

Cosmology and Ethics

Mark A. Bullock 3/15/05

The night sky is a primal wonder. More than anything else in our immediately-sensed environment, the infinity of the night sky spurs a longing to understand our own existence. Realizing that we are beneath a vastness and majesty beyond our own experience impels us to know ourselves and our place in all that there is. This is a religious impulse, perhaps *the* religious impulse. It is also the impulse of cosmology.

From Astronomy to Cosmology

Cosmology is, however, a uniquely modern science of the history, structure, and dynamics of the universe. Although "astronomy" is a transliteration from the Greek, the word "cosmology" is a 17th century coinage on the basis of an imaginary Greek term. It thus denotes a new, uniquely scientific way to deal with the primal wonder about the night sky, one designed to replace those myths which were the primordial efforts to respond to such wonder.

The myths upon which traditional societies were built were inspired by and speak to the origins of humankind and its place in the Universe. Because the nature of the firmament is unknowable via our direct senses, these myths were until recently untestable and therefore perennial. The birth of technology changed this. Tools that take advantage of natural laws and allow us to manipulate those laws changed what was knowable. Systematic observations of the motion of the planets, motivated by Tycho Brahe's (1546-1601) desire to find God's perfection in the sky, led Johannes Kepler (1571-1630) to a model of the solar system with the Sun at its center. Timepieces and levers set the stage for Isaac Newton's (1643-1727) grasp of gravity and its implications for the cosmos. Newton's Calculus, a kind of conceptual technology, captured physical law with a generality and precision of breathtaking scope.

Today, fossil light from the beginning of time is collected by immense machines, both on Earth and in space, and analyzed electronically to reveal the most intimate details of the Universe and its beginnings. Modern cosmology weaves a creation story that passes the tests of science. The same methodology that has decisively laid out for us physical truth and the ability to control nature has allowed us to know the extent and origin of all that there is. In doing so, the inevitable imperial nature of science takes over, displacing the old myths with cold certainty, loosening the ground beneath religions, belief systems, and structures of morality. As science replaces these old, foundational beliefs in its sweep of globalization, it becomes complicit in the moral confusion of our age.

Can Heaven survive the heat death of the Universe? Will the cherished views of countless cultures that have gone before us, on the origin and meaning of human existence be another casualty of modern science? As astronomers divine the mysteries of the origin and evolution of the Universe, are they culpable for the elimination of world views that may have had very real purposes, but did not stand up to the scrutiny of scientific methodology?

The Emergence of the Big Bang Theory

In 1929 Hubble announced his discovery that the recessional velocities of galaxies were proportional to how far away they were. The furthest galaxies were receding the fastest, as measured by the Doppler shifts of their emitted light. The constant of proportionality became known as the Hubble constant. The implications of this relationship are profound. The simplest way to explain it is that at some time in the very distant past, all the galaxies were packed together. The reciprocal of the Hubble constant is approximately the age of the Universe -- about 14 billion years.

But how far back in time can we see? What immense, sophisticated, and expensive instruments are required to see something so esoteric as the first light of the Universe? In fact, you can see the radiation from the explosion of the Big Bang in almost every living room in the U.S, in almost any household in the world. Unplug the cable from your television set and adjust it to a channel where there is no broadcast. Part of that chaotic, somewhat disturbing pattern, known as 'snow' is the microwave echo of the Big Bang, released when the Universe became transparent 200,000 years after it was born.

In 1965, Arno Penzias and Robert Wilson of Bell Laboratories were working on a state-of-the-art antenna for the emerging technology of satellite telecommunications. Wherever they pointed their antenna in the sky, they heard a constant hum. In one of the most extraordinarily serendipitous discoveries in science, the Cosmic Microwave Background (CMB) radiation had been found, and at a frequency exactly in agreement with the theory of the Big Bang (Sciama 1973). Since the Big Bang, space has been cooling as it expands. If we run the movie of the Universe's evolution backward to the point where all the galaxies coalesce, we find that the 'primeval egg' began expanding at nearly the speed of light 14 billion years ago. From the inferno of creation to now, thermodynamics predicts that space should have cooled to 2.7 degrees Celsius above absolute zero. The frequencies Penzias and Wilson heard in the Cosmic Microwave Background correspond to exactly this temperature.

Cosmology and nuclear physics began to merge when scientists started to consider the first three minutes of the Universe, a point made vividly clear in Steven Weinberg's book, *The First Three Minutes: A Modern View of the Origin of the Universe* (Weinberg, 1977). During this time, all the fundamental particles, the neutrons, protons, and electrons that make up atoms, and the rest of the fundamental particle zoo, were formed. As the Universe expanded and cooled mostly hydrogen nuclei were formed, but some fraction of them teamed with neutrons to make helium, deuterium, and lithium. According to nuclear physics, the relative amounts of each of these elements are quite sensitive to the conditions of the early Universe. From this period of nucleosynthesis right after the Big Bang, nuclear physics predicted that the Universe should have been formed with about 76% hydrogen, 24% helium, and less than 1% heavier elements. In a stunning success for the Big Bang theory, spectroscopists have shown that wherever we look in the Universe, these ratios prevail.

With the evidence in hand: (1) Hubble's observation that the Universe was expanding (2) The measurement of the Cosmic Microwave Background, and (3) The correct prediction of nucleosynthesis during the first three minutes of the Universe, the Big Bang is now accepted as the real story of our Universe. But there have been some adjustments to it in the past few years.

The Structure of the Universe

A map of the Universe as it is currently understood is shown in Fig. 1a (Gott *et al.* 2004). The bottom of the chart is the center of the Earth and the top of the chart is the farthest we can see, the Cosmic Microwave Background. The scale is logarithmic, so that any given quarter inch on the chart represents 10 times the distance of the quarter inch below it. Two populations of artificial satellites populate space immediately above the Earth: Low orbit satellites at about 200 miles, and geostationary satellites at 23,000 miles. They are the green dots. The planets, asteroid belt, and Kuiper belt can be seen in the bottom half of the chart. The Kuiper belt is a vast ring of large comets that orbit the Sun outside Pluto. Midway on the chart is the Oort cloud, a much larger spherical shell of comets, loosely bound to the Sun. Nearby stars, galactic stars, and the center and edge of our galaxy follow as we move outward. The Milky Way is part of the 'local group', a loose collection of about two dozen galaxies that are gravitationally bound. Beyond that is the large scale structure of the Universe. Galaxies fill the heavens in these vast reaches, but they are not randomly placed. Not only do they form clusters, but there are also coherent structures that are significant fractions of the size of the Universe. The 'Great Wall' is one such structure – a long filament of galaxies that is 300 million light years from Earth. In fact, the large scale structure of the Universe is foamy and filamentary, as shown in Fig. 1b (Gott *et al.* 2004). In this figure, each point represents a galaxy – the foamy nature of the Universe can be seen out to 2.7 billion light years in this diagram. The foam seems to become less dense as we go out from the Earth, or, equivalently, further back in time. In fact, it extends as far back as we can see. The blank wedge-shaped regions are places in the sky where we cannot see out of our galaxy. This is the plane of the Milky Way.

The foamy structure of the Universe must be indicative of the small, quantum asymmetries that were imparted during the Big Bang itself. One can imagine that a perfectly spherical explosion would result in a smooth, uniform Universe with no structure at all. But somehow, small asymmetries must have been present, and amplified by the force of gravity as the Universe evolved and expanded. However, the structure that is seen is not consistent with the amount of matter and energy that we see in the Universe. There doesn't appear to be enough gravity to hold it all together, which is where 'dark matter' comes in.

Dark Matter

The direct evidence for dark matter is simple. Galaxies usually exist in gravitationally bound clusters of a few to several dozen. The motion of the galaxies around their common center – and this is simply Newtonian physics -- is completely inconsistent with the amount of matter that we see. The motion of the individual galaxies within a cluster can only be explained by the existence of an additional, strong gravitational field. In fact, every galaxy or cluster must have a spherical halo of matter around it that is undetectable with electromagnetic radiation, but is 5 times more abundant than the matter in the galaxies themselves. Little else is known about this mysterious cold dark matter, but its existence is generally accepted and there is a vigorous scientific effort to detect it directly.

The Cosmic Microwave Background and Dark Energy

The microwave background has structure, too. If the Universe began as a microscopic primeval egg, it must have been undergoing vigorous quantum fluctuations in energy, shape, and even dimensionality. The imprint of those quantum fluctuations is seen in the spatial structure of the microwave background shown in Fig. 2. To an incredible degree, however, (about 1 part in a million), the microwave background is uniform. This implies that at one time, the Universe was small enough that it could come to thermal equilibrium, but then grew rapidly, freezing in both the large scale isotropy and the quantum fluctuations. This freezing in would have happened during an 'inflationary' period, when the Universe accelerated outward at an exponential rate. This is a decidedly non-intuitive move for a Universe to make. What caused the Universe to accelerate in the first place? In the old 'Standard Model' of the Big Bang, without inflation, a prime mover is required, but it is only at the instant of creation. The explosion casts matter and energy outward, expanding under this initial, unimaginable force, but eventually slowing down as gravity worked to pull everything back to the center. The central question in cosmology for last half of the 20th century has been, "What is the density of the Universe"? If the density is too low, gravity will never win and the Universe will expand forever. If the density is high, beyond a critical point, the Universe will eventually slow to a stop and begin to fall in on itself. The end is the 'Big Crunch', perhaps followed by reincarnation as the cycle begins all over again. Neither of these scenarios appears to be the likely fate of our Universe, however, based on the smooth nature of the microwave background radiation. Instead, the Universe appears to exist in a state just in between these, like a penny that has landed on its edge. It seems that the Universe is flat, a spacetime geometry that means the Universe will continue to expand forever, albeit more and more slowly, approaching a stop at t equals infinity. The problem is that when we add up all the mass and energy and dark matter, the Universe is shy of the total amount required for a flat geometry by a factor of two.

Here is where two problems are solved at once by the inflationary theory. There are quantum mechanical reasons to suspect that the vacuum itself has energy. That is, there is some underlying fabric that wildly undulates, popping fundamental particles into existence from nothing and swiftly returning them to the weave. These particles have been observed, although the nature of this fabric and the energy it imparts to the vacuum remain entirely mysterious. At one time, Einstein postulated such an energy, which he inserted into his equations as a cosmological constant. His motivation was to produce a model of a steady state universe, infinite and isotropic in time and space, largely because he felt this was more aesthetically reasonable than a Universe that began with a Big Bang. Although Alexander Friedman showed that the Big Bang was a valid solution to Einstein's equations, Einstein abhorred it. But he abhorred the *ad hoc* adjustment to his equations even more, and when the empirical evidence for a Big Bang could not be ignored, he declared the cosmological constant his biggest mistake. Now, on new empirical grounds, it must be included again, although a fundamental theory of its origins will probably require the achievement of a Grand Unified Theory, a theory of everything, that string theory seems to promise for the future (Greene 2003).

This quantum vacuum energy is called the dark energy, and there is twice as much of it as everything else that we can see and measure. The dark energy has been implicated in the inflationary era of the Universe. It may have been the driving force.

Still, aside from problems with identifying the quantum vacuum energy with the missing energy of the Universe, the invention of the dark energy itself seems contrived.

There has, however, been an extraordinary discovery in the past five years whose status has steadily increased. From very carefully measuring the red-shifts, and hence recessional velocities of galaxies deep into the Universe, cosmologists have been able to map the evolution of the expansion rate of the Universe. What they found, to everyone's astonishment, is that although the Universe slowed down steadily after inflation, due to gravity, about 5 billion years ago *it began to speed up again* (Greene 2003). Today, the Universe is not only expanding, but its expansion rate is increasing. The Universe is accelerating, and something must be causing it. The culprit is the dark energy that permeates the vacuum.

The Story of The Creation

The most modern creation story, which has developed only in the last decade, is surely not the final answer. A final theory will only emerge when there is a full understanding of how gravity is related to the other three forces, and when the theories of gravitation and quantum mechanics are united. Enormous conceptual progress has been made with the development of string theory and its big brother, M (or membrane)-theory. String theory envisions particles as one-dimensional strings, vibrating not only in our known Universe, but also within 6 other hidden dimensions, curled too small to see but existing at every point in space (Greene 2003). The extraordinary and bizarre claims of this theory will not be discussed here, but it will be noted that a majority of cosmologists and theoretical physicists consider string theory to be the most promising, testable avenue for developing a true 'Theory of Everything'.

In the beginning there was an incredibly hot, multidimensional nugget, about one Planck scale (10^{-33} cm) in length. According to string theory, this Planckian egg is the smallest that anything can be. Squeezing it tighter makes it bigger and cooler. String theory avoids the singularity of the conventional Big Bang theory by considering the behavior of matter and energy at the very finest scales. It cannot yet say, however, what may have existed before this state, although this is currently a vigorous area of research. The nugget had the entire mass of the Universe in it, and it was rapidly and randomly undergoing transitions in its 10-dimensional topography. Between 10^{-36} and 10^{-34} seconds after the start of time three dimensions suddenly broke free of their confining strings, and inflated ferociously in a violent, exponential expansion. Alan Guth of M.I.T. first showed that inflationary expansion of the Universe was a particular solution to Einstein's equations, and that it explained a deeply perplexing aspect of the Cosmic Microwave Background, its overall isotropy. The remaining dimensions stayed curled together, fundamentally influencing the nature of the particles and forces that become manifest in the three macroscopic dimensions. At one hundred-thousandths of a second, quarks began to clump into protons and neutrons. Meanwhile, as the Universe cooled, something strange was happening to the force within it. It was born with only one force, but as it cooled, it underwent phase transitions, whereby new forces were cleaved from the original one. Ultimately, for reasons far from understood, the Universe ended up with four forces: gravitation, electromagnetism, and the weak and strong nuclear forces. From one hundredth of a second to 3 minutes after the big bang, the elements were formed. At 200,000 years, the Universe had cooled enough that

stable atoms could form. In other words, the Universe cooled from a plasma to a gas, and became transparent. The photons streaming outward at that time are the blips we see on our TV sets. Perhaps a billion years after the Big Bang, galaxies began to form. The Universe continued to expand at close to the speed of light, but gravity's relentless action caused its expansion to slow. However, nine billion years after the origin of the Universe, its expansion began to accelerate, most likely due to the repulsive force of the quantum vacuum energy. If this trend continues, the Universe's acceleration will cause galaxies to fly ever more rapidly away from each other. Someday, even the closest galaxy will be too far away to see; they will be beyond our light horizon. Someday, all the fuel for stars will be used up, first the hydrogen, then helium, carbon and oxygen, until the last sun flickers and the Universe is plunged into eternal darkness.

The Ethical and Political Dimensions of Cosmology

For many scientific disciplines, the cause-and-effect relationship between scientific outcomes and the well being of people is of extreme importance. Simply put, scientific results and their technological progeny are the dominant forces shaping our world's future. What role science will play in determining the quality of life for every human being on the planet is, of course, determined by the elite that funds it. In this way, all of scientific enterprise is embedded in the greater moral problem of how individuals and groups should conduct themselves. Is it better for the powerful to channel their efforts solely for competitive self-benefit, or to distribute knowledge and technology among all people? What are the consequences of pushing technologies on societies that may not want them? For some fields, these issues spring immediately from contemplating the promise and implications of their projects. If we can choose the human qualities of a future person through genetic engineering, who is to decide what these will be, and to whose progeny they will go? Other subjects may be further afield, but the stunning conceptual shift forced on us by the quantum nature of the infinitesimal in the 1920's has led to by far the most transforming technology in history: electronics.

Cosmology evokes a sense of the most benign, most *pure* of sciences. The fascination of contemplating what's out there, combined with the fact that we can't *do* anything to it lends the study of space its alluring innocence. That of course, is the old view – cosmology today is coming dangerously close to asking God some rather direct questions.

To some degree, scientific disciplines can be categorized by how influential ethics is thought to be in the field. Indeed, the ethical weight of astronomy, compared with that of genetics, lends it a kind of lightness and purity, which is perceived by the people who fund it. Virtually everyone on the planet has at one time or another gazed up and rested briefly in that human space where we wonder what it all is and what it all means. The pursuit of these wonders feels ennobling, partly perhaps because of the human space it comes from, and partly because it is difficult to imagine how contemplation of the stars above us could remotely alter our own fate.

The modern science of cosmology is perhaps as far removed from the day to day concerns of humanity as any human endeavor could be. Futurists may conjure colorful uses for the discoveries of scientific research on the nature and origin of the Universe, but we are not dealing here with transistors or life-extending drugs. No one argues that cosmology is studied because of its economic impact. Does this mean that the study of

the Universe *has* no economic impact? Not at all. The latest discoveries in astronomy have always depended upon progress in computer, space, and detector technology (Tegmark 2002). Synergism between the astronomical sciences and industrial and military concerns is strong and growing. Both enterprises benefit.

Conclusion

As self-aware beings, we share a special, emergent property of the Universe -- consciousness. Is the quality of this aspect of Nature in some way different from, say, the way space is curved from the distribution of mass in the Universe? What is special about the way living, replicating systems employ available resources to thrive, to evolve, and to produce beings that are capable of probing the deepest questions about their existence? Is mind a statistically unlikely property to emerge from a Universe with 1,000,000,000,000,000,000,000 solar systems? Or is the quality of mind something ubiquitous and unifying – like gravitation or other universal physical laws? Science is now engaged in exploring the origin and nature of the Universe like never before, and possibly the role of life and consciousness within it.

Every culture has or had a cosmology. Science has become the *sine qua non* of truth, and its revelations today are taken as gospel. Science's insights into the nature of the Universe are therefore assumed to or allowed to subsume all prior knowledge. It is incumbent upon all scientists to ask if their work speaks to living together in harmony, or whether it interferes. Where is the role of heart or spirit in the exploration of the cosmos, or for that matter, in any scientific endeavor? The scientific study of the origin and structure of the Universe is an incredible journey, yielding answers to questions that were once the purview of religion and myth. What is done with this knowledge, and what its ultimate meaning for us may be, should be an essential component of the science of cosmology.

References

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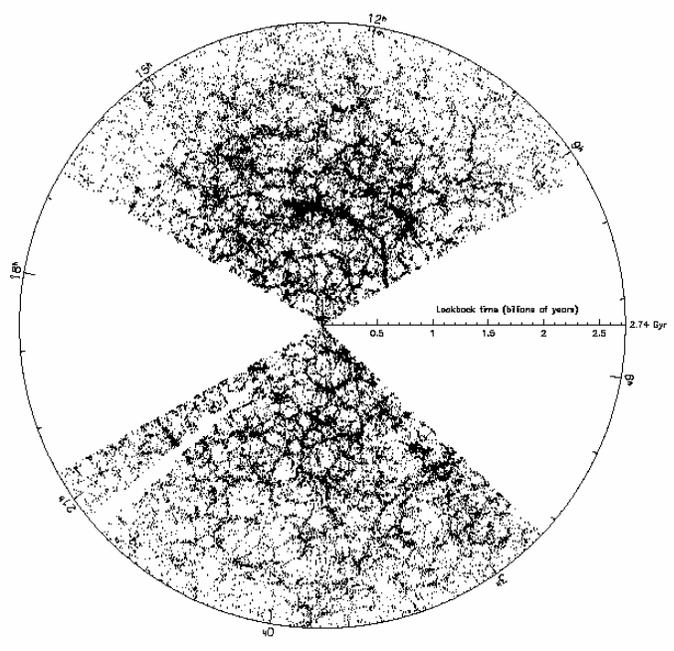
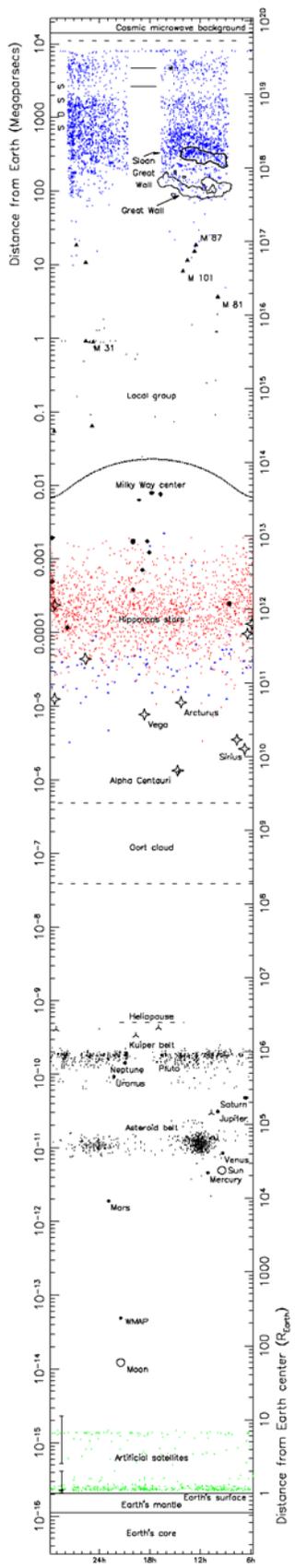
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Figure Captions

Figure 1a. A map of the Universe (Gott *et al.* 2004). The vertical axis is distance on a logarithmic scale. At the bottom is the center of the Earth, and at the top is the most distant feature of the Universe, the Cosmic Microwave Background.

Figure 1b. A map of the Universe out to 2.74 billion light years from the Earth (Gott *et al.* 2004). The scale is linear. Galaxies are represented by dots; the large scale, foamy, bubbly, filamentary structure of the Universe is visible. The blank wedges on the left and right are due to our lack of ability to see outside our own galaxy in these regions. They are in the plane of the Milky Way.

Figure 2. The afterglow of the Big Bang. This image is a map of the very edge of the Universe – looking so far back in time and space that all we see is the heat from the creation cataclysm. The Universe has expanded and cooled since then, leaving all of space at about 2.7 degrees above absolute zero. This remarkable image shows variations in the temperature of that fireball that encode the properties of the earliest moments of creation. Within this light are infinitesimal patterns, quantum fluctuations in the microscopic universe that mark the seeds of what later grew into clusters of galaxies and the vast structure we see all around us. Temperature varies by only millionths of a degree, but theories about the evolution of the universe make specific predictions about the extent of these temperature patterns. This portrait of the microwave background radiation was taken by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft in 2002. The observed temperature variations strongly support the Big Bang, Inflationary model of the origin of the Universe, and point to an age for the Universe of 13.7 billion years. Credit: NASA/WMAP Science Team.



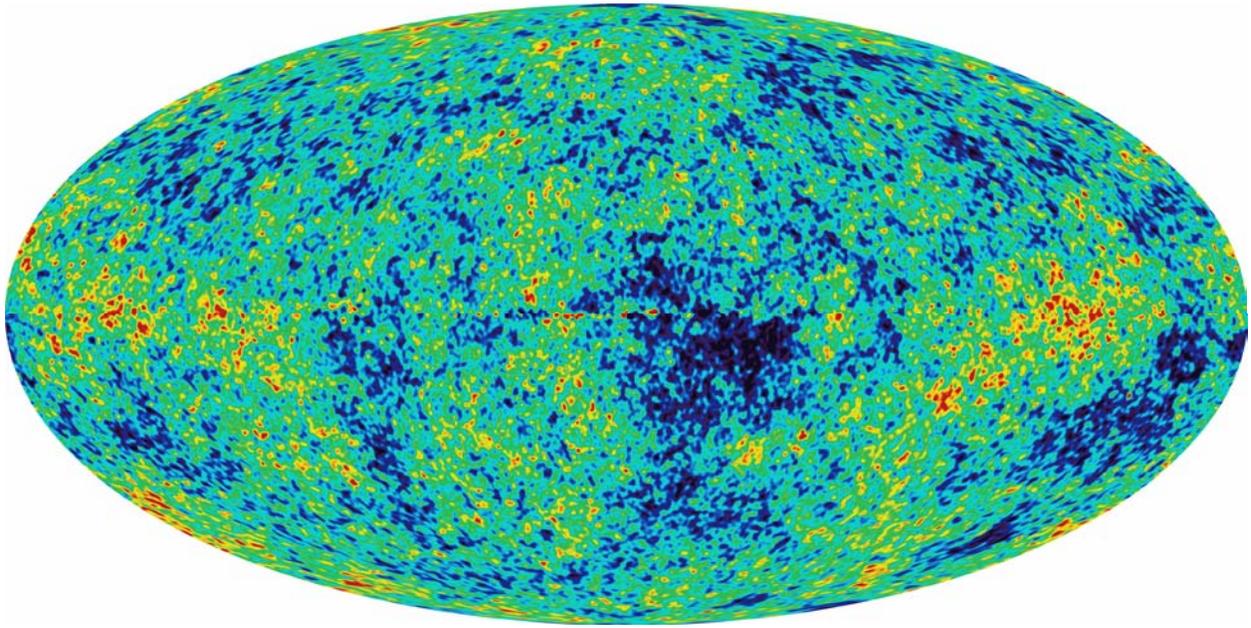


Figure 2.