USING SI UNITS IN ASTRONOMY

A multitude of measurement units exist within astronomy, some of which are unique to the subject, causing discrepancies that are particularly apparent when astronomers collaborate with other disciplines in science and engineering. The International System of Units (SI) is based on a set of seven fundamental units from which other units may be derived. However, many astronomers are reluctant to drop their old and familiar systems. This handbook demonstrates the ease with which transformations from old units to SI units may be made. Using worked examples, the author argues that astronomers would benefit greatly if the reporting of astronomical research and the sharing of data were standardized to SI units. Each chapter reviews a different SI base unit, clarifying the connection between these units and those currently favoured by astronomers. This is an essential reference for all researchers in astronomy and astrophysics, and will also appeal to advanced students.

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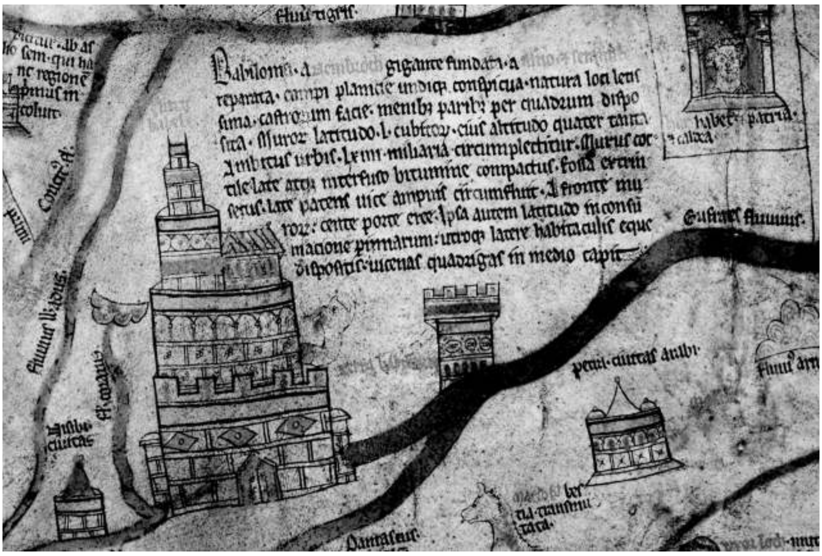
Preface

Other than derogatory comments made by colleagues in university physics departments on the strange non-standard units that astronomers used, my first unpleasant experience involved the *Catalog of Infrared Observations* published by *NASA* (Gezari *et al*., 1993). In the introduction, a table is given of the 26 different flux units used in the original publications from which the catalogue was compiled – no attempt was made to unify the flux measures. The difficulties of many different ways of expressing absolute and apparent flux measures when trying to combine observations made in different parts of the electromagnetic spectrum became all too apparent to me when preparing a paper (Dodd, 2007) for a conference on standardizing photometric, spectrophotometric and polarimetric observations. This work involved plotting X-ray, ultraviolet, visible, infrared and radio frequency measurements of selected bright stars in the open cluster IC2391 as spectra with common abscissae and ordinates. Several participants at the conference asked if I could prepare a 'credit card' sized data sheet containing the conversion expressions I had derived. As is usually the case, I was otherwise engaged at the time in comparing my newly derived coarse spectrophotometry with a set of model stellar atmospheres, so the 'credit card' idea was not acted upon. However, the positive response to my paper did make me realize that there was a need in the astronomical community for a reference work which, at the least, converted all the common astronomical measurements to a standard set. The answer to the question 'Which set?' is fairly self evident since it was over 40 years ago that scientists agreed upon a metric set of units (Le Système International d'Unités or SI units) based on three basic quantities. For mass there is the kilogram, for length the metre and for time the second. This primary group is augmented by the ampere for electric current, the candela for luminous intensity, the kelvin for temperature and the mole for amount of substance. From these seven it is relatively easy to construct appropriate physical units for any occasion: e.g., the watt for power, the joule for energy or work, the newton for force and the tesla for magnetic flux density.



The thirteenth-century *Mappa Mundi* illustration of the Tower of Babel. (© The Dean and Chapter of Hereford Cathedral and the Hereford Mappa Mundi Trust.)

It is possible to express even the more unusual astronomical quantities in SI units. The astronomical unit, the light year and the parsec are all multiples of the metre – admittedly very large, and non-integral, multiples from ∼150 billion metres for the astronomical unit to ∼31 quadrillion metres for the parsec. Similarly, one solar mass is equivalent to $\sim 2 \times 10^{30}$ kilograms and the Julian year (365.25 days) to ∼31.6 million seconds. So in each of these cases we could use SI units, though quite obviously many are unwieldy and a good scientific argument for using special astronomical units may readily be made.

In many areas of astronomy, the combination of research workers trained initially at different times, in different places and in different disciplines (physics, chemistry, electrical engineering, mathematics, astronomy etc.) has created a Babel[1]-like situation with multitudes of units being used to describe the same quantities to the confusion of all.

Astronomers participate in one of the most exciting and dynamic sciences and should make an effort to ensure the results of their researches are more readily available to those interested who may be working not only in other branches of astronomy but also in other fields of science. This can be done most readily by using the internationally agreed sets of units.

[1] The story of the Tower of Babel is set out in the Hebrew Bible in the book of Genesis, chapter 11, verses 1–9, and relates to problems caused by a displeased God introducing the use of several different, rather than one spoken language, to the confusion of over-ambitious mankind. A depiction of the Tower of Babel that appears on the thirteenth-century *Mappa Mundi* in Hereford Cathedral Library is shown in the reproduction above.

However, stern, but sensible, comments from the reviewers of the outline of the proposed book, plus a great deal more reading of relevant astronomical texts on my part, has led to a better understanding of why some astronomers would be reluctant to move away from non-standard units. This applies particularly in the field of celestial mechanics and stellar dynamics, where the International Astronomical Union approved units include the astronomical unit and the solar mass. However, this in itself should not act as a deterrent from adding SI-based units alongside the special unit used, with suitable error estimates to illustrate why the special unit is necessary.

In a recent book review in *The Observatory*, Trimble (2010) admitted to appending an average of about two corrections and amplifications per page in not only the book she had just reviewed but also in her own book on stellar interiors (Hansen *et al*., 2004), and Menzel (1960) completed the preface to his comprehensive work *Fundamental Formulas of Physics* by stating: ‘In a work of this magnitude, some errors will have inevitably crept in.’

Whilst, naturally, I hope that this particular volume is flawless, I must confess I consider that to be unlikely! The detection and reporting of mistakes would prove of considerable value and, likewise, comments from readers and users of the book on areas in which they believe it could be improved would be welcome. My own experience using various well-known reference works and textbooks, to some of which I had previously assigned an impossibility of error, was that they all contained mistakes; some travelled uncorrected from one edition to the next and others in which correct numerical values or terms in an algebraic equation in an earlier edition were incorrectly transcribed to a later.

The most radical suggestions in this book are probably: a simple way of describing and dealing with very large and very small numbers; the use of a number pair of radians rather than a combination of three time and three angular measures to locate the position of an astronomical body; and the replacement of the current ordinal relative-magnitude scheme for assigning the brightness of astronomical bodies by a cardinal system based on SI units in which the brighter the object the larger the magnitude.

Writing a book such as this takes time. Time during which new values of astronomical and physical constants may become available. I have referenced the various sources of constants published before the end of 2010 that were used in the preparation of tables and in the worked examples presented. Readers are invited to substitute later values for the constants, as a valuable exercise, in the worked examples should they so wish.

In conclusion, it is important to bear in mind that the primary purpose of this book is to act as a guide to the use of SI units in astronomy and not as an astronomical textbook.

Acknowledgements

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The Bureau International des Poids et Mesures (BIPM) for permitting the use of the English translations of the formal definitions for each of the SI units and some of the tabular material contained in the 8th edition of the brochure *The International System of Units (SI)* (BIPM, 2006).[2]

The Dean and Chapter of Hereford Cathedral for permission to use a print of part of the *Mappa Mundi* that shows an imagined view of the Tower of Babel.

The Canon Chancellor of Salisbury Cathedral for permission to use their translation from the Latin of clause 35 of the Magna Carta.

Writing a book such as this has benefitted considerably from the availability of online data sources. Those which were regularly consulted included: the Astrophysical Data Service of NASA; the United States Naval Observatory for astrometric and photometric catalogues; the European Southern Observatory for the Digital Sky Surveys (DSS) and the HIPPARCOS and TYCHO catalogues; SIMBAD for individual stellar data; the Smithsonian Astrophysical Observatory for DS9 image analysis software, and many of the other databases and virtual observatory sites listed in Chapter 12.

At an individual level, the inspiration to start this work is due in part to: Mike Bessel, Ralph Bohlin, Chris Sterken, Martin Cohen and other participants at the Blankenberge conference on standardization who expressed an interest in the paper I presented there. Denis Sullivan of the School of Chemical and Physical Sciences of the Victoria University of Wellington provided the enthusiasm and logistical support to continue with this work, and with Mike Reid was responsible for improving my limited skill with LaTeX. Harvey McGillivray, formally of the Royal Observatory

[2] Please note that theses extracts are reproduced with permission of the BIPM, which retains full internationally protected copyright.

Edinburgh, provided me with COSMOS measuring machine data of the double cluster of galaxies A3266. The desk staff at Victoria University of Wellington library and the librarian of the Martinborough public library were of great assistance in sourcing various books and articles. The proofreading was bravely undertaken by Anne and Eric Dodd. To all these people I express my thanks.

My aim was to write a book that would prove of use to the astronomical community and persuade it to move towards adopting a single set of units for the benefit of all. I hope it succeeds!