Dealing with Distance from Star

John Pickle, sciencepickle.com

How To Deal With Average Orbit Radii Different From Earth

As electromagnetic radiation is emitted from a star, in general, it travels radially outward. So the energy emitted at a given instance in time moves away from the star in an expanding surface of a sphere (illustrated in Figure 1). The surface area of a sphere is $4 \pi r^2$, so the energy is being distributed over an ever growing area that is proportional to the square of the distance travelled (r^2). Since the energy emitted from a star is generally constant over a period of a year (there are important fluctuations in the short term), the radiative energy flux (energy / unit time / unit area) decreases at the rate of increase in the area of the sphere. Using I to represent the energy flux and r is the distance from the star:

$$I \text{ (at distance r from star)} = I \text{ (at the star)} / r^2$$

or $$I(r) = I_0 / r^2$$

If we know the energy flux at a known distance from a star, as we do for the energy flux from the Sun reaching Earth, then we can calculate the energy flux at any other distance from the star:

$$I(r_1) = I_0 / r_1^2$$

$$I(r_2) = I_0 / r_2^2$$

Rewriting each in terms of I_0: $I_0 = I(r_1) * r_1^2 = I(r_2) * r_2^2$

Then: $I(r_2) / I(r_1) = r_1^2 / r_2^2$

Where r_1 and r_2 are two distances along the path of the radiation from the source.

We can work in absolute values of energy flux, but to help work more efficiently with the Star-Planet Connection scenarios, we can also work in relative terms. If $r_2 = 2 r_1$ then

$$I(r_2) / I(r_1) = r_1^2 / r_2^2 = r_1^2 / (2r_1)^2 = 1/4$$

This means the energy flux for a planet that is twice as far away from the star is 1/4 of the energy flux for planet that is closer to the star. For the Star-Planet Connection software, multiply the Total Daily Solar Energy by the relative energy flux (1/4 in this case) to analyze the impact of being twice as far away from the star compared to Earth's distance to the Sun.

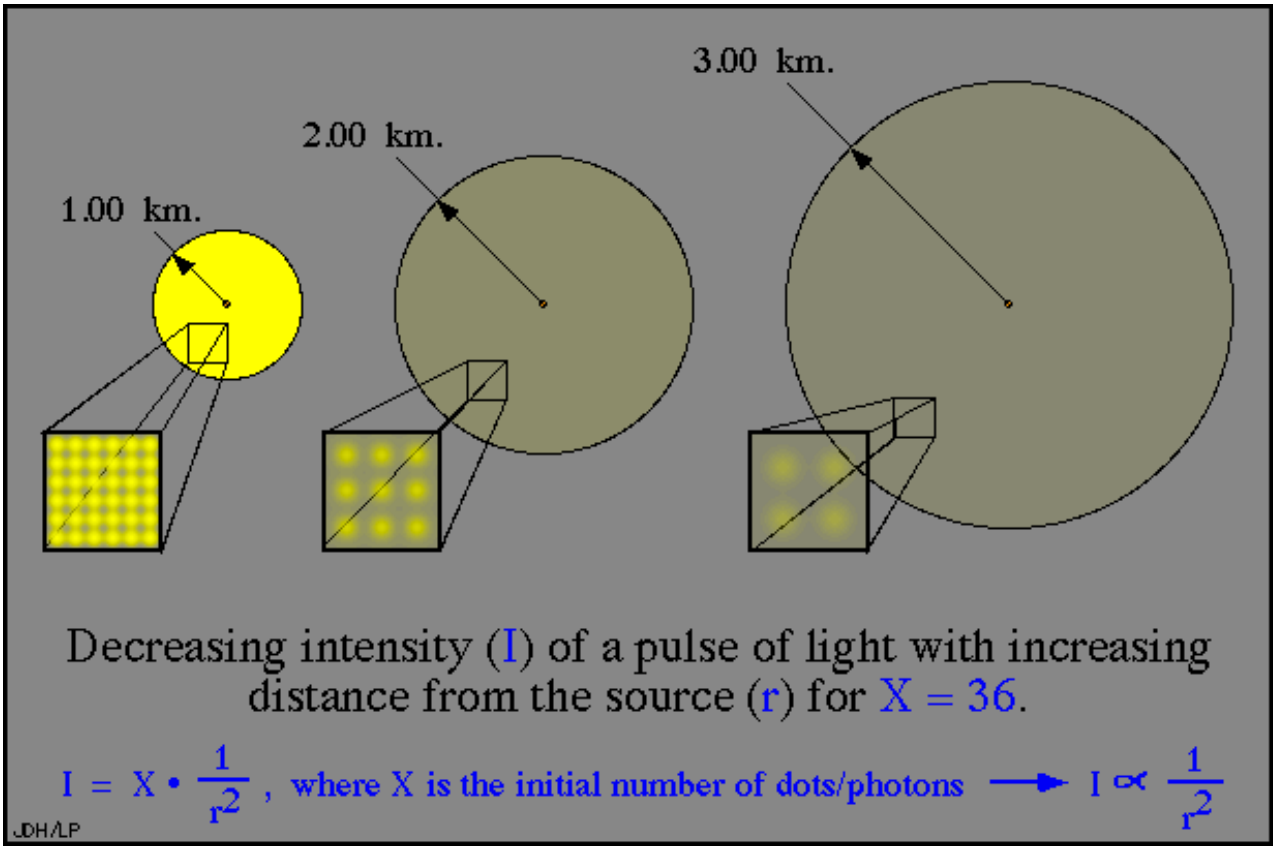

Figure 1. How a beam of sunlight spreads out as it travels away from the star. From http://eesc.columbia.edu/courses/ees/climate/lectures/radiation/heat_xfer.html

Table 1 shows the absolute values of the Sun's radiation energy flux reaching the planets in our solar system.

Distance Relative to Earth's Distance from Sun	Solar Radiation [Wh/m²]	
0.39	8987.51	Mercury
0.723	2615.12	Venus
1	1367.00	Earth
1.524	588.57	Mars
5.2	50.55	Jupiter
9.5	15.15	Saturn
19.2	3.71	Uranus
30.1	1.51	Neptune
39.5	0.88	Pluto

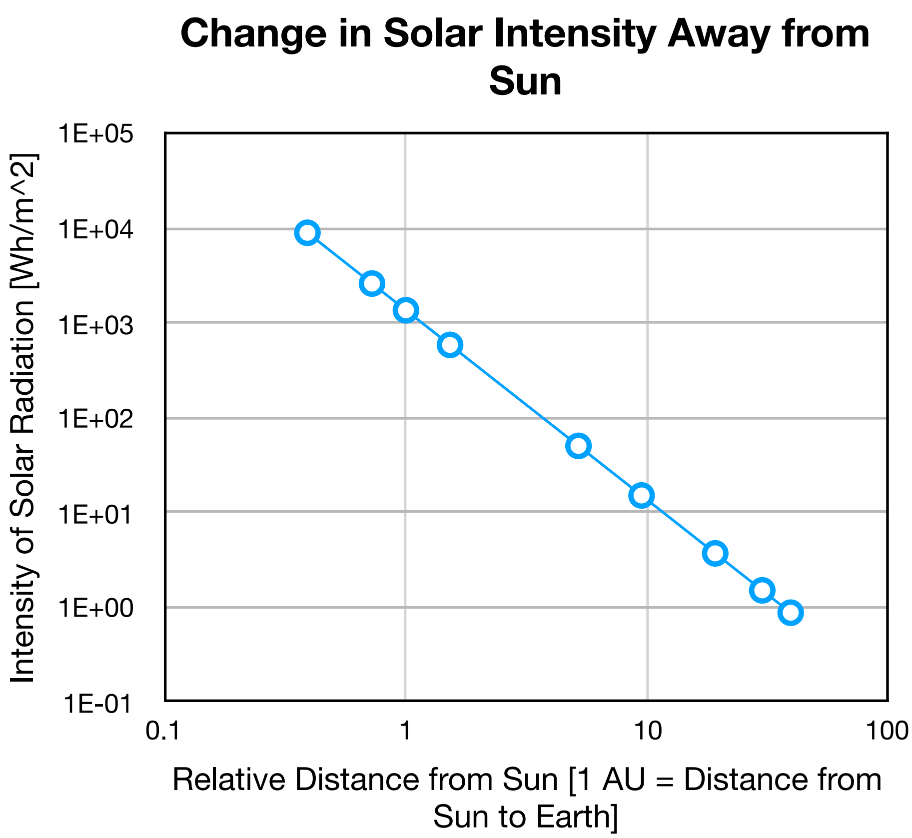

Figure 2. Logarithmic graph of the absolute values of the Sun's radiation energy flux reaching the planets in our solar system.

Table 2 shows the relative values of the Sun's radiation energy flux reaching the planets in our solar system.

Distance Relative to Earth's Distance from Sun	Percent Solar Radiation	
0.39	657.5	Mercury
0.723	191.3	Venus
1	100.0	Earth
1.524	43.1	Mars
5.2	3.7	Jupiter
9.5	1.1	Saturn
19.2	0.3	Uranus
30.1	0.1	Neptune
39.5	0.1	Pluto

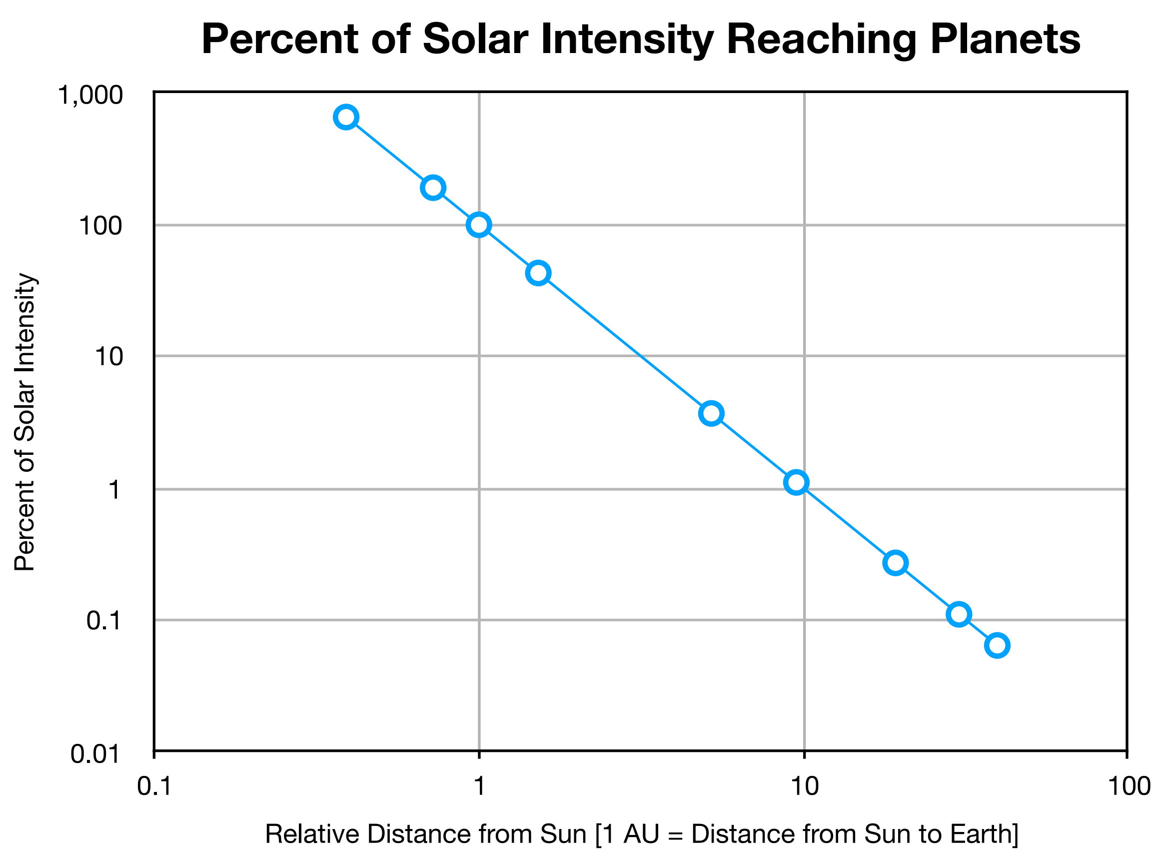

Figure 2. Logarithmic graph of the relative values of the Sun's radiation energy flux reaching the planets in our solar system.

Example 1

Say you wanted to calculate the maximum daily solar intensity reaching Mars, which has an obliquity of 25.19º (round off to 25.0º) and an eccentricity of 0.093. Use Star-PlanetConnection with these values and change precession to find the maximum total daily solar radiation reaching Mars but from 1 AU (the average distance of the Earth to the Sun). At this obliquity, the greatest total daily solar radiation will be at a pole during the summer solstice that occurs while at perihelion (Sol 4). The value is 16,854 Wh/m^2. Then multiply this by 0.431 (which is 43.1%) to adjust for the average distance of Mars from the Sun, so the most Mars daily solar radiation experiences is 7264 Wh/m^2.

Example 2

What if you wanted to find the distance away from the Sun a planet with an obliquity of 25º and an eccentricity of 0.10 needed to be to experience 75% of the 13,525 Wh/m^2, the maximum total daily solar radiation on Earth with its current obliquity, eccentricity, and precession? This value occurs at the South Pole on Dec 21 (sol 355). The maximum for this planet is 14,146 Wh/m^2, so to decrease it to .75 x 13,525 or 10,144 Wh/m^2, which is 71.7% of planet's maximum for 1 AU. The planet would need to be 1.18 times further from the Sun than Earth.

$$I_{unknown} / I_{1\ AU} = 0.717 = (r_{1\ AU} / r_{unknown})^2$$

$$r_{1\ AU} / r_{unknown} = \sqrt{(0.717)} = 0.847$$

$$r_{unknown} = r_{1\ AU} / 0.847 = 1.18\ r_{1\ AU}$$

Other Changes

What else changes when the average distance of the planet to the star increases? If the mass of the planet or star doesn't change, the farther from the star, the longer it takes to complete the orbit, so the year is no longer 365 days or sols and the seasons will be longer. Basically, expand (or compress if the distance to the star decreases) the 'Yearly Trends' x-axis to visualize the trends the planet will experience during its orbit.