Part 1

THE DATING OF THE ALMAGEST

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Introduction

1. A BRIEF DESCRIPTION OF THE ALMAGEST

The Almagest is the famed mediaeval oeuvre that deals with astronomy, spherical geometry and calendar issues. It is believed to have been written by Claudius Ptolemy, an astronomer, mathematician and geographer from Alexandria. Historians date his lifetime to the II century A.D. We shall cite some brief information about Ptolemy below. However, one must instantly point out that, according to certain specialists in the history of astronomy, "Likewise his works, the personality of Ptolemy was treated rather strangely by history. His contemporaries have left no historical records of either his life or his endeavours … We don't know so much as the approximate dates of Ptolemy's birth and death or indeed any other details of his biography" ([98], page 6). Figs. 0.1, 0.2, 0.3, 0.4, 0.5 and 0.6 reproduce ancient portraits of Ptolemy.

According to Scaligerian chronology, the Almagest was created in the reign of the Roman emperor Antoninus Pius, who reigned in 138-161 A.D.

Let us instantly point out that the very literary style of the epoch, which is at times excessively grandiloquent and meandering, is more likely to hail from the epoch of the Renaissance than "deep antiquity", when paper and parchment (let alone books) were luxuries. See for yourselves – the Almagest begins like this.

"O Sire, it appears to me that the true philosophers made the most laudable distinction between philosophy in theory and practice. Indeed, even notwithstanding earlier attempts to unite the two, one could always see a great difference between them. Firstly, although certain moral virtues might be possessed by a great multitude of uneducated people, no study of the ways of the Universe is possible without prior education. Secondly, the former benefit the most due to incessant activity, whereas the latter relish in the advancement of theoretical research. We therefore deem it necessary to let our mental conceptions control our actions most rigidly on the one hand, so as to refer to a perfect and elegant ideal all the time, and, on the other, to direct most of our energy towards familiarising ourselves with a multitude of exquisite theories and learning many more things pertaining to the discipline commonly referred to as mathematics in the narrow sense of the word … If we are to educe the primordial reason that has set the Universe in motion in the simplest form, it was the immanent and invisible God. The next section is theology … The section that studies the material and the ever-changing qualitative aspects such as whiteness, warmth, sweetness, softness etc., is called physics … Finally, the discipline concerned with the qualitative motions and shapes … can be defined as mathematics" ([704], pages 5-6).

The style is perfectly typical for late mediaeval scientific (or, as they are also called, scholastic) works of the XV-XVII century. One most vivid detail is the reference to an invisible and immanent God by Ptolemy – a characteristic element of the Christian dogma,

Fig. 0.1. Ancient drawing of Ptolemy dating from 1584. Ptolemy is holding a Jacob's rod. Thevet. Les vrais protr. et vies d'hommes illustres… Paris, 1584. Taken from [704], page 431.

Fig. 0.2. Ancient sculpture depicting Ptolemy from the cathedral of Ulm (around 1469-1474). The statue was made by Jorg Sirlin the Senior. Taken from [704], page 448.

Fig. 0.3. Ancient depiction of Ptolemy from the ***Global Chronicle*** by Hartmann Schedel. Augsburg, 1497. Taken from [90], page 25.

Fig. 0.4. Ancient portrait of Ptolemy, where he looks like a typical mediaeval European. Taken from [98], page 7.

quite alien to the polytheism of the Olympians. And yet Scaligerian chronology tries to convince us that Christianity only became the official religion in the IV century A.D., and the "ancient Greek Ptolemy" from the II century A.D. is clearly considered a pre-Christian author by the historical authorities.

We would like to introduce the reader to the Almagest's table of contents, given that this fundamental scientific oeuvre is hardly a popular read nowadays. According to the Scaligerite historians, it was written almost two thousand years ago.

It has to be pointed out that certain researchers consider the existing division of the Almagest into chapters to be more recent than the book itself, likewise the names of the chapters ([1358], pages 4-5). However, this fact is of no importance to us presently, since our only goal is to familiarise the readers with the structure of the Almagest.

Fig. 0.5. Ancient portrait of Ptolemy. Wood engraving, XVI century. Taken from [1160], page 25.

Fig. 0.6. Ancient drawing of Ptolemy on the "Cosmosphere" of Vassily Kiprianov, 1707. Ptolemy is wearing something that resembles an Ottoman turban. Taken from [90], page 212.

The Almagest: table of contents.

Volume 1.
1. Foreword.
2. On the continuity of narration.
3. On the spherical nature and motion of the heavens.
4. On the spherical nature of the Earth in general.
5. The Earth as the centre of the heavens.
6. The Earth as a point as compared to the heavens.
7. On the immobility of the Earth.
8. On two different main kinds of celestial motion.
9. On individual concepts.
10. On the sizes of the chords.
11. Chord table.
12. On the arc between the two solstices.
13. Preliminary data for spherical geometry equations.
14. On the arcs between the equinoctial circle and the slanting circle (the equator and the ecliptic, in other words).
15. Declination table.
16. On the sunrise phases in the straight sphere.

Volume 2.
1. On the general location of the inhabited part of the Earth.
2. How to calculate the horizontal arc between the equator and the ecliptic knowing the maximum daytime duration.
3. How to find the height of the pole under similar assumptions and vice versa.
4. How to calculate when and how often the Sun happens to be right above one's head for different areas.
5. How to calculate the gnomon proportions in relation to the length of the meridian shadow during solstices and equinoxes, knowing the values mentioned above.
6. A list of individual parallels' special characteristics.
7. On simultaneous ascensions in the slanting spherical circle part that crosses the middles of zodiacal constellations and the equinox circle (the equator).
8. 10-degree arc ascension timetable.
9. On individual issues related to the ascension times.
10. On the angles constituted by the circumference that crosses the middles of zodiacal constellations (ecliptic) and the meridian circle (meridian).
11. On the angles between the ecliptic and the horizon.
12. On the angles and arcs formed by the same circumference (the ecliptic) and the circumference that crosses the horizon's poles.
13. The values of angles and arcs for different parallels.

Volume 3.
1. On the duration of a year.
2. Tables of mean Solar motion.
3. On the hypotheses related to even circular motion.
4. On the visible irregularity of solar motion.
5. On defining the irregularity quotients for different position.
6. Solar anomaly table.
7. On the mean solar motion epoch.
8. On the calculation of the solar position.
9. On the inequality of daytime and nighttime.

Volume 4.
1. What observations the lunar theory must be based on.
2. On lunar periods.
3. On individual values of the Moon's mean motions.
4. Tables of mean lunar motions.
5. On the identical nature of the events observed under the simple hypothesis of lunar motion, either eccentric or epicyclical.
6. The definition of the first (or simple) lunar inequation.
7. On the adjustment of the Moon's mean motions by longitude and anomaly.
8. On the epoch of the Moon's mean motions by longitude and anomaly.
9. On the adjustment of the Moon's mean positions and their epochs by latitude.
10. The table of the first (or simple) lunar inequation.

11. On the fact that the discrepancy between the lunar inequation value of Hipparchus and the one discovered by the authors results from calculations and not from a priori assumptions.

VOLUME 5.

1. On the construction of the astrolabe.
2. On the hypotheses of the double lunar inequation.
3. On the value of the lunar inequation that depends on the Moon's position in relation to the Sun.
4. On the proportion value of the lunar orbit's eccentricity.
5. On the "declination" of the lunar epicycle.
6. How to calculate the position of the Moon geometrically, relying on periodic movements.
7. Construction of the full moon inequation table.
8. The full moon inequation table.
9. On calculating the position of the Moon in general.
10. On the fact that the syzygy difference produced by the lunar eccentricity is marginal.
11. On the lunar parallax.
12. On the construction of the parallax instrument.
13. Estimating the lunar distances.
14. On the values of visible diameters of the Sun, the Moon and the shadow of the Earth in syzygies.
15. On the distance to the Sun and various implications of this calculation.
16. On the sizes of the Sun, the Moon and the Earth.
17. On individual values of solar and lunar parallaxes.
18. Parallax table.
19. Parallax definition.

VOLUME 6.

1. On the new moons and the full moons.
2. Compilation of the mean syzygy table.
3. New moon and full moon tables.
4. How to calculate the mean and the true syzygy.
5. On the limits of solar and lunar eclipses.
6. On the intervals between eclipse months.
7. The construction of eclipse table.
8. Eclipse tables.
9. Lunar eclipse calculations.
10. Solar eclipse calculations.
11. On the "eclipse declination" angles.
12. Eclipse "declination" table.
13. "Declination" definition.

VOLUME 7.

1. On the immobile stars, whose position in relation to one another never changes.
2. On the retrograde motion of the immobile star sphere alongside the ecliptic.
3. On the circular nature of the retrograde motion of the immobile star sphere around the ecliptic poles.
4. On the methods of compiling an immobile star catalogue.
5. Northern Hemisphere constellation catalogue.

VOLUME 8.

1. The Southern Hemisphere constellation catalogue.
2. On the position of the Milky Way's circumference.
3. On the construction of the cosmosphere.
4. On the configuration characteristic for the immobile stars.
5. On simultaneous ascensions, culminations and descents of immobile stars.
6. On the first and last moments of the immobile stars' visibility.

VOLUME 9.

1. On the order of the spheres of the Sun, the Moon and the five planets.
2. On the aims of our planetary hypotheses.
3. On the five planets returning periodically.
4. Mean longitudinal motion table and the anomaly of the five planets.
5. Primary postulations concerning the hypotheses of five planets.
6. On the character of the hypotheses and the respective discrepancies.
7. Estimating Mercury's apogee position and its movements.

8. How planet Mercury gets the closest to the Earth twice in one move.
9. On the size and proportions of Mercury's anomalies.
10. Mercury's periodic motion rectified.
11. On the epoch of Mercury's periodic motion.

Volume 10.

1. Estimating the apogee of Venus.
2. On the size of the planet's epicycle.
3. On the relations between the eccentricities of planet Venus.
4. On the amendment of the planets' periodic motions.
5. On the epoch of the periodic motion of Venus.
6. Preliminary data about other planets.
7. Estimating the eccentricity and the apogee of Mars.
8. Estimating the epicycle of Mars.
9. Rectification of the periodic motion of Mars.
10. On the epoch of the periodic motion of Mars.

Volume 11.

1. Estimating the eccentricity and the position of Jupiter's apogee.
2. Estimating the epicycle of Jupiter.
3. The amendment of its periodic motion.
4. On the epoch of Jupiter's periodic motion.
5. Estimating the eccentricity and the position of Saturn's apogee.
6. Estimating the epicycle of Saturn.
7. The amendment of its periodic motion.
8. On the epoch of Saturn's periodic motion.
9. How the periodic motion can be used for a geometric calculation of the true positions.
10. The construction of the anomaly table.
11. Tables for the estimation of the longitudes of the five planets.
12. On calculating the longitudes of the five planets.

Volume 12.

1. On the preliminary considerations concerning retrograde motion.
2. The calculation of Saturn's retrograde motion.
3. The calculation of Jupiter's retrograde motion.
4. The calculation of Mars's retrograde motion.
5. The calculation of Venus's retrograde motion.
6. The calculation of Mercury's retrograde motion.
7. Stationary point table construction.
8. Stationary point tables. Amended anomaly value.
9. Estimation of the maximal possible distances between Venus, Mercury and the Sun.
10. Tables of maximal distances between the planets and the true position of the Sun.

Volume 13.

1. On the hypotheses that concern the latitudinal motion of the five planets.
2. On the character of motion in the alleged inclinations and obliquities in accordance to the hypotheses.
3. On the size of the obliquities and inclinations.
4. The construction of tables for the individual values of longitudinal discrepancies.
5. Table for latitudinal calculations.
6. Latitudinal discrepancy calculations for the five planets.
7. First and last visibility moments for the five planets.
8. How certain particular details of Venus and Mars ascending and descending correspond to consensual hypotheses.
9. The method of estimating the distance to the Sun for individual cases of heliacal ascensions and descents.
10. Tables of heliacal ascensions and descents for the five planets.
11. Epilogue.

Therefore, the Almagest consists of 13 volumes, which occupy 430 pages of a broadsheet modern edition ([704]).

This book is also concluded in the most remarkable manner. The epilogue is as follows:

"After we have made it all come to pass, o Sire, and considered nearly everything that I believe necessary to be considered in such an oeuvre, inasmuch as the time that has passed appears to have helped with perfecting the precision of our discoveries – by no means having an idle boast as an ulterior motive, but rather in order to be of use to science; may our present work have an apropos and a fitting ending" ([704], page 428).

As we can see, Ptolemy's work is dedicated to a certain "Sire", or Czar. Historians appear to be greatly surprised by this fact. Modern commentary is as follows: "This name [Sire = Czar – Auth.] was rather popular in Hellenistic Egypt in the epoch in question. We have no other data about this person – we don't even know whether he was associated with astronomy in any way at all" ([704], page 431). However, the very fact that the Almagest was associated with the name of a certain Czar can be proven by the following circumstance. Apparently, "Ptolemy was also ascribed royal ancestry in late antiquity and in the Middle Ages" ([704], page 431). Also, the very name Ptolemy (or Ptolomy) is presumed to have been the dynasty name of the Egyptian kings who reigned after Alexander the Great ([797], page 1076).

At any rate, according to Scaligerian chronology, the Ptolemaic dynasty left the stage around 30 B.C. ([797], page 1076) – more than a hundred years earlier than Ptolemy the astronomer, in other words. Thus, the only thing that precludes us from identifying the epoch of the Ptolemaic rulers as the epoch of Ptolemy the astronomer is Scaligerian chronology. Apparently, in the Middle Ages, when Scaligerian chronology had not yet existed, the Almagest was ascribed to the Ptolemaic kings and none other – naming them as the organisers of this grandiose endeavour or the customers who had ordered this astronomical tractate. This is why the Almagest was canonised, becoming absolutely authoritative for a long time to follow. It is easy enough to understand why the book begins and ends with a dedication to a certain Czar, or Sire. It was the royal textbook on astronomy, in a way. We shall find out just when it was written in the present book.

The first volume of the Almagest voices a number of general principles, in particular the following:

1. The sky is really a celestial sphere and rotates as such.

2. The Earth is a sphere located at the centre of the Universe (heavens).

3. The Earth can be considered a point in space as compared to the distance to the sphere of immobile stars.

4. The Earth is immobile ("doesn't travel from place to place").

Many of these claims were educed from the Aristotelian philosophy according to Ptolemy himself. Furthermore, Volumes 1 and 2 are collections of elements of spherical astronomy – the spherical triangle theorems, the method of measuring the arcs (angles) by known chords etc. Volume 3 relates the theory of visible annual motion of the Sun, discusses the dates of equinoxes, the length of a year etc. Volume 4 considers the length of a synodal month, which is the cycle of lunar phase repetition. It consists of circa 29 days, 12 hours, 44 minutes and 2.8 seconds. The same book relates the theory of lunar motion. Volume 5 discusses the construction of certain observation instruments and continues the research of the theory of lunar motion. Volume 6 describes the theory of solar and lunar eclipses.

The famous star catalogue that contains around 1020 stars is part of the seventh and the eighth volumes of the Almagest, which also discuss the properties and characteristics of immobile stars, the motions of the stellar sphere etc.

The last five volumes of the Almagest contain a theory of planetary motion. Ptolemy mentions five planets, namely, Saturn, Jupiter, Mars, Venus and Mercury.

2. A BRIEF HISTORY OF THE ALMAGEST

As we have already pointed out, Scaligerian chronology believes the Almagest to have been created in the reign of Emperor Antoninus Pius, in 138-161 A.D. Furthermore, it is presumed that the last observation included in the Almagest dates from 2 February 141 A.D. ([1358], page 1). The period of Ptolemy's observations that the Almagest is based upon falls over 127-141 A.D.

The Greek name of the Almagest translates as "Systematic Tractate on Mathematics", emphasising the fact that the Almagest represents the epoch's sum total of Greek mathematical astronomy. It isn't known whether other astronomical textbooks comparable to the Almagest existed in the epoch of Ptolemy. Modern scientists attempt to explain the unprecedented success of the Almagest among the astronomers and scientists in general by a chance loss of the majority of all the other astronomical works of the epoch ([1358]). The Almagest was the main textbook on astronomy in the Middle Ages. If we are to believe the Scaligerian chronology, it served in this quality for fifteen hundred years, no less, making a tremendous impact on mediaeval astronomy in Islamic and Christian lands up until the XVII century A.D. The authority of this book in the mediaeval scientific community compares to nothing but Euclid's "Elements".

As it is pointed out by Toomer, for instance ([1358], page 2), it is exceptionally hard to trace the history of the Almagest and its influence in the "antiquity" (between the II century A.D. and the Middle Ages). One usually judges the role of the Almagest as the standard textbook for "advanced students" in the period of the so-called decline of the "antiquity" by the comments of Pappus and Theon of Alexandria ([1358], page 2). The Scaligerian version of history tells us of a "lugubrious and taciturn epoch" that is presumed to have followed – we shall discuss it in detail in Chapter 11. For the meantime, let us just point out the following characteristic of this fictitious Scaligerian "stagnation age" as given by a modern specialist in the history of astronomy: "After the astonishing efflorescence of the ancient culture on the European continent came a lengthy period of stagnation and even regress in certain aspects – a 1000-year period commonly referred to as the Middle Ages … Not a single astronomical discovery of any significance was made in this millennium" ([395], page 73).

Furthermore, Scaligerian history is of the opinion that in the VIII-IX century the Almagest "emerged from obscurity" due to a growing popularity of Greek science in the Islamic world and was translated into Syrian; this was followed by several Arabic translations. At least five such translation versions are known to have existed by the middle of the XII century A.D. See more about this in Chapter 11. Today it is believed that Ptolemy's work, originally written in Greek, was still copied and even studied in the East, Byzantium in particular, but not the West. "In the Western Europe, all knowledge of this work remained lost up until the early Middle Ages. Although several translations were made from Greek to Latin in the Middle Ages, the primary source for the rediscovery of the Almagest in the West was a translation from the Arabic made by Gerhard of Cremona in Toledo and finished by 1175 A.D. Greek manuscripts [of the Almagest – Auth.] started to reach the West in the XV century; however, it was Gerard's text that remained the basis of books on astronomy for ages and generations to come, up until the compilation of a concise version of the Almagest by Purbach and Regiomontanus … This was the first printed version of the Almagest (Venice, 1515). The sixteenth century witnessed a wide propagation of the Greek text (published by Hervagius in Basel in 1538) and the waning of the Ptolemaic astronomical system's influence, not so much caused by the work of Copernicus (which has been clearly influenced by the Almagest, be it the form or the conceptions voiced therein) as by those of Tycho Brahe and Kepler" ([1358], pages 2-3).

3. THE PRINCIPAL STAR CATALOGUES OF THE MIDDLE AGES

And so, the Almagest (its star catalogue in particular) ranks as the oldest more or less informative and detailed astronomical work that has reached our day and age. The approximate Scaligerian dating of the Almagest is the II century A.D. However, it is assumed that Ptolemy used the star catalogue of Hipparchus, his predecessor who had lived in the II century B.C. The catalogue in question has not survived in its original form. Likewise other mediaeval catalogues, the Almagest catalogue contains circa 1000 stars, whose positions are indicated as their latitudes and longitudes in ecliptic coordinates. It is presumed that no other star catalogues but the one contained in the Almagest were known before the X century A.D.

Finally, according to Scaligerian chronology, the first mediaeval star catalogue was compiled in the X century A.D. in Baghdad by al-Sufi, an Arabic astronomer. His full name is Abd al-Rahman ben Omar ben Mohammed ben Sala Abu al-Husain al-Sufi (903-986 A.D., qv in [544], Volume 4, page 237). The catalogue of al-Sufi has survived; a closer study reveals it to be identical to the same old Almagest catalogue. However, if the surviving copies and editions of the Almagest contain a star catalogue rendered to circa 100 A.D. by precession as a rule (although there are exceptions), the catalogue of "al-Sufi" is the very same catalogue rendered by precession to the X century A.D. This fact is known quite well to astronomers – see [1119], page 161, for instance. Let us also point out that rendering a catalogue to a random desired historical epoch was an easy enough task. A certain constant would be added to the longitudes of stars – the same value for each and every star. This is a very simple arithmetical operation; actually, the Almagest describes it in great detail.

The next surviving catalogue in Scaliger-Petavius chronology was compiled by Ulugbek in Samarqand (1394-1449 A.D.). None of the three is very precise, since they all indicate star coordinates using a scale with a step of 10 arc minutes. Next, we have the famed catalogue of Tycho Brahe (1546-1601), which is already substantially more precise. Brahe's catalogue is believed to be the greatest advance of mediaeval instruments and observation technology in general. Post-Tychonian catalogues are abundant; however, they are of no interest to us presently.

4. THE REASON WHY THE DATING OF THE OLD STAR CATALOGUES IS AN IMPORTANT ISSUE

Every new star catalogue is the result of a great body of work conducted by an observing astronomer; most likely, a whole group of professional observers who needed all the professionalism, concentration and meticulousness they could muster as well as the ability to use state-of-the-art measurement instruments of their epoch to the maximum. Apart from that, a catalogue required a corresponding astronomical theory, or cosmology. Thus, each and every ancient catalogue was the epitome of its epoch's astronomical thought. By analysing a catalogue we can find out a lot about the epoch's quality of measurements, the level of astronomical knowledge etc.

However, in order to comprehend the results of a given catalogue's analysis, one must know the date of its compilation. Any change of date automatically changes our estimates, our concept of the catalogue etc. And it isn't always an easy task to calculate the date of a given catalogue's creation – this can be observed best in case of the Almagest. Initially, in the XVIII century, the veracity of the Scaligerian version, which attributed Ptolemy to the alleged II century A.D., was considered indisputable. However, in the XIX century a more meticulous analysis of the stellar longitudes contained in the Almagest revealed that precession-wise these longitudes correspond to the epoch of the II century B.C. – the epoch of Hipparchus, in other words. This is how A. Berry relates the situation: "The seventh and the eighth volumes [of the Almagest – Auth.] contain a star catalogue and a description of the precession. The catalogue, which includes 1028 stars (three of them double) appears to be virtually identical to that of Hipparchus. It doesn't contain a single star that could be seen by Ptolemy in Alexandria and could not be seen by Hipparchus on the Rhodes. Moreover, Ptolemy claims to have defined the value of precession as 36" (and erroneously so) after a comparison of his observations to the data of Hipparchus and other astronomers. Hipparchus considers this value as the least possible result, whereas for Ptolemy it is the final estimate. The positions of stars in Ptolemy's catalogue correspond the most to their true positions in the time of Hipparchus, taking into account the alleged annual precession of 36", and less so – to their actual positions in Ptolemy's epoch. It is therefore very likely that the catalogue in question has got nothing in common with Ptolemy's original observations, being de facto the very same catalogue as that of Hipparchus, with compensated precession only slightly altered by the observations of Ptolemy and other astronomers" ([65], pages 68-69).

The issue of dating the catalogue becomes crucial in this case. Ever since the XVIII century the astronomers and the specialists in history of astronomy have been analysing the Almagest catalogue and the Almagest in general, trying to "sort out" the data it contains, distinguish between the observations of Hipparchus and Ptolemy etc. A great deal of literature has been written about the dating of the observations that the Almagest catalogue is based on. We are by no means attempting to analyse it in depth here and refer the interested reader to [614], for instance, where one can find a guide to the respective publications.

We have another question to ask – is it possible to create a mathematical method that permits dating the ancient star catalogue "from within" – in other words, by using nothing but the numeric information contained in the star coordinates that the compiler of the