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III. *On the Nature and Construction of the Sun and Fixed Stars.*
By WILLIAM HERSCHEL, LL.D. F.R.S.

[Concluded from Page 123.]

It will now be easy to bring the result of these observations into a very narrow compass. That the sun has a very extensive atmosphere cannot be doubted; and that this atmosphere consists of various elastic fluids, that are more or less lucid and transparent, and of which the lucid one is that which furnishes us with light, seems also to be fully established by all the phænomena of its spots, of the faculæ, and of the lucid surface itself. There is no kind of variety in these appearances but what may be accounted for with the greatest facility, from the continual agitation which, we may easily conceive, must take place in the regions of such extensive elastic fluids.

It will be necessary, however, to be a little more particular as to the manner in which I suppose the lucid fluid of the sun to be generated in its atmosphere. An analogy that may be drawn from the generation of clouds in our own atmosphere, seems to be a very proper one, and full of instruction. Our clouds are probably decompositions of some of the elastic fluids of the atmosphere itself, when such natural causes, as in this grand chemical laboratory are generally at work, act upon them: we may therefore admit, that in the very extensive atmosphere of the sun, from causes of the same nature, similar phænomena will take place; but with this difference, that the continual and very extensive decompositions of the elastic fluids of the sun are of a phosphoric nature, and attended with lucid appearances, by giving out light.

If it should be objected, that such violent and unremitting decompositions would exhaust the sun, we may recur again to our analogy, which will furnish us with the following reflections. The extent of our own atmosphere, we see, is still preserved, notwithstanding the copious decompositions of its fluids in clouds and falling rain; in flashes of lightning, in meteors, and other luminous phænomena; because there are fresh supplies of elastic vapours continually ascending to make

good the waste occasioned by those decompositions. But it may be urged, that the case with the decomposition of the elastic fluids in the solar atmosphere would be very different, since light is emitted, and does not return to the sun, as clouds do to the earth when they descend in showers of rain. To which I answer, that, in the decomposition of phosphoric fluids, every other ingredient but light may also return to the body of the sun. And that the emission of light must waste the sun, is not a difficulty that can be opposed to our hypothesis: for, as it is an evident fact that the sun does emit light, the same objection, if it could be one, would equally militate against every other assignable way to account for the phenomenon.

There are, moreover, considerations that may lessen the pressure of this alledged difficulty. We know the exceeding subtilty of light to be such, that in ages of time its emanation from the sun cannot very sensibly lessen the size of this great body. To this may be added, that, very possibly, there may also be ways of restoration to compensate for what is lost by the emission of light, though the manner in which this can be brought about should not appear to us. Many of the operations of Nature are carried on in her great laboratory which we cannot comprehend, but now and then we see some of the tools with which she is at work. We need not wonder that their construction should be so singular as to induce us to confess our ignorance of the method of employing them, but we may rest assured that they are not a mere *lusus nature*. I allude to the great number of small telescopic comets that have been observed, and to the far greater number still that are probably much too small for being noticed by our most diligent searchers after them. Those six, for instance, which my sister has discovered, I can from examination affirm, had not the least appearance of any solid nucleus, and seemed to be mere collections of vapours condensed about a centre. Five more, that I have also observed, were nearly of the same nature. This throws a mystery over their destination, which seems to place them in the allegorical view of tools, probably designed for some salutary purposes to be wrought by them; and, whether the restoration of what is lost

lost to the sun by the emission of light, the possibility of which we have been mentioning above; may not be one of these purposes, I shall not presume to determine. The motion of the comet, discovered by Mr. Messier in June 1770; plainly indicated how much its orbit was liable to be changed by the perturbations of the planets; from which, and the little agreement that can be found between the elements of the orbits of all the comets that have been observed, it appears clearly that they may be directed to carry their salutary influence to any part of the heavens.

My hypothesis, however, as before observed, does not lay me under any obligation to explain how the sun can sustain the waste of light, nor to shew that it will sustain it for ever; and I should also remark that, as in the analogy of generating clouds, I merely allude to their production as owing to a decomposition of some of the elastic fluids of our atmosphere, that analogy, which firmly rests upon the fact, will not be less to my purpose, to whatever cause these clouds may owe their origin. It is the same with the lucid clouds, if I may so call them, of the sun. They plainly exist, because we see them; the manner of their being generated may remain an hypothesis—and mine, till a better can be proposed, may stand good; but, whether it does or not, the consequences I am going to draw from what has been said will not be affected by it.

Before I proceed I shall only point out, that, according to the above theory, a dark spot in the sun is a place in its atmosphere which happens to be free from luminous decompositions; and that faculæ are, on the contrary, more copious mixtures of such fluids as decompose each other. The penumbra, which attends the spots, being generally depressed, more or less, to about half way between the solid body of the sun and the upper part of those regions in which luminous decompositions take place, must of course be fainter than other parts. No spot favourable for taking measures having lately been on the sun, I can only judge, from former appearances, that the regions in which the luminous solar clouds are formed, adding thereto the elevation of the faculæ, cannot be less than 1843, nor much more than 2765 miles

miles in depth. It is true that in our atmosphere the extent of the clouds is limited to a very narrow compass; but we ought rather to compare the solar ones to the luminous decompositions which take place in our *aurora borealis*, or luminous arches which extend much farther than the cloudy regions. The density of the luminous solar clouds, though very great, may not be exceedingly more so than that of our *aurora borealis*. For, if we consider what would be the brilliancy of a space two or three thousand miles deep, filled with such corruscations as we see now and then in our atmosphere, their apparent intensity, when viewed at the distance of the sun, might not be much inferior to that of the lucid solar fluid.

From the luminous atmosphere of the sun I proceed to its opaque body, which, by calculation from the power it exerts upon the planets, we know to be of great solidity; and from the phenomena of the dark spots, many of which, probably on account of their high situations, have been repeatedly seen, and otherwise denote inequalities in their level, we surmise that its surface is diversified with mountains and vallies.

What has been said enables us to come to some very important conclusions, by remarking, that this way of considering the sun and its atmosphere removes the great dissimilarity we have hitherto been used to find between its condition and that of the rest of the great bodies of the solar system.

The sun, viewed in this light, appears to be nothing else than a very eminent, large, and lucid planet, evidently the first, or, in strictness of speaking, the only primary one of our system, all others being truly secondary to it. Its similarity to the other globes of the solar system with regard to its solidity, its atmosphere, and its diversified surface, the rotation upon its axis, and the fall of heavy bodies, leads us on to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe.

Whatever fanciful poets might say in making the sun the abode of blessed spirits, or angry moralists devise in pointing it out as a fit place for the punishment of the wicked, it does

not appear that they had any other foundation for their assertions than mere opinion and vague surmise; but now I think myself authorised, *upon astronomical principles*, to propose the sun as an inhabitable world; and am persuaded that the foregoing observations, with the conclusions I have drawn from them, are fully sufficient to answer every objection that may be made against it.

It may, however, not be amiss to remove a certain difficulty, which arises from the effect of the sun's rays upon our globe. The heat which is here, at the distance of 95 millions of miles, produced by these rays, is so considerable, that it may be objected, that the surface of the globe of the sun itself must be scorched up beyond all conception.

This may be very substantially answered by many proofs drawn from natural philosophy, which shew that heat is produced by the sun's rays only when they act upon a calorific medium; they are the cause of the production of heat, by uniting with the matter of fire which is contained in the substances that are heated; as the collision of flint and steel will inflame a magazine of gunpowder, by putting all the latent fire it contains into action. But an instance or two of the manner in which the solar rays produce their effect, will bring this home to our most common experience.

On the tops of mountains of a sufficient height, at an altitude where clouds can very seldom reach to shelter them from the direct rays of the sun, we always find regions of ice and snow. Now, if the solar rays themselves conveyed all the heat we find on this globe, it ought to be hottest where their course is least interrupted. Again, our aéronauts all confirm the coldness of the upper regions of the atmosphere; and since, therefore, even on our earth, the heat of any situation depends upon the aptness of the medium to yield to the impression of the solar rays, we have only to admit, that, on the sun itself, the elastic fluids composing its atmosphere, and the matter on its surface, are of such a nature as not to be capable of any excessive affection from its own rays: and, indeed, this seems to be proved by the copious emission of them; for if the elastic fluids of the atmosphere, or the matter contained on the surface of the sun, were of such a nature

as to admit of an easy, chemical combination with its rays, their emission would be much impeded.

Another well known fact is, that the solar focus of the largest lens, thrown into the air, will occasion no sensible heat in the place where it has been kept for a considerable time, although its power of exciting combustion, when proper bodies are exposed, should be sufficient to fuse the most refractory substances*.

It will not be necessary to mention other objections, as I can think of none that may be made but what a proper consideration of the foregoing observations will easily remove; such as may be urged from the dissimilarity between the luminous atmosphere of the sun and that of our globe will be touched upon hereafter, when I consider the objections that may be assigned against the moon's being an inhabitable satellite.

I shall now endeavour, by analogical reasonings, to support the ideas I have suggested concerning the construction and purposes of the sun; in order to which it will be necessary to begin with such arguments as the nature of the case will admit, to shew that our moon is probably inhabited. This satellite is of all the heavenly bodies the nearest, and therefore most within the reach of our telescopes: accordingly we find, by repeated inspection, that we can with perfect confidence give the following account of it:—

It is a secondary planet, of a considerable size; the surface of which is diversified, like that of the earth, by mountains and vallies. Its situation with respect to the sun is much like that of the earth, and, by a rotation on its axis, it enjoys an agreeable variety of seasons, and of day and night. To the moon our globe will appear to be a very capital satellite, undergoing the same regular changes of illuminations as the moon does to the earth. The sun, the planets, and the starry constellations of the heavens, will rise and set there as they do here; and heavy bodies will fall on the moon as they do

* The subject of light and heat has been very ably discussed by Mr. De Luc, in his excellent work, *Idées sur la Météorologie*, Tome I. part 2. chap. 2. section 2. *De la Nature du Feu*; and Tome II part 3. chap. 1. section 2. *Des Rapports de la Lumière avec la Chaleur dans l'Atmosphère*.

on the earth. There seems only to be wanting, in order to complete the analogy, that it should be inhabited like the earth.

To this it may be objected, that we perceive no large seas in the moon: that its atmosphere (the existence of which has even been doubted by many) is extremely rare, and unfit for the purposes of animal life: that its climates, its seasons, and the length of its days, totally differ from ours: that without dense clouds (which the moon has not), there can be no rain; perhaps no rivers, no lakes. In short, that, notwithstanding the similarity which has been pointed out, there seems to be a decided difference in the two planets we have compared.

My answer to this will be, that that very difference which is now objected will rather strengthen the force of my argument than lessen its value: we find, even upon our globe, that there is the most striking difference in the situation of the creatures that live upon it. While man walks upon the ground, the birds fly in the air, and fishes swim in water; we can certainly not object to the conveniences afforded by the moon, if those that are to inhabit its regions are fitted to their conditions as well as we on this globe are to ours. An absolute, or total sameness, seems rather to denote imperfections, such as Nature never exposes to our view; and, on this account, I believe the analogies that have been mentioned fully sufficient to establish the high probability of the moon's being inhabited like the earth.

To proceed, we will now suppose an inhabitant of the moon, who has not properly considered such analogical reasonings as might induce him to surmise that our earth is inhabited, were to give it as his opinion that the use of that great body, which he sees in his neighbourhood, is to carry about his little globe, that it may be properly exposed to the light of the sun, so as to enjoy an agreeable and useful variety of illumination, as well as to give it light by reflection from the sun when direct day-light cannot be had. Suppose also that the inhabitants of the satellites of Jupiter, Saturn, and the Georgian planet, were to look upon the primary ones, to which they belong, as mere attractive centres, to keep together their orbits, to direct their revolution round the sun, and

to supply them with reflected light in the absence of direct illumination. Ought we not to condemn their ignorance, as proceeding from want of attention and proper reflection? It is very true that the earth, and those other planets that have satellites about them, perform all the offices that have been named for the inhabitants of these little globes; but to us, who live upon one of these planets, their reasonings cannot but appear very defective, when we see what a magnificent dwelling-place the earth affords to numberless intelligent beings.

These considerations ought to make the inhabitants of the planets wiser than we have supposed those of their satellites to be. We surely ought not, like them, to say "the sun" (that immense globe, whose body would much more than "fill the whole orbit of the moon) is merely an attractive "centre to us." From experience we can affirm, that the performance of the most salutary offices to inferior planets is not inconsistent with the dignity of superior purposes; and, in consequence of such analogical reasonings, assisted by telescopic views, which plainly favour the same opinion, we need not hesitate to admit that the sun is richly stored with inhabitants.

This way of considering the sun is of the utmost importance in its consequences. That stars are suns can hardly admit of a doubt. Their immense distance would perfectly exclude them from our view, if the light they send us were not of the solar kind. Besides, the analogy may be traced much farther. The sun turns on its axis: so does the star Algol: so do the stars called β Lyræ, δ Cephei, η Antinoi, $\circ$ Ceti, and many more; most probably all. From what other cause can we so probably account for their periodical changes? Again, our sun has spots on its surface: so has the star Algol, and so have the stars already named, and probably every star in the heavens. On our sun these spots are changeable: so they are on the star $\circ$ Ceti, as evidently appears from the irregularity of its changeable lustre, which is often broken in upon by accidental changes while the general period continues unaltered. The same little deviations have been observed in other periodical stars, and ought to be ascribed

ascribed to the same cause. But if stars are suns, and suns are inhabitable, we see at once what an extensive field for animation opens itself to our view.

It is true that analogy may induce us to conclude, that, since stars appear to be suns, and suns, according to the common opinion, are bodies that serve to enlighten, warm, and sustain a system of planets, we may have an idea of numberless globes that serve for the habitation of living creatures. But if these suns themselves are primary planets, we may see some thousands of them with our own eyes, and millions by the help of telescopes, when at the same time the same analogical reasoning still remains in full force with regard to the planets which these suns may support.

In this place I may, however, take notice, that, from other considerations, the idea of suns or stars being *merely* the supporters of systems of planets, is not absolutely to be admitted as a general one. Among the great number of very compressed clusters of stars I have given in my catalogues, there are some which open a different view of the heavens to us. The stars in them are so very close together, that, notwithstanding the great distance at which we may suppose the cluster itself to be, it will hardly be possible to assign any sufficient mutual distance to the stars composing the cluster, to leave room for crowding in those planets, for whose support these stars have been, or might be, supposed to exist. It should seem, therefore, highly probable that they exist for themselves; and are, in fact, only very capital, *lucid*, primary planets, connected together in one great system of mutual support.

As in this argument I do not proceed upon conjectures, but have actual observations in view, I shall mention an instance in the clusters No. 26, 28, and 35, VI. class, of my catalogue of nebulae, and clusters of stars. (See Phil. Trans. Vol. LXXIX. Part II. p. 251.) The stars in them are so crowded that I cannot conjecture them to be at a greater apparent distance from each other than five seconds, even after a proper allowance for such stars, as, on a supposition of a globular form of the cluster, will interfere with one another, has been made. Now, if we would leave as much room between

tween each of these stars as there is between the Sun and Sirius, we must place these clusters 42104 times as far from us as that star is from the sun. But, in order to bring down the lustre of Sirius to that of an equal star placed at such a distance, I ought to reduce the aperture of my 20-foot telescope to less than the two-and-twenty hundredth part of an inch; when certainly I could no longer expect to see any star at all.

The same remark may be made with regard to the number of very close double stars, whose apparent diameters being alike, and not very small, do not indicate any very great mutual distance: from which, however, must be deducted all those where the different distances may be compensated by the real difference in their respective magnitudes.

To what has been said may be added, that, in some parts of the milky way, where yet the stars are not very small, they are so crowded, that in the year 1792, Aug. 22, I found by the gages that, in 41 minutes of time, no less than 258 thousand of them had passed through the field of view of my telescope*.

It seems, therefore, upon the whole, not improbable that, in many cases, stars are united in such close systems as not to leave much room for the orbits of planets or comets; and that consequently, upon this account also, many stars, unless

* The star-gages ran thus:

From $19^h 35'$ to $19^h 51'$ 600 stars in the field

$19 51 - 19 57$ 440

$19 57 - 20 12$ 360

$20 12 - 20 16$ 260

The breadth of the sweep was $2^{\circ} 35'$, the diameter of the field $15'$, and the mean polar distance $73^{\circ} 54'$. Then let

F, be the diameter of the field of view,

S, the number of stars in each field,

B, the breadth of the sweep, plus F,

T, the length of the sweep, expressed in minutes of space,

ϕ , the sine of the mean polar distance,

C, the constant fraction ,7854,

and the stars in these four successive short sweeps will be found by the expression $\frac{BTS\phi}{F^2 C}$ equal to 133095.36601. 74866. 14419. or in all 258981.

we

we would make them mere useless brilliant points, may themselves be lucid planets, perhaps unattended by satellites.

POSTSCRIPT.

The following observations, which were made with an improved apparatus, and under the most favourable circumstances, should be added to those which have been given. They are decisive with regard to one of the conditions of the lucid matter of the sun.

Nov. 26, 1794. Eight spots in the sun, and several subdivisions of them, are all equally depressed.

The sun is mottled every where.

The mottled appearance of the sun is owing to an inequality in the level of the surface.

The sun is equally mottled at its poles and at its equator; but the mottled appearances may be seen better about the middle of the disc than towards the circumference, on account of the sun's spherical form.

The unevenness arising from the elevation and depression of the mottled appearance on the surface of the sun, seems in many places to amount to as much, or to nearly as much, as the depression of the penumbrae of the spots below the upper part of the shining substance, without including faculae, which are protuberant.

The lucid substance of the sun is neither a liquid nor an elastic fluid; as is evident, from its not instantly filling up the cavities of the spots, and of the unevenness of the mottled parts. It exists, therefore, in the manner of lucid clouds swimming in the transparent atmosphere of the sun; or rather, of luminous decompositions taking place within that atmosphere.