# Genesis: Science and the Beginning of Time

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## ABSTRACT

Humankind has always been concerned with its origins, its place in the universe, and its future prospects. The Bible, a sacred epic, begins with: "B'reishit bara' Elohim et ha-shamayim v'et ha-aretz," or "*In the beginning, God created the heaven and the earth*." The first three lines, Genesis I:1-3, are an inspiring statement of creation. Modern science is attempting to understand in its own terms the evolution of our universe from "the beginning." This talk will explore what has been learned to date, and what more we hope to learn, using observation, theory, and computational simulations for our beginning, existence, and future.

## INTRODUCTION

[Musical background: "*In the Beginning God,*" Duke Ellington[1]]

*In the beginning*
*God created the heaven and the earth.*
*Now the earth was unformed and void,*
*And darkness was upon the face of the deep,*
*And the Spirit of God hovered over the face of the waters.*
*And God said: "Let there be light. And there was light."*

(Genesis I:1-3)

*"Mankind is led into the darkness beyond our world by the inspiration of discovery and the longing to understand."*

(President of the United States, George W. Bush, Sunday, February 2, 2003, mourning the loss of the seven crew members of the Shuttle Columbia)

Since the earliest humans first noticed the stars above us, we have longed to understand the heavens. They are still mysterious, but in the last century, we have substantially advanced our understanding. The purpose of this talk is to describe the discoveries, interpretations, and speculation that currently illuminate our perspective. We are privileged to live in an era where these fundamental questions can be addressed through experiment, theory, and computational simulations: "*…greatly advancing our understanding of the universe, the laws that govern it, and perhaps even our place within it.*"[2]

We shall start as close as we can come to the "Beginning," the origin of the universe, proceeding through the steps that modern science believes map the path from the beginning to the present to the future. We pass through epochs where observation and theory describe events critical to the evolution and future of our world. These epochs represent "The BIG questions" which we are now able to place in theoretical perspective, and in many cases, to probe experimentally. That the consequences of these primordial events are evident today shows how fortunate we are to live in this exciting period of discovery. There is so much more to learn, much of which will undoubtedly correct our conventional wisdom, if the future is anything like our past!

The Big questions are set out in Fig. 1. Our subsequent discussions will refer to each of the eight epochs that describe the physical path from the beginning to the present. The time periods are remarkable for their span: from the earliest, ten billionths of a trillionth of a trillionth of a trillionth of a second after the beginning, the "Big Bang",[3] to the latest, the present era, some four-hundred thousand trillion seconds (fourteen billion years) later, or a relative time scale of *sixty-one orders of magnitude*!

The road map, outlining the universe's journey from its origins, is illustrated in Fig. 2. It has not always been a smooth journey, from an initial period of *cosmic inflation*; to the origin of *ordinary matter* as we know it, comprising only 5% of the known energy of the universe; to the origin of *dark matter*, comprising another 30% of the known energy of the universe; to the birth of the first few elements of the periodic chart (H, He, Li); to the formation of the galaxies; to the origin of the chemical elements as we know them; to the present period where 2/3rds of the known energy of the universe is in a dark energy, which we have only very recently discovered; to destiny. These momentous events have taken place over $14 \pm 1$ billion years, with positions in time as shown in the upper part of the figure. The tools on earth and in the heavens that we use to stake out these cosmic signposts are listed in the lower part of the figure, along with the accelerators and telescopes of the future that will be needed to further guide our understanding.

The logarithmic time scale of Figs. 1 and 2 illuminates the richness of the earliest moments of our universe. Inflation took place perhaps ten trillionths of a trillionth of a trillionth of a second after the Big Bang; the origin of ordinary matter a hundredth of a millionth of a trillionth of a trillionth of a second after the Big Bang; the birth of the lightest elements three minutes after the Big Bang; and the formation of the galaxies and the heavier elements three hundred million years after the Big Bang.

It has been a momentous ride from the primordial fireball to our world of today. As we learn more of the richness of our creation, there will surely be surprises ahead. Destiny will follow from the present composition of the universe—dark energy, dark matter, and ordinary matter will inexorably determine our fate.

The epochs exhibited in Figs. 1 and 2 will be treated individually, with reference to experiments underway or planned that probe the present consequences of those events that transpired so long ago. Our insatiable curiosity drives these investigations [*"Almost in the beginning was curiosity"* (Isaac Asimov, 1965)]. Their consequences will change the way we think, aspire, and dream. They contribute to the fabric of our philosophy, and to the very meaning that science can provide to our existence.

For decades, the questions of how the universe evolved from t = 0 has touched the intellectual core of the fields of astronomy and physics. The size, age, and shape of the universe have been measured and its major constituents catalogued. In both astronomy and physics, the scientific focus is shifting from discovering "What?" to understanding "Why." It has become apparent that many of the new frontiers for both fields lie at the astronomy-physics interface. The Department of Energy's Office of Science research programs in high energy and nuclear physics have led many of the advances we have made so far, and they are strategically positioned to sharpen our understanding as we move forward. In addition, they are driving the development of many of the tools that will allow us to make progress in the decades to come. *"The study of the very large (Cosmology) and the very small (Elementary Particles) is coming together."* [4]

## I. The Beginning: Superstring Era

"*Prior to the existence of the universe, time did not exist.*" (Nahmanides[5])

We now believe that our entire visible universe began as a tiny dot[6] containing all of the energy that we see in the galaxies of brightly shining stars, and much more energy that we do not see. This incredibly hot dense state and its subsequent expansion is what we call the "Big Bang." The expansion was extremely rapid for the first tiny fraction of a second – an "inflationary" period. Space continued to expand more slowly for another 14 billion years, has grown immensely large, and is still expanding today.

It is important to note that it is *space itself* that is expanding. Albert Einstein taught us that space and time are properties of the universe, rather than a separate place in which the universe resides and an independent timeline along which events occur. A space-time continuum was created at the moment of genesis and has been expanding ever since. *There was no time before the universe began and there is no space beyond it.* The space-time of our universe is curved by the matter and energy it contains, a curvature whose effects we perceive as the force of gravity.

In these earliest times of our universe, the temperature was extremely high, ten trillion trillion times the current temperature of the interior of our sun, what we call the Planck temperature. At this stage, all forces were unified into a single force. In our current epoch, we see four fundamental forces of nature - the strong nuclear force (which binds quarks together to form protons, neutrons, and other particles), the weak nuclear force (with a very short range, typically 1/100 the size of an atomic nucleus, responsible for some kinds of radioactivity, such as beta decay), the electromagnetic force, and gravity. In the earliest universe, the laws of physics were simpler: they obeyed a beautifully symmetric simplicity called "supersymmetry."

The temperatures in this primordial universe were so high that all of the elementary constituents of matter -- quarks, neutrinos, electron-like particles, even those that today we can only produce with our highest energy accelerators and those that we cannot yet create here on earth -- were produced in abundance. The matter particles such as different quarks could swap identities and were indistinguishable from each other. "Unification and simplicity have been the eternal Holy Grail of physicists and artists: Aristotle wanted to reduce all substance to five elements; Picasso said that a painter should work with as few elements as possible." [7]

Physicists are now developing string theory, a new theoretical understanding of this primordial universe that promises to combine gravity with the three other fundamental forces of nature, a unification long sought by Einstein himself, but in vain. To accomplish this unification, extra spatial dimensions are required, in addition to our familiar three space dimensions and one time dimension. String theory also tells us that at this earliest stage, the universe was characterized by supersymmetry, and that each of the elementary constituents of matter (fermions) and force-carrying particles (bosons) that we know today had a supersymmetric partner of the other type that was copiously produced.

## II. Grand Unified Theory (GUT) Era

*"Now the earth was unformed and void,*
*and darkness was upon the face of the deep;*
*and the Spirit of God hovered over the face of the waters."* (Genesis I.2)

When the universe cooled below the Planck temperature, the elegant totally unified world ended. Gravity was now distinguishable, but the other three of the four fundamental forces of nature were still unified. That there is a temperature at which these three forces come together is a central tenet of the efforts to develop a Grand Unified Theory (GUT).

Because a GUT represents only three of the four fundamental forces (gravity is omitted), it cannot be the ultimate fundamental theory of nature. Further, "even the simplest GUT contains over twenty free parameters (i.e., numbers such as the charge and mass of an electron that must be measured experimentally before the theory can be used to make predictions). Most particle physicists believe that the ultimate theory will be much simpler, with few if any free parameters."[8] Nevertheless, this work provides grounds for the next development: the transition to a state where the strong force separated from the weak and electromagnetic, which remained together in the so-called *electroweak* force.

## III. Inflation Era (the ultimate free lunch[9])

*"…while a mighty wind (ruach elohim) swept over the waters."* (Genesis I.2 [10])

After the universe had expanded and cooled for just ten trillionths of a trillionth of a trillionth of a second, and the temperature "dropped" to one billion trillion times the temperature of the center of our sun, the elegant grand unified world ended. This cooling caused the remaining non-gravitational single basic force of the GUT era to split into the strong and electroweak forces. This was a phase transition like the transition from liquid phase to solid phase when water freezes. During this phase transition, the GUT field in a region of the universe entered into a "false vacuum" state, for reasons not yet established. A false vacuum is a not a stable state (we call it metastable) because it can tunnel quantum mechanically to an energy density minimum (a stable true vacuum state), but nevertheless can endure for a period long by early universe standards. Because the energy density in a false vacuum changes little, it corresponds to a negative pressure, which, by general relativity, generates a repulsive gravitational force.

This antigravity force caused the region to inflate at an astonishing rate, its size increasing enormously in an *inflationary epoch* of ten billionths of a trillionth of a trillionth of a second (a thousand times the lifetime of the superworld, but still a very short time). During this period, the energy density of the GUT field in the expanding region remained nearly constant, so that its total field energy grew rapidly with its increasing volume. The inflationary epoch ended when much of that field energy decayed into a hot "soup" of elementary particles. The universe then continued to expand, but at a much slower rate. It is possible that the new accelerated expansion we see today is also caused by a symmetry breaking, giving rise to a "*dark* energy." [11]

The huge growth in energy from nearly nothing seems to violate a key principle of physics, conservation of energy. However, when you consider that the growth of positive energy is balanced by the growth of negative energy stored in the gravitational field as the universe expands, the total energy of the universe can be conserved even as we get all that matter from nothing. It isn't really from nothing – it's "borrowed" from gravity. You could call it the ultimate free lunch[9] – or perhaps the ultimate long-term mortgage!

The corresponding inflationary influence of the more recent dark energy has been observed directly by two groups independently,[11] and may provide a window into the era of inflation. This epoch is the horizon of our current experimental investigations, for we are now making detailed maps of the next epoch called the electroweak era (see Sec. IV). We cannot yet access earlier epochs although, with searches for proton decay and hidden dimensions, we are beginning to try!

Between inflation and the electroweak era, the particles we know today parted company with their supersymmetric partners. Most of the supersymmetric partners decayed to lighter particles, but the lightest of them was presumably stable and should still exist in the universe. Physicists are searching for evidence of this lightest supersymmetric particle (LSP) in cosmic rays and are also trying to produce supersymmetric particles with colliding beams at accelerators. The Office of Science Fermi National Laboratory's Tevatron collides protons head-on with antiprotons, and the Large Hadron Collider (LHC) being built at CERN with substantial U.S. participation, will start colliding protons with protons in 2007. An electron-positron collider called the International Linear Collider is now being considered by nations in America, Europe, and Asia for construction as the world's next major high energy accelerator and, if built, will provide a key resource in the coming decades for detailed studies of such fundamentally new phenomena.

## IV. Electroweak Era

*"Earth with its mountains, rivers and seas,*
*Sky with its sun, moon and stars:*
*In the beginning all these were one, and the one was chaos.*
*Nothing had taken shape; all was a dark swirling confusion,*
*Over and under, round and round.*
*For countless ages this was the way of the universe,*
*Unformed and illumined,*
*Until from the midst of Chaos came P'an Ku…"*
("Heaven and Earth and Man," Chinese Myths and Fantasies)

A "long time" (a tenth of a billionth of a second) later, the universe had cooled down considerably, to only one hundred million times the temperature of the interior of our sun. This cooling produced another important phase transition—the separation of the unified electroweak force into its weak and the electromagnetic components. In addition, the *Higgs field* appeared throughout space. This field has not yet been observed, but it is expected to manifest itself in the form of a particle called the Higgs boson, responsible for the mass of the elementary particles that make up the matter in our universe. The Higgs boson has been the object of an intense search at the highest energy colliders. If its mass is low enough, the Tevatron may have enough energy to produce it within the next few years. If not, it could be found after the higher energy LHC begins operations in 2007. The discovery of the Higgs field would be a profound advance in physics, as it is believed to be the source of mass for all matter.

At about a millionth of a second, further cooling led to our very existence—the dominance of matter over antimatter. In this era, there were large numbers of thermal *quark-antiquark* pairs, 30 million *antiquarks* for every 30 million and 1 *quarks*.[12] Most of the antimatter has annihilated with matter, leaving only the one part in thirty million excess of matter to dominate the universe, as pictured in Fig. 3.

How do we surmise this?[13]

1. The Moon: Neil Armstrong did not annihilate, therefore the moon is made out of matter.
2. The Sun: Solar cosmic rays are matter, not antimatter.

3. The other planets: We have sent probes to almost all. The survival of these probes demonstrates that the solar system is made of matter.
4. The Milky Way: Cosmic rays sample material from the entire galaxy. In cosmic rays, protons outnumber antiprotons ten thousand to one.
5. The universe at large: If there were antimatter galaxies then we should see gamma emissions from annihilation. Its absence is strong evidence that at least the nearby clusters of galaxies (e.g. Virgo) are matter-dominated. Finally, causality prevents the separation of large chunks of antimatter from matter fast enough to prevent their mutual annihilation in the early universe.

Yet from accelerator experiments, we know that for each quark or lepton created in a high energy collision, its antiparticle is also created. Thus when these matter particles were created from energy in the early universe, an equal number of their antiparticles should also have been created. The particles and antiparticles should all have collided and annihilated each other, leaving only light, but in fact a net excess of matter survived. Something must have caused more matter than antimatter to be created in the early universe.

We believe a tiny asymmetry (*CP violation)* observed in the fundamental interactions of elementary particles played a key role in causing that matter-antimatter imbalance. Studies of CP-violating processes are underway now at the SLAC B Factory and a similar electron-positron collider in Japan. The challenge is to tie the CP violation we observe in the laboratory to the creation of quarks and leptons in the early universe. We may also get hints about the existence of the early superworld from high statistics experiments studying very rare decays at the B Factory. With data from an International Linear Collider, we could pinpoint the unification of forces and particles.

The net excess of matter took the form of extremely hot and dense plasma of quarks and leptons, as well as gluons (bosons that carry the strong force). After a few millionths of a second, the plasma had cooled sufficiently that the quarks could bind into separate *hadrons*, combinations of quarks bound by gluons, and survive. Protons and neutrons are the most familiar hadrons and combine to form the nuclei of atoms. We know that this phase change from quark-gluon plasma to hadrons took place, because no isolated quarks have ever been seen; they are prisoners for life inside hadrons. Experimenters at the Office of Science Brookhaven National Laboratory's RHIC collider are trying to give a few of these prisoners a brief parole, heating up the hadrons enough by smashing nuclei together at high energies to temporarily reverse the process and create tiny and short-lived samples of the quark-gluon plasma. Early results from this new research facility are encouraging nuclear physicists to hope that microcosms of the quark-gluon plasma may soon be produced and identified.

## V. Particle Era

*" Yes, my hand laid the foundations of the earth;*
*my right hand spread out the heavens.*
*When I call them, they stand forth at once."* (Isaiah 48.13)

When the universe reached the ripe old age of 1 second, and temperatures dropped to a refreshing one-thousand times the current temperature of the center of our sun, another important phase change took place - protons and neutrons fused together to form the light nuclei such as deuterium, helium, and lithium.  Heavier nuclei were not created until much later (a billion years), when the nuclear furnaces called stars were formed.  The very heaviest nuclei are only formed in the explosions of stars, brilliant supernovae whose light can be seen from across the universe.  Because humans need many of these heavy elements for life, we can truly say that we are made of stardust.  Experiments at accelerators are essential to study nuclear reactions among the many nuclear varieties (*isotopes*) that participate in fusion reactions in stars and supernovae.  Many isotopes live only for very short times and a proposed new Rare Isotope Accelerator facility (RIA) would provide beams of these rare isotopes to study how nuclei are formed in stars.

## VI. Recombination Era

*"And God said: 'Let there be light.'  And there was light."*  (Genesis I.3)

At about three hundred thousand years after t = 0, the temperature of the universe cooled to one ten-thousandth of the current temperature of the center of our sun, or about 3,000 degrees Centigrade.  At this lower temperature, the neutral atoms that had been forming from the combinations of nuclei and electrons, but immediately breaking up because of collisions, could now recombine and survive.  Prior to this point, photons of light scattering off free electrons scrambled their directions and were trapped in local regions.  However, this scattering did not disturb their energy spectrum.  After the recombination of nuclei and electrons, the previously trapped light was free to propagate across the universe.  This radiation was discovered in 1965 as a microwave background radiation reaching earth from all directions.  Observing this Cosmic Microwave Background (CMB) radiation allows us to compare the light coming from parts of the universe that are very distant from us and from each other.  The CMB reveals the distribution of matter in the universe as it was about half a million years after the Big Bang, before the creation of stars and galaxies.

We have unequivocal evidence for asymmetries in the CMB, on the order of one part in a hundred thousand, or 0.001%, from the 1992 Cosmic Background Explorer (COBE) satellite.  Such a small deviation from perfect smoothness may seem unimportant, but it is absolutely critical: the attractive effect of gravity acting over the past fourteen billion years has turned this tiny lumpiness into the structure that exists today.  Moreover, the level of lumpiness revealed by COBE and other experiments is just what is needed to account for the structure observed today, one of the great successes of hot Big Bang cosmology.[14]

## VII. Galaxy and Star Formation

*"And God set them in the firmament of the heaven to give light upon the earth,"*
(Genesis I.17)

About one billion years after the Big Bang, the temperature had cooled to 15 Kelvin (-258 degrees Centigrade), and the heavens as we know them took form. This condensation into stars and galaxies resulted from tiny quantum fluctuations present at the beginning and observable to us today from the fluctuations in the microwave background radiation. Without this "granularity," tiny though it was (0.001 %), our world would be a big uniform soup without the structure we see as stars and galaxies. Thus, our world can be traced back to the beginning, when the lumpiness of the early universe was the cause of our very existence.

But the world we see, the ordinary matter and energy that we know and understand, is only a tiny part of the mass and energy of the entire universe. Experimental evidence overwhelmingly convinces us that there is much more matter and energy in the universe than we can see. Fig. 4 displays the composition of the universe as we now think we know it. The stars in the heavens, combined together, form less than one-half of one percent of the mass and energy budget of the universe. Where is the rest of it?

We know from the acceleration of the expansion of the universe that dark energy comprises sixty five percent of the total mass and energy of the universe. But we do not know its physical origin or how it manifests itself as *anti-gravity*.

We know from studying the rotation of galaxies that a third of the mass and energy budget of the universe today is in the form of *dark matter*, which affects the motion of galaxies by gravity but emits no radiation. By studying the distribution of galaxies with the Sloan Digital Sky Survey, a ground-based telescope, we are studying the structure of dark matter on cosmic scales. With data from present and future ground-based telescopes, we can see *gravitational lensing*, the subtle distortion of distant images by the gravitational tug of dark matter. Dark matter cannot be explained as planets and burned-out stars, because they are much fewer and lighter than stars. It must consist primarily of weakly interacting massive elementary particles. Neutrinos are one example. They have recently been shown to have a tiny mass and could contribute as much as ten percent of dark matter. The lightest supersymmetric particle (LSP) mentioned above may also contribute to dark matter. Other experiments search for dark matter particles reaching earth as cosmic rays. Accelerator experiments are searching for many kinds of dark matter, but it remains a mystery waiting to be solved.

## VIII. Present Era

*"In the sweat of thy face shalt thou eat bread,*
*till thou return unto the ground;*
*for out of it wast thou taken;*
*for dust thou art,*
*and unto dust shalt thou return."* (Genesis III:19)

We believe the time of our modern era, the world as we now know it, is fourteen billion years after the beginning, at a temperature of 2.7 Kelvin, or—270.4 Centigrade. In as short a time as the last three decades we have, using accelerators and detectors in space and on the ground, come to a fundamental understanding of the constituents of matter that make up the visible universe. We have also come to realize that nearly all of the energy of the universe is manifested in forms that we don't understand: dark energy and dark matter.

The dark energy, possibly similar to that which caused the inflationary epoch described above, now dominates the universe, contributing nearly two thirds of its energy. Its outward push overcomes the inward pull of gravity and causes the expansion of the universe to accelerate rather than to slow down as was long believed. This surprising discovery of an accelerating expansion was recently made by studying supernovae,[11] and there are plans to launch a dedicated supernova telescope called SNAP into space to investigate dark energy much more thoroughly. By using supernova to map out the history of the expansion of the universe we can learn about the ends of time – both the earliest birth pangs like inflation, and the future destiny of our universe.

Most of the universe is invisible to us and full of mystery. There will be surprises as we continue to probe the beginning from our vantage point some fourteen billion years later. Our knowledge has evolved in discrete surprises. Thus, our very conception of the nature of our universe has changed, even over the time scale of decades. Fig. 5 uses a color guide to display the make up of energy and matter as we thought we understood it in the 1970's through the following decades to the present. The fact that dark energy and exotic dark matter now comprise 95% of our universe, while the galaxies of bright stars that fill the heavens are less than one percent, is a good lesson, compelling humility. "Our world," the universe that we see directly, is a mere sprinkling of visible matter on the vast reaches of dark matter and energy.

As we struggle to understand the mysteries confronting us, we are looking back in time ever closer to t = 0. We are constructing and planning a variety of new experiments that will allow us to probe ever closer to the moment of genesis. Telescopes and space probes, coupled with frontier accelerator facilities on the ground, are allowing us to make enduring and important scientific advances.

These are exciting times, and we anticipate that the investigations, led by the Office of Science, are going to change the way we think about the world we live in. It may be that in another decade, discoveries at the Large Hadron Collider (CERN in Switzerland) and the International Linear Collider (not yet under construction, and site not chosen) will confirm that we live embedded in a higher dimensional universe. Or, they may reveal new forces and new particles that we cannot now imagine. Cosmic ray, neutrino, and gravitational radiation observatories now under construction or being planned will open new windows to the heavens. Probes in space such as SNAP (SuperNova/Acceleration Probe) will allow us to investigate the nature of the mysterious dark energy that seems to surround us, and perhaps give clues as to its origins. New telescopes on the ground may help us understand what dark matter really is.

What we know is overwhelmed by what we don't know. We ask questions such as "What are we made of?" and "Where did we come from?" It is the essential optimism and, yes, fundamental arrogance of mankind that makes us believe we can discover the answers.

*Finis origine pendent*, wrote the poet Manlius. *The end depends on the beginning*. This is especially apt for the cosmos, where the mysterious dark energy is now accelerating the expansion of the universe, suggesting that the Big Bang may end with a lonely whimper.

*"Every man prays in his own language, and there is no language that God does not understand."* (Duke Ellington, 1965)

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[2] *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century*, Committee on the Physics of the Universe (National Academy Press, Washington, D.C., 2003), Executive Summary.

[3] Coined by F. Hoyle in a BBC radio series in the 1940s.

[4] Ref. 2, xvi. "The Committee on the Physics of the Universe dedicates this report to a dear friend and valued colleague, David N. Schramm. His vision, research, enthusiasm, and energy helped to open this blossoming area of research, and his strong voice helped bring it to the attention of astronomers and physicists alike." The quote is from a viewgraph in his own hand that concisely summarized his vision.

[5] *Genesis and the Big Bang*, Gerald L. Schroeder (1992, Bantam Books, New York), p. 58, referencing Nahmanides (Rabbi Moses ben Nahman, also known as Ramban, c.e. 1194-1270, Spain, Israel) *Commentary on the Torah*, Genesis I:4, 5.

[6] Schroeder's account (*ibid*, p. 65) of Nahmanides, *Commentary on the Torah*, Genesis I.1, reads: "At the briefest instant following creation all the matter of the universe was concentrated in a very small place, no larger than a grain of mustard."

[7] Alan Lightman, *Foreword, The Inflationary Universe*, Alan H. Guth (Perseus Books, Cambridge, 1997), p. xi.

[8] *The Inflationary Universe,* Alan H. Guth (Perseus Books, Cambridge, 1997), p. 135.

[9] *ibid*, Chapter 1.

[10] *The New American Bible*, Catholic Version of the Bible in English (World Bible Publishers, Inc., Iowa Falls, IA 50126, USA, 1987), p. 8. All other biblical quotations used in this text are from *Pentateuch & Haftorahs,* Second Edition (Soncino Press, London, 1960).

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[12] *The Early Universe*, Kolb and Turner.

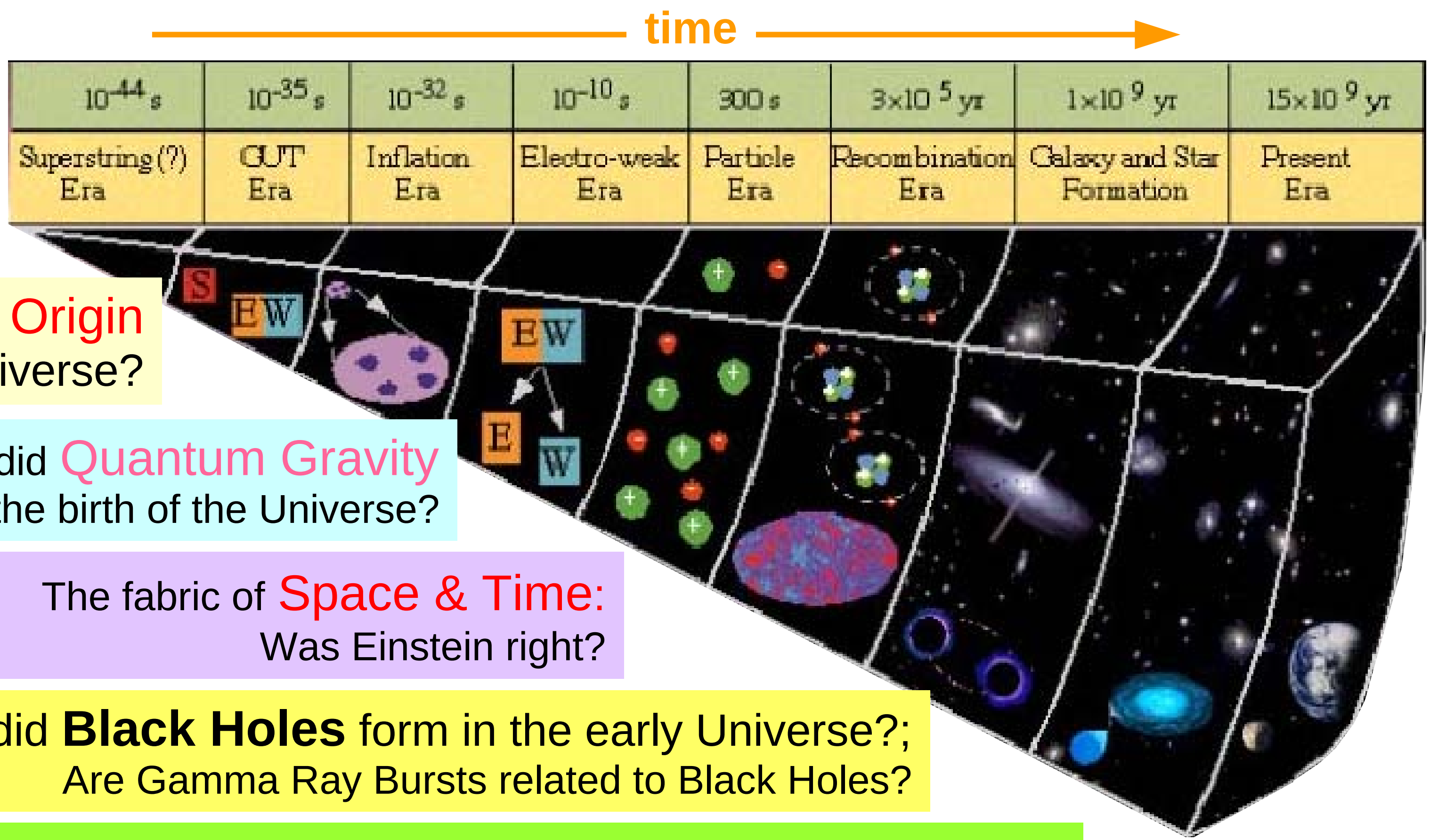
[13] "*Baryogenesis – Why Are There More Protons Than Antiprotons*," David Brahm, www.weburbia.demon.co.uk/physics/baryogenesis.html.

[14] Ref. 2, section 3.3

## FIGURE CAPTION

Fig. 1a. *The BIG Questions* (courtesy of Jonathan M. Dorfan). The epochs (Eras) are ordered by their time after the instant of the "Big Bang." Scientific units are used for the time of the beginning of each epoch. To translate to decimals, $10^{-10}$ s would equal 0.0000000001 sec, while $3 \times 10^{5}$ yr would equal 300,000 years (or $9.5 \times 10^{12}$ s, equal to 9,500,000,000,000 sec, or 9.5 trillion seconds). GUT stands for Grand Unified Theory. The strong force (red "S") and the unified electroweak force (orange "E" joined with the blue "W") are manifest in the GUT Era. The electroweak symmetry is broken in the Electro-weak Era, hence the separation of the joined orange "E" and blue "W" into separate orange "E" and blue "W". The BIG Questions are associated with their respective epoch.

# The BIG questions




?

What is the Origin of the Universe?

What role did Quantum Gravity play in the birth of the Universe?

The fabric of Space & Time: Was Einstein right?

How did **Black Holes** form in the early Universe?; Are Gamma Ray Bursts related to Black Holes?

What is **Dark Matter**? Does **Dark Energy** really exist?

How did **Galaxies** form? Which came first, Black Holes or Galaxies?

How does our star work? Is **Life** in our galaxy unique?

What is the **ultimate fate** of the Universe?

**FIGURE CAPTION**

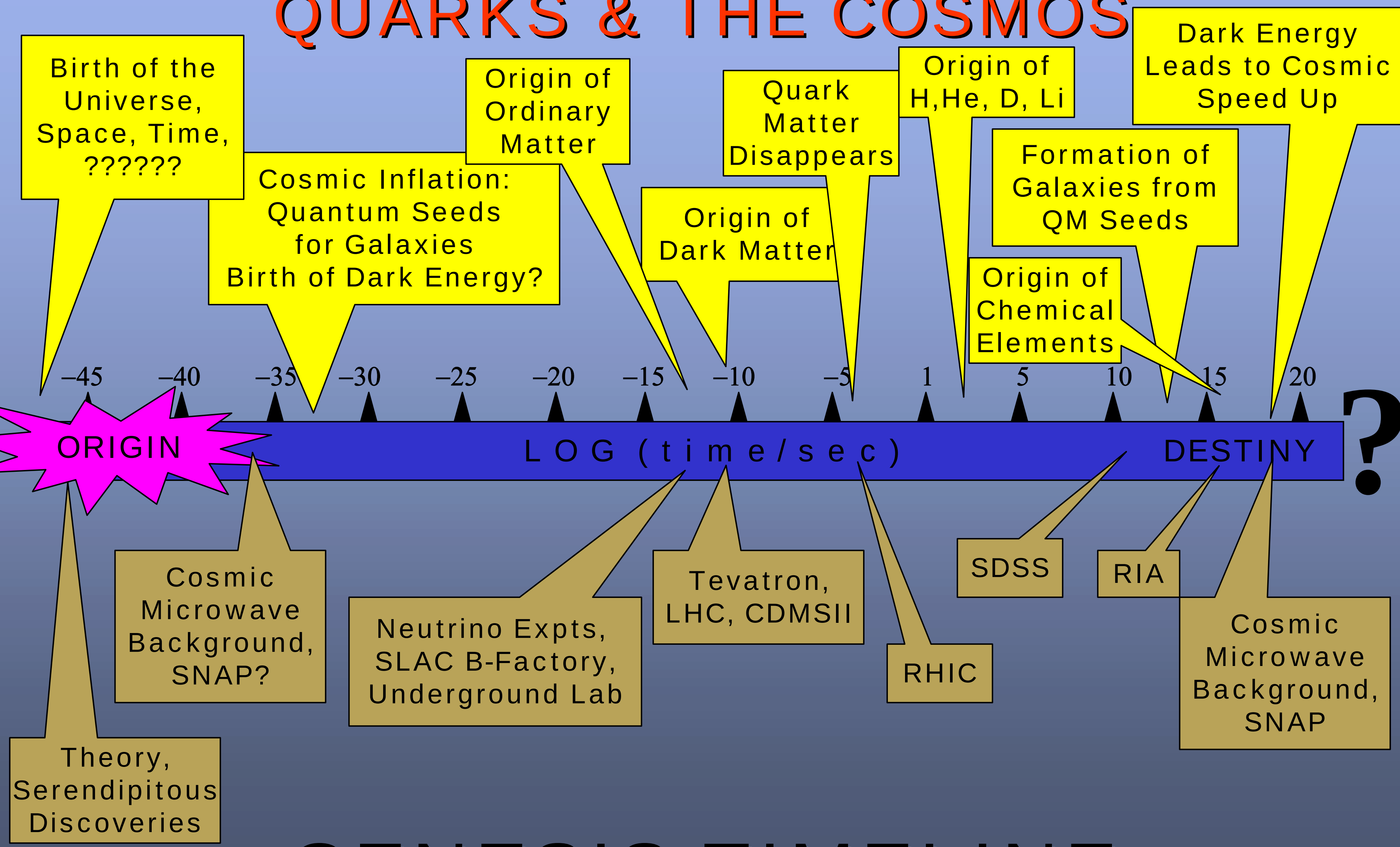
Fig. 1b. The table (courtesy of Jonathan M. Dorfan) translates time into more common language and exhibits the temperatures for each epoch. To relate to our present era, the temperatures for each epoch are also given in terms of the temperature of the center of our sun.

| | Superstring (?) Era<br><br>The Beginning | GUT Era<br><br>Separation of Gravity | Electro-weak Era<br><br>Elementary Particles | Particle Era<br><br>Matter over Antimatter | Recombination Era<br><br>Formation of Atoms | Galaxy/Star Formation Era<br><br>Formation of Heavy Nuclei | Present Era<br><br>Acceleration of Universe |
|---|---|---|---|---|---|---|---|
| Time (Sec./Yrs) | $10^{-44}$ s<br><br>ten billionths of a trillionth of a trillionth of a trillionth of a second | $10^{-37}$ s<br><br>one tenth of a trillionth of a trillionth of a trillionth of a second | $10^{-10}$ s<br><br>one tenth of a billionth of a second | $10^{2}$ s<br><br>one hundred seconds | $3x10^{5}$ y<br><br>three hundred thousand years = nine trillion seconds | $10^{9}$ y<br><br>one billion years = thirty thousand trillion seconds | $14x10^{9}$ y<br><br>fourteen billion years = four hundred thousand trillion seconds |
| Temperature (Kelvin) | $10^{32}$ | $10^{28}$ | $10^{15}$ | $10^{9}$ | 3000 | 15 | 2.7 |
| Temperature Relative to Center of our Sun ($10^{7}$ Kelvin) | ten trillion trillions | one billion trillions | one hundred millions | one hundred | one ten thousandth | one millionth | one ten millionth |
| Energy (GeV) | $10^{19}$ | $10^{15}$ | $10^{2}$ | $10^{-4}$ | $3x10^{-10}$ | $10^{-12}$ | $2.3x10^{-13}$ |

## FIGURE CAPTION

Fig. 2. *Deep Connections: Quarks & the Cosmos* (courtesy of Michael S. Turner). The time scale of Fig. 1 is used. The epochs, characterized by their physical characteristics (above the time line) have consequences for us in our epoch. Those consequences are being measured by experiments (below the time line) currently underway or planned. SNAP stands for SuperNova/Acceleration Probe, an orbiting space telescope with a two meter mirror and a wide-field camera of a billion pixels (a conventional electronic camera might have four million pixels). SLAC B Factory stands for the Department of Energy, Office of Science, Stanford Linear Accelerator, located in Palo Alto, California, which produces large numbers of B mesons. Tevatron stands for the proton/anti-proton collider located at the Department of Energy, Office of Science, Fermi National Accelerator Laboratory (Fermilab), in Weston, Illinois, outside of Chicago. Currently, this machine is the world's highest-energy physics user facility. LHC stands for the Large Hadron Collider, currently under construction at CERN, the European Organization for Nuclear Research, located near Geneva, Switzerland. CDMSII stands for Cryogenic Dark Matter Search. It is a search for the nature of dark matter, looking for the Weakly Interacting Massive Particle (WIMP), and is located in the Soudan mine, near Ely, Minnesota. RHIC stands for Relativistic Heavy Ion Collider at the Department of Energy, Office of Science, Brookhaven National Laboratory, located in Upton, New York. SDSS stands for the Sloan Digital Sky Survey, the most ambitious astronomical survey project ever undertaken, located at Apache Point Observatory, in New Mexico. RIA stands for the Rare Isotope Accelerator, a proposed project to probe unstable isotopes with an overabundance of protons or neutrons, which tend to decay quickly. It would serve as a roadmap for the creation of the heavy elements through the furnaces of supernovae.

# DEEP CONNECTIONS: QUARKS & THE COSMOS




# GENESIS TIMELINE

M.S. Turner, v2

## FIGURE CAPTION

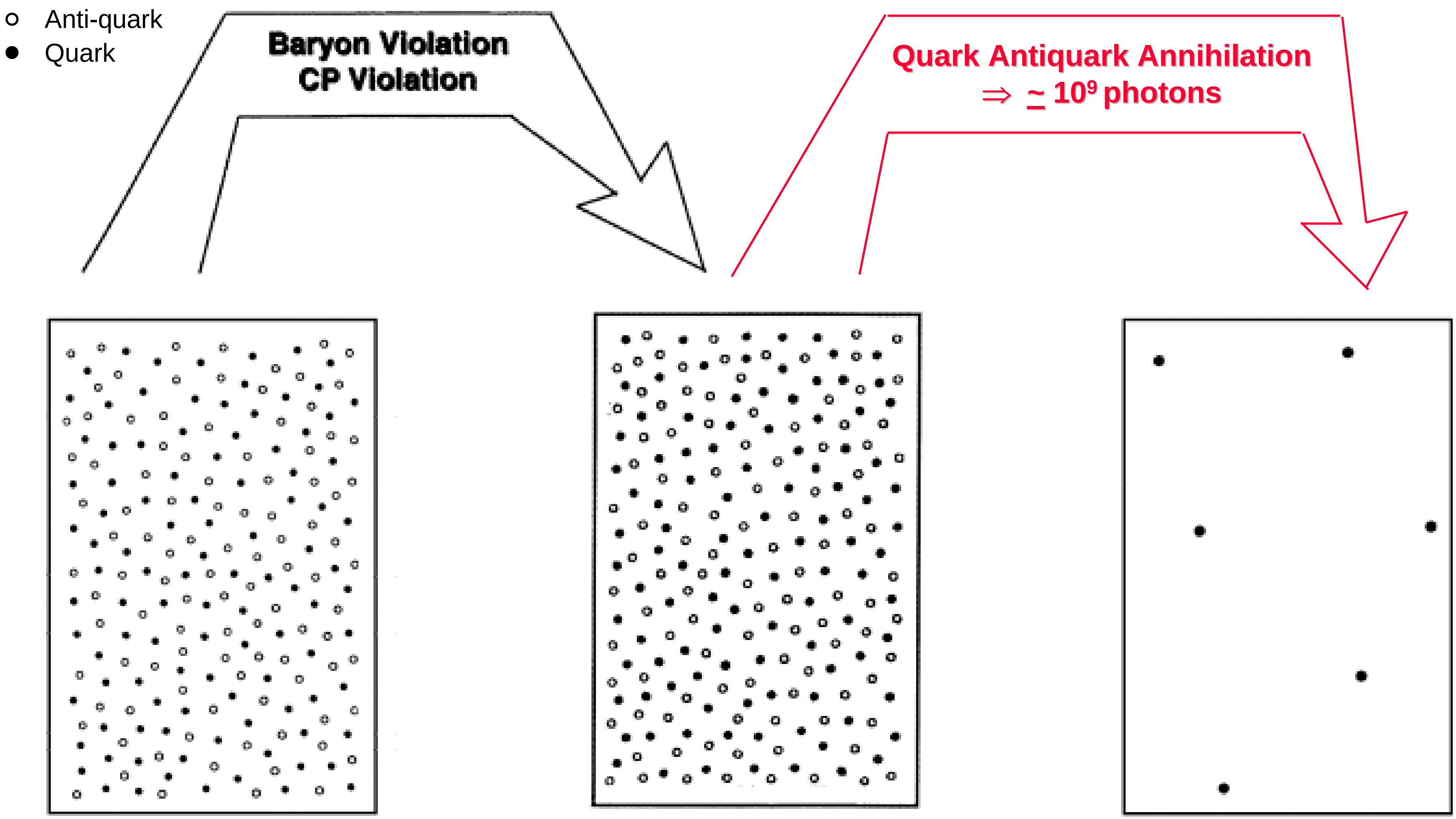
Fig. 3 *The First 1/1000 Seconds After the Big Bang* (courtesy of Jonathan M. Dorfan). A diagram of how ordinary matter came to dominate the universe as we see it. In 1967 Sakharov enumerated the three necessary conditions for us to exist [from David Brahm (www.weburbia.demon.co.uk/physics/baryogenesis.html)]:

1. **Baryon number violation** (A baryon is a massive, strongly interacting elementary particle, such as a proton or a neutron. Ordinary matter as we know it consists largely of baryons). This means that baryon number (B) cannot be conserved in all reactions if matter is to dominate over anti-matter.

2. **C (charge symmetry) and CP (charge times parity symmetry) violation.** There must be a preference for matter over anti-matter, or the B-violation will take place at the same rate in both directions, leaving only a tiny statistical excess, perhaps only enough matter to make one star in the observable universe.

3. **Thermodynamic Nonequilibrium.** Because CPT (charge times parity times time symmetry) guarantees equal masses for baryons and anti-baryons, chemical equilibrium would drive the necessary reactions to correct out any developing asymmetry. Hence there must be thermodynamic nonequilibrium conditions.

# The First 1/1000 Seconds After the Big Bang



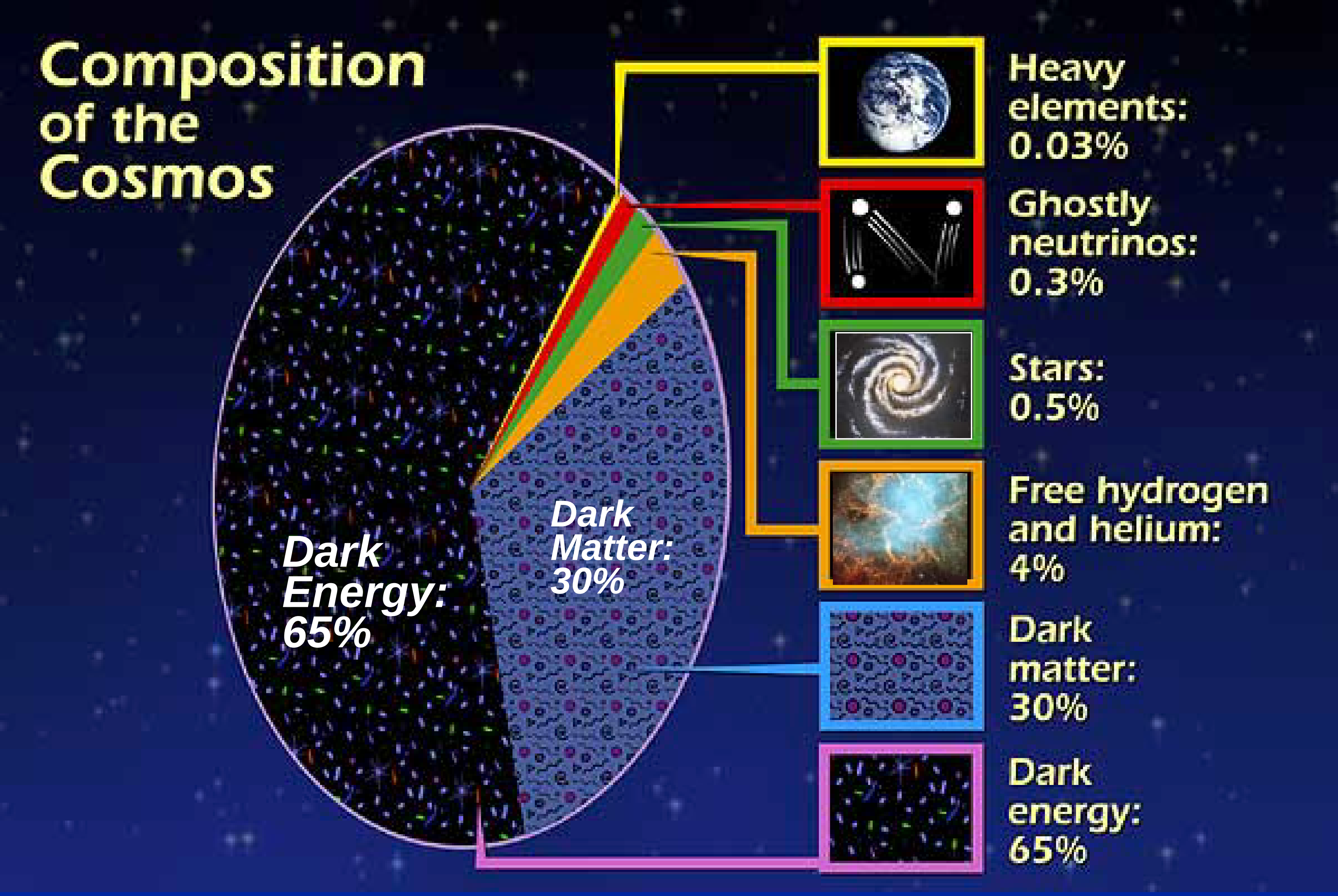

**$10^{-35}$ SECOND** — # Quarks = # Antiquarks

**$10^{-32}$-$10^{-4}$ SECOND** — Slight excess ~ few parts / $10^9$ of Quarks Over Antiquarks

**$10^{-3}$ SECOND - NOW** — Excess Quarks survive to produce protons, neutrons ie. Matter

## FIGURE CAPTION

Fig. 4 *Composition of the Cosmos* [(Illustration credit: Ann Field, Space Telescope Science Institute (STScI)]. The composition, as we now believe we understand it, of the universe. Dark energy (Sec. III), only recently discovered, accounts for two-thirds of the mass and energy budget of the universe, while exotic dark matter (Sec. VII) comprises thirty percent. The visible universe, as we see it, contributes less than half of one percent!



Composition of the Cosmos
Dark Energy: 65%
Dark Matter: 30%
Heavy elements: 0.03%
Ghostly neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: 30%
Dark energy: 65%

## FIGURE CAPTION

Fig. 5 *Our Changing View of the Universe* (courtesy of Jonathan M. Dorfan). Conceptions of the universe have changed sharply over the past few decades: from a comfort zone in the 1970's, where the universe was thought to be constructed entirely from "ordinary" dark visible matter; to today where exotic dark matter and dark energy, unknown thirty years ago, now comprise 96% of the total mass and energy budget of the universe! Concomitantly, the kind of matter we are made of accounts for only around 4% of the total mass and energy budget of the universe. "This may imply, as the Ptolemaic epicycles did, that we are lacking a deep enough understanding of the laws of physics underlying our universe. It is even possible that what we call dark matter and dark energy are the signatures of some unknown aspect of gravity or spacetime itself!" [Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century].

# Our changing view of the Universe