Are We Alone in the Universe?

Professor John Lattanzio
Monash Centre for Astrophysics
Monash University
Australia

Monash Centre for Astrophysics

Thanks!

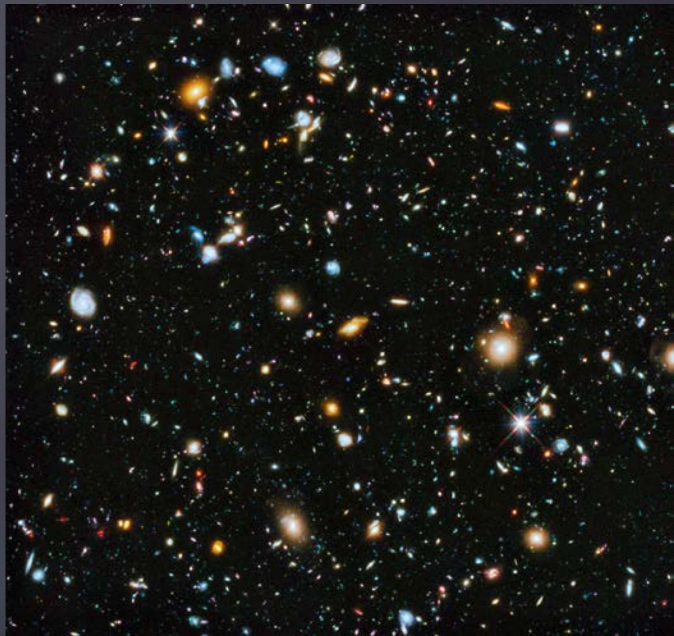
1) Honors Carolina
2) Morehead-Cain Scholars Program
3) UNC Department of Physics and Astronomy

for inviting me to serve as the 2018 Morehead-Cain Alumni Visiting Distinguished Honors Professor

I: LIFE ON EARTH: COULD IT HAPPEN ELSEWHERE?

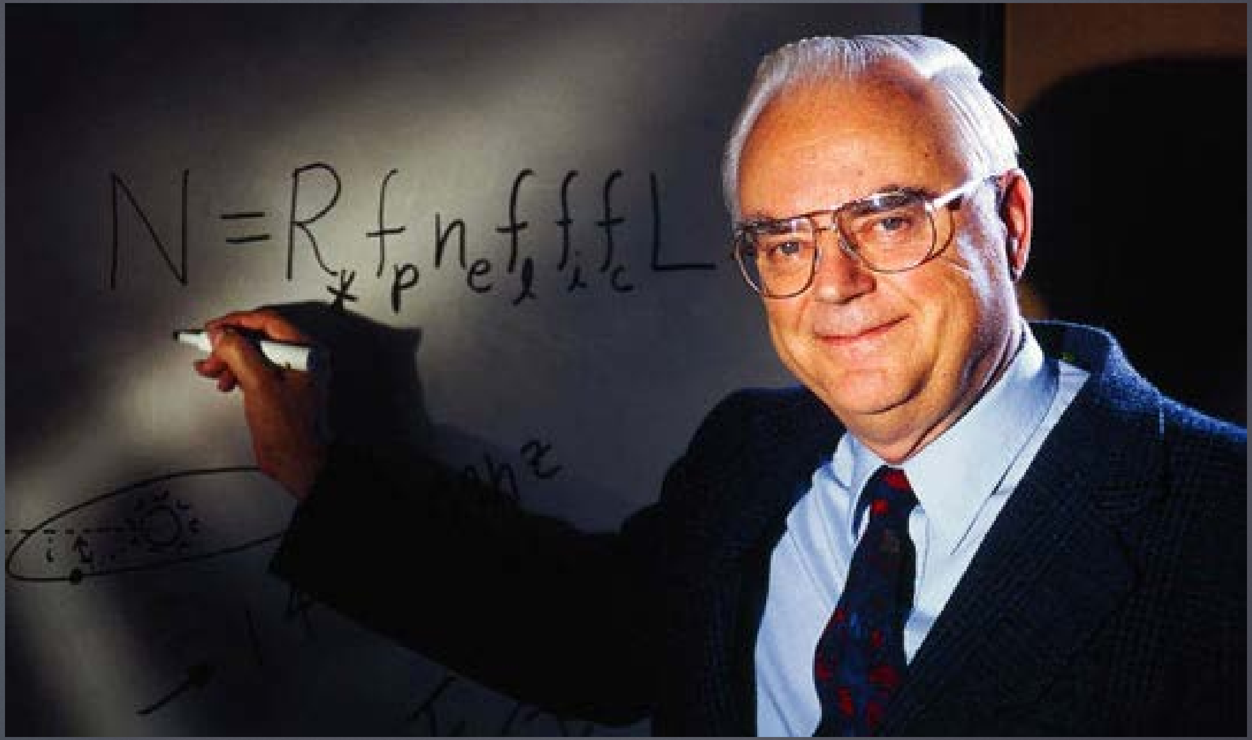
II: MAKING ALIENS

III: TALKING WITH ALIENS



How Many Civilizations are there?

The Drake Equation



It's not quantitative … but it is informative … and can guide our thinking

Let N = number of communicating civilizations in the galaxy right now

N = number of suitable planets in the galaxy

× chance of a communicating civilization arising on a suitable planet

× survival fraction

$$N = N_{astro} \times f_{bio} \times (\text{lifetime term})$$

$$= (N_{\star} \times f_s \times N_p \times f_e) \times (f_L \times f_i \times f_c) \times L/L_{MW}$$

Investigate each term…

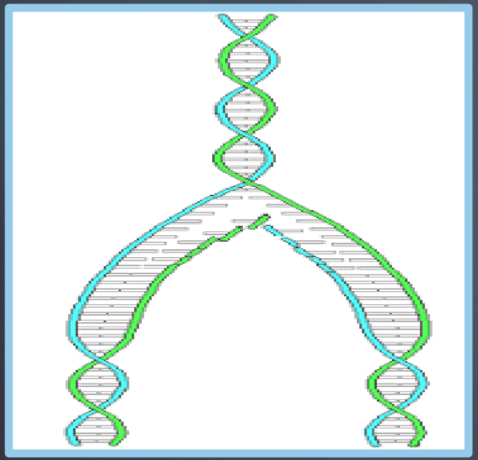
Drake Equation

$N_\star$ ×

f_s ×

N_p ×

f_e



f_L ×

f_i ×

f_c ×

L/L_{MW}

$= N$

Number of Stars in the Galaxy

$N_\star$

We actually know this pretty accurately!

$N_\star = 3 \times 10^{11}$
$= 300{,}000{,}000{,}000$
$= 300$ billion
$= 300{,}000$ million

$$N_\star = 3 \times 10^{11}$$

Fraction of stars suitable for life

f_s

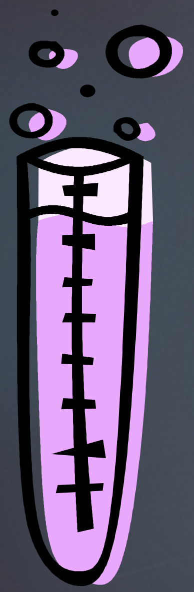
What makes a star suitable?

What do we need from the star?
How do stars vary?

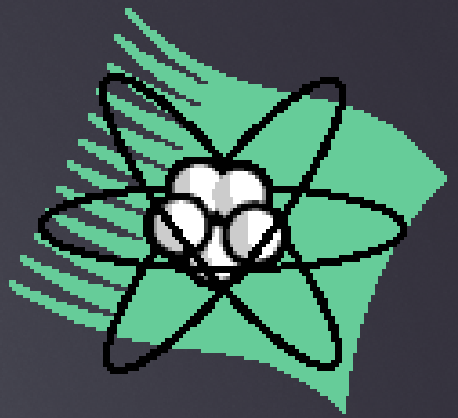
Energy of the Stars

- Most energy we are familiar with is *chemical energy*
- It is released from re-arranging chemical bonds in atoms and molecules
- This is what powers cars, BBQs, and even rockets (as we will see later)

- But it does not provide enough energy to power the stars!



Nuclear Energy



- The key is Einstein's formula for mass-energy equivalence:

  $E=mc^2$

- This relates a change in mass to a change in energy

H “burning” in the Sun

The simplest nuclear reactions involve fusing 4 H nuclei (protons!) into one He^4 nucleus (an α particle)

$$^{1}H + {}^{1}H + {}^{1}H + {}^{1}H \rightarrow {}^{4}He$$

Mass of a proton = m_p = 1.673×10^{-27} kg

Mass of a ^{4}He = m_α = 6.645×10^{-27} kg

Difference in mass = “mass defect”

$= 4\,m_p - m_\alpha$

$= 4.7 \times 10^{-29}$ kg

Mass is lost each time!

H “burning” in the Sun

- Each reaction releases an energy $E = mc^2$
- So in our case that is

$$E = (4.7 \times 10^{-29}) \times (3.0 \times 10^{8})^2 \text{ kg m}^2/\text{s}^2$$

$$= 4.3 \times 10^{-12} \text{ Joule}$$

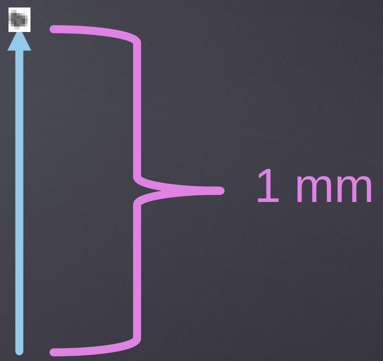
$$= \text{not much}$$

Poppy seeds….

Take one….

Cut into 1000 pieces….

How far can we lift it?



Take one piece…

But there are lots of reactions!

- We can calculate how many of these reactions occur
- The Sun emits 3.90 x 10^{26} Joule/s
- So that is

$3.90 \times 10^{26} / 4.3 \times 10^{-12}$ reactions per second

$= 9 \times 10^{37}$ reactions per second

That is a HUGE number!

How much mass is this?

- There are 9×10^{37} reactions per second
- Each reaction destroys 4.7×10^{-29}kg
- So the total mass destroyed each second is:

  $(9 \times 10^{37}) \times (4.7 \times 10^{-29}\text{kg}) = 4.2 \times 10^{9}$ kg

That's 4.2 million tonnes per second!

How much H burns?

- Since we now know how many reactions there are per second…

  …we can work out how much H is burned each second.

There are 9×10^{37} reactions

Each consumes 4 H nuclei

So we burn $4 \times m_p \times 9 \times 10^{37} = 4 \times 1.673 \times 10^{-27}$ kg $\times 9 \times 10^{37}$

$= 6{,}02 \times 10^{11}$ kg

= 602 million tonnes per second!

How much He is produced?

- Since we now know how many reactions there are per second…

  …we can work out how much He is produced each second.

There are 9×10^{37} reactions

Each produces one ^{4}He nucleus

So we produce $m_{\alpha} \times 9 \times 10^{37} = 6.645 \times 10^{-27}$ kg $\times 9 \times 10^{37}$

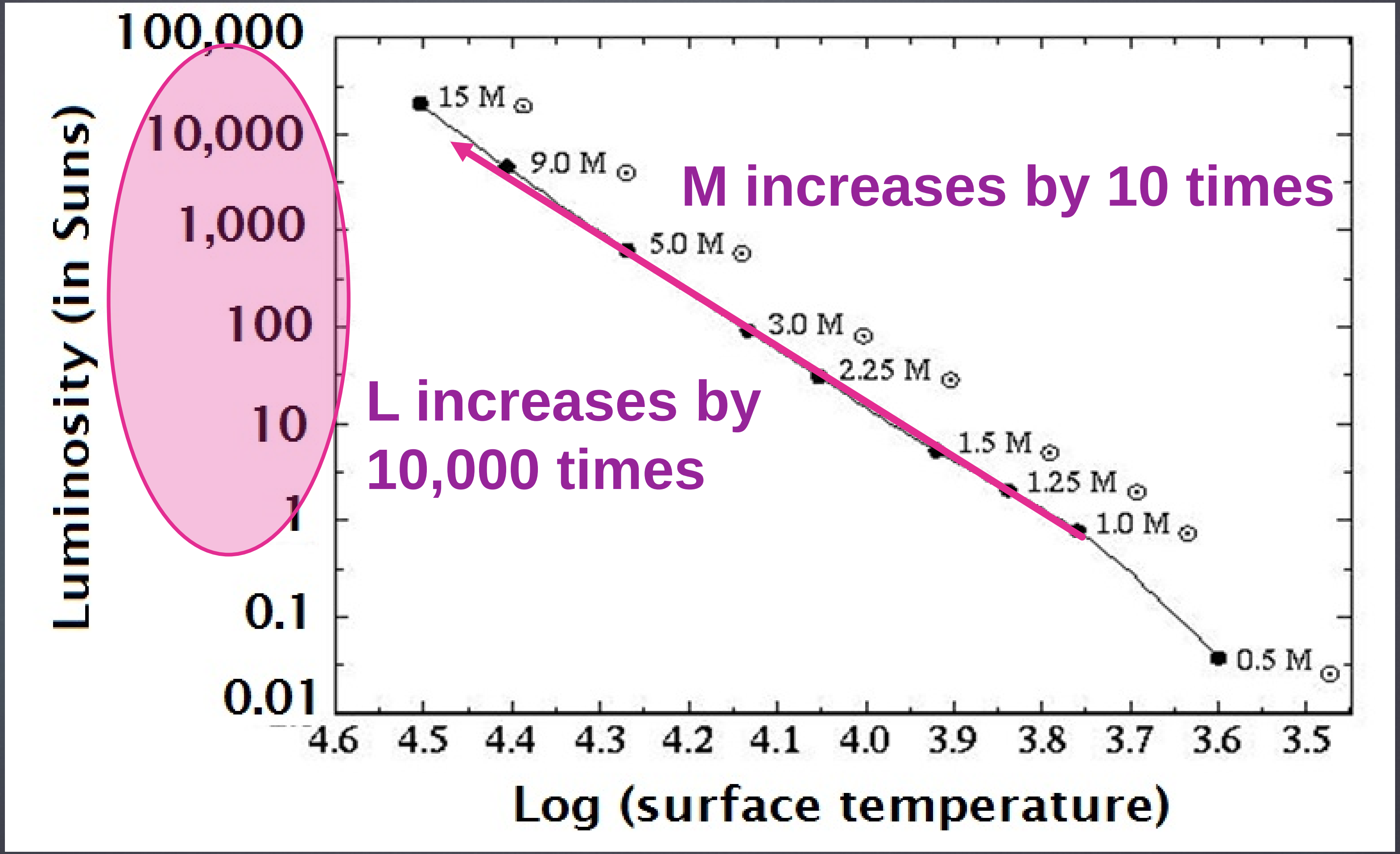
$= 5.98 \times 10^{11}$ kg

= 598 million tonnes per second!

And as we might hope – the difference between these is 4 million tonnes as we calculated initially!

The Main Sequence

- By making models for different masses we have learned that the **Main Sequence** is a sequence of stars of **different mass**



Mass-Luminosity Relation

- One can show that roughly we can relate mass M to luminosity L by: $L \propto M^3$

- So to make this an exact equation we insert a constant k which we have to determine:

$$L = kM^3$$

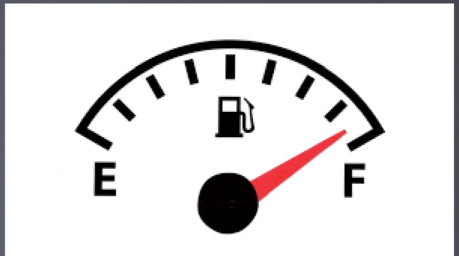
- If we measure mass and luminosity in solar units then k=1 because the Sun has a mass of 1 and a luminosity of 1 ☺

- The symbol for the Sun is ☉, so we can write the mass-luminosity relation as

$$\frac{L}{L_{\odot}} = \left(\frac{M}{M_{\odot}}\right)^3$$

How does this affect lifetimes of stars?

- Stars live while they have fuel to burn



- Massive stars burn brightly and use fuel quickly

- Massive stars do not live very long…

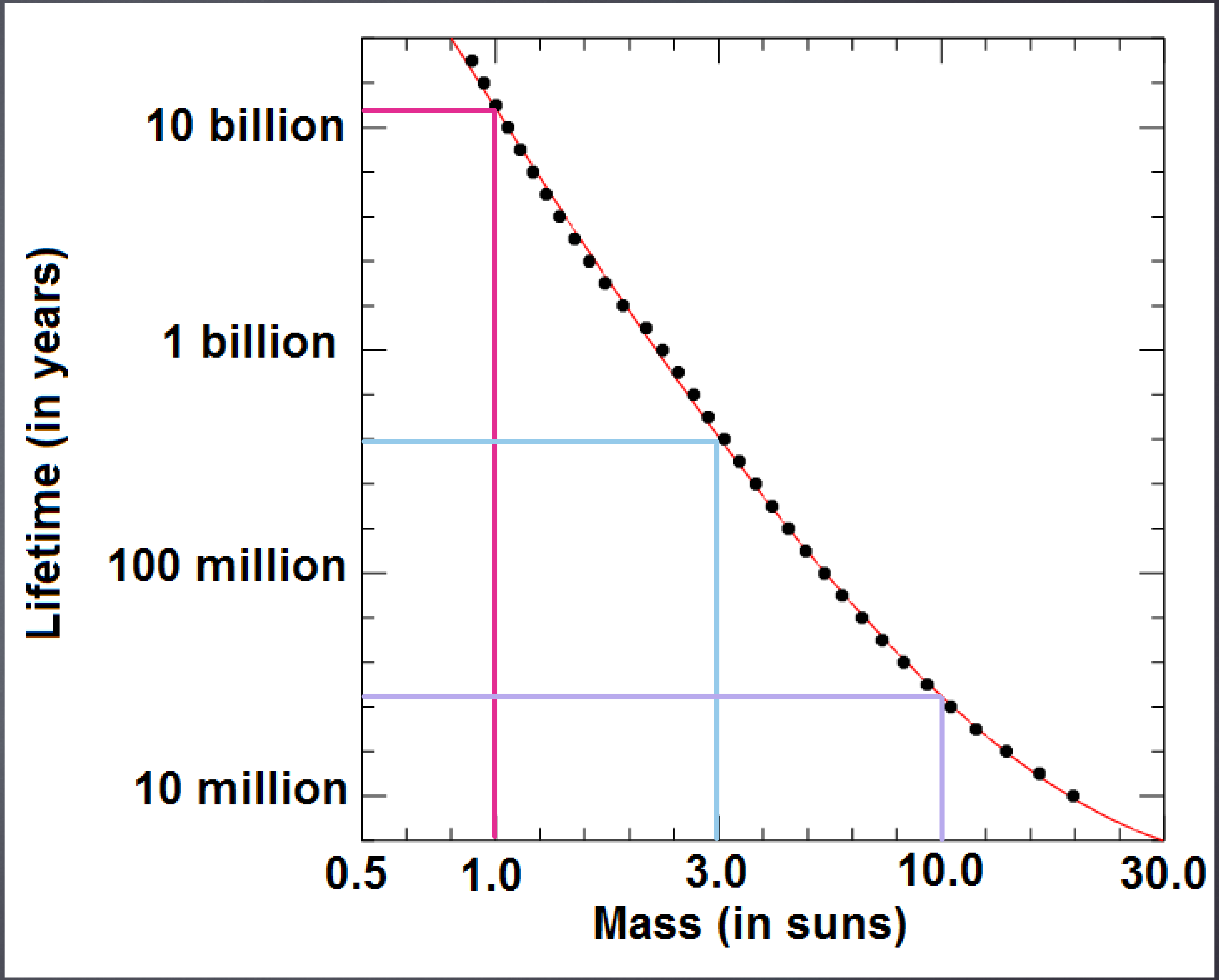
- The Sun will live for about 10 *billion* years
- A 10 solar mass star lives for about 30 *million* years

Stellar Ages

Sun: 10 billion years

M = 3 times Sun: 400 million years

M = 10 times Sun: 30 million years



Mass-age relation

- We can use the mass-luminosity relation to derive a mass-age relation
- The amount of fuel available is just the mass of the star.
- So the lifetime is the rate of using fuel (the luminosity) divided by the amount of fuel available (the mass)
- Lifetime t is proportional to M/L
- Of course the star cannot use all of it mass…it can only burn where it is hot (in the middle)
- So we out in a constant of proportionality again

$$t = k\left(\frac{M}{L}\right) = k\left(\frac{M}{M^3}\right) = \frac{k}{M^2}$$

Mass-age relation

- Lets again measure things in solar units.
- The lifetime of the Sun is $t_\odot = 10^{10}$ years
- So for a star of a different mass M we get

$$\frac{t}{t_\odot} = \left(\frac{M}{M_\odot}\right)^{-2}$$

These relations are *approximate*. The values used in lectures are the result of very detailed computer calculations. But the essence is in these simple equations!

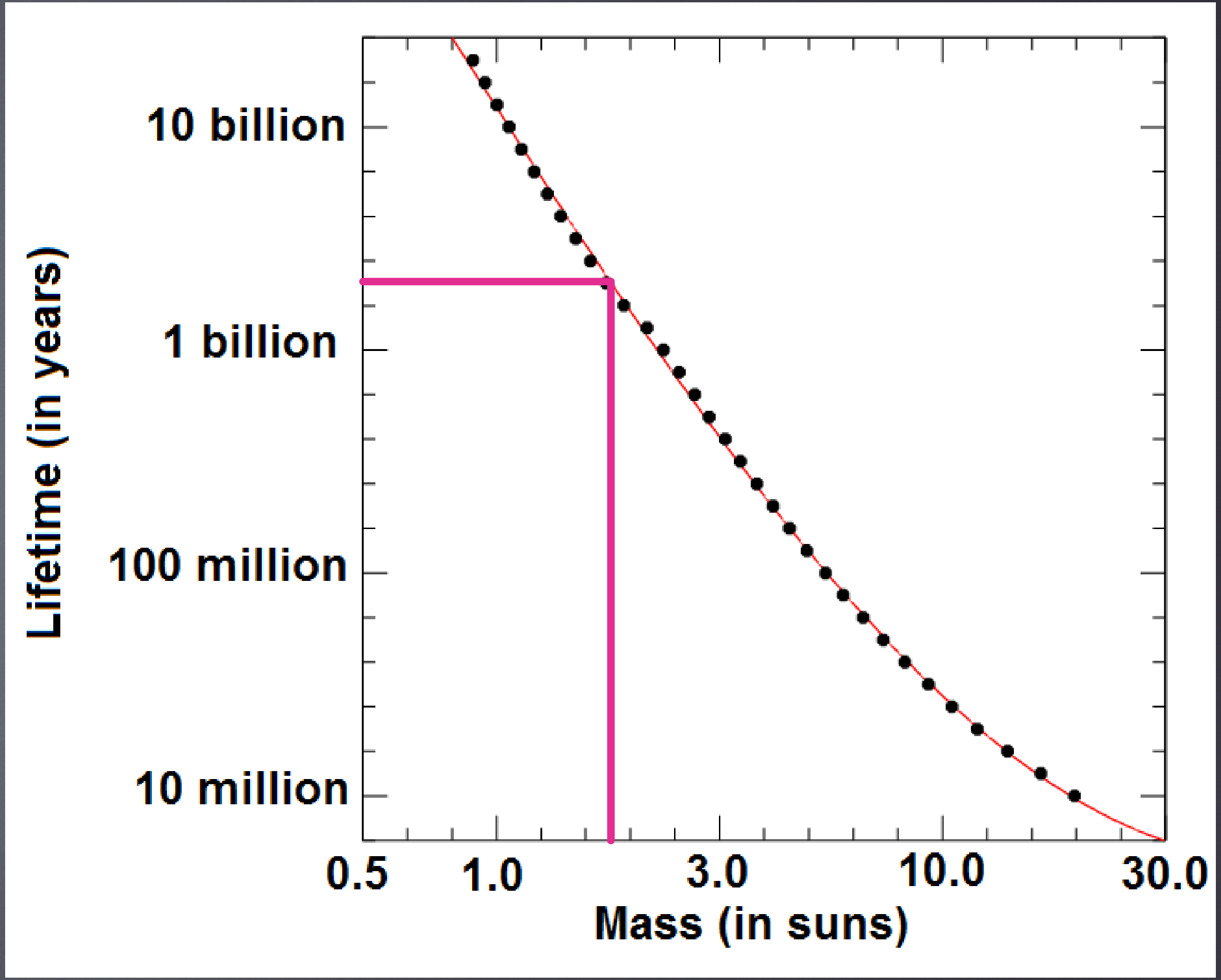
How long do we need?

- How long does it take to produce a communicating civilization?
- Clearly we need the star to live at least that long…
- Earth?

0.5 billion years for first life

4 billion years for large life

4.5 billion years for us to develop communication technology



Maybe assume 2 billion years as a minimum?

This gives a maximum mass of about 2 Suns.