FROM TYCHO BRAHE TO ISAAC NEWTON: FERDINAND VERBIEST'S ASTRONOMICAL INSTRUMENTS IN THE ANCIENT OBSERVATORY OF BEIJING

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In 1674, the Jesuit scientist Ferdinand Verbiest designed and directed the construction of six large astronomical instruments for the Chinese emperor Kangxi and installed them on the terrace of the Astronomical Observatory of Beijing.

These instruments were accompanied by two texts in Chinese explaining the theoretical framework, construction and use. The two texts were the Yi Xiang Zhi (Instrument Description) and the Yi Xiang Tu (Instrument Design), and they are of course closely connected, since the latter is the ichnographic outline of the former; in fact, the Yi Xiang Tu contains 105 prints, numbered from 1 to 117, with one unnumbered illustration showing the now famous complete view of the instruments on the observatory terrace (Fig. 1).

The preface illustrates a quite rational work plan allowing the practical use of the tables of instrument design: they are not connected and so they can be drawn out one by one in order to follow the descriptions and instructions contained in the other text, the Yi Xiang Zhi(1).

Leaving aside the problems of the dating of these two texts and the connection between them and F. Verbiest's Latin texts[(2)], it is to be emphasized that the Jesuit's scientific production in Chinese was enormous compared with his religious production, so that we can consider Verbiest, together with Johann Schreck (Terrentius)[(3)], Johann Adan Schall von Bell[(4)] and Giacomo Rho[(5)], more a modern man of scien-

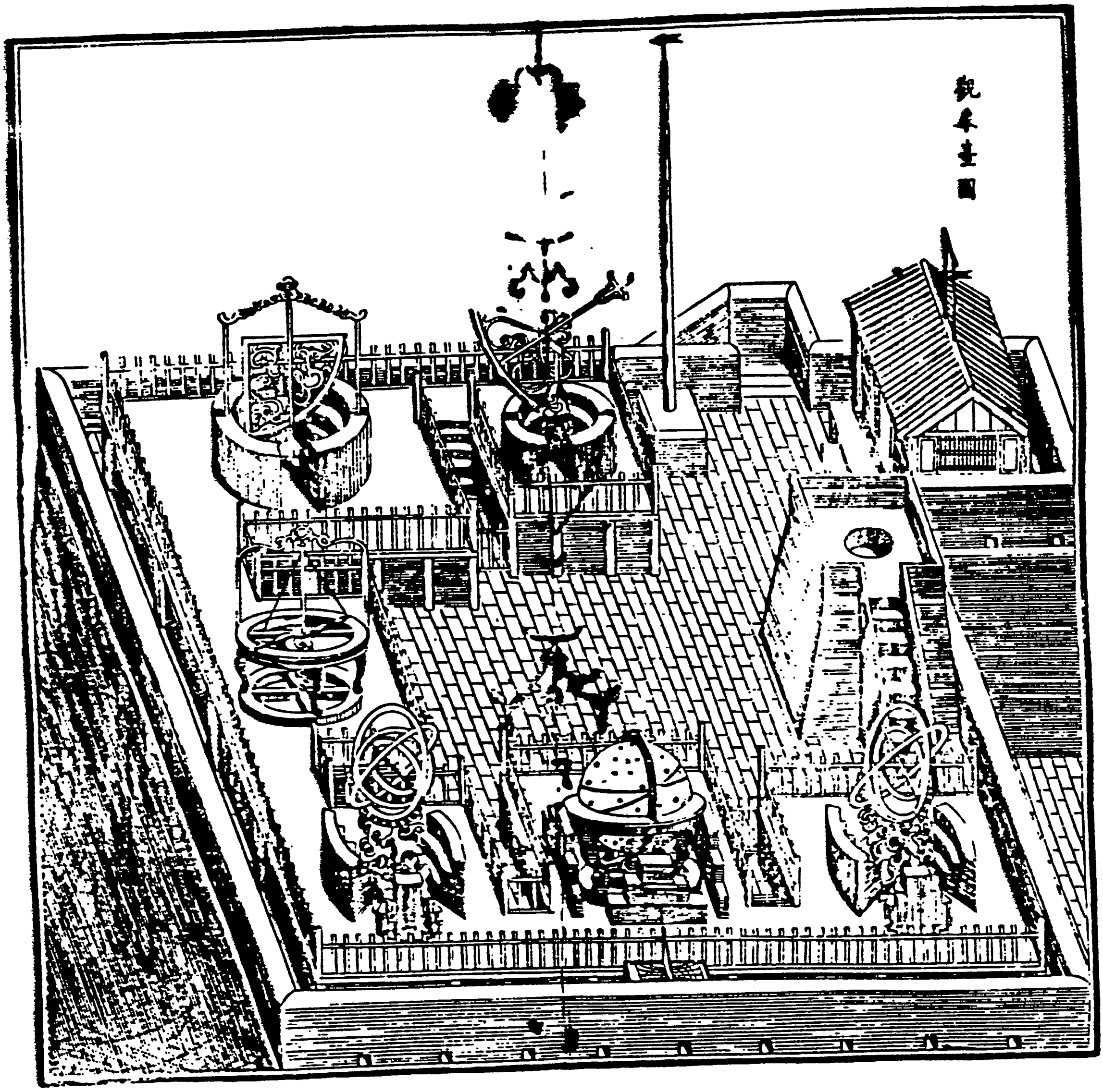


FIGURE 1: The general prospect of the Peking Observatory in the unumbered woodcut of the Yi Xiang Tu of F.Verbiest (by copy of Vatican Library).

ce, even though he was not free of contradictions, than a man of the Church.

The Instruments

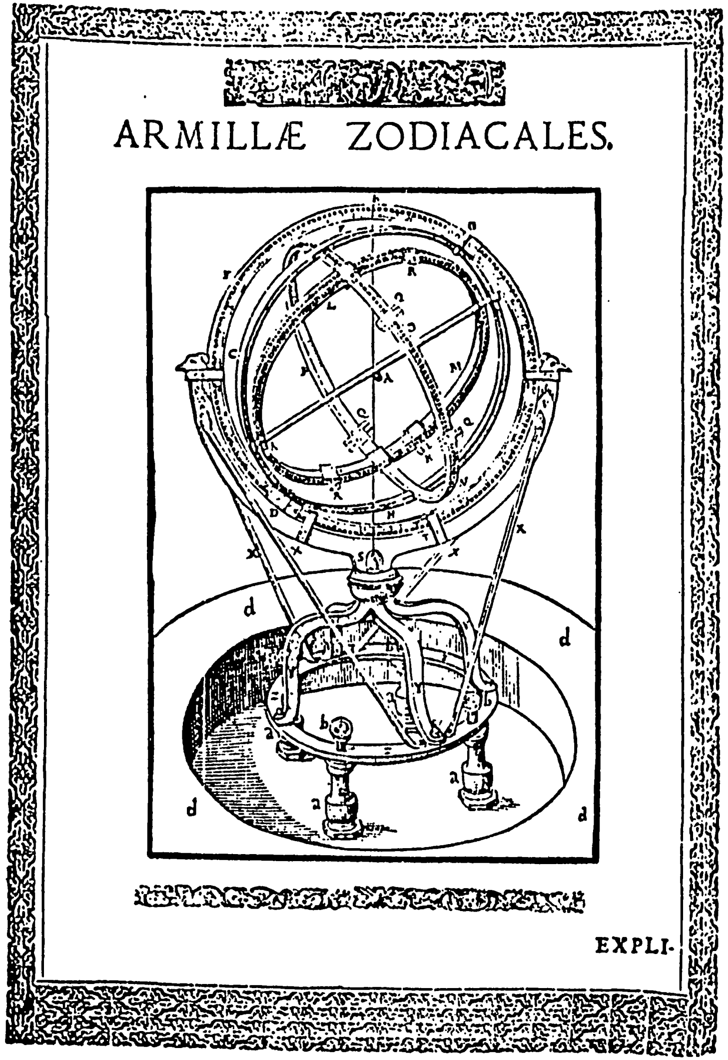
Let us ask ourselves along with Granger: "Is a science possible without instruments? ... Absolutely not. One cannot, however, but underline the role that pure theatrical illusion plays often by artificial instrumentation in every type of counterfeit knowledge"(6).

Now then, the instruments planned by Verbiest and built under his direction for the Beijing Observatory could be used to back up the accusation of "pure theatrical illusion" because of their wonderful artistic workmanship which seems to take precedence over their technical use. In order to confute this impression, let us observe the instruments more closely.

The prototypes of Verbiest's six instruments are traceable to those illustrated and described by Tycho Brahe in his Astronomiae Instauratae Mechanica of 1598(7); these are:

- ecliptic armillary sphere (Fig. 2);
- equatorial armillary sphere (Fig. 3);
- horizon circle (Fig. 4);
- quadrant (Fig. 5);
- sextant (Fig. 6);
- celestial globe (Fig. 7).

A first summary technical comparison between Verbiest's instruments and those of Tycho Brahe was carried out by A. Chapman(8), but this comparison, although it is of great interest to our subject, does not take into consideration the close relation existing between the illustrations (of the Yi Xiang Tu) and the explanatory text (Yi Xiang Zhi), nor does the author refer directly to any Chinese source.



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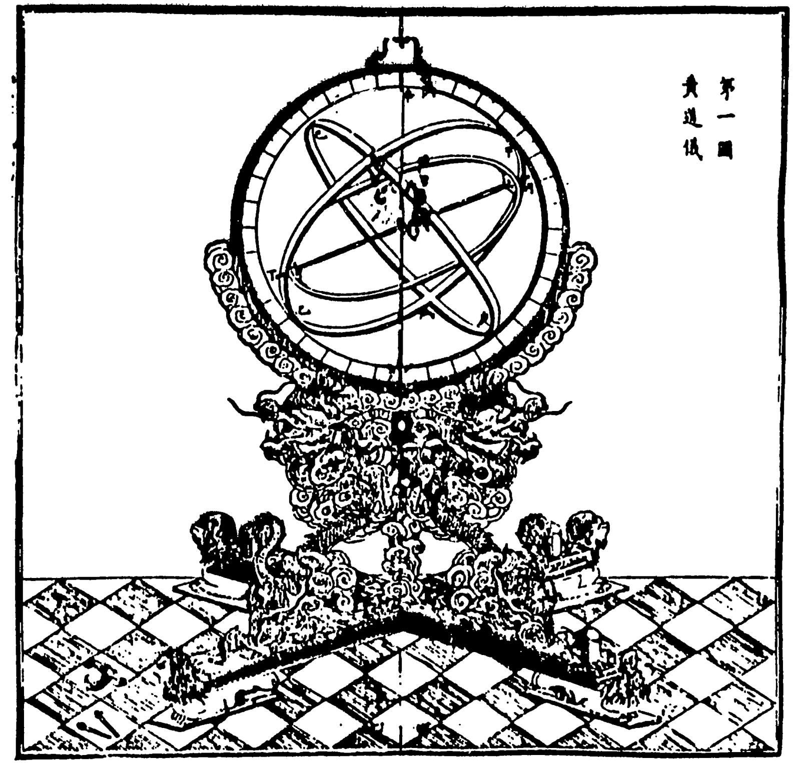
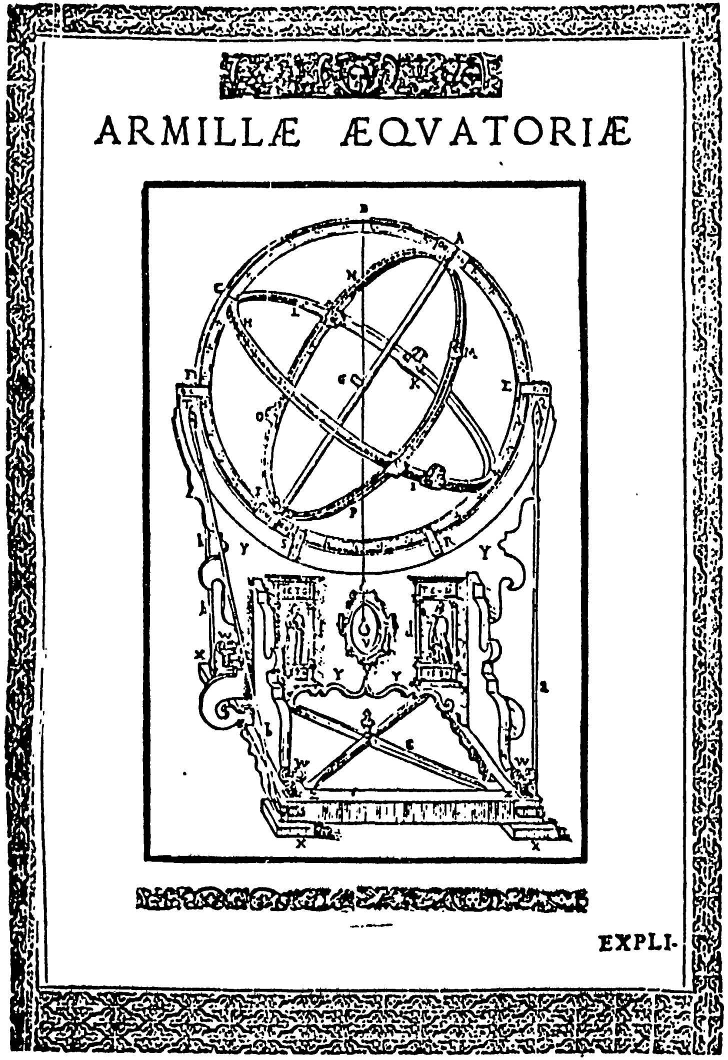


B

FIGURE 2:

Simple ecliptic armillary sphere by ...Mechanica of T.Brahe (A) and by Yi Xiang Tu ov F.Verbiest(B).



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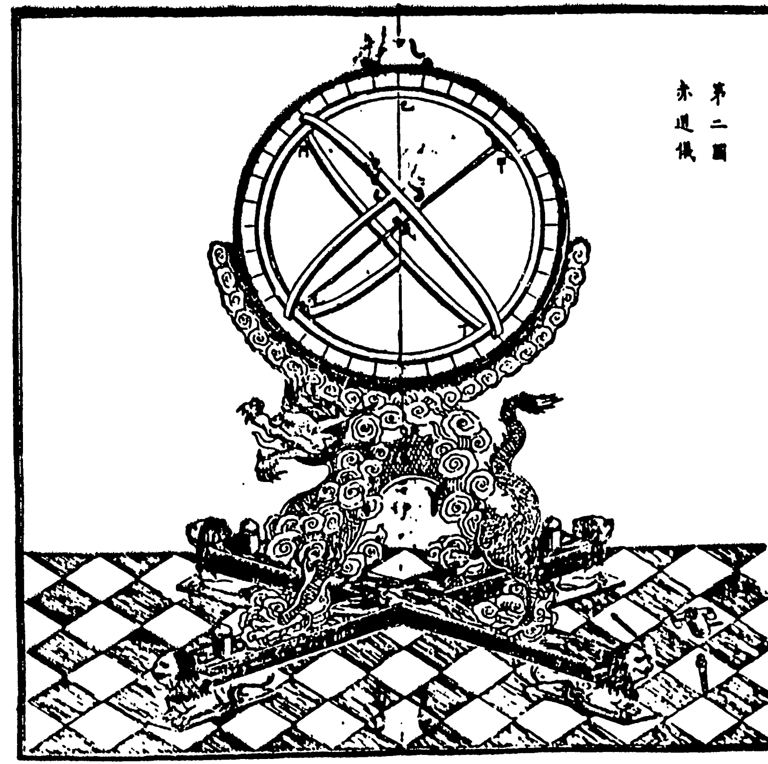

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FIGURE 3:

Simple equatorial armillary sphere by ...Mechanica of T.Brahe (A) and by Yi Xiang Tu of F.Verbiest(B).

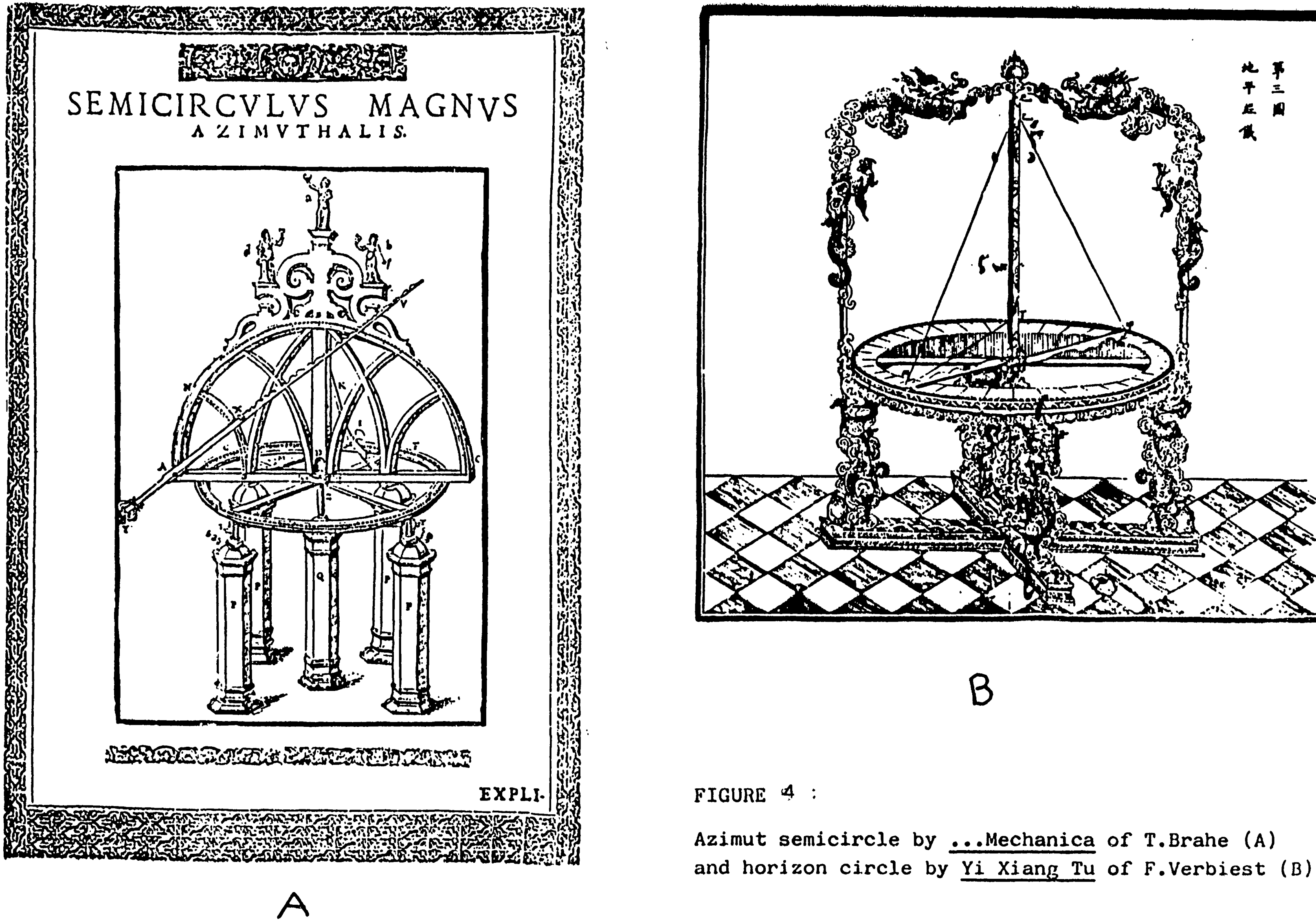
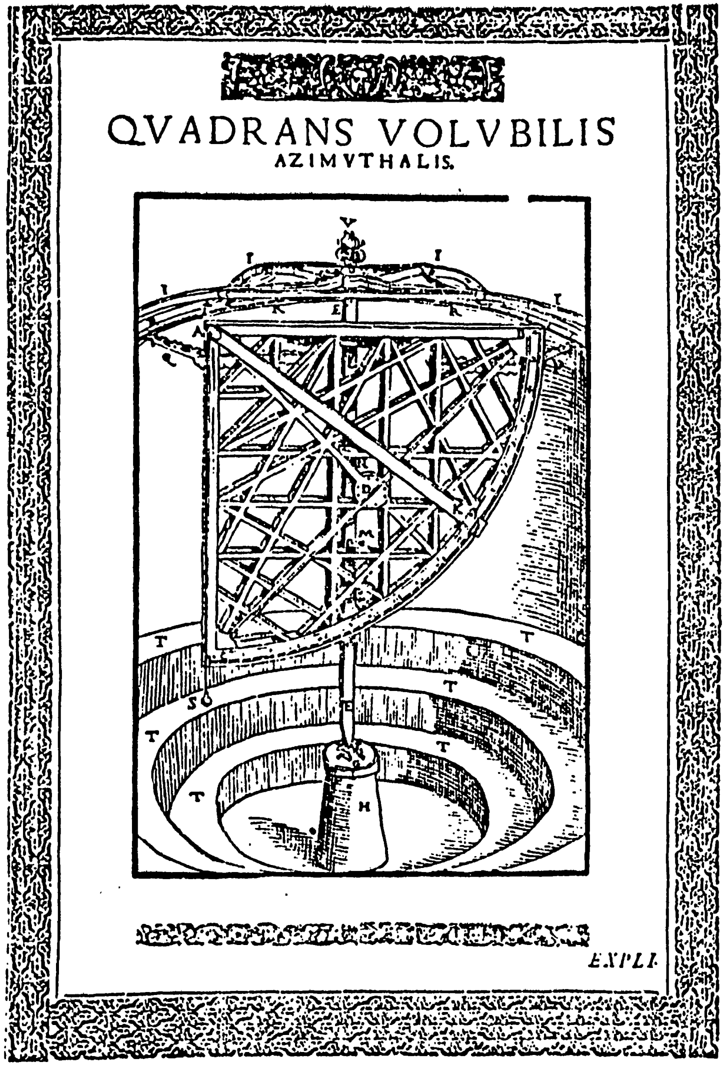


FIGURE 4 :

Azimut semicircle by ...Mechanica of T.Brahe (A) and horizon circle by Yi Xiang Tu of F.Verbiest (B).



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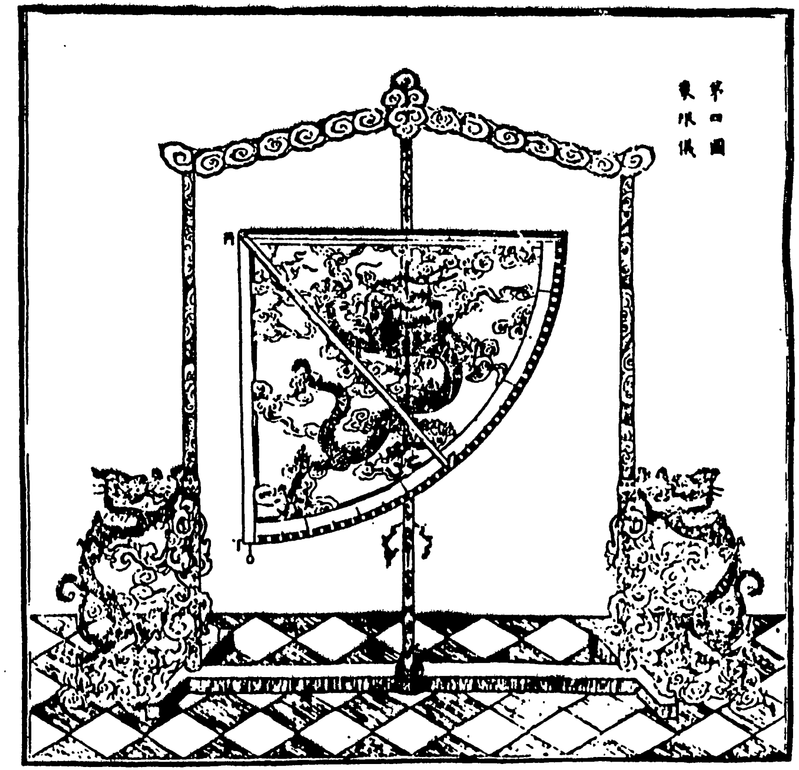

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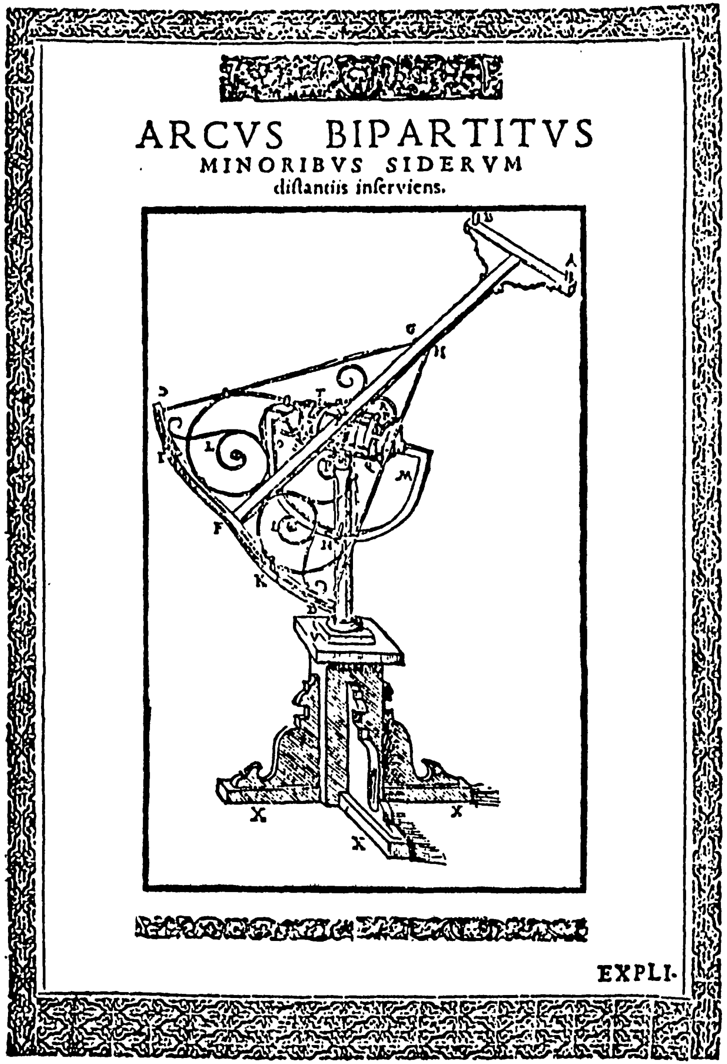
FIGURE 5:

Quadrant by *...Mechanica* of T.Brahe (A) and by *Yi Xiang Tu* of F.Verbiest (B).



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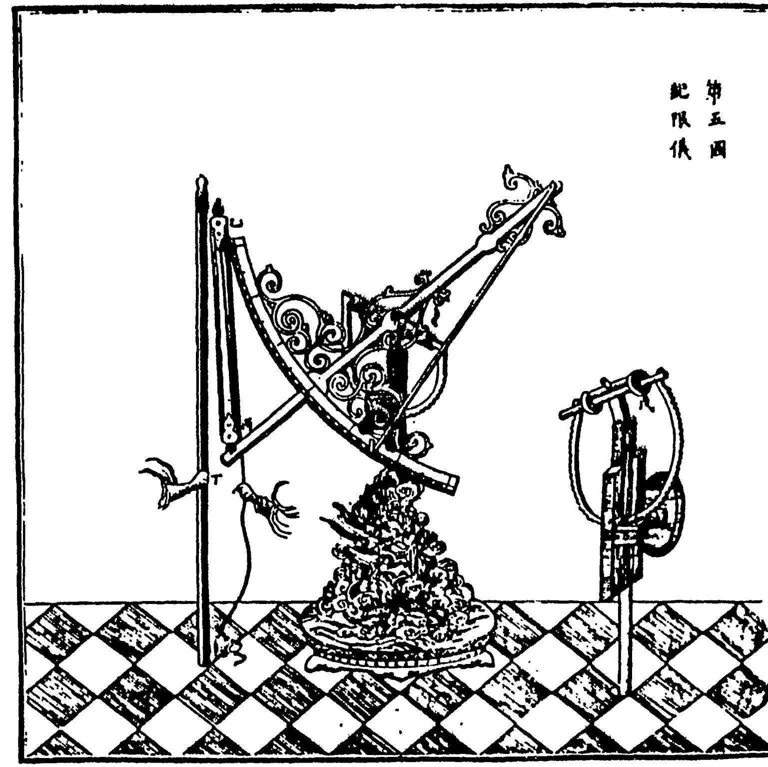
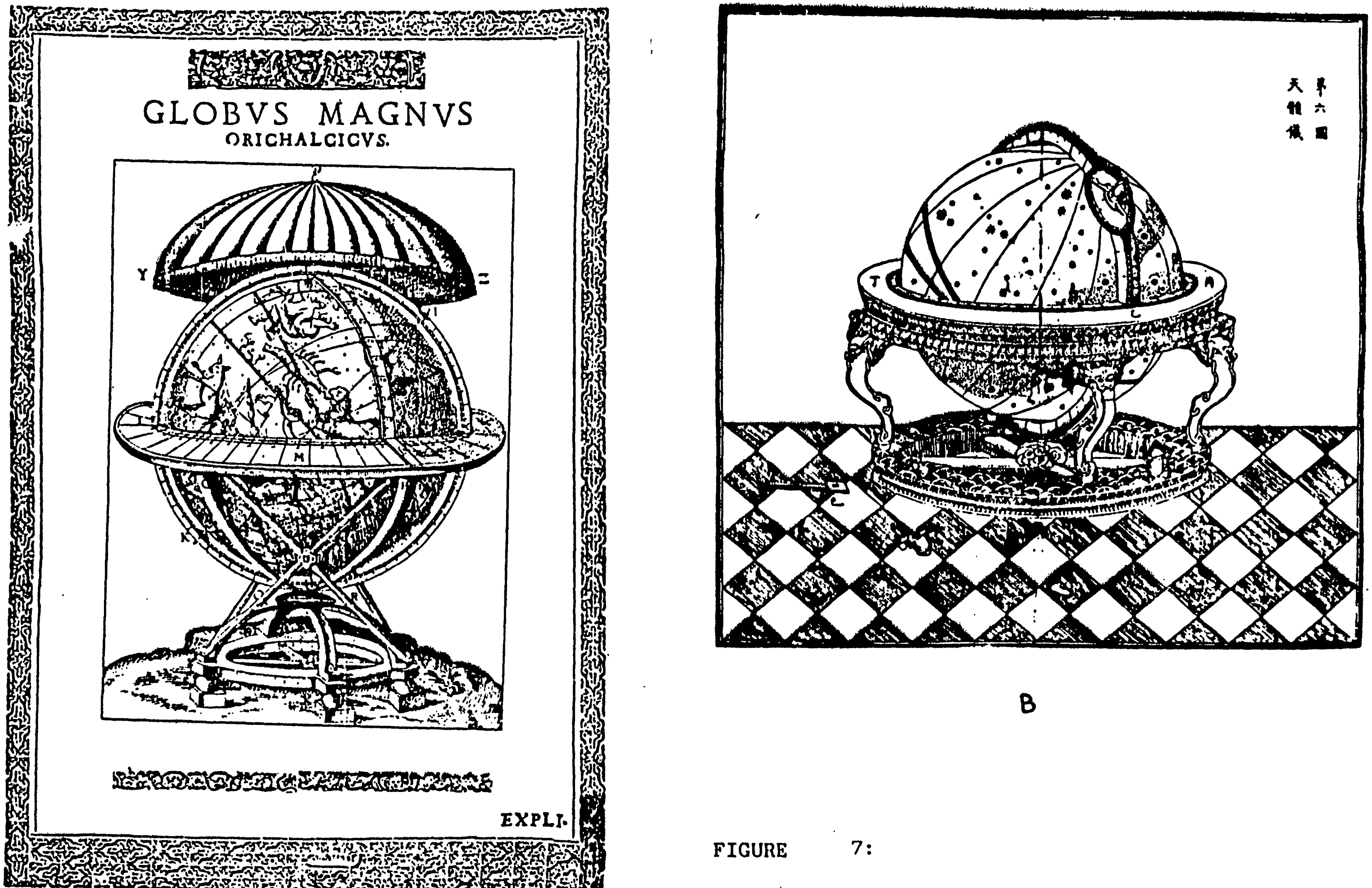


B

FIGURE 6:

Bipartite arc by ...Mechanica of T.Brahe (A) and sextant by Yi Xiang Tu of F.Verbiest (B).



A

B

FIGURE 7:

Celestial globe by <u>...Mechanica</u> of T.Brahe (A) and by <u>Yi Xiang Tu</u> of F.Verbiest (B).

As has been indicated above, we prefer to postpone the undertaking of a detailed technical examination of the instruments until we have a full translation of the Yi Xiang Zhi; at that time it will be possible to make a meaningful comparison of what was written by Verbiest with the technical characteristics given by Tycho Brahe in his work, as well as to reconstruct the sequences of the development of the instruments from Tycho to Verbiest, tracing both the Chinese technical influences and Western ones lent by other famous European builders from whom Verbiest might have drawn as, for example, Gemma Frisius, Thomas Gemini, Walter Arsenio, Gerhard Mercatore, Girolamo della Volpaia, Johannes Hevelius and still others.

From elements that have emerged so far, some of the technical characteristics relative to some of the instruments and their representation as regards the Brahian tradition can be summarized in the following points:

- F. Verbiest, unlike T. Brahe and the other European designer-scientists, could avail himself of the refined Chinese bronze technology and thus realized more compact and steady carrying structures;
- both the instruments and the relative construction processes can be illustrated in a very accurate fashion and follow the European models, even though some of the technical solutions adopted by Verbiest turn out to be innovative; this demonstrates that the Jesuit was knowledgeable in the developments in instrumentalization from the time of Tycho until he left Europe (1657);
- the ecliptic armillary sphere built by Verbiest to measure the positions of the planets(9) was more elaborate than that of Tycho, but both illustrate the graduated scale with alternating black and white notches as was the custom of the time; both use a screw-set in order to align the instruments. Furthermore, Tycho shows his sphere in a

small well while Verbiest, even though he illustrates it on a chess-board type pavement (used by Tycho on other occasions), accompanies the Yi Xiang Tu (and therefore the Liber Organicus...) with tables explaining a construction of the well which will then be built on the terrace of the Beijing Observatory;

- the armillary equatorial sphere which Verbiest built to observe the equinoxes[10] is identical to that of Tycho, but differs sensibly from those already used by the Chinese, which were more complex in that they adopted a greater number of rings: those of the equator and of the horizon in the outer nest and the ecliptical ring in the inner nest[11] and furthermore used double rings.

Among the innovations introduced by the Jesuit scientist was the introduction of the equinoctial colure of the semicircular bracing ring which sustains the equatorial circle only in the southern hemisphere, and this sharply reduced the difficulties in observing the heavens near the equinox.

- Verbiest's graduated scales, besides the problems indicated concerning the division into 360 degrees, was a very efficacious system of reading that used the method of diagonal lines and represented the most advanced system of the reading of a scale with the naked eye before the use of telescopic sights.
- Verbiest's sextant is mounted on the azimuth and its geared setting renders the instrument more stable compared to the ball mounting used by Tycho (and Hevelius); furthermore, the pulley and tackle permit one to follow celestial objects more delicately than with the stabilizing spikes that Tycho had used in his Sextans Astronomicus Trigonicus Pro Distantiis (Fig. 8). Verbiest's technical solution is very interesting and may have been suggested by the bipartite arc of Tycho (Fig. 6A) which has a semi-circular clamp mounting which cannot, however, do the work of a gear.

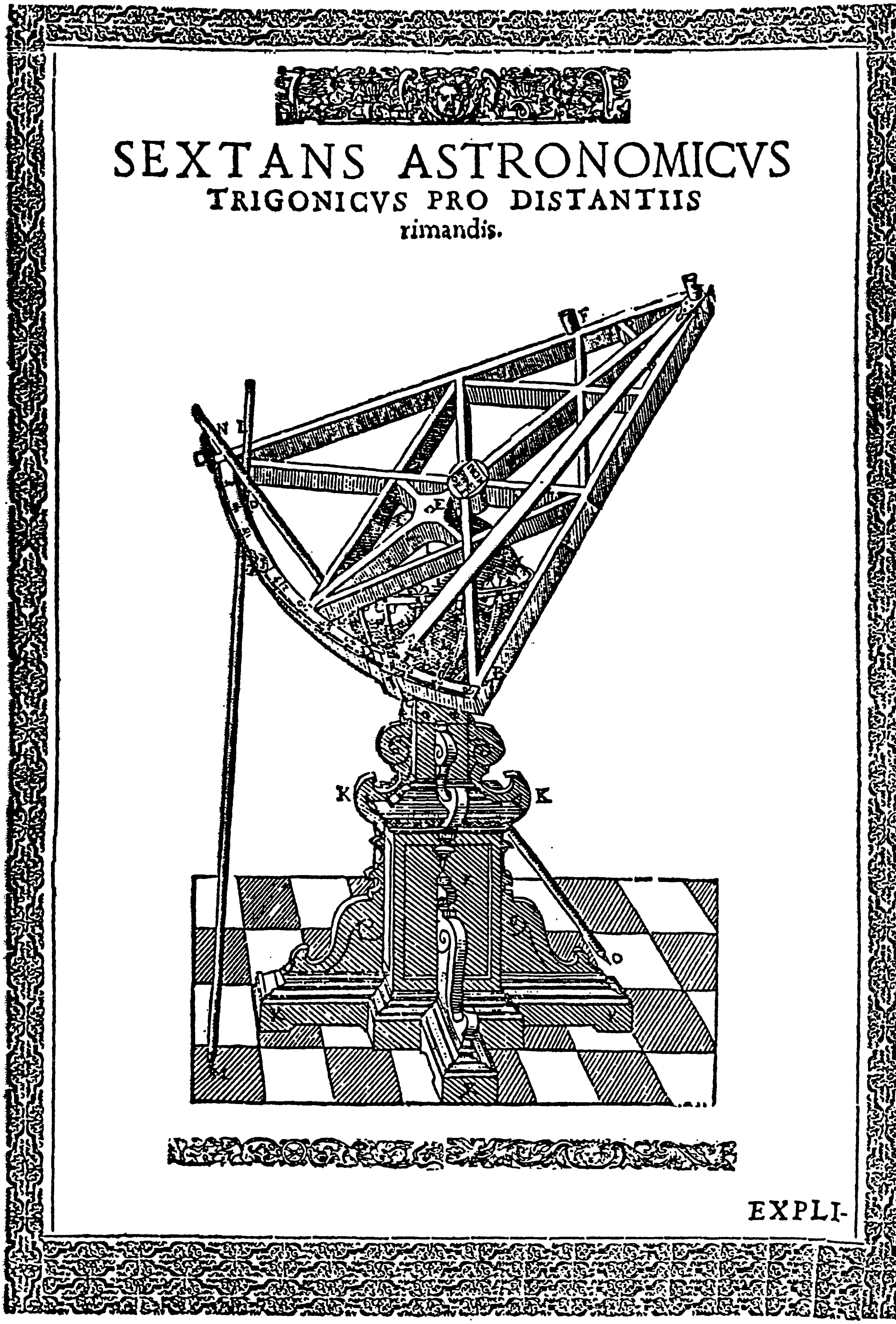


FIGURE 8: Six-foot sextant by ...Mechanica of T.Brahe; note the stabilizing spikes and the ball mounts.

We note also:

- the circles on Verbiest's instruments are graduated 360 degrees, unlike the Chinese which are graduated 360 1/4 degrees; the division by sixtieths of degrees and minutes operated by Verbiest were less precise than the decimal system in tenths and hundredths of the Chinese.

In reviewing the points above, one may notice that Ferdinand Verbiest's instruments were not built merely for show; therefore one must not be taken in by the decorative motifs of the instruments, which surely represent the most outstanding feature for whoever approaches them for the first time.

Let us remember again that in China the custom of decorating scientific instruments with symbolic figures (dragons, animals, clouds, etc.) was already in use with instruments much older than Verbiest's as, for example, the splendid equatorial armillary sphere built by Guo Shoujing (1276), his equatorial torquetum (1270) and the ancient armillary sphere of Su Song (1090) which was also endowed with clockworks[12].

Thus Verbiest did nothing but resort to a congenial decorative mode in keeping with Chinese tastes which had already been codified for centuries, and was necessary for objects used under the direct supervision of the Emperor. Certainly, we do not hold that the artistic aspect is wholly secondary in the scientific instruments of Ferdinand Verbiest. In fact, they prefigure as true art objects for both the complexity of the ornaments and the balance of spatial relationships. Of course, only the ability of the Chinese in bronzework permitted the practical realization of these instruments which, we are sorry to note, do not appear in any manual of oriental art history.

Conclusions

In re-evaluating the course of Chinese science, it is to be emphasized that Verbiest and other previous Jesuit scientists introduced into China an astronomy profitable for calendrical science, but this was less advanced than Chinese astronomy itself in the same period. This ancient Chinese astronomy was certainly more innovative than European astronomy with regard to intuition (for example, in the concept of the "infinite"), theoretical models (for example, in the early use of equatorial coordinates) and instrumentation (for example, in the equatorial armillary sphere).

However, we cannot generalize this reasoning, and it would be more suitable to carry out a systematic study of the scientific body of writing produced by the Jesuits in Chinese. Let us remember that only a critical analysis of these texts would permit an objective evaluation of the work undertaken in China by the followers of the Society of Jesus. First of all, the weight of scientific titles compared to those of religious divulgation for each author must be considered; from the studies that we have already undertaken in this direction by historians of science and sinologists have re-emerged personalities such as Johann Schreck, Giacomo Rho and Johann Adam Schall von Bell, who seems inexplicably to have been granted with the merits of the others of his brotherhood, in addition to his own, which were great.

One cannot deny that these scientists were knowing participants in a magic moment in the history of science: the encounter (or confrontation) between two scientific systems, and it is just as undeniable, as much as one might wish to prove the contrary, that they were the representatives of a modern way of doing science (even though it was not free from contradictions, as is demonstrated by the great use of mathematics in the study of natural phenomena and the close connection between theory and practice, science and technics.

One of the accusations made against the Jesuit scientists is that they propagandized the astronomic system of Tycho Brahe and not that of Copernicus in China. But, one can reply, Tycho's view, although less advanced than the Copernican one, was more recently formulated. On the other hand, even in Europe, in spite of the fact that Galileo and Kepler had solidified the Copernican theory, it was necessary to wait for the Principia of Newton (1687) in order to recast physics, substituting Galileo's law of circular inertia with the law of linear inertia, or to enunciate a clear conception of force as the cause of acceleration more than of motion or, what is more, in order to introduce the concept of the law of gravitation with which they were able to explain the laws of planetary motion and those of the fall of heavy bodies.

It is in this light of evaluation, which can never be determined a priori, that one must also examine the work of Ferdinand Verbiest. For example, instead of underlining the fact that the building of the ecliptic armillary sphere was a step backwards compared to the equatorial astronomy already adopted by the Chinese, one might remember that at present there is a re-evaluation of the ecliptic coordinates which turn out to be useful in theoretical astronomy to determine the orbits of heavenly bodies.

We emphasize that it is precisely in the building of instruments that Verbiest can be classified without doubt among the aforementioned scientists who paved the way in the history of instrumental development. With these Verbiest has in common the rigorous planning method and the yearning (ambition?) for divulgation, as attested by his sophisticated theoretical and iconographic manuals, which explain the construction, installation and use in detail.

Furthermore, in the instruments of Verbiest, as in those of the major instrument builders operating at that time in Europe, the knowing search for precision is revealed, which manifested itself in the attempt to resolve the three principal problems conatural with astronomical devices:

- the accurate sight of the object studied;
- the accurate alignment and division of graduated circles;
- the accurate reading of graduations.

The diligence with which the French and German troops siezed them after the sack of Beijing in 1900 is witness to the fact that Verbiest's instruments represented a significant step in the history of science and art, and still do today.

The French kept the instruments which they had appropriated (the quadrant, the ecliptic and equatorial armillary spheres, the quadrant altazimuth of B. K. Stunf built in 1714 and the famous equatorial torquatum of Guo Shoujing of 1270) in their Embassy and returned them only in 1902.

To get back the instruments taken by the Germans and brought to Berlin (the celestial globe, the sextant and the horizon circle of Verbiest in addition to the equatorial armillary sphere built by I. Koegler in 1744 and a Chinese equatorial armillary sphere), the Chinese had to wait until the end of the First World War, when the Treaty of Paris (Article 1131) imposed the restitution of the instruments taken by the Germans, and returned to Beijing in 1921.

The ancient Beijing Observatory, closed to all but a few scholars for decades, was reopened on April 1st, 1983. The Chinese press has recently given great relief to Verbiest's instruments and this, in addition to underlining the renovated interest of the Chinese in the study of the history of astronomy, has confirmed the fact that the instruments themselves represent, in a crucial manner, the cultural link between Europe and China.

R E F E R E N C E S

(1) Cf. I. IANNACCONE, Syncretism between European and Chinese Culture in the Astronomical Instruments of Ferdinand Verbiest of the Ancient Peking Observatory, in "Atti del Colloquium Verbiest", Leuven, sett. 1988, in print.

(2) Cf. I. IANNACCONE, Un'ipotesi sull'"Yi Xiang Tu" ed il "Liber Organicus..." di Ferdinand Verbiest, in 'Asia Orientale', Dic. 1983, vol. VII, in print.

(3) Cf. I. IANNACCONE, Johann Schreck (Terrentius): Scienziato, Linceo, Gesuita e Missionario nell'Impero dei Ming, in 'Asia Orientale', vol. V/6, 1987, pp. 49-85.

(4) Cf. I. IANNACCONE, G. ARPAIA, Galileo e il sincentrismo: introduzione delle scoperte galileiane e del telescopio nella Cina del XVII secolo, in 'Atti del VII Congresso Nazionale di Storia della Fisica', Padova 1986, pp. 223-229.

(5) Cf. I. IANNACCONE, G. ARPAIA, Giacomo Rho: un astronomo italiano del '600 IN Cina, in 'Atti del VIII Congresso Nazionale di Storia della Fisica', Napoli 1987, pp. 241-246.

(6) Cf. G. G. GRANGER, E' possibile una scienza senza strumenti?, in 'Gli strumenti nella Storia della Filosofia della Scienza', ed. G. TAROZZI, Bologna 1985, pp. 47-66.

(7) T. BRAHE, Astronomiae Instauratae Mechanica (Wandesburgi 1598), trad. ed. H. RAEDER, E. and B. STROMGREN, Kobenavn 1946. Also, cf. V. E. THOREN, New Light on Tycho's Instruments, in 'Journal of History of Astronomy', vol. IV, 1973, pp. 25-45; cf. W. G. WESLEY, Tycho Brahe's Solar Observations, in 'Journal of Astronomy', vol. X, 1979, pp. 96-101.

(8) Cf. A. CHAPMAN, Tycho Brahe in China: The Jesuit Mission to Peking and the Iconography of European Instrument-Making Process, in 'Annals of Science', vol. 41, 1984, pp. 417-443.

(9) Cf. H. BOSMANS, Ferdinand Verbiest, Directeur de l'Observatoire de Pekin, in 'Revue des Questions Scientifiques', vol. 21, 1912, p. 273.

(10) Ibid.

(11) Cf. J. NEEDHAM, Science and Civilisation in China, vol. III, Cambridge 1959, pp. 339-382; also cf. H. MASPERO, Les Instruments Astronomiques des Chinois au temps des Han, in 'Melanges Chinois et Buddiques' vol. VI, 1939, pp. 183 sgg.

(12) Cf. J. NEEDHAM, WANG LING, D. J. DE SOLLA PRICE, Heavenly Clockwork, the Astronomical Clocks of Medieval China, Cambridge 1960, reprint 1986.