IS THERE INTELLIGENT LIFE ON EARTH ?

There are places, in and around our great cities, where the natural world has all but disappeared. You can make out streets and sidewalks, autos, parking garages, advertising billboards, monuments of glass and steel, but not a tree or a blade of grass or any animal-besides, of course, the humans. There are lots of humans.

Only when you look straight up through the skyscraper canyons can you make out a star or a patch of blue--reminders of what was there long before humans came to be. But the bright lights of the big cities bleach out the stars, and even that patch of blue is sometimes gone, tinted brown by industrial technology.

It's not hard, going to work every day in such a place, to. be impressed with ourselves. How we've transformed the Earth for our benefit and convenience! But a few hundred miles up or down there are no humans. Apart from a thin film of life at the very surface of the Earth, an occasional intrepid spacecraft, and some radio static, our impact on the Universe is nil. It knows nothing of us.

YOU'RE AN ALIEN EXPLORER entering the Solar System after a long journey through the blackness of interstellar space. You examine the planets of this humdrum star from afar-a pretty handful, some gray, some blue, some red, some yellow. You're interested in what kinds of worlds these are, whether their environments are static or changing, and especially whether there are life and intelligence. You have no prior knowledge of the Earth. You've just discovered its existence.

There's a galactic ethic, let's imagine: Look but don't touch. You can fly by these worlds; you can orbit them; but you are strictly forbidden to land. Under such constraints, could you figure out what the Earth's environment is like and whether anyone lives there?

As you approach, your first impression of the whole Earth is white clouds, white polar caps, brown continents, and some bluish substance that covers two thirds of the surface. When you take the temperature of this world from the infrared radiation it emits, you find that most latitudes are above the freezing point of water, while the polar caps are below freezing. Water is a very abundant material in the Universe; polar caps made of solid water would be a reasonable guess, as well as clouds of solid and liquid water.

You might also be tempted by the idea that the blue stuff is enormous quantities - kilometers deep - of liquid water. The suggestion is bizarre, though, at least as far as this solar system is concerned, because surface oceans of liquid water exist nowhere else. When you look in the visible and near-infrared spectrum for telltale signatures of chemical composition, sure enough you discover water ice in the polar caps, and enough water vapor in the air to account for the clouds; this is also just the right amount that must exist because of evaporation if the oceans are in fact made of liquid water. The bizarre hypothesis is confirmed.

The spectrometers further reveal that the air on this world is one fifth oxygen, O_2. No other planet in the Solar System has anything close to so much oxygen. Where does it all come from? The intense ultraviolet light from the Sun breaks water, H_2O_2 down into oxygen and hydrogen, and hydrogen, the lightest gas, quickly escapes to space. This is a source of O_2, certainly, but it doesn't easily account for so much oxygen.

Another possibility is that ordinary visible light, which the Sun pours out in vast amounts, is used on Earth to break water apart-except that there's no known way to do this without life. There would have to be plants-life-forms colored by a pigment that strongly absorbs visible light, that knows how to split a water molecule by saving up the energy of two photons of light, that retains the H and excretes the O, and that uses the hydrogen thus liberated to synthesize organic molecules. The plants would have to be spread over much of the planet. All this is asking a lot. If you're a good skeptical scientist, so much O, would not be proof of life. But it certainly might be cause for suspicion.

With all that oxygen you're not surprised to discover ozone (O_3) in the atmosphere, because ultraviolet light makes ozone out of molecular oxygen (O_2). The ozone then absorbs dangerous ultraviolet radiation. So if the oxygen is due to life, there's a curious sense in which the life is protecting itself. But this life might be mere photosynthetic plants. A high level of intelligence is not implied.

When you examine the continents more closely, you find there are, crudely speaking, two kinds of regions. One shows the spectrum of ordinary rocks and minerals as found on many worlds. The other reveals something unusual: a material, covering vast areas, that strongly absorbs red light. (The Sun, of course, shines in light of all colors, with a peak in the yellow.) This pigment might be just the agent needed if ordinary visible light is being used to break water apart and account for the oxygen in the air. It's another hint, this time a little stronger, of life-not a bug here and there, but a planetary surface overflowing with life. The pigment is in fact chlorophyll: it absorbs blue light as well as red, and is responsible for the fact that plants are green. What you're seeing is a densely vegetated planet.

So the Earth is revealed to possess three properties unique at least in this solar system-oceans, oxygen, life. It's hard not to think they're related, the oceans being the sites of origin, and the oxygen the product, of abundant life.

When you look carefully at the infrared spectrum of the Earth, you discover the minor constituents of the air. In addition to water vapor, there's carbon dioxide (CO_2), methane (CH_4), and other gases that absorb the heat that the Earth tries to radiate away to space at night. These gases warm the planet. Without them, the Earth would everywhere be below the freezing point of water. You've discovered this world's greenhouse effect.

Methane and oxygen together in the same atmosphere is peculiar. The laws of chemistry are very clear: In an excess of O_2, CH_4 should be entirely converted into H_2O and CO_2. The process is so efficient that not a single molecule in all the Earth's atmosphere should be methane. Instead, you find that one out of every million molecules is methane, an immense discrepancy. What could it mean?

The only possible explanation is that methane is being injected into the Earth's atmosphere so quickly that its chemical reaction with O_2 can't keep pace. Where does all this methane come from? Maybe it seeps out of the deep interior of the Earth-but quantitatively this doesn't seem to work, and Mars and Venus don't have anything like this much methane. The only alternatives are biological, a conclusion that makes no assumptions about the chemistry of life, or what it looks like, but follows merely from how unstable methane is in an oxygen atmosphere. In fact, the methane arises from such sources as bacteria in bogs, the cultivation of rice, the burning of vegetation, natural gas from oil wells, and bovine flatulence. In an oxygen atmosphere, methane is a sign of life.

That the intimate intestinal activities of cows should be detectable from interplanetary space is a little disconcerting, especially when so much of what we hold dear is not. But an alien scientist flying by the Earth would, at this point, be unable to deduce bogs, rice, fire, oil, or cows. Just life.

All the signs of life that we've discussed so far are due to comparatively simple forms (the methane in the rumens of cows is generated by bacteria that homestead there). Had your spacecraft flown by the Earth a hundred million years ago, in the age of the dinosaurs when there were no humans and no technology, you would still have seen oxygen and ozone, the chlorophyll pigment, and far too much methane. At present, though, your instruments are finding signs not just of life, but of high technology-something that couldn't possibly have been detected even a hundred years ago: You are detecting a particular kind of radio wave emanating from Earth. Radio waves don't necessarily signify life and intelligence. Many natural processes generate them. You've already found radio emissions from other, apparently uninhabited worlds-generated by electrons trapped in the strong magnetic fields of planets, by chaotic motions at the shock front that separates these magnetic fields from the interplanetary magnetic field, and by lightning. (Radio "whistlers" usually sweep from high notes to low, and then begin again.) Some of these radio emissions are continuous; some come in repetitive bursts; some last a few minutes and then disappear.

But this is different: A portion of the radio transmission from Earth is at just the frequencies where radio waves begin to leak out of the planet's ionosphere, the electrically charged region above the stratosphere that reflects and absorbs radio waves. There is a constant central frequency for each transmission, added to which is a modulated signal (a complex sequence of on's and off's). No electrons in magnetic fields, no shock waves, no lightning discharges can generate something like this. Intelligent life seems to be the only possible explanation. Your conclusion that the radio transmission is due to technology on Earth holds no matter what the ons and offs mean: You don't have to decode the message to be sure it is a message. (This signal is really, let us suppose, communications from the U.S. Navy to its distant nuclear-armed submarines.)

So, as an alien explorer, you would know that at least one species on Earth has achieved radio technology. Which one is it? The beings that make methane? Those that generate oxygen? The ones whose pigment colors the landscape green? Or somebody else, somebody more subtle, someone not otherwise detectable to a spacecraft plummeting

by? To search for this technological species, you might want to examine the Earth at finer and finer resolution-seeking, if not the beings themselves, at least their artifacts.

You look first with a modest telescope, so the finest detail you can resolve is one or two kilometers across. You can make out no monumental architecture, no strange formations, no unnatural reworking of the landscape, no signs of life. You see a dense atmosphere in motion. The abundant water must evaporate and then rain back down. Ancient impact craters, apparent on the Earth's nearby Moon, are almost wholly absent. There must, then, be a set of processes whereby new land is created and then eroded away in much less time than the age of this world. Running water is implicated. As you look with finer and finer definition you find mountain ranges, river valleys, and many other indications that the planet is geologically active. There are also odd places surrounded by vegetation, but which are themselves denuded of plants. They look like discolored smudges on the landscape.

When you examine the Earth at about 100-meter resolution, everything changes. The planet is revealed to be covered with straight lines, squares, rectangles, circles- sometimes huddling along river banks or nestling on the lower slopes of mountains, sometimes stretching over plains, but rarely in deserts or high mountains, and absolutely never in the oceans. Their regularity, complexity, and distribution would be hard to explain except by life and intelligence, although a deeper understanding of function and purpose might be elusive. Perhaps you would conclude only that the dominant life-forms have a simultaneous passion for territoriality and Euclidean geometry. At this resolution you could not see them, much less know them.

Many of the devegetated smudges are revealed to have an underlying checkerboard geometry. These are the planet's cities. Over much of the landscape, and not just in the cities, there is a profusion of straight lines, squares, rectangles, circles. The dark smudges of the cities are revealed to be highly geometrized, with only a few patches of vegetation - themselves with highly regular boundaries - left intact. There are occasional triangles, and in one city there is even a pentagon.

When you take pictures at a meter resolution or better, you find that the crisscrossing straight lines within the cities and the long straight lines that join them with other cities are filled with streamlined, multicolored beings a few meters in length, politely running one behind the other, in long, slow orderly procession. They are very patient. One stream of beings stops so another stream can continue at right angles. Periodically, the favor is returned. At night, they turn on two bright lights in front so they can see where they're going. Some, a privileged few, go into little houses when their workday is done and retire for the night. Most are homeless and sleep in the streets.

At last! You've detected the source of all the technology, the dominant life-forms on the planet. The streets of the cities and the roadways of the countryside are evidently built for their benefit. You might believe that you were really beginning to understand life on Earth. And perhaps you'd be right.

If the resolution improved just a little further, you'd discover tiny parasites that occasionally enter and exit the dominant organisms. They play some deeper role, though, because a stationary dominant organism will often start up again just after it's

reinfected by a parasite, and stop again just before the parasite is expelled. This is puzzling. But no one said life on Earth would be easy to understand.

All the images you've taken so far are in reflected sunlight-that is, on the day side of the planet. Something most interesting is revealed when you photograph the Earth at night: The planet is lit up. The brightest region, near the Arctic Circle, is illuminated by the aurora borealis-generated not by life, but by electrons and protons from the Sun, beamed down by the Earth's magnetic field. Everything else you see is due to life. 'The lights recognizably outline the same continents you can make out in daytime; and many correspond to cities you've already mapped. The cities are concentrated near coastlines. They tend to be sparser in continental interiors. Perhaps the dominant organisms are desperate for seawater (or maybe oceangoing ships were once essential for commerce and, emigration).

Some of the lights, though, are not due to cities. In North Africa, the Middle East, and Siberia, for example, there are very bright lights in a comparatively barren landscape-due, it turns out, to burnoff in oil and natural gas wells. In the Sea of Japan on the day you first look, there is a strange, triangular-shaped area of light. In daytime it corresponds to open ocean. This is no city. What could it be? It is in fact the Japanese squid fishing fleet, using brilliant illumination to attract schools of squid up to their deaths. On other days, this pattern of light wanders all over the Pacific Ocean, seeking prey. In effect, what you have discovered here is sushi.

It seems sobering to me that from space you can so readily detect some of the odds and ends of life on Earth-the gastrointestinal habits of ruminants, Japanese cuisine, the means of communicating with nomadic submarines that carry death for 200 cities-while so much of our monumental architecture, our greatest engineering works, our efforts to care for one another, are almost wholly invisible. It's a kind of parable.

BY THIS POINT your expedition to the Earth must be considered highly successful. You've characterized the environment; you've detected life; you've found manifestations of intelligent beings; you may even have identified the dominant species, the one transfixed with geometry and rectilinearity. Surely this planet is worth a longer and more detailed study. That's why you've now inserted your spacecraft into orbit around the Earth.

Looking down on the planet, you uncover new puzzles. All over the Earth, smokestacks are pouring carbon dioxide and toxic chemicals into the air. So are the dominant beings who run on the roadways. But carbon dioxide is a greenhouse gas. As you watch, the amount of it in the atmosphere increases steadily, year after year. The same is true of methane and other greenhouse gases. If this keeps up, the temperature of the planet is going to increase. Spectroscopically, you discover another class of molecules being injected into the air, the chlorofluorocarbons. Not only are they greenhouse gases, but they are also devastatingly effective in destroying the protective ozone layer.

You look more closely at the center of the South American continent, which-as you know by now-is a vast rain forest. Every night you see thousands of fires. In the

daytime, you find the region covered with smoke. Over the years, all over the planet, you find less and less forest and more and more scrub desert.

You look down on the large island of Madagascar. The rivers are colored brown, generating a vast stain in the surrounding ocean. This is topsoil being washed out to sea at a rate so high that in another few decades there will be none left. The same thing is happening, you note, at the mouths of rivers all over the planet.

But no topsoil means no agriculture. In another century, what will they eat? What will they breathe? How will they cope with a changing and more dangerous environment?

From your orbital perspective, you can see that something has unmistakably gone wrong. The dominant organisms, whoever they are-who have gone to so much trouble to rework the surface-are simultaneously destroying their ozone layer and their forests, eroding their topsoil, and performing massive, uncontrolled experiments on their planet's climate. Haven't they noticed what's happening? Are they oblivious to their fate? Are they unable to work together on behalf of the environment that sustains them all?

Perhaps, you think, it's time to reassess the conjecture that there's intelligent life on Earth.

LOOKING FOR LIFE ELSEWHERE: A CALIBRATION

Spacecraft from the Earth have now flown by dozens of planets, moons, comets, and asteroids-equipped with cameras, instruments for measuring heat and radio waves, spectrometers to determine composition, and a host of other devices. We have found not a hint of life anywhere else in the Solar System. But you might be skeptical about our ability to detect life elsewhere, especially life different from the kind we know. Until recently we had never performed the obvious calibration test: to fly a modern interplanetary spacecraft by the Earth and see whether we could detect ourselves. This all changed on December 8, 1990.

Galileo is a NASA spacecraft designed to explore the giant planet Jupiter, its moons, and its rings. It's named after the heroic Italian scientist who played so central a role in toppling the geocentric pretension. It is he who first saw Jupiter as a world, and who discovered its four big moons. To get to Jupiter, the spacecraft had to fly close by Venus (once) and the Earth (twice) and be accelerated by the gravities of these planets-otherwise there wasn't enough oomph to get it where it was going. This necessity of trajectory design permitted us, for the first time, to look systematically at the Earth from an alien perspective.

Galileo passed only 960 kilometers above the Earth's surface. With some exceptions-including pictures showing features finer than 1 kilometer across, and the images of the Earth at night-much of the spacecraft data described in this chapter were actually obtained by *Galileo*. With *Galileo* we were able to deduce an oxygen atmosphere, water, clouds, oceans, polar ice, life, and intelligence. The use of instruments and protocols developed to explore the planets to monitor the environmental health of our

own-something NASA is now doing in earnest-was described by the astronaut Sally Ride as "Mission to Planet Earth."

Our success in detecting life on Earth with *Galileo*, without making any assumptions beforehand about what kind of life it must be, increases our confidence that when we fail to find life on other planets, that negative result is meaningful. Is this judgment anthropocentric, geocentric, provincial? I don't think so. We're not looking only for our kind of biology. Any widespread photosynthetic pigment, any gas grossly out of equilibrium with the rest of the atmosphere, any rendering of the surface into highly geometrized patterns, any steady constellation of lights on the night hemisphere, any non-astrophysical sources of radio emission would betoken the presence of life. On Earth we have found of course only our type, but many other types would have been detectable elsewhere. We have not found them. This examination of the third planet strengthens our tentative conclusion that, of all the worlds in the Solar System, only ours is graced by life.

We have just begun to search. Maybe life is hiding on Mars or Jupiter, Europa or Titan. Maybe the Galaxy is filled with worlds as rich in life as ours. Maybe we are on the verge of making such discoveries. But in terms of actual knowledge, at this moment the Earth is unique. No other world is yet known to harbor even a microbe, much less a technical civilization.