Read + highlight to answer conclusion.

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Star Light, Star White: Stars of Many Colors

On a clear night, one of my favorite activities is to haul out my telescope and simply look at stuff in the sky. Usually, I have the 'scope set up in my yard, somewhere out of the way of trees, streetlights, and other obstacles. Still, a neighbor always manages to see me and drops by to take a peek.

The last time this happened, my neighbor brought her two school-age kids. They were being home-schooled and needed a science credit. She figured a night outside with a telescope would count.

After we looked at the Moon, Saturn, Jupiter, and a few other showpieces, the kids wanted to see a star through the telescope. I cautioned them that the stars would just look like points of light, and not disks. No ordinary telescope can magnify images that much. Then I turned the 'scope to Vega, one of the brightest stars in the sky. Without saying anything else, I let them take a look.

The gasps of delight were wonderful. "It's like a gem!" one of them breathed. "I can't believe how blue it is!"

I expected that reaction. My neighbor's daughter looked away from the 'scope and I pointed out Vega to her in the sky. She looked at it for a moment, and then said, "I didn't know stars really had color. I thought they were all white."

I expected that, too. I hear it a lot. Despite this common belief, stars *do* have color, and some are quite beautifully hued. Most look white because of our eyes; the fault lies with us and not the stars.

Amazingly, immense objects like stars emit colors because of the tiniest things of all: atoms.

Stars are basically giant balls of gas. Near the center, the immense pressure of the outer layers squeezes the atoms of gas together. When you squeeze something, it gets hot. The pressure is so high in the centers of stars like the Sun that the temperature can reach millions of degrees. At temperatures this high, the nuclei of atoms—their centers, composed of positively charged protons and neutral neutrons—smash into each other and stick together in a process called **nuclear fusion.** This process releases energy in the form of very energetic light called gamma rays.

Light acts like a messenger, transferring energy from one place to another; in this sense, light and energy are the same thing. The gamma rays don't get far before getting absorbed by another nucleus. They are promptly re-emitted, move out again, and get reabsorbed. This process happens over and over, countless trillions of times, and the energy of fusion in the center of the star works its way out to the surface.

When a gamma ray smacks into a subatomic particle, the particle increases its energy. In other words, it gets hot. Near the core the temperature can be millions of degrees, but the temperature drops with distance from the core. Eventually, near the surface of the star, the temperature is a comparatively chilly few thousand degrees Celsius (compare that to room temperature here on Earth, which is about 22 degrees Celsius).

This temperature is still more than enough to strip electrons from their parent atoms. All these particles near the Sun's surface are zipping around, bumping into each other, absorbing and emitting energy in the form of light. For a long time, it was a major problem in physics to figure out just how the Sun emitted this light. Around the year 1900, Max Planck, a German physicist, imagined that the particles in the Sun were like little oscillators, little vibrating springs. The mathematics of how oscillators give off energy is well understood, so he had grand hopes of figuring out how the Sun emits light.

But he couldn't get it to work. He assumed that the light was emitted in the form of a wave, and that each particle gave off a certain color of light. According to the physics of the time, any particle could emit any amount of energy it wanted. Planck, however, saw that this didn't really represent how a star emits light. He solved the problem by restricting the amount of energy each particle could produce. He realized that the emitted energy was *quantized,* meaning that the particles could only produce energy in even multiples of some unit. In other words, a star could give off 2 units of energy (whatever those units may be), or 3 or 4, but not 2.5, or 3.1. It had to be an integer, a whole number.

This was rather distasteful to Planck, who had no prior reason to assume this would be true. For centuries physicists assumed that energy flowed continuously, and not in tidy little bundles. Planck's model of quantized energy was flying in the face of all that. However, his model fit the data a lot better. He saw that it made the math work, so he published it.

This was how quantum mechanics was born.

Planck was right; light does come in a sort of minimum-energy packet. We call it a **photon.** Einstein used this idea in a paper about how light can eject electrons from metals, and he called it the **photoelectric effect.** Nowadays we use this effect to make solar panels, which provide power to devices from cheap calculators to the Hubble Space Telescope. Despite common belief, Einstein won his Nobel prize for this work and not his more celebrated work on relativity.

When Planck made his assumption about quantized energy, he found an interesting thing: the amount and color of the light a star emits depends on its temperature. If two stars were the same size, he determined, the hotter one would emit more light, and that light would be bluer than from the cooler star. Blue photons have more energy than red ones, and so a hotter star, with more energy, makes more energetic photons. A star at a certain temperature emits light at *all* different colors, but it emits most of its light at *one* specific color.

What this means is that a cool star, say around 2,500 degrees Celsius, emits its peak light in the red. A hotter star, near 6,000 degrees Celsius, peaks in the green. If the star gets even hotter, it emits mostly blue. Past that, the peak actually can occur in ultraviolet light, invisible to the naked eye.

That's the first key: the color of a star depends on its temperature. So, by measuring a star's color we can determine that temperature. The math for this is so well understood, as a matter of fact, that if we measure the amount of light a star gives off we can also determine how big it is. Amazingly, we can take a star's temperature and measure its girth just by looking at it! That's quite a feat given that the nearest star besides the Sun is 40 trillion kilometers (25 trillion miles) away.

However, just because a star's light peaks at a certain color doesn't mean it *looks* like it's that color. As an example, I give you the Sun: its color peak is actually in the green part of the spectrum, yet it looks white to us (go back and read chapter 4, "Blue Skies Smiling at Me," for more about our white Sun). The Sun gives off light at the blue and red ends of the spectrum as well, and it's the mix of all these colors that counts. Think of it this way: if I bake a batch of chocolate chip cookies, I put in more flour than anything else. Yet the cookies don't taste just like flour; they are a mix of all the other flavors, too. So it is with stars; the Sun emits more green light than any other one color, but it's the mix that makes the Sun white.

An interesting, and ironic, side note is that there are no intrinsically green stars. No matter what temperature a star is, the mixing of the colors guarantees that the overall color is not green. There are a couple of stars usually described as green by astronomers, but these are in binary systems; that is, they are very near another star. Usually, the other star is reddish or orange, and that can make something that is actually white look green in contrast. I have seen this myself; it's really weird to see a star glow green near its ruddy companion.

So if stars are all these different colors, why do most of them look white?

Look again. Which stars looks white? If you start with the brightest stars in the sky, you may notice a clue: many of the brightest stars are blue-white or red. Sirius, the brightest star in the nighttime sky, is bluish. If you can see Sirius then perhaps Betelgeuse is also up, and it is quite orange. Antares, the heart of the constellation Scorpius, is rusty red. The name Antares means "rival of Mars" because their colors are so similar.

But as you go down the list, you'll notice that stars seem to lose their color as they get dimmer. Eventually, at some minimum brightness, all fainter stars look white. Clearly this is not something intrinsic to the stars, but to something inside of us.

That something is the construction of our eyes. We have two different kinds of cells in our retinae that detect light. **Rods** are cells that can determine the intensity, or brightness, of the light entering our eyes. **Cones** are cells that differentiate colors. (I used to get them mixed up, but now I think that *co*nes see *co*lors, which makes it easier). Rods are very sensitive and can even detect single photons if conditions are right. Cones, on the other hand, are just a tad dim of vision. They need to see lots of light before they can figure out what color it is. So, while a dim star may be bright enough for your rods to detect, allowing you to see the star, it may not be bright enough to trip your cones, and so you see no color. The star simply looks white. The star itself may be blue or orange or yellow, but there simply isn't enough light hitting your cones for them to figure out what's what.

That's a benefit of using telescopes of which many folks aren't aware. A telescope is more than an instrument used to magnify distant objects. A telescope collects light like a bucket collects rain. The bigger the bucket, the more rain you can collect. The bigger the telescope, the more *light* you collect. That light is redirected and focused into your eye, so even a faint star looks much brighter. Some stars that look white to the naked eye can be seen in their true color when viewed with a telescope. Even better, bright stars look even more colorful.

That's why the star Vega looked like a jewel to my astonished neighbor. Vega is the fourth-brightest star in the night sky, and it is one of the few to show color to the unaided eye. Take a peek through a telescope, though, and you see it in all its sapphire glory.

This brings me to a final thought. I love taking out my own telescope any old time, but the best night of all to do this is Halloween, when there are lots of kids around. Every year, my wife Marcella takes Zoe, our daughter, down the street trick-or-treating while I stay home. That way I can not only give out candy but also show the kids Jupiter or Saturn through the 'scope. Most of them have never looked through a real telescope before, and it's pretty nice to hear them exclaiming out loud when they see Saturn's rings.

I used to live in a fairly tough neighborhood, and some of the kids trick-or-treating looked like they were what teachers call high risk—prone to all sorts of problems, the least of which was dropping out of school. Yet these kids were the ones most likely to be shocked when they looked through my telescope and saw the moons of Jupiter. They would say, "Neat," or "Tough," or "Tight," or whatever the current jargon is for saying, "Wow!" Their cool exteriors were momentarily dropped when shown what the universe looks like up close.

A lot of people say that the current generation of children is bored and jaded. I heartily recommend that these people stop by an amateur astronomer's house some October 31. Maybe they'll see just how wrong they are.