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Article abstract

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# The Set of Alfonsine Tables Underlying Giovanni Bianchini's Planetary Tables

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## Abstract

The analysis of astronomical tables has proven to be a powerful tool to understand the transmission of astronomical knowledge. Further, the study of the major sets of tables compiled or in circulation in the Middle Ages has contributed significantly to mapping the thousands of tables preserved in medieval manuscripts. The present paper focuses on the relationship between two specific sets of tables, both in the framework of Alfonsine astronomy: one of hitherto uncertain authorship and a much larger one compiled by the Ferrarese astronomer Giovanni Bianchini (d. after 1469).

### About the Authors

JOSÉ CHABÁS is professor emeritus at the Universitat Pompeu Fabra (Barcelona, Spain) and has been working on the history of late medieval and early modern astronomy. His latest book, *Computational Astronomy in the Middle Ages: Sets of Astronomical Tables in Latin* [Madrid, 2019], surveys the major astronomical tables in that period. He contributed to this article within the framework of the European Research Council project ALFA Shaping a European Scientific Scene: Alfonsine Astronomy (grant agreement 723085), a project in which he remains actively engaged.

BERNARD R. GOLDSTEIN, university professor emeritus in the Dietrich School of Arts and Sciences of the University of Pittsburgh, has been collaborating with José Chabás for close to three decades. Among their joint publications are *The Alfonsine Tables of Toledo* [Kluwer, 2003]; *Essays on Medieval Computational Astronomy* [Brill, 2015]; and “The Medieval Moon in a Matrix: Double Argument Tables for Lunar Motion”, *Archive for History of Exact Sciences* 73 (2019) 335–359.

**Keywords** Giovanni Bianchini, astronomical tables, Alfonsine astronomy, double argument tables

**A**stronomy in the Middle Ages consisted of many activities, but here we restrict our attention to some tables compiled in Europe in the 15th century. Most of these tables belong to the Alfonsine tradition, which began in Castile in the 13th century and was later diffused from Paris in the 14th century.<sup>1</sup> The tables in this tradition, or corpus, did not challenge the Parisian Alfonsine Tables (henceforth: PAT) that were produced in Paris in the 1320s.<sup>2</sup> In fact, the astronomical models and the relevant parameters were left basically unchanged. Rather, the focus was on presentation, generally with the goal of making the tables more user-friendly, that is, requiring less computational work by the user and more computational work by the compiler. In this paper, we examine a manuscript in Naples that contains a set of tables that were probably compiled by Giovanni Bianchini.

While in the service of the d'Este family in Ferrara, Bianchini compiled a great number of original astronomical tables and wrote treatises on arithmetic and algebra.<sup>3</sup> Among his astronomical works, his major computational endeavor was a set of tables for the planets called *Tabulae astronomiae*.<sup>4</sup> This set was completed by 1442 and was frequently copied, despite the large number of tables it contains.<sup>5</sup> Among the early users of Bianchini's *Tabulae*

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<sup>1</sup> Chabás and Goldstein 2003; Chabás 2019, 237–276.

<sup>2</sup> There is no modern edition of PAT based on the manuscripts, of which there are hundreds. Hence, we refer to the *editio princeps* [Ratdolt 1483] and to specific manuscripts.

<sup>3</sup> On his life and works, see Federici Vescovini 1968; Boffito 1907–1908; Magrini 1917. On his mathematical activity, see Rosińska 1984, 1996, 1998, 2006.

<sup>4</sup> For Bianchini's *Tabulae astronomiae* for the planets, see Chabás and Goldstein 2009; for the *Tabulae magistrales*, see Chabás 2016; for the *Tabulae primi mobilis*, see Van Brummelen 2018, 2021; for the *Tabulae eclypsiium*, see Chabás and Goldstein 2021.

<sup>5</sup> See Chabás 2019, 346–348 for a list of manuscripts and editions of Bianchini's *Tabulae astronomicae*. There are usually 85 tables in manuscript copies, and 67 in the first edition [Bianchini 1495]. In the second edition [Bianchini 1526], the number

*astronomicae* were, notably, Georg Peurbach (1423–1461) and Regiomontanus (1436–1476).<sup>6</sup>

As we demonstrated in Chabás and Goldstein 2009, the *Tabulae astronomiae* depend on PAT, and they also exhibit many special features that gave Bianchini's tables a completely different presentation from those on which they were based. One such characteristic feature is the organization of the tables for the planets according to their periods of anomaly, an unprecedented approach. Another distinctive feature is the compilation of extensive double argument tables for the true positions of the Moon and the planets, where the vertical argument is time in days within an anomalistic period. Likewise, the true positions of the Sun and the Moon at mean conjunction are presented as large double argument tables. Yet another feature of the *Tabulae astronomiae* is the extent of the enterprise: the numerical tables occupy 316 pages in the first edition, of which 274 contain the above-mentioned double argument tables and have a total of about 315,000 sexagesimal numbers, including entries and arguments as compared, for example, to the first edition of PAT, with its roughly 51,000 sexagesimal numbers.

### A manuscript in Naples

In a manuscript in Naples, Biblioteca Nazionale, MS VIII.C.36, 1r–13v [MS N],<sup>7</sup> there is a set of tables for the planets copied “senza dubbio”, according to the online catalog, at the court of Lionello d'Este in Ferrara in about 1445, where it is attributed without argument to Giovanni Bianchini.<sup>8</sup> After quite a number of blank pages, the rest of the manuscript is devoted to treatises on astronomical instruments by other authors: the astrolabe by Masha'allah, the quadrant vetus, and the solid sphere. It is worth noting that this manuscript was written by the same hand and in the same place as another manuscript in the same library, MS VIII.C.34, which contains a complete copy of Bianchini's *Tabulae astronomicae* for the planets.

In MS N, signs of  $60^\circ$  are used everywhere, as in many sets of tables in the Alfonsine corpus. We note that the set of tables in MS N is limited to the planets,

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of tables increased to 112, whereas in the third edition [Bianchini 1553], there are 85 tables.

<sup>6</sup> For accounts on Peurbach and Regiomontanus, see Shank 2005a, 392–393 and 2005b, 439–441.

<sup>7</sup> This manuscript was examined by José Chabás during a visit to the Naples National Library in 2021 in the framework of the European Research Council project ALFA.

<sup>8</sup> Available at [https://manus.iccu.sbn.it/opac\\_SchedaScheda.php?ID=181877](https://manus.iccu.sbn.it/opac_SchedaScheda.php?ID=181877).

and there are only tables for mean motions, equations, planetary stations, and the solar apogee. This set does not include tables usually found in other large sets, such as tables for trigonometric functions, parallax, syzygies, or eclipses.

### Mean motions

In MS N, there are tables for the mean motions of 17 different quantities [see [Table 1, pp. 44–45](#)]. The mean motions are given in collected and expanded years rather than in sexagesimal multiples of a basic daily parameter, as is the case in a great number of manuscript copies of PAT. In almost all cases we are given six subtables. One is for collected years from 40 to 2400 at intervals of 40 years, another for expanded years from 1 to 40 at intervals of 1 year. There are also two subtables for each day from 1 to 31 and for each hour and sexagesimal fractions of it from 1 to 60. The last two subtables are for months, both in a common and a leap year. For the apogees and fixed stars there are no subtables for hours and leap years, and for the access and recess of the eighth sphere (i.e., for trepidation) only the table for hours is missing.

We have compared the entries in MS N with those in various sets of PAT, including the *editio princeps* [[Ratdolt 1483](#)]. In addition to the mean motion tables found in this edition, MS N adds tables for the center of the Moon, that is, the double elongation, and for the anomalies of the three superior planets. Among the manuscripts of PAT meeting these two criteria (large number of mean motion tables presented in collected and expanded years), we have selected for comparison a mid-15th-century manuscript: Vatican, MS Pal. lat. 1376.<sup>9</sup> On ff. 24v–34r there is a very complete set of Alfonsine mean motion tables, the entries of which are given with a higher precision than in MS N. The comparison is shown in [Table 1](#) [see [Table 1, pp. 44–45](#)], where the first column indicates the folio number in MS N, the second refers to the relevant heading, and columns 3 and 4 show the entries for 1 day or 1 year (for very slow motions) and for 40 years, respectively. The corresponding entries in the Vatican manuscript are given in blue type and those in the *editio princeps* of PAT in dark red type.

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<sup>9</sup> For a detailed description of this manuscript of more than 400 folios copied at the abbey of St Emmeram in Regensburg, see [Schuba 1992](#), 94–102.

		$1^y$	$40^y$
1r	Apogees and fixed stars	0,0;0,26° 0,0;0,26,25,51°	0;17,38° 0;17,37,57,33°
1v	Access and recess of the 8th sphere	0,0;3,5° 0,0;3,5,0,58°	2;3,26° 2;3,25,42,51°
		$1^d$	$40^y$
2r	Mean motion of the Sun, Venus, and Mercury	0,0;59,8° 0,0;59,8,19,37° 0,0;59,8,19,37,19,13,56°	0;17,38° 0;17,37,57,33°
3r	Mean motion of the Moon	0,13;10,35° 0,13;10,35,1,15° 0,13;10,35,1,15,11,4,45°	4,27;7,35° 4,27;7,35,7,27°
3v	Mean center of the Moon	0,24;22,53° 0,24;22,53,23° 0,24;22,53,23,15,43,41,18 <sup>oa</sup>	2,53;39,54° 2,53;39,54,20°
4r	Mean anomaly of the Moon	0,13;3,54° 0,13;3,53,57,30° 0,13;3,53,57,30,21,4,13°	1,19;28,53° 1,19;28,52,40,30°
5r	Mean argument of lunar latitude	0,13;13,46° 0,13;13,45,39,22° 0,13;13,45,39,22,25,53,45°	5,20;47,18° 5,20;47,17,32,5°
5v	Mean elongation	0,12;11,27° 0,12;11,26,41,38° 0,12;11,26,41,37,51,50,39°	4,26;49,57° 4,26;49,57,9,54°
6r	Node	0,0;3,11° 0,0;3,10,38,7° 0,0;3,10,38,7,14,49,10°	0,53;39,42° 0,53;39,42,24,38°
6v	Mean motion of Saturn in longitude	0,0;2,1° 0,0;2,5,35,48 <sup>ob</sup> 0,0;2,0,35,17,40,41°	2,9;23,14° 2,9;23,14,13,15°
7r	Mean motion of Saturn in anomaly	0,0;57,8° 0,0;57,7,44,54°	3,50;54,24° 3,50;54,23,44,40°

8r	Mean motion of Jupiter in longitude	0,0;4,59° 0,0;4,59,5,27° <sup>c</sup> 0,0;4,59,15,27,7,23,50°	2,14;29,12° 2,14;29,12,34,31°
8v	Mean motion of Jupiter in anomaly	0,0;54,9° 0,0;54,9,4°	3,45;48,26° 3,45;48,25,23°
9v	Mean motion of Mars in longitude	0,0;31,27° 0,0;31,26,38,40° 0,0;31,26,38,40,5,0°	1,36;37,56° 1,36;37,55,40,17°
10r	Mean motion of Mars in anomaly	0,0;27,42° 0,0;27,41,41°	4,23;39,42° 4,23;39,42,16°
11r	Mean motion of Venus in anomaly	0,0;36,59° 0,0;36,59,27,24° 0,0;36,59,27,23,59,31°	0,7;17,42° 0,7;17,41,52,2°
12r	Mean motion of Mercury in anomaly	0,3;6,24° 0,3;6,24,7,43° 0,3;6,24,7,42,40,52°	0,28;55,18° 0,43;55,17,41,51° <sup>d</sup>

<sup>a</sup> There is no table for the center of the Moon in PAT. However, since this quantity is defined as the double elongation, its entries are found in the table for the lunar elongation from the Sun for even values of the argument.

<sup>b</sup> Read 0,0;2,0,35,48.

<sup>c</sup> Read 0,0;4,59,15,27.

<sup>d</sup> Read 0,28;55,17,41,51.

Table 1. A comparison of the mean motion tables in the Naples manuscript

The entries in MS N agree in all cases, except for the three indicated in Table 1 with the corresponding rounded values in the Vatican manuscript. The three cases seem to be copyist errors in that manuscript rather than errors in computation, since they only affect one sexagesimal place. Note, for example, that in the case of the mean motion of Saturn in longitude, the value for 1<sup>d</sup> in PAT when multiplied by 365;15<sup>d</sup> times 40 years yields the entry in MS N for 40 years:

$$0,0;2,0,35,17,40,41^\circ \cdot 365;15 \cdot 40 = 2,9;23,14^\circ.$$

The entries in MS N agree in all cases with the rounded entries in the *editio princeps* of PAT, and all entries for 40 years can easily be derived from the long parameters of the daily motion. This demonstrates that all parameters



used in the mean motion tables in MS N are those specific to Alfonsine astronomy. This in itself comes as no surprise.

We now compare the entries in MS N with those in Bianchini's *Tabulae astronomicae*.

In the manuscripts and editions of Bianchini's set of planetary tables, the mean motions are presented differently from MS N and are not always directly comparable with it. When this is possible (mean motion of the Sun, Venus, and Mercury; the Moon in longitude and anomaly; argument of lunar latitude; and the lunar node), the entries in both sets agree exactly. When direct comparison is not possible, which is the case for all planets, one has to take into account that Bianchini's planetary tables are organized in terms of anomalistic periods. For each planet, Bianchini computes the corresponding period of anomaly and introduces a new quantity, called *superatio*, which is the time in days and hours exceeding a multiple of the anomalistic period. The other new quantity in Bianchini's planetary tables is called the *motus*, and it is the increment in longitude or anomaly after one or more periods of anomaly. With these basic parameters, Bianchini constructs the various tables for the mean motions that appear in his *Tabulae astronomicae*.

For example, in Bianchini's tables for Mars, we are told that the anomalistic period is  $779^{\text{d}} 22;23^{\text{h}}$  and the corresponding *motus* is  $48;44^{\text{h}}$  [Chabás and Goldstein 2009, 66]. This period is obtained by dividing  $360^{\circ}$  by the daily motion in anomaly found in MS N, f. 10r, where the entry for 1 day is  $0;27,42^{\circ/\text{d}}$ . Higher precision can be obtained from the entry for 40 years ( $4,23;39,42^{\circ}$ , also on f. 10r), yielding a value of  $0;27,41,40,57^{\circ/\text{d}}$ . Thus,

$$360/0;27,41,40,57 = 779;55,57^{\text{d}} = 779^{\text{d}}22;23^{\text{h}},$$

in agreement with the value given by Bianchini in his planetary tables.

The corresponding *motus* can also be derived from MS N, taking into account that  $779^{\text{d}} 22;23^{\text{h}} = 2^{\text{y}} 49^{\text{d}} 22;23^{\text{h}}$ . On f. 9v, we are given the relevant entries for the mean motion in longitude of Mars:

2 years	$0,22;34,10^{\circ}$
30 days	$0,15;43,19^{\circ}$
19 days	$0, 9;57,26^{\circ}$
22 hours	$0;28,50^{\circ}$
23 minutes	$0; 0,30^{\circ}$

The sum is  $48;44,15^\circ$ , also in agreement with the value given by Bianchini for the *motus* of Mars in his planetary tables. The rest of the entries displayed in them derive from these basic parameters.

As an example, let us consider now the entries in Bianchini's planetary tables for Mars for 40 years:  $571^d 5;13^h$  (*superatio*) and  $2,37;17^\circ$  (*motus*) [Bianchini 1495, l3r-v]. To obtain these values, we note that in 40 years (14,610 days), 18 periods of anomaly have elapsed ( $779^d 22;23^h \cdot 18 = 14038^d 18;47^h$ ). Thus,

$$14610^d - 14038^d 18;47^h = 571^d 5;13^h$$

is the excess in time over a multiple of periods of anomaly, in agreement with the value given by Bianchini in his *Tabulae astronomicae*. The corresponding *motus*,  $2,37;17^\circ$ , is obtained by multiplying the *motus* for 1 period derived above,  $48;44,15^\circ$ , by 18 periods.

We conclude that the unusual entries for the mean motions in Bianchini's planetary tables derive from a set of tables, such as that in MS N.

### Radices

In most of the mean motion tables, MS N provides radices for the Incarnation, AD 1400 and 1440 for Ferrara and occasionally for Rome, Bologna, and Siena. As was the case with the mean motions, some radices are directly comparable with those in the *Tabulae astronomicae*. For the Sun, Venus, and Mercury, the radices for Ferrara are given in MS N as  $4,38;17,34^\circ$  (Incarnation),  $4,48;34,42^\circ$  (1400), and  $4,48;52,20^\circ$  (1440) [see f. 2r]. Similarly, for the lunar node, the entries displayed are  $1,31;55,42^\circ$  (Incarnation),  $2,50;5,27^\circ$  (1400), and  $3,43;45,9^\circ$  (1440) [see f. 6r]. All six values agree exactly with those in the *Tabulae astronomicae* [Chabás and Goldstein 2009, 37].

For those values not directly comparable because of the different approach adopted in the *Tabulae astronomicae*, consider as an example the case of Mars. MS N gives the data in Table 2.

Mars	Longitude	Anomaly
Incarnation, Ferrara	$0,41;23,40^\circ$	$3,56;53,55^\circ$
1400, Ferrara	$3, 3;31, 8^\circ$	$1,45; 3,34^\circ$
1440, Ferrara	$4,40; 9, 4^\circ$	$0, 8;43,16^\circ$

Table 2. Radices for Mars in MS N (9v-10r)

We first note that for all three dates, the anomaly of the planet results from subtracting the longitude to the radix of the Sun [see above]. Thus, for the Incarnation, that is, for the epoch of the Christian era, 1 January AD 1, which is Julian Day Number 1721424

$$4,38;17,34^{\circ} - 0,41;23,40^{\circ} = 3,56;53,54^{\circ},$$

and analogously for the two other dates.

The radices for Mars in the *Tabulae astronomicae* are taken from the edition of 1495, l3v; they are shown in Table 3.

Mars	<i>Superatio</i>	<i>Motus</i>
Incarnation, Ferrara	513 <sup>d</sup> 5;40 <sup>h</sup>	2,12;25 <sup>o</sup>
1400, Ferrara	227 <sup>d</sup> 14;38 <sup>h</sup>	1, 4;14 <sup>o</sup>
1440, Ferrara	18 <sup>d</sup> 21;29 <sup>h</sup>	4,30;15 <sup>o</sup>

Table 3. Radices for Mars in Bianchini's *Tabulae astronomicae*

It is convenient to keep in mind that 513<sup>d</sup> 5;40<sup>h</sup> of *superatio* at the Incarnation has to be understood as meaning that the anomaly of Mars was 0<sup>o</sup> at this time before the Incarnation. Now, knowing that the anomaly was 3,56;53,55<sup>o</sup> at the Incarnation, as indicated in MS N [see Table 2, p. 47], it is a simple matter to deduce the time it takes Mars to move between these two events at the rate of the mean motion in anomaly, 0;27,42<sup>o/d</sup>, a value that is also given in MS N, 10r. The result is 513<sup>d</sup> 3;18<sup>h</sup>, close to the value in Bianchini's *Tabulae astronomicae*. However, taking a more precise value of the mean motion in anomaly, 0;27,41,41<sup>o/d</sup> [see Table 1, pp. 44–45], the agreement is much better, 513<sup>d</sup> 5;39<sup>h</sup>, indicating that Bianchini computed with more precise parameters than those displayed for one day.

The corresponding *motus* in Bianchini's *Tabulae astronomicae* can also be derived from the entries in MS N. As explained above, the *motus* is the motion in longitude since the anomaly was last 0<sup>o</sup>. At a velocity of 0;31,27<sup>o/d</sup> in longitude, or more precisely 0;31,26,39<sup>o/d</sup> [Table 1, pp. 44–45], during this time Mars moves 513d 5;40h · 0;31,26,39<sup>o/d</sup> = 4,28;58,16<sup>o</sup>. Subtracting the result from the radix in longitude at the Incarnation, 0,41;23,40<sup>o</sup> [Table 2, p. 47], we obtain 2,12;25,24<sup>o</sup>, in agreement with the value given in Bianchini's text in Table 3. Analogous calculations can be made for the other celestial bodies.

As was the case for the mean motions, the radices in Bianchini's planetary tables could derive from a set of tables such as that in MS N.

### Equations

In MS N, we are given equations for the following items: access and recess of the eighth sphere (1v), the Sun (2v), the Moon (4v), Saturn (7v), Jupiter (9r), Mars (10v), Venus (11v), and Mercury (12v). All equations are strictly Alfonsine and correspond to those embedded in the double argument tables in Bianchini's *Tabulae astronomicae*. Although not included in the first edition of 1495, tables for the planetary equations are found in copies of the manuscripts of the *Tabulae astronomicae*, as well as in the second edition [Bianchini 1526].<sup>10</sup>

### Other tables

MS N has two other tables: one is for the first planetary stations (13r) and the other for the solar apogee (13v).

In the table for planetary stations, the argument is given for each integer degree, from  $0,1^\circ$  to  $3,0^\circ$ . The entries represent the first stations of the planets and are presented in five columns, one for each of the planets. They are displayed in signs of  $60^\circ$ . This table is already found in manuscripts of Bianchini's *Tabulae astronomicae* as well as in the edition of 1526, but not in the edition of 1495. [Chabás and Goldstein 2009, 100, table 81].

The second table lists the values of the solar apogee for 1,200 years, from AD 1200 ( $1,28;6^\circ$ ) to AD 2400 ( $1,36;41^\circ$ ), at steps of four years. The entries are given in minutes. There is an additional column for the motion of the solar apogee in a year (*motus in anno*) given in seconds and ranging from  $40''$  to  $16''$ . According to the table, the solar apogee reaches  $1,30^\circ = 90^\circ$  in the years 1376 to 1380. A similar and more complete table is found in Bianchini's *Tabulae astronomicae*,<sup>11</sup> with entries also at intervals of four years, from AD 1–2000, but given to seconds rather than minutes. The common entries for the solar apogee and its *motus in anno* are compatible. We note that this unequal motion of the solar apogee corresponds to the Alfonsine model of a variable precession.<sup>12</sup>

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<sup>10</sup> Chabás and Goldstein 2009, 51–58, 69–79 (double argument tables) and 99–100 (planetary equations).

<sup>11</sup> Chabás and Goldstein 2009, 40–41, table 8, columns 4 and 5.

<sup>12</sup> On the Alfonsine model for trepidation/precession, see, e.g., Chabás and Goldstein 2020–2021, 53–57.

## Conclusion

All tables in the set in MS N are based on the parameters of Alfonsine astronomy as are those in Bianchini's magnum opus, the *Tabulae astronomicae*. MS N is restricted to tables for the luminaries and the planets, and the entries in the corresponding tables in Bianchini's magnum opus agree. As has been argued above, it is quite straightforward to compile the relevant parameters used by Bianchini in his innovative double argument tables in his magnum opus from the tables in MS N. We are thus persuaded that the tables in Naples, MS VIII.C.36 underlie Giovanni Bianchini's *Tabulae astronomicae*.

Was Bianchini the compiler of the set in MS N? It is difficult to give a definitive answer to this question, for nowhere in the manuscript is it stated explicitly that he compiled this set. MS N was copied at the court of Bianchini's patron Leonello d'Este in Ferrara in about 1445 by the same hand and at the same time as another manuscript, also in Naples, Biblioteca Nazionale [MS VIII.C.34], containing a complete copy of Bianchini's *Tabulae astronomicae*, dated shortly earlier, in 1442. Hence, on the basis of both internal and external evidence, as well as the specific relationship between the two manuscripts in Naples, we conclude that it is most likely that Giovanni Bianchini was the compiler of the tables in MS N.

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