (e.g. in China or Japan, see Sect. 3.4) would have observed SN 1006 in mid April, as they could have observed later in the night, when SN 1006 was higher above the horizon. The professional Chinese and Japanese astronomers have observed all night. The Yemeni observers, though, may have observed mainly around and shortly after sunset, close to the time of the last prayers.

3.3 Rising of SN 1006 before the Moon on Apr 17 only from Yemen

It is well possible that the Yemeni (and other Arabic) observers checked for the full moon on the evenings of Apr 15, 16, and 17 (full moon on Apr 16 at 9:35h UT), in order to know the date in their lunar month relative to the full moon.

While on AD 1006 Apr 16, the Moon was above the horizon earlier than the location of SN 1006 as seen from Yemen, the Moon rose half an hour after SN 1006 on Apr 17 and even later on Apr 18, so that an observation of SN 1006 may appear more probable on Apr 17 from Yemen. At the other relevant observing sites (Morocco, Iraq, Japan, and in particular also in Cairo, Egypt, and Kaifeng, China), the Moon was rising before SN 1006 even on Apr 17, e.g. 20 minutes before the SN 1006 as seen from Kaifeng, today’s name of the capital of China at that time.

This consideration does not exclude that other observers further north (e.g. in China or Japan) would have observed SN 1006 in mid April close to full moon, because the moon was sufficiently well separated from SN 1006, so that SN 1006 may have been observable – depending on its brightness. The Yemeni observers had a particular good reason (full moon) to observe in mid April.

3.4 Possible observation in Japan on Apr 16 or 28

In the medieval Japanese chronicle Ichidai Yoki, an independent and original source based on Abe Yoshinasa, teacher in astronomy, we can read:

[AD 1006 Apr 28:] ... in 3rd year, 3rd lunar month, 28th day wuzi [25], a guest star entered Qi, (Stephenson et al. 1977). The date given as 3rd year, 3rd lunar month, 28th day corresponds to AD 1006 Apr 28. East Asian reports often specify the date in addition with the day count in the sexagenary system of numbering days continuously from 1 to 60. However, as discussed in SG02, there is no day called wuzi (25) in the third lunar month of that year; the name and number of the day AD 1006 Apr 28 is gengwu (7); the relevant characters (wu and zi compared to geng and wu) are very similar, so that already Kanda (1935) suggested that this guest star was indeed observed on the 28th day of that lunar month, i.e. already on AD 1006 Apr 28 (and that, later on, a scribe made a mistake with the date

Note that the Chinese and Japanese started the day-count in each (lunar) month with what we call new moon, i.e. conjunction of moon and sun,
Table 1  Times of apparent rising of SN 1006, sunset, and moonrise for Şan‘ā‘, Yemen and Kaifeng, China (times given in UT). We also list the separation (sep) between SN 1006 and the moon for the dates given, as seen from Şan‘ā‘ (left) and Kaifeng (right) – always given for two hours after local moonrise, so that both the SN and the moon were visible. Bold face times indicate cases, where SN 1006 rose before the Moon (e.g. on Apr 17 in Şan‘ā‘, but not in Kaifeng.

| 1006     | SN rise | sunset | moonrise | sep SN/Moon | SN rise | sunset | moonrise | sep SN/Moon |
|----------|---------|--------|----------|-------------|---------|--------|----------|-------------|
| Apr      |         |        |          |             |         |        |          |             |
| 15       | 15:54   | 15:16  | 14:34    | 26.2°       | 12:34   | 10:57  | 10:05    | 27.6°       |
| 16       | 15:50   | 15:17  | 15:27    | 20.4°       | 12:30   | 10:57  | 11:05    | 20.7°       |
| 17       | 15:46   | 15:17  | 16:20    | 22°         | 12:26   | 10:58  | 12:06    | 20.8°       |
| 18       | 15:42   | 15:17  | 17:17    | 30.1°       | 12:22   | 12:59  | 13:07    | 23.3°       |
| 19       | 15:38   | 15:18  | 18:14    | 41.4°       | 12:18   | 12:59  | 14:07    | 38.9°       |
| 20       | 15:34   | 15:17  | 19:10    | 54.4°       | 12:14   | 11:00  | 15:07    | 51.9°       |

戊午 → 戊子

**Fig. 1** Chinese characters: If the Chinese characters have unintentionally changed due to a mistake made by a copying scribe from those shown in the left (wuwu, i.e. day 55) to those shown in the right (wuci), the original date of the observation could have been AD 1006 Apr 16.

number). However, as pointed out by SG02, two separate scribal errors need to be assumed. The 28th day of the lunar month (i.e. 1006 Apr) would definitely be a few days before the Chinese (2nd day of the fourth lunar month, i.e. May 2/3) and Arabic observations, the latter being at the beginning of Sha‘bân, i.e. beginning of May, and 1006 Apr 30 for ‘Ali ibn Ridwan.

It is very well possible that the latter character in the sexagenary date alone was mistranscribed. If Kanda (1935) is correct regarding his emendation of the second character in the sexagenary date (from zi to wu), but the first character (wu) is left to stand as it is in the received text, the date becomes a wuwu day (55). AD 1006 Apr. 16. Wu might easily be mistranscribed as zi, as both characters contain two horizontal and one vertical strokes; the two characters are differentiated by an initial curved stroke in wu and hooks at the end of the first and third stroke of zi. See Fig. 1.

The 16 Apr date is then not the 28th day of the lunar month, as also specified in the source. However, such dates often consist only of the year of the emperor, the number of the lunar month, and the date in the sexagenary system, leaving out the day within the lunar month (see, e.g., Sect. 3.5). It is possible that the original source did not contain such a lunar day, but that it was amended later, or that 16 was mistranscribed as 28. If we posit a wuwu day (Apr 16), then the Ichidai Yoki record corresponds very closely to that of the Yemeni observers. However, just as the sexagenary

as confirmed by the fact that all of the dates of solar eclipses from (at least) AD 700 to 1200 are dated to the first day of the month, see listing in Xu et al. (2000), while the Arabs started the lunar month day count with the first sighting of the crescent (Quran, Sura 2, 189).

date casts doubt on the Apr 28 date, the lunar date casts doubt on the possible Apr 16 date. The dating of the event in the Ichidai Yoki remains uncertain. There are two other reports from Japan on this SN: Meigetsuki (13th century) and Dainihonshi (completed AD 1715) both list a report for May 1, see e.g. SG02, but it is obvious that the latter depends on the former. The report discussed here from Ichidai Yoki is an independent medieval chronicle of unknown date.

According to SG02, the observation of SN 1006 within a few days at different places in Arabia (30 Apr to May 2 only) as well as in China and Japan (about May 1) may provide evidence against an earlier observation elsewhere. We have to see that there were 8 to 6 days from the earliest previously accepted first observation (28 Apr in Japan or 30 Apr in Cairo) to the latest reported first observation (May 6 in China: 3rd year, 4th lunar month, day wuyin [=AD 1006 May 6]. A Zhoubo star appeared ... from SG02 from Wenxiao Tongkao), which is quite a long time for such a bright SN, in particular also for an observation around the new moon.

A possibly relatively long time between the first observations in the different countries (it may have been even more days between the first detections in different countries) can also be seen as evidence for unstable weather at least in some of those places. E.g., Rada & Neuhäuser (2015) provided evidence for bad weather on AD 1006 May 1 in Antiochia, now Turkey, and maybe Mosul, Iraq: The reports from there mention explicitly Saturday, the 2nd of Sha‘bân and Friday, the 1st of Sha‘bân, respectively, so that both started the month of Sha‘bân on the evening of (our) Thursday, May 2, even though the crescent new moon would have been well visible at those sites on the evening of May 1. The non-detection of the crescent on May 1 may indicate bad weather.

3.5  Possible early observation on Apr 3 in the SE in China

Reports of an even earlier sighting run as follows:
(i) Wenxian Tongkao: Jingde reign period, third year, third lunar month (day) yist [42] (=AD 1006 Apr 3). A guest star [ke xing] appeared (chu) in the south-east direction,
(ii) Songshi Annals: Jingde reign period, third year, third...
lunar month (day) yisi [42] (=AD 1006 Apr 3). A guest star [ke xing] appeared at the south-east, and
(iii) Songshi Astronomical treatise: Jingde reign period, third year, third lunar month (day) yisi [42] (=AD 1006 Apr 3). A guest star [ke xing] appeared at the south-east, the complete citations from SG02 with their additions in round brackets and our additions in square brackets.

This guest star may have been another object, e.g., a comet (SG02). There are, however, also a few arguments in favour of a possible interpretation of this guest star as SN 1006:
(a) The guest star was seen in the south-east like SN 1006.
(b) The more general word for guest star [ke xing] was used and not a more specific word for broom star or tailed star [hui xing] or fuzzy star [xing bo], which would have indicated a comet.
(c) There are no additional Chinese or other records available on any additional comet or other object in or around early April.
(d) An important political meeting on April 17 is reported, which could have been a consequence of the very bright magnitude of the new star: On the jiwel day (Apr 17), admonitory ministers were summoned to court and asked to speak openly about what should and should not be done (Song shi 7.130), but the reason for the meeting is not specified.

That the information from China about this SN is sparse, in particular for April and May, may be due to the difficult interpretation at that time: A solar eclipse was expected for 1006 May 30, which would have to be interpreted in a more negative sense for the emperor; the new star became a Zhoubo star, for which the historic Chinese texts offered both positive or negative interpretations (SG02). Once it became obvious that the solar eclipse did not take place at the capital, it was not necessary any more to consider a negative interpretation (for both eclipse and the new star), so that one could opt for the positive interpretation of the new Zhoubo star, which of course met the approval of the emperor. This is fully consistent with the Chinese texts dated to May 30, see SG02, and it could possibly explain why Chinese sources are unusually quiet about the bright new star in its first few weeks.

3.6 No other East Asian observations Apr 17-28/30 (and Apr 4-15)
If the Japanese have observed SN 1006 on Apr 16 (and maybe the Chinese already on Apr 3), then again later since May 1, it would be surprising that there are no reports left from the professional astronomers in China and Japan about any observations inbetween, i.e. from Apr 17 to the end of April (or even Apr 4 to 15).
Are there any East Asian observations known for the intermediate periods from Apr 17 to the end of April (or even from Apr 4 to 15)? Are there any East Asia night reports before 1006 Apr 16, where no guest star is men-
tioned? There is only one Chinese observation known for April 1006, namely for AD 1006 Apr 14 reporting:
Empress Zhenzong of Song, 3rd year of the Jingde reign period, 3rd month, day bingchen (53).
In the north a scarlet vapour extending across the sky (and a white vapour penetrated the Moon),
citing from Xu et al. (2000), a slightly different translation in Keimatsu (1975), both from Songshi 60.1308, without the text in brackets also in Yau et al. (1995). This is a probable aurora according to the criteria given in Neuhausen & Neuhauser (2015), namely northern directions, auroratypical colour, and night-time (implicitly given with the moon).

What is reported as a white vapour penetrating the Moon may well be some halo effect around the Moon, which is well possible two days before full moon; for a discussion of the aurora sighting around full moon, see Chapman et al. (2015).

There are indeed no additional East Asian observations known for the remaining time of AD 1006 Apr 17 until the end of April.
There is evidence for the fact that relevant Chinese documents are missing:
... on the 2nd day of the 4th lunar month the Zhoubo star was seen. The official astronomer reported it immediately. The [Song] Shilu [for] the Xi-angfu reign period, 9th year, 4th lunar month, [day] gengchen should be consulted for further details, quoting SG02 from Xu Zizhi Tongjian Changbian – however, the mentioned Song Shilu is lost (SG02).

Furthermore, there is also evidence that Zhou Keming, a prominent astronomer in China, was on a mission in April

8 In the list of candidate aurorae in Hayakawa et al. (2015), this event is listed twice, once with 1006 Apr 14 [red] V[apour] n[orth] [in] Kaifeng [moon phase] 0.46 (near full moon) and once with 1006 Apr 14 W[hite] V[apour] near the moon [in] Kaifeng [moon phase] 0.46 (near full moon); one of the two texts is from the astronomical treatise (Tianwen zhi) to the Songshi, the other from its treatise on general omenology (Waxing zhi). In the same list of candidate aurorae in Hayakawa et al. (2015), there is an additional entry: 1006 May [without day] Y[ellow] V[apour] near the moon [in] Kaifeng, also from Songshi; the translation of this entry is: On this date yellow vapour like a pillar penetrated the moon. The date for this event is uncertain; however, it is as given as the guimao (40) day in the fourth month, when in fact there was no guimao day in the fourth month; a guimao day did occur at the beginning of the fifth month (1006 May 31) and at the beginning of the third month (1006 Apr 1) – both, however, so close to new moon that the text (penetrated the moon) does not fit to the given sexagenary date. There is another instance of the same phrase (Yellow vapour like a pillar penetrated the moon) dated to the 4th month of the 3rd year of the Tianxi reign period (AD 1019) given without the guimao date, though there is a guimao date in that month; it is possible that the event somehow got transposed to the wrong reign period; Hayakawa et al. (2015) list Y[ellow] V[apour] for 1019 May 8, but by mistake omitted here near the moon, which is clearly given in the original Chinese; they give 0.04 as moon phase (new moon May 7), so that again the text (near the moon) is not consistent with the moon phase for this date; though the entry does not actually specify which day within the lunar month the event occurred on, the guimao day (40) in that lunar month was AD 1019 May 23, i.e. close to full moon (May 21/22), when a lunar halo display would be possible. In any case, this event is not an aurora, but more likely a lunar halo pillar.
1006, so that he may not have been able to consult documents (for the interpretation) on SN 1006 early. In the Biography of Zhou Keming (AD 954-1017), we can read:

During the 3rd year of the Jingde reign period, a large star appeared in the sky at the west of Di. No one could determine (its significance) ... At the time, (Zhou) Keming was away on a mission to Lingnan, On his return, he urgently requested to reply ... He said: "I have checked the (astrological manuals) Tianwen Lu and the Jingzhou Zhan ... the star is known by the name Zhoubo, which is yellow in colour and really brilliant in its light. The country where it is visible will prosper greatly ..." The Emperor approved and acceded to his request. He then promoted him to the post of Librarian and Escort of the Crown Prince, cited from SG02 with their additions in brackets.

We can see that Zhou Keming was on a mission to Lingnan (southern China, Goldstein and Ho Peng Yoke 1965), while the guest star first appeared, that no one present could (or was allowed to) interpret its astrological meaning, and that – upon his return – he checked the old documents about the astrological meaning of the bright guest star, identified it as Zhoubo star, and reported his interpretation to the Emperor.

Other historical documents specify that the Emperor was informed on AD 1006 May 30:

[AD 1006 May 30:] The Director of the Astronomical Bureau reported that previously, on the 2nd day of the 4th lunar month [May 1], during the initial watch of the night, a large star had been seen. Its colour was yellow ... According to the star manuals, there are four categories of auspicious stars. One of them is called Zhoubo; its colour is yellow and it is really brilliant; it presages great prosperity to the state over which it appears ... The officials congratulated the Emperor, from SG02 from Song Huiyao Jigao. The astronomer, who is informing the Emperor here, is also called superintendent astronomer in the same document.

Furthermore, we can read:

Jingde reign period, 3rd year [AD 1006-1007], there was a large star seen in the sky ... Zhou Keming, the chief official of the Spring Academy reported that according to the Tianwen Lu and the Jingzhou Zhan, the star was a Zhoubo, from SG02 from Shaofu Yitang Qinghua, also quoted in Goldstein and Ho Peng Yoke (1965), who point out that the Tianwen Lu and Jingzhou Zhan are lost.

That the information from China about this SN is sparse, in particular for April and May, may be due to the difficult interpretation at that time, i.e. until after the expected solar eclipse at the end of May, as mentioned in Sect. 3.6.

3.7 Possibly bad weather (monsoon) in East Asia

The East Asian monsoon affects large parts of China, Korea, and Japan; the onset of the summer monsoon with pre-monsoonal rain over South China is typically in early May, but can also start a few days or weeks earlier; the summer monsoon with many rainy phases starts in the South China Sea and then moves northward to Japan (June) and Korea (July). There are no East Asian night-time observations known at all between AD 1006 Apr 17 and the end of April. For AD 1006 Apr 14, we have evidence for a halo display in the south as seen from China (see above: white vapour penetrated the Moon). The lack of reports for the time AD 1006 Apr 17 until the end of April may be due to either bad weather or the fact that the reports were lost.

3.8 SN 1006 observed in St. Gallen for 3 months

A monk from St. Gallen, Switzerland, reported for AD 1006:

Nova stella apparuit insolitae magnitudinis, aspectu fulgurans, et oculos verberans, non sine terrare. Quae mirum in modum aliquando contractior, aliquando diffusior, et iam extinguebatur interdum. Visa est autem per tres menses in intimis finibus australi, ultra omnia signa quae videntur in coelo, cited after Pertz (1826) from the Annales Sangallenses maiorores (covering AD 709-1056); its second part (AD 919-1056) was written by different authors, Hepidannus being one of them, a St. Gallen monk, who lived in the 2nd half of the 11th century and died AD 1088, i.e. not necessarily an eyewitness of SN 1006 himself. The above text was translated as follows:

[AD] 1006. A new star of unusual size appeared, it was glittering (fulgurans) in appearance and dazzling (verberans) the eyes, causing alarm. In a wonderful manner it was contracted, sometimes spread out, and moreover sometimes extinguished. It was seen, nevertheless, for three months in the inmost limits of the south, beyond all the constellations which are seen in the sky,

citing Stephenson et al. (1977) and SG02 with their brackets and additions; for what they translate as constellations, the Latin has signa, which can mean signs or zodiacal signs.

The relevant part about the length of the observation of SN 1006 is Visa est autem per tres menses, i.e. per tres menses, which clearly means for three months or throughout three months, e.g. from the beginning of some month 1 (not necessarily a calendar month) until the end of month 3. With for three months, the author of this part of the St. Gallen annales did not necessarily mean three full months, he may have rounded down or up (i.e. 2.5 to 3.5 months). The wording clearly does not mean in three (different, subsequent calendar) months, which could then have meant that it was observed first at the end of month 1 (e.g. May)
Fig. 2  Visibility of SN 1006 from St. Gallen: The altitude (in degrees) of (the position of) SN 1006 is plotted versus the azimuth (in degrees) for St. Gallen. The black line shows the mountain top as seen towards the south from St. Gallen monastery (700 m high) according to Stephenson et al. (1977) with Mount Säntis as highest peak at 2503 meter. The additional curve shows the path of the position of SN 1006 as seen from St. Gallen. Since Jul 18, the position of SN 1006 would be seen after sunset only as plotted (in green) to the right of the (rightmost, green) line, i.e. not visible any more above the horizon or the mountains; since Jul 10, the position of SN 1006 is seen after sunset only as plotted (in pink or green) to the right of the (pink) line; since Jun 22, the position of SN 1006 is seen after sunset only as plotted (in blue or pink or green) to the right of the (blue) line (i.e. visible for all azimuths \( \geq 4^\circ \)); and since Apr 25, the position of SN 1006 is seen after sunset as plotted (in red or blue or pink or green), i.e. it was above the mountain (except of course behind the mountain top at azimuth \( \sim 6^\circ - 10^\circ \) for a brief period). If SN 1006 was seen in St. Gallen \( \text{for three months} \), i.e. at least for 2.5 months, and if it was visible last around Jul 10 (for about one minute after sunset) or earlier, then the first observation should have been in April. Given that the observer described the star to be \textit{sometimes extinguished}, he must have been at an altitude such that the star, within the night, was sometimes seen above the mountain and sometimes being briefly occulted by the mountain top, so that the star was seen between \( \sim 4^\circ \) to \( \sim 5^\circ \) above a perfectly flat horizon (given the height of Mount Säntis). Therefore, the altitude of the observer was somewhere between 700 m and \( \sim 1100 \) m.

and last at the beginning of month 3 (e.g. July). It is noteworthy to mention that the St. Gallen chronicle does not mention the duration of visibility just in passing, but explicitly \( \text{nevertheless, for three months} \), in spite of the difficult conditions (high mountains, strong extinction).

The southern horizon as seen from St. Gallen has high mountains with Mount Säntis straight towards the south being the highest one with 2503 m, located 20 km south of St. Gallen. The monastery is at an elevation of some 700 m, but the monks may have observed from a slightly higher point nearby; e.g. somewhat closer to the mountain. The highest point in today’s St. Gallen is 1074 m. The summit of Mount Säntis as seen from either the monastery or the higher point is only \( \sim 4^\circ \) to \( \sim 5^\circ \) above a perfectly flat mountain-less horizon. While the monk may in principle have observed from an even higher point, since the location itself is not specified in the text, the range in degrees given above, i.e. only about one degree from \( \sim 4^\circ \) to \( \sim 5^\circ \) above horizon, must indeed be as small as given: the text specifies that it [SN 1006] \( \text{... moreover sometimes extinguished} \). The observer tells us that SN 1006 was sometimes seen and sometimes extinguished, which is well possible given the
mountain range, where higher parts sometimes block the star light. Hence, this statement limits the range in altitude and, therefore, also the range in the height of the observing location, wherever it was (even if outside the monastery). See Fig. 2.

If the star observed in St. Gallen was indeed SN 1006, then SN 1006 ($\delta_{1006} = -37^\circ 34'\pm 3'$) was only up to $5^\circ$ above a perfectly flat (mountain-less) horizon at its location ($47^\circ 25'\pm 3'$ north). However, the horizon was furthermore limited by mountains (SG02): At an eastern azimuth, the true horizon due to mountains barely allowed celestial observations below $4^\circ$ above the perfect flat horizon, while at a western azimuth of $\geq 10^\circ$, celestial objects $\leq 3^\circ$ above the perfect flat horizon were visible (Fig. 2). (If the observer went to a place higher up than the monastery, then SN 1006 could be seen a bit better and maybe a bit longer, but one criterion of seeing it for the last time only in the very last minute after sunset is already very hard.)

We can now estimate the time of the year when SN 1006 was visible from St. Gallen above the mountains, see Fig. 2.

Let us first estimate the last observing date: Given that there were no day-time observations reported for SN 1006 (except the report from Morocco: its first appearance was before sunset), we can assume that SN 1006 was visible only after local sunset in St. Gallen. Due to its very low altitude and strong atmospheric extinction as seen from St. Gallen, a day-time observation of SN 1006 from St. Gallen is much less likely than from any other place, where SN 1006 was seen. For SN 1006 being $3^\circ$ above the perfect flat horizon (but less than 1 degree above the mountains), it was last visible from St. Gallen on AD 1006 July 10 at an extinction corrected apparent magnitude of about $-1 \pm 1$ mag; and on June 22 with $\sim -2 \pm 1$ mag for about one minute after sunset for $5^\circ$ above the perfectly flat horizon (but less than one degree above the mountain); see Fig. 2; we have neglected refraction here, which would amount to less than $1^\circ$.

If it was last visible on or around July 10 (or earlier), when was it first sighted? As mentioned above, with for three months, the author(s) of the St. Gallen annales means at least 2.5 months, namely until July 10 (or earlier), see above. Then, he would have started to have seen SN 1006 on or around April 25 or earlier. On and around April 25, SN 1006 would have been $\geq 3^\circ$ above a perfectly flat St. Gallen horizon (and about one degree above the mountains) for quite some time after sunset.

There is no regular weather pattern (like a monsoon in East Asia) in St. Gallen and central Europe as a whole in late April or early May (except maybe that the weather changes a lot in Europe in April), it could have been clear on many evenings. That not many other observers have noticed SN 1006 in Europe can be due to its extreme southerly declination, so that only very experienced and educated scholars (like monks) would detect it.

Also the Annales Beneventani (southern Italy, $6^\circ$ south of St. Gallen) report about a new bright star in 1006 and use the wording per tres menses (for three months):

AD 1006: Clarissima stella effulsit, et sicctitas magna per tres menses fuit,
which we translate as follows:

A very brilliant star shone, and a large drought happened for three months, (also given in SG02)

It is quite likely that the two items reported, a new bright star and a three-month drought, are meant to be connected. Given that this observer located $6^\circ$ south of St. Gallen and that he does not have high mountains towards the south, he should have been able to observe SN 1006 for longer than in St. Gallen – and indeed, while the St. Gallen report (for three months) can mean at least 2.5 months, the Beneventani report (for three months can mean up to 3.5 months, both may be rounded, they are not inconsistent with slightly different time spans.

A few more European annals mention a cometes for AD 1006, namely Liége and Lobbes, Belgium, also Venice, Italy, as well as Metz and Mousson, France (SG02). Some of them are further north than St. Gallen, but probably just report what they heard from St. Gallen. That they use the Latin word cometes (usually translated as comet) should not worry us, because at that time it meant transient celestial object, like the Arabic nayzak. The annals from St. Gallen and Benevento, though, do not use the word cometes for 1006 indicating that the observers there noticed that this transient celestial object was different from what we today call a comet – indeed, a new/very brilliant star.

4 Summary

We have discussed the Arabic texts of the observation of SN 1006 by al-Yamani and Ibn al-Dayba from Yemen, also in comparison with other Arabic, East Asian, and European observations, in particular in regard to the early sighting around AD 1006 Apr 16 and 17.

The relevant information from al-Yamani, the more original text, is as follows:

- In the night of mid-Rajab, in the year 396h, a star appeared ..., i.e. possibly already in the evening of AD 1006 Apr 17 $\pm 2$,
- a star appeared from the east at half an hour after sunset, which is consistent with AD 1006 Apr 17 evening,

These two statements are fully consistent with each other: only on and around 17 April 1006 (mid-Rajab 396h), SN 1006 rises half an hour after sunset as seen from Yemen.

SG02 rejected such an early sighting, but based only on the derived variant from Ibn al-Dayba:

In the year 396h, in the night of mid-Rajab, a star like Venus appeared. It regularly rose half an hour after sunset.

Here, the additional information about the rising time 30 min after sunset is corrupt (it did not rise regularly half an hour after sunset).

Additional European sightings do not mention the date or length of the observations (SG02).
SN 1006 was discovered in Arabia and Asia around April 30/May 1 (but maybe even around April 3 in China and April 16/17 in Japan and Yemen), all these dates are around either new moon or full moon. The observations may have been facilitated by the observation or search for the moon phase in order to know the relative date within the lunar month. Societies with a lunar calendar perform more celestial observations around new and full moons.

Also, a somewhat rare opportunity to observe at the same time during the night the four planets Venus, Mars, Jupiter, and Saturn (together even with the Moon until May 17) started just on AD 1006 May 1, so that additional observations in the first hours of the nights may have started around May 1, even though close conjunctions of three planets did not happen, which were otherwise often reported by the Chinese. Then, since May 22, Mercury was also seen together with the four other naked-eye planets at the start of the nights, namely until the end of June (May 31 to June 15 also with the Moon). For AD 1006 Aug 5, it was noticed that Mercury, Jupiter, and Venus met in Liu, etc. did not happen, which were otherwise often reported by the auto-biography of Ibn al-Daybā'.

We presented the following evidence in favour of an early observation (earlier than the end of April):

– The report that *a star appeared from the east at half an hour after sunset* (mid-Rajab 396h) is fully consistent with AD 1006 Apr 17 ± 2, but it would not be consistent with late April or early May.

– *Sanā‘*, Yemen, is quite high (~ 2400 m) and far south, both facilitating an early observation.

– The Yemeni observer may have undertaken observations of the moon phase since around AD 1006 Apr 16 (full moon) in order to know the relative date within the lunar month; SN 1006 was near the full moon in the south-east. The other Arabic observers, who observed SN 1006 first at the end of April or early May, were searching for the crescent new moon, in order to start a new month.

– A guest star was seen in Japan possibly already on April 28 – or even on April 16 (we suggest this alternative possibility for the Japanese text).

– A guest star was seen in China on Apr 3 in the SE, i.e. the correct direction for SN 1006; neither a tail nor motion relative to the stars were mentioned.

– There are no reports about any other East Asian observations known for the period from Apr 17 until the end of April, possibly due to lost documents or bad weather.

– It may be that SN 1006 was not observable in East Asia in the 2nd half of April 1006 due to early monsoon.

– SN 1006 was observed in St. Gallen, Switzerland, for three months and was last visible there 3° (or 5°, respectively) above the horizon AD 1006 July 10 (June 22, respectively) for about one minute after sunset, so that the first observation should have been in April.

We found multiple evidence for an early observation in mid April: a new star on April 17 ± 2 in Yemen, detection of a new star in St. Gallen already in April, a new star on April 16 (or 28) in Japan, and a possible observation on Apr 3 in China. That there are not more records could be due to bad weather or lost document, or because the Chinese had problems with the interpretation given the expected solar eclipse for end of May. It could be that more records will be found:

"Ali ibn Riḍwān wrote of SN 1006 that other scholars from time to time have followed it."

Acknowledgements. We acknowledge the Moon phase predictions by Rita Gautschy on www.gautschy.ch/~rita/archast/mond/Babylonerste.txt. WR would like to thank Sahi Hassoun al-Ta’i of Hilla University College for obtaining the second manuscript from the Wadod Center; we would like to acknowledge the Wadod Center for indexing and editing books, which was established in memory of Ms. Sheikha al-Murry. RN also thanks the Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt, where he consulted the al-Hubaisi & al-Sanabānī edition of al-Yamānī’s work *Bahjat az-zaman ft tārīkh al-Yaman* as well as the auto-biography of Ibn al-Dayba’. RN acknowledges Frank Giessler for providing an electronic data file for the altitude of the St. Gallen mountain tops (from Stephenson et al. 1977) for plotting Fig. 2. We would like to thank an anonymous referee for good suggestions, also for focusing our discussion.

References

al-Hubaisi, A. & al-Sanabānī, M.A. (Eds.), 1988, al-Yamānī: Bahjat az-zaman ft tārīkh al-Yaman, Dar al-Hikma al-Yamania, Sanā‘, Yemen

Brecher, B.R., Lieber, E., Lieber, A.E., 1978, Nat, 273, 728

Burleigh, M.R., Heber, U., O’Donoghue, D., Barstow, M.A., 2000, A&A, 356, 585

Chapman, J., Neuhäuser, D.L., Neuhäuser, R. Csikszentmihalyi, M., 2015, AN, 336, 530

Clark, D.H. & Stephenson, F.R., 1977, The Historical Supernovae, Pergamon

Cook, D., 1999, JHA, 30, 131

Damon, P.E., Kocharov, G.E., Peristykh, A.N., Mikheeva, I.B., Dai, K.M., 1995, CRC 2 (24th International Cosmic Ray Conference, Vol. 2), 311

deBlois, F.C., 2000, *Tārīkh*, in: Bosworth, C.E., van Donzel, E., Heinrichs, W.P., Lecomte, G. (Eds.) Encyclopaedia of Islam, new edition, Vol. X, Leiden: Brill

Dreyer, J.E. 1906, History of the planetary system from Thales to Kepler, Oxford Univ. Press

Firestone, R.B., 2014, ApJ, 789, 29

Gardner, F.F. & Milne, D.K., 1965, AJ, 70, 754

Gautschy, R., 2014, Zeitschrift für Ägyptische Sprache und Altertumskunde 178, 1

Gautschy, R., 2014, JHA, 45, 79

Goldstein, B.R., 1965, AJ, 70, 105

Goldstein, B.R. & Ho Peng Yoke, 1965, AJ, 70, 748

Gonzalez-Hernandez, J.I., Ruiz-Lapuente, P., Tabernero, H.M., Montes, D., Canal, R., Mencez, J., Bedin, L.R., 2012, Nat, 489, 533

Green, D.A., 2009, Bull. Astron. Soc. India, 37, 45

Hamuy, M., Phillips, M.M., Suntzeff, N.B., Schommer, R.A., Maza, J., Smith, R.C., Lira, P., Aviles, R., 1986, AJ, 112, 2438

Hartner, W., 1965, Isis, 56, 438
