A HISTORY OF VARIABLE STAR ASTRONOMY TO 1900 AND SLIGHTLY BEYOND

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Abstract

A brief account is presented of the progress of variable star astronomy, from the earliest beginnings up to 1900. While massive amounts of observational data had been collected before 1900, satisfactory theories to account for them had been found only for Algol-type eclipsing binaries, and tentatively for β Lyrae type, but none yet for intrinsic variables.

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The earliest catalogue of variables star, by Edward Pigott (1753–1825) in 1786, contained only twelve verified variables, of which four were novae, and an additional list of 39 suspects. However, some 130 other novae had already been found by that time (now listed in the **General Catalogue of Variable Stars**, hereinafter **GCVS**). The majority had been found in China, but only about a dozen had been recorded in the West. Ho Peng Yoke (1962) cites 581 discoveries that were recorded in Chinese sources between 532BC and 1600AD. In most of these cases the apparition was probably a comet; twelve, including N1054, the progenitor of the Crab nebula, appeared to be authentic, while 72 additional cases are doubtful. Earlier, in 1905, Agnes Clerke (1842–1907) in her book, **The System of the Stars**, had accepted eleven discoveries made prior to 1600AD as real novae (134BC, and 123, 173, 386, 389, 393, 827, 1006, 1203, 1230 and 1572AD).

The increase in numbers of known novae is shown in Table I. In Figure 1 the open circles represent the logarithm of the total numbers of known novae at intervals of fifty years from 1550 through 1850, and at 25 year intervals thereafter. The solid dots give the corresponding numbers of variable stars of all sorts found in successive published catalogues. The ancient nova discoveries are not

included in any but the more recent variable star catalogues, nor were the early catalogues consistent on the inclusion of any novae.

In a span of three centuries the numbers of known novae did not increase spectacularly: from 121 in 1600 to 161 in 1900. Since then the numbers have a little more than doubled, to 340 by 1975. The numbers of the other kinds of variables, on the other hand, have increased from one in 1600 to about 700 in 1900 to over 25,000 in 1975 and now about 28450. Table II lists the variables other than novae that had been found up to 1800, only 13 in all. Before dry plates were applied to the photography of stellar fields in about 1880, few if any variable stars were discovered as a result of systematic searches. Novae with their large changes in brightness were more likely to be discovered by pure chance (for example during searches for minor planets) than were other types of variables, the Mira type running a distant second. The majority of current discoveries of novae have still depended on lucky chance rather than systematic search, although many searches have been conducted, especially by amateur groups, the AAVSO in particular.

In Figure 1 the two curves intersect at about 1880, when "ordinary" variables and novae were known in about equal numbers. But now the ratio of recorded novae to other types of variables has decreased from 121 novae to one Mira variable in 1600, to one nova among four variables in 1900, to one in 76 by 1975. Also marked in Figure 1 are dates important in the analysis of discovery rates. Hampering the verification of discoveries had been the lack of adequate star charts and reliable magnitudes, alleviated when F. W. A. Argelander (1799–1875) published his **Uranometria Nova** in 1843, and the **Bonner Durchmusterung** catalogues beginning in 1859, with corresponding charts. The initiation by E. C. Pickering (1846–1919) of the Harvard Observatory photographic plate collection in 1882 resulted in unprecedented large numbers of discoveries. The preparation by Father J. G. Hagen (1847–1930) of his now famous **Atlas Stellarum Variabilium** (1899–1908) proved a tremendous asset especially to active amateurs. On the other hand, the two world wars somewhat slowed the trends of progress.

Not included in the above discoveries are the variable stars in globular clusters discovered by Solon I. Bailey

(1854–1931), nor supernovae except those with named designations in the **GCVS**. In 1889 E. C. Pickering had found one variable near M3 and in 1890 David Packer of London found two near M5. It was not known whether these belonged to the clusters or were foreground stars. Then in 1893 Bailey at the Harvard southern station in Arequipa, Peru, began systematically photographing ω Centauri and other globular clusters, initiating what was to become one of the major research fields at Harvard. By 1902 he had found over 500 variables among twenty three clusters. Pickering commented that the clusters examined covered only one thirty thousandths part of the whole sky yet contained as many variables as were known in the whole rest of the sky.

Discovery Techniques

Nearly all the discoveries of variables before the advent of photography were made by pure chance, observers familiar with the constellations noticing either the presence of a previously unrecognized star or, as in the case of the discovery of Algol, the absence of a star where one was usually seen. Such serendipitious discoveries still occasionally occur visually, and are often made when photographs are examined for other purposes. Systematic searches by visual methods were rare. An outstanding example was an examination by A. Safarik (1829–1902) between 1883 and 1888 of 22 red stars to find out if all were variable. He found 13 of them were. In recent years similar searches have been carried out photoelectrically to discover whether stars with certain spectral peculiarities are variable.

Early methods for the photographic discovery of variable stars have involved a number of techniques:

1. Laborious looking back and forth from one plate to another hoping to spot changes -- a hopelessly laborious eye-straining procedure.

2. Simply superposing one negative on another. Also inefficient.

3. Multiple series of exposures on the same plate. Excellent for studying the light curves of stars already known to show rapid variation, or for studying the shapes of eclipses of Algol type variables with relatively short durations of

minimum. Costly in plates for searches for new variables.

4. The "positive-negative" method, first attributed to Hagen. A negative of a sky field is superposed on the positive of a plate taken at another time. Variables stand out when, relative to neighboring stars of approximately the same magnitudes, the black image on the upper plate is either too large or too small in comparison with the white image on the positive. This is the method that was adopted at Harvard Observatory for the vast majority of the nearly 13,000 variables discovered there before 1955. At Harvard the positives were slightly enlarged (one percent) over the negatives to make it easier to discover the stars that were fainter on the positive, all other stars appearing to have white halos around the black negative images. At the time of the establishment of the AAVSO in 1911 over three fourths of all the then known variables had been discovered at Harvard by this technique.

5. Use of early stereo-comparators. This instrument is designed so that the images of two plates mounted side by side are seen superposed, but with the right eye viewing one plate, the left the other. Max Wolf (1863-1932) used this technique successfully in 1901. He reported the rediscovery of S Orionis and ten new variables in a field in Orion: four of these are now named variables, three are in the NSV catalogue, one has been ignored, presumably because its reported amplitude was only 0.5magpg, and another Wolf himself considered spurious as it is a component of a close double. The remaining star (84.1901, 1855 coordinates 5h 28.8m -5° 3', 14.5-16.0mag_{pg}) with a reported amplitude of 1.5mag_{pg} does not appear in any modern catalogue. In 1904 C. Pulfrich (1858-1927) pointed out that changes between the two plates could be more readily detected by slightly displacing the images (making all the combined images look like double stars) than by superposing them exactly.

6. The blink microscope, first designed by Pulfrich in 1902. Here the stereocomparator was modified for monocular vision and a devise interposed for alternately viewing the two plates in rapid succession, making variable stars appear to blink. Pulfrich realized that the eye perceives sudden changes in brightness more readily than fixed changes as seen in the stereoscopic microscope. The most successful

application of the blink microscope was by W. J. Luyten (1899-) for the Bruce Proper Motion Survey, in the course of which he discovered 2350 new variables, reported in 1938.

7. Spectroscopic discoveries. In 1881, before he had acquired photographic equipment for the purpose, Pickering used a direct vision spectroscope at the 15-inch "Great Refractor" to search visually for stars with peculiar spectra. Thus he noted that the spectrum of the star later named U Puppis resembled that of Mira. He confirmed its variability and commented, "A method of detecting such objects is thus indicated, far more rapid than the usual one of repeatedly observing the magnitude of the same star." The real triumph came when Mrs. Williamina P. Fleming (1857-1911) in 1890 discovered that red stars whose spectra show emission features are variable stars, and that novae also have characteristic emission spectra. In agreement with Pickering's earlier visual discovery, her discovery proved that a single spectrum plate could suffice to identify such stars as variable. Her first discovery was in 1887, the nova V Persei, which at the time of discovery she suspected of being a long period (Mira type) variable. Her second nova, IL Nor, discovered in 1893, was immediately correctly identified as a nova and has therefore generally been cited as her first nova. In all, between 1887 and 1911 she found 10 novae on the basis of their spectra alone, and some 300 other variable stars, most of them by their spectra. In 1866, John Birmingham (1816-1884) had discovered Nova T CrB; that same year Sir William Huggins (1825-1910) examined the spectrum visually and described its spectral peculiarities, thereby preceding the Harvard astronomers in recognizing that the spectrum of a nova differs from those of more ordinary stars.

Observations and Photometry

Discovery is only the first step. For ascertaining the types of variability and ultimately interpreting the physical processes responsible for the variations, extensive accurate observations are usually essential. Hipparchus (c190-120BC) in 127BC was the first to attempt to assign magnitudes to stars in general. His catalogue was inspired by a puzzling new star — the nova of 134 BC. Had it been accidentally omitted from earlier records or was it in fact a new star? He called the brightest stars first magnitude,

the faintest visible to the naked eye, sixth.

E. Pigott, who discovered η Aquilae (then called η Antinoi) in 1784, made the ingenious but not really practical suggestion for determining magnitudes by pulling the eye piece of the telescope out of focus until the star just disappeared. He graduated the draw tube in order to calibrate the magnitude differences.

In 1828 Sir John Herschel (1792–1871) pointed out that the difference between first and sixth magnitude stars amounted to a ratio of almost exactly 100 in brightness. (For estimating the difference in brightness between two stars, he used two identical telescopes on the same mounting, but varied the aperture of one of them so as to reduce the brighter image in that telescope to match the fainter star at full aperture.) By 1850 N. R. Pogson (1829–1891) perfected and standardized the magnitude system to the one now universally adopted, namely

$$(m_2 - m_1) = 2.5119(\log I_1 - \log I_2).$$

The scale would thus be extended indefinitely to fainter stars. The magnitudes of variable stars could then be referred to sequences of standard stars of known magnitude. In the early work on variables, however, nearby comparison stars of already known magnitude were seldom available. Observers picked arbitrary comparison stars and simply described the variable as brighter or fainter than the selected stars. Good determinations of light curves were hence slow in achievement Most active in the advancement of variable star astronomy was Argeländer, who, among his many other achievements, was the one to propose the adopted system for naming variables: R for the first variable discovered in any constellation, then S through Z. How surprised he would have been at the necessity for extending his system to accommodate several thousand variables in a single constellation!

Already in 1796 Sir William Herschel (1738–1822) had proposed a scheme for estimating the brightness of a variable in terms of steps of the least perceptible difference between two comparison stars. Argeländer improved upon this, introducing the step method still frequently adopted, especially before magnitudes of the comparison stars can be accurately determined. The observer estimates

the number of steps between the comparison stars, and between the variable and each of two comparison stars bracketting the brightness of the variable. The extensive observations according to this method by William Herschel on the bright northern stars and by Argeländer on variable stars were only partially published by their authors. Olcott describes Pickering's joy when copies of the unpublished observations were turned over to him when he visited Europe in 1883. Pickering reduced all of Argeländer's step-estimates on sixteen long period variables to magnitudes on the Harvard photometric system and published them in the **Annals of the Harvard Observatory**. Pickering's manuscript copies of Argelander's unpublished observations are now in the possession of the AAVSO. In all, Argeländer must have made some 15,000 estimates on variable stars, nearly all made by naked eye or with an opera glass. Moreover, Argeländer was an inspiring teacher and director, who also appealed to amateur astronomers to take up the observation of variable stars. Among the students and younger contemporaries whom he inspired as observers were Edward Schönfeld (1828-1891), Argeländer's successor as director of the observatory at Bonn, Germany; Eduard Heis (1806-1877); K. N. A. Krüger (1832-1896), Argeländer's son-in-law; J. F. J. Schmidt (1825-1884); and Benjamin Gould (1824-1896). Pickering reduced and published extensive observations of long period variables by two of these: about 1500 estimates on thirty one variables made by Schönfeld in 1855-1859; and some 8000 observations on five variables by Schmidt in 1845-1880.

At Harvard, O. C. Wendell (1845-1912) observed 17 circumpolar variables between 1889 and 1899 at the 15-inch refractor, using the Argelander step method, and analyzed their light curves, published in 1900; and from 1890 to 1901 he similarly observed 58 long period variables, but published only the ledgers of magnitudes, no further analyses.

In 1889 Pickering published **An Index to Observations of Variable Stars** in which he tabulated the numbers and sources of all observations of variable stars that had come to his attention for the years 1840 through 1888. The total, for 225 variables, amounted to 125,720 observations contributed by 37 observers from eleven different countries (Argentina, Austria, Canada, England, Germany, Greece, Holland, Ireland,

Russia, Sweden, and U.S.A.) — an impressive early indication of international cooperation. Besides naked eye, opera and field glasses, refractors ranging from 2 to 17.25 inches had been used.

Extremely important to the analysis of variable stars is the determination of magnitude sequences. At Harvard accurate visual photometry had already engaged Joseph Winlock (1826–1875), Pickering's predecessor as Director of the Harvard Observatory. Under Winlock's direction C. S. Peirce (1839–1914) used a Zöllner photometer to determine magnitudes for 494 bright stars. J. C. F. Zöllner (1834–1882) had invented his polarizing photometer in 1860. When Pickering became the Director of the Harvard College Observatory in 1877, long before his acquisition of photographic equipment, he had been concerned with visual photometry. Not completely satisfied with the Zöllner polarizing photometer, Pickering invented numerous others. His first was the meridian photometer with which he and his staff measured the magnitudes of 4260 stars north of −30° and brighter than 6.2mag, published in 1884 and known as the "Harvard Photometry," or "HP." Other photometers used with different telescopes enabled him to determine magnitudes to ninth magnitude. By 1908 (in the "Harvard Revised Photometry", abbreviated to "HR") magnitudes were published for 9110 bright stars to 6.5mag and (in other volumes) for 36682 fainter stars, now covering the whole sky, both northern and southern hemispheres, since the Harvard Southern Station at Arequipa, Peru, had been established in 1890. These magnitudes could serve as useful standards for variable star comparisons. The photometric observations were then extended to still fainter stars, to the determination of selected comparison stars, or to the direct determination of variable star magnitudes.

Meanwhile, in 1885 C. Pritchard (1808–1893) at Oxford had produced his **Uranometria Nova Oxoniensis** giving magnitudes determined by wedge photometer of all the naked eye stars north of −10° (2784 stars). These he compared with the Harvard Photometry, finding 140 (or only four percent) discrepancies greater than a third of a magnitude. From these he suspected seven stars of being variable, the largest discrepancies, exceeding 0.9mag occurring for 42 Orionis (now NSV 2318), and 45 Orionis; otherwise the largest discrepancy was 0.67mag. G. Müller and P. Kempf

(1851–1925 and 1856–1920, respectively) in 1894 and 1899 brought out their determinations of magnitudes for stars brighter than 7.5mag in northern zones 0° to 40°. The mean difference between these and the Harvard values for 799 stars in common is only 0.17mag, including systematic differences depending on the colors assigned by Müller and Kempf, varying from +0.29mag for white stars to −0.06mag for those they designated as yellow.

With the advent of photographic discoveries, entirely new magnitude sequences needed to be determined. Although Pickering gave much thought to photographic photometry as soon as the first variables were found photographically, it was some twenty years and well into the twentieth century before photographic magnitude systems were put on a firm foundation. Then, in 1907, Mrs. Fleming published photographic sequences for 222 variables. Scales were devised, called "fly–spankers," by making a series of six exposures: 3, 9, 27, 81, 243, and 729 seconds. Successive images on the fly–spanker formed a scale on which successive images differed by a constant (approximately one–magnitude) interval. Series for well defined stars were then cut from the plate and mounted with a wire handle. Superposing this scale over the plates showing the variable (taken with the same telescope), the magnitude intervals between the comparison stars and between the variable and the comparison stars could be read. As in the case of Argeländer's step method, the fly spanker scale estimates could be reduced to actual magnitudes once the true magnitudes of some of the comparison stars were determined.

The earliest photographic sequences suffered from the handicap that only visual magnitudes of field stars were available for calibration. But Pickering had already ascertained that the differences between photographic and visual magnitude depended upon the spectral class. By 1911 Mrs. Fleming had determined the spectral classes of sequence stars in 48 Harvard Standard Regions, tabulated their magnitudes from the visual photometric determinations, and applied corrections depending on spectral class to obtain photographic magnitudes. Meanwhile Henrietta Leavitt (1868–1921), who in 1908 discovered the period–luminosity relation for Cepheids in the Magellanic Clouds, had, as a volunteer while still an undergraduate at Radcliffe in 1896, worked on the photometry of stars around the North Pole.

Later she was to devote her prime energies to the establishment of the North Polar Sequence and compatible revised magnitudes in the 48 Harvard Standard Regions. This had been envisioned by Pickering as early as 1884, but not completed and published until 1917.

The North Polar Sequence consists of 46 selected stars with photographic magnitudes ranging from 4.48 to 21.10, and corresponding photovisual magnitudes for the 23 brightest stars ranging from 4.4 to 13.34. In the Standard Regions the faint limiting photovisual magnitudes ranged from 10.96 to 13,98; the photographic from 15.43 to 19.0. In 1905 J. C. Kapteyn (1851–1922) had announced his plan of Selected Areas, and the results were published at Harvard in 1917–23 and at Mount Wilson (by Sears, Kapteyn and van Rhijn) in 1930. Although the Selected Areas have largely supplanted the Harvard Standard Regions these earlier sequences are still provisionally useful when they are closer to new variables than any of the Selected Areas and more modern photoelectric determinations are not yet available.

Magnitudes for variable stars determined before 1900 are, for the most part, only minimally reliable, although they were certainly adequate for type and period determination. In Argelander's time variables were loosely divided into three categories: temporary stars (novae), periodically varying stars, and irregular variables or those with undetermined periods. F. W. H. A. von Humboldt in his **Cosmos** (1850) beautifully describes what was known at the time, quoting especially from the work of Argelander, who provided a table of 24 periodic variables with periods for 22. Moreover, Argelander noted that the periods were not always constant, nor that the magnitudes at maximum were always the same. For Mira he derived a complicated formula including four sine terms to represent the recurrent times of maximum. In the case of χ Cygni he felt that the observations required not only a 406 day period but also probably two secondary periods of about 100 and 8.5 years. (That the period has been increasing is indicated in current catalogues, but Argelander's secondary periods have not been verified; they are now of interest mainly as early suggestions that variables might have multiple or changing periods.) Analysis of all available observations of Algol revealed that its period of about 2.867d had progressively decreased by 4 seconds between 1784 and 1842; subsequently

it decreased 7 more seconds by 1966 according to the most recent period given in the **GCVS**. Argelander attempted to fit the observations of β Lyrae to a formula with both quadratic and cubic terms in the epoch.

Early Interpretations

After a variable star has been discovered and its light curve established, the next and most vital task is to decipher why the light and spectrum change as they appear to do. How were these changes interpreted before 1900?

For intrinsic variables numerous speculations had been put forward to explain the variations in brightness or spectral characteristics. By analogy with sunspots, star spots and stellar rotation were frequently suggested but seldom found satisfactory. Both ejected materials and stellar collisions were repeatedly considered, again with inconclusive results. Some of the best descriptions of once current hypotheses may be found in the various treatises published by Agnes Clerke between 1885 and 1905. Miss Clerke was the outstanding woman astronomer of her era, now unjustly almost forgotten. She recalled that Pickering was the first to attempt to classify the variables primarily by their light curves and periods. This could be considered the first step toward seeking the causes of variation, although Pickering himself (aware that insufficient data could lead to false conclusions) specialized in the collection of important observational data rather than in its interpretation. His groupings were Class I, the novae (among which he already included the unusual η Carinae whose famous outbreak in about 1843 had been observed by Sir John Herschel at the Cape); Class II, Mira type, with periods of several months; Class III, irregular variables; Class IV, variables with periods of a few days, typical examples being δ Cephei and β Lyrae; and Class V, Algol-like variables.

Class I (Novae). One of the earliest theories (other than religious) to account for novae or "new" stars was proposed by Tycho Brahe (1546-1601), a co-discoverer of the nova (later called supernova) of 1572 which had been seen five days earlier by Wolfgang Schuler in Würtemburg. Tycho assumed that the cosmical vapors of the Milky Way coalesced, becoming luminous stars -- that novae were in fact new creations. Someone else suggested the hypothesis that the

star was always intrinsically bright, but was first moving toward, then away from the earth, the variation corresponding to the change in distance -- a curious assumption since there was no corresponding change in position, and (though unsuspected at the time) the necessary change in distance would have been fantastic indeed. As early as 1622 Fortunius Licetus (1577-1657), about whom Lippincott's **Biographical Dictionary** says "he had more erudition than judgment," is said to have listed as many as 20 hypotheses, including acts of God as well as some suggestions smacking of later more sophisticated but still unacceptable theories. G. B. Riccoli (1598-1671) proposed that one side of the star was bright, the other dark, and when God wanted to send a message to the people He suddenly turned the bright side toward the earth!

Later, collision and explosion theories both seemed promising. When Huggins observed the spectrum of the nova of 1866, T CrB, he interpreted what he saw as the spectrum of a solar type star with a very peculiar emission spectrum superposed. He ventured the opinion,

> "The sudden blazing forth of this star, and then the rapid fading away of its light, suggest the rather bold speculation that, in consequence of some great internal convulsion, a large volume of hydrogen and other gases were evolved from it. The hydrogen; by its combination with some other element... giving out the light represented by the bright lines, and at the same time heating to the point of vivid incandescence the solid matter of the photosphere."

Isaac Newton (1643-1726) attributed the flare up of novae to the appulse of comets. Numerous later theories similarly considered collisions with comets, meteor streams, asteroids, swarms of asteroids, and planets. More promising were theories involving two stars either in collision or close encounter, as in the tidal theory proposed by W. Klinkerfues (1827-1884). In 1901 W. H. Pickering (1858-1938), brother of E. C. Pickering, believed to find evidence in the spectra of Nova Persei that collision theories are not valid. The contending theories involved eruptions analogous to solar prominences but on a much vaster scale. The causes of the eruptions, except in the case of the tidal theory, were not clear. In 1903, Agnes Clerke

summarized existing theories in her **Problems in Astrophysics**, concluding that very little was known of a positive nature and that "we must be content, in the main, with negative inferences." The most promising theory at the time was that stars in the Milky Way, where most novae had been observed to occur, occasionally get entangled in diffuse nebulae, and this, analogous to the effects of the collisions of meteoroids with our atmosphere, produces the tremendous outbursts. But as late as 1928 H. Ludendorff (1873–1941) commented that there still was no satisfactory theory to account for nova outbursts.

Class II (Long Period Variables). Mira was not only the first long period variable to be discovered, its period was the first to be carefully analysed. I. Boulliau (1605–1694) in 1667 ascertained that successive cycles were not of the same exact duration, nor were the magnitudes at maximum equal. Thus right from the beginning there were complications that needed to be explained. Boulliau envisioned the star as a rotating globe almost uniformly dim except for one very bright spot. P. L. M. de Maupertuis (1698–1759) suggested the star was in the form of a millstone seen at different angles at different times. Pigott, on the other hand, assumed Mira was being eclipsed by an opaque satellite. Sir William Herschel, who observed Mira in 1777–1780, gave two alternative hypotheses: 1) that the star was surrounded by Saturn-like rings which were sometimes seen face-on, at other times edge-on; and 2) the star was spotted like the sun and in rotation. R. Wolf (1816–1893), a prime authority on sunspots, in 1852 also pointed out that the shape of the sunspot cycle and its irregularities from cycle to cycle were analogous to the light curves of variable stars, a relationship he considered of utmost importance, implying similar causes. But Klinkerfues in 1879 showed that in order to account for the observed amplitude in brightness, a star like Mira would have to show 15 to 20 times as many spots on one side of the star as the sun showed at maximum activity, and none on the other side. Klinkerfues in 1865 had suggested satellites revolving about the star in highly eccentric orbits, raising tremendous tides at periastron passage. Sir Norman Lockyer (1836–1920) in 1889 proposed that Mira type variables were "incipient doubles" caused by the interaction of two colliding meteoroid swarms; however, later spectroscopic investigations failed to reveal any doubling. W. W.

Campbell (1862–1938) in 1898 noted a curious tripling of the blue hydrogen lines, which he suggested might indicate changes in the physical condition of the star, and which Miss Clerke in 1905 interpreted as due to powerful magnetic action. The difference in apparent radial velocity between the absorption and emission lines supported the contention that the star was ejecting hydrogen gas at enormous velocity. In regard to stars with late type spectra, Miss Clerke inferred that their variability must arise in or above the photosphere: "Variability is an index to circulatory changes." It was not until 1926 that A. S. Eddington (1882–1944) in his **Internal Constitution of the Stars** showed that the pulsation theory applied to Mira type stars as well as to Cepheids.

Pickering had subdivided his Class II into two categories, IIa representing the "ordinary" variables of long period, discussed above, and Class IIb represented by U Geminorum and SS Cygni. In 1899 E. Hartwig (1851–1923) proposed that SS Cygni is accompanied by a companion in a highly eccentric orbit causing eruptions at periastron and that a rapid rotation of the line of apsides would cause the apparent irregularities in the occurrence of the maxima. Ahead of his times, he suggested that the outbursts in these stars appeared analogous to nova phenomena with the difference that nova explosions were believed to occur only once. Indeed, Tycho's nova of 1572 had at the time been declared by an astrologer, Cyprianus Leovitius (1524–1574), as a recurrence of the novae of 945 and 1264. Pigott in 1786 had derived a period of about 300 years; and Sir John Herschel has been quoted in the **Astronomical Register** in 1863 as thinking it possible it might recur in 1872. However, D. F. J. Arago in 1842 refuted any connection between the three objects upon which the period had been based. (Klinkerfues, incidentally, wistfully commented that such a periodicity would "favor an orderly system", making *all* variables periodic.) In 1883 W. T. Lynn (1835–1907) researched the evidence, rectifying some errors in the literature, and concluded that the earlier objects were probably comets, not novae. This has in fact been substantiated at least in the case of 1264 by old Chinese records where that object is unambiguously described as a comet. No authentic cases of recurrent novae were recognized until the twentieth century when three, U Sco (1863, 1906 and 1936), T Pyx (1890, 1920 and 1944), and RX Oph (1898

and 1933) clearly proved to be recurrent.

In 1915 Miss C. Furness (1869–1936), discussing the U Geminorum stars, stated, "All attempts to detect a law in the changes of the period have failed." It was mid-20th century before stars of this class were to be recognized as dwarf novae rather than as a subdivision of long period variables.

Oddly included among Pickering's Class II was T Tauri, the progenitor of the class now considered pre-main sequence stars associated with nebulosity. In 1903 Miss Clerke remarked in her **Problems in Astrophysics**, "Isolated stars with nebular appurtenances are, for the most part, steady light-givers. T Tauri, however, discovered by [J. R.] Hind [1823–1895] in 1852 makes an exception." Miss Clerke urged that it be diligently observed until some rational principle of causation could be established. She considered it more analogous to the novae than to the long period variables. Of other variables associated with nebulosity, "the Orion kind," she declared, "They show the quality believed to characterize suns in a primitive stage." Here are the seeds of modern thoughts.

Class III (Irregular Variables). The **Provisional Catalogue of Variable Stars**, compiled by Annie J. Cannon (1863–1941) and published by Pickering in 1903, describes this class as "variables of small range or irregular variation according to laws as yet unknown." A representative example was α Herculis (discovered by William Herschel in 1795), now classified SRc. The catalogue includes 87 stars classified III. All but one of those for which spectral classes were available were *M* or *N* type stars. The exception, u Her, type *B3*, has subsequently been found to be a two-day eclipsing binary.

Class IV (Short Period Variables). This class was divided into two sub-classes: IVa, the "ordinary variables of short period," typified by δ Cephei, and IVb, those with alternating bright and faint minima, of which β Lyrae and U Scuti were typical examples. As both IVa and IVb were for a long time considered to be binaries let us examine IVb first.

The prototype star, β Lyrae, had been discovered by

the brilliant deaf mute, John Goodricke (1764–1786), who also noted that older star catalogues disagreed as to the magnitude of this star. Moreover, Goodricke derived a remarkably accurate period of 12d 19h (the current but ever changing value being 12d 21.9h). He did not, however, give any suggestion as to the cause of the variability.

In 1866 P. A. Secchi (1818–1878), observing visually, noticed bright lines in the spectrum of β Lyrae. In 1883, E. von Gothard (1857–1909) discovered variability in these emission lines, while Mrs. Fleming in 1891 detected dark companions to the bright lines. Then Pickering, also in 1891, from an examination of both the light curve and variations in the spectrum, concluded that the most natural explanation for the doubling of the bright lines in the spectrum is that the star is revolving in a circular orbit and that β Lyrae, like β Aurigae, is a double but with components of different spectral class. However, he added, "The phenomena may also be due to a meteor stream, or an object like our Sun revolving in 12d 22h and having a large protuberance extending over more than 180° in longitude." G. W. Myers' (1864–1931) analysis in 1898 came closest to current beliefs, namely two ellipsoidal bodies almost in contact revolving about one–another, the larger body being about 0.4 times as bright as the smaller. However, later investigations still continue to defy satisfactory explanation of all the spectral complexities of this particular star, continuing to confirm Miss Clerke's verdict that "nearly everything connected with β Lyrae *is* more or less disquieting." About a similar star, U Pegasi, there was speculation whether it was a pair of stars or a single pear–shaped star. At the turn of the century it was common belief that probably all short–period variables are binaries.

The Cepheids (Class IVa), also called "blink" stars, had, until well into the 20th century, been considered as peculiar varieties of eclipsing binary systems with eccentric orbits. Generally the spectra of Cepheid variables revealed only one component, but with periodically shifting lines, interpreted as indicating single–lined spectroscopic binaries. But in 1897 A. A. Belopolsky (1854–1934) analysed the spectra of η Aquilae and concluded,

" It will be seen that the times of minimum brightness

and the times for which the velocity in the line of sight is zero do not coincide. For this reason the changes in the brightness of the star cannot be explained as a result of eclipses, and some other explanation must be sought. It is very remarkable that this is also true of the variable δ Cephei."

The eminent Karl Schwarzschild (1873–1916), discussing both β Lyrae and η Aquilae in 1900, remarked that although some of the spectroscopic details of β Lyrae were still puzzling, the binary theory for it was, in the main, convincing. Not so for η Aquilae, for which he found that the variations might be produced by changes in temperature or by tides according to Klinkerfues' tidal theory; but neither of these hypotheses would fully explain both the light and spectral changes. Yet Miss Clerke in her book, **The System of the Stars** (1905), while giving the reference to Belopolsky's work, still maintained,

"There need be no hesitation in affirming that the pattern of variation set by δ Cephei is prescribed by the circling, in an identical period, of a usually non–luminous companion."

Most of the hypotheses attributed to the long–period variables were also applied to the Cepheids, and found equally wanting. Miss Clerke (in her discussion of the long period variables) summarized the state of theories at the beginning of the current century thus:

"The track of recent astronomical progress is strewn with the dilapidated remnants of hypotheses invented to explain the strange phenomena of stellar variability. Nevertheless, much has been learnt as to their relationships and essential nature;" further, "The time has scarcely yet come to formulate a general theory of stellar variability."

Between 1878 and 1889 A. Ritter (1826–1908) wrote a long series of theoretical papers entitled "Untersuchungen über die Höhe der Atmosphere und die Constitution gasformiger Weltkörper." Already in 1879 he had suggested pulsation to account for stellar variability. However, Eddington was to find Ritter's theory of heat–transfer within a star not valid. Then H. C. Plummer (1875–1946),

who has been credited with being the first to anticipate Eddington by proposing a pulsation theory to replace the unsatisfactory binary theories, wrote in 1913,

> "If the new theory came to be established on independent evidence, we should be compelled to contemplate the necessity of giving up the hypothesis of binary systems as a common type among stars. On the contrary, it would be more plausible to attribute the vibration to a mere radial pulsation in the atmosphere of the star. For particular classes of variables this alternative theory would appear entirely feasible, and there is nothing against it in the case of an ordinary star which shows only one spectrum."

The most decisive arguments against the almost universal binary hypotheses came the following year from Harlow Shapley (1885–1972), who stated,

> "It seems a misfortune, perhaps, for the progress of research on the causes of light variation of the Cepheid type, that the oscillations of the spectral lines in nearly every case can be so readily attributed, by means of the Doppler principle, to elliptical motion in a binary system."

In the case of some giant stars he found that the binary hypothesis led to the inconcievable conclusion that the orbit of the system had a diameter only one tenth of the radius of the star itself! The pulsation theory was finally put on a sound mathematical basis by Eddington in 1926.

Class V (Algol Stars). Algol was only the second variable, apart from Novae, to have been discovered, by G. Montanari (1633–1687) in 1667; but it was the first for which a correct interpretation was tentatively offered by the eighteen-year-old Goodricke, who, in 1783 reported to the Royal Society,

> "I should imagine it could hardly be accounted for otherwise than by the interposition of a large body revolving about Algol, or some kind of motion of its own whereby part of its body, covered with spots or such like matter, is periodically turned toward the earth."

His binary theory was not generally favored when it was found that it implied large stars close together, in contrast to the wide separation of well known visual double stars. J. Ashbrook (1918–1980) at the 60th anniversary of the AAVSO recalled that E. C. Pickering in 1881 gave the first "solid evidence" that Algol and U Cephei are eclipsing binaries. This was fully substantiated in 1889 by H. C. Vogel's (1841–1907) spectroscopic determination of the orbital elements and dimensions of the components.

By 1900 approximately 25 Algol-type eclipsing binaries had been discovered. Some anomalies in their spectra or light curves were detected, but no evidence was yet found for an assumed third body. It was believed that the two component stars could be deformed by rotation; hence further spectrographic investigations were advocated, and these led to many fundamental discoveries during the following decades.

PARTIAL BIBLIOGRAPHY
of Materials Cited or Consulted

Ashbrook, J. 1968, "C. Pulfrich, A Short Footnote to Lunar History," **Sky and Telescope, 35**, 215.

----------1971 "Variable Star Observing in America before AAVSO," **AAVSO Abstracts**, 1-3.

Arago, D. F. J. 1842, "Analyse historique et critique de la Vie et des Travaux de Sir William Herschel," **Annuaire presenté au Roi par le Bureau des Longitudes**, Paris, 249-608.

---------- 1855, "Popular Astronomy," translated from the French by W. H. Smythe and R. Grant, London, **1**, 249-274.

Argelander, F. W. A. 1843, **Uranometria Nova**, Berlin.

---------- 1844, "Aufforderung an Freunde der Astronomie," **Schumacher's Jahrbuch**, 122-254, section on variable stars, 207-254. Translated from the German by Annie J. Cannon, 1912, **Pop. Ast., 20**, 91-99, 148-156, 207-217; also reprinted in part in Shapley and Howarth, "A Source Book in Astronomy," 229-237.

---------- 1859-1862, **Bonner Durchmusterung**, originally called "Bonner Sternverzeichniss," Vols.1-3, with supplementary volume, 1886, by E. Schönfeld for stars -2° to -23°.

---------- 1869, "Beobachtungen und Rechnungen über veränderliche Sterne," **Bonn Beobachtungen, 7**, 315-517.

Bailey, S. I. 1902, "Variable Stars in the Cluster ω Centauri," **Harvard Ann., 38**, 252pp.

Belopolsky, A. A. 1897, "Researches on the Spectrum of the Variable Star η Aquilae," **Astrophys. Jour., 6**, 393-399.

Birmingham, J. 1878, "The Variability of Stars," **Observatory, 1**, 17-18.

---------- 1878, "The Red Stars, Observations and Catalogue," **Trans. Roy. Irish Acad., 26**, No. 7. Reviewed in **Observatory, 1**, 371-373.

Boulliau, I. 1682, "Astronomia Philolaica." *See* R. Wolf, 1872, p. 365.

Brahe, Tycho 1573, "De Nova Stella," 52pp; translation by J. H. Walden, 1928; *reprinted in part by* Shapley

and Howarth (1929), **A Source Book in Astronomy**, 13–19.

Campbell, L., and Jacchia, L. 1941, **The Story of Variable Stars**, Philadelphia, 226pp.

Campbell, W. W. 1899, "Notes on the Spectrum of o Ceti," **Astrophys. Jour., 9**, 31–36.

Cannon, A. J. 1919, "Edward Charles Pickering," **Pop. Ast., 27**, 177–183.

Clerke, A. M. 1902, **History of Astronomy During the Nineteenth Century**, fourth ed., London, 489pp.

---------- 1903, **Problems in Astrophysics**, London, 567pp.

---------- 1905, **The System of the Stars**, London, 403pp.

---------- 1905, **Modern Cosmogonies**, London, 287pp.

Eddie, L. A. 1895, "The Short Period Variable δ Cephei," **Astrophys. Jour., 3**, 227–8.

Eddington, A. 1926, **The Internal Constitution of the Stars**, Cambridge, England, 407pp.

Fleming, W. P. 1907," A Photographic Study of Variable Stars," (Sequences for 222 variable stars) **Harvard Ann. 47**, 1–113.

---------- 1912, "Photographic Magnitudes of 107 Variable Stars of Long Period," ***ibid.***, 119–280.

---------- 1912, "Stars Having Peculiar Spectra," **Harvard Ann., 56**, 165–226.

Furness, C. 1915, **Introduction to the Study of Variable Stars**, Boston and New York, 327pp.

Goodricke, J. 1783, "A Series of Observations on, and a Discovery of, the Period of the Variation of the Light of the Bright Star in the Head of Medusa, Called Algol," **Phil. Trans., 73**, 474–482; *abridged version reprinted in* Shapley and Howarth (1929), **A Source Book in Astronomy**, 152–154.

---------- 1784, "On the Periods of the Changes of Light in the Star Algol," **Phil. Trans., 74**, 287–292.

---------- 1785, "Observations of a New Variable Star" (β Lyrae) ***ibid.***, **75**, 153–164.

---------- 1786, "A series of Observations on, and a Discovery of, the Period of the Variation of the Light of the Star Marked δ by Bayer, Near the Head of Cepheus," ***ibid.***, **76**, 48–61.

Hagen, J. G. 1899–1908, **Atlas Stellarum Variabilium** (six series), Berolini, Italy.

Hartwig, E. 1899, "Ephemeriden Veränderlicher Sterne für 1900," **Vierteljahrschrift der Ast. Gesellschaft, 34**, 315.

Herschel, John F. W. 1838, "Descriptions of η Argus and the Magellanic Clouds," Results of Observations at the Cape of Good Hope, 1834–1838; *reprinted in* Shapley and Howarth (1929), **A Source Book in Astronomy**, 238–244. *See also* Hoffleit 1984.

---------- 1849, "Outlines of Astronomy," Philadelphia, 488–495, 520–529.

Herschel, F. Wilhelm 1780, "Astronomical Observations on the Periodical Star Collo Ceti," **Phil. Trans., 70**, 338–344.

---------- 1796, "On the Method of Observing the Changes that Happen to the Fixed Stars; with some Remarks on the Stability of the Light of our Sun. To which is added a Catalogue of Comparative Brightness for Ascertaining the Permanency of the Lustre of Stars," ***ibid.*, 86**, 166–226.

---------- 1796, "On the Periodical Star α Herculis; with Remarks Tending to Establish the Rotatory Motion of the Stars on Their Axes. To which is Added a Second Catalogue of the Comparative Brightness of Stars, ***ibid.*, 86**, 452–482.

---------- 1797, "A Third Catalogue of the Comparative Brightness of the Stars; with an Introductory Account of an Index to Mr. Flamsteed's Observations of the Fixed Stars Contained in the Second Volume of the **Historia Coelestis**. To which are Added Several Useful Results Derived from That Index," ***ibid.*, 87**, 293–324.

----------1799, "A Fourth Catalogue of the Comparative Brightness of the Stars," ***ibid.*, 89**, 121–144.

Hind, J. R. 1852, "Auszug aus einem Schreiben des Herrn Hind an die Redaction," **Ast. Nachrichten, 35**, 371.

Hoffleit, D. 1984, "Elias and Francis Loomis on Variable Stars, 1866–69," **Jour. A. A. V. S. O., 13**, 67–77.

Ho Peng Yoke 1962, "Ancient and Mediaeval Observations of Comets and Novae in Chinese Sources," **Vistas in Astronomy, 5**, 127–226.

Huggins, W. 1866, "On a New Star," **Mon. Not. Roy. Ast. Soc. 26**, 276.

Humboldt, A. von 1850, **Cosmos, 3**, Stuttgart and Tübingen, Chapter IV, 215–262; translation from German by E. C. Otte, London, 1880, **3**, Chapter IV, 201–247.

Kapteyn, J. C. *See* Pickering, 1917, 1923 and Sears 1930.

Klinkerfues, E. F. W. 1865, "Ueber den Lichtwechsel der Veränderlichen," **Nachr. d. K. Gesellschaft d. Wissenschaften u. d. Georg–Augusts Univ., Göttingen, 21**, 1–9.

---------- 1879, "Der Wunderbau des Weltalls," (revision of an earlier 1855 text of same title by J. H. von Mädler) Berlin, 479–495.

Kopal, Z. 1974, "Pigott, Edward and Pigott, Nathaniel," **Dictionary of Scientific Biography, 10**, 607–608.

Kukarkin, B. V., *et al.* 1969–71, **General Catalogue of Variable Stars,** Moscow, vols. I–III, and Supplements, 1971, 1974, 1976.

Kukarkin, B. V., and Kholopov, P. N., *et al.*, 1982, **New Catalogue of Suspected Variable Stars**, 360pp.

Leavitt, H. 1912, "Periods of 25 Variable Stars in the Small Magellanic Cloud," **Harvard Circ. No. 173**, 3pp.

-------- 1917, "The North Polar Sequence," **Harvard Ann.,71**, 47–232.

-------- 1917, "Harvard Standard Regions," ***ibid.***, 233–314.

Lockyer, J. N. 1890, **The Meteoric Hypothesis**, London, 327, 472.

Ludendorff, H. 1928, "Die Veränderlichen Sterne," **Handb. der Astrophys., Berlin, 6**, 251–198.

Luyten, W. J. 1938, "A Catalogue of 2350 Variable Stars Found with the Blink Microscope," **Pub. Ast. Obs. Univ. Minnesota, 2**, No. 6, 79–119.

Lynn, W. T. 1883, "The Star of 1572," **Observatory,** 6, 126, 151–152.

Metcalf, J. H. 1919, "Edward Charles Pickering," **Vierteljahrschrift der. Ast. Gesellschaft, 54**, 274–278.

Müller, G. and Hartwig, E. 1918–1922, **Geschichte und Literatur des Lichtwechsels,** Vols. I – III.

Müller, G. and Kempf, P. F. F. 1894, "Photometrische Durchmusterung," **Potsdam Pub., 9**, 501pp. and 1898, ***ibid.***, **13**, 465pp. *Reviewed in* J. G. Hagen (1899), **Vierteljahrschrift der Ast. Gesellschaft, 34**, 288–297.

Myers, G. W. 1898, "The System of β Lyrae," **Astrophys. Jour.**, **7**, 1–22.

Olcott, W. T. 1920, "Memorial to Edward Charles Pickering," published by the AAVSO, 18pp.

Packer, D. 1890, "On a New Variable Star near the Cluster 5M Librae," **The Sidereal Messenger**, **9**, 381.

-------- 1891, "New Variable Stars Near the Cluster 5M Librae," ***ibid***, **10**, 107.

Peirce, C. S. 1878, "Photometric Researches Made in the Years 1872–1875," **Harvard Ann.**, **9**, 181pp.

Pickering, E. C. 1881, "Dimensions of the Fixed Stars, with Especial Reference to Binaries and Variables of the Algol Type," **Proc. Am. Acad. Arts and Sci.**, **16**, 1–37. *Review in* **Observatory**, **4**, 116–121.

---------- 1881, "Variable Stars of Short Period," ***ibid.***, 257–284; *also in* **Observatory**, **4**, 225–231, 264–272, 284–295.

---------- 1881, "New Variable Star in Puppis," **Ast. Nachrichten**, **100**, 13–14.

---------- 1882, "The Wedge Photometer," **Proc. Am. Acad. Arts and Sci.**, **17**, 231–233.

---------- 1882, "A Plan for Securing Observations of the Variable Stars," Pamphlet, privately published, 15pp.

---------- 1883, "Instructions for the Observation of Variable Stars," **Observatory**, **6**, 114–116.

---------- 1883, "Extract from Professor Pickering's Address before a Late Meeting of the Liverpool Astronomical Society," **The Sidereal Messenger**, **2**, 281–283.

---------- 1883, "The Wedge Photometer," **The Sidereal Messenger**, **1**, 105–108.

---------- 1884, "Sir William Herschel's Observations of Variable Stars," **Proc. Am. Acad. Arts and Sci.**, **19**, 269–278.

---------- 1884, "Recent Observations of Variable Stars," ***ibid.***, 296–309.

---------- 1885, "Observations with the Meridian Photometer," **Harvard Ann.**, **14**, 512pp.

---------- 1890, "Discussion of the Uranometria Oxoniensis," ***ibid.***, **18**, 15–27.

---------- 1890, "Index to Observations of Variable Stars," ***ibid.***, 214–258, 303–308.

---------- 1891, "Variable Stars of Long Period," Cambridge, Mass., privately pub., 4pp.

---------- 1891, "Spectrum of β Lyrae," **Ast. Nachrichten, 128,** 39–42; **Obs., 14,** 341.

---------- 1895, "Variable Star Clusters," **Harvard Circ.** No. 2, 2pp.

---------- 1898, "Variable Stars in Clusters," ***ibid.***, No. 33, 4pp.

---------- 1900, "Observations of Variable Stars by Argelander," **Harvard Ann., 33,** 29–74.

---------- 1900, "Observations by Schönfeld," ***ibid.***, 75–93.

---------- 1900, "Observations by Schmidt," ***ibid.***, 95–133.

---------- 1901, "Variable Stars of Long Period," **Haarlem Arch. Nederland. Sci. Exac. et Nat., (2), 6,** 133–136.

---------- 1903, "A Provisional Catalogue of Variable Stars," **Harvard Ann., 48,** 91–123.

---------- 1908, "Revised Harvard Photometry," ***ibid,***. **50,** 252pp.

---------- 1909. "Durchmusterung Zones Observed with the Twelve Inch Meridian Photometer," ***ibid.***, **70,** 235pp.

---------- 1929, *Excerpts from papers of 1881 and 1891 in* Shapley and Howarth (1929), **A Source Book in Astronomy,** 372–376.

Pickering, E. C. and Kapteyn, J. C. 1917, "Durchmusterung of Selected Areas" (0° to +90°, S.A. 1–115), **Harvard Ann., 101,** 368pp.

Pickering, E. C., Kapteyn, J. C., and Van Rhijn, P. J. 1923, "Durchmusterung of Selected Areas," (–15° and –30°, S.A. 116–163), ***ibid.***, **102,** 276pp.

Pickering, W. H. 1894, "A Study of Nova Aurigae and Nova Normae," **Ast. and Astrophys., 13,** 201–204.

---------- 1901, "Nova Persei," ***ibid.***, **13,** 277–278.

Pigott, E. 1785, "Observations of a New Variable Star" (η Aquilae), **Phil. Trans., 75,** 127–136.

------- 1786, "Observations and Remarks on Those Stars Which the Astronomers of the Last Century Suspected to be Changeable," ***ibid.***, **76,** 189–219.

------- 1797, "On the Periodical Changes of Brightness of Two Fixed Stars," ***ibid.***, **87,** 133–141.

------- 1805, "An Investigation of all the Changes in the Variable Star in Sobieski's Shield, from Five Years' Observations, Exhibiting its Proportional Illuminated Parts, and Its Irregularities of

Rotation; with Conjectures Respecting Unenlightened Heavenly Bodies," *ibid.*, **95**, 131–154.

------- *Also see* Kopal 1974.

Pogson, R. N. 1908, "Observations on Thirty-one Variable Stars," **Mem. Roy. Ast. Soc.**, **58**, xxxv + 143pp.

Pritchard, C. 1885, "On Dr. Wilsing's Experimental Examination of the Wedge Photometer, *and* (II.) On the Degree of Accuracy Attainable by Means of that Instrument," **Mon. Not. Roy. Ast. Soc.**, **46**, 2–18.

---------- 1885, **Uranometria Nova Oxoniensis**, Oxford, 117pp.

Plummer, C. H. 1914, "Note on the Velocity of Light and Doppler's Principle," **Mon. Not. Roy. Ast. Soc.**, **74**, 660–663.

Pulfrich, C. 1901, "Ueber einige stereoskopische Versuche," **Zeitschrift f. Instrumentenkunde**, **21**, 221–224.

--------- 1902, "Ueber neuere Anwendungen der Stereoskopie und über einen hierfür bestimmten Stereo-Komparator," *ibid.*, **22**, 65–81.

--------- 1904, "Ueber die Nutzbarmachung des Stereo-Komparators für den monokularen Gebrauch und über ein hierfür bestimmtes monoculares Vergleichs-Mikroskop," *ibid.*, **24**, 161–166.

--------- 1910, "Ueber die Nutzbarmachung des Stereo-Komparators für photometrische und spektrographische Messungen und für die Messung von Sterngrössen," *ibid.*, **30**, 1–6.

--------- *See* Ashbrook 1968.

Ritter, A. 1878–1889, "Untersuchungen über die Höhe der Atmosphare und die Constitution gasformiger Weltkorper," **Ann. d. Physik und Chemie, neue Folge**, **5 – 36**.

-------- 1879, *ibid.*, **8**, 157–183, *esp. the section* "Lichtwechel der veränderlichen Sterne," 179–183.

-------- 1881, *ibid.*, **13**, 360–377, *esp. pp.* 366–371.

Roberts, A. 1895, "Close Binary Systems and Their Relation to Short Period Variations," **Astrophys. Jour.**, **2**, 283–292.

Safarik, A. 1888, "Ueber den Lichtwechsel einiger Sterne aus der Bonner Durchmusterung und aus Schjellerup's und Birmingham's Catalogen rother Sterne," **Ast. Nachrichten**, **120**, 277–282.

Schwarzschild, K. 1900, "Die Veränderlichen β Lyrae und η Aquilae," **Pub. Kuffner Obs.**, Wien, **5**, c,

100–138.

Sears, F. H., Kapteyn, J. C., and van Rhijn, P. J. 1930, "Mount Wilson Catalogue of Photographic Magnitudes in Selected Areas 1–139," **Carnegie Inst. Washington Pub**. No. 402.

Secchi, P. A. 1866, "Nouvelles Recherches sur l'Analyse Spectrale de la Lumière des Etoiles," **Comptes Rendus, Acad. Sci., Paris, 66**, 621–628.

---------- 1867, **Catalogo delle Stelle di cui si e Determinato lo Spettro Luminoso**, Parigi, 32pp., *esp*. p.21.

---------- 1868, **Spettri Prisma delle Stelle Fisse**, Rome, 48pp.

Shapley, H. and Howarth, H. E. 1929, **A Source Book in Astronomy**, pp. 13–19, 152–154, 229–244, and 372–376.

Steavenson, W. H. 1931, "Variable and 'New' Stars," in T. E. R. Phillips and W. H. Steveanson, **Splendours of the Heavens**, New York, Ch. 15, pp 584–614.

Stratton, F. J. M. 1928, "Novae," **Handb. d. Astrophys., Berlin, 6**, 251–298.

Strohmeier, W. 1977, "Variable Stars, Their Discoverers and First Compilers from 1006 to 1975," **Veroff. d. Remeis–Sternwarte Bamberg Ast. Inst. der Univ. Erlangen–Nürnberg, 12**, No. 129, 27pp.

Sutton, P. R. 1911, "A Review of Some Theories Advanced in Explanation of the δ Cephei Type of Variable," **Pop. Ast., 19**, 408–414.

Thomas, H. L. 1948, "The Early History of Variable Star Observing to the XIX Century,". Ph.D. Thesis, Radcliffe College. (Cited by permission of author.)

Todd, D. P. 1905, **Stars and Telescopes**, Boston, 254–272.

van Rhijn, P. *See* Pickering 1923, Sears, 1930.

Vogel, H. C. 1889, "Spektrographische Beobachtungen an Algol," **Ast. Nachrichten, 123**, 289–292.

Waterfield, R. L. 1838, **A Hundred Years of Astronomy**, New York, 239–279.

Wendell, O. C. 1900, "Circumpolar Variables," **Harvard Ann., 37**, 1–144.

---------- 1902, "Fifty–Eight Variable Stars of Long Period," **ibid.**, 147–281.

Wolf, M. 1901, "Die Verwendung des Stereocomparators in der Astronomie," **Ast. Nachrichten, 157**, 80–86.

Wolf, R. 1852, "Vergleichung der Sonnenfleckenperiode mit

den Lichtperioden der Veränderlichen," **Mitt. Naturwissen. Gesell., Bern, 3**, 261.

------- 1852, "Beobachtungen von Sonnenflecken 1851 und der totalen Mondfinsterniss 1852 Januar 6 auf der Berner Sternwarte," **Ast. Nachrichten, 34**, 159–160.

------- 1872, "Die Veränderlichen und neuen Sterne," **Handb. der Math., Phys., Geodasie, und Astron., Zürich, 2**, 364–370.

Yoke, Ho Peng. *see* Ho Peng Yoke.

TABLE I

Discovery of Novae

Year	*Number*	*Total*
2296BC	1	1
2241	1	2
1400	1	3
600–0BC	9	12
0–1000AD	61	73
1000–1500	43	116
1500–1550	1	117
1550–1600	4	121
1600–1650	7	128
1650–1700	8	136
1700–1750	0	136
1750–1800	1	137
1800–1850	2	139
1850–1875	4	143
1875–1900	18	161
1900–1925	42	203
1925–1950	64	267
1950–1975	73	340
Total	340	

TABLE II

Variables Other Than Novae Discovered before 1800

Year	*Name*	*Type*	*Discoverer*
1596	o Cet	M	D. Fabricius
1667	Algol	EA	G. Montanari
1670	R Hya	M	Suspected by Montanari, re-discovered 1704 by G. F. Maraldi
1676	X Sgr	δ Cep	Suspected by E. Halley, rediscovered by J. Schmidt 1866
1686	χ Cyg	M	G. Kirch
1780	R Leo	M	J. A. Koch
1784	β Lyr	EB	J. Goodricke
1784	δ Cep	δ Cep	J. Goodricke
1784	η Aql	δ Cep	E. Pigott, possibly already discovered by J. Byrgius in 1612
1787	44i Boo	EW	W. Herschel
1795	α Her	SRc	W. Herschel
1795	R CrB	RCr	E. Pigott
1795	R Sct	RVa	E. Pigott

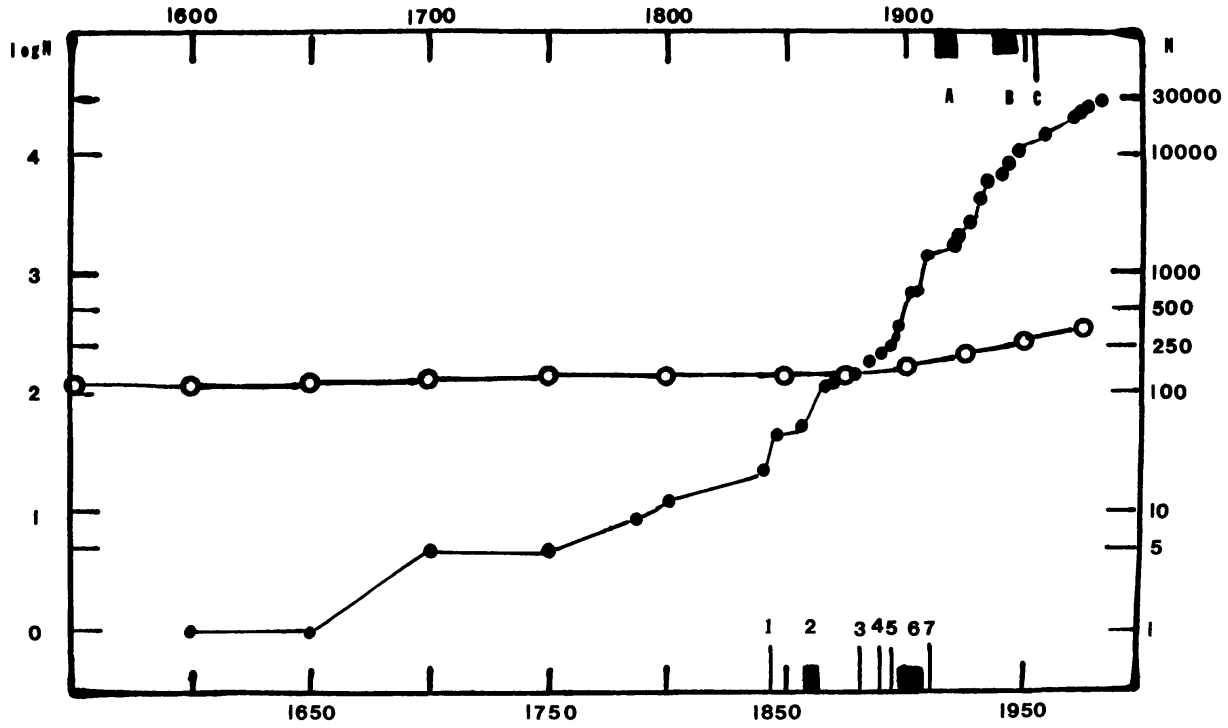

Figure 1. Total numbers of novae (open circles) and ordinary variables (dots) discovered by 1550 to 1975. Marked at top, deterrents to further discovery: A) World War I; B) World War II; C) discontinuance of routine photographic discovery programs at Harvard Observatory. Marked at bottom, incentives to further discovery: 1) Argelander's **Uranometria Nova**; 2) the **Bonner Durchmusterung**; 3) beginning of systematic photographic work at Harvard Observatory; 4) organization of British Astronomical Association with a Variable Star Section; 5) first discoveries of variable stars by their spectra; 6) Hagen's **Atlas Stellarum Varibilium**; and 7) founding of the AAVSO.