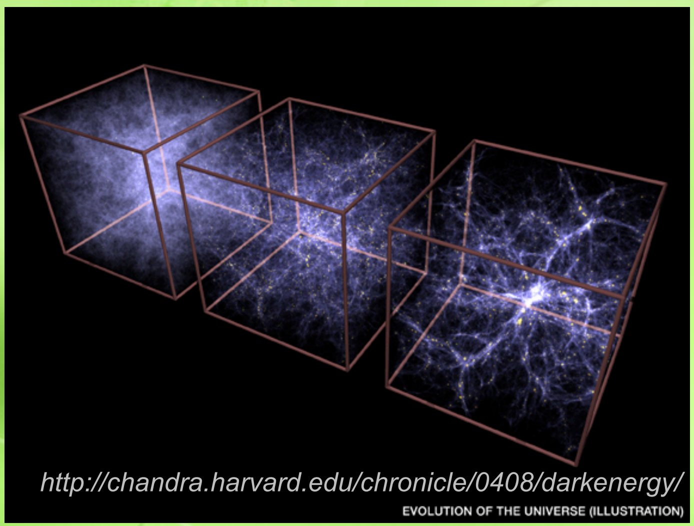
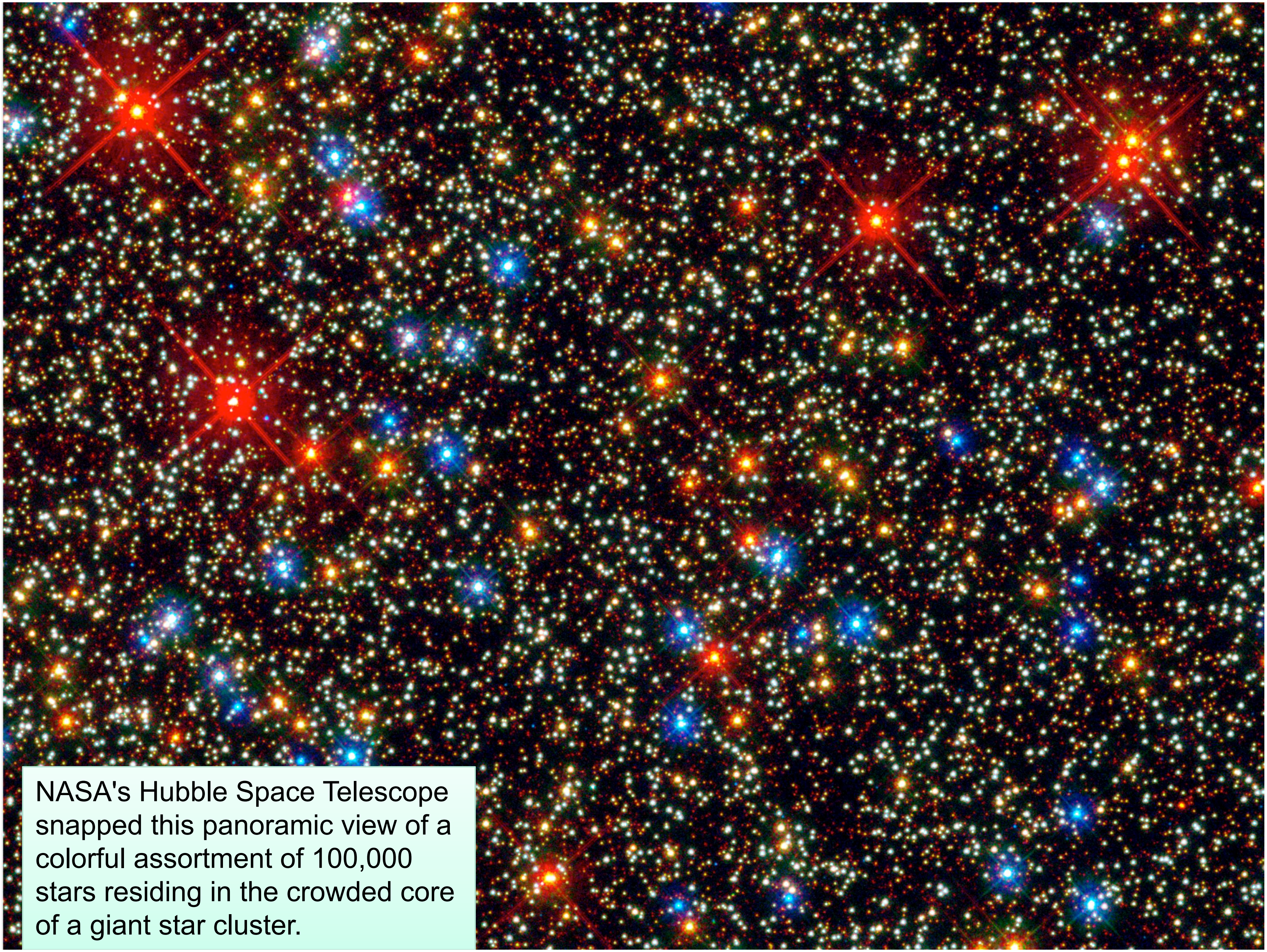
Assembling the Earth: A Brief History of the Universe

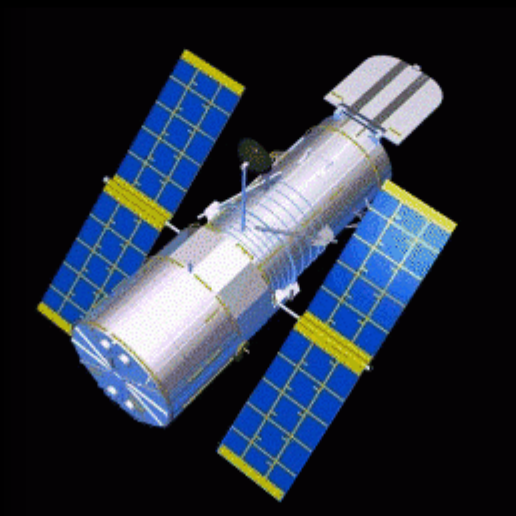


- The Big Bang
- Star formation
- Elemental synthesis
- Earth’s Sun
- Planetary formation



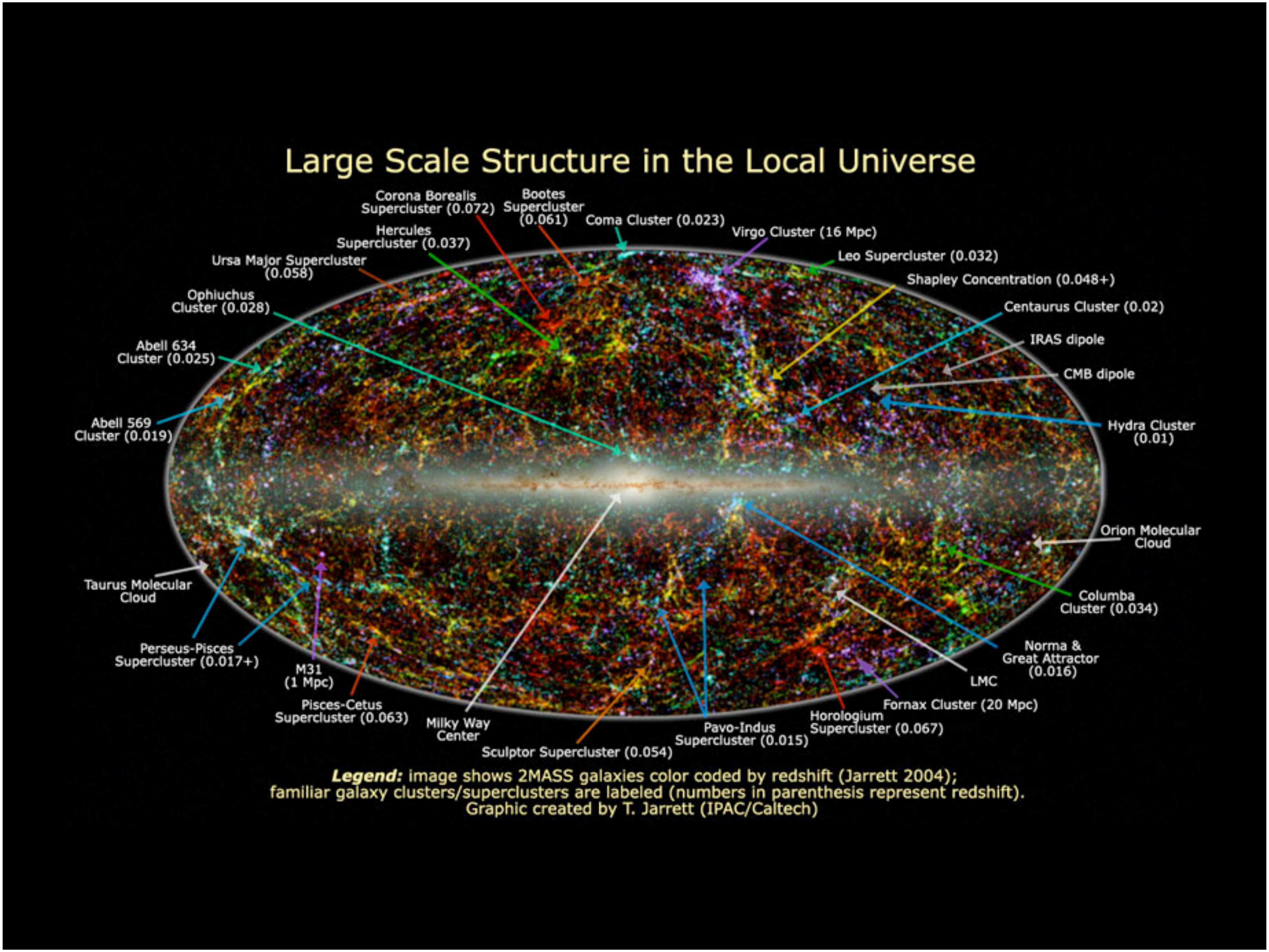
NASA's Hubble Space Telescope snapped this panoramic view of a colorful assortment of 100,000 stars residing in the crowded core of a giant star cluster.

Hubble Space Telescope



Mapping to Date:

Millions of galaxies

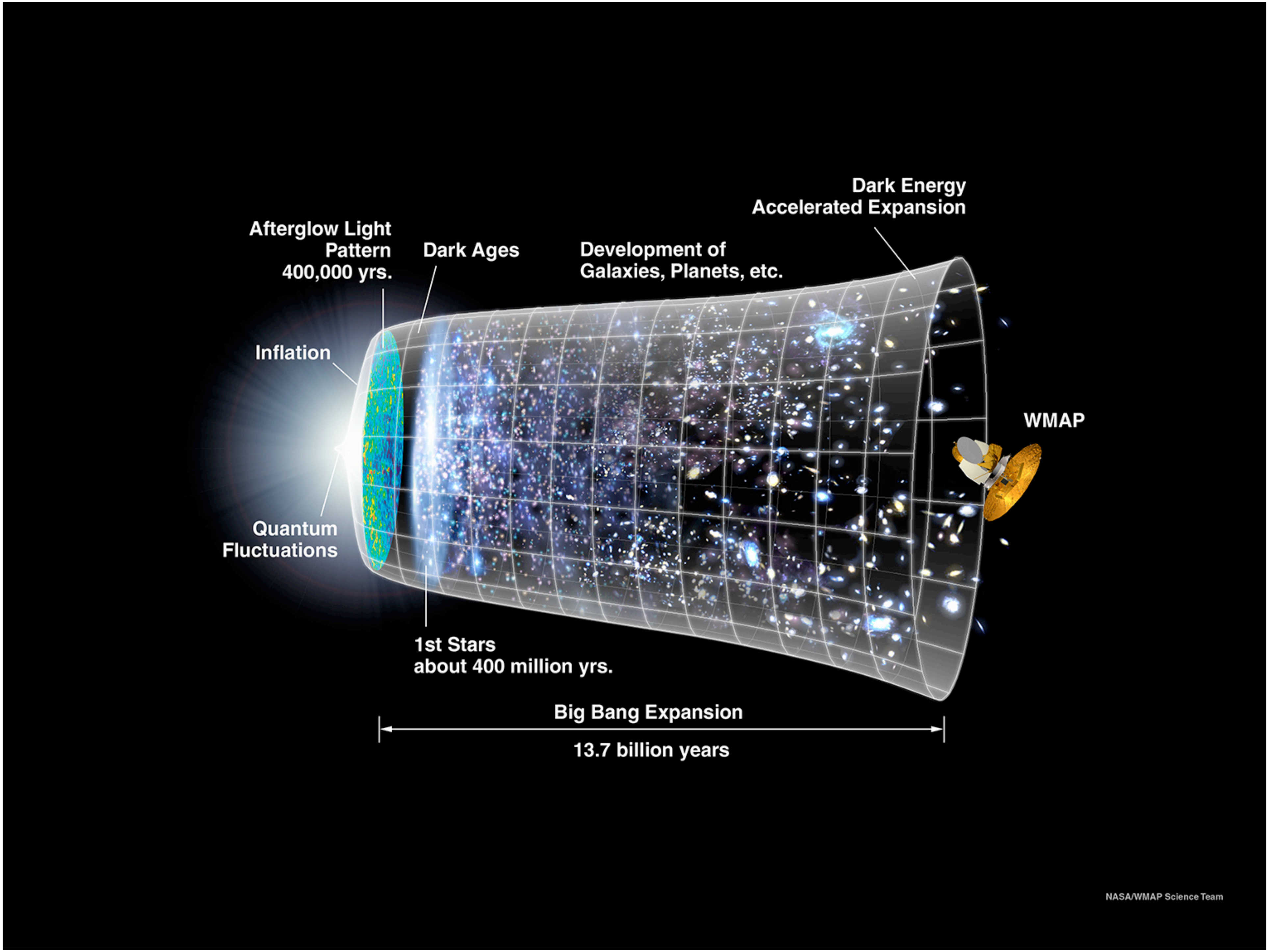

Large Scale Structure in the Local Universe
Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02)
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Abell 569 Cluster (0.019)
Hydra Cluster (0.01)
Orion Molecular Cloud
Taurus Molecular Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
M31 (1 Mpc)
Norma & Great Attractor (0.016)
LMC
Fornax Cluster (20 Mpc)
Pisces-Cetus Supercluster (0.063)
Milky Way Center
Pavo-Indus Supercluster (0.015)
Horologium Supercluster (0.067)
Sculptor Supercluster (0.054)
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004);
familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent redshift).
Graphic created by T. Jarrett (IPAC/Caltech)

How did the universe get to be this way?

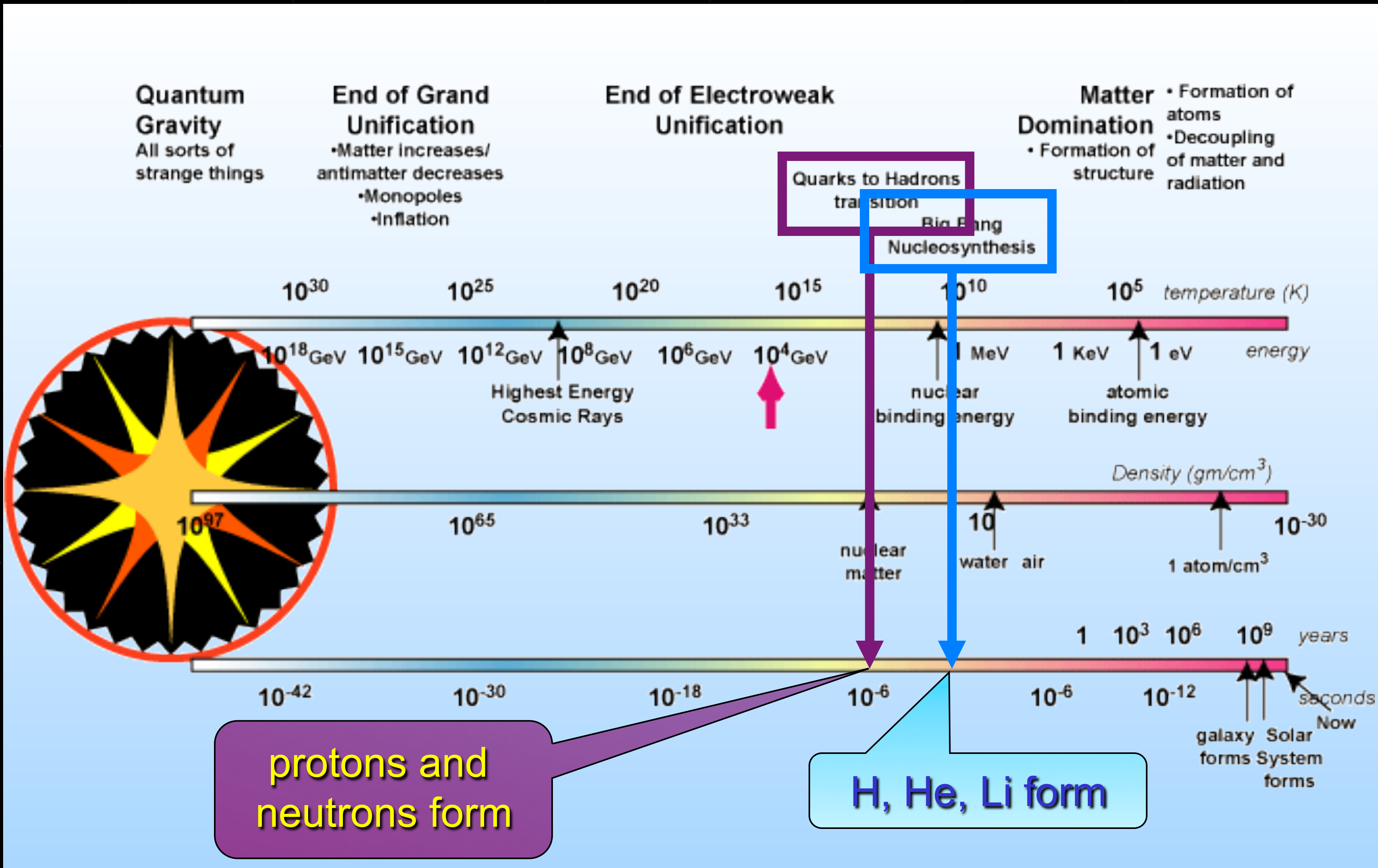
- Humans have observed only a small portion of the Universe, but other than our members of our own galaxy and our galaxy's nearest neighbors, all objects we have observed are moving away from us.
- There's nothing wrong with us - the objects are moving away from each other, too. In other words, the universe appears to be expanding.
- If we run the tape backwards, and re-compress the universe, there was a time (perhaps 14 billion years ago), when the entire universe was unimaginably dense and small.
- The event that led to the expansion from that dense universe is called the "Big Bang."

The Big Bang Hypothesis

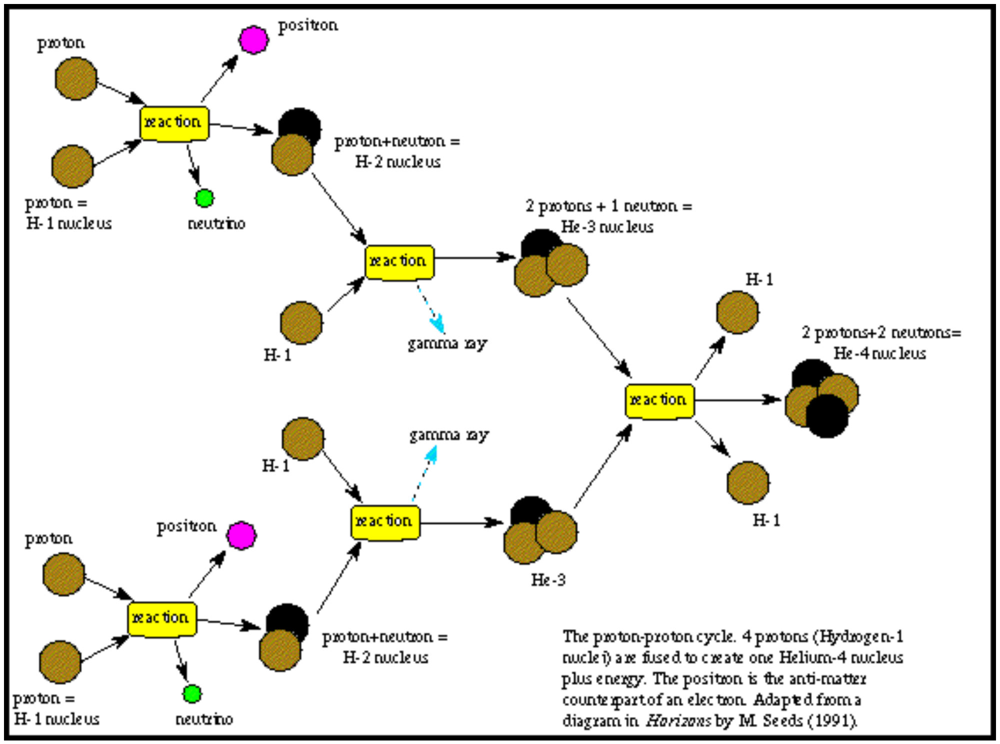
- Approximately 13,750,000,000 (~13.8 billion) years ago, the entire universe was compressed into an unimaginably dense "space".
- Instability led to a cosmic explosion – allowing matter, energy, time and space to expand. None of our familiar forces (gravity, weak force, strong force or electromagnetism) worked under these conditions.
- As the expansion continued, the density of matter and energy decreased, eventually allowing low energy matter like quarks and electrons, protons and neutrons, and finally atoms and molecules to form.
- Gravitational attraction caused stars to form, which grouped together to form galaxies.
- The universe still radiates at about 3.7 degrees Kelvin – a signal that can detected coming from every sector of space.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
NASA/WMAP Science Team

The early universe was a very different place!



Nucleosynthesis – Making New Elements

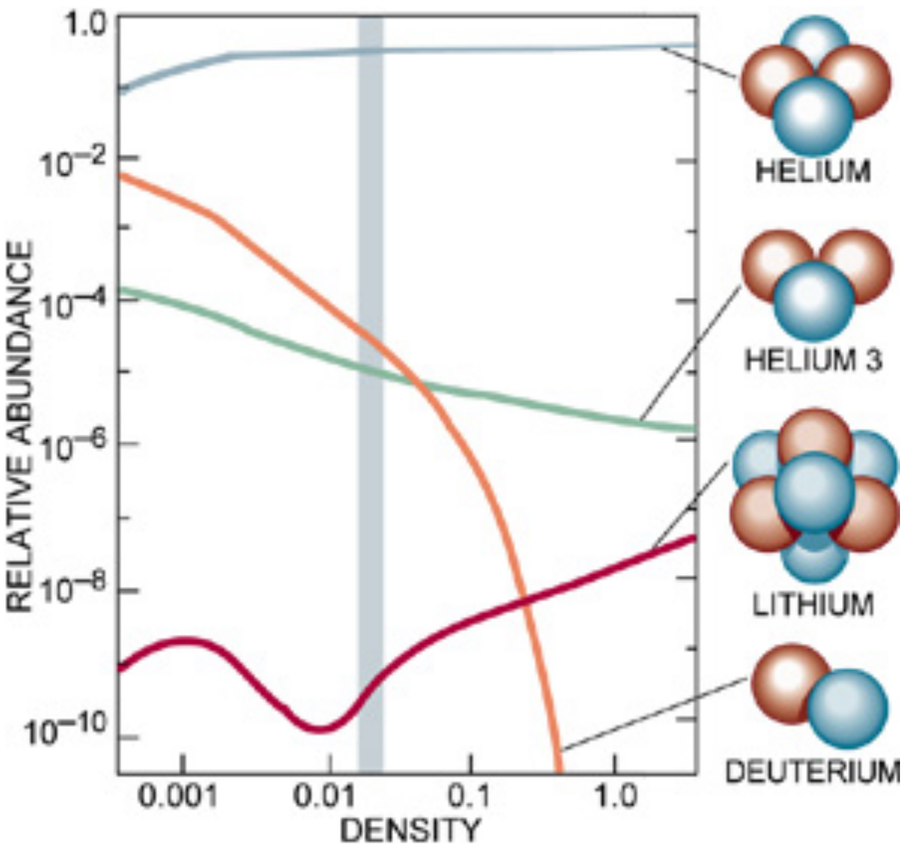


Hydrogen Fusion

Given enough energy, protons can "hit" each other hard enough for the strong nuclear force to overcome electromagnetic repulsion.

In the modern universe, hydrogen fusion takes place in the hearts of stars. It is also the basis of thermonuclear bombs.

Big Bang Elements

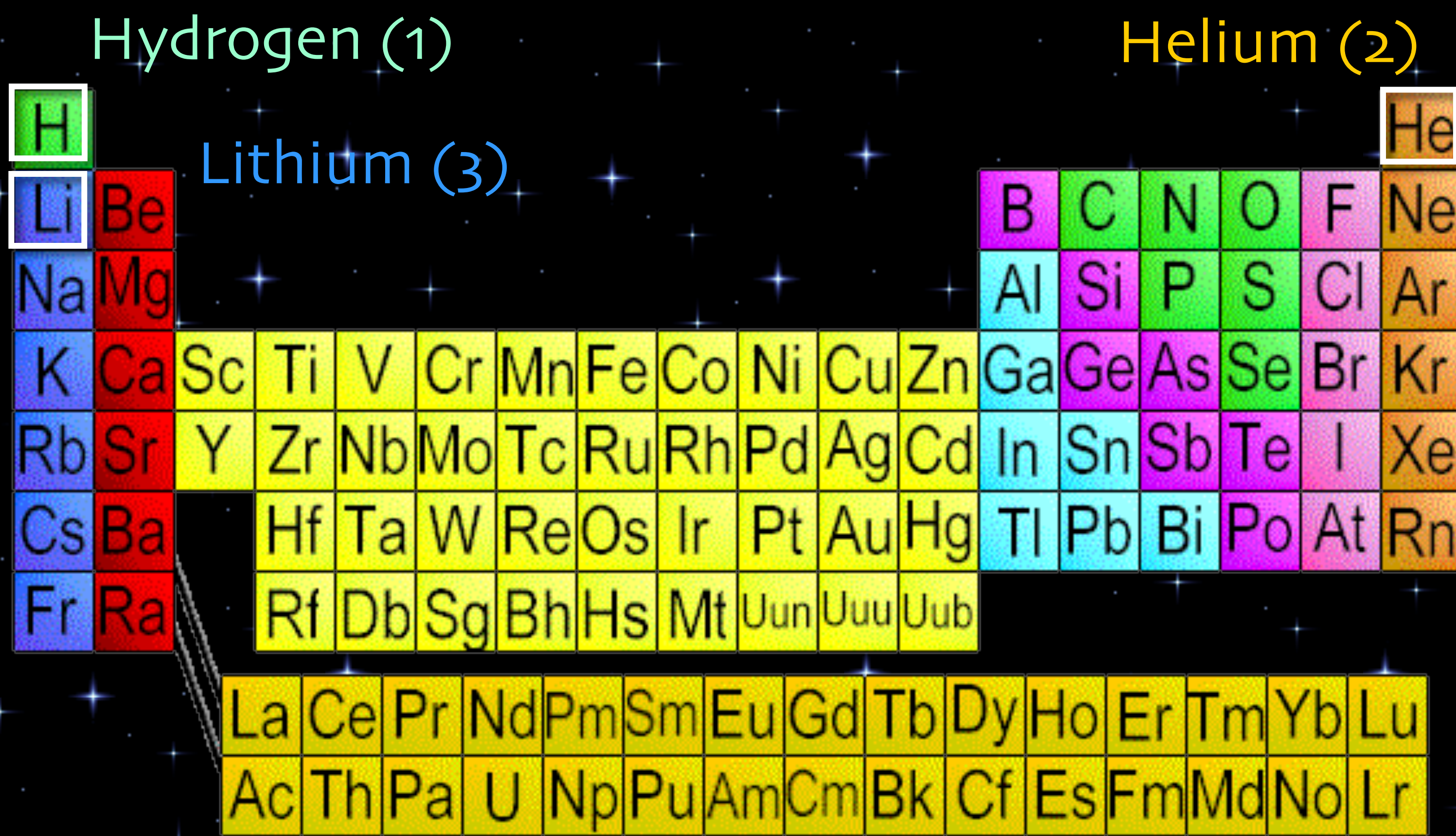


Baryons (protons and neutrons) formed at a time when there was still lots of energy available to shoot them around.

As the baryons knocked into each other, some stuck, forming isotopes of the elements hydrogen, helium and lithium.

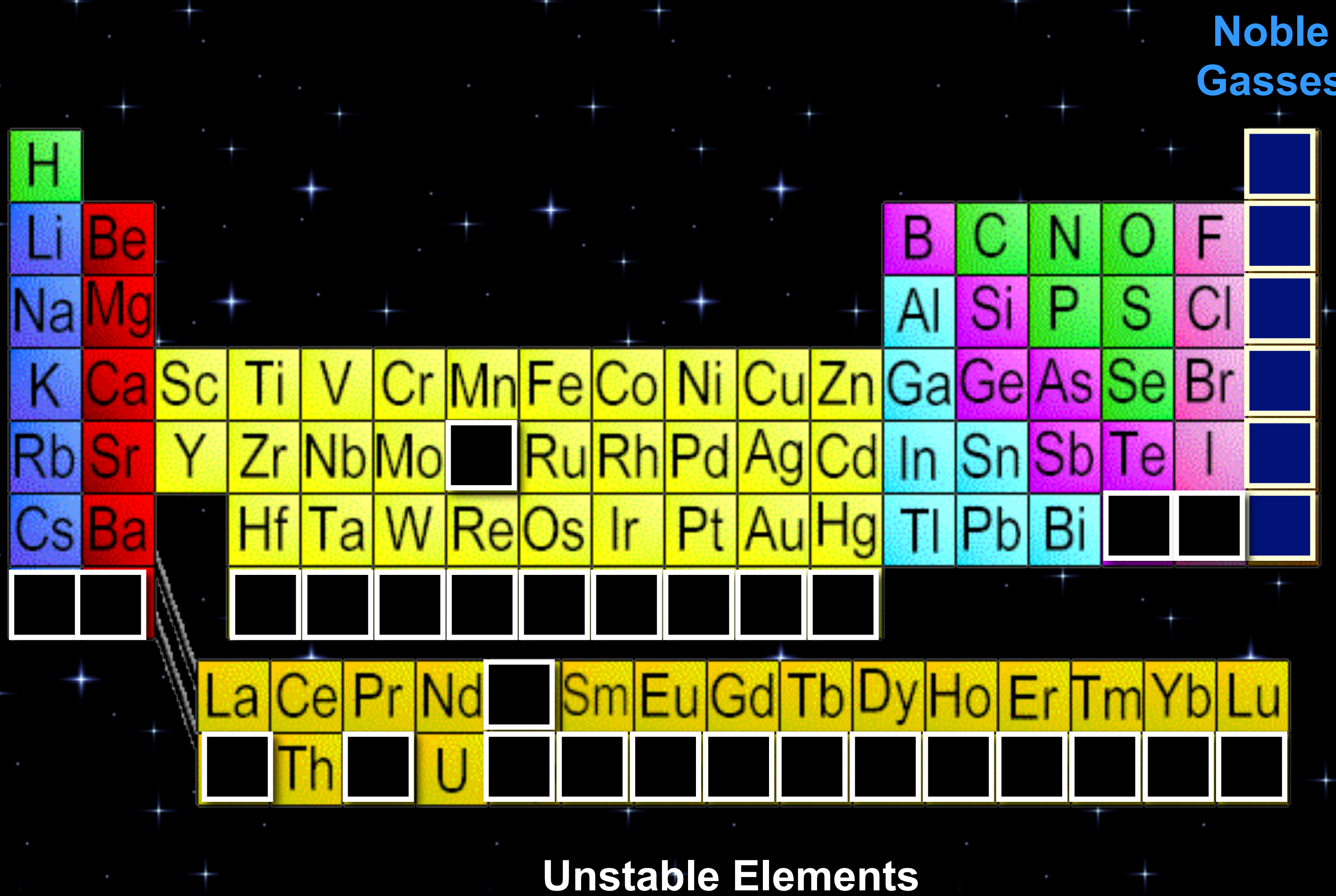
There was not enough energy to form heavier elements.

Big Bang Elements

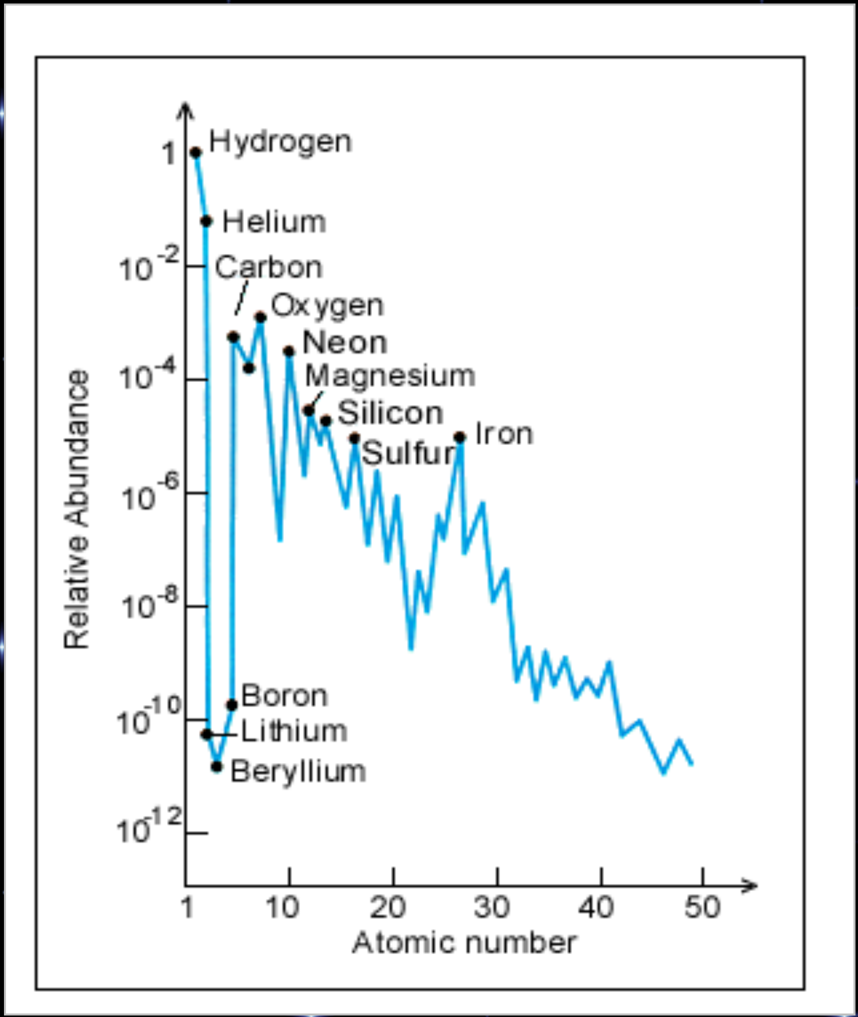


Elements formed during and soon after the Big Bang.

Elements of the Earth's Crust



Composition of Star Nebulae



H	1,000,000
He	98,000
O	850
Ne	120
N	100
Fe	47
Na	2
Other	100

The modern, visible universe is still primarily hydrogen and helium, but with other elements

These elements were not made during the Big Bang, and have been assembled in the billions of years since then.

http://www.astronomynotes.com/

Post-Big Bang Elements

Where were (and are!) these heavier elements formed?

Both in the hearts of living stars and during some of their explosive deaths…

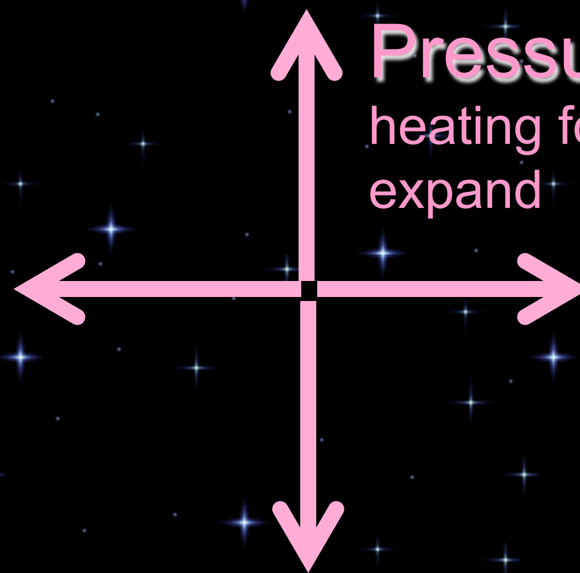
A Star is Born

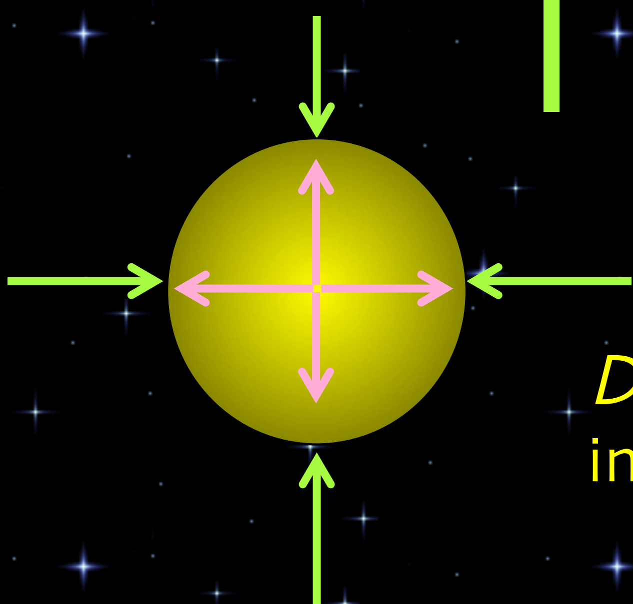
- Clouds of matter (mostly hydrogen) are drawn together by mutual gravitational attraction.
- The concentration of matter at the center of gravity increases, increasing pressure and temperature and somewhat countering gravity.
- Nuclear fusion of hydrogen fires up in the proto-star, adding enormous amounts of heat, and pushing outwards against pull of gravity.
- Star reaches equilibrium between forces, and becomes stable. (or it does not, and fails to become a stable star).

Stellar Birth – Reaching Equilibrium

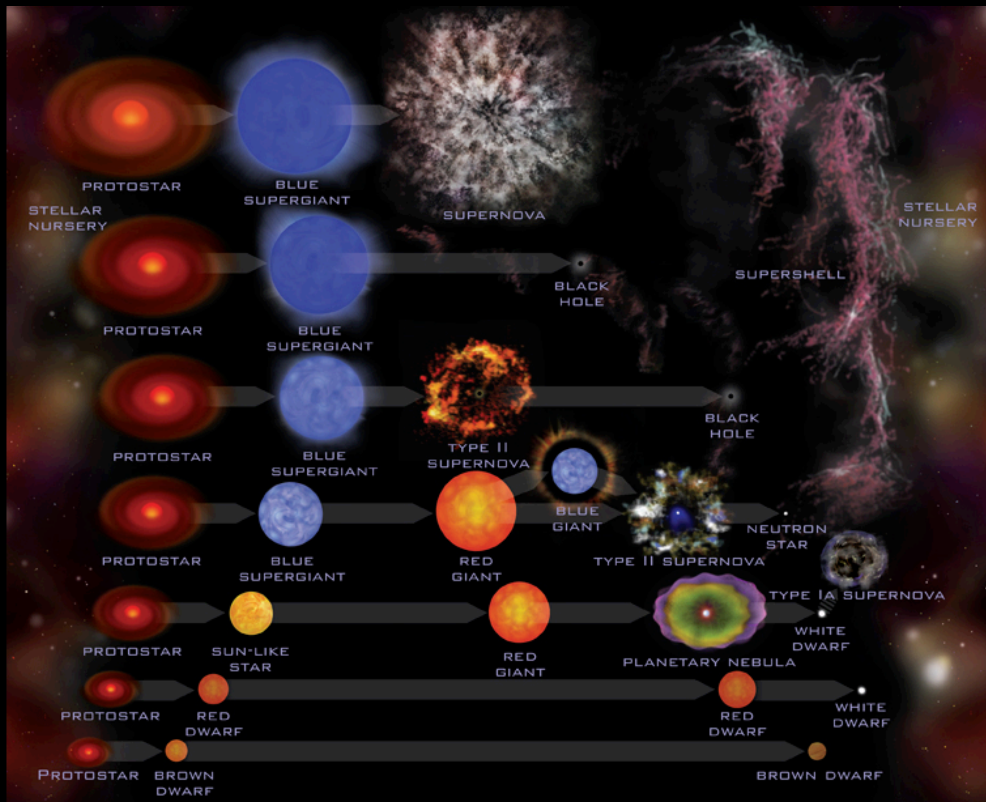
Gravity
mutual attraction draws matter in cloud together

Pressure
heating forces cloud to expand





Dynamic Equilibrium - outward and inward forces (mostly) equalize



Stars – Agents of Change

Most stars transform hydrogen to helium in their cores for most of their lives.

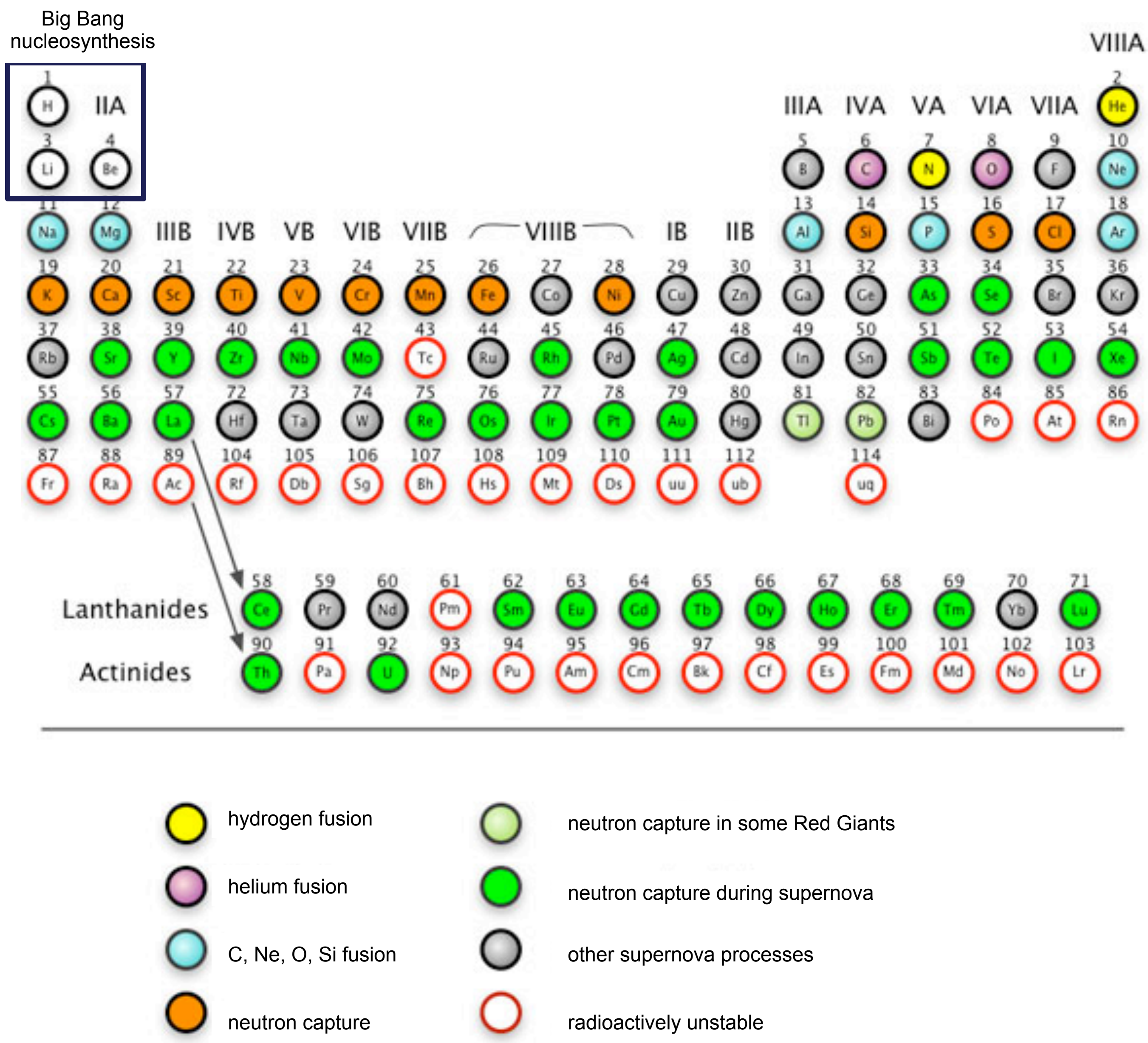
When the hydrogen starts to run out, the outward pressure weakens, causing the star to collapse and raising the temperature in the core.

If the temperature is high enough, helium will begin to fuse to form larger elements.

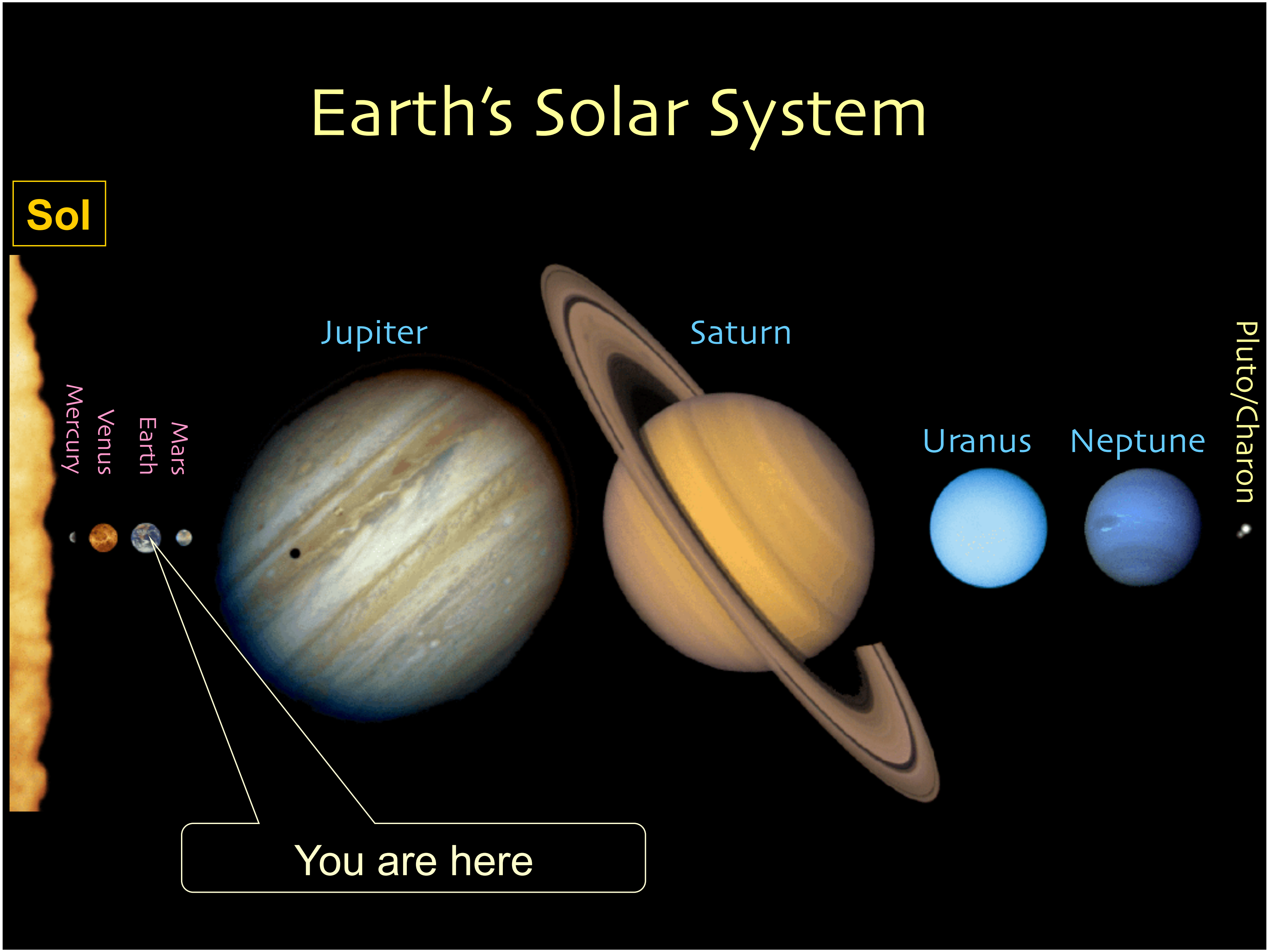
Large stars can synthesize elements up to iron while still maintaining their integrity, although they do become unstable. Synthesizing iron absorbs energy instead of releasing it, so once iron synthesis begins, the star is doomed.

Very large stars can deplete their fuel so quickly that when their fuel is exhausted, they collapse in spectacular fashion. The pressure in the core degenerates matter to form a core made of neutrons (or goes further to form a black hole). The collapsing star bounces off the core and explodes, creating a supernova. Enough energy is released in these explosions to create the other elements in the universe.

Nucleosynthesis



http://tingilinde.typepad.com/starstuff/2004/07/we_are_the_dust.html


Earth's Solar System
Sol
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto/Charon
You are here

Earth's Solar System

- Viewed from "above" Earth's north pole, all of the planets orbit in the same direction (counterclockwise). The Sun and all of the planets except Venus rotate in the same direction (counterclockwise). Most moons (including Earth's moon) orbit counterclockwise.

- The rocky inner (terrestrial) planets (Mercury, Venus, Earth, Mars) are basically rocks with thin atmospheres.

- The gaseous outer (Jovian) planets (Jupiter, Saturn, Uranus, Neptune) are mostly made of gases and ice.

- The Sun contains ~98% of all matter in the Solar System.

- The age meteorites and moon rocks indicate that the Solar System is about 4,600,000,000 (4.6 billion) years old).

Nebular Hypothesis

NASA's Hubble Space Telescope image of 4 young stars in the Orion Nebula, each surrounded by a protoplanetary disk of matter.

- The structure of the Solar System can be explained if the planets formed from a protoplanetary disk of material orbiting around the young Sun.
- The planets formed as material in this disk of matter collided and stuck together, obtaining higher gravity and thus attracting even more matter

When hydrogen fusion began in the young Sun, the energy blew much of the lightweight material out of the inner Solar System. This material eventually became part of the Jovian planets and their moons (as well as other, smaller objects in the outer Solar System like asteroids), while the heavier material that remained became the inner planets.

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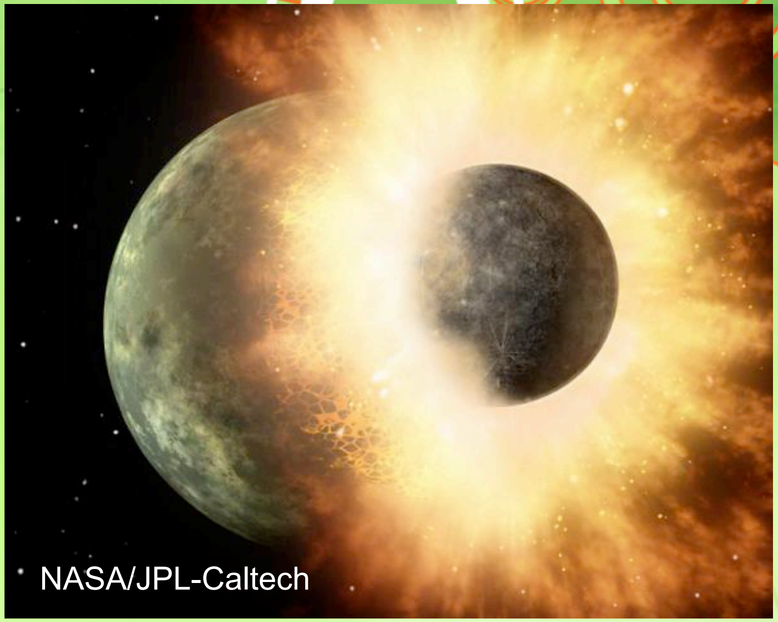
Formation of the Earth and Earth's Moon

- Like the rest of the Solar System, Earth's early history was quite violent, with large planetoids smashing into it perhaps a dozen times.
- One of the last, and certainly most violent, collisions resulted in the formation of Earth's moon. The colliding planetoid might have been as large as Mars.


NASA/JPL-Caltech

The heat produced by these collisions caused partial melting of the otherwise solid Earth, and probably is responsible for the differentiation of the Earth's interior into a very dense iron/nickel core surrounded by less dense silicate rocks of the mantle. The crust has the lowest density of the three layers, and is composed of silica-rich material distilled from the mantle (a topic we will revisit when talking about plate tectonics).

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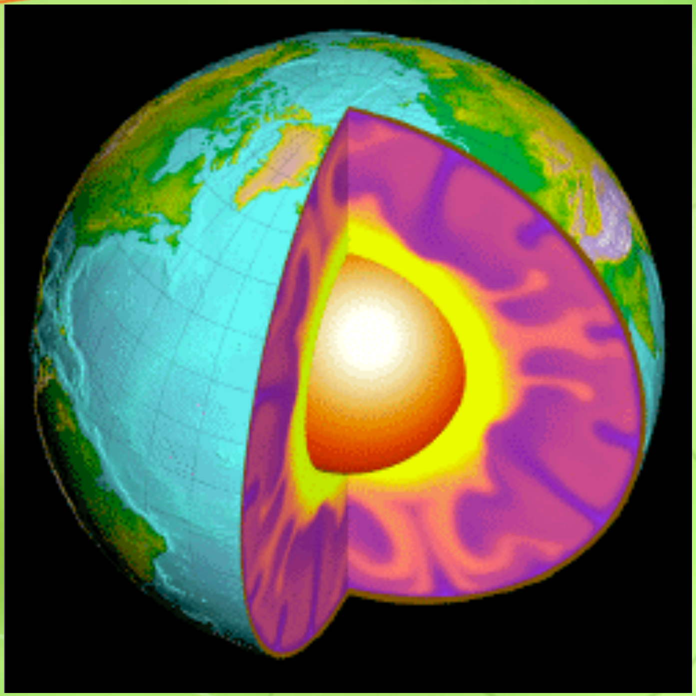

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The interior of the Earth is still quite warm. In addition to the original heat left over from its violent formation, the inside is kept warm by the decay of radioactive isotopes, which formed during the deaths of stars earlier in the history of the Universe. This heat creates the force that drives plate tectonics on the surface of the Earth.