The Yellow Sun Paradox

Stephen R. Wilk

There are a few things you can count on in this world: The sky is blue; grass is green; and the sun is yellow…right?

Nicolas Raymond

Though I am old with wandering
Through hollow lands and hilly lands,
I will find out where she has gone,
And kiss her lips and take her hands;
And walk among long dappled grass,
And pluck till time and times are done
The silver apples of the moon,
The golden apples of the sun.

— The last verse of *The Song of Wandering Aengus* by William Butler Yeats (1865-1939)

If you ask preschool children to draw the sun, they'll make a yellow circle, often with visible rays emanating from it (and maybe a smiling face). The "gold ball" in the story *The Princess and the Frog* represents the Sun, says mythologist Joseph Campbell, because gold is the solar metal. Egyptian, Celtic, Chinese and Aztec representations of the sun are made of gold as well. And if you ask an average person on the street what color the sun is, he or she would say it was yellow.

And yet the sun is *not* yellow. In fact, sunlight is the very definition of white light. If the sun were truly yellow, the colors of everything we see would be subtly altered. As anyone who works in a lithographic facility knows, working under truly yellow light can be unnerving. The CIE coordinates of the standard illuminants all lie close to (0.3, 0.3), the white locus of the color diagram.

So the sun is undoubtedly white, yet everyone seems to perceive it as yellow. What gives? Phil Plait, who manages the Web site "The Bad Astronomer" (on which he exposes examples of bad astronomy), has put forth some possible explanations for why people perceive the sun as yellow.

One is that the same Rayleigh scattering that is responsible for the sky's blueness also makes the sun appear yellow, since some of the blue has been scattered out. (This is the most common suggestion I hear when I mention the paradox to people.) But the amount of blue light scattered out is far too small to have a noticeable effect on the sun's color. The CIE standard illuminants already have the effects of scattering built into them, and they predict a white sun.

A second suggestion is that the sun seems yellow because we are comparing it to a blue sky. Perception studies show that the background can affect the color we perceive. But, as Plait points out, if white objects appeared yellow in the sky, then clouds would seem yellow, and they're not.

A third possibility is that yellow is the most accurate representation of the sun's color when it is low in the sky—the only time we can look at it without hurting our eyes. When the sun is high, it's too bright to look at. As it approaches the horizon, more of its light gets scattered away by the atmosphere, so you can glance at it more easily. The sun's color changes because of that scattering: It goes from yellowish to orange to red and finally magenta. Plait finds this claim interesting but he has some doubts. He remembers the sun most when it is glowing magenta on the horizon, yet on the whole he does not perceive it as red.

To get to the bottom of this, I modeled the passage of light from the sun through an atmosphere that scattered according to a strict Rayleigh scatter $1/\lambda^4$ law. I assumed Illuminant D65 (noon daylight), a scattering cross-section that depends upon the inverse fourth power of the wavelength (and a loss exponential in the product of this cross-section times the optical path length, multiplied

by a constant), and the usual three standard color functions. I then calculated the CIE chromaticity coordinates (x,y) in the usual fashion by numerical integration of the product of the illuminant, scattering function and color over wavelength space, then normalizing the chromaticity coordinates X, Y and Z.

The results were interesting. The starting point, with negligible scatter, was the Illuminant D65 "white point" of (0.313, 0.329). However, as soon as the path lengthened, the trajectory of the locus of the apparent sun color started moving directly toward the spectral locus at about 570 nm, which is about as yellow as you can get. It continued toward this point for some time before veering off slowly toward 580 nm, which is still well within what is generally termed "yellow." Then it gradually turned orange and then red, and asymptotically approached the deep red terminus of the spectral locus.

Its trajectory superficially resembles the Planckian locus, representing the perceived color of a blackbody radiator as it cools—but the differences are significant. The blackbody starts not at the white center, but at the limiting point of (0.328, 0.502), at the light-blue color of blue heat. It then arcs across, skirting the edge of the white region at about 6,000 K before cutting across the yellow range, between about 4,000 K and 2,500 K, and asymptotically approaching the red end of the spectral locus. The difference is that the Planckian locus curve starts in the blue and spends much less of its length in the yellow portion of the color diagram.

So, until the sun gets very low in the sky and starts to change from orange to red, it spends all of its time as either white or yellow. As soon as it is attenuated enough to look at even fleetingly, it appears yellow, and it remains this way until it rapidly begins to change color at sunset.

It's not just coincidental that the sun appears mostly yellow—this color is the complement of the blue sky. On the chromaticity diagram, it is diametrically opposite the blue sky locus, which this calculation sets at (0.2279, 0.2312) in the limit of small amounts of scatter. The chromaticity coordinates of the blue sky change very slowly with increased scatter distance, ultimately moving toward the white locus as the scattering length approaches infinity. When you subtract this blue from the white, you get yellow as a residue. So, in essence, each of the possible explanations put forth by Plait are, in a sense, correct.

As soon as the sun is attenuated enough to look at even fleetingly, it appears yellow, and it remains this way until it rapidly begins to change color at sunset.

Another possible reason for why we view the sun as yellow could arise from our ancestors. Early humans would naturally view the sun as a "fire in the sky," since they were accustomed to using fire to warm themselves and prepare food. They would believe the sun to be yellow-orange—the most prominent color in flames consisting of soot heated by combustion. And their experience would confirm this belief; they would see a yellow sun in the sky—as soon as it was dim enough to be viewed directly.

Stephen R. Wilk (swilk@comcast.net) is an optical engineer based in Saugus, Mass., U.S.A.

References and Resources

>> F. Birren. *The Story of Color: from Ancient Mysticism to Modern Science*, Crimson Press, Westport, Conn., U.S.A. (1941).

>> M.N. Perrin. "Calibrating the Color Temperature Relation: The B-V Color of the Sun," Annales de Physique **6** (1-2), 115-20 (1981).

>> P.C. Plait. *Misconceptions and Misuses Revealed, from Astrology to the Moon Landing "Hoax,"* Wiley and Sons. (2002). Also see his Web site at http://blogs.discovermagazine.com/badastronomy/.

>> The Munsell Color Laboratory Resources Page: www.cis.rit.edu/mcsl/online/cie.php.