


AST1002




## ***Galaxies and Beyond***

Chapter 19  
The Beginning of Time

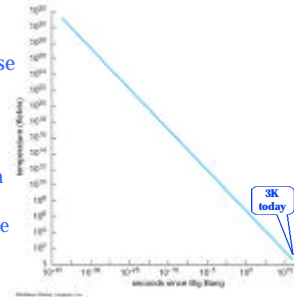
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## ***The Beginning of Time***

- The expanding universe is becoming less dense and cooler as time goes on
- Apply physics
  - It must have been much denser and much hotter in the past



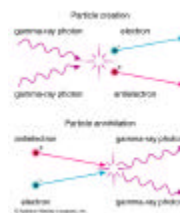
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## ***The Beginning of Time***

- Extreme conditions yield extreme physics
  - Conversion of energy to mass and mass to energy
  - Mass energy:  $E=mc^2$



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## ***The Beginning of Time***

- Extreme conditions yield extreme physics
  - Today we know four forces
    - Gravity
    - Electromagnetism (magnets and electric charges)
    - the Strong Force (holds the nucleus together)
    - the Weak Force (causes radioactivity)
  - In early times some of these forces were combined

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## ***The Beginning of Time***


### The First Instant

- The Planck era
  - Understanding this period would require a blend of quantum mechanics and general relativity theory
  - Alas, no such blend has been worked out




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## ***The Beginning of Time***

- The GUT era (Grand unified theories)
  - The universe expands and cools
  - Forces at this time were
    - Gravity
    - GUT force (a combination of the strong, weak, and electromagnetic forces)



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### The Beginning of Time

- The GUT era
  - At the end of the GUT era, the GUT force separated into
    - The strong force
    - The electroweak force
  - The energy release may have caused a rapid "inflation" of the universe

10<sup>-35</sup> seconds  
10<sup>-43</sup> seconds  
GUT Era

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### The Beginning of Time

- The Electroweak era
  - Radiation fills space
  - Particles appear and instantly disappear through particle creation - annihilation
  - The electroweak force separates into the weak force and the electromagnetic force

10<sup>-10</sup> seconds  
10<sup>-35</sup> seconds  
Electroweak Era

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### The Beginning of Time

- Separation of Forces

10<sup>10</sup> seconds 10<sup>45</sup> seconds 10<sup>43</sup> seconds

strong force  
weak force  
electromagnetic  
GUT force  
"super force"

Confirmed by experiment  
Predicted by theory

relative strength of force  
temperature (K)

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### The Beginning of Time

- The Particle era
  - Temperatures drop enough that protons and antiprotons are no longer created from energy
  - For every 1 billion antiprotons there were about 1 billion and one protons
  - They annihilated each other leaving only protons (which are still here today)
  - Neutrons appear in the same fashion

0.001 seconds  
10<sup>-10</sup> seconds  
Particle Era

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### The Beginning of Time

- Era of Nucleosynthesis
  - Nuclei fuse and break apart
  - The universe continues to expand and cool
  - As density decreases, nuclei eventually remain fused; leaving 75% hydrogen nuclei, 25% helium nuclei

3 minutes  
300 seconds  
Era of Nucleosynthesis

protons, neutrons, electrons, neutrinos, antineutrinos  
normal matter is 75% hydrogen, 25% helium

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### The Beginning of Time

- The Era of Nuclei
  - The universe continues to expand and cool
  - At 300,000 years and 3000K electrons become bound to H and He nuclei
  - Photons no longer bounce off of electrons and instead stream freely across space

300,000 years  
3 minutes  
Era of Nuclei

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## The Beginning of Time

- Era of Atoms
  - Clouds of cold gas form
- Era of Galaxies
  - Galaxies form from protogalactic clouds

Timeline labels: 1 billion years, 380,000 years, present, 1 billion years.

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## The Beginning of Time

- Evidence for the Big Bang
  - The Cosmic Background Radiation
    - The photons freed at the end of the era of nuclei (at 300,000 years and 3000K)
  - The relative abundances of Hydrogen and Helium

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## The Beginning of Time

- The Cosmic Background Radiation
  - Robert Wilson and Arno Penzias (researchers at Bell Labs) found unexpected “noise” in the signal from a radio telescope
  - Characteristics
    - Black body energy distribution
    - Black body temperature  $\approx 3$  K
    - Seen in every direction in space

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## The Beginning of Time

- The Cosmic Background Radiation
  - At the start of the era of atoms the universe was filled with black body radiation at a temperature of 3000K
  - The universe has expanded by x1000 since then
  - The radiation today would have a temperature of 3K

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## The Beginning of Time

Graph labels: relative intensity, wavelength (nm).

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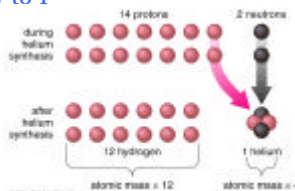
## The Beginning of Time

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### The Beginning of Time

- Relative abundances of H and He
- When the temperature became right for helium creation the ratio of protons to neutrons was 7 to 1
- Result:
  - 75% H
  - 25% He



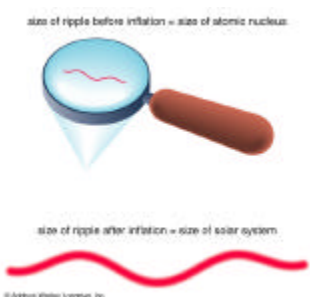
The diagram illustrates the process of Big Bang nucleosynthesis. It shows 14 protons (red spheres) and 2 neutrons (black spheres) combining to form 12 hydrogen atoms (each with 1 proton and 1 neutron) and 1 helium atom (with 2 protons and 2 neutrons). The atomic mass of hydrogen is 1, and the atomic mass of helium is 4.

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### The Beginning of Time

- Inflation




The diagram illustrates cosmic inflation. A magnifying glass is shown over a small ripple, labeled "size of ripple before inflation = size of atomic nucleus". Below it, a much larger ripple is shown, labeled "size of ripple after inflation = size of solar system".

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### The Beginning of Time

- Inflation



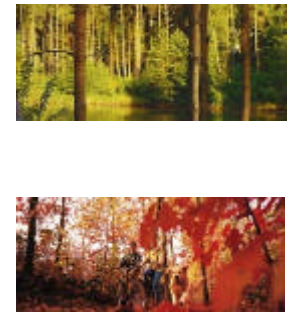
The diagram shows a small blue sphere representing the early universe, which then expands into a large, flat, light blue surface, illustrating the concept of inflation.

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### The Beginning of Time

- Olbers' Paradox



Two photographs of forests are shown. The top one shows a lush green forest, and the bottom one shows a forest with vibrant autumn foliage in shades of orange and red.

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**Questions and/or Comments?**

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or visit <http://www.astro.ufl.edu/~oliver/>