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MONITORING SOLAR-TYPE STARS

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ABSTRACT

Old UBV and recent uvby photometry of solar-type dwarfs and other standard stars yield an upper limit of variability (determined by observational errors) of about 0.004 mag rms. A factor two improvement in this upper limit is achievable.

INTRODUCTION

Current measurements of the total solar flux have a short-term precision of ∿0.1 percent and promise to yield a long-term accuracy better than 1 percent. Small variations of the total solar flux have been detected on a time scale of days by the Solar Maximum Mission (see elsewhere in these proceedings), and a possible change of the solar spectral irradiance in the visible region on a longer time scale may have occurred (ref. 1). In both cases, the change amounted to less than 0.5 percent, so in addressing the question of luminosity variation of solar-type stars, we must seek out photometric data with extremely high long-term accuracy. Absolute photometry of starlight in the visible and near-infrared approaches an accuracy of 1 percent only with great difficulty (ref. 2), but relative photometry, in which one star is compared with other(s) nearby in the sky is routinely done with a precision of ∿0.3 percent over time scales of months. Maintaining this precision over a decade is considerably more problematical but is feasible.

It is probably safe to state that the variations of solar-type main-sequence dwarf stars do not exceed ∿1%, because if larger variations were common, they would undoubtedly have been detected during the extensive photometric surveys of the past 30 years. A number of these stars have, in fact, been used as photometric standards.

PHOTOMETRIC STUDIES

BV PHOTOMETRY OF SOLAR-TYPE STARS

Jerzykiewicz and Serkowski published in 1966 (ref. 3) the results of a twelve-year photometric study in which 16 F- and G-type dwarf stars were

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observed about ten times per year in the blue (B) and yellow (V) passbands of the UBV system. *To my knowledge, this program was the only long-term photometric study specifically addressed to the question of variability of solar-type stars.* These stars served as their own standards, thus eliminating errors caused by making transformations to an independent network of UBV standards. However, the stars were spread over seven hours of right ascension and were often observed at high airmasses; consequently, various systematic errors are likely to be present at some significant level.

A substantial effort was made to maintain the long-term stability of the measurements, but "improvements" in instrumentation were inevitable. In particular, a variety of photomultipliers was used, sometimes cooled by dry ice and sometimes operated at ambient temperature. The photometry of standard stars, Uranus, and Neptune has subsequently been analyzed for systematic effects related to changes in the instrumentation or the brightness and colors of the various objects (ref. 4). None could be found, although there was a systematic monotonic drift in one of the instrumental transformation coefficients during the course of the program.

Jerzykiewicz and Serkowski concluded that ". . . for none of these stars does the standard deviation of the yearly mean magnitude exceed 0.008 and for the stars 40 Leo, β CVn, and η Boo, this deviation is less than 0.004 mag." As shown in figure 1, taken from ref. 3, the peak-to-peak range of these stars is ~0.01-0.02 mag.

What is the likelihood that the observed variations are intrinsic? Simple statistical tests provide little guidance: For example, a closer look at the published nightly magnitudes of individual stars reveals that there were very few statistical outliers. Hence, the fluctuations of the annual mean magnitudes cannot be substantially reduced by rejecting individual bad data points here and there. Furthermore, inspection of figure 1 reveals little correlation between one star and another, as would be expected in the case of systematic instrumental difficulties.

The internal night-to-night consistency of the magnitudes of individual stars improved dramatically after 1961, presumably owing to improvements in equipment or technique. This is illustrated in figure 2, where we have replotted the annual mean magnitudes (shown in figure 1) for two typical stars, ρ Gem (F0V) and 61 Vir (G6V), in order to include error bars indicating the standard errors of the annual mean magnitudes. The average number of observations per year was 8 from 1955 to 1961 and 11 from 1962 to 1966; hence, the statistical weights of the annual data points are comparable. The standard error of a single observation was 0.015 mag prior to 1961 and 0.007 mag afterwards.

Figure 3a is a histogram of the standard deviations of the annual mean V magnitudes of these 16 stars for the years 1962-1966. The average standard deviation is 0.004 mag, and the largest standard deviation is 0.006 mag. The average peak-to-peak variation (from figure 1) is 0.009 mag.

These values certainly provide a reliable upper limit for the variability of this sample of stars over this time interval. The weight of largely circumstantial evidence (viz., the changes in instrumentation, the frequent observations at high airmass) and the absence of a set of "control" stars showing smaller annual fluctuations than solar-type dwarfs argue strongly against a positive detection of variability. Indeed, the authors themselves concluded that ". . . no evidence of variability . . . has been detected . . ."

RECENT RESULTS

Beginning in the late 1960s, two developments promised an improvement in the ultimate accuracy of ground-based photoelectric photometry. Direct-current recording techniques were largely replaced by photon-counting methods, thus largely eliminating amplifier gain calibration and linearity problems. Intermediate-band uvby photometry utilizing interference filters offered relative freedom from the substantial photomultiplier-dependent color effects present in the broadband UBV photometric system. (These were especially troublesome in the V passband, whose shape on the long-wavelength side of the maximum was defined solely by the sensitivity of the photomultiplier.)

Unfortunately, no study comparable in scope and longevity to the one described above has been conducted using the uvby system. To proceed further, we consider some measurements obtained for other purposes using, coincidentally, the same 0.4-meter telescope used for the previous program. The incidental nature of these observations seriously compromises their usefulness for the purpose we now, belatedly, assign to them. Nonetheless, they are worth examining, and we shall demonstrate that modern equipment has allowed us largely to duplicate the result of Jerzykiewicz and Serkowski under otherwise unfavorable circumstances.

Since 1972, a set of ∿60 stars, including by chance 14 F-, G-, and early K-type dwarfs, has been used as standard stars for b (472 nm) and y (551 nm) photometry of planets and satellites at the Lowell Observatory (ref. 1, 5). Because these stars were used as standards, they were observed at a variety of airmasses and at all seasons of the year. But, most importantly, from early 1974 on, there were no changes in the photometer, the electronics, or the telescope, all of which were reserved solely for this particular program.

To achieve reasonable statistics, we have divided the data into three-year bins (1972-1974, 1975-1977, 1978-1980) and compared the range of variability of the 14 solar-type dwarfs to 14 other standard stars (giants and early-type dwarfs) for which comparable data were available. Figures 3b and 3c show, respectively, the distribution of peak-to-peak fluctuations seen in the three-year averages observed in these two sets of stars. For both groups, the average range of the three-year mean magnitudes was 0.004 mag. Figure 4 shows the amplitudes as a function of spectral type.

The two distributions do not differ significantly in shape, leading us to conclude that in both cases the observed "variations" are simply errors of observations.

Observers of variable stars routinely obtain differential magnitudes of pairs of stars with a short-term (days) precision of 0.002 mag or better. The following example demonstrates the accuracy attainable under tightly controlled conditions for a small group of stars near one another in the sky.

As part of the Lowell program described above, several groups of planetary comparison stars have been observed since 1972 (ref. 5). These are field F-, G-, and early K-type stars of unknown luminosity class selected for similarity of color and magnitude to the corresponding planet. As an example, we consider the Neptune comparison stars, a group of 16 stars in the magnitude range $6.7 < \underline{V} < 9.2$ located on a ∼15° arc of the ecliptic at declination ∼-22°. The typical number of observations per year was ∼6. All 16 stars were observed near transit each night during the course of about an hour at an average airmass ∼1.8. Extinction and time-dependent instrumental effects are thus minimized; and, although the average airmass was high, the differential airmass between one star and the others was usually quite small. After reduction to an ensemble mean, the average standard deviation of the annual mean magnitudes was 0.003, and the largest was 0.005 (figure 3d).

On the basis of this experience, it is reasonable to expect that a set of solar-type stars passing near the zenith could be monitored with an accuracy approaching 0.002 mag over a similar length of time. We estimate that a ten-year study involving ∼25 stars could be carried out at a cost of $500K (1980 dollars) using conventional ground-based, non-automated facilities. With an automated telescope, the data rate could be increased by about a factor of two at a dollar cost of an order of magnitude higher.

REFERENCES

1. Lockwood, G. W., Thompson, D. T., and Lumme, K.: A Possible Detection of Solar Variability from Photometry of Io, Europa, Callisto, and Rhea, 1976-1979. Astron. J., vol. 85, July 1980, pp. 961-968.

2. Tüg, H., White, N. M., and Lockwood, G. W.: Absolute Energy Distributions of α Lyrae and 109 Virginis from 3295 Å to 9040 Å. Astron. Astrophys., vol. 61, 1977, pp. 679-684.

3. Jerzykiewicz, M., and Serkowski, K.: The Sun as a Variable Star. Lowell Observatory Bulletin, no. 137, 1966 (vol. VI, no. 18, pp. 295-323).

4. Lockwood, G. W.: Analysis of Photometric Variations of Uranus and Neptune Since 1953. Icarus, vol. 35, 1978, pp. 79-92.

5. Lockwood, G. W.: Secular Brightness Increases of Titan, Uranus, and Neptune, 1972-1976. Icarus, vol. 32, 1977, pp. 413-430.

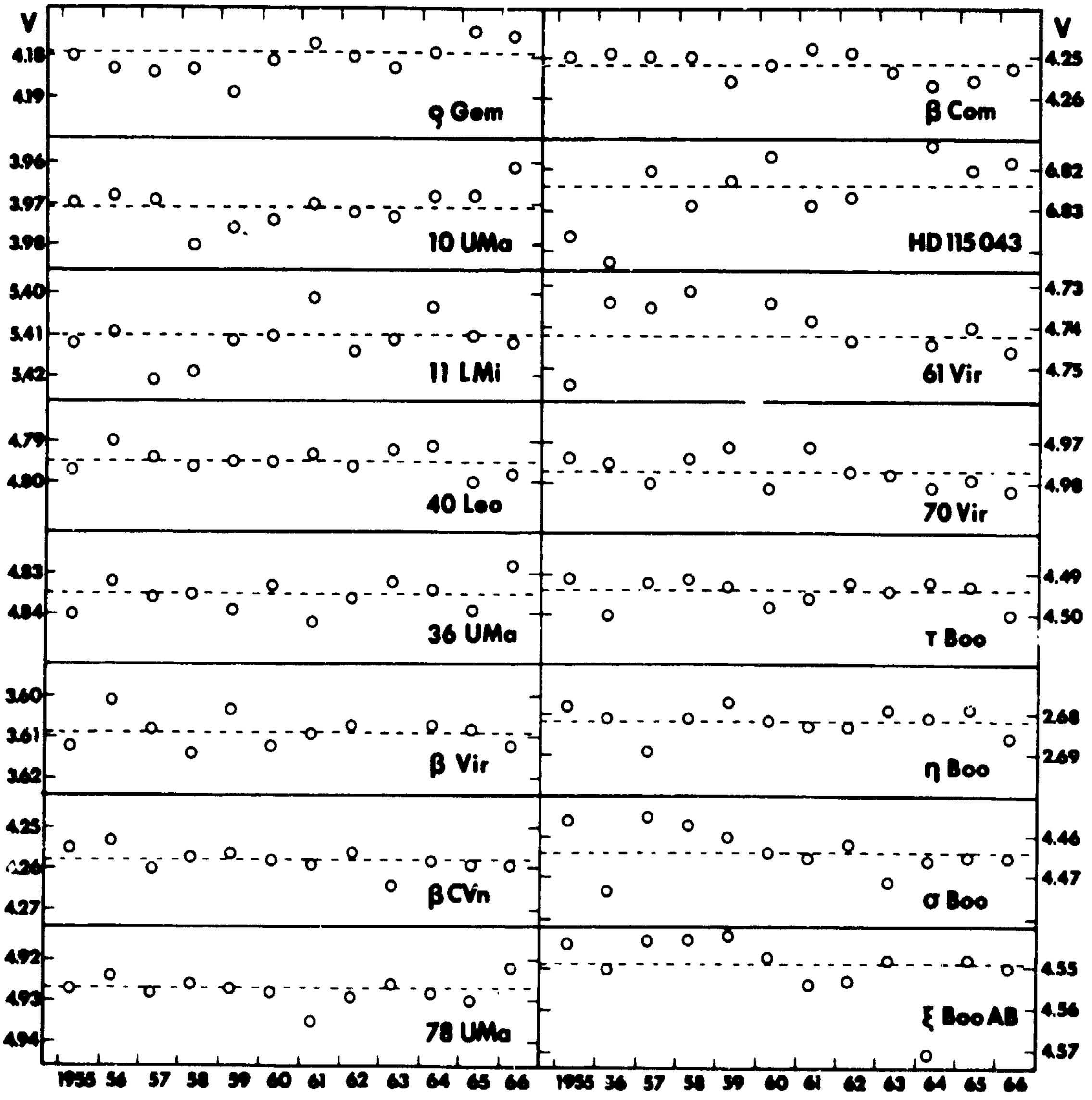


Figure 1. Annual mean V magnitudes of 16 F- and G-type dwarfs (from ref. 3).

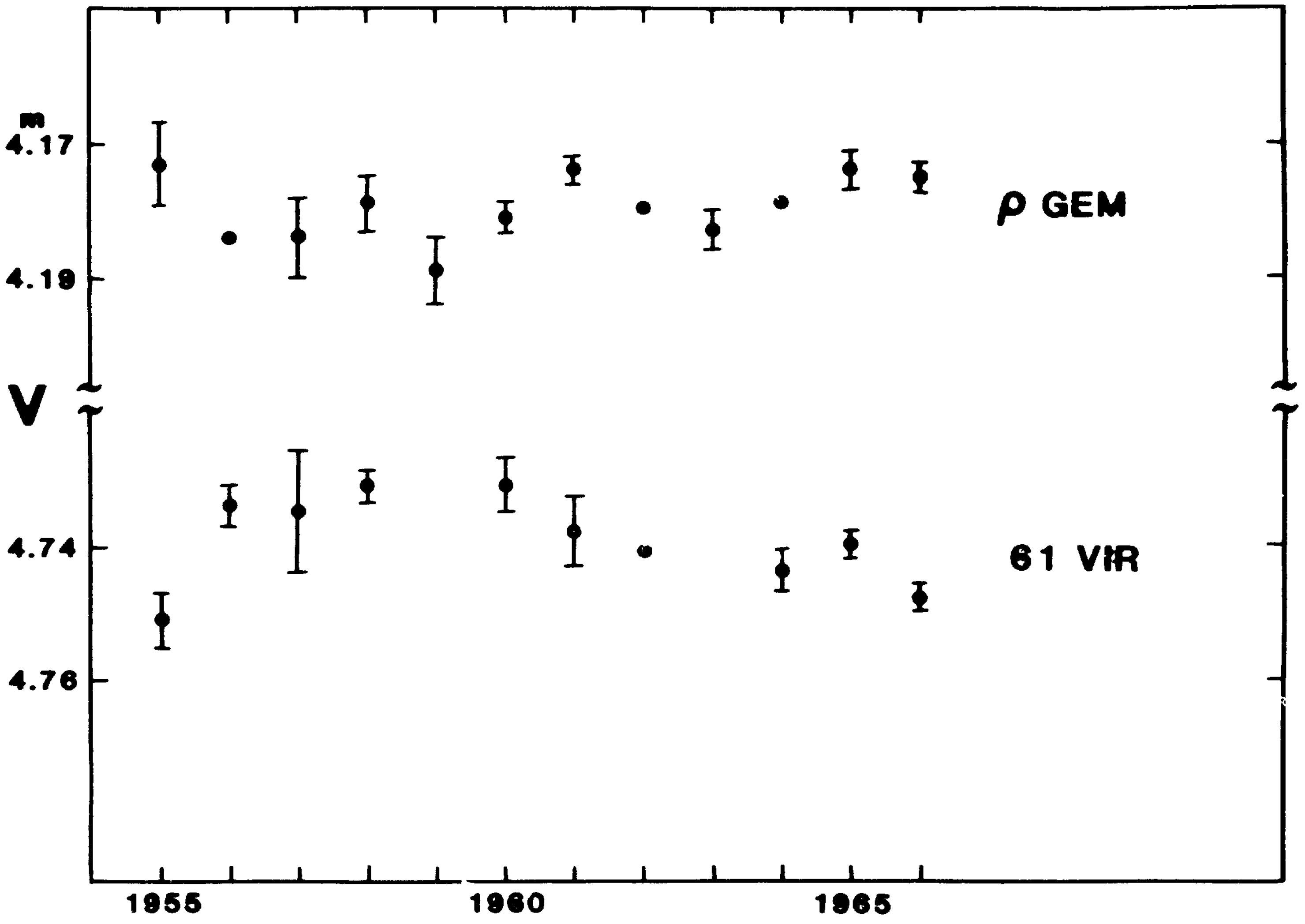
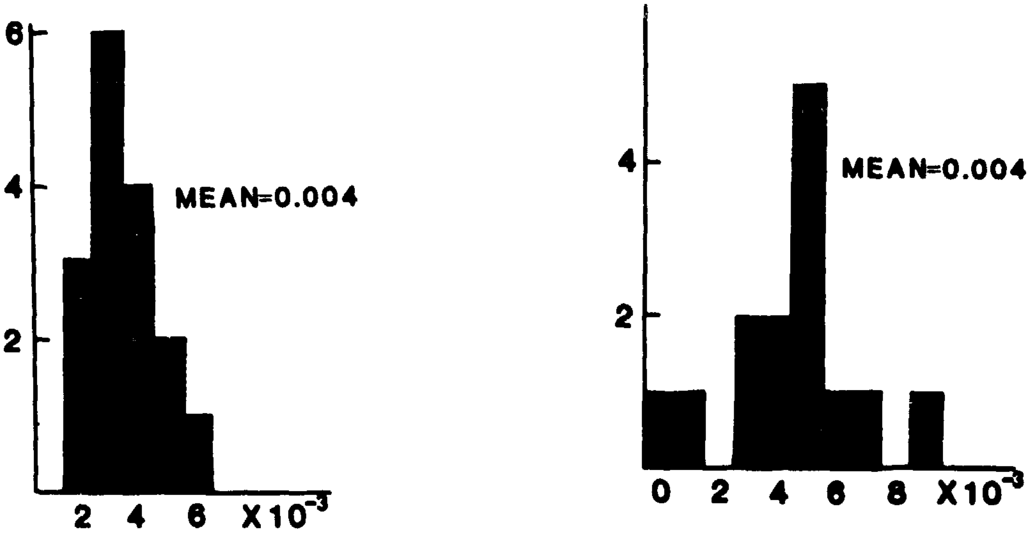
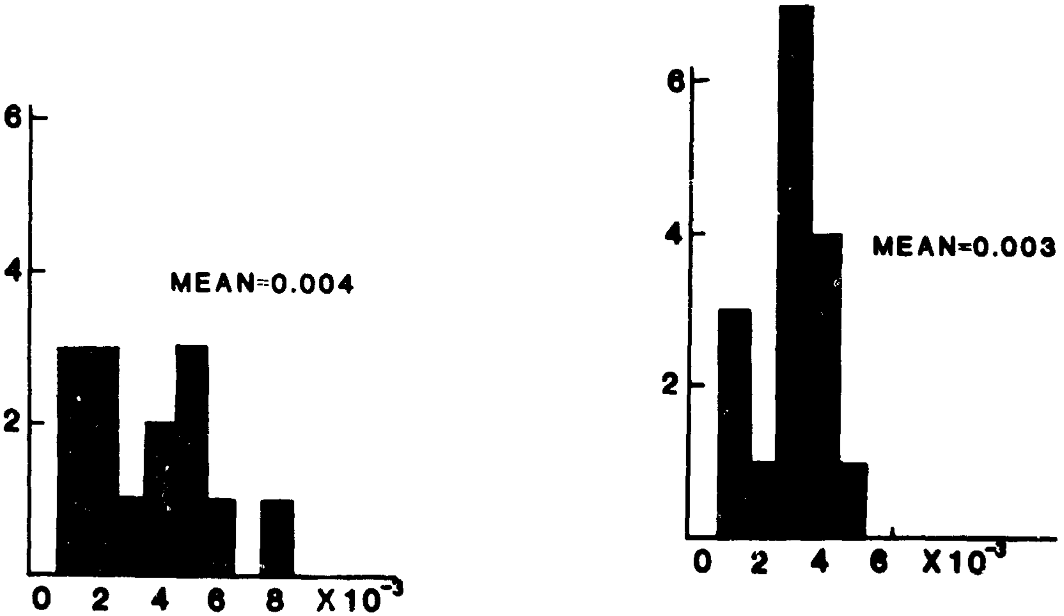


Figure 2. Annual mean V magnitudes of ρ Gem (FOV) and 61 Vir (G6V) showing the standard errors of the mean annual magnitudes. The average number of observations per year is 10.



3a. Standard deviations of the annual mean V magnitudes of 16 F- and G-type dwarfs observed between 1962 and 1966

3b. Peak-to-peak ranges of the three-year mean y magnitudes of 14 F-, G-, and early K-type dwarf standard stars observed between 1972 and 1980



3c. Peak-to-peak ranges of the three-year mean y magnitudes of 14 standard stars, excluding solar-type dwarfs

3d. Standard deviations of the annual y magnitudes (reduced to the ensemble mean) of 16 F-, G-, and early K-type field stars observed between 1972 and 1980

Figure 3

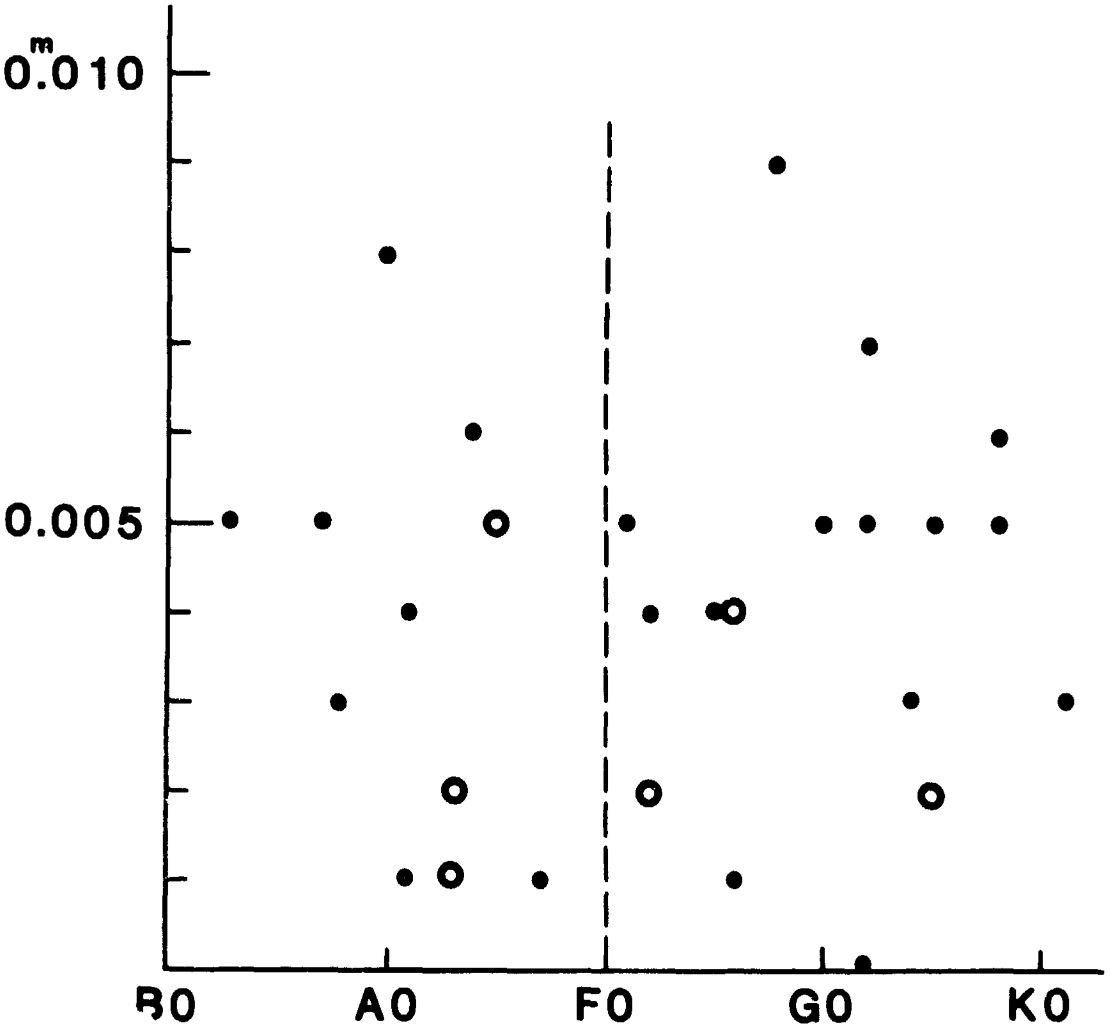


Figure 4. Peak-to-peak amplitudes of three-year mean y magnitudes of standard stars. (Open circles) - giants or unknown. (Filled circles) - dwarfs and sub-giants.