Solar Images Taken with Calcium K-Line Filters

Howard L. Cohen
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Howard Eskildsen's beautiful images of the Sun uploaded to the AAC website may appear strange and unfamiliar to those used to observing the Sun in "white light." Don't know why? This article may help

Howard Eskildsen often uploads some of his wonderful and exquisite solar images to the Alachua Astronomy Club's website as he did at the beginning of 2014 January. However, these images may appear alien compared with pictures we often associate with the Sun. (See Howard's images at **http://tiny.cc/vs0f9w**.)

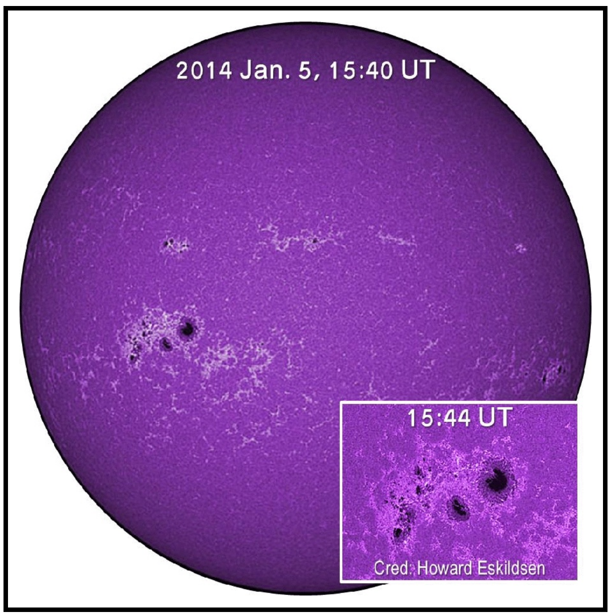

Fig. 1. Ca II K-Line Photograph of Sun's Chromosphere. Residual light within the solar calcium K-spectral line of ionized calcium was used to make this photograph (Lunt B600 filter). See text for further explanation. At the beginning of 2014 January a major active region appeared. Enlarged inset shows this active sunspot region. (Photo Credit: Howard Eskildsen.)

For example, Howard's recent pictures taken in early January 2014 show whole disk images of the Sun including enlargements of a currently active region. In fact, these photographs show one of the largest sunspot groups of the current solar cycle! **(See Figure 1.)**

But, some viewers may wonder why the images are not only violet in color but also display structures not usually or easily seen when observing the Sun with traditional "white light" (or *continuum*) solar filters—filters that transmit light over broad sections of the visible light spectrum.

For those interested in knowing more about these images, the following gives a summary about the nature of these photos.

Although some of this material may appear semi-technical, most readers should still glean a better understanding of what these pictures represent and convey.

The Calcium K-Line Filter

Howard took these images using a special ionized calcium K-line filter. The central wavelength of this special filter is 393.4 nm, the fundamental wavelength of the calcium K-line (abbreviated **Ca II K-line**). Unlike filters that transmit light over a wide range of wavelengths ("broad band" filters), this filter is a "narrow band" filter that transmits light over a very narrow range of wavelengths, typically less than a few tenths of a nanometer. (A nm is an abbreviation for a *nanometer*, or one billionth of a meter.)

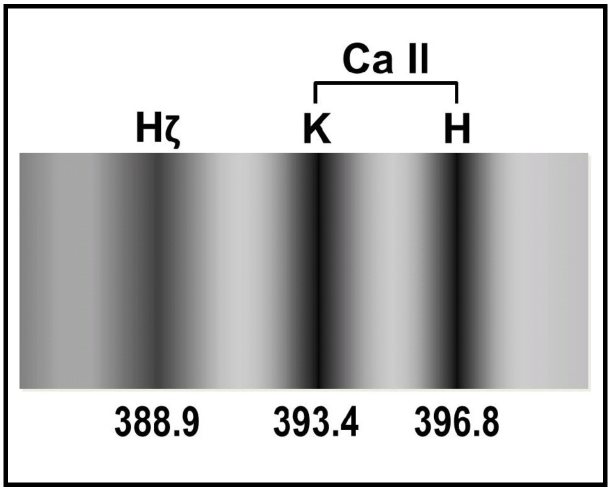

Fig. 2. The H and K lines of Ca II (ionized calcium) in the Solar Spectrum. This *simulated* section of the solar spectrum shows the H and K Ca II dark (absorption) lines. Hζ is a hydrogen absorption line (designated by the Greek letter *zeta*). These two Ca II lines are the strongest absorption lines in the visible solar spectrum. However, the Ca II H-line can blend with a line due to another hydrogen line (hydrogen *epsilon* or Hε) not shown in this simulated image. Wavelengths below each dark line are in nanometers. Note: Stellar spectra are not usually imaged in color but in monochrome for better sensitivity and resolution. (Figure by H.L. Cohen.)

At this wavelength in the solar spectrum, *singly ionized calcium* in the lower solar atmosphere or *chromosphere* strongly absorbs light. This absorption causes the spectrum to darken over a small range of wavelengths (several tenths of a nanometer). **See Figure 2** and following pages for more about ionized calcium.

Using residual light in this narrow range of wavelengths to photograph the Sun effectively produces an image of the *chromosphere* (or “color sphere”). These images are therefore different from more familiar “white light” images—images that show the Sun’s visible surface or *photosphere* (“light sphere”).

So, white light images use light over a wide or broad range of wavelengths in the visible spectrum (e.g., orange light) to allow observers to view or image the Sun. This, therefore, is in contrast to chromospheric images that use a very narrow, special range of wavelengths.

Note: *Hydrogen alpha filters,* centered on the **Hα-line** at 656.3 nm (in red part of the spectrum) are also often used to image the solar chromosphere. Calcium and hydrogen narrow band filters are more expensive to make than the more commonly known and used broad band filters that produce more “normal looking” views of the Sun.

The Chromosphere

This gaseous material is the almost transparent lower atmosphere of the Sun just above the *photosphere* or “light sphere” (the visible disk of the Sun). The chromosphere also lies below the outer solar *corona* (“crown”), the exquisite halo seen during total solar eclipses.

Although the temperature of the chromosphere is actually many times hotter than the photosphere, the density of the chromosphere is so low that chromospheric light is very weak and normally invisible to the eye except possibly during total solar eclipses.

During totality, the chromosphere can appear as a narrow, reddish or pinkish band of light around the edge of the eclipsing moon. (From this appearance comes the name “color sphere.”)

The Solar Spectrum

The solar spectrum visible to the human eye covers a wavelength *range* of about 310 nm (from 390 to 700 nm). The human eye sees the short wavelength end as deep violet, the long wavelength end as red.

The solar spectrum is most intense in yellow-greenish wavelengths, in the wavelength region where the eye is most sensitive. When we view all visible wavelengths together, this light blends and we see the Sun as a whitish (not greenish or yellowish) star.

Thus, the K-line falls near the limit of sensitivity of the human eye to very short visible light wavelengths, at the border between deep violet and ultraviolet radiation. Some call this the "near ultraviolet," a part of the light spectrum, which is difficult for the human eye to see. In fact, solar features that show up in Ca II K-line *images* are generally invisible to the human eye!

Ca II K-line filters use the *remaining light not absorbed* at the position of the K-line to produce Ca II K-line images of the Sun.

That is, this dark absorption line is not completely dark or "black." Instead, residual amounts of energy in this line passes through the K-line filter to produce an image of the solar chromosphere.

Calcium K-Line Images are Sometimes False Colored

The Ca II K-line thus falls at the extreme short wavelength end of the visible spectrum (very deep violet). However, sensors used to record the Ca II K-line images are often *monochrome* to produce higher detail with more sensitivity.

In these instances, a "false color" is sometimes used to render the monochrome image violet or blue. This helps remind viewers that light from within the Ca II K-line, in the near ultra violet part of the spectrum, produced these images.

Singly Ionized Calcium in Solar and Stellar Spectra

Calcium is a common chemical element in the Earth's crust (fifth most abundant by mass). Nevertheless, calcium in the atmospheres of stars is not only rare but often partially *ionized* one or more times. *Singly ionized calcium* is a form of calcium (an "ion") and has one of its twenty electrons missing.

In astronomy, this ion of *singly ionized calcium* is designated "calcium two" or **Ca II**. (Ca I is *neutral calcium* containing all of its twenty electrons and is electrically neutral while Ca III is *doubly ionized calcium* with two electrons missing.)

Spectrometers that produce *spectra* of the Sun often use a narrow entrance slit to allow sunlight to enter the instrument. (A *spectrum* orders radiant energy, such as light, according to the changing wavelengths of the radiation.) This technique produces a spectrum showing a dark line, called the Ca II K-line, at the position of the calcium absorption in the spectrum. **(See Figure 2 again.)**

Another Ionized Calcium Line: The Ca II H-Line

A second dark line, the **Ca II H-line,** also occurs at a slightly longer wavelength at 396.8 nm. Astronomers have traditionally used the Ca II H-line less due to possible contamination from a nearly overlapping absorption line from neutral hydrogen (**H-epsilon** or **Hε** at 397.0 nm). However, high resolution spectra can help avoid this problem.

Be careful not to confuse the calcium H-line (Ca II H) with hydrogen lines which also use the letter "H" with Geek letters (Hα, Hβ, Hγ, etc.) to designate various lines of hydrogen.

The H and K spectral lines (and others) are named after the German physicist, Joseph von Fraunhofer (1787–1826), who studied the solar spectrum.

Ionized Calcium, a Principal Spectral Features of the Solar Spectrum

Did you know Ca II H and K-lines are principal spectral features of cooler stars such as the Sun?

In fact, the Ca II H and K-lines are the strongest absorption lines in the visible solar spectrum!

Yes, hydrogen is overwhelming more abundant in the Sun (75% by mass) than calcium (possibly less than 0.01% by mass). Nevertheless, temperatures in the solar atmosphere are too cool for the abundant hydrogen to absorb enough light to produce dark spectral lines. However, these cooler solar temperatures are ideal for the formation of strong H and K-lines of ionized calcium though calcium is a rare solar element.

In stars with atmospheres both cooler and hotter than the Sun, singly ionized calcium lines become weaker. In very hot stars these stellar lines disappear since these higher temperatures cause singly ionized calcium to ionize further. And, in cooler stars than the Sun, less calcium becomes ionized so the lines of Ca II also begin to weaken.

Interstellar Calcium

Did you know that some hot stars, which should be too hot to show absorption lines of Ca II, surprise us by showing weak Ca II lines? These lines are often narrower than other stellar spectral lines. In addition, these lines may also not share the same *Doppler shift* displacement with other spectral lines, lines displaced in wavelength due to the star's motion in space. **See Figure 3.**

Historically, the presence of these narrow spectral lines puzzled astronomers.

However, we now recognize these Ca II lines are *interstellar.* They are due to absorption of light, not by the star's atmosphere, but by rarefied ionized calcium in the interstellar medium between the star and Earth! Therefore, these lines are not subject to the line broadening effects of stellar atmospheres and need not share in the star's space motion.

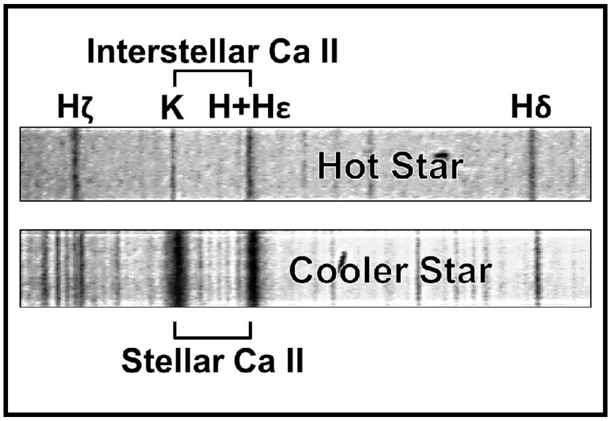

Fig. 3. Interstellar Ca II in the Spectrum of a Hot Star. The *interstellar medium* rather than absorption by the star's atmosphere produced the Ca II K and H-Lines in this spectrum of a hot star, HD190967 (top). These *interstellar lines* are often narrower than its stellar spectral lines. (However, the Ca II H-line sometimes blends with the hydrogen Hε line making it broader.) Compare these two interstellar lines with the stellar Ca II lines in a much cooler star's spectrum, HD187691 (bottom). This figure also labels two lines produced by stellar hydrogen, Hδ and Hζ. (Be careful not to confuse these two hydrogen lines with the Ca II H-line.) Notice the stellar Ca II lines in the cooler star (bottom) are much stronger than this star's hydrogen lines, Hδ and Hζ although the star's atmosphere has little calcium. (Photo Credit: H.L. Cohen.)

Images of the Solar Chromosphere

So, Ca II images of the Sun are inherently pictures of the absorbing chromospheric gas, that is, the lower solar atmosphere—the solar *chromosphere*. These lines of ionized calcium are among the most sensitive indicators of the chromospheric structure of the Sun. They provide information on the shape and vertical height of solar atmospheric structures. They are also important tools for understanding the atmospheres of the cooler stars including the Sun.

The K-line is also sensitive to magnetic fields in the solar chromosphere. This material produces less absorption of light if magnetic fields are strong allowing regions to appear lighter than areas with weaker magnetic fields.

However, sunspots, which have strong magnetic activity, still appear dark, as also seen in usual white light photography, being cooler than surrounding surface areas. Theory suggests that very strong, localized magnetic fields inhibit hot gases from rising. This causes cooler regions to form—sunspots. So, the absence of radiant emission from the underlying surface still causes chromospheric sunspot regions to appear dark at sunspot locations compared to surrounding areas.

Therefore, Ca II images show magnetic solar structures not easily seen in white light images. Some visible features include *plages, pores, supergranulation cells* and *chromospheric networks.*

Summary of Some Solar Chromospheric Features

Faculae, also sometimes seen faintly in white light images (especially near the solar limb as in **Figure 4** on next page), are brighter regions in chromospheric pictures. Faculae result from concentrations of magnetic field lines between *solar granules* (solar convection cells).

Chromospheric plages (also called *floccule*) are extensions of photospheric faculae into the chromosphere above. They are also bright areas within solar active regions associated with sunspot activity. They can often help predict future occurrences of sunspot formation.

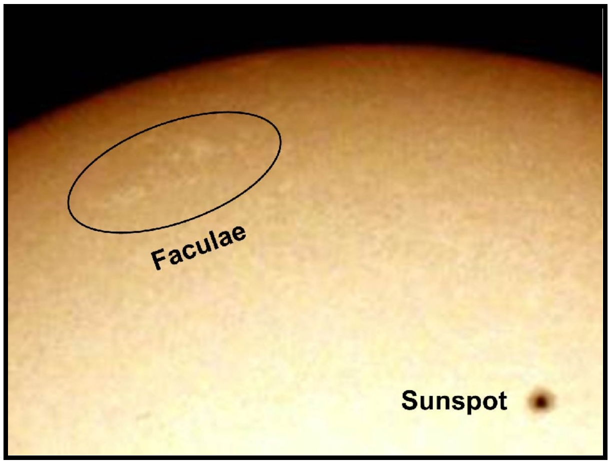

Fig. 4. Faculae in White Light Images. Broad band filters easily show sunspots (bottom right) on the solar photosphere. However, even this type of "white light" image sometimes reveals faint faculae against the slightly darker solar limb. Can you see them at the upper left? (The orangey color of this photograph results from the use of a filter that primarily transmits only orange light.) Nevertheless, chromospheric images can reveal much more as in Figure 1. (Photo Credit: H.L. Cohen.)

Solar pores are small sunspots that are forming although they may never develop further.

Supergranulation cells are larger regions than individual *granules* that have convective horizontal flows. Solar granulation gives the Sun a grainy appearance and result from convection currents—tops of granules are bright where hot ionized gas (a *plasma*) rises while edges of granules are dark where gas cools and descends.

Chromospheric networks have web-like appearances and develop from solar material with embedded magnetic fields flowing radially outward and down toward outer boundaries.

Study Howard Eskildsen's photos on the Alachua Astronomy Club's website and see if you can find some of these solar chromospheric features. ¤

Howard L. Cohen *(not to be confused with Howard Eskildsen) is an emeritus professor in the University of Florida's Department of Astronomy and a founding member of the Alachua Astronomy Club, Inc.*