IBN BĀṢO'S UNIVERSAL PLATE AND ITS INFLUENCE ON EUROPEAN ASTRONOMY

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1. INTRODUCTION

The development of universal astronomical instruments in Latin Europe between the 13th and the 17th centuries was greatly influenced by instruments developed in the Muslim world, both in the East and the West, during the Middle Ages.

In the 11th century, Andalusian astronomers developed a number of original instruments with which they tried to improve on the possibilities of the conventional astrolabe, an instrument which had proved its usefulness as an analog computer, by making all the trigonometric calculations needed to solve problems of spherical astronomy easier. The influence of their achievements on the work of later astronomers, not only in Europe but also in al-Andalus, in the north of Africa, and in the Near East, Egypt and Syria, for instance, is well known.

2. IBN BĀṢO

Among them is found a *muwaqqit* whose name was Abū 'Alī al-Ḥasan b. Muḥammad b. Bāṣo. Originally from eastern Andalusia (*Sharq al-Andalus*), he was a theologian, mathematician, astronomer and chief of the timekeepers in the great mosque of Granada a post which implies great liturgical responsibility. His biographer, Ibn Khaṭīb, emphasizes his great skill in the production of astronomical instruments and states that he was both an inventor and the author of treatises. He died in Granada in H. 716 / A.D. 1316 (1).

Ibn Bāṣo was the author of a treatise on the use of a plate of sines entitled *Risālat al-ṣafīḥa al-muŷayyaba ḏāt al-awtār*, that is to say, "Treatise on the use of the plate of sines provided with chords". This treatise is composed of 59

1. Cf. LISĀN AL-DĪN IBN AL-JAṬĪB : *Al-Iḥāṭa fī ajbār Garnāṭa* ed. 'Abd Allāh 'Inān (Cairo, 1973) vol. I p. 468 ; G. SARTON, *Introduction to the History of Science*, (Baltimore, 1927-1931) vol. III p. 696 ; H. SUTER, *Die Mathematiker und Astronomen der Araber. Abhandlungen zur Geschichte der mathematischen Wissenschaften*, 10 (Leipzig, 1900) n. 381 b, p. 157 ; C. BROCKELMANN, *Geschichte der Arabischen Literattur. Supplementband*, I p. 869 ; J.A. SANCHEZ PEREZ, *Biografías de matemáticos árabes que florecieron en España* (Madrid, 1921) p. 79 ; H.P.J. RENAUD, *Notes critiques d'histoire des sciences chez les musulmans. I. — Les Ibn Bāṣo* "Hesperis", 24 (1937) pp. 1-12 ; *Additions et corrections à Suter*, "Isis", 18 (1932) n° 381 b, p. 172 ; J.M. MILLAS, *Don Profeit Tibbon. Tractat de l'assafea d'Azarquiel* (Barcelona, 1933) pp. XXXVII-XXXVIII ; *Estudios sobre Azarquiel* (Madrid-Granada, 1943-1950) pp. 448-449 and J. SAMSO, *A propos de quelques manuscrits astronomiques des bibliothèques de Tunis : Contribution à une étude de l'astrolabe dans l'Espagne musulmane.* "Actas del II Coloquio Hispano-Tunecino" (Madrid-Barcelona, 1972) pp. 176-182.

chapters and is preserved in manuscript 5550 of the National Library of Tunis. It has not yet been studied.

Ibn Bāṣo also wrote a treatise on the use of a device that he called *al-ṣafīḥa al-jāmi'a li-jamī' al-'urūḍ* (general plate for all latitudes) in 160 chapters. This treatise, completed in A.D. 1274, is preserved in three extant manuscripts now in El Escorial (ms. 961), in the National Library of Tunis (ms. 9215) and in the Royal Library of Rabat (ms. 4288).

A few abridgements of this second treatise are also extant. The most remarkable of them is the one entitled *Nubḏa lāmi'a li-mā yata'allaq bi-l-ṣafīḥa al-jāmi'a*, (Note on the general plate), which is the only known source describing the construction of this plate, a subject which does not appear either in Ibn Bāṣo's treatise or in the other extant abridgements. The author of this treatise was a Moroccan *faqīh* of the 17th century called Sulaymān b. Aḥmad al-Fishtā lī. The process described for its construction is based on Euclidean geometry : circles and arcs of circle are traced given three points on them or one point and the centre. There are no trigonometric formulae in these instructions.

2.1. Ibn Bāṣo's general plate

The lines traced on Ibn Bāṣo's general plate following the aforementioned procedure are different from the lines we find on a conventional astrolabe plate.

The reason is that the *ṣafīḥa* described in this treatise corresponds, in fact, to the western plate of horizons. It basically consists of a northern projected astrolabe plate on which horizons have been multiplied and horizontal coordinates have been omitted, in order to convert it into a universal instrument, to give it the possibility of being used at different latitudes.

The lines represented on a conventional astrolabe plate are, basically, the projection of the horizon corresponding to a given locality, its horizontal coordinates, that is to say, its circles of altitude or *al-muqantarāt* and its vertical circles. We also find the projection of the equator, the tropic of Cancer and the tropic of Capricorn, which determines the outer circle of the plate.

The characteristic that makes Ibn Bāṣo's plate different is the choice of the lines of the sphere that can be found on it.

First of all, there is a complete set of horizons that Ibn Bāṣo says can be traced every 6 degrees "or however one prefers". The equator is one of these horizons. It can be considered the one representing a 90 degree latitude.

In addition, there are two sets of concentric circles, whose centres are the two points east and west of the equator to which they are perpendicular. They are, therefore, parallel to the equatorial meridian which passes through the points east and west of the equator. Ibn Bāṣo calls these circles *qīsī* (arcs) and also *ajzā' al-ufuq* (horizon divisions) because, as they are perpendicular to the horizons, they divide them in equal parts. These arcs are employed to change the coordinate system, from horizontal into equatorial and vice versa, by a turn equivalent to the colatitude of the locality in which one is operating.

Finally, there is a set of concentric circles, parallel to the equator, which can be found towards the north ranging from 0 to 90 degrees called *madārāt* (pa-

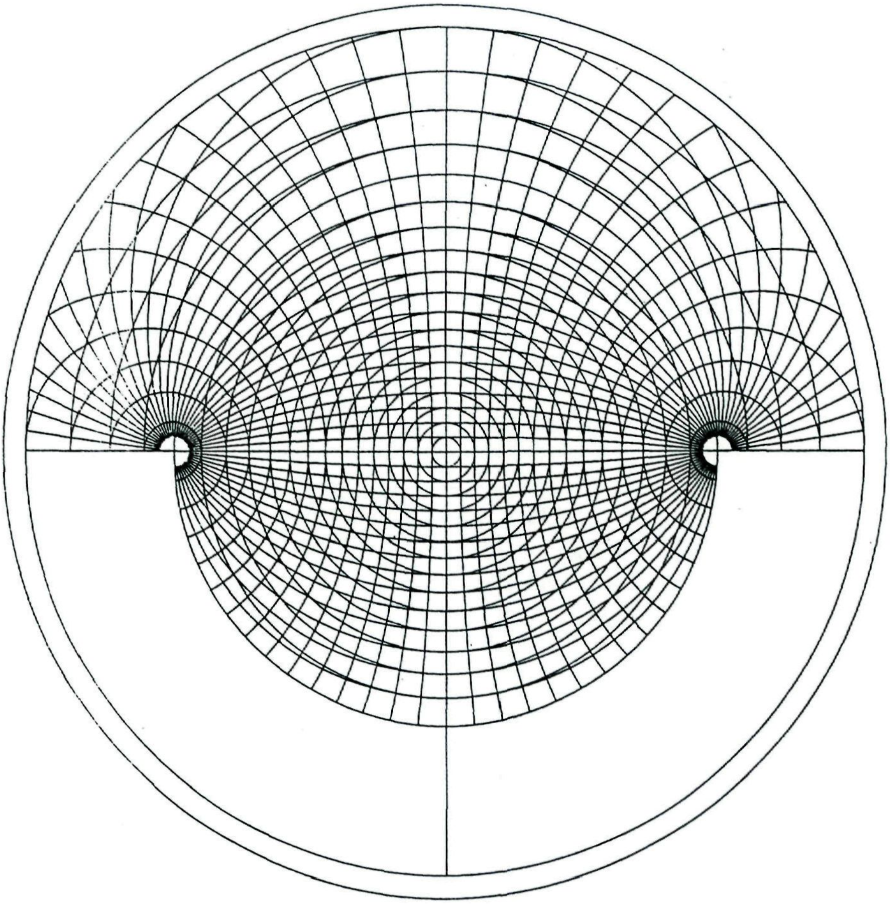

Fig — Ibn Bāṣo's General Plate.

rallels of declination) and towards the south, between the equator and the tropic of Capricorn. The latter have been reduced to one half and Ibn Bāṣo calls them *anṣāf dawā'ir al-mayl* (semicircles of declination). If we consider the equator to be a horizon for a 90 degree latitude, all these parallels can be considered in turn as *al-muqantarāt* for this latitude.

The instrument also has an alidade that can rotate, describing diameters of the plate which are the projection of equatorial meridians. But if we considered the equator as the horizon corresponding to a 90 degree latitude, these diameters would be considered as the vertical circles for that latitude. The equator is, therefore, the only horizon of this plate with a complete coordinate system. The way of using this plate is by employing this set of coordinates when operating with any other horizon. To do that, and bearing in mind that what this instrument measures is relative positions, what must be done is a change in the coordinate system as mentioned above by using the arcs.

Another interesting procedure is described by Ibn Bāṣo in some chapters of the treatise on the use of this plate. These chapters are devoted to what Ibn Bāṣo calls southern stars. He describes them as stars situated between the tropic of Capricorn and the southern pole, that is to say, stars which are not represented in the rete of a conventional astrolabe. In order to work with these southern stars, this astronomer assumes the possibility of considering the plate as if it were a northern and southern superimposed projection in the same way as in the meridian stereographic projection the eastern and the western hemispheres are superimposed in order to obtain the representation of the whole sphere. When doing that, Ibn Bāṣo considers the equator as the outer circle of the representation, dismissing the sector comprised between it and the tropic of Capricorn. The centre is considered as the projection of the two poles of the sphere. The parallels of declination are northern and southern parallels at the same time. This way of using the plate converts it into the precursor of some later instruments found both in Europe and in the Muslim world.

2.2. Surviving examples of Ibn Bāṣo's plate

This "general plate for all latitudes", which Ibn Bāṣo claims to have invented himself, usually appears among others, in western astrolabes, from the 14th century onwards, and, in spite of its apparently difficult method of use, it is relatively frequent and it seems to have had great success because very few western astrolabes appear to lack this plate.

During the period that I spent in Frankfurt, Professor King gave me valuable information about many astrolabes which contain this plate. In fact, he has listed about 24 examples in the catalogue which he is currently working on. The most relevant for me, for many reasons, is one made in Damascus in the year H. 734/A.D. 1333-4 by al-Mizzī, an Egyptian astronomer born in 1291. He studied in Cairo and later lived in Damascus, where he worked as *mu'aḏḏin* in the great mosque. He also wrote several treatises on the use of astronomical instruments. The plate made by him, following Ibn Bāṣo's projection, has been included in an astrolabe made in Tunis by Ḥusayn b. 'Alī (2) in the year H. 709/A.D. 1309. This astrolabe is preserved in the Whipple Museum of the History of Science in Cambridge (3). This example provides an idea of the influence of this kind of projection not only in the north of Africa but also in the eastern Muslim world.

This influence is also reflected in the presence of one example of this kind of projection among the plates belonging to an Indo-Persian astrolabe made in the year A.D. 1570 by Ilāh-Dād, who was the first of a family of astrolabists in Lahore. This instrument is now preserved in the Museum of the History of Science in Oxford (4).

3. INFLUENCES ON IBN BĀṢO'S WORK

Ibn Bāṣo's plate has its origins in some earlier instruments that I will try to describe in a few words.

3.1. Eastern plate of horizons

The first instrument that could have given Ibn Bāṣo some ideas to develop his general plate could be the eastern plate of horizons. There are, however, several differences between this plate and Ibn Bāṣo's general plate, because the eastern plate of horizons has reduced the arcs of horizon to one half of these which are represented for the latitude of different localities and form several groups which usually range from four to eight. The invention of this plate is ascribed to one Hanash (5) who, according to D. King, must be identified with Ḥabash al-Ḥāsib, an astronomer of the 9th century (6).

3.2. Al-Zarqālluh's saphea and Ibn Khalaf's universal plate

But the influence exerted by some Andalusian astronomers of the 11th century on Ibn Bāṣo's work is also deep and clear. These astronomers are 'Alī b. Khalaf and al-Zarqālluh known as Azarquiel. They worked in the court of al-Ma'mūn of Toledo (1037-1075) and devised two similar instruments called respectively *lámina universal* or *orizon universal* (universal plate) (7) and *azafea* (saphea)

2. Cf. L.A. MAYER, *Islamic Astrolabists and their Works*, (Geneva, 1957), p. 48 and D.A. KING *A Catalogue of Medieval Astronomical Instruments : Astrolabes, Quadrants and Sundials* (In preparation) 1.6.7.
3. Cf. D.J. BRYDEN, *Sundials and Related Instruments*, The Wipple Museum of the History of Science, Catalogue 6. (Cambridge, 1988) n° 362.
4. Cf. (F. MADDISON), *A Supplement to a Catalogue of Scientific Instruments in the Collection of J.A. Billmeir Esq., C.B.E.* (Oxford, London, 1957) p. 20, n° 159 and D.A. KING *A Catalogue of Medieval Astronomical Instruments...* 2.4.1. On the family of astrolabists from Lahore cf. G. WIET, "Une famille de fabricants d'astrolabes" *Bulletin de l'Institut Français d'Archéologie Orientale*, 36 (1936) pp. 97-99.
5. Cf. R.T. GUNTHER, *The Astrolabes of the World.* 2 vols. (Oxford, 1932), (Reimpr. London, 1976) vol. I p. 7 n. 12.
6. D. ca. 864. Cf. D.A. KING, "On the Early History of the Universal Astrolabe in Islamic Astronomy and the Origin of the Term *Shakkāzīya* in Medieval Scientific Arabic" *Journal for the History of Arabic Science*, 3 (1979) pp. 244-257, specially p. 255 n. 22 and D.A. KING, *Astronomical Instrumentation in the Medieval Near East.*
7. Cf. M. RICO Y SINOBAS, *Libros del Saber de Astronomía del Rey D. Alfonso X de Castilla. Compilados, anotados y comentados por...* t. III (Madrid, 1864) pp. 1-132.

in the translation of the treatises on their use extant in Alfonso X's *Libros del Saber*. Both instruments are based on the superimposition of a double stereographic meridian projection. The centre of projection are the vernal and the autumnal points and the plane of projection is the colure of solstices which also forms the outher circle of the plate. But, on the face of the ṣafiḥa we find the equatorial coordinates and the ecliptic ones are sometimes incompletely represented as is described in the treatise on the *shakkāziyya* written by Azarquiel (ms. Rabat 6664) and sometimes completely as described in his treatise on the *zarqāliya* (ms. Escorial, 962). The horizon is here represented by the alidade, the stars are engraved on the face of the plate and the rete is completely omitted. In the *lámina universal*, only one set of coordinates is represented on the face. This instrument has a rete with one half of another set of coordinates represented on it and it is possible to rotate the second over the first (8).

The diagram formed on Ibn Bāṣo's plate, by the superimposition of horizons and arcs in the sector comprised between the circle of the equator and the pole which is obtained from a standard polar stereographic projection, is identical to the one we find on the plate of 'Alī ibn Khalaf's universal astrolabe or on al-Zarqālluh's *ṣafīḥa* (9). The latter are obtained, however, from an *equatorial* stereographic projection. In this respect we should remember that the procedure for the transformation of coordinates with Ibn Bāṣo's instrument (by a turn equal to the colatitude of the place), is usually employed when using *ṣafīḥas* but not with astrolabes. But, in the prologue to his treatise on the general plate, Ibn Bāṣo feels obliged to state the independence of his plate from al-Zarqālluh's *ṣafīḥa* possibly because he was aware of the influence exerted by this instrument on his own work. It is quite evident that Ibn Bāṣo reelaborated the principles that structured these plates, giving them a new point of view and, therefore, new possibilities of use. In the following centuries, certain astronomers adopted that idea and reelaborated it in different ways. The result was some curious instruments in which polar and equatorial stereographic projections were combined in order to obtain the advantages of both systems as we will see in a moment.

4. INFLUENCE OF IBN BĀṢO'S PLATE IN LATER INSTRUMENTS

We can follow the influence of Ibn Bāṣo's work both in the Muslim world and in Latin Europe.

4.1. In the Muslim world

As we have seen, Ibn Bāṣo's plate was widely reproduced in later astrolabes but we can also find some different instruments which have a connection with his plate.

8. Cf. J.M. MILLAS, *Un ejemplar de azafea árabe de Azarquiel* "Al-Andalus" 9 (1944) pp. 111- 119.
9. Millás Vallicrosa saw these similarities when he described the general plate included in an astrolabe preserved in Tetuan but his interpretation of this plate was closer to the azafea than it really is. Cf. J.M. MILLÁS VALLICROSA, "Tres instrumentos astronómicos árabes de los museos de Tetuán y Madrid" *Al-Andalus*, 12 (1947) pp. 49-56, especially pp. 52-53. There is a similar interpretation in S. García Franco, *Catálogo crítico de astrolabios existentes en España* (Madrid, 1945) p. 178.

4.1.1. The universal plate from Oxford

One of these instruments is preserved in the Museum of the History of Science of Oxford, catalogued with the number 57-19. It was made by 'Alī b. Ibrāhīm al-Ḥarrār in Tāzà (Morocco) in the year H. 728 / A.D. 1327-8. It has been described as a not very common example of *lámina universal*. But the rete has the projection of the ecliptic which implies that the outer circle of the instrument is the equator instead of the colure of the solstices, as in *ṣafīḥas*, or the tropic of Capricorn, as in astrolabes. This kind of ecliptic projection was mentioned by Michel in his *Traité de l'Astrolabe* (10) and it had been described, among others, by al-Bīrūnī (973-post 1050) (11) and Abū-l-Ḥasan 'Alī al-Marrākushī (fl. 1275-1282) (12).

There is no surviving treatise on the use of this instrument but it clearly seems to be a conjunction of a universal plate and a plate of horizons of Ibn Bāṣo's type. In fact, the appearance of the face of this instrument is exactly the same as we obtain if the diagram between the equator and the tropic of Capricorn is omitted from Ibn Bāṣo's plate. This could have been the idea of the maker of this instrument who lived in the north of Africa just after Ibn Bāṣo in a period in which contacts between the two sides of the straits of Gibraltar were very frequent.

4.1.2. Ibn al-Sarrāŷ's instrument

There is another instrument which has many points of contact with the preceding one. It was created by an astronomer called Šihāb al-Dīn Aḥmad ibn Abī Bakr, known as Ibn al-Sarrāŷ. He worked in Aleppo in the first half of the 14th century. We are talking about a very complex instrument which was the inspiration of later European examples (13).

There are certain similarities between the set of coordinates in the rete of this astrolabe and the one belonging to Ibn Khalaf's *universal plate* and also between the ecliptic projected in al-Ḥarrār's instrument and in this one. But here we only

10. Cf. H. MICHEL, *Traité de l'Astrolabe* (Paris, 1947) pp. 69-70.

11. Cf. AL-BIRUNI, *Kitāb fī-istī'āb al-wuŷūh al-mumkina fī ṣan'at al-asṭurlāb* ms. 5540 Aḥmadiyya, Tunis, fol. 19 v°. This projection is described with the name *al-āsī* (myrtle shaped).

12. Cf. *Ŷāmi' al-mabādi wa-l-gāyāt fī 'ilm al-mīqāt*. ms. 3343 Istambul. Facsimile Ed. Institut für Geschichte der Arabisch-Islamischen Wissenschaften (Frankfurt, 1984) p. 69 and L.A.SEDILLOT, *Mémoire sur les instruments astronomiques des Arabes* "Mémoires présentées par divers savants à l'Académie Royale des Inscriptions et Belles Lettres de l'Institut de France" (Paris, 1844) p. 182, reprinted Institut für Geschichte der Arabisch-Islamischen Wissenschaften (Frankfurt, 1984).

13. His name was Šihāb al-Dīn Aḥmad ibn Abī Bakr known as Ibn al-Sarrāŷ. Cf. H. SUTER, *Die Mathematiker* ... n. 508, p. 199 ; C. BROCKELMANN, *Geschichte*, II p. 126 and Supplementband, II p. 156 ; R. GLUNTHER, *The Astrolabes* ... vol I pp. 284-285 ; D.A. KING, A *Survey of the Scientific Manuscripts in the Egyptian National Library* Publications of the American Research Center in Egypt (Winona Lake, 1986) n° C 26 ; *The Astronomy of Mamluks* "Isis" 74 (1983) pp. 531-555, repr. in "Islamic Mathematical Astronomy" Variorum Reprints (London, 1986) III ; *The Astronomical Instruments of Ibn al-Sarrāj : A brief Survey* "Islamic Astronomical Instruments" Variorum Reprints (London, 1987) and *Universal Solutions to Problems of Spherical Astronomy from Mamluk Egypt and Syria.* "A Way Prepared" (New York, London, 1988) pp. 160-163.

have a half of this projection. The names of the northern signs are superimposed on the southern ones.

According to D. King, who has studied this instrument and its inventor, it can be used as universal in five different ways, which gives an idea of its complexity. The only example preserved of this instrument is housed in the Benaki Museum in Athens.

4.2. In the Latin world

The interest of these universal instruments in Latin Europe began in the 13th century at the later and it continued until the 17th century without interruption.

4.2.1. Jean de Lignères

Poulle devoted a study to the saphea in the Latin West, in which he described an instrument created by Jean de Lignères (14), an astronomer of the 14th century of the School of Paris. This instrument seems to have been a saphea *shakkāziyya* in which the coordinates related to the ecliptic have been omitted and, on the other side, it has a very particular rete if considered a saphea, because it has been traced by polar stereographic projection. This rete is called *circulus mobilis* and it has an outer semicircle and an arc of a circle which corresponds to the projection of the ecliptic in the same way as we have seen in Ibn al-Sarrāŷ's instrument. It can be used as a safiha but, as Poulle says, it could also be considered as a plate of horizons. This method of use simplifies some processes that are more difficult to solve when using a saphea.

4.2.2. Regiomontanus

In the following centuries, some European astronomers reproduced this kind of instrument, a combination of the two types of stereographic projection. For example, in 1534, Johann Schöner published, under the name of Regiomontanus, a treatise on the use of an instrument which has the same aforementioned characteristics and which also uses the same kind of rete, that is to say, the *circulus mobilis* of Jean de Lignères.

4.2.3. Arsenius

Another similar instrument was made by *Arsenius*, who was Gemma Frisius' nephew. It is preserved in the Museum of the City of Cologne. On the back we can again see this kind of projection : the ecliptic is represented twice on the plate and twice on the rete (15).

14. On Jean de Lignères cf. G. SARTON, *Introduction* ... vol. III p. 649 ; J. D. NORTH, *Richard of Wallingford*, 3 vols. (Oxford, 1976) vol. II pp. 29-31, 259-261 and E. POULLE, *John of Lignères* "Dictionary of Scientific Biography" vol. 7 pp. 122-128. On his plate cf. E. POULLE, *Un instrument astronomique dans l'occident latin, la "saphea"* "A Guiseppe Ermini" (Spoleto, 1970) pp. 499-501.

15. Once again it was D. King who drew my attention to this instrument. It is described in R. DIECKHOFF, "Cosmographia planisphaeria". - *Kölner Museums-Bulletin Berichte und Forschungen aus den Museen der Stadt Köln*, 2 (1990) pp. 23-44.

4.2.4. John Blagrave

There is at least one other kind of instrument with the same characteristics made in England and called *Margarita Mathematica* or *Mathematical Jewel.* Its inventor was John Blagrave of Reading (d. 1611) (16). This instrument is a reinvention of Ibn al-Sarrāŷ's astrolabe. John Blagrave published a treatise on its use in 1582 and interest in it continued for almost another century. In 1658 John Palmer wrote a treatise on this instrument entitled *The Catholic Planisphaer wich Mr. Blagrave calleth the Mathematical Jewel.*

4.2.5. Odon van Maelcote

In his *Traité de l'Astrolabe,* Henri Michel describes an instrument invented by a Jesuit from Brussels called Odon Van Maelcote (Malcotius, 1572-1614) (17). This instrument is called *Astrolabium aequinoctiale* and it is very similar, if not identical, to the instrument preserved in Oxford.

In the Catalogue of an exhibition held in Brussels in 1957 (26 April-30 May) Michel describes an astrolabe by van Maelcote established for the latitude of Brussels with Gemma Frisius' Astolabum Catholicum on one side and the double astrolabe on the other. It had been made by a friend of van Maelcote called Lambert Damery. Michel says that the instrument is not complete. In 1607, Damery's son, Léonard, wrote an abridgement in which he describes this instrument. It was entitled *Astrolabium Aequinoctiale. Per modum compendii a Leonardo Damerio Leodiensi in lucem editum* and it was published by Velpius. It is now preserved in the Bibliothèque Royale Albert I of Brussels.

5. CONCLUDING REMARKS

All these are only a few examples of the interest shown by European astronomers in this kind of projection and are also evidence for the evolution of this combination of equatorial and polar stereographic projection which offers the advantages of both of them increasing their possibilities.

Ibn Bāṣo seems to have been the first to describe its method of use because, as far as I know, there are no other examples or treatises on its use before the end of the 13th Century. It is true that we know partial descriptions of related instruments and Ibn Bāṣo may not have been the first astronomer to see the advantages of this combination of projections but, in any case, he seems to have been the first to explain it, as we have seen, in such a detailed way.

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16. On John BLAGRAVE cf. R.D. GUNTHER, *The Astrolabes...* vol. II, p. 578 and H. MICHEL, *Traité ...* p. 163. A description of this instrument can be found in R.D. GUNTHER, *The Astrolabes ...* vol. II pp. 492-501. The treatise on its use by John Blagrave was published in 1582.
17. Van Maelcote wrote a treatise on the use of this instrument which was published in 1607 and reprinted in 1610. On his biography cf. H. MICHEL, *Traité ...* p. 174 and R. GUNTHER, *The astrolabes of the World* (Oxford, 1932) vol II p. 573.

SUMMARY

Ibn Bāṣo, an astronomer who lived in Granada in the 13th century, wrote a treatise on the use of a universal plate devised to be used in conjunction with an astrolabe.
This plate was widely diffused in the Islamic World until the 18th century and also was the inspiration of some astronomical instruments made in Europe between the 14 th and the 17 th centuries.
The paper describes the characteristics of Ibn Bāṣo's *universal plate*, the most remarkable surviving examples of it and its influence on later astronomers both in the Islamic World and in Europe.