

LETTERS TO PROGRESS IN PHYSICS

The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere II. Continuous Emission and Condensed Matter Within the Corona

Pierre-Marie Robitaille

Department of Radiology, The Ohio State University, 395 W. 12th Ave, Columbus, Ohio 43210, USA.
robitaille.1@osu.edu

The K-corona, a significant portion of the solar atmosphere, displays a continuous spectrum which closely parallels photospheric emission, though without the presence of overlying Fraunhofer lines. The E-corona exists in the same region and is characterized by weak emission lines from highly ionized atoms. For instance, the famous green emission line from coronium (FeXIV) is part of the E-corona. The F-corona exists beyond the K/E-corona and, like the photospheric spectrum, is characterized by Fraunhofer lines. The F-corona represents photospheric light scattered by dust particles in the interplanetary medium. Within the gaseous models of the Sun, the K-corona is viewed as photospheric radiation which has been scattered by relativistic electrons. This scattering is thought to broaden the Fraunhofer lines of the solar spectrum such that they can no longer be detected in the K-corona. Thus, the gaseous models of the Sun account for the appearance of the K-corona by distorting photospheric light, since they are unable to have recourse to condensed matter to directly produce such radiation. Conversely, it is now advanced that the continuous emission of the K-corona and associated emission lines from the E-corona must be interpreted as manifestations of the same phenomenon: condensed matter exists in the corona. It is well-known that the Sun expels large amounts of material from its surface in the form of flares and coronal mass ejections. Given a liquid metallic hydrogen model of the Sun, it is logical to assume that such matter, which exists in the condensed state on the solar surface, continues to manifest its nature once expelled into the corona. Therefore, the continuous spectrum of the K-corona provides the twenty-seventh 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]

Providence has made of the pastoral State of Iowa one of the most important locations in the history of solar physics. From primitive observatories in Des Moines and Burlington respectively, William Harkness and Charles Young monitored the total eclipse of August 7, 1869 [2, 3], an event which still has the power to redefine our understanding of the corona.

From the heart of Iowa, William Harkness “obtained a coronal spectrum that was continuous except for a single bright green line, later known as the coronal line K1474” on the Kirchhoff scale [3, p. 199]. Harkness concluded that the corona was “a highly rarefied self-luminous atmosphere surrounding the Sun, and, perhaps, principally composed of

the incandescent vapor of iron” [3, p. 199]. Eventually, John Evershed provided additional photographic evidence that the corona displayed a continuous spectrum without Fraunhofer lines and he established the wavelength of Harkness’ K1474 coronal line at 5303.3 Å [4]. In addition, Evershed would document the presence of two other coronal spectral lines [2–4]. Today, the gaseous models of the Sun do not support the idea that the corona of the Sun is self-luminous. Rather, it is currently believed that the continuous coronal spectrum arises from the scattering of photospheric light by relativistic electrons in the outer solar atmosphere. In this work, Harkness’ conclusion will be re-evaluated, with the intent of demonstrating that the K-corona is indeed self-luminous, as first postulated in 1869 [3, p. 196–205].

To begin understanding the corona, it is important to properly classify the spectra which it produces. It was the spectrum of the inner corona, or K-corona, which was measured long ago by Harkness, Young, and Evershed [2–4] and which has been the subject of several classic reports [5–10]. For nearly one hundred years, the inner coronal spectrum was known to be polarized [6, 10]. According to Bernard Lyot, this polarization did not extend beyond ~ 6’ from the limb, increased rapidly as observations were made towards the Sun,

and remained constant within $\sim 3'$ of the solar surface [6].* Textbooks now state that the polarized K-corona can extend to distances approaching 10 solar radii ($\sim 160'$) [12, p. 187].

As Gustav Kirchhoff understood [1], Fraunhofer lines are produced when light is absorbed by gaseous atoms located above the level of the solar surface where the continuous photospheric spectrum is emitted. The absorption of light by these atoms superimposes dark lines onto the thermal spectrum of the Sun. As a result, the photospheric spectrum is always characterized by the presence of Fraunhofer lines. Conversely, these dark lines are absent in the continuous spectrum of the inner corona [13–15]. This was certainly the finding which convinced William Harkness that the corona was self-luminous [3]. For if the inner corona was simply scattering light produced by the photosphere, the Fraunhofer lines should be visible. This is the case in the outer corona, or F-corona, where photospheric light is being scattered by dust particles contained in the interplanetary medium [13, p. 33].

Within the gaseous models of the Sun, the absence of Fraunhofer lines in the K-corona is explained by scattering photospheric light with high energy electrons (see e.g. [13, p. 33] and [16]). The corona in these models has no means of directly generating a continuous spectrum. As a result, gaseous models must assume that the continuous component of coronal emission originates at the level of the photosphere. Coronal electrons must then be used to broaden the Fraunhofer lines, making them disappear from the spectrum monitored in the K-corona [13–16].

Oddly, while the gaseous models invoke electron based scattering of Fraunhofer lines, causing them to disappear in the K-corona, scattering by dust particles preserves the lines of the F-corona. The situation is further complicated because the K-corona is in the same physical space as the E-corona, which is producing emission lines, including the coronal line at 5303.3 \AA [13–16]. The Fraunhofer lines are being broadened by electrons in the K-corona, but emission lines from the same region of the solar atmosphere, namely in the E-corona, remain visible and sharp. Presumably, this occurs because only a small fraction of the photospheric light is being scattered. By analogy, only a small fraction of the E-corona should be scattered. Hence, it would not be expected that the emission lines from the E-corona would be affected in a noticeable manner.

The corona is so tenuous, its emission is ~ 1 – 100 million times less intense than that of the photosphere [13, 15]. Still, the continuous nature of its emission, and the absence of Fraunhofer lines in the inner corona has been well documented [2–10].

Speaking of the continuous coronal spectrum, Athay et al. would comment that “*It is well known (Grotrian 1931; Allen 1946) that the coronal continuum is essentially a repro-*

duction of the photospheric continuum and does not change color with height” [9]. Yet, Grotrian’s [5] and Ludendorff’s discovery (see [9]) that “*the color of the corona is the same as that of the Sun*” was not completely supported by Allen [8]. In fact, Athay [9] was misquoting Allen [8]. The latter actually found that “*microphotograms for solar distances varying from $R=1.2s$ to $R=2.6s$ show that the coronal radiation reddens slightly as the distance from the Sun is increased*” [8]. Allen’s measurements had extended farther above the photosphere than those of Crotrian and Ludendorff, helping to explain why his predecessors had not reported reddening [8, p. 140].

Reddening of the continuous spectrum implied that the corona was cooling when one moved away from the solar surface, as would be expected. The presence of emission lines from highly ionized atoms in the E-corona appeared to be making the opposite point, the corona seemed to be much warmer than the photosphere. This issue will be addressed in detail in a separate treatment [17]. For the time being, suffice it to emphasize that the K-corona possesses a continuous spectrum which appears to be blackbody in nature and which reddens slightly with distance from the solar surface.

In the end, the simplest means of accounting for the continuous emission observed in the K-corona, the absence of overlying Fraunhofer lines, and the presence of sharp emission lines in this same region of the solar atmosphere, is to invoke a condensed matter model of the Sun [18–20]. In 1869, William Harkness had concluded that the corona was self-luminous, precisely as expected should this layer possess condensed matter.

In this regard, when the Sun is active, it is known to expel enormous amounts of material into its corona in the form of flares and coronal mass ejections. Within the liquid metallic hydrogen model of the Sun [18–20], the presence of condensed matter within the corona and the existence of an associated continuous spectrum presents little difficulty, as metallic hydrogen has already been hypothesized to be metastable (see [17] for a detailed discussion). As a result, once condensed metallic hydrogen has been produced in the solar interior, it is expected that it could retain its condensed state under the lower pressures in the corona.

The presence of condensed matter in the K-corona immediately accounts for the existence of a continuous spectrum from this region of the solar atmosphere.

At the same time, the Fraunhofer lines are not visible because insufficient levels of gaseous atoms are present in the K-corona to significantly absorb coronal radiation. Therefore, scattering by relativistic electrons does not need to be invoked to account for the presence of a continuous spectrum in the K-corona devoid of Fraunhofer lines. Conversely, the F-corona is indeed produced by the scattering of photospheric light by dust particles in interplanetary space.

As such, the continuous spectrum of the K-corona can be said to represent the twenty-seventh line of evidence that

*When visualized from the Earth, the solar diameter corresponds to $\sim 32'$ or $\sim 1920''$ [11]. One arc-second, ($''$), corresponds to ~ 700 km on the Sun [12, p. 123].

the Sun is condensed matter and the seventh Planckian proof (see [21, 22] and references therein for the others).

Dedication

Dedicated to Thomas Kerner Helgeson and Barbara Anne Helgeson who have shown the author, and provided him with, the very best from Iowa.

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