Title: A Plan for Securing Observations of the Variable Stars

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A PLAN

FOR

SECURING OBSERVATIONS

OF THE

VARIABLE STARS.

BY

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DIRECTOR OF THE HARVARD COLLEGE OBSERVATORY.

CAMBRIDGE:
JOHN WILSON AND SON.
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FOR several reasons the investigations here proposed are especially suited to observers under very various conditions. The work is capable of indefinite sub-division. Small as well as large telescopes may be employed and many observations are needed which can best be made with an opera-glass or field-glass, or even with the naked eye. No attachment is needed to an ordinary telescope, so that no additional expense on this account is required. Useful observations may be made by an unskilled observer provided that he is capable of identifying a star with certainty. The work is quantitative, and the observer has, therefore, a continual test of the increased accuracy he has acquired by practice. As a portion of the investigation will probably lead to the discovery of interesting objects, the observations will possess an interest often wanting in quantitative research. The aid of the professional astronomer is earnestly requested for this scheme. Suggestions by which it may be modified and improved will be gratefully received. The professional astronomer, in consequence of his greater skill, instrumental appliances, and command of his own time, could fill gaps in the work, and thus greatly increase its value as a whole. Such observations could often be made in the intervals of other work or at times unsuitable for the observations to which he was especially devoting himself. It should be added that especial care will be taken not to interfere with observations of variable stars now in progress. Observers of these objects are particularly requested to notify the writer what work they propose to carry out, so that a needless repetition of it may be avoided.

It is on the amateur and student of astronomy that we must depend largely for the success of the plan here proposed. Many such persons spend evening after evening at their telescopes without obtaining results of any permanent value. Either no publication is made and the results are therefore valueless, or time is spent on objects that can be much more usefully examined with a larger instrument. Most commonly the observer has no special plan and spends many hours without result, while the same time might have been employed with equal pleasure to himself and results of great value collected. Those who have not tried it do not realize the growing interest in a systematic research and the satisfaction in feeling that by one's own labors the sum of human knowledge has been increased.

Much valuable assistance might be rendered by a class whose aid in such work has usually been overlooked. Many ladies are interested in astronomy and own telescopes, but with two or three noteworthy exceptions their contributions to the science have been almost nothing. Many of them have the time and inclination for such work, and especially among the graduates of women's colleges are many who have had abundant training to make excellent observers. As the work may be done at home, even from an open window, provided the room has the temperature of the outer air, there seems to be no reason why they should not thus make an advantageous use of their skill. It is believed that it is only necessary to point the way to secure most valuable assistance. The criticism is often made by the opponents of the higher education of women that, while they are capable of following others as far as men can, they originate almost nothing, so that human knowledge is not advanced by their work. This reproach would be well answered could we point to a long series of such observations as are detailed below, made by women observers. Variable stars may be defined as those which exhibit a varying degree of brightness at different times. The following classification of them is believed to be a natural one. (Proc. Amer. Acad. xvi, 1, 257.)

I. Temporary stars, or those which shine out suddenly, sometimes with great brilliancy, and gradually fade away. Examples, Tycho Brahe's star of 1572, new star in Corona, 1866.

II. Long period variables, or those undergoing great variations of light, the changes recurring in periods of several months. Examples o *Ceti* and χ *Ceti*.

III. Stars undergoing slight changes according to laws as yet unknown. Examples, *a Orionis* and *a Cassiopeiæ*.

IV. Short period variables, or stars whose light is continually varying, but the changes are repeated with great regularity in a period not exceeding a few days. Examples, β *Lyræ* and δ *Cephei*.

V. Algol stars, or stars which for the greater portion of the time undergo no change in light, but every few days suffer a remarkable diminution in light for a few hours. This phenomenon recurs with such regularity that the interval between successive minima may be determined in some cases within a fraction of a second. Examples β *Persei* (Algol) and S *Cancri*.

Stars belonging to the first of these classes are seen so rarely that the apparent discovery of one is to be received with the utmost caution. On the other hand, the importance of early observations of such an object is so great that no pains should be spared to secure an early announcement if one is really found. On the best star charts many stars are omitted of the brightness of the faintest objects given. But any star much brighter than these should be measured by the method given below, and a watch kept to see if any change takes place. If it proves to be a temporary star an immediate announcement should be made. If a telegram is sent to this Observatory the object will be at once examined, and, if verified, notification will be made in this country and in Europe with the name of the discoverer or sender of the telegram. A similar notification may be sent of any suspected objects, which will be examined in the same way, and announced at once if they prove to be of interest. It is essential that the position of the object should be given with all the precision practicable, and that a letter should be sent by the next mail giving the observations in detail. This often proves of the greatest value in case the object is not readily found. It also serves to establish the claims of the first discoverer.

Nearly three quarters of the known variables belong to the second class. Most of them undergo very large changes of light, and may therefore be observed with comparative ease. Our knowledge of their variations is however very defective. Hitherto the attention of observers has been directed principally to determining the times at which they attain their maximum light, while their light at intermediate times has been neglected. It is now proposed to secure observations of these objects once or twice in every month, so that their light curves or variations throughout their entire periods may be determined. Again, many observers are accustomed to state their brightness in magnitudes without giving any clue to the scale which they employ. In most cases such observations have little value owing to the uncertainty of the scale of the fainter magnitudes.

According to Dr. Gould and some other observers most of the visible stars undergo slight changes of light and should therefore be assigned to the third class of variables. It is probable that our Sun also belongs to this class, as it is not likely that its light is the same during the maximum and minimum of the sun spot period. At present we are unable to tell in which case the light would be greatest. It by no means follows that when the spots are most abundant the Sun’s total light is least, for the remaining portions of the Sun may then have an increased brightness more than compensating for their diminished area. As long as the suspected variations in light of the stars are small, not exceeding half a magnitude for instance, they seem in the present state of science to have comparatively little interest. They are so liable to be affected, or even caused, by errors of observation, that the observation of such objects does not seem now to be advisable. Doubtless many such so-called variables are really due to errors caused by moonlight, the proximity of brighter stars, varying position of the images on the retina of the observer, and other similar causes. They will not therefore be considered further in this paper.

The stars of the fourth class as compared with the second are relatively few in number, and the changes in light small. While many of them need observation, especially to determine their light curves more precisely, it is advised that this work be left to those who have acquired a high degree of skill in these observations. That the work may be of value it is essential that the errors should be extremely small. As, however, nearly all are visible in an opera-glass, a skilful observer unprovided with a telescope may secure valuable results by their observation. This remark applies with especial force to many of those discovered in the southern heavens by Dr. Gould.

The phenomena of the Algol stars are in many respects the most striking of any. The rapidity of the changes, their surprising regularity, and the comparative rarity of these objects, combine to render the discovery of each new one a matter of unusual interest. As in the case of stars of the fourth class, however, the study of their light curves should be left to those who have acquired especial skill in this work. This is particularly desirable, when, as in this case, the unaided eye enters into competition with photometric apparatus, by which, as some think, it should properly be altogether replaced.

An elaborate bibliographical work on the variable stars has been undertaken at this Observatory by Mr. Chandler. It will include the collection of all available published observations of known or suspected variables. A catalogue of suspected variables has thus been prepared, doubtless containing many stars which are really important variables. But it is also likely that many objects have been introduced in the list by errors in the original observations. Such stars often appear in one catalogue after another of suspected variables, and it is difficult to prevent the continued circulation of such an error. Of course if an experienced observer at any time estimates a star as above or below its normal brightness, it is impossible to prove that the observation was not correct, and the star really variable. No amount of subsequent observing could prove that it had not then, and then only, an abnormal brightness. We can, however, prove that in all probability it does not belong to one or more of the above classes, and thus make it more and more probable that the observation is due to an error. If the star varies in light by one magnitude, what will be the chances that we shall get a series of

observations having a range of variation of one fifth of a magnitude? Evidently on the average, there will be only one chance out of five that any observation shall fall in the same fifth of a magnitude as another. The chances for three such observations will be only 1/25 and for four 1/125, etc. These ratios expressed decimally are .2, .04, .008, 0016, .0003, etc. Since the separate determinations of the light of a constant star by the method given below should not differ more than two or three tenths of a magnitude, it is obvious that if the variations of the star are large, a few observations would generally establish this fact. If the star belongs to class four, observations on half a dozen evenings would hardly fail to show the variation. Conversely, if no such variation is detected we may be almost certain that the star is not a variable of that class, or at least that the variation, if any, is not large. If the star belongs to class two, it will change so slowly when near its maximum or minimum that a variation might not be noted if the observations are near together. An interval of several months should therefore be allowed to take place, or perhaps it would be better to wait until the star is again visible the following year. The total variation in light is usually so great in these stars that the change will often be visible at the first glance.

To prove that a star does not belong to the fifth class is a matter of much greater difficulty. In fact it is almost impossible to prove that it may not be an Algol star with a long period between the minima. Since these stars may have their full brightness for nine tenths of the time, it is obvious that they may be examined again and again without happening to be seen at the time of a minimum.

On the other hand, during a considerable portion of the time when it is varying, the light will be so much less than usual that a careful measurement is not needed to detect the change. Moreover, it will be useless to look for an increase of light, and the observation may be so planned as to detect a diminution only.

If we assume that only during one tenth of the time the change in light will be sufficient to be perceptible, the chance on any given evening will be 9 out of 10 or 9/10 that the star will have its full brightness. For two evenings the chance will be $(9/10)^2$ for three $(9/10)^3$, etc. These quantities expressed decimally are .9, .81, .73, .66, .59, .53, .48, etc. Even after seven nights' observations, on which no change is noted, it will only be about an even chance that the star may not still be of the Algol type. A different method of observing is therefore recommended when the star is supposed to belong to this class. Select for comparison a star slightly fainter, so that a moment's glance will satisfy the observer that the suspected variable is the brighter. It is only necessary to repeat this observation night after night. If the star is bright enough to be visible with a field glass, a few seconds will be sufficient for this observation after the observer has become familiar with the vicinity. The fact that the light is normal, and the time to the nearest minute, should be recorded after each observation. When convenient, it is well to repeat the inspection two or more times during the night, as in determining the period all the observations will have a value, provided that they are separated by intervals of more than two or three hours. If the star is ever found below its normal brightness, comparisons should be made with the adjacent stars, and continued as long as possible, or until it has regained its usual brightness. The most complete proof that a star was not of the Algol type would be for observers in the polar regions to examine it at intervals of a few hours for several days, or for observers in different longitudes to make the same observations. If it could thus be watched for a week or fortnight by enough observers to avoid interference by clouds, it would be nearly certain that it is not an Algol star unless its period is greater than that of any such object as yet discovered.

The problems to be undertaken may be defined as follows:—

1. To observe all the long period variables once or twice every month throughout their variations according to such a system that all the observations may be reduced to the same absolute scale of magnitudes.

2. To observe the stars whose variability is suspected and prove either that they are really variable, or that in all probability they do not belong to the first, second, or fourth class. If any are thought to belong to the fifth class, to watch them until such a variation is proved, or is shown to be improbable.

All of this work will depend on the possibility of readily determining the brightness of a star according to such a method that all the observations can ultimately be reduced to the same system. Herschel and Argelander have independently invented what appears to be the true method to be followed. If a star is seen to be very nearly equal to several others, from their light we can at any time define its brightness. It is essential that at least one of the stars selected should be a little brighter, another a little fainter, than the star to be observed. The range within which its light is known is thus also defined. Such observations will far exceed in value any direct estimate of magnitude. When stars are to be compared many times, it is convenient to designate them by letters for brevity. Let *v* represent a star which is suspected to be variable, and *a* an adjacent star of nearly equal brightness. Owing to fluctuations in the atmosphere, each star will appear to be constantly varying in brightness. If the stars appear equal after a careful examination, or if one appears brighter as often as it appears fainter than the other, we may denote this equality by *av* or *va*, these terms having precisely the same meaning. If one of the stars is suspected to be brighter, that is, if it appears sometimes brighter and sometimes fainter, but more frequently brighter, the interval may be designated as one

grade. The observation may be written *a* 1 *v* or *v* 1 *a*, the brightest star being named first. If one star is certainly brighter than the other, the difference, however, being very small, so that they sometimes appear equal, the difference will be two grades, and may be written *a* 2 *v* or *v* 2 *a*. Greater intervals may be estimated as three or four grades, but such observations have much less value. It is found in practice that a grade thus estimated will slightly exceed a tenth of a magnitude. A useful exercise for an observer is to select two stars of known magnitude and several others of intermediate brightness. Arrange them in a series in the order of brightness, and estimate the intervals in grades. The difference in magnitude of the first stars divided by the total number of grades gives the value of one grade. By using different intermediate stars, the same standard stars may be employed repeatedly. The following well-known polar stars will be convenient, since they are always visible:— *a Ursæ Minoris*, 2.2 magn.; γ *Ursæ Minoris*, 3.0 magn.; δ *Ursæ Minoris*, 4.4 magn.; 51 *Cephi*, 5.4 magn.; λ *Ursæ Minoris*, 6.5 magn. The above method is essentially that of Argelander. Sir William Herschel had already employed a method which differed mainly in his notation, a . , and — being equivalent to one, two, or three grades.

In all work of this kind the observer must look directly at the star he is observing at the moment, and never try to compare two stars by a simultaneous inspection of both. After examining one star until he has a distinct impression of its average brightness, freed from the momentary changes due to atmospheric disturbance, he should observe the other in the same manner. Alternate observations of the two stars, each observation lasting for a few seconds, will give a truer impression than can be derived from a simultaneous observation in which the two images must be differently placed on the retina.

The principal objection to this method is the difficulty of determining the value of a grade, as it is liable to vary with the observer, the time, the condition of the air, and the brightness of the stars. These difficulties are avoided by the following method. Select two stars for comparison; one, *a*, slightly brighter than the star to be measured, *v*, the other, *b*, slightly fainter. The interval between *a* and *b* should never exceed one magnitude. Estimate the brightness of *v* in tenths of the interval from *a* to *b*. Thus, if *v* is midway between *a* and *b* the interval will be five tenths, and we may write *a* 5 *b*. If *v* is nearly as bright as *a*, we may have *a* 1 *b* or *a* 2 *b*; if *v* is not much brighter than *b*, we may have *a* 8 *b* or *a* 9 *b*. An advantage of this method is that larger intervals in brightness may be used between the comparison stars, and accordingly less distant stars employed. An increase in distance of the stars always renders the comparison more difficult. We can also obtain many independent comparisons by using several comparison stars. If we have *m* stars brighter and *n* fainter, we shall only have $m + n$ independent measures by the method of grades, while we may have $m\ n$ comparisons by estimating tenths, since estimates may be made in terms of the intervals between each brighter and each fainter star. On the other hand, especially when observing stars not very near together, it is a decided advantage to have to compare two stars rather than three. Each method has its advantages, and that to be used should doubtless depend on the temperament of the observer.

Several precautions are needed to secure the best results. No observations should be made near the horizon; and, when the objects examined are at any considerable zenith distance, stars differing several degrees in altitude should be avoided. If the stars are bright and there is no choice, a correction may be made for the error due to the varying absorption at these different altitudes if the time of observation has been noted. When using a telescope or opera-glass, the stars should be brought in turn to the centre of the field, as when near the edge they will not appear of their true brightness. This is found to be better than placing them at equal distances from the centre. In selecting comparison stars, the proximity of a brighter star is very objectionable, causing a large error, which varies with the magnifying power used. Double stars should be avoided if the power used is sufficient to show the companion. Comparing stars of different colors is also objectionable.

Any persons who desire to take part in these observations are requested to communicate with the writer, and send answers to the questions given below.

1. What is the location of your point of observation? In the city or in the country, on the ground, from a roof, or from a window? Is any part of your horizon obstructed, or can you observe in all parts of the sky?

2. What is the aperture, focal length, and name of maker of your telescope? also the lowest magnifying power and largest field of view you can obtain with it? Have you a field-glass or opera-glass?

3. Can you identify bright and faint stars from their designations or right ascensions and declinations? Have you Heis' Atlas Cœlestis Novus, the Uranometria Argentina, the Durchmusterung, or other maps and catalogues of the stars?

4. Would you prefer to observe the known or the suspected variables, or to divide your time between them?

For convenience in making the reductions and for future reference, it is essential that all the observations should be made according to the same system. Observers are accordingly requested to adopt the following form. Use half-sheets of letter paper (eight inches by ten), writing only on one side and leaving a margin of half an inch for binding. Begin with a new sheet every evening, and write the date and location (township and state) on the first line. Each

sheet when completed should be signed, and all should be numbered consecutively. When several sheets are used on the same night, the date should be entered on each. The record should be made in pencil, and all subsequent remarks or corrections added or interlined with ink, taking especial care not to obliterate or render illegible the original record.

A general statement should be made each evening of the condition of the sky, as “clear,” “hazy,” “passing clouds,” etc. The time of beginning and ending work should also be noted. One line should be assigned to each comparison. The hour and minute should be written to the left, and the comparison next to it. The right-hand half of the line will be left blank for reducing the observation.

Certain evenings or portions of evenings must also be devoted to the selection of the comparison stars of suspected variables. If they are contained in maps which are available, the letters assigned to each star may be marked on the maps and lines drawn to show with what suspected variable star they are associated. If preferred, a sketch may be made of the neighboring stars and the letters entered on them. This sketch with a proper description should be entered on the observing sheets described above, and a copy should be retained for reference. Every month the observations will be interrupted by moonlight, and accordingly, three or four days before the full moon, all the sheets that have accumulated should be mailed, addressed Harvard College Observatory, Cambridge, Mass. An acknowledgment will be sent at once, so that if this is not received a second notification should be sent.

To attain success it is particularly important that the plan should not be local or national. Observers in the southern hemisphere are much needed, and for some purposes those in various longitudes. It is hoped that among the many amateurs of Europe, and especially of England, may be found some ready to participate in this work. No restriction regarding the observations or publication is intended; but it is hoped that a large addition to our present knowledge of the variable stars may be secured, without interfering with what would otherwise be obtained. Copies of this pamphlet and further information will be furnished on application. Any persons desiring to participate are requested to address the writer, sending answers to the questions given above. The details will differ with each observer, and will be arranged by correspondence. Apart from the value of the results attained, it is believed that many amateurs will find it a benefit to accustom themselves to work in a systematic manner, and that they will thus receive a training in their work not otherwise easily obtained outside of a large observatory. The lesson should be taught that time spent at a telescope is nearly wasted, unless results are secured worthy of publication and having a permanent value. Those who have once accomplished such work are likely in the future to appreciate its value, and will often continue to do useful work in some other department of practical astronomy, if not in that of variable stars. The education of a class of skilled observers would be a work of no less value than the results anticipated from the observation of the variable stars.

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