INTRODUCTION

In recent years much effort has been devoted to the study of medieval astronomical tables compiled or extant in Latin in order to understand the way mathematical astronomy was developed, used and transmitted by its practitioners. However, no global review of the sets which include these tables has yet been undertaken. This monograph is an attempt to survey the major sets of tables in Latin used by astronomers in the late Middle Ages and the early modern period, and to unveil the connections between them. In a way, it aims at serving as a complement for the Latin world to Kennedy's survey of Islamic astronomy tables (1956). The collections of tables reviewed in the present book were compiled from about the second half of the eleventh century to the beginning of the sixteenth century. In addition to these time limits, there are also geographical and linguistic limits. All sets considered in this book —except those briefly addressed in Part I, Before al-Andalus—, were assembled in Europe, starting in al-Andalus, the Muslim part of the Iberian Peninsula, and later on in England, France, Italy, Spain, and Central Europe, in a general tendency moving from south to north. Many of these sets were originally written in Latin, and this was indeed the main language in which astronomy was diffused to the rest of Europe and beyond during this period. However, Latin was not the only language used for scientific purposes in the West. Other sets were first written in Arabic, Castilian, and Hebrew. Those that had a notable impact on astronomers, whether table-makers or table-users, and were mainly transmitted in Latin have been incorporated into this survey. Another restriction derives from the selection of the material: no almanacs or similar are included, even though some had a remarkable diffusion, such as those compiled by Jacob ben Makhir in the early fourteenth century or Abraham Zacut in the late fifteenth century (both composed in Hebrew and translated into Latin shortly thereafter), containing very interesting tables. Moreover, no individual tables have been retained, important as they may have been as, for example, the

table for computing syzygies by Nicholaus de Heybech by the end of the fourteenth century. In any case, this book does not pretend to be an exhaustive review of all tabular material generated in the Middle Ages; rather, it is a study of the sets of tables most frequently used by medieval astronomers working in Latin.

A set of astronomical tables is a toolbox offering the practitioner an instrumental series of numerical tables to address most of the problems in mathematical astronomy he intended to solve and to carry out the computations needed for that purpose. It is usually the case that these sets are accompanied by texts, called *canons*, explaining their use, although they very rarely indicate how the tables were computed. This is indeed the pattern followed in Arabic zijes, after the Arabic term *zīj*, that is, a handbook of astronomical tables with an explanatory text. As will be seen, in the fifteenth century Latin sets of tables progressively lost this Arabic flavor for they no longer addressed all possible astronomical issues; rather, they focused on specific problems such as the motion of the planets, the computation of eclipses, or problems in spherical astronomy.

One characteristic feature of sets of tables in Latin is that they are less clearly delimited than Arabic zijes, to the point that it is not always possible to define precisely which tables belong to a specific set. The boundaries of the set get loose. This is particularly true with the most widely diffused sets in that period, such as the Toledan Tables, mainly disseminated in Latin despite its Arabic origin, and the Parisian Alfonsine Tables, of which hundreds of copies has been preserved. Moreover, for a given set of tables, it is extremely rare to find two identical copies, not only because of the scribal errors they may contain, but mostly because of the addition or deletion of one or another table, as well as for changes in their structure and ordering. A good example is provided by the numerous sets with the label "Alfonsine Tables", for which no two manuscripts contain the same tables, a feature that persists until the end of the fifteenth century. This is even true for the two earliest printed editions of the Parisian Alfonsine Tables, dated 1483 and 1492, a comparison of which is presented in Chapter 13. Throughout the period under consideration, when astronomical knowledge was mainly transmitted in man-

uscripts, many of the copyists included in a given set some tables not belonging to it or chose not to copy all of them, or even modified the number of entries in a table, at their convenience. This implies a number of problems when defining a set of astronomical tables. To overcome this difficulty, a way which has proven to be useful consists in comparing a reasonably large number of manuscripts, a principle applied here for the first time to the Tables of John of Lignères for 1322 (see Chapter 8).

All sets of tables compiled in the four centuries considered here can be grouped in two broad categories, depending on the frame of reference chosen for the position of the celestial bodies and, therefore, the organization of their mean motion tables. In Ptolemy's *Almagest* celestial coordinates are counted from the vernal point, that is, the intersection of the ecliptic and the equator. These tropical coordinates were said by medieval scholars to be computed on the 9th sphere. The zij of the late ninth-century Eastern astronomer al-Battānī, which had a profound impact in al-Andalus, and later in European astronomy, followed Ptolemy in this respect. The tradition represented by al-Battānī is often referred to as the Greek tradition. The other astronomical tradition developed in the Iberian Peninsula is the Indian tradition and it is represented by the zij of al-Khwārizmī, compiled in Baghdad in the first half of the ninth century, which reached al-Andalus soon thereafter. In this tradition the celestial coordinates are counted from a fixed point in relation to the stars. These sidereal coordinates were said to be computed on the 8th sphere, according to medieval terminology. The difference between the two coordinate systems is called precession. The zij of Ibn al-Kammād (Chapter 2), followed the zij of al-Khwārizmī in the use of sidereal coordinates, as did Ibn al-Zarqālluh (Azarquiel) in his *Almanac.* The same frame of reference, the 8th sphere, had been used in the Toledan Tables (Chapter 1), which gathered tables from both traditions, and in a few sets derived from them, as well as in the Castilian Alfonsine Tables (Chapter 5). In the twelfth century, several table-makers chose to use tropical coordinates instead, in the tradition of al-Battānī and Ptolemy. The Parisian Alfonsine Tables (Chapter 13) adopted this frame of reference, and so did almost all subsequent collections of tables.

The sets of tables are presented here in chronological order, as far as possible, grouped in three parts and preceded by a short chapter to establish the background for the work of Andalusian table-makers. This includes a brief survey of the tables compiled by Ptolemy, both in the *Almagest* and the *Handy Tables*, as well as those in the zijes of al-Khwārizmī and al-Battānī (Part I, Before al-Andalus) for, as will be seen, these sets of tables compiled by eastern astronomers were those that had a major influence on medieval western astronomers. Part II (Chapters 1-4) deals mainly with the two principal astronomical traditions developed in al-Andalus and subsequently in the rest of the Iberian Peninsula, starting with the tradition of al-Khwārizmī, which was predominant, and with special focus on the Toledan Tables. In Part III (Chapters 5-13) the emphasis is on the Castilian Alfonsine Tables developed in Toledo in the second half of the thirteenth century and later recast by a series of astronomers, mainly in Paris, whose work ended up in what is called the Parisian Alfonsine Tables. Part IV (Chapters 14-23) presents a variety of later collections of astronomical tables, mostly in the Alfonsine framework, taking us to the beginning of the sixteenth century, with an emphasis on their user-friendliness.

Each chapter in this book starts with a general view of the set under examination, followed by a summary of the tables it contains, a census of primary sources whether in manuscript form or in print, and a list of references in the secondary literature relevant to the set or some specific tables in it. Much time has been devoted to locating manuscripts containing each of the sets reviewed here. Many manuscripts were directly examined at the libraries, others online, and still others in catalogues, where the information does not always give a reliable description of the astronomical tables. The bibliography given in each chapter aims at providing basic tools to further study the subject and does not pretend to be exhaustive.

As will be noticed in the description of the tables, emphasis is given to those elements that highlight their influence on the work developed by subsequent table-makers and the transmission of astronomical knowledge. Many tables in one set were integrated with no change into later sets, other tables were modified or adapted to

local situations. As will be argued in this book, the sets of astronomical tables, and the tables themselves, evolved throughout the Middle Ages without challenging the Ptolemaic geometrical models underlying them and occasionally changing the associated parameters, and still others were compiled anew. This evolution, rarely in response to new observations, aimed at facilitating the task of practitioners, by generating new tables or recasting old ones to reduce the computational effort in using them and to avoid errors in the process of solving astronomical problems, thus enhancing user-friendliness, which was the main driving force, not observation. It should be stressed that this evolution was also made possible by the contributions of many scholars who found ways, often very ingenious, to find tabular solutions to astronomical problems, and it was led by the aim of practicality, in such a way that the sets of tables compiled by astronomers could ease the computing tasks of table-users and thus enlarge the practice of astronomy, in a fruitful collaboration between table-makers and table-users.

Sets of tables carry astronomical knowledge, which is transmitted through the individual tables. This transmission is not always limited to reproducing mechanically specific tables. In many cases it is what could be called innovative appropriation, when something useful or new, or both, is added to a table: higher precision, more entries, adaptation to local coordinates, different format, and occasionally even new underlying parameters. In many ways medieval astronomers introduced new procedures within well-established traditions and presented them in the form of astronomical tables, which superseded or competed with previous ones. Of especial interest is the case of the Parisian Alfonsine Tables, of which there were different ways of presenting them, such as the Oxford Tables, the Tables for the Seven Planets, the *Tabulae resolutae*, and the tables by Giovanni Bianchini, among others. Globally, as far as tables in this period are concerned, innovation is mostly in presentation.

All astronomical tables have something to say, especially regarding the transmission of astronomical ideas and the practices of their compilers. Moreover, the analysis of individual tables and sets of tables have proven to be a powerful instrument to unveil such

transfers of knowledge and to explain the continuous evolution of table-making.

In this book a considerable effort has been made in identifying the various sets of tables examined as found in many manuscripts and to a much lesser extent in printed editions. More than 350 manuscripts have been reviewed, mostly by direct examination.

This monograph may serve as a guide for researchers in identifying sets of tables, especially those where no general heading is given or where the name of the author does not explicitly appear, as is the case in many manuscripts. It may also serve as a tool to identify isolated astronomical tables in miscellaneous manuscripts or even those mixed in with other tables, in order to better understand the author's or the copyist's approach in compiling a particular set of tables. In this sense, this monograph complements another one, published in 2012 by José Chabás and Bernard R. Goldstein, under the title *A Survey of European Astronomical Tables in the Late Middle Ages*, where astronomical tables are examined individually by theme. The present book also aims at fostering research on new or insufficiently studied topics on mathematical astronomy, such as the Tables of John of Lignères, those of Prosdocimo de' Beldomandi, and the various sets of tables compiled by Giovanni Bianchini, the leading Italian table-maker in the mid-fifteenth century.

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this monograph on medieval sets of astronomical tables, the CSIC actively continues to promote the development of a discipline, history of medieval astronomy, in search of new scholarship both in Spain and beyond.

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