Essays on Medieval Computational Astronomy by José Chabás and Bernard R. Goldstein

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Everyone who has worked in medieval astronomy over the past few decades is aware of the extensive and pioneering collaboration of José Chabás and Bernard Goldstein. Working as a team from opposite sides of the Atlantic Ocean, these two scholars have been helping to do for medieval European computational astronomy what is also underway for other medieval astronomical cultures: to map out specifically what is available in the manuscripts, to come to grips with the contents of the astronomical and mathematical theories, and to trace developments and influences through subcultures and time-periods. In Latin texts, this project will take decades, if not longer. But it would be inconceivable without Chabás and Goldstein's accomplishments to date.

The book under review is a collection of 12 essays dealing with the technical contents of astronomical manuscripts containing numerical tables. These essays have all appeared previously in various journals between 1992 and 2013; therefore, the volume has the feel of a book published in the Variorum series. (Readers looking for a synthetic work should seek out the authors' *Survey of European Astronomical Tables in the Late Middle Ages* [Chabás and Goldstein 2012]). However, the essays have been edited and typeset in a uniform style, provided with an index, and enhanced with several minor corrections and updates. (Who among us has not wished at some point for the opportunity to release our work again in an updated edition?) The theme of numerical tables encompasses a large part of medieval European astronomy, given that tables were the primary device for converting the geometric models of the motions of the heavenly bodies into tools for prediction. The central theme woven throughout the book is that the primary mission of the table-makers was not to generate theories to fit better with observations but rather to redesign tables to enhance their usability for an audience with less

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than stellar computational skills. In this respect, the volume's ingenuity is evident.

Notwithstanding the technical nature of the subject, the writing style is very clear. Nevertheless, it may be difficult for all but the most committed scholars, already deeply engrained in this field, to make much headway without a substantial commitment of time and energy. Thus, it seems best to devote the rest of this review to providing a road map through the various papers—illustrating their points and bringing forward the most important of the authors' findings. The essays are divided into four categories:

(1) tables of solar/lunar conjunctions and oppositions;
(2) tables of the motions of the planets;
(3) analyses of several collections of tables from beginning to end; and
(4) a pair of additional studies.

Part 1

The first three essays, tightly intertwined, concern the development of tables for the computation of true syzygies of the Sun and Moon from their mean syzygies. Syzygies (conjunctions and oppositions) are moments when the Sun and Moon have the same longitude or longitudes separated by 180° in the celestial sphere and are the only times when eclipses can occur. The problem is a tricky one. The velocities of the Sun and Moon both vary over time and their 'mean longitudes' are positions of theoretical bodies moving uniformly according to the average speed of the true bodies. It is, therefore, easy to find a mean syzygy but much harder to find the corresponding true syzygy. In the *Almagest*, Ptolemy solved the problem with a computational method (not involving numerical tables) using an approximation based on the assumption that the Sun and Moon travel at constant speeds between the moments of mean and true syzygy.

The second essay, 'Computational Astronomy: Five Centuries of Finding True Syzygy', which should be read first, provides a survey of methods for finding true syzygy using tables. It begins with a description of a rather simple method, not much more than an extension of Ptolemy's method to tabular form, by the 12th-century Spaniard Ibn al-Kammād. A more sophisticated approach by John of Saxony (*ca* 1330) takes into account the variable lunar velocity; but it is somewhat complicated computationally and was not adapted for use with tables.

This sets the stage for Nicholaus de Heybech (*ca* 1400), an otherwise obscure figure who produced a tabular method of solving the syzygy-problem that retains the improved accuracy obtained by allowing the Moon's speed to vary. The authors concentrate on these tables in all three of the papers in part 1, especially in the first essay, 'Nicholaus de Heybech and his Table for Finding True Syzygy', where the method is carefully analyzed. The authors find that Nicholaus' tables rely partly on those of John of Genoa, a contemporary of John of Saxony. Here for the first time the authors emphasize a point that they return to frequently: Nicholaus' tables were valued due to their *user-friendliness*, which enhances both usability and reliability of results.

The third essay, 'Transmission of Computational Methods within the Alfonsine Corpus: The Case of the Tables of Nicholaus de Heybech', illustrates the influence of Heybech's work especially on the *Tabulae verificate* (possibly by Polonius in Salamanca, 1460) and the tables of Abraham Zacut (1513). The second essay then concludes the story, illustrating approaches by such later luminaries as John of Gmunden, Peurbach, and Copernicus. Again, the authors stress that computational efficiency, not observation, was the central force that drove their research.

Part 2

The next three essays approach the range of tabular methods that were devised for determining planetary positions as a function of time—the heart of the astronomical project. Almost all of the European medieval tradition follows the planetary model found in Claudius Ptolemy's works of the second century AD, the *Almagest* and the *Handy Tables*. (One exception to this is the role of al-Khwārizmī's *zīj*, which was inspired by the Indo-Iranian tradition and influenced European astronomy through its Spanish presence.) This model breaks the planets' positions into *longitudes* (position along the ecliptic) and *latitudes* (position above/below the ecliptic) and deals with them separately. A planet's longitude is conceived in three parts: its *mean longitude*, the position of an imaginary object traveling at the planet's average speed; its *equation of center*, a correction accounting for the fact that the Earth is displaced from the center of the planet's large orbital circle (its deferent); and its *equation of anomaly*, a correction accounting for the planet's position on the epicycle. The latter is a function of two variables for which Ptolemy constructed an approximation that allows it to be tabulated with an arithmetical combination of several single-argument tables.

The first essay to read in this section is the last one, 'Computing Planetary Positions: User-Friendliness and the Alfonsine Corpus'. This survey encapsulates the developments that led from Ptolemy's tables to those found in 15th- and early 16th-century Europe. The authors describe various of the most important tables that found their way to Spain and Europe, noting that very few changes from the Ptolemaic paradigm are found until the early 14th century. However, the pace then picks up markedly. The first innovation is the *displacement* of the tables for planetary equations. Since these corrections must sometimes be added and at other times subtracted, they were a source of confusion and potential error. The compilers of some of the new tables added a constant value to every entry in the table for the equation of center (a vertical displacement) so that the correction would always be added, and then adjusted the tabular structure elsewhere to remove this constant. This simplified the process for the user, making it less prone to error. Sometimes tables would also be displaced horizontally in order to counterbalance displacements made elsewhere. These methods had been invented in eastern Islam a few centuries earlier but as far as we can tell they were not transmitted to Europe at the time. Other innovations included separating tables that required different arguments—in the Ptolemaic tradition tables had been gathered together into a single grid, regardless of the natures of the independent variables—and combining the effects of the corrections into a single large double-argument table. These improvements again led to increased user-friendliness and, therefore, greater reliability in practice.

The other two essays in this section deal with specific sets of tables within the story of the survey in essay 2. Essay 5, 'Displaced Tables in Latin: The Tables for the Seven Planets for 1340', deals with an anonymous set of tables of almost 100 pages that were probably composed in southern France. There are no accompanying instructions, so the authors carefully and painstakingly analyze each table to reconstruct its purpose and to identify the astronomical parameters embedded within it. They discover no fewer than 40 applications of the technique of displacement, especially in the planetary equation-tables. Essay 4, 'Ptolemy, Bianchini, and Copernicus: Tables for Planetary Latitudes', describes especially Bianchini's latitude-table, but also the tables for the same purpose by Copernicus in manuscript that were based on Bianchini's. One curiosity is a variation in the computation of one of the three components of latitude, where eastern and western astronomers differed in their understanding of Ptolemy's instructions. The method employed by Bianchini and his colleagues would eventually be criticized by Copernicus in *De revolutionibus*, although the manuscript studied here (composed when Copernicus was a student) adopts it.

Part 3

Here we find a set of detailed studies of four collections of astronomical tables. In each case the authors analyze each table meticulously, extracting parameters when they are readily accessible and comparing the entries with other tables in the same genre. Generally, the central purpose is to understand the structure and use of the tables, and then to determine lines of influence, both leading up to the tables under study and emerging from them. In a great majority of cases, the analysis is successful.

Two studies are related directly to the evolution of the Parisian Alfonsine Tables in the early 14th century: essay 8, 'Early Alfonsine Astronomy in Paris: The Tables of John Vimond', and essay 9, 'John of Murs's Tables of 1321'. John of Vimond's tables were composed in Paris only a couple of years before the Parisian Alfonsine tables came together. The authors demonstrate that the main source of this work was the Castilian Alfonsine tables. They find several innovative structures within the various tables, designed once again to make computing life easier for the user. The date is established to be around 1320, just before John of Murs. It is peculiar that the latter does not mention the former; they must have been familiar with each other's work. John of Murs, soon to be one of the co-authors of the Parisian Alfonsine tables, compiled the collection of 132 (and another set called the *Parefit*) not long before. The 1321-tables, which are entirely devoted to the Sun, Moon, and planets, are accompanied by terse canons. Although their structures often deviate from the illustrious Parisian Alfonsine tables, they rely on the same models and parameters. Of note are the syzygy-tables, which are the first to deal with the motions of the Sun and Moon separately. The authors find connections with the Castilian Alfonsine tables but also more traces of John of Vimond's work than had been thought previously to exist.

The other two essays are not directly related to the above or to each other. 'Andalusian Astronomy: *Al-Zīj al-Muqtabis* of Ibn al-Kammād' discusses a treatise surviving only in Latin that was written in Córdoba some time in the 12th century. Given the number of commentaries and references to it that are found in later works, al-Kammād seems to have been a figure to be reckoned with in al-Andalus. Within the *zīj*, the authors discover material that dates back to the ninth-century *Mumtaḥan Zīj*, as well as astronomical content that ended up in the Tables of Barcelona. Among the other findings is an unusual set of planetary latitude tables: those for the superior planets follow the model of Ptolemy's *Almagest*, while those for the inferior planets follow the *Handy Tables.*

'Isaac Ibn al-Ḥadib and Flavius Mithridates: The Diffusion of an Iberian Astronomical Tradition in the Late Middle Ages' compares the tables of two lesser-known figures, finding the latter' tables to be based almost entirely on the former's. Ibn al-Ḥadib was a Spanish Jew who left for Sicily in the late 14th century, presumably to flee anti-Jewish riots. His tables, intended for predicting eclipse, are based on neither the Toledan Tables nor the Parisian Alfonsine tables. Rather, they rely on a Hebrew tradition located in Spain and southern France. Flavius Mithridates (a pen name for William Raymond of Moncada), an Italian working about a century later, converted from Judaism to Christianity and split his interests between astronomy and translating Kabbalistic texts into Latin. Mithridates does not mention the Hebrew source for his tables, possibly to improve his standing with his patron. The influence of the Andalusian tradition on both works may be seen in several ways, notably in their use of a proper motion of the solar apogee, which is not found in other medieval European traditions.

Part 4

The book concludes with a pair of essays that do not fit easily into any of the other sections. 'Ibn al-Kammād's Star List' deals with a table giving the locations of 30 stars in his *Zīj al-Muqtabis* that seems to have had a surprisingly large influence. The authors find copies of this list in a dozen manuscripts in Hebrew, Arabic, and Latin, dating through to the end of the 15th century. They describe especially the variations between the manuscripts, preferring to deal with issues of transmission rather than attempt to reconstruct the original list. Nevertheless, they do reach the conclusion that the list is likely to have been assembled in Islamic Spain, possibly by Ibn al-Kammād himself.

The last essay in the volume, 'Astronomical Activity in Portugal in the Fourteenth Century', concerns the only known manuscript that fits this description. Most of it is a copy of the Almanac of 1307, but the first 12 folios comprise a collection of tables that have sometimes been called an 'almanac of Coimbra'. The authors demonstrate that this document, consisting of calendrical, astronomical, and astrological topics, is not an almanac. Rather, it is a diverse collage of tables taken mostly from the tradition of the Toledan Tables, especially the *Almanac perpetuum* by Jacob ben Makhir.

Although there is hardly anything new in this book, the combination of the 12 reprinted papers is helpful in several ways. It brings the authors' research together in a format that may reach a wider audience that might not have sought out the individual essays. It updates some of the authors' studies to include their most recent findings. Finally, it allows one to move easily back and forth between the essays, thus helping readers to form a more rounded picture of what we know so far of medieval Latin astronomy.

BIBLIOGRAPHY

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