We have been attempting to detect alien technological civilisations since the 50s with SETI.

To motivate SETI Frank Drake came-up with the Drake Equation to attempt to quantify the number of alien technological civilisations in the Galaxy.

I’m going to argue that any number that comes from the Drake Equation is, at best, rubbish – but that looking at the unknowns is very useful to at least try and understand the level of our ignorance and see what questions we might want to ask.
15.1 SETI – what are we looking for?

The Search for Extra-Terrestrial Intelligence

Rather than simply looking for extra-terrestrial life, SETI aims specifically to find alien technological civilisations.

By technological civilisation, SETI means intelligent aliens with the technological ability to produce a detectable (electromagnetic) signal of its presence.

Historically this has been a radio signal, but now optical signals are also being searched for (maybe gravitational waves??).
15.2 SETI

At first it was assumed that the general radio emissions from alien civilisations would be detectable, however natural radio noise means that low-level signals would be undetectable at even moderate distances. (In addition, the use of tight-beam communication, satellites and optical fibres has meant that our radio emissions into space have decreased over the past few years.)

Thus SETI searches for deliberate attempts by aliens to signal their existence.
15.2 SETI – the waterhole

Most attempts to look for signals concentrate in the 'waterhole' at 1440-1620 MHz between the Galactic background and Cosmic Microwave Background. In particular there are an H and OH line in this region, and it is assumed aliens would see the significance of H+OH=H$_2$O
15.2 SETI – the waterhole

WE’VE SEARCHED DOZENS OF THESE FLOOR TILES FOR SEVERAL COMMON TYPES OF PHEROMONE TRAILS.

IF THERE WERE INTELLIGENT LIFE UP THERE, WE WOULD HAVE SEEN ITS MESSAGES BY NOW.

THE WORLD’S FIRST ANT COLONY TO ACHIEVE SENTIENCE CALLS OFF THE SEARCH FOR US.

xkcd.com – check it out if you’ve never heard of it...
15.3 The Drake equation

The Drake equation is an attempt to quantify the number of communicating alien civilisations in the Galaxy \( (N_{\text{civ}}) \):

\[
N_{\text{civ}} = N_{\text{star}} f_{\text{plan}} N_{\text{hab}} f_{\text{life}} f_{\text{intel}} f_{\text{comm}} f_{\text{exist}}
\]

where

- \( N_{\text{star}} \) = number of stars in the Galaxy,
- \( f_{\text{plan}} \) = fraction of stars with planets
- \( N_{\text{hab}} \) = number of potentially habitable planets per star with planets
- \( f_{\text{life}} \) = fraction of potentially habitable planets with life
- \( f_{\text{intel}} \) = fraction of planets with life that develop intelligence
- \( f_{\text{comm}} \) = fraction of intelligences that communicate
- \( f_{\text{exist}} \) = fraction of a planet's life that communication occurs

There are variations on this theme.
The number of stars in the Galaxy is a relatively well-known quantity, estimated to be $N_{\text{star}} \sim 10^{11}$ (best guess is about 400 billion).

The number of stars in external galaxies can be relatively well determined from their integrated spectra, the main uncertainty is in the numbers of M-dwarfs – which are the most numerous stars, but also the faintest.

The main uncertainty for the number of stars in the Galaxy comes from an uncertainty in the size of the Galaxy. Our distance from the centre is normally taken to be $\sim 8$ kpc, but some estimates put it as low as 6 kpc.
15.3 The Drake equation: $f_{\text{plan}}$

The fraction of stars with planets appears to be at least $\sim$20-30% for those stars that have been surveyed using the Doppler method.

However, this method is biased towards observing G-dwarfs with high metallicity....

$$f_{\text{plan}} = 20-60 \%$$

(Note that the bulk of stars with $[\text{Fe/H}] > -0.3$ are relatively young).
The (average) number of potentially habitable planets/moons per star is highly uncertain.

It depends on what is meant by 'potentially habitable'. The Solar System may have has at least 6 potentially habitable bodies: Venus (pre-runaway greenhouse – would this have happened with life?), Earth (obviously), Mars (certainly habitable in the past – possibly life now?), Io (volcanic heating), Europa (sub-surface ocean?) and Titan (liquids?).

Does migration destroy potentially habitable planets?

What really matters is the value of the next term...
15.3 The Drake equation: \( f_{\text{life}} \)

On what fraction of 'potentially habitable' planets does life arise? This must be >0 as we exist...

The rapid development (few hundred my) of life on Earth suggests that this might be high – ie. that life is easy to produce from non-life.

BUT:
- Did life have to develop early (so as to avoid a runaway greenhouse as on Venus??), if so the rapid development of life of Earth tells us nothing.
- Even if life is easy to make on Earth – was there anything special about the early Earth, or is liquid water + chemicals + energy enough?

(see lecture 14)
This fraction includes three different factors:

ONE: The development of advanced life – how likely is simple unicellular life to develop into complex multicellular life? Are events like the development of eukaryotic cells, sexual reproduction, the Cambrian explosion the natural result of so many years (and how many?) of evolution, or do some/all of them require specific environmental triggers that often do not occur? (Without 'snowball earth' would we have had animals? How likely is a similar event on other planets?)

We even need to ask if once life is started, does it always continue? If Venus developed life, that life is now gone. If Mars developed life, it has probably not developed advanced life.
TWO: The development of intelligent life – if advanced life arises how likely is intelligence? It can be argued that intelligence helps survival and so is a natural product of evolution.

THREE: As SETI searches for alien technological civilisations, intelligence is not enough – that intelligence must produce a technological civilisation.

If chimps and dolphins are intelligent, they have not produced a technological civilisation – could they? Does intelligence always lead to technology (With chimps maybe? Not with dolphins?)
What fraction of intelligent alien *technological* civilisations (ATCs) communicate (either on purpose or not, currently SETI requires this to be a deliberate attempt to communicate)?

ATCs may well not want to communicate their existence? There is currently a moratorium on anybody attempting to communicate our existence (following the Aricebo message). Why advertise your presence – who knows what's out there?

Alternatively, communication can pass-on information and knowledge between ATCs (if a signal could be decoded, and even then would it mean anything, or would alien mentalities be so different as to make communication meaningless?).
For what fraction of a planet's lifetime does communication occur?

Would an ATC communicate for 100s, 1000s, or 1000000s of years? Once started, why would they stop? Maybe ATCs have a limited life before destroying themselves/their ecology? Maybe technology advances so rapidly the need to communicate using such 'simple' methods as the EM spectrum lasts only a short time?

Next lecture we'll discuss these points in detail when we talk about the Fermi Paradox.
15.3 The Drake equation: numbers

The number of communicating alien civilisations in the Galaxy

\[ N_{\text{civ}} = N_{\text{star}} f_{\text{plan}} N_{\text{hab}} f_{\text{life}} f_{\text{intel}} f_{\text{comm}} f_{\text{exist}} \]

- \( N_{\text{star}} \) = few \( \times 10^{11} \)
- \( f_{\text{plan}} \) = 20-50%??
- \( N_{\text{hab}} \) = 0.1-5???
- \( f_{\text{life}} > 0 \) (we exist) ???????
- \( f_{\text{intel}} > 0 \) (we exist) ????????????
- \( f_{\text{comm}} \) = ?????????????????????????????
- \( f_{\text{exist}} \) = ?????????????????????????????????????????

(number of '?' gives an uncertainty estimate)
Proponents of the Drake equation often forget a crucial factor: timescales of Galactic and biological evolution.

The Galaxy is ~10 Gyr old, and life on Earth has taken 4.5 Gyr (0.5 Gyr to life + 3.5 Gyr to animals + 0.5 Gyr to humans) to achieve an intelligent technological civilisation.

Is 4.5 Gyr quick or slow for an 'average' planet? If it is quick, then most stars even if they could develop ATCs have not done so yet, and may not do before they die.
15.3 Is the Drake equation pointless?

YES.

It is impossible to obtain a number that makes any sense whatsoever as our knowledge of almost all of the terms is limited at best.

NO.

At least it allows us to examine the levels of our ignorance...
15.3 Is the Drake equation pointless?

The Drake Equation

\[ N = R^* \cdot f_p \cdot n_e \cdot f_i \cdot f_c \cdot L \cdot B_s \]

- Number of communicating civilizations in our galaxy
- Probability that life on a planet becomes intelligent
- Number of life-supporting planets per solar system
- Amount of bullshit you're willing to buy from Frank Drake

xkcd.com again...