

# Beyond the

*Astronomers have opened new windows on the universe by studying the kinds of "light" we can't see with our eyes.*

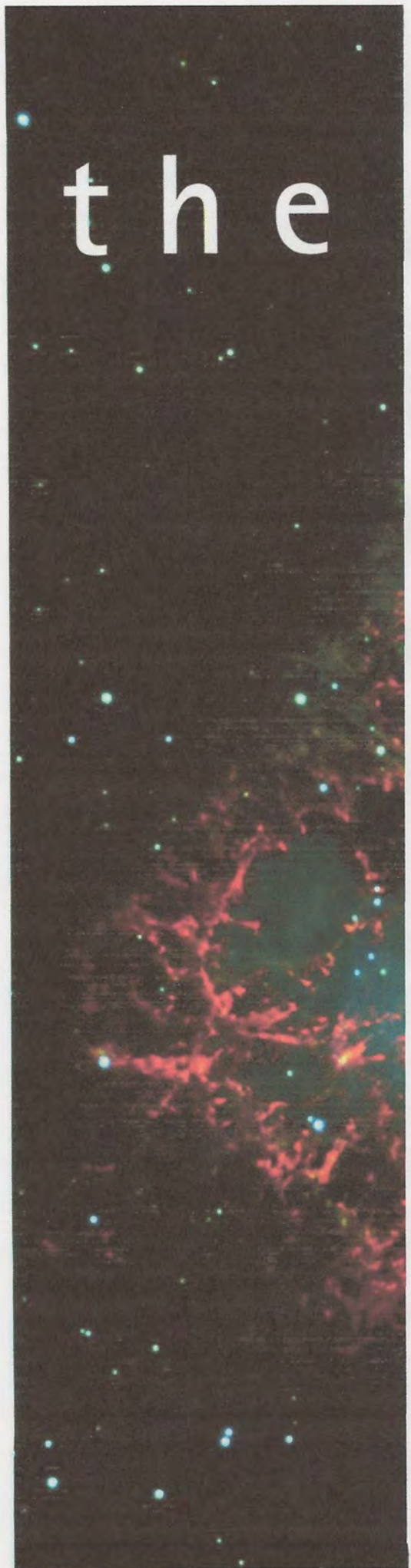
by James B. Kaler

It's everywhere around you. It pervades Earth, the sky, the universe, and is bouncing off and passing through you at this very moment. It can be highly destructive yet is utterly necessary for life. For astronomers, it's by far the most important way of unlocking the secrets of the cosmos.

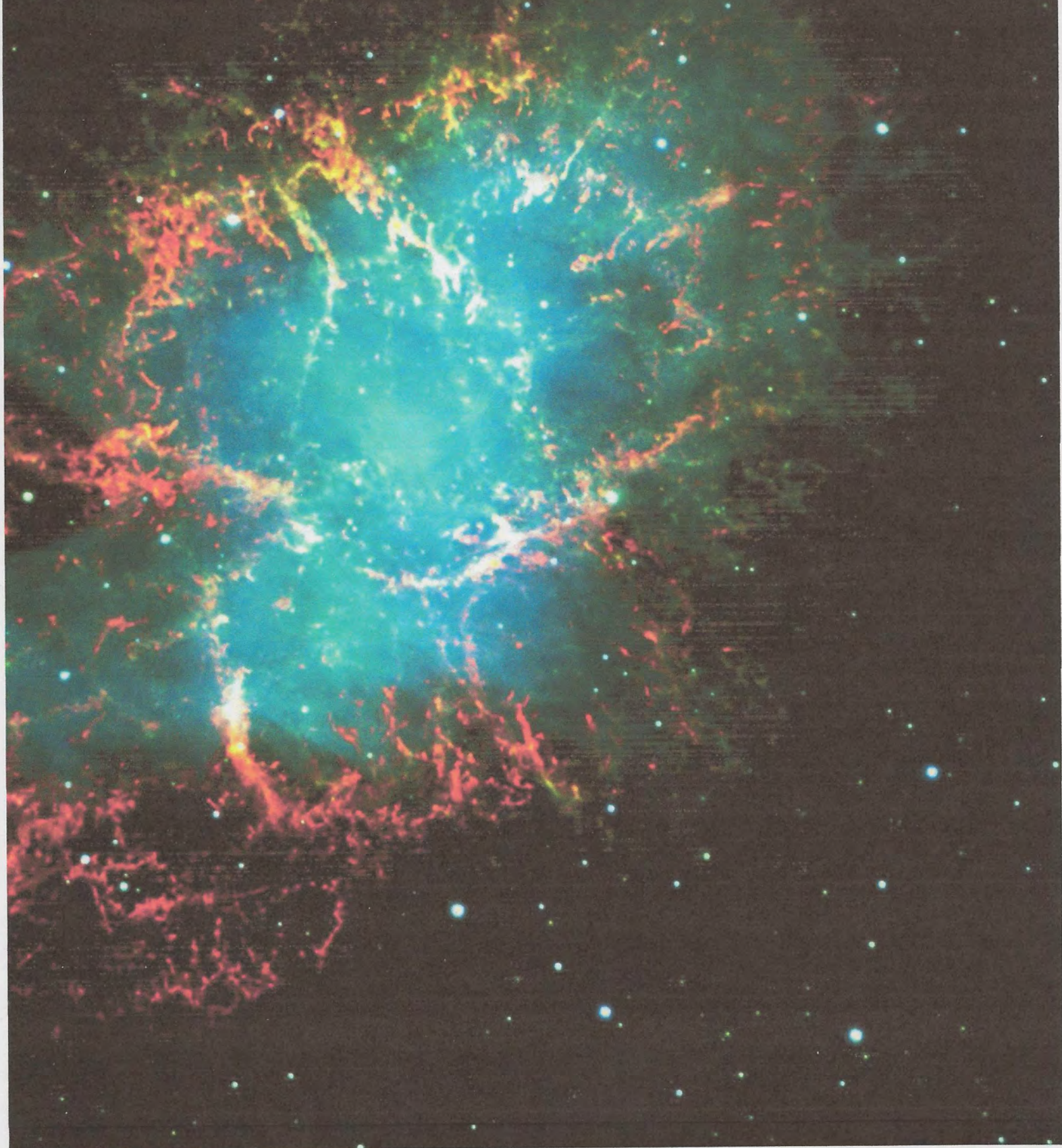
We know it best as light. But the light we see with our eyes is just a tiny sliver of a vast electromagnetic spectrum produced by everything from comets to quasars. We can understand little about the universe without an understanding and appreciation of visible light and its invisible partners in the electromagnetic spectrum: radio waves, infrared light, ultraviolet light, x rays, and gamma rays. All these different forms of light are fundamentally the same thing.

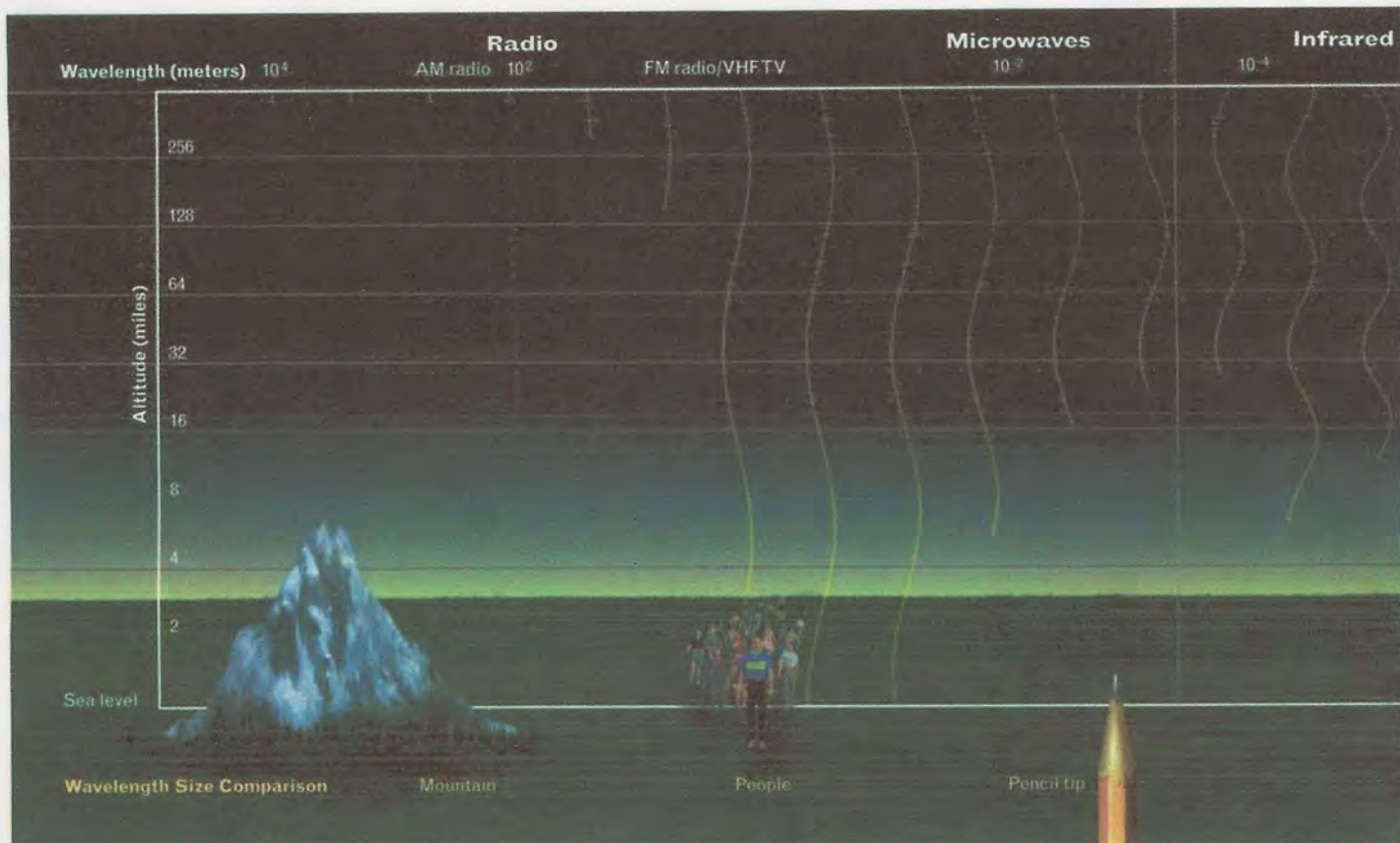
Scientists now know that light can be described as a train of waves that carries energy. These waves are in fact the universe's principal means for transmitting energy. Unlike water and sound waves, however, light does not need a substance through which to travel. Instead, it consists of waves of alternating electric and magnetic fields that move through a vacuum at the cosmic speed limit of 186,000 miles (300,000 kilometers) per second. The different kinds of light are waves that have different lengths between consecutive crests or troughs.

Europe's Very Large Telescope captures the Crab Nebula in visible light. ESO



# Rainbow





## Energy Carriers

Visible light and its cousins are not equal-opportunity carriers of energy. Besides being viewed as waves, light can also be viewed as consisting of massless particles known as photons. The shorter the wavelength, the higher the energy of a photon. X rays, whose wavelengths are shorter than a virus, have such high energy that they can penetrate the human body. This allows physicians to use x rays for medical tests. But overexposure to x rays can damage the body's cells, causing cancer.

Gamma rays, which are released in atomic-bomb blasts, have even shorter wavelengths — the size of atoms. Gamma-ray photons carry more energy than x-ray photons, and are thus even deadlier. We do not yet know the energy limit that gamma rays may have. The wavelength limits of the electromagnetic spectrum remain unknown.

The various colors of visible light have wavelengths somewhat less than a thousandth of a millimeter, about the size of bacteria. Visible light packs enough energy to stimulate chemical reactions in your eye, allowing you to see.

Ultraviolet light, which has wavelengths shorter than visible light but longer than x rays, begins to carry enough energy to be dangerous. Solar

ultraviolet light causes sunburn at the same time the sun's infrared light tempts us to go outdoors.

Infrared light, which is also known as infrared radiation (when referring to the electromagnetic spectrum, scientists often use "light" and "radiation" interchangeably), falls between visible and radio. If you place your hand next to your cheek, you can feel infrared light as heat pouring from your skin.

Waves longer than about a millimeter belong in the radio spectrum, which extends to mountain-sized waves many miles long. Because they have such long wavelengths, radio waves do not carry much energy and are thus not particularly harmful, as evidenced by the good health of those who live or work next to megawatt radio transmitters. Only at certain shorter radio wavelengths (called microwaves), where the waves are vigorously absorbed by water, can they be dangerous.

## Kaleidoscope of Colors

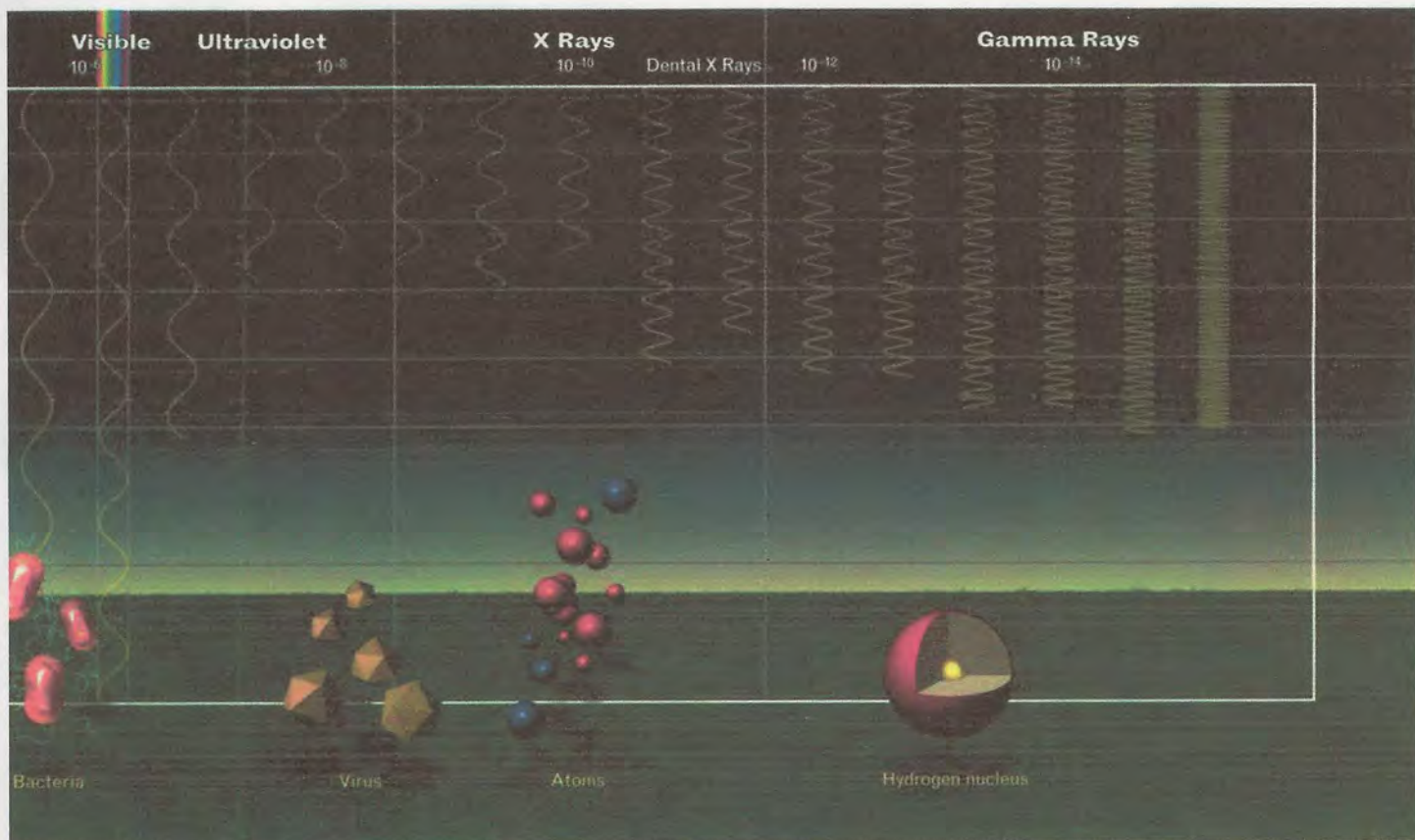
In 1666, Isaac Newton took the first step toward understanding visible light when he passed sunlight through a prism and watched it separate into a kaleidoscope of colors. Just like the wavelength differences between various parts of the electromagnetic spectrum,

the variety of colors comprising visible light are made of waves that have different lengths between successive crests or troughs. Red waves are the longest, violet the shortest.

William Herschel, the discoverer of Uranus, was the first to explore the region beyond the rainbow of visible light. In 1800, he reported on experiments to determine the heating power of different colors, in which he let a spectrum of light fall on a set of thermometers. To his surprise, he found that the greatest heat was produced off the red end of the spectrum where nothing was visible. "Radiant heat," he proclaimed, "will at least partly consist, if I may be permitted the expression, of invisible light." Herschel had discovered infrared radiation.

In the mid-19th century, astrophotographers began to explore the other end of the spectrum. Photographic emulsions are particularly sensitive to shorter wavelengths of light, blue and violet. Astronomers discovered that stars and nebulae radiate beyond violet light, hence the term "ultraviolet."

Physicists completed the picture in the late 19th and early 20th centuries with the discovery of radio waves, ultraviolet light, x rays, and gamma rays. Astronomers came to realize that



Astronomy: Elisabeth Rowan

many astronomical bodies radiate little or no visible light at all and remain hidden without full spectral exploration. Trying to understand the universe through visible light alone is like listening to a Beethoven symphony and hearing only the cellos. Only by studying images and spectra taken across the entire electromagnetic spectrum can astronomers appreciate the full scope of the universe.

In the 1930s, Karl Jansky, an engineer for Bell Labs, took the first step in opening up the entire electromagnetic spectrum when he discovered radio

#### Radiation Double Talk

The term "radiation" has a confusing dual meaning. In the early days of the study of radioactive elements, scientists discriminated among alpha rays, beta rays, and gamma rays. Alpha rays turned out to be high-speed helium atoms (helium nuclei are still commonly called "alpha particles"); beta rays were electrons. As a result, we must distinguish between "particle radiation," which now means a flow of any high-speed energetic particles, and "electromagnetic radiation," which includes all the forms of light, including radio waves, visible light, and gamma rays.

waves from deep space using a simple antenna. Radar technology developed during World War II eventually led to the radio telescopes of today. Radio telescopes "hear" nothing. Their mission is to map where radio waves are coming from so astronomers can learn about the radiating bodies' physical conditions. The way in which radio telescopes work is similar to optical (visible light) telescopes. They have large, curved collecting surfaces that reflect incoming radio photons to amplifiers and receivers.

Because radio waves have long wavelengths, they are not good at resolving small structures. To maximize resolution, astronomers build very large radio telescopes up to 1,000 feet (300 meters) across. Still, these telescopes have about the resolution of the human eye. Astronomers electronically coordinate individual radio telescopes hundreds of miles apart or synchronize their observations with clocks to construct "virtual" telescopes of continental size. Such radio interferometers can resolve details far sharper than anything current optical telescopes can see.

After developing radio astronomy in the mid-20th century, astronomers turned their attention to the rest of the electromagnetic spectrum. After lan-

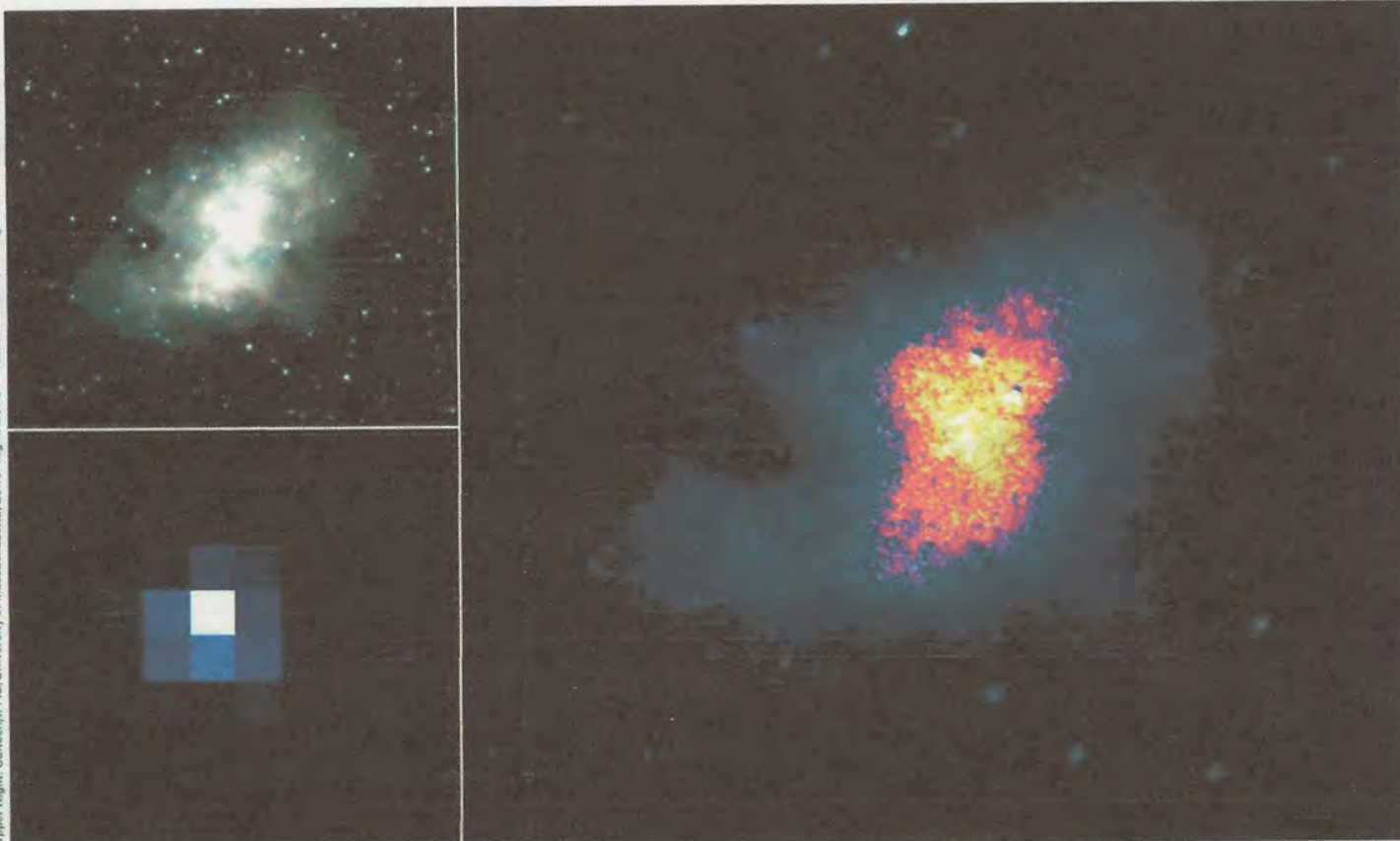
**Visible light makes up just a small portion of the electromagnetic spectrum. Gamma rays have wavelengths the size of an atomic nucleus, while the longest radio waves are the size of mountains. The atmosphere allows some radio wavelengths and visible light to penetrate all the way to sea level, but it absorbs or blocks light at other wavelengths.**

guishing since the days of Herschel, the field of infrared astronomy has come alive in the last 20 years with the advent of good detectors that can be fitted to optical telescopes. More recently, astronomers bridged the gap between radio and infrared — millimeter waves and microwaves — and have now mastered the entire long-wave realm of the spectrum. Herschel would be proud.

#### A Blessing and a Curse

Astronomers had to wait until the Space Age before they could open up the short-wave realm of the electromagnetic spectrum. That's because Earth's atmosphere absorbs almost all high-energy radiation. While this might sound like bad news for astronomers, it's actually good for all living things.

The atmosphere blocks radiation just to the short-wave side of violet light, allowing only a little bit of ultraviolet to sneak through. This protects



us from harmful ultraviolet light and x rays from solar magnetic storms. Much of the ultraviolet is blocked by ozone high in the stratosphere. Without this ozone layer, living on Earth's surface would be hazardous to one's health.

So what can astronomers do if they want to observe the kinds of light that are absorbed by the atmosphere? High mountaintops and dry south polar air are a help, but they do not really get to the root of the problem. The only recourse is to go into space.

Following a series of rocket experiments in the 1960s, Uhuru, the Einstein Observatory, ROSAT (Röntgen Satellite, after the discoverer of x rays), and now the Chandra X-ray Observatory have examined the x-ray region. Astronomers have used these satellites to map hot gas in galaxy clusters, explore the nature of expanding clouds from exploded stars, and examine the impact of the solar wind on comets.

The Compton Gamma Ray Observatory, which fell back to Earth last June, and other gamma-ray satellites have explored the highest-energy part of the spectrum. They have been hit about once a day with the mysterious gamma-ray bursts from deep space.

The International Ultraviolet Explorer (IUE) was launched in 1976.

Designed to last for three years, it was recently decommissioned after an amazing 20 years of service, a testimony to superb engineering. IUE and other ultraviolet satellites have revealed clusters of hot, newborn stars in distant galaxies, among other things.

While a few infrared bands make it to the surface, carbon dioxide and water vapor in the atmosphere absorb most infrared light before it reaches the ground. Infrared astronomers will go to almost any length to limit the water vapor over their heads, including putting telescopes in airplanes and establishing observatories in the bitter cold of the South Pole, which is one of the driest places on Earth.

In 1983, the Infrared Astronomical Satellite (IRAS) mapped the sky in four infrared bands. IRAS collected so much data that an institute dedicated to the satellite is still doing business at the California Institute of Technology. The Infrared Space Observatory (ISO) followed, and late next year the Space Infrared Telescope Facility (SIRTF) will greatly extend astronomers' knowledge of the infrared universe.

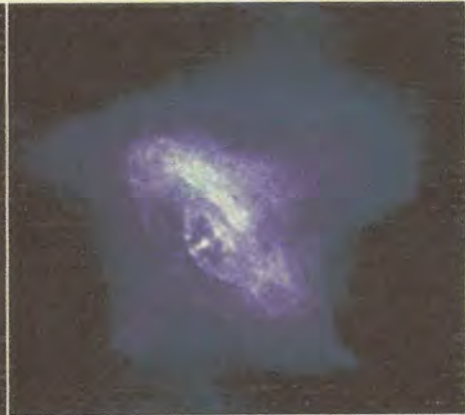
Even though many radio wavelengths can reach Earth's surface, astronomers still launch radio telescopes into space. A Japanese space

radio telescope, HALCA, works with radio telescopes on the ground to form an interferometer twice as big as Earth.

Hubble is the king of space telescopes. It is the only one that has general visible-light capability, allowing it to produce images that we can recognize but with a wonderful difference. All visible light wavelengths make it to the surface on a clear night, but Earth's atmosphere causes stars to twinkle, which degrades images made of celestial bodies. From above the atmosphere, the stars stare serenely down at us, allowing Hubble to see the heavens with 10 times the detail that is generally achieved from Earth's surface. Hubble can also observe well into the ultraviolet and infrared.

### The Temperature Connection

Light is produced when atoms release stored energy. In the simplest case, the kinds of electromagnetic radiation that a body emits depend on its temperature, which is a measure of its internal energy. Measurements of different kinds of waves thus allow astronomers to determine temperature. In addition, from the way that electromagnetic radiation interacts with matter, astronomers can determine chemical compositions, velocities, and



Far left: NRAO; Left: NASA/CXC/SAO

The Crab Nebula (M1) assumes different appearances depending on wavelength. At the far upper left, the 2MASS survey captures the Crab at infrared wavelengths. Below that is a picture from the Compton Gamma-Ray Observatory (gamma-ray instruments have extremely poor resolution). To the right of those images is an ultraviolet image taken from the ASTRO satellite. On this page, the large image was taken at radio wavelengths by the Very Large Array. Above, Chandra images x-ray emission from the central region of the Crab Nebula. Each image shows different characteristics of this supernova remnant.

other physical properties of objects that range from icy cold to scorching hot.

Cold objects such as interstellar clouds of gas and dust don't have enough energy to radiate x rays or even visible light. The enormous rift that divides the Milky Way in two consists of thick dust that visible light cannot penetrate. Because the dust blocks starlight, the clouds are chilled to only a few degrees above absolute zero and radiate best at radio and long infrared wavelengths. Molecules form within these clouds, where the dust protects them against the ravages of stellar radiation.

Just as you can hear a radio on a foggy day in which you can barely see the car in front of you, radio and infrared waves can punch through interstellar dust, allowing astronomers to probe within the dark clouds and see clearly across our galaxy. Until astronomers examined the clouds with sensitive radio telescopes in the early 1960s, they had almost no hint of the huge variety of molecules that exist in space and lacked knowledge of the most massive units of the galaxy, giant molecular clouds. The low temperatures allow the gas to contract gravitationally to form stars, so without radio and infrared astronomy, there would be no way to observe how stars are born.

As a body's temperature increases, it can radiate at higher energies. At a few hundred degrees above absolute zero, objects radiate strongly in the shorter wave infrared. That's why an infrared camera can take your picture at night. Astronomers use infrared light to study the advanced stages of star formation and warm dust ejected by dying stars.

At a few thousand degrees, a body produces visible and even some ultraviolet light (in addition to infrared and radio). The surface temperatures of most stars lie between 3500° F and 90,000° F (2000° C and 50,000° C) and are, like the heated filaments of light bulbs, powerful emitters in the visible. Cool stars radiate most of their energy in the infrared. Hot stars radiate mostly in the ultraviolet, so without examination of these spectral bands, astronomers would lack a great deal of important information.

Now boost the temperature to 1 million degrees F (about half a million degrees C) and out pour x rays, and at higher temperatures yet, gamma rays. Thermonuclear reactions at the center of the sun, at 27 million degrees F (15 million degrees C), produce gamma rays that are reduced in energy by their passage through the cooler solar envelope. What begins as a single gamma

ray photon in the sun's core emerges at the surface as thousands of visible-light photons. Our sun appears relatively quiescent when viewed in visible light. But an examination in x rays reveals spectacular loops of gas heated to millions of degrees by solar magnetism. Without this knowledge, astronomers can make no sense of the solar wind, solar activity, and their effects on Earth.

X rays and gamma rays also originate from exploded stars. X rays are produced in enormously hot gas that lies within clusters of galaxies and by matter falling into black holes. Gamma rays seem to burst forth from collapsing supermassive stars (or even colliding neutron stars) in distant galaxies.

Our century has seen the entire electromagnetic spectrum opened for business. With new detectors, new satellites, and imaginative plans for future exploration, astronomical objects will yield up their various secrets at an ever-accelerating pace, allowing a fuller understanding of our universe. **A**

---

*James B. Kaler studies stellar evolution at the University of Illinois. He is the author of many books, the most recent of which is Cosmic Clouds. He describes a different star each week at [www.astro.uiuc.edu/~kaler/sow/sow.html](http://www.astro.uiuc.edu/~kaler/sow/sow.html).*