

The Drake equation brings out the importance of understanding how long an intelligent civilization exists. This relates to the life of a star. The sun's lifetime has been estimated from the fact that it gives off 3.9×10^{26} Watts (Joules/second), and comparing this luminosity to the energy available. Let's consider two estimates. For sanity, convert all quantities to SI units and don't use more than 3 significant digits.

1. Gravitational energy

The gravitational energy released by bringing an object of mass m from far away to a distance r from a second object of mass M is $U = GMm/r$

- Write and evaluate an integral for the energy released by assembling a spherical body of radius a and uniform density ρ as a series of shells of radius dr .
- Use this result to estimate the energy released by assembling the sun, assuming a density of 1.4 gm/cm^3 and radius $7 \times 10^5 \text{ km}$.
- How long in millions of years could the sun live if this were the source of its energy?

2. Nuclear energy

Measuring the luminosity of the sun is equivalent to measuring the rate at which the nuclear reactions produce energy in the core of the sun. In this reaction



energy is released because some of the mass of the H atoms is converted to energy.

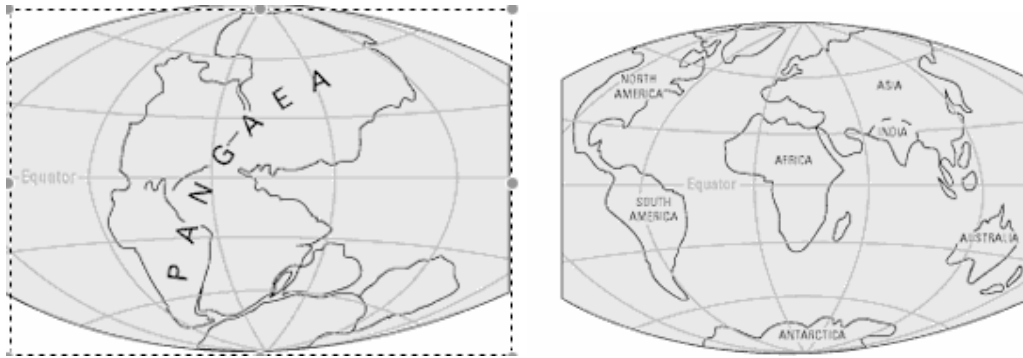
Mass of 1 Hydrogen atom: $1.673 \times 10^{-27} \text{ kg}$

Mass of 1 Helium atom: $6.644 \times 10^{-27} \text{ kg}$

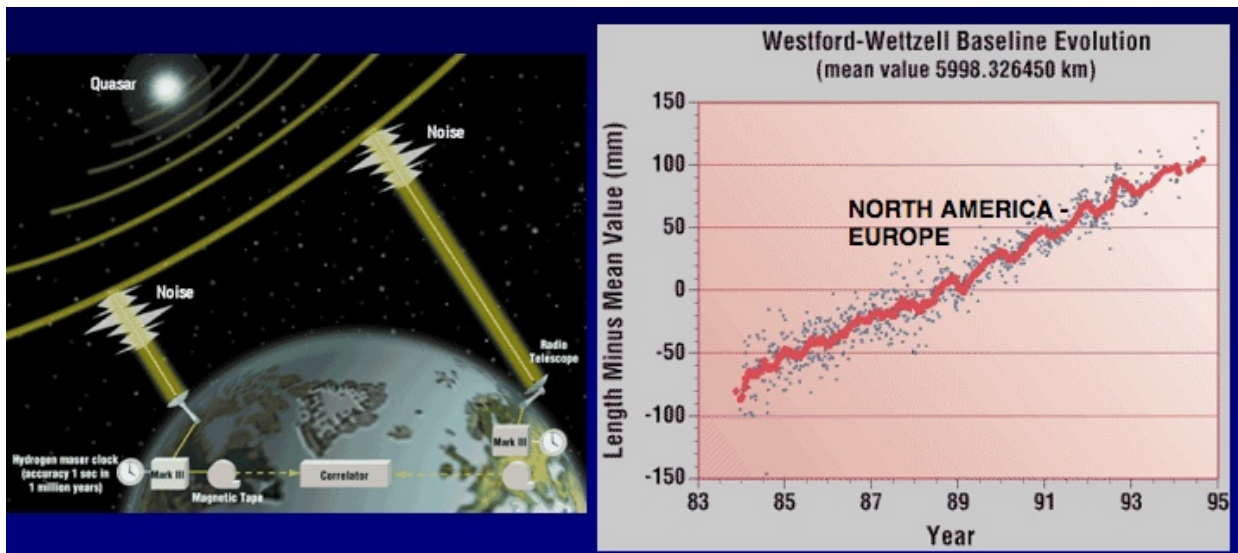
- Find the difference in mass between 1 He atom and 4 H atoms.
- Use $E = mc^2$ to find the energy released by producing one He atom from 4 H atoms.
- Since the sun gives off 3.9×10^{26} Watts (Joules/second), how many hydrogen atoms are being destroyed every second?
- The sun will remain a main sequence star until it runs out of hydrogen fuel in its core. The core of the sun contains about 10% of its total mass, $2 \times 10^{30} \text{ kg}$. How long in millions of years will it take until the sun has used up all the hydrogen atoms in the core.

3. Geological comparison.

During the controversy over the age of the sun, comparisons were made with geological estimates. A modern version would be to look at how long it has taken sea floor spreading to open the Atlantic Ocean.



a) The graph shows the changing distance over about a decade between Germany and Massachusetts. The data are from regular measurements of the difference in arrival times of signals from distant quasars at two radio telescopes. Measure the rate of change in mm/yr.



b) Use a map to find the width of the North Atlantic Ocean.

c) At the current rate, how long in millions of years would the opening of the Atlantic have taken?

d) What fraction of the Earth's age is this?

4.6 Ga

4. Timeline. A challenge in thinking about life on earth or other planets is the very long time scale. To help you, mark key dates and events on two time lines corresponding to the life of the sun. Turn this one in and keep the other to use and update during the quarter.

Label the following with heavy tic marks and brief text:

-3.8 Ga: End of the Hadean Eon. The Hadean (named after Hades, Greek god of the underworld) began with the accretion of the Earth and spans the periods of differentiation, heavy bombardment, and formation of the early atmosphere.

- 2.5 Ga: End of the Archean Eon, by the end of which most of the continents formed and life appeared in the form of archaea and bacteria.

- 542 Ma: End of the Proterozoic Eon, during which multicellular organisms appeared and the atmosphere became rich in oxygen. The Hadean, Archean, and Proterozoic are collectively called the Precambrian.

- 0 Ga (the present). Present end of the Phanerozoic Eon, during which life diversified into complex forms, first in the sea and then on land.

Label the following events with smaller tick marks and brief text. These ages are still under investigation, but approximate ones are fine for our purposes.

- 4 Ga: oldest rocks

- 3.2 Ga: oldest microfossils: single cells (prokaryotes)

- 2.3 Ga: change from oxygen-poor to oxygen-rich atmosphere

- 1.1 Ga: assembly of Rodinia supercontinent

- 750 Ma: breakup of Rodinia supercontinent

- 475 Ma: first land plants

- 340 Ma; first reptiles

- 300 Ma: assembly of Pangaea supercontinent

- 230 Ma: first dinosaurs

- 200 Ma: breakup of Pangaea supercontinent

- 195 Ma: first mammals

- 65 Ma: death of dinosaurs

- 200 ka: *Homo Sapiens*

6.4

billion
years
from
today

5. From Ward & Brownlee (Chapter 3) explain how the abundance of elements in a planetary system depends upon the age of its star.

6.) After watching <https://www.youtube.com/watch?v=w4kkKx-Wcoo> explain what and where the Midcontinent Rift is, and how it formed. Mark the age when it formed on the timeline in Question 4, and compare this age to the history of life. What does this tell us about the relative timing of plate tectonics and complex life?