LETTERS TO PROGRESS IN PHYSICS

Commentary Relative to the Emission Spectrum of the Solar Atmosphere: Further Evidence for a Distinct Solar Surface

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The chromosphere and corona of the Sun represent tenuous regions which are characterized by numerous optically thin emission lines in the ultraviolet and X-ray bands. When observed from the center of the solar disk outward, these emission lines experience modest brightening as the limb is approached. The intensity of many ultraviolet and X-ray emission lines nearly doubles when observation is extended just beyond the edge of the disk. These findings indicate that the solar body is opaque in this frequency range and that an approximately two fold greater region of the solar atmosphere is being sampled outside the limb. These observations provide strong support for the presence of a distinct solar surface. Therefore, the behavior of the emission lines in this frequency range constitutes the twenty fifth line of evidence that the Sun is comprised of condensed matter.

Every body has a surface.
St. Thomas Aquinas [1]

Observationally, the chromosphere of the Sun represents a rarefied region located immediately above the solar surface [2–5]. In 1877, Father Angelo Secchi described the chromosphere in detail including, most notably, a description of its spicules [6, p. 31-36]. For just a few seconds prior to and following the onset of totality during solar eclipses, the "flash" emission spectrum of the chromosphere can be detected. Typically, such studies focus on the visible and ultraviolet regions of the electromagnetic spectrum.

The existence of the visible "flash" spectrum has been known since the early days of spectral analysis. In fact, the famous D3 line, first observed in a prominence during an eclipse, would lead to the discovery of helium on the Sun by Pierre Jules César Janssen and Joseph Norman Lockyer [7, 8]. Since then, great attention has been given to identifying the lines which are contained within the flash spectrum of the chromosphere, particularly through the efforts of astronomers like John Evershed [9, 10] and Donald Menzel [11, 12]. In 1909, George Ellery Hale and Walter Adams photographed the flash spectrum outside of eclipse conditions, opening up new avenues for the study of the chromosphere [13, 14]. Today, spectroscopic emission lines in the visible spectrum of the chromosphere and corona continue to be relevant and spectacular images of the solar atmosphere have now been obtained using spectroscopic lines from highly ionized iron (e.g. FeX–FeXIV) [15–18].

Photographing the chromosphere is slightly more complex in the ultraviolet range, since UV light is absorbed by the Earth's atmosphere. As a result, that spectral region of the flash spectrum could not be sampled until the launch of scientific rockets after World War II [3, p. 180]. In 1946, while at the U.S. Naval Research Laboratory, Baum, Johnson, Oberly, Rockwood, Strain and Tousey [19] obtained the first measurements of the Sun's ultraviolet spectrum using a V2 rocket. A flurry of activity in this area soon followed [20–25] and the ultraviolet spectrum of the Sun has now become a field of great scientific interest [26–28].

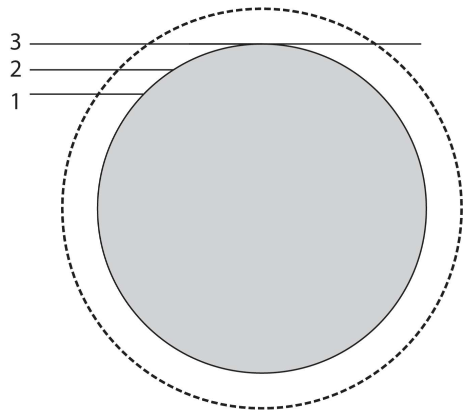

Fig. 1: Schematic representation of path lengths present when the outer atmosphere (area outlined by dashes) of the Sun (body in gray) is viewed from the Earth. Paths 1 and 2 terminate on the solar surface. Just beyond the limb, path 3 samples the front and back side of the solar atmosphere, resulting in a two fold increase in line intensity. This figure is an adaptation based on Fig. 2.4 in [28].

An elementary observation constitutes the focus of this work: the intensity of ultraviolet and X-ray emission lines increases dramatically, as observations are moved from the center of the solar disk to the limb of the Sun. The problem is illustrated in Figure 1. Harold Zirin describes the associated findings as follows: "*The case in the UV is different, because the spectrum lines are optically thin. Therefore one* *would expect limb brightening even in the absence of temperature increase, simply due to the secant increase of path length. Although the intensity doubles at the limb, where we see the back side, the limb brightening inside the limb is minimal . . . Similarly, X-ray images show limb brightening simply due to increased path length.*" [29]. This situation is observed both in the ultraviolet and in the X-ray spectrum of the Sun which sample processes in the chromosphere and the corona [28, p. 38-39]. An exquisite image of this effect has been published [28, p. 38].

Though this simple observation appears almost trivial as a source of scientific comment, it nonetheless demands attention; for it provides strong evidence that the body of the Sun is not gaseous in nature. If the Sun is gaseous, then these effects should not be visible as sampling extends beyond the solar limb. As such, this observation constitutes the twenty fifth line of evidence that the Sun is comprised of condensed matter (see [30–32] and references therein for the others).

Dedication

This work is dedicated to Amir Abduljalil in recognition of his many years of faithful scientific collaboration throughout my career in magnetic resonance imaging, and for his undying service to The Ohio State University relative to the design, assembly, and operation of the world's first ultra high field magnetic resonance imaging system [33].

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