2 DEVELOPMENT OF ZĪJ LITERATURE IN INDIA

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Muslim astronomy, or to be more precise, Graeco-Arabic astronomy in Medieval India had its origin in West-Central Asia whence it passed to this country. Valuable contributions were made to it by Arabic and Persian knowing scholars. Hence in order to evaluate these contributions it is essential to know the nature, origin and development of this system, to examine important zījes prepared in West-Central Asia and to understand how they influenced the preparation of their counterparts in India.

GRAECO-ARABIC ASTRONOMY

Nature of Graeco-Arabic Astronomy

Graeco-Arabic astronomy is geo-centric. The earth, a tiny point in comparision with the vast dimensions of the universe is at its centre. The universe consists of thirteen concentric spheres, four terresterial and the remaining nine celestial.[1] Of the latter each of the seven lower ones are made up of a number of components called eccentrics and epicycles.[2] The eccentrics revolve with uniform circular velocity round different centres, not coincident with that of the universe. Each of the seven planets with the exception of the Sun is studied within an epicycle, which in its turn is fixed in the eccentric and the latter in the main sphere called *"al-Mumaththal"*. The sum total of the motions of the *mumaththal* together with those of the eccentric and epicycle determines the apparent motion of that planet. The next outer or the eighth sphere is studied with fixed stars and is called *Falak-uth-thawābit*. The ninth or the outermost sphere is called *Falak-ul-Aflāk* and was assumed to rotate on its axis in about 24 hours. This rotation causes the succession of day and night.[3]

Origin and Development of Graeco-Arabic astronomy in West Asia

Foundation of Muslim astronomy was laid in the very beginning of Islam, which enjoined upon its followers a meaningful observation of celestial phenomena.[4] Astronomy proper started from the reign of second Abbasid Caliph al-Manṣūr[5] (A.D. 753-774) when the *Almagest*[6] and the *Brāhmasphuṭa-Siddhānta* were translated into Arabic. The scientific movement[7] started by Al-Manṣūr reached its climax in reign of his great grandson Al-Māmūn[8] (A.D. 813-833) who built the two observatories at Baghdad and Damascus.[9] The movement continued after him as well. Great astronomers like the sons of Musā bin Shākir, Habash the computer, Al-Kindī, al-Mahānī, Al-Narauzī, Thābit bin Qurra, Sulaymān bin 'Iṣma, to name only a few, flourished after Al-Māmūn. But more renowned than the rest was Albatignius, the illustrious author of *Az-zij aṣ-Ṣābi.*

The tenth century A.D. was the golden period of Muslim astronomy. The Balkanization of the Muslim world provided a new momentum to the progress of astronomy, as different rulers vied with one another in the patronage of science and scientists. It was the age of great astronomers such as Abū Ja'far al-Khāzin in Khurāsān, Ibn ul-A'lam, 'Abdur Raḥmān-aṣ-Sūfī, and Aḥmad bin 'Abdul Jalīl as-Sijzī in Shīrāz (the last named advocated the helio-centric theory), Abul-Wafā' al-Buzjānī at Baghdad, al-Khujandī, the inventor of *Fakhri* sextant at Raj and Abū Naṣr bin Iraq (the teacher of al-Bīrūnī and the discoverer of sine theorem of plane and spherical trigonometry in Khwārazm).

The later half of the tenth and the first half of the eleventh century produced four eminent astronomers of exceptionally high calibre: Avicenna and Al-Bīrūnī in the east, and Ibnul-Haytham.[11] and Ibn Yūnus in the west (Egypt). It was in the beginning of the eleventh century that al-Bīrūnī was exiled into India and introduced the study of Graeco-Arabic astronomy in this country.[12]

In the later half of the eleventh century, the Saljūq Sulṭān Malik Shāh built an observatory to determine the true time of vernal equinox[13] and to reform the calendar, and introduced the *Malikī Era.*

The twelfth century produced a good number of important astronomical works such as Al-Khurqi's *Muntah al-idrāk* and *At-tabṣira,* Al-Khāzinī's *Zij-i Sanjarī* and Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at.*[14]

Then came the eruption of Tartar marauders who in the middle of the thirteenth century devasted Central and Western Asia. But even this unprecedented calamity could not interrupt the progress of astronomy. Under Halākū, Naṣīrud-Dīn Tūsī built the famous Marāgha Observatory[15] and wrote *Tadhkira* and *Zij-i Īlkhānī,*[16] which served as a model for subsequent zījes. His pupil composed two important astronomical works *Nihāyat ul-idrāk* and *Tuḥfa-i Shahīya.* He also wrote an encyclopaedia, *Durrat-ut-tāj.*[17] In the following century good commentaries were written on astronomical texts such as "Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at* and Ṭūsī's *Tadhkira and Zij-i Īlkhānī*[18].

Development of Graeco-Arabic astronomy in Central Asia

In the latter half of the fourteenth century the centre of scientific activities shifted to Central Asia. Tīmūr, besides being a famous conqueror, was also a great patron of science and letters[19] and this tradition also continued in his dynasty. His grandson Ulugh Beg was himself a great scholar of mathematical sciences.[20] He founded the first academy of science of modern times. The four members of this academy were Qāḍī Zādeh Rūmī (the commentator of Chaghmīnī's *al-Mulakhkhaṣ fil-Hay'at,* Ghaiyāth ud-Dīn Jamshed Kāshī (the author of *Zij-i Khāqānī*), Mu'īn-ud-dīn Kāshī and 'Alā uddīn Qaushjī[21] (the de-facto author of *Zij-i Ulugh Beg*). The king also erected an observatory at Samarqand (A.D. 1420) under the directorship of Qāḍī Zādeh and Jamshed Kāshī, and after their death, under that of Qaushjī.[22] The findings of the observatory were compiled by the king with the help of Qaushjī in what was subsequently called *Zij-i Ulugh Beg.*[23] After Ulugh Beg and Qaushjī, the centre of astronomy was shifted to India.

ZĪJES PREPARED IN WEST-CENTRAL ASIA

PRE-TARTAR ZIJES

Nature of a Zij :—

A *zij* is a set of a number of astronomical tables prepared directly or indirectly on the basis of the findings of a particular observatory.

In Indian literature the term *zij* seems to have been explained first by Abul Faḍl in his *Āin-i Akbari* and later on by Mullā Farīd, the court astronomer of Emperor Shāhjahān in his astronomical work *Sirāj ul-Istikhrāj* and *Zij-i Shāhjahāni.*[25] As Mullā Farīd was himself the author of an important *zij,* his description is to be preferred. He prefaces his description with that of an observatory (in Arabic Raṣad) and says :

> "Raṣad means the observation of different celestial bodies with the help of instruments specifically manufactured for that purpose and to determine with their help, the positions of the stars in the sky (i.e. their longitudes and latitudes), to measure their movements, their distances from one another and from the earth, their sizes and such other conditions. When the movements of the stars have been determined, in accordance with the set principles of astronomical observations, they are carefully entered in a register. And that register is called a *Zij.*[26]

Then he divides the *zijes* into two classes :

(i) *Zij-i Raṣadi* or observational tables which are prepared directly from the findings of an observatory, such as *Zij-i Ulugh Beg* compiled directly at Ulugh Beg's observatory in Samarqand.

(ii) *Zij-i Ḥisābi* or computational tables. As it is not easy to build an observatory which entails tremendous cost and requires highly sophisticated instruments, generally later astronomers brought up-to-date the parameters of a previously compiled *Zij-i raṣadi.* Such tables are called *Zij-i-Ḥisābi.* The est bexample of this class is *Zij-i Shāh-Jahāni* which is essentially an up-to-date revision of *Zij-i Ulugh Beg.*[27] Major portion of *zij* literature in Arabic and Persian comes under the class *Zij-i Hisābi.*

Important zijes before Al-Birūni :

The first ever *zij* among Muslim astronomers was prepared by Al-Fazārī, the court astronomer of Caliph Al-Manṣūr (A.D. 753-774) under his command.[28] It was based upon *Brāhmasphuṭa-Siddhānta,* though the years employed in its computation were the Arabian (Ḥijrī years).

Al-Fazārī's colleague Y'aqūb bin Ṭāriq who was also impressed by a member the Indian astronomical mission wrote another *zij* entitled *az-Zij-al-Maḥlūl min-as Sindhind* (Astronomical Table solved with the help of *Siddhānta*).[29]

Some twenty years later an observational table entitled *az-Zij al-Mushtamil* was compiled by Aḥmad Bin Muḥammad an-Nahāwandī, the Director of the observatory at Jundisāpūr[30] (c. 741 A.H.).

Then came Al-Māmūn (A.D. 813-833) who as stated before built the Baghdad and Damascus observatories.[31] The participants especially 'Abbās bin Sa'īd al-Joharī and Sanad bin 'Alī prepared their own (private) tables. But officially the record was entered in what was called *Az-Zij Al-Mumtaḥan* (the Tested Tables), the authorship of which is generally attributed to Yaḥyā bin 'Alī Manṣūr, the chief astronomer of Māmūn.[32]

But more important than these tables was the one by Muḥammad bin Mūsā Al-Khwārazmī. In this *zij* were fused the three astronomical systems, the Greek *Almagest*, the Persian *Zij-i Shahriyār* and the Indian *Siddhānta*.[33]

The movement started by Al-Māmūn continued after his death as well. Two astronomers of exceptional calibre flourished among his successors :—

Aḥmad bin 'Abdullāh, also called Ḥabash-Al Ḥasīb composed three *Zijes* :— *Zij-as Sindhind* based on Indian Siddhānta; a revised edition of Al-Māmūn's *Az-Zij-al-Mumtaḥan* and a small table called *Zij-ash-Shāh* (very probably based on *Zij-i Shahriyār*.[34]

The other were the Banū Mūsā (the sons of Mūsā bin Shākir, the astronomer). They built their own observatory, the findings of which they entered in a book entitled *Sanat ush-Shams* (solar year) also ascribed to Thābit bin Qurrah.

In order to highlight the continuity of astronomical activities in Islam, a few very important zījes are mentioned below :

Chief among them was Al-Battānī's *Az-Zij-as-Sābi* which he compiled from the findings of his own observations extending from A.D. 877 to 918.[35] About this *zij* Ibn-ul Qifṭī says, "I know no one among Muslim astronomers", who reached the intellectual status of this savant.[36] Consequently great number of *Ḥisābi Zijes* (Computational Tables) were based upon Al-Battānī's Tables.

Another important *zij* was prepared by Al-Battānī's contemporary Faḍl bin Ḥātim an-Narayzi and dedicated to the Caliph al-M'utaḍid (A.D. 892-901). Hence it is called *Az-Zij Al-M'utaḍidī*.[37]

Among the later contemporaries of Al-Battānī was the family of Banī Amājūr. The members of the family made astronomical observations with which they composed twelve *zījes*.

The golden period of Islamic astronomy commenced with the political ascendancy of the Buwayhids. The encouragement the new dynasty gave to astronomy resulted in the writing of a number of standard works, including *zijes* such as :

1. *Zij-As-Safāih* of Abu J'afar al-Khāzin;[38]
2. *Al-Majisṭi* of Abul-Wafā al-Buzjānī;[39]
3. *Al-Majisṭi-ash-Shāhi* of Abū Naṣr bin Irāq, the teacher and patron of Al-Bīrūnī;[40]
4. *Zij-i Ibn-ul-A'lam,* which was perhaps the best contribution of this period,[41] as it was relied upon by Naṣiruddīn al-Ṭūsī in the compilation of his Īlkhānic Tables.[42]

Astronomical works of Al-Birūni

Al-Bīrūnī was a versatile and prolific writer who composed a great number of books on astronomy and allied subjects. But the work that has immortalized him in the history of astronomy is his *Qānūn- al-Mas'ūdi*[43] (Canon Masudicus) also called *Zij-i Mas'ūdi*. Like Ptolemy's *Almagest*, it is also divided into thirteen books *(maqālas)*. He also wrote commentaries on al-Khwārazmī's "Tables".[44] In some of them he defended him against the criticism of his adversaries.

Zijes written after Al-Bīrūni

After Al-Bīrūnī's *Qānūn al-Mas'ūdi* the best *zij* was written by his contemporary Ibn Yūnus called *Az-Zij al-Kābir al-Ḥakimi* as the author dedicated it to the Fātmid Caliph of Egypt Al-Ḥakīm Billāh (d. A.D. 1020).[45] Its importance lies in that it was one of the two *zijes* Ṭūsī relied upon in the computation of his *Zij-i Īlkhāni.*[46]

A period of lull followed Al-Bīrūnī's death. But it was not altogether barren. Malik Shāh of Saljūkī dynasty built an observatory under the directorship of the famous poet-astronomer 'Umar al-Khayyām.[47] Its findings were recorded in a book called by Abul Faḍl as *Zij-i Khayyām.*

Another important *zij* was composed during the later part of Saljūkī rule. It was written by 'Abdur Raḥmān-al-Khāzin and was dedicated to the reigning Sultan Sanjar. Hence its name *Zij-i Sanjari.*[48]

Post Tartar Zījes

With the Tartar occupation of middle East, there commenced a new period of Islamic astronomy that inaugurated a new phase of *zij* literature. Hitherto the bifurcation between an astronomical Text and astronomical table was not clearly defined. Moreover, major portion of a *zij* was devoted to the description of astronomical principles and comparatively less space was given to tables. For instance, *Az-Zij-as-Sabi* consists of fifty-seven chapters, greater number of which are on the demonstration of astronomical principles. Similar is the case with *Zij Ibn Yūnus* and *al-Qānūn al-Mas'ūdi* or *(Zij-i Mas'ūdi).*

Of the many *zijes* prepared in this period, three are most important, as they exercised an enduring influence on the preparation of subsequent *zijes*, especially in India. They are *Zij-i Ilkhāni, Zij-i Khāqāni* and *Zij-i Ulugh Beg.*

Zij-i Ilkhāni. It was an observatorial *zij,* prepared on the basis of the observations made in Marāgha observatory. This observatory was built by Halakū Khān, the Īlkhānī ruler of Irān on the advice and directorship of Khwāja Naṣīruddīn at-Ṭūsī in A.D.1258. It was built in Marāgha near Tabrīz. Besides the Director Naṣīruddīn Ṭūsī, four other eminent scholars were also invited to participate in the working of the observatory. They are, as given by Ṭūsī in the preface of this *zij,* Fakhruddīn of Marāgha, Mu'yyad uddīn al-'Urḍī from Damascus, Fakhruddīn of Akhlāṭ from Tiflis and Najmuddīn Dabīrān from Qazwīn.[49]

Though the working of an observatory takes at least thirty years, but as Halākū Khān was making haste, the work was finished in about twelve years. The results were recorded in this *Zij* in A.D. 1271. And as by this time Halākū had died, it was dedicated to his son and successor Abā Qa'ānī.[50]

Zij-i-Ilkhāni started a new pattern. The whole content of astronomical topics was divided into three parts, chronology, spherical trigonometry and astronomy and planetary motions. Hence this *zij* consists of three *maqālas* (of astronomical importance), namely, (i) On different eras, (ii) The movements of the stars and their positions (longitude and latitude); and (iii) Determination of the time of ascendents.

To these three *maqālas* was added a fourth on astrological predictions. This arrangement was followed by subsequent writers of *zijes* (except by Jamshed Kāshī). Every *maqāla* is followed by a number of tables.

Zij-i Khāqāni. This *zij* was prepared by Ghyāthud-dīn Jamshīd of Kāshān. He found some defects in Ṭūsī's Īlkhānic Tables and he set to amend them. He gives a list of about fifty improvements made by him on *Zij-i Ilkhāni* of Ṭūsī. Hence its name *Az-Zij al-Khāqāni ll Takmil iz-zij il-Ilkhāni.* He started to write this *zij* in A.D. 1374[51] while he was in his native town of Kāshān. Then he was invited by Ulugh Beg to participate in his constituted Academy at Samarqand.[52] There he completed this *zij* in 1413 and dedicated it to Ulugh Beg.[3]

Zij-i Khāqāni consists of the following six *maqālas:* eras; trigonometry and allied subjects; positions of the stars (their longitudes and latitudes; important arts; determining the ascendent from different data, and miscellaneous astronomical and astrological topics.

MS copies of this *zij* are very rare. The cataloguer of India Office Library says that the unique copy of this *zij* is there in the Library. But another copy seems to exist in Central Library, Hyderabad.[54] Rājā Jai Singh Sawāi, the builder of Delhi

Observatory and the author of *Zij-i Muhammad Shāhi* had a copy of this *Zij* and had studied it. It is extant in his library.

Zij-i Jadid-i Sulṭāni. This is the famous *zij* of Ulugh Beg. He was very much interested in intellectual sciences, especially in mathematics, and wanted to build an observatory in order to perpetuate his name.[55] He translated his project into practice in 1420. A suitable site for this purpose was selected near Samarqand, and necessary instruments and equipments were procured and the observatory began to work,[56] first under the supervision of his teacher (in mathematics) Qāḍī Zādeh Rūmī and Maulānā Ghiyāth-uddīn al-Kāshī. But before any tangible result could be found, both the directors died one after the other. The work then was entrusted to Maulānā 'Alāuddīn al-Qaushjī, who was Ulugh Beg's pupil in mathematics. Qaushjī under the overall supervision of Ulugh Beg carried out the project and compiled the *Zij* in A.D. 1438. This *zij*, like Īlkhānī Tables, is also divided into four *maqālas*, e.g. eras, the motions of the stars and their longitudes and latitudes, determining the ascendent from given data, and astrological prediction.

No important *zij* seems to have been prepared after Ulugh Beg's *zij* in Iran or Central Asia. Some zījes were prepared in West Asia, but they did not influence the *zij* literature of India.

WEST-CENTRAL ASIAN ZĪJES IN INDIA

In Pre-Mughal Times

The earliest reference to *zijes* composed in West-Central Asia is met with during the reign of later Ghaznavids when the poetscribe Mas'ūd S'ad Salmān, while writing an ode in praise of the heir-apparent 'Abul Qāsim Maḥmūd, predicted his glorious coronation. This prediction was based on the data provided by the astronomical tables, *Zij-i Battāni* and *Kitāb-ut-Tafhim* of Al-Bīrūnī.[58]

The former has already been referred to. The latter is not a *zij* in the technical sense of the term, but a compendium of mathematical and astronomical sciences. Still it contains a number of tables, e.g. the gazetteer and the star catalogue.

Zijes enumerated by Abul Faḍl in Ā'in-i Akbari.

Abdul Faḍl apparently possessed a great interest in astronomy and consequently, after describing the meaning of *raṣad*, gave a long list of 86 *zijes* in his *Ā'in-i Akbari.*[59] But unfortunately this list is not arranged chronologically, nor scientifically. This list shows that scholarly circles in Akbar's time was acquainted with a large number of Islamic *zijes*. These *zijes* are listed in Appendix A.

Zijes listed by Mullā Farid

In the regin of Akbar's grandson Shahjahān, Mullā Farīd, the court astronomer prepared his astronomical table entitled *Kārnāma-i Sāḥil Qirāni, Zij-i Shāhjahāni.* In this *zij*, like Abul Faḍl, he first describes what is meant by a *raṣad* (observatory)

and a *zij*. Then he classifies the latter into *Zij-i Raṣadī* (Observational Tables) and *Zij-i Ḥisābī* (Computational Table). Among the former class he typifies *Zij-i Ulugh Beg* (which he calls *Zij-i Samarqandī*). Another example of this class is *Zij-i Battānī*.[60] Among the later class he mentions his own table as a typical example. The list of *zijes* given by Mullā Farīd is listed in Appendix B.

Zijes studied by Rājā Jai Singh Sawāi

Sawāi Rājā Jai Singh in order to correctly determine the exact time of performing religious rites was obliged to study the current astronomical works, written by Hindu as well as Muslim and European astronomers. Among the works written by Muslims, he mentions the following: *Zij Jadid Sa'id Gurjānī* (i.e. *Zij-i Ulugh Beg*), *Khāqānī (Zij-i Khāqānī of Jamshed Kāshi)*, *Tashilāt-i Mullā Chānd Akbar Shāhi (Tashil Zij-i Ulugh Begi of Mullā Chānd)* and *Mullā Farid Shāhjahānī (Zij-i Shāhjahānī)*. Of these the first two had been compiled outside India (already dealt above), whereas the last two were prepared in India (see below).

ZĪJES COMPILED IN MEDIEVAL INDIA

Beginning and Progress of Astronomical Studies in Muslim India

Beginning of Graeco-Arabic Astronomy in India

Astronomical studies in Muslim India started from eleventh century when the celebrated Al-Bīrūnī exiled from his native country[62] continued his investigations in the North-Western part of the sub-continent. Besides learning indigenous sciences he determined the latitudes of some of the cities[63] of the region and what is more important tried to measure the length of one degree of the meridian and thereby determined the length of earth's circumference.[64]

The process of assimilation of West-Central Asian learning was continued by the Indian scribe class. For example, the poet-scribe Mas'ūd Sa'd Salmān learnt astronomy from an old companion of his, named Bahramī, and soon acquired proficiency in this science.[65]

Astronomy during Delhi Sultanate

(i) *Mamlūk rule*. The scribe class was generally conversant with mathematical sciences including astronomy as is evident from an ode of Amīr Khusro which he composed in praise of his teacher Shahāb Mahmara. Amīr Khusro was himself well-acquainted with astronomy especially with the science of fixed stars. He composed a poem on "Twenty-eight lunar Mansions",[66] called *(al-Manāzil)*. It was during this period that the first *zij* in India was prepared (see below).

(ii) *Khiljī* rule. Astrology (and for that reason astronomy) reached its climax in the reign of 'Alā uddīn Khiljī when there was an ever increasing demand for astrologers.[67] Some of these astrologer-astronomers had acquired such proficiency in their subjects that they could construct astronomical observatories.[68]

(iii) *Tughlaq rule.* Among the Tughlaq rulers, Fīroz Shāh Tughlaq was highly skilled in astronomy especially in astrolabe making. He effected important improvements in the construction and designs of astrolabes.[69] The extraordinary interest taken by the ruler in the theory and construction of astrolabes did not leave the subjects (not only Muslim, but Hindu as well) uninfluenced. The first treatise on astrolabe in Sanskrit was written during the reign of Fīroz Tughlaq by Mahendra Sūrī, called *Yantrarāja.*[70]

(iv) *The period of disintegration.* Some of the Provincial dynasties that sprang up after the break-up of Delhi Sultanate also showed interest in the patronage of astronomy. Chief among them was the Bahmanī dynasty of Deccan where Sulṭān Fīroz Shāh Bahmanī ordered the first astronomical observatory in India to be built at Bālāghāt in 810 A.H., some ten years earlier than that of Ulugh Beg's at Samarqand.[71] He was so much interested in these sciences that he himself used to give lectures on *Tadhkira* (a standard work on astronomy by Naṣīruddīn Ṭūsī) thrice a week.[72]

Astronomy under the early Mughals

(i) *Bābur and Humāyūn.* The Mughals brought with them the scientific traditions of Central Asia. Though Bābur relied more on his sword than on astrological prophecies, he, however, did not deviate from his family traditions and employed an astrologer (who must be skilled in astronomy as well) at his court.[73]

But Bābur's son and successor, Humāyūn was himself a great astronomer and spent his time in the company of scholars well-versed in this science.[75] He intended to build an observatory, for which suitable site was chosen and necessary instruments had been collected.[76] But death would not allow this project to be completed. Even before his fatal fall from the stair-case of Sher Mandal, he was engaged in astronomical activities. He was waiting for the rising of the planet Venus.[77]

(ii) *Akbar and Jahāngīr.* Akbar in his zeal for the propagation of his newly invented "Dīn-i Ilāhī" enjoined upon his followers the study of Nujūm (astronomy).[78] It was during his reign that the versatile Amīr Fatḥullāh of Shīrāz reformed the calendar[79] and instituted the new Ilāhī Era. Under his orders Amīr Fatḥullāh, with the help of Abul Faḍl and some Sanskrit scholars translated Ulugh Beg's tables into Sanskrit.[80] Abul Faḍl himself was greatly interested in astronomy and devoted a considerable part of his *Āin-i Akbarī* to the rudiments of this science.[81]

Jahāngīr, though not much interested in astronomy was nevertheless very much impressed by the prophecies made by his Court-astrologer Jyotika Rai.[82] Jahāngīr's vazir Āṣif Khān was a great scholar of astronomy.[83]

(iii) *Shāhjahān and Aurangzeb.* Mullā Maḥmūd Jaunpurī, the auther of *Shams-i Bazighah* submitted to the Emperor Shāhjahān his scheme for the construction of an observatory. But it could not be sanctioned due to paucity of funds.[84] Other eminent

scholars of astronomy during Shāhjahān's reign were Mullā Farīd (see below) and Mullā Murshid of Shīrāz.[85]

Aurangzeb's indifference to this science could not arrest the progress of astronomy, which continued, independent of court patronage in the family of Aḥmad Ma'mār specially his son Luṭfullāh, who translated into Persian aṣ-Sūfī's *Ṣuwar-ul-Kawākib*[86] and grandson Imāmuddīn, the author of At-taṣrīḥ, a commentary on Bahāuddīn 'Āmilī's astronomical text *Taṣhriḥ-ul-Aflāk*.[87] Another scholar of astronomy during this time was Mullā'Iṣmat-ullāh of Sahāranpūr, who translated the commentary of the *Almagest* and *Tashrih ul-Aflāk*.[88]

Astronomy under the later Mughals

The fratricidal wars that ensued after Aurangzeb's death disrupted the peace of the country, so essential normally for the progress of science. But it is curious to note that as far as astronomy was concerned it was the most fertile period. It was during this period that the first (and also the last, of its kind) observatory was built in India. This was the famous observatory at Delhi (1724) built by Rājā Jai Singh, who also built four other observatories at Jaipūr, Vārānasī, Mathurā and Ujjain.[89] The findings of Delhi observatory furnished the requisite material for the compilation of *Zij-i Muḥammad Shāhi* (see below).

With the British conquest of the sub-continent, Mughal rule came to an end. Still Graeco-Arabic astronomy struggled hard to survive. And it was during the troubled thirties of the last century that a scholar Ghulām Ḥusain of Jaunpur wrote a great mathematical and astronomical compendium.[90] Besides writing other astronomical works, he also prepared a *zīj* (see below).

In the present century Maulānā Aḥmad Raḍā Khān of Bareilly wrote glossaries on Naṣīruddīn Ṭūsī's *Zij-i Īlkhāni* and *Jāmi'Bahādur Khāni*[91]

ZĪJES PREPARED IN PRE-MUGHAL INDIA

Zij-i Nāṣiri

It was the first *zij* prepared in India, of which history has preserved some details. It was prepared by Maḥmūd bin 'Umar, who dedicated it to the reigning Sulṭān of Delhi Naṣīr al-Dīn Abū-l-Muzaffar Maḥmūd bin Shams al-dīn Iltutmish. Hence its name *Zij-i Nāṣiri*.[92] As this Sulṭān reigned from 644 to 664 A.H. (A.D. 1246-1265), it must have been completed much before 1265 when observations were being made in the Marāgha Observatory, which were to be utilized as the basis for compiling the renowned "*Īlkhāni Tables*" of Khwāja Naṣīr al-dīn Ṭūsī. The later tables were completed during the reign of Abā Qa'an (1270-1280) who succeeded his father Hulākū Khān. Hence India preceded Iran in the preparation of *zij* at-least by a decade.

Unfortunately like so many other works of scholarship, this *zīj* also could not withstand the ravages of time. But it was extant in the days of Abul Faḍl who mentions its name in his list of *zījes*[93] (see Appendix A, *zīj* no. 72).

However, Storey, in his work *Persian Literature*, points to a unique manuscript copy of this *zīj* in a private library of Ṭabrīz owned by Ḥusain Aba Nakẖjawanī,[94] A transcript of some part of this *zīj* was made and is reported to be in Mullā Firoz Library, Bombay.

Zīj-i Jāmiʿ Maḥmūd Shāh Khiljī

This is the only *zīj* prepared in pre-Mughal India that is accessible to us. A copy of this *zīj* (very probably the unique one) is preserved in Bodlian Library Oxford (No. 1522) of the Persian manuscripts.[95] But unfortunately it is defective, surely at the beginning, as it abruptly begins with "the importance of astronomical science" without the usual praise of the Creator and His Prophet. The second chapter is also wanting, as the last (the twenty-second) section of the first chapter is immediately followed by the colophon, which means in unequivocal terms as follows: "Here ends the book, *Zīj-i Jāmiʿ Maḥmūd Shāh Khiljī*".[96] But the author states at the end of the Introduction (Col. 3.1) that this book consists of an introduction, two chapters and a *khātima*.[97] He also promises in the last section of the book, to describe additional items later on, but this promise has not been fulfilled in the manuscript before us.

The author's name is not mentioned anywhere in the extant folios of the present copy. It might have been stated in the missing folio. Likewise the title of the book is not definitely known. The space (on fol. 3a line 5 of the xerox copy)[98] where the author intended to mention it is blank. The title given above is based on the colophon.

The author commenced this work in 852 A.H. (A.D. 1448) at the request of some of the nobles who were interested in astronomy for preparing almanac. But owing to his preoccupations with other engagements he could not complete it. In 865 A.H. (A.D. 1460-61) he was pressed by his patron, Ḥabībuddīn Muhīb-ullāh to complete it, and accordingly he rewrote it, revised some solved examples and updated the tables. Unfortunately all these drafts were destroyed when Bidar, his native city was devastated and all his belongings were plundered. In the following year 866 A.H. (1461-1462 A.D.) the king conquered the cities of the Deccan and he was commanded by him to prepare an astronomical table, which embodied the gist of previous tables and comprised different astronomical processes. He completed this arduous task and dedicated the book so written to the king.[99] His (the king's) name is also not clearly mentioned.

The book (as the author himself states) was to consist of a *muqaddama* (prolegomena), two chapters, and a *khātima* (epilogue).[100] The *muqaddama* consists of thirty-six sections. Section I is on the definitions of *raṣad* (observatory), *zīj* (astronomical tables) and a number of geometrical terms. Then he gives a short account of arithmetic

which comprises fifteen sections (from section II to XVI). Section XVII is on mensuration. Sections XVIII to XXIV are devoted to astronomical arithmetic based on sexagesimal system. The next twelve sections are on astrolabe; section XXV on the components of the astrolabe and the remaining eleven on the uses of this instrument.

The first chapter deals with the knowledge of different calendars (eras), the determination of planetary motions (with reference to their longitudes and latitudes) and related topics. It consists of twenty-two sections: The first section explains what is meant by a calendar and its several parts such as night, month and year. The next four sections are on the following calendars: Ḥijrī, Roman, Persian and Malikī (instituted during the reign of Saljūq Sulṭān Malik Shāh). The fifth section is on the conversion of these four calendars into one another. Then follows section seven comprising a lengthy description of Turkish (Uighur) calendar consisting of eleven *qism* or parts. Section ten is on the motion of the Sun. Section eleven is on the motion of the Moon. Section twelve is on the motion of the five wandering planets. Section thirteen deals with the description of the above motions, and section fourteen with conjunction and apposition, while the next three sections are devoted to other aspects of planetary motions. Sections eighteen and nineteen deal with astrological problems. Sections twenty and twenty-one are on lunar eclipse and solar eclipse respectively.

In the last (twenty-second) section, the author says that the above-mentioned topics are generally considered sufficient for preparing an almanac. Still there are some more items which are also entered in it such as Coptic, Turkish (?) and Jewish calendars. Some astrologers also add astrological and other predictions including the effects of the moon when it enters different signs of the Zodiac and the twenty-eight lunar mansions.

In the end, the author cautions that astrological predictions are probable and not certain. Only those procedures are worthy to be believed that are based on arithmetical computations, as they are free from doubts except when some error creeps into them.

As to the sources of the *zīj* under review, the author was much impressed by *Ilkhānic Tables* of Khwāja Naṣīr-ud-dīn Ṭūsī.[101] But he differs from him in chapterization. Tusi's *zij* is divided into four *maqālas*, but the author of *Zīj-i Jāmi'* has redistributed their content. He has also added a number of mathematical topics of interest from other sources. In the prologomena, while giving definitions of geometrical terms, he seems to follow Ṭūsī's *Tadhkira* and the sections on astrolable and its uses seem to be based on his (Tūsī's) *Bist Bāb:* twenty chapters on astrolabe. Besides *Ilkhānic Tables* he does not refer to any other source by name. But there are sufficient reasons to conclude that he consulted a number of *zījes* in vogue at that time, as he himself says, he often intended to prepare a *zij* by making selections from current *zījes.*[102] However, certain phrases of his *Zīj-i Jāmi'* are reminiscent of Jamshed Kāshī's *Zīj-i-Khāqānī* which had been composed some thirty-six years earlier.

There are only some tables on calendrical conversion, but no astronomical table of planetary motion in the present copy of the *Zij*.

ZĪJES PREPARED DURING THE REIGN OF GREAT MUGHALS

Tashīl Zij-i Ulugh Begī

It was prepared by Humāyūn's trusted friend and companion Mullā Chānd, son of Bahā-ud-dīn. He accompanied him (Humāyūn) when he was obliged to flee from India to seek refuge in the protection of Shāh Tahmasb of Iran. But as his queen Hameeda Begam who was about to give birth to his son Akbar, he was obliged to leave her in the fort of Amarkot. He also left Mullā Chānd with her so that he could correctly report the time of birth of the new born and prepare his horoscope which Abul Faḍl has reproduced in his *Akbar Nāma*.

After Humāyūn's death, Mullā Chānd entered the service of his son and successor Akbar, as his court astronomer. It was during this service (in the early part of it) that he made a simplified version of Ulugh Beg's Tables, as he had been persistently requested by his friends to write a *Tashīl* of the *zij* (of Ulugh Beg). He acceded to their request and prepared a simplified version (easy to understand). A unique copy of this *zij* is preserved in Jaipur State Library*, Mullā Chānd made some revision and alteration in the arrangement of the original *Zij-i Ulugh Beg*. He divided his work like the original into three *maqālas*. The first is on different calendars and eras, the second on the determination of the times of ascendents and what pertain to them, and the third on determining the positions of the stars and allied subjects.

In the scheme of arrangement, he has often differed from the original *Zij-i Ulugh Beg*. Major portion of the first *maqāla* on chronology in the original *Zij-i Ulugh Beg* is devoted to Chinese and Uighur calendar, whereas Mullā Chānd in the context of changed political, social and cultural conditions did not give importance to this calendar. But what he failed to realize (and subsequent *zij* writer, e.g. Mullā Farīd and Jai Singh as also Abul Faḍl were obliged to take note of) was the importance of Samvat Era. This lacuna may be due to the fact that he wrote his *Tashīl* before Hindu community and its culture was recognized as something not to be ignored.

The second *maqāla* on spherical trigonometry and astronomy in the original consists of twenty-two chapters, whereas in the *Tashīl* it contains twenty-four chapters. He substituted chapter 15 of the original, "On the Determination of Meridian Line," with a chapter (18th in the *Tashīl*), "On the determination of the inclination of a line that is drawn in the plane of the horizon". He added a new chapter (18th in the *Tashīl*) "On the determination of the sine of the mean motion" between the seventh and eighth chapters of the original. He also added two more chapters between the twenty-first and twenty-second of the original and gave them the title, "On the determination of ascendent from the direction of the star". He also changed the order of chapter seventeen of the original, "On the determination of the

*The author is thankful to the present Mahārājā of Jaipur who permitted him to consult it and take notes.

amplitude of visibility", and assigned it the twelfth place in his scheme. There is not much difference between the original and the *Tashil* in this *maqāla*. Every *maqāla* is followed by a number of tables which he updated from the original with the help of planetary equations.

Zij-i Shāhjahānī

More important than *Tashil* of Mullā Chānd is the Shāhjahānī tables written by a scholar astronomer.

The author. The author's name was Farīd Uddīn. He came from a family of scholars who were held in high esteem by kings and rulers of bygone days. His father Hāfiẓ Ibrāhīm was a great scholar of his time.[103] Mullā Farīd received his early education from his father. Then he went to the school of Shāh Niẓām of Narnol and learnt from him. Finally he became the pupil of Amīr Fatḥ ullāh Shīrāzī who was decidedly the greatest scholar of intellectual sciences of his time. Under his guidance he acquired a high degree of proficiency in different sciences and was soon recognized as one of the greatest scholars of his time.[104]

He entered the service of Khān-i Khānān, the governor of Gujarāt in 1006 A.H. It was in this year that he wrote an astronomical text named *Sirāj al-istikhrāj* comprising a *muqaddama* (introduction) and nine chapters. He dedicated it to Khān-i Khānān. He continued in his service till 1024 A.H. and perhaps after that as well till he was introduced to Shāhjahān in the second year of his accession, when he presented his newly prepared tables entitled *Zij-i Shāhjahānī*.[105]

He died, according to the author of *Ṭabaqāt-i Shāhjahānī*, in 1039 A.H. But this seems incorrect as the positions of stars are calculated for the year 1041 A.H. in which year he must have been alive hail and hearty, actively engaged in astronomical activities.[106]

Mullā Farīd wrote many works chief among which were *Sirāj al-istikhrāj*, as stated dedicated to Khān-i Khānān in 1006 A.H. and *Zij-i Shāhjahānī* to be described shortly. He is reported by the author of *Ma'āthir-i Raḥīmī* to have also written a *zij* in the name of Khān-i Khānān. This *zij* is possibly identical with *Sirāj al-istikhrāj* which is not mentioned in *Ma'āthir*.

The genesis of the Tables. The idea of writing a fresh *zij* was not of Mullā Farīd. It came from Vazir Āṣif Khān who in order to immortalize the name of his son-in-law (Shāhjahān) thought of starting a new era like that of *Jalāli* era of Malik Shāh Saljūqī or Ilāhī era of Akbar. The proposal was put up before Shāhjahān for his approval and consequently a royal decree was issued. Mullā Farīd was commissioned to prepare a new set of astronomical tables with the collaboration of his brother Mullā Ṭayyib and other scholars of Muslim and Hindu astronomy under the over-all supervision of the Vazir Āṣif Khān.[107] As there was not sufficient time for fresh observations and also the age and health of Mullā Farīd did not permit him to endure the strain of astronomical observations (for, if we believe the statement of *Ṭabaqāt i Shāhjahānī*

he could not survive the compilation of his *zij*) the proposed *zij* was to be based on *Zij-i Ulugh Beg* which was the nearest in point of time, most reliable and most correct of all the *zijes*.[108] The result was the *Zij-i Shāhjahānī*, its full title being *Kārnāma-i Saḥib Qirān-i Thāni, Zij-i Shāhjahāni.*

The Court Chronicler Muḥammad Sāleḥ Kamboh speaks very highly of this *zij* which in his words pushed into oblivion and disuse even *Zij-i Ulugh Beg* on which it was based. The Emperor Shāhjahān was so much impressed by its utility that he ordered it to be translated into *Hindi* (i.e. Sanskrit) for the use of general public.[109]

The Zij. Like its predecessors, *Zij-i Ilkhāni* and *Zij-i Ulugh Beg*, this *zij* is also divided into four *maqālas*, preceded by a very informative introduction. The latter is sub-divided into five *qisms* or parts dovoted to (1) the nature of a *raṣad* (observatory), *zij* (astronomical tables), *tashil* (simplified tables or *zij* made easy) and *Taqwim* (almanac), and their uses (first *qism*), (2) special features of this *zij (Zij-i Shāhjahāni)* on account of which it is to be preferred to other *zijes* of the past (second *qism*), (3) numerical "affinities" between the content of this *zij* and the royal names and titles (third *qism*), (4) the corrections, inventions (improvements upon) and additions made to Ulugh Beg's Tables (fourth *qism*), and (5) defining the era, year, month, day and its parts (fifth *qism*).

The four *maqālas* are the same as those given in *Zij-i Ilkhāni* and *Zij-i Ulugh Beg:* The first *maqāla* on eras consists of ten chapters, e.g. (1) the Ilāhī calendar, (2) Ḥijrī calendar, (3) Greek calendar, (4) Persian *(Yazdjardi)* calendar, (5) Malikī (Jalālī) calendar, (6) transformation of the above five calendars into one another. (7) Indian (Samvat or Śaka) calendar, (8) Transformation of Hijrī calendar into Indian and vice versa. (9) Chinese and Uighur calendar; this is by far the most lengthy chapter, as it consists of ten sections treating different topics relative to Chinese calendar, (10) important days (festivals) of different calendars.

The second *maqāla* entitled "Determination of Times and the Ascendent of every Planet" is concerned with spherical astronomy. The third *maqāla* deals with the determination of the motion of planets and their positions in longitudes and latitudes.

The text of these two *maqālas* is the ad verbatim reproduction of the corresponding *maqālas* of *Zij-i Ulugh Beg* with occasional changes. But the text of each of these *maqālas* is followed by a great number of tables. For instance in the British Museum Ms copy the text of the second *maqāla* occupies only eight folios, whereas the tables cover some sixty-eight folios. Similarly the text and tables of the third *maqāla* occupy eight and three hundred and nineteen folios respectively.[110]

However the tables were not only copious and updated, but very much improved in comparison with Ulugh Beg's *zij*. Some of these improvements were borrowed from preceding scholars especially from Mawlānā Rozbahan of Shīrāz and some were his (author) original contribution.[111]

With these additions, Mullā Farīd presented a highly improved edition of *Zij-i Ulugh Beg,* and perhaps the court chronicler Moḥammad Sāleh Kanboh did not exaggerate when he observed that this *zij (Zij-i Shāhjahānī)* relagated Ulugh Beg's tables into disuse.

ZĪJES PREPARED DURING THE TIME OF LATER MUGHALS

Zij-i Muḥammad Shāhī

By far the most valuable contribution Medieval India made to the advancement of astronomy was the building of Muḥammad Shāhī Observatory at Delhi (popularly known as Jantar Mantar) and the compilation of *Zij-i Muḥammad Shāhi* on the basis of its observations.

The Observatory. Muḥammad Shāhī observatory at Delhi is the first of its kind (and also the last) ever built in this country. No other monument of this type had ever been built in India. There were astronomers during the reign of 'Alā'ud-dīn Khiljī capable of erecting an observatory, but they never thought of it. Humāyūn thought of building an observatory, for which suitable site was selected and necessary instruments and requisite equipment had been collected but death did not allow him to bring this idea into practice. Sulṭān Fīroz Shāh Bahmanī of Deccan ordered his court astronomers in 810 A.H. to build an observatory at Bālā Ghāt. They began to build it, but the project had to be left incomplete owing to the death of the chief director.

Providence had reserved the credit of building the first ever observatory in India to the reign of Mughal Emperor Muḥammad Shāh and the untiring efforts of the Rajput Prince Rājā Jai Singh Sawāi.

The Background. The de facto builder of this observatory Rājā Jai Singh was a great scholar of his time in mathematical sciences,[112] (especially astronomy), for which he had a natural aptitude. At the same time he was an orthodox Hindu and insisted on the performance of religious duties and rites at their proper times.[113] To achieve this purpose he took advantage of his astronomical knowledge. He studied astronomical tables, not only those based on Hindu astronomy (*siddhānta jyotiṣa*), but also on Muslim *'Ilm ul-Hay'at* (Graeco-Arabic astronomy) and modern European astronomy. But the times of different celestial phenomena (especially of eclipses) which he calculated with the help of these tables would not very often tally with those of their actual occurrence.[44] He brought this matter to the knowledge of the Emperor who commanded him to build, with the collaboration of the exponents of different systems of astronomy (Hindu *Jyotiṣa,* Muslim *'Ilm-ul-Hay'at* and European astronomy), an observatory and prepare a fresh set of astronomical tables based on its observations.[115]

The Building of the Observatory

He obeyed the imperial command and set to work. But the difficulty was that there existed no model of an observatory.[116] To surmount this obstacle he studied

works of Muslim scholars on the construction and uses of astronomical instruments and got a number of them, like those used by the astronomers of Ulugh Beg's observatory at Samarqand, manufactured by local artisans.[117]

But these metallic instruments could not satisfy him, as besides being small, not admitting fine and minute divisions, they soon became unserviceable. Hence he was obliged to replace them by masonary instruments made of lime and stone[118] (actually huge buildings). In the preface of *Zīj-i-Muḥammad Shāhī* he gives the names of three of them, *Samrāṭ Jantar, Jai Prakāsh* and *Rām Jantar*. With their help, observations were made and recorded in a fresh *zīj* which was dedicated to the Emperor Muḥammad Shāhī. Hence it was called *Zīj-i-Muḥammad Shāhī*. It was completed in 1728 A.D.

The Zīj. Like the astronomical parts of the preceding *zījes (Zīj-i Ilkhānī, Zīj-i Ulugh Beg* and *Zīj-i Shāhjahānī) Zīj-i Muḥammad Shāhī* is also divided into three *maqālas*.

The first *maqāla* is on calendars. The Raja was more practical and therefore would not waste his time in describing obsolete eras, such as Greek or Persian eras. He was content with (i) the Hijrī era which was in vogue at that time (ii) the Muḥammad Shāhī era, which he instituted in order to immortalize the name of his overlord, (iii) the Hindu Era or Samvat which was current among the majority community and hence a social necessity, and (iv) the Christian era for which he foresaw the importance to be attached in future.

Consequently the first *maqāla* is divided into following four chapters:

I On the determination of Hijrī Era

II On Muḥammad Shāhī Era

III On Christian Era, and

IV On Indian Era, known as Samvat. This chapter is further sub-divided into two sections, e.g. (a) finding the Samvat from Hijrī year, and (b) finding Hijrī year from the Samvat.

On the other hand, the second *maqāla* is divided into nineteen chapters as follows:

I On sine and versine.

II On the determination of the tangent of a quantity and vice versa.

III On the determination of the second declination of the ecliptic from the celestial equator.

IV On the determination of the distance of a star from the celestial equator.

V On the determination of the maximum upper and lower culmination of a star in equatorial zone.

VI On the determination of the ascendent of (places on) terrestrial equator.

VII On the determination of the equation of day, the diurnal arc, the nocturnal arc and the hours of day and night.

VIII On the determination of ascendents (finding ascension as a function of latitude).

IX On the converse of the determination of ascendents.

X On the determination of the ascendent of transit.

XI On the determination of the ascendent of the rising and setting of stars for terrestrial equator.

XII On the determination of the azimuth from the upper and lower culmination.

XIII On the determination of the upper culmination from the azimuth.

XIV On finding the terresterial meridian (or line of north and south).

XV On finding the longitude and latitude (of a place).

XVI On the determination of the amplitude of the time of visibility.

XVII On the determination of the distance between two stars.

XVIII On the determination of the ascendent from the upper culmination.

XIX On the determination of the upper or lower culmination of the stars from ascendents.

This *maqāla* ends with a conclusion on the importance of a gazetteer for the preparation of an almanac, and therefore, on the description of the longitude and latitude of some important cities. As a whole, the second *maqāla* is an ad verbatim reproduction of the latter with minor changes. The most prominent of these changes was the deletion of the chapter on the determination of the direction of *Qibla.* (Mecca), a topic that had been invariably treated in all astronomical texts and tables from the time astronomy was studied by Muslims.

The third *maqāla* entitled "The determination of motions of stars and their positions (longitudes and latitudes)" is on planetary motions only. For other topics discussed in the corresponding *maqālas* of Īlkhānīc tables and those of Ulugh Beg, he added a *khātima,* the end-chapter.

However, the third *maqāla* of *Zij-i-Muḥammad Shāhī* consists of a *muqaddama* and four chapters. The *muqaddama* is on the equation of time. The four chapters are devoted to the motions of the Sun, the Moon, the outer planets (Saturn, Jupiter and Mars) and the inner ones (Venus and Mercury). Each of the first two chapters is further sub-divided into three sections, the first on mean motion, the second on their *taqwīm* and the third consists of different tables, such as that of mean motion, equation etc. The last two are divided into two sections each, the first on mean motion and the second on determining the *taqwīm.*

The *khātima* consists of seven sections as follows :

I. Lunar eclipse.

II. Solar eclipse.

III. Determination of the time of the visibility of the new Moon. (It is in this section that the author claims to have got a telescope constructed by artisans of his household and then verified with its help some of the discoveries made by Galileo, see below).[119]

IV. Appearance and disappearance of wandering planets.

V. Appearance and disappearance of the so-called fixed stars.

VI. Rising and setting of lunar mansions.

VII. The positions (celestial longitudes and latitudes of some sixty and odd stars determined by the astronomers of Muḥammad Shāhī Observatory).

The Tables. There are about 147 tables in this *zīj* (according to Aligarh MS) Their *maqāla*-wise distribution is as follows: first *maqāla*-10; second *maqāla*-64 (including two trigonometrical tables, one of sines and the other of tangents, and a geographical gazetteer giving longitudes and latitudes of some 136 places); third *maqāla*-67; *khātima*-6. In the third *maqāla* on planetary motions, the number of tables appended with every planet is as follows: Sun-6; Moon-21; Mars-7; Jupiter-8; Saturn-8; Venus-7. These figures differ from those given by Hunter in his article "Some account of the Astronomical Labours of Jaya Sinha", published in *Asiatick Researches*, 1793. According to him these figures are as follows: Sun-9; Moon-12; Mars-11; Jupiter-10; Saturn-11; Mercury-11; Venus-11. It seems the manuscript consulted by Hunter was different from the Aligarh one, which is substantially in agreement with a number of other mss copies. For instance according to Aligarh MS, the number of early *zījes* studied by Jai Singh as recorded by him in the preface of *Zīj-i Muḥammad Shāhi* is four whereas Hunter gives only three, omitting *Zīj-i Shāhjahānī* mentioned in other copies.

Special Features of Zīj-i Muḥammad Shāhi. This is the first *zīj* prepared in the East that clearly shows the influence of modern European astronomy, both in theory as well as in practice.

(a) The stories of new discoveries made in Europe were constantly trickling into the learned circles of India (specially of Delhi) through European scholars who under the title of *Dānāyān-i Firang* (wise men of the West) constituted an important section of the intelligentsia. It was through them that the astronomers of the Raja came to know how after a long series of trials and errors, Kepler succeeded in explaining the motions of different planets. So these scholars after a bitter controversy agreed to employ Kepler's first law for solving the anomalies of planetary motions, only if it was not in conflict with their basic principle of geo-centric universe. For this purpose they made two modifications in this law.

(i) They divested it of its helio-centric context, and

(ii) They excluded from its purview the Earth, which still continued to occupy in their system the middle, if not the central, position. Thus they extended it to regulate even the motion of the Sun, which in Kepler's theory was stationary and occupied a focal, if not the central, position.

(b) It was the first observatory in India that employed telescope for astronomical observations. The astronomical mission sent by Jai Singh to Portugal brought with them a telescope made there.[120] Then he got another telescope manufactured by local artisans, as he states in the *zij* itself.

"As our artisans have constructed the telescope so excellent that with its aid we can see bright and luminous stars even about midday in the middle of the sky. By employing such powerful telescope, the newmoon can be seen ever before the time, the astronomers have determined for its rays to begin emanating. And also after it has entered the prescribed limit of its invisibility, it still remains visible (through the telescope).[121]

Then he set to verify what was told to him about the discoveries made by Galileo and others, and to his great joy he found them true. He himself states the results of new experimentation.

"We also found the form and behaviour of some of these planets contrary to what the earlier scholars have recorded in current works. They are as follows:

First : We observed with our own eyes that Venus and Mercury obtain light, like the Moon, from the Sun, because we found that their light is diminished or increased according to their distance from the Sun.

Second : We have observed Saturn and found that it has the shape of an ellipse, i.e. out of its two diameters intersecting at right angles, one is smaller than the other.

Third : We found four shining stars approximately near the equator of Jupiter revolving round it.

Fourth : We saw a number of spots distinct from one another on the surface of the solar disc and found them completing their round on the solar disc, along with the rotation of the Sun itself, in about one year."[122]

One more deviation was made by Jai Singh from the traditional Graeco-Arabic astronomy which conceived the so-called "fixed stars" as stationary. But he proposed an altogether different theory and observed in *Zij-i Muḥammad Shāhi*.

"Those stars that are termed "Fixed Stars" in the terminology of astronomers are not fixed and stationary in reality. Nor do they move with one rate of velocity, but with different velocities.[123]

(c) The Rājā and his colleagues also solved a baffling problem of trigonometry. This related to finding out the sine of one degree and its parts (minutes and seconds etc.). Ulugh Beg by devising a scientific method for finding the sine of an angle one third of another of known sine, was able to compute geometrically the sine of one degree. But Jai Singh and his colleagues went one step further and found out geometrical method for determining the sine of one minute etc. as well. He says :

"As the determination of the sine of one minute is dependent on the method of finding the sine of an angle, one fifth of another of which the sine is known, we with the grace of the Creator of the Universe were enabled to determine the sine of an angle, one fifth of another of known sine so that we could determine geometrically the sine of one minute as well."[124]

Jāmiʿ Bahādur Khānī

It is a great compendium of mathematical and astronomical sciences. The author Maulānā Ghulām Ḥusain of Jaunpur came of a learned family. He received his early education from his father. Then he went abroad for higher education and acquired proficiency in different mathematical sciences, which included the science of astronomy. He was invited by Raja Bahādur Khān of Tikari, where he composed *Jāmiʿ Bahādur Khānī* (1835) and *Zij-i Bahādur Khānī* (1844) and dedicated them to the Raja, hence their titles. Afterwards he went first to Banaras and finally to Murshidabad where he died in 1279 A.H.[125]

He began to write this compendium *(Jāmiʿ Bahādur Khānī)* in 1833 and completed it the next year. Within a space of one year and two months he wrote such a voluminous treatise comprising 657 pages of big size.[126] As an apology for writing this book, he says, "Since the time of al-Barjandī (died 1249 A.H.), no comprehensive book dealing with astronomy and allied sciences (arithmetic, geometry and optics) and at the same time matching with *Almagest* and commentaries on "*Tadhkirah* (of Naṣīr al-Dīn Ṭūsī) has appeared in Persian language.....so I undertook to write this book."[127]

The *Jāmiʿ* comprehensively deals with the following branches of mathematics: geometry, optics, arithmetic, trigonometry, astronomy, and preparation of *zījes* The chapter on "Astronomy" comprises 256 pages. The section on introduction deals with the definition of astronomy and its fundamental principles, e.g. form of celestial sphere and terresterial elements, astronomical instruments and the techniques of observation, form of component spheres and details of their composition and velocities, description of the Earth and peculiarities of different zones and distances and sizes of different celestial bodies.

In the epilogue, the author discusses the reasons of difference between the findings of various observatories.

No other book on astronomy on the pattern of *Jāmiʿ-Bahādur Khānī* is known except al-Bīrūnī's "*Kitāb at-Tafhim*", of which the first two parts are devoted to geometry and arithmetic and the remaining three to astronomy, astrolabe and astrology. But the treatment of astronomy is not so thorough as in[128] *Jāmiʿ Bahādur Khānī*".

There are a number of astronomical tables, besides trigonometrical tables, geographical gazetteer and a revised star catalogue. The importance of the tables consists in the fact that their proof correction was meticulously done by the author

himself with the result that it is free of errors, specially in figures, which is so common in astronomical works whether printed or hand-written.

Zij-i Bahādur Khāni

It is perhaps the next best *zij* after *Zij-i Muḥammad Shāhi,* as it was completed with the help of fresh astronomical observations made by the author. As regards his proficiency in astronomy, no further proof is needed after a thorough study of his *Jāmi' Bahādur Khāni* and other astronomical works such as his commentories on Ptolemy's *Almagest* and Bahāuddīn Āmuli's tract on astrolabe etc.

The Background. After the author Ghūlam Ḥusain completed *Jāmi' Bahādur Khāni* in 1834 and dedicated it to his patron Rājā Khān Bahādur Khān, he submitted to him the following proposal:

> "Now that I have made a comprehensive compendium of mathematical sciences, it is hoped that your honour would give your attention to what is the practical result of all these sciences, and that result is the compilation of a fresh set of astronomical tables, which is in need of constant revision and reform in all successive periods of time, and this must be based on fresh astronomical observations.
>
> But the later project has never been possible without the (financial) assistance from the upper (wealthy) class of the society. Moreover, recently European scholars have designed and manufactured highly sophisticated and fine astronomical instruments, which have made astronomical observations independent of big and clumsy instruments used by Graeco-Arabic astronomy. It may also be submitted that many of these new instruments are already there in the stores of your household.
>
> "Hence if (fresh) observations of stars (and their different aspects) are made for some years, the difference between the observed times (of their actual occurrences) and that which is computed with the help of *Zij-i Muḥammad Shāhi* will be eliminated. Moreover, this humble self has been observing and keeping a proper record of these observations and this will also help in the preparation of the new Tables."[129]
>
> In response to this request of the author, his patron observed :
> "We ourselves had such idea in our mind from a long time, and now that you have submitted this proposal, we seriously intend that this project be duly executed."[130]

This remark of the Rājā encouraged the author, who single-mindedly devoted himself to the observations of different aspects of the stars (planets) such as their longitudes, latitudes and their diameters and also to systematically record their periods of changes. He occupied himself in this activity for six years besides the earlier nine years, as stated above. He also added to the knowledge so gained during

these fifteen years, the findings of earlier astronomers and with the resultant knowledge corrected and revised different astronomical tables, such as those of the inclinations, mean motions and equation of different planets and entered them in a fresh *zij*, named "*Zij-i Bahādur Khāni*" so that any one who so desires, might determine with its help, the almanacs of fixed stars and planets, occurrences of eclipses, time of visibility of newmoon, the relative positions and conjunctions of different planets for a long time to come.

The Zij : It consists of a *muqaddamah* and seven chapters. The *muqaddamah* is on the nature of a *zij* and discusses the reasons for the necessary revision of the tables in successive periods of time. The various *maqālas* deal with the following topics:(1) arithmetical computation both using Indian numerals of decimal system of notation and the sexagecimal system; (2) on different eras and their reductions from one to the other; (3) determination of the time of ascendent and allied matter; (4) determination of the motions of stars, their longitudes and latitudes, determination of solar and lunar eclipses, visibility of new moon, appearance and disappearance of remaining five wandering planets and fixed stars etc.; (5) determination of *tithi, nakṣatras joga, karaṇa* and the method of finding them; (6) the relative positions of the planets with respect to one another and their conjunction and some arithmetical computations relating to astrology; and (7) astrology and its predictions relating to the ascendents of the year and personal horoscopes, and determinations of auspicious times.

In the second *maqāla,* besides discussing the usual eras, i.e. Creation, Deluge, Coptic (i.e. pertaining to Bakht Naṣar), Greek (after Alexander, the Great), Chinese and Uighu, Hijrī, he has also discussed the Samvat and Gregorian calendars.

The third *maqāla* consists of some twenty-three chapters more or less the same as as in Uighur Beg's tables and *Zij-i Muḥammad Shāhi.*

The Tables. These tables concern as usual the trigonometrical tables of sine, tangent, and cotangent; first inclination; second inclination; *Maṭāliʿ al-Burūj;* hours of midday, and the number of *gharhies* for the total day and night at the place of observation; the real hours corresponding to the degrees of Sun's motion, and geographical gazetteers. Then there are a number of tables corresponding to that in the 2nd *maqāla* of the *Zij-i Muḥammad Shāhi.* The tables pertaining to the *taqwīm* of the Sun were prepared one for his native city of Jaunpūr and the other for Calcutta. The tables pertaining to the mean equations, distances and (apparent) diameters of the Sun were computed from his own observations, as he claims.

Special Features of Zij-i Bahādur Khāni

Besides the corrections made by the author in the earlier tables of mean motions etc. of the *zijes* of ancient astronomers, this *zij* has a number of special features. It has a *maqāla* on the mathematics of astronomy. The terms and symbols used in almanac are explained. Three additional calendars Bangla, Gregorian and Fasli are added to the current eras. Tables of *tithis, nakṣatras, karaṇas* etc. according to Indian *Jyotiṣa* are also incorporated to help those who act according to *Jyotiṣa.* Compound

equations of lunar anomalies are tabulated corresponding to degrees of zodiacs. The ancients computed *Maṭāli' al-Burūj* to the latitude of the extremity of habitable world and ignored those that were beyond that latitude. But as the Europeans have explored the land beyond that limit, consequently the tables of *Maṭāli' ul-Burūj* to latitude 67 degree which is the complement of solar eclipticity (i.e. $23\frac{1}{2}$ degree) are also added to the existing ones. As necessity often arises for astrological predictions, a chapter on astrological prognostications is also added.[131]

Minor Zijes Prepared in India

Some more minor *zijes* are also reported in catalogues of Indian libraries to have been prepared in this country. But as their microfilms were not available, details about them cannot be given. They are :

Zij-i Ashki by Kundan Lāl Ashkī,[132] Central Library, Hyderabad;
Zij-i Hindi by Mīrzā Gul Beg Munajjim,[133] Raḍā Library, Rampur;
Zij-i Niẓāmi by Khwāja Bahādur Ḥusain Khān,[134] Central Library, Hyderabad;
Zij-i Mir 'Alami by Safdar 'Alī Khān,[135] Central Library, Hyderabad;
Zij-i Safdari by Safdar 'Alī Khān,[136] Sālār Jang Library, Hyderabad; and
Zij-i Sulaimān Jāhi by Rustam 'Alī Khān,[137] Raḍā Library, Rampūr.

But more important is a glossary on *Zij-i Ilkhāni*.[138] It was written by a great scholar of modern times, Maulana Ahmad Raza Khan of Bareilly in 1892-93 A.D. This glossary is based on the commentary of the renowned Persian scholar Niẓāmuddīn A'araj of Nīshāpūr. The learned author wrote only on the second *maqāla* of Īlkhānic Tables, but has provided very useful information, not generally found in other works on astronomical texts and tables.*

*The author acknowledges gratefully the cooperation and assistance provided by Prof. S.M.R. Ansari and Mr. Sahban Ahmad of IHMMR (New Delhi). Thanks are also due to Miss Saroj Verma for typing carefully a difficult text. Finally he, is especially grateful to Dr. A. K. Bag (INSA, New Delhi) for his patience and kindness.

APPENDIX — A

ZĪJES ENUMERATED IN Ā'ĪN-I AKBARĪ

1. *Zīj-i Majūr* (Amajur, the Turk).
2. *Zīj-i Ibburkhas* (Hipparcus).
3. *Zīj-i Baṭlimūs* (Ptolemy).
4. *Zīj-i Fīthāghurath* (Pythagoras).
5. *Zīj-i Zardasht.*
6. *Zīj-i Thāūn Iskandarani* (Theon of Alexandria).
7. *Zīj-i Sabat-i Yūnānī.*
8. *Zīj-i Thābit bin Qurrah.*
9. *Zīj-i Ḥasan bin Sinān.*
10. *Zīj-i Thābit bin Mūsā.*
11. *Zīj-i Muḥammad bin Jābir Battānī* (Albatignius).
12. *Zīj-i Aḥmad bin 'Abdullāh Jaha* (Ḥabash).
13. *Zīj-i Abū Rayḥān* (very probably *al-Qānūn al-Mas'ūdi*).
14. *Zīj-i Khālid bin 'Abdul-Malik* (one of the participants in al-Mamūn's observatories).
15. *Zīj-i Yaḥyā bin Abi Manṣūr* (very probably the famous *az-Zīj-ul-Mumtaḥan*).
16. *Zīj-i Ḥāmid* (the tables of Abū Hāmid Aḥmad bin Muḥammad as-Saghanī).
17. *Zīj-i Mughni.*
18. *Zīj-i Sharqi.*
19. *Zīj-i Abul Wafā' al-Buzjānī.*
20. *Zīj-i Jāmi' Kaya Koshiyār.*
21. *Zīj-i Bāligh Kaya Koshiyār.*
22. *Zīj-i 'Aḍūdi Kaya Koshiyār.*
23. *Zīj-i Sulaymān bin Muḥammad.*
24. *Zīj-i Abū Ḥāmid Anṣārī.*
25. *Zīj-as Safā'ih* (of Abū J'afar al-Khāzin).
26. *Zīj-i Abul Farh* (? Taraj) *Shirazi.*
27. *Zīj-i Majmū'a.*
28. *Zīj-i Muktār.*
29. *Zīj-i Abul Ḥasan Ṭūsī.*
30. *Zīj-i Aḥmad bin Ishāq Sarkhāsi* (probably Aḥmad bin Muḥammad bin aṭ-Ṭayyib as-Sarkhāsī, the pupil of alkindī and the teacher of the Caliph al-Mu'taḍid).
31. *Zīj-i Fazārī* (probably Ibrāhīm bin Ḥabīb al-Fazārī. He based his *zij* on *Brahmasphuṭa Siddhānta*).
32. *Zīj-i Hārūnī* (probably Hārūn al-Munajjim, an astrologer of Baghdād).
33. *Zīj-i Adwār-i Qarayn* (a table containing cycles of conjunctions).
34. *Zīj-i Y'aqūb bin Ṭāriq* (probably his *Zīj al-Maḥlūl*).
35. *Zīj-i Khwārazmī* (Muḥammad bin Mūsā Khwārazmī).
36. *Zīj-i Yūsufī.*

37. *Zij-i Wafi.*
38. *Zij-i Sam'āni* (according to al-Fihrist Sam'ān was the commentator of Ptolemy's Canon).
39. *Zij-i Jozharayn* (a table ralating to Jouzharayn, which are the head and tail of Draco, or the two points of intersection of the ecliptic and the orbit of the Moon).
40. *Zij-i Ibn Saḥra.*
41. *Zij-i Abul Faḍl Mashāzi* (probably Māshā' Allāh, the Jewish astrologer Ibn al-Aṯhra).
42. *Zij-i Āāsimi.*
43. *Zij-i Kabīr Abu Ma'ashar* (Latin Abbumaser first an opponent and afterward a pupil of Al-Kindī and a prolific writer).
44. *Zij-i Sanad bin 'Alī* (a renowned astronomer and participant in al-Mamun's observatory).
45. *Zij-i Ibn-ul-A'alam* (court astronomer and teacher of Buwahid Prince Adudud Daulah. His tables were relied upon by Naṣīruddīn Ṭūsī in the preparation of his *Zij-i Ilkhāni*).
46. *Zij-i Shahryarān* (the famous Persian astronomical tables of Sasanid Period, translated by al-Tamimi).
47. *Zij-i Arkand* (Sanskrit *Ahargaṇa*. Al-Bīrūnī revised its earlier Arabic translation).
48. *Zij-i Ibni-ṣ-Ṣufi.* (The Epitome of Ulugh Beg's Tables by Shaikh Muhammad bin Abil-Falah aṣ-Sufī al-Miṣrī with additional tables and notes).
49. *Zij-i Sahlān Kāshi.*
50. *Zij-i Ahwāzi* (probably the same, who wrote according to *al-Fihrist* a commentary on Euclid's *Elements*).
51. *Zij-i 'Urūs Abū J'afar Bushanji* (not traceable).
52. *Zij-i Abul Fatḥ* (the same who according to Ḥājīkhalīfā ammended the Samarqandī Tables).
53. *Zij-i Akkah Rahbi* (not traceable).
54. *Zij-i Qānūn-i Mas'ūdi* (of al-Bīrūnī).
55. *Zij-i Mu'atabar Sanjari* (of Abul Fatḥ 'Abdur Raḥmān al-Khāzinī, which he dedicated to the Saljūq Sulṭān Sanjar).
56. *Zij-i Wajiz Mu'atabar* (probably an abridgement of no. 55).
57. *Zij-i Aḥmad bin 'Abdul Jalil as-Sijzī* (an eminent astronomer of mid-tenth century A.D. who was the advocate of helio-centric system among the Muslims).
58. *Zij-i Muḥammad Jamasp Ṭabri* (not traceable).
59. *Zij-i 'Adli* (or 'Adanī).
60. *Zij-i Asābi'ai.*
61. *Zij-i Taylsān.*
62. *Zij-i Sulṭān 'Alī Khwārazmi* (full name of the author was 'Alī Shāh bin Muḥammad bin al-Qāsim. He was the author of a table called *Shahi*. He also epitomised Īlkhānic Tables and gave it the name of *'Umdat-ul-Ilkhānia*).
63. *Zij-i Tākhir (?) Naswi.*
64. *Zij-i Kirmāni.*

65. *Zij-i 'Alāi' Shirwāni* (full name of the author was Fakhruddīn Abul Ḥasan 'Alī bin al-Karīm ash-Shīrwānī, also known as al-Fahād. He was the author of another five tables).
66. *Zij-i Rāhiri* (probably Zāhidī, not traceable).
67. *Zij-i Mustaufī.*
68. *Zij-i Muntakhab Yazdi.*
69. *Zij-i Abu Rāzi Yazdi.*
70. *Zij-i Qaydūrah* (not traceable).
71. *Zij-i Iklili.*
72. *Zij-i Nāṣiri* (very probably of Muḥammad bin 'Umar Rāzī and dedicated to Nasīruddīn Maḥmūd, son of Iltutmish.
73. *Zij-i Mulakhkhaṣ.*
74. *Zij-i Dastūr.*
75. *Zij-i Murakkab.*
76. *Zij-i Maqlāma.*
77. *Zij-i 'Aṣā.*
78. *Zij-i Shastalah.*
79. *Zij-i Mas'il.*
80. *Zij-i Khatā'i.*
81. *Zij-i Dailami.*
82. *Zij-i Mufrad Muḥammad Ayyūb* (a very important *zij* in Persian).
83. *Zij-i Kāmil Abū Rashīd* (based on Albatignius' Tables, *Zij-i Al-Battani*).
84. *Zij-i Ilkhāni* (of Naṣīruddīn Ṭūsī).
85. *Zij-i Khāqāni* (of Ghiyāthuddīn Jamshīd Kāshī).
86. *Zij-i Gurgāni* (i.e. Ulugh Beg's Tables. The author, Ulugh Beg was the grandson of Tīmūr Gurgānī. Hence this title. The original title of this *zij* was *Zij-i Jadid Sulṭāni*).

APPENDIX — B

ZIJES ENUMERATED BY MULLĀ FARĪD IN HIS *Zīj-i Shāhjahānī*

1. *Zīj-i Jamia'* of Koshyār
2. *Zīj-i Balīgh* of Koshyār
3. *Zīj-i Mufrad* of Muḥammad Ayyūb Ṭabrī
4. *Zīj-i Kāmil* of Abū Rashīd Dānishī
5. *Zīj-i Sālār* of Ḥusayn Sālār
6. *Zīj-i Mughnī*
7. *Zīj-i Muṣṭaufī*
8. *Zīj-i Muḥkam*
9. *Zīj-i Zāhidī*
10. *Zīj-i Tākhir* of 'Ali Muṣṭaufī Shīrwānī Bakwāhī
11. *Zīj-i Sanjari* of 'Abdur Raḥmān Khāzinī
12. *Zīj-i Alā'ai* (which he says was based on *Zīj-i Sherwānshāh*)
13. *Zīj-i 'Umda i Īlkhānī* by 'Alī Shāh Khwārazmī
14. *Zīj-i Khāqānī* which was the compliment of Īlkhānī Tables by Maulana Jamshed Rāshī.
15. *Zīj-i Sultani* of Muhammad bin Khwaja 'Alī Wamkahiwī
16. *Zīj-i Abū Ḥāmid Anṣāri*
17. *Zīj-i Abul Faraḥ Shīrāzī*
18. *Zīj-i Abul Ḥasan Ṭūsi*
19. *Zīj-i Kāfī Iskandari*
20. *Zīj-i Adwar Akwar*
21. *Zīj-i Ashrafī*
22. *Zīj-i Raḥīmī*
23. *Zīj-i Kāsifī*
24. *Zīj-i Shāṭiri* (may be *Zīj-i Ibn-i Shāṭir*)
25. *Zīj-i Mazharī*
26. *Zīj-i Quṭbī*