The Cosmos

Planets & Life

PHYS 214

Dr Rob Thacker

Dept of Physics (308A)

thacker@astro.queensu.ca

Please start all class related emails with “214:”

Today's Lecture

- The Drake Equation: putting it all together
  - What values of N could we expect?
  - Given a value of N, what is the average distance between these civilizations?
  - How long might colonization of the galaxy take?

Things to remember about the Drake Equation

- It corresponds to the number of civilizations we can expect to detect – it isn't an estimate of how many are out there (that would mean removing $p_c T$ and replacing with the lifetime of the civilization L)
  - Sometimes people argue that because we are here the minimum value is N=1 – but this isn't technically correct (there has to be 1 civilization to detect others)
- As we saw in the last lecture, the detection of signals could be the trickiest issue of all
  - A powerful narrow beam signal has to be targetted towards us – we can't hope to detect average "radio leakage" right now
  - Note that perhaps in 50 years a follow-on to the SKA (far side of the moon perhaps?) might start making SETI research very interesting…

Our "best values"

$$N = R^* p_p n_E p_l p_i p_c T$$

Variable	Value	"Confidence"
R^* (lecture 9)	(2-4¶ $M_\odot$ yr^{-1} *now*) ~20 yr^{-1}	Factor of 2?
p_p (lecture 17)	0.1	Factor of 2?
n_E (lecture 17)	1	Factor of 3?
p_l (lecture 27)	0.1	Factor of 5?
p_i (lecture 27)	0.1	Factor of 10?
p_c (lecture 27)	0.1	Factor of 10?
T (lecture 27)	1 yr	Factor of 10000?

¶ *This is the total mass of stars formed (of different masses) at the current epoch, the value was larger in the past, so we'll take an average value of 20* yr^{-1}

So we get…

$$N = 20 \times 0.1 \times 1 \times 0.1 \times 0.1 \times 0.1 \times 1 = 0.002$$

- If we take *all* the largest possible values we expect for all the variables then we get
  - N=120,000
- Similarly, if we take the smallest possible values then we get
  - $N=3 \times 10^{-11}$
  - So we really would be alone!

Uncertainties in our "well known" values

- R* really is quite well understood, however the Drake equation as it stands doesn't really consider whether the star is of the right type (such as lifetime arguments)
  - Early estimates for R* were low by perhaps a factor or 4, while the lifetime argument and difficulty of life around M dwarf stars biases R* back down again
- The 0.1 value for p_p is a lower limit
  - Planet detection so far has largely relied upon Doppler methods which actively select for large gas giants close in to the star
  - This value could reasonably be as high as 0.5

Comparison to other evaluations of N

- Frank Drake & colleagues (1961) assumed the following values as their "best guess"

Variable	Value
R*	10
p_p	0.5
n_E	2
p_l	1.
p_i	0.1
p_c	1.
T	10000 yr

$$N = 10 \times 0.5 \times 2 \times 1 \times 0.1 \times 1. \times 10000 = 10000$$

Things to think about

- Regardless of whether we consider the Drake equation, or the REH equivalent, there is one important point:
  - If any one of the variables is extremely small then N will be too (unless the broadcast lifetime is very long)
- Try not to just play with the numbers to get what value you want
  - Let the "science" tell you what the most probable outcomes are
    - While the outcome might be "unromantic" it is still very exciting
  - Of course the harsh reality is we have little idea what the final 4 (especially the last 2) parameters should be

How far away would we expect them to be?

- Assuming civilizations are confined to the disk of the galaxy we can do a very rough estimation
- Volume of disk is $\propto$ disk area $\times$ disk thickness(T)

$$V = \pi r^2 T$$

- If the N civilizations are spread out perfectly evenly then each one effectively occupies a volume

$$V_c = V / N$$

Average distance between civilizations

- For simplicity, lets assume each region is a cube of size d, then

$$d = \sqrt[3]{V_c} = \sqrt[3]{V / N} = \sqrt[3]{\pi r^2 T / N}$$

- For two cubes of size d abutting one another the distance between civilizations at the cube centres is also d
- For the most optimistic values we considered the effective distance becomes

$$d = \sqrt[3]{\pi (16\,\text{kpc})^2 \times (0.5\,\text{kpc}) / 120000} = 0.15\,\text{kpc} \approx 500\,\text{ly}$$

Not very close at all!

Large distances

- For the values assumed by Drake & colleagues the average distance is even larger

$$d = \sqrt[3]{\pi (16\,\text{kpc})^2 \times (0.5\,\text{kpc}) / 10000} = 0.35\,\text{kpc} \approx 1100\,\text{ly}$$

- However, this calculation assumes that civilizations are equally likely to be anywhere in the disk
  - Not true, stars are not distributed evenly in the disk (more in the centre as we discussed)
  - It also ignores issues relating to the GHZ
- Lastly this is an average value, there is a finite probability of two civilizations being closer

Crichton's Critique

- Michael Crichton (the author) gave a lecture in 2003 that blasted SETI research
- Let's take a look at a few comments:

1) On the Drake Equation:

"This serious-looking equation gave SETI an serious footing as a legitimate intellectual inquiry. The problem, of course, is that none of the terms can be known, and most cannot even be estimated."

Crichton's Critique

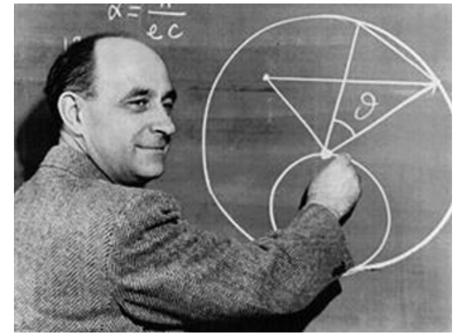
2) "*The only way to work the equation is to fill in with guesses. And guesses-just so we're clear-are merely expressions of prejudice. Nor can there be "informed guesses." If you need to state how many planets with life choose to communicate, there is simply no way to make an informed guess. It's simply prejudice.*"

3) "*As a result, the Drake equation can have any value from "billions and billions" to zero. An expression that can mean anything means nothing.*"

You can find a response here…

http://stephenschneider.stanford.edu/Publications/PDF_Papers/Perry2003.pdf

Fermi Paradox



- Before we discuss issues relating to SETI, it is interesting to look at an argument attributed to the physicist Enrico Fermi
- How long would it take a civilization to colonize the galaxy? Let's give a very crude argument…
  - Unfortunately we have to make some assumptions to get somewhere…
  - Let's assume that they've built ships that travel at speed fc where f is some fraction (<1) of the speed of light c
  - If the average distance between habitable worlds is d, then the time of flight will be $t=d/fc$

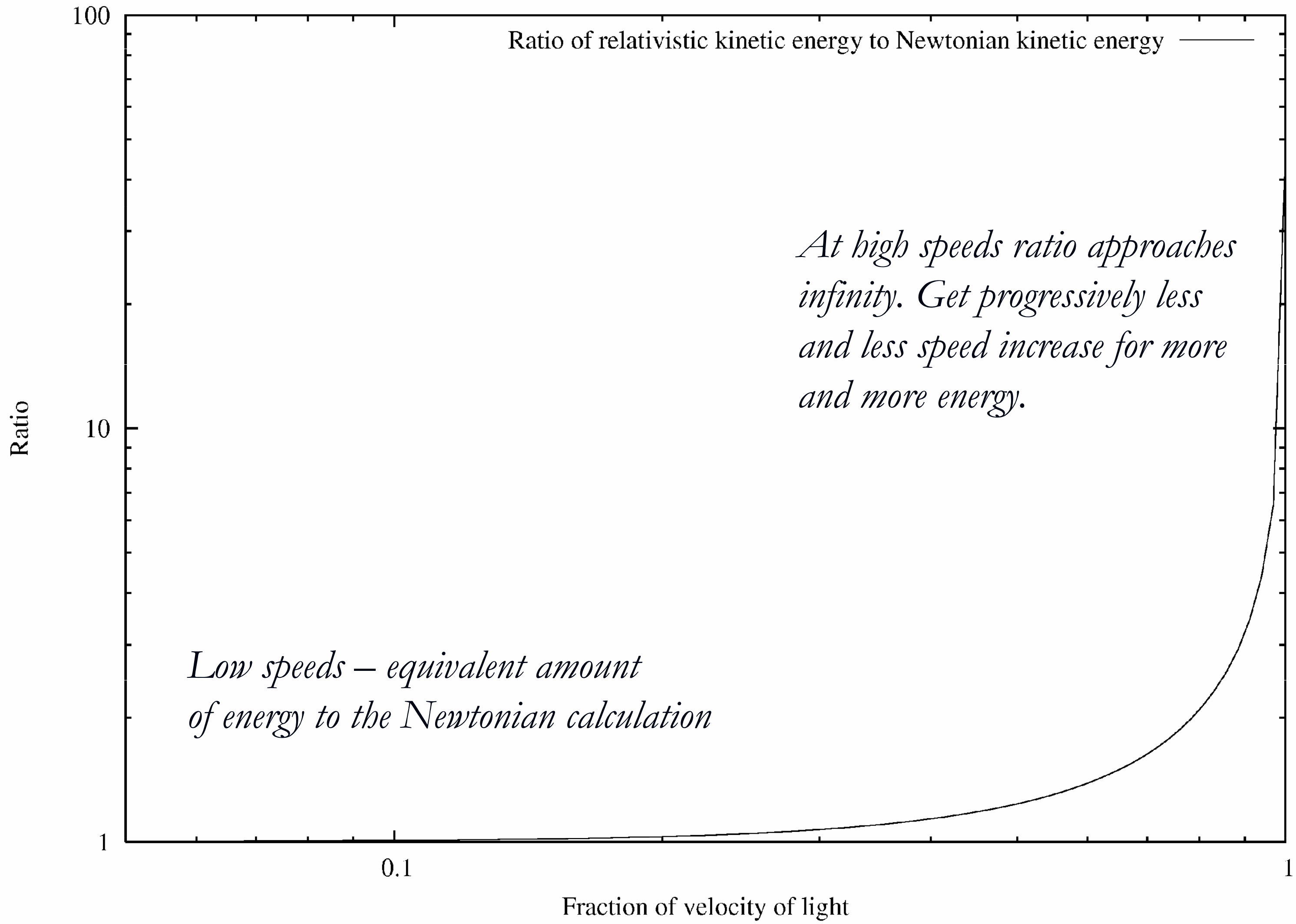
What speeds could we achieve?

- The physics of interstellar travel is *well understood* and is goal for future generations (just when? – who knows…)
  - Instead of just estimating the energy you need as $\frac{1}{2}mv^2$ you must use a formula from special relativity:

$$E_k = mc^2\left(\frac{1}{\sqrt{1-v^2/c^2}} - 1\right) = mc^2(\gamma - 1)$$

- At low speeds (small v) this formula is indistinguishable from $\frac{1}{2}mv^2$
- However, as $v \rightarrow c$ the energy required to accelerate an object to speed v becomes infinite
  - So we can never have f=1
- For a sufficiently small spacecraft we can potentially reach speeds around 0.1c (f=0.1)
  - Many of these ideas were worked out in the 60s & 70s
- However you need an incredibly efficient energy source – e.g. nuclear fusion, matter-anti matter combination…

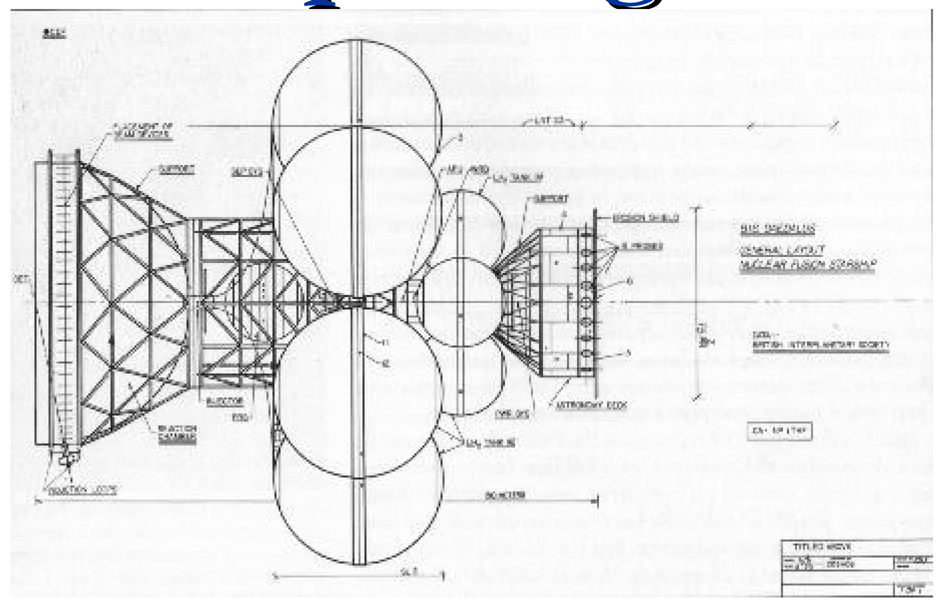
Energy for v→c

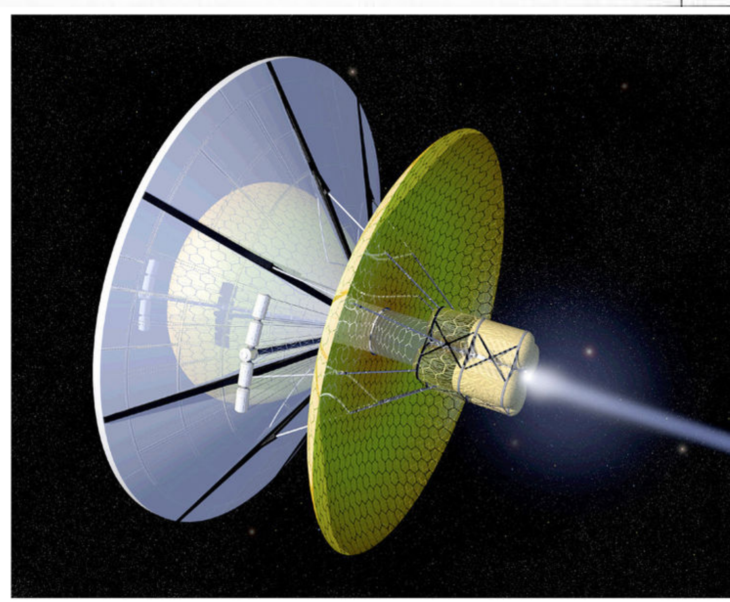


Interstellar spaceship designs

- Project Daedalus (1973)
  - Speed ~ 0.12c
  - Propulsion: “pulsed” fusion
  - 2 stage design, 50,000 tons of fuel!
- Interstellar ramjet (1960s)
  - Uses interstellar medium as fuel
  - Potentially better – don’t need to carry so much fuel
    - Can achieve higher speeds than Daedalus
  - Many more engineering problems to over come though

People do take this seriously!





Galactic colonization

- When the ships reach a habitable planet, we assume N_0 colonists carried on the ship (say 10000) begin a civilization that grows at at rate *g*, say 2% a year
  - This is actually quite a low growth rate for frontier populations - doubles every 35 years
    - exponential growth constant k= ln(1+*g*)
  - How long does it take the population to reach say, a critical value *P* (say) 10 billion, at which point they send another ship:

$$P = N_0 e^{kt} \Rightarrow (P / N_0) = e^{kt} \quad \text{and taking logs}$$

$$\ln(\mathrm{P/N_0}) = \mathrm{kt} \Rightarrow \mathrm{t} = \ln(\mathrm{P/N_0})/\mathrm{k}$$

$$\Rightarrow t = \ln(10^6) / \ln(1.02) \approx 700 \text{ years}$$

Colonization “step”

- Thus each successive “step” in the colonization takes

$$t_{step} = t_{travel} + t_{grow} = \frac{d}{fc} + \frac{\ln\left(\frac{P}{N_0}\right)}{\ln(1+g)}$$

- Suppose d is 100 ly and f is 0.01 (so that ships travel 1% the speed of light)

$$t_{travel} = \frac{d}{fc} = \frac{100\ \text{ly}}{0.01 \times 1\ \text{ly yr}^{-1}} = 10000\ \text{yr}$$

$$\text{Hence } t_{step} = 10000 + 700 = 10700\ \text{yr}$$

Time to cross galaxy

- So it takes approximately 10700 years to spread 100 ly
  - Implies the average speed of colonization is 0.093c
- Taking galaxy to be 100 000 light years across this implies a time to reach across the galaxy of

$$\frac{100000\ \text{ly}}{0.0093 \times 1\ \text{ly yr}^{-1}} \approx 10\ \text{million yr}$$

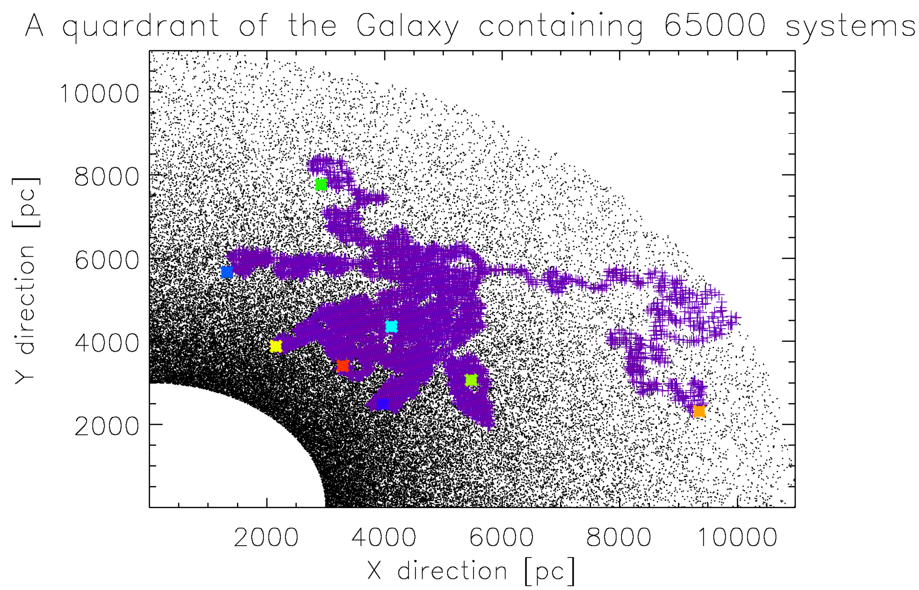
- Which is 10,000 times smaller than the age of the Universe
  - So if they aliens are out there and they wanted to colonize, they'd probably be here already
    - Is that a reasonable conclusion to draw?

Problems with the argument (and there are many!)

- ***Firstly, we've just looked at how long it takes to go in one particular direction, rather than how long it actually takes to "fill space"***
- Even our simple estimate might be too low:
  - not all colony ships might reach their destination safely
    - Didn't include a parameter for this
  - new colonies might not be interested in launching more colony ships
    - Didn't include a parameter for this
  - perhaps colonies don't grow as quickly as we've assumed (change g)
- But the distance crossing estimate could be too high as well:
  - perhaps there's a faster mode of travel (change f)
  - planets might launch another colony ship faster (change P)
  - maybe the distance between habitable planets is larger, which actually speed their progress (change d)

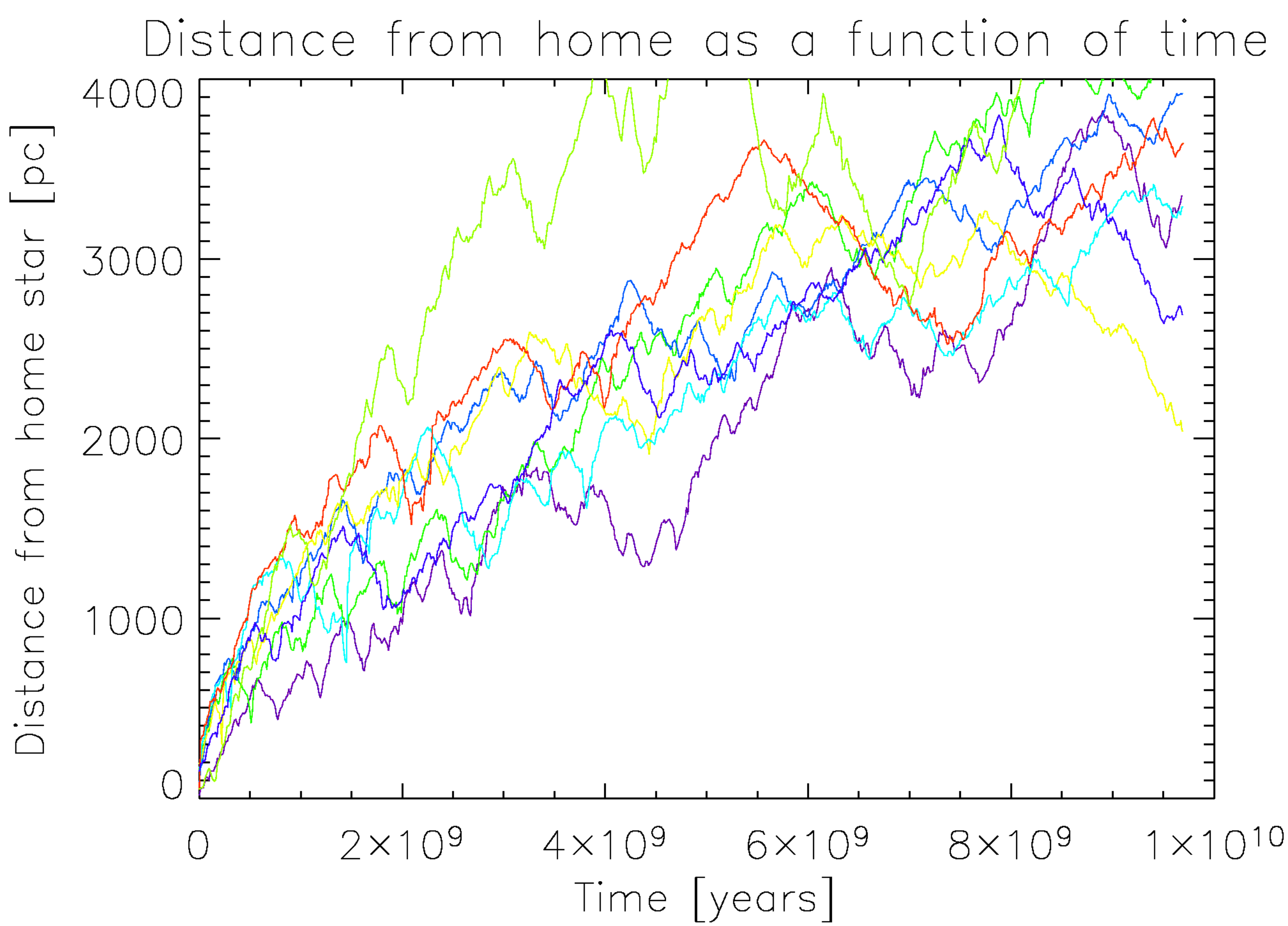
Bjørk's scenario (2007)

- Rasmus Bjørk (Niels Bohr Institute, Denmark) simulated how long it actually takes to fill up a region using a *fixed* number of probes
  - This is quite different to the strategy we mentioned previously
- Each of the initial 8 probes carries 8 sub-probes, & travel at 0.1c



http://arxiv.org/abs/astro-ph/0701238

Exploration for this scenario is much slower



Summary of lecture 28

- Prospects for finding ETI don't look good!
  - Our best guess values come out around 0.002!
  - The most optimistic values place N around 120,000, but this seems incredibly unlikely
  - The lower end of our estimates, primarily if societies don't decide to communicate, is ~0
- For our most optimistic estimate of N=120000 the distance between civilizations is about 500 ly on average
  - For N=10 the distance grows to 10000 ly
- Colonization could occur over fairly short time scales if we allow replication of probes
  - A small -- fixed number -- of probes will take a long time

Next lecture

- More on SETI