FURTHER INVESTIGATIONS ON PLANETARY INFLUENCE UPON SOLAR ACTIVITY*

1. IN a previous communication by us to this Society, an abstract of which was published in the Proceedings, vol. xiv. p. 59,† we showed some grounds for believing that the behaviour of sun-spots with regard to increase and diminution, as they pass across the sun's visible disc, is not altogether of an arbitrary nature. From the information which we then had, we were led to think that during a period of several months sun-spots will, on the whole, attain their minimum of size at the centre of the disc. They will then alter their behaviour so as, on the whole, to diminish during the whole time of their passage across the disc; thirdly, their behaviour will be such that they reach a maximum at the centre; and, lastly, they will be found to increase in size during their whole passage across the disc. These various types of behaviour appear to us always to follow one another in the above order; and in a paper printed for private circulation in 1866, we discussed the matter at considerable length, after having carefully measured the area of each of the groups observed by Carrington, in order to increase the accuracy of our results. In this paper we obtained nineteen or twenty months as the approximate value of the period of recurrence of the same behaviour.

2. A recurrence of this kind is rather a deduction from observations more or less probable than an hypothesis; nevertheless, it appeared to us to connect itself at once with an hypothesis regarding sun-spot activity. "The average size of a spot" (we remarked) "would appear to attain its maximum on that side of the sun which is turned away from Venus, and to have its minimum in the neighbourhood of this planet." In venturing a remark of this nature, we were aware it might be said, "How can a comparatively small body like one of the planets so far away from the sun cause such enormous disturbances on the sun's surface as we know sun-spots to be?" It ought, however, we think, to be borne in mind that in sun-spots we have, *as a matter of fact*, a set of phenomena curiously restricted to certain solar latitudes, within which, however, they vary according to some complicated periodical law, and presenting also periodical variations in their frequency of a strangely complicated nature. Now these phenomena must either be caused by something within the sun's surface, or by something without it. But if we cannot easily imagine bodies so distant as the planets to produce such large effects, we have equal difficulty in imagining anything beneath the sun's surface that could give rise to phenomena of such a complicated periodicity. Nevertheless, as we have remarked, sun-spots do exist, and obey complicated laws, whether they be caused by something within or something without the sun. Under these circumstances, it does not appear to us unphilosophical to see whether as a matter of fact the behaviour of sun-spots has any reference to planetary positions. There likewise appears to be this advantage in establishing a connection of any kind between the behaviour of sun-spots and the positions of some one prominent planet, that we at once expect a similar result in the case of another planet of nearly equal prominence, and are thus led to use our idea as a working hypothesis.

3. We have now a larger number of observations at our disposal than we had in 1866. We had then only the groups observed by Carrington, the positions and areas of all of which we had accurately measured. We have now in addition five years of the Kew observations, for each group of which the positions and areas have been recorded by us in our previous communications to this society. We have thus altogether observations extending from the beginning of 1854 to the end of 1860, forming the series of Carrington; and observations extending from the beginning of 1866, forming the Kew series, as far as this is yet reduced. We have, in fact, altogether a nearly continuous series, beginning a year or two before one minimum, and extending to the next, and thus embracing rather more than a whole period.

We propose in the following pages to discuss the behaviour with regard to size of the various groups of these two series, as each group passes from left to right across the sun's visible disc. Unfortunately for this purpose, a large number of groups has to be rejected; for, on account of bad weather, we have frequent blank days, during which the sun cannot be seen, and on this account we cannot tell with sufficient accuracy the behaviour of many groups as they pass across the disc. In our catalogue of sun-spot behaviour, we have only retained those groups for which, making the times abscissæ, and the areas ordinates, we had sufficiently frequent observations to enable us to construct a reasonably accurate curve exhibiting the area of the group for each point of its passage across the disc. From these curves a table was then formed denoting the probable area of each non-rejected group at the following heliographic longitudes (that of the visible centre of the disc being reckoned as zero):—

$$-63^\circ - 49^\circ - 35^\circ - 21^\circ - 7^\circ + 7^\circ + 21^\circ + 35^\circ + 49^\circ + 63^\circ;$$

in fact, giving the area of the group for the ten central days of its progress, and rejecting those observations that were too near the sun's border on either side, on account of the uncertainty of measurement of such observations. We have succeeded in tabulating in this manner 421 groups of Carrington's series, and 373 groups of the Kew series up to the end of 1866, in all 794 groups. In this catalogue the area is that of the whole spot, including umbra and penumbra; and in measuring these areas a correction for foreshortening has always been made, as described in a paper which we presented to this society, and which constitutes the first series of our researches. These areas are expressed in millionths of the sun's visible hemisphere.

4. When we began this present investigation into the behaviour of spots, we soon found reason to conclude that in the case of sun-spots the usual formula for foreshortening is not strictly correct. Perhaps if a sun-spot were strictly a surface-phenomenon, the usual formula might be correct, though even that is doubtful; for the earth as a planet may not impossibly affect the behaviour of all spots as they cross the disc, so as to render the formula somewhat inexact. However this may be, a spot is probably always surrounded more or less by faculous matter, forming in many cases a sort of cylindrical wall round the spot. Now the effect of such a wall would be to allow the whole spot to be seen when at or near the centre of the disc, but to hide part of the spot as it approached the border on either side. A spot thus affected would therefore appear to be more diminished by foreshortening than the usual formula would indicate; and we should therefore expect, if this were the case, that, on the whole, after making the usual allowance for foreshortening, spots would nevertheless be found deficient in area near the borders as compared with their area at the centre of the disc. As a matter of fact we have something of this kind, as will be seen from the following table, in which we have used the whole body of spots forming the catalogue to which we have made allusion.

In this table the first column denotes the heliocentric longitude from the centre of the disc reckoned as zero; the second denotes the united areas at the various longitudes of all those groups from both series, the behaviour

* By Warren De La Rue, D.C.L., F.R.S., Balfour Stewart, LL.D., F.R.S., and Benjamin Loewy, F.R.A.S. Read before the Royal Society, March 14, 1872.

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of which we have been able to obtain with accuracy; while the third column exhibits the residual factor for foreshortening, which will bring the areas of the second column into equality with each other.

TABLE I.

Longitude observed.	United areas of all groups at longitude of column 1.	Residual factor for foreshortening necessary to equalise the areas of column 2.
−63°	147,508	1·229
−49	156,758	1·156
−35	168,697	1·075
−21	176,417	1·028
− 7	178,990	1·013
+ 7	181,336	1·000
+21	178,638	1·015
+35	175,747	1·032
+49	171,140	1·059
+63	162,541	1·115

5. From the above table it appears that the average behaviour of spots, as far as can be judged from the information at present attainable, is not quite symmetrical as regards the centre of the disc. Without attempting at present to enter into an explanation of this remarkable phenomenon, we may point to it as a confirmation of our view previously stated, that most spots are accompanied by a wall-shaped surrounding of facula. Observations show that on the whole the life-history of the facula begins and ends earlier than that of the spot which it surrounds, and that throughout a gradual subsidence of this elevated mural appendage seems to be taking place. But such a diminution of the wall discloses more of the spot itself, and hence the spot-areas, measured on the eastern half of the hemisphere, might be expected, *cæteris paribus*, to be smaller than those observed in the western half, a fact strikingly demonstrated by the above table.

Our present object, however, is not to account for the average behaviour of spots, but rather to investigate the causes or concomitants of a departure from this average behaviour. We have, therefore, in all cases made use of the factors given in the above table as those which, judging by the average behaviour, tend to equalise the areas that pass the various longitudes. We have called this *earth-correction*, and have limited our discussion to any well-marked behaviour that remains after the earth-correction has been applied.

Let us now divide the whole mass of observations into four portions, depending upon the position of the planet Venus with reference to the earth or point of view. First, let us take each occasion on which the planet is in the same heliographic longitude as the earth, that is to say, when the earth and Venus are nearly in a line on the same side of the sun.

Let us use five months' observations for each such occasion, extending equally on both sides of it; thus, for instance, if the planet Venus and the earth had the same heliocentric longitude on September 30, 1855, we should make use of sun-spots from the middle of July to the middle of December of that year as likely to represent any behaviour that might be due to this particular position of Venus. Let us do the same for all similar occasions, and finally add all the spots thus selected together. We have thus obtained a mass of observations which may be supposed to represent any behaviour due to this position of the planet Venus with reference to the earth or point of view.

Secondly, let us now take each occasion on which Venus is at the same longitude as the extreme right of the visible disc, that is to say, 90° before the earth, and do the same as we did in the previous instance, using five months' observations for each occasion We shall thus, as before, obtain a mass of observations which may be supposed to represent the behaviour due to a position of Venus 90° before the earth. Thirdly, let us obtain in a similar manner a mass of observations representing the behaviour of sun-spots for a position of Venus 180° before the earth, Venus and the earth being now at exactly opposite sides of the sun; and fourthly, let us finally obtain, in a similar manner, those observations representing the behaviour of sun-spots when Venus is 270° before the earth, being now of the same heliocentric longitude as the extreme left of the visible disc.

These four series of five months each will in fact split up the whole body of observations into four equal parts, the synodical revolution of Venus being nearly twenty months. The following table exhibits these series after the earth-correction has been applied to each. It also represents each series reduced so as to exhibit its characteristic behaviour for an average size of spot = 1000.

TABLE II.

Longitude.	Sum of areas corrected for earth-effect.							
	(A) Venus=Earth+0°.		(B) Venus=Earth+90°.		(C) Venus=Earth+180°.		(D) Venus=Earth+270°.	
		1000		1000		1000		1000
−63°	48905	+54	60573	+56	44031	−16	27776	−152
−49	48385	+42	59869	+43	44075	−15	28881	−118
−35	47508	+23	60210	+49	43606	−25	30023	− 84
−21	46203	− 4	59847	+43	43974	−17	31331	− 44
− 7	45026	−30	58493	+20	45084	+ 7	32711	− 1
+ 7	43603	−61	56496	−15	47446	+61	33791	+ 31
+21	44134	−49	54867	−44	47768	+68	34547	+ 55
+35	45306	−25	54184	−55	46821	+47	35068	+ 71
+49	46476	+ 1	54782	−46	43693	−23	36285	+107
+63	48742	+49	54473	−51	40875	−87	37143	+135
	464288	10000	573794	10000	447373	10000	327556	10000

7. We may do the same for the planet Mercury as we have done for Venus, that is to say, we may split up the whole body of observations into four parts, representing the behaviour of sun-spots when Mercury is in the same four positions with respect to the earth as those which are given for Venus in the above table. Only in this case we must bear in mind that, owing to the eccentricity of Mercury's orbit, this planet will sometimes take a longer,

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and sometimes a shorter time to go from one configuration to another. Thus, for instance, we have

Mercury = earth + 0° on March 24, 1854;
Mercury = earth + 90° on May 6, 1854;
and Mercury = earth + 180° on May 29, 1854.

We should therefore take the observations between April 15, 1854, and May 18, 1854, as representing the behaviour of sun-spots due to a position of Mercury 90° before the earth, and so on for other cases. The following table has been constructed on this principle, and it may be regarded as exhibiting for Mercury precisely what the second table exhibited for Venus.

TABLE III.

Longitude.	Sum of areas corrected for earth-effect.							
	(A) Mercury=Earth+0°		(B) Mercury=Earth+90°.		(C) Mercury=Earth+180°.		(D) Mercury=Earth+270°.	
		1000		1000		1000		1000
−63°	45298	+22	45555	+85	39034	−84	50409	+ 0
−49	45492	+26	44183	+52	40288	−54	49868	−10
−35	45978	+36	41723	− 7	42303	− 8	48996	−28
−21	43870	−11	41398	−14	44554	+46	48453	−39
− 7	42568	−40	41386	−15	45266	+62	48817	−31
+ 7	42384	−44	41096	−21	45502	+68	49844	−11
+21	42885	−33	41460	−13	44817	+52	51341	+18
+35	44270	− 2	40649	−31	42740	+ 3	53000	+51
+49	45780	+32	40337	−39	41478	−27	51772	+27
+63	44922	+14	42157	+ 3	40122	−58	51562	+23
	443447	10000	419944	10000	426104	10000	504062	10000

8. The following is a table constructed on a precisely similar principle with reference to the planet Jupiter:—

TABLE IV.

Longitude.	Sum of areas corrected for earth-effect.							
	(A) Jupiter=Earth+0°.		(B) Jupiter=Earth+90°.		(C) Jupiter=Earth+180°.		(D) Jupiter=Earth+270°.	
		1000		1000		1000		1000
−63°	29348	− 34	35369	−20	48871	−25	42794	+39
−49	28665	− 57	35256	−24	50118	− 1	43163	+48
−35	28836	− 51	35176	−25	51432	+26	40747	−11
−21	28623	− 57	34962	−32	51029	+18	41318	+ 3
− 7	28779	− 53	35739	− 9	51116	+20	40500	−17
+ 7	30321	− 1	36494	+11	50360	+ 9	40599	−15
+21	31309	+ 31	37264	+32	50266	+ 3	40979	− 5
+35	31488	+ 36	36935	+24	50489	+ 7	41579	+ 9
+49	32400	+ 67	36584	+13	49558	−11	40876	− 7
+63	34017	+119	37147	+30	47792	−46	39373	−44
	303786	10000	360926	10000	501231	10000	411928	10000

9. If we now examine the two tables for the planets Venus and Mercury, we shall find in them indications of a behaviour of sun-spots appearing to have reference to the positions of these planets, and which seems to be of the same nature for both. This behaviour may be characterised as follows:—the average size of a spot would appear to attain its maximum on that side of the sun which is turned away from Venus or from Mercury, and to have its minimum in the neighbourhood of Venus or of Mercury.

10. The apparent behaviour is so decided with regard to Venus, that the whole body of observations will bear to be split up into two parts, namely, Carrington's series and the Kew series, in each of which it is distinctly manifest. The following treatment will serve to render this effect more visible to the eye.

In Table II., column (A) (Venus = earth + 0°), we have ten final numbers denoting the behaviour of a spot of average area = 1,000 at ten central longitudes as follows:

$$+54+42+23-4-30-61-49-25+1+49.$$

Let us take the mean of the first and second of these, the mean of the second and third, and so on, and we get the following nine numbers:—

$$+48+32+10-17-45-55-37-12+25.$$

Performing the same operation once more, we obtain the following eight numbers, corresponding to the eight central longitudes:—

$$+40+21-3-31-50-46-25+7.$$

In Table V. we have exhibited the results obtained by this process.

11. If we now refer to the table of Jupiter, we find that we cannot detect the same kind of behaviour that we did in the case of Venus and Mercury. We cannot say that such a behaviour does not exist with reference to this planet; but, if it does, it is to such an extent that the observations at our disposal have not enabled us to detect it.

12. The following evidence from a different point of view goes to confirm the results we have now obtained.

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We might expect, if there really is a behaviour of sun-spots depending upon the position of Venus, and of the nature herein stated, that the average area of a spot as it passes the central longitude of the disc ought to be greatest when Venus is 180° from the earth, and least when Venus and the earth are together, and the same ought to hold for Mercury and for Jupiter, if these planets have any influence. Taking the mean of the four central areas as giving the best value of the araea of a spot its passes the centre, we have for Venus the following results :—

TABLE V

Longitude.	Venus (whole series).	Venus (Carrington's series).	Venus (Kew series).	Mercury (whole series).
°	(A) (B) (C) (D)	(A) (B) (C) (D)	(A) (B) (C) (D)	(A) (B) (C) (D)
−49	+40+48−18−118	+ 8+30−10−160	+117+58−27−46	+28+45−50−12
−35	+21+46−20− 82	+ 9+24− 5− 95	+ 47+58−39−59	+21+ 6− 6−26
−21	− 3+39−13− 43	+ 1+24+10− 37	− 16+45−38−52	− 6−12+36−34
− 7	−31+17+15− 3	−12+16+36+ 16	− 74+13− 9−36	−33−16+60−28
+ 7	−50−14+49+ 29	−23+ 2+53+ 58	−113−29+45−20	−40−18+63− 9
+21	−46−40+60+ 53	−15−20+46+ 82	−119−57+77+ 4	−28−20+43+19
+35	−25−50+34+ 76	+ 4−45+13+100	− 91−56+59+36	− 1−28+ 7+36
+49	+ 7−50−22+105	+14−50−40+118	− 9−44+ 1+82	+19−27−27+32

Mean of 4 central areas,

(A)	(B)	(C)	(D)
44741	57426	46068	33095

and the number of groups for these are as follows :—

229 265 150 181

hence the mean area of one group will be,—

195 217 307 183

from which we get (A) = 195 ; mean of (B) and (D) = 200 ; (C) = 307 ; that is to say, A is least, and C is greatest.

Doing the same in the case of Mercury, we get

(A) = 204 ; mean of (B) and (D) = 217 ; (C) = 246 ;
and finally, doing the same in the case of Jupiter, we get

(A) = 185 ; mean of (B) and (D) = 207 ; (C) = 282 ;
it thus appears that in all these cases the same order is preserved.

13. We leave it to others to remark upon the nature and strength of the evidence now deduced as to a connection of some sort between the behaviour of sun-spots and the positions of the planets Venus and Mercury. We think, however, it must be allowed, that the investigation is one of interest and importance, and we trust that arrangements may be made for the systematic continuance of solar observations in such localities as will ensure to us a daily picture of the sun's disc.

The influence of blank days in diminishing the value of a series of sun-observations is very manifest. We have been able to record the behaviour across the sun's disc of 421 groups of Carrington's series for a total number of 885 groups, and we have been able to record the same behaviour for 373 out of 544 groups observed at Kew. Thus, out of a total of 1,429 groups, we have only been able to record the behaviour of 794. Nor are the records which we have obtained so perfect as we could wish, on account of blank days, which make interpolations necessary. It is therefore of much importance for the future of such researches as the present that there should be several observing-stations so placed that we may reckon on having at least a daily picture of the sun's disc.

It will be easily seen that such observations are very different from experiments which may be multiplied *ad libitum* ; for in this case Nature gives us in a year or in ten years a certain amount of information, and no more ; while it depends upon ourselves to make a good use of the information which she affords.

It is already universally acknowledged that we ought to make the best possible use of the few precious moments of a total eclipse ; but such observations must necessarily be incomplete unless they are followed up by the equally important if more laborious task of recording the sun's surface from day to day.

RHINOCEROSES

THE few species of Rhinoceros which now exist on the world's surface are divisible into two distinct groups, one of which inhabits Africa, the other certain portions of Asia. The Asiatic rhinoceroses are readily distinguishable from their Æthiopian brethren by the presence of incisor teeth throughout life, and by the remarkable folds of the skin. In the African rhinoceroses the incisor teeth are absent, or rather never cut the gums, and the skin is smooth, or, at all events presents scarcely any appearance of the peculiar folds which distinguish the Asiatic species.

Commencing with the Asiatic group, the great Indian rhinoceros (*Rhinoceros unicornis*) is the largest, oldest, and best known species. Of this animal the Zoological Society's Collection contains two adult specimens—a female, purchased in 1850, and a male, presented by Mr Grote in 1864. But long before the arrival of these animals the large Indian rhinoceros was represented in the Society's Collection by a specimen which died in 1849, and which formed one of the subjects of Prof. Owen's elaborate memoir upon the anatomy of this animal, published in the Society's "Transactions," vol. iv., p. 31.

The habitat of the large Indian rhinoceros is the wooded district called the Terai, which lies along the foot of the Himalayas from Nepaul to Bhotan, and thence extends into Assam.

The Sondaic rhinoceros (*Rhinoceros sondaicus*) appears to be very like its larger brother in general conformation, having but one horn on its nose, and the same complicated folds of the skin. It is, however, much smaller in size, and, according to the best authorities, presents certain well-marked cranial characters, which render it easily distinguishable. This rhinoceros was, until recently, supposed to be confined to Java, Sumatra, and Borneo, in which latter island, however, its existence in the present epoch is somewhat problematical.*

Mr. Blyth, however, has recently shown that the one-horned rhinoceros of the Malay peninsula is in all probability referable to this species, and that the rhinoceros which occurs in the Sunderbunds of Bengal is most likely the same animal.

Of the Sondaic rhinoceros, the Zoological Society has

* See Busk in Proc. Zool. Soc. 1869, p. 409, and Fraser, *ibid.*, p. 29.

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