LICK OBSERVATORY

UNIVERSITY OF CALIFORNIA

BULLETIN No. 24

RESULTS OF THE SEARCH FOR AN INTRA-MERCURIAL PLANET AT THE TOTAL SOLAR ECLIPSE OF 1901, MAY 18

One of the questions investigated at the eclipse of 1901, by the Crocker Expedition from the Lick Observatory, was that of the existence of any planets between Mercury and the Sun. My preliminary report* of the eclipse observations contained the results of the examination at the station in Sumatra of the plates exposed for this purpose. This examination was made under unfavorable conditions. Star images were found on only half of the plates. It was planned, therefore, to make a more thorough search at Mt. Hamilton after the return of the expedition.

THE REGION TO BE SEARCHED.

The investigations of Leverrier and others have shown that there is a considerable motion of the line of apsides of the orbit of Mercury which can not be traced to any known body in the solar system. This motion would be explained by a planet, or a ring of small planets, revolving between Mercury and the Sun, nearly in the plane of the Sun's equator. This consideration seems to make a search far from this plane unnecessary at present. As to the mean distance of such a hypothetical body from the Sun, there is less to guide us. An extension of Bode's law of distances would place it at one-fourth the distance of Mercury. This law, however, is entirely empirical; it does not hold at all for Neptune, and but little confidence should be placed in it. Owing to the great eccentricity of Mercury's orbit, its elongations vary between 18° and 28° . The eccentricity of the hypothetical orbit of an intra-Mercurial body is, so far, purely conjectural. It would seem that the maximum elongation could hardly exceed 18° and that in all probability it would not exceed 12° or 13° .

At the time of the eclipse the Earth was but

$17^\circ 48'$ from the ascending node of the Sun's equator. The minor axis of the projection of the hypothetical orbit was, therefore, but $1\frac{1}{2}^\circ$ in length. This is on the assumption that the plane of the hypothetical orbit coincided closely with that of the Sun's equator. Assuming, however, that the nodes differed by 90° , the projection of the minor axis would still be but 5° in length for an orbit whose elongation was 18° . Thus a belt but slightly wider than 5° , and 36° in length in the direction of the Sun's equator, would include all orbits on the assumption of an elongation not exceeding 18° , and an inclination of $7\frac{1}{4}^\circ$ or less.

THE TELESCOPES.

Early in the year 1900, several months previous to the eclipse of that year, Professor Campbell and the writer independently designed lenses which we thought would be efficient for the purpose of an intra-Mercurial planet search. Upon comparing notes we found that they were practically the same, having apertures of 5 or 6 inches, and focal lengths of 15 or 16 feet. As the duration of the 1900 eclipse was too short for an effective search, the plans for such an instrument were made with reference to its use at the long eclipse of 1901. The preparations for this eclipse were necessarily hurried, and the instrument could not be constructed as originally planned. Two achromatic lenses of 3 inches aperture and 11 feet 4 inches focus, were very kindly loaned by Professor E. C. Pickering, Director of the Harvard College Observatory. These lenses were designed for an intra-Mercurial search by Professor W. H. Pickering, and used by him at the eclipse of 1900. Two exactly similar lenses were constructed for the Lick Observatory by Alvan Clark & Sons.

Each of these four lenses was mounted in a tube

* *Lick Observatory Bulletin* No. 9.

of sheet steel. The tubes tapered from 5 inches square at the object-glass end to the size of a 14x17 inch plate holder at the other. The four tubes were fastened together rigidly in a framework of wood, and mounted directly on an axis parallel to the Sun's axis, which permitted of their being moved along the direction of the Sun's equator. This secondary axis was mounted in a large polar axis of box construction. A strong iron arc with clamp and stops enabled the changes of pointing to be made which were necessary to cover the different fields. The polar axis was driven by a clock operating at the extremity of a sector of 10 feet radius.

The telescopes were arranged in two pairs, making an angle of 18° with each other. The two telescopes comprising each pair were parallel, so that duplicate exposures were obtained of each region, simultaneously. Plates 14x17 inches in size were used, giving a field of $5^\circ 54'$ in width, and $7^\circ 8'$ in length. The longer axes of the plates were placed in the direction of the Sun's equator. The plates overlapped sufficiently to insure covering the entire region. The region covered by the negatives embraces an elongation of 19° on either side of the Sun.

From the star images on the photographs of the corona obtained at previous eclipses with the 5 inch, 40 feet-focus camera, it was expected that a lens of 3 inches aperture would show stars down to 8.7 magnitude with 90 seconds exposure in a clear sky. As images of stars even fainter than this were secured at the recent eclipse, through clouds which obstructed fully three-fourths of the light, these lenses are much more efficient than was expected. Had the sky been clear, stars as faint as 10th magnitude would undoubtedly have been recorded. The darkening of the films by the light of the sky in 90 seconds, even with the greater illumination from the clouds, is not objectionable. Lenses of 4 or even 5 inches aperture could be used, and longer exposures given.

THE NEGATIVES.

The negatives show that the mounting was very rigid, and that any vibrations occasioned by the changing of plate holders and of the instrument ceased very soon. The star images near the centers of the plates are almost perfectly round and very sharp. Near the edges of the plates there is some distortion, but not sufficient to prevent the identification of comparatively faint stars.

The plates used were Seed's Gilt Edge, 14x17 inches in size, sensitometer No. 27. Three exposures were made with each of the four cameras.

Following is a list of the negatives secured:

No.	Exposure.	Coördinates of Center of Plate.	
		α	δ
A_1	90 ^s	4 ^h 32 ^m	+ 24° 20'
B_1	90		
C_1	90	3 22	+ 17 40
D_1	90		
A_2	90	4 10	+ 22 20
B_2	90		
C_2	90	3 1	+ 15 20
D_2	90		
A_3	75	3 47	+ 20 20
B_3	75		
C_3	75	2 41	+ 12 50
D_3	75		

The cameras *A* and *B* were parallel and hence covered the same region of sky; likewise the cameras *C* and *D* were parallel. Hence the negatives A_1 and B_1 , C_1 and D_1 , A_2 and B_2 , etc., are duplicates.

Owing to an uncertainty of about 20 seconds in some of the counts near the middle of totality, the mean times of exposure are not assigned. The negatives numbered 1 were taken during the early part of totality, those numbered 2 during the middle part, and those numbered 3 during the last part.

THE EXAMINATION OF THE PLATES.

As soon as possible after the eclipse, at the station in Sumatra the negatives were superposed and examined. All the star images were marked as they were found. After the examination of an entire plate, a comparison was made with the chart plate of the same region of the sky, which had been secured with the same instrument before leaving Mt. Hamilton. All objects observed were identified as known stars.

After the return of the expedition, preparations were made for a more thorough examination of the negatives. An easel was constructed which allowed all portions of the negatives to be examined in a comfortable position for the observer. An eye-piece of $1\frac{1}{2}$ inches focus was used, covering a field of one inch diameter on the negative. To insure all parts of the field being seen under good conditions, an area of only $\frac{1}{2}$ inch square was examined at a time. The original negatives were used, the film of one being placed against the back of the duplicate. The eye-piece was focused on a plane midway between the films; and as the power was not high both images were seen in sufficiently good focus at the same time. Another method promising some advantage over this one would be to take *one* of the negatives *through* the glass. The two plates could then be placed film to film, and a higher power used with less fatigue to the eye.

With the improved conditions, the re-examination showed a number of faint stars which had been missed in the first search; and some star images were finally found on all the plates. All suspicious objects

were marked and at the conclusion of the work on each pair of plates were carefully examined with a higher power. The effect of the increasing cloudiness is evident on these plates, as on the other photographs taken at this eclipse, the last exposure showing only naked eye stars. All objects were identified with catalogued stars. The following summary of the results of the search is appended:

No. of Plates.	Star Images.		Total Number.	Remarks.
	Original Search.	Added by Re-exam- ination.		
A_1 } B_1 }	29	21	50	Faintest stars = one each of 9.1, 9.2, and 9.3 visual magnitude.
C_1 } D_1 }	37	14	51	Faintest stars = two each of 8.6 and 9.0 visual magnitude.
A_2 } B_2 }	26	9	35	Faintest stars = one each of 8.7 and 8.8 visual magnitude.
C_2 } D_2 }	0	26	26	Faintest stars = three of 8.3, one each of 8.6 and 8.7 visual magnitude.
A_3 } B_3 }	0	3	3	One star each of 6.0, 6.2, and 6.5 visual magnitude. Mer- cury and Venus are bright objects on the plates.
C_3 } D_3 }	0	5	5	One star each of 4.0, 5.2, and 6.5 visual magnitude and two of 6.0 visual magnitude.
Total	92	78	170	

The following list contains the B.D. number and magnitude of the stars found on these plates.

No.	Magnitude.	No.	Magnitude.
+ 9°359	4.0	+ 16 432	8.6
+ 11 377	5.2	433	8.5
+ 12 436	5.2	436	8.5
452	6.3	443	8.3
+ 13 494	8.0	444	8.5
496	7.5	450	7.5
503	8.6	454	8.3
514	8.3	458	7.3
529	8.3	484	6.0
535	7.0	497	7.5
+ 14 457	6.0	+ 17 493	6.7
480	6.0	527	7.5
502	7.5	545	8.2
503	8.0	550	8.3
518	7.8	564	6.5
526	8.7	565	8.5
550	7.3	573	8.3
559	8.3	575	7.0
565	7.3	584	8.3
+ 15 400	6.5	+ 18 432	7.0
425	8.3	459	7.3
430	6.5	461	8.0
442	8.0	465	8.2
447	7.0	475	9.0
450	7.3	476	8.5
474	9.0	484	6.5
493	8.0	487	8.3
507	7.9	489	8.6
+ 16 393	8.0	492	8.3
398	8.0	494	8.3
423	7.9	503	8.2

No.	Magnitude.	No.	Magnitude.
+ 18 514	8.3	+ 22 721	8.3
517	7.3	724	9.2
+ 19 505	8.3	725	8.5
509	8.0	728	8.7
510	7.5	735	8.7
523	7.5	736	9.3
530	8.1	737	8.5
537	7.0	739	4.7
547	8.0	743	8.0
549	8.0	754	8.7
554	8.2	+ 23 609	6.0
561	8.0	624	7.2
562	7.0	627	7.5
672	6.2	648	7.0
+ 20 573	7.2	654	8.7
578	8.2	672	7.5
602	6.0	684	6.5
621	6.2	701	7.0
721	8.1	705	8.0
724	5.7	715	6.5
731	8.8	723	8.7
733	6.2	724	8.9
740	7.0	729	7.3
741	7.2	733	6.8
744	6.5	738	8.3
748	9.0	739	7.0
751	6.2	741	8.4
761	8.3	742	9.1
+ 21 572	6.5	747	8.5
585	5.0	750	8.2
587	6.5	756	7.7
618	6.0	757	6.5
623	5.8	758	7.4
641	8.0	761	7.9
642	4.3	763	8.3
643	6.0	770	9.0
644	7.5	772	8.0
647	6.5	777	6.2
657	8.0	+ 24 654	7.3
670	7.5	663	7.3
671	7.8	674	6.3
680	8.2	683	8.8
+ 22 602	6.0	689	8.0
637	7.0	709	6.5
649	6.0	+ 25 707	5.7
657	7.0	720	7.3
670	7.5	723	8.3
696	4.5	731	7.5
699	6.2	746	7.5
707	7.8	+ 26 731	7.0
710	9.1	752	7.6
712	7.4	+ 27 701	6.0

The distribution of the stars on the negatives indicates a comparatively uniform effective exposure over all parts of each plate. On nearly all of the negatives a number of stars fail to show whose visual magnitudes are considerably brighter than the faintest on the same plates. The photographic charts indicate, however, that such discrepancies are, with only a few exceptions, due to the character of the stars' spectra.

BRIGHTNESS AND SIZE OF A BODY IN THIS REGION.

Before drawing any conclusions from these observations it is desirable to determine the relative bright-

ness and size which any bodies in this region would have, by means of other members of the solar system. The asteroids seem to be best suited for such an investigation, as they probably most nearly resemble the hypothetical intra-Mercurial planet in size and condition of surface. The determination of the diameters of the four principal asteroids by Barnard renders these bodies the most suitable for such work.

MAGNITUDES AND DIAMETERS OF THE FOUR PRINCIPAL
ASTEROIDS.*

Asteroid.	Visual Magnitude.	Diameter. Miles.
Ceres	7.5	485
Pallas	8.5	304
Juno	9.5	118
Vesta	6.6	243
Arithmetical Mean	8.0	290

The above magnitudes are those obtained at the Harvard College Observatory by photometric means. The results show such a wide range in albedo that the simple mean has been taken to represent the relation between magnitude and diameter for the group.

Assuming that the distance of the "mean asteroid" from the earth at the time of opposition is 153 million miles, we find that such a body, if transported to a distance of 28 million miles from the Sun (corresponding to an elongation of 18°), and seen from the Earth at elongation, would be 110 times as bright. This corresponds to an increase of brightness of 5.1 magnitudes. Such a body would be relatively brighter near superior conjunction and fainter near inferior conjunction. An intra-Mercurial planet at the above mean distance from the Sun would have to be only one-tenth the diameter of the "mean asteroid" to appear of the same brightness.

From the dimensions and magnitudes of the four brighter asteroids we find that on the average one of these bodies 300 miles in diameter, seen at the opposition distance of the "mean asteroid", would appear of the 8.0 magnitude. Hence an intra-Mercurial planet of similar constitution and 30 miles in diameter should appear as a star of 8.0 magnitude.

If the hypothetical planet were closer to the Sun, the difference of brightness and size would, of course, be correspondingly greater than that found above.

CONCLUSIONS.

Of the six fields embraced in this search, four show stars from 8.7 to 9.3 visual magnitude. The remaining two fields contain no stars fainter than 6.5 visual magnitude. A detailed examination of the magnitudes and types of spectra has been made of

all the brighter stars in the two fields most affected by the clouds. It has been found that all stars brighter than 6.0 visual magnitude have been recorded on all the negatives, with two exceptions. These are B.D. $+11^\circ 360$, 5.1 magnitude, and $+21^\circ 585$, 5.0 magnitude. The star B.D. $+21^\circ 585$ is found on plates A_2 and B_2 , but not on plates A_3 and B_3 . According to the Draper Catalogue, the photographic magnitudes of these two stars are respectively 6.1 and 5.2. The latter is a red star.

As we have no photographic magnitudes of the asteroids, it is necessary to make some assumption regarding the difference between the photographic magnitude of the faintest stars on the plates and the brightness of a planetary body in our system. The faintest stars on the negatives will, in general, be those whose light is more strongly actinic than that of a planetary body of the same visual magnitude. It is perhaps fair to assume that the difference between a sirian and a solar type star will, on the average, be about one magnitude. Hence if all the stars of 6.0 magnitude in the region are recorded on the negatives, a planet of 5.0 magnitude should be visible also. Applying the same criterion to the four regions showing stars from 8.7 to 9.3 magnitude, we may conclude that any planets in those regions from 7.7 to 8.3 magnitude should have been recorded. As already stated, all objects on the negatives have been identified.

These observations indicate, therefore, with the exception to be noticed later, that there is no planetary body as bright as 5.0 visual magnitude within 18° of the Sun whose orbit is not inclined more than $7\frac{1}{4}^\circ$ to the plane of the Sun's equator. They further indicate that in two-thirds of this region there was no such body as bright as $7\frac{3}{4}$ magnitude. The possible exception to be noted is that at the time of the eclipse such a body or bodies might be directly in line with the Sun or with the brightest portion of the corona. The area covered by the Moon's disc and corona was, however, less than one two-hundredth that of the region searched. Owing to the increased cloudiness at the end of totality, the search is not quite complete to the fainter magnitude, yet it seems altogether probable that were there any considerable number of bodies as bright as $7\frac{3}{4}$ magnitude, some of them would have been detected. A planetary body 34 miles in diameter would, under the conditions considered, appear as a star of $7\frac{3}{4}$ magnitude. The total mass required to produce the change observed in the orbit of Mercury is about one-half the mass of that planet. It would require, therefore, no less than seven hundred thousand bodies 34 miles in diameter and as dense as Mercury to equal such a disturbing mass. It has lately been suggested that the pertur-

*Micrometrical Determinations of the Diameters of the Minor Planets Ceres, Pallas, Juno, and Vesta * * by E. E. Barnard, *Monthly Notices Royal Astronomical Society*, LVI, 55.

bations might be due to a ring of bodies outside of Mercury's orbit. It would seem, however, that a ring of matter so situated should affect the motions of Venus to some extent.

From the observations detailed above it does not seem possible that sufficient matter exists in the region close to the Sun in the form of bodies of

appreciable size to account for the observed perturbations. Perhaps the finely divided matter composing the Zodiacal Light is sufficient in the aggregate to cause such a disturbance of Mercury's orbit.

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August 13, 1902.

DISCOVERY OF TWO VARIABLE STARS IN THE NEBULA N.G.C. 7023

This is one of the nebulae on Professor Keeler's program of work for the Crossley Reflector. A photograph of it was taken on November 7, 1901, with an exposure of three hours; but as the star images were not good, another negative was secured on August 27, 1902, with an exposure of four hours. A comparison of the two negatives led to the detection of two variable stars within the nebulosity. The positions of these stars, referred to the central star in the nebula, are as follows:

	<i>p.</i>	<i>s.</i>
<i>A</i>	6°.2	107°.1
<i>B</i>	138.6	87.4

As the interval between the epochs of the two negatives was nearly ten months, another plate was obtained on September 1 to determine if the periods were short. The slight but certain changes observed in the interval of five days, point to comparatively short periods although the variations in brightness continue in the same directions.

The stars were examined visually with the Crossley Reflector on September 1. Star *A* was just visible, its magnitude being estimated at $16\frac{1}{2}$. The following magnitudes have been assigned to the variables:

			<i>A</i>	<i>B</i>
1901	November	7	$14\frac{1}{2}$	$16\frac{1}{2}$
1902	August	27	$16\frac{1}{2}$	$15\frac{1}{2}$
	September	1	$16\frac{1}{2}$	$15\frac{1}{2}$

There are a number of faint stars in the nebulosity, differing slightly in brightness, which form an excellent scale for differential comparisons. No accurate magnitudes of any of them are known at present, however.

So far as I am aware, no variable stars have heretofore been known to exist in the nebulae.

The nebula N.G.C. 7023 is one of unusual interest. It consists of very irregular streamers and masses of nebulosity folded about a 7th magnitude star. The nebula is about $15'$ across and is situated in the center of a region almost devoid of stars, in a very suggestive way.

Acknowledgments are due to Messrs. Joel Stebbins and R. H. Curtiss, Fellows in the Lick Observatory, for their assistance in the taking of the photographs.

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September 5, 1902.