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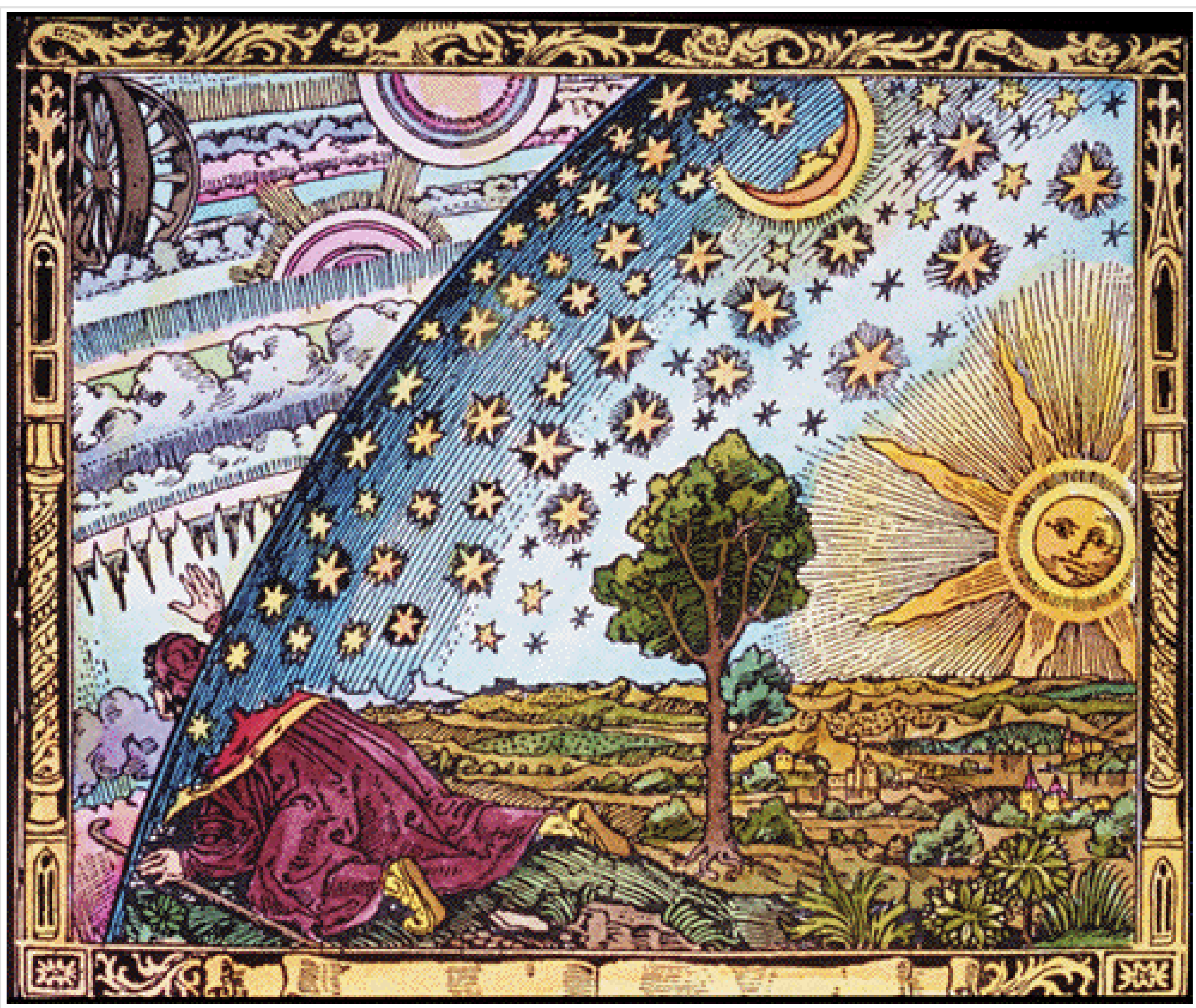
Stellar luminosity: The true brightnesses of stars

by Bruce Mcclure • 3 min read • original

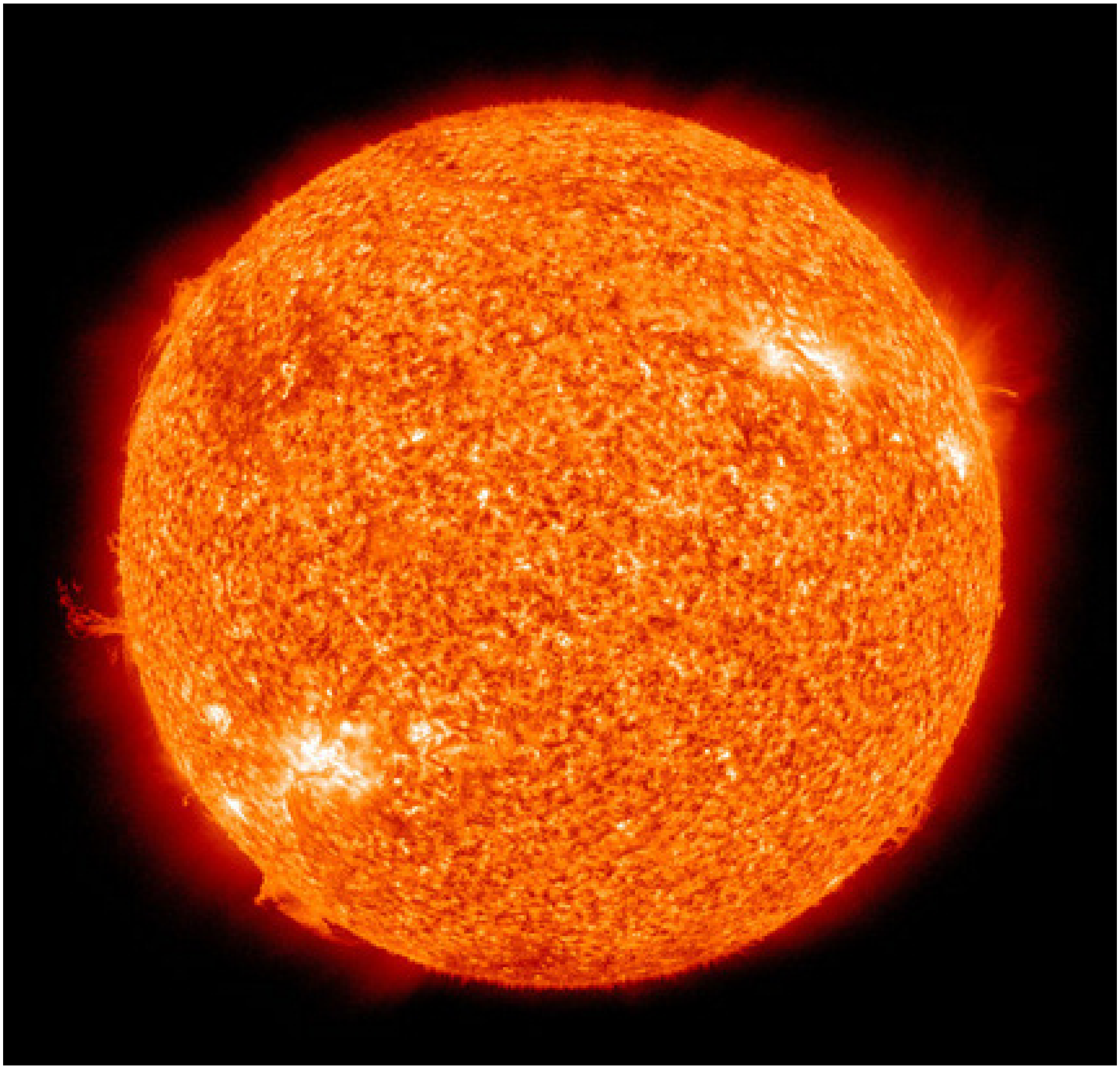


This Renaissance woodcut is called Empedocles Breaks through the Crystal Spheres.

The ancient astronomers believed the stars were attached to a gigantic crystal sphere surrounding Earth. In that scenario, all stars were located at the same distance from Earth, and so, to the ancients, the brightness or dimness of stars depended only on the stars themselves.

In our cosmology, the stars we see with the eye alone on a dark night are located at very different distances from us, from several light-years to over 1,000 light-years. Telescopes show the light of stars millions or billions of light-years away.

Thus today when we talk about a star's brightness, we might mean one of two things: its *intrinsic* brightness or its *apparent* brightness. When astronomers speak of the *luminosity* of a star, they're speaking of a star's *intrinsic brightness*, how bright it really is. A star's *apparent magnitude* – its brightness as it appears from Earth – is something different and depends on how far away we are from that star.



Astronomers often list the luminosity of stars in terms of solar luminosity. The sun has a radius of about 696,000 kilometers, and a surface temperature of about 5800 Kelvin, or 5800 degrees above absolute zero. Freezing point of water = 273 Kelvin = O^{0} Celsius

For instance, nearly every star that you see with the unaided eye is larger and more luminous than our sun. The vast majority of stars that we see at night with the eye alone are millions – even hundreds of millions – of times farther away than the sun. Regardless, these distant suns can be seen from Earth because they are hundreds or thousands of times more luminous than our local star.

That's not to say that our sun is a lightweight among stars. In fact, the sun is thought to be more luminous than 85% of the stars in our Milky Way galaxy. Yet most of these less luminous stars are too small and faint to see without an optical aid.

A star's luminosity depends on two things:

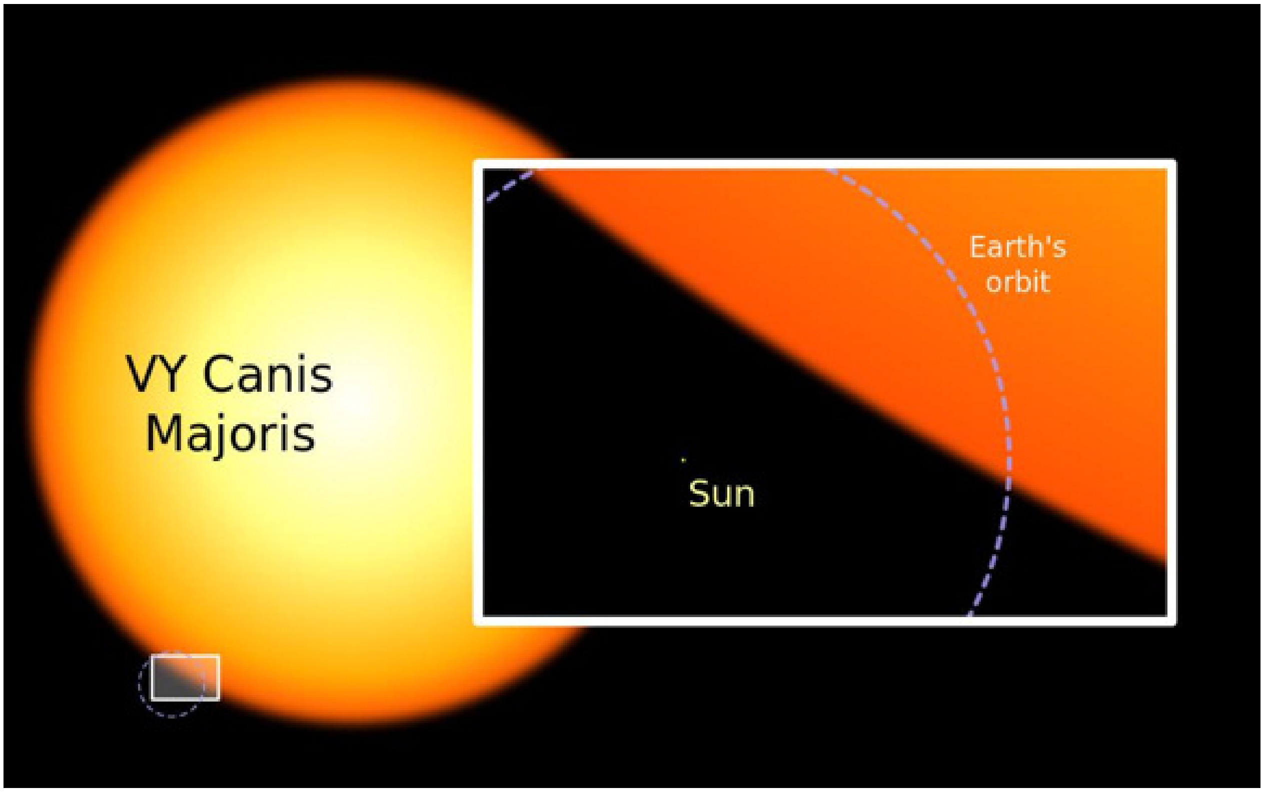
1. Radius measure
2. Surface temperature

Radius measure

Let's presume a star has the same surface temperature as the sun, but sports a larger radius. In that scenario, the star with the larger radius claims the greater luminosity. In the example below, we'll say the star's radius is 4 solar (4 times the sun's radius) but has the same surface temperature as our sun.

We can calculate the star's luminosity – relative to the sun's – with the following equation, whereby L = luminosity and R = radius:

$L = R^2$
$L = 4^2 = 4 \times 4 = 16$ times the sun's luminosity



Although the star VY Canis Majoris in the constellation Canis Major has a much cooler surface temperature than our sun, this star's sheer size makes it a super-luminous star. Its radius is thought to be around 1400 solar and its luminosity 270,000 solar.

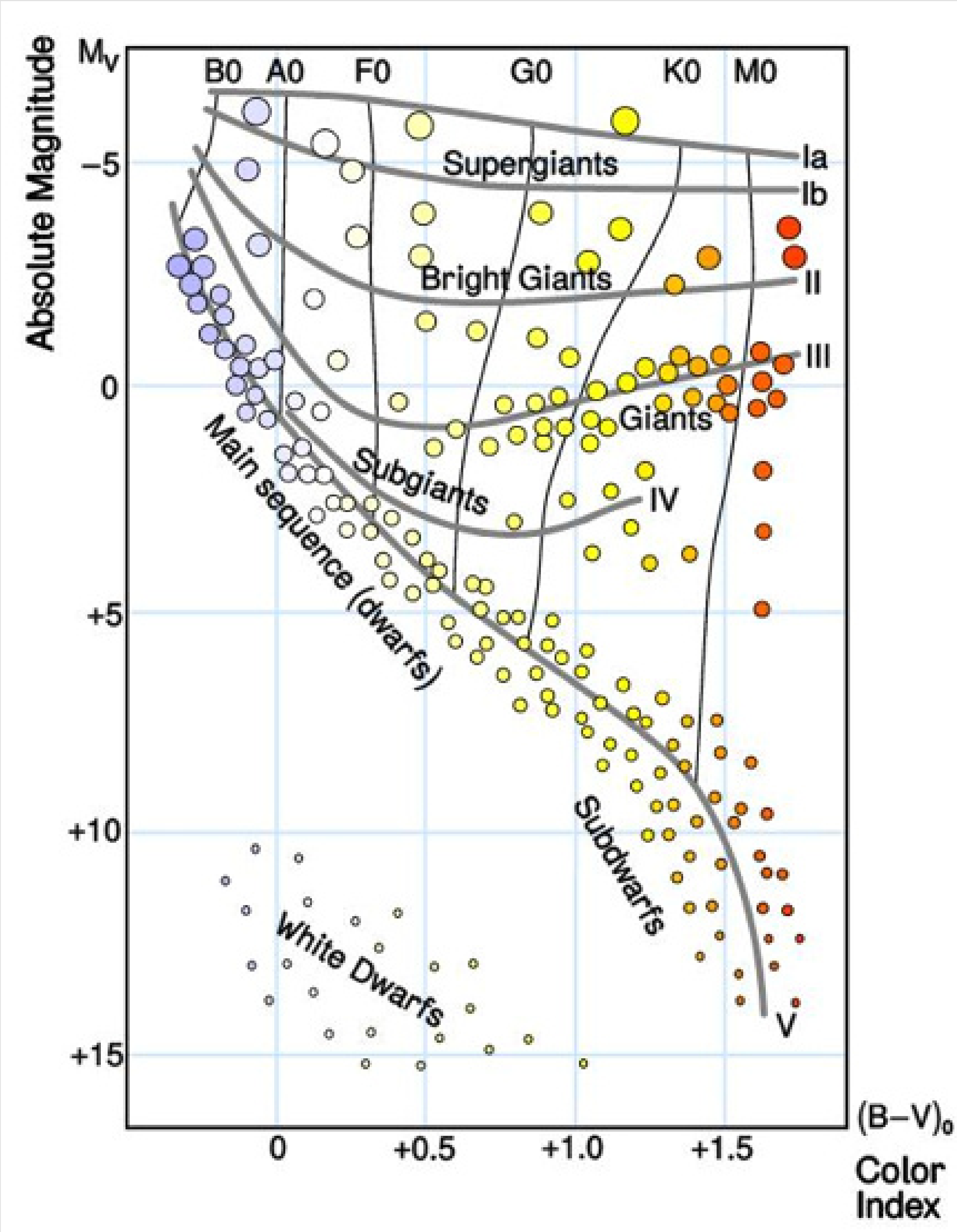
Surface temperature

Also, if a star has the same radius as the sun but a higher surface temperature, the hotter star exceeds the sun in luminosity. The sun's surface temperature is somewhere around 5800 Kelvin (9980^o Fahrenheit). That's 5800 degrees above absolute zero, the coldest temperature possible anywhere in the universe. Let's presume a star is the same size as the sun but that its surface temperature is twice as great *in degrees Kelvin* (5800 x 2 = 11600 Kelvin).

We use the equation below to solve for the star's luminosity, relative to the sun's, where L = luminosity and T = surface temperature, and the surface temperature equals 2 solar.

$L = T^4$
$L = 2^4 = 2 \times 2 \times 2 \times 2 = 16$ times the sun's luminosity

Luminosity of Star = $R^2 \times T^4$



The HR Diagram categorizes stars by surface temperature and luminosity. Hot blue stars (>30,000 Kelvin) at left and cool red stars (

The luminosity of any star is the product of the radius squared times the surface temperature raised to the fourth power. Given a star whose radius is 3 solar and a surface temperature that's 2 solar, we can figure that star's luminosity with the equation below, whereby L = luminosity, R = radius and T = surface temperature:

$L = R^2 \times T^4$
$L = (3 \times 3) \times (2 \times 2 \times 2 \times 2)$
$L = 9 \times 16 = 144$ times the sun's luminosity

Color and surface temperature

Have you ever noticed that stars shine in an array of different colors in a dark country sky? If not, try looking at stars with binoculars sometime. Color is a telltale sign of surface temperature. The hottest stars radiate blue or blue-white, whereas the coolest stars exhibit distinctly ruddy hues. Our yellow-colored sun indicates a moderate surface temperature in between the two extremes. Spica serves as prime example of a hot blue-white star, Altair: moderately-hot white star, Capella: middle-of-the-road yellow star, Arcturus: lukewarm orange star and Betelgeuse: cool red supergiant.

Bottom line: Some stars look bright because they're near Earth. Others are truly extremely bright members of our Milky Way galaxy. Astronomers call the true, intrinsic brightness of a star its luminosity. The luminosity of any star depends on size and surface temperature. Some extremely large and hot stars blaze away with the luminosity of a million suns!

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