The variable star ?ta geminorum

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THE VARIABLE STAR
η GEMINORUM

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PROEFSCHRIFT TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE WIS- EN NATUURKUNDE AAN DE RIJKS-UNIVERSITEIT TE UTRECHT, OP GEZAG VAN DEN RECTOR MAGNIFICUS DR. B. J. H. OVINK, HOOGLEERAAR IN DE FACULTEIT DER LETTEREN EN WIJSBEGEERTE, VOLGENS BESLUIT VAN DEN SENAAT DER UNIVERSITEIT TEGEN DE BEDENKINGEN VAN DE FACULTEIT DER WIS- EN NATUURKUNDE TE VERDEDIGEN OP WOENSDAG 4 JULI 1928 DES NAMIDDAGS TE 3 UUR

DOOR

EVERT HENDRIK VOGELENZANG
GEBOREN TE MEPPEL

GEBROEDERS HOITSEMA — 1928 — GRONINGEN.

AAN MIJN MOEDER EN AAN DE
NAGEDACHTENIS VAN MIJN VADER.

Het verschijnen van dit proefschrift biedt mij een welkome gelegenheid allen, die tot mijne wetenschappelijke vorming hebben bijgedragen, mijn hartelijken dank te betuigen.

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CONTENTS.

INTRODUCTION.

As early as 1843 J. F. J. SCHMIDT, then in Hamburg, suspected η Geminorum to be a variable star, but more than twenty years elapsed before he felt sure of it. From September 27th 1863 he made observations at Athens and his increased activity in the observation of the variable stars soon confirmed his suspicion. On the 24th of October 1865 he writes in his diary: „Der 24. Oktober gilt mir als Tag der Entdeckung der Veränderlichkeit von η". [1]) Till the eve of his death, which occurred on February 6th 1884, SCHMIDT kept the star under regular observation.

During the period 1884—1887 the star was neglected but in 1887 PLASSMANN began to observe η and from that year onward the star has been regularly kept in view by a sufficient number of observers.

HOFFMEISTER published a discussion of PLASSMANN's observations of the period 1887—1913 [2]). He derived the following elements:

$$\text{Min.} = 2410707{,}4 + 232{,}177\ E,$$

which formula represents the minima with a mean error of 29,8 days. He suggests an analogy of the light-curve with the light curve of an eclipsing binary.

In „Geschichte und Literatur der veränderlichen Sterne" GUTHNICK discussed the whole material [3]) but as it appears that he used the minima as published by the observers and by HOFFMEISTER, it is hardly possible to consider this discussion as trustworthy. His conclusions with regard to such things as the jump in epoch of + 65 days and the analogy with Algol must therefore be considered as premature. His formulae are:

$$\text{Min.} = 2402537 + 231{,}8\ E \text{ and } 2410715 + 231{,}8\ E.$$

In connection with the work of GUTHNICK the classification by LUDENDORFF [4]) may be mentioned here. LUDENDORFF considers η Geminorum to be the prototype of a new class of variable stars to which class V1 (R) Sagittae, V13 (RU) Cephei

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1) *Astronomische Nachrichten* Nr. 1687.

2) *Mitteilungen der V. A. P.* 24, 15 (1914).

3) Nr. 378, p. 188.

4) *Astronomische Nachrichten* Nr. 5126.

and V5 (V) Ursae majoris are supposed to belong. A relation with the RV Tauri stars is considered possible by him. In „Handbuch der Astrophysik" [1]) LUDENDORFF classes η among the stars of the Mira Ceti type with light-curve β 4 (symmetric light-curve, very broad maximum with brightness remaining constant for a considerable time). He writes [2]): „Unter den Me Sternen kommt die Kurvenform β4 nicht vor, und von den Mirasternen der übrigen Spektralklassen sind nur die Lichtkurven von η Geminorum (Ma) und S Aurigae (N) mit β4 bezeichnet. Man hat vielfach eine „η *Geminorum-Klasse*" unterscheiden zu müssen geglaubt. Dies ist weder notwendig noch zulässig, denn offenbar ist die Lichtkurve nur ein extremer Fall einer β Kurve, und im übrigen scheint sich η nicht grundsätzlich von manchen anderen Angehörigen der Mira-Klasse zu unterscheiden". As the remarks of LUDENDORFF originate in the results arrived at by GUTHNICK the same criticism may be applied to them as to GUTHNICK.

Spectroscopic evidence does not confirm the reality of the Algol type for this star, the spectral class being Ma; η seems to be a spectroscopic binary [3]). A comparison of the variation of the radial velocity as found by the Lick observers with the light-curve will be given in § 8 of this paper. I tried to get some more spectroscopic work done on this star but without success.

As a treatise on the whole material available has never been published I undertook this research at the instigation of Prof. NIJLAND.

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[1]) Band VI Zweiter Teil (Berlin, Jul. Springer, 1928) p. 99, 110, 114.
[2]) p. 130.
[3]) *Lick Bulletin* 1, 158.

CHAPTER I.

DETERMINATION OF THE LIGHT-CURVE.

§ 1. Material available.

The material at hand consists of a small number of photometric measurements and of a far greater number of estimates made according to well known methods (ARGELANDER, NIJLAND, fractional method).

Since only a few series of observations have been published, the greater part had to be obtained from the observers themselves or from the astronomers in care of the manuscripts My special thanks are due to Prof. LUDENDORFF, Potsdam, and Prof. KÜSTNER, Bonn, for copies of the observations made by SCHMIDT, to H. GROUILLER, Lyons, for a copy of LUIZET's work and to F. DE ROY, Antwerp, for the observations made by members of the Variable Star Section of the British Astronomical Association. The observations made by PLASSMANN, KNOPF, DE ROY, NIJLAND, RYVES, SCHARBE, LANDWEHR, MÖLLES, WIRTZ und VON STEMPELL were handed over to me in their original form by the courtesy of the observers themselves. My own observations completed the material, making a total of **9151** observations, covering the period **1843–1924**. In the following table a summary is given of the publications and manuscripts used.

The photometric measurements available [1]) do not appear in this list, since they are too few in number to be taken into consideration here. It is a well known fact that the value of observations made by means of the photometer is often greatly exaggerated and this over-estimation leads to the belief that a few measurements will suffice to derive a trustworthy light-curve.

Short series of photometric measurements will hardly ever be of any importance in the study of an irregular and difficult object such as η Geminorum. The measurements of KAISER and SCHELLER and those of PICKERING are therefore excluded from the discussion.

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[1]) KAISER and SCHELLER, *Astron. Beob. Sternwarte Prag*, **2**, 23, PICKERING. *Harvard Annals*, **24**, 254; **46**, 237.

Table I.

Author.	Period.	Number of Observ.	Reference.
SCHMIDT	1843—1884	3388	copies Potsdam and Bonn.
SCHÖNFELD	1872—1875	123	Ver. Sternw. Astr. Inst. Heidelb. **1**, (1900).
ROSICKY	1886—1887	10	copy by HACAR in MS.
PLASSMANN	1887—1924	1450	Beob. Ver. St. and MS (1913—1924).
MARCKWICK	1888—1919	213	MS. B. A. A.
KNOPF	1890—1891	16	MS.
LUIZET	1898—1917	751	copy Lyons.
ORR	1900—1901	13	MS. B. A. A.
WORSELL	1900—1902	23	MS. B. A. A.
CHILD	1900—1902	64	MS. B. A. A.
VON STEMPELL	1901—1918	161	MS.
KOPFF	1902	18	Heidelb. Astr. Publ. **1**, 190.
GOETZ	1902—1904	28	ibid. **2**, 68.
OAKS	1903—1906	36	MS. B. A. A.
DE ROY	1903—1924	621	MS.
SCHILLER	1904—1905	26	Heidelb. Astr. Publ. **2**, 100.
FIELD	1904—1906	39	MS. B. A. A.
NIJLAND	1904—1924	494	MS.
RYVES	1905—1924	522	MS.
LOHNERT	1905—1906	39	Heidelb. Astr. Publ. **3**, 115.
MITCHELL	1906—1920	80	MS. B. A. A.
SCHARBE	1907—1922	166	MS.
LANDWEHR	1907—1910	87	MS.
BROWN	1908—1922	268	MS. B. A. A.
BACKHOUSE	1908—1916	13	MS. B. A. A.
GREENWOOD	1908	12	MS. B. A. A.
VOGELENZANG	1915—1918	130	MS.
MÖLLES	1915—1924	192	MS.
WIRTZ	1920—1923	176	MS.

Of the observations enumerated in the preceding table 630 had to be rejected for the following reasons.

OAKS. 36 estimates all in the form: η *about* $n <$ [1]) μ $(n = 1 - 7)$.

BACKHOUSE. 13 estimates in a period of 5 years; differences up to 12 steps are recorded.

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[1]) The symbols $<$ and $>$ denote fainter resp. brighter than.

FIELD.	39 estimates, all with very large differences in steps; differences of 10 and 12 steps occur repeatedly.
GREENWOOD.	12 observations in the form $\eta\ n < \mu$ $(n = 1 - 5)$.
MITCHELL.	42 observations in 1906—1907, a series consisting almost entirely of one-sided estimates in the form $\mu\ n\ \eta$; $\varepsilon\ n\ \eta$. Nevertheless the minimum 2417666 is clearly indicated.
MARCKWICK.	213 estimates in the form: η $\frac{3}{4}$ magn. smaller than μ, more than $\frac{1}{2}$ magn. smaller than μ, much smaller than ε, not far from ε, plainly smaller than μ, and so on. Large step-differences and one-sided estimates.
CHILD.	64 estimates, 62 of which are one-sided with differences up to 8 steps.
ORR.	13 estimates, all recorded as follows: between μ and δ, nearer to μ than to δ etc.

Since the observations of KNOPF, ROSICKY, WORSELL, KOPFF, GÖTZ, SCHILLER, LOHNERT and those of MITCHELL (1919—1920) form very short series, it seems obvious that these observers cannot have had the practice necessary for dealing with the difficulties of η Geminorum.

I wish to add some remarks concerning two methods of observation which are often used, notwithstanding the objections repeatedly raised against them [1]). I refer in the first place to the fractional method. The fractional method (POGSON, PICKERING) is based upon the erroneous opinion that the photometrically determined magnitudes of the comparison stars are exact. The exactness of these values is, however, often not very great, the mean error of the H. P. magnitudes reaching 0.105 m [2]). This is partly to be ascribed to the fact that the colour error has not sufficiently been eliminated. The observing book of the observer who uses the fractional method often only contains the magnitudes resulting from comparisons which are not recorded in detail [3]). It is undeniable that this method takes much less time than the ARGELANDER (resp. NIJLAND) method, but even if the observations are recorded more in detail, nothing can be concluded as to the observer's conception of the interval between the comparison stars used.

The observation by means of the fractional method can easily lead to the use of would-be steps of „0,1 m". Let us consider an interval a—b, photometrically found to be 0,4 m.; the observer takes $\frac{1}{4}$ of this interval as unit. His estimates

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1) cf. HAGEN, *Die Veränderlichen Sterne*, Bnd. I, p. 276—280.

2) FETLAAR, *Recherches Utrecht* IX (1) (1923) p. 9.

3) See HAGEN, o. c. p. 277/278 and the monthly reports of the American Association of Variable Star Observers in "*Popular Astronomy*".

in these „steps” will, as a matter of fact, be affected by the errors resulting from inaccurate magnitudes of the comparison stars. His value of one step, nominally 0,1 m., will be variable in an irregular way. Moreover, he is apt for the sake of convenience to compare the variable star with only one comparison star, using this „unit”. It will be clear that the difficulties in the discussion of these observations often appear to be almost insuperable, as, for want of data, it is questionable whether the assumption 1 step = 0,1 m. can be relied upon. One-sided estimates, *occasionally* made by observers using the ARGELANDER method of course are excluded from this criticism.

Of the older observers SCHMIDT has made an extensive use of the one-sided method. It is to be regretted that the weight of his numerous observations is considerably diminished by this procedure and also by his large step-value.

The *American Association of Variable Star Observers* and the *Association Française d'Observateurs d'Etoiles Variables*, the latter working along the same lines as the American Association, would, in my opinion, materially improve the results of the work done by their respective members by rejecting all observations made by the „time-saving” methods mentioned above. The A. F. O. E. V. in particular published observations, such as those by BUTTERWORTH, often consisting of estimates in the form $v\,n\,a$, resp. $a\,n\,v$ ($n = 1$ *to* 12! steps). Admitting that BUTTERWORTH's observations are astonishingly good, as GROUILLER maintains, I might emphasize the danger of the example set by him to other observers who lack the virtuosity necessary for this method and who only wish to have their names mentioned in the redactional columns as authors of „listes d'observations extrêmement importantes”.

§ 2. Reduction of the observations.

The reduction of the observations consists in the construction of the step-scale of the comparison stars for each observer; the comparison of this scale with the magnitudes of the comparison stars as determined photometrically; the adaptation of the latter values to the individual step-scales; the determination of the photometric value of one step and finally the deduction of one set of photometric magnitudes for the comparison stars applicable to all observers. With the aid of this final photometric scale the observations are calculated.

Before being able to combine into a step-scale the differences observed between the comparison stars, these differences should be corrected for atmospheric extinction. This, of course, does not relieve us from the necessity of applying the same correction in the final computation of the observations.

To the direct application of an extinction table there are several objections. MÜLLER's table, for instance, has been derived from observations made at Potsdam and on the top of the Säntis and is therefore, strictly speaking, only valid for these places. The difficulty of each extinction table [1]) is, that it naturally cannot take into account the local peculiarities of every place and the meteorological circumstances of the epoch of the observations. Large discrepancies have been recorded for instance at Catania, where the value for this correction appeared to vary with the azimuth [2]).

The automatic application of an extinction table should, in my opinion, always be condemned, unless the stars considered are located in a small field of a few square degrees and in this case the importance of a correction amounting perhaps to a few hundredths of a magnitude will hardly be in proportion to the work involved.

In this paper I have made an attempt to meet the difficulties mentioned above by proceeding in the following way. For each observer two comparison stars were selected satisfying the essential conditions of being sufficiently distant one from the other and at the same time being frequently used throughout the whole period of observation. The observed intervals between these stars, expressed in steps, were plotted on squared paper by taking these differences as ordinates and the corresponding sidereal times as abscissae. At the same time I plotted the differences corrected for extinction by means of MÜLLER's table, adopting for the photometric value of one step the value which had resulted from a provisional reduction, and taking the interval observed at the sidereal time with minimum extinction as zero. The curves that may be drawn through both sets of points are expected to coincide. If this is the case the correction for extinction can be applied unmodified; if not, the extent to which the „theoretical" value has to be modified can easily be derived.

As, owing to the very complex nature of the phenomenon of atmospheric absorption, it will never be possible to calculate the required correction *exactly*, an approximate method such as the one proposed above, will, in my opinion, sufficiently meet the needs of the computer. I wish it to be clearly understood that I am quite aware of the imperfection of this method which, moreover, can only be used when step estimates are available, estimates made by means of the fractional method cannot be corrected in this way.

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1) Recently an extinction table has been published by H. VAN DER LINDEN. *Annal. Obs. Royal Belg.* 3me serie II, 1 (1928).

2) HAGEN, o. c. p. 394.

A. *The observations by* J. F. J. Schmidt.

These observations have been made, with the naked eye, partly at Hamburg, Düsseldorf, Bonn, Olmütz, Vienna, Rome, but by far the greater part at Athens. Schmidt made a large number of estimates by means of Argelander's method, viz. 3388 in 2877 nights, but it is very much to be regretted that he disregarded the advice given by Argelander concerning the desirability of comparing the variable with at least two comparison stars. Schmidt made 3117 estimates with the aid of only one, 156 with 2, 114 with 3 and 1 with 4 comparison stars.

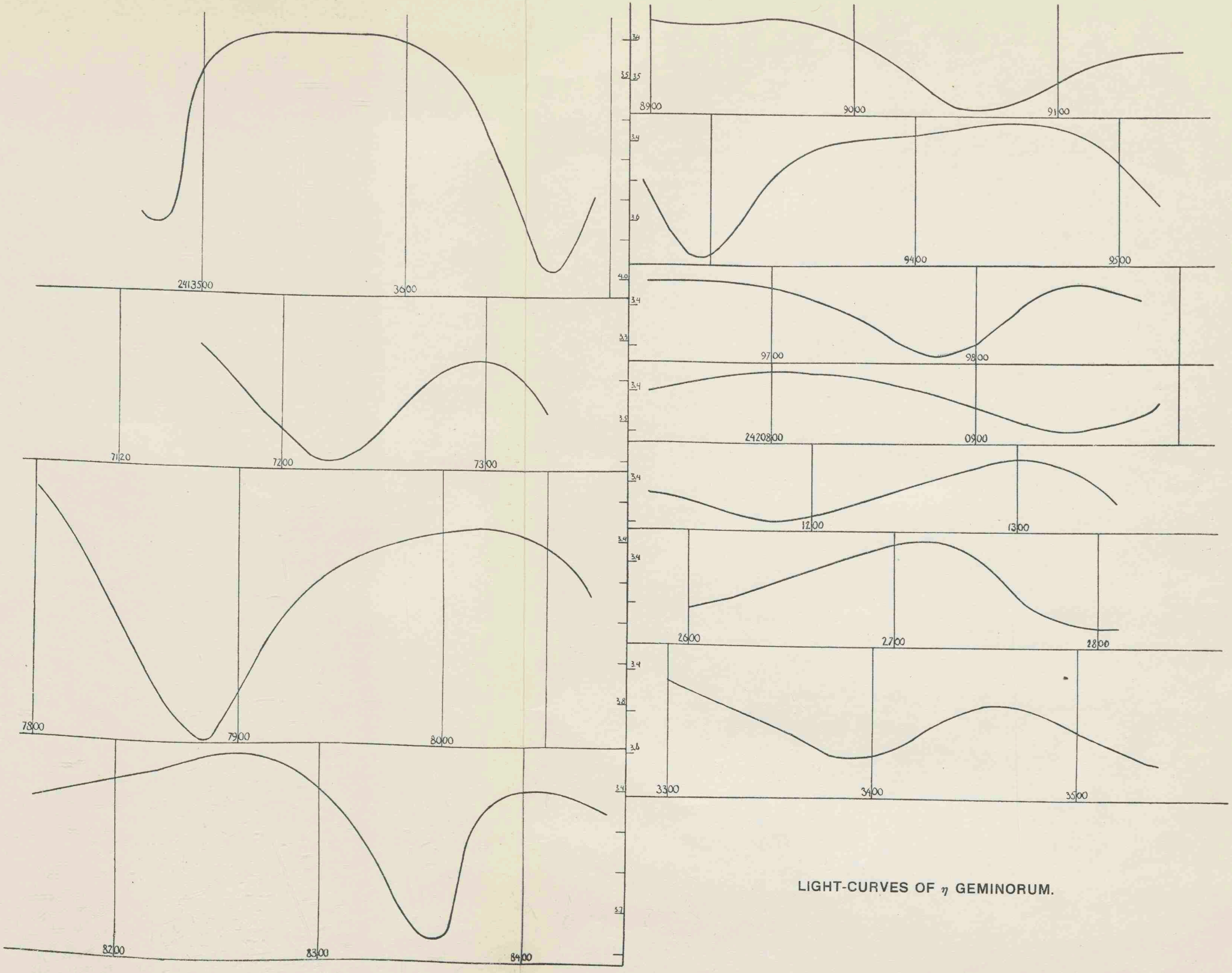
The comparison stars used are μ (3383), ε (9), ν (227) and 1 Fl. = *Propus* Geminorum (155), the numbers in brackets denoting the number of comparisons made with each of them. As about 92 % of all observations have been made by comparing η with μ only, the result of an investigation regarding the question of the correction for extinction cannot be of much value, considering the facts that the observed intervals suitable for this investigation are scattered over a period of about 40 years and that the number of these intervals is therefore relatively small. Moreover any correction for extinction will be superfluous for all observations in which μ is used, since the numerical value of the differential extinction μ—η appears to be neglectable during the greater part of the year. In fact, this differential extinction reaches 0,1 m. only from 12—13 h. S. T. Nevertheless I decided to study two intervals with a view to obtaining a step-scale. These intervals are μ—ν and ν – P, P designing 1 Fl. Geminorum.

The interval μ—ν can be derived from 209 observations in the form $\mu\, a\, \eta$; $\eta\, b\, \nu$ giving a mean value of 4,65 steps. Schmidt's step-value shows a slight tendency to increase in the course of the period of observation, I found for the period

1847—1867	(63 obs.)	μ—ν	4,54 steps
1868—1872	(90 obs.)		4,63 „
1873—1884	(56 obs.)		4,35 „ .

The following table contains the intervals μ—ν arranged in the order of progressive sidereal time, the column headed $\mu\nu$ calc. containing the value of the interval μ—ν at minimum extinction + the calculated differential extinction (taken from the Potsdam table and converted into steps by adopting the value of one step as 0.2 m.). D = $\mu\nu$ obs. — $\mu\nu$ calc.

Up to about 8^h30 there is a fair agreement between the observed and the calculated intervals but in the lower part of the table the deviation from the calculated values becomes too great to be explained by the accidental errors. They might be accounted for by admitting for Athens a considerably larger value for the extinction than Müller's table gives. In that case however, a still larger deviation should have been found in the first part of the table as the



LIGHT-CURVES OF η GEMINORUM.

Table II.

Sider. Time.	$\mu-\nu$ obs.	$\mu-\nu$ calc.	D.
h.	steps	steps	steps
0 30	5,20	4,75	+ 0,45
1 30	4,03	4,50	— 0,47
2 30	3,95	4,40	— 0,45
3 30	4,28	4,30	— 0,02
4 30	4,11	4.30	— 0,19
5 30	4,71	4,30	+ 0,41
6 30	4,55	4,25	+ 0,30
7 30	4,26	4,30	— 0,04
8 30	4,75	4,30	+ 0,45
9 30	4,96	4,35	+ 0,61
10 30	5,36	4,40	+ 0,96
11 30	5,83	4,60	+ 1,23

differential extinction at 0—2 h. S. T. is greater than at 8—12 h. A satisfactory explanation by means of the extinction seems to me therefore impossible.

For the interval $\nu - P$ 104 observations in the form $\eta a \nu$; $\eta b P$ are available, giving a mean value of + 0,38 steps for the difference between these stars. An arrangement in the order of progressive sidereal time is given in Table III. This table contains only the columns S. T., ν—P obs. and corr. (= correction for extinction converted into steps). A column ν—P calc. cannot be given for reasons which will appear below.

Table III.

Sider. Time	ν—P obs.	corr.
h.	steps	steps
1 30	+ 0,55	+ 0,3
2 45	+ 0,77	+ 0,15
3 40	+ 0,85	+ 0,1
4 50	+ 1,07	+ 0,05
6 30	+ 0,55	0
7 36	+ 0,55	0
8 20	+ 0,18	0
9 12	— 0,20	0
10 00	— 0,15	0
10 36	— 0,30	0

As will be seen from the lower part of this table the estimates of this interval are affected with a systematic error which cannot be easily explained by means of the theory of extinction. An explanation might be found in the variation of the position of the constellation with respect to the horizon. As the deviations for both intervals studied point to an apparent diminution in the brightness of the star ν in the order of progressive sidereal time, this explanation seems to be near the truth.

I adopted the following step-scale for the comparison stars used by SCHMIDT.

$$P = 0 \qquad \nu = 0{,}4 \qquad \mu = 4{,}65$$

B. *Observations by* E. SCHÖNFELD.

The observations, 123 in number, have been made at Mannheim with the aid of an opera-glass. They are printed in „Veröffentl. Sternw. Heidelberg" [1]), where also a scale of steps of the comparison stars is given viz.

ν [2]) Geminorum = 0 $\qquad \theta = 4{,}5 \qquad \varepsilon = 11{,}3.$

The stars ε and θ are used in 92 estimates, θ and ν in 10 cases. From a study of the interval ε—θ I found that the correction for extinction can be applied unmodified for the period 3—8 h. S. T., but from 0 to 3 and from 8 to 11 h. the value of the table must be reduced by 50 %. For the mean value of the interval ε—θ, corrected in this way, I find 7,0 steps.

From ten estimates the interval θ—ν was found to be 4,9 steps, the full correction for extinction having been applied. The star μ has been used by SCHÖNFELD only once, giving a difference of 3 steps between μ and ε.

As the colour of the stars ε and θ differs considerably, ε being RG-, θ WG, the influence of the moonlight on the interval $\varepsilon-\theta$ was studied by means of 30 estimates. No appreciable influence was found, the mean value coming out at 7,0 steps.

The following step-scale was adopted.

$$\nu = 0 \qquad \theta = 4{,}9 \qquad \varepsilon = 11{,}9.$$

C. *Observations by* J. PLASSMANN.

As I stated in the Introduction to this paper, HOFFMEISTER has published an extensive discussion of the observations made by PLASSMANN in the period 1888—1913.

Up to 1907 PLASSMANN used 6 comparison stars viz. 1 Fl., ν, μ, ε, θ Geminorum and θ Aurigae. The observations of the period 1907—1924 consist

[1]) 1, 98 (1900).

[2]) l. c. we find v, certainly a misprint.

entirely of comparisons with μ and ν Geminorum only and all the observations have been made with the same instrument (a STEINHEIL astronomical binocular) throughout this period [1]). For these reasons I undertook the discussion of the 848 observations made after 1907, considering a renewed reduction of the observations before that date superfluous, the light-curve deduced by HOFFMEISTER having been placed at my disposal by the courtesy of this astronomer.

From a study of the interval $\mu-\nu$ HOFFMEISTER found PLASSMANN's step-value to be subject to two variabilities, one with a period of about 5 years and the other with a period of one year giving a maximum for the interval $\mu-\nu$ in April and a minimum in November. The periodicity first mentioned is most probably to be ascribed to personal influences, the second to the extinction.

I have studied the interval $\mu-\nu$ starting from the 833 values for this interval resulting from 848 observations. The secular change is clearly indicated but the periodicity of 5 years does not persist after 1907. Instead I find a gradually decreasing value for the interval, the curve shows in the first years a marked periodicity of 3 years but the amplitude of this variation diminishes rapidly as will be seen in the following table. In deviation from HOFFMEISTER I calculated the *seasonal*- and not the *yearly*-value of the interval. In table IV n denotes the number of intervals used and d the deviation of the seasonal value from the mean (10,23 steps).

Table IV.

Season	n	$\mu-\nu$	d	Season	n	$\mu-\nu$	d
		steps				steps	
1907/08	19	10,68	— 0,35	1916/17	38	10,50	— 0,27
1908/09	35	10,80	— 0,57	1917/18	51	10,33	— 0,10
1909/10	30	11,65	— 1,42	1918/19	59	9,93	+ 0,30
1910/11	31	12,13	— 1,90	1919/20	61	10,00	+ 0,23
1911/12	40	10,59	— 0,36	1920/21	65	9,38	+ 0,85
1912/13	34	10,70	— 0,47	1921/22	92	9,80	+ 0,43
1913/14	48	11,25	— 1,02	1922/23	59	9,72	+ 0,51
1914/15	44	10,37	— 0,14	1923/24	72	9,18	+ 1,05
1915/16	41	10,33	— 0,10				

The following table (Table V) contains the intervals $\mu-\nu$ arranged in the order of progressive sidereal time, the column $\mu-\nu$ *calc.* containing the values

1) 1888—1907 PLASSMANN used feebler instruments.

10,0 + *calculated differential extinction*, D = (μ—ν obs.) — (μ—ν calc.) and d' = 10,23 — (μ—ν obs.).

Table V.

Sidereal Time	n	μ—ν obs.	μ—ν calc.	D	d'
h		steps	steps		steps
0 41	26	9,68	11,0	— 1,3	+ 0,55
1 32	45	10,02	10,45	— 0,43	+ 0,21
2 32	78	10,20	10,20	0	+ 0,03
3 32	64	10,05	10,10	— 0,05	+ 0,18
4 30	60	10,10	10,10	0	+ 0,13
5 27	61	10,00	10,10	— 0,10	+ 0,23
6 31	51	9,57	10,00	— 0,43	+ 0,66
7 30	64	10,10	10,07	+ 0,03	+ 0,13
8 34	72	10,22	10,10	+ 0,12	+ 0,01
9 30	95	10,33	10,10	+ 0,23	— 0,10
10 30	89	10,62	10,20	+ 0,42	— 0,39
11 29	71	10,72	10,30	+ 0,42	— 0,49
12 33	57	10,48	10,8	— 0,3	— 0,25

Obviously the application of the correction for extinction will deteriorate the value of the observations made at 0—2 h. S. T.

In connection with the peculiarities of PLASSMANN's step-value the reduction of his observations to a constant value for the interval μ—ν proves necessary. For this constant value I started with the mean resulting from all observations viz. 10,23 steps [1]. It will be clear from the tables given above that the method for the reduction can only be an empirical one. Starting from the values given in the columns d and d' of the tables [2] I proceeded in the following way [3]. The observed differences in steps between η and the comparison stars are multiplied by the factor $\frac{10{,}23}{10{,}23 - (d + d')}$, for instance:

season 1912/1913 Sidereal Time 9^h30
$d + d' = (-0{,}47) + (-0{,}10) = -0{,}57$
the multiplicator is $10{,}23/(10{,}23 + 0{,}57) = 0{,}95$.

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[1] This value is in excellent accordance with the result of the discussion by HOFFMEISTER of the observations 1888—1913 viz. 10,26 steps.

[2] I preferred to use the values d and d' unsmoothed.

[3] Following HOFFMEISTER

This method assures homogeneous values for the step-differences between η and the comparison stars throughout the whole period of observation.

D. *Observations by* M. LUIZET.

LUIZET has made 751 observations of η Geminorum covering the period 1898—1917. Although the notation used differs somewhat from the usual one, it is clear from the manuscript that he observed according to the ARGELANDER method.

The comparison stars used are μ, ε, ξ and δ Geminorum. The interval $\varepsilon—\xi$, being the one most frequently observed, has been chosen to study the influence of the extinction on the observations. From 335 observations it was found, however, that the application of a correction for extinction would not improve the results, the value for this interval remaining almost constant throughout the whole year. Consequently the correction for extinction has not been applied. I wish to add that I tried to explain this remarkable fact by an error caused by the varying position of the triangle $\varepsilon\xi\eta$ with respect to the horizon. But in my opinion it is impossible to separate the very complex causes of this phenomenon from one another (including the selective absorbtion in the atmosphere and the, unknown, order of comparison of η with ε and ξ by the observer) in a satisfactory way. Obviously it will make a difference whether the observation is made in the order $\varepsilon—\eta—\xi$ resp. $\xi—\eta—\varepsilon$, $\eta—\xi$; $\eta—\varepsilon$ etc. Untraceable personal influences therefore play a considerable part[1]).

The following step-scale was derived from 115 observations of the interval $\mu—\varepsilon$, 68 of $\mu—\xi$, 335 of $\varepsilon—\xi$, and 55 of $\xi—\delta$.

$\delta = 0$ $\xi = 3{,}9$ $\varepsilon = 9{,}55$ $\mu = 11{,}3$ steps.

E. *Observations by* F. DE ROY.

DE ROY made 621 observations, covering the period 1903—1924, by means of the NIJLAND interpolation method. The construction of a step-scale is rendered difficult by the fact that the observed differences between the variable and the comparison stars do not always have the meaning of steps but are principally supposed to give the *ratio* of the differences. NIJLAND has called attention to the desirability of giving this ratio in connection with the individual step-values. Very often, however, this condition is not fulfilled and f.i. *a1v2b* is recorded in cases in which *a2v4b* would much better suit the difference between *a* and *b*. DE ROY himself says: „.... the intervals (1—1 or 1—2 of course excepted) in

1) See also HAGEN, o. c. pag. 225.

some measure denote steps". De Roy has used the following comparison stars μ, ε, ξ, θ, δ, $\varkappa$, ι, ν, υ and 1 Fl. Geminorum. In 541 observations ε and ξ are used. Excluding the observations giving differences between ε and ξ of 2 and 3 steps for the reasons given above, I find from 404 estimates for this interval 5,05 steps. As this value is found to be practically constant throughout the whole year the influence of extinction on the observations can safely be regarded as imperceptible. This correction has therefore not been applied.

F. *Observations by* P. M. Ryves.

These observations have been made by means of Argelander's method but a somewhat frequent use has been made of one-sided estimates obtained by comparing η with μ and ε Geminorum simultaneously.

Ryves's work consists of two series of observations viz. 450 from 1905 to 1913 and 72 from 1923—1924, the place of observation was Zaragoza and the instrument the naked eye. The comparison stars used are μ, ε, θ, ν and 1 Fl. Geminorum and on a few occasions θ Aurigae. Of these μ and ε were used exclusively in about 63 % of all observations.

The interval between these stars has been studied in five groups, the result of the investigation being given in the following table.

Form of observation	number	$\mu-\varepsilon$
		steps
a. $\mu > \eta$; $\varepsilon > \eta$	124	0,81
b. $\mu < \eta$; $\varepsilon < \eta$	7	0,86
c. $\mu > \eta$; $\varepsilon < \eta$	41	1,57
d. $\mu = \eta$; $\eta > \varepsilon$ resp. $\mu > \eta$; $\varepsilon = \eta$	101	1,20
e. μ $2\frac{1}{2}$ or more $> \eta$ (η in minimum)	54	1,28

On behalf of the calculation of the mean value of this interval only the groups *c* and *d* are used, the resulting value is 1,3 steps. An opportunity to study the interval error is presented by the circumstance that 14 intervals have been more or less directly (i. e. via η) observed. The following table contains the values found for the intervals mentioned in the first column; in the second column the directly observed differences and in the third the values obtained by the addition of the intermediate intervals are found.

$\mu-\theta$	7,2	7,1
$\mu-\nu$	11,0	10,2
$\mu-$1 Fl.	12,6	12,1
$\varepsilon-\nu$	9,2	8,9
$\varepsilon-$1 Fl.	11,0	10,8

This table points to the existence of a small *negative* interval error.

The star $\varkappa$ has been excluded from the discussion for the following reason. From the intervals observed between $\varkappa$ and the other comparison stars the brightness of $\varkappa$ is found to be about equal to 1 Fl. whereas H. P. and P. D. give

$\varkappa$	H. P. (Draper) 3,62	P. D. 3,75
1 Fl	4,30	4,37

Probably the star has been mistaken for v (H. P. 4,26), the more so as De Roy did not find any irregularity in this respect.

The influence of the extinction, studied by means of the interval $\mu-\theta$, appeared to be neglectable.

The following step-scale was adopted:

1 Fl. = 0 $\quad \nu = 1{,}9 \quad \theta = 5{,}0 \quad \varepsilon = 10{,}8 \quad \mu = 12{,}1$.

G. *Observations by* A. A. Nijland.

In the period 1904 to 1924 Nijland obtained 494 observations. The estimates were made at Utrecht with the aid of a field-glass and using the comparison stars ε, μ, ξ, θ, δ, λ, ι Geminorum. 393 observations of the interval $\varepsilon-\xi$ are available to study the influence of the extinction From the discussion of these observations the following conclusion was drawn. The table-value of the correction for extinction, must be applied unmodified to the observations made from 4 to 10 h. S. T. For the observations made at 2—4h. and 10—13 h. S. T. the theoretical correction is to be diminished 50 %, from 0—2h. 75 %. The construction of the step-scale for which the correction for extinction, modified in this way, has been applied, lead to the following result.

$\iota = 0 \quad \theta = 1{,}4 \quad \lambda = 2{,}1 \quad \delta = 3{,}1 \quad \xi = 4{,}8 \quad \varepsilon = 11{,}3 \quad \mu = 11.7$.

H.

The series of observations by von Stempell, Scharbe, Landwehr, Brown, Vogelenzang, Mölles and Wirtz being of less importance than the others, owing to their rather small number or the short period covered by them, will not be treated in detail. Only the results of my discussion and a few remarks will be given here.

a. G. von Stempell.

The use by this observer of four different instruments made a reduction of all observations to one instrument unavoidable, the more so as two instruments appeared to give values for the red stars smaller by about 2 steps than instrument I (an army fieldglass) and the naked eye. The following step-scale was derived.

$$\nu = 0 \quad \varepsilon = 6{,}8 \quad \mu = 7{,}4.$$

b. S. Scharbe (Jekaterinoslaw).

Three instruments were used; a reduction to one of them was proved necessary by the differences in the conception of the brightness of the red stars found for the separate instruments. The step-scale is

$$\nu = 0 \quad 1\ \text{Fl.} = 0{,}4 \quad \delta = 4{,}5 \quad \varepsilon = 10{,}0 \quad \mu = 11{,}0.$$

c. G. Landwehr (Münster).

The following step-scale was found

$$1\ \text{Fl.} = 0 \quad \nu = 1{,}5 \quad \varepsilon = 11{,}4 \quad \mu = 11{,}9.$$

d. A. N. Brown (Silchester).

The construction of a step-scale being impossible owing to the fractional method of observation used by this observer, the observations were reduced by means of the final photometric scale.

e. E. H. Vogelenzang (Hilversum).

The stars ε and ξ were used exclusively throughout the whole period of observation. The interval between these stars was found to be 4,9 steps.

f. Mölles.

These observations are made according to a fractional method. Mölles adopted for the interval $\mu - \varepsilon$ 2 steps and for $\varepsilon - 1$ Fl. 4 steps. 1918 February 18th these values are suddenly changed and from this date $\mu - 1$ Fl. = 8 steps. A further change occurred in 1921 January when Mölles abandoned this method for the original Argelander step-method which gave the following step-scale

$$1\ \text{Fl.} = 0 \quad \nu = 1{,}4 \quad \varepsilon = 7{,}4 \quad \mu = 8{,}7.$$

g. C. Wirtz (Kiel).

The estimates were found to be subject to a large interval-error, the interval $\mu - \nu$ being 9,1 steps when observed via η and 13,3 steps when δ was used as an intermediate. The step-scale is

$$\nu = 0 \quad \delta = 6{,}7 \quad \varepsilon = 12{,}8 \quad \mu = 13{,}3.$$

The following table contains a recapitulation of the step-scales deduced from the observations of each observer separately.

Table VI.

Observer	Comparison Stars								
	1 Fl.	ν	ι	θ	λ	δ	ξ	ε	μ
SCHMIDT	0	0,4							4,65
SCHÖNFELD		0		4,9				11,9	
PLASSMANN		0							10,2
LUIZET						5,5	9,4	15,05	11,3
DE ROY							4,8	9,85	
NIJLAND			0	1,4	2,1	3,1	4,8	11,3	11,7
RYVES	0	1,9		5,0				10,8	12,1
VON STEMPELL		0						6,8	7,4
SCHARBE	0,4	0				4,5		10,0	11,0
LANDWEHR	0	1,5						11,4	11,9
VOGELENZANG							4,8	9,7	
MÖLLES	0	1,4						7,4	8,7
WIRTZ		0				6,7		12,8	13,3
P. D.	4,37	4,42	3,96	3,84	3,75	3,69	3,63	3,21	3,06
colour	G	GW—	G—	WG	GW—	WG	GW—	RG—	RG
H. P. (Draper)	4,30	4,06	3,89	3,64	3,65	3,51	3,40	3,18	3,19
spectr.	G5	B5	K0	A2	A2	F0	F5	G5	Ma

From a preliminary discussion it was found, that the photometric magnitudes for the comparison stars given by the Potsdam Durchmusterung suited the step-scales of the majority of the observers much better than the values taken from the Harvard (DRAPER) Photometry. There is however one exception viz. ν Geminorum. In this case the P. D. gives $\nu <$ 1 Fl. whereas 4 out of 5 observers who used both stars find $\nu >$ 1 Fl. Only SCHARBE is in accordance with the P. D. but there may be some bias in his case.

By a graphical method which has been described in detail by several writers [1]), the step-scales were compared with the photometric magnitudes of the

1) FETLAAR, *Recherches astr. Utrecht* IX (1) (1923) p. 3, 4 fig. 1*b*.

P. D. and the latter values changed to the extent necessary to ensure a constant step-value throughout the whole step-scale. Table VII contains the result of this reduction. It will be clear that only the observers who made use of 3 or more comparison stars are mentioned in this table.

Table VII.

Observer	Comparison Stars								
	1 Fl.	ν	ι	θ	λ	δ	ξ	ε	μ
SCHMIDT	4,37	4,24							3,06
SCHÖNFELD		4,26		3,83				3,22	
LUIZET						3,85 [1]	3,62	3,20	3,08
NIJLAND			3,93	3,84	3,79	3,73	3,62	3,20	3,17
RYVES	4,39	4,21		3,85				3,21	3,06
VON STEMPELL		4,24						3,20	3,09
LANDWEHR	4,38	4,22						3,18	3,12
WIRTZ		4,24				3,68		3,19	3,13
SCHARBE		4,20				3,74		3,19	3,09
Mean	4,38	4,23	3,93	3,84	3,79	3,75	3,62	3,20	3,10

It will be seen from this table that, ν excepted, only small corrections had to be introduced to the original P. D. values. The step-scale of MÖLLES has not been taken into consideration for the reasons given above.

The mean values found for the photometric magnitudes are used in the final reduction of the observations. This is quite justifiable as the values found for the single observers agree closely. The photometric values for the steps of each observer as they result from this final photometric scale are given in the following table.

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[1]) This value seems to indicate, that the sensitiveness of LUIZET to yellow is greater than of other observers.

Table VIII.

Observer	Step-value
	m.
SCHMIDT	0,26
SCHÖNFELD	0,09
PLASSMANN	0,11
LUIZET	0,07
DE ROY	0,08
NIJLAND	0,07
RYVES	0,11
VON STEMPELL	0,15
SCHARBE	0,12
LANDWEHR	0,11
VOGELENZANG	0,09
MÖLLES	0,15
WIRTZ	0,08

§ 3. Reduction of the observations to one observer. [1])

With a star like η Geminorum an opportunity is presented for reducing all observations to one observer, the star having been observed over a long period and frequently on the same night by several observers.

In the case of η Geminorum however the material falls into two parts viz. the periods 1847—1884 and 1887—1924, the former consisting of the observations made by SCHMIDT and of SCHÖNFELD's relatively short series. Owing to SCHMIDT's defective method of observation a reduction of SCHÖNFELD to SCHMIDT can not be expected to give results of much importance. From 78 observations made simultaneously I find:

47 positive residuals (in the sense SCHÖNFELD – SCHMIDT)
30 negative ,,
to both sides up to 0,39m.

[1]) Miss J. C. THODEN VAN VELZEN has deduced a formula (Proefschrift, Utrecht, 1928) which enables her to calculate the necessary reduction for the cases in which a coloured variable has been observed by means of white comparison stars. In our case however, the comparison stars ν, 1 Fl., ε, μ and ξ show more or less the same colour as η and as, moreover, the amplitude is very small there is no room here for applying Miss THODEN VAN VELZEN's results.

Treating these residuals separately for the maximum and minimum phases of the light-curve I find:

at maximum 41 positive and 2 negative residuals
at minimum 6 „ „ 28 „ „ .

Considering the fact, that in the brighter phases of the light-variations SCHMIDT compared η only with μ and that, as his large step-value indicates, his eyes were not very sensitive, not much value can be attributed to SCHMIDT's estimates at maximum. A conclusion with respect to an Algol-analogy can certainly not be drawn from SCHMIDT's observations.

The reduction of the observations to one observer has therefore been restricted to the observations of the period 1887—1924.

For the purpose of this reduction it would be natural to take the observer whose contributions have been most continuous and spread over the longest period namely PLASSMANN, but the peculiarities of this observer which we have already mentioned suggest a comparison with the next candidate, viz. DE ROY. The results of the comparisons are given in Table IX. The second column gives the number of the observations made simultaneously, the third the resulting difference PLASSMANN—OBSERVER; the fourth and fifth columns give the results of the comparison with DE ROY.

Table IX.

Observer	n	Pl.—O.	n	De R.—O.
		m		m
PLASSMANN	—	—	202	—0,160
DE ROY	202	+0,160	—	—
LUIZET	97	+0,085	62	—0,097
NIJLAND	143	+0,113	140	—0,032
RYVES	60	+0,30	48	+0,195
VON STEMPELL	13	—0,070	2	—0,12
SCHARBE	36	+0,343	36	+0,150
BROWN	66	+0,242	70	+0,080
LANDWEHR	39	+0,065	39	—0,150
VOGELENZANG	64	+0,120	45	—0,080
MÖLLES	65	+0,004	32	—0,160
WIRTZ	88	+0,118	21	—0,030
	873		697	
Mean error		±0,126		±0,115

The mean error resulting from the comparisons with De Roy being smaller than the m. e. of the column Pl.—O., De Roy has been chosen for the final reduction.

Before proceeding to discuss the light-curve based on the newly reduced observations I wish to apply a final criterion as to whether I now have the right to consider this curve as homogeneous. Following J. van der Bilt and starting from the 697 differences between De Roy and the other observers, I calculated by means of the m. e. found, the number of cases which can be expected to be found within certain limits, if these differences had been purely accidental errors. The following table shows that there is a satisfactory accordance between the calculated and the observed numbers

Limits	O	C	O—C
m. m.			
0,00—0,10	455	427	+ 28
10 20	182	210	— 28
20 30	42	51	— 9
30 50	18	9	+ 9

From this table it appears that the homogeneity of the light-curve is satisfactorily established.

§ 4. The light-curve.

A description of the general features and of the details of the light-curve derived from the observations made by Schmidt will be given in connection with the list of the minima in the following chapter.

In order to derive the light-curve 1887—1924, in which of course gaps of at least 100 days are expected to occur owing to the star's place near the ecliptic, the values of the brightness of η were condensed into a number of means representing the mean brightness at intervals of about 10 to 20 days. These mean values were plotted on squared paper, on a scale of 1 mM. equalling 2 days and 0,01 magn., and a smooth curve was drawn through the points.

Total number of observations	5010
„ „ „ points	573
Number of points above the curve	229
„ „ „ below „ „	216
„ „ „ on „ „	128
Recurrences of the sign of the deviation . .	213
Changes „ „ „ „ „ „ . .	232
Largest positive deviation	0,17 m.
„ negative „	0,12 m.

The mean deviation of the points above and below the curve does not exceed 0,03 magn.

The ordinates of the light-curve were read off for intervals of 20 days (Greenwich mean noon). During periods of rapid change the readings were made every 10 days. The results are given in the following list. Curves representing the light-variations during a few selected seasons are reproduced on the Plate.

Sharp and flat maxima and minima alternate in an irregular way with periods of approximate constant brightness. The maxima become more distinct in proportion to the number of the observers contributing to the light-curve. The amplitude of the variations varies from 0,1 to 0,8 magn. The ascending as well as the descending branches in some instances seem to show a secondary curvature, displaying degenerated minima or maxima. A noteworthy feature of the light-curve is the recurrence of the same brightness at maximum viz. 3,35 m. The existence of a long periodicity in the sense found for V 14 (RV) Tauri is thereby rendered very improbable. Apart from this constancy of the maximum brightness the most regular phenomenon of the light-curve is the recurrence of the greatest number of minima at periods of about 235 days.

In the light-curve 1887—1924 (12890 days) the results of observations covering about 7410 days are embodied. As 33 gaps occur amounting to a total loss of 5480 days, the light-variation during this period is only known to the amount of 58 %. It would therefore be premature to attempt to explain the irregularities of the light-curve by a second or even a third periodicity, the more so in consideration of the long period and small amplitude of the principal variation.

The Light-curve.

J. D.	η	J. D.	η	J. D.	η
2410290	3,32 m.	2412780	3,47 m.	2414940	3,29 m.
0300	3,38	2800	3,47	4960	3,29
0310	3,40	2820	3,47	4980	3,29
0320	3,42	2840	3,47	5000	3,29
0330	3,44	2860	3,45	5020	3,29
0340	3,44	2880	3,42	5040	3,29
0350	3,46	2900	3,41	5060	3,29
0360	3,50	2920	3,41	5080	3,29
0370	3,60	2940	3,42	5100	3,33
0380	3,72			5120	3,36
0390	3,90	3120	3,37	5140	3,41
		3140	3,40		
0650	3,42	3160	3,43	5400	3,33
0660	3,43	3180	3,45	5420	3,33
0670	3,45	3200	3,47	5440	3,34
0680	3,47	3220	3,50	5460	3,36
0690	3,48	3240	3,61	5480	3,38
0700	3,50	3260	3,65		
0710	3,50	3280	3,53	5680	3,24
0720	3,47	3300	3,40	5700	3,29
0730	3,44			5720	3,34
0740	3,41	3470	3,85	5740	3,40
0750	3,38	3480	3,88	5760	3,46
0760	3,37	3500	3,50	5780	3,52
		3520	3,41	5800	3,53
0920	3,50	3540	3,40	5820	3,54
0940	3,52	3560	3,40	5840	3,54
0960	3,52	3580	3,40	5860	3,52
0980	3,48	3600	3,42		
1000	3,44	3620	3,48	6040	3,55
1020	3,43	3640	3,63	6060	3,53
1040	3,44	3660	3,87	6080	3,51
1060	3,44	3670	3,98	6100	3,50
1080	3,45	3680	3,94	6120	3,47
1100	3,46	3690	3,83	6140	3,47
				6160	3,45
1300	3,44	3880	3,47	6180	3,44
1320	3,45	3900	3,63	6200	3,42
1340	3,45	3920	3,78	6220	3,40
1360	3,46	3930	3,87		
1380	3,47	3940	3,91	6420	3,33
1400	3,49	3950	3,85	6440	3,35
1420	3,51	3960	3,79	6460	3,37
1440	3,55	3980	3,67	6480	3,41
1460	3,58	4000	3,54	6500	3,48
1480	3,63	4020	3,50	6520	3,56
		4040	3,48	6540	3,60
1660	3,42			6560	3,60
1680	3,43	4240	3,50	6580	3,53
1700	3,44	4260	3,48	6600	3,39
1720	3,40	4280	3,46		
1740	3,36	4300	3,48	6780	3,35
1760	3,33	4320	3,50	6800	3,35
1780	3,30	4340	3,52	6820	3,35
1800	3,29	4360	3,50	6840	3,35
1820	3,28	4380	3,49	6860	3,36
				6880	3,33
2440	3,46	4600	3,33	6900	3,35
2460	3,46	4620	3,53	6920	3,37
2480	3,46	4630	3,64	6940	3,35
2500	3,46	4640	3,62	6960	3,33
2520	3,47	4650	3,49		
2540	3,48	4660	3,40		
2560	3,48	4680	3,30		
		4700	3,28		
		4720	3,28		
		4740	3,29		
		4760	3,33		

J. D.	η
2417140	3,25 m.
7160	3,32
7180	3,43
7200	3,52
7210	3,57
7220	3,60
7230	3,60
7240	3,57
7250	3,52
7260	3,47
7270	3,42
7280	3,39
7290	3,36
7300	3,36
7320	3,41
7330	3,48
7440	3,95
7450	4,00
7460	3,95
7470	3,86
7480	3,76
7490	3,65
7500	3,60
7520	3,52
7540	3,46
7560	3,40
7580	3,35
7600	3,33
7620	3,40
7640	3,60
7650	3,72
7660	3,79
7670	3,79
7680	3,72
7690	3,62
7700	3,53
7800	3,28
7820	3,42
7840	3,60
7850	3,69
7860	3,78
7870	3,85
7880	3,89
7890	3,86
7900	3,78
7910	3,68
7920	3,60
7940	3,50
7960	3,44
7980	3,40
8000	3,38
8020	3,37
8040	3,39
8060	3,45
8070	3,53

J. D.	η
2418160	3,44 m.
8180	3,41
8200	3,39
8220	3,37
8240	3,34
8260	3,32
8280	3,34
8300	3,40
8310	3,45
8320	3,52
8330	3,60
8340	3,69
8350	3,76
8360	3,76
8370	3,56
8380	3,45
8400	3,40
8420	3,41
8440	3,45
8530	3,39
8540	3,44
8550	3,52
8560	3,65
8570	3,82
8580	3,77
8590	3,60
8600	3,50
8620	3,45
8640	3,42
8660	3,39
8680	3,37
8700	3,36
8720	3,35
8740	3,36
8760	3,37
8780	3,41
8800	3,51
8900	3,35
8920	3,36
8940	3,35
8960	3,34
8980	3,37
9000	3,39
9020	3,45
9040	3,53
9060	3,57
9080	3,55
9100	3,50
9120	3,45
9140	3,43
9160	3,42
9270	3,53
9280	3,62
9290	3,68
9300	3,68
9310	3,63
9320	3,56
9340	3,45
9360	3,40
9380	3,39
9400	3,38
9420	3,37
9440	3,35
9460	3,36
9480	3,37
9500	3,44
9520	3,54

J. D.	η
2419640	3,34 m.
9660	3,34
9680	3,34
9700	3,35
9720	3,38
9740	3,42
9760	3,48
9780	3,52
9800	3,49
9820	3,41
9840	3,35
9860	3,35
9880	3,38
9990	3,48
2420000	3,54
0020	3,52
0040	3,45
0060	3,41
0080	3,39
0100	3,38
0120	3,37
0140	3,37
0160	3,37
0180	3,39
0200	3,42
0220	3,46
0240	3,51
0380	3,67
0400	3,67
0420	3,66
0440	3,65
0460	3,61
0480	3,57
0500	3,53
0520	3,49
0540	3,45
0560	3,41
0580	3,39
0600	3,38
0620	3,40
0740	3,40
0760	3,38
0780	3,37
0800	3,35
0820	3,36
0840	3,37
0860	3,38
0880	3,41
0900	3,44
0920	3,47
0940	3,50
0960	3,48
0980	3,46
0990	3,43

J. D.	η	J. D.	η	J. D.	η
2421120	3,42 m.	2422200	3,38 m.	2423300	3,42 m.
1140	3,45	2220	3,40	3320	3,47
1160	3,47	2240	3,42	3340	3,51
1180	3,49	2260	3,43	3360	3,55
1200	3,48	2280	3,43	3380	3,60
1220	3,45	2300	3,45	3400	3,60
1240	3,42	2320	3,49	3420	3,56
1260	3,39	2340	3,53	3440	3,52
1280	3,36	2360	3,56	3460	3,48
1300	3,33	2380	3,52	3480	3,50
1320	3,35	2400	3,49	3500	3,54
1340	3,40	2420	3,48	3520	3,58
1350	3,44	2440	3,48	3540	3,62
1480	3,37	2600	3,51	3660	3,44
1500	3,39	2620	3,48	3680	3,44
1520	3,40	2640	3,45	3700	3,45
1540	3,42	2660	3,41	3720	3,46
1560	3,43	2680	3,38	3740	3,48
1580	3,45	2700	3,35	3760	3,53
1600	3,46	2720	3,34	3780	3,50
1620	3,48	2740	3,38	3800	3,49
1640	3,50	2760	3,48	3820	3,48
1660	3,52	2780	3,53	3840	3,46
1680	3,52	2800	3,56	3860	3,45
1700	3,47	2810	3,56	3880	3,46
1720	3,40			3900	3,48
		2940	3,32	3920	3,56
1860	3,40	2960	3,36		
1880	3,42	2980	3,40		
1900	3,44	3000	3,44		
1920	3,45	3020	3,47		
1940	3,47	3040	3,49		
1960	3,47	3060	3,49		
1980	3,45	3080	3,48		
2000	3,43	3100	3,47		
2020	3,40	3120	3,46		
2040	3,39	3140	3,45		
2060	3,40	3160	3,45		
2080	3,48	3180	3,47		

CHAPTER II.

THE MAXIMA AND MINIMA.

§ 5. List of the minima deduced from the light-curve.

From the observations made by Schmidt during the period 1843—1865 only two minima could be derived viz.

J. D. 2394682 and J. D. 2394925

A third one at 2399020 is indicated but the observations are too few in number to include this minimum in the final list. The two minima mentioned above however are sufficiently established by series of 28 and 36 observations respectively.

The following list contains all minima I was able to derive from the material discussed in the preceding chapter. The first column contains the reference-number, the second the Julian Date, the third the magnitude at minimum, the fourth the duration reckoned as the time between the preceding and the following full brightness, the fifth the diminution in brightness with respect to the preceding maximum, the sixth the type for the designation of which I adopted the following scheme:

I. descent and ascent both smooth.
II. descent smooth, ascent disturbed.
III. descent disturbed, ascent smooth.
IV. descent and ascent both disturbed
a. $M - m < \frac{1}{2}$ (M = preceding maximum).
b. $M - m = \frac{1}{2}$.
c. $M - m > \frac{1}{2}$.

The columns headed E and O—C contain the results of § 7 and will therefore be referred to later on.

Table X.

No.	J. D.	magn. *m*	D *d.*	*d* *m*	Type	Remarks	E	O—C *d*
1	2394682						−34	+18
2	4925						−33	+28
3	2402543	4,0	110	1,0	II a		0	− 8
4	3025	3,8	120	0,7	I b		+ 2	+11
5	3721	4,0	85	0,9	I c		5	+13
6	3940	3,45	?	0,2	?	1	6	+ 1
7	4161	4,0	130	0,8	I a		7	−10
8	4375	4,4	130	1,25	IV a	2	8	−28
9	4845	4,0	90	0,75	IV b	3	10	−21
10	5084	4,0	80	0,8	II b	4	11	−14
11	5536	4,1	130	0,9	I a	4, 5	13	−25
12	6030	4,1	170?	0,9	?	6	15	+ 5
13	6233	4,1	130	0,95	IV a	7	16	−24
14	6263	3,8	30	0,2	?	7	(16	−12)
15	6685	4,1	110	0,85	I a		18	−36
16	6947	3,8	105	0,7	I c		19	− 6
17	7398	3,6	120	0,4	I c?		21	−19
18	8132	3,8	105	0,55	I? c		24	+19
19	8388	3,65	60	0,4	?	8		
20	8423	3,65	30	0,3		8		
21	8501	4,1	85	0,7	I c	8		
22	8537	3,4	25	0,2	b	8		
23	8569	3,55	30	0,3	I a	8		
24	8752	3,6	70	0,4	I c?	9	27	+10
25	8840	3,6	100	0,4	IV b?	9		
26	9151	3,6	100	0,35	I c	10		
27	2410700	3,5	90?	0,2?	c?	11	35	+30
28	3254	3,7	110?	0,35	I b		46	+22
29	3478	3,9	60?	0,5	I? c		47	+13
30	3673	4,0	> 100	0,6	I b?		48	−25
31	3938	3,9	> 120	> 0,5	I a		49	+ 6
32	4338	3,55	50	0,1		12		
33	4636	3,7	100	0,4	I b		52	+ 5
34	5805	3,6	?	> 0,4	I c		57	+ 6
35	6530	3,6	140	0,3	I? c	13	60	+31
36	7224	3,6	150	0,4	I b		63	+23
37	7450	4,0	?	0,65	I c		64	+16
38	7666	3,8	110	0,5	I a		65	− 1
39	7884	3,9	160	0,65	I a		66	−17
40	8100	3.9	> 100?	0,5?	I a?	14	67	−36
41	8356	3,8	100	0,5	I c		68	−14
42	8574	3,9	120	0,6	I b		69	−29
43	9062	3,6	140	0,25	I b		71	− 9
44	9298	3,7	> 100	0,4?	?		72	− 8
45	9780	3,5	120	0,2	I c		74	+ 8
46	2420008	3,6	> 60	0,3	?		75	0
47	0240	3,55	> 80	0,2	?		76	− 1
48	0440	3,65	?	?	?	15	77	−35
49	0938	3,5	140	0,15	I b		79	− 6
50	1180	3,5	150	?	I b		80	+ 2
51	1664	3,55	150?	0,2	c		82	+17
52	1955	3,5	?	?	?	16		
53	2360	3,55	140	0,2	?		85	+10
54	2580	3,55	?	?	?	17	86	− 5
55	2810	3,55	> 100	0,2	?		87	− 9
56	3050	3,5	160	0,2	?		88	− 4
57	3385	3,65	140	0,25	b	18		
58	3764	3,55	?	0,2	?		91	+ 4

REMARKS.

1. fairly certain.
2. steep descent disturbed by a 15 days period of constant brightness.
3. disturbed from 4815—4835 and from 4865—4835.
4. SCHÖNFELD's observations confirm this date.
5. ascent slightly disturbed?
6. fairly certain.
7. a double minimum; the mean (6245) gives for E = + 16 O — C = — 12*d*
8. light-variations very irregular from 8350—8585; the calculated dates of the minima are 8346 and 8578 of which the former is indicated by a decrease from 8290 to 8311 whereas the latter may be identified with No. 23, O—C being — 9 days. According to SCHMIDT's observations the star seems to have been subject to a strong disturbance.
9. The effect of the disturbance mentioned in Rem. 8 may account for the abnormal curve during this season. SCHMIDT notes, however, the disturbing influence of the proximity of Jupiter on the observations made during this season. From 8750—8860 the „normal" curve is disturbed by a secondary maximum at 8790. From the curve 8700—8750 and 8860—8890, 8820 is found to be the date of the „normal" minimum E = 27 (O—C = + 10 days).
10. secondary minimum?
11. uncertain.
12. secondary.
13. flat, ill-defined.
14. observations are missing from 8080 to 8140; very uncertain.
15. from 0400 to 0480 practically constant; very uncertain.
16. flat, but clearly indicated; secondary? E = 84 (2116) is indicated by descent from 2045—2085.
17. fairly certain.
18. good; secondary? Minimum E = 90 (3525) is indicated by descent from 3480 to 3535.

The list of minima published by GUTHNICK in „Geschichte und Literatur" contains a few minima which do not figure on my list for the following reasons.

First series (observations by SCHMIDT)

2404624	nearest observations	67	days before and			26	days after this date.			
5330	„ „	30	„	„	„	34	„	„	„	„
5772	„ „	109	„	„	„	16	„	„	„	„
7146	„ „	20	„	„	„	76	„	„	„	„

7655 only a slight depression between 7600 and 7700?

Second series

As, to all appearance, GUTHNICK copied the dates from HOFFMEISTER's discussion of PLASSMANN's observations, I add HOFFMEISTER's remarks between brackets.

2415125	only descent partly observed (rather good; few observations).
5377	incomprehensible (flat; difficult).
6062	ascending from 6040 (flat).
6970	incomprehensible (descent observed; later).
9522	minimum unobservable, only descent partly observed (very indistinct).

§ 6. The maxima.

In the earlier publications not much attention has been paid to the maximum phase of the light-curve of η Geminorum. HOFFMEISTER finds a slight indication of a few maxima but does not give any details. He considers the light-curve at maximum to run horizontal and consequently gives a table containing the values of the „normal" brightness during the period 1888—1913. GUTHNICK is of the same opinion, he considers the observations of maxima to be of doubtfull value and, moreover, cannot discover any regularity in their order of appearance. Both HOFFMEISTER and GUTHNICK note the striking resemblance to an Algol-curve and the latter suggests that this resemblance might be a permanent feature of the light-curve.

The statements of these writers originate in the observations by SCHMIDT and PLASSMANN. I readily admit that some parts of the light-curve given by SCHMIDT's observations at first glance strongly suggest a typical Algol-curve but on a closer view the presence of a number of maxima becomes evident. As I pointed out before, SCHMIDT's defective method of observation and his large step value can easily lead to an unreliable curve at maximum, but by SCHÖNFELD's short series of observations an opportunity is presented of deciding whether I am right in considering the maxima in SCHMIDT's light-curve to be real.

As will be seen from the following table the supposition of constant brightness at maximum and the striking resemblance with the Algol curve is not confirmed. It appears to be evident that the maxima are the more distinct the greater the number of observers co-operating.

Table XI contains the reference number, the Julian Date, the magnitude at maximum and remarks.

Table XI.

No.	J. D.	magn. *m.*	Remarks.
1	2402625		uncertain
2	4295		uncertain
3	4530		quite certain
4	5220	3,3	5235 (Schönfeld)
5	5460	3,4	5465 „
6	5950	3,4	5955 „ flat
7	6151		quite certain
8	6340		flat
9	6870		uncertain
10	7040		flat
11	7300		preceded by secondary minimum about 7245
12	8000		not quite certain, followed by secondary minimum?
13	8900		not quite certain
14	2413580	3,4	very flat
15	7300	3,4	
16	7600	3,3	
17	7784	3,3	
18	8016	3,4	
19	8258	3,3	
20	8400	3,4	uncertain
21	8730	3,4	
22	8945	3,4	uncertain
23	9440	3,3	preceded by secondary minimum?
24	9620	3,3	flat, uncertain
25	9853	3,3	
26	2420115	3,4	flat, uncertain
27	0590	3,4	
28	0820	3,4	flat
29	1298	3,3	
30	2037	3,4	
31	2720	3,4	
32	3140	3,4	
33	3464	3,4	
34	3680	3,4	
35	3870	3,4	

REMARKS.

The brightness at maximum is not given for the dates deduced from SCHMIDT's light-curve. SCHMIDT found η to be $^1/_2$ to 1 step fainter than μ, equalling 3,2 to 3,35m.

The maxima between 2408000 and 2408900 are not inserted as they belong to the period of strong disturbance mentioned above.

It appears from this table that the brightness at maximum always reaches practically the same value, the existence of a second long periodicity as found for V 14 (RV) Tauri is thereby rendered very improbable.

§ 7. Elements of the variation.

From the observations by PLASSMANN HOFFMEISTER deduced the following formula

$$\text{Min.} = 2410707{,}4 + 232{,}177\ \text{E.}$$

This formula represents the 21 minima observed by PLASSMANN with a mean deviation (*mittlerer Fehler*) of ± 20,9 days. HARTWIG adopted this formula for the Ephemeris in the „Vierteljahrschrift der A. G." [1]. In his discussion in „Geschichte und Literatur" GUTHNICK is of opinion that two separate formulae are necessary to represent the observations. The minima observed by SCHMIDT are given by

$$\text{Min.} = 2402537 + 231{,}8\ \text{E}$$

the minima of the second series, mainly those of PLASSMANN, by

$$\text{Min.} = 2410715 + 231{,}8\ \text{E.}$$

Accordingly, GUTHNICK adopts a jump in epoch of + 65 days somewhere between 1883 and 1888. The accurate date of this assumed jump cannot be given as the observations are practically missing during the period 1883—1888 [2]. In my opinion this jump in epoch therefore cannot be considered as proved; its only merit is to represent the minima by formulae leaving relatively small residuals O – C.

The occurrence of sudden changes in epoch being nowhere firmly established [3] I tried to deduce one formula which represents all minima satisfactorily.

By means of a constant period of 232,7 days, resulting from a rough calcu-

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1) See f. i. **51**, p. 278 No. 330 (1916). In V. J. S. **50** and **51** HARTWIG gives 232,477 days, certainly a misprint.

2) It is not clear how GUTHNICK got to the statement:
„1884—1888 scheint der Lichtwechsel kaum merklich gewesen zu sein".

3) See LUYTEN, Proefschrift, Leiden 1921.

lation, and a zero epoch 2402543 a linear ephemeris was calculated. The resulting residuals O—C were plotted in decimal parts of the period as ordinates in a graph where the number of epochs elapsed were taken as abscissae.

From this diagram (Fig. 1) it is seen that a parabola indicating a uniform *increase* of period will sensibly decrease the residuals O—C.[1]) Accordingly the minima were calculated by means of the provisional formula

$$\text{Min.} = 2402543 + 231{,}4\ \text{E} + 0{,}02\ \text{E}^2$$

resulting in a decrease of O—C of 24 %.

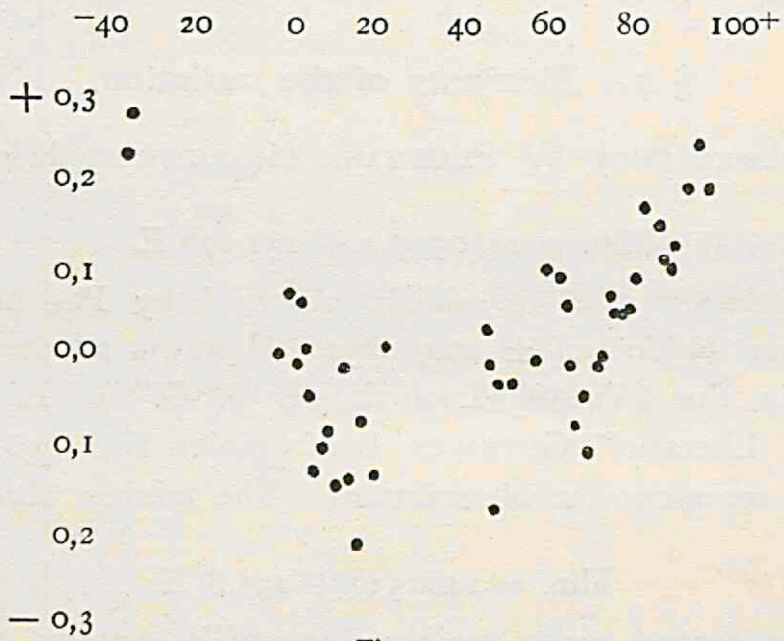

Fig. 1.

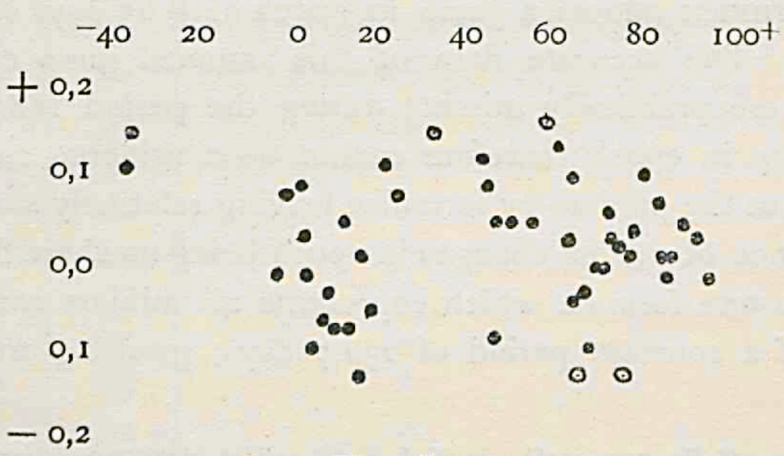

Fig. 2 [2]).

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1) A sine term with the very long period of about 140 E would be a second alternative.

2) The minima 27, 35, 40 and 48 being very uncertain (see Table X, page 27) are represented by circlets.

Finally this formula was corrected according to least squares by means of 29 minima of equal weight, the result being

$$\text{Min.} = 2402551{,}6 + 231{,}31\ E + 0{,}0193\ E^2.$$

This formula gives the values O—C of table X on page 27 (the mean is ± 17,8 days) which are also shown in Fig. 2.

By means of two recent minima observed by NIJLAND and which are not included in our discussion, a comparison is rendered possible of the formulae deduced by HOFFMEISTER, GUTHNICK and myself.

Min. obs. (NIJLAND)	calculated		
	HOFFMEISTER	GUTHNICK	VOGELENZANG
	O—C days		
2424473	+ 67	+ 82	— 1
4925	+ 55	+ 70	— 10

From this discussion it follows that a secular increase of the period of η Geminorum is pretty certain, notwithstanding the occurrence of some strong disturbances.

On a close inspection of Fig. 2 it seems that the introduction of a sine term with a period of about 20 periods will improve the representation of the observations. At present, however, this is not imperative as the oscillations flatten out after E = + 70 in proportion to the number of observers contributing to the light-curve.

If we calculate the maxima according to the formula

$$\text{Max.} = 2402551{,}6 + 115{,}7 + 231{,}31\ E + 0{,}0193\ E^2$$

and group the residuals O—C (the uncertain maxima are excluded) the following table results, the third column of which contains the numbers for the minima.

O—C limits days	Number of residuals	
	maxima	minima
0— 9	11	19
10—19	6	13
20—29	0	9
30—55	7	5

From this table it is clear that the maxima giving large residuals must be treated separately. From the O—C of the remaining maxima the correction of the epoch of the formula was found to be + 3 days. 17 out of 24 maxima are therefore represented by the formula

$$\text{Max.} = 2402670{,}3 + 231.31\,E + 0{,}0193\,E^2$$
$$M - m = 118{,}7 \text{ days}$$

i.e. the mean light-curve is slightly asymmetrical with respect to the maximum.

The residuals exceeding 30 days fall into two groups, viz.

5 positive giving a mean value O—C = + 41 days
2 negative „ „ „ „ „ = — 36 „

These maxima may be explained by adopting the existence of a secondary variation causing a depression of the curve about $^1/_2$ P after the minimum, thereby causing a shift of the expected date of the maximum.

I have not been able to discover any regularity in this secondary variation owing to the material at present available being rather defective.

§ 8. General remarks and summary of the results.

As I stated in the introduction to this paper there is only one source giving information concerning the radial velocity of the system η Geminorum. The following values are taken from „Lick Bulletin", the data, for the sake of convenience, being converted into Julian Dates.

J. D.	Rad. Vel. KM/sec. [1]
2415035	+ 14,9
5041	+ 15,0
5671	+ 22,1
5695	+ 20,3
5723	+ 22,8
5783	+ 24

This table shows that the system is receding from the sun with a velocity varying from 14,9 to 24 KM/sec. A comparison of the values of this table with the light-curve reveals the following facts.

[1]) The probable error of these values is < 1 KM/sec.

a. The dates 5035 and 5041 are found to belong to a very broad maximum of the light-curve extending from 4940 to 5060 (η = 3,3m), after which date η decreases.

b. The increasing radial velocity as given by the observations at 5695,5723 and 5783 corresponds with a decreasing brightness of the star towards the minimum observed at 5805 (η = 3,53 m.).

Thus the existence of a relation between the variations of the radial velocity and the light-variations *during this period* seems to be beyond doubt, although the large differences in the radial velocity observed at the same apparent magnitude of the star (viz. η = 3,3 rad. vel. + 14,9 and + 21 KM) indicate that the cause of the variations of the radial velocity can only partially account for the light-variations.

A remarkable fact is found in the coincidence of the maximum of approaching velocity with the maximum brightness. This is anologous to the δ Cephei stars whereas Mira Ceti shows just the reverse [1]).

It is very much to be regretted, that owing to a lack of sufficient data concerning the radial velocity, these results remain uncertain and render impossible an insight into one, at least, of the causes of the light-variations.

It follows, that it would be premature to attempt to explain the variability of η Geminorum.

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1) *Handbuch der Astrophysik VI* (2) p. 136.

SUMMARY OF RESULTS.

1. The light-curve of η Geminorum is variable. The designation $\beta 4$, as given by LUDENDORFF applies only to a few periods.
2. The light-curve shows a sufficient number of maxima and does not in any respect resemble an Algol-curve.
3. The brightness at maximum reaches always the same value, the amplitude of the variation is variable between the limits 0,2 and 1,0 m.
4. An indication has been found of the occurrence of double maxima and consequently secondary minima. Secondary minima have most probably lead to the irregularities found by GUTHNICK. A relation with the RV Tauri stars is not improbable.
5. The length of the period shows a secular increase viz.

$$\frac{dP}{dE} = + 0{,}0386 \text{ days}$$

and accordingly the period increased from

231,3 days in 1865 to 235,0 days in 1924.

6. The new formula, for which all observations up to 1924 are used, reads:

$$\text{Min.} = \text{J. D. } 2402551{,}6 + 231{,}31 \,.\, E + 0{,}0193 \,.\, E^2.$$

J. W.

STELLINGEN.

I.

De door Guthnick aangenomen sprongsgewijze verandering in de epoche van η Geminorum is door hem niet voldoende gerechtvaardigd en is bovendien onnoodig.

II.

Tegen de zoogenaamde fractioneele methode ter waarneming van veranderlijke sterren zijn ernstige bezwaren.

III.

Hoewel toepassing van de correctie voor extinctie in vele gevallen onvermijdelijk is kunnen de hiervoor bestaande tabellen niet zonder meer worden gebezigd.

IV.

De asymmetrie der lichtkromme van de Cepheiden behoeft geen argument tegen de pulsatietheorie te zijn.

V.

De dislocatietheorie der katalyse geeft geen voldoende verklaring van de werking der waterstofionen. (Boeseken, Rec. **39** (1920), p. 623).

VI.

Het is niet waarschijnlijk, dat de electrolyse onder invloed van een sterk magnetisch veld van een, optisch inactieve, oplossing van een zout van het type CXY (COOMe) (COOAlc) optisch actieve producten op zal leveren. (Jaeger, Principle of Symmetry (1920) p. 321).

VII.

De vorming van saccharose uit zetmeel in aardappelen is niet bewezen.

VIII.

Ten onrechte eischt de Pharmacopee voor alle zetmeelsoorten een maximum van 16 % voor het vochtgehalte.

IX.

De bepaling, dat moederkoorn niet langer dan een jaar in voorraad gehouden mag worden heeft geen zin. (Ned. Pharm. V p. 417).

X.

De methode door het Stroopbesluit voorgeschreven ter bepaling van het gehalte aan saccharose plus invertsuiker in huishoud- en keukenstroop is gebaseerd op de onjuiste veronderstelling, dat zetmeelstroop een constante samenstelling heeft. Het stellen van minimum eischen betreffende het saccharose (+ invertsuiker) gehalte is overigens onnoodig. (Staatsblad 96 (1924) bijlage).