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Some Facts and Hypotheses regarding Variable Stars.

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THE vast majority of the stars are as invariable in their brightness as they are in their apparent positions in the sky. But there are many exceptions and these exceptions are sufficiently numerous to entitle variable stars to be placed in a distinct class by themselves, and within this class of variable stars there are many sub-classes. Thus some show a gradual and alternate increase and decrease of light between definite limits, occurring within regular intervals. Others attain a certain maximum and then decline to absolute extinction, and then again re-appear. Some are continuous in their processes of change. Others are quite irregular in their fluctuations. Others have variable maxima and minima. Others have blazed out and never been seen again. Some have long periods and others have short and so forth. Very little attention curiously enough had been given by astronomers to these various classes of variable stars until about twenty years ago. The credit of the discovery of several hundreds of such stars is due chiefly to the labours of quite a few astronomers such as Dr. Chandler, J. E. Gore, and Dr. Roberts of the Cape Observatory. In view of the fact that this sort of work is highly interesting and is well within the compass of amateurs, it is curious that it should have been so neglected. The binocular and even the naked eye has accomplished most of the spade work in this direction. The variation is judged by comparisons made with neighbouring stars. Of late the number of discoveries made has been greatly increased by the introduction of the photographic dry-plate, a large number have been detected by the comparison of the photographic star charts made at the American observatories of Cambridge and Harvard. The photographed spectra of stars which present a peculiar "colonnaded" appearance immediately mark them off as variables. The photographic method has been especially successful in showing us the extraordinarily large number of variables that are to be found in star clusters and nebulæ. But for ordinary single variable stars there is no better method than that of the naked eye or the mere opera glass, comparing the variable with adjacent stars at the time of its maximum and minimum. It must then be carefully noted to which of the neighbouring stars it is then equal, or a shade brighter or fainter. A really useful work can be done in this direction by the amateur. For it demands no expensive instruments nor any mathematical knowledge and skill, but only a modicum of patience and zeal. The professionals of the observatories gladly welcome records of observations sent in by the amateur, especially as owing to more pressing and technical work, they have little time themselves to devote to the observation of variables. For it must be admitted that some time must necessarily be wasted in extracting these comparatively few variables (which only number about 20 in a million) from the mass of the ordinary denizens of the sky, which are of no peculiar interest. In order to obtain precise quantitative results in the matter of the variation of the light of variables however, instruments of great precision have lately been invented for accurately measuring their varying brightness. Such are the " photometers." They are of two distinct types. The first depends upon the equalization of two lights, and the second on the extinction of light. In the first method, the standard light of a known star, or of an artificial star is varied in a measurable manner, until it is reduced to the same magnitude as that of the variable under discussion. Thus a graduated wedge of neutral-tinted glass can be passed in front of the standard star until the star is dimmed so as to equal in magnitude the variable. If the variable is brighter than the known comparison star, of course the wedge process must be reversed, and be used upon the variable. The better method, however, is that of extinction, as then we have no need of a comparison star. The wedge is passed in front of the variable until its light is just extinguished. The reading at which the extinction occurs varies with the brightness of the star, and hence its brightness can be measured. There is one drawback to this method, namely, its greater liability to error due to the uncertainties of the atmosphere. Hence it is still necessary to check the state of the atmosphere first of all by observing the error in the extinction point of a standard star, and thus to be able to measure accurately at the time of observation the true magnitude of the variable. Variables possess very different ranges of variation. Some only range between a fraction of a magnitude. Others range through as many as eight magnitudes, and are as much as a thousand times brighter at maximum than at minimum. In many cases both their colour and spectra change regularly during the course of their variations. Dr. Chandler's catalogue of 1896 contains 383 stars asserted to be unquestionably variable. Of these 300 are regularly periodic. Of these again he makes fourteen to belong to the Algol type, twenty to the Eta Aquilæ class, and no less than 250 to the Omicron Ceti type. There are 6 with periods varying from 25 to 60 days, it being doubtful as to which class they should be assigned. Thirty are certainly wholly irregular in their variation, and there are about 50 stars whose period has not yet been assigned, and about 150 which are suspected of variation. The new variables are mostly telescopic. When a new variable is discovered, it is now customary to designate it either by the name of the discoverer or by one of the last letters of the alphabet joined with its constellation. Professor Pickering and Bailey of Harvard were the first to make the startling discovery that a vastly preponderating number of variables can be found in certain of the star clusters. Some clusters contain none, others a very large number. In star-cluster Messier 5, in Libra, there are 85 variables out of a total of only 900 stars, in Omega Centauri there are 122, and in Messier 3 in Canes Venatici there are as many as 132. Altogether 600 variables have been found in star clusters up to the present. The variations of these star-cluster variables are curiously alike. They nearly all go through a cycle of an average of 12½ hours, ranging from a 10-hour to a 14-hour period. They all slowly and gradually lose their light, and then remain at about half-brightness for some time, and then suddenly rush back to their maxima with startling rapidity. This suddenness of the return to full light is very remarkable, and hitherto the phenomenon has received no satisfactory explanation. Some variables are very irregular in their fluctuations. The most remarkable of such stars is Eta Argus, or Eta Carinæ, 59 degrees south (it can be well observed from Calcutta, but is too far south to be seen from England or North Europe), which varies from the first magnitude as in 1843, down to the seventh magnitude; which is its present brightness. Between 1677, when Halley observed it, and 1800, as far as can be judged from the existing records, Eta Argus oscillated in brightness between the second and fourth magnitude. Between 1800 and 1826 it rose rapidly in brightness, and between 1838 and 1850 it was never below standard first magnitude. Careful observations were made of its variations by J. Herschel in 1837 at the Cape Observatory. He records how astonished he was on December 16, 1837, at coming across an apparently new star of the first magnitude. He, however, soon recognized it from its position as Eta Argus, and adds that it increased till January 2, 1838, until it equalled Alpha Centauri. It decreased again till it was only equal to Aldebaran, but blazed up in 1843, till it was second only to Sirius in the whole heavens. At its brightest it gives 25,000 times more light than at its dimmest. Eta Argus is enveloped in a nebula. Professor Loomis is of opinion that after a further period of watching this star, it may not improbably be found to have a period of about 70 years, but if this is really so, it is absolutely unique among the variables. Several variables are known such as R. Andromedæ which possess as large or even larger a range of variation than Eta Argus, but none are nearly so bright. R. Andromedæ is never brighter than the sixth magnitude and sinks to the thirteenth. Eta Argus is a most puzzling source of speculation. The vastness of the changes that must take place there absolutely staggers the imagination.

But perhaps the most curious of all celestial phenomena are the so-called temporary stars or "Novæ." Such stars suddenly burst into existence as it were and then as a rule gradually fade away. There are fifteen recorded cases of stars suddenly blazing up and then fading away again. Hipparchus drew up his famous catalogue as a result of seeing a Nova in 134 B.C., his object being to leave behind him a record of the sky as it appeared in his day, in view of possible future change. A Nova was observed in 389 A.D. in Aquila. Another famous Nova was the star seen by Tycho when out walking one November evening in 1572. It appeared in Cassiopæa, and became as bright as Venus and was even visible by day. But after 15 months, it absolutely disappeared, and has never been seen again. Janesen observed a Nova in Cygnus in the year 1600, of the 3rd magnitude. Kepler has recorded that he observed a star in Ophiuchus, which became more brilliant than Jupiter, and after two years faded rapidly away, leaving absolutely no trace behind it. In May 1860 a new star blazed out in Corona Borealis. It was noticed by at least five observers who have recorded their discovery. And Schmidt, who was examining that part of the heavens a week before the discovery, gives it as absolutely certain it was not there before the above date. Ten years later, he discovered a new star of the 3rd magnitude in Cygnus. In a few weeks it faded away. Huggins examined it spectroscopically, and found it similar to our Sun when at its maximum, but as it faded away its spectrum changed to that of a nebula with three bright lines. Altogether eight Novæ have been recorded as observed in the 19th century. Of late years the most notable Nova is that of Auriga, discovered in 1892 by an amateur astronomer named Anderson at Edinburgh. It quickly reached the fourth magnitude, but after three months it sank to the twelfth, after another four it again rose to the ninth, and then faded away. This star was afterwards found on a plate exposed at Harvard on December 10, 1891, but it was not to be found on a plate exposed two days earlier. Its spectrum was examined, and was found to be double, one a bright-line, and the other an absorption spectrum. The lines too were shifted in such a way as to indicate that two stars were moving in opposite directions ; the bright-line mass receding from, and the darkline mass approaching us. Their velocities were exceedingly large and variable ranging up to 500 miles a second. It has been conjectured, that in the case of Eta Argus, two large bodies may have passed very near each other and thus produced great tidal disturbances, causing immense eruptions corresponding to solar prominencies, only on a vastly larger scale. Eight months later the star which had sunk to the 11th magnitude rose again to the ninth, and then Campbell found its spectrum to have become that of a planetary nebula. If astronomers had the leisure to carefully observe all the multitudes of the smaller stars, a vast number would be probably found to be Novæ. There are certainly important physical resemblances between those already observed and examined. But much more work needs to be done on such stars, before we can hope to arrive at any true explanation of their vagaries. Many hypotheses have been put forward. These sudden conflagrations might possibly be caused by two dark bodies colliding, and setting up enormous heat by impact. Or again, a star too faint to have been seen before, might be lighted up by plunging through a nebulous mass of matter. The latter hypothesis seems preferable to the former, since on the former supposition, the sudden sinking down to invisibility could hardly be accounted for. The last Nova was discovered only 13 years ago in Perseus. It came to be surrounded by a nebula which was apparently spreading out at an enormous rate into space. It looked as though the star was ejecting matter that was travelling outward at a velocity equal to that of light, or nearly 200,000 miles a second. It is probable, however, that there was in reality no emission of matter at such enormous velocity outward from the star, but that the star, in passing through a nebula, and in so doing becoming incandescent, was thus lighting it up. We were thus beholding the actual motion of light, as it travelled out and away from the incandescent star, at a rate of 186,000 miles a second. If this is the true theory, we can calculate that the Nova must have been at a distance from us of 300 light years. As a sub-division of the temporary stars, it may be mentioned the "Missing stars." By comparing the present aspect of the heavens and modern catalogues with ancient records and star atlases, many stars are now found to be missing. No doubt many such "missing" stars can be accounted for on the hypothesis of mistaken entries, whether on the part of the recorder, or in the reduction of the observation, or even in the printing. It is certain that in not a few cases one of the planets has been mistaken for a star. There is no known instance of a new star appearing and remaining permanently bright. However, it is certain that there are genuine cases of missing stars, which cannot be explained away by any supposition of mistaken entries. It may be that such stars are in reality periodic, possessing a periodicity far exceeding the limits of time within which the heavens have been observed with any scientific accuracy. In this case they will at some future epoch re-appear. Quite another type of variable star includes the regularly periodic variables. These can be divided roughly into three classes. The first class we will call the short-period variables. The most notable of these are Delta Cepheus, Eta Aquilæ, and B. Lyræ. Delta Cepheus passes from minimum to maximum in 38 hours and from maximum to minimum in 91 hours. Eta Aquilæ departs from and returns to maximum in a 7·189 days cycle. Beta Lyræ, which was discovered to be a variable by Goodricke in 1789, is a most curious and interesting variable. It has two maxima and two minima of unequal values. The whole period being 12·5 days. From minimum which is 4½ magnitude, it rises in 2½ days to its greatest maximum of 3·4, it then gradually sinks in 5 days to 3·9 its lesser minimum, and in 4 days more rises to its lesser maximum of 3·5, and then rapidly sinks again to its greatest minimum of 4·5. A further very remarkable fact is that this period is not constant, but is probably itself periodic. From 1784 onwards the period was lengthening, but the lengthening was not constant but became gradually slower, until in 1840 the lengthening ceased, and since then the period has been shortening. So much for the short period variables. The most conspicuous of our second class or the long-period variables is Omicron Ceti, generally known as Mira—" The Wonderful." This was the first variable to be subjected to scientific scrutiny. David Fabricius notified his discovery on the 13th August of 1596. It has been carefully observed ever since. Its period is 11 months. During most of this time, though invisible to the naked eye, it can be easily seen with the aid of binoculars. Once in 11 months it rises rapidly to its maximum, remains at maximum for about a fortnight, and then gradually faints away to its former long period of faintness, taking about three months out of the eleven to make its changes. Its maximum is not constant however. Sometimes it attains to the brightness of a brighter second magnitude star, and sometimes not even to that of a fourth magnitude. The period of return to maxima is not constant, but varies by several weeks. A large majority of the variables belong to the Mira class of long-period, all of them being of a distinctly reddish hue, and most having a "colonnaded" bright-line spectrum. The mean period of variation which Argelander computes as 331·3 days is not constant, but subject to a larger periodical fluctuation of 29,700 days during which the mean period of 331·3 days varies to the extent of plus or minus 25 days. Its maximum variation in brightness is also probably periodic. At its maximum its spectrum shows a large number of bright lines, most of them probably due to hydrogen, but many as yet remain unidentified. The strange conduct of such stars as Mira may perhaps be due to eruptions similar in kind to, though vastly greater in scale than, the solar prominences. Their periodicity is after all no more mysterious than is the periodicity of the sun-spots. There are less than 100 stars of the third class of periodical-variables known to us, whose most notable member is Algol or Beta Persei, the "Demon star." Its R. A. is 3 hours and Decl. 40 degrees 23 minutes. Two smaller stars will be seen on either side of it. In Autumn after sunset it will be in the N. E., in Spring in the N. W., and in Winter north of the Zenith. The shortness and great regularity of the variations of this Algol type ranging from 4 hours up to 13·2 days is a characteristic. They suffer a partial eclipse at short intervals. When at its brightest Algol is of 2·1 magnitude, and when least bright is less than 3·8. Hence at minimum it is only one-sixth as bright as at maximum. Its whole period is 2·89 days, which is constant, except for a very slow secular lengthening. It falls from maximum to minimum in 1½ hours, remains at minimum for 20 minutes, and returns to maximum in 3½ hours. These changes have been noticed from ancient times, but were not studied accurately until Goodricke pointed them out in 1782. The spectroscope has proved that such variables as Algol are binaries, too close to be separated by any telescope. The shift of the lines of the spectrum shows Algol as alternately approaching and retreating from us, as though it were one star revolving in an orbit. From 12 to 18 hours before obscuration Algol is receding from us at 27 miles a second, after the minimum it is approaching us at the same rate. The brighter component is regularly eclipsed by the darker one, their orbits being in the same plane with the Earth. In other cases where the diminution of light is less marked than in the case of Algol, both stars are probably bright. When one is behind the other, we should receive less light than when they are side by side. In the case of

Algol it can be calculated that Algol is 3,250,000 miles distant from his dark companion, and that their diameters are 840,000 miles and 1,060,000 miles respectively. Their united mass is two-thirds of the Sun's mass, and their density only one-fifth of his. Judging from certain irregularities in the proper motion of this pair, it is probable that the pair is itself revolving around another distant dark body in a period of 130 years. The irregularities, however, may with equal probability be due to a slow revolution of the orbital apsides of the pair. One of the most remarkable of the variables of the Algol type is V. Puppis, lately discovered by Dr. Roberts. Its period is only 1·5 days. The astounding conclusion has been arrived at, that the two components are revolving round one another in actual contact. We will now take a further survey of the hypotheses we have already touched upon, to account for these curious variations of star magnitude. One of the most striking things in the whole range of astronomy is the suddenness and the vast scale of the outburst of light on the part of certain types of variable stars. Many hypotheses more or less satisfactory have been put forward to account for these astounding phenomena. Certainly no single explanation could account for all the various types of variable stars, and probably no sure and safe explanation can as yet be given for irregular variables. We will hazard a few hypotheses. Perhaps in some cases the outbursts may be due to the collision from time to time between two previously dark or semi-dark bodies. We know for several reasons that there do exist dark bodies, and that they may move with great velocity. The outburst would thus appear where previously nothing had been seen. The objection to this theory is the rapidity with which the conflagration dies down, until it soon becomes invisible. Another objection to the collision theory is that, when we consider the smallness of the diameter of stars compared with the vastness of the distances between them in space, calculations of probabilities of collisions would not lead us to expect anything approaching the number of the temporary stars actually observed. On the other hand it is not necessary to suppose an actual collision of their surfaces. It would be sufficient in many cases for them to pass very near each other, in order to produce very vast upheavals and consequent outbursts of light. Perhaps a better theory for temporary stars, is that a dark body may become incandescent by passing with great velocity through a nebulous mass. The gradual dying down of the light would correspond to its gradual exit from the nebula, as the nebulous matter on the outskirts became more and more rarified, and hence the star became less and less incandescent. It is not impossible that these outbursts are due to something akin to solar prominences on a vastly greater scale. In the case of the Nova of 1866, Huggins found its spectrum greatly resembled that of the Sun, and that it behaved in a manner very similar to the Sun's spectrum during periods of great solar activity. The position of the spectrum lines showed that the outburst was due to glowing hydrogen travelling outwards at an enormous velocity. Its spectrum, like our Sun's, was a continuous one, crossed by dark absorption lines. Huggins attributed the outburst merely to an exceptionally vast emission of hydrogen, which by its own light and by heating up the whole surface of the star was sufficient, he thought, to account for the great accession of light. We know the red flames round the Sun are caused by eruptions of hydrogen from his interior, and that these eruptions are accompanied by a great brightening of portions of his surface, which we call faculæ. Newton thought that outbursts were due to the falling into the star of bodies of a cometary nature. But this hypothesis has many objections, and in any case it could not account for periodicity. Herschel considered the variations nothing more than magnified Sun spots, and that the periodicity could be accounted for by the combination of axial rotation with the periodicity of the spots themselves, in like manner as our Sun has a spot-periodicity of approximately 11 years. The light of the variable would be greatest when spots were least and *vice versâ*. If an observer were far enough away, he would perceive our Sun to be a variable star, although indeed the variation would be very much less than that of any star which we denominate as "variable." It is not in the least impossible to the nature of stellar composition, to suppose that very much vaster spot-systems could exist in other stars than in our Sun, without inducing disruption or disintigration. May not another hypothesis be not altogether impossible, namely, that some stars may owing to enormous rotational velocity be spheroids of so great oblateness, as to have the form of their flat disks, something after the fashion of Saturn and his rings, and many of the nabulæ? May not the axis of rotation vary in inclination towards the Earth, so as sometimes to be seen perpendicularly when it would give its maximum light, and sometimes to be seen edgewise and then to be too thin to be visible? This theory would at best account for "periodicity." Again, may it not be that some stars are revolving, along with their surrounding nebula, and that the nebula may extend out from the star very irregularly, or be very irregular in density, in such a manner as to present to our view a much thicker veil to the star on one side, as star and nebula rotate together, than on another. Again may there not be planets in other systems of greater size though of vastly less density than their primaries (Saturn, for example, is far less dense than the Sun), so that in circulating in their orbits, which may periodically vary in inclination, they may thus cut off sometimes more and sometimes less of the light of their primaries, and thereby account for the varying maxima and minima of so many of the variables. Another theory to account for temporary stars, and also variable stars of the Mira class, has been put forward by Lockyer. He supposes that such stars are in a primitive condition of close aggregates of meteoric bodies, not yet condensed or compact globes, and that each such aggregate has another smaller aggregate circulating round it in a very eccentric elliptical orbit with very small perihelion distance, such that when in perihelion, the one meteoric aggregate will graze the other, and thus set up an immense number of violent collisions between individual meteorites, without disturbing the general orbital motion as a whole. The great irregularity of the stars of this class seems, however, to be an objection although not an altogether insuperable one to such a theory. It is very probable that the more regular and punctual variables may all of them be proved to be spectroscopic binaries ; the variation being due in part at least to eclipse, and also in part perhaps to certain tidal interactions, the nature of which is at present obscure. The odd and even minima occurring as they do in several instances at unequal intervals, certainly indicate very eccentric orbits. We will conclude by venturing to suggest, that the true explanation of the variations of the greater number of variables will be found to be, not in any one single hypothesis, such as we have put forward above, but in every variety of combination of these hypotheses.

Note on the Proper Motion of 61 Virginis (B.D.—17°3813).

BY T. P. BHASKAR SHASTRI, B.A.

THE star 61 Virginis (Mag. 5th) lies in the portion of the heavens allotted to the Nizamiah Observatory for the astrographic catalogue.