Chapter 14

Little Green Men

In the 1930s, a radio show on a Martian invasion of New Jersey brought panic to the eastern United States. With space exploration, Martian movies are now comedies or period pieces. Aliens need to purchase tabloids to read about themselves. So far the tabloid clientele is Earthlings.

The fictional aliens of my youth were green. I think this came from the belief that food is scarce on Mars so that plants would also function as animals. They were little, I think for the same reason. Alien invasion stories provide a politically correct enemy for a war, just like modern tabloids do not fear alien libel suits. They provide a nice venue for social commentary. The 1898 book *War of the Worlds* by H. G. Wells centers on British society, especially the irrelevancy and impotence of their clergy in the modern technological world. The then-new scientific concepts of germ theory of disease and evolution by natural selection play major roles.

It is not productive to discuss the sociology of unknown aliens at great length. Science fiction writers are better at it than scientists anyway. I will return to what aliens might be like after I discuss how our own intelligence evolved and how it may aid our survival. I will then get on to finding ET.

Getting street smarts

We are intelligent but what does that mean? Microbes and plants respond to their environments but in a programmed way. Animals have programmed instincts. Humans are so ingrained for acting on learned information that it is hard to demonstrate instincts for complex behavior. Psychologists take innate fear of heights and fear of snakes as topics for serious study. It may be accurate to say that humans have evolved so that infants easily learn these fears as soon as they become mobile.

Darwin defined intelligence as the ability to learn from the environment and modify one's behavior to one's advantage. As Darwin showed, this degree of intelligence exists in earthworms. I will up the bar some to the ability to learn from the environment and teach one's offspring. This widespread ability is the seed for technological intelligence. Two clades of animals held lottery tickets to becoming a machine-making organism: the cephalopods (like squid and octopus), and the vertebrates. The cephalopods did poorly in the Cretaceous-Paleogene mass extinction. Squid and octopi have large brains and dexterous arms. Octopi take care of their young but are solitary. Squid are social but do not care for their young. The pre-adaptation of social technology just did not arise.

Numerous vertebrates show the seeds of technological intelligence. Our close relatives chimpanzees and bonobos (pigmy chimpanzees) have some tool making and abstract communications ability. So does our more distant relative, the gorilla. This is not surprising in that the common ancestor dates back only 5 to 10 million years. The New World Capuchin monkeys use tools and crush millipedes as insect repellents. Our last common ancestor is about 40 million years. Still more distantly related carnivores use tools. The sea otter is famous for this in California. The raccoon and black bear probably belong on the list, but it is not clear whether they picked up the habit by watching humans. Elephants, dolphins, crows and seagulls have complex learned behavior. These organisms will require millions of years of evolution (with the right selective pressures) to reach machine making. No one would try to teach any non-human terrestrial species calculus.

Human evolution. Evolution to the point of chimpanzees did not trouble Alfred Wallace, but the next step to a conscious human did. The problem is obvious. Our language and machine making abilities make us far too fit. We need not be able to discuss the philosophy of Kant to organize a zebra hunt. Grunts and pointing would serve to get the hunters in the right places. Sticks and stones would work perfectly well once a zebra was cornered. Wallace was not a racist like many Europeans of his day. He knew that so-called savages did perfectly well when exposed to Western learning, but he thought that savage peoples did not need to think to live. That is, the intelligent brain evolved before there was any use for it. Natural selection could no more do this then cause a mushroom to become intelligent.

Wallace did not understand a savage lifestyle. Real savages live by their wits. They spend much time learning and transmitting acquired information. For example, it takes a lot of knowledge to survive in the Arctic. How long would you last without modern technology? *Lost in the Barrens* (1956) ISBN 0-553-27525-9 by Farley Mowat (b. 1921) is a fictional account of two teenagers stranded in the Arctic.

In fact, humans are highly adapted to learn and transmit acquired knowledge. Our long infancy provides time for learning and our prolonged adulthood provides the teachers. In detail, our stone-age evolution was akin to sexual selection, but might better be called cultural selection. The human with good communication skills and imagination got to breed more often than did the boring dullard.

The genes that code for conscious action and abstract communication are recent modifications of older genes, probably in the last hundred thousand years. Civilization then took off quickly. We have gone from starting to plant crops to landing on the Moon in the last 10,000 years. There is only one intelligent species on the Earth because once cultural selection kicks in evolution is fast. The transmission and improvement of learned technology is even faster. The chance of two species in one solar system reaching this stage at the same time is miniscule.

The evolution of a second intelligent species on the Earth will occur only if we let it. Science fiction stories, like *The Planet of the Apes*, have already alerted us to the danger of breeding or genetically engineering another intelligent species as slaves. The social agenda of the movie plot is antislavery, antiracism, and antiwar for which the breeding practicality is irrelevant. If we have squid slaves, we will soon have squid rebellion with much human support. We will have to share the planet with them or perish. Having squid study oceanography is efficient and intriguing. The real danger comes in that wisdom is dearer than knowledge. Millions of years of evolution for social behavior have not freed humans from wars. I tremble with what an engineered species would do.

Scaffolding: Genes and complex life. So far intelligence does not seem that difficult. Given time several extant clades on the Earth might achieve it. Humans just happened to hold the winning lottery ticket that was drawn first. A higher hurdle was going from microbial to complex multicellular life. This happened just once.

I retreat a bit to the discovery of DNA and the genetic code. All the cells in our body have the same chromosomes and genes (except red blood cells that lack them and the germ cells that have half a set), but the cells in your big toe are a lot different from the cells in your liver and your eye. Studies of fruit flies showed that control genes make eye cells grow in the eye. Further work showed that this biological innovation occurred just once. The control genes in plants, fungi, and animals are all related. There have been many gene duplications, but the genes are highly conserved. Squid genes sometimes function in fruit flies.

The control genes allow the body to grow indirectly. We start to grow gills that will be no use, but the control genes redirect this growth later on. The butterfly is vastly different from the caterpillar. The control genes tell the right structures to grow at the right time. Cell death is often planned. Our hair and fingernails are dead cells. Oak leaf cells die in the northern fall.

The control genes are highly conserved because their failure is disastrous, like an organ growing in the wrong place or not at all. Fruit fly breeders have legs growing on antennae and eyes in the wrong place, which would be lethal in the wild. A gross failure of the control genes is teratoma, several forms of cancer with a mélange of cell types in the tumor.

Control genes were a difficult biological innovation. Complex cell types are far different than just getting cells to join in filaments. All that is needed then is a mutation where the cells remain attached after dividing or regroup in a consortium. Control genes did not evolve quickly once some oxygen was in the air and ocean (Figure 1). The vacancy sign on the niche for large plants, animals, and fungi hung out for nearly a billion years. The role of gradually increasing oxygen levels on the evolution of large organisms is still poorly understood.

Figure 1: The trilobite *Elrathia kingii* hung out in Utah about 500 million years ago. Specimens are available in many rockshops. It lived in very oxygen-poor water at the bottom of a shallow sea. Other species have inhabited similar environments since that time indicating that abundant oxygen is unnecessary for animal life. However, oxygen-poor environments are rare and transient, an evolutionary dead end for animals on the Earth. We breathe abundant oxygen because we are a wide-ranging successful species that evolved in a common persistent environment. Animal-like organisms may have evolved intelligence in oxygen-free or oxygen-poor environments on other planets. Small sulfate "breathing" animals called oligochaetes exist in the ocean. They have microbes within their cells that do the chemical reaction, but are not fully independent of oxygen. Photo by the author.

Cambrian explosion: more about complex life. By the time of Darwin, it was evident that large shelly fossils are abundant in Cambrian and younger rocks. Complex life including representatives of the major taxa of the animal "kingdom" called Phyla appeared quickly during the Cambrian. As with mass extinction, several hypotheses attracted paleontologists: (1) there could be a gap in time in the geological record below preserved Cambrian beds so the explosion is an illusion. (2) There could have been a long period where animals lived but did not have shells. Soft-bodied organisms are poorly preserved as fossils. (3) The explosion could be a real event of rapid evolution.

Subsequent careful searching uncovered fossils of soft-bodied organisms below Cambrian beds and the tracks they left on the seafloor. The appearance is still rapid over tens of million years. There is no systematic gap in the geological record.

Studies of control genes and embryonic development tell the basic story. The ancestor of animals had two layers of cells, the outside "skin" and the lining of the gut. Corals and jellyfish retained this arrangement during their evolution. Recent paleontological work shows the photosynthetic (chloroplast-bearing) ancestors of plants lived before 1400 million years ago. Tiny ancestral animals lived by 1200 million years ago. Molecular genetic work shows that the split between plants and animals-fungi occurred before the plant ancestor acquired chloroplasts. Genes from organelles, including chloroplasts, jump into the nucleus. Fungi and animals lack such genes.

One clade of animals *Bilateria* evolved bilateral symmetry (your left side is more or less like your right one). They evolved three layers of cells: your skin, your stomach and gut lining, and your interior cells between the skin and the gut. This biological innovation freed the middle layer from the need to absorb food or to protect the outside. It differentiated into numerous cell types. For example, muscles develop from the middle layer, giving rise to the term mesomorph for a muscular person.

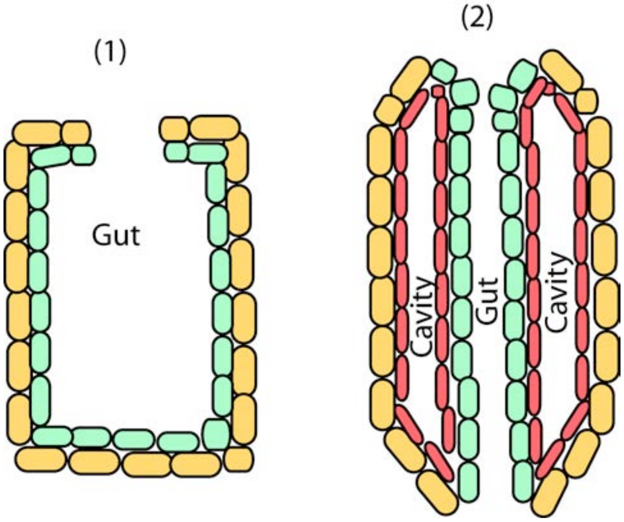


Figure 2: (1) Jellyfish belong to a group of animals that retained having two cell layers, skin and gut cells. (2) Bilateral animals have a third layer that can form cavities between the gut and the skin including blood vessels. Both arrangements are serviceable and have evolved considerable complexity in extant life.

The initial organism was simple. Both ends functioned as mouth and anus, which allowed the animal to eat continuously. Before this time, organic matter that settled to the seafloor was buried immediately by thin layers of sediments and thus unavailable to animals on the seafloor. The mouth end of an animal could bore a little bit into the sediments and eat. Successful organisms soon eat up their food in shallow sediments; worms that could bore to the frightening depths of a millimeter and then a centimeter did better and survived. Sediments after this time are typically stirred (bioturbated) by animals rather than being finely laminated.

Oxygen concentration in the air and in the ocean built up at this time. The mechanism is not fully understood. Clearly, bioturbation limited the localities that organic matter could be deposited and then deeply buried into sediments. It also likely affected the return of just buried nutrients including phosphorus to the ocean. More oxygen allowed larger worms to burrow more deeply.

Details of the evolution are still cloaked in time. The initial worm organism could function either back or belly up. Then individuals with specialized mouths and anuses and specialized backs and bellies did better than the simple starting organisms. Some innovations occurred in multiple ways. The "vein" in the belly of a shrimp corresponds to your backbone. The mouth of a shrimp may well correspond to your anus. Free worm food on the seafloor soon came into short supply. Shells then evolved once some of the animals evolved to eat others rather than organic matter on the seafloor. This happened many times in different ways. As on the battlefield, there is a trade off between armor and mobility. Immobile organisms like clams often evolve armor. The thick skin of a relatively immobile elephant functions as armor. Mobile squid and octopi evolved from shelly ancestors.

Figure 3: The worldwide appearance of the trilobite *Olenellus* once by convention marked the start of the Cambrian period. The organism had well developed eyes. Its exoskeleton (like a lobster's) functioned as armor. The segments are obvious. The tail of this specimen is missing. Paleontologists now include somewhat older less showy shelly and trace (burrow) fossils in the Cambrian with a starting date of 543 million years. From Henry A. Ward's (1834-1906) 1866 *Catalogue of Casts of Fossils*. He sold plaster casts of museum specimens. His company Ward's Natural Science continues to sell trilobite reproductions as a small part of its large inventory.

The Cambrian explosion is the adaptive radiation following the biological innovation of *Bilateria*. Evolution soon locked in subsequent innovations in the early descendents of the simple Bilaterian. For example, much of the rest of the anatomy of a shrimp has evolved to function with the month at its front end. A vast number of genes would have to mutate in just the right way at one time for the shrimp to function rectum-backwards.

The taxonomic explosion of Phyla originating in the Cambrian is a statement that the lock in of recognizable characteristics occurred quickly. That is, the common ancestor of each Phylum locked in suites of macroscopic characteristics that 1800s paleontologists and biologists could track in its progeny. Molecular biologists and embryologists have sorted out much of the family tree of the Phyla back to the original bilaterian. For example, echinoderms, like starfish and sea cucumbers, are closely related to vertebrates, even though there is little superficial resemblance.

The explosion concept is also a restatement that a second group of organisms with good nervous systems, senses, and mobility has not evolved from microbes, fungi, plants, or non-bilateral animals. Jellyfish come closest. They are quite complex and motile. Box jellyfish have organs that function as crude eyes and school to hunt prey. No jellyfish, however, has a good nervous system.


(Mivart's splitting worm)

Why do we die? The early bilateria could produce sexually or vegetatively by having one organism divide through its middle into two. It proved advantageous for our ancestors for the new segments to remain attached forming a "segment worm." When the worm got too long, it split in its middle into two worms. This organism, like its original unsegmented ancestor, was still potentially immortal. The multiple segments were originally identical but our worm evolved specialized segments, now seen in our vertebrae. This innovation allowed considerable complexity that made the organism more fit as an active swimmer in the sea. Soon organs from different segments mingled within the organism so that vegetative reproduction became problematic and then impossible. The advantage of complexity outweighed the loss of division. At that time about 550 million years ago, our indivisible segment organism passed a death sentence upon all its descendents. Sexual reproduction has since then been obligatory to our ancestors.

Thermoregulation: If your feet are cold put on your hat. Thermoregulation is certainly necessary for our brain to function intelligently. We get delirious from a fever or hypothermia. Cold woodsmen and mountain climbers perish when they are too cold to act rationally. They even take off their clothes to warm up.

Evolutionarily, it was efficient for a brain to work at a single temperature. Maintaining this temperature is costly. We need to eat far more food for our weight than a “cold-blooded” animal. We are prone to head injury. Our large brain makes childbirth dangerous. Evolution has reached a compromise where the baby’s head just fits through, but the mother hips are still usable for walking, and the time taking care of the helpless baby is not too large. An intelligent egg-laying organism would find other follies with the live birth of a large baby.

Thermoregulation by a warm-blooded body though costly is easy. It evolved at multiple times in mammals, birds, large sharks, and large tuna. It even occurs in the skunk cabbage, which heats itself to bloom in the early spring. But thermoregulation is unnecessary in the deep ocean. The water temperature stays the same and the organism need not expend any energy to keep its brain at a constant temperature. An intelligent organism living in this environment would come up with lots of reasons why warm-blooded land organisms cannot be smart.

Spare change: Large one-celled organisms. We expect macroscopic organisms to be multicellular. So much so that our chauvinistic term “higher organisms” is equivalent to multicellular organisms. Yet there is considerable overlap in size between multicellular and one celled organisms. We have already seen sand-sized formanifera that paleontologists used to date rocks. They are bigger than small insects and mites. Even larger foraminifera lived on the ancient seafloor and large species continue to do so. These one-celled organisms exceed the size of the smallest vertebrates. Some eat small animals.

Rice-shaped fusilinids perished in the mass extinction of the end of the Paleozoic. They approached a centimeter in length. They were locally abundant enough that some limestones are almost totally composed from their fossils. The name refers to their resemblance to musket bullets.

Some nummulites were even larger, up to several centimeters across. The name comes from the Latin word for coin. It is descriptive. Some are larger than U.S. quarters (Figure 4). They lived in the early Tertiary and were extinct by 23 million years ago. As with fusilinids, they sometimes make up the bulk of a limestone. Their fossils are common in the rocks used by the Egyptians to build the Pyramids.

Both fusilinids and nummulites show considerable complexity, as do extant giant foraminifera. The spiral pattern in nummulites is intricate. That is, different parts of the cell have different functions analogous to the myriad of cell types in animals. Foraminifera did not evolve to the point that they had good senses, like vertebrates and squid. Competition with already existing animals may have kept evolution in that direction in check. These lineages arose after the seafloor already teemed with well-adapted animals. The story might have been different if their lottery ticket for a large organism had been drawn before there were other animals around.

Figure 4: Nummulites were large one-celled foraminifera. The species lived about 50 million years ago near what are now the pyramids of Egypt. Herodotus recognized such specimens as fossils of marine organisms. Specimens from Jim Ingle. Photo by the author.

Again an intelligent one-celled organism might come up with dead-end follies of multicellular organization. Here ‘tis my try. Having a nucleus in each of a countless number of cells is a great waste of phosphorus in the DNA and nutrients in general. A multicelled organism risks mutation and cancer each time a cell divides. A one-celled organism can keep its genetic material sequestered out of harm's way. It risks division only to reproduce and need not partake in sexual reproduction in every generation.

(Foraminifera have complex sexual practices that would fill their tabloids; some analogous to fish spawning.) It might even be able to transmit its learned knowledge in the asexual generations.

Here is a link to a site about large foraminifera. It can be followed to several other sites. http://www.bowserlab.org/

Planetary Stewardship

I now switch from how we got here to how we may stay. Any aliens we find have likely been intelligent for a geological period of time. Statistically, we will see the successful cultures, not those that quickly bring about their own demise. How can we survive for a geological time ourselves? The immediate big danger is at our own hand, and scientists are not much help with politics. How do we avoid natural hazards for which science can help? What can science do to avoid fouling the Earth?

The population explosion. The writings of Thomas Malthus (1766-1834) greatly influenced Charles Darwin. The basic point is undeniable. Population tends to grow geometrically. For example if each woman gave birth to 4 children that survived to breed, the population would double each generation. It would increase by 1000 times in 10 generations and a million times in 20. The population would outstrip any conceivable resources before it left people with no place to stand.

Malthus believed that we could avoid this disaster by conscious planning. He advocated changes in the British poor laws. He advocated voluntary increasing the age of marriage. However, he did not feel it was necessary for the gentry to limit their fecundity.

I flash ahead to my youth in the 1950s. At that time, there were the western countries still recovering from World War II, the secretive countries behind the Iron Curtain, and the Third World. Conditions in the First World were those that Malthus hoped for but certainly not a utopia. People could reasonably expect to survive into early old age. Families limited their size to around two or three children.

The Third World suffered from the Malthusian disaster. Women married as soon as they could biologically bear children. They continued to procreate until they died or were biologically too old. Many children died before reaching their fifth birthday. The survivors endured pestilence, famine, and sometimes war. The birthrate and death rates came into balance with a life expectancy of around 35 years.

High birthrates in a squalid society are rational for an individual, though detrimental at large. Children provide useful work once they reach the age of eight. The only social security system for the fortunate few who survive to old age is to have lots of adult children who can dole out pittances. A period of peace and plenty is reason to beget and multiply in the hope that a few of one’s offspring will survive the impending dearth and strife. Pessimists in the First World feared that any improvement would be instantly swamped by more population growth.

To make matters worse, the racist views of many in the 1950s were that the Third World situation was hopeless. I was taught in school that life is cheap in the Orient and I was in the Michigan not Mississippi. Despite the fact that the scourge of medieval barbarism had devastated Europe only a few years before, non-European peoples were viewed as somehow being unable to conduct their own affaires. Mothers admonished children who wasted food with stories of starvation in China. Concern about this matter was idiomatic for misdirecting one's efforts were they could do no good. Triage was a serious solution, familiar to the discharged military. The West was OK (like a scratched soldier) and did not need help. Much of the Third World (like a soldier hit by a tank shell) was beyond help. The West needed to identify a few savable Third World countries as its burden.

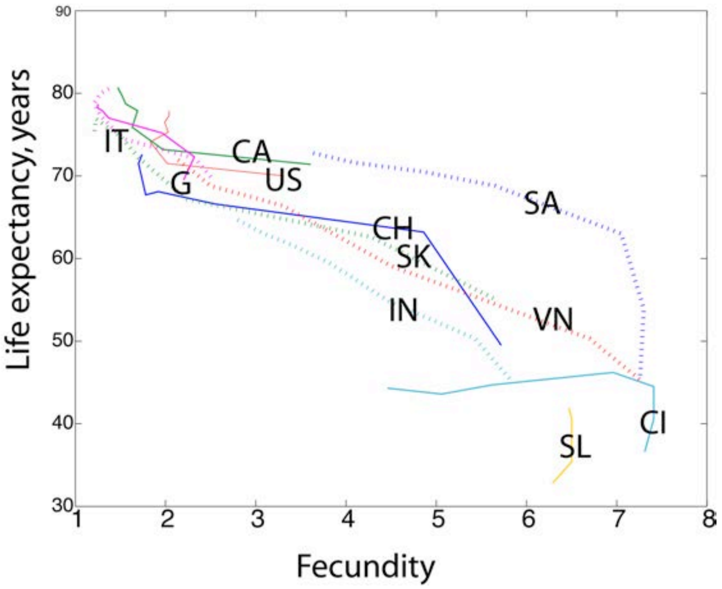


Figure 5: The fecundity (number of childbirths per woman during her lifetime) versus life expectancy for 1960 to 2004. Western countries represented by Canada (CA), United States (US), Greece (G), and Italy (IT) already had long life expectancies at the start of the interval. Their birth rates decreased. South Korea (SK) and Viet Nam (VN), and China (CH) have moved from high birthrates and low life expectancies to conditions similar to western countries. India (IN) and Saudi Arabia (SA) are moving in that direction. Third World squalor persists in Sierra Leone (SL) and Côte d'Ivoire (CI). AIDS greatly reduces life expectancy in these African countries. Data from earthtrends.wri.org.

Let's see what actually happened during the intervening 50 years. I pick lifetime birthrate per woman as a measure of long-term population growth. It needs to be slightly above 2 for stability in a country with good heath. Infant morality and life expectancy are good proxies for the real standard of living. They avoid comparison of different economic systems, rural and urban lifestyles, climates, and currencies. I am not worried here about access to luxuries.

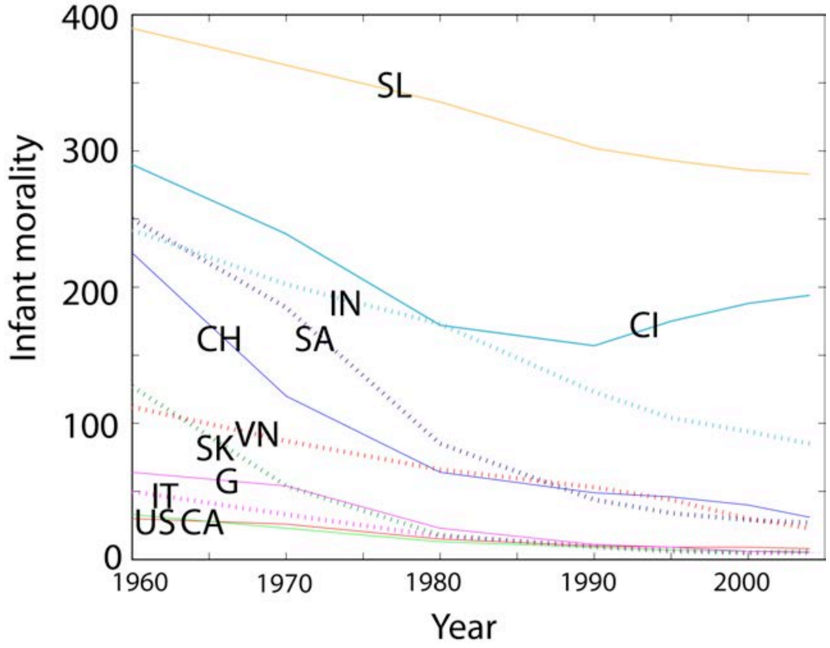


Figure 6: Infant mortality per thousand births in the countries in Figure 3. Only Sierra Leone and Côte d'Ivoire maintain high rates. The rate in India continues to decline. Data from earthtrends.wri.org.

In fact, much of the world now enjoys long life expectancies and has small family size. This includes the two largest countries, China and (much of) India. The birth rate dropped both in countries with highly centralized governments and countries with more capitalistic systems. Infant mortality has waned. Pockets of Third World conditions persist mainly in Subsahara Africa where AIDS is a major cause of adult and infant mortality.

Basic health is not expensive. Vaccines and sanitation go a long way, so does keeping insects from spreading diseases like malaria. Tropical climates need not imply bad health.

Economically poor tropical countries like Viet Nam have done well and are approaching the standards in well-off Western Countries.

Most of the current increase in global population is the transient from longer life expectancy, not birthrate. For example, the population would double if the life expectancy increased from 35 to 70 years because twice as many people would be living at a given time. This effect is somewhat offset by women giving birth later in life. There are fewer generations alive for a given life expectancy. Demographers (social scientists who study population trends) estimate that the world population will peak at 9 billion before decreasing slowly. This level is sustainable if issues related to energy can be managed.

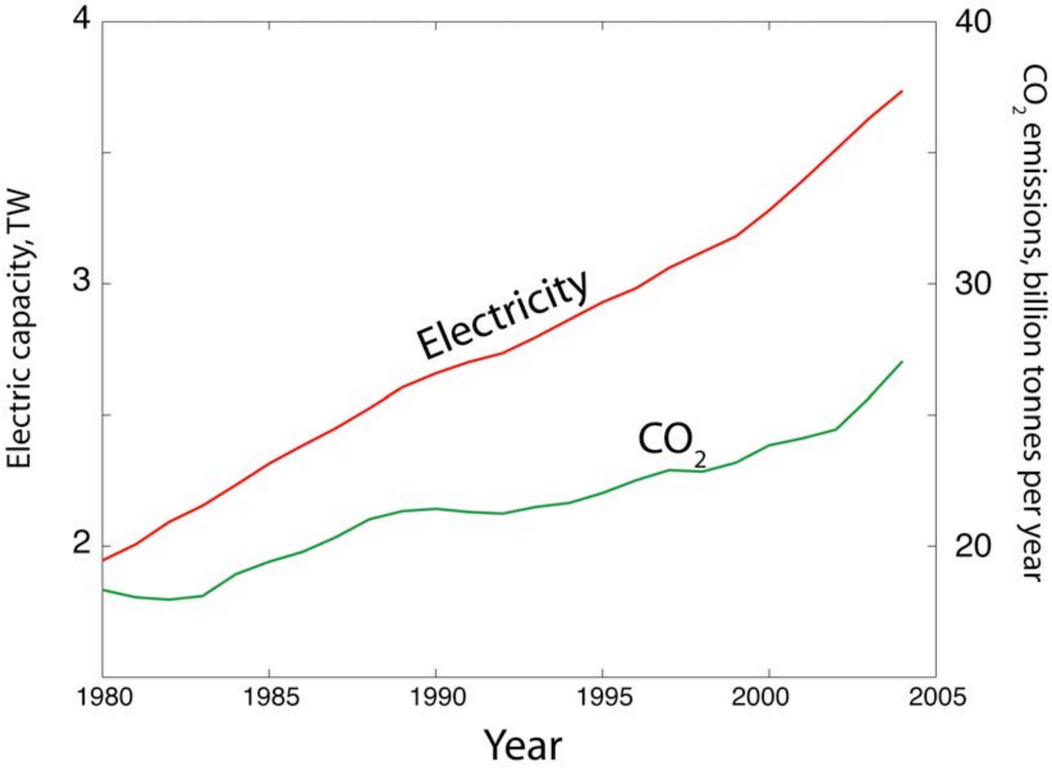


Figure 7: Global electric generation capacity in terawatts (10^{12} W) and CO_2 generation per year in billion tonnes (metric tons). The current rate of CO_2 release is about 60 times the rate that geological processes bury organic carbon in sediments. Data from U.S. Department of Energy. http://www.eia.doe.gov.

Energy and global warming. Our standard of living depends on machines that consume vast amounts of energy. The fear that we would run out of energy sources, particularly petroleum, has been around since before World War II. (Access to petroleum dominated theatre-level strategy, triggered Japan's entry into the conflict, and determined the German strategy in Russia.) More recently, scientists have shown that our burning of fossil fuels, including coal, natural gas, and petroleum, has increased the concentration of carbon dioxide in the Earth's atmosphere. CO_2 is a potent greenhouse gas. Climatologists have strong evidence that the global mean temperature is in fact increasing as expected in an enhanced greenhouse. Year to year and local variations make the current change imperceptible when not viewed globally over decades. Newspapers may well run stories on the Ice Age during a cold winter and ones on global warming in the next heat wave.

The greenhouse will not turn the Earth into Venus conditions. Similar releases of CO_2 and high temperatures have occurred in the last 60 million years. The concentration of CO_2 then was a few times the present level. Still it will be quite unpleasant. Climate belts will change and agriculture will become much less reliable. The Greenland and West Antarctic ice sheets may melt flooding coastal cities. Famine and land loss may well trigger war.

The problems of running out of oil and continued burning of oil causing greenhouse problems might seem contradictory. They are to some extent, but the technology to extract vast quantities of natural gas from shale has recently unlocked vast reserves. There are also far more coal reserves than oil reserves. A shortage of oil will bring the temptation to substitute coal for oil. The technology to make synthetic oil from coal for transportation exists. Germany applied it during World War II. It currently does not compete effectively with oil that comes from wells.

I begin with the energy “crisis,” as reliable non-CO_2-producing energy will alleviate both problems. I use electrical generation capacity to quantify the necessary size of alternative energy resources. The global rate of all other energy use is comparable to this quantity.

The current electric capacity (energy per second, power for those with physics) is less than 4 terawatts. This is equivalent to 4 trillion watts or 4 billion kilowatts. A middle-class 4-person home consumes about a kilowatt. The current generation capacity if equitably distributed would bring the Earth’s population to middle-class standards. The capacity will increase as more of the world becomes prosperous, but generation is within a factor of 2 or so of that needed when the population peaks. Conservation by more efficient electrical devices is already slowing the demand in developed countries.

Currently about 68% of the world’s electricity generation capacity uses fossil fuels, petroleum, coal, and natural gas. Hydroelectric dams generate 20%, nuclear plants 10%, and other renewable methods, like solar, wind, and plant-material (biomass) burning 2%. Many of the suitable places for dams have already been taken. Hydroelectricity is not likely to expand greatly.

Wind power will continue to expand. The technology works and dates back to antiquity. Wind is distributed; windmills are particularly efficient in remote locations that are not easily reached by the power grid. Given that the technology works, it has come under some opposition from environmentalists. Don Quixote tilted against windmills to oppose modernity so the problem is not new. It is a type example where the quest for perfection kills workable solutions. No conceivable power source is devoid of some cost and some consequence. Some windmills do kill birds; large slowly turning blades do not have this problem. Cats and cars kill far more birds than do windmills. Windmills are unsightly particularly where wealthy influential people have coastal estates. They do make some noise.

In fact, much of the rural United States did get its electricity from windmills in the 1920s. The windmills charged 15-volt batteries. Farmers ordered 15-volt appliances by mail, for example, from the Sears Catalog. Rural electrification rules did not allow windmills to contribute to the power grid, eliminating 80 years for technological improvements.

Nuclear power has a bad image in the United States. It produces radioactive waste and political opposition has so far prevented construction of a waste storage facility or better yet reprocessing of the waste. Still nuclear power has the positive aspect that it generates zero carbon dioxide. There is plenty of uranium to sustain power plants for hundreds of years. The technology is mature and does work. One can avoid tsunami simply by keep nuke plants well above sea level.

Much of the problem is that each U.S. plant was planned separately and litigated in the U.S. court system. Passenger airplanes provide analogy. No one would fly if each plane was designed and built separately in the one-plane airline’s garage. In fact, no one would even allow planes in their airspace. Passenger airplanes are quite, but not absolutely safe because there are a few standard models in worldwide use. Problems can be recognized and fixed often before they cause lethal trouble. Crews are well trained for the few models in use. The economies of scale keep down costs. Reactor technology outside of the United States is evolving towards this model. Unlike planes, reactors are sedentary and can be built from massive materials. Reactors are safe if their mode of failure leads to stable shutdown.

Solar power is essentially unlimited and inexhaustible over geological times if it can be made efficient. Vertical sunlight supplies about 1 kilowatt per meter squared. A 100% efficient array of photoelectric collectors spread over a square kilometer would generate a million kilowatts or 1 gigawatt. A modern nuclear reactor does this on about this much land. One roof full of collectors could power a suburban block. It would take a 64-km square array to match the current 4-terrawatt global capacity. Obviously the sun does not shine at night so a few times this area would be needed to supply the world. We would need a way to store power for use at night and also a way to ship power to cloud-bound and Polar Regions.

More practically, the collectors might be somewhat better than current ones and have 10% efficiency. We would need 40000 square kilometers of arrays on line at any one time. This area (200 by 200 kilometers) of arrays would easily fit in the American deserts. Arrays will go in at a modest rate at first. Power companies are obviously reluctant to deploy huge installations that will soon be obsolete.

There are solar alternatives for transportation. We can charge batteries. You could charge while you are parked. On long trips, you would pull in to a station and exchange your discharged battery for a charged one. Less efficiently, we could use solar power to make fuel like hydrogen, ethanol, or methane to burn in the cars. Fuel cells that directly generate electricity from chemical energy would then help. Airplanes will still need to burn something.

Biomass burning is basically a form of solar energy where green plants act as photochemical receptors. The technology has worked since our ancestors started campfires over a million years ago. Limited amounts of the gas (as ethanol) in your car come from biomass. The fuel production is not a net source of CO_2 to the air. It turns CO_2 from the air into ethanol and the burning turns it back to CO_2.

However, it is difficult to scale up biomass ethanol production. Modern farmers use heavy equipment like tractors and lots of energy. They need to make much more ethanol than they burn for the method to be attractive. To replace all the U.S. gasoline, an area exceeding that of a corn-belt state would need to be devoted to ethanol production. Using algae in tanks with CO_2 from power plants shows some promise as a way to make Diesel oil. The net effect is to use the carbon in the coal twice.

To address only global warming, we could try to send CO_2 into the subsurface where it would remain sequestered for geological time. The engineering task is daunting even if we compressed the CO_2 into a liquid. We would need to rid ourselves of tens of cubic kilometers every year. This is comparable to the volume of fossil fuel production. Sequestration will have to be efficient so it does not consume the energy we get from burning the fuel. One possibility is to burn coal underground and keep the CO_2 trapped.

What would happen if we converted to nuclear, wind, and solar power and kept our CO_2 emissions at pre-industrial rates? There would be almost immediate relief from much of the greenhouse effect. The upper mixed layer of the ocean is in dynamic equilibrium with the air. It turns over and is replaced by deep ocean water every 10 years or so. By then the CO_2 concentration in the air would be about half way back to the pre-industrial value. In 20 years we will be back into the range of pre-industrial values.

However, we have added a net amount of CO_2 to the global ocean. It will take up to a million years for reaction of the CO_2 in seawater with rocks (that is the rock component $CaSiO_3$ reacting to $CaCO_3$ and SiO_2) on the seafloor to fully restore seawater.

I do not advocate a head in the sand approach. Rather, global warming and conservation in general are manageable and we have some reason for optimism. Science has given us a technology that has led to energy and climate problems. It has also alerted us and provided possible fixes. Governmental action, like taxing CO_2 generation, will help. History shows that this may not be necessary. Kerosene put whale oil lamps out of business and electric lights put gaslights and kerosene lamps out of business. Cars were far less polluting than horses and soon much cheaper overall. Efficient solar power should displace less renewable and less dependable alternatives once its relative cost drops modestly. Like with wind power, it already faces some opposition from gentry-centered environmentalists.

Serious study of the climate is needed; a little global warming might even keep us out of an ice age. We need informed international agreement, once we have the luxury of not needing to release CO_2.

Shine it like a comet of revenge,
A prophet to the fall of all our foes!

First Part of King Henry the Sixth, Act III. Scene II.
William Shakespeare (1564–1616)
The Oxford Shakespeare, 1914

Comets and Asteroids: Harbingers of doom. Mundane natural disasters, like earthquakes, tsunamis, and hurricanes, pose no global threat. There will continue to be casualties but they will be local. We need to be concerned about the disaster that befell the dinosaurs, the impact of asteroids. Most dinosaurs that ever lived did not die from asteroids, but all the living dinosaurs died at the same time. There were no dinosaurs except for one bird species to carry on.

Astronomers have made a good survey of the larger asteroids in the solar system. Earth-crossing asteroids are complete down to a 10-km diameter. None are heading our way. We cannot relax and give the all-clear sign, though. The impact of a 1-km diameter asteroid would incinerate a continent-sized area and plunge the Earth into global winter. It would not wipe us out but would put civilization at risk. Statistically this is the most dangerous size class. Smaller objects have disastrous but more local effects, the danger drops off rapidly below 300-meter diameter. Larger ones are quite rare. We do not have to worry much about Tunguska and Meteor Crater sized projectiles. These are the smallest objects that can damage the surface. They hit every few hundred years, but most of the Earth's surface is sparsely populated. Technology will concentrate on them only when the larger objects are well in hand.

What do we do about 1-km class objects? Actually they are not hard to detect. In fact, NASA did not show much interest at first because only tens of million dollars are needed to set up a land-based network of telescopes. Observations are now underway and we will have orbits for 90% of the (1400) 1-km diameter objects by the end of the decade. It is feasible to work down to the 50,000 300-m diameter objects.

Most likely we will not find any objects on a collision course. 1-km diameter objects hit statistically about once in a million years. Unless we find an object coming our way in the initial survey we will have decades to centuries of warning time. Asteroid orbits are very well behaved and quite predictable. Asteroids jump out of their orbits like trains from tracks only in bad movies. We will keep track of the asteroids we find and continually update orbit estimates.

What if we find an asteroid heading our way? We will most likely have warning and time to act. Shooting them down at the last moment is futile. We would first land a transmitter on the asteroid to confirm its orbit. The Earth is small compared to the vastness of the solar system so only a nudge is needed. Blowing it up with an H-bomb replaces one dangerous object with several. Two practical suggestions are to set off a small nuclear explosion away from the asteroid to spall off a layer of rock. The equal and opposite force on the asteroid accelerates it into a new orbit. NASA has large ion-drive motors on the drawing board that have enough thrust to move a small asteroid. This option can be tested on a safe asteroid before we really need it.

Comets are a more serious problem but only 1/10 of the risk. We can get good orbits for periodic comets, like Halley's, but comets come in from beyond the orbit of Pluto. We do not have the technology to detect even several kilometer-sized objects in the region. We would have to check out millions of objects to find the few dangerous ones. We detect most comets after they have started to flare. We may have only months of warning. We do not yet have a good way to deflect comets.

Break glass and open in case of danger in 400 million years. The Sun is getting more luminous with time and plate tectonics will grind to a halt. We do not know which will occur first, but the failure of the Sun is more ominous. What will a high-tech civilization do about it? It can do nothing with the Sun itself. The problem is like tweaking Venus to make it clement. At the start of the red giant phase over 5 billion years from now, the Sun will be only twice as luminous as now.

Our descendents may try to cut the flux of sunlight to the surface. We have already seen that volcanic dust and impact dust cools the surface. The needed mass of dust is huge and it does not stay up more than a few years. Sulfur-burning planes at high altitude might do some good, as sulfur stays up longer than dust. (This is one of the least practical suggestions to fight current global warming.) We could genetically engineer plants and marine plankton so that they release more volatile sulfur compounds into the air. It might be possible to create a dust ring in orbit around the Earth. Given the time available, mirrors in orbit seem more controllable.

We might get rid of the light after it comes in. One can increase the albedo of the Earth with large arrays of mirrors. Ice naturally increases the albedo of the Earth so this will work at first, given the millions years to get ready. Efficient solar cells could collect light and broadcast it to space as radio waves.

One can fight the water vapor part of the runaway greenhouse to some extent by covering the low-latitude ocean so it does not evaporate. This would destroy much of the Earth's biology, so it is really a last resort.

Changing the Earth's orbit is not easy. One could crash asteroids into the Moon so that the Earth-Moon system moves out from the Sun and the Moon moves toward the

Earth enough to keep it at its present distance. Many large asteroids or comets would be needed to have any effect. The dust generated in Earth orbit might be more useful as already noted.

We could genetically engineer ourselves to withstand higher temperatures. There is a limit to this unless we prevent the greenhouse from getting hotter than 100°C or so.

Our descendents may choose to retreat. They will have to do this or die at the end. First to Mars as it becomes clement and then the asteroids, the satellites of Jupiter and out beyond Pluto in the red giant stage. When the Sun becomes a white dwarf, its heat will cease to be a danger, but it will no longer be a source of light. The technology will have to find another star or work out a way not to need one.

Where are the ET and what are they like?

Extraterrestrials visit the every week in tabloids, but why do we not really see any? One explanation is that we are really alone. This reasoning is called Fermi's paradox after the physicist Enrico Fermi (1901-1954). Given the length of cosmic time, the vastness of space cannot keep determined ET at home. The nearby stars are under a million AU away. A spaceship can move around the stars in hundreds of thousand years at the velocities of our space probes. John von Neumann (1903--1957) proposed a stronger form of the paradox. One alien civilization could colonize solar systems and then build their population to where they could branch off to yet another star. They could use self-replicating machines. The doubling time need not be fast. For example, a million year doubling time would let them occupy every star in our galaxy in 40 million years.

It is hard to discuss unknown aliens, but our science fiction writers have provided some clues. As we have already seen, any successful ET will have a morbid fear of unchecked geometrical expansion. They might think twice before releasing a plague of self-doubling machines on a galaxy were they plan to live.

The perfect may be the enemy of the workable when it comes to travel to other stars. For example, we could design a self-contained spaceship that would reach nearby stars in hundreds of thousand years with present technology, although it would be prohibitive to build in practice. Anyone boarding this vessel would risk having their distant descendents being overtaken, once technology improved.

Successful civilizations will recognize the inefficiency of manned exploration. For starters, it seems a lot of work to cross the galaxy just to frighten the guy in the tabloid. They will develop excellent remote sensing. They will already know there is oxygen-producing biota on the Earth if it is close enough for them to visit. Unlike the Martians in *The War of the Worlds*, they may have a healthy respect for our germs and for returning alien organisms to their own planet. Finally, they will have discovered that contacting other alien civilizations is an efficient way to gather remote information.

Calling ET. How do we call ET? Either radio waves or lasers will work. It is really easy to communicate between nearby stars with someone who knows that the message is coming. The physics are like combining a lighthouse with a foghorn. See primer on signals and communication. The beam from the lighthouse rotates so the observer sees short intense pulses of light. The amplitude of the pulses is far above the ambient light. If the lighthouse sent out the available signal in all directions, it would be weak everywhere. The mariner would have trouble seeing it. The foghorn broadcasts in all directions, which awakens landlubbers. It has pulses but they take up about half of the time. It has a single tone or a carefully modulated tone. Our ears are good at recognizing tone, the vibration frequency of sound waves. The mariner can hear the controlled tone above the din of crashing waves much easier than an uncontrolled signal. Our eyes can tell the frequency of light, color, but they are not good at it. Lighthouse technology (*pharology* for those who want a large vocabulary) evolved before lasers. Modern navigation has rendered many lighthouses obsolete.

How do we communicate with someone on a planet around another star? First assume that the receiver knows that the signal will be coming. We will first aim the signal at the recipient similar to how a lighthouse beam is pointed horizontally to be aimed at sailors (rather than birds). We then need to make the signal more intense than the ambient noise in space and probably our Sun. We do this by pulsing the signal, like a lighthouse, so that our available energy arrives with large amplitude. We will modulate the signal frequency, like a foghorn. We need to be careful that enough radio or laser signal arrives so that it behaves like a macroscopic signal. That is, we need to have a lot of quanta hit the receiver (for those with some physics).

What do we need for success? A large radio telescope can communicate with another one anywhere in the galaxy. A military laser for shooting down this or that can communicate with optical telescopes on other stars if the beam can be aimed within the other solar system. A pointer laser would do if we could point it accurately enough to fall only on an earth-sized planet. ET will be able to phone if she knows we are here and really tries.

What about picking up a broadcast signal (like a foghorn) that is not aimed specially for us or a signal casually sent out to a vast number of stars, one at a time? By definition, ET's intelligence here is limited to the ability to make radios or lasers. The SETI project has been doing this for a few decades, so far with no success. It is privately funded since the small item on NASA's budget was a prime target for congressmen to get big laughs. The technology is improving to where the radio SETI can search much of the sky while ordinary radio astronomy goes on. Given the low cost, the effort is well worth doing. Optical SETI is much less advanced.

Radio waves from TV and radar have leaked out of our atmosphere for over 60 years. Any ET with radio telescopes that periodically check nearby stars would have detected us. The boring part of the task can be fully automated, even with our technology. A return signal could have come only from the modest number of stars within 25 light years of the Earth. It will take centuries for the radio waves to reach millions of stars, with time to send a return message.

There is a way to speed things up if ET is not vigilant. Astronomers observe supernova. Once they detect one, many of the radio telescopes and the optical telescopes on a planet will be pointed that way. To get detected, we need merely broadcast a signal in the direction that the supernova light is heading after it passed us for a few days after we see it. ET will have his eyes open and ears up.

Where may ET be chatty? Around red dwarf and red giant stars. The red dwarf stars last almost forever and may have tidally heated planets. They may harbor several billion year-old civilizations eager to locate recently technological ones. The inhabitants of red giant systems have had space travel thrust upon them. They may be looking for greener pastures and trying to save their history if not themselves. At the least, civilization spread out over icy objects far from the star will generate a lot of laser and radio traffic.

Thou shall not covet? I have promised not to drone on at length about unknown aliens and their sociology. We have seen that only two steps from prebiotic chemistry to humans seem hard; first getting life started and then getting complex multicellular life. The anthropic principle keeps us from reading too much into either one. ET needs only a semi-stable environment where large organisms can exist. Moderate instability is actually helpful as it favors intelligent rather than programmed response.

What will ET not want from us? She is not likely to have a big demand for tabloids. Neither will ET find us edible; both our organic chemistries are complex and different. She will not covet our technology except as antiquities that go back a geological time on her own planet. She will not want our planet for living space; there are countless uninhabited ones. Our air and water are not likely to be of her taste.

What do we have to give ET? Information, which would be very difficult for her to obtain remotely or by space exploration. We have a wealth of social information. Their sociologists would not reject the history of a whole new planet. Their geologists and biologists will grab additional new well-documented cases. It will take some time to get the two-way communication on line, but both ends will share much of science. It will take time to bring our science up to theirs. I leave further aspects of our reaction to science fiction writers.

Executive summary: Reality and dogma

Our search for ET is like looking for lost car keys. We either find them or not. We cannot tell whether we are close or far from finding them until we actually do. We look where there is light enough to search. SETI uses methods that would actually work. ET smart enough to send us signal would be aware of these methods, although they may well have selected alternatives that have escaped us.

Our own evolution and history is a guide. Our planet will remain serviceable for a geological time unless we muck it up. Population is stabilizing without draconian measures. We do not need to greatly improve present technology to be self-sustaining. We have a good chance of avoiding wars of desperation over famine.

It is more difficult to avert war motivated by medieval worldviews that reject science. Science fiction stories, like *Dune* and *Star Wars*, show that a medieval social system with racial chastes, slavery, and warlords does not mix well with technology. They make for epically interesting times. Unlike the protagonists in these stories, we do not have recourse to real magic.

Our science progressed by expelling dogma and trusting observations and logic. It has brought technology and good communications. As Pope Gregory and the opponents of St. George Mivart's, education breeds heresy against accepted dogma. Even a tinge of doubt damps the fire of intolerant zeal. Ambitious youth see science and technology has paths to wealth and glory. The clergy is a less lucrative option. In much of the world, it attracts those wishing to do good works, not those seeking gain power to spread their wrath.

Still, clergy in many parts of the world have tenaciously clung to their power with fortified certitude. Two fanatical groups who are sure God is on their side are a time-honored recipe for war. One will do in a pinch. The Taliban retrieved medieval squalor in a country that had been barely touched by modernity. Autocrats feel justified in regarding the lives of their populations cheap when the mean annual income will not buy a good pair of sneakers. A captive media easily radicalizes the hopeless poor and the idle elite. Most other militants do not have the immediate option of imposing squalor. To function and conquer, they need to selectively reject parts of science but guard its technological fruits.

In contrast, the professional Creationists and the New Agers in the United States are relatively benign. They strive for political power but typically do not impose their way by violence. Faith and recourse to mysticism are options in a free society. Their free speech is a bulwark against totalitarian religion. Still scientists need to resist the intrusion of Creationism into K-12 science. Selective Creationist dogma does not intrude on most mundane technology. It and alternative medicine may come under scrutiny when we need the real science of pathogens and their evolution if a pandemic breaks out.

The medieval worldview results from valid observations; it is a profound mistake to regard it with contempt. Pre-scientific logic personalizes events and does not account for sampling bias. I reiterate the illusions that I have discussed at the start of this book. I begin with the weak antropic principle that we need to be here to observe. Looking broadly, we sense Providence. We find that the Earth suits us and that we are well suited for the Earth. Examining our body and other organisms, we sense Design. We, like all other organisms, have evolved for the conditions we actually faced. As a widespread organism, we find ourselves fit.

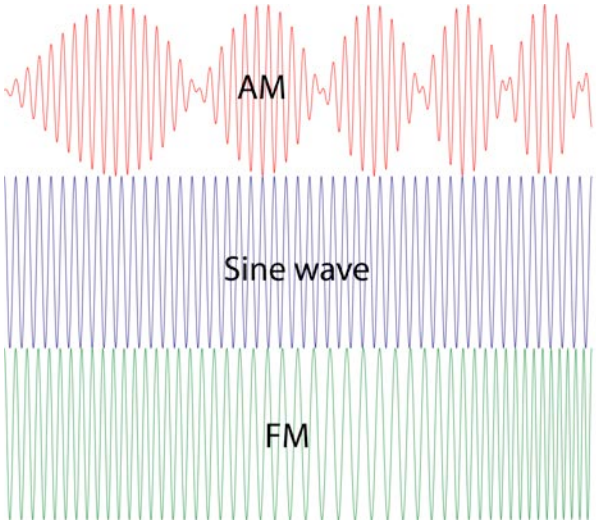
Looking at our personal and species' histories, we sense good luck to the point of Miracle. We may sense Purpose in our ancestors' chain of fortune. This is survivor bias. Again one can question only live witnesses. The ancestors of a fly that lays 200 eggs each generation have beat far more severe odds. These odds tell us nothing about the survival of the fly on my desk. Swat!

We see the effects of and attach importance to recent and nearby events much more than ancient and distant ones, the illusion of Propinquity of those wanting to learn words. Geologically the Earth is active. It appears young before onerous systematic study. The planet though small in the universe is extremely important to us. With regard to microbial life and ET, technology limits the search to near our abode.

We may attach improbability to the rise of our intelligence, civilization, and science because it just occurred. The most recent past is always the youngest history. For example, you have been reading this page less than one trillionth of the age of the Earth and been living less than a one hundred millionth of the age of the universe. These fractions give no insight into the probability of my authorship and your book purchase.

We tend to attach meaning and moral implications to natural events. As individuals and society, we to not have to look far back or wide to find bad deeds, giving the illusion of Chastisement. Neither to we need to look far or wide after good fortune to see Benevolence reward good behavior. The concept of impersonal natural phenomena was a major contribution of classical science. Modern science and astrobiology began when Bruno and Galileo extended this concept to the astronomical heavens.

Primer on signals and communication



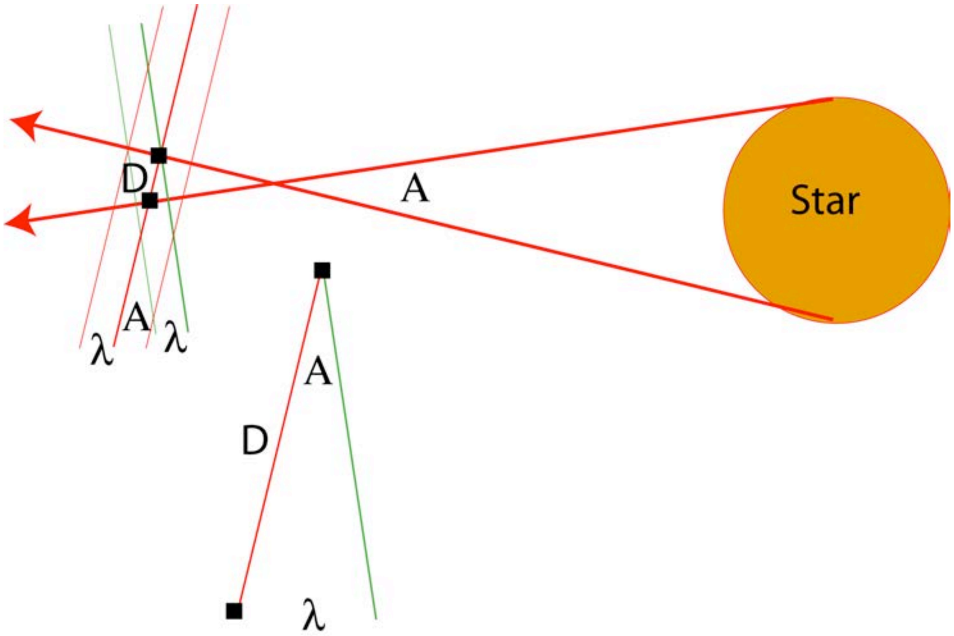
ET in possession of lasers or radio telescopes will be will aware of the basics of signal processing and communications. Starting with foghorns, one can send out a simple sine wave as a signal. It is easily received but carries almost no information. The entire signal is predictable once some of its has been recorded. To carry information (that is something the recipient does not already know) like with DNA, the signal needs to have both order and unpredictable complexity.

The amplitude modulation (AM) radio in your car is a sine wave with the peaks and troughs regularly spaced. The envelope (the curve drawn through the peaks and troughs) carries the information. The frequency modulation (FM) radio has constant amplitude peaks and troughs, but the spacing (frequency) of the peaks and troughs varies to carry information. A foghorn may modulate frequency. It also uses a crude form of amplitude modulation, turning the signal on and off in beeps.

In both cases, the signal involves a range of frequencies on each side of the carrier frequency of the sine wave. One needs a large range of frequency (band width) to transmit information rapidly. However to function, the signal must be above the ambient noise over its frequency band. A trade off exists between having a broadband signal with lots of information and a narrowband signal that is above the noise level. ET will need to operate at the narrow band end to have the signal arriving at a distant planet above the noise level.

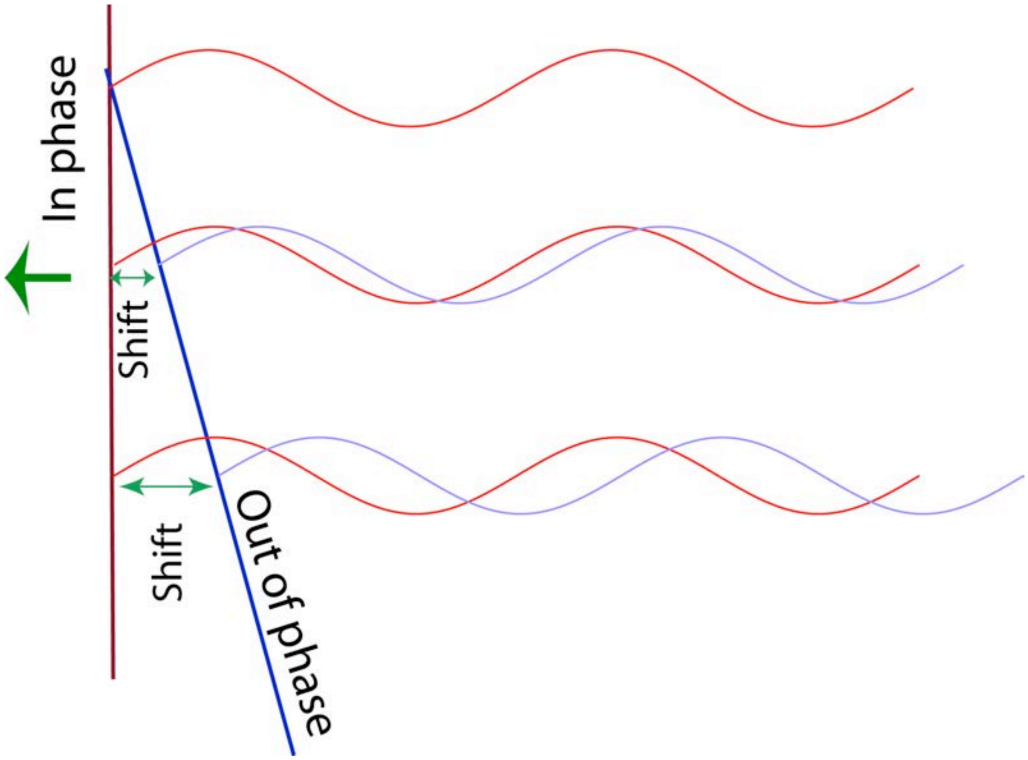
You tune your radio to one station frequency at a time depending on whether you want the news or rap music. The SETI program does not have a channel guide for ET. They record the raw signal and then look at each frequency band. This is done efficiently with modern computers and electronics. You do this when you scan for stations.

Now applying the lighthouse analogy, stars are far away and ET’s signal will come from a point in the sky. We can cut down on ambient noise if we focus at a point. Your eye and brain do this automatically with a lighthouse beacon.



One needs a large detector to resolve a distant object or to focus finely on a point. The problem is the same as trying to resolve the disk of a nearby star with an array of telescopes (called an interferometer). We have for simplicity 2 detectors, a distance *D* apart. As drawn, light comes in from each limb of the star. The ray paths are not parallel and differ by an angle *A* (greatly exaggerated). The wave fronts from the two rays are not parallel, also by the angle *A*. The wave front from the lower limb arrives at the two detectors at the same time. The wave fronts from the upper limb arrive at the 2 detectors at different times. If we sum the signal from the two detectors it will enhance the signal from the lower limb and degrade the signal from the upper limb.

As the angle *A* is small, we can use radians (1 radian ~ 57°). The angle of resolution $A \approx \lambda / D$. This formula also applies to broadcasting antennas. We need an antenna of size *D* to collimate signal to wavelength λ into a beam of angle *A*. It is easily to collimate short wavelength laser signal than long wavelength radio signal if one has a target in mind.



Radio waves are moving right to left. The signals would arrive in phase at the vertical detector line but out of phase at the actual detector array. One scans for signals coming in the horizontal direction by shifting the arrival times and summing. The actual detector is a 2-D grid array on the Earth's surface that checks for signal coming from all points in the visible part of the sky.

Modern SETI detectors are gridded arrays of many radio telescopes. A signal coming from directly above arrives at all the telescopes at the same time. The array would be quite inefficient if it could look only in that direction. One can shift the arrival times of the signals so that ones coming from a particular direction are in phase. The modern SETI engineers do not know which way to look so they look in all directions at the same time by summing the individual signals with different shifts.

Checking all frequencies and all directions in the sky guarantees that the array will occasionally detect a promising signal well above the apparent noise background. The SETI engineers are well versed in the statistics of how often adding up random signal will give high amplitude. The array also picks up human signal from the ground and from space. The SETI teams mark frequency-points in sky combinations that give promising signal for further examination. So far they have found no repeatable ET source.

Notes and Exercises

Serious science fiction is an entertaining source of speculation about social development on the Earth and ET. You can follow the evolution of our attitudes as science has provided more information.

Reprints of the original *The War of the Worlds* are available from web-based booksellers. You can check out the original book, the 1953 movie, and the 2005 movie. The aliens' armament improves over that time. The cleric is the butt in the original. Check out his character in the movies.

Science fiction stories, including those by Larry Niven and the movie *Logan's Run*, deal with draconian methods of population control. If you are an avid reader, compile and compare examples. What methods were employed? How well did they fare? What problems did they generate? How do these vary with publication year?

Many of the original *Star Treks* were social commentary. If you are fan, you will be able to compile the issues, the solutions, and conflicts. You will also see how our society has addressed them in the intervening time. A fan of the original *Planet of the Apes* series can do the same.

You can get pro and con arguments about wind, solar, and nuclear power off the web and in numerous publications. A tractable project would critically focus on one method and one line of argument. One could do the same with global warming or a method to avert it.

Ad hominum (to the person) arguments are in principle avoided in science in favor of addressing logic and data. However, press releases very rarely contain enough information untrained public and press (or even scientists) judge on their own. We are in practice left with the track records and credentials of the claimants. Vested interests are a red flag; leading science journals demand that authors reveal potential conflicts of interest.

Still, it has proven easy for the people and organizations that deny global climate change to have wide access to the press. A typical argument is that X harmful is not fully proven, there is still controversy (never mention that it is of our own making), and that it is premature to act. Their track record gives them little credibility. Part of the motivation is economic with strong conflicts of interest; the deniers and their organizations date back to tobacco industry apologists. The rightwing dogma that any interference of industry by the government is evil socialism or even communism has played a large part. Historically, rightwing scientists achieved considerable prestige during WW II and the Cold War. Some of these aged individuals are still active. The deniers are quick to publicize any error (even typographical) by climate scientists.

Virtually every scientific discovery on harmful environmental effects of industrial substances has come under scathing attacks, including DDT, the ozone hole, and acid rain. The deniers claimed that replacing each would require untold expense. Actually, DDT was replaced after indiscriminant outside spraying rendered insects resistant and the product worthless. Freon was replaced with compounds that did not place chlorine in the upper atmosphere. Part of the chemical industry accepted the scientific result and knew that wealth would accrue to them if they found viable safe substitutes. Low-sulfur coals and scrubbers have lessened sulfur release into the atmosphere and hence acid rain.

Back to tobacco, cigarettes were informally called "coffin nails" when I was a child in the late 1950s. But it was still considered very rude to object to smoking well into the 1970s. The deniers vigorously opposed evidence that second-hand smoke is very harmful. They were singularly ineffective. Smoking regulation came in before the evidence of serious harm from second-hand smoke was fully in hand. The majority of nonsmokers were not primarily worried about cancer; they just did not want to put up with stench and nuisance breathing problems.

See *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*, Naomi Oreskes and Erik M. Conway, Bloomsbury Press, 2010.

A sampling bias exists if we concentrate too much on our own evolution and particularly our intelligence. That is, there is inevitably a trend toward increasing intelligence (measured by brain size to body size) over geological time once we have defined ourselves as the end point. This paper argues against the widely held view that evolution given time will converge to an intelligent species in at least one line of descent. The author supports the search for ET, recognizing his reasoning leads to a testable hypothesis. Lineweaver, C.H. 2008 Paleontological Tests: Human-like intelligence is not a convergent feature of evolution. In From Fossils to Astrobiology, Eds J. Seckbach and M. Walsh, Springer, 353-368.