"Unity in the Whole Structure"

• “…How is it possible by any methods of observation yet known to the astronomer to learn anything about the universe as a whole? It is possible only because the universe, vast though it is, shows certain characteristics of a unified and bounded whole. …science shows unity in the whole structure, and diversity only in details.”

> Simon Newcomb, 1906

What I’m Going to Talk About

• The Big Bang Theory of the Formation of the Universe
  – Radiation, Matter and the Physical Laws
    • Kirchhoff’s Spectroscopic Laws
    • Planck’s Radiation Curves
    • Stefan-Boltzmann Law
    • Newton’s Law of Motion
    • Maxwell’s Equations
    • Hubble’s Law
    • Einstein’s General Theory of Relativity
• The Formation of Galaxies and Stars

The Big Bang Begats

• Macrocosmos
• Quantum Fluctuation
• Radiation
• Electron / Positron
• Higgs Fields
• Inflation
• Cosmos / Universe
• Strong Force
• Proton
• Nuclear Fusion
• Beta Radioactivity
• Gas
• Electric Charge
• Rocks
• Life

Some Basic Physics

• Kirchhoff’s Spectral Laws
  – Continuous Spectrum
    • any body (ideal blackbody) that is at a temperature above 0 K
  – Emission Spectrum
    • any low pressure gas that you place a high voltage across
  – Absorption Spectrum
    • any low pressure gas placed between a blackbody and the observer

Bohr’s Atom

• Best described the workings of the Hydrogen atom
  – one proton and one electron “around” the proton moving in orbits that are discretized (quantized) so that no intermediate orbits are allowed
Planck’s Radiation Curves
• A way to depict frequency (inverse of wavelength) versus intensity

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
  \[ E = \sigma T^4 \]

Kepler’s Laws
• Kepler’s First Law of Planetary Motion
  – planets orbit sun in an ellipse with sun at one focus
• Kepler’s Second Law of Planetary Motion
  – planets sweep out equal areas in equal times
    • travel faster when closer, slower when farther
• Kepler’s Third Law of Planetary Motion
  – orbital period squared is proportional to semi-major axis cubed
  \[ P^2 = a^3 \]

Question
The Stefan-Boltzmann 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

Newton’s Laws I
• Newton’s First Law of Motion
  – body at rest tends to stay at rest and body in uniform motion will stay in straight line uniform motion unless acted upon by an outside force
• Newton’s Second Law of Motion
  – the acceleration of a body is proportional to the force being applied
  \[ F = m a \]
Newton’s Laws II

• Newton’s Third Law of Motion
  – for every force there is an equal and opposite force (action and reaction)
• Newton’s Law of Gravitational Attraction
  – force is proportional to masses and inversely proportional to the distance squared
  \[ F = \frac{G m M}{r^2} \]

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

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 towards microwave region of the spectrum

Maxwell’s Electromagnetism

• Electricity according to Gauss
  – relates electricity to electric charge
  \[ \nabla \cdot E = \frac{\rho}{\varepsilon} \]
  \[ \nabla \times E = 0 \]
  \[ \nabla \cdot B = 0 \]
  \[ \nabla \times B = \mu_0 J + \mu_0 \varepsilon \frac{\partial E}{\partial t} \]
• Faraday’s Law
  – relates electric fields to magnetic fields
• Magnetism according to Gauss
  – relates magnetism to electricity
• Ampere-Maxwell Law
  – relates magnetic field to electricity

Question

You take an object and move it three times the distance that it was from a light source. The amount of light that the object will now receive from the source is
A three times as much as it did originally
B one-third (1/3) times as much as it did originally
C one-half (1/2) as much as it did originally
D one-quarter (1/4) as much as it did originally
E none of the above

Einstein’s Relativity Theories

• Special Theory of Relativity
  – speed of light constant in all reference frames
    • time dilation and simultaneity
    • length and mass
    • addition of velocities
• General Theory of Relativity
  – Principle of Equivalence
  – curvature of space-time
Question
The representation of gravity as a curvature of space similar to a flexible rubber sheet was first expressed in
A Einstein’s Special Theory of Relativity.
C Newton’s Laws of Motion.
E Heisenberg’s Uncertainty Principle.

Hubble’s Law
- The further away a galaxy is, the greater its recessional velocity and the greater its spectral red shift.

\[ v = H_0 d \]

The value of the Hubble constant, \( H_0 \), is not known with certainty but best value today is approximately 67 km/s/Mpc.

Question
If galaxy A is sixteen times more distant than galaxy B, then according to the Hubble Law, galaxy A will recede at a velocity _________ than galaxy B.
A 16 times faster
B 8 times faster
C 4 times faster
D 2 times faster
E 0.125 times faster

Hubble’s Conclusion
- From Hubble’s Law we can calculate a time in the past when universe was a point.
- Big bang occurred about 13-15 billion years ago.
  - Big bang formally proposed by Gamow based upon such evidence.
    - Big bang theory progenitors existed in looser manner.
Gamow’s Big Bang and Hoyle’s Steady State

- Steady State Universe
  - universe looks same and will look same
  - continuous creation
- Big Bang Universe
  - universe began in "big bang" or "ylem"
  - single point of creation

“In The Beginning”

- "In the beginning, God created the particles and the antiparticles. Now the temperature was high, and the particles and the antiparticles were in equilibrium…And God said, ‘Let there be light’…and He separated the photons from the particles and antiparticles. God called the photons “bosons” and the particles and antiparticles He called “fermions.” And there was pair production and there was photon creation -- the first 10^-43 seconds."
  - Eric Schulman
  - from "A Briefer History of Time"

Details of the Big Bang

- The littlest of physics
- The Big Bang & ensuing Cosmic Eras
  - The Vacuum Era
  - The Planck Epoch and The Inflationary Epoch
  - The Radiation Era
  - Light and Baryons
  - The Electroweak Epoch and The Strong Epoch
  - Decoupling and the creation of matter
  - The Matter Era
  - Transition to matter
  - Galaxy Formation Epoch and Stellar Epoch
  - The Degenerate Dark Era
  - Dead Star Epoch and Black Hole Epoch
- Whither the future?

The Littlest of Physics

- Space, Time, Matter and Forces
- Types of Matter
  - Quarks -> Baryons
    - protons, neutrons
  - Electrons -> Leptons
    - electrons, neutrinos, muons
- Types of Forces
  - gravity, electromagnetism, strong, weak

Back to the Beginning

- The universe began as an infinitely dense cosmic singularity which began its expansion in the event called the Big Bang, which can be described as the beginning of time
- During the first 10^-43 second after the Big Bang, the universe was too dense to be described by the known laws of physics

The Vacuum Era

- The Planck Epoch
  - <10^-43 sec. and about 10^{19} GeV (1 GeV = 10^9K)
  - we just don’t know
- The Inflationary Epoch
  - >10^-43 sec., < 10^-32 sec.
  - expansion driven by “repulsive gravity”
Inflation was one of several profound changes that occurred in the very early universe. Had inflation not taken place, the present-day observable universe would have had to have been relatively large just after the Big Bang. Once the inflationary epoch had ended, the universe continued to expand in a more gradual way down to the present day.

In the inflationary model, the present-day observable universe was very tiny just after the Big Bang. This region, as well as the rest of the universe, then underwent a tremendous expansion during the inflationary epoch.

---

Four basic forces explain all the interactions observed in the universe:

<table>
<thead>
<tr>
<th>Force</th>
<th>Relative strength</th>
<th>Particles exchanged</th>
<th>Particles on which they operate</th>
<th>Range</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>1</td>
<td>gluons</td>
<td>quarks, antiquarks</td>
<td>$10^{11} \text{GeV}$</td>
<td>building, proton, neutron, and more together</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>$\frac{1}{32}$</td>
<td>photons</td>
<td>charged particles</td>
<td>infinite</td>
<td>building atoms together</td>
</tr>
<tr>
<td>Weak</td>
<td>$10^{-4}$</td>
<td>intermediate vector bosons</td>
<td>quarks, electrons, neutrinos</td>
<td>$10^{-15} \text{GeV}$</td>
<td>radioactive decay</td>
</tr>
<tr>
<td>Gravitational</td>
<td>$6 \times 10^{41}$</td>
<td>gravitons</td>
<td>everything</td>
<td>infinite</td>
<td>holding the solar system together</td>
</tr>
</tbody>
</table>

---

The Radiation Era

- Creation of light
- Creation of baryonic matter
- Electroweak epoch
- Strong epoch
- Decoupling of weak interaction
- Creation of nuclei of the light elements
- Decoupling of radiation spectrum

---

The Matter Era

- Transition from radiation domination to matter domination
- Last scattering
- Dark Ages
- Galaxy Formation Epoch
- Bright Ages
The Degenerate Dark Era

- Whither the future?
  - death of stars
  - black hole domination
  - What will happen to the remaining matter in the universe
    - Ultimately sucked into black holes?
    - Ultimately all black holes combine?
    - Ultimately all spit out in a new 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 inflation</td>
<td>&lt;10^-43 sec.</td>
</tr>
<tr>
<td></td>
<td>Inflationary Epoch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Radiation Era</td>
<td>Electroweak Epoch</td>
<td>Formation of leptons, bosons,</td>
<td>10^-10 sec.</td>
</tr>
<tr>
<td></td>
<td>Strong Epoch</td>
<td>hydrogen, helium, deuterium</td>
<td>1 sec. - 1 month</td>
</tr>
<tr>
<td></td>
<td>Decoupling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Matter Era</td>
<td>Galaxy Epoch</td>
<td>Galaxy formation</td>
<td>2-2 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 engulff</td>
<td>100 billion - ???</td>
</tr>
</tbody>
</table>

Question

Within what era of the Big Bang are we now living?
A Electromagnetic Era
B Radiation Era
C Matter Era
D Planck Era
E GUTS Era

Question

In what era was the universe was dominated by all portions of the electromagnetic spectrum?
A Microwave Era
B Radiation Era
C Matter Era
D Invisible Era
E Visible Era

Given the above geometric possibilities of the universe, within which geometry do triangles contain less than 180 degrees?
A Closed Geometry
B Open Geometry
C Flat Geometry
D Both Open and Closed Geometry
E Both Flat and Closed Geometry

Again considering the above geometric representations, within which geometry(ies) will two parallel beams of light never meet?
A Closed Geometry
B Open Geometry
C Flat Geometry
D Both Open and Closed Geometries
E Both Flat and Open Geometries
Question

The Grand Unification Theories (GUTS) allow for the combining of the following forces
A electric and magnetic forces
B weak and strong forces
C weak and electromagnetic forces
D strong and electroweak forces
E all named forces above.

Question

Protons and neutrons, both known as nucleons are made up of what particles?
A muons
B positrons
C electrons
D quarks
E neutrinos

Question

The inflationary cosmological model
A refers to space overruns.
B predicts that the density of the universe is much less than the critical density.
C is the only model that is consistent with the observed expansion of the universe.
D has replaced the Big Bang model, which is no longer believed by most astronomers.
E helps explain why the background radiation is so nearly the same in all directions.

A Thoughtful Break

• “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

The Evidence So Far

• Evidence for a “Big Bang”
  – expansion of the universe
    • 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

What CMB means?

• Cosmic Microwave Background
  – Remember Wien’s Law
  – Remember Doppler
  – COBE results
Cosmic Background

- How hot would the cosmic background radiation be?
  - close to 3 K
  - first detected by Penzias and Wilson of Bell Labs
    - Didn’t know what it was
    - Explained by Robert Dicke of Princeton
    - Didn’t get a piece of the Nobel Prize with Penzias and Wilson
  - confirmed by COBE satellite

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

Astronomers use supercomputers to simulate how the large-scale structure of the universe arose from primordial density fluctuations

Linking the CMB to the Galaxies

- Galaxies are grouped into clusters rather than being scattered randomly throughout the universe
String Theories Attempt to Unify Physical Forces

- The search for a theory that unifies gravity with the other physical forces suggests that the universe actually has 11 dimensions (ten of space and one of time), seven of which are folded on themselves so that we cannot see them.
- The idea of higher dimensions has motivated alternative cosmological models.
- No evidence to support string theories at this time.

What I Talked About

- The Big Bang and Everything Within
- The Evidence for the Big Bang
  - Hubble’s Law
  - Cosmic Microwave Background
  - Abundance of chemical elements
- A touch of strings