HIGHLIGHTS OF VARIABLE STAR ASTRONOMY 1900 - 1986

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Abstract

This paper reviews 20th century progress in two areas of variable-star research: classification of variability and techniques of observation.

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1. Introduction

I am not a historian, so I have chosen here to describe some highlights of variable star astronomy since 1900, rather than to attempt a scholarly historical review. The highlights must surely reflect my personal biases, but I hope that they also reflect the interests of the AAVSO, and of you the reader. In addition to the highlights, there are of course numerous other studies which have laid groundwork, filled in gaps, or tied up loose ends. For broader and deeper views of the subject, you might consult Lang and Gingerich (1979), Payne-Gaposchkin (1978), Sawyer Hogg (1984), Shapley (1960), and Struve and Zebergs (1962).

I will discuss the individual types of variables, and the techniques used to observe them. There are some more general topics which I could have discussed at greater length: the exponentially increasing numbers of variables (currently about 30,000) and professional variable star astronomers (currently about 250), the coordination of variable star astronomy by the International Astronomical Union's Commission on Variable Stars, the change in the "style" of research from long-term projects at local observatories to short-term projects at remote national observatories, the growth of coordinated "campaigns" to observe variable stars with a variety of ground-based and space-based instrumentation, and the development of computer-based approaches to the publication and archiving of variable star information and data. Needless to say, variable star astronomy is an exciting and expanding field, in which there is still a place for the amateur: there are many more variables than variable star astronomers!

2. The Classification of Variables

Prior to 1900, variables were classified primarily by the shape, amplitude, and time scale of their light curves. With the development of spectroscopy and other modern astronomical techniques, it became possible to classify them by their physical properties. The Hertzsprung-Russell diagram of absolute magnitude plotted against spectral type (Hertzsprung 1905; Russell 1914) has become a powerful tool for classifying variables in this way, and comparing them with theoretical "models."

Eclipsing Variables

Eclipsing variables are binary stars - pairs of stars in mutual orbit. Because the orbit is seen almost edge-on, each star periodically eclipses the other, causing the total brightness to decrease. The basic theory of the light variations - including how to determine the properties of the orbit and the stars from the light

curve - was worked out in a series of early papers by Henry Norris Russell and Harlow Shapley. Their methods of light curve **analysis** have largely been replaced by methods of light curve **synthesis** (Wilson and Devinney 1971; Wood 1971) which are more effective and are well-suited to modern electronic computers.

The study of eclipsing variables is interesting in itself, but it is perhaps most important because eclipsing variables are **close** binary stars. The evolution of each star is influenced by the gravitational force of the other star. Mass may flow from one star to the other, or may be lost from the system completely. The stars interact with each other. The consequences are particularly spectacular if one of them is a collapsed star - a white dwarf, neutron star, or black hole.

Cataclysmic Variables

Cataclysmic variables, including novae, dwarf novae, and related stars, are another example of close binary stars. Their binary nature is the key element in our understanding of these stars. It was suspected in the 1940's and earlier; the turning point was probably the discovery by Merle Walker (1954) that DQ Her was an eclipsing binary. (As a by-product, Walker noted that, at certain phases of the eclipse curve, there was also variability on a time scale of about a minute. This was seen as rapid wiggles on the output of a chart recorder! Such rapid oscillations have now been found to be common in cataclysmic variables.) By the 1960's, it was accepted that all cataclysmic variables were close binaries consisting of a normal G or K type star accompanied by a white dwarf (Kraft 1963; 1964). Material from the normal star flowed into an "accretion disc" around the white dwarf; the accreted material was responsible in one way or another for the nova or dwarf nova outburst.

Novae have now been observed as far away as the Virgo cluster of galaxies (Pritchet and van den Bergh 1986). Novae were discovered in the Andromeda Galaxy M31 as early as 1917 (Curtis, Ritchey, and Shapley 1917). From these, it was eventually realized that there was a relationship between the absolute visual magnitude of a nova at maximum and its rate of decline. This relation could be calibrated using the bright novae in our own galaxy (or by assuming a distance to M31 determined independently), and novae could be used as distance indicators. The recent discovery of novae in the Virgo cluster (at magnitude B ~ +25!) was possible because of the development of sensitive electronic light detectors and because of the superb site and optical quality of the Canada-France-Hawaii telescope.

Supernovae

Whereas the eruptions of novae and dwarf novae are relatively superficial, the eruption of a supernova transforms a star into a collapsed core (usually) and a rapidly expanding nebula. Walter Baade and Fritz Zwicky (1943), in a great intuitive leap, came to this conclusion and even speculated correctly that the source of the supernova's energy might be gravitational collapse. Supernovae are central to many aspects of astrophysics: they are an end point of stellar evolution, a source of the chemical elements heavier than helium, the progenitors of pulsars, an accelerating mechanism for cosmic rays and a source of heating and turbulence in the interstellar gas. They are the most luminous stellar objects - variable or non-variable - and they can even be used as distance indicators. The discovery of a supernova in the host galaxy of the quasar 1059 + 730 provides evidence for the very great distance of these mysterious objects (Campbell et al. 1985).

The understanding of supernovae has been greatly aided by modern technology. Large telescopes and sensitive electronic detectors enable

the spectra of these very faint objects to be recorded. These spectra may then be compared with theoretical predictions of models (it requires a supercomputer to produce a reliable synthetic spectrum of an exploding model star). In this way, astronomers can obtain clues about how the explosion occurred, and in what kind of star. Simple technologies still contribute to supernova research, however; many supernovae are discovered visually, mostly by AAVSO member Robert O. Evans, in Australia!

Rotating Variables

From supernovae, the most spectacular and rarest variables, we now come to rotating variables, the most inconspicuous and probably the most numerous variables. Rotating variables are stars whose surface layers are not uniform in brightness, and which therefore vary in brightness as the star rotates. Until recently, the only well-understood rotating variables were the **peculiar A stars** or **spectrum variables** - A-type stars in which the non-uniform surface brightness was an indirect result of a very strong magnetic field. About 10 years ago, however, a group of rotating spotted stars called RS CVn stars was identified (Hall 1976). These stars have become very popular with photometrists with small, backyard telescopes, which are well suited to long-term studies.

Pre-Main-Sequence Variables

The understanding of very young variable stars has increased greatly during this century. Alfred Joy (1945) was the first to make extensive studies of the T Tau stars - the most numerous pre-main-sequence variables. Since then, George Herbig has been a leader in the study of these and other pre-main-sequence stars (see, for example, his excellent synthesis of our knowledge of the FU Ori stars (Herbig 1977)).

Pulsating Variables

The Cepheid variables are probably the most important and best-known pulsating stars, because their period-luminosity relation allows them to be used as distance indicators. The discovery of the period-luminosity relation by Henrietta Leavitt (1912) was based on a photographic survey of the Magellanic Clouds, carried out with a 24" photographic refractor from 1893 to 1906 in Arequipa, Peru. 1777 variables were found in these very crowded fields! Leavitt noted that the brighter Cepheid variables had longer periods; since all the variables were at roughly the same distance, the brighter variables were the most luminous.

Slightly more than a decade later, Cepheids figured in one of the most important developments in 20th-century astronomy. Using the newly-commissioned 100-inch telescope on Mount Wilson, Edwin Hubble (1925) obtained 65 plates of M33 and 130 plates of M31, extending to photographic magnitude +19.5. He identified many Cepheids (fainter than +18.3 at maximum!) and determined their distance to be 285,000 parsecs using the period-luminosity relation. This distance is less than half the presently-accepted distance: Hubble did not allow for interstellar absorption of light, and both his magnitude sequence and his period-luminosity relation were incorrectly calibrated. Nevertheless, his result was firm enough to establish that M31 and M33 were far beyond our own Milky Way galaxy, and were in fact galaxies like our own.

The refinement of the calibration of the Cepheid period-luminosity relation has taken almost a century; see Fernie (1969) for an excellent review, and Madore (1985) for a discussion of the current situation. A major breakthrough occurred in the 1950's when John Irwin (1955) serendipitously rediscovered (!) Cepheids in one or two galactic star clusters whose distances were independently known.

RR Lyr stars have also proven to be useful as distance indicators, though they are less luminous than Cepheids and can therefore not be seen to such great distances. From studies of RR Lyr stars in our galaxy, it is known that their absolute visual magnitude is about +0.6. These stars have also been found in large numbers in globular star clusters in and around our galaxy. They provide the main method for determining the distance to these clusters, and hence for determining the extent of our own galaxy. About 1950, RR Lyr stars figured indirectly in a major revision of the extragalactic distance scale. Walter Baade used the newly-commissioned 200" telescope to search for RR Lyr stars in M31, and expected to find them. He did not, because M31 was in fact twice as far away as was believed at the time! The RR Lyr stars in M31 were finally discovered in 1985 at magnitude +26 by Pritchet (1986) using sensitive electronic detectors on the Canada-France-Hawaii telescope.

Pulsating variables, as well as being useful as distance indicators, provide valuable information about the internal properties and processes in stars: our understanding of pulsating variables has progressed hand-in-hand with our understanding of stellar structure and evolution in general. The classification of pulsating variables in the Hertzsprung-Russell diagram was an important first step, of course. Harlow Shapley (1914) presented a general review and discussion of the empirical evidence for stellar pulsation. This was followed closely by Arthur Eddington's (1918) fundamental studies of the theory of stellar pulsation, based on an understanding of the internal structure of the stars; his book **The Internal Constitution of the Stars** must rank among the "great books" of modern astronomy. Nevertheless, although Eddington (1941, 1942) speculated about the cause of stellar pulsation, it was not until the 1950's that S. A. Zhevakin (1953), John Cox (1958), and others demonstrated that the source of the pulsation was a thermodynamic "engine" effect in the outer layers of some stars, where hydrogen and particularly helium were partially ionized.

Electronic computers have recently had a great impact on our understanding of stellar pulsation, because of their ability to carry out complex numerical "experiments" called **simulations.** An impressive example is the simulation of the pulsation of models of RR Lyr stars with different properties done by Robert Christy (1964, 1966). By comparing the simulated light and velocity curves with the observed ones, he was able to deduce much about the properties of the actual RR Lyr stars.

3. Techniques of Variable Star Astronomy

Progress in variable star astronomy has been greatly influenced by the development of new instruments and new techniques: larger telescopes at better sites; better detectors (including ones sensitive to infrared and radio radiation); space telescopes which are capable of recording ultraviolet, x-ray, and gamma-ray radiation. It should be remembered, however, that these new techniques **augment** rather than **replace** the old ones, and that the skill and insight with which the new (and old) techniques are used is also a factor.

Visual Observations

Until a century ago, the visual technique was the **only** technique for observing variable stars. It is still appropriate for measuring the approximate brightness of large-amplitude variables. Happily for the AAVSO, visual observations have become **more** important and **more** in demand in the era of space-based astronomy, particularly for monitoring the state of outburst of cataclysmic variables when observations of these stars are being made by spacecraft.

Photographic Observations

The photographic plate is still unequalled in its ability to

record large amounts of information, and store it in permanent fashion. There are hundreds of thousands of astronomical plates in archives, which can be used at any time, present or future. The role of photography in discovering the Cepheid period-luminosity relation, and using it to determine the distance to M31, has already been mentioned. Another important application has been the study of variables in globular clusters, which has yielded much important information about the properties, structure, and evolution of these stars. These intensive studies have occasionally yielded important results long after they were carried out. Only recently, for instance, have astronomers realized that some RR Lyr stars pulsate with not one but two periods. Many observations are required to disentangle these two periods but, once this is done, the periods can be used to derive masses and other important evolutionary information about these stars (see the study of such stars in IC4499 by Clement et al. (1986), for instance).

Photoelectric Observations

Joel Stebbins (1910) carried out the first astronomical photoelectric photometry, using selenium cells, and he and other pioneers made many important studies using a variety of apparatus "spun off" from the communications industry. Unfortunately, many of these early studies are now neglected or forgotten. One which is of direct interest to the AAVSO is a survey of the variability of red giant stars by Stebbins and C. M. Huffer (1930). They found that, whereas G and K giant stars are seldom if ever variable, M giants are. A few M0-M1 stars are slightly variable, about half of M2-M3 stars are variable, and almost all M4-M5 stars are variable by a few tenths of a magnitude. These are stars which are on the AAVSO photoelectric photometry program. The red stars on the AAVSO visual program are the rare, large-amplitude, M6-M9 stars.

By optimizing the equipment and procedures for photoelectric photometry, an accuracy of 0.003 magnitude or better can be obtained. With this accuracy, very-small-amplitude "microvariables" can be discovered and studied. The peculiar A-type rotating variables have already been mentioned; there are also beta Cep and delta Sct stars among others. Michel Breger, one of the "millimag photometrists," has outlined the procedures for precision photometry in his survey of delta Sct stars (Breger 1969).

The development of **high-speed photometry** has led to the discovery of variables with time scales of minutes or less. The first of these were discovered using conventional techniques: the rapid variability of DQ Her (Walker 1954) has already been mentioned; Arlo Landolt (1968) discovered rapid oscillations in white dwarfs. Observations of such stars are now made with special high-speed photometers which can receive and store measurements on magnetic tape or disc at the rate of one per second or faster.

Until about a decade ago, photoelectric photometers were expensive and difficult to build, but with the development of microelectronics this situation changed, and photometers became available to "the masses." Many amateur and professional astronomers with small telescopes took up photometry. At about the same time, RS CVn stars were recognized as an interesting class of variables (Hall 1976), and many small-telescope observers began to contribute to "campaigns" and cooperative projects on these and other stars (Hall and Genet 1984).

We have now entered the age of automatic photoelectric telescopes (APT's). Such telescopes have been used in space for years, and a few pioneers have developed and operated small ground-based facilities of this kind. The APT developed by Louis Boyd, Russell Genet, and Douglas Hall (1985) is the first to be used extensively by professional astronomers - presently on a somewhat experimental basis. The

refinement and evolution of APT's will be an interesting development for the 1990's.

Spectroscopic Observations

We should not forget that, in many kinds of stars, the spectroscopic variations are **at least** as conspicuous as the brightness variations. An excellent general reference on this topic is **Stellar Atmospheres** (Greenstein 1960), which contains chapters on (among other things) novae and other cataclysmic variables, flare stars, Mira stars, zeta Aur stars, Be and P Cyg stars, symbiotic stars, and Cepheids. Until recently, individual astronomers or observatories carried out regular long-term monitoring of such stars, but the "style" of astronomical research has changed somewhat and long-term studies - though important - are not as frequently carried out.

Radio Observations

Radio radiation is produced by dilute gases (with or without magnetic fields in them) and by energy changes within atoms and molecules. Many variables produce radio radiation - not from their surfaces, but from gases which they eject into space: supernovae, novae, flare stars, symbiotic stars, Mira stars, and the like. In many cases, the radio radiation is variable; RS CVn stars, for instance, show cyclic bursts of radio radiation on a time scale of hours. Unfortunately, few large radio observatories are able to do long-term monitoring of radio variables, or to cooperate flexibly with optical observatories. Perhaps someday amateur radio observatories can fill this gap!

Infrared Observations

Infrared radiation is produced by cool objects such as cool stars and dust clouds. Some of these (such as Mira stars) can be seen at visual wavelengths, though less brightly; others (such as cool dust clouds) cannot, and are therefore a more interesting product of this technique. Dust shells have been found around novae, pre-main-sequence stars, and many kinds of pulsating stars: Mira stars, RV Tau stars, and R CrB stars. These shells may be driven off the stars by their pulsation - a process which would significantly affect the evolution of the star. Infrared observations were first made early in this century, and the technique was refined in the 1960's with the development of sensitive infrared detectors by the military. Near-infrared photometry is now within the capability and budget of the small observatory.

Ultraviolet Observations

Ultraviolet radiation is produced by energetic particles, such as those in hot stars and in gases falling into strong gravitational fields. Ultraviolet radiation can only be detected from above the atmosphere, using rockets and satellites, so ultraviolet astronomy truly came of age with the launching of the first satellite UV telescopes in the 1960's. The International Ultraviolet Explorer Satellite (IUE) launched in 1978, has been (in my opinion) the most successful astronomical satellite yet, functioning far beyond its expected lifetime and generating hundreds of significant astronomical papers. The tens of thousands of IUE UV spectra now archived form a veritable treasure trove for astronomers now and in the future.

X-ray and Gamma-ray Observations

X-rays and gamma-rays come only from particles which have energies equivalent to temperatures of millions of degrees or higher. Such temperatures do not exist in normal stars, but are achieved only by particles which are accelerated by electromagnetic processes or by strong gravitational fields. Indeed, the most interesting sources of

these high-energy radiations are close binaries in which one component is a white dwarf, neutron star, or black hole. The identification and study of such x-ray binaries has been a major achievement of x-ray astronomy.

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