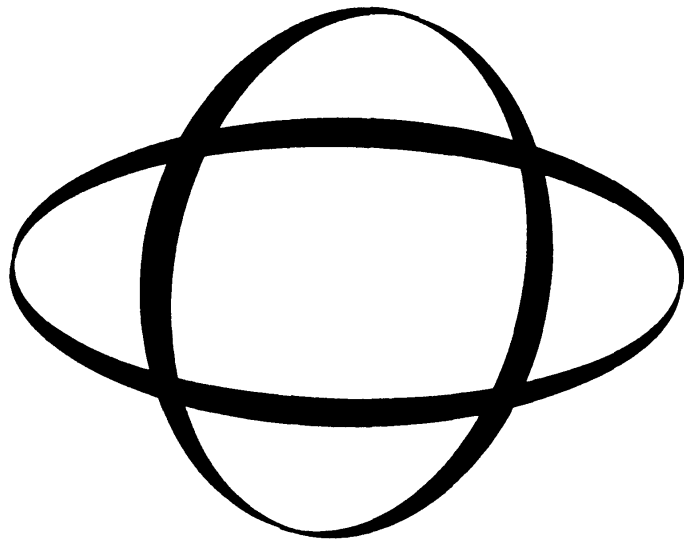


A. T. Fomenko
V. V. Kalashnikov
G. V. Nosovsky



**GEOMETRICAL
and STATISTICAL METHODS
of ANALYSIS of STAR
CONFIGURATIONS**

DATING PTOLEMY'S ALMAGEST



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Preface

This book is devoted to a problem that lies at the crossroad of several sciences: statistics, geometry, celestial mechanics and computational astronomy, the problem of dating ancient star catalogs from an analysis of their contents, on the basis of modern knowledge of how the visible picture of the sky evolves with time. A vivid example is the problem of dating the star catalog of the famous Ptolemy's *Almagest*. The problem has a long and involved history; see a review of publications on the subject in the book of R. Newton¹.

The *Almagest* is traditionally attributed to Claudius Ptolemy (about the 2nd century AD). Yet, some investigations (mainly, the ones carried out in the 18th–19th centuries) revealed some contradictions between the astronomic data contained in the catalog and the astronomic reality of the 2nd century AD. This led to a hypothesis that Ptolemy had in fact used for the *Almagest* a star catalog compiled by Hipparchus (whose lifetime is traditionally attributed to the 2nd century BC), presumably having added some observations of his own. The reader can find a discussion of this hypothesis (and some others) in classical works^{2,3}. A more recent book of R. Newton¹ presents a thorough statistical and astronomical analysis of the *Almagest* as a whole, and in particular of the star catalog it contains. R. Newton contends that his analysis gives an irrefutable proof of most observational data contained in the catalog being counterfeit. In any case R. Newton insists on the necessity of an overall revision of our views of the position and the role of the *Almagest* in the history of science. In fact, a similar conclusion and the inference that an essential redating of the *Almagest* is necessary had been suggested long before

R. Newton by N. A. Morozov in his fundamental book *History in the Light of Natural Sciences*, published in 1928–1932 under the title *Khristos (Christ)* (see Ref. 4). It should be noted that the astronomical and mathematical arguments of N. A. Morozov are diverse from the ones of R. Newton, but they lead to a similar conclusion about the necessity of a revision of the traditional views of the *Almagest*. A lot of additional criticism on the subject can be found in the cycle of works of A. T. Fomenko^{5–13}, devoted to the development of new empirico-statistical methods for detecting dependent narrative texts and for dating the events they describe (in particular, astronomic events).

We stress, however, that the investigations we expose in this book are completely independent of the methods and arguments used in the aforementioned works and that we do not use the hypotheses suggested therein.

In this book we suggest a new method for dating ancient star catalogs. The method uses, in particular, the investigation of proper motions of stars. Since these motions are now measured with a very high accuracy (on the basis of astronomic observations of the last two centuries), it is possible to compute the positions of stars in the past. Comparing these with the ones indicated in a star catalog, we can try to determine the time when the observations were made, and consequently the approximate time of compilation of the catalog. However, a practical implementation of this seemingly simple idea encounters major difficulties, both of technical and fundamental nature. Coping with these difficulties requires the new statistico-geometrical method we present in this book. The foundations of the method have been exposed in Refs. 14 and 15. Our approach involves both statistical and geometrical ideas; the latter are necessary because of the geometrical nature of the object we deal with, the evolution of a point set (the set of stars) in the celestial sphere.

We have tested the method on some reliably dated medieval star catalogs, and also on some artificially created catalogs. In the latter case the catalogs were compiled with the help of a computer; of course, the compiler knew the “date of compilation”, but the researcher did not. The date was sealed in an envelope to be unsealed only after getting a date from the method. The procedure proved the efficiency of the method: the “date of compilation” was always within the interval it produced.

Then we applied the method to the star catalog of the *Almagest*. The results thus obtained contradict the traditionally accepted date and imply the necessity of its considerable “rejuvenating”.

The main body of this book does not involve any historical questions or questions concerning the origins of the data. Thus, we concentrate on the contents of the star catalog itself, and do not even raise any questions concerning the rest of the *Almagest* (the star catalog constitutes the seventh and the eighth books of the *Almagest*).

However, for the reader’s convenience, we have supplemented the book with the *Addendum* containing an exposition of some problems and conjectures on dating the *Almagest* as a whole. We should stress once more that the main body of the book is entirely independent of the *Addendum*. The

Addendum is intended for a reader wishing to proceed with the study of the questions we raise in the main body of the book toward understanding the origins of the data. A reader interested in mathematical and astronomical aspects alone may confine himself to the main body of the book.

The structure of the book is the following.

The *Introduction* provides a brief review of the contents of the *Almagest*, and in particular of its star catalog. We also give a brief review of other star catalogs and explain our interest in the problem of dating catalogs.

Chapter 1 provides some necessary information from astronomy, astrometry and history of observational equipment and methods for measuring coordinates of stars.

In *Chapter 2*, we carry out a preliminary analysis of the star catalog of the *Almagest*. We discuss here various problems that arise in connection with the catalog (for example, the ambiguity in identification of stars), the accuracy of altitudes and longitudes in the catalog, and some peculiarities of the catalog (such as the Peters' sine curve).

In *Chapter 3*, we analyze some attempts to date the star catalog of the *Almagest* based on the most obvious ideas. We show that no straightforward elementary methods lead to a reliable date, and reveal the difficulties behind these failures.

In *Chapter 4*, we start the description of our new method for dating star catalogs. Here we discuss the "Who is who?" problem, the problem of identification of the stars described in the catalog with the ones known in modern astronomy.

Chapter 5 presents mathematical backgrounds for the statistical analysis of the catalog. Here we classify various errors that occur in the catalog, and suggest methods for their detection and for compensation for the systematic component.

In *Chapter 6*, we carry out a global statistical processing of the catalog and of its basic parts. We apply several statistical characteristics to various pieces of the celestial sphere, which enables us to distinguish the "well-measured" and "poorly measured" pieces. The ensuing decomposition of the sky into the "homogeneous areas" (with contrasting accuracy of measurement) implies a new view of the structure of the *Almagest*.

In *Chapter 7*, we apply two different dating procedures, statistical and geometrical, to the catalog of the *Almagest*; the two estimates turn out to agree.

In *Chapter 8*, we suggest an explanation for the "Peters' sine curve", based on the previous results; we also discuss here the value of the angle between the equatorial plane and the ecliptic given in the *Almagest*.

In *Chapter 9*, we apply our method to the catalogs of Tycho Brahe, Ulugh Beg, Hevelius and Al Sûfi (As-Sûfi).

Chapter 10 is devoted to determination of the date using other parts of the *Almagest*. The ensuing results demonstrate perfect agreement with our date for the star catalog. Finally, we obtain the period of time that captures the observations fixed in the *Almagest* (500–1350 AD), and reconstruct

the “Ptolemaic chronology”, that is, Ptolemy’s concepts of global chronology (nowadays concealed by the erroneous tradition of recalculating Ptolemy’s dates into the years AD). It turns out that similar concepts can be found in several sources of the 13th–14th centuries. Thus, the *Almagest* keeps to a chronological tradition, nowadays forgotten, but actual in the 13th–14th centuries, which differs much from the chronology we are used to today.

The book is concluded by the *Addendum*, containing a brief review of problems connected with dating the *Almagest* as a whole. We treat this material as supplementary, and do not use it in the main body of the book, although it is probably of some epistemological interest.

The book is supplemented with tables containing some astronomic data we use in the text.

The book contains a lot of material represented in tabular and graphical form. We call reader’s attention to figures and graphs, which contain much important information, necessary for a fuller understanding of the book. We number the figures and tables consecutively within every chapter and chapter number precedes the number of the figure. Thus “see Figure 2.1” means “see Figure 1 in Chapter 2”.

We use the techniques of mathematical statistics, modern geometry, celestial mechanics and astrometry. Therefore some chapters require an acquaintance with basic mathematical notions. Yet, we tried to make the mathematics we used as simple as possible, and we hope that this book will be accessible to a reader familiar with the elements of mathematics at the level of a second-year student in mathematics. The book is intended not only for specialists in natural sciences, but also for the historians interested in modern mathematical and statistical methods. See also the book: A. T. Fomenko, *Empirico-Statistical Methods for Analysis of Narrative and Numerical Sources with Applications to the Problems of Ancient and Medieval History and Chronology*, vols. 1,2. Kluwer Acad. Publ. (in print).

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A. T. Fomenko
V. V. Kalashnikov
G. V. Nosovsky

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