The Universal Context of Life
(Chap 3 – Bennett & Shostak)

28 January 2010 - Lecture 4
2 February 2010 – Lecture 5
HNRS 228 - Astrobiology
Prof. Geller
Overview of Chapter 3

The Universe and Life (3.1)
- Age, Size, Elements, Laws

The Structure, Scale, and History of the Universe (3.2)
- Planets, Solar System, Galaxy, Local Group, Supercluster, Universe
- Big Bang Theory of creation of universe
  - Evidence for expansion, age and composition

The Nature of the Worlds (3.3)
- The solar system and its formation
Overview of Chapter 3

- A Universe of Matter and Energy (3.4)
  - Atoms, Energy, Electromagnetic Radiation, Spectroscopy
- Changing Ideas about the Formation of the Solar System (3.5)
  - Nebular Condensation Model
Food for thought...

“The grand aim of all science is to cover the greatest number of empirical facts by logical deduction from the smallest number of hypotheses or axioms.”

– Albert Einstein, 1950
1st Law of Thermodynamics

In an isolated system, the total amount of energy, including heat energy, is conserved.

ENERGY IS CONSERVED
2nd Law of Thermodynamics

- Two key components
  - Heat flows from a warmer body to a cooler body
  - Entropy increases, remains constant, or increases in time
Phases and Phase Diagram
Question for Thought

Why are astronomical distances not measured with standard reference units of distance such as kilometers or miles?

A Because astronomical distances are so large.
B Because astronomers are lazy.
C Because it was all figured out by the Greeks.
D Because it was meant to torture students.
E Because astronomical distances are so small.
Question for Thought

What is a light year and how is it defined?

A. It is a unit of distance.
B. It is defined as the distance traveled by light in a year.
C. It is about 6 trillion miles.
D. It is about 10 trillion kilometers.
E. All of the above are true.
Planck’s Radiation Curves

- A way to depict frequency (inverse of wavelength) versus intensity
Nature of Light

The Electromagnetic Spectrum
Which of the following groups have electromagnetic wavelengths, **all** of which are **shorter** than visible light:

- **A** ultraviolet, microwave, radio
- **B** ultraviolet, x-ray, gamma ray
- **C** infrared, microwave, radio
- **D** all of the above have wavelengths shorter than visible light
- **E** none of the above have wavelengths with all shorter than visible light
iClicker Question

Which of the following groups have electromagnetic wavelengths, all of which are longer than visible light:

A ultraviolet, microwave, radio
B ultraviolet, x-ray, gamma ray
C infrared, microwave, radio
D all of the above have wavelengths shorter than visible light
E none of the above have wavelengths with all shorter than visible light
Planck radiation curves have which characteristics plotted on its two axes?

A temperature and velocity
B temperature and wavelength
C spectral type and temperature
D intensity and frequency
E frequency and wavelength
Wien’s Law

- Peak wavelength is inversely proportional to the temperature of the blackbody.
Stefan-Boltzmann Law

- Energy radiated by blackbody is proportional to the temperature to the 4th power

\[ E = \sigma T^4 \]
Wien's Law relates which two properties of an object?

A temperature and velocity
B temperature and peak wavelength
C temperature and energy radiated
D focus and wavelength
E Doppler shift and wavelength
If you turn up the temperature of a thermostat from 300 Kelvin to 1200 Kelvin, how much more energy will be required to heat the chamber?

- A 64 times
- B 256 times
- C 4 times
- D 81 times
- E 16 times
Doppler Shift

- A change in measured frequency caused by the motion of the observer or the source
  - Classical example of pitch of train coming towards you and moving away
  - wrt light it is either red-shifted (away) or blue-shifted (towards)
iClicker Question

- Two objects are moving closer together. Each will see the other's light
- A red-shifted.
- B better than if moving apart.
- C richer in heavier elements.
- D blue-shifted.
- E shifted into the microwave region of the spectrum.
The Birth of Stars Like Our Sun

- Gas cloud
- Fragmentation
- Protostar
- Kelvin-Helmholz Contraction
- Hayashi Track
- Ignition
- Adjustment to Main Sequence
The Structure of Stars Like Our Sun

- Core
- Radiative Zone
- Convective Zone
- Photosphere
- Chromosphere
- Corona
How Bright is It?

- Apparent Magnitude (from Earth)
- Absolute Magnitude

Apparent brightnesses of some objects in the magnitude system.
How Hot Is It?

Remember Wien’s Law
Spectral Classes

- O, B, A, F, G, K, M
- There are also subclasses 0...9
H-R Diagram
Question for Thought

Describe the forces that keep a star in a state of hydrostatic equilibrium.

- **A** Fusion generated energy that pushes out from the center of a star.
- **B** Gas pressure that maintains a push out from the center.
- **C** The weight of the star (gravity) that keeps pulling the stellar material to the center of its mass.
- **D** All of the above.
Death of Stars like Sun

- Hydrogen Core Depletion
- Hydrogen Shell Burning ("Red Giant Branch")
- Helium Flash
- Helium Core Burning/Hydrogen Shell Burning ("Helium MS" "Horizontal Branch")
- Helium Core Depletion
- Helium Shell Burning
- Asymptotic Giant Branch
- Planetary Nebula
- White Dwarf
Question for Thought

What is the Hertzsprung-Russell diagram?

A. A plot of temperature vs. luminosity.
B. A plot which you can use to estimate the approximate age of a star cluster.
C. A plot that allows you to follow the life cycle of a star.
D. A plot of temperature vs. absolute magnitude.
E. All of the above are true.
Question for Thought

Which of the following stars have the longest life span?

- A  O type stars
- B  B type stars
- C  G type stars
- D  K type stars
- E  M type stars
Question for Thought

What is a nova?

A. The explosive outburst of a star that is part of a binary star system.
B. A white dwarf that accumulates hydrogen on its surface until it builds up so much hydrogen around the carbon core, that it gets hot enough to cause fusion.
C. A fusion explosion of the shell of a carbon-rich core white dwarf.
D. A very high increase in the luminosity of the star that can occur many times, as it is not destroyed in the process.
E. All of the above are true.
Question for Thought

What is a supernova?

A The catastrophic explosion of a star.
B The result of a star that is so massive that it goes through all of the fusion steps possible up to iron, then explodes catastrophically.
C Explosions of stars that result in the formation of either a neutron star or black hole.
D All of the above.
Question for Thought

How do you explain that red giants are very bright?

- A They are very hot and large.
- B They are relatively cool but very large.
- C Their brightness is due solely to their surface temperature.
- D They are relatively small but very hot.
- E None of the above are true.
Question for Thought

What is the proper sequence in the life cycle of a star with a mass similar to our Sun?

- A Gas cloud, Fragmentation, Protostar, Kelvin-Helmholz Contraction, Hayashi Track, Ignition, Adjustment to Main Sequence, Hydrogen Core Depletion, Hydrogen Shell Burning, Helium Flash, Helium Core Burning/Hydrogen Shell Burning, Helium Core Depletion, Helium Shell Burning, Planetary Nebula, Asymptotic Giant Branch, White Dwarf
- B Gas cloud, Fragmentation, Protostar, Kelvin-Helmholz Contraction, Hayashi Track, Ignition, Adjustment to Main Sequence, Hydrogen Core Depletion, Hydrogen Shell Burning, Helium Flash, Helium Core Burning/Hydrogen Shell Burning, Helium Core Depletion, Helium Shell Burning, Asymptotic Giant Branch, Planetary Nebula, White Dwarf
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Galaxies

- Elliptical Galaxies
- S0 (lenticular) Galaxies
- Spiral Galaxies
- Barred-Spiral Galaxies
- Irregular Galaxies
Question for Thought

What is the Hubble classification of our Milky Way galaxy?

- A An elliptical galaxy (E2).
- B An irregular galaxy.
- C A regular spiral galaxy (Sb).
- D A barred spiral galaxy (SBb).
- E A spherical galaxy (E0).
Question for Thought

Which of the following describes the structure of the Milky Way Galaxy?

- A. It consists of a core, or central bulge region.
- B. It consists of spiral arms.
- C. Its spiral arms are engulfed in gas and dust of what is referred to as the disk of the galaxy. The Milky Way Galaxy also has a bar. It is a barred spiral galaxy.
The Big Bang

- Afterglow Light Pattern 400,000 yrs.
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- Inflation
- Quantum Fluctuations
- 1st Stars about 400 million yrs.
- Big Bang Expansion 13.7 billion years
# The Big Bang

## Summary Timescale

<table>
<thead>
<tr>
<th>Era</th>
<th>Epochs</th>
<th>Main Event</th>
<th>Time after bang</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Vacuum Era</td>
<td>Planck Epoch</td>
<td>Quantum fluctuation</td>
<td>(&lt;10^{-43}) sec.</td>
</tr>
<tr>
<td></td>
<td>Inflationary Epoch</td>
<td>Inflation</td>
<td>(&lt;10^{-10}) sec.</td>
</tr>
<tr>
<td>The Radiation Era</td>
<td>Electroweak Epoch</td>
<td>Formation of leptons, bosons, hydrogen, helium, and deuterium</td>
<td>(10^{-10}) sec.</td>
</tr>
<tr>
<td></td>
<td>Strong Epoch</td>
<td></td>
<td>(10^{-4}) sec.</td>
</tr>
<tr>
<td></td>
<td>Decoupling</td>
<td></td>
<td>1 sec. - 1 month</td>
</tr>
<tr>
<td>The Matter Era</td>
<td>Galaxy Epoch</td>
<td>Galaxy formation</td>
<td>1-2 billion years</td>
</tr>
<tr>
<td></td>
<td>Stellar Epoch</td>
<td>Stellar birth</td>
<td>2-15 billion years</td>
</tr>
<tr>
<td>The Degenerate Dark Era</td>
<td>Dead Star Epoch</td>
<td>Death of stars</td>
<td>20-100 billion yrs.</td>
</tr>
<tr>
<td></td>
<td>Black Hole Epoch</td>
<td>Black holes engulf?</td>
<td>100 billion - ????</td>
</tr>
</tbody>
</table>
The Evidence So Far

Evidence for a “Big Bang”

- expansion of the universe
  - Distant galaxies receding from us
    - everywhere the same
- remnants of the energy from the “Big Bang”
  - a very hot body that has cooled
    - 2.7 K cosmic background radiation
- the primordial abundance of chemical elements
Cosmic Background

How hot would the cosmic background radiation be

- close to 3 K
  - first noticed by Penzias and Wilson
  - confirmed by COBE satellite
    - Mather and Smoot won 2006 Nobel Prize for this
What CMB means?

- Remember Wien’s Law
- Remember Doppler
- COBE results

![Graph showing Wien's law with a peak at a certain wavelength and temperature values](image)

![COBE results with temperature gradients and ΔT values](image)
Putting it into context

- Taking the perspective of the universe with you at the center
The CMB remainder...

- Using COBE DIRBE data for examining the fine differences
  - fine structure of the universe
  - led to the galaxies and their location
Questions to Consider About Solar System Formation

How did the solar system evolve?
What are the observational underpinnings?
Why are some elements (like gold) quite rare, while others (like carbon) are more common?
Are there other solar systems? What evidence is there for other solar systems? (to be discussed later in semester)
Observations to be Explained

- Each radioactive nucleus decays at its own characteristic rate, known as its half-life, which can be measured in the laboratory. This is key to radioactive age dating, which is used to determine the ages of rocks.
- The oldest rocks found anywhere in the solar system are meteorites, the bits of meteoroids that survive passing through the Earth’s atmosphere and land on our planet’s surface.
- Radioactive age-dating of meteorites, reveals that they are all nearly the same age, about 4.56 billion years old.
- Radioactive dating of solar system rocks
  - Earth ~ 4 billion years
  - Moon ~4.5 billion years
Observations to be Explained

- Most orbital and rotation planes confined to ecliptic plane with counterclockwise motion
- Extensive satellite and rings around Jovians
- Planets have more of the heavier elements than the sun
Abundance of the Chemical Elements

At the start of the Stellar Era

- there was about 75-90% hydrogen, 10-25% helium and 1-2% deuterium

NOTE WELL:

- Abundance of the elements is often plotted on a logarithmic scale
  - this allows for the different elements to actually appear on the same scale as hydrogen and helium
  - it does show relative differences among higher atomic weight elements better than linear scale
- Abundance of elements on a linear scale is very different
Log Plot of Abundance

Logarithmic Plot of Chemical Abundance of Elements

Relative Abundance

Chemical Species

H  He  C  N  O  Ne  Mg  Si  Si  Fe
Another Log View

Chemical Abundance vs. Atomic Number (Logarithmic Plot)
A Linear View of Abundance

Linear Plot of Chemical Abundance

Relative abundance

Chemical Species

H  He  C  N  O  Ne  Mg  Si  Si  Fe
Another Linear View

Chemical Abundance vs. Atomic Number (Linear Plot)
Question for Thought

What is the source of the chemical elements of the universe?

A. All chemical elements were formed in the big bang.
B. All chemical elements beyond #4 were formed in stars and their explosions.
C. All chemical elements up to Uranium are formed in stars during their life cycle.
D. All chemical elements are born in supernovae explosions.
E. All the above are true.
iClicker Question

The most abundant chemical element in the solar nebula

A  Uranium
B  Iron
C  Hydrogen
D  Helium
E  Lithium
# Planetary Summary

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass (Earth=1)</th>
<th>Density (g/ cm³)</th>
<th>Major Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.06</td>
<td>5.4</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Venus</td>
<td>0.82</td>
<td>5.2</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>5.5</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Mars</td>
<td>0.11</td>
<td>3.9</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Jupiter</td>
<td>318</td>
<td>1.3</td>
<td>H, He</td>
</tr>
<tr>
<td>Saturn</td>
<td>95</td>
<td>0.7</td>
<td>H, He</td>
</tr>
<tr>
<td>Uranus</td>
<td>14</td>
<td>1.3</td>
<td>Ices, H, He</td>
</tr>
<tr>
<td>Neptune</td>
<td>17</td>
<td>1.7</td>
<td>Ices, H, He</td>
</tr>
</tbody>
</table>
Other Planet Observations

- Terrestrial planets are closer to sun
  - Mercury
  - Venus
  - Earth
  - Mars

- Jovian planets furthest from sun
  - Jupiter
  - Saturn
  - Uranus
  - Neptune
Some Conclusions

- Planets formed at same time as sun
- Planetary and satellite/ring systems are similar to remnants of dusty disks such as that seen about stars being born (e.g. T Tauri stars)
- Planet composition dependent upon where it formed in solar system
Nebular Condensation Physics

- Energy absorbed per unit area from sun = energy emitted as thermal radiator
- Solar Flux = Lum (Sun) / 4 \times distance^2
- Flux emitted = constant \times T^4 \text{ [Stefan-Boltzmann]}
- Concluding from above yields
  \[ T = \frac{\text{constant}}{\text{distance}^{0.5}} \]
## Nebular Condensation Chemistry

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Freezing Point</th>
<th>Distance from Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)</td>
<td>10 K</td>
<td>&gt;100 AU</td>
</tr>
<tr>
<td>H(_2)O</td>
<td>273 K</td>
<td>&gt;10 AU</td>
</tr>
<tr>
<td>CH(_4)</td>
<td>35 K</td>
<td>&gt;35 AU</td>
</tr>
<tr>
<td>NH(_3)</td>
<td>190 K</td>
<td>&gt;8 AU</td>
</tr>
<tr>
<td>FeSO(_4)</td>
<td>700 K</td>
<td>&gt;1 AU</td>
</tr>
<tr>
<td>SiO(_4)</td>
<td>1000 K</td>
<td>&gt;0.5 AU</td>
</tr>
</tbody>
</table>
Nebular Condensation (protoplanet) Model

- Most remnant heat from collapse retained near center
- After sun ignites, remaining dust reaches an equilibrium temperature
- Different densities of the planets are explained by condensation temperatures
- Nebular dust temperature increases to center of nebula
A Pictorial View

Gas pressure attempting to expand the cloud

Gravitational force attempting to collapse the cloud

The cloud spins more rapidly as it collapses because of conservation of angular momentum
Pictorial View Continued

Side View

Side View:

Top View

Protosun

Protoplanets

Collapsing Protoplanet
HST Pictorial Evidence?
HST Pictorial Evidence?
More Pictorial Evidence

Disk of gas and dust

Central star (blocked out in telescope to make disk visible)

Size of Pluto’s orbit

10 μm = 0.01 mm

1 cm
iClikcer Question

As a planetary system and its star forms the temperature in the core of the nebula

A  Decreases in time
B  Increases in time
C  Remains the same over time
D  Cannot be determined
iClicker Question

As a planetary system and its star forms the rate of rotation of the nebula

A  Decreases in time
B  Increases in time
C  Remains the same over time
D  Cannot be determined
Understanding the origin and evolution of the solar system is one of the primary goals of

A  relativity theory.
B  seismology.
C  comparative planetology.
D  mineralogy.
E  oceanography.
Nebular Condensation Summary

- Solid Particles collide, stick together, sink toward center
  - Terrestrials -> rocky
  - Jovians -> rocky core + ices + light gases
- Coolest, most massive collect H and He
- More collisions -> heating and differentiating of interior
- Remnants flushed by solar wind
- Evolution of atmospheres