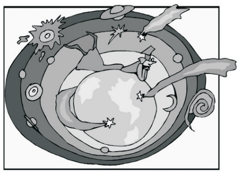
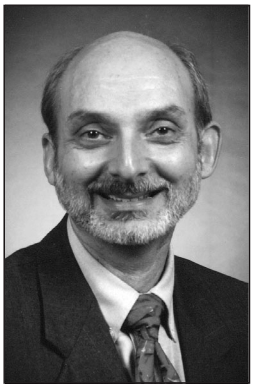


The Thrice-Supported Big Bang

Perry G. Phillips



Perry G. Phillips

"… A threefold cord is not quickly broken" —Ecclesiastes 4:12.

One cannot dismiss the Big Bang as "just a theory." Various lines of evidence confirm the "hot Big Bang" as the best model for the origin of the universe. The most widely known piece of evidence is Hubble's Law (galaxy redshifts), but the universal abundances of light elements and the cosmic microwave background radiation add convincing support to the hot Big Bang model. This paper discusses these three lines of evidence with emphasis on the last two.

Theological implications of the Big Bang are also discussed. Among ancient Near Eastern cosmologies, only the Bible presents the universe as having a beginning ex nihilo. Two historic alternatives to the Big Bang that avoid a beginning are presented and rejected. Finally, Gentry and Humphreys have proposed young-earth creationist models contrary to the Big Bang. We find their galactocentric cosmologies fail scientific and theological scrutiny.

The Big Bang is not "merely a theory." A number of cosmic observables are naturally explained only by Big Bang cosmology.

The hot Big Bang is widely accepted as the standard explanation for the origin of the universe. According to this model, the universe began in an unimaginably hot, dense state that started to expand. In time, it cooled to the point where particles and atoms formed. Eventually, gravity organized this matter into galaxies and associated objects we observe today.

The Big Bang is not "merely a theory." A number of cosmic observables are naturally explained only by Big Bang cosmology. These observables are Hubble's Law (galaxy redshifts), the ratio of the abundances of light elements to hydrogen, and the cosmic microwave background radiation. These key pieces of evidence form the threefold cord of support for the Big Bang.

This article serves as an introduction and/or a review for those who have heard about the Big Bang but who have not had time to investigate supporting evidence for its validity.[1] In light of this evidence, we will see that opposing theories to the Big Bang—the steady state theory, oscillating universes, and recent young-earth proposals—lack scientific credibility. We also discuss theological implications of Big Bang cosmology.

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First Key Evidence: Hubble's Law and the Expansion of the Universe

Of all evidence in support of the Big Bang, Hubble's Law—that distant galaxies are receding from us and that their recession speeds increase linearly with distance—is probably the best known. For decades, Hubble's Law was the foundational experimental evidence for Big Bang cosmology. Although this paper concentrates on the light element abundances and the cosmic microwave background radiation, completeness warrants a summary of Hubble's Law.

Until 1929, astronomers were convinced that the cosmos as a whole was static. They believed that the universe was infinite in extent with no beginning and no end. Stars and galaxies came and went, but the universe looked basically the same from all locations for all time. No one expected a dynamic universe that changed size with time.

Suspicions that the universe might not be static were first raised in the 1920s by Georges Lemaître, Willem de Sitter, and Alexander Friedmann. These three formulated cosmological models that showed that a static universe was impossible. They based their models upon Albert Einstein's equations of General Relativity, which he developed in 1916.

To the discomfiture of many astronomers, most of their models indicated that the universe had a beginning! Before the work of Lemaître, de Sitter, and Friedmann, Einstein himself was aware that his equations led to non-static models, so he modified his equations with a term known as Λ in order to keep the universe static. Even with Λ, however, solutions for universes that expand with time—implying a beginning—were soon found. Einstein ignored these solutions until 1929 when Edwin Hubble published his famous observations showing that the universe is expanding.[2]

Hubble showed that the speed of recession of a distant galaxy is proportional to its distance from earth. That is, the more distant the galaxy, the faster it is receding.[3] This observation confirmed the work of Lemaître, de Sitter, and Friedmann, and today remains one of the key evidences in favor of the Big Bang.

Second Key Evidence: Abundances of Light Elements

The universe has an interesting chemistry; about 25% of the mass of atoms is helium and about one out of every 30,000 hydrogen atoms is deuterium. What accounts for these ratios, which are consistent on a cosmic scale? As we shall see, the Big Bang explains these universal abundances as a natural outcome of its early history.

In the 1940s, Ralph Alpher and Robert Hermann, in collaboration with George Gamow, realized that the early universe was hot enough to "cook" hydrogen into light elements, such as deuterium and helium.[4] To understand this process, however, we must first trace the thermal and the particle history of the universe for its first three minutes.

Planck Era

The study of the universe requires the application of general relativity theory—which deals with space, time, and gravity—and of quantum mechanics, which describes the interaction of particles and photons. Unfortunately, neither of these theories applies to the universe before it was 10^{-43} seconds old. Before this time, known as the *Planck Era*, the very fabric of space-time was too chaotic to be described by known physical laws.[5] Hence, our description of the universe begins 10^{-43} seconds after its creation.

The temperature of the universe at the end of the Planck Era was an inconceivable 1.4×10^{32} kelvins.[6] Only photons and neutrinos existed, for no stable particles could survive this high temperature.[7] The universe was not static; it began expanding and as it expanded, the temperature dropped.

Hadron Era

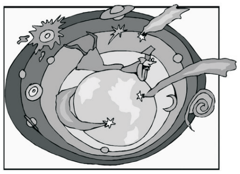
One millisecond after the Big Bang, the universe "cooled" to 10^{13} kelvins. At this temperature the energy of photons equals the rest energy of quarks (the constituents of protons, neutrons, and certain mesons). Equilibrium existed between the creation and the destruction of quarks[8] as long as the temperature remained above 10^{13} kelvins, but once the temperature dropped below 10^{13} kelvins, quarks ceased to be created.

The universe has an interesting chemistry; about 25% of the mass of atoms is helium and about one out of every 30,000 hydrogen atoms is deuterium. What accounts for these ratios, which are consistent on a cosmic scale?

Think of the formation of quarks as a *phase change*. This is similar to what happens when steam turns to liquid water. That is, water can exist as steam at high temperature, but once the temperature cools enough, steam condenses into liquid water. Similarly, when the temperature dropped below 10^{13} kelvins, quarks "condensed out." The photons also cooled to the point where they no longer had the energy to create new quarks.

Quarks and antiquarks have identical rest mass; hence, one expects equal numbers of both particles to have condensed out when the temperature dropped below 10^{13} kelvins. But quarks and antiquarks annihilate each other when they meet, so once quark/antiquark pairs ceased to be created, total annihilation should have taken place. Only photons—the result of quark/antiquark annihilation—should exist today. This, however, is not the case; antiquarks were wiped out, but a small number of quarks survived along with the photons.

There are presently about two billion photons for every *baryon* (protons and neutrons are baryons). Three quarks comprise one baryon; this means that for every two billion quark/antiquark annihilations, three quarks remained



along with two billion photons. (These photons, as we shall see, reveal the structure and the future history of the universe.)

So how do the light elements give evidence for the Big Bang? … If these abundances [of light elements] are observed throughout the cosmos, then there is very strong evidence that the Big Bang's early history matches theory.

Apparently, an asymmetry[9] in the creation and/or the destruction of quarks prevented complete annihilation, thereby allowing quarks to dominate over antiquarks, and subsequently for matter to dominate over antimatter.[10] The remaining quarks quickly formed protons and neutrons that later built up the light elements. First, however, the temperature had to drop; otherwise, the photons would break up the nuclei of the elements as fast as they formed.

Lepton Era

About one second after the Big Bang, the temperature fell to 10 billion kelvins. This is a critical temperature. Photons at this temperature have the same energy as the rest mass of an electron/positron pair. (The positron is the antiparticle of the electron.) This means that photons freely generated electrons and positrons as long as the temperature was above this threshold. As the temperature dropped, however, electrons and positrons ceased to be created. They subsequently annihilated, but just as in the case of quarks, an asymmetry in the process left an excess of electrons over positrons. Since the number of positive and negative charges is always in balance, the universe did not wind up with an excess charge. This means that the number of electrons matched the number of protons.

The combination of a proton and an electron produces a neutron (and an antineutrino), so neutrons formed as long as the temperature remained above 10 billion kelvins and a prodigious number of electrons were around. The drop in temperature below 10 billion kelvins stopped electron/positron pair production. Most electrons annihilated with positrons, thereby dropping their number considerably. Cessation of electron production quenched further production of neutrons, which at this time numbered about one neutron for every five protons.[11]

Nucleosynthesis

Protons and neutrons have a great affinity for each other, but at the end of the lepton era the temperature was too high for light elements to form through proton/neutron bonding. Any attempt to bond was thwarted by the photons, which had more than enough energy to destroy newly formed nuclei.

About one minute later, however, the temperature dropped to one billion kelvins. At this stage, protons and neutrons could bond without dissolution by energetic photons. In the next two minutes, neutrons and protons combined to form the light elements. When the neutrons were used up,[12] light element production ceased.

Table 1 summarizes the relevant factors leading to the production of light elements.

Light Elements and the Big Bang

So how do the light elements give evidence for the Big Bang? Given the constraints discussed above, one can calculate the primordial abundance of light elements. If these abundances are observed throughout the

Table 1. A Summary of the Early History of the Universe

Time since creation	Temperature of the universe (kelvins)	Major activity
< 10^{-43} second	> 10^{32}	*Planck Era*. Presently known physics cannot describe the universe at this time.
1 millisecond	Ten trillion (10^{13})	*Hadron Era*. Quarks and antiquarks form and annihilate leaving a residue of quarks to form protons and neutrons.
1 second	Ten billion (10^{10})	*Lepton Era*. Electrons and positrons form and annihilate leaving a residue of electrons. Neutron formation ceases.
1–3 minutes	One billion (10^{9})	*Nucleosynthesis*. Protons and neutrons combine to form light elements until neutrons are used up. Light element production ceases.

cosmos, then there is very strong evidence that the Big Bang's early history matches theory.

One observational problem exists with this scenario. Many physical processes in the universe destroy deuterium; only the Big Bang created deuterium.[13] Hence, the amount of deuterium has been decreasing ever since its formation. Helium, on the other hand, is produced by stars, so its abundance has increased throughout the universe's history. Astronomers must, therefore, hunt down localities of deuterium and helium in which their primordial abundances have not changed.

Fortunately, such locales exist. High resolution observations of the absorption spectra of quasars reveal the presence of deuterium. The absorption lines originate in very distant clouds that lie between the quasars and us. The light producing these spectra has traveled billions of years to reach us. As such, the spectra reflect the chemical composition of the clouds billions of years ago before substantial changes could take place in their original elemental abundances. The observations are difficult to make, for only one deuterium atom is expected for every 30,000 hydrogen atoms, but the observations confirm theoretical calculations.[14]

Quasar absorption spectra also reveal primordial helium. In addition, one can observe helium in the atmosphere of stars that have very small metal abundances. These stars are very old and formed from material from an early age of the universe.[15] From quasar absorption spectra and from low metal stars we find that the ratio of helium to hydrogen conforms to the theoretical prediction of 25% by mass.[16]

All in all, primordial helium and deuterium abundances throughout the universe match expectations, thus forming the second key evidence of support for the Big Bang.

Third Key Evidence: Cosmic Microwave Background Radiation

General Background Radiation

The universe emits microwave radiation in whatever direction one observes. This radiation has a specific temperature and spectrum. What is its origin? Can any theory of the universe naturally account for it?

Alpher, Hermann, and Gamow, who predicted the cosmic light element abundances, theorized in the late 1940s that a remnant of the brilliant radiation in the early stages of the Big Bang should pervade the universe today. Their theory first received observational support in 1965 by Arno Penzias and Robert Wilson, who won the Nobel Prize for their achievement. Other observations ensued, culminating in observations by the COBE satellite in the early 1990s.

The cosmic microwave background radiation (CMBR) has all the requisites of *blackbody radiation* (also called *Planck radiation*). This is the kind of radiation emitted by objects that are in thermal equilibrium with their surroundings. Blackbody radiation has a unique spectrum for any temperature, and this is precisely the kind of radiation predicted by Alpher, Hermann, and Gamow. COBE detected CMBR characteristic of an object emitting blackbody radiation at 2.73 kelvins (Figure 1). Only the Big Bang naturally accounts for the origin, spectrum, and present temperature of the CMBR, thereby further substantiating the Big Bang view of the cosmos.

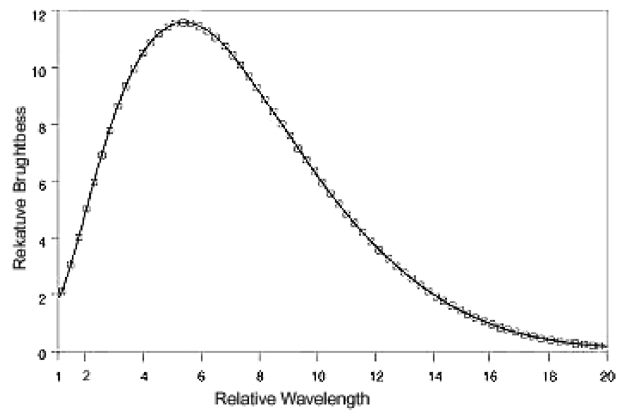


Figure 1. The solid curve represents the expected spectrum of blackbody radiation at a temperature of 2.73 kelvins. The COBE results, represented by the boxes, fit exactly on this curve, which is a pure blackbody spectrum as predicted by Alpher, Hermann, and Gamow. (NASA Goddard Space Flight Center and the COBE Science Working Group)

Anisotropies in the Background Radiation

Superimposed upon the blackbody radiation, COBE also found that the CMBR intensity varies slightly from place to place across the sky. Specifically, patches of sky about seven degrees in diameter (roughly 14 times the diameter of the moon) are alternately slightly warmer or cooler than the average 2.73 kelvins background (Figure 2). These differences, which depend on the direction of observation, are called *anisotropies*. The temperature between patches varies about one part in 10^5 from the mean background temperature.

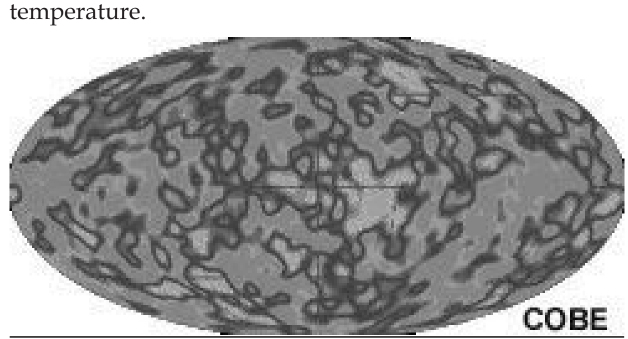
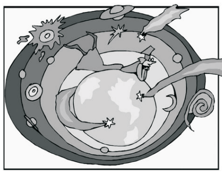


Figure 2. COBE anisotropy results. Various shades represent regions in space with slightly differing temperatures. (NASA Goddard Space Flight Center and the COBE Science Working Group)



What do the redshift, light element abundances, CMBR, dark matter, and dark energy have to do with the Big Bang? The answer is that only *the hot Big Bang unifies these disparate observations into a coherent whole. Other cosmologies can be contrived to mimic some observations, but they fail miserably at other points.*

Origin of the CMBR

Earlier we described the origin of quark/antiquark pairs and their eventual annihilation into photons, except for the few quarks that remained to form the baryons of today's universe. The photons emanating from the annihilation have become the CMBR. Of course, the expansion of the universe has highly redshifted the photons from the gamma ray to the microwave region of the spectrum.

We also described nucleosynthesis, which occurred at a temperature of about one billion degrees. At this temperature, the elements were *ionized*. Electrons could not bond with the nuclei to form neutral atoms. The atoms collided with such force that the electrons could not attach themselves to a single nucleus without being knocked away. Energetic photons also kept the electrons on the move through what is known as *Thompson scattering*. As such, the universe consisted of a mixture of protons and light element nuclei immersed in a sea of electrons and photons, thereby forming a *photon-baryon fluid*.

This condition lasted 380,000 years until the universe cooled to 3000 kelvins. At this temperature, neither collisions between atoms nor photons had enough energy to ionize the light elements to a great extent.[17] Electrons and nuclei formed neutral atoms. Since bound electrons do not interact with radiation as strongly as free electrons, the photons could now travel long distances unimpeded by the electrons. At this point, the radiation *decoupled* from the matter in the universe.

Photons from the *Decoupling Era* continue their flight through the cosmos to this day. These are the photons detected by COBE. The photon temperature, however, has decreased from 3000 kelvins to 2.73 kelvins because of the cooling effect of the universe's expansion.

As an aside, one does not require fancy equipment to detect the CMBR. It is possible to "see" it on a TV screen on a set that receives its signal from an antenna. Simply tune to a channel with no signal (where only "snow" appears). CMBR photons comprise a few percent of the snow. The picture will not win a prize, but it does show an echo of creation!

CMBR Anisotropies

We have explained the origin and the nature of the CMBR, but how did its anisotropies originate? To answer this question, we must examine the properties of the universe soon after the Planck Era.

At the end of the Planck Era, the size of the universe was only as large as the distance light could travel in 10^{-43} seconds, which is on the order of 10^{-33} centimeters. Newtonian physics does not work on this scale. *Quantum physics*, on the other hand, can be used to describe the behavior of the universe at this stage. One of the principles of quantum physics is that no collection of particles, photons, or energy distribution is entirely uniform. This means that quantum density fluctuations existed throughout the early universe.

Quantum physics (specifically, quantum field theory) also predicts that between 10^{-35} and 10^{-33} seconds after the Big Bang the size of the universe increased enormously, some 10^{58} to 10^{60} times. This phenomenon, called *inflation*,[18] was first proposed by Alan Guth around 1980. Inflation took quantum induced density fluctuations and made them enormous, increasing their size by the same factor that the universe expanded. These density variations persisted until the decoupling era. Denser regions were more compressed, so they were a bit warmer than their surroundings. Photons emitted from these regions, therefore, were warmer than photons emitted by cooler regions, and this temperature difference gives rise to the COBE anisotropies.

In a sense, COBE reveals pre-inflationary quantum fluctuations that have grown to cosmic proportions!

Acoustic Waves Anisotropies

Smaller angular-sized anisotropies than those measured by COBE overlie the CMBR. They arose from sound waves, or *acoustic waves*, which existed in the universe before the decoupling era. Acoustic waves also influenced the CMBR, and this influence can be detected today. These anisotropies argue strongly for the hot Big Bang, but before making this connection, we must understand how acoustic waves arose. We will also see how acoustic wave anisotropies provide information about the universe's geometric structure, baryon density, and the amounts of dark matter and dark energy.

Before the decoupling era, the universe was a mixture of particles and photons, and this mixture acted like a fluid in which acoustic waves originated. They arose as follows: Quantum fluctuations created regions of greater density, and the stronger gravitational attraction in the denser regions attempted to compress the associated matter. The photons, however, were not so easy to compress; they exerted an outward pressure through their interaction with the free electrons, and this made the region expand. Thus, a tug of war ensued between the gravitational attraction and the photon repulsion. As such, oscillations developed, thus setting up acoustic waves that traveled throughout the universe.

As an illustration of this effect, consider Figure 3. The two balls represent particles that are being drawn by gravity toward the bottom of the bowl. The spring represents photons. As gravity pulls the balls together, the spring joining them is compressed and begins to exert an opposing force. Eventually, the spring's repulsive force exceeds the attractive gravitational force and the balls begin to move apart, only to be pulled back together again by gravity. Just as an oscillation develops in the ball/spring system, so an oscillation arises in the photon-baryon fluid from the competition between gravitational attraction and photon repulsion.

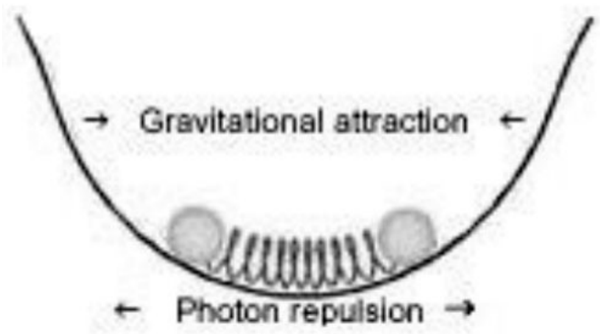


Figure 3. Illustration of gravitational attraction and photon repulsion that give rise to acoustic waves before the decoupling era. (Adapted from Wayne Hu, http://background.uchicago.edu/)

The contest between gravity and the photons continued until the decoupling era. At that time, free electrons became bound to form neutral atoms. Bound electrons do not scatter photons easily. The photons were now free to roam the universe, but they had a "memory" of the compressed and rarified regions from which they originated. Here's why: As the acoustic waves traveled through the universe, they alternately compressed and rarified the matter through which they passed. The compressed matter heated up, which in turn heated the photons interacting with hotter free electrons. At the moment of decoupling, the photons from the compressed regions were somewhat warmer than average, while those from the rarified regions were somewhat cooler. Since the photons no longer interacted with electrons, they traveled unimpeded from the time of decoupling to the present. The expansion of the universe has lowered their initial temperature difference to a few millionths of a kelvin, but they still carry a temperature imprint of the acoustic waves from what is called *the surface of last scattering*.[19]

A map of acoustic wave anisotropies appears in Figure 4. It is similar to the map from COBE, except that the scale of the anisotropies is on the order of one degree. (One degree is twice the angle subtended by the moon.) As we shall see, the angular scale of these anisotropies turns out to be one of the most accurate measures of the geometrical structure of the universe.

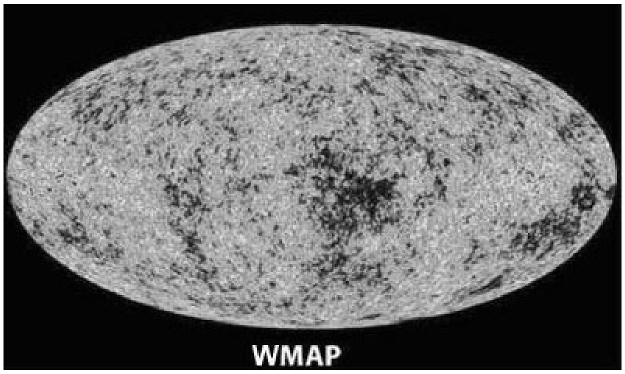


Figure 4. Composite map for the Wilkinson Microwave Anisotropy Probe (WMAP). WMAP displays finer detail than COBE. The angular separation of the anisotropies is on the order of one degree. The map reveals the minute temperature differences from the surface of last scattering. Light patches are warmer than dark ones. Compare these results to those of COBE in figure 2. (NASA/WMAP Science Team)

Geometry of the Universe

One question of supreme interest to cosmologists is whether the universe will expand forever or eventually collapse upon itself. The outcome depends on the average density of the universe.[20]

General relativity connects the geometry of the universe to its density. At the *critical density* (10^{-29} grams/cubic centimeter, or about five hydrogen atoms per cubic meter), the universe is *flat*. This means that if one were to draw a (very) large triangle across the universe—say hundreds of millions of light years on a side—the sum of its angles would be 180 degrees. This is what we expect when we draw a triangle on a flat sheet of paper. A flat universe is also called a *critical* universe.

On the other hand, if the density is greater than critical, the mutual gravitational force between all segments of the universe is able to "bend" the universe so its geometry resembles that of a sphere. On a sphere, the sum of the angles of a triangle adds up to more than 180 degrees. This kind of universe has *positive curvature* and is called *closed*.

Conversely, if the density is less than critical, the geometry resembles that of a saddle. The sum of the angles of a triangle drawn upon a saddle is less than 180 degrees. A saddle has *negative curvature*, and such a universe is called *open* (Figure 5).

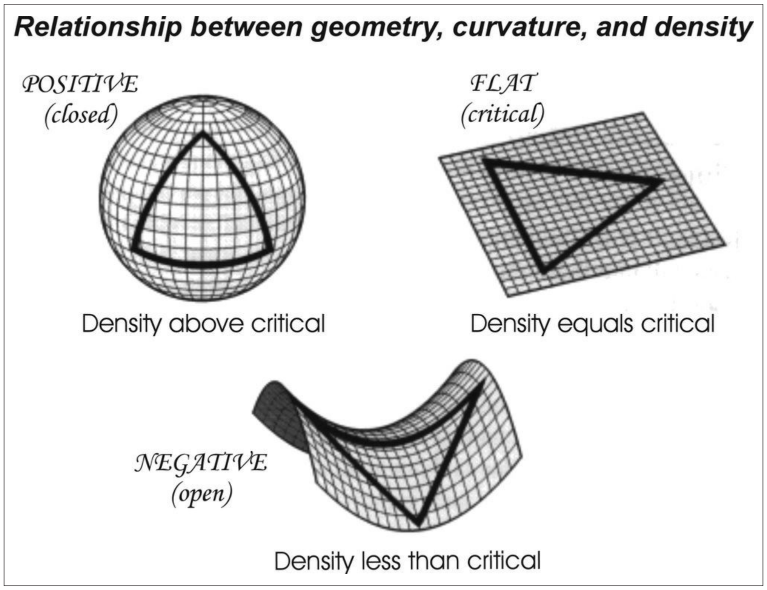


Figure 5. The geometry of the universe and its correlation to the critical density.

Using the CMBR to Determine the Geometry of the Universe

Cosmologists can calculate the length of the acoustic waves at the decoupling era and predict their presently observable angular size. This angle should be about one degree *if the universe is flat*.[21] On the other hand, if the universe is closed, then the anisotropies will appear larger than one degree. Conversely, for an open universe, they will appear smaller than one degree (Figure 6).

Figure 7 shows an angular size "power spectrum" of acoustic anisotropies. That is, the graph correlates temperature differences across the sky for varying angular sizes. The main peak near one degree matches what has been calculated for a flat universe.

A flat universe substantiates a major prediction of the inflationary scenario. As an analogy why this is so, think of a sphere that expands 10^{58} to 10^{60} times. Regardless of its initial curvature, for all practical purposes the surface of the sphere will appear flat after expanding. The same holds for the universe.

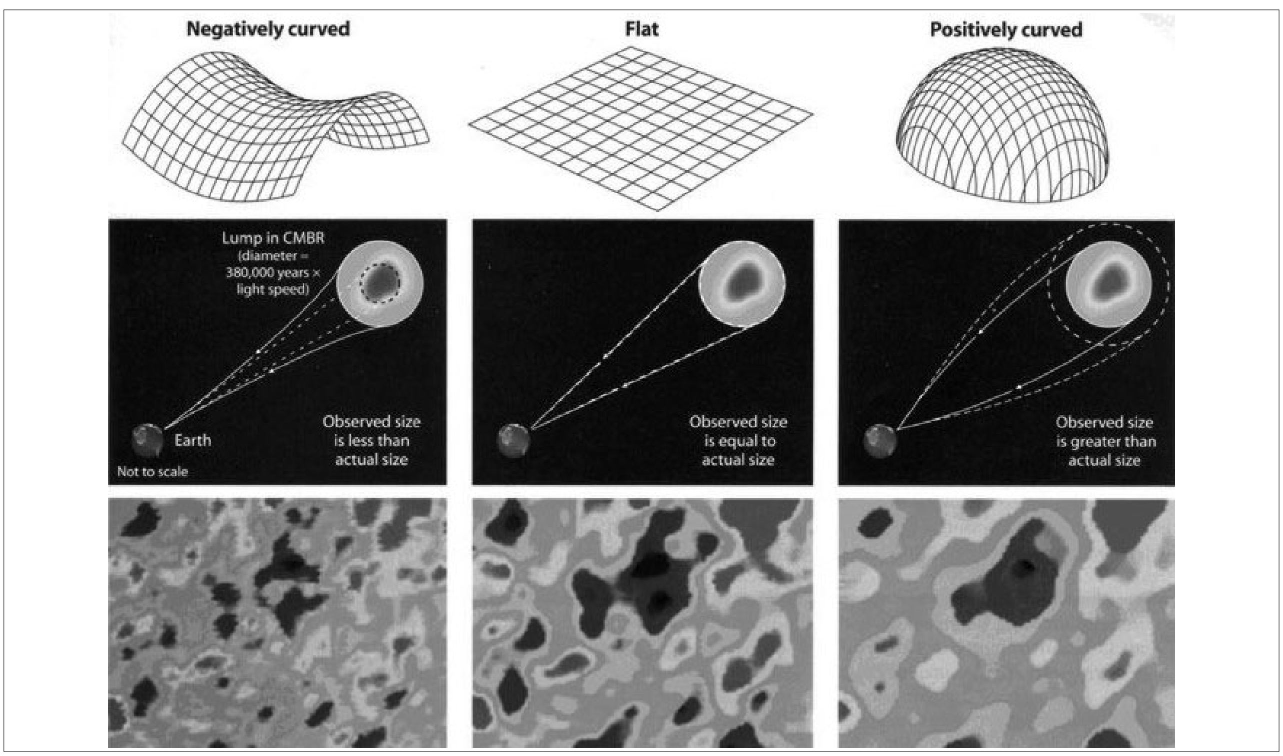


Figure 6. Sounding out the shape of space. *Top row*: On scales comparable to our visible universe, space can exhibit negative curvature (left column), no curvature (middle column), or positive curvature (right column). *Middle row*: This curvature determines the angular diameter of the baby universe's largest sound waves as seen on today's microwave sky. *Bottom row*: These false-color images show hypothetical maps of the CMBR. As it turns out, WMAP and several earthbound instruments all agree that the visible universe is flat—strongly supporting the inflation theory of the universe's origin. They have determined that the microwave sky is lumpiest on scales between ½° and 1°, as predicted for a flat universe, which is one with a critical cosmological density. (Graphics and caption from Wendy L. Freedman and Michael S. Turner, "Cosmology in the New Millennium," *Sky & Telescope* [October 2003]. Copyright © 2003 by Sky Publishing Corp., reproduced with permission of the publisher.)

Acoustic anisotropy data reveal that our universe will expand forever; never will it collapse upon itself and rise again from the ashes like the proverbial Phoenix!

Finally, we note that the size of galaxy superclusters matches the linear dimensions of the acoustic anisotropies in the CMBR.[22] This is not coincidental; the correspondence provides good evidence that acoustic waves gave rise to superclusters. Again, another observable in the universe is nicely explained by Big Bang cosmology.

Baryon Loading

Notice that Figure 7 has a second peak at about one-third of a degree. This peak is also significant, for it shows the baryon density of the universe. Baryons are massive compared to electrons, so they do not respond as quickly to the compression and expansion phases of passing acoustic waves. Their relative immobility—called *baryon loading*—causes harmonics in the main acoustic wave. The baryon loading harmonic appears as a second peak in Figure 7.

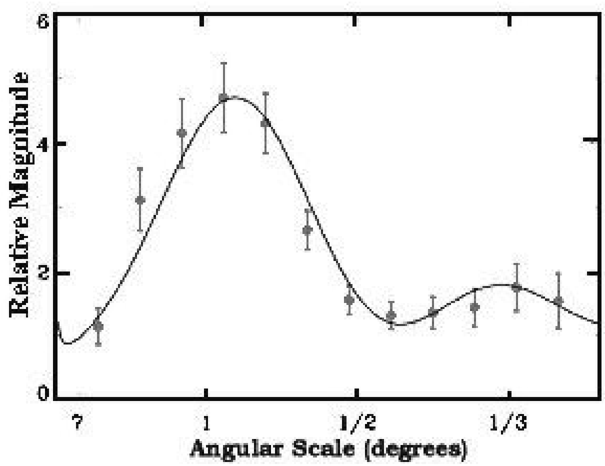


Figure 7. Temperature anisotropy and subtended angular diameter. The vertical scale is a measure of the temperature differences. The curve represents the best fit to the observed points. The vertical bars extending from the data points are the observational errors in the measurements. Notice the clear peak around one degree, which indicates a flat universe. The importance of the second peak is discussed below. (Adapted from BOOMERANG balloon data.)

Baryon loading depends upon the relative density of baryons to other kinds of matter in the universe. *The greater the density of baryons, the smaller is the size of the second peak relative to the first, and vice-versa.* Present measurements indicate that the baryon density of the universe is a little over 5%.[23]

Dark Matter

Astronomers have known for a long time that the universe contains far more matter than revealed by visible light. This statement holds true even when all available forms of radiation are examined across the entire spectrum—from gamma rays to radio waves. One may ask, therefore, if this *dark matter* (also called *cold dark matter*) cannot be observed, how do we know it is there?[24]

Dark matter reveals itself through its gravitational attraction. For example, when we observe galaxy clusters, we find that some galaxies are moving so fast that they would have escaped from their parent cluster if a stronger gravitational field were not keeping them bound—a stronger field than inherent simply in the cluster's visible matter. Dark matter keeps the galaxies at home in the cluster.

Additionally, material in the outer regions of our own galaxy is rotating too rapidly about the galactic center to be contained by the gravitational force produced solely by our galaxy's visible matter. In other words, if the galaxy did not contain more matter than what is visible, its outer regions would have spun off by now. We find the same phenomenon exhibited by other galaxies, as well.

Dark matter does not interact directly with photons; its only interaction with other forms of matter is through its gravitational field. Nevertheless, dark matter influenced the CMBR anisotropies. Dark matter's gravity modulated the acoustic wave oscillations in the decoupling era, and this modulation shows up as another peak in the CMBR anisotropy data. The amount of dark matter determines the height of the third peak (Figure 8).

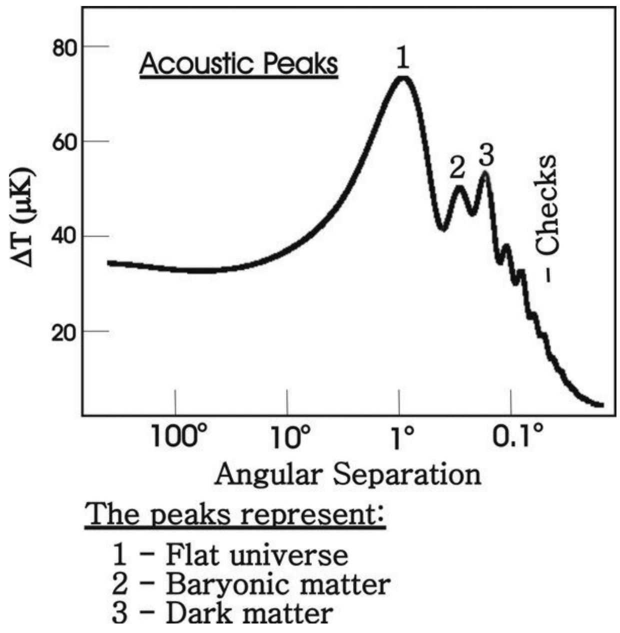


Figure 8. This diagram is an extension of Figure 7 and shows the harmonic peaks caused by *baryon loading* (labeled *baryonic matter* in the diagram) and by *dark matter*. The portion of the diagram marked *checks* are other harmonic peaks that can corroborate the calculations giving rise to the first three peaks. Discussion of the "checks" is beyond the scope of this paper. (Adapted from Wayne Hu, http://background.uchicago.edu/.)

Figure 9 presents the combined results from numerous CMBR observations as of this writing. The height of the third peak near 0.2 degrees corresponds to dark matter that makes up about 25% of the total content of the universe. We still do not know what comprises cold dark matter, yet there is five times more of it than the matter we are made of!

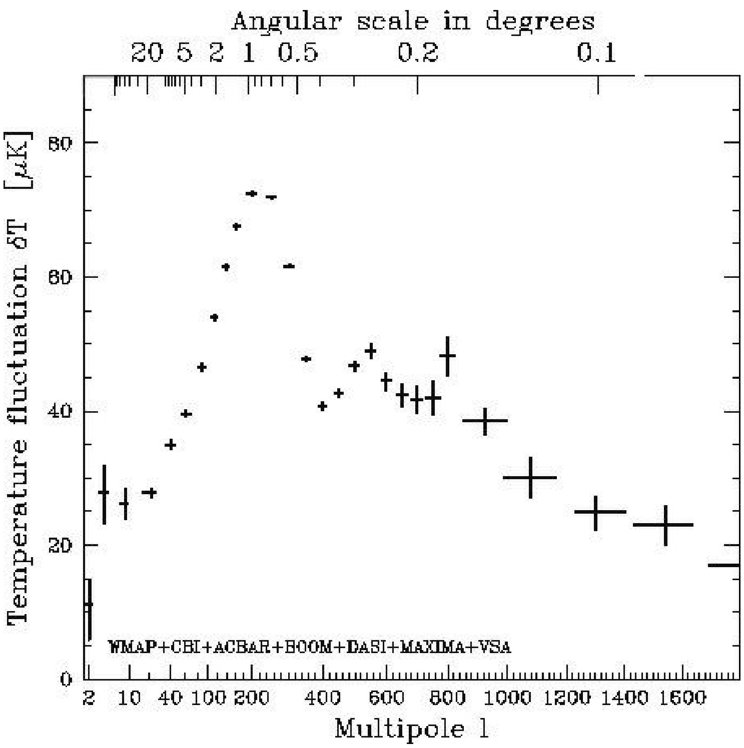


Figure 9. Latest observational results from various experimental groups (listed at bottom left of graph). The points average the measurements to show the prominence of the peaks. (Adapted from Tegmark. See Max Tegmark's web site at www.hep.upenn.edu/ ~max/cmb/experiments.html for continuous updates of this diagram.)

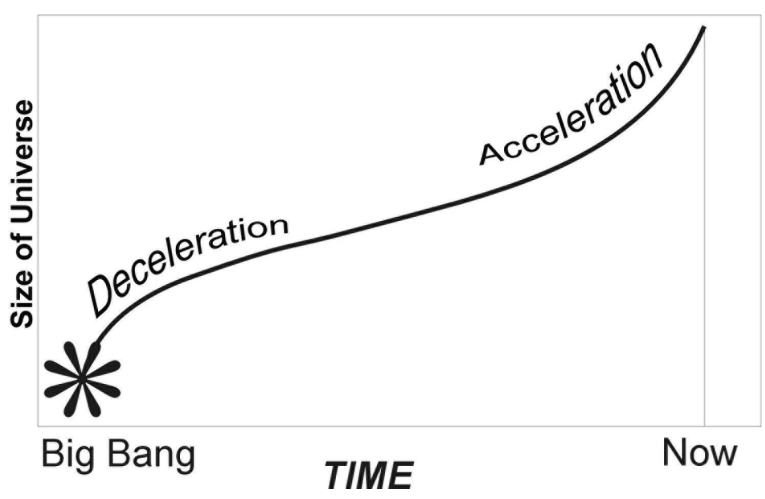


Figure 10. Gravitational attraction slowed the universe's expansion at first, but now a mysterious *dark energy* is causing the universe's expansion rate to increase.

Polarization

The final aspect of our discussion of the CMBR deals with *polarization*. Polarization refers to the orientation of the electric field of the photons. Light reflected from flat surfaces, such as a pool of water, is polarized, which is why polarized sunglasses are able to eliminate most of the reflection.

Under most circumstances, one expects blackbody radiation to be unpolarized. A slight polarization in the CMBR is anticipated, however, from the scattering of photons by electrons that have not yet formed neutral atoms toward the end of the decoupling era.[25]

One also expects polarization of starlight from the first stars created after the decoupling era. These stars would ionize neutral hydrogen, and the electrons formed by ionization would polarize the starlight scattering off of them. Since this process occurred soon after the decoupling era, the polarized starlight would be redshifted into the microwave region.

Whatever the process, polarization of the CMBR was predicted, and now this prediction has been observed by the Degree Angular Scale Interferometer, or DASI.[26] CMBR polarization becomes yet another piece of evidence in favor of the Big Bang.

Dark Energy

Astronomers are able to measure the distance to a galaxy and to correlate that distance with its recession speed. This gives rise to Hubble's Law. In the last few years, however, astronomers have discovered that distant galaxies are farther away than expected by the Hubble relationship. This effect reveals itself in the objects used to measure distances—Type Ia supernovas.

Supernovas are exploding stars. Their explosive energy is so immense that for a couple of weeks a supernova can outshine an entire galaxy. Since they are exceedingly bright, they can be seen for great distances and thus be used as distance indicators.[27]

The recession speed of a supernova is readily measured, and by Hubble's Law its "Hubble distance" can be inferred. The problem, however, is that at great distances Type Ia supernovas appear dimmer than expected. The best explanation for this phenomenon is that their dimness results from their being more distant than their recession speed and Hubble's Law indicate. The simplest way to interpret this effect is that the universe's expansion rate has begun to accelerate. This has taken the supernovas farther away than expected, which makes them appear dimmer than anticipated. Figure 10 illustrates this phenomenon.[28]

The accelerating expansion was totally unexpected. Some kind of *dark energy* exists that is causing this behavior, but its makeup is unknown.[29] Moreover, dark energy turns out to be the major component of the universe, as illustrated in Figure 11.

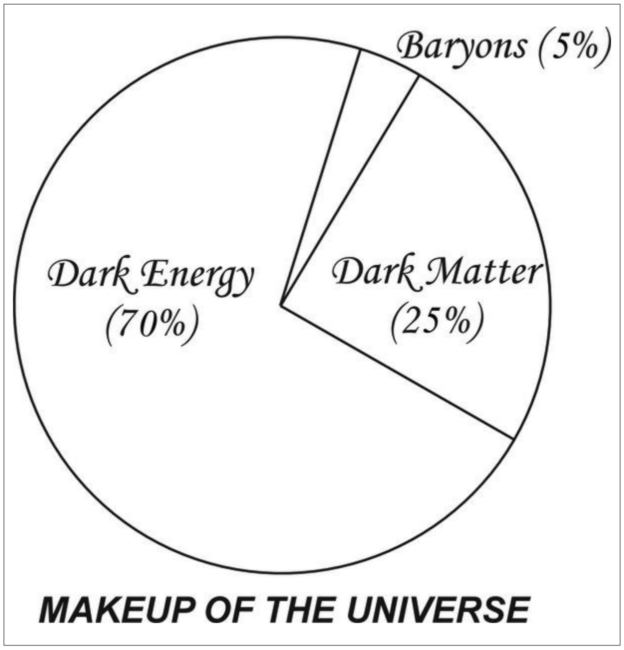


Figure 11. Component makeup of the universe. Notice that most of the universe is made up of non-baryonic matter. The combined mass/energy equivalence of all components of the universe points to a flat universe. These proportions are based upon WMAP and SDSS data. (See http://map.gsfc.nasa.gov and www.sdss.org for details.)

So strange are the results for the makeup of the universe from studying the CMBR and Type Ia supernovas that one can legitimately ask, "Can we trust these results? Is there an independent method one can use to measure the makeup of the universe?"

The answer to both of these questions is a resounding "Yes!" Surveys of tens of thousands of galaxies reveal that the universe resembles a collection of soap bubbles with large voids surrounded by thin walls of galaxies. The Sloan Digital Sky Survey (SDSS) has observed over *two hundred fifty thousand* galaxies, and the density of the constituents of the universe that produce the observed structure conform, within a couple percent, to those inferred from WMAP.[30]

Dark Energy, Geometry, and Future of the Universe

Before the discovery of dark energy, cosmologists correlated the future of the universe to its geometry. To wit, without dark energy, a closed universe expands up to a point and then collapses upon itself. This is because a closed universe has a high enough density for the gravitational field to slow down and to reverse the expansion. Eventually, everything in a closed universe slams together in a "Big Crunch."

Critical universes, on the other hand, are on the exact boundary between continuous expansion and eventual collapse. Open universes expand at a faster rate than critical. Critical and open universes expand forever.

With dark energy, however, the geometry of the universe does not determine its future. Dark energy acts as a cosmic repulsive force providing a continuous expansion for all universes, regardless of their curvature. Since our universe has a large dark energy component, it will expand forever.[31]

In spite of the weirdness of dark matter and of dark energy, the combined mass/energy of the universe adds up to the critical density. This is further evidence for a flat, critical universe predicted by inflation.

Tying It All Together

So what do we make of all this? What do the redshift, light element abundances, CMBR, dark matter, and dark energy have to do with the Big Bang? The answer is that *only* the hot Big Bang unifies these disparate observations into a coherent whole. Other cosmologies can be contrived to mimic some observations, but they fail miserably at other points.

The conclusion is clear: The threefold cord of support for Big Bang cosmology consists of solid evidential fiber!

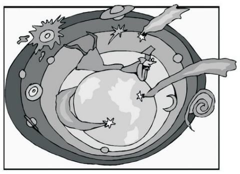
Theological Implications

Creation ex nihilo

Historically, Judeo-Christian theology has interpreted the first verse of the Bible as meaning that God, through his sovereign will, created the entire universe out of nothing (creation *ex nihilo*). Unlike ancient Near East or Hellenistic cosmologies, the God of the Bible did not begin with pre-existing matter.[32]

The Big Bang fits in well with creation *ex nihilo*. In the words of Robert Jastrow:

> Now we see how the astronomical evidence leads to a biblical view of the origin of the world. The details differ, but the essential elements in the astronomical and biblical accounts of Genesis are the same: the



chain of events leading to man commenced suddenly and sharply at a definite moment in time, in a flash of light and energy.[33]

A classic attempt to circumvent a beginning was made in 1948 by Fred Hoyle, Herman Bondi, and Thomas Gold. They proposed their "Steady State" universe based on the "Perfect Cosmological Principle."[34] A consequence of the perfect cosmological principle for an expanding universe is that matter has to be created continuously to make up for its decreasing density over time. In other words, matter has to pop into existence and form galaxies at the same rate as they disappear beyond the universe's horizon. As such, Steady State cosmology was dubbed "continuous creation" cosmology.[35]

Historically, Judeo-Christian theology has interpreted the first verse of the Bible as meaning that God, through his sovereign will, created the entire universe out of nothing (creation ex nihilo*). … The Big Bang fits in well with creation* ex nihilo.

Steady State cosmology, however, has no mechanism for producing the CMBR and its anisotropies, or the universal light element abundances. As such, this theory is studied for its historical interest rather than as a viable alternative to the Big Bang.[36]

Another attempt to avoid a beginning is the oscillating universe, which became popular in the mid-twentieth century and was advocated by Carl Sagan in his PBS *Cosmos* series. Basically, the universe is like an accordion that expands and contracts in the course of several hundred billion years. The universe expands to its maximum extent and then collapses upon itself in a "big crunch," out of which it begins anew with another big bang. This cycle of "bang" to "crunch" repeats forever.

Historically, oscillating universes had three major problems.[37] First, thermodynamic considerations predict that subsequent universes will have proportionately greater ratios of radiation to matter, and this leads to longer cycling times for each oscillation. If we are the result of an infinite number of past cycles, then our universe should be a radiation-only universe. Clearly this is not the case, which means that our universe, at best, is only a few cycles old.

Second, we have no theory as to how a big crunch turns into a big bang. One requires a quantum theory of gravity to attempt to solve this problem, and even with such a theory there is no guarantee that a mechanism exists.

Third, recent data that the universe's expansion rate is accelerating drives the final nail in the coffin of the oscillating universe. Dark energy will prevent the universe from collapsing upon itself. As such, oscillating universes are not seriously considered today, although they are hailed as "scientific evidence" in support of Hindu cosmology by some adherents of Hinduism.[38]

For now, the standard hot Big Bang remains the best explanation for the creation of the universe.[39] Future theories may elucidate further the moment of creation, but in the words of Joseph Silk:

> If a better theory of the universe is forthcoming, there seems little doubt that it will incorporate the big bang theory as an appropriate description of the observable universe … in the same way that Einstein's theory of gravitation encompassed and generalized the concepts of Newtonian gravitation.[40]

The Big Bang and Young-Earth Creationism

In many Christian circles, Big Bang cosmology is denied, ignored, or reviled, especially by those who do not accept that the universe is billions of years old. Some have attempted to reformulate the Big Bang in a young-earth framework, while others have resorted to nonconventional theories to explain the cosmological redshift—as though the validity of the Big Bang rests solely on the redshift.[41]

One of the latest attempts to reinterpret the Big Bang in a young-earth framework is that of Robert V. Gentry's Cosmic Center Universe (CCU), which has evolved from his earlier New Redshift Interpretation.[42] Basically, Gentry sets up a universe centered upon our own galaxy. He adds a "non-zero vacuum energy density" that causes the galaxies to recede from the Milky Way in such a way as to give Hubble's Law of recession. Unlike Friedmann-Lemaître models, however, the galaxies are not fleeing because of expanding space; rather, the galaxies are moving *through* space at speeds that vary with distance so as to give the Hubble Law for small distances.[43]

Gentry's model also invokes a spherical shell of galaxies at roughly the Hubble distance from the center.[44] This shell is massive enough to cause a gravitational redshift of its emitted radiation such that its initial temperature drops to 2.73 kelvins by the time it reaches earth. Inhomogeneities in this shell account for the anisotropies in the CMBR.

Gentry's CCU is ingenious, but it is totally contrived. Whereas Big Bang cosmology gives rise in a natural fashion to the present temperature of the CMBR, Gentry has to set the temperature of the radiation emitted by his galactic shell to match what is seen at earth after it has been gravitationally redshifted. Gentry also has to set up the speeds of the receding galaxies to match what naturally occurs in an expanding universe.

Second, based upon principles of nucleosynthesis, Big Bang cosmology correctly predicts the universally observed abundances of the light elements helium, deuterium, and lithium. Gentry's theory has no mechanism for generating these abundances; thus, their observed amounts occur simply by chance. For these and other reasons,[45] Gentry's theory is not a serious contender to Big Bang cosmology.

Reversing Copernicus

Finally, a few words should be said concerning recent attempts to bring the earth close to the center of the universe.[46] Not only is Gentry's CCU "galactocentric," so is a new proposal by D. Russell Humphreys. Humphreys points to the bunching up of galaxy redshifts into regularly spaced intervals as indicating that the galaxies are laid out in concentric, spherical shells that are evenly spaced around the Milky Way.[47]

Humphreys's galactocentric universe fits in with his theology. Earth is central to God's redemptive plans, and earth's physical position in the universe reflects its theological centrality. Humphreys, therefore, rejects the "Copernican Principle," which states that there is no preferred location or center in the universe.

The Copernican principle leads to the conviction that the universe—on a very large scale—is homogeneous and isotropic. Homogeneity and isotropy are foundational to Big Bang cosmology. As such, Humphreys also rejects the Big Bang in favor of his spherical, onion-layered universe.

Unfortunately, Humphreys errs at several critical junctures. First, his theological predilection is a throwback to pre-Copernican thinking. Christians have long realized that the Bible does not insist that the earth be the center of the universe for it to be central to God's plans.[48] Humphreys has substituted a new, supposedly biblically-based galactocentrism for the old, errant, supposedly biblically-based geocentrism.

Second, Humphrey's presumed quantized redshifts are based on obsolete datasets. The recent and ongoing Two-Degree Field Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS) show not a shred of the redshift quantization claimed by Humphreys.[49] Apparently, the supposed quantizations were largely the result of improper data analysis or too small a sample to be legitimate. This is not surprising; many factors distort the true motion of galaxies in the universe. These distortions affect determining the correct value for the redshift of a galaxy.[50]

In summary, Big Bang cosmology indicates that the universe had a beginning, and this fits in with traditional Judeo-Christian doctrine of creation *ex nihilo*. Attempts to avoid a beginning, such as the Steady State Theory or an oscillating universe, are unsupported by the scientific evidence.

As for two contemporary young-earth creationist alternatives to the Big Bang, we find that Gentry's CCU and Humphreys's "quantized redshift" galactocentric universes fail scientific and theological scrutiny. The hot Big Bang remains the best model of the universe.

Conclusions

We have made great progress in understanding the overall structure and history of the universe. Our universe began in the finite past. Its density is critical (i.e., it is geometrically flat), and it contains far more dark matter and dark energy than baryons, even though baryons comprise the matter most familiar to us. The universe will expand forever. Dark energy guarantees that it will never collapse upon itself to be reborn sometime in the future.

Our understanding of the very large (general relativity) and the very small (quantum mechanics) has revealed secrets of the universe hidden since creation. Hubble's Law, the abundances of the light elements, and the CMBR show that the Big Bang model of the universe is essentially correct. To this writer, the evidence is so overwhelming that arguing against the Big Bang is akin to arguing for a flat earth.

"It is the
glory of God
to conceal a thing,
but the
glory of kings
(and cosmologists?)
to search out a matter"

—Proverbs 25:2.

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Notes

[1] I have attempted to strike a balance between articles that are too short to do justice to the evidence and book length works that deluge the reader with piles of data. The annotated bibliography at the end points to helpful works for those who wish to pursue the topic further.

[2] When Einstein learned of Hubble's results, he said that putting Λ into his equations was the biggest blunder of his life. For an enjoyable history of this period, see Robert Jastrow, *God and the Astronomers* (New York: Warner Books Edition, 1978). Today, Λ has come back into the picture in a big way, as I bring out below.

[3] This is true for distances of hundreds of millions of light years. At smaller distances, the random motions of galaxies overwhelm the Hubble effect. Since galaxies are receding from us, light emitted by them is shifted to longer wavelengths, which for visible light is the red end of the spectrum. Hence, astronomers refer to the Hubble relationship as the cosmic redshift effect.

[4] Other light elements formed during this period were tritium, helium-3, and lithium-7, where the number represents the mass number (the sum of the number of protons and neutrons). I will discuss only deuterium and helium-4 in this paper.

[5] Physicists are currently seeking to understand the nature of gravity and particle behavior during the Planck Era. Theories based upon strings, quantum loops, branes, and super-symmetry have been formulated, but their success is limited.

[6] The kelvin temperature scale is zero at absolute zero and positive from there on. Zero degrees centigrade (or Celsius) is 273 degrees kelvin, and one degree change in the centigrade scale is the same on the kelvin scale. Also note that rather than use the term "degrees kelvin," most scientists just say "kelvins." For a rough conversion of high kelvin temperatures to equivalent Fahrenheit temperatures, multiply the kelvin temperature by 1.8.

[7] Actually, "virtual" particles of all sorts existed. If photons have enough energy, then by Einstein's famous equation $e = mc^2$, the photons can spontaneously form pairs of particles each of whose "rest mass" equals half the energy of the photons. Hence, quantum mechanics allows for particles to be created from energetic pho-

tons, but they are immediately destroyed by mutual annihilation or by other photons. Thus, the early universe is home to zillions of photons and particles that are in a continuous process of creation and annihilation.

8In reality, both quarks and *antiquarks* appeared and disappeared, but here I have lumped both species into the generic term "quarks." Antiquarks are the *antimatter* form of quarks. Quarks and antiquarks annihilate when they come into contact, releasing gamma rays.

9We do not have a clear understanding of the asymmetry, but suffice it to say that without it we would not exist!

10Minute quantities of antimatter can be created in particle accelerators and by high energy cosmic rays, but for all practical purposes, the observable universe is devoid of antimatter.

11The difference in the rest masses between protons and neutrons fixes this ratio. See Joseph Silk, *The Big Bang*, 3rd ed. (New York: W. H. Freeman, 2001), 422; and Barbara Ryden, *Introduction to Cosmology* (San Francisco: Addison Wesley, 2003), 182.

12Neutrons have a mean lifetime of eleven minutes, so some neutrons decayed before being captured by protons. This dropped the neutron/proton ratio from 0.2 to 0.15. This ratio has remained constant since the end of cosmic nucleosynthesis.

13Nuclear reactions in stars also produce deuterium, but this deuterium quickly converts to helium and is not released into the interstellar medium. In the Big Bang, however, the temperature dropped fast enough to allow some deuterium to survive. (Deuterium requires a high temperature to fuse into helium.)

14David Kirkman, et al., "The Cosmological Baryon Density from the Deuterium to Hydrogen Ratio towards QSO Absorption Systems: D/H Towards Q1243+3047," *Astrophysical Journal Supplement Series* 149, no. 1 (2003). Online at http://arxiv.org/ PS_cache/astro-ph/pdf/0302/0302006.pdf.

15Metals are generated in the last stages of a supernova explosion. The explosion spreads the metals into the surrounding medium from which later stars form. They, in turn, have a higher metal abundance than the stars that preceded them. When these stars become supernovas, metals enrich the surrounding medium even more. In this way successive generations of stars contain more metals than previous generations. Since stars spend most of their lives converting hydrogen to helium, supernovas also add helium to the mix, so its abundance also increases with progressive generations of stars. Astronomers seek metal poor stars to measure the helium abundance because they know these stars are older and less "polluted" by non-primordial helium.

16Gary Steigman, "BBN and the Primordial Abundances," http://arxiv.org/PS_cache/astro-ph/pdf/0501/0501591.pdf. Helium abundance measurements are lower than predicted, but as Steigman points out: "The culprit may be the astrophysics [measurements] rather than the cosmology." If, however, WMAP observations of baryon density are believed, then observed helium abundances correspond to Big Bang nucleosynthesis theory. See Richard H. Cyburt, et al., "New BBN Limits on Physics beyond the Standard Model from 4-He," http://arxiv.org/PS_cache/astro-ph/pdf/0408/0408033.pdf.

17At 3000 kelvins, some photons have enough energy to ionize hydrogen, but their number is not sufficient to alter what follows.

18These are high-end values for inflation. For a sense of scale, if two objects were one inch apart before inflation, they would be two million trillion trillion trillion *light years* apart after inflation! Of course, the universe was far smaller than one inch when inflation began, but these numbers give a sense of the magnitude of the expansion. Some propose an expansion of "merely" 10^{22} to 10^{30} times. Whatever value one chooses, the inflationary growth of the universe is mind-boggling.

19We emphasize here that the acoustic wave anisotropies are different than the inflation induced anisotropies discussed earlier and detected by COBE.

20"Density" does not refer only to baryons; it includes dark matter and dark energy, both of which are discussed below.

21For a mathematical derivation, see Ryden, *Introduction to Cosmology*, 161–5.

22Ron Cowen, "Repulsive Astronomy: Strengthening the Case for Dark Energy," *Science News* 164, no. 5 (August 2003): 67; Ryden, *Introduction to Cosmology*, 162; and Ron Cowen, "Modern Echoes of the Early Universe," *Science News* 167 (January 15, 2005): 35; Govert Schilling and Joshua Roth, "Galaxy Maps Reveal Long-Sought Waves" *Sky and Telescope* 109, no. 5 (May 2005): 8; "The Cosmic Yardstick—Sloan Digital Sky Survey Astronomers Measure Role of Dark Matter, Dark Energy and Gravity in the Distribution of Galaxies," www.sdss.org/news/releases/20050111.yardstick.html; and Daniel Eisenstein, et al., "Detection of the Baryon Acoustic Peak in the Large-Scale Correlation Function of SDSS Luminous Red Galaxies," http://arxiv.org/abs/astro-ph/0501171.

23Max Tegmark, et al., "Cosmological Parameters from SDSS and WMAP," available at http://arxiv.org/abs/astro-ph/0310723. We only "see" about one-third of the total baryonic matter in the universe in the form of galaxies and their associated, visible components (stars, planets, bright and dark nebulas, etc.). Two-thirds is in the form of large conglomerations of intergalactic hydrogen, which is detected by its absorption of radiation emitted by distant quasars. See Ron Cowen, "Visible Matter: Once Lost But Now Found," *Science News* 162, no. 6 (10 August 2002): 83.

24*Cold dark matter* is not to be confused with dark *baryonic* matter. The latter is made up of baryons. We do not know what constitutes the former.

25This effect was first discussed by Martin Rees, "Polarization and Spectrum of the Primeval Radiation in an Anisotropic Universe," *The Astrophysical Journal* 153 (July 1968): L1–L5. His paper is online at http://adsabs.harvard.edu/journals_service.html. A polarization "primer" by Wayne Hu and Martin White is available at http://xxx.lanl.gov/abs/astro-ph/9706147.

26Joshua Roth, "Polarized Microwaves Bolster New Cosmology," *Sky & Telescope* 104, no. 6 (December 2002): 20–1. The most recent evidence points to the second reason for the polarization by stars that formed about 200 million years after the Big Bang. See Bertram Schwarzschild, "WMAP Spacecraft Maps the Entire Cosmic Microwave Sky with Unprecedented Precision," *Physics Today* 56, no. 4 (April 2003): 21–4. More information about DASI is available at http://astro.uchicago.edu/dasi/.

27Type Ia supernovas have a well-defined intrinsic brightness that can be compared with their observed brightness to infer their distance. See Saul Perlmutter, "Supernovae, Dark Energy, and the Accelerating Universe," *Physics Today* 56, no. 4 (April 2003): 53–60.

28Type Ia supernovas are not the only indicators of an accelerating expansion. Correlations between galaxy clustering and the CMBR show the same effect. See Ron Cowan, "Repulsive Astronomy: Strengthening the Case for Dark Energy," *Science News* 164, no. 5 (2 August 2003): 67.

29A readable discussion of dark energy is Sean Carroll's "Dark Energy and the Preposterous Universe," *Sky and Telescope* 109, no. 3 (March 2005): 32–9. Many associate dark energy with Einstein's famous "cosmological constant" lambda (Λ) that he added to his field equations but later disowned. Lambda acts as a cosmic repulsive force that accelerates the expansion of the universe. See Silk, *The Big Bang*, 23, 24, 100–1. For a thorough discussion of the cosmological constant, see Sean M. Carroll, "The Cosmological Constant," *Living Reviews in Relativity*, 4 (2001): 1–80. Also online at http://arxiv.org/PS_cache/astro-ph/pdf/0004/0004075.pdf. This article requires some knowledge of general relativity.

30Max Tegmark, et al., "Cosmological Parameters from SDSS and WMAP."

31We note here that if dark energy were attractive, then all universes would end in a big crunch, regardless of their curvature. For details, see Ryden, *Introduction to Cosmology*, 91–4.

32Whether the Bible teaches creation *ex nihilo* depends upon the interpretation of Gen. 1:1. For a review of whether Genesis 1:1 should be translated as an independent clause (implying creation *ex nihilo*) or a dependent clause (implying God used previously existing material), see John J. Davis, "Genesis 1:1 and Big Bang Cosmology," in *The Frontiers of Science & Faith: Examining Questions from the Big Bang to the End of the Universe* (Downers Grove, IL: InterVarsity Press, 2002), 11–25. I accept the historical and the grammatical evidence that the clause is independent.

[33]Robert Jastrow, *God and the Astronomers* (New York: Warner Books Edition, 1978), 3–4. Jastrow reached this conclusion a quarter of a century ago, and it is valid today. Jastrow's comment is particularly interesting since he declares himself an agnostic in this book. Jastrow also shows various scientists' troubled reactions to the evidence that the universe had a beginning.

[34]The "Cosmological Principle" states that on a large enough scale (about 300 million light years), the universe is homogeneous and isotropic. The "Perfect Cosmological Principle" extends homogeneity and isotropy into the dimension of time. That is, the physical characteristics of the universe have remained constant throughout eternity.

[35]When Thomas Gold was confronted with objections to continuous creation because it violated the law of conservation of mass/energy, he would remind his critics that the same is true for big bang cosmology. The only difference is that the Big Bang violated mass/energy conservation all at once while continuous creation does this in small steps. As he would say, "The difference is one big miracle versus a bunch of tiny miracles." (This is a figure of speech; Gold did not believe in miracles.)

[36]A good summary of the history of and the problems with the steady state theory appears in George Smoot and Keay Davidson, *Wrinkles in Time* (New York: Wm. Morrow & Co., 1993), 66–86. For personal reflections on the motivation for proposing the steady state theory, see Herman Bondi, "The Cosmological Scene 1945–1952," in *Modern Cosmology in Retrospect*, ed. B. Bertotti, R. Balbinot, S. Bergia, and A. Messina (Cambridge: Cambridge University Press, 1990), 189–96. Hoyle continued to rail against the Big Bang to his dying day despite the evidence that his objections were wrong. Unfortunately, young-earth creationists still refer to Hoyle (along with his colleagues Burbridge and Narlikar) for evidence against the Big Bang. (For example, see Henry M. Morris, "The Cosmic Bubbleland," in *Back to Genesis* 150 [June 2001], a–b. Also available online at: www.icr.org/pubs/btg-a/btg-150a.htm).

[37]John D. Barrow, *The Origin of the Universe* (New York: Basic Books, 1994), 29–31; and P. J. E. Peebles, *Principles of Physical Cosmology* (Princeton: Princeton University Press, 1993), 367–8.

[38]E.g., www.atributetohinduism.com/Hindu_Culture.htm. "Hinduism is the only religion that propounds the idea of life-cycles of the universe. It suggests that the universe undergoes an infinite number of deaths and rebirths. Hinduism, according to Carl Sagan:

> … is the only religion in which the time scales correspond … to those of modern scientific cosmology. Its cycles run from our ordinary day and night to a day and night of the Brahma, 8.64 billion years long, longer than the age of the Earth or the Sun and about half the time since the Big Bang."

[39]For other alternatives to the hot Big Bang besides those discussed here, along with their problems, see Silk, *The Big Bang*, 385–401, and Davis, *Frontiers*, 25–36.

[40]Silk, *The Big Bang*, 407.

[41]See, for example, the hypothesis for a cosmic time slowdown advanced by D. Russell Humphreys, *Starlight and Time: Solving the Puzzle of Distant Starlight in a Young Universe* (Colorado Springs: Master Books, 1994). His arguments have been thoroughly refuted, albeit he refuses to acknowledge this. Readers can follow the exchange between Humphreys and his critics and decide for themselves: P. G. Phillips, "D. Russell Humphreys's Cosmology and the 'Timothy Test,'" *Creation Ex Nihilo Technical Journal* 11, part 2 (1997): 189–94; J. D. Sarfati, "D. Russell Humphreys's Cosmology and the 'Timothy Test' A Reply," *Creation Ex Nihilo Technical Journal* 11, part 2 (1997): 195–8; and D. R. Humphreys, "Timothy Tests Theistic Evolutionism," *Creation Ex Nihilo Technical Journal* 11, part 2 (1997): 199–201. For a rejoinder to the last two articles, see P. G. Phillips, "Rejoinder to Humphreys and Sarfati Responses," at www.ibri.org/Papers/Timothy_Test/Timtest_Rejoinder.htm. Also see Samuel R. Conner and Don N. Page, "*Starlight and Time* Is the Big Bang," *Creation Ex Nihilo Technical Journal* 12, no. 2 (1998): 174–94. A list of articles that challenge Humphreys's thesis, along with attempted responses to his critics, appears at www.trueorigin.org/ca_rh_03.asp.

[42]Robert V. Gentry, *Modern Physics Letters A* 12, no. 37 (1997): 2919. Also online at http://arxiv.org/abs/astro-ph/9806280. Gentry's other publications on this subject are online at www.orionfdn.org/papers/other-papers.htm.

[43]That is, for cosmological redshifts with $z < 1$. For small velocities, z is the ratio of the galaxy's velocity to that of light.

[44]The Hubble distance is the distance light travels during the age of the universe. It is about 14 billion light years.

[45]See Ryan Scranton's "Debunking Robert Gentry's 'New Redshift Interpretation' Cosmology" for details at www.talkorigins.org/faqs/nri.html. Note that Scranton wrote his piece when Gentry had a shell of hot hydrogen gas rather than a shell of galaxies at the Hubble distance. Even so, a shell of galaxies will also be unstable. Also see the debate between J. Brian Pitts and Gentry on the latter's view of energy conservation in Big Bang cosmology in *Perspectives on Science and Christian Faith* 56, no. 4 (December 2004): 260–84. Pitts points out the deficiencies in Gentry's position.

[46]This is not geocentrism, but "galactocentrism." That is, our galactic center is the center of the universe. The position of the solar system in our galaxy is accepted as a necessary condition for life to exist on earth.

[47]A summary of Humphreys's thesis is found in "The Battle for a Cosmic Center," *Impact* 350 (August 2002), which is also available online at www.icr.org/pubs/imp/imp-350.htm. His extended article is "Our Galaxy is the Center of the Universe, 'Quantized' Redshifts Show," *Ex Nihilo Technical Journal* 16, no. 2 (2002): 95–104. Quantized redshifts are discussed by William G. Tifft and W. John Cocke of the University of Arizona. They summarize their work in "Quantized Galaxy Redshifts," *Sky & Telescope* (January 1987): 19–21.

[48]See the helpful discussion by Daniel Danielson, "Copernicus and the Tale of the Pale Blue Dot" at www.english.ubc.ca/%7Eddaniels.

[49]E. Hawkins, S. J. Maddox, and M. R. Merrifield, "No Periodicities in 2dFGRS Redshift Survey Data," *Monthly Notices of the Royal Astronomical Society* 336, no. 1 (October 2002): L13. SDSS results appear at http://arxiv.org/abs/astro-ph/0310725. Since the universe resembles a collection of soap bubbles with large voids, observing galaxy populations in any direction will reveal galaxy distances bunched in multiples of the diameter of the voids. The voids are approximately 300 million light years across. This correlates to a redshift $z = 0.024$, which is 100 times greater than the presumed periodicity upon which Humphreys bases his conclusions.

[50]Dr. John Huchra, Harvard-Smithsonian Center for Astrophysics, in a personal communication (25 October 2003) says:

> First, it is hard to define a "velocity" for a galaxy at better than a few km/s. That is because different components of the galaxy often have slightly different centers-of-mass (e.g., in spiral galaxies, most of the neutral hydrogen is in the disk and not the central bulge or nucleus, and the nucleus can be moving with respect to the center of mass of the whole galaxy with a small velocity as is probably the case in our own Milky Way). It's also often the case that measurements of different features in a galaxy or quasars will give different velocities (different spectral features, that is) because of internal motions, infall, outflow, etc. There are well-known offsets of several hundred km/s between the quantum mechanically permitted and forbidden emission lines in active galactic nuclei because of source geometry.

Dr. Huchra has completed many galaxy surveys and is an expert in the observational difficulties.