Alles Introductory Biology Lectures

An Introduction to Science and Biology for Non-Majors

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Part Two: The Conceptual Framework of Biology

Cosmological Evolution

“I don't pretend to understand the Universe,

it's a great deal bigger than I am.

People ought to be more modest.”

—philosopher Thomas Carlyle (1795-1881)

“I don't know why we are here,

but I'm pretty sure that it is not in order to enjoy ourselves.”

—philosopher Ludwig Wittgenstein (1889-1951)

Part Two: The Conceptual Framework of Biology

Introduction

If you look at the sum of scientific knowledge, and that is where we are in our attempt to define science, it is daunting. To make sense of it, we need a conceptual map, as scientific facts, by themselves, explain little. Therefore, what is the theoretical framework that ties this sum of knowledge together?

Cosmological Evolution

Science at the beginning of the twenty-first century can make some bold, yet simple observations:

1. the universe has evolved

2. we are a result of that evolution

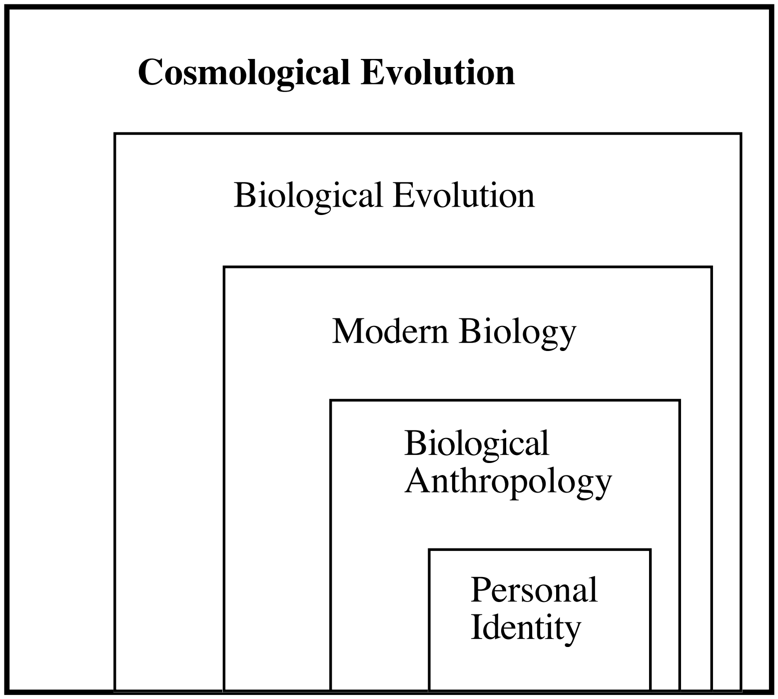
Allan Sandage on Stellar Evolution

"The idea that stars change as they age, and that these changes, in turn, alter their local environment and the chemical makeup of their parent galaxy stands in the same relation to astronomy as the Darwinian revolution does to biology. It is a conceptual breakthrough that makes possible the modern understanding of the origin, evolution, and fate of the universe.

We are the product of the stars. This is one of the most profound insights to have arisen out of twentieth-century astronomy. Life is clearly a property of the evolving universe made possible by stellar evolution."—Sandage, 2000

Allan Sandage was co-discover of quasars and the astronomer heir of Edwin Hubble’s project to determine the rate of expansion of the universe.

Increasingly Inclusive Concepts in Science



The concept of cosmological evolution encompasses all of scientific knowledge and provides a framework on the largest scale for understanding our world.

Cosmological Evolution and Historical Systems

- To understand cosmological evolution, we must see the universe as an historical system.

- An historical system is one whose past will shape the course of its future.

- Such systems are characterized by a unique chronological sequence of events that gives rise to unique initial conditions in the present.

- System, as used here, is a set of integrated, interacting parts.

- Integrated implies that a system forms from a series of events in the past into a evolving entity in the present. Integrated also implies that unordered entities are acted upon by a process that then forms a new and stable entity from these parts.

- A process, in turn, is a sequenced set of changes that transforms something from one state to another.

Galaxy NGC 4414, a spiral galaxy like our own Milky Way, is approximately 62 million light years from Earth, a distance equal to about 364 million, trillion miles.

Web Reference
http://hubblesite.org/newscenter/archive/1999/25/

Historical systems have the following characteristics.

1. Change is inherent in historical systems.

2. Historical systems are closed systems where the output of the processes of the system is the only input to the system.

3. Because of this, there is a chronological sequence in which the universe developed.

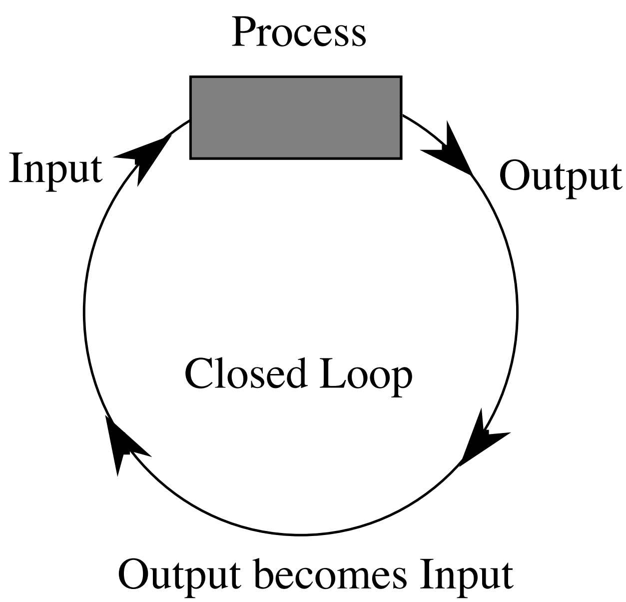
4. As the universe developed, levels of stable phenomena were built upon other, more basic levels.

5. These levels of stable phenomena have accumulated through time.

6. Life on Earth is one of these natural levels of stable phenomena.

5. Because historical systems evolve, evolutionary processes can explain the development of all these levels.

Cause and Effect in a Closed System



Point: The universe is a closed, historical system. The fundamental process that produces change in the universe is its expansion, and, indeed, the universe has evolved through time. The history of life on Earth is but a small part of that evolution, and the processes that produced life on Earth are one and the same as those for the universe itself.

Biological evolution is only a part of the larger phenomenon of the evolution of the universe.

For more on Historical Systems go to:
http://fire.biol.wwu.edu/trent/alles/CausalityEssays.pdf

Natural Levels of Organization in the Physical World

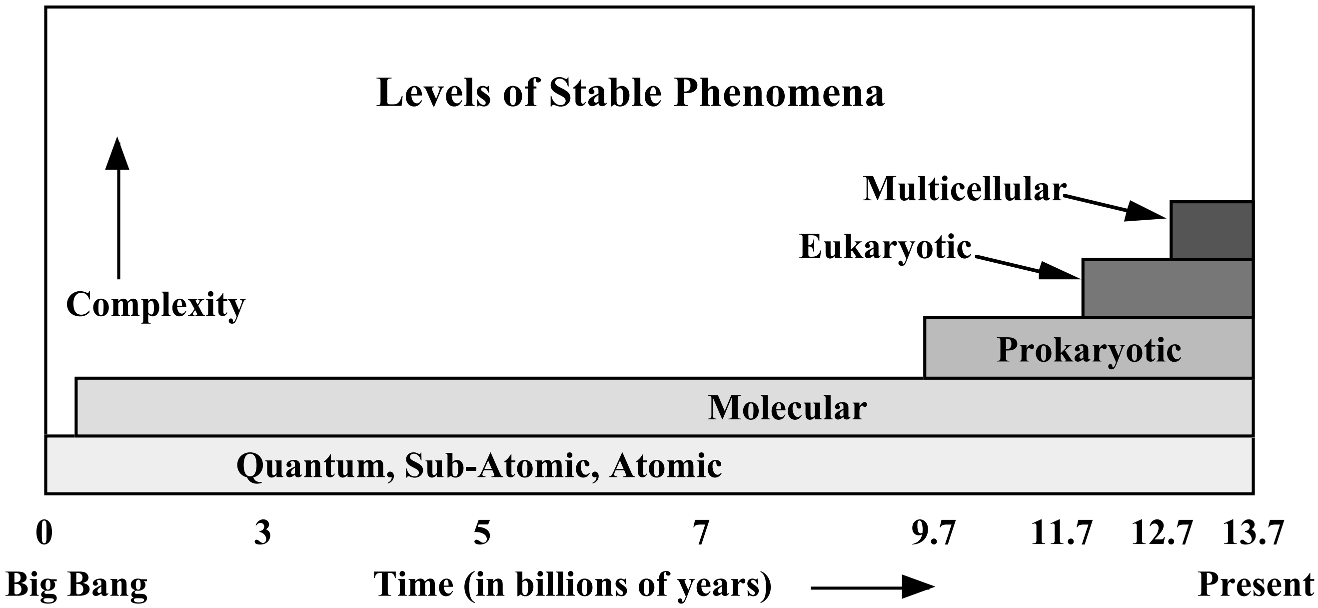
Natural hierarchical levels of organization or “levels of stability” (Bronowski 1977) are inherent in historical systems. A natural hierarchical level is defined by the occurrence of a new, novel and stable phenomenon that increases the level of causal complexity of the system enough to give rise to a new level of spontaneous self-organization.

These levels are characterized by their stability through time and can be identified by the following features:

1. a unique scale in size—“on being the right size”

2. a new spontaneous organization of matter or “self-organization”

3. new emergent properties or processes—“more than the sum of the parts”


Levels of Stable Phenomena
Complexity
Multicellular
Eukaryotic
Prokaryotic
Molecular
Quantum, Sub-Atomic, Atomic
0
3
5
7
9.7
11.7
12.7
13.7
Big Bang
Time (in billions of years)
Present

The Quantum Level (origin ~ 1×10^{-32} second after time zero)

1) Scale in size—1×10^{-35} meter (Planck's length) to 1×10^{-16} meter

2) Self Organization—by ~ 1×10^{-12} second after the Big Bang, radiation had cooled enough to form quarks (this is the "Quark Soup")

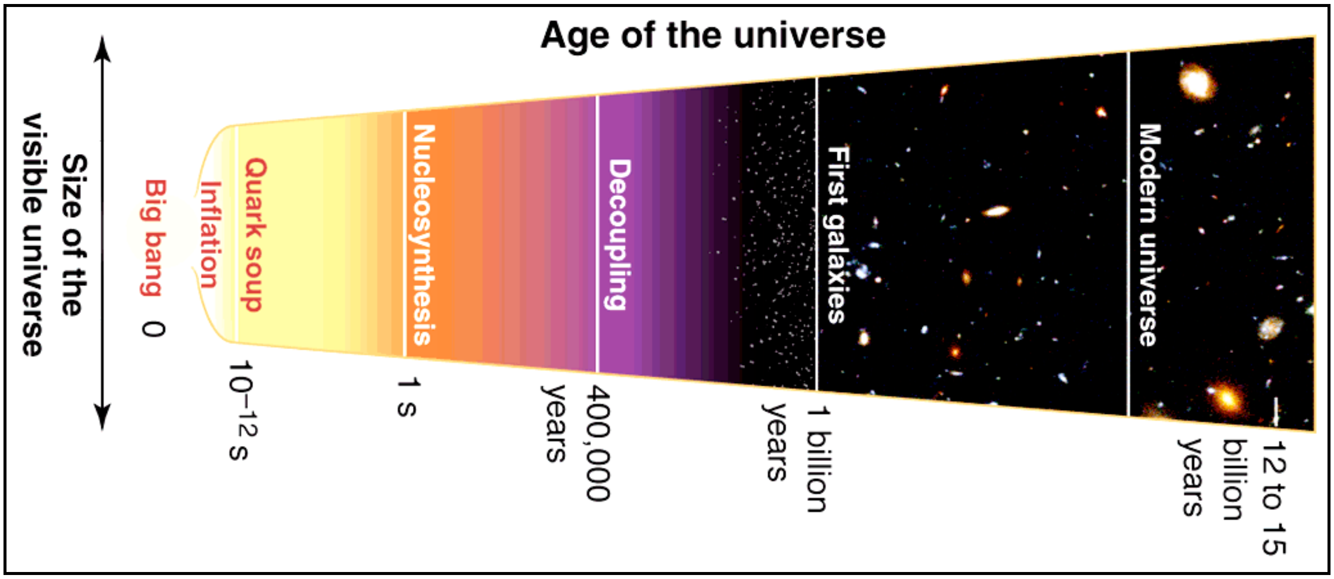
3) Emergent Properties & Processes—matter forms from energy

The Sub-Atomic Level (origin ~ 1 second after time zero)

1) Scale in size—1×10^{-15} to 1×10^{-10} meter

2) Self Organization— at ~ 1 second after the Big Bang, the universe had cooled enough for quarks to form protons; electrons to form from radiation; and protons and electrons to interact to form neutrons

3) Emergent Properties & Processes—formation of the first atomic nuclei (this is "Nucleosynthesis")



The Standard Big Bang Model of the Evolution of the Universe

Before the Bang

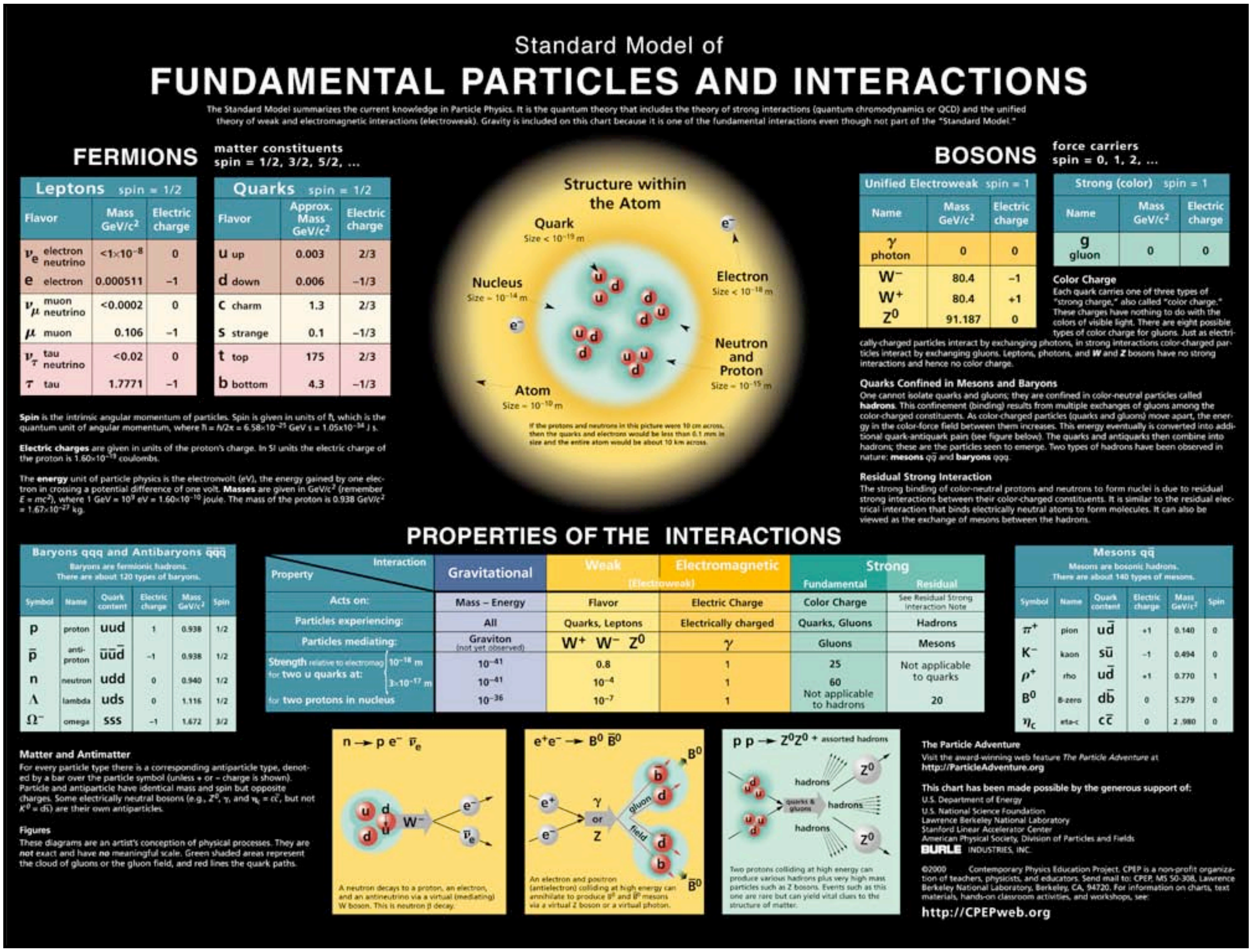
An Interview with two University of Washington Astronomy Professors

Modern physics enables astrophysicists to calculate the size and density of the universe at any time in its 13.7-billion year history—right back to the Big Bang. Scientists are very proud of this accomplishment. "Only the first 10^{-43} seconds remain obscure," notes a self-confident UW Astronomy Professor Bruce Margon.

But what happened before the big bang? That stops Astronomy Chair Craig Hogan dead in his tracks. "What, you're not greedy or anything, are you?," he asks with incredulity that anyone would not be satisfied to know what happened over 13.7 billion years after the big bang.

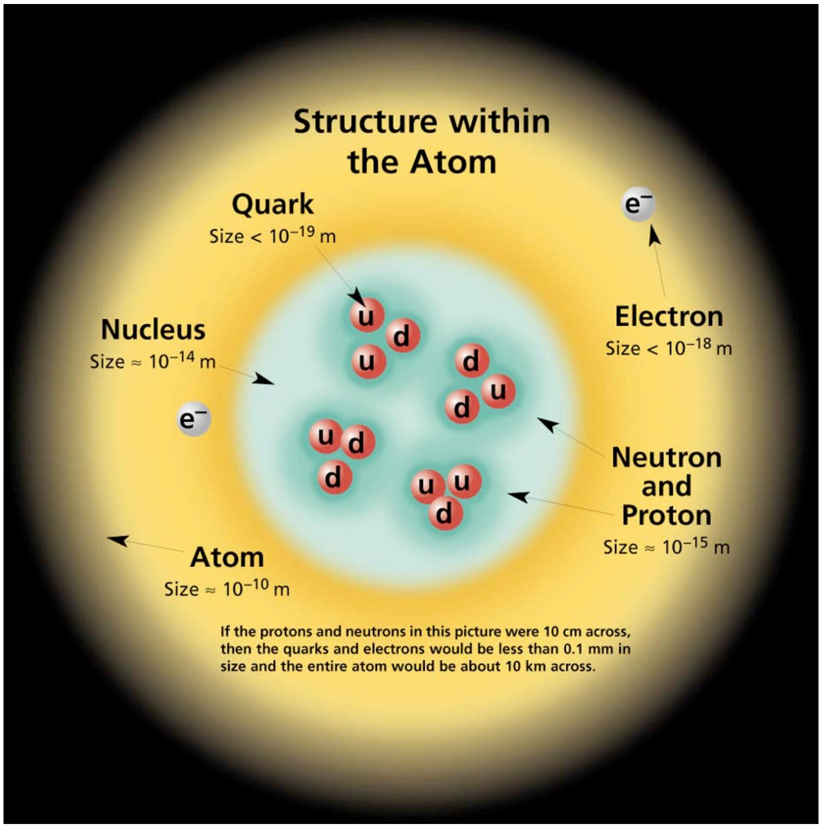
And then he pauses, thoughtfully: "What happened before?," he muses. "No one could really know. All memory of that time is lost, everything from then is forgotten. That was a period of such catastrophic instability that it just doesn't remember what came before it. We probably could never find out, either. There just isn't any information left over from it."

Margon has addressed this question, too. As he told the Washington Post last year, "One would think that if someone has trouble reconciling religion with physics, they would like the Big Bang. It has beautiful elements of ultimate mystery."



The Standard Model of Sub-Atomic Particle Physics

Web Reference
http://www.particleadventure.org/

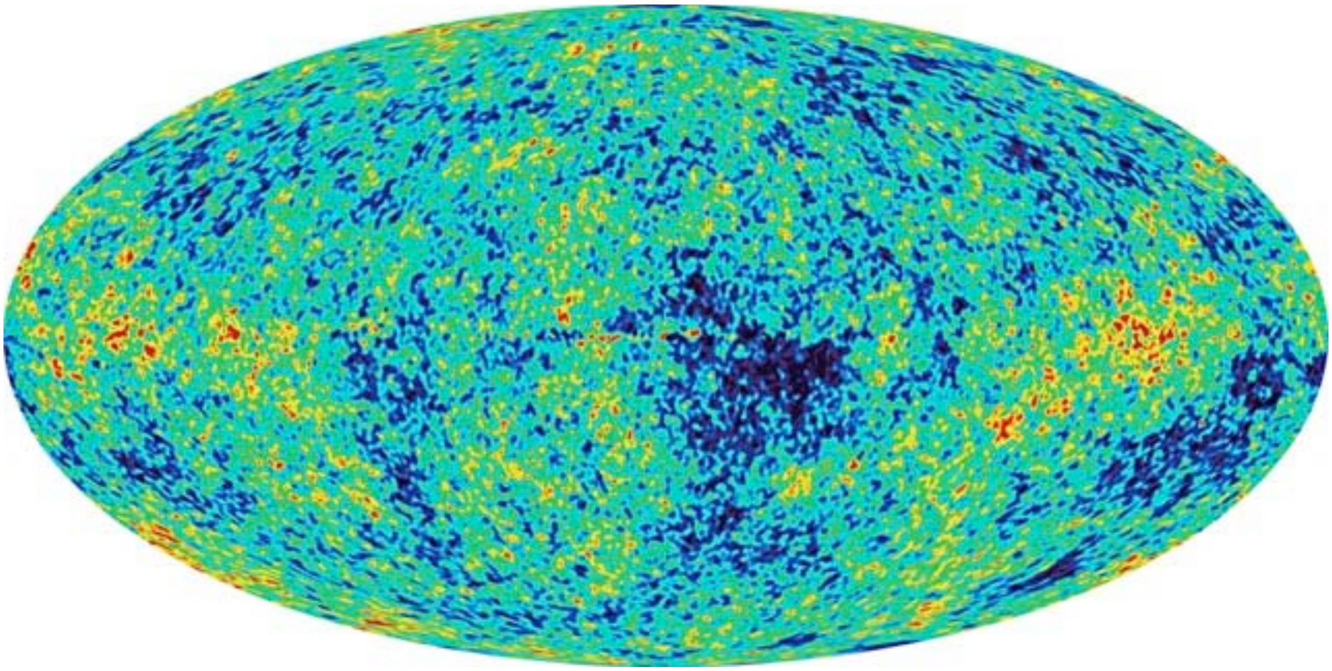


The Atomic Level (origin ~ 400,000 years after time zero)

1) Scale in size—one ten billionth of human scale or 1 x 10^{-10} meter

2) Self Organization—protons capture electrons and form the light elements hydrogen and helium

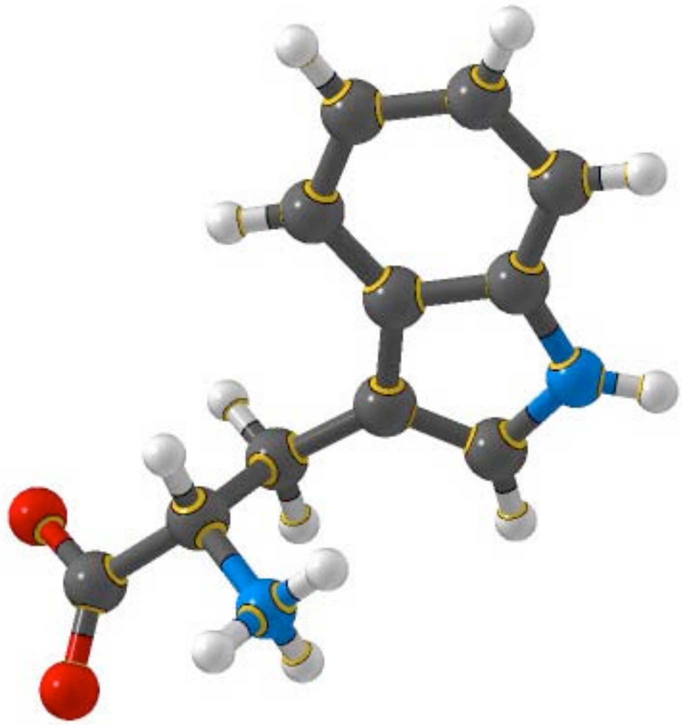
3) Emergent Properties & Processes—primary or **Big Bang nucleosynthesis**; the properties of the elements hydrogen and helium; the decoupling of matter and radiation; and the origin of the cosmic microwave background radiation



Cosmic Microwave Background Radiation
from 380,000 years after the origin of the Universe

Full Sky Map from the Wilkinson Microwave Anisotropy Probe

Web Reference
http://map.gsfc.nasa.gov/m_mm.html



The Amino Acid Tryptophan

The Molecular Level (origin ~ 200 million years after time zero)

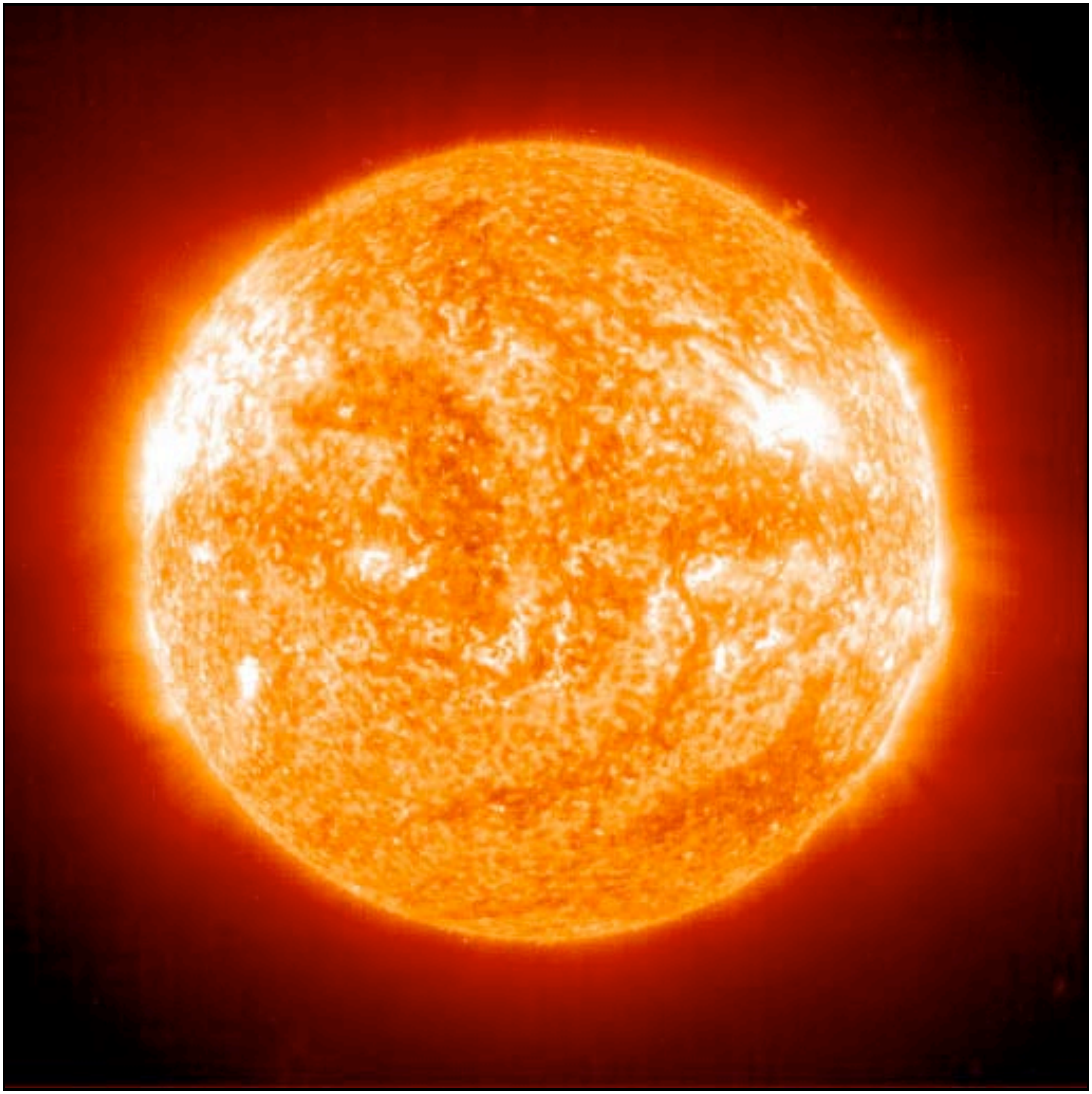
1) Scale in size—one billionth of human scale or 1×10^{-9} meter

2) Self Organization—formation of the first stars; formation of the heavy elements; formation of molecules by electromagnetic forces

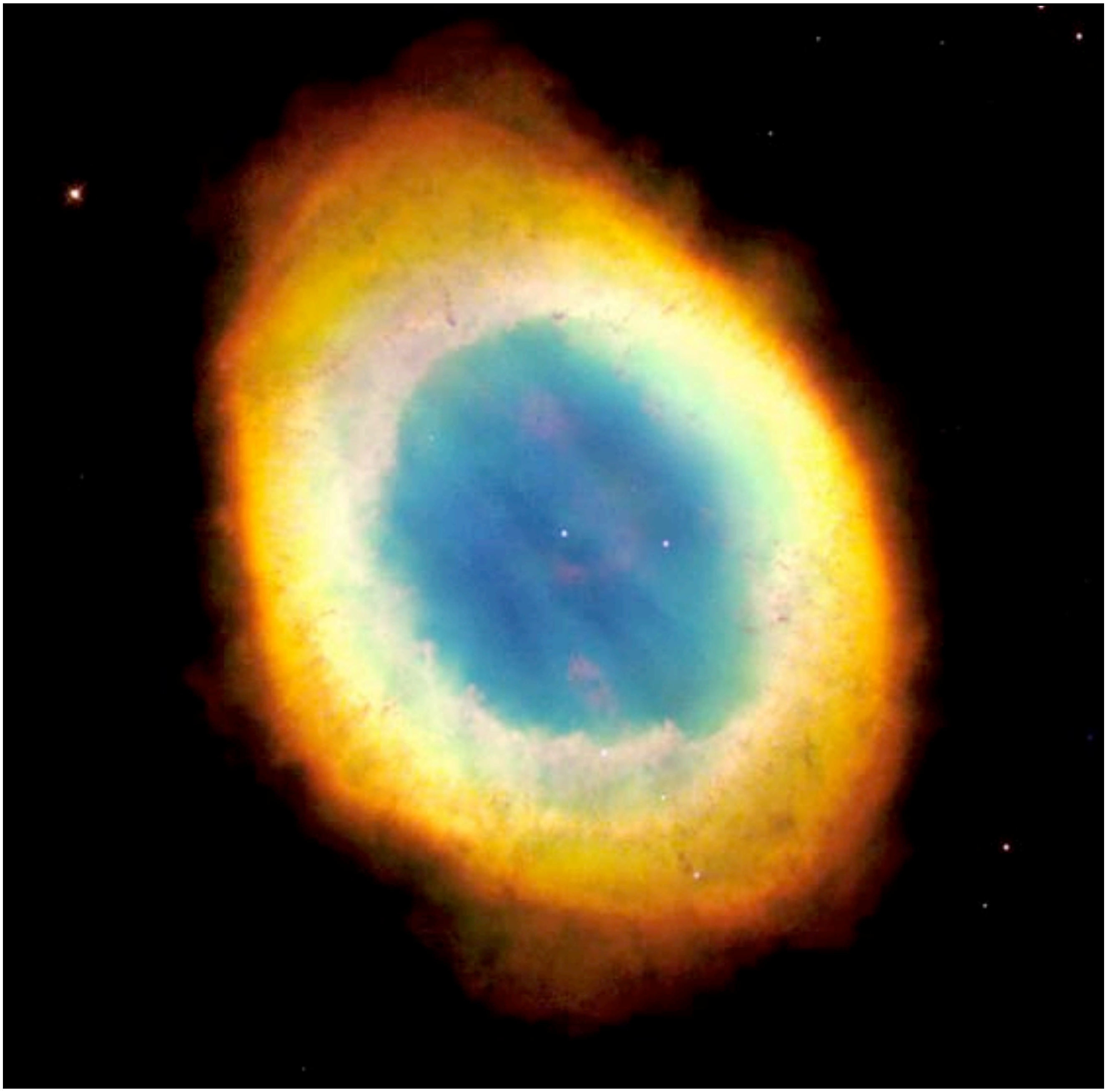
3) Emergent Properties & Processes—production of heavy elements in stars—secondary or **stellar nucleosynthesis**; all the properties of molecules as opposed to elements—complex chemistry is now possible

For more on the nucleosynthesis of the elements go to:
http://fire.biol.wwu.edu/trent/alles/Origin_of_Elements.pdf

Star forming regions in spiral galaxies are concentrated in the arms of gas that spin about the central core. Note the dark bands of gas in the spiral arms of the Whirlpool galaxy pictured above.

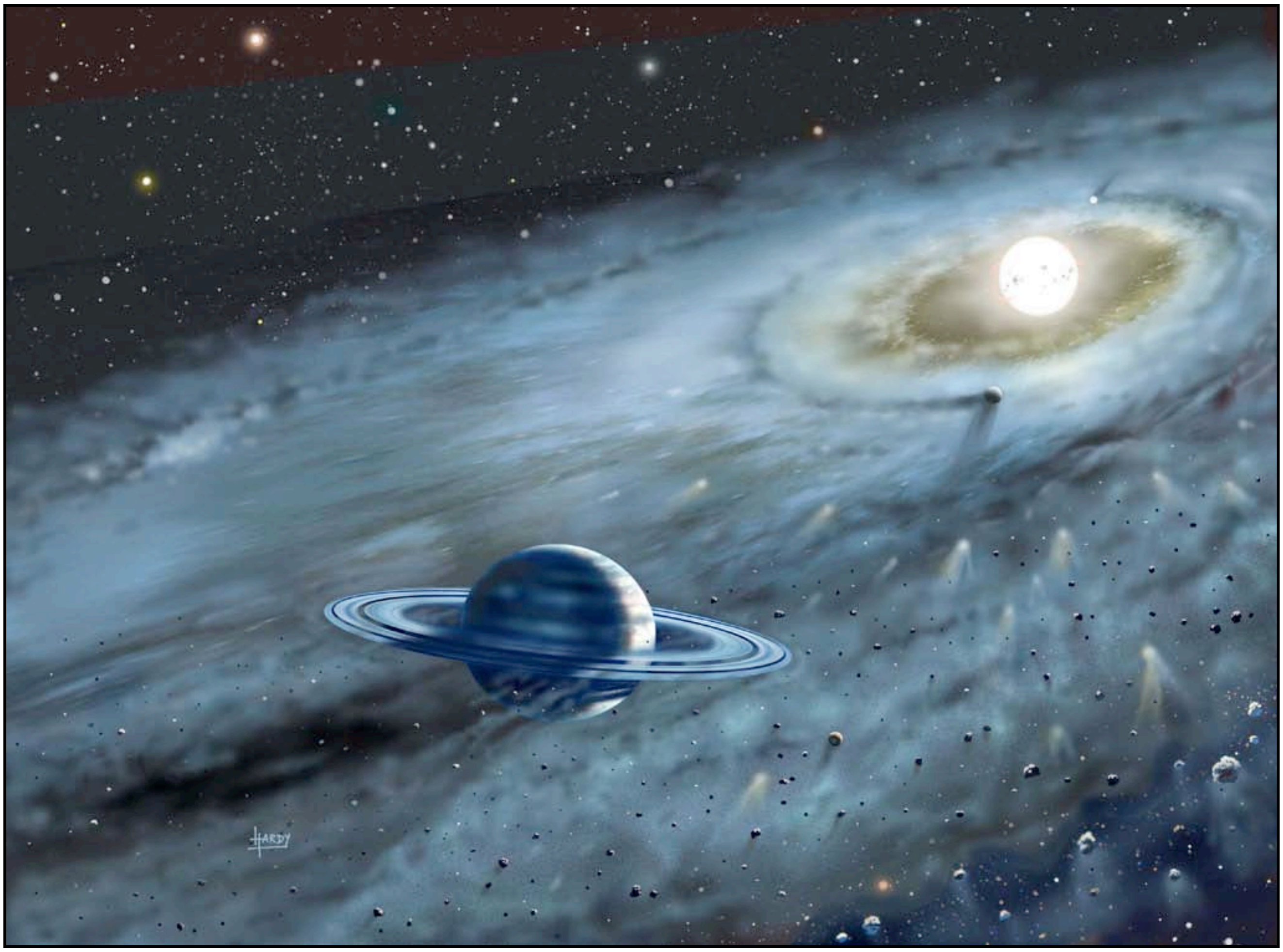


Stars are the only place in our universe where the elements heavier than hydrogen and helium are produced.



Stars the size of our Sun are fated to cast off their outer shell of gas into space creating a nebula similar to the Ring Nebula pictured above. This nebula is ~ one light-year in diameter and is located some 2,000 light-years from Earth. The colors are ~ true, and represent three different chemical elements: helium (blue), oxygen (green), and nitrogen (red).

The heaviest elements are produced in supernova explosions of massive stars that are at least eight times the size of our Sun. The Crab Nebula, pictured above, was produced by a supernova explosion witnessed by Chinese astronomers in 1054 A.D.. Now approximately 10 light years in diameter, it is still expanding at about 1,100 miles/sec.



Once enough time had elapse for the life and death of at least two generations of massive stars, the universe was enriched enough in heavy metals for the formation of solar systems and planets like our own. Above is an artist's impression of the early formation of a solar system similar to ours that includes stony planets like the Earth near the central star and gas giant planets like Jupiter and Saturn further away. Five billion years ago our solar system formed much the same way leading to the conditions, approximately four billion years ago, that gave rise to life on Earth.

Web Reference
http://antwrp.gsfc.nasa.gov/apod/ap021011.html

http://exoplanets.org/

The Prokaryotic Level (origin ~ 4000 million years ago)

1) Scale in size—one millionth of human scale or 1×10^{-6} meter

2) Self Organization—organization of complex macro-molecules into a self-reproducing unit—the cell

3) Emergent Properties & Processes—**the origin of life**—Archaebacteria & Eubacteria; natural selection; speciation; self-reproduction by binary fission; anaerobic and aerobic respiration; photosynthesis

Bacteria, such as the E. coli pictured above, are prokaryotes.

The Eukaryotic Level (origin ~ 2000 million years ago)

1) Scale in size—1 x 10^{-5} to 1 x 10^{-4} meter or ten to a hundred times larger than the prokaryotic

2) Self Organization—endosymbiotic mutualism of primitive eukaryotes and prokaryotic bacteria to form true eukaryotic cells

3) Emergent Properties & Processes—endosymbiotic mutualism; origin of Kingdom Protista; evolution of sexual reproduction (origin ~ 1100 million years ago)

Paramecia are single cell eukaryotic protists.

The Multicellular Level (origin ~1000 to 600 million years ago)

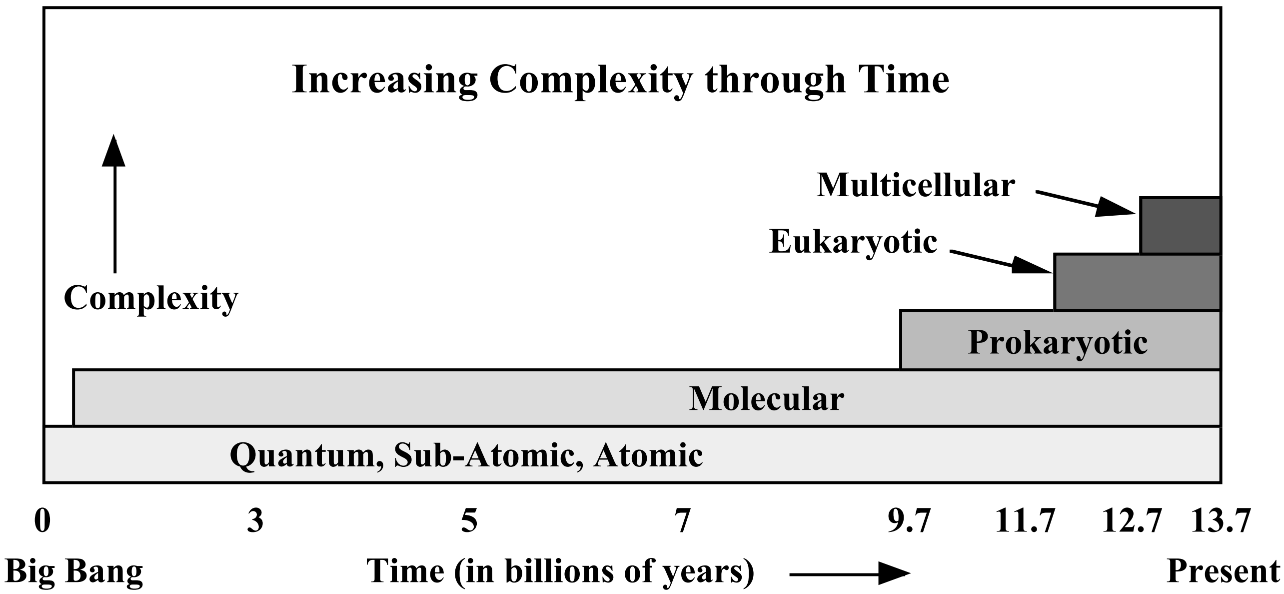
1) Scale in size—one thousandth of human scale to human scale or
1×10^{-3} to 1 meter

2) Self Organization—multicellular organization by cell types into tissues and organs, to whole organisms

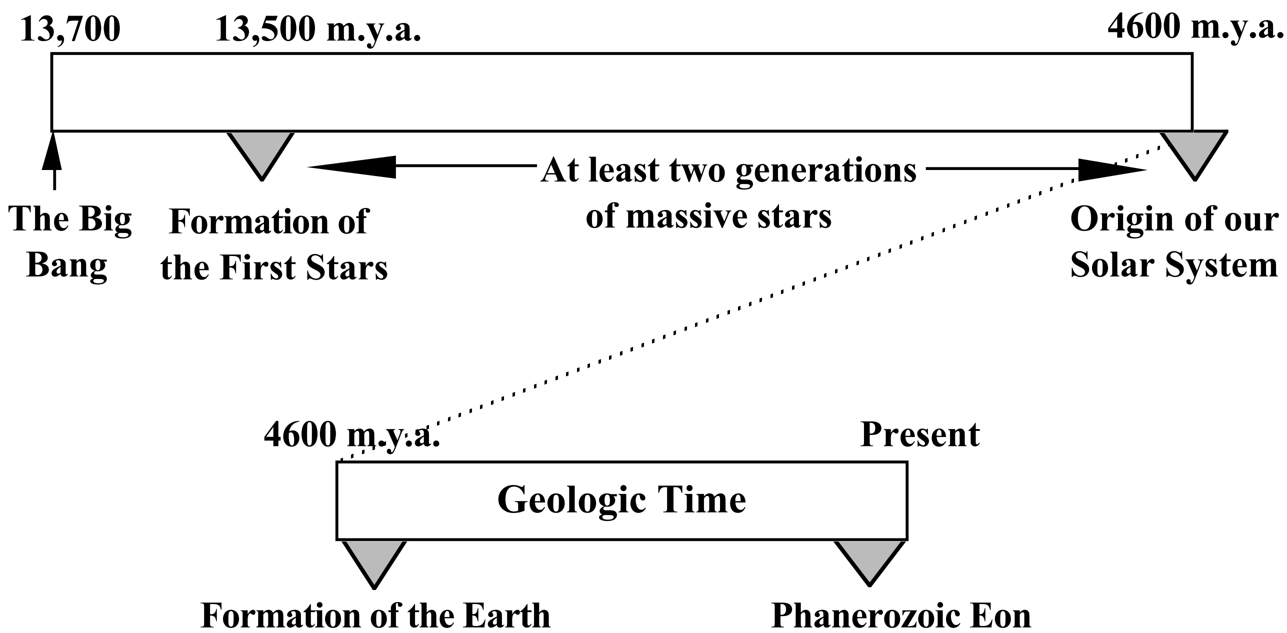
3) Emergent Properties & Processes—cell specialization; emergence of large life forms; origin of Kingdoms Fungi, Plantae, and Animalia; social behavior; language

An average **Blue Whale** is between 75 and 80 feet long, and weighs between 110 to 150 tons (300,000 pounds), making them the largest known animal ever to exist.

(Photograph by Mike Johnson)


Increasing Complexity through Time
Complexity
Multicellular
Eukaryotic
Prokaryotic
Molecular
Quantum, Sub-Atomic, Atomic
0
3
5
7
9.7
11.7
12.7
13.7
Big Bang
Time (in billions of years)
Present

Cosmological Timeline



All dates are in millions of years ago (m.y.a.).

The Evolution of the Universe—The Short Version

"Yes, the universe had a beginning [13.7 billion years ago]. Yes, the universe continues to evolve. And yes, every one of our body's atoms is traceable to the big bang and to the thermonuclear furnace within high-mass stars. We are not simply *in* the universe; we are part of it. We are born from it." Neil de Grasse Tyson (1998)

Neil de Grasse Tyson, an astrophysicist, is the director of New York City's Hayden Planetarium.

Astronomical Distances—How big is “Big”?

The diameter of the Earth is 7926.4 miles or 12,756.3 kilometers (km). The average separation of the Earth from the Sun is 149.6 million km. This is 11728 times the Earth’s diameter. This defines an Astronomical Unit (AU) which is the preferred unit of measure for distances within our solar system. Converted to miles the Earth is 93 million miles from the Sun. It takes light 8.3 minutes to travel from the Sun to the Earth.

A light year or the distance light travels in a year is used to measure distance outside of our solar system. It is 9.45 trillion kilometers or 5.88 trillion miles. To put a light year in perspective, an Astronomical Unit is 0.0000158 of a light year.

The speed of light (c) is one of the fundamental constants in nature. The speed of light in a vacuum is exactly c = 299,792,458 m/s (meters per second). This is 299,792 kilometers per second or 186,300 miles per second (the conversion factor is km x 0.62143 = miles). The speed of light is normally rounded to 300,000 km/sec or 186,000 miles/sec.

When people refer to the speed of light, they refer to the definition above—the speed of light in a vacuum. The speed of light depends on the material that the light moves through—for example: light moves slower in water, glass and through the atmosphere than in a vacuum. The ratio whereby light is slowed down is called the refractive index of that medium. In general for astronomical distances, the difference in the speed of light in other mediums is ignored because of the emptiness of space.

Some Representative Distances

• The Solar System is about 80 Astronomical Units in diameter or **7.44 billion miles**.

• The nearest star to Earth (other than the Sun) is Proxima Centauri about 4.3 light years or **25.3 trillion miles** away.

• Our galaxy (the Milky Way) is about 100,000 light years in diameter (**588 thousand trillion miles**).

• The nearest galaxy to the Earth is the Large Magellan Cloud about 50 kilo parsecs away. A parsec is 3.26 light years making the Large Magellan Cloud 1,540,000,000,000,000,000 kilometers away (which is about **1 million, trillion miles**).

“The universe is not just stranger than we imagine,

it is stranger than we can imagine.”

(paraphrase of J.B.S. Haldane from *Possible Worlds*, 1927)

References for Cosmological Evolution

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For more on Cosmological Evolution go to:
http://fire.biol.wwu.edu/trent/alles/Cosmic_Evolution_index.html

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