

LETTERS TO PROGRESS IN PHYSICS

The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere III. Importance of Continuous Emission Spectra from Flares, Coronal Mass Ejections, Prominences, and Other Coronal Structures

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The solar corona and chromosphere are often marked by eruptive features, such as flares, prominences, loops, and coronal mass ejections, which rise above the photospheric surface. Coronal streamers and plumes can also characterize the outer atmosphere of the Sun. All of these structures, fascinating in their extent and formation, frequently emit continuous spectra and can usually be observed using white-light coronagraphs. This implies, at least in part, that they are comprised of condensed matter. The continuous spectra associated with chromospheric and coronal structures can be viewed as representing the twenty-eighth line of evidence, and the eighth Planckian proof, that the Sun is condensed matter. The existence of such objects also suggests that the density of the solar atmosphere rises to levels well in excess of current estimates put forth by the gaseous models of the Sun. In this work, the densities of planetary atmospheres are examined in order to gain insight relative to the likely densities of the solar chromosphere. Elevated densities in the solar atmosphere are also supported by coronal seismology studies, which can be viewed as constituting the twenty-ninth line of evidence that the Sun is composed of condensed matter.

In order to explain the occurrence of the dark lines in the solar spectrum, we must assume that the solar atmosphere incloses a luminous nucleus, producing a continuous spectrum, the brightness of which exceeds a certain limit. The most probable supposition which can be made respecting the Sun's constitution is, that it consists of a solid or liquid nucleus, heated to a temperature of the brightest whiteness, surrounded by an atmosphere of somewhat lower temperature.

Gustav Robert Kirchhoff, 1862 [1]

Observation of a white-light flare was initially reported by Richard Carrington in 1859 [2]. Though once considered rare events [3,4], the production of such emission has now become associated with many, if not all, flares [5]. It has been well-established that hard X-ray class flares (\geq M5) emit white-light [3]. However, the mechanism for producing this light has remained elusive [6, 7], despite the prevalence of these objects [3–5]. Devoid of condensed matter, a gaseous model has little means to account for the generation of white-light flares. In 2010, Watanabe et al. [8] proposed that the emission generated by white-light flares was associated with electrons accelerated to half of the speed of light [9]. More than 150 years after Carrington's discovery, astrophysicists advanced a scenario through which white-light could be produced within the theoretical constraints imposed by accepting the idea of a gaseous Sun [10–14].

Beyond solar flares, many coronal structures are associated with the emission of white-light. These include prominences and coronal mass ejections [15–23], streamers [24–26], plumes [27], and loops [28–30]. Indeed, coronal structures have long been observed with white-light coronagraphs [25, 26], an instrument invented by Bernard Lyot [31, 32].

The existence of white-light in coronal structures presents a significant problem for the gaseous models of the Sun [10–14]. In these models, white-light at the photosphere is produced by a vast sum of processes (bound-bound, bound-free, free-free, and scattering) taking place within the Sun itself (see [33] for a complete review of this topic). In order to generate the thermal spectrum at the surface, this light must leave the hypothetically gaseous solar body through a photospheric layer regarded as an 'optical illusion' created by a dramatic change in solar opacity [34]. The current solution is so convoluted that it has been described by the author as the Achilles' Heel of gaseous solar models [33]. In no other instance is a simple spectroscopic line, such as the thermal spectrum of the Sun, produced by the extensive summation of vastly unrelated spectroscopic processes [33]. Furthermore, the mechanisms associated with the generation of the solar spectrum are of no value in explaining the thermal emission from graphite on Earth, material from which Planckian radiation was initially studied [33]. As a result, these approaches are not relevant in accounting for the thermal signature of the Sun [33].

The observation of white-light in coronal structures only

acts to accentuate this problem for the gaseous models. These objects are fleeting and devoid of the long time-lines (millions of years) currently required by the gaseous models to produce white-light from the center of the Sun. Moreover, these structures lack the large complement of processes summed within the gaseous models of the Sun to generate the white-light of the photosphere [33]. As a result, though some of the same mechanisms are invoked [3, 4], scientists who adhere to the gaseous models must now have recourse to additional effects: the scattering of photospheric light [16] or the acceleration of electrons to sub-relativistic velocities [8].

In the end, the simplest means of accounting for the presence of white-light, both on the photosphere and within coronal structures, is to recognize that the Sun is comprised of condensed matter [35–37]. The material found on the photosphere is being ejected into the solar atmosphere. Hence, it can be found within the corona. In fact, since photospheric metallic hydrogen has been hypothesized to be metastable (see [35] and references therein), it is reasonable that material ejected into the corona remains partially metallic in nature. In time, sparse filaments of condensed metallic hydrogen might come to constitute the framework for coronal streamers for instance, helping to explain why these objects also emit white-light. As a result, it is now advanced that the white-light emission of coronal structures constitutes the twenty-eighth line of evidence (see [35–39] and references therein for the others), and the eighth Planckian proof, that the Sun is comprised of condensed matter.*

Unlike the gaseous models of the Sun [10–14], the metallic hydrogen model [35–37] advances that the solar body has a nearly uniform density throughout which approaches $\sim 1 \text{ g/cm}^3$ at the level of the photosphere. Thus, the presence of condensed matter, expelled from the photosphere into the chromosphere and corona, strongly suggests that the densities in these regions are not negligible. In sharp contrast, within the context of a gaseous Sun and calculated electron densities, the coronal solar atmosphere is said to possess “*densities which are many trillions times smaller than that of the gas composing the Earth’s atmosphere; in fact, coronal densities are low enough to be considered an almost perfect vacuum in laboratories*” [40, p. 284]. These statements are directly linked to the use of the gaseous equations of state [10, p. 130ff] and the belief that the solar body retains most of its mass in its core [10–12]. As a result, the question must naturally arise as to whether or not trillion fold decreases in densities, relative to the Earthly atmosphere, are reasonable for the solar corona. This is especially concerning relative to the realization that the Sun is expelling condensed matter [35–39] into its outer atmosphere.

*The Planckian proofs are all related to thermal emission in condensed matter. They do not imply that the objects which are the subject of these proof necessarily display a perfect thermal spectrum. The proofs are invoked when the spectrum is continuous and when an object’s emissivity is most simply accounted for by invoking condensed matter.

To get some sense of reasonable densities for the corona, one can have recourse to the characteristic features of planetary atmospheres, with several important cautionary notes. First, the temperatures around the Sun and the inner planets are not at all comparable. Second, the molecular weight of material around the Sun might be either much smaller, or in the case of condensed hydrogen, *much larger*, than found in planetary atmospheres. Thirdly, the solar atmosphere might have substantial local density fluctuations well beyond anything observed in planetary atmospheres. This is especially relevant since condensed matter is being expelled into a partially gaseous solar atmosphere. These factors will impact the comparisons that can be extracted.

Consider the known densities of the Earth’s atmosphere at sea level (1.229 kg/m^3 or 0.0012 g/cm^3 [41]) while taking into account that the Sun/Earth ratio of acceleration due to gravity is a factor of 28 [42]. The simple product of these values (ignoring temperature effects and assuming that the Sun’s atmosphere is composed of particles of the same mean molecular weight as in the Earth’s atmosphere (28.97 g/mole [43])), results in a density of 0.0336 g/cm^3 near the solar surface. This is well above current estimates for the solar atmosphere. In fact, the gaseous models of the Sun predict that, as one proceeds out from the photosphere to the top of the chromosphere, the density drops from $\sim 10^{-7} \text{ g/cm}^3$ to $\sim 10^{-15} \text{ g/cm}^3$, respectively [44, p. 32].

In reality, the aforementioned assumption that the average molecular weight in the lower solar atmosphere is similar to the Earth’s cannot be correct. At the same time, temperature effects should substantially raise the amount of material found in the Sun’s atmosphere. The Sun is known to expel matter into the corona and, if this is condensed matter, may have local densities well beyond that found in the atmosphere of the Earth at sea level. But even this simple calculation, based on the characteristics of the Earth’s atmosphere, points to significant problems with current estimates of chromospheric densities, inferred from gaseous solar model [44] which it exceeds by a factor on the order of 10^5 – 10^{10} . Similar conclusions can be reached by considering Venus [45] or Mars [46].

Though some may dislike such comparisons, as too many variables could alter the final result, the author is not attempting to set a final density for the lower atmosphere of the Sun. The discussion rests simply in highlighting that the currently accepted solar values are well outside the bounds of reason, especially when considering that the Sun is much hotter than the inner planets and constantly expelling matter into its corona. This implies that a much higher average molecular weight for the solar atmosphere can be expected than one based on the atomic weight of hydrogen. Unlike the Sun, the inner planets do not eject much material into their atmospheres. As a result, the atmosphere of the Sun is likely to possess great local variability in its densities. This may also be true when comparing the atmosphere of the quiet Sun near the solar poles with that above the equator, as a result of coro-

nal holes above the former.

Finally, it remains highly significant that, when a comet approaches the Sun, it can result in intense shock wave propagation throughout the corona (e.g. [47]). Such behavior calls for highly elevated atmospheric densities. It is not reasonable to expect that shock waves and seismic activity could propagate within a corona whose density remains inferior to earthly vacuums. As such, seismological findings and shock wave propagation are highly supportive of the realization that the solar chromosphere and corona are much denser than currently surmised from the gaseous models of the Sun. Along these lines, it is concerning that the Sun can be studied using coronal helioseismology [48–51] which suggests a twentieth line of evidence that it is comprised of condensed matter. It is not possible to conduct coronal seismological studies in an atmosphere sparser than the best laboratory vacuums. Seismology is a science which can be applied exclusively to the condensed states of matter.

Dedication

Dedicated to Gregory Gribbon, my longtime Canadian childhood friend, in thanksgiving for his faithfulness and support.

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