Memoirs of the College of Science, University of Kyoto, Series A,
Vol. XXX, No. 2, Article 5, 1962.

ASTROMETRIC OBSERVATION OF THE ANNULAR ECLIPSE AT TANEGASHIMA ISLAND ON APRIL 19th 1958

Part I. Geodetic Work and Inspection of the Lunar Profile

BY

Shigetsugu FUJINAMI, Kiitiro HURUKAWA and Kiyomasa FURUTA

(*Received May 9, 1962*)

ABSTRACT

The lunar profile was measured on the plates taken at the annular eclipse in April , 1958. The mean square error in the measurement of limb height at a point was of order of $\pm 0''.15$, but that of personal defference between two persons was estimated as $\pm 0''.25$. Comparing our final result with both Hayn's and Weimer's, it was found that a general trend is in accordance with each other, but Hayn's profile is deficient in minutes configuration whereas Weimer's shows more details than ours.

In addition the geodetic work for determining the longitude and the latitude of our observation site was briefly reported.

1. Introduction

On the occasion of the annular eclipse on April 19th, 1958, we made the observations for examining the lunar profile by means of the photographic telescope with focal length of 8 meters at the ground of the Nishino Junior High School (λ=E 130° 53′ 15″.6, φ=N 30° 22′ 12″.1, h=141 meters) in a village near the south edge of Tanegashima Island, Kagoshima Prefecture, Japan.

Though our observation-station was apart about 55 kilometers to the north from the central line of the eclipse, the annular phase was observed for six minutes under fairly good sky condition. The Sun's altitude was 64° at the beginning of the partial phase, 69° at the middle of the annular phase, and 51° at the end of the partial phase. During the eclipse, we took 87 plates of photograph in all, including 63 of the partial phase, 14 of the annular phase and 10 for the orientation. Three pictures in Fig. 1 are some samples of our photographs. The members of our observation corps were Shigetsugu Fujinami, Kiitiro Hurukawa, Kiyomasa Furuta, Ryoichi Isoda and Tamiyuki Tsujimura.

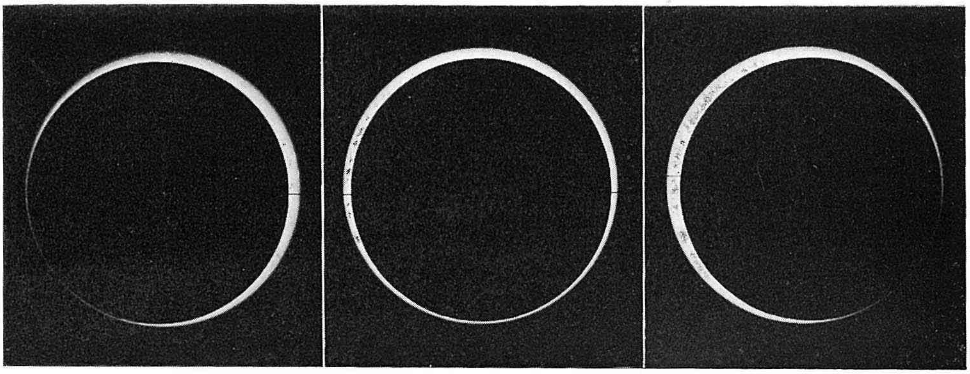

Fig. 1. Photograph of the annular eclipse, taken by the observation corps of Kyoto University at Tanegashima Island, Japan, on April 19th 1958. Right: $3^h50^m35^s$ (U.T.), Center: $3^h52^m48^s$, the maximum phase, Left: $3^h55^m34^s$. The black horizontal line, appeared on the Sun's desk, is a wire's silhouette which is available for the orientation.

2. Geodetic work at our observation-station

We carried out meridian observations to decide the longitude and latitude of the place of our eclipse observation, using a Bamberg broken-telescope transit with 6.5 centimeters aperture. For this purpose, the usual method was adoped; the Horrebow-Talcott method for the latitude observation and the method by the meridian transit-time for the longitude one. Owing to the bad weather conditions during the period March 26~April 16, only each two nights were available for determining either the longitude and the latitude. As the results of reduction referring FK 3, the astronomical coordinates of our Bamberg instrument were found to be

Astronomical longitude: E $130° 53' 15''.58 \pm 0''.31$

($E\ 8^h 43^m 33^s.039 \pm 0^s.021$)

Astronomical latitude : N $30° 22' 12''.24 \pm 0''.11$.

The value of latitude based on Boss' General Catalogue, however, became to be slightly smaller, namely $12''.21 \pm 0''.13$. It is remarked that the above results are not free from the personal error of observer (K. Furuta). The concrete pier on which we settled the Bamberg instrument has been kept as a sort of geodetic mark.

On the other hand, the values of geographic longitude and latitude of a point corresponding to the north-east corner of the roof of Nishino Elementary School were informed by courtesy of the Geographic Survey Institute which determined these values previously from the aerial surveying photograph taken in September, 1947. By means of traverse-surveying, we decided the relative location of the place to our Bamberg instrument. It resulted that the place was to be at a distance of 98.66 meters ($3''.69$ in longitude) to the west and 86.67 meters ($2''.81$ in latitude) to the north. The height of the pier-top was also estimated from the height of the point informed from the G.S.I. The geographic coordinates of our Bamberg instrument obtained in this way were found as follows:

Geographic longitude: E $130° 53' 9''.26$
(E $8^h 43^m 32^s.616$)
Geographic latitude : N $30° 22' 6''.88$
Height above sea-level: 142 meters.

Accordingly, the plumb-line deviation at the observation site turns out to be

$$\begin{cases} \Delta\lambda = \lambda_{ast} - \lambda_{geo} = +6''.3\,, \\ \Delta\varphi = \varphi_{ast} - \varphi_{geo} = +5''.4\,, \end{cases}$$

$$\begin{cases} \xi = \Delta\varphi = +5''.4\,, \\ \eta = \Delta\lambda \cos\varphi = +5''.5\,. \end{cases}$$

The result is in accordance with a general tendency of the plumb-line deviation over the southern part of Kyushu.

As regards the relative location of the photographic instrument for the annular eclipse observation, the coelostat was apart some 5 meters to south-east from the Bamberg transit instrument. Based on the azimuth determination by a theodolite and the distance measurement by a steel tape, the geodetic coordinates of the place of our coelostat were reduced as follows:

(The center of the first mirror of coelostat.)
Astronomical longitude: E $130° 53' 15''.6 \pm 0''.2$
(E $8^h 43^m 33^s.04 \pm 0^s.01$)
Astronomical latitude : N $30° 22' 12''.1 \pm 0''.1$
Height above sea-level : 141 meters.

3. Description of the photographic observation

We set the photographic telescope in the horizontal mounting with a coelostat system. The whole view of our horizontal telescope is shown in Fig. 2 which was taken on the day of annular eclipse. In the picture, the long tube supported horizontally by four concrete piers is of the photographic telescope.

The objective lens of our instrument was photographic achromate of doublet type ; The focal length is 7991 millimeters (at d-line), effective aperture 100 millimeters, and so the aperture ratio is $F/80$. The diameter of solar image on our photographic plate was 74 millimeters apporoximately, and the scale on the plate was 0.0388 millimeters per second of arc. In taking photographs of the eclipsed Sun, we used always a strong absorbing orange filter in front of the objective to take off the chromatic aberration in the shorter wave region than 480 millimicrons. The objetive lens and filter were made by Nippon Kogaku Co., Tokyo,

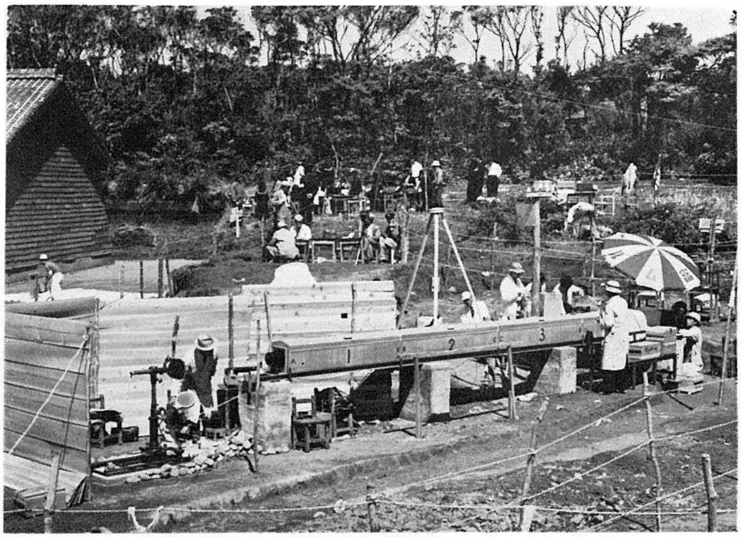

Fig. 2. Whole view of our photographic instrument to observe the annular eclipse. A horizontal long tube, seen on the front side, is the photographic telescope. A coelostat system and objective lens are seen to the left end of the tube, and a focal plane shutter and plate-holder are put to the right end of the tube, shaded by a beach parasol from direct sun-shine.

The telescope tube of 8 meters length had the structure of double shells to diminish the thermal effect due to the sun-shine. The outer tube had some breadth pipes on the roof and bottom surfaces. The telescope tube was laid along the north-south line approximately. In Fig. 2 the right end of the tube directs to the north, and the coelostat and its mirror system are seen to the left side of the telescope tube or to the south side.

We used two pyrex-glass mirrors with aperture of 20 centimeters, made by Osaka Industrial Research Institute, for the first and second mirrors of our coelostat system. But we still suffered from some variation of the focus of the telescope, caused by the heating of mirrors, glass filter and objective lens by the sun-light. We recorded the amount of the variation of the focus by reading the position of plate-holder at every exposure during the whole eclipse. As usual, at first period of receiving the sun-light the focal length of our instrument is prolonged rapidly by some 7 centimeters, and then it shortens gradually and approaches to the normal focal length in about 40 minutes. On the day of the eclipse, at first period when we started to take photograph, the focal length of our instrument was 8030 millimeters, in the annular phase it became the shortest or 8002 millimeters, and then at the last period of the eclipse it was prolonged again to 8047 millimeters.

Photographic apparatus with a focal-plane shutter and plate-holder was put at the north end of the tube, being the right side in Fig. 2, and this part was shaded from the direct sun-shine by a beach parasol. The photographic plate was 12×16.5 centimeters in size and 1 millimeter in thickness. The sensitive emulsion of the plate was of unusual low sensitivity and fine grainness, supplied by courtesy of the Research Laboratory of Fuji Film Co.. The photographic plate was of a regular type in the spectral sensitivity. But, the actual sensitive color region was limited to the range of $480 \sim 510$ millimicrons by using a strong absorbing orange filter. The suitable exposure time for photographs of the partial phase was 1/50 seconds, while as for the annular phase it was 1/10 or 1/15 seconds. The exposed plates were developed in six minutes at solution temperature of 20°C, using the normal developer, Fuji's Korectol.

To get the correct time of the instant of photographic exposure, we made use of an electric contact point into our shutter mechanism to be connected electrically to a relay of our chronograph. The electric point was adjusted so as to close the electric circuit at the instant when the preceding membrane of the focal plane shutter pass through the center of the photographic field. The electric current signal was recorded on the running paper-tape in the chronograph which was recording simultaneously the time signal from Radio (JJY) and from Chronometer (NARDIN, for the mean-time). The running speed of the paper-tape of the chronograph was about six centimeters per second during the eclipse.

4. Inspection of the lunar profile

In order to determine the relative position between the Sun and Moon on the eclipse photographs in large scale, it seems important to consider the influence of zigzagness on the lunar periphery. So, first of all, we inspected how much details in zigzagness were detected along the Moon's silhouetted periphery on our photographic plate, and then compared the observed profile of the Moon with Hayn's profile and Weimer's.

One of us (S. Fujinami) had noticed the significance of deriving the lunar profile in particular through the whole circle with the aid of the annular eclipse photographs in large scale. We would get directly the lunar profile referred to the common mean level through the east and west semi-circle of the Moon from the annular eclipse photographs. Though all of our 14 plates of the annular phase have pretty good image definition, they are not the finest. Then, we were obliged to give up our plan to get a complete profile connecting the east and west limb circle.

A series of three plates with excellent image definition was taken at around

0.7 magnitude of partial phase after the annular phase. Using those three plates, we could inspect the lunar profile only on the west circle limited the range from 196° to 346° in position angle referring to the north direction of Moon's rotation axis. The reference data for those plates are shown in Table 1.

Table 1. The referential data for the photographic plates which were served in measurement of the lunar profile.

Plate number	Photographed time (U.T.)	Sun's altitude	Eclipse		
			Magnitude	Position angle	
				from North	from Vertex
	h m s	°		°	°
B-10	4 20 29.29	65.5	0.73629	69.21	33.54
B-11	26 27.15	64.6	0.68522	68.71	30.78
B-12	30 27.22	63.8	0.65083	68.41	29.07

Measurement of photographic plates

As the first procedure to get the Moon's profile from our plates, we measured the rectangular co-ordinates, x and y, of points on the lunar limb for every degree of the position angle and those of conspicuous points of inflexion. The measuring instrument was a usual micro-comparator with the magnifying power of 15. To know the position angle of the measured points of the lunar periphery, we applied a transparent circular protoractor to fit just inside of the lunar periphery of each negative plate as concentrically as possible. The transparent protoractors were made by the photographic copying from ordinary circular protoractor, and their radii were selected to be by about 0.1 millimeter smaller than the computed mean radius of the lunar image. An appearance of the lunar periphery of measured plate with the transparent protoractor is shown in Fig. 3. The origin

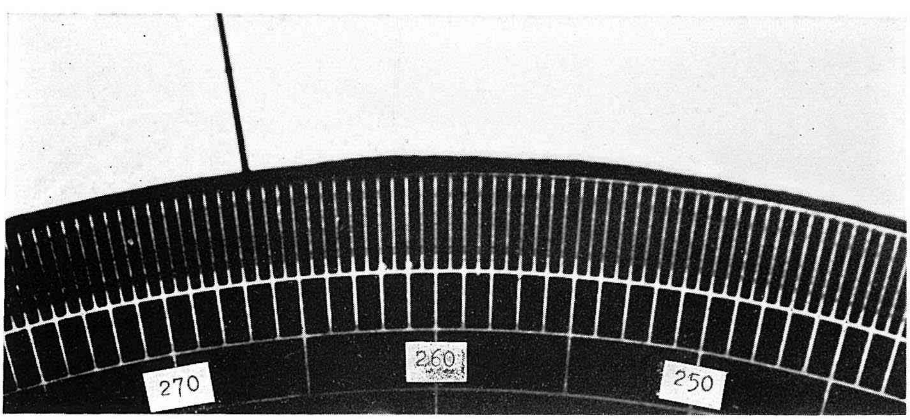

Fig. 3. A part of the lunar periphery on the measured plate B-11, enlarged by about 8 times from the original. Calibrated values of position angle along the lunar periphery are arbitrary values. Subtracting 1°.7 from those values, we get the values of position angle, π, reckoned from the north direction of lunar axis.

of the position angle was determined from the direction of the cusp chords.

Method of reduction

After the measurement of the rectangular co-ordinates of the points along the lunar periphery, we decided the position of the approximate center of the lunar image using some ten points on the periphery. Then, we computed the radial distance from the preliminary center to every measured points, and added the corrections for the distortion of the lunar edge, which was due to refraction in the earth's atmosphere, to the measured radial distance. As the refraction corrections, we adoped the data from *Connaissance des Temps 1940*. Table 2 gives

Table 2. Corrections of the effect of differential refraction.

V		Plate: B-11, ($4^h 26^m$ U.T.) Moon's zenith distance=25°.38		
		Δh	Δl	
		″	″	mm
60°	300°	+0.161	+0.079	+0.003
70	290	.110	.037	.001
80	280	.056	.010	.000
90	270	.000	.000	.000
100	260	−0.056	+0.010	.000
110	250	.110	.037	+0.001
120	240	.161	.081	.003
130	230	.206	.133	.005
140	220	.247	.189	.007
150	210	.280	.242	.009
160	200	.301	.283	.011
170	190	.316	.311	.012
180		.323	.323	.012

V : Position angle along the lunar periphery, reckoned from the direction of the zenith.
Δh: Differential refraction.
Δl: Refraction correction, applied to the measured radius of the lunar image. The linear value, expressed with a millimeter unit, is the amount of correction which should be added to the linear radius on our plate, taken with the focal length of 8016 millimeter.

the corrections to be added to the measured radii of the various position angles. The effects from the other kinds of distortion of the image seemed to be negligible, which was caused by the tilt of the plate toward the focal plane and by the optical aberration.

After applying the refraction correction, the mean level of lunar edge was assumed to be circular. To get the true deviation of the periphery from the mean level with the perfect circular form, we carried out the reduction in the following way by using the measured radii from the preliminary center (**1**). As the equation of condition for determining the limb irregularities, h, we put

$$aX+bY+Z+\left\{h-l'-\frac{d^2}{2R_0}\sin(\phi-P)\right\}=0\,, \tag{1}$$

where, referring to Fig. 4,

$$a=\cos P\,, \qquad X=d\cos\phi\,,$$
$$b=\sin P\,, \qquad Y=d\sin\phi\,,$$
$$l'=l-R_0\,, \qquad Z=R-R_0\,,$$

and, R_0 is an approximate value of R, and X, Y and Z are unknowns which should be determined from the preliminary radii, l.

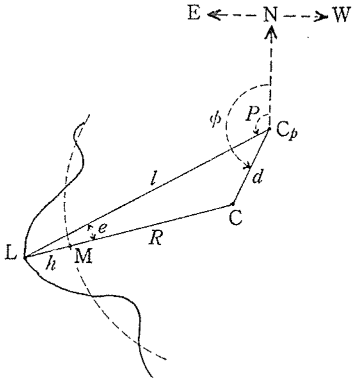

Fig. 4. Determination of the true center and mean level of the measured profile.
C and C_p : true and preliminary centers respectively,
N : fundamental direction (north) in the polar coordinate system,
d and ϕ : polar coordinates of C with respect to C_p,
l and P : polar coordinates of L (on the limb) with respect to C_p, and also, $l=C_pL$: measured radius,
R=CM : lunar mean radius,
h=ML : height of L above mean level,
e : the angle CLC_p.

Firstly, we obtained a preliminary solution using only some ten of the equations, neglecting the small term, $\frac{d^2}{2R_0}\sin(\phi-P)$, in the last group. And then, for the values of h, we adopted Hayn's values (**2**), applied with small correction due to the change of the lunar distance, to make the mean level of the observed contour coincide with Hayn's. The points selected for making one set of the equations of condition were well identified on Hayn's contour, and these were evenly distributed over the whole range of the observed limb.

By the preliminary solution, we may estimate the values of d and ϕ. Then, applying such values and using the complete equation of condition, we get the final solution from the thirty-five equations. Lastly, applying the values, X, Y

and Z, of the final solution to the relation (1), we get the limb irregularities, h, for every individual value of the measured radii, l'. The heights on the lunar periphery derived in this way are shown in Fig. 5.

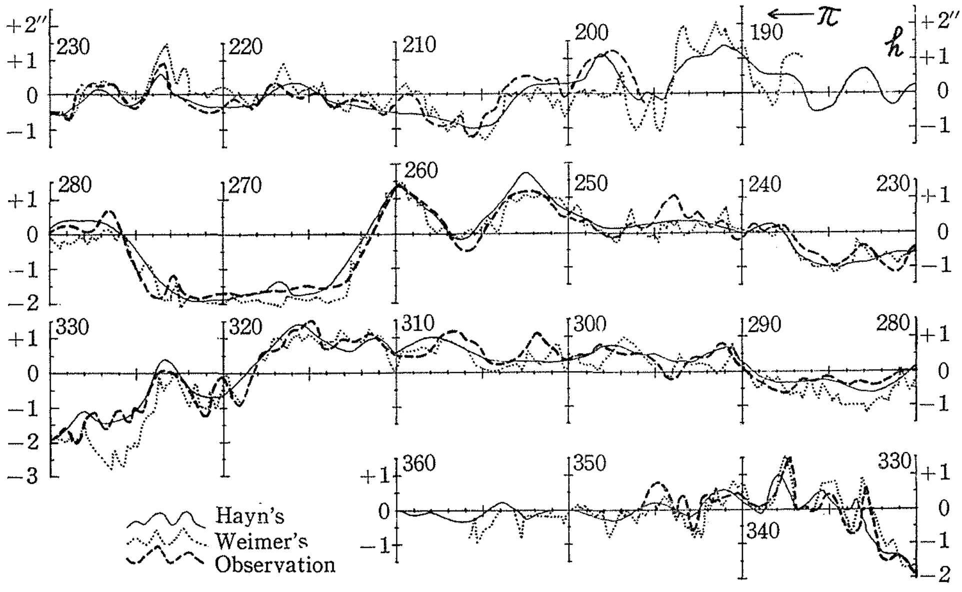

Fig. 5. The observed luner profile (broken-line curve), Hayn's (full-line) and Weimer's (dotted line). Horizontal scale gives position angle in degrees along the lunar periphery, and vertical scale gives heights in second of arc referred to mean level.

Observed lunar profile

In Fig. 5, the heavy broken-line curve shows the lunar profile given by our observation, and the full-line curve is from Hayn's chart, while the dotted curve is from Weimer's. The observed profile was represented with one figure using the mean values from the three measured plates, because the three plates were taken within only ten minutes. Those profiles correspond to the lunar libration when the observer's selenographic longitude was $-2°.55$, the latitude $-0°.10$ and the position angle of the lunar axis $-22°.3$. Those values were culculated for the observed epoch of the plate B-11, $4^h 26^m$ (U.T.), using the American Ephemeries 1958.

Accuracy of measured heights

The accuracy in measured irregularity, h, was estimated from the mean-square error of five measurements for each of adequately selected points. The mean-square error from five measurements was found to be $\pm 0''.15$ in arc or 0.006 millimeters in linear scale on our plate, and also the mean-square error of the single measurement was $\pm 0''.31$ or ± 0.012 millimeters.

However, the mutual comparison of the profiles measured on three plates shows larger deviation at the corresponding points than that expected from values of the mean-error aforementioned. Fig. 6 is an example showing the scattering of observed heights in the range of $250°\sim270°$ in π. In the figure, black dots are the measured values from the the plate B–10, white dots are from the plate B–11, and small triangular marks are from the plate B–12, while the broken-line curve

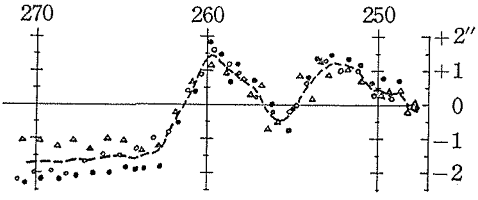

Fig. 6. An example showing the scattering of observed heights, as seen on each of profiles from three plates. Horizontal and vertical scales are the same as in Fig. 5. Black dots are from the plate B–10, white circles from B–11 and small triangular marks from B–12. Depending on those values, the observed profile was as shown by a broken-line curve.

shows an approximate mean profile which was estimated by comparing the dots from the three plates. The mean-square error of the mean profile was $\pm0''.2$ for the points showing fairly good correspondence on the three plates, while it was $\pm0''.5$ for those with large scattering in measured heights. The large scattering in measured value seems to be caused by the effect of atmospheric scintillation to the photographic image and also by the personal change in perception of the lunar limb on the photographic plate.

Personal change on the observed lunar profile

To estimate personal change in perception of the lunar limb, two of us (S. Fujinami and K. Hurukawa) measured the plate B–10 independently and compared the respective profiles. We both measured some 220 points in the tracing along the lunar periphery ranging 166° in position angle. Among the measured points on the both profiles, 76 points were correspondent completely in position angle, and 44 points had the displacement less than $0°.1$. It seemed that at least 120 points in total had probably the same feature in their appearance on the photographic image. Hence, from the two observer's measurements of the lunar limb irregularity, h, of those 120 points we estimated the mean-squre error of personal change $\pm0''.25$ in arc or 0.01 millimeters in linear scale.

Comparison between observed lunar profile and Hayn's or Weimer's

Accepting the existence of several errors which have been described above, we could say as follows: Hayn's profile has not very large discrepany in smoothed figure, but it is too smooth in comparison with the observed profile; Weimer's profile has much more details than in the observed profile; in other words, our observation instrument was able to detect the details of lunar profile having intermediate features between Hayn's profile and Weimer's.

Acknowledgments

It was fortunate for us that teachers and many boys at Nishino Junior High School gave us much assistance for making our observing ground and for setting our observation instrument. We wish to express our hearty thanks to them for their assistance. Our thanks are also due to the retired Professor Toshima Araki, Professor Kiyoshi Yabuuchi and Professor Tsutomu Shimizu, Kyoto University, for their kind advices and suggestions. The present work was carried out by a grant-in-aid of the Ministry of Education.

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