Alles Introductory Biology Lectures

An Introduction to Science and Biology for Non-Majors

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Part Three: The Integration of Biological Knowledge

The Origin of our Solar System

and

Geologic Time

“Out of the cradle

onto dry land

here it is

standing:

atoms with consciousness;

matter with curiosity.”

Richard Feynman

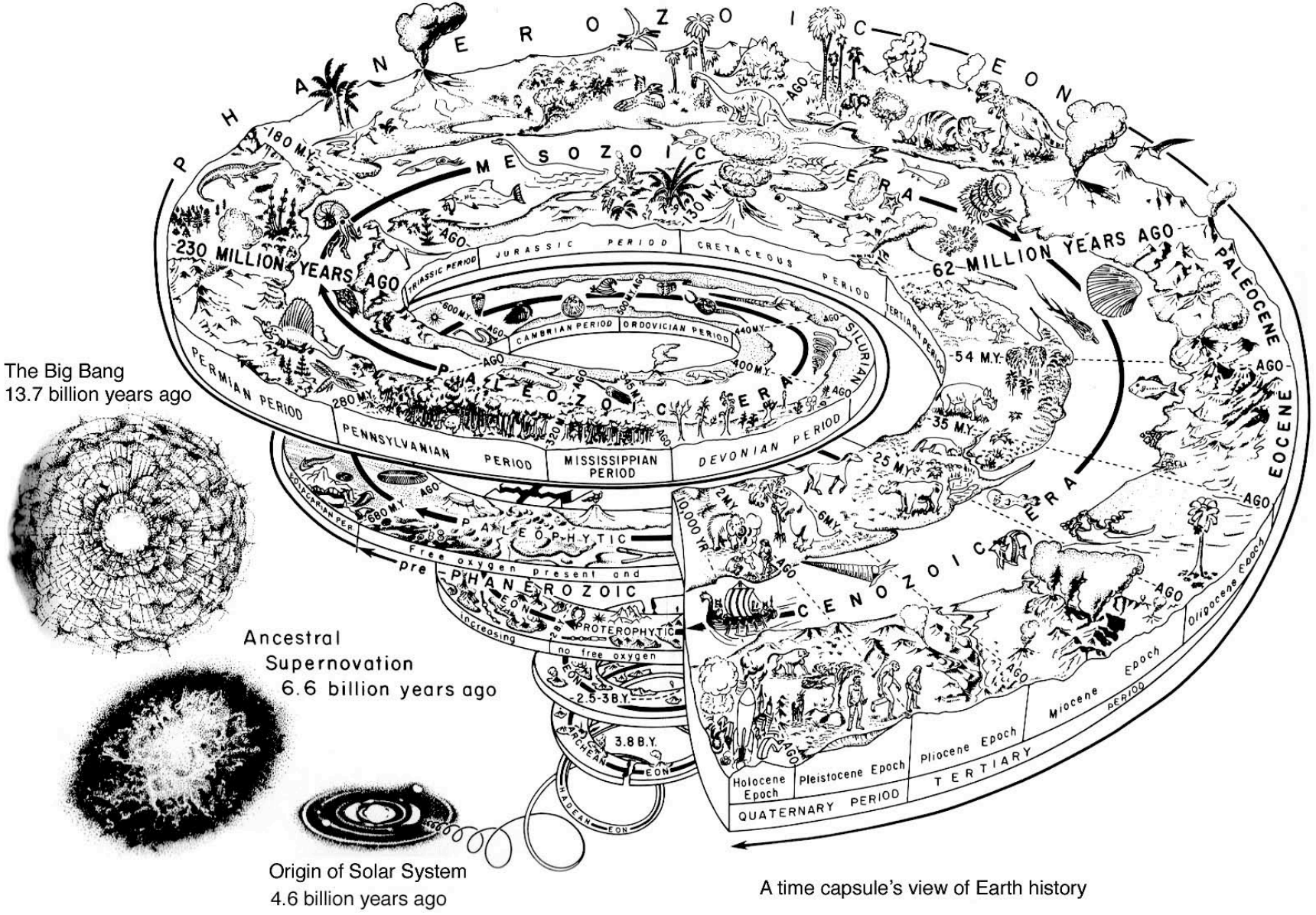
Introduction

> "Science analyzes experience, yes, but the analysis does not yet make a picture of the world. The analysis provides only the materials for the picture. The purpose of science, and of all rational thought, is to make a more ample and more coherent picture of the world, in which each experience holds together better and is more of a piece. This is a task of synthesis, not of analysis."—Bronowski, 1977

• Because life on Earth is an effectively closed historical system, we must understand that biology is an historical science. One result of this is that a chronological narrative of the history of life provides for the integration of all biological knowledge.

• The late Preston Cloud, a biogeologist, was one of the first scientists to fully understand this. His 1978 book, *Cosmos, Earth, and Man: A Short History of the Universe*, is one of the first and finest presentations of "a more ample and more coherent picture of the world."

• The second half of this course follows in Preston Cloud's footsteps in presenting the story of the Earth and life through time.



From Preston Cloud's 1978 book *Cosmos, Earth, and Man*

On the Origin of our Solar System and the Age of the Earth

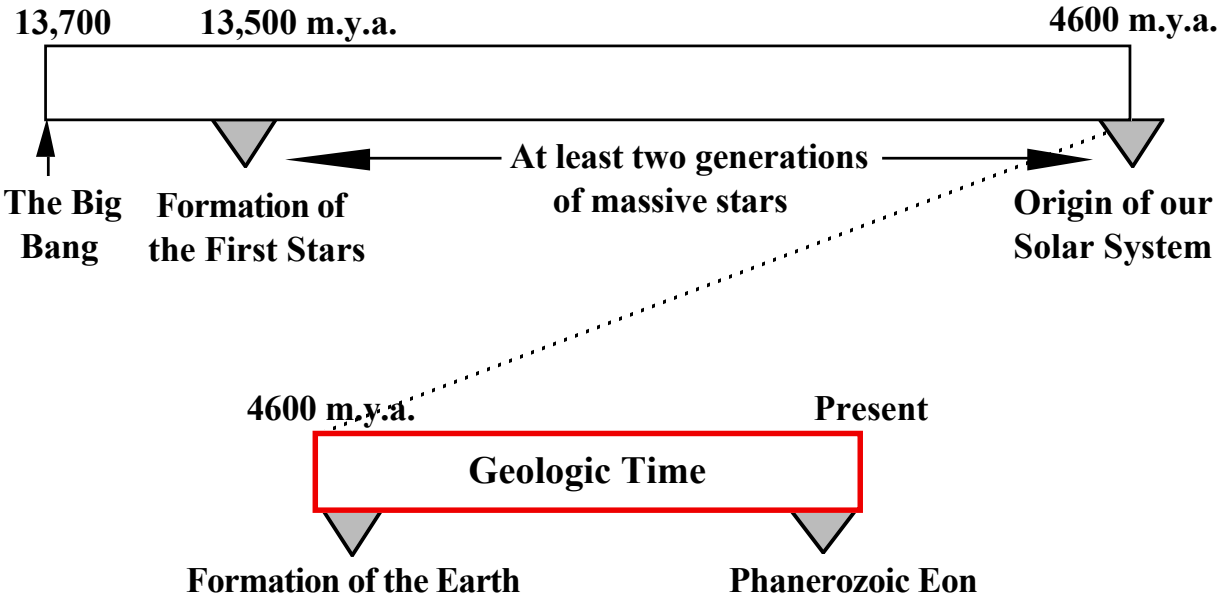
How did the Sun and the planets form, and what lines of scientific evidence are used to establish their age, including the Earth's?

1. **the Sun's luminosity**

2. **the radiometric age of Moon rocks**

3. **the radiometric age of meteorites**

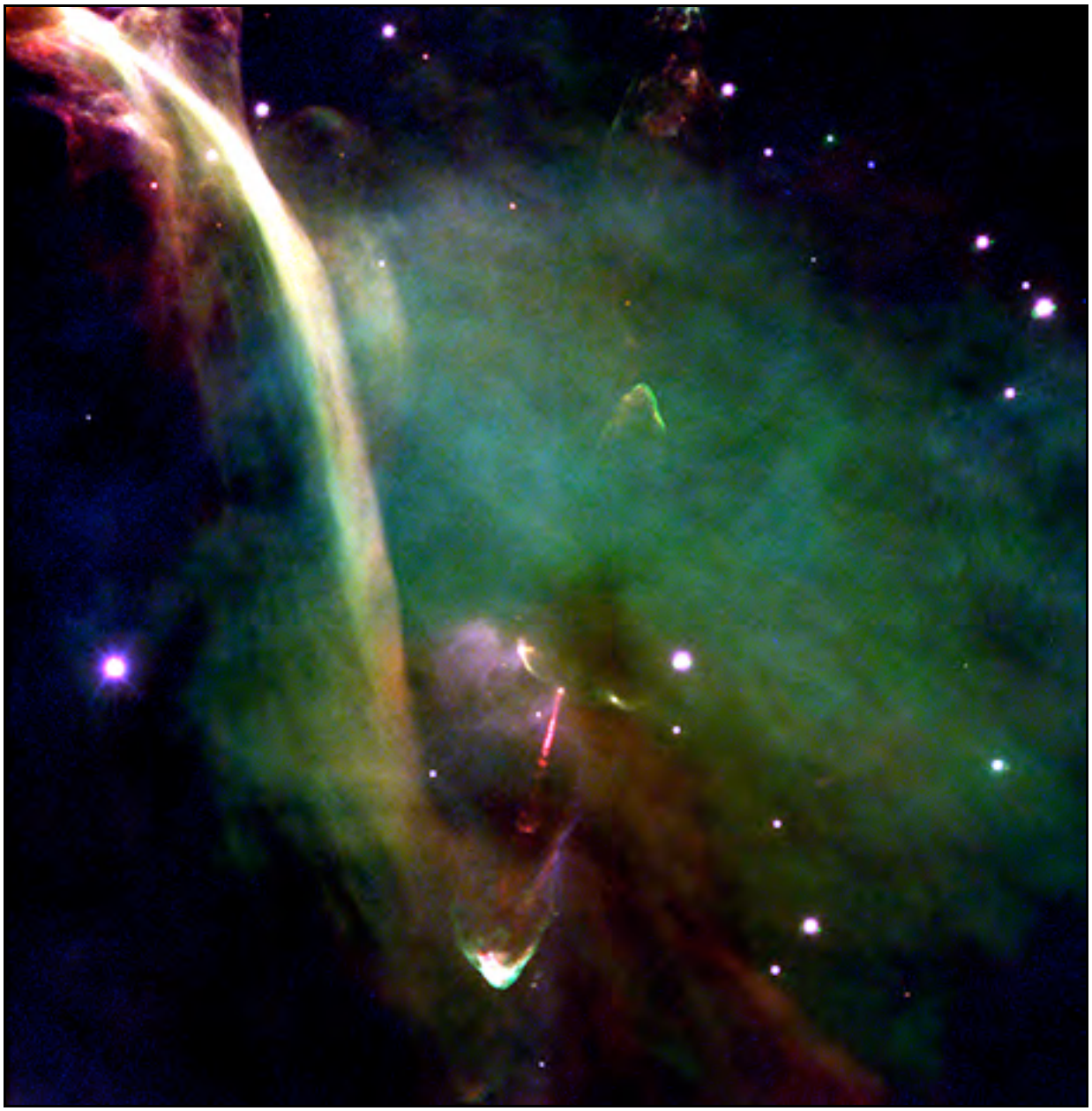
Cosmological Timeline



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

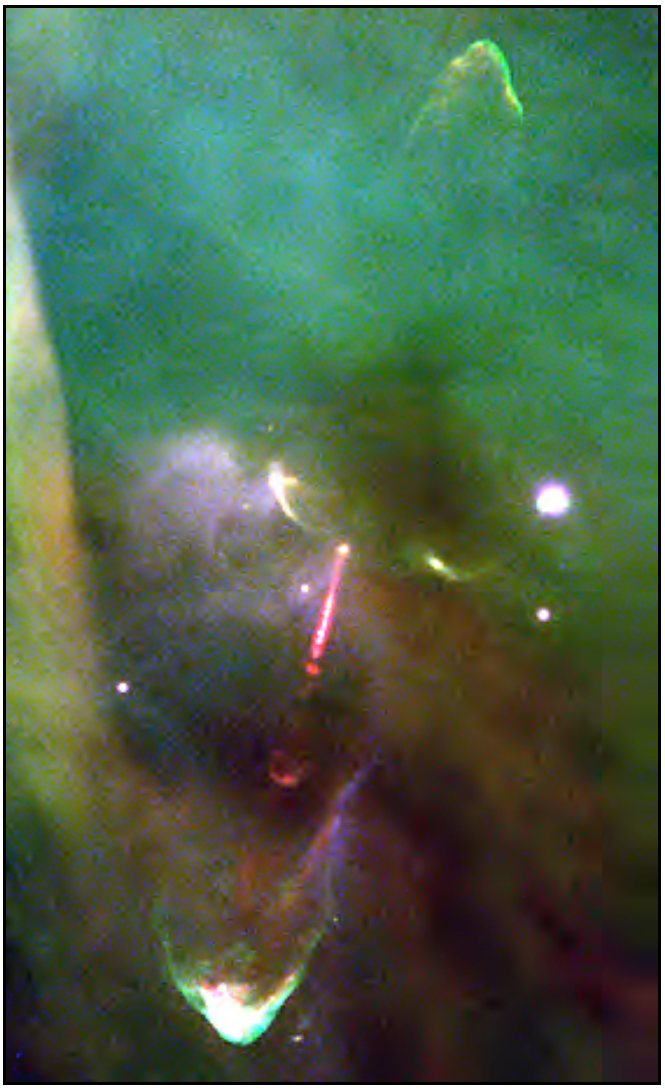
Star formation starts when clouds of interstellar gas are disturbed, as by a nearby supernova explosion, and begin to collapse under the influence of gravity. The cloud above is the top of one of the pillars in the Eagle Nebula.

(Image courtesy of NASA)



Local regions of the gas cloud condense into a rotating disk. The example shown here is protostar HH-34 in the Orion Nebula.

(Image courtesy of European Southern Observatory)



As the disk collapses further jets of matter are ejected at high speeds from the top and bottom of the disk. The bright red portion of the jet shown above is ~ 450 billion miles long.

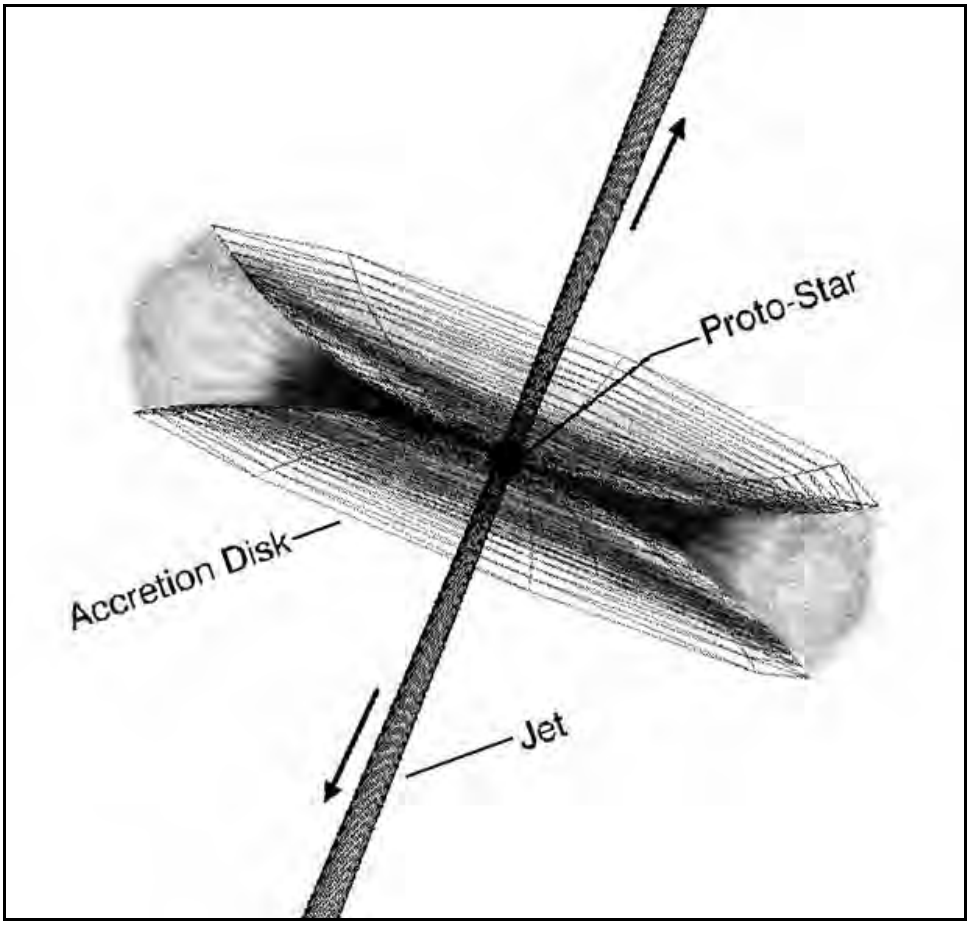


Diagram of HH-34 Circumstellar Disk and Jets

(Figure courtesy of NASA)

When enough matter has accreted to the center of the disk the protostar will ignite and start the thermonuclear burning of its hydrogen becoming a new star in the process.

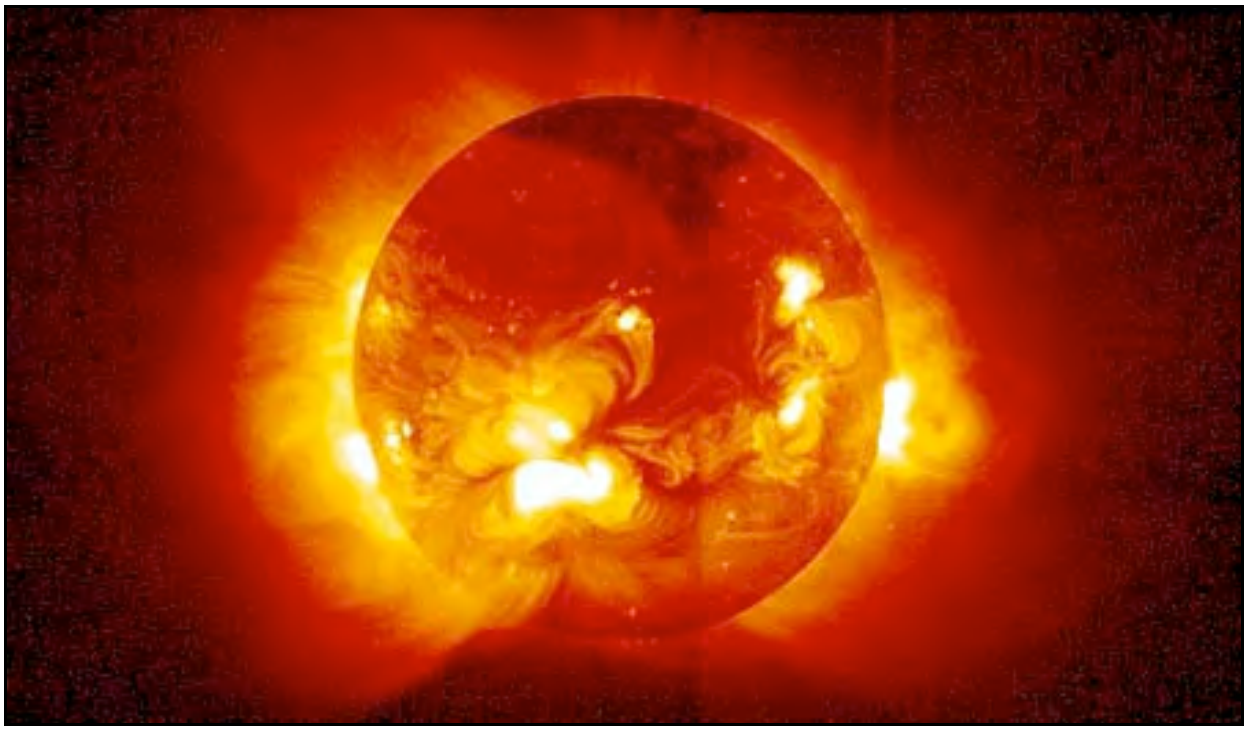
(Painting from Ray 2000)

A dusty beginning. As comets streak by, a small, scarred planetesimal (foreground) forms from the dust encircling a young sun.

A solar wind produced by the ignition of the new star will blow most of the gas from the accretion disk leaving larger grains of dust that accrete together eventually forming planetesimals. Finally in the process, the larger planetesimals will collide forming planets.

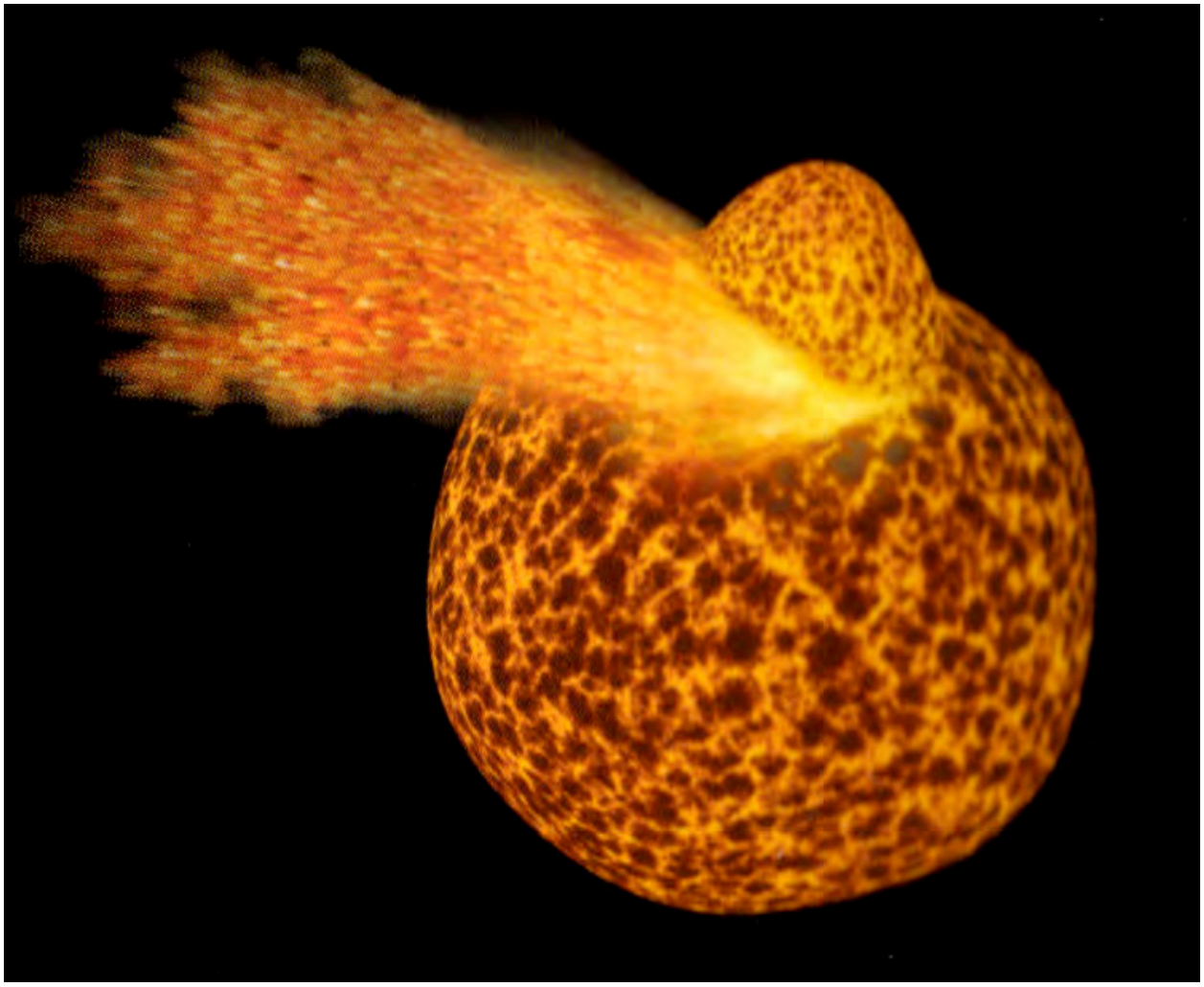
(Painting from Schilling 1999)

For more on the formation of our solar system go to:
http://fire.biol.wwu.edu/trent/alles/Star_Formation.pdf



The Sun's luminosity relative to its mass gives an estimate of ~ 5000 million years for the age of the Sun.

Web Reference
http://solar-center.stanford.edu/

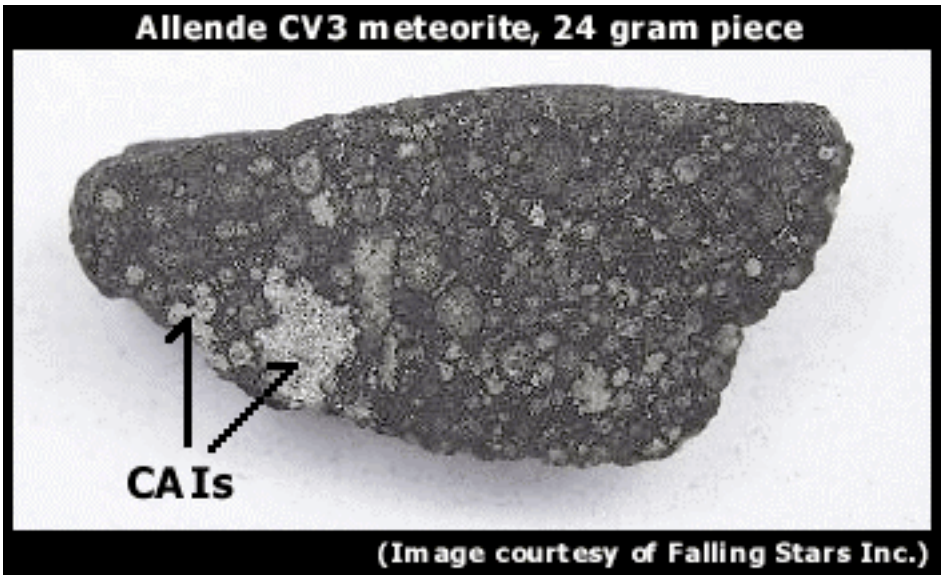


The leading hypothesis for the formation of the Moon states that shortly after the formation of the Earth a Mars size planetesimal collided with the Earth throwing off lighter crustal debris into orbit. The debris then formed the Moon by accretion (Lee, et al, 1997).

(Painting from Tyson, et al, 2000).

The radiometric age of the Moon is ~ 4500 million years old (Touboul, et al, 2007).

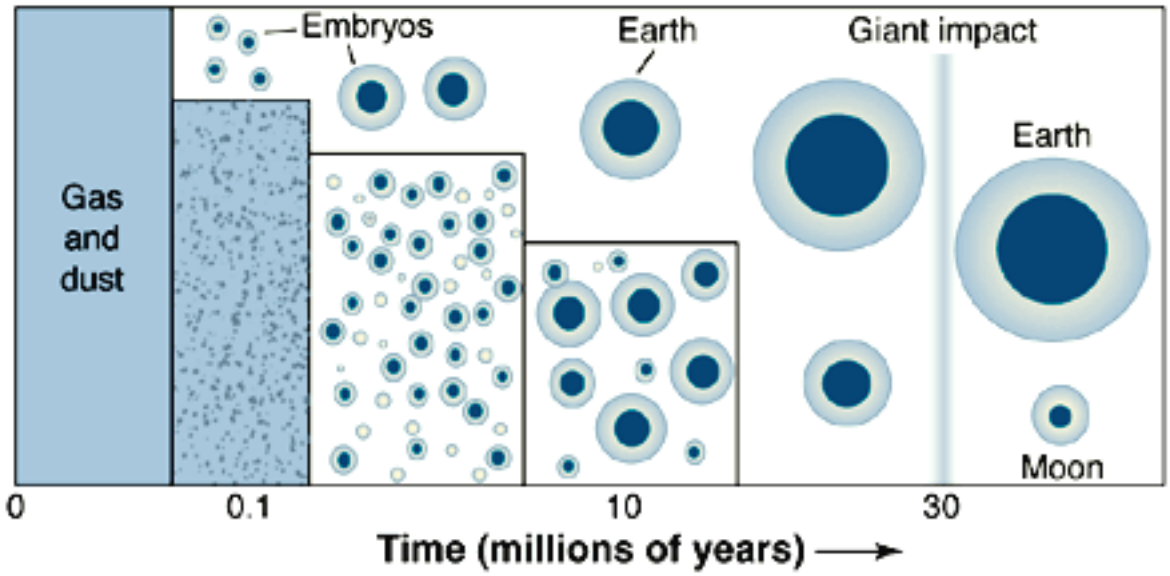
For further information about the Moon go to:
http://www.nineplanets.org/luna.html



The oldest materials that formed in the Solar System are inclusions rich in calcium and aluminum found within carbonaceous chondrite meteorites. Nicknamed CAIs (for Calcium-Aluminum-rich Inclusions), these objects are thought to have been some of the first solids to form after the cloud of gas and dust began to heat up. **CAIs have ages of 4566 million years.**

Recent reports on the tungsten (W) isotope composition of meteorites, (Jacobsen, 2003), have led to a revised time scale for the formation of the terrestrial planets. The results show that most of planet **Earth had formed within ~10 million years after the formation of the solar system some 4567 million years ago** (when the first solid grains formed in the solar nebula). The Moon-forming event happened ~ 60 million years after solar system formation, when the Earth was fully grown.

Web Reference
http://www.psrd.hawaii.edu/Dec98/OriginEarthMoon.html



The Formation of Earth: "The first new solid grains formed from the gas and dust cloud called the Solar Nebula some 4567 million years ago. Within 100,000 years, the first embryos of the terrestrial planets had formed. Some grew more rapidly than others, and within 10 million years, ~ 64% of Earth had formed; by that time, proto-Earth must have been the dominant planet at 1 astronomical unit (the distance between Earth and the Sun). Accretion was effectively complete at 30 to 60 million years, when a Mars size impactor led to the formation of the Moon. The figure is not to scale."

(Figure 1, from Jacobsen, 2003)

For more on our Solar System go to:
http://nineplanets.org/

Geologic Time and the Limits of Human Perception

Our perception of time is limited. The issue is again scale,
but now of time rather than size.

Points:

1. Because of our limited life experience we are locked in "human time".

2. "The Last Six Minutes" Phenomenon—we equate the present to the past, as if the world has always been as it is now.

3. Human Time opposed to Geologic Time—human time is at the wrong scale for understanding the history of life.

Native Amnesia

"**We are born in ignorance of the events that took place before our birth, and through the study of history we seek to overcome this native amnesia.** We can hear about the most recent events by asking our parents and grandparents, who remember them. History from the times before living memory is written in documents, both the original writings of people long gone and the books written by scholars of history. Through the words represented by symbols on paper we are carried back through 5,000 years, back to the earliest writings, learning the thoughts and deeds of the people who lived before us.

Yet 5,000 years takes us back only a *millionth* part of the lifetime of the Earth. Back beyond the invention of writing stretches an almost endless abyss of time, during which the events took place which determined the kind of creatures we are and the kind of world we live in. It is only in the last couple of centuries that we have learned to decipher the events of this forgotten eternity and to write down its history."

Walter Alvarez from his book *T. rex and the Crater of Doom* (1997)

Geologic Dating

How are dates arrived at for the geologic time scale?

1. **Steno's Law**—also know as the **Law of Superposition**—states that, if undisturbed, lower sedimentary layers are always older than upper layers.

2. Using Steno's law layers of sedimentary rocks that contain different fossils give **relative dates** for those fossils.

3. **Radiometric dating** using radioactive isotopes gives absolute dates.

For more on geologic dating go to:
http://pubs.usgs.gov/gip/geotime/contents.html

http://en.wikipedia.org/wiki/Nicolas_Steno

Layers of sedimentary rocks are thousands of feet thick in the Grand Canyon of Arizona.

(Photograph by Louis Maher http://www.geology.wisc.edu/~maher/air.html)

For more on the geology of the Grand Canyon go to:
http://fire.biol.wwu.edu/trent/alles/GrandCanyon.pdf

The Geologic Time Scale

The units of time, starting with the longest, are Eons, Eras, Periods, and Epochs. All dates are in millions of years ago (m.y.a.).

Hadean Eon — 4600 to 4000 m.y.a.

major events: formation of the Earth

meteorite impact age

Archean Eon — 4000 to 2500 m.y.a.

major events: origin of life

evolution of photosynthesis

evolution of aerobic respiration

Proterozoic Eon — 2500 to 542 m.y.a.

major events: evolution of complex eukaryotes

evolution of sexual reproduction

evolution of multicellular life

Collectively, the first three eons are known as the **Precambrian.**

(Note: All dates are based on the 2009 version of the geologic time scale by the International Commission on Stratigraphy unless otherwise noted.)

Web References

http://www.stratigraphy.org/upload/ISChart2009.pdf

http://www.nmnh.si.edu/paleo/geotime/

Phanerozoic Eon — 542 m.y.a. to the Present

Eras of the Phanerozoic Eon

Paleozoic — 542 to 251

Mesozoic — 251 to 65

Cenozoic — 65 to Present

Periods of the Paleozoic Era

Cambrian — 542 to 488
Ordovician — 488 to 444
Silurian — 444 to 416
Devonian — 416 to 360
Carboniferous — 360 to 299
Permian — 299 to 251

Periods of the Mesozoic Era

Triassic — 251 to 200
Jurassic — 200 to 145
Cretaceous — 145 to 65

Periods & Epochs of the Cenozoic Era

Paleogene Period

Paleocene — 65 to 56
Eocene — 56 to 34
Oligocene — 34 to 23

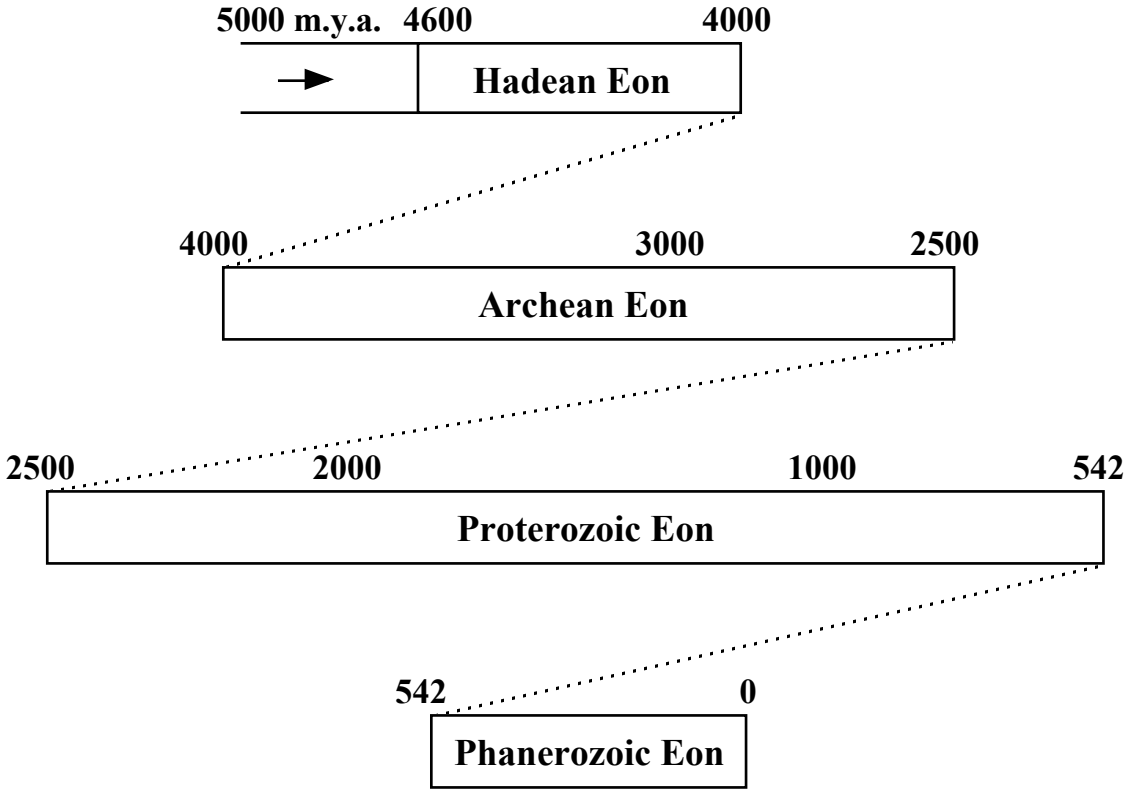
Neogene Period

Miocene — 23 to 5.3
Pliocene — 5.3 to 2.6

Quaternary Period

Pleistocene — 2.6 to 0.01
Holocene — 0.01 to the present

Geologic Timeline



Major Features of Life on Earth

In studying the history of life on Earth it is important to note the major features of that history. The issue is the degree of resolution we use; we want to be able to see the forest as well as the trees.

1. **Microbial life forms (single cell) are the dominant form of life on Earth** both from the view of longevity and in terms of sheer biomass—life's dominant form is microbial.

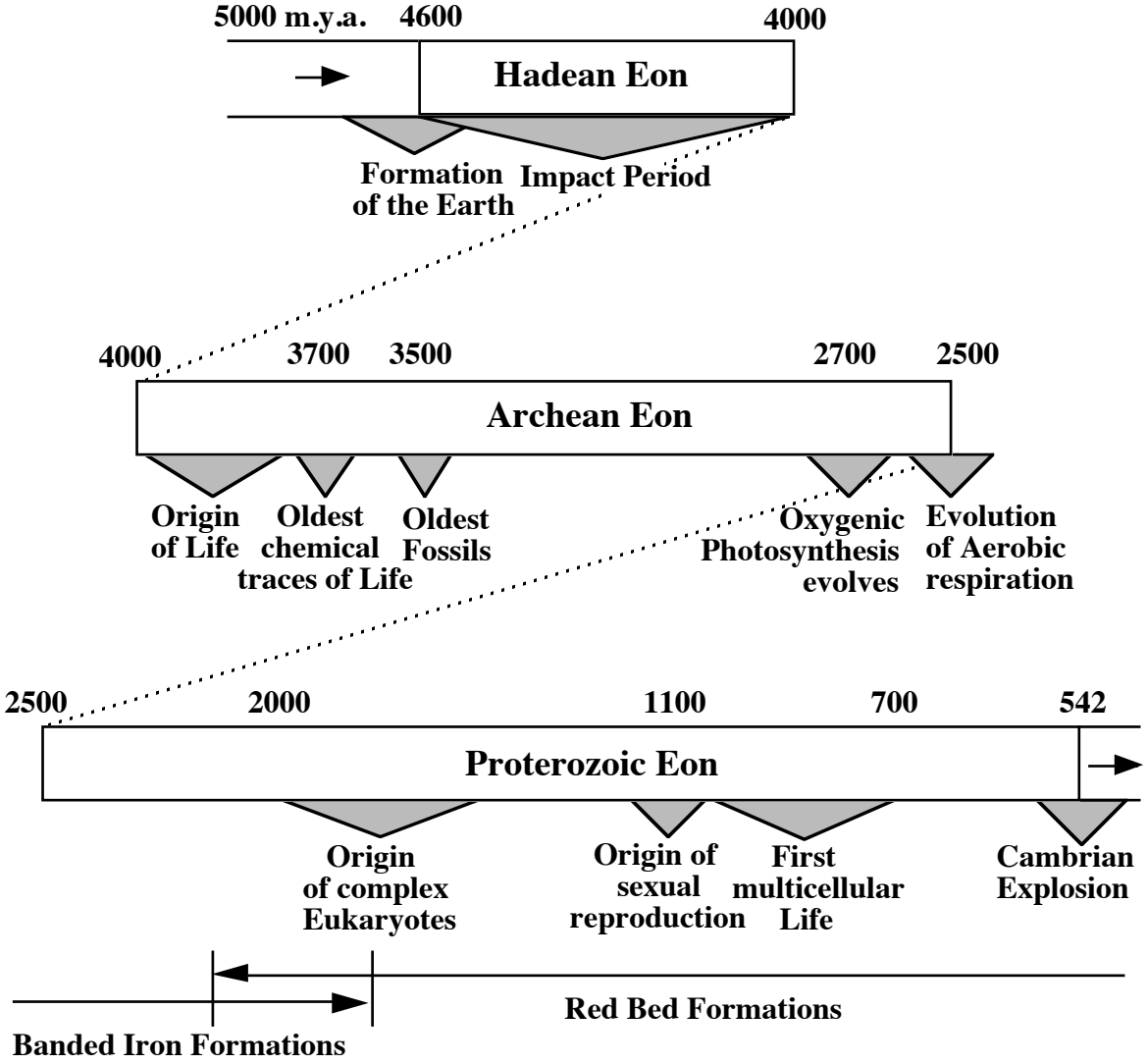
2. **The vast majority of life for almost all of the history of life on Earth lived and does live in the sea**—life's predominant habitat is the sea.

3. **Life has evolved from the small to the large.**

4. **Life has evolved from the simple to the complex.**

5. There is a necessary **sequence to the history of life's evolution**, even though that history was not pre-determined.

The Precambrian



Major Events in the Precambrian

1. the formation of the solar system
2. the formation of the Earth
3. end of meteorite impact period
4. the origin of life (anaerobic prokaryotes)
5. the evolution of photosynthesis (photoautotrophic prokaryotes)
6. the evolution of aerobic respiration (heterotrophic and autotrophic, aerobic prokaryotes)
7. start of oxygen build-up in the Earth's atmosphere
8. the evolution of complex eukaryotic cells (heterotrophic and autotrophic eukaryotic protists)
9. the evolution of sexual reproduction
10. the evolution of multicellular life (fungi, plants, and animals)

Web Reference
http://www.peripatus.gen.nz/paleontology/MaiLinEvo.html

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