

## DID IBN SĪNĀ OBSERVE THE TRANSIT OF VENUS 1032 AD?\*

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The Persian polymath Abū ‘Alī Ibn Sīnā (980-1037 AD), known to early Western sources as Avicenna, records in one of his works, *Compendium of the Almagest* that ‘I say that I saw Venus as a spot on the surface of the sun’. The date and place of the observation are not given. This statement has been quoted subsequently by some Muslim astronomers, for example, by Naṣīr al-Dīn al-Ṭūsī (1201–1274 AD). A transit of Venus indeed took place in Ibn Sīnā’s time, on 24 May 1032 AD (Julian). Did Ibn Sīnā see this transit or did he merely see a sunspot? The question was addressed by Bernard Goldstein in 1969 who concluded that “this transit may not have been visible where he lived”. The conclusion was based on the input provided to him by Brian Marsden who in turn used mathematical tables prepared by Jean Meeus in 1958 and gave sets of limiting terrestrial latitudes and longitudes from where the Contact I and II could be just observable.

We have re-examined the question employing Espenak’s Transit predictions as also Jubier’s. The astronomical circumstances of the transit episode and the specific commentary on the monumental work *Kitāb al-Shifā’* of Ibn Sīnā show that he could indeed have obtained a glimpse of the transit of Venus just before sunset from the place – Isfahan or Hamadan. That is also the best time to view with one’s naked eyes, should ground conditions permit. In other words, when Ibn Sīnā said he saw Venus on the surface of the Sun, he meant it. We consider also if Ibn Sīnā’s observation could be that of a sunspot. Although the sunspot possibility can not be dismissed altogether, it does not emerge as a cogent proposition. His statement that every conjunction does not result in a transit can come

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from an actual observation only. Ibn Sīnā's claim perhaps fills an important gap in the history of astronomy for the period 1030 AD onwards and bears testimony to his observational acumen and computational precision.

**Key words:** Ibn Sīnā, Islamic astronomy, Pre-telescopic transit observations, Transits of Venus

## 1. INTRODUCTION

Abū ‘Alī Ibn Sīnā (Avicenna; Şafar 370 AH/–428 AH or 980-1037 AD), the renowned Persian natural philosopher, mathematician, physician, poet and prolific author of works ranging from philosophy to sciences and treatises on medical sciences,<sup>1,18</sup> has stated in one of his works to have seen Venus as a spot on the surface of the Sun. In the modern times, the observation was discussed by Goldstein<sup>2</sup> when he examined the microfilm of Ibn Sīnā's Arabic text *Compendium of the Almagest* from the Bibliotheque Nationale, Paris. In the work that is a commentary on Ptolemy, Ibn Sīnā describes the unusual observation where he likens the disc of Venus as “a mole on the face of the sun”<sup>3</sup> and concludes that Venus was, at least sometimes, *below the Sun*.<sup>4</sup> As Hadavi<sup>5</sup> has pointed out, Ibn Sīnā states this observation also in his philosophical work *al-Isharāt wa al-Tanbihāt* (meaning *Pointers and Admonitions*, or *Instructions and Remarks*). The date and place of the observation are not given. Ibn Sīnā's Venus observation was specifically cited by Naşīr al-Dīn al-Ṭūsī (1201–1274 AD), the most acclaimed Persian astronomer and natural philosopher at whose instance the Marāgha observatory was built with a view to produce precise astronomical tables and take down planetary movements, while confirming Ptolemy's planetary order in his astronomical work *Risālah Mu‘iniyya* in Persian, and later by the astronomer Cyriacus (lived ca. 1482 AD) among others.<sup>3,5</sup>

The transits of Venus are rare — about 12 in a millennium, either in June (at the descending node) or in December (at the ascending node). In some historical records, instances have been cited, suggestive of naked eye witnessing of the transits of Venus, for instance by the 16<sup>th</sup> century BC Assyrians and by medieval Arab astronomers in the years 840, 1030, 1068 and 1130 AD,<sup>6,7</sup> etc. No transit happened in any of the specified years and the sightings could be of sunspots only. Compared to the other pre-telescopic instances, we find Ibn Sīnā's observation to be relatively convincing and

amenable to some exploration. After the telescope, the first of the transits of Venus as predicted by Johannes Kepler (1571–1630 AD) happened on Dec 7, 1631 AD. The French astronomer Pierre Gassendi (1592–1655 AD), who had already watched the transit of Mercury on Nov 7, 1631, tried to watch the transit of Venus the following month from Paris but did not succeed.<sup>8</sup> The accuracy of the prediction in Kepler’s (1627) *Tabulae Rudolphinae* on the one hand, the Contact IV was already over at 06:47 UT<sup>29</sup> before the Sun rose at Paris (sunrise 07:34 UT). Looking through Kepler’s tables, the British astronomer Jeremiah Horrox (1618–41 AD) deduced the next to be on November 24, 1639<sup>8</sup> (December 4, Greg). He planned and was able to observe it employing projection technique from a place fifteen miles north of Liverpool, possibly Hoole as also his friend William Crabtree from near Manchester.<sup>8</sup> It was James Gregory in 1663, and later Edmund Halley in 1691,<sup>9</sup> who proposed that one should be able to determine solar trigonometric parallax and deduce an unprecedentedly precise measure of distance to the Sun from the timings of ingress and egress of the transit of an inner planet when observed from different locations on the Earth. Halley died in 1742. The next transits of Venus were to happen in 1761 and 1769. As the time drew near, the forthcoming transits evoked great scientific interest in Europe to observe these from different parts of the globe. What then followed is history, and well documented, vide Kurtz (2004) and van Roode (2012).

## 2. GOLDSTEIN’S OBSERVATION

Ibn Sīnā’s description amounts to a naked eye observation of the transit of Venus. There indeed was a transit on May 24, 1032 AD (Julian). However, there are also some questions raised thereabout, the foremost being if it was a sunspot that he may have seen.<sup>10</sup>

Goldstein<sup>2</sup> was well within reason to pose time constraints that severely limit the claim. He cites Ptolemy who considered the possibility of transits by planets that lay below the Sun in the order and observed that “even if a planet did transit the Sun, it might not be visible on account of the brightness of the Sun and the small area of it that the planet would cover.”<sup>11</sup> In Ptolemy’s planetary order, transits would happen at inferior and superior conjunction both. According to Goldstein,<sup>11</sup> the medieval astronomers picked up the threads concerned as they were to reconcile Ptolemy’s model

with actual observations. He cites from literature the examples where al-Kindī (800/803–870/873 AD, etc.), Ibn Sīnā, Ibn Rushd (1126–98 AD) and Ibn Bājja (ca.1095–1138/9 AD) may have observed transits of the planets that are *below the Sun*. Goldstein<sup>2</sup> examined in detail the claims and found these dismissible on grounds of chronology and feasibility. It is only the report of Ibn Sīnā's observation that he dwelt upon more but concluded that "this transit may not have been visible where he lived".<sup>12</sup> Not certain where exactly Ibn Sīnā was on May 24, 1032 AD, Goldstein based this conclusion on the likely time window Brian G Marsden<sup>12</sup> provided him in a personal communication of Nov 8, 1967 on the basis of mathematical tables prepared by Meeus (1958). The limits to the time of observation were deduced for a latitude spread between 30°–40°N and a longitude range correspondingly constrained by the Contact I (earliest possible at 15 21 UT) to 52°.8–59°.3E and by Contact II (latest possible at 16 07 UT) to 41°.3–47°.8E, west of which the respective contacts could be observed. Marsden regarded Meeus' UT values correct to within about 15 minutes.<sup>12</sup>

Goldstein's<sup>12,13</sup> conclusion was not location specific. Besides, the above contact timings are slightly inconsistent with more modern transit predictions by Espenak<sup>29</sup> (see later). According to the latter, the interval between the first two contacts was 16 minutes.

The fact is that there is no additional information on Ibn Sīnā's observation. It was severally cited but we do not find anything of a follow up. Similarly, there are no discussions that are more definite than Goldstein's.<sup>12</sup> In this paper, we examine the astronomical circumstances specific to the cities of Isfahan and Hamadan Ibn Sīnā may have observed the transit from employing Fred Espenak's Transit predictions,<sup>29</sup> as also the part of Xavier Jubier's website<sup>30</sup> dealing with solar transits (see later), and see if the question can be resolved.

### 3. IBN SĪNĀ'S ASTRONOMICAL INCLINATIONS

Ibn Sīnā's times were when Islamic astronomy was in ascension. The pre-Islamic Persia was already rich in astronomical literature and bore upon it influence of Indian works.<sup>3,14</sup> In 813 AD, Caliph al-Ma'mūn (786–833 AD) founded a school of astronomy in Baghdad. A turning point in the history of the Islamic astronomy came with Ptolemy's monumental work

that was translated into Arabic as *Kitāb al-Majisī* in the 9<sup>th</sup> Century (829–30 AD) in the Caliph's times and an astronomical observatory established at Baghdad in 829 AD. Ptolemy's work greatly influenced the Islamic astronomy. The science evolved with time, in the Middle East, North Africa and Spain, into a sophisticated system that did not serve the crucial ritual needs alone.<sup>15,16</sup>

Ibn Sīnā had studied Ptolemy's *Almagest* in his younger days while at Bukhara (985-1005 AD<sup>4</sup>) as also Aristotle's logic and Euclid's geometry.<sup>17</sup> Apart from writing monumental works on the medical sciences such as the *Kitāb al-Shifā'* (the book of remedy/healing), Ibn Sīnā produced many on philosophy and astronomy. He had lived at Hamadan through the years 1015–23 AD where he wrote several portions of the *Kitāb al-Shifā'* and moved to Isfahan where during 1023–37 AD, he spent the rest of his life, though he died and was interned at Hamadan only.<sup>18</sup> The city has an impressive *Avicenna Tomb* to his honour. Sally Regep<sup>19</sup> lists nine astronomical works considered authentic among the many attributed to Ibn Sīnā.

At Isfahan, Ibn Sīnā made astronomical observations for his patron Sultan Alā' al-Dawla<sup>20</sup> whom he advised on matters of literature, science and philosophy as also accompanied on most of his military expeditions. Alā' al-Dawla was a great patron of scholars and poets and arranged regular Friday evening discussions with Ibn Sīnā on science and philosophy. Ibn Sīnā is said to have built an astronomical observatory at Isfahan with the assistance of his student and biographer Abū 'Ubayd al-Jūzjānī and from his observations prepared ephemerides.<sup>21,22</sup> In his account of the life of Ibn Sīnā, al-Jūzjānī has this to say<sup>23</sup>:

“One night in the presence of Alā' al-Dawla someone mentioned the discrepancies contained in the ephemerides compiled on the basis of the ancient astronomical observations, and so the Amīr ordered the Master to devote himself to the observation of these stars, and he allocated whatever funds he needed. The Master set about it and charged me with obtaining the required instruments and hiring those skilled in making them, so that many of the problems came to light. The discrepancies in the matter of observation had occurred because of the great number of journeys and the attendant errors.”

There are some crucial astronomical observations to his credit.<sup>24</sup> Commenting on the *Almagest*, Ibn Sīnā felt that Ptolemy's observations had deficiency and needed to be improved upon with new observations.<sup>25</sup>

The society Ibn Sīnā lived in was rigorous Islamic. His own language was Fārsī (Persian) but that of his education was Arabic. As Afnan<sup>26</sup> writes of him, "...his many writings ran directly counter to religious dogma. To these may be added his behaviour in public and his utter disdain of conformity." As we get it from Nazemi,<sup>27</sup> Ibn Sīnā "founded new ways in Islamic Philosophy and (was) even sometimes accused by his enemies that he is not very religious but other Islamic scholars call him with the name of *Hujjat al-Haq* (Proof of God)". In respect of what follows, there are two comments of relevance that we need to keep in sight. The first one is by Sally Regep<sup>4</sup>:

"Ibn Sīnā's astronomical knowledge and works may be viewed as less developed than those of his contemporaries such as Ibn al Haytham and Bīrūnī; nevertheless, he had an impact upon later writers, and several general points can be made about his astronomical work..."

and

"Ibn Sīnā's treatise on instruments includes a description of a large instrument with an improved sighting system that theoretically could provide considerably improved accuracy. Also, his summaries tend to emphasize the role of observation. Noteworthy as well are Ibn Sīnā's criticisms of the poor instruments and observations of Ptolemy and Hipparchus."

The second, as Saliba<sup>3</sup> puts it, is,

"...although there are claims in Avicenna's works of direct observations, he did not seem to have had access to a functional observatory, nor did he seem to have had a systematic program of observations that he wished to complete."

Ibn Sīnā had corresponded with the legendary al-Bīrūnī (973–1048 AD) of Khwarazm on matters related to astronomy, physics and philosophy. The other prominent mathematician-astronomer of his time was Ibn al-Haytham (965–1040 AD<sup>1</sup>). We have no commentary from either of them on the unusual conjunction of Venus with the Sun in 1032 AD. Bibliographical references to Ibn Sīnā's works and to works on Ibn Sīnā can be found in this website.<sup>28</sup>

#### 4. IBN SĪNĀ'S TRANSIT OBSERVATION

The circumstances of the transits of Venus since the advent of Islam until around the times of Ibn Sīnā are as follows (Table 1)<sup>29</sup>.

**Table 1**

Date	Transit Contact Times (UT)					Minimum Sep. "	Sun RA h	Sun		Transit Series
	I h:m	II h:m	Greatest h:m	III h:m	IV h:m			Dec °	GST h	
0667 Nov 23	18:20	18:36	22:24	02:11	02:27	99.2	16.172	-21.21	4.338	4
0789 May 24	11:33	11:48	15:24	19:00	19:15	307.6	4.300	21.52	16.389	3
0797 May 22	06:41	07:18	08:32	09:45	10:23	866.6	4.151	21.14	16.243	5
0910 Nov 23	17:28	17:44	21:28	01:11	01:27	207.9	16.312	-21.53	4.475	4
1032 May 24	15:18	15:34	19:03	22:32	22:48	373.4	4.463	21.87	16.539	3
1040 May 22	10:02	10:29	12:23	14:18	14:45	791.8	4.314	21.52	16.393	5

In his commentary on Ptolemy, Ibn Sīnā writes of his unusual observation. His statement is variously described – e.g., the disc of Venus as “a mole on the face of the sun”,<sup>3</sup> and the conclusion that Venus was, at least sometimes, *below the Sun*.<sup>4</sup> How did Ibn Sīnā know that the spot he saw was Venus? That is not easy to answer but it can be only when one is pursuing the target diligently.

When one is following the planet until its heliacal setting before its conjunction with the Sun and subsequently its heliacal rising, he would also learn how close it is going to pass by the ecliptic. From the speed of its movement, he should be able to calculate when Venus is likely to pass the Sun’s longitude (the conjunction). A transit has to be seen, if it is to be described in the words Ibn Sīnā’s observation has come down to us. It is therefore reasonable to consider it a true observation. Al-Ṭūsī believed it and so he spoke about it in his own Redaction of the *Almagest* (*Tahrīr al-Majisṭī*)<sup>31</sup>:

“I [Naṣīr al-Dīn] say: al-Shaikh al-Raʿīs abū ‘Alī b. Sīnā [Avicenna] mentions in (one of) his books that he had seen Venus as a spot (*khāl wa shāma*) on the surface of the Sun....”

Al-Ṭūsī quoted also another author, Ṣaliḥ bin Muḥammad, on this. Goldstein examined the microfilm of Ibn Sīnā’s Arabic text *Compendium of the Almagest* with the Bibliotheque Nationale, Paris (a copy dated 673 AH – 1274/5 AD) and presented Ibn Sīnā’s observation<sup>31</sup>:

“I say that I saw Venus as a spot on the surface of the Sun.”

This is verbatim quotation that al-Ṭūsī cited in his “Redaction of *Almagest*”. If only al-Ṭūsī had lived another year, he himself would have come across the same situation of Venus heading towards the position of the Sun and to *pass below* it yet another time on May 25, 1275 AD (Julian) even though the Sun would have set over Tabriz (38 04N, 46 18E) at 16:08 UT before the transit began at 19:00 UT. One can only wonder, if they weighed the idea whether Venus repeated such motion below the Sun and if there was some periodicity to that.

Where did Ibn Sīnā observe the transit from? From his various biographies, e.g., by Afnan (1958), Gohlman (1974) and McGinnis (2010), and some on the internet, we are not able to ascertain if it was from Isfahan. There is hardly any pointer to this even when one leafs through the life of Alā’ al-Dawla who had in the times the Ghaznavids to tackle, now and then. Let us first recollect from Afnan<sup>32</sup>:

“When Mas‘ūd, the equally ambitious son, entered Iṣfahān in 1030 (421 A.H.), ‘Alā’ el-Dowleh fled, and it may be presumed that Avicenna accompanied him. It was then that his house was plundered and his library carried off to Ghazna, only to be destroyed about a century later by the invading Ghūrīd Turks. Accounts of the sequence of political events during this period are contradictory, and the dates not very reliable....”.

Above, Mas‘ūd is Sultan Maḥmūd’s (r. 998 – 1030 AD) son. From Sheila Blair,<sup>33</sup> we learn that in May 1030 AD, just when Alā’ al-Dawla was about to lose battle, Mas‘ūd got news of Sultan Maḥmūd’s death and needed to return to Ghazna and “to contest his brother” for the throne. He immediately settled for a cessation of war with Alā’ al-Dawla. In the following years, Alā’ al-Dawla worked to consolidate his position but until death in 1041 AD he fought the Ghaznavids, intermittently.<sup>33</sup> In the course of a military expedition to Hamadan that he accompanied Alā’ al-Dawla on, Ibn Sīnā suffered from a severe attack of colic.<sup>32</sup> That was sometime in 1034 AD the year Alā’ al-Dawla took on the Sultan Mas‘ūd’s forces<sup>34</sup> at Karaj.<sup>35</sup> Self-medication aggravated Ibn Sīnā’s health further. He was in a bad shape when brought back to Isfahan, from which he could never recover completely, given to indulgence as he was.<sup>32</sup> From Goodman<sup>36</sup> we learn that Ibn Sīnā devoted the early 1030s to working on his philosophical tract *al-Isharāt wa al-Tanbihāt* (Pointers and Admonitions). In the tract, Ibn Sīnā states the



coveted observation<sup>5</sup> whereas it is not clear from any of the works on Ibn Sīnā if there was a military expedition he accompanied or whether he was living away from Isfahan and north-west of it in the times circa 1032 AD.

Some authors differ from the above in their accounts of the last few years of his life. O'Connor and Robertson state that Ibn Sīnā made astronomical observations from Isfahan as well as Hamadan.<sup>90</sup> Said<sup>37</sup> states that towards the end of his life, Ibn Sīnā had carried out astronomical observations at Hamadan. There are similar indications in other writings on him, many on the internet. Nazemi<sup>38</sup> holds that after the invasion by Sultan Mas'ūd, Ibn Sīnā had "left Isfahan and went to the west of Iran near Hamedan city where he lived till his death...", and where during the period he finished the astronomy part of *al-Shifā'*. Nazemi<sup>38</sup> adds that according to some, Ibn-Sīnā was in Hamadan twice in his lifetime, first, after his escape from prison whereafter he lived for a few years in Hamadan before he returned to Isfahan and completed *al-Shifā'* according to his observation, and the second time, when he accompanied Alā' al-Dawla in his military expedition to Hamadan.

Ibn Sīnā's biographies draw mostly from his disciple al-Jūzjānī's account. As we get it from them all, it was in 1023 AD Ibn Sīnā escaped from prison and eventually reached Isfahan to his great welcome and joined the court of Alā' al-Dawla,<sup>39</sup> the year is 1024 AD as according to Gutas.<sup>40</sup> Most of the accounts concur about the first stay at Hamadan during 1015 – 1023/24 AD and the 1037 AD expedition. Already with ill health, his last expedition to Hamadan so deteriorated his condition that he died and was buried there itself in June or July 1037 AD.<sup>18</sup> It therefore remains to be settled if there was an expedition also in 1032 AD, west or north-west of Isfahan.

In what follows, we consider astronomical circumstances specific to Hamadan and I(E)sfahan, both. Geographically, the places are 369 km apart. The differences in the respective longitudes and latitudes are minor (vide Fig. 1) but can jolt the claimed observation. It may be presumed that at Hamadan/Isfahan, the astronomers were basically equipped, with astronomical tables and instruments such as astrolabe, a gnomonic device etc. and had put these to use for following the path of the planet and the Sun.

In the matter of observations on the day from either of the places, the transit was critically timed. It began close to the sunset time as is obvious



Fig. 1. Map of Iran; adopted from: <http://www.iranologie.com/iran/iran2.html> (University of Michigan)

from the circumstances cited below. Nevertheless, that is also the best time to view with one's naked eyes, subject to the conditions on ground.

#### 4.1 At Hamadan ( $34^{\circ}47'54''\text{N}$ , $48^{\circ}30'54''\text{E}$ )

At Hamadan, as the moment of the transit approached, the Sun was only a few degrees above the horizon. An observer should be able to see, in principle at least and possibly aided by a diminishing sunlight and sky,

a black spot after the First Contact at 15:18 UT. At this moment, the various Solar System objects are positioned as in Table 2a.

**Table 2a**

	Right Ascension	Declination	Distance (AU)	From 34°47'54''N Altitude	48°30'54''E Azimuth
Sun	4h 27m 2s	+21° 50.3'	1.016	5.203	113.054 Up
Mercury	5h 23m 56s	+25° 13.7'	1.232	17.971	108.678 Up
Venus	4h 28m 20s	+21° 49.4'	0.290	5.440	112.866 Up
Moon	13h 56m 50s	-6° 32.7'	60.8 ER	31.937	-53.360 Up

The respective celestial positions (also those in the Table 3a below), computed from John Walker’s site,<sup>41</sup> are apparent right ascension (R.A.) and declination (Dec.) with respect to the true equator and equinox of date. These positions are geocentric. At the time of the Contact I, the planet clings onto the eastern limb of the Sun but, its being close to the sunset time, would appear to ingress apparently from almost its top (vide Fig. 2). At Hamadan, the sunset was at 15:48 UT that day. The 30 minutes after the Contact I were crucial as the planet gradually moved in. The Contact II happened 14 min before the Sun set. With the Sun at an altitude 2°.207 (at Contact II), that gave a small window, yet an extraordinary opportunity in a pre-telescopic era, to witness reappearance act by a planet that had vanished a few days ago in the glare of the Sun, as a black spot against its disc while it approached its conjunction with the latter. The above values are for a mathematical (or astronomical) horizon. Hamadan (1850 m) is in a mountainous region, at the foothills of Mt. Alwand (3574 m) and it must be settled, if one can get the view and visibility an astronomer would always aspire for. As the sky turned dark, Ibn Sīnā would also have found Mercury and Saturn in the constellation of Gemini hovering above the horizon after the Sun set.

The interactive Google map for the 1032 transit by Jubier,<sup>30</sup> producible through his website, gives us the circumstances presented in Table 2b.

The geographical point in Hamadan for which the Tables 2a & 2b are generated is the centre of the *Imam Khomeini Square*. Our choice of location is arbitrary, staying close to the present-day centre of the city. In the

Table 2b, the quantity P is the position angle of Venus and V the time “o’clock” position on the Sun’s face of the contact point.<sup>30</sup> The asterisk(\*) in the Table 2b implies the event occurring when the Sun is below the horizon. The software<sup>30</sup> labels the date of the transit as May 23, 1032 and for that Jubier<sup>51</sup> clarifies: “By default the given date is in UT time, as indicated by the column header. However adding a parameter to the URL it’s possible to specify a local time, but then another click to a location that is in a different timezone will report the wrong local time”. These transit calculations do not account for atmospheric refraction.

**Table 2b**

34° 47' 53.92" N <—> 34.79831° (central Venus transit)  
48° 30' 53.44" E <—> 48.51484°

Event ( $\Delta T=1390.7s$ )	Date	Time (UT)	Alt	Azi	P	V	Sep
First external contact (C1)	1032/05/23	15:15:47	+05.6°	292.7°	95°	08.8	973.1"
First internal contact (C2)	1032/05/23	15:31:36	+02.7°	294.9°	97°	08.8	915.5"
Maximum transit	1032/05/23	19:00:57*	-28.4°	333.4°	162°	06.6	387.7"
Second internal contact (C3)	1032/05/23	22:32:21*	-27.4°	029.1°	227°	04.4	915.4"
Second external contact (C4)	1032/05/23	22:48:27*	-25.7°	032.8°	229°	04.4	973.0"

#### 4.2 At Isfahan (32°39'5"N 51°40'51"E)

At Isfahan from where Ibn Sīnā may have observed, the transit turns out to be even more critically timed as the Contact I happened only minutes before the sunset. The respective positions of the various objects at the time of Contact I are as follows<sup>41</sup>:

**Table 3a**

	Right Ascension	Declination	Distance (AU)	From 32°39'5"N Altitude	51°40'51"E Azimuth
Sun	4h 27m 2s	+21° 50.3'	1.016	1.925	114.868 Up
Mercury	5h 23m 56s	+25° 13.7'	1.232	14.768	110.769 Up
Venus	4h 28m 20s	+21° 49.4'	0.290	2.165	114.685 Up
Moon	13h 56m 50s	-6° 32.7'	60.8 ER	35.333	-51.669 Up

At Isfahan, the Sun set at 15:30 UT on the day whereas the Contact II happened 4 min after that (Sun altitude:  $-1^{\circ}.102$ ). That is again for a mathematical horizon. Isfahan is at a height  $h = 1590$  m above the sea level. As pointed out by Nazemi,<sup>42</sup> the geographical situation is such that there are not many geographical blockages “and in the center of today’s Esfehān you could observe such transit.” Grant a horizon that is visible, add to this the increased distance to the horizon seen from the altitude of Isfahan, i.e., the apparent horizon [the point where the line of sight is tangent to the surface of the Earth [ $\equiv \cos^{-1} R_{\oplus}/(R_{\oplus}+h) \sim 1^{\circ}.28$ ;  $R_{\oplus}$  the radius of the Earth], and the refraction effects at the horizon. The latter vary place to place and day to day. In the present circumstances, it can be taken approximately equivalent to twice the angular diameter of the Sun. Thus, a net gain of several minutes is available and the planet’s cutting nearly fully into the disc of the Sun, until the time it sets, can qualify as “a mole on the face of the sun”. Hamadan, further up north of Isfahan, had the advantage of a longer day.

In contrast, the interactive Google map made for the 1032 transit by Jubier<sup>30</sup> gives us the following circumstances:

**Table 3b**

**32° 39' 04.55" N  $\longleftrightarrow$  32.65126° (central Venus transit)**  
**51° 40' 50.70" E  $\longleftrightarrow$  51.68075°**

Event ( $\Delta T=1390.7s$ )	Date	Time (UT)	Alt	Azi	P	V	Sep
First external contact (C1)	1032/05/23	15:15:42	+02.4°	294.6°	95°	08.8	973.1"
First internal contact (C2)	1032/05/23	15:31:32*	-00.5°	296.7°	97°	08.8	915.4"
Maximum transit	1032/05/23	19:01:10*	-31.5°	336.0°	162°	06.6	387.7"
Second internal contact (C3)	1032/05/23	22:32:42*	-27.8°	032.7°	227°	04.4	915.4"
Second external contact (C4)	1032/05/23	22:48:48*	-25.9°	036.3°	229°	04.4	973.0"

The transit calculations in the Table 3b do not account for atmospheric refraction. The geographical point in Isfahan for which the Tables 3a & 3b are generated is where the present day *Chahar Sough Naghashi* and the *Roknolmolk* flyovers cross. Our choice of location is arbitrary, staying close to the present-day centre of the city. Between the Table 3a and Table 3b, the disparity in the Sun’s altitudes at the Contacts I and II is small but non-trivial. These together imply that even in Isfahan, the Contact II is reachable

just before the sunset when one considers the gains in the Sun's altitude due to atmospheric refraction and elevation of the place of observation.

## 5. WAS THE OBSERVATION SERENDIPITOUS?

In view of the above, we can take it that an observation was made. It is then legitimate to ask: Was the observation serendipitous, or Ibn Sīnā was guided by the perplexing path the planet was taking, towards a syzygy?

### 5.1 The heliacal setting, conjunctions and rising of the planet

We believe Ibn Sīnā did not just stumble upon the transit on the day. That can be when one is working with *zījēs* (astronomical tables) and observing systematically. With reference to a certain epoch, it was possible for the Muslim astronomers to determine dates of greatest elongation and the first conjunction of an inferior planet. Ibn Sīnā would know that the forthcoming conjunction of Venus ( $\lambda_{\text{♀}} = \lambda_{\text{☉}}$ ) is inferior and that when it is. The last superior conjunction of Venus with the Sun had happened on August 2, 1031 AD and they may have observed the heliacal setting and rise of the planet then too. In the event of an inferior conjunction, the movement of the planet is brisk so that the dates of its heliacal setting and rising are much closer than these are around a superior conjunction. Knowing that its inferior conjunction was drawing near, Ibn Sīnā may well have been following up the movement of Venus towards the Sun until it was lost in its glare.

Incidentally, Ptolemy in the *Almagest* considered the question of heliacal rising and setting of planets and determined *arcus visionis* for the visible planets. Rather than delve into a complex subject, it would suffice to know the values he gave for Venus and for Jupiter, as 5° and 10° respectively, etc. Kennedy and Agha<sup>43</sup> provide a brief description of Ptolemy's criterion for the visibility of a planet and list a number of *zījēs* (astronomical tables) that contain planetary visibility tables. These had been adopted from Ptolemy and the Indian sources. For Venus, majority of the Indian texts give 9°, 11° for Jupiter, etc.<sup>44</sup>

For an observer based at Isfahan and Hamadan, the dates around the conjunction when a nearly 9° altitude difference between Venus-Sun is attained are May 18 and June 03, 1032 AD (Julian) respectively.<sup>41</sup> These dates are for an astronomical horizon – the horizontal line through the point of

observation and normal to the radius vector through the centre of a spherical Earth that ignore effects of refraction, haze and moonlight and the observer's definition of an astronomical twilight etc., and are for perspective only.

## 5.2 The planet's visibility within the heliacal zone

We can refresh on the daytime visibility of the visible planets since it is the first order limitation before the prospective observers of the times while tracking the luminaries. There are claims to seeing Venus by naked eye while the Sun is up. That may seem plausible when it is at a sizeable solar elongation and the sky is clear.<sup>45</sup> However, back in 1880, a letter from H L Baldwin published in *The Observatory* in this regard is interesting. Baldwin,<sup>46</sup> from Denver (Colorado), tried to verify a statement in an astronomy text that Venus is not visible daytime to an unaided eye within one month of its superior conjunction with the Sun. He tried and could see the planet daytime on several days around its superior conjunction with the Sun that happened on July 13, 1880. He even gave its apparent magnitude, ranging from 5.5 to 3.5 as estimated in his observations on different days. The closest Baldwin viewed Venus, and easily so, was on July 25 at 10:20 a.m. when it lay at a longitudinal distance of  $3^{\circ}38'$  from the Sun, magnitude about 3.5 to 4. He was confident that had the atmosphere, mostly poor during July 15-24, been as pure on July 18 as it was on July 25, he would have been able to view the planet that then stood a mere " $1^{\circ} \frac{2}{3}$ " from the Sun. Baldwin's values for the apparent magnitude should be negative only.

In comparison, Jupiter (mag.  $-2.9$  at opposition,  $-1.6$  to  $-1.8$  at superior conjunction) can generally be seen unaided when the Sun is down to  $-5^{\circ}$  in altitude by which time the sky brightness reduces to the extent that the right contrast becomes available.

With which brightness  $m$  the planet would shine just as the transit begins across the Sun? The well known  $\cos \theta$  – factor is very critical here that decides the brightness of fraction of the disc illuminated, even while the planet is at its nearest to us. One can make a simple calculation assuming that the Earth and Venus follow concentric, coplanar circular orbits. If  $\theta$  is the phase angle between the Sun, Venus and the Earth ( $= 0^{\circ}$  at superior conjunction), the fraction of the observable disc of the planet is  $f = (1 + \cos \theta)/2$  and its apparent brightness proportional to  $f/d^2$  where  $d$  is distance of the planet from the Earth. In contrast, the elongation  $\phi$  is the

angle between Venus, Earth and the Sun. At the time of Contact I, the elongation is the sum of the angular radii of the Sun and Venus. Using the law of cosines, the respective distances of the objects can be related and  $m$  computed<sup>47</sup>.

With Jet Propulsion Laboratory's Horizons ephemeris system,<sup>48</sup> we compute the brightness  $m$  attained by Venus on May 18 and Jun 03, 1032 AD at the time of its heliacal setting and rising in the twilight respectively. When the altitude difference is  $\sim 9^\circ$ ,  $m = -4.06$  mag. and  $-4.12$  mag. on the respective dates. At Contact I, a minuscule fraction of its disc is still illuminated ( $f \sim 10^{-5}$ ) so that  $m \sim +5$ , suggesting that Venus is not completely lustreless. Only, it will be invisible to the naked eye, even when the Sun is close to the horizon.

### 5.3 The *zīj*es and the attainable precision

To recall, a *zīj* comprises of tables of observational data on the motion of the Sun, the Moon and the planets and times of day and night and guidelines for the astronomers to use for astronomical computations and predictions.<sup>49</sup> The *zīj*es were based on the geocentric model of Ptolemy, refined with corrections and improvements that had been going on since the last two hundred years. A majority of the *zīj*es were computational tables (*Zīj-i Hisābī*) only. A few astronomical tables, the *Zīj-i Raṣadī*, were prepared from direct observations at a *raṣadgāh* (observatory).<sup>50</sup> In the later period, *zīj*es were compiled mostly in Persian.

The first *zīj* was prepared by Caliph al-Manṣūr's court astronomer al-Fazārī that he based on the *Brāhmasphuṭa Siddhānta* of Brahmagupta (628 AD). By the 9<sup>th</sup> Century, tables with positions of the Sun, the Moon and the five planets corresponding to each day in a particular year, were being prepared in Baghdad in Arabic.<sup>50</sup> Of these, the *zīj*es extant prior to the times of Ibn Sīnā are those of Ḥabash al-Ḥāsib al-Marwāzī (ca. 850 AD) and al-Battānī (see later). In his exposition on the Leipzig manuscript of a recension of a 10<sup>th</sup> Century *Mumtaḥan Zīj*, one of the earliest *zīj*es extant, Dalen<sup>52</sup> points as to how astronomers would compute the time difference between the setting of the Sun and the planet taking its latitude into account. The *Zīj* cites  $5^\circ 40'$  as the value of the arc of visibility of Venus.<sup>52</sup> Once inside its heliacal altitudes, the planet's path could be known with reference to the tables of its position and motion.



A *zīj* greatly facilitated astronomical computations. From the mean motion tables, an astronomer would be able to know, approximately, the position of a planet some time in the future as also determine how far it had drifted from its initial position. Since the motions are not uniform and retrograde too, the position would need to be regularly fixed for which correction factors could be found in the appropriate tables. Thus, an astronomer could determine the number of days elapsed since or would elapse until the first or last visibility of a planet, and from the difference in the velocity of the planet and the Sun the time of its first or last visibility.<sup>52</sup> That would also enable computation of the geocentric distances to the Sun and the planet.

The central question now is the precision attained in measurement of angle and time in Ibn Sīnā's times. As we get it from Roche,<sup>53</sup> Ptolemy claimed a minimum error of observation of  $\pm 10'$ . Shuttleworth<sup>54</sup> mentions that Abū al-Zarqālī (1029 – 1087 AD) improved upon the Greek astronomical devices and developed big mural sextants and quadrants with which one could reach an angular precision of a few seconds of arc. Al-Jazārī (1136 – 1206 AD) constructed the first mechanical clock that could measure time to the hour. These developments are some time after Ibn Sīnā, and we can only make a guess about the instrumental precision reached in his times. Similarly, we may ask for the precision attained in computations. The cue comes from the precision attained in the prediction of eclipses. Ibn Yūnus (d. 1009 AD), the great Egyptian astronomer and mathematician, reported observations of about 30 solar and lunar eclipses, including many observed by himself that occurred during the period: 829–1004 AD.<sup>55</sup> These and certain other records enabled him to refine the eclipse computations and to determine longitude difference between the places of observations of the predicted eclipses. The Muslim astronomers measured timings by measuring altitudes of the Sun or Moon or a bright clock-star that they reduced to local time using astrolabes and the *zījes*. Stephenson and Said<sup>56</sup> cite from an account of a solar eclipse of Aug 17, 928 AD where the observers were able to measure the altitude of the eclipsed Sun, observing its reflection in water to a third of a division of the measuring ring that itself was graduated in thirds of a degree.

In his work *al-Zīj al-Ḥākīmī al-Kabīr*, Ibn Yūnus mentions his observation of a conjunction of Mercury and Venus in longitude on the

evening of May 19, 1000 AD. He noticed Mercury a third of a degree north of Venus.<sup>57</sup> We find that the conjunction (in RA) happened in the constellation of Gemini at 17:45 UT with the respective declinations differing by  $\Delta\delta = 23'.1$ .<sup>41</sup> Said and Stephenson<sup>58</sup> examined and computed afresh the data available in the Arabic works of Ibn Qurra (836 – 901 AD), Ibn Yūnus, al-Battānī (850 – 929 AD) and al-Bīrūnī and deduced that the average error in the meridian altitudes measurements by the Arab astronomers between 830 – 1020 AD, generally taken at the solstices and the equinoxes, was  $\sim 0^\circ.02$ . In their computations, the timing discrepancy in the prediction of eclipses from the extant *zījes* was not way off the observed timings for it came to be a fraction of an hour.<sup>59</sup> That gives us an idea of computational and possible instrumental precision to be attained, while constant ephemeris corrections with new observed data worked to advantage. In the end, it depended on how accurately one could graduate a circle. In the eclipse measurements, Stephenson and Said<sup>56</sup> infer typical errors of about  $1^\circ$ , correspondingly the timing error being about 4 minutes.

How did a singular measurement fare in an observation? Grant a small error to the graduations and scales on the instrument that creep in the process of fabrication, and whether mounted or hand-held, one would wish it still be better than a degree. Angular diameter of the Moon/Sun is a good guide but let us take a least count of  $\sim 1^\circ$  a handy astrolabe might give them. The earliest surviving astrolabe is the one of 315 A.H. (927 – 928 AD) by the mathematician-astronomer Nastulus, extant in the Kuwait National Museum.<sup>60</sup> King<sup>61</sup> recently described a new instrument of Nastulus, datable ca. 900 AD, which is “in the form of an astrolabe”. It is made in brass, diameter 19.2 cm and total height 26.7 cm, with a ring on top (to hold or hang) and where precision markings engraved to  $1^\circ$  are clearly noticeable.

#### 5.4 The transit re-created

We now have a fair idea of precision attained by the medieval Muslim astronomers. We can recreate the transit and size up the transit zone from the limiting circumstances. Imagine Ibn Sīnā equipped with tables corresponding to the meridian of a reference location. It would contain mean positions of the planets starting from a particular epoch. One needs to add the mean motions of the objects for the elapsed time to determine their

current mean position. To correspond to the current location, corrections for the difference between the geographical longitudes ( $\Delta\phi$ ), generally provided in the mean motion tables in a  $z\bar{ij}$ , are applied. In the course of matching computed positions with the true positions, Ibn Sīnā would have come across the peculiar situation where in the wake of its heliacal setting, the planet's path was going to cross the ecliptic well nigh the position of the Sun. That no one had encountered before. During the last superior conjunction that happened on Aug 2, 1031 AD at 16:00 UT (Isfahan), Venus had actually bypassed the Sun by over a degree.<sup>41</sup>

To know the exact timing of the Contacts I - IV in a transit is very difficult, for both objective and subjective reasons. That is because of the optical effects (atmospheric seeing and instrumental diffraction)<sup>62</sup> and the solar limb darkening<sup>63</sup> distorting the silhouette of the planet's disk – the black drop effect that may seem to last from seconds to a minute.<sup>64</sup> Ibn Sīnā sensed what was coming but he could not have known exactly when the planet may arrive at the Sun. Also, he could not know he would see Venus if it did so.

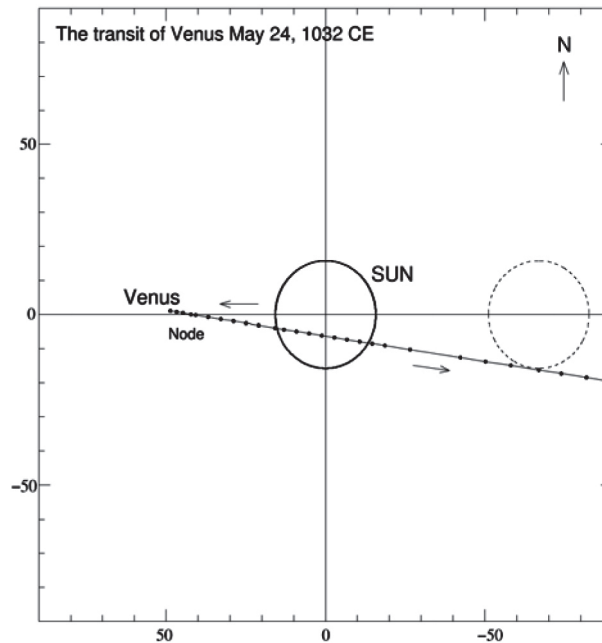
In the Table 4 are the respective ecliptic positions of the Sun and Venus (in degrees) on a few dates of interest as computed with JPL's Horizons ephemeris system.<sup>48</sup> We have also included the respective positions what Ptolemy's Model would give for the two, using van Gent's Almagest Ephemeris Calculator<sup>65</sup>:

**Table 4**

Date, time 1032 AD	<i>Almagest</i>				Modern				
	Sun		Venus		Sun		Venus		
	$\lambda$	$\beta$	$\lambda$	$\beta$	$\lambda$	$\beta$	$\lambda$	$\beta$	
<b>May 18, 15:27 UT, sunset</b> 57;29,22 0;00,00 (the day of heliacal setting)	77;29,12	1;57,33	62.8162116	0.0000	72.4101528	1.3112578			
<b>May 24, 15:18 UT, transit Contact I</b> 63;09,42 “	75;00,59	0;56,55	68.5378791	“	68.8019536	-0.0654322			
<b>Jun 03, 01:24 UT, sunrise</b> 72;04,35 “ (the day of heliacal rising)	69;27,54	-0;52,29	77.5181506	“	63.3835937	-2.1589099			

*Note:* The semicolon in the numbers is the sexagesimal point. That is, 57;29,22 means 57°29'22".

The orbit of Venus is inclined by  $3^{\circ}.39'$  to the ecliptic plane and the transit occurs depending on where the node is placed with respect to the Sun. It is limited by the points on the ecliptic on either side of the node where grazing incidence would take place. We term it the transit zone, vide Fig. 2. In the present case, these points are separated by  $\sim 4^{\circ}$ , spaced apart in time by  $\sim 58$  hours. It will be realistic to presume that Ibn Sīnā's possible computational errors were smaller than that. Venus passed its descending node on May 24, 1032 AD at 08:38 UT (Julian) and the grazing latitudes  $\beta \sim \pm 0^{\circ}.27$  on May 23, 05:00 UT and May 25, 12:13 UT respectively.<sup>48</sup> Note that the asymmetry in time spans between the grazing incidences with respect to the node is the same way as it is in between the time spans of heliacal



**Fig. 2.** An illustration of the transit event of 24 May 1032 AD, showing the descending node and the contacts drawn to the scale using values computed with JPL's Horizons system, including the angular diameters of the objects [ $57''.63$  (Venus) and  $1888''.58$  (Sun) respectively]. The  $x$ -axis is the longitude difference  $\Delta\lambda$  ( $\lambda_V - \lambda_{\odot}$ ), in arcmin, between the respective ecliptic longitudes that should be increasing from right to left. The  $y$ -axis is ecliptic latitude  $\beta$  (arcmin). The Sun (broken and continuous circle) moves W-to-E (right to left) along the  $x$ -axis while Venus (the dot) moves left to right along the sloping line. The first dot (extreme left) corresponds to Venus as at 07:00 UT. The planet passed its descending node by 08:38 UT and made the Contact I with the Sun at 15:18 UT at the position angle  $PA = 104^{\circ}.445$ , and Contact III at 22:32 UT respectively (see text).

setting-to-conjunction and conjunction-to-heliacal rising respectively. The heliacal dates above correspond to an altitude difference of  $\sim 9^\circ$ .

As a parallel, we give in the Table 5 the respective positions (*sexagesimal*) at the node and at the conjunction what Ptolemy’s Model<sup>65</sup> would give:

**Table 5**

<i>Almagest</i>	$\lambda$	$\beta$
May 29, 1032 CE, 14:00 UT, Venus at the node		
Sun	67;50,30	0;00,00
Venus	72;13,50	0;00,05
Jun 01, 1032 CE, 09:30 UT, conjunction		
Sun	70;30,11	0;00;00
Venus	70;29,48	-0;33,06

In Ptolemy’s model, the planet passed its node – the descending node, on May 29, 1032 AD, 14:00 UT. The date when the differences in the respective (geocentric) ecliptic longitudes  $\lambda$  and latitudes  $\beta$  (in degrees) of the Sun and the planet reach a minimum is June 1, 1032 AD, Thursday and, strikingly, the transit itself is missed, by  $\sim 17'$ . It would be naive to expect Ptolemy’s algorithm, with his astronomical constants, to work nine hundred years in the future. The contemporary, observation-based *zīj*es would be more precise.

It may be noted that the *Almagest* Ephemeris Calculator<sup>65</sup> gives values to the last second and the last arcsecond though positions at such precision were not measurable in Ptolemy’s times. On this, van Gent<sup>66</sup> comments that

“the discrepancy between the *Almagest* date of the Venus-Sun conjunction (1 June 1032 [Julian]) and the true date (24 May 1032 [Julian]) is due to the errors in Ptolemy’s theory of Venus which (nearly a millennium after Ptolemy) become rather large. A much better agreement would surely be expected when one uses more contemporary Islamic astronomical tables (such as those of al-Battani).”

Al-Battānī (850 – 929 AD) was an accomplished Arab astronomer and mathematician. His *al-Zīj al-Ṣābi'* (Treatise on Astronomical Tables) was a major work based on his own observations, from 877 to 918 AD,<sup>67</sup> including the eclipses that had a great impact on astronomy in the times to

come. The *Zīj* demonstrated the solar apogee having moved from its stated position that was considered fixed by Ptolemy in Gemini and rectified the values of the various astronomical constants (obliquity of the ecliptic to 23;35 degrees, the longitude of the solar apogee, precession to 1° in 66 years etc.) astronomers used, the planetary orbits etc. The *Zīj* also carried a catalogue of fixed stars for the year 880–881 AD,<sup>68</sup> and even the geographical coordinates of places, etc. That suggests the medieval astronomers' errors would be comparatively smaller. Incidentally, after Ptolemy died in 170 AD, there was a transit of Venus not many years later, on Nov 22, 181 AD (the last one being on May 23, 60 AD), Contact I at 19:36 UT.<sup>29</sup> However, here too, using the *Almagest* Ephemeris Calculator, we find that Venus passed its node on Nov 19 and its minimum separation from the Sun occurred at  $\beta=0;55,07$  degrees on Nov 25, at about 01:00 UT. Thus, the transit was missed by more than half a degree in latitude with respect to the Sun. For errors comparatively smaller than what resulted for the transit of 1032 AD, Ptolemy's model was not all that crude for his times. Ptolemy was appreciative of the peculiar planetary movements and to describe these, his model grew to be more complex. According to van Gent,<sup>69</sup>

“Ptolemy's theory for the latitude of Venus was perhaps too simplistic. If Ptolemy had more and better observations of Venus his model for the apparent motion of Venus would probably have worked better”.

To adjudge whether Ibn Sīnā had got the inkling of what was coming, the foregoing computations need to be done using al-Battānī's tables, or for that matter, Ibn Sīnā's own tables if available and with the new values of the astronomical constants he had determined. These would have enabled him to compute the mean positions of the planet and the Sun for several weeks on either side of the day of conjunction. Within the transit zone, the planet should meet the Sun. In the event the predicted positions came to be in sufficient conformity with the true positions such that Venus landed on the day of conjunction within the transit zone, it makes for an achievement for his times.

It may be stipulated that Ibn Sīnā followed the planet in real time, continuing the watch on the day of conjunction for hours. One may ask why did he specifically choose a place where horizon was available? As it is, one would want to follow the target for as long as possible. Besides, on location,

Ibn Sīnā would not be alone. The look out may have continued right until the sunset when it was time for change of day, and prayer too;<sup>70</sup> see also our *Notes*.<sup>71</sup>

Notably, eight years later, the transit of Venus recurred in 1040 AD on May 22 but there are no indications in literature of repetition of such an observation by others.

### 6. THE PLANET IN TRANSIT OR A NAKED-EYE SUNSPOT?

Goldstein<sup>72</sup> cited a newspaper report of the naked eye sighting of Venus in transit in 1874 from Hawaii, where people kept ready smoked glass to view the Sun at 3:30 in the afternoon. Similarly, the Reverend Johnson<sup>73</sup> reported the planet Venus distinctly visible to the unaided eye through a darkened glass during the transit on Dec 6, 1882 observed by a number of persons at Bridport.

Can the event be resolved by naked eye at all? The limit of detection by normal human eyes (20/20 vision) is ~ one minute of arc. That is also the apparent diameter of Venus while transiting across the face of the Sun (diameter 31'48" on May 24, 1032 AD; Venus diam.: 57".64).<sup>48</sup> Actually, here, we have the case of detection by contrast on a bright extended object. Since the contrast is as good as 100%, it improves the resolution visually but is limited by smearing due to scattering and the resolving power of the observer. Writing about the stunning 2012 Venus Transit image taken with the Hinode spacecraft, Morrison<sup>74</sup> comments –

“..... (Venus had an angular diameter of 58 arc seconds during the transit - about 1/30th of the Sun’s diameter) I find it interesting that with solar glasses (seen from New Zealand) Venus appeared as a very clear circular disk against the Sun’s surface. As the Eye’s resolution is only about 30 arc seconds, theoretically one should not be able to see a distinct disk - but we can. I suspect that this is similar to the fact that we see a very sharp edge to the Moon but it really should be a little blurred. I think these observations show that our brain does quite a bit of work on the images captured by our retina!”

That was because one knew that the planet was in transit. What made Ibn Sīnā think, should Venus pass the Sun, it can be noticeable? Since it is possible to stare at the Sun around the sunset time for relatively longer moments, Ibn Sīnā should have been able to notice a black spot on it. If that

was not a sunspot, and he was convinced that it is the planet, it constitutes to be a remarkable observation. As significant is the first indication in history that the planet Venus had a finite (angular and physical) size.

Ibn Sīnā does not say where exactly on the body of the Sun he saw the 'mole'. The planet in transit touches the Sun at its eastern limb, near the equator. Its traverse is never equatorial though (vide the Fig. 2). Anyone who observed the transit on May 24, 1032 AD around the sunset would notice the cut or spot nearly on top of its disc. The position angle (PA) of Venus with reference to the centre of the disk of the Sun, measured north to east, can be expressed as  $\sim \pi/2 + \sin^{-1} \beta/r$  where  $\beta$  is the ecliptic latitude of the planet at the time of Contact I and  $r$  the angular radius of the Sun. For  $\beta = -0^\circ.0654322$  (Table 4), the PA is  $104^\circ.445$ . A large sunspot would normally appear near the equator. Here, the PA of Venus is not so large as to discredit the sunspot idea. On June 03, 1032 AD when Venus *rose*, the Sun had rotated about its axis so much that the spot, if a sunspot, having reached the other limb of the disc, might still be around. This fact would be noticeable. Appreciative of the planet's speed around the days of the conjunction, the continuance of a spot(s) through the days ever since the conjunction would only perplex them as to why Venus is where it should not be. Alternatively, Ibn Sīnā may as well have seen the spot close to the western limb that vanished as the Sun turned it away the following day. Should that be so, we have the peculiar case of an observer misled into a conclusion, vetted by some later astronomers, that is right but drawn from a misperception.

One is aware of claims to seeing sunspots by naked eye, even those with size smaller than one minute of arc. For example, an author<sup>75</sup> mentions of nine seen in the first two months of 1907, and Bart Bok (1906-83) while observing the total solar eclipse of Feb 16, 1980 from the Jawalgera Camp of the Indian Institute of Astrophysics (IIA)<sup>76</sup> mentions of a naked-eye sunspot. Keller and Friedli<sup>77</sup> have determined the threshold limit of sunspots observable to naked eye on the basis of observations made by twenty observers. They found that a normal eye can detect a sunspot of 41" in penumbral diameter and 15" in umbral diameter. Their measured limit from the tests is 19".3, which indicates that the visibility is contributed by the umbral and the penumbral diameters both. At 1 AU, a spot of the size of the Earth will



subtend an angle of 17".6. Solar astronomers express size of a sunspot as fraction of the visible area of the Sun, the unit being 'millionth'. A spot of the Earth's area is 169 millionths while big spots are generally 300-500 millionths. For example, on March 29, 2001, the active region AR9393 on the Sun reached a size 2400 millionth, or, about 14 times as big as the Earth and the biggest since 1991 though there have been many still bigger.<sup>78</sup> In the years 1980, 1991 and 2001, the Sun was very near its peak activity.

It is not obvious if the Muslim astronomers had any clear perception of sunspots. A Sun with spots was philosophically challenging. Such sightings did come up for discussion or commentary among the Muslim astronomers but would be dismissed and instead, taken as transits. Odenwald<sup>6</sup> mentions of claims of dark spots seen on the Sun's disc in the years 840, 1030, 1068 and 1130 AD that were thought to be transits of Mercury or Venus; see also Goldstein (1969). Mercury in transit is not visible by naked eye. The transits of Venus occurred in the years 789, 797, 910, 1032, 1040, 1153 and 1275 AD, and so on. The transit timings *vis à vis* the geographical locations of the observers rule out some of the transit claims (vide Table 1). Therefore, the above-mentioned claims could be to sunspots only.

Finding a sunspot by naked eye suggests the Sun was active in 1032 AD. In that case, there does not have to be only one big spot on the Sun. We crosscheck this aspect from the works on the pre-telescopic sunspot observations and the re-constructed history of the solar cycle; one may see Usoskin<sup>79</sup> for an overview. One of these works provides a detailed analysis of the data on atmospheric Carbon – 14 deposits in tree rings, inversely related to sunspot number. In the process, one encounters periods of grand minima in solar activity in history, when the sunspots disappeared almost completely. One such grand minimum may have occurred in the year 1040 AD.<sup>79,80</sup> A transition from normal high activity to such minima is sudden that can occur within a period of a few years without signs of a precursor.<sup>81</sup> That suggests the year 1032 AD could be one of high solar activity. On the other hand, there are pointers to a quiet Sun over a long period of time around the date in a similar study by Clark and Stephenson<sup>82</sup> that they based on the ancient records of sunspot observations in China and Korea, vide their Fig 1. One limitation is that these authors got fewer records in the 11<sup>th</sup> Century than in the 12<sup>th</sup> Century. Also, according to the study by Vaquero,<sup>83</sup> the Sun was quiet around this period, vide his Figure 1a where he presents the 50-

year moving average of the number of annual naked-eye sunspots recorded over the past 22 centuries. It is probable that in 1032 AD, the Sun was quiet.

### 7. HISTORICAL SIGNIFICANCE OF VENUS

A more basic question before us is why planet Venus became the object of attention. Ibn Sīnā lived in a rigorous Muslim society. Though their motivation was astronomical than mere religious or cultural ? the vestiges of the pagan times — it is worthwhile to look briefly at the latter aspects.

*Venus* has been worshipped in many ancient cultures. *Venus* is a Roman goddess, also personified as the Greek goddess *Aphrodite*, the Babylonian *Ishtar* and the Sumerian *Inanna*, etc. The Mayans' rituals centred around the cycles of Venus. Venus in Persian mythology is the goddess *Anahita*, *Naheed* in modern Persian, and *Zuhra* in Arabic, both feminine and symbolizing female power. Its significance can be gauged from the fact that in *Surah 86:1-3* of the *Qurān* there appears a word *al-Tāriq* that refers to the planet Venus. The various translations of the word are: the bright star, the morning star, the night visitor.

Venus, one among the triad of the foremost celestial bodies, has held a crucial position in the planetary order of Ptolemy. Its eccentric conduct presented a challenge to the geocentric worldview. In Ptolemy's scheme, the centre of the main orb (sphere), called the deferent lay between the Earth and another point, equant. The epicycles moved on the deferent but about the equant, not about the Earth. As Goldstein<sup>84</sup> observes,

“Fundamental to Ptolemy's geocentric system is the nesting hypothesis: that the maximum distance of one planet from the earth is equal to the minimum distance of the planet above it..... With rare exceptions medieval astronomers supported the nesting principle, but they considered the order of the planetary spheres to be an open question. There were three views: Mercury and Venus both lie beneath the sun; Mercury is below the sun and Venus above it; Mercury and Venus both lie above the sun. I think it is fair to say that a modern scientist confronted with this situation would try to predict the time of a forthcoming planetary conjunction with the sun and then would observe to see if a transit occurred, for Ptolemy himself had indicated this method of resolving the question. Only a positive result would be conclusive, because Ptolemy had already

suggested that the body of a planet might be too small to be seen against the sun. We may then ask if such a procedure was technically feasible for a medieval astronomer. The first part of his work would be to predict the conjunction for a planet near one of its nodes.....”.

The last point above is what we are trying to make a case for in the present context. Venus was a prime object of interest to the Muslim world for more reasons than one and was keenly followed. Observations of motions of the planets interested them – around the times of opposition and conjunctions as also the ecliptic crossing, and precise determination of their longitudes and latitudes.<sup>85</sup> Venus has a synodic period of 584 days. It conjuncts the Sun twice during this cycle, called inferior and superior conjunctions. In a span of eight years, there occur five alignments between the Sun, Venus and the Earth. These conjunctions trace out in the sky a five-pointed star, namely, a pentagram, also termed a pentacle (a pentagram enclosed in a circle). The synodic cycle begins with the inferior conjunction. The Babylonians knew that Venus appears at the same spot in the sky in eight years.<sup>6,86</sup> The Muslim astronomers were familiar with the cycle implying that the conjunction was anticipated. Ibn Sīnā was aware of the pattern of conjunctions and so routinely followed the heliacal settings and risings of the planet. The synodic period being 583.92 days, the initial point drifts slightly by the time Venus returns to trace out the next eight years cycle. Therefore, the pentagram is not a perfect one. The points of the pentagram move about the ecliptic too. A transit happens when a point of the pentagram aligns with the node.

The New Moon happened on May 12, 1032 AD and Mercury had its superior conjunction with the Sun the following day. Just as they saw the first lunar crescent, a bright Venus stood nearby. As the days passed, Venus grabbed greater attention for it was rushing to its heliacal setting and inferior conjunction with the Sun. With planetary positions in hand and from its angular speed-up, Ibn Sīnā could have computed the approximate epoch when Venus was likely to conjunct with the Sun and later rise in the opposite direction. His precision may not be so bad as to not detect the fact the planet would cross the ecliptic a short while before the conjunction. To recall, Venus crossed this point (i.e., its node) on May 24 by 08:38 UT, over six hours before it arrived at the Sun (vide Fig. 2 above).

### 8. DISCUSSION

The question whether Ibn Sīnā carried out the observation from Isfahan or Hamadan, and the year 1032 AD, is not settled. The terrain and visibility – the line-of-sight conditions towards the horizon at Hamadan/Isfahan – are as much a concern, for these are deciding factors in respect of the claimed observation. We are not able to ascertain if it was a field observation, made from some other place, crucial if from west or north-west of Isfahan. Should eyesight be an issue? Our celebrated observer, 52 and beset with an imperfect health, indulged and was much discussed about in the corridors of power for leading an Epicurean's life.<sup>87</sup> Therefore, as per the claim, what did he observe – the planet against the disc of the Sun or just a sunspot?

Ibn Sīnā would not know if his own location in longitude could matter in the observation, although transits can be viewed from a large spread in latitude and longitude over the globe; the angle the Earth subtends at the distance of Venus while at its inferior conjunction is ~1 arcmin. Being located where he was made the situation acute but it also gave an opportunity of a less strenuous visual. Ibn Sīnā's description translating into the observation of the transit of Venus can have credence if the conditions were ideal at the location of observation. Nazemi<sup>42</sup> points out that the topography is such that “in the center of today's Esfehnan you could observe such transit about 15 minutes before sunset”.

Or, was the observation mistimed; the observation might actually be that of a sunspot? The year 1032 AD may or may not have been one of active Sun. If it was a sunspot, there could as well be some more and some visible, emerging now and then. That Ibn Sīnā would be able to notice in the days to come. One therefore asks why should he refer to the spot, specifically as Venus?

In other words, when Ibn Sīnā said he saw Venus on the surface of the sun, he meant it. Pouria Nazemi<sup>38</sup> has provided us the crucial passage (in Arabic) from astronomy chapter in the *Kitāb al- Shifā'*,<sup>88</sup> reproduced below, together with his own translation -

أما كرة الزهرة وكرة عطارد فإن الأقدمين رتبوهما تحت كرة الشمس وبعض من تأخر عنهم رتبهما فوق كرة الشمس أيضاً إذ لم يجدوهما تكسفان الشمس وهذا غير واجب فإنه يجوز أن لا يكون مجزئهما تحت الشمس في السطح الذي يمر بأبصارها ومركز الشمس ومع ذلك تكون تحت كرة الشمس ولا تكسفان الشمس كما يكون في أكثر اجتماعات الشمس مع القمر أقول إنى رأيت الزهرة كذالك وشامة في صفحة الشمس.

Tr:

“But the spheres of Venus and Mercury are under the sphere of the Sun. But some recent scientists said that these spheres are over the sphere of the Sun. Because they couldn’t see Venus eclipsing the Sun. But this eclipse (transit) is not (always) necessary. Because it is possible they (Venus and Mercury) pass from under the surface of Sun and we can not see them in front of the disc of Sun. That is just like the situation that happens during Moon and Sun conjunction. AND I SAY, I SAW MYSELF, VENUS LIKE A BLACK DOT ON THE DISC OF SUN.”

In *al-Shifā’* passage we have reproduced above, Ibn Sīnā explains why a transit does not take place at every conjunction. He contests also those who differed and placed Venus, or even Mercury and Venus both, above the Sun. That is a fundamental deduction, more significant than the sighting alone. It can come only from an actual observation and an understanding of Ptolemy’s model. While it bears testimony to Ibn Sīnā’s command over the science, to us the observation also suggests that the venue might be way up north-west of Isfahan, possibly near Hamadan.

The size of a planet was expressed in terms of brightness for that was the only convenient way, not angular or physical size. Ibn Sīnā’s observation provided the first direct proof that Venus has a physical dimension and that its orbit has nodes. A logical thinking would have turned it into a cogent handle to confront the curious inverse relation between size and distance that is inherent to Ptolemy’s model. However, there is no such after-thought by Ibn Sīnā or his commentators to carry the implications to the next logical level. Ptolemy does not consider sizes of the planets in *Almagest* but in his *Planetary Hypotheses* where he deals with his models of planetary motion he speaks about sizes, though only corresponding to their mean distances and not of the variations with distance. Ptolemy had propounded in the *Planetary Hypotheses* a magnitude scale for stars, 1 to 6, where the apparent brightness of a star was a measure of its apparent size; though he did not write down such a scale for planets. The medieval Muslim astronomers presumed that the apparent sizes of the planets were according to their (apparent) brightness. In that sense, if the planet Venus did not appear to change much in its brightness, accordingly it did not vary much in size. What in reality stems from the combined effect of fraction of the disc of Venus that is illuminated at a given time and its angular size, they

saw as being contrary to Ptolemy's model. Therein, Venus measured one-tenth of the size of the Sun at its mean distance and in consequence it would attain an implausibly large value of 2/5th of the size of the Sun when nearest the Earth. To circumvent this difficulty, a 13<sup>th</sup> Century Arabic text assigned the one-tenth figure to the planet's minimum distance.<sup>89</sup>

### 9. CONCLUSION

In this paper, we have explored the pros and cons of a scenario built from a brief statement attributed to Ibn Sīnā: "I say that I saw Venus as a spot on the surface of the sun", or, "AND I SAY, I SAW MYSELF, VENUS LIKE A BLACK DOT ON THE DISC OF SUN".

We have considered astronomical circumstances of the transit event employing Espenak's Transit Predictions as also Jubier's, specific to the cities of Isfahan and Hamadan. They suggest that Ibn Sīnā could indeed have obtained a glimpse of the transit of Venus just before sunset from either of the places, though circumstances are more critical at Isfahan. Between the two places, it is more likely to be a place west or north-west of Isfahan, probably Hamadan itself. Despite the apparent confidence, Ibn Sīnā's claim appears to have been evaluated in isolation only. It is detached from an even more significant statement in the *Kitāb al-Shifā'*, wherein explaining his observation he argues out others saying just as it happens during the conjunction of Moon and Sun, a transit does not take place at every conjunction because Venus has a different angle with the ecliptic. In other words, there exist nodes in the path of the planet Venus. Ibn Sīnā's observation has in it also the first direct proof that the planet is a material body with a finite angular (and physical) size.

We have also considered whether Ibn Sīnā's observation could be that of a sunspot. As we learn from some works on the historical sunspot sightings, and reconstruction of the solar cycle over the past two millennia, it is probable that ca.1032 AD, the Sun was rather quiet. That is not to wish away the sunspot possibility altogether. However, for a people, who diligently tracked the planets, from their heliacal setting and rising and conjunctions with the Sun and made observations to construct planetary paths with a precision at sub-degree level to constantly improve upon their *zījes* (astronomical tables) so that Ptolemy's model could work better, mistaking a sunspot for Venus does not seem a cogent proposition.

There is no doubt that the entire episode left a legacy entailed by more questions before the Muslim astronomers than answers. We do not come across accounts that carried forward Ibn Sīnā's contention based on his observation. By logical extension, Ibn Sīnā should have repeated his observation when the next conjunction befell. Any observation of the superior conjunction of March 15, 1033 AD that followed the transit would have been valuable and distinguished his claim. More importantly, it would have given us an idea of his precision with instruments and tables when we look at the circumstances on the date<sup>41</sup> – Sun: R.A. = 00h 00m 01s, Dec. = +0° 0.1'; Venus: R.A. = 00h 00m 08s, Dec. = "1° 26.3'; 00:00 UT.

While drawing our own inferences, if we have faced more questions than answers, that is because of several limitations. The worst thing in the entire episode is that the date and place of the observation are not given, unusual for a people ever at work with their astronomical equipments. Add to that a small but finite error in judgment arising from our own simple computations. In fairness, the author himself should visit the scene of action. In the absence of all these, our considerations leave still a smaller room for uncertainty in Ibn Sīnā's claim than is made out from Goldstein's (1969) observation. Goldstein's conclusion was general, since the astronomical circumstances were less precise and not location specific. Here, in our examination, we have more precise transit timings and specific locations. Ibn Sīnā's statement that every conjunction does not result in a transit can come from an actual observation only. It suggests also that the venue of observation could be way up north-west of Isfahan, possibly Hamadan or a place near it. Ibn Sīnā's claim fills an important gap in the history of astronomy for the period 1030 AD onwards and bears testimony to his observational acumen and computational precision.

#### 10. ACKNOWLEDGEMENTS

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## 11. NOTES AND REFERENCES

1. Bijli, 2004, pp. 114-119.
2. Goldstein, 1969, p. 56; see also his discussion on p. 57, *Notes 14*.
3. Saliba, 2011, Section on *Astronomy*.
4. Regep, Sally, 2007, p. 571; also see Goldstein, 1969, p. 57, *Notes 14*.
5. Hadavi, 1986, p. 686; also see Hadavi, 1987, pp. 690-691.
6. Odenwald, 2012, Section: *Ancient History: Pre-1631 A.D.*
7. Johnson, 1882, p. 41.
8. Whatton, 1859, p. 17 and pp. 43-45.
9. Teets, 2003, pp. 336-337.
10. Goldstein, 1972, p. 44.
11. Goldstein, 1969, pp. 50-51; see also his *Notes 2*.
12. Goldstein, 1969, pp. 52-53 and his *Notes 16*. The *Notes 16* provides the calculation made by Marsden that he based on the tables of the transits of Venus for the period 3000 BC to 3000 A.D. by Meeus, 1958.



13. Goldstein, 1969, p. 55.
14. Neugebauer, 1975, p. 8.
15. Sharif, 1966, p. 1284.
16. Gingerich, 1986, p. 68.
17. Afnan, 1958, pp. 57-59.
18. Afnan, 1958, p. 75.
19. Regep, 2007, pp. 570-572: To cite a few, there is a treatise on celestial bodies [cosmology; *Maqāla fī al-ajrām al-samāwiyya (al-'ulwiyya)*], a book of complete astronomical observations (*al-Arṣd al-kulliyā*), a commentary on Ptolemy - *Tahrīr al-majisī*, written at Jurjān during 1012-14 AD, a work against astrology [*Maqāla (Risāla) fī ibtāl 'ilm (ahkām) al-nujūm*] and a treatise on astronomical instruments (*Maqāla fī al-ālāt al-raṣadiyya*), written at Isfāhan. The work on Ptolemy was later revised and incorporated into the mathematical section of his encyclopaedic work *Kitāb al-Shifā* that Ibn Sīnā completed at Isfāhan. The work contains nine books on logic, eight on natural sciences, four on mathematics, geometry, astronomy and music, and metaphysics.
20. Goodman, 2006, p. 37.
21. Sadykov, 1980, p. 44.
22. Asimov, 1986, p. 228.
23. Gohlman, 1974, pp. 67-69. It may be noted that Gohlman's is the only critical edition of the Arabic autobiography/biography of Ibn Sīnā; see also Afnan, 1958, pp. 70-72.
24. Regep, 2007, pp. 570-572: In the *Kitāb al-Shifā*, Ibn Sīnā discusses the movement of the solar apsides, regarded fixed by Ptolemy in the *Almagest* at Gemini 5;30°, as apparent from a substantial change noted in the position of the Sun's apogee (the point of its minimum velocity) with respect to the equinoxes since Ptolemy's time to eighteen degrees of Gemini in his times. That is about the apsidal precession of the major axis of the Earth's orbit, resulting from the gravitational perturbation by other planets. Ibn Sīnā measured a new value for precession of the equinox at 1° in 66 years. The Andalusian astronomer Abū Ishāq Ibrāhīm al-Zarqālī of Toledo (1029-87 AD) is credited with being the first to appreciate the apsidal precession with respect to stars (that he put at 12".04 per year and the apogee at longitude 77°50') as distinct from the precession of the equinoxes. However, in Ibn Sīnā's work we see an independent recognition of the distinction, prior to al-Zarqālī's. Ibn Sīnā gave the obliquity of the ecliptic at 23:33:30 degrees that he cited in his work against Ptolemy's value of 23;51 degrees. He also quoted the value obtained in the times of Caliph al-Ma'mūn as being 23;35 degrees and commented how the obliquity had decreased further over the time. He measured a more accurate value for the longitude of Jurjān (Gurgan) from Baghdad at 9;20° (conventional value 8°0; modern 10°.3) from

observations of the culmination of the Moon at the former place where he lived during 1012-14 AD, etc. See also Saliba (2011), Section: *Astronomy*, Sadykov, 1980, p. 44 and Prince (2001).

25. Afnan, 1958, p. 226.
26. Afnan, 1958, p. 78.
27. Nazemi, 2012, personal communication, email dated Feb 23.
28. Islamic Philosophy Online (2001-2007).
29. Espenak, 2012; here, one may find details on the Venus transits, as also explanations to our Table 1.
30. Jubier, 2012a: the part of his website dealing with solar transits.
31. Goldstein, 1969, pp. 52-53; see also his *Notes* 12 on p. 57.
32. Afnan, 1958, p. 74.
33. Blair, 1992, p. 104.
34. Goodman, 2006, p. 44.
35. McGinnis, 2010, p. 25.
36. Goodman, 2006, p. 41.
37. Said, 1986, p. 264.
38. Nazemi, 2012, personal communication, email dated Feb 06.
39. Gohlman, 1974, pp. 63-65.
40. Gutas, 1987/2011.
41. Walker, 2012; we have used Walker's program for some computations in this paper. The ephemerides in our Tables 2 and 3 match well the high accuracy planetary ephemerides produced with the IMCCE's (2012) Ephemeris Generator using the Planetary Theory INPOP10a.
42. Nazemi, 2012, personal communication, email dated Feb 15.
43. Kennedy and Agha, 1960, pp. 135-139.
44. Shukla, 2000 in Sen and Shukla, 2000, p. 253. Independently, the *Sūrya Siddhānta* (ca. 400 AD, and a work in progress until as late as 1100 AD) devotes a chapter to the heliacal rising and setting of the planets, the *nakshatras* (lunar mansions) and some prominent stars. Over the time, the subject has been dealt with in relation to the Moon, the planets and certain prominent stars by many Indian astronomy texts, including Brahmagupta's *Brāhmasphuṭa Siddhānta* that was known to the Muslim astronomers as *al-Zīj al-Sindhind* etc. Islamic astronomy had adopted these works ever since their introduction late in the 8<sup>th</sup> Century AD. According to Brahmagupta, the heliacal altitude for Venus is 9° (mean), for Jupiter it is 11°, etc.

45. The reader may find an interesting account on this in Walker's 2012 website.
46. Baldwin, 1880, pp. 573-574.
47. *Anonymous*, 2006, p. 4-5.
48. Jet Propulsion Laboratory's Horizons ephemeris system.
49. King et al., 2001. The Section 1 gives a general introduction to *zīj*es. Specific to the longitude of observation, a *zīj* would provide epoch position and mean motion of a planet and eventually its true ecliptic position.
50. Ghorī, 2000, pp. 26-27; see also King et al., 2001, p. 26.
51. Jubier, 2012b, personal communication, email dated Sept. 07.
52. van Dalen, 2004, pp. 25-26.
53. Roche, 1998, p. 29.
54. Shuttleworth, 2010, *Islamic Astronomy*.
55. Stephenson and Said, 1991, p. 195.
56. Stephenson and Said, 1991, pp. 196-197.
57. King, 2008a, "Ibn Yūnus....."
58. Said and Stephenson, 1995, p. 129.
59. Said and Stephenson, 1996, p. 262; see also Said and Stephenson, 1997, p. 48.
60. Gingerich, 1986, p. 70D.
61. King, 2008b, p. 101.
62. Proctor, 1882, p. 224.
63. Duval et al., 2005, p. 175.
64. Maor, 2000, p. 95.
65. van Gent, 2012a, *Almagest Ephemeris Calculator*.
66. van Gent, 2012b, personal communication, email dated Jan. 30.
67. Ghorī, 2000, p. 28.
68. Sharif, 1966, p. 1288.
69. van Gent, 2012c, personal communication, email dated Feb. 15.
70. The *Maghrib* (dusk) prayer is the fourth of the formal daily prayers offered soon after the sunset, i.e., after the Sun sets completely below the horizon. Whether Ibn Sīnā was particular about the rituals is less certain, his entourage might be so. That depends on how well Islam was implanted in the land in the times. By the tenth Century, we learn, the religion had reached deep into the countryside (see Anisi as in the *Notes* 71

below). That also brought along the Islamic lunar calendar where the day changes at sunset and a month begins with the actual sighting of the first lunar crescent post sunset. We also know that the Persian solar calendar (commencing from the vernal equinox) remained in use for centuries after the Arab occupation of the land.

71. Anisi, 2007, p. 12.
72. Goldstein, 1969, p. 49; also see Goldstein, 1972, p. 44.
73. Johnson, 1883, p. 75.
74. Morrison, 2012, *Explore Astronomy*, June 2012, "Image of the Month".
75. author 1907, p. 116.
76. Bok, 1980, p. 5.
77. Keller and Friedli, 1992, p. 88.
78. Spaceweather.com, 2012.
79. Usoskin, 2008, pp. 3-88.
80. Stuiver and Quay, 1980, p. 18.
81. Usoskin, 2008, p. 50.
82. Clark and Stephenson, 1978, p. 400.
83. Vaquero, 2007, p. 14.
84. Goldstein, 1972, pp. 42-43.
85. See Gul-Badan Begam (16<sup>th</sup> Century), p. 54. Few can equal the passion of the second Mughal Emperor Humāyūn (1508-56) who had a keen interest in astronomy and was an acclaimed astronomer who could handle astrolabes. Gul-Badan Begam (1523-1603) was Babar's (1483-1530; r. 1526-30) daughter. She narrates in the *Humāyūn-Nāma* how Humāyūn had a fatal fall on Friday the January 24, 1556 (Julian) headlong off a staircase in his bid to answer the call to prayers from the neighbouring mosque while descending from top of his library in Shīr Mandal in Delhi where he had gone to observe at the sunset time "the rising of Venus, with the object of fixing a propitious hour for a reception...". Three days later, on Jan. 27, Humāyūn died. Venus was past its superior conjunction that happened on Dec. 19, 1555, 13:00 UT. It reached an altitude difference of  $\sim 5^\circ$  with the Sun on Jan. 11, 1556 and  $\sim 9^\circ$  on Jan. 29. That means what Humāyūn went up for was not a mere seeing but to confirm the 'rising'. That depended on what heliacal altitude he considered for Venus. The planet stood that day nearly  $8^\circ$  above the horizon at sunset (12:27 UT).
86. Sen, 2000, pp. 116-117; in the *Pañcasiddhāntikā*, Varāhamihirā refers to the equivalence between 1151 revolutions of Venus and its 720 synodic periods, thus implying a longitude gain of  $215\frac{1}{2}$  degrees by Venus in each synodic period.

87. Afnan, 1958, p. 77; also see McGinnis, 2010, pp. 16-17.
88. Nazemi, 2012, in his email of Feb 15, has pointed to an online source of historical scientific books in Arabic (in html); the link to *Kitāb al-Shifā'*: the chapter on "Astronomy" is available at: <http://www.alwaraq.net/Core/AlwaraqSrv/bookpage?book=514&session=ABBBVFAGFGFHAAWER&fkey=2&page=1&option=1>, and that the section with Ibn Sīnā's passage on the transit observation is under the menu right side of the page under the title: المقالات التاسعة والعاشره والحادية عشر (Articles ninth, tenth and eleventh).
89. For an excellent discussion, see Goldstein, 1997, p. 6 and Goldstein, 1972, p. 44.
90. O'Connor and Robertson, 1999.

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