

Climate Change workshop #5

Why is the Sun's Luminosity increasing?

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The Sun's luminosity is increasing about 5% every billion years. We can show this by considering the Sun as an ideal gas and calculating how its density and temperature change as the number of particles change due to fusion burning.

Recall that the primary fusion pathway in the Sun is $4 \text{ H} \rightarrow 1 \text{ He}$, that the primordial ratio of H/He is about 9/1, and that the Sun converts about 10% of its H in its lifetime of 10 billion years.

Consider 110 particles in the Sun at present. How many will there be in 10 billion years?

Now		10 billion years later
100 H	→	90 H
10 He	→	$10 + 10/4 = 12.5 \text{ He}$

$n_1 = 110 \quad \rightarrow \quad n_2 = 102.5 \text{ particles}$

The fractional change in number of particles is $n_2 - n_1 / n_1 = \Delta n / n = -7.5 / 110$ per 10 billion years.

Now apply this to the ideal gas law, $PV = nRT$, where P = pressure, V = volume, n = number of particles, R = gas constant, and T = temperature.

If we assume $PV/R = \text{constant}$, then $nT = \text{constant}$: if the number of particles in the Sun decreases, its temperature will increase:

$$\frac{\Delta n}{n} = \frac{-\Delta T}{T}$$

If the temperature of the Sun increases, its Luminosity (or power emitted) will also increase. The Stefan-Boltzmann relation tells us that the radiant flux = power/area of any blackbody depends on its temperature T and size: $\text{Flux} = \sigma T^4 = L/\text{area}$. If we again neglect any changes in the Sun's size, this means that $L \sim T^4$ or

$$\frac{\Delta L}{L} = \frac{4\Delta T}{T} = 4\left(\frac{-\Delta n}{n}\right) = -4\left(\frac{-7.5}{110}\right) = \frac{30}{110}$$

We find an increase of about 30% in ten billion years. If the process is linear, this would yield an increase of 3% in one billion years – close to the actual 5%.

(The process is not quite linear, and we have neglected changes in size and pressure.)