AST 309L: Part I.A

The Drake Equation and Its Implications

Galaxies like ours: How many of these 100 billion stars might have planets, with life, or with “intelligent” life? We can organize the issues we have to address with the “Drake equation.”

NGC 4414

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Requirements for successful ETI search: Basic factors in the Drake equation

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), …

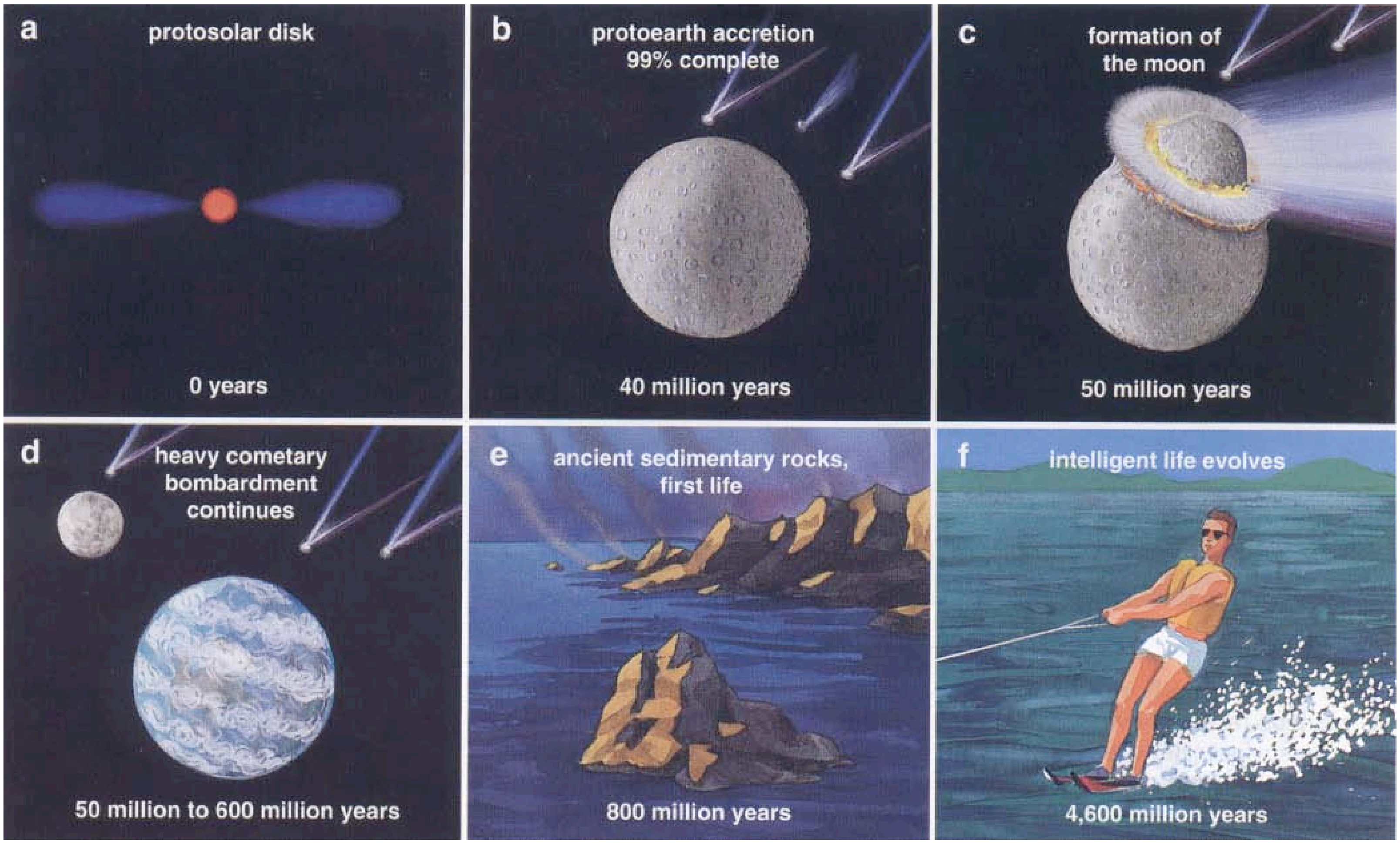
life--How probable or improbable? Need to understand how life arose and developed on Earth (our only example). We will spend the 2nd part of this course discussing the many theories, experiments, and types of evidence related to this.

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.)

The Drake equation is just a symbolic way of asking what the probabilities are that a sequence of events like those below (and more) might occur in other planetary systems.



Another way of looking at the sequence of events required symbolically represented by the Drake equation:

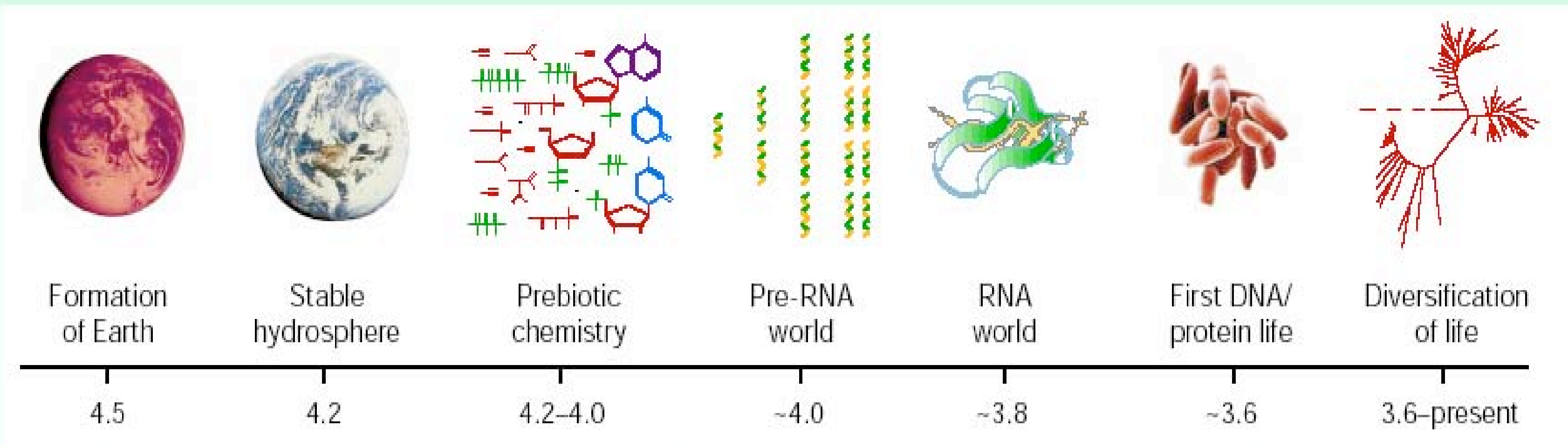
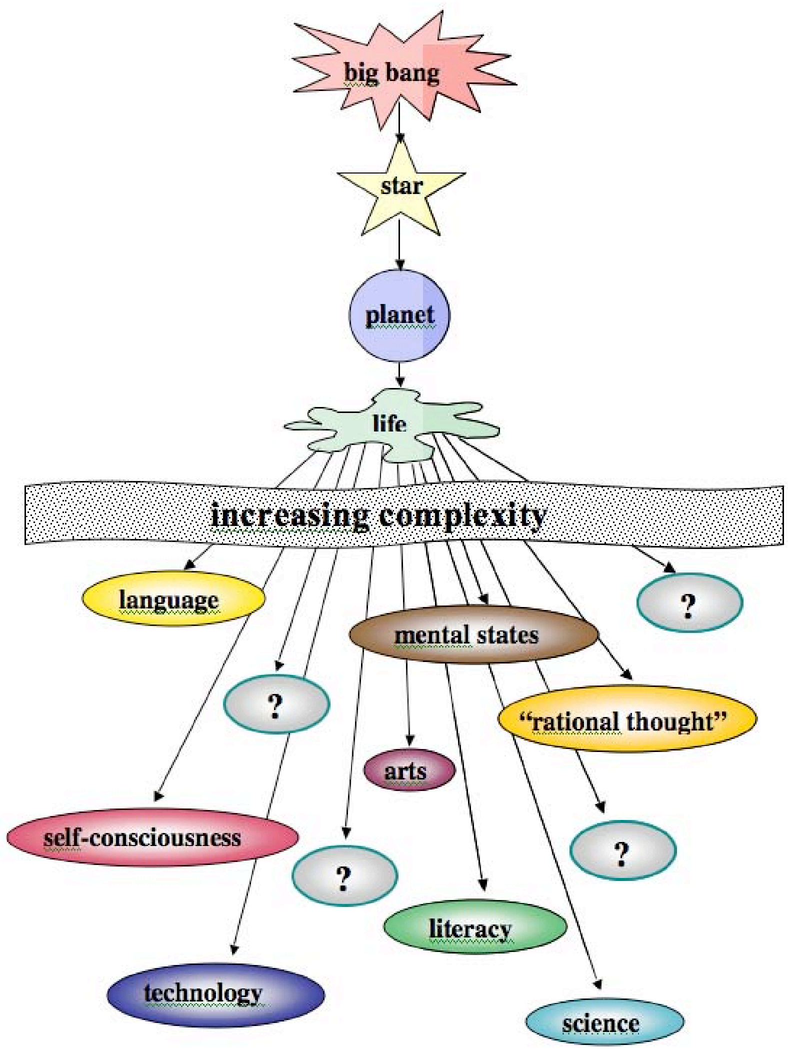


Figure 1 Timeline of events pertaining to the early history of life on Earth, with approximate dates in billions of years before the present.

For communication with extraterrestrial life, we need to understand the likelihood of life developing into some form that participates in the modes of cognition that we do--this brings up the questions of the inevitability of "intelligence" and representational language (last part of course). Certainly not obvious!



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:

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

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

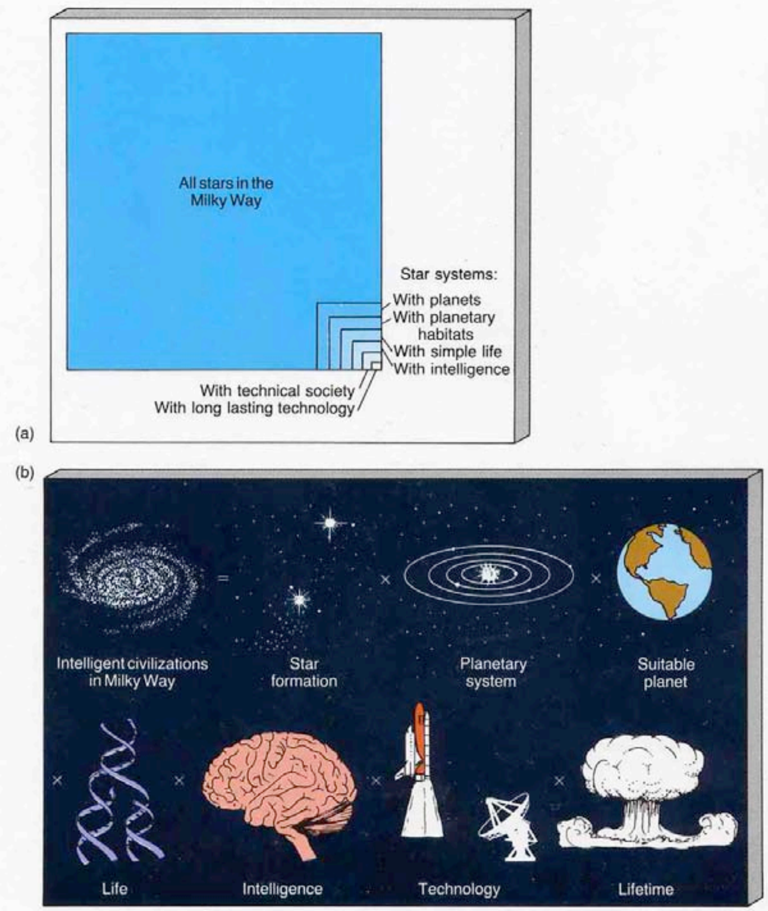
Notice that the ratio in the last factor gives the fraction of time that the civilization is "on". (A "light switch" analogy will be discussed in class).

[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.]

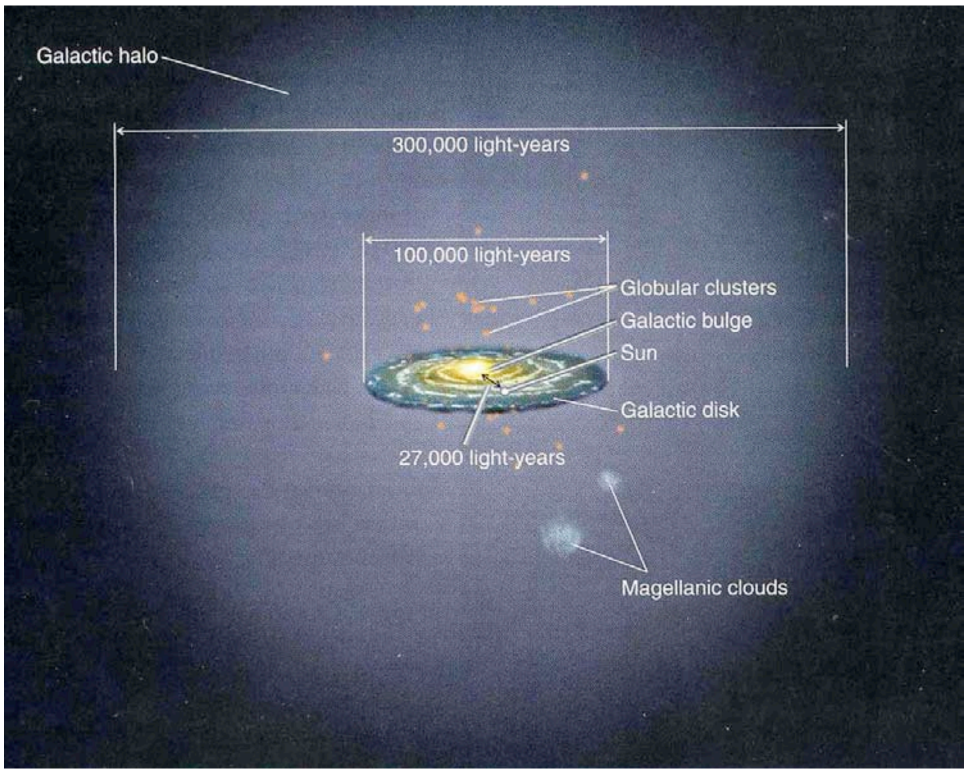
It is important to understand the relation between the number of civilizations N and their average separation, since that is what determines whether any communication (at the speed of light) is possible. We discuss this further below. First, let's see that **if N is large enough for two-way communication,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

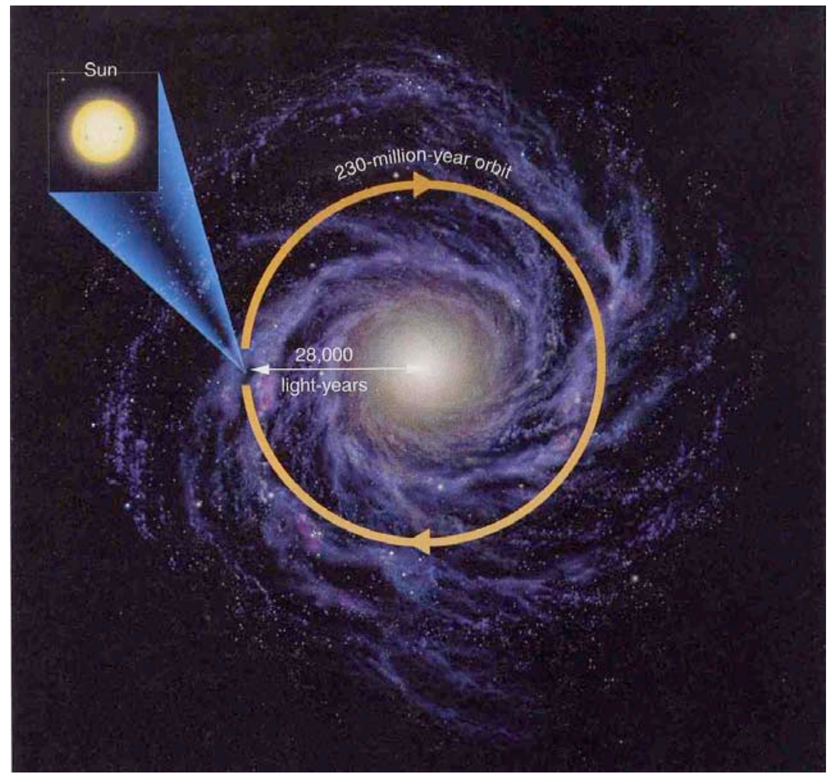
Three ways to look at the Drake equation, and the basic question(s) we are addressing in this course:

the number of technological, intelligent civilizations now present in the Milky Way Galaxy = rate of star formation, averaged over the lifetime of the Galaxy × fraction of those stars having planetary systems × average number of planets within those planetary systems that are suitable for life × fraction of those habitable planets on which life actually arises × fraction of those life-bearing planets on which intelligence evolves × fraction of those intelligent-life planets that develop technological society × average lifetime of a technologically competent civilization.

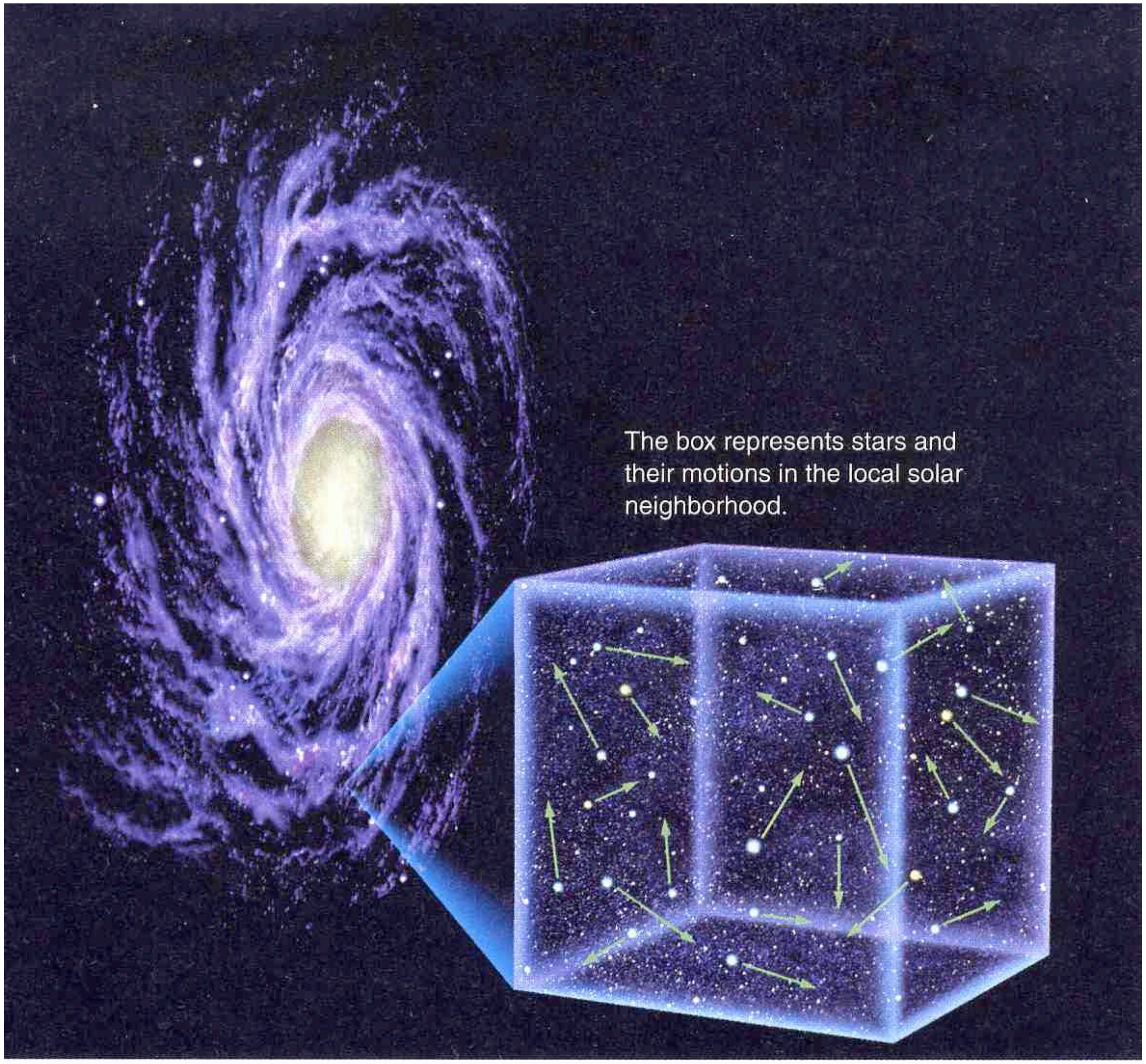


Our place in the Galaxy. The disk is ~100,000 l.y. across, Sun is about 30,000 l.y. from center. **Think about times for communication at the speed of light!** Clearly we can only search for life among the nearest stars, and for that to be successful, it has to be that a significant fraction of all stars must have life, "N" must be very very large (later we will see just how large, and what this implies).

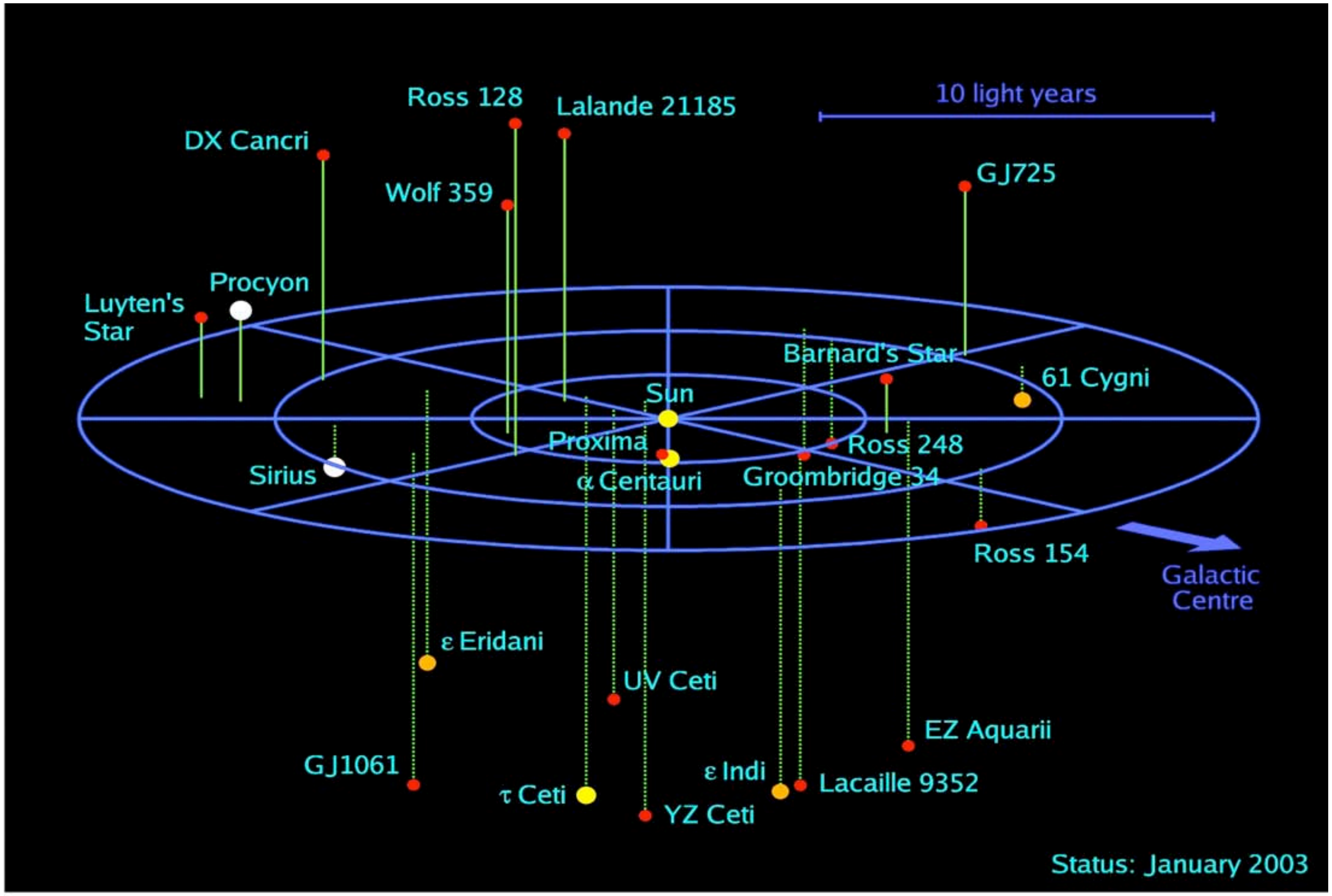




Because of the enormous size of our Galaxy and the finite speed of light, we have to concentrate on detecting signs of life, or communicating life, from stars less than about 100 light years distant.



The nearest stars to the Sun--out to about 15 light years



3D Map of Known Stellar Systems in the Solar Neighbourhood

ESO PR Photo 03c/03 (13 January 2003)

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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.)

$\Rightarrow$ **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— assumes the civilizations are so rare that they are spread out in the 2-dimensional Galactic 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

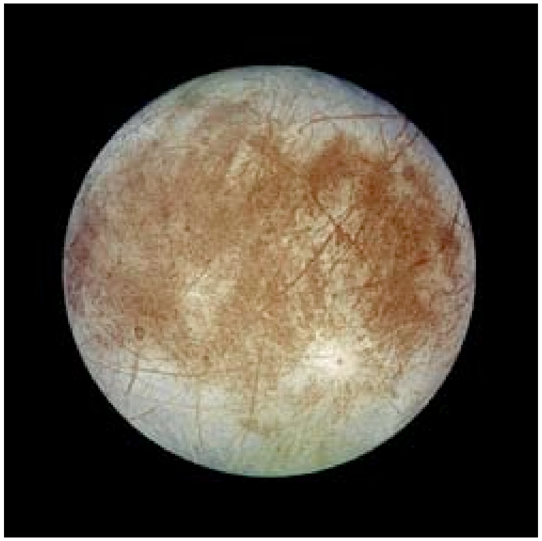
Actually if N is greater than about 10,000 most of the civilizations will be so nearby that we should treat them as if they were distributed in a spherical volume, so the formula should read (roughly)

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

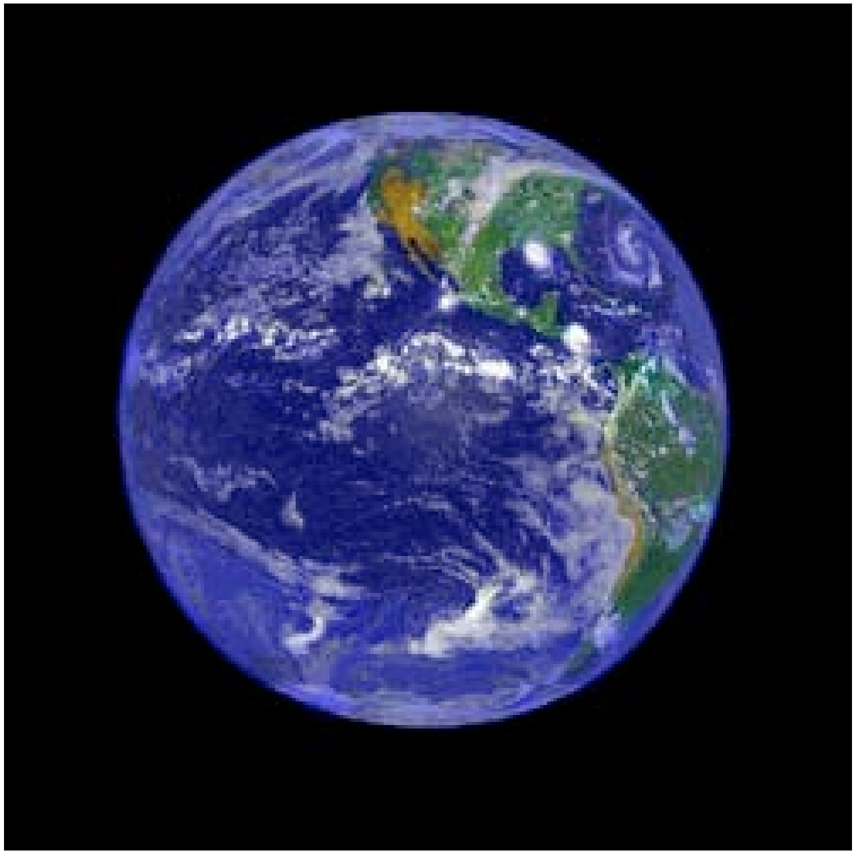
The results are very similar. e.g. if N = 1,000, d~1,000 l.y; if N = 1,000,000, d~ 100 l.y.

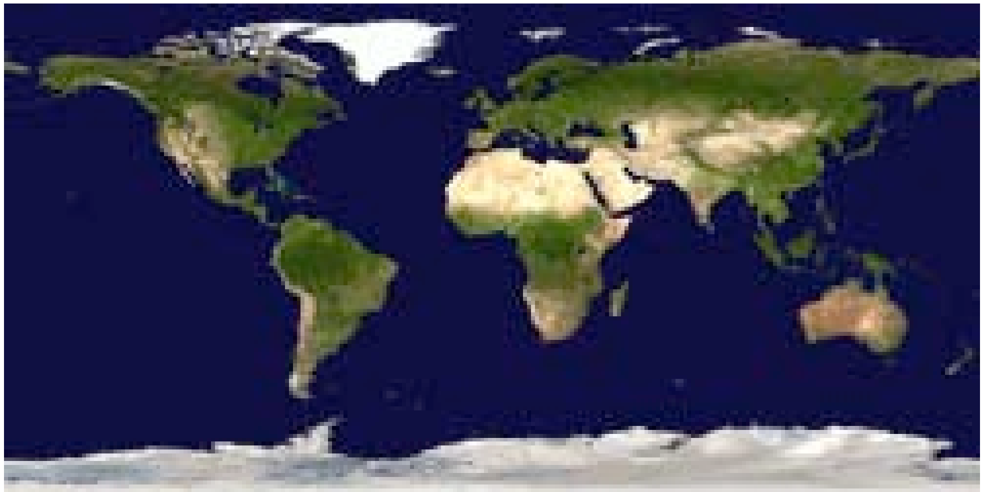
The basic point is: If two-way communication is going to be feasible (at the speed of light!), the galaxy had better have *at least* millions of civilizations! And we have already seen that for this to be true (N very large) L must be enormous, so two-way communication means we would likely be communicating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

Likely requirement: A solid surface (and probably atmosphere), so need a planet or a large moon. Below (clockwise): Venus, Mars, Jupiter, Europa. And by now, nearly 150 extrasolar planets known. Not just any solid body will do!



Primary requirement: liquid water (we'll see why later), so must be at right distance from the parent star ("habitable zone"). Also probably atmosphere (so planet can't be too small. or atmosphere escapes), continental masses (for geobiochemical cycles), …

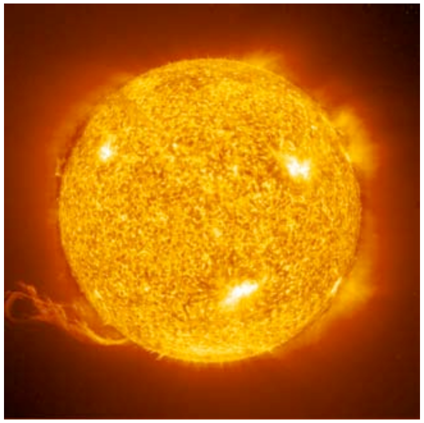




⇒ So we are describing a terrestrial-like world (have to be careful about Earth-centrism!)--we need to know how frequently they occur around other stars. (So far, detection is beyond technical capabilities of even largest telescopes, but should find out in about 5-10 years. That is why we will discuss detection of extrasolar planets at length.

What fraction of stars are suitable for habitable planets?

Our Sun: seems optimum for us,
but is still active in UV and x-rays

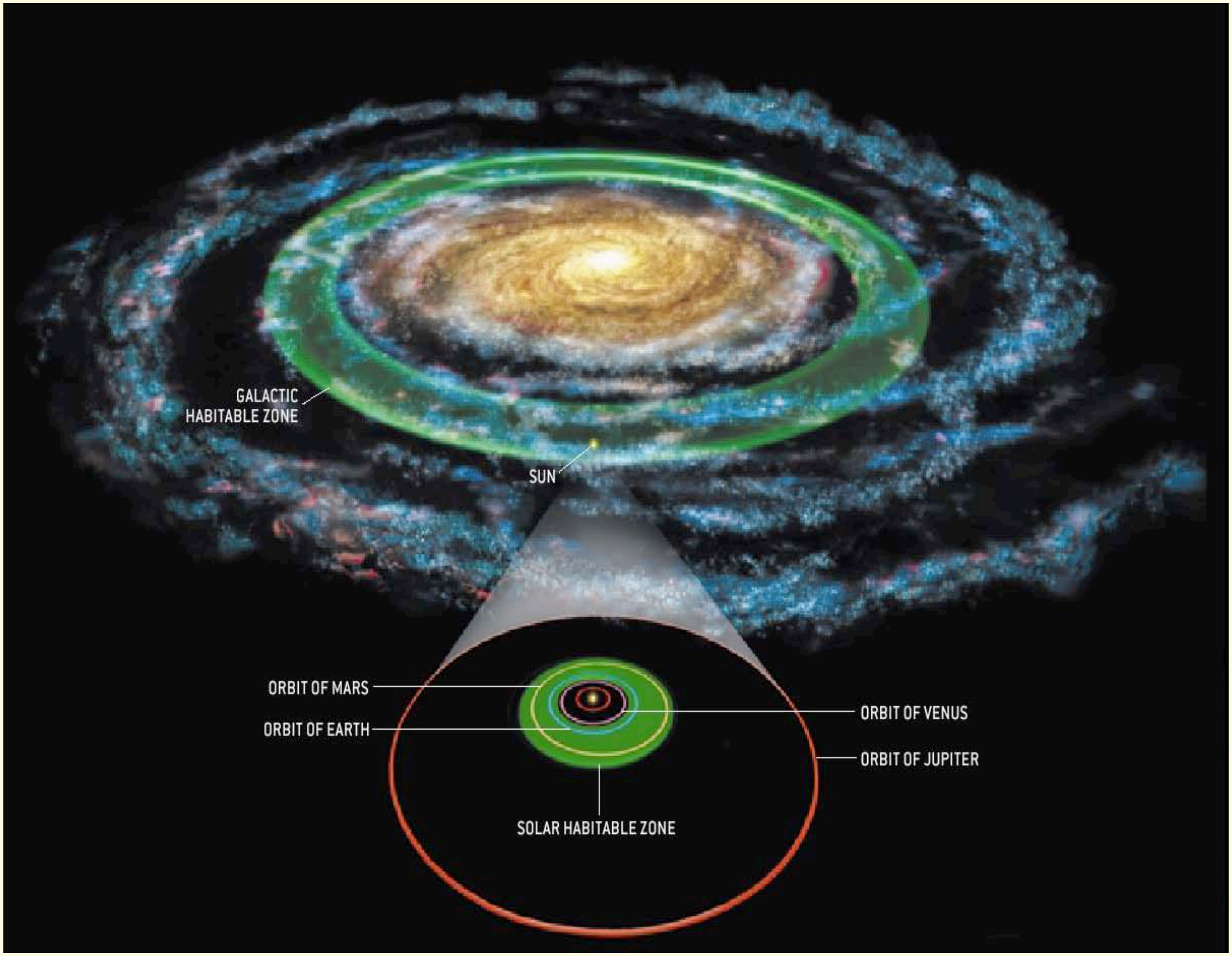


What about planets orbiting lower-mass
very red (M-type) stars?

Can planets orbiting binary
stars be habitable?

Life *might* require a very large moon, like ours (left), for tides, magnetic field protection, stability of rotation axis… **But** if our moon formed by an unlikely impact (right), chances for life might be small elsewhere.

Maybe only a small part of our Galaxy is suitable for life--
this is the idea of a "The Galactic Habitable Zone"



Conditions on the early Earth, around the time of the appearance of the first "life"

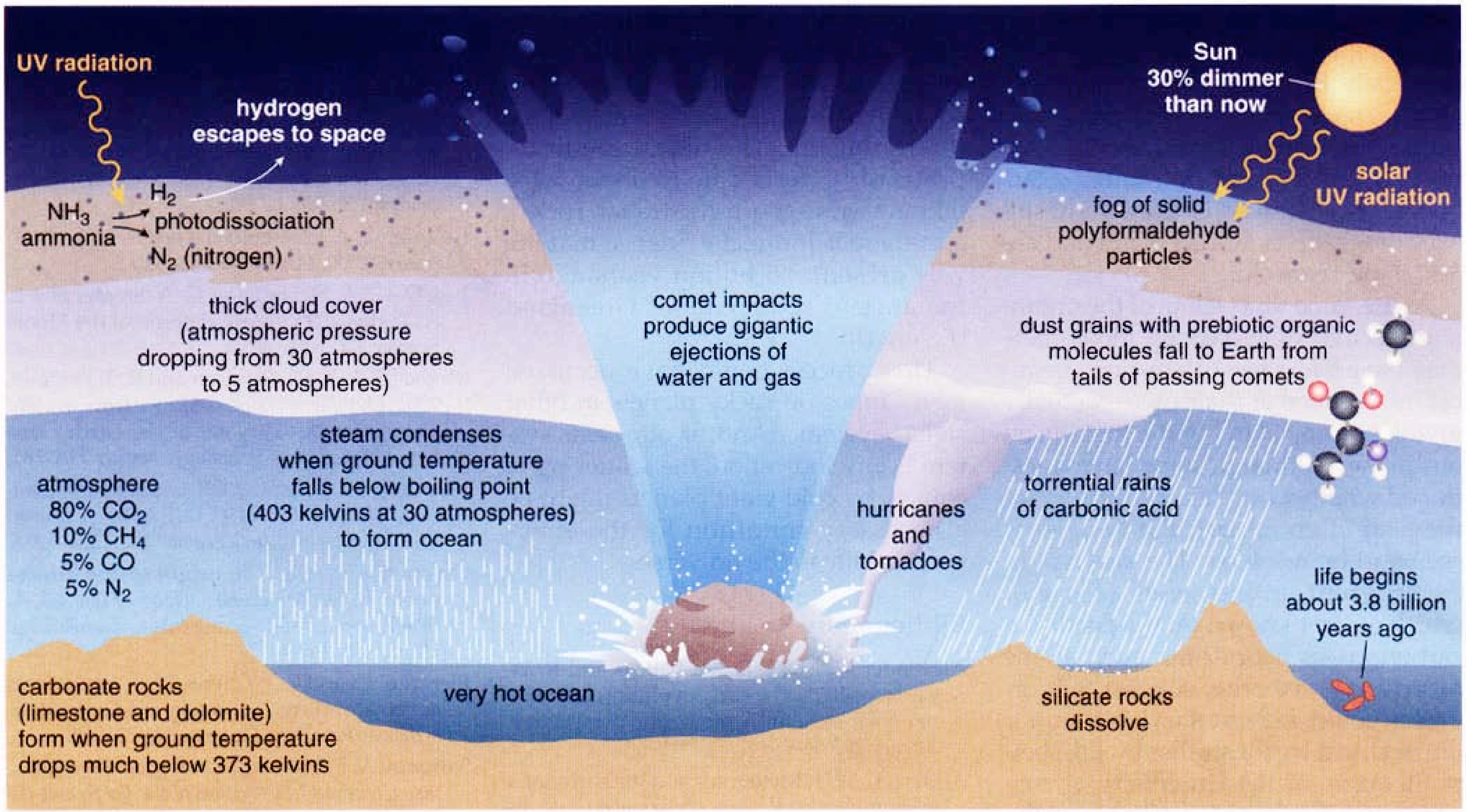


Figure 11. The primeval biosphere awoke to a tempestuous world of intermittent comet impacts, a steaming-hot ocean, a very thick atmosphere and torrential acid rains. Giant comet impacts would have ejected large amounts of material into space and spun off violent hurricanes and tornadoes. Although the atmosphere was originally rich in carbon dioxide (CO_2), photodissociation would have gradually increased the proportion of nitrogen in the atmosphere, while releasing hydrogen into space. Silicate rocks, dissolved by the acidic rain, would have been gradually replaced by carbonate rocks. Prebiotic organic molecules, delivered by the comets, would have provided the "seed" for the evolution of the first life.

Important times in the past (in millions of years)

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.

➡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

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