The Drake Equation

$R_*$  average star formation rate (yr$^{-1}$)
$F_p$  fraction of stars with planets
$N_e$  number of planets (per star) that could support life
$F_l$  fraction of planets that could support life that develop life
$F_i$  fraction of planets with life that develop intelligence
$F_c$  fraction of intelligent species that develop IS communication
$L$  lifetime of civilizations

$N = R_* f_p n_e f_l f_i f_c L$
Drake’s estimates for the Drake Equation

5 \quad R_* \quad \text{average star formation rate (yr}^{-1})
0.5 \quad F_p \quad \text{fraction of stars with planets}
2 \quad N_e \quad \text{number of planets (per star) that could support life}
1 \quad F_l \quad \text{fraction of planets that could support life that develop life}
0.2 \quad F_i \quad \text{fraction of planets with life that develop intelligence}
1 \quad F_c \quad \text{fraction of intelligent species that develop IS communication}

10,000 \text{ L lifetime of civilizations}

\[ N = 10,000 \]

\[ \frac{10^4}{3 \times 10^{11}} = 30 \text{ ppb!} \]
A) ☹ People (or et equivalents) are short-lived. As vermin of a planet, technologically savvy organisms do themselves in, in short order. Earth would be better off without us!

B) ☺ Technological species are the only hope for long term survival of advanced life on planets. People can divert asteroids- dolphins cannot. People can survive and terraform for billions of years until the Sun becomes a red giant!
Are we as bad as some of us think? Are we lemmings?

The Voluntary Human Extinction Movement - VHEMT

What do humans do for the Earth's biosphere that isn't about humans?
Longevity of species

>99% of Earth’s species are extinct
Most species last a few million years
Some last for $>10^8$ years
How long can people last?
Will we be the last animal standing?
Are we nearly extinction proof?

Sharks have lasted 100’s of millions of years
Major mass extinctions in the fossil record

The evolution of sludge-life to people was greatly influenced by these chance events.
Long term threats to advanced life

- Impacts
- Misc mass extinction events
- Loss of CO$_2$
- Loss of Oceans
- Red Giant Sun

Effects due to the increasing brightness of the Sun
~10% per billion years until the red giant phase
Number of habitable planets

![Graph showing the number of habitable planets over time. The x-axis represents time in Gyr (Giga-years), with key points marked as Big Bang, Earth's Origin, and Present. The y-axis represents the number of habitable planets, with a logarithmic scale. The graph shows a logarithmic increase in the number of habitable planets from the Big Bang to the Earth's Origin, with a significant decrease by the Present. Two curves are present: one for primitive life, starting from a low number, and another for complex life, starting from a higher number than primitive life. The complex life curve shows a decrease, indicating a decline in the number of habitable planets for complex life.]
Without interdiction - all intelligent life on planets will be done in by impacts.

All planets are exposed to impacts!
Earth has many intelligent species, but only humans have science and technology.
Events in Earth’s Future

Next glacial cycle?
Return of Supercontinent
Decline in CO$_2$
Devolution
Mass extinctions
End of plants & animals
Loss of oceans
Merge with M31
Red Giant Sun
Lunar impact
Even if we can’t prevent the loss of CO$_2$ and the loss of the oceans, we can live in artificial environments. We already live in highly modified environments. Humans have the potential to survive to see the red giant Sun!
For good & bad
Humans control the fates of kilogram and larger land organisms

We are likely to control much of future life

Alexis Rockman