An introduction to
the Drake Equation

Zach Meisel

Ohio University - ASTR1000

How many intelligent, communicating extraterrestrial civilizations are out there?

- The Drake Equation is a tool to approach this question in a semi-quantitative way
- The number of civilizations that we could communicate with (N) is determined by
  the rate of star formation (R),
  the fraction of those stars with planets (f_p),
  the number those planets for a given star that are habitable (n_e),
  the fraction of those habitable planets that develop life (f_l),
  the fraction of those life-developing planets that result in intelligent life (f_i),
  the fraction of civilizations that develop the ability to communicate over long distances (f_c),
  and the lifetime of that civilization (L)
- Putting it all together:

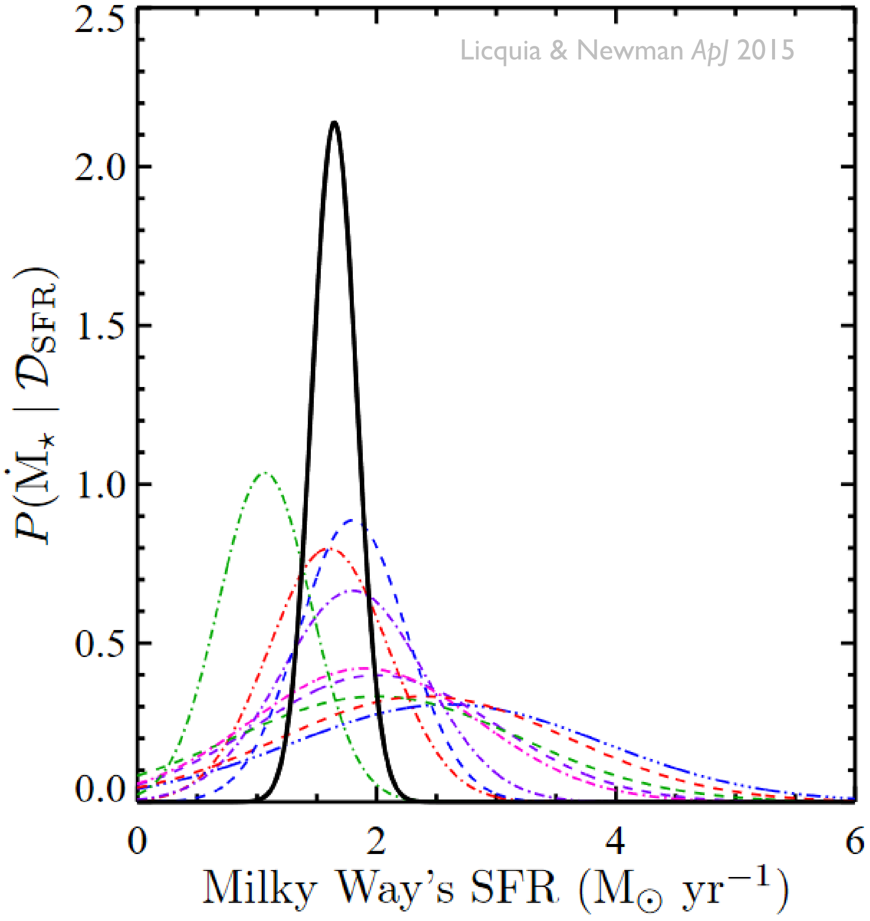
$$N = \boldsymbol{R f_p n_e} f_l f_i f_c L$$

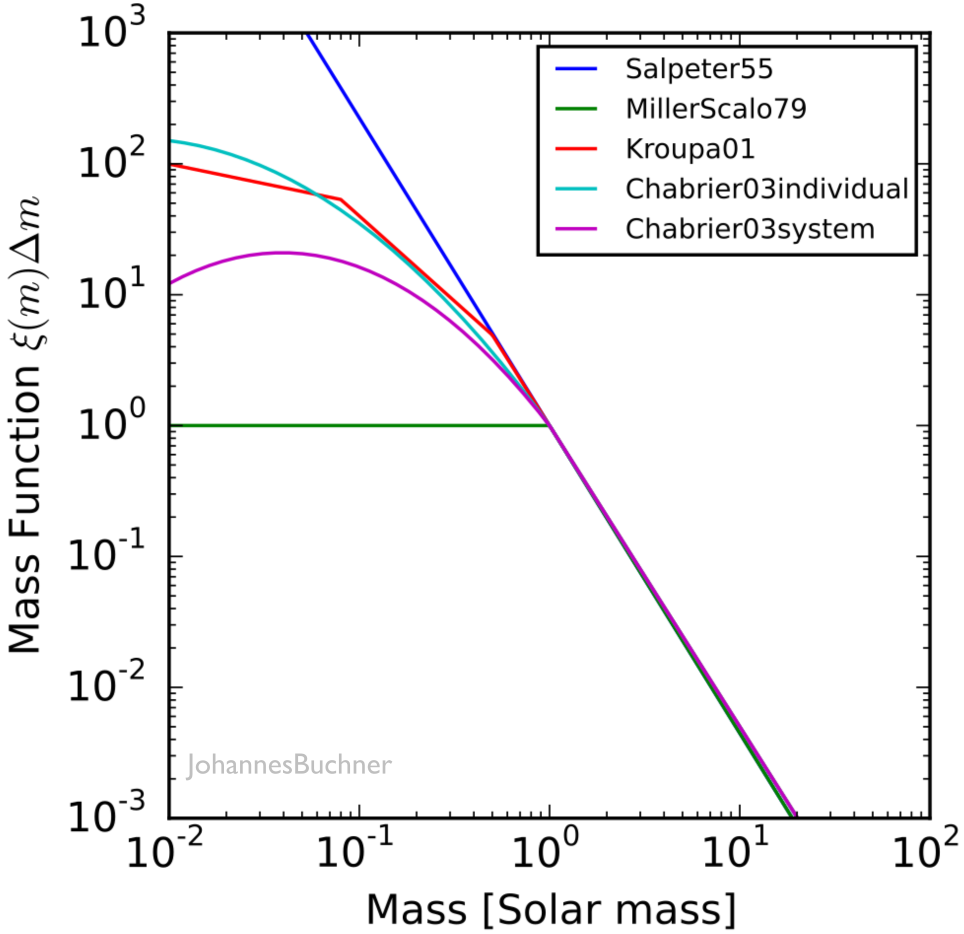
readily quantifiable

(much) more speculative

R in $N = Rf_p n_e f_l f_i f_c L$

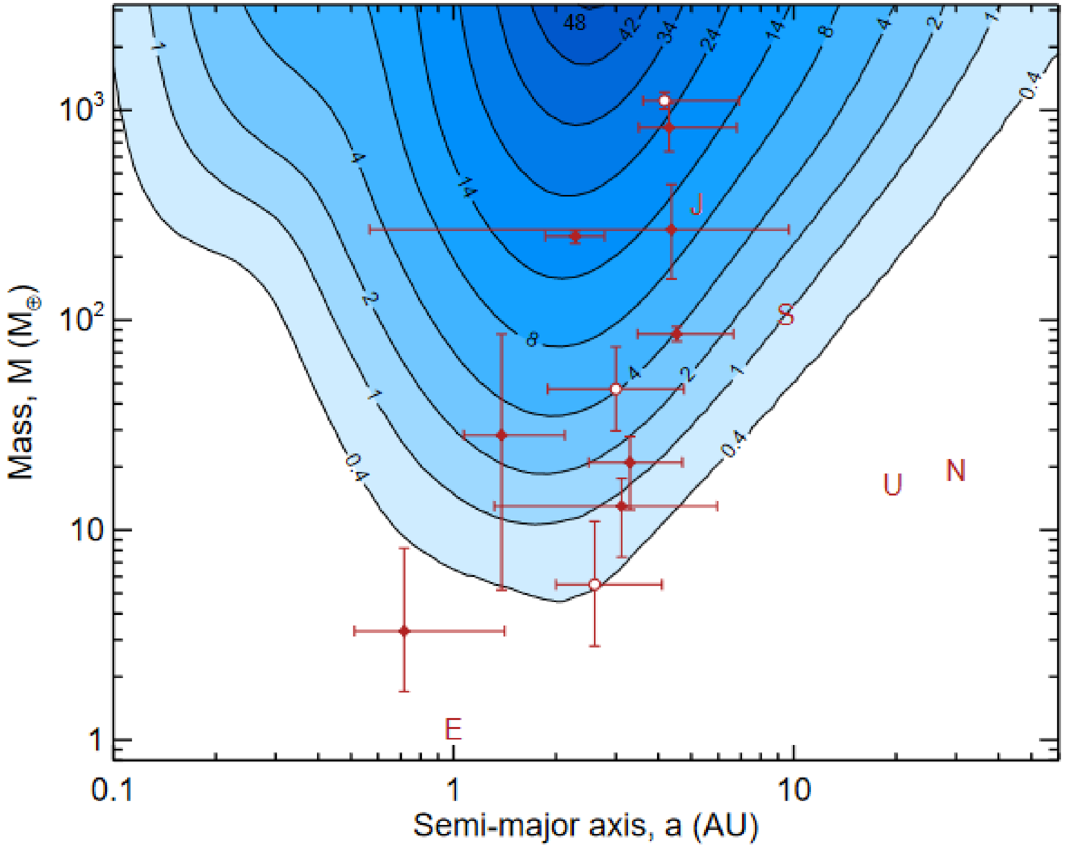
- The rate of star formation can be calculated by considering the mass of stars in the Milky Way, an initial mass function, and stellar lifetimes to arrive at something like ~4 stars/year


Licquia & Newman *ApJ* 2015

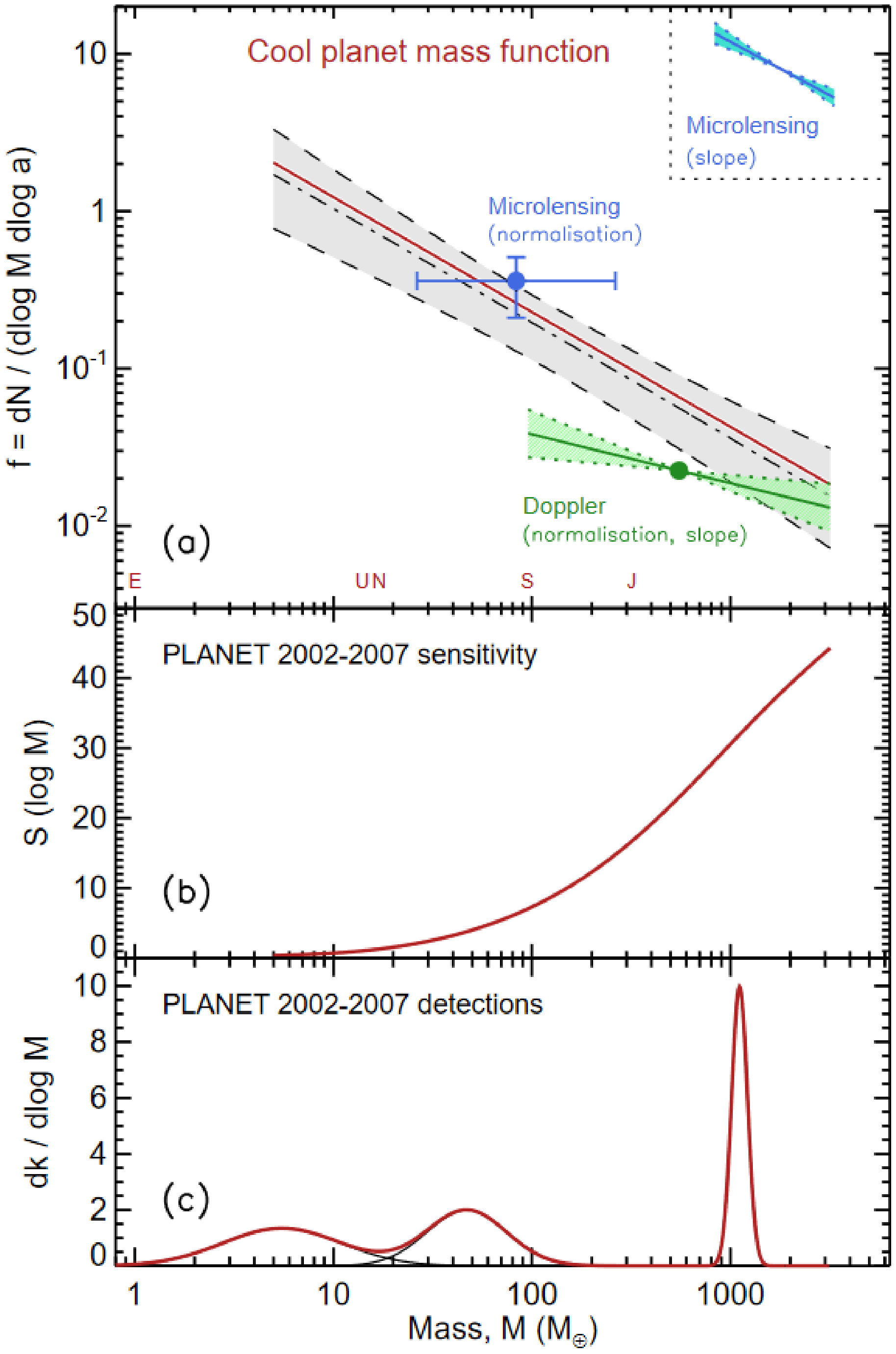

JohannesBuchner

f_p in $N = R f_p n_e f_l f_i f_c L$

- The fraction of stars with planets is thought to be ~1, taking into account the sensitivity of exoplanet detection methods and assuming a planetary mass function



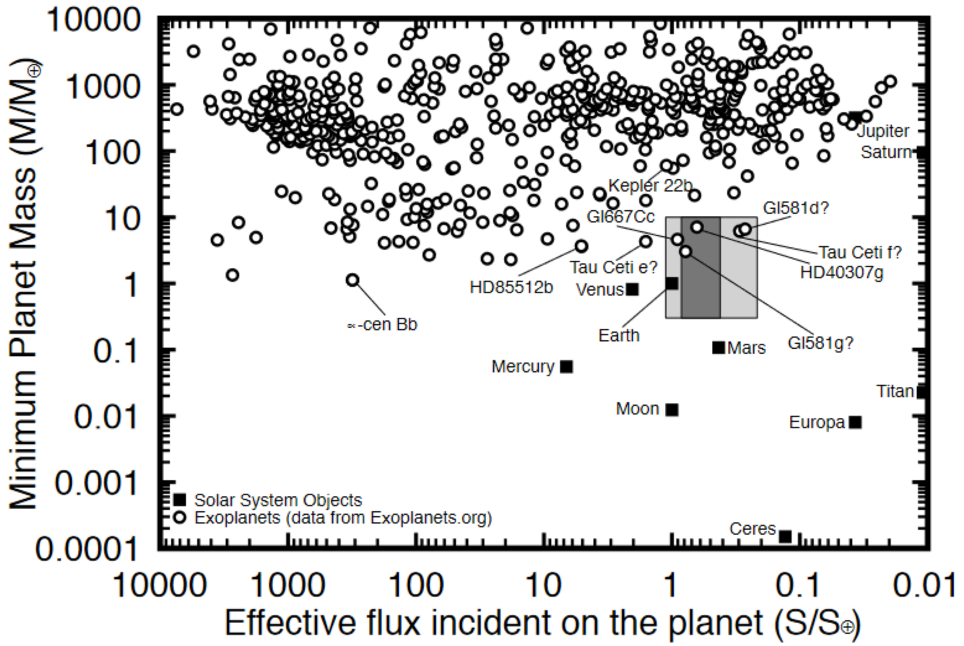
Cassan et al. *Nature* 2012

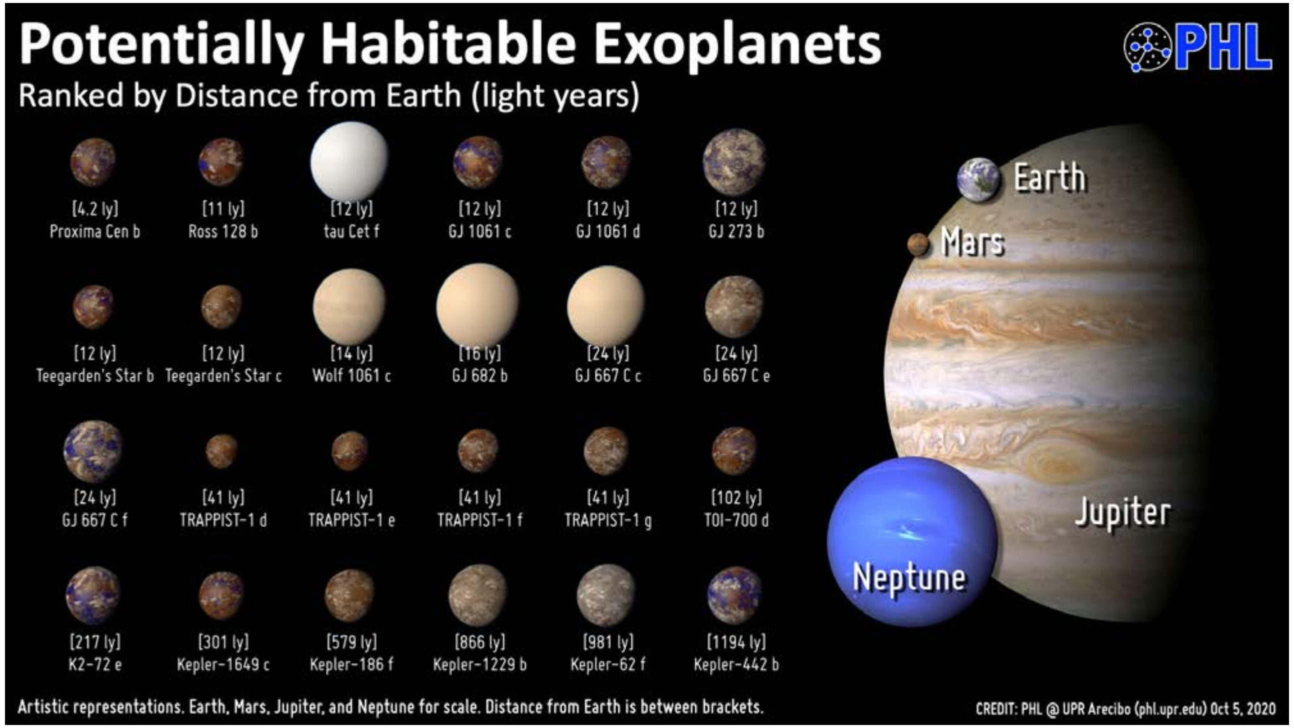


n_e in $N = R f_p n_e f_l f_i f_c L$

- The number of habitable planets per planet-hosting star is based on the criterion adopted for habitability (e.g. atmosphere conditions, moons, methane-based life, light flux, temperature)
- Using a (likely) rocky surface and (likely) ability to sustain liquid water, ~60 of the ~4,600 exoplanets detected to date are considered potentially habitable. Adding moons into the picture (see Intro to Solar System Life) probably doubles this number
- So ~0.02 isn't unreasonable, though detection bias & expanding criteria for habitability could make this ~1

Kopparapu et al. *ApJ* 2013





f_l in $N = R f_p n_e f_l f_i f_c L$

- Since we don't know how life began (see Intro to Habitability), estimating the fraction of habitable planets that actually develop life is a bit philosophical
- In favor of a high fraction:
  - Life developed on Earth more or less right away
  - The "mediocrity principle" is that, statistically, drawing from a random sample will yield something pretty average relative to the rest of the sample. (i.e. You are not special)
- In favor of a low fraction:
  - Life on Earth appears to have a universal common ancestor (use the same genetic code, have similar protein sequences)
  - No signs of life (yet) on the other plausibly habitable bodies in the solar system
  - Lab experiments (see Intro to Habitability) have yet to create something resembling life, so it's clearly not completely trivial
- So, this number can be as tiny as you like, or 1. Let's not be egotists & call it 1.

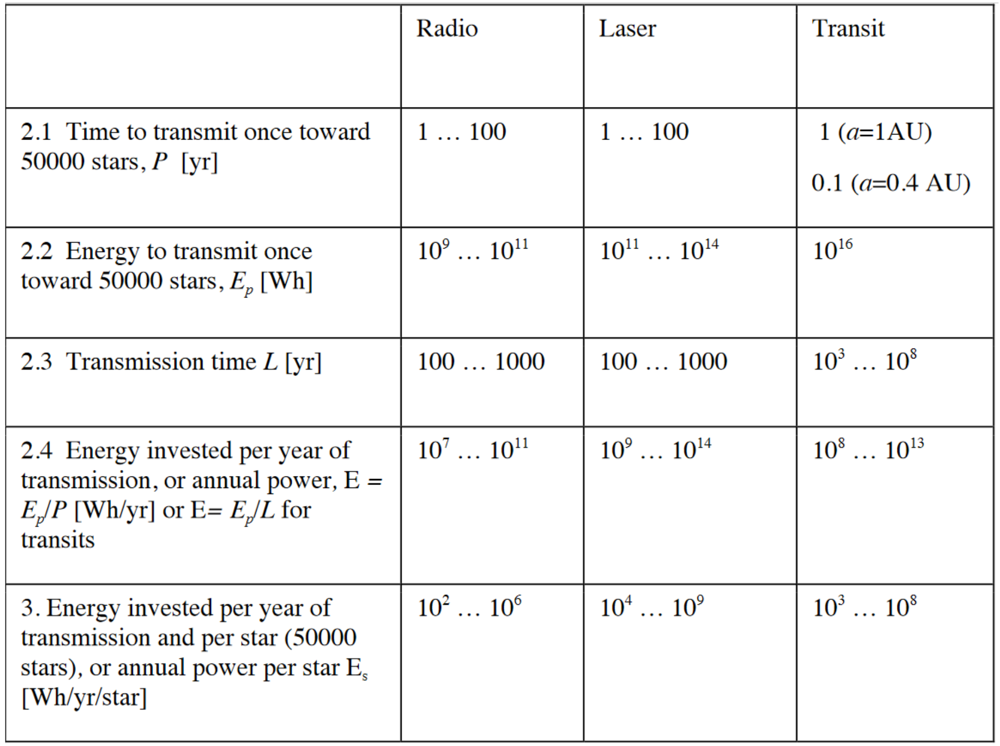
f_i in $N = R f_p n_e f_l f_i f_c L$

- The next big step is from life to intelligent life, which is again mostly philosophical. This also depends on what you define as "intelligent".
- In favor of a high fraction:
  - The evolutionary record on Earth demonstrates increasing complexity with time
  - Again, the mediocrity principle
  - If you treat each species on Earth as a separate experiment, lots are intelligent enough to communicate and social, several use tools, etc.
- In favor of a low fraction:
  - If you treat each species on Earth as a separate experiment, only one species has become intelligent enough to have a reasonable shot at extraterrestrial communication
  - While there's a shot microbial life could have existed on Mars, it is pretty clear intelligent life never developed
  - Intelligent life seems to take ~4.5 Gyr to evolve (like Earth)
- Again, this number can be as tiny as you like. You can be humble and call it 1.
- A relatively optimistic estimate would allow for microbial life on all habitable environments in the solar system (see Intro to Solar System Life), but only intelligent life on recent Earth, so ~0.05

f_c in $N = R f_p n_e f_l f_i f_c L$

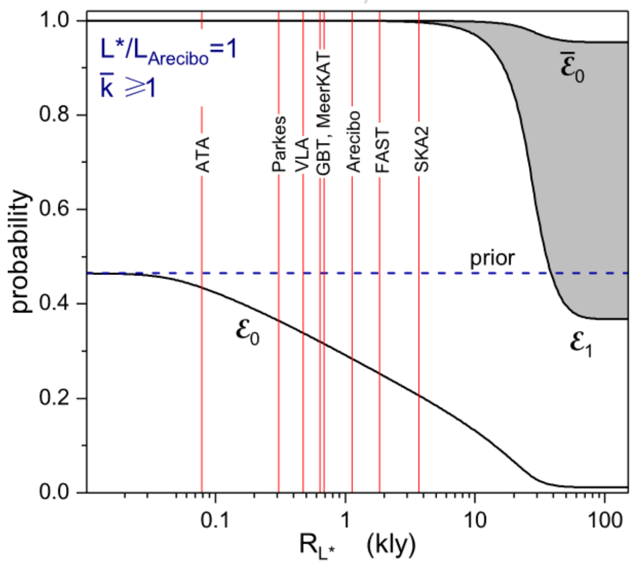
- The fraction of intelligent life forms that develop the ability to communicate makes an assumption about our ability to receive this communication.
- "Communication" could mean different things. Radio and laser signals are realistic for a civilization like ours, but a much older civilization could maybe engineer artificial satellites to create unique transit signals (see Intro to Exoplanets)
- Our ability to communicate is relatively puny.
With current & near-future telescopes, we would only have a chance of detecting a very-strong Earth-like radio signal (Arecibo) out to a few kly and a strong-but-regular signal (military radar) out to a few-hundred ly
- Again, appealing to mediocrity, we are pretty dumb and have managed some (relatively minor) communication. So let's be humble and assume ~1.

L. Arnold *Int.J.Astrobio.* 2013



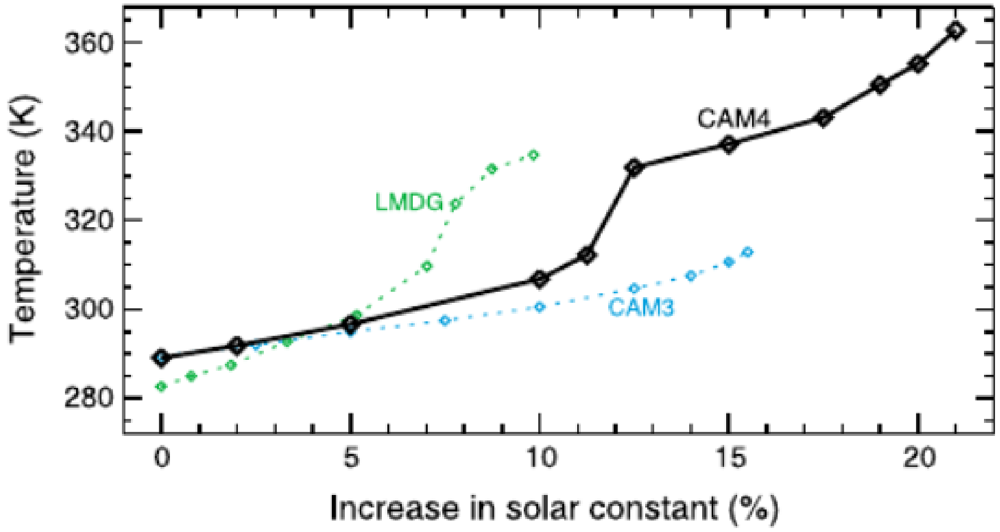
	Radio	Laser	Transit
2.1 Time to transmit once toward 50000 stars, P [yr]	1 … 100	1 … 100	1 (a=1AU) 0.1 (a=0.4 AU)
2.2 Energy to transmit once toward 50000 stars, E_p [Wh]	10^9 … 10^{11}	10^{11} … 10^{14}	10^{16}
2.3 Transmission time L [yr]	100 … 1000	100 … 1000	10^3 … 10^8
2.4 Energy invested per year of transmission, or annual power, E = E_p/P [Wh/yr] or E= E_p/L for transits	10^7 … 10^{11}	10^9 … 10^{14}	10^8 … 10^{13}
3. Energy invested per year of transmission and per star (50000 stars), or annual power per star E_s [Wh/yr/star]	10^2 … 10^6	10^4 … 10^9	10^3 … 10^8

Grimaldi & Marcy *PNAS* 2018

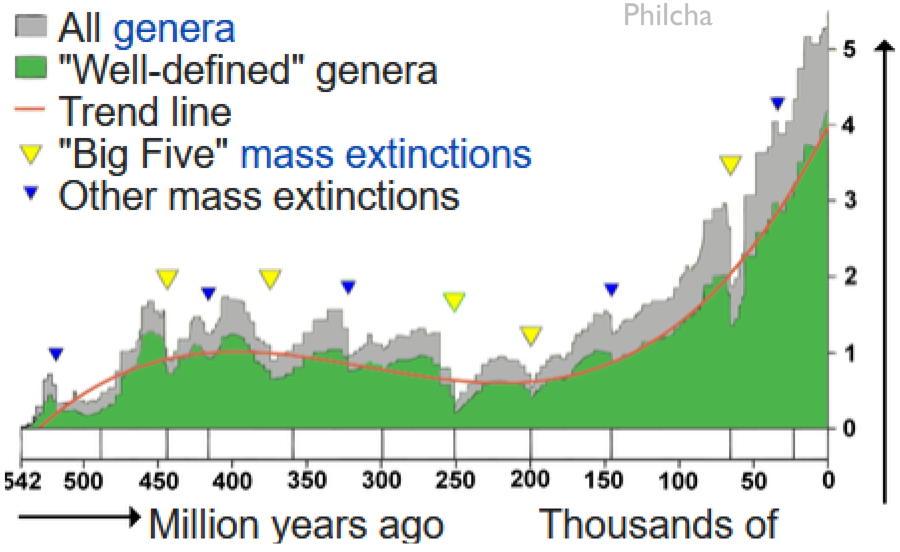


L in $N = Rf_p n_e f_l f_i f_c L$

- The lifetime of a communicating civilization depends on how long the civilization can survive and how long it will choose to communicate (i.e. maybe smart civilizations hide)
- A very optimistic view is that a civilization will communicate until the host planet is no longer viable. On Earth, that will be ~1Gyr, based on the increase of solar brightness over time (see Intro to Low Mass Stellar Evolution)
- A somewhat pessimistic view is that major extinctions happen every 30Myr or so
- A very pessimistic, but probably more realistic, view is that major civilizations only last for centuries. It's also pretty plausible that we'll blow ourselves up within the next 100 years



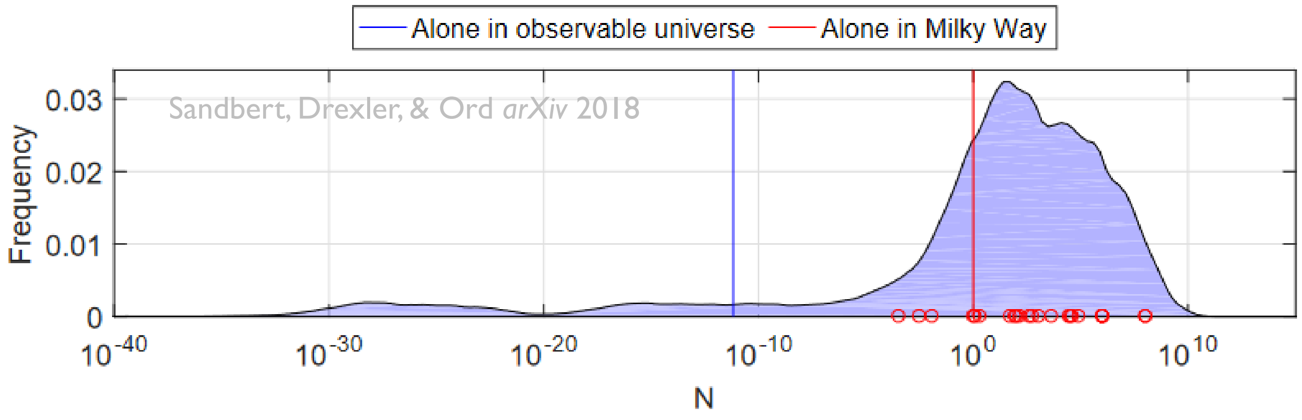
Wolf & Toon J. Geophys. Res.:Atm. 2015



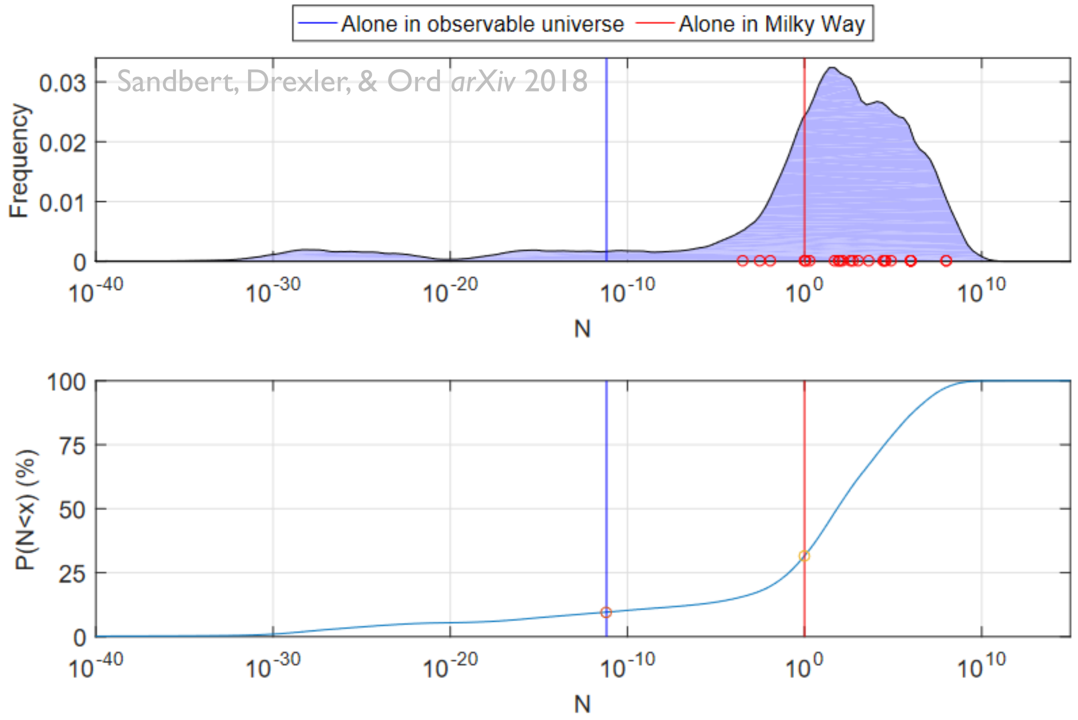
Philcha

N Estimates

- Taking the high-end of the estimates presented here, $N = R f_p n_e f_l f_i f_c L$ =(4/yr)(1)(1)(1)(1)(1)(1Gyr) = 4e9 in the Milky Way
  - Radio telescopes can maybe rule this out already, since we should be able to detect civilizations within a few-hundred ly, which comprises ~10^6 stars. That is ~10^{-5} of all stars in the Milky Way. So, we should have detected ~thousands already
- For the optimistic, but slightly more conservative estimates presented, $N = R f_p n_e f_l f_i f_c L$=(4/yr)(1)(0.02)(1)(0.05)(1)(30Myr) = 1.2e5 in the Milky Way
- Under those same slightly conservative assumptions, but "we'll all blow ourselves up", N=0.4 in the Milky Way. I.e. it's just us here, but we could look to nearby galaxies.
- The "wisdom of the crowd" is that there are something like several tens of communicating civilizations in the Milky Way
- …which would put the nearest one at a few thousand ly.
- Such a civilization would be plausibly detectable with near-future technology



The Fermi Paradox



- Scrooges like to remind us of the Fermi Paradox: if life is so common, why don't we see it?
- It could be one (or more) of the Drake Equation parameters are really small. This is known as "The Great Filter"
- Integrating the distribution based on lots of people's best guesses, there's a ~10% chance we're completely alone in the universe
- Before you get discouraged, note that given our poor ability to detect signals (so far), there could easily be tens of thousands of communicating civilizations in the Milky Way (…a Star Trek universe)
- We could use the Fermi Paradox in reverse: As our ability to detect distant signals improves, this places limits on parameters in the Drake Equation