Astroinformatics: The Importance of Mining Astronomical Data in Binary Stars Catalogues

A.A Abushattal *, A. A Alrawashdeh, and A. F. Kraishan

Department of Physics, Al-Hussein Bin Tala University, P. O. Box 20, 71111, Ma'an, Jordan.

Abstract

The field of Astroinformatics offers exciting new perspectives on astronomical discovery through the implementation of advanced data mining procedures. Data deluges transform research practices and methodologies across various scientific disciplines, including day-to-day astronomical research. It is essential to use innovative algorithms and methods to process astronomical data and its variety. Descriptive Data Mining was used in this study to clarify the importance and effectiveness of obtaining common data between three binary star catalogs. These catalogues are The Ninth Catalogue of Spectroscopic Binary Orbits (SB9), The Sixth Catalog of Orbits of Visual Binary Stars (6COVBS), and The Fourth Catalog of Interferometry Measurements of Binary Stars (4CIMBS). We collect scattered data from the Ninth Catalog in its latest edition in 2021, which contains astronomical information for approximately 4021 binary systems. Then we search for the orbits of these binary systems in the 6COVBS to calculate the physical and the orbital properties with high accuracy. After that, we use the 4CIMBS to look for new observations of these stars in 66,225 resolved stars in its latest edition 2020 to calculate new orbits. As a result of this research, we have found about 600 standard systems among these catalogues, which are valuable data to calculate many physical properties of such binary stars, starting from individual masses, by the combination of the spectroscopic orbital solution with the visual orbital solutions. Furthermore, calculate the orbital parallax for each system with high accuracy compared with those from space missions such as Gaia and Hipparcos give us a new and essential method to verify the validity of the data from those satellites.

Keywords: *astroinformatics, aata Mining, binary Star catalogues, visual and spectroscopic binary star*

1. Introduction

Astroinformatics, which covers a variety of multi-disciplinary applications of e-Astronomy, is now classified as a new academic research field by data-oriented astronomy. There are many computational methods and software for working with astronomical surveys and catalogues. These include data modelling, data mining, data access, digital astronomical database, machine learning, statistics, and other software (Borne, 2009, Brescia et al., 2017, Siemiginowska et al., 2019, Vavilova, 2016).

A binary star consists of two stars whose components are gravitationally bounded, so they orbit the same centre of mass. A fixed movement around the centre of mass can be considered as a primary movement, while a relative movement (the secondary movement) can be considered a secondary movement. The majority of the observed stars appear to be binary or belong to multiple systems with three to four components, according to estimates (e.g., Al-Wardat et al., 2017, Duquennoy & Mayor, 1991, Raghavan et al., 2010). Astrophysics and Astrodynamics are interested in binaries and multiple stars for many reasons. The mass of stars plays a fundamental role in studying their evolutionary tracks. As well as obtaining information on sizes, parallaxes, and orbital elements it is possible to get information on other physical parameters of interest, including aspects such as luminosity and the orbital elements (Al-Tawalbeh et al., 2021, Docobo et al., 2018, Hussein et al., 2022).

Many observatories equipped with large refractors and telescopes were constructed around the world at the beginning of the 20th century, especially in Europe and North America, for the observation of binaries. Due to these various research lines, double stars have drawn the attention of many relevant astronomers. Traditional classifications for the binaries include visual, spectroscopic, and eclipsing binaries, based on the

*Ahmad.Abushattal@ahu.edu.jo, Corresponding author

doi:https://doi.org/10.52526/25792776-22.69.2-251

methods used to discover and study them. Four methods are used To establish binary nature: a direct visual observation through an eyepiece, a photographic camera (traditional camera or CCD), or speckle interferometry using modern high resolution techniques. There are other cases when the binary cannot be resolved optically, even with large telescopes. However, other methods are possibly using the Doppler-Fizeau effect (spectroscopic binaries) to observe the periodic variation of spectrum lines. Eclipses are frequently accompanied by periodic variations in the magnitude of the stellar companion (Abushattal et al., 2019a, Docobo et al., 2017, ?).

Furthermore, binary systems serve as a "shop window" through which many physical processes can be observed : mass loss, mass exchange, variability of components, relativistic processes, the Nova phenomenon, the Flare phenomenon, X-ray Binaries, Wolf-Rayet components, etc. From a dynamical perspective, these include perturbations, the discovery of dark components, such as brown stars and exoplanets, orbit calculation methods, etc (Abushattal et al., 2019b, Taani et al., 2019a,b, 2020). Using two or three different techniques, it has been possible to study a number of binaries thanks to precision devices attached to large telescopes.

The purpose of this paper is to highlight the importance of creating a common database across different catalogues. That will enable us to compare data about binary stars that can serve as a starting point for determining their physical and orbital characteristics will assist in answering questions about the formation and development of stars and searching for Earth-like planets around Sun-like stars.

1.1. The Ninth Catalogue of Spectroscopic Binary Orbits (SB9)

Batten and collaborators continue their series of compilations of spectroscopic binary orbits over the past 55 years with the Ninth Catalogue of Spectroscopic Binary Orbits http://sb9.astro.ulb.ac.be. The new Catalogue contains the orbits for 2386 systems as of 2004. In addition, three straightforward applications are presented, highlighting some differences between this catalogue and its predecessors: (1) Completeness assessment: period distribution of SB1s and SB2s, (2) Shortest periods across the H-R diagram; (3) Relationship between periods and eccentricities (Pourbaix et al., 2004). Several contributors from around the world contribute to the compilation of SB9. Data from new orbits should be contributed directly by the authors. In SB8 there was more information included for each new system in the notes, but it will be less in SB9 due to the growing volume of data. In contrast, SB9 provides multiple orbits and individual radial velocities for each system (depending on the system's orbits). ADS bibliographic service is linked to references.

A new automatic grading system is in the process of being developed, which will allow for the entry of grades for new orbits. The grades of old orbits are listed as (5 being the best, 1 being the worst). Some elements (such as centre-of-mass velocity V_0) of double-lined binaries are listed only if they were determined separately for primary and secondary components, since the elements are meant to reflect the actual Keplerian motion of stars rather than the radial velocity curve that they are derived from.In the WEB page of SB9, you can search for your object of interest by identifying it in common catalogues (like HD, BD, HIP), by bibcode, or by coordinates. Enter identifier and number, separated by space, for uncommon identifiers (like nearby stars or cluster members).

1.2. The Sixth Catalog of Orbits of Visual Binary Stars (6COVB)

Over the past three decades, the field of visual double star work has undergone revolutionary changes thanks to the advent and maturation of interferometry. A large telescope equipped with speckle interferometry can produce astrometric results that are much more accurate (down to milliarcseconds) than those available from micrometry and other visual methods. At the time of the Fourth catalog publication, only a few orbits were calculated where Speckle played a significant role, despite Speckle being available since 1970. Many orbits now include speckle results exclusively, despite its popularity growing in the 1980s. In 1983, speckle was at its peak, but now long-baseline interferometry and Navy Precision Optical Interferometry are perhaps in a similar stage of maturity; multi-aperture telescope arrays are being used to observe a growing number of binaries, once considered exclusively spectroscopists' property. In the coming decades, the distinction between spectral and visual regimes will become less significant as new interferometers improve in magnitude sensitivity. In catalogs such as this one, only a subset of a binary's elements will be published, as spectroscopic and visual "combined solutions" become more common.

Creating a new catalogue requires grading each orbit. The Fourth Catalog grading scheme assessed

doi:https://doi.org/10.52526/25792776-22.69.2-251

orbital coverage, the number of observations, and the overall quality of observations on a numerical scale (1 = definitive, 5 = indeterminate). They graded observers numerically based on their qualitative assessment of individual observers and their accumulated experience (Matson et al., 2020).

1.3. The Fourth Catalog of Interferometry Measurements of Binary Stars (4CIMB)

The Georgia State University center for High Angular Resolution Astronomy (CHARA) began tabulating binary star observations made with their speckle camera using the speckle interferometry technique in 1982 using the Fourth Catalogue of Interferometric Measurements of Binary Stars. As time progressed, the Speckle catalog included all published astrometric and photometric data from high-angular-resolution methods for binary stars (and single stars observed by duplicate surveys). The results from various infrared speckle or imaging surveys were also included, even though some are not really considered high resolution. The catalogue includes 24 bands of right ascension. While the catalog is updated regularly, statistics are only updated occasionally. In addition to the astrometric data, this catalogue contains 73,894 photometric observations

2. Methodology

In this work, a large amounts astronomical data are processed and collected from various Spectroscopic and visual catalogues through computer programs. Then sort and identify the commonalities among them and arrange them so that they are easily accessible. In order to benefit from them and to make them accessible to researchers in the field of astrophysics and specialists in studying binary stars.

Ground-based telescopes and space observatories collect a vast amount of data over the electromagnetic spectrum. In this article, we introduce Astroinformatics as a new data-oriented approach and advanced methodology for processing astronomical surveys and catalogues using astroinformation resources. Interoperability between different astronomical archives and data centres allows easy access to astronomical data. Figure 1 illustrates the importance of astroinformation as a link between data science and astronomy.

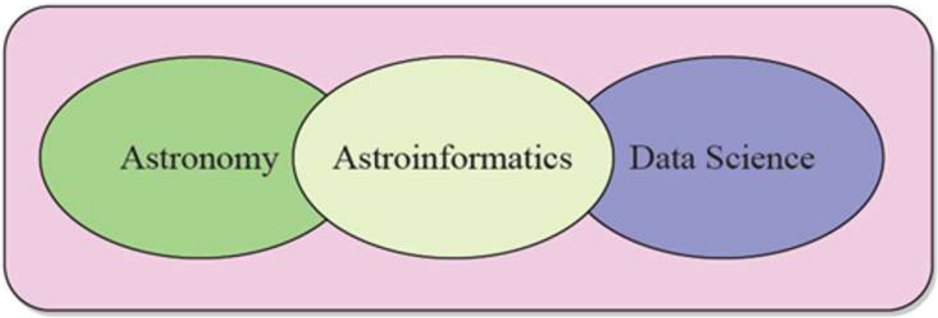

Figure 1. In Astronomy and Data Science, Astroinformatics acts as a bridge.

The Fourth Interferometric catalogue is available in plain text and gzipped plain text formats. In each system, there are two parts: an identification line containing catalogue numbers, followed by individual measurements sorted by observation date. An ID line format change has been made to accommodate longer names. Observations are accompanied by acronyms linked to reference files. Links to notes files are also included with the notes. Additionally, it provides links to pairs with visual or astrometric orbits published in the Sixth Orbit catalogue. WDS, Interferometric, and Orbit catalogues all use the same notes file. In the notes file, additional systems will be included in addition to those in this catalogue. To facilitate faster linking to the files, the notes file was divided into 24 smaller ones because it was much larger than the measurements file. (Hartkopf et al., 2004).

In comparison to prior editions, SB9 is capable of storing unlimited stellar identifiers per system, although important catalogues (HD, HIP, etc.) still remain the preferred sources for stellar identification. To match the level of precision used by other catalogues, this catalogue was built with a different epoch and equinox than 1900.0. Declination and Right Ascension are now given to the hundredth of a second. This catalogue also provides information about uncertainties associated with orbital parameters. NASA Astrophysics Data System (ADS) specifies an orbit's bibliographic reference by its 19-character bibliography code ("bibcode"). In the absence of a bibcode, a special code indicates that the reference appears in the Notes section of

doi:https://doi.org/10.52526/25792776-22.69.2-251

the Catalogue. Using SB9's web interface, you can view specific orbits at your convenience. Both catalog identifiers and coordinates can be used to search for systems. The selection criteria are met by several systems, and users are asked to pick one. The user can choose from several orbits. To help you choose among the orbits, a list of publication years is provided. HTML links are used to display the displayed information. Directly connecting to ADS makes it easy to retrieve the abstract, coordinates, spectral type, apparent magnitude, identifiers, and orbital parameters of a paper. The interface can also automatically generate an orbit plot (if actual observations are available). The corresponding figure has a link to a PostScript version. On the SB9 main page, researchers can also download a compressed version of the SB9 database if they are interested in previewing the properties of a sample of these systems rather than browsing one orbit. It is virtually impossible to limit the distribution of the database when combined with other public access catalogs through Unix-like tools like sort and join, as well as scripting languages like Python and Awk (Pourbaix et al., 2004).

The Sixth Catalogue of Orbits of Visual Binary Stars contains about ten thousand orbits of binary stars. Observations are the ultimate gauge of a model's accuracy, and scientists use them to test predictions. A couple shortcomings in the original format were addressed in March 2005 by extensively modifying the Sixth Orbit catalogue. The first request was that published formal errors for orbital elements be included when they were available in the catalogue. Recent developments in interferometry, such as long-baseline interferometry, have also led to shorter periods and smaller semi-major axes of orbits. Because of this, both formal errors and higher precisions were accommodated in the master file. It is now possible to quote periods in centuries, minutes, milliarcseconds, microarcseconds, and arcseconds, as well as T0 in Julian dates and Julian dates, as well as fractional Besselian years, by using the flags added to the period and semi-major axes columns. In order to decrease the width of the web catalogue, two lines are used per orbit. In addition to the errors, some catalogue names (such as HD and Hipparcos) and other items are stacked along the bottom of the page (Muller et al., 2006).

Therefore, we have used astronomical data science and its specialized programs to process the data in each of the previous three catalogues. Then, we worked on linking them with each other, searching for the stars shared between those catalogues, and forming a unified database containing the visual spectroscopic binaries. The figure 2 represents the Summary of this process.

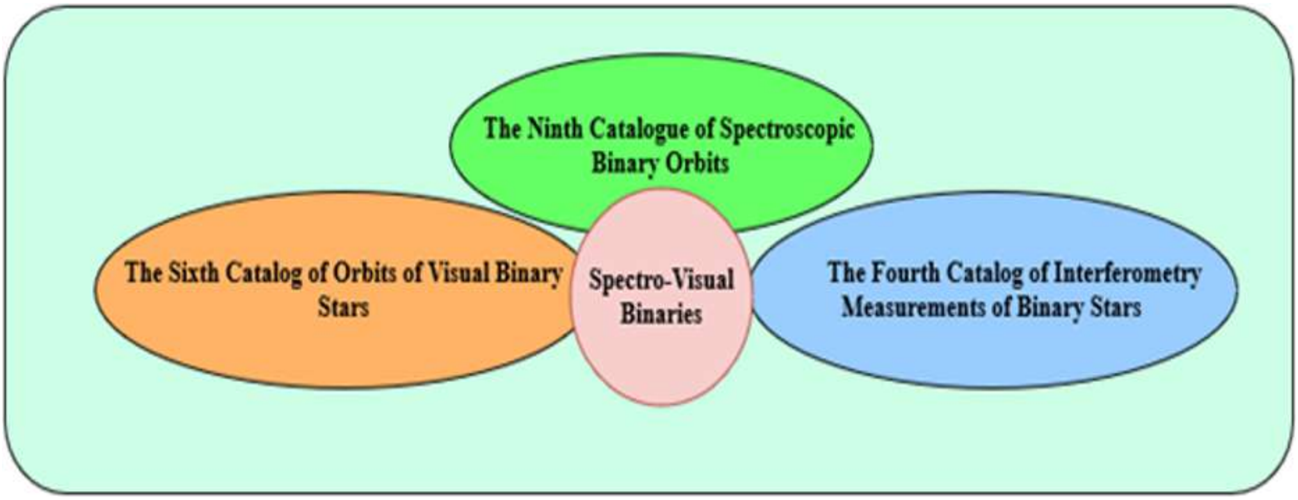

Figure 2. In all catalogues, the common Spectro-visual stars could be found.

3. Results

As a result of this work, two important sciences are brought together: observational astronomy, which studies and monitors many astronomical objects and stores their data, as well as astronomical information, which processes and arranges that data, making it easier for researchers to reach their goals. Research results can be summarized as follows: finding a field of knowledge based on the link between astronomical data, data science, and precision-visual binaries. We combined data from the three catalogues; the Ninth catalogue of Spectroscopic Binary Orbits (SB9), the Sixth catalogue of Orbits of Visual Binary Stars (6COVBS), and the Fourth Catalog of Interferometry Measurements of Binary Stars (4CIMBS). After applying the research

doi:https://doi.org/10.52526/25792776-22.69.2-251

method, more than 600 common systems have been found in the previous three catalogs. These systems provide the starting point for researchers working on binary stars to determine their physical and orbital properties accurately. The data will be published on the official website of Al-Hussein Bin Talal University's, Department of Physics.

4. Conclusions and Future Work

Our study involved processing binary star catalogues with big data programs and identifying spectroscopic binary stars as a common database. Therefore, it is necessary to work on finding joint research groups specializing in data science and observational astronomy that analyze these observed data, which are in different astronomical catalogues, and prepare them for use in the various astrophysical sciences such as observational astronomy and astrobiology.

Acknowledgements

Thanks to Gor Mikayelyan, the Scientific and Local Organizing Committee of the International Conference "Space Sciences and Technologies" at Byurakan Astrophysical Observatory (BAO).

References

Abushattal A. A., 2017, PhD thesis, Universidade de Santiago de Compostela

Abushattal A. A., Docobo J. A., Campo P. P., 2019a, The Astronomical Journal, 159, 28

Abushattal A., Al-Wardat M., Taani A., Khassawneh A., Al-Naimiy H., 2019b, in Journal of Physics: Conference Series. p. 012018

Al-Tawalbeh Y. M., et al., 2021, Astrophysical Bulletin, 76, 71

Al-Wardat M., Docobo J., Abushattal A., Campo P., 2017, Astrophysical Bulletin, 72, 24

Borne K. D., 2009, arXiv preprint arXiv:0909.3892

Brescia M., Djorgovski S. G., Feigelson E. D., Longo G., Cavuoti S., 2017, Astroinformatics

Docobo J. A., Griffin R. F., Campo P. P., Abushattal A. A., 2017, Monthly Notices of the Royal Astronomical Society, 469, 1096

Docobo J., Balega Y., Campo P., Abushattal A., 2018, Double Stars Information Circular, 196, 1

Duquennoy A., Mayor M., 1991, Astronomy and Astrophysics, 248, 485

Hartkopf W. I., Mcalister H. A., Mason B. D., 2004

Hussein A. M., Al-Wardat M. A., Abushattal A., Widyan H. S., Abu-Alrob E. M., Malkov O., Barstow M. A., et al., 2022, The Astronomical Journal, 163, 182

Jack D., Hernández Huerta M. A., Schröder K.-P., 2020, Astronomische Nachrichten, 341, 616

Matson R., Williams S., Hartkopf W., Mason B., 2020, United States Naval Observatory, Washington, DC

Muller R., Cersosimo J., Rosado-de Jesus I., Cotto D., Miranda V., Martinez C., Centeno D., 2006, Journal of Double Star Observations, 2, 138

Pourbaix D., et al., 2004, Astronomy & Astrophysics, 424, 727

Raghavan D., et al., 2010, The Astrophysical Journal Supplement Series, 190, 1

Siemiginowska A., Kuhn M., Graham M., Mahabal A. A., Taylor S. R., 2019

Taani A., Abushattal A., Mardini M. K., 2019a, Astronomische Nachrichten, 340, 847

Taani A., Karino S., Song L., Mardini M., Al-Wardat M., Abushattal A., Khasawneh A., Al-Naimiy H., 2019b, in Journal of Physics: Conference Series. p. 012029

Taani A., Khasawneh A., Mardini M., Abushattal A., Al-Wardat M., 2020, arXiv preprint arXiv:2002.03011

Vavilova I., 2016, Odessa astronomical publications, pp 109–115

doi:https://doi.org/10.52526/25792776-22.69.2-251