# Part I---Introduction: planets, and habitable planets

**star**--about $10^{11}$ in our galaxy. Average separation is a few light years. (Compare with size of Galaxy: about 100,000 light years)

**planet**--indirect arguments from theory as well as direct observations of extrasolar planets suggest *giant* planets may be very common. But Earth-like (much smaller, rocky) planets?

**habitable planet**--requires liquiad? Liquid water? Nearly everyone agrees this is fundamental (we'll discuss why later). Requires special temperature range, and so only certain range of distances from star.
Probably additional factors for habitability, like planetary mass (for atmosphere), …

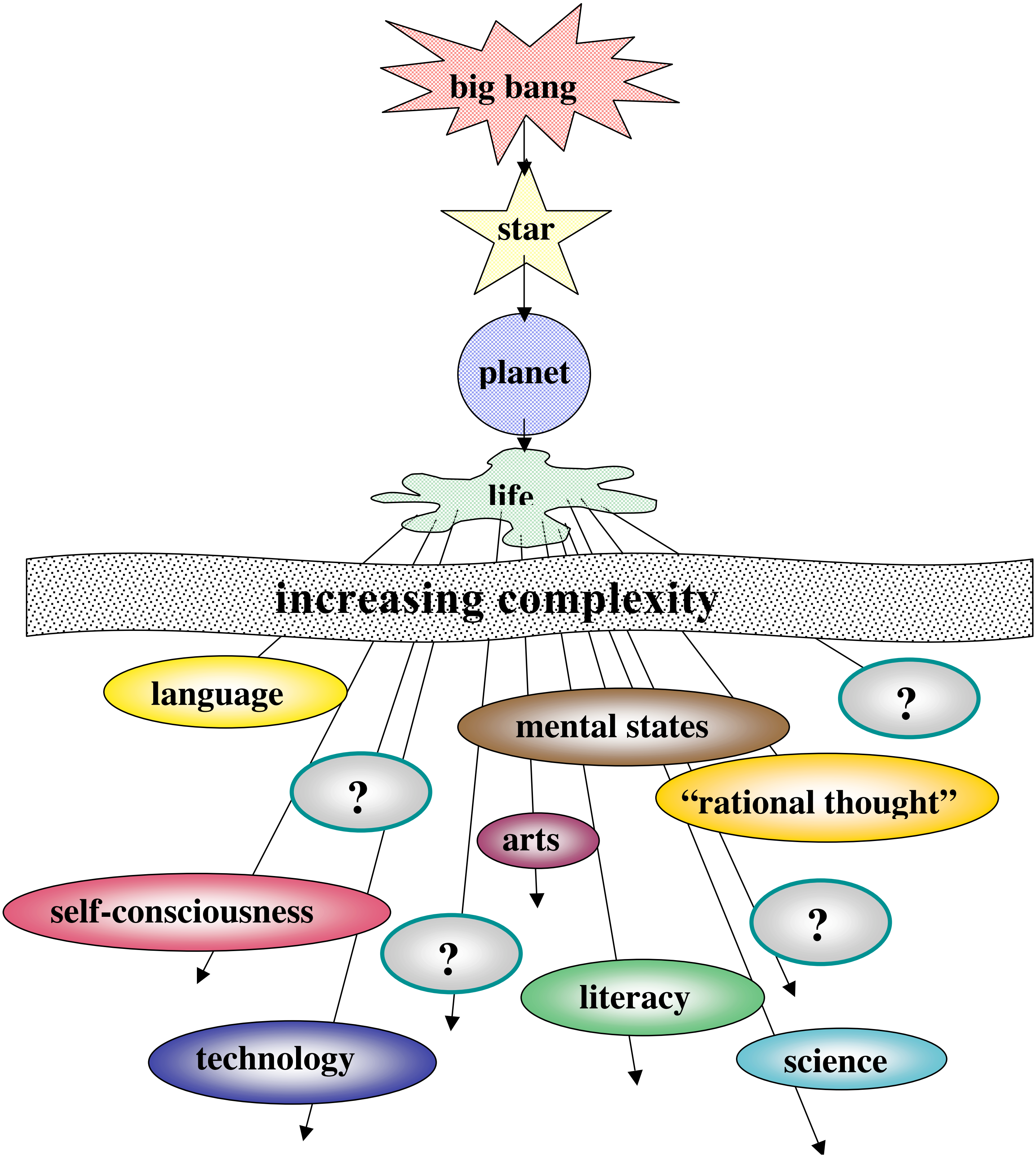
**life**--How probable or improbable? Need to understand how life arose and developed on Earth (our only example). We will spend the 2nd part of this course discussing the many theories, experiments, and types of evidence related to this.

**intelligence**--What does this mean? Are there different "types"? Why think that extraterrestrials would share our forms of cognition? Compare cross-cultural, cross-species, cross-historical cognition.

**communication**—representation, language. How likely? Other forms?

**length of time spent communicating**—we expect any *nearby* civilizations to have had a *long* lifetime. (We'll see why this is so shortly.)

Another way to look at the problem is: What is the likelihood or probability that the following sequence of events will occur, ending up with the rather peculiar group of phenomena listed at the bottom branching? And are there many other possible branchings that we haven't thought of, or are incapable (for, say, biological reasons) of thinking of?



# The “Drake equation”

Main purposes of discussing this equation are:

1. To organize the topics that we need to discuss in detail.
2. To demonstrate that in order for Galactic civilizations to be close enough for communication to be feasible, the average lifetimes of civilizations must be VERY large.

You will never be asked to do calculations using this equation; it is just a handy symbolic tool for discussion.

Multiply together the separate probabilities for:

**star, planet, habitable planet, life, intelligence, technology**

to obtain an estimate of the number of communicating civilizations in our galaxy N:

$$N = N_* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot (L/L_{\text{Galaxy}})$$

where $N_*$ is the number of stars in our Galaxy ($\sim 10^{11}$), L is the average lifetime spent in the phase in question (e.g. technological and communicative) and $L_{\text{Galaxy}}$ is the age of our Galaxy ($\sim 10^{10}$ yr).

(The formula is written slightly differently in different sources, but the idea is the same. BSJ [pp. 274-277] use “$N_{HP}$” for the product $N_* \cdot f_p \cdot n_e$ above (number of habitable planets) and “$f_{now}$” in place of $(L/L_{\text{Galaxy}})$, but they mean the same thing. The “original” Drake equation that is usually used is given on p. 276, and uses the rate of star formation $R_*$ and L instead of $N_*$ and $L/L_{\text{Galaxy}}$ but the product is equivalent. Thinking about this will sharpen your understanding of the equation, but if it makes sense to you and you remember that we are really only using it to make a couple of points, you’ll be ok.)

Notice that the ratio in the last factor gives the fraction of time that the civilization is “on”. (A “light switch” analogy will be discussed in class).

[We could also include factors for fraction of planets with oceans, or large moons, or enough metals for communicating technology, or other effects that might be important, but we’ll come back to that later in the course.]

It is important to understand the relation between the number of civilizations N and their average separation, since that is what determines whether any communication (at the speed of light) is possible. We discuss this further below. First, let's see that if N is large enough for two-way communication, the lifetimes L of these civilizations must be (on average) *extremely* large.

**Example**: Number of planets with *life*

If we leave out $f_i$ and $f_c$ (i.e. assume they are unity—all life forms develop our kind of intelligence and technology and try to communicate), we are calculating the number of life-bearing planets in our Galaxy <u>at any given time</u> (like now). We know there has been life on our planet for 3 billion years, so take L = 3 billion. Let's be optimistic about $f_p$ (0.1), $n_p$ (1), and $f_l$ = (0.1). Then

$$N_{life} \sim 10^{11} \times 0.1 \times 1 \times 0.1 \times (3 \text{ billion}/10 \text{ billion}) = 300 \text{ million}$$

300 million planets with life in our Galaxy! That's roughly1 out of 1000 stars. This means that the nearest life-bearing planet might only be 10-100 light years away, close enough that in the future *we may be able to detect such planets and obtain their spectra* (that is the primary goal of astrobiology space missions for the next decade).

**This result is a major reason for exerting most of our effort toward detecting signatures of biochemistry in the spectra of planets orbiting nearby stars. You will be reading and hearing a lot about "biosignatures" in this class soon!**

But if we are interested in planets with *communicating life*, even if $f_i$ and $f_c$ = 0.1 (optimistic!), we only get

$$N_{comm} \sim 10^{11} \times 0.1 \times 1 \times 0.1 \times 0.1 \times 0.1 \times L_{comm} / 10 \text{ billion}$$
$$= L_{comm}$$

*If* $L_{comm}$ is only 1000 yr (roughly 10 times our age), then $N_{comm} \sim 1$ (unlikely to be *any* others: we are essentially alone). And this is the "optimistic case" with large values of the various Drake equation probabilities, where we are getting N = L. Many people think it is very likely that $N \sim 10^{-4}$ L or even much smaller. (See later pictures.)

⇒ **So for communicating civilizations to be numerous, L must be very large, e.g. $\gtrsim 10^6$ years!**

What would such a civilization with a very long lifetime be like?
e.g. genetically-engineered photosynthetic, disease-free humanoids with regenerating brains and extremely long lifespan?

or replicating conscious bio-computers?
or beings that have transcended the level of ideas, concepts, etc.? etc.

In any case, the point is that **if the Galaxy is populated enough so that we can communicate with them, we had better be prepared to encounter civilizations that have been around *much* longer than us.**

## Significance of N: Distance to our nearest neighbors

In most respects the Drake equation is merely a nice way to organize the categories of questions we must consider in developing strategies for SETI. But it is still interesting to consider the implications of the number "N" of currently communicating civilizations in our galaxy.

Why? Because large N means that such civilizations are more densely located in our galaxy, so that the expected distance (call it "d") to one is smaller. Let's look at some numbers.

Can show that, roughly, the average distance to the nearest civilization is related to N by (will explain in class—this is for stars in a disk):

$$d \sim 100{,}000/N^{1/2} \text{ l.y. (light years)}$$

If N = 100, d ~ 10,000 l.y. ——> forget it!
10,000, d ~ 1,000 l.y.
1,000,000, d ~ 100 l.y.
100,000,000, d ~ 10 l.y. ——> worth attempting contact

Actually this formula is only valid for N less than about 10,000 (because it assumes the civilizations are so rare that they are spread out in the 2-dimensional Galactic disk. If N is greater than this, then most of the civilizations will be so nearby that the disk of our Galaxy doesn't enter into it (explained in class), so the formula should read (roughly)

$$d \sim 10{,}000/N^{1/3} \text{ l.y.}$$

The results are very similar. e.g. if N = 1,000, d~1,000 l.y; if N = 1,000,000, d~ 100 l.y.

**The basic point is**: If <u>two-way</u> communication is going to be feasible (at the speed of light!), the galaxy had better have *at least* <u>millions</u> of civilizations! And we have already seen that for this to be true (N very large) L must be enormous, so two-way communication means we would likely be communicating with a civilization *far* older (and probably much more "advanced") than ours.

**Time Scale for Origin of Planets and Life**

It will be very useful to have a rough idea of the times involved in the various topics that we'll be discussing. You should eventually memorize the numbers down to the horizontal line.

Millions of Years Ago: What Happened

14,000 Big Bang—origin of our (part of the) universe (can memorize as "10 billion")

4,600 Origin of planets and Sun (only took about 10 million yr.)

4,400 Earth cools enough for water to condense (evidence from ancient zircons)

3,800 Era of heavy bombardment (by planetesimals) ends (probably molten until then)
[End of part I of course]
3,500 Origin of life (?) How??
[End of part II of course]
3,000 Anaerobic photosynthetic bacteria (no oxygen in Earth's atmosphere yet)

2,500 Earth's atmosphere fills up with oxygen from photosynthesis

1,500 Eukaryotes arise (more complex cells; maybe primitive algae)

1,000 Origin of meiosis (sex)

1,000 Snowball Earth? (Completely glaciated, even at equator)

600 Multicellular organisms ("Cambrian explosion")—huge increase in complexity
First skeletons and easily recognizable fossils

2 Homo erectus
0.2 Homo sapiens

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0.006 Sumerians invent "civilization"
0.002 Roman Empire conquers Europe
0.0004 British Empire "civilizes World"
0.00004 DNA double helix discovered; SETI begins
0.000004 you enrolled at UT