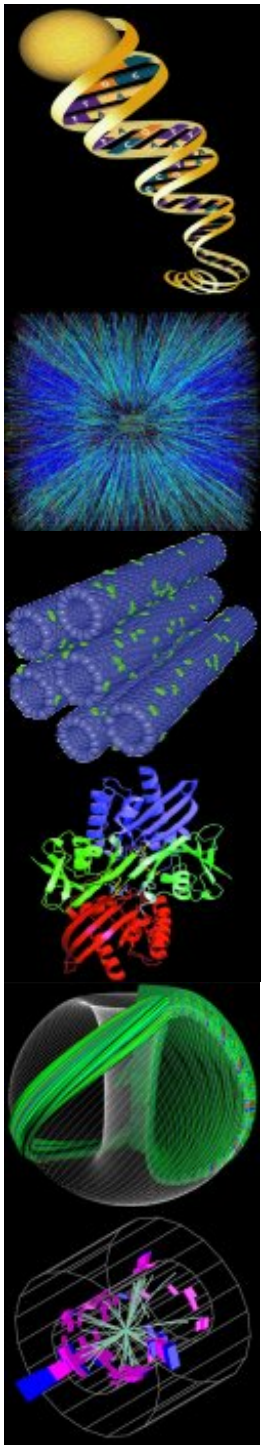

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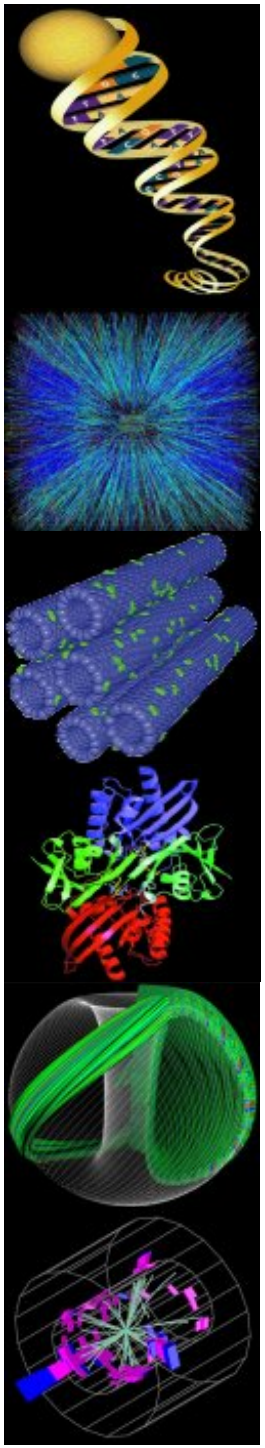
Genesis: Science and the Beginning of Time

Dr. Raymond L. Orbach
Director, Office of Science

World Year of Physics • Brown Bag Lunch Discussion
April 6, 2005



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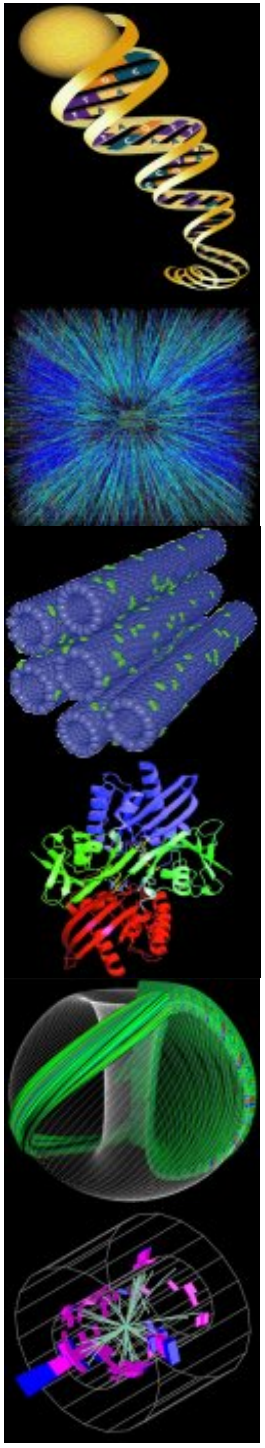
ABSTRACT

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 terms the evolution of our universe from "the beginning." This talk will explore what has been learned using observation, theory, and computational simulations about our physical beginning, existence, and future.



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"There is no way that you can look at the stars, at the Earth, at the moon, and not come to realize that there is a God out there who has a plan and who laid out the universe and the heavens."

Rick D. Husbands, Commander, Space Shuttle Columbia

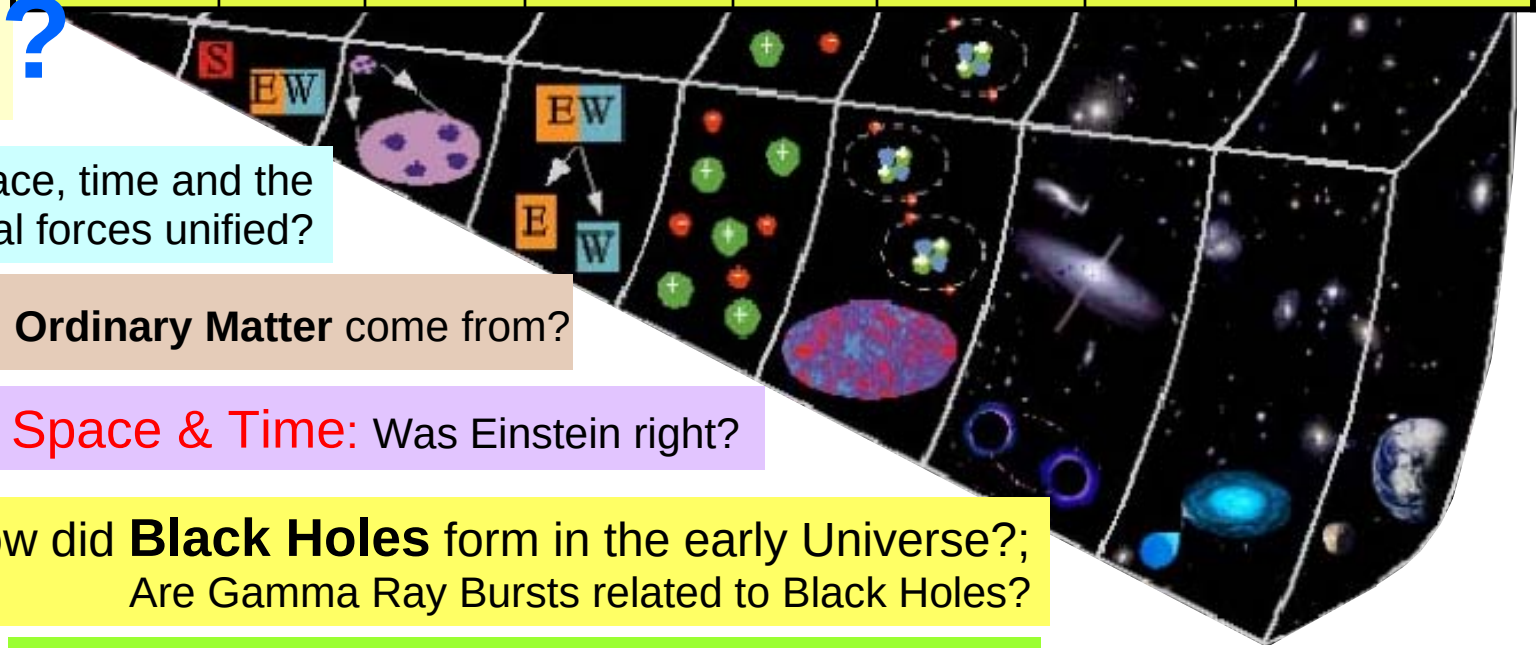
"Mankind is led into the darkness beyond our world by the inspiration of discovery and the longing to understand."

President George W. Bush
Sunday, February 2, 2003

The BIG questions

time

10^{-44}s	10^{-35}s	10^{-32}s	10^{-10}s	300 s	3.8×10^{5}yr	2×10^{8}yr	15×10^{9}yr
Superstring (?) Era	GUT Era	Inflation Era	Electro-weak Era	Particle Era	Recombination Era	Galaxy and Star Formation	Present Era



What is the Origin of the Universe? ?

How are space, time and the fundamental forces unified?

Where did **Ordinary Matter** come from?

The fabric of Space & Time: Was Einstein right?

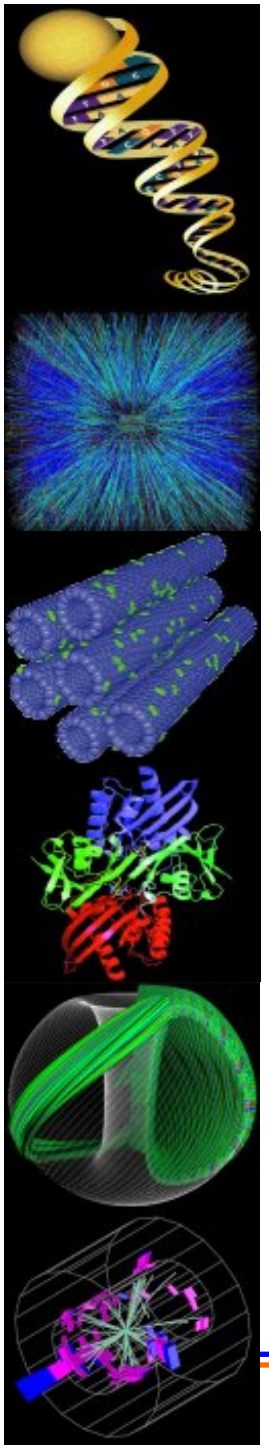
How did **Black Holes** form in the early Universe?;
Are Gamma Ray Bursts related to Black Holes?

What is **Dark Energy**? What is **Dark Matter**?

How did **Galaxies** form? What role did **Neutrinos** play in shaping the universe?

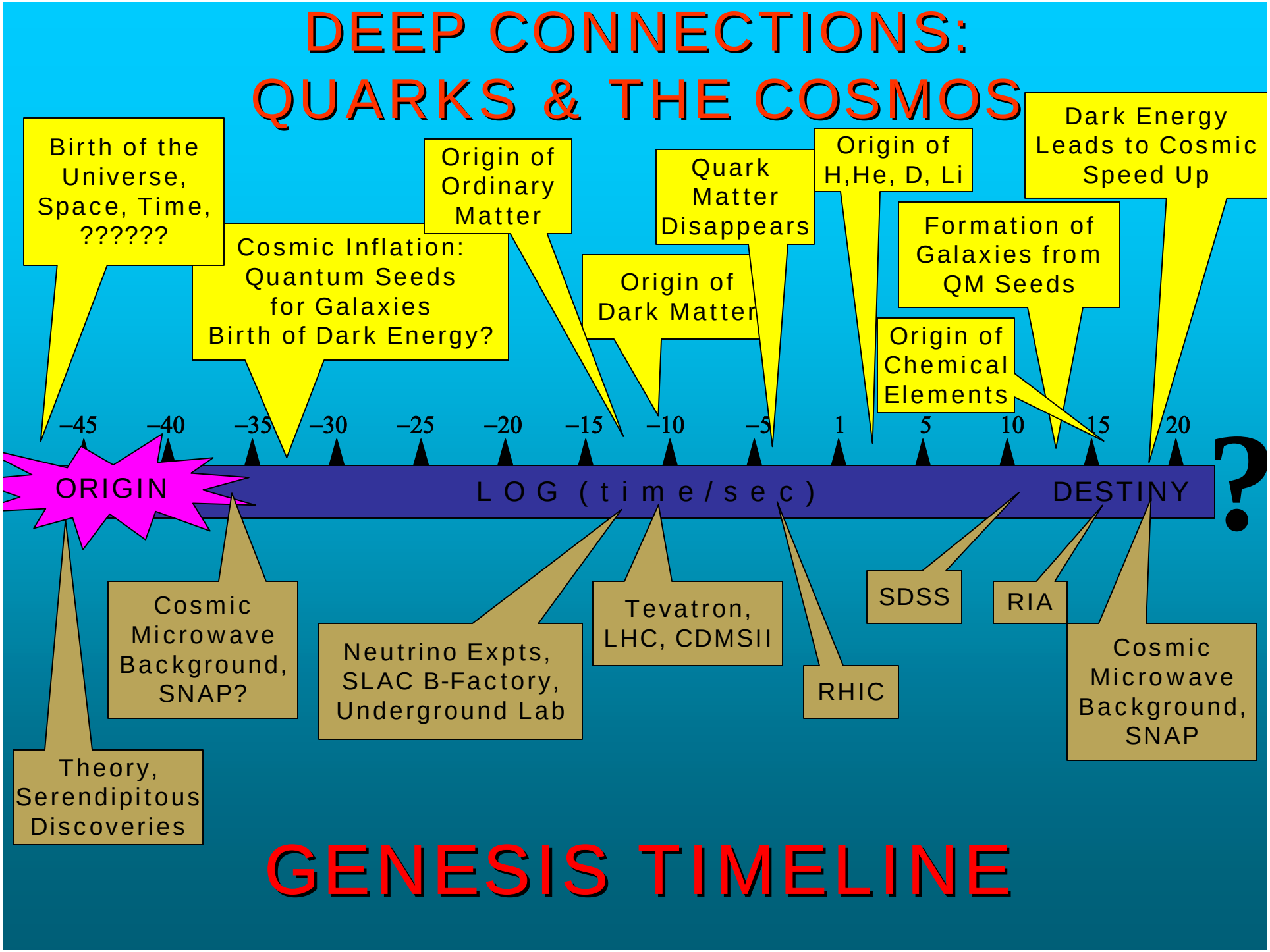
How does our star work? Is **Life** in our galaxy unique?

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



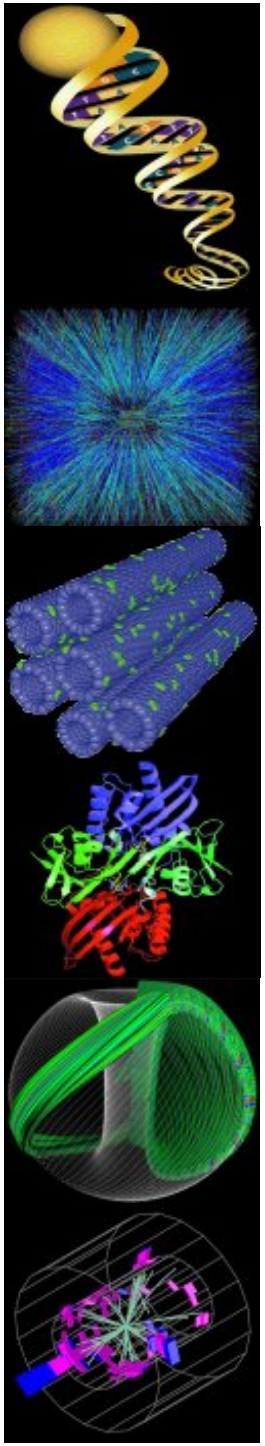
The BIG consequences

- I. Superstring Era: The Beginning.
- II. Grand Unified Theory Era (GUT): Separation of gravity.
- III. Inflation Era: The origin of elementary particles.
- IV. Electroweak Era: The dominance of matter over antimatter
- V. Particle Era: Formation of the lightest nuclei (deuterium, helium, lithium).
- VI. Recombination Era: Formation of atoms, release of primordial radiation.
- VII. Galaxy and Star Formation: Formation of the heaviest nuclei
- VIII. Present Era: Acceleration of the universe


DEEP CONNECTIONS:
QUARKS & THE COSMOS
Birth of the Universe, Space, Time, ??????
Cosmic Inflation: Quantum Seeds for Galaxies Birth of Dark Energy?
Origin of Ordinary Matter
Origin of Dark Matter
Quark Matter Disappears
Origin of H,He, D, Li
Formation of Galaxies from QM Seeds
Origin of Chemical Elements
Dark Energy Leads to Cosmic Speed Up
–45
–40
–35
–30
–25
–20
–15
–10
–5
1
5
10
15
20
ORIGIN
LOG (time/sec)
DESTINY
?
Theory, Serendipitous Discoveries
Cosmic Microwave Background, SNAP?
Neutrino Expts, SLAC B-Factory, Underground Lab
Tevatron, LHC, CDMSII
RHIC
SDSS
RIA
Cosmic Microwave Background, SNAP
GENESIS TIMELINE

The BIG questions

	Superstring (?) Era The Beginning	GUT Era Separation of Gravity	Electro-weak Era Elementary Particles	Particle Era Matter over Antimatter	Recombination Era Formation of Atoms	Galaxy/Star Formation Era Formation of Heavy Nuclei	Present Era Acceleration of Universe
Time (Sec./Yrs)	10^{-44} s ten billionths of a trillionth of a trillionth of a trillionth of a second	10^{-37} s one tenth of a trillionth of a trillionth of a trillionth of a second	10^{-10} s one tenth of a billionth of a second	10^{2} s one hundred seconds	3.8×10^{5} y three hundred eighty thousand years = twelve trillion seconds	2×10^{8}y two hundred million years = six thousand trillion seconds	1.37×10^{10} y 13.7 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}	3×10^{-10}	10^{-12}	2.3×10^{-13}



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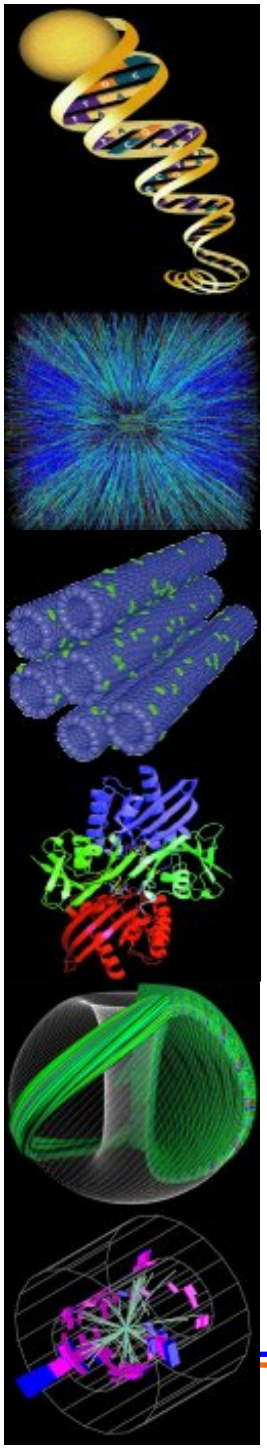
“The Study of the very large (Cosmology) and the very small (Elementary Particles) is coming together.”

Dr. David N. Schramm

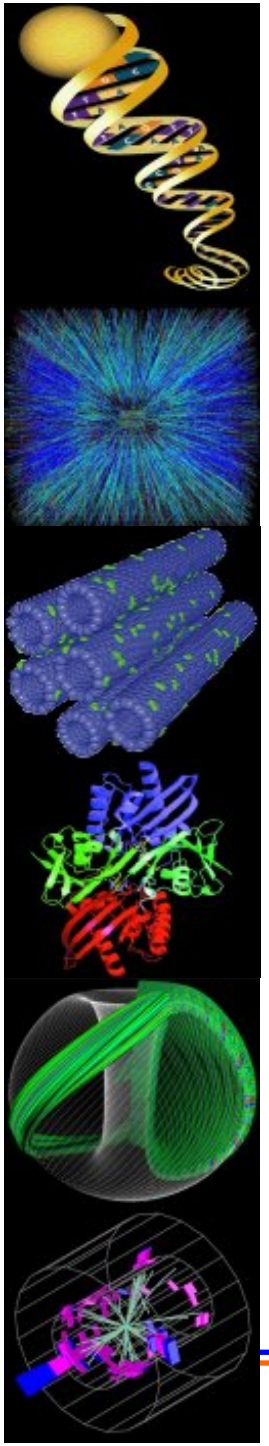


I. Superstring Era: The Beginning

"Prior to the existence of the universe, time did not exist." Nahmanides

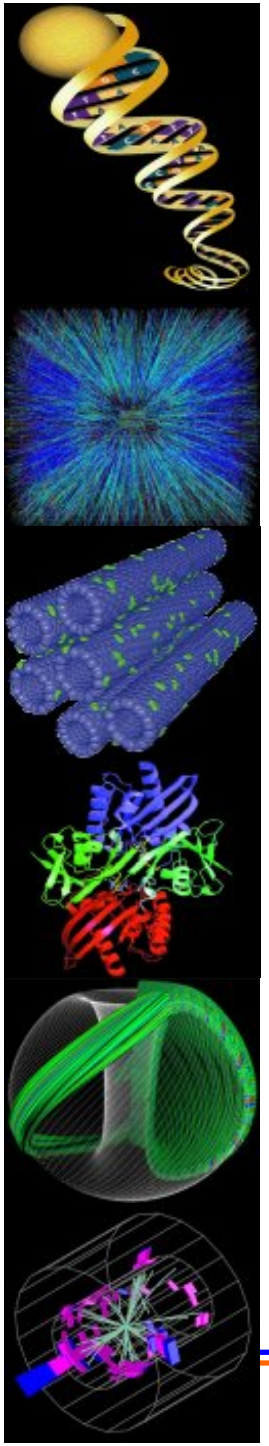
Our visible universe began as a tiny dot containing all of the energy that we see in the galaxies of brightly shining stars, and much more energy that we do not see. This incredibly hot dense state and its subsequent expansion is what we call the "Big Bang."

Space *itself* is expanding. Space and time are properties of the universe (Einstein). *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.



The temperature was extremely high, ten trillion trillion times the temperature of the interior of our sun (called the Planck temperature). All of the elementary constituents of matter, even those 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 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." (Lightman)



II. Grand Unified Theory (GUT) Era: Separation of Gravity

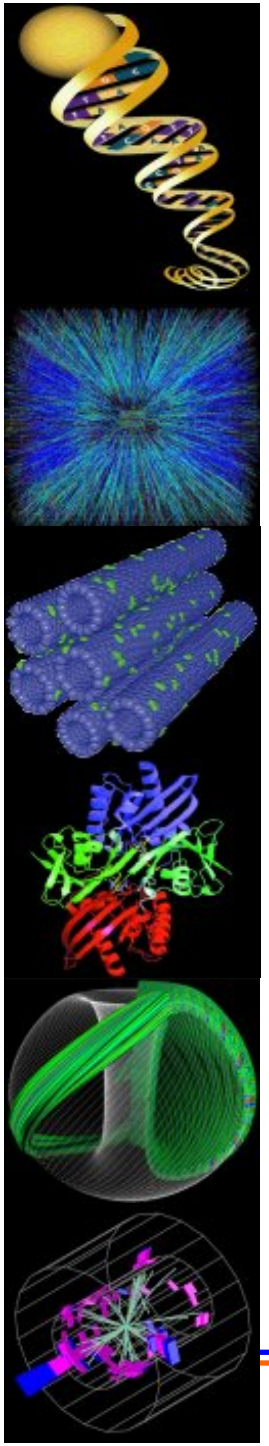
Genesis 1:2

"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."

When the universe cooled below the Planck temperature, one-tenth of a trillionth of a trillionth of a trillionth of a second after the Big Bang, 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).

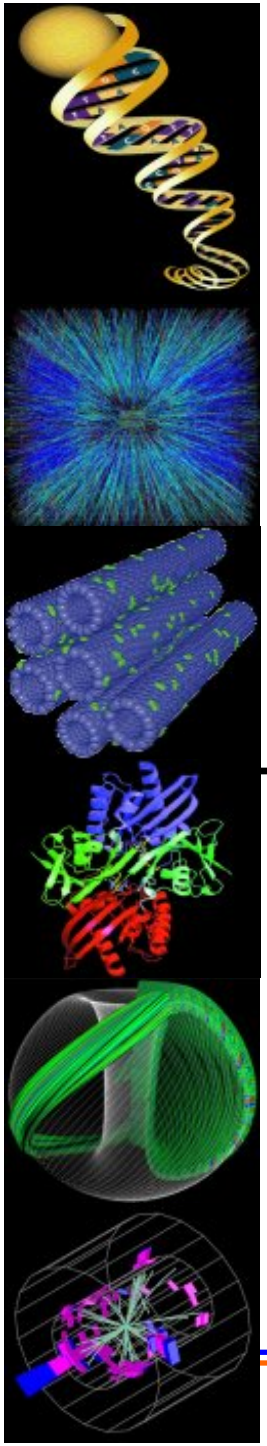


III. Inflation Era: The origin of elementary particles

"…while a mighty wind (ruach elohim) swept over the waters." (Genesis 1.2)

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. An 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).

The inflationary epoch ended when much of the energy decayed into a hot "soup" of elementary particles. The universe then continued to expand, but at a much slower rate. The new accelerated expansion we see today, a consequence of *dark energy*, could be this antigravity force, and therefore a window into the era of inflation.



IV. Electroweak Era: The dominance of matter over antimatter

"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 around.
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

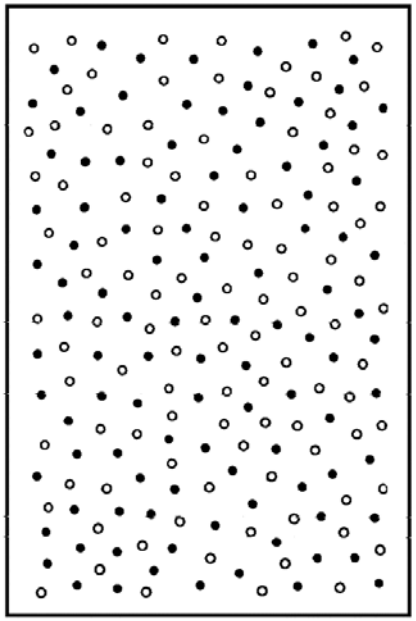
A "long time" (a tenth of a billionth of a second) later, the universe had cooled down considerably, to only one hundred million times the temperature of the interior of our sun. At about a millionth of a second, further cooling led to our very existence – the dominance of matter over antimatter. Most of the antimatter has annihilated with matter, leaving only the one part in thirty million excess of matter to dominate the universe at a thousandth of a second after the Big Bang .

The First 1/1000 Seconds After the Big Bang

- Anti-quark
- Quark

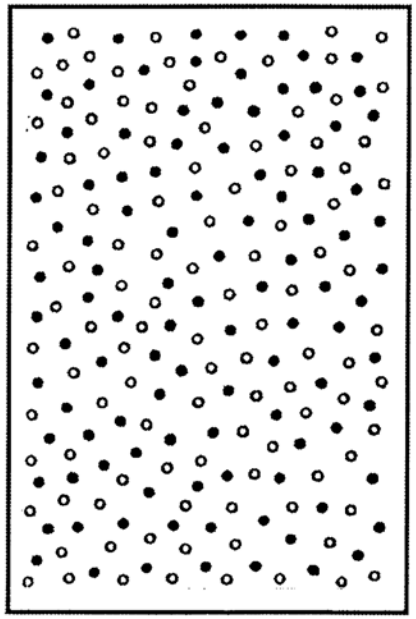
Baryon Violation
CP Violation

Quark Antiquark Annihilation
⇒ ~ 10^9 photons



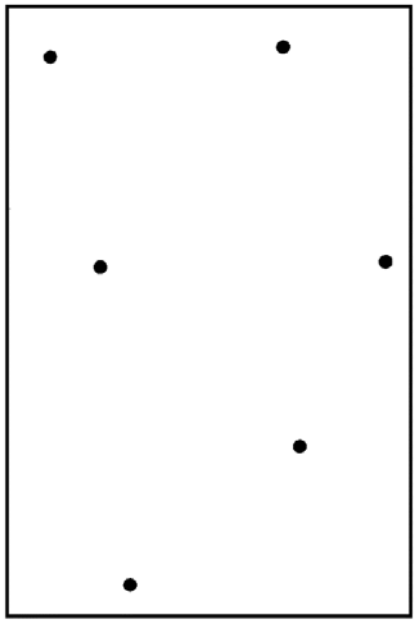
10^{-35} SECOND

 # Quarks = # Antiquarks



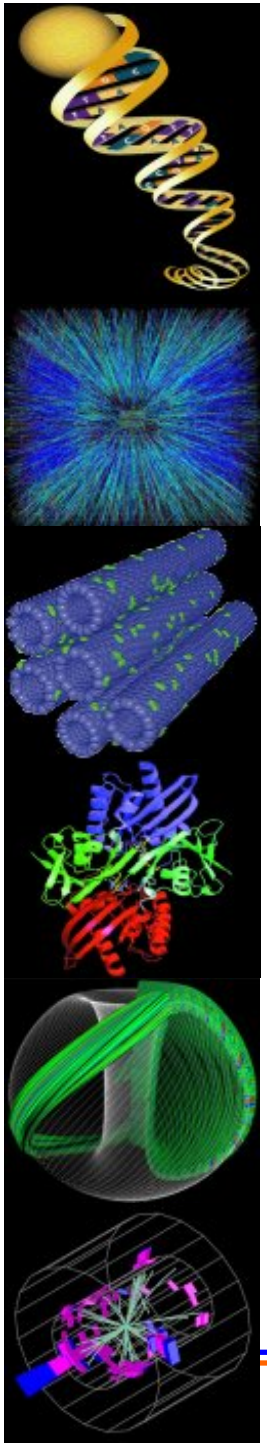
10^{-32}-10^{-4} SECOND

Slight excess ~ few parts / 10^9 of Quarks Over Antiquarks



10^{-3} SECOND - NOW

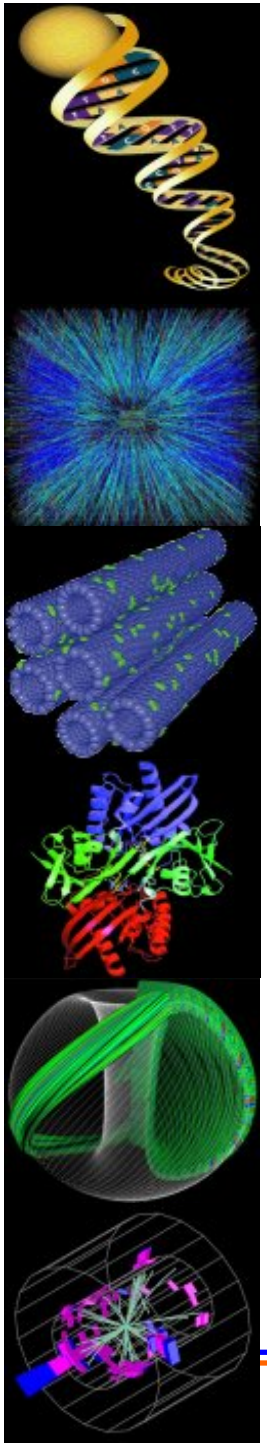
Excess Quarks survive to produce protons, neutrons ie. Matter



How do we know this?

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.

Something must have caused more matter than antimatter to be created in the early universe. We believe a tiny CP symmetry violation (CP=charge x parity) observed in the fundamental interactions of elementary particles played a key role in causing that matter-antimatter imbalance (SLAC).

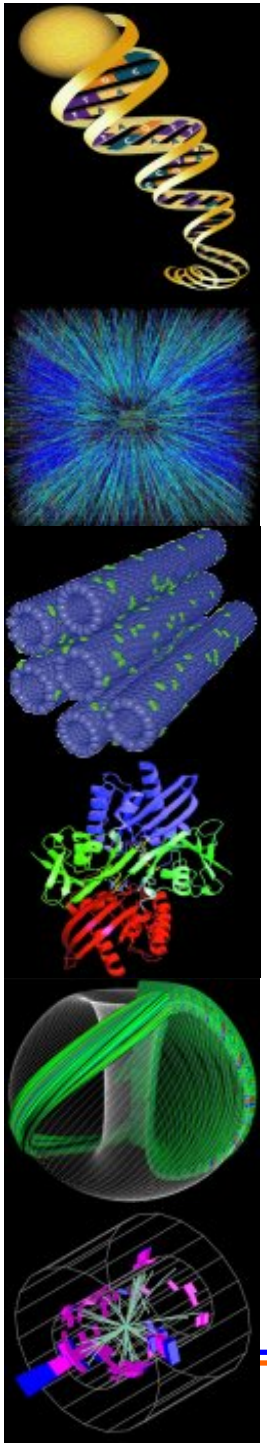


V. Particle Era: Formation of the lightest nuclei (deuterium, helium, lithium)

Isaiah 48.13

"Yes, my hand laid the foundation of the earth;
my right hand spread out the heavens

When the universe reached the ripe old age of 1 second, and temperatures dropped to one-thousand times the current temperature of the center of our sun, another important 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 (two hundred million 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.

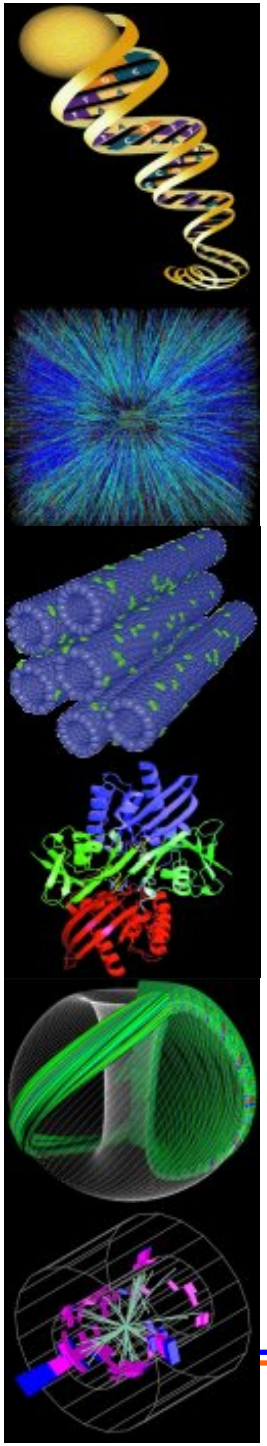


VI. Recombination Era: Formation of atoms, release of primordial radiation

Genesis 1:3

"And God said: 'Let there be light.' And there was light."

At three hundred and eighty 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. 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. Photons of light previously scattered off free electrons, scrambling their directions and trapped in local regions. After recombination, 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, revealing 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.



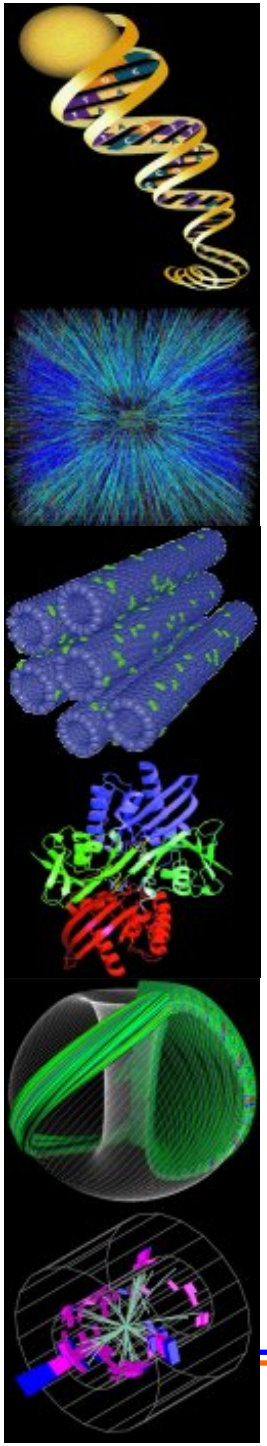
VII. Galaxy and Star Formation: Formation of heaviest nuclei

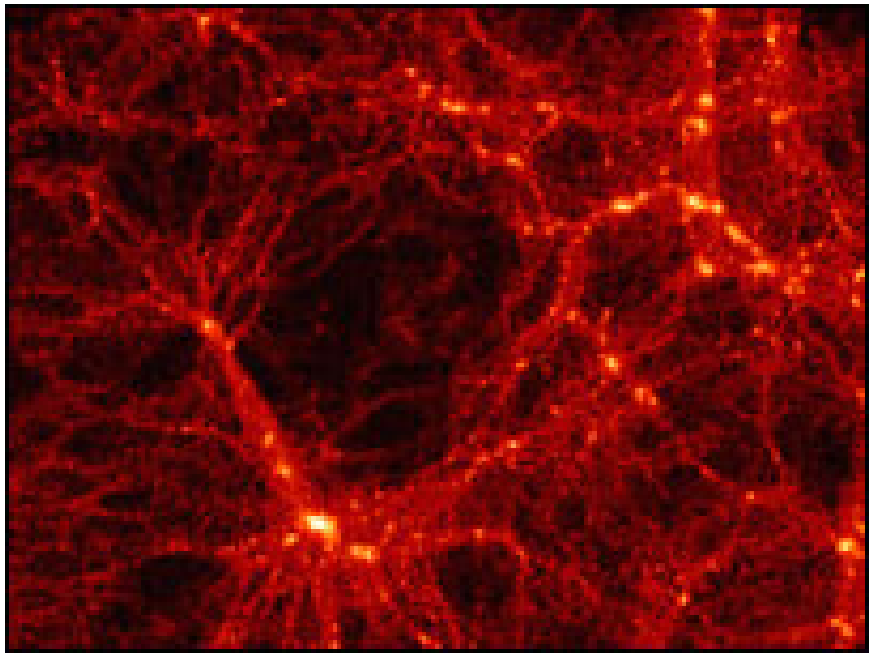
Genesis 1:17

"And God set them in the firmament of the heaven to give light upon the earth,"

About two hundred million years after the Big Bang, the temperature had cooled to 15 Kelvin (- 258 degrees Centigrade), and the heavens as we know them took form. 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 (WMAP). 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. The lumpiness of the early universe was the cause of our very existence.

Astronomers have just shown (January 11, 2005) how the present pattern of galaxies in the universe grew from tiny fluctuations in the density of matter just after the Big Bang. In the early Universe, the interaction between gravity and pressure caused a region of space with more ordinary matter than average to oscillate, sending out waves very much like the ripples in a pond when you throw in a pebble. These ripples in the matter grew for a million years until the Universe cooled enough to freeze them in place. We now see the imprint of these ripples.

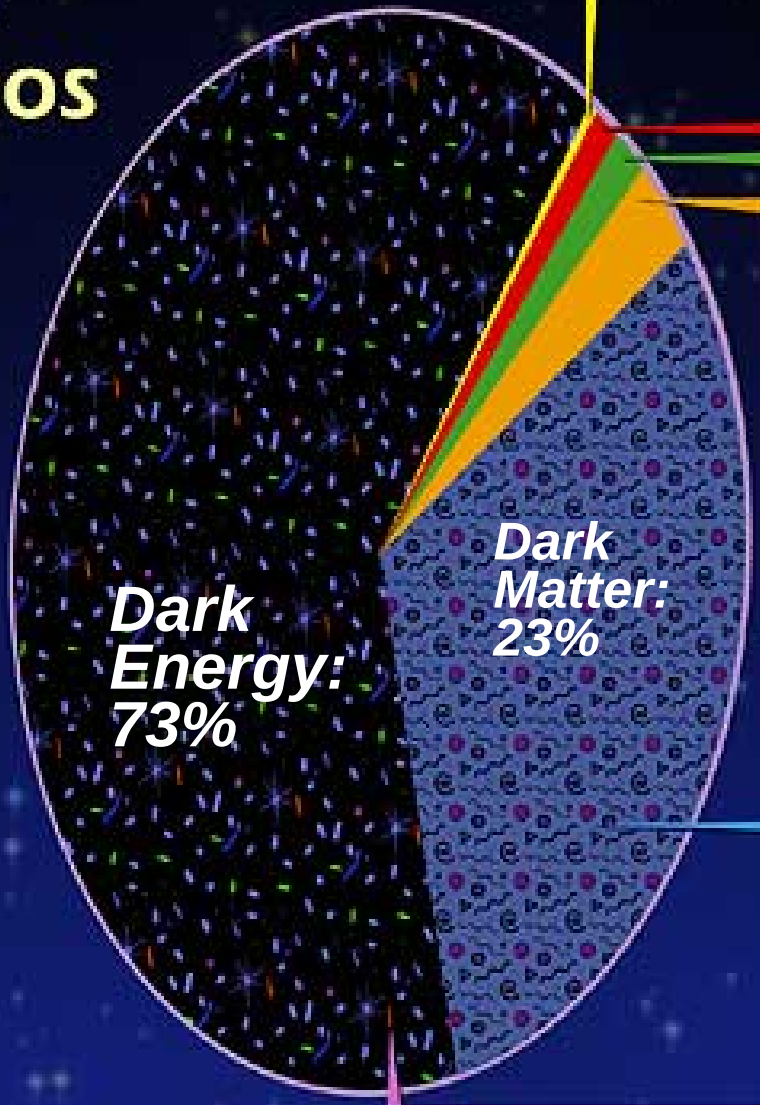




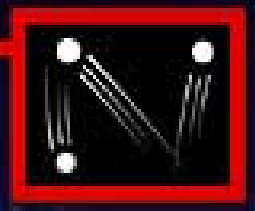
These ripples have now expanded in our universe so that there is slight excess of galaxies with separations of 500 million light-years.

The ordinary matter and energy that we know and understand, is only a tiny part of the mass and energy of the entire universe. There is much more matter and energy in the universe than we can see. 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?

Composition of the Cosmos



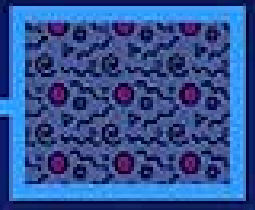
Heavy elements: 0.03%



Ghostly neutrinos: 0.3%

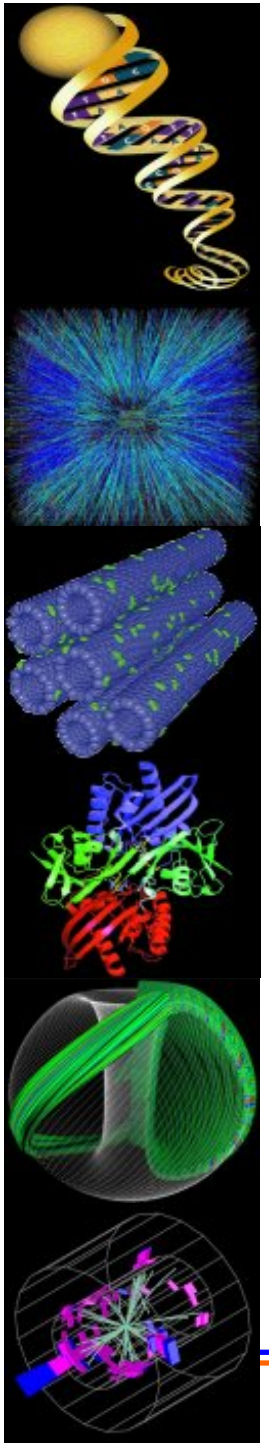
Stars: 0.5%

Free hydrogen and helium: 3%



Dark matter: 23%

Dark energy: 73%

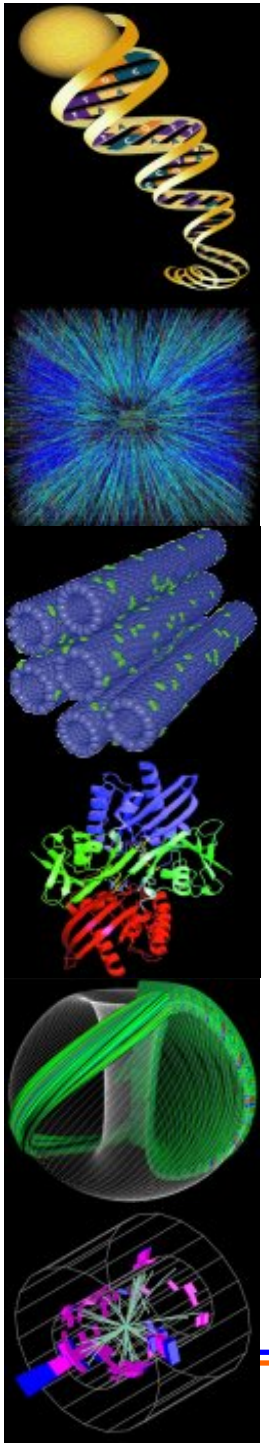


DARK ENERGY

We know from the acceleration of the outermost portions of the universe that dark energy comprises seventy three 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 (SNAP)*.

DARK MATTER

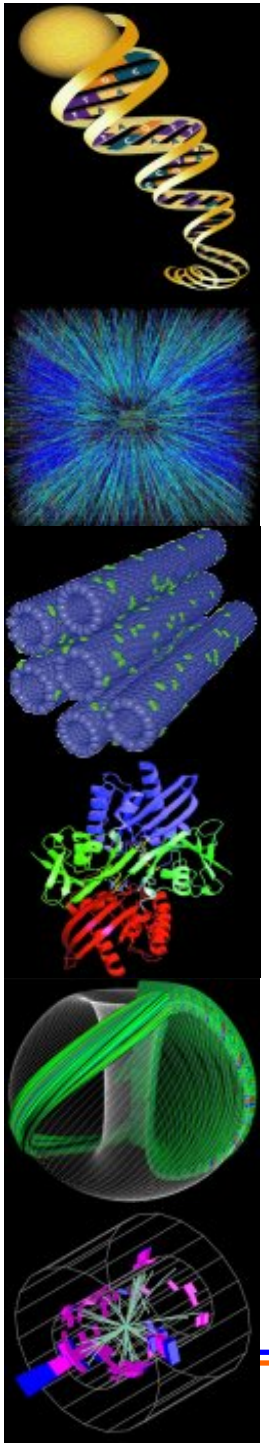
We know from studying the rotation of galaxies that twenty three percent of the mass and energy budget of the universe today is in the form of *dark matter*, which affects the motion of galaxies by gravity but emits no radiation. Accelerator experiments are searching for many kinds of dark matter, but it remains a mystery waiting to be solved (Fermi National Laboratory, LHC).



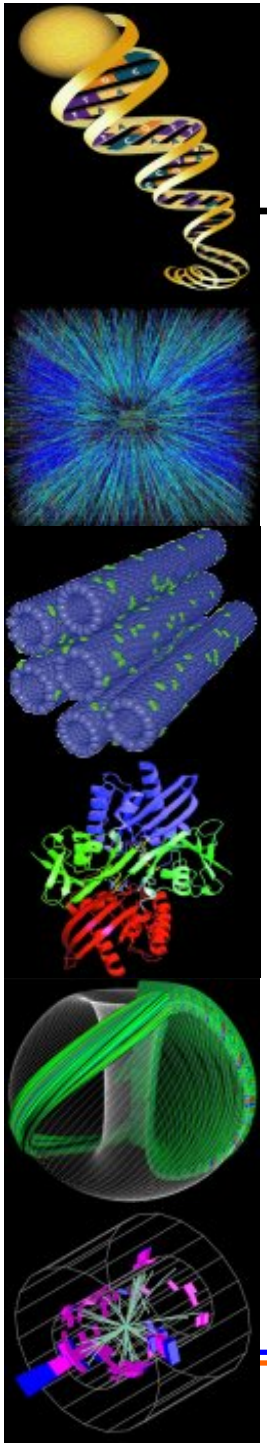
VIII. Present Era

Genesis III:19
"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."

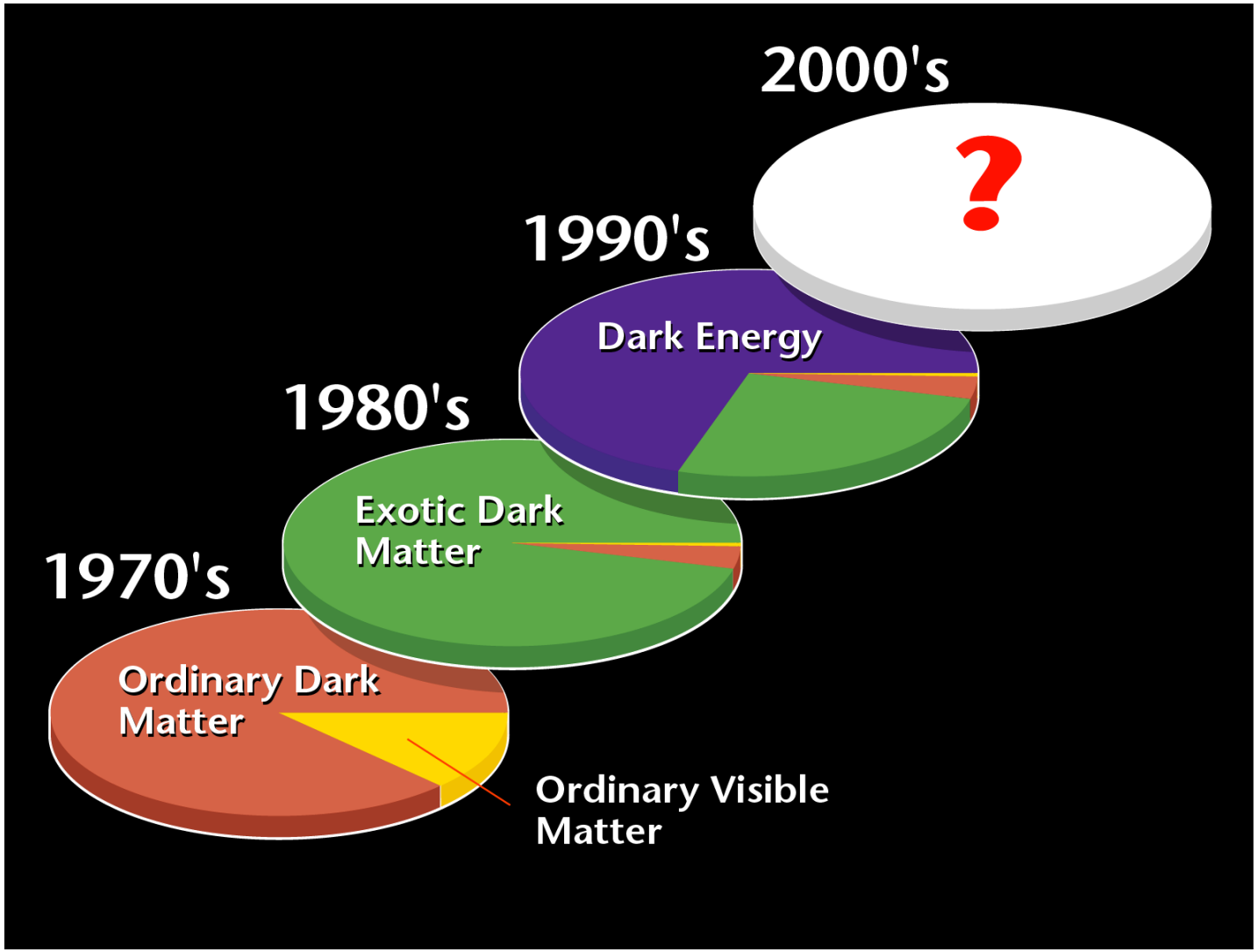
We believe the time of our modern era, the world as we now know it, is 13.7 billion years after the beginning. In as short a time as the last three decades we have, using accelerators and detectors in space and on the ground, come to a fundamental understanding of the constituents of matter that make up the visible universe.

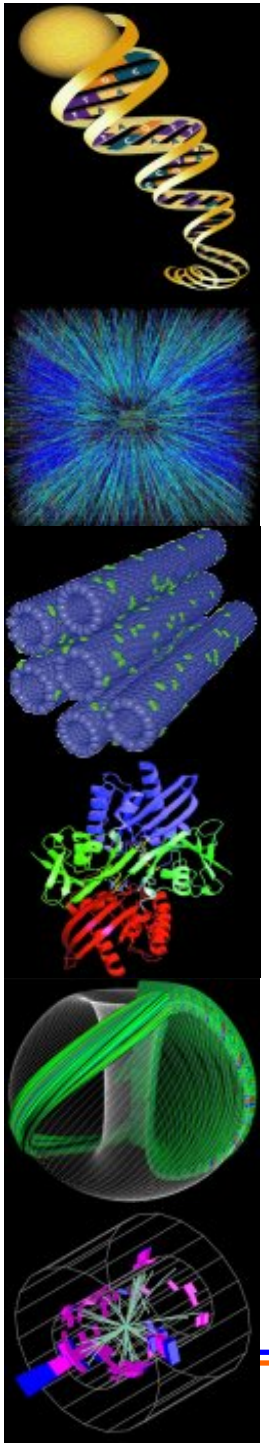


Most of the universe is invisible to us and full of mystery. There will be surprises as we continue to probe the beginning from our vantage point 13.7 billion years later. Our knowledge has evolved in discrete surprises. Thus, our very conception of the nature of our universe has changed, even over the time scale of decades. The fact that dark energy and exotic dark matter now comprise 96% of our universe, while the galaxies of bright stars that fill the heavens are less than one-half 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.



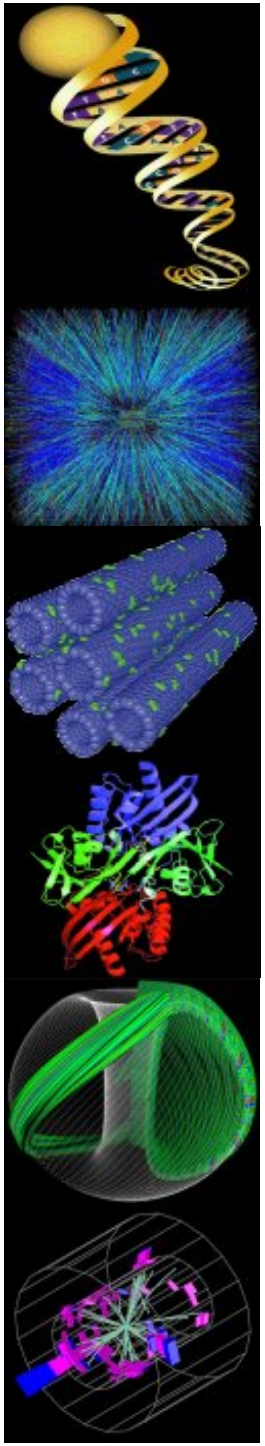
Our changing view of the Universe





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, chutzpah, 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, which may have driven inflation at ten trillionths of a trillionth of a trillionth of a second after the beginning, is now accelerating the expansion of the universe 13.7 billion years later, suggesting that the Big Bang may end with a lonely whimper.



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"Every man prays in his own language, and there is no language that God does not understand."

Duke Ellington, 1965

Duke Ellington's Concert of Sacred Music