# THE MILTON BUREAU REVISITED

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**Abstract**

Under the direction of Cecilia Payne-Gaposchkin and Sergei Gaposchkin, a program was subsidized by the Milton Fund of Harvard Observatory in 1937 for the study of all variable stars then known to be brighter than tenth photographic magnitude at maximum. This included some 1512 stars for which a grand total of 1,263,562 estimates of magnitude were made, ranging from a low of 16 (except for a few novae) to 4084 observations per star. The sky had been divided into 54 fields, and the results of the measurements presented field by field in two volumes of the *Annals* of Harvard Observatory. Then, in another volume, the results were discussed in four sections, each dealing with a particular class of variable: 1, those of RV Tauri type; 2, the eclipsing variables; 3, Cepheids and RR Lyrae variables; and 4, the red variables, especially Mira-type and semiregular variables.

For the present paper, many of these results have been compared with modern determinations in the 1985–87 version of the *General Catalogue of Variable Stars* (GCVS). In particular, there are numerous instances of disagreement as to whether a star should be classified RV or SR. Although there are many instances where the Milton Bureau determinations of types of variability differ from the types given in modern catalogues, the reasons for the differences are generally understandable.

For 17 RV Tauri type stars in this survey multiple periods have now been determined. Many of these still deserve continued observations in order to ascertain the constancy of the periods and improve the accuracy of their longest reported periods.

## 1. Introduction

The Harvard collection of photographic plates was started by Director E. C. Pickering in 1882. One of his purposes was for the study of variable stars. Later he reported (Pickering 1904; Shapley 1943): “A satisfactory plan has been prepared for organizing a corps of observers at a cost of about five thousand dollars a year, for studying these photographs.” The Carnegie Institution assigned $2500 for the first year, but this was not renewed, and this systematic variable star project had to be discontinued. However, Pickering (1904) reported that some 9000 measurements had been made at that time on four Algol-type eclipsing variables at minimum. These served as the basis of Russell and Shapley’s investigations of the light curves of eclipsing binaries (Shapley 1912a, 1912b).

In the late 1930’s, at a “Hollow Square” conference , Cecilia Payne-Gaposchkin reminded the audience of Pickering’s intended project and proposed that it be resumed. (At the observatory, regular weekly colloquia were occasionally replaced by “hollow squares,” long narrow tables arranged in a square so that all participants could see one another. Instead of one long lecture, short reports on current matters were discussed informally.) Payne-Gaposchkin proposed that all variable stars known in 1936 to reach photographic magnitude brighter than 10.0 at maximum (Schneller 1936) should be examined on the Harvard patrol plates. Shapley responded favorably to her suggestion. The Milton Fund of Harvard University, which had previously supported a number of other projects (on variable stars, meteors, and solar eclipse expeditions), was applied to the establishment in 1937 of the "Milton Variable Star Bureau" with Cecilia Payne-Gaposchkin and her husband Sergei in charge (Shapley 1939). With the collaboration of 29 part-time assistants, the project was completed in 1953, much of the work having been delayed during WWII.

## 2. The program

The sky was divided into 54 fields in seven zones 30° wide in declination: Field 1 at the north galactic pole; Field 54 at the south galactic pole. The plates to be examined were made with 1.5-inch Cooke lenses: AC series in the northern hemisphere, first at Cambridge, later at the Oak Ridge station; AM in the southern Hemisphere, first at Arequipa, Peru, later at Bloemfontein, South Africa. The scale of the photographs was 600"/mm and the 8 x 10-inch plates covered 35° in declination. Most plates reached a limiting magnitude of 12pg, but some went to 14pg. The earliest plates were taken in 1898, the latest used in 1947.

Work was begun at the south pole and continued toward the north. This was because less was then known about the southern than the northern variables. Summaries of the results were published for stars in fields 54 to 28 in *Harvard Annals* Volume 115, and for fields 27 to 1 in *Harvard Annals* Volume 118, both completed in 1952 (Payne-Gaposchkin and Gaposchkin 1952a, 1952b). These volumes did not include all the individual observations, but summarized dates of maxima and minima, giving types of variability and periods where applicable. Results were based on a total of 1,263,562 estimates of magnitude for 1512 stars. *Harvard Annals* Volume 113 included four sections (Table 1), each devoted to a more detailed discussion of a particular class of variable: No. 1 (Payne-Gaposchkin *et al.* 1943), RV Tauri types; No. 2 (Gaposchkin 1953), eclipsing binaries; No. 3 (Payne-Gaposchkin 1954a), Cepheid and RR Lyrae stars; and No. 4 (Payne-Gaposchkin 1954b), red variables (including mainly Mira type and semiregular variables). This volume included many stars not represented in Volumes 115 and 118. Thus Volume 113 includes 53 variable stars not listed in the Index of the 54 fields in Volume 118.

Numerous of the selected stars were questioned as to their variability, and for others the assigned class of variability was questioned. The frequencies of these are summarized in Table 2 (left half). At the time of compilation of the stars to be measured, the numbers of categories of types of variability adopted were more limited than now. The Gaposchkins used only eleven categories, whereas the current GCVS uses over 100 classes or sub-classes. Those used by the Gaposchkins in their Milton Bureau surveys were the following : Long, Semi, RV, Irr, Cep, RR, Ecl, R CrB, U Gem, Z Cam, and Nova. All of the questioned items have been compared with the modern GCVS (Kholopov *et al.* 1985–87; Samus *et al.* 1990). Of the 103 items for which the variability was questioned, 36 have now been confirmed as variable and types assigned. Of the 43 whose types were questioned (right half of Table 2), 21 are accordant with modern classifications, 16 are discordant with the GCVS (Table 3), while the rest are still dubious. (In the tables I have translated the Gaposchkins' notation from "Long" to "Mira," and from "Semi" to "SR.")

I have made a random selection of 100 variables, one or two in each of the 54 Fields, to ascertain approximately what percentage of the stars whose classification was not questioned in the Milton Bureau's results appear to be misclassified. Among these only two gave classes discordant with those in the GCVS, namely: RR Ant,

Table 1. Numbers of variable stars in major categories.

| *Type* | *Milton* | *HA 113* | *Analysis* | *Light curves* | |
|---|---|---|---|---|---|
| | | | | *Single* | *Mean* |
| RV | 22 | 14 | 14 | 11 | 0 |
| E | 283 | 281 | 281 | 281 | 0 |
| Cep | 128 | 132 | 240 | 127 | 16 |
| W Vir | 9 | 9 | 9 | 0 | 0 |
| RR Lyr | 51 | 84 | 89 | 0 | 15 |
| M | 398 | 390 | 95 | 46 | 0 |
| SR | 339 | 313 | 78 | 47 | 0 |
| Irr | 39 | 2 | 0 | 2 | 0 |

Table 2. Numbers of stars questioned as to variability or type of variation.

| *Categories* | *Number* | *Type Questioned* | *Number* |
|---|---|---|---|
| Non Existent | 1 | Eclipsing | 6 |
| Var? | 49 | Long Period | 4 |
| Not Variable | 25 | Cepheid | 2 |
| cst | 4 | Cluster type | 1 |
| cst? | 3 | Small range | 1 |
| Undefined | 2 | Semiregular | 16 |
| ? | 8 | Irregular | 7 |
| blank | 10 | Regular? | 1 |
| too faint | 1 | Periodic? | 1 |
| | | Nova | 3 |
| | | Ellipsoidal | 1 |
| TOTALS | 103 | | 43 |

changed from SR to Lb, and AO Vir, from SR to M. A sampling of another 100 stars in eight randomly selected fields indicated 8 stars, or only 8%, showing discordant classifications (second part of Table 3). The two constellations with the most named variables in the Index of HA 118 are Cygnus with 70 stars and Sagittarius with 79. Of these, 9 in Cygnus and 2 in Sagittarius had not yet had types assigned in HA 118. Of the remainder, 6 in Cygnus and 2 in Sagittarius were discordant with the more recent GCVS-assigned classes. Thus, among 338 stars examined, the Milton Bureau classifications differ from the modern for only about 24 stars, or 7%. However, many of those discordances could be understood if the time-span of one of the series of observations being interpreted were relatively short, for example, making the differentiation between Irregular and SR, or between SR and RV, unclear. Indeed, the star UU Her, which Payne-Gaposchkin includes as one of her RV Tauri stars, Zsoldos *et al.* (1993) describe as a "double-mode semiregular variable."

Table 4 gives a list of some of the differences in classification of type of variability assigned before the Gaposchkins undertook their extensive survey (Schneller 1936), the types asssigned by the Gaposchkins at the time of their measurements of the magnitudes, their subsequent assignments in their Index after the survey was completed, and the classes adopted in their final analyses where the stars were arranged by type of variability, and finally the designations in the 1985–87 edition of the GCVS. Confusion between naming a variable SR or RV appears to be quite frequent.

Table 3. Questioned classifications as revised in GCVS.

| *Types Assigned by Milton Bureau* | *GCVS* |
|---|---|
| *1st Two Samples of 100 Stars Each* | |
| Eclipsing (2) | Isa, S Dor |
| Long period = M (3) | 2 SRa, 1Int |
| Semi = SR (7) | 4 Lb, 1each Lc, Ia, E+Nl |
| Cepheid (1) | SRd |
| Cluster type = RR (1) | $\delta$ Sct |
| I (1) | cst: |
| Regular (1) | SR |
| TOTAL 16 | 8% |
| *3rd Sample from 149 stars in Cygnus and Sagittarius* | |
| Eclipsing (2) | Cep, RV |
| M (1) | SRa |
| SR (4) | 2 Lb, 1 M, 1 Z And |
| I (1) | SRb |
| TOTAL 8 | 5% |

Although the expected limiting magnitude at maximum was intended to be 10.0p, nearly 500 of the stars examined by the Milton Bureau turned out to be fainter than this limit. Seven stars are included in the Gaposchkins' final lists that have been found to have magnitudes at maximum fainter than 13.0p. These are very red stars: four are modern spectral class C (formerly called N type spectra), and no spectral classes are known for the other three (YZ CrA, Mira type; AY Mon, eclipsing; and S Tel, type of variability unknown).

In his analysis of the eclipsing variables, Sergei Gaposchkin comments that the fact that so many stars are fainter than the initially-prescribed limiting magnitude at maximum "is a commentary on the unreliability of the magnitudes in catalogues of variable stars." To a considerable extent this is certainly true. However, a major reason for the large numbers of discrepancies in these Milton Bureau limiting magnitudes may be ascribed to the fact that only visual magnitudes had been available for these stars in 1937. The Gaposchkins converted the visual to tentative photographic by applying standard color indices to those stars for which spectral classes were available, or where the color indices might be inferred from the types of variability. This procedure is at best uncertain, especially for stars in the Milky Way where color excess was not yet well understood in the late 1930's. A sampling of 150 of the long period variables (HA 113 Part 4) yielded 51 that have magnitudes at maximum fainter than 10.00. Of these, 23 had only visual magnitudes in the 1937 general catalogue (Schneller 1936). The (p-v) differences (Gaposchkin results minus the early visual) range from 1.5 to 4.7, with an average of 2.5. The stars for which early photographic magnitudes had been available have differences (new minus old) ranging from -0.7 to + 2.1, averaging +1.1. The results for neither group are good by modern standards, but the assumed color indices obviously gave much the poorer predictions as to which stars would lie within the specified limiting photographic magnitudes.

Table 5 indicates the total numbers of variables represented in each of the four sections of HA113, and the corresponding numbers that are fainter than the

Table 4. Some revisions of assigned types.

| *Name* | *1937* | *Fields* | *Index* | *HA 113* | *GCVS* |
|---|---|---|---|---|---|
| Z And | Nova? | SR or Nova | Nova | SR+Nova | Z And |
| RR Ant | Unknown | SR | SR | SR | Lb |
| AC Aqr | No Type* | Cep? | Cep? | — | SRd |
| BS Aqr | RR | RR | RR | — | δ Sct |
| CY Aqr | RR | RR | RR | — | SX Phe |
| S Aql | No Type* | M | M | M | SRa |
| GY Aql | No Type* | SR | RV** | SR | SR |
| RY Ara | Unknown | SR | SR | SR | RV |
| S Aur | No Type* | M | M | M | SR |
| UY CMa | No Type* | SR | RV | RV | SRd |
| T Cen | M | M | M | M | SRa |
| RU Cen | RV? | E | E | E | RV |
| XY Cen | Unknown | SR | SR | — | Lb |
| V644 Cen | — | — | — | E | γ Cas |
| W Cep | Irr | SR or Irr | — | SR | SRc |
| S Crv | Irr | SR | SR | SR | Lb |
| U Crv | No Type* | SR | SR | SR | M |
| XX Cyg | RRb | — | — | RR | SX Phe |
| AD Cyg | Irr? | SR | SR | — | Lb |
| AX Cyg | Unknown | SR? | SR | SR | Lb |
| BF Cyg | Unknown | SR | SR | SR | Z And |
| CH Cyg | No Type* | SR | SR | SR | Z And+SR |
| CY Cyg | Irr | SR | SR | — | Lb |
| V369 Cyg | No Type* | SR | SR | SR | M |
| P Cyg | Nova | Nova | Nova | — | S Dor |
| S Dor | Irr | E? | E? | E | S Dor |
| SS Gem | RV | SR | SR | RV | RVa |
| AB Gem | Unknown | Var? | SR? | — | Lb |
| UU Her | Dbl. Per.* | SR | RV | RV | SRd |
| CE Her | RR | — | — | RR | CWB |
| RW Hya | No Type* | SR | SR | SR | Z And |
| XY Lyr | Irr | Irr | SR | — | Lc |
| U Mon | RV | SR | SR | RV | RVb |
| UY Mon | β Lyr | E | E | E | δ Cep |
| AX Per | Irr | SR | Irr | SR | Z And |
| FN Sgr | Novalike | Nova | Nova | — | Z And |
| V540 Sgr | Irr | SR | SR | SR | Lc |
| V1017 Sgr | — | Nova | Nova | — | Z And |
| AI Sco | Dbl. Per.* | SR | RV | Dbl. Per. | RVb |
| Y Scl | Irr | Irr | Irr | SR | SRb |
| VY Tau | Unknown | M: | M: | M: | Int |
| RW Vir | Irr | SR? | SR? | SR | Lb |
| AO Vir | No Type* | SR | SR | SR | M |
| CE Vir | — | SR | SR | SR | RV: |
| S Vul | No Type* | Cep? | RV | — | δ Cep |
| V Vul | RV | SR | RV | RV | RVa |

** Periods given, but no types assigned. ** Probably error.*

anticipated 10.00p limit for maxima. Whereas for Volumes 115 and 118 the measurements were held strictly to the stars that were expected to be brighter than this limit, Numbers 2–4 of HA 113 included stars known to be fainter, without specifying by what criteria they had been chosen for measurement.

Table 5 . Summary of major types of variables in HA 113.

| *HA 113* | *Type* | *No.* | *No. Fainter than 10.00p* | *Remarks* |
|---|---|---|---|---|
| I. 1943, C. P. G. | RV Tau | 14 | 3 | |
| II. 1953, S. G. | Eclipsing | 281 | 68 | |
| III. 1954, C. P. G. | Cepheids | 135 | 21 | |
| | W Vir | 9 | 2 | |
| | RR Lyr | 84 | 61 | No magnitudes in HA 113* |
| IV. 1954, C. P. G. | Mira | 390 | 116 | |
| | Semiregular | 313 | 122 | |

** For these RR Lyrae stars, maximum magnitudes were taken from the GCVS.*

## 3. The variables of RV Tauri type

The discussion of the stars then classified as RV Tauri type (Payne-Gaposchkin *et al.* 1943) was published in HA 113 nearly a decade before the systematic field-by-field observations were completed and published in HA 115 and 118. Listed in HA 113, p. 2, were 29 stars then classified as RV Tauri type, of which five are now classified as SR, and one a Cepheid (S Vul). Only 14 of the 29 were included in the detailed survey, two of which are now reclassified as semiregular, SRd (UY CMa and UU Her). The rest of the 29 were considered too faint for the planned survey. The reasons for the discrepancies in classification are understandable, especially when only relatively short spans of observations were available. The reputed characteristic of alternating deep and shallow minima, with occasionally a deep observed when a shallow is expected (or vice versa) is not always apparent. For example, compare the strips JD 24000–26000 and JD 28000–29000 of Figure 1 for UU Her from HA 113, which shows only occasional examples of the alternating deep and shallow minima typical of RV light curves. Some dips at major maxima could simply be considered accidental errors in the observations. This star, classified RV in HA 113 in 1943, was classified SR by S. Gaposchkin in 1952 (HA 118, p. 81). and is called SRd in the GCVS. Its idiosyncracies had earlier been discussed by Gerasimovic (1928) and by Gerasimovic and Walton (1928). Gerasimovic found that the star sometimes varied in a period of 45 days, at other times 72 days, and concluded, “The investigation shows that UU Herculis has nothing in common with RV Tauri variables.... It is a peculiar variable or a representative of a type of variation hitherto unknown.” In some cases the SR or RV light curves can be interpreted as representing beat-frequency phenomena resulting from relatively constant fundamental and overtone pulsations. Thus UU Her appears to be pulsating simultaneously in periods of approximately 45, 72, and 90 days (Beyer 1948).

An elegant illustration of the beat-frequency phenomenon is given by Pollard *et al.* (1992, 1993) for U Mon and RU Cen, reproduced here as Figure 2 (Pollard *et al.* 1993). The dots give the actual observations, the solid curves the computed curves based on the two periods 32.21 and 63.90 days for RU Cen, and 46.18 and 92.08 days for U Mon. John Percy (1993) has given a superb analysis of AAVSO visual observations of U Mon between 1962 and 1992, revealing cycles of 2475 days (Figure 3). While S. Gaposchkin’s

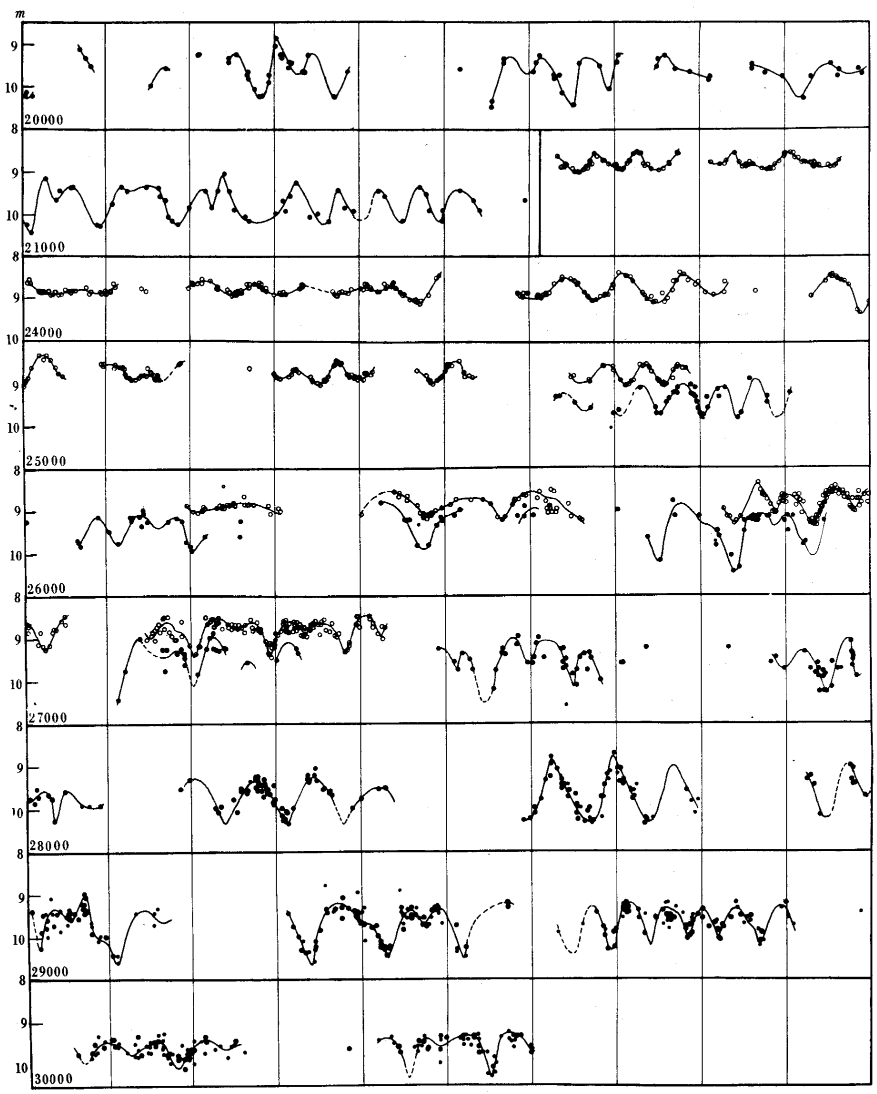


Figure 1. Light curve of UU Her 1913–1941 (from Payne-Gaposchkin *et al*. 1943, p. 13). JD values are 2400000+.

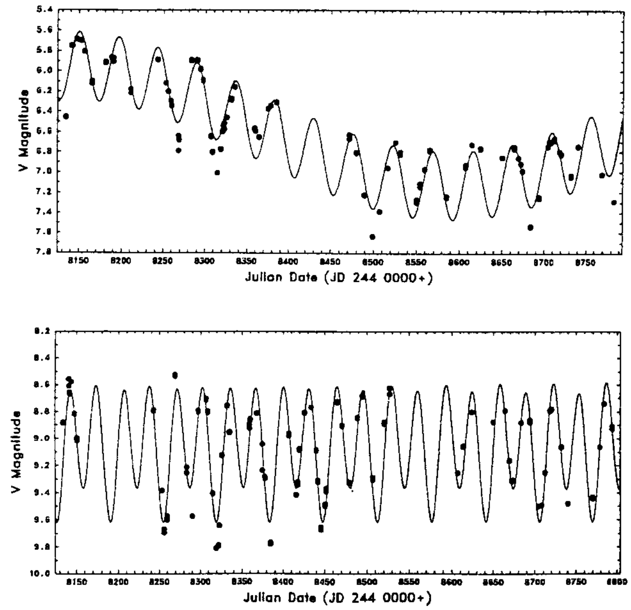


Figure 2. Light curves of U Mon (upper) and RU Cen (lower), illustrating the beat-frequency phenomenon. From Pollard *et al.* 1992, p. 216. *Courtesy of the Royal Astronomical Society of New Zealand*.

observations of this star, spanning 1899 to 1942, are not as well spaced as the later AAVSO visual observations, they are not inconsistent with this long period. The observations shown in Figure 2 are also consistent with the 2475-day period.

UY CMa, included among the RV stars in HA 113, has otherwise been classified SR. No graph of the observations is included in HA 113, but the data are too sparsely grouped to be certain of any clear RV characteristics. The published period of 114.6 days fits most of the Harvard observations.

The index to the 54 fields studied (HA 118, pp. 225–239) includes 22 stars classified as RV type, eight in addition to those studied in HA 113 No. 1. (These were not included among the RV in HA 113 because the first section of HA 113 came out long before the completion of the systematic examination of all the 54 fields.) Of the eight, only one (AI Sco) is now called RV in the GCVS, and another is now called

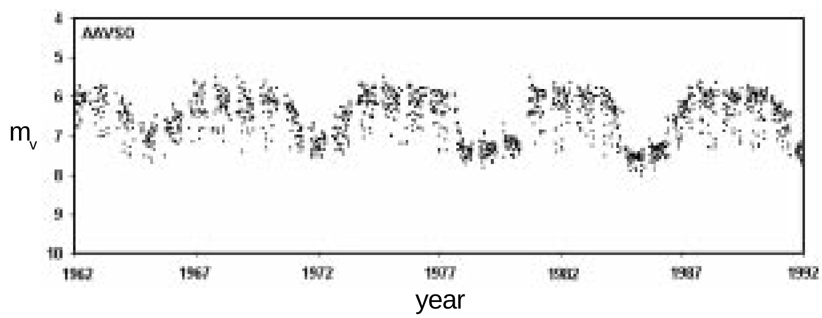


Figure 3. Light curve of U Mon, revealing cycles of 2475 days (see Percy 1993). *Courtesy of the AAVSO.*

δ Cep type (S Vul). On the other hand, two classified SR in the Index (SS Gem and U Mon) were called RV in 1937, in HA 113 in 1943, and again in the 1985 GCVS.

Since the work of the Gaposchkins, considerable efforts have been made to derive periods, particularly multiple periods, for RV Tauri type stars. Thus Pollard *et al.* (1996) in New Zealand published new observations for eleven RV Tauri stars for each of which they found two periods as shown in Table 6, the combination of the two accounting for the primary and secondary minima in the light curves. To these I have added other periods for the same stars from the GCVS. For others of the RV stars discussed in HA 113 Part 1, multiple periods have been found for RV Tau, 78.73 and 1224 days; UU Her, 45, 90, and 71 days; and R Sge, 70.77 and 1112 days. The New Zealand (Pollard *et al.* 1996) observations span from 472 to 1276 days per star, too short in most cases for the detection of as long secondary periods as have been reported for U Mon, RV Tau, and R Sge. Although AI Sco is on their list, they do not mention that it had been reported by S. Gaposchkin as an SR star with periods 71.0 and 999.6 days (HA 115 p. 158), and by Payne-Gaposchkin with periods 71.78 and 960 days (HA 113 p. 208).

For the 14 variables treated in this section of the Milton Bureau publications, results are given in greater detail than in any other section of the three relevant volumes of the *Harvard Annals.* Only this section gives finder charts, sequences, and all the magnitude estimates for the stars included, and plots of the observations are given for all but two. The other sections only summarize the observations but do not list the individual values. (If they had, the volumes would have been incredibly larger.)

Among the stars included in Sergei Gaposchkin's compilations of eclipsing binaries is the star RU Cen. The recent GCVS, however, classifies it as RV Tauri type. The history of the classification of this star is remarkable. It was discovered by Kapteyn in 1896, but he had insufficient observations to assign a type of variation. Subsequent observers have classified it as irregular, Cepheid, β Lyrae type, and (intermittently) RV Tau, as indicated in Table 7.

Figure 4 is a copy of observations of RU Cen obtained by D. J. K. O'Connell, S. J. (1960). This clearly shows the RV Tauri characteristics of alternating deep and shallow minima. That Gaposchkin was able to find an eclipsing period ostensibly accurate to six decimal places, 64.776998 days (*sic*, probably intended 64.726998) is remarkable, especially after O'Connell found that a period of 64.727 days fits all alternate cycles from about JD 2424575 to 2429110, regardless of which minimum is the primary, which the secondary. But if the star were eclipsing there would have been no shift between primary and secondary minima.

## 4. The eclipsing variables and some S Doradus types

In Part 2 of HA 113, Sergei Gaposchkin (1953) analysed 281 presumed eclipsing variables measured by the Milton Bureau, for all of which he published mean light curves. Cecilia Payne-Gaposchkin, in the Introduction to the Milton Bureau fields, commented on eclipsing variables (HA 115, p. 3) that, "One of the most important products of the present research will be the study of the changes of period for eclipsing stars, and the detection of apsidal motions." Unfortunately, Sergei Gaposchkin does not mention changing periods or apsidal motions. He states (HA 113, p. 70), "I have refrained from discussing the extensive material here available on the physical properties of eclipsing stars, which may be more properly treated in a separate communication." Unfortunately no such communication materialized.

The list of eclipsing variables in HA 113 includes six stars not mentioned in the Index of the Milton Bureau fields. On the other hand, the Index to the Milton Field variables does include 47 eclipsing variables that are not included among S. Gaposchkin's tabulations and mean light curves. The missing stars have been

Table 6. Multiple periods for RV Tauri stars.

| *Star* | *P1* | *P2* | *P3* | *Source* |
|---|---|---|---|---|
| SX Cen | 16.49 | | 600 | O'Connell 1933a |
| | 16.46 | | 600 | O'Connell 1933b |
| | | 32.78 | 620 | Payne-Gaposchkin 1954b |
| | | 32.86 | 615 | GCVS |
| SU Gem | 24.6 | | 700 | O'Connell 1933b |
| | | 50.12 | 689.6 | Payne-Gaposchkin 1954b |
| | | 50.0 | 680 | GCVS |
| RU Cen | 32.30 | 64.60 | | Pollard *et al.* 1996 |
| | | 64.73 | | O'Connell 1960 |
| | | 64.78 | | Gaposchkin 1953 |
| | | 64.73 | | GCVS |
| AD Aql | 33.04 | 66.07 | | Pollard *et al.* 1996 |
| | | 64 | | Payne-Gaposchkin 1943 |
| | | 65.4 | | GCVS |
| AI Sco | 35.50 | | 980 | O'Connell 1933a |
| | 35.62 | | 980 | O'Connell 1933b |
| | 35.52 | 71.05 | | Pollard *et al.* 1996 |
| | 35.52 | 71.78 | 960 | Payne-Gaposchkin 1954b |
| | | 71 | 966.6 | GCVS |
| AR Pup | 38.89 | | | Pollard *et al.* 1996 |
| | | 75.0 | 1218 | Payne-Gaposchkin 1943 |
| | | 74.58 | ~1200 | GCVS |
| V453 Oph | 40.33 | 80.66 | | Pollard *et al.* 1996 |
| | | 81.30 | | GCVS |
| AR Sgr | 44.43 | 88.87 | | Pollard *et al.* 1996 |
| | | 87.87 | | Payne-Gaposchkin 1943 |
| | | 87.87 | | GCVS |
| U Mon | 46.16 | 92.31 | | Pollard *et al.* 1996 |
| | | 92.26 | 2320 | Payne-Gaposchkin 1943 |
| | | 91.32 | 2320 | GCVS |
| DF Cyg | 49.9 | | 750 | O'Connell 1933b |
| | 49.8 | | 782 | Payne-Gaposchkin 1954b |
| | 49.81 | | 780.2 | GCVS |
| IW Car | 67.5 | | 1500 | Payne-Gaposchkin 1954b |
| | ~72.0 | | | Pollard *et al.* 1996 |
| | 67.5 | | 1500 | GCVS |
| R Sct | 70.18 | 140.37 | | Pollard *et al.* 1996 |
| | | 145.6 | | Payne-Gaposchkin 1943 |
| | | 146.5 | | GCVS |
| R Sge | 70.84 | | | Payne-Gaposchkin 1943 |
| | 70.770 | | 1112 | GCVS |
| UU Her | 71.06 | 90.40 | | Payne-Gaposchkin 1943 |
| | 71 | 90 | | GCVS |
| RV Tau | 78.6 | | 1227 | Payne-Gaposchkin 1943 |
| | 78.73 | | 1224 | GCVS |
| V820 Cen | ~80 | | | Pollard *et al.* 1996 |
| | | 150 | | GCVS |
| RY Ara | 145.2 | 290.3 | | Pollard *et al.* 1996 |
| | 143.5 | | | Payne-Gaposchkin 1954b |
| | 143.5 | | | GCVS |

Table 7. Selected successive classifications of RU Cen.

| *Year* | *Type* | *Reference* |
|---|---|---|
| 1896 | ? | Kapteyn |
| 1925 | Irr | Nijland |
| 1927 | Cepheid | Shapley and Walton |
| 1928 | β Lyrae | Hertzsprung 1928 |
| 1930 | Cepheid | Shapley and Payne |
| 1934 | RV? | Prager |
| 1936 | RV? | Schneller |
| 1948 | RV | Kukarkin and Parenago |
| 1951 | RV | Rosino |
| 1953 | E | Gaposchkin 1953 |
| 1958 | E | Kukarkin *et al.* 1958 |
| 1960 | RV | O'Connell 1960 |
| 1985 | RV | Kholopov *et al.* 1985 (GCVS) |

rejected for a variety of reasons: too bright for the photographic plates used, too faint, or having too small an amplitude for reliable phase determinations.

In view of the confusion as to the type of variability of RU Cen, I have checked the 17 other stars in Gaposchkin's list of eclipsing stars with periods in excess of 20 days to see if any have been reclassified differently in the modern variable star catalogues. All but two are still classified as eclipsing stars. S Dor, discovered in 1897 by Williamina Fleming (Pickering 1897), was reported by E. C. Pickering (1898) as varying between 8.2 and 9.4p. In the GCVS it was assigned a special class in its own name, S Dor type; and V644 Cen is now called a questioned γ Cas type. In 1984, Conti (1997) succeeded in renaming the S Dor type LBV type, meaning Luminous Blue Variables (Conti 1997; Gallagher 1997). The reclassications have depended more on the spectral and theoretical properties of the stars than on the shapes of their light curves. Objecting to this reclassification were de Jager and van Genderen (1989), who pointed out that a number of yellow and red supergiants showed similar characteristics to the Luminous Blue Variables, citing especially V766 Cen, G8Ia-0, and Var A = No. 96 in M33, spectral class FIa-M3 (both originally questioned S Dor Type). The behavior of Var A in M33 is discussed in detail by Humphreys *et al.* (1987) indicating similarities to η Carinae. De Jager and van Genderen comment that "the conventional name S Dor variables seems more appropriate" than the term LBV. Nevertheless, Kazarovets *et al.* (1999), in the recent *74th Special Name List of Variable Stars*, have classified 119 stars found to be variable by Hipparcos as LBV or questioned LBV. No spectral classes were cited for these, but (B-V) color indices were given. Of the 119 stars only three were assigned color indices greater than 0.400, namely V977 Cen, 0.495, V999 Cen, 0.406, and DT Cru, 0.435. These color indices correspond roughly to spectral classes F5-G, consistent with either LBV or S Dor types. The GCVS records 15 stars as S Dor type. Their spectra are as shown in Table 8; only one (V766 Cen) is recorded as late as G8.

The Milton Bureau light curves for both S Dor and V644 Cen show a close resemblance to Algol types, although that for S Dor also shows about a quarter of a magnitude variation at maximum in a period on the order of nine years. The deep minima are about a magnitude fainter than maximum. The light curve published by Gaposchkin in 1943 is most intriguing (Figure 5a). The separation of his secondary (about 0.03pg brighter than the deepest minimum) from the primary is somewhat shorter between 1891 and 1900 than between the following pair, 1930 and 1940. If this were indeed an eclipsing system this might suggest a highly eccentric orbit with a rotating line of apsides.

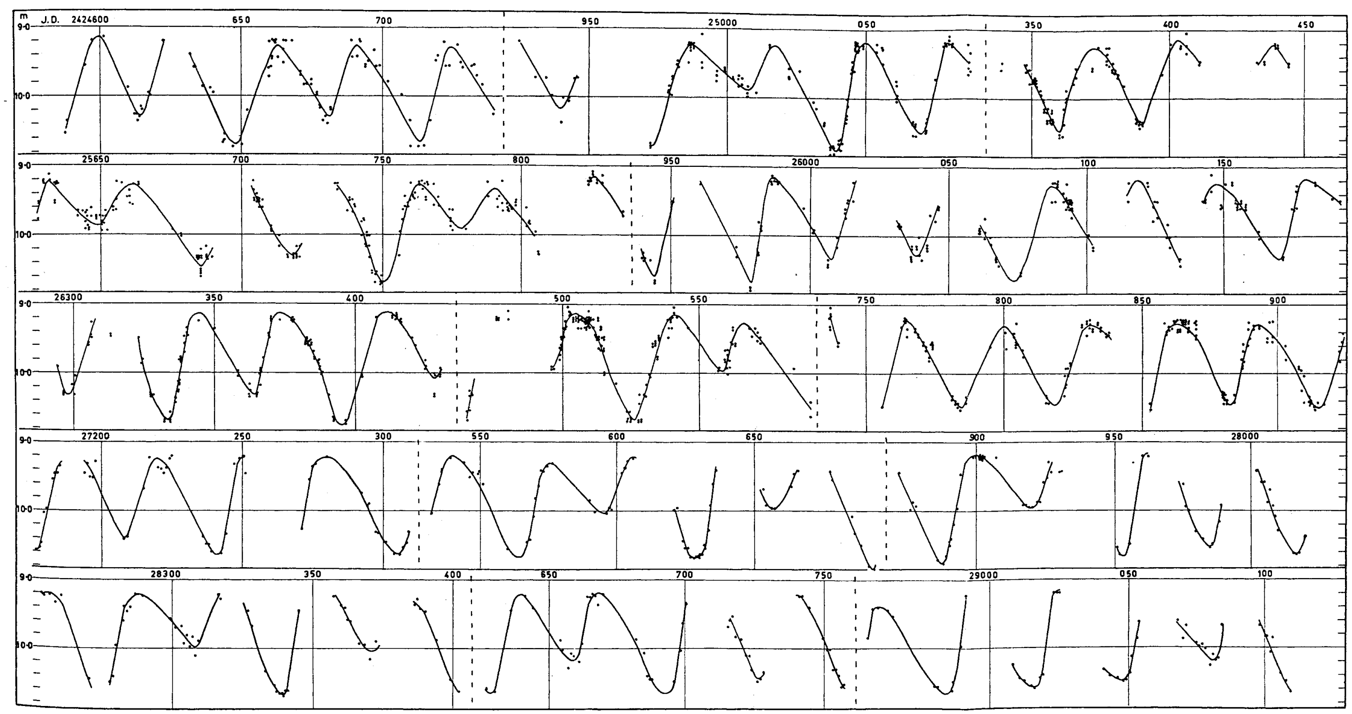


Figure 4. Light curve of RU Cen 1926–1938 (from O'Connell 1960).

Table 8. S Dor type stars in GCVS (1985-87).

| *Star* | *Sp* | *Milton max* | *GCVS* | |
|---|---|---|---|---|
| AE And | e | | 14.1 | p |
| AF And | e | | 15.0 | p |
| AG Car | B0I-A2Ieq | Irr | 7.1 | p |
| HR Car | B2eq | | 8.2 | p |
| η Car | pec(e) | Nova | -0.8 | v |
| KM Cas | B1eaI-II | | 8.78 | V |
| V766 Cen | G8Ia-0 | | 8.7 | p |
| V840 Cyg | A1II | | 10.2 | p |
| V1478 Cyg | Bep | | 13.8 | p |
| P Cyg | B1Iapeq | Nova | 3 | v |
| S Dor | A0-5eq | Ecl? | 8.6 | B |
| V4029 Sgr | B9Iapeq | | 8.12 | V |
| V917 Sco | OBea | | 11.9 | B |
| $\zeta^1$ Sco | B1Iaep | | 4.66 | V |
| Y Tri | A-FIe | | 15.4 | p |

Wesselink (1956) observed S Dor five times in 1953–1955, appearing to refute the periods indicated by Gaposchkin. The star appeared to decline from 9.22 to 10.04p in the interval studied by Wesselink. The reason for the large discrepancy of Wesselink's magnitudes from those of Gaposchkin and O'Connell is possibly that the Harvard and Riverview plates showed only the blend of the variable with a 12th magnitude companion 13" south of the variable. Later Thackeray (1965), and still later Alexander and Thackeray (1971) provided observations at minimum in 1964. Spoon *et al.* (1994) gave a curve clearly defining the minimum of 1985, and Wolf and Kaufer (1997) showed a light curve for 1987–1996 showing a visual minimum in 1993, and Lamers (1995) and Lamers *et al.* (1998a) gave a light curve showing a high maximum at 9.0V, shallow minima at 9.6 in 1977 and 1980, and deep minima 10.2 and 10.0V in 1985 and 1993. Finally, the AAVSO provided visual observations (Mattei 1999) from December 23, 1976, to May 20, 1977, all exceptionally bright at visual magnitude 8.0, the last 7.9 (all estimates by the same observer). Further AAVSO observations (Mattei 1999) (Figure 5b) from November 24, 1992, to December 16, 1998, revealed a deep minimum November 24 to March 2, 1993. Thus, deep minima occurred roughly in the following years: 1891, 1900, 1930, 1940, 1955, 1964, 1985, and 1993, with successive intervals of about 9, 30, 10, 15, 9, 11, and 8 years. Note in addition, the two shallow minima at 9.8 and 9.9pg between 1900 and 1930, at intervals of about 10 and 8 years. Similar small-amplitude variations occurred in the visual AAVSO observations, but at intervals of only about 750 days. Moreover, Lamers *et al.* (1998b) have found microvariations in a period of 195 days with amplitude 98 millimagnitudes, and 131 days with amplitude 48 mmag.

An investigation by de Groot *et al.* (1996) analyzes available data from 1889 to 1994. Some of their conclusions seem to contradict Gaposchkin's light curve (Figure 5a). They claim, "It is possible to identify cycles unambiguously leading to a primary period of 2501 ± 25 days (or 6.8 years)" and also indicate a long-term phase of 35 years and a secondary period of 8.2 years. In 1997, van Genderen *et al.* discussed the light curve from 1889 to 1995, after reducing all the observations to a common photographic system. They report no deep minima after the 1964–1965 minimum, but that cycles of small amplitude occurred at intervals ranging from 2.2 to 15.6 years. Indeed, on their plot the minimum of 1965 reached a low of 11.5p whereas all the other minima became no fainter than 10.5p.

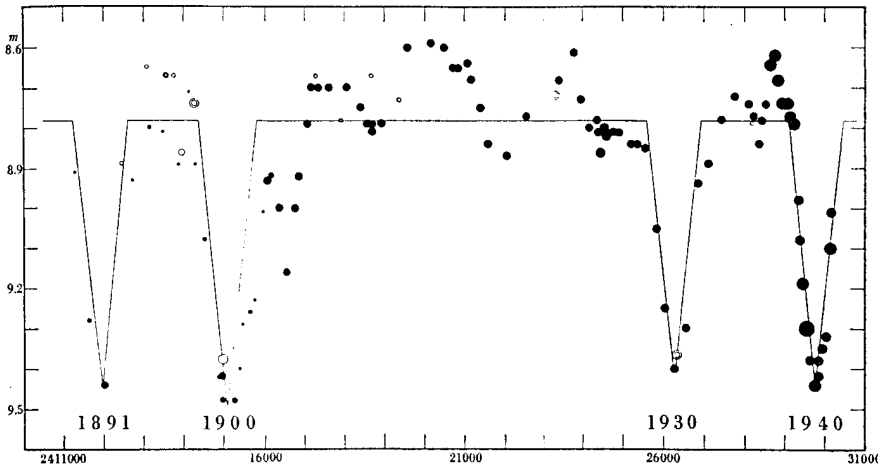


Figure 5a. Light curve of S Dor (from Gaposchkin 1943, p. 175), plotted photographic magnitude versus time.

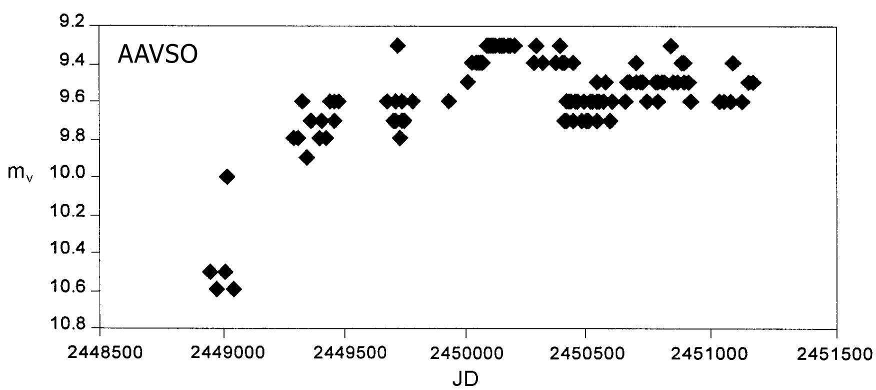


Figure 5b. Light curve of S Dor (Mattei 1999).

For V644 Cen S. Gaposchkin gave a curve spanning over 56 years. It shows a secondary minimum of depth about 0.1p, and descent to primary minimum about 0.6p fainter. The interval from secondary to primary is about 45 years, with no gaps large enough for intermediate minima. The variable had been discovered in 1949 by O'Connell (1951) on plates taken at Riverview Observatory in the Philippines. His observations cover the last third of the interval observed by S. Gaposchkin and confirmed the descent to the deep minimum. In 1977, Hopp and Kiehl at Bamberg obtained photographic observations showing the star at maximum JD 2438472 to 2442718 (March 17, 1964, to November 1, 1975). Finally, in 1987, Davies *et al.* obtained visual observations and color indices indicating that the brightness decreased steadily from 9.9p at JD 2444742 (May 17, 1981) to 10.3 at JD 2445715 (June 15, 1984), and began to increase to 10.2 by JD 2445809 (April 18, 1984). A combination of all these observations (Figure 6) indicates an interval between the two deep minima of about 35 years. These new observations would indicate that the period might be about 88 years or longer. Gaposchkin had indicated that the period should be longer than 22,000 days, or 60 years. If we ignore the early shallow minimum as being only within the likely errors of observation, the light curve of V644 Cen bears a strong resemblance to S. Gaposchkin's of S Dor. Like S Dor, if this were interpreted as an eclipsing variable the orbit would be highly elliptical. This variable deserves occasional continued attention to anticipate the next minima. Will the star prove to have a constant period or be irregular? S. Gaposchkin's classification of S Dor and V644 Cen as eclipsing was not unreasonable on the basis of the data available to him.

AG Car is another star that has been classified S Dor type in the GCVS, but had been called irregular by S. Gaposchkin. It was studied by N. Greenstein at Harvard in 1938. She found it to vary mostly between 8th and 9th photographic magnitude, but found only one conspicuous maximum, in 1908. In an extensive examination of all published data from 1889 to 1994, de Groot *et al.* (1996) and van Genderen *et al.* (1997) found multiple periods of 371.4 and 390 days with a beat cycle of 21.6 years. However, much of the light curve, which shows the star at minimum more frequently than at conspicuous maxima, bears little resemblance to those of S Dor or V644 Cen. (See Figures 7a and b, based on Lamers 1995 and Sterkin *et al.* 1997.)

## 5. The Cepheid and RR Lyrae stars

Part 3 of HA 113 deals with Cepheids, W Virginis, and RR Lyrae stars. Whereas Payne-Gaposchkin notes that there were 135 classical Cepheids, nine Population II Cepheids, and 51 RR Lyrae stars measured in HA 115 and 118, her analyses deal with 132 classical Cepheids, nine population II Cepheids, and 84 RR Lyrae type stars. There are 11 Cepheids in the Index in Vol. 118 that are not in HA 113, and one in HA 113 not in the Index in HA 118. Nine RR Lyrae stars in HA 118 are missing in HA 113, but 39 in HA 113 were not included among the Milton Bureau program stars. The majority of those dropped from the original program turned out to be either too faint or not variable. The vast majority of the additional stars in HA 113 are fainter than the stars on the original Milton Bureau program. (They were probably measured on other than the patrol plates, plates reaching much fainter magnitudes.)

Light curves are given for all but five of the classical Cepheids (KL Aql, too faint; Y Oph, W Sgr, and X Sgr, too small amplitudes for reliable light curves; and SZ Cyg, variable period), and there are none for the W Virginis stars. No light curves are given for individual RR Lyrae stars. However, there is a figure (reproduced here as Figure 8) in which mean light curves for Cepheids and RR Lyrae types are arranged in order of increasing period, including a total of 240 Cepheids. All the light curves were arbitrarily revised to show percentage of amplitude versus percentage of period. The Cepheids were then separated into 16 groups and the mean of all curves in each group plotted. These mean curves (left section of Figure 8) clearly show how the shapes

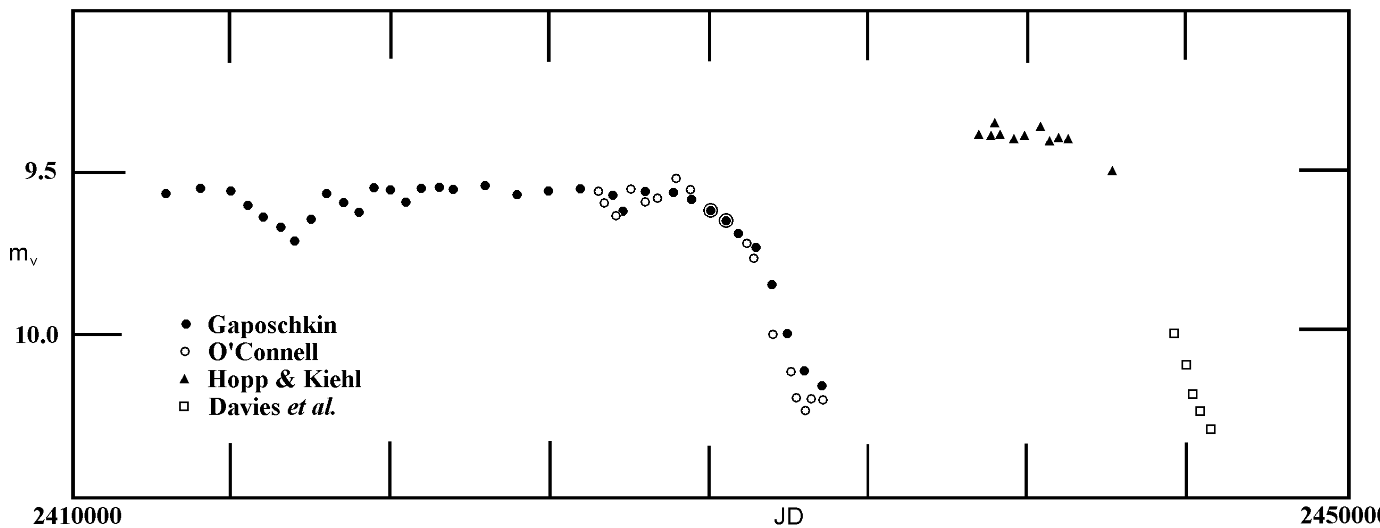


Figure 6. Composite light curve of V644 Cen showing an interval between the two deep minima of about 35 years.

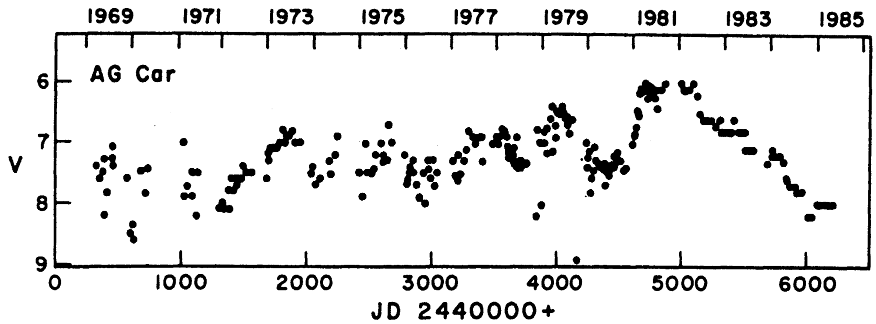


Figure 7a. The visual light curve of the LBV AG Car between 1969 and 1985. Notice the variability on all time-scales from weeks to years (from Lamers 1995). *Courtesy of the Astronomical Society of the Pacific Conference Series.*

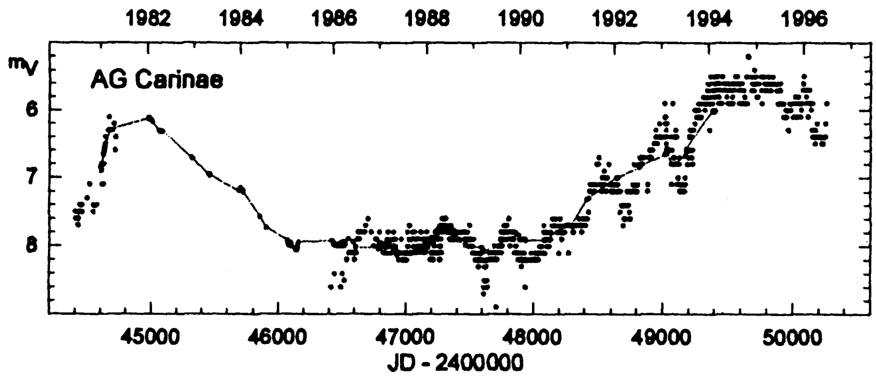


Figure 7b. Light curve of AG Car. The continuous line connects photoelectric *y* data, the dots are visual estimates (from Sterken *et al.* 1997). *Courtesy of the Astronomical Society of the Pacific Conference Series.*

of the light curves change with increasing period. Likewise the right-hand column of light curves in Figure 8 shows a similar progression with increasing period, based on 89 RR Lyrae stars. As early as 1919, H. Ludendorff had indicated that such a progression of shape of Cepheid light curves with increasing period occurs, and later Hertzsprung (1926) gave further details. But these curves, as presented by Payne-Gaposchkin, demonstrated the progressions in the most convincing manner.

**6. The red variable stars**

Two major groups of stars are studied in Part 4 of HA 113, the long period (Mira type) variables, 390 stars, and semiregular variables, 313 stars. All of these were contained in the Index to the Milton Fields in HA 118. On the other hand, there are 8 Mira type and 26 SR in the HA 118 index that are not included in HA 113. Of the eight Mira type (EM Aql, V Aur, RX Car, SU Car, S Cep, VV Her, VY Tau, and UY Vel), all were too faint photographically to be included in the final analyses. However, the final list of long period variables in HA 113 Part 4 does contain 118 other stars fainter than the prescibed 10.0p at maximum that were not included in the original program. Thirteen of the stars listed as Mira type are now classified as SR.

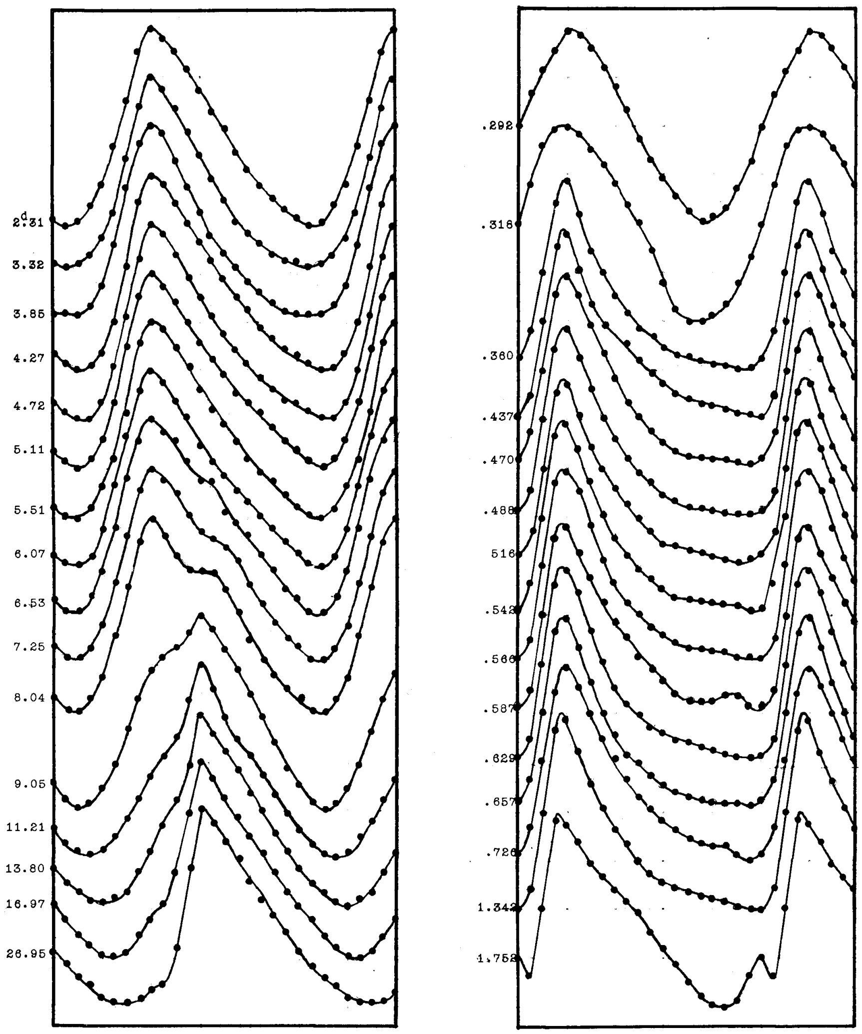


Figure 8. Mean light curves for Cepheids (left panel) and RR Lyrae types (right panel) arranged in order of increasing period and plotted as percentage of amplitude versus percentage of period. The curves clearly show how the shapes of the light curves change with increasing period (from Payne-Gaposchkin 1954a, p. 173).

14 of the 26 stars on the Milton Bureau program classified semiregular that are missing from HA 113, Part 4, are still classified SR in the GCVS. The other 12 have been reclassified: eight are now designated Lb or Lc; three, RV: SX Cen, SS Gem, and U Mon; and one, V Sge, E+Nl.

Of the 313 variables of SR type listed in HA 113, 34 are no longer classified SR but have been reclassified as follows:

14 Lb 5 M 4 Z And 4 Lc 2 RV 1 E 1 Ia 1 Insb 1 UG 1 Nc

Light curves were not provided for long period or semiregular variables in HA 113, but for about 100 stars of these types in fields 54 through 44 (the first fields examined, in the southern hemisphere) light curves are given in HA 115. These are the only fields for which any light curves were presented in HA 115 and 118.

**7. Stars with multiple periods**

At the conclusion of her discussion of the Red Variables, Payne-Gaposchkin added two pages on stars with double periods. They were distributed as follows, with the average ratio of P2 to P1 reasonably constant in each group:

| | | |
|---|---|---|
| 42 | of spectral class M | P2/P1 = 9.4 |
| 17 | ” ” ” N | 12.2 |
| 9 | ” ” ” F-K | 19.4 |
| 5 | RR Lyr type | 97.5 |
| 73 | Total | |

Of this total the GCVS classified 58 SR, 7 RV, 5 RR, 2 M, and 1 Lc. All seven RV are included in Table 6.

**8. Stars called Irregular in the Milton Bureau**

The Index of the Milton Bureau variables, in HA 118, notes 15 stars as Irregular (Table 9). AG Car has already been discussed as a currently classified S Dor type. AX Per is erroneously designated irregular in the Index, but is called semiregular both in Field 3 and among Payne-Gaposchkin's list of semiregular variables. Y Scl is called irregular in Field 45, but is also included in the HA 113 list of semiregular stars. The list in Table 9 covers nearly all categories of standard types in the GCVS.

Table 9. Stars classified Irr in Milton HA 118 but differently in GCVS.

| *Name* | *GCVS* | *SP* |
|---|---|---|
| AC Car | SRb | M7III |
| AG Car | S Dor | B0I-A2Iep |
| γ Cas | γ Cas | B0.5Ivpe |
| ρ Cas | SRd | F8pIa-K0pIa-O |
| RW Her | cst? | — |
| TZ Her | cst? | F5 |
| UY Her | cst | A2 |
| U Hya | SRb | C6,(N2) |
| UX Leo | EA/SD: | F4 |
| XX Oph | Symbiotic | Bpeq+M5 |
| AG Peg | Nc | WN6+M3III |
| X Per* | γ Cas | O9.5III-Vep |
| AX Per* | Z And | M3epIb:-A0 |
| Y Scl | SRb | M4 |
| WY Vel | Z And | M3epIb:+B |

**SR in HA 113*

## 9. Conclusions

Intercomparisons between the types of variability assigned by the Milton Bureau and the corresponding designations in the GCVS show numerous discordances. However, it would be unfair to call all of the earlier classifications mistakes. Most are understandable when it is taken into account that many of the former workers were more limited by accepted names for types of variability than at present. Multitudinous revisions of definitions, and additions of new classes have been introduced since 1950, some dependent on a knowledge of the spectral classes which were more scantily known at mid-century. For the most part the Milton Bureau types were reasonable interpretations based on what was known at the time. The percentage of discordances amounts to only about 7%.

Regardless of controversies as to the classification of the light curves of variable stars, it is well to remember the existence of the vast amounts of data compiled by the Milton Bureau. As new astrophysical theories to account for the variations keep proliferating, the existence of large quantities of acceptable early observations can help in establishing the correctness of new theories.

There is still room for disagreement as to how certain light curves are to be classified. They can be applied as entertainment. For an astronomical party, show a few of the light curves that had been diversely classified, removing all identifications and authorships. Then ask all the amateur and professional astronomers present to vote what he/she thinks the type should be called. How many will agree with GCVS, how many with the early Milton Bureau? Opinions may be far from unanimous!

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