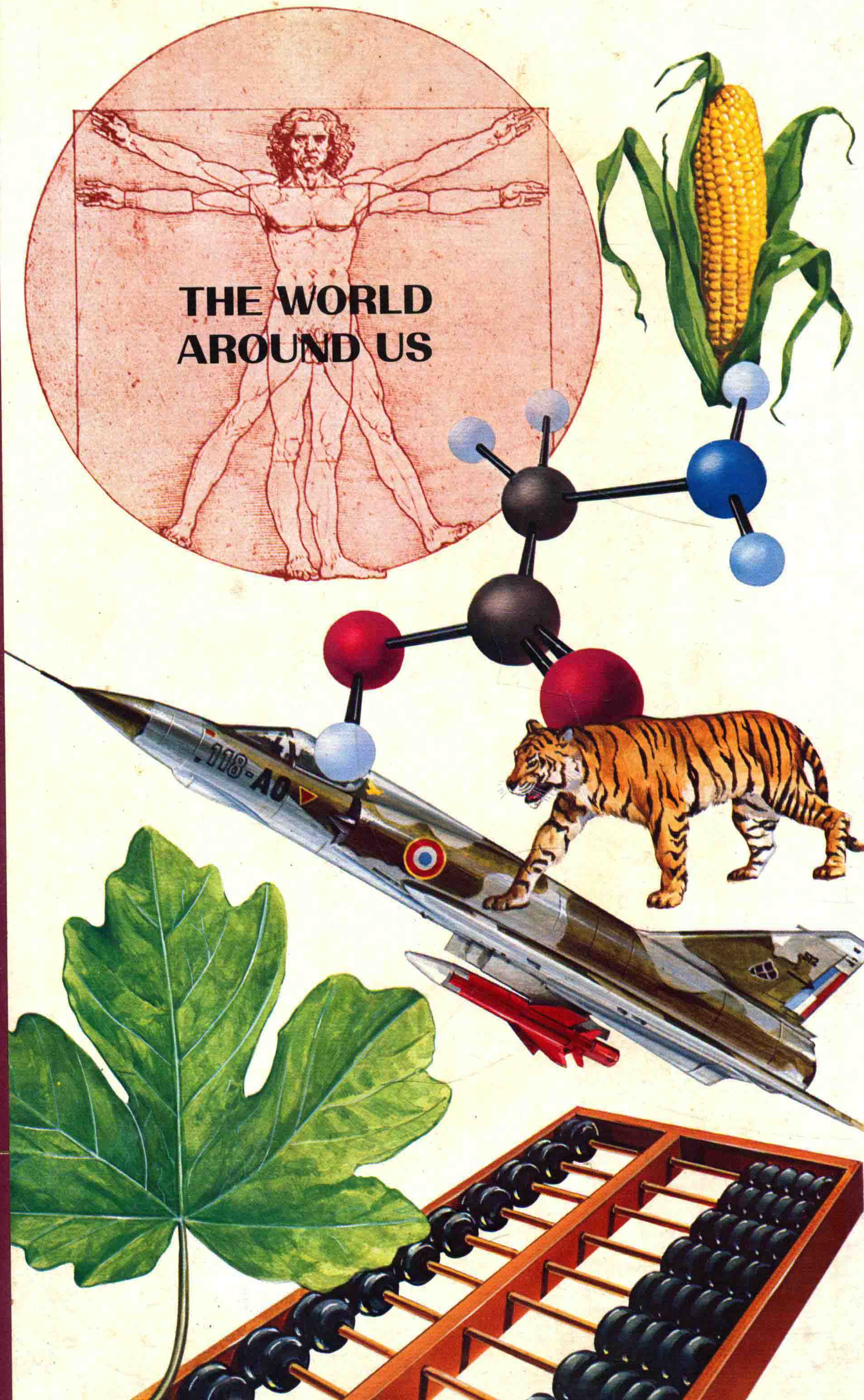
SCIENCE AND TECHNOLOGY ILLUSTRATED

THE WORLD AROUND US



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Science
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The World Around Us

Volume 17

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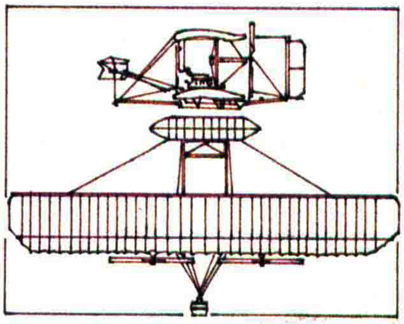
Contents

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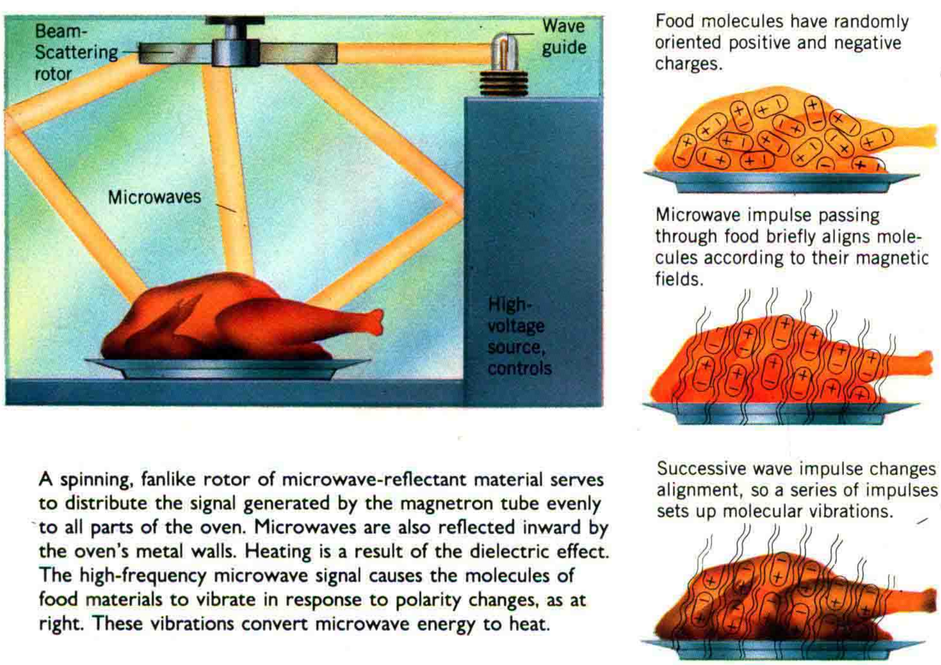
Microwave Oven

You can put a meal into a microwave oven and cook it in just a few minutes. When you take the food out, it will be steaming hot, completely cooked inside and out, but the oven itself and the food container will be at room temperature.

Microwaves are part of the electromagnetic spectrum. They range from 1 mm to 30 cm in wavelength, or from 300,000 megahertz to just under 100 megahertz in wave frequency. Radio waves have longer wavelengths or lower frequencies, while infrared waves have shorter wavelengths and higher frequencies.

The oven's metal surfaces do not get hot because their molecular composition reflects the microwaves. Glassware and polymer, or "plastic" utensils used in cooking, meanwhile, are "transparent" to the microwaves. The microwaves, neither reflected nor absorbed, simply pass unchanged through these materials to the food, the way radio or television waves pass through the walls of a house.



A spinning, fanlike rotor of microwave-reflectant material serves to distribute the signal generated by the magnetron tube evenly to all parts of the oven. Microwaves are also reflected inward by the oven's metal walls. Heating is a result of the dielectric effect. The high-frequency microwave signal causes the molecules of food materials to vibrate in response to polarity changes, as at right. These vibrations convert microwave energy to heat.

How Food Is Cooked

Foods placed in a microwave oven, however, respond quite differently than do metal or glass. First, they readily absorb microwave energy. Second, as they do so, conditions arise for the conversion of microwave energy into kinetic energy at the molecular level, with heat being the crucial by-product for the chef.

The basis for this phenomenon is a physical characteristic of all materials known as the "dielectric property." This simply refers to the unique ability of any material to conduct, absorb, or reflect electromagnetic energies to varying degrees over the spectrum of electromagnetic frequencies. In other words, all materials can absorb, reflect, or conduct electromagnetic energy—the only question is to which band on the spectrum they are most responsive in each case.

Water and food materials with high water content are strongly absorptive of electromagnetic energy at the microwave frequency commonly used in ovens (2,450 megahertz), while metal is a reflector and glass and plastic are conductors at that same frequency.

How Microwaves Are Produced

One megahertz equals 1 million cycles or oscillations per second. An oscillating type of electron tube called a magnetron is used to generate microwave energy in ovens for home use. Like other vacuum tubes, magnetrons are essentially cylindrical. They make use of cathodes and anodes—positively and negatively charged rods respectively. Along the long axis is a thermionic cathode. This is a metal pole that, when heated to incandescence, sends out electrons from its coating of oxides.

An anode ring concentrically surrounds the cathode. The space between cathode and anode serves as an interaction chamber. The inner walls of the anode ring feature several evenly spaced grooves that open into larger spaces inside the anode. These openings are resonant cavities.

When an electric current enters and heats the cathode to around 2,900°F. (1,600°C.), electrons are given off. In a normal vacuum tube, the electrons would be immediately attracted to the anode. In a magnetron, however, this does not occur right away. The reason is that, as its electrons are emitted, they are simultaneously drawn into a curved trajectory around the cathode by a circulating force imposed by a permanent magnet.

The interaction of electric and magnetic fields creates a wheel-shaped "cloud" of densely packed electrons that whirl around the cathode at about one-twentieth the speed of light.

Some electrons fly from the cloud and bombard the resonant cavities. The effect is somewhat like a wind blowing across and into a bottle. A signal—that is to say, a frequency—will result. Just what this frequency will be depends on the size and shape of the bottle. This same principle holds true in a magnetron's resonant cavities, which are of such shape and size that the "wind" of electrons creates microwaves of the desired frequency.

At this point, the magnetron has developed a strong, stable radio-frequency field of microwave energy.

Moving the Waves to the Food

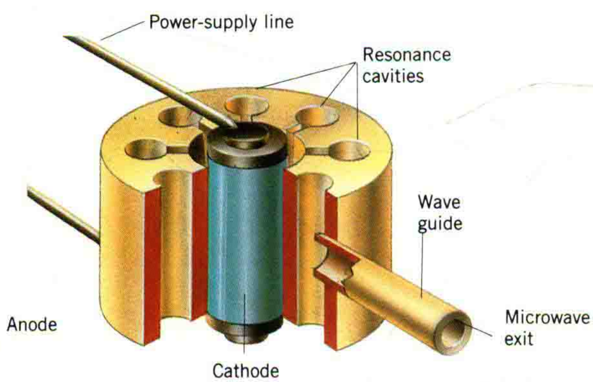
Microwave energy that develops in the resonant cavities is picked up by an antenna in one of the cavities. The antenna wire leads out of the anode and ends, protruding, in a ceramic vacuum dome that is positioned within a waveguide. There, the oscillating electromagnetic energy is released from the tip of the wire as a microwave radio-frequency field—in other words, as microwave energy.

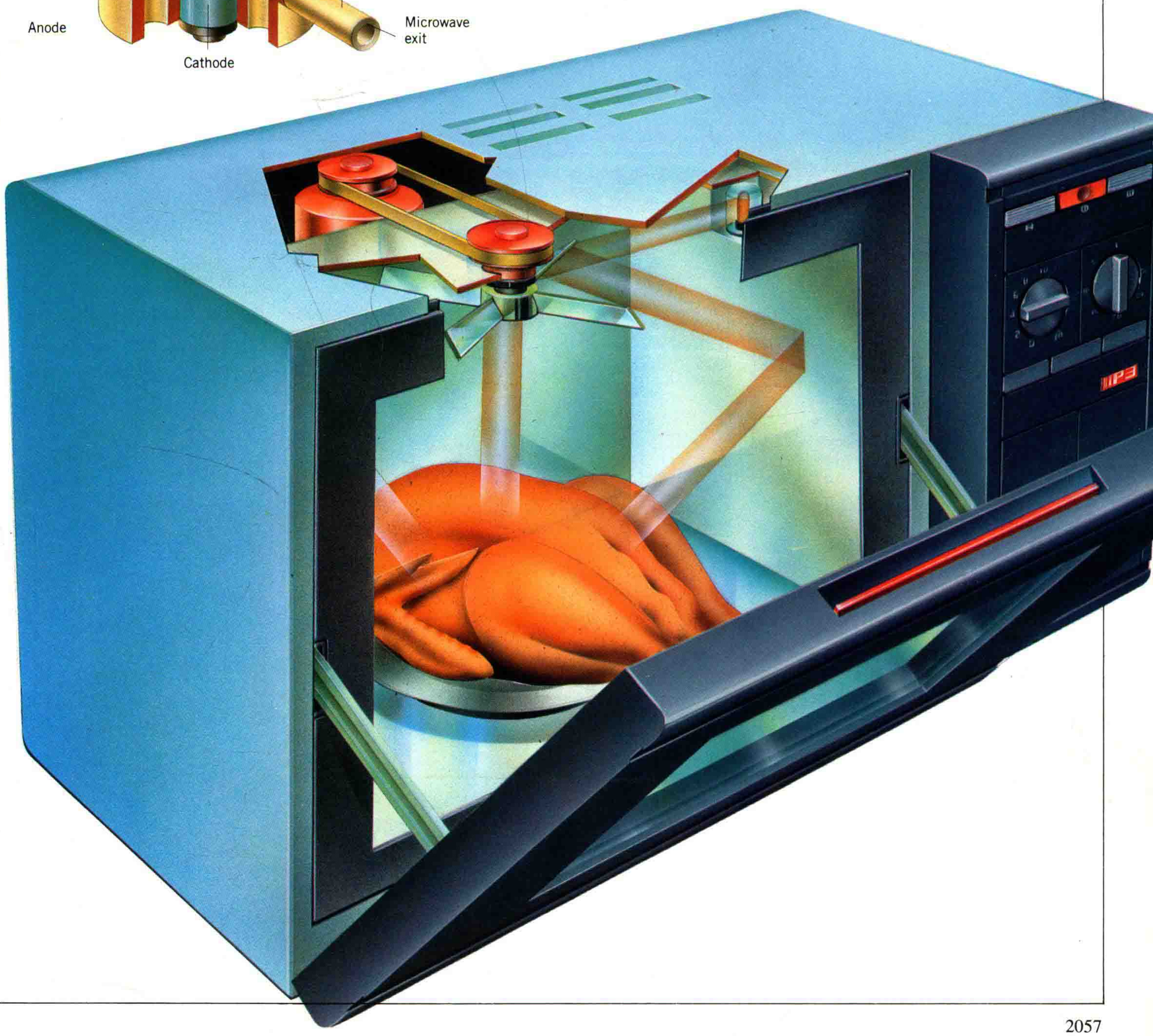
The waveguide is a rectangular metal pipe in cross section. Like air ducts in a house, the waveguide's function is to channel the microwaves to the oven cavity where the food is to be cooked.

Microwaves can be dangerous to human tissues, depending upon their wavelengths. The higher the frequency, the greater the tendency to burn the skin and other exposed areas, such as the eye. In microwave ovens, the metal housing prevents the microwaves from escaping. In order to allow users to see the food during oven operation, however, perforated metal screens are employed. Questions have been raised about their effectiveness in blocking microwave radiation.

Right: Composite photograph of a roast in a microwave oven. Microwaves cook food from the inside out, so surface browning is limited. Some of these ovens employ conventional electric heating elements to brown foods, since people prefer their food to have the appearance of being fully cooked.

Below: Cutaway diagram of a magnetron tube, showing its main parts, and large drawing of a household microwave oven, with the metal rotor used to scatter the microwave signal visible through the cutaway top.





If every autumn you get the feeling that it is the same flock of geese heading south, by way of your backyard, chances are that your feeling might be right. European and North American geese are true migrants, which means that at regular intervals—in their case, every fall—they start a voyage from a fixed location, go to a predetermined destination, and then return to their place of origin.

Migration is a pattern common not only among birds but also among some fish, mammals, and insects. Animals migrate in search of food, of a suitable place to reproduce, hibernate, or molt (molting is the process by which old bird feathers fall out and are replaced by new ones). Migrations can be of astonishing length—the Arctic tern, for example, travels 11,000 miles (almost 18,000 km), from the northernmost reaches of North America, Asia, and Europe to Antarctica, where it goes to breed.

The Process of Migration

Scientists still do not fully understand the process of migration, but experiments in which birds and fish are tagged and their movements followed have revealed some interesting data. It has been found, for example, that birds taken from their nesting places and released from unfamiliar localities can find their way home. Before taking off, they determine the direction they must take, then hold a straight, steady course the entire time they are in flight. It is thought that birds owe their navigational prowess to an extraordinary ability to register "readings" of the Earth's magnetic field and a sensitivity to the Earth's rotation, but no one has yet been able to identify the specific organs that accomplish these tasks.

It is believed that birds that migrate during the day use the Sun's angle to the horizon as a navigational aid. Birds that are exposed to irregular patterns of daylight—i.e., birds deprived of darkness for several days—show disturbed migratory patterns and have been found to lose their way for a time. That the internal clock of these birds has been upset is certain, but the specific way in which this light-regulated internal rhythm affects migration remains a mystery.

Not all birds, however, travel by day. Those that migrate by night, it has been found, use the stars to chart and keep to their course. Birds taken from their homes, then released in a planetarium in which the stars were arranged in an autumnal pattern, oriented themselves and embarked on their "usual" migrational path.

Experiments indicate that fish also use the Sun as a directional aid, especially salmon and parrot fish. Light passing through water is difficult to follow, however, and fish living in deep water rely primarily on currents.

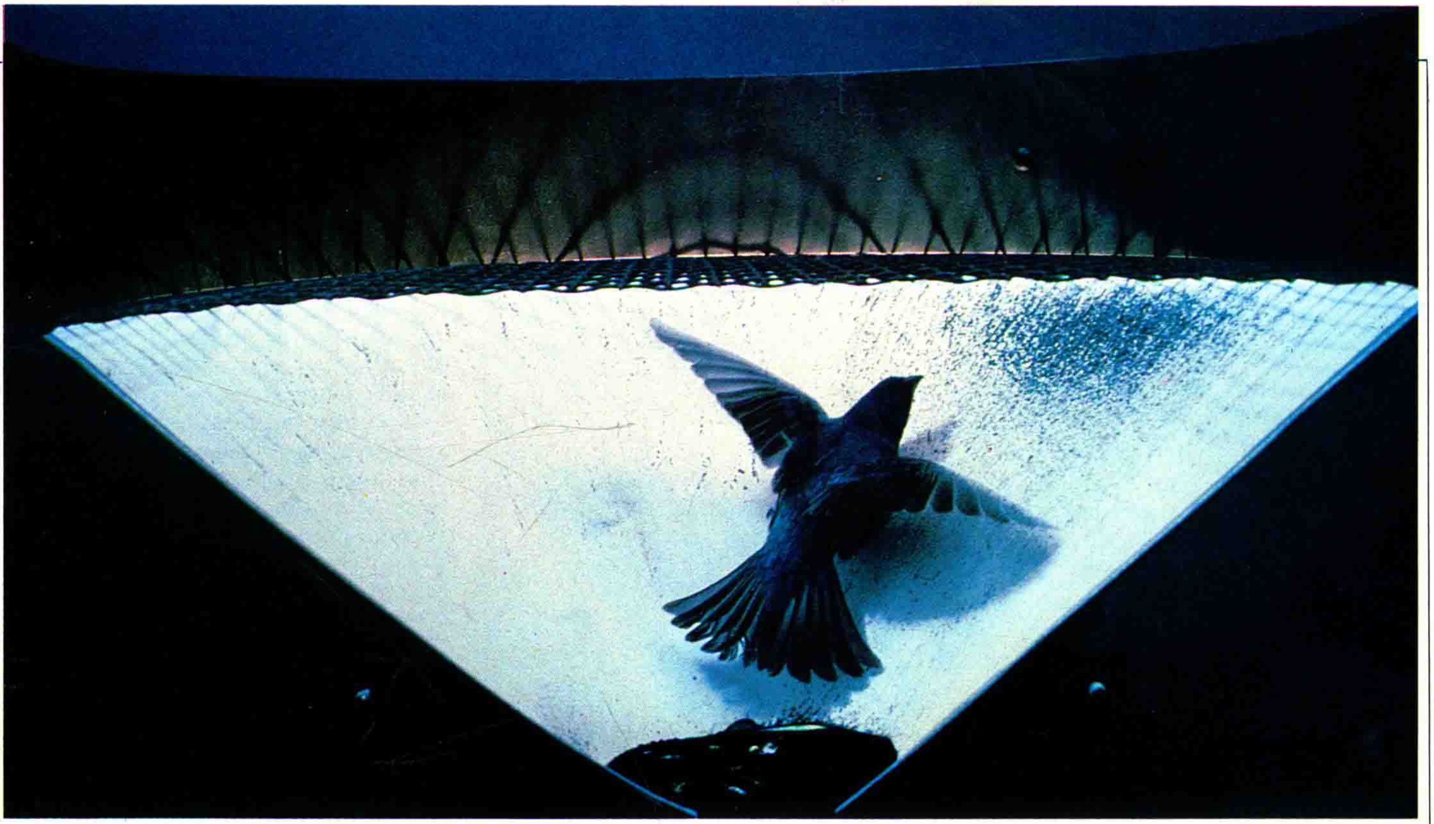
Landmarks, such as rivers, mountain ranges, climate zones, and bodies of water, also have a role in determining migration routes. However, scientists believe that landmarks play a rather minor role compared to that of navigational sense, especially in long migrations.

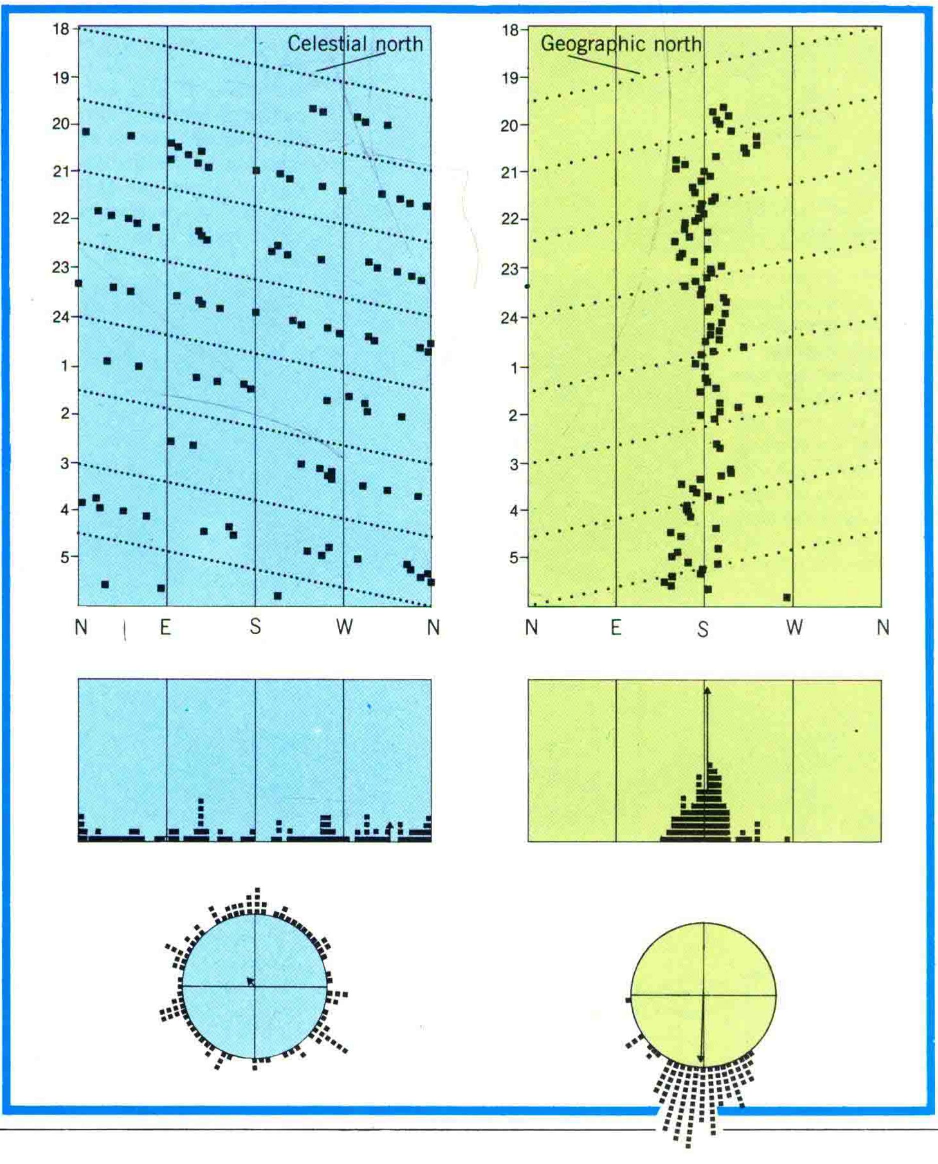
It is also thought that evolution is a factor in migration routes. Animals first had to change habitats during the Ice Age, when their previously temperate homes became frigid. After the great ice sheets began to melt, birds returned to their original (still cold) habitats to breed, where the food supply, owing to the previous retreat of the population, was plentiful. Contemporary bird migration routes, according to this theory, are the same routes used by their ancestors at the end of the glacier age. The yellow wagtail, to cite one example, probably lived originally in Alaska. The glaciers, though, forced the wagtail to find more hospitable environs, and today, this bird winters in Africa and southeast Asia.

Like other cyclical physical processes (menstruation, for example), an animal's readiness to migrate is triggered by the endocrine system. This has been most extensively studied in birds and eels. In the fall, the body accumulates fats, which serve as a sort of fuel during arduous travel. Hormone levels, controlled by the pituitary gland, also rise just prior to migration. These changes alone, however, do not induce a bird to take flight. Ecological conditions, such as weather, wind strength and direction, and immediate food supply, also have an effect.

Right: Migrating terns may cover as much as 11,000 miles (8,000 km).

Above: Diagrams illustrate results of an experiment conducted in a planetarium on the migratory orientation of night-flying birds. At top, birds oriented themselves by the stars to select the appropriate direction of flight. If the position of the stars was rotated, as at center, the birds also changed direction. If the star pattern projector in the planetarium was turned off, as below, the birds became disoriented and failed to maintain a pattern. In nature, however, if the stars are invisible—for example, on a very cloudy night—birds seem to use visual landmarks to orient themselves.





Top: Photograph of a bird in an Emlen funnel, a device used to research migratory habits. The funnel contains a reservoir of ink. As the bird attempts to escape, it marks the funnel with traces of ink.

Left: Diagrams indicate results of the experiment using a blackcap. Blue section indicates geographic orientation; green, celestial orientation. As one can see, no matter which direction the Emlen funnel was turned, the blackcap always attempted to fly to a point opposite the North Star.

Above: Bird being banded. The metal collar, which does not injure the bird, allows its migratory pattern to be traced if it is recaptured.

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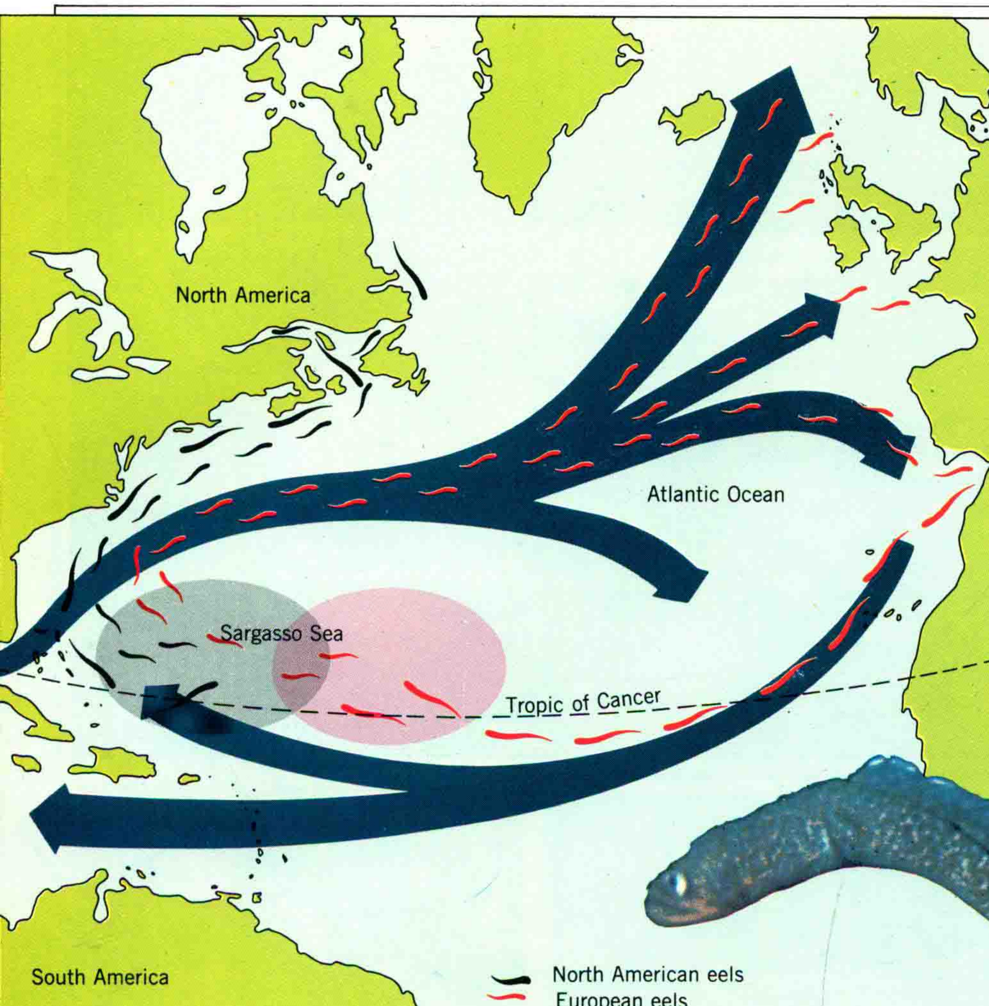
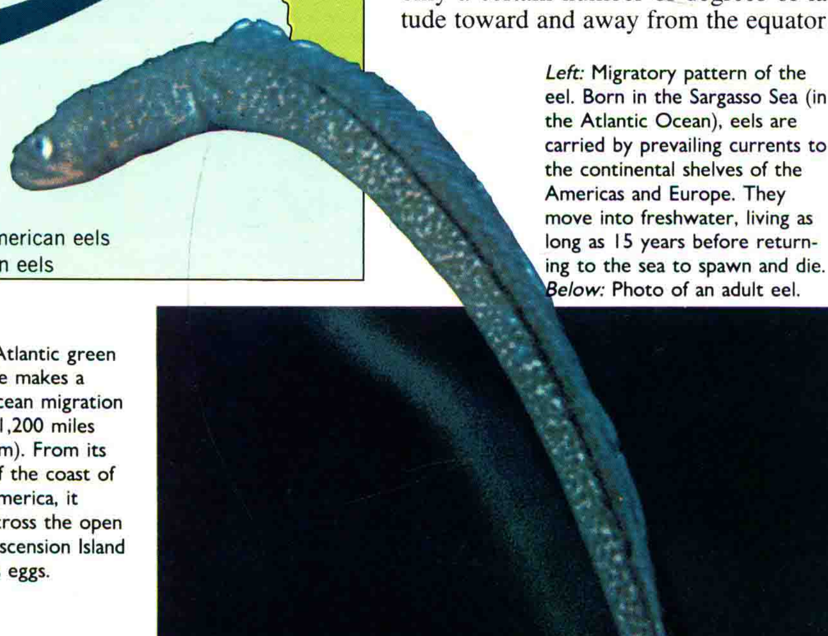


Left: Migratory pattern of the eel. Born in the Sargasso Sea (in the Atlantic Ocean), eels are carried by prevailing currents to the continental shelves of the Americas and Europe. They move into freshwater, living as long as 15 years before returning to the sea to spawn and die. *Below:* Photo of an adult eel.

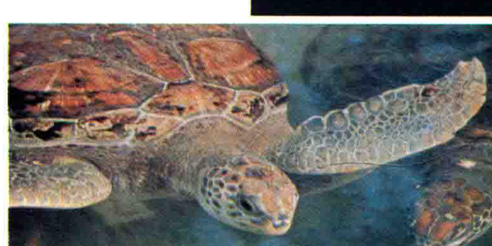


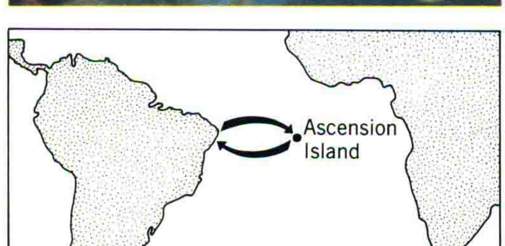
Migratory Habits Among Birds

Because bird migration is one of the most obvious cycles in nature, and because birds are fairly easy to observe, their migratory habits have been well documented. Most birds migrate in flocks, even if they live alone or in small family groups during the rest of the year. Geese, ducks, pelicans, and cranes fly in a V formation, with the point in the direction of their destination. Birds fly more quickly during migration than at other times; starlings migrate at speeds ranging from 43 to 49 miles (68-78 km) per hour; pintails at 31 to 51 miles (50-70 km) per hour; and rooks at 32 to 45 miles (50-72 km) per hour. Most birds migrate at fairly low altitudes, with passerine (perching) species usually keeping to under 200 feet (60 m). There are exceptions, though; among them are Indian geese, which have been spotted at altitudes nearing 30,000 feet (9,000 m). Though there are exceptions, birds also tend to avoid flying over oceans and other large bodies of water, deserts, and mountain ranges. European species that winter in Africa almost without exception make water crossings by way of Spain to Morocco, Sicily to Tunisia, and from Asia Minor to Egypt, all across narrow strips of sea. North American birds wintering in South America rarely fly over the Caribbean by way of the West Indies; instead, they take the route with the shortest water crossing, which is from Panama to Venezuela, or from Florida to Cuba and the Yucatan. In winter, Central America has more species of birds than anywhere else, and the Malayan peninsula comes in second. Birds with restricted diets are forced to make longer migrations.

In North America, birds tend to migrate from north to south, though Canadian geese migrate northwest (Hudson Bay) to southeast (Chesapeake Bay). Western European species tend to migrate less (owing to the temperate climate) than eastern European species. In Africa and other tropical areas, migratory patterns are tied to the rhythm of the wet and dry seasons. In Africa, the equator acts as a boundary to many species, which will not cross it, and serves to regulate migratory patterns in general, as most birds migrate only a certain number of degrees of latitude toward and away from the equator.

Below: Atlantic green sea turtle makes a yearly ocean migration of over 1,200 miles (2,000 km). From its home off the coast of South America, it swims across the open sea to Ascension Island to lay its eggs.





Migratory Habits Among Fish

Like birds, certain fish make long migrations in search of food. White tuna, for example, migrate from the waters surrounding the Azores and the Canary Islands to the waters near Iceland. Others, like salmon, live in the sea but migrate to freshwater in order to breed. Others, such as the European eel and the North American eel, do the opposite. Salmon have extraordinary migratory patterns. They lay eggs in the beds of cold, freshwater lakes and streams. The young remain there for 2 to 6 years and then swim to the sea, where they spend their adult life, which generally lasts several years. They then make their way back to the exact stream in which they were hatched, lay their eggs, and die. They often travel great distances, from Norway to Scotland, for example. Salmon navigate primarily according to the position of the Sun; they are able to recognize their original home through the smell and temperature of the water and land and rock formations.

Migratory Habits Among Mammals

Most land-dwelling mammals do not migrate. Among those that do are caribou, which move south in July from the North American Arctic to wander in no particular direction through the northwestern barrens (lands with sparse vegetation). Elk, dall sheep, and mule deer migrate in circular routes through the North American plains.

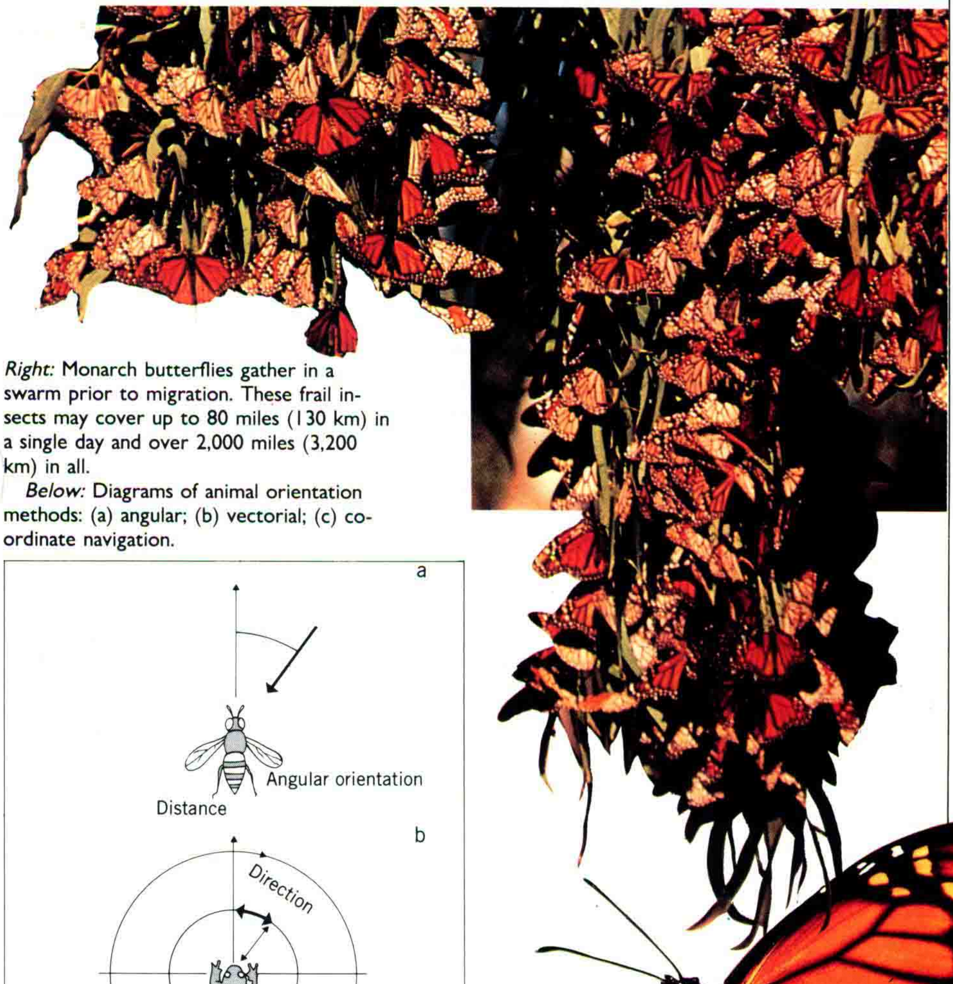
In Africa, zebras and wildebeests migrate according to the rainy season. Herds travel as much as 1,000 miles (1,600 km), gathering during dry seasons at oases and water holes.

Bats of Europe, Asia, and North America are migrants. The German large-eared bat winters in Brandenburg until March or April, then travels to northern Germany some 160 miles (260 km) away. North American species summer in New England, Canada, and the northern parts of the Midwest, and winter as far south as Georgia and Florida.

Migration not only is of obvious benefit to migrants, it has ecological importance as well. Food supply becomes depleted in heavily populated areas, and if animals did not migrate to less populated areas, plentiful food sources would go to waste there. Though we still do not fully understand the workings of migration, we are certain that it is integrally tied to other basic cycles, such as those of the seasons, reproduction, vegetal growth, and patterns of light and darkness.

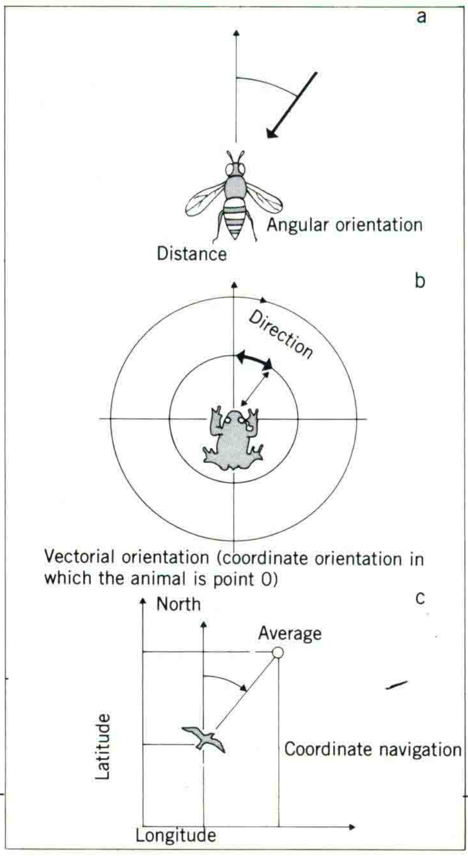
Migrating animals are a signal that other cycles are changing. Flocks of birds beating across the sky give an indication that several intricate and intricately related cycles are in flux.

Left: Photo of a lemming. These furry rodents periodically become so numerous in one area that they consume all the available food. When this happens, thousands of lemmings spontaneously migrate in one direction. If this path crosses a river or sea, the lemmings unhesitatingly hurl themselves to their deaths in the water.



Right: Monarch butterflies gather in a swarm prior to migration. These frail insects may cover up to 80 miles (130 km) in a single day and over 2,000 miles (3,200 km) in all.

Below: Diagrams of animal orientation methods: (a) angular; (b) vectorial; (c) coordinate navigation.

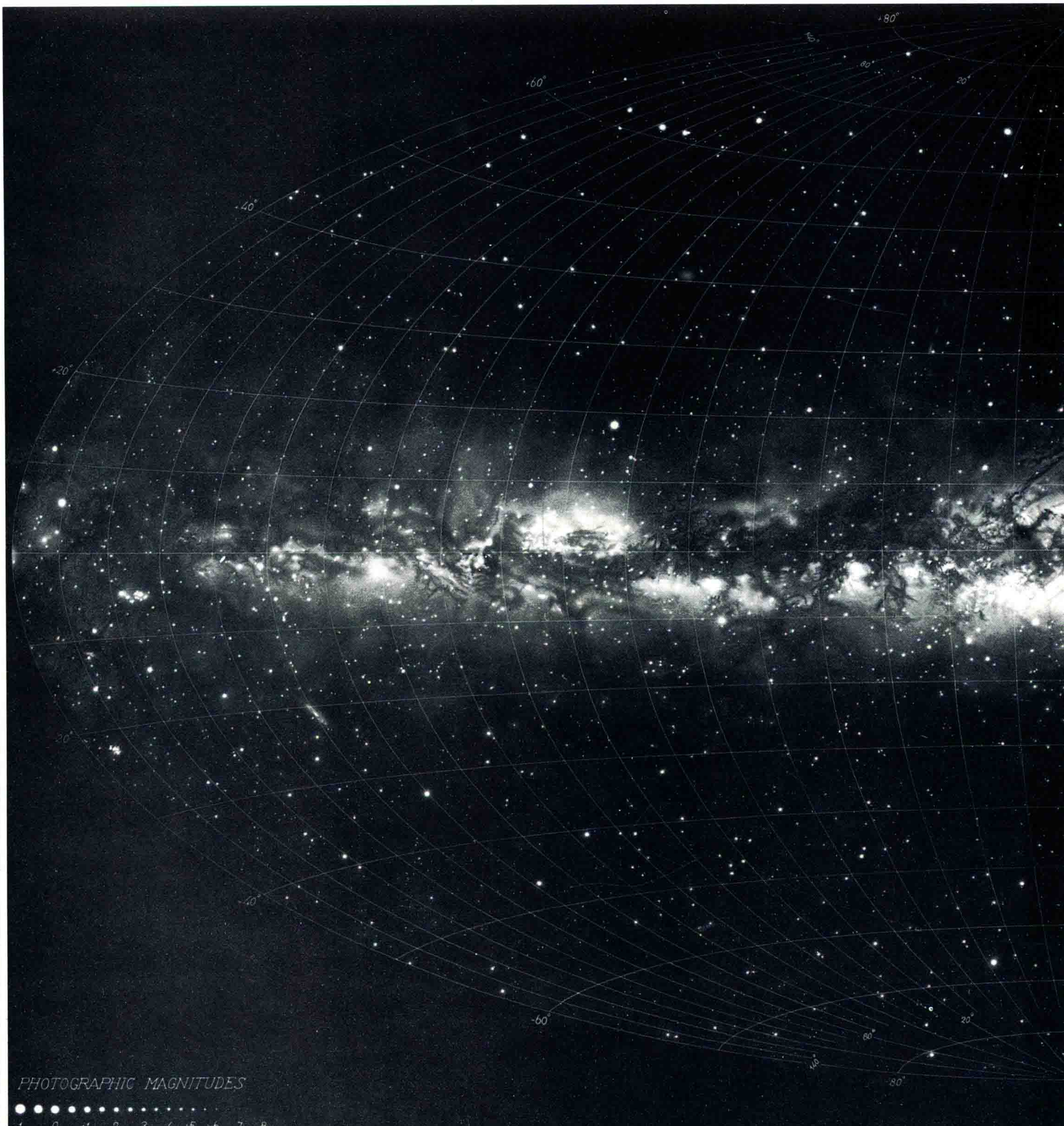


If you stand outdoors and search the horizon on a starry night, you will see a glowing band of white light, stretching from one side of the horizon to the other. The Greeks called this luminous arc the heavenly *gala* ("milk") or *galaxias* ("milky way"), which we have taken into English as both "Galaxy" and "Milky Way." Some Greeks even knew that it was actually the light of many stars, although most ancients had mistaken ideas of its true nature.

It was not until Galileo built his first telescope in 1609 that many of the Milky Way's stars could actually be distinguished. Today, with the assistance of advanced telescopic equipment and high-speed computers, it is possible to know more of this star complex than simply meets the eye, although much remains unknown about the 100,000 million stars that make up the Galaxy.

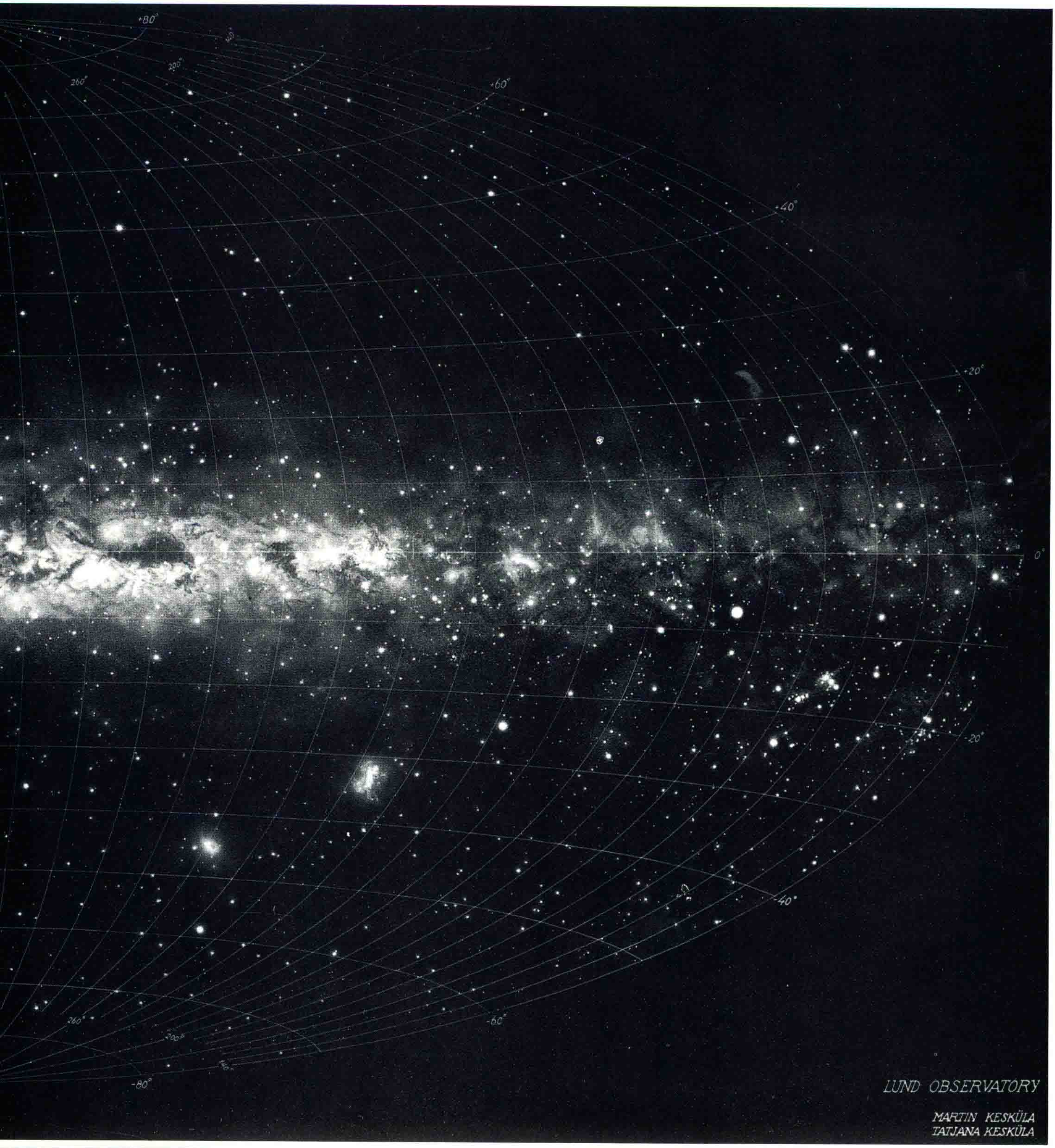
Magnitudes

That the Milky Way is large there is no doubt. But just how large is it? And what does it really look like? While estimates



Below: The luminous band in the center of the photograph is the Milky Way. This image, made at the Lund Observatory in Sweden, is actually a composite of individual photographs of the night sky. The occasional dark zones appearing on the face of the Milky Way are caused by clouds of interstellar dust that block the light of stars behind them.

of size and shape do exist, it is important to remember that the distances involved are almost impossible to imagine in the terms we generally use. For the purpose of keeping numbers small, stellar magnitudes are often referred to in the form of light-years—the distance light travels over the course of one earth year, which works out to about 5.878×10^{12} miles (9.46×10^{12} km)—quite a long way. In the Galaxy, however, which has been shown to have a flattened shape (actually, stars are arranged along radiating arms, which spiral out from a central hub, much like a pinwheel), a single light-year is comparable to a city block on Earth. All told, the disk of the Milky Way is about 100,000 light-years across and 5,000 light-



years thick. The Sun, just one of the thousands of millions of stars of the Galaxy, is about 30,000 light-years from the center. We, together with all the stars in the Milky Way, spin around this center at a rate of one revolution in about every 250 million years. One revolution ago, Earth was in the Permian period, when reptiles were beginning to evolve, and the Earth's climate was enduring an ice age.

Composition of the Galaxy

Even though there are thousands of millions of stars in the Galaxy, only a small percentage of the available space is taken up by their presence. In between lies the interstellar medium, also known as outer space, consisting of about 90 percent hydrogen and 10 percent helium together with small percentages of heavier elements including carbon, nitrogen, oxygen, magnesium, and neon. Even though all of this is at an extremely low density, outer space is not the perfect vacuum it was long thought to be. The interstellar medium is quite old, dating back to the big bang that may have given birth to the Universe 20,000 million years ago. Mixed in is a certain amount of interstellar dust, rock, and ice crystals, which mix freely throughout the medium in the form of condensed clouds.

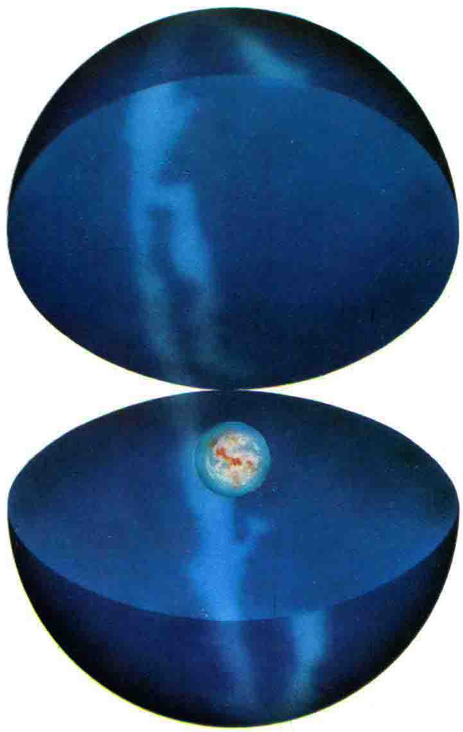
The amount of the heavier elements in outer space is constantly, although slowly, rising, because they are manufactured in the cores of stars made mostly of hydrogen and helium. As old stars die, occasionally blowing up in supernova eruptions, these heavy elements are spread about freely in the interstellar medium. As new stars form and evolve, the proportion of these elements rises.

Population I and Population II Stars

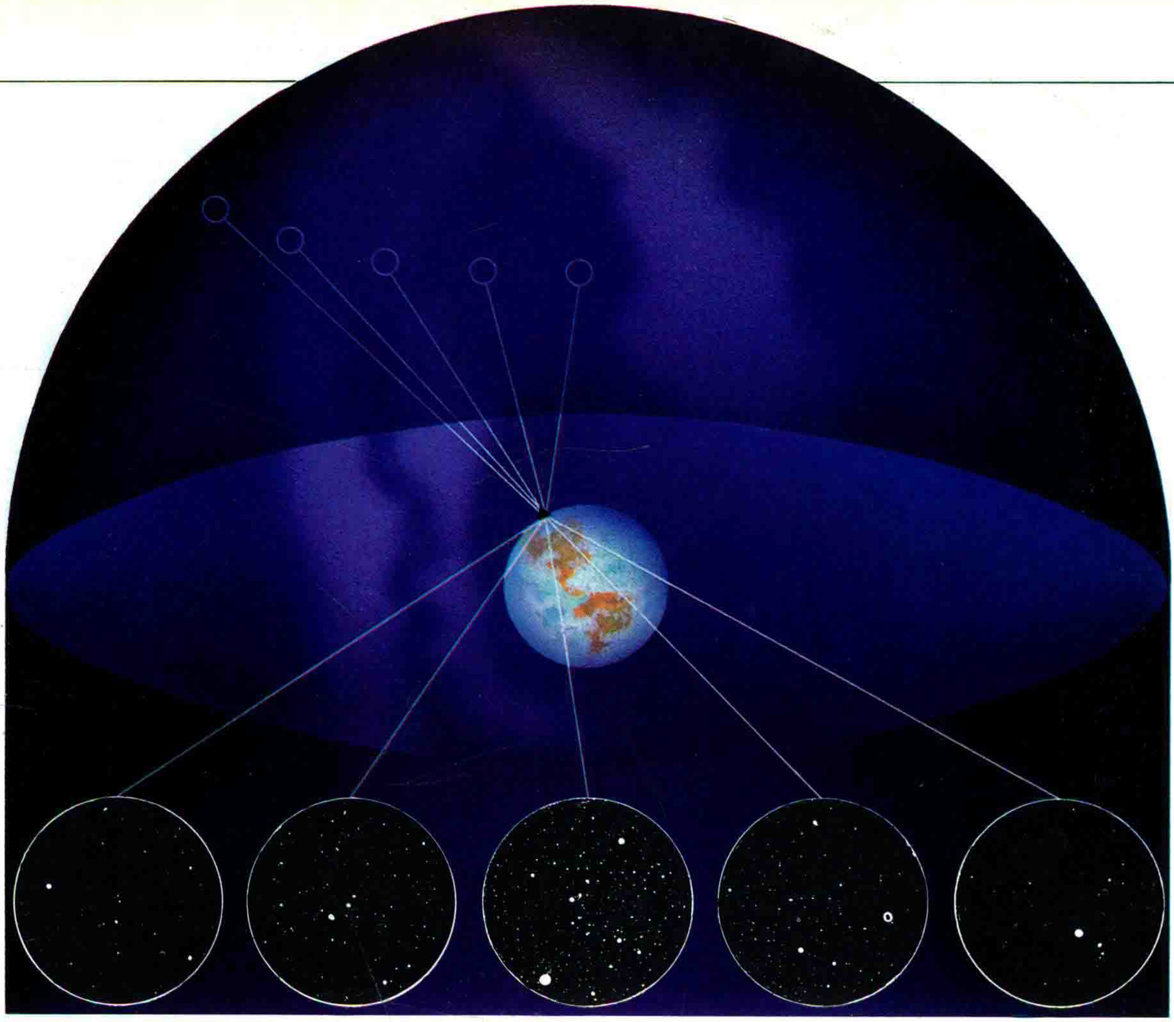
Our knowledge of the physical composition of certain stars is directly related to our knowledge of stellar ages and to our sense of the age of the Galaxy as a whole. Younger stars, like our Sun, generally contain appreciable amounts of the heavy elements manufactured in earlier stages of the evolution of the Galaxy, recondensed and given new life. These are population I stars, and they constitute a significant amount of the main spiral network of which we are a part. Older stars, called population II stars, show only slight traces of anything other than hydrogen and helium. These stars are rarer than population I stars, as most have burnt out by now. They are usually found on the periphery of the galactic spiral and in what is known as the galactic halo.

Clusters and the Galactic Halo

Clusters of stars, which are simply closely related star groups, occur fre-



Left: The Earth is within the Milky Way, though in a relatively peripheral position. Seen with the naked eye, the individual stars of which our Galaxy is composed are not clearly visible, and the Milky Way has the appearance of a bright band in the sky. Optical magnification, as shown below, is necessary to distinguish the individual stars, though only the brightest can be seen from Earth.



Left: Illustration shows, in simplified form, sampling method used to measure distribution of stars in the Milky Way and other star groups. Relatively small areas of the sky, as shown in the telescopic images, are taken to be statistically representative of much larger areas of space. On the basis of star counts in these small zones, extrapolations can be made about the form of the entire stellar group.

quently in the Galaxy. They may contain only five or six stars or as many as a million. It is generally assumed that, no matter what the size of a cluster, all the stars in it must have formed simultaneously (by which an astronomer means within a few million years of each other). Therefore, observations of different types of stars in one cluster can be useful to astronomers interested in stellar evolution.

The largest clusters, called globular clusters for their condensed, spherical formations, occupy an interesting position in the Milky Way, which may tell us something about the evolution of the Galaxy. Most of these clusters—several hundred have been found—travel above and below the plane of the spiral limbs in a spherical region called the galactic halo. It is believed that the Milky Way once filled this sphere, that it only collapsed into its present state gradually, under the force of gravity. If this is the case, then these massive formations must have been left behind, too huge to have been moved from their ancient positions. Indeed, astronomers have shown that these are some of the oldest stars in existence, some probably as old as the Galaxy itself—14,000 million years.

A Galactic Map

Much of what we know about our Galaxy we have concluded through observations based on the way it looks. Fortunately, stellar positions and motions are governed by relatively simple physical laws, the same laws Newton arrived at in his 17th-century description of gravity. Granted, our powers of observation are greater than his were, and we are able to draw conclusions about regions of the Galaxy thousands of millions of miles away. But what about those areas we cannot directly observe? One modern method of "looking" into the Galaxy is by means of radio waves, which, with our visual records, have made it possible to construct a picture of the Milky Way.

If radio waves were visible, we would probably get a fairly bright illumination from the direction of the galactic network. This is because molecules of hydrogen, the stuff most of the Universe is made of, have been found to emit a strong radio wavelength, detectable by specially designed "telescopes," sensitive to the 21-centimeter wavelength of this particular emission. By training it on specific regions in the sky, it is possible to get a good "look" at what is out there, simply by observing the intensity of, and variations in, these received radio pulses. Readings on the 21-centimeter line (so called because it represents a particular line in the electromagnetic spectrum) have done more for the assembly of a galactic picture than any other form of astronomical observation.

The core of the Milky Way, a region extremely dense in hydrogen, is practically invisible to radio detection, because this particular radiation is not emitted by molecules that have combined in groups, an occurrence common under the higher pressures at the center. For this region, readings are taken on a number of other radio lines, one of which is radiated by the heavier carbon monoxide often present in combination with hydrogen in the interstellar medium. Nevertheless, the center of the Milky Way is a place we know little about. As research techniques improve, we will undoubtedly know more, but even in the distant future, much may be left to speculation. This is the hurdle we must finally jump if we are to gain greater understanding of our immense little corner of the Universe.

See also COSMOLOGY; GALAXY; RADIO ASTRONOMY; SUPERNOVA.

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