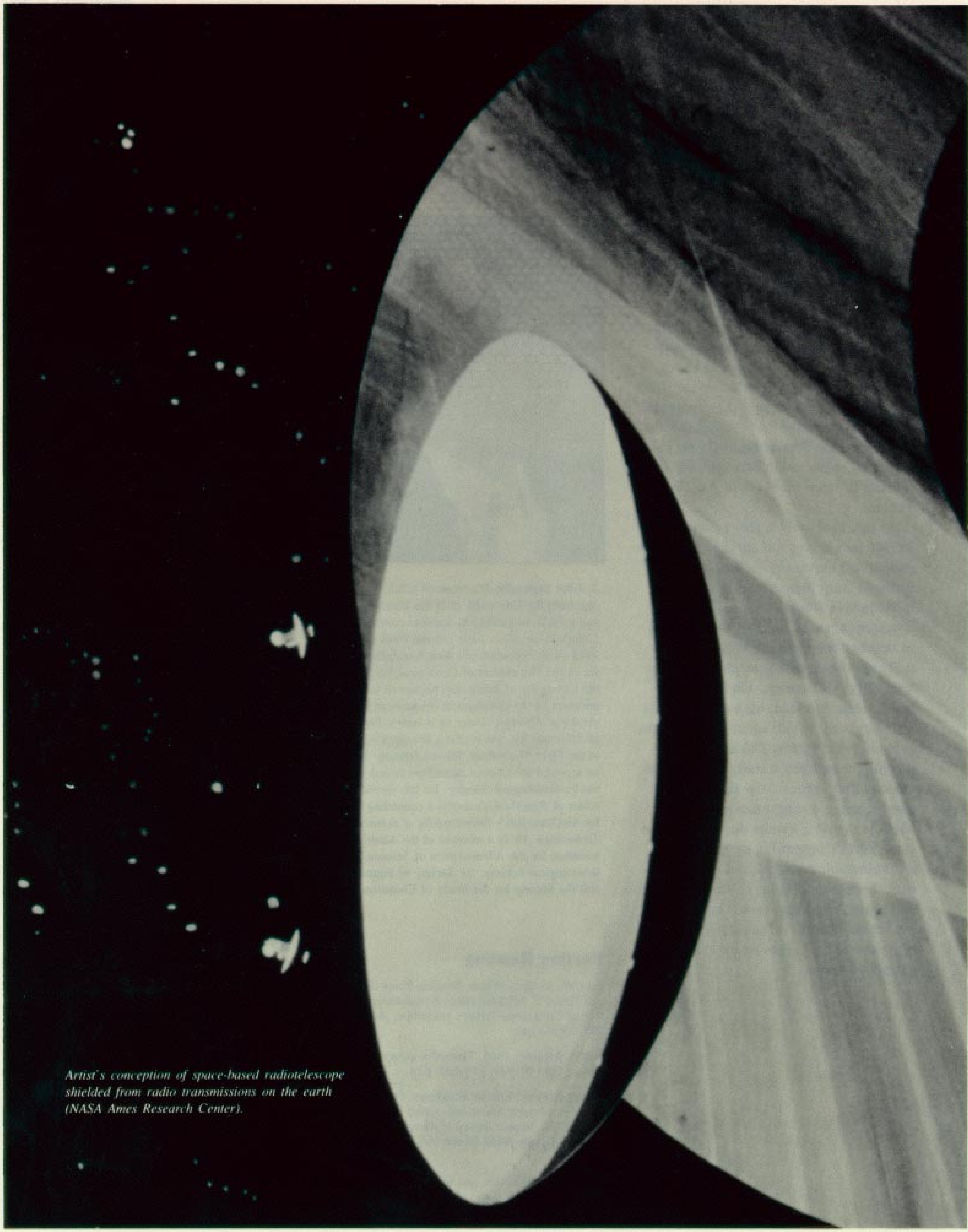
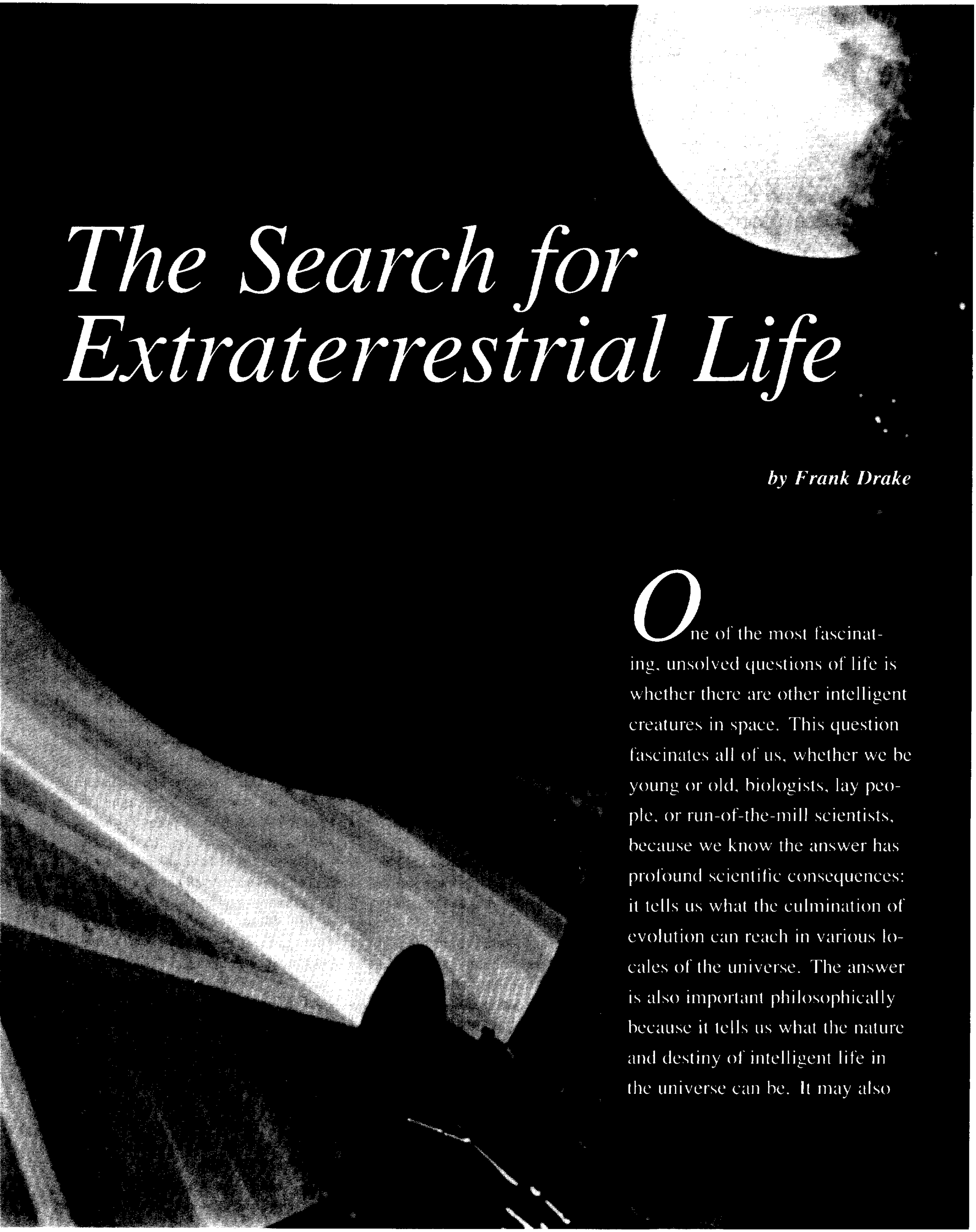


Artist's conception of space-based radiotelescope shielded from radio transmissions on the earth (NASA Ames Research Center).



The Search for Extraterrestrial Life

by Frank Drake

One of the most fascinating, unsolved questions of life is whether there are other intelligent creatures in space. This question fascinates all of us, whether we be young or old, biologists, lay people, or run-of-the-mill scientists, because we know the answer has profound scientific consequences: it tells us what the culmination of evolution can reach in various locales of the universe. The answer is also important philosophically because it tells us what the nature and destiny of intelligent life in the universe can be. It may also answer personal questions about the significance of our role in the universe and what we can accomplish. Presumably, an answer might also show us how to obtain important scientific and technological information from other civilizations—knowledge we would not otherwise gain except by hundreds of years of hard, expensive effort. Thus the question of whether extraterrestrial intelligence exists is important for reasons that range from the most profound philosophical level to the very practical and technical levels.

Nowadays we generally break the question into two parts. First we ask about our expectations for intelligent life in space based on what we know of biology, the arrangement of the universe, and the laws of physics. This part guides us about the difficulty of the search, the possible closeness of the nearest civilizations, the expected number of civilizations in the galaxy, and the range of life that might be found. These answers in turn serve as guidance for the second, more practical question: What is the most promising way to search for that life?

The Number N of Detectable Civilizations

$$N = R f_s f_p n_e f_l f_i f_c L$$

where

R = average rate of star formation in galaxy (stars/year)
f_s = fraction of stars that are "good suns"
f_p = fraction of good stars with planetary systems
n_e = number of planets per star within ecoshell
f_l = fraction of ecoshell planets on which life develops
f_i = fraction of living species that develop intelligence
f_c = fraction of intelligent species achieving electromagnetic communication
L = lifetime in electromagnetic communicative phase (years)

How Many Other Worlds?

The number of detectable civilizations N that might exist in our galaxy can be represented by the nice, neat equation shown above. In this equation the "good suns" associated with f_s are stars whose production of light has the length and constancy needed for the evolution of intelligent life. Also, the fraction of intelligent species f_c that achieve electromagnetic communication are those that develop the technology needed to make them detectable in the galaxy.

The equation plays two roles. First, it tells us what we need to know: Looking at it, we see what the other unanswered questions about life are. Second, because the equation is a simple product—there are no exponential or logarithmic parameters, no gamma functions, no sines or cosines, or such—it tells us that all the things we need to know are equally important. The chain of factors is only as strong as its weakest link.

The product of all the factors except the last one gives the rate of production of potentially detectable civilizations in the galaxy. Using the best numbers we have, which frequently are only crude guesses, we arrive at a rate of about one per year. If we now multiply by the mean longevity of highly technical civilizations L, *we* find the total number of detectable civilizations in the galaxy: $N \approx L$.

Now all these factors are, in fact, questions. The rate of star formation is an astronomical question, and we happen to know the answer quite well—about twenty per year since the birth of the galaxy. Realistically, this number is the only one we know well. We know the fraction of good suns fairly well, but the fraction of stars that have planets is currently seen only through a glass darkly. Intimations of planet formation in the disks of dust around nearby stars, in the detection of a brown dwarf around a star, and so forth suggest that more than 10 per cent of the stars have planetary systems. As yet, though, we haven't confirmed that estimate to any degree of certainty. Models of planetary formation suggest there will be two planets in each system suitable for life, but there is no physical evidence other than our own system to support such an answer to this astrophysical question.

Now we come to the questions about life. What fraction of potential life-bearing planets give rise to life? The experiments that have been done now in a host of laboratories show a multitude of pathways giving rise to the chemicals of life. Moreover, if that is not good enough, these chemicals seem to be carried in from outer space by comets and asteroids. It is pretty clear that we know quite a bit about this question: the fraction must be very close to one.

The next three factors—the fraction of living systems that give rise to intelligence, the fraction of those that give rise to technology, and finally the longevity—are fascinating in themselves, and I will dwell on these factors a little more than on the previous ones. In fact, we usually quickly wave our hands over the last factor and move on, but it is one of the most important unanswered questions about life.

Is Intelligence Inevitable?

Until recently the fraction of systems that give rise to intelligence was quite controversial. Intelligence was believed to be the artifact of a limited series of freak events in the course of evolution and thus occurred only rarely in systems of living things. In other words, it was thought to be an anomaly in the universe—a view that some people still hold. However, over the years evidence has increased to support the idea that intelligence will arrive by one or another of many evolutionary paths. If one examines the fossil record, the only feature that one always sees increasing in power or size is the brain. We have had larger creatures, faster flying creatures, faster running creatures, more vicious creatures, but we have never had creatures on the surface of the earth that were smarter than the ones we have today. In fact, many studies of the cranial capacity of creatures have shown the increase in intelligence to be very monotonic over the course of time.

Figure 1 shows the distribution of brain mass versus body weight both for reptiles and mammals living now and for archaic reptiles and mammals that lived about seventy million years ago in the period before the Cretaceous-Tertiary boundary. Surprisingly, we find for each group not a scatter diagram but a well-defined relationship in which brain mass goes essentially as body weight to the two-thirds power, a rule that has applied through all evolutionary eras for which we have good data.

Each of the four groups shown in Fig. 1 occupies a clearly defined region. For example, the archaic reptiles (the dinosaurs) were, of course, much larger than current reptiles, and they occupy a region higher both in body weight and brain weight than the region occupied by the living reptiles. But when we compare mammals to reptiles *at a given body weight,* we find the archaic mammals have approximately four times the brain mass of the archaic reptiles, whereas the living mammals have twenty times the brain mass of the living reptiles. Although the change is more dramatic for the mammals than for the less evolutionarily advanced reptiles, there has been a definite increase for both. One can make plots using different or more finely divided time intervals, and one always finds a monotonic increase in brain size with time.

The host of statistical evidence showing the increase supports the idea that, in one way or another, an intelligent creature will appear on a life-supporting planet. In fact, if competition did not take its toll, there would most likely eventually be a *large* number of intelligent creatures on each planet.

An interesting bit of evidence for this last conjecture is the recent discovery of dinosaurs that had relatively large brain masses. Their brains were not as large as those of humans by any stretch of the imagination, but the mass was larger than that of the typical dinosaur brain. These creatures include one known as an ostrich dinosaur that lived in Mongolia and the northern United States, one with the delightful name of *Stenonychosaurus inegualis* that stood about six feet tall and weighed a little over a hundred pounds, and my favorite, a cute

BRAIN-BODY WEIGHT RATlO

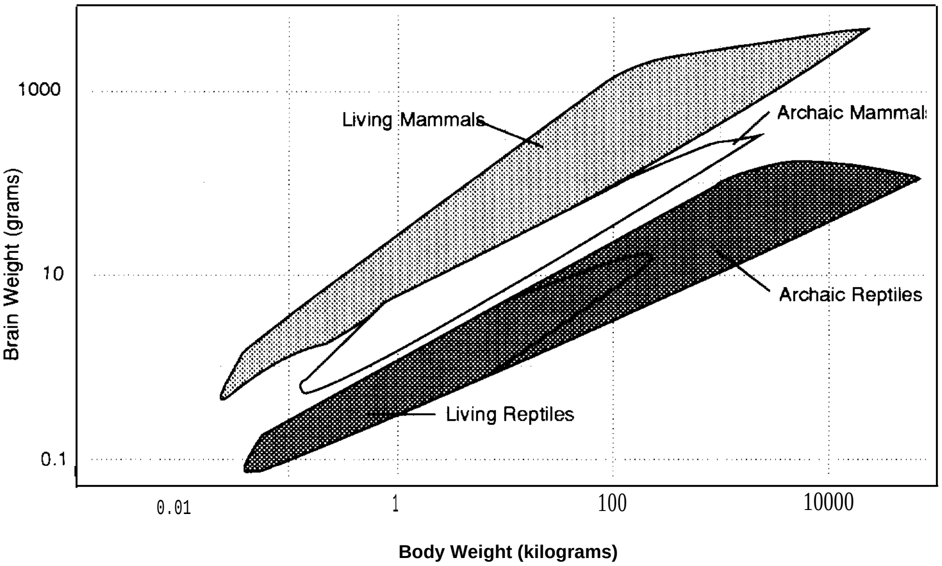


Fig. 1. A logarithmic plot of brain weight versus body weight for living mammals, living reptiles, archaic mammals, and archaic reptilea, where archaic means 70 million years ago during the age of the dinosaurs. The plot shows that each group follows the typical two-thirds power relationship. The average statistical increase in brain mass for a given body weight over those 70 million years has been on the order of a factor of 10, but the 20-fold increase for the mammals is significantly larger than the 4-fold increase for the reptiles.

critter called *Saurornithoides,* which means reptile with feet like a bird.

The saurornithoides (Fig. 2) had about the same height and weight as we do, stood on its feet using its forearms as we use our arms, and had the equivalent of an opposable thumb. It used its intelligence and its "hands" to catch its favorite food, rat-like animals—the things that Jack Sepkoski calls vermin—that were the original mammals, our ancestors. Most interesting, the saurornithoides had a rather large brain case: Its brain mass was not the few grams typical of dinosaurs but was of the order of a hundred grams, Although smaller than that of a human infant, that mass is getting there, folks. If the saurornithoides had had another ten or twenty million years, it could well have been the first intelligent creature on earth. Your mommy and daddy, your spouse, your girlfriend or boyfriend would have looked like the creature in Fig. 2. We would have had to redesign the furniture, and we would all be looking forward to a dinner of vermin. But that was not to be. Before sauronithoides became intelligent enough to preserve itself from catastrophe, a catastrophe happened, and the earth was left to the vermin. Sixy-five million years later the vermin are us.

The sauronithoides are an example of creatures that could have led to a very weird species of intelligent life on the earth, although an intelligent species can probably be much weirder depending upon who wins the evolutionary race. Regardless, we now expect intelligence to be capable of arising over and over again on a planet. This expectation, of course, leads one to ask: If we wipe ourselves out what will be the next intelligent creature? I have a favorite candidate, although no one ever believes me when I say it's the squirrel. But anyone with a bird feeder knows they are very intelligent. So there it is, standing in the wings-on its two hind feet using its forepaws—ready to take over if things go wrong.

A SAURORNITHOIDES

Fig. 2. This relatively intelligent dinosaur used its "hands" and intelligence to catch vermin, our mammalian ancestors.

Space Colonies?

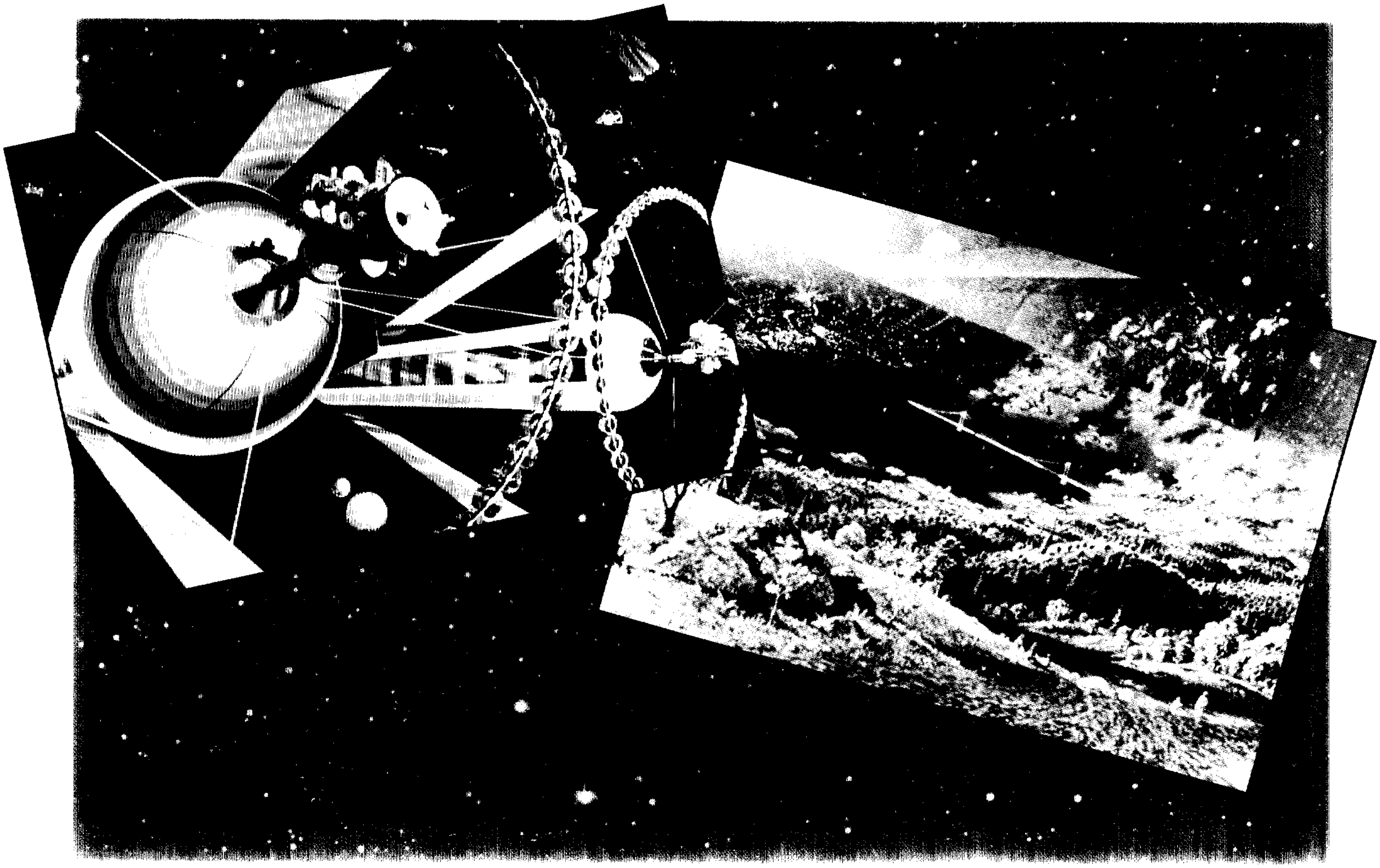
What about the development of technology? Such development happened independently three times on earth: in the Middle East, in China, and in Central America. In each case, population pressure triggered the development of organized agriculture, which, in turn, created the need for tools and then artisans to construct the tools. Of course, the artisans quickly learned they could make weapons, and then it was only an instant in cosmic time from stone axes to video tape recorders and motorcycles. It seems that technology should be very common in the universe.

What becomes of technical civilizations'? Many people feel our civilization is very primitive in the sense that, as we have seen in the history of many other civilizations, there is a great panorama of technical development ahead of us. One scenario is the colonization of space, which could create living room for literally billions and billions of people. Today we have the technology to build great space colonies, although they would be very expensive. A typical colony might be twenty miles long and several miles in diameter, and it would slowly rotate in space with its long axis pointed toward the sun (Fig. 3). Huge mirrors, inclined to reflect sunlight through windows, would create daylight inside. Initially, one might think that a space colony would be a horrible place to live, but it could be delightful with landscapes, lakes, rivers, and a force resembling the earth's gravity due to the slow rotation (a few revolutions a minute) of the colony. Moreover, you could have a bug-free environment and made-to-order weather: open the mirrors a lot to have Hawaii week or close the mirrors most of the way to have an Aspen skiing week.

In this scenario civilizations eventually leave their dreadful home planets and colonize space, where literally tens or thousands of millions live in wondrous splendor. What do they do in these colonies? They make *other* colonies. This very heady concept creates a picture of almost everyone living in colonies. The only people left on the earth are park rangers because the planet has been made a national park. People take their kids down on the Gray Line Space Shuttle to show them how terrible it was for their grandmommy and granddaddy who had to endure tornadoes and storms and mosquitoes and other horrible things.

Whether or not the colonization of space is the course of the future for civilizations is important for our equation because it affects our estimates of both the longevity of civilizations and how brilliantly they might shine to the universe. Notice that my discussion has now become unscientific because, for the first time, I am talking about something we don't know has actually happened in the universe. Everything up to this point we know happened at least once.

Carrying this idea further, one can't avoid thinking that colonization must occur elsewhere and intelligent civilizations are destined to colonize the stars



of our galaxy. Such a thought may have occurred first to none other than Enrico Fermi, who, one day at Los Alamos about forty years ago, started going around asking: “Where are they’?” He had made an analysis similar to mine, estimating how many civilizations might be out there and how fast they were created, Given the continuous march of technology he felt that, even at slow interstellar flight speeds, a civilization could populate the entire galaxy in only a hundred million years—a small fraction of the age of the galaxy. This estimate suggests that the first intelligent civilization to embark on a such an enterprise should have already taken over the whole galaxy and thus arrived at the earth. Where are they? Some people, including Eric Jones at Los Alamos, have taken this idea very seriously and worked very hard exploring [he possibilities and obstacles to interstellar colonization.

Now is it possible that something is wrong and we are, in fact, alone in the galaxy’? Everything we know seems to indicate that colonists should be out [here, but, if so. why have they not yet come to the earth? Well, there are a variety of solutions to this Fermi paradox. Perhaps there are cosmic hazards to space travel of which we are unaware. Or perhaps the colonization follows a diffusion equation. If instead of moving outward radian}, colonization is best described by a random walk, then it takes about the age of the galaxy to colonize the entire galaxy. In other words, the colonists should not be here yet-but tomorrow they will come out of the sky!

Galactic Colonization?

The argument I favor is simply that it makes better sense to colonize in your own system than to endure the costs and hazards of going to other stars, There may indeed be enormous numbers of civilizations of great technical prowess that don’t bother to come to earth in person, In other words, I assume that an intelligent civilization will colonize space *only* if it gets a good bang for its buck, that is, only if the quality of life for its expenditure is equivalent to the lifestyle it would get for the same amount of resources, energy, or money in its own system. But, you say, we do not know what the cost of interstellar colonization is or what the propulsion systems are and what they cost, and so forth. However, the way to get a minimal cost is to use the minimum kinetic energy required for interstellar colonization. Such an approach yields a cost figure in the absence of any knowledge about the actual physics of the propulsion systems, In other words, we assume the energy used per colonist is no greater than the energy required [o give a good life to that colonist back in the home system and *all* of the energy is used in the kinetic energy of the spacecraft. Such assumptions surely yield a very conservative lower limit.

If E is the energy ratio per colonist, we equate that to kinetic energy to get the velocity of the spacecraft $(v = \sqrt{2E/m})$. What is a reasonable energy ratio for a human being? The most energy-rich country in the world is the United States, which, during a recent year, consumed a total of about 10^{20}”

joules of energy. The population is on the order of 250 million, which yields about 4×10^{11} joules per person per year. If a lifetime is about a hundred years, lifetime energy consumption per person is around 4×10^{13} joules. This energy ratio takes you to Europe, buys you ice cream cones and corn on the cob, makes your car go, and all that.

What spacecraft velocity does this limit yield? If we allow a spacecraft mass of ten tons per colonist—about the per-passenger mass of a typical airliner—the velocity of the spacecraft is ninety kilometers per second. That velocity is pretty fast—about ten times the velocity of our Voyager or Viking spacecraft. The time to go ten light years, which is probably the minimum distance to a suitable star, is forty thousand years. Now that picture is a little discouraging—you are sitting in a DC-9 for forty thousand years eating airline food and watching the same movies over and over again.

If we abandon this approach and, instead, assume a velocity high enough to get to the star in a hundred years, that is, a couple of generations, the energy required *per colonist* is $2 \times 10^5 E$. In other words, a trip that takes place in a reasonable amount of time uses the same energy as does a good life in the home system for 200 thousand people. What makes this approach even more unrealistic is that, besides not allowing for inefficiencies in the production of fuel and in the propulsion system, we have arrived at the distant star at a very high speed and have no energy remaining with which to stop. We just go whistling through the system and out the other side! If we take proper rocket-mass ratios and so forth, the actual energy *per colony* for a hundred colonists is about 200 million E, that is, the same energy needed to support the entire population of the United States for their lifetime. To launch a mission we would have to shut down America for a hundred years.

Much less energy is required to build space colonies in one's own system. The energy required to accelerate ten tons to a velocity sufficient to go ten light years in a hundred years—the example I just discussed—is about 10^{18} joules. The energy required to put ten tons in lunar orbit, that is an orbit in the solar system with an orbital velocity that will keep it from falling, is about 6×10^{11} joules. The ratio of energy required for interstellar as compared to solar system colonization is thus about 10^7. Although one might argue that very advanced civilizations will have access to much greater energy resources, a factor of 10^7 is very hard to overcome.

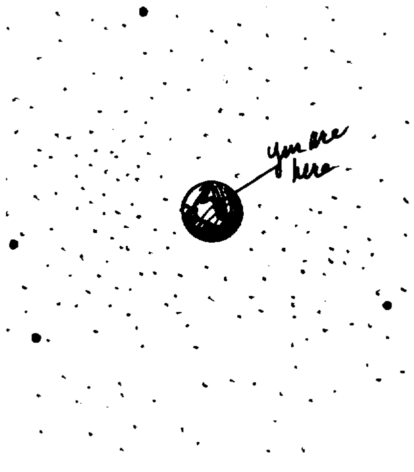
Lord Kelvin said that you don't know anything in science until you put numbers to it. I feel the idea of colonization is one for which we have to pay attention to the numbers. A dumb civilization might go to the stars, but a smart one will, I think, stay right at home. There is enough energy from the sun to support, believe it or not, somewhere between 10^{20} and 10^{22} human beings, depending upon the quality of life. That number is about 10^{12} times as many people as there are now—which seems like enough. A civilization can do all that at home for about one ten-millionth the cost of doing it at the stars. Where are they? They are probably living in great splendor in their own home systems, and they are there in great numbers for us to find.

(By the way, I would recommend the analysis of the energy required for interstellar colonization as a project for the Economics and International Studies Section here at Los Alamos. I ought to also mention that that section includes the esteemed economist Robert Drake, who happens to be my brother.)

Notice that my argument raises one of the important questions of life for which we do not know the answer: What is the limit of energy that intelligent civilizations manipulate? Do civilizations go to the stars, colonize their own systems, or stay on their own planets? To answer that we need to know how much energy they generate, manipulate, and store. Of course, there may not be a single answer to the question; it may depend on motivations, anatomies, or who knows. However, the answer is crucial to understanding what may become of intelligent civilizations, what we might find in space, and what we should be looking for. The question thus affects *how we* search for civilizations.

Where Do We Search?

Suppose we start our search outwards in space. What is the best strategy? Where should we look to find civilizations fastest? One's intuition says we should look at the nearest stars similar to the sun because the signals will be strongest from them. Surprisingly, that is wrong. If you look at normal stars in



FAINT AND BRIGHT STARS

Fig. 4. Because intrinsically bright stars are relatively rare, their distance from the earth is typically much larger than that of the dimmer stars.

the night sky, the brightest and easiest to detect are, with few exceptions, not the closest. Bright stars are in fact very distant; moreover, most of the twenty nearest stars are very faint and invisible to the naked eye (Fig. 4 and Table I). This strange situation can be understood by looking at the distribution of intrinsic brightness: faint stars are plentiful and bright stars are rare (see "Are They Near or Far?"). As a result, the typical distance of a bright star from the earth is much greater than the typical distance of a faint star. But if the intrinsically bright stars are bright enough. as they indeed are, they will still outshine the brightest of the nearby stars.

The same thing is true of cosmic radio sources. The brightest, or apparently brightest, cosmic radio sources are not the nearest ones in our own galaxy but the most distant, the quasars. So again we have a situation where the easiest things to detect are not the closest but the farthest.

Thus it may not make sense to look at the nearest stars after all. Perhaps, instead, we should look at the *most* stars we can to locate the intrinsically brightest civilizations. Whether this is right depends again on the maximum amount of energy a civilization can manipulate. Is there an enormous range of energies'? If so, the right strategy is to look for the rare but intrinsically bright civilization. On the other hand, if civilizations all operate at about the same energy level, the right strategy is to look at the nearest stars. Unfortunately, we can't know which answer is right until we have found other civilizations.

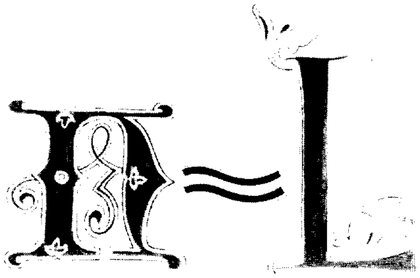
Table 1

Of these stars, the three that are *both* bright and near are shown in bold.

The Twenty Brightest Stars	The Twenty Nearest Stars
Achernar	Groombridge 34
Aldebaran	L726-8
Capella	τ Ceti
Rigel	ϵ Eridani
Betelgeuse	**Sirius**
Canopus	Luyten +5°1668
Sirius	**Procyon**
Procyon	Wolf 359
Pollux	Lalande 21185
Regulus	Ross 128
Acrux	**α Centauri**
Spica	Barnard's star
Agena	Cincinnati 2456
Arcturus	Ross 154
α Centauri	61 Cygni
Antares	Lac 8760
Vega	ϵ Indi
Altair	L789-6
Deneb	Lacaille 9352
Formalhaut	Ross 248

What Will We Find?

Now as I said earlier, this type of reasoning coupled with our best estimates for the various factors leads to the prediction that the number of detectable civilizations in space is roughly of the order of *L,* the average longevity in years of civilizations in a communicative phase:



$$N \approx L$$

I've used an elaborate font for the equation here because, in science, when you don't know something very well, it's more impressive and compelling to write it with fancy letters.

It is, of course, arrogant to try to say anything about the value of *L.* We have been a detectable civilization for only about forty years now—since the advent of television! Studies have shown that the strongest and most detectable signs of the earth, by far, are our television broadcasts, and we have become brighter every year as the power of these broadcasts has increased. About three hundred stars are now receiving Kukla, Fran, and Ollie and Uncle Miltie, and each year about ten more stars join in. Despite our terrible ignorance about the value of *L,* there is a relevant point, as we will see, that comes out of any discussion of this factor.

We make an estimate for *L* by imagining possible ways that civilizations might terminate (Table 2). This process is a guess, and everyone is invited to make their own estimates or invent other ways that civilizations might reach the end of the line.

The first category is total destruction, that is, MAD is actually invoked on the planet. The detectable lifetime for a civilization that ends with such an event might typically be fifty years. Let's guess that the probability of the event happening might be 10 per cent—that is, one in ten systems destroy themselves through war.

Another event is the cosmic accident such as a large asteroid crashing to the surface of the earth. The time between such collisions is very long—millions of years—so the probability for this event is very small.

Another possibility is the degeneration of culture; that is, the quality of life simply goes down as the world drifts into a subsistence culture. The television stations, of course, get turned off. Such civilizations may be detectable for 10^4 years, and let's guess that there's a 10 per cent probability of this occurring.

Although that last category requires very wild guesses, the next is more reasonable: becoming invisible due to superior technology. If we detect civilizations by their television programs and they all go to fiber optics or cable tele-

Table 2

An estimate of L, the lifetime of a technologically advanced civilization. In this case the total weighted value for L of 12,000 years is almost entirely the result of the "no limitation" civilization, a rare society ($P_{exist} = 10^{-3}$) that achieves a long lifetime (10^7 years), say by dodging the perils of nuclear war and building large numbers of space colonies in their own planetary system.

Limitation On L	L_c (yr)	P_{exist}	$L_c * P_{exist}$ (yr)
Total Destruction	50	0.1	5
Cosmic Accident	10^6	10^{-6}	1
Degeneration of Culture	10^4	0.1	1000
Invisibility Due to Superior Technology	10^3	0.7	700
Abandonment of Technology	10^3	0.1	100
No Limitation	10^7	10^{-3}	10,000
		1.0	L = 12,000 yr

vision, they may vanish from the scene. In fact, for people like me, cable television is very bad news. The second most impressive sign of our existence, by the way, are the military radars of the Soviet Union and the United States, so cable television and peace on earth are both bad news. I'll be optimistic about this category, giving it a seventy per cent chance of happening and a lifetime of a thousand years before the civilization actually becomes invisible.

Abandonment of technology is, in a way, related to degeneration of culture, and I've given this possibility similar numbers: a thousand-year lifetime and a 10 per cent probability of happening.

Finally we have the "no limitation" category: civilizations that build space colonies and transmit to those colonies, to their interstellar spacecraft, and what not. They may exist for 10 million years, but we will guess that only rarely-one in a thousand times—does a civilization accomplish this.

Now, to get the total L we multiply the lifetime in years times the probability for each category, then sum—in other words, we calculate the weighted mean value of L. Using my guesses the answer is 12,000 years. The main point I want to make, however, is that the final value comes almost entirely from the contribution of the no-limitation category—a category to which we assign a probability of 10^{-3}! In other words, the result is strongly influenced by something we know very little about, something for which we may know the exponent by only a factor of two or three. The long-lived civilizations control L, and all the other categories amount to only a drop in the bucket.

What happens if you carry this to an extreme and assume that in some cases civilizations achieve immortality? By the way. immortality for a living species is not out of the question. Jack Sepkoski says that extinction is good because it makes it possible for evolution to speed up. Likewise, death within a species is good because it allows more members of the species to pass through that ecological niche, raising the chances for favorable mutations. At some time on the earth there could well have been an immortal species, but if there were also species that were ***not*** immortal, the ones that died evolved and got better and better until they ate all the immortal ones. That's why we don't see any immortal species today.

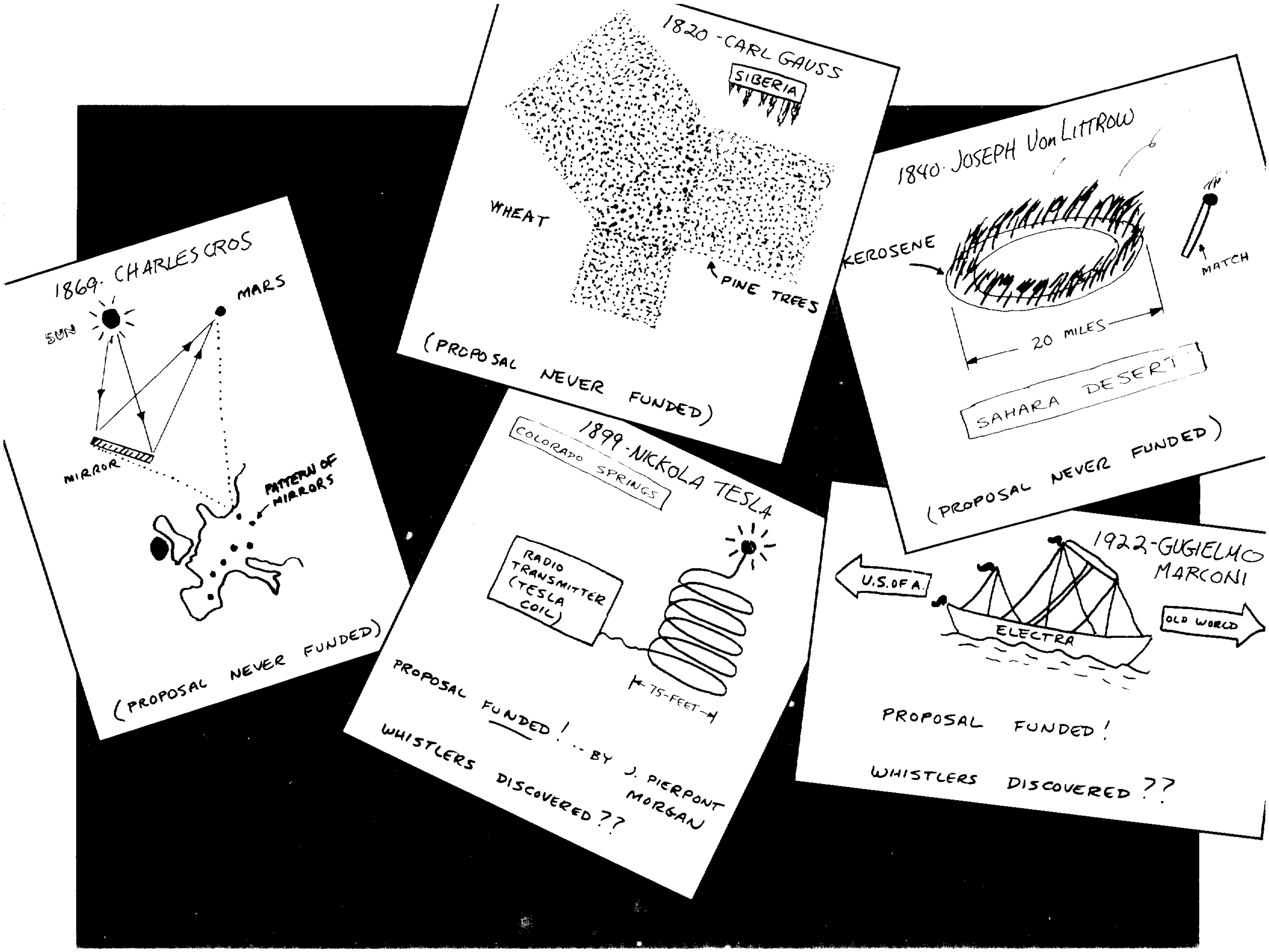
Although evolution selects for death—and death is a good thing to have until the species is intelligent enough to look after such things—there is nothing in physics or biology that requires death; it's an artifact of evolution. It could well be that there are civilizations clever enough to undo that part of evolution and become immortal.

Say we make the same analysis as before except represent the immortal civilization as one with a lifetime on the order of the age of the galaxy or the age of the oldest of the suitable stars (Table 3). Given a probability of 1 per cent-one in a hundred civilizations that actually achieve immortality-we get a value for L of 10 million-essentially all from the immortal civilizations. If we divide the weighted lifetime for each category by the total weighted lifetime L, we get the probability of discovering a civilization in any particular category. For example, the probability that you are going to find a civilization that is about to self-destruct is 5×10^{-7}. The

Table 3

A second estimate of L in which the "no limitation" society has been replaced with the "immortal" society, that is, one with a lifetime equal to that of the galaxy ($L_c = 10^9$ years). We quess that 1 per cent of the technological civilizations achieve this state of biological immortality. The last column, which gives the probability of detecting each particular type of society P_{detect}, shows that immortal societies, if they exist, are the ones that will almost certainly be found.

Limitation On L	L_c (yr)	P_{exist}	$L_c \cdot P_{exist}$ (yr)	P_{detect}
Total Destruction	50	0.1	5	$5 \cdot 10^{-7}$
Cosmic Accident	10^6	10^{-6}	1	10^{-7}
Degeneration	10^4	0.1	1000	10^{-4}
Invisibility	10^3	0.7	700	$7 \cdot 10^{-5}$
Abandonment of Technology	10^3	0.1	100	10^{-5}
Immortality	10^9	0.01	10^7	**0.9998**
			L = 10,002,000 yr	



probability of finding a civilization that will go invisible is 7 x 10^{-5}. Once again, my main point is that even if only a small percentage of civilizations are very long-lived, they're the ones we're going to find. We'll find the very old ones, the very technically competent ones.

To some people, such as George Wald, this last idea is worrisome. He thinks such a discovery may be a great blow to us because the superiority of the other civilization will be destructive to our self-image. Nevertheless, the idea gives guidance to our search. We should expect to find the civilizations that are very different from us and that are practicing technology very different from what we are used to,

Now where does this analysis lead us? In general, we do not adopt values of 10 million for *L;* we adopt the more conservative figure of about ten thousand years. If that figure is accurate. there are on the order of ten thousand civilizations in the galaxy, about one in ten million stars has a civilization we can detect, and the nearest civilizations are about a thousand light years distant.

Rockets or Radio?

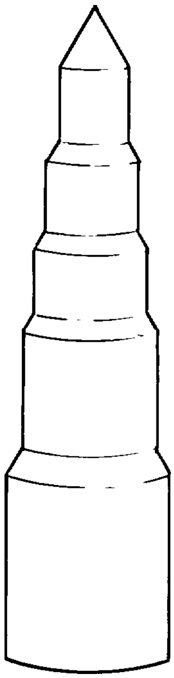
So now we ask the next great unsolved question of life: *What* is the most promising way to search a thousand light years and at least ten million stars? First, let's review some old ideas about communicating with extraterrestrial civilizations. The great mathematician Carl Friedrich Gauss proposed cutting a pattern into the forest of Siberia: a central region planted in wheat in the form of a right triangle and a square of pine trees adjacent to each side (Fig. 5a). He thought the pattern would be visible to powerful telescopes It least across the solar system and maybe far out in the universe. If so, this would prove not only that there was intelligent life on earth but that we understood the Pythagorean theorem! The proposal was never funded.

Another great scientist, in this case the physicist Joseph von Littrow, had a similar idea (Fig. 5b). He proposed digging big trenches in the Sahara Desert, perhaps in the form of circles and triangles twenty miles across. He would then apply a very sophisticated technoogy by tilling the trenches with kerosene and lighting them with a match, thus making flaming geometric figures visible across the solar system. The proposal was never funded.

The French physicist Charles Cros suggested using mirrors to reflect sunlight to Mars (Fig. SC). The mirrors would be placed across some sophisticated part of the world, such as Europe, in a pattern that the extraterrestrials would recognize as. say, the big dipper, again revealing intelligent life on earth. Again the proposal was never funded.

Not too long ago and not too far from

SPEC SHEET FOR THE ULTIMATE ROCKET



Fuel: Matter-Antimatter
Cruising Speed: *0.7c*
Flight Plan: Round Trip between Earth and Another Star

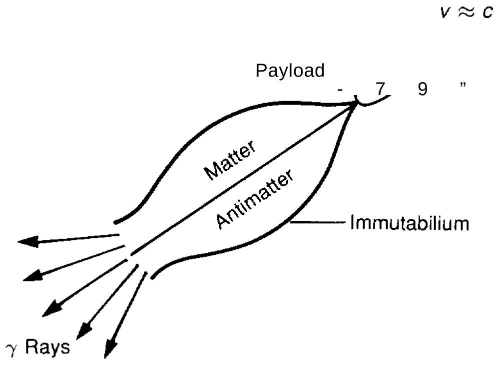
	Tons	Energy (Years of U.S. Electrical Consumption)
Payload	1000	**
Fourth Stage	1400	21,000
Third Stage	3400	51,000
Second Stage	8200	123,000
First Stage	20,000	305,000
Total	34,000	500,000

Fig. 7. Numbers such as those presented here imply that it may be considerably more beneficial to stay within one's own planetary system than to colonize the galaxy.

Los Alamos, Nickola Tesla finally got onto the right track by sending radio messages (Fig. 5d). He built one of the largest Tesla coils in the history of the world in Colorado Springs. It was 75 feet in diameter and about 150 feet high. Funded by J. Pierpont Morgan, it succeeded in standing people's hair on end for miles around when it was turned on. He actually received signals—strange, regular chirps that sounded very intelligent—and he believed he had detected another civilization. Knowing the frequencies at which the device received, we now think he discovered a phenomenon called whistlers: radio waves that propagate very slowly in the magnetosphere of the earth.

Figure 5e is another project that was funded! Guglielmo Marconi, the inventor of radio, also listened for signals from outer space and heard the same chirping sounds that Tesla had heard. He too thought he had discovered signals from other worlds, but again he was probably reporting whistlers.

What about rockets? Many of us who have gone to the movies think that rockets are the way to communicate with other worlds. But, as we've already seen, the speeds developed by chemical rockets will mean literally millions of years to go a thousand light years and return. So we have to use the sort of thing invented at Los Alamos.



THE ULTIMATE ROCKET

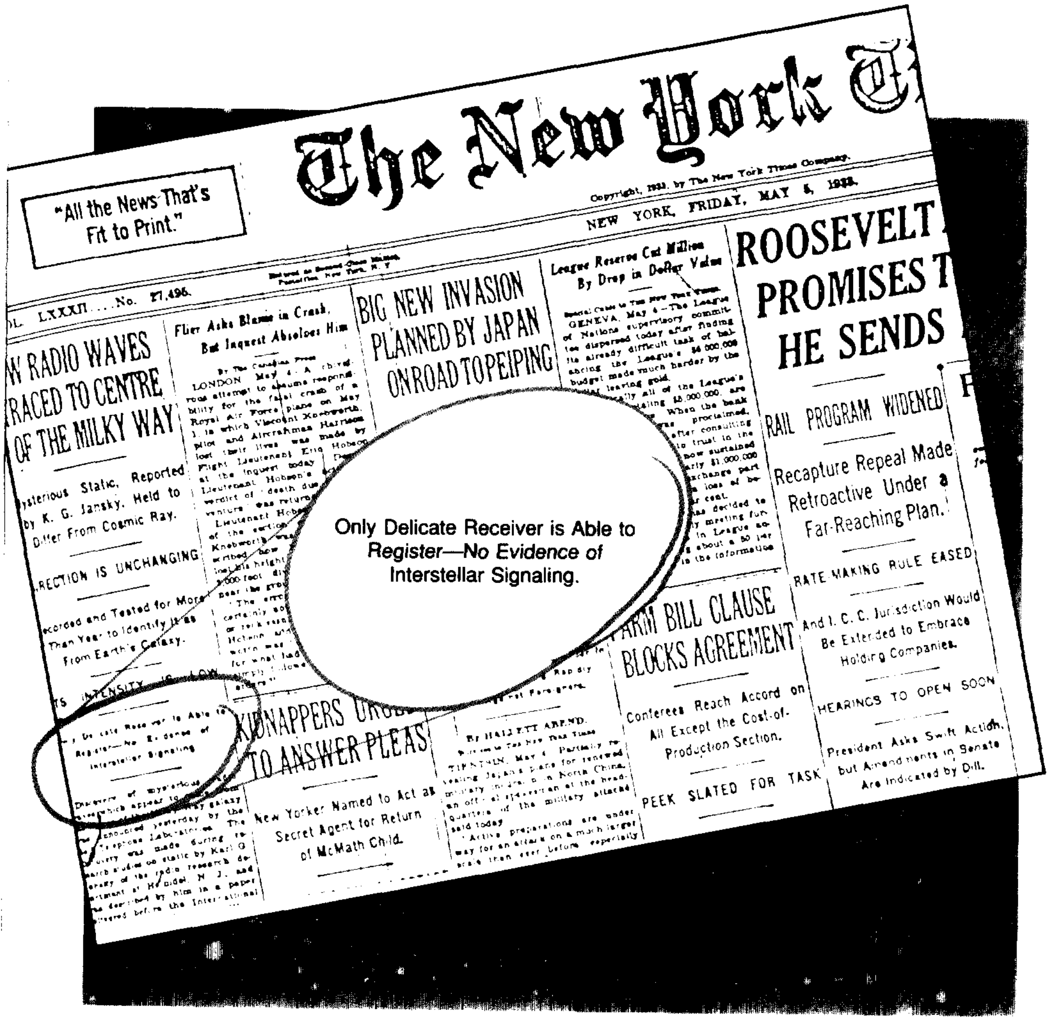
Fig. 6. Although the matter-antimatter rocket is simple in concept, a tricky technical problem remains to be solved: a material—here called immutabilium—needs to be invented that will hold both fuels until they are needed!

The ultimate rocket (Fig. 6) is very simple: it has two tanks that contain matter and antimatter. Of course, there's a small technical problem—what do you build the rocket with so that the whole device doesn't just go bang! The material is called *immutabilium.* We know its name, but its invention is left as a technical problem to you. As you know, when matter meets antimatter there is complete annihilation and a great big blast of gamma rays.

Now such rockets can go at nearly the speed of light, thus simulating what Captain Kirk and Mister Speck do every night on television when they zip from one planet to another within the hour. However, even if we solved the technical problems of building a matter-antimatter rocket, it wouldn't be very practical.

Figure 7 illustrates a rocket designed for a payload of a thousand tons and a cruising speed of seven-tenths the speed of light. It takes off, cruises close to the speed of light for as far as you want to go, then lands. Somebody gets out, looks around, takes some pictures, gets back on, returns to earth, again at seven-tenths the speed of light, and lands. Why seven-tenths? According to special relativity that's the speed at which the crew ages at the same rate it's traveling—the crew will be ten years older if they travel ten light years.

The rocket weighs thirty-four thousand tons. Of that, thirty-three thousand tons is fuel, half of which is matter. We get the matter by connecting our garden hose to the tank and filling it up. But the other sixteen thousand five hundred tons is antimatter, which has to be made. We don't know how to make that amount of antimatter or how to store it or how to make the immutabilium. But even if we did accomplish all that, it would take at least as much energy as there is in sixteen thousand five hundred tons of matter. That mass times the velocity of light squared equals five hundred thousand years of the total electric power production in the United States—



The New York T

"All the News That's Fit to Print."

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NEW YORK, FRIDAY, MAY 5, 1933.

L. LXXXII....No. 27,496.

W RADIO WAVES RACED TO CENTRE OF THE MILKY WAY

ysterious Static, Reported by K. G. Jansky, Held to Differ From Cosmic Ray.

RECTION IS UNCHANGING

ecorded and Tested for More Than Year to Identify It as From Earth's Galaxy.

TS INTENSITY IS LOW

Flier Asks Blame in Crash, But Inquest Absolves Him

BIG NEW INVASION PLANNED BY JAPAN ON ROAD TO PEIPING

League Reserve Cut Million By Drop in Dollar Value

ROOSEVELT PROMISES T HE SENDS

RAIL PROGRAM WIDENED

Recapture Repeal Made Retroactive Under a Far-Reaching Plan.

RATE-MAKING RULE EASED

And I. C. C. Jurisdiction Would Be Extended to Embrace Holding Companies.

HEARINGS TO OPEN SOON

President Asks Swift Action, but Amendments in Senate Are Indicated by Dill.

ARM BILL CLAUSE BLOCKS AGREEMENT

Conferees Reach Accord on All Except the Cost-of-Production Section.

PEEK SLATED FOR TASK

KIDNAPPERS URGE TO ANSWER PLEAS

New Yorker Named to Act as Secret Agent for Return of McMath Child.

Only Delicate Receiver is Able to *Register—No Evidence of* Interstellar Signaling.

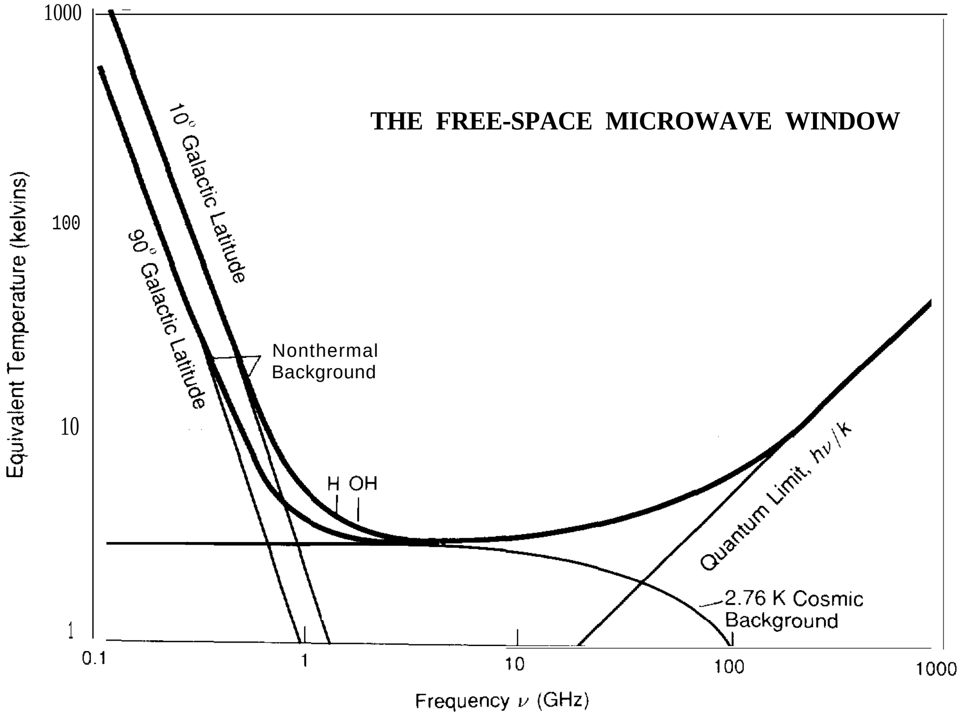


Fig. 9. The optimum electromagnetic frequencies for interstellar search and communication lie between the galactic nonthermal background at low frequencies and the quantum limit *hv/k* that rises at higher frequencies. The bottom part of the minimum is the 2.76-kelvin cosmic background, a residue of the big bang. FM, television, and radar frequencies lie in this window also. Since a great deal of the nonthermal background radiation is a result of relativistic electrons orbiting in magnetic fields throughout our galaxy, the strength of this background varies with the galactic latitude of the observation.

for one mission, and we need ten million missions to explore the galaxy! If that isn't enough, the rocket has a bad side effect when it takes off: it incinerates one hemisphere of the earth, At least there'd no longer be any problem finding a site for nuclear waste disposal, but the Sierra Club would object.

Anyway, the analysis shows that Captain Kirk and Mister Speck have lied to us. You can't call up Scotty and order warp seven to go anywhere in the galaxy in two minutes, Whether or not one transfers things through space depends, of course, on how much energy a civilization can manipulate and whether one goes slowly rather than fast. However, I think the answer here is that you don 't transport things through space, you transport information.

Is there a cheap way to transport information at the speed of light? The answer is yes. One uses electromagnetic radiation as guessed by Tesla and Marconi as long ago as 1933, When the *New York Times* announced the discovery of cosmic radio emission by Jansky at Bell Telephone Laboratories (Fig. 8), the lowest headline said: "No evidence of interstellar signaling." Even then they wondered if radio was the means by which one world would find another.

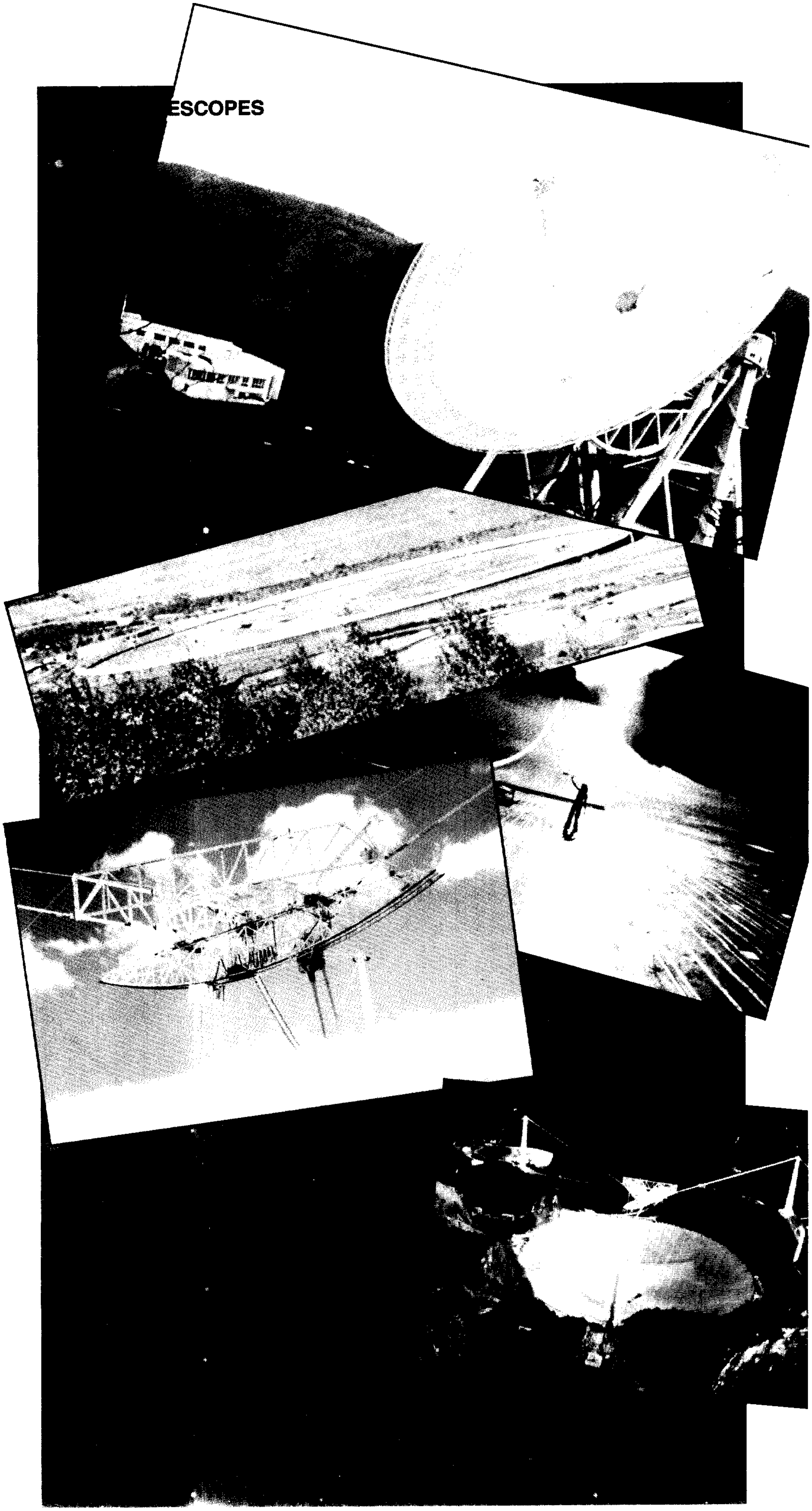
The Cosmic Haystack

Since that time a great deal of thought has been given to the subject, and we have repeatedly arrived at the conclu-ion that radio waves are best. This idea is correct not because of the status of our technology or the particular prowess that we have at certain wavelengths compared to others but rather because of fundamental limitations due to the arrangement of the universe and the laws of physics. For instance, the second law of thermodynamics sets limits on noise levels that can 't be overcome by any technology, Certain minima in the noise levels, however, lead to optimum frequencies for interstellar search and communication.

One of the limits is the quantum nature of light. Light comes in packets, and *hv/k* gives the equivalent temperature of the noise associated with this quantum aspect of light (Fig. 9). A second source of noise is radio emission of relativistic electrons orbiting in the magnetic fields of our galaxy. These electrons produce radiation with a steeply rising spectrum that essentially jams radio telescopes. The third source of radiation (it's interesting that it plays a role) is that left over from the big bang. It's normally called the cosmic background and has an equivalent temperature of about 3 kelvins.

Every advanced civilization can sum these curves precisely as we have and arrive at the very pronounced minimum in the microwave region where wavelengths are on the order of a few centimeters. This minimum is true for us, true for every civilization. In fact, I suspect the curve in Fig. 9 has been shown many times in our galaxy looking exactly like it does there. except the letters are written in funny ways that we wouldn't understand. The dish antennas that people have in their back yards operate at that same point precisely because it has the minimum noise and the greatest sensitivity, making the receivers cheaper. The upshot is that any intelligent civilization will be using this region copiously for its own communications and perhaps to communicate with other civilizations.

Likewise, we can search with the most sensitivity in this region, and our searches have been concentrating there. We happen, of course, to have good instruments for this purpose. The Bonn telescope in Germany (Fig. 10a) is a hundred meters across and can detect signals from distances of hundreds of light years. The main radio telescope of the Soviet Union in the northern Caucasus (Fig. 10b) is a 600-meter-diameter



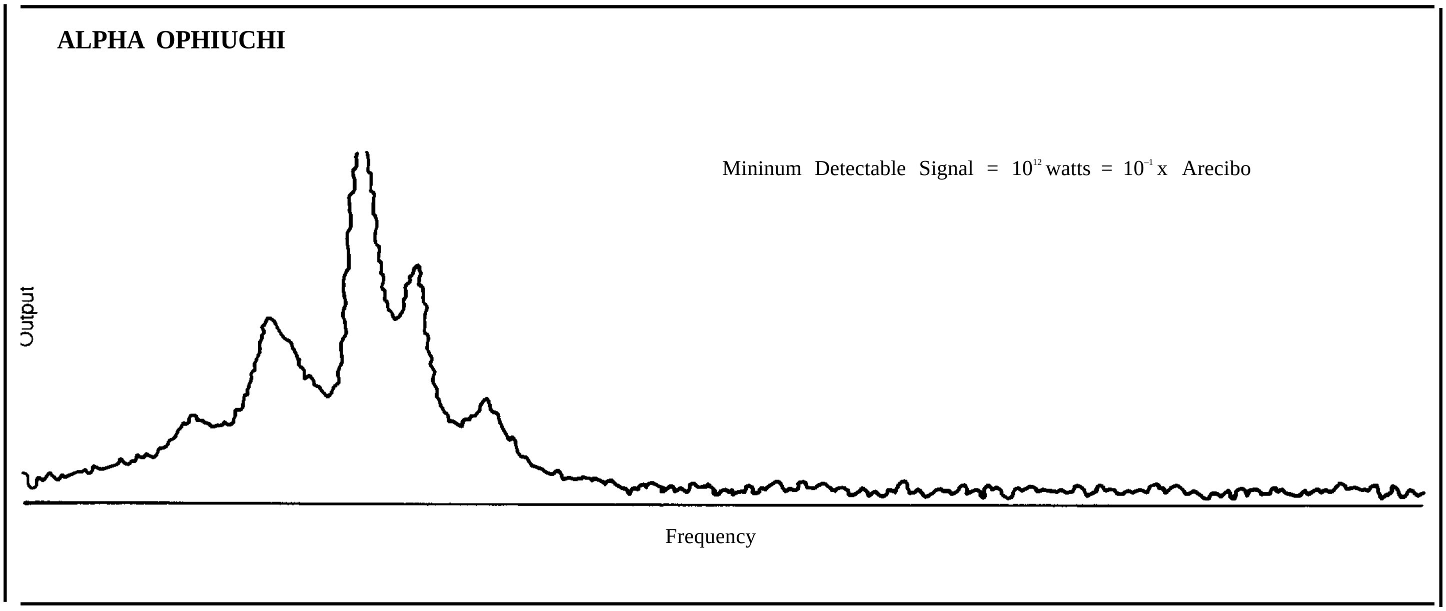


Fig. 11. For this search the Arecibo telescope in the receiving mode was pointed at a Ophiuchi, a star 54 light years from the earth. A 3000-channel spectrometer was used with output integrated over a time of twenty minutes (the jogs in the spectrum are the boundaries between adjacent channels). The large signals are emissions of neutral hydrogen in the star's atmosphere at the 21-centimeter wavelength. No other signals are present even though a radio telescope emitting at a tenth of the power of an Arecibo would have been detectable.

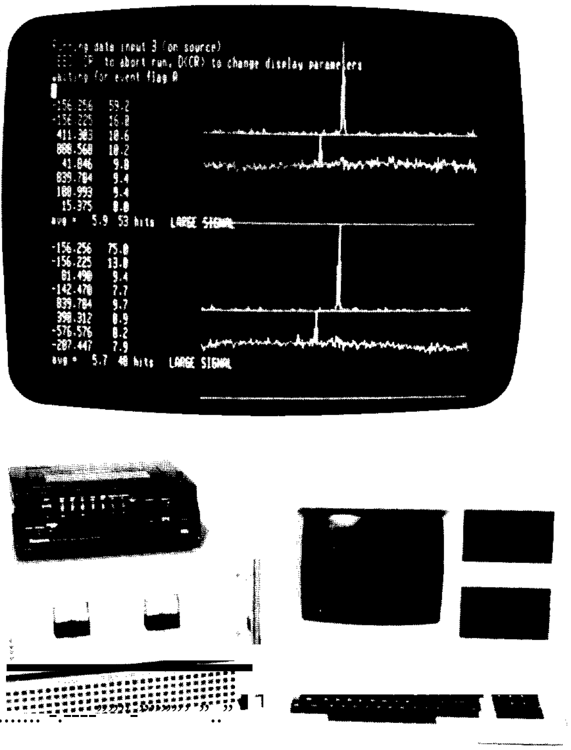
ring of reflectors, each 10 meters high. All the reflectors are moved and tilted under computer control to focus radiation on a central point.

The telescope with the largest collecting area in the world is the Arecibo radio telescope (Fig 10c-e), which is 1000 feet across with 20 acres of collecting area—more combined collecting area than all the other telescopes in the world put together. The radiation is focused on a suspended platform fifty stories in the air. The three towers holding the platform are each 10 feet taller than the Washington Monument. And if that doesn't give you a feel for its size, the bowl would hold 357 million boxes of corn flakes. The 38,778 surface panels, each about 2 square meters in size, are all put in place to an accuracy of about 1 millimeter.

The telescope has a 0.5-megawatt radar transmitter, and when that signal is focused by the big dish, the power density in the beam is equivalent to what could be radiated, without the dish, by a twenty -million-million-watt transmitter. Such power is twenty times the total electric power production of the earth. Thus, when Arecibo is transmitting, it produces the strongest directed signal leaving the earth. In fact, the signal is about a million times brighter than the radio emission of the sun. Civilizations can outshine their stars. The signal is detectable by a similar instrument, not just from a distance of a thousand light years, but from anywhere in the galaxy. So we can reach out the required thousand light years and touch someone.

Figure 11 shows data from a search in which the Arecibo telescope, in the receiving mode, was pointed for twenty minutes at α Ophiuchi, which is fifty-four light years distant. The 3000-channel spectrometer being used detected large signals from neutral hydrogen at the 21 -centimeter wavelength, but no signals that could be interpreted as other life. Had there been an Arecibo at α Ophiuchi, it might have made a signal as large as the neutral hydrogen signal, so it is easy to detect manifestations of life that are even weaker than we ourselves manifest. Sensitivity is not the problem.

The problem is dealing with the large number of frequency channels in the radio window of optimum sensitivity. Only in recent years have we begun to cope by making use of modem computer technology. The first step in this direction (Fig. 12) was a system so small it was called suitcase SETI (Search for Extra Terrestrial Intelligence). The system costs only $20,000, uses a personal computer, a video tape recorder for data acquisition, and a custom-made Fourier transformer that allows one to



```
Running data input 3 (on source)
[illegible] to abort run, D(CR) to change display parameters
waiting for event flag 0

-156.256   59.2
-156.225   16.0
 411.383   10.6
 888.568   10.2
  41.846    9.8
 839.784    9.4
 180.993    9.4
  15.375    8.0
avg =   5.9  53 hits   LARGE SIGNAL

-156.256   75.0
-156.225   13.0
  81.490    9.4
-142.470    7.7
 839.784    9.7
 398.312    8.9
-576.576    8.2
-287.447    7.9
avg =   5.7  48 hits   LARGE SIGNAL
```

THE SUITCASE SETI

Fig. 12. Pictured is a Search for Extraterrestrial Intelligence system that costs only $20,000 but is capable of measuring 128,000 frequency channels simultaneously. An improved version capable of handling 8 million channels is now in continuous operation at Harvard University.

measure 128,000 channels simultaneously. When this system is searching, it picks out the band in the spectrum with the most intense signal and then increases signal resolution by displaying channels just in that region. The system. developed by Paul Horowitz, has now been expanded to 8 million channels and is being used continuously at Harvard University to search for extraterrestrial signals.

When we examine the search problem carefully, we see that we have a large II-dimensional search to explore, where *n* is of the order of seven. We must deal realistically with the ten-million-star problem, the thousand-light-year problem, and the fact that there are literally tens or hundreds of millions of possible frequency channels. even in the relatively narrow band of optimum wavelengths. Furthermore, what signal format is appropriate. pulses or continuous wave? Is the signal on all the time or only occasionally? Is it polarized?

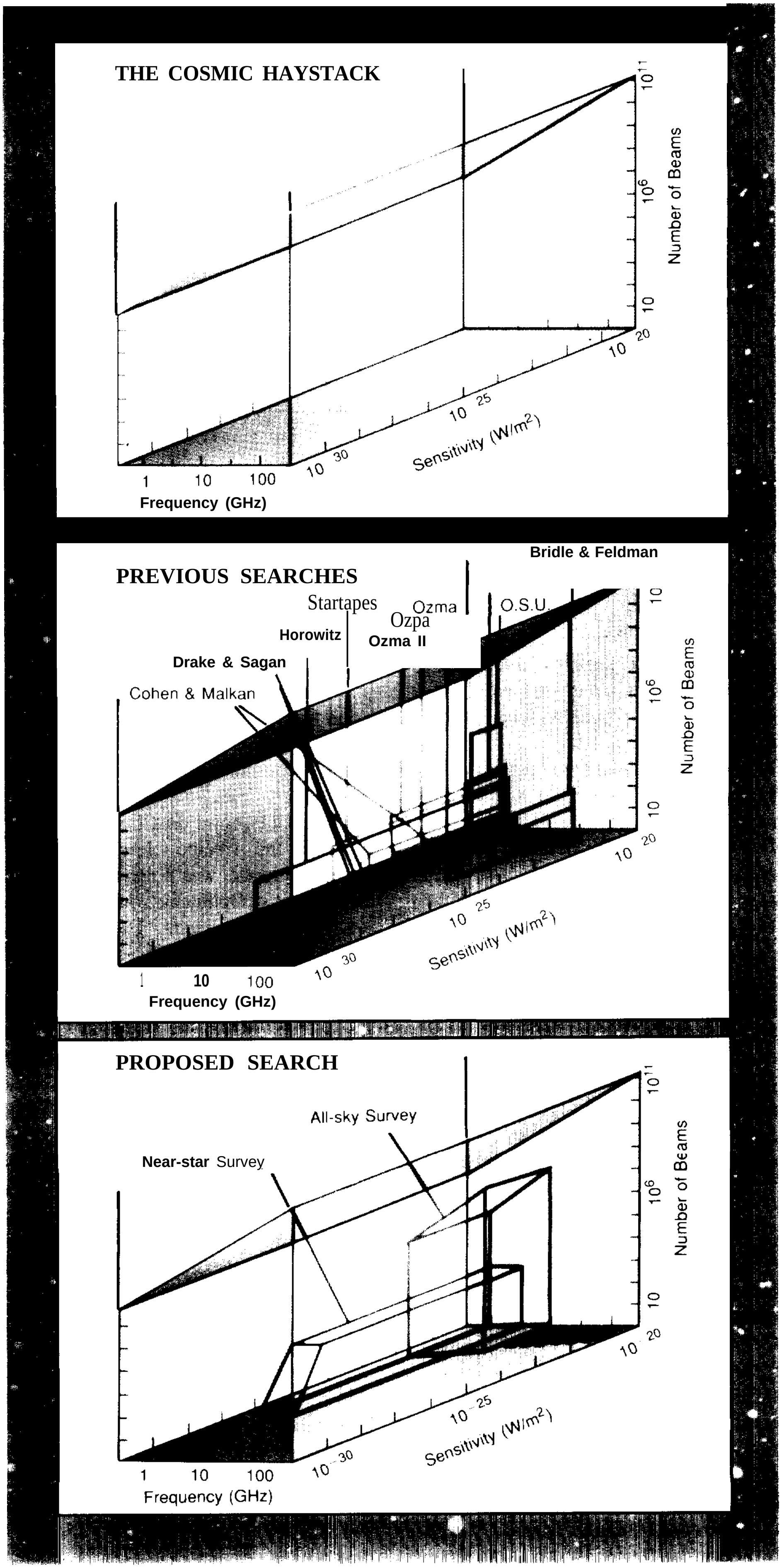
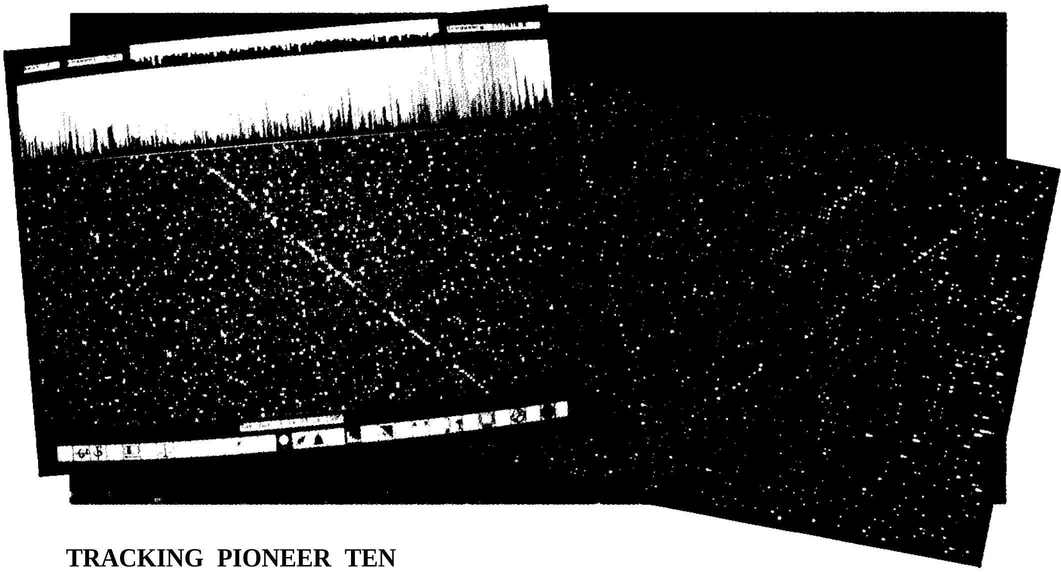


Fig. 13. (a) The *three* most difficult variables to cover in the search for extraterrestrial intelligence are signal strength at the earth (represented by sensitivity in watts per square meter), frequency coverage (in gigahertz), and receiving direction (represented by the number of beams examined). (b) The volume of the cosmic haystack covered in previous searches is actually very small: the width of each search volume shown is gossamer thin in frequency and, moreover, is plotted along a logarithmic scale. (c) The volume of cosmic haystack to be covered in a proposed ten-year search includes an all-sky survey that will examine most of the brighter stars in the sky over a large range of frequencies and a near-star survey that will examine fewer stars (nearby solar types) over a larger range of brightnesses. Although the frequency range examined for the latter survey will be smaller than for the all-sky survey, it will still be much greater than in previous searches.



TRACKING PIONEER TEN

Fig. 14. (a) The 1-watt signal emanating from Pioneer Ten (currently beyond Pluto 3.3 billion miles from the earth) is monitored by displaying a 128,000-channel spectrum horizontally every second, allowing the eye to pick out the signal as a diagonal line. The multichannel spectrum analyzer that generated these data is essentially what will be used at the NASA Ames Research Center to search for extraterrestrial intelligence. (b) Another example, a simulation, shows how this computerized system can detect signals that are even weaker (by a factor of ten or a hundred) than those from Pioneer Ten. (Photos courtesy NASA.)

(This last question is easy since one need measure only two polarizations.) The hardest problems to deal with are frequency coverage, signal strength at the earth, and direction, or the stars we point our receiver at. These variables—sensitivity, frequency, and number of places searched—make up what we call *the comic haystack* (Fig. 13a). Somewhere in the faint signals of that haystack are the diamonds: signals from other civilizations. Figure 13b shows the searches that have actually been done, starting in 1960 with project Ozma, in which only two stars were looked at. Although the volume of the cosmic haystack that has been searched may look impressive, in fact, it isn’t. The width of each of the search volumes is gossamer thin in frequency, and, besides, the scale is logarithmic. So we have hardly touched the cosmic haystack, and it is not surprising that we have not yet detected the signal of an extraterrestrial civilization.

We are currently putting together a search funded by NASA and operated from the NASA Ames Research Center that will cover a much greater volume of the cosmic haystack (Fig. 13c). In fact, it will do ten million times more searching than all previous searches put together. It will contain two components: an all-sky survey to cover the possibility that the easiest civilizations to find are the farthest by looking at every star in the sky, and a high-sensitivity, near-star search that will be successful if the nearest civilizations are the easiest to detect. For such an effort we must have an enormous frequency coverage, which will be done using a multichannel spectrum analyzer that is a broad-band. 8-million-channel system with an overall bandwidth of 250 megahertz connected to a dedicated VAX computer and disk system.

The project goal is to search the volume of the cosmic haystack shown in Fig. 13c for ten years. The system is currently being debugged and improved at the Goldstone tracking station at NASA using a 100-foot dish antenna. In fact, the system has already been used to detect the most distant intelligent signal ever received at the earth: the one coming from the Pioneer Ten spacecraft, which is currently beyond Pluto at a distance of 3.3 billion miles, radiating a total power of 1 watt. Detecting 1 watt 3.3 billion miles from the earth using a 100-foot dish with a pretty good maser is outstanding!

The detection process is impressive. In this case, a Sun computer searches 128,000-channels of the output of the multichannel spectrum analyzer for strong signals. On finding a signal, the data are restricted to about a thousand channels in that region, and a spectrum is taken once per second. These spectra are represented as adjacent horizontal lines; the eye can pick out the signal from Pioneer Ten as a line of points slanting very clearly through the data (Fig. 14a). If you had only a single spectrum, you couldn’t be sure of the signal because of other equally strong points. Only with the ensemble and the diagonal line is the signal’s presence clear, which is why you need a computer. It must search not for signals in individual channels but for patterns. In fact, the signal could be ten or a hundred times fainter than the one from Pioneer Ten and still be automatically detected by the system (as in the simulations of Fig. 14b).

Heretofore a human being could do this job but now only a computer can. For example. Fig. 15a is a raster of information like that shown in Fig. 14. Is there evidence of an intelligent signal there? I’ll even tell you that it consists not of a steady signal but of five equally spaced pulses along a diagonal line. See if you can find the points, then turn the page for the answer (Fig. 15b). Embarrassed’? The NASA system is

A SIGNAL?

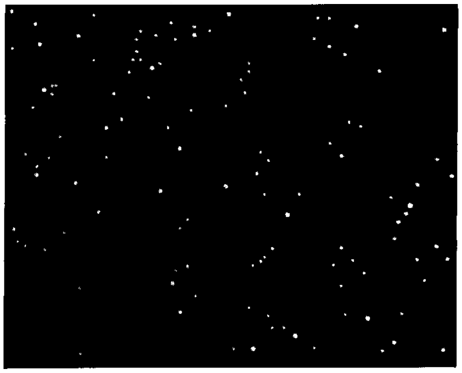
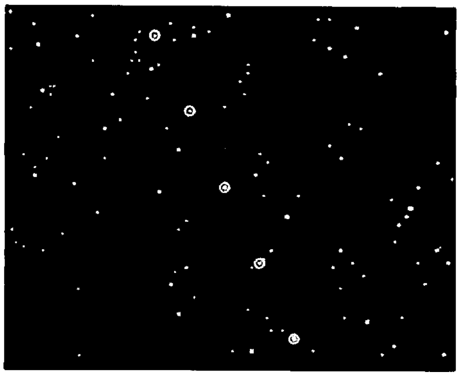


Fig. 15a. Can you spot the signal in this data? Although not continuous, the signal consists of five equally spaced pulses along a diagonal line. When you’ve completed your analysis, turn the page to see the computer’s selection.



THE SIGNAL REVEALED

Fig. 15b. The NASA system will be programed to locate patterns such as this one among scattered, random signals.

programmed to find this type of information in real time, and the system will be used in a very powerful search for, hopefully, as many years as needed.

That is where we stand with our searching. As you recognize, we could do a lot more if we spent a lot more money. There wasn't a lot of hardware in the figures, but that is what we've been able to buy with the funds coming from NASA over the last few years.

Messages

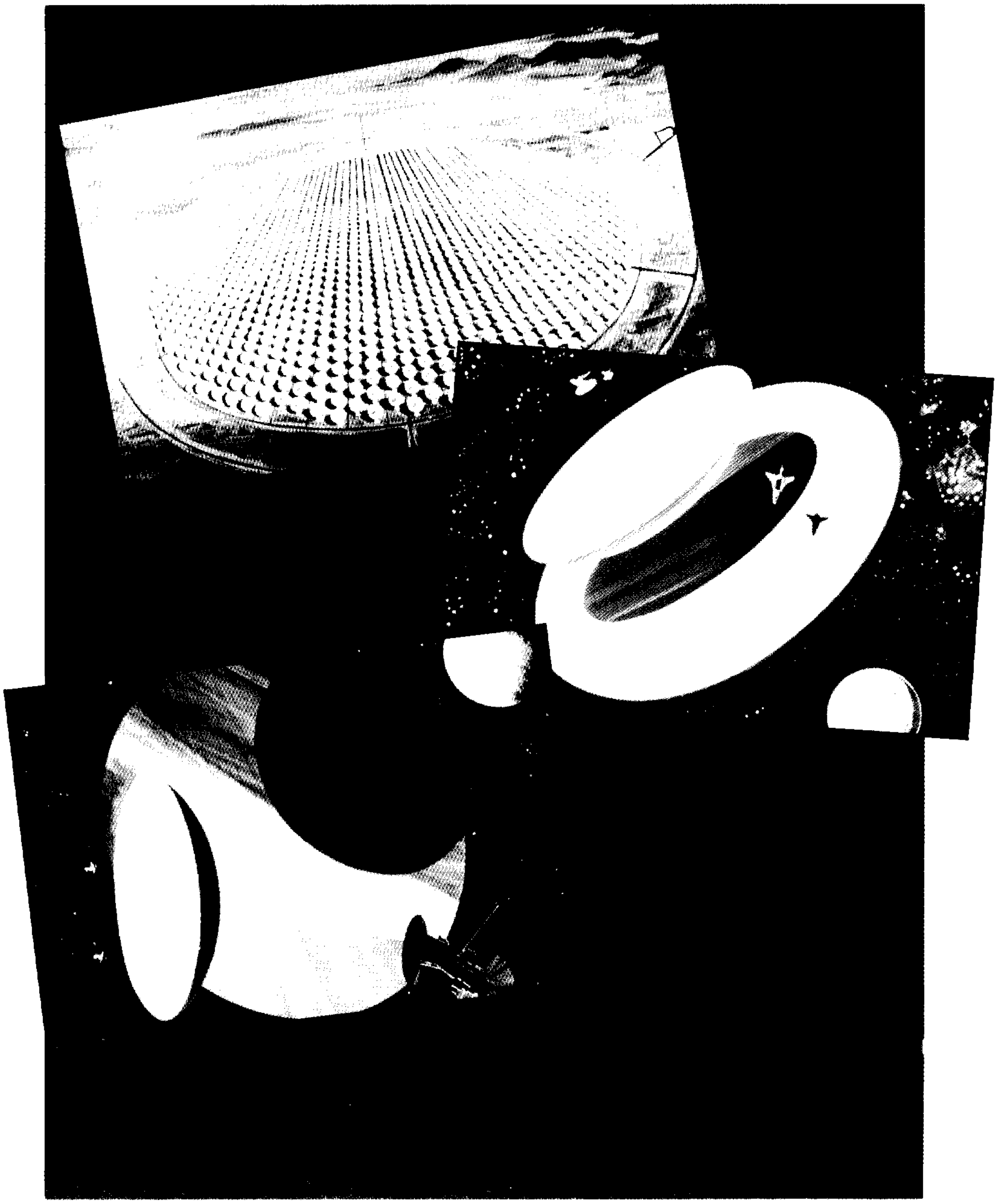
I now want to address one last grand unanswered question of life: Can we communicate with them? A number of messages have already been sent into space: two on Pioneer X and XI, two on Voyager I and H, and a radio message sent from Arecibo. How do we communicate with another civilization in a way that we think will work despite not having a common language (fluent Galactic) and no prior contact? My example is a message that is in outer space on both Voyager I and II. (One of these spacecraft recently went by Uranus on its way to Neptune; the other is flying out of the solar system.) Each craft has a gold-plated box inscribed with rather strange hieroglyphics (Fig. 16). Those hieroglyphics hopefully tell another intelligence that there's a record in the box. The record contains one and a half hours of music ranging from Brahms and Beethoven to ethnic music and Blind Willie Nelson—Earth's greatest hits. There are greetings in fifty languages and a long section on the sounds of the earth that range from volcanoes and rainstorms to a baby crying. Finally there are ten minutes of recorded television pictures.

The instructions on the box tell how to convert the waveforms on the record to pictures. Figure 17 represents a small sample that should indicate how we think pictures can be used to communicate simply and without language. (The fact that a cat can recognize a bird through a window but not on the screen of a television gives pause because the cat could be the extraterrestrial who doesn't see things when they're presented as a flat picture. Let's hope other civilizations understand how two-dimensional pictures work.) Some of the pictures show aspects of the earth; all show things that are special about us. We don't tell them about mathematics

or the laws of physics—they know such things already.

Look at Fig. 17 and try to imagine yourself as an extraterrestrial knowing nothing about humanity. What would you make of these pictures'? There are. of course, potential problems of ambiguity. In the Monument Valley picture, which of the animals are being herded, which are doing the herding? We show pictures of different ethnic groups implying that our planet is not a single homogeneous society, but does the smile on the Guatemala field hand mean that he is friendly or that he is getting ready to bite? The fact that he's carrying a machete in his right hand may reinforce the last interpretation. A nice stroboscopic picture of the famous gymnast Cathy Rigby, which has never been published except in outer space, shows the articulation of the human body and what it can do in five seconds. The mountain climbing picture was ostensibly included to prove that we are adventurous but may also show that some of us are crazy. We have tall trees and water in crystalline form on the earth. Some of our creatures have to rake things at a certain time of year when certain things fall off the trees. We have competitive sports, but again if you look carefully you'll see that all four of the creatures have one leg shorter than the other. Is this some subspecies or a second intelligent species? Looking even closer you'll see that all four creatures are four inches oft' the ground. Have they discovered anti-gravity on the planet earth? Some of the aliens may see the frog and say, "Thank goodness! There's the intelligent creature, and it looks just like us."

All these pictures and more can be sent over a radio link with little effort



in less than one second. There is also the potential of receiving similarly rich information in a few seconds without asking a question and having to wait thousands of years for the answer. Such richness is in our future, although we probably will have to build huge radio systems to achieve that capability. But we know how to do such things now; there is no technology that we don't already have, there will just be a lot to build—billions of dollars worth. Although we could build the system on the earth, it might be better in space—large dishes shielded from the earth by huge screens that keep manmade transmissions out of the system (Fig. 18). With a diameter of 5 kilometers, the system could be one of our most idealistic and grandest projects, perhaps, in the long run, one of the best things we could do with our space transportation system. Whether or not we do this depends on how much wisdom and idealism there is on this planet, and that, of course, is one of the other great questions of life. How good are we? ■

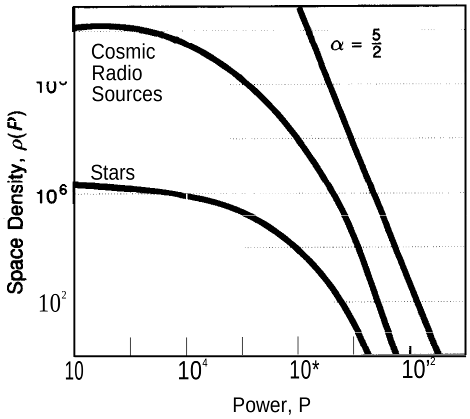
Questions and Answers

Question: Does the unit of time that is peculiar to the earth-our year—affect the results of the equation for the number of intelligent civilizations?
Drake: It would if we did things in terms of years but the number *N* is unitless. The equation is a rate of production in things per year times *L* in years. Thus years cancels out and the unit of time we use doesn't matter.

Question: Why have you chosen inefficient rockets for your examples?
Drake: You are getting into the sophistication of rockets. It's true that what is really important to the rocket is momentum ejected rather than energy. and so there are optimized versions of the antimatter-matter rocket. For example, rather than using the energy to expel gamma rays it can be used to expel hydrogen atoms that serve essentially as propelling pellets. In that way, you can increase the efficiency but only by factors of two, three, or four. Qualitatively there is no difference. With regard to the interstellar ram jet, that. of course, is a nice way to go if you can. But scoops that are hundreds of kilometers across are required to collect the hydrogen atoms, which, in turn, must be funneled to a central point and used efficiently in a fusion reactor, Whether all that technology is possible we do not know. If it were possible you could achieve pretty high speeds.

Question: Is the intent of our listening effort to receive messages or just to expand technology in this area?
Drake: We are listening in the radio spectrum for a variety of signals but signals that would all be *intentionally* transmitted. We are looking for continuous wave signals, we are looking for pulse trains, we are looking for drifting pulse trains, we are looking for polarization-modulated waves—all the various things that Maxwell's equations allow in electromagnetic radiation. It's this aspect that's special about the NASA search over previous searches. Previous ones have searched only for continuously transmitted signals at a fixed frequency. The NASA project looks for all varieties of signals, and that's what costs a lot and requires a big computer capacity.

Are They Near or Far?



THE LUMINOSITY FUNCTION

How does one determine which civilizations might be more detectable, those near or those far from us? Suppose that technological civilizations radiating energy at a power level P in the range dP occupy space with a certain density $\rho(P)$. If the minimum power we can detect at the earth is $P_{\min}$, the number of civilizations that are detectable from a distance R is then given by

$$n(P) = \rho(P)\frac{4}{3}\pi R^3 \left(\frac{P}{P_{\min}}\right)^{\frac{3}{2}}. \qquad (1)$$

If we now assume that the density of radiating civilizations obeys a power-law distribution, $\rho(P) = KP^{-\alpha}$, where K and α are undetermined constants, then $n(P) \propto P^{\frac{3}{2}-\alpha}$. The ratio of the detectable civilizations above and below a certain power level P_1 is thus

$$\begin{aligned}\frac{N_{P>P_1}}{N_{P<P_1}} &= \frac{\int_{P_1}^{\gamma P_1} n(P)\,dP}{\int_0^{P_1} n(P)\,dP}\\ &= \frac{\int_{P_1}^{\gamma P_1} P^{\frac{3}{2}-\alpha}\,dP}{\int_0^{P_1} P^{\frac{3}{2}-\alpha}\,dP} \qquad (2)\\ &= \frac{\gamma^{\frac{5}{2}-\alpha}-1}{1},\end{aligned}$$

where N is the integrated number of detectable civilizations in the specified range, P_1 is a breakpoint power level, and γP_1 is the maximum power a civilization might radiate. In general, the maximum power will be orders of magnitude larger than P_1, and $\gamma \gg 1$.

Now what does this equation tell us about the bright, detectable civilizations? Are they near or far from us? If the ratio represented by Eq. 2 is greater than 1, the number of bright civilizations detectable despite large distances from the earth will be larger than the number of dim civilizations detectable only when they are close. In other words, the brightest civilizations as seen from the earth are more likely to be far away if this ratio is greater than 1. This will be the case if

$$\begin{aligned}&\gamma^{\frac{5}{2}-\alpha} > 2,\\ \text{or}\quad &\alpha + \frac{\ln 2}{\ln \gamma} < \frac{5}{2}.\end{aligned} \qquad (3)$$

In general, the brightest power levels are orders of magnitude larger than the threshold power P_1, so the $\ln 2/\ln\gamma$ term in Eq. 3 will be negligible. We can thus simply say that if $\alpha < 5/2$, the brightest civilizations as detected at the earth are far from us. As the exponent in the power law approaches 5/2, we move to the other extreme: The ratio in Eq. 2 goes to O. In other words, the dim stars dominate, and we will most likely find our civilizations among the close stars.

The figure above represents plots of the space density of objects emitting at power P versus that power in arbitrary units. Thus the $\alpha = 5/2$ line represents the situation of dim, near objects completely dominating as the type of object detectable at the earth. However, we see that both the plot for cosmic radio sources and, even more so, the plot for stars deviate considerably from the $\alpha = 5/2$ line, implying that it is the distant, bright civilizations that are more likely to be detected at the earth. ■

Star fields courtesy of Galen Gisler, Los Alamos National Laboratory.

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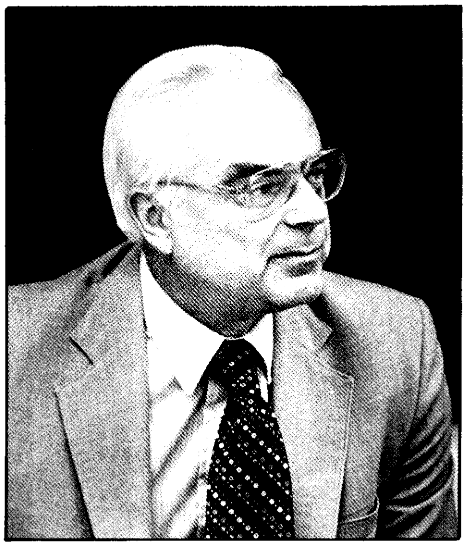
Monument Valley: Ray Manley, Shostal Associates; Fallen leaves: Jodi Cobb, (c) National Geographic Society; Sequoia and snowflake: photo by Josef Muench (Robert F. Sisson, (c) National Geographic Society); Tree toad: David Wickstrom; Man from Guatemala: United Nations; Mountain climber: Gaston Rebuffat; Gymnast Cathy Rigby: (c) 1971 Phillip Leonian, photographed for Sports Illustrated; Olympic sprinters. Picturepoint London.



Frank Drake earned his Bachelor of Engineering, Physics, with honors at Cornell University and his M.S. and Ph.D. in astronomy at Harvard University. While a professor at Cornell he was director of the Arecibo Observatory in Puerto Rico. From 1971 to 1981 he was the director of the National Astronomy and Ionospheric Center, and about three years ago he moved from the east to the west coast to become Dean of Natural Sciences at the University of California, Santa Cruz. Although he has done a variety of work in astrophysics, including research on pulsars and the radio noise from Jupiter, he is most widely known for his belief that intelligent life exists elsewhere in the universe. Beginning in 1960 with pioneering efforts on Project Ozma, he became a leading authority on methods to detect signals emitted by extraterrestrial life. He and Cad Sagan helped design the messages that have left our solar system inscribed on plaques and records aboard the Pioneer and Voyager spacecraft.