

TAMAS in brief: how and why care about astronomical tables?

For centuries across Eurasia, astronomical tables were constructed, compiled and copied to meet a wide range of religious, ritualistic and political needs, to make calendars, to predict the future astrologically, to understand the natural world. Such tables circulated among cultures and were appropriated and transformed by a great diversity of actors. Thus, the numerical data conveyed in these tables provide rich evidence for ancient scientific practices. For example, in tables we can recover how complex, massive numerical computations were handled in the ancient world and thus contribute to the history of computational mathematics. Tables also reveal how astral phenomena were modelled and how reasoning and prediction were shaped. As written documents of a special type, falling between computation per se and data storage, astronomical tables expose epistemic writing practices in their layouts on the page and their combination into “sets” of tables. Created by complex computation with often-interlinked algorithms, circulating tables generally were adapted to new contexts and purposes rather than recomputed from scratch. Thus in addition to their individual contents, astronomical tables viewed more generally can provide unmatched sources for studying the transmission of computational know-how, writing technologies and layouts, theoretical models, and numerical parameters. With enhanced digital editorial and analytical tools, scholars will be able to chart previously unrecognized paths of circulation, to learn how large collections of tables were shaped, and to track the spread and appropriation of particular computational practices.

A central goal of *TAMAS* is to bring together emerging and more senior scholars. By working together through carefully selected case studies, such collaboration encourages both the transmission of tacit know-how generally not found in scholarly publications as well as the critical reappraisal of the traditional or fundamental research questions in the discipline.

The project will focus on two sets of questions:

- What type of database should we design in order to “edit” sources of the ancient astral sciences in the context of the digital humanities? How can a single tool handle diverse tabular layouts, different types of numbers, different kinds of errors and variants between copies, as well as the differences in publishing results in paper and digital formats?
- What kinds of tools should we create to explore materials within this database and to analyse these sources? How can we employ modern computational power with the necessary attention to the historical computation practices of the actors? How can we describe the algorithms presented in texts and their eventual effective uses in computing tables?

These two groups of questions are obviously closely related and need to be treated together in order to guarantee the compatibility of the analytical tools with the database on which they should operate. For the first group of questions we intend to produce innovative table- and parameter-databases and to develop new ways to publish our research in conjunction with well established journals in the field such as the *Journal for the History of Astronomy* and *SCIAMVS*. For the second set of questions we will create shared, historically based computation routines allowing us to explore in new ways the numerical content of astronomical tables. These efforts will be based on original, individual cases studies on specific sources by each participant in the project. These studies will be published as a book that will be the first exploration, of this breadth, of these methodological issues [See Van Dalen (1993)].

Why do we need TAMAS now? Current status of the field

How astronomical tables were usually addressed?

Ancient astronomical tables often appear in manuscripts separated from texts. Thus the first task of the historian is simply to identify the type of table under consideration. Once the type is identified the scholar must assign it to a tradition and relate it to other known works or authors. During the twentieth century, these were the two main questions addressed by historians of ancient astronomy. They generally published their work in the form of surveys. In surveys, tables and manuscripts are not edited but rather are described and summarised. The work is unequally advanced in different traditions: Latin and Arabic have sources benefited from more attention, even if some essential works are still waiting publication,

than have Chinese or Sanskrit sources. [See Chabás J. and Goldstein B.R. (2012); Kennedy, E. S. (1956); Neugebauer, O. (1975); Pedersen, O. (1974); Pingree, D. (1956); Toomer, G. J. (1968), Sivin, N. (2009)]

Some important methodological tools were shaped to tackle these questions. The first issue sought to identify the geometrical model and/or the function of which the table is thought to represent, more or less precisely and accurately. The second question tried to identify, by means of statistical analysis and recomputation, the specific parameters of the underlying model or function. These tools, partly because they are removed from actors' practices and categories, are very powerful and when used in an historically sound way can produce important results. [See van Dalen, B. (1993)]

The first approach of the surveys, using modern tools, has generated sound, mathematical understanding of ancient astronomical tables: we are able to reproduce most of the ancient astronomical tables and to interpret them in an astronomically meaningful way. However these recomputations usually generate "computational noise"; we are able to reproduce not each individual numerical value but rather a statistical approximation of the table as whole. This noise reflects the distance between our and historical actors' mathematical practices. Many of the new insights we hope to extract from the numerical values of the tables will depend on our ability to build tools to analyse this noise. The second approach of the surveys has allowed the definition of tradition and corpuses. Tables sharing models and parameters are identified in manuscripts which can then be arranged in corpuses. Important contexts of change in the way astronomical tables are designed as well as in their transmission have thus been identified.

The emergence of new questions: toward the need of new tools

Some of the methodological questions we are now raising have also matured in the context of recent research projects devoted to the history of mathematics. The ANR project History of Numerical Tables (Dominique Tournès, Paris 7) organised in June 2010 a seminar at the *Institut Henri-Poincaré* under the title *Méthodologie de l'étude historique des tables numériques* during which a first attempt was made to map some of the issues at stake here. Another important step was made with the redaction of a chapter *Tools of the Table Crackers: Using Quantitative Methods to Analyze Historical Numerical Tables* by Clemency Montelle, Glen van Brummelen and Matthieu Husson, to be published in the collective book resulting from the *History of Numerical Tables* project. This essay distinguishes between general methods applied to a range of astronomical tables and more *ad hoc* ones designed to fit a specific problem in one table. In August 2013, during the International Congress for the History of Science in Manchester, Christopher Cullen and Matthieu Husson organised a symposium entitled *Using modern computing tools to analyse and explicate ancient astronomical sources: opportunities and challenges* which confirmed the importance of this topic for the history of ancient astronomy as whole. Recently two projects devoted to ancient astronomy and tables were launched. *Ptolemy Arabus et Latinus (PAL)*, Benno van Dalen, Munich) aims at surveying and editing Ptolemaic works in the Arabic and Latin traditions. *History of Astronomical and Mathematical Sciences in India (HAMSI)*, Clemency Montelle, Canterbury University NZ) aims at surveying and editing second millennium astronomical works in Sanskrit. Close relations exist between these two projects, each devoted to a particular set of sources, and the broader methodological one proposed here. The ERC project *Mathematical Sciences of the Ancient World* (Karine Chemla, Paris 7) addressed from January 2014 to March 2015 the general topic of mathematical practices in relation to the astral sciences. The methodological questions we raise here were not directly addressed in that project but its research helped us develop a new awareness to certain features of astronomical tables. For instance we now pay closer attention to the kind of numbers and the kind of arithmetical operations astronomers used. Likewise we began to see more historically credible ways to consider numerical tables as strings of numbers manipulated in particular ways by actors. Finally in June of 2015 we organised a workshop at the Paris Observatory, *Analysing and editing numerical tables from ancient astral sciences*, which is at the root of the present proposal.

Proposed research: how to create the necessary methodological shift?

A bottom up approach based on creative international collaboration

The purpose of TAMAS is twofold:

1. to build collectively a set of editorial and analytical tools for ancient astronomical tables which enables us to extract the different layers of information contained in these tables;

2. to prepare a book for publication on the methodological questions raised in the shaping of these tools in the context of specific case studies.

By building collaboration among specialists of a wide diversity of sources for the ancient astral sciences TAMAS will make a significant, original contribution to the history of sciences.

It is essential for us that this methodological effort is made cooperatively by scholars specialised in sources written in different ancient languages. First because it is already known that tables, parameters, computation practices, etc. circulated all across Eurasia in the pre-modern world and we should prepare now the tools which will enable future historians to address with precision these circulations [Husson M. and Montelle C. (eds.) (2014)]. Second because this effort will be rewarded by the flexibility and robustness of the tools we will create mainly in a bottom up fashion. Third because we consider that every research in the history of the ancient sciences which help attenuate the too strong cultural wholes like “Chinese science” or “Indian science” or “European science” built in the 19th century mainly along languages boundaries of the sources is healthy for the discipline in general.

We propose to untangle the set of issues we are facing in two main types of questions: the first points in the direction of corpuses of tables and their edition. The second points in the direction of the numerical content of tables and the tools to analyse them. Obviously this distinction reflects directly the fact mentioned above that we have today a growing access to two new resources: manuscript databases and computation power. Note also that the distinction echoes the two main outcomes of the survey type of analysis: the creation of corpuses of tables, the ability to statistically model them with modern mathematical tools. Organising the work along these two questions is appropriate if we want to take the best possible advantages of previous research and new resources in the field. Yet we are also aware that it is ultimately in the articulation of these two aspects that we will be able to create the methodological shift needed to deepen our understanding of ancient astral sciences traditions: the tools to analyse the numerical content of tables will be more accurate and powerful if they can rely on cleverly built tables databases and reciprocally the tables databases will be more refined if they can rely on insights given by historically sensible recomputation tools.

The complexity of these questions makes inappropriate a purely top down and abstract approach. This is why we tackle them by putting together and discussing case studies from our own area of expertise rather than by trying to specify a priori, from an armchair analysis, what the characteristic of a good astronomical tables database should be. Moreover apart from being heuristically more efficient, we believe that this mainly bottom up approach will produce flexible answers to our problems which will in turn be more likely to evolve as our understanding of the sources grows.

Shaping efficient research questions

As a consequence we will develop briefly the questions surrounding the edition of corpuses of tables and the questions contiguous to the analysis of their numerical content drawing freely from instances discussed during the June 2015 workshop by various members of the proposed project.

A first set of question relates to the edition of corpuses of tables, they include:

- What type of database should we design in order to “edit” ancient astronomical tables in the context of the digital humanities? How to account for the table layouts, the different types of numbers, the different types of errors and variants between copies of the “same” work?
- How to account for the different hands in the manuscripts? The mark of uses? The specific collection of tables assembled in one manuscript? The other non-tabular texts which may be found in the same manuscript?
- How to account for the eventual cohabitation of several manuscripts containing astronomical tables in the library of the same historical actors be it an individual or an institution? How to handle large traditions which may contains hundreds of testimonies for the “same” set of astronomical tables? How to account for the situation of one of these testimonies in relation to the whole tradition?

- How to account for the diffusion of a set of tables in their temporal, geographical and sociological dimensions? How to account for the reconfigurations and variations which inevitably occur in the course of such circulations.

A second set of question relates to the analysis of the numerical aspects of astronomical tables, they include:

- When analysing the numbers in the tables, how to articulate the modern computation power with the necessary attention to the actual computation practices of the actors? To what extent and for what purposes can we rely on modern “real numbers” and modern function in our recomputation of tables? In which cases and for what type of inquiry should we be more faithful to the actors’ numbers, arithmetical operations and trigonometrical procedures?
- When such accuracy is required how can we build tools which enable us to represent the actors’ algorithms inside a digital computer? How to tackle the implicit and tacit component of the actors’ computation procedures when implementing them?
- What are the potential uses of statistical tools in exploring the noise created by our recomputation? How do they match with intuition build with other modern device to represent data likes graphs or array of numbers? What sort of statistical tests could be useful in order to asses if a particular set of errors contains symmetries, or to determine the value of an underlying parameter in a table, or test a dependency between tables, or explore if rounding is dominant other truncation in a specific set of computations?
- For what sort of questions should we tend toward the uses of general tools working for a large class of tables and for what sort of questions should we rely on more flexible and *ad hoc* analysis devices?

These questions and other related ones will be tackled in the proposed project and we began this work during the June 2015 workshop.

Design original collaboration and publication formats

Finally issues concerning the way to publish this new type of research will also be addressed by *TAMAS*. In astronomical tables surveys only the results of the analysis are published. As a matter of fact it is difficult to publish in a book or a paper the source codes or the spreadsheets employed to unravel such or such aspects of an astronomical table. New standards of scientific publications, new ways to share and quotes each other works and contributions, will be defined and adapted from those already in use in hard sciences and in the open source community, so that scholars, journal and book editors can cooperate fruitfully in a safe and stimulating environment. Discussion on these issues were also organised during the June 2015 during a round table with the participation of the editors of two key journals in the field of history of astronomy: James Evans for the *Journal for the History of Astronomy* and Nathan Sidoli for *SCIAMVS*.

Expected outcomes: An international collective book and an intelligent tables database

Tables database: an innovative edition and mathematical analysis reference tool

Our first aim is to build common tools which will be useful in each of our fields of expertise. These tools will take the form of intelligent databases. We intend to build them in a bottom up and ordered way in two layers which will be progressively enriched and interconnected.

Situating the tables in their tradition: Astronomical parameters and computation routines

The first layer of the database will contains:

- A. Parameters and key numbers values
- B. Ideal computation routines which allow generating ideal astronomical tables from any appropriate parameters in A.

Astronomical tables are often built around key numbers which allow to identify and to recompute them quickly. For instance the value for the declination of the ecliptic is a key number for a solar declination tables; The maximum equation of the sun and the sun eccentricity are key numbers for a solar equation table etc. These numbers were used as hints in the survey literature to classify tables. By idealised computation routines we mean routines which rely on modern numbers and function to reproduce

ancient astronomical tables. For instance a solar declination table can be modeled by the following function $\delta = \arcsin(\sin(\lambda) \sin(\varepsilon))$ where λ is the longitude of the Sun at any time of the year and ε the obliquity of the ecliptic. A and B will work together as a tool helping the historian to quickly identify the tables they are faced with and the tradition to which it belongs. It stores in a dynamic way some of the results obtained by the survey type of studies. On the long term this database will also be useful for other actors in the field as it would provide a curator for instance with a reliable information when they catalogue a manuscript containing astronomical tables. This first layer of the database can be rapidly compiled to contain representative information which would justify it to be made publicly available.

Analysing actors textual and mathematical practices: contextualised editions and computations

The concept

The second layer of the database will provide a more contextualised, closer to the manuscript sources type of information. It will be of use to design new ways to explore and edit astronomical tables as well as to analyse in a more refined manner the textual and mathematical practice linked to them. It will be longer to compile and more experimental. The number of extent manuscript containing astronomical tables in the Chinese, Sanskrit, Arabic and Latin sources is enormous: the orders of magnitudes are in thousands for the Latin sources, hundreds of thousands for the Arabic sources and probably a million for the Sanskrit sources. Our aim thus will be to obtain proof of concept for this layer by showing its efficiency on a limited portion of the sources. This second layer will contain:

- C. Diplomatic transcription of tables
- D. Tools to generate different dynamic “editions” of the tables in order to explore the database
- E. Contextualised computation routines to turn the tables database into a computation tool

In C we intend to store and encode diplomatic transcription of tables as they are found in the manuscripts. The layout of the manuscript will be respected; the distribution of the tables in the manuscript on different folios will be conserved. The type of numbers and units will be kept, the scribal and computing errors, trace of uses, marginal notes, various hands also. Codicological and palaeographical information about the manuscript will be encoded as well in C. This layer of the database will be useful in studying the textual practice of astronomers and will also be the base on which D and E will rely. D will propose tools to explore C so as to allow the production of “dynamic” edition. Selecting a particular set of manuscripts and a particular table the user will be able to generate an edition and a critical apparatus from these testimonies. They will be able to choose the way this edition is generated: which stemmatic methods they prefer, which base manuscript, etc. In the case of large corpus of tables this will allow to explore a tradition from the perspective of various contexts. One could for instance compare the Alphonsine astronomy in Cracow to the Alphonsine astronomy in Vienna in the 15th century. The computation routines of E will be programmed with the same software than those of B (scilab and Excel) so as to be interoperable with them. By contextualised computation routines we mean that they should respect the actors’ type of numbers, their way to perform arithmetical and trigonometrical operations with them, their way to interpolate, round and truncate. In itself this portion of the database will be a very useful tool also for the history of mathematics as it will embody various cultures of computation in the astral sciences and allow tracing overlap, transmission and evolution between them. Astronomical tables were computing devices. E is there to transform the data in C into these computing devices in an historically sensible way. With C and D one will be able to compare different sort of sine tables, with E one will be able to compare not only the sine tables but also the sine values they produce.

Obtaining proof of concept: reinforcing the team with a Postdoctoral student

An initial version of C and D is currently being developed inside the *HAMSI* project for the Sanskrit sources. Our aim in *TAMAS* will be to extend this work by integrating astronomical tables coming from Latin, Arabic or Chinese sources and adjoining to the tables (C) and the edition tools (D) the computation routines (E) which makes tables alive as computing devices. As we’ve said above the scope of the source is too important to envisage now more than a proof of concept on some specific subsets of them. Hence we’ll be working in two specific directions.

First we want to show that C and D can be used as an “edition” tool for specific tables set from different traditions. Thus in addition to the edition of a Sanskrit tables set which will be completed inside the *HAMSI* project within the next two years we intend to edit also an important and so far little studied set

of tables in the development of the Alfonsine corpus the *Tabule magne* of John of Lignières (1325, Paris). The *Tabule magne* were compiled at a time where the type of numbers used in astronomy were evolving in Europe and the different manuscripts copies of the set testify this evolution. Moreover some tables of this set are double entries. Hence the *Tabule magne* present interesting challenges for the database in a manageable context where the number of manuscript to be considered is reasonable.

Second we intend to show that C and D can be used to explore cross-culturally a particular type of tables. In this purpose we will prepare a cross-cultural database of sine tables. We've chosen this specific type of tables because they are fundamental to second millennium astral sciences all across Eurasia. Moreover they represent a small but diverse and interconnected subset of our sources on which most of the technical issues we need to tackle for the general database will appear in a situation where they can be handled.

The computation routines developed in E will be chosen so as to operate on the tables included in C and D. For instance 14th century routines for manipulating the *Tabule magne* will be implemented, or the sine tables from the various traditions will be accompanied by the appropriate computation routines for instance, actors' linear or second order interpolation to generate non-tabulated entries.

It is in this context that a Postdoctoral student will be a key contribution for the success of *TAMAS*, bringing his own set of sources he will be able to devote himself to the technical elaboration of these layers of the database in close connection with the computer engineer of the project.

A new reference: an international collective book

The second main output of this project will be the publication of a collective book presenting case studies around which we explore the methodological challenges surrounding the analysis of astronomical tables. This book will be an important contribution to the field, not least for the wide range of cultures it will cover. Although the database will focus primarily on traditions emerging with and after the formation of Arabic mathematical astronomy, the book will include studies of earlier traditions including the Cuneiform and Greek material. More significantly, the book will be first publication of this breath that deals with methodological issues regarding the analysis of astronomical tables. We hope that it will become the new standard reference for the discipline [van Dalen, B. (1993)]. Work on this second aspect also started during the June 2015 workshop where we examined together different case studies brought by the members of the team. We are now ready to prepare draft chapters to be discussed in detail at our next general meeting. We intend to present the publication in 2017 during a dedicated symposium organised at the next international conference for the history of science in Rio de Janeiro.

Getting things done: a proposed time line

Members of the team are part of different scientific institutions on the five continents. The success of the project thus requires a simple and well-defined organisation and time line. This schedule will allow each member to adhere to the common objectives and have a clear vision of what his own contribution will be. Modern communication tools greatly facilitate collaboration across such large geographical distances, especially when the goal involves the gradual construction of an online database. It is nonetheless essential that the team come together regularly at the same place over a sufficiently long period of time (at least one week) so as to allow for deepened scientific exchanges. Such meetings will take place every six months at the Paris Observatory. They will alternatively convene the whole team plus eventual exceptional participants during the summers, and a smaller scientific committee during the winters.

The first of these meeting was held in June 2015 at the Paris Observatory and provided a productive occasion to explore in depth the questions and research we are describing in this proposal.

By January 2016: Material for the first layer of the database (A and B) will be assembled and a meeting of the scientific committee will be held to tackle two points. First, work with a programmer will begin so that the content of the first layer of the database can be made available, first to the team by June 2016 and then to the wider public by the end of 2016. Second, the scientific committee will refine the book proposal for the project and will organise the scientific aspects of the summer 2016 workshop.

In June 2016: The whole team will convene at the Paris Observatory. The main task for this meeting will be a thorough, collective editorial review of each of participant's contribution to the collective book.

Some time will be also devoted discussing the project's database. Its first layer (A and B) will be demonstrated and discussed; a midterm diagnosis will be made of the second layer of the database (C, D and E).

In January 2017: With final versions of each member's contribution for the collective book at hand, a meeting of the scientific committee will be held to prepare the final version of the book and write a common introduction. The first layer of the database (A and B) will be made public and work will begin with a programmer on the next layer of the database (C, D and E) so as to make them available to the team by the summer 2017 and to the public by the end of 2017. The scientific committee will also organize a dedicated symposium to present the team's work to the International Conference for the History of Science.

Summer 2017: Symposium in Rio de Janeiro at the International Conference for the History of Science. Second layer of the database (C, D and E) is made available to the team.

December 2017: The scientific committee will meet to make public the second layer of the database (C,D and E) and discuss further development of the project.

Short bibliography

Chabás J. and Goldstein B.R. (2012), *A survey of European astronomical tables in the late middle ages*, Brill

van Dalen, B. (1993) *Ancient and Mediaeval Astronomical Tables: Mathematical Structure and Parameter Values*. Utrecht: Utrecht University

Husson M. and Montelle C. (eds.) (2014) *Transmission of Arabic astronomical tables in Chinese, Latin and Sanskrit*, SUHAYL special issue, (13)

Kennedy, E. S. (1956) *A survey of Islamic Astronomical tables*, Transactions of the American Philosophical Society, 46.2. Philadelphia

Pedersen, O. (1974), *A survey of the Almagest*, Odense

Pingree, D. (1956), *Sanskrit astronomical tables in the united state*; Transactions of the American Philosophical Society, 58.3. Philadelphia

Toomer, G. J. (1968) "A survey of the Toledan Tables", *Osiris*, 15:5-174

Matthieu Husson (CNRS, SYRTE-Observatoire de Paris)