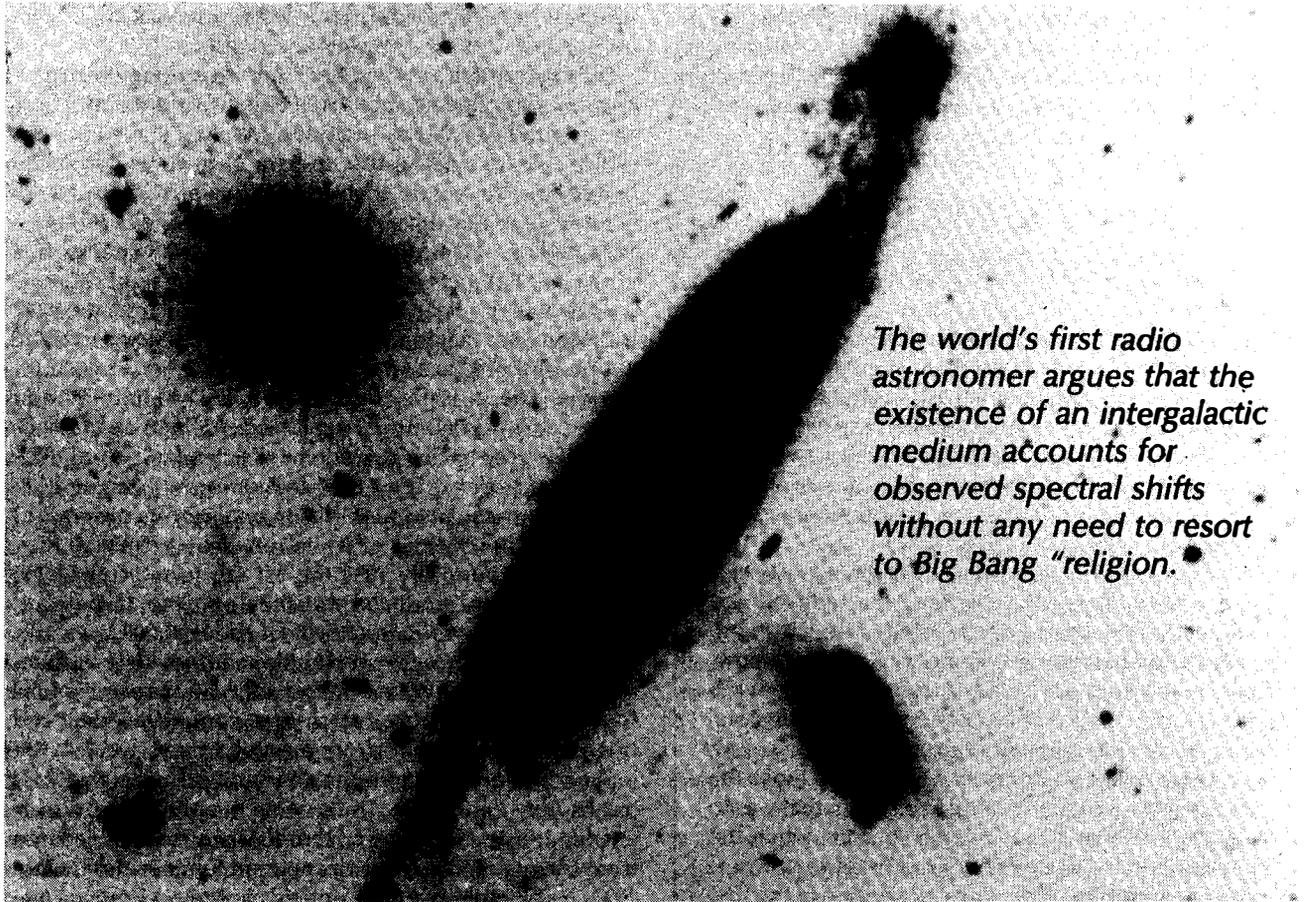


# The Big Bang Is Bunk



*The world's first radio astronomer argues that the existence of an intergalactic medium accounts for observed spectral shifts without any need to resort to Big Bang "religion."*

by Grote Reber

Halton Arp

**T**he whole business of Big Bang Creationism is very shaky and based upon dubious assumptions. The underlying questions have become lost in the sands of time and are no longer taught, even in astronomy schools. Lately, Big Bang Creationists have far overplayed their hand, making themselves look like fools. However, because the old-line scientific trade journals are also dominated by reactionary fuddy-duddies, there is not much opportunity for readers to examine the underlying issues. Accordingly, it is appropriate that these matters be brought forward in a popular scientific magazine. Everyone can examine them at leisure, and I'll be pleased to receive direct comments from readers.\*

Where did this Big Bang idea come from?

In 1842, Johann Christian Doppler, a Viennese mathematical physicist, predicted that if a source of radiating waves

and an observer of those waves were in relative motion, the wavelength at the observer would change. When they are approaching, the wavelength would shorten; when they are separating, the wavelength would lengthen.

This was confirmed experimentally for sound by the Dutch scientist Buys Ballot in 1845. He used whistles on steam locomotives, the fastest device available in that day. Seventy-three years later, at age six, I independently discovered the same phenomenon, also using whistles on railway locomotives. In retrospect, I had a very clear idea of how it was, but no idea of what it was, much less why. It created a schism between mother and small son; mother was no physicist. (Such is a good story in its own right.)

Three examples of the Doppler phenomenon are shown for the case of light waves (Figure 3). In (a), the double stars have a substantial range of orbital period from days to years, a randomness independent of the distance from the source to the observer. On the average, the double stars at large distance are not rotating any faster or slower than similar pairs nearby. In (b), the rotation of the Sun will be the same whether viewed from Mercury, Earth, Pluto, Alpha Centauri, or the Andromeda Nebula. In (c), the Earth tags along

*Does the extremely thin, hot gas between galaxies—the intergalactic medium—account for increases in redshift observed in increasingly distant galaxies? The two galaxies shown here are NGC 5296 and 5297.*

with motion of the Sun in respect to other stars. Each star has its own specific motion, and this randomness averages out. The distant stars are not approaching or receding from the observer any faster or slower than nearby stars.

In these and other examples, the Doppler phenomenon consists of equal and opposite spectral shifts—toward the red when recession lengthens the observed wavelength, and toward the blue when approach shortens it. These shifts are separated by a null—a point at which there is no shift—

## How the Big Bang Got Its Start

The Big Bang theory of the universe arises from one of the possible solutions to the field equation in Einstein's theory of general relativity. Einstein's own solution specified a universe neither expanding nor contracting. Sir Arthur Eddington, the British astronomer who promoted Einstein's theory, was also an advocate for a solution that required the universe to expand or contract.

After the initial mathematical work on relativity theory had been done, the Big Bang theory itself was invented by a Belgian priest, Georges Lemaître, improved upon by an avowed atheist, George Gamow, and is now all but universally accepted by those who hold advanced degrees in astronomy and the physical sciences, despite its obvious absurdity.

Lemaître posited a primeval egg about 30 times the volume of the Sun, containing everything that was to form the universe. The universe "began" when the egg exploded for unexplained reasons. The universe has been expanding ever since, according to the theory, and will either continue to expand and cool forever, or else its expansion will eventually be overtaken by self-gravitation. In the latter case, it will collapse upon itself again.

Gamow argued that the egg was made of neutrons and their decay products—a mixture of neutrons, protons, electrons, and radiation—being too hot for helium nuclei to form. When the bang occurred, the mess cooled, allowing the formation of helium nuclei. The relative abundance of hydrogen and helium estimated for the universe—11 to 1—is found to be that expected from Gamow's theory.

The theory also predicts that the explosion should have left behind a universal background radiation. Since a background microwave radiation at 2.7 K has undeniably been found, Big Bangers claim that this must be the predicted radiation.

Hubble's Law was seized upon by the advocates of Big Bang cosmology as supposed proof that the universe is expanding. Some scientists who reject the Big Bang nonetheless think the evidence for the expansion of the universe is strong.

—David Cherry

and are independent of distance from the observer. The Doppler phenomenon has been used since the last quarter of the 19th century to study double stars, motions of the Sun, and rotation of celestial objects. There are always equal and opposite redshifts and blueshifts separated by null. The shifts are very small, from a few to a few tens of kilometers per second, and are independent of distance.

During the 18th century, the French astronomer Charles Messier compiled a list of these objects, and the numbers he assigned to galaxies (noted as M1, M2, and so on) are still in use today. The first spectra of galaxies—or *white nebulae* as they were then called—were made by Vesto Slipher at the Lick Observatory near San Jose, California, in 1912 (Slipher 1914). By 1925, the list of such spectra had grown to 41 objects. The unexpected finding was that spectra of white nebulae showed *only* redshifts. These were 0.2 to 0.6 percent, far larger than any other celestial object. The nature of these fuzzy patches was a matter of conjecture. George Ellery Hale, director of the Mount Wilson Observatory in California, organized a debate on this subject before the National Academy of Sciences in April 1920, but lack of evidence prevented any conclusion. During 1928, Milton Humason at Mount Wilson undertook a program of measuring the spectra of white nebulae. Again *only* redshifts were found. By 1935 the list ran to more than 150 nebulae. Some produced redshifts of 13 to 14 percent, equivalent of a *symbolic* velocity of about 40,000 km/sec.

During this time, Edwin Hubble, another staff astronomer at the Mount Wilson Observatory, was searching for Cepheid variable stars, stars that continually dim and brighten with a period from a few hours to weeks. The longer the period of a Cepheid variable star, the greater is its absolute luminosity. Thus, when the period and apparent luminosity are known, the distance may be secured from the ratio of absolute to apparent luminosities. In late 1924, Hubble discovered Cepheids in the Andromeda Nebula (M31), which demonstrated that M31 is at a vast distance, far outside our own Milky Way. The white nebulae are separate stellar systems comparable in size to our own galaxy. This discovery was sufficiently newsworthy to rate a story on page 6 of the *New York Times*, Nov. 23, 1924.

Close collaboration disclosed that the redshifts measured by Humason were approximately proportional to distance as measured by Hubble. According to Hubble, "Humason assembled spectra of nebulae and I attempted to estimate distances—Humason's adventures were spectacular" (Hubble 1953). Humason is a name to remember.

### Redshifts and Irrationality

From the very beginning, it was clear the spectral shifts were not the Doppler phenomenon for two reasons: First, as astronomers 50 to 60 years ago realized, there were no blueshifts; second, the shifts were proportional to distance. As Humason writes in 1931, "It is not at all certain the large redshifts observed in the spectra are to be interpreted as Doppler effect." Hubble in 1937 calls it a "sheer assumption" (p. 54). R.H. Baker states in 1930, "The significance of these remarkable 'apparent' velocities is left open for the present." Fritz Zwicky in 1957 writes, "I refer here to the origin and to the supposed expansion of the universe. . ."

(p. 27). Hale in 1931 states that "Other physical causes may explain a large part of the shift of the spectral lines." Even as late as 1962, Otto Struve has misgivings: "But are we sure that nothing ever happens to a ray of light even if it travels over distances of 10 billion light years?"

During the 1930s, the cause of redshifts was still an open question. Big Bang cosmology had not yet become enshrined as a creed of religious dogma, as some cosmologists even admit. For example Peter Goldreich, an enthusiastic Big Bang supporter, writes in 1976, "Although cosmologists like to think of their subject as a science, it has much in common with religion." During recent years, Big Bang cosmology has become a form of creationism, with its creation date being 5 billion to 20 billion years ago, depending on the preference of the devotee.

In spite of all the evidence against it, the assumption was made that the spectral shifts were Doppler shifts. Intelligent, rational, educated people do not make irrational assumptions; there must be some reason for this peculiar mental aberration. There is: It is an earlier background assumption, rarely mentioned, or even implied, that intergalactic space is empty, a void. Once that assumption is made, it removes any possibility of light interacting with an intergalactic medium. There is nothing left except relative motion.

Now, this background assumption is very bad and indicates a lack of knowledge of elementary physics. Suppose, once upon a time, intergalactic space was an empty void. Material would immediately begin expanding into it. The only way this process could be stopped would be for everything to have zero kinetic energy at absolute zero. Clearly, this is not reality; however, the assumption was made. Again, rational people do not make ridiculous assumptions; there must be some reason. In this case, the reason is simply that because astronomers could not find any intergalactic material, none must exist.

There were dissenters from this ignorant conceit. According to Hubble, "The fact that we have not been able to detect any matter in internebular space does not necessarily exclude its existence, even in considerable quantity" (1937, p. 20). And Zwicky has some acid comments about people who think intergalactic space is empty (1957, p. 25).

It is clear that I have had little use for Big Bang Creationism, looking upon it as ignorant humbug and voodoo. However, I urge readers not to be too hard on astronomers; they are ordinary people immersed in their own special interests, conceits, and prejudices.

### My Entry into the Fray

How did I get mixed up in all this? Purely by accident through the back door.

By the early 1950s, radio astronomy had become respectable and even popular. The trend was to look for emission of ever shorter wavelengths, and the science seemed to be in good hands. I decided to try for observations at longer wavelengths. Since these long waves must get through the ionosphere, the best locations for observing will be where the electron density is lowest. Examination of a vast amount of ionospheric data disclosed that there are two bands of about 35° latitude radius centered on north and south mag-

netic poles that meet this requirement. The very best place for observing will be where the band is at the lowest geographic latitude, giving access to the sky as close as possible to the celestial equator and then up to the celestial pole.

These places are (in the north) Georgian Bay in south-eastern Ontario, Canada, and (in the south) southern Tasmania, Australia. The former looks out on the northern sky and the periphery of the Milky Way, a relatively uninteresting region. The latter looks out on the southern sky including the galactic center, the Magellanic Clouds, and so on. This, and adventure in a foreign country made me choose the southern one as a start.

I arrived in Sydney, Australia, aboard the *Orion* on Nov. 1, 1954. During 1955-1960, I made preliminary observations to get the feel of things. Cosmic static was getting through the ionosphere and was of unprecedented strength. All this was very encouraging. Accordingly, I decided to set up properly with an antenna system that could be called a hectometer radio telescope, for observations at a wavelength of 100 meters. During 1961 and 1962, I constructed an elaborate array consisting of 192 dipoles placed atop 128 wooden poles 80 feet long set 10 feet into the ground. The overall size was 3,520 feet in diameter, providing a pick-up area of 223 acres. The beam could be adjusted to any position in the north-zenith-south plane from south celestial pole to celestial equator. East-west scanning was provided by rotation of the Earth. At 2,085 kilohertz (khz) the beam was 7.1° in diameter at zenith. I made observations continuously from Feb. 4, 1963, through May 10, 1967 (Reber 1968, 1977, 1986).

At meter wavelengths and shorter, the radio sky is much like the optical night sky. There is a dark background with small sources sprinkled over it. The Milky Way shows up as a bright band across the background. I rather expected something similar to this at hectometer waves; however, the situation was completely different and quite unexpected. At 2,085 khz the sky is similar to the daytime optical sky. It has a high intensity with maximum intensity at the galactic poles. There are assorted low-intensity patches, like optically thick clouds scattered along the Milky Way, which absorb the background radiation. The lowest intensity is at the galactic center. These clouds are probably low-temperature plasma, rather similar to the ionosphere here on Earth.

The high-intensity background lies definitely outside the Milky Way as shown by absorption patches. Also, assorted known radio sources such as in Centaurus, Fornax, Pictor, and so forth, could be found. Accordingly, the background is at some great distance. The Small Magellanic Cloud seemed to have a small absorption dip. This suggests the presence of low-temperature plasma in the Large Magellanic Cloud similar to the Milky Way. These observations agree with optical findings. Further investigation suggested the background becomes opaque just beyond the source Pictor at 330 megaparsec, or a billion light-years.

### Source of High-Intensity Background

What is the source of the background radiowaves measured at 144 meters? A reasonable guess is that intergalactic space is filled with free electrons and protons. About one pair per 100 cubic centimeters will be adequate. The kinetic

# Grote Reber: Pioneer of Radio Astronomy

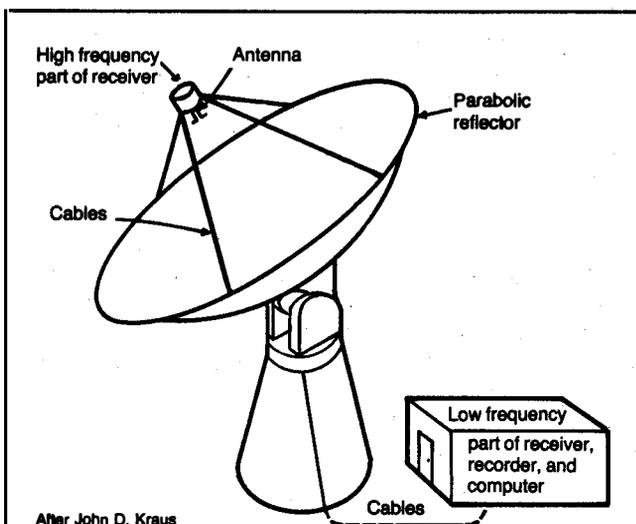


Figure 1

## HOW A RADIO TELESCOPE WORKS

The simplest radio telescope is a parabolic dish and an antenna, in combination with a radio receiver. Radiowaves are reflected by the dish, whose parabolic shape focuses them on a single point above the center of the dish, where the antenna is placed. The receiver can be tuned to the wavelength the observer chooses. To produce a radio brightness map of part of the sky for a given wavelength, the dish must cover the area by scanning it, in the same way that the eye covers a page by reading it line by line.

Modern radio telescopes use computers to reassemble the information into a two-dimensional map or picture.

Grote Reber, a radio engineer and ham radio enthusiast, became interested in radiowaves from space in 1932, when Karl Jansky at Bell Laboratories first discovered their existence.

Reber wrote to leading astronomers, offering them his expertise in radio electronics so that radiowaves from space could be systematically studied. No astronomer would take up his offer; they could not imagine any astrophysical mechanism by which such radio signals could be generated. Perhaps it was just an experimental error or even a hoax, some astronomers told him. At the same time, most radio engineers were indifferent to the problem. As a result, Reber became, on his own, the first—and for 10 years the world's only—radio astronomer.

Reber began by designing a parabolic dish to gather the radiowaves and a radio receiver to put at the dish's focal point (Figure 1 shows a basic radio telescope design). When he solicited bids for construction, Reber found the cost far beyond his reach, so he built it himself in his yard in Wheaton, Illinois, on weekends. He was not the first to employ such a device. John Kraus, then at the University of Michigan, was also following Jansky's work, and Kraus used a searchlight reflector in 1933 in an attempt to detect radiowaves from the Sun at 15 mm wavelength. Kraus's experiment was unsuccessful, however, for want of sufficient sensitivity in the receiver.

Reber was determined to map the spatial distribution of radio signals on the sky, while also discovering how it varied by wavelength. The reflector antenna design allowed for the reception of different wavelengths by merely changing the receiver at the focus. To get the maximum resolution, the parabolic dish should be as big as possible, while the wavelength should be as short as possible. If Planck's law of thermal emission applied,

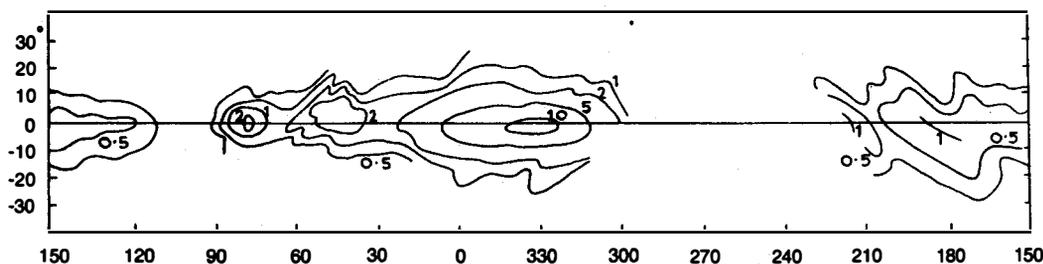


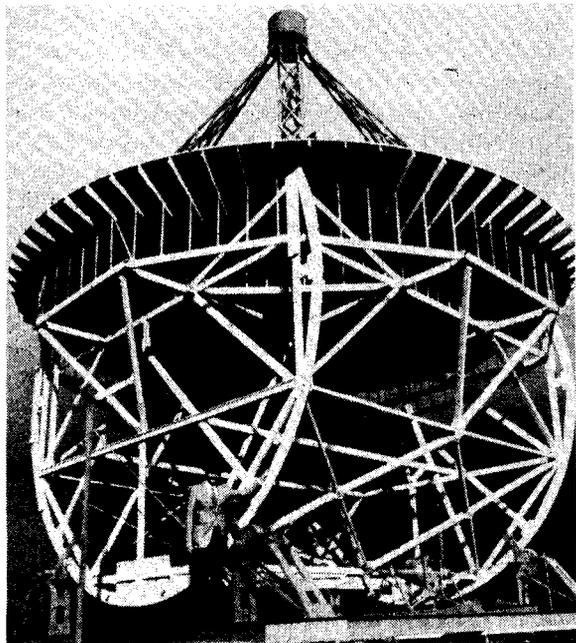
Figure 2

## REBER'S 1944 MAP OF THE GALACTIC CENTER

Reber made the first radio maps of the Milky Way—the equatorial plane of our galaxy. This is his 1944 contour map of the strength of radio emission in the galactic plane at a wavelength of 1.87 meters. The contours are denoted in units of watts per square meter per circular degree per megacycle of bandwidth.

The peak intensity, enclosed in the contour for 10 units (at center), is the galactic center in the constellation Sagittarius.

Source: Reber, "Cosmic Static," *Astrophysical Journal* Nov. 1944, p. 279.



Reber poses with his first radio telescope. Originally built in 1937 in his yard in Wheaton, Ill., its home today is the National Radio Astronomy Observatory at Green Bank, W. Va., where this picture was taken in 1988.

the shorter wavelengths would also be stronger.

At a cost of \$1,300, Reber built a 31-foot-diameter radio telescope during the summer of 1937. In the initial observations, he sought radio emissions from the Sun, Moon, planets, and the brightest stars—first at 9.1 cm (3,300 megacycles) and then at 33 cm (910 megacycles)—but none was a source of radio emission. Then in 1939, he moved to 1.87 m (160 megacycles) and at last detected radio emission from sources that were concentrated in the Milky Way. When the Earth's rotation caused his scope to pass across the Milky Way, Reber would read off the intensity of the radiowaves on a microammeter at 1-minute intervals.

Because of interference from passing automobiles, Reber had to confine his observing to the period of minimum traffic—from midnight to 6 AM. He slept between supper and midnight each night, observed until 6 AM, and then droyetowork at the Stewart-Warner Company, where he designed radio receivers.

Reber reported his first findings in a paper he submitted to the *Astrophysical Journal* in 1940. The editor could find no reviewer who would defend the paper, and therefore, according to the rules of scientific publishing, he could have rejected it. Instead, he decided to publish a possibly erroneous paper rather than risk rejecting what might be groundbreaking work.

Reber not only produced the first radio maps of the galactic plane (Figure 2), but also correctly identified the mechanism of radio emission as encounters between free electrons and positive hydrogen ions in interstellar space.

energy of electrons is equal to an apparent temperature of  $3.5 \times 10^6$  degrees. (The nomenclature is bad because the electron will have a different temperature at every wavelength.) The electrons lose their energy by encounters with protons, which I call *free-free transition*. Others refer to it as *bremstrahlung* or braking radiation (Figure 4). The chances of a close encounter with considerable loss of energy is small. Conversely, the chance of a distant encounter with trivial loss of energy is large. Thus, the spectral distribution will have an inverse intensity-frequency relation. Such is the observed case.

The universe has been around a long time. If the free electrons are continuously losing energy by free-free transitions, their kinetic energy must be replenished from somewhere. This worried me, and then I had an idea: Perhaps the light photons traveling through intergalactic space somehow lose a bit of their energy to electrons. The desired mechanism is a Compton transition. Each time a photon approaches an electron, the photon transfers some of its

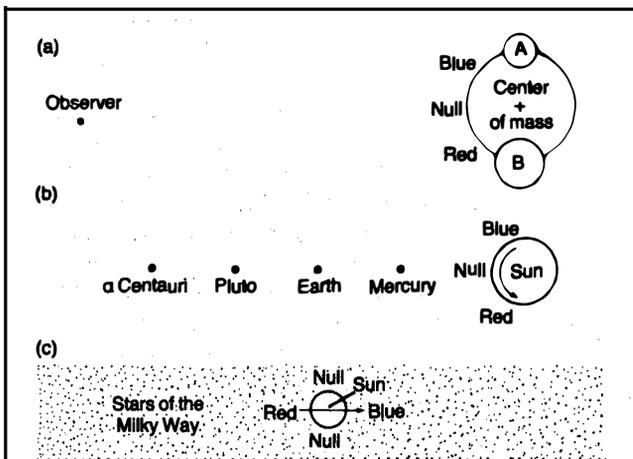


Figure 3  
THE DOPPLER PHENOMENON

In (a), two stars are in orbit about a common center of mass. The spectrum of star A, while it is approaching the observer, is shifted toward the blue. Meanwhile the spectrum of star B, while it is receding from the observer, is shifted toward the red. At the moment when there is no receding or approaching motion with respect to the observer, the spectra will not be shifted.

In (b), the spectrum of light reaching the observer from an approaching limb of the Sun will be blueshifted, while the spectrum from a receding limb will be redshifted. The shifts will be the same, regardless of whether the observer is sited on Mercury, Earth, Alpha Centauri, or anywhere else.

The motion of the observer rather than the motion of the object is illustrated in (c). The small proper motion of the Sun with respect to the stars of its neighborhood is shown. The observer on the Sun or any of its planets participates in this motion, seeing blueshifted spectra for all stars in the forward direction, and redshifted spectra for all stars in the aft direction.

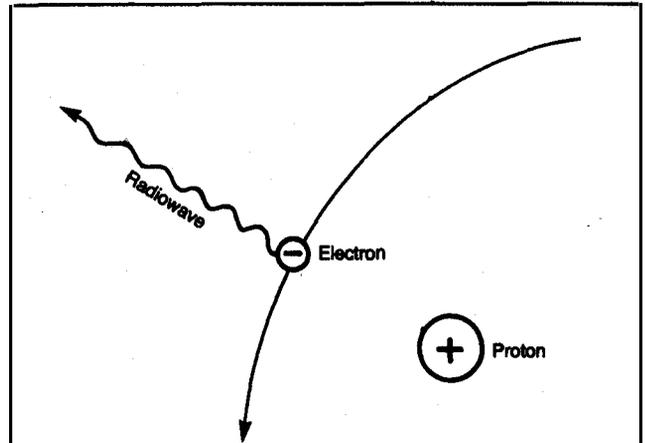
energy to the electron and is slightly deflected in its path, a situation shown in Figure 5. The energy loss will be proportional to the number of encounters, and these in turn are proportional to distance. The energy of a photon is  $E = \hbar c/\lambda$ , where  $\hbar$  is Planck's constant,  $c$  is the velocity of light, and  $\lambda$  is wavelength. Since  $\hbar$  and  $c$  are fixed,  $\lambda$  must increase as  $E$  decreases. Accordingly, the shift  $\Delta\lambda/\lambda$  will be proportional to distance. This is exactly what the optical observations tell us. Clearly, the spectral shifts have nothing to do with relative motion. Hubble comments, "Light may lose energy during its journey through space, but if so, we do not yet know how the energy loss can be explained" (1937, p. 30).

The size of the scatter radius in Figure 5 will be on the order of 0.01 arc second at 330 megaparsec, and increases with distance. This may well account for the increasingly fuzzy pictures we obtain of increasingly distant objects.

Another matter is worthy of consideration. As light photons travel through the maze of electrons in intergalactic space, some will lose more than average energy and some will lose less than average. Accordingly, if we start with all photons having equal energy, a monochromatic line in a spectrum will broaden as distance increases. But nothing is known about this subject.

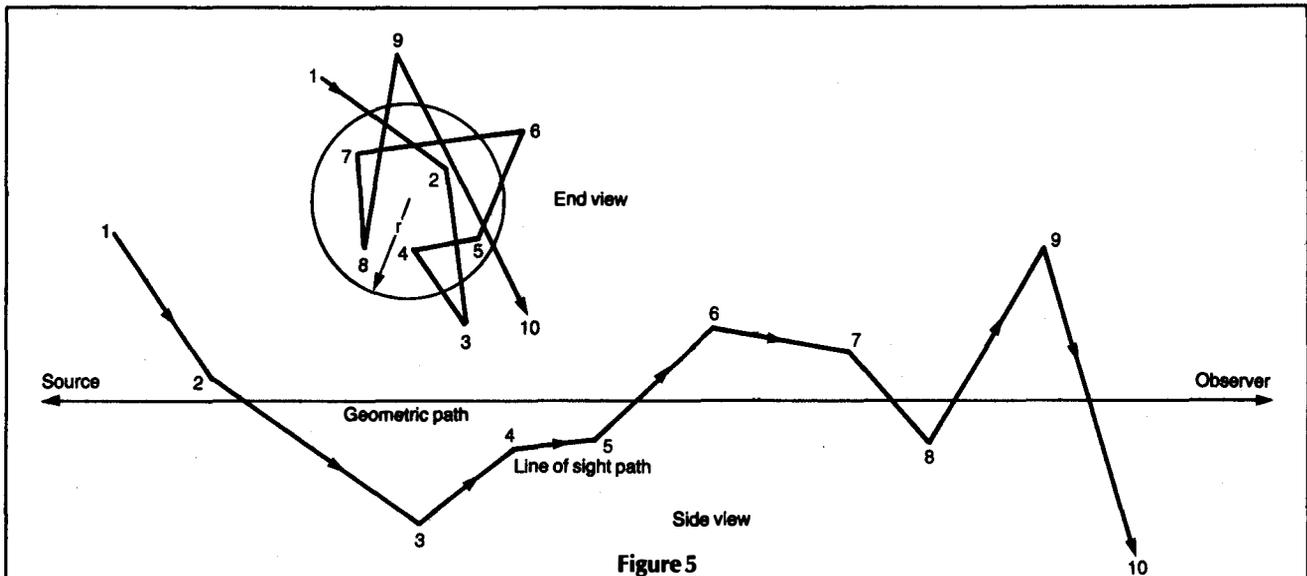
#### What Hubble Really Said

Edwin Hubble is usually portrayed as a promoter of the expanding universe, but evidence indicates quite the op-



**Figure 4**  
**BRAKING RADIATION AND THE INTERGALACTIC BACKGROUND**

*What is the source of intergalactic background radiation that becomes "bright" at long wavelengths? Interactions between free protons and free electrons, called bremsstrahlung or braking radiation, would produce the observed background. When a free electron passes close to a free proton, the electron emits electromagnetic energy. The closer the encounter, the shorter the wavelength of the emitted energy.*



**Figure 5**  
**DO COMPTON TRANSITIONS EXPLAIN REDSHIFTS?**

*If the free electrons in intergalactic space are continuously losing energy through braking radiation (Figure 4), their energy must be replenished somehow. Perhaps the light photons traveling through space are the source, transferring energy in what is known as the Compton transition.*

*When a photon approaches an electron, the photon transfers energy to it and the photon is slightly deflected in its path. The photon's energy loss will be proportional to the number of encounters; hence, the greater the distance of the source, the greater the energy loss or redshift. Less energetic photons are those with longer (redder) wavelengths, and more energetic ones are those with shorter (bluer) wavelengths.*

*Shown here is the line-of-sight path (end view and side view) of a photon undergoing 10 encounters with electrons in intergalactic space, and the net or geometric path of the same photon.*

posite. I met him only once for a few minutes one morning in January 1952. I was on my way to Hawaii and located him in his office in Pasadena, Calif. My mission was to check up on my mother: Could Hubble remember the name of his seventh and eighth grade teacher in Wheaton, Illinois? "Yes," he said, "it was Miss Grote." Apparently my mother made an impression on him. (I cannot remember the names of my teachers in those grades.)

At that time I had no interest in cosmology. However, being a guest, I thought it appropriate to talk about something interesting to him: Hubble seemed only mildly interested and appeared to feel that everything possible to say had already been said many times over. Furthermore, if future progress were to be made, it would require some new and different kind of evidence. Pursuing existing techniques would merely lead farther down a dead-end road. I asked him what kind of new and different observations should be made, but he had no suggestion to offer (Reber 1977, p. 5).

Some years later I stumbled onto a letter Robert A. Millikan wrote to the astronomer H.S. Shelton on May 15, 1952. Millikan, who measured the charge of the electron, was a close associate of Hubble. Millikan says: "Dr. Hubble never committed himself to the theory of the expanding universe. . . . Personally I should agree with you that this hypothesis [Compton collisions] is more simple and less irrational for all of us."

Now let us see what Hubble says himself:

The disturbing features are all introduced by the recession factor, by the assumption that redshifts are velocity shifts. The departure from linear law of redshifts, the departure from uniform distribution, the curvature necessary to restore homogeneity, the excess material demanded by the curvature; each of these is merely the recession factor in another form. These elements identify a unique model among the array of possible expanding worlds, and, in this model, the restriction in time-scale, the limitation of the spatial dimensions, the amount of unobserved material, is each equivalent to the recession factor.

On the other hand, if the recession-factor is dropped, if redshifts are not primarily velocity shifts, the picture is simple and plausible. There is no evidence of expansion and no restriction of time-scale, no trace of spatial curvature and no limitations of spatial dimensions (1937, p. 63).

Hubble concludes, "We seem to face, as once before in the days of Copernicus, a choice between a small finite universe, and a universe indefinitely large plus a new principle of nature" (p. 66).

I submit that Hubble was looking for this principle of *tired light*. A hundred years from now, people will look back on the Big Bang Creationists and their antics with laughter, much as we laugh at those who argued over how many angels can dance on the head of a pin!

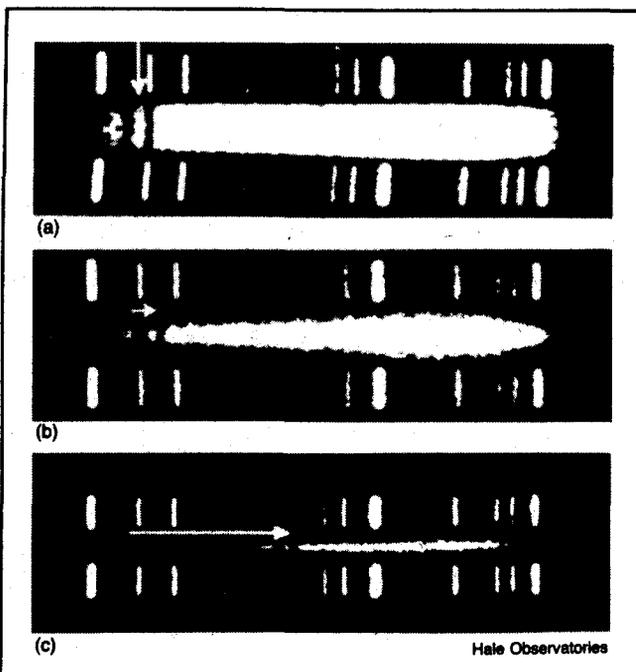
*Astronomer Grote Reber, 77, observes and writes in Tasmania.*

## References

- R.H. Baker, 1930. *Astronomy*, Urbana, Ill.: University of Illinois Press. 1st ed., 1930, p. 497; also 3rd ed., 1947, p. 284.
- P. Goldreich, 1976. *Focus on the Stars*, New York: Shakespeare Head Press, p. 217.
- G.E. Hale, 1931. *Signals from the Stars*, New York: Scribners, p. 130.
- E. Hubble, 1937. *The Observational Approach to Cosmology*, Oxford University Press.
- \_\_\_\_\_, 1953. "The Law of Redshifts," *Monthly Notices of the Royal Astronomical Society*, 113:659.
- M. Humason, 1931. "Apparent Velocity-shifts in the Spectra of Faint Nebulae," *Astrophysical Journal*, 74:35-42.
- G. Reber, 1968. "Cosmic Static at 144 Meters Wavelength," *Journal of the Franklin Institute*, 285:1-12.
- \_\_\_\_\_, 1977. "Endless Boundless Stable Universe," University of Tasmania (Hobart) Occasional Paper No. 9.
- \_\_\_\_\_, 1986. "Intergalactic Plasma," *IEEE Transactions on Plasma Physics*, PS-14:678-682 (Dec. 1986).
- V.M. Slipher, 1914. "The Radial Velocity of the Andromeda Nebula," *Lowell Observatory Bulletin* No. 58.
- H.S. Shelton, 1953-54. "The Red Shift in Spectra of Distant Nebulae," *Observatory*, April 1953, p. 84; Aug. 1953, p. 159; Dec. 1953, p. 243; Aug. 1954, p. 169. See p. 171 of last item.
- O. Struve, 1962. *The Universe*, Cambridge, Mass.: MIT Press, p. 151.
- F. Zwicky, 1957. *Morphological Astronomy*, Berlin: Springer-Verlag, p. 27.

## Notes

- \* Readers may write to Grote Reber in care of *21st Century* or at General Delivery, Bothwell, Tasmania, Australia 7030.



**Figure 6**  
**REDSHIFTED SPECTRA OF GALAXIES**  
**AT INCREASING DISTANCES**

The calcium H and K emission lines of a galaxy, indicated by the vertical arrow in (a), are recognizable in each of the spectra—but are shifted increasingly toward the red as the galaxy's distance increases (see horizontal arrows). The spectrum of galaxy NGC 221 at 2.6 megaparsecs (Mpc) distance is shown in (a). Galaxy NGC 4473 at 28.8 Mpc is shown in (b); and a galaxy in the Gemini cluster at 287.5 Mpc is shown in (c). One megaparsec is 3.26 million light years.