On the Theory of Sunspots Proposed by Signor Kirchoff

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Eileen Reeves (Department of Comparative Literature, Princeton University, Princeton, New Jersey, 08544) and Mary Posani (Department of French and Italian, The Ohio State University, Columbus, Ohio, 43221) provide a translation of Father Pietro Angelo Secchi's classic work "*Secchi A. Sulla Teoria Delle Macchie Solari: Proposta dal sig. Kirchoff*" as it appeared in *Bullettino Meteorologico dell' Osservatorio del Collegio Romano*, 31 January 1864, v.3(4), 1–4. This was the first treatise to propose a particulate photosphere floating on the gaseous body of the Sun. The idea would dominate astrophysical thought for the next 50 years. Secchi appears to have drafted the article, as a response to Gustav Kirchhoff's proposal, echoing early Galilean ideas, that sunspots represented clouds which floated above the photosphere. Other than presenting a new solar model, noteworthy aspects of this work include Secchi's appropriate insistence that materials do not emit the same light at the same temperature and his gentle rebuke of Kirchhoff relative to commenting on questions of astronomy.

We gestured in passing in the second number of volume II [of the *Bullettino Meteorologico dell'Osservatorio del Collegio Romano*] to the theory offered by Signor Kirchoff, as a substitution for the current view, about sunspots. This theory has been something of a sensation, since it is the view of a scientist who has rightly gained immense popularity and esteem for his magnificent discoveries concerning the solar spectrum. For this reason, some consideration of his theory is in order, and we will avail ourselves of the various studies that have recently appeared.

Signor Kirchoff rejects both the theory of Herschel and that of Wilson. We will first permit ourselves the observation that it is one thing to refute Herschel's theory, and quite another to refute Wilson's, and that when the first is laid to rest, the second one hardly collapses. Herschel maintained that the solar nucleus was solid, dark, and covered by two layers of luminous clouds, one a certain distance above the other, separated from each other by a non-luminous layer, and he attributed the sunspots to ruptures in these layers. The nuclei formed the body of the sun, which was relatively darker, and visible through the openings in both of these atmospheres; the penumbras were caused, according to Herschel, by the larger rupture in the second luminous layer. Signor Kirchoff does not like the idea of these two atmospheres, and in truth, we have never accepted them either, because they were not necessary, and they were always obliged to rupture together. As a result of our numerous studies, carried out with powerful instruments and with close attention, we concluded that the penumbra was for the most part formed by filamentous currents of the single photosphere that enveloped the sun, or of the same material, rendered so thin that it was transparent. We called attention to the presence of hazes and cirri, lighter than the nuclei, but darker than the penumbras, that were sometimes found within the sunspots; in this we confirmed the discovery of Signor Dawes, who has justifiably complained that until now, no one who studies this phenomena has paid attention to this matter.

Among the issues that have most recently engaged the attention of solar observers is the structure that Signor Nasmyth has called the "willow-leaf" shape. That is, when one observes the sun using reflectors of great size and oculars without darkened lenses,* but in which the light has been weakened, in order to render it tolerable to the eye, by the reflection of a strip of glass, the structure of the sun looks as if it is formed of many elliptical and luminous pieces, elongated in the shape of leaves, and piled one upon the other. They appear more isolated and detached from each other around the penumbras, where they resemble numerous leaves crossing each other, and they are extended in more isolated fashion within the very core of the nucleus.

We have not yet had the opportunity to observe this [willow-leaf] pattern, but we see that even Signor Dawes is in the same circumstances: he finds that the solar structure described by Sir John Herschel, that is, composed of a sort of luminous flakes, is what most closely resembles the appearances observed over the course of many years of research, and in regard to the penumbras, he agrees that there are bright parts, like currents that make their way into the nuclei crossing through the penumbra and retaining all the splendor of the photosphere, and not of the penumbra. This squares with what we ourselves have always observed, and we likewise have always insisted on the three types of substances that are to be seen in each spot: the true nucleus, the penumbra, and the semi-luminous cirri. In order to explain these phenomena, there is no need to rely on two strata of luminous clouds. What suffices, instead, is a simple incandescent photosphere, mixed with less luminous vapors — as one sees in eclipses

**Offuscanti* refer to the dark colored lenses of the type Christoph Scheiner and others put on telescopes if they were observing rather than projecting sunspots.

— in which the ruptures develop, for reasons difficult to ascertain but easy to conjecture, and through which tears one could see the central and less bright part of the star.

But it is precisely this central and darker part that appears a great absurdity to Signor Kirchoff. He asks how it can be maintained that upon contact with such an incandescent body, and under radiation as strong as that of the photosphere, the nucleus itself has not also reached incandescence and fusion. That is [in his view] an absurdity contrary to all the laws of physics. With all the respect that is due to such a distinguished scientist, we believe that this is an exaggeration. First of all, no one has ever said that the nucleus was cold, and if it is dark, it is only in relative terms; Galileo himself said as much in his own epoch, and photography proves the chemical intensity of the nuclei [of sunspots] is so active that in order to obtain an image, one must act instantly, for otherwise the nuclei also are indistinguishable from the photosphere. The difference, therefore, has little to do with their luminosity, and if we were to see one of these nuclei in isolation, perhaps we would hardly be able to distinguish it from an adjacent portion of the sun. Kirchoff relies greatly on the principle that all substances become luminous at the same temperature in order to prove that the core of the sun must be as bright as the photosphere. Here it seems to us that two quite different matters have been conflated: that is, the point at which bodies begin to excite luminous waves capable of being perceptible to the eye, and the fact that all [substances] at the same temperature should be *equally luminous*. We can accept the first of these propositions, and wholly reject the second. In furnaces we see gases of entirely different luminosity from that of solids, and the strongest [hottest] flame that is known — that is, that of the oxyhydrogen blowpipe — is it not one of the least luminous? Thus the conclusion that the parts that form the solar nucleus should be as luminous as the photosphere can hardly be maintained. Nor does it follow that what we call "nucleus" should be either *solid*, or notably less elevated in temperature, but only in a less luminous state; it could even be liquid or gaseous, and only in this state will those lively specific actions that take place in the photosphere fail to occur. The analogy with all planets, as Soret has rightly observed, tells us that the heavier parts should accumulate on the lower stratum, and the lighter ones on the surface, and between these are the gases and the more tenuous materials from whose modifications sunlight is produced. Thus there no longer remains the much-sung absurdity of admitting that beneath the extraordinarily incandescent layer of the photosphere there could be another stratum, perhaps equally warm, but less luminous than it, and that makes itself visible to us when the more incandescent layer of the photosphere itself ruptures.

Moreover, if we reflect carefully, it is not possible to concede an absolute identity in temperature in the various parts of the sun. Indeed, the continuous labor that takes place in that body and the continuous emission of heat suppose that one part must remain in an ongoing state of chemical alteration, and another must be on the verge of entering it; the former might be the photospheric part, and the latter the central and less luminous region, precisely as we observe in ordinary fires. And we would not like to omit the fact that if we were to concede the argument of someone in favor of a sun where all parts are of an equal temperature, that the same could be concluded, following the same logic, about our own furnaces. We are not saying this as if the sun were actually a furnace in which wood were burned; we are saying, rather, that the work itself that takes place to conserve solar activity supposes the existence of some parts that are more intense, and others that are less so. Were this not the case, we would risk regarding the sun as a merely incandescent body, which Thomson has demonstrated could not remain luminous for even a few thousand years.

Treating Wilson's theory as absurd shows that this notion has been confused with that of Herschel, when in fact there is some difference between the two. Wilson said only that the sunspots were cavities, and subsequent observations have verified this *fact*. But no one ever said that these cavities had within them a void, in the rigorous sense of that word; rather, the cirri that can be observed across [the cavities] show that they are full of a less incandescent gas, but that sometimes can be very clearly seen turning in vortices and currents. Now if this is the case, what are these cavities if not simply spaces full of less luminous, and thus less incandescent, material? Signor Kirchoff prefers to imagine them as clouds or rather cooler masses. There is not, in fact, much to distinguish the two hypotheses, finally, provided that the terms are well defined. The difference is further diminished if we see the origin of such clouds that is attributed to vortices and cataclysms, which is the cause that we, too, have often attributed to the origin of the sunspots.

The only point of controversy that remains is to decide if that black [part] that is called the "nucleus" is a part of that general ground that remains beneath the photosphere, or if it was produced by the opacity of a cloud or a cooler mass which prevented the rays from the more luminous part beneath from reaching us.

This issue can only be resolved after scrutiny of the shapes and the phases of the sunspots themselves, and not in *a priori* fashion. Now the study of their shapes does not agree at all with that of clouds as far as we can judge from what happens in our atmosphere and what can reasonably be imagined to take place in an incandescent atmosphere such as that of the sun.

In fact, sunspots present themselves to us from the outset like black pores, in which it would not be difficult to recognize the idea of clouds, but soon enough all analogy vanishes. Because if the pore expands until it has the appearance of a spot, it can be observed that its edges are ragged, and the penumbra is formed *entirely of very fine rays converging towards the middle of the shape*. The nucleus does not always

present the outlines of the penumbra in rigorous fashion, as has been said several times, but rather, a *protruding* angle of the luminous material against the nucleus corresponds to an angle *sloping* into the penumbra, just as would a cascade of material that fell from the walls into the nucleus, which would leave a scarp (*talus*) whose slope would increase as greater amounts of material flowed. These are the phases of all sunspots as long as they are in the first stage, which seems to be that of formation and complete development, after which the phase of dissolution follows.

Thus it is apparent that this first phase cannot show us anything that is similar to what should happen when a cloud forms. The cloud should appear like a less luminous mass, and should be either decisively separated from other warmer ones as are our cumulus clouds, or shaded on the edges like our stratus clouds; that radiating shape and the appearance of currents running into a cavity and forming a distinct scarp will not ever be observed, in any guise, at least in what we can perceive and reasonably conjecture about our clouds. Whatever the theory of sunspots might be, their appearance must first of all be explained, and this appearance has yet to be explained by any theory that compares them to clouds.

When the sunspot has reached its full development, it shows vast black surfaces in which brilliant threads erupt like radiant torrents all around the photosphere, twisting in long contorted lines within the nuclei and breaking, as noted earlier. Now if we were to judge what is happening there on the basis of what happens in our atmosphere, these eruptions of warm masses within cold ones, occurring in such fashion that they remain distinct and constantly separated, cannot be observed by us at all, nor does it appear that they can be formed, because the cloudy opaque mass would either block them from our view, or the mass itself would diminish the light, thus cooling down the torrent that penetrates within [the nuclei] with that linear movement. Now as we have already observed several times, and as Signor Dawes has recently repeated as well (in the latest number of the *Monthly Notices*) the filaments of the photosphere that penetrate into the nuclei maintain an extremely brilliant light, as bright as the photosphere itself. Such a structure for the sunspots hardly confirms the idea of clouds.

When the sunspot is in the last phase of dissolution, the penumbra is less regularly radiated, and it seems formed of the thinnest and most tenuous part of the photosphere itself. In this phase it can be said that it has some analogy with clouds, but a theory, of course, must give an account of all the phases. There is, moreover, a circumstance of which the analogy with clouds explains nothing, and that is the presence of faculae that surround the sunspots.

These faculae are nothing other than the crests of the tempestuous waves excited by the photosphere, waves whose peaks emerge from the denser stratum of the solar atmosphere, as I have shown at length in other publications. They seem in fact formed by the photospheric matter that has been hurled about by the internal force that creates the sunspot. If the sunspot were nothing but a cloudy formation, there would be no explanation for why its contours should be agitated and violently thrown into disarray. Everything indicates that the sunspots are centers in which the temperature is less, and I have demonstrated as much with the thermoscope. But it is also clear that the source of these lacunae is rather an eruption coming from the inside of the nucleus, rather than a simple drop in temperature produced in the photosphere by factors analogous to those in terrestrial meteorology, which would be difficult to imagine in the sun, whereas internal eruptions cannot be avoided in a body placed in such conditions.

But there is something more: Herschel, in order to explain the penumbras proposed two layers to the photosphere, just as Signor Kirchoff proposed two layers of clouds which were always obliged to appear together, the one above the other. These two strata are surely a pure expedient to explain the penumbras, of whose composition we have already spoken, and which can be explained merely by proposing a simple photosphere with those features that are inseparable from fires of this sort. The hypothesis of the clouds has been frequently been raised, but always by those who either have not carried out much solar study, or who have undertaken it with imperfect and mediocre instruments. Thus this hypothesis has always been rejected by those who had at their disposal better means of observation. There is no need of the goal of proposing a less luminous nucleus, nor of that effort (as perhaps has been excessively emphasized) to revive the old fantasies of the habitability of the sun, because if the Creator had wanted to make this star habitable there would have been no need to place men of flesh and blood like us there, as they would be incinerated within a few seconds; nor is there any need to imagine, for that reason, that the black layer is like a tent to shelter such inhabitants from excessive rays. These matters might be useful to amuse the readers of a treatise of Fontenelle or of those who follow in his tracks. We are saying only that without contradicting the laws of physics, first, that the photospheric layer might possess a brilliance greater than that of the internal nucleus; second, that what we call "nucleus" absolutely does not need to be imagined either solid or liquid, but might even be gaseous alone, but more dense; third, that in spite of the proximity of the photospheric layer, it might have not only a different light, but also a different temperature; and fourth, that the appearances of the different shapes of the sunspots absolutely rule out cloud-like structures, and we see nothing in the sunspots that has sufficient analogies with the way in which our clouds are formed, or the changes through which they go.

We wanted, therefore, to say these things less to object to such a distinguished physicist, than to prevent science from taking a retrograde course, especially since history shows that persons of great authority in one branch [of knowledge] often drag along, under the weight of their opinion, those who are less experienced, even in matters where their studies are not

sufficiently deep and where they should not have such influence. We hardly pretend to have given a true theory of the sunspots, but we believe merely, as has been demonstrated, that the notion that they are clouds is surely one of the most infelicitous of hypotheses that can be imagined.

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