1
Introduction

1.1 Variable stars

G. Jasniewicz

All stars display variations of brightness and colour in the course of their passage through subsequent stages of stellar evolution. As a rule, however, a star is called *variable* when its brightness or colour variations are detectible on time scales of the order of the mean life time of man. The variations may be periodic, semi-periodic or irregular, with time scales ranging from a couple of minutes to over a century. It is this kind of variable star which is the topic of this book. The typical time scale, the amplitude of the brightness variations, and the shape of the light curve can be deduced from photometric observation, and those quantities place the star in the appropriate class. For example, a star of the UV Ceti type typically has brightness variations (the so-called flares) of several magnitudes in an interval of time as short as a few minutes, whereas a Cepheid shows periodic variations of about one magnitude in a time span of several days. However, spectral type, luminosity class and chemical composition are complementary important spectroscopic parameters that are needed for classifying variable stars according to the *origin* of their variations.

Due to stellar evolution, a variable star discloses long time-base variations of its amplitude and of its typical duration of the cycle of variability: for a short-period binary star, variations of the period and of the times of minimum or maximum of the light curve can be explained by modifications in the mass transfer between both components; for a δ Scuti type star, a change of the period can be due to a change of the radius by the evolution of the star from the dwarf stage to the giant stage. On the other hand, for the RV Tauri type stars, the origin of the observed abrupt changes of period is still not understood.

Thus, variations on long time scales of the typical photometric parameters of variable stars give us information on the physical processes which are responsible for the observed brightness and colour variations. Therefore it is of crucial importance that astronomers undertake long-term observing programs of variable stars and also archive all photometric measurements done in the past and today.

Archiving of variable-star photometric data

Proper archiving is crucial for a complete understanding of the mechanisms of variability. Archives can also help to solve ambiguities: it can happen that period analysis on a set of data yields a period different than a previously published one, simply because the methods and the understanding of statistics of period analysis have evolved. Unfortunately, access to original data today is not a simple issue in our international astronomical community. Indeed, if a list of data is very extensive, the majority of the astronomical journals will not accept it for publication, not even in their Supplement Series. Therefore, observers themselves do archive their own data and, occasionally, make them available for public use. Thus, in order to prepare the light curves for this book, we have asked authors for their unpublished data. Not entirely to our surprise, no more than one out of every five responded positively.

We emphasize here that, in order to avoid the definitive loss of unpublished observations of variable stars, the International Astronomical Union (IAU) has asked its Commissions 27 (Variable Stars) and 42 (Close Binary Systems) to archive the photometric observations of variable stars. These Archives replace lengthy tables in scientific publications by a single reference to the archival file number, and they also contain many valuable observations which have never been used for scientific publication. M. Breger, at Vienna Observatory, was for many years the coordinator of the IAU Archives; today the conservator is E. Schmidt of the University of Nebraska at Lincoln. Electronic storage and retrieval of photometric data from the Archives can be done by communicating with the Centre de Données de Stellaires (CDS); some files can be electronically obtained free of charge from CDS. Copies of all existing files can be obtained in paper form from three archives, viz. from P. Dubois (CDS, France), from P.D. Hingley (Royal Astronomical Society, Great Britain) and from Y.S. Romanov (Odessa Astronomical Observatory). Lists of the available files in the Archives are regularly announced in the *Information Bulletin on Variable Stars* (*IBVS*, Konkoly Observatory, Budapest) and the *Bulletin d'Information du CDS* (see Jaschek & Breger, 1988). Detailed reports on the file contents are published by Breger (1988).

We also mention that several amateur associations, such as the Association Française des Observateurs d'Etoiles Variables (AFOEV), the American Association of Variable Stars Observers (AAVSO), the Royal Astronomical Society of New Zealand (RASNZ) and the British Astronomical Association (BAA) have their own archives in computer-readable form – the bulk of these data, however, are visual estimates by eye.

Variable-star monitoring programs

A large variety of observing programs of variable stars is presently in progress all over the world. An important part of all major astronomical journals is devoted to individual stars which display regular or erratic variations of brightness. Announcements of newly discovered novae and supernovae or of drastic changes in cataclysmic stars are published by the Central Bureau for Astronomical Telegrams (Brian G. Marsden) that depends on IAU Commission 6. Observations of variable stars can be quickly published by *IBVS* and, since 1995, also in purely electronic form in *The Journal of Astronomical Data* (*JAD*, TWIN Press, Sliedrecht, The Netherlands).

The importance of studies of stellar variability on long time scales has been emphasized above. Long-term observing programs of variable stars are in progress in major observatories. One such program, Long-Term Photometry of Variables (LTPV), has been operating since 1982 at the European Southern Observatory (ESO) in Chile (Sterken, 1983), with archived data at SIMBAD. This book contains several graphs made with these data ('based on LTPV data', see, for example, Fig. 2.1), the data tables can be found in Manfroid *et al.* 1991a, 1991b, 1994a, 1994b, and in Sterken *et al.* 1993a, 1993b, 1995b, 1995c. More than a few advantages and problems of coordinated campaigns and of long-term monitoring have been elucidated by Sterken (1988, 1994). The benefits of ground-based support of space observations of variable stars are obvious: in the case of very hot stars (white dwarfs, central stars of planetary nebulae, etc.), the bulk of radiated energy is at the short wavelengths and is not detectable from earth. For example, simultaneous IUE and ground-based photometric observations of the binary central star of the planetary nebula Abell 35 have strongly contributed to clarify the nature of the so-called 'Abell 35'-type objects: such binaries experience chromospheric activity as RS CVn-like binaries (Jasniewicz *et al.* 1994b); besides, the late-type giant stars in the nuclei display characteristics common to the FK Comae stars (Jasniewicz *et al.* 1987, 1994a).

The advantages of observations collected at discrete geographical longitudes are also clear because quasi-contiguous sequences of measurements can in principle be collected, and then the amplitudes of the alias periods resulting from the period searches can be significantly reduced.

The contributions by amateur variable-star observers also play an important role in the continous monitoring of variable stars; that is especially the case for cataclysmic stars and long-period variables such as the Mira Ceti type stars. In this book the behaviour of variable stars on very-long time scales is illustrated by means of light curves kindly provided by the AAVSO and by individual amateurs.

Searching for new variable stars

Several ground-based and space projects will, in the coming years, considerably increase the number of known variables. We focus on two examples, viz. the HIPPARCOS/TYCHO projects, and the search for massive compact galactic objects.

HIPPARCOS (HIgh Precision PARallax COllecting Satellite) was launched by the European Space Agency (ESA) on August 8, 1989. The HIPPARCOS mission is now accomplished, and processing of the collected astrometric and photometric data (about 100 000 measurements) is progressing.

An ambitious photometric program is the TYCHO photometric survey with the satellite HIPPARCOS. The TYCHO program involves photometric observation in two colours of about 1 000 000 stars across the sky. Photometry is based on the star-mapper signal and two detectors at effective wavelengths λ428 and λ534 nm. The two filters B_T and V_T of the TYCHO experiment differ slightly from the standard Johnson B and V filters (Mignard *et al.* 1989, see Fig. 1.1). Several thousand confirmed standard stars were used for calibrating the photometric system. Every program star was observed about 100 times during the satellite's life time (January 1990 to March 1993); thus the TYCHO project will yield a substantial number of new variable stars. However, for stars fainter than $V_T = 10$, the survey will become non-homogeneous. In using empirical detection probabilities and statistics of known variable stars, various authors (Jaschek 1982, Mauder & Høg 1987, Halbwachs 1988) have estimated the numbers of new variable stars expected to be found in the TYCHO photometric survey. According to Mauder & Høg (1987) the number of variables brighter than $B = 11$ would be at least doubled for most types of variability (see Table 1.1). Several hundred Cepheids and thousands of eclipsing binaries should be discovered by means of TYCHO. A methodological strategy for analyzing the photometric data of the TYCHO space experiment has been announced by Heck *et al.* (1988). In order to identify new variable stars, various statistical algorithms will have to be applied, especially algorithms

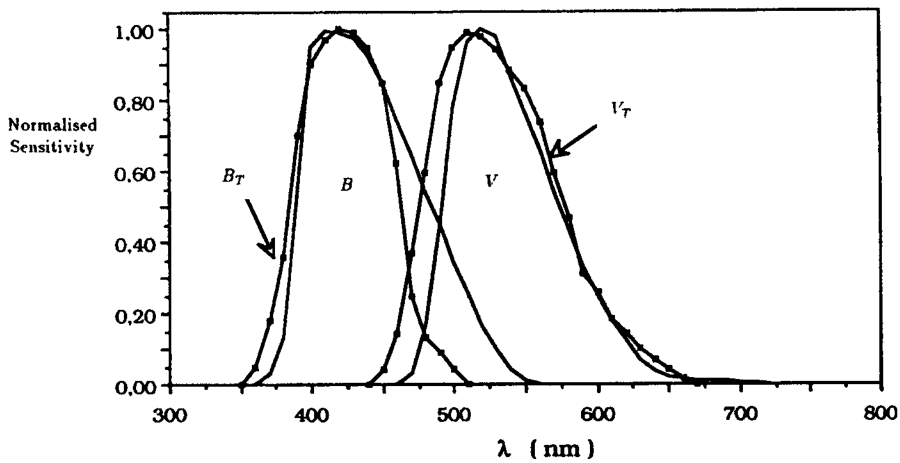

Figure 1.1 Normalised response curves for TYCHO B_T, V_T compared to $B; V$ (from Mignard *et al.* 1989).

which allow to distinguish a variable signal from noise, and also algorithms for period analysis. The next step will be to assess the type of variability of each newly-discovered variable star. The present book can be a helpful tool for this task because it brings an exhaustive and up-to-date compilation of light curves of all known types of variable stars.

A second key project is the ground-based microlensing experiments dedicated to the search for massive compact objects (black holes, brown dwarfs, etc.) in our galactic halo. According to Paczýnski (1986) massive dark bodies might act as gravitational microlenses, temporarily amplifying the apparent brightness of background stars in nearby galaxies. The most widely known microlensing experiments are the Polish-American OGLE (Optical Gravitational Lensing Experiment) project, the American-Australian MACHO (Massive Compact Halo Object) project and the French EROS (Expérience de Recherche d'Objets Sombres) project. Besides the discovery of microlensing events, a very interesting sub-product of all these experiments is the discovery of numerous variable stars among stars in the Large Magellanic Cloud (MACHO and EROS) and towards the Galactic Bulge (OGLE). An EROS catalogue of new eclipsing binary stars in the bar of the Large Magellanic Cloud has already been published (Grison *et al.*, 1994) and many other papers are in preparation. A lot of insights into stellar evolution should follow from these newly-discovered variables, and it will be a very rewarding enterprise to store the entire resulting data set in various locations for archival purposes.

Table 1.1 Number (N) of known variables brighter than the limit B_{lim} and the predicted number of variables detectable by TYCHO, including the known ones (from Mauder & Høg, 1987)

Type	B_{lim}	Number of variables: Known N	Number of variables: TYCHO detections	Remarks
δ Cep	11	173	1000	The number of detections should be a lower limit if a substantial fraction of stars with low amplitude exists
RR Lyr	11	(155)	100	Same remark as for δ Cep stars
δ Sct	9	8	> 50	$A \geq 0.1$ mag
δ Sct	10	13	> 50	$A \geq 0.2$ mag
α^2 CVn	11	14	> 100	$A \geq 0.1$ mag
EA	11	710	2000	About 80% of all EA detectable
EB	11	706	1500	Probably complete detection by TYCHO
EW	11	88	100	If the expected number of EW stars with low amplitude is correct, there could even exist about 1000 such objects
LPV, SR, IRR	11	2400	some 100	Some 1000 could perhaps be found

1.2 Nomenclature of variable stars

C. Sterken

For a working definition of the concept of variable star, we refer to Section 1.1; for a slightly too broad definition, we mention ‘A star is called variable, when it does not always appear to us with constant brightness…’ (Schiller 1923). If one of the brighter objects of a constellation turned out to be variable, its Bayer notation (Greek or Roman letter followed by the genitive of the Latin constellation name) was employed as the name of the variable. The visual observations leading to the compilation of the *Bonner Durchmusterung (BD)* by Argelander in the middle of the 19th century led to the discovery of a substantial number of new variable stars. Thus, Argelander introduced a specific nomenclature for those variables that had no Bayer number in a constellation by designating these stars by the Roman capital letters R, S, T, U, V, W, X, Y and Z attached to the Latin name of the constellation. With the introduction of the photographic plate, the number of variable stars in each constellation quickly exceeded the capacities of Argelander’s scheme, and the Astronomische Gesellschaft (AG) extended the scheme by adopting double

Roman letters RR to RZ, SS to SZ, etc. That extension brought the number of possible variable star names per constellation from 9 to 54. When that number turned out to be insufficient, AA to AZ, BB to BZ, etc. (but omitting J) was used. That second extension brought the number of stars to be assigned a name to 334 per constellation. According to Hoffmeister (1984), the Dutch astronomer Nijland proposed that a new and uniform system of nomenclature be introduced, and suggested that R, S, ... QZ be replaced by V 1, V 2, ... V 334 with subsequently discovered variables being labeled V 335, V 336, etc., the highest number then referring to the exact number of variables known in that specific constellation.[1] That suggestion was not entirely accepted for reasons of convenience, since many names of variables, like U Gem and RR Lyr, had already been assigned a specific class of variables, but it became in widespread use for labeling all variables that cannot be named in the extended Argelander nomenclature, i.e. from V 335 onwards. In principle, this system can be used for any possible number of variables that are discovered in a single constellation. However, with the advent of the discovery of larger and larger numbers of variables by space- and ground-based surveys (see Section 1.1), a discussion has been opened at IAU Commission 25 on the question whether such a scheme should be maintained, or whether one should produce a new scheme based on a system that directly and unequivocally refers to the position of the star in a reference coordinate system.

For novae a special nomenclature was used for a long time: older novae are designated by the label *Nova* followed by the constellation and the year in which they appeared (to the observer), for example Nova Cygni 1600. When necessary, the running number of the nova that erupted in this constellation that year is added. This system of labeling is still used as a *provisional* designation until the nova has been assigned a definite variable-star designation (thus, for example, Nova Vul 1968, number 2 has become LU Vul). Since the assignment of variable-star designations to novae was not carried out in the first decades of the 20th century, the chronology and the variable-star designations do not run parallel, for example, AT Sgr = N Sgr 1900, V 737 Sgr = N Sgr 1933, V 1016 Sgr = N Sgr 1899, V 1148 Sgr = N Sgr 1948.

A similar nomenclature is used for supernovae, where the year of appearance and a sequel character is used, for example, Supernova 1987a. However, supernovae – as extragalactic objects – never receive another variable-star designation (with the exception, of course, of well-known galactic supernovae, such as SN 1572 Cas = B Cas, SN 1604 Oph = V 843 Oph).

Alternative designations for specific stars used in this book are, besides the

1. See also André (1899).

HD and HR numbers: He 3 (Henize 1976), R ('Ratcliffe Catalog': R 1–R 50 in the SMC, R 51–R 158 in the LMC, Feast *et al.* 1960), S (Henize 1956), and WR (see also van der Hucht *et al.* 1981). As in the case of supernovae, the main reason for such alternative nomenclature is that these stars are extragalactic variables, to which no variable star designation is assigned.

The specific problem of assigning a unique name to a variable star is, of course, only part of the more universal problem of labeling celestial objects in a clear and internally consistent system. Variable-star observers using two-dimensional detectors quite often discover numerous variable stars to which neither a variable-star name, nor another designation had been given previously. This, especially, is the case when observing open clusters using such detectors with high quantum efficiency. In addition, such investigations necessitate the earmarking of quite a number of non-variable comparison and standard stars. Instead of extending existing schemes, some authors, unfortunately, find it necessary to replace previously assigned designations (even HD and HDE numbers allocated more than half a century ago) by private numbering schemes and acronyms that involve the initials of their own names.

In order to avoid the practice of creating new appellations out of thin air spreading like wildfire, the IAU has issued a public notice '*Specifications concerning designations for astronomical radiation sources outside the solar system*'[1] that shows how to refer to a source or how to designate a new one.

For general information, in particular about existing designations, one should consult Fernandez *et al.* (1983), Lortet & Spite (1986), Dickel *et al.* (1987), Jaschek (1989), and Lortet *et al.* (1994).

1.3 The classification of variable stars

C. Sterken

Variable-star specialists know that it is a very difficult enterprise to construct a physically sound and consistent taxonomy of classes and types of variable stars. One of the very first attempts at classification of variable stars was the scheme of Pickering (1881), who recognised five classes, viz. *new stars [novae], long-periodic variables, irregular variables, short-period variables* and *eclipsing variables*. Classification schemes based on a physical mechanism (e.g. Newcomb 1901) were doomed to fail as long as it was not understood that stellar pulsation can be the cause of variations (Plummer 1913, for reviews on pulsations and oscillations in stars we refer to Osaki & Shibahashi 1986, Osaki 1987, and to Watson 1988 for the impact of non-radial pulsations on

1. Accessible on *ftp anonymous* at node **cdsarc.u-strasbg.fr**

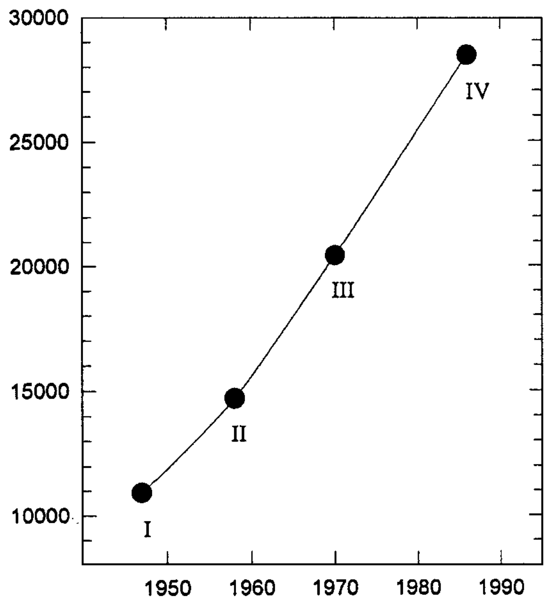

Figure 1.2 Number of variable stars listed in the four editions of *GCVS* (based on information from Samus' 1990).

flux changes). From then on, three *phyla* were always recognised: irregular variables, pulsating variables, and binary systems. Meanwhile, the classification of variable stars has undergone a change that, as Cecilia Payne-Gaposchkin puts it 'recalls the suppression of the Linnaean system by the modern system of botanical classification' (Payne-Gaposchkin 1978).

A first classification outline was published in 1960 (*Trans. IAU* 10, 398) and was based on the recommendations of the *IAU* made in Moscow in 1958. Since then, this classification has frequently been reworked and extended. A principal source of information on the latest classification of variable stars is the 4th edition of the *General Catalogue of Variable Stars* (*GCVS*, Kholopov *et al.* 1985a, 1985b, 1987a, 1990 – Volumes I, II, III and IV).[1] *GCVS* contains a classification and miscellaneous data on almost 30 000 variable stars which had been assigned variable-star names up to 1982. Not surprisingly, *GCVS* is somehow considered as the bible of systematic placement in variable star knowledge. Supplements to the *GCVS*, the well-known *Name List of Variable Stars*, appear regularly in the Information Bulletin on Variable Stars (*IBVS*, IAU Commission 27 & 42), e.g. Kholopov et al. (1987b, 1989). We also refer to *The New Catalogue of Suspected Variables* (*NSV*, Kukarkin *et al.* 1982), which

1. Compilation and publication of *GCVS* started in 1948 under the auspices of IAU, with an intended frequency of publication of a new edition every 10 years.

contains data on almost 15 000 unnamed variable objects. Figure 1.2 illustrates the steady increase in the number of known variable stars through the past half century, as measured by the number of entries in the four consecutive editions of *GCVS*. Users of *GCVS* and *NSV* should know that these works are not just a mere compilation, but are based on a critical evaluation of all underlying data, as expressed by Samus' (1990) in the case of an announced nova (V 600 Aql – 'Nova' Aql 1946), which was proven to be an asteroid during the preparation of *GCVS*. The 5th volume of *GCVS* is the first systematic catalogue of extragalactic variables, listing data on variables in nearby galaxies, viz. LMC, SMC, Andromeda Nebula (M31), Triangulum Nebula (M33) and some dwarf galaxies. The majority of extragalactic variables belong to Cepheid types – Fig. 1.3 illustrates the type distribution in the four mentioned galaxies – except for M31, where the number of novae approaches the abundance of the Cepheid types (Lipunova 1990). For a comprehensive overview on variable stars, see Duerbeck & Seitter (1982, 1995).

Astronomers who are familiar with the above-mentioned works must notice that every newly-published catalogue or review paper introduces new classes or subclasses of variable stars, and that the classification in itself, at the same time, not only refines, but also becomes, occasionally, less and less consistent, including even the classification of the same object in different classes,[1] or the transfer of an object from one class to another (and back) as time passes. Such changes, of course, reflect the progress and understanding in the field – a progress that is not only due to more and more sophisticated detection techniques, but also to the increasing time baseline along which data are being collected. An illustrative example of the latter point is the case of the 'ex-constant star' – that is, a star that turns out to be a variable only after many years of measurements become available for analysis. Another aspect of published classification schemes is the pronounced vagueness with which some classes are being defined; the *GCVS*, for example, lists several subclasses where members are characterised by the label 'poorly studied', a fact that eventually will lead to more refinement and to the definition of new classes and subclasses. Looking over the past decade, we have seen new classes like the rapidly-oscillating Ap stars and the slowly-pulsating B stars, to name only two.

The actual classes do not have clear-cut borders, since these borders directly depend on the parameter that is being used for the classification (see also M. Feast's remarks on the classification of Cepheids in Section 3.7). If that parameter is directly related to the wavelength range in which the data are

1. Not by error, but by the fact that some variable stars are polymorphic – see, for example the Be stars (Section 3.3), where signatures of rotation, pulsation, orbital motion, eruptions and even X-rays are seen.